Physics 214 UCSD/225a UCSB

Lecture 15

- Parton Density Functions
  - What do they look like?
  - Some processes that measure them.
- parton-parton luminosity
  - how to calculate it.
  - some crude scale factors for LHC vs Tevatron, and how they derive themselves from the PDFs.

Recap of parton structure function

- There is only one F(x).
- It is made out of the incoherent sum of *probabilities for finding a given type i of parton at a given x* in the proton:

$$2xF_1(x) = F_2(x) = \sum_i e_i^2 x f_i(x)$$

- The experimental problem is thus to *extract $f_i(x)$ from a large variety of measurements*.
- We'll mention some of these measurements in a moment.

e-proton vs e-neutron

Isospin for valence quarks.

$u^p = d^n = u(x)$
$d^p = u^n = d(x)$
$s^p = s^n = s(x)$
$u - ubar = u_v$
$d - dbar = d_v$

=>

$$\frac{1}{x} F_2^{ep}(x) = \frac{1}{9}\left[4u_v(x) + d_v(x)\right] + \frac{12}{9} S(x)$$

$$\frac{1}{x} F_2^{en}(x) = \frac{1}{9}\left[u_v(x) + 4d_v(x)\right] + \frac{12}{9} S(x)$$

Here S(x) refers generically to sea quarks, while 12/9 accounts for the sum of e^2 for u,d,s and their anti-quarks in the sea.

Note: charm and beauty is ignored in this discussion, and SU(3) flavor symmetry is assumed for sea partons.

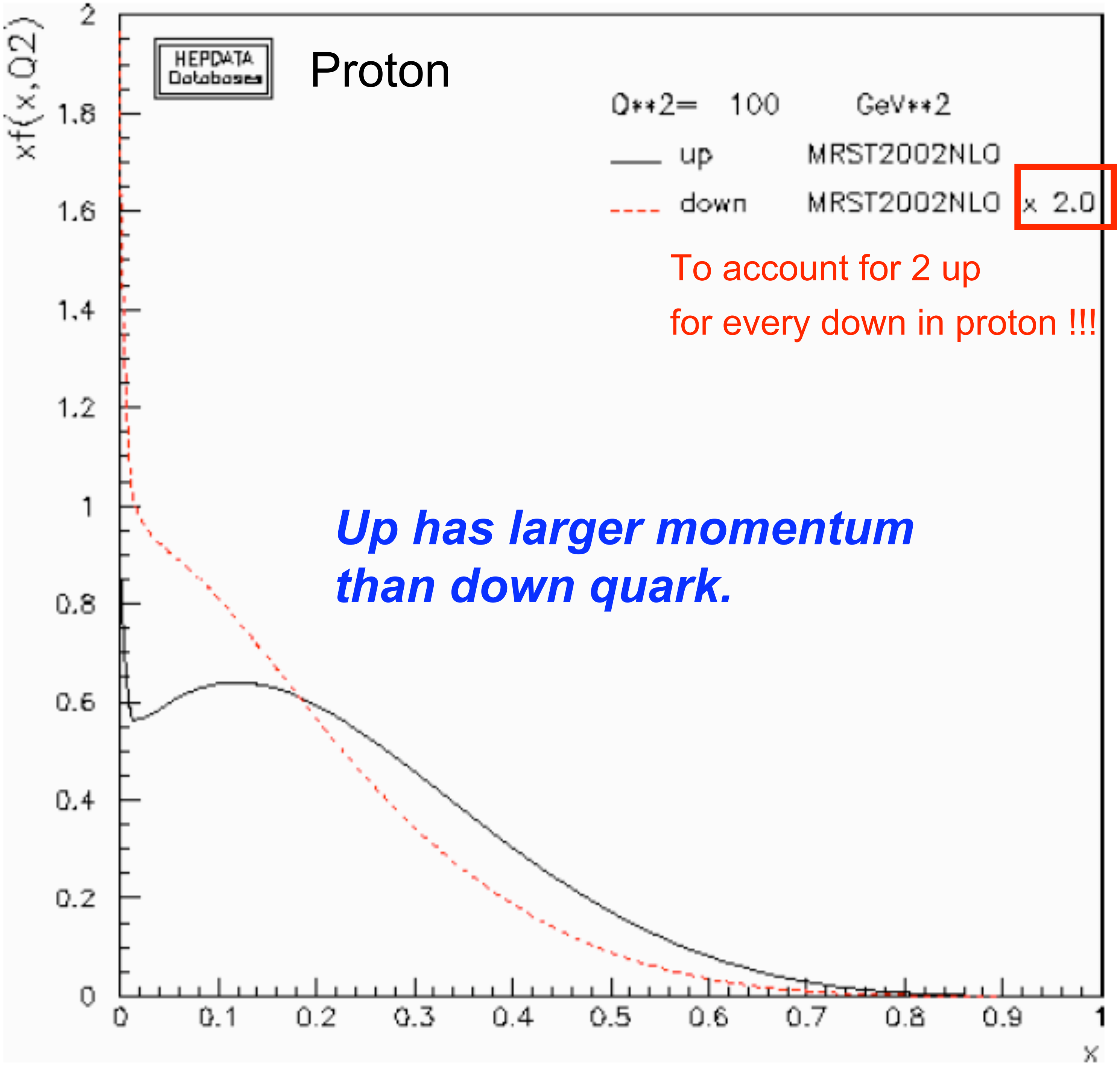
Some observations

- Since gluons create the sea q-qbar pairs, one should expect a momentum spectrum at low x similar to bremsstrahlung:

=> S(x) -> 1/x as x -> 0 at fixed Q^2 .

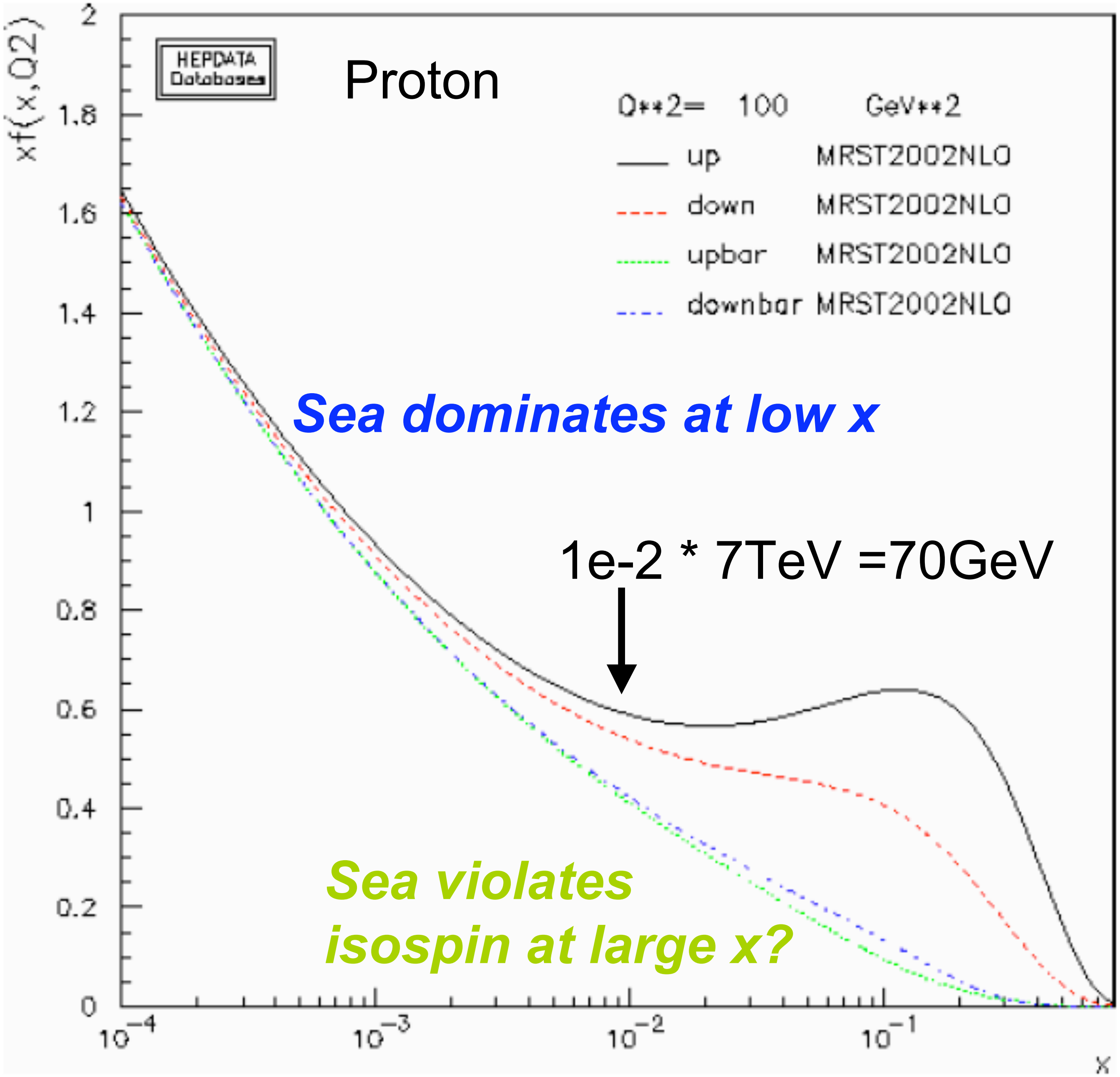
=> F^{ep}/F^{en} -> 1 as x -> 0
=> F^{ep}/F^{en} -> $(4u_v + d_v)/(u_v + 4d_v)$ as x -> 1

- Experimentally, we observe:
  F^{ep}/F^{en} -> 1 as x -> 0 as expected.
  F^{ep}/F^{en} -> 0.25 as x -> 1 => u_v appears to dominate at high x.

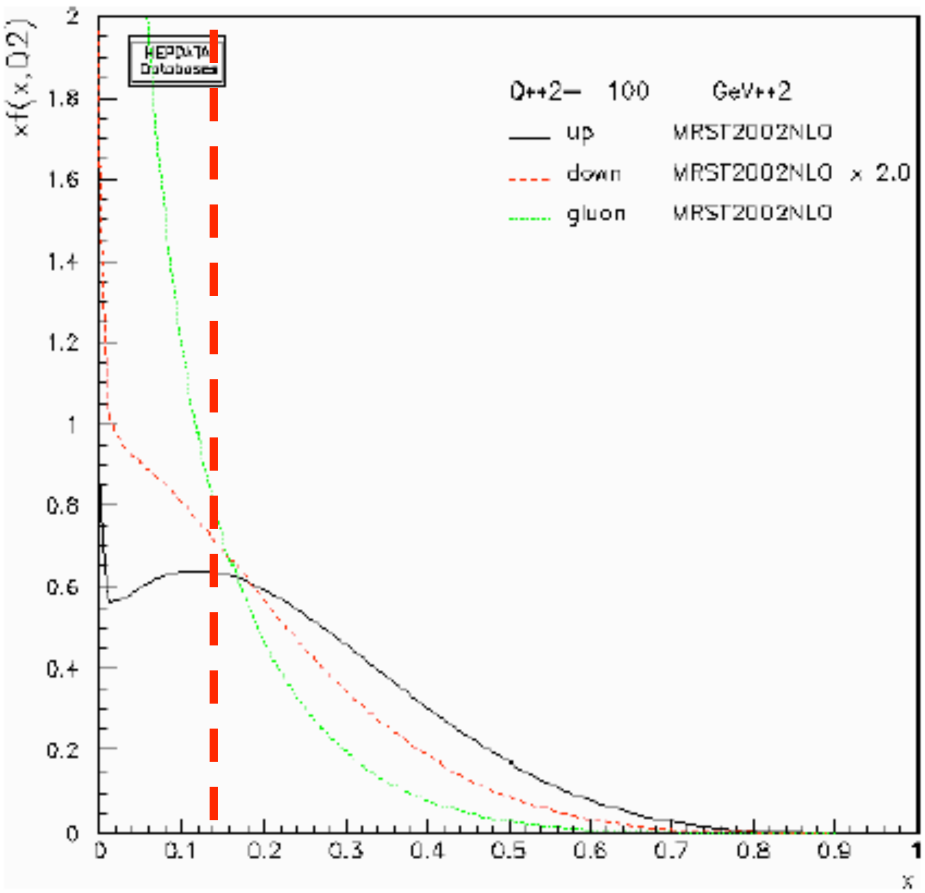


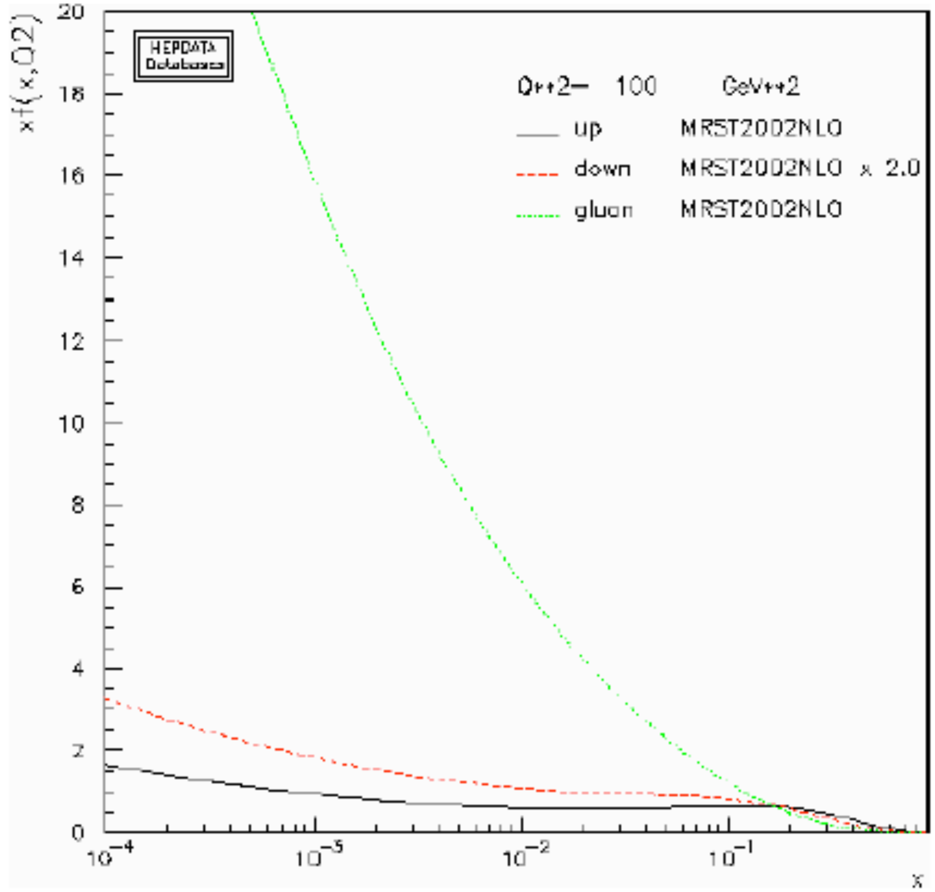
Up has larger momentum than down quark.

PDFs from http://durpdg.dur.ac.uk/hepdata/pdf3.html



A 14TeV collider can be pp instead of ppbar !!!





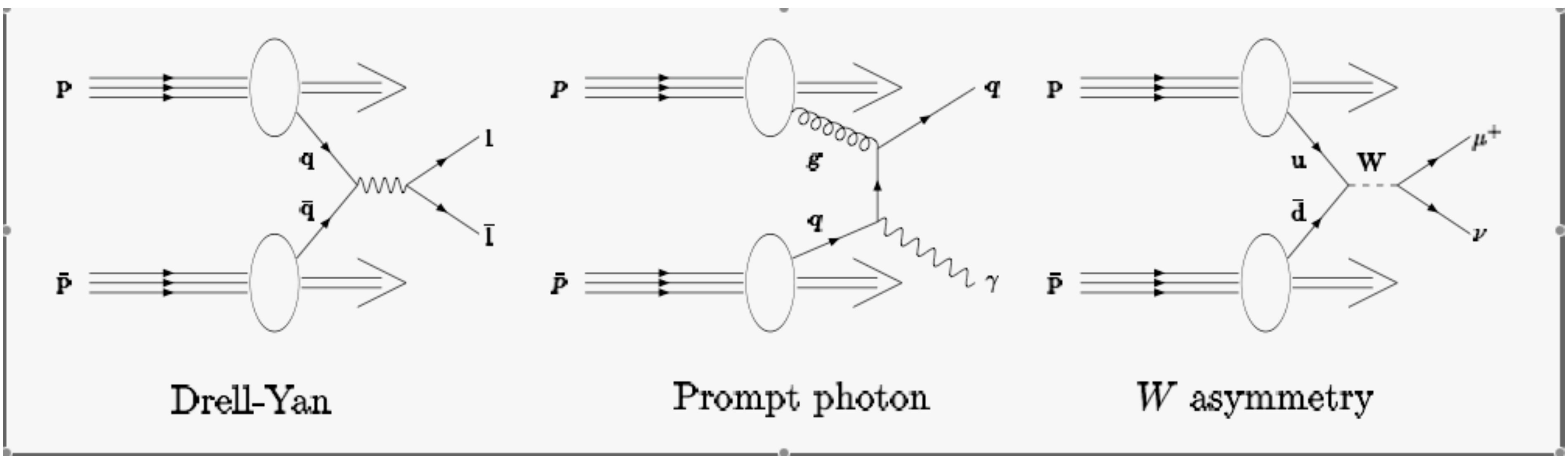
Gluons dominate at low x .

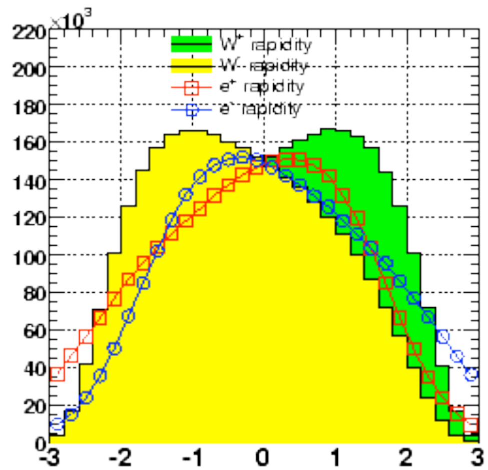
To set the scale, x = 0.14 at LHC is 0.14 * 7TeV = 1TeV

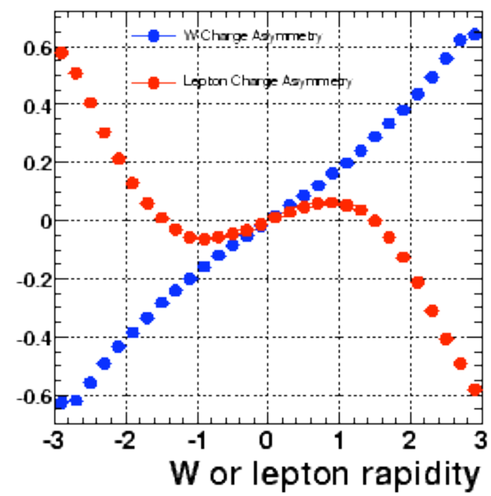
=> The LHC is a gluon collider !!!

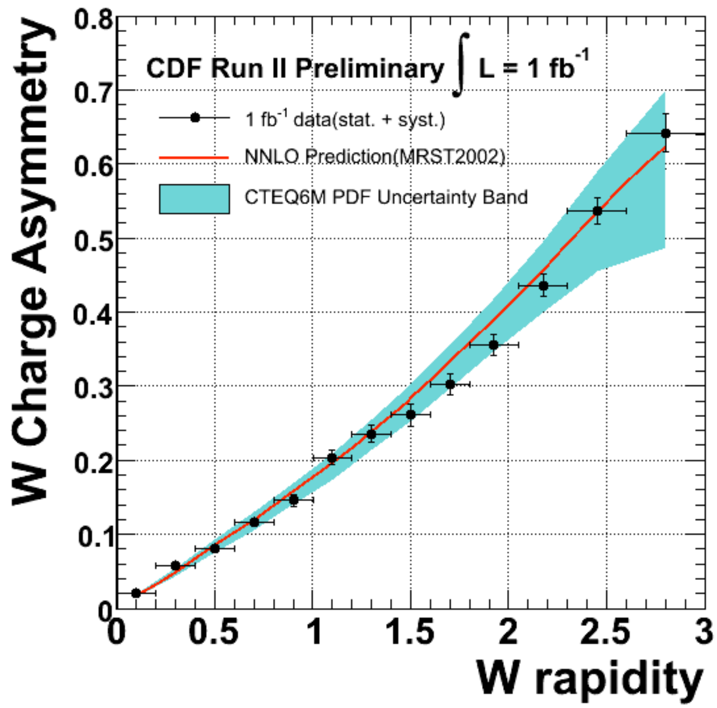
Ways to measure PDFs

- The HERA collider collides electrons on protons. This has produced a wealth of data.
  - Including measurement of the charm content of the proton by reconstructing charmed mesons in the final state.
- In addition, hadron collider data from these processes are used to fit PDFs:



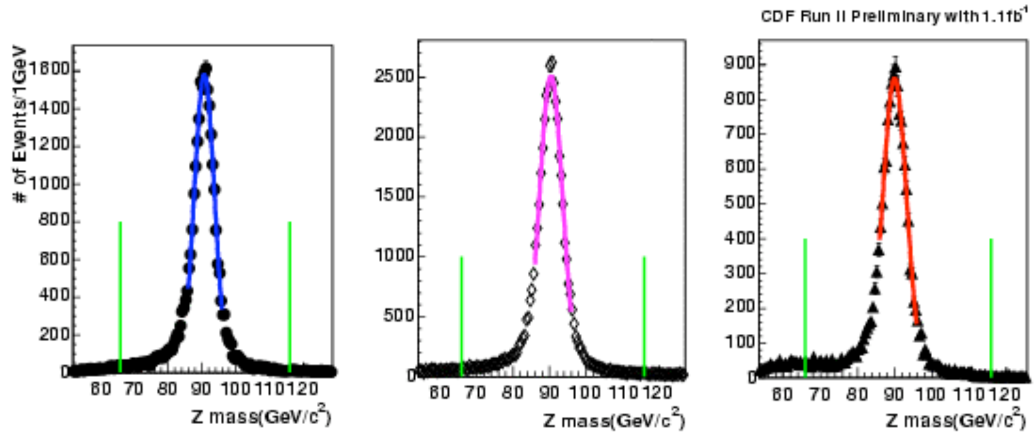


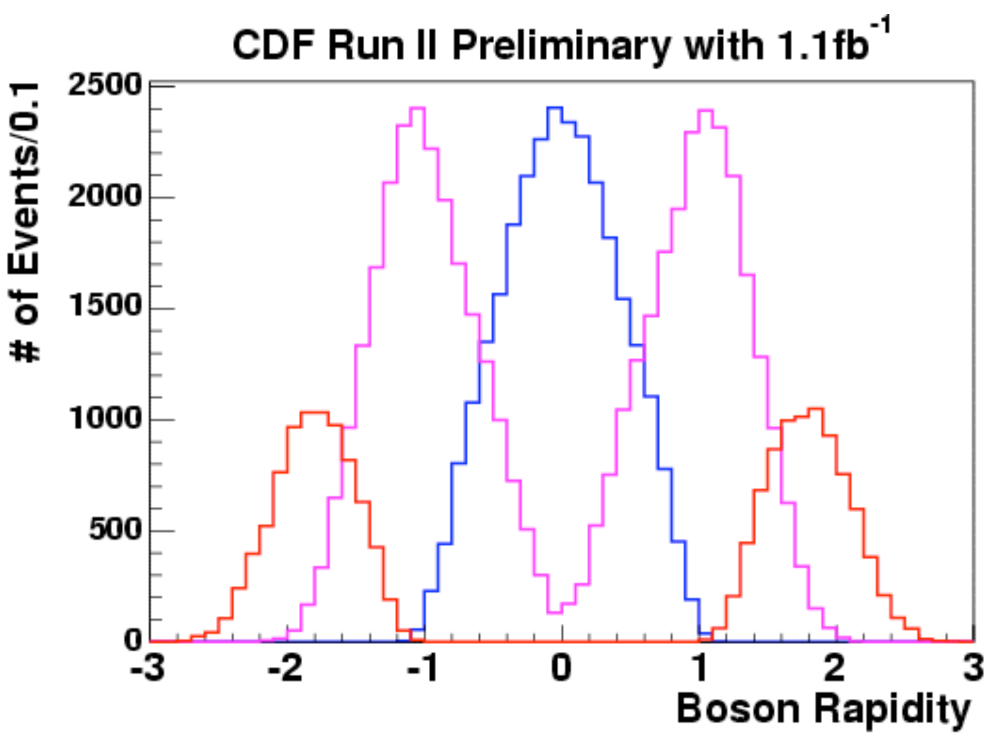




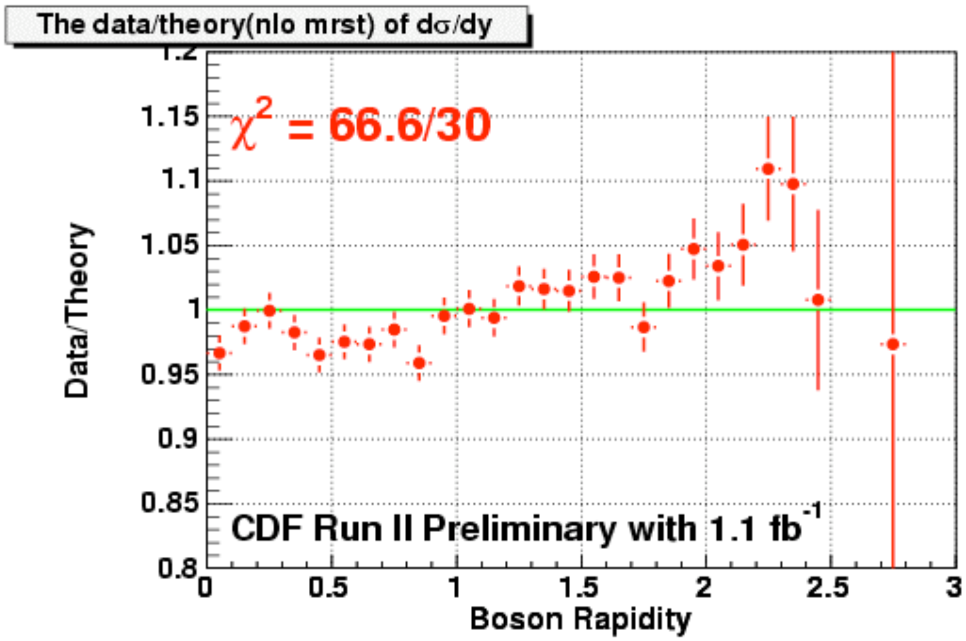
Most sensitive probe of d/u momentum ratio in proton at $Q^2 \sim M^2_W$.

Drell-Yan at Z pole
from CDF





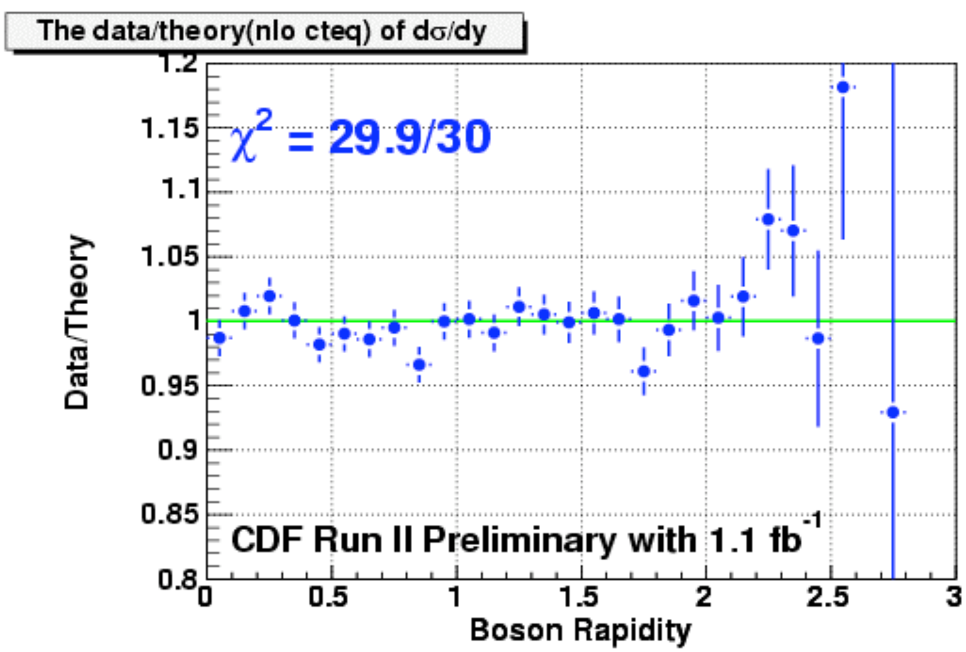
Different detection topologies:
Central-Central,
Central-forward,
Forward-forward



DY vs rapidity from CDF for two different PDF sets.

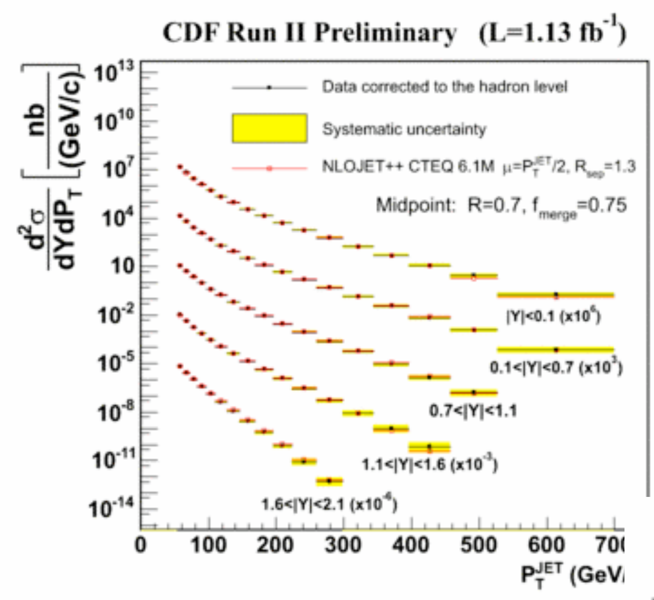
In both cases the total cross section is normalized to what's seen in data.

The differences are small but noticeable.



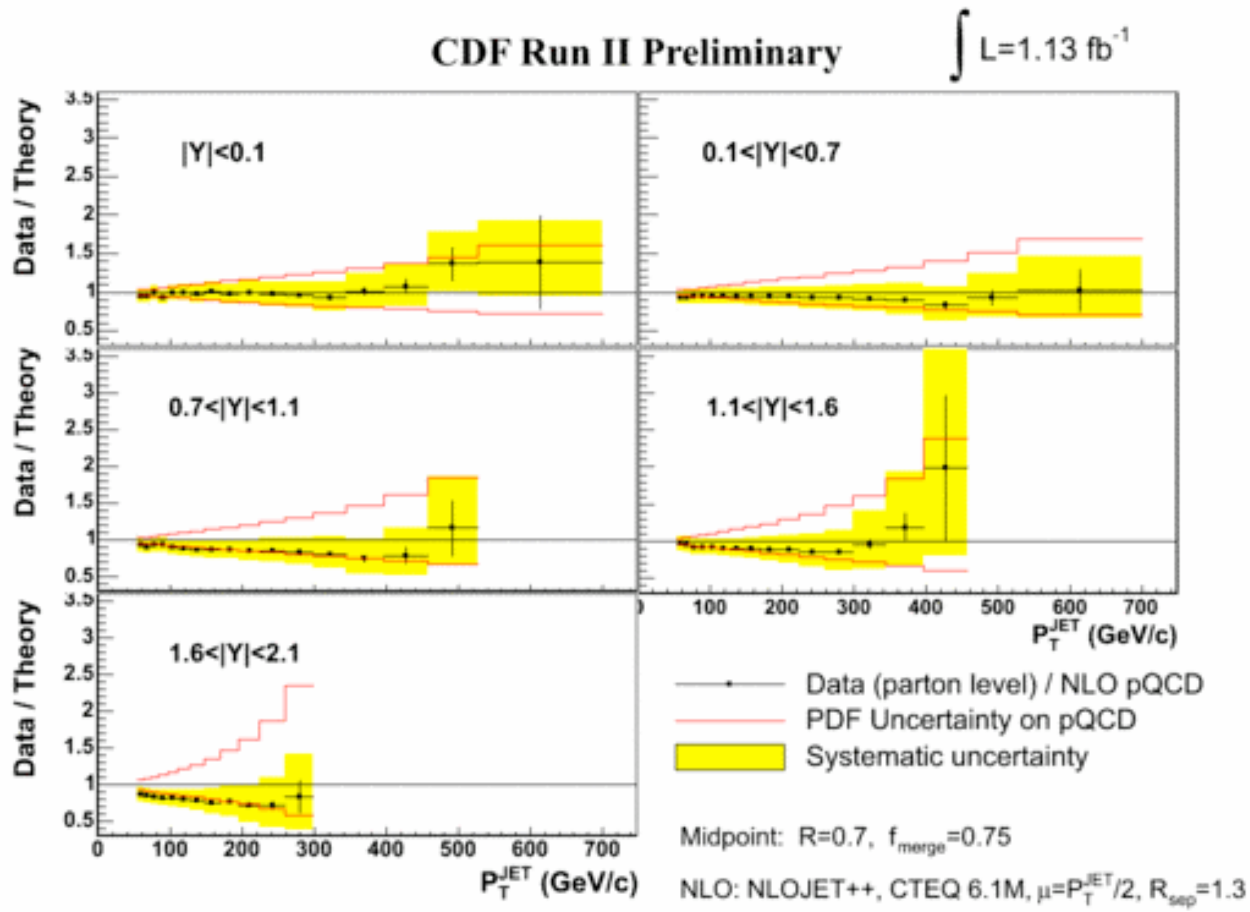
Inclusive Jet production at CDF vs pT for different rapidity ranges.

Yellow = experiment systematics
Black = experiment data & stats
Red = PDF uncertainty

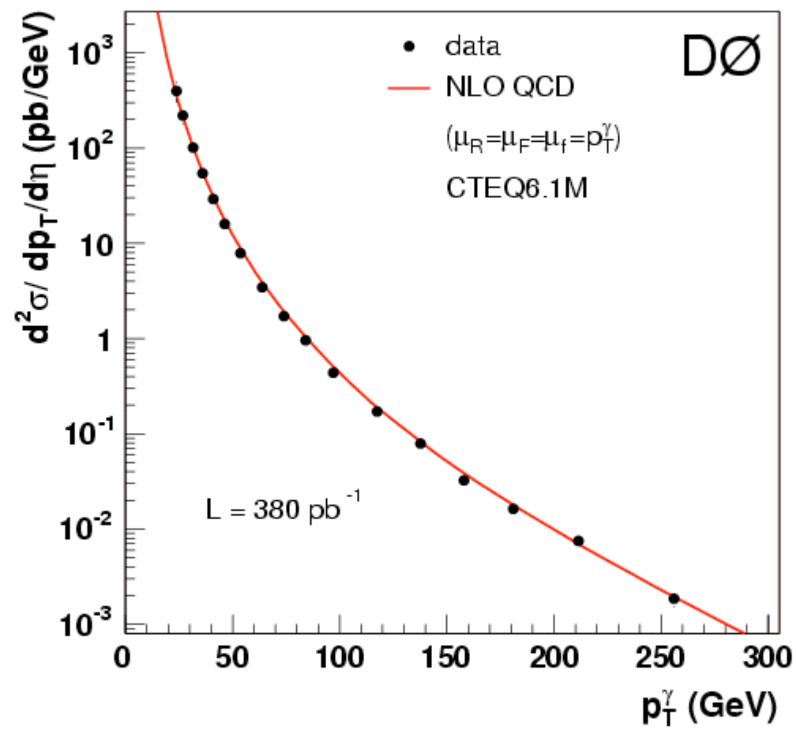


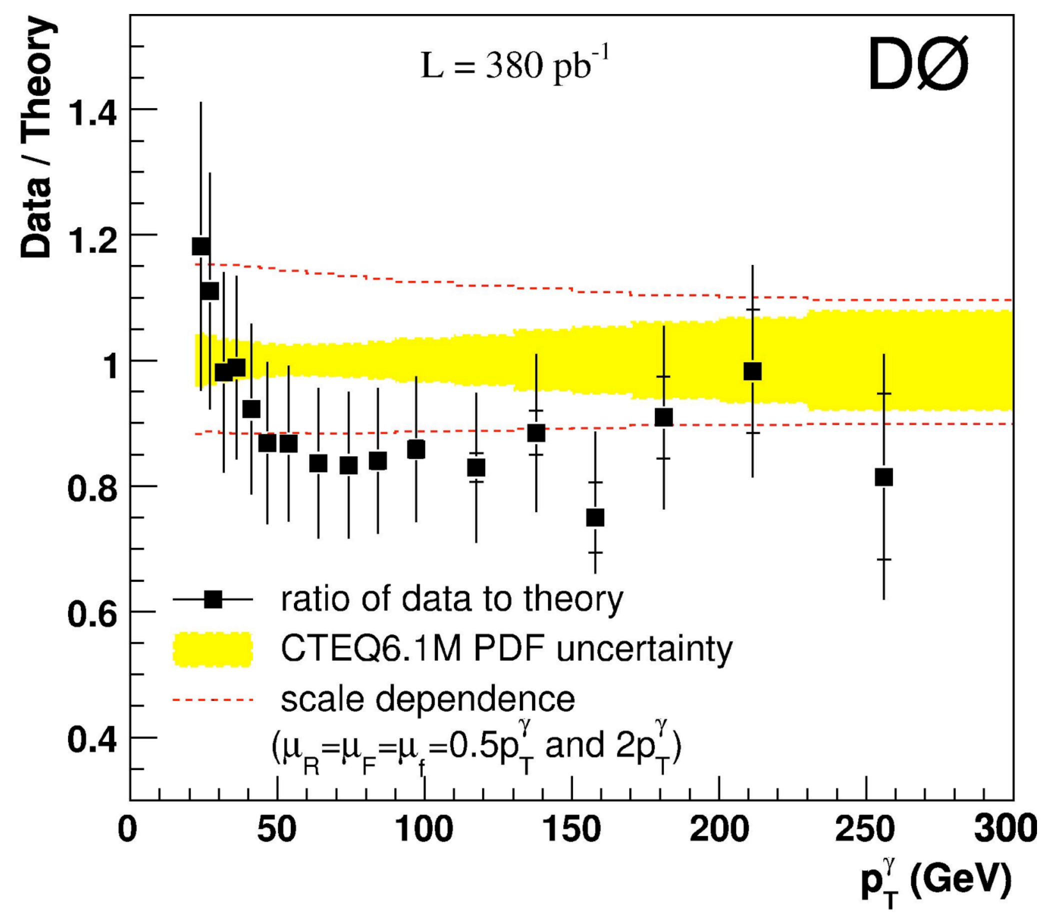
PDF uncertainty significant for large rapidity.

Note:
500GeV => x=0.5

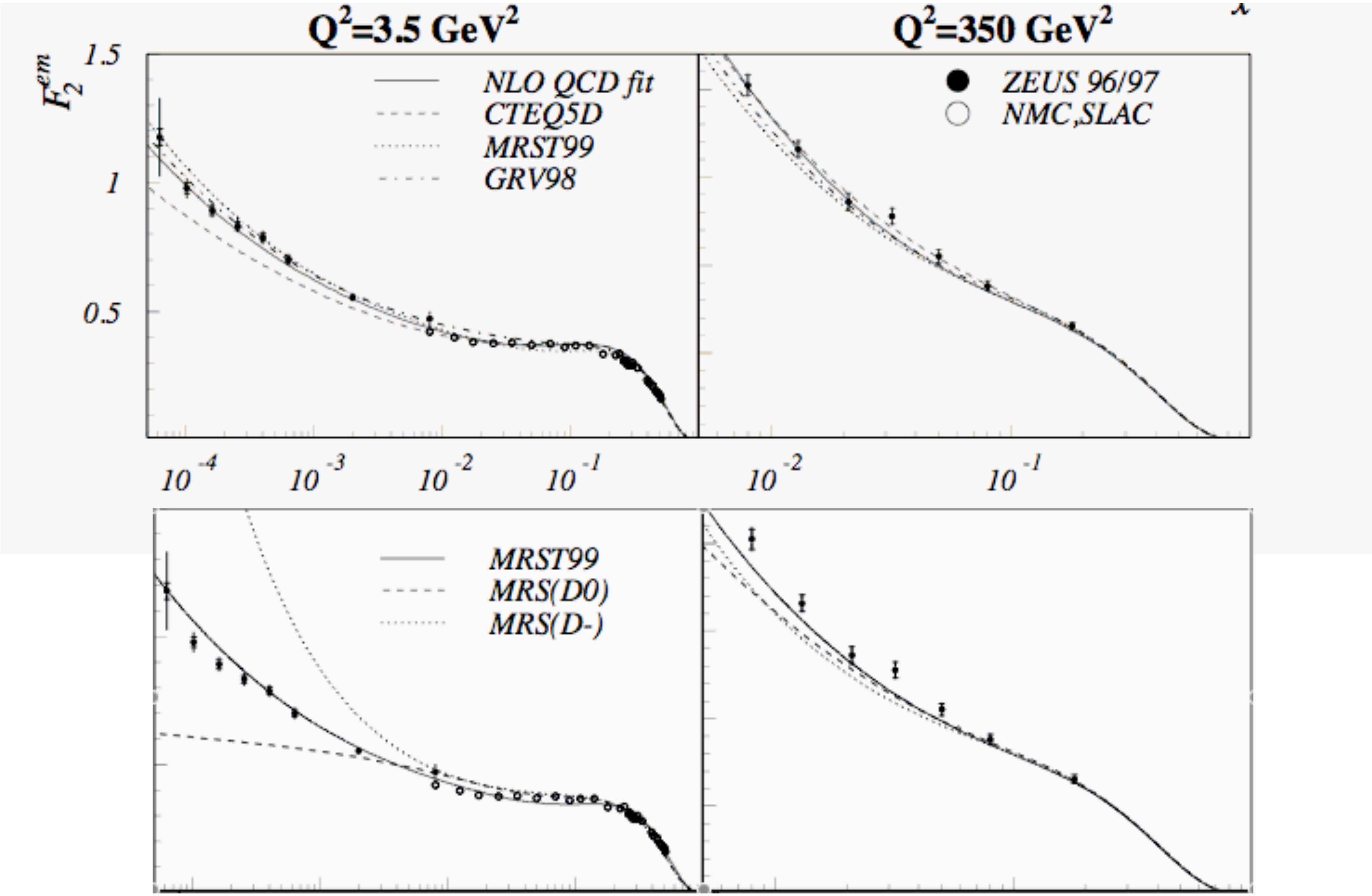


Prompt photons at D0





Comparing e-proton data with PDFs.
Top = state of the art ~2001, includes early HERA data.
Bottom = history for one set of PDFs compared to 2001 data.



pp (or ppbar) collision

- Use Feynman diagrams to calculate σ for collision of partons of type i and j at CM energy E. Call this:

$$\hat{\sigma}_{ij}\left(\hat{s}\right) \equiv \hat{\sigma}_{ij}\left(E^2\right)$$

- To get the cross section of pp, I then need to integrate over all possible x_i,x_j with: $\hat{s} = x_i x_j s$
- In other words, a pp collider is a “broadband collider” spanning a wide range of CM energies, as well as types of colliding partons (!), with propabilities given by the product of PDF of the types of particles colliding.

Let's explore this formally

$$\frac{d\sigma(pp \to f)}{d\hat{s}} = \sum_{ij} \hat{\sigma}_{ij}(\hat{s}) \int_0^1 \int_0^1 dx_i dx_j f_i(x_i) f_j(x_j) \delta(\hat{s} - x_i x_j s)$$

$$= \sum_{ij} \frac{\hat{\sigma}_{ij}(\hat{s})}{\hat{s}} \int_0^1 \int_0^1 dx_i dx_j f_i(x_i) f_j(x_j) \delta\left(1 - x_i x_j \frac{s}{\hat{s}}\right)$$

$$\tau = \frac{\hat{s}}{s}$$

<- to save some writing.

$$\frac{d\sigma(pp \to f)}{d\tau} = \sum_{ij} \frac{\hat{\sigma}_{ij}(\hat{s})}{\tau} \int_0^1 \int_0^1 dx_i dx_j f_i(x_i) f_j(x_j) \delta\left(1 - \frac{x_i x_j}{\tau}\right)$$

$$\frac{d\sigma(pp \to f)}{d\tau} = \sum_{ij} \frac{\hat{\sigma}_{ij}(\hat{s})}{\tau} \int_\tau^1 dx_i \frac{\tau}{x_i} f_i(x_i) f_j\left(\frac{\tau}{x_i}\right)$$

Cross section as a function of parton-parton Luminosity

$$\frac{d\sigma\left(pp \to f\right)}{d\tau} = \sum_{ij} \frac{\hat{\sigma}_{ij}\left(\hat{s}\right)}{\tau} \int_{\tau}^{1} dx_i \frac{\tau}{x_i}{}_i \, f_i(x_i) f_j\left(\frac{\tau}{x_i}\right)$$

$$\boxed{\frac{d\sigma\left(pp \to f\right)}{d\tau} = \sum_{ij} \frac{dL_{ij}}{d\tau} \hat{\sigma}_{ij}\left(\hat{s}\right)}$$

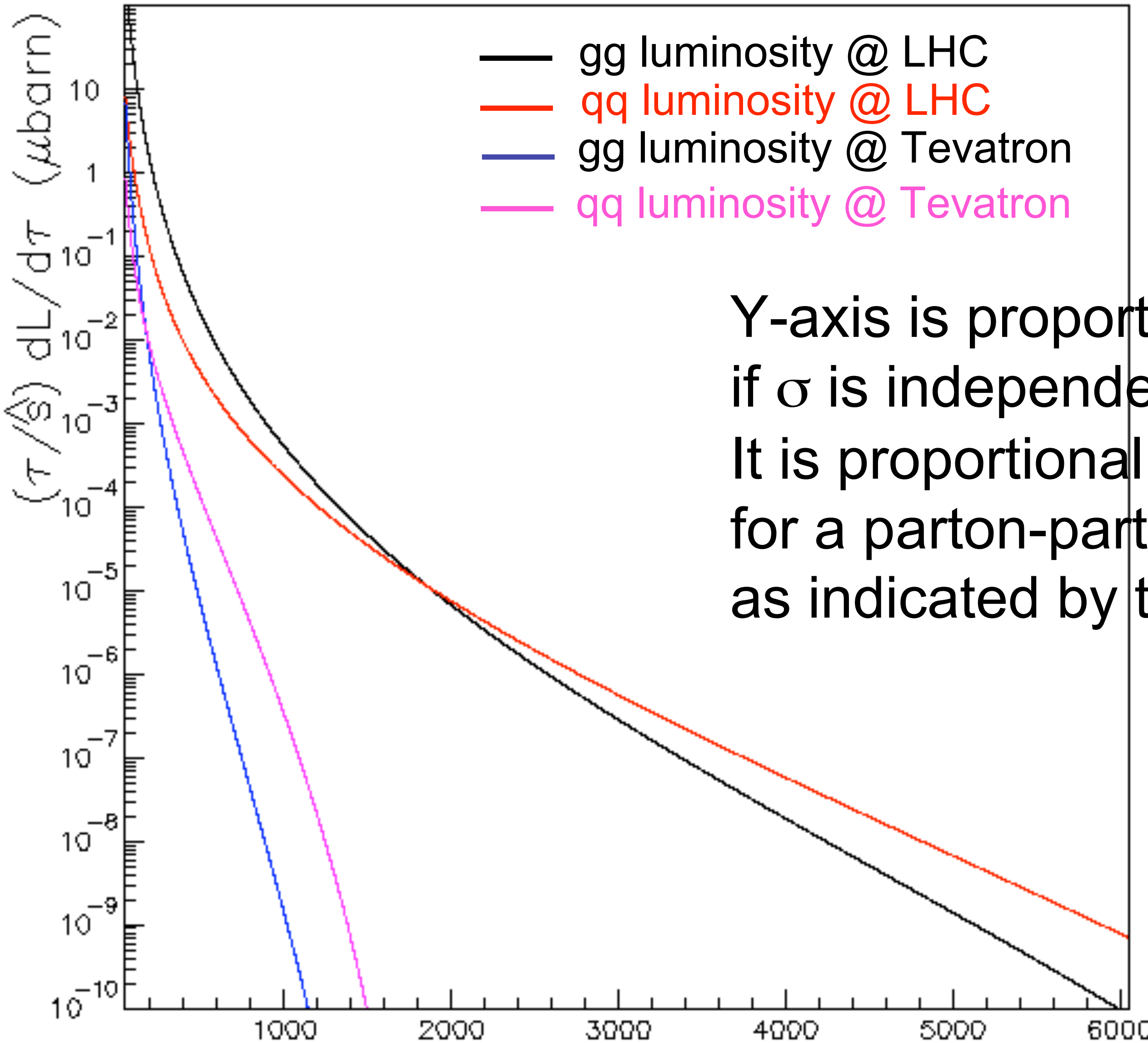
$$\frac{dL_{ij}}{d\tau} = \frac{1}{1+\delta_{ij}} \int_{\tau}^{1} \frac{dx}{x} \left[f_i(x) f_j\left(\frac{\tau}{x}\right) + f_i\left(\frac{\tau}{x}\right) f_j(x) \right]$$

Discussion of parton-parton Luminosity

$$\frac{dL_{ij}}{d\tau} = \frac{1}{1+\delta_{ij}} \int_{\tau}^{1} \frac{dx}{x} \left[f_i(x) f_j\left(\frac{\tau}{x}\right) + f_i\left(\frac{\tau}{x}\right) f_j(x) \right]$$

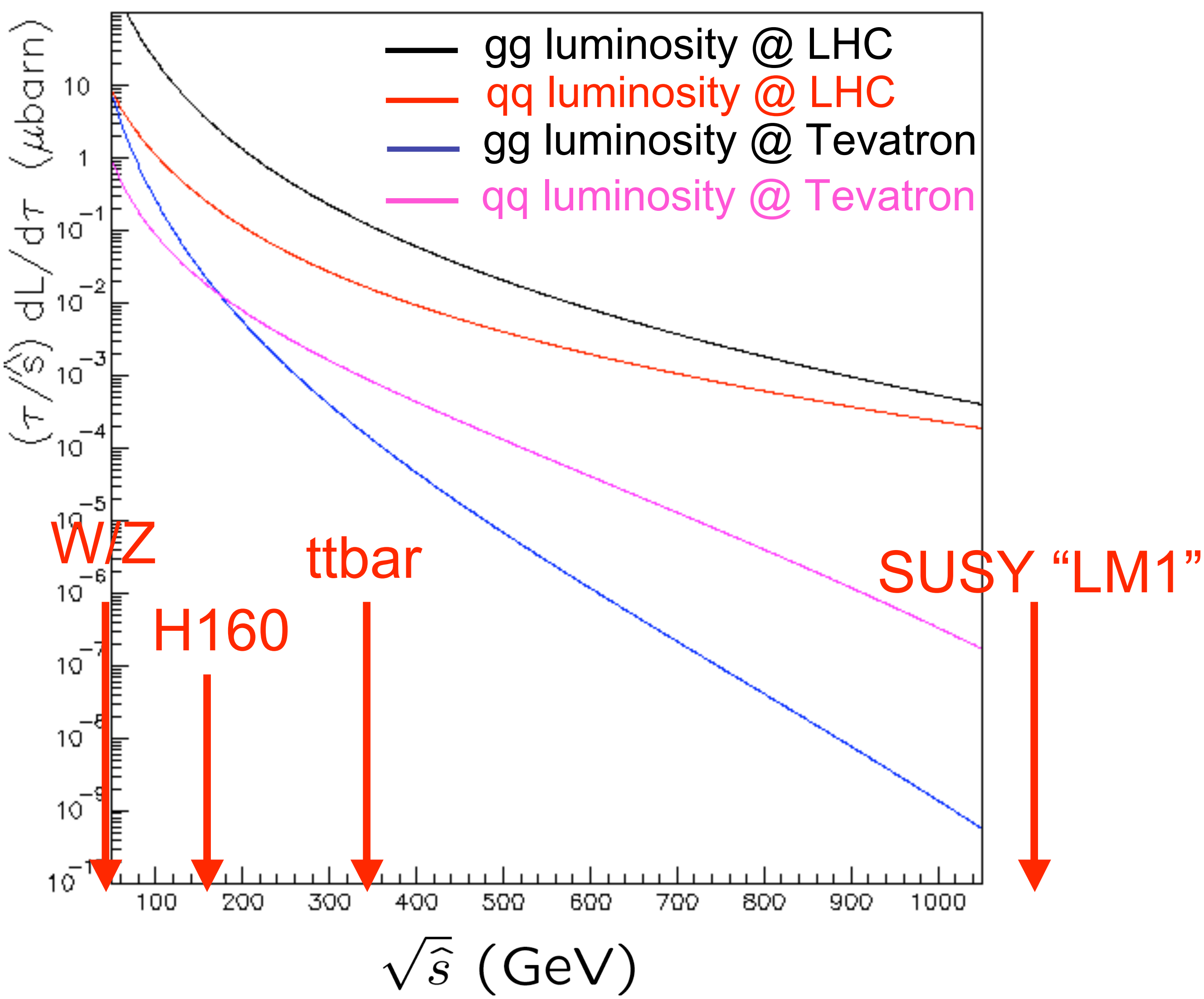
- Function of dimensionless quantity:
  - Scaling => independent of CM energy of proton proton collisions.
- However, $\hat{\sigma}_{ij}(\hat{s}) \equiv \hat{\sigma}_{ij}(E^2)$ depends on E. The collider characteristics only help us understand the energy scale E^2 accessible given an S for proton-proton collisions.

Adding in the Scale

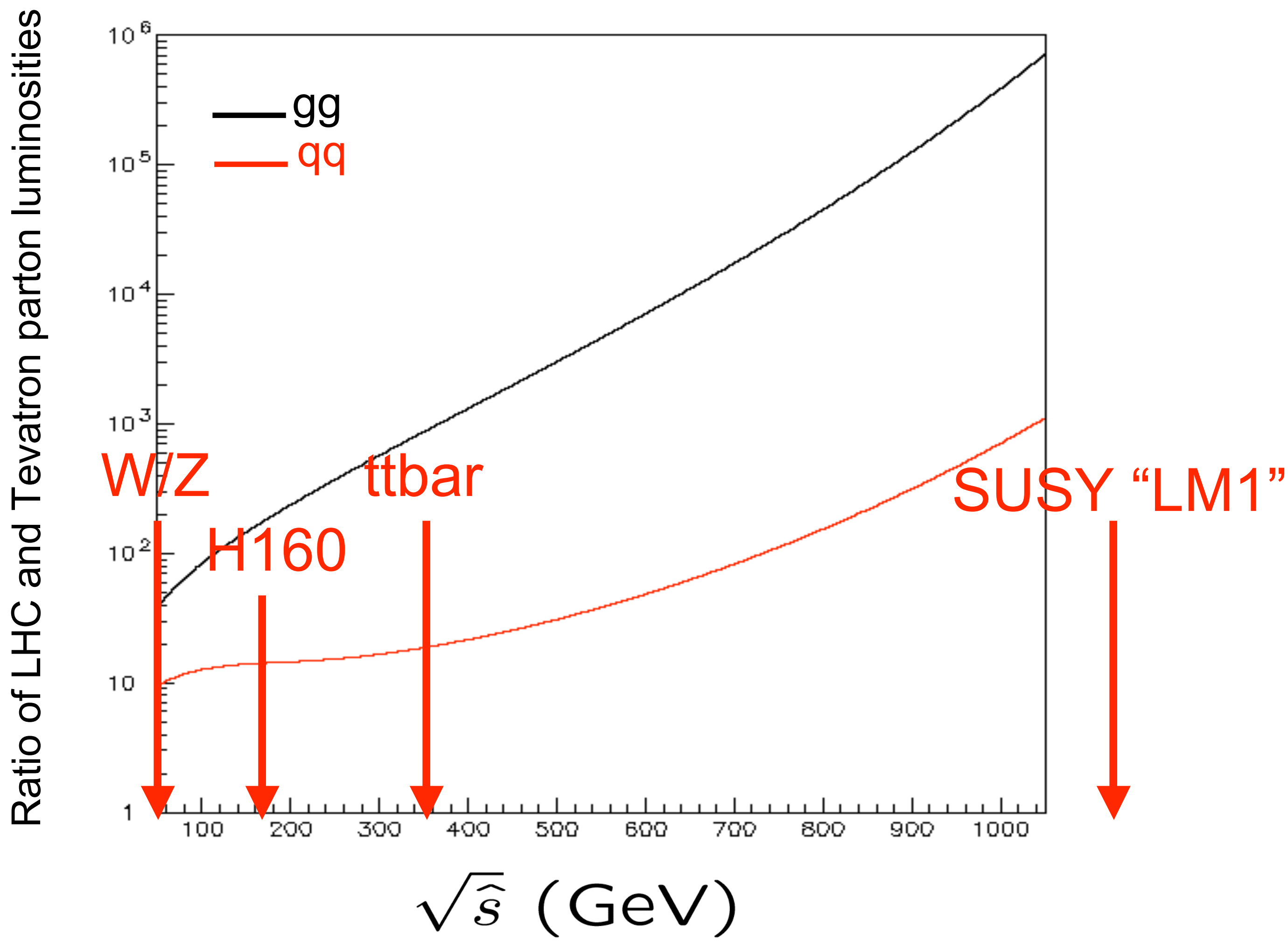


Y-axis is proportional to σ
if σ is independent of $\hat{s}$
It is proportional to probability
for a parton-parton collision with $\hat{s}$
as indicated by the x-axis.

Zooming-in on the < 1 TeV region



LHC vs Tevatron



1st (simplistic) rule of thumb:

- For 1 TeV gg processes, 1 fb^{-1} at FNAL is like 1 nb^{-1} at LHC
- For 1 TeV qq processes, 1 fb^{-1} at FNAL is like 1 pb^{-1} at LHC

Cross sections at 1.96TeV versus 14TeV Tevatron vs LHC

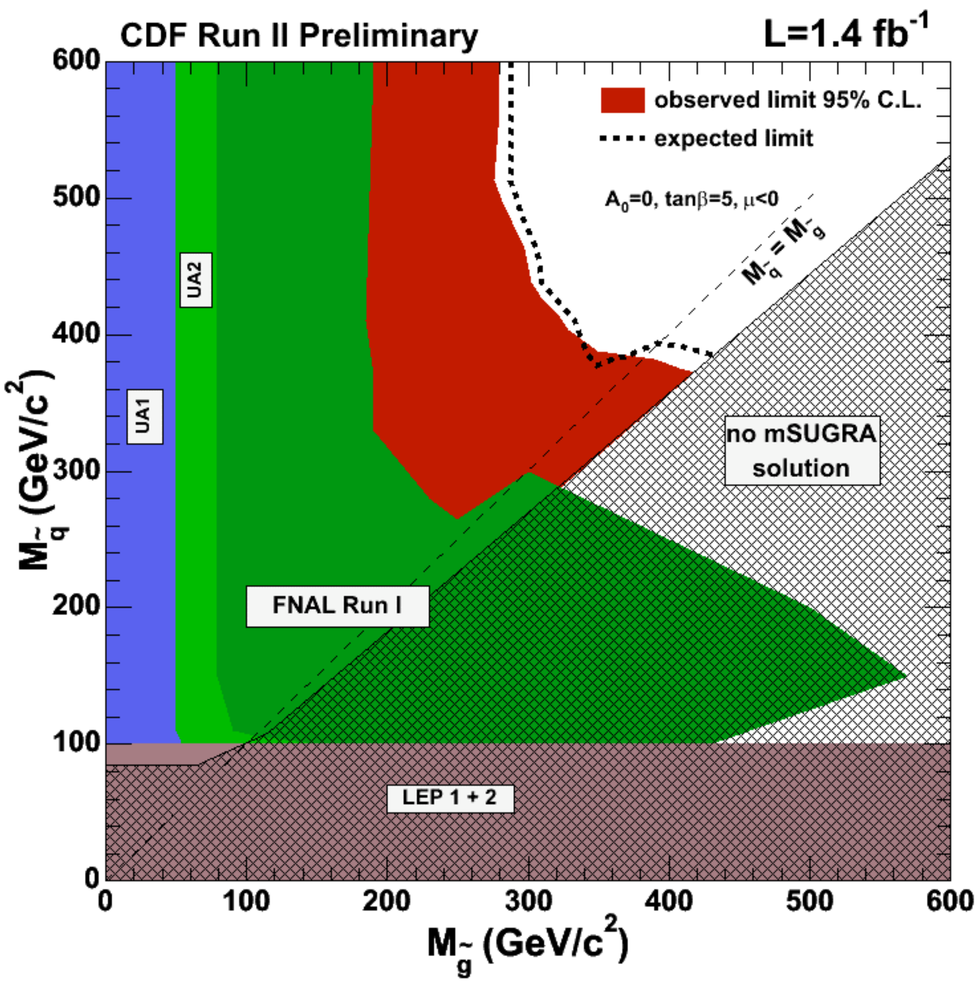
	Cross section		Ratio
$Z \rightarrow \mu\mu$	260pb	1750pb	6.7
WW	10pb	100pb	10
H_{160GeV}	0.2pb	25pb	125
$mSugra_{LM1}$	0.0006pb	50pb	80,000

At $10^{32}cm^{-2}s^{-1}$ CMS might accumulate $10pb^{-1}$ in one day!

… and SUSY might not exist in nature.

Example new physics Scenario: mSugra at CDF and CMS

Run 1 to Run 2 is x10 in lumi.



CMS did detailed study for "LM1" point with

$m_{squark} = 560$GeV

$m_{gluino} = 610$GeV

Could be discovered with only $\sim 14pb^{-1}$ in ll & MET & jj IFF detector and bkg were sufficiently understood!

With $14pb^{-1}$ we will have:

- ~ 25,000 $Z \rightarrow \mu^+\mu^-$
- ~ 500 top dilepton

⇒Ready for Discovery while commissioning ongoing!

Dijet Mass from CDF