CMS Results at $\sqrt{s}$=7 TeV

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LHC-Forum,

Desy Seminar, December 14, 2010

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Outline

Introduction: The Compact Muon Solenoid

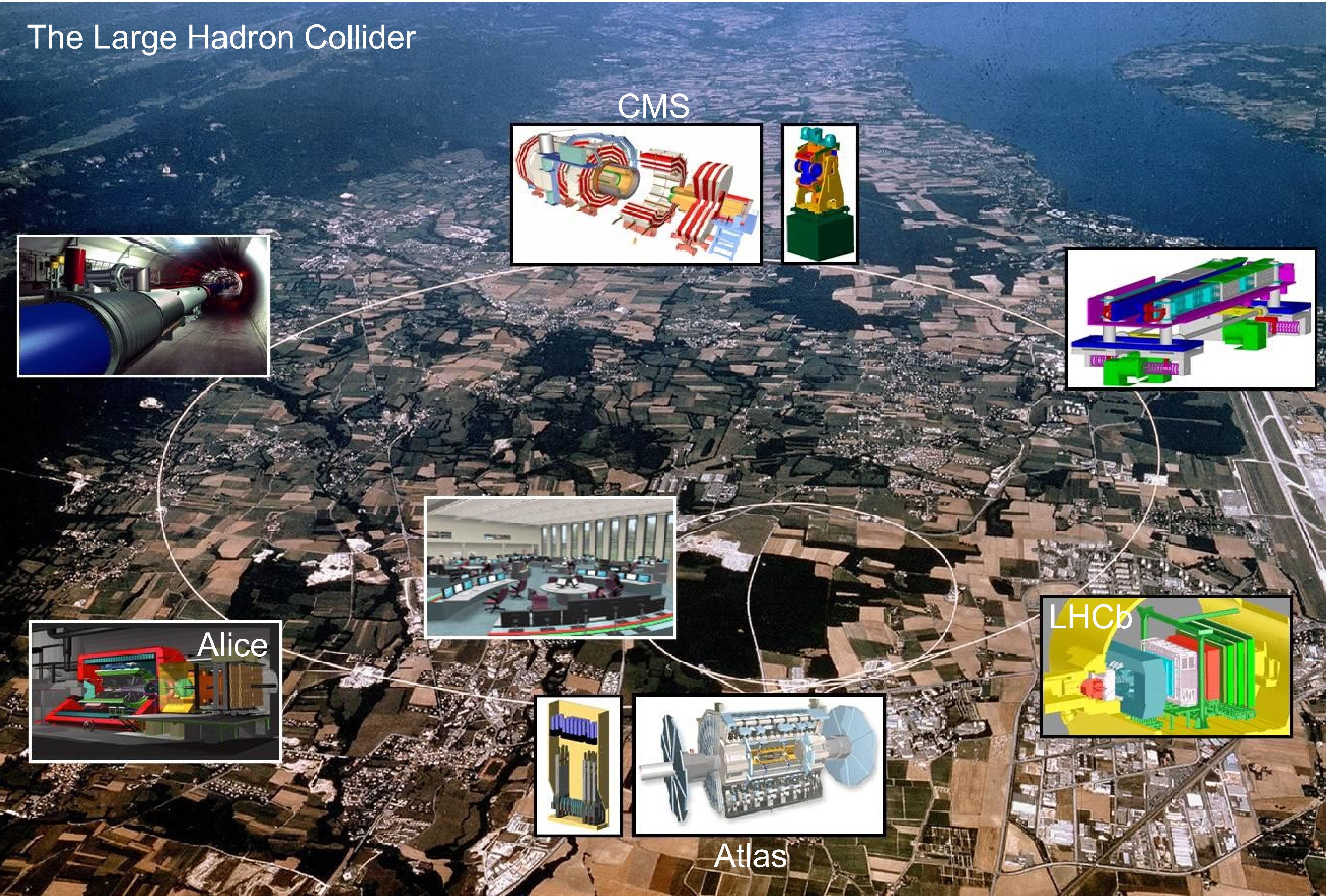
Detector Performance
- Luminosity
- Tracking, Vertexing, Alignment
- Jet and MET reconstruction

Physics Analysis Results
- Standard Model
  - Jet cross-section measurement
  - Di-jet resonances
  - W / Z measurements
  - Top measurements
- Searches for New Physics
  - Supersymmetry searches
  - Stopped gluino search
  - Higgs searches

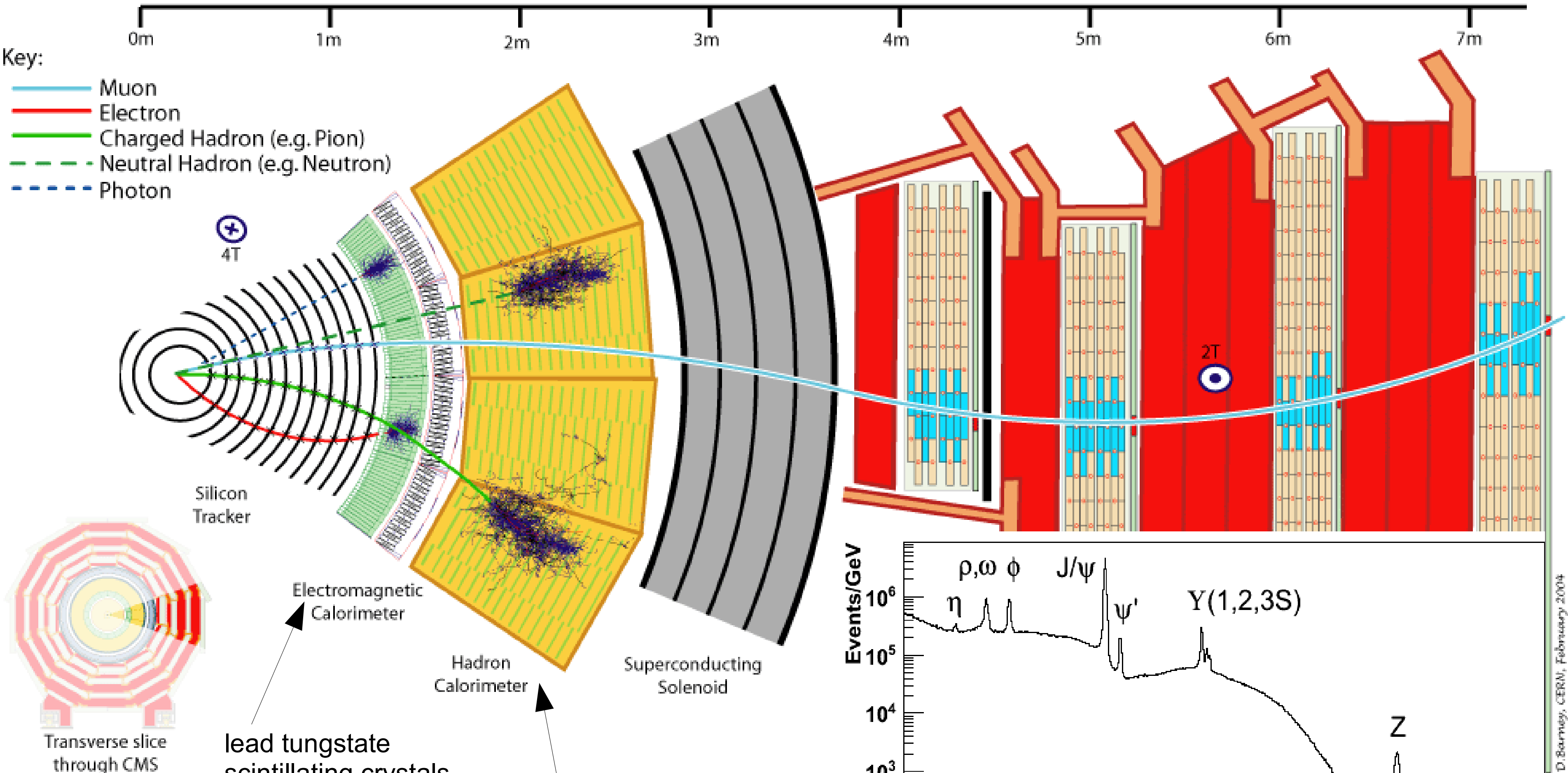
Conclusion

Introduction

The Large Hadron Collider

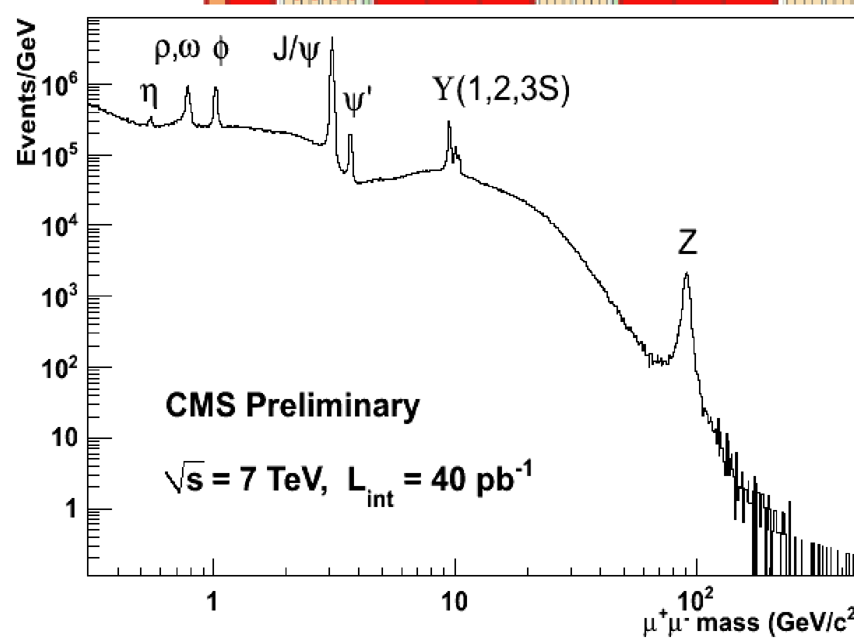


The CMS detector



lead tungstate scintillating crystals

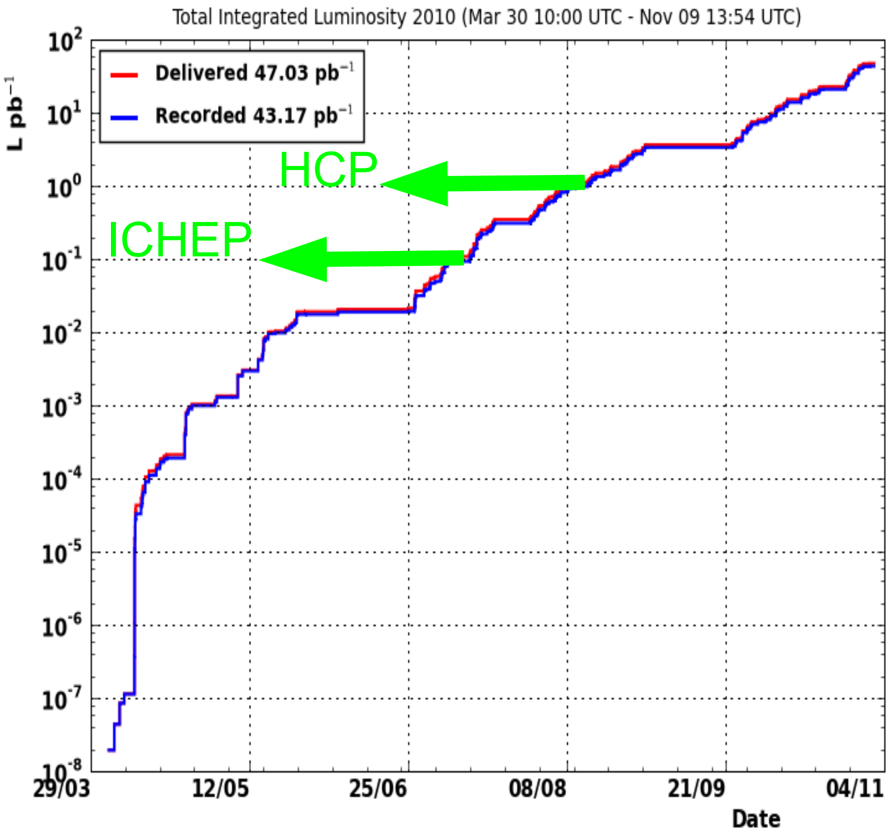
sampling calorimeter alternating absorber & plastic scintillators



Luminosity

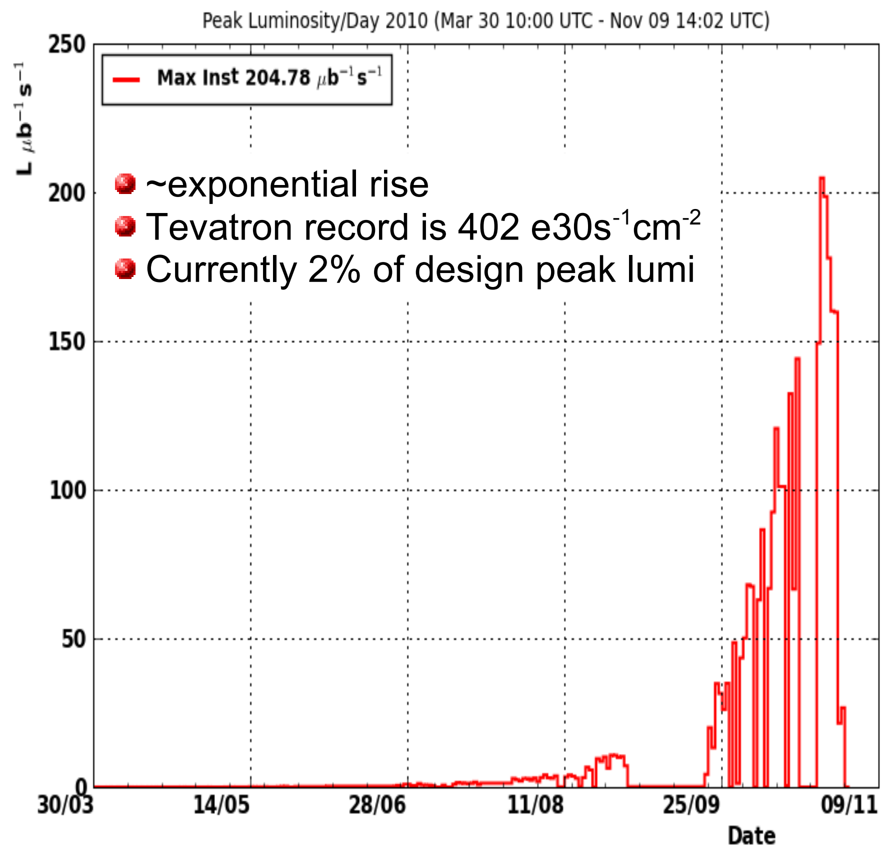
Proton – proton collisions at $\sqrt{s}$ = 7 TeV

Integrated recorded Luminosity 43 pb^{-1}



(log-scale)

Instantaneous Luminosity up to 205 μb^{-1}s^{-1} (205 e30 s^{-1}cm^{-2})



(linear-scale)

CMS results 2010

Physics Analysis	Papers	Preliminary results
QCD	6	13
Forward Physics	0	2
B Physics and Quarkonia	1	4
Electroweak	0	2
Top	1	1
Higgs	0	0
Super-symmetry	0	1
Exotica	3	6
Heavy Ions	0	0
Summary	**11**	**29**

Physics Object	Papers	Preliminary results
B-tag and Vertexing	0	1
Tracking	1	5
Electrons and Photons	0	4
Jet and MET	0	8
Muons	1	2
Particle-Flow and Tau	0	4
Summary	**2**	**24**

O(10) more papers currently in collaboration review

Will show only selected physics analysis results in this talk!

All CMS results can be found at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Detector Performance

Luminosity measurement

Instantaneous luminosity is measured online:

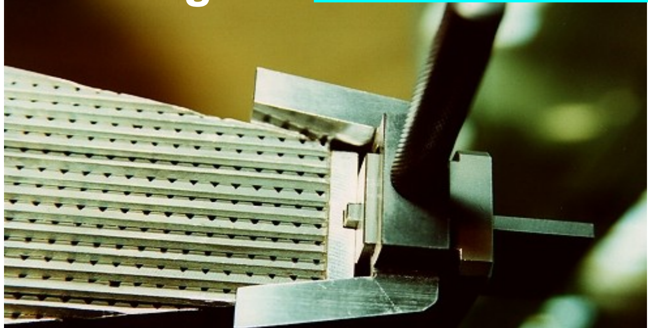
- utilizing the occupancy of the hadronic forward calorimeter (HF)

Offline methods for cross-checks

- utilizing HF and tracking/vertex info.

→ good agreement between online and offline

HF wedge: PAS EWK-10-004

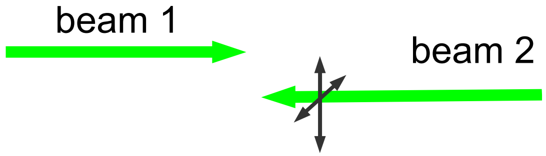


Iron absorber & Cerenkov light detecting quartz fibers

Absolute luminosity calibration using

- Monte Carlo
- Beam current measurements, beam size estimation using a van-der-Meer scan

} agree within 7%



Dominant uncertainty from shapes (3%) and from beam intensity measurement (5%+5%). These uncertainties are expected to drop.

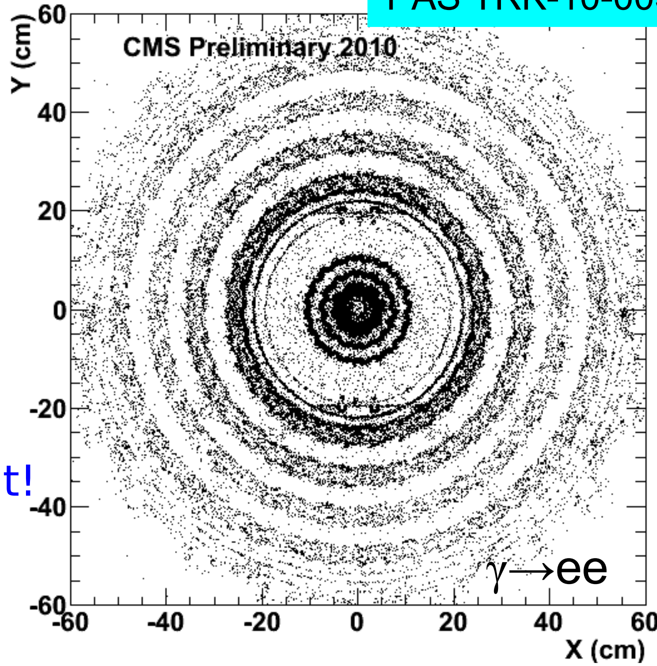
Error	Value (%)
Beam Background	0.1
Fit Systematics	1.0
Beam Shape	3.0
Scale Calibration	2.0
Zero Point Uncertainty	2.0
Beam Current Measurement	10.0
Total	11.0

Lumi-uncertainty of 11% is important for all cross-section measurements (and limits)!

Tracking: Material Budget

DESY/UHH: contributions to alignment

PAS TRK-10-003

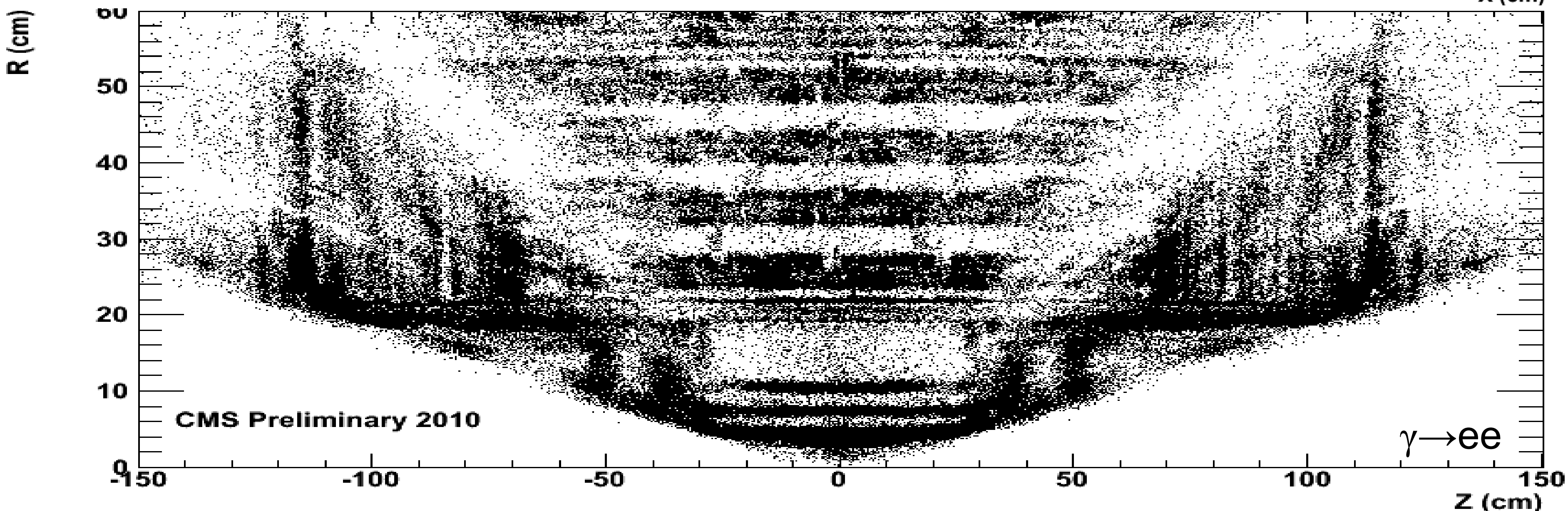


Picture of the tracker, taken by the tracker itself:

- Used $\gamma \rightarrow e^+e^-$ conversions
- Similar analysis done for hadronic interactions
- Independent method using multiple-scattered tracks

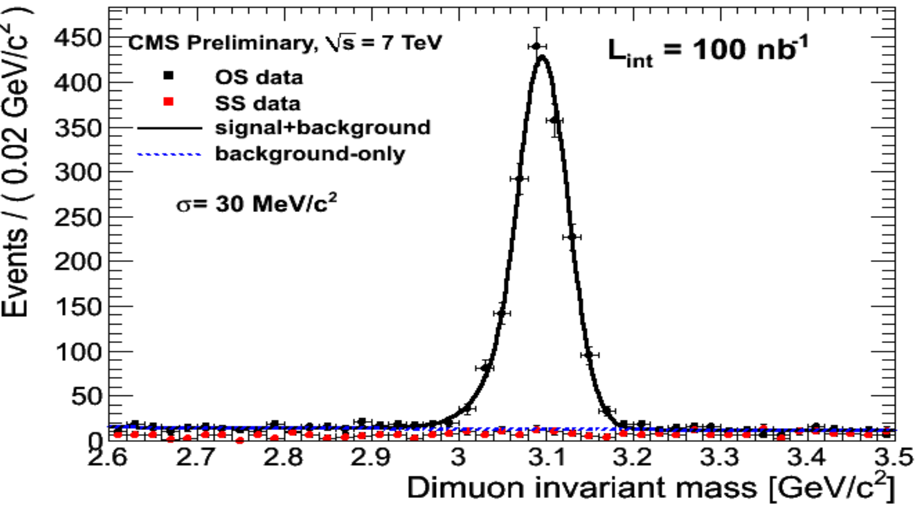
→ Difference real tracker to MC is better than 10%

Analysis required good tracking, vertexing, and alignment!

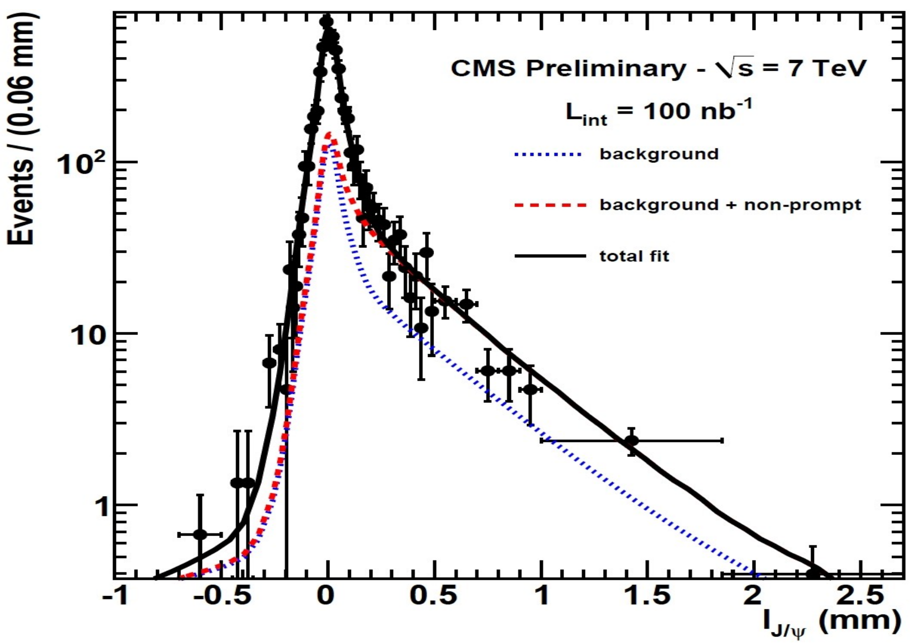


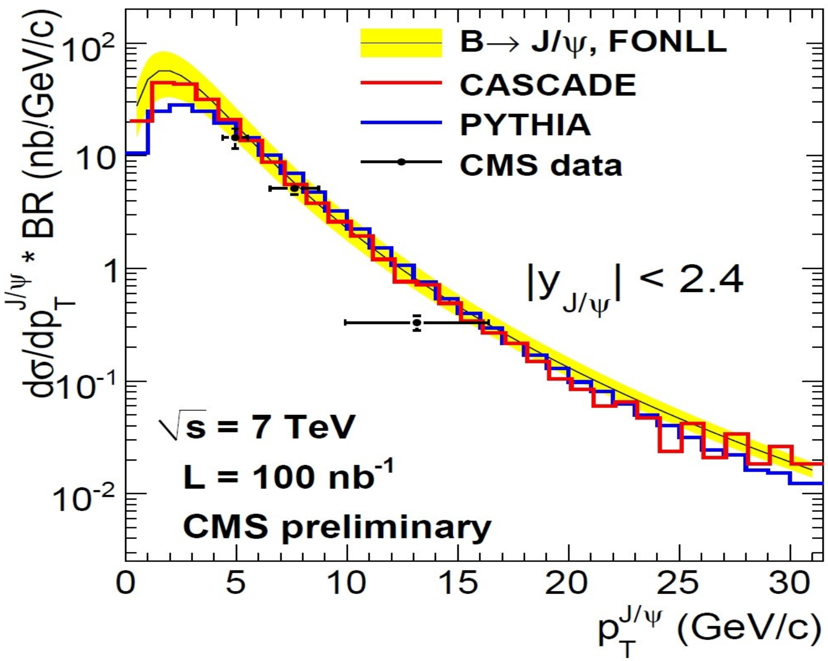
Tracking, Vertexing, Alignment: B→J/Ψ

PAS BPH-10-002



- Two muon selection
- Primary vertex reconstruction
- Measure decay length of B
- Differential cross-section for non-prompt J/Ψ production





→ Consistent with SM expectations.

Jet Performance for different Algorithms

UHH: contributions to jet calibration & resolution

PAS JME-10-010

"Calo-Jets"

- based only on calorimeter energy depositions

"Jet plus Track" (JPT)

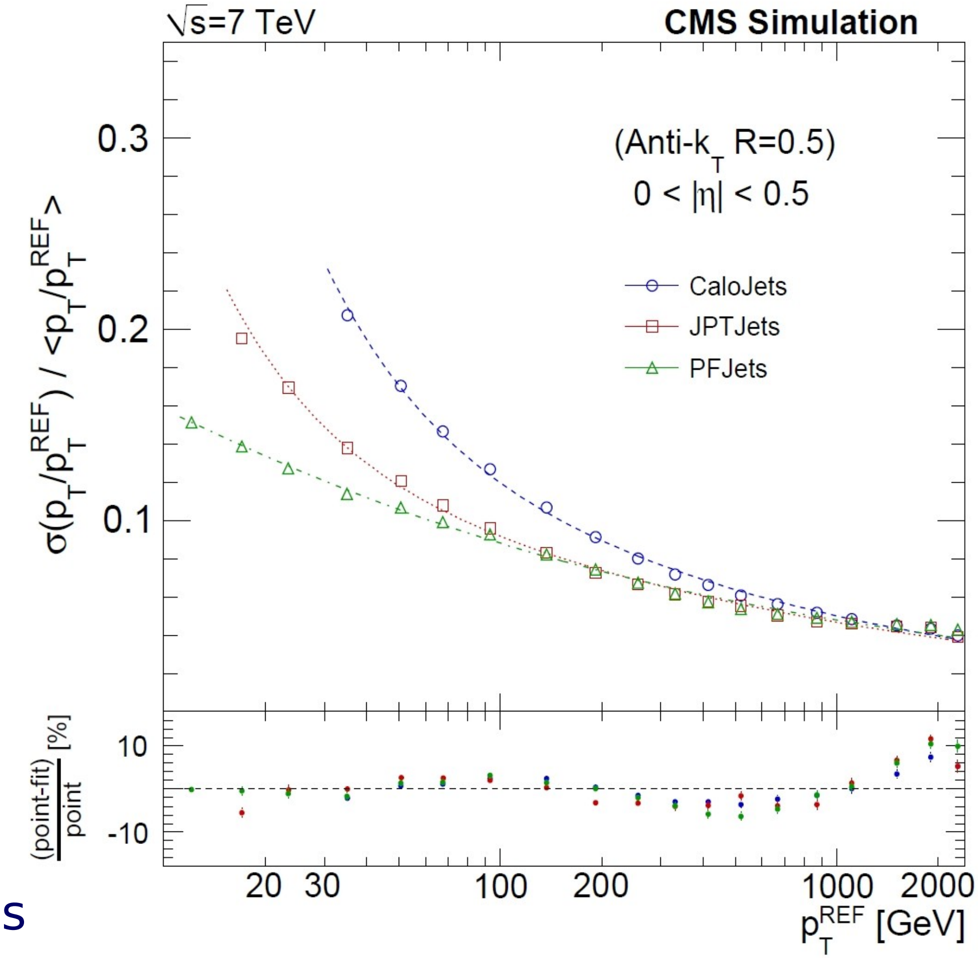
- improving calorimeter measurements by better tracker resolution

"Particle Flow" (PF)

- aims to reconstruct any single particle, based on all sub-detectors, prior to jet clustering
- makes best use of all available information
- improves jet-resolution, enables usage of low pT jets

→ Used in many published analyses

Jet resolution



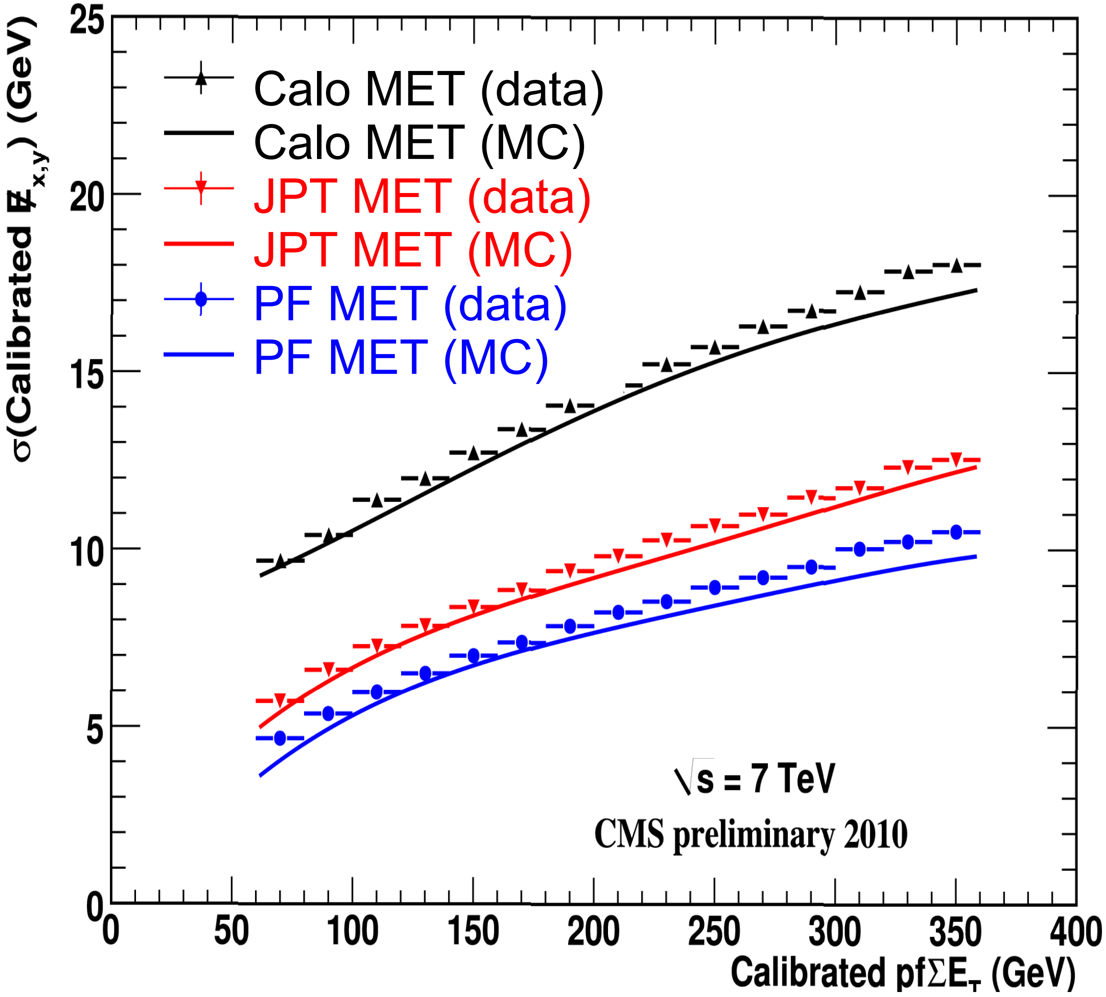
MET performance

UHH: contributions to MET calibration

PAS-JME-10-004

MET resolution

Calibrated Gaussian core resolution versus the calibrated pf-MET in events containing at least two jets with pT > 25 GeV

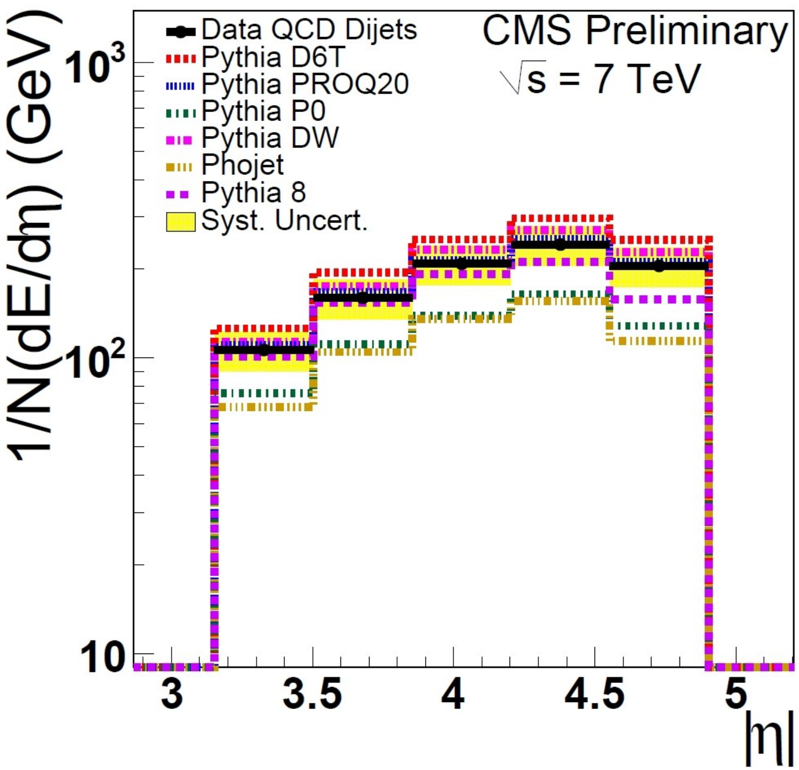


Standard Model Measurements

Jet cross-section measurement

Forward jet analysis performed by DESY

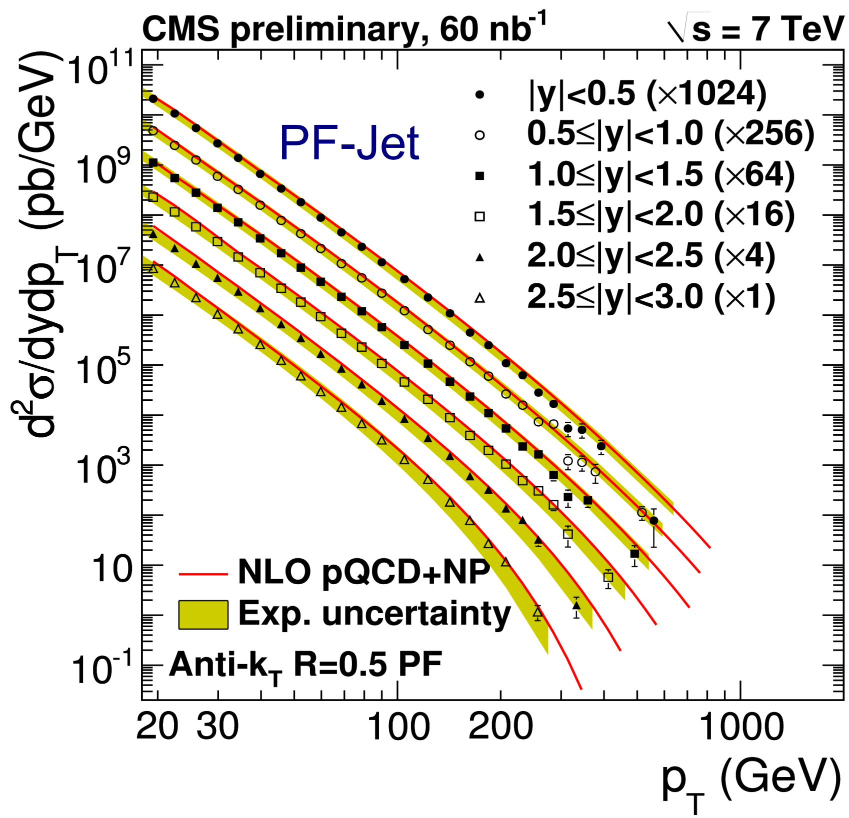
Forward energy flow



Energy-flow measurement at large rapidities is sensitive to different models of multiparton interactions.

Inclusive jet cross-section measurement

$$\frac{d^2\sigma}{dp_T dy} = \frac{C_{res}}{\mathcal{L}\cdot\epsilon}\cdot\frac{N_{jets}}{\Delta p_T\cdot\Delta y}$$



The finite jet resolutions are considered using an ansatz-method.

→ NLO pQCD and up-to-date PDFs work at $\sqrt{s}$ = 7 TeV !

Di-jet resonances

Phys. Rev. Lett. 105, 211801 (2010)

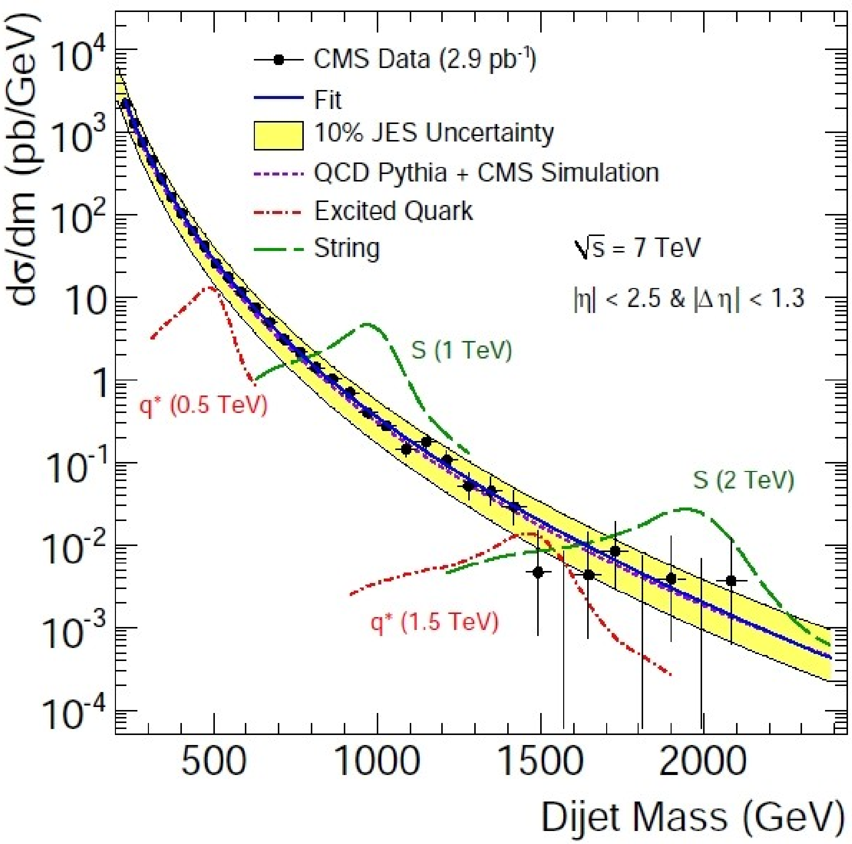
Fit spectrum with

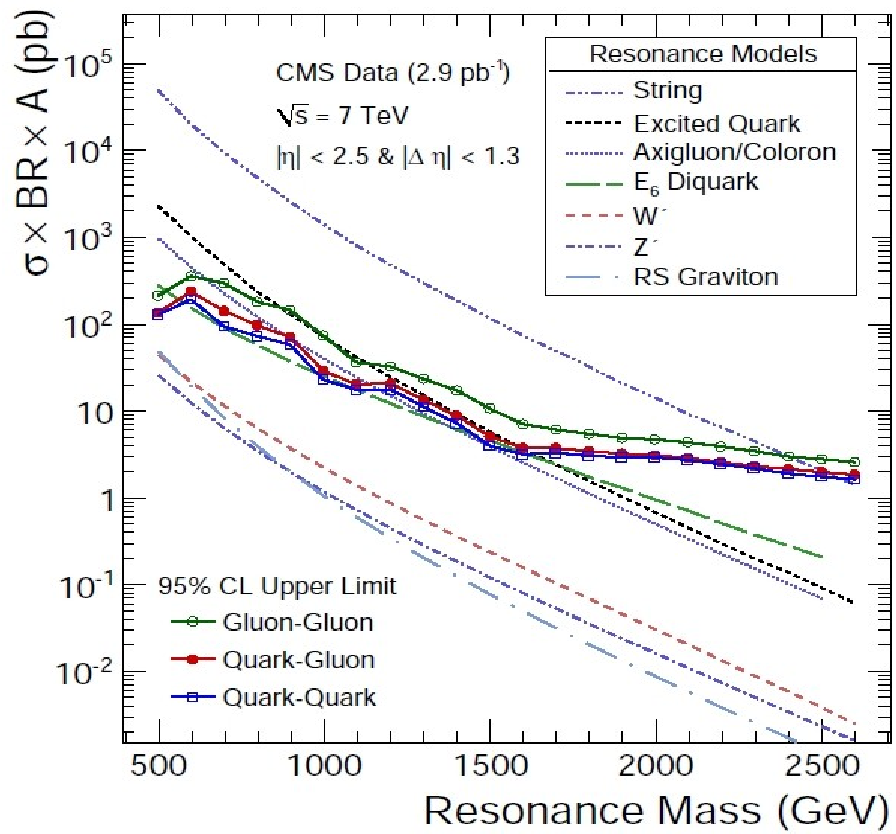
$$\frac{d\sigma}{dm} = \frac{P_0(1-m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3\ln(m/\sqrt{s})}}$$

four free parameters, $chi^2 = 32$, for 31 d.o.f.

The data are well described by smooth function. No sign for narrow resonances.

Excluded e.g.:
String resonances < 2.50 TeV
Excited quarks < 1.58 TeV



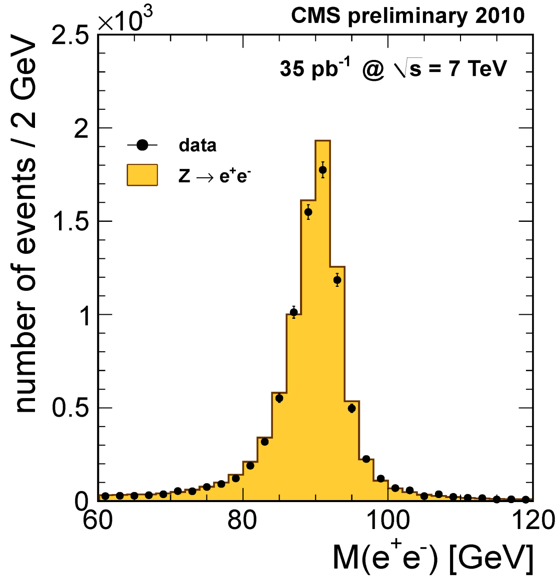


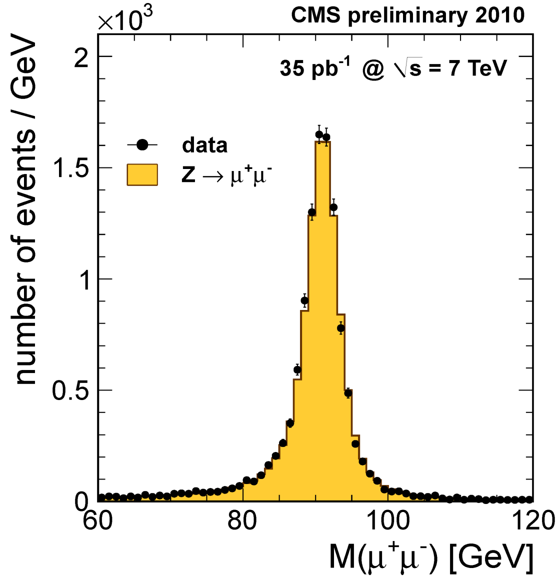
Electroweak physics

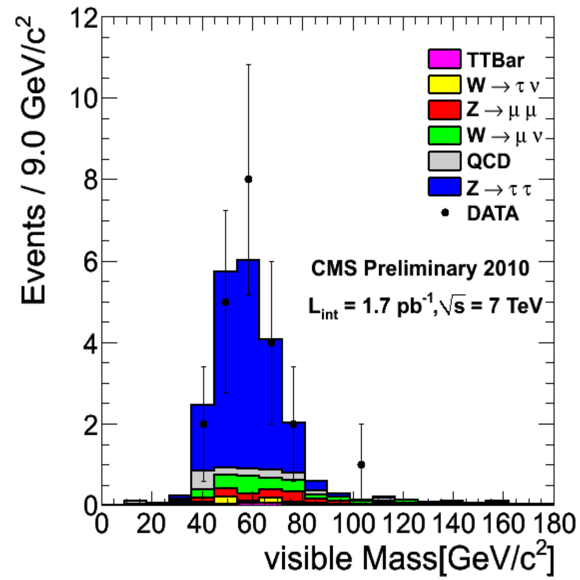
Submitted to JHEP, hep-ex:1012.2466

electron channel | muon channel | tau channel

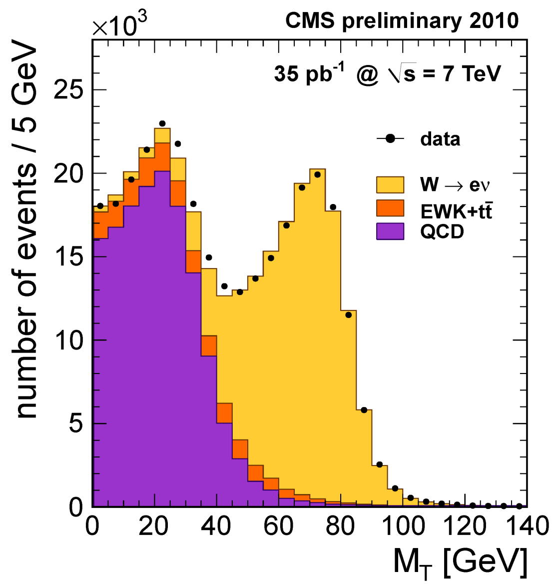
Z-boson

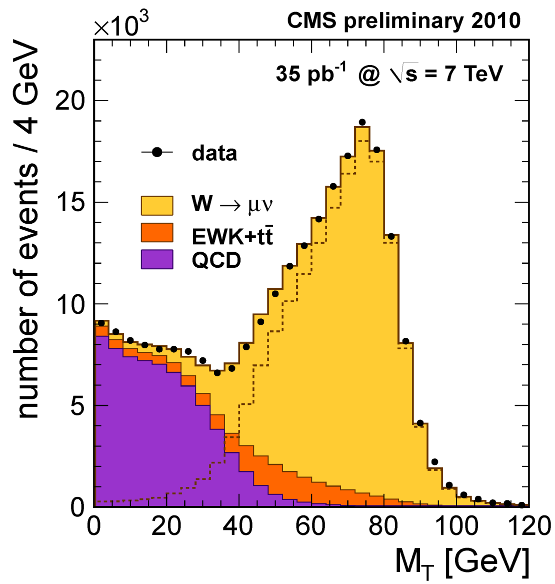


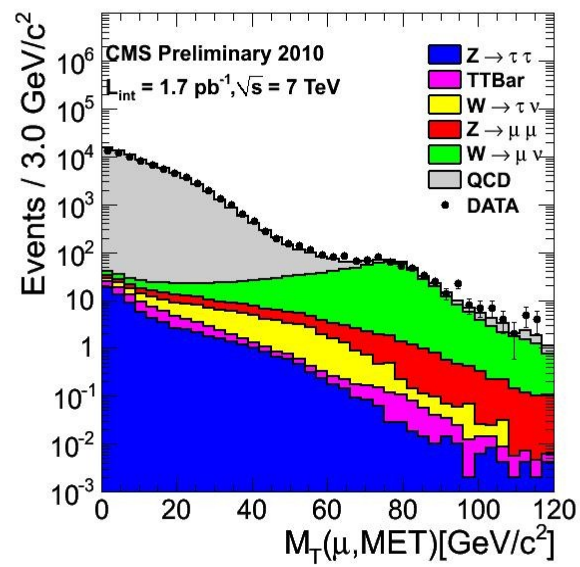




W-boson



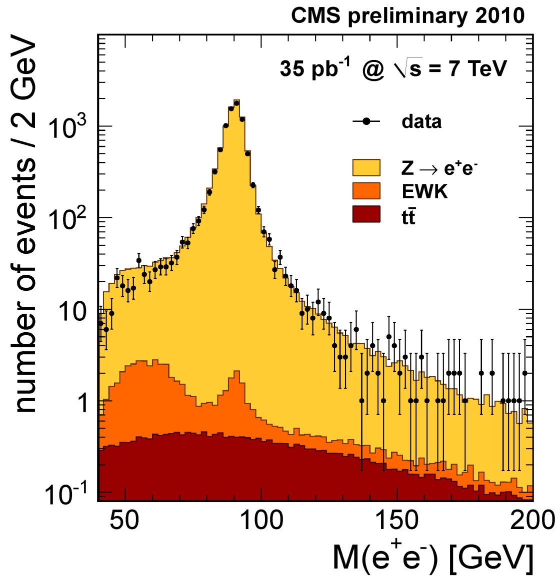


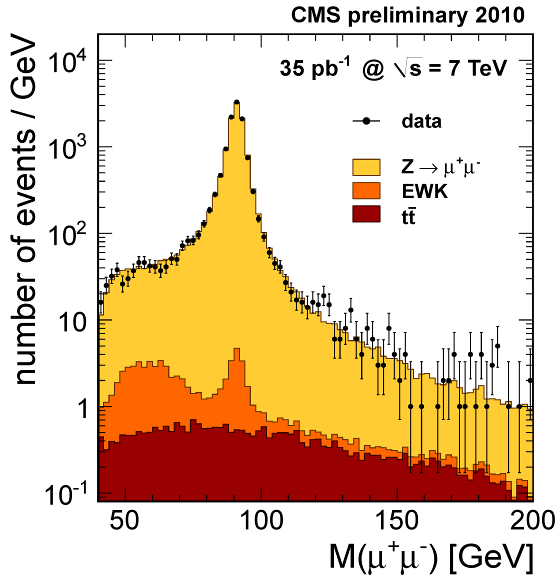


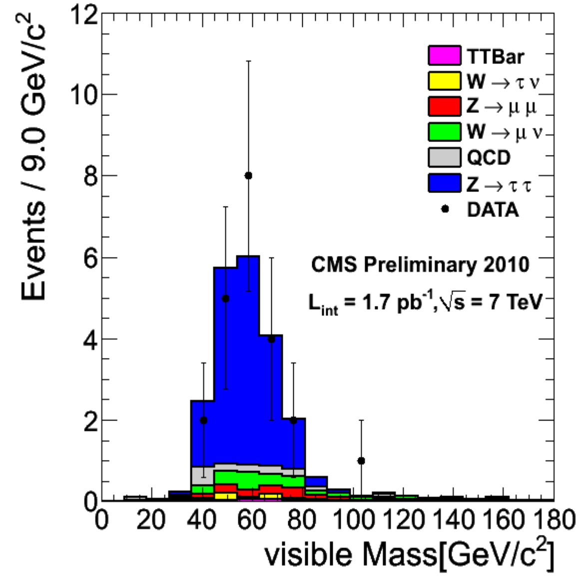
Electroweak physics

electron channel | muon channel | tau channel

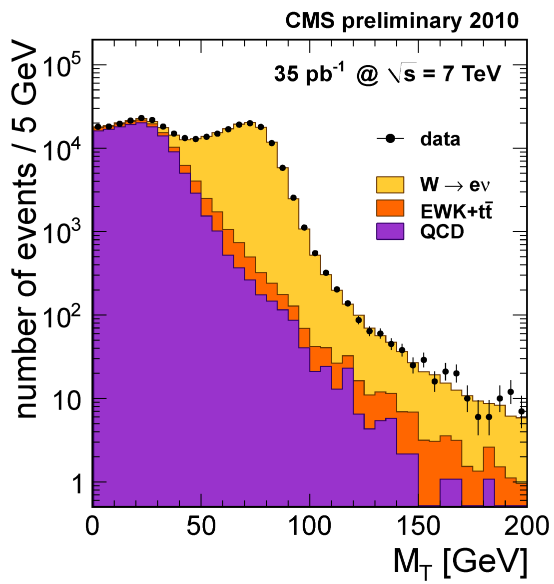
Z-boson

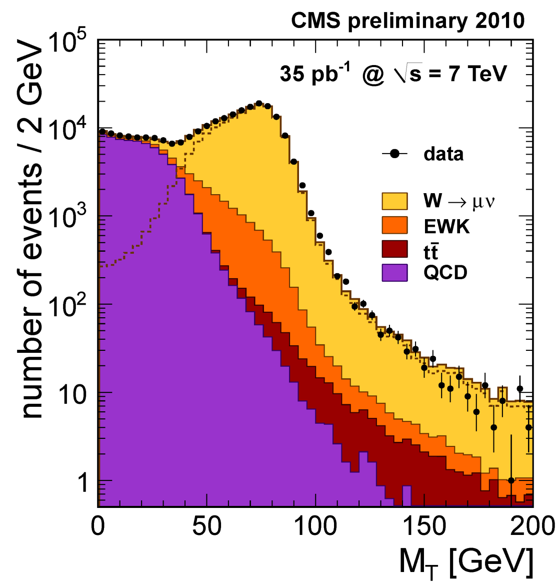


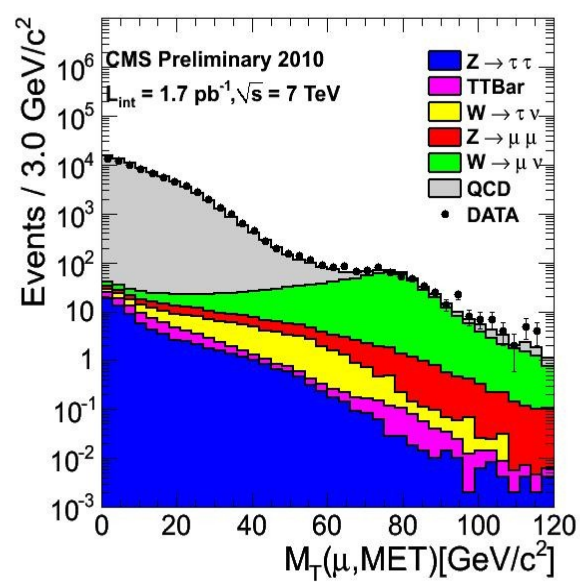




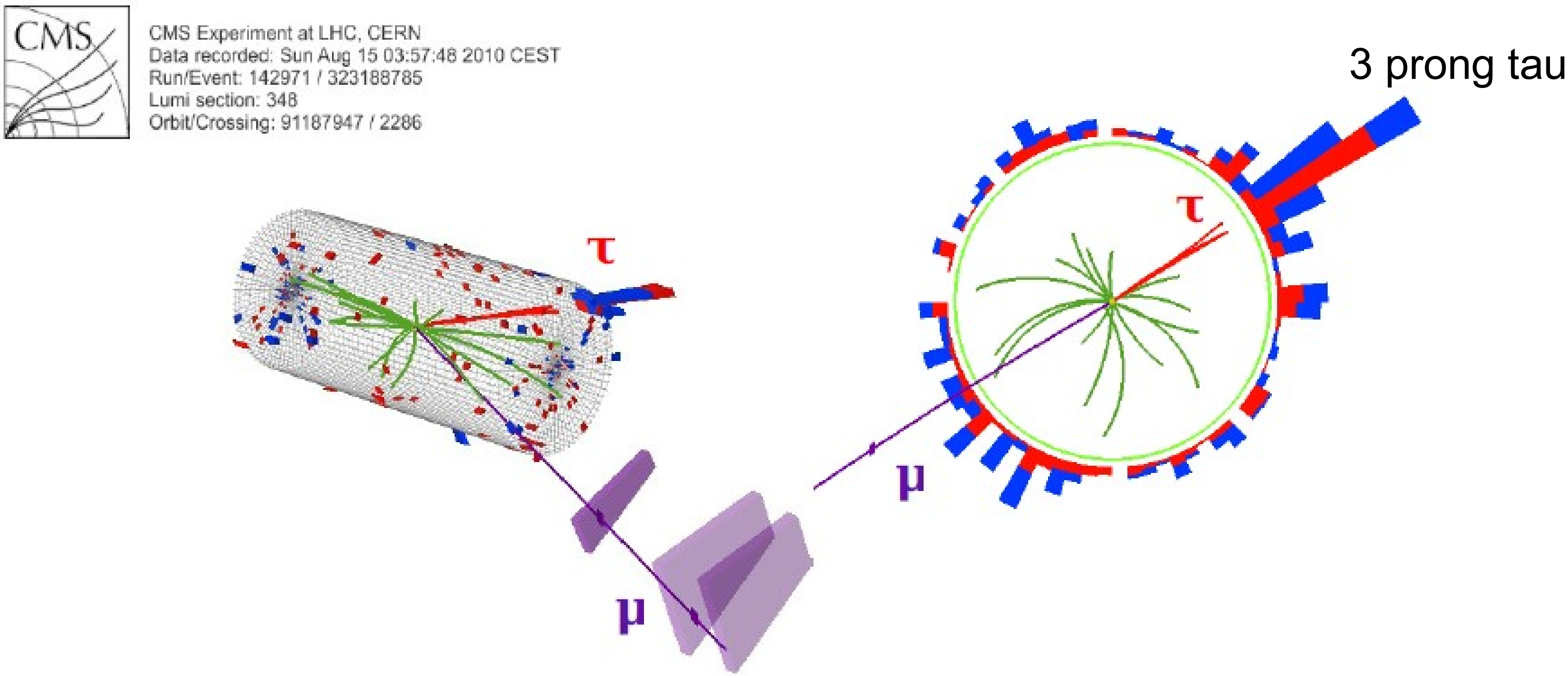
W-boson







$Z \to \tau\tau \to \mu\tau_{had}$ candidate event



	pT	η	mass
muon	32 GeV	1.7	
tau (3 prong)	37 GeV	1.5	1.2 GeV

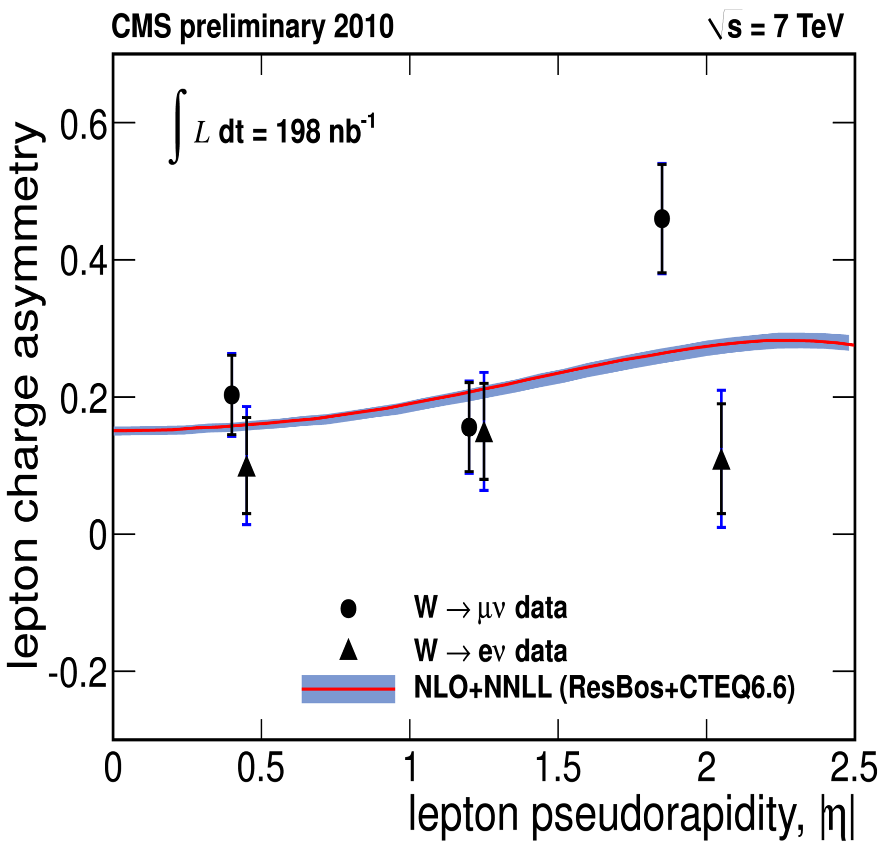
Visible mass = 70 GeV
M_T(muon, MET) = 4 GeV

Electroweak physics results

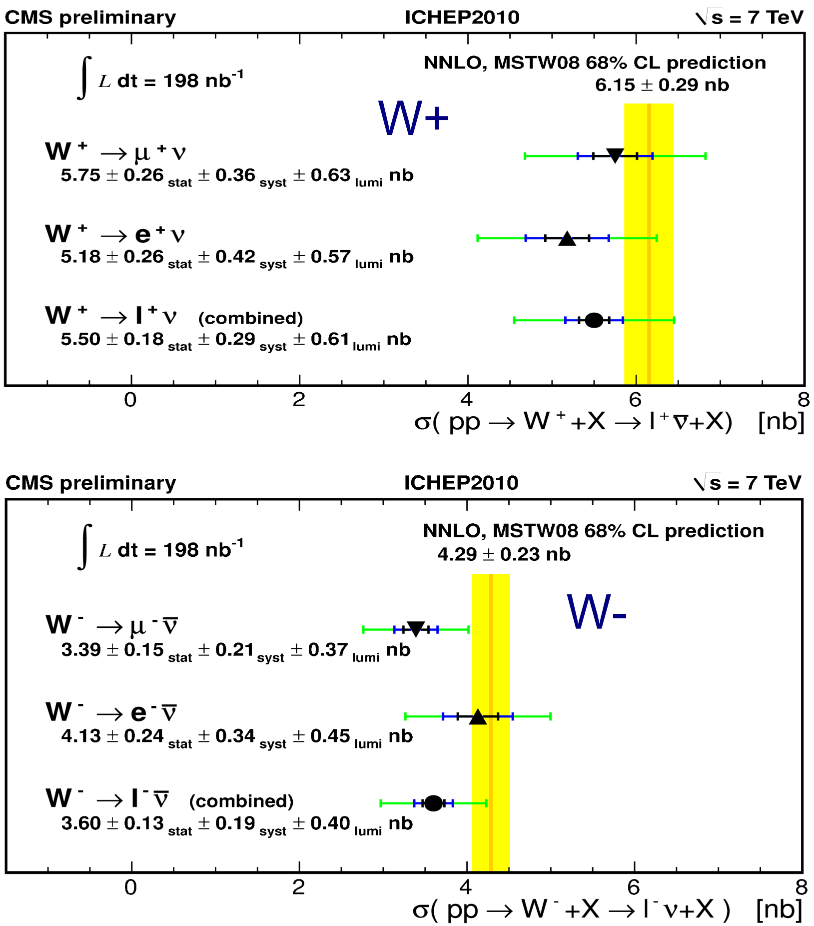
Due to the prevalence of up over down-quarks in pp-collisions the production rate of W+ and W- bosons is different: An asymmetry of 0.2 is expected using current theoretical predictions and PDFs.

Lepton-charge asymmetry, $W \rightarrow l\nu$

$$A(\eta) = \frac{d\sigma^{(+)}/d\eta_\ell - d\sigma^{(-)}/d\eta_\ell}{d\sigma^{(+)}/d\eta_\ell + d\sigma^{(-)}/d\eta_\ell}$$



$W^\pm \rightarrow l^\pm\nu$ cross-section



In agreement with SM (within lumi uncertainty)

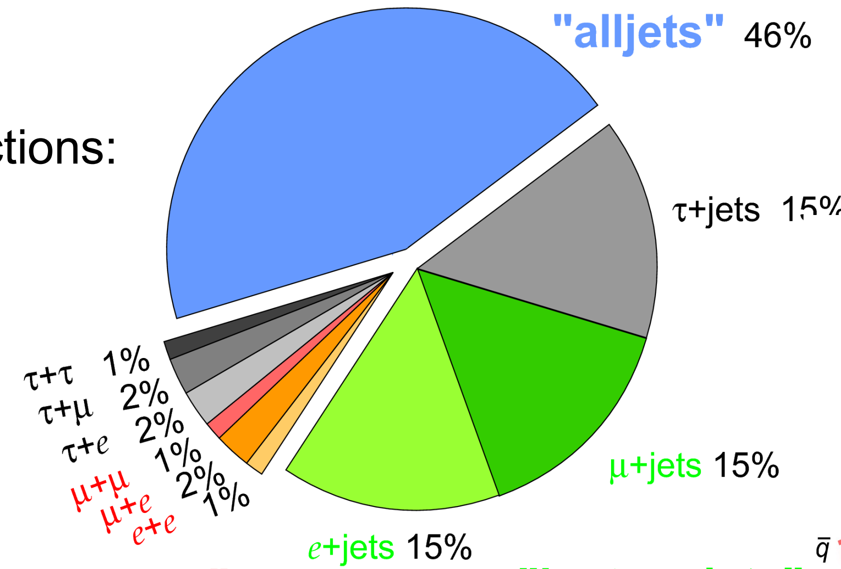
Top physics

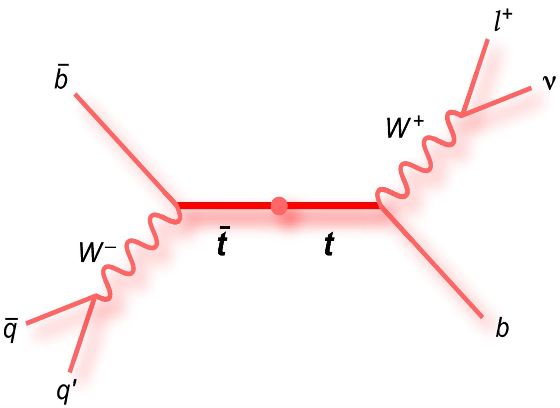
DESY: tt→dilepton
UHH: tt→lepton+jets, all jets

Top pair branching fractions:

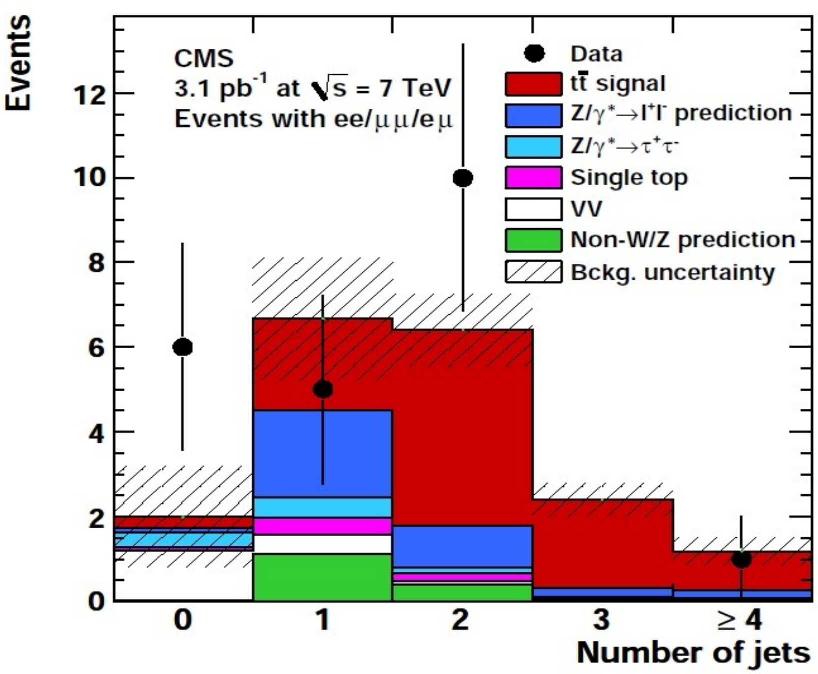
$\sigma_{NLO}(pp\to tt) = 158$ pb

Comparison Tevatron:
σ=7-8 pb

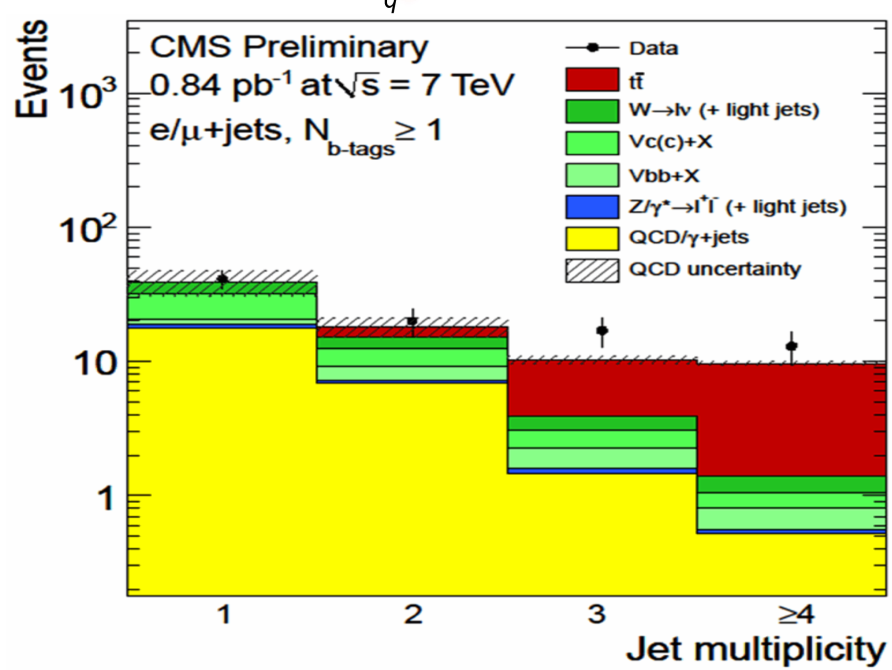




"dileptons"



"lepton+jets"

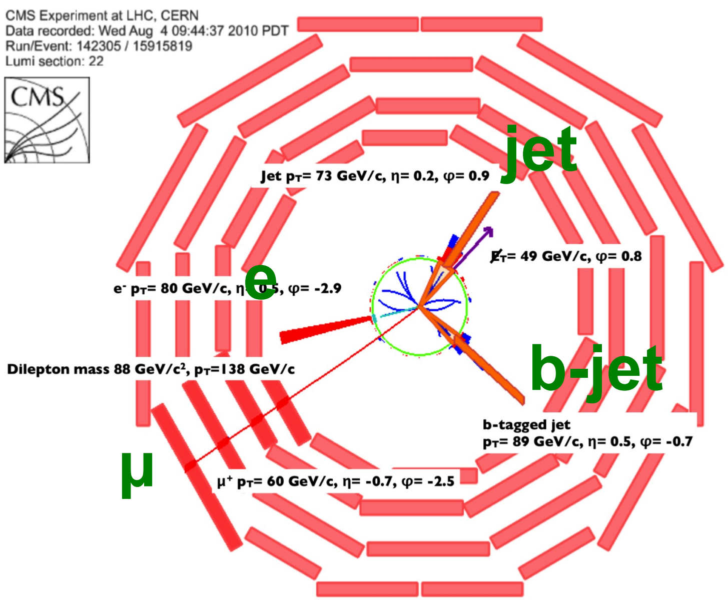


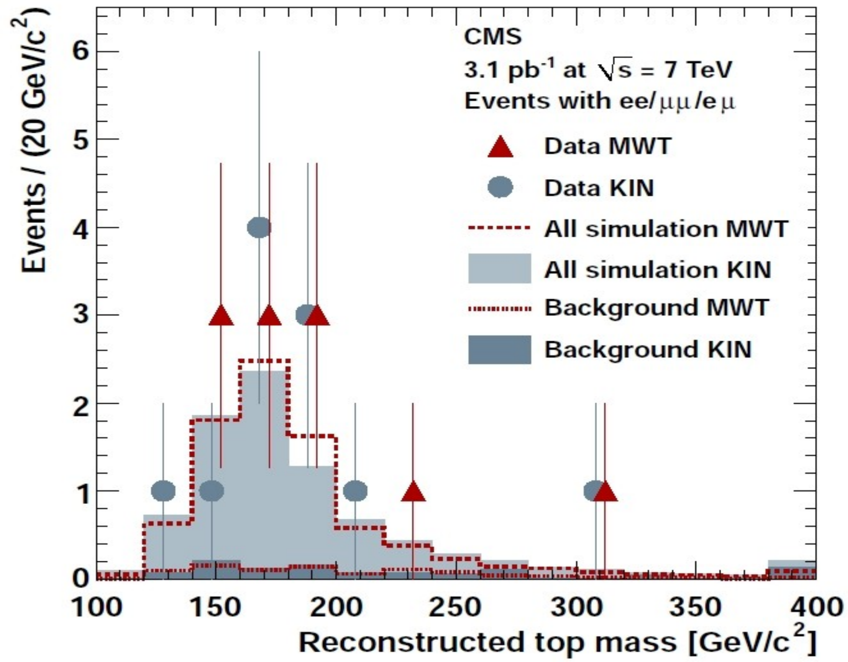
Top cross-section measurement

DESY: tt→dilepton
UHH: tt→lepton+jets, all jets

arXiv:1010.5994, submitted to PLB

Di-lepton channel (e / μ) only, 3.1 pb^{-1}





Source	Number of events
Expected $t\bar{t}$	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
Drell-Yan $Z/\gamma^{\star} \to \tau^+\tau^-$	0.18 ± 0.09
Drell-Yan $Z/\gamma^{\star} \to e^+e^-, \mu^+\mu^-$	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	2.1 ± 1.0
Expected total, including $t\bar{t}$	9.8 ± 1.8
Data	11

Systematic uncertainties: (lepton eff., jet-energy scale, multiple interac., ...)

6.4% Signal
11% Background
11% Luminosity

σ(pp→tt)=194±72(stat)±24(sys)±21(lumi) pb

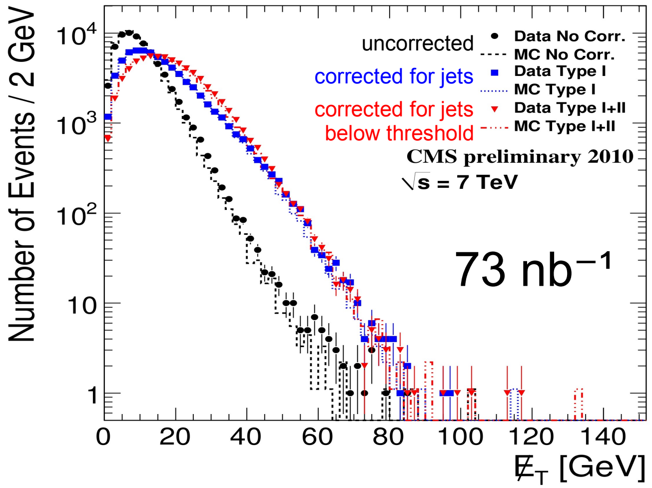
Searches for New Physics

Search for SUSY in the hadronic channel

UHH: all-hadronic
DESY: SS & OS di-lepton

PAS JME-2010-004

Traditional SUSY search in all-hadronic final state requires large MET and searches for an excess over the SM in the tail



→ requires extraordinary good understanding of detector and SM-background

→ data-driven background estimation methods have been developed

All strategies are currently in approval using the full data-sample of ~40 pb^{-1}

Alternative all-hadronic analysis not based on MET (but $\alpha_T = p_{T,jet\ 2} / M_T$).

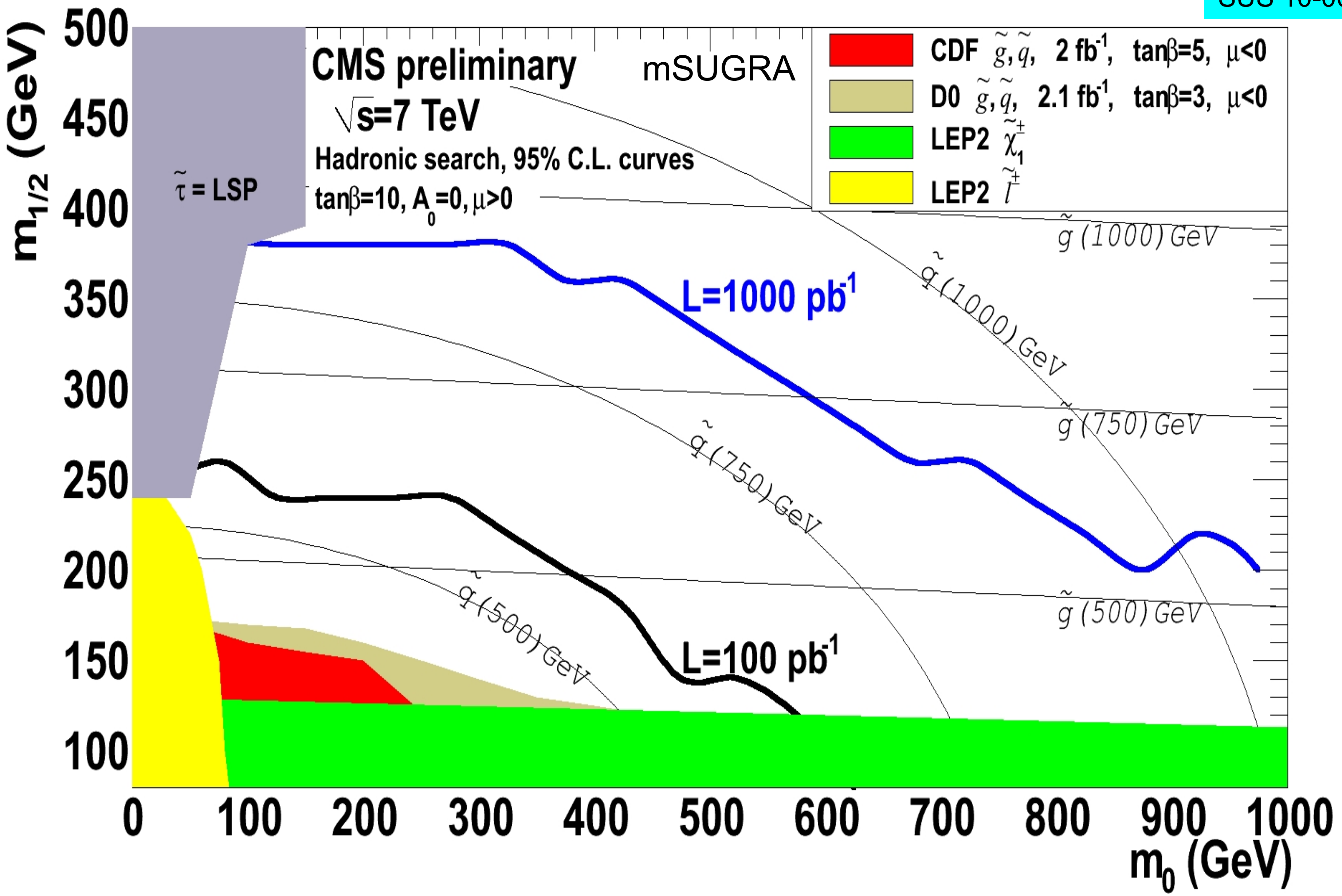
Photon analyses (GMSB)

Lepton analyses:

- Inclusive single lepton
- Like-sign and unlike-sign di-leptons
- Tri-lepton searches

Expected sensitivity for SUSY

SUS 10-001



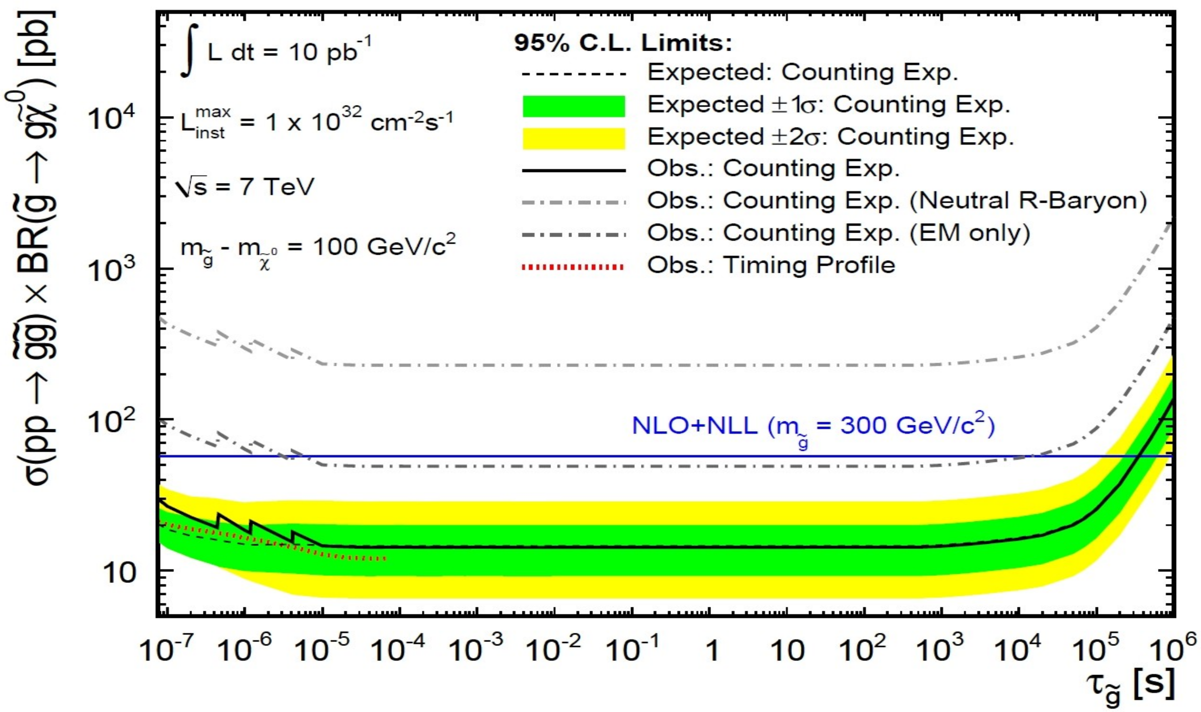
Stopped gluino search

arXiv 1011.5861, submitted to PRL

- Many models predict heavy stable charged particles (SUSY, split-SUSY, hidden-valley, GUTs)
- Long-lived gluinos can hadronize to R-hadrons ($\tilde{g}g$, $\tilde{g}q\bar{q}$, $\tilde{g}qqq$), can "rest" in the detector
- Special designed triggers, to look for decays when there is no beam

Lifetime [s]	Expected Background ($\pm$ stat. $\pm$ syst.)	Observed
1×10^{-7}	$0.8 \pm 0.2 \pm 0.2$	2
1×10^{-6}	$1.9 \pm 0.4 \pm 0.5$	3
1×10^{-5}	$4.9 \pm 1.0 \pm 1.3$	5
1×10^{6}	$4.9 \pm 1.0 \pm 1.3$	5

Background:
Satellite bunches, Cosmics, Instrumental noise



Excluded:
m(gluino) < 370 GeV for lifetimes from 10ms to 1000s

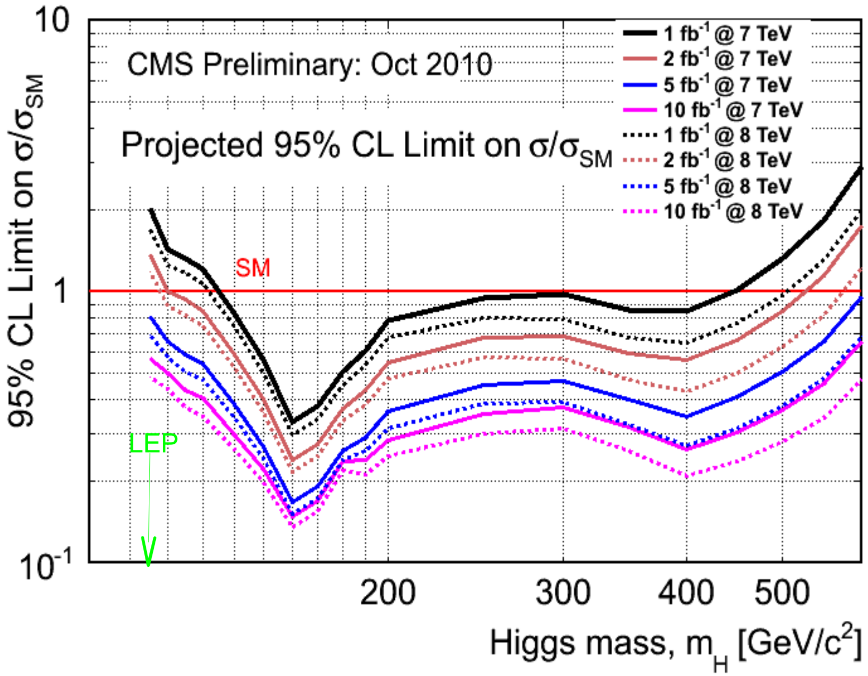
(assumes BR($\tilde{g} \to \tilde{\chi} g$) = 100%)

Significant extension of previous DØ limits.

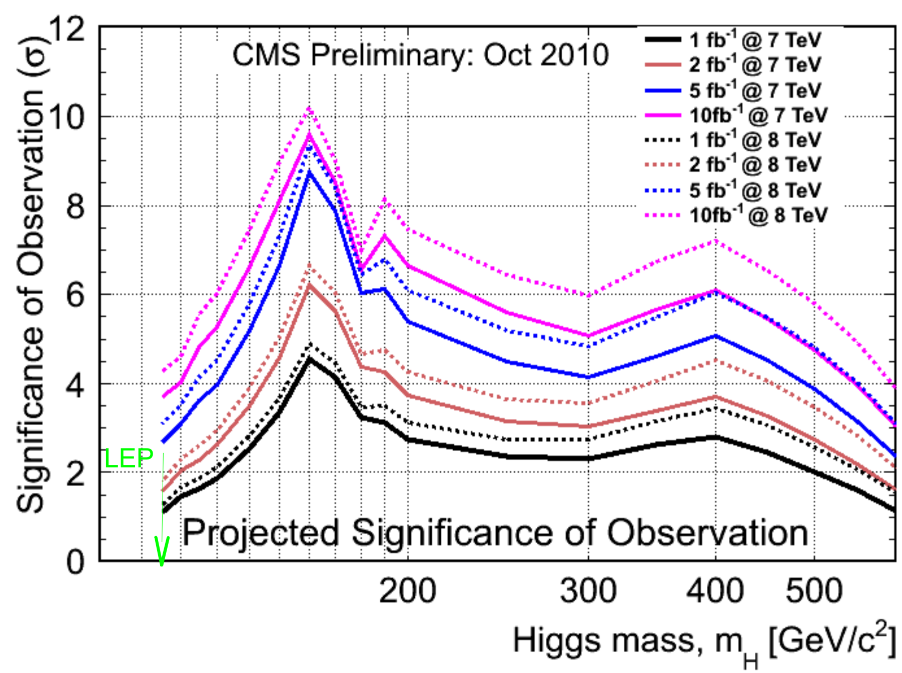
Higgs Sensitivity

DESY: H→ττ→μμ, bbΦ→bbbb

Expected Limits on SM Higgs



Expected Discovery Significance SM Higgs



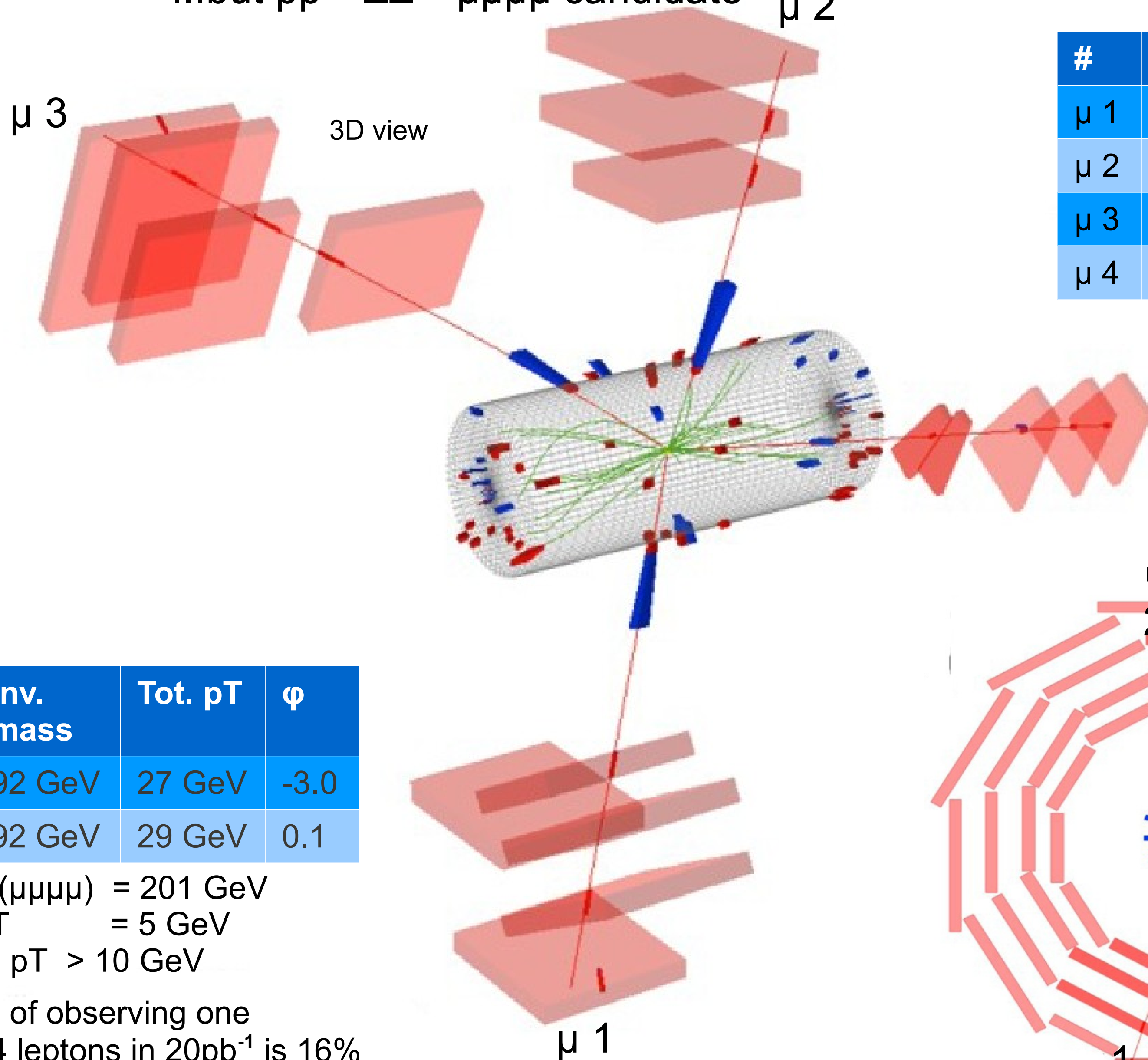
- 95% CL Limit in a wide mass range possible with 1 fb^{-1} (i.e. mid 2011)
  Ralph Assmann, Dresden 2010: "2 fb^{-1} at 8 TeV reasonable in 2011, ultimate reach up to 7.6 fb^{-1}"
- Discovery of a low-mass SM Higgs requires effort and (more) time

Considered channels: H→WW→2l2ν, H→ZZ→4l, H→ZZ→2l2ν, H→ZZ→2l2b, H→γγ, VBF H→ττ, VH→V(bb), ZH→Z(WW)→(ll)(lνjj), WH→W(WW)→(lν)(lνjj) (same sign di-leptons); scaled from 10 TeV studies.

Sorry, (probably) no H→ZZ→μμμμ

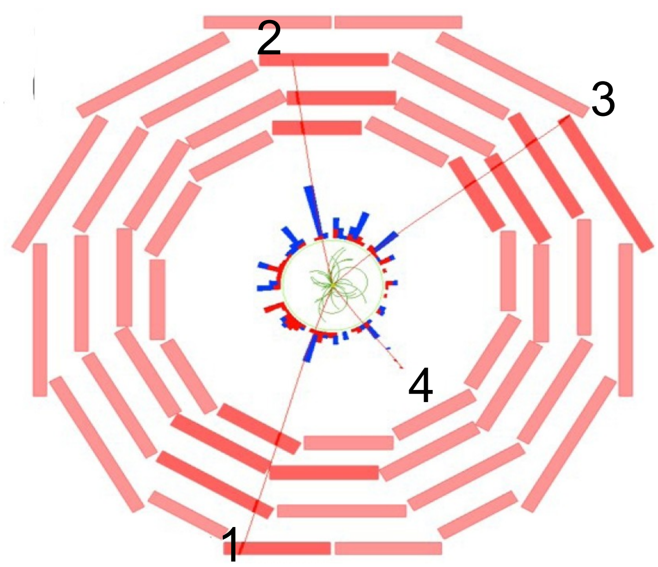
DP-2010-038

...but pp→ZZ→μμμμ candidate



#	pT	η	φ
μ 1	48 GeV	-0.4	-1.9
μ 2	43 GeV	0.2	1.8
μ 3	26 GeV	-0.8	0.8
μ 4	20 GeV	2.0	-1.0

r-φ view



	Inv. mass	Tot. pT	φ
μ1+μ2	92 GeV	27 GeV	-3.0
μ3+μ4	92 GeV	29 GeV	0.1

Inv. mass (μμμμ) = 201 GeV
Missing ET = 5 GeV
No PF jets pT > 10 GeV

Probability of observing one pp→ZZ→4 leptons in 20pb^{-1} is 16%

Conclusion

- Excellent performance of the LHC machine and the CMS detector!
  The number of published results is amazing:

- The standard model has been largely rediscovered by LHC.

- Many searches for new physics are already now compatible with Tevatron.

- Is there a most interesting CMS result in 2010?

  Perhaps the surprisingly high level of understanding of the detector, the algorithms, and the physics objects (tracking, alignment, MET, particle-flow, jet-calibration...)

Backup

Angular correlations

J. High Energy Phys. 09 (2010) 091

Correlation defined as

$$R(\Delta\eta,\Delta\phi) = \left\langle (\langle N\rangle - 1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_{bins}$$

with

$$S_N(\Delta\eta,\Delta\phi) = \frac{1}{N(N-1)}\frac{d^2N^{\mathrm{signal}}}{d\Delta\eta d\Delta\phi}$$

$$B_N(\Delta\eta,\Delta\phi) = \frac{1}{N^2}\frac{d^2N^{\mathrm{mixed}}}{d\Delta\eta d\Delta\phi}$$

Signal: Any two-particle correlation in one event

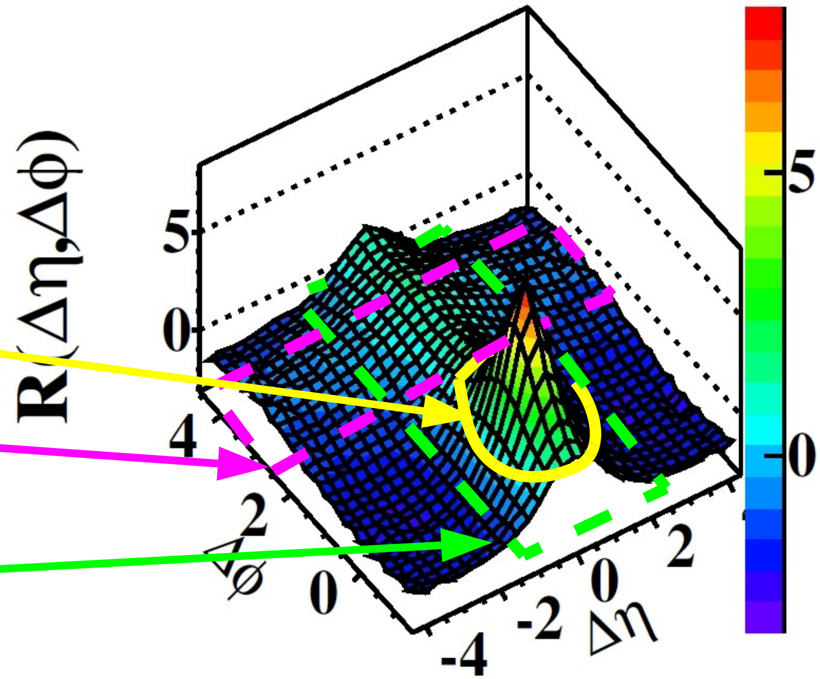
Backgd: Any two-particle correlation from different events (with same track multiplicity).

Use minimum bias and high track-multiplicity triggered events.

Hard pT clusters, i.e. the two particles are inside the same jet

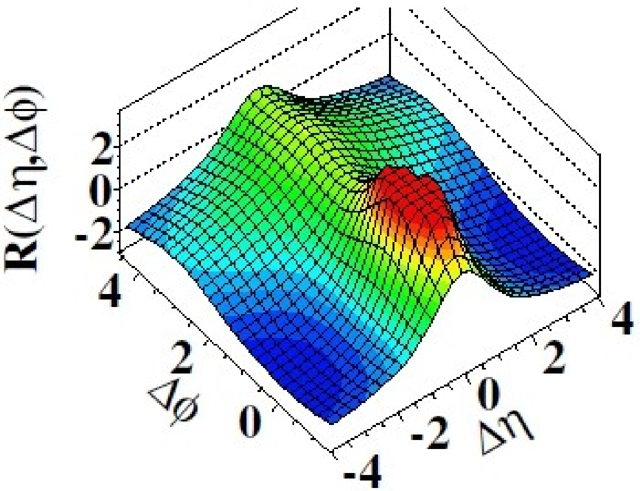
Recoiling jet (momentum conservation)

Hadronization and decay of clusters with low pT, e.g. string fragmentation

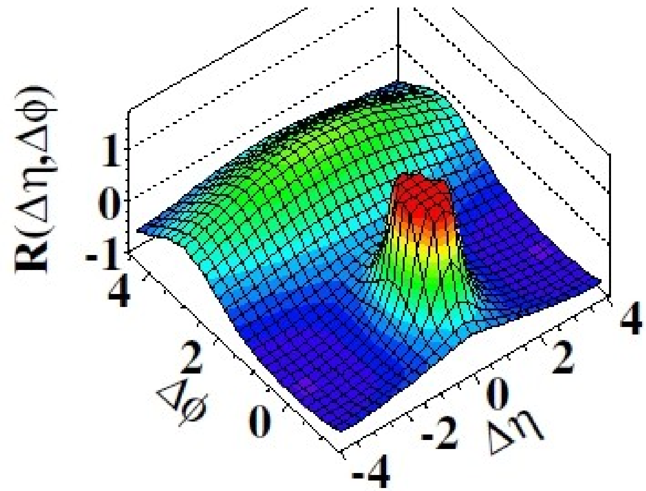


Angular correlations

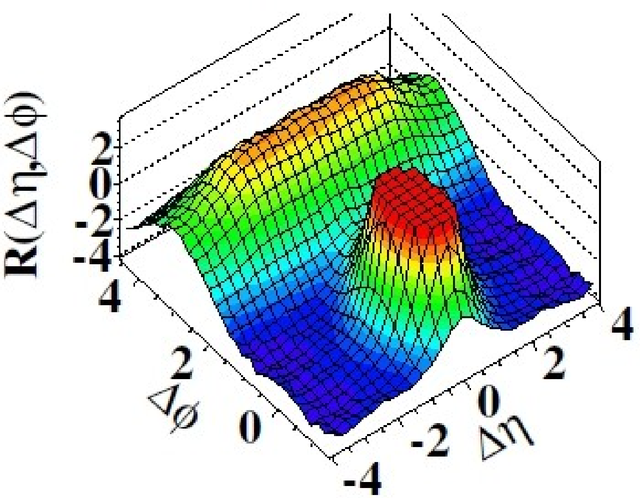
(a) CMS MinBias, p_T>0.1GeV/c



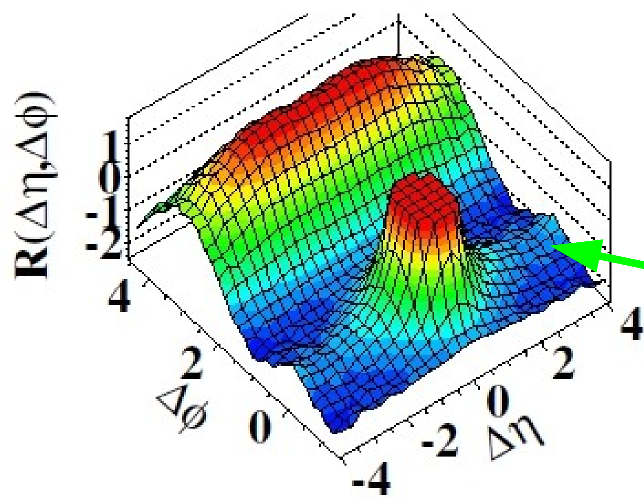
(b) CMS MinBias, 1.0GeV/c<p_T<3.0GeV/c



(c) CMS N ≥ 110, p_T>0.1GeV/c

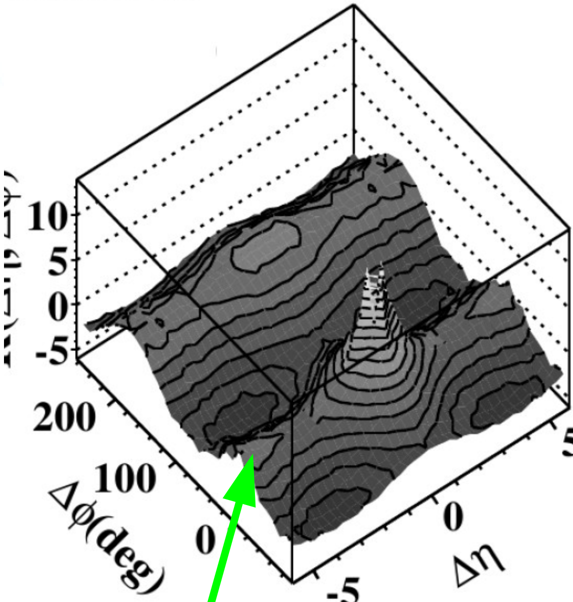


(d) CMS N ≥ 110, 1.0GeV/c<p_T<3.0GeV/c



Phobos Heavy Ions

Au+Au 200 GeV



Ridge unexpected in pp-collisions

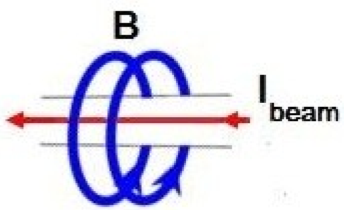
LHC beam current measurement (principle)

http://lhc-closer.es/php/index.php?i=1&s=4&p=7&e=1

"For LHC beam are used two DC current transformers (DCCT) and two fast beam current transformers (FBCT) per ring
(eight transformers in total).

In a very simple approximation the transformers work as follows:

Beam creates, such as a current-carrying wire, a magnetic field B.
The transformer "feels" this magnetic field.

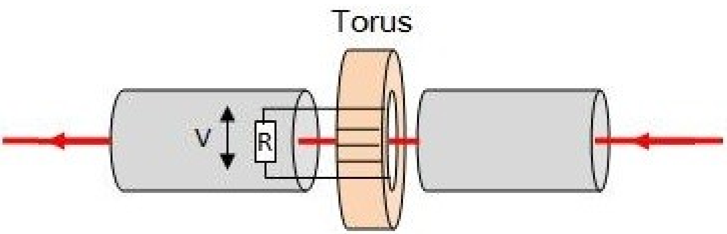


The Torus guides this magnetic field which produces a secondary current Isec on the secondary winding on the torus.
The beam acts as primary winding with Nbeam =1.

Ibeam/Isec= Ntorus/Nbeam ⇒ Ibeam = Ntorus · Isec

By using Ohm's Law, V = R · Isec, so Isec = V / R

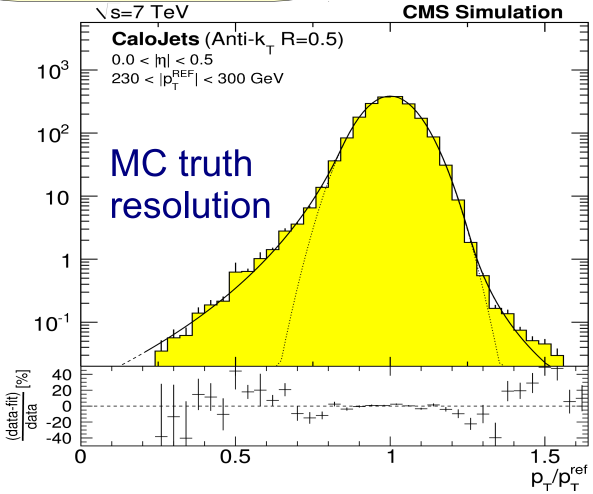
→ Ibeam = Ntorus·V / R



Obviously, things are "a little bit" more complicated in reality... "

Jet (Gaussian) Resolution

UHH: non-Gaussian jet resolution



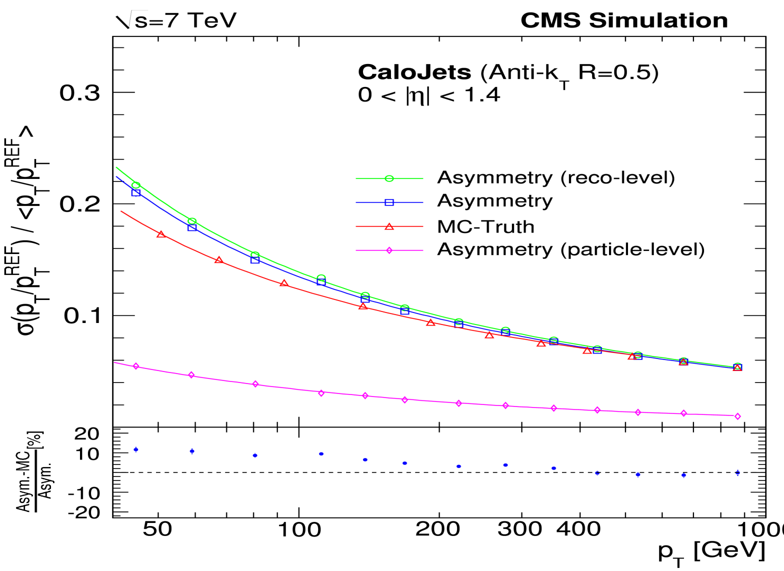
Jet resolution can be measured in QCD di-jet events, using

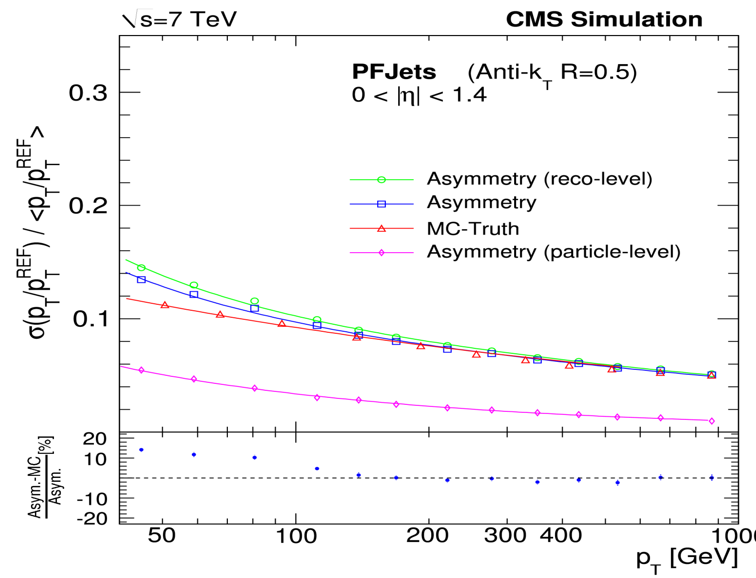
$$A = \frac{p_T^{\text{jet1}} - p_T^{\text{jet2}}}{p_T^{\text{jet1}} + p_T^{\text{jet2}}}$$

the width of the asymmetry translates to jet resolution as

$$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$

Effect of a third jet is considered by extrapolation to pT (3rd jet) → 0.





The jet resolution is described in good approximation by a Gaussian.
However, i.e. for BSM searches especially the non-Gaussian tails become very important! Searching for SUSY means understanding the tails! →In pre-approval.

CMS mSUGRA benchmark points

Low mass (LM) mSUGRA benchmarks

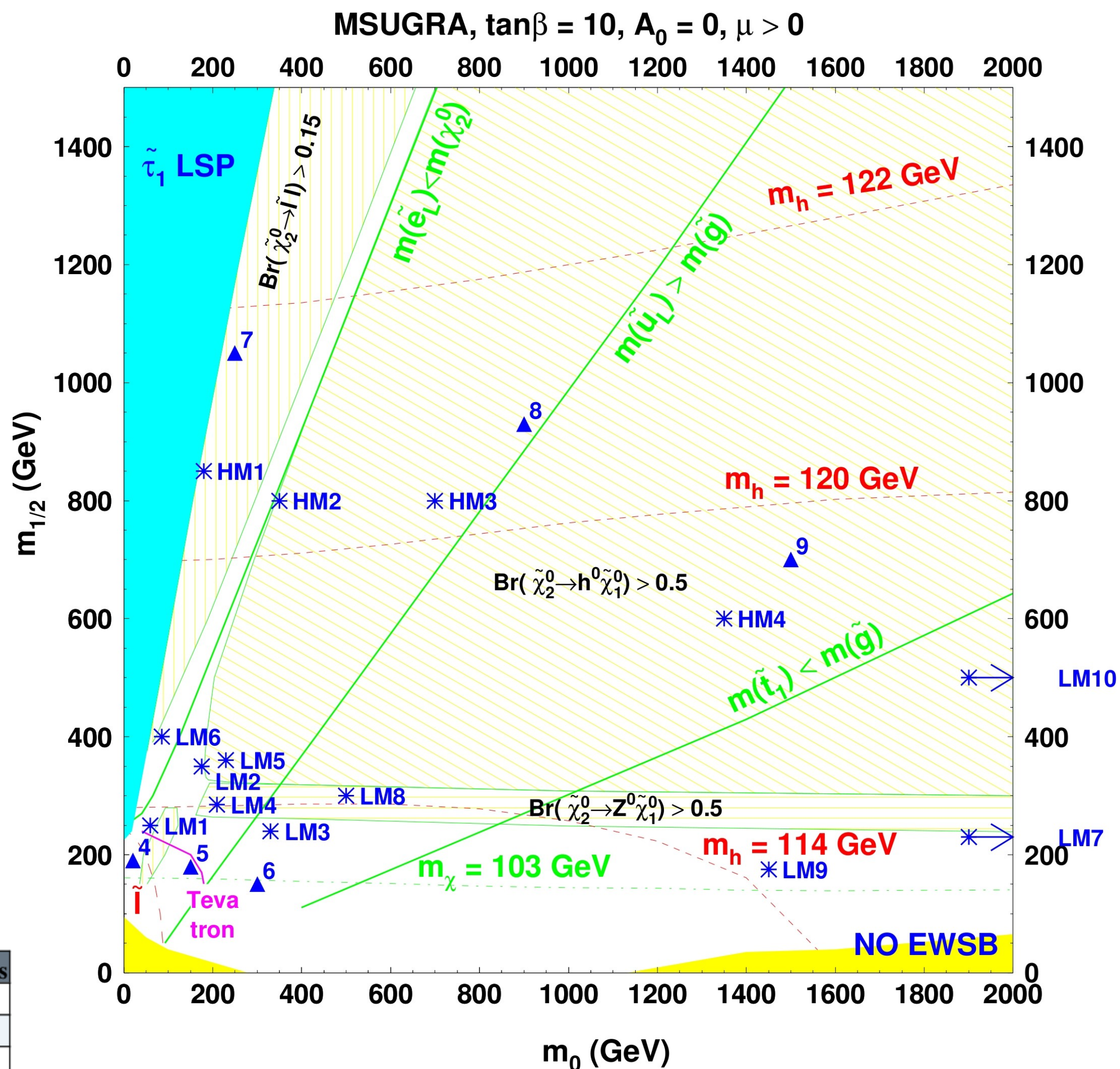
Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
LM0	200	160	–400	10	1	
LM1	60	250	0	10	+	
LM2	185	350	0	35	+	
LM2mhf360	185	360	0	35	+	
LM3	330	240	0	20	+	
LM4	210	285	0	10	+	
LM5	230	360	0	10	+	
LM6	85	400	0	10	+	
LM7	3000	230	0	10	+	
LM8	500	300	–300	10	+	
LM9	1450	175	0	50	+	
LM9p	1450	230	0	10	+	
LM9t175	1450	175	0	50	+	mtop = 175
LM10	3000	500	0	10	+	
LM11	250	325	0	35	+	
LM12						TBD
LM13						focus point, TBD

High mass (HM) mSUGRA benchmarks

Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
HM1	180	850	0	10	+	
HM2	350	800	0	35	+	
HM3	700	800	0	10	+	
HM4	1350	600	0	10	+	

GMSB (GM) benchmarks

Benchmark	Lambda	M_mess	N5	C_Grav	tanb	sgn(mu)	Notes
GM1b	80	160	1	1	15	+	
GM1c	100	200	1	1	15	+	
GM1d	120	240	1	1	15	+	
GM1e	140	280	1	1	15	+	
GM1f	160	320	1	1	15	+	
GM1g	180	360	1	1	15	+	



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