B. Foster

Oxford

DIS 2008

UCL

April 11th 2008

Thanks to

plenary

speakers

& convenors

for help

& advice

Disclaimer

- core of DIS is the structure of the proton – this will be core of my summary – this in itself is enormous subject – spreading across HERA, ν experiments, Tevatron and LHC - it also contains diffraction and VM production, spin.

  Many other topics discussed at this conference - QGP, Higgs production, exotic physics & searches – I will touch on them briefly but not do them justice.

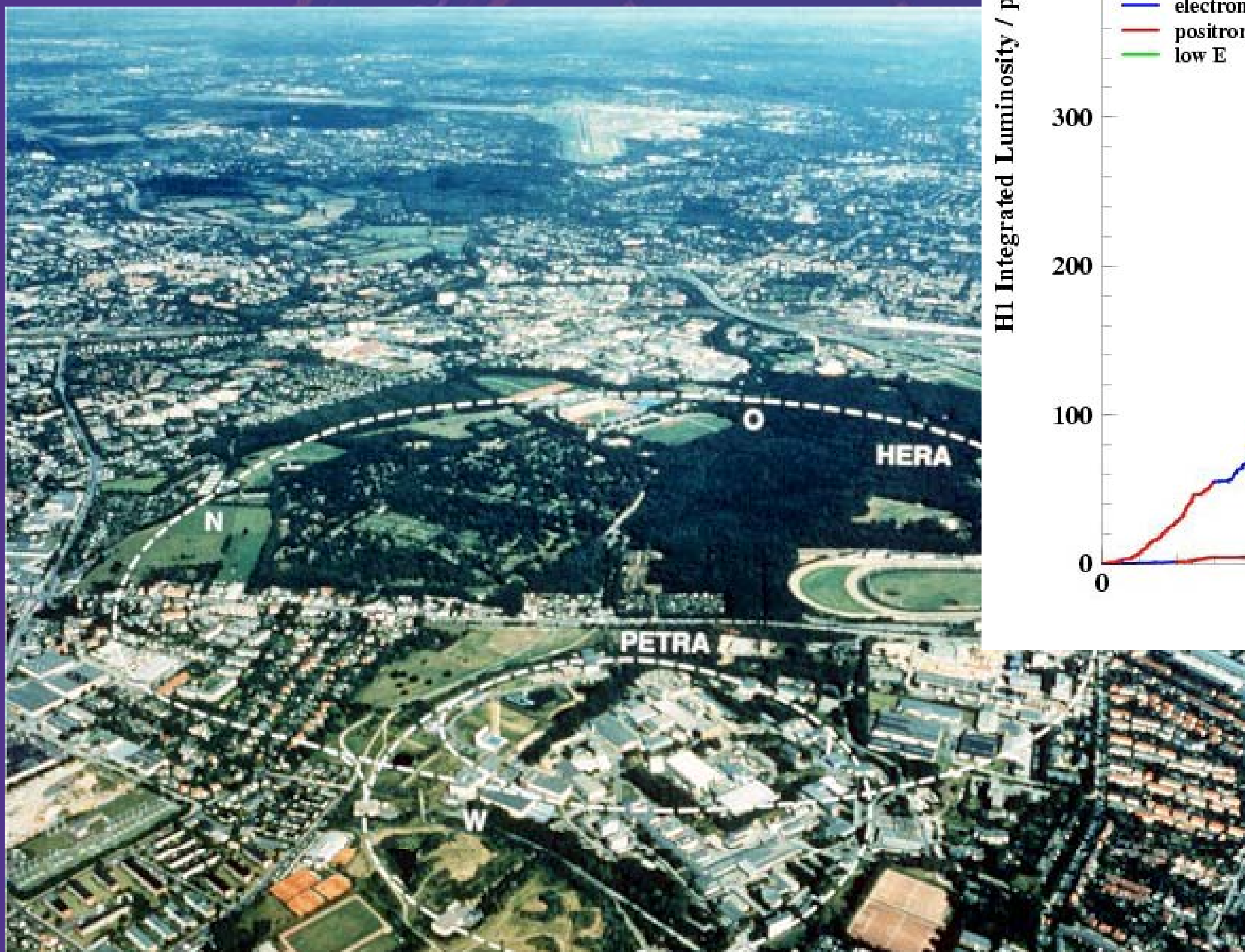
The Bottom Line

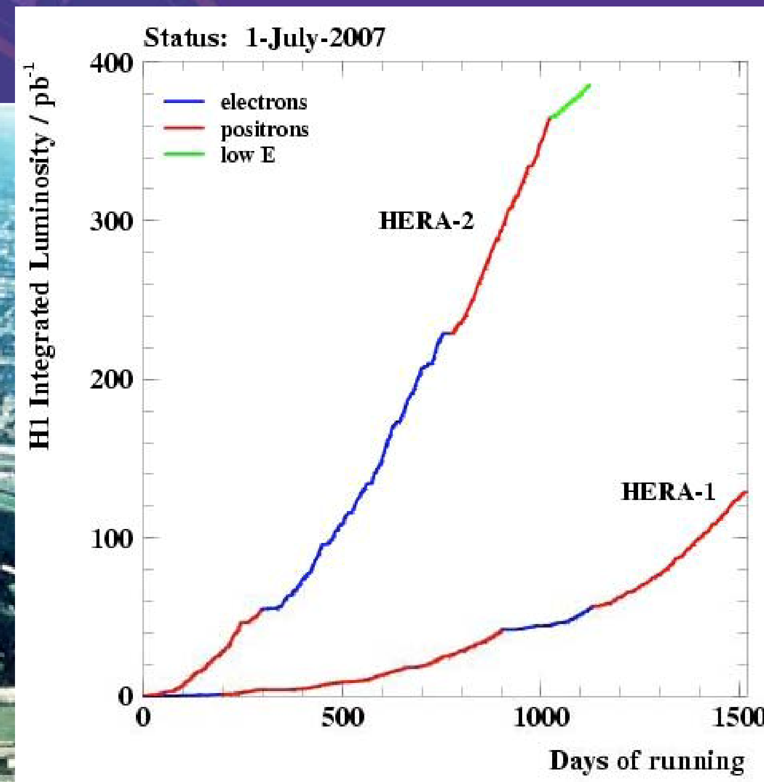
- **What message should you take home from this conference?**

  1) F_L measurement is a major achievement
  2) H1 & ZEUS working together make the difference
  3) The future is bright!

HERA

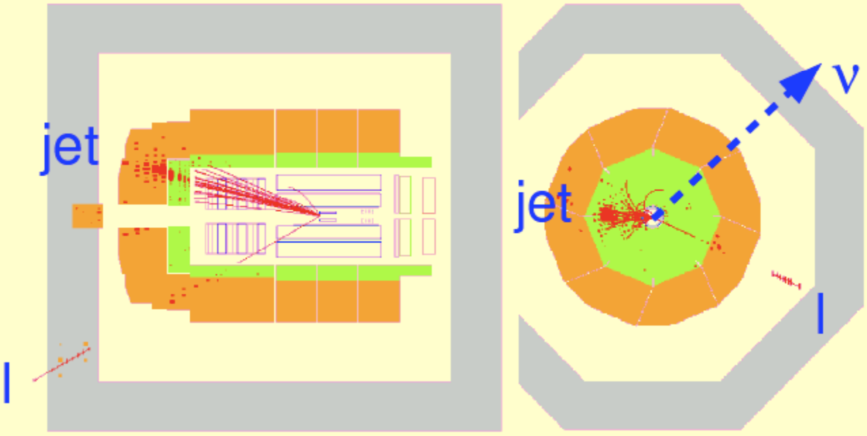
- Gone but not forgotten





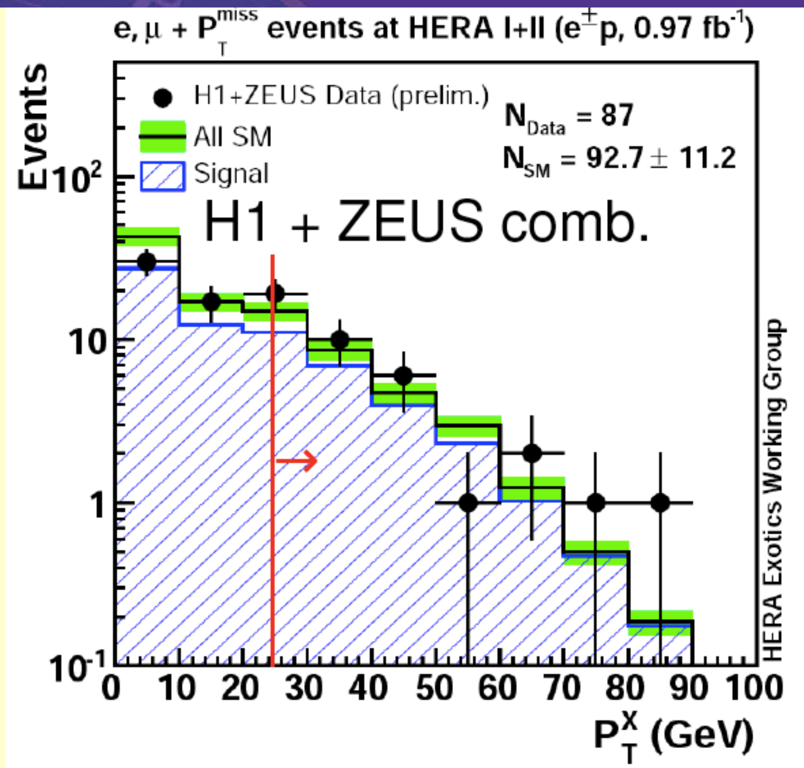
Leptons and Missing p_t

- topology: (H1 Collab., Phys. Lett. B561 (2003) 241)



signature for single W prod.

ep → eX W
↳ lν



Results for $p_T^X > 25$ GeV (H1/ZEUS e±p):

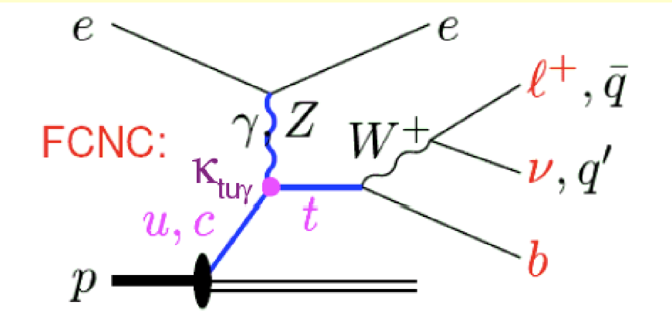
electron	muon	electron + muon
16 (13.3 ± 1.7)	13 (12.0 ± 0.24)	29 (25.3 ± 3.2)

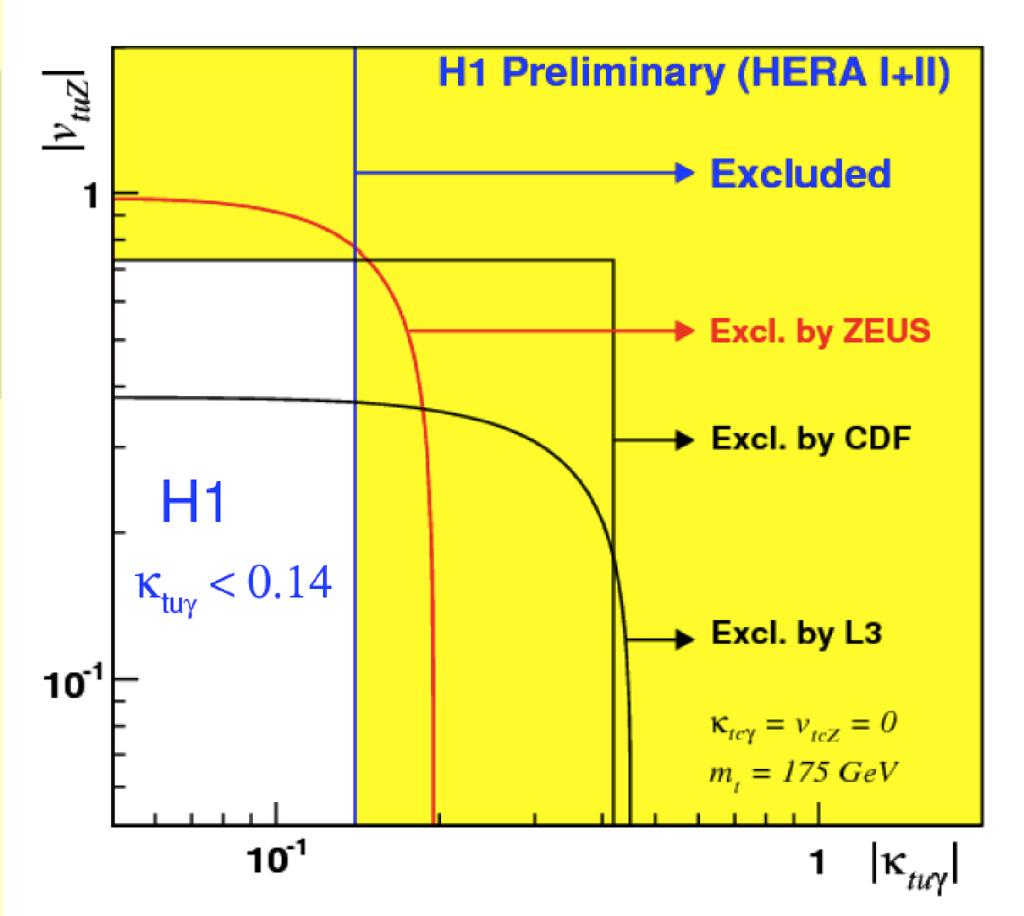
→ H1/ZEUS combined data consistent with SM prediction

FCNC & Top production

SM cross section negligible at HERA

→ high sensitivity to anomalous top quark production





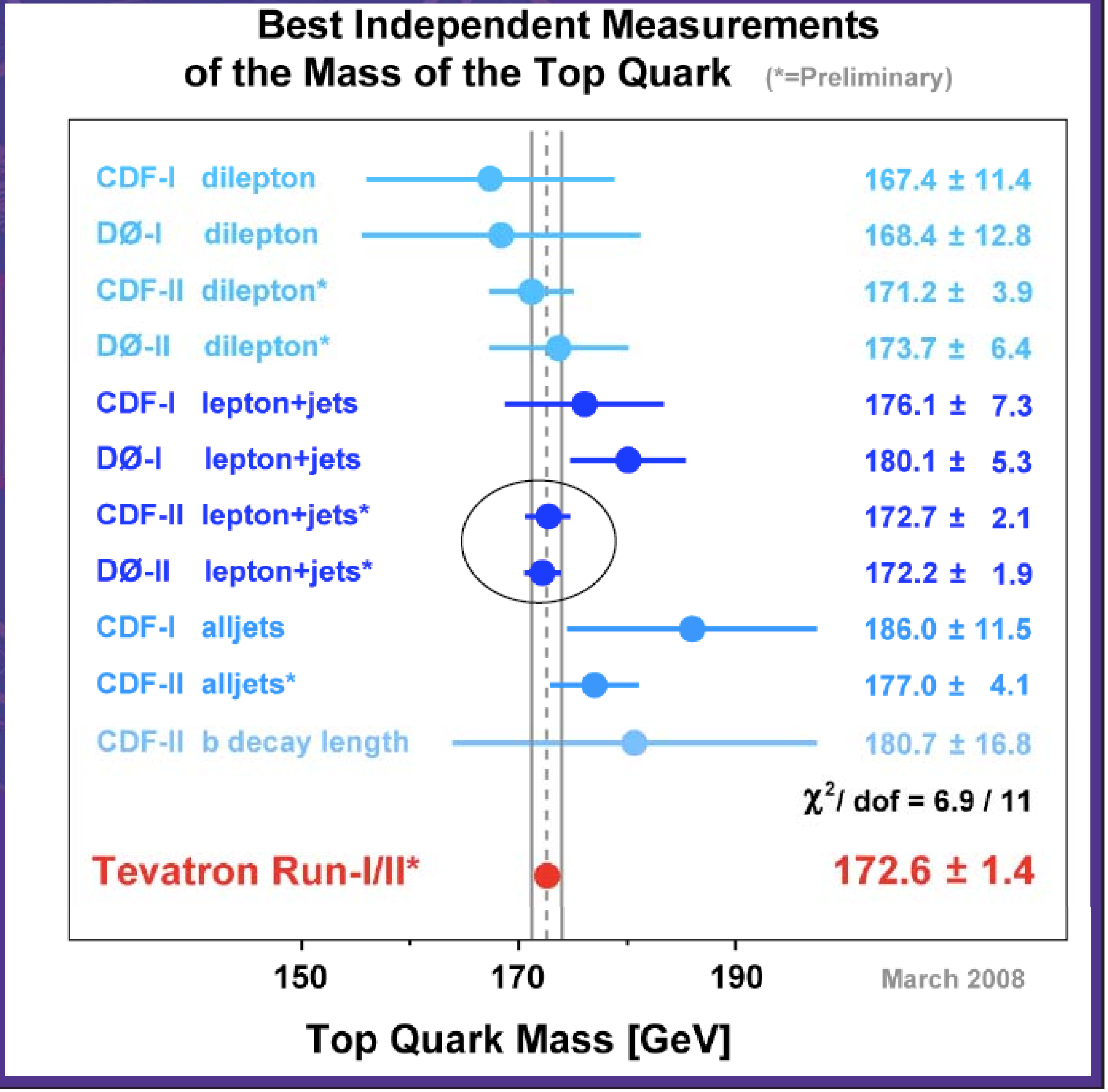
final states:

- 3-jet
- lepton + jet + p_T^{miss}

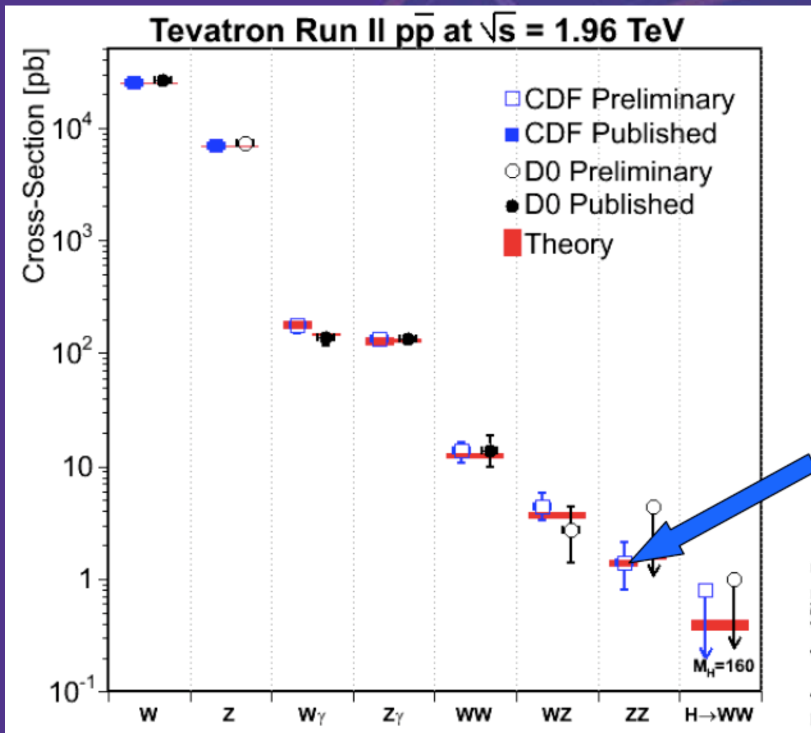
HERA most sensitive on coupling $\kappa_{tu\gamma}$

Top mass

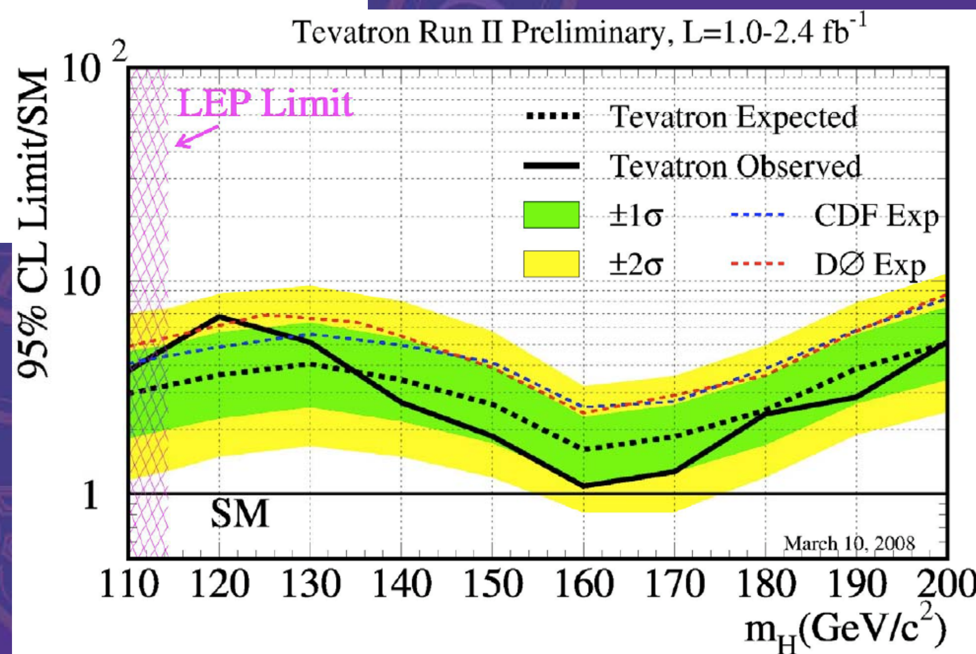
- Vital for EW fits & Higgs constraints.
- D0 results based on 271 events



Down the σ ladder at Tevatron



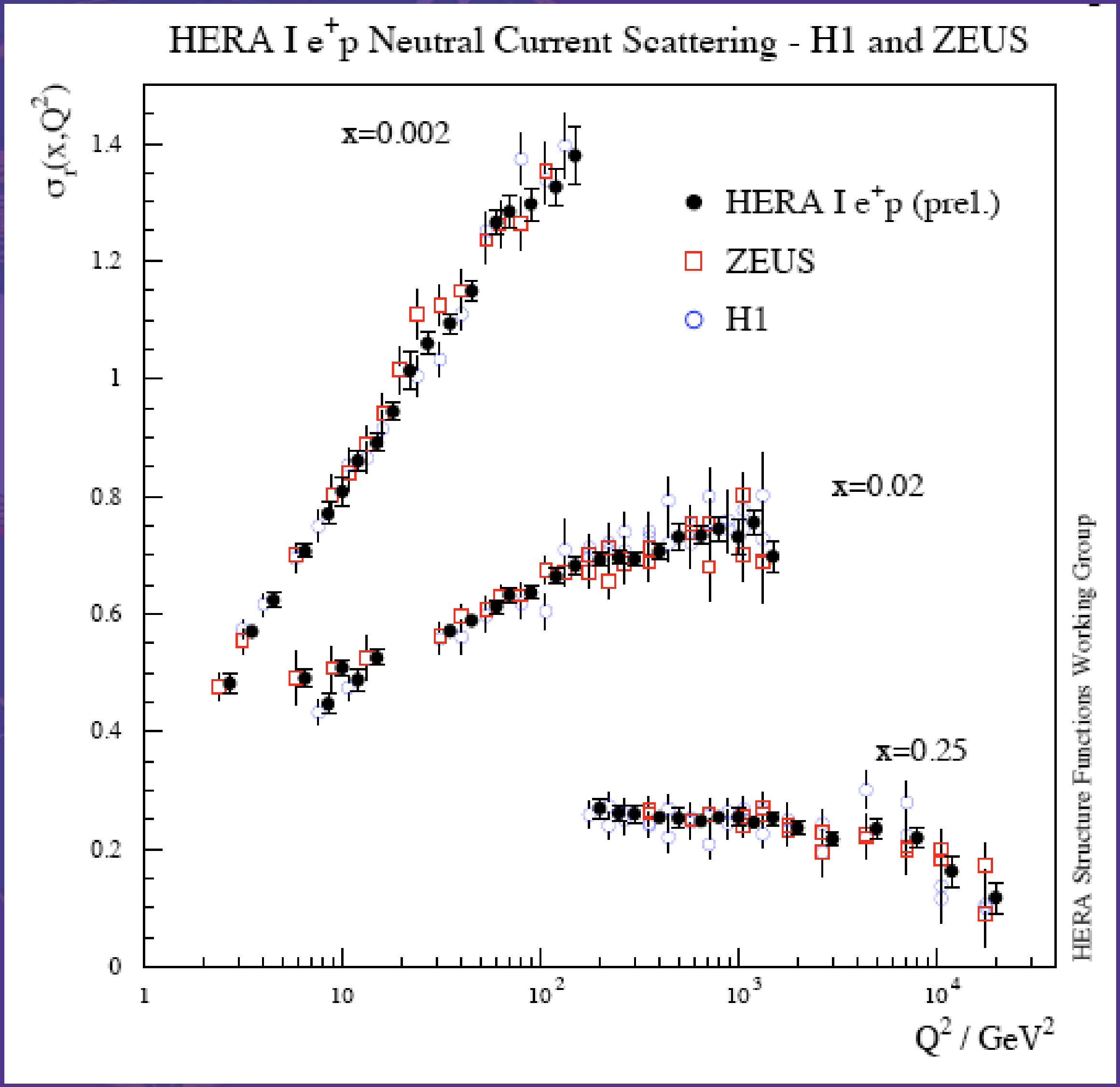
We are here



Higgs already observed @ CERN

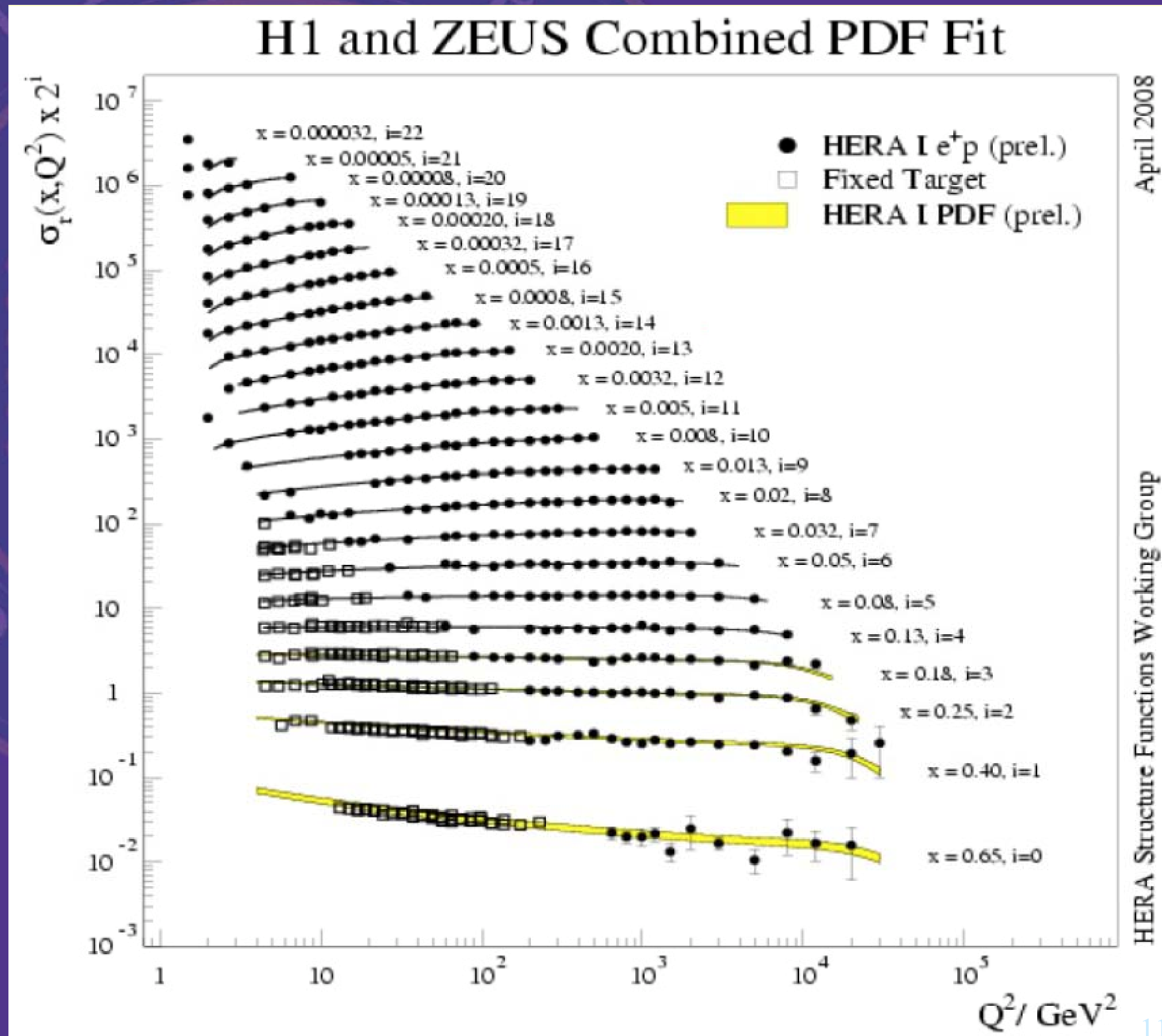
Combined HERA σ_r

- It's always good to combine 2 data sets: worst is gain by √2!
- ZEUS & H1 very different: systematics reduced; cross-calibration



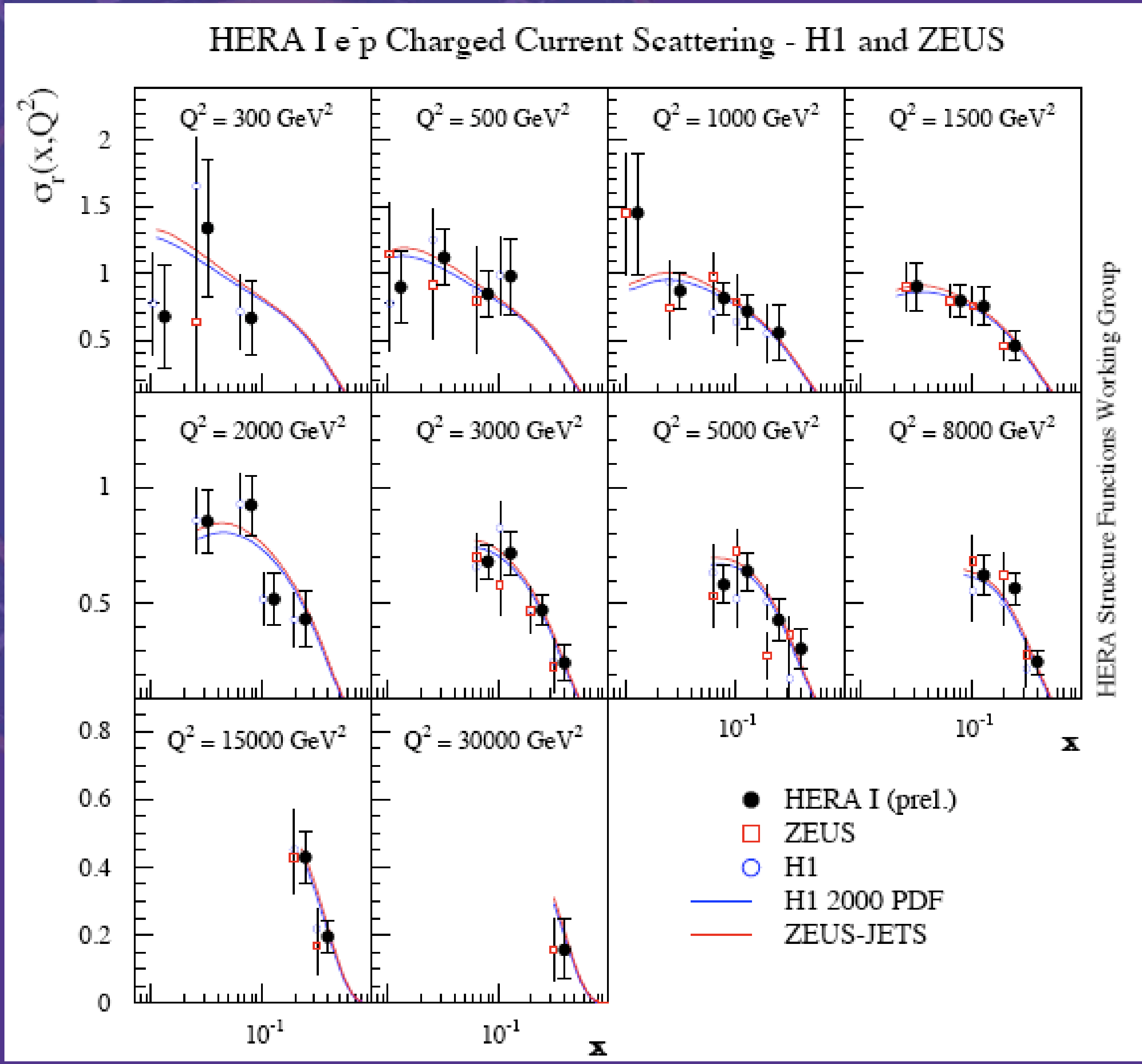
Combined HERA σ_r

- Isn't this beautiful? ZEUS & H1 working together make the difference



Combined HERA CC

- Isn't this beautiful? ZEUS & H1 working together make the difference



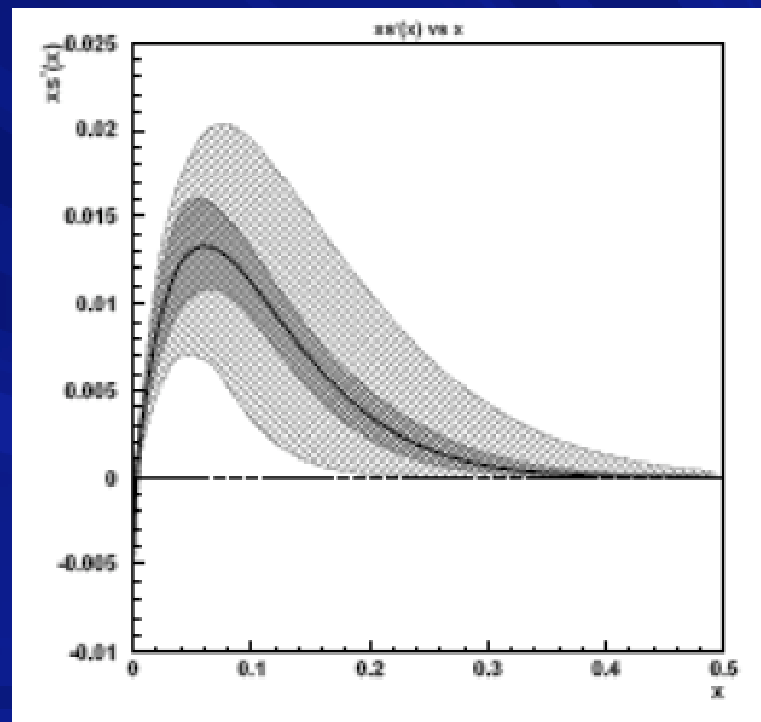
Strange asymmetry

- **Brodsky first suggested this might be ≠ 0 because of intrinsic strangeness. NuTeV NLO analysis:**

- NuTeV NLO analysis (Phys.Rev.Lett.99:192001,2007) is near zero, but slightly positive
  - will shift central value towards standard model and increase uncertainties
  - at NLO, with CTEQ6 as base PDF

$$S^{-} = \int x(s-\bar{s})dx = +.00196 \pm 0.00065$$

(additional unc. of 0.00128 from external inputs, primarily B(c $\rightarrow \mu$))

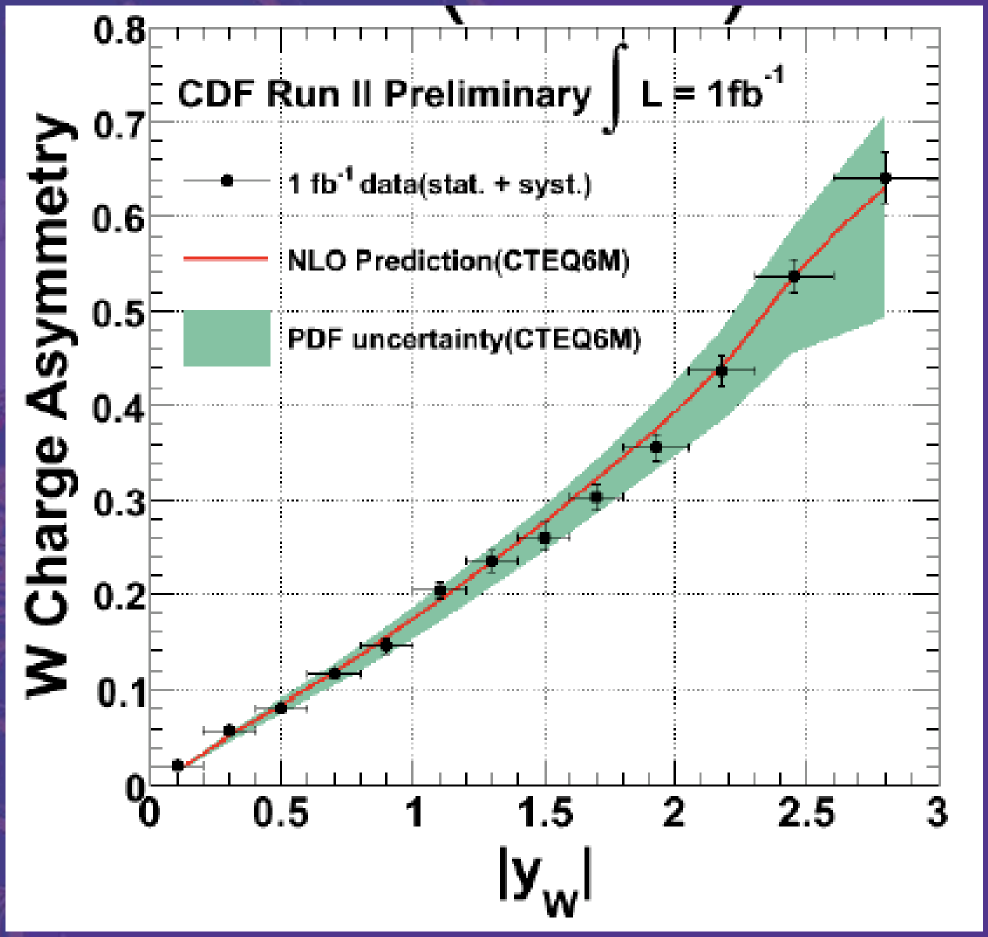


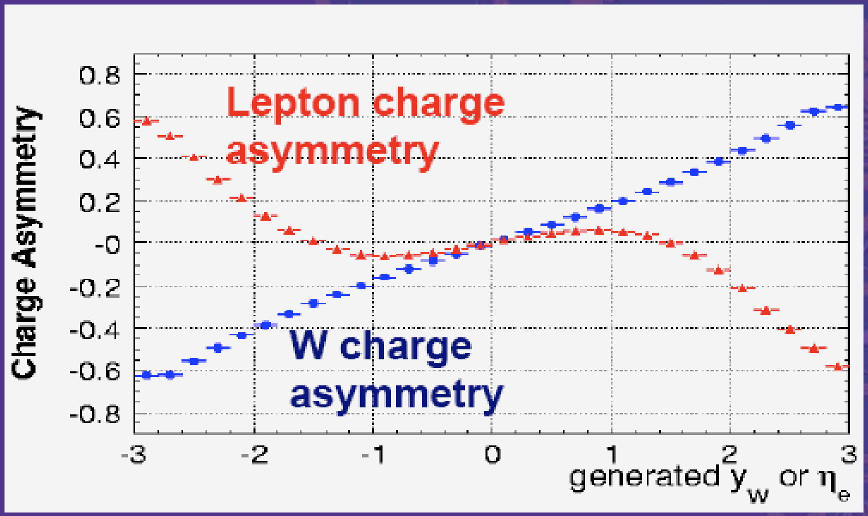
courtesy heroic efforts of D. Mason, P. Spentzouris

W asymmetry

- New more sensitive method by weighting to get W not lepton y.

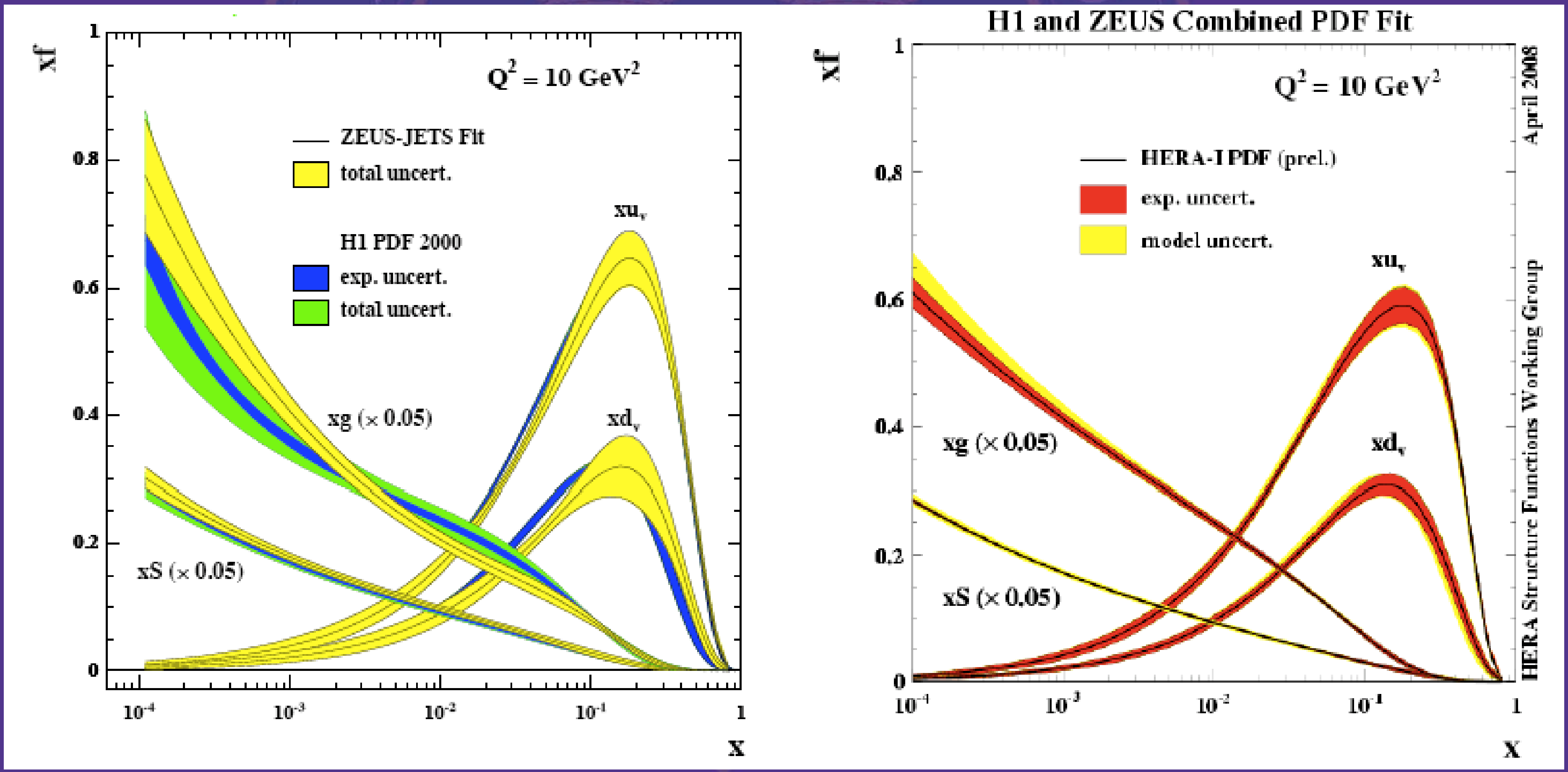
$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W} \approx \frac{u(x1)d(x2) - d(x1)u(x2)}{u(x1)d(x2) + d(x1)u(x2)}$$





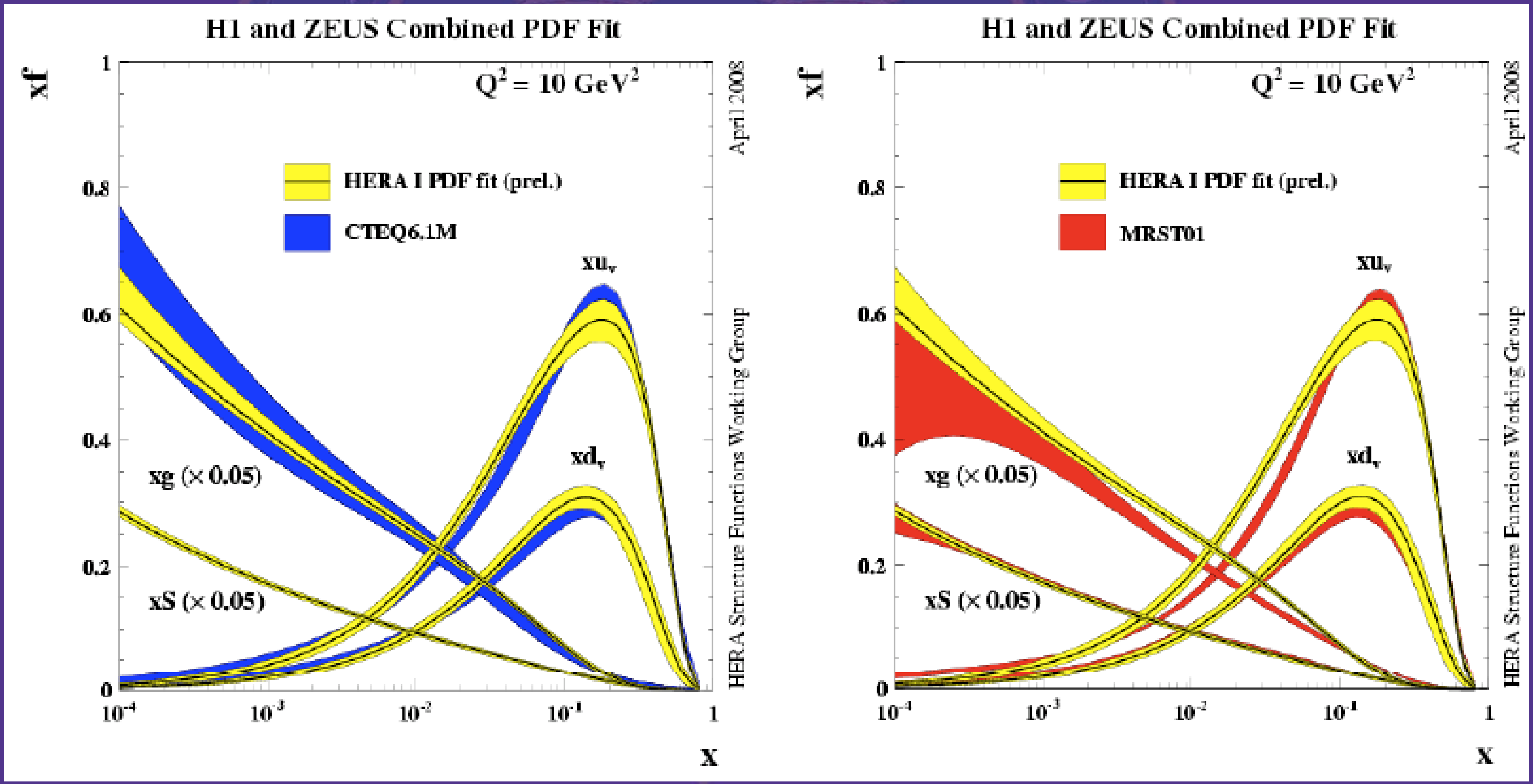
HERA PDF determination

- FromH1/ZEUS data we can construct a HERA PDF.



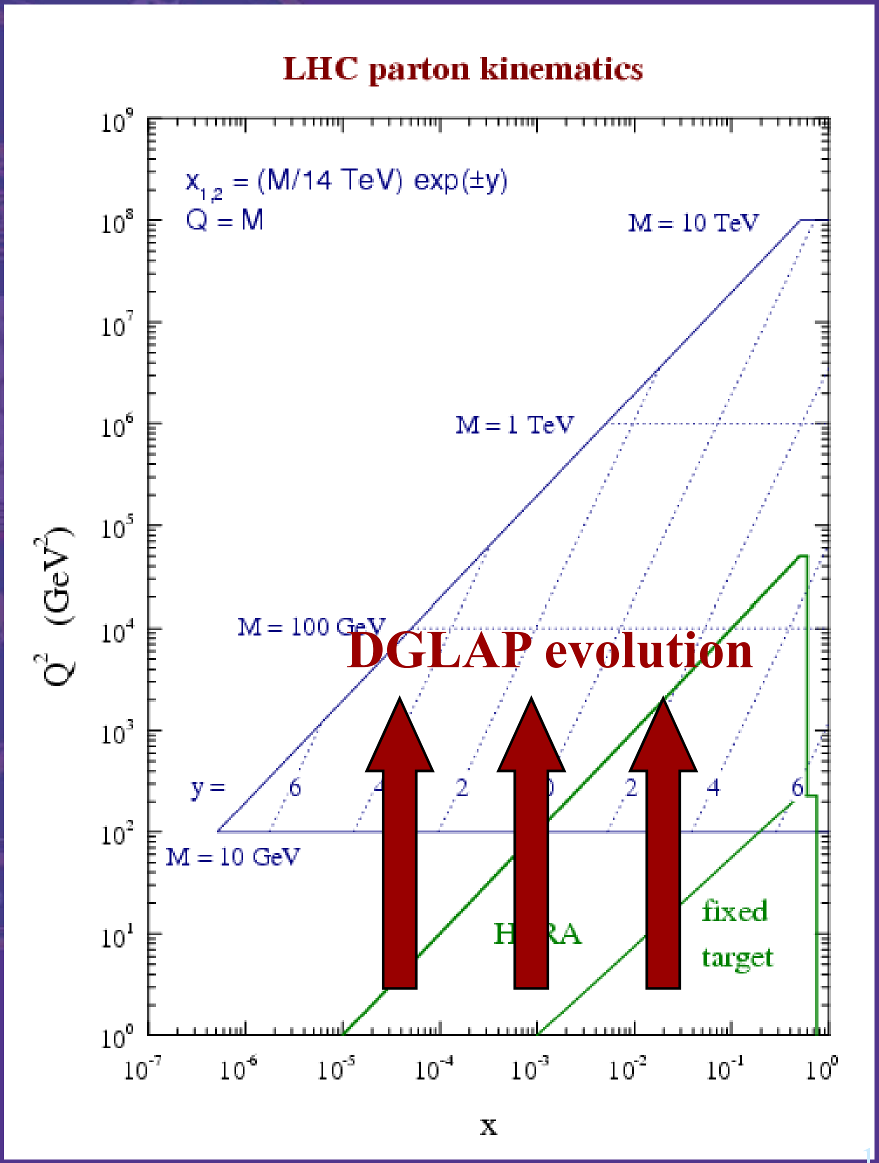
MRST/CTEQ/HERA

- Competitive with and different approach to global fitters such as CTEQ/MRST.



Why does it matter?

- LHC SM calibrations and discovery channels depends crucially on extrapolations from currently measured PDFs.



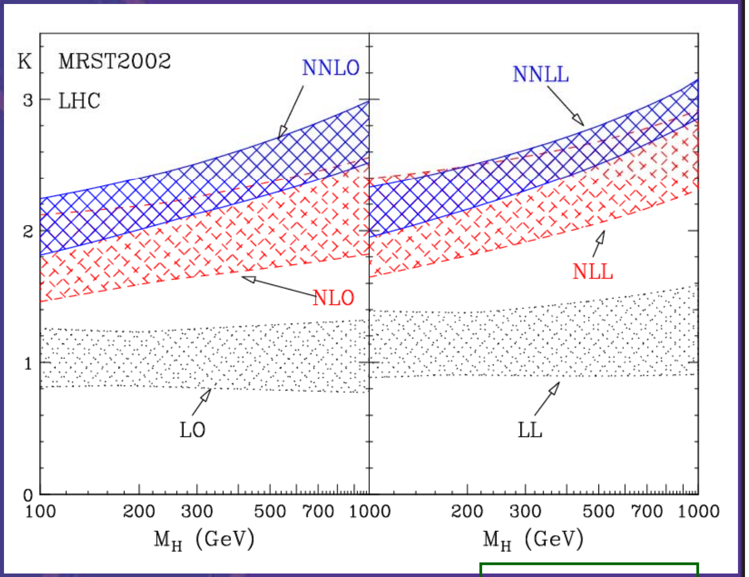
Why does it matter?

- Example 1: $\sigma(M_H=120\ \text{GeV})$ @ LHC

  $\delta\sigma_{pdf} \approx \pm 3\%,\quad \delta\sigma_{ptNNL0} \approx \pm 10\%$

  $\delta\sigma_{ptNNLL} \approx \pm 8\%$

→ $\delta\sigma_{theory} \approx \pm 9\%$



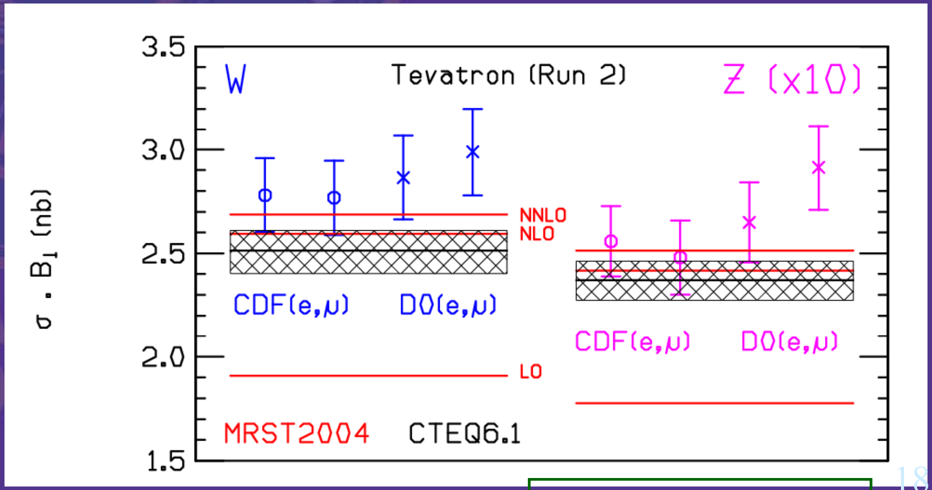
Catani et al, hep-ph/0306211

- Example 2: $\sigma(Z^0)$ @ LHC

  $\delta\sigma_{pdf} \approx \pm 3\%,\quad \delta\sigma_{ptNNL0} \approx \pm 2\%$

→ $\delta\sigma_{theory} \approx \pm 4\%$

- Example 3: quantitative limits on New Physics depend on pdfs



Campbell, Huston, S (2007)

F_L issues for PDFs

$$\frac{\partial F_2}{\partial \ln Q^2} \simeq \alpha_S P^{qg} \otimes g + \ldots$$

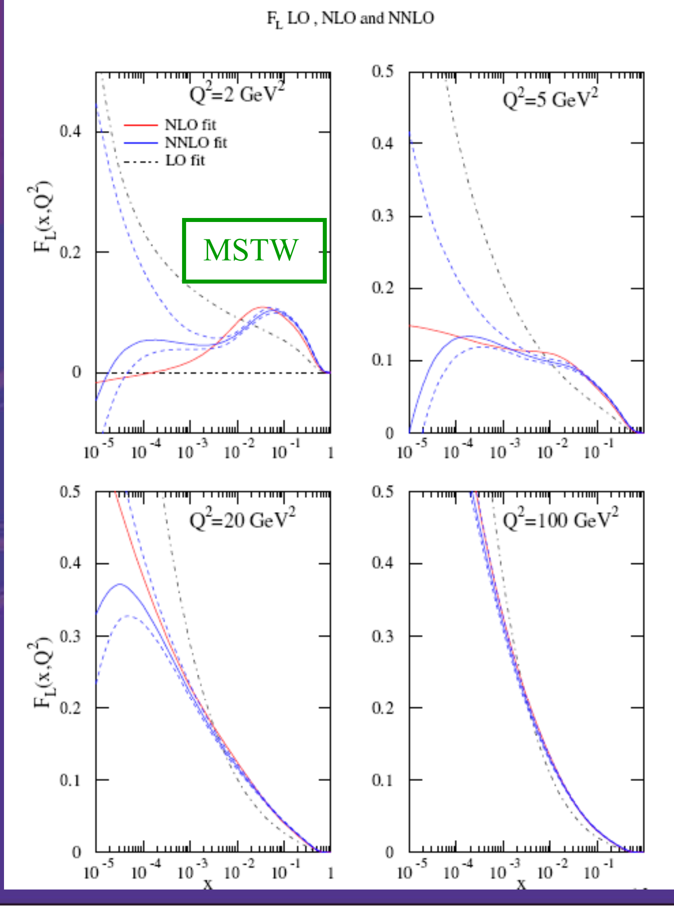
$$F_L \simeq \alpha_S C_{Lg} \otimes g + \ldots.$$

- an independent measurement of the small-x gluon
- test of the assumptions in the DGLAP LT pQCD analysis of small-x F_2
- visible instability in MSTW analysis (impact of negative gluon and large NNLO coefficient function)
- higher–order ln(1/x) and higher-twist contributions could be important

– Moch, Vermaseren, Vogt.

The NNLO $\mathcal{O}(\alpha_s^3)$ longitudinal coefficient function $C^3_{Lg}(x)$ given by

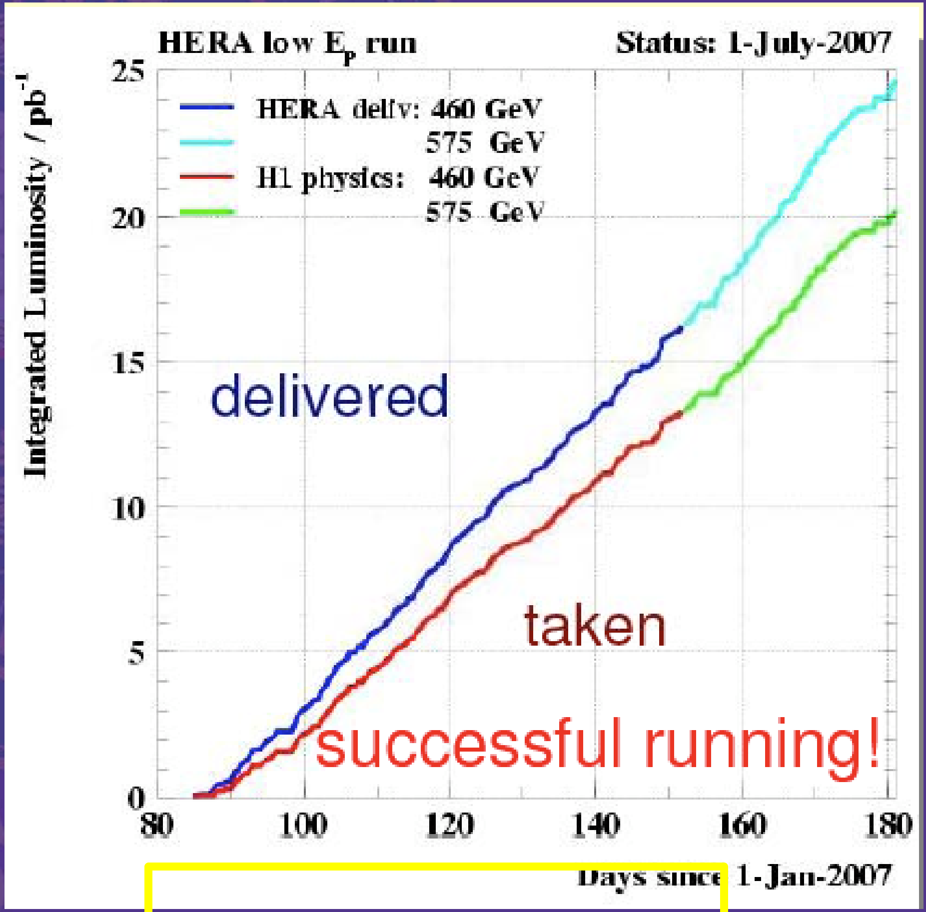
$$C^3_{Lg}(x) = n_f \left(\frac{\alpha_S}{4\pi}\right)^3 \left(\frac{409.5 \ln(1/x)}{x} - \frac{2044.7}{x} - \ldots\right).$$



Measurement of F_L

- Why F_L?
  - F_L is an integral part of proton's structure on same level as F_2 and xF_3
  - In QPM $F_L = 0$; non-zero F_L generated purely by gluon & QCD
  - F_L sensitive to g(x) and probes different facets of QCD evolution.

$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

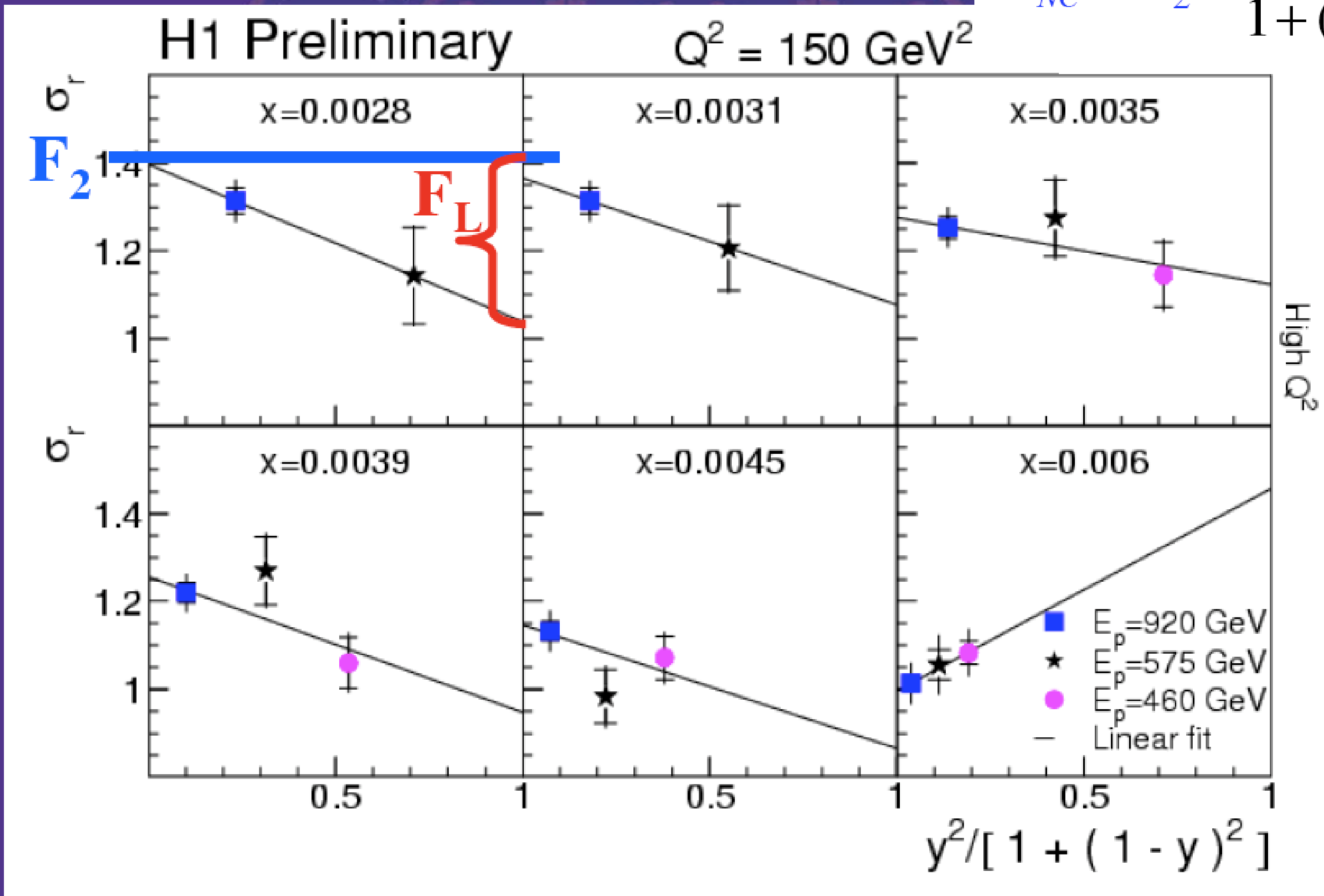


$y = Q^2/sx$

Measurement of F_L

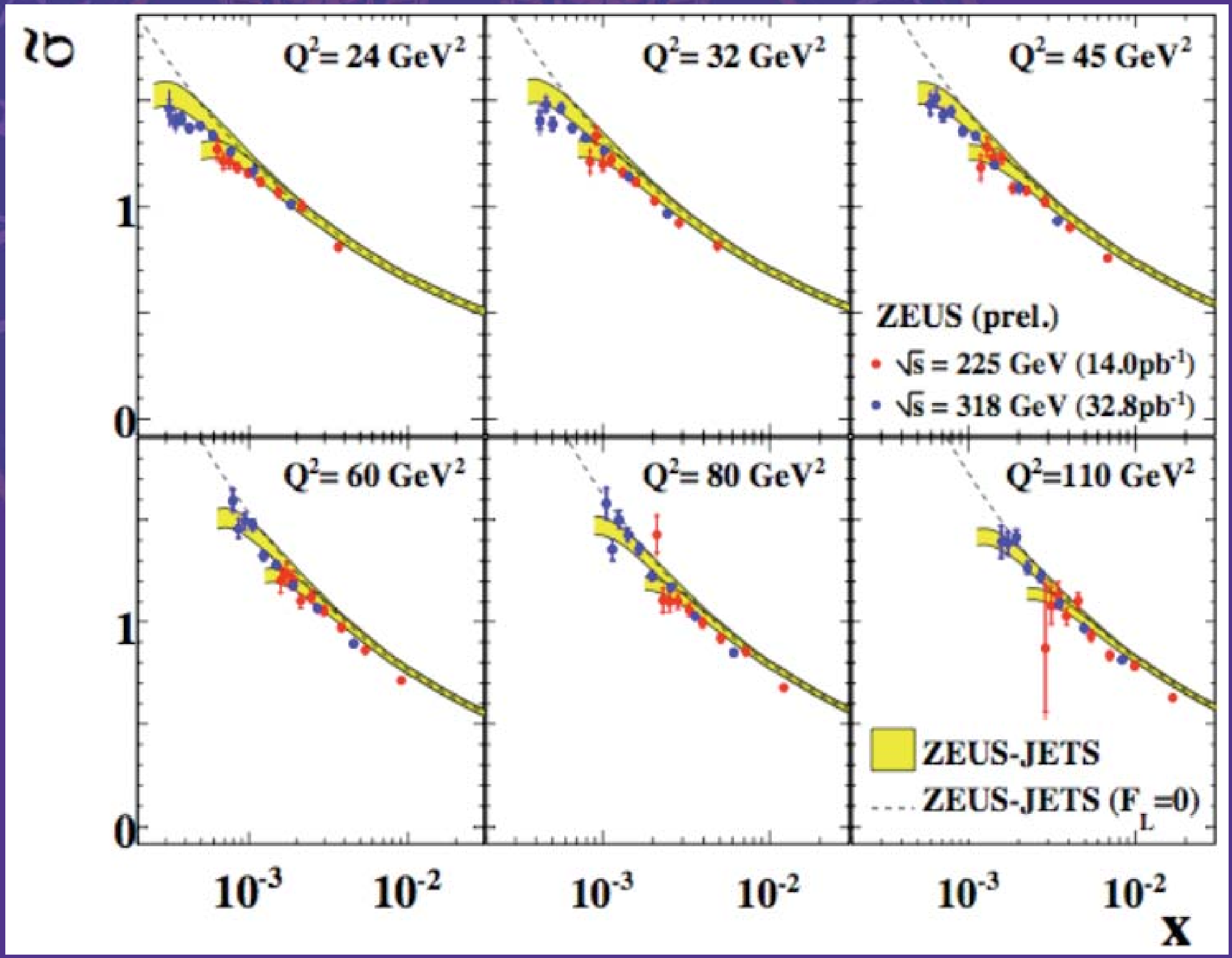
- H1 Rosenbluth plot

$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

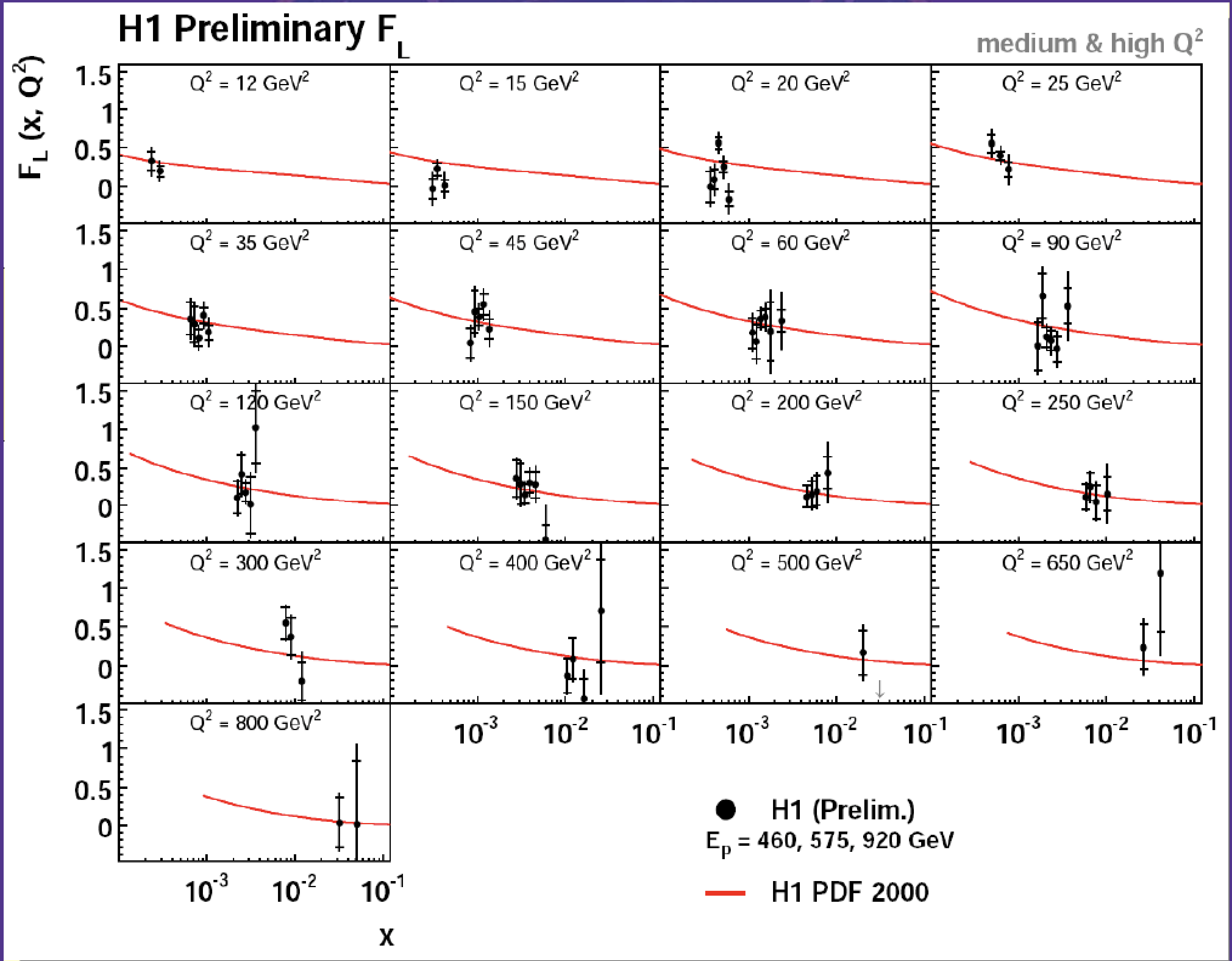


Measurement of F_L

- **ZEUS reduced cross section** $\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$

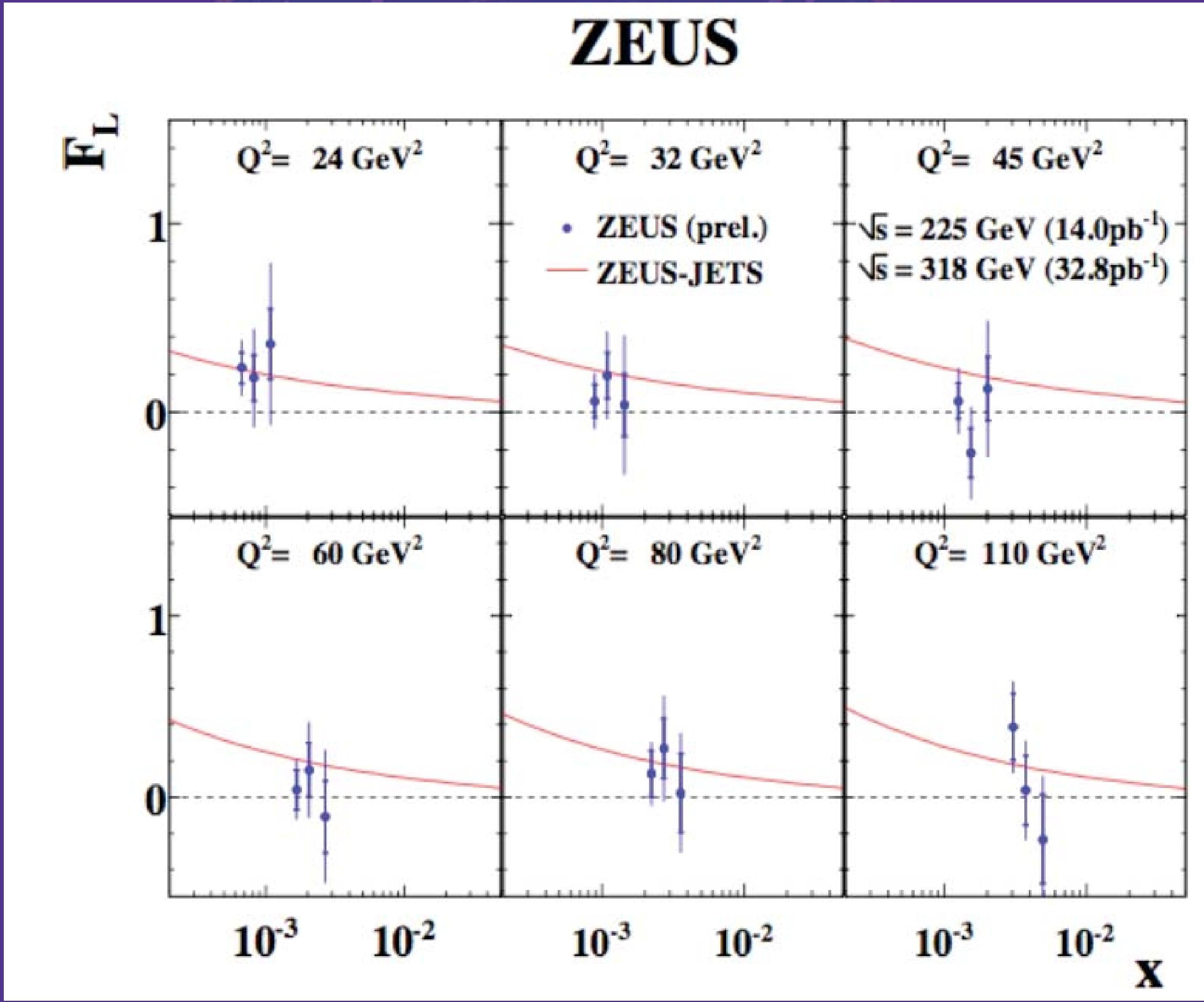


H1 F_L

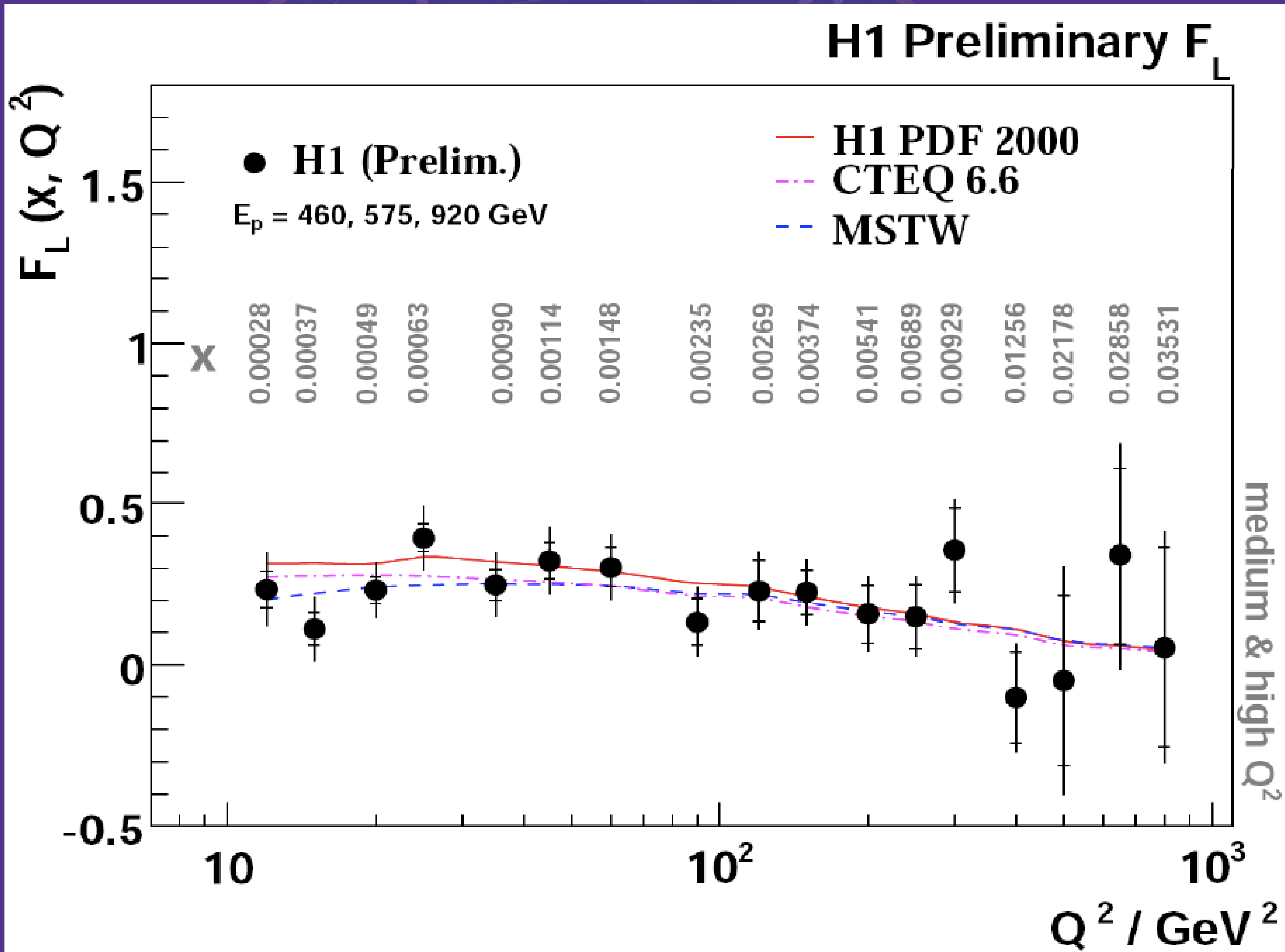


H1 Preliminary F_L
medium & high Q^2
$F_L(x, Q^2)$
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 90 GeV^2
Q^2 = 120 GeV^2
Q^2 = 150 GeV^2
Q^2 = 200 GeV^2
Q^2 = 250 GeV^2
Q^2 = 300 GeV^2
Q^2 = 400 GeV^2
Q^2 = 500 GeV^2
Q^2 = 650 GeV^2
Q^2 = 800 GeV^2
1.5
1
0.5
0
10^{-3}
10^{-2}
10^{-1}
x
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1 PDF 2000

ZEUS F_L


ZEUS
F_L
Q^2= 24 GeV^2
Q^2= 32 GeV^2
Q^2= 45 GeV^2
ZEUS (prel.)
ZEUS-JETS
$\sqrt{s}$ = 225 GeV (14.0pb^{-1})
$\sqrt{s}$ = 318 GeV (32.8pb^{-1})
Q^2= 60 GeV^2
Q^2= 80 GeV^2
Q^2= 110 GeV^2
1
0
10^{-3}
10^{-2}
x

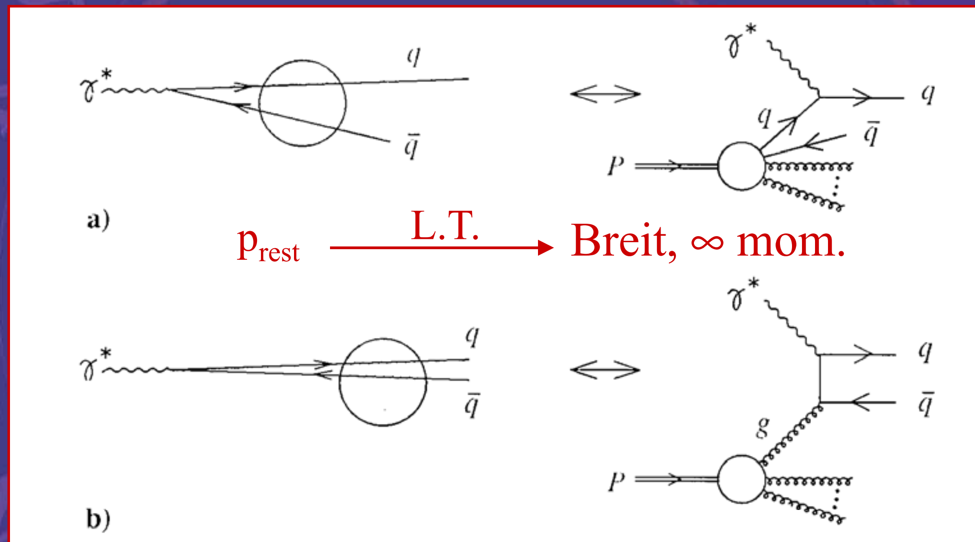
H1 F_L vs PDFs



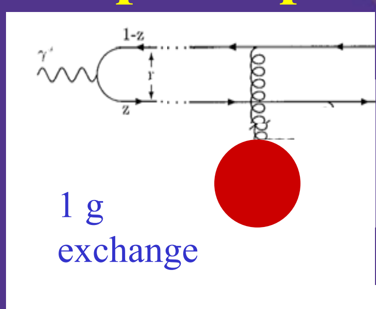
H1 Preliminary F_L
$F_L(x, Q^2)$
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1 PDF 2000
CTEQ 6.6
MSTW
x
0.00028
0.00037
0.00049
0.00063
0.00090
0.00114
0.00148
0.00235
0.00269
0.00374
0.00541
0.00689
0.00929
0.01256
0.02178
0.02858
0.03531
medium & high Q^2
1.5
1
0.5
0
-0.5
10
10^2
10^3
Q^2 / GeV ^{2}

Dipole models

- Many contributions on dipole models & saturation: DIS & diffraction; RHIC physics etc…



- In principle offers unification of inclusive DIS, diffraction



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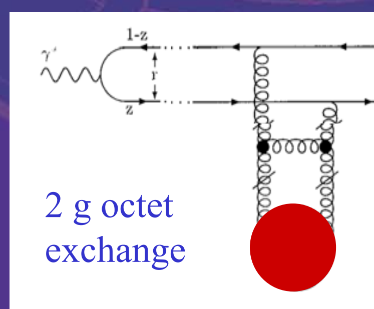
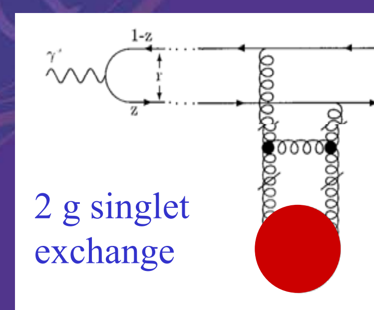
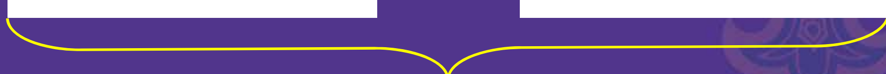




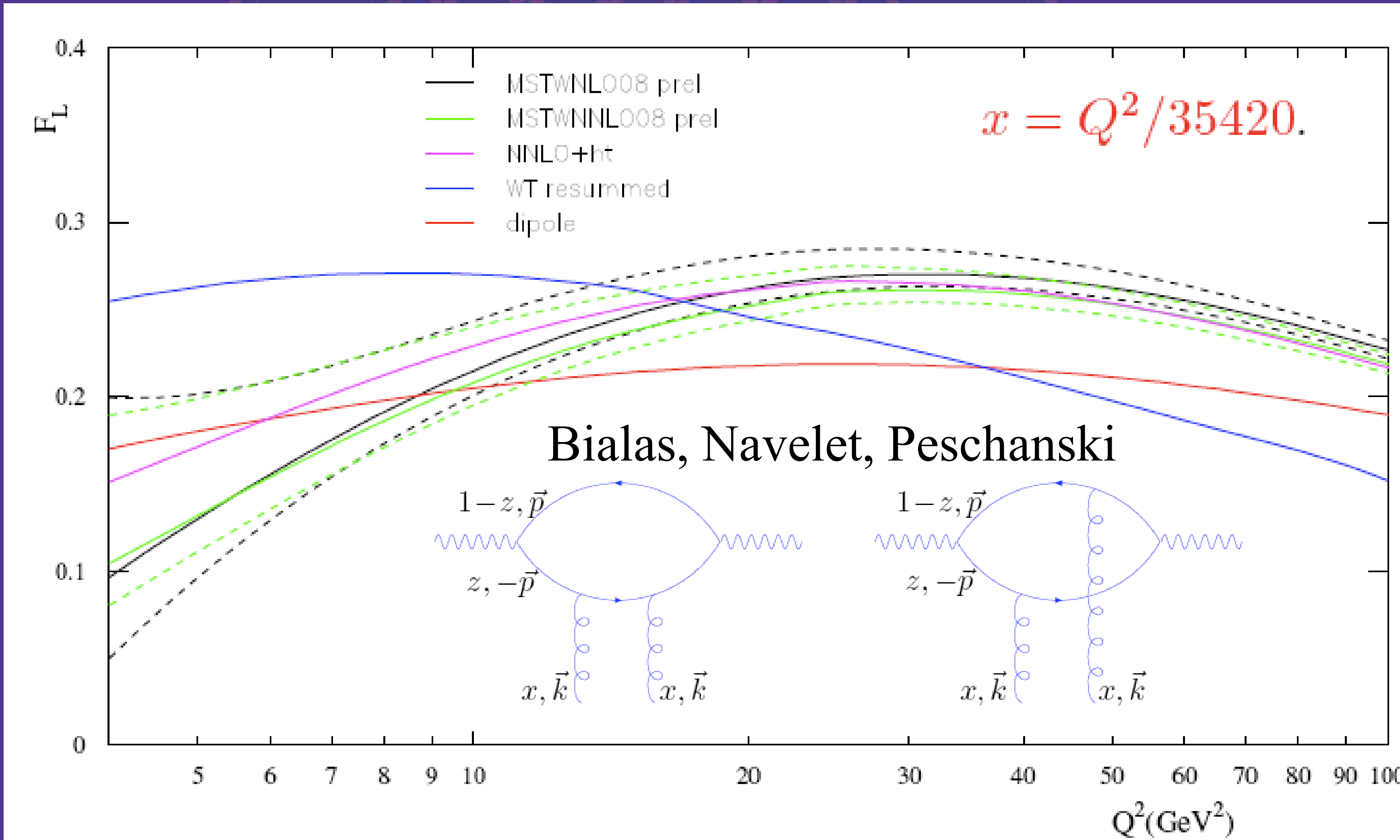


Inclusive F_2

Diffraction

Dipoles & F_L

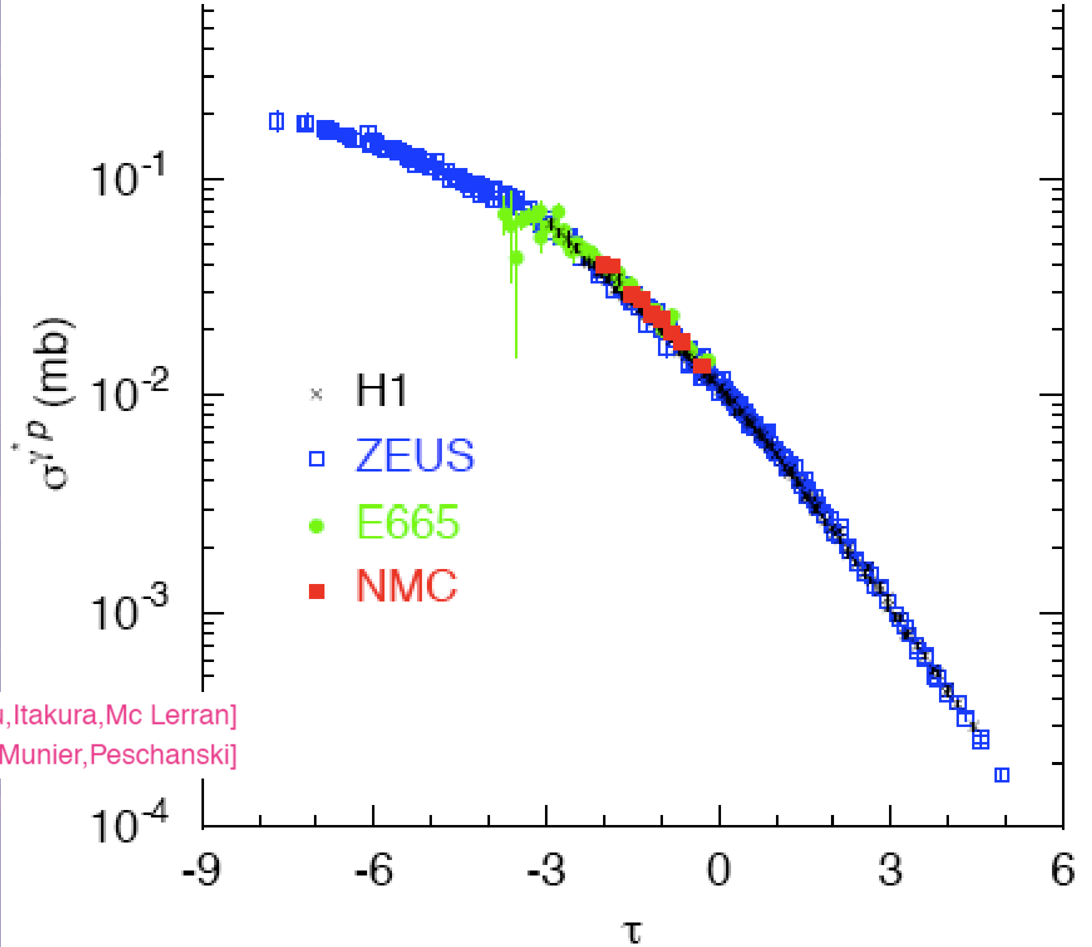
- **Can the data give a precision sufficient to discriminate between such models?**



Dipoles, DIS & HQ

- Use Balitsky-Kovchegov models to calculate scattering amp. T – G. Soyez.

[A. Stasto, K. Golec-Biernat, J. Kwiecinski, 2001]



$$\sigma^{\gamma^* p}(x, Q^2) = \sigma^{\gamma^* p}(\tau)$$

with $\tau = \log(Q^2) - \lambda \log(1/x)$
$= \log(Q^2/Q_s^2)$

Geometric scaling

Saturation scale:

$$Q_s^2(x) = Q_0^2\, x^{-\lambda}$$

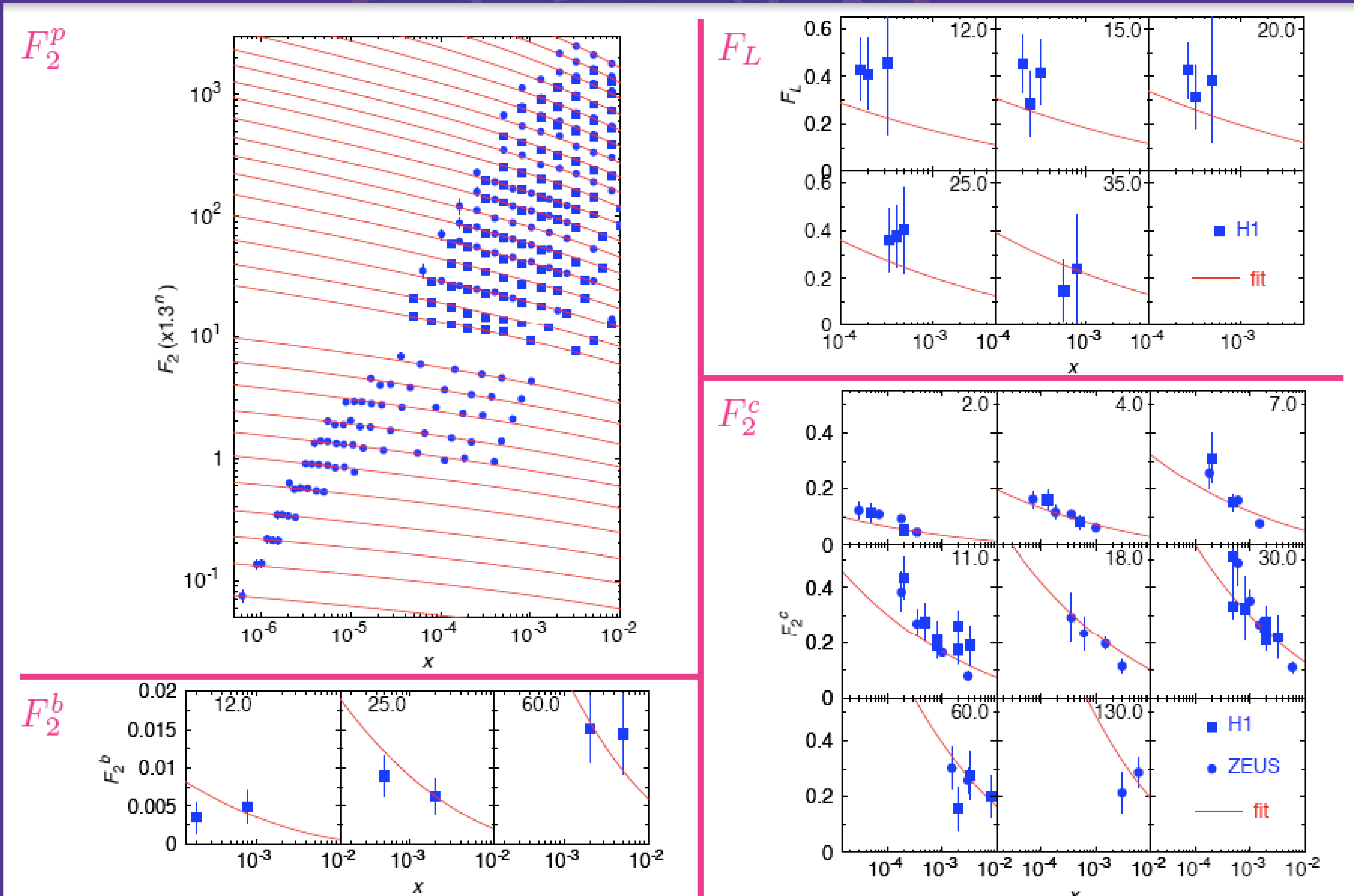
Solution: $\left(\rho = \log\left(\frac{4}{r^2 Q_s^2}\right);\ \bar{\alpha} = \alpha_s N_c/\pi\right)$

$$T(r;x) \overset{rQ_s \ll 1}{\propto} \exp\left(-\gamma_c \rho - \frac{\rho^2}{2\bar{\alpha}\chi''_c Y}\right)$$

[Iancu,Itakura,Mc Lerran]
[Munier,Peschanski]

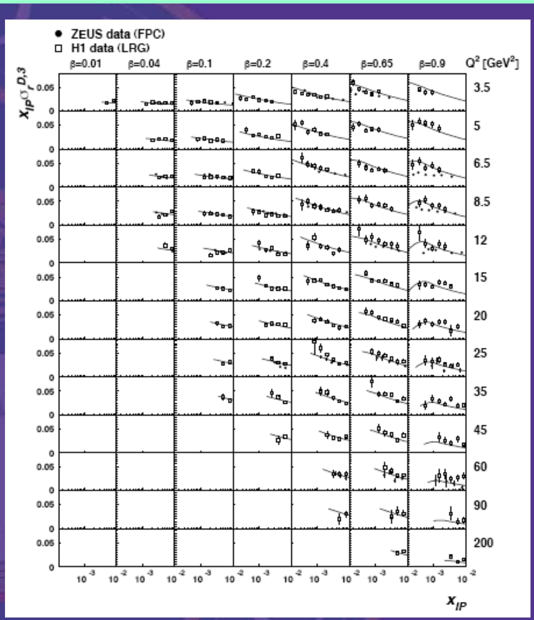
- **High-energy QCD predicts scaling from saturation.**

Dipoles & HQ

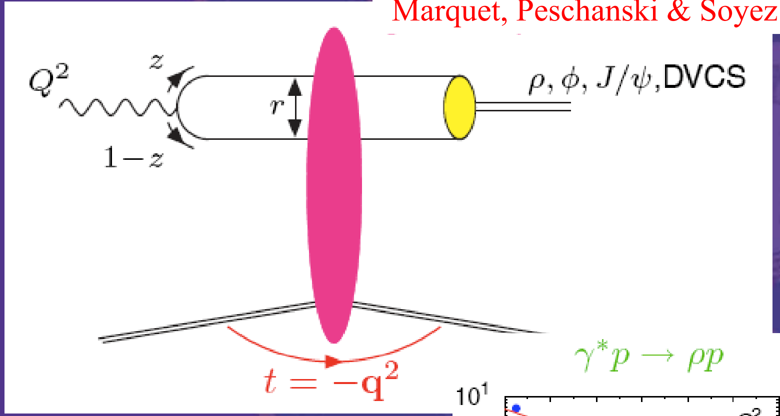

F_2^p
F_2 (x1.3^n)
x
F_L
12.0
15.0
20.0
25.0
35.0
H1
fit
F_2^c
2.0
4.0
7.0
11.0
18.0
30.0
60.0
130.0
H1
ZEUS
fit
F_2^b
12.0
25.0
60.0

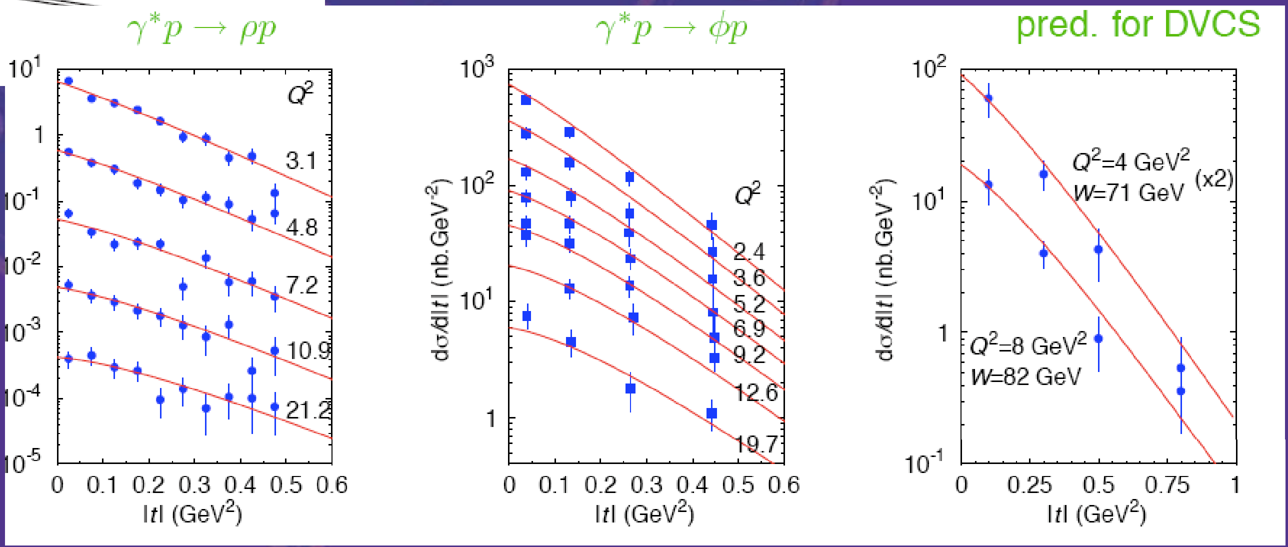
Dipoles & Diffraction

- $F_2^D \sim T^2$ – good fit
- VM & DVCS



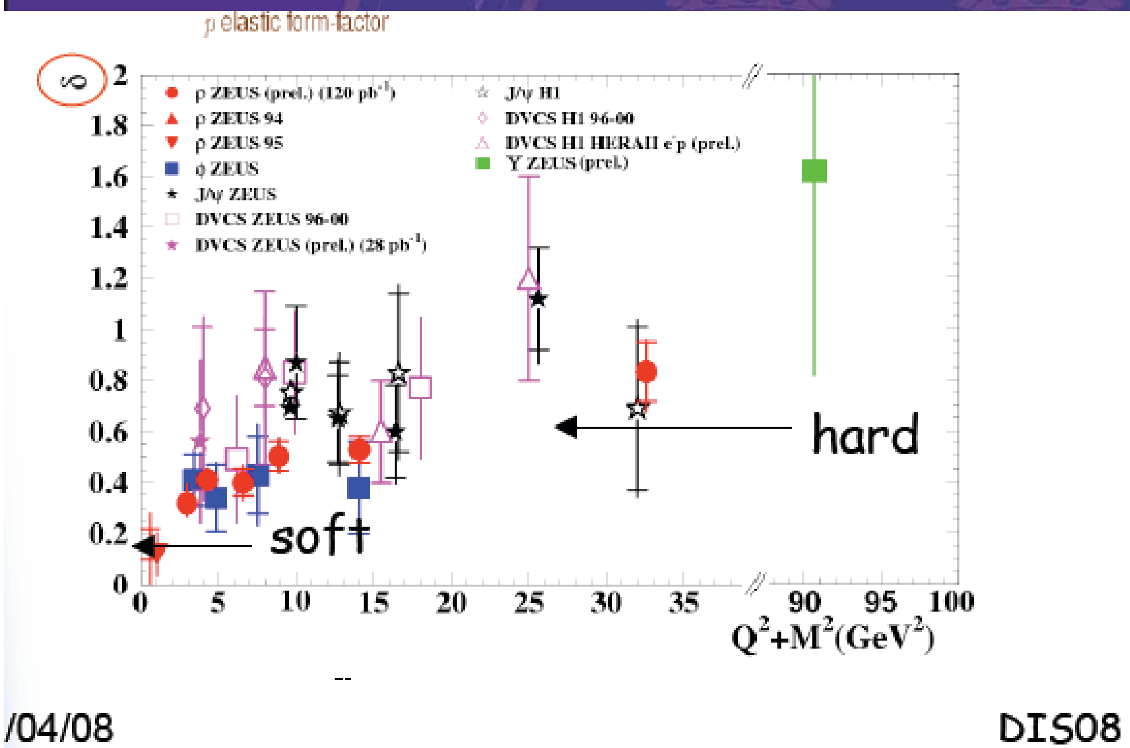
Marquet, Peschanski & Soyez

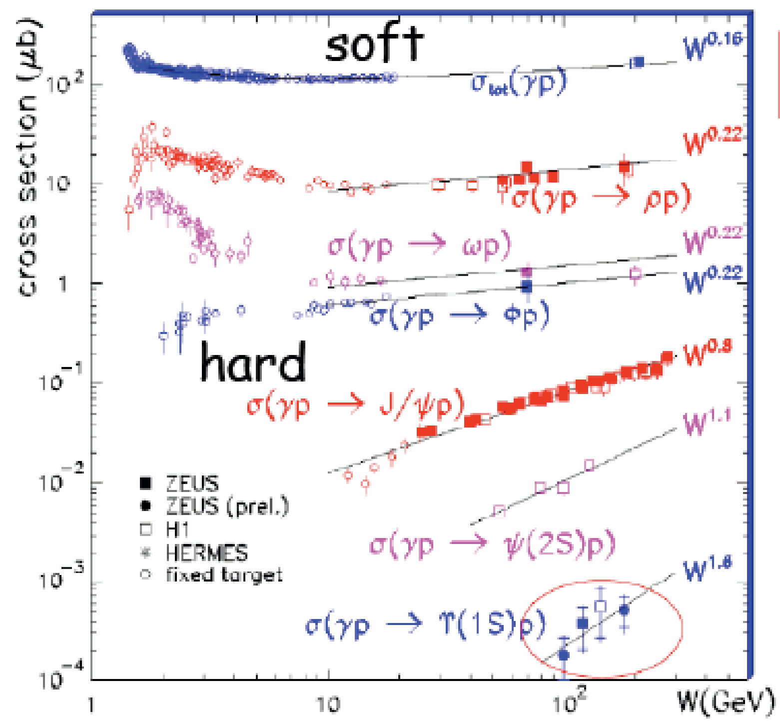




Vector mesons & DVCS

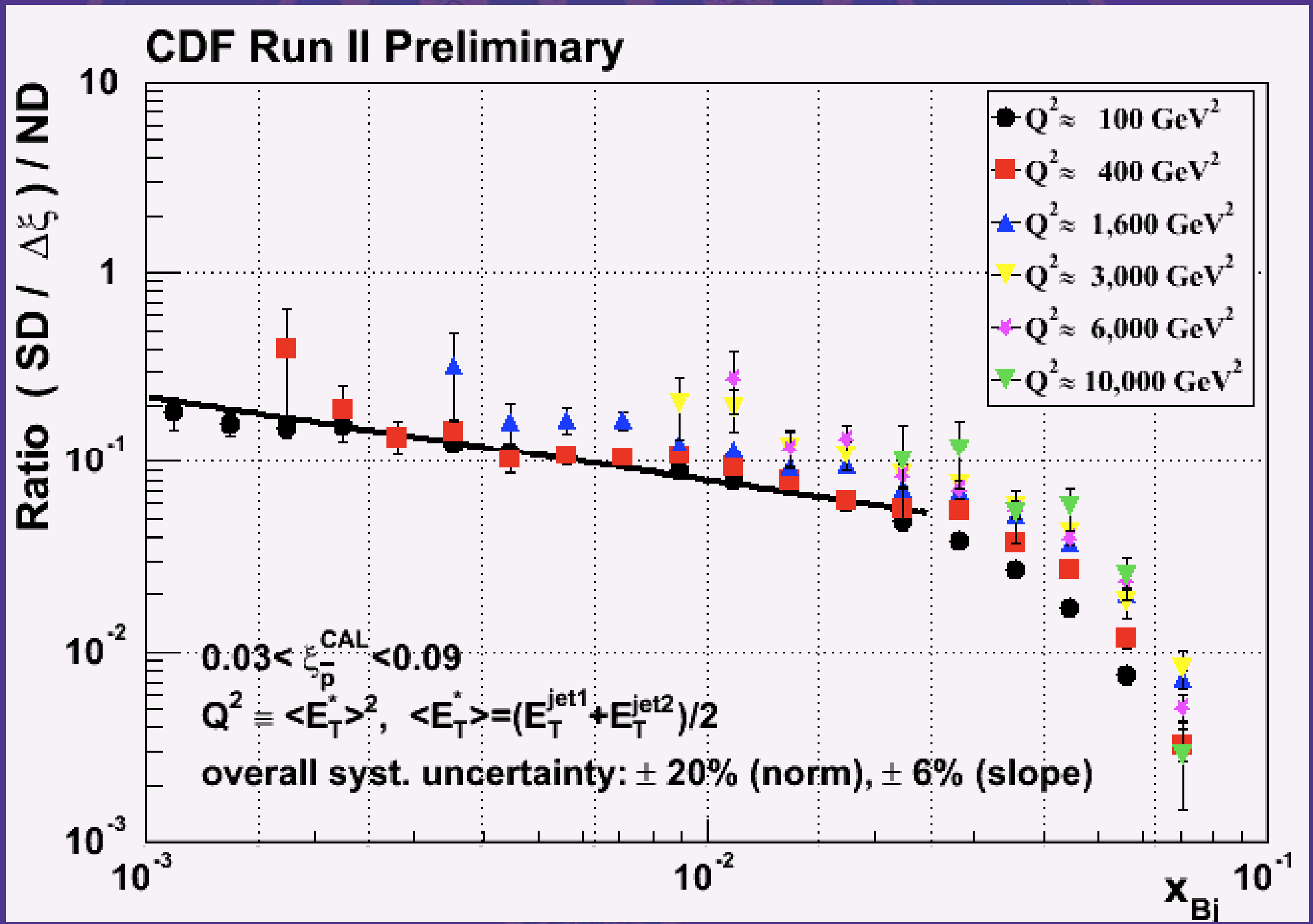
- Uniquely clean lab. to look at some aspects of diffraction. $\sigma(W) \sim W^{\delta}$





Diffraction at Tevatron

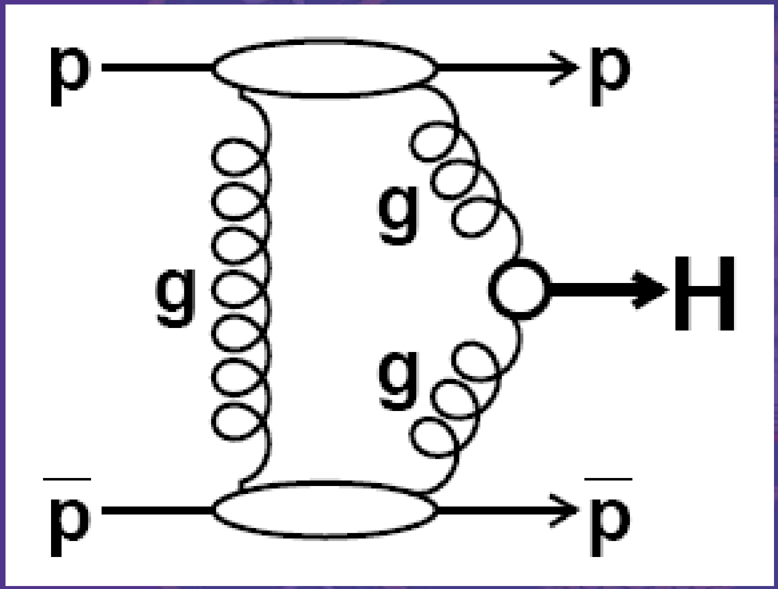
- Clean isolation of diffraction at Tevatron possible via forward p, pbar tagging.



- **Pomeron evolves like the proton!**

Diffractive Higgs

- **Tevatron data favour ExHuME model:**

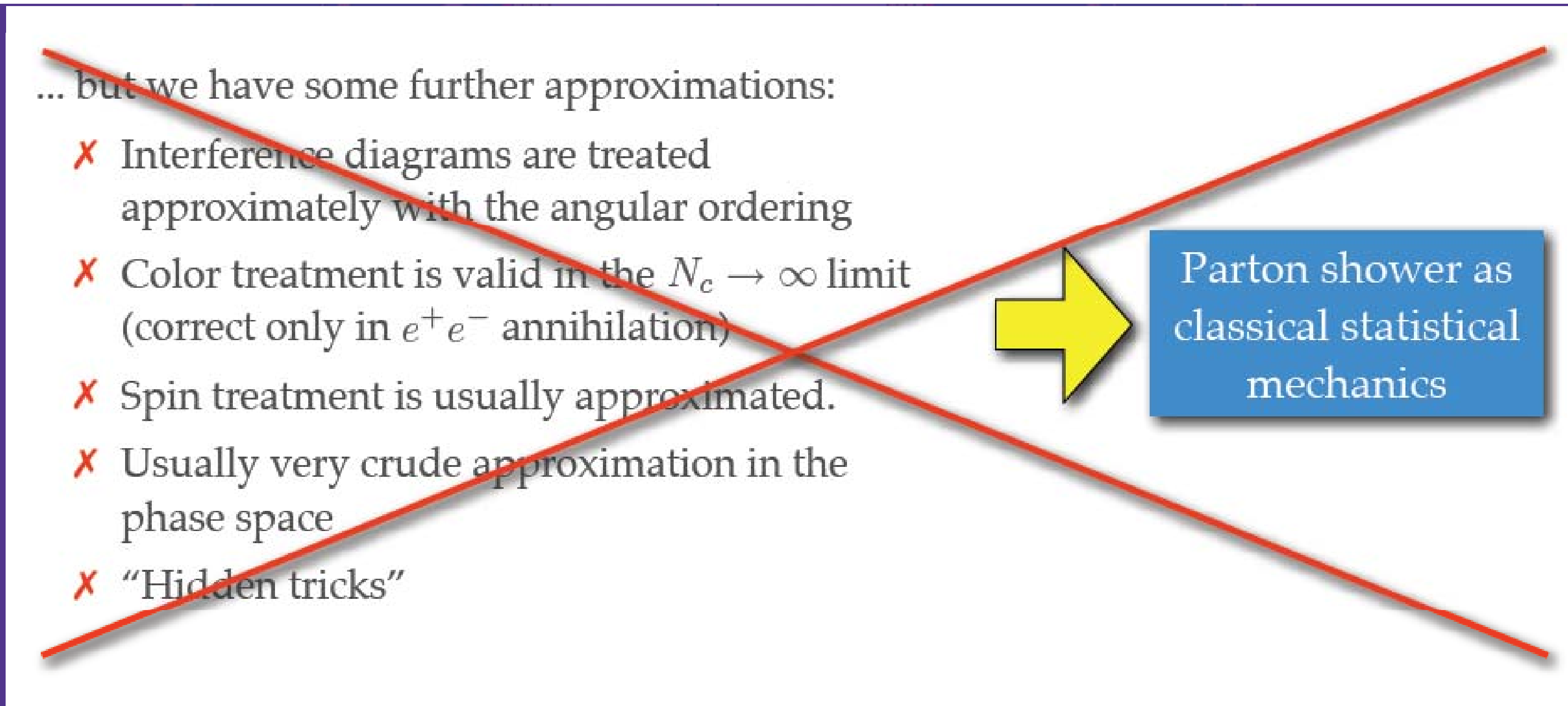


- **rather than Pomeron-based DPEMC. Gives clearer basis for calculations for LHC.**

QCD & generators

- **At DIS2007, Znagy:**

In this talk I had more ✗ than ✓. I addressed several questions and the current MCs don't give reasonable answers. In the parton shower program we have a lot rather *nonsystematic* approximation and *"tricks"*. They could cause big problem at LHC.



QCD & generators

- At DIS2008, Laenen:

Order	$2 \to 1$	$2 \to 2$	$2 \to 3$	$2 \to 4$	$2 \to 5$	$2 \to 6$
1	LO					
α_s	NLO	LO				
α_s^2	NNLO	NLO	LO			
α_s^3	NNNLO	NNLO	NLO	LO		
α_s^4					LO	
α_s^5						LO

- LO well-understood, now more efficient than ever
- NLO: a flood of new developments
- NNLO $2 \to 2$ close..
- NNNLO: for $F_2(x,Q)$, from same foundry at NNLO splitting functions

Moch, Vermaseren, Vogt

QCD & generators

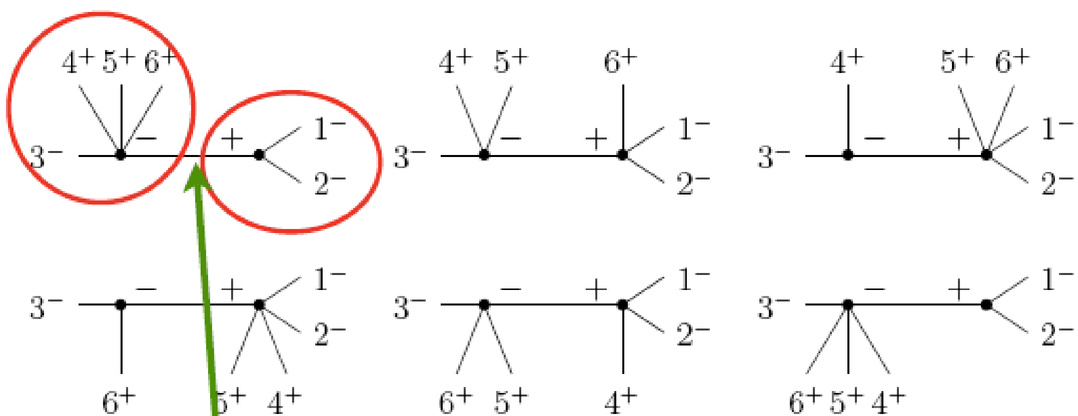
- **Complexity of calculations:**

For gg →ng number of diagrams grows factorially

n	2	3	4	5	6	7	8
diagrams	4	25	220	2485	34300	559405	10525900

- **New wine from old bottles: Twistor simplifications**

Post-twistor recursion



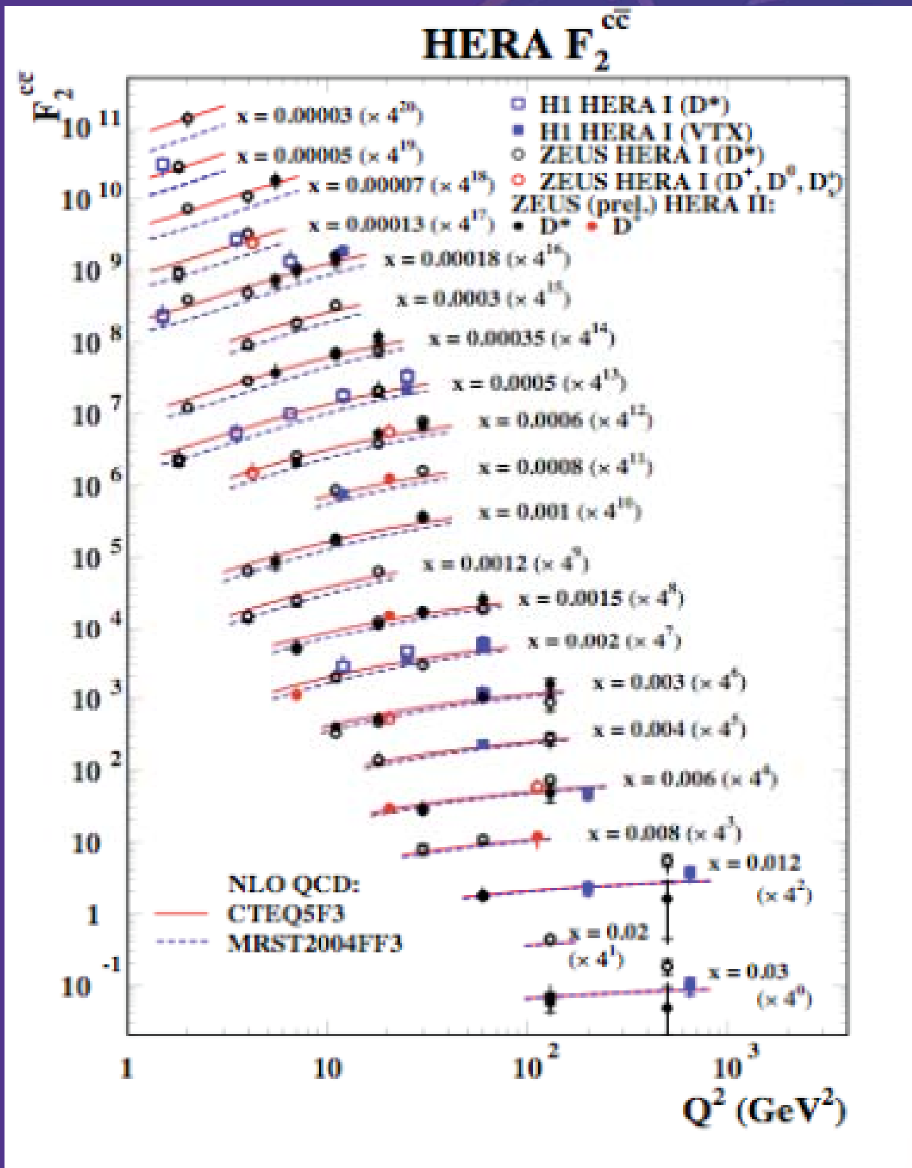
Reduces 220 diagrams to 6.

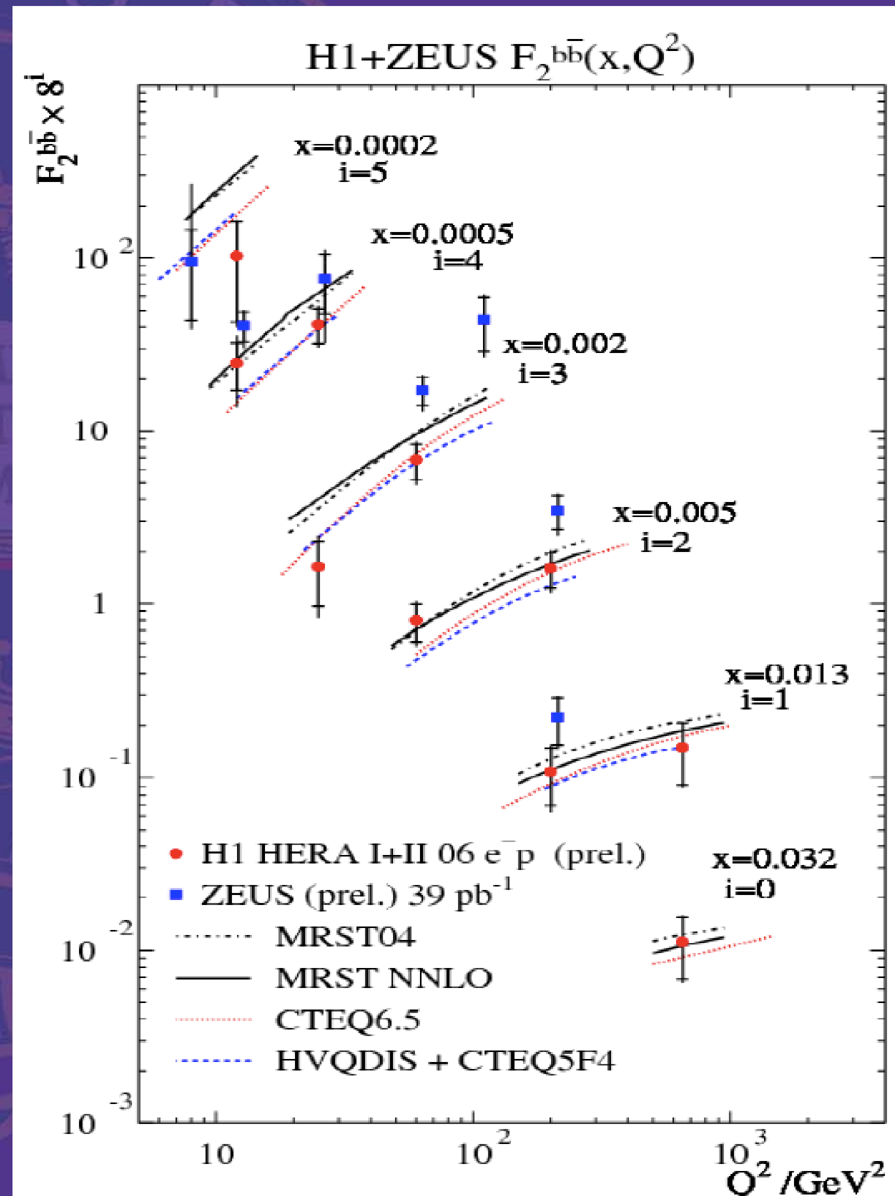
QCD & generators

- Twisters were a 70's craze…..

- Bottom line – much sunnier outlook!

Heavy quarks





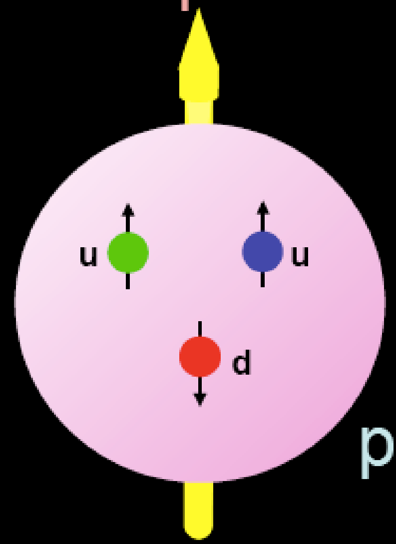
Spin physics

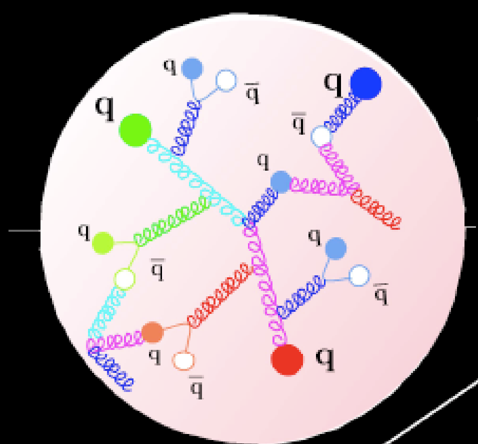
Where does the proton's spin come from?

p is made of 2 u and 1d quark
(Constituent Quark Model)

$$S = \tfrac{1}{2} = \Sigma S_q$$

Explains magnetic moment
of baryon octet





QCD dynamics: Sea quarks and gluons

Check via electron scattering and find
quarks carry only ~1/3 of the proton's spin!

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Jets,pions,A_{LL}

Spin physics

Global Analysis of Helicity Parton Densities and Their Uncertainties

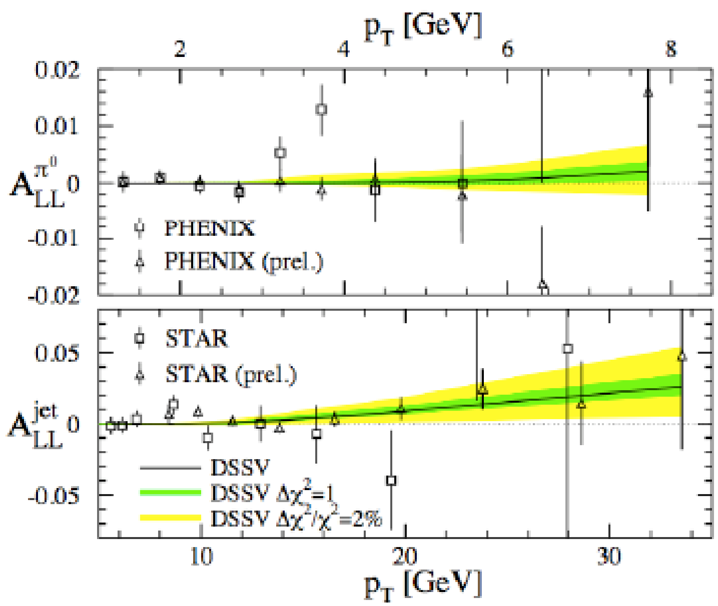


FIG. 1: Comparison of RHIC data [4] and our fit. The shaded bands correspond to $\Delta\chi^2 = 1$ and $\Delta\chi^2/\chi^2 = 2\%$ (see text).

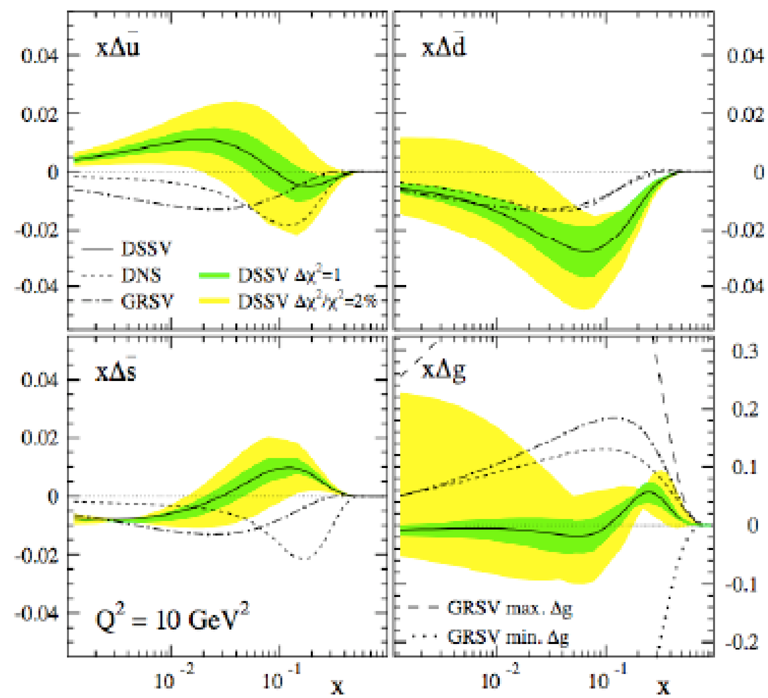
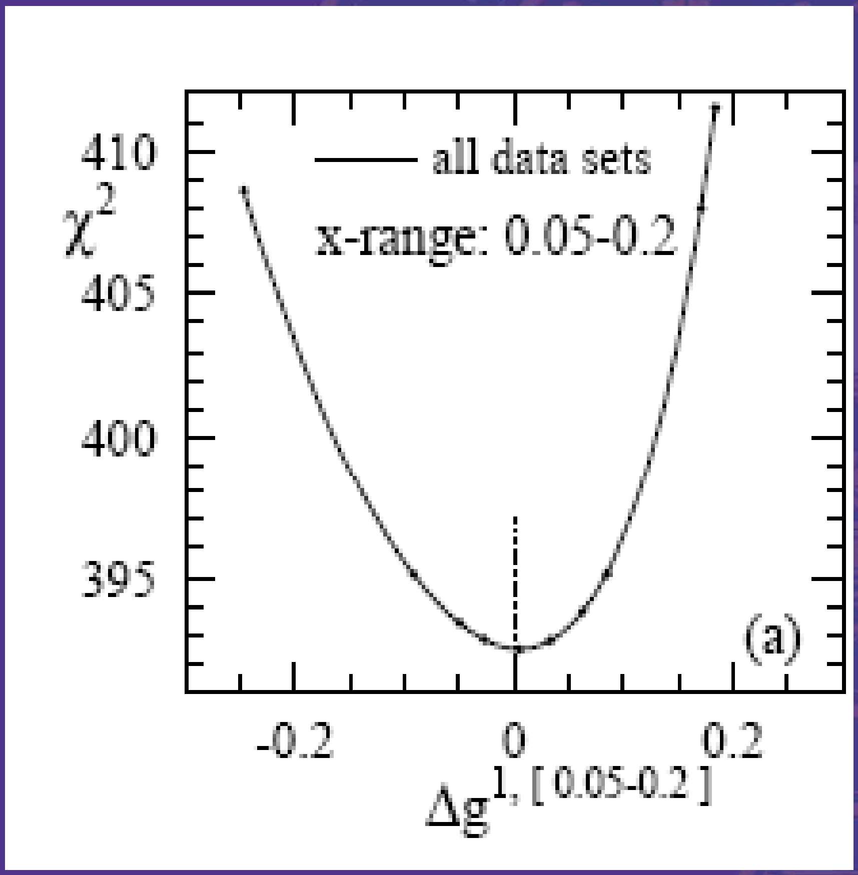


FIG. 2: Our polarized sea and gluon densities compared to previous fits [6, 8]. The shaded bands correspond to alternative fits with $\Delta\chi^2 = 1$ and $\Delta\chi^2/\chi^2 = 2\%$ (see text).

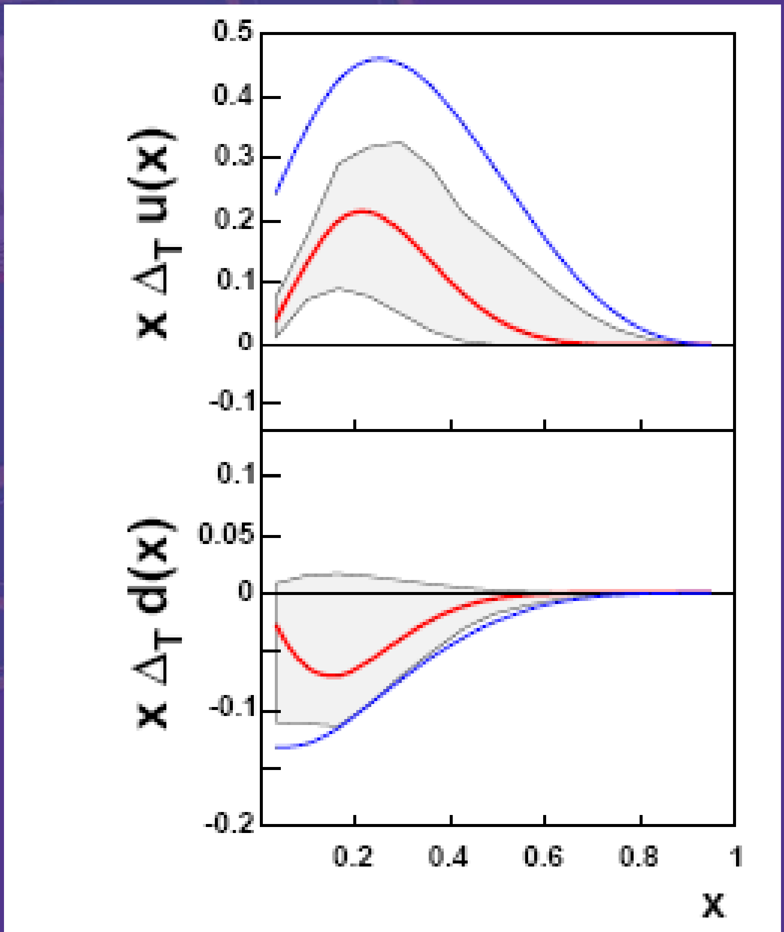
de Florian, Stasso, Stratmann & Vogelsang

Spin physics

- Gluon polarisation ~ 0.

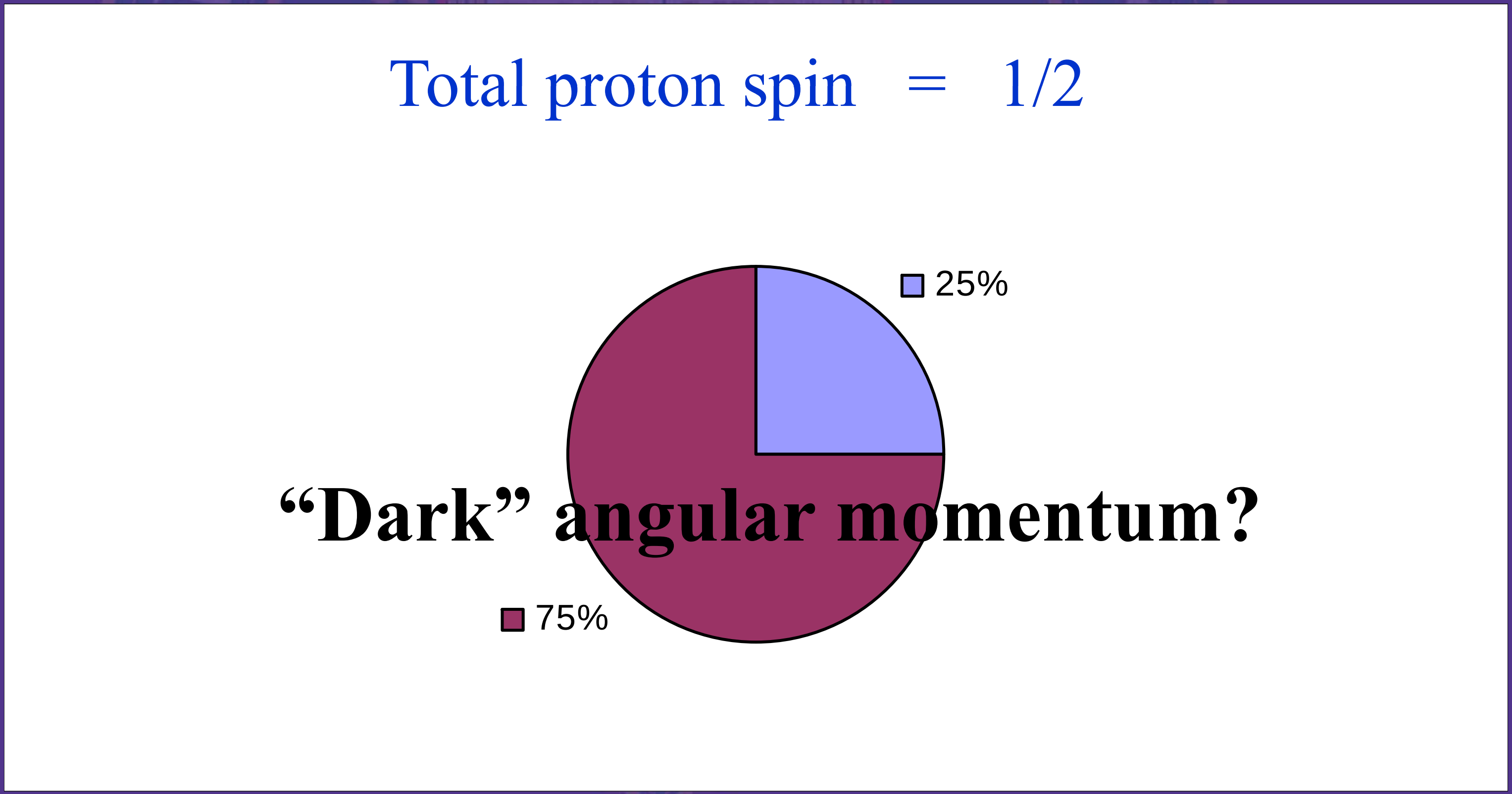


- First measurement of Transversity for u &d from semi-inclusives, HERMES & COMPASS

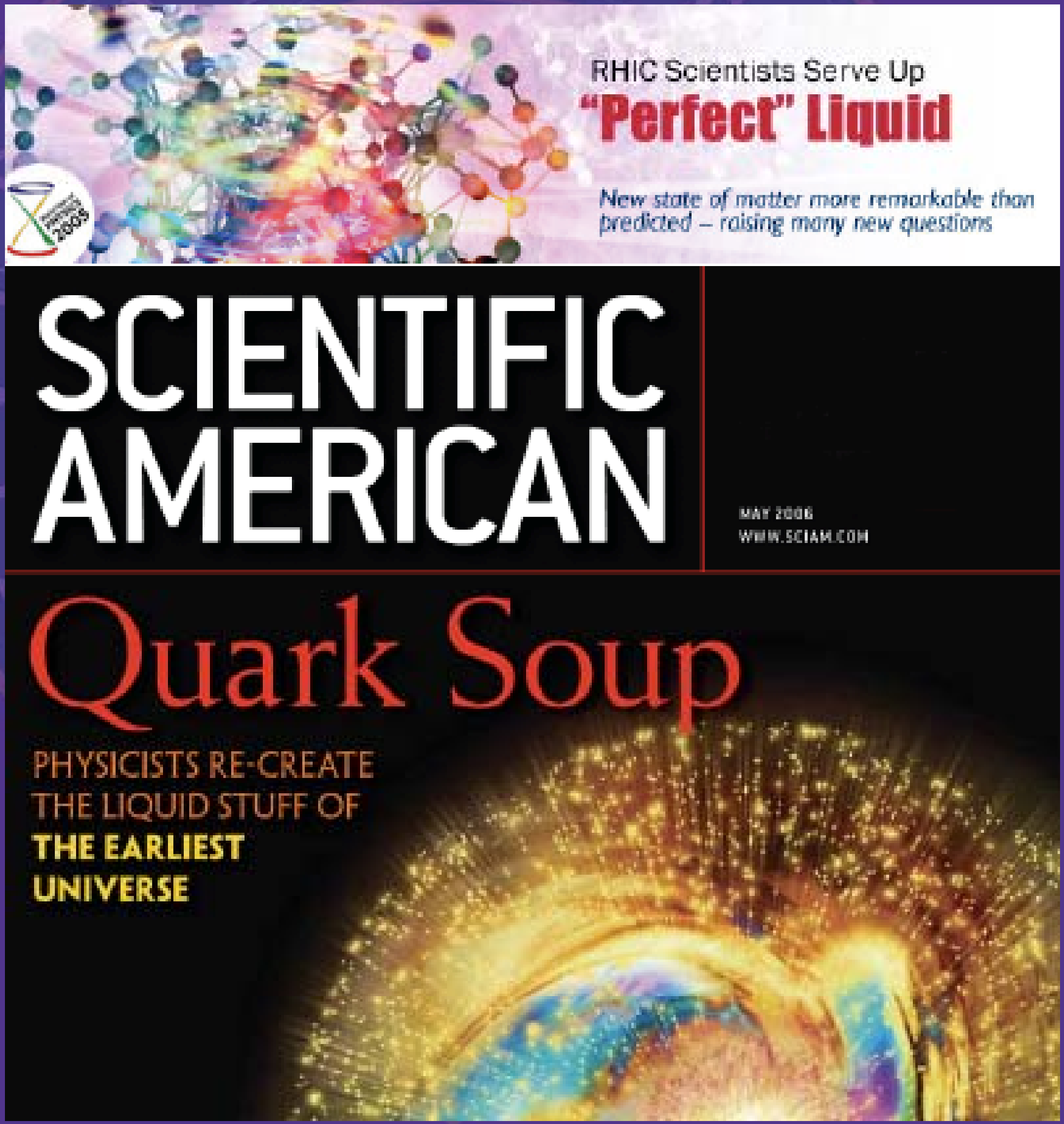


Spin physics

- We still need to find a way to measure the great majority of the nucleon's spin. Needs upgraded JLAB, RHIC…..

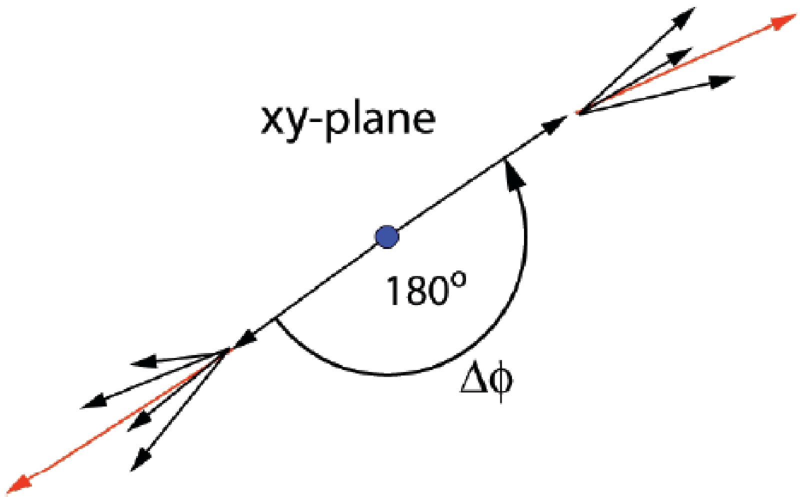


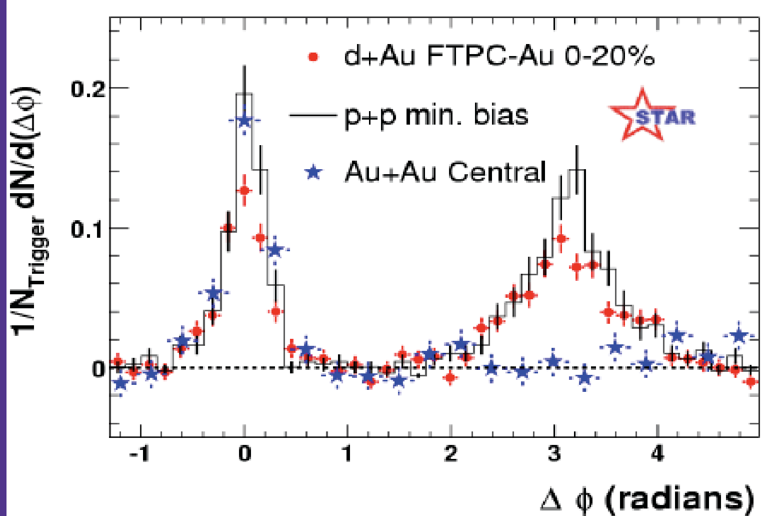
sQGP


RHIC Scientists Serve Up
"Perfect" Liquid
New state of matter more remarkable than predicted – raising many new questions
SCIENTIFIC AMERICAN
MAY 2006
WWW.SCIAM.COM
Quark Soup
PHYSICISTS RE-CREATE THE LIQUID STUFF OF THE EARLIEST UNIVERSE

sQGP

High-p_T Suppression – Matter is Opaque

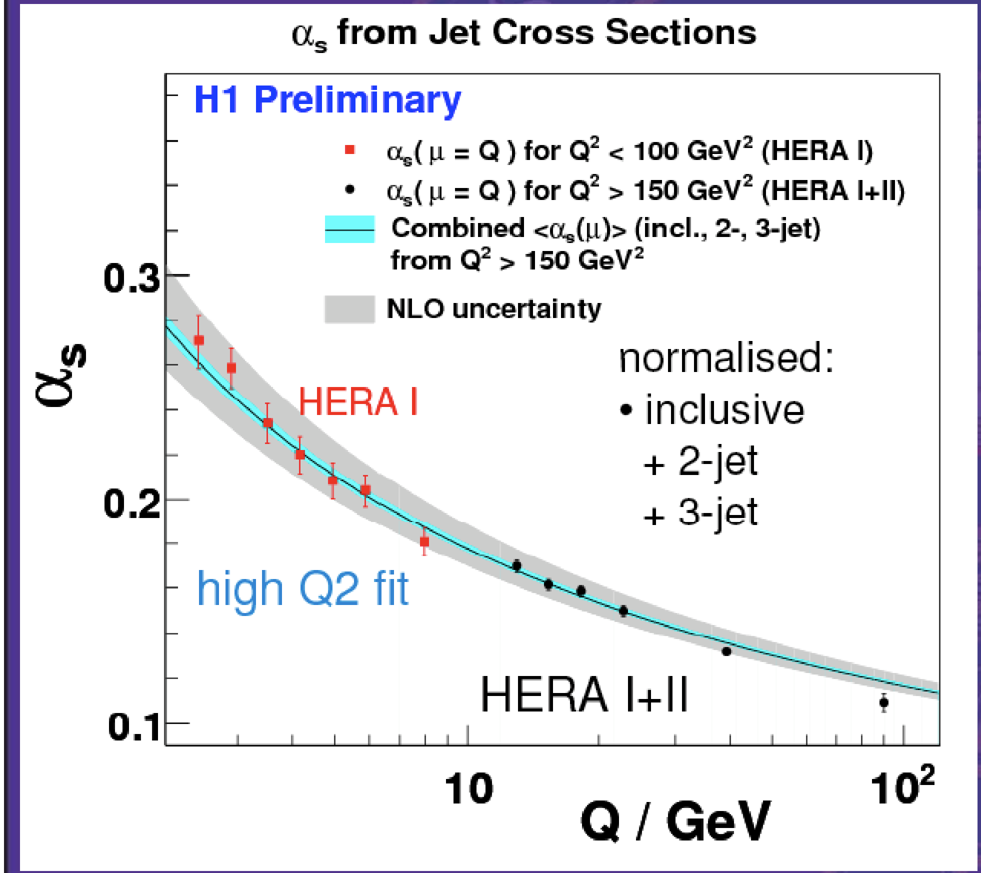




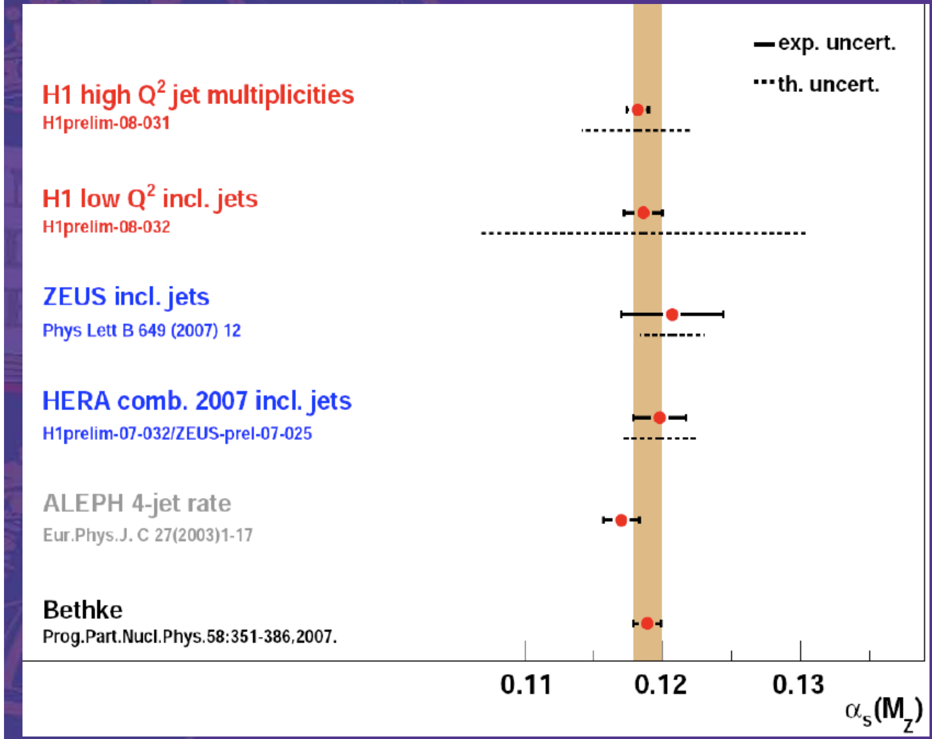
Observations at RHIC:

1. Photons are not suppressed
   - Good! γ don't interact with medium
   - N_{coll} scaling works
2. Hadrons are not suppressed in peripheral collisions
   - Good! medium not dense
3. Hadrons are suppressed in central collisions
   - Huge: factor 5
4. Azimuthal correlation function shows ~complete absence of "away-side" jet
   - Partner in hard scatter is absorbed in the dense medium

α_s



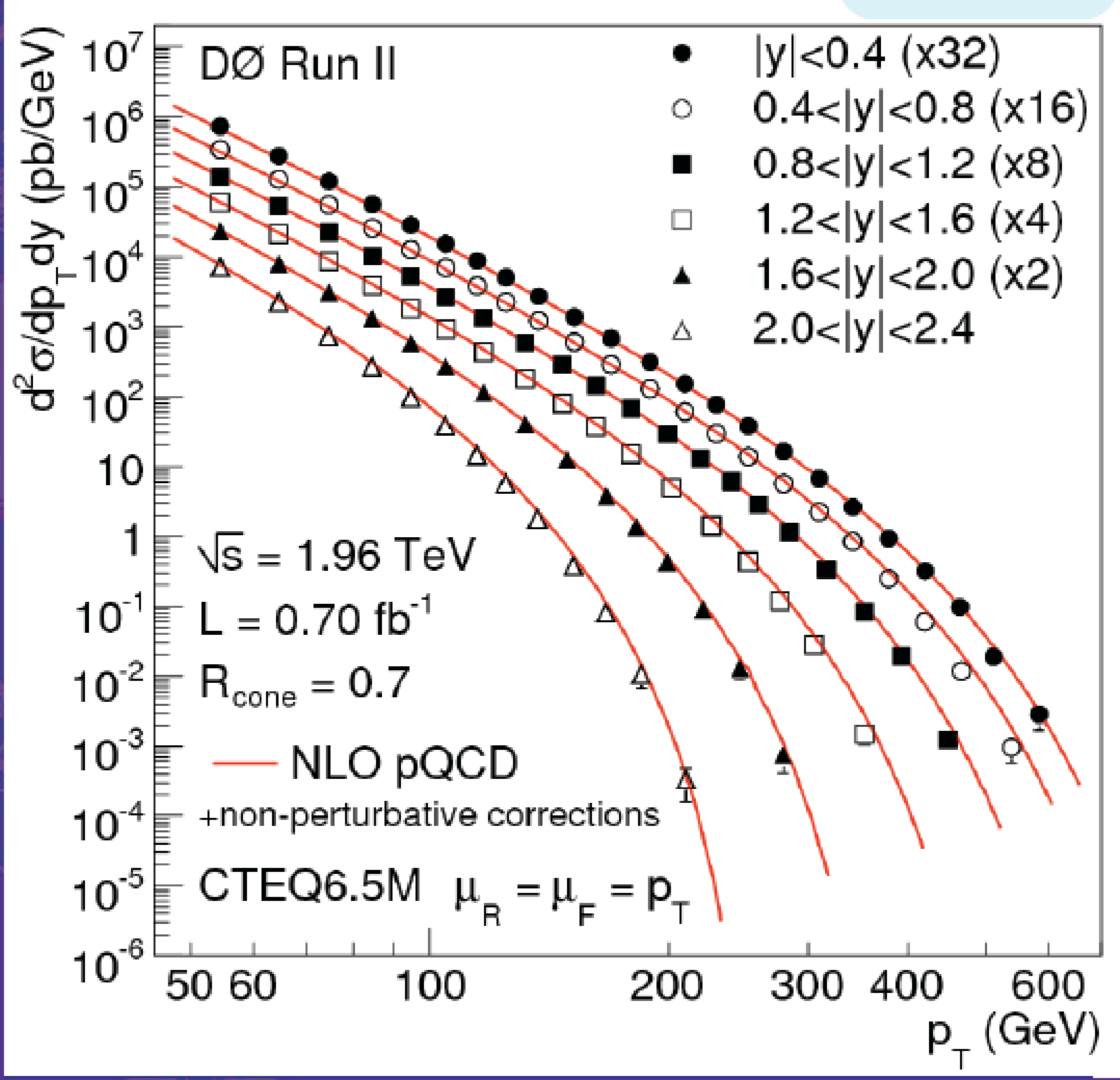
α_s from Jet Cross Sections
H1 Preliminary
$\alpha_s(\mu = Q)$ for $Q^2 < 100$ GeV^2 (HERA I)
$\alpha_s(\mu = Q)$ for $Q^2 > 150$ GeV^2 (HERA I+II)
Combined $<\alpha_s(\mu)>$ (incl., 2-, 3-jet) from $Q^2 > 150$ GeV^2
NLO uncertainty
normalised:
• inclusive
+ 2-jet
+ 3-jet
HERA I
high Q2 fit
HERA I+II
α_s
0.3
0.2
0.1
10
10^2
Q / GeV



exp. uncert.
th. uncert.
H1 high Q^2 jet multiplicities
H1prelim-08-031
H1 low Q^2 incl. jets
H1prelim-08-032
ZEUS incl. jets
Phys Lett B 649 (2007) 12
HERA comb. 2007 incl. jets
H1prelim-07-032/ZEUS-prel-07-025
ALEPH 4-jet rate
Eur.Phys.J. C 27(2003)1-17
Bethke
Prog.Part.Nucl.Phys.58:351-386,2007.
0.11
0.12
0.13
$\alpha_s(M_Z)$

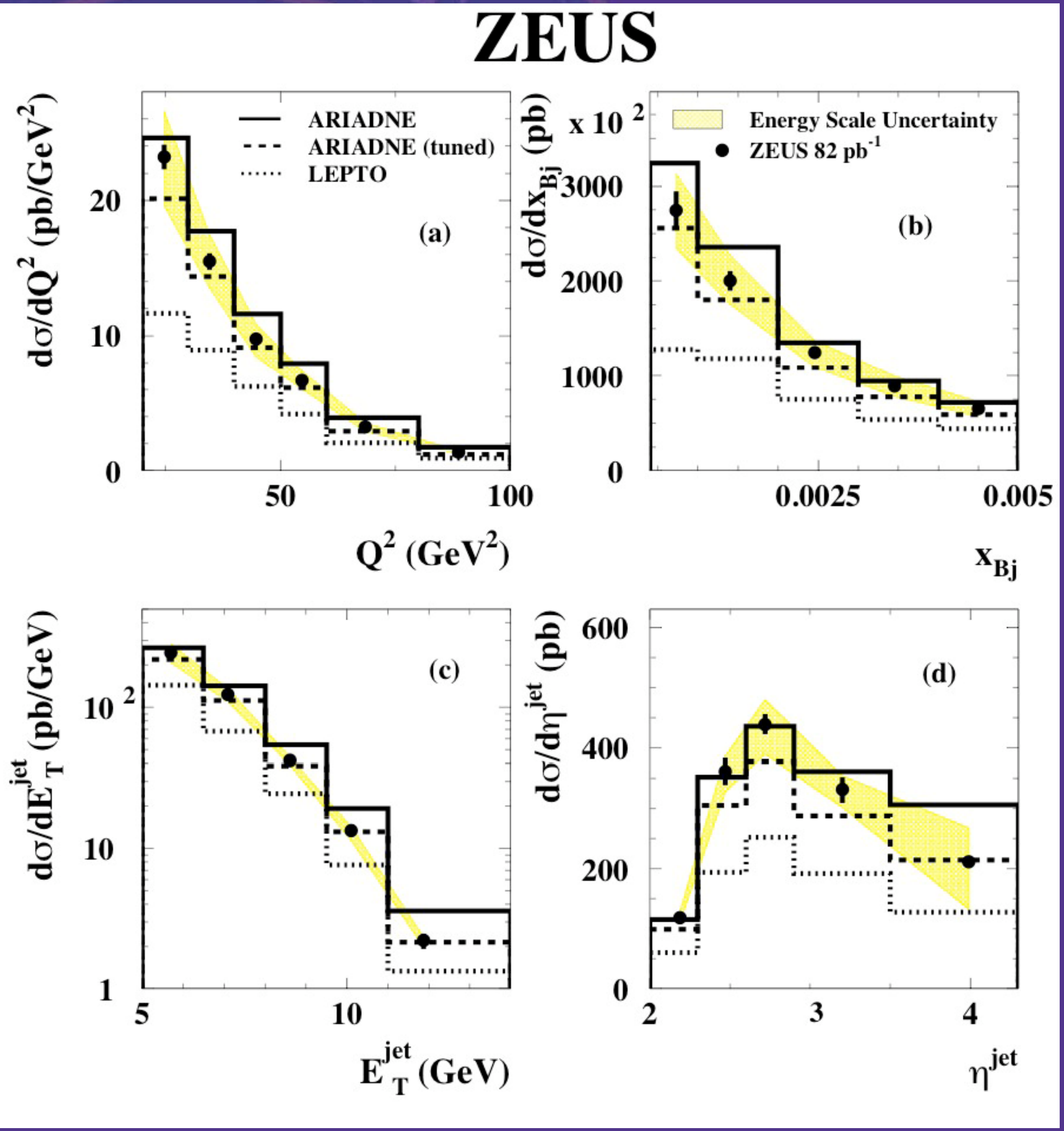
Jet physics @ Tevatron

- Excellent description of jet data over 10 orders of magnitude.



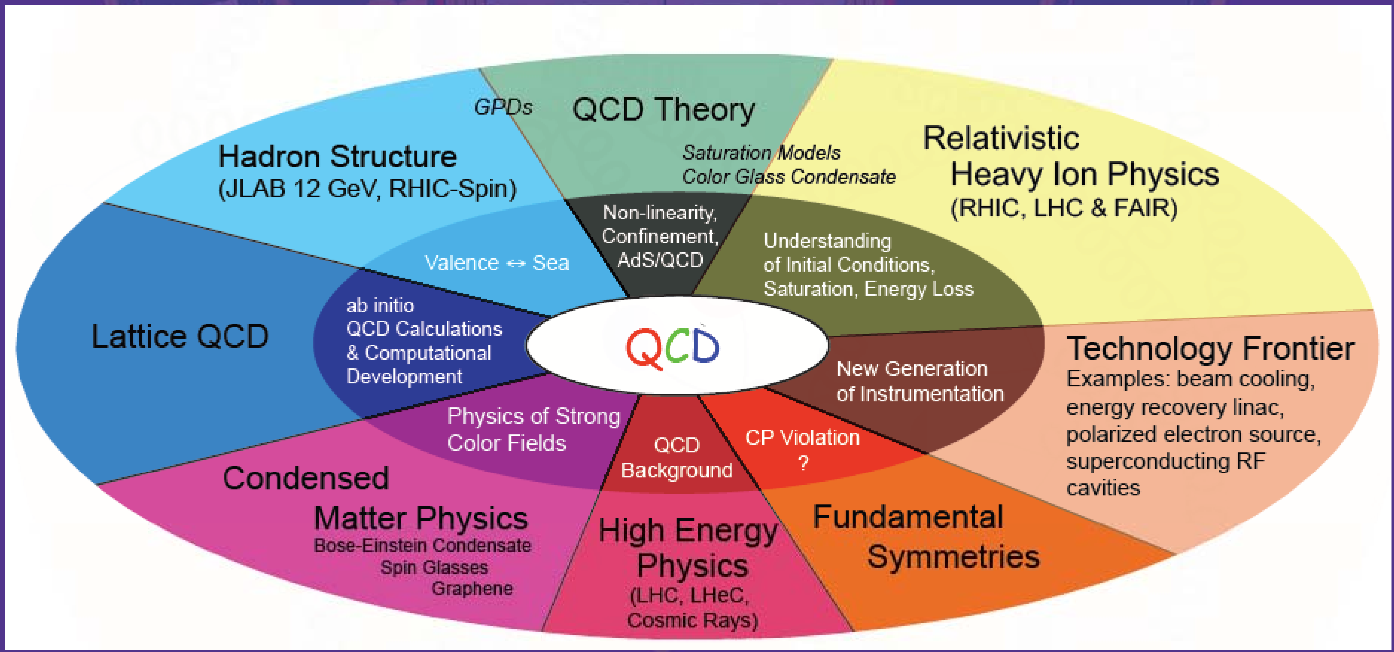
Forward jets

- **Only Ariadne seems able to fit all the data.**



Future facilities

- Fortunately the future facilities have just been summarised.
- Very impressive potential for JLab & RHICII upgrades and EIS



Future facilities

- **LHeC blessed by ECFA for CD study.**

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Deep inelastic electron-nucleon scattering at the LHC

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E-mail: klein@ifh.de

Abstract: The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, 10^{33} cm^{-2}s^{-1}, and high energy, $\sqrt{s} = 1.4$ TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond 10^6 GeV^2 and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

Keywords: Accelerator modelling and simulations (multi-particle dynamics; single-particle dynamics); Large detector systems for particle and astroparticle physics.

2006 JINST 1 P10001

hep-ex/0306016

Organisation:
steering group
07: working groups
09: CDR
11: TDR
for consideration when LHC has revealed sth

Scientific Advisory Committee

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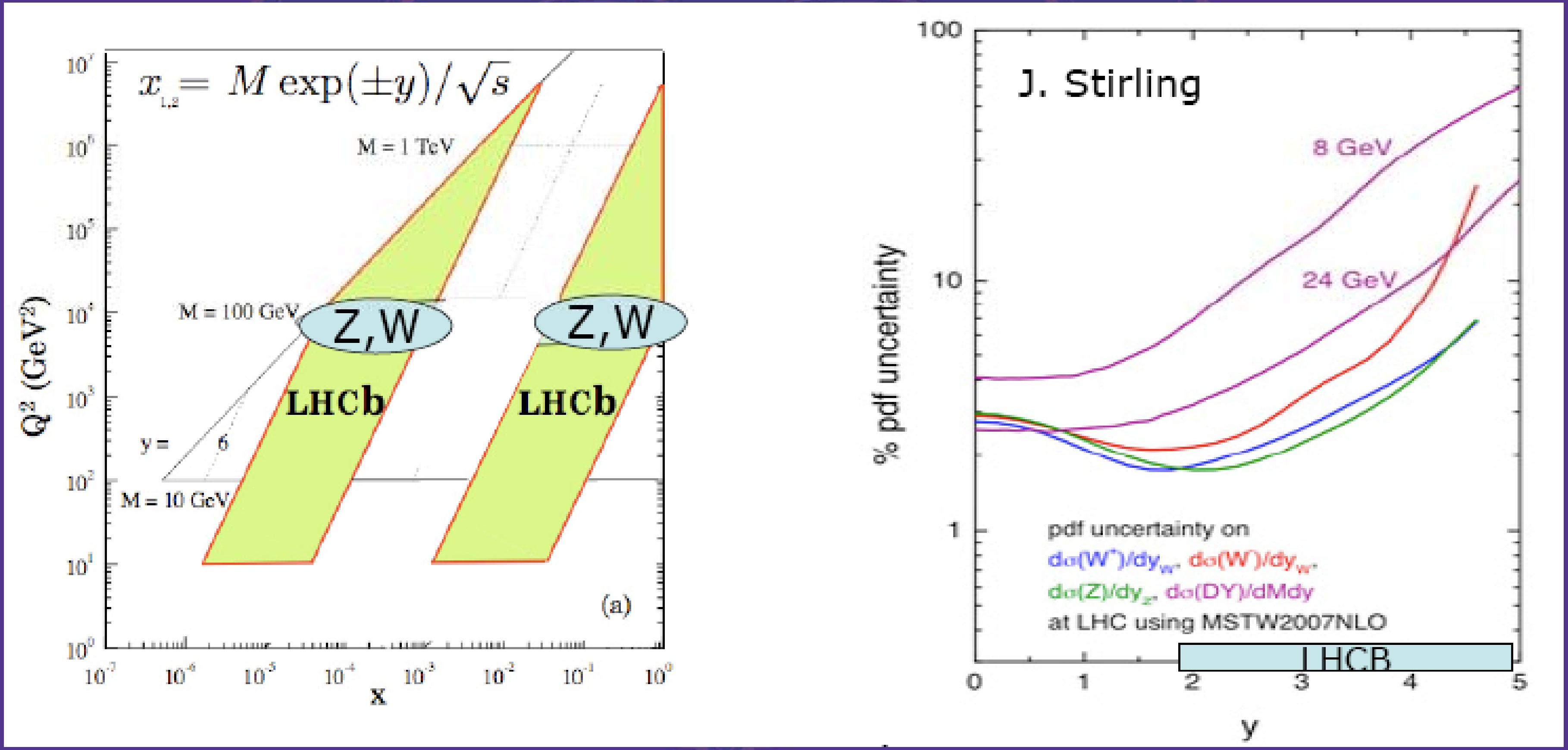
Few invitations still outstanding

The baton passes to LHC

- LHCb has unique reach in (x, Q^2) via DY & Z, W production.



The baton passes to LHC

- Can significantly improve PDFs in region where saturation effects expected.

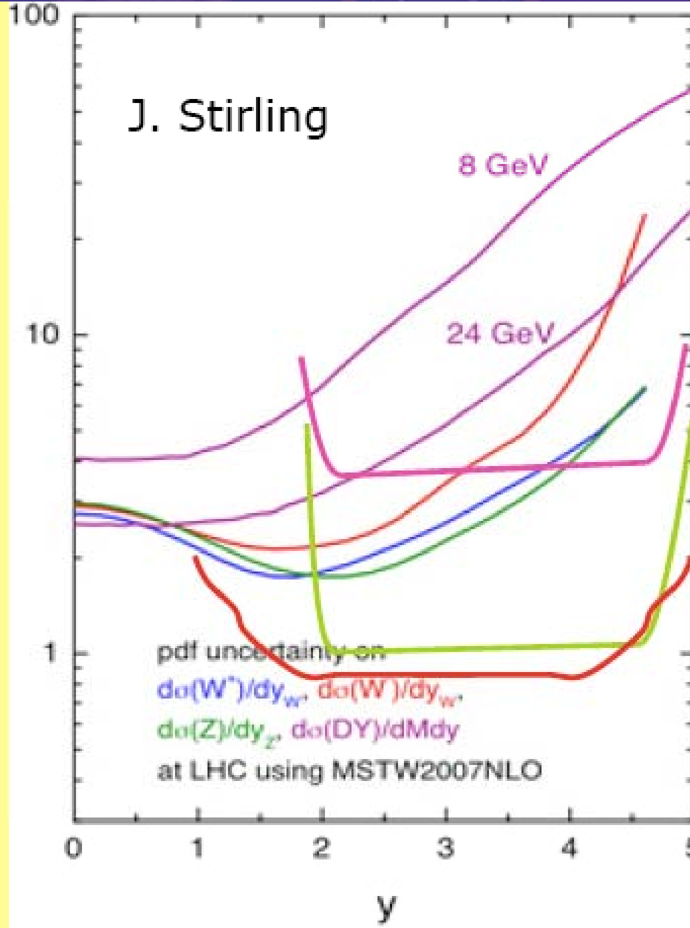
$\frac{d\sigma}{dy}, \frac{d\sigma}{d\eta}$ for Z and W (lepton) can be measured to 1%

Luminosity will be dominant systematic.

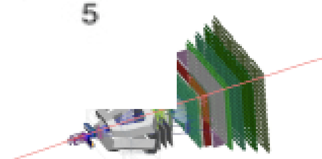
Test SM/ Constrain PDFs to 1% using ratios / shape

LHCb unique in being able to select γ^* down to $x \sim 10^{-6}$ and $Q^2 \sim 25 GeV^2$.

Significant improvement possible to knowledge of gluon pdf.

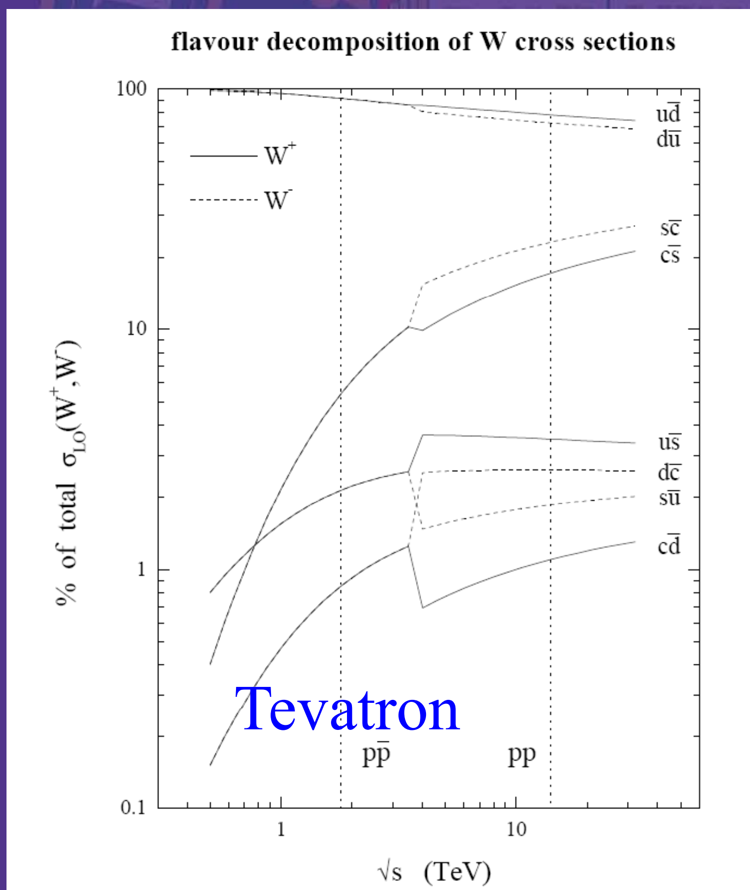


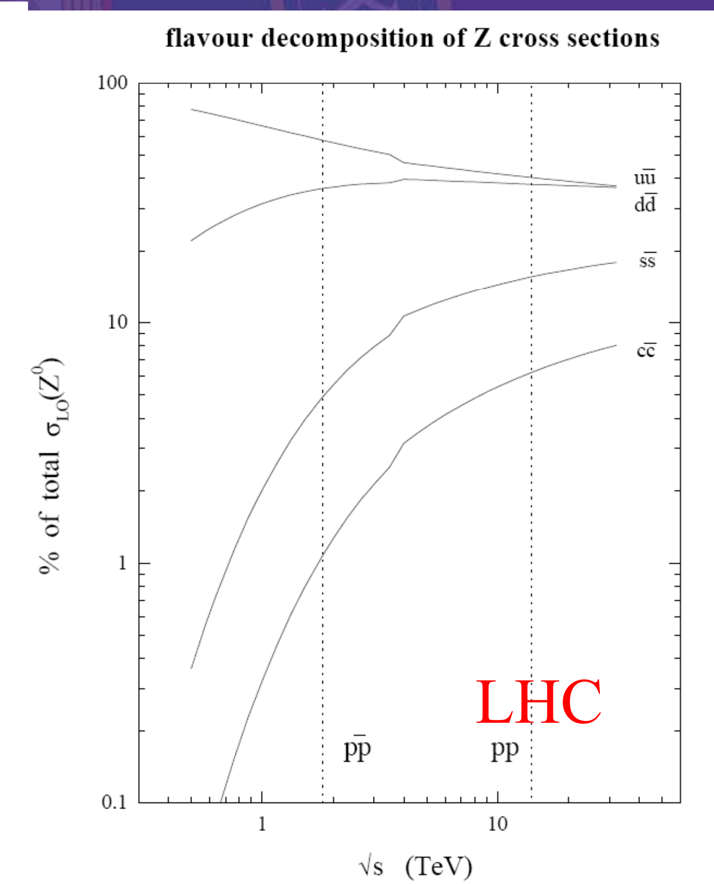
Experimental expectations with 1fb-1



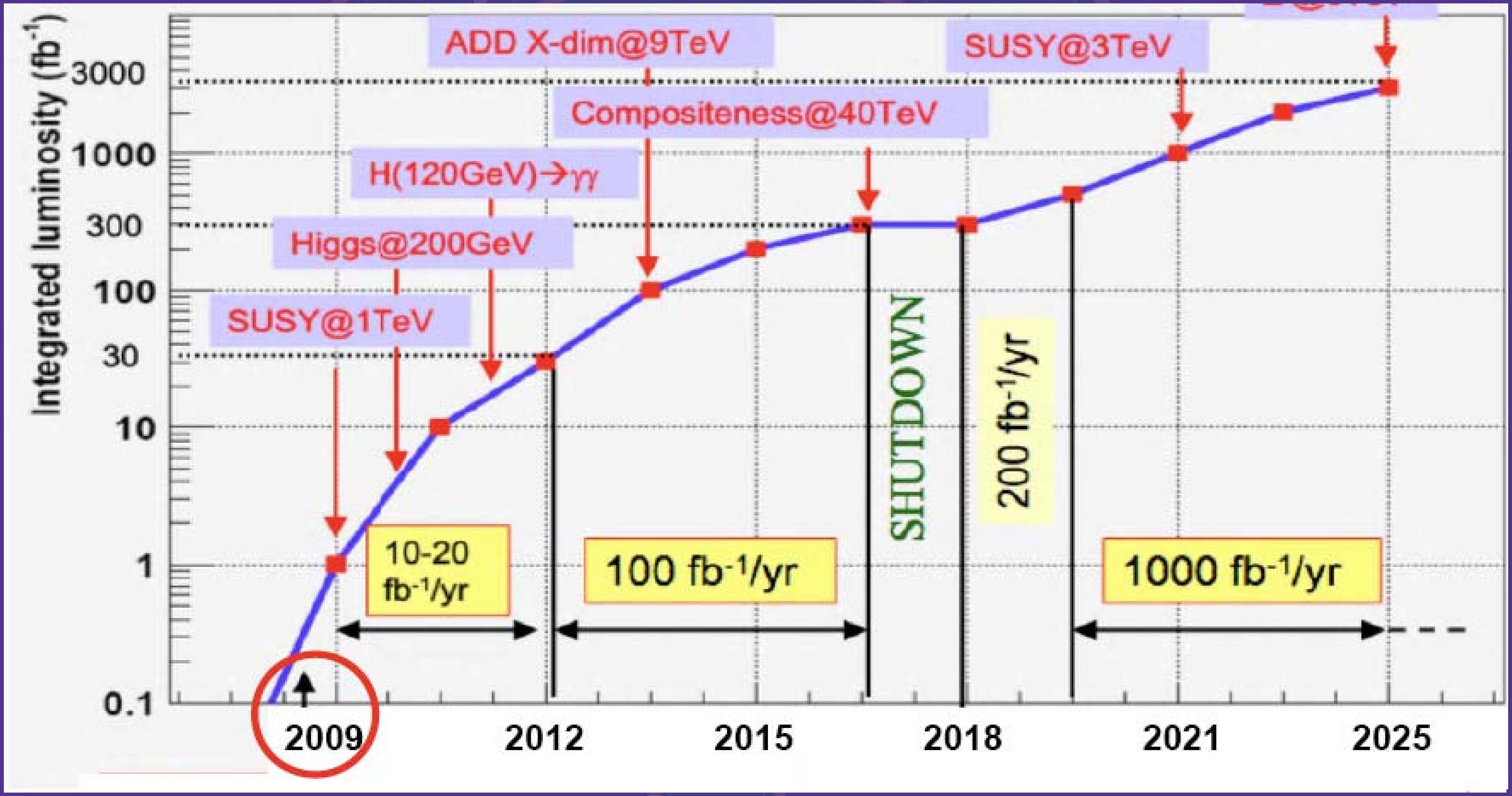
The baton passes to LHC

- W,Z production depends much more on poorly known PDFs than Tevatron. Opportunity & threat.



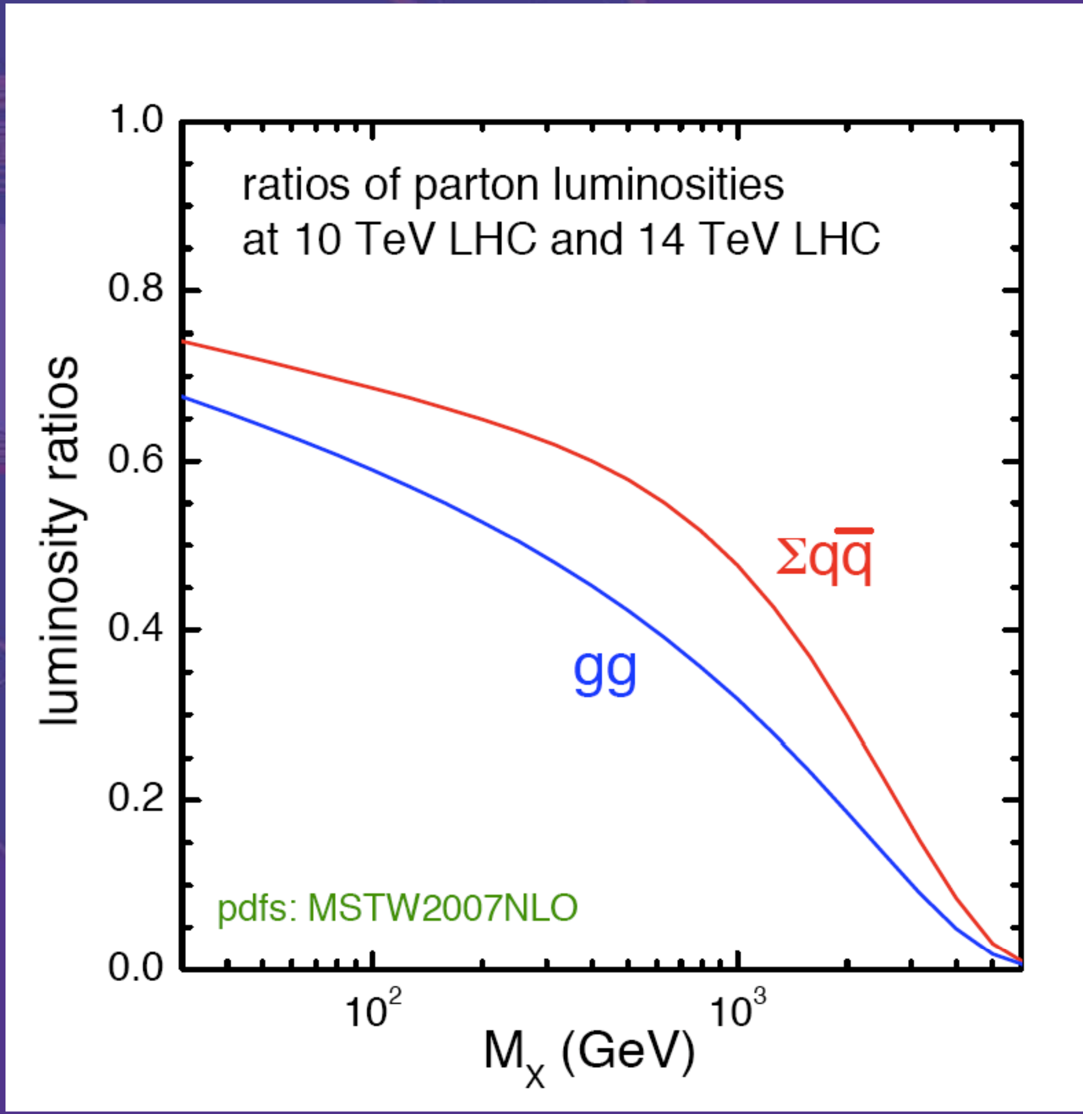


The baton passes to LHC



The baton passes to LHC

- And finally …. just to prove that, as Aharon always reminds us - this really is a workshop!



The Bottom Line

- **What message should you take home from this conference?**

  1) F_L measurement is a major achievement
  2) H1 & ZEUS working together make the difference
  3) The future is bright!

The Bottom Line

- DIS has never been more relevant and vital!
- We owe it to future generations to publish the full HERA statistics – H1/ZEUS combined – as soon as possible. That won’t be tomorrow – but it will be worth waiting for!
- Great future facilities on the blocks!


S
W
E
N

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CRICKET
"British Baseball"
VAN CORTLANDT PARK, RANDALLS ISLAND AND OTHER BALLFIELDS RE-ECHO WITH SOUNDS OF ENTHUSIASTIC FANS ROOTING FOR ANTIGUA, GRENADA, MONTSERRAT, ST. KITTS, TRINIDAD, AND OTHER CHAMP CRICKET TEAMS!
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