HERA and the LHC

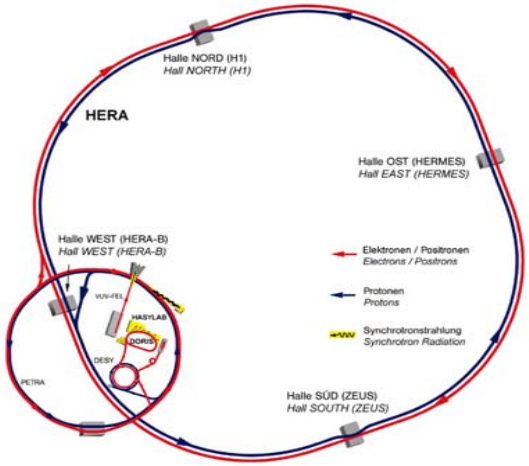
2nd workshop on the implication of HERA for LHC physics

- Selected Highlights of the First Workshop
- Goals for the 2nd Workshop
- Few Organizational Matters

A De Roeck CERN)
and H. Jung (DESY)
06/06/06

Why HERA and the LHC?

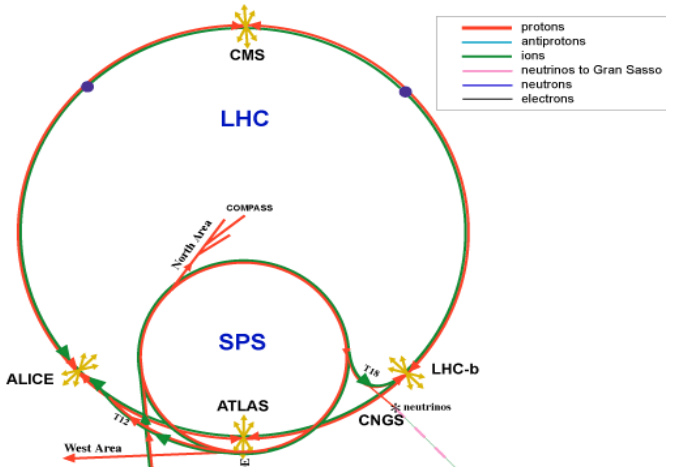
electron proton collider HERA
$\sqrt{s}$ = 320 GeV



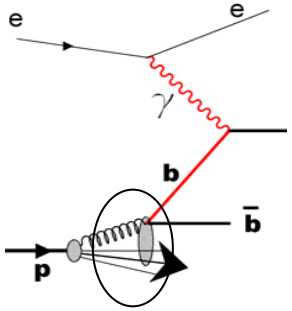
typical range

$$\sqrt{\frac{Q^2}{s}} \sim 0.01$$

proton proton collider LHC
$\sqrt{s}$ = 14 TeV



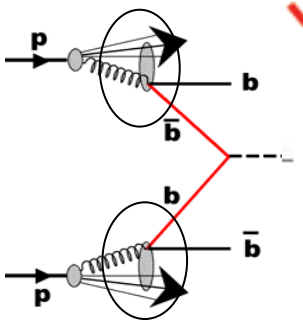
HERA: QCD
structure of the proton



$$\sqrt{\frac{Q^2}{s}} \sim 0.01$$

for $Q^2 \sim 10\ \mathrm{GeV}^2$

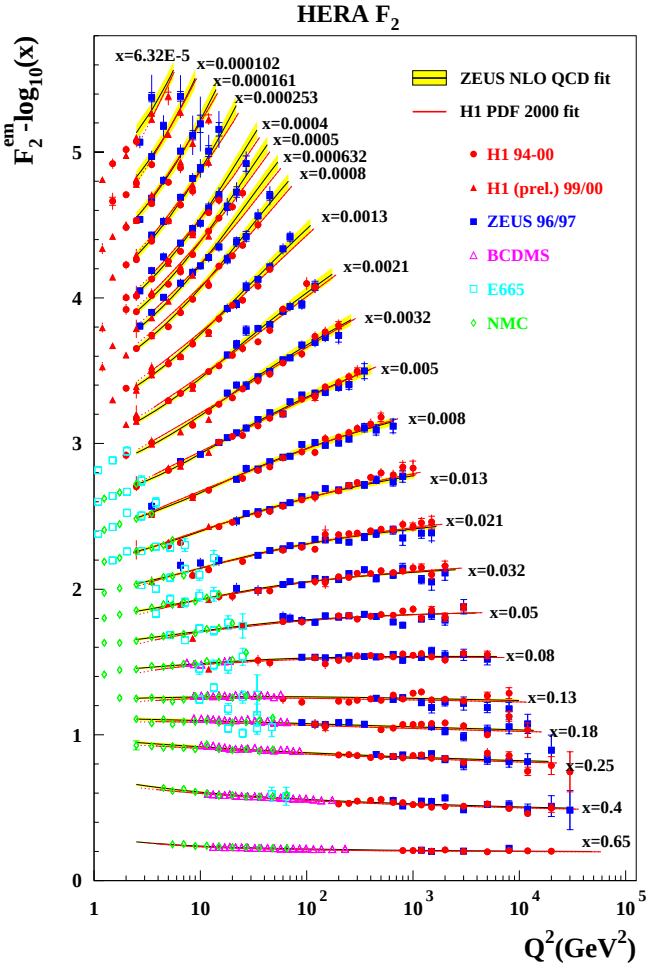
LHC: Higgs, SUSY etc,
but mostly QCD...

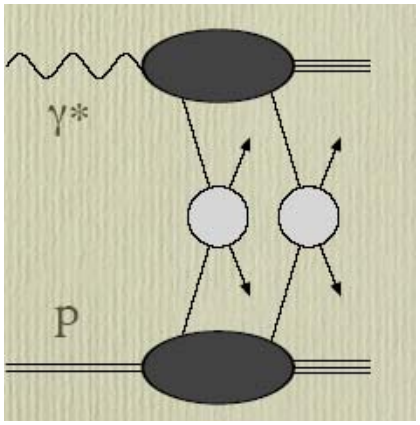


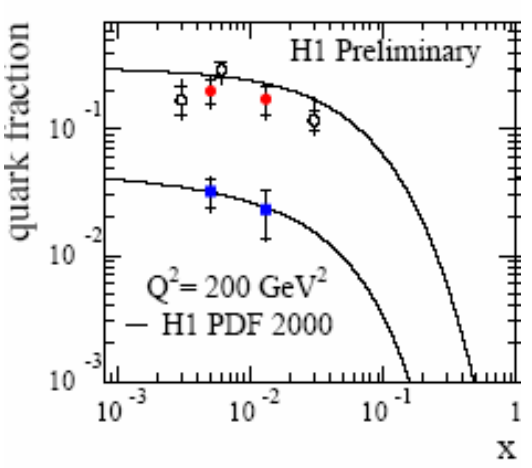
$$\sqrt{\frac{M^2}{s}} \sim 0.01$$

for $M \sim 140\ \mathrm{GeV}$

Examples: HERA→ LHC





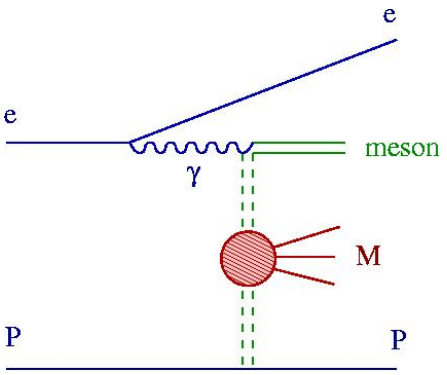


Underlying event:
tunable elementarity
of one beam particle
γp ↔γ*p collisions
LHC: event complexity

B-production: B quark
PDFs of the proton
LHC: Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: diffractive
scalar production



Workshop Aims

http://www.desy.de/~heralhc

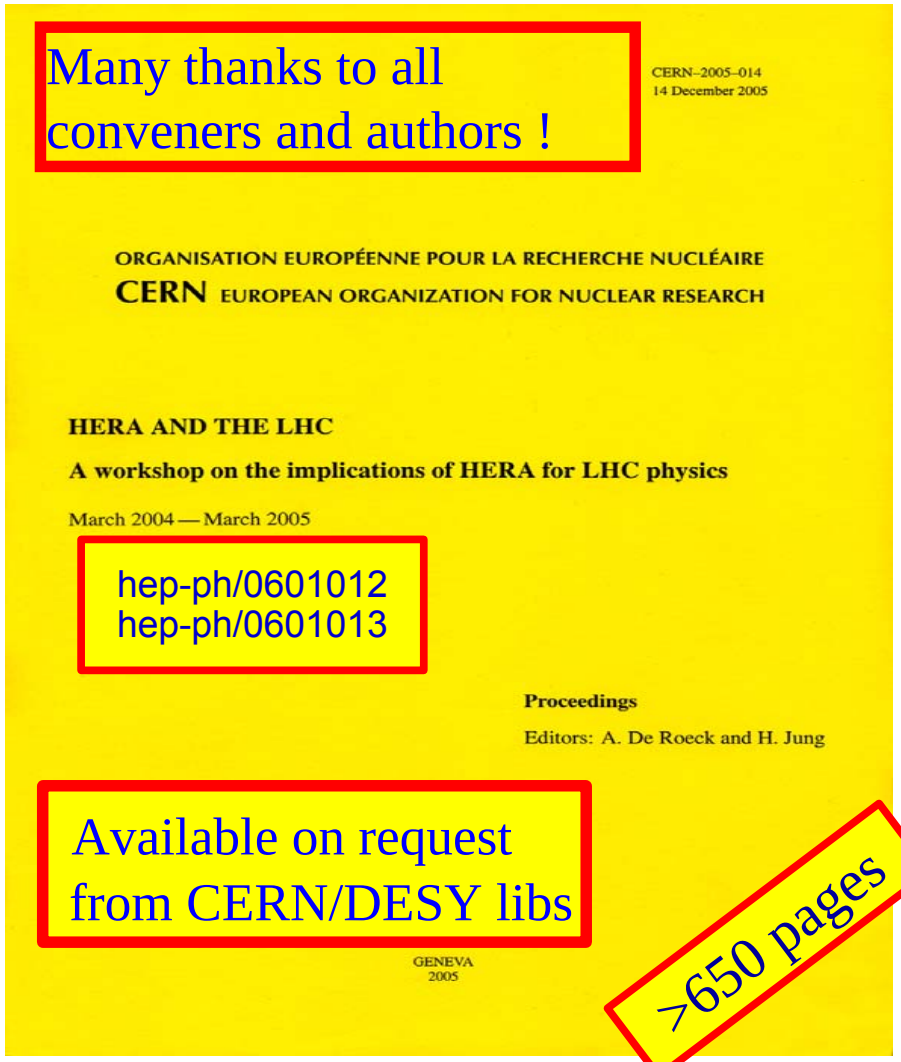
- To identify and prioritize those measurements to be made at HERA which have an impact on the physics reach of the LHC.
- To encourage and stimulate transfer of knowledge between the HERA and LHC communities and establish an ongoing interaction.
- To encourage and stimulate theory and phenomenological efforts related to the above goals.
- To examine and improve theoretical and experimental tools related to the above goals.
- To increase the quantitative understanding of the implication of HERA measurements on LHC physics.

Workshop Chairs
H. Jung, ADR

⇒ Five Working Groups
- Parton density functions
- Multi-jet final states
- Heavy quarks (charm and beauty)
- Diffraction
- MC-tools

6 major meetings in 12 months

Proceedings



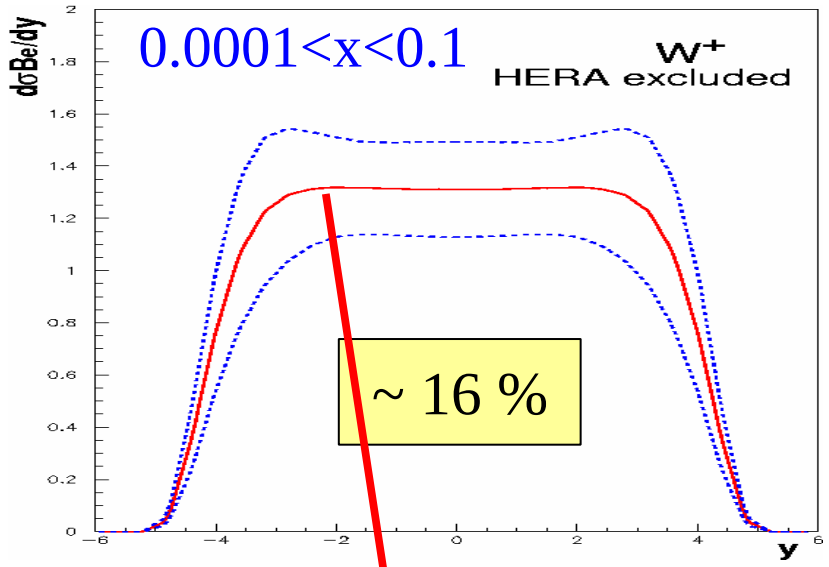
- Phase I of this workshop concluded with the proceedings
- However an important link between communities has been established.
- March 05': We should not just let it fade away, but strongly exploit it, to the benefit of both communities.
- Therefore keep momentum with one HERA/LHC meeting per year

2006	CERN:	6-9 June
2007	DESY	date to be determined
2008	CERN	(first LHC physics?)

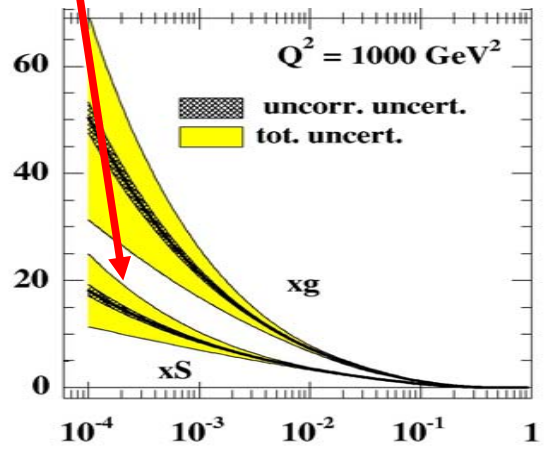
- Keep also good contacts with TeV4LHC workshop activities (started Sept.2004)

HERA Impact on the LHC

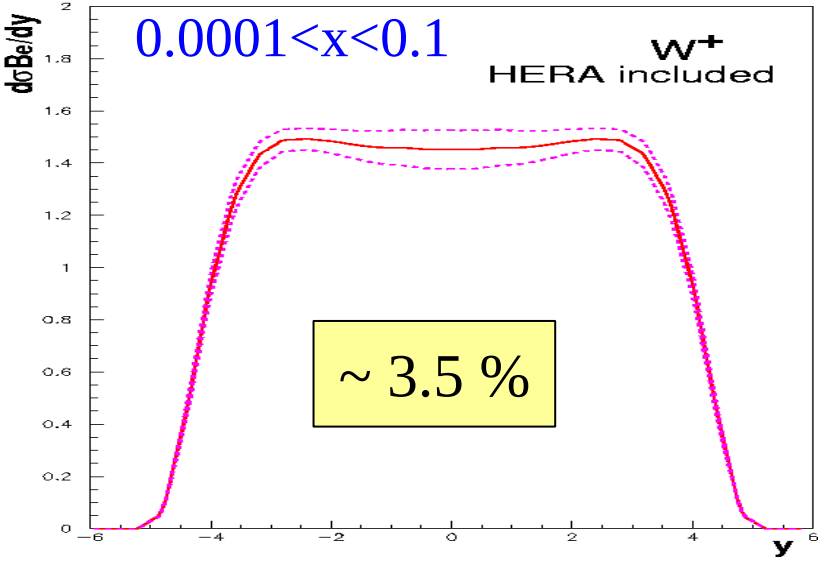
- W prod. at LHC without HERA:



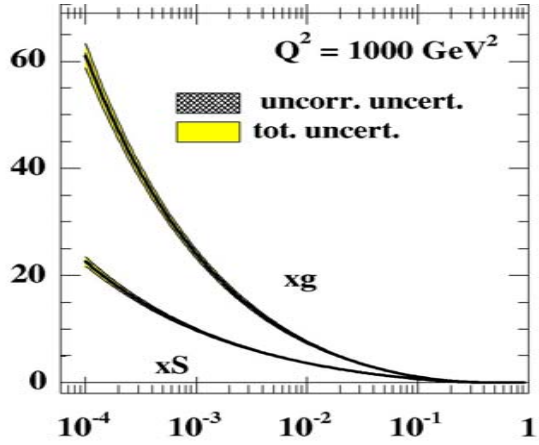
- PDFs without HERA:



- W prod. at LHC including HERA

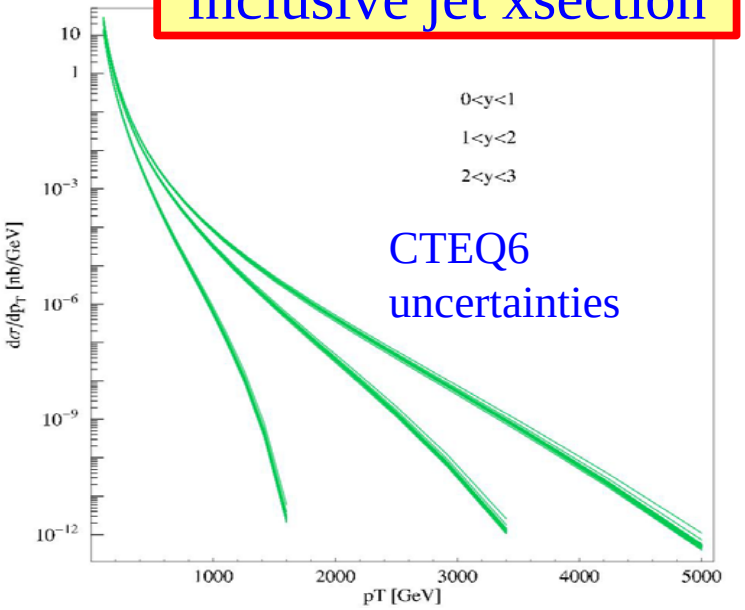


- PDFs including HERA:



Precise PDFs for the LHC

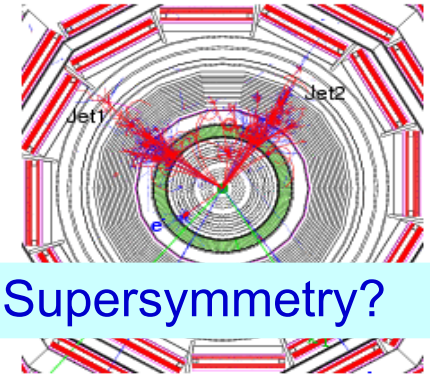
inclusive jet xsection



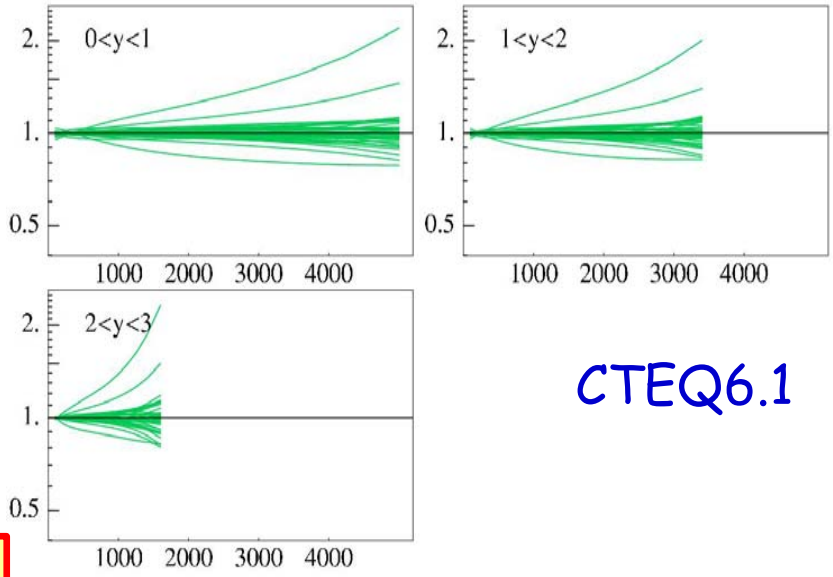
D.Stump et al hep-ph/0303013

Signature for new physics
➔ jet x-section

Discovery potential depends on precise PDFs

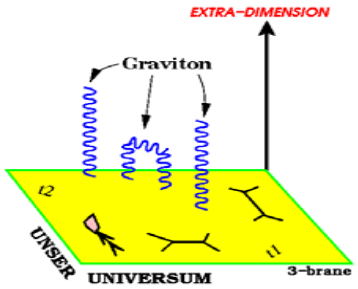


Supersymmetry?



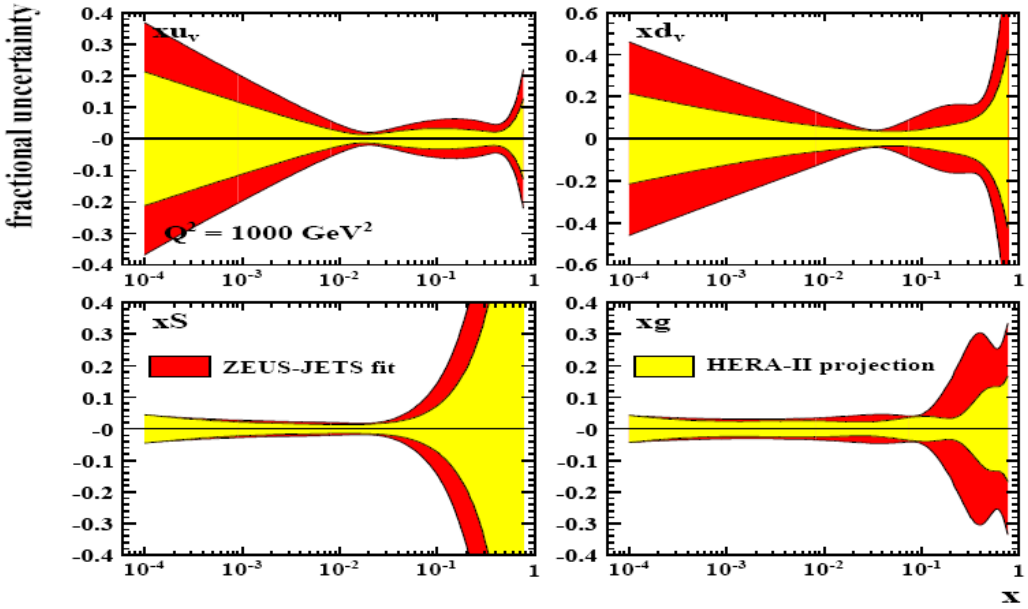
CTEQ6.1

Extra Dimensions?



Precision determination of PDFs needed ... understanding QCD is the key to new physics

Impact of Future HERA Data



- Improvement in PDF precision with projected 700 fb^{-1} of data in HERA-II
- Includes jets in DIS and γp
- Note only HERA (ZEUS) data are used in the fits

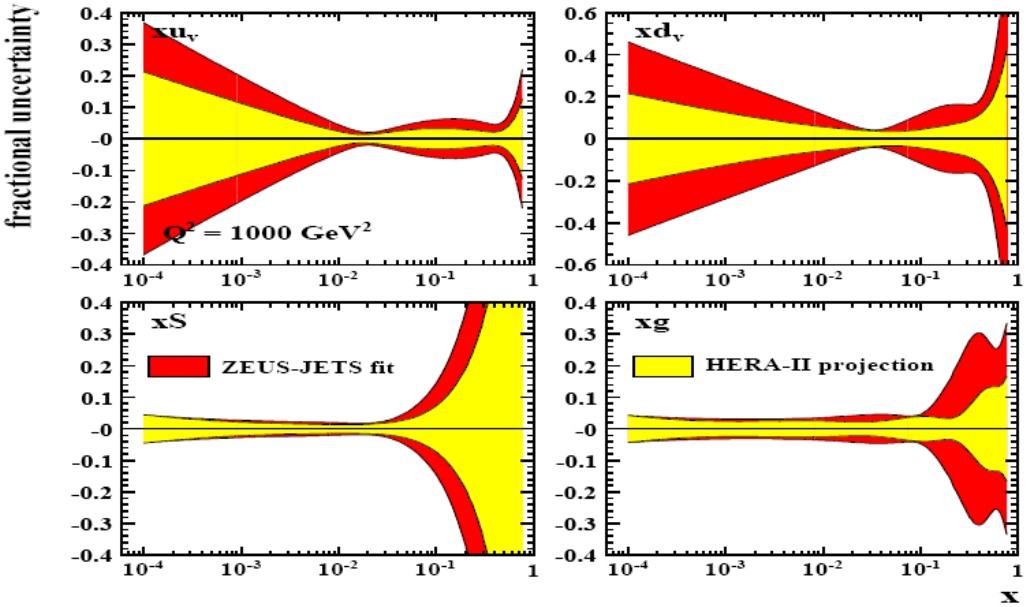
data sample	kinematic coverage	HERA-I $\mathcal{L}$ (pb^{-1})	HERA-II $\mathcal{L}$ (pb^{-1}) (assumed)
96-97 NC e^+p [7]	$2.7 < Q^2 < 30000$ GeV^2; $6.3 \cdot 10^{-5} < x < 0.65$	30	30
94-97 CC e^+p [10]	$280 < Q^2 < 17000$ GeV^2; $6.3 \cdot 10^{-5} < x < 0.65$	48	48
98-99 NC e^-p [8]	$200 < Q^2 < 30000$ GeV^2; $0.005 < x < 0.65$	16	350
98-99 CC e^-p [11]	$280 < Q^2 < 17000$ GeV^2; $0.015 < x < 0.42$	16	350
99-00 NC e^+p [9]	$200 < Q^2 < 30000$ GeV^2; $0.005 < x < 0.65$	63	350
99-00 CC e^+p [12]	$280 < Q^2 < 17000$ GeV^2; $0.008 < x < 0.42$	61	350
96-97 inc. DIS jets [13]	$125 < Q^2 < 30000$ GeV^2; $E_T^{Breit} > 8$ GeV	37	500
96-97 dijets in γp [14]	$Q^2 \lesssim 1$ GeV^2; $E_T^{jet1,2} > 14, 11$ GeV	37	500
optimised jets [17]	$Q^2 \lesssim 1$ GeV^2; $E_T^{jet1,2} > 20, 15$ GeV	-	500

Gwenlan
Cooper-Sarkar
Targett-Adams
hep-ph/0509220

PDF Uncertainties: Improvements

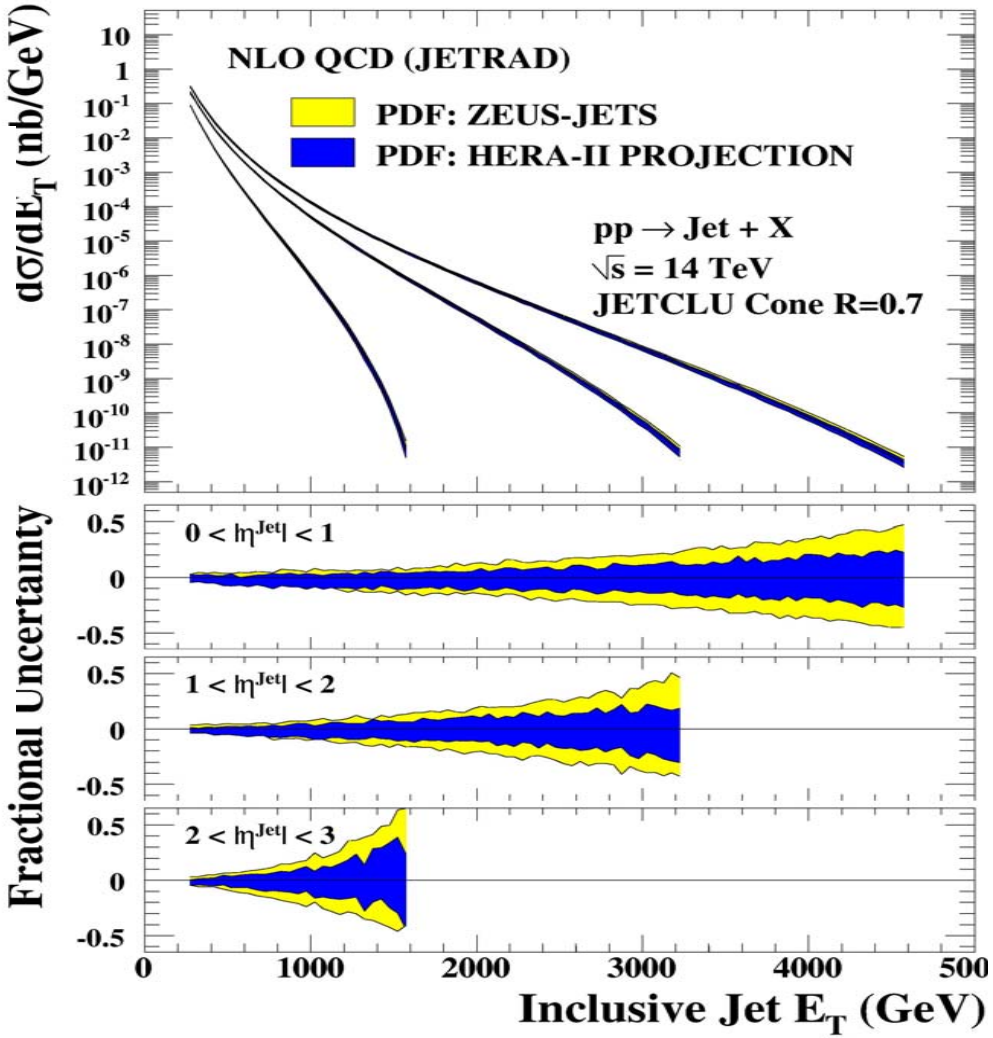
Using jets together with F_2 (at large Q^2)

quark and gluon uncertainties



high statistics from HERA II is important (assumed 700 pb^{-1})

from C. Gwenlan, A. Cooper-Sarkar, C. Targett-Adams

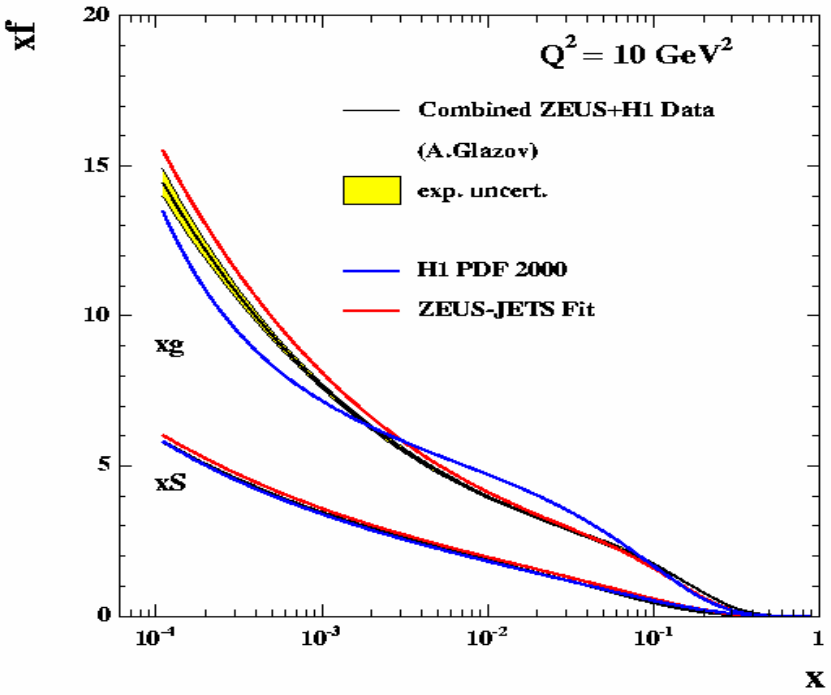


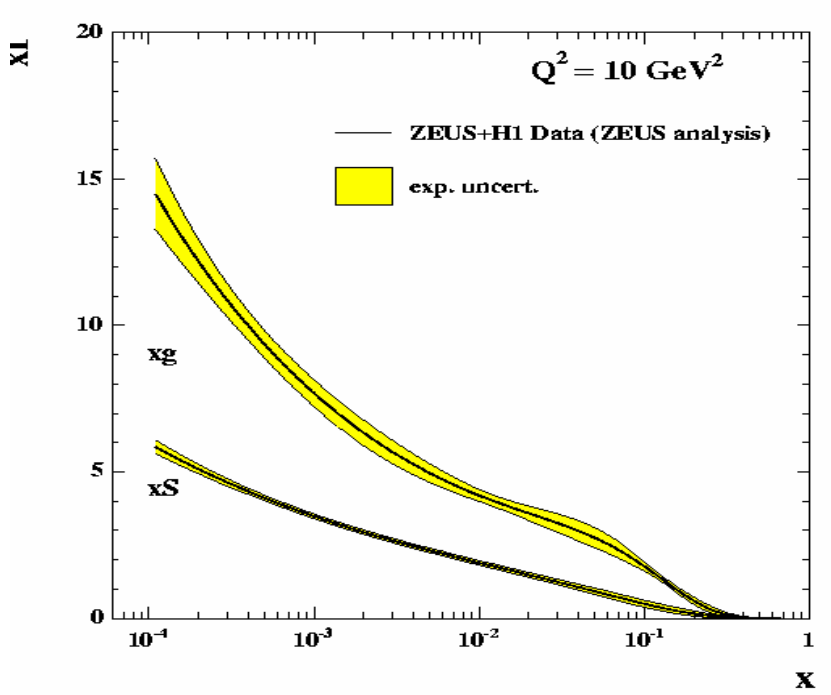
Error on LHC jet xsection reduced !!!

Average HERA data

From M. Cooper-Sakar, C. Gwenlan and S. Glazov

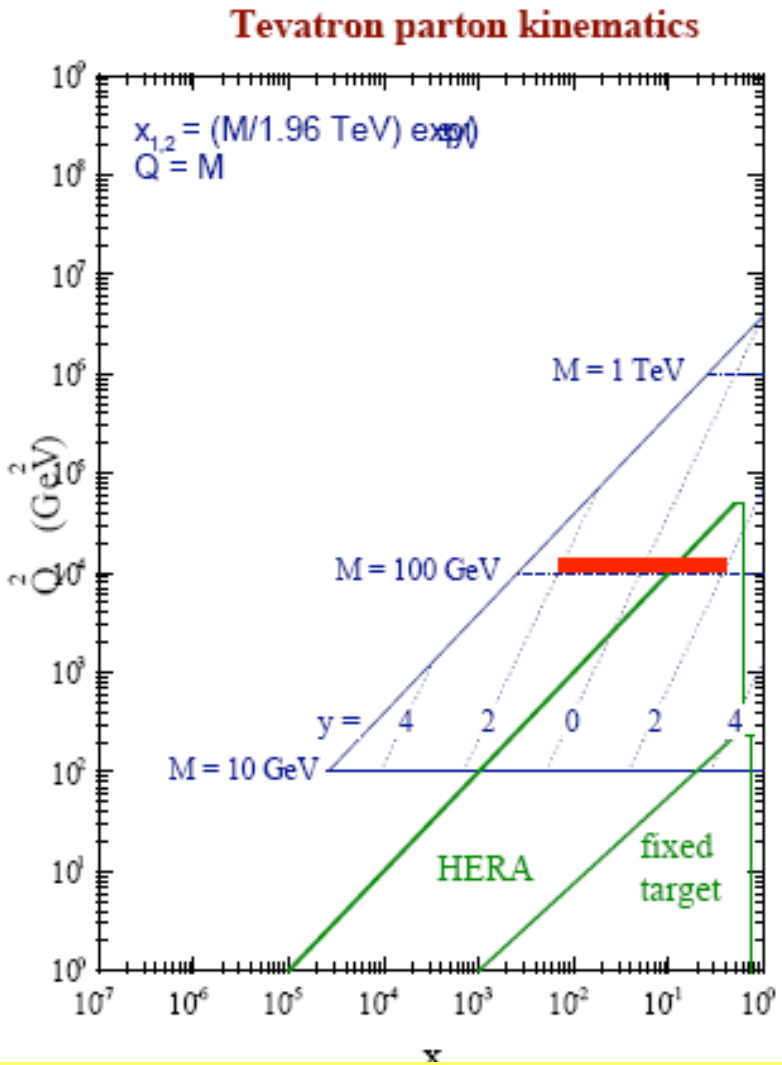
- Average H1&ZEUS data sets
- Combined PDF fit to H1& ZEUS

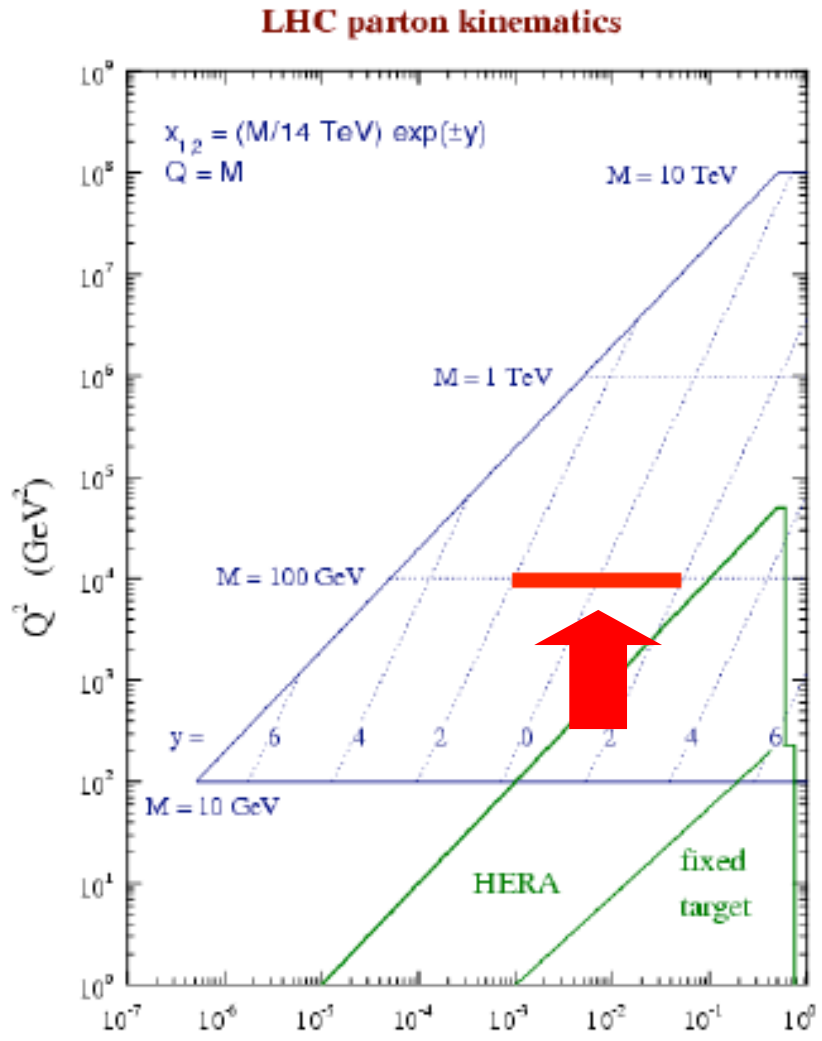




Much reduced uncertainties ....
Model independent analysis of data desirable
get THE HERA – PDF !!!!!

LHC Kinematics/QCD evolution

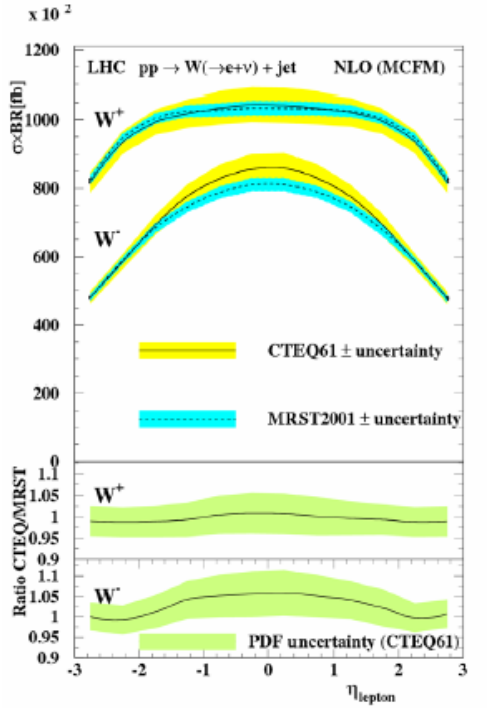


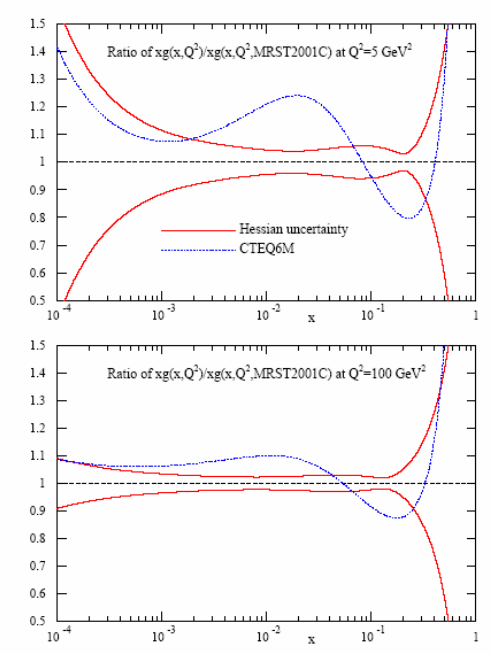


Evolution of PDFs to high Q2 & low x important at the LHC
Precision? Level of approximation? CCFM/BFKL?, non-linear effects?

Impact of the measurement of F_L

H. Stenzel





R. Thorne

F_L could referee the gluon distribution!
F_L is like F_2: little theoretical ambiguity (compared to e.g. F_2^c)

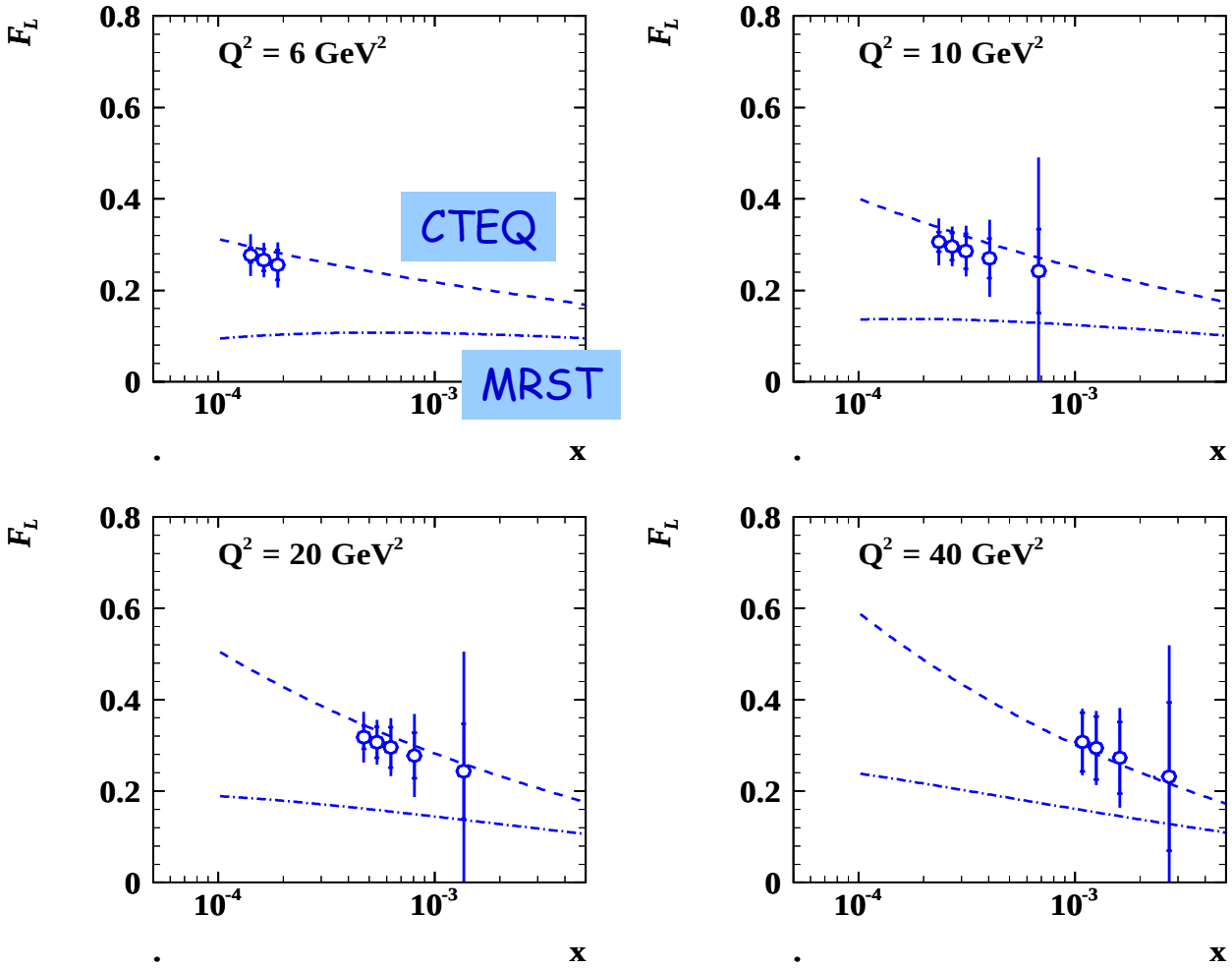
$$\sigma_r = F_2 - y^2/[1+(1-y)^2]\cdot F_L = F_2(x,Q^2) - f(y)\cdot F_L(x,Q^2)$$

Need to lower the energy of proton or electron beam for this measurement

Measuring F_L

Detailed study for H1, with 2 lower proton beam energy settings

Feltesse/Klein et al



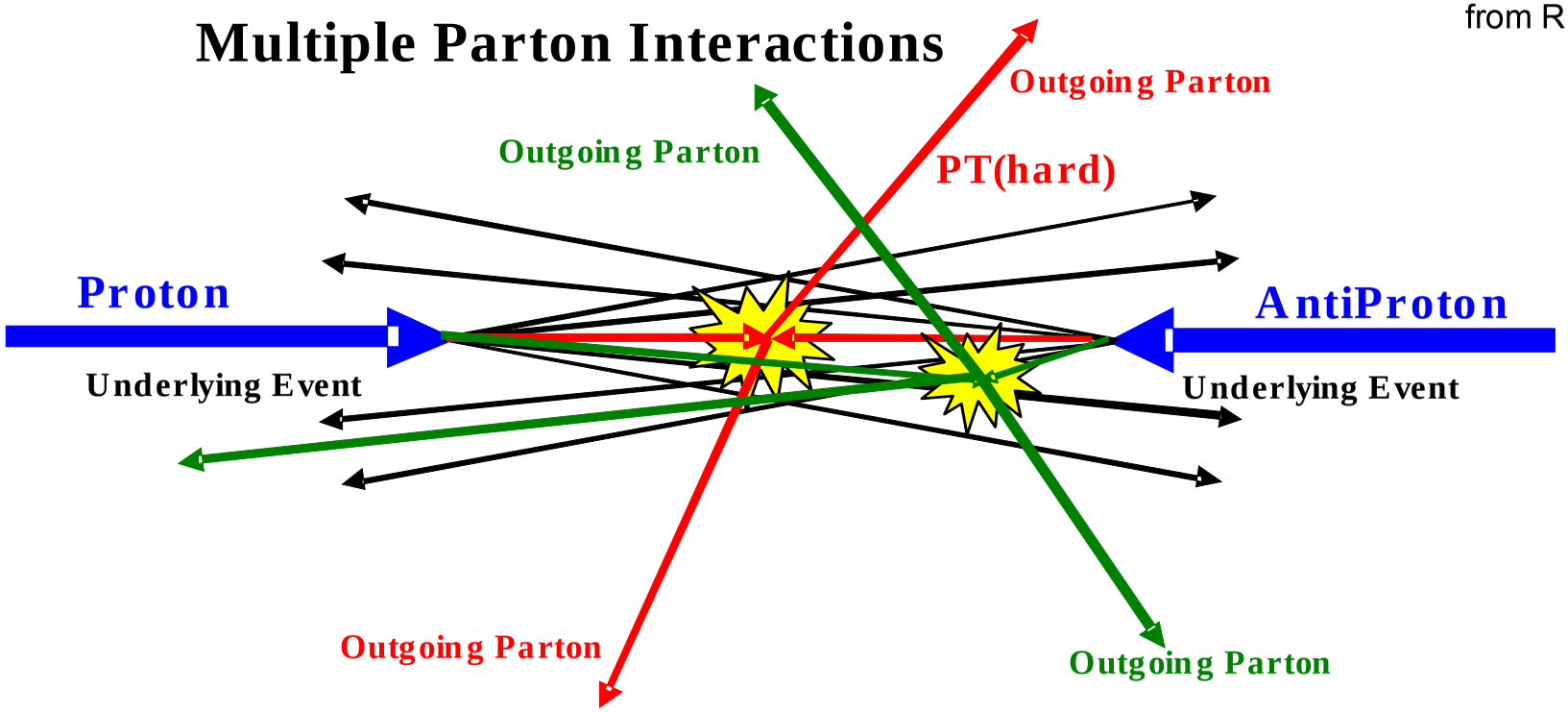
FL can referee between MRST and CTEQ gluons

FL is gluon driven

Looks like F_L may happen in 2007 !

Underlying event/multiple interactions

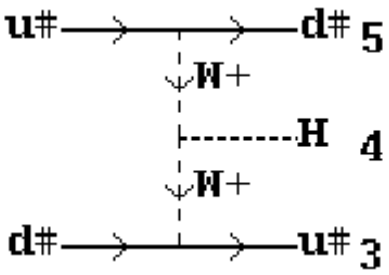
from R. Field



What is the underlying event (UE), multiple parton interactions (MI)?

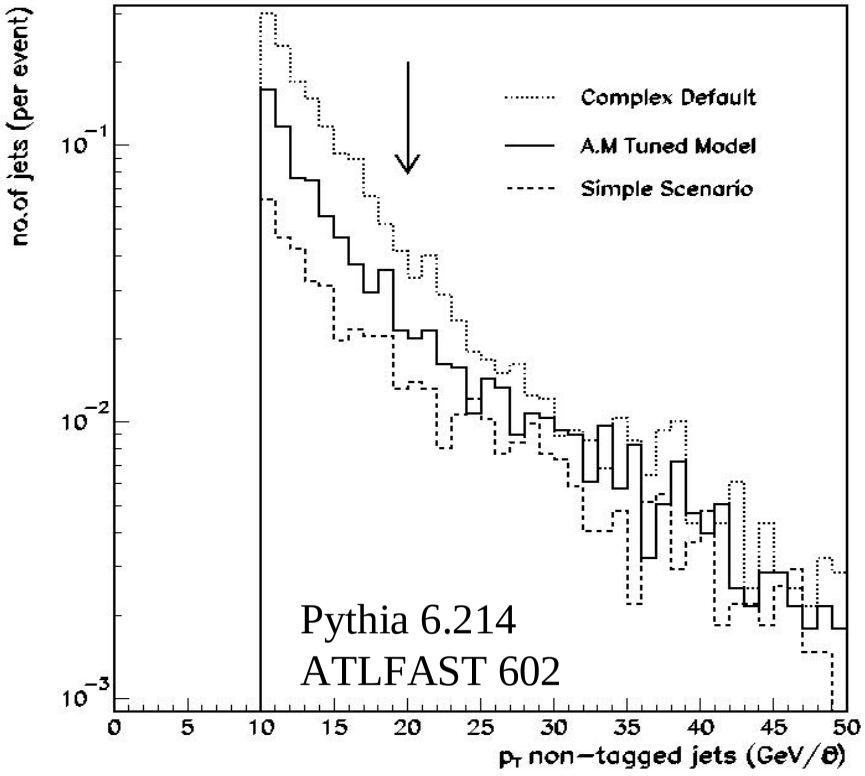
- Everything, except the LO process we're currently interested in
  - parton showers
  - additional remnant – remnant interactions
- NOT pile-up events (luminosity dependent)

Effect of underlying event on central jet veto in VBF Higgs

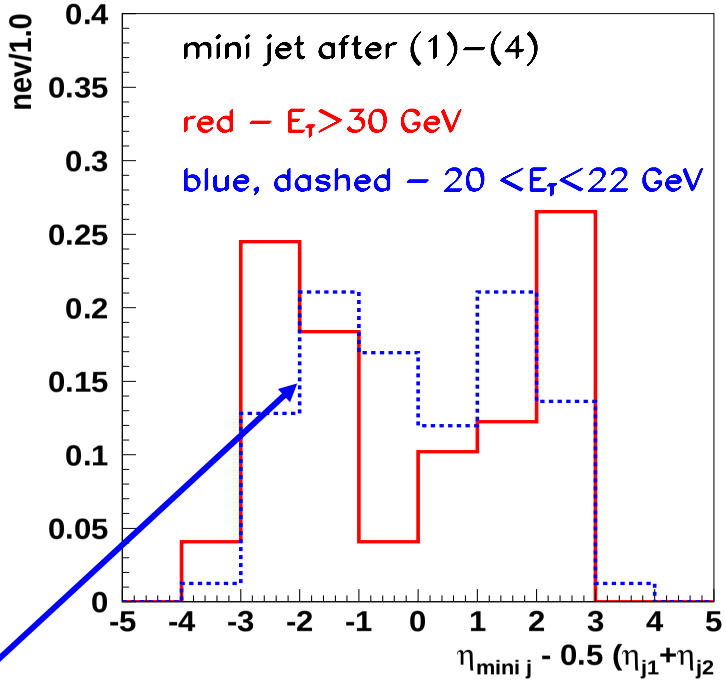


H->WW*->2l in qqH prod.

Uncertainty of the central jet veto efficiency due to UE model; ATLAS.



Rapidity of the central jet in Higgs events; CMS; full simulation, $L=2x10^{33}cm^{-2}s^{-1}$

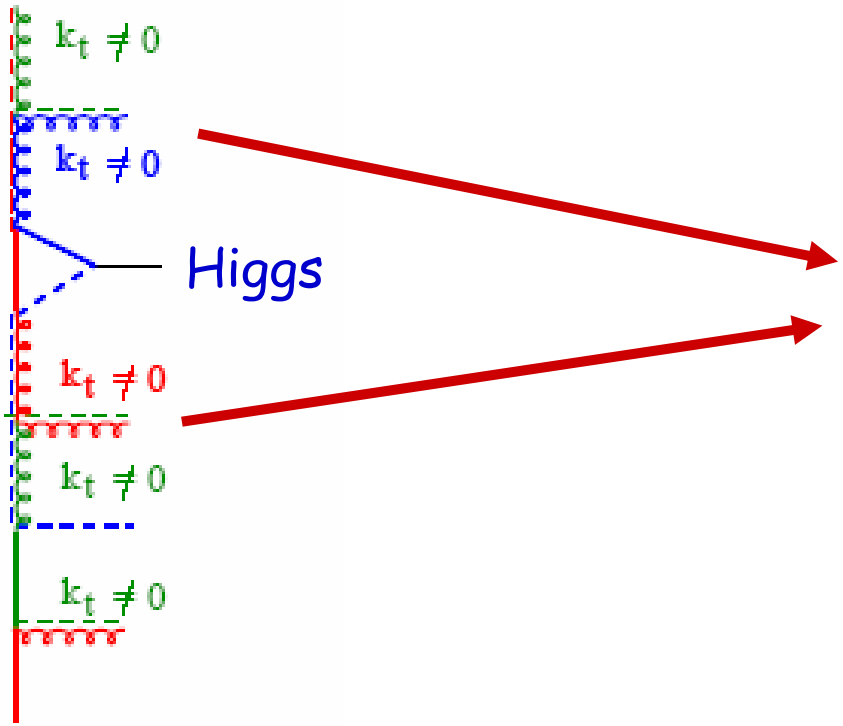


Model	CJV efficiency	Significance
Default pythia	85%	8.2
Default DG	75%	7.7
AM tuning	79%	7.9

"bkg. like" behaviour for soft jets; fake jets: pile up+UE+detector

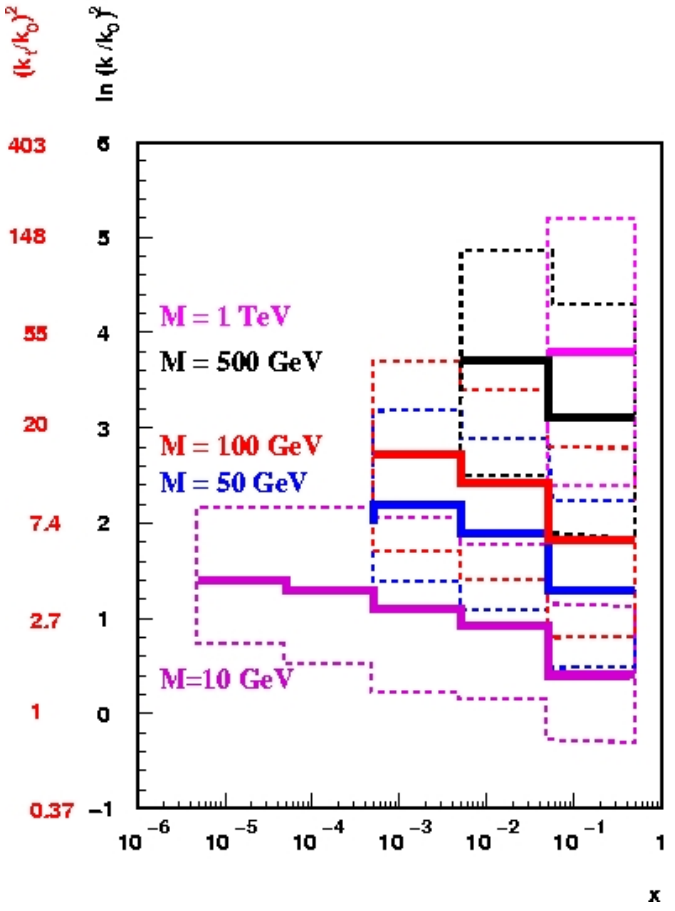
Initial k_T at HERA and LHC

Initial k_T in the hard scattering



Jung

Cascade calculation



$\langle k_T \rangle$ large $\Rightarrow$ unintegrated parton PDFs will be needed

Test predictions at HERA Large k_T effects affect Higgs searches

Measure unintegrated PDFs $f(x,Q^2,k_T^2)$ at HERA via final states

Deviations: non-linear effects in QCD evolution?

GribovLevinRyskin-MuellerQiu equation:

$$\frac{\partial xg(x,Q^2)}{\partial \log Q^2} = \left.\frac{\partial xg(x,Q^2)}{\partial \log Q^2}\right|_{DGLAP} - \frac{9\pi\alpha_s^2}{2Q^2}\int_x^1 \frac{dy}{y} y^2 G^{(2)}(y,Q^2)$$

$$x^2 G^{(2)}(x,Q^2) = \frac{1}{\pi R^2}\left(xg(x,Q^2)\right)^2$$

- non-linear (quadratic) correction

has "–" sign

➔ Q^2 evolution is ***slower***

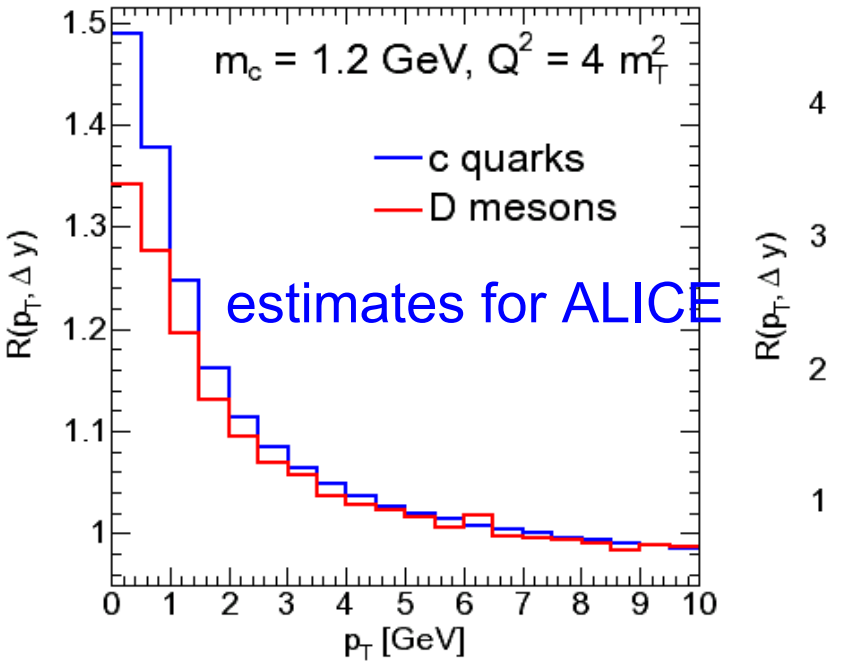
- refit HERA F_2 data, reduces F_2^{DGLAP} at

low x and moderate Q^2

- $xg(x,Q^2)$ at low Q^2 (<10 GeV^2) and

x (<10^{-3}) is larger than in DGLAP

A. Dainese et al



➔ Get these non-linear effects better understood from HERA !

➔ Precise HERA data important !!!

➔ connection to MI, diffraction ...

Non-linear effects at LHC

Nonlinear evolution equation for uPDF:
(Balitsky-Kovchegov equation)

$$f(x,k^2) = \tilde{f}^{(0)}(x,k^2) + K^1 \otimes f - K^2 \otimes f^2$$

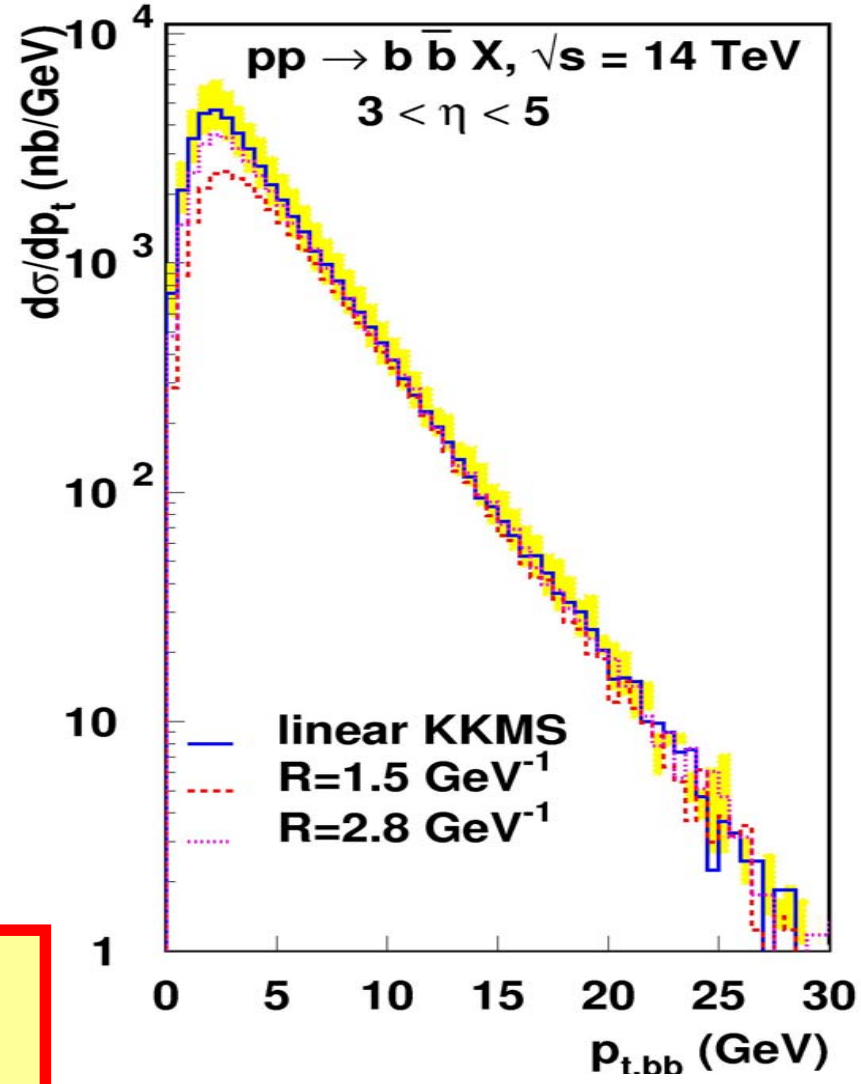
$$\tilde{f}^{(0)}(x,k^2) \rightarrow \text{input}$$

$$K^1 \otimes f \rightarrow \text{BFKL}$$

$$K^2 \otimes f^2 = \left(1 - k^2 \frac{d}{dk^2}\right)^2 \frac{k^2}{R^2} \times$$

$$\int_x^1 \frac{dz}{z} \left[\int_{k^2}^{\infty} \frac{dk'^2}{k'^4} \alpha_s(k'^2) ln\left(\frac{k'^2}{k^2}\right) f(z,k'^2)\right]^2$$

Bottom suppression due to non-linear effects in BK

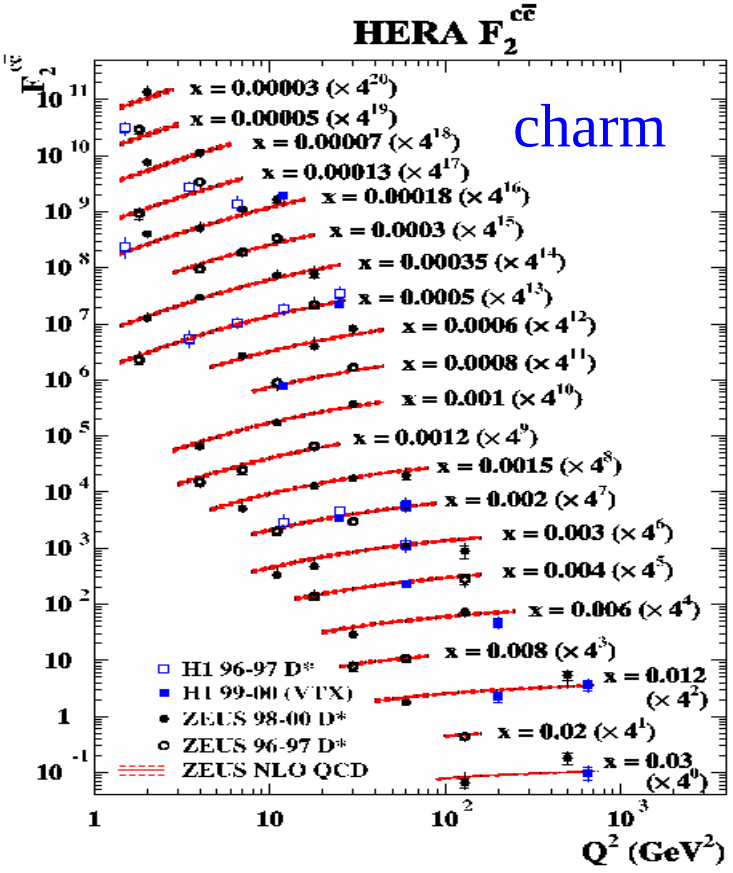


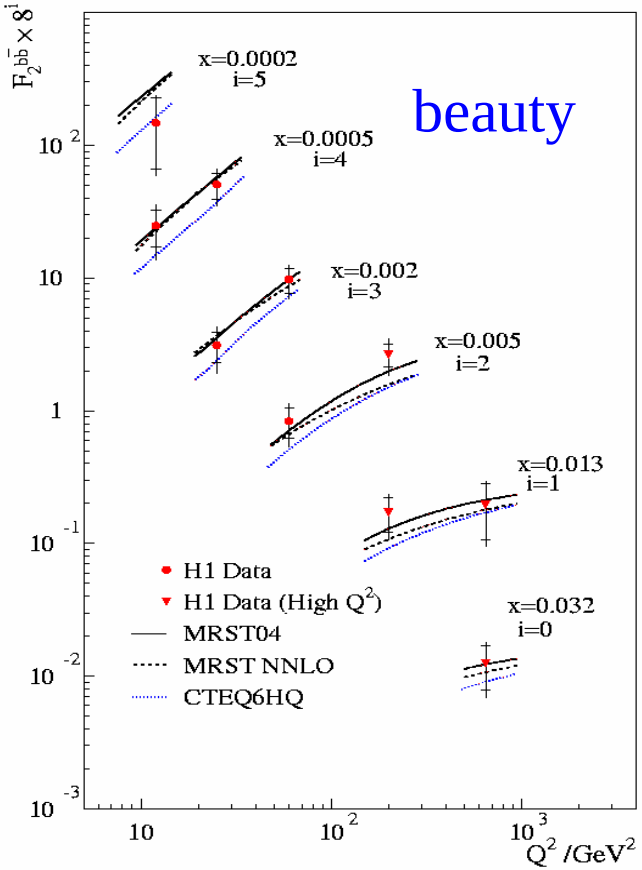
- Significant effects...
- up to factor of 2 in hot spot scenario
- factorization still ok ?

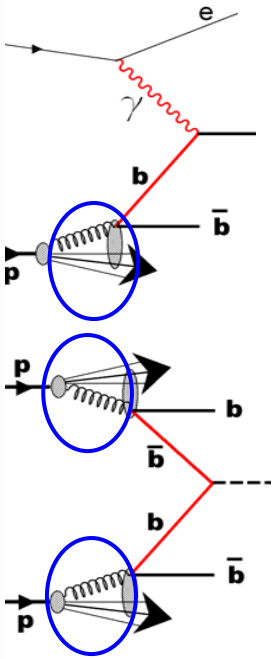
HERA: Heavy Quark PDFs at large Q^2

- Current H1 (HERA I) analysis

From O.Behnke, A. Geiser, A. Meyer, M. Wing







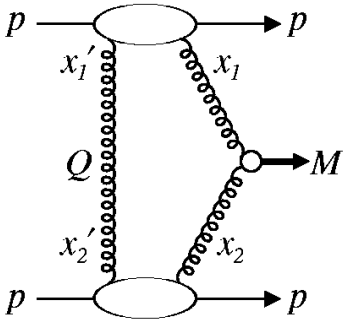
- HERA II analysis (expect factor 10 more), larger kinematic range, both exp. with CST/MVD

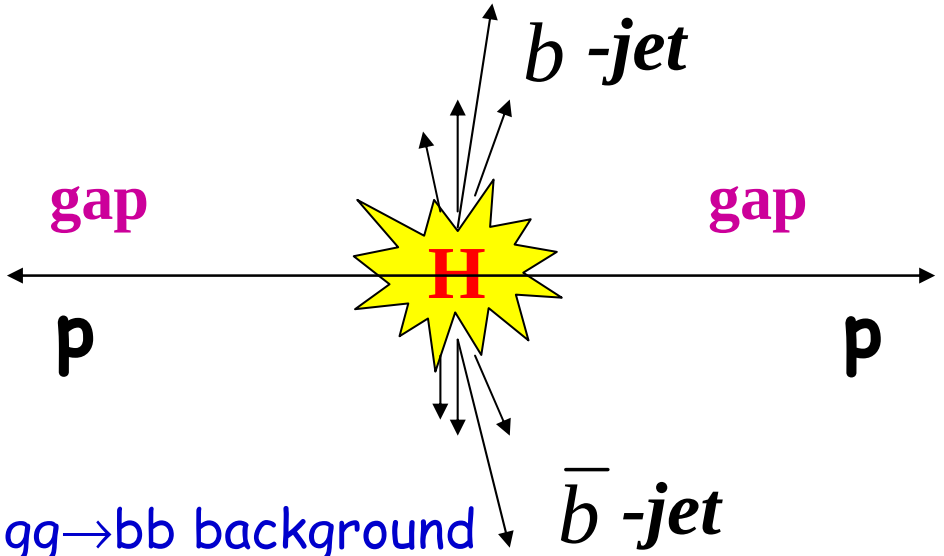
➔ Understand *b*-production mechanism (...remember *b*-puzzle at the TeVatron...)

➔ **NOTE:** gluon drives heavy quark PDFs .... transverse momenta ????

Exclusive Higgs Production

Exclusive diffractive Higgs production pp→ p +H+ p : 2-10 fb
Cross section 'stabelized' during the previous workshop



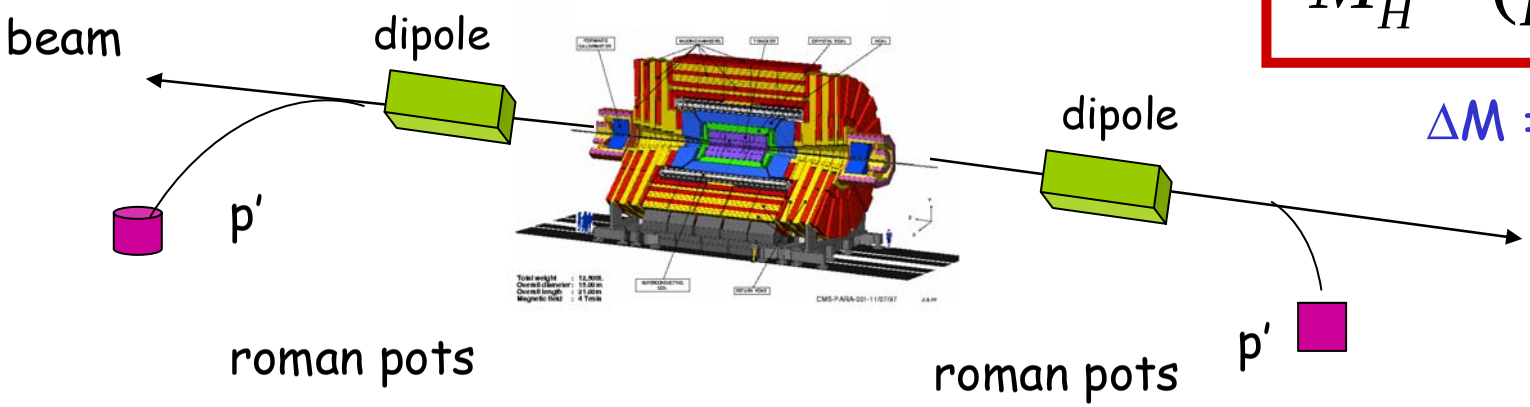


E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. …

Advantages Exclusive:
- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

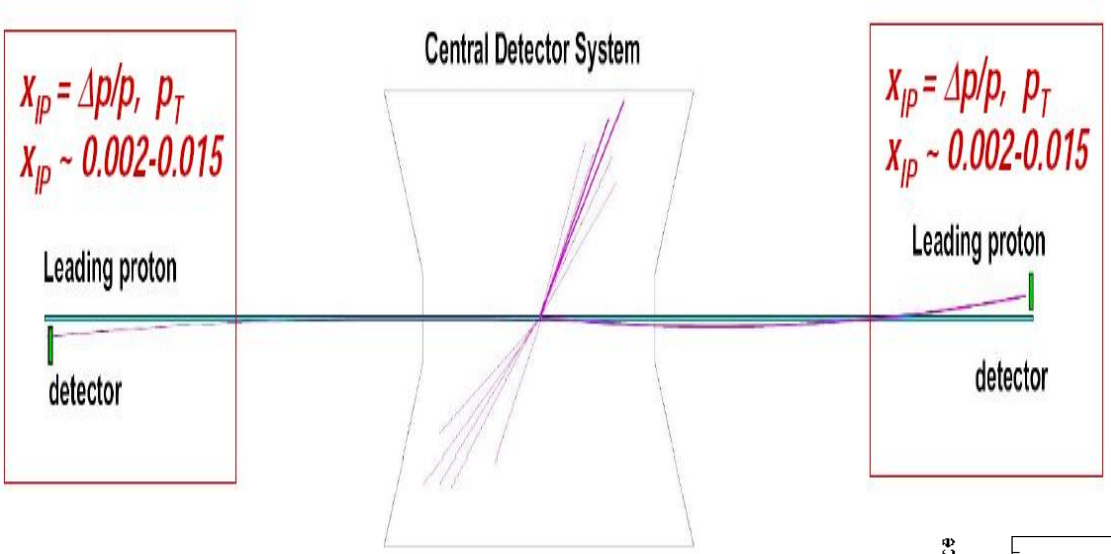
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



Experimental effort started
See B. Cox

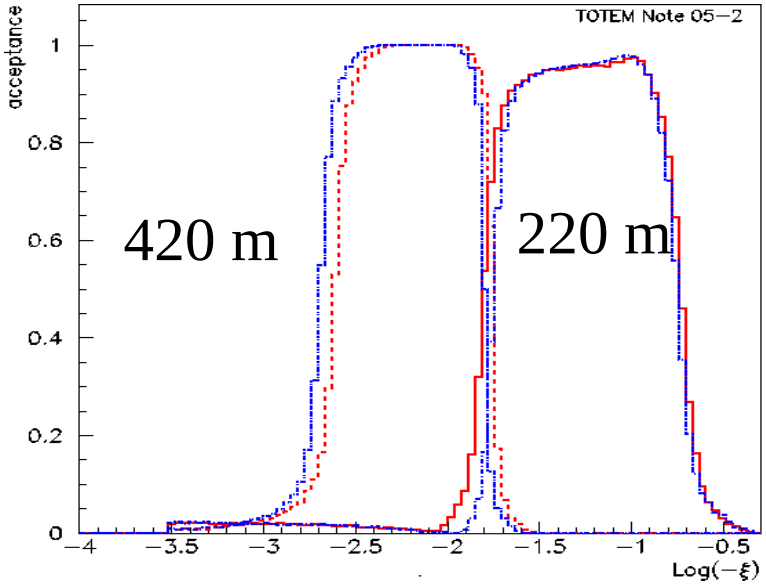
Measurement of exclusive Higgs



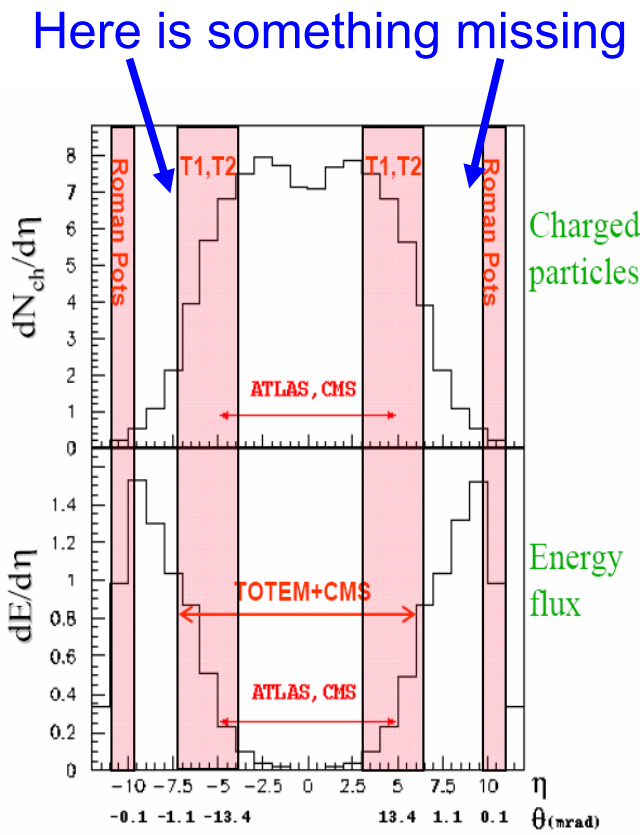
B. Cox, M Grothe, H. Kowalski et al.

- Detector stations at 220 m and 420 m from Interaction point
- 420 m station is in cold region.... – *Hamburg pipe*

- goal: mass resolution 1 GeV for Higgs with
- 420 m stations are needed for low mass Higgs
- other issues:
  - triggers
  - gap-survival
  - rates

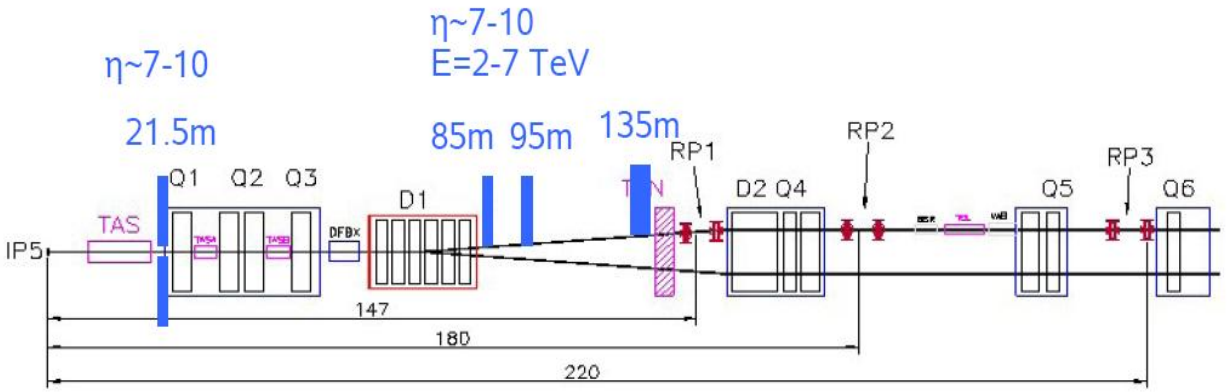


Ideas for upgrading forward region



from V. Andreev, A. Buniatian, L. Lytkine, M. Kapishin, HJU

- important for UHECR (hadron showers at E ~ 10^{17} eV)
- important region for small x QCD: MI – saturation – diffraction – gap-survival
- possibilities:
  - small angle tagging: micro-stations
  - calorimetry



MC and other Tools

- Parton distribution library:
  - LHAPDF now official carrier of the PDFs
    - Used by LHC experiments in generators
    - HERA pdfs have been added
    - Allows error uncertainty estimates
    - Pion and photon added, particularly for HERA. F2D next?
- NLOLIB framework for NLO QCD programs
  - Uniform user interface/interface to HZTOOL
  - e+e-/ep included, pp can be added
- HZTOOL/JetWeb/RunMC/Cedar(?) for tunning
  - All HERA results to be included, some e+e-. Include more pp?
- RAPGAP, Cascade Monte Carlos for inclusive and diffractive pp
- Plenty of exchange on other MC tools, leading to new MC tools and comparisons with ep where possible
- Continuation of the MC@LHC 2003 workshop , concerning validation

  $\Rightarrow$A new MC@LHC workshop this summer 2006: June 17-26

Nutshell: Results for the LHC

- Parton Distribution Functions
  - Dialogue/discussion between PDF fitters and community that delivers the data.
  - Combined data (H1/Zeus Datasets for F2, F2D), other data (e.g. TeV. jets)?
  - Discrepancies between PDFs will be ironed out, eg via to new measurements. Fits with 1-σ bands available.
  - Quantitative estimates for low-x/large-x resummation available
  - Timescale for the full program 1-2 years, i.e. just in time for the LHC

    $\Rightarrow$ Will lead to more precise PDFs: maybe factor 2? (personal guess/hope)
- Diffraction
  - Improved understanding on the DPE/Higgs production and cross section
- Final states
  - Lots of work/progress on underlying events (tuning), gap survival
- Heavy quarks
  - Saturation effects measurable at low pt
  - Heavy quark parton distributions eg. for Higgs cross section calculations.
- Tools
  - Tool developments ongoing strongly…

Goals and suggestions for 2nd workshop

H. Jung/ADR

- **precision determination of PDFs, including uPDFS and generalised PDFs**
  - what precision can be expected in 2007/2008 from the HERA and perhaps combined with other data and with the improvements in theory? This was started in the first workshop but is it the final word for LHC preparation
  - how does it affect LHC measurments quantitatively
  - combined H1/ZEUS parton data sets (started at the previous)
  - can we judge which PDF is preferred (MRST/CTEQ...) in 2007/2008 eg.from FL or LHC measurements?
- **MI/underlying events/jets**
  - uncertainties for top/Higgs production
  - underlying event tuning at HERA (as for the Tevatron data)
    - testing new underlying event models with data
    - new advised parameter set for underlying events
  - Quantative uPDFs and MI influence for SUSYHiggs discoveries
  - Understanding MI interactions with HERA data (AGK,...)
  - uncertainties for gap-survival probabilities for the LHC
  - Test HO/resummed jet predictions at HERA

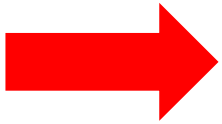
Goals and suggestions for 2nd workshop

- **Heavy Quarks: details of production mechanisms**
  - beauty at HERA -> top at LHC ?
  - higher orders
  - small x/ large x resummations
  - saturation effects
  - Include HERA charm data for gluon constraints in fits (like the jets)
- **diffraction and small x**
  - saturation and non-linear effcts:
  - what is the saturation scale, where HERA can help
  - is saturation relevant for LHC, and where ?
  - physics of the forward region
  - elastic protons
  - jets in 6 < eta < 11
  - what can be learned from total xsection sigma_tot for ptcut in multiple scatterings ?
  - How to relate diffraction with multiple scatterings
  - continuing studies on the exclusive Higgs production and detection

Goals and suggestions for 2nd workshop

MC & Tools

- HZTool -> relevanca also for MC@NLO
- benchmarking of xsections for HERA and LHC: jets, W/Z, Higgs, HQ, diffraction
- Tools for pdf fits including proper treatment of alphas, different evolution (DGLAP LO/NLO/NNLO, CCFM/BFKL) proper treatment of data uncertainties extraction of PDFs, uPDFs, generalised PDFs
- NLO programs and libraries
- SCET type of QCD generators for multi-jet production?



Keywords: tools, phenomenological progress, and quantitative estimate for the impact of HERA on LHC measurements

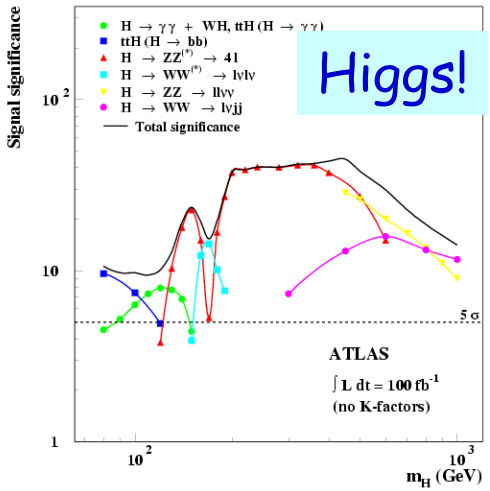
Final words: Organization this week

- Rooms
  - Plenary sessions are Main Auditorium (Tue/Thu) and 40-S2-A01 (Fri)
  - All parallel sessions in B40 and council chamber (WG3/Friday)
- Buffet Dinner on Thursday: location: B501 (restaurant-1/glass box)
  - Buy your ticket with at the secretariat: 20 CHF
- Secretariat: here (coffee break) and B40-5-B02

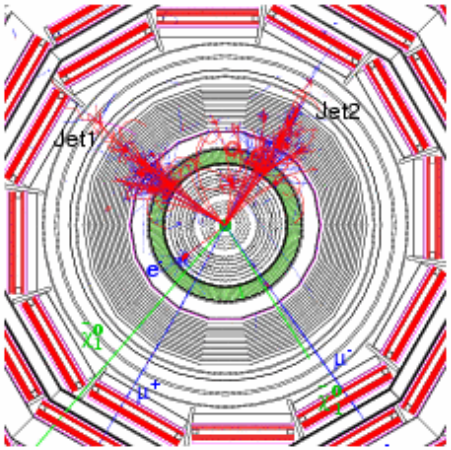
Have a good workshop

Backup

Physics at the LHC: pp @ 14 TeV

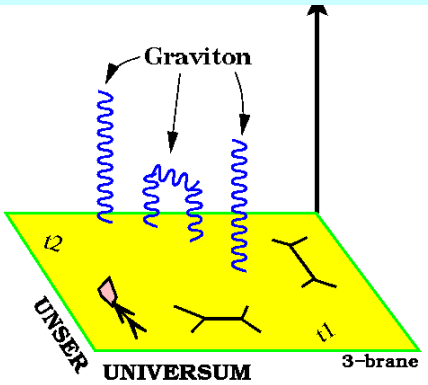


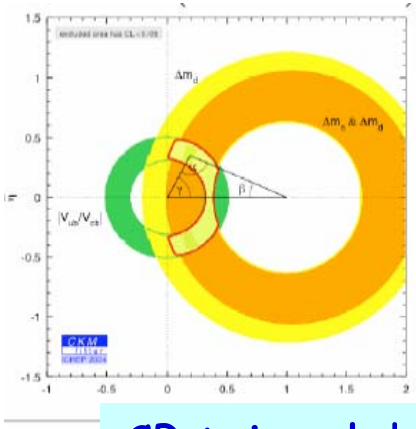
Higgs!



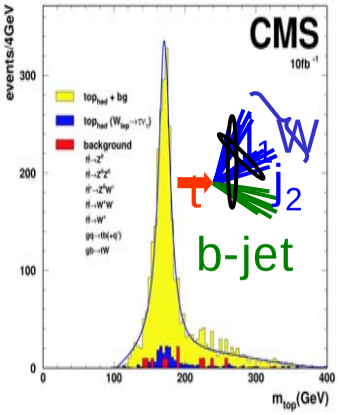
Supersymmetry?

Extra Dimensions?





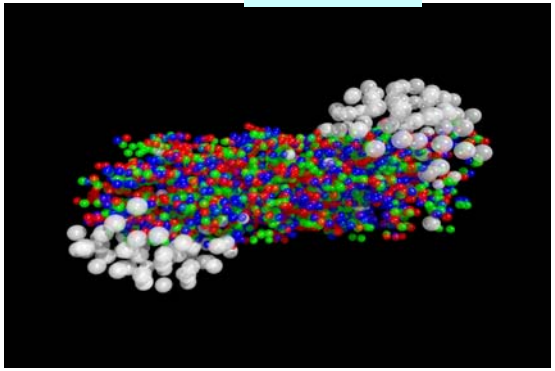
CP triangle!



Precision measurements e.g top!

Split SUSY?

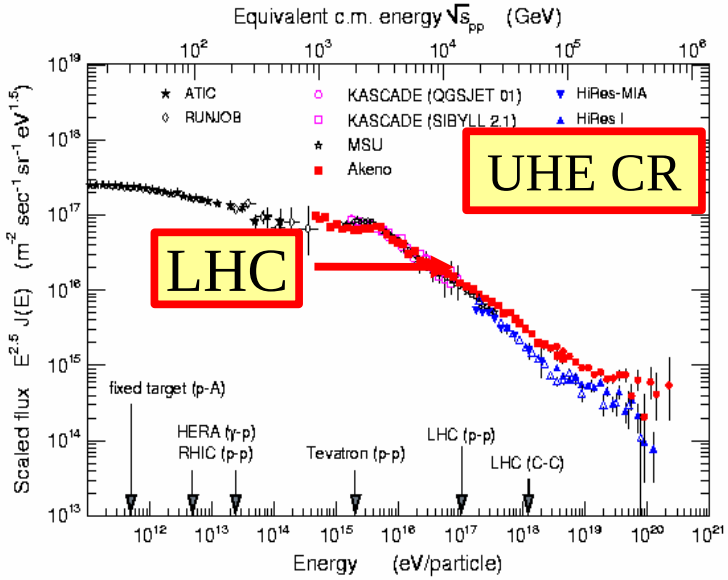
QGP?



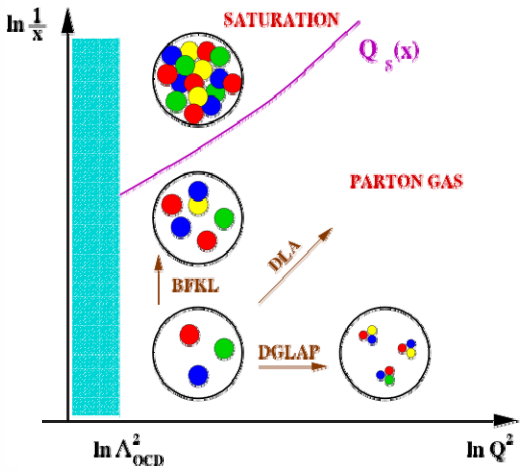
But also QCD, diffraction, b & c physics,… especially in the early phase
These need to be understood for precision measurements, bkg understanding etc
Important role for HERA data & HERA expertise ☞ This workshop

Physics at the LHC: other examples

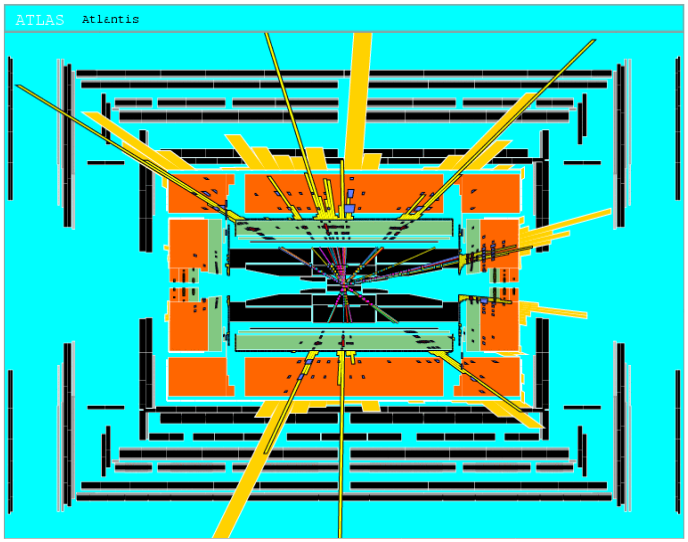
High energy hadron showers



Color glass Condensate

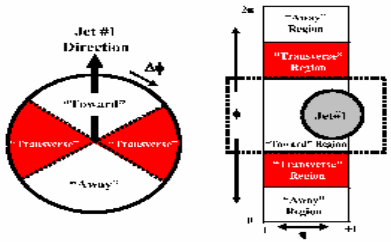


Multi Jet event:
Is it Multiple Interaction
or Black hole production



QCD @ LHC in its own!!!
High scale QCD, jets, UHECR, smallest x,
parton saturation - new phase in QCD - non-linear phenomena

Multiple Interactions at LHC



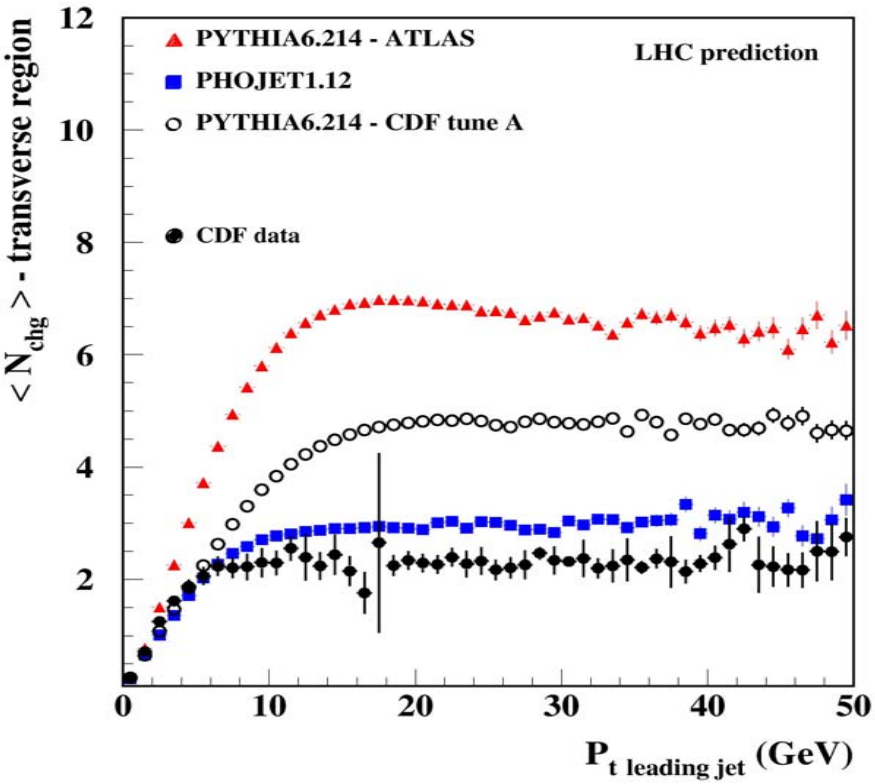
Charged multiplicities in transverse region

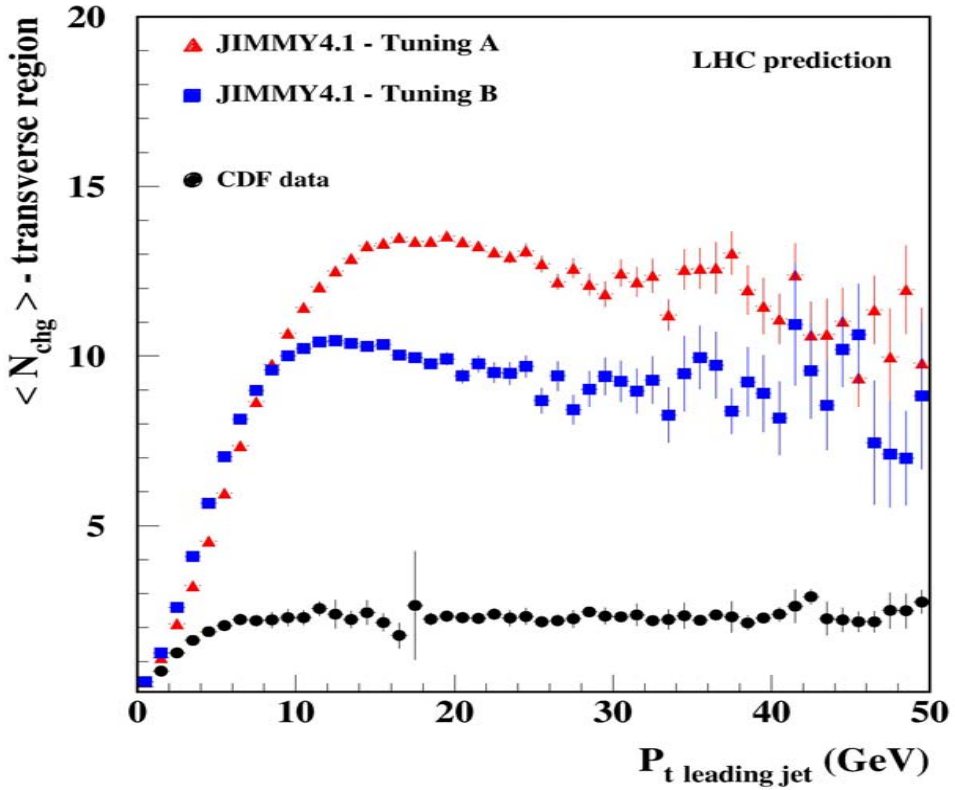
Models tuned to Tevatron data

C. Buttar et al

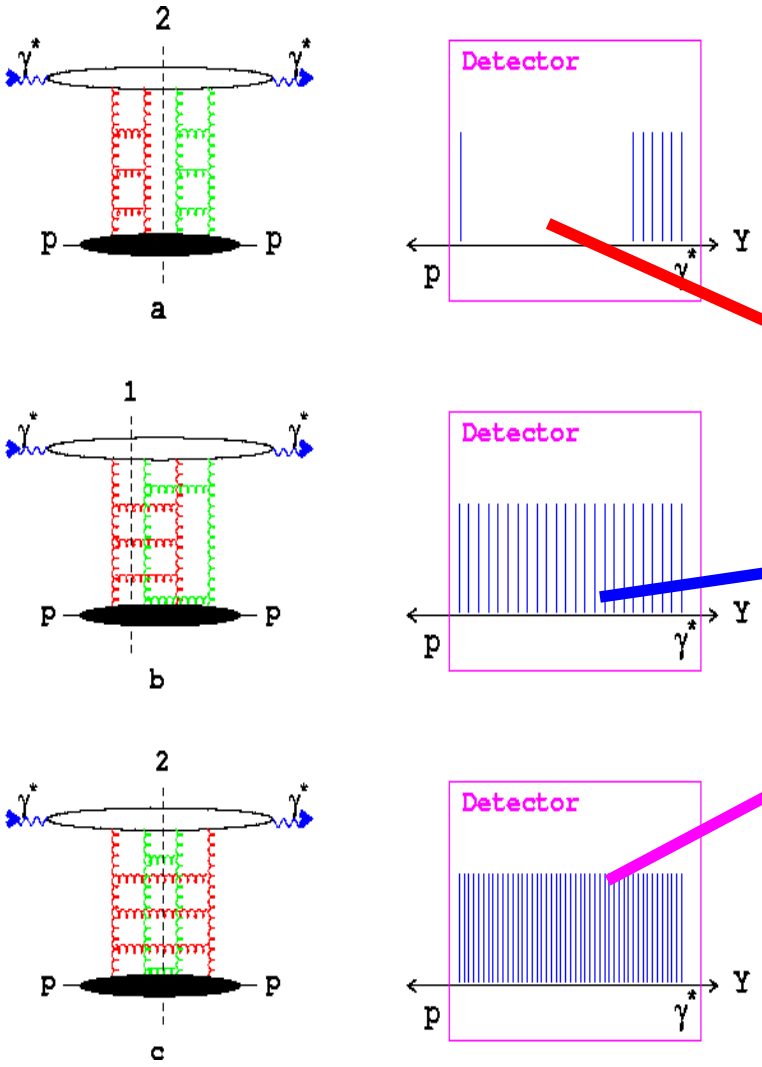
- give HUGE differences at LHC ...
- better understand multiple interactions

...





Towards understanding of MI



Bartels, Kowalski, Sabio-Vera

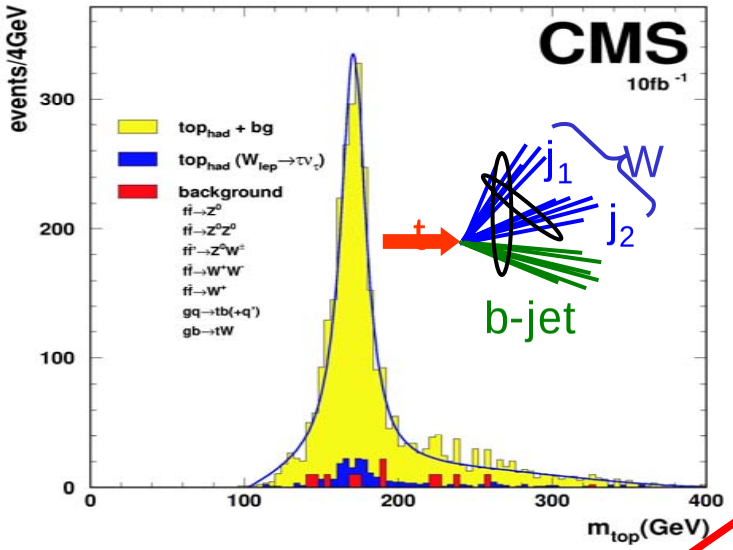
- Cutting rules (AGK) extended to QCD
- Relate diffraction, saturation and multiple scatterings
- All from the same amplitude, but different factors:
  - +1 Diffraction
  - - 4 Saturation
  - +2 Multiple Interactions

- Extended now also to pp !!!!
  - further work needed ...

➔ HERA is the place to understand MI !!!!
(TeVatron to tune MC !!!)

➔ Towards the description of *"everything"* !!!!!

Multiple Interactions and top mass

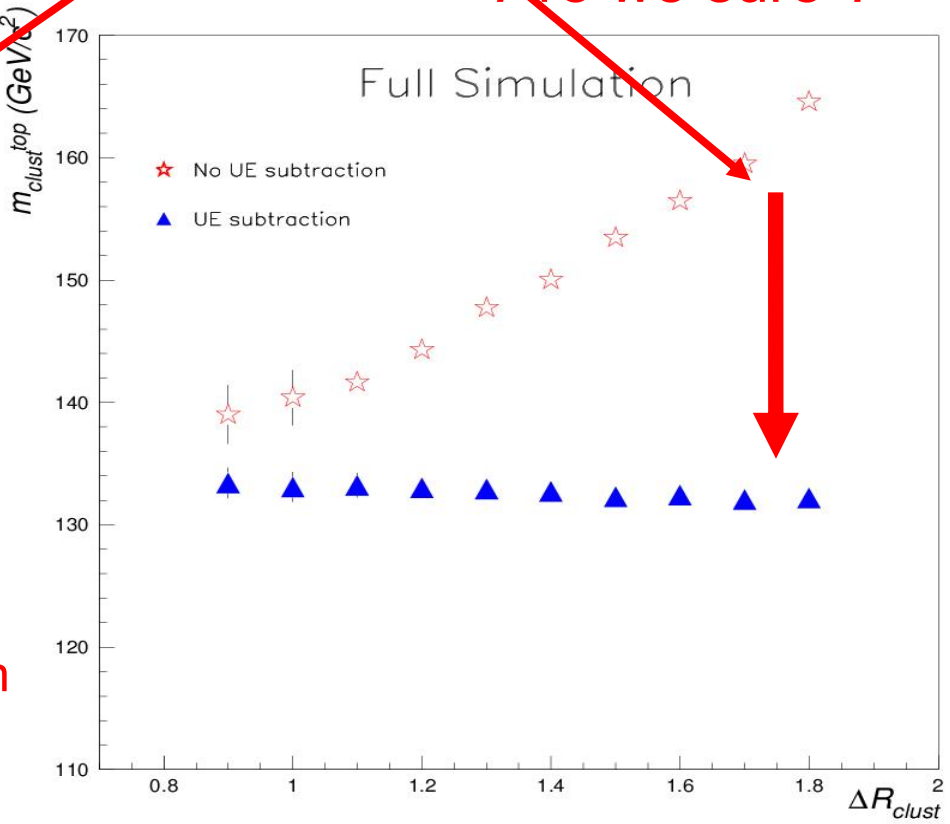


Source of error in GeV	Lepton+jets inclusive sample	Lepton+jets large clusters sample	Dilepton	All jets high pT sample
Energy scale				
Light jet energy scale	0.2	-	-	0.8
b-jet energy scale	0.7	-	0.6	0.7
Mass scale calibration	-	0.9	-	-
UE estimate	-	1.3	-	-
Physics				
Background	0.1	0.1	0.2	0.4
b-quark fragmentation	0.1	0.3	0.7	0.3
Initial state radiation	0.1	0.1	0.1	0.4
Final state radiation	0.5	0.1	0.6	2.8
PDF		-	1.2	-

from M. Mangano

hep-ex/04003021

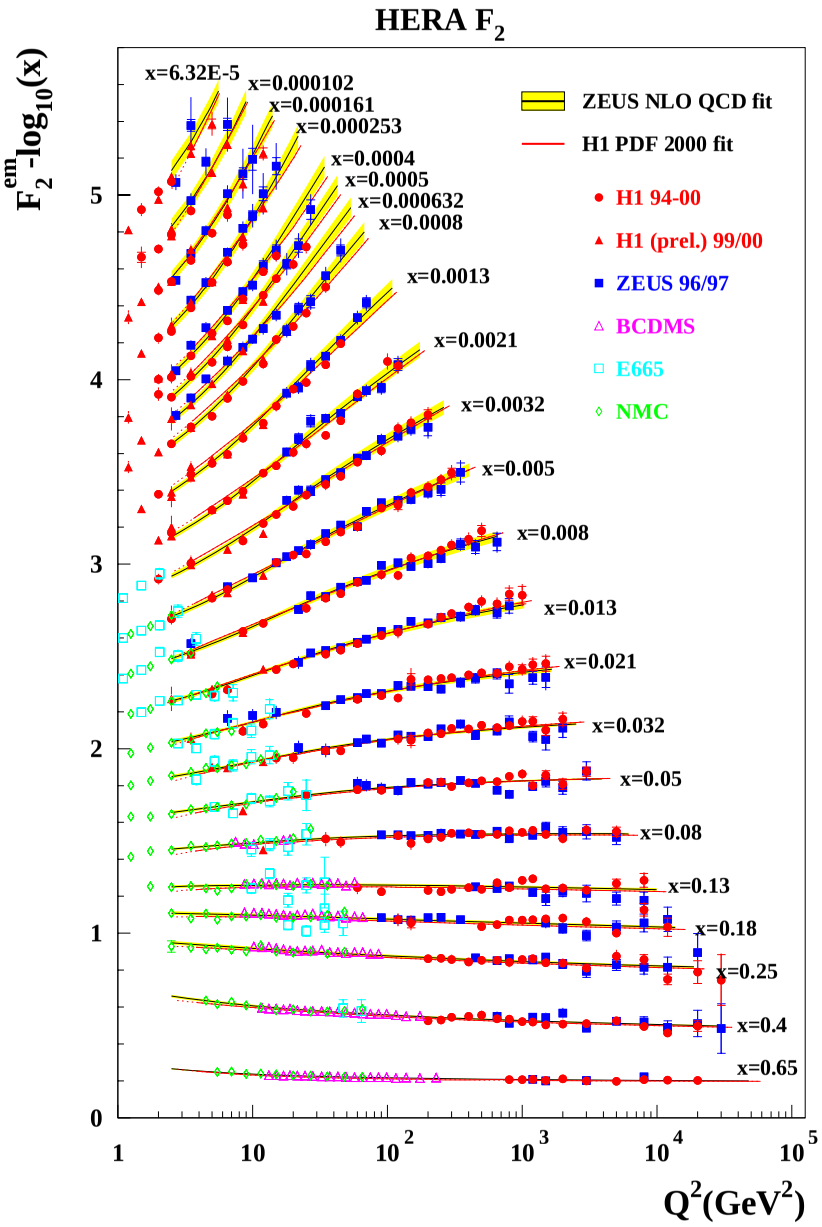
Are we sure ?

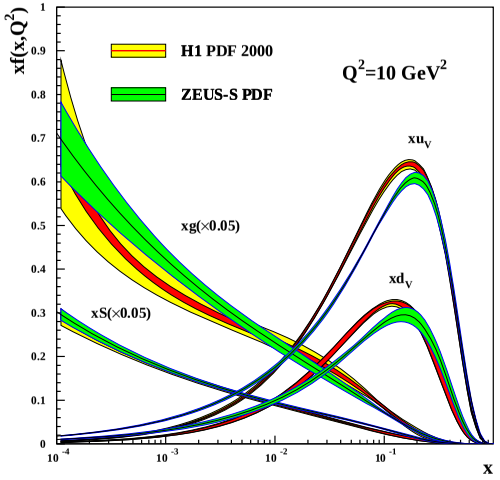


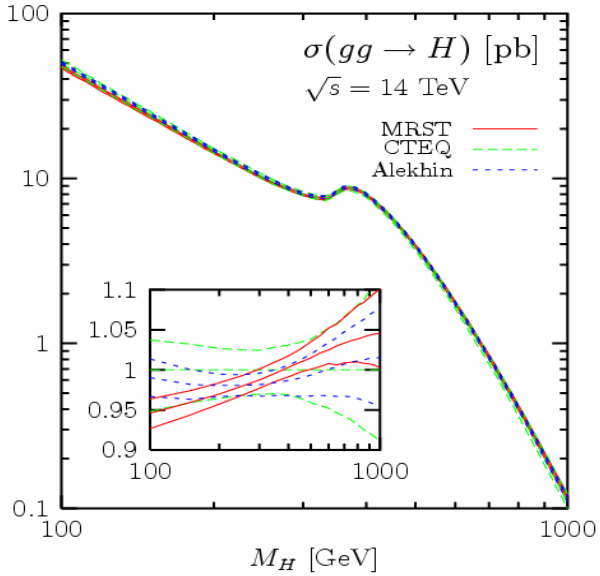
- Multiple Interactions
- Jet fragmentation properties, jet profiles
- Final state QCD radiation
- B-fragmentation

Significant effects on top mass determination
Better understand them !!!

WG1: PDFs







Simple spread of existing PDFs gives up to 10% uncertainty on Higgs cross section

⇒ we have to do better than that!

QCD Evolution of PDFs

At the LHC: momentum fractions x_1 and x_2 determined by mass and rapidity of X

HERA measurements do not cover the LHC region, eg. for central Higgs production
$\Rightarrow$PDFs evolved via DGLAP equations from (x,Q^2_0) to (x,Q^2)

Note: W,Z, Higgs production needs PDFs from the x range 10^{-4} – 10^{-1}

Is it safe?

Q. is NLO (or NNLO) DGLAP sufficient at small x? Are higher-orders $\sim \alpha_s^n \log^m x$ important? CCFM? BFKL?
Non-linear effects? Saturation?

E.g. R. Thorne: yes low-x resummations are important and can lead to >10% differences