Remarks on Deep Inelastic Scattering

Max Klein

Summary of the International Workshop on DIS and QCD, Tsukuba, Japan, April 2006

[klein@ifh.de]

Past

The Physics of DIS at past Rochester Conferences

Results

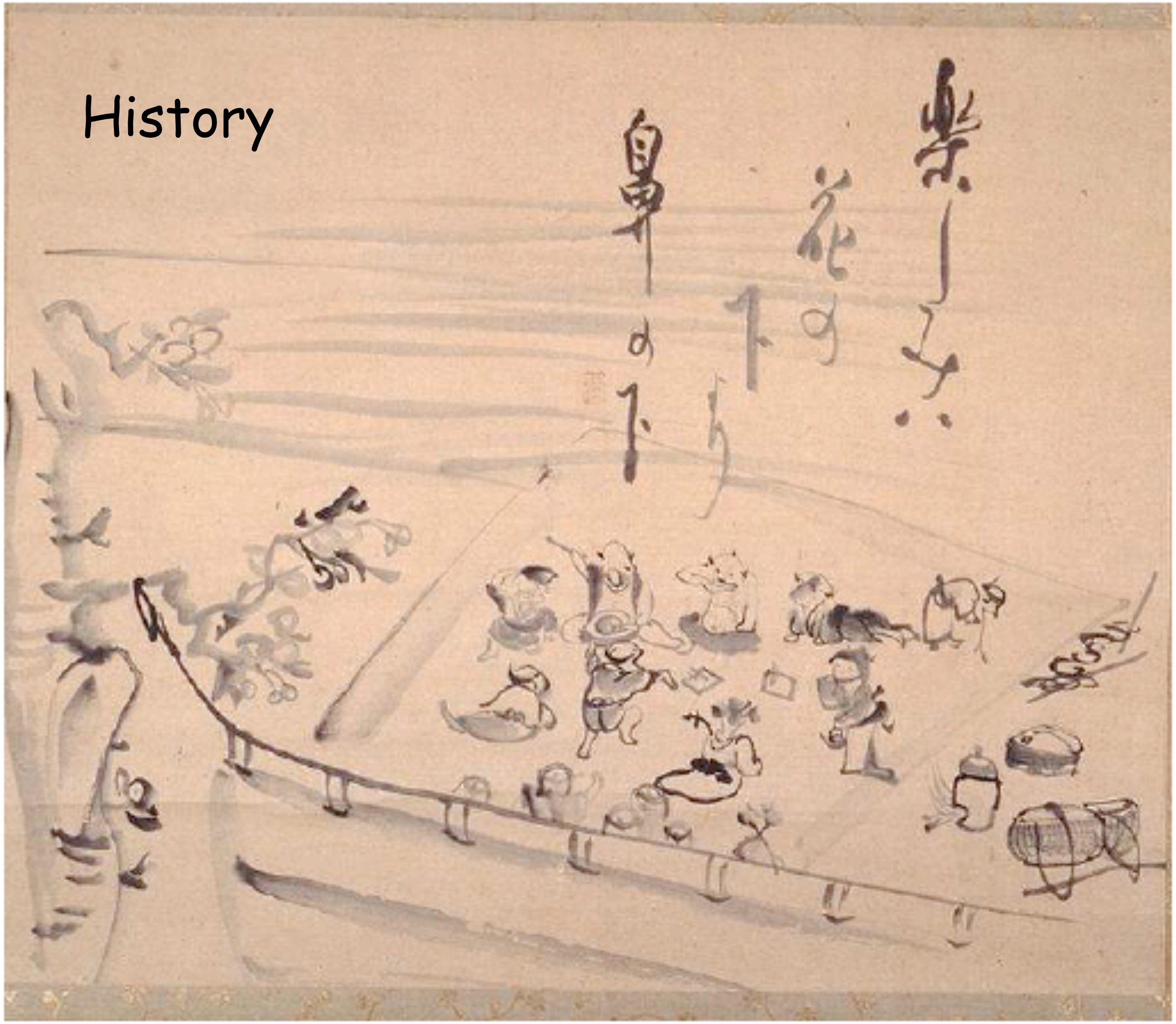
Some highlights for Rochester 2006 and the LHC

Hopes

Regarding developments towards a future of DIS

Complementary to AC-05

History



The DIS 1806 Conference ?

HIGH ENERGY NUCLEAR PHYSICS

Proceedings of the Sixth Annual Rochester Conference,

April 3–7, 1956

Compiled and Edited by

J. BALLAM, V. L. FITCH, T. FULTON,
K. HUANG, R. R. RAU, S. B. TREIMAN

Rochester 1956

Rochester 1956

HIGH ENERGY NUCLEAR PHYSICS

Proceedings of the Fifth Annual Rochester Conference,

January 31 - February 2, 1955

Compiled and Edited by

H. P. NOYES, E. M. HAFNER, G. YEKUTIELI AND B. J. RAZ

Department of Physics, The University of Rochester

Conference co-sponsored by
THE UNIVERSITY OF ROCHESTER and the NATIONAL SCIENCE FOUNDATION
in cooperation with
the Atomic Energy Commission, the Office of Naval Research and the International
Union of Pure and Applied Physics

Rochester 1955

Tuesday Afternoon: Accelerator Physics, R. F. Bacher presiding.

Hofstadter opened the discussion with a presentation of some of the extremely elegant electron-scattering work being done by a large group consisting of himself and J. Fregeau, B. Hahn, R. Helm, A. Knudsen, R. McAllister, and J. McIntyre.

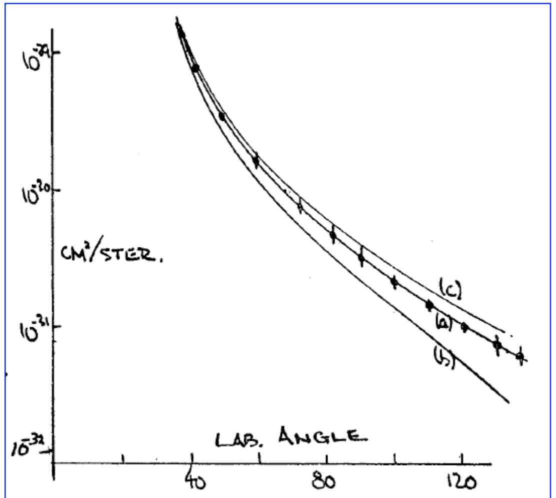


Fig. 2

of the moment is considerably larger. The deviation of the experimental curve from the Rosenbluth cross section (c) suggests that there is a finite size to the proton. $\lambda\!\!\!^{-}$ at this energy is about 10^{-13} cm. so that we expect, roughly speaking, a proton radius of this order to be significant in giving deviations. The experimental curve can, in fact, be analyzed a little more closely by inserting form factors into the Rosenbluth expression. An estimate of the proton radius from such an attempt is the value $(7.0 \pm 2.4) \times 10^{-14}$ cm., if one assumes that both the charge and the moment are diffused over the same volume. There is not enough experimental information to separate the two finite-size effects; in principle, however, the separation can be effected experimentally from work of this kind done at a variety of energies.

Some lessons from 50 years ago

You need to build an accelerator before you can do pioneering physics.

You then may present discoveries in an accelerator session, in particular if your colleagues don't know how to term the field. It seems

"electron - nucleon scattering" was born 50 years ago.

You don't need powerpoint to present a discovery, once you made one.

The idea of running HERA at different energies to separate the two basic formfactors (G_E, G_M --> $\nu W_2, W_1$ --> F_2, F_L) isn't really original.

Proceedings of the

XIIIth INTERNATIONAL CONFERENCE

ON HIGH-ENERGY PHYSICS

Sponsored by: International Union of Pure and Applied Physics
United States Atomic Energy Commission
University of California
Held at Berkeley, California, August 31 - September 7, 1966

Rochester 1966

CURRENT TOPICS IN PARTICLE PHYSICS

Murray Gell-Mann

What can we look forward to hearing? Something which we can certainly look forward to hearing, although not necessarily with pleasure, is a lot of discussion among the different kinds of theorists about whether one should work with "S-matrix theory" or "field theory" or "Lagrangian field theory" or "abstract field theory," and I would like to suggest,

...

if all the efforts that we expend on the discussions on which form of field theory one should use were devoted to arguing for a higher-energy accelerator so that we can do more experiments over the next generation and really learn more about the basic structure of matter.

Rochester 1966

FUNDAMENTAL THEORETICAL QUESTIONS

M. Froissart, Rapporteur

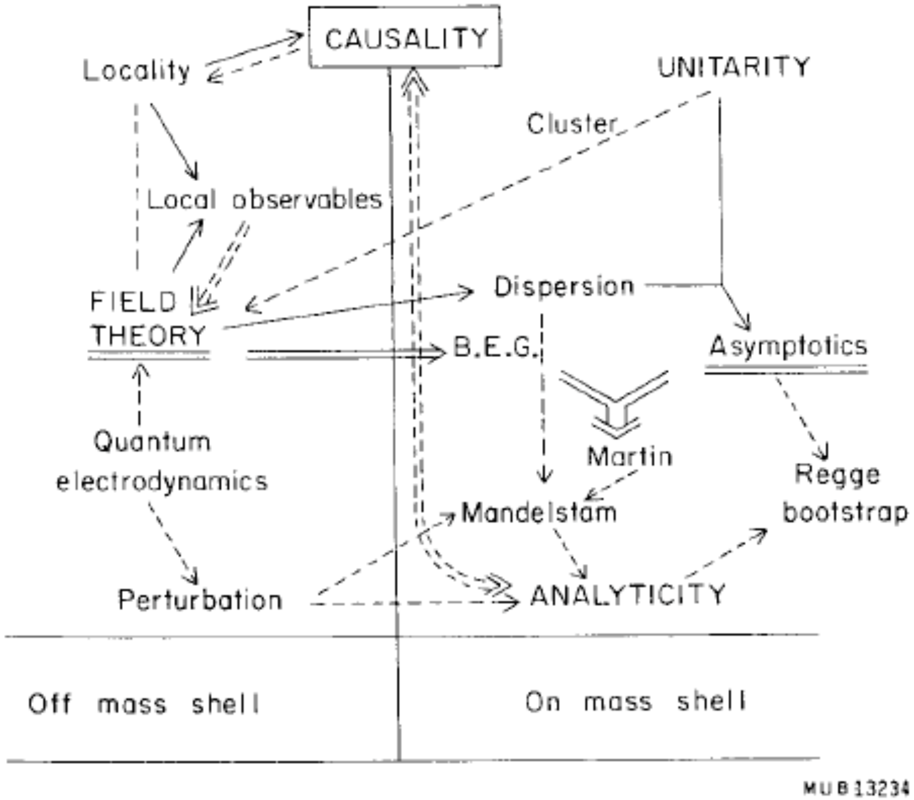


Fig. 1-1. Logical map of "Fundamental" concepts.

ELECTRODYNAMIC INTERACTIONS

S. D. Drell, Rapporteur

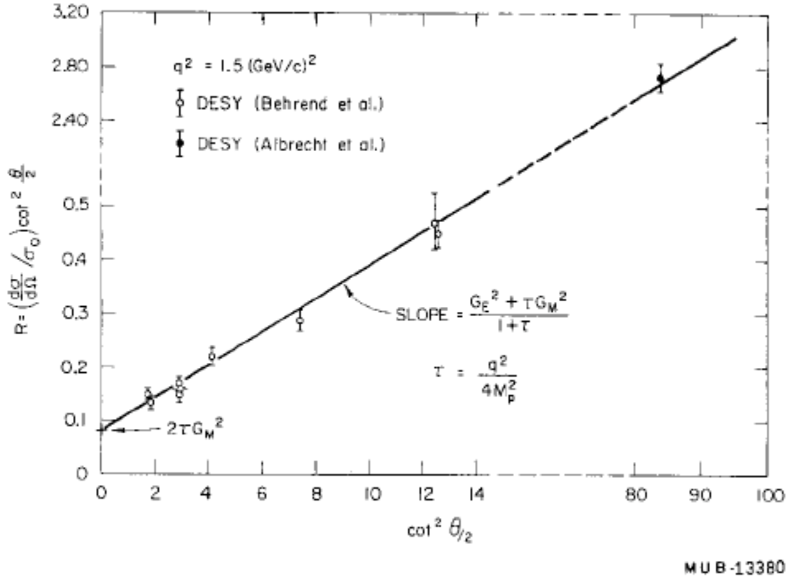
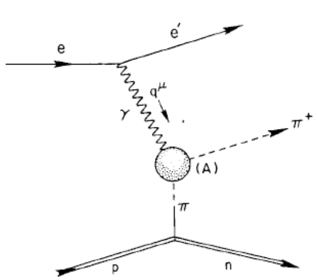
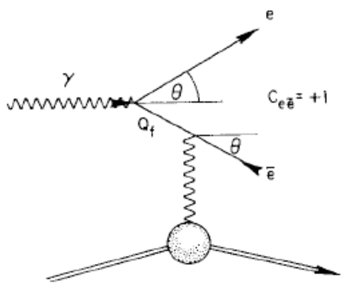
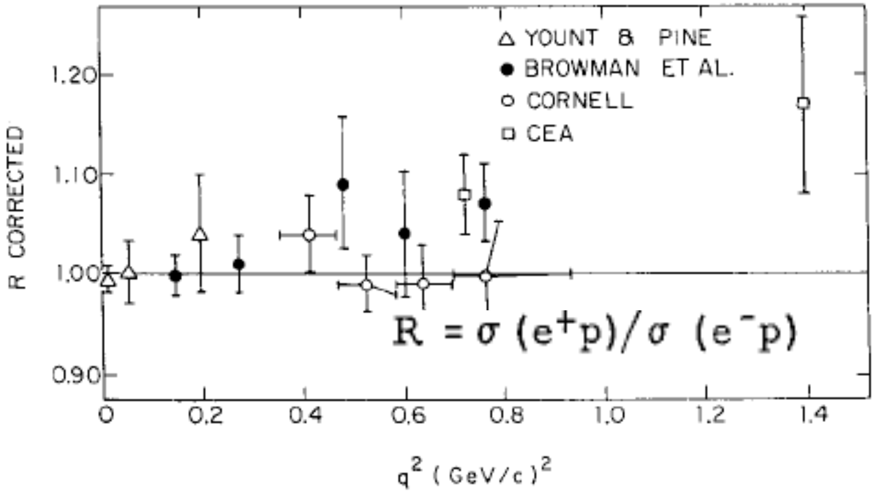


Fig. 6-1. Test of the Rosenbluth straight line for $q^2 = 1.5\ (\mathrm{GeV}/c)^2$.







Drell: I have a remark to myself which I didn't make which says, "what would I like to see measured?" Let me just say briefly that I'd very much like to see inelastic electron or muon cross sections measured; they provide the inelastic nucleon form factors that are of great interest in their own right. Moreover they are also the necessary input that goes into neutron-proton mass-difference calculations, if their isovector structure can be measured, or into the hyperfine-structure calculation, if their spin structure can be determined. Also there are some sum rules, asymptotic statements derived by Bjorken and others, as to how these inelastic cross sections should behave in energy, some of which were mentioned in Dashen's talk on current algebra, and which can be checked experimentally.

Rochester 1966

Some observations for the time of 40 years ago

Theory has progressed enormously, by then and since then.

Theorists had demanded the community to move forward.

Many of the questions and today's diagrams were already there
while quarks and gluons had still to be found.

Discoveries cannot be presented every 10 years, but
electron-nucleon scattering experiments made steady progress.

Drell knew about the 2 mile linac,
a "bold extrapolation of existing technology" (Taylor),
which would find scaling in inelastic ep interactions soon after.

You can make the best remark in your own question & answer period..

Труды
XVIII
Международной
конференции
по физике
высоких
энергий

Тбилиси, июль 1976 г.

A Lesson:

You may discover scaling violations and organise DIS parallel sessions, but

you get little attention if
at the same time new particles are discovered:
D0 - charm 30 years ago

You better still write your Proceedings contribution for later someone may be interested.

Contributions to Rochester 1976

DEEP INELASTIC CHARGED CURRENT NEUTRINO INTERACTIONS

B.Barish, F.Bartlett, A.Bodek, D.Buchholz, W.Brown, F.Jacquet, F.Merritt, F.Sciulli, L.Stutte, H.Suter

California Institute of Technology

H.E.Fisk, G.Krafczyk

Fermilab

Charged and neutral currents

MEASUREMENTS OF THE NUCLEON STRUCTURE FUNCTION IN MUON DEEP INELASTIC SCATTERING AT 100 AND 150 GEV/C

H.L.Anderson, V.K.Bharadwaj, N.E.Booth, R.M.Fine, W.R.Francis, B.A.Gordon, R.H.Heisternberg, R.G.Hicks, T.B.W.Kirk, G.I.Kirkbride, W.A.Loomis, H.S.Matis, L.W.Mo, L.C.Myrianthopoulos, F.M.Pipkin, S.H.Pordes, T.W.Quirk, W.D.Shambroom, A.Skuja, L.J.Verhey, W.S.C.Williams, Richard Wilson and S.C.Wright

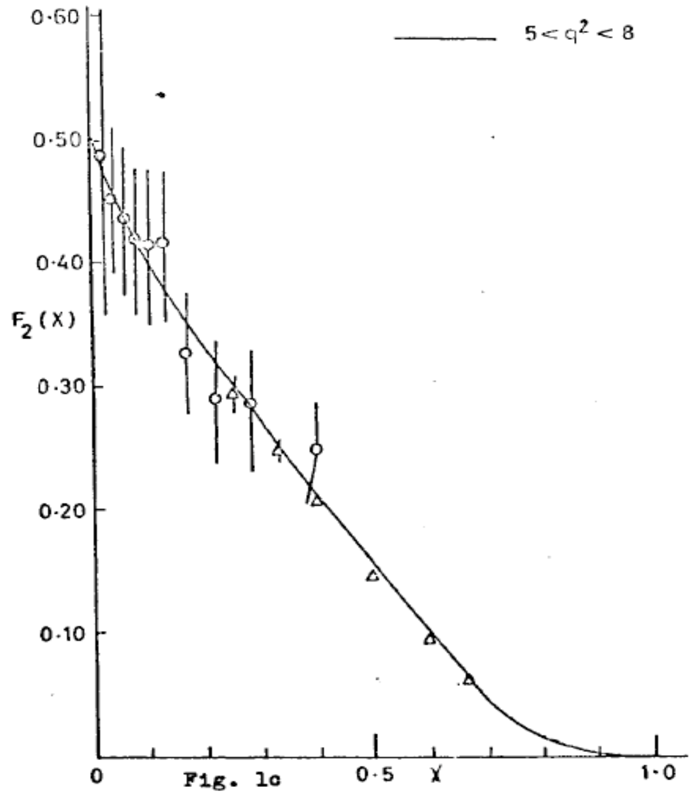


Fig. 1c

An attractive and complete explanation of the behaviour of this data is to be found in renormalizable field theories. The observed behaviour of $F_2(x,q^2)$ as a function of q^2, the constancy of the integral $\int_0^1 F_2(x,q^2)\,dx$ as a function of q^2 and the small value of R at small x are predicted by these theories.

Theory wisdom 30 years ago

DEEP INELASTIC SCATTERING

V.I.Zakharov
ITEP, Moscow, USSR

Conclusions to the Talk

- parton model works not bad indeed,
- asymptotic freedom may show up,
- the overall picture has not yet settled in but it may be simple (rather small effective coupling constant at (1–2) GeV^2 + precocious scaling + preasymptopia).

As to the applications:

- lepton-nuclear scattering can be used to probe the nature of nuclear forces and to study the space-time picture of the parton model,
- if partons + quantum chromodynamics are reliable, then there are no major theoretical problems with describing charmed particles production.

THE UNCONFINED QUARKS AND GLUONS

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy and Imperical College, London, England

1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

...

Dogmas are absolutely essential for the progress of Science but they become tragic if they succeed in stopping experimentation designed to prove them wrong.

Proceedings of the
XXIII International Conference
on
High Energy Physics

16–23 July 1986
Berkeley, California USA

DIS Contributions to ICHEP86

A HIGH-STATISTICS MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION $F_2(x,Q^2)$ FROM DEEP INELASTIC MUON-CARBON SCATTERING AT HIGH Q^2

Bologna-CERN-Dubna-Munich-Saclay Collaboration

presented by
M. Virchaux
DPhPE, CEN Saclay, France

Preliminary Results from a Precision Measurement of the x, Q^2 and Nuclear Dependence of $R = \sigma_L/\sigma_T$

* Presented by S.E.Rock, The American University

PHYSICS AT FUTURE HIGH ENERGY COLLIDERS

C.H.Llewellyn Smith

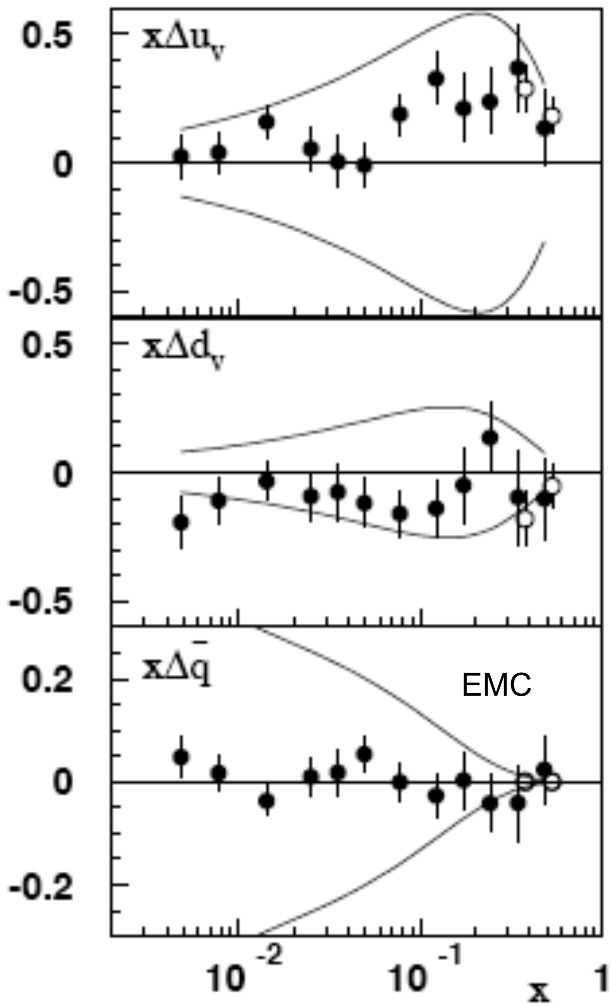
Department of Theoretical Physics
1, Keble Road,
Oxford, OX1 3NP,
England.

To summarize: ep machines are sometimes regarded as poor sisters of e^+e^- and pp machines, but we should remember the story of Cinderella: poor sisters may strike rich and Hera or subsequent ep machines may be spectacularly successful if there are major surprises in the charged current or if lepto-quarks exist.

Rochester 1996

In 1996, at Warsaw, DIS was rather dominating the field. No new particles had appeared. HERA showed its first accurate measurements. Spin!

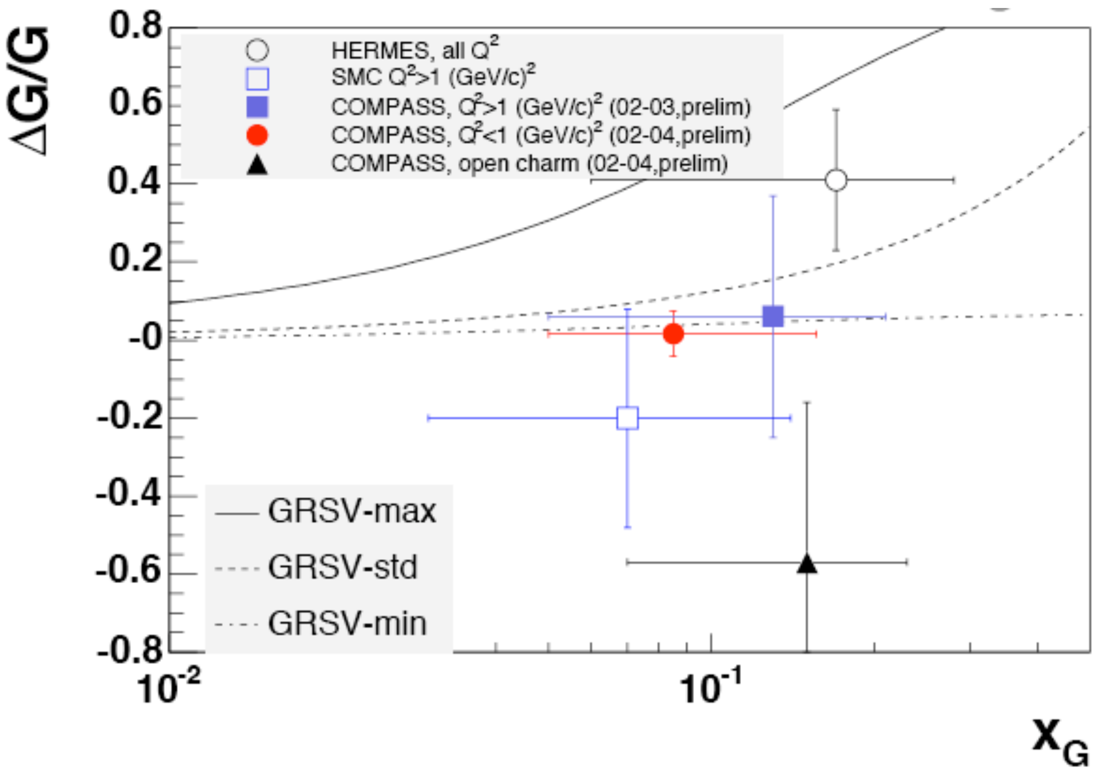
In the preface of the HERA 96 Workshop proceedings, yet, Bjoern Wiik writes, “we have just scratched the surface of HERA physics”.



Polarised quark distributions

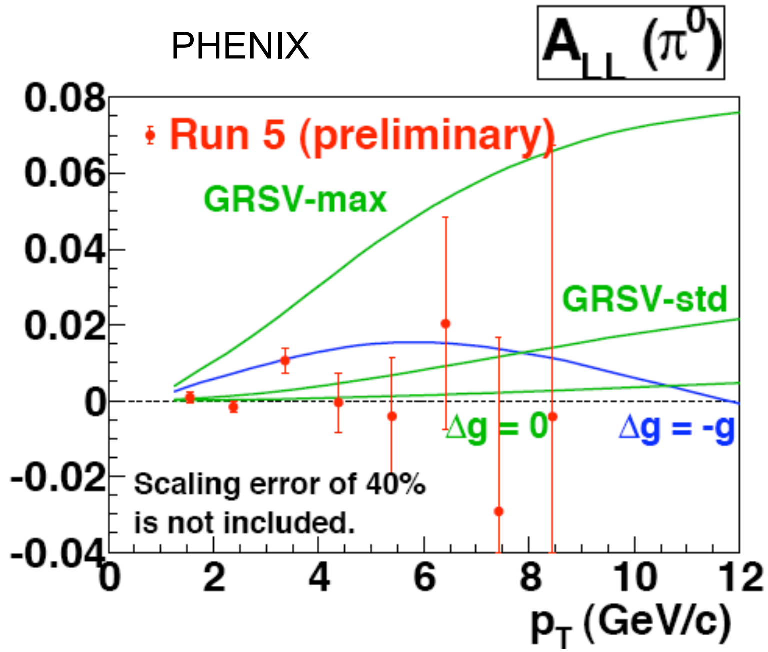
The COMPASS experiment has been recommended at CERN to determine the gluon polarisation from the open charm production in the photon-gluon fusion process. The option to have polarised protons at HERA is under the study and several processes have been proposed to investigate the gluon polarisation there. J.Nassalski

Gluon Spin Contribution?



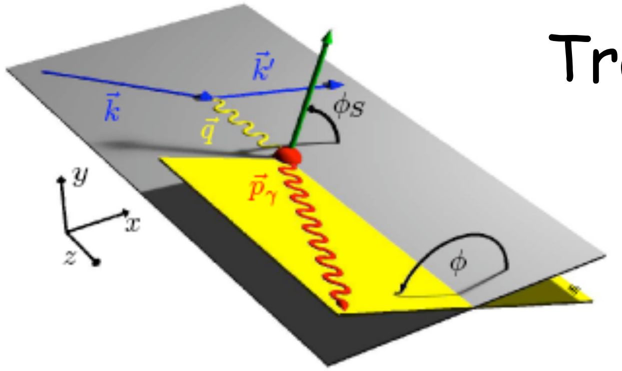
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q+g}$$

$$\Delta\Sigma = 0.31 \pm 0.04$$

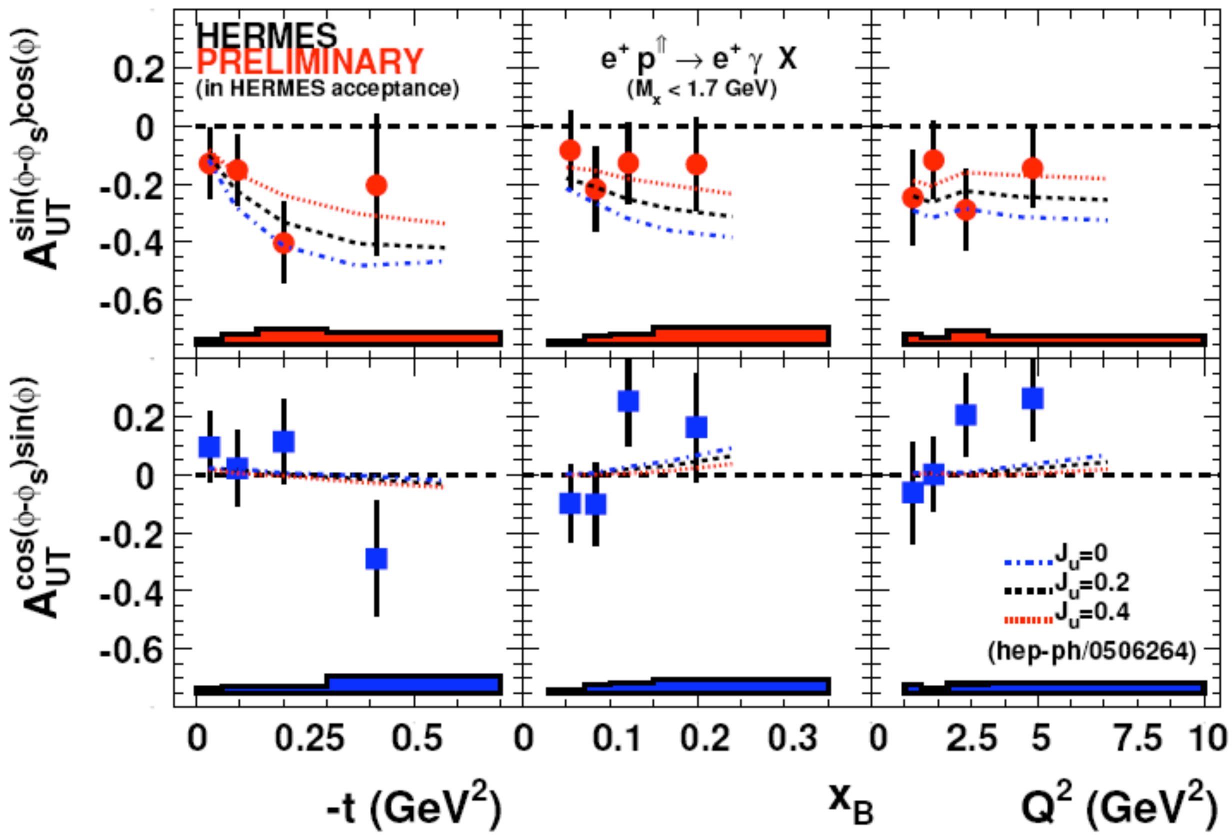


Spin physics needs an eN collider with high polarisations at variable beam energies and high intensity

Tranverse Target Spin Asymmetry



2002-2004



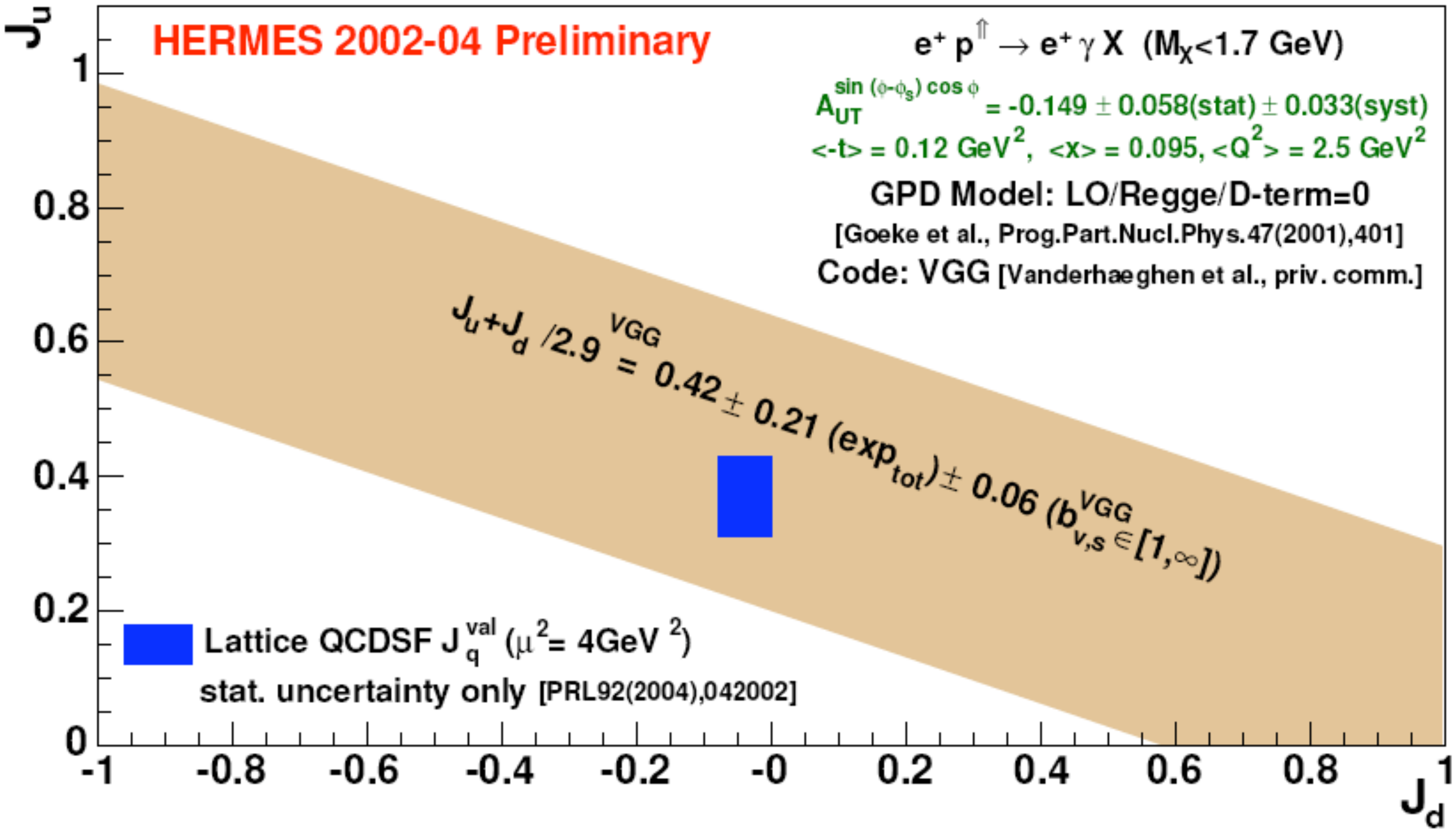
DVCS-BH Interference.

A_{UT} sensitive to GPD E which is related to J(i)

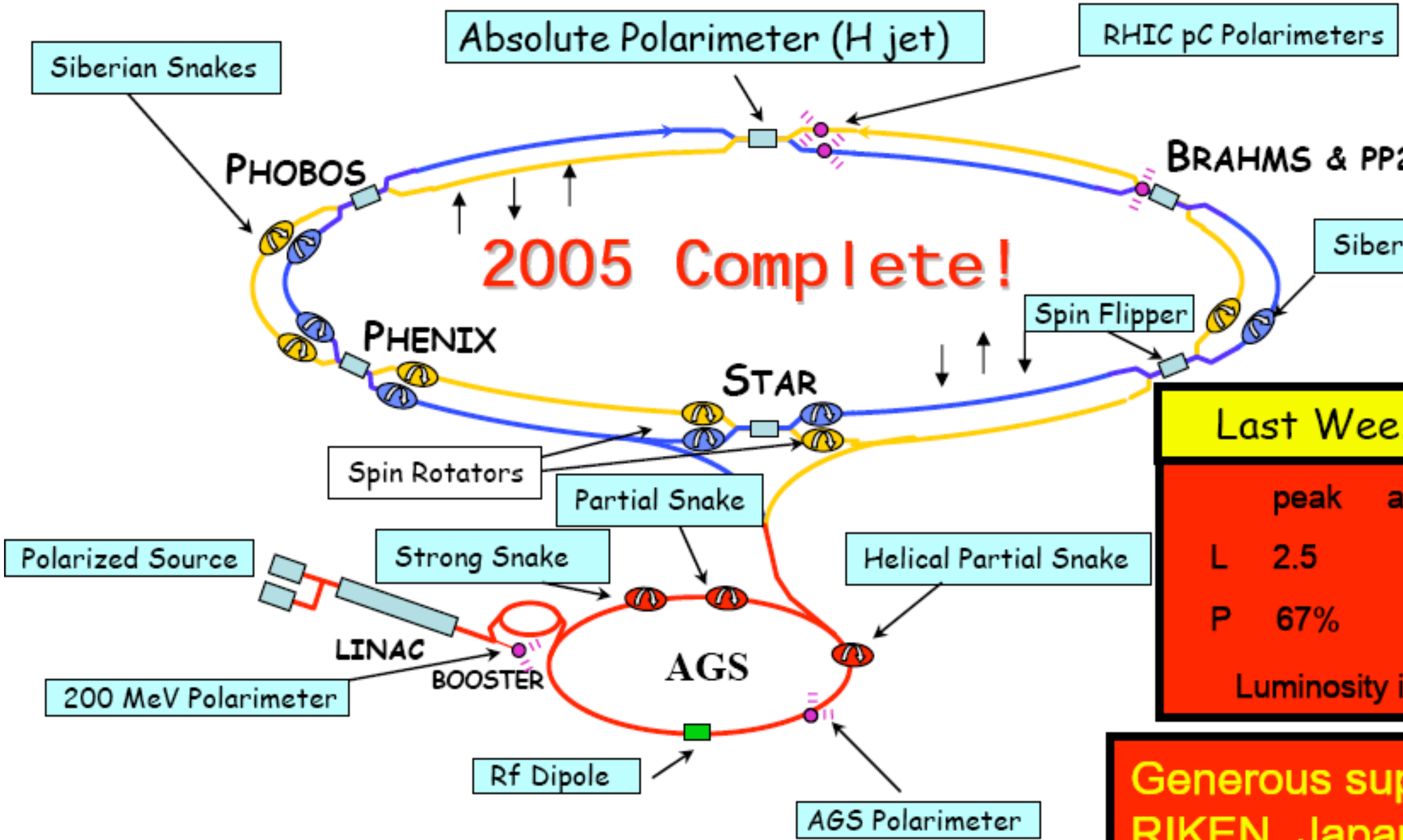
Towards accessing J_q

$$\chi^2_{exp}(J_u, J_d) = \frac{\left[A_{UT}^{\sin(\phi-\phi_S)\cos\phi}|_{exp} - A_{UT}^{\sin(\phi-\phi_S)\cos\phi}|_{VGG}(J_u, J_d)\right]^2}{\delta A^2_{stat} + \delta A^2_{syst}}$$

Model-Dependent



RHIC spin



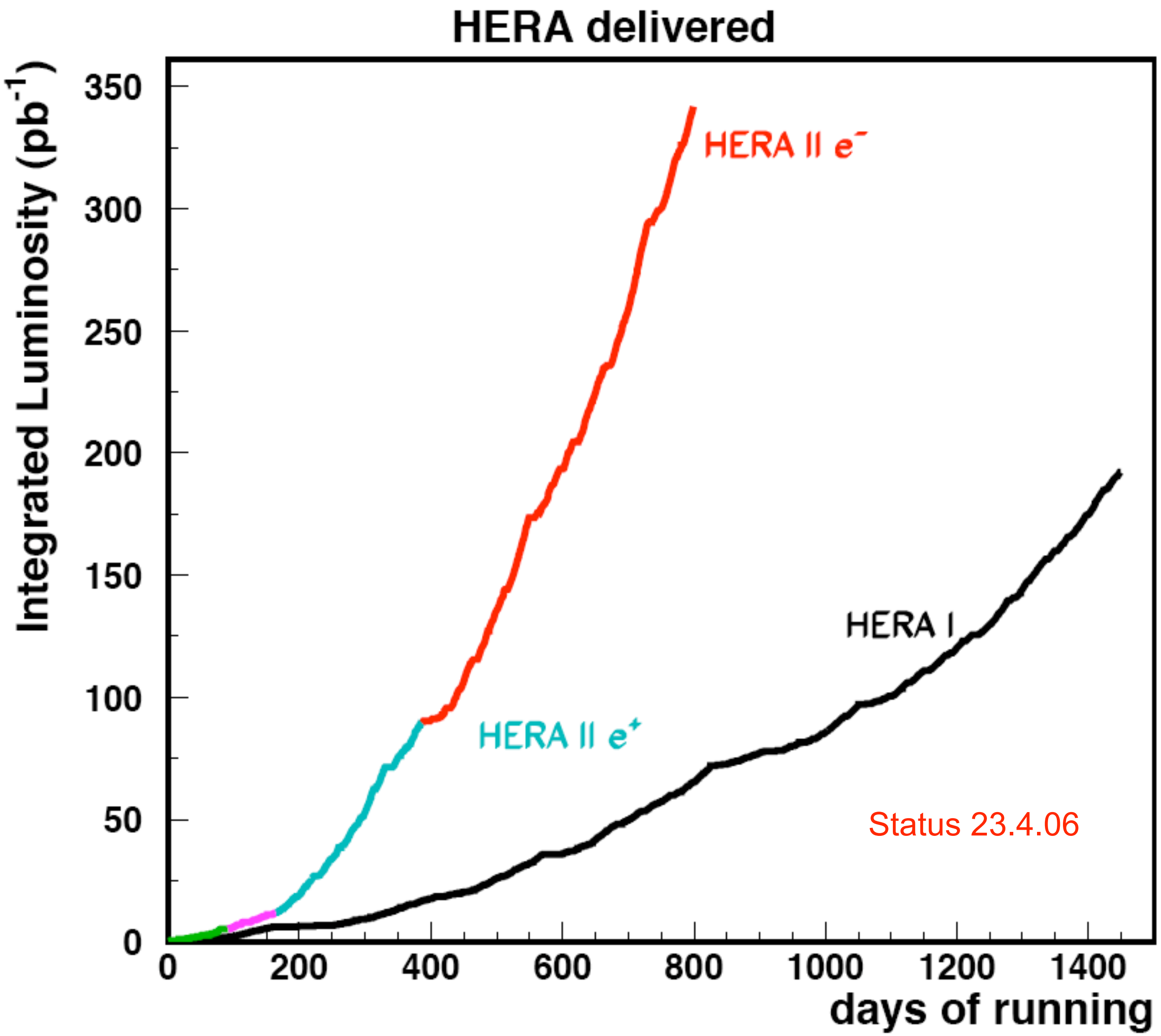
Last Week at RHIC

	peak	average → design	
L	2.5	1.2	6.0
P	67%	61%	70%

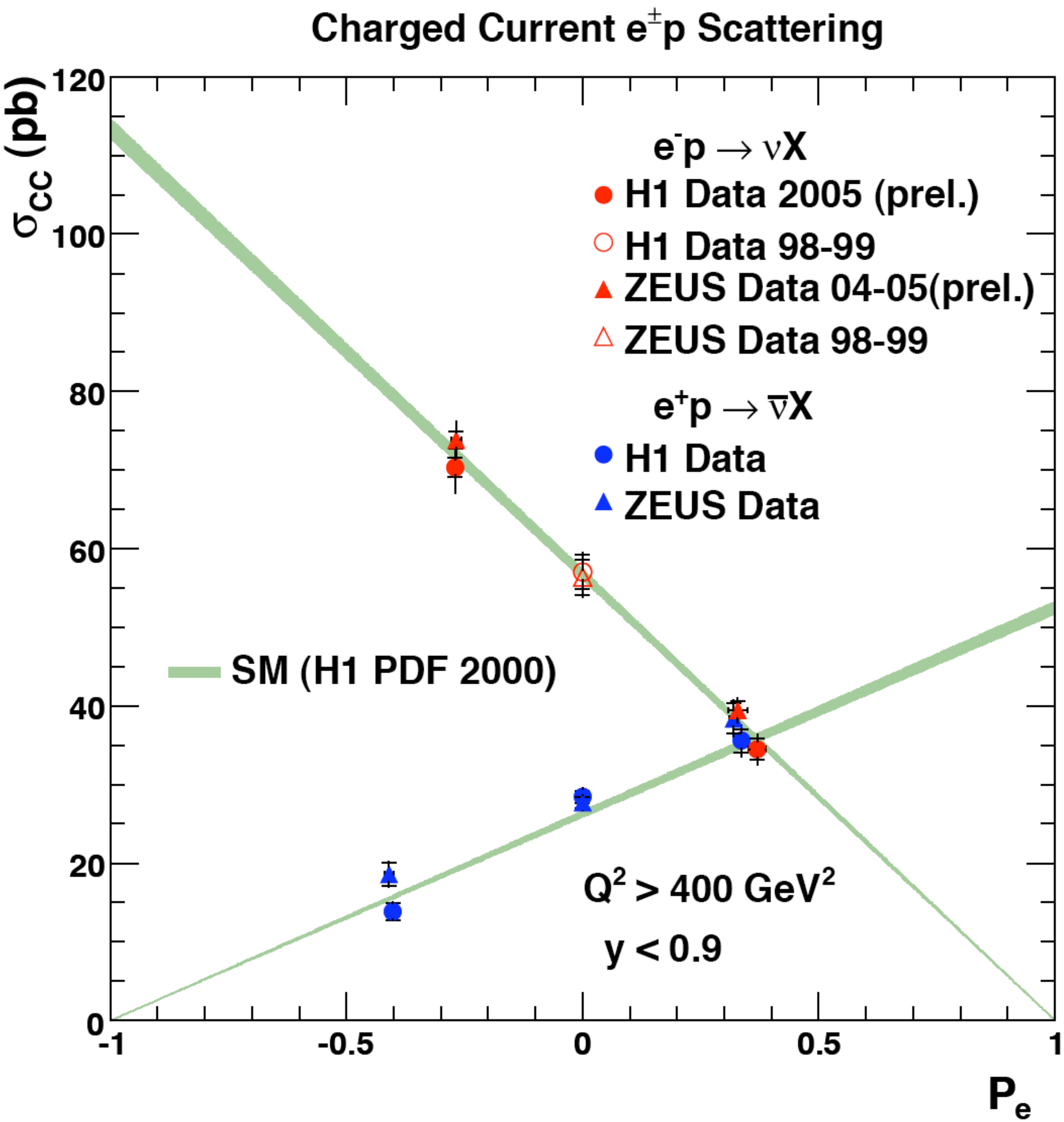
Luminosity in $10^{31}cm^{-2}s^{-1}$

Generous support from RIKEN, Japan and DOE

All instrumentation is in place for the planned measurements on spin dependent gluon distributions and transverse spin.



HERA delivered
Integrated Luminosity (pb^{-1})
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
days of running
HERA II e$^-$
HERA II e$^+$
HERA I
Status 23.4.06

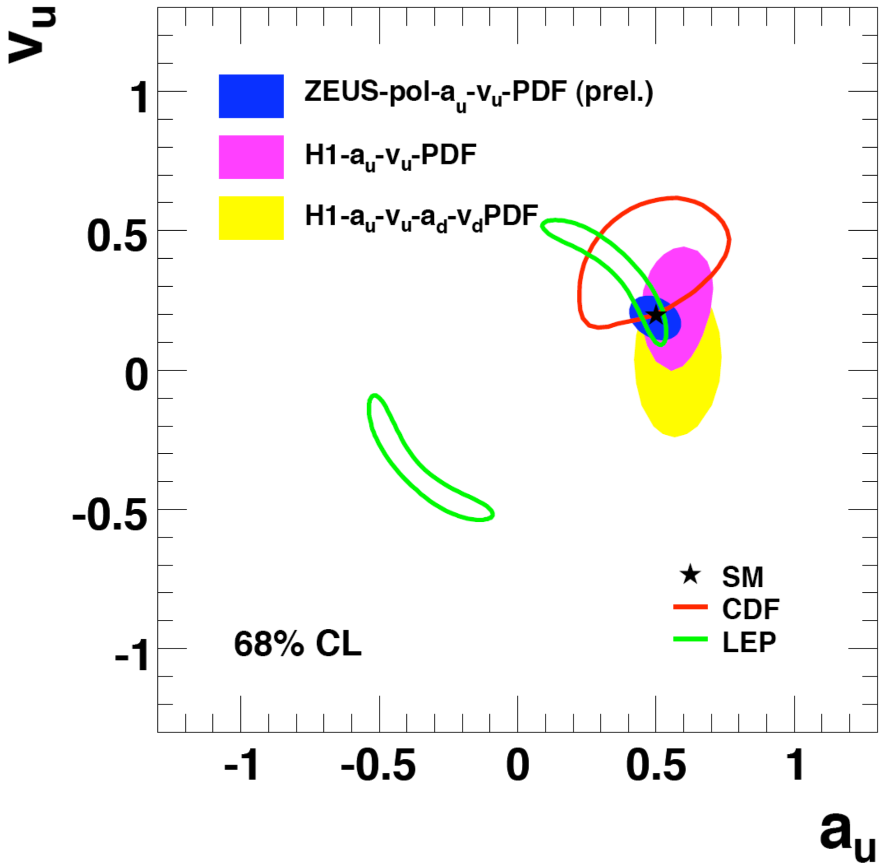


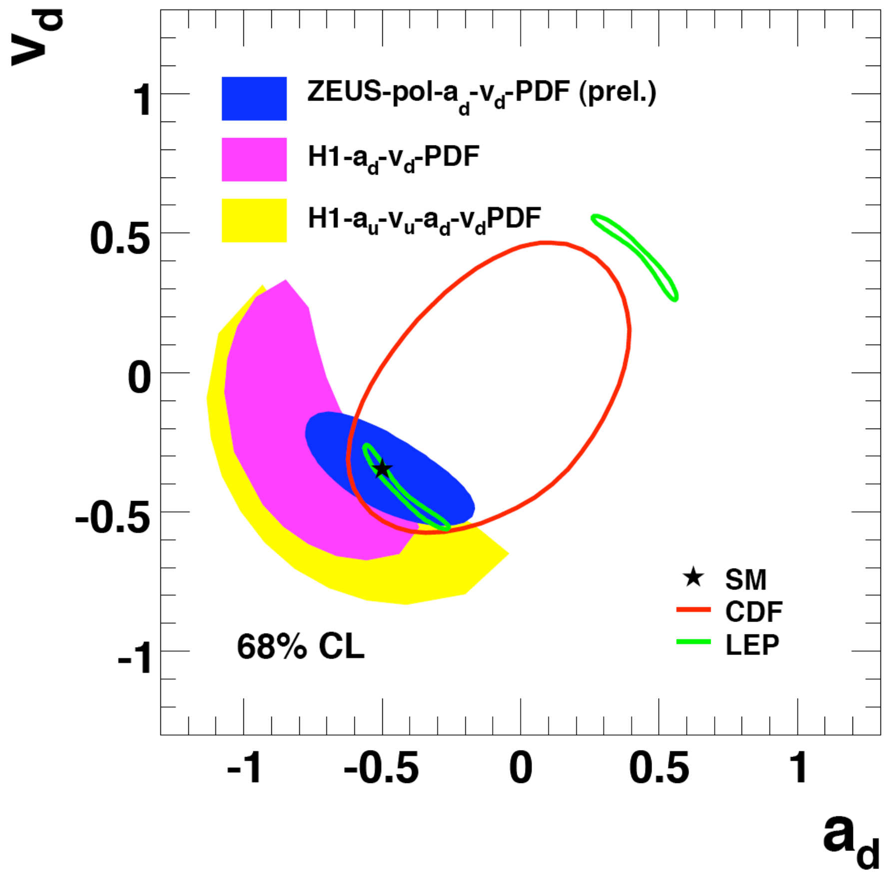
M_{W_R}>230 GeV

guess from 4 measurements

Towards Electroweak Precision Physics with HERA

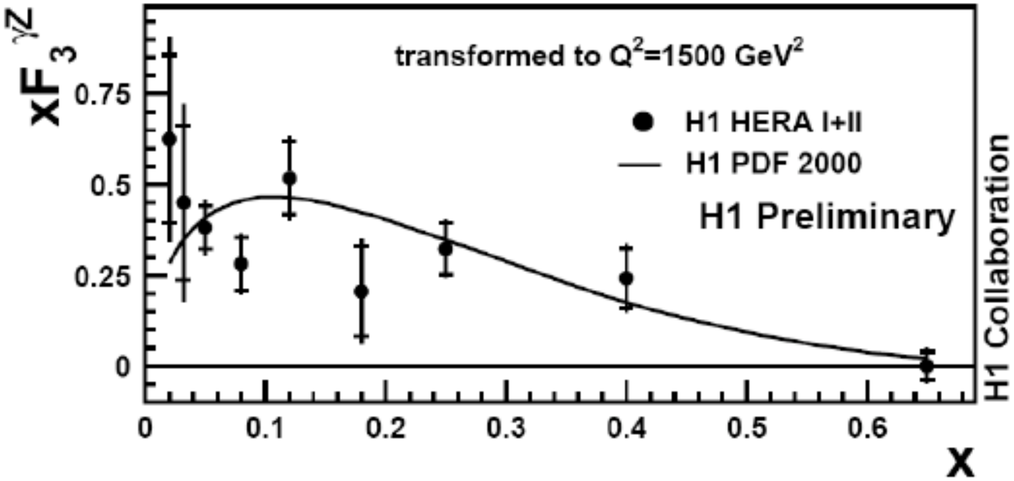
Determination of the weak light quark-Z couplings





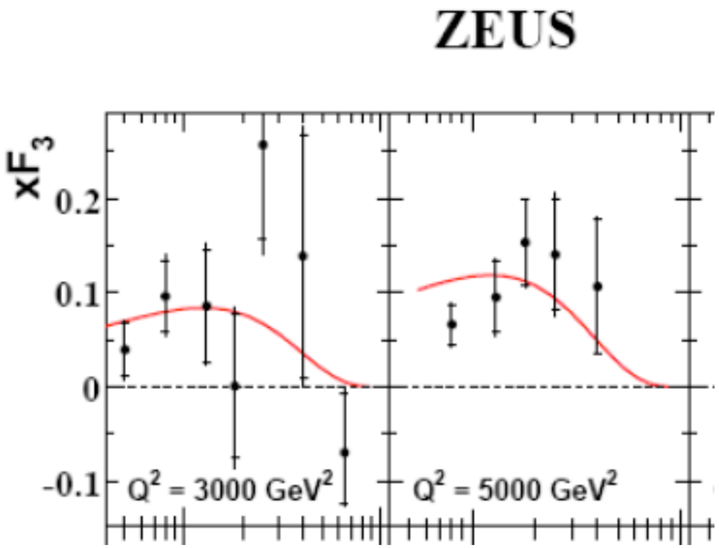
Note the impressive PV results by Jlab

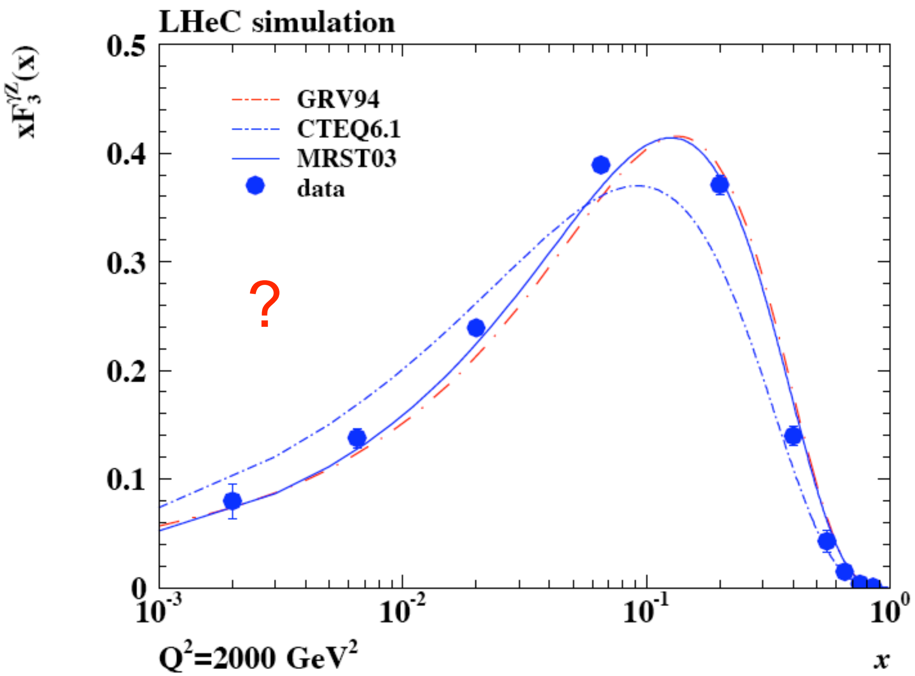
xF_3 and the sea quark symmetry



$$2x[a_u e_u(U - \overline{U}) + a_d e_d(D - \overline{D})]$$

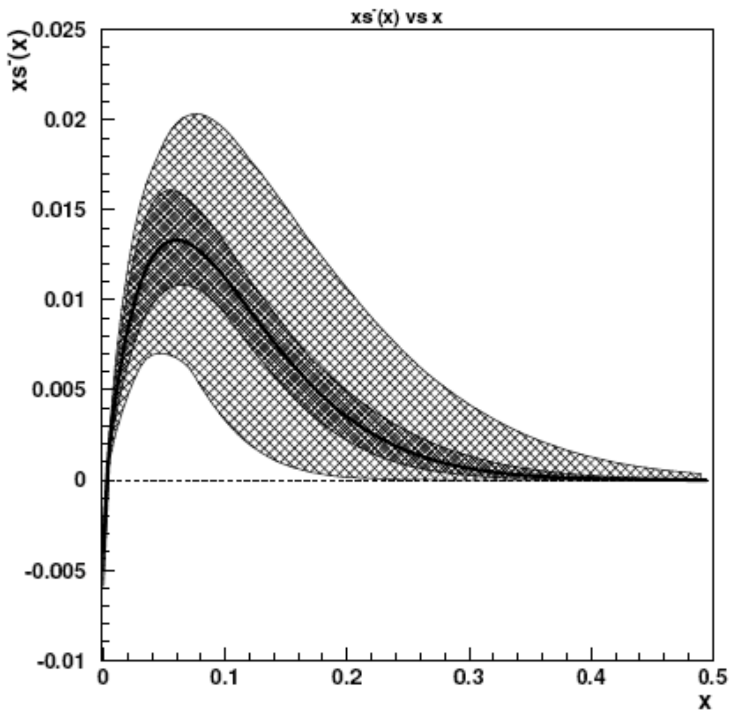
$$q_s(x,Q^2) = \bar{q}(x,Q^2)\,?$$

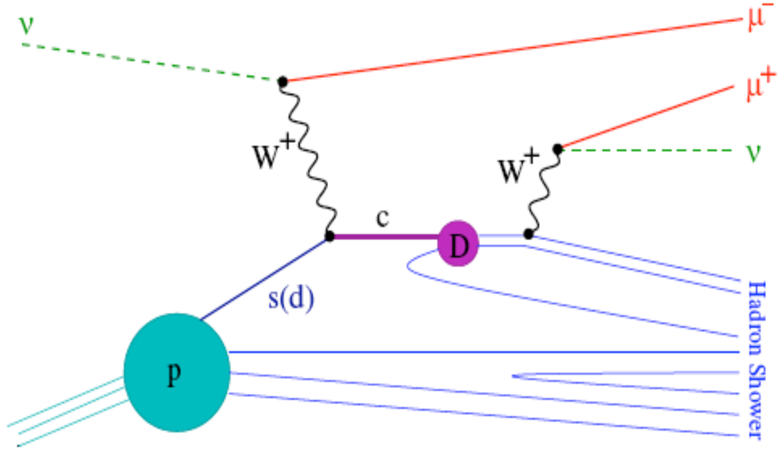




and higher Q^2

NuTeV strange asymmetry





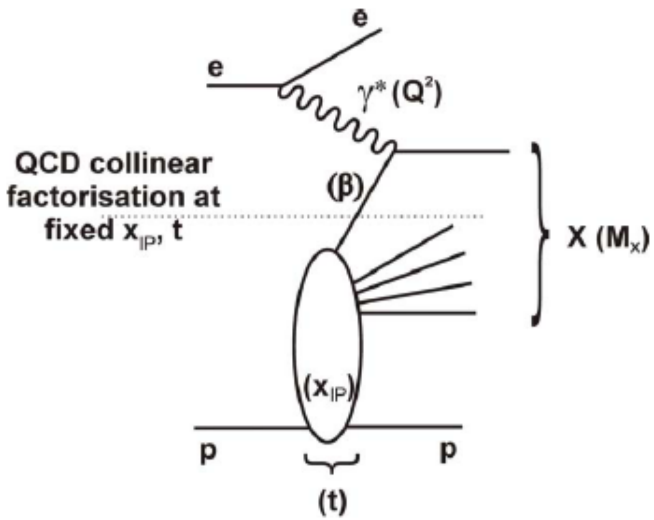
0.22773 ± 0.00135 (stat) ± 0.00093 (syst)

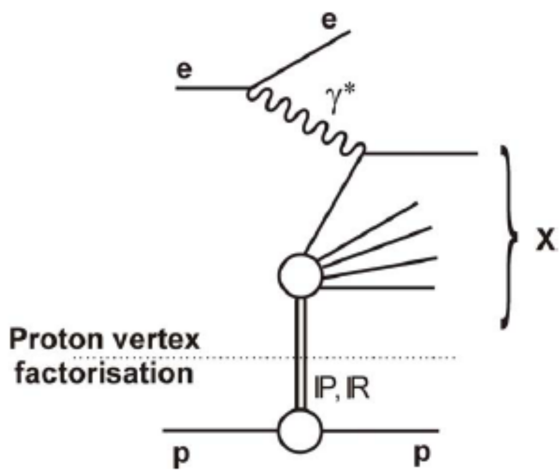
(Zeller et al: PRL 88 (2002) 091802)

Strange sea asymmetry predicted in various non-perturbative models.
Also, at NNLO, in pQCD due to different collinear splitting of q into q and anti-q [Catani et al.] (sign?)
<s-sbar>=0 as p is non-strange

Diffractive Progress

Huge amount of new data presented by the Collider experiments





Diffractive, universal?
conditional q,g densities

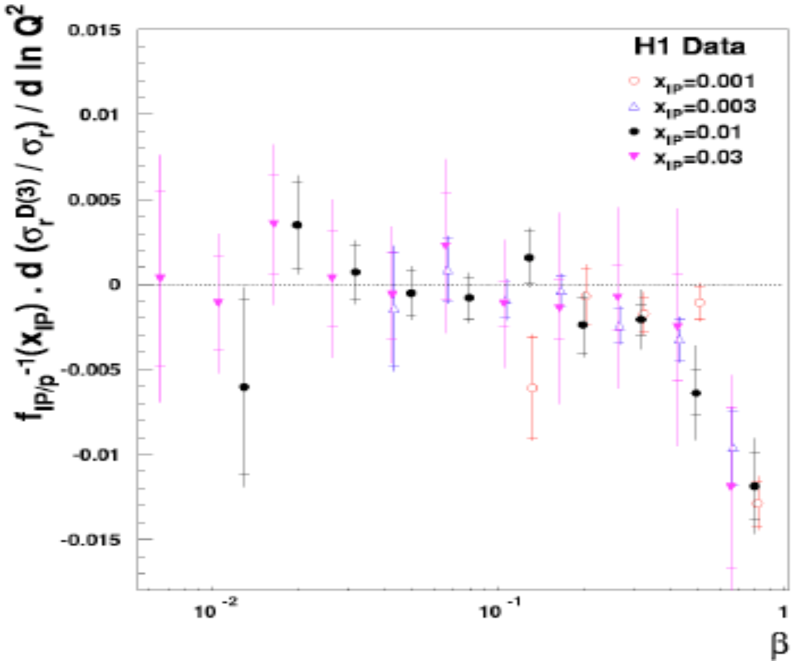
$$f_i^D(x,Q^2,x_{IP},t) = f_{IP/p}(x_{IP},t)\cdot f_i^{IP}(\beta = x/x_{IP},Q^2)$$

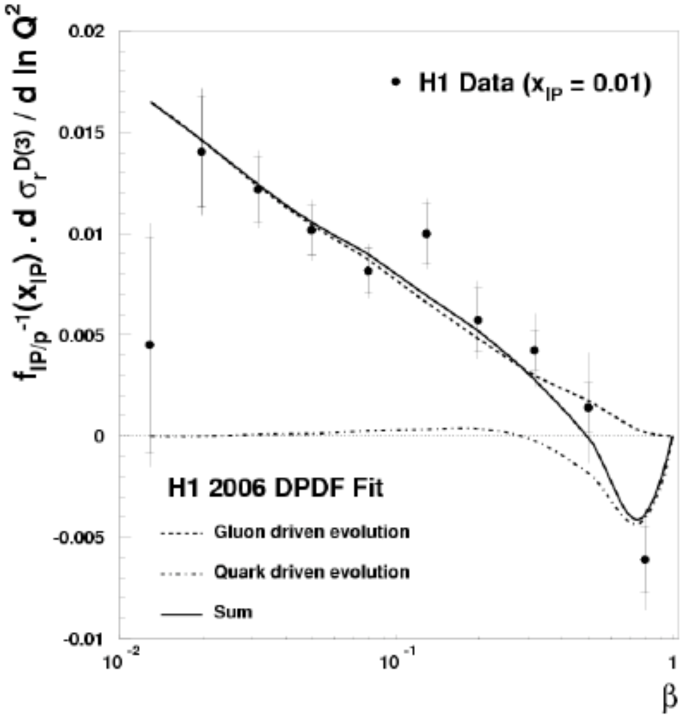
QCD

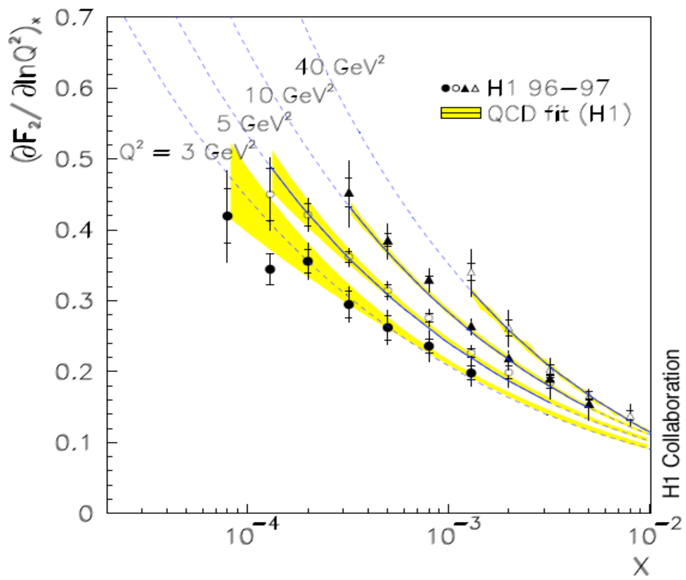
phenomenology

Tagged and rap. gap data to check

Diffraction resembles inclusive DIS

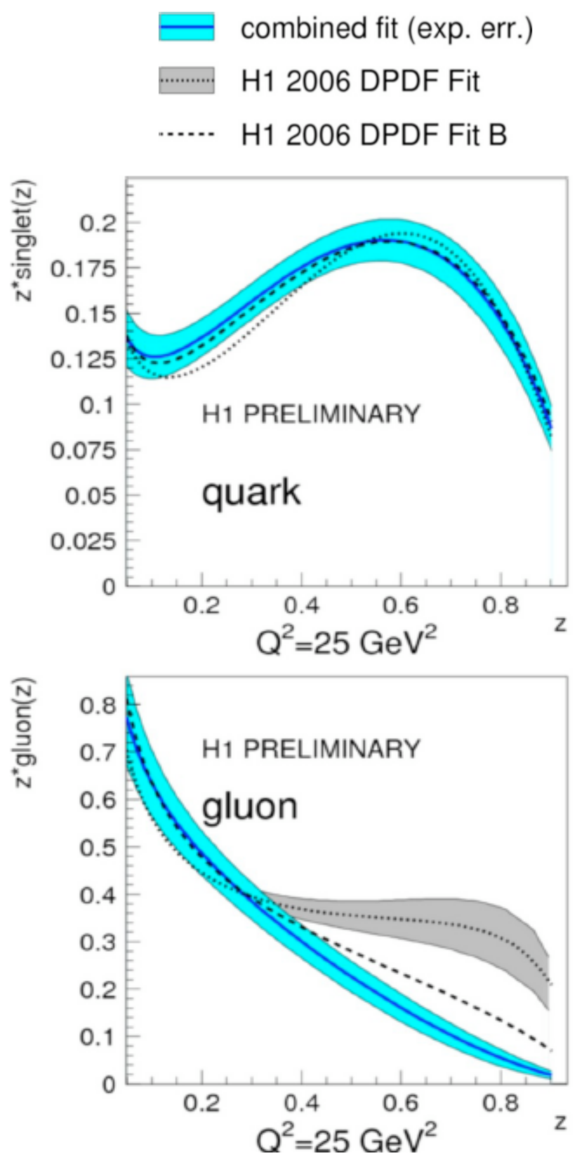


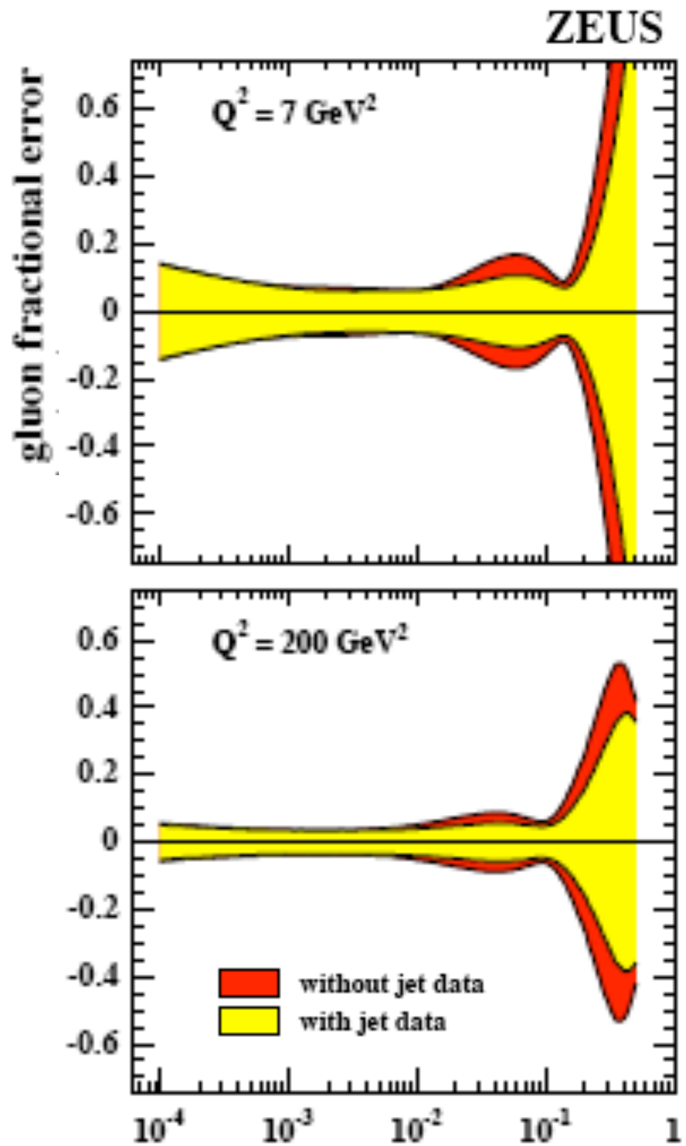




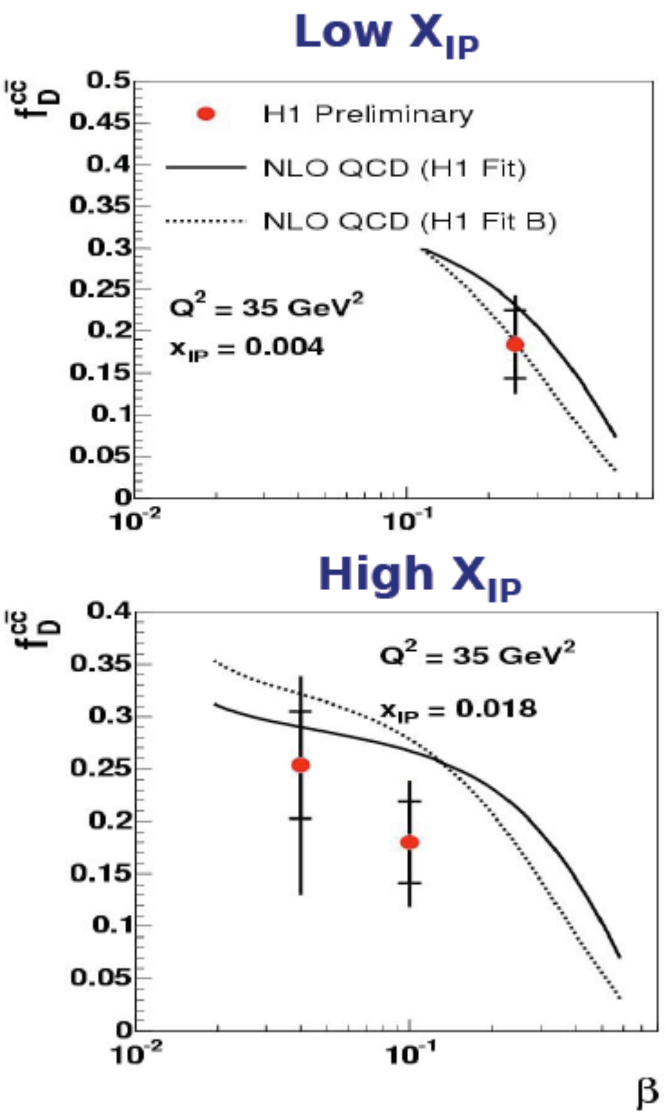
$$\text{If} \quad \frac{d(\sigma_r^D/\sigma_r)}{d\ln Q^2} \sim 0 \text{ , then } \frac{1}{\sigma_r^D}\frac{d\sigma_r^D}{d\ln Q^2} \approx \frac{1}{\sigma_r}\frac{d\sigma_r}{d\ln Q^2}$$

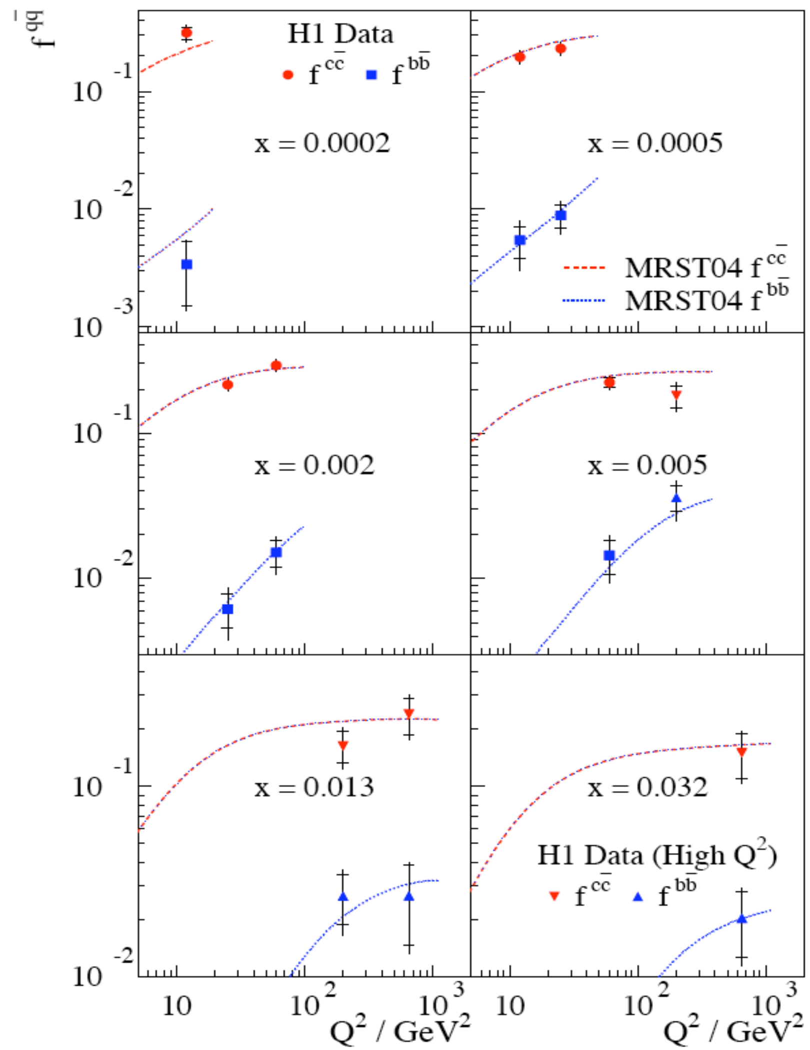
Diffraction resembles inclusive DIS





Diffraction resembles inclusive DIS





Summary DIS06 M.Klein

Lifetime data: 20% is charm at low x

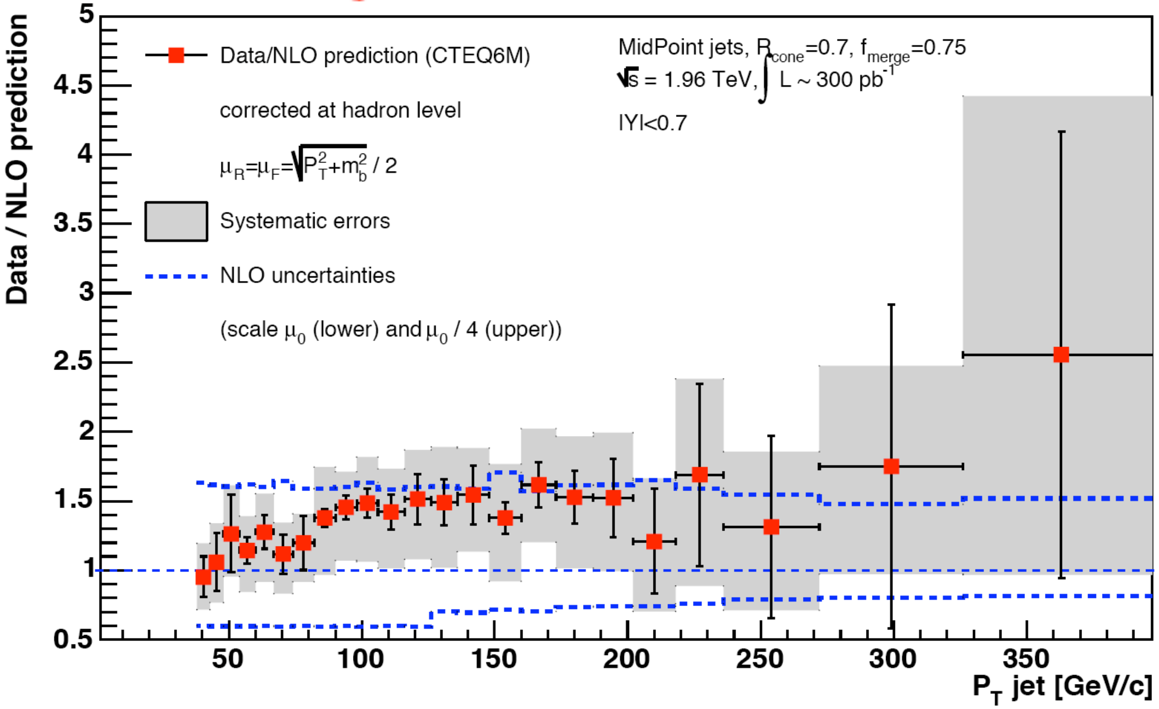
For the 1st time the transverse size of gluons was measured and it's smaller than or about the electromagnetic size.

M. Strikhman

BFKL Pomeron in string models

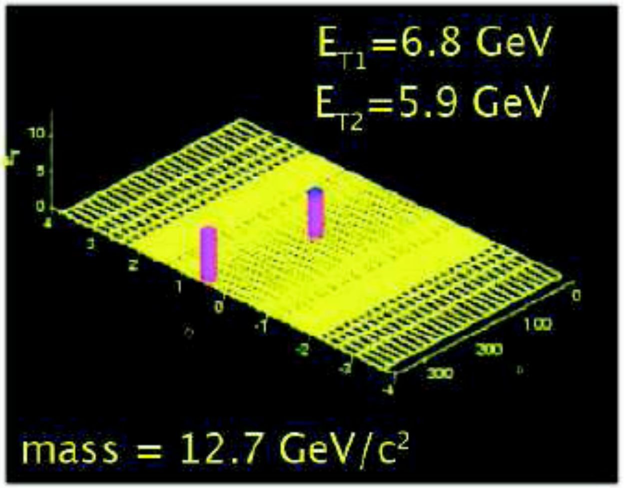
G. S. Danilov* [1] and L. N. Lipatov‡ [1,2]

Inclusive b jet cross section *CDF RunII Preliminary*



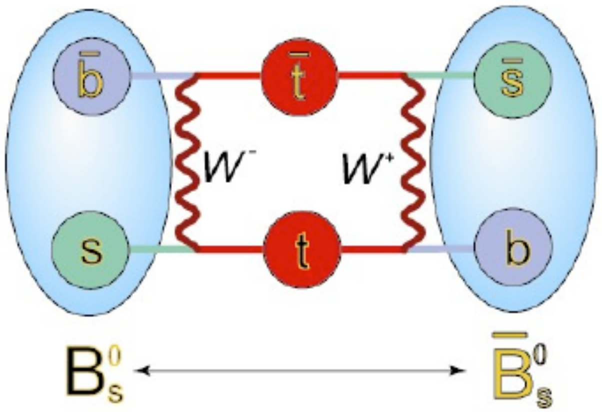
$\gamma\gamma-$ exclusive

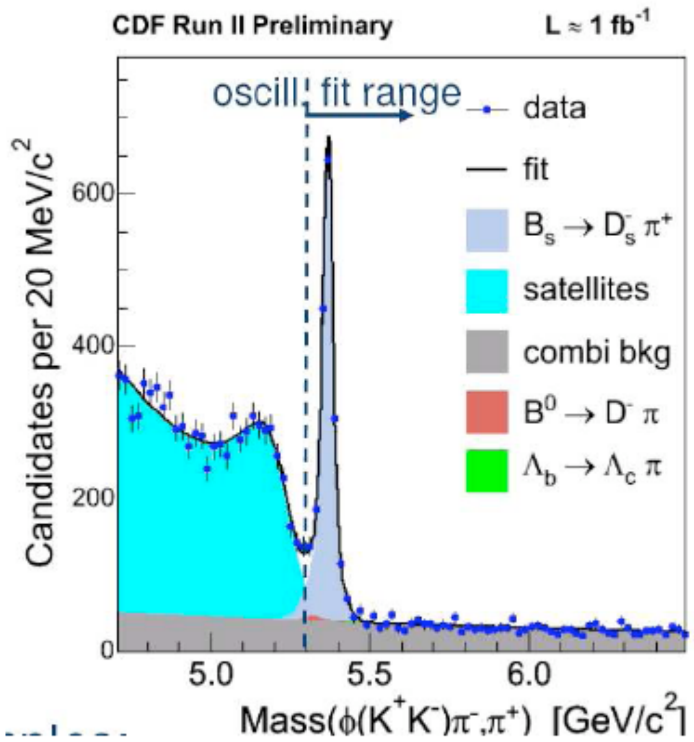
$3^{+2.9}_{-0.9}$ 46 pb^{-1}

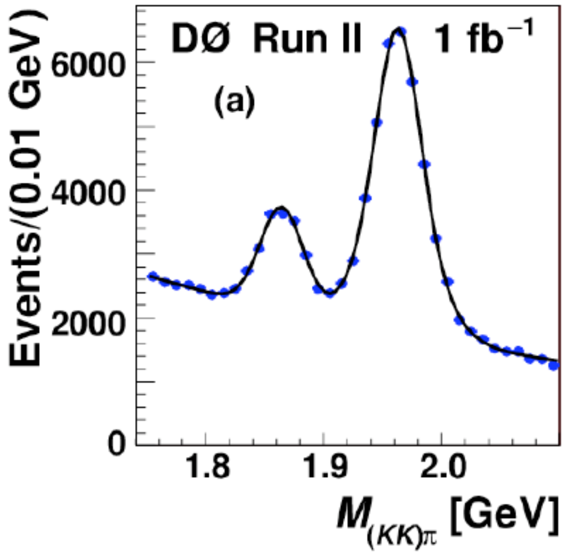


B oscillation frequency

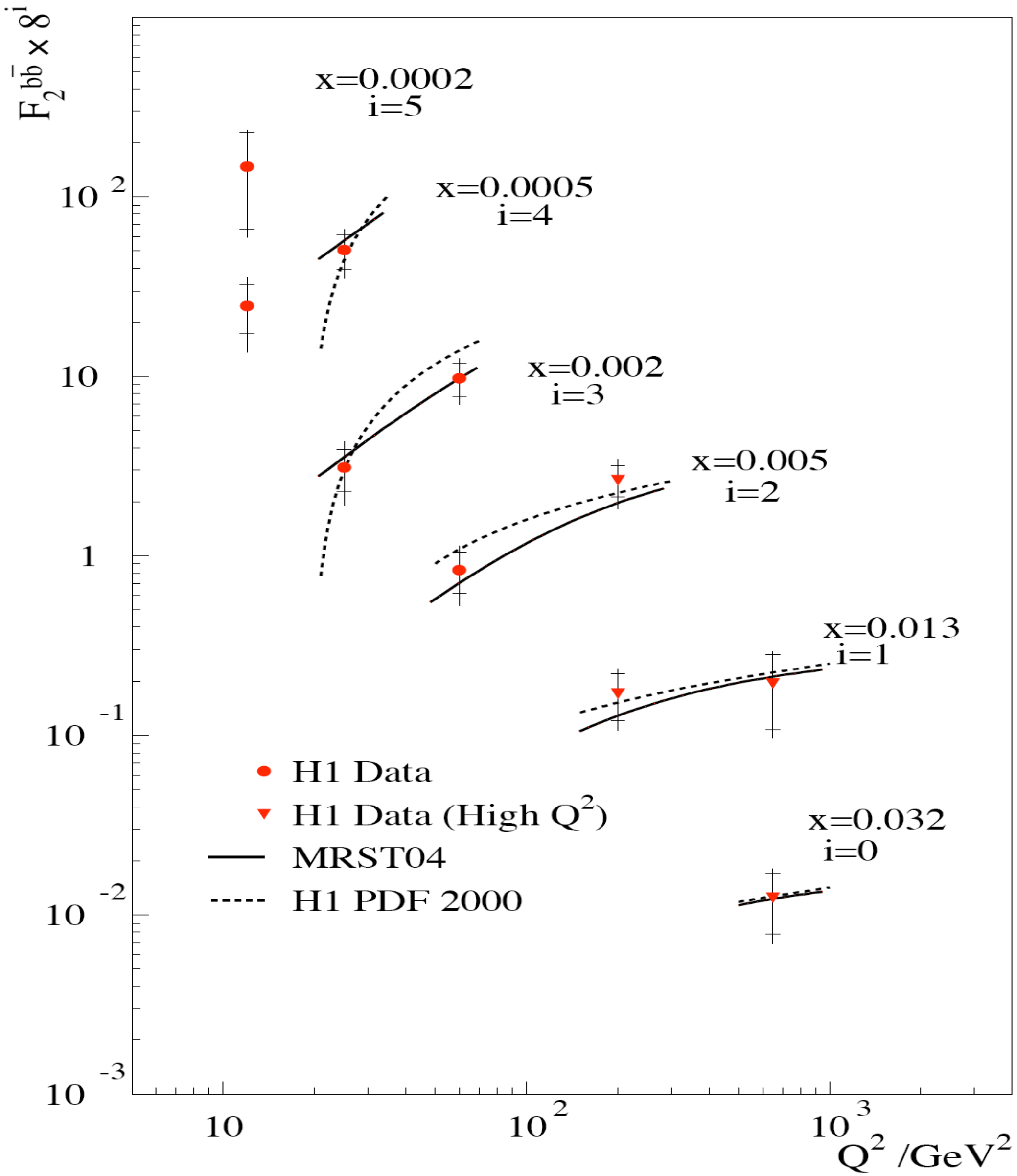
- Standard model prediction: $16.7 < \Delta m_S < 25.4$ ps^{-1}







- $17 < \Delta m_S < 21$ ps^{-1} at 90% CL (DØ)
- $\Delta m_S = 17.33^{+0.42}(stat) \pm 0.07(syst) ps^{-1}$,
  $17.00 < \Delta m_S < 17.91$ ps^{-1} at 90% CL ,
  $16.94 < \Delta m_S < 17.97$ ps^{-1} at 95% CL (CDF)
  $(V_{td}/Vts = 0.208^{+0.008}_{-0.007})$



Beauty Quark Density

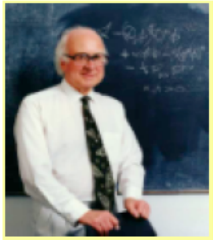
Beauty is ~1-2% of total

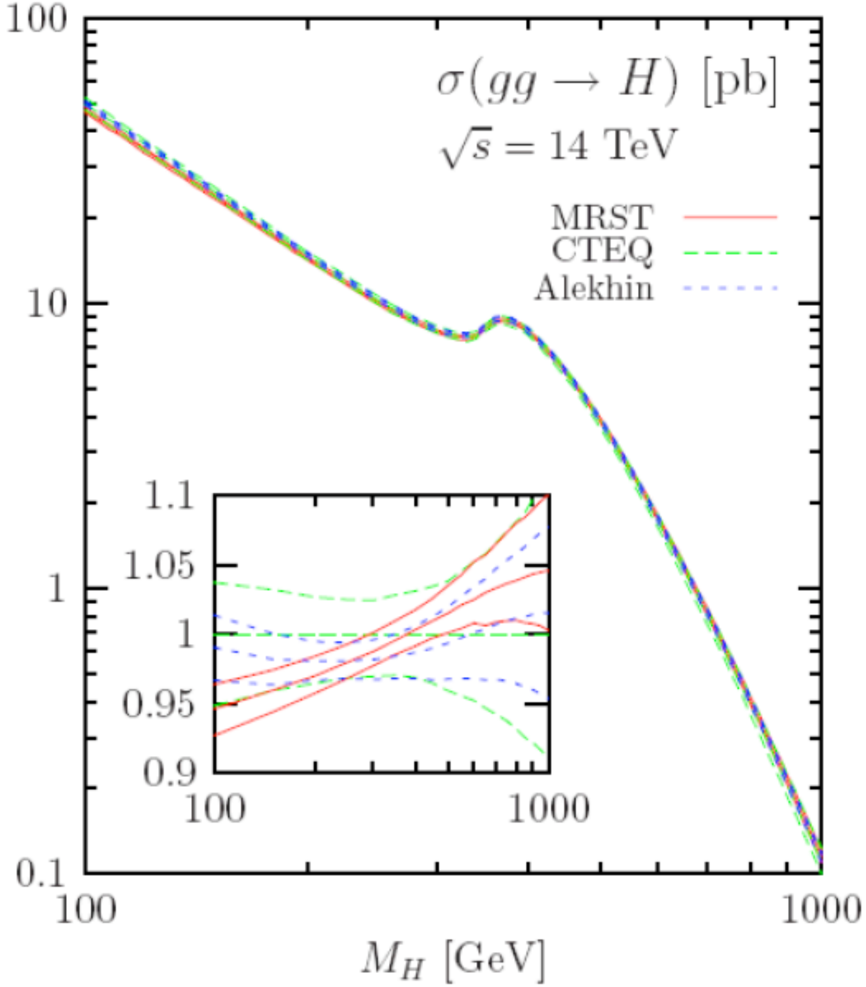
Difficult measurement
(Luminosity, Silicon)

Important for the LHC
(may reach 10% accuracy)

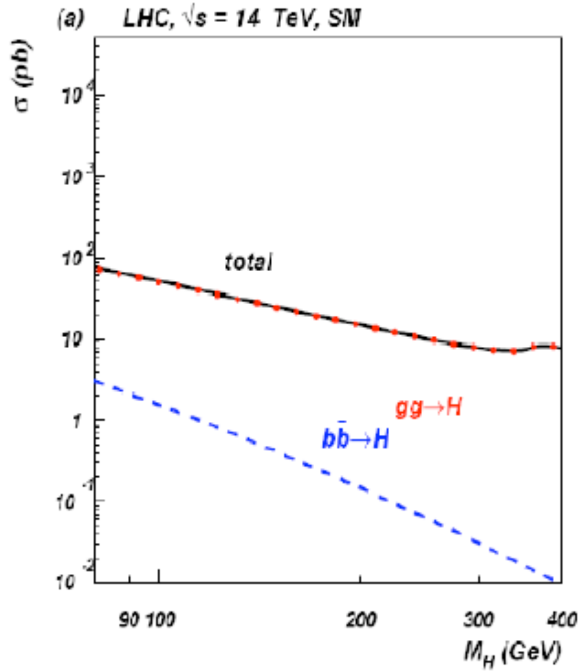
There is beauty below M_b^2

Strong theory effort
to formulate QCD near
threshold ongoing

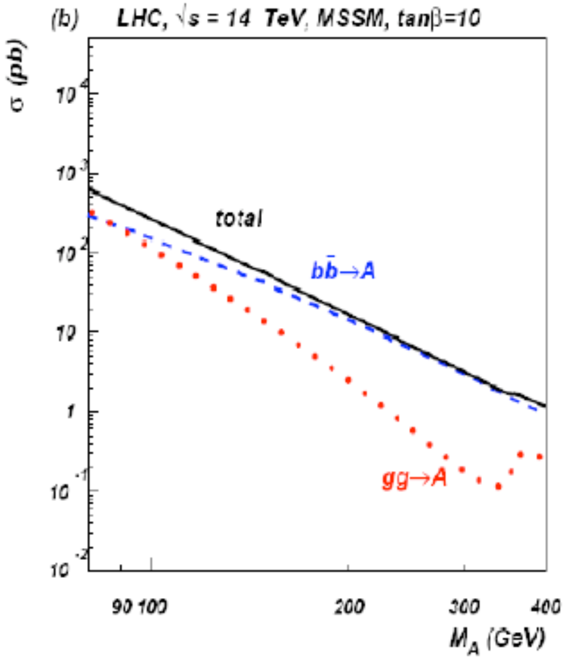




σ(gg → H) [pb]
√s = 14 TeV
MRST
CTEQ
Alekhin
100
10
1
0.1
100
1000
M_H [GeV]
1.1
1.05
1
0.95
0.9
100
1000

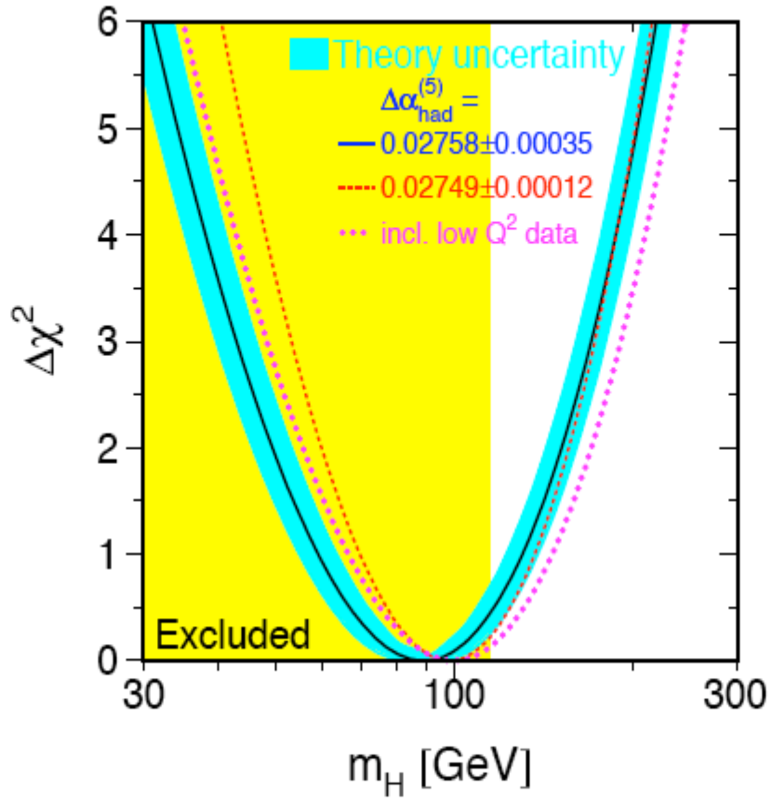


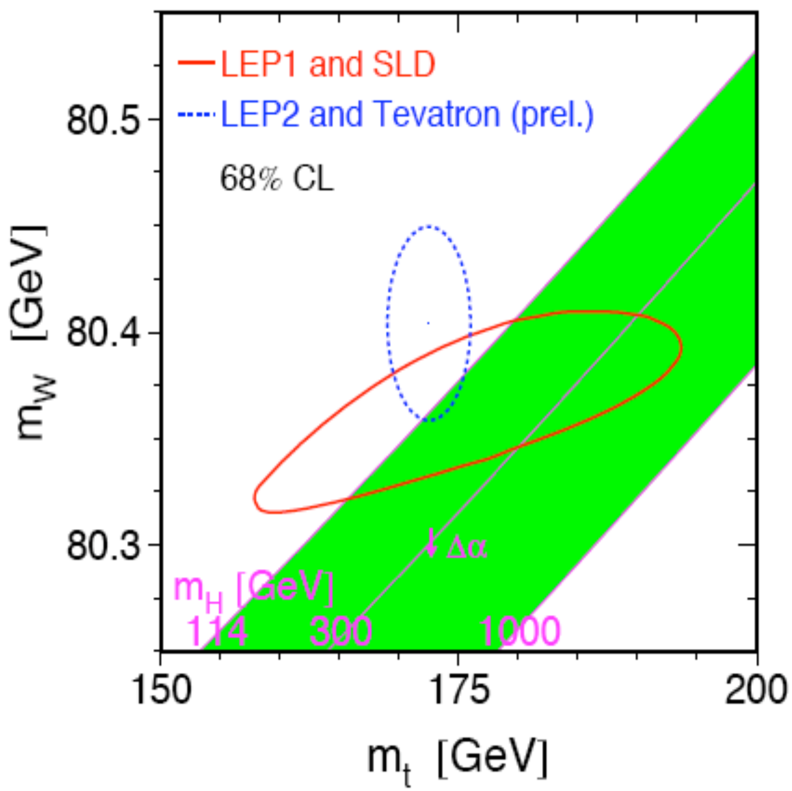
(a) LHC, √s = 14 TeV, SM
σ (pb)
total
gg→H
bb̄→H
90 100
200
300
400
M_H (GeV)



(b) LHC, √s = 14 TeV, MSSM, tanβ=10
σ (pb)
total
bb̄→A
gg→A
90 100
200
300
400
M_A (GeV)

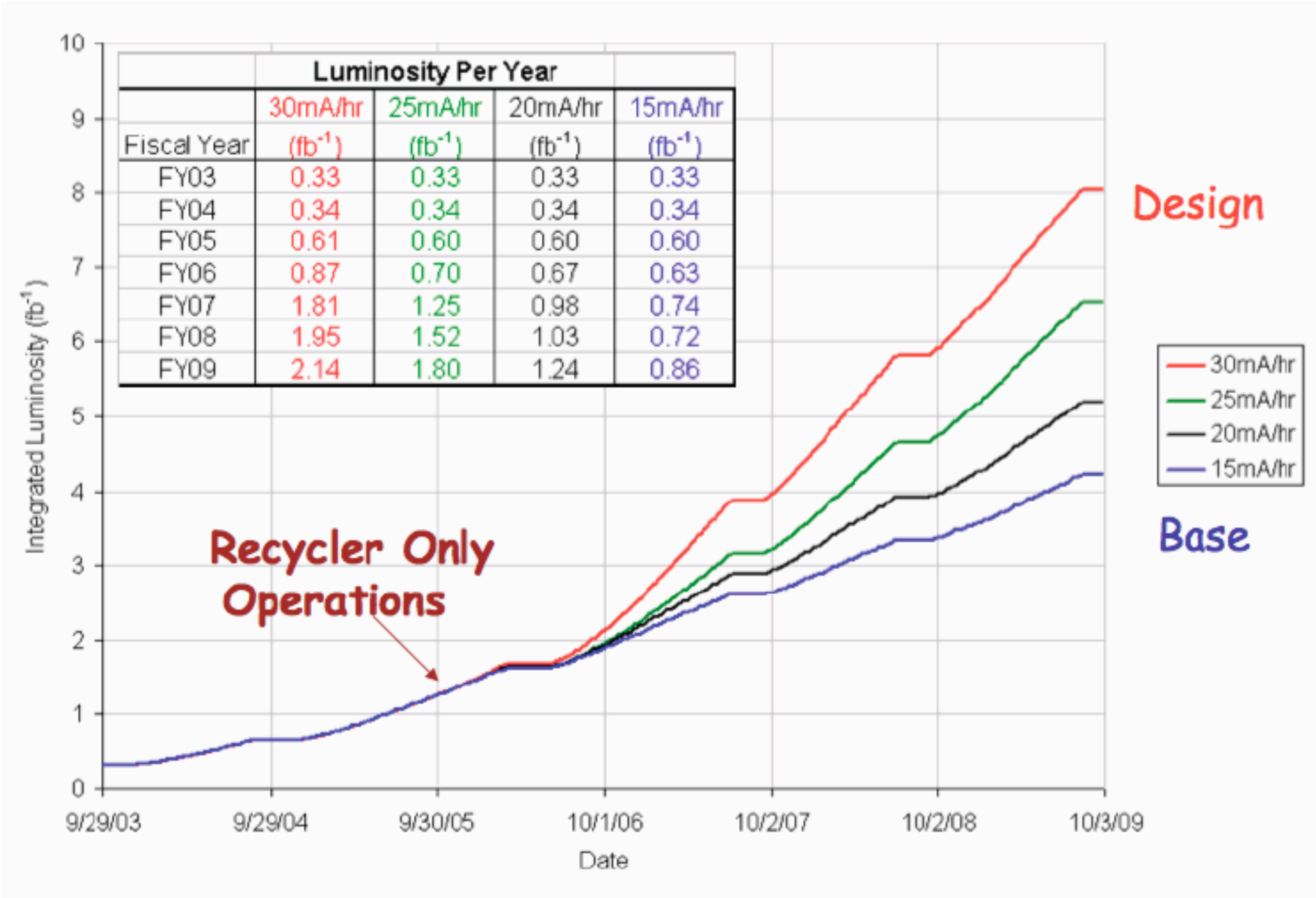
- $M_{Higgs} = 89 + 42 - 30$ GeV (68% CL), and < 175 GeV at 95% CL





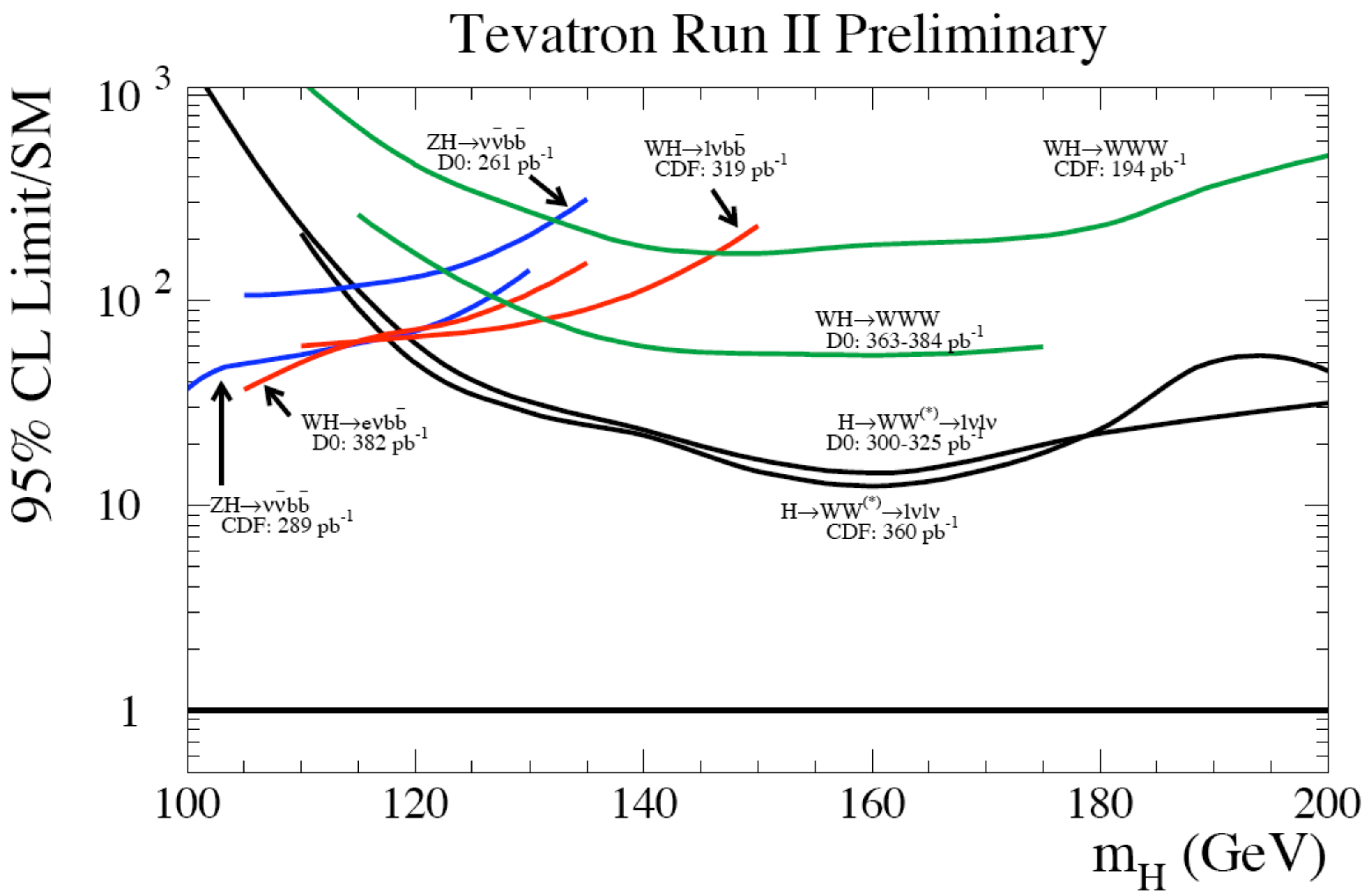
Fermilab Accelerator Division

Integrated Luminosity



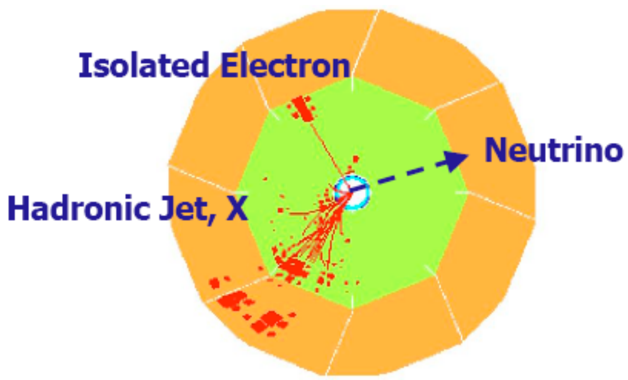
Luminosity Per Year

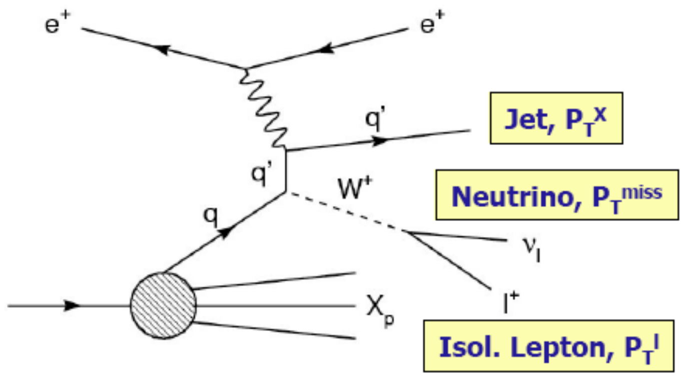
Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86



Tevatron Run II Preliminary
95% CL Limit/SM
10^3
10^2
10
1
100
120
140
160
180
200
m_H (GeV)
ZH→νν̄bb̄
D0: 261 pb^{-1}
WH→lνbb̄
CDF: 319 pb^{-1}
WH→WWW
CDF: 194 pb^{-1}
WH→WWW
D0: 363-384 pb^{-1}
WH→eνbb̄
D0: 382 pb^{-1}
H→WW$^{(*)}$→lνlν
D0: 300-325 pb^{-1}
ZH→νν̄bb̄
CDF: 289 pb^{-1}
H→WW$^{(*)}$→lνlν
CDF: 360 pb^{-1}

Discoveries? Isolated Leptons at HERA





$P_T^X > 25$ GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
H1 e^+p data 158 pb^{-1}	9 / 2.3 ± 0.4 (80%)	6 / 2.3 ± 0.4 (84%)	15 / 4.6 ± 0.8 (82%)
H1 e^-p data 121 pb^{-1}	2 / 2.4 ± 0.5 (62%)	0 / 2.0 ± 0.3 (76%)	2 / 4.4 ± 0.7 (68%)
H1 $e^{\pm}p$ data 279 pb^{-1}	11 / 4.7 ± 0.9 (69%)	6 / 4.3 ± 0.7 (78%)	17 / 9.0 ± 1.5 (73%)

98-05 e^-p (143 pb^{-1})	$3/2.86 \pm 0.46 (53\%)$
99-04 e^+p (106 pb^{-1})	$1/1.50^{+0.12}_{-0.13} (78\%)$
98-05 $e^{\pm}p$ (249 pb^{-1})	$4/4.4 \pm 0.5 (61\%)$

ZEUS full data on isolated electrons presented here. Different

Further studies underway to obtain comparable and complete results, also on multilepton events (4/1.1).

Expect to ~ double statistics by end of HERA running.

Theory

Wednesday Afternoon: Summary session, R.E. Marshak presiding

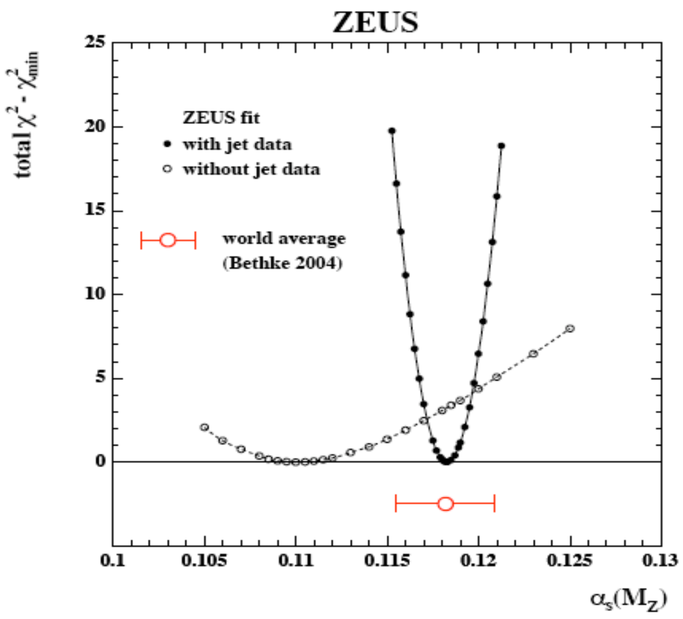
The theoretical session was summarized by F. J. Dyson.
I'm glad to say I'm supposed to finish in half an hour, because as a matter of fact, to summarize a theoretical session is almost a contradiction in terms. So what I shall do is to choose two or three topics which seem interesting. This is not fair to the other people, but it can't be helped. Of the nine speakers, a group of five, namely Serber, Fierz, Feynman, Peierls, and Leh mann, were talking about technical points inside the theory which it does not seem worthwhile to discuss here. What these people have been trying to do is to get a better understanding of the methodological nature of relativistic field theory, namely, the whole question of whether the relativistic field theories have solutions, and what these solutions mean.

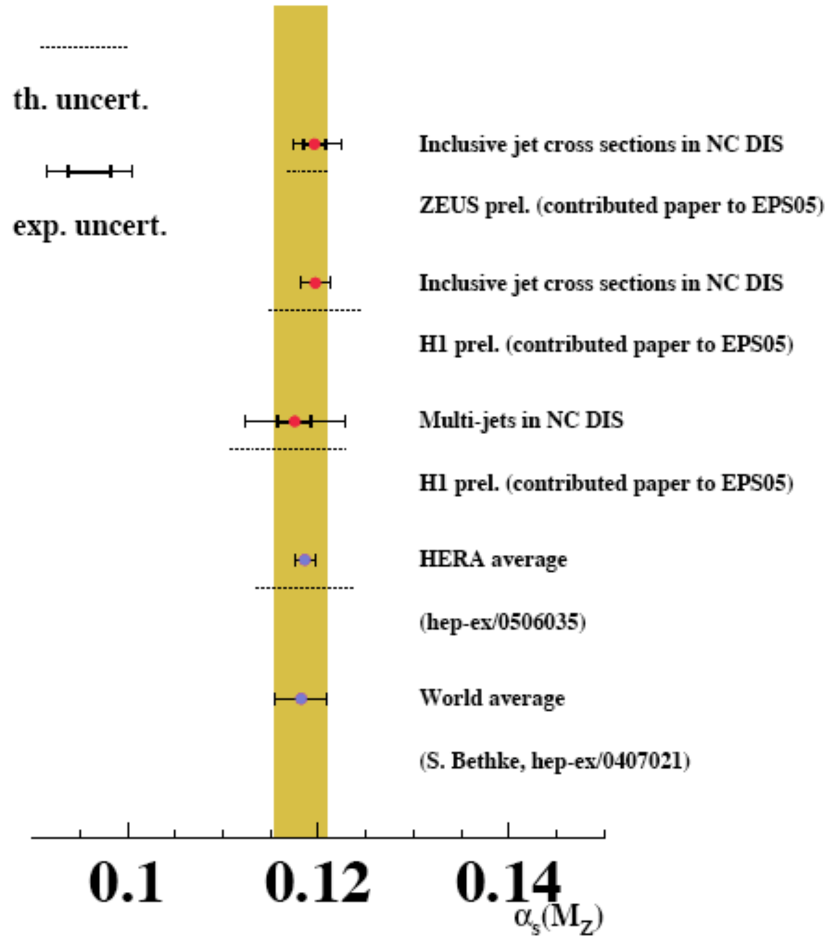
Rochester, proceedings 1955

Strong Coupling Constant

α_s determination

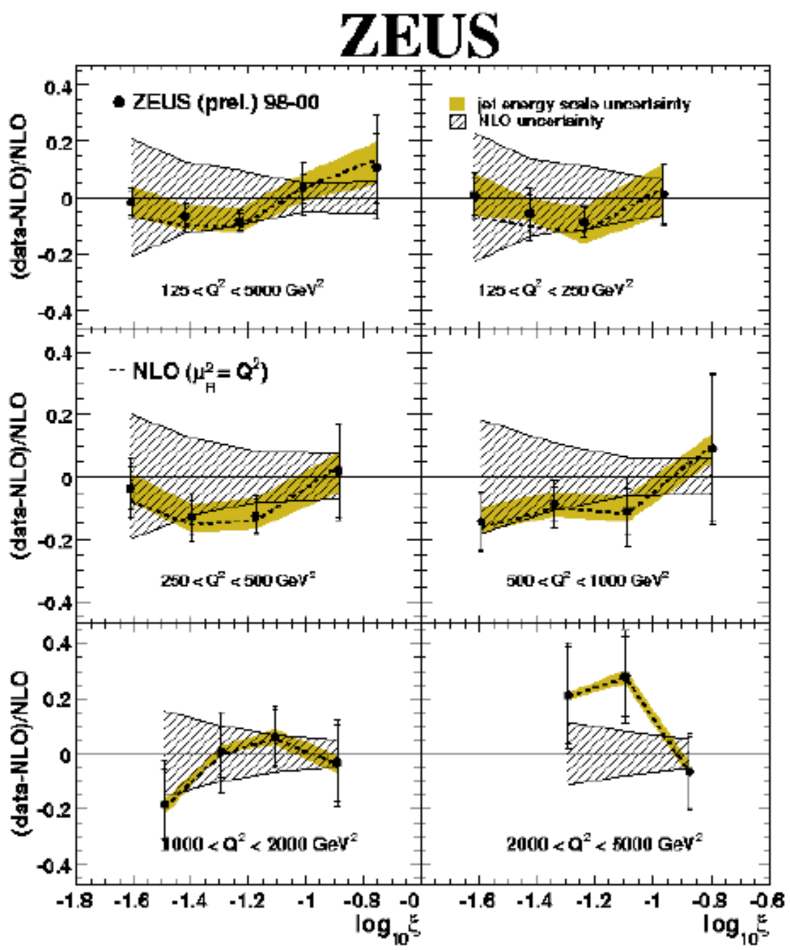
	$\alpha_s(M_Z^2)$	expt	theory
NNLO			
MRST03	0.1153	±0.0020	±0.0030
A02	0.1143	±0.0014	±0.0009
SY01(ep)	0.1166	±0.0013	
SY01(νN)	0.1153	±0.0063	
BBG	**0.1134**	$^{+0.0019}_{-0.0021}$	
World Average	**0.1182**	**±0.0027**	
H1	0.1155+-0.0017+-0.005		





High precision will tell whether the analysis of inclusive DIS data only leads to a significantly smaller α_s

Renormalisation Scale Uncertainty?



e.g. Dijets in DIS

¶ Theoretical uncertainties:

- scale: $0.5,2\mu_R \rightarrow \pm 5\text{-}10(20)\%$
- PDF: 40 CTEQ6 sets → ±2-5%
- α_S: CTEQ6AB → less than ±4%

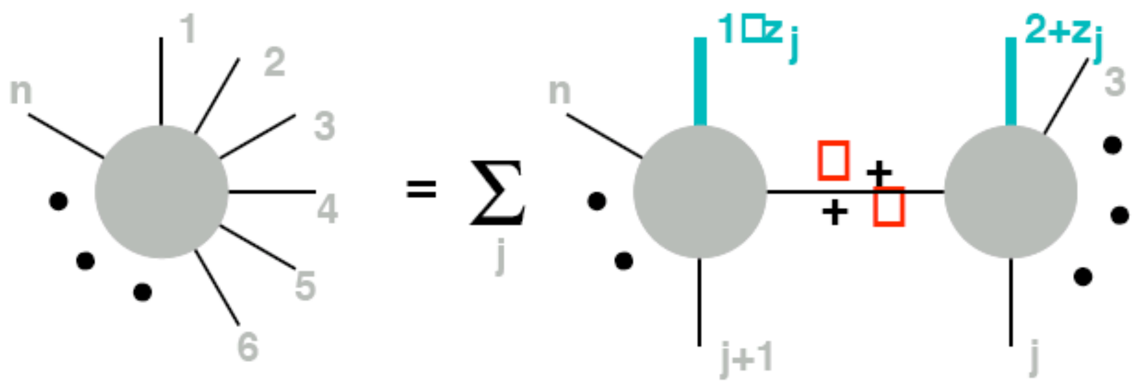
Inclusive

$a_s^{NLO} - a_s^{NNLO} \sim 0.001$
which is 5 times smaller
than the so-called thy error

contacted KE, WvN, SB -->

Why not take srqt(0.5,5), i.e.
0.5 … 2 Q^2 in the inclusive case?

Britto-Cachazo-Feng (BCF): Join smaller sub-amplitudes by a *propagator*. Sub-amplitudes made *on-shell* by analytic continuation ($\pm z_j$) of two reference momenta:



Britto, Cachazo & Feng hep-th/0412265; *idem.* + Witten hep-th/0501052

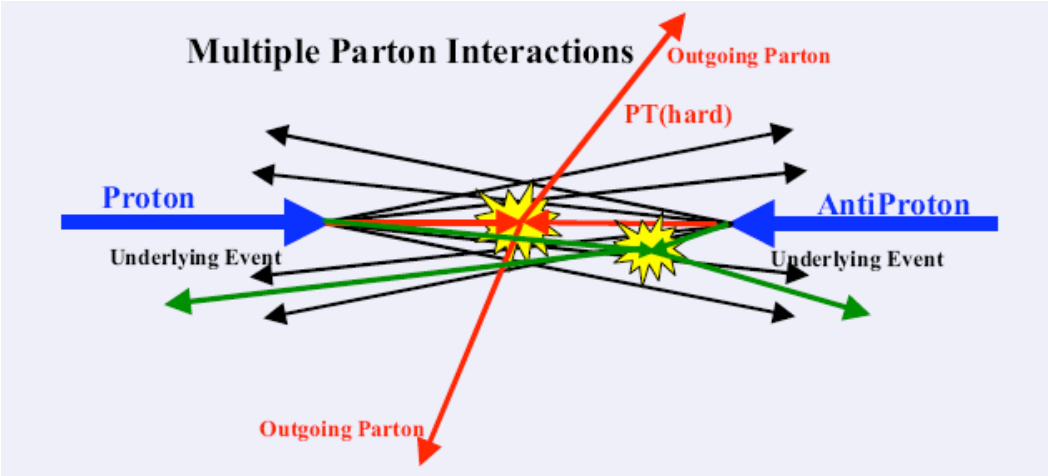
Earlier (related) rules: Cachazo, Svrcek & Witten hep-th/0403047

Proof based on analytic structure of tree-graphs (they are a sum of poles in complex plane) — *very general.*

Simplicity lies in on-shellness of sub-amplitudes and the need for just a scalar propagator to join them.

LHC: 200 eight-jet events / fb^{-1}

Towards the LHC



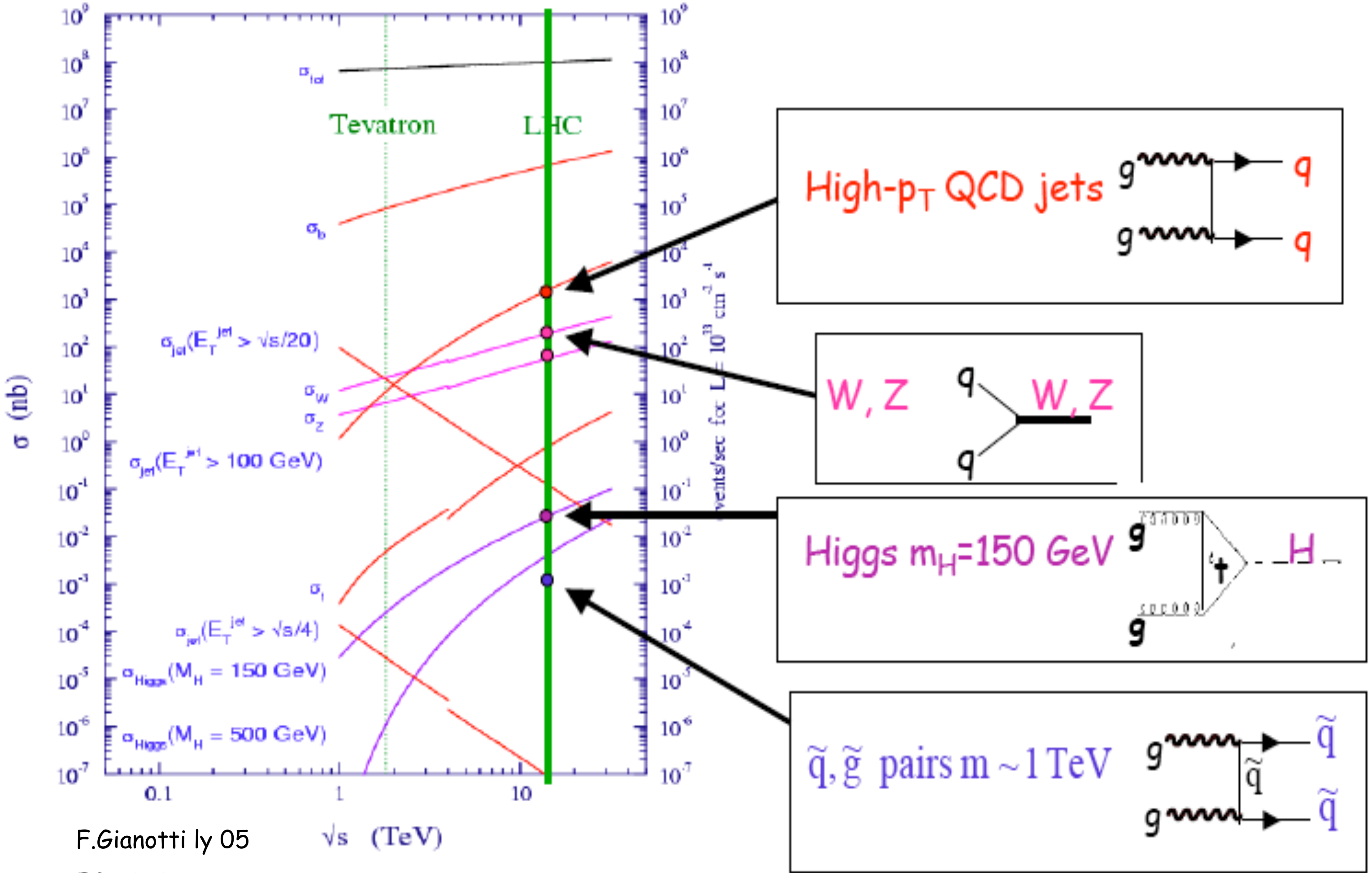
Underlying (overlaying) event(s)
from the Tevatron --> LHC ?

big efforts in theory and
simulation techniques
and programmes (MC@NLO,
ThePEG, Ariadne, Pythia, …)

"4 jet events in ZEUS"

The only place where success appears before work is a dictionary

G.Dissertori Lisbon05



F.Gianotti ly 05

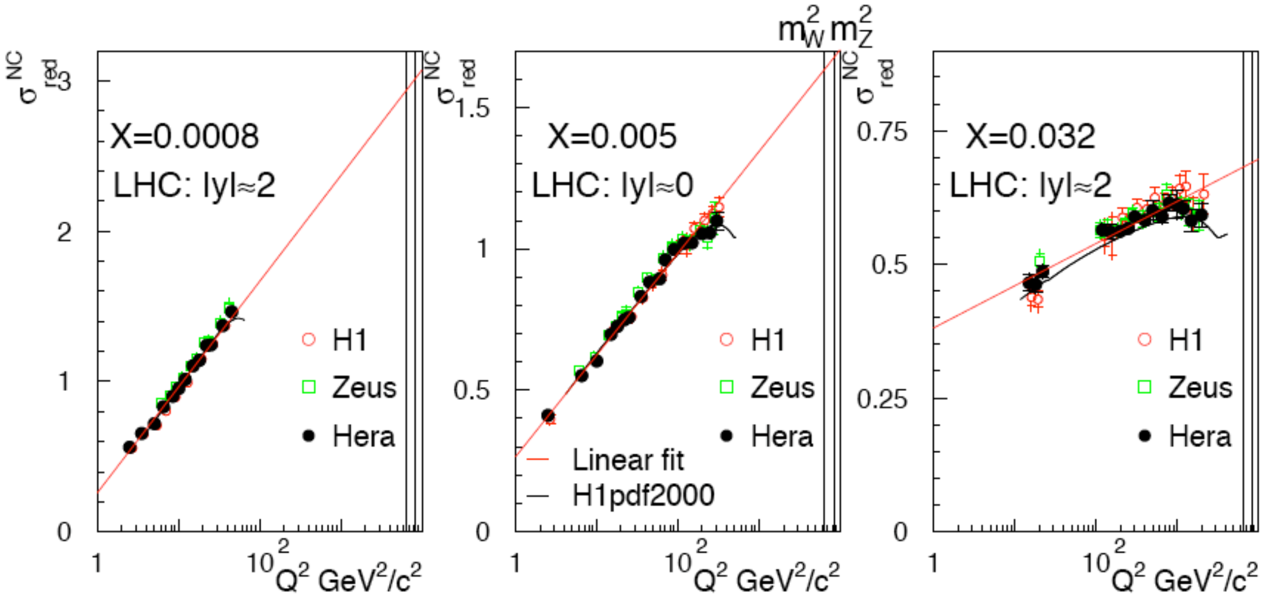
FG, M.Mangano

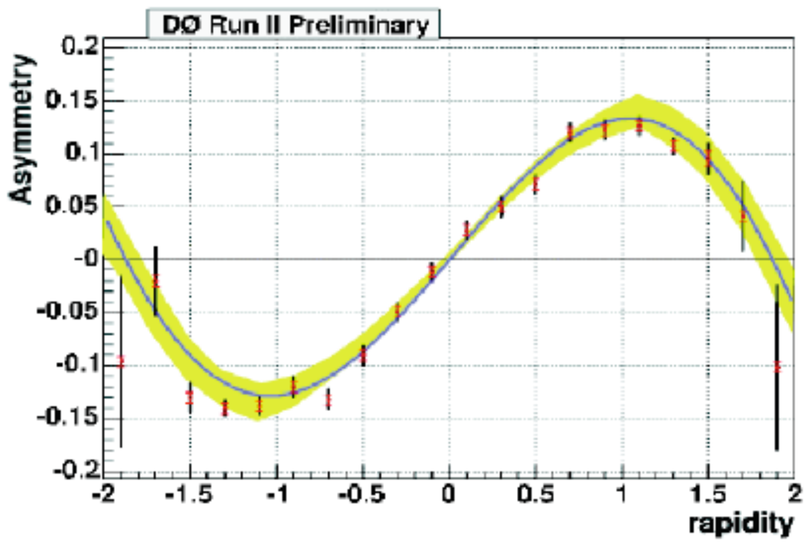
hep-ph/0504221

Towards the LHC

W,Z physics

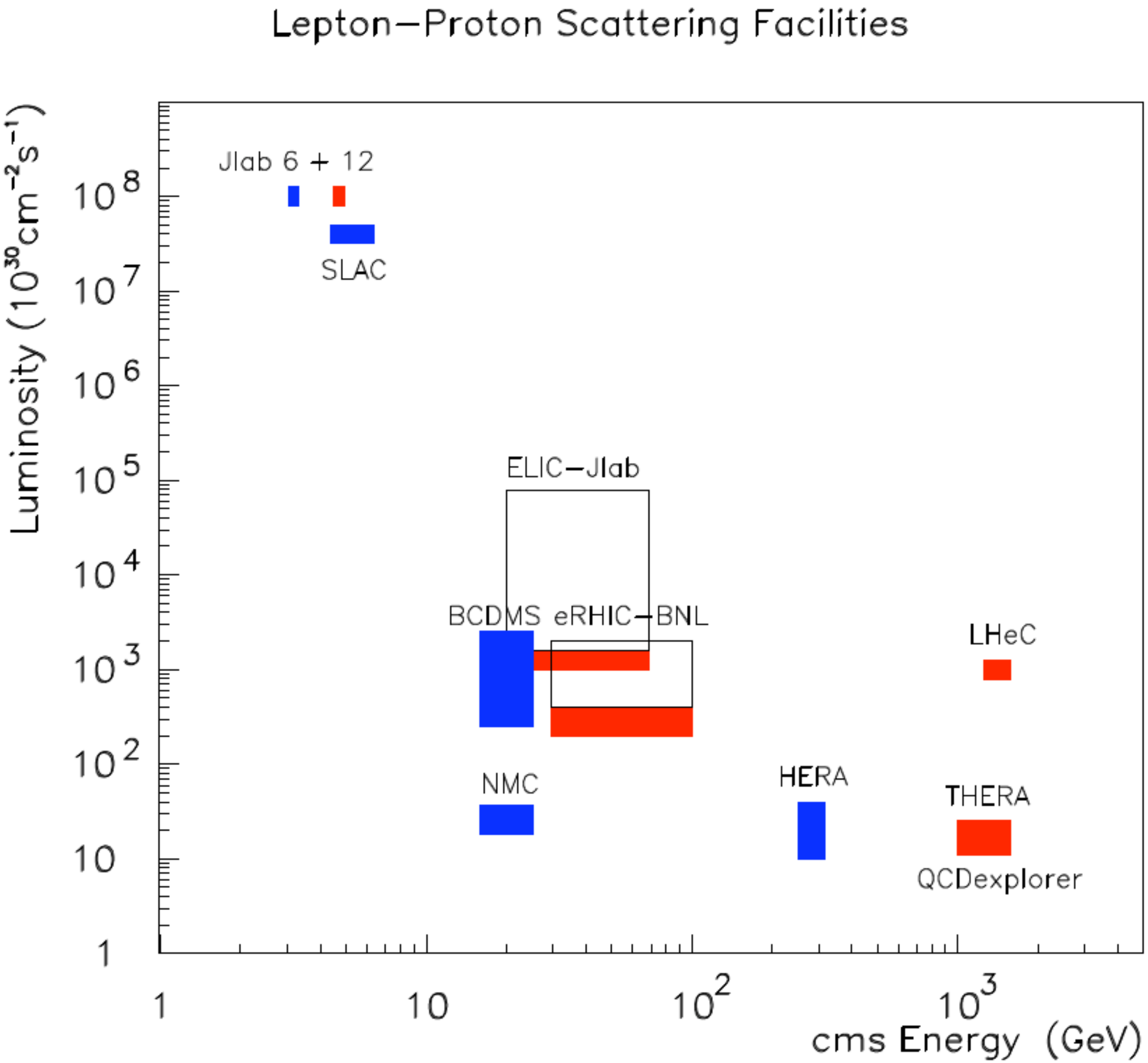
-QCD@LHC
-luminosity
-calibration





'F_2 corresponds to W,Z production'
extrapolation from HERA needs pQCD
combine H1+Z data and measure well

$$A = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy} \approx \frac{d}{u}$$



now
then

Summary DIS06 M.Klein

Parton interaction developments at the energy frontier*)

	1970			2000		2015
DIS	Bjorken scaling – QPM, PV neutral currents asymptotic freedom		….	(high) parton densities diffraction QCD		?
e^+e^-	J/Ψ	gluons	…..	3 neutrinos electroweak theory		… ILC
pp	charm,	W,Z,bottom	top		LHC …	

*) incomplete

The standard model emerged as a result of decades of joint research in e^+e^- , ep, pp/hh accelerator experiments, including quark and neutrino mixing.
Low x physics related to AA and to high energy neutrino physics.
There is no quantitative understanding of Tevatron data without HERA.
Physics is more than the often quoted "dualism" between e^+e^- and pp.

[The D(KET) version of EU-HEP history (9.3.06) ignores HERA,t…]

DIS07 Munich April


HERA AND THE LHC
2nd workshop on the implications of HERA for LHC physics
6-9 June 2006
CERN, Geneva
CERN
DESY
Parton density functions
Multijet final states and energy flow
Heavy quarks
Diffraction
Monte Carlo tools
Organising Committee:
G. Altarelli (CERN), J. Blümlein (DESY),
M. Botje (NIKHEF), J. Butterworth (UCL),
A. DeRoeck (CERN) (chair), K. Eggert (CERN),
E. Gallo (INFN), H. Jung (DESY) (chair),
M. Klein (DESY), M. Mangano (CERN),
A. Morsch (CERN), G. Polesello (INFN),
O. Schneider (EPFL), R. Yoshida (ANL)
Advisory Committee:
J. Bartels (Hamburg), M. Della Negra (CERN),
J. Ellis (CERN), J.Engelen (CERN),
G. Gustafson (Lund), G. Ingelman (Uppsala),
P. Jenni (CERN), R. Klanner (DESY),
L. McLerran (BNL), T. Nakada (CERN),
D. Schlatter (CERN), F. Schrempp (DESY),
J. Schukraft (CERN), J. Stirling (Durham),
W.K. Tung (Michigan State), A. Wagner (DESY),
R. Yoshida (ANL)
www.desy.de/~heralhc
heralhc.workshop@cern.ch