



Accelerating Science and Innovation

HERA and the Future of Particle Physics

Past few decades

“Discovery” of Standard Model

through synergy of

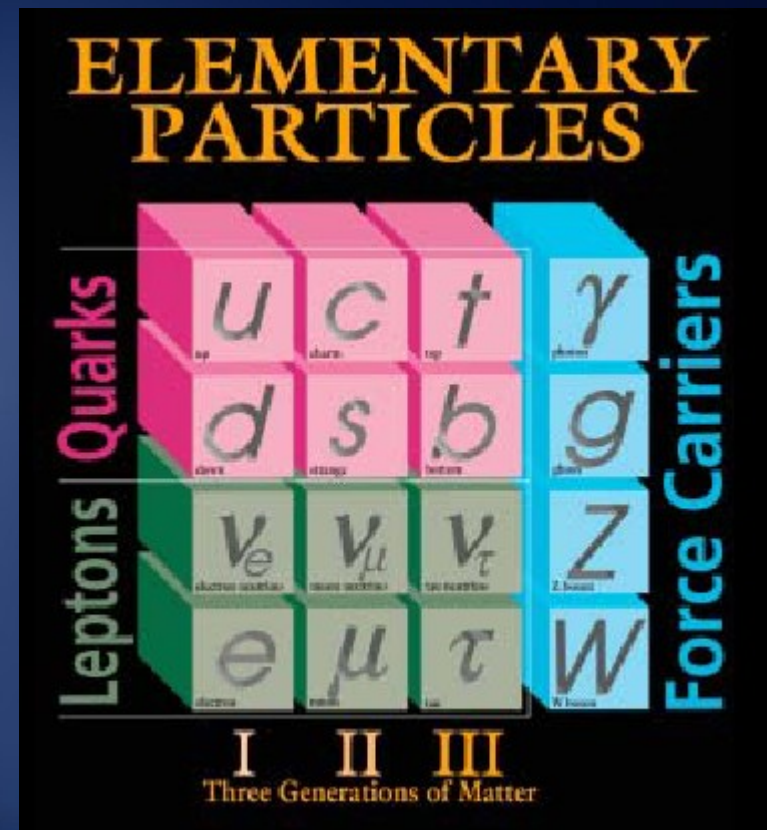
hadron - hadron	colliders	(e.g. Tevatron)
lepton - hadron	colliders	(HERA)
lepton - lepton	colliders	(e.g. LEP, SLC)

What have we learned the last 50 years or Status of the **Standard Model**

The physical world is
composed of
Quarks and Leptons
(**Fermions**)

interacting via force carriers
(**Gauge Bosons**)

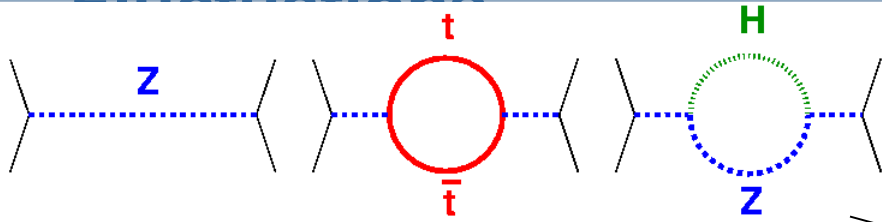
Last entries:	top-quark	1995
	tau-neutrino	2000



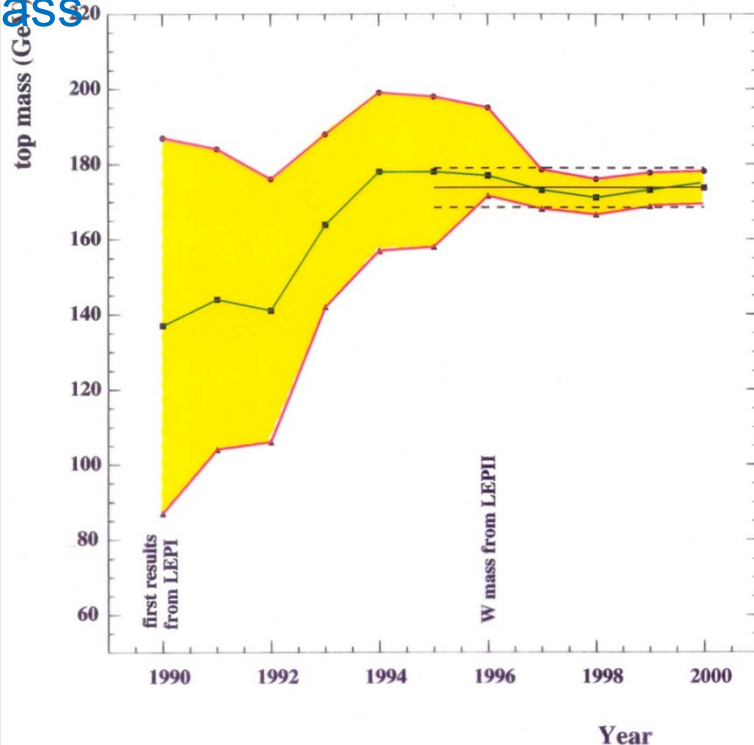
1 March 2010

Test of the SM at the Level of Quantum

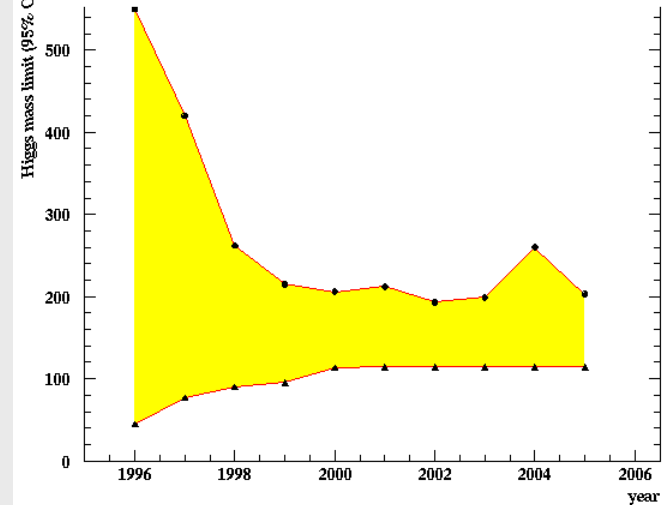
Fluctuations



indirect determination of the top mass

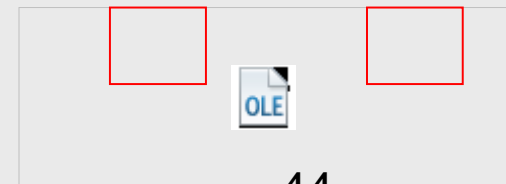


prediction of the range for the Higgs mass



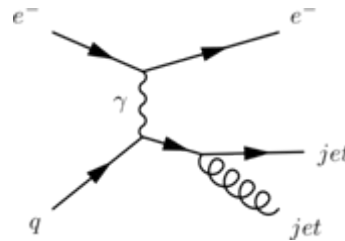
possible due to

- precision measurements
- known higher order electroweak corrections

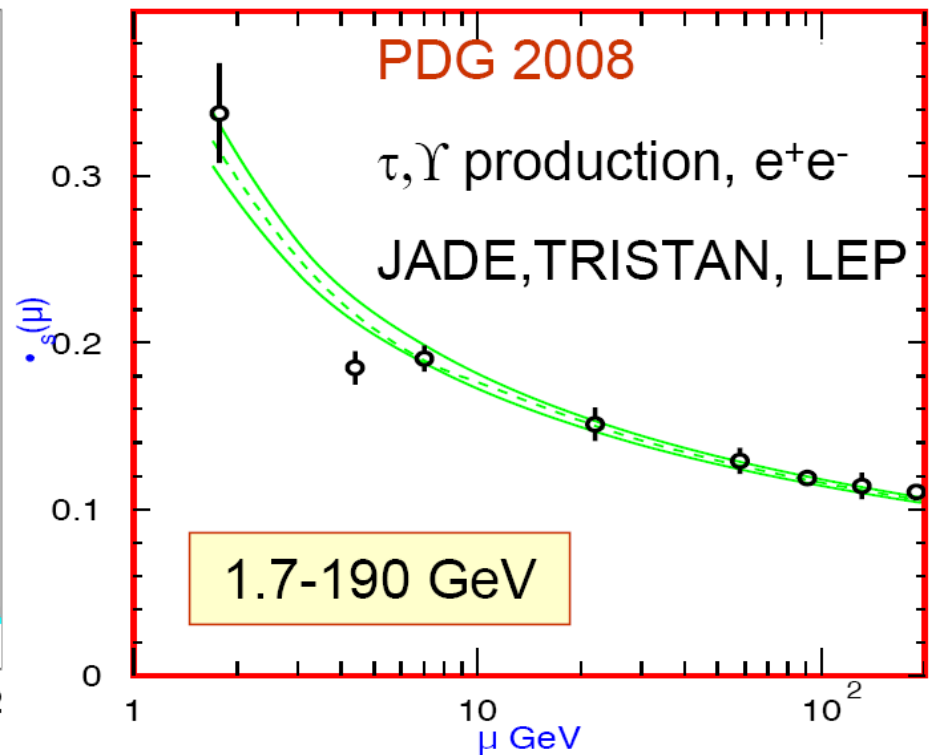
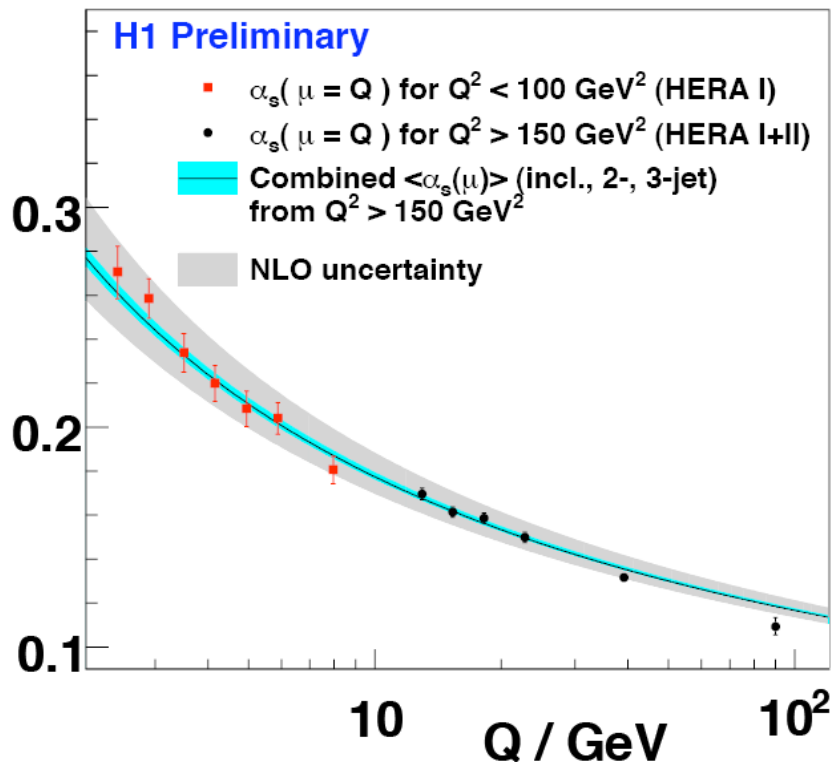


HERA: Tests of QCD

> Running of α_s



α_s from Jet Cross Sections

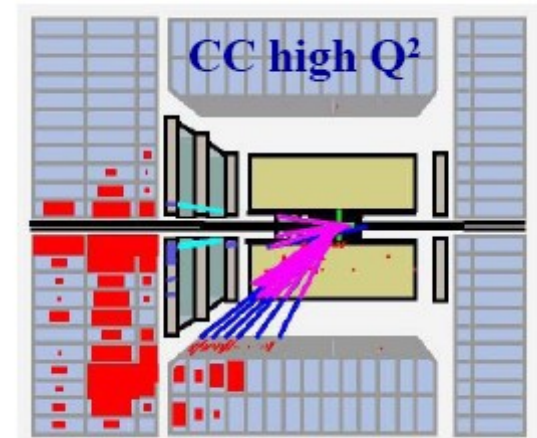
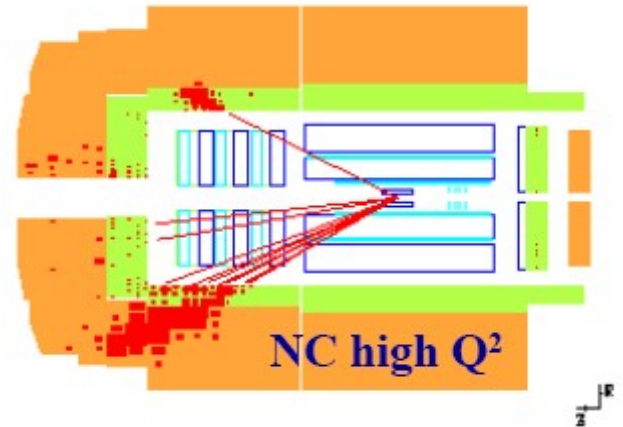
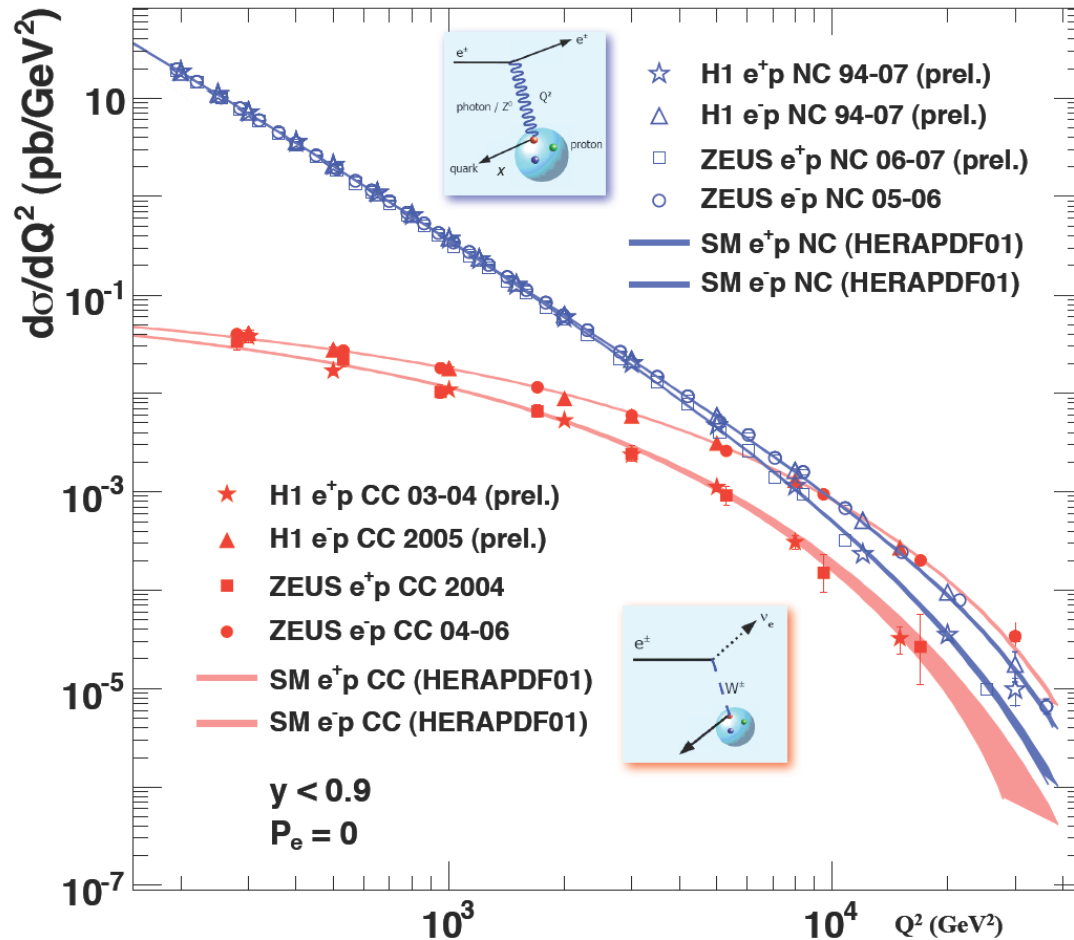


$$\alpha_s(M_Z) = 0.1168 \pm 0.0007 (\text{exp.}) \begin{matrix} +0.0046 \\ -0.0030 \end{matrix} (\text{th.}) \pm 0.0016 (\text{PDF})$$

HERA: Tests of Electroweak Interactions

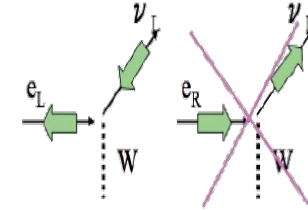
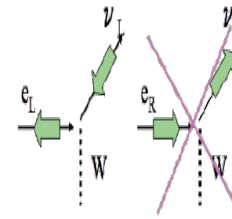
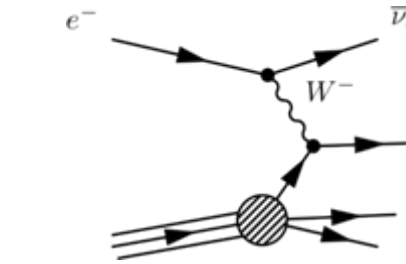
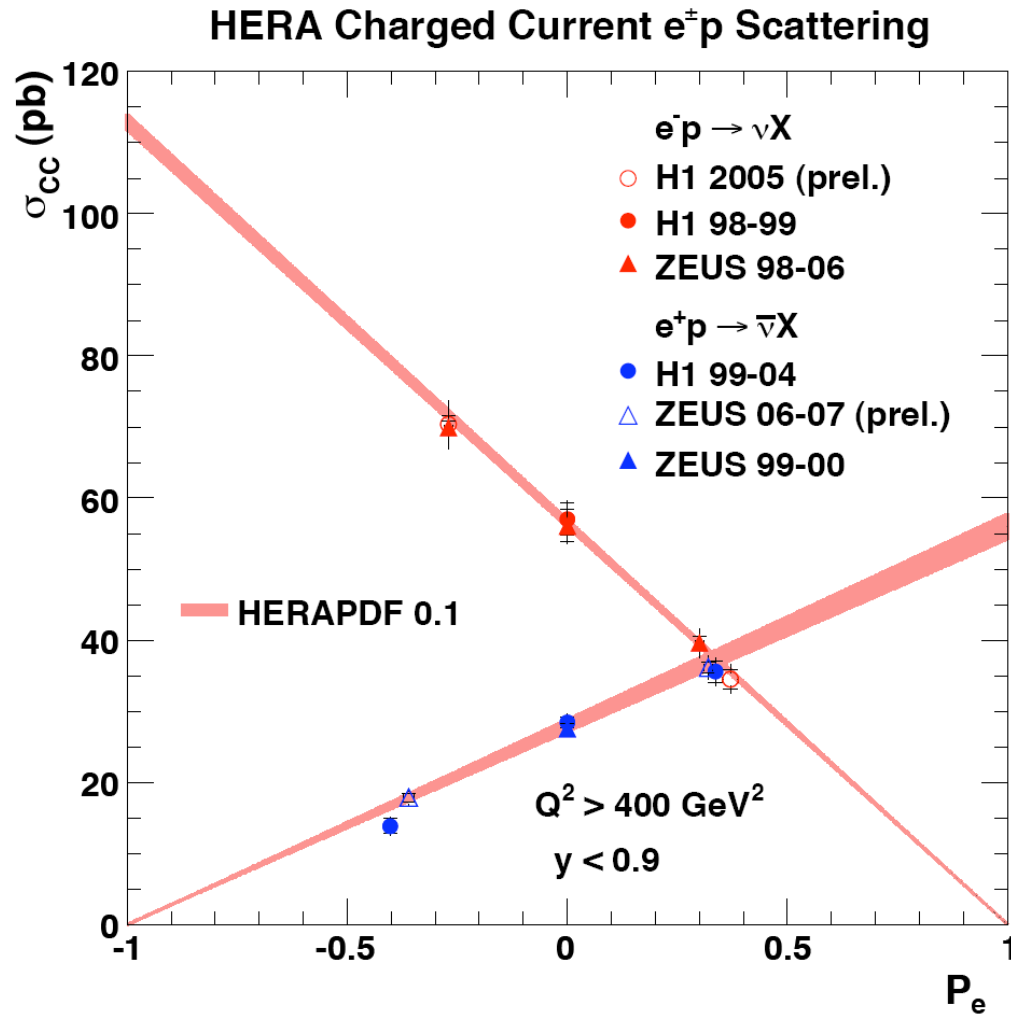
Textbook example: **electromagnetic and weak interactions become equally strong at high energies**

HERA I & II



HERA: Tests of Electroweak Interactions

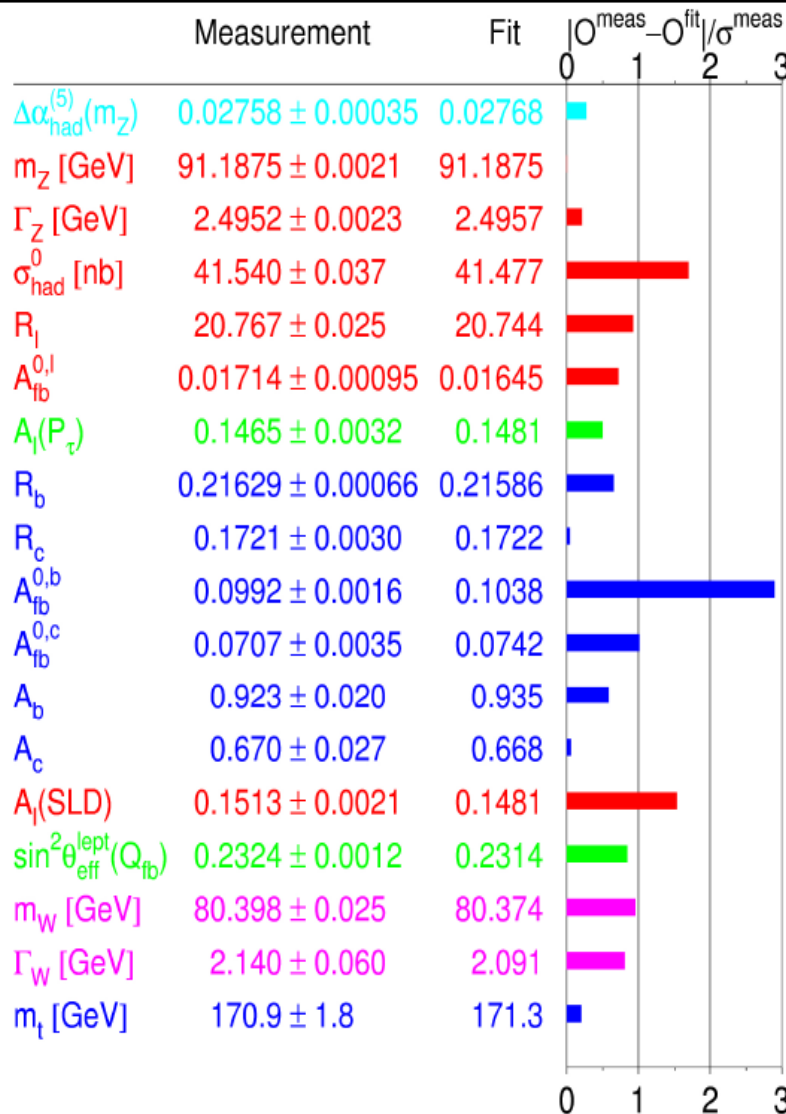
> Polarised CC cross section



> No right-handed charged currents

Status recent Summer Conferences

Standard Model Analysis



Fit to 17 high- Q^2 observables
plus $\Delta\alpha_{\text{had}}$:

$$\chi^2/\text{ndof} = 18.2/13 \text{ (15.1\%)}$$

Largest χ^2 contribution:

$A_l(\text{SLD})$ vs. $A_{\text{fb}}^0(b)$ (LEP)

Without this point,
the fit is too good!

Decrease value of
leptons by M_W

$A_{\text{fb}}(b)$ has largest pull: 2.9σ !

however ...

... many key questions open

Key Questions of Particle Physics

origin of mass/matter or
origin of electroweak symmetry breaking

unification of forces

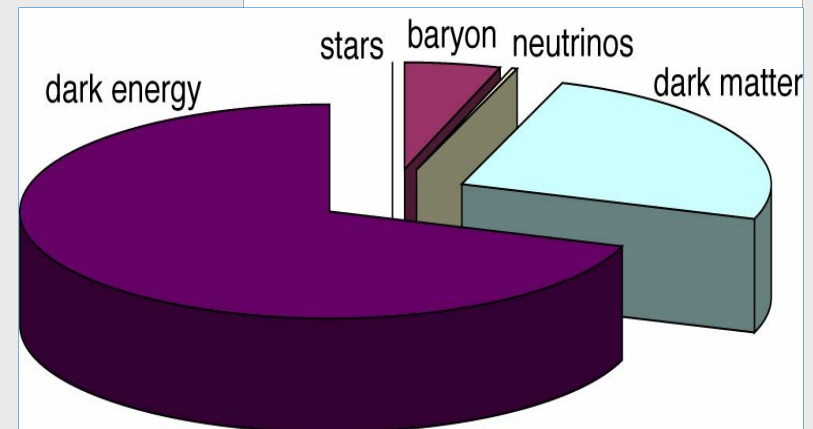
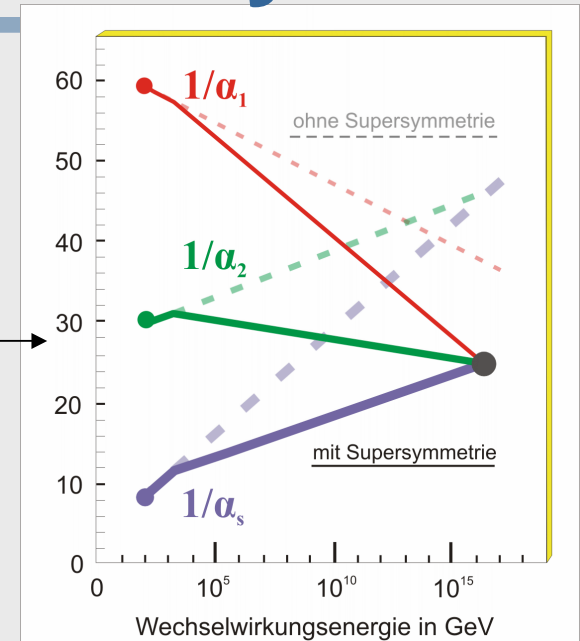
fundamental symmetry of forces and
matter

unification of quantum physics and
general relativity

number of space/time dimensions

what is dark matter

what is dark energy



Solutions?



Standard



Technicolor

New (strong) interactions produce EWSB

Extensions of the SM gauge group :

Little Higgs / GUTs / ...

For all proposed solutions:
new particles should appear
at **TeV** scale or below
□ **territory of the LHC**

Selected NP
since 1957
Except P.
Higgs

Successful for ever ??

Supersymmetry

New particles at \approx TeV scale, light Higgs
Unification of forces
Higgs mass stabilized
No new interactions



Extra Dimensions

New dimensions introduced
 $m_{\text{Gravity}} \approx m_{\text{EW}}$ □ Hierarchy
problem
solved

New particles at \approx TeV scale

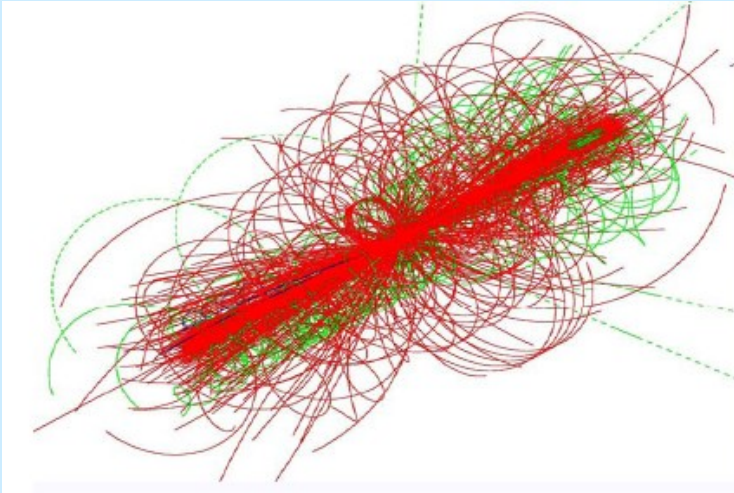
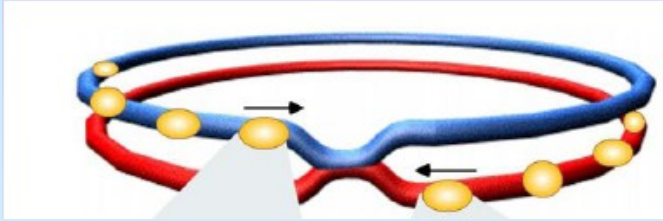
Enter a New Era in Fundamental Science

Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.

Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
at ECM up to 14 TeV



Proton-Proton Collisions at the LHC



§ **2808 + 2808 proton bunches**
separated by 7.5 m

→ **collisions every 25 ns**
= 40 MHz crossing rate

§ **1011 protons per bunch**

§ **at 1034/cm²/s**

≈ 35 pp interactions per crossing
pile-up

→ **≈ 109 pp interactions per second !!!**

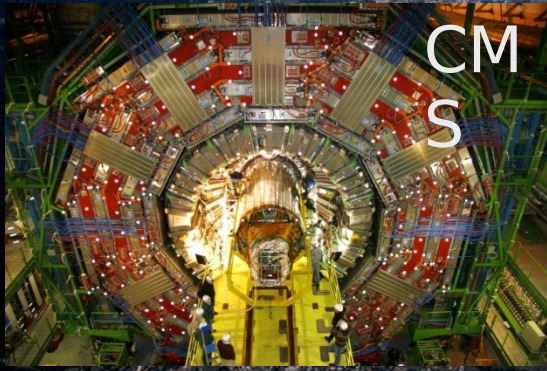
§ **in each collision**

≈ 1600 charged particles produced

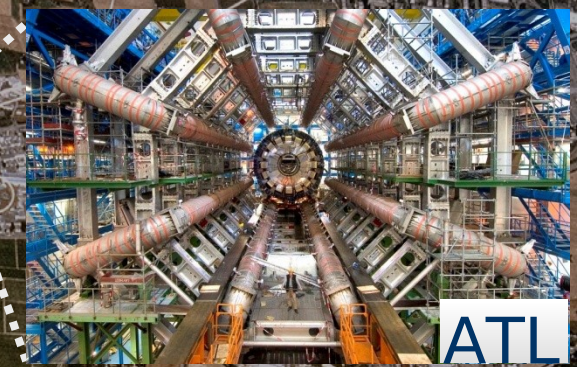
enormous challenge for the detectors
and for data collection/storage/analysis

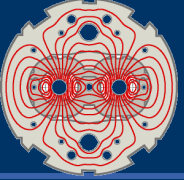
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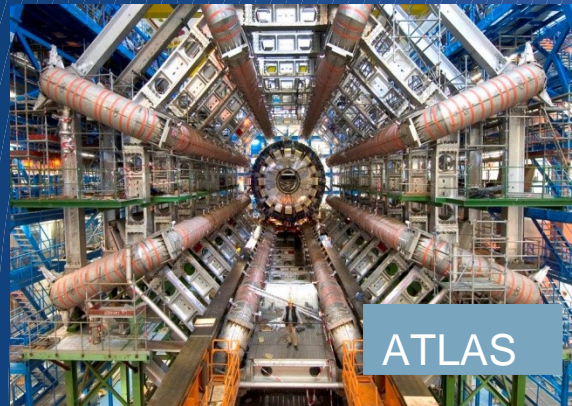
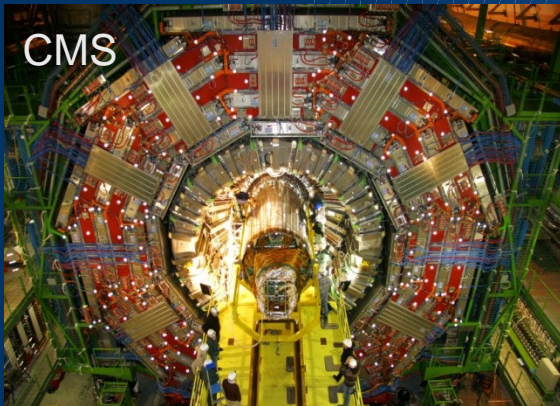




LHC Experiments \square complementary



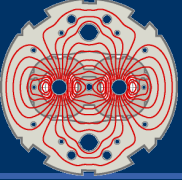
Specialised detector to study b-quarks \square CPV



General purpose detectors



Specialised detector to study heavy ion collisions



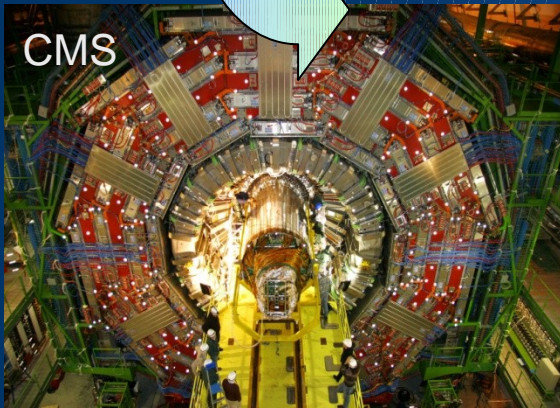
LHC Experiments □ complementary



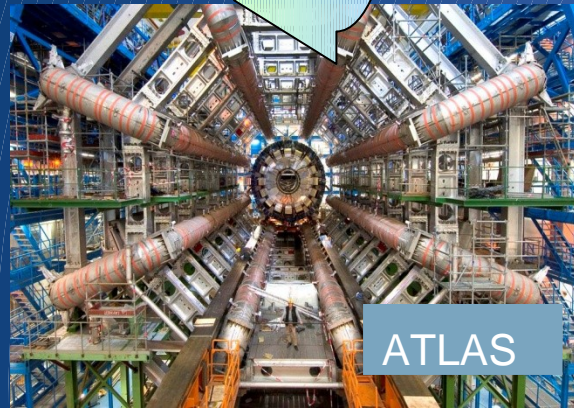
Overlap
in
physics
reach



LHCb



CMS

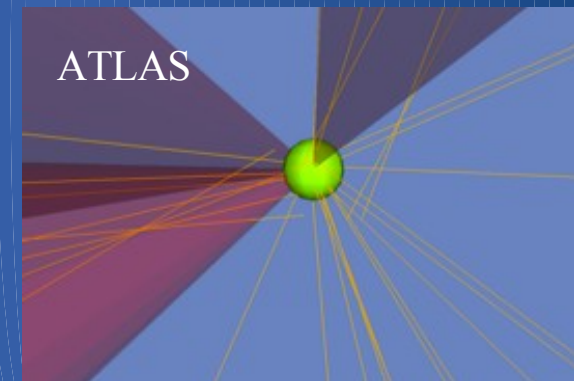
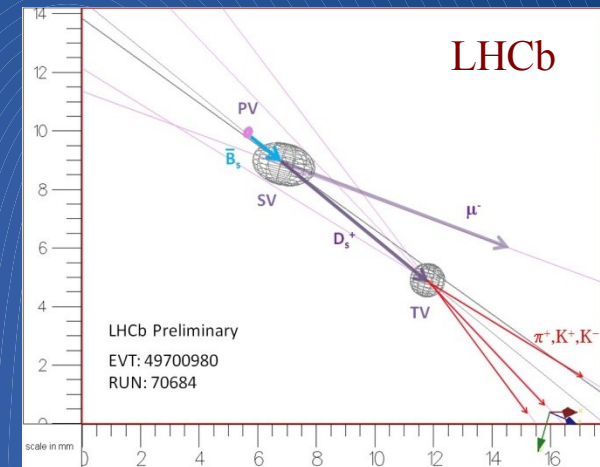


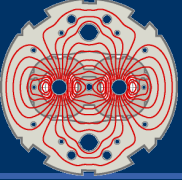
ATLAS



ALICE

Key feature: reconstruct
secondary vertex





LHC Experiments ☐ complementary

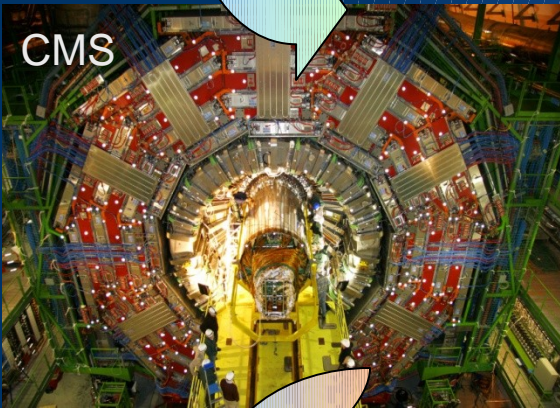


Overlap
in
physics
reach

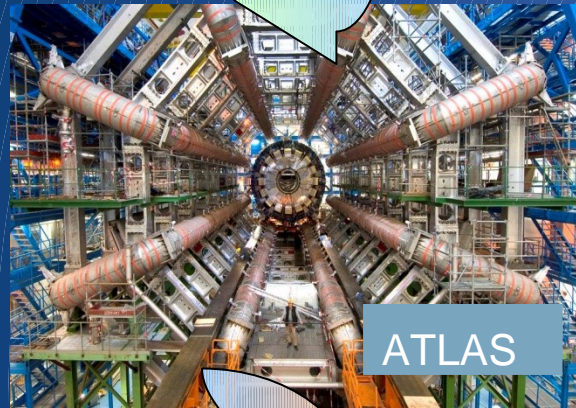


LHCb

CMS



ATLAS

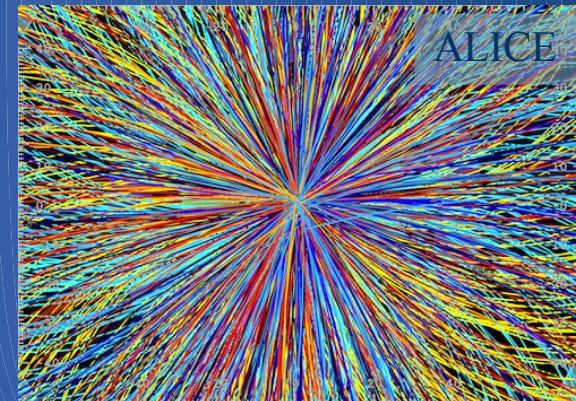
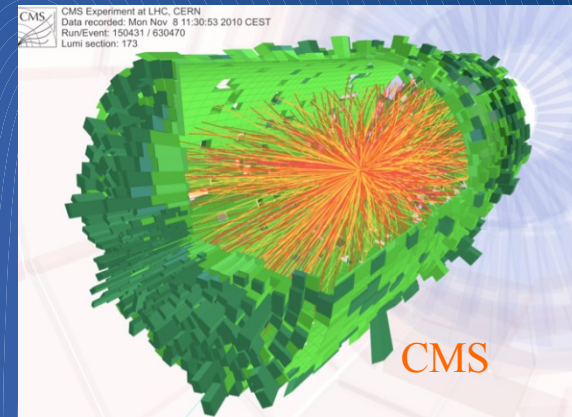


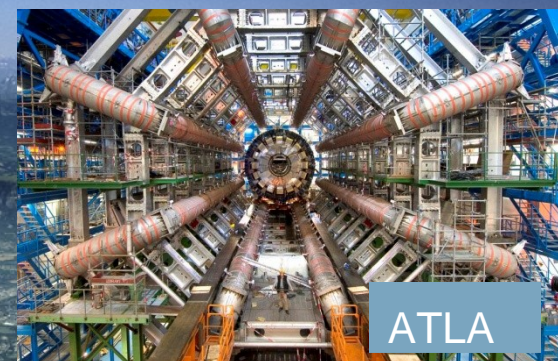
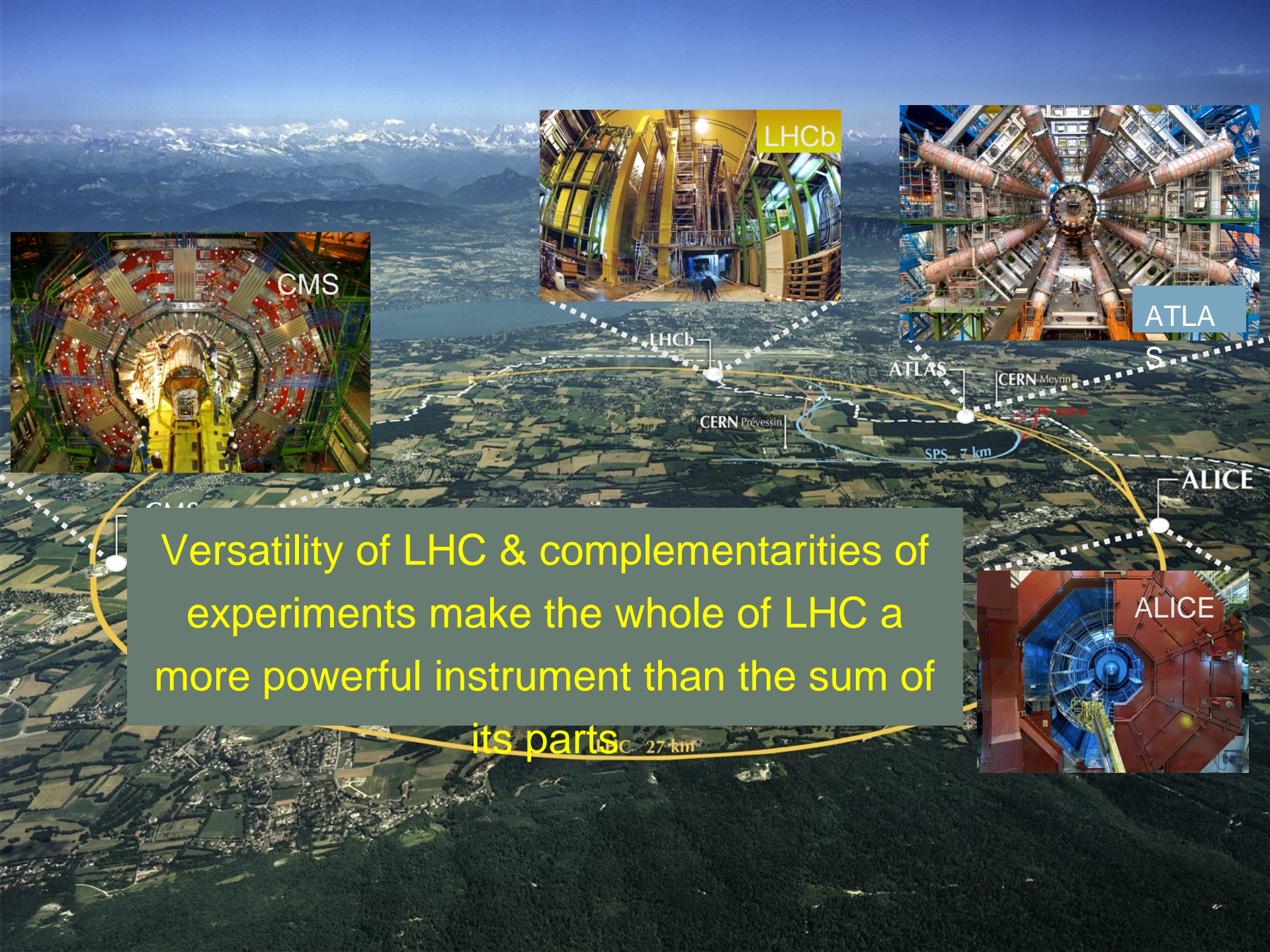
ALICE



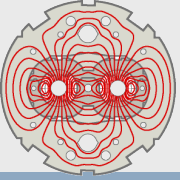
Overlap
in
physics
reach

Key feature: reconstruct
> 20'000 charged tracks in
one event

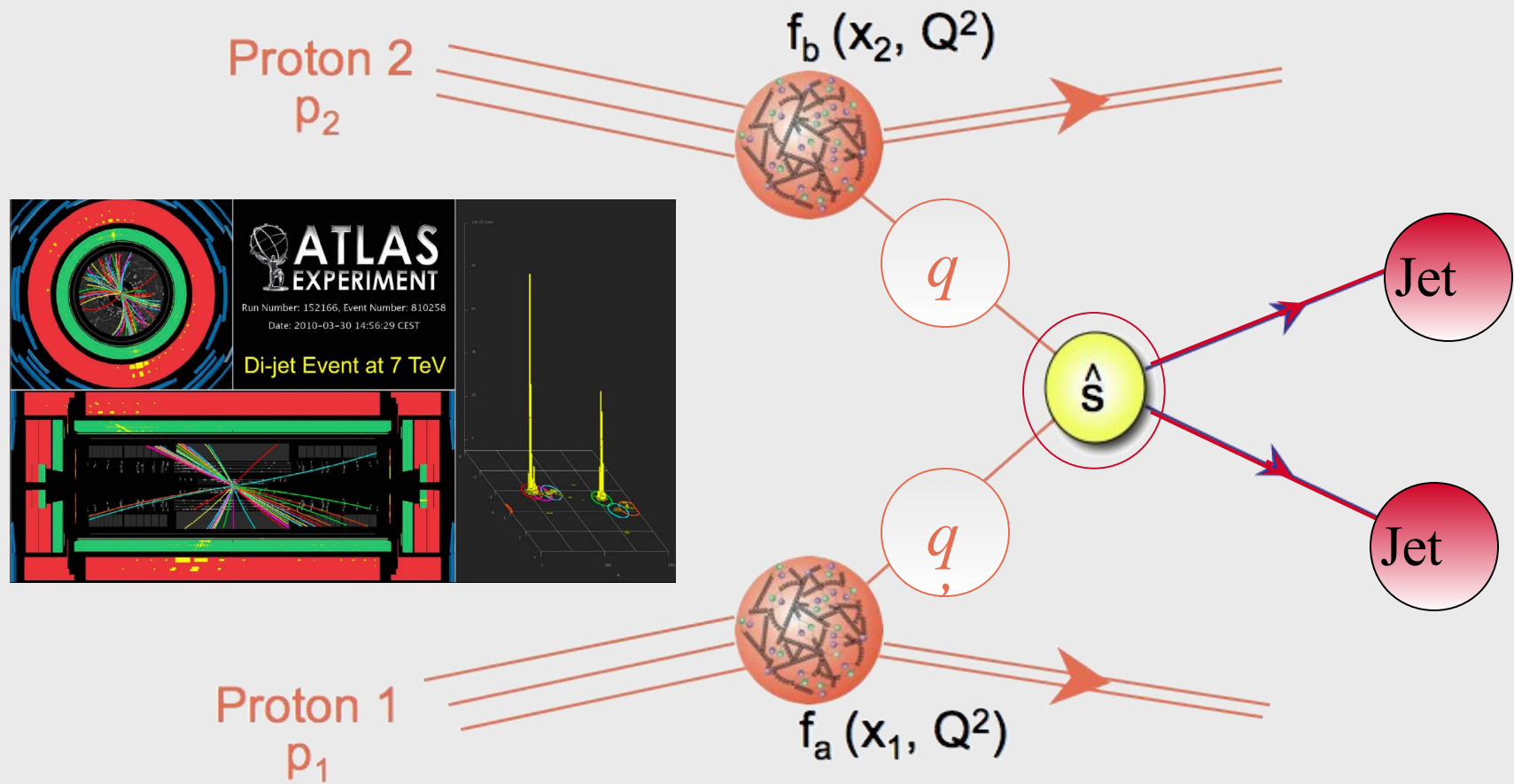




Versatility of LHC & complementarities of experiments make the whole of LHC a more powerful instrument than the sum of its parts



Basic processes at LHC

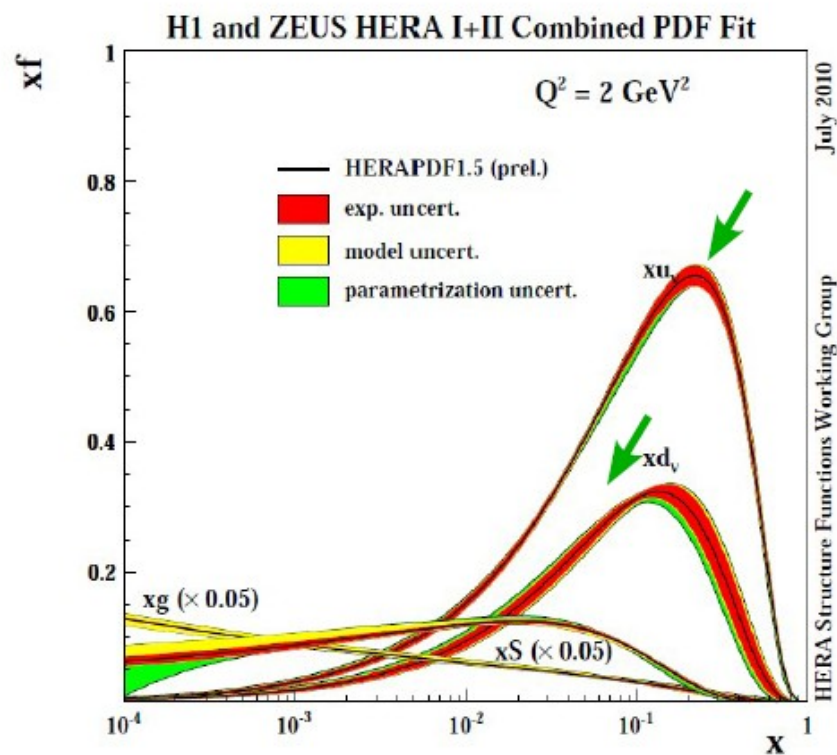
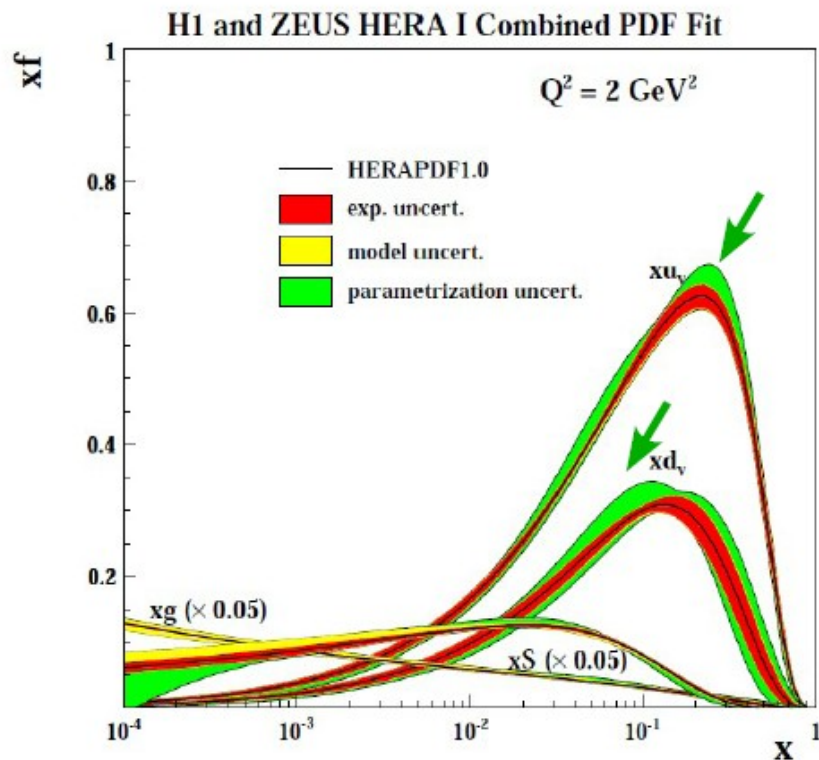


Fits to new combined HERA data: HERAPDF1.5

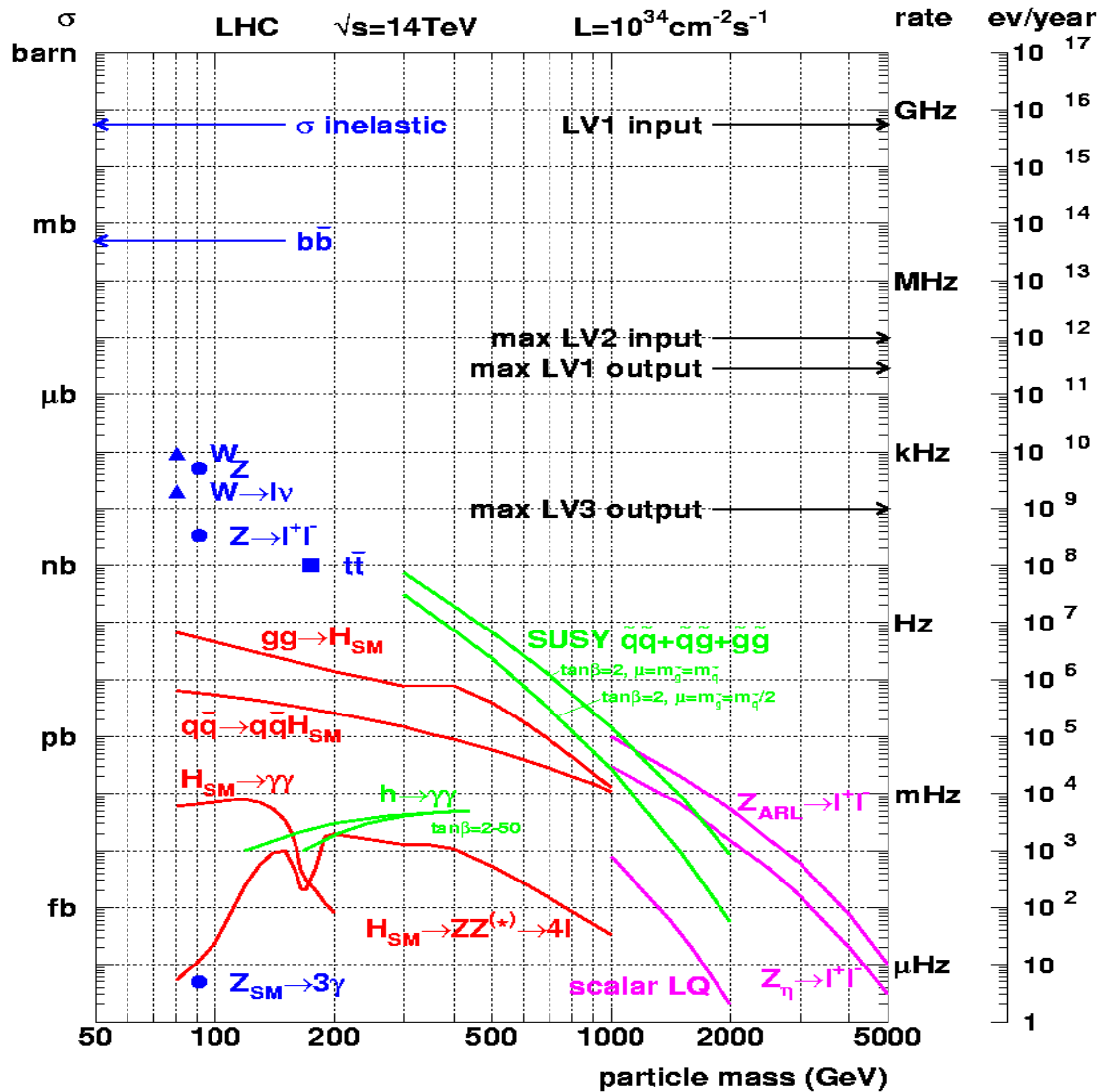


HERAPDF1.0

HERAPDF1.5

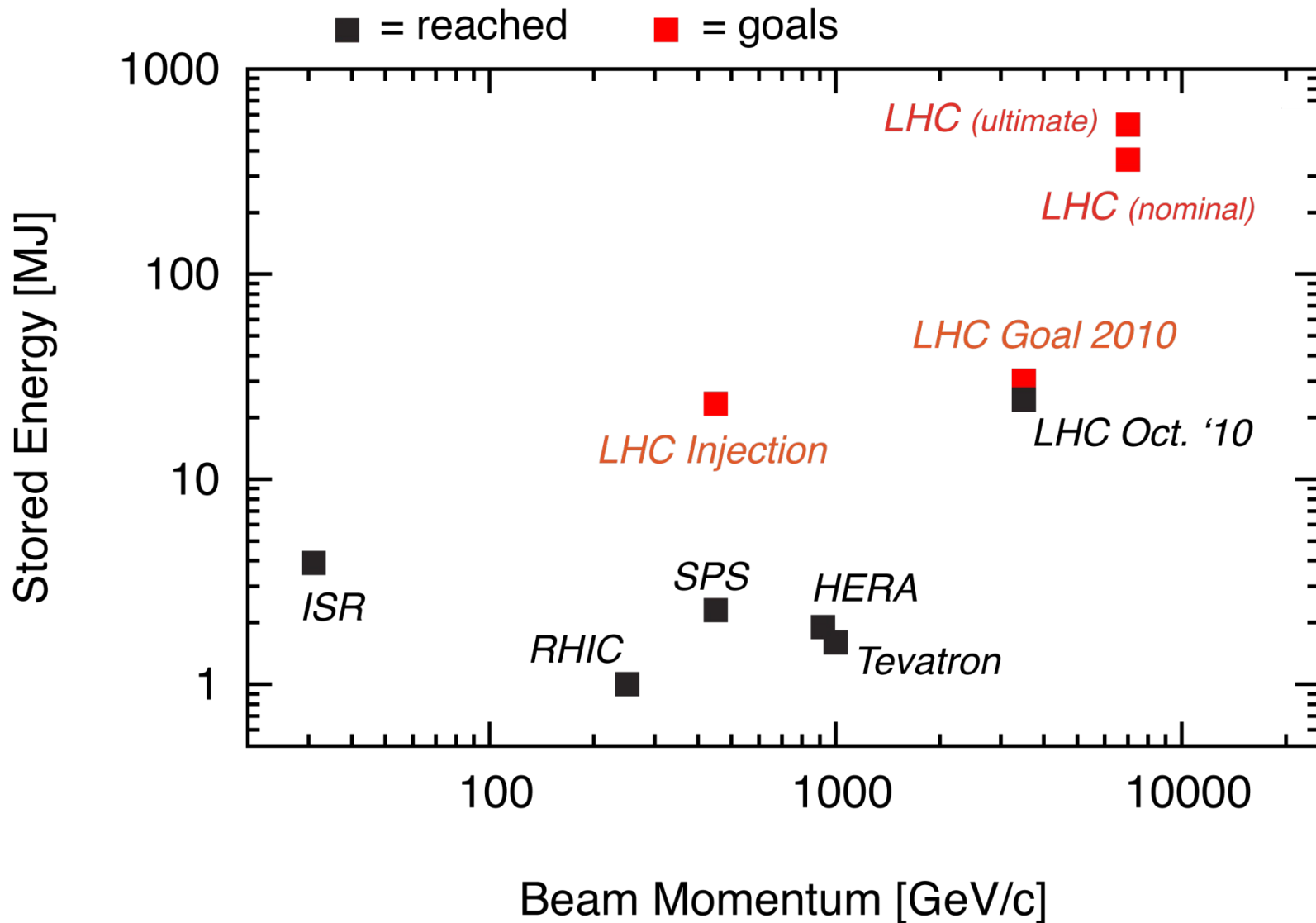


Cross sections at the LHC



New Physics!!

Stored Energy in the LHC



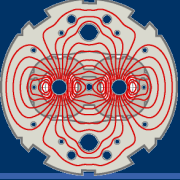
Overall LHC efficiency in 2010

65%
availability

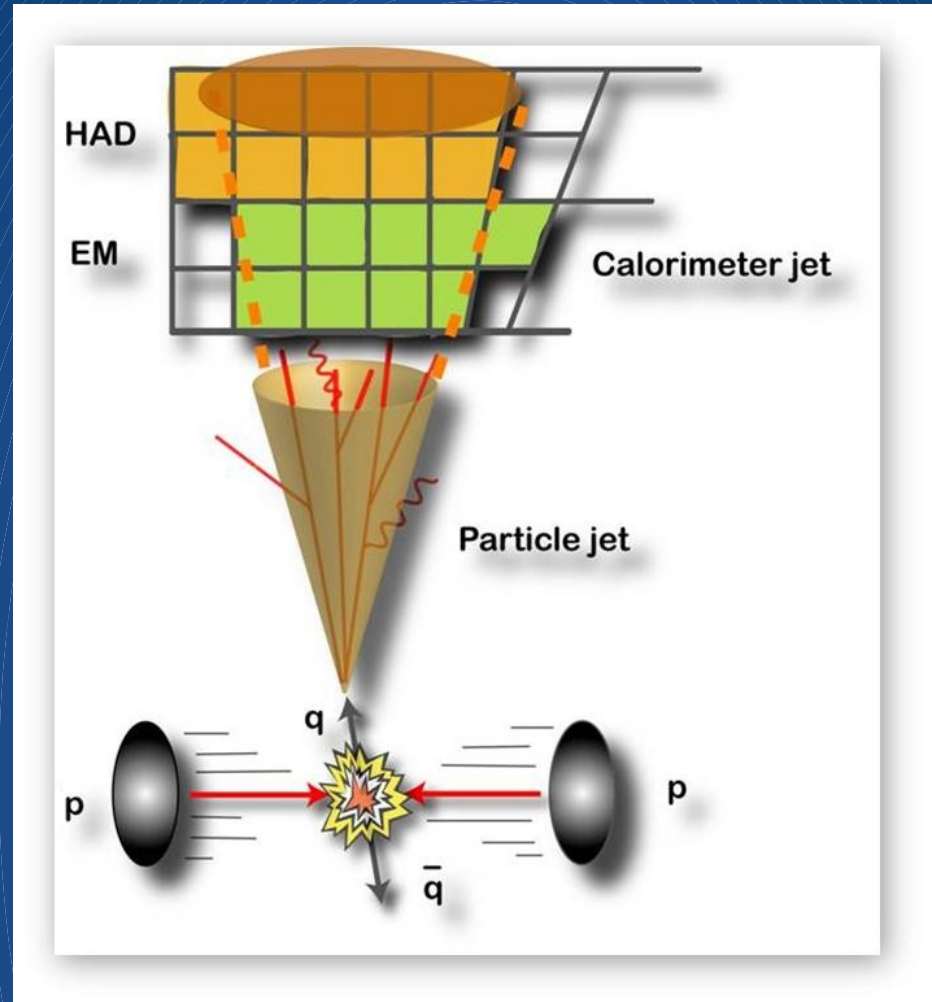
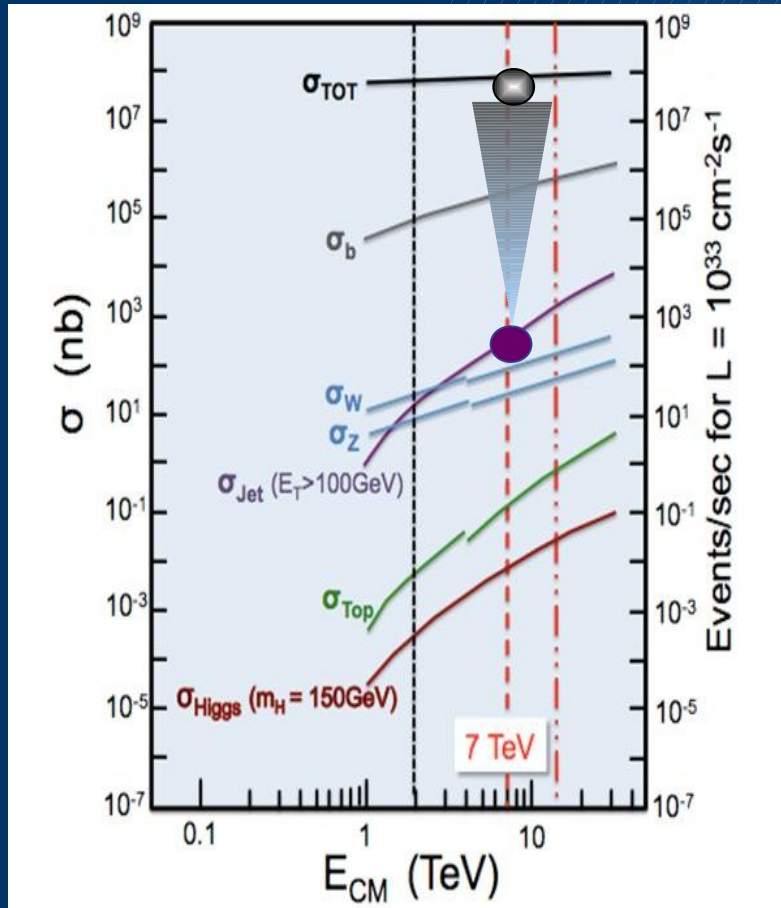
!
~50/pb
delivered



Great achievement for the
first year of operation!

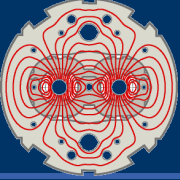


Jet production at 7 TeV



Important tests of pQCD and detector performance

Germany and CERN / January 2011



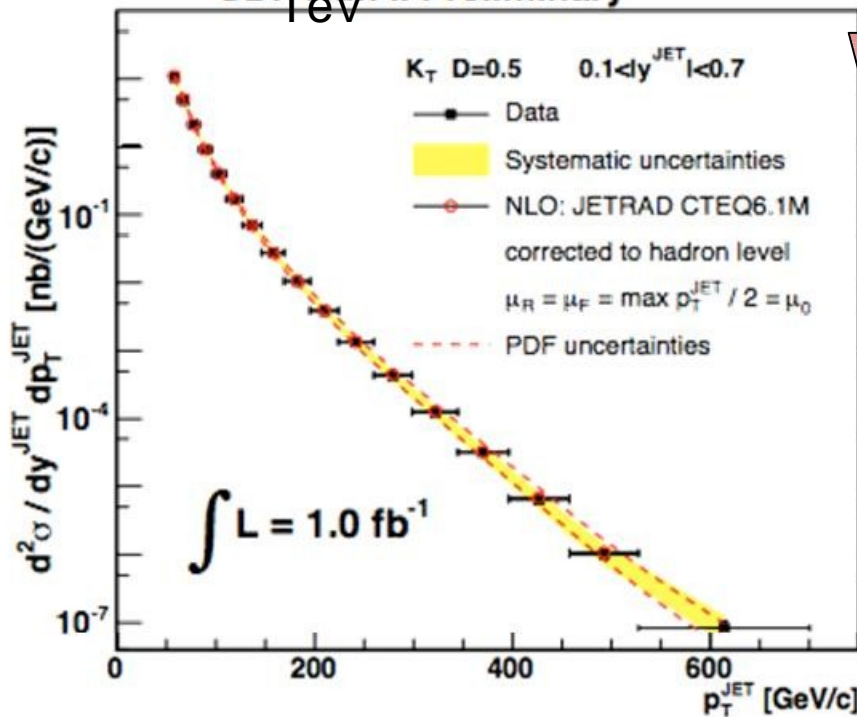
Jet production at 7 TeV



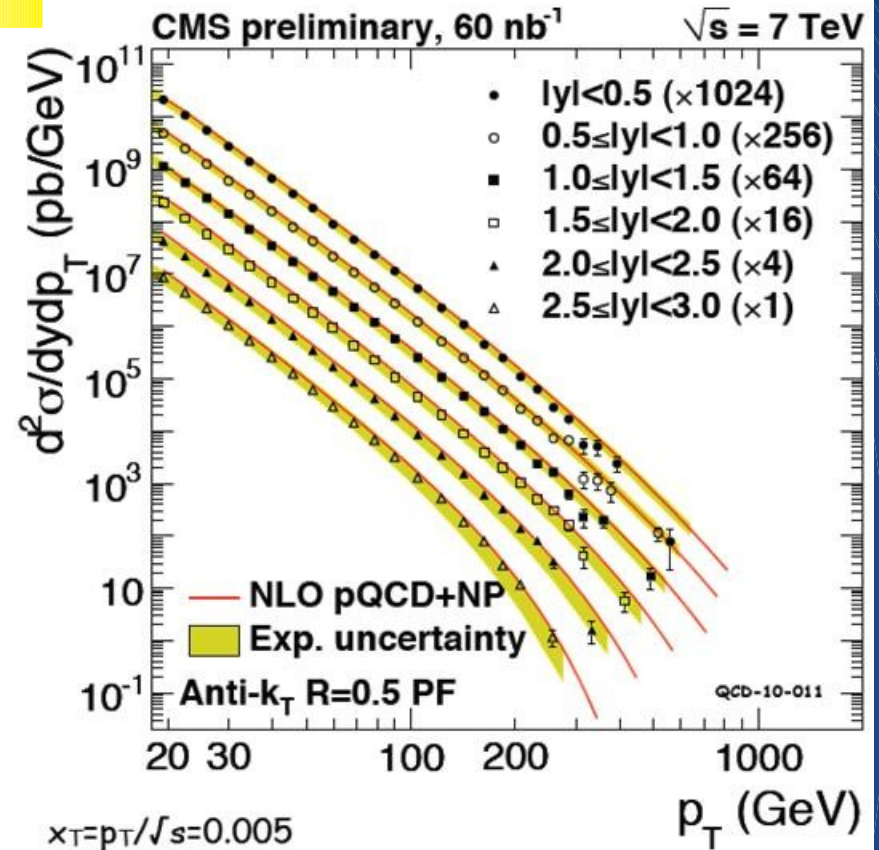
Tevatron
ECM= 2
TeV

Fact
or
>104
in
integ
r. L

CDF Run II Preliminary

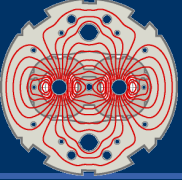


LHC
 $E_{CM} = 7 \text{ TeV}$

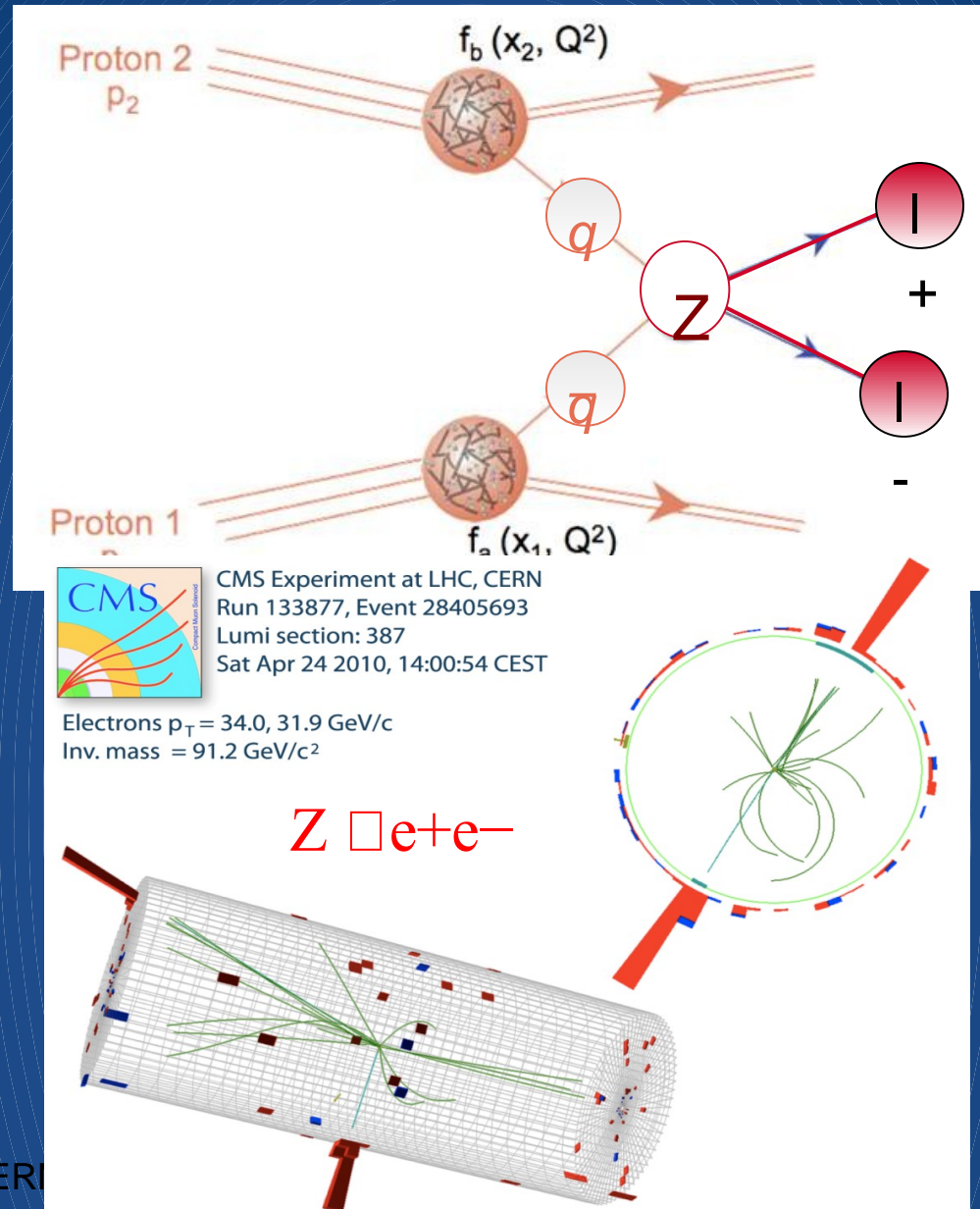
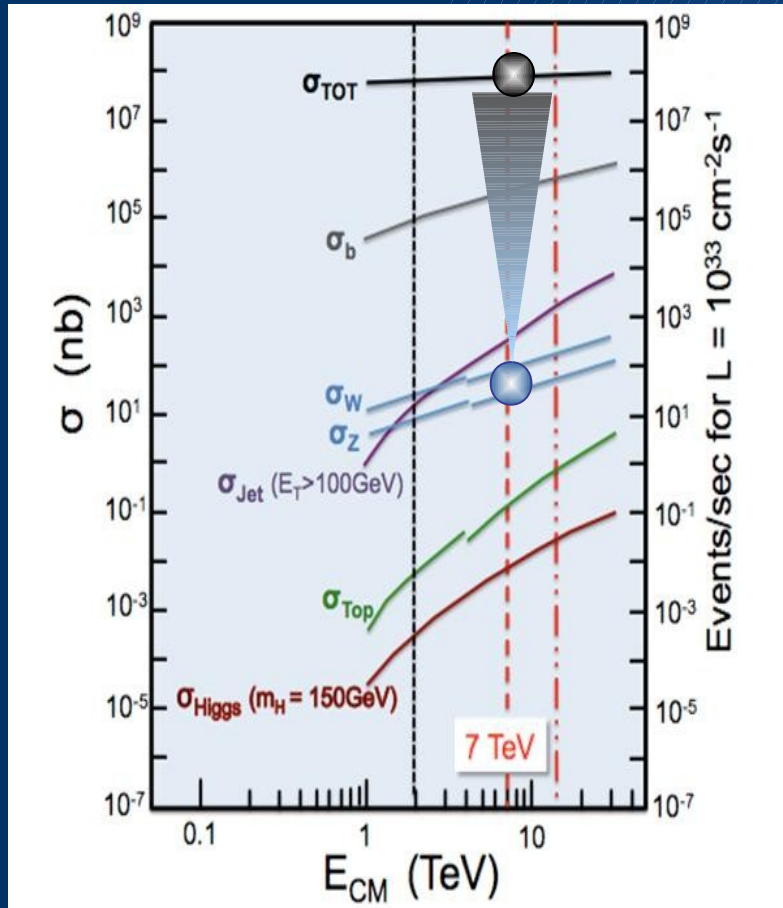


Important test of pQCD over many orders of magnitude

Germany and CERN / January 2011

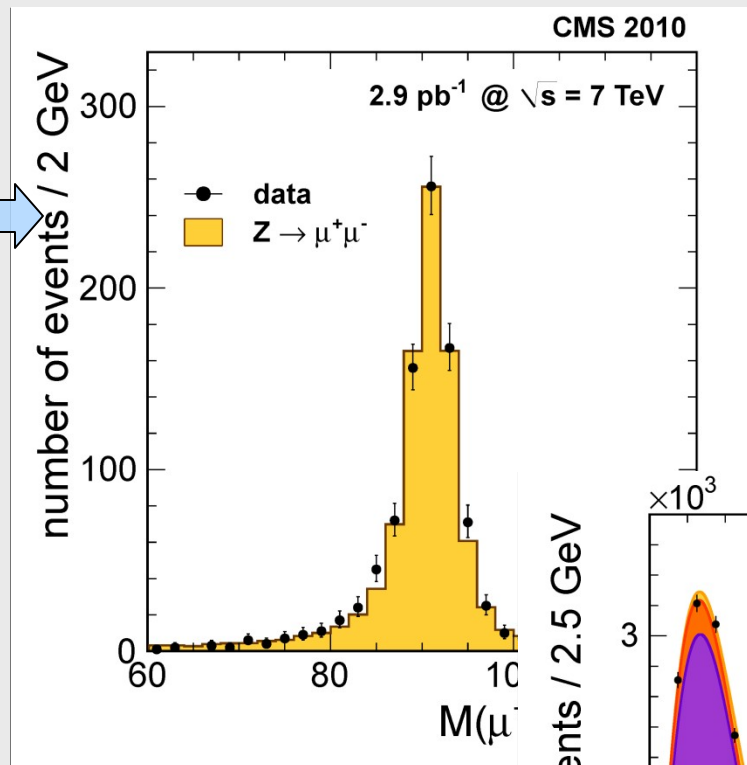
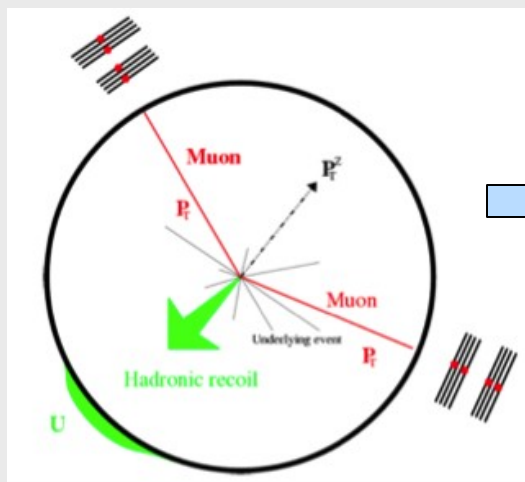


W and Z production at 7 TeV

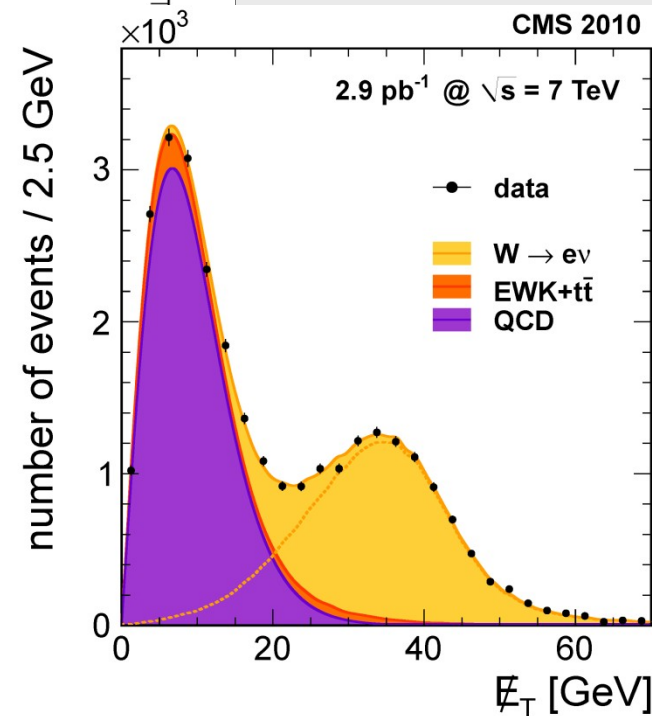
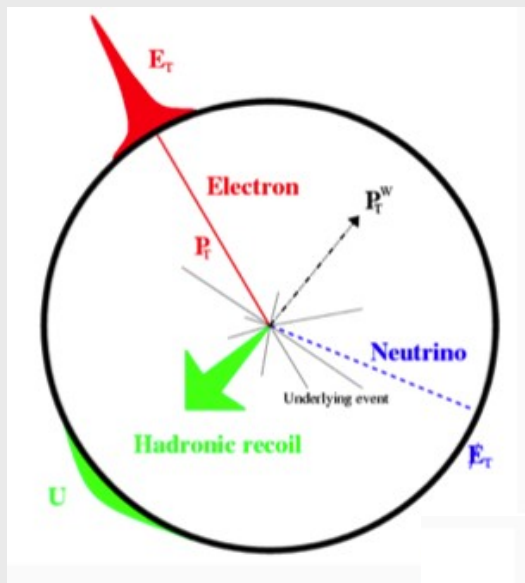


W and Z production at 7 TeV

Z



W



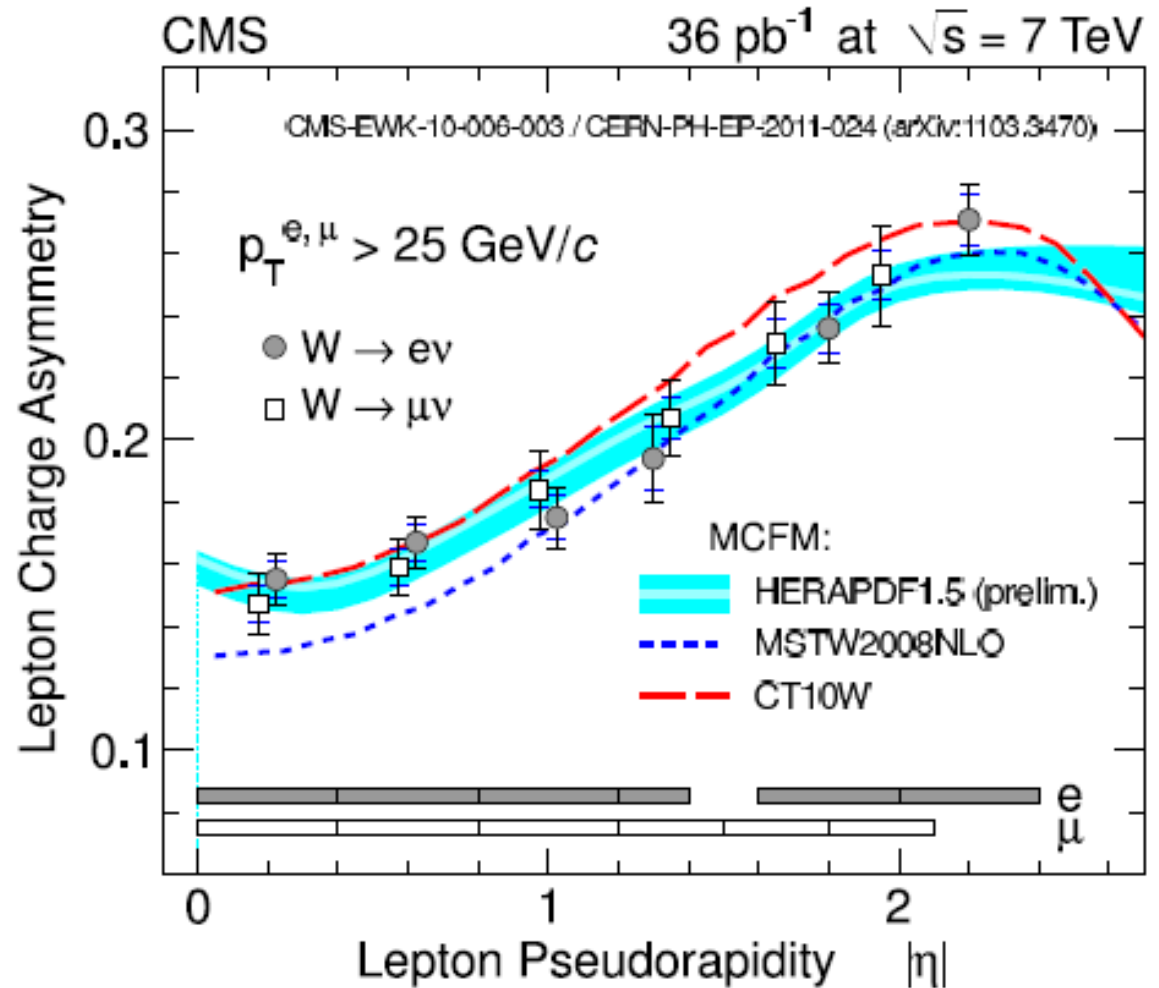
> Combination of experiments

§ e.g. proton structure

> HERA PDF important to describe LHC results

§ e.g. W asymmetry

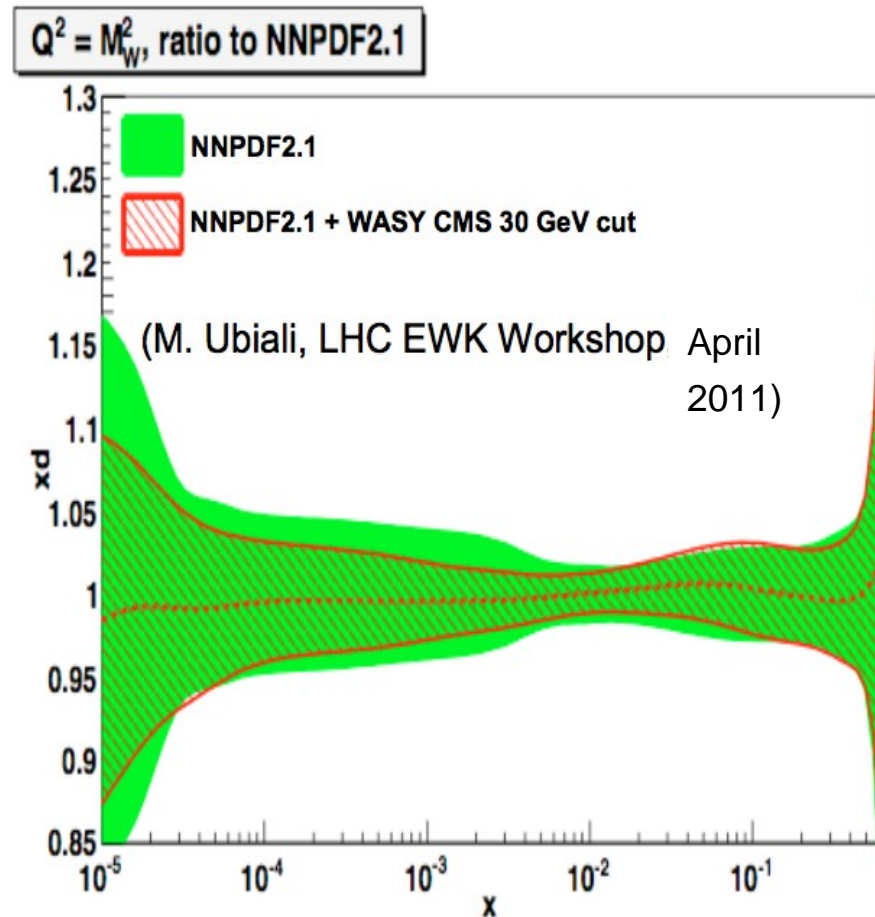
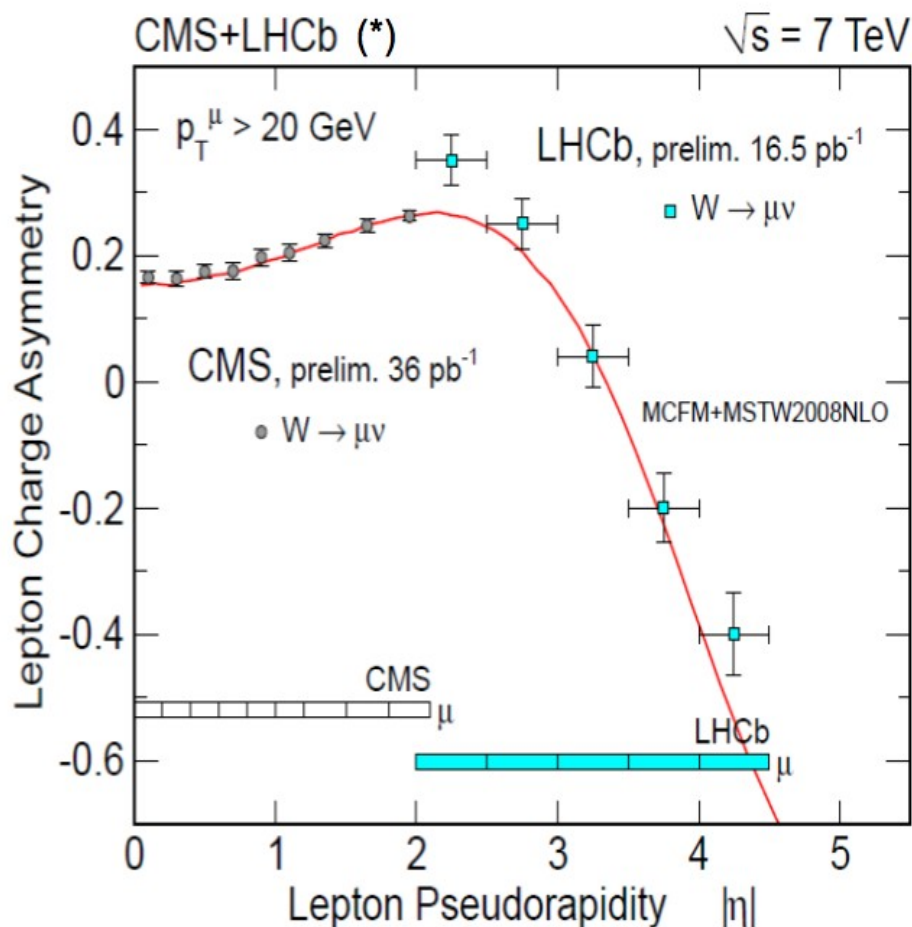
$$\mathcal{A}(\eta_\ell) = \frac{d\sigma_{W^+}/d\eta_{\ell^+} - d\sigma_{W^-}/d\eta_{\ell^-}}{d\sigma_{W^+}/d\eta_{\ell^+} + d\sigma_{W^-}/d\eta_{\ell^-}}$$

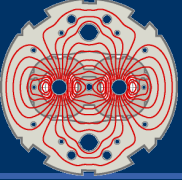




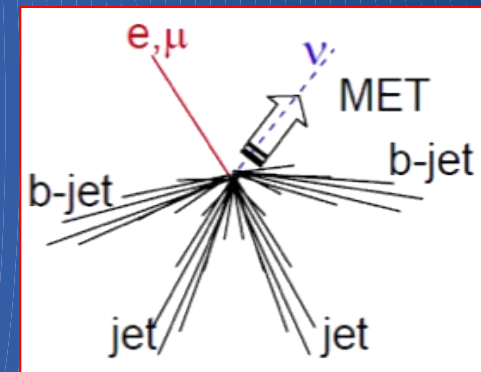
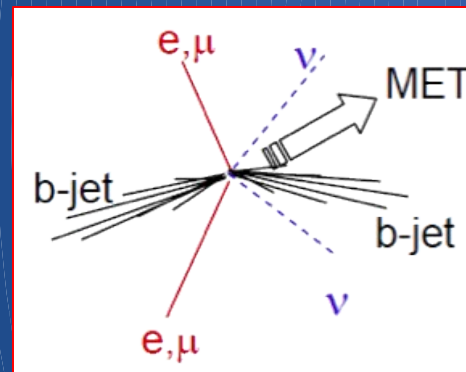
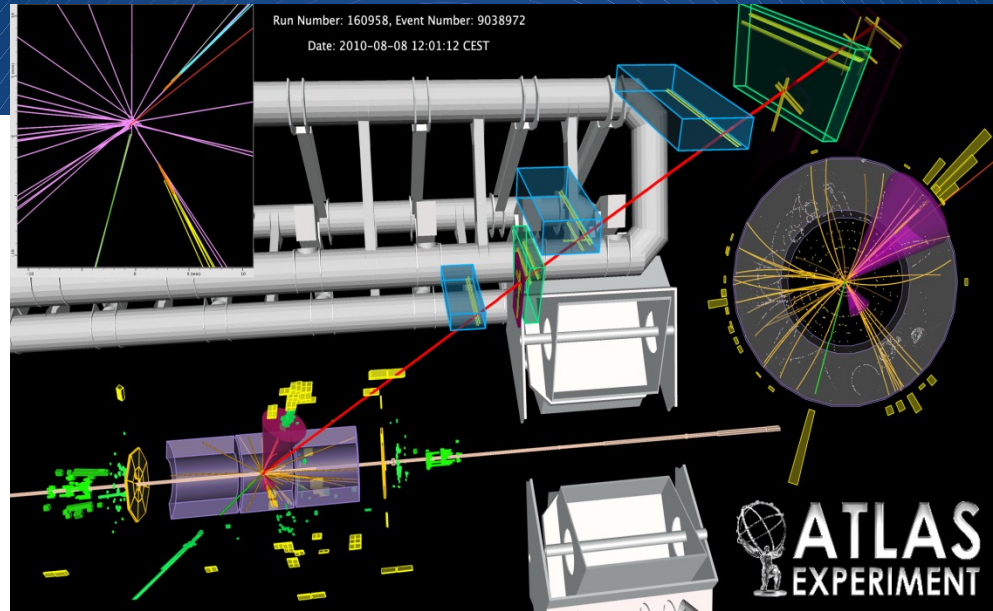
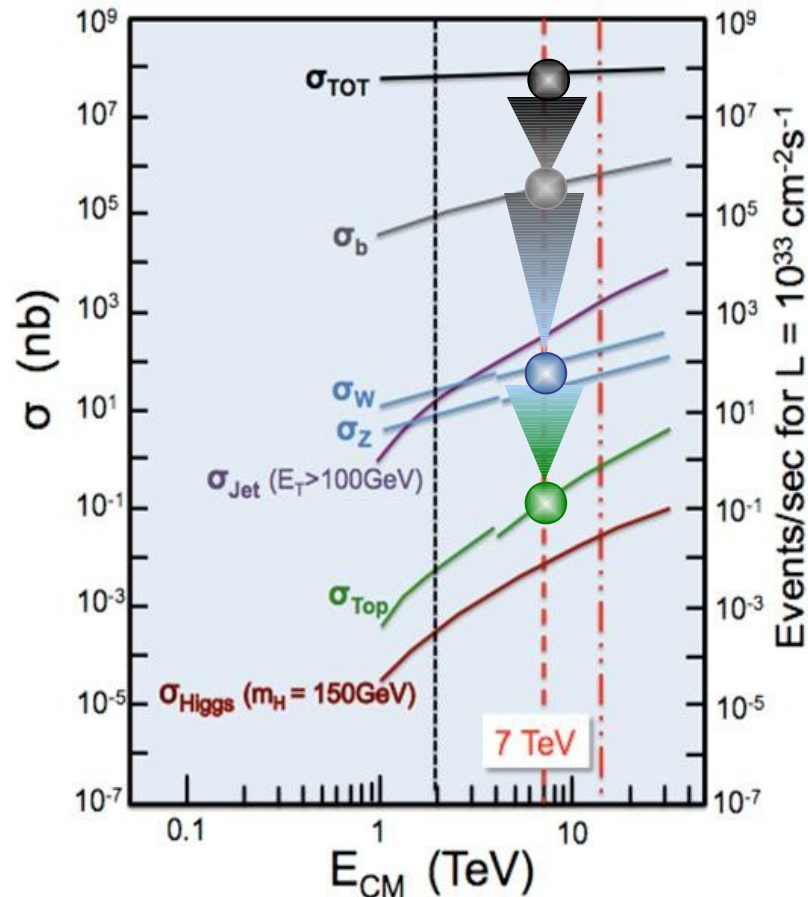
Lepton charge asymmetry in inclusive W

We are able to produce precision EWK measurements good enough to constrain significantly the PDF global fits





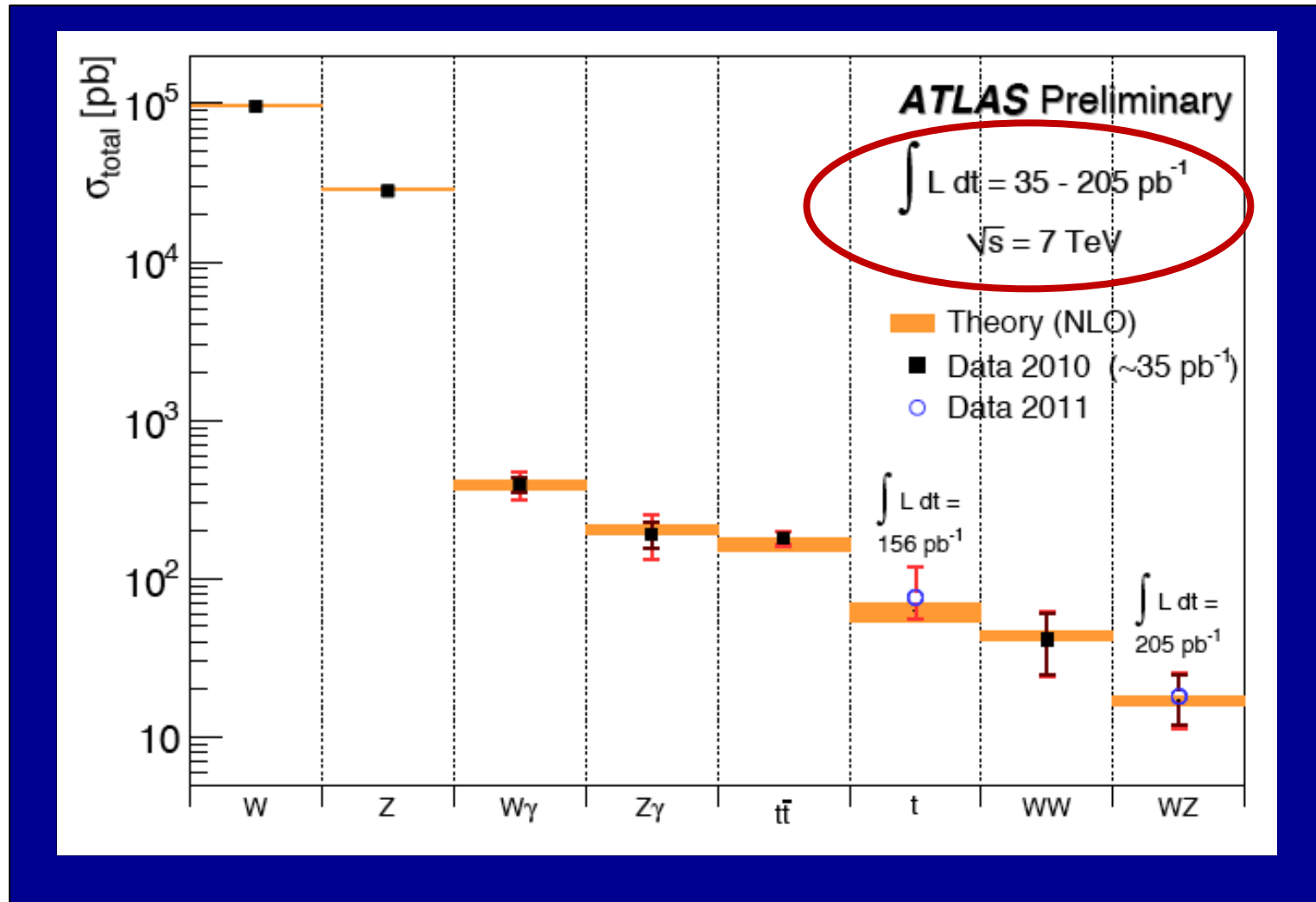
Top quark production at 7 TeV



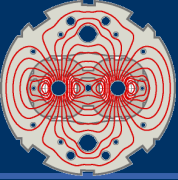
di-leptons

Lepton + jet

Summary of main electroweak and top cross-section measurements



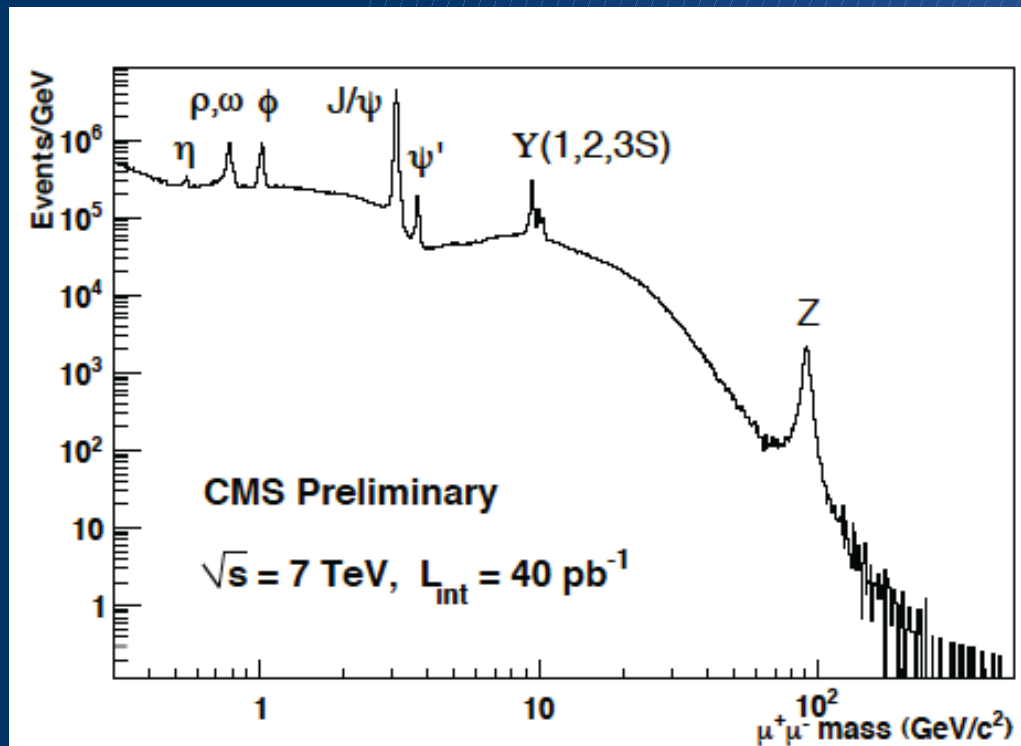
- Measuring cross-sections down to $\sim 10 \text{ pb}$
Uncertainties dominated by systematics in all cases except $Z\gamma$, WW, WZ
- Good agreement with SM expectations (within present uncertainties)
- Experimental precision starts to challenge theory for W, Z, top-pairs



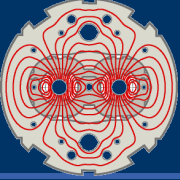
Excellent performances 2010

Excellent start-up in 2011:

already some **1.3/fb** (!) delivered



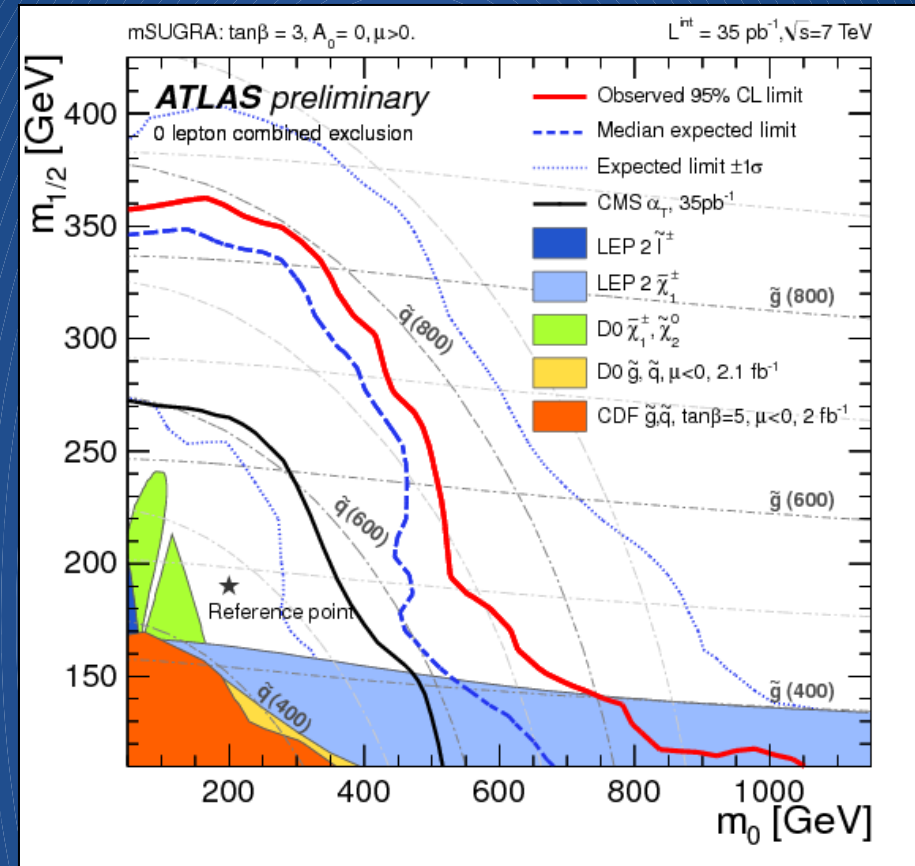
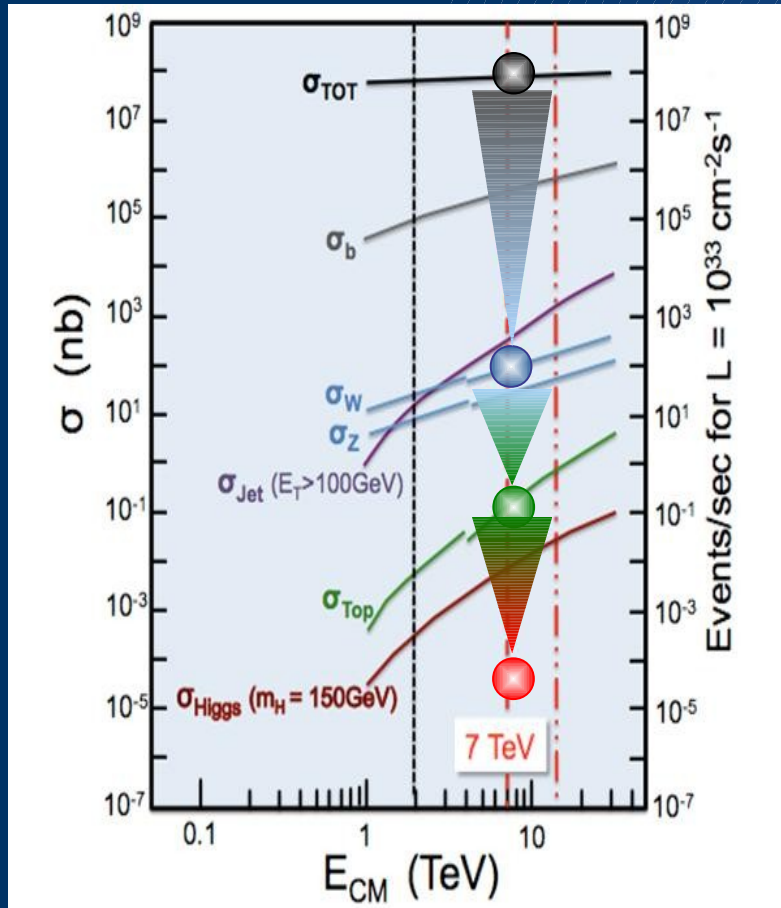
- q Experiments demonstrated readiness in the exploitation of the 7 TeV p-p and 2.76 TeV Pb-Pb data;
- q analyses proceeded very rapidly;
- q Experiments have about completed their journey through the Standard Model ... and have started to take us into uncharted territories



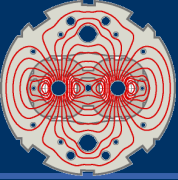
Physics beyond the Standard Model ?



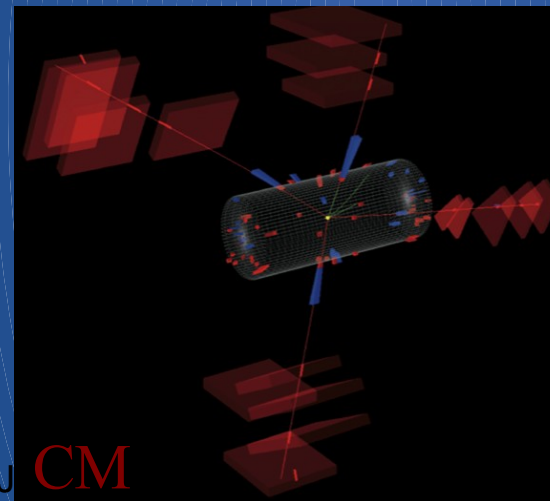
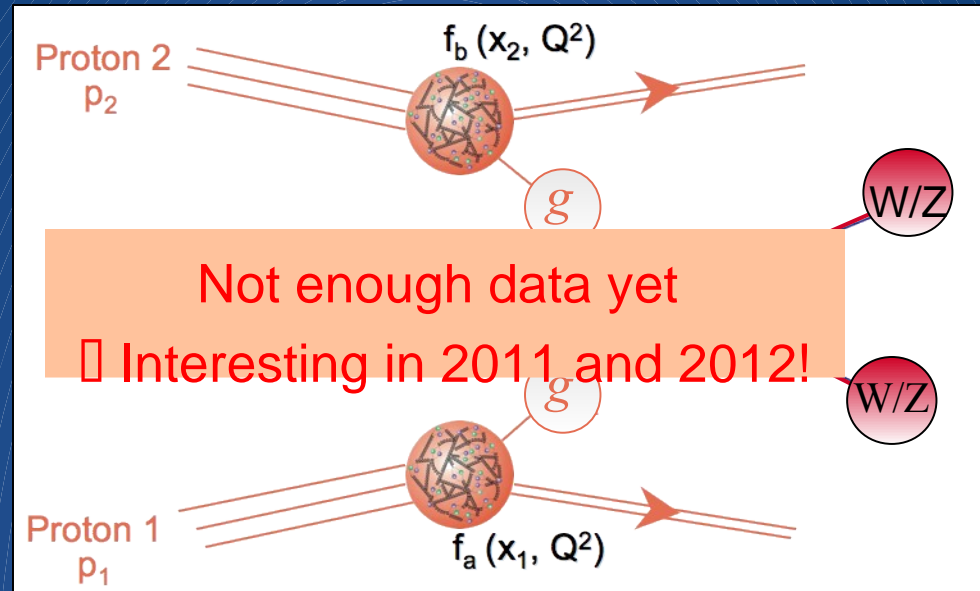
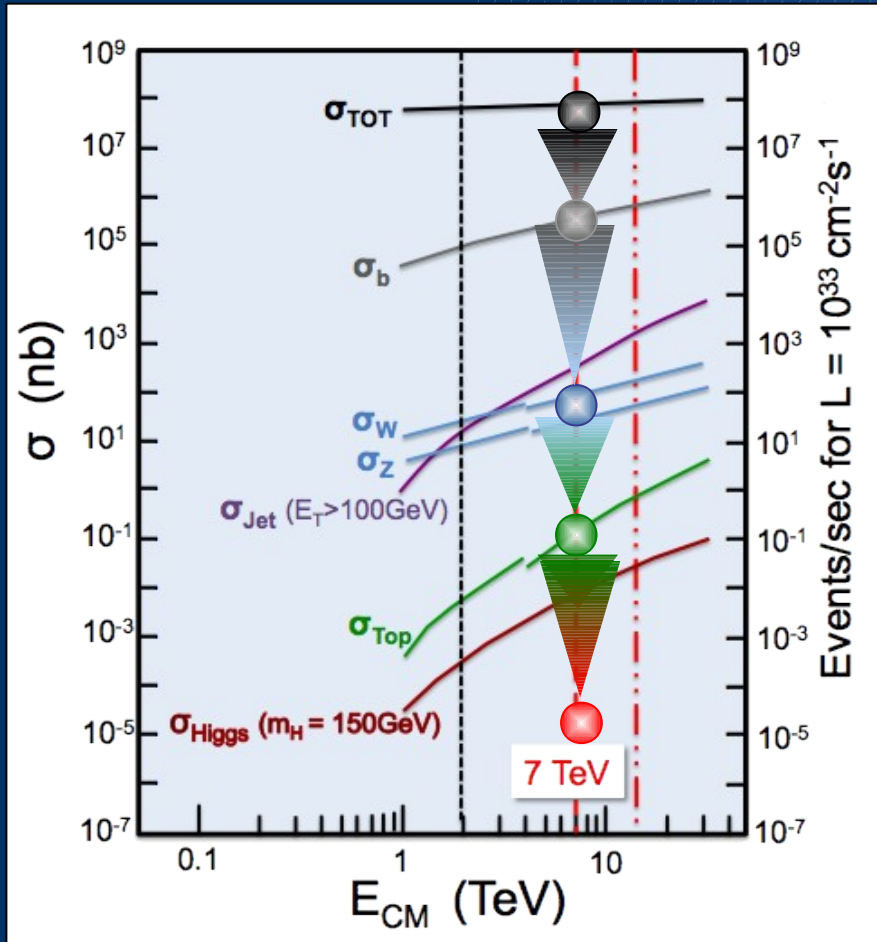
Searches for Supersymmetry



Most stringent limits to date



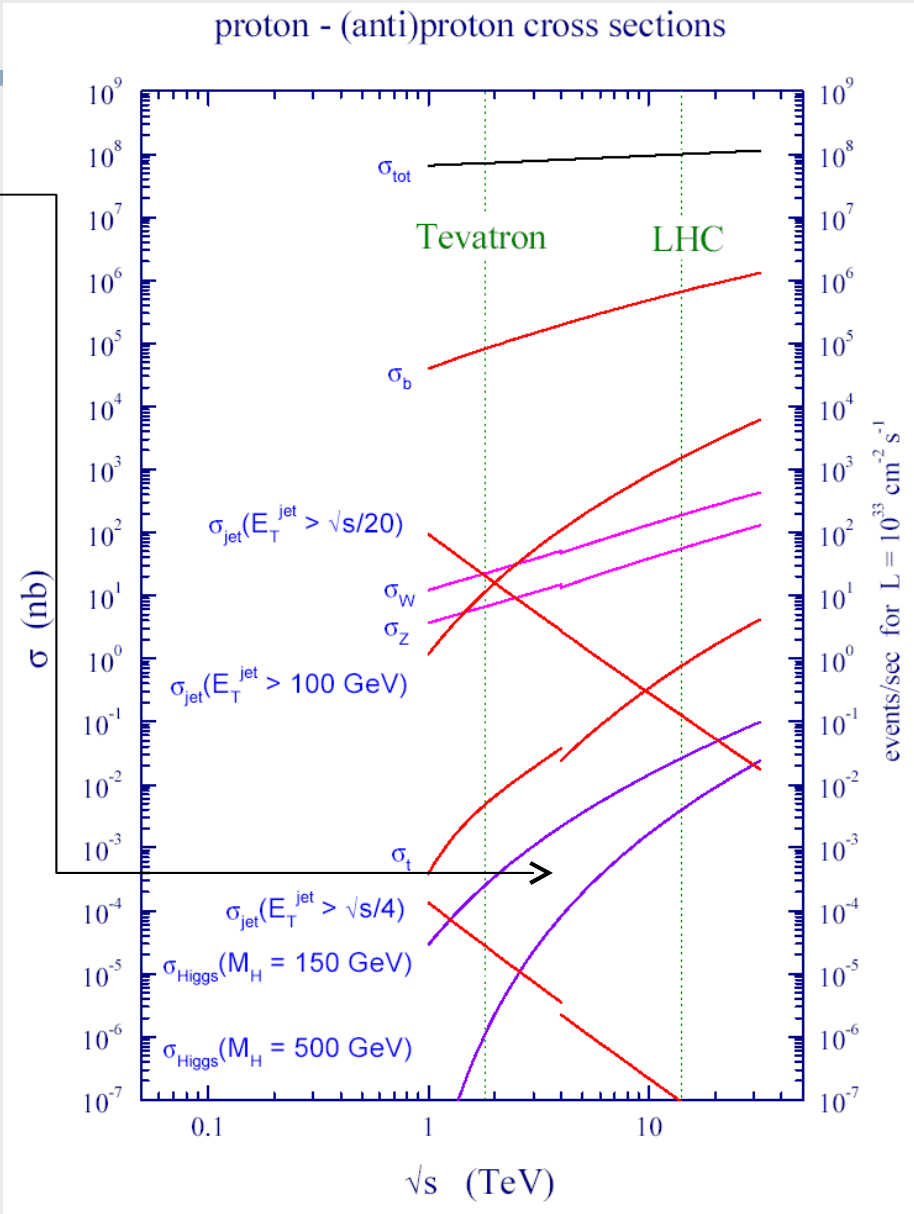
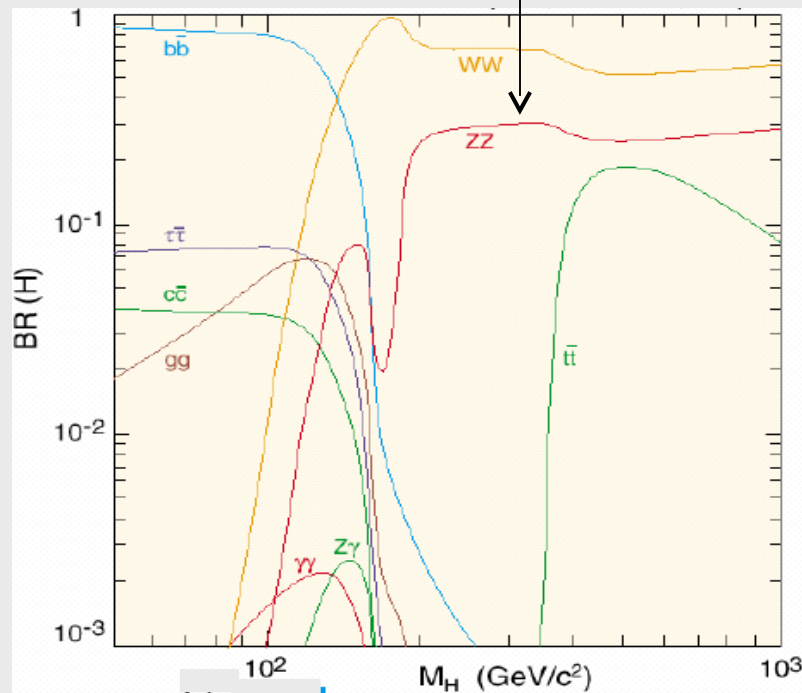
Higgs-Boson at 7 TeV



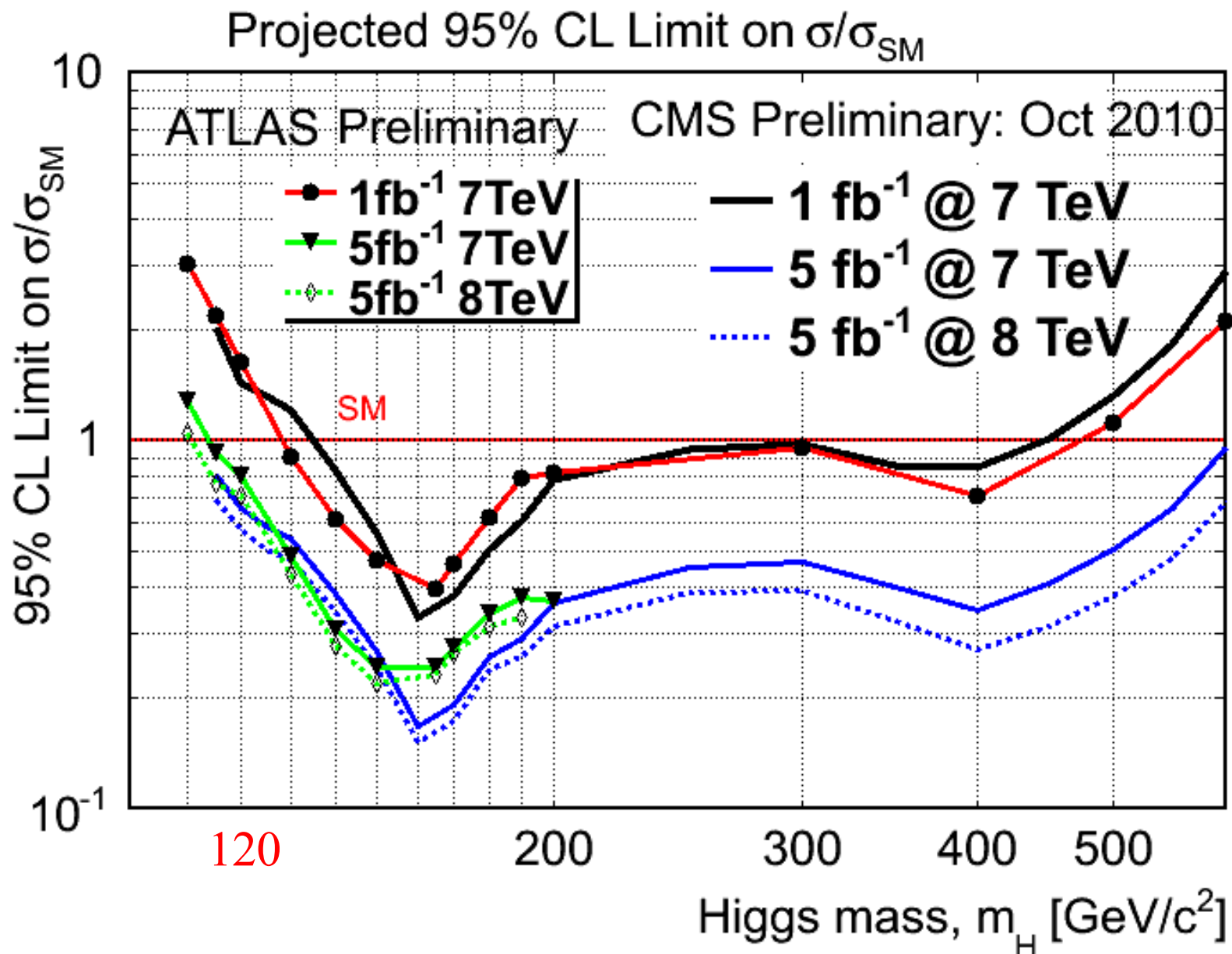
Search for the Higgs-Boson at the LHC

Production rate
of the Higgs-Bosons
depends on its mass

as well as its decay possibilities
("Signature (or picture)"
as seen in the detector)



CMS & ATLAS Projections Compared



Summary of Prospects

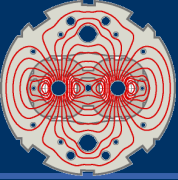
SM Higgs Search Prospects (Mass in GeV)

ATLAS + CMS $\approx 2 \times \text{CMS}$	95% CL exclusion	3 σ sensitivity	5 σ sensitivity
1 fb-1	120 - 530	135 - 475	152 - 175
2 fb-1	114 - 585	120 - 545	140 - 200
5 fb-1	114 - 600	114 - 600	128 - 482
10 fb-1	114 - 600	114 - 600	117 - 535

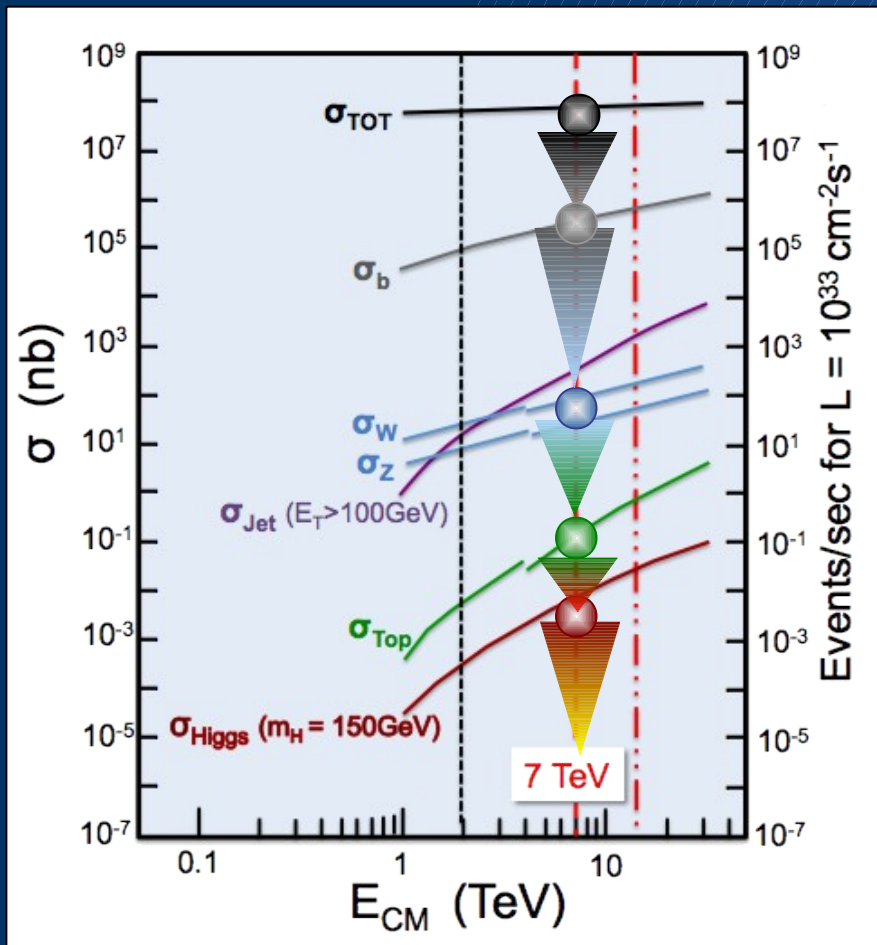


Higgs Boson, if it exists between masses of (114 - 600 GeV) will either be discovered or ruled out in \approx next two years

▣ Decided to run in 2011 and 2012



The 2011 and 2012 run ...



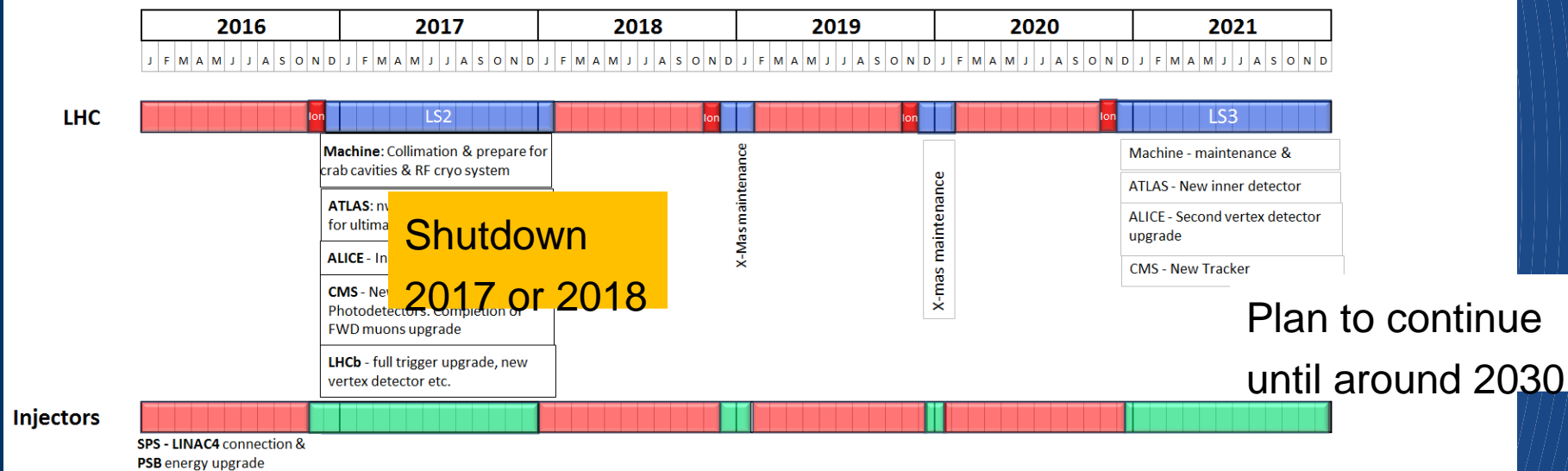
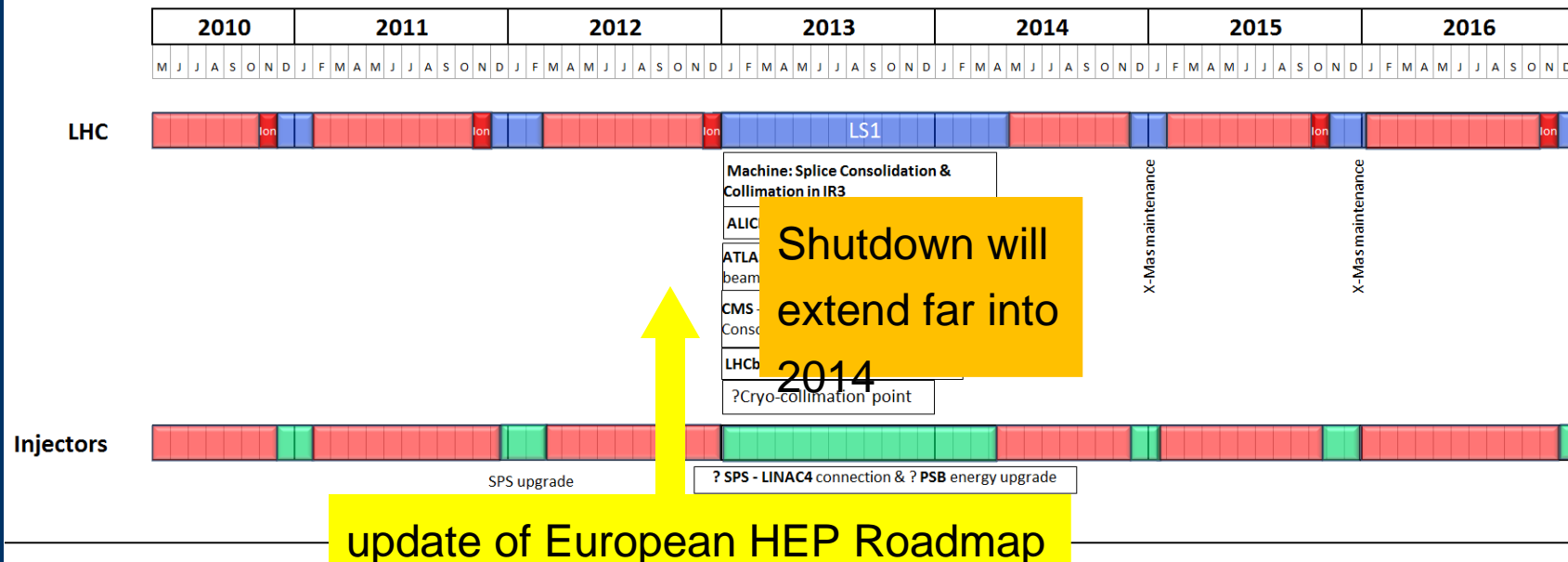
Search for physics beyond SM

- q Discovering new particles
- q Making precise measurements of properties of known particles/forces: e.g. LHCb: $B_s \rightarrow \mu^+\mu^-$

□ will enter new territory !



New *Rough Draft* 10 year plan



An aerial photograph of a landscape, likely a valley or coastal plain, showing a patchwork of agricultural fields in various shades of brown and green. A large, thin white circle is drawn over the central part of the image, encompassing a significant portion of the landscape. The text "beyond LHC ?" is written in a bold, yellow, sans-serif font across the middle of the image, partially overlapping the white circle. The background shows a mix of rural and urban areas, with some buildings and roads visible. The overall tone is somewhat somber due to the muted colors of the landscape.

beyond LHC ?

Next decades

Road beyond Standard Model

through synergy of

hadron - hadron colliders (LHC, HL/HE-LHC?)

lepton - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (ILC or CLIC) ?)

Linear e+e-Colliders

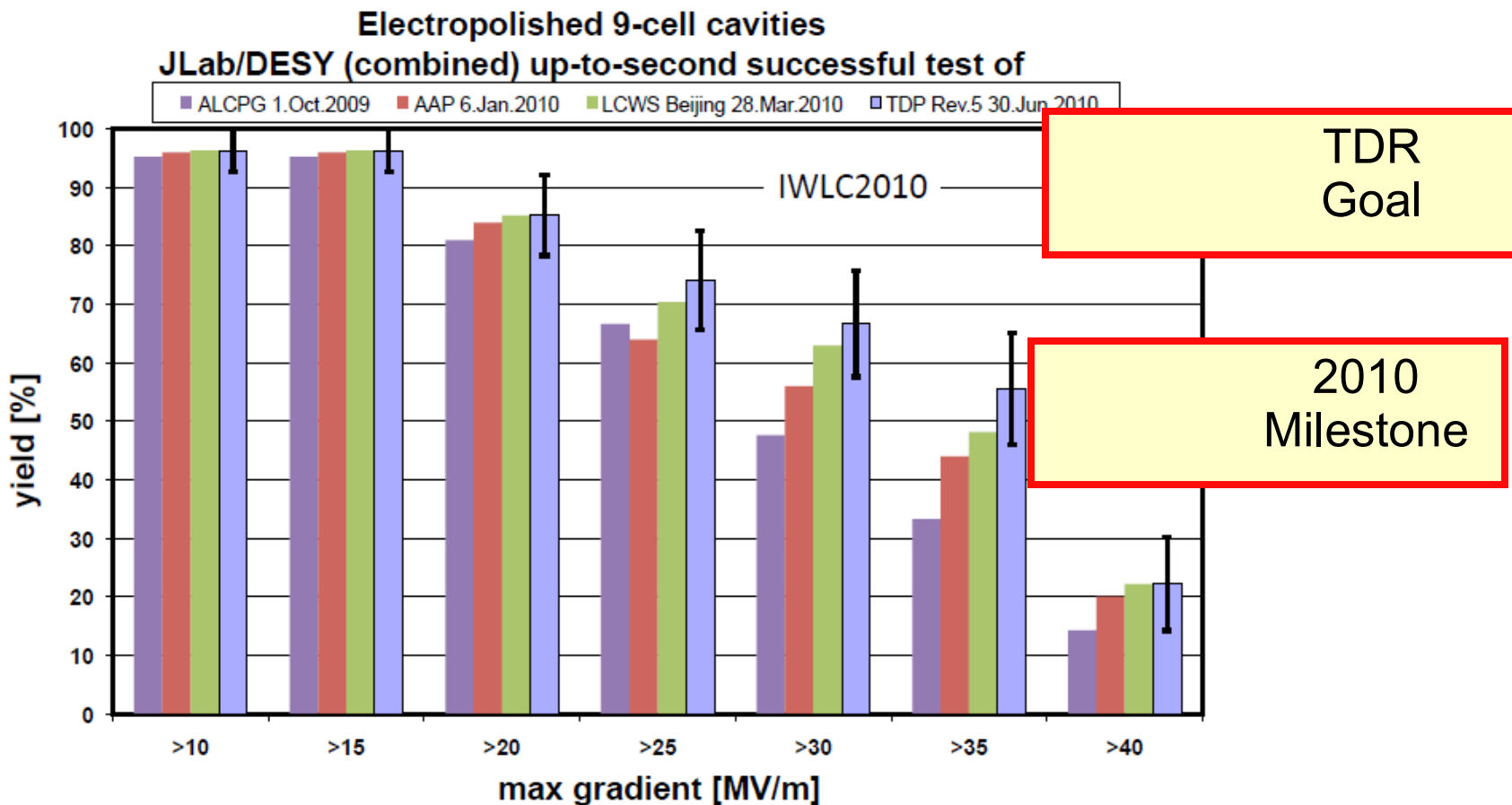
- n The machine which will complement and extend the LHC best, and is closest to be realized, is a Linear e+e- Collider with a collision energy of at least 500 GeV.

PROJECTS:

- TeV Colliders (CMS energy up to 1 TeV) □ Technology ~ready
ILC with superconducting cavities
- Multi-TeV Collider (CMS energies in multi-TeV range) □ R&D
CLIC □ Two Beam Acceleration



Cavity Gradient Milestone Achieved



22-Jan-11

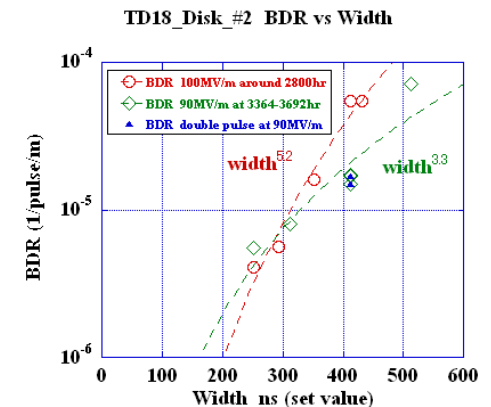
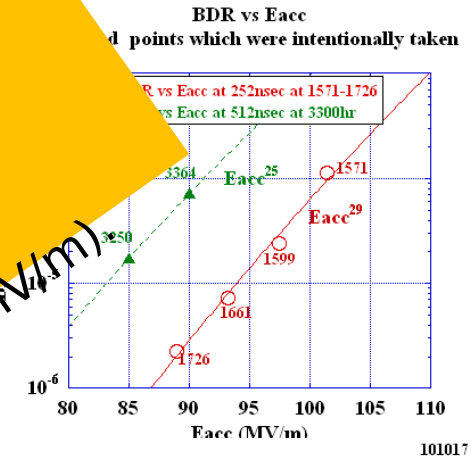
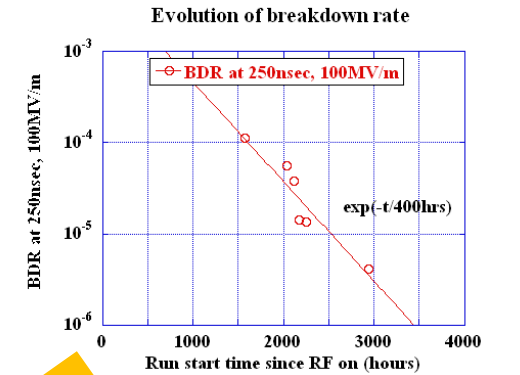
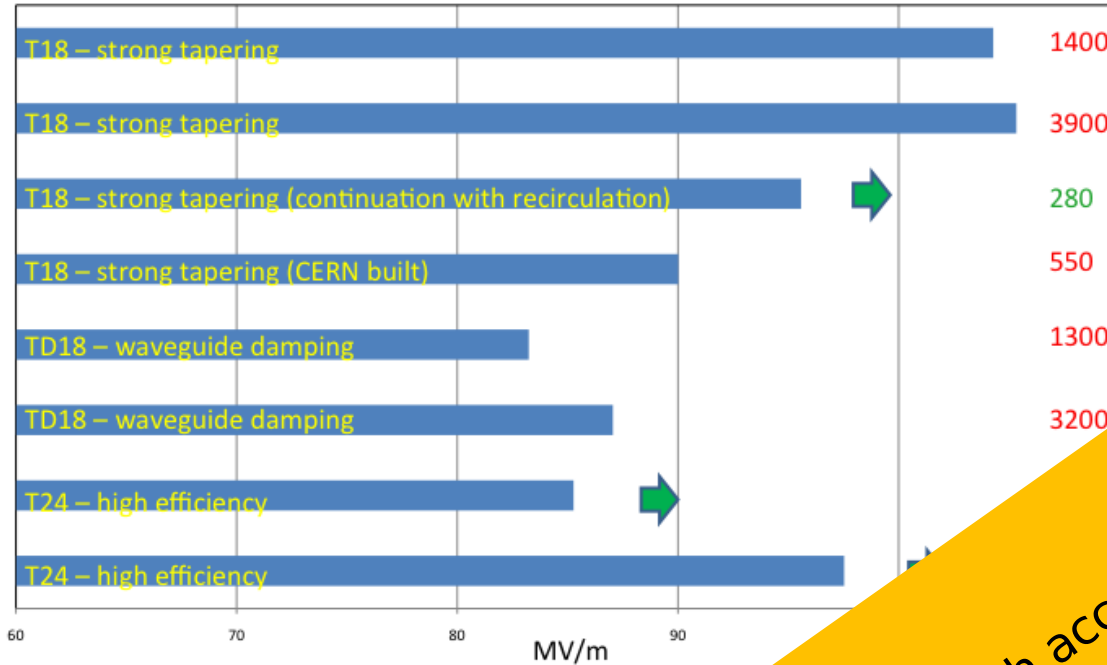
Global Design Effort

4242

ILC - SLAC



Gradient at CLIC $4 \cdot 10^{-7}$ BDR and 180 ns pulse length



T18 and TD18 built and tested at SLAC and KEK

- real prototypes with improved design are T24 and TD24
- measurements in plot on the right for TD18 at KEK



Today:
CTF3 running with accelerating structures reaching design value (100 MV/m)

Next decades

Road beyond Standard Model

through synergy of

hadron - hadron colliders (HL/LHC)

lepton - lepton colliders (LHeC ??)

LHC results will guide the way at the energy frontier

electron - lepton colliders (LC (ILC or CLIC) ?)

Past decades saw precision studies of 5 %
of
our Universe □ Discovery of the Standard
Model

The LHC is delivering data

We are just at the beginning of exploring
95 % of the Universe

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exciting prospects