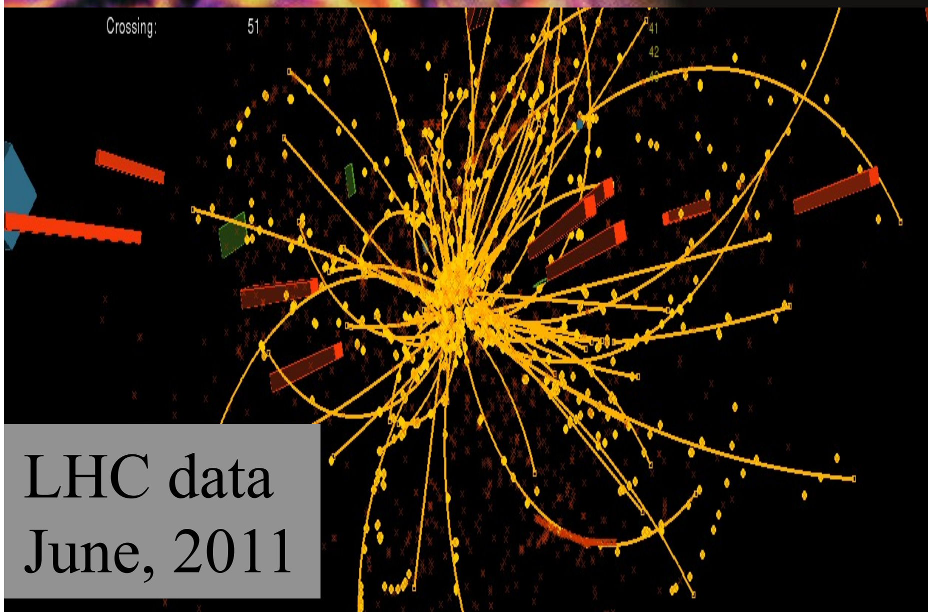
Recent Results from CMS & the Impact of the LHC Physics Center @ FNAL



LHC data
June, 2011

Outline:
LHC/CMS/Electroweak
/top/SUSY Exotica/ Higgs/
LHC Physics Center

30-mile 'donut' to spin out atomic secrets

World's mightiest atomic accelerator, so huge it will span the border between two European countries, may unlock deep mysteries of the universe—and unleash virtually unlimited supplies of vital electric power.

by Hans Fantel

It will be so big you can see it in its entirety only by looking down from a mountaintop or airplane. A circular tube with a mind-boggling circumference of 30 miles, it's the largest machine ever conceived. It's still in the planning stage, but represents the most ambitious concept yet for building an atomic particle accelerator—popularly known as an atom smasher.

Why the incredible size? Such devices need a long path to accelerate their subatomic particle "bullets" up to the tremendous velocities required to penetrate and break down matter at the atomic level—just as a jumbo jet needs a long runway to get up to flying speed. The longer the path, the greater the acceleration that can be achieved.

Is such a giant merely a paper dream? By no means. The technology for building it exists—the final design, financing, location of construction site, and certain political considerations must still be worked out. But atom smashers have been getting bigger and more powerful all the time—a sign of even more ambitious projects to come. The famed Brookhaven accelerator, half a mile in circumference, is already dwarfed by a similar one with a four-mile girth at Fermilab in Batavia, Ill., currently the biggest atom smasher in the world. And now being planned is another, more modern installation for Brookhaven that will outpower them all—at least until that 30-mile monster goes into operation.

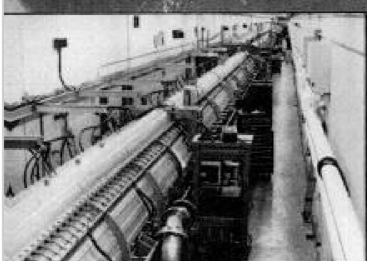
The newly proposed superaccelerator still has no official name. It's just called the VBA—short for Very Big Accelerator, which is an understatement if there ever was one. While the primary objective of the VBA will be to explore the properties of the atom and physical laws governing the universe, its findings may also lead to new ways of mass-producing nuclear energy in safe, economical, commercially usable quantities. If so, such discoveries might well provide virtually unlimited supplies of urgently needed electric power.

Since the VBA will be such a gigantic and costly undertaking, it is unlikely that any one nation could afford to foot the bill by itself. Thus the United States, the Soviet Union and several European countries are expected to chip in, making the project a truly international effort.

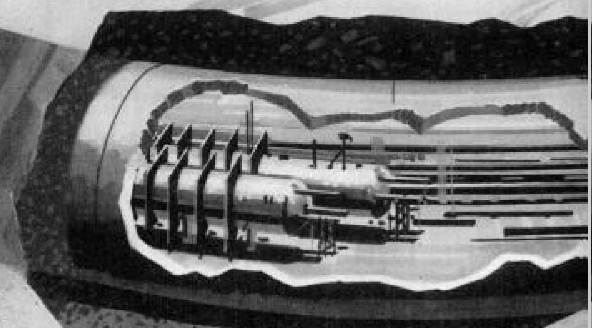
While a site has not been definitely

Map below shows one possible site for proposed new 30-mile-long atomic accelerator. If plan is adopted, the mammoth ring would span the boundary between France and Switzerland near Lake Geneva. It would be a joint international venture, built and operated by several countries.

Plan for new Brookhaven accelerator has twin tubes whirling counterrotating proton beams. Future 30-mile atom smasher depicted at left may use same arrangement.

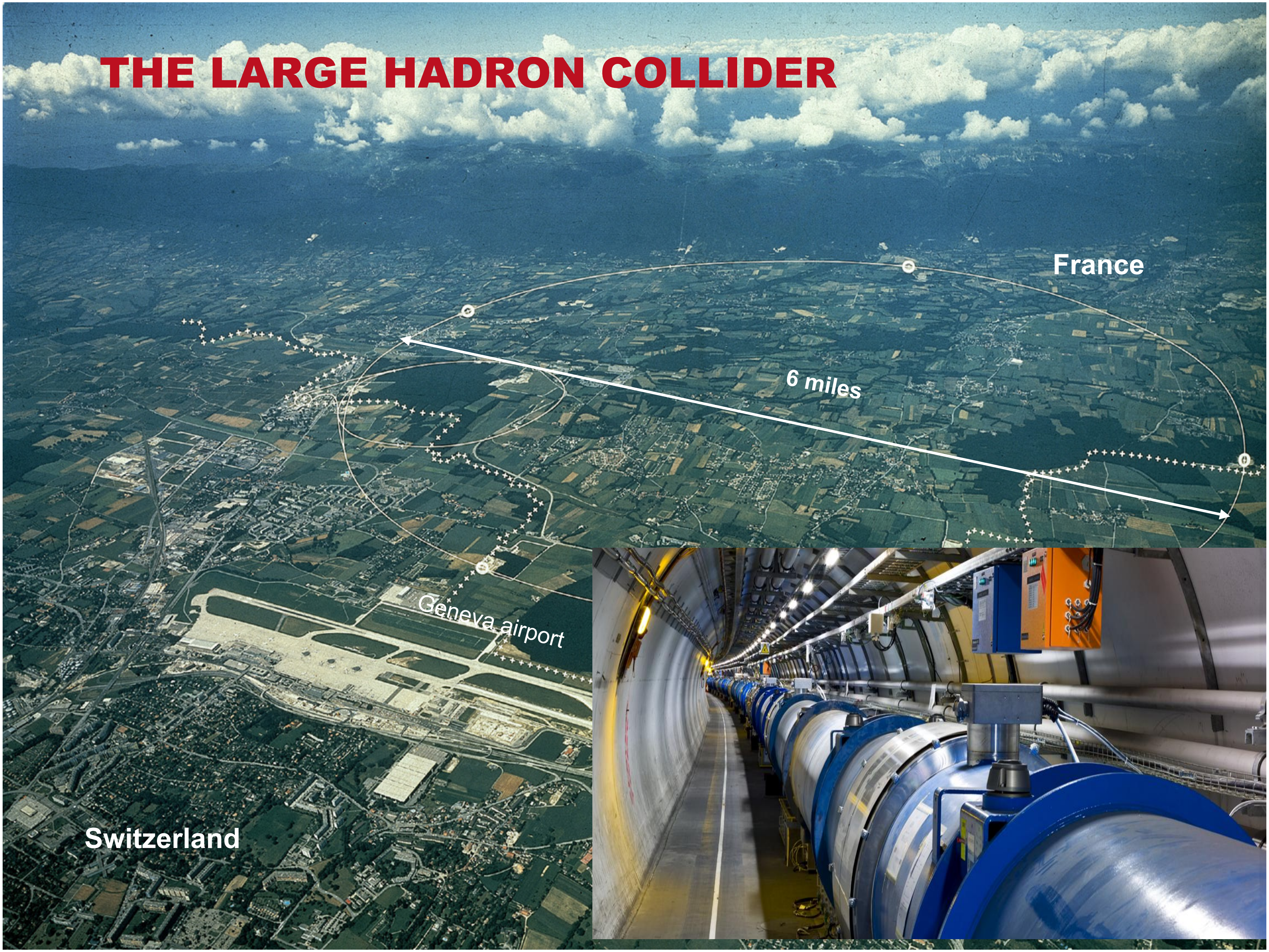


Like an entry ramp to a superhighway, this 500-foot-long linear (straight-line) accelerator at Fermilab pushes protons up to velocities needed to enter high-speed lanes in main circular accelerator. Such "preboosters" will be used in proposed 30-mile atom smasher shown above.



Popular Science, **April 1978**

- **TeV-scale proton collider**
- **international collaboration**
- **helium-cooled super-conducting magnets**
- **"electronic bubble chambers"**


THE LARGE HADRON COLLIDER
France
6 miles
Geneva airport
Switzerland

We are still in the inflationary era of the LHC

849/pb
(June 14 2011)

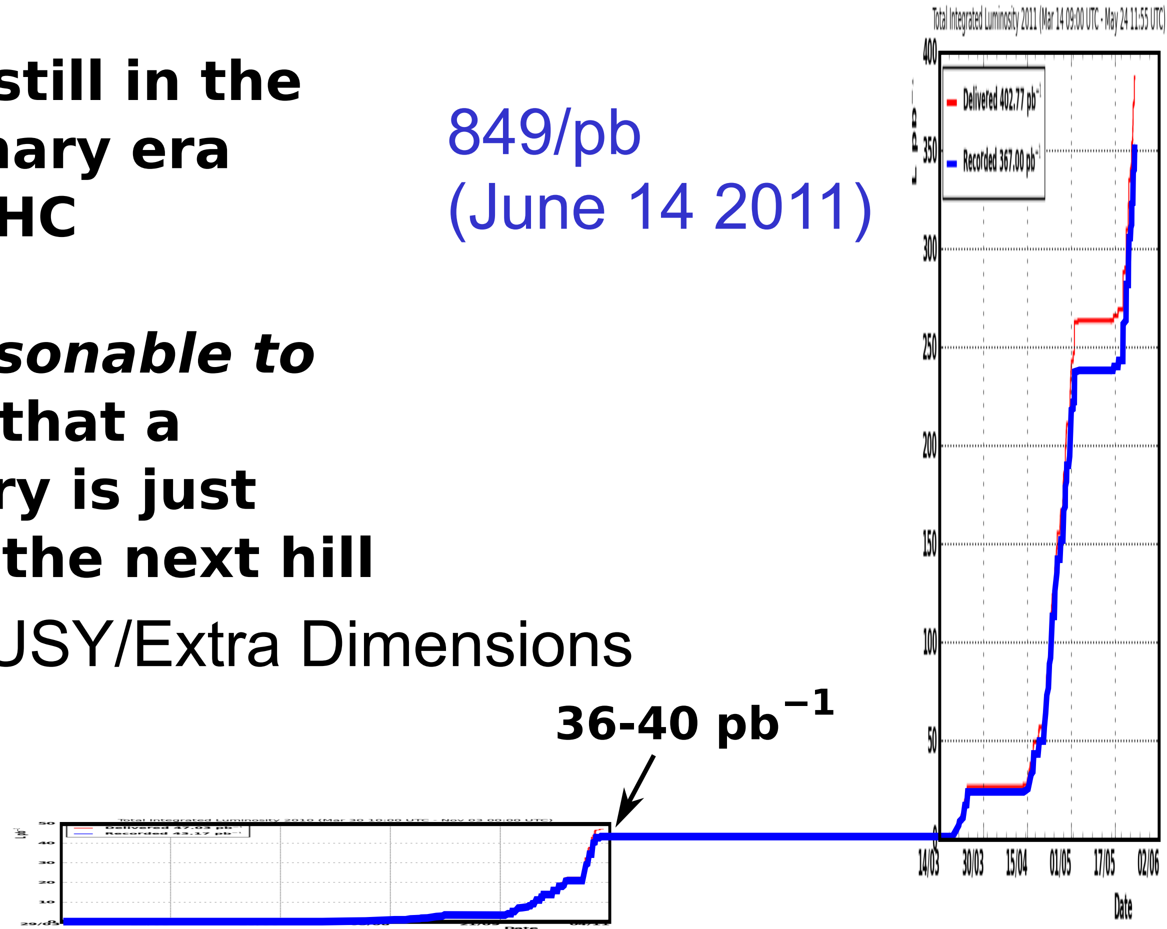
It is *reasonable to believe* that a discovery is just beyond the next hill

Higgs/SUSY/Extra Dimensions

10^{33} cm^2/s

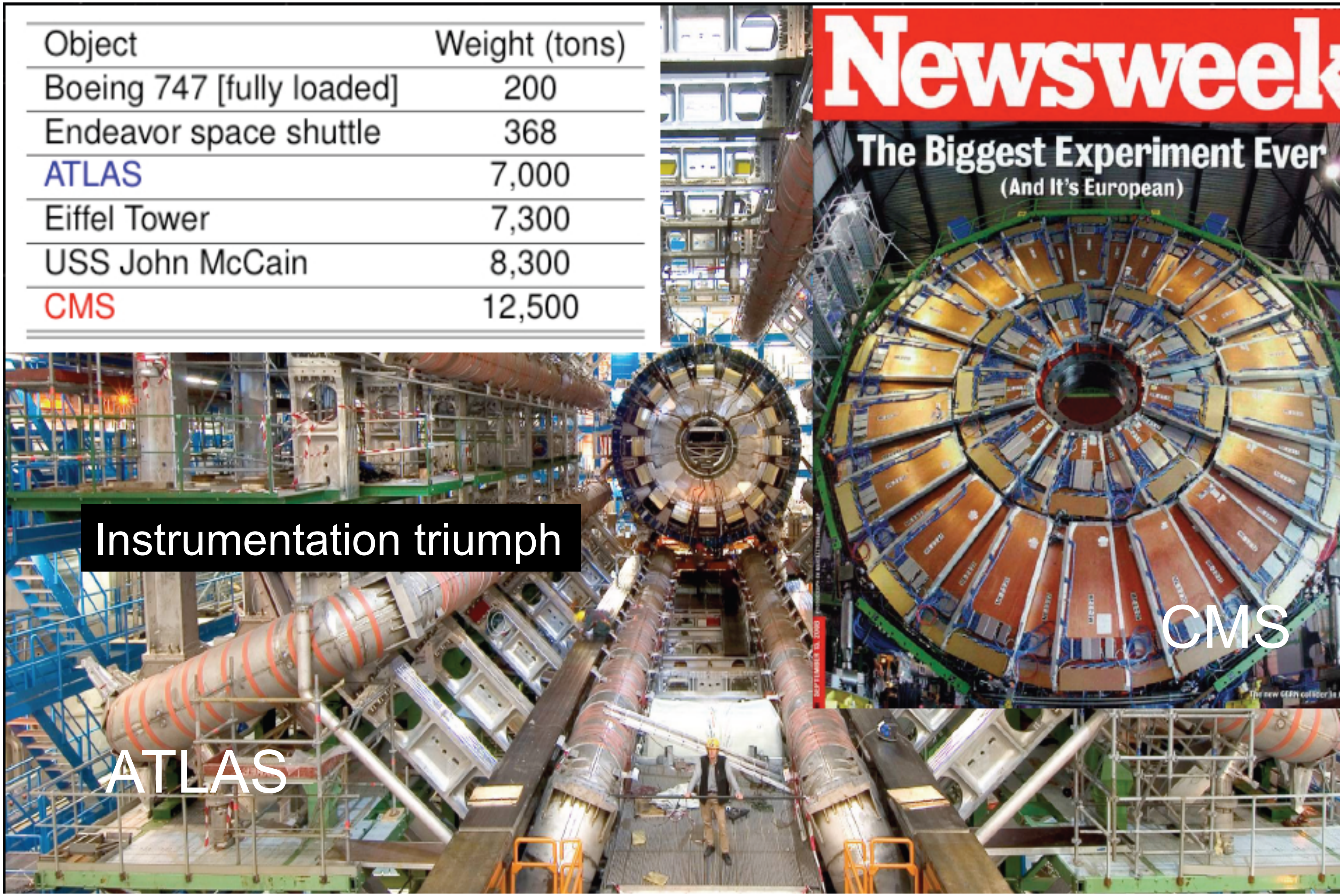
= 1 Z → μμ per second

(to scale)



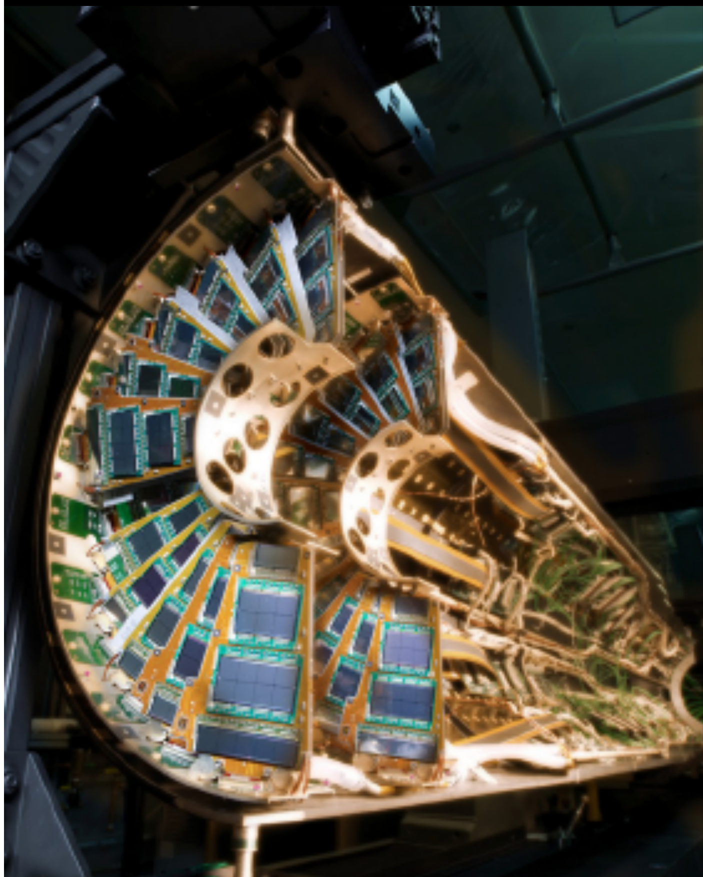
Mar 2010 **Nov 2010** **Mar 2011** **now**

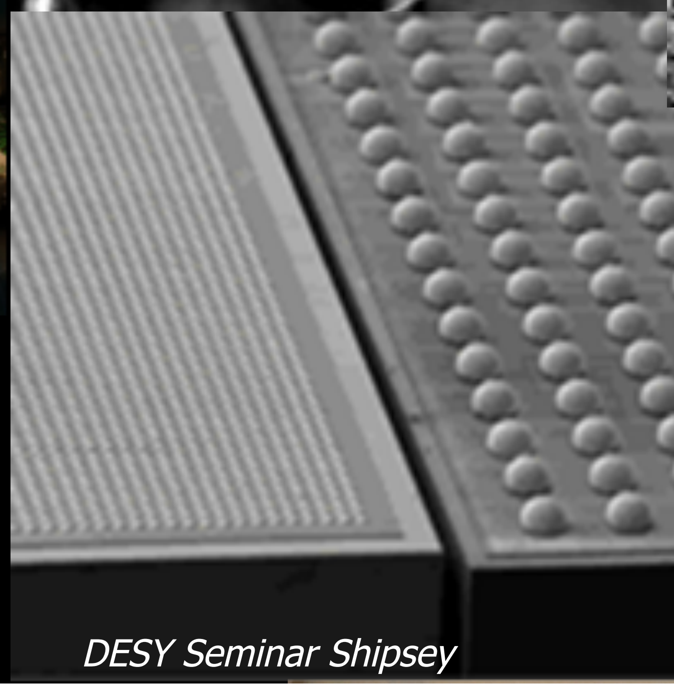
Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
USS John McCain	8,300
CMS	12,500

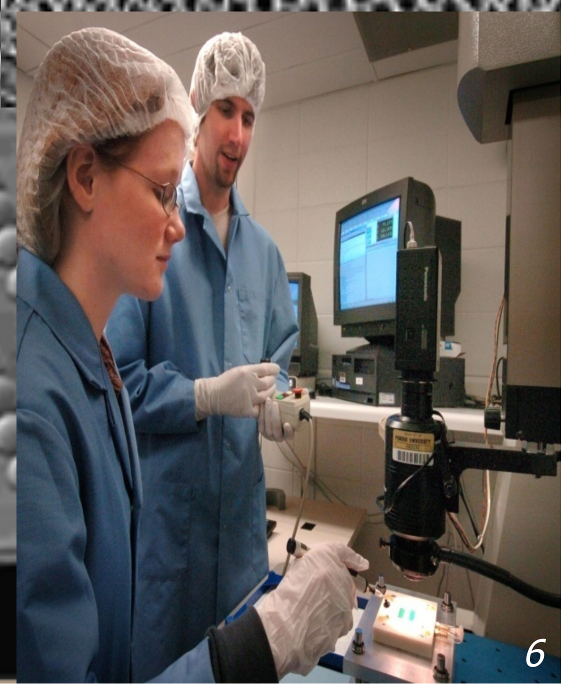


DIGITAL CAMERAS THE SIZE OF CATHEDRALS

AS INTRICATE AS A FLY'S EYE

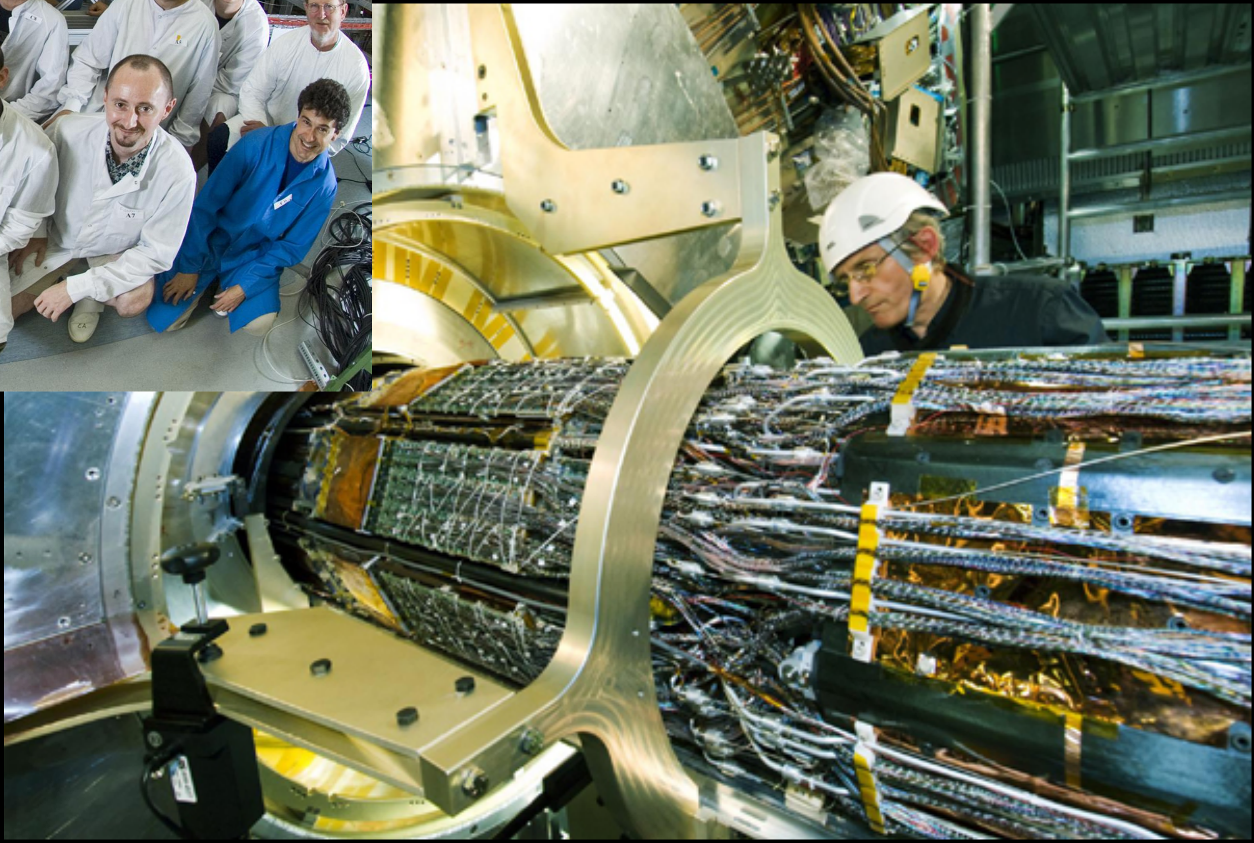






At the heart of CMS & ATLAS are silicon digital cameras

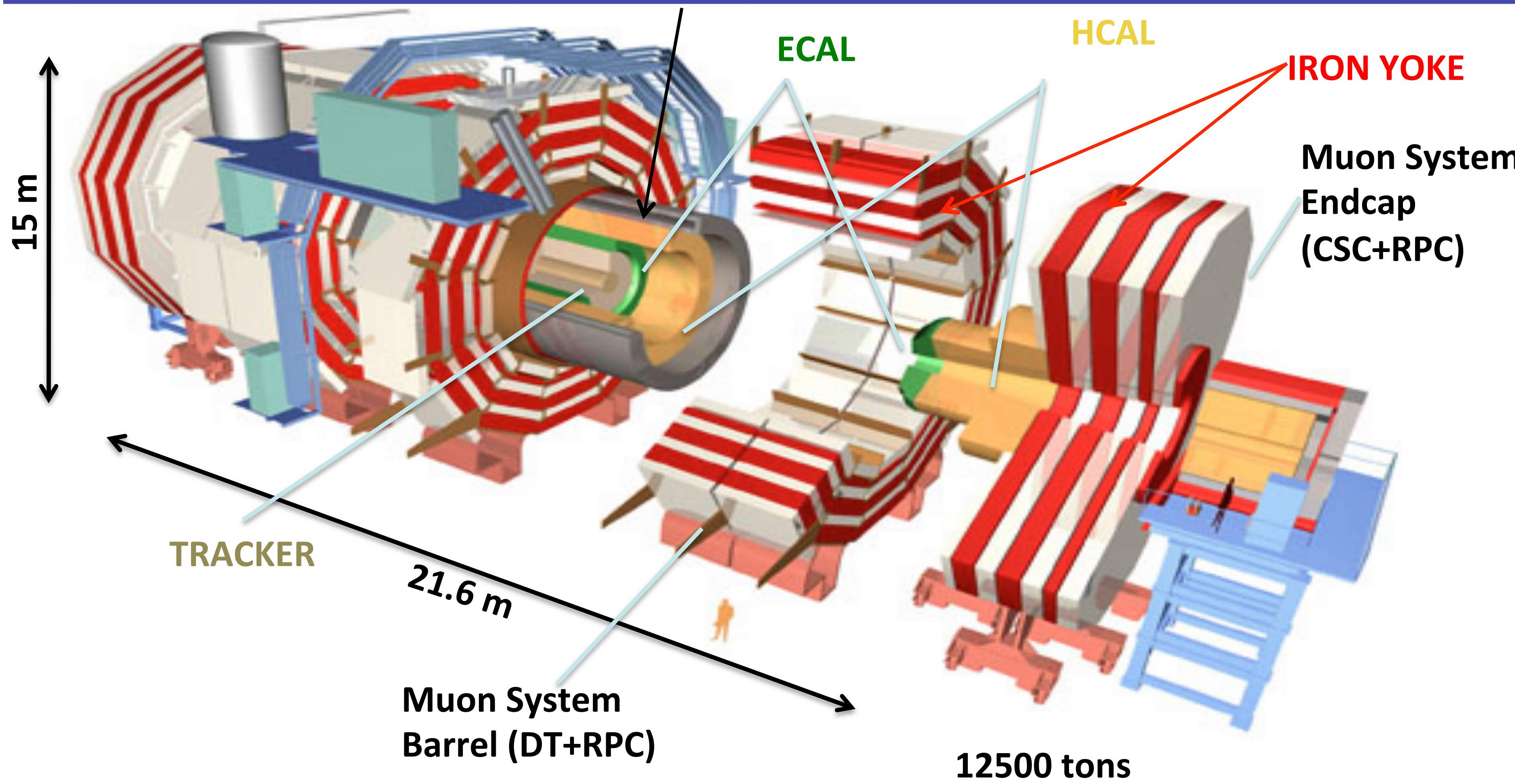
& PRECISION OF A SWISS WATCH

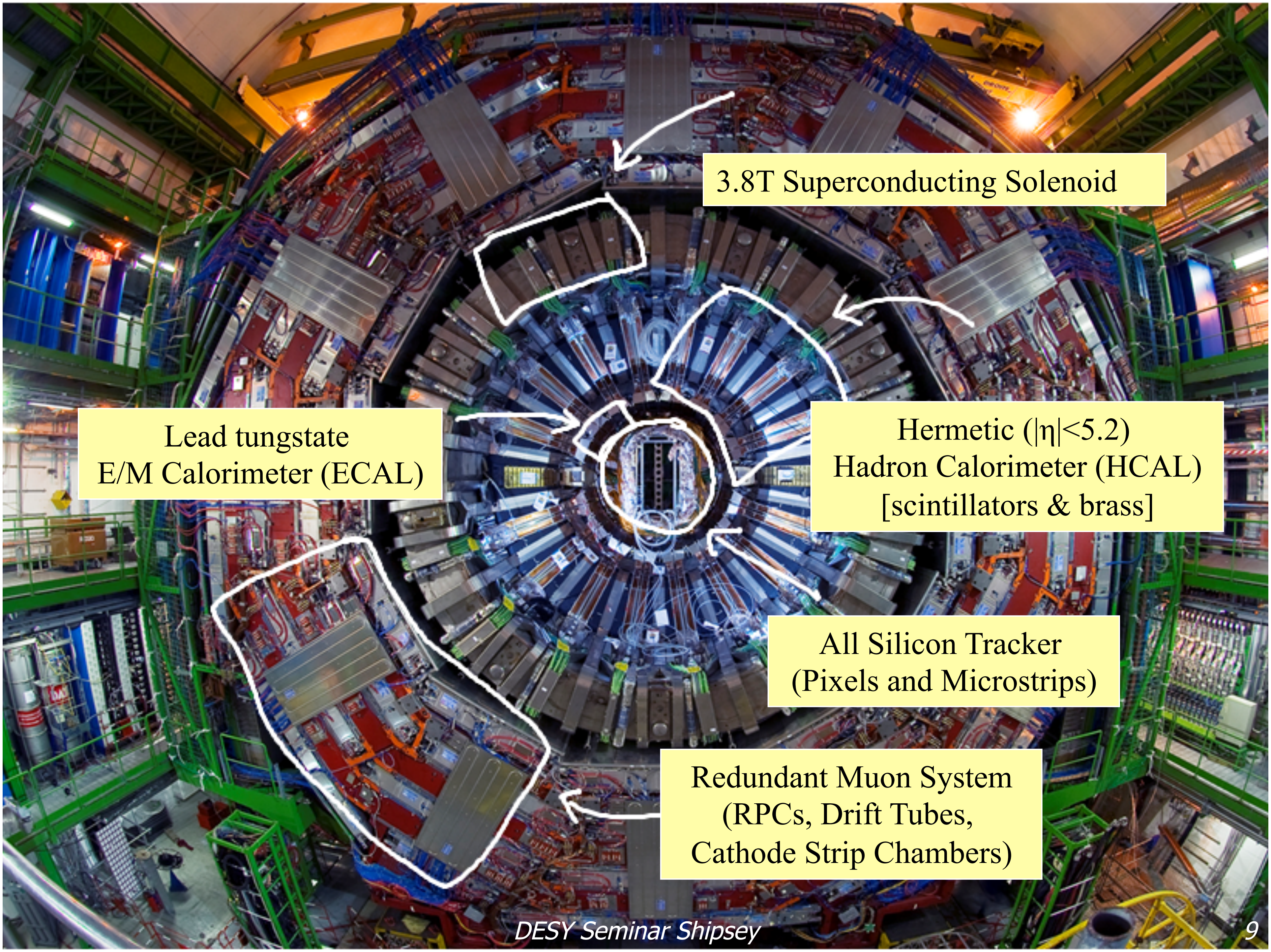


ATLAS silicon
camera sector

The CMS Detector

General purpose, hermetic experiment. Compact fully solenoidal design.
All central tracking and calorimetry inside a superconducting solenoid (B=3.8T)-> Large BL^2

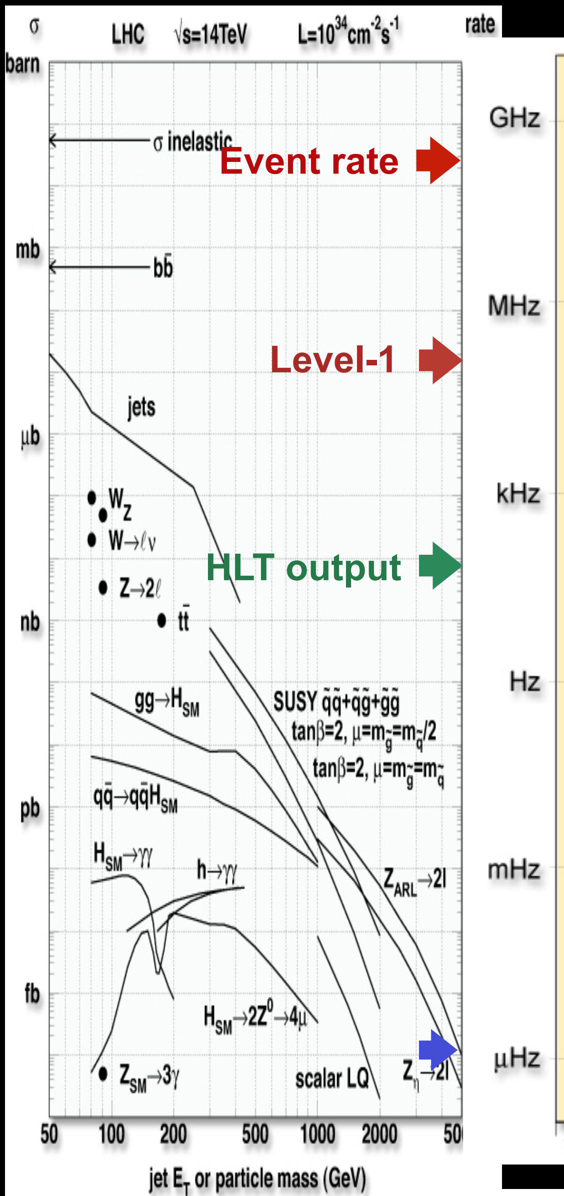


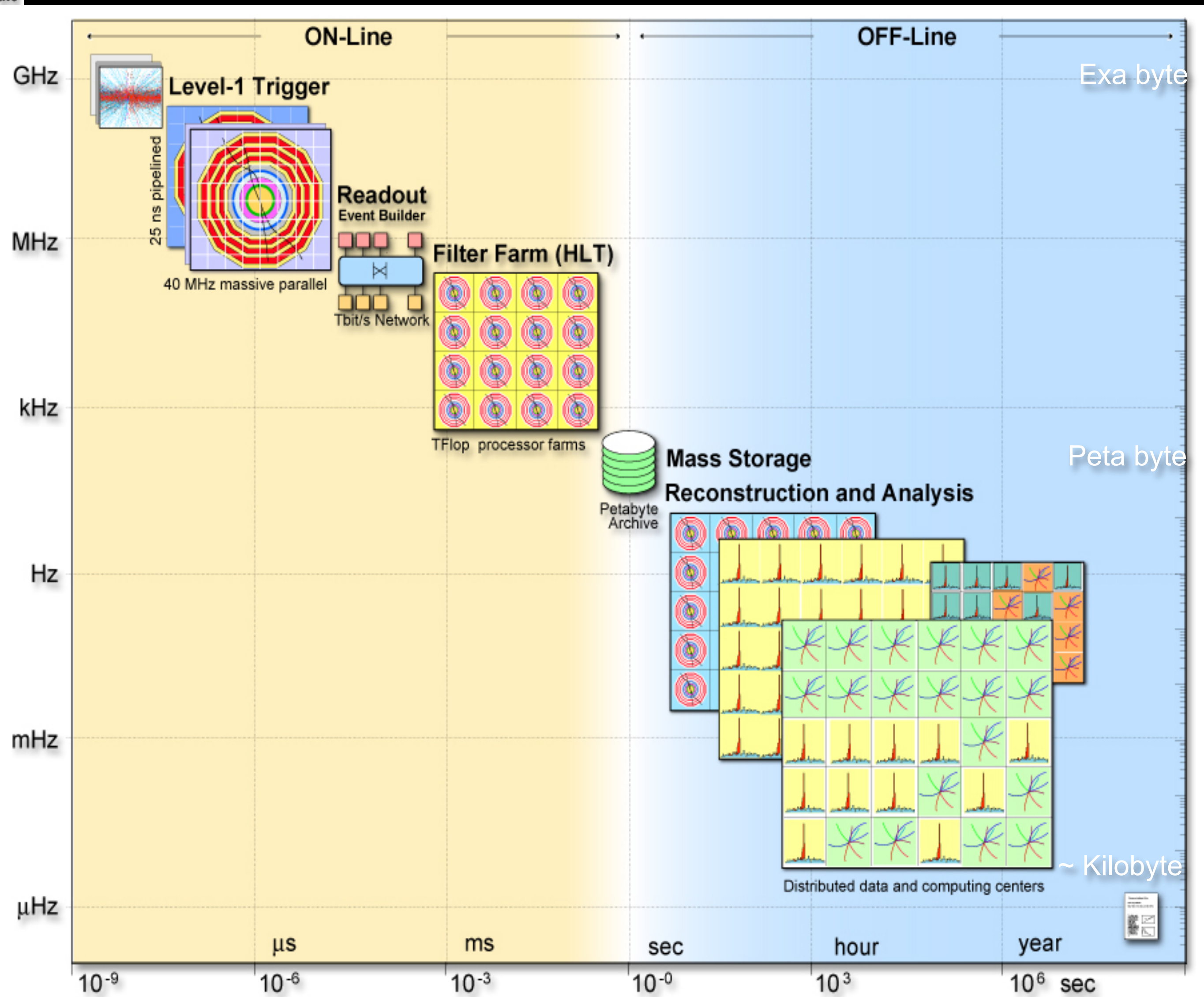

3.8T Superconducting Solenoid
Lead tungstate
E/M Calorimeter (ECAL)
Hermetic (|η|<5.2)
Hadron Calorimeter (HCAL)
[scintillators & brass]
All Silicon Tracker
(Pixels and Microstrips)
Redundant Muon System
(RPCs, Drift Tubes,
Cathode Strip Chambers)

CMS Detector

(Some of the) 3170 Scientists and Engineers (800 Graduate Students) from 182 Institutions in 39 countries

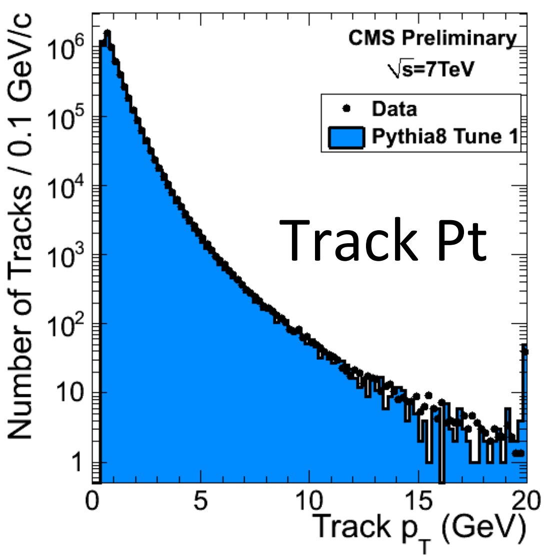
TRIGGER & DATA ACQUISITION

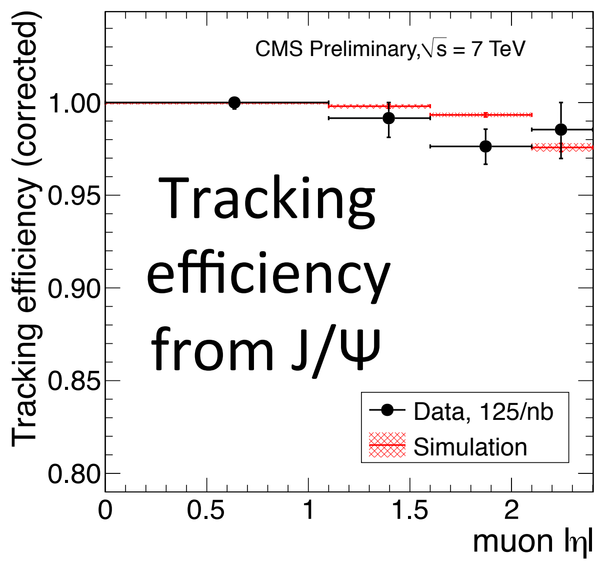


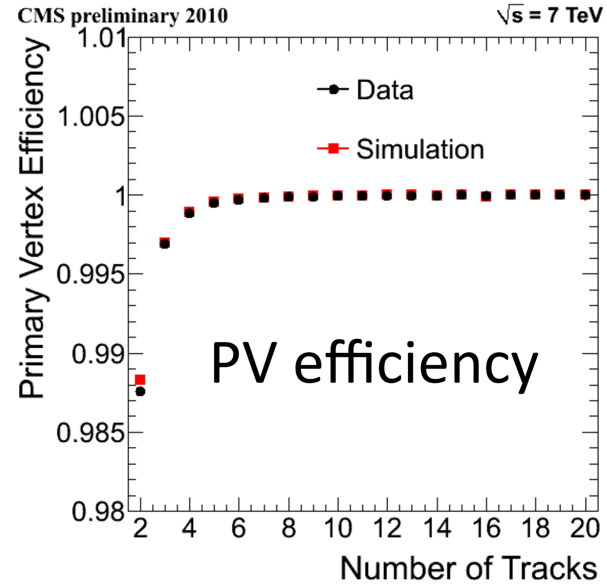


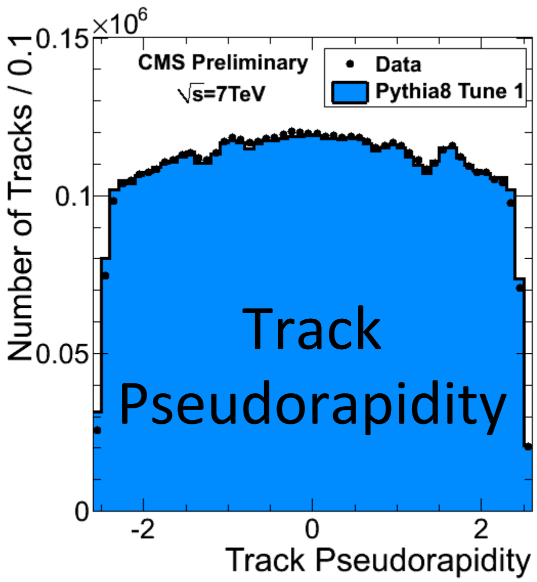
Tracker Performance

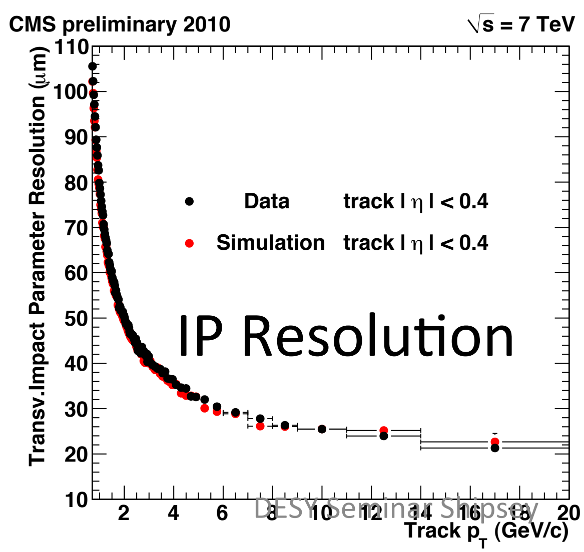
- 75 million channels, 200 m^2 of silicon > 98% operational
- Remarkable agreement between data and simulation

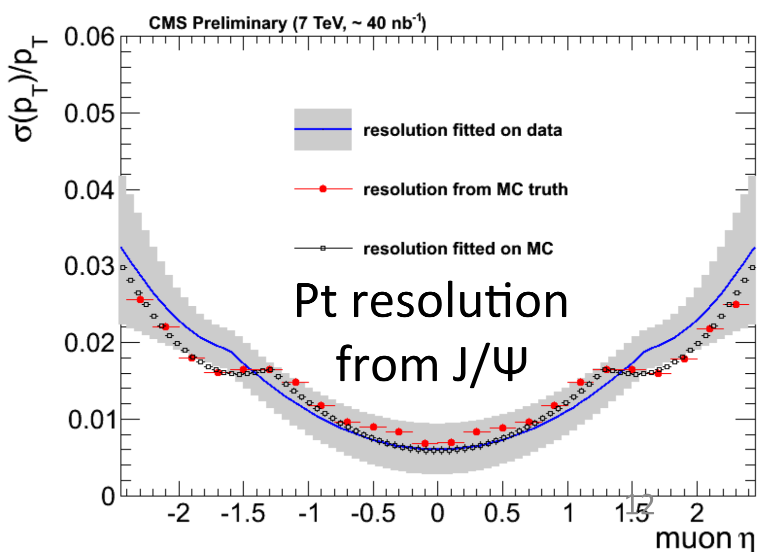








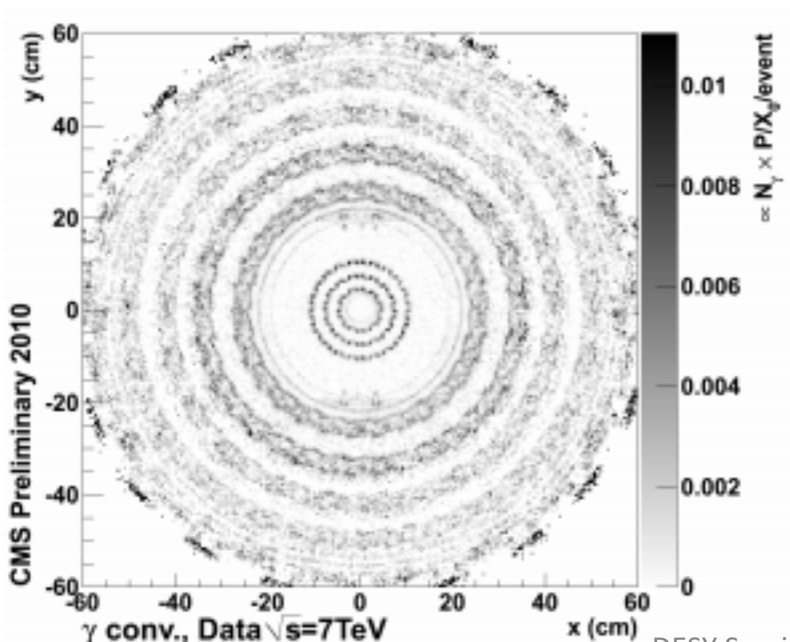




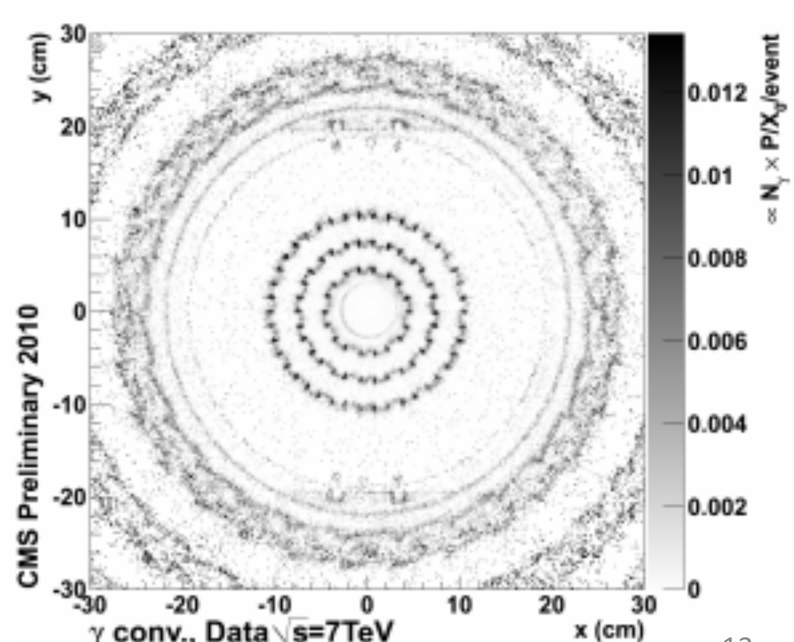
The Silicon Strip Tracker

- Excellent tracking performance allows to see the Tracker from photon conversions

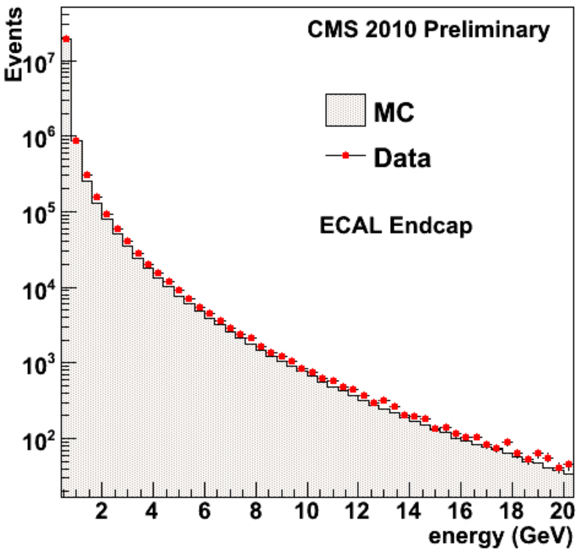
Silicon Strip Tracker inner barrel

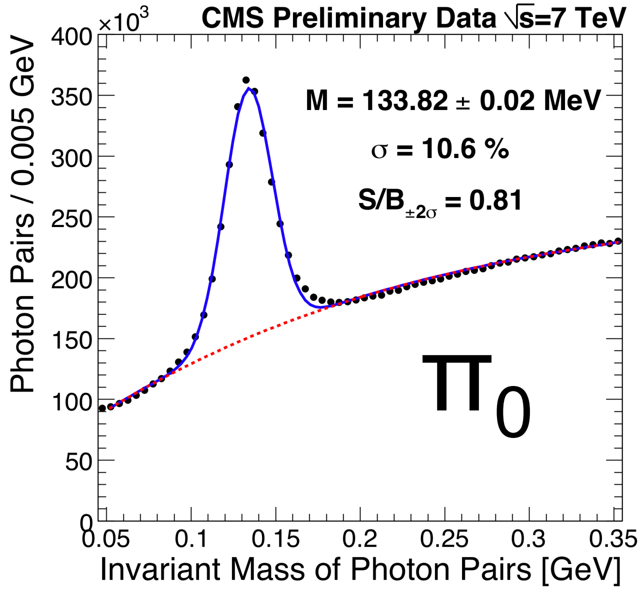


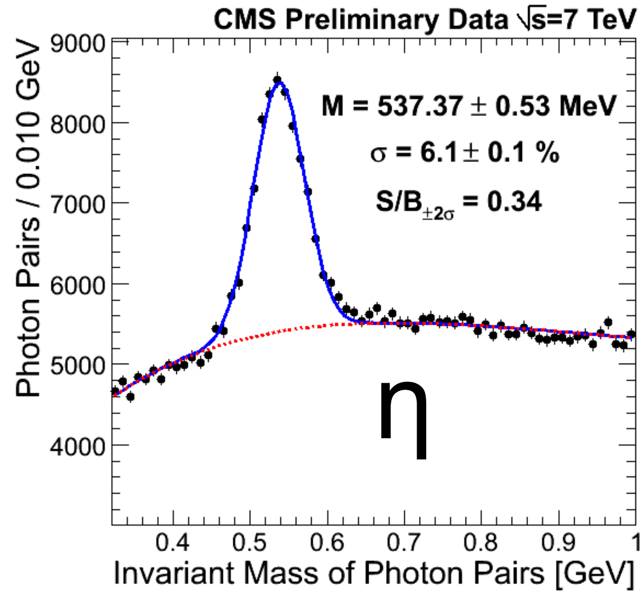
Zoom to the pixel barrel

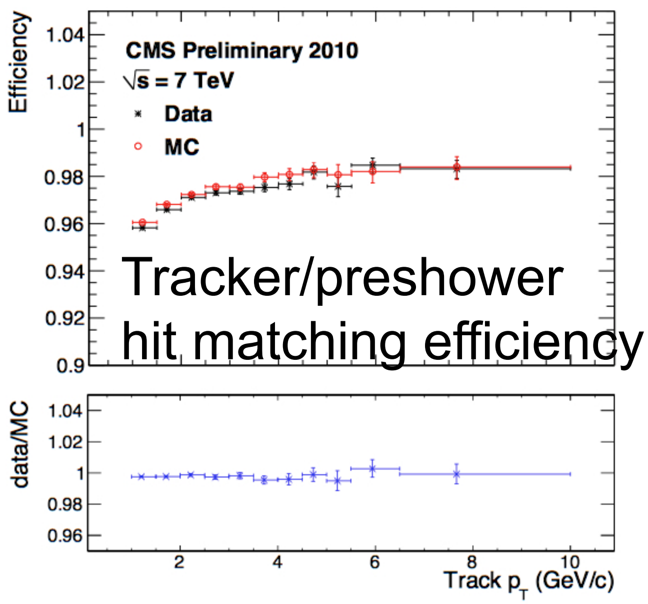


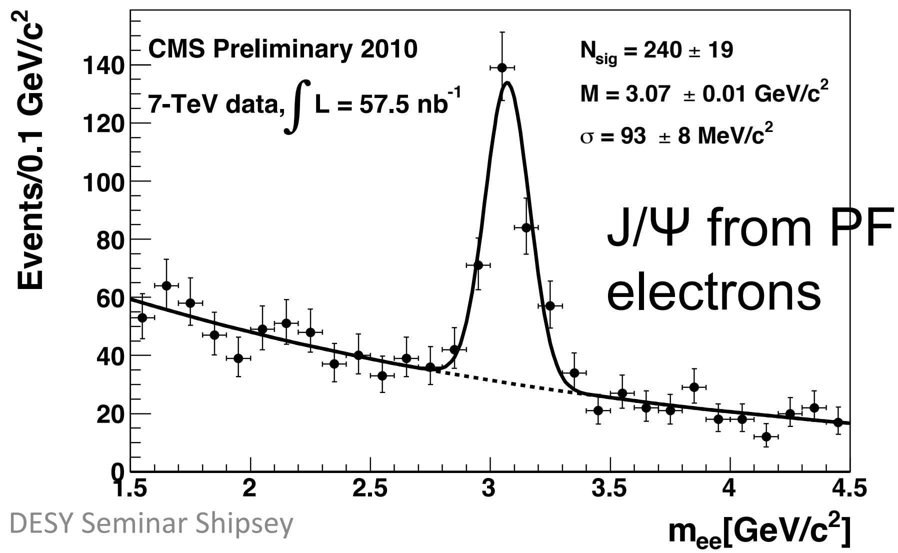
ECAL performance







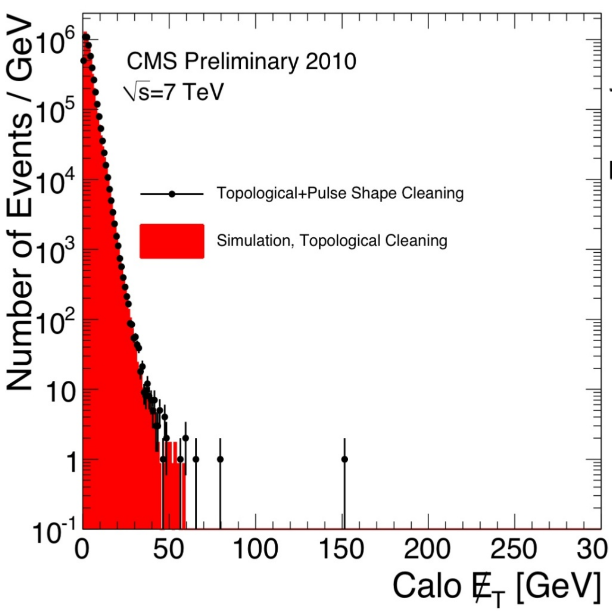




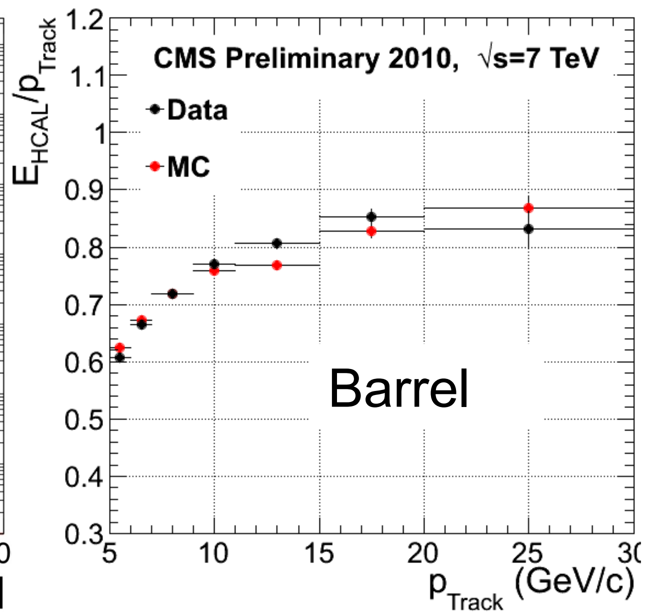
HCAL Performance

- Very good performance of noise cleaning
- Excellent agreement with simulation

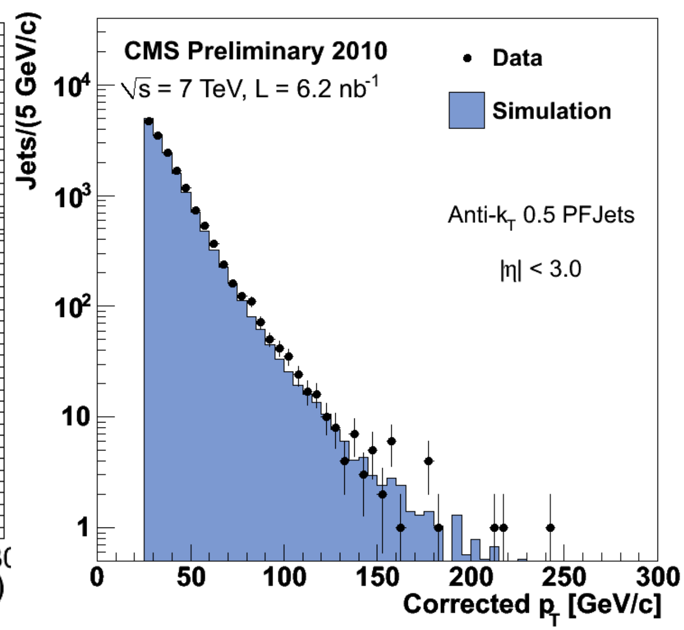
Calorimetric MEt



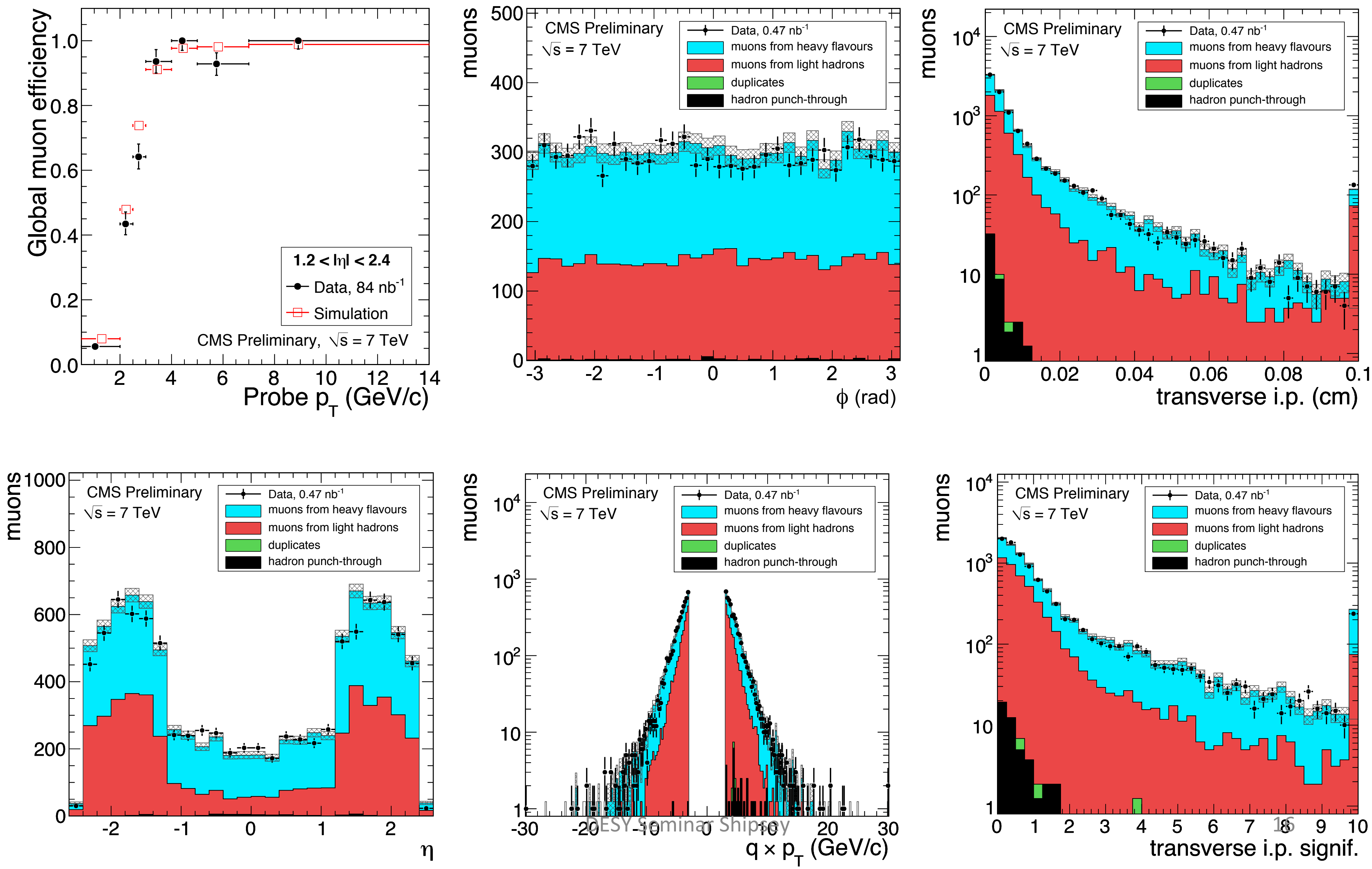
Mean response vs track momentum



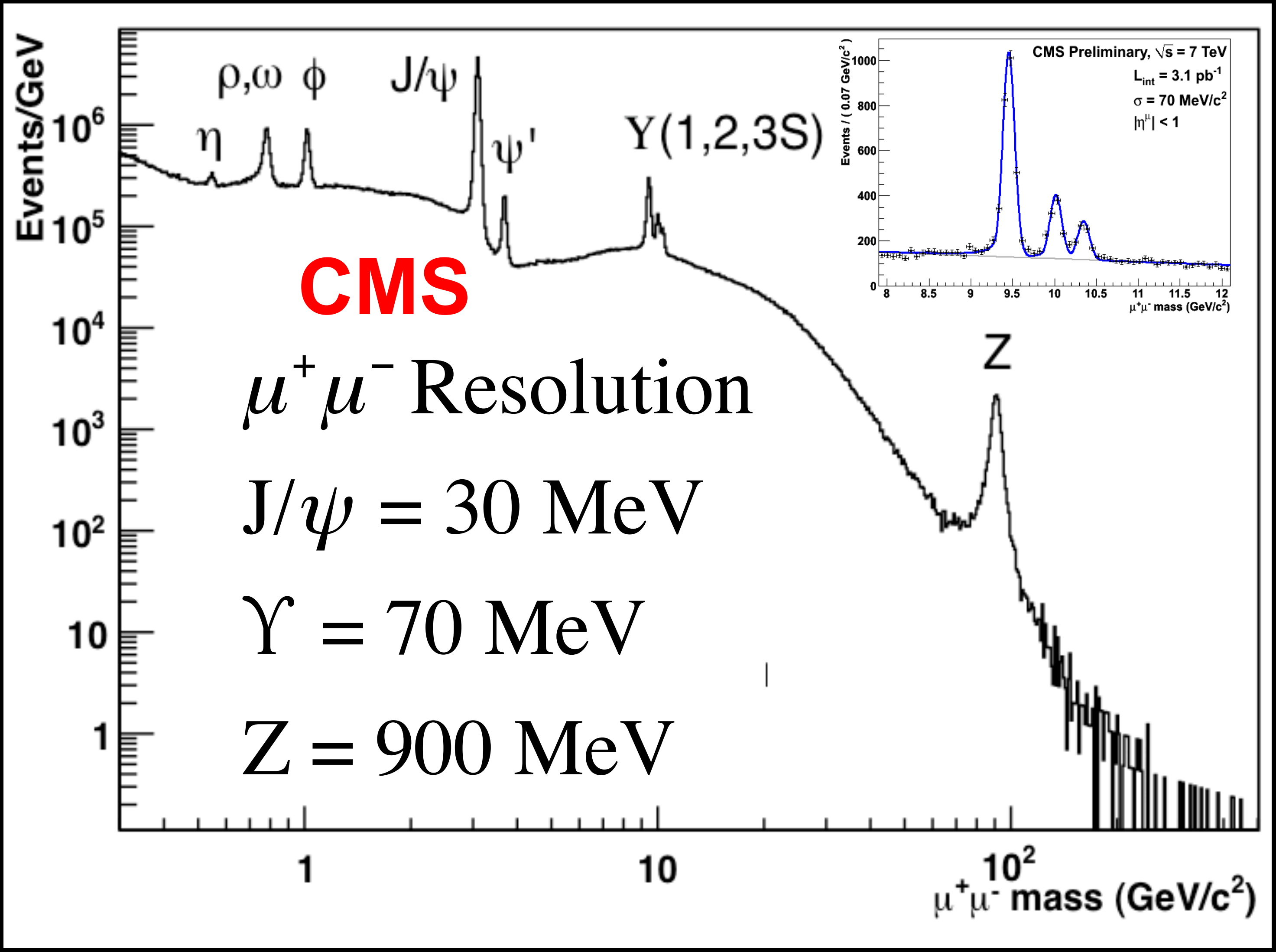
Jet Pt in data and simulation



Muon Performance

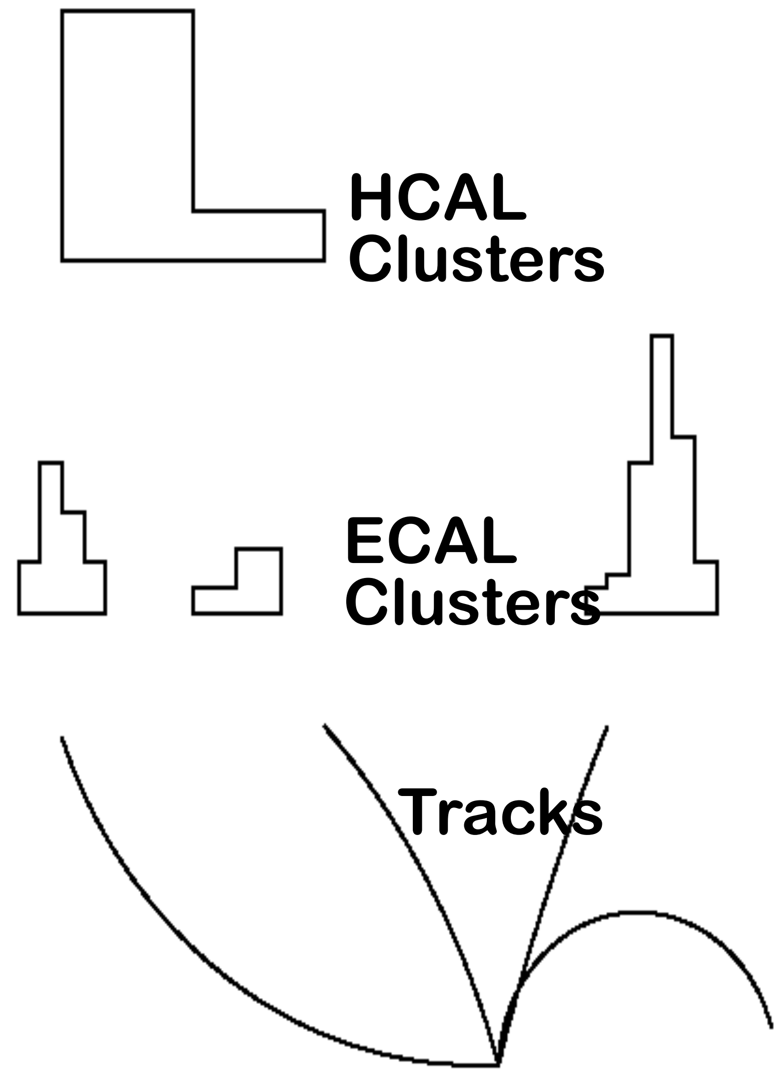


A spectroscopists delight
rediscovering the Benchmarks of the Standard Model



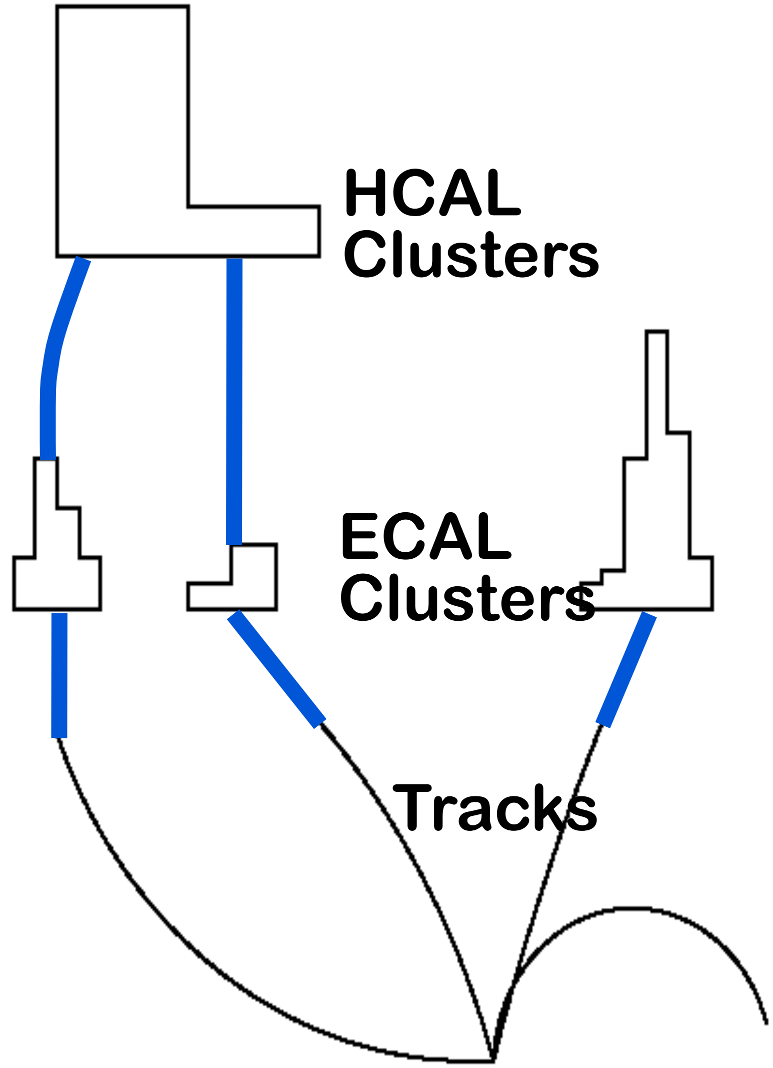
Particle Flow in CMS

- Reconstruct and identify all >> individual particles <<
  - γ, e, μ, $\pi^{\pm}$, K_L^0, pile-up $\pi^{\pm}$, converted γ & nuclear interaction $\pi^{\pm}$,...
  - Use best combination of all CMS sub-detectors for E, η, φ, pID
- Provide consistent & complete list of ID'd & calibrated particles for
  - Tau reconstruction
  - Jet reconstruction
  - Missing Energy determination
  - Any other, analysis specific, objects (event or jet shape vars, etc)
- Use Redundant Information, where ever possible (calo vs tracking)
  - Better energy calibration
  - Better energy resolution
  - Better noise rejection



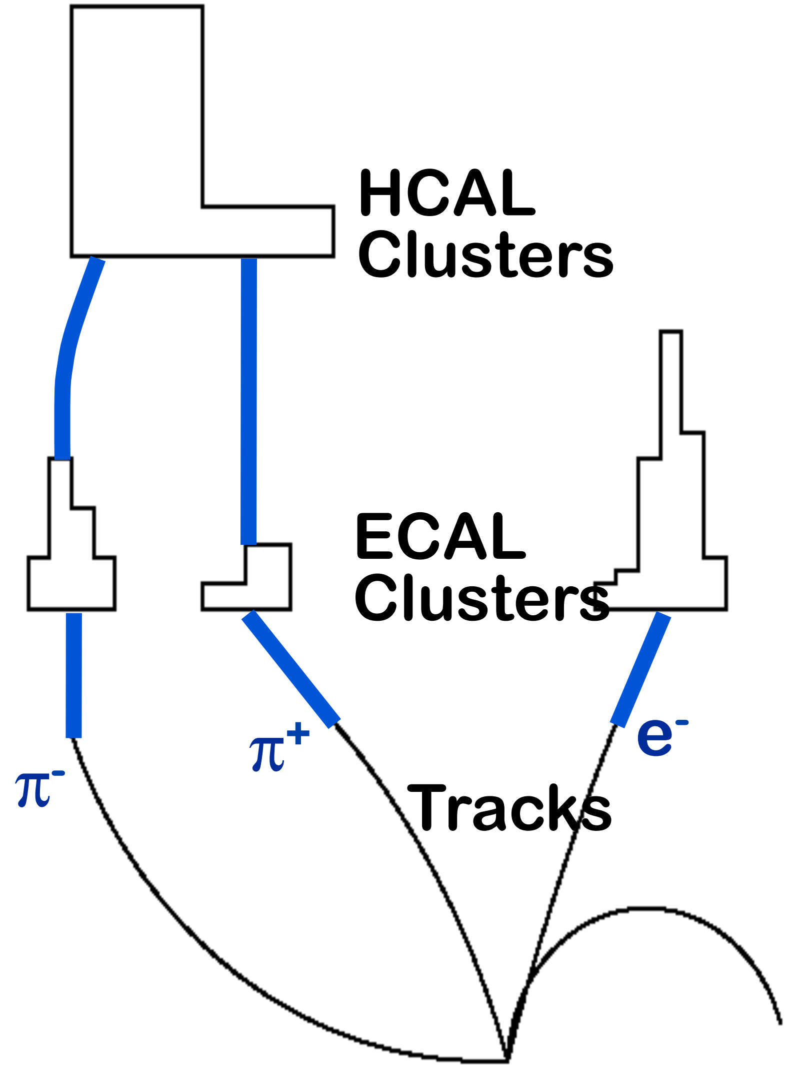
Particle Flow in CMS

- Reconstruct and identify all >> individual particles <<
  - γ, e, μ, $\pi^{\pm}$, K_L^0, pile-up $\pi^{\pm}$, converted γ & nuclear interaction $\pi^{\pm}$,...
  - Use best combination of all CMS sub-detectors for E, η, φ, pID
- Provide consistent & complete list of ID'd & calibrated particles for
  - Tau reconstruction
  - Jet reconstruction
  - Missing Energy determination
  - Any other, analysis specific, objects (event or jet shape vars, etc)
- Use Redundant Information, where ever possible (calo vs tracking)
  - Better energy calibration
  - Better energy resolution
  - Better noise rejection



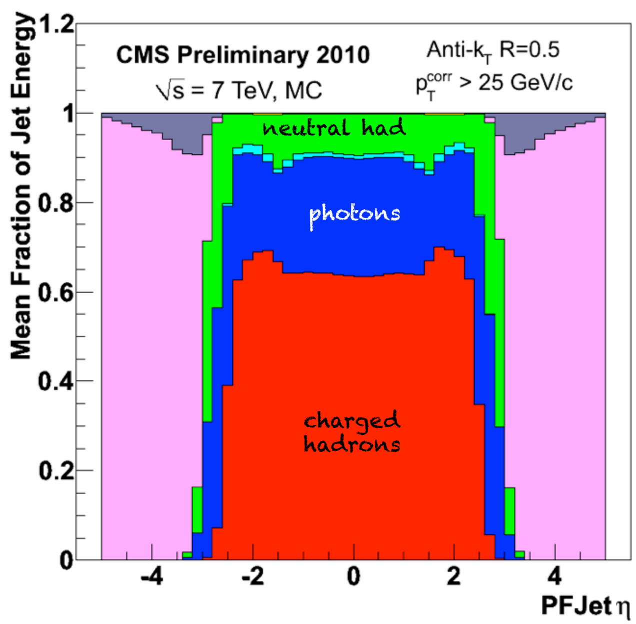
Particle Flow in CMS

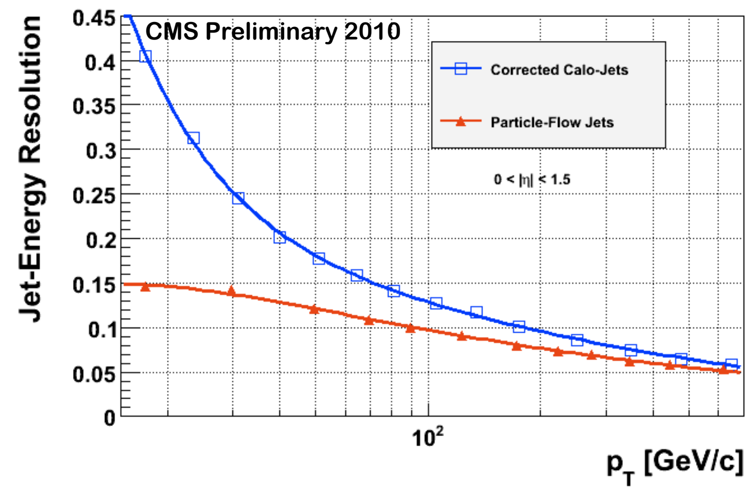
- Reconstruct and identify all >> individual particles <<
  - γ, e, μ, $\pi^{\pm}$, K_L^0, pile-up $\pi^{\pm}$, converted γ & nuclear interaction $\pi^{\pm}$,...
  - Use best combination of all CMS sub-detectors for E, η, φ, pID
- Provide consistent & complete list of ID'd & calibrated particles for
  - Tau reconstruction
  - Jet reconstruction
  - Missing Energy determination
  - Any other, analysis specific, objects (event or jet shape vars, etc)
- Use Redundant Information, where ever possible (calo vs tracking)
  - Better energy calibration
  - Better energy resolution
  - Better noise rejection



Jets & Missing ET from Particle Flow

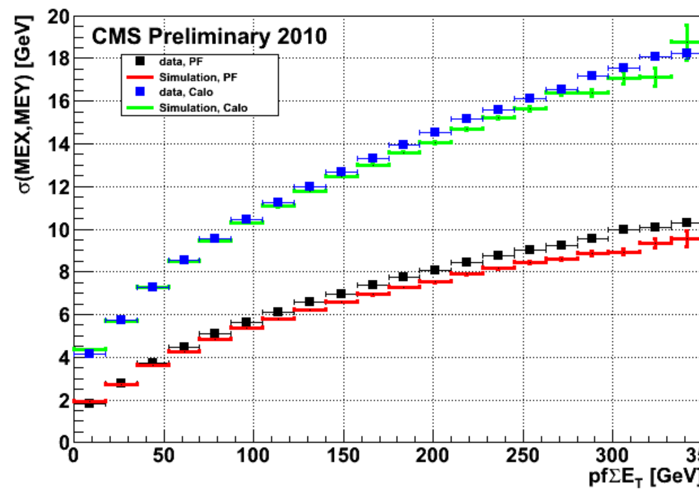
- The list of reconstructed particles form a global event description:
  - { $\mu^\pm$, $e^\pm$, γ, $\pi^\pm$, K_L^0, pile-up particles, etc }
- `Jets` formed by clustering reconstructed particles

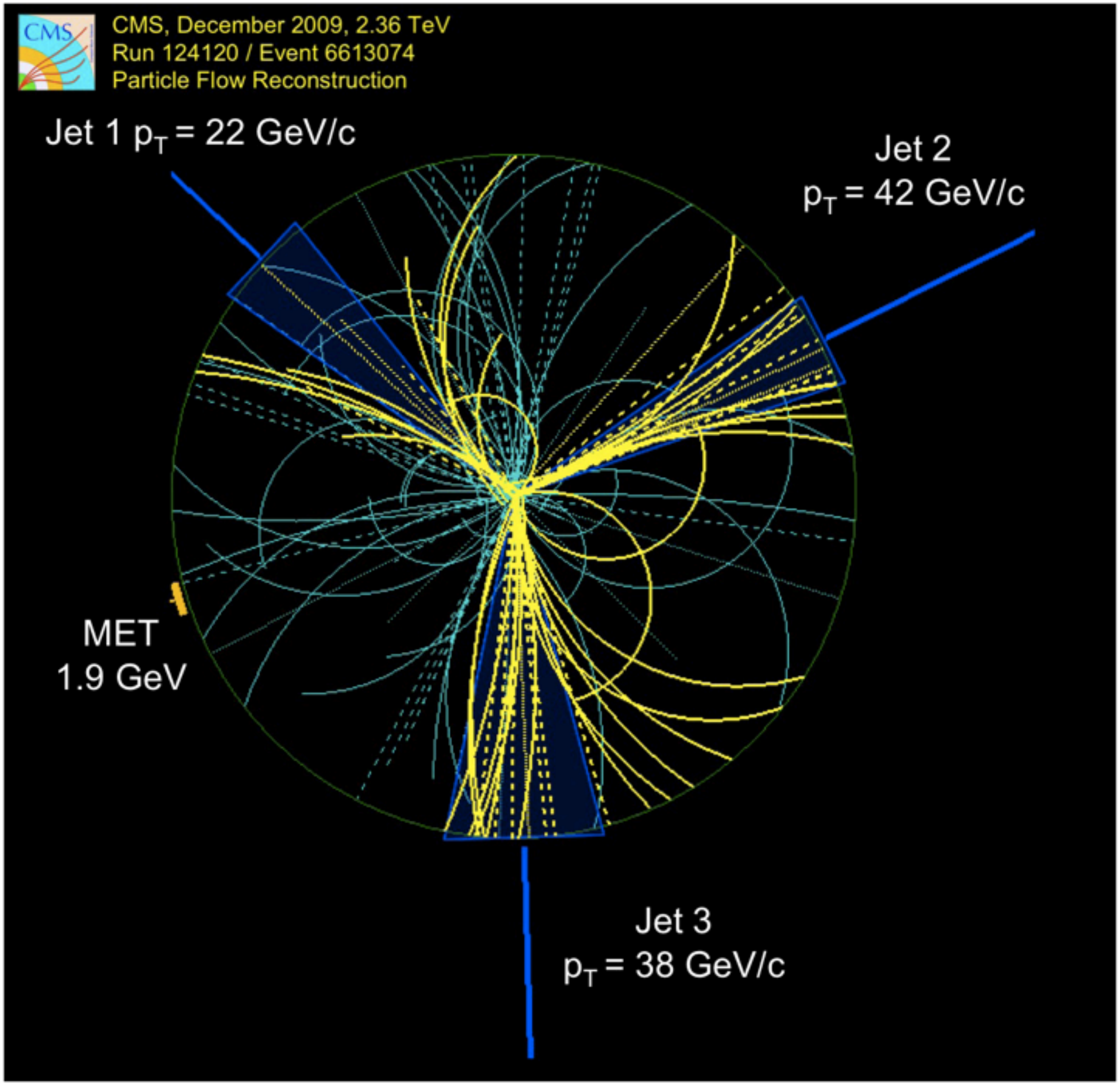


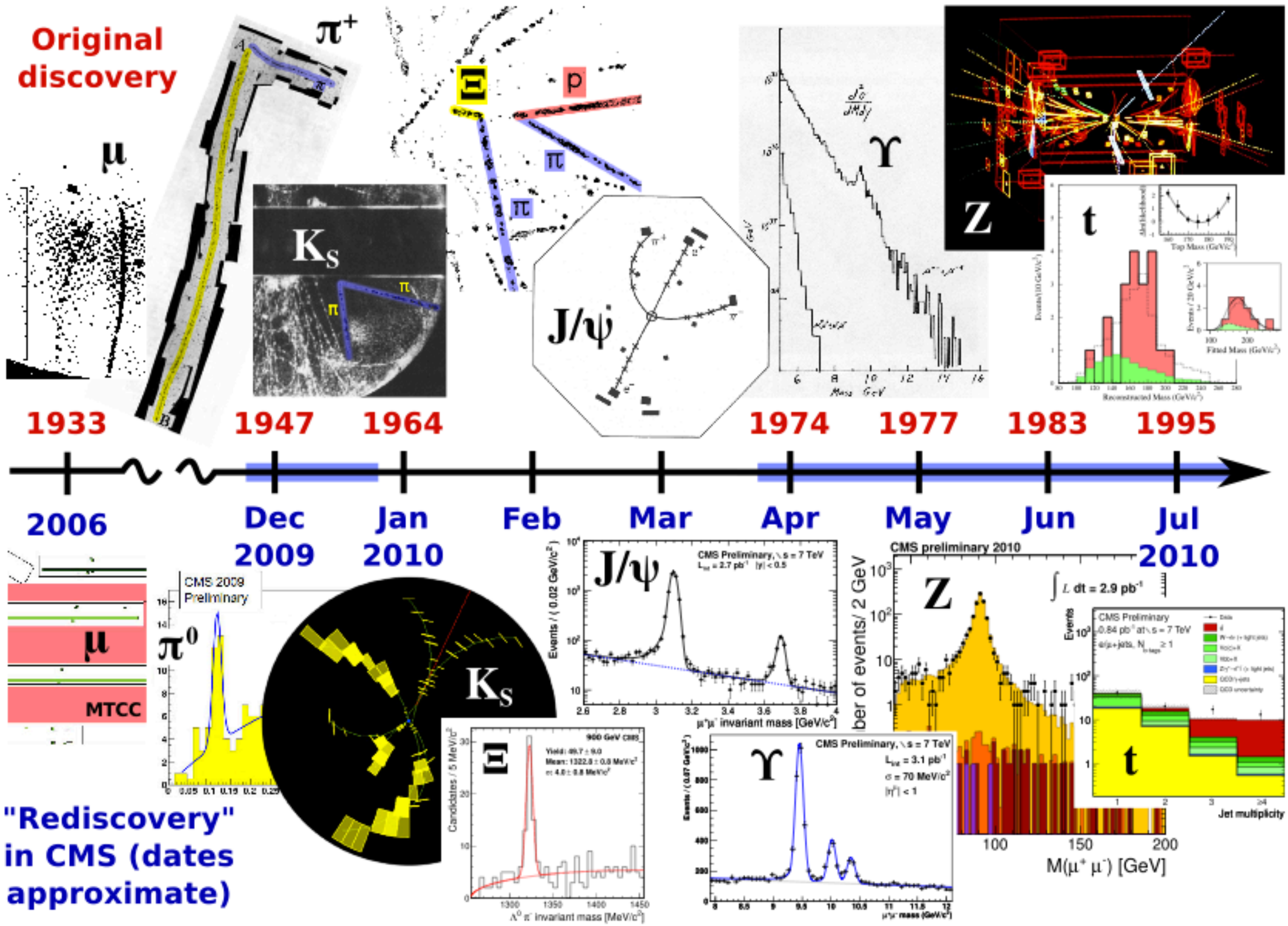


- `MET` formed from transverse momentum vector sum over all reconstructed particles:

$$\vec{\not{E}}_T = -\sum_{\text{particles}} (p_x \hat{\mathbf{i}} + p_y \hat{\mathbf{j}})$$




CMS, December 2009, 2.36 TeV
Run 124120 / Event 6613074
Particle Flow Reconstruction
Jet 1 p_T = 22 GeV/c
Jet 2
p_T = 42 GeV/c
MET
1.9 GeV
Jet 3
p_T = 38 GeV/c


Original discovery
μ
π+
KS
π
Ξ
p
J/ψ
ϒ
Z
t
1933
1947
1964
1974
1977
1983
1995
2006
Dec 2009
Jan 2010
Feb
Mar
Apr
May
Jun
Jul 2010
MTCC
π0
CMS 2009 Preliminary
CMS Preliminary, √s = 7 TeV
μ+μ- invariant mass [GeV/c2]
CMS preliminary 2010
M(μ+ μ-) [GeV]
Jet multiplicity
Λ0 π- invariant mass [MeV/c2]
"Rediscovery" in CMS (dates approximate)

CMS papers on Collision Data… so far

1. Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV
2. Measurement of the $t\bar{t}$ production cross section and the top quark mass in the dilepton channel in pp collisions at $\sqrt{s}$=7
3. Search for First Generation Scalar Leptoquarks in the *eνjj* Channel in pp Collisions at $\sqrt{s}$= 7 TeV
4. Suppression of excited Υ states in PbPb collisions at $\sqrt{s_{NN}}$= 2.76 TeV
5. Measurement of W*γ* and *Zγ* production in pp collisions at $\sqrt{s}$=7 TeV
6. Long-range and short-range di hadron angular correlations in central PbPb collisions at $\sqrt{s_{NN}}$= 2.76 TeV
7. Search for supersymmetry in events with a lepton, a photon, and large missing transverse energy in pp collisions at $\sqrt{s}$= 7 TeV
8. Measurement of the Polarization of W Bosons with Large Transverse Momenta in W+Jets Events at the LHC
9. Charged particle transverse momentum spectra in pp collisions at $\sqrt{s}$= 0.9 and 7 Te
10. Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy at the LHC
11. Measurement of the B0Production Cross Section in pp Collisions at $\sqrt{s}$= 7 TeV / CMS Collaboration
12. Measurement of the differential dijet production cross section in proton-proton collisions at sqrt(s)=7 TeV
13. Search for Neutral MSSM Higgs Bosons Decaying to Tau Pairs in pp Collisions at sqrt(s)=7 TeV
14. Measurement of the Inclusive Z Cross Section via Decays to Tau Pairs in pp Collisions at sqrt(s) = 7 TeV
15. Search for Large Extra Dimensions in the Diphoton Final State at the Large Hadron Collider
16. Measurement of the Lepton Charge Asymmetry in Inclusive W Production in pp Collisions at sqrt(s) = 7 TeV
17. Search for Physics Beyond the Standard Model in Opposite-sign Dilepton Events in pp Collisions at $\sqrt{s}$= 7 TeV
18. Search for Resonances in the Dilepton Mass Distribution in pp Collisions at $\sqrt{s}$= 7 TeV
19. Search for Supersymmetry in pp Collisions at $\sqrt{s}$= 7 TeV in Events with Two Photons and Missing Transverse Energy
20. Search for a W' boson decaying to a muon and a neutrino in pp collisions at $\sqrt{s}$= 7 TeV
21. Study of Z boson production in PbPb collisions at √sNN= 2.76 TeV
22. Measurement of W+W−Production and Search for the Higgs Boson in pp Collisions at $\sqrt{s}$= 7 TeV
23. Search for Heavy Bottom-like Fourth Generation Quark in tW Final State at CMS in pp Collisions at $\sqrt{s}$=7TeV.
24. Strange Particle Production in pp collisions at $\sqrt{s}$= 0.9 and 7 TeV
25. Measurement of BB Angular Correlations based on Secondary Vertex Reconstruction at $\sqrt{s}$=7TeV in CMS
26. Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp collisions at $\sqrt{s}$=7TeV
27. Observation and studies of jet quenching in PbPb collisions $\sqrt{S_{NN}}$= 2.76 TeV
28. First Measurement of Hadronic Event Shapes in pp collisions at $\sqrt{s}$=7TeV
29. Dijet Azimuthal Decorrelations in pp Collisions at $\sqrt{s}$=7TeV
30. Measurement of Bose–Einstein Correlations in pp Collisions

CMS papers on Collision Data… so far

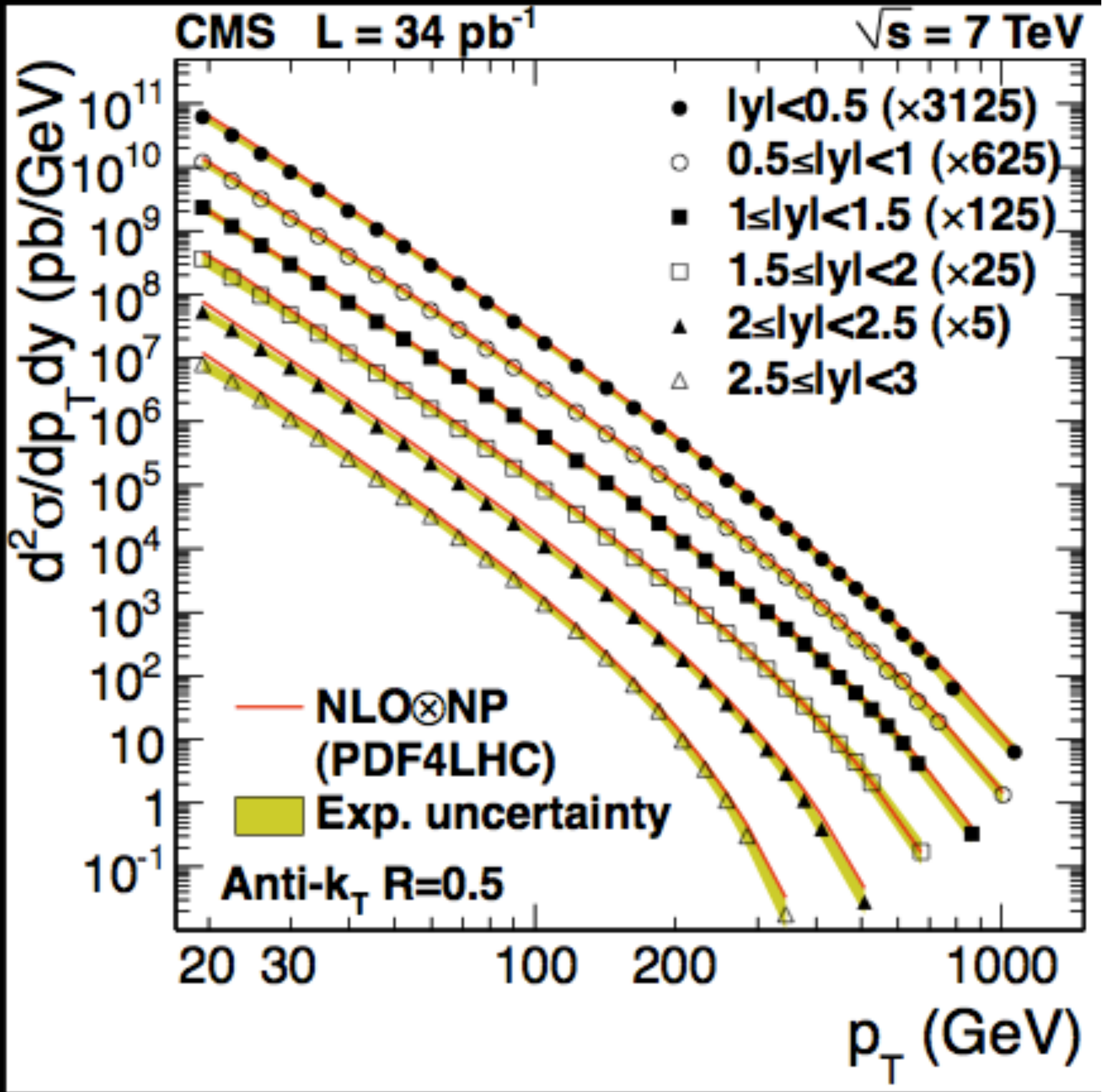
31. Inclusive b-hadron production cross section with muons in pp collisions
32. Search for Heavy Stable Charged Particles in pp collisions
33. Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy
34. Measurement of the B+ Production Cross Section in pp Collisions at √s = 7TeV
35. Search for a heavy gauge boson W' in final states with electrons and large missing ET in pp collisions
36. Upsilon production cross section in pp collisions at √s = 7TeV
37. Search for Pair Production of Second-Generation Scalar Leptoquarks in pp Collisions at √s= *7TeV*
38. Search for Pair Production of First-Generation Scalar Leptoquarks in pp Collisions at √s= *7TeV*
39. Search for Microscopic Black Hole Signatures at the Large Hadron
40. Measurements of Inclusive W and Z Cross Sections in pp Collisions at √s = *7TeV*
41. Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at √s= 7TeV
42. Search for Stopped Gluinos in pp collisions at √s= *7TeV*
43. Charged particle multiplicities in pp interactions at √s= 0.9, 2.36, and 7 TeV
44. Prompt and non-prompt J/ production in pp collisions at √s= 7TeV
45. First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions
46. Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at √s= *7 TeV*
47. Search for Dijet Resonances in 7 TeV pp Collisions at √s=7TeV
48. Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC.
49. CMS Tracking Performance Results from Early LHC Operation.
50. First Measurement of the Underlying Event Activity at the LHC with √s = *0.9 TeV*
51. Transverse-momentum and pseudorapidity distributions of charged hadrons inppcollisions ats√= 7 TeV
52. First Measurement of Bose-Einstein Correlations in pp collisions at √s=0.9 and 2.36 TeV at the LHC
53. Transverse momentum and pseudorapidity distributions of charged hadrons at √s=0.9 and 2.36 TeV

+20 currently in Collaboration Review + others in preparation on results presented at the Winter Conferences and at Quark Matter 2011.

Current estimate of the CMS Scientific Production from the 2010 data > 80 papers.

Inclusive Jet Cross Section

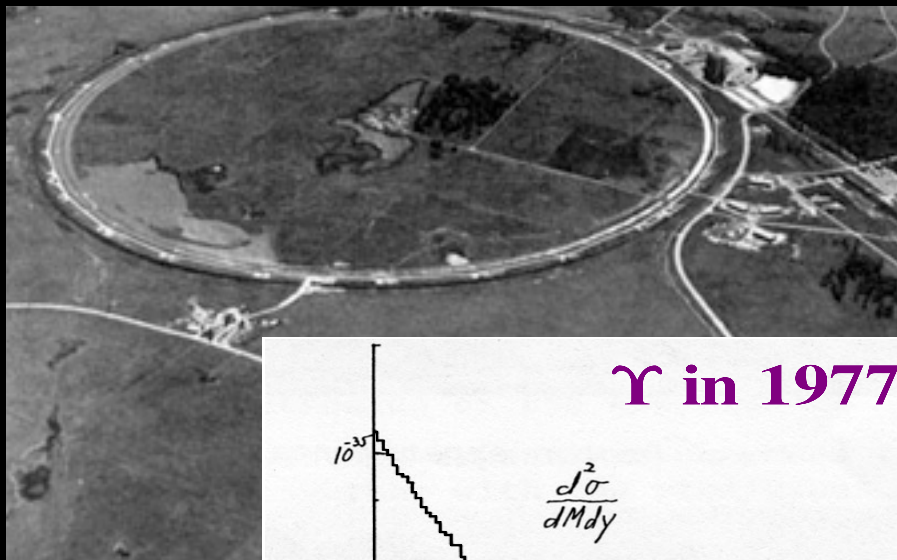
- From pT = 18 GeV to pT = 1 TeV!
- Extending to very low pT thanks to Particle Flow
- dominant systematic uncertainty:
  - Jet Energy Scale: ~3-4%
- Corrected for jet energy scale and resolution (i.e. corrected to particle-level)
- Inclusive jet pT spectra are in good agreement with NLO QCD

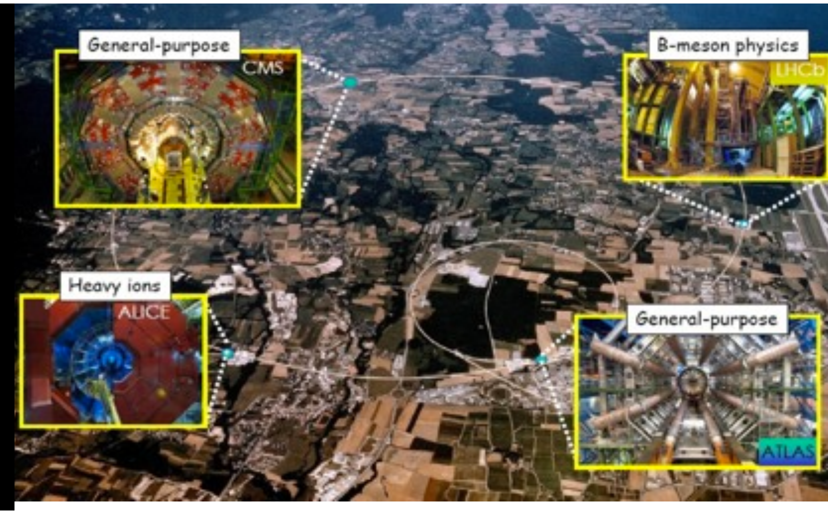


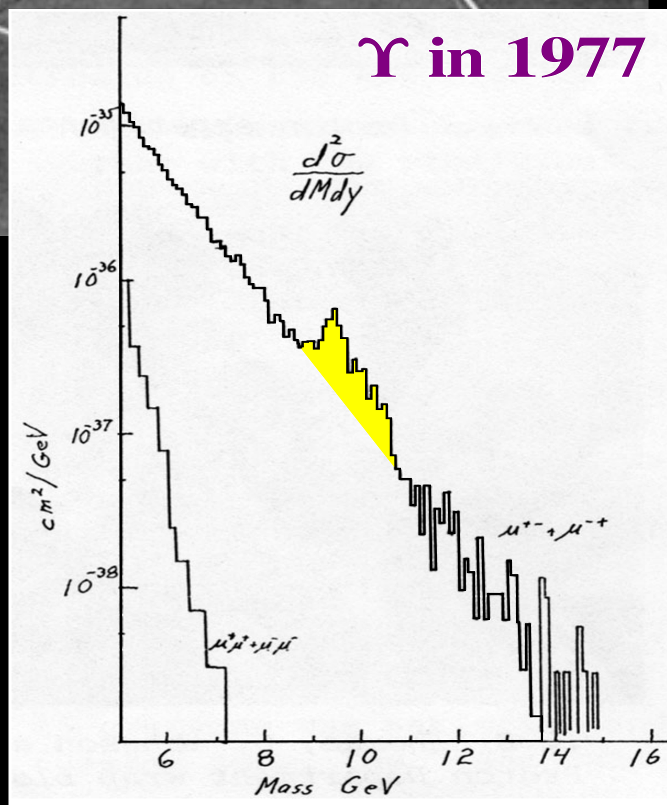
Upsilon Production

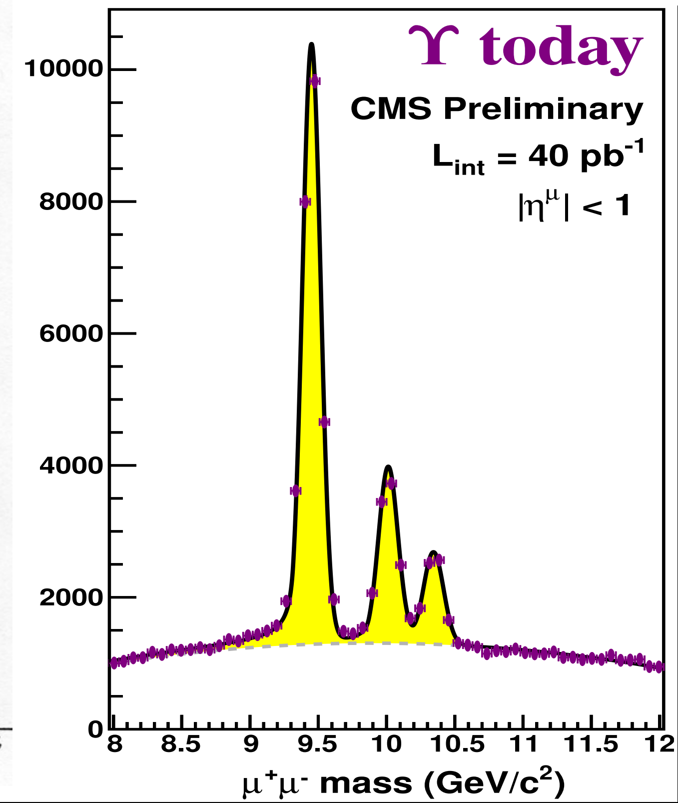
- phenomenology
  - large *b*-quark mass ⇨ non-relativistic effective approaches better realized
  - no feed-down from long-lived *b*-hadrons
- unprecedented energy regime
  - extended reach, *eg* probe p_T>20GeV, best discriminate between models
  - high cross section (and luminosity) ⇨ bottomonia produced copiously
  - allow new era of bottomonium precision measurements
- heavy ion
  - 1 month per year dedicated to heavy-ion physics run
  - cross sections ~50 times larger, energy density ~3 times higher than at RHIC ⇨ will allow first significant measurements of the Υ resonance family
  - improve overall understanding of the cold and hot nuclear matter effects
  - LHC calls for precision studies of bottomonia at high temperature

The Upsilon then & now

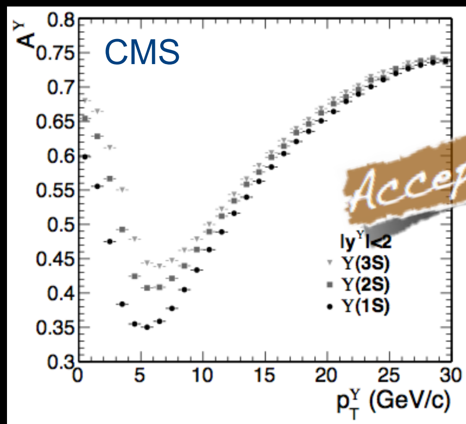




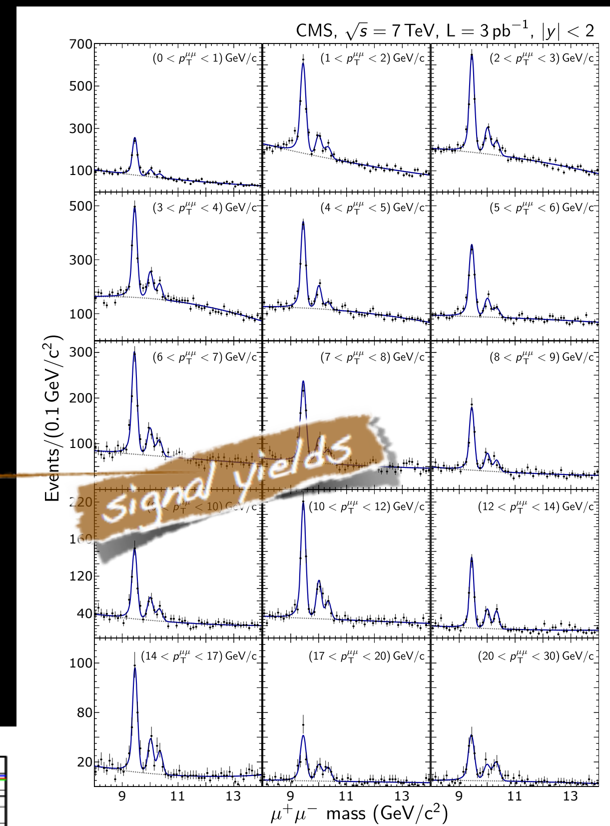


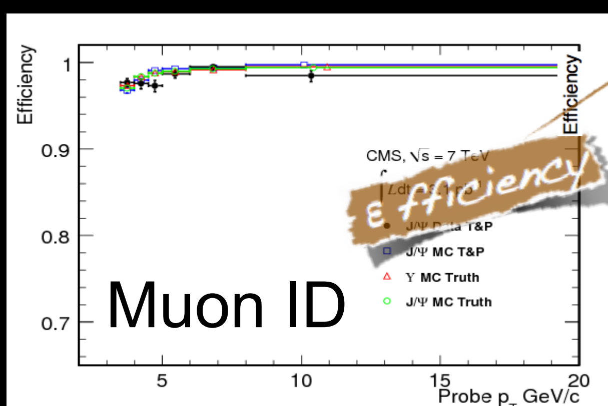


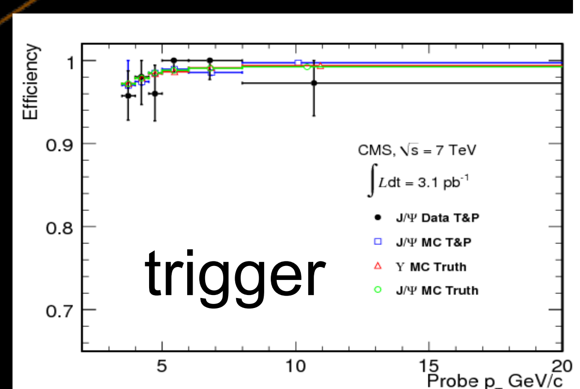
Υ cross-section ingredients



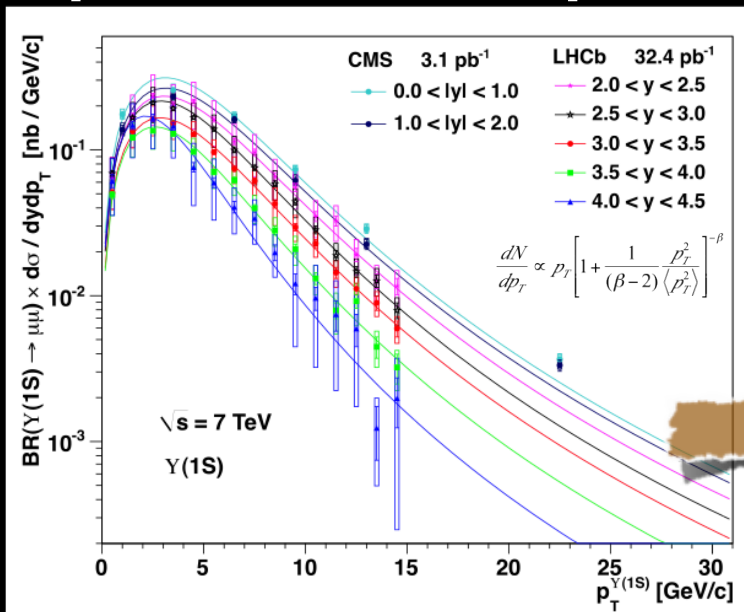
$$\frac{d^2\sigma}{dp_T dy}\cdot\mathcal{B}\left(\Upsilon(nS)\to\mu^+\mu^-\right)=\frac{N^{\rm fit}_{\Upsilon(nS)}(\mathcal{A},\varepsilon)}{\mathcal{L}\cdot\Delta p_T\cdot\Delta y}$$

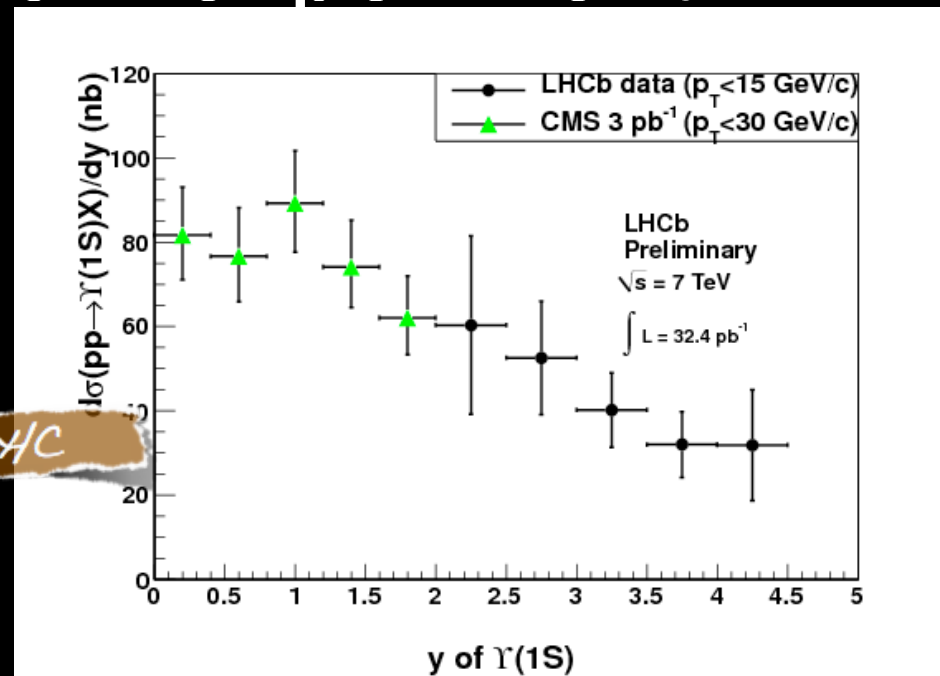


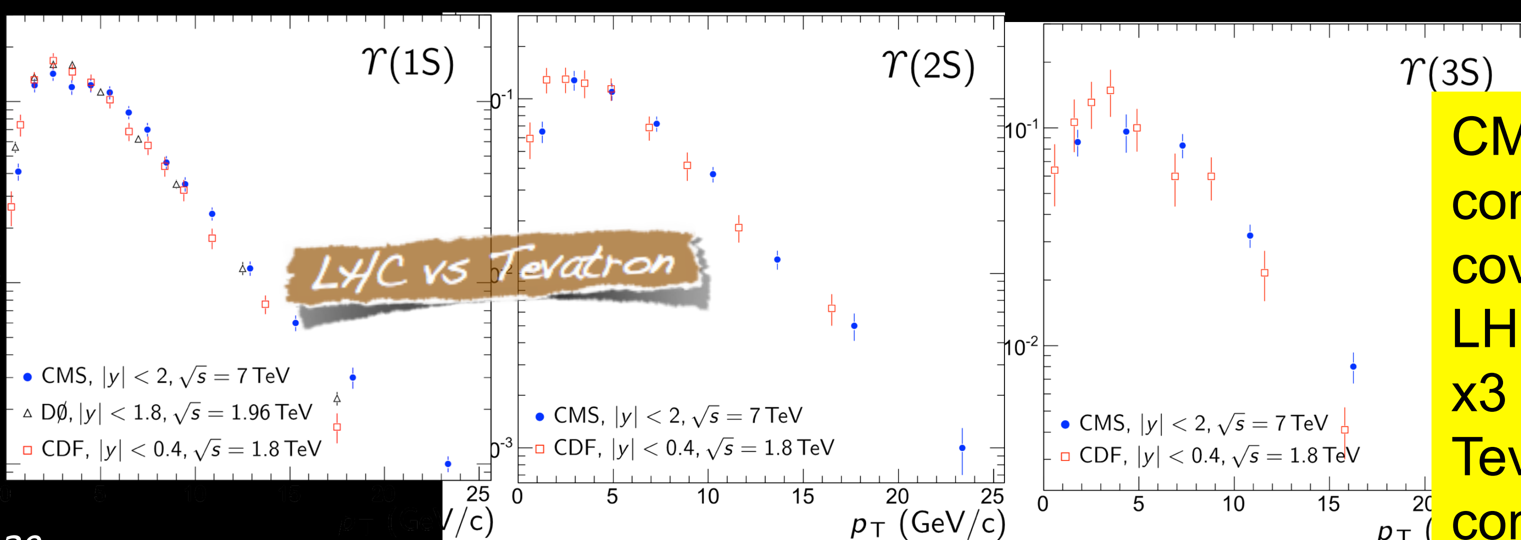




Upsilon comparison: experiment







CMS & LHCb complementary coverage
LHC cross section x3 larger than Tevatron, shape consistent

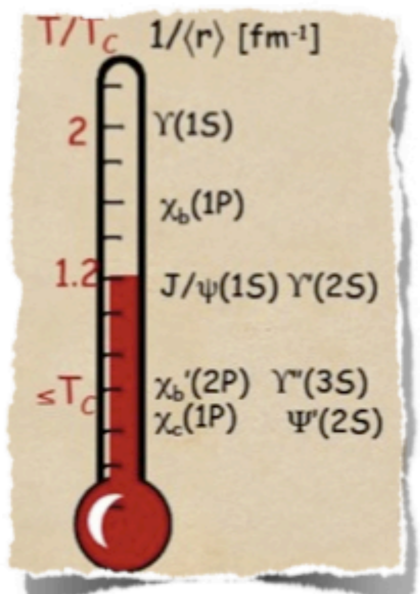
Upsilons as a probe of heavy ion collisions

- at high temperatures, strongly interacting matter becomes a plasma of quarks and gluons
- suppression of quarkonia is a classical prediction of QGP signature
  - color screening of the binding potential [T.Matsui, H.Satz PLB178, 416 (1986)]
  - suppression pattern indicates the medium temperature (*'QGP thermometer'*)

- bottomonium measurements at LHC help characterize the dense matter produced in heavy-ion collisions beyond the SPS and RHIC charmonium results
  - the Υ family of states is an expected powerful probe
  - Υ(1S) is the most tightly bound state ➪ last to melt down
  - provide 3 different states/handles for probing the hot medium
- quantitative bottomonium measurements accessible for first time
  - large production rates ➪ sizable datasets
  - exploit excellent mass resolution

State	Υ (1S)	χ_b (1P)	Υ′ (2S)	χ'_b (2P)	Υ″ (3S)
m (GeV/c^2)	9.46	9.99	10.02	10.26	10.36
r_0 (fm)	0.28	0.44	0.56	0.68	0.78

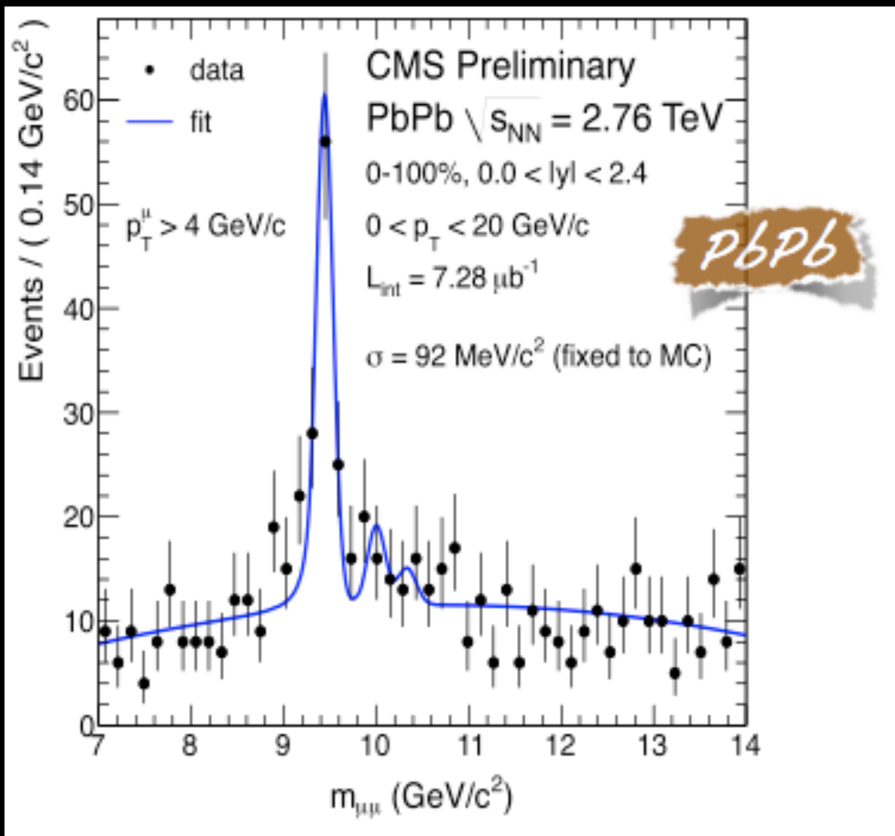
decreasing binding energy ⟶



Tc ~ 150-170MeV

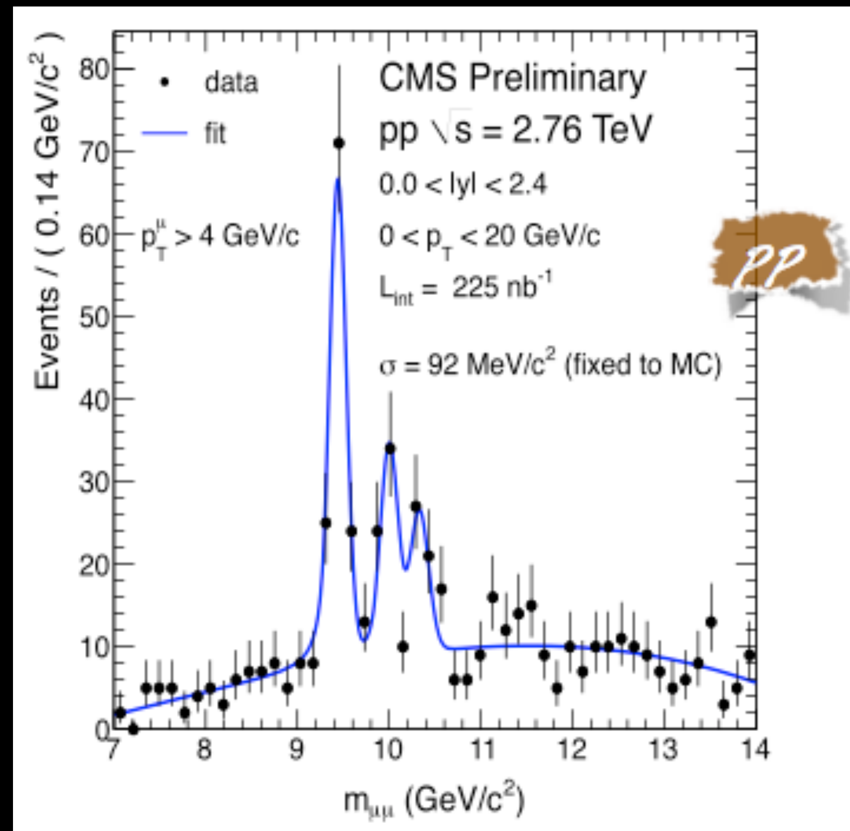
Sequential melting

PbPb run 2010 @2.76TeV (7.28μb^{-1})



$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

pp run 2011 @2.76TeV (225 nb^{-1})



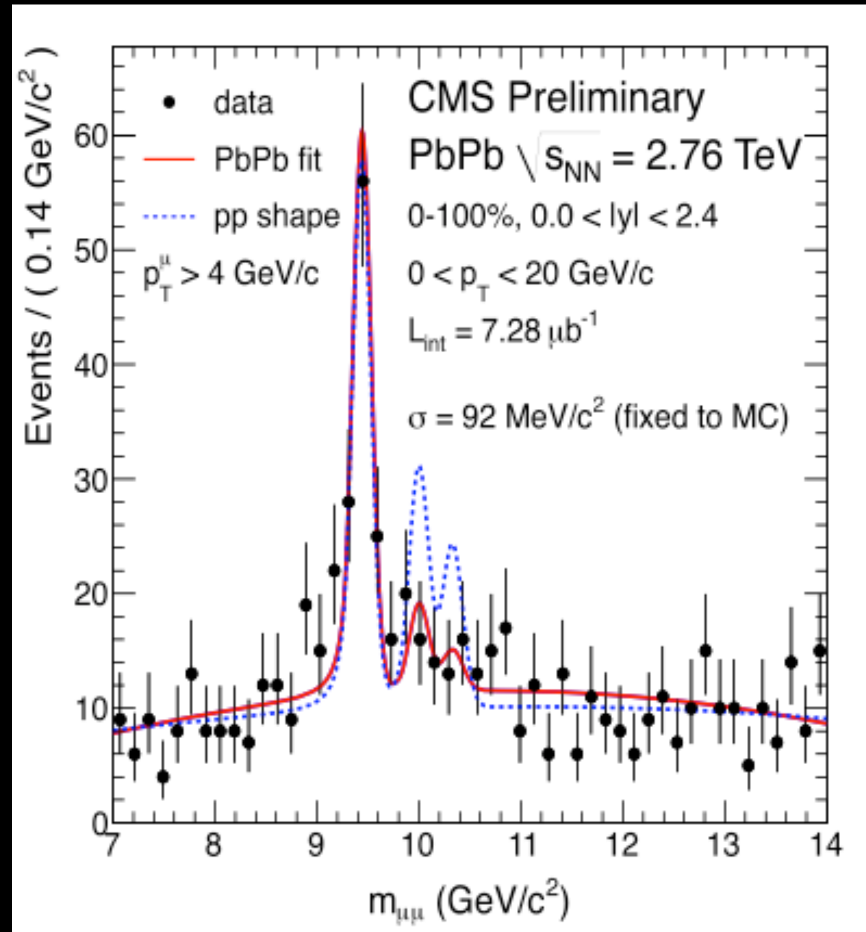
$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02$$

First Observation of Sequential Υ Melting in Heavy Ion Collisions

- extract double ratio directly from simultaneous fit to both samples

$$\chi = \frac{\Upsilon(2S+3S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

- advantages of double ratio
  - acceptance, efficiency, luminosity cancel
  - remaining systematics 9% from fit lineshape model
  - measurement is statistics dominated

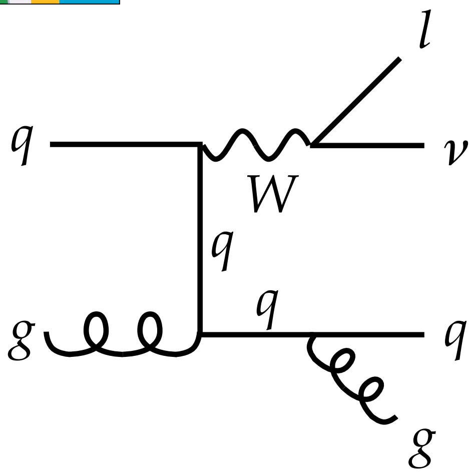


~2.4 σ

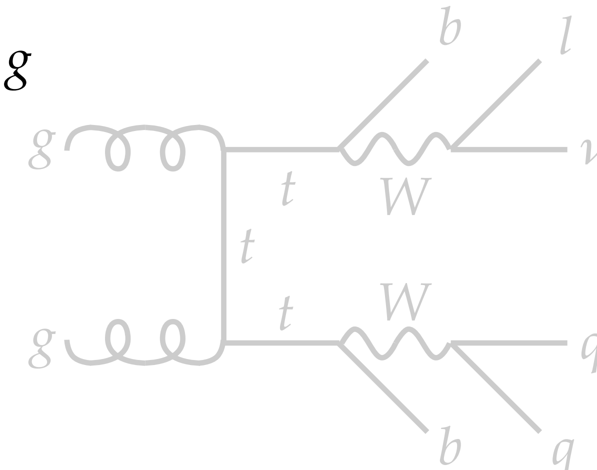
- p-value<1% (probability of background fluctuation)

Descending* the staircase of the SM…

Electroweak



Top

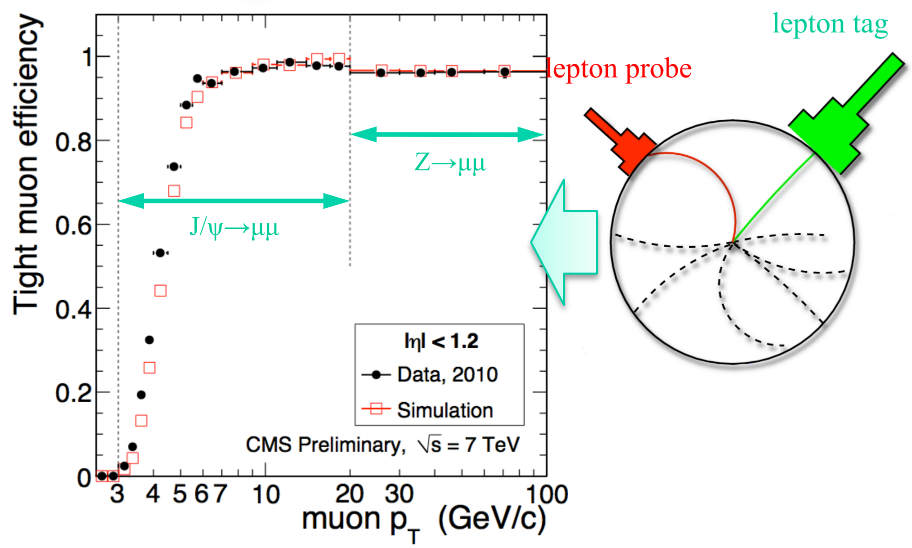


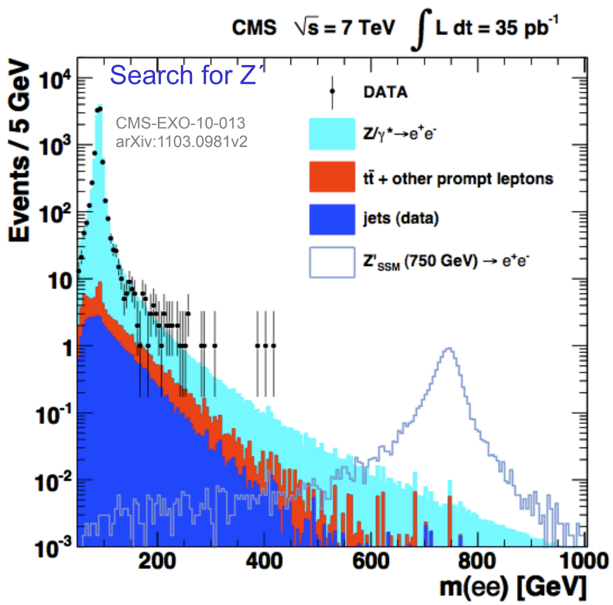
…to New Physics

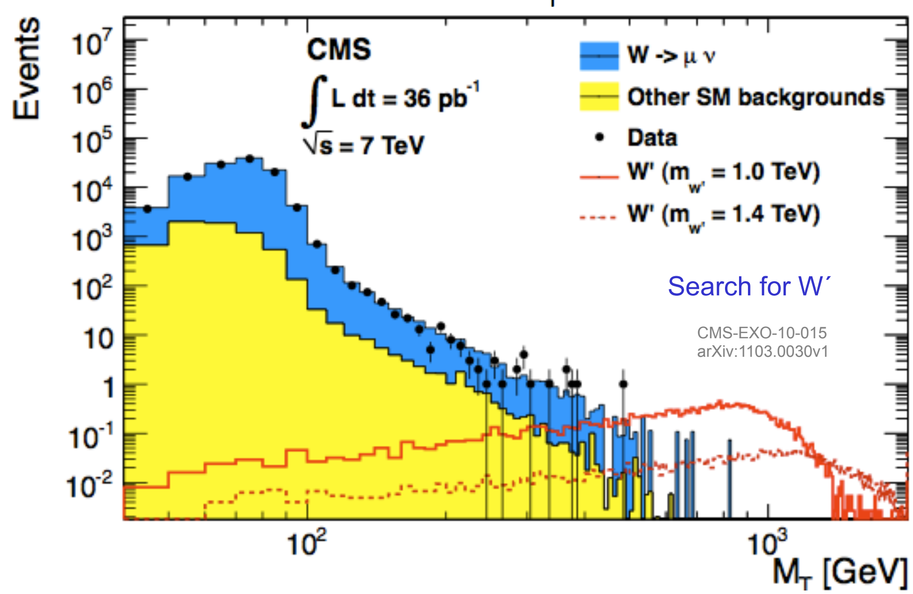
*Adapted from Michael Peskin

EWK as tool and background

- W and Z are also tools to understand and calibrate the detector
  - Tag and probe method for efficiency measurements
  - Lepton scale and resolution, …
- Many searches have EWK processes as main backgrounds
  - Studying EWK processes means keeping backgrounds under control

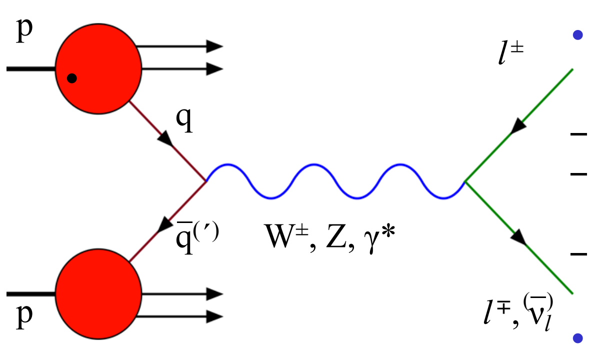






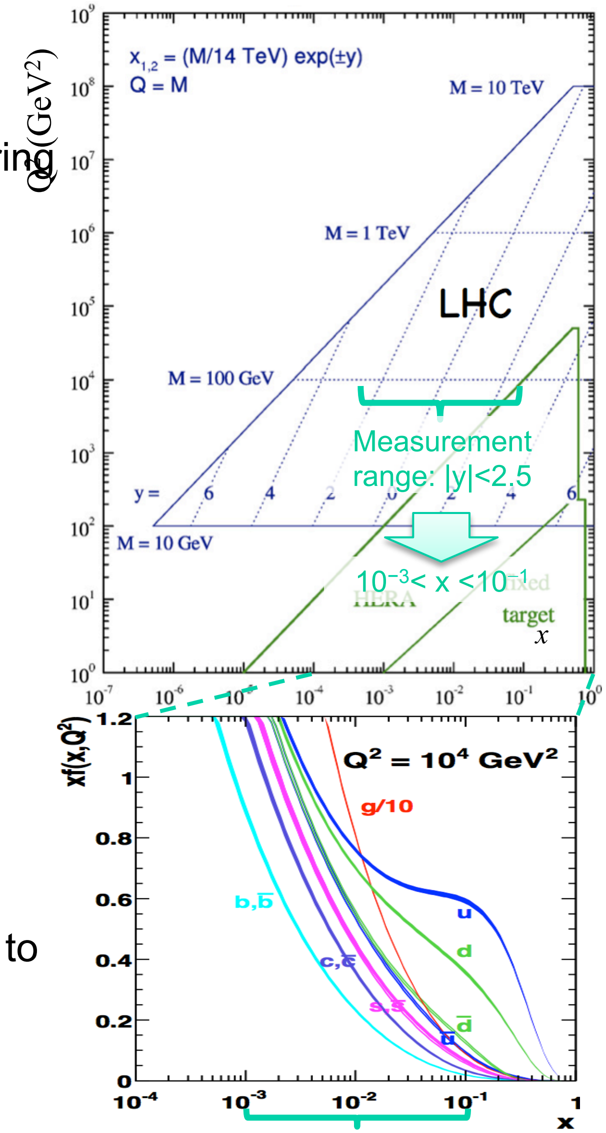
W and Z production at LHC

- W and Z production in pp collisions proceeds mainly form the scattering of a valence quark with a sea anti-quark
- The involved parton fractions are low ($10^{-3} < x < 10^{-1}$) and scattering of a sea quark with a sea anti-quark is also important
- W production is charge asymmetric: $\sigma(W^+)/\sigma(W^-)$~1.43 (< 2, as from valence + sea only) in the Standard Model
- W and Z events produce very clean signals and allow to perform precision measurements
  - Large background control samples are available in data and reduce the need to rely on simulations



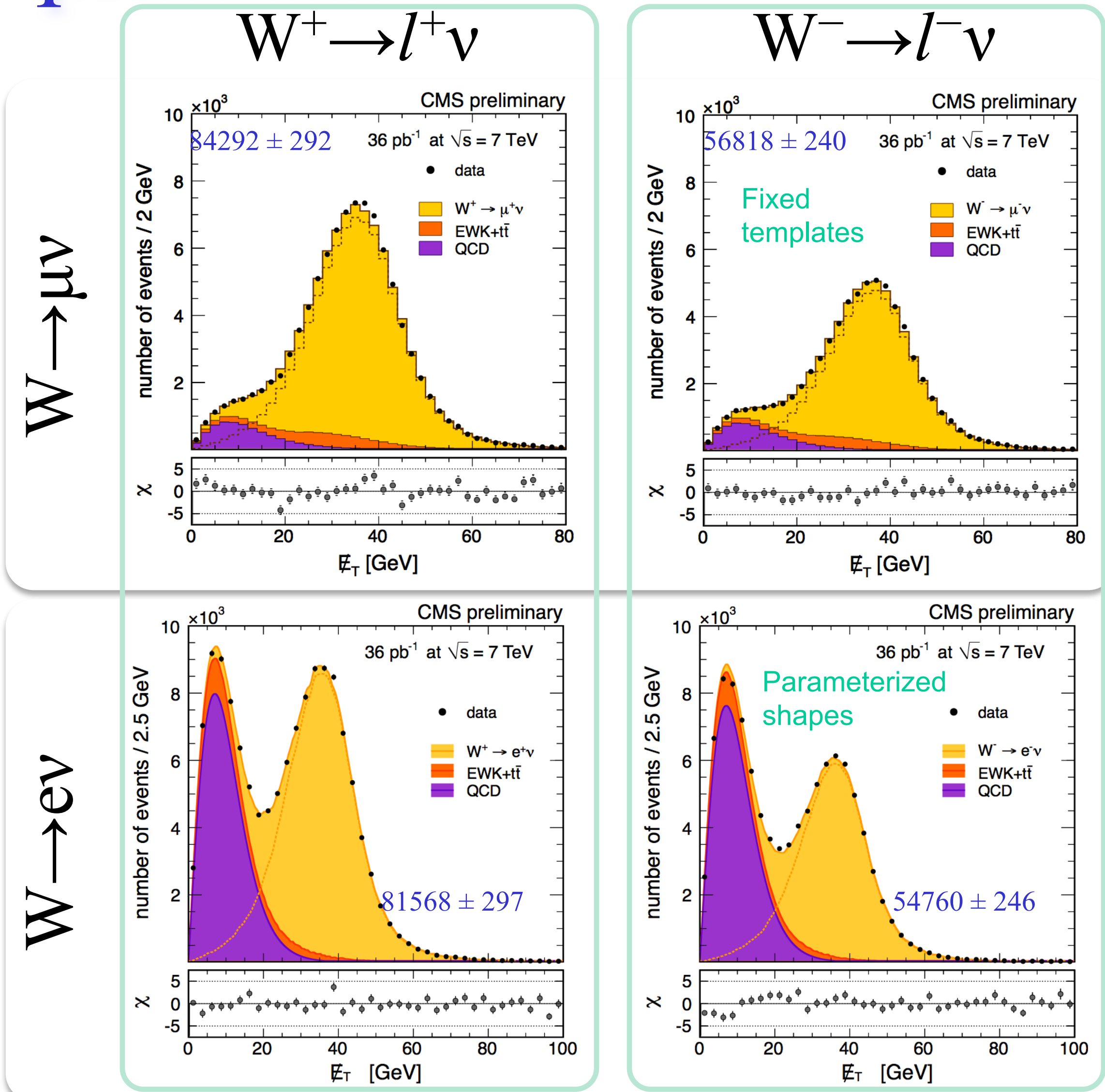
$$Q^2 = m^2_{W,Z} = x_1 x_2 s$$

- Accurate theoretical predictions are available
  - NLO event generators: POWHEG and MC@NLO
  - NNLO cross section and differential distributions: FEWZ, RESBOS, DYNNLO
  - Uncertainties in valence and sea PDF limit the accuracy of theoretical predictions
- Differential distributions are sensitive to PDF



W^+ and W^- production

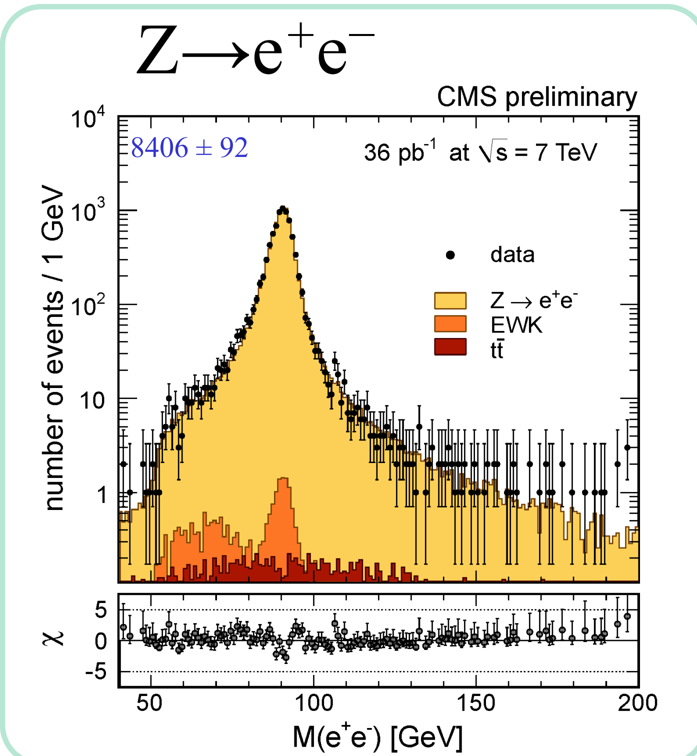
- Fit separately positive and negative lepton missing E_T spectra to extract $\sigma(W^+)$ and $\sigma(W^-)$
- Alternatively, fit simultaneously the total yield and ratio to extract $\sigma(W^\pm)$ and $\sigma(W^+)/\sigma(W^-)$
- In the ratio several uncertainties cancel

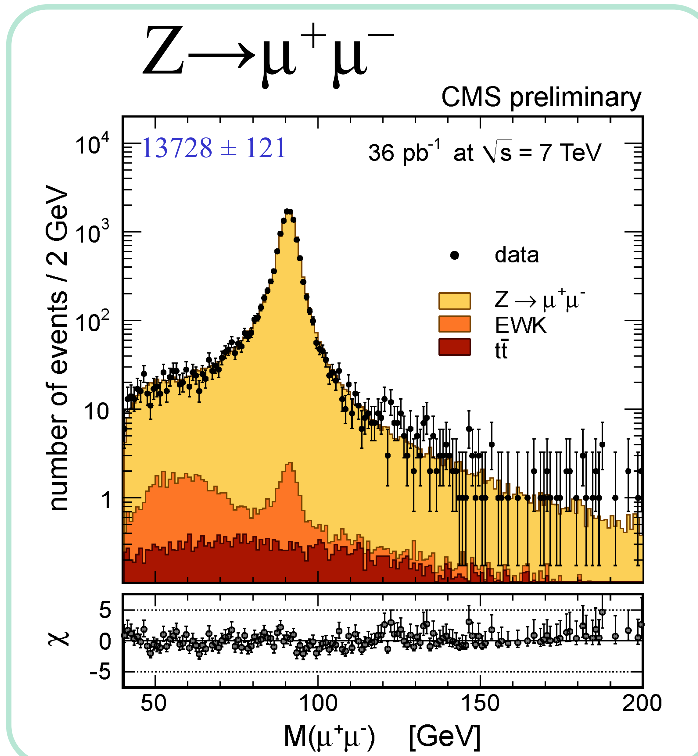


CMS-PAS-EWK-10-005

$Z \rightarrow ll$ analysis

- Isolated di-lepton pairs with p_T>20 (μ), 25 GeV (e) and η within trigger fiducial region. Mass range: $60 < m_{ll} < 120$ GeV
- Fit simultaneously yield and efficiencies using different di-lepton categories (μμ)
- Cut and count analysis using tag & probe efficiencies (ee)

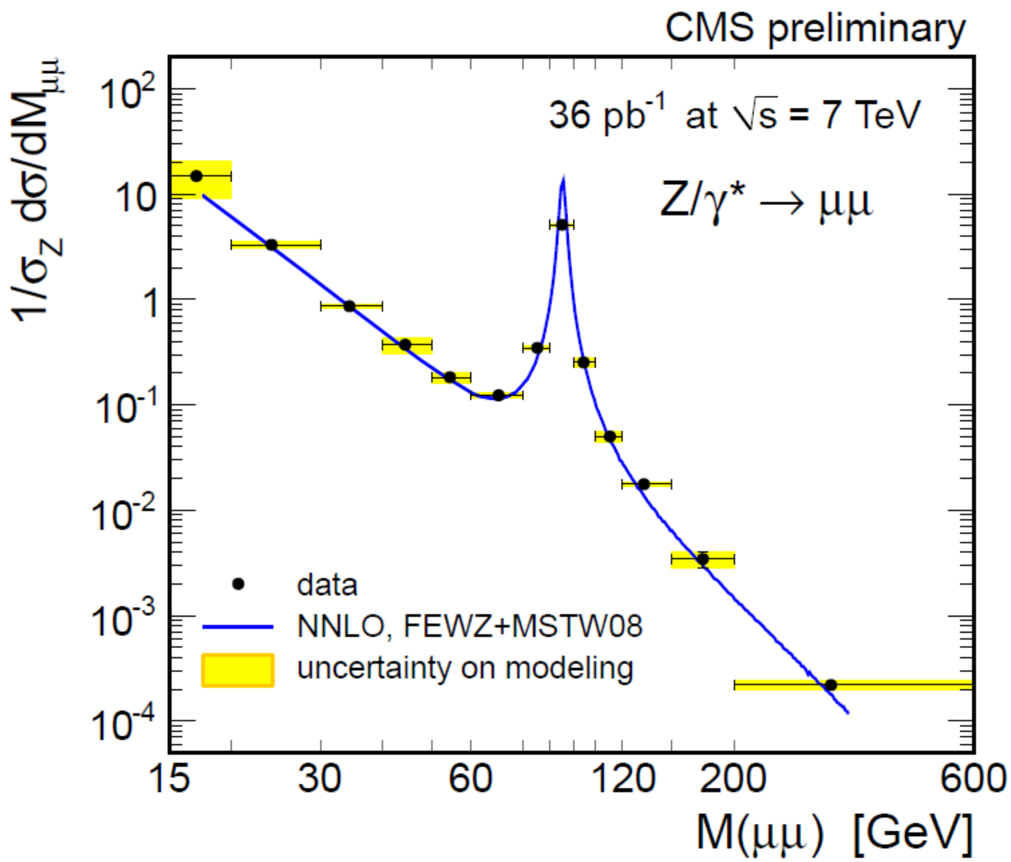




Drell-Yan mass spectrum

- Drell-Yan spectrum is
  - Important background in high mass
  - Sensitive to PDFs
- Asymmetric kinematic cuts on the muons
  - To collect more data in low mass region
  - $p_T > 16$ GeV with |eta| < 2.1
  - $p_T > 7$ GeV with |eta| < 2.4
- Unfolding correction for detector resolution effect
  - FSR effects are corrected using simulation
- Good agreement with NNLO calculations at FEWZ

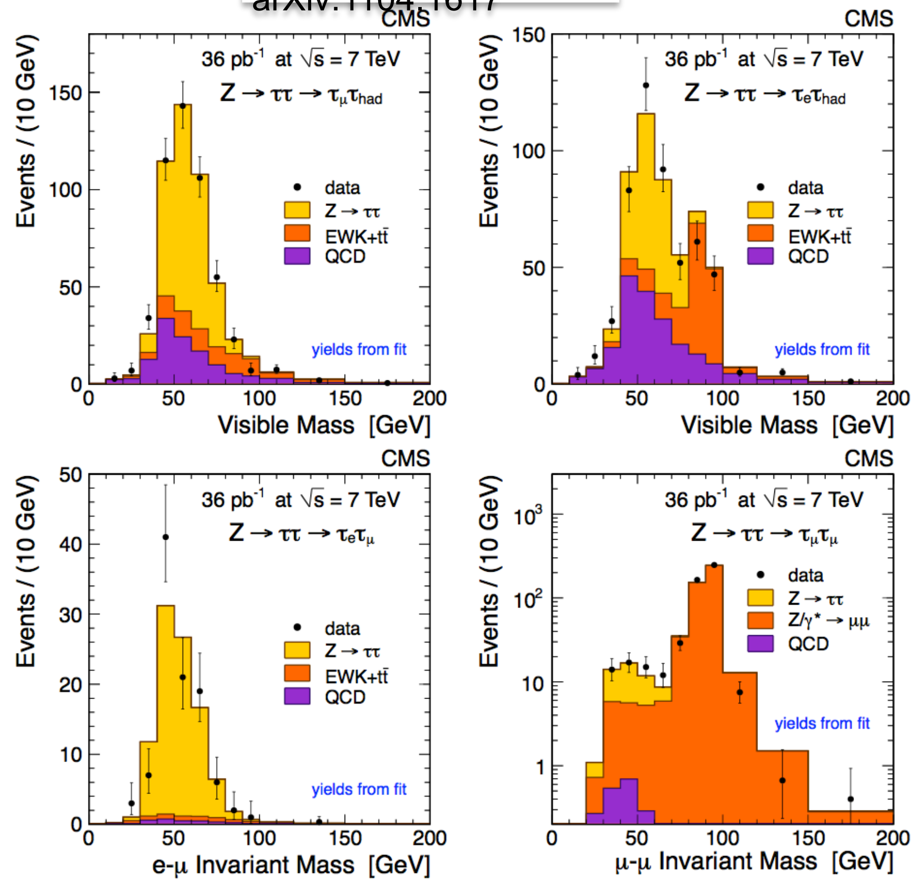
CMS PAS EWK-10-007

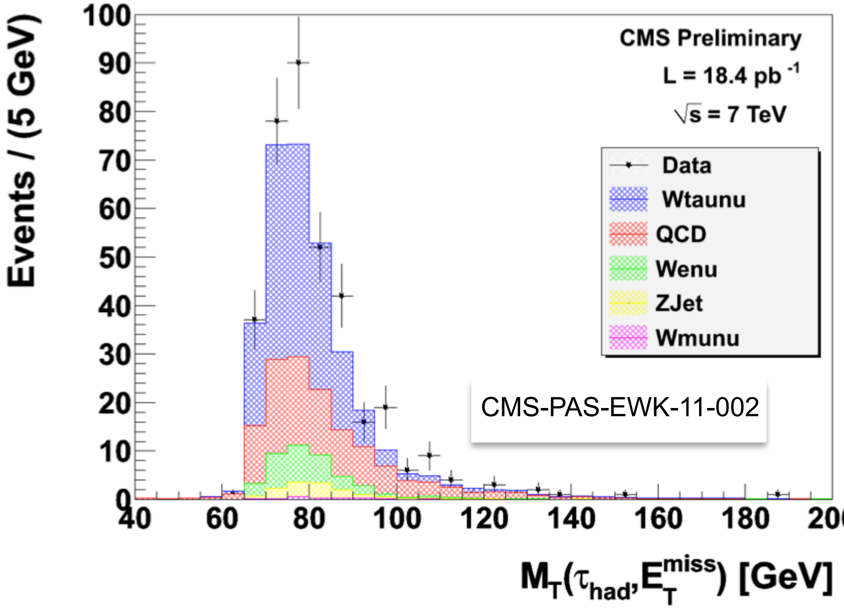


Z→ττ, W→τν

CMS-PAS-
EWK-10-013
arXiv:1104.1617

- Benchmark for searches using taus ($H^+\to\tau\nu$, $H\to\tau\tau$, …)
- Particle Flow: combine tracker and calorimeter measurements to determine particle candidates
- Main systematic: tau id (23%) fit from data
- Challenging trigger on tau plus missing E_T for $W\to\tau\nu$
  - $p_T(\tau) > 20$ GeV, p_T(track)>15 GeV, missing E_T >25 GeV



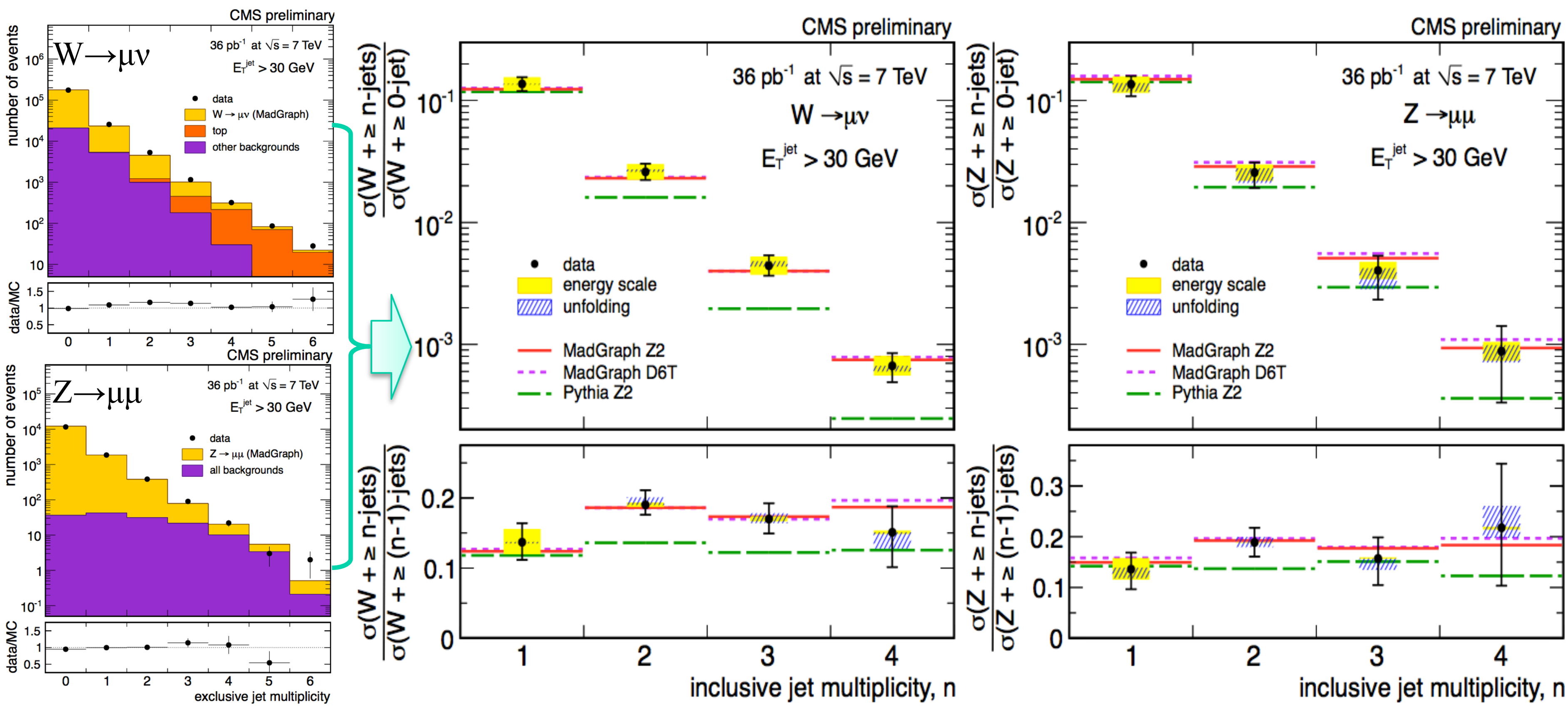


Process	Events
W→τν (sim.)	174 ± 3
EWK (sim.)	46 ± 2
QCD (sideband)	109 ± 6
Data	372

W, Z + *n* jets

CMS-PAS-EWK-10-012

- Important test of perturbative NLO predictions and background to Higgs and many searches
- Jets reconstructed from Particle Flow using anti-k_T algorithm (R=0.5), E_T > 30 GeV
- Systematics dominates, mainly due to energy scale and unfolding for large *n* (Singular Value Decomposition, assuming MadGraph jet migration from particle-level jets)
- Agreement with MadGraph, discrepancies with Pythia observed



W, Z + n jets scaling

- Berends-Giele scaling:

$$\frac{\sigma(V+ \geq n - \text{jets})}{\sigma(V+ \geq (n+1) - \text{jets})} = \alpha + \beta \times n$$

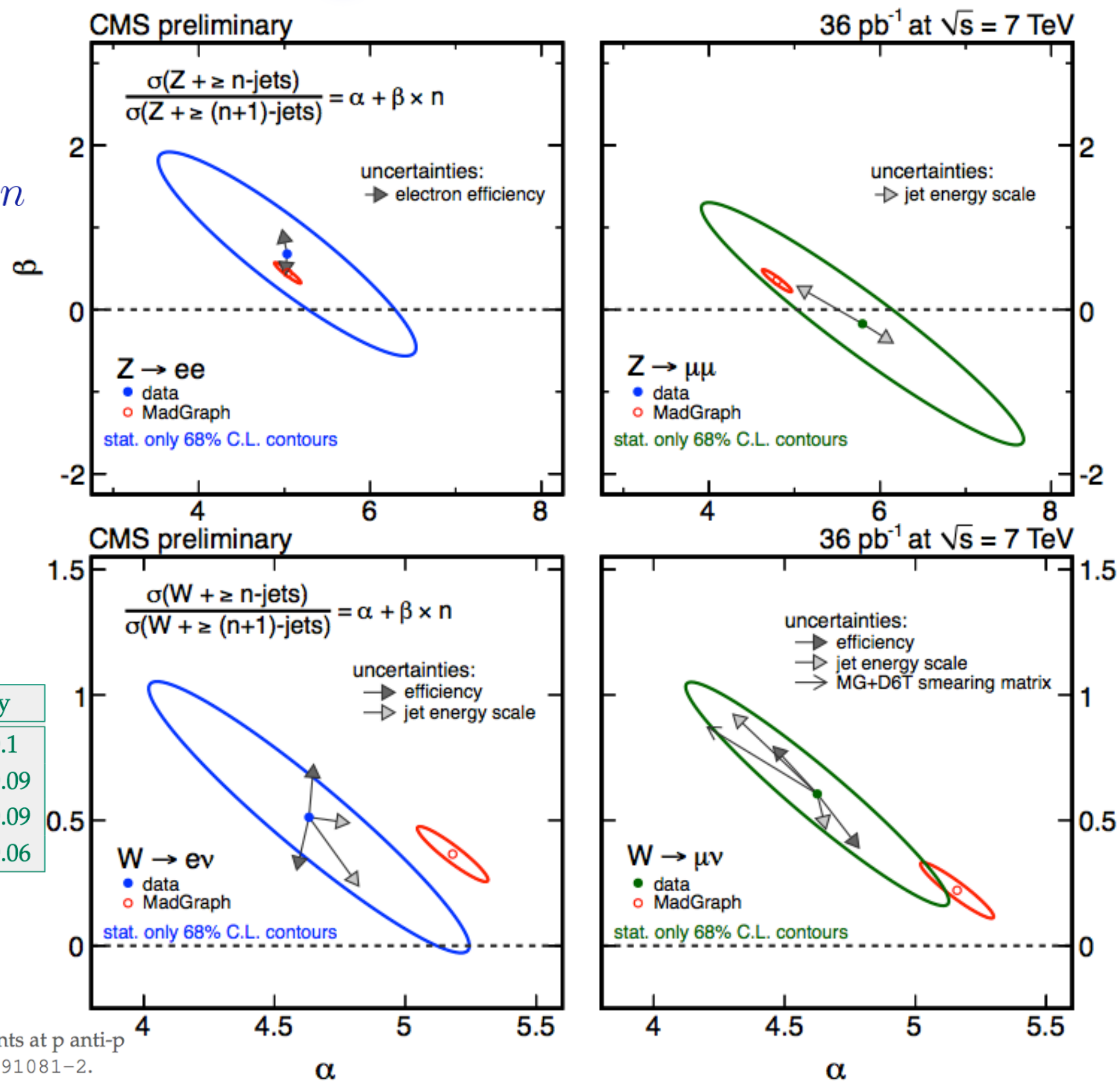
- Expected ~ constant with n

electrons

		data	stat	JES	$\epsilon(\ell)$	Theory
Z	α	5.0	± 1.0	$^{+0.1}_{-0.0}$	$^{+0.00}_{-0.06}$	5.04 ± 0.10
	β	0.7	± 0.8	$^{+0.08}_{-0.04}$	$^{+0.3}_{-0.6}$	0.45 ± 0.08
W	α	4.6	± 0.4	$^{+0.2}_{-0.0}$	$^{-0.05}_{+0.02}$	5.18 ± 0.09
	β	0.5	± 0.4	$^{+0.0}_{-0.3}$	± 0.2	0.36 ± 0.07

muons

		data	stat	JES MC	$\epsilon(\ell)$	D6T tune	Theory
Z	α	5.8	$\pm$ 1.2	± 0.6	± 0.1	+0.3	4.8 ± 0.1
	β	-0.2	$\pm$ 1.0	± 0.3	± 0.1	-0.0	0.35 ± 0.09
W	α	4.3	± 0.3	± 0.2	± 0.2	-0.4	5.16 ± 0.09
	β	0.7	± 0.3	± 0.2	± 0.3	+0.3	0.22 ± 0.06

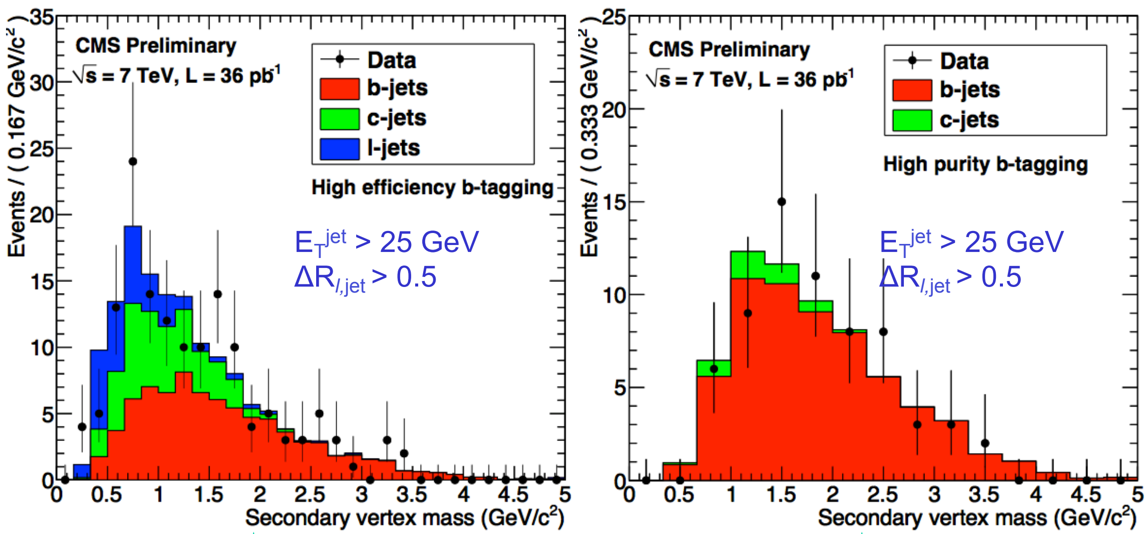


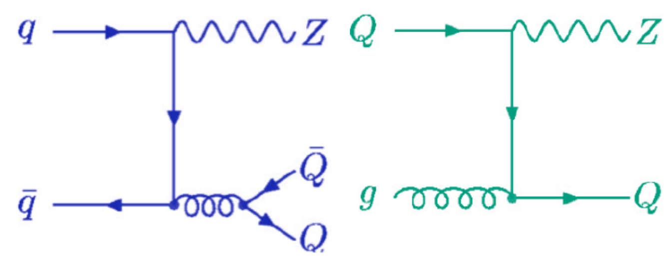
F. A. Berends, W. T. Giele, H. Kuijf et al., "Multi-jet production in W, Z events at p anti-p colliders", *Phys. Lett.* **B224** (1989) 237. doi:10.1016/0370-2693(89)91081-2.

Z+b jets

CMS-PAS-EWK-10-015

- Two production mechanism: b pair produced from qq, gg scattering ("fixed flavour"), or single b quark at partonic level ("variable flavour")
- Selection: two isolated leptons forming a Z, no missing E_T (top veto), b-tagging (lifetime)
- B-tagging purity determined from template fit to the distribution of the invariant mass of tracks associated to the secondary vertex





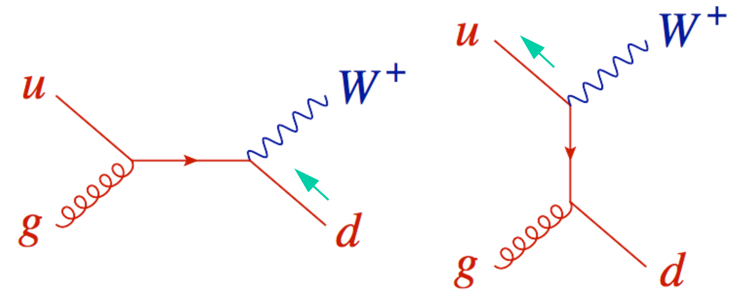
$$\mathcal{R} = \frac{\sigma(pp \to Z+b+X)}{\sigma(pp \to Z+j+X)}$$

Results are in agreement with theory within uncertainties (including theory)

Sample	$\mathcal{R}(Z \to ee)$ (%), $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\mathcal{R}(Z \to \mu\mu)$ (%), $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

W polarization in W+jets

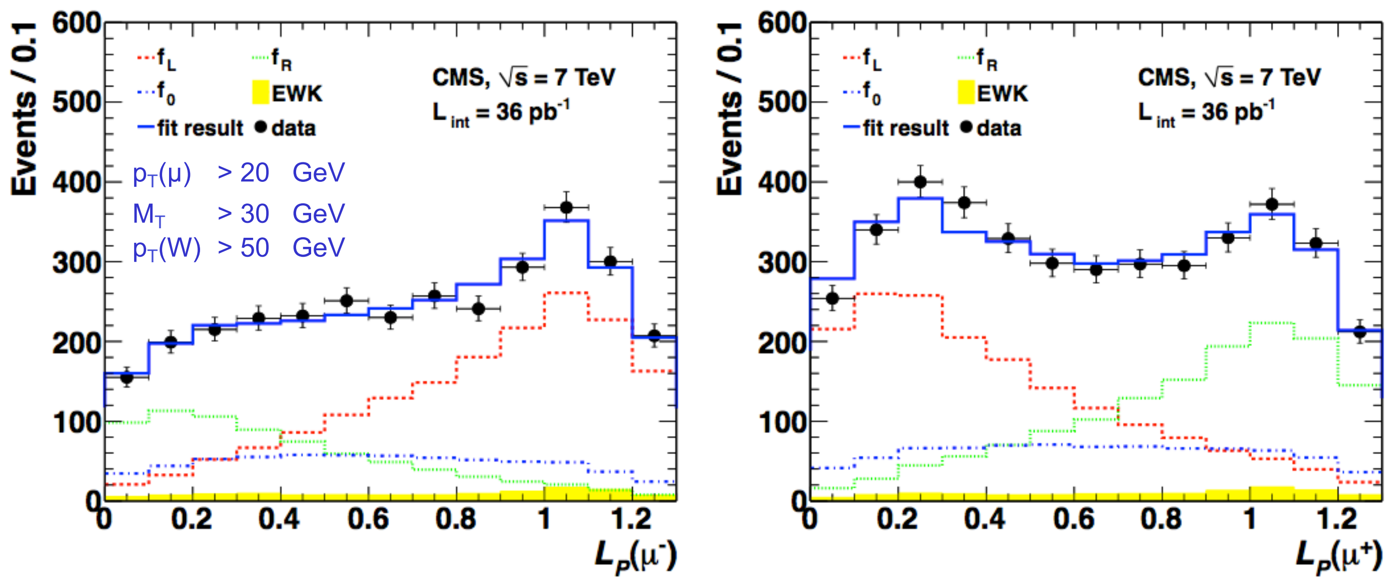
- V-A W-quark coupling imposes L-polarized quarks ($m_q \approx 0$), high W p_T imply large W f_L, the exact value depending on amounts of different contributions
- Important for searches beyond SM with signals having different W polarization / lepton distributions
- Polarization should be measured in the W rest frame (experimentally inaccessible):

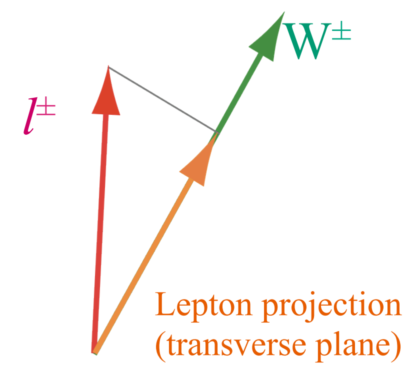


$$\frac{d\Gamma}{\Gamma d\cos\theta^*} = \frac{3}{8}\left[f_R(1+\cos\theta^*)^2 + f_L(1-\cos\theta^*)^2\right] + \frac{3}{4} f_0 \sin^2\theta^* \qquad f_R + f_L + f_0 = 1$$

- Using lepton projection instead

$$L_P = \frac{\vec{p}_T(l)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2} \simeq \frac{1+\cos\theta^*}{2}$$



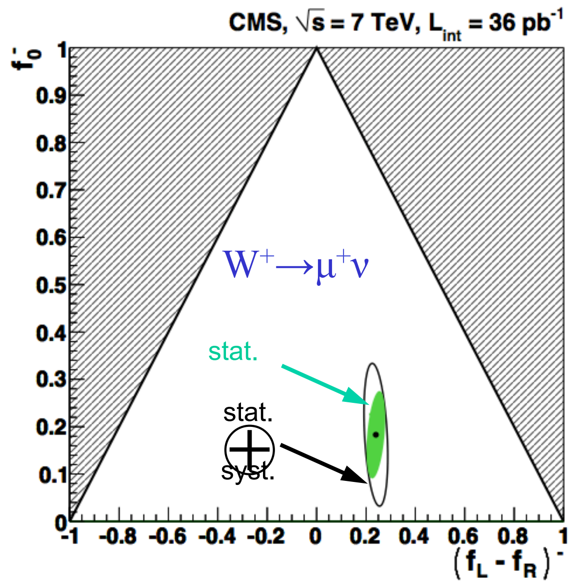


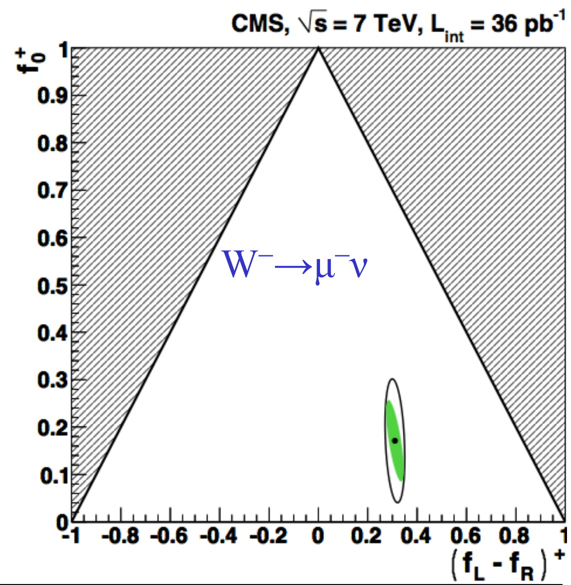
W p_T as lepton plus missing E_T

W polarization results

CMS-PAS-EWK-10-014
arXiv:1104.3829 (→PRL)

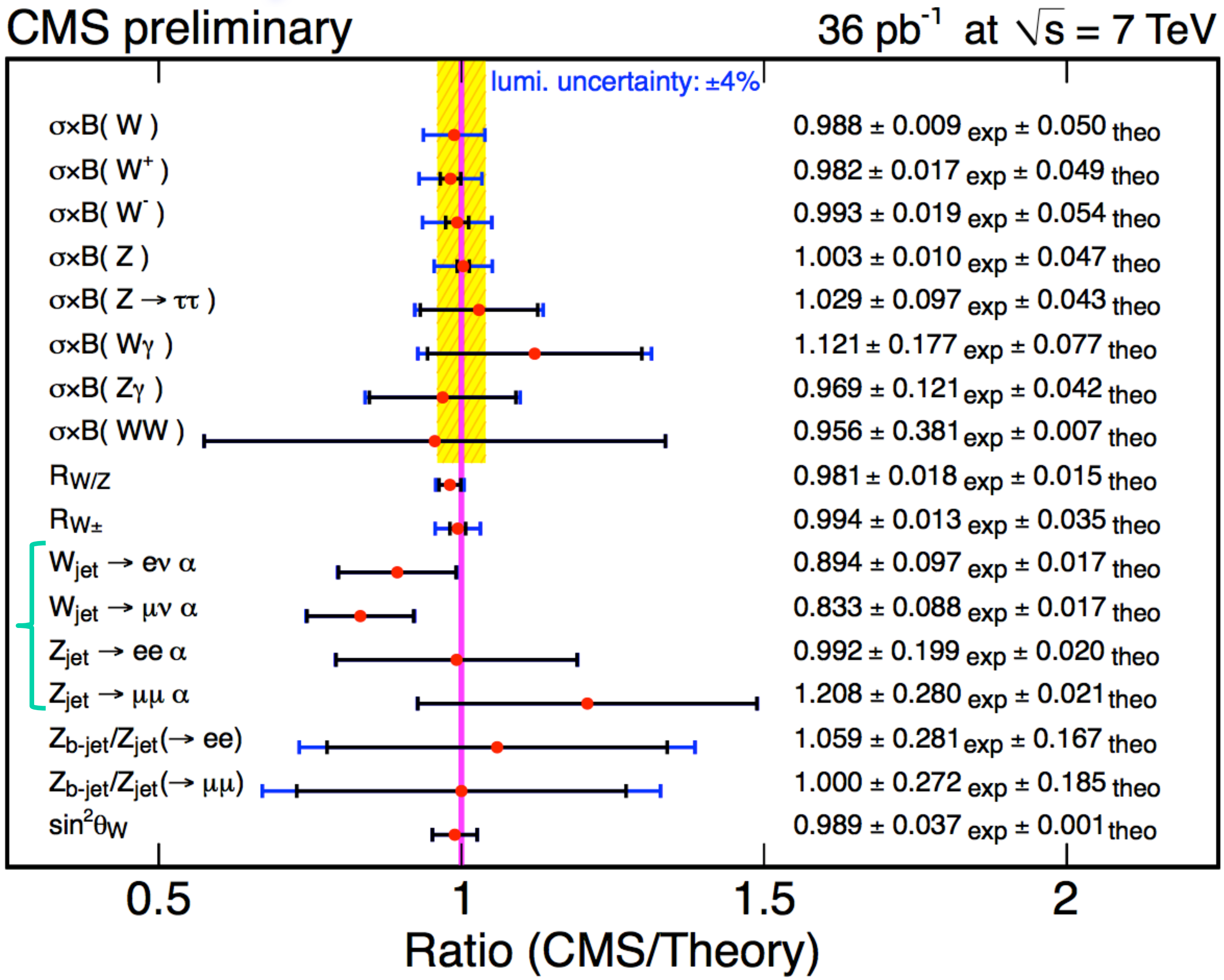
- More precise measurement with muons
  - smaller background: ~250 / 14000





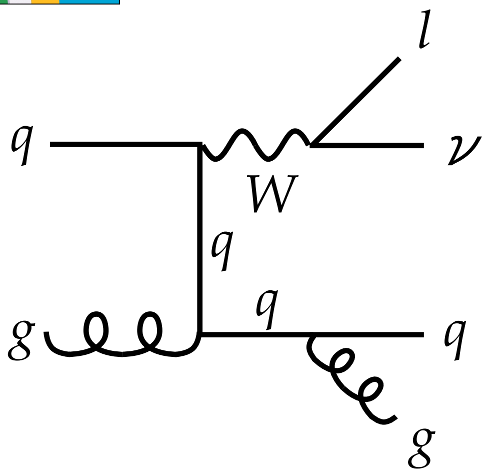
Uncertainty	$(f_L - f_R)^-$	f_0^-	$(f_L - f_R)^+$	f_0^+
	Muon channel			
Recoil energy scale	±0.029	±0.123	±0.011	±0.092
Recoil resolution	±0.012	±0.006	±0.012	±0.004
Muon scale	±0.002	±0.007	±0.004	±0.008
Total uncertainty	±0.031	±0.123	±0.017	±0.099

Summary of CMS EW results



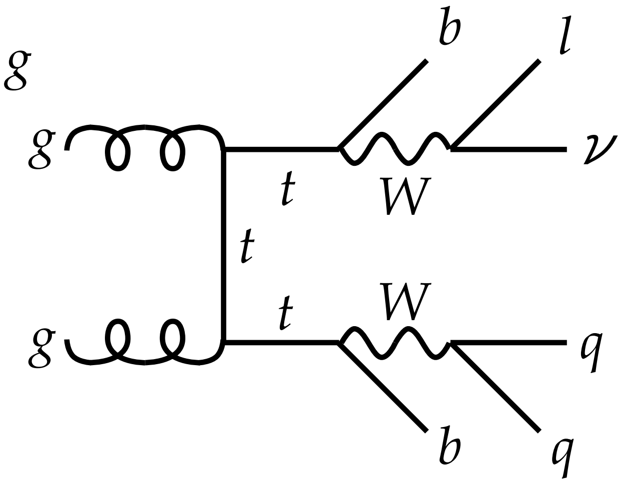
$$\frac{\sigma(V + \geq n - \text{jets})}{\sigma(V + \geq (n+1) - \text{jets})} = \alpha + \beta \times n$$

Descending* the staircase of the SM...

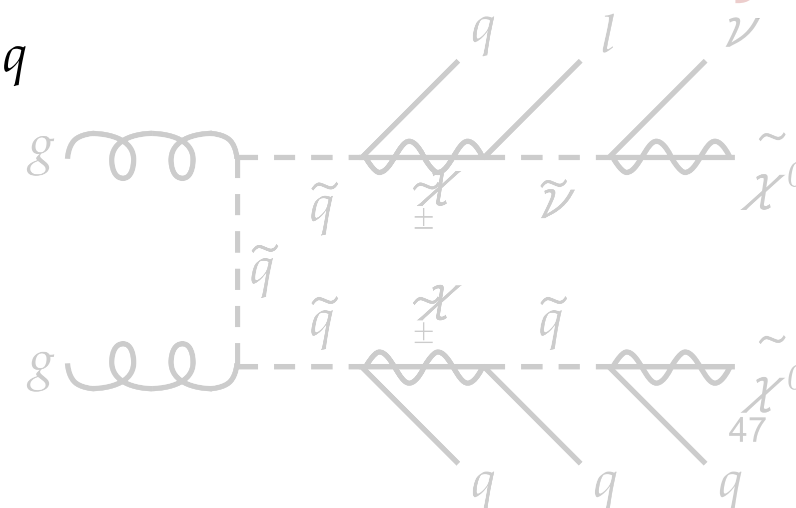


Electroweak

Top



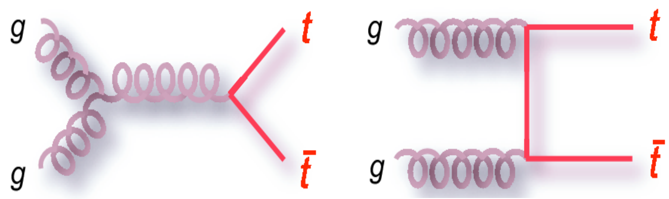
...to New Physics



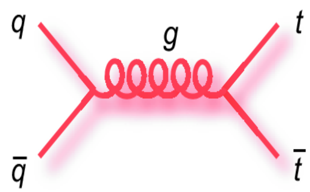
*Adapted from Michael Peskin

Top Production

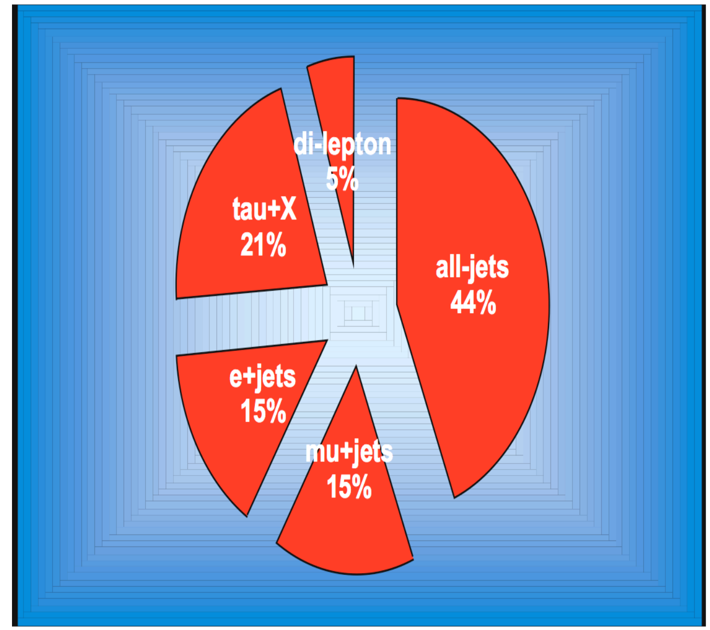
- Pair production in 7 TeV pp collisions:



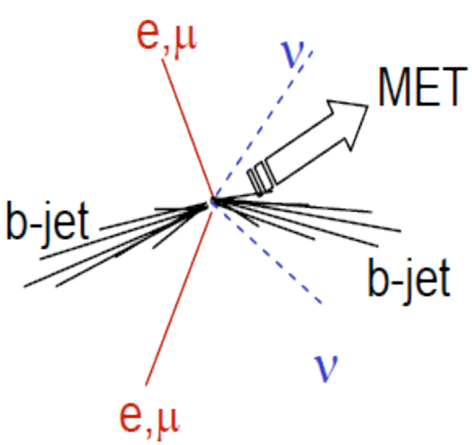
~85%

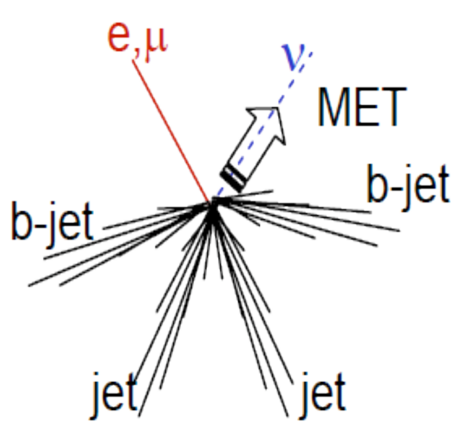


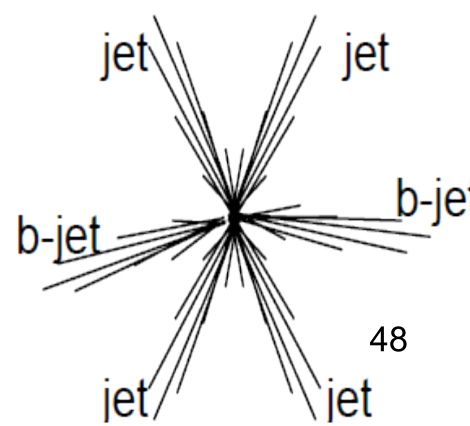
~15%



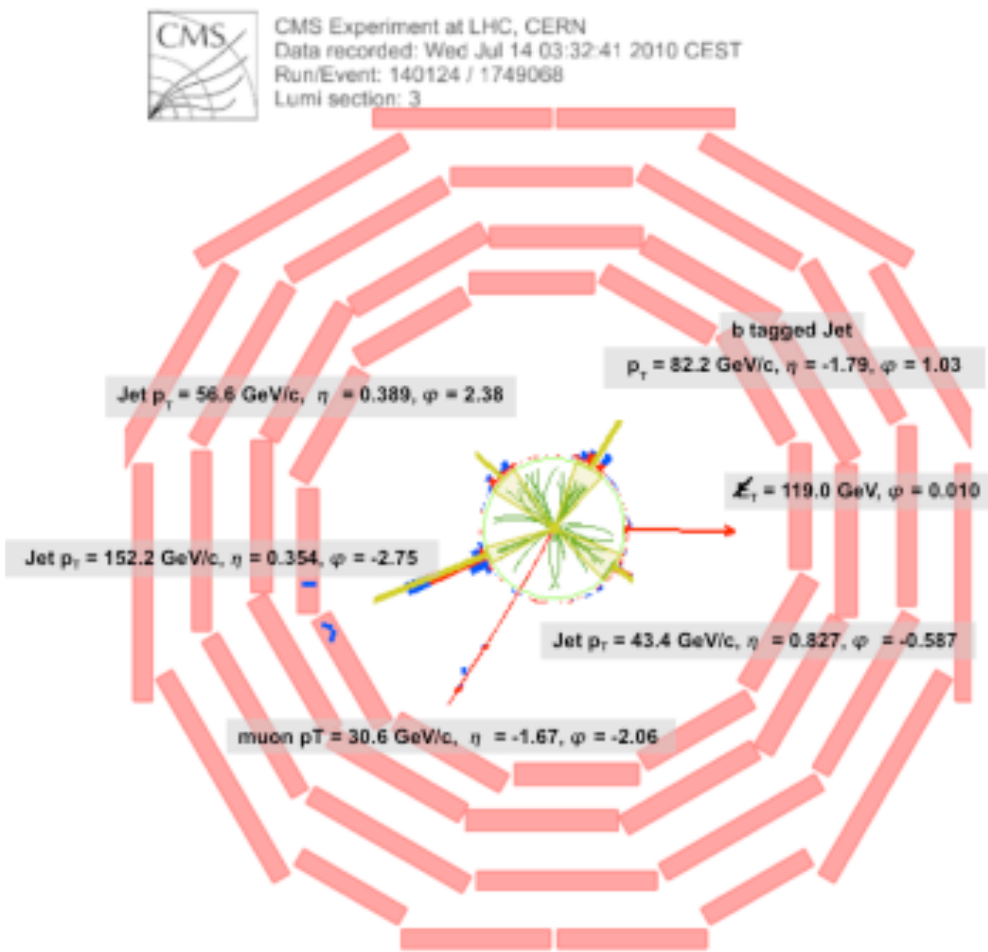
- BR(t->Wb) ≈ 1 in Standard Model
- Analysis strategy depends on W decay modes

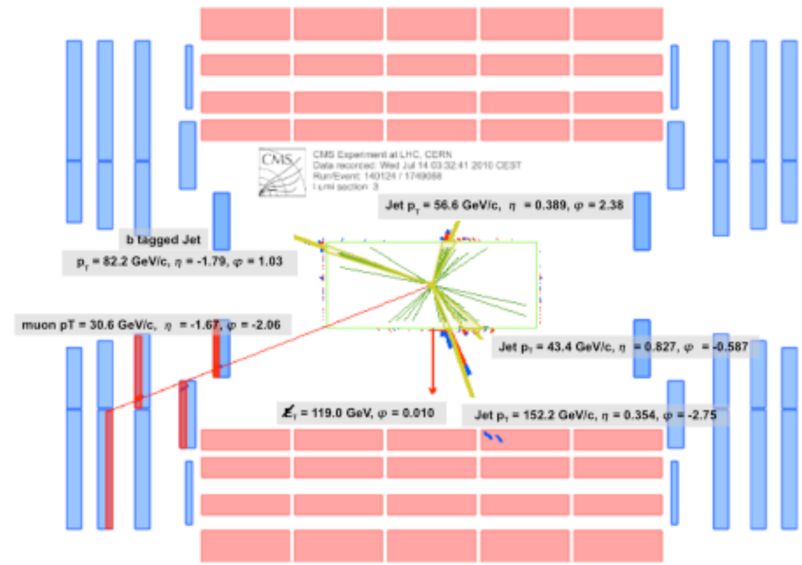


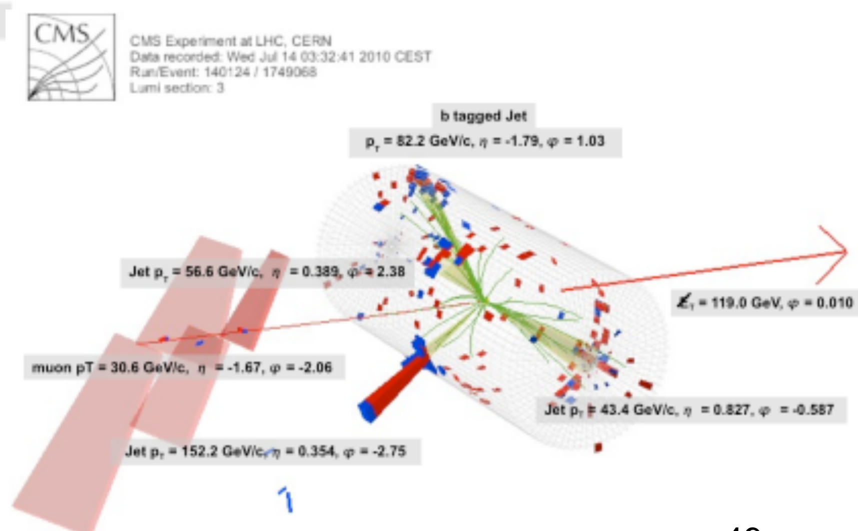




Top Quark Candidate



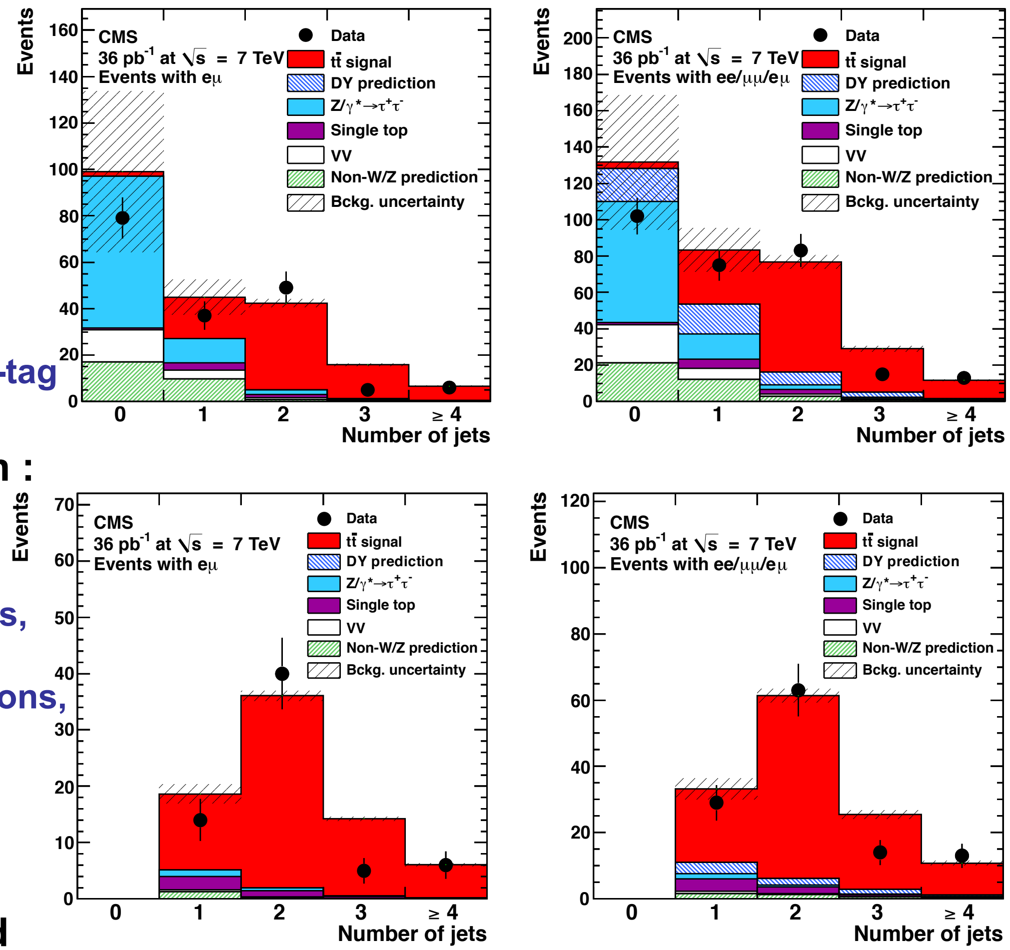




$t\bar{t}$ Cross Section - Dilepton Channel (submitted to JHEP, arXiv:1105.5661)

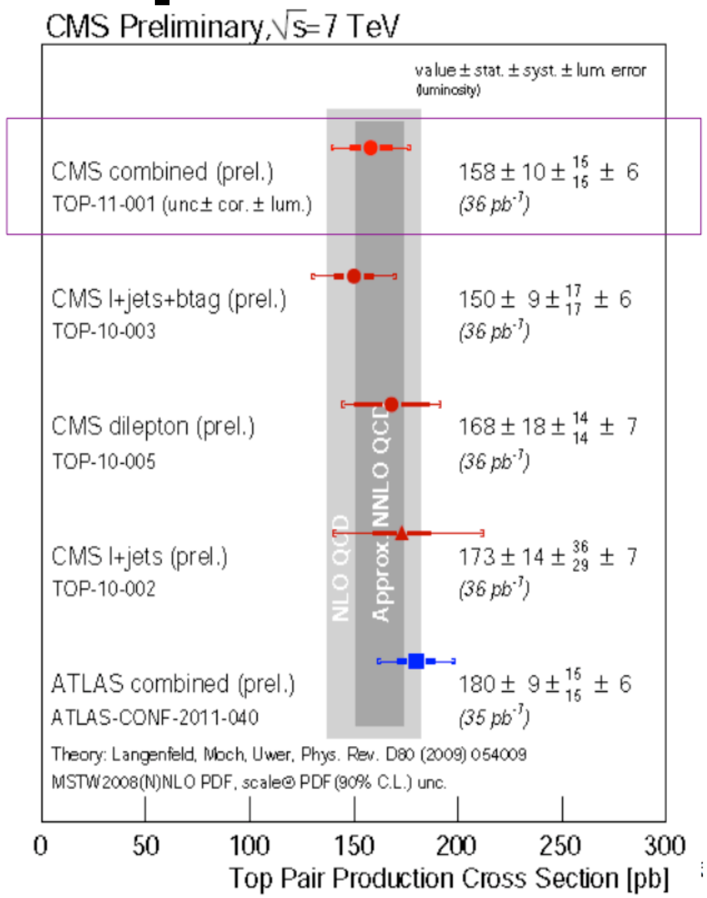
- **Event Selection**
  - two opposite charge leptons:
  - $p_T > 20$ GeV/c, $|\eta| < 2.5$ (2.4) for e (μ), Isolated in tracker and calorimeter
  - invariant mass selection:
    - $M_{ll} > 12$ GeV/c2, $M_{ll} \neq [91 \pm 15]$
  - jets selection:
    - corrected Jet, $p_T > 30$ GeV/c, $|\eta|<2.5$
  - For each channel, for 2 jets no b-tags, 2 jets 1 b-tag and 1 jet no b-tags
- **Main backgrounds** after leptonic selection :
  - Drell-Yan → ll: main background,
    - rejected by Z veto, jets and $E\!\!\!/_T$, estimated from data
  - W+Jets, semi-lept. tt, QCD: from non-W/Z decays, estimated from data
  - Single top tW, diboson, Z→ττ: small cross-sections, estimated from MC
- Very clean channel, thanks to b-tagging
  - Cut and count experiment
- Event counting with dedicated data-driven techniques for the estimation of background contributions in e^+e^-, $\mu^+\mu^-$, and $e^\pm\mu^\mp$ channels
- Combination taking correlation into account using Best Linear Unbiased Estimated

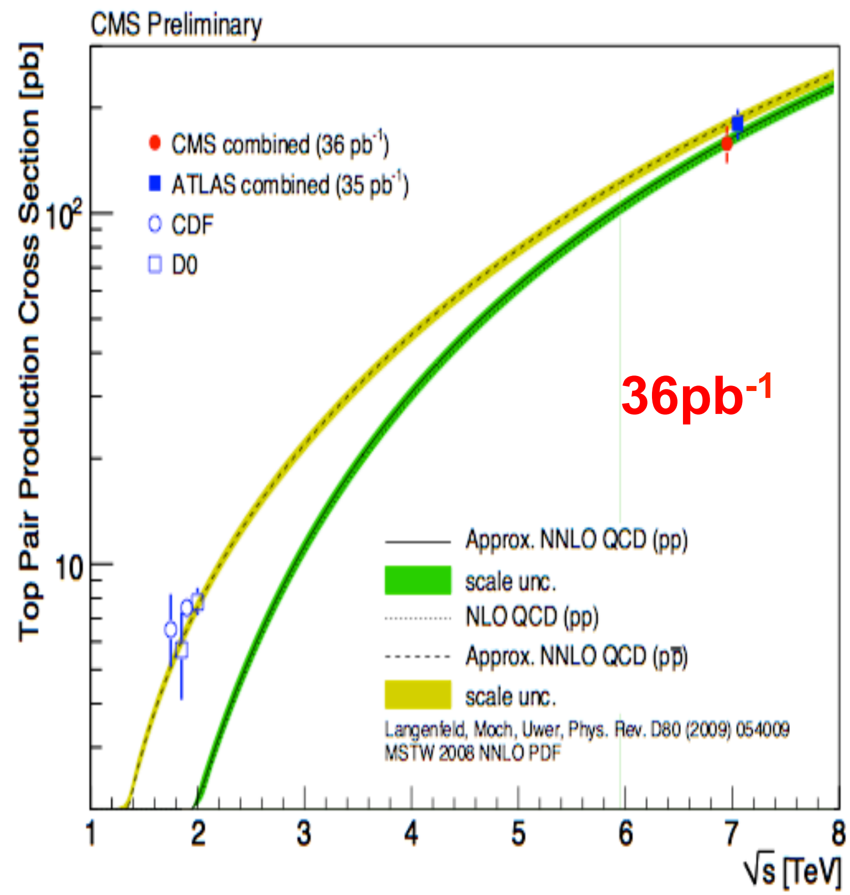
¾(t t̄) = 168 § 18(stat) § 14(sys) § 7(lum) pb



σ= 168 ± 18(stat) ±14(sys) ± 7(lum) pb

Top cross section combined result

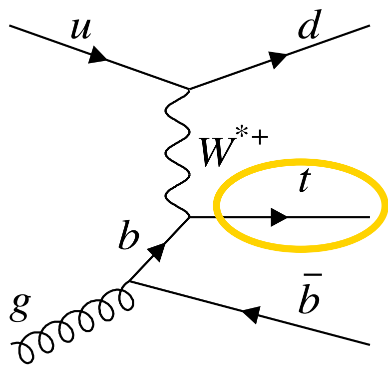




- **Combined measurement has precision of 12%**
- **Very good agreement with approximation NNLO theory**
- **Comparable to world average**

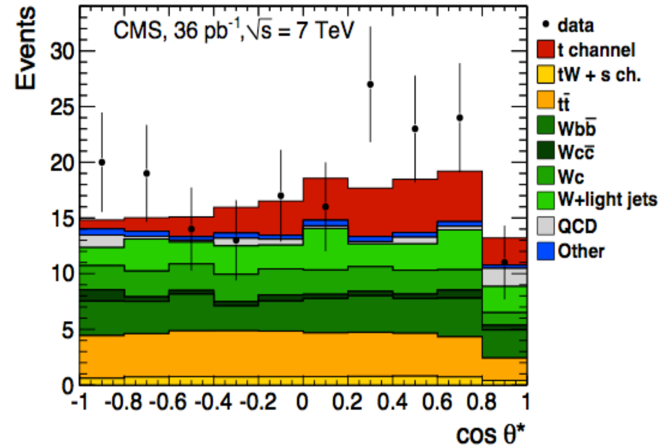
CMS-TOP-10-003-001; CMS-TOP-10-002-002; **arXiv:1105.5661** ; CMS-TOP-11-002

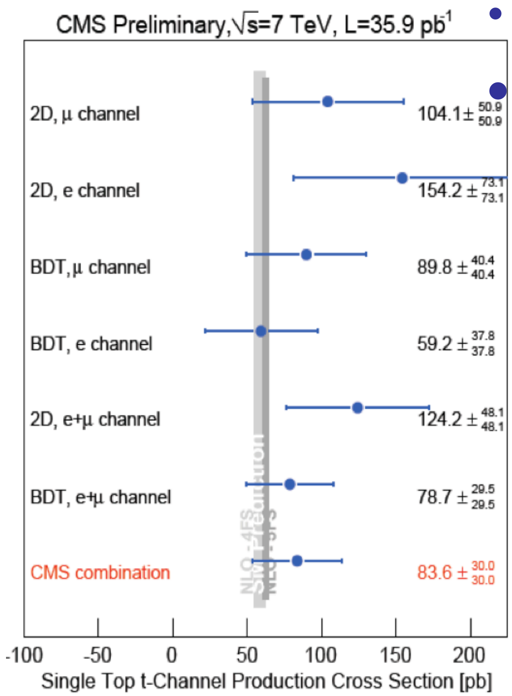
Single top @LHC: the challenge of tiny cross sections with large background.

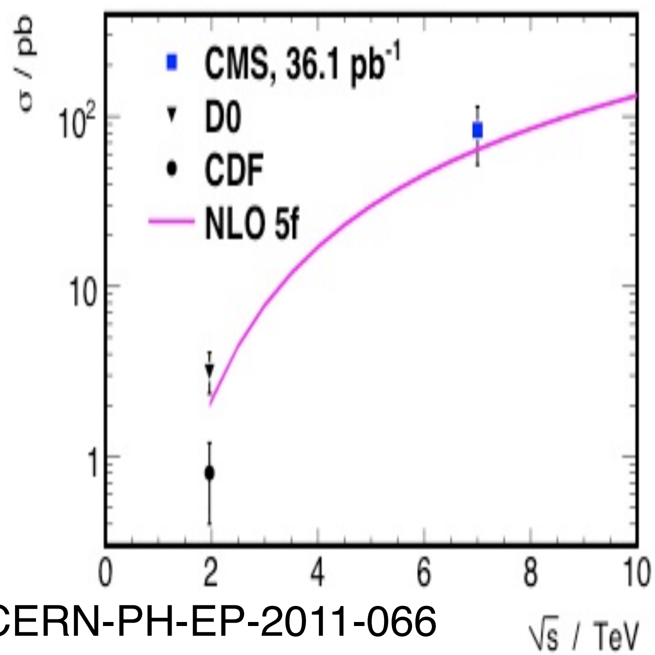


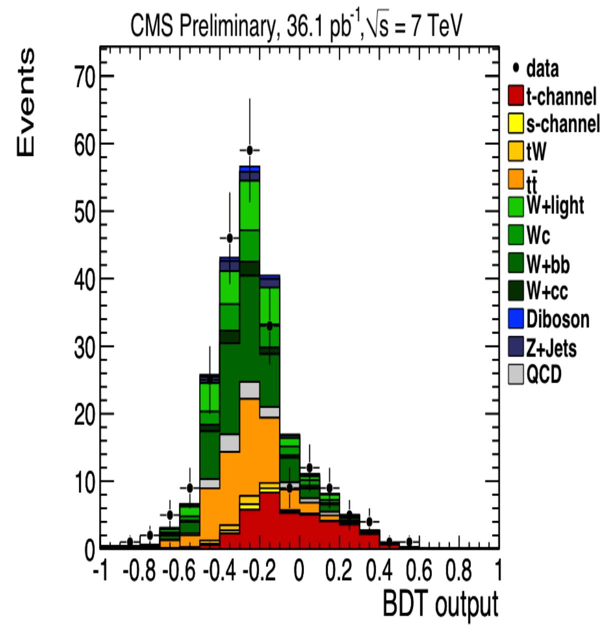
- **Example of finding tiny signals with lepton, MET, b-tag and jets**
- **Two different analyses (cut based and BDT): three different channels.**
- **Very challenging analysis.**

σ=83.0±29.8±3.3(lumi)pb



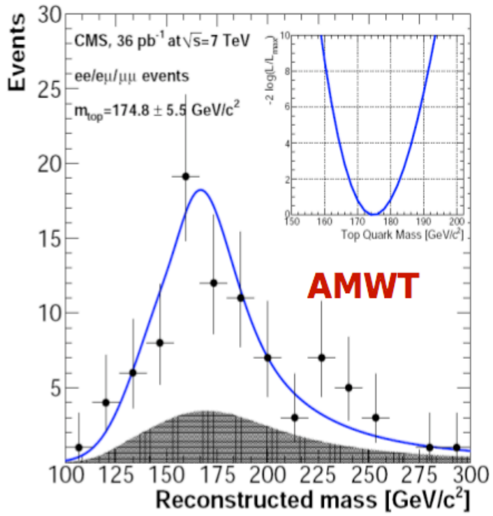






CMS PAS TOP-10-008-002; CERN-PH-EP-2011-066

Top mass

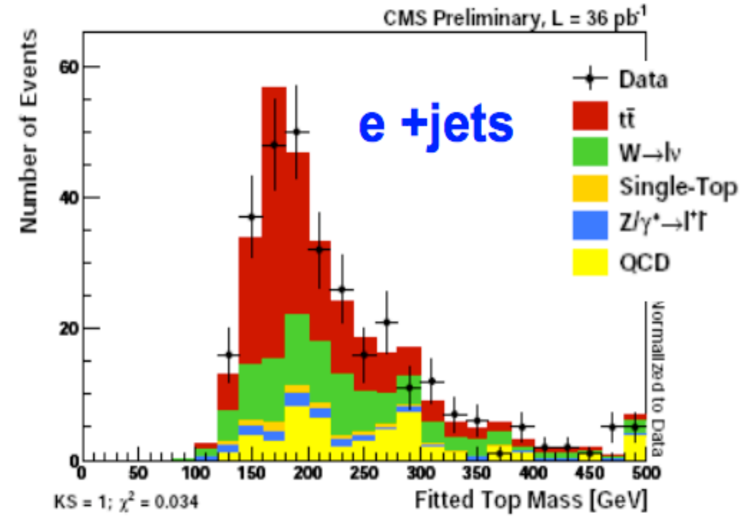


Dilepton channel

M_{top}=175.5±4.6±4.6 GeV/c^2

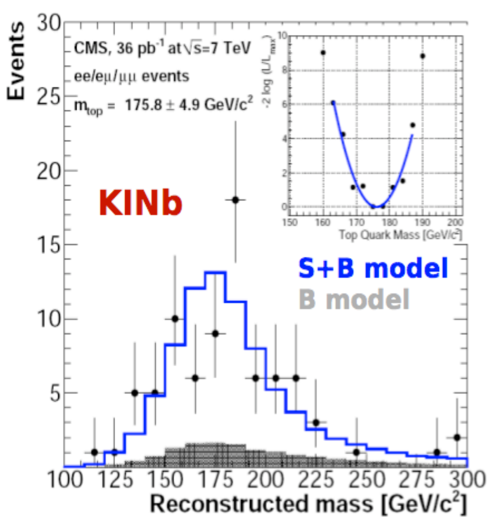
Lepton+jets channel

M_{top}=173.1±2.1±2.8 GeV/c^2



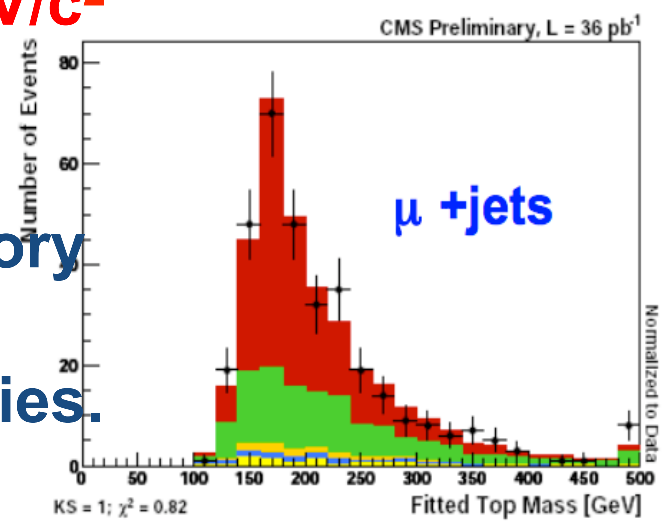
CMS combination

M_{top}=173.4±1.9±2.7GeV/c^2



2% precision

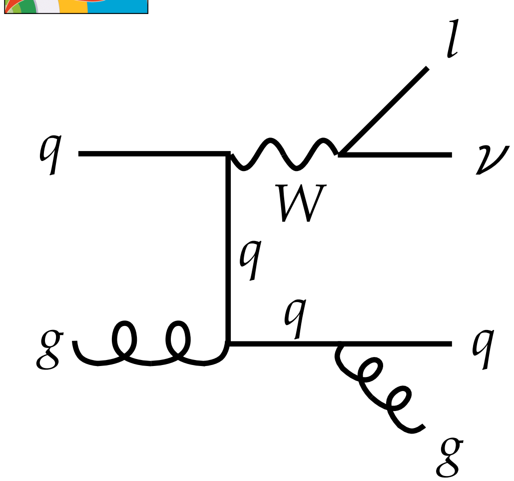
LHC is now a top factory
→ detailed
studies of top properties.



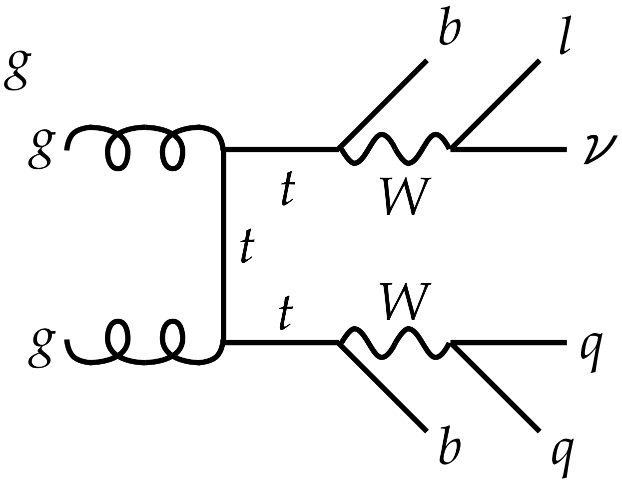
arXiv:1105.5661 ; CMS-TOP-11-002 ; CERN-PH-EP-2011-055

Descending* the staircase of the SM…

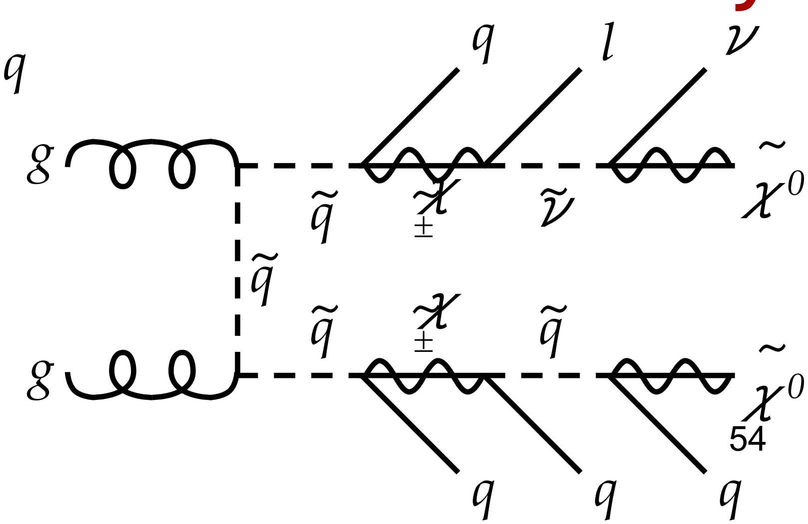
Electroweak



Top



…to New Physics



*Adapted from Michael Peskin

The Higgs

Searching for the mechanism of electroweak symmetry breaking, we seek to understand

why the world is the way it is.

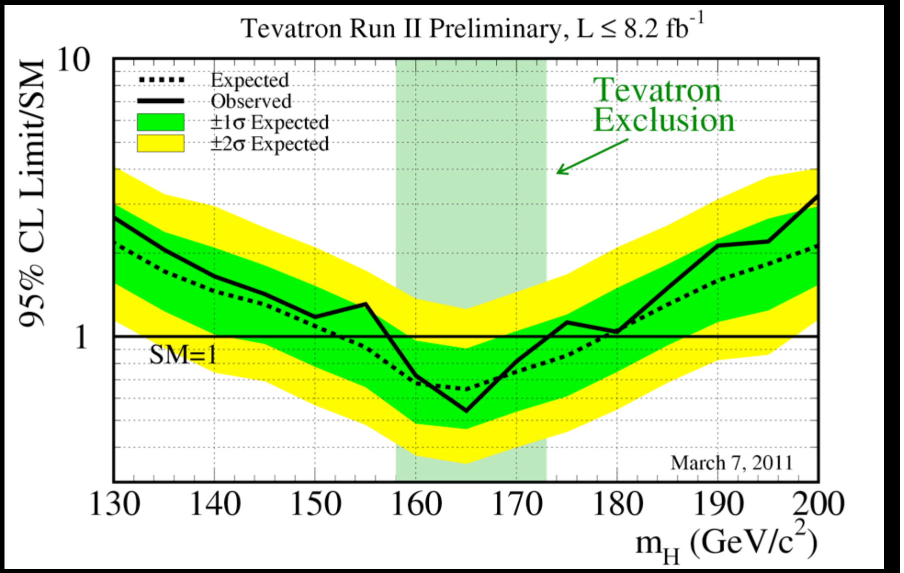
This is one of the deepest questions humans have ever pursued, and

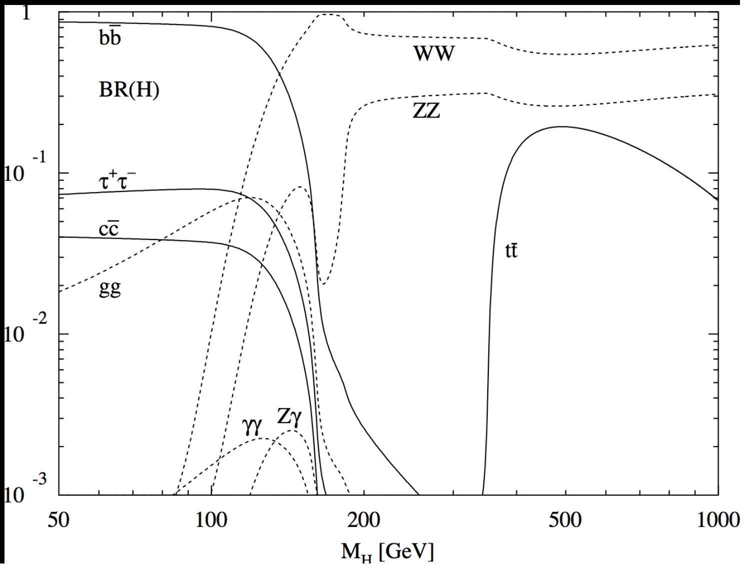
it is coming within the reach of particle physics.

Slide adapted from talk by Chris Quigg

Higgs Search Landscape

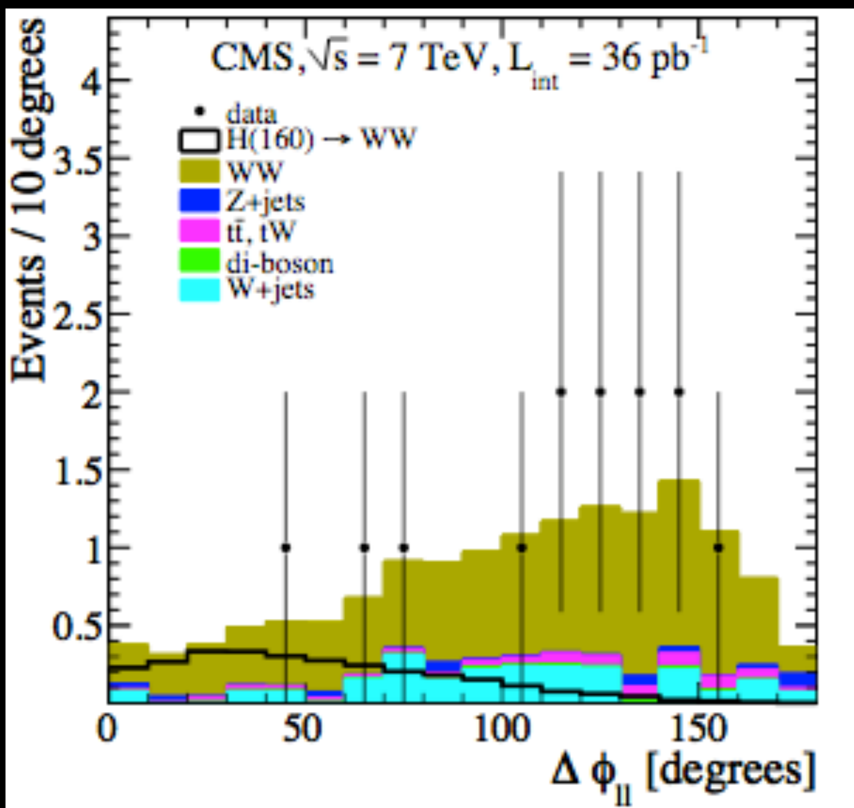
Bo Jayatilaka; CONF-11-044-E

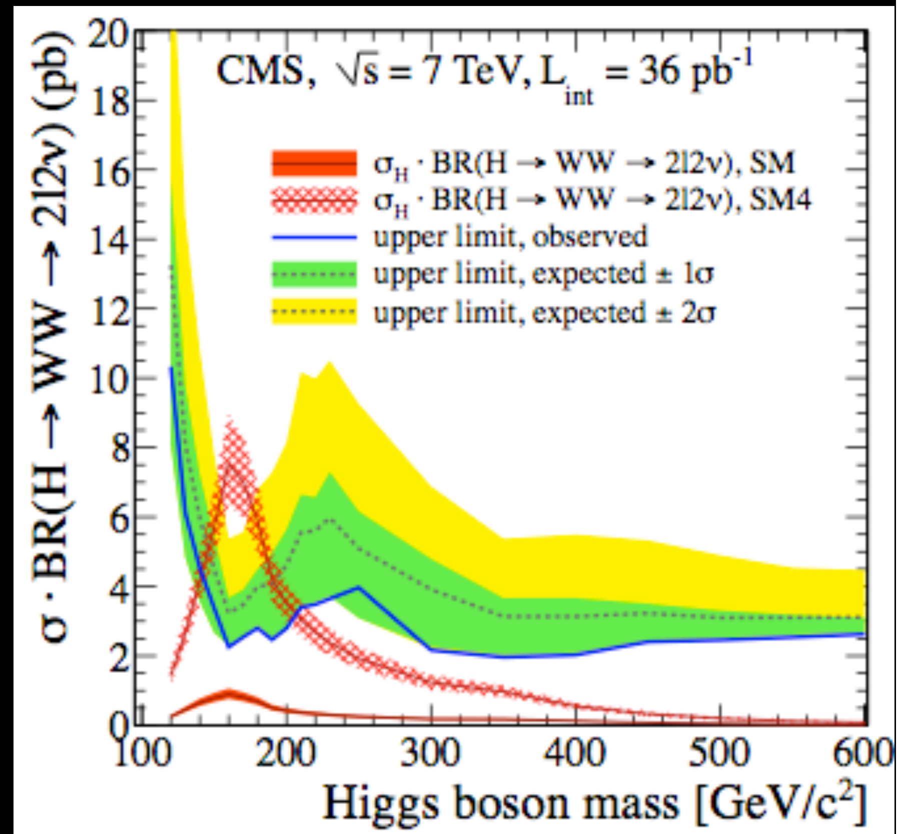




H→WW→2l 2ν

- same pre-selection as for WW analysis, including a jet veto
- Then : 2 analyses
  - cut-based (lepton ΔΦ, lepton mom.)
  - Boosted Decision Tree with 15% higher eff. for same bkgnd



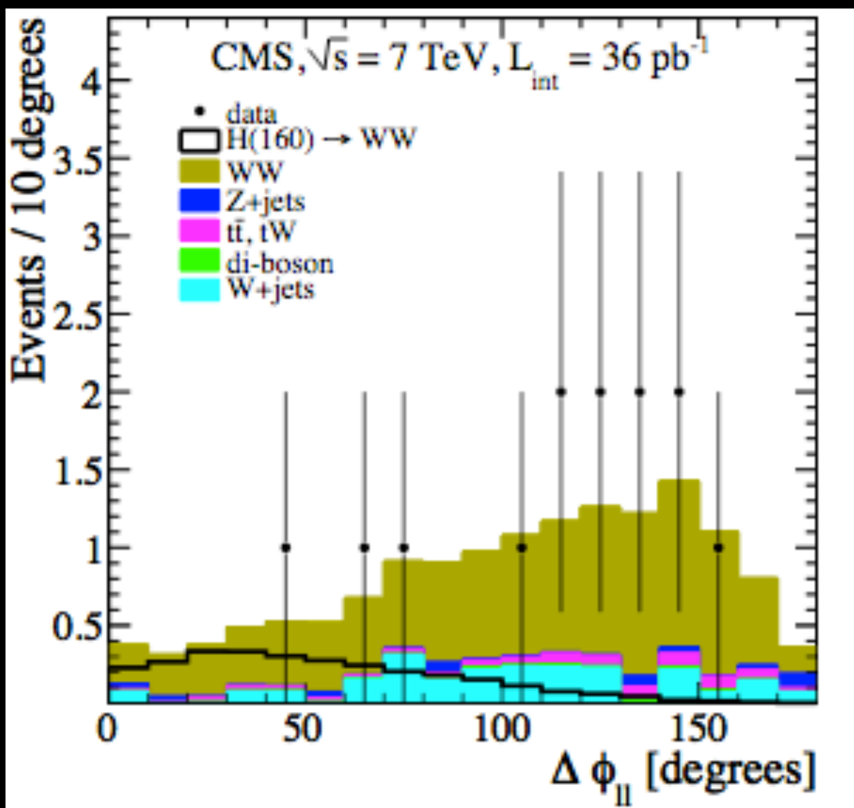


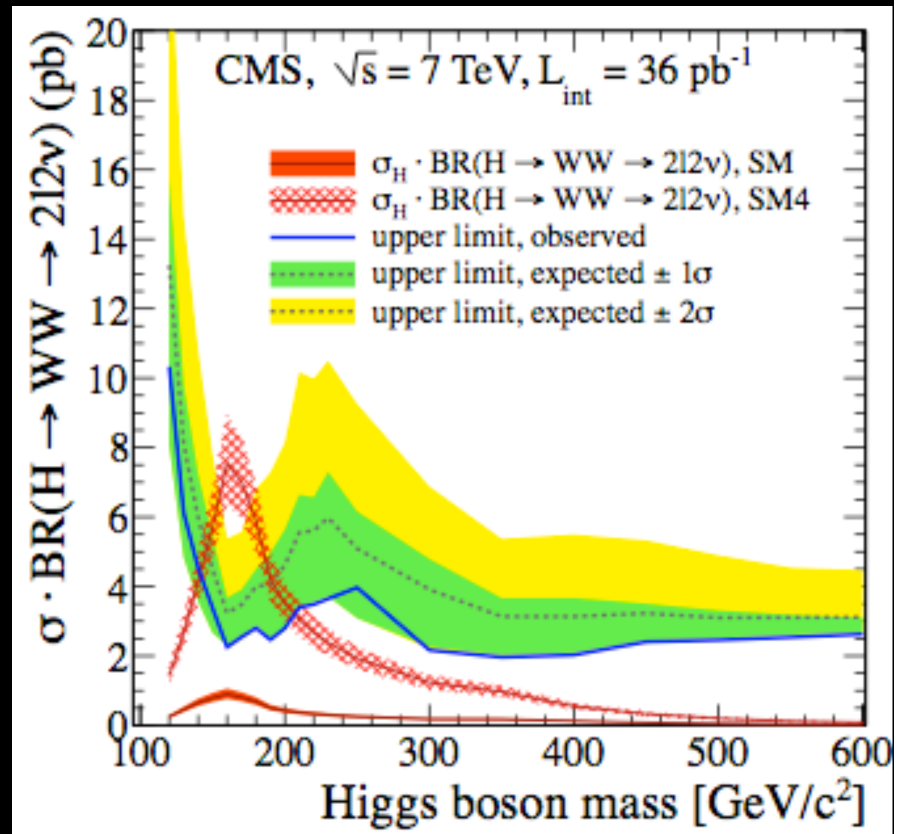
SM excluded ~x3 SM expectation at~x3 SM expectation at M_H=160 GeV
SM-like Higgs in 4-gen model excluded for (144 < M_H< 207) GeV

arXiv:1102.5429, *Phys. Lett. B 699 (2011) 25-47*

H→WW→2l 2ν

- same pre-selection as for WW analysis, including a jet veto
- Then : 2 analyses
  - cut-based (lepton ΔΦ, lepton mom.)
  - Boosted Decision Tree with 15% higher eff. for same bkgnd

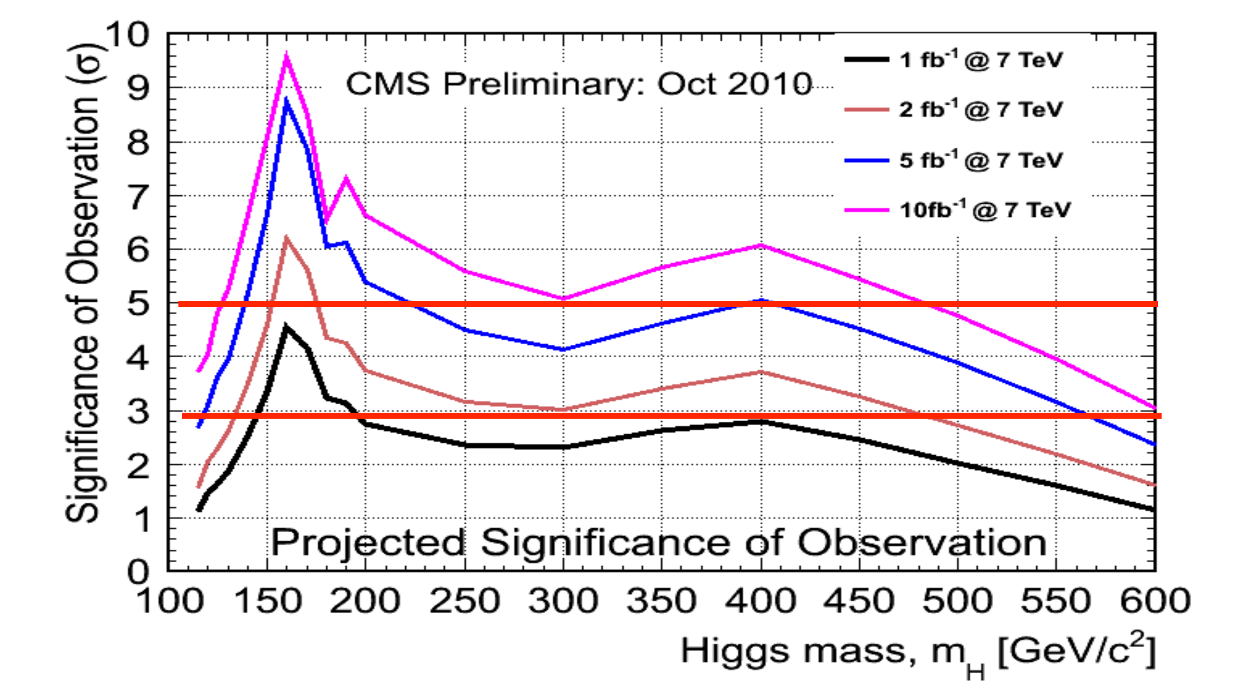




SM excluded ~x3 SM expectation at~x3 SM expectation at M_H=160 GeV
SM-like Higgs in 4-gen model excluded for (144 < M_H< 207) GeV

arXiv:1102.5429, *Phys. Lett. B* *699 (2011) 25-47*

Higgs Search

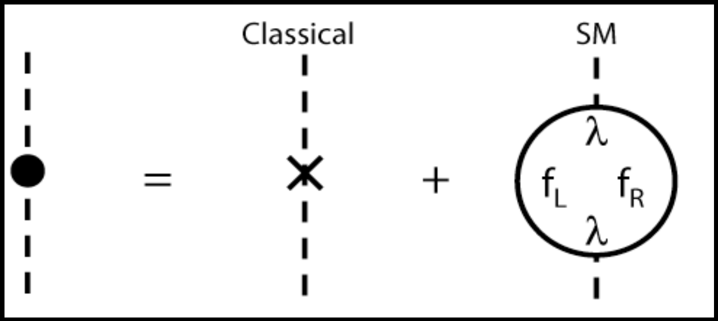


Tevatron: proposed Run III did not materialize. Tevatron will runs until Sept 2011 (10/fb)
2.4σ expected sensitivity 114 - 200 GeV ; 3σ at 115 GeV

2011-12 Run: ATLAS + CMS: 3σ discovery or 95% CL exclusion 114 - 600 GeV

If Higgs is found a major milestone final missing piece of SM. The end of the beginning of a ~30 year quest to understand electroweak symmetry breaking.
Next stage: Is it really the SM Higgs? Determine properties couplings, spin, width etc.
Is our simplest picture of the origin of mass correct or is electroweak symmetry breaking intertwined with beyond standard model physics?
Both LHC and future lepton colliders will contribute

Problems with the Higgs particle

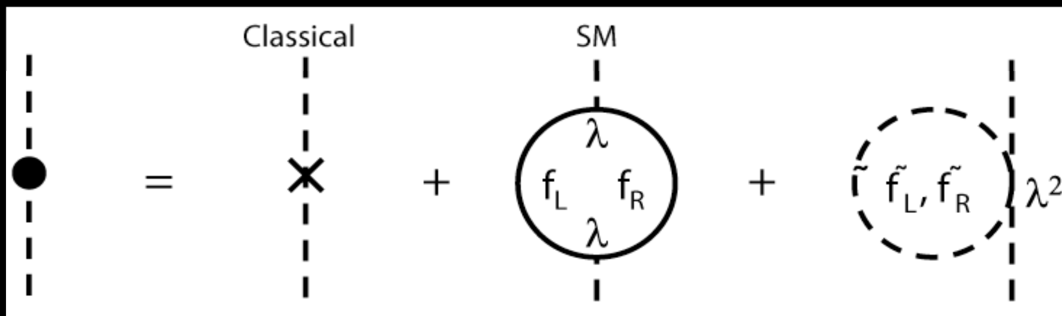


$$m_h^2 = (m_h^2)_0 - \frac{1}{16\pi^2}\lambda^2\Lambda^2 + \ldots ,$$

- Higgs mass:
  - Virtual particles contribute to the Higgs mass via "loop corrections" that diverge quadratically!
    - Λ is a huge quantity! Could be the Planck scale (10^{19} times the mass of the proton i.e. 10^{19} GeV)

Slide adapted from talk by Joe Incandela

The cure comes from partner particles



Cancellation

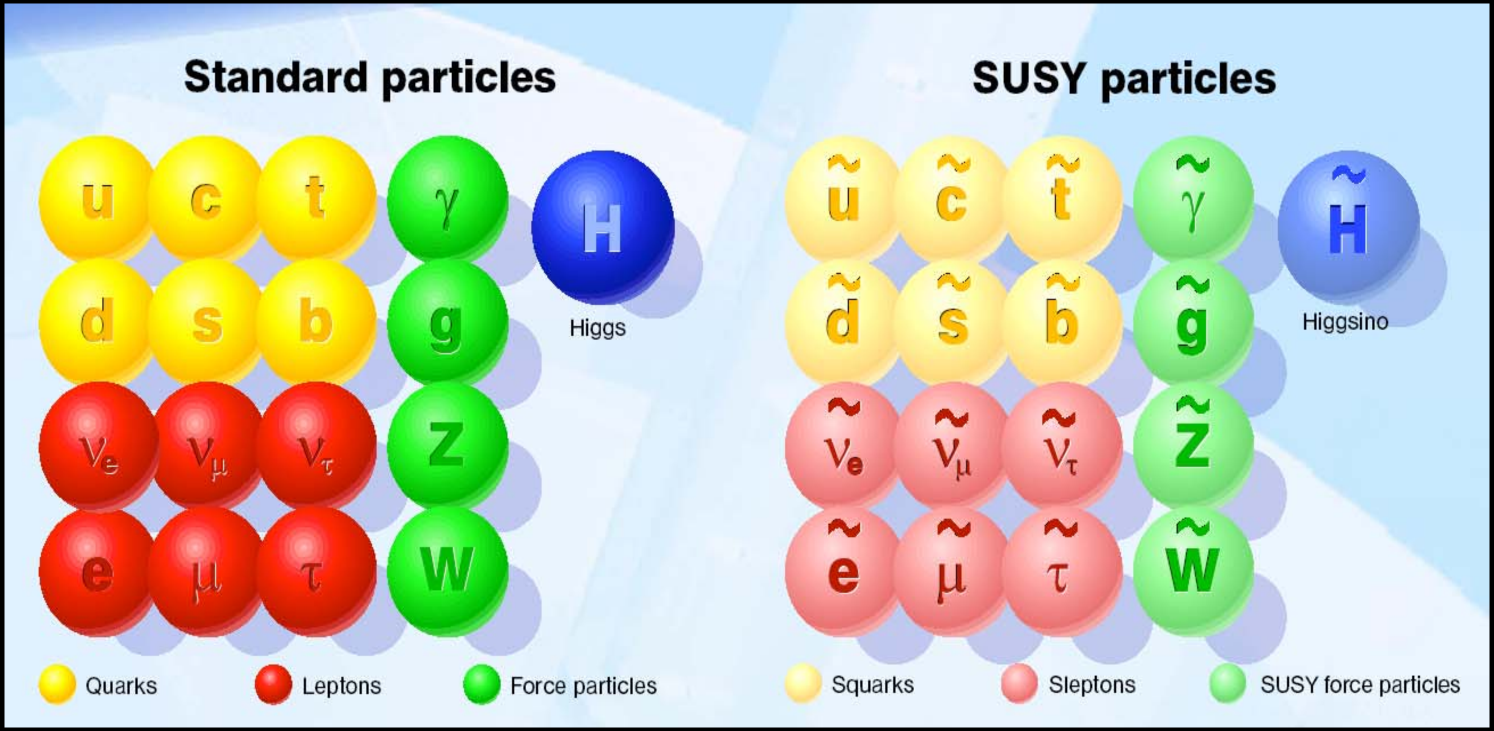
$$
\begin{aligned}
m_h^2 &= (m_h^2)_0 - \frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2 + \dots \\
&\approx (m_h^2)_0 + \frac{1}{16\pi^2}(m_{\tilde{f}}^2 - m_f^2)\ln(\Lambda/m_{\tilde{f}}),
\end{aligned}
$$

- Partner particles fix this:
  - Need same coupling λ
  - Need partners to have roughly similar masses
    - Otherwise the logarithmic term becomes too large, which would require more fine-tuning.

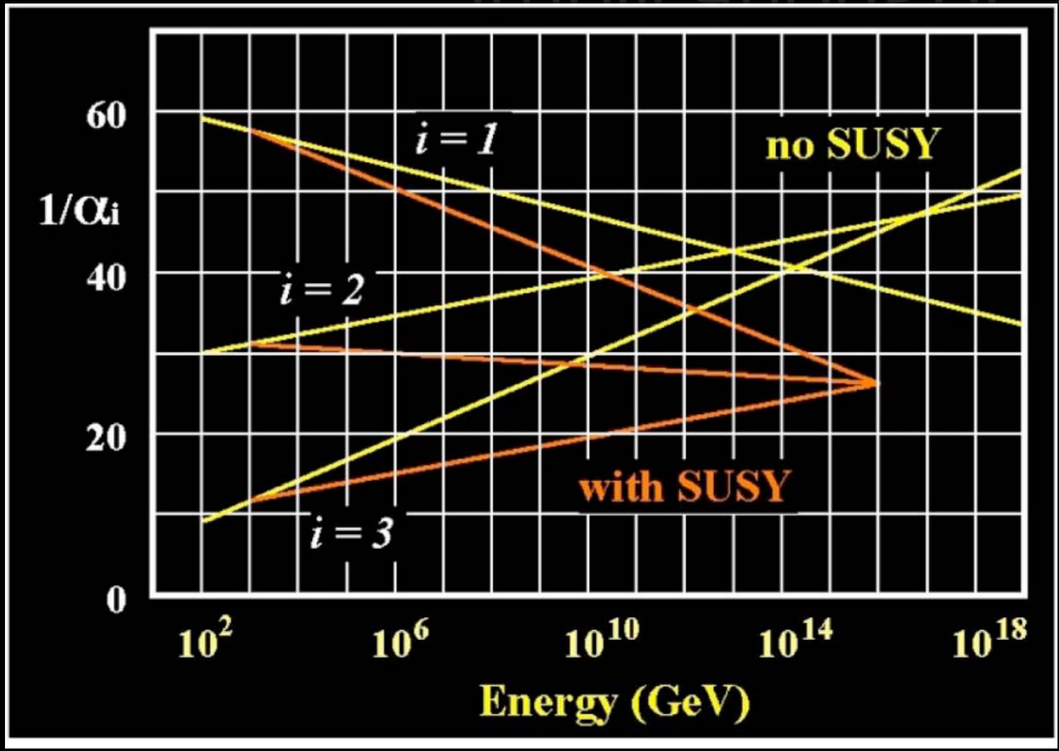
Slide adapted from talk by Joe Incandela

SuperSymmetry

- For each ½ integer spin particle (Fermion) there is an integral spin (Boson) partner and vice versa
  - Complete spectrum of partners to standard model particles
  - They are heavier and their spins are different by ½ unit



Implications of SuperSymmetry



SUSY unifies the strength of all forces at high energy & predicts stable non-interacting particles (dark matter candidates)

Supersymmetry: the leading candidate for physics beyond SM
A more complex Higgs sector and connects Higgs physics to flavor physics and cosmology

Example of a SUSY model Minimal Supergravity (mSUGRA)

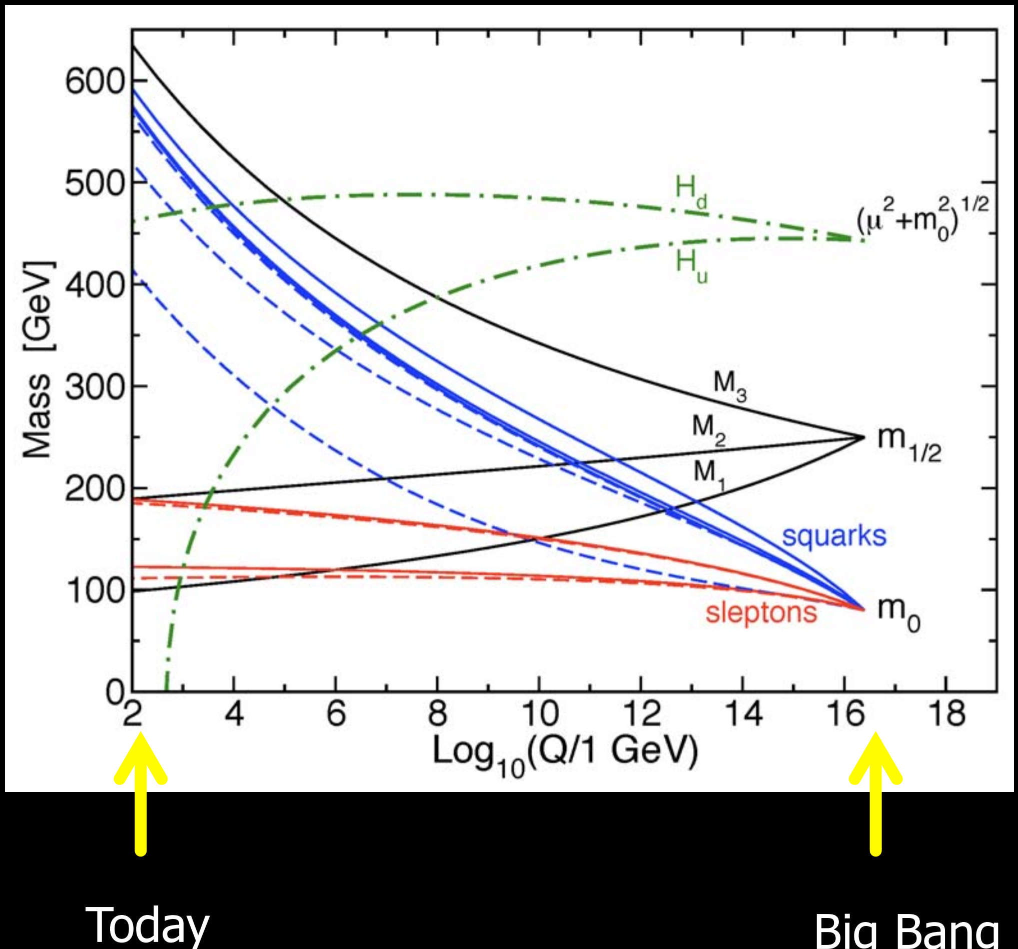
SUSY has >100 free parameters

Derive all of them at the unification scale from a minimal set

Five main parameters
m_0 $m_{1/2}$ A_0 $\tan\beta$ and sign(μ)

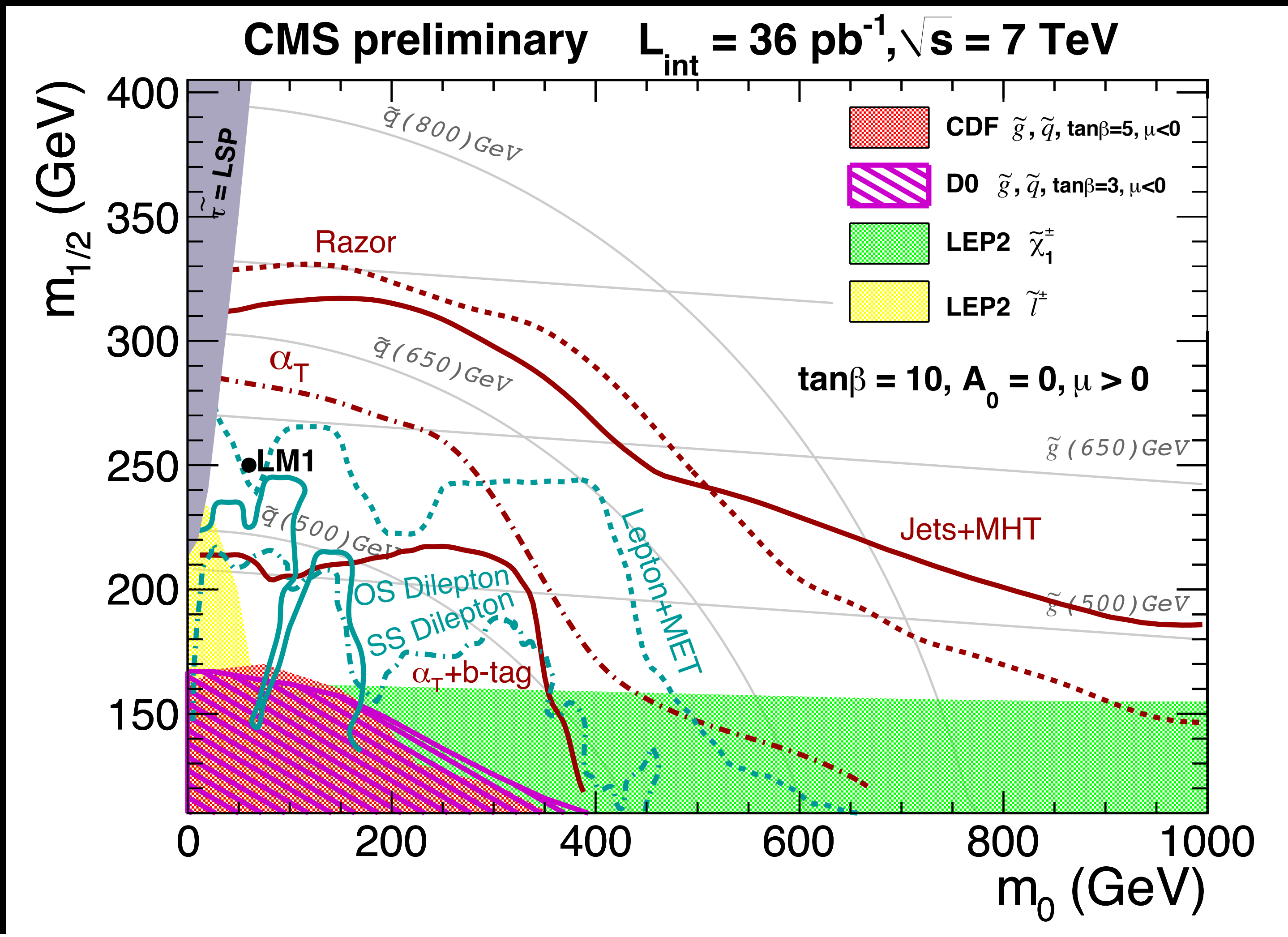
m_0 & $m_{1/2}$ are universal masses

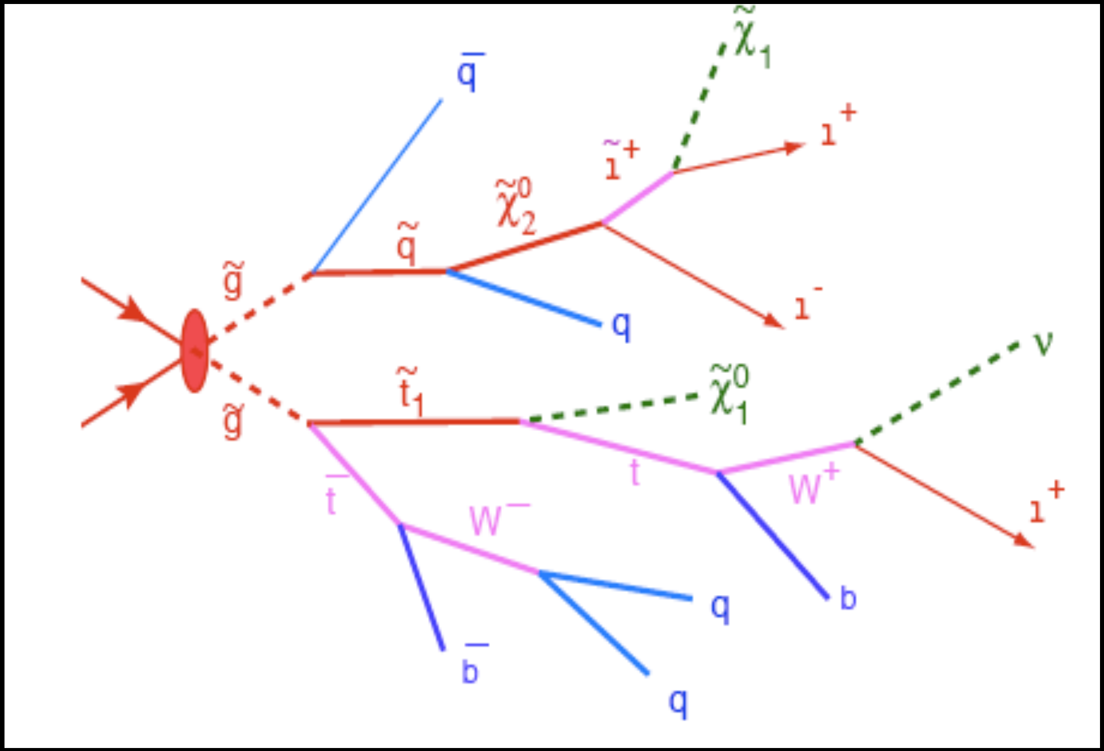
Their values at t=0 are unknown
Values now depend on values then



Searches for SUSY

- Observed limits from several 2010 CMS SUSY searches plotted in the CMSSM (m_0, $m_{1/2}$) plane

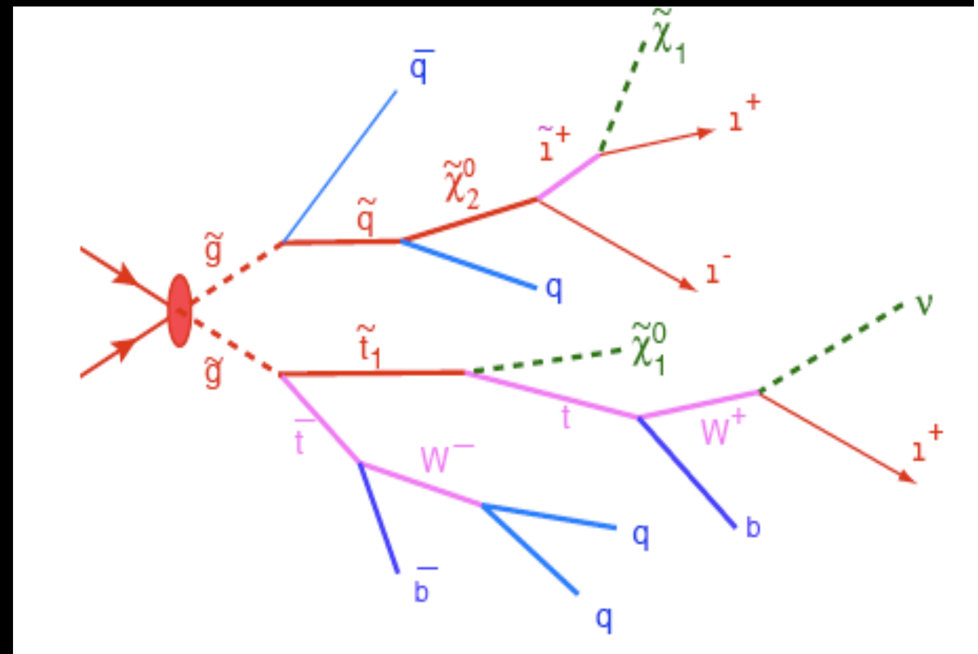




Typical SUSY topology gluino pair-produced MET+jets +leptons

Searches for SUSY

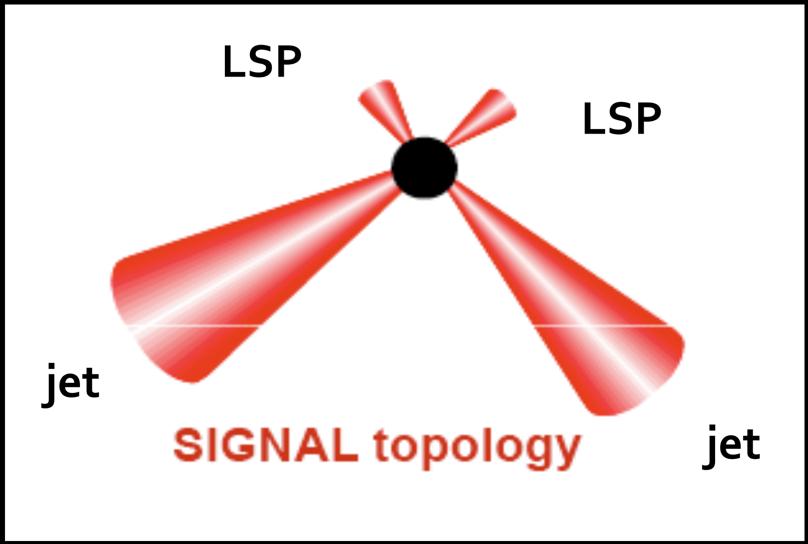
- Generic missing energy signatures
- Categorized by number of leptons and photons
- Many include jet requirement > strong production
- All counting experiments at this point

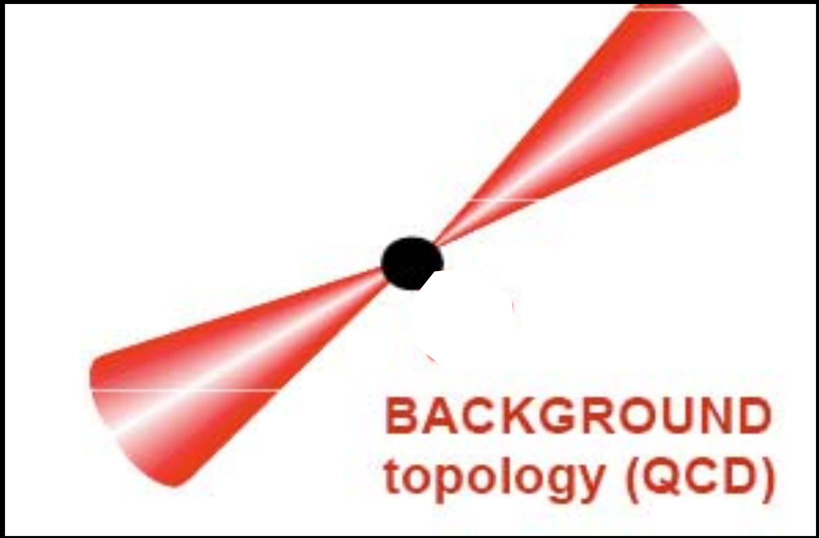


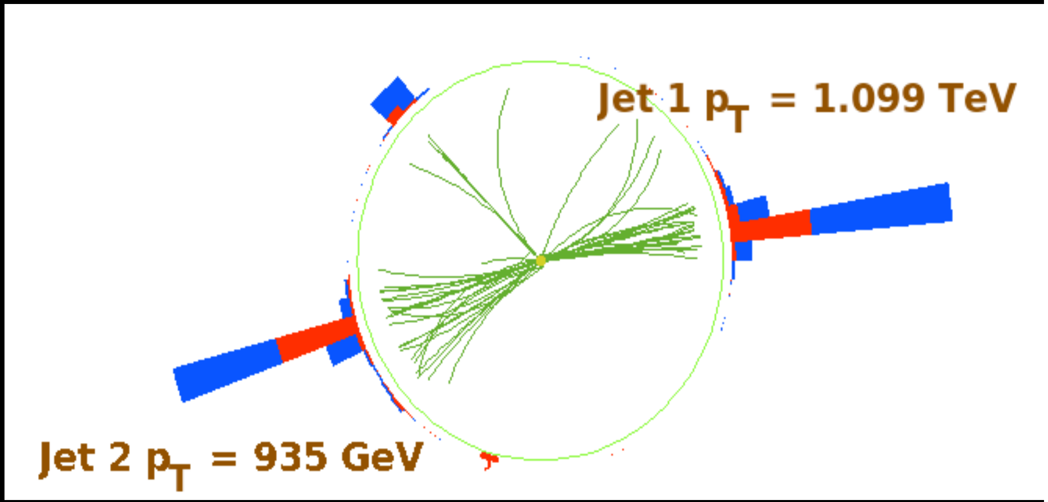
Typical SUSY topology gluino pair-produced MET+jets+leptons

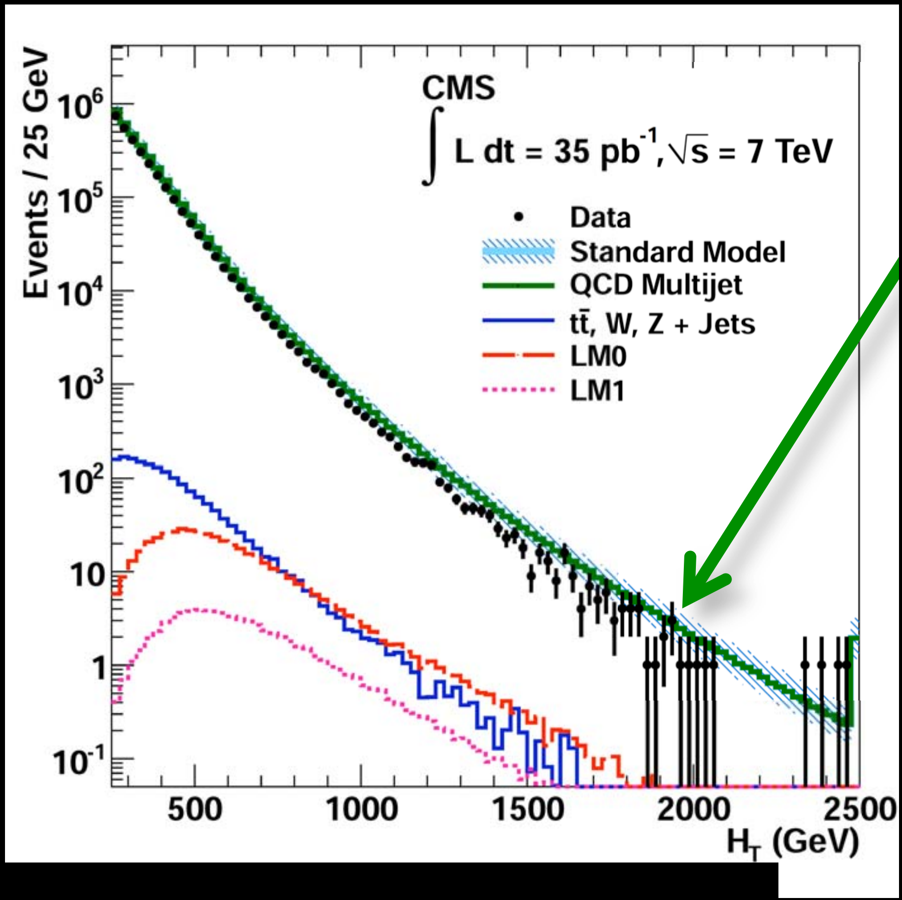
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

Jet + MET

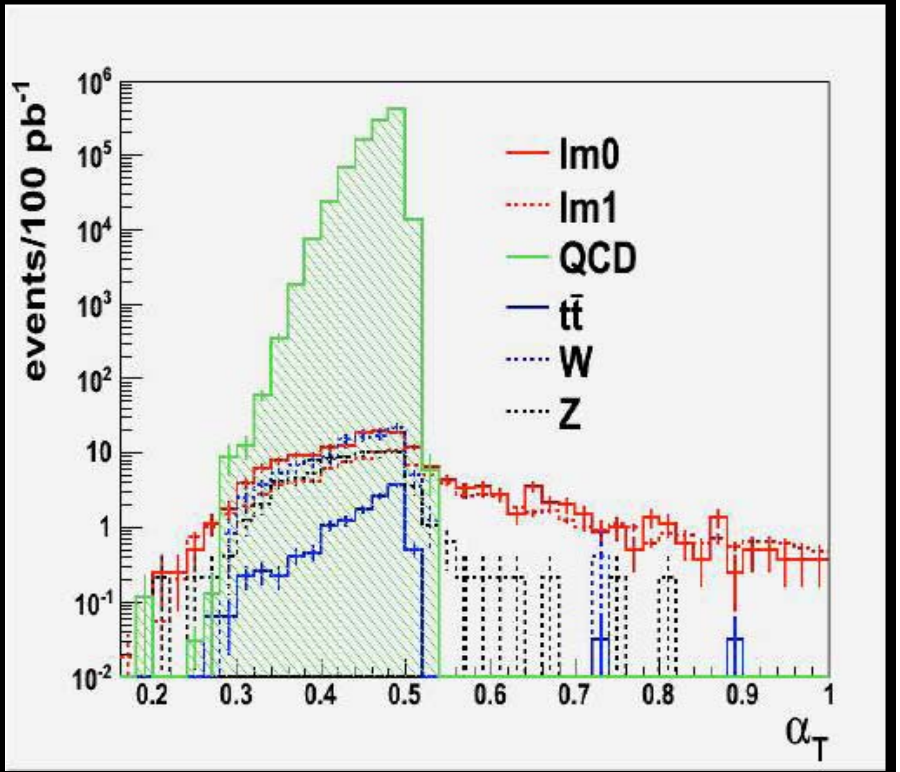

LSP
LSP
jet
SIGNAL topology
jet


BACKGROUND
topology (QCD)


Jet 1 p_T = 1.099 TeV
Jet 2 p_T = 935 GeV



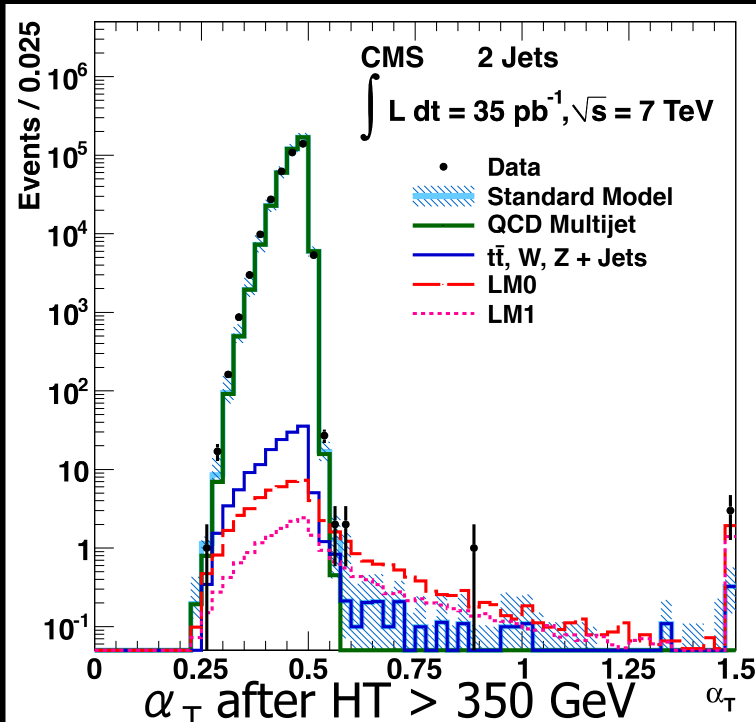
Dominant jj background
Use kinematic variable that separates signal from background
Also: Z(->nunu)+jets W+jets and top

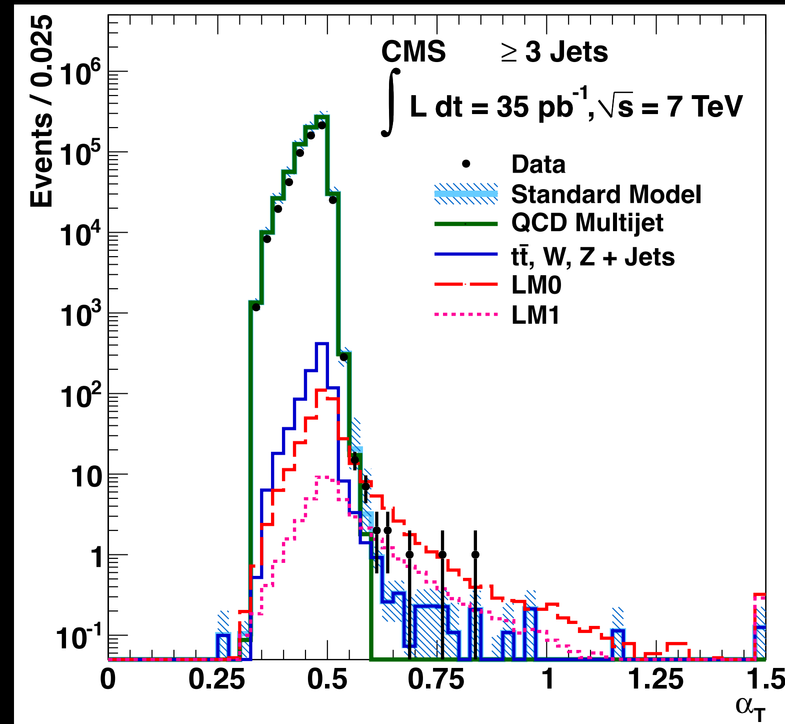


Plot shows CMS Simulations

$$\alpha_T = \frac{E_{Tj2}}{M_{Tj1j2}} = \frac{\sqrt{E_{Tj2}/E_{Tj1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

α_T = 0.5 back-to-back well measured jets
α_T < 0.5 back-to-back if energy mismeasured
α_T >0.5 if jets are not back -to-back

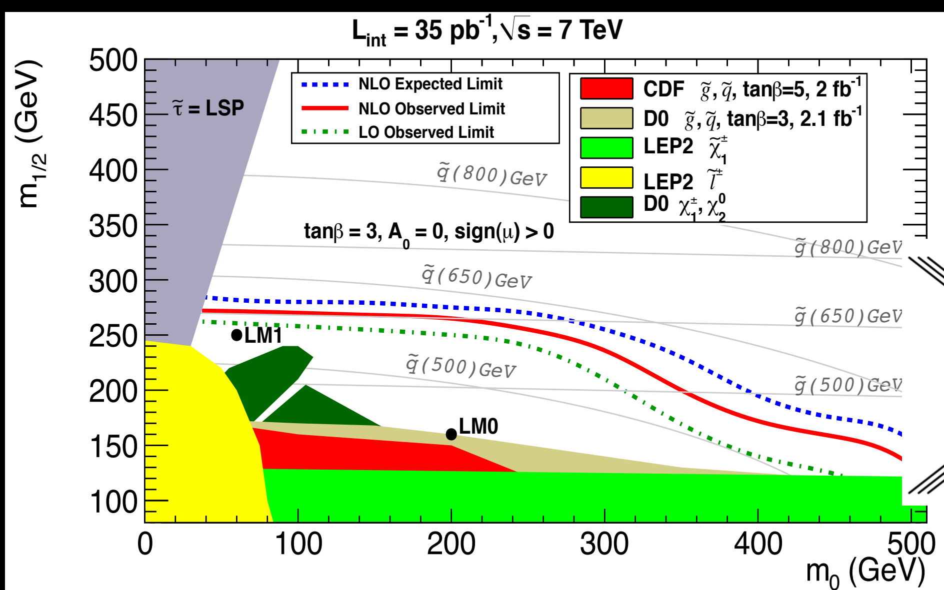


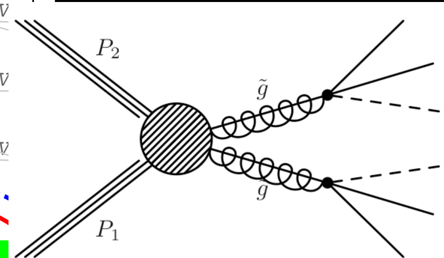


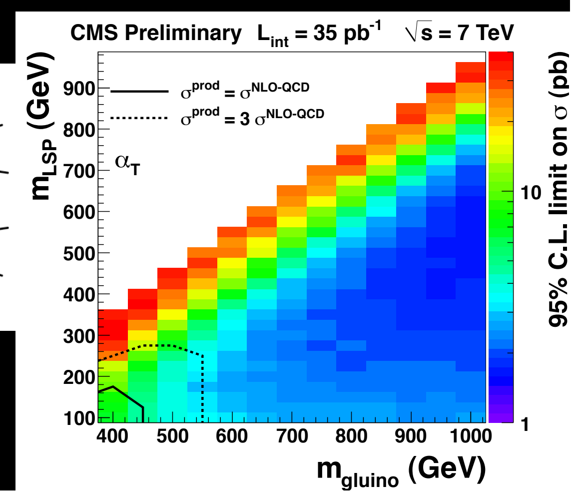
arXiv:1101.1628 PLB 698 (2011) 196

Simplified gluino model

MH_T selection exclusion limit





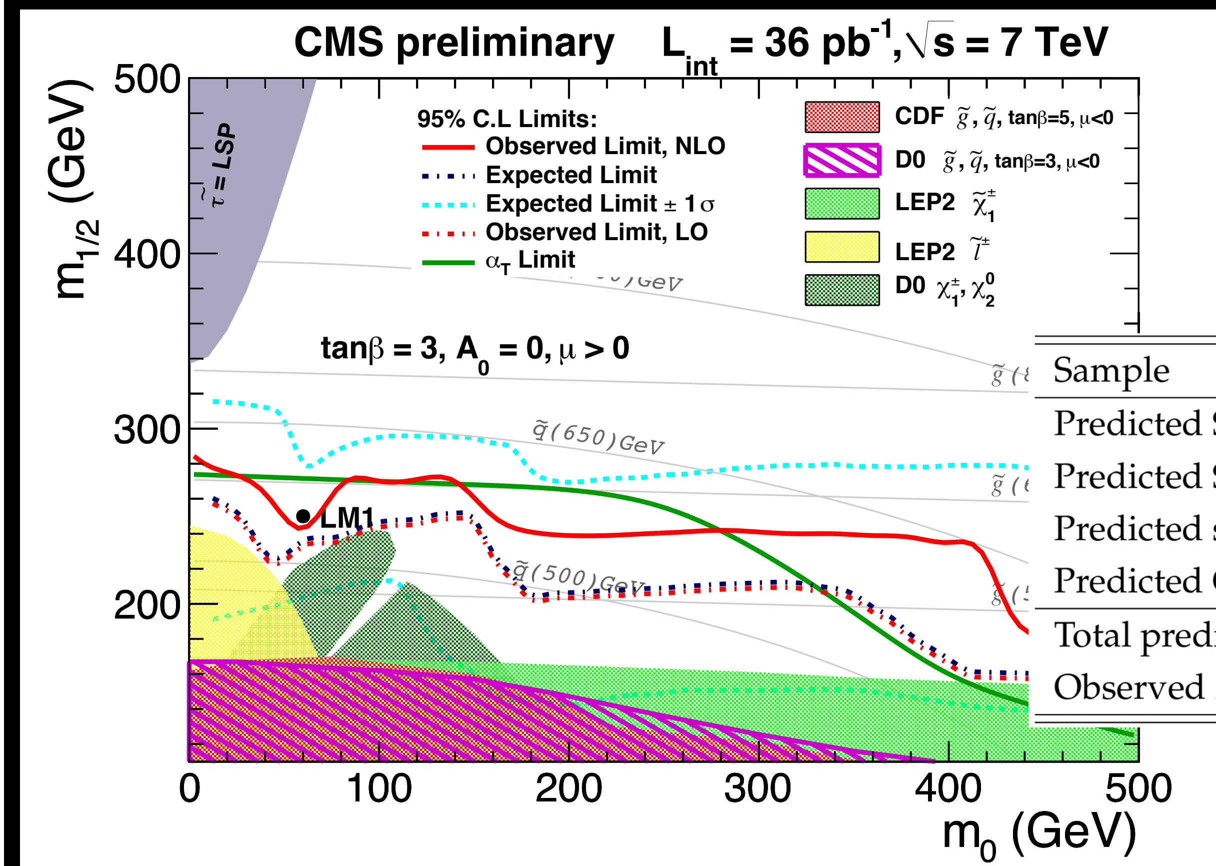


DESY Seminar Shipsey

CMS PAS-SUS-10-006

Single lepton

- Exactly one isolated e or μ $p_T > 20$ GeV
- At least 4 jets $E_T > 30$ GeV $|\eta| < 2.4$
- Background from top and W+jets from simulation, all the rest from data



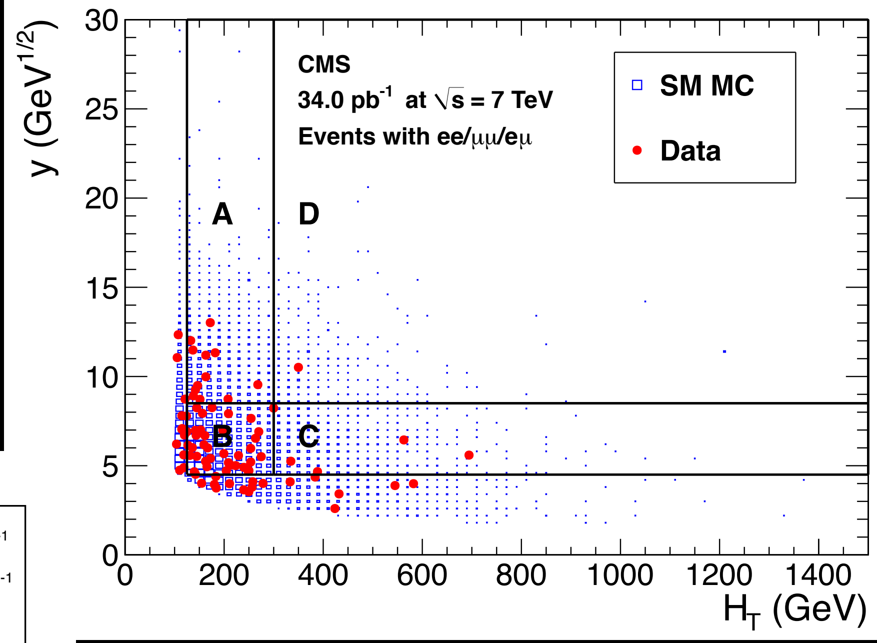
95% CL exclusion

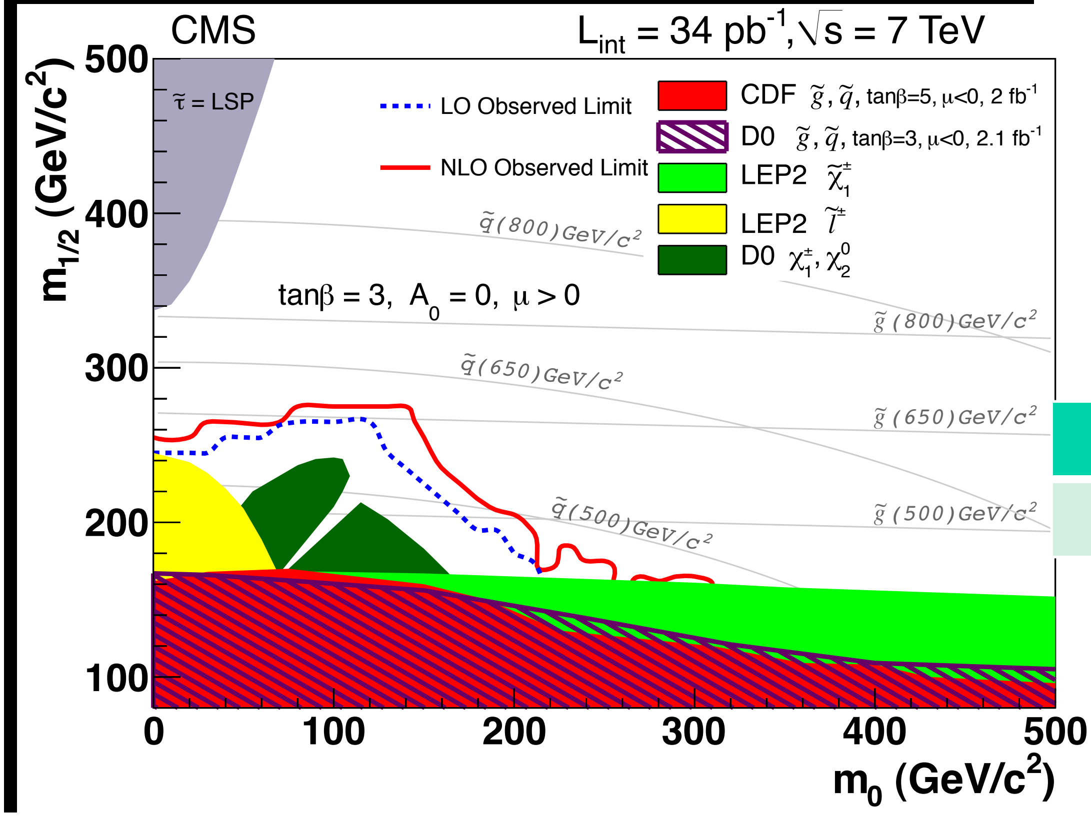
Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0

Opposite-sign dileptons

arxiv:1103.1348

- Adding a second lepton rejects W+jets leaving mostly top background
  - Estimated from data with ABCD method
- Observed events consistent with SM prediction





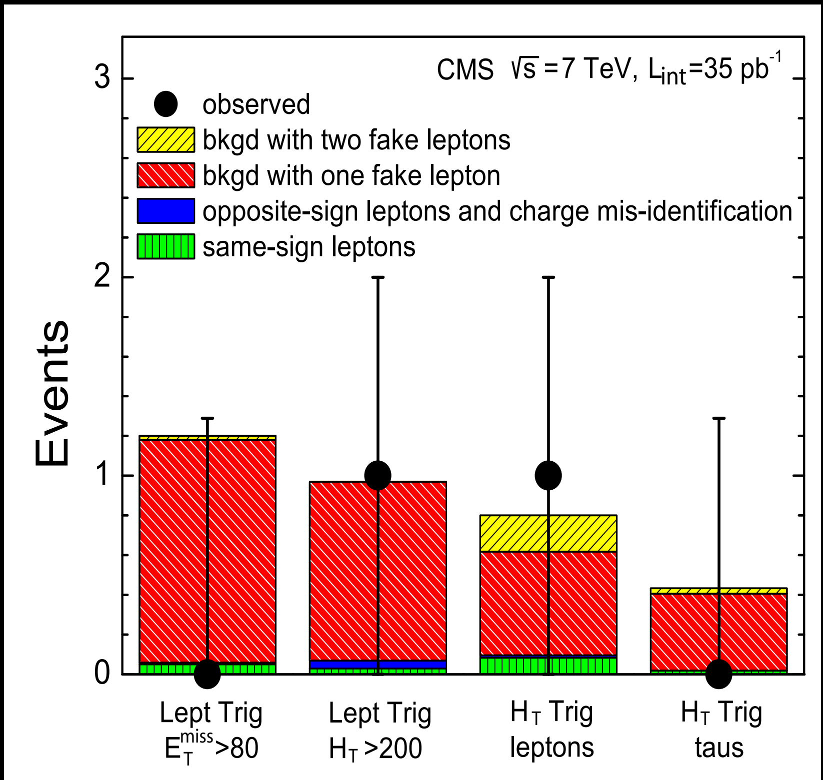
	Predicted	Observed
Region D	1.4 ± 0.8	1

Same sign dileptons

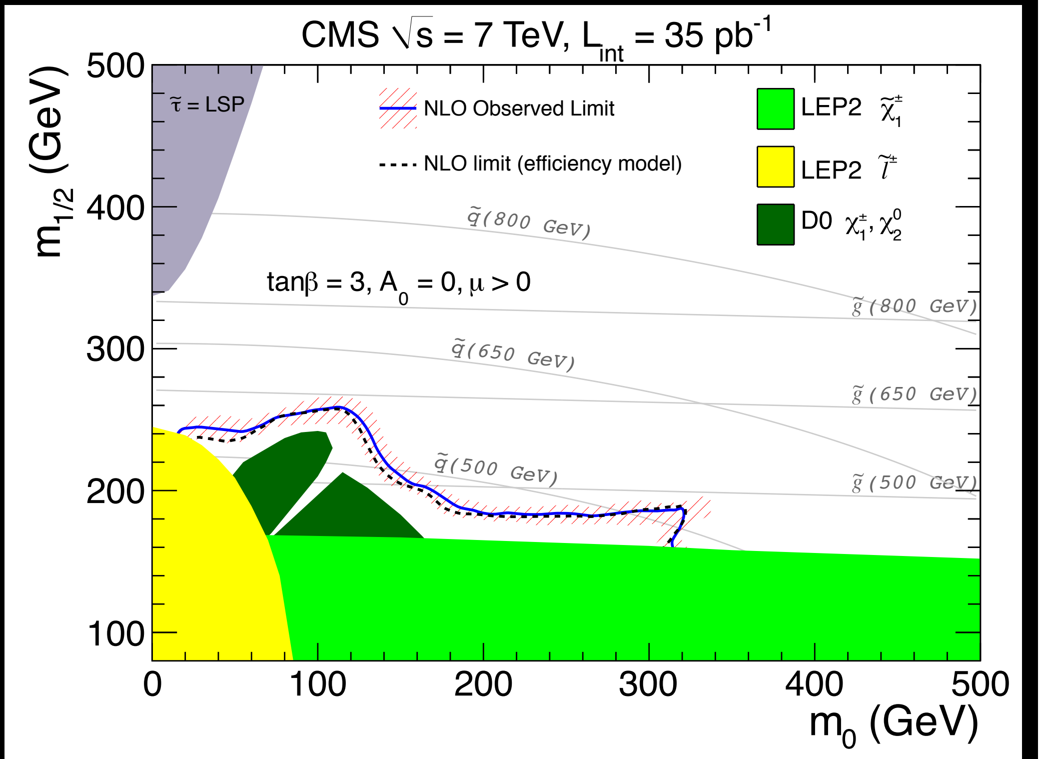
arxiv:1104.3168

- Essentially absent in the SM (dominant bkgd misid leptons)
- Search in all three lepton species and four search regions
- Similar sensitivity as in OS for small tan β
- Tau not yet included in limit

Observed events

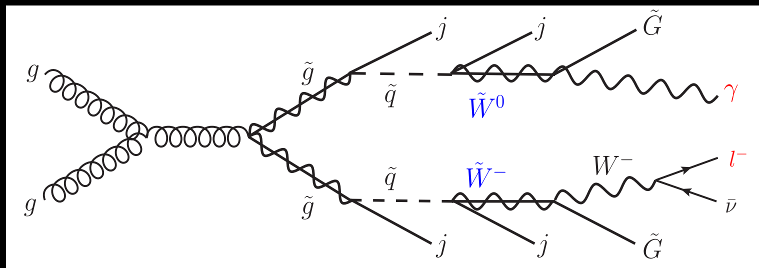


CMSSM exclusion limits

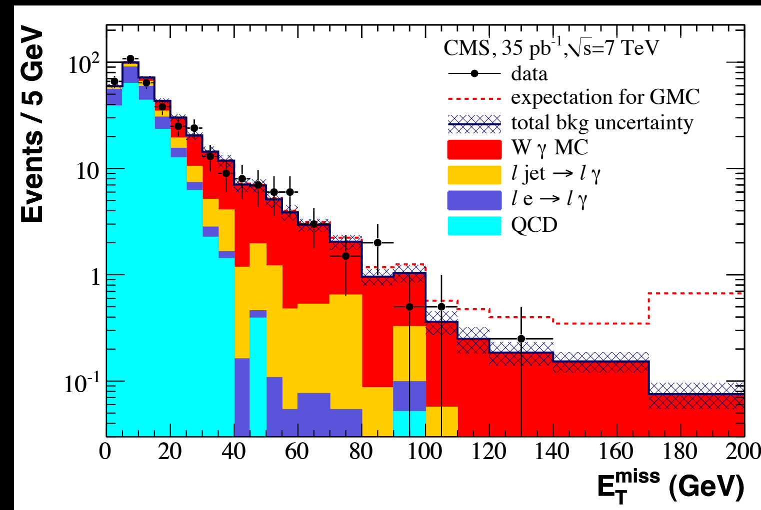


Photon + Lepton + MET

arxiv:1105.3152

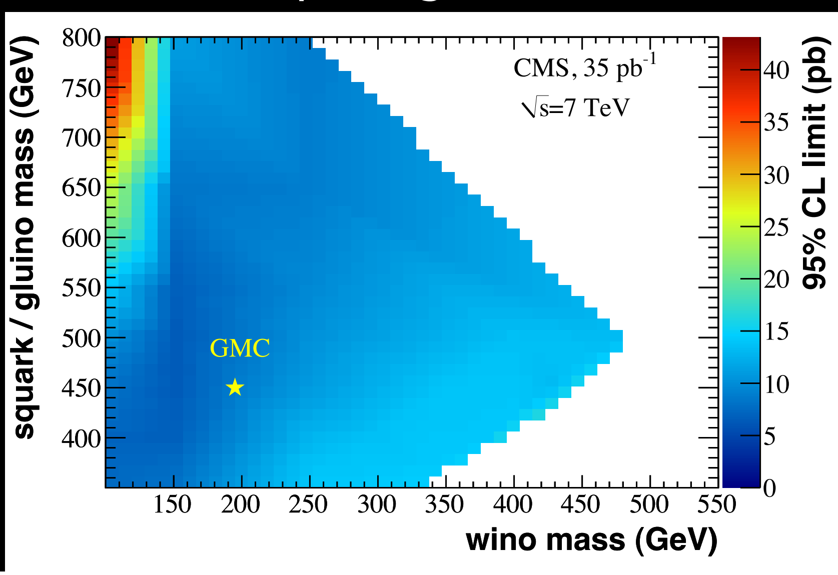


- γ +l expected when lightest neutral and charged gauginos are mass degenerate
- Main background W γ (from MC)
- Other sources estimated from the data



95% CL exclusion for squark/gluino mass vs wino mass (the area below the curve is excluded)

95% CL upper limit on the cross section as a function of squark/gluino mass vs wino mass

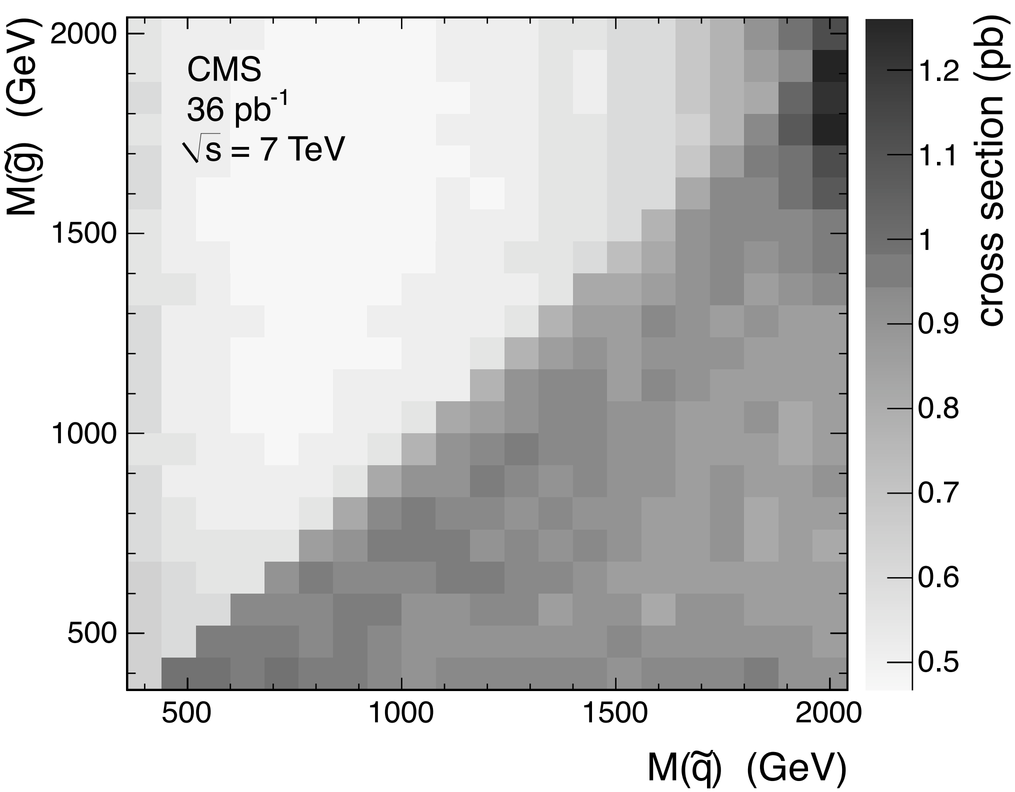


Di-photons

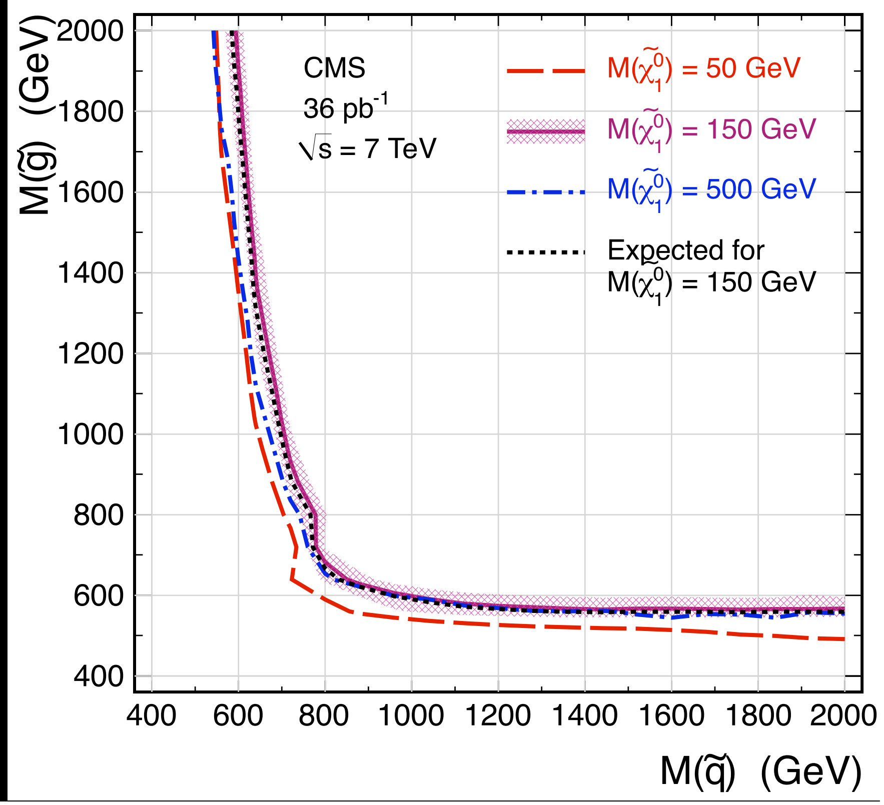
arxiv:1103.0953

- At least two isolated photons, one jet and MET
- Observed 1 event with MET > 50 GeV
  - consistent with 1.2 ± 0.8 from SM
- Set limits for the general gauge mediated (GGM) SUSY

95% CL upper limits for GGM production cross section for a neutralino mass of 150 GeV

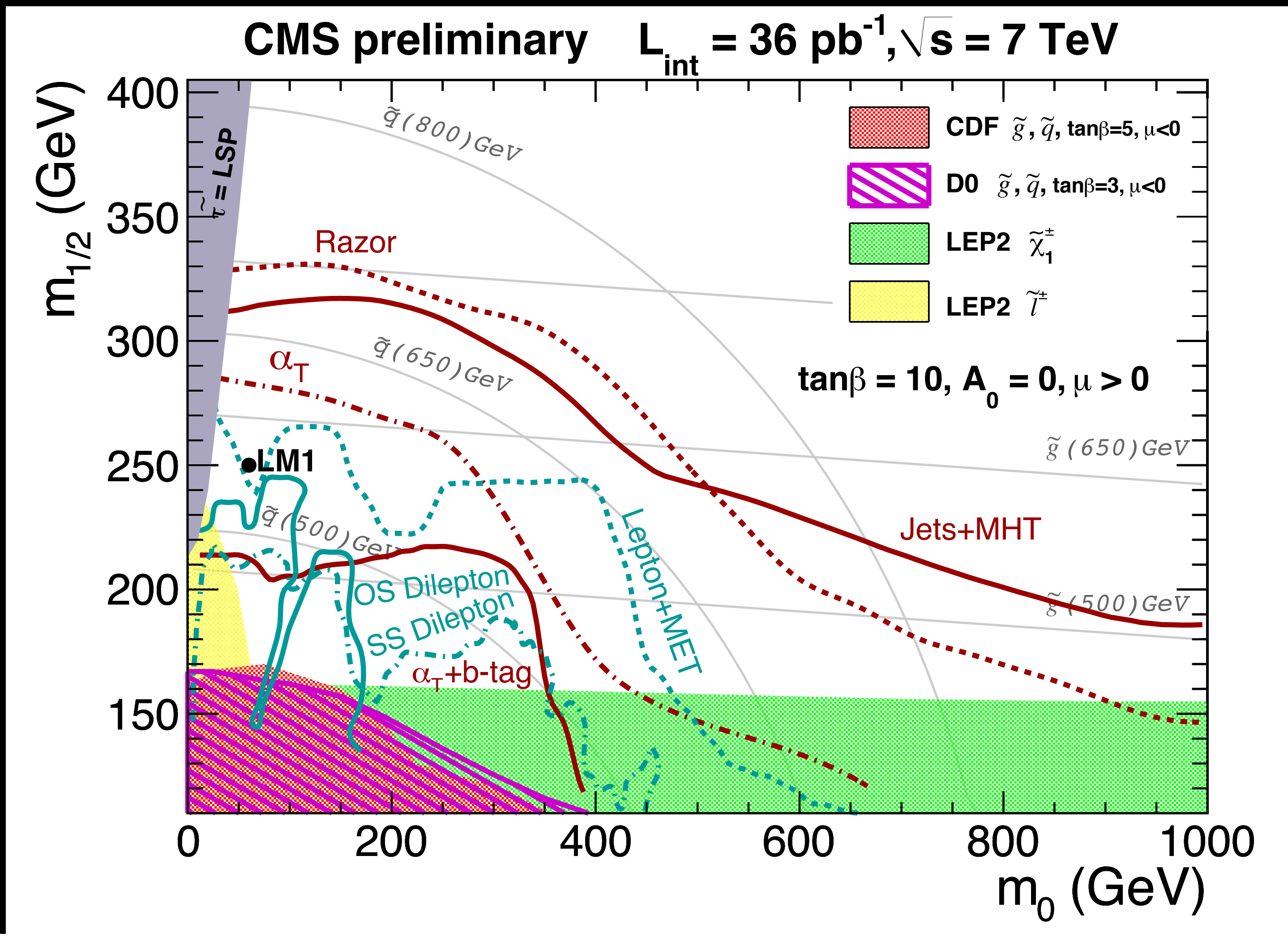


Lower 95% CL limits on squark & gluino masses in the benchmark GGM model

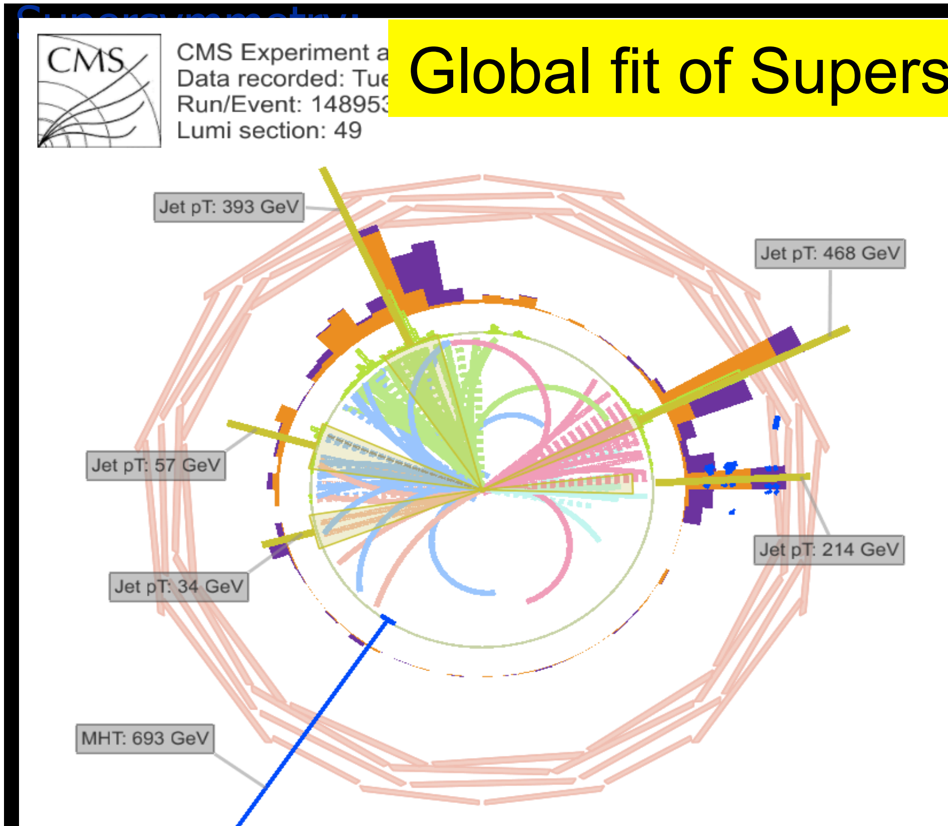


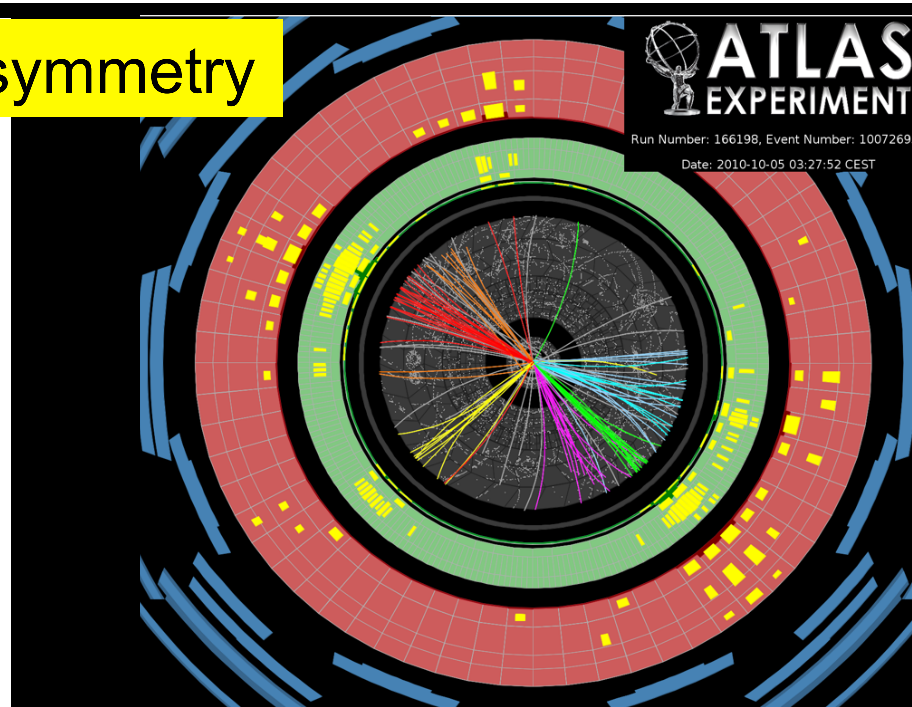
Summary of Searches for SUSY

- Observed limits from several 2010 CMS SUSY searches plotted in the CMSSM (m_0, $m_{1/2}$) plane



Global fit of Supersymmetry





Experimental Data

Global Fit of SUSY :

- **Precision Particle Physics data**

•Flavour observables (*e.g.* B-Physics, g-2

- Electroweak observables (*e.g.* m_t, m_W)

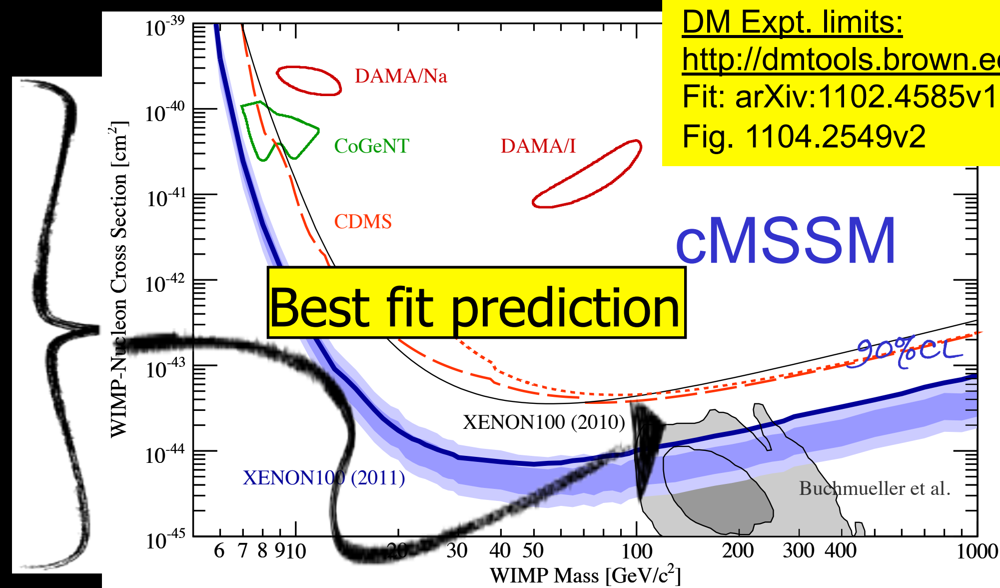
Cosmology/astrophysical data

Relic density (WMAP)

LHC data

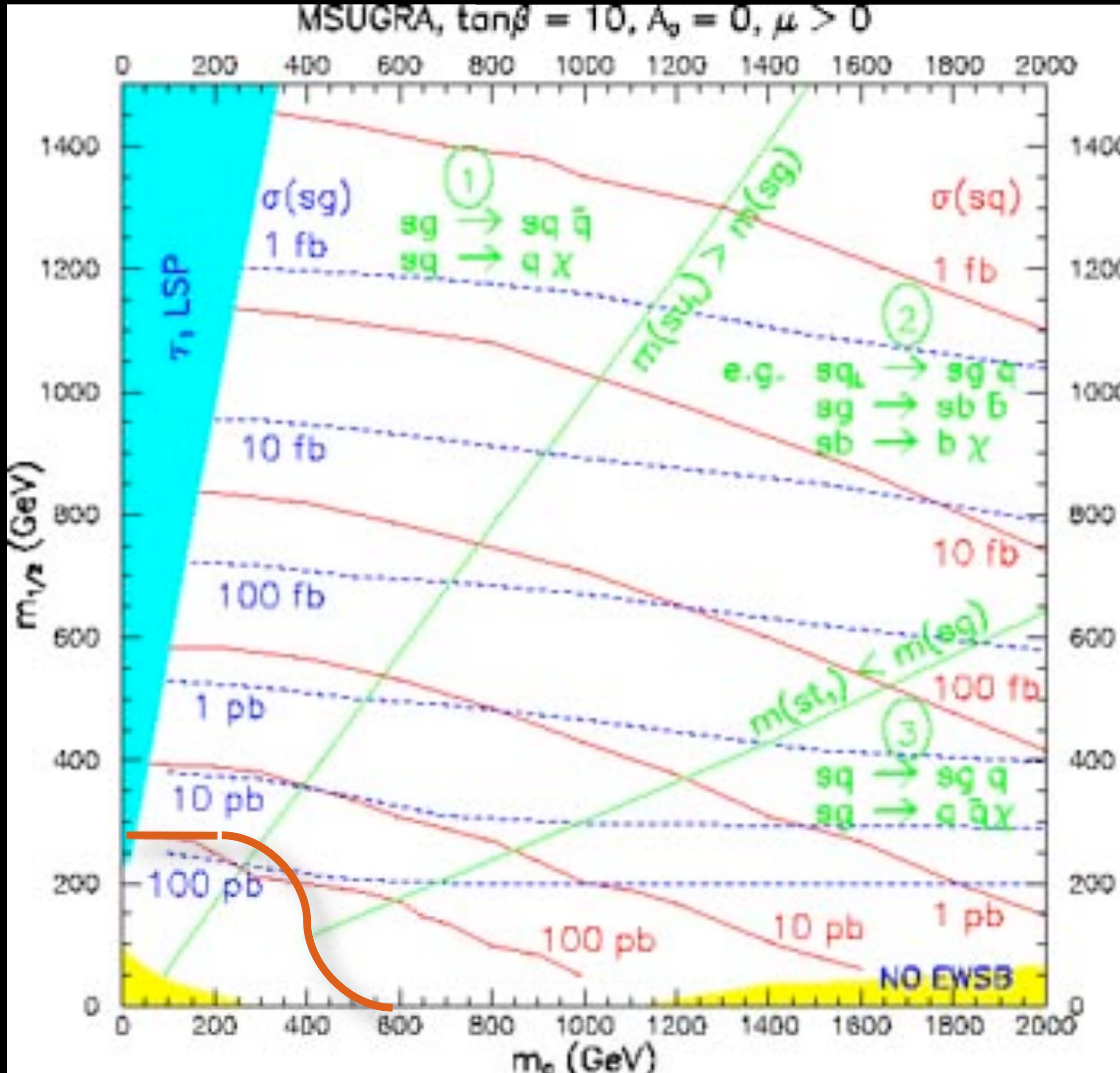
Direct searches

XENON100 direct Dark Matter search cuts into allowed fit region.



DM Expt. limits:
http://dmtools.brown.edu/
Fit: arXiv:1102.4585v1
Fig. 1104.2549v2

We have only begun…



Exotica

Jet: resonances

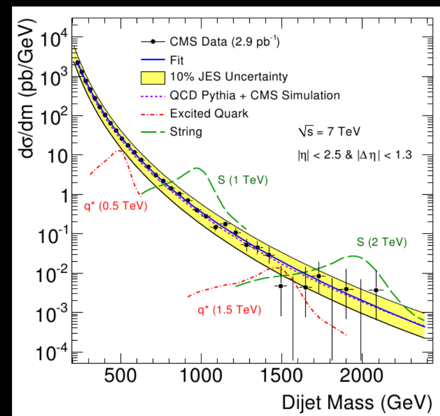
Generic searches for hadronic resonances
dijet: hep-ex/1010.0203

$$Z' \to q\bar{q} \quad G^* \to q\bar{q}$$

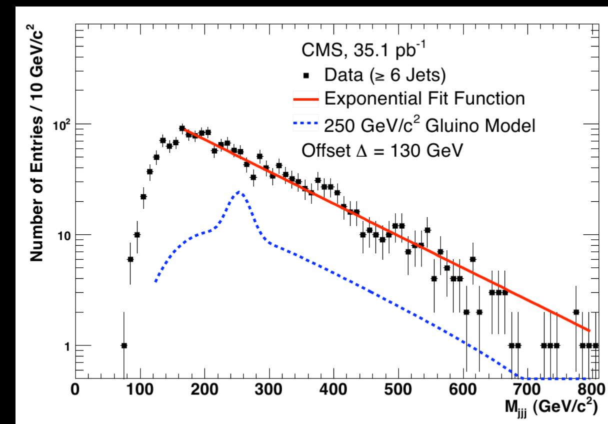
multijet: PAS EXO-11-001
"quix" or RPV

$$\tilde{g} \to qq\bar{q}$$

Dijet mass



Trijet mass



Jet: resonances

Generic searches for hadronic resonances

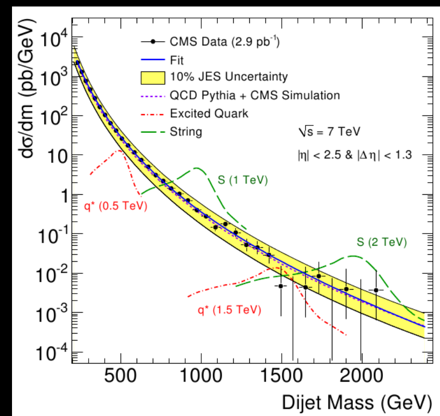
dijet: hep-ex/1010.0203

$Z' \rightarrow q\bar{q} \quad G^* \rightarrow q\bar{q}$

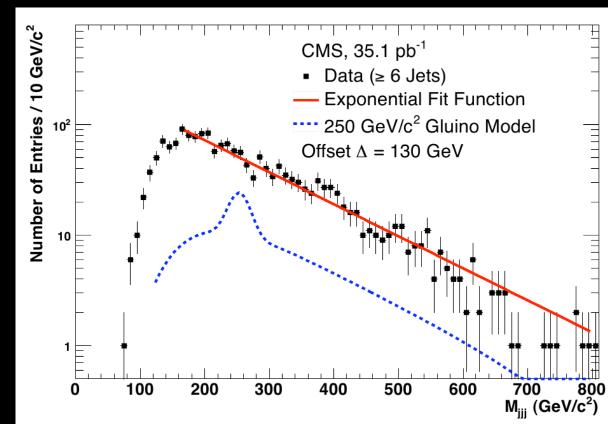
multijet: PAS EXO-11-001

"quix" or RPV $\tilde{g} \rightarrow qq\bar{q}$

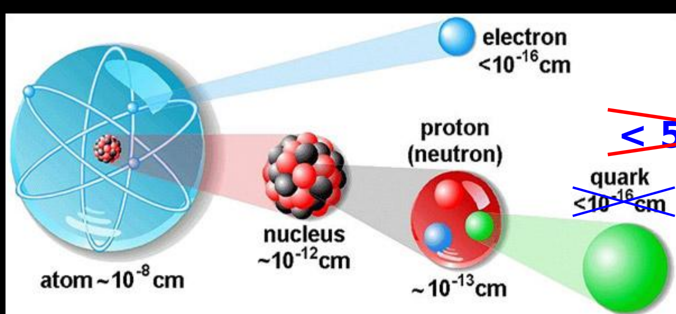
Dijet mass



Trijet mass



Dijet angular distributions



~~$< 5.0\times10^{-18}$ cm~~

(Oct 2010, 2.9 pb^{-1})

$< 3.6\times10^{-18}$ cm if destructive

$< 3.0\times10^{-18}$ cm if constructive interference

(Feb 2011, 36 pb^{-1})

Centrality ratio

$$R_\eta = \frac{N_{jj}(|\eta| < 0.7)}{N_{jj}(0.7 < |\eta| < 1.3)}$$

New limits on quark compositeness:

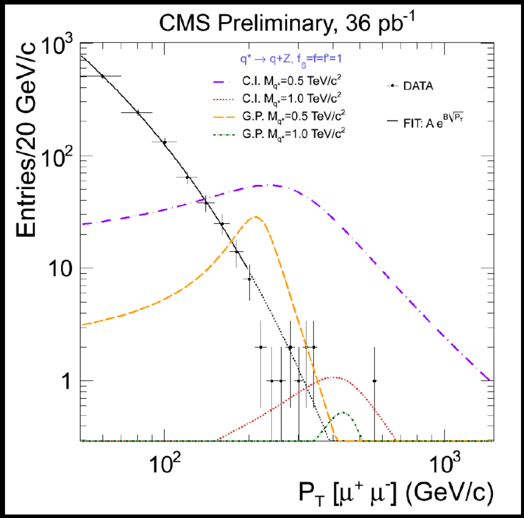
$\Lambda^+ > 5.6$ TeV (destr.)

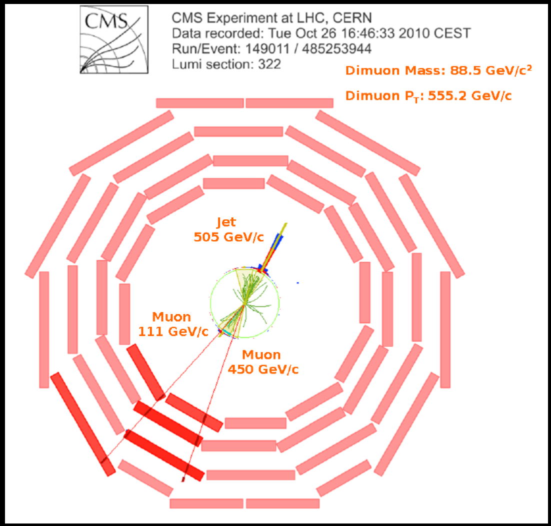
$\Lambda^- > 6.7$ TeV (constr.)

hep-ex/1010.4439 and
hep-ex/1102.2020 (update)

Leptons: other resonances

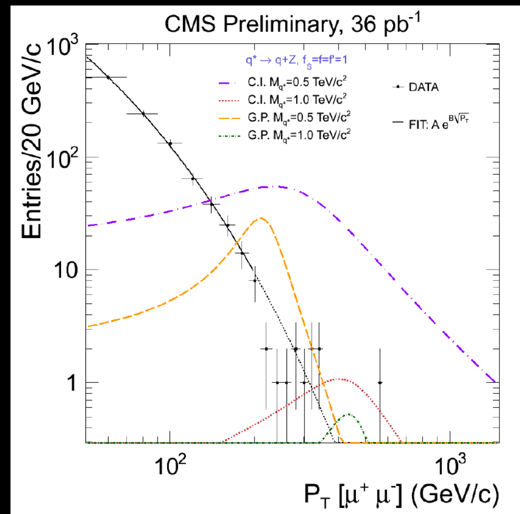
Z boson p_T spectrum
Channel for generic
Neutral to heavy-to-light
decays q*➔qZ
PAS-EXO 10-025

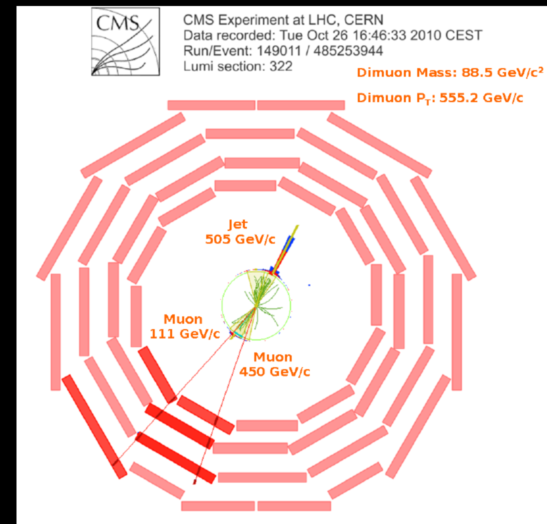




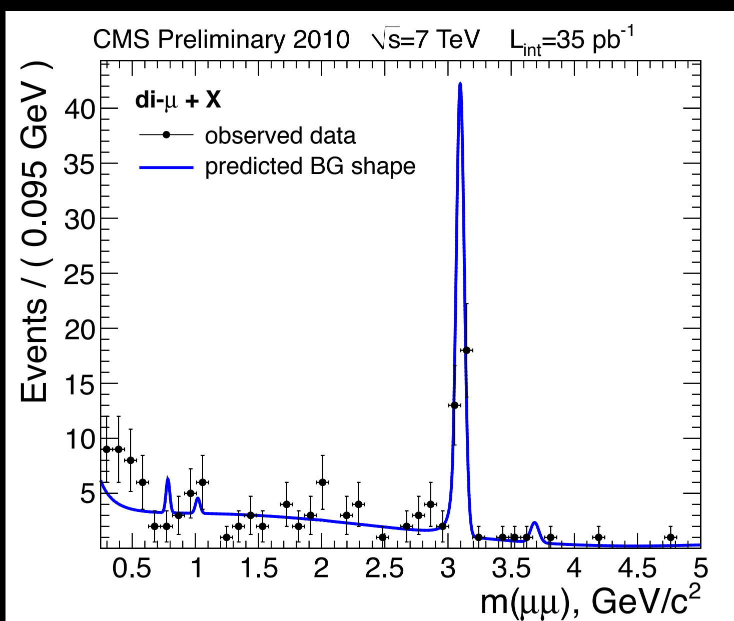
Leptons: other resonances

Z boson p_T spectrum
Channel for generic
Neutral to heavy-to-light
decays $q^* \rightarrow qZ$
PAS-EXO 10-025

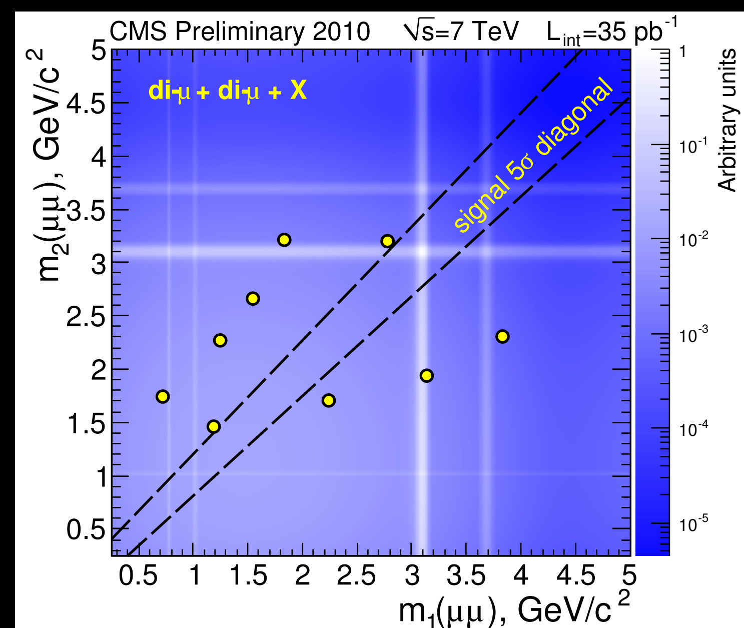




Lepton jets: one or more low mass high p_T $\gamma_{dark} \rightarrow ll$ from a hidden sector

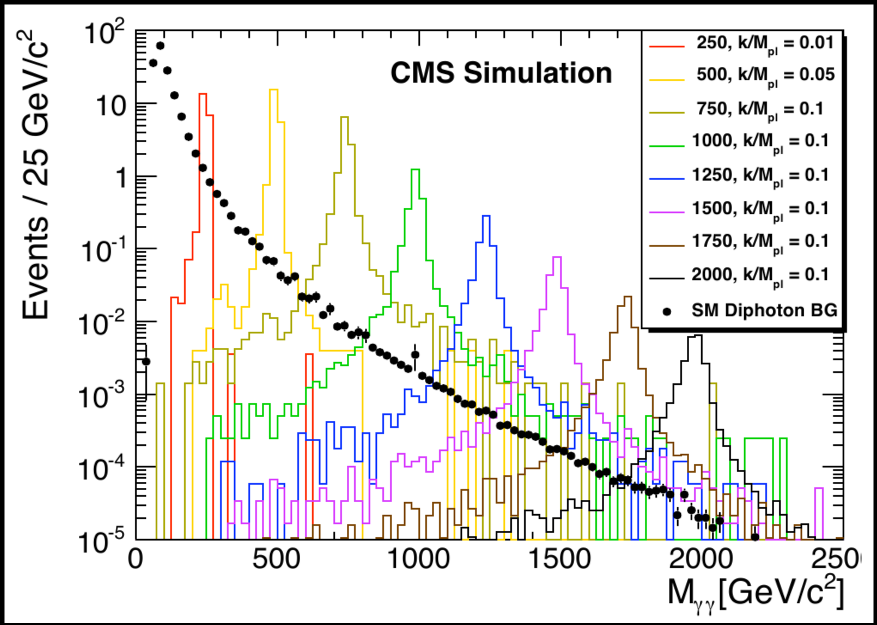


← High p_T dimuons
2 dimuons per event→



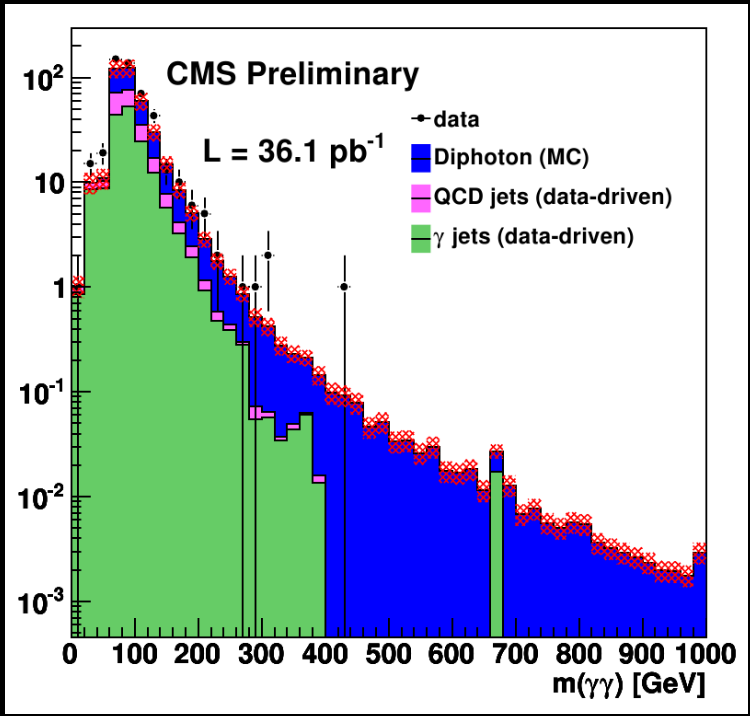
Diphoton mass spectrum

G* resonance simulation



limits with data in PAS EXO 10-019

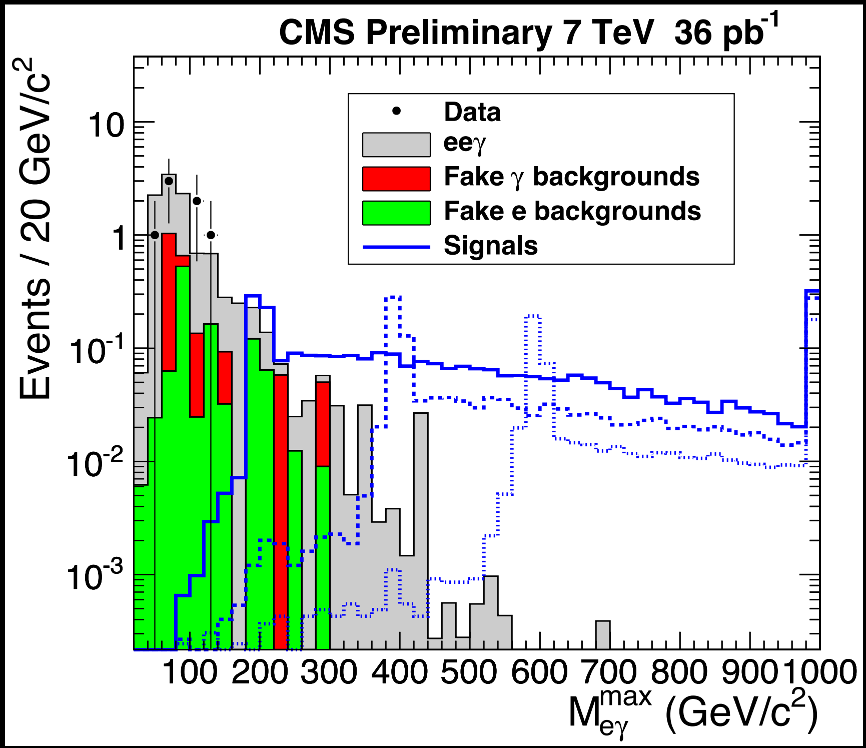
Data with non-resonant Large Extra Dimensions prediction



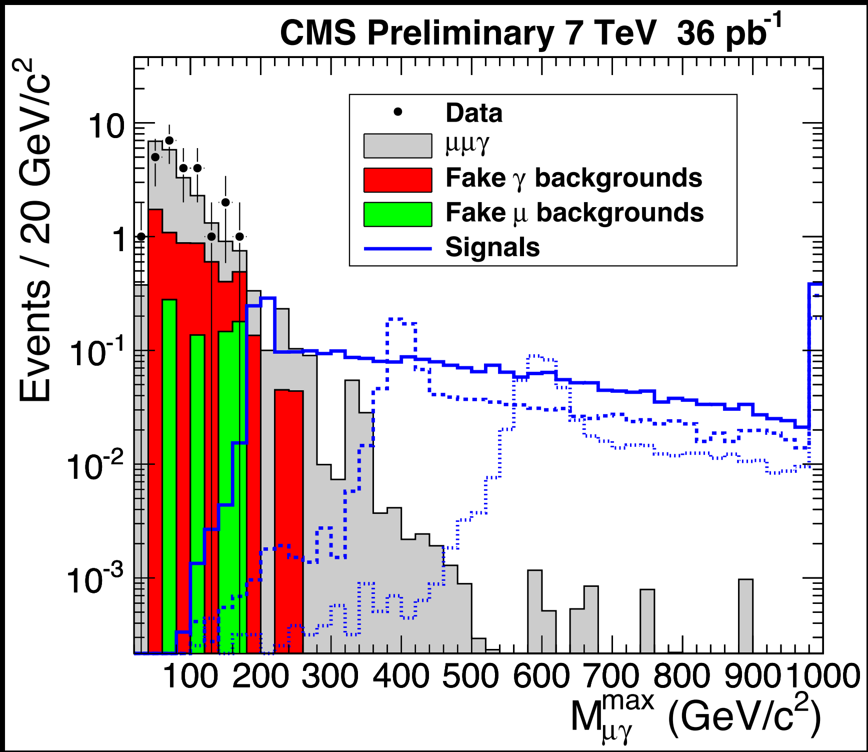
Hep-ex/1103.4279

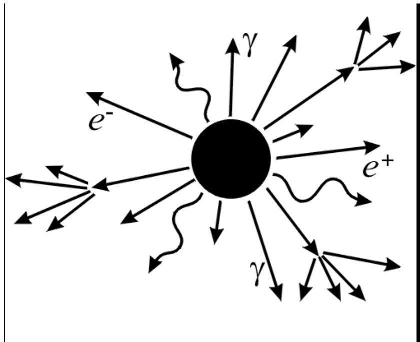
Cross-channels: lepton + photon

Search for $e^* \rightarrow e\gamma$



Search for $\mu^* \rightarrow \mu\gamma$

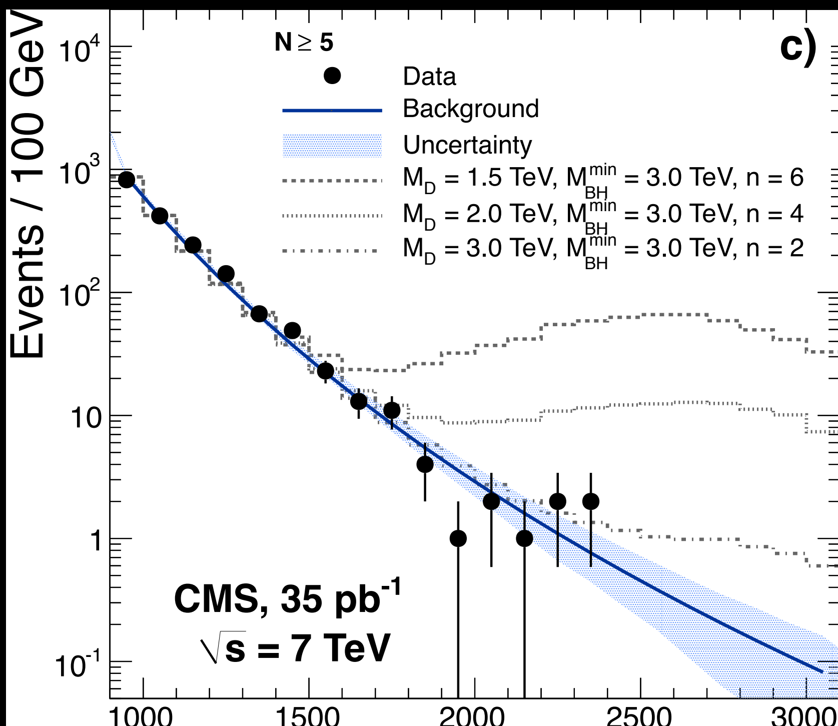


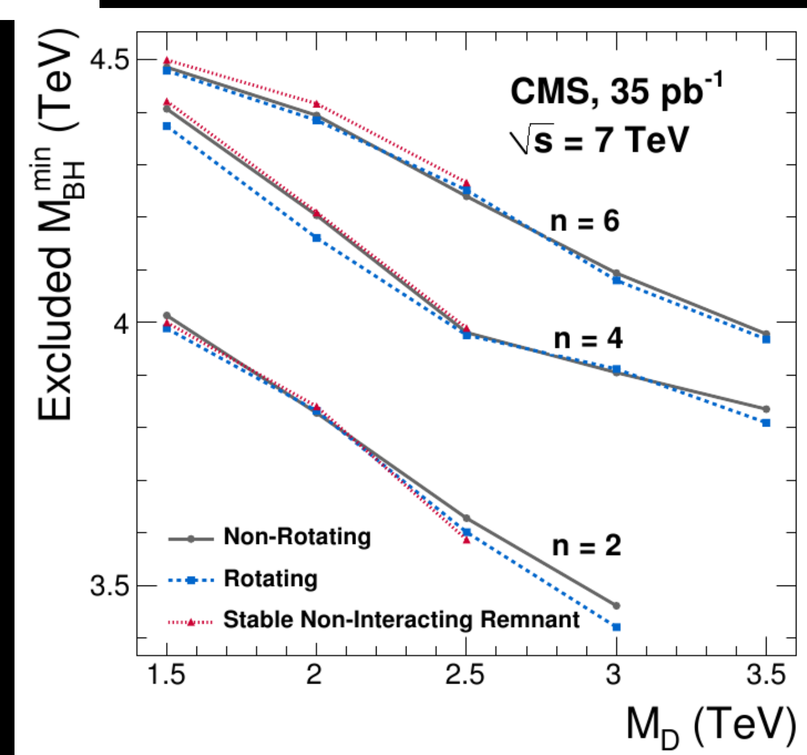


Microscopic black holes

$$S_T = \sum_{E_T > 50\ \mathrm{GeV}} E_T \text{ of jets, } e, \gamma, \mu$$

Set limits on (4 + n)-D Planck scale M_D



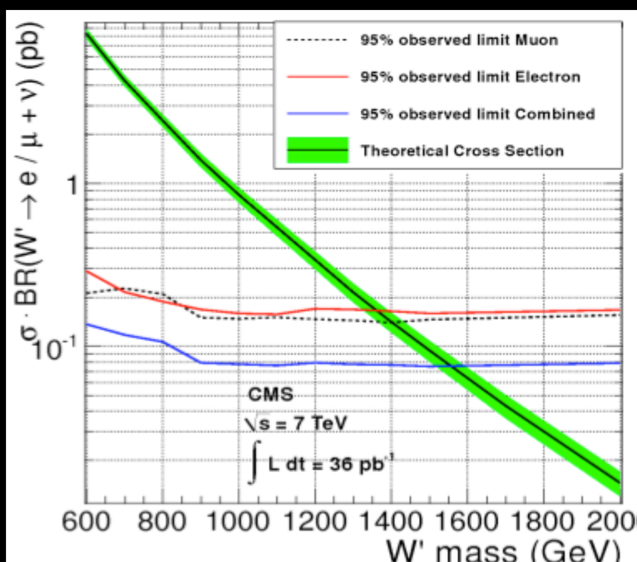


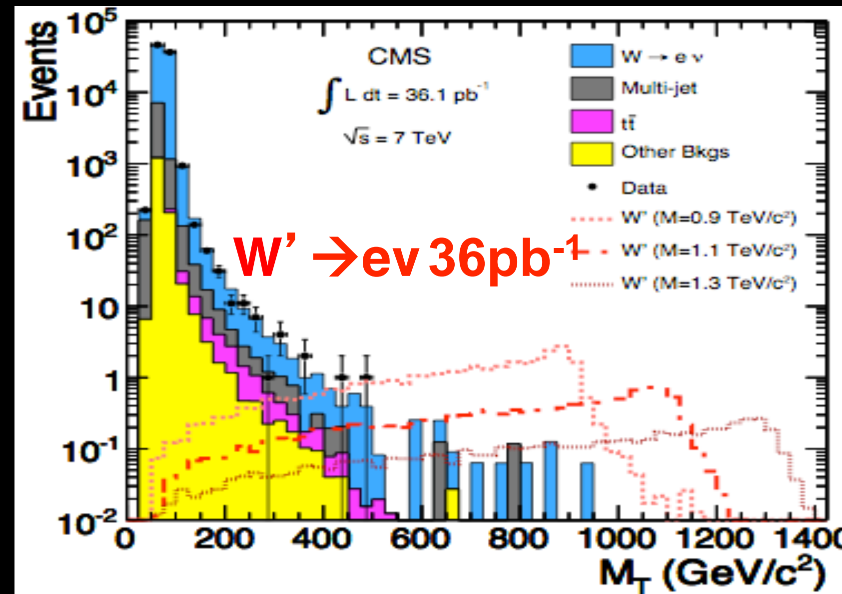
Consistent with standard model backgrounds, dominated by QCD multijet production, for various final-state multiplicities. Limits on the minimum black hole mass: **3.5–4.5 TeV**, for a range of parameters in a model with large extra dimensions. **arXiv:1012.3375**; ***Phys. Lett. B697 (2011)***)

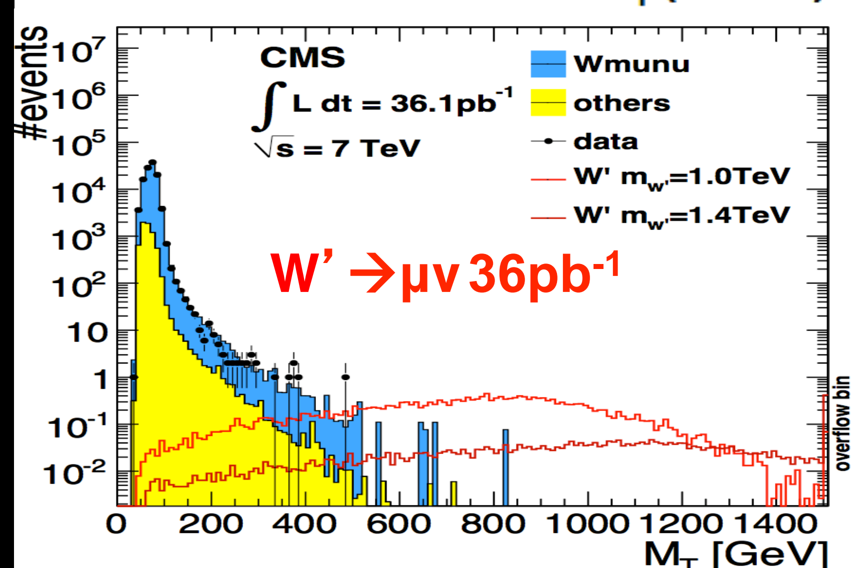
Search for massive vector bosons

limits on W' and Z' exceeding the current limits set by the Tevatron experiments.

Assuming standard-model-like couplings and decay branching fractions we exclude a W' with mass<1.58 TeV (95%CL)

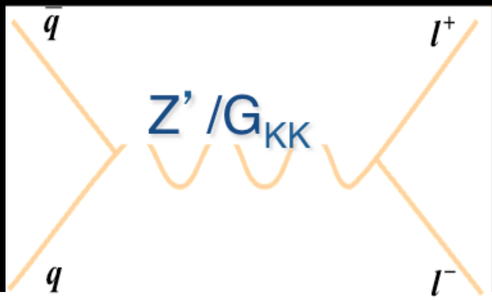




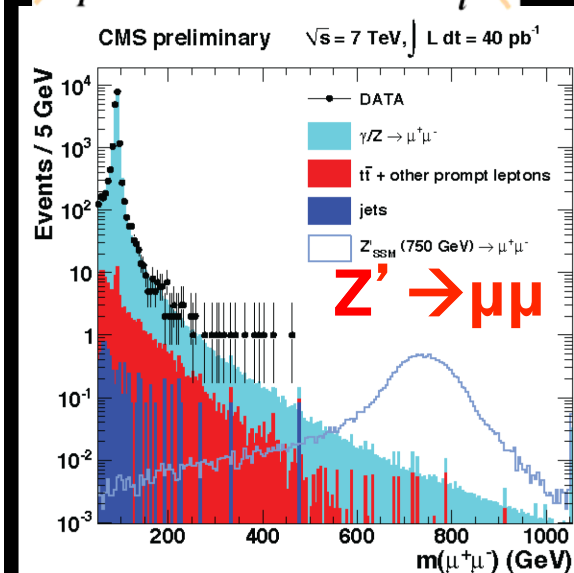


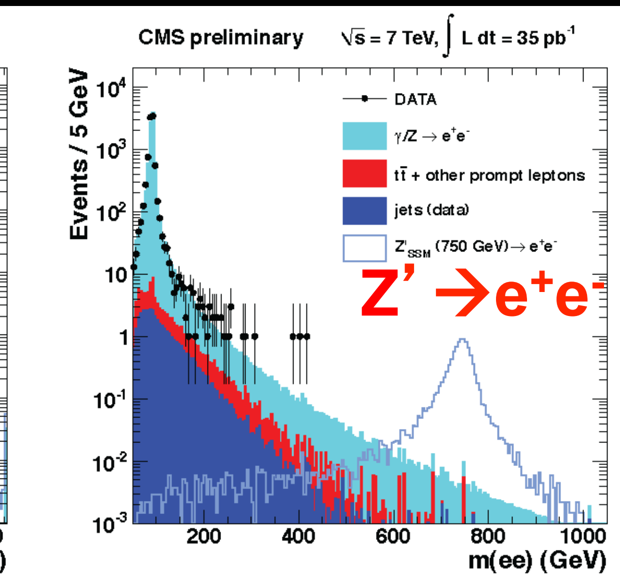
arXiv:1103.0030 Submitted to Physics Letters B.

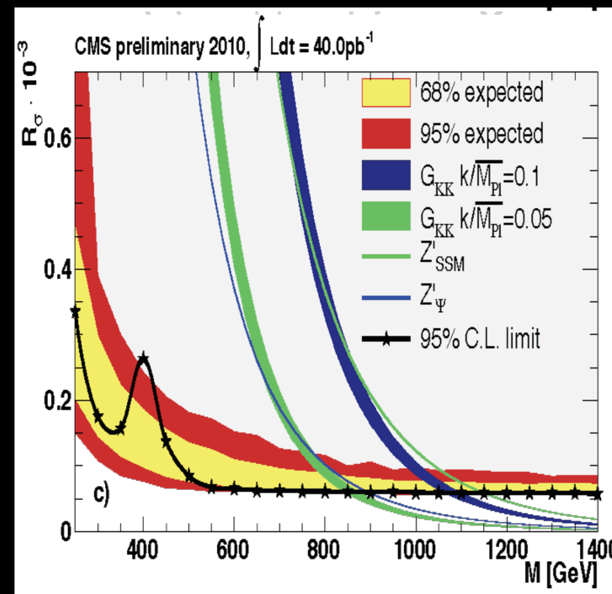
Search for Z' in dileptons



High mass tail of the Z.
spectra are consistent with known SM processes.



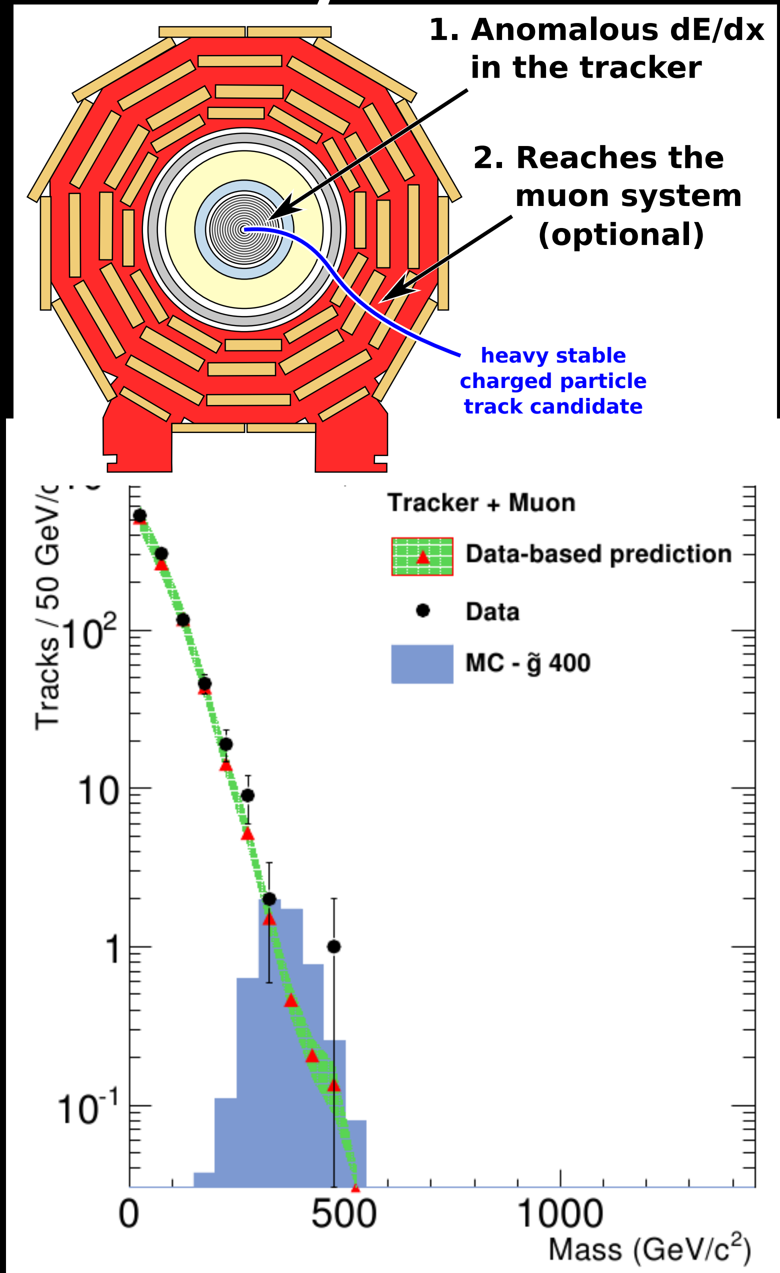




By combining the $\mu^+\mu^-$ and e^+e^- channels, the following 95% C.L. lower limits are obtained: **1140 GeV** for the Sequential Standard Model Z'_{SSM}, **887 GeV** for Super-String inspired models, Z'_{ψ}. RS Kaluza-Klein Gravitons are excluded below **855-1079 GeV** at 95% C.L. for values of couplings parameters (k/M_{Pl}) 0.05-0.1.

arXiv:1103.0981 ; CMS-EXO-10-013 .

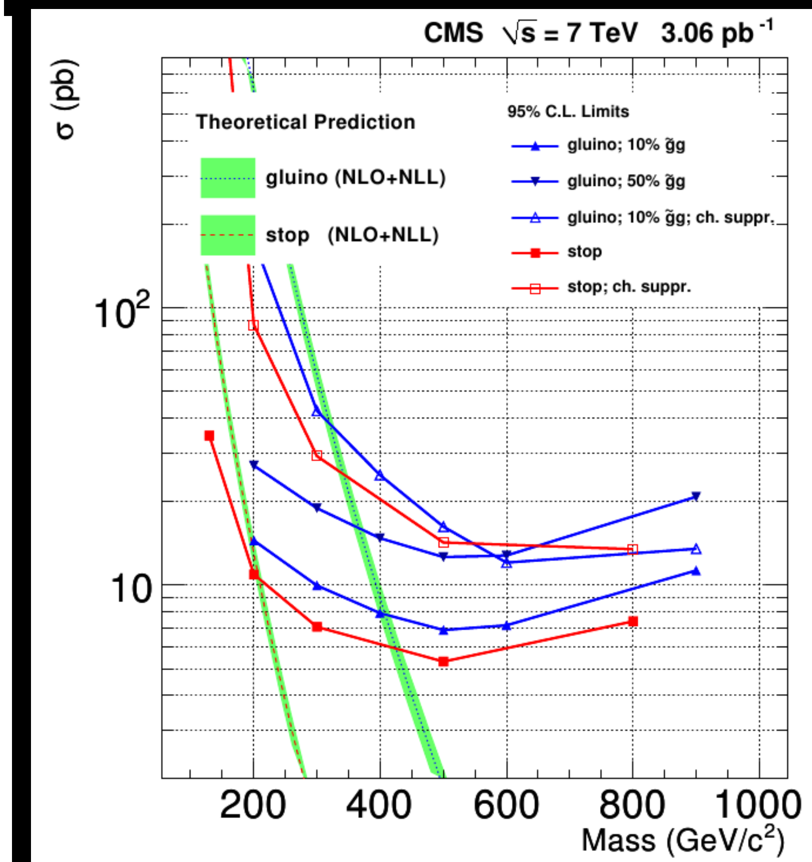
Heavy stable charged particles



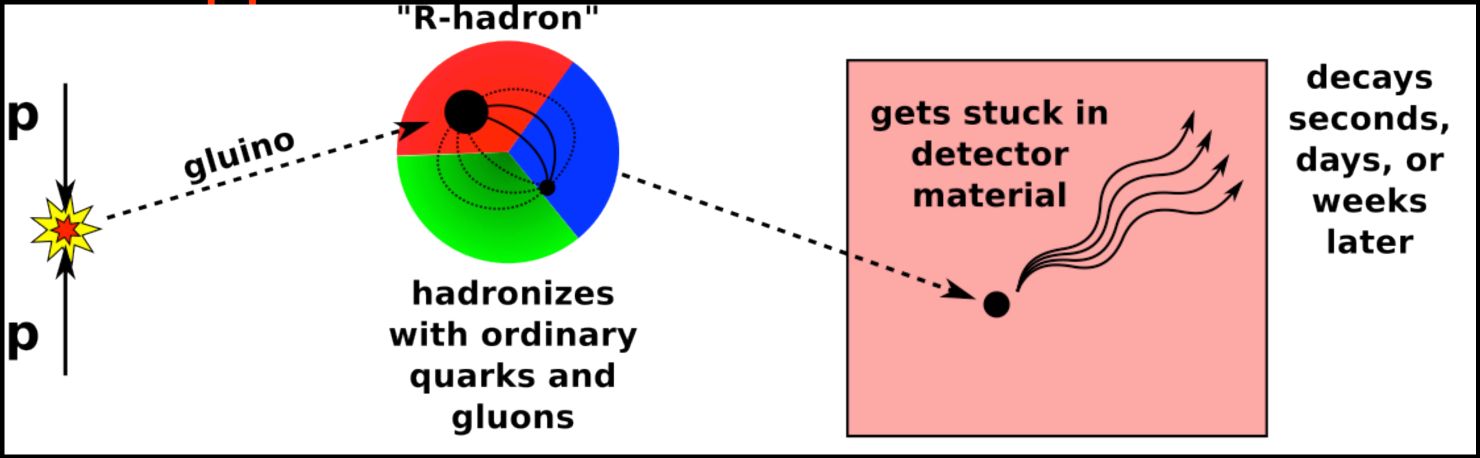
Search for anomalously large dE/dx (for p > 15 GeV/c)

Any particle with $\beta \ll 1$ is BSM

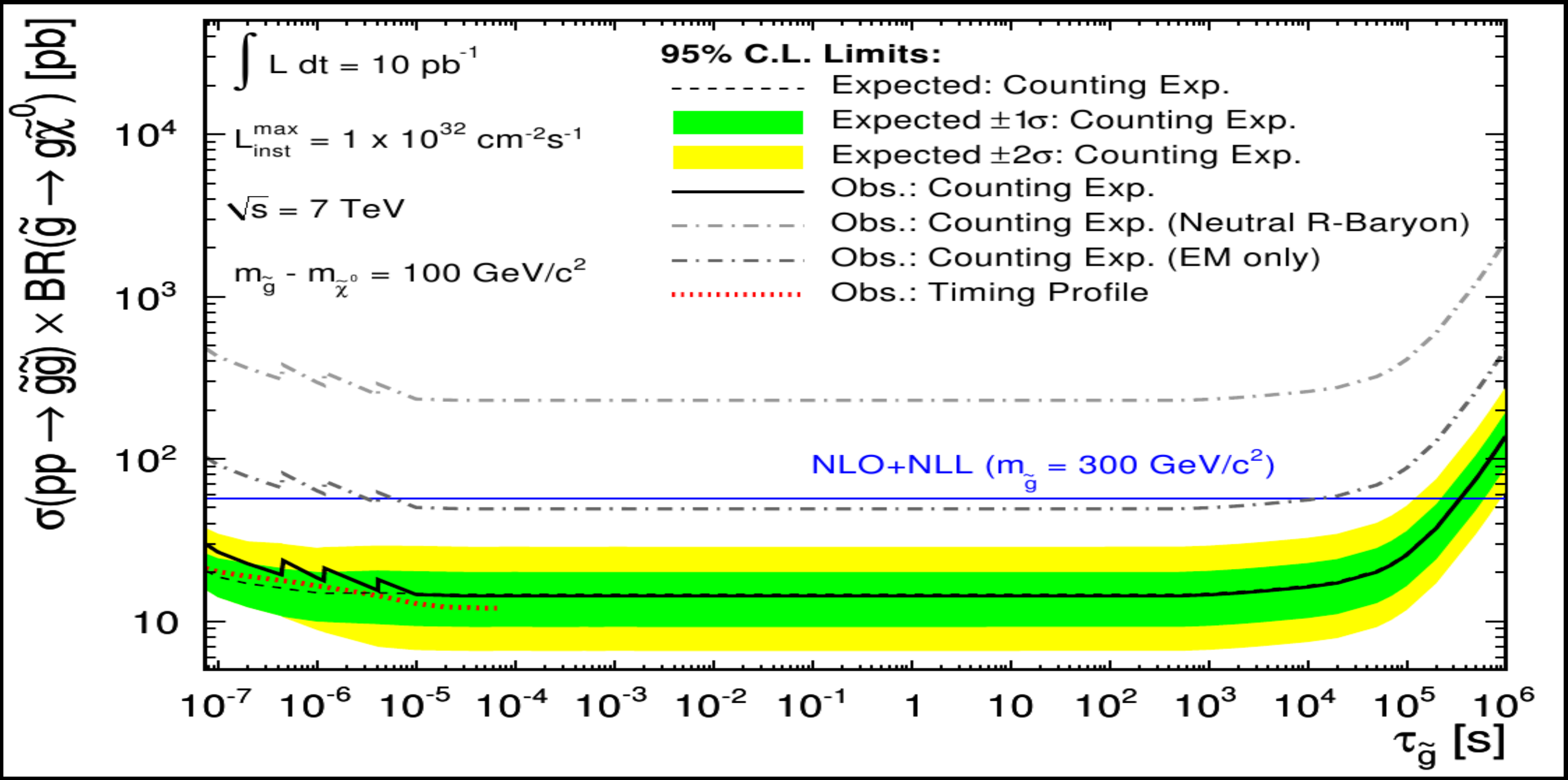
Calculate mass from dE/dx and $|\beta|$



Stopped Gluinos



Hep-ex/1011.5861



The LHC Physics Center @ FNAL

- New website: http://lpc.fnal.gov
- A regional center for physics analysis excellence in CMS
- Population ~100 CMS physicists at any one time *(trebles in house group)*
- *Pictured*: 11 of the first 29 CMS publications, all with LPC involvement

LHC Physics Center

- LPC is a CMS physics analysis & detector upgrade regional center, supported by DOE, NSF, and Fermilab
- Coordinators: Rick Cavanaugh (UIC/FNAL), Ian Shipsey (Purdue)
- The LPC serves CMS by enabling CMS physicists to participate in CMS remotely, economically, and transparently.
- Offers proximity to:
  - Broad expertise in CMS detectors and physics analysis
  - Opportunities to contribute to LHC upgrade work
  - Direct multi-institutional collaboration
  - outstanding computing resources
  - Remote operations to fulfill shift requirements
  - Software support from many of the core CMS developers
  - Seminars, workshops, and schools
  - Enhanced exposure and engagement with CMS
- Office space for visitors, and, for outstanding applicants, various levels of financial support
- Population ~100 CMS physicists at any one time *(trebles in house group)*

CMS physics & object activities with LPC involvement span the complete range of the CMS program with many CMS conveners based at LPC

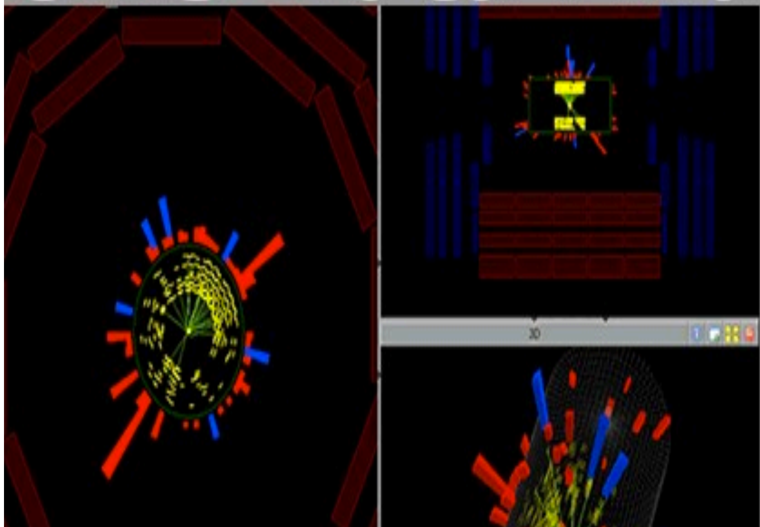
LPC Fellows Program

- Competitive, international application process selects ~dozen CMS physicists, chosen by LPC management board (CMS, USCMS, FNAL stakeholders) to maximize physics analysis impact of LPC.
- Students, postdocs, and faculty eligible for 6-12 month appointments, with varying levels of cost-sharing with home institutes
- Expectations of >=50% occupancy at LPC, supported by a travel budget with frequent trips to CERN
- Expectation of intellectual and collaborative engagement with the LPC community & CERN

2011 Fellows note most from larger institutions

Senior Fellows	Junior Fellows
C. Gerber (UIC)	J.P. Chou (Brown)
E. Halkiadakis (Rutgers)	M. De Gruttola(Napoli)
A. Ivanov (KSU)	A. Drozdetskiy (Florida)
J. Konigsberg (Florida)	A. Everett (Purdue)
C. Leonidopoulos (CERN)	K. Hahn (MIT)
J. Olsen (Princeton)	G. Kukartsev (Brown)
P. Wittich (Cornell)	D. Lopes-Pegna (Princeton)

CMS Data Analysis School



CMS DATA ANALYSIS SCHOOL
Jan 25-29 2011 at LPC, FNAL

From Benchmarks of the Standard Model to First Discoveries

- CMSDAS: intensive 5-day workshop for new CMS members
- 90% hands on, 10% talks, including cutting-edge projects with possibility of physics discovery at the school;
- Studyig collision data: ~60 students ~60 facilitators, 20% international
- Was local in 2010. A Collaboration-wide event in 2011 for the first time.
- Supported by CMS software team at CERN as well as local LPC software support
- Legacy: CMS online “Workbook” of exercises compiled for use collaboration wides and as basis for future schools
- Students join the analysis team post school through to publication

View Full Size

This school was formerly known as EJTERM. A link to the EJTERM 2010 site can be found here.

LPC Impact

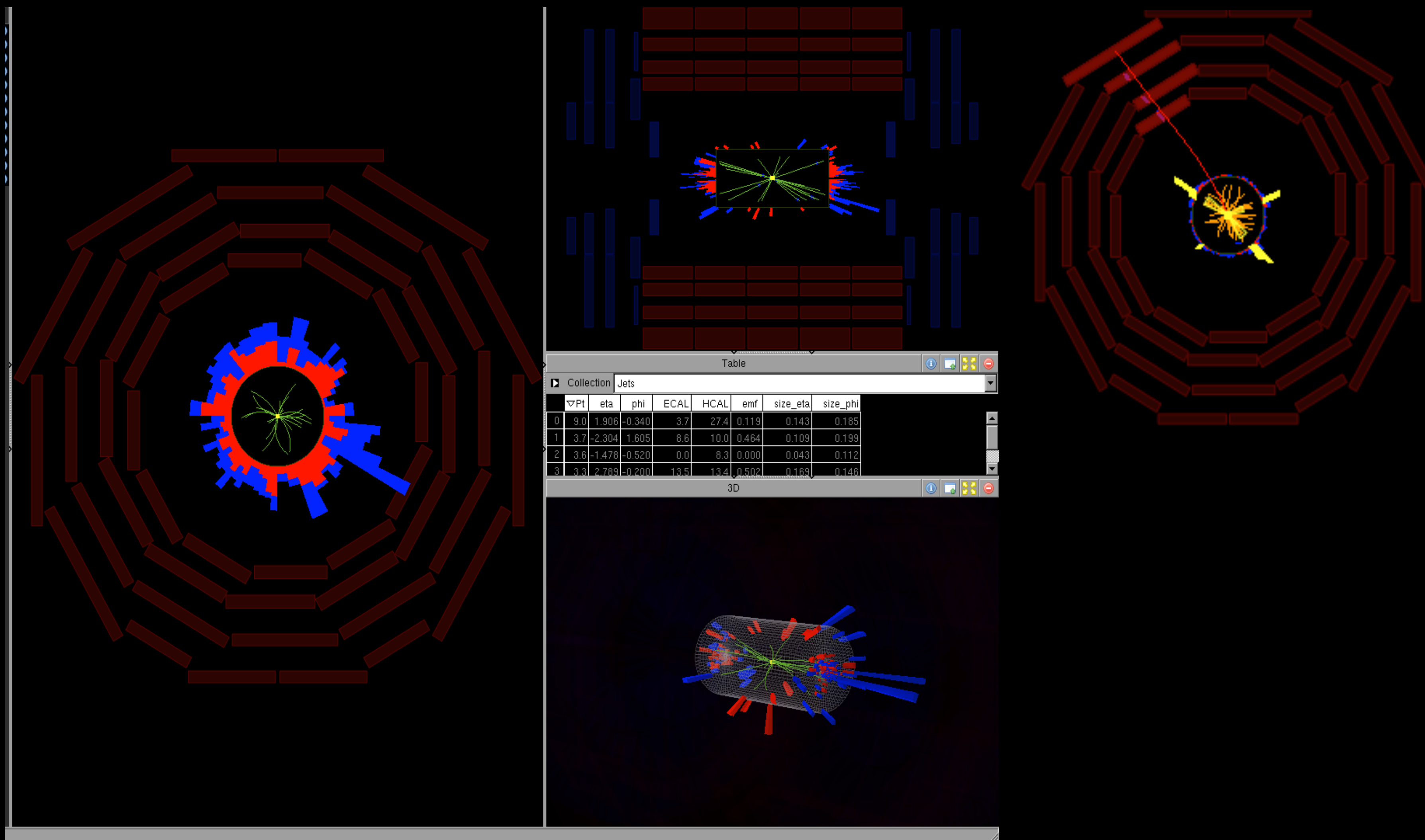
- ~1/3 of CMS papers have LPC involvement
- The fellows program has attracted outstanding applicants
- Guest & Visitor program applications and acceptances have doubled
- The Data Analysis School has become a CMS-wide event

- Other around the globe and ATLAS have expresed interest in creating further regional centers
- Current and past LPC postdoc residents are getting permanent jobs

The time is right to develop further LPC physics centers to engage and enable the global LHC community

Start of 2011 pp Operation

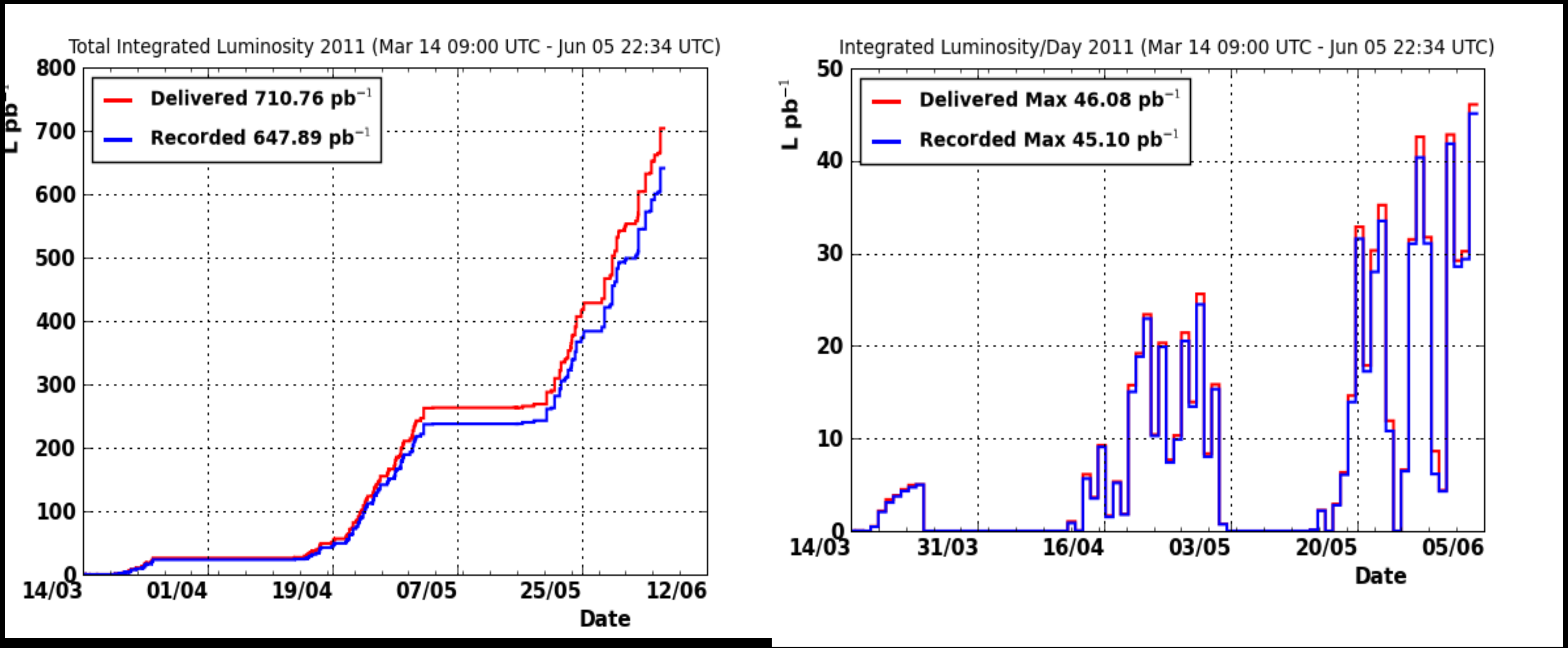
Sunday March 13, 18:20 Stable beams in LHC CMS taking data.



LHC and CMS operations 2011

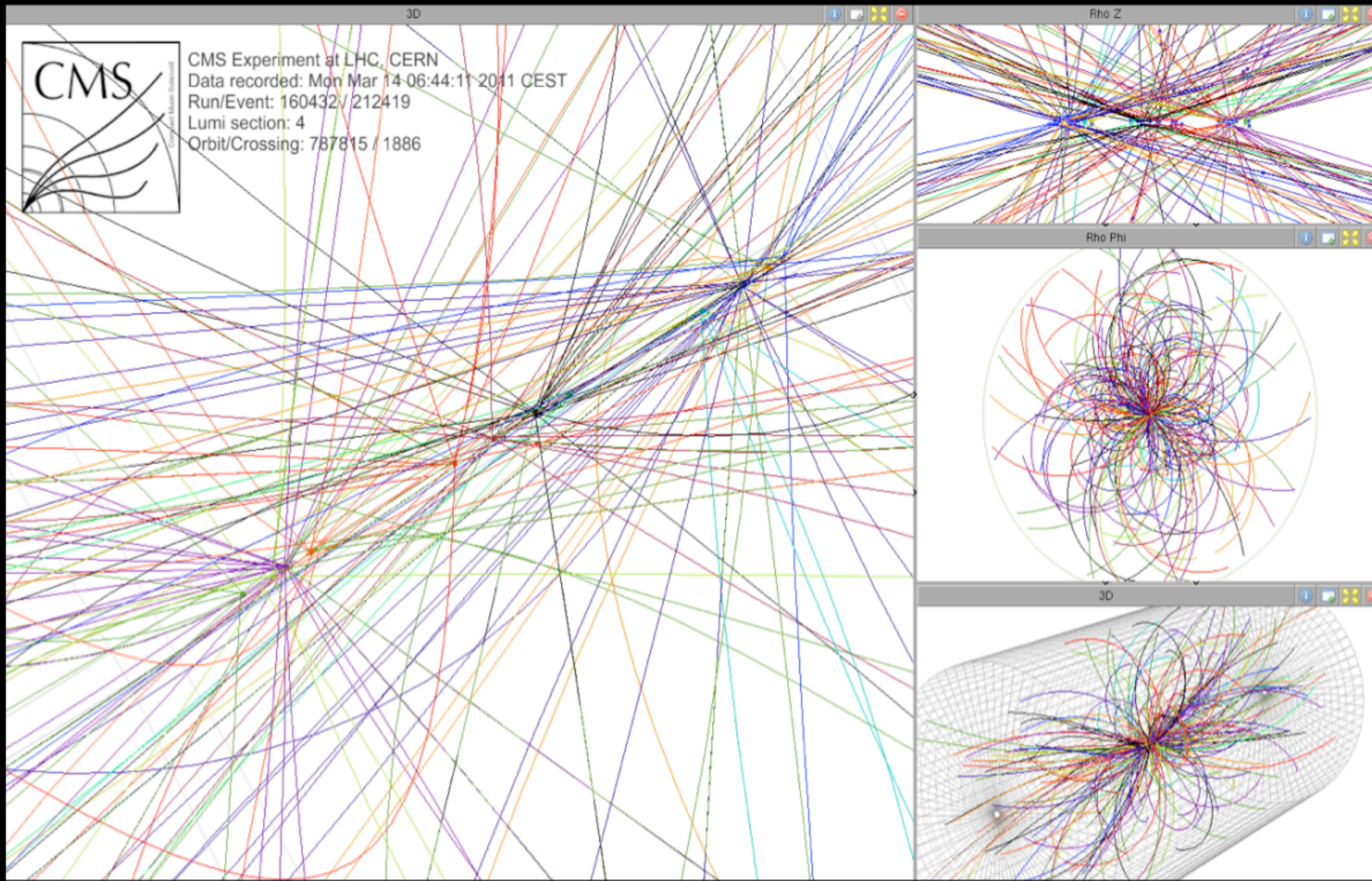
1092 bunches in LHC (1042 colliding in CMS); **new world record in peak luminosity** for hadron colliders **1.27e33**.

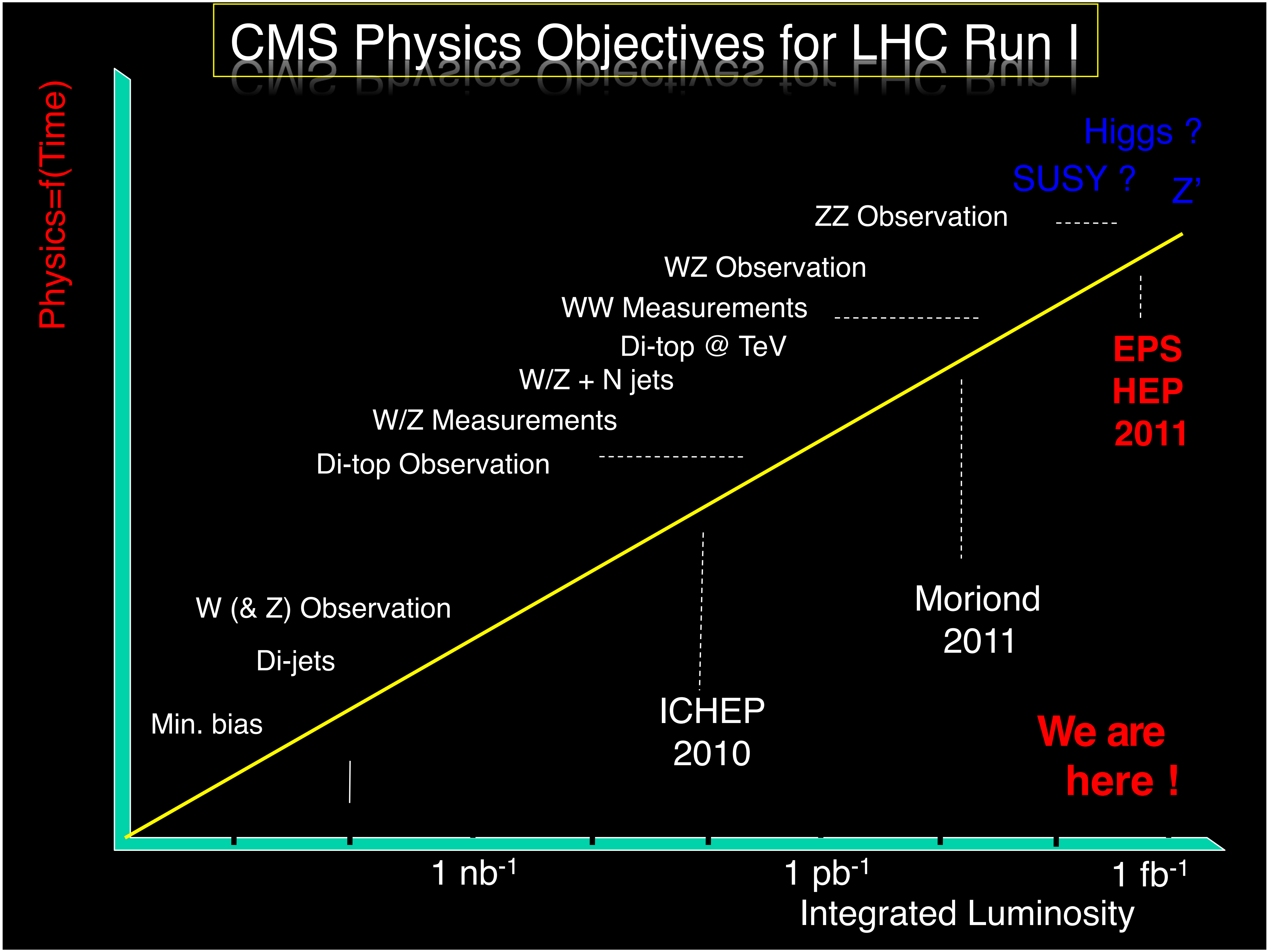
~711pb^{-1} delivered by LHC and **~648pb^{-1}** collected by CMS. **CMS data taking efficiency >91%. We can now record >45pb^{-1}/day (= total in 2010)**



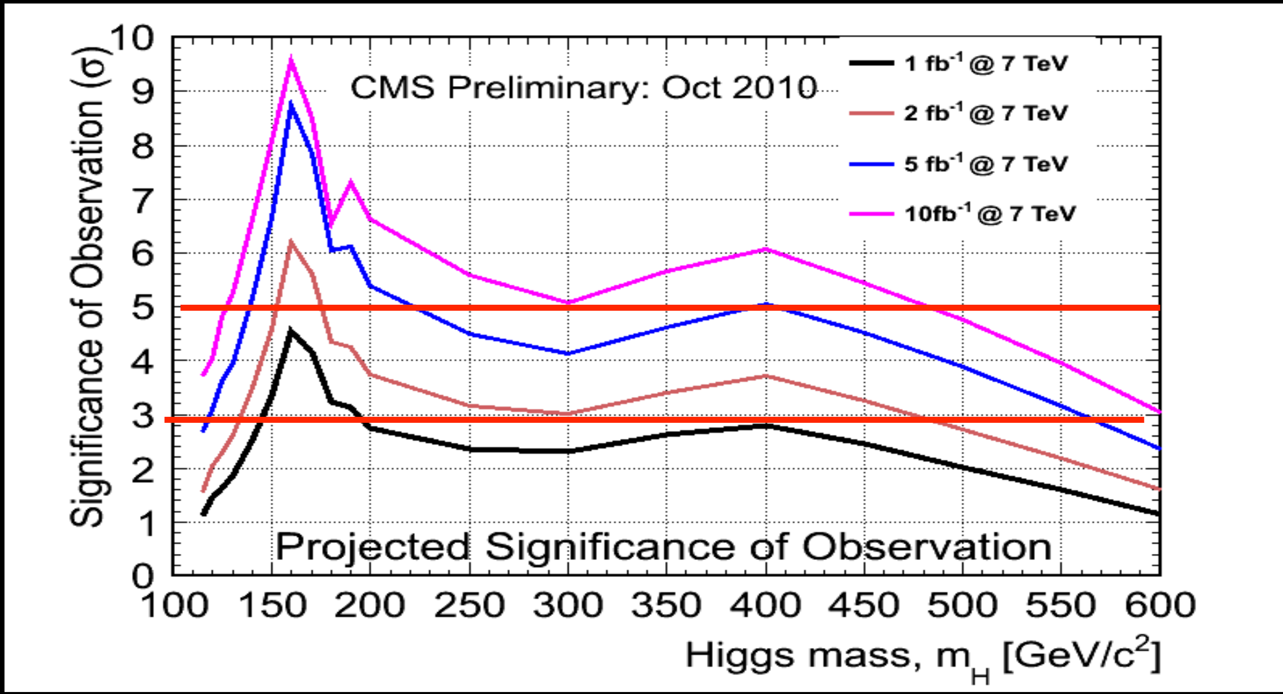
The goal of collecting 1fb^{-1} of data before the end of June will be exceeded.

The challenges of 2011 data taking




CMS Physics Objectives for LHC Run I
Physics=f(Time)
Higgs ?
SUSY ?
Z'
ZZ Observation
WZ Observation
WW Measurements
Di-top @ TeV
W/Z + N jets
W/Z Measurements
Di-top Observation
EPS
HEP
2011
W (& Z) Observation
Di-jets
Min. bias
Moriond
2011
ICHEP
2010
We are
here !
1 nb-1
1 pb-1
1 fb-1
Integrated Luminosity

The Opportunities of 2011



Conclusion

The 2010 run has been successful. >50 papers published or submitted expect total haul to be ~80

•Key ingredients: superb performance of the machine, detector, and a globally distributed scientific effort (analysis and computing) of unprecedented scale, suggesting a new paradigm in scientific collaboration; one in which significant numbers of scientists are no longer co-located at the host lab, and where a remote regional center, the LHC Physics Center at FNAL has made significant contributions

• So far it looks that we are able to cope with the challenges of instantaneous luminosity higher than 1E33 and <n> interactions per crossing ~10.

• Prospects for SUSY, Higgs & Exotica in 2011-12 are very promising.

• Signals of New Physics might appear any moment.

•CMS public results at
• https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

References

- For the dE/dx:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/DPGResultsTRK
- For the muon performance:
  - http://cdsweb.cern.ch/record/1279140?ln=en
- For the Tracker performance:
  - http://cdsweb.cern.ch/search?cc=CMS&ln=en&p=reportnumber%3ATRK+6531_a%3AData&f=&action_search=Search&c=CMS+Physics+Analysis+Summaries&c=&sf=&so=d&rm=&rg=10&sc=1&of=hb
- For the ECAL performance:
  - http://cms-project-ecal-p5.web.cern.ch/cms-project-ECAL-P5/approved/Calor_7tev.php
- Particle Flow (J/Psi->e+e- plot):
  - http://cdsweb.cern.ch/record/1279347/files/PFT-10-003-pas.pdf
- HCAL:
  - https://twiki.cern.ch/twiki/bin/viewauth/CMS/HcalDPGApprovedResults
  - and in particular this https://twiki.cern.ch/twiki/pub/CMS/HcalDPGApprovedResults/HCALApproved_ICHEP2010_DPS.ppt
  - and this https://twiki.cern.ch/twiki/pub/CMS/HcalDPGApprovedResults/HCALApproved_ICHEP2010.ppt
- For SUSY:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
  - http://indico.cern.ch/getFile.py/access?resId=0&materialId=slides&confId=130468
  - http://indico.in2p3.fr/getFile.py/access?contribId=109&sessionId=3&resId=0&materialId=slides&confId=4403
- For Higgs:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

Additional material