Spear-fishing at the LHC:

Using Electroweak Bosons to understand the Proton Structure at High Energy

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University of Virginia HEP Seminar

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Outline

- The Large Hadron Collider and the Experiments
- Collision Environment of the LHC
  - Parton distributions in the infinite momentum frame
- Collider measurements
  - W charge asymmetry
  - Relevance of the forward direction
  - Z boson rapidity and transverse momentum
- Prospects for 2010 and 2011

Design Parameters

COM Energy : 14 TeV

Peak Luminosity : 10^{34} $cm^{-2}s^{-1}$

Bunch spacing : 25 ns

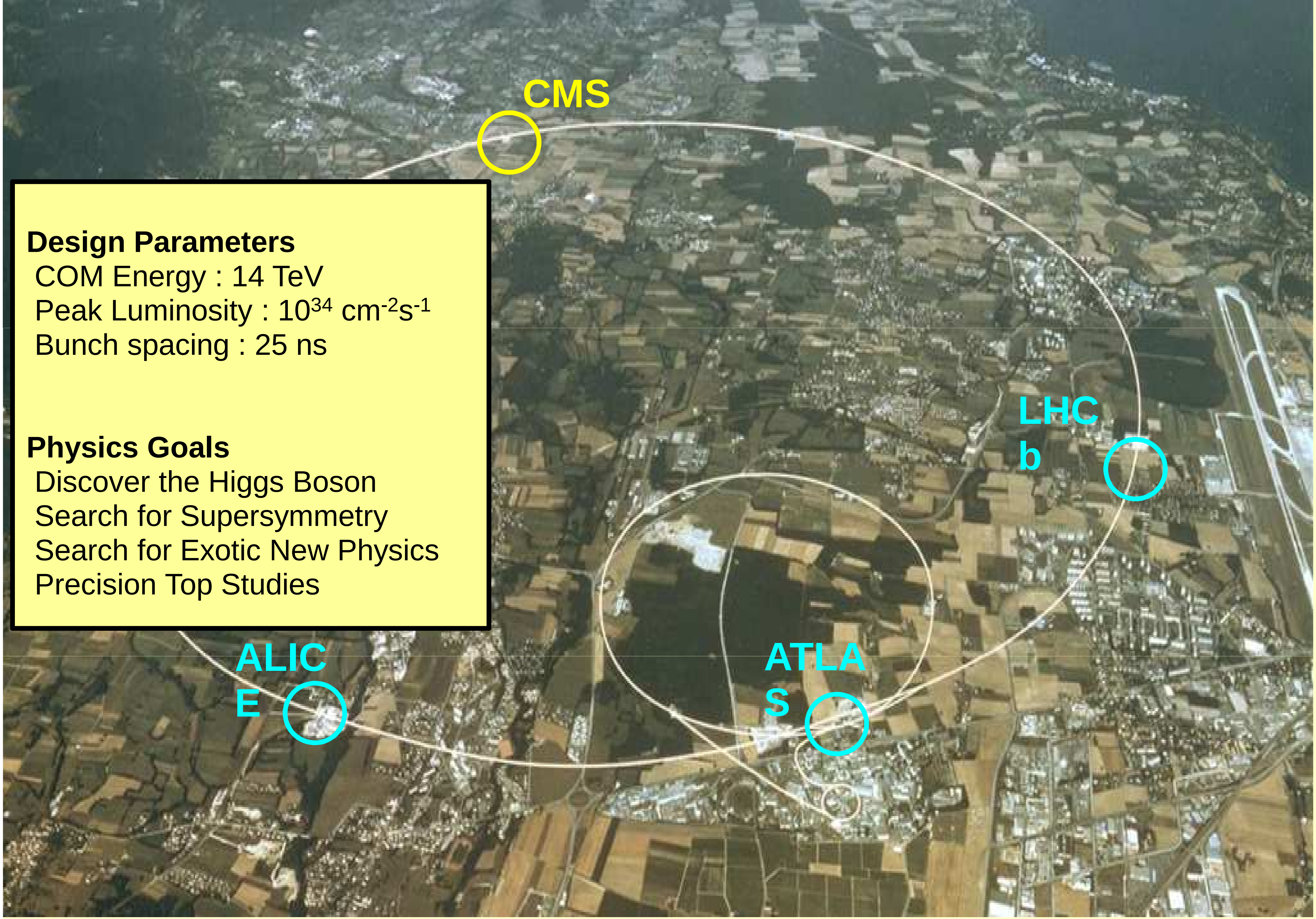
Physics Goals

Discover the Higgs Boson

Search for Supersymmetry

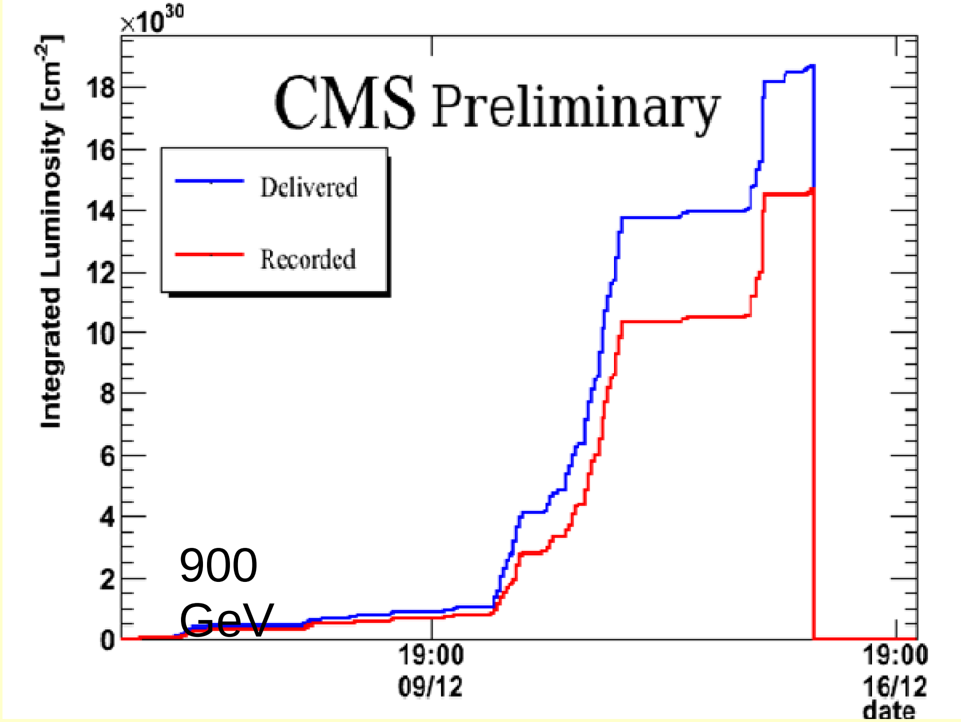
Search for Exotic New Physics

Precision Top Studies



LHC Operation To Date

- 2009
  - ~30 Fills of collisions at 900 GeV
  - 2 Fills of collisions at 2.36 TeV
- 2010
  - Approximately 200 mb^{-1} collected so far in the two weeks since first collisions



CMS Detector

CALORIMETERS

SUPERCONDUCTING COIL

ECAL
Scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE

TRACKER

Silicon Microstrips
Pixels

Total weight : 12,500 t Overall diameter : 15 m Overall length : 21.6 m Magnetic field : 3.8 Tesla

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)

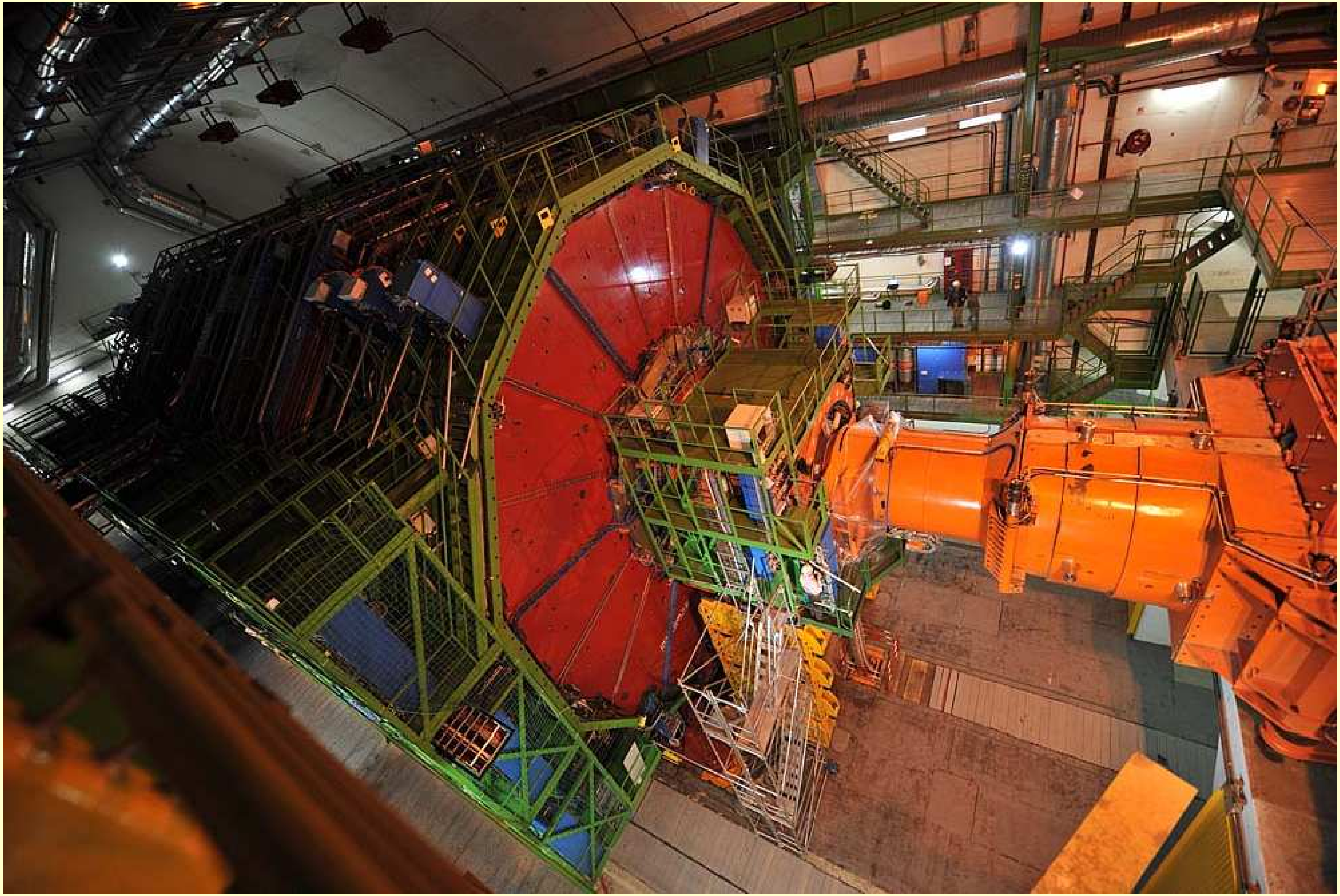
Resistive Plate Chambers (**RPC**)

MUON BARREL

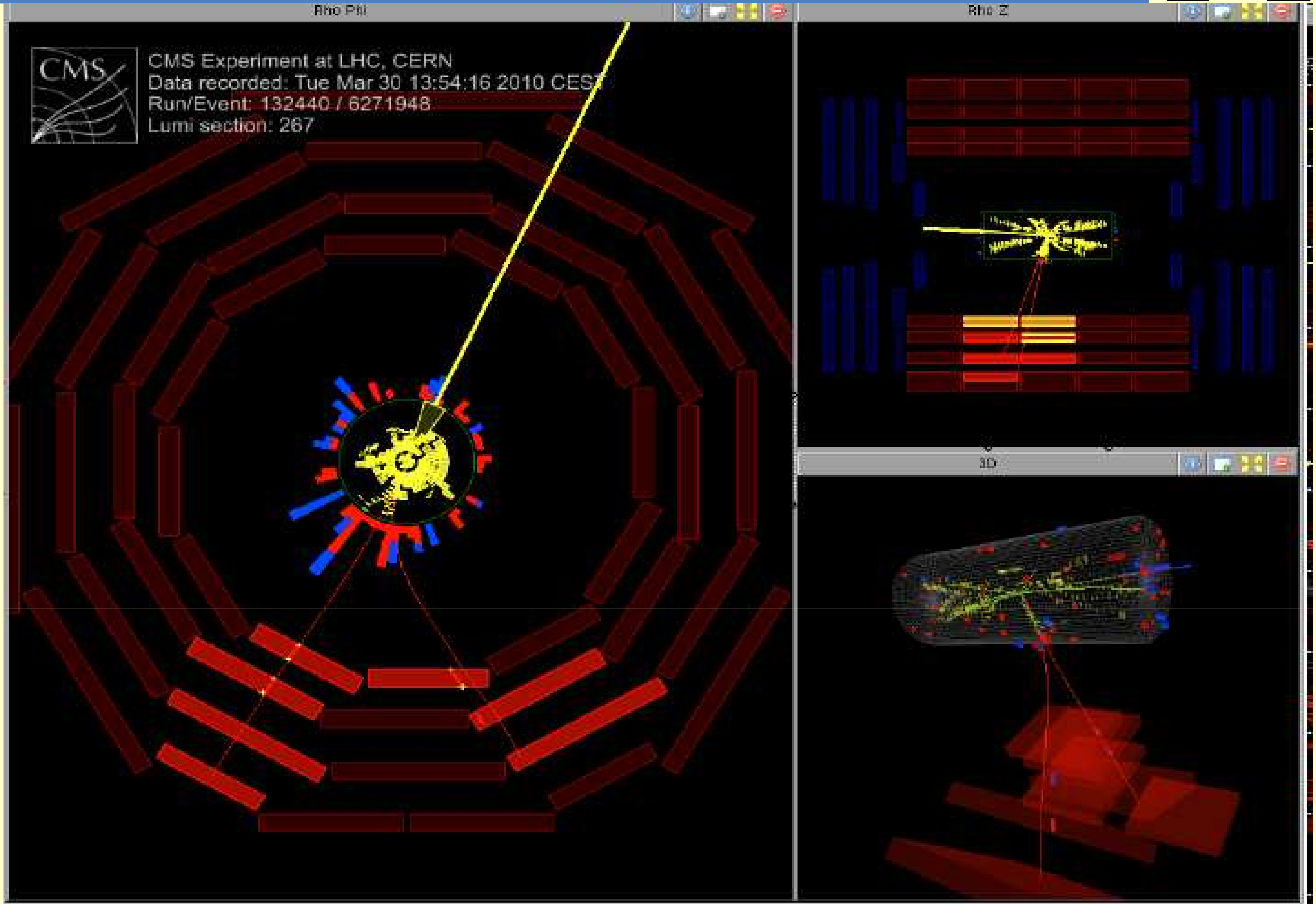
Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

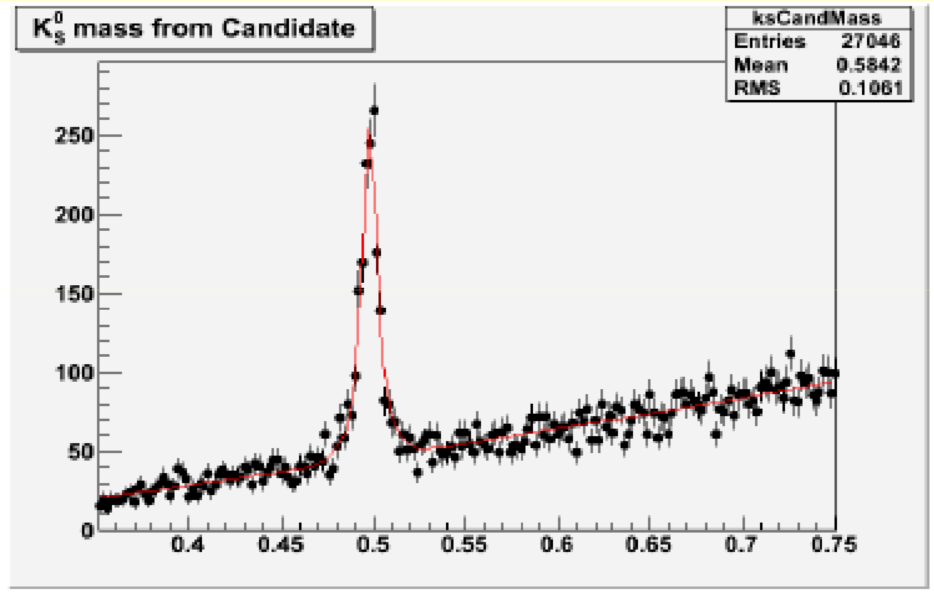
CMS Detector: Collision Configuration

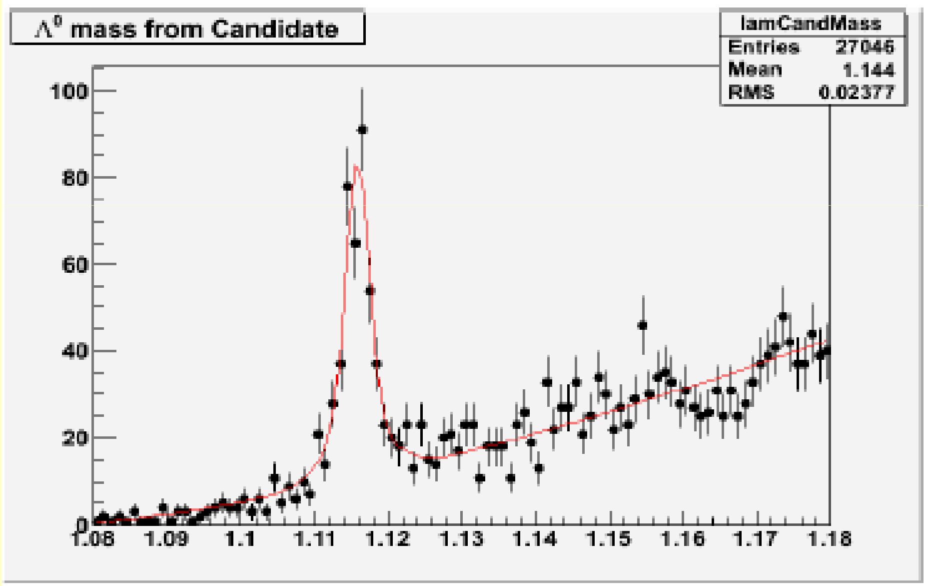


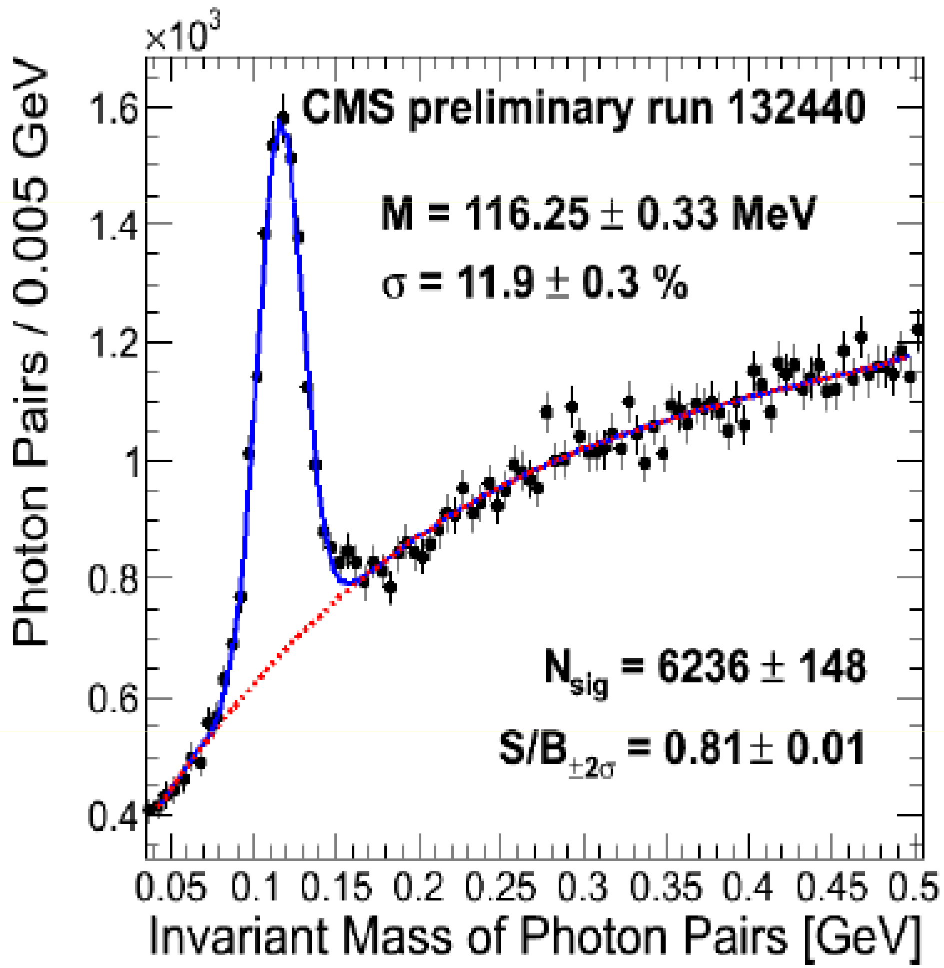
Sample 7 TeV Event



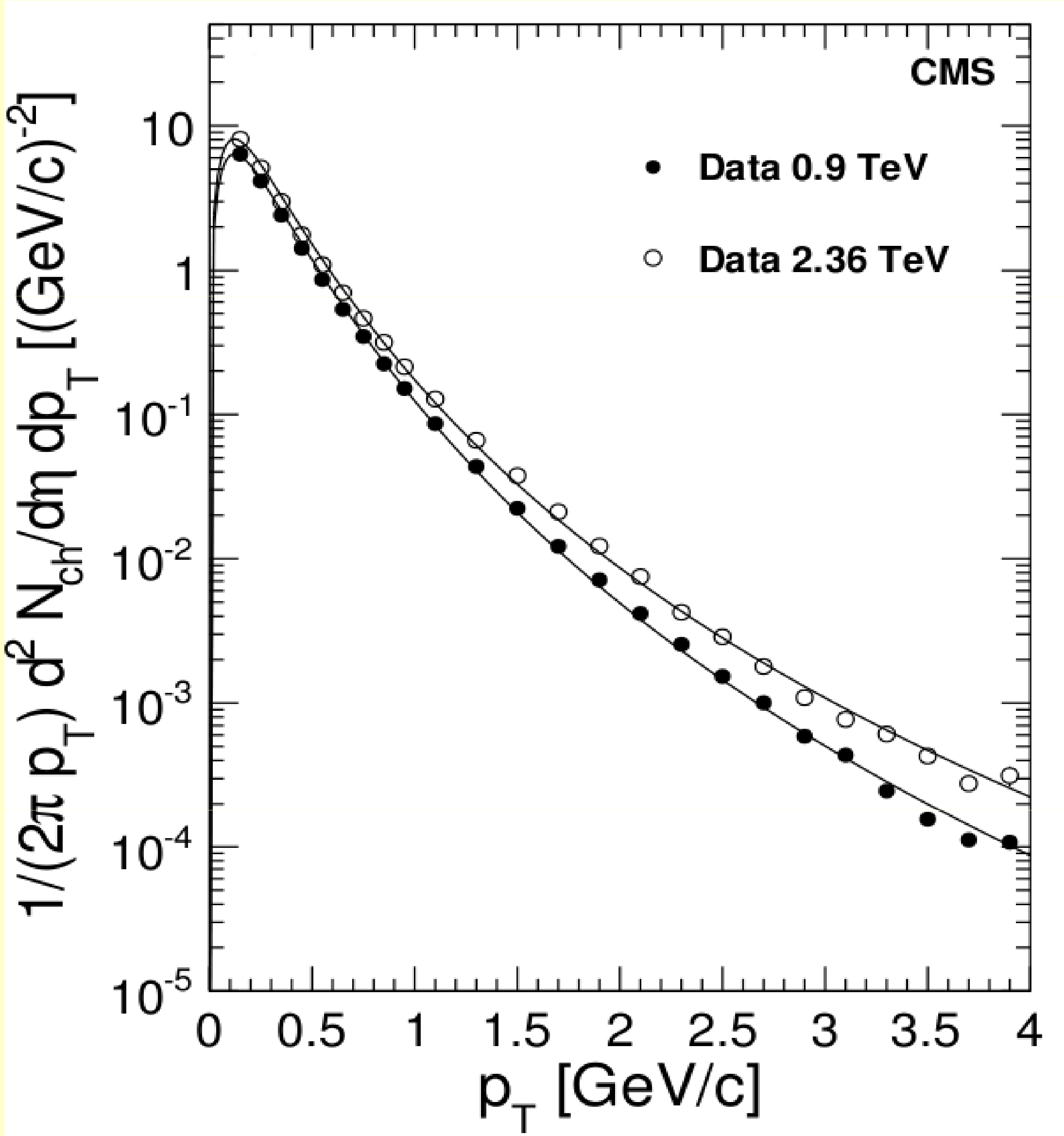
Resonances Observed at 7 TeV... so far!

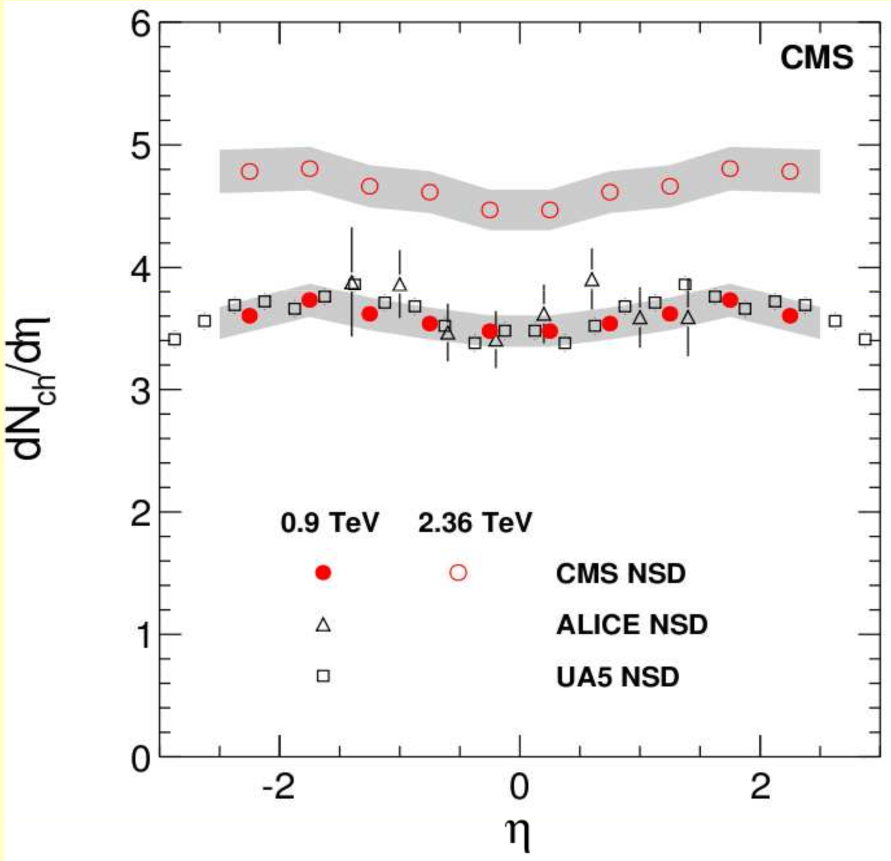






CMS Physics Yield to Date





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The future background

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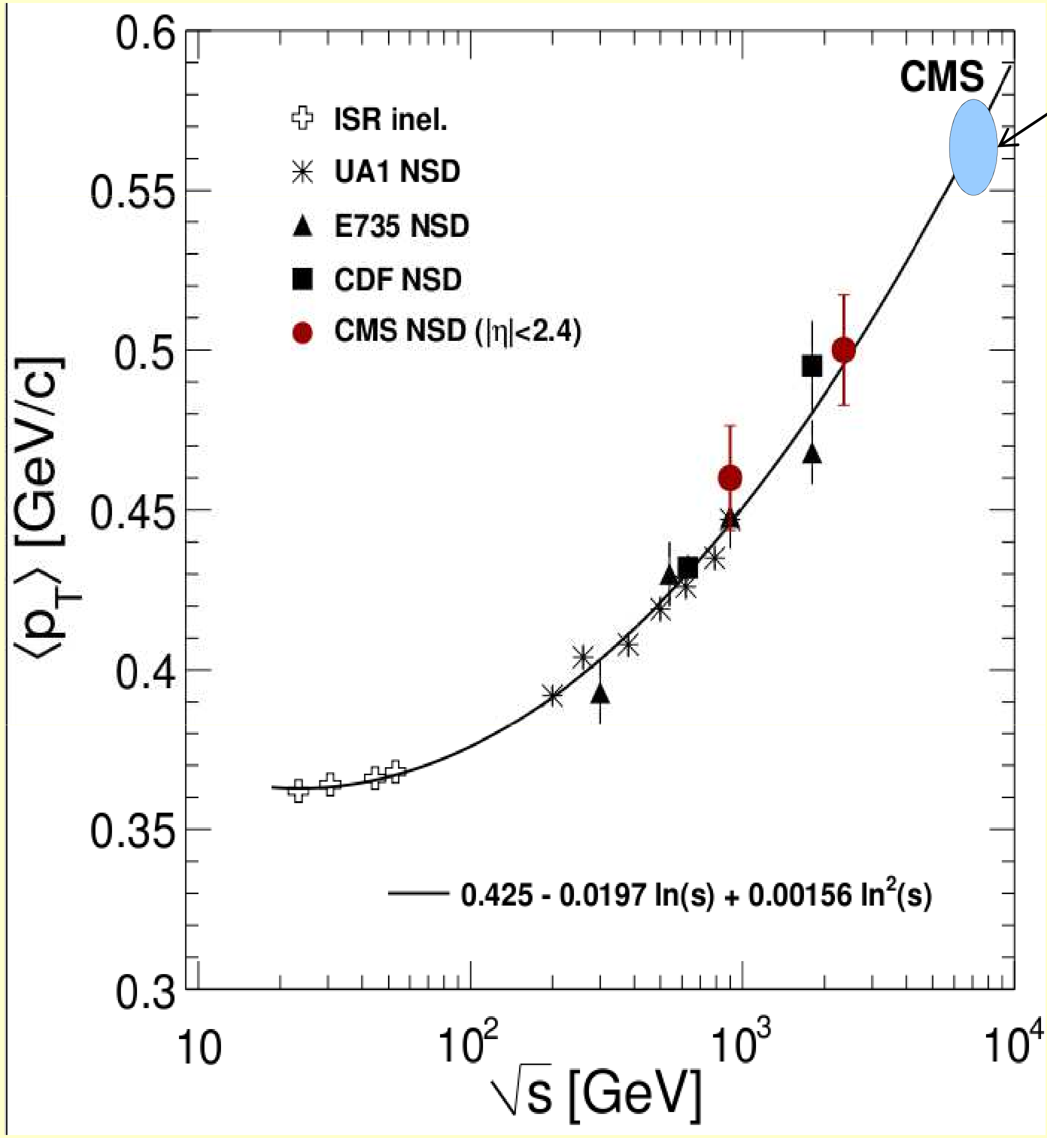
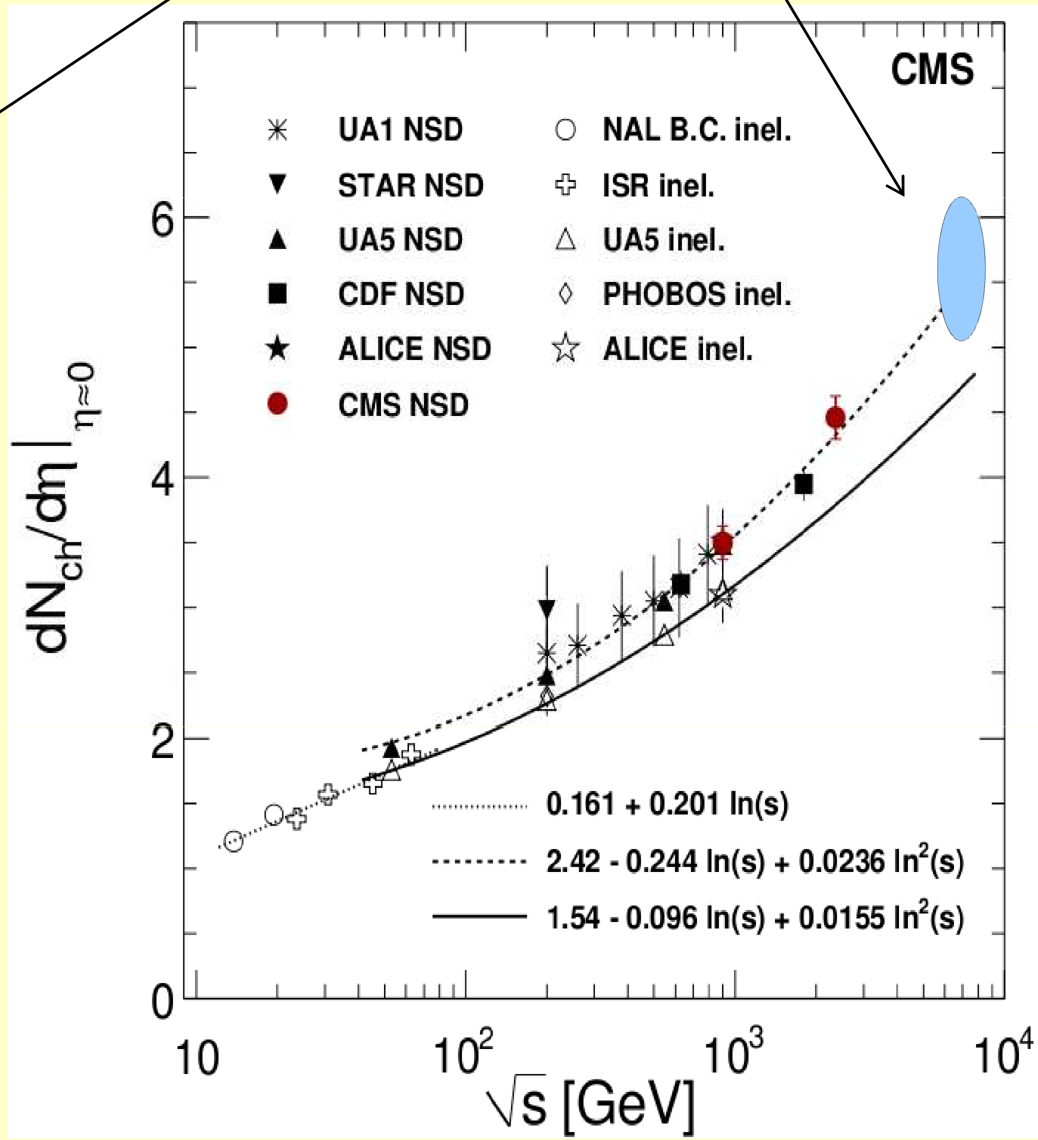
2010/2011 Operating Point (7 TeV)

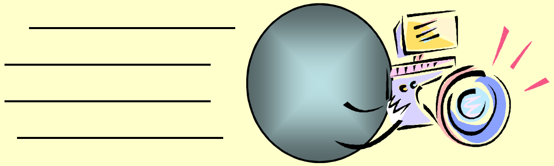


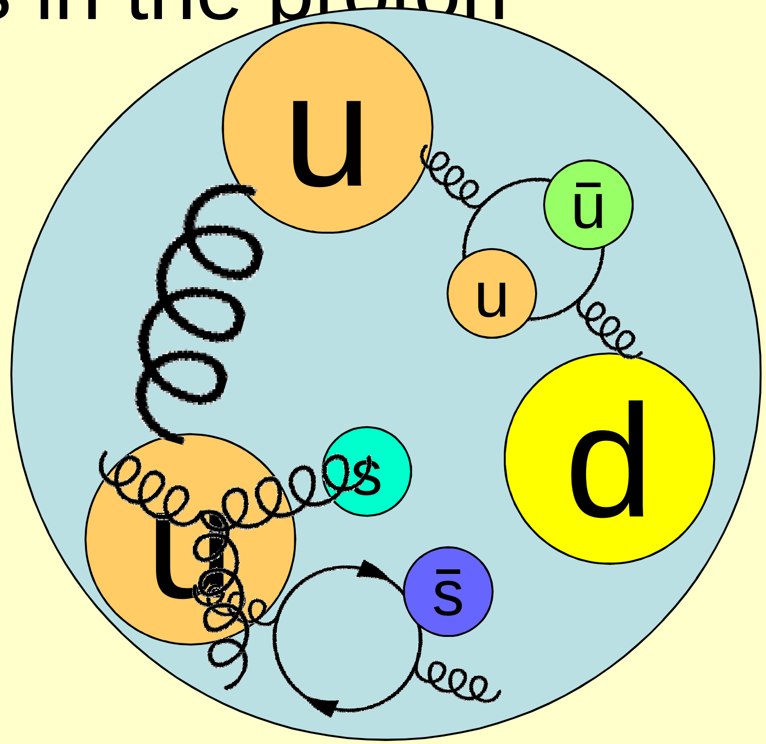


The Collision Environment at the LHC

A Hadron Collider or a Parton Collider?

- Strong coupling: rapid exchange of energy between the gluons and quarks in the proton

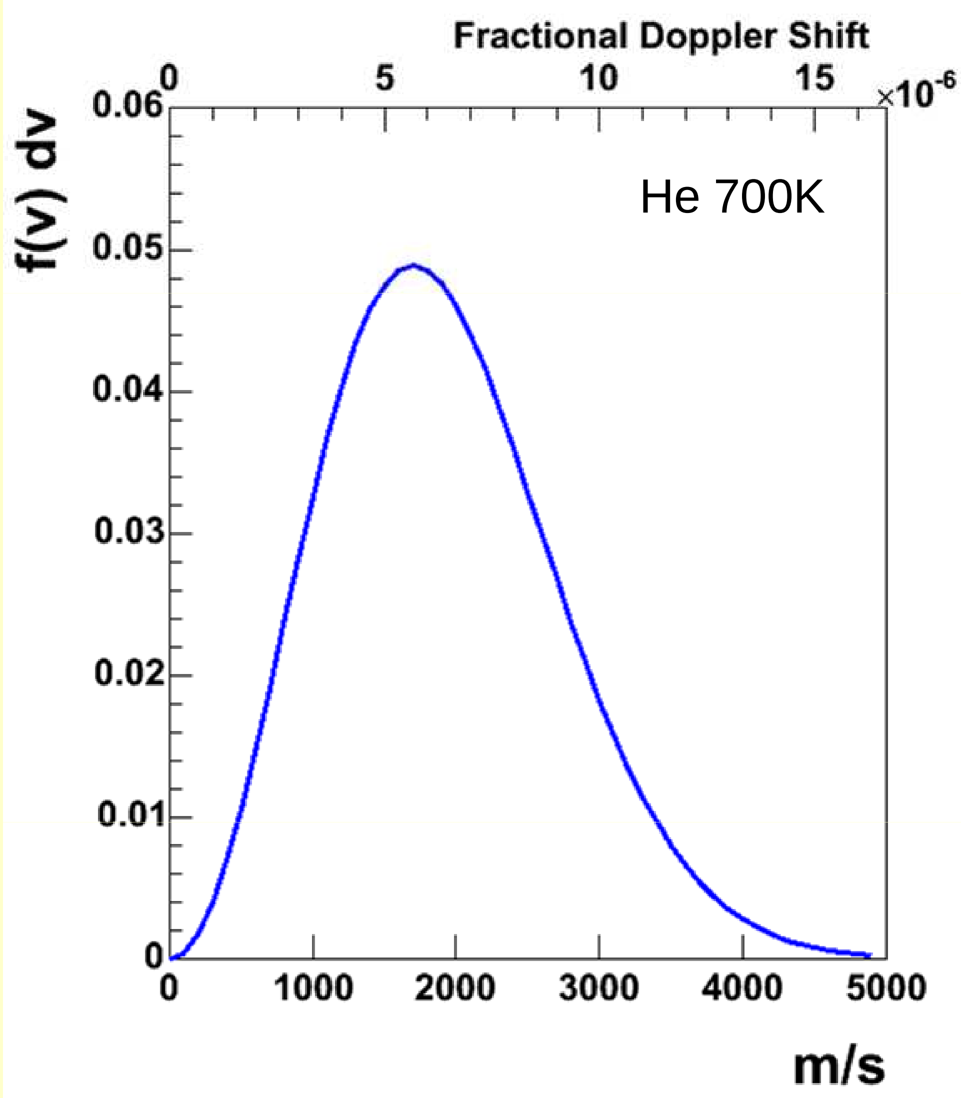




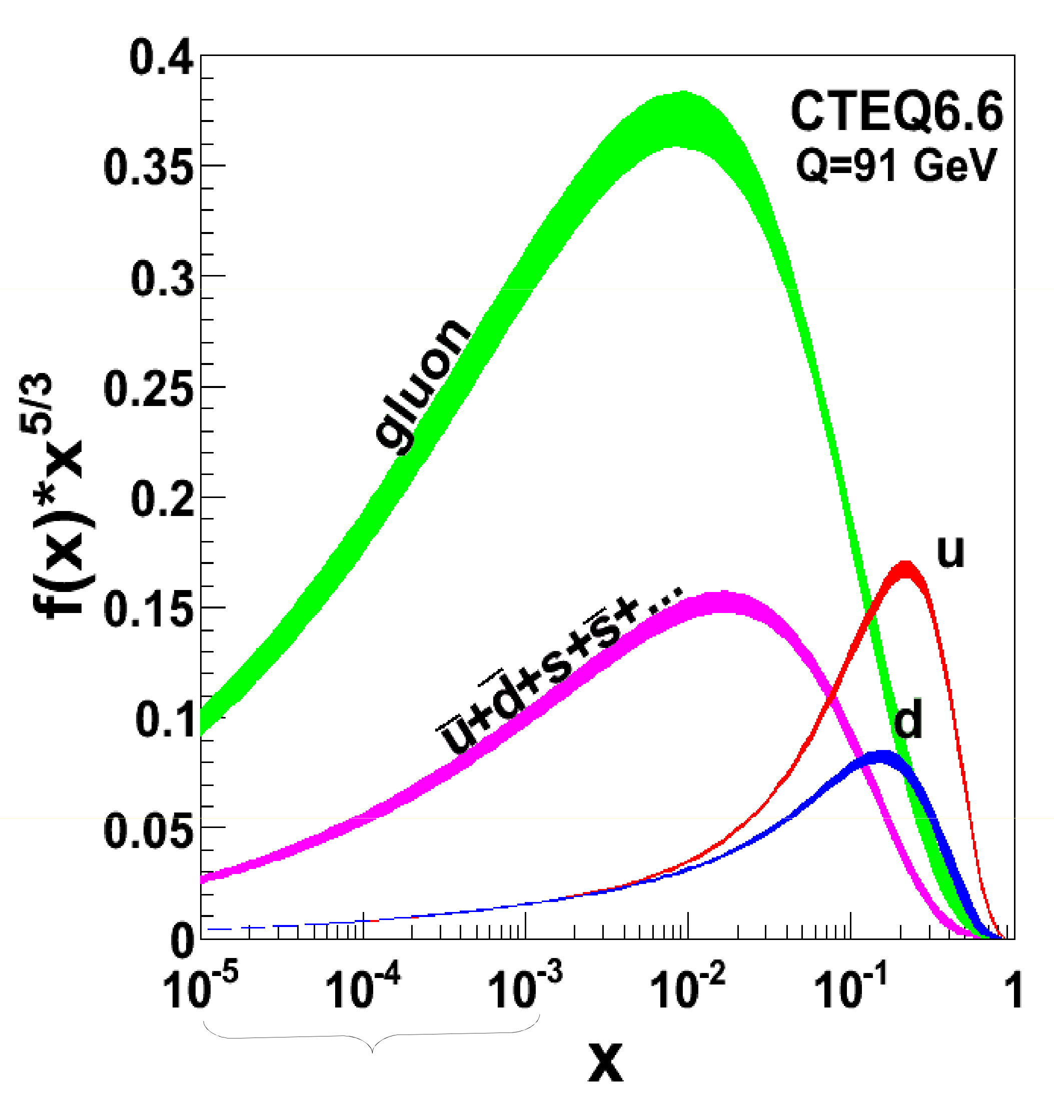
- For collisional physics, we can "freeze" the hadron if $t_{col} << t_{int}$
- Can't prepare the conditions in the hadron at the moment of interaction : distribution of possibilities

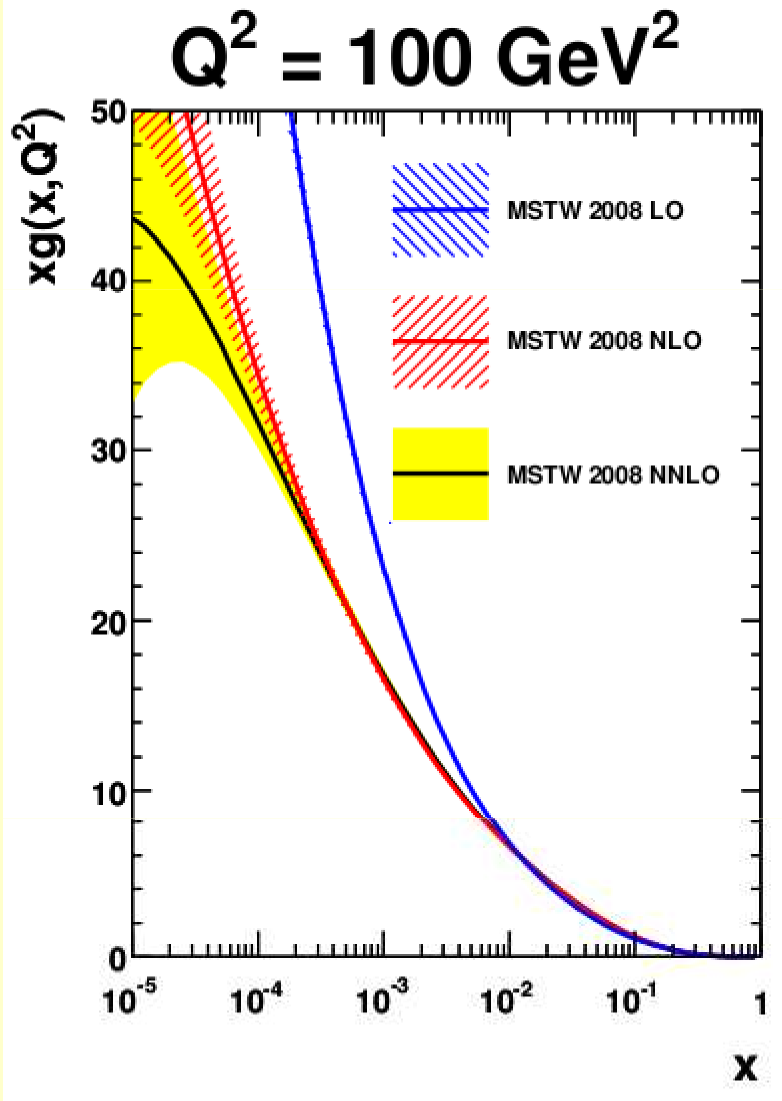
Classical Probability Distribution

- The Maxwell Speed Distribution can be used to obtain the range of Doppler shifts expected from a gas at a given temperature.
- Photon absorption => thermal line broadening

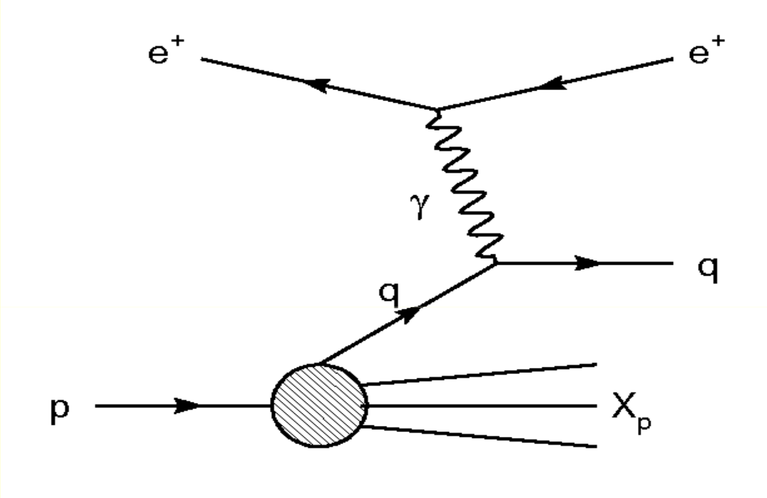


State of Knowledge of the PDFs



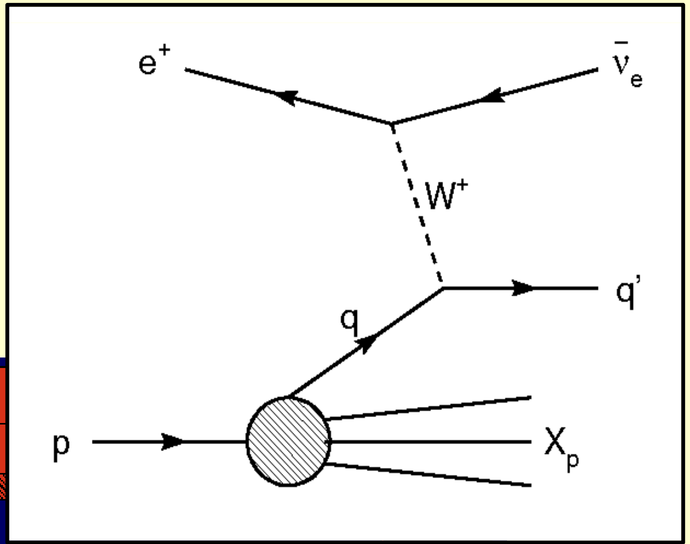


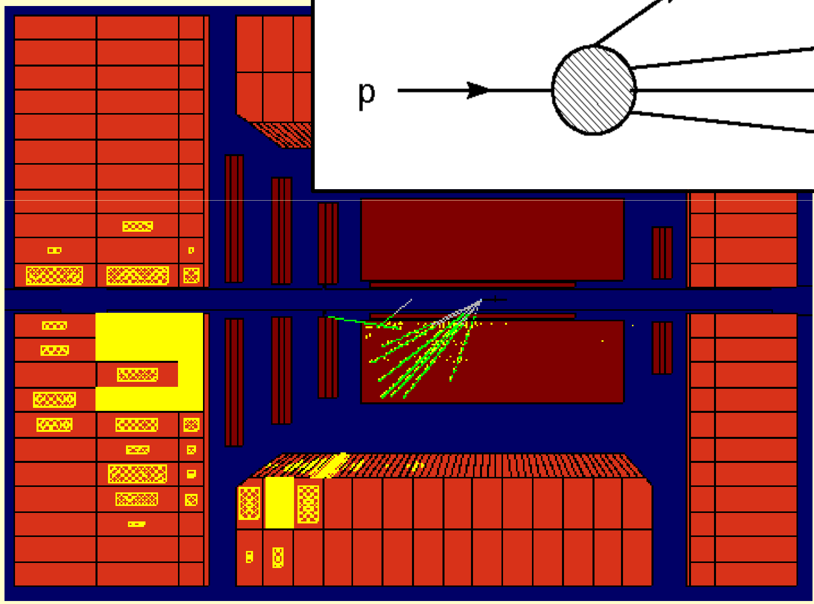
Deep Inelastic Scattering

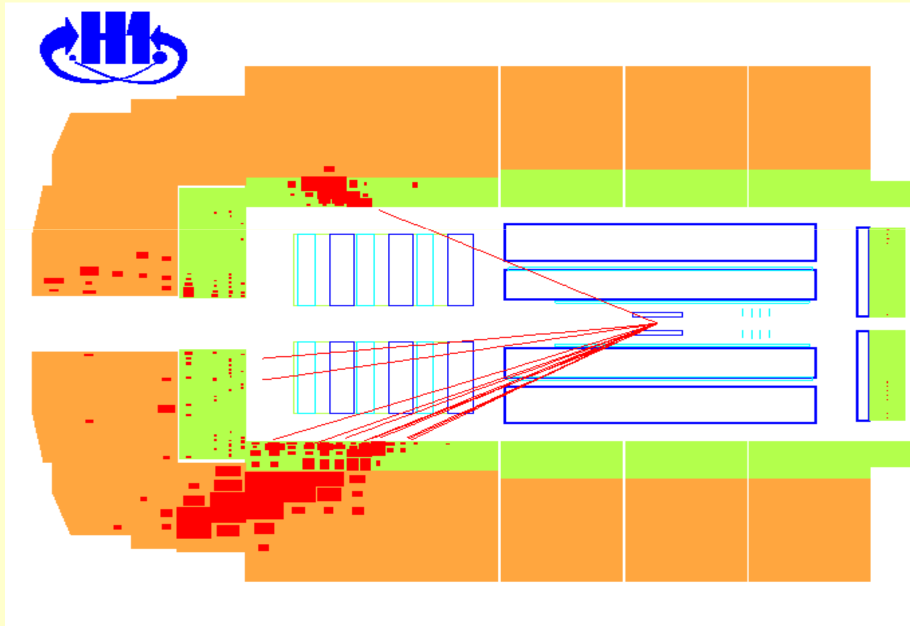


Measuring PDFs at HERA

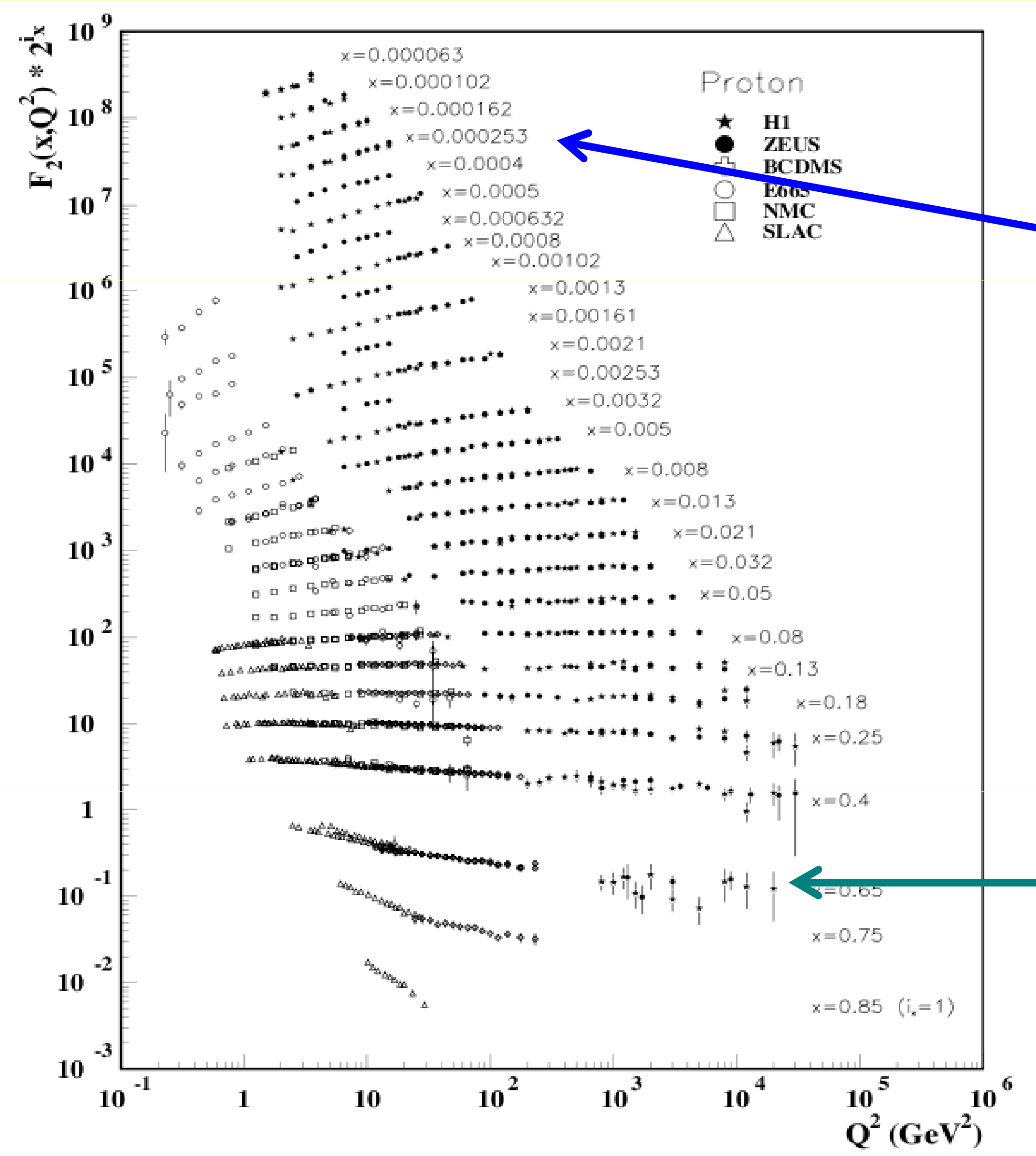
920 GeV Protons
27.5 GeV Electrons or Positrons

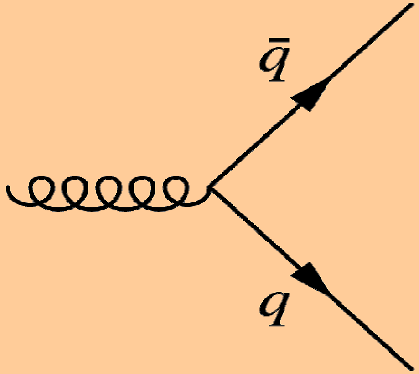




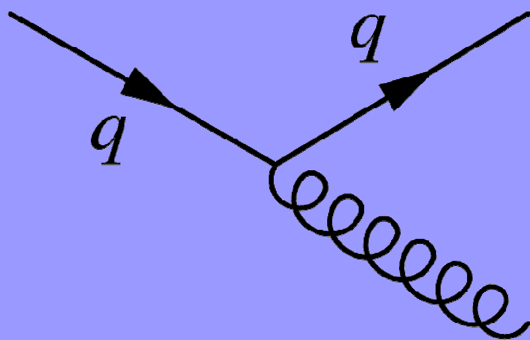


Some Known Behaviors





Gluon splitting processes increase the density of quarks with small *x* observed at high Q^2

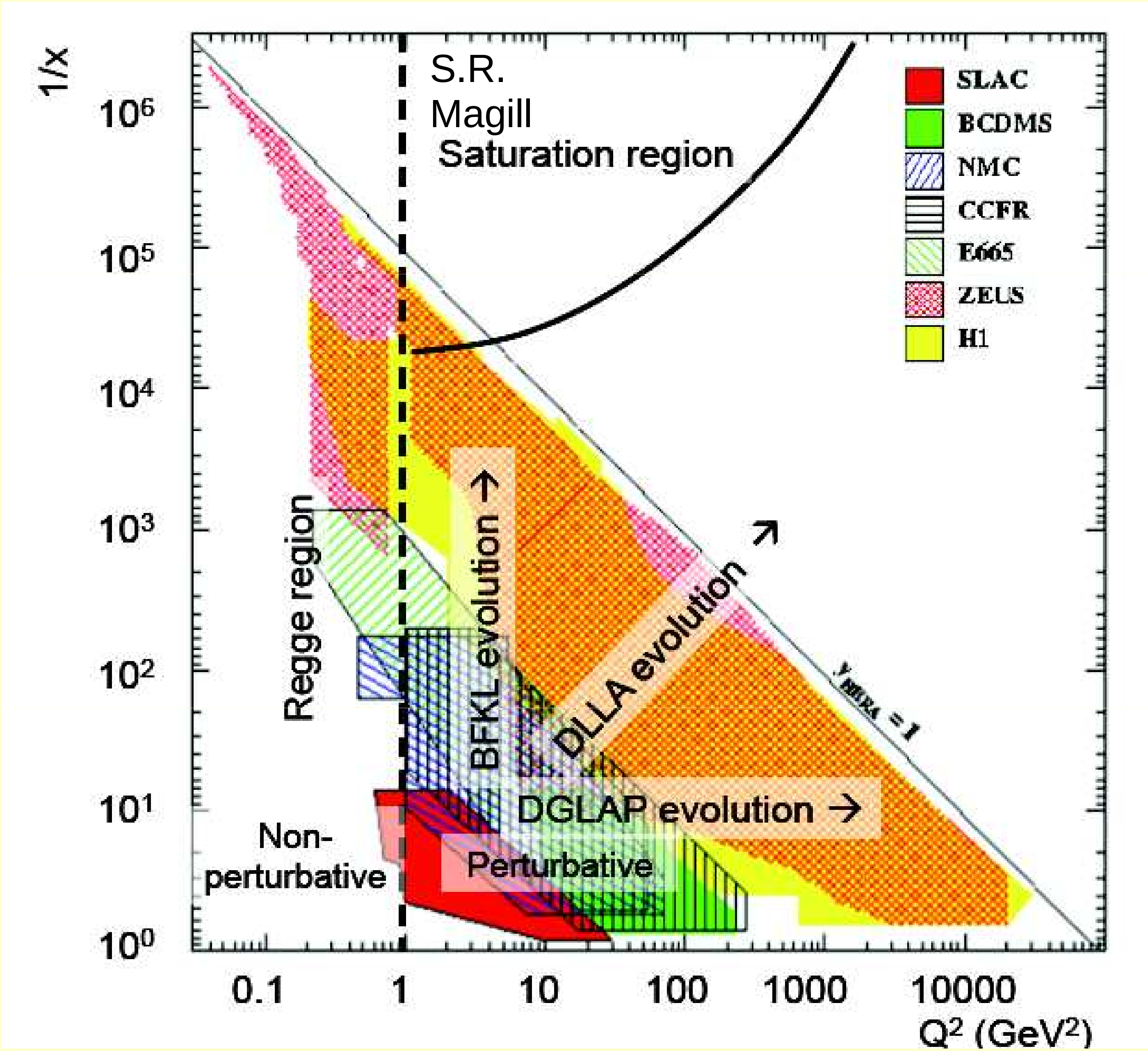


Gluon radiation processes decrease the density of quarks with large *x* observed at high Q^2

Suspected Behaviors at LHC x, Q^2

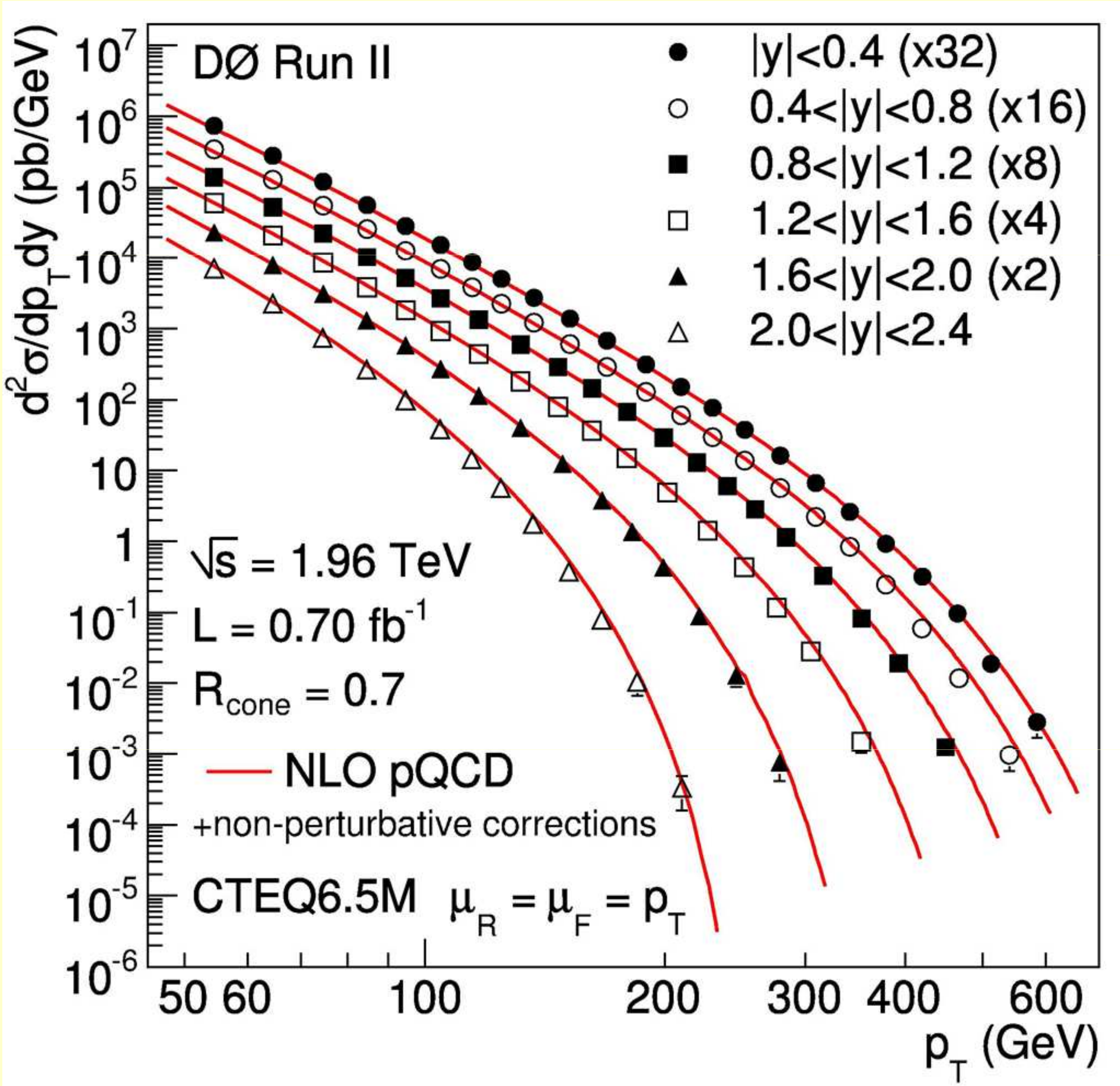
- Gluon saturation effects at small x ($x<10^{-4}$) and moderate Q^2 ($< 100\ GeV^2$)
  - Observations from heavy ion colliders: how do they transform into the kinematically relevant regime at LHC?
- New terms in PDF evolution equations at small x ($x<10^{-4}$) and large Q^2 ?
  - Theoretical arguments ongoing for some time: is LHC the point where DGLAP becomes insufficient?
- Parton correlations : enhanced probability for two “separate” parton-parton interactions
  - Measurements ongoing at low Q^2, also observed at Tevatron: how does this effect scale to LHC and how can we include it in background modelling?

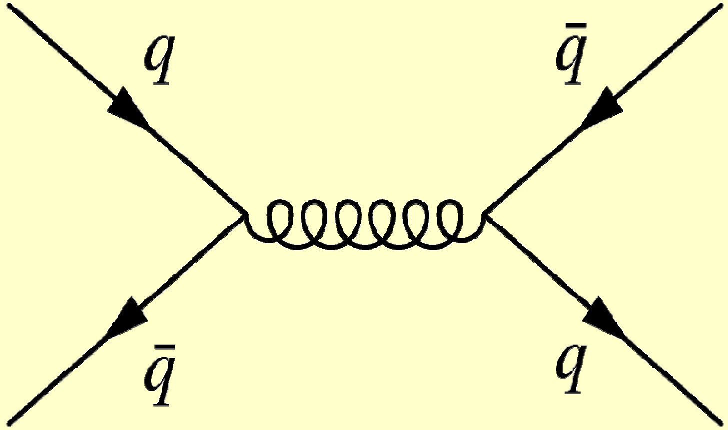
PDF Evolution



Constraining the PDFs at a Hadron Collider

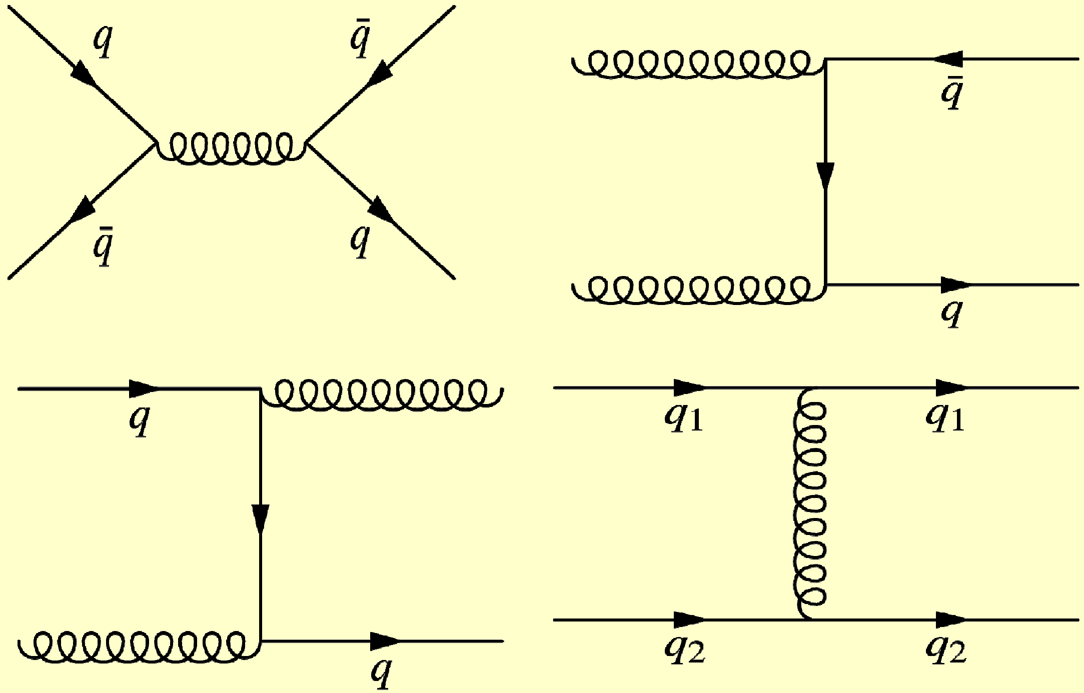
Quark probes at the Tevatron

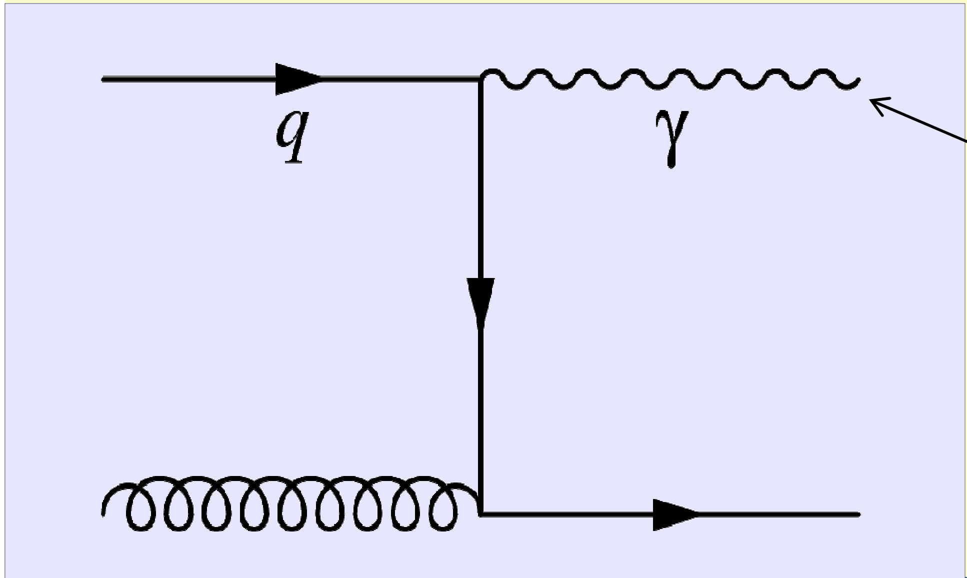




- Direct availability of valence anti-quarks (antiproton) makes the annihilation diagram dominant, particularly at high Q^2
- Theory is relatively straight-forward (for QCD)

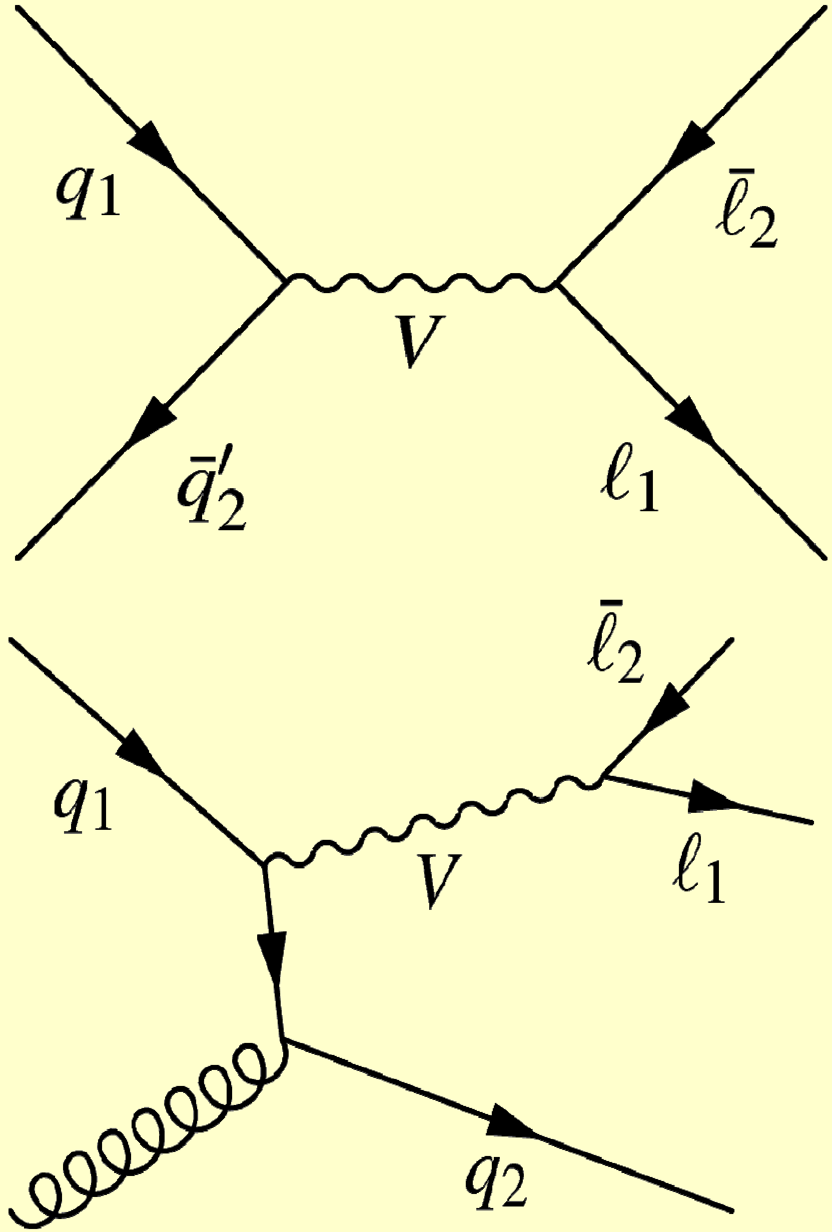
Quarks and Photons at LHC





- Jet challenges
  - Resolution, energy scale, acceptance
- Theoretical challenges
  - Appropriate integration over many contributing diagrams
- Photon challenges
  - Reliable identification (suppressing jets with leading p^0)

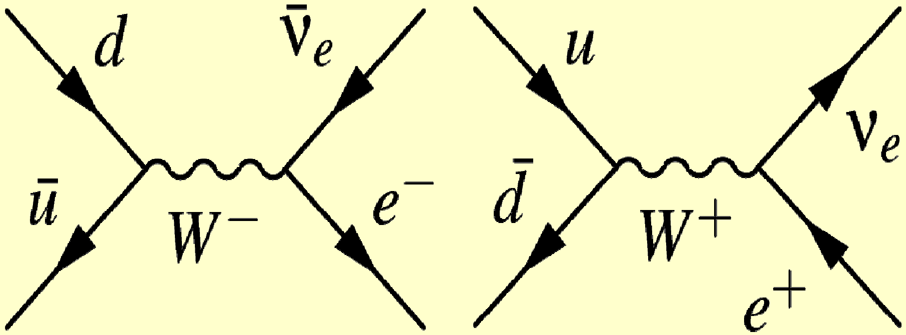
Using weak bosons as probes

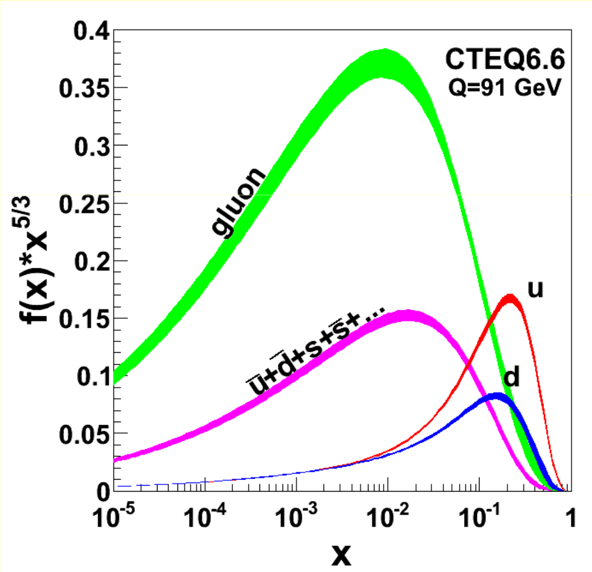


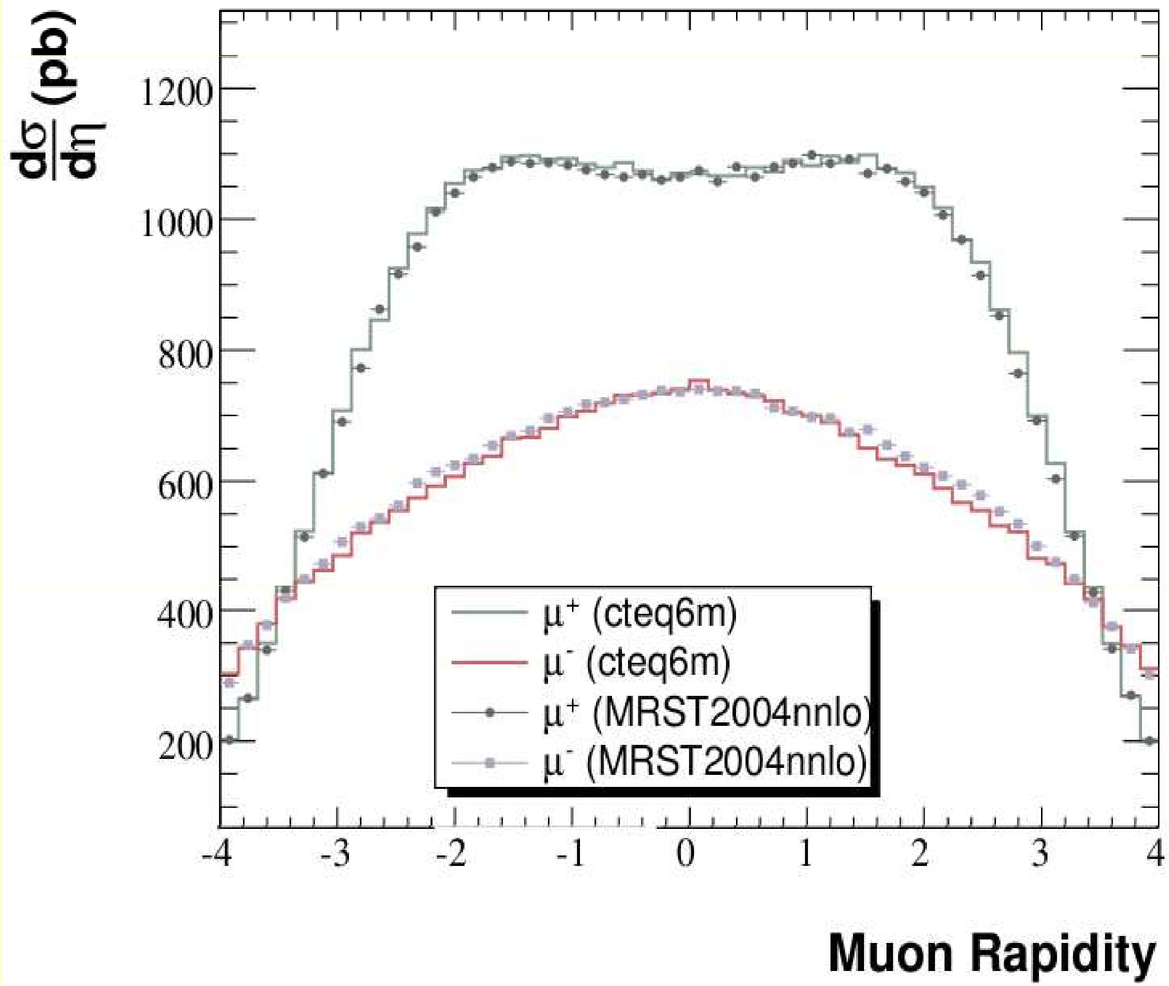
- Lepton reconstruction has high precision, electroweak bosons have relatively few backgrounds
  - Z can be fully reconstructed with lepton/track quantities only
  - W produces energetic leptons and has a high cross-section
- Theory advantages of weak-scale physics

W Charge Asymmetry

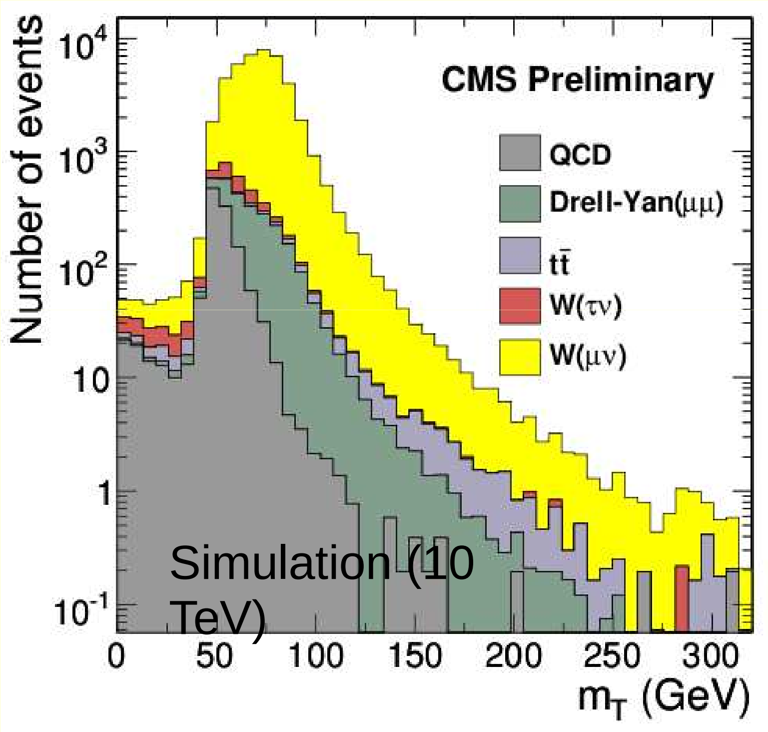
$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}.$$

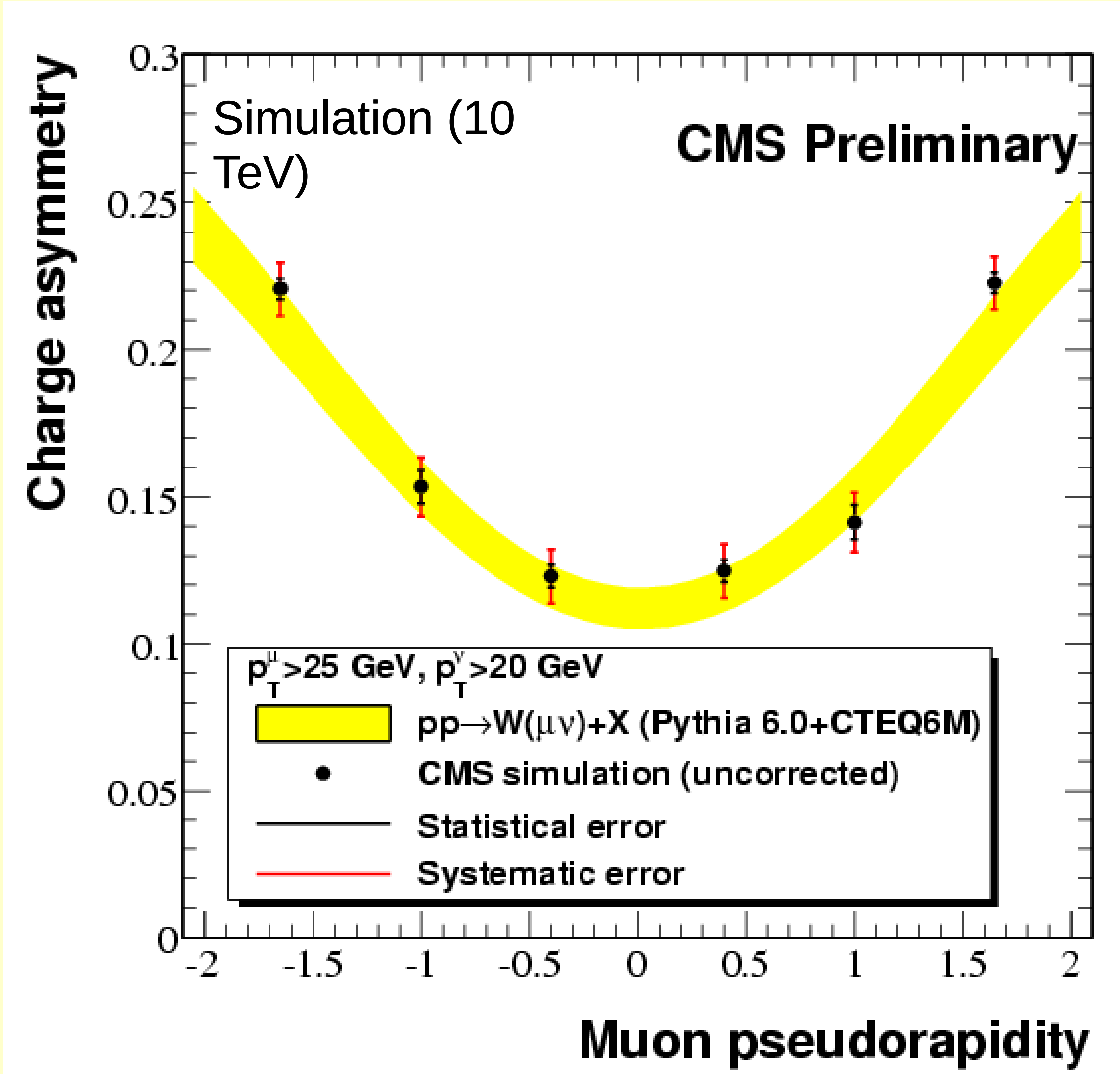






CMS Measurement with Muons

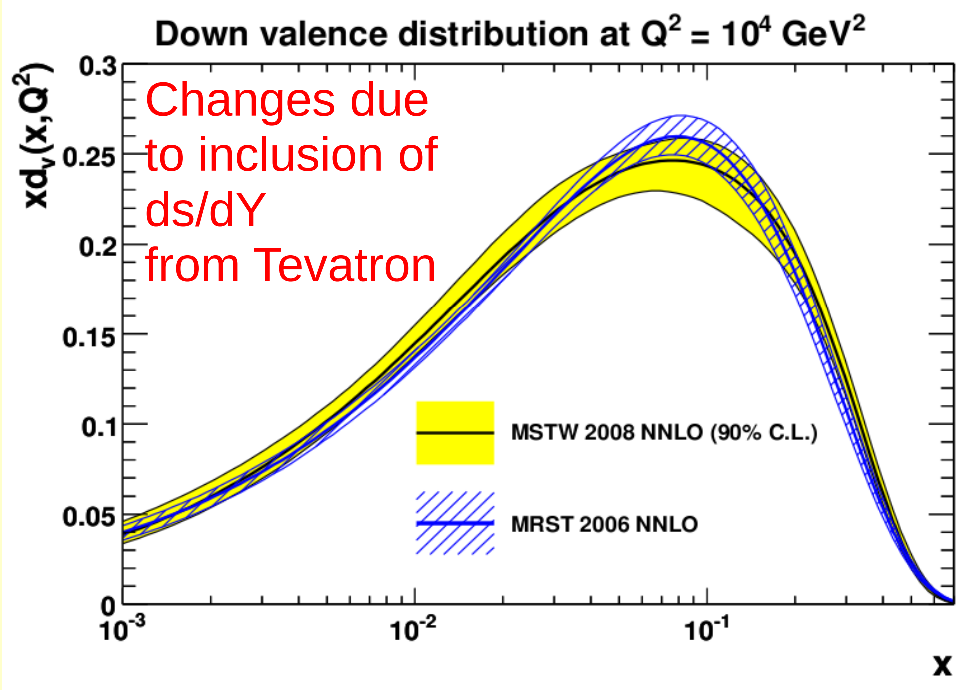


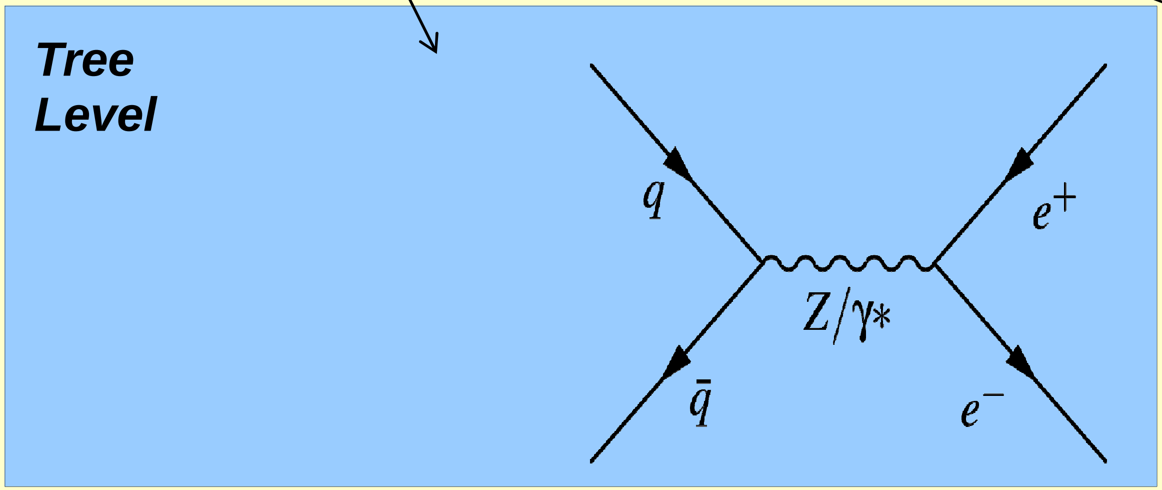


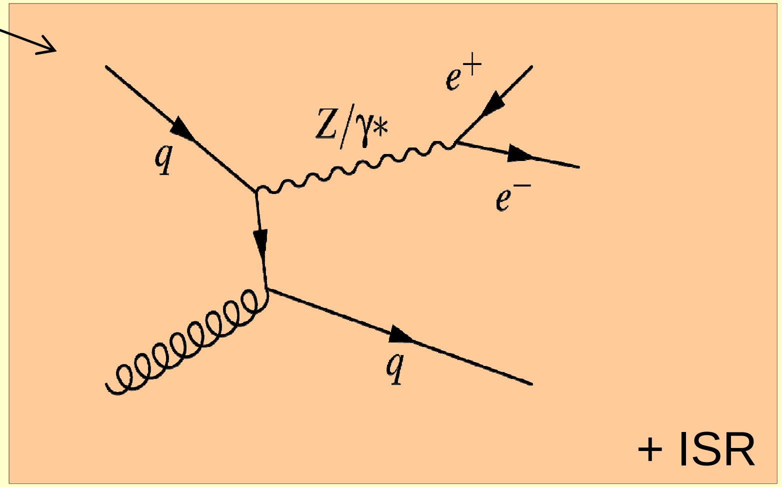
- Dominant systematic errors:
  - Efficiency determination : 1%
  - Acceptance : 1% (considered entirely to be a theory error in this analysis)

Measurement with Z Bosons

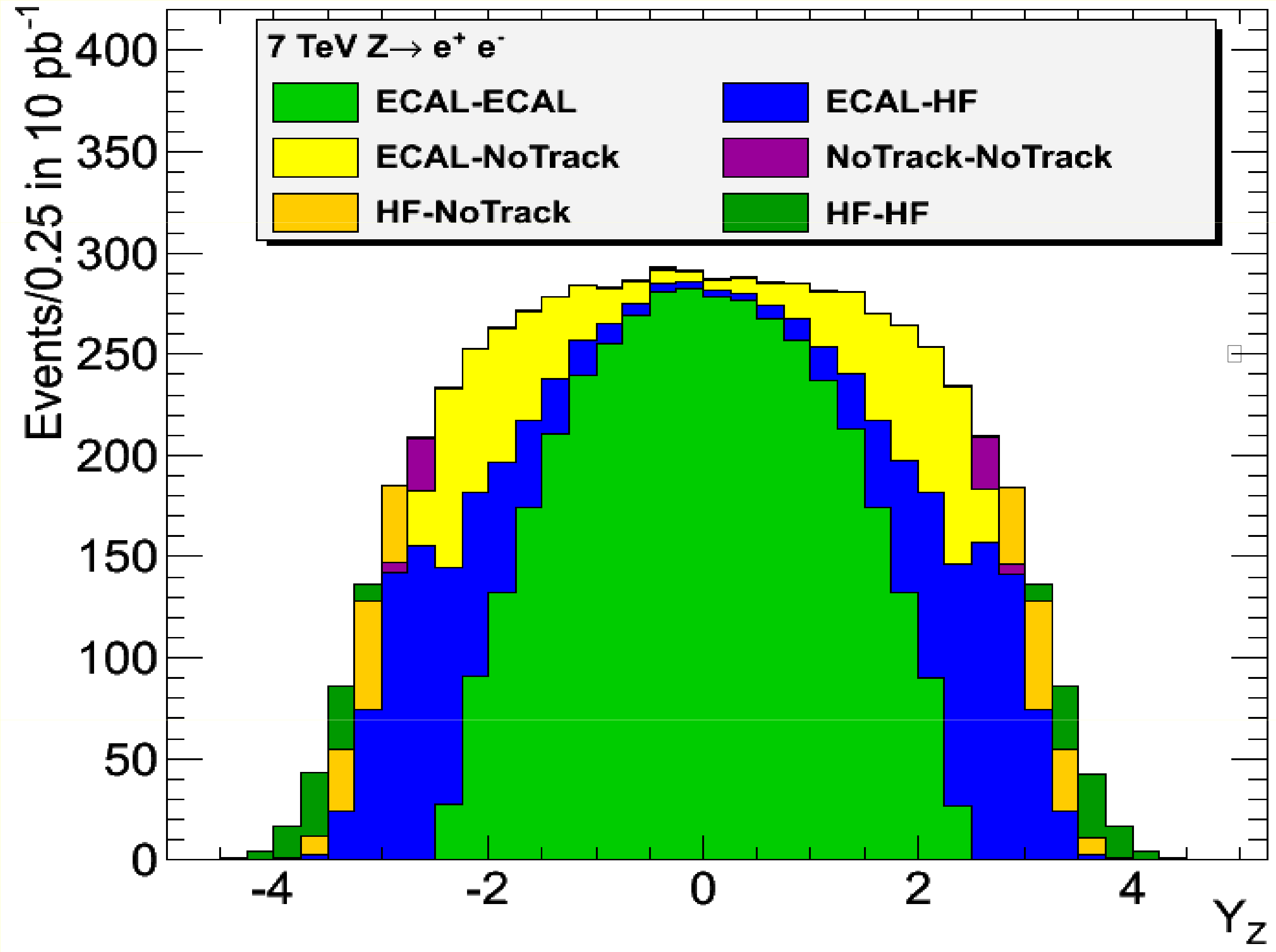
- Two differential measurements give strong information about the PDFs







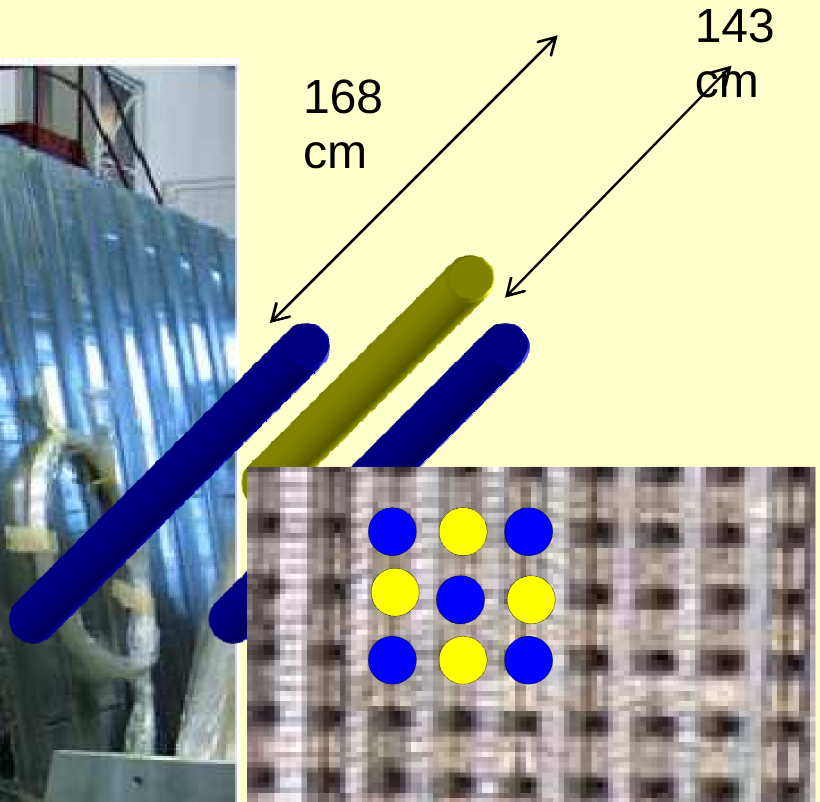
Relevance of the Forward Region

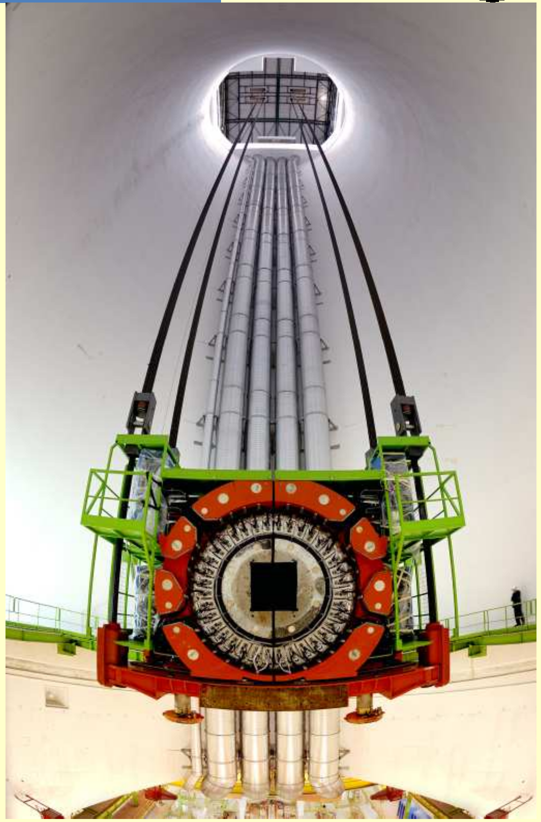


Region beyond Y=2 can be accessed only by including the forward calorimeter (and cannot be accessed in Z→mm)

– Provides access to $x < 2 \times 10^{-3}$

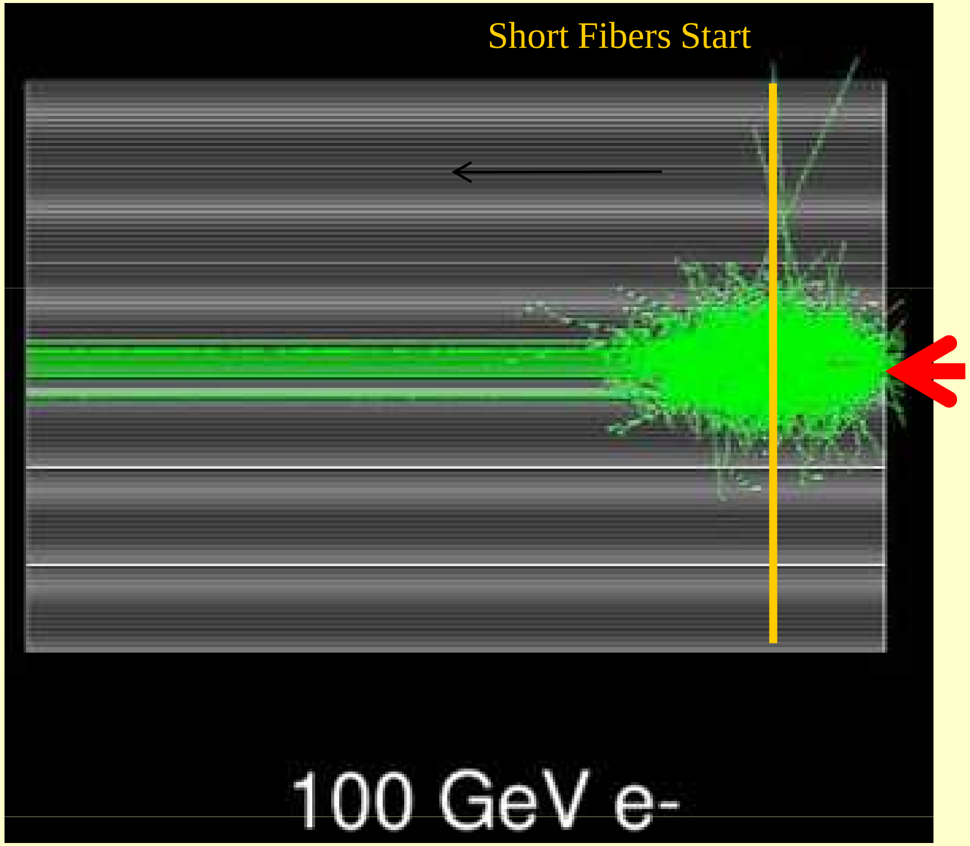
CMS Forward Calorimeter

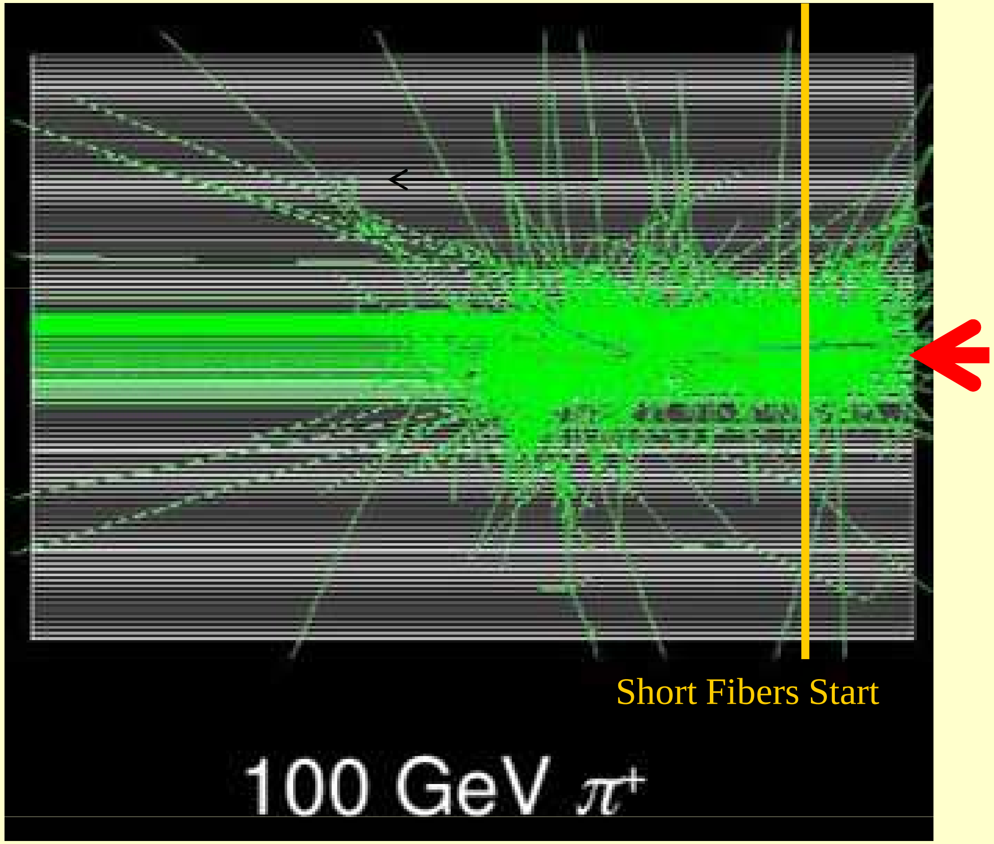




- Iron/quartz fiber Cerenkov calorimeter
  - System of long and short fibers provides partial compensation of e/h response
- Covers $3<|\eta|<5$

Reconstructing Electrons with the HF





Electrons will put some signal into the short fibers, but most will remain in the long.

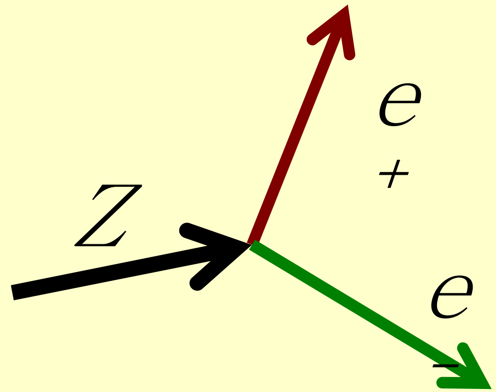
Charged pions will put similar signals into both sets of fibers.

Use longitudinal (short/long) and transverse shower shape variables to identify electrons

Rapidity Measurement

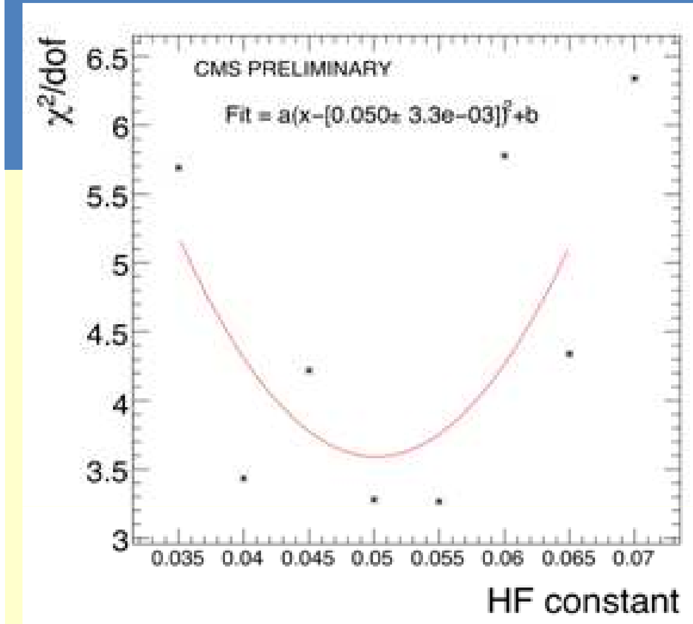
$$\frac{1}{\sigma}\frac{d\sigma(Z\rightarrow e^+e^-)}{dY}\bigg|_i = \frac{(\epsilon\times A)}{N^{obs}-N^{bkg}}\frac{N_i^{obs}-N_i^{bkg}}{\Delta_i(\epsilon\times A)_i}$$

Shape measurement: many systematics cancel

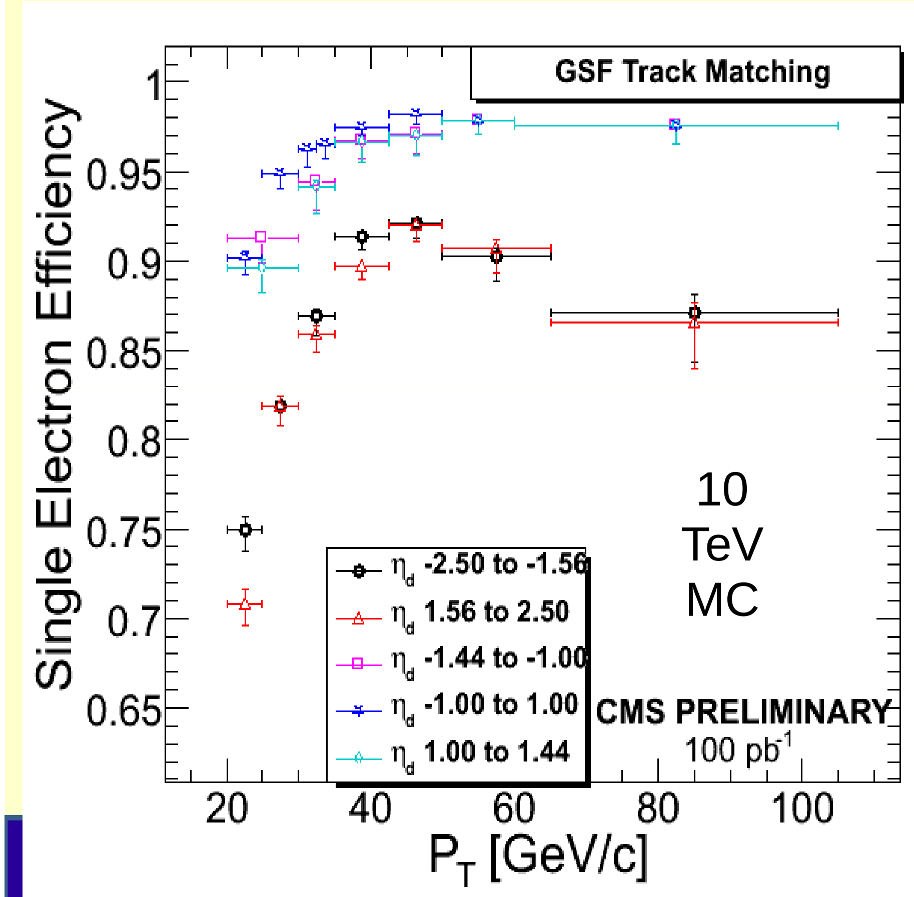


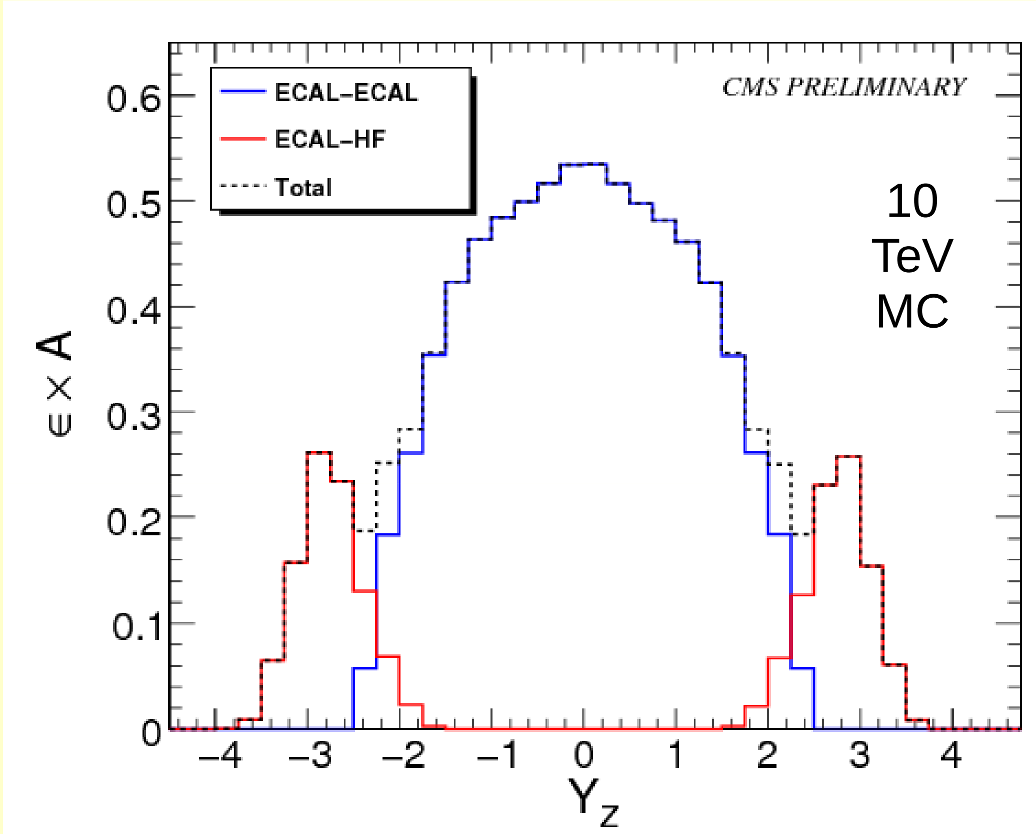
Determine efficiency*acceptance product by Monte Carlo integration of experimentally-determined single-electron efficiencies

ntal Inputs



Efficiencies (tag-and-probe) +
Smearing (fit to data) +
Monte Carlo Z distribution:





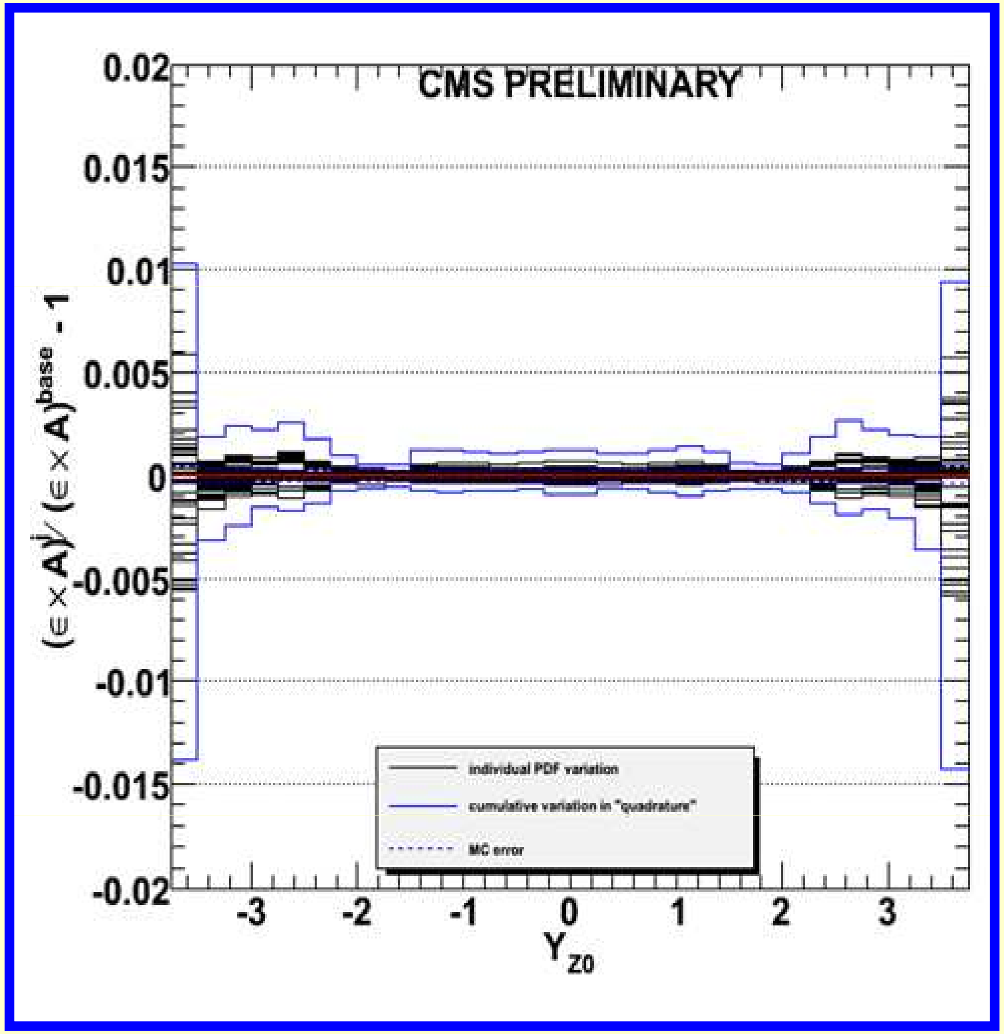
PDF Sensitivity and Uncertainty

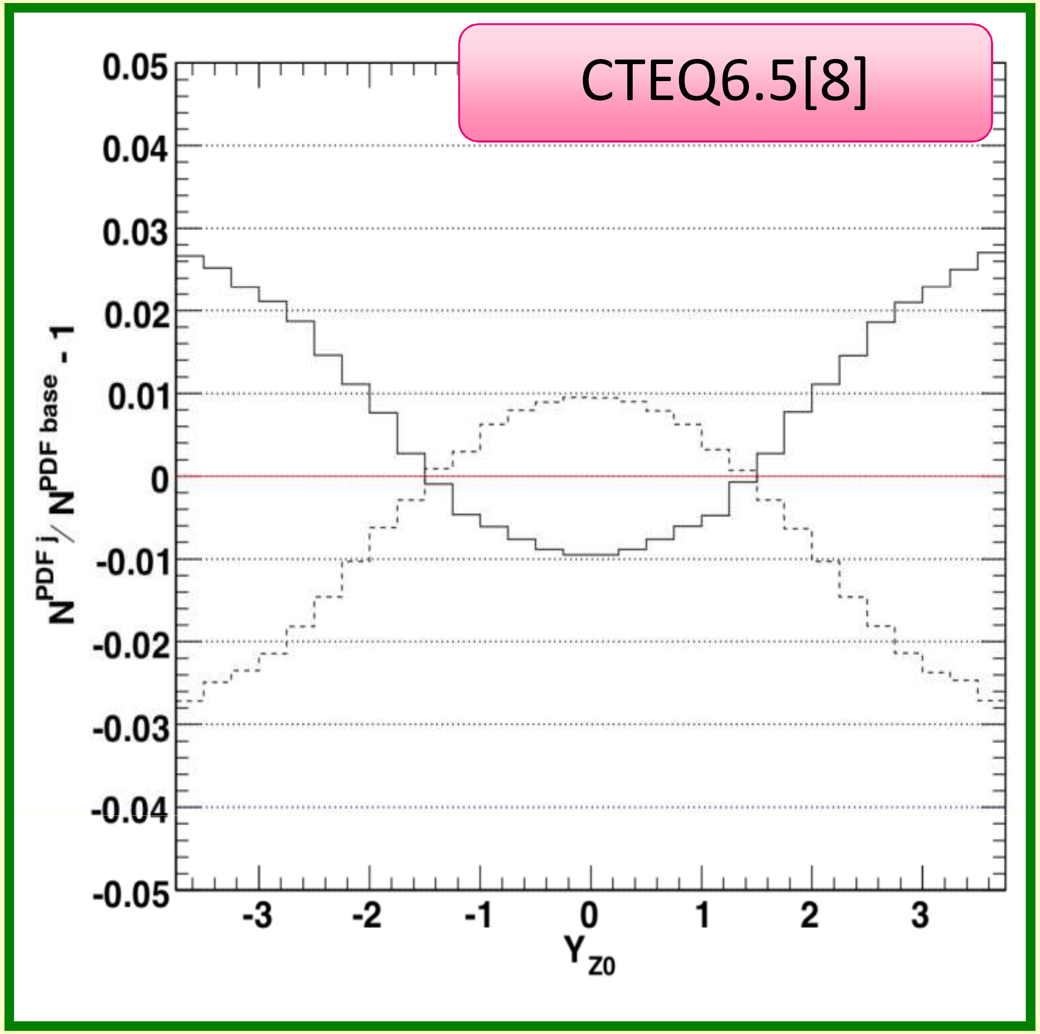
$$\frac{1}{\sigma}\frac{d\sigma(Z\rightarrow e^{+}e^{-})}{dY}\bigg|_{i} = \frac{(\epsilon\times A)}{(\epsilon\times A)_{i}}\frac{N_{i}^{obs}-N_{i}^{bkg}}{\Delta_{i}(N^{obs}-N^{bkg})}$$

If the PDFs are different from the base expectation, then we should observe the ratio to vary as a function of the *i*-th bin.
This is the PDF measurement sensitivity.

We want to make sure the ratio of the Eff*Acc for a given Y bin does not change for different PDFs.
Assign a systematic error to this.

PDF Sensitivity and Errors

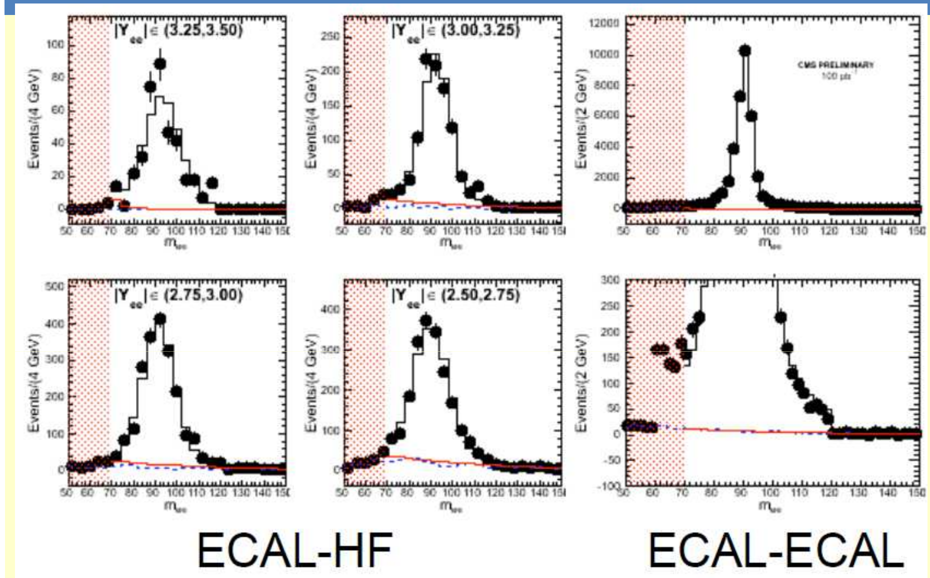


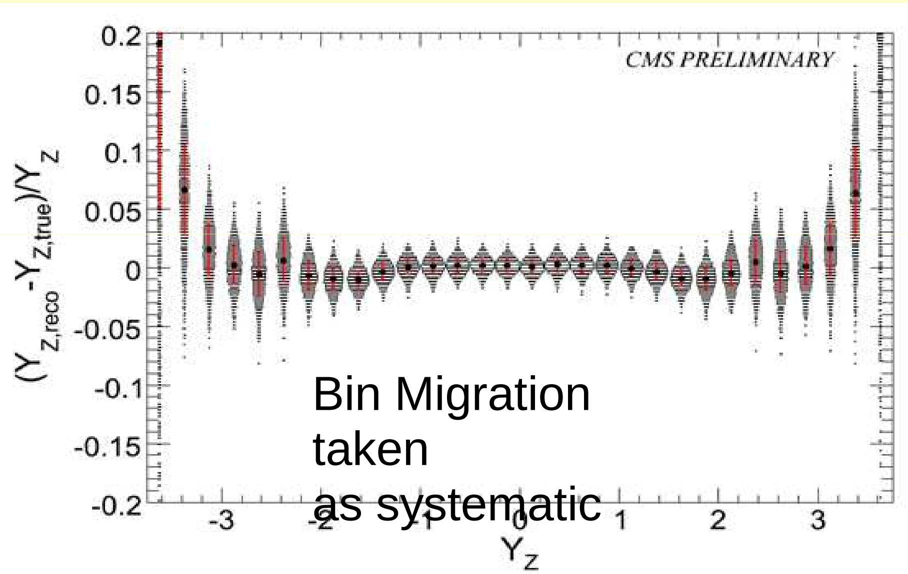


Systematic error < 0.2%

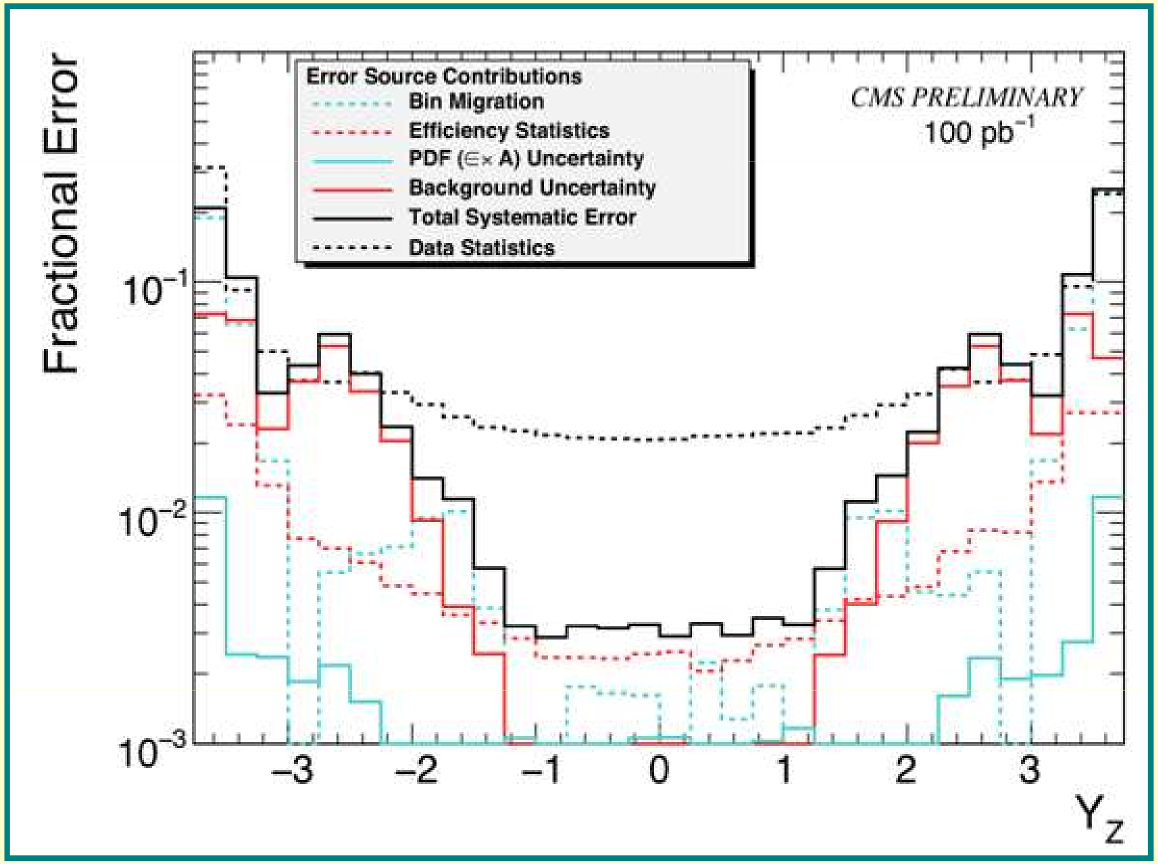
Sensitivity of O(2%)
Large |Y| is important

Systematic Error Sources



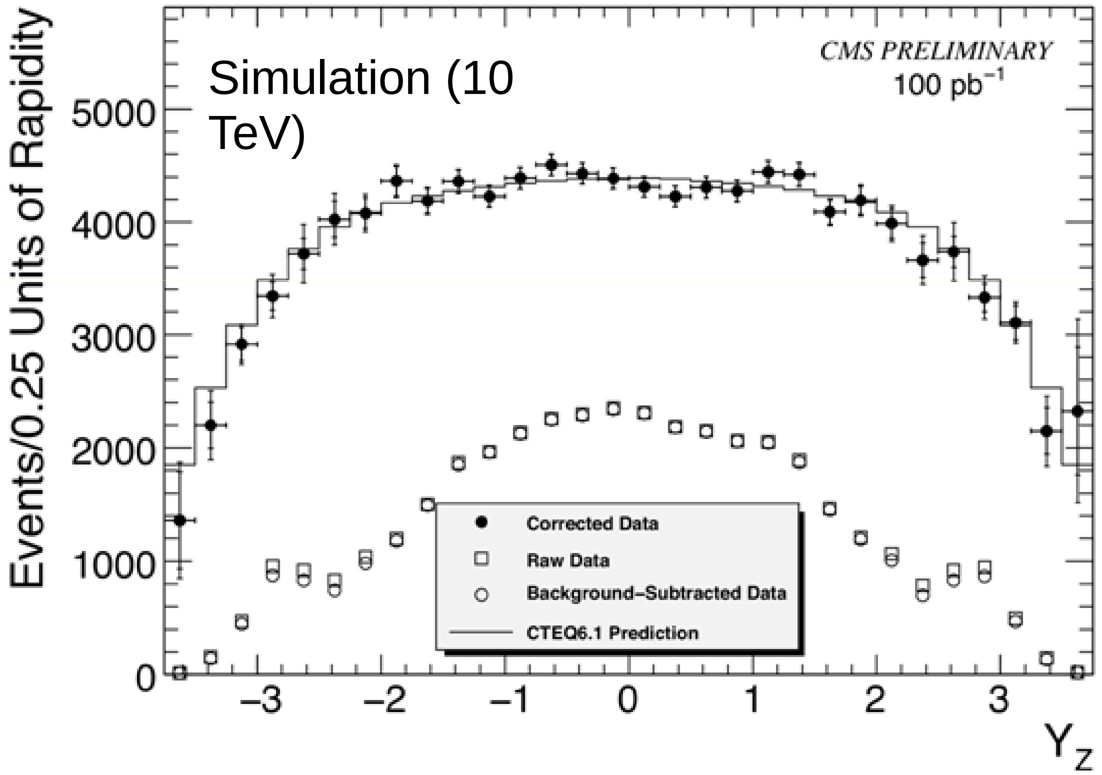


Bin Migration
taken
as systematic

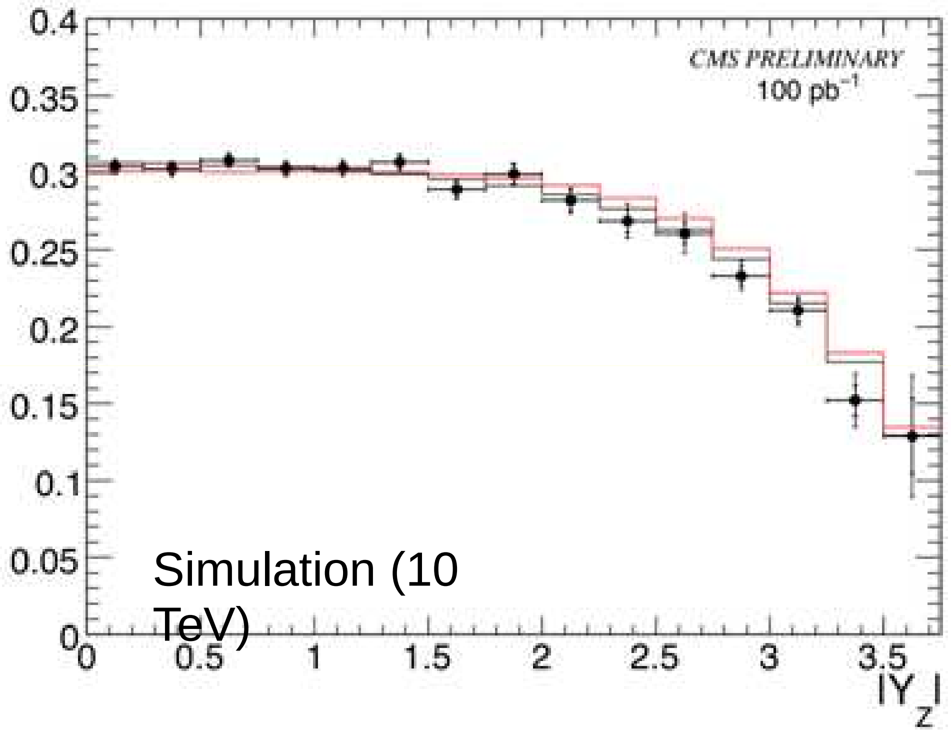


All plots are simulation (10 TeV)

Sensitivity for 10 TeV

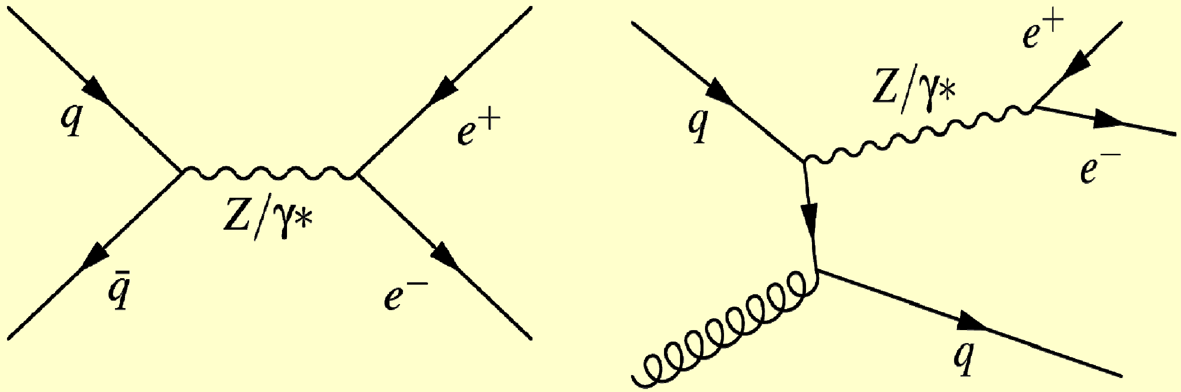


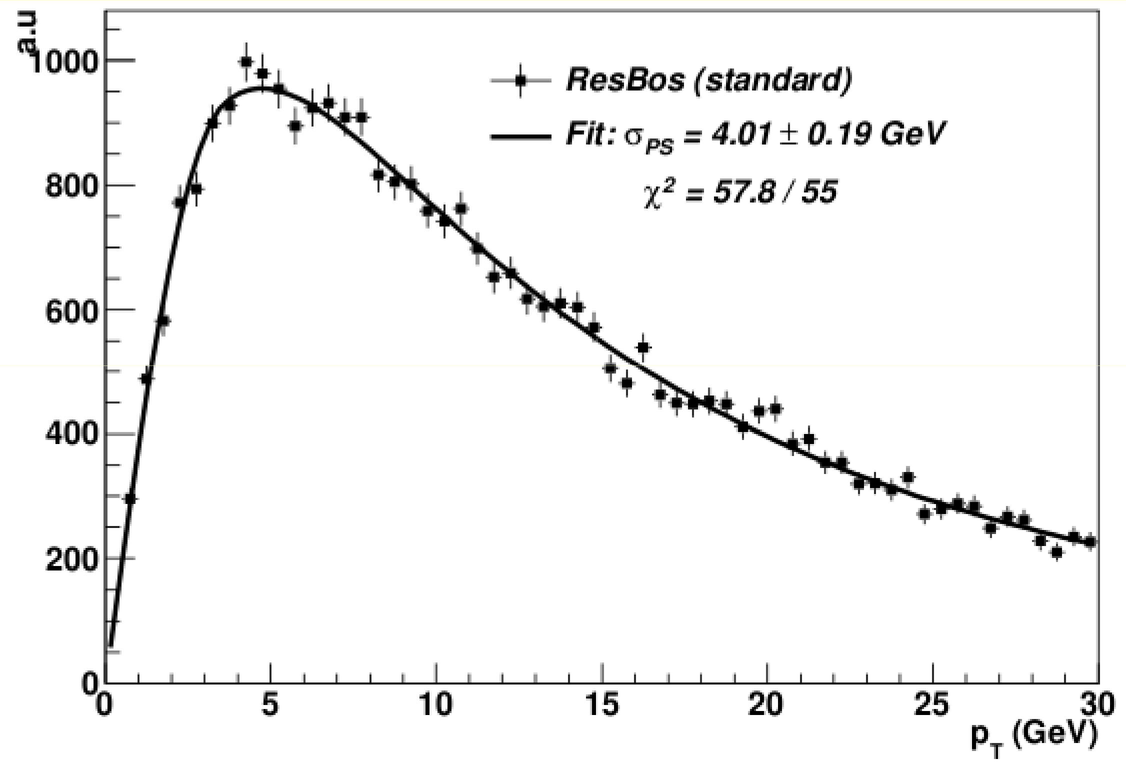
As we assume no global forward/backward structure at LHC, we can fold over the distribution to reduce some errors:

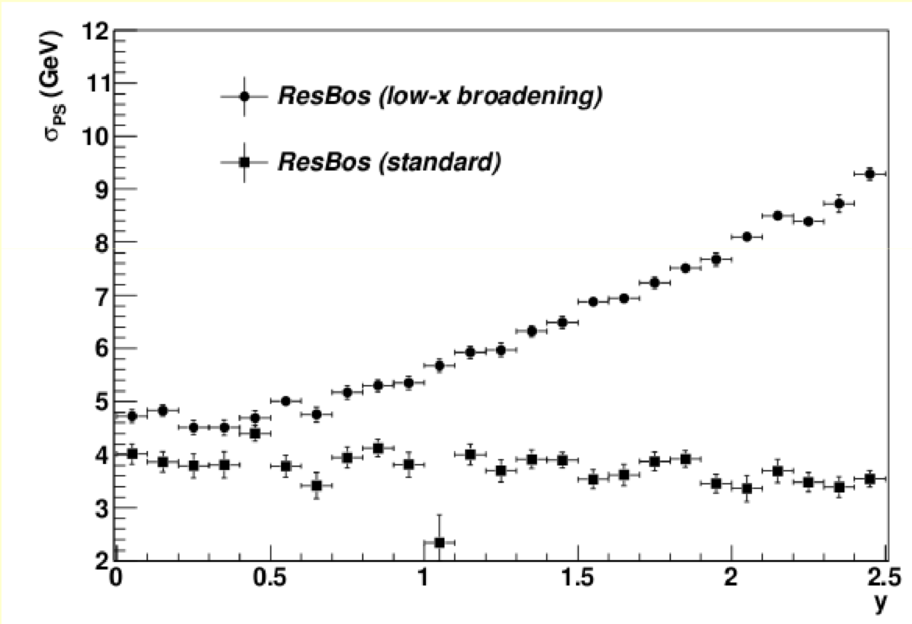


Signal is visible for 10 pb^{-1}, but errors are too large for a measurement

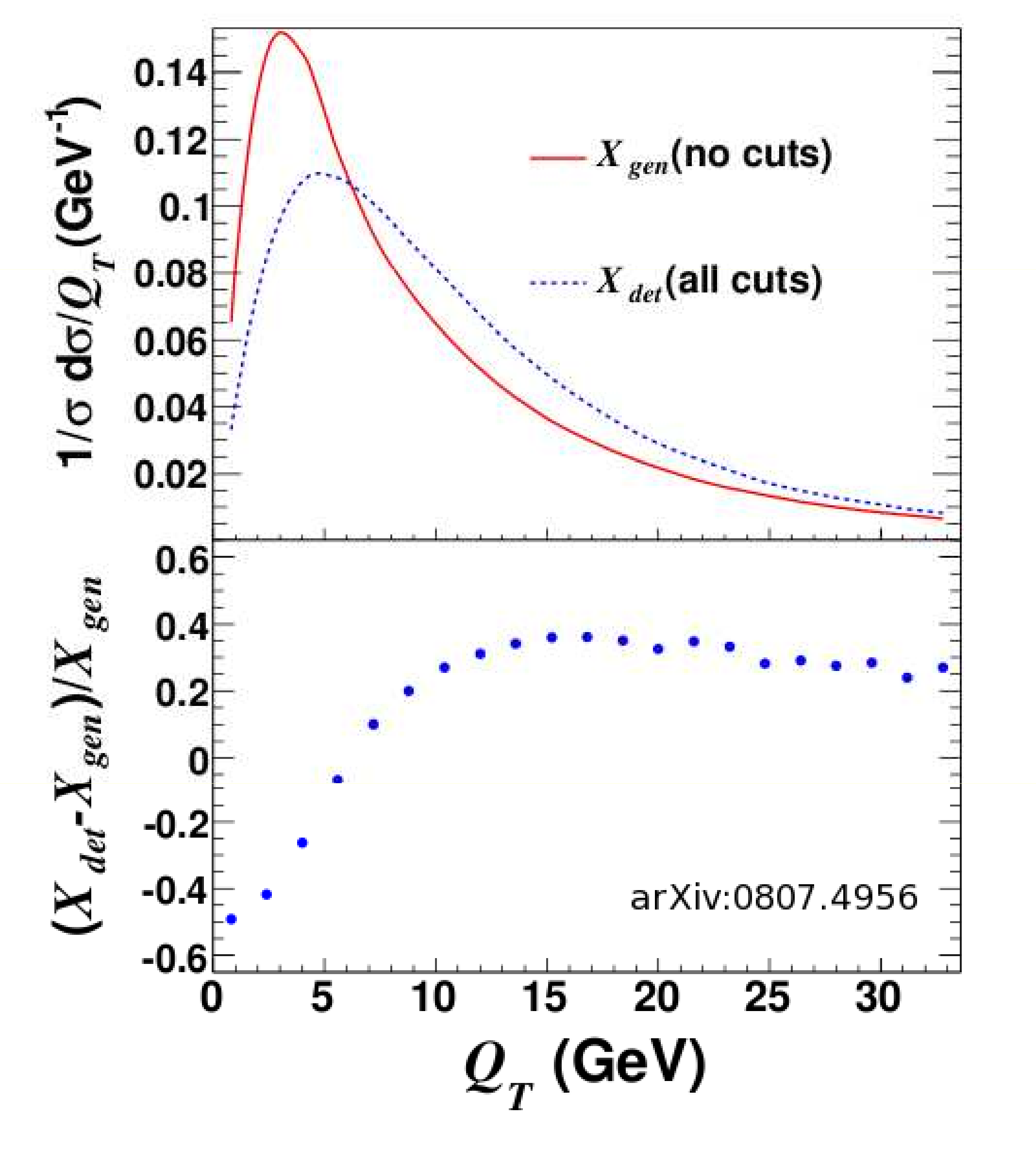
The Second Dimension : p_T

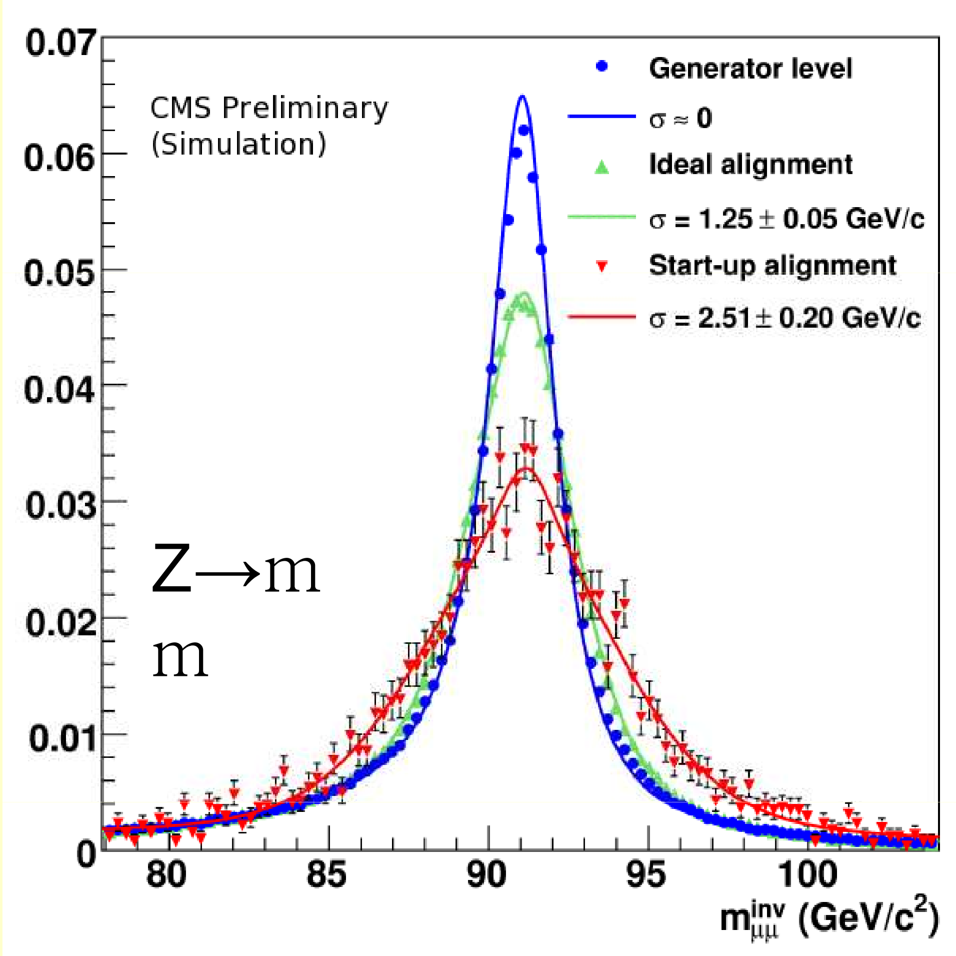






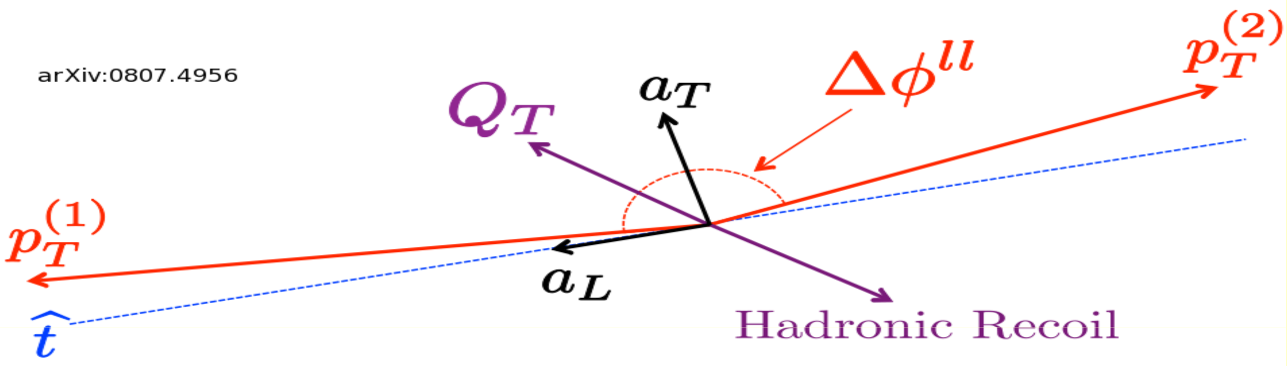
Bin Migration Effects

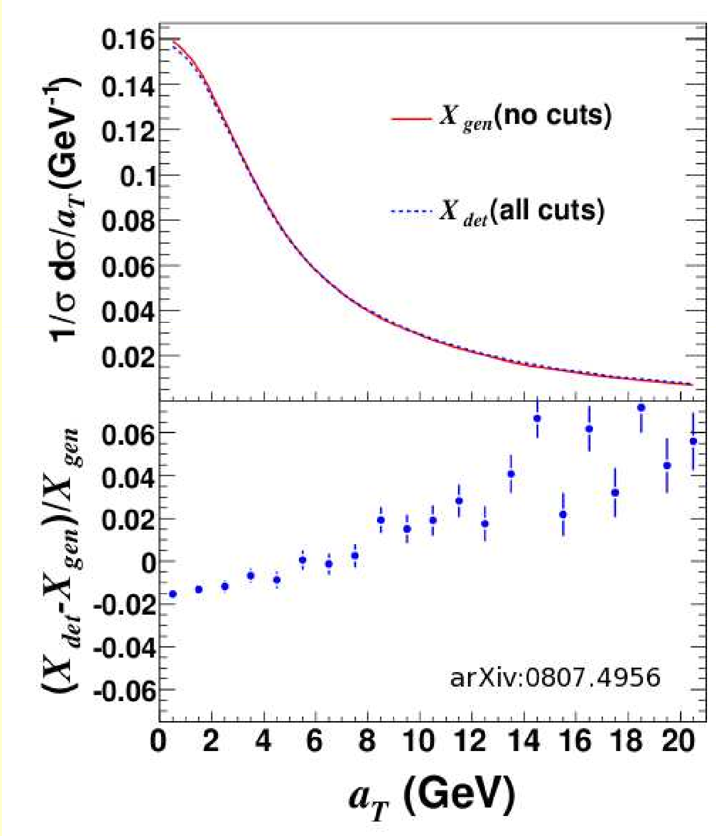


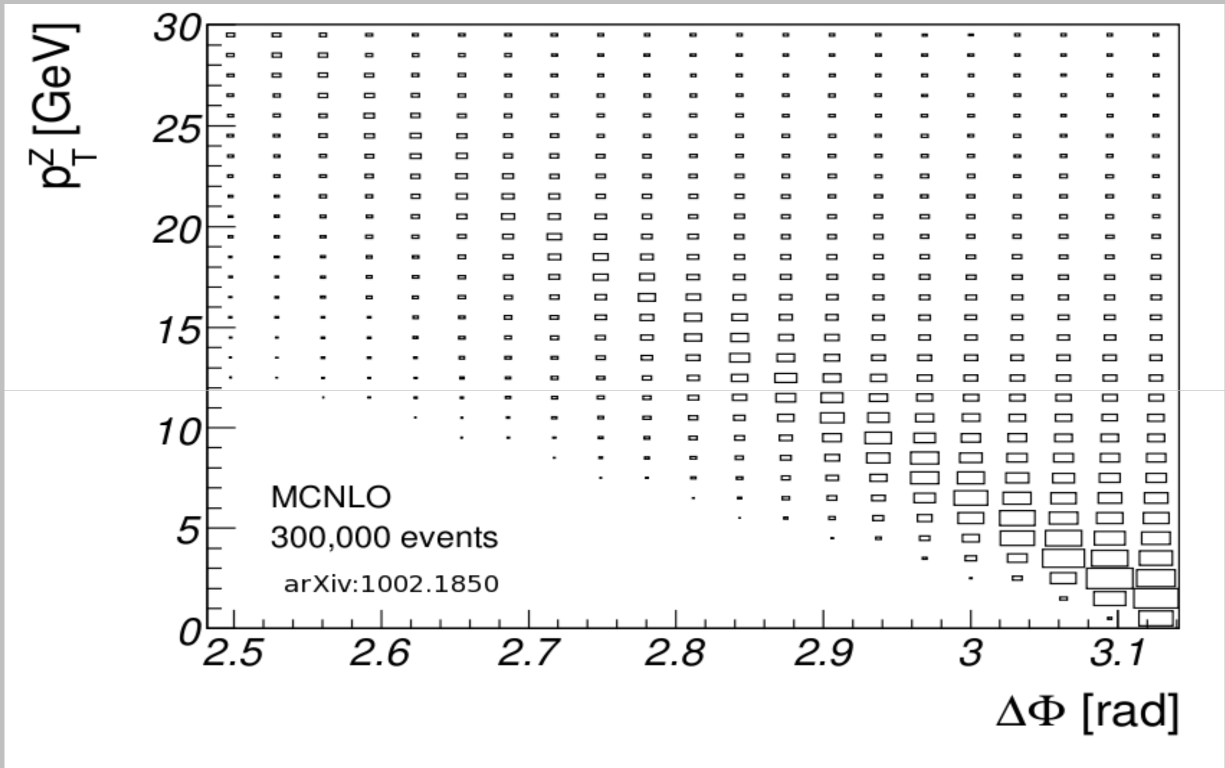


NB: "Start-up" is much more poorly aligned than the actual CMS current conditions (quite close to Ideal based on cosmics and beam taken to date)

Strategies to manage resolution



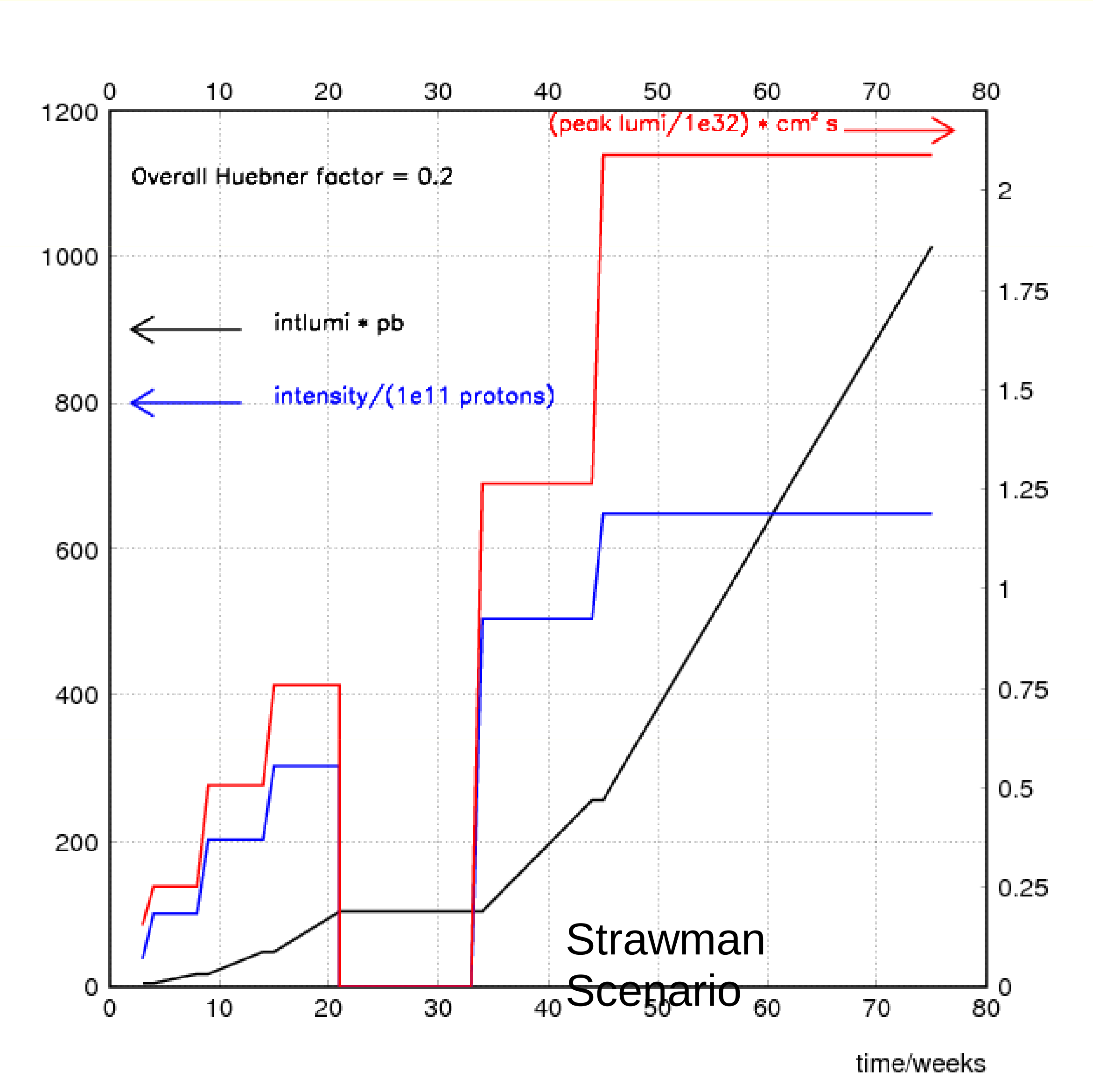




Use MC to predict a transformation matrix between the lepton-lepton azimuthal angle and the Z p_T

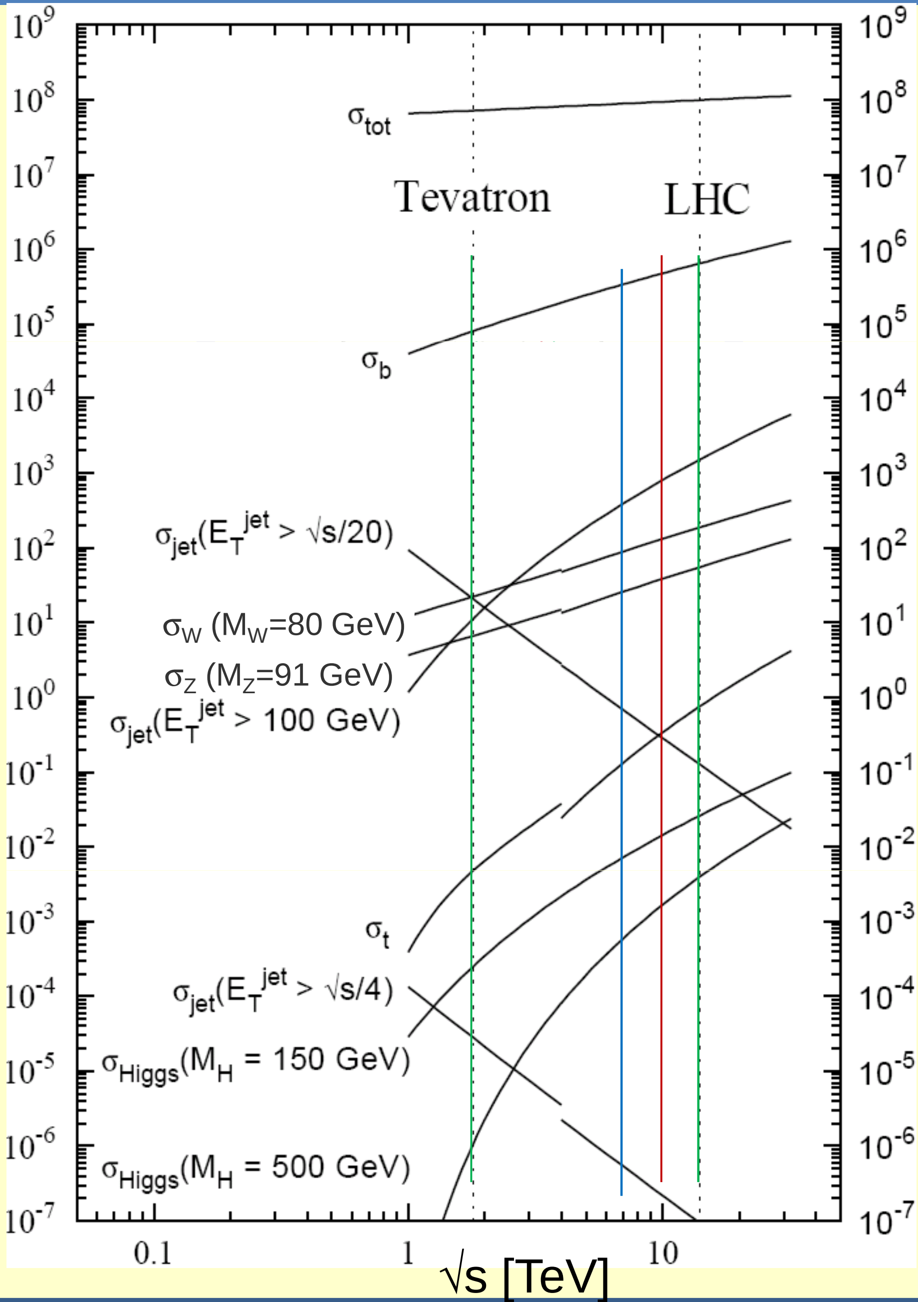
Prospects for 2010, 2011, and beyond...

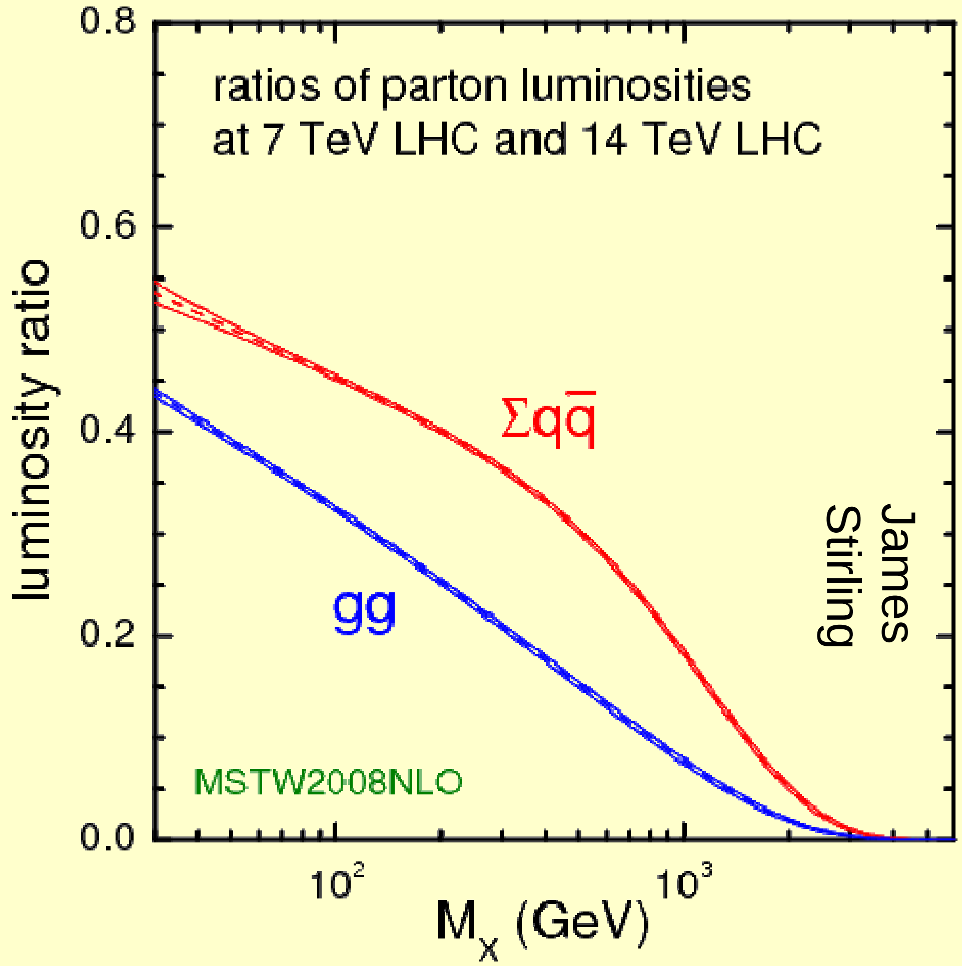
LHC Operations for 2010/2011



- No detailed planning available, but a few crucial features outlined
  - All running at 7 TeV
  - Target ~ 100 pb^{-1} for 2010
  - Target ~ 1 fb^{-1} for 2011
- After 7 TeV run, a long shutdown to prepare for higher energy

Physics Reach for 7 TeV Dataset





- $1\ fb^{-1}$ is enough to pass the Tevatron in everything except perhaps the Higgs search

Conclusions

- The LHC has recently achieved stable collisions at 7 TeV, 3.5 times higher than any previous collider
  - Luminosity is currently low, but will increase steadily through the year
- The 1 fb-1 expected for the 2010/2011 run is sufficient to make significant discoveries in the areas of supersymmetry or other new physics
- The collision environment must be validated before any major new discovery can be proven => requires in situ constraints on the parton density functions and the nature of the target protons at 7 TeV
  - Expect results from these studies in 2010 or early 2011!