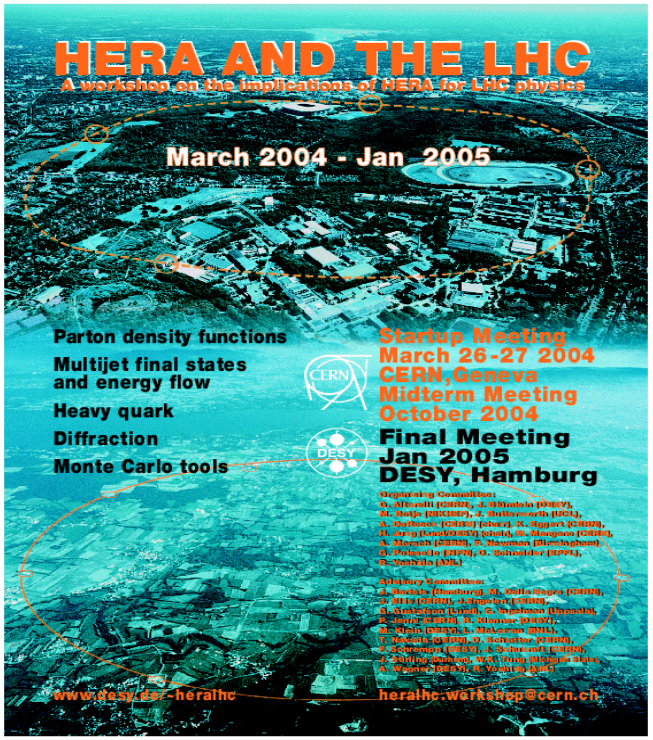
HERA and the LHC

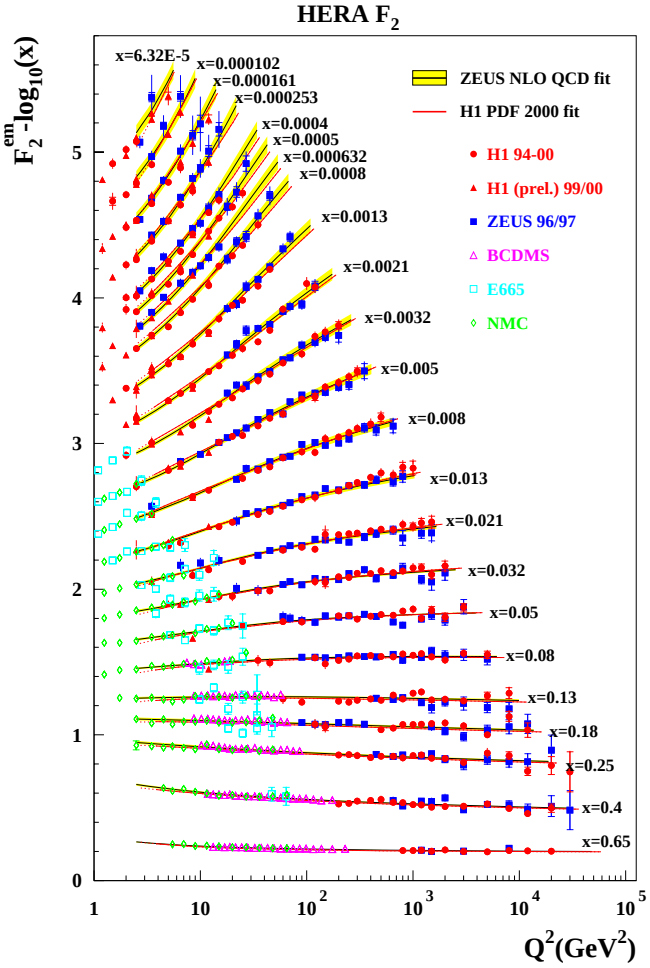
Workshop on the implication of HERA for LHC physics

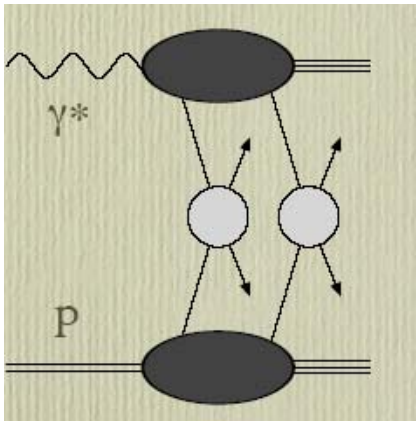


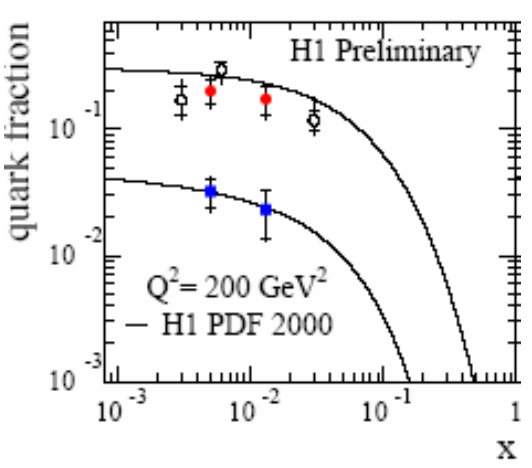
A De Roeck
CERN

- Selected Highlights of the First Workshop
- Goals for the 2nd Workshop

Examples: HERA→ LHC





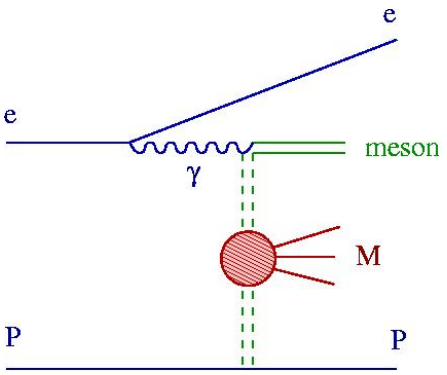


Underlying event:
tunable elementarity
of one beam particle
γp ↔γ*p collisions
LHC: event complexity

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

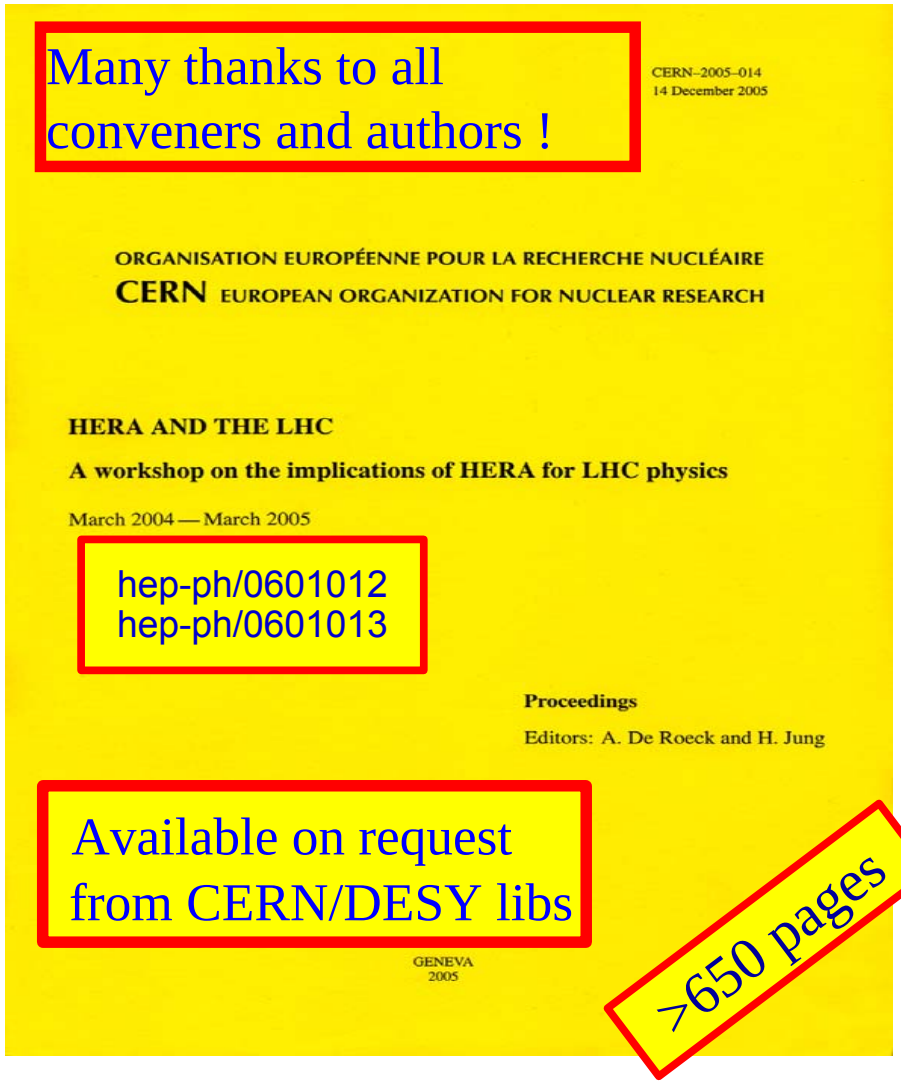
- To identify and prioritize those measurements to be made at HERA which have an impact on the physics reach of the LHC.
- To encourage and stimulate transfer of knowledge between the HERA and LHC communities and establish an ongoing interaction.
- To encourage and stimulate theory and phenomenological 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

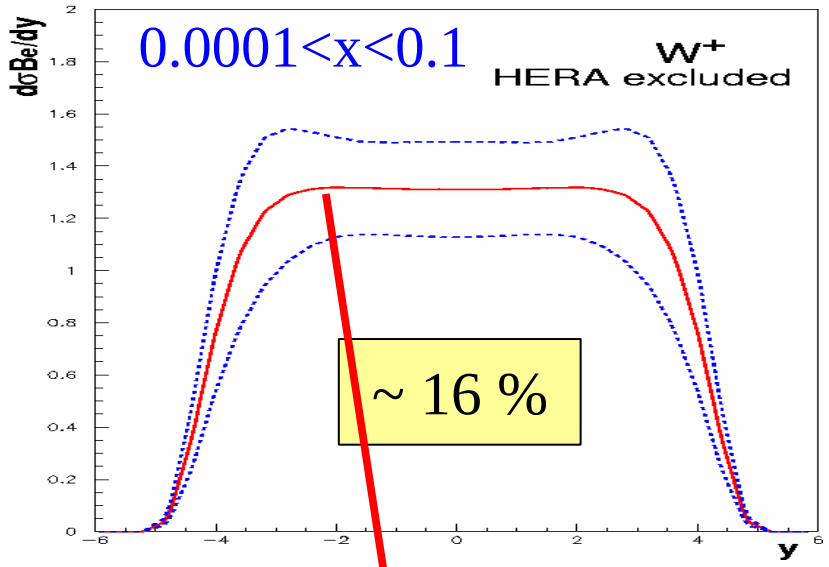
2006	CERN:	6-9 June
2007	DESY	March or May/June 07
2008	CERN	(first LHC physics?)

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

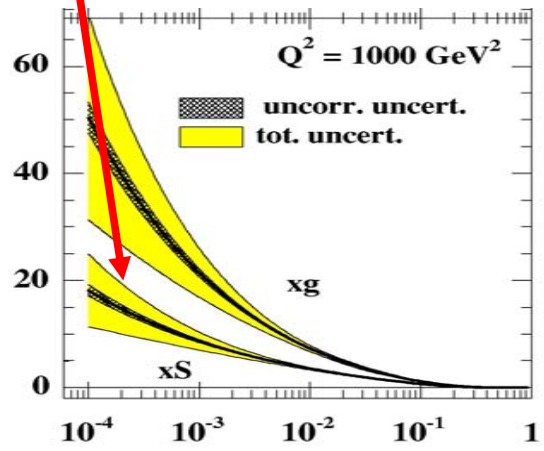
June Workshop: 17 plenary talks
80 parallel talks
150 participants

HERA Impact on the LHC

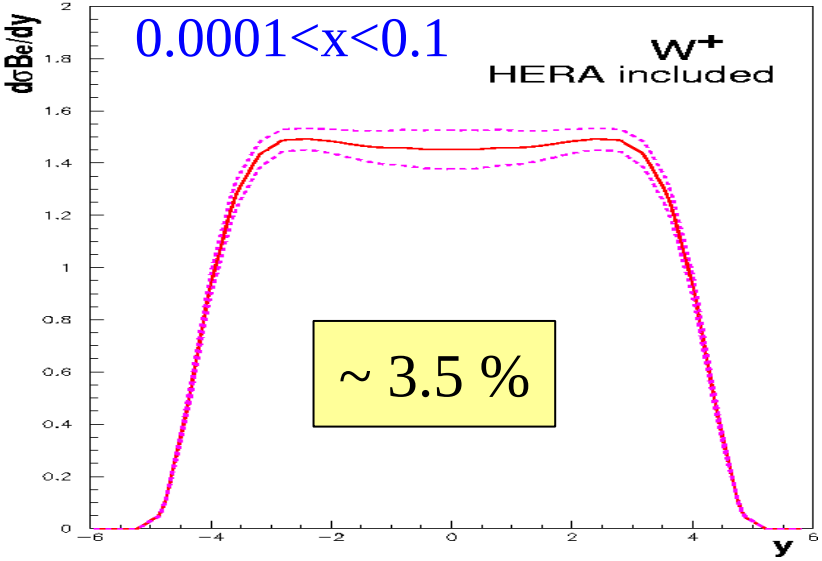
- W prod. at LHC without HERA:



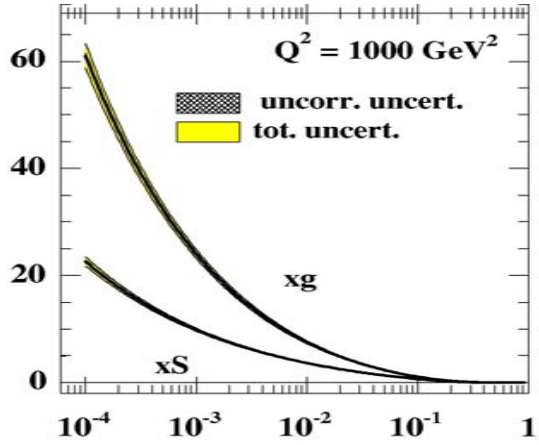
- PDFs without HERA:



- W prod. at LHC including HERA

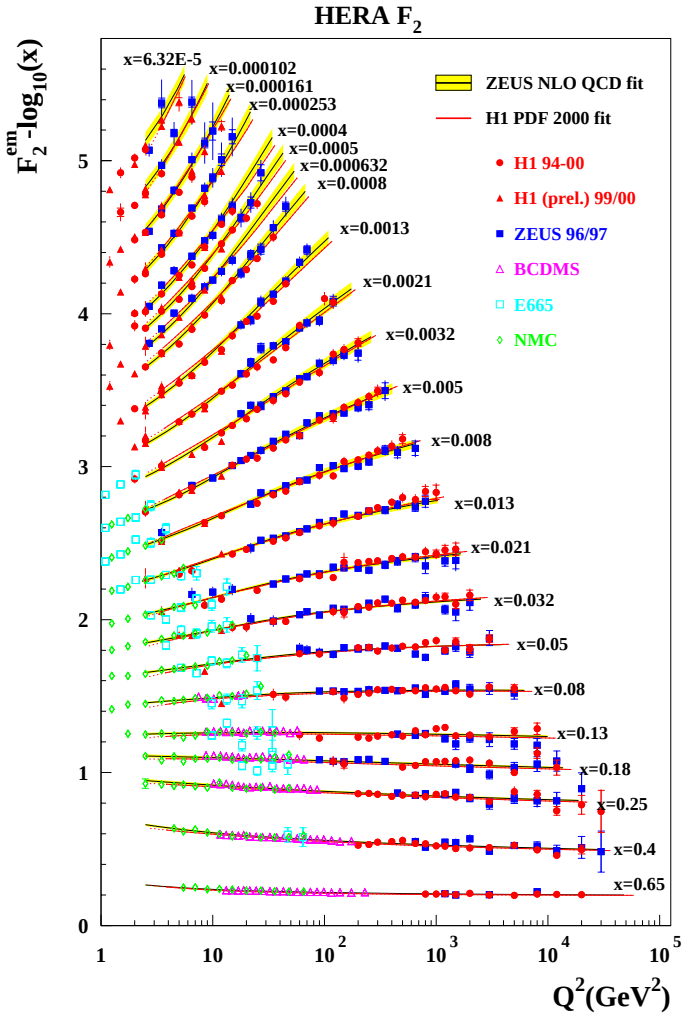


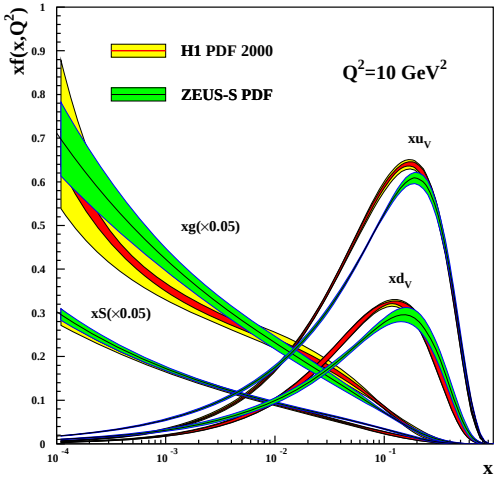
- PDFs including HERA:

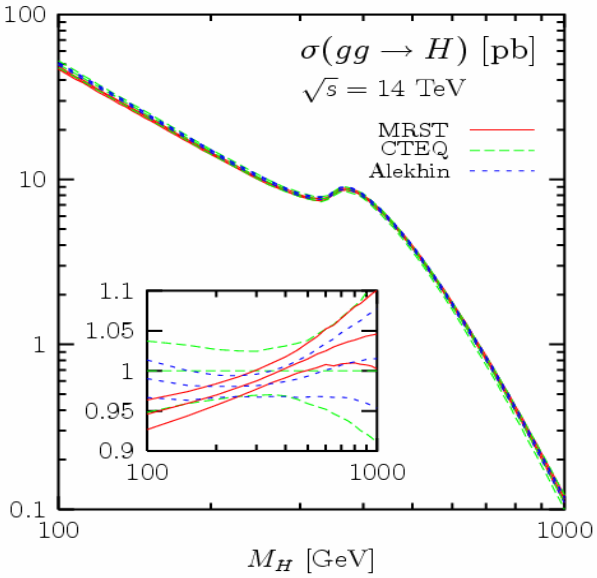


Parton Density functions

- Collinear PDFs



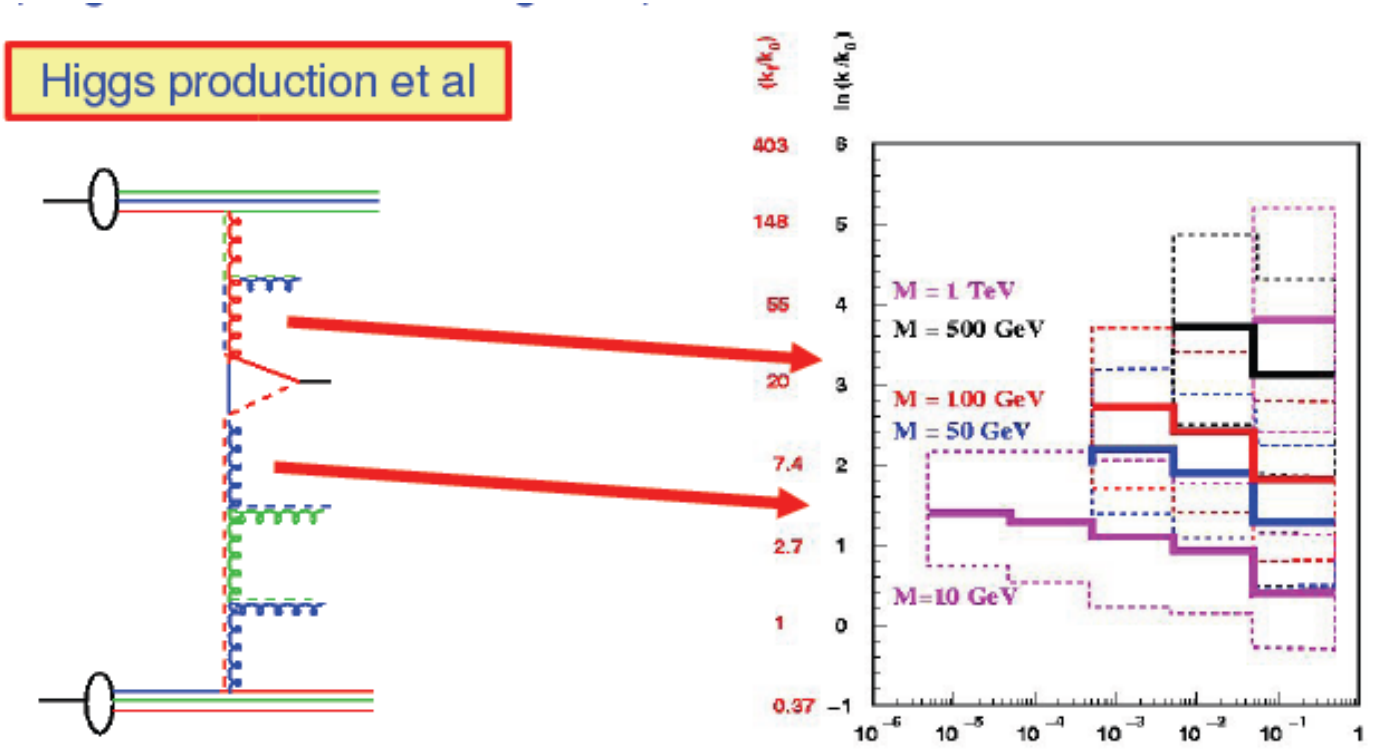




Simple spread of existing PDFs gives up to 10% uncertainty on Higgs cross section

Parton Density functions

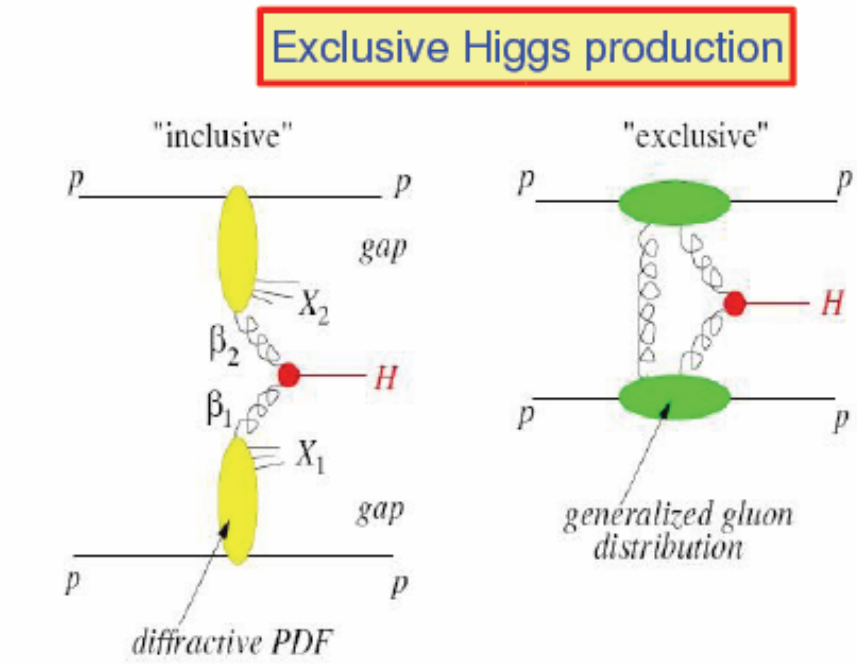
- Collinear PDFs
- Unintegrated PDFs



Large k_T effects may affect Higgs searches/measurements

Parton Density functions

- Collinear PDFs
- Unintegrated PDFs
- Difractive and Generalized PDFs

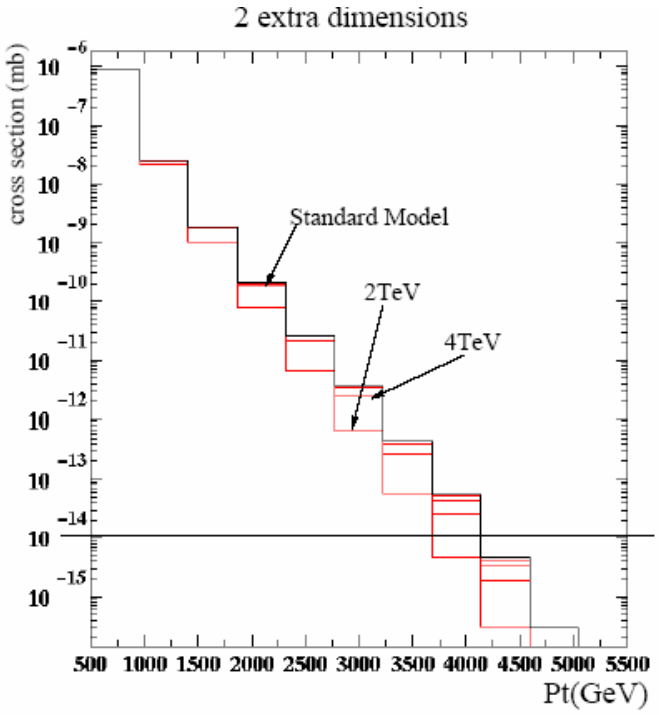


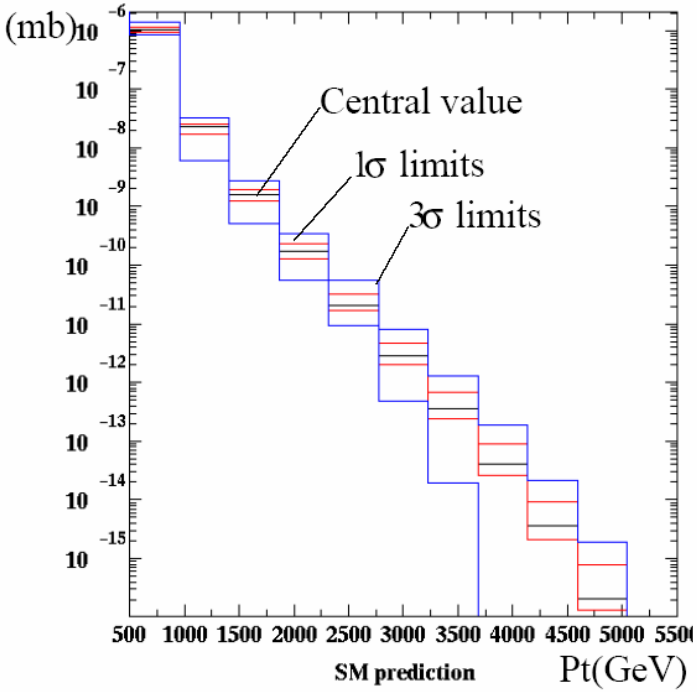
All these PDFs can be addressed at HERA via
- inclusive,
- semi-inclusive,
- diffractive,
- vector meson
- DVCS

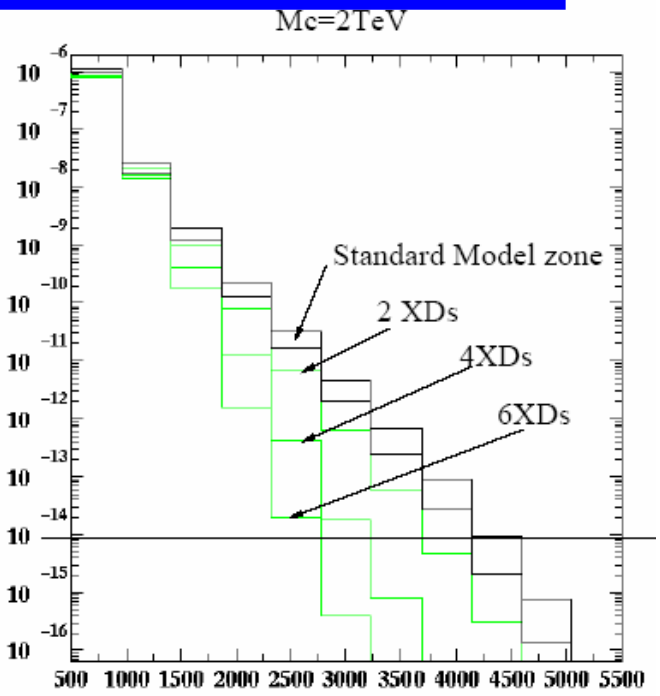
...measurements

PDFs & ADD extra dimensions: di-jet final state

Graviton exchange contributions reduce the cross section (interference)







S. Ferrag

Reduction of the sensitivity due to PDF uncertainty (CTEQ6)

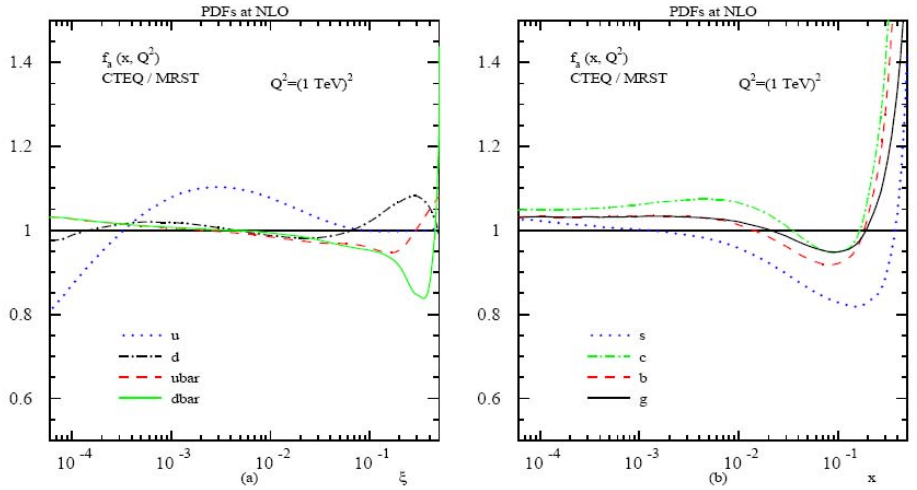
	2 extra-dimensions	4 extra-dimensions	6 extra-dimensions
Theoretically	5 TeV	5 TeV	5 TeV
including PDF uncertainties	< 2 TeV	< 3 TeV	< 4 TeV

PDFS and ADD/RS: Di-lepton final states

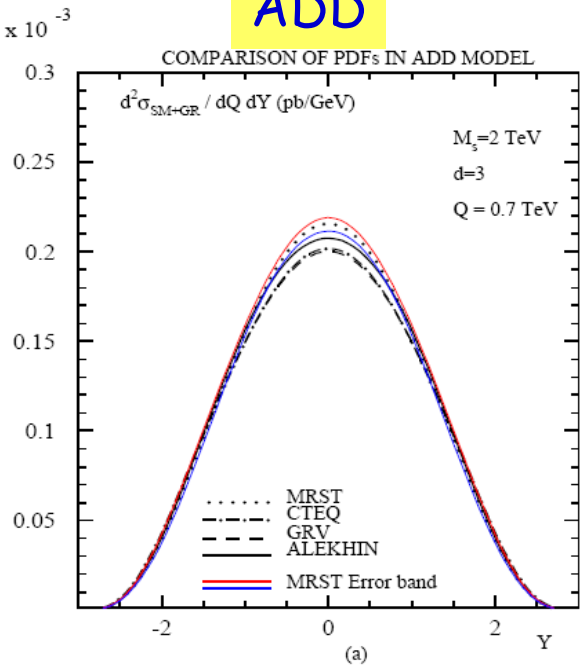
Kumar et al. hep/0604135

- Q^2 = 1 TeV → 7.5% uncertainty
- Q^2 = 1.5 TeV → 12.5% uncertainty
- Can get to >30% for large masses!

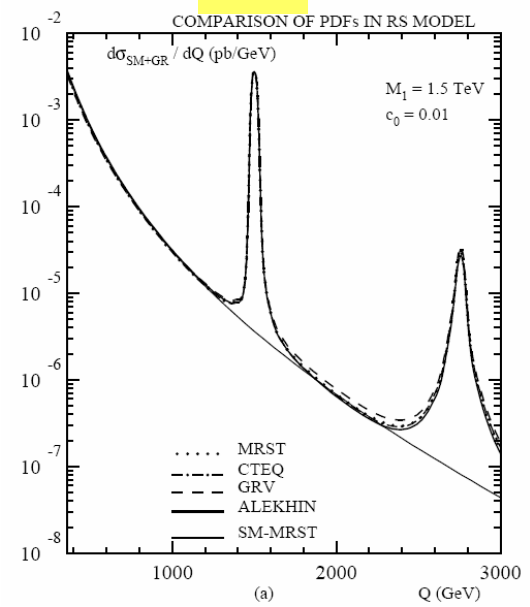
Using MRST set

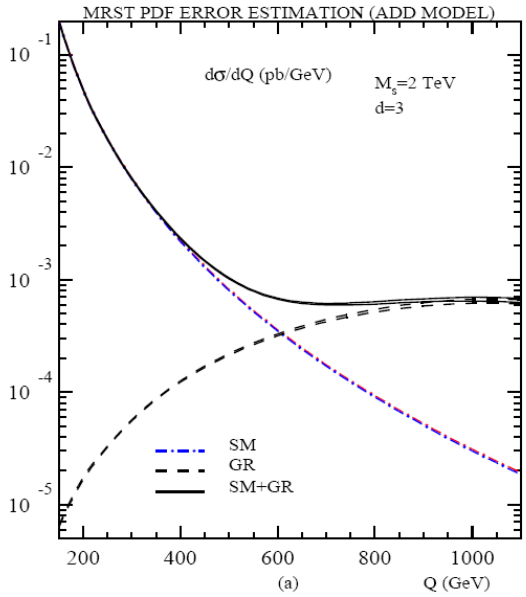


ADD

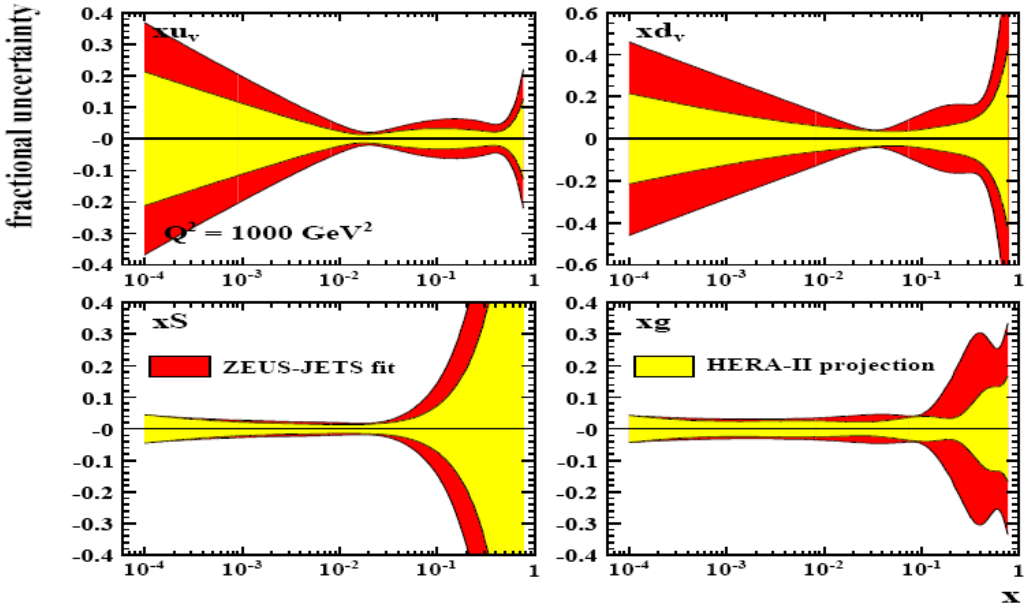


RS





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

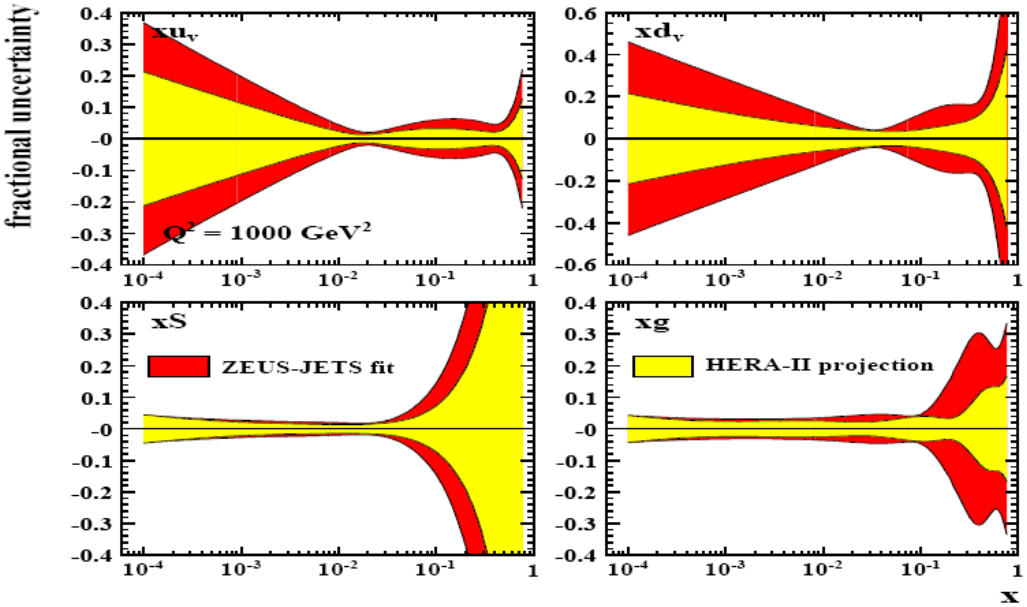
data sample	kinematic coverage	HERA-I $\mathcal{L}$ (pb^{-1})	HERA-II $\mathcal{L}$ (pb^{-1}) (assumed)
96-97 NC e^+p [7]	$2.7 < Q^2 < 30000$ GeV^2; $6.3 \cdot 10^{-5} < x < 0.65$	30	30
94-97 CC e^+p [10]	$280 < Q^2 < 17000$ GeV^2; $6.3 \cdot 10^{-5} < x < 0.65$	48	48
98-99 NC e^-p [8]	$200 < Q^2 < 30000$ 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

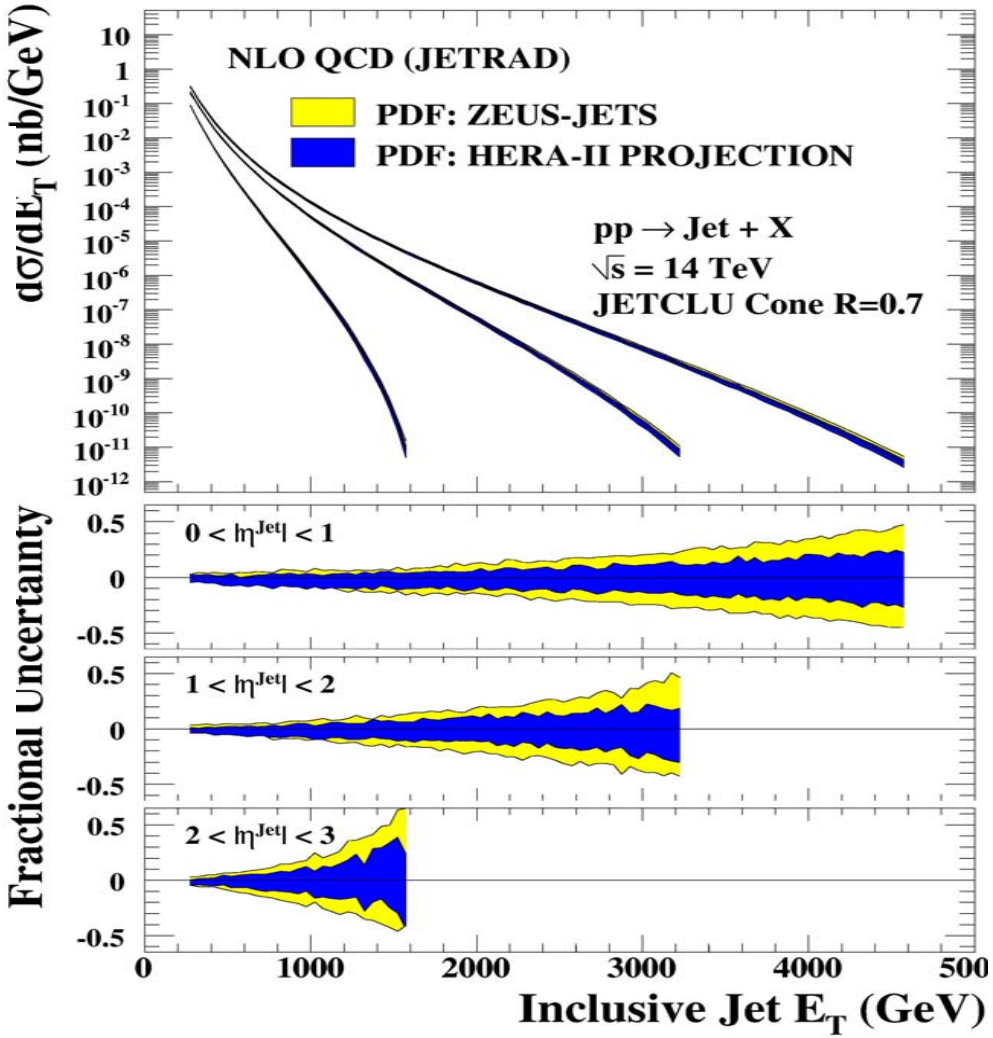
Using jets together with F_2 (at large Q^2)

quark and gluon uncertainties



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

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

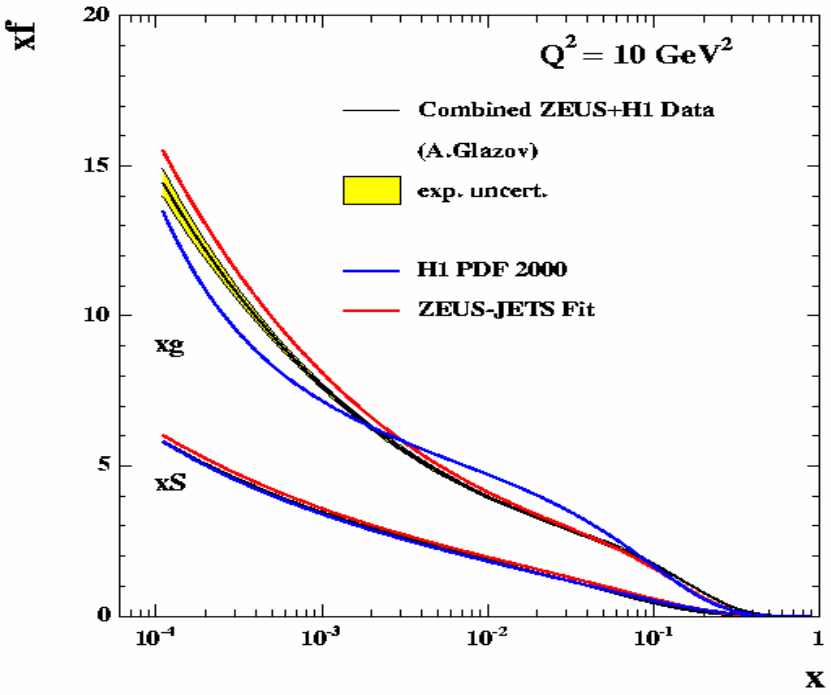


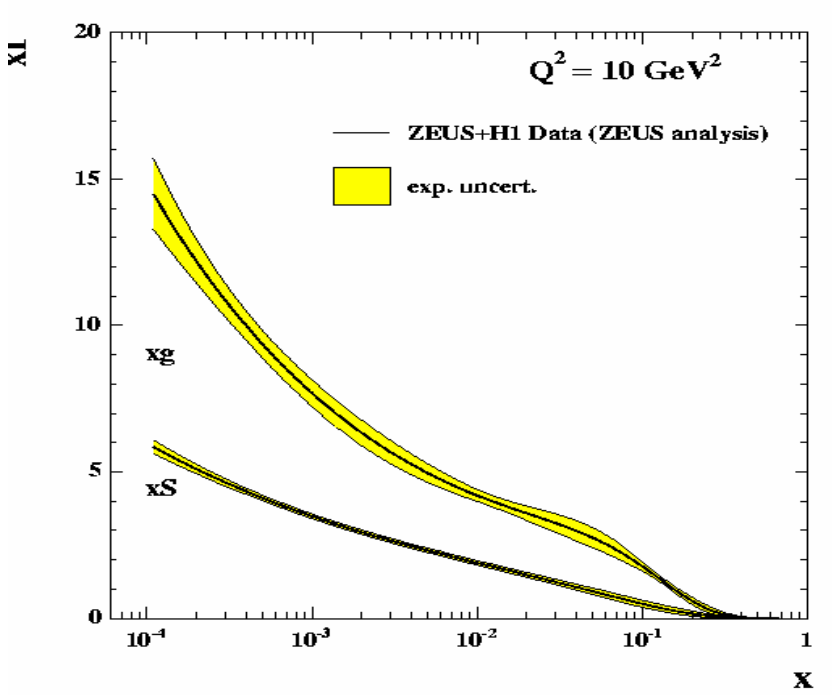
Error on LHC jet xsection reduced !!!

Average HERA data

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

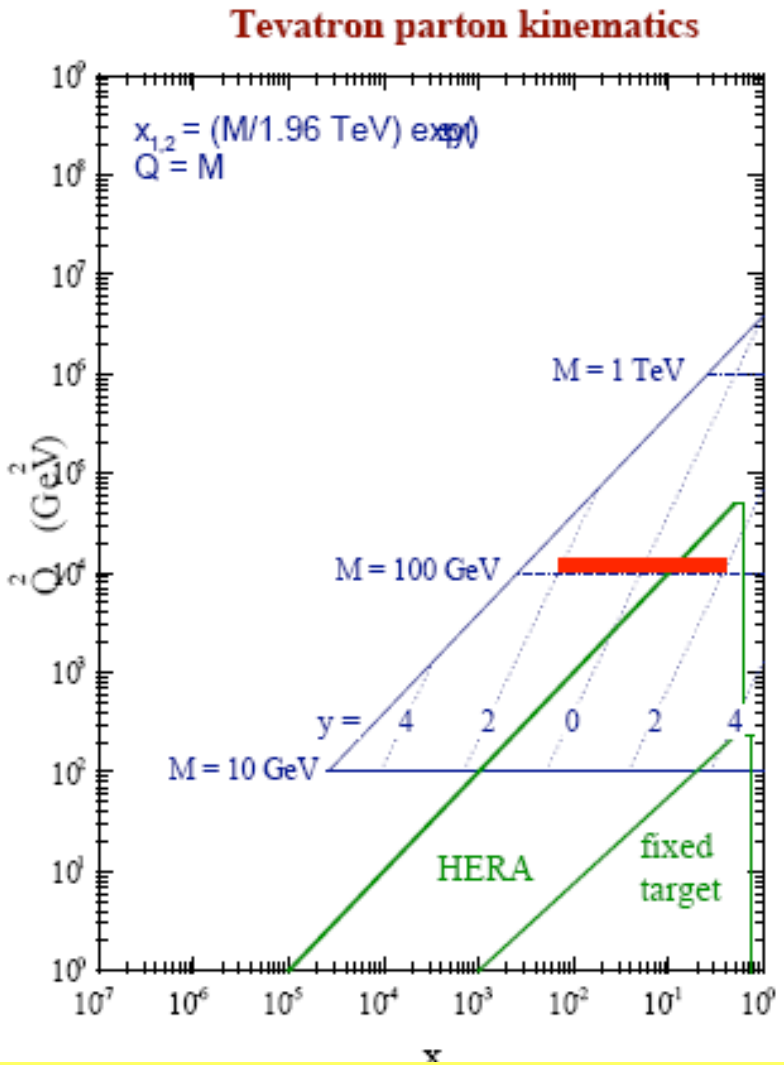
- Average H1&ZEUS data sets
- Combined PDF fit to H1& ZEUS

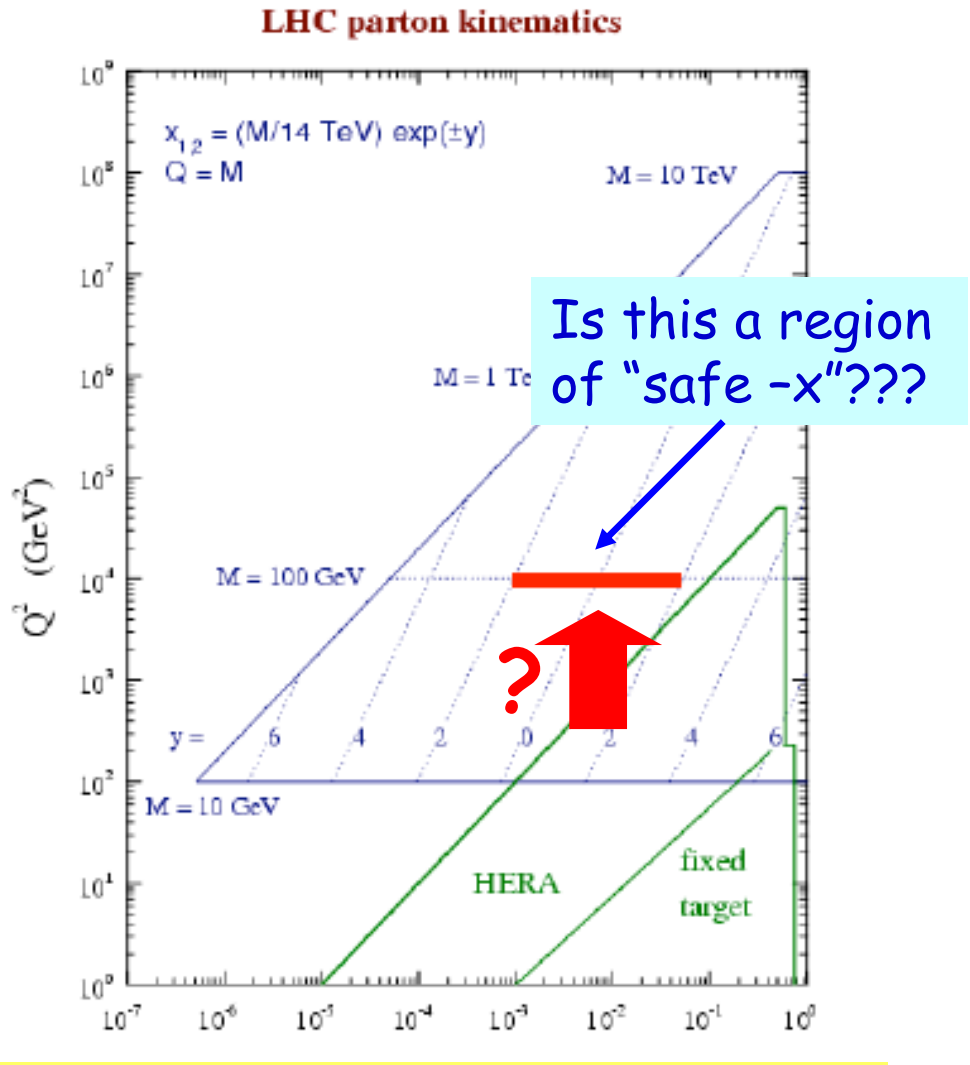




Much reduced uncertainties ....
Model independent analysis of data desirable
get THE HERA – PDF !!!!!

LHC Kinematics/QCD evolution

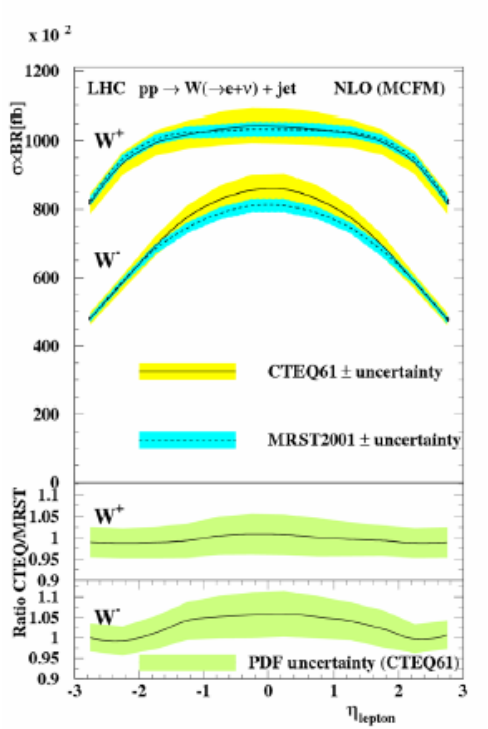


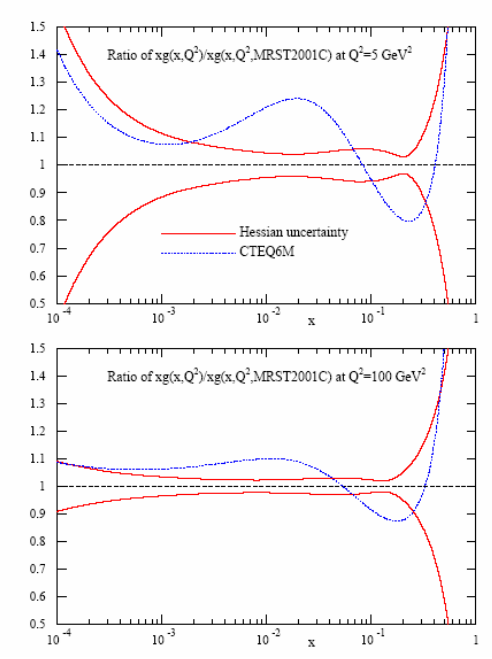


Evolution of PDFs to high Q2 & low x important at the LHC
Precision? Level of approximation? CCFM/BFKL?, non-linear effects?

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)

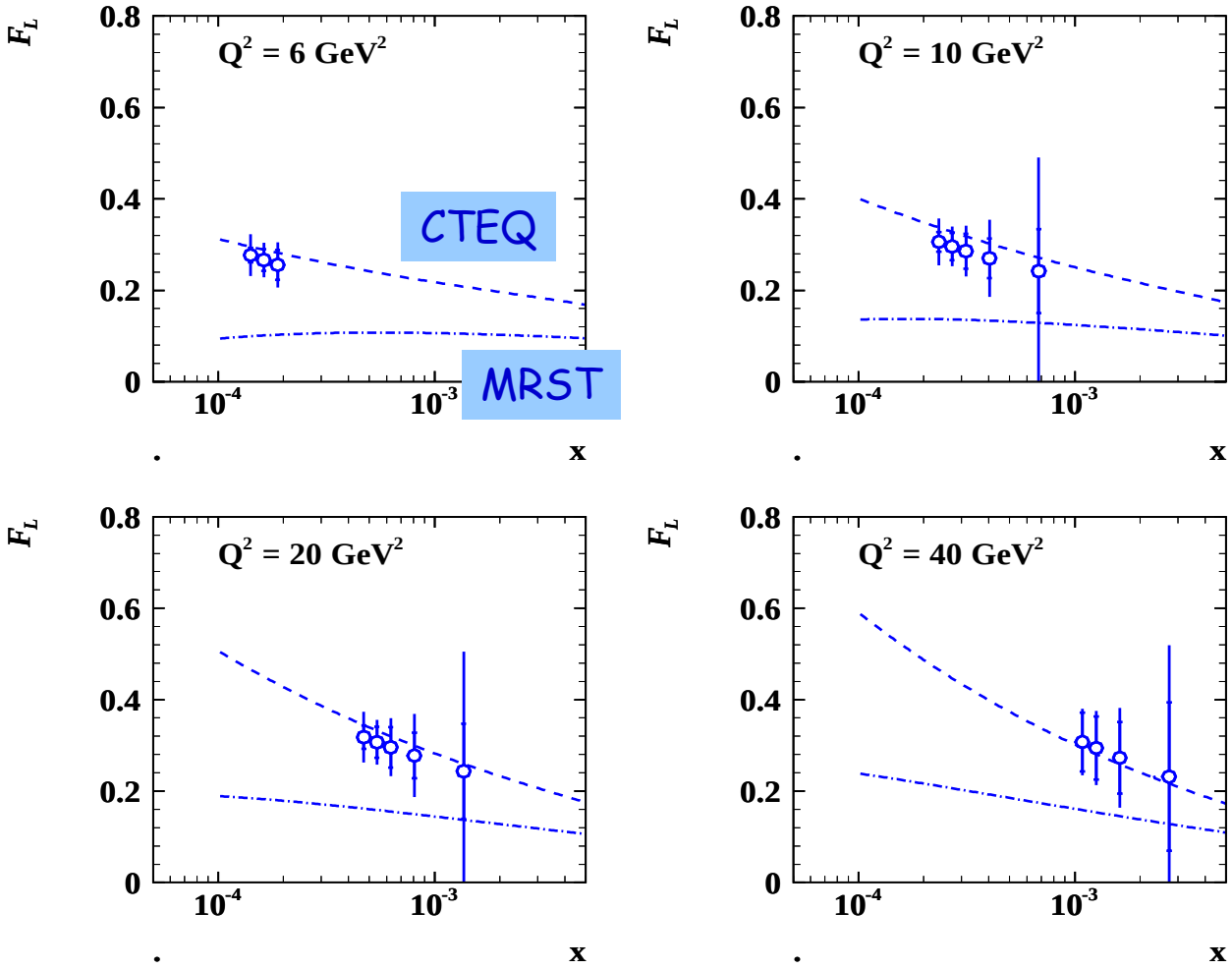
$$\sigma_r = F_2 - y^2/[1+(1-y)^2]\cdot F_L = F_2(x,Q^2) - f(y)\cdot F_L(x,Q^2)$$

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



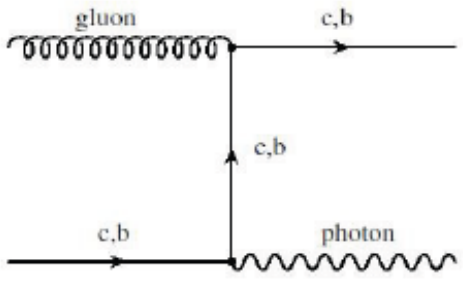
F_L can referee between MRST and CTEQ gluons

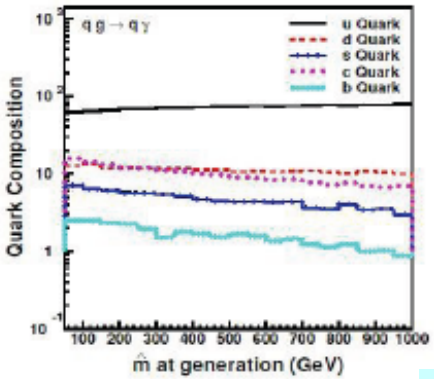
F_L is gluon driven

F_L measurement at HERA in 2007 !

PDF determination at LHC

- charm quark PDF





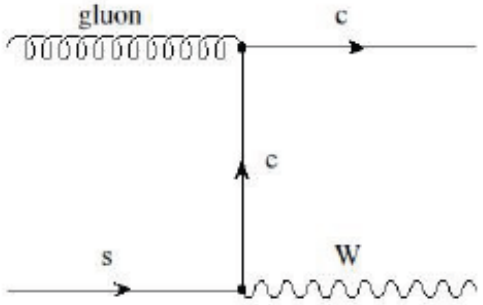
K. Mazumdar et al

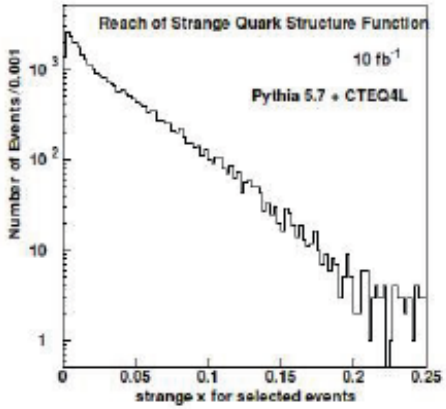
- ➔ ~ 10^5 c+b events in 10 fb^{-1} with p_t^{muon} >10 GeV
- ➔ x_c,x_b probed in $0.05<x_c,x_b<0.1$ with 10% stat.accuracy

Also W-W+ spectra, jets, photons,... See Eg. M. Cooper-Sarkar et al.

- ~ 20% of these γ+jet events are from $gc/b \to \gamma c/b$.
- Select semileptonic decays of heavy mesons in γ+jet events

- strange quark PDF

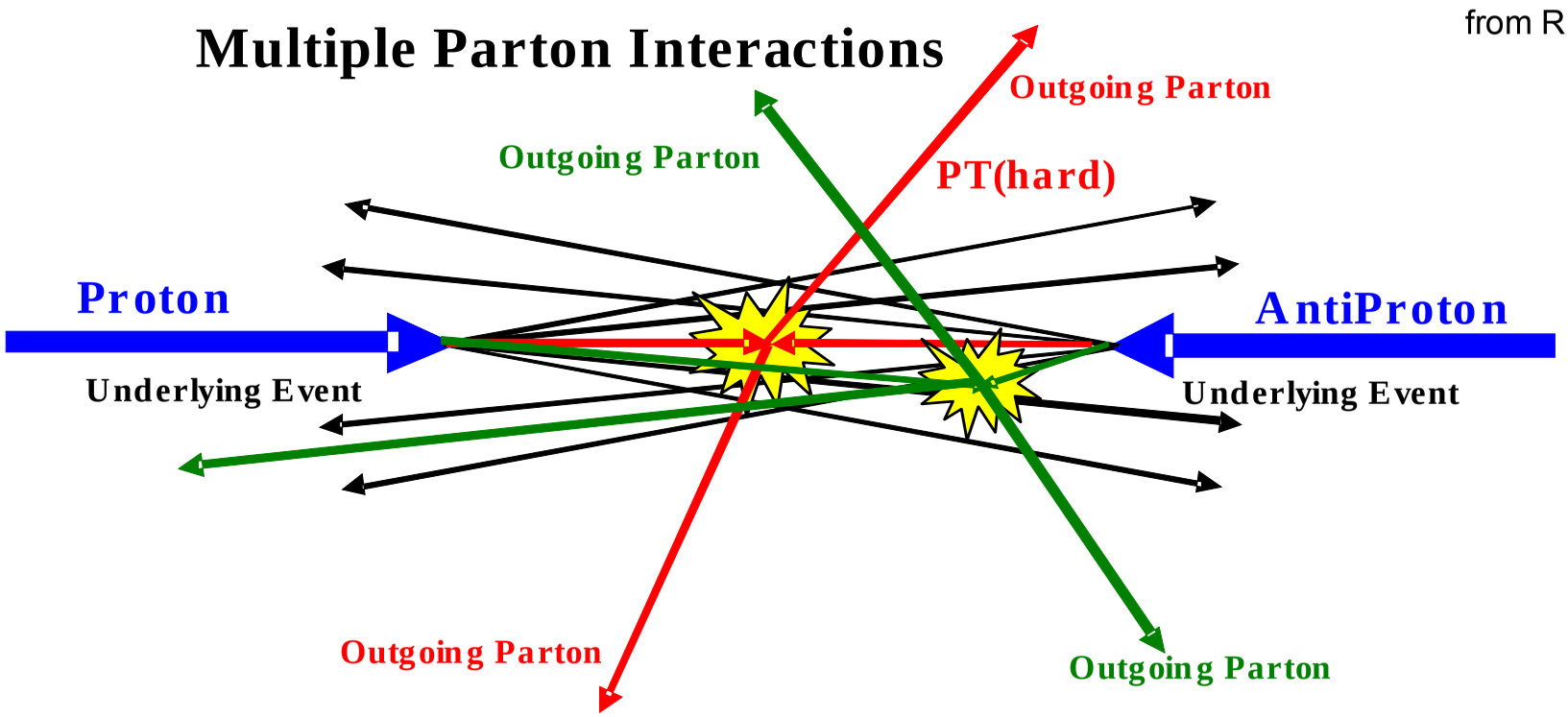




- ➔ x_s ~0.1 for 10 fb^{-1} with 10% stat. accuracy
- need u,d uncertainties
- simulation of final state including frag.fct and PS

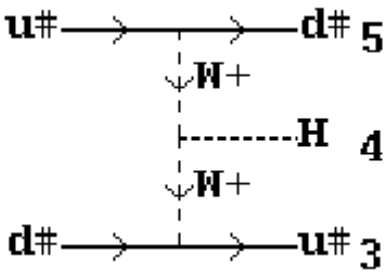
- WG1 convenors: Should form a "group" from ATLAS, CMS, LHCb, ALICE, H1, ZEUS and theoretical PDF experts

Underlying event/multiple interactions



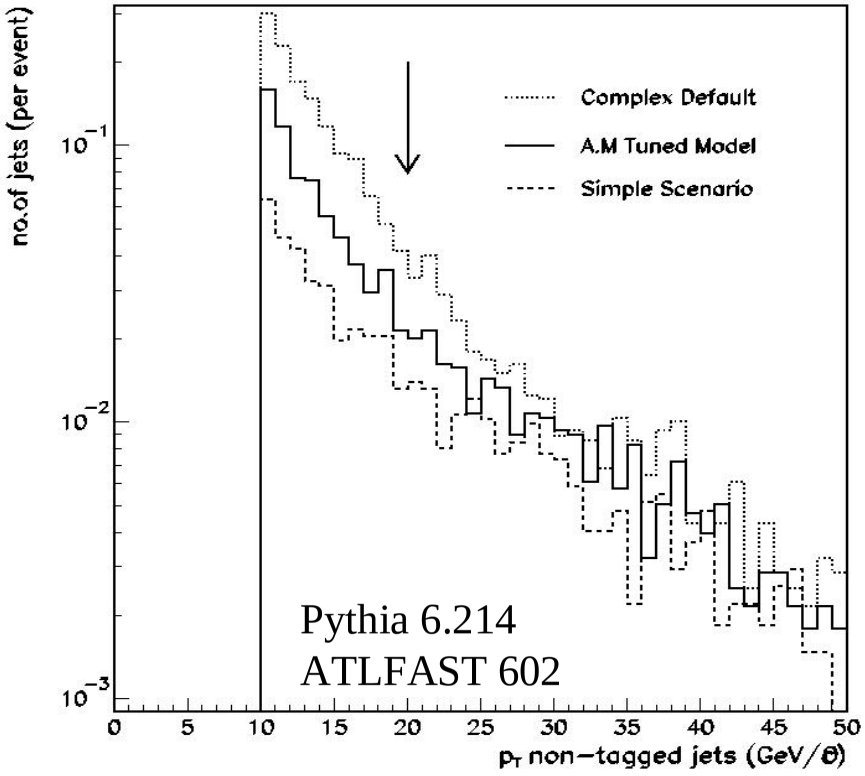
- Studies and tunes made on Tevatron/lower energy data
- ⇒ Do the Tevatron tunes work for HERA?
- New models on the market that should be tested (new Pythia, Jimmy, Sherpa)

Effect of underlying event on central jet veto in VBF Higgs

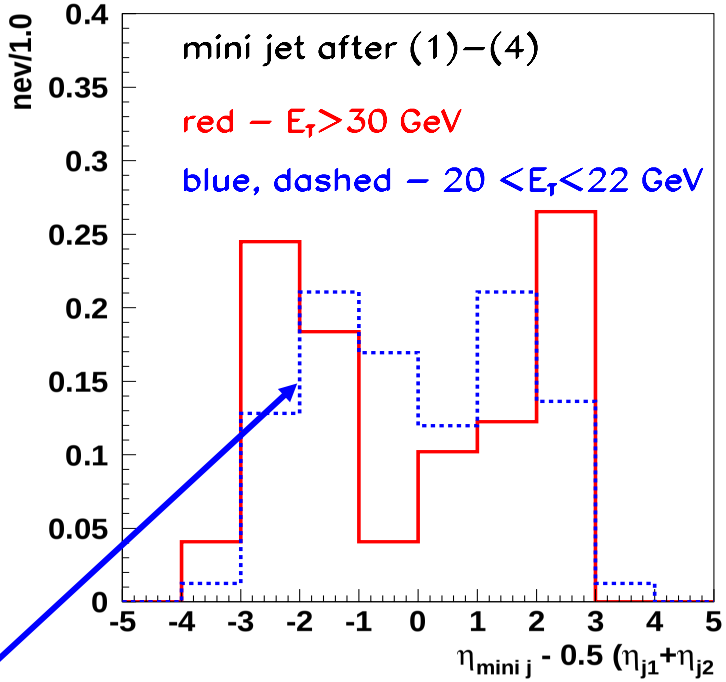


H->WW*->2l in qqH prod.

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



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



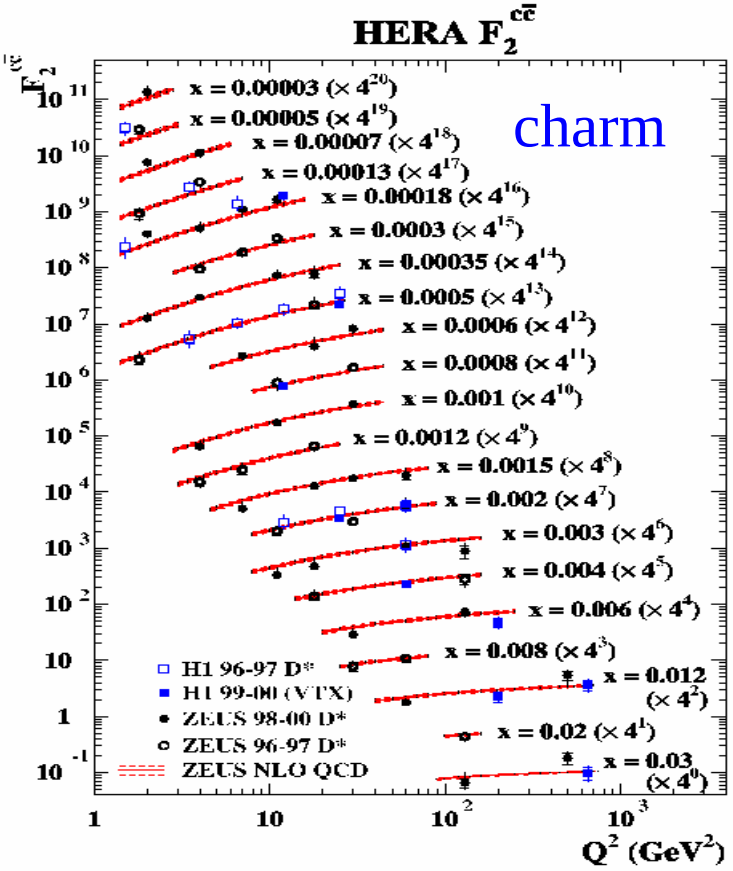
Model	CJV efficiency	Significance
Default pythia	85%	8.2
Default DG	75%	7.7
AM tuning	79%	7.9

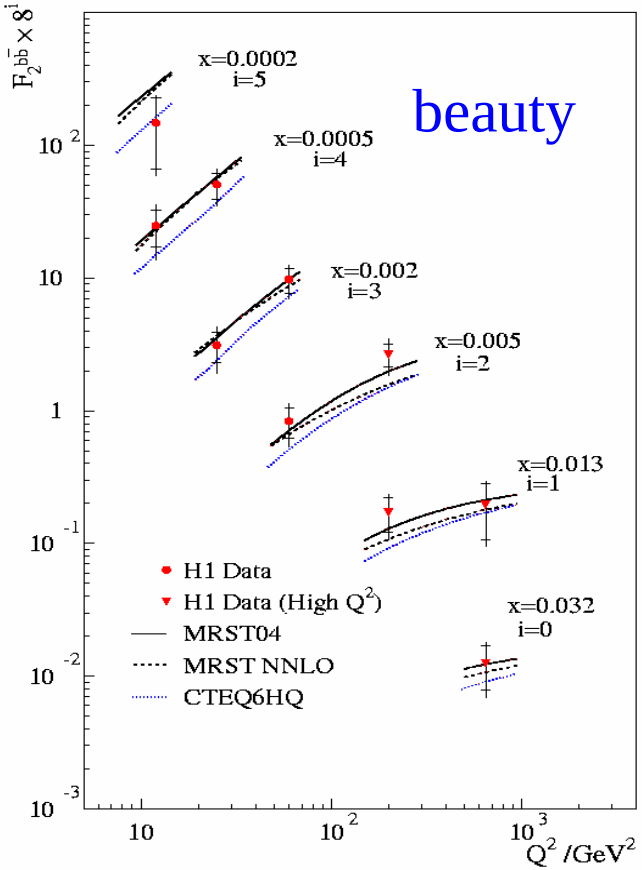
"bkg. like" behaviour for soft jets; fake jets: pile up+UE+detector

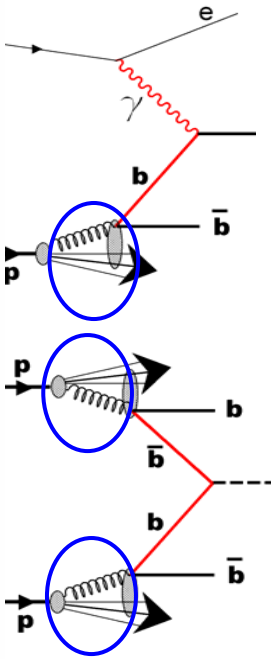
HERA: Heavy Quark PDFs at large Q^2

- Current H1 (HERA I) analysis

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







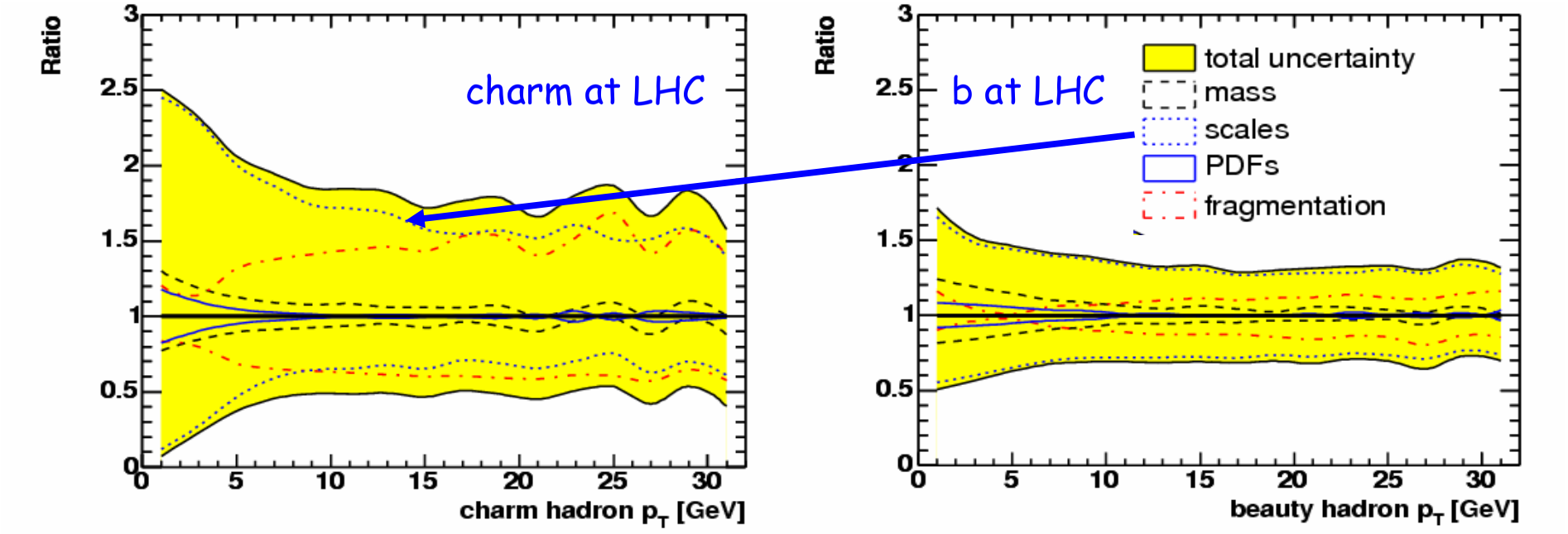
- HERA II analysis (expect factor 10 more), larger kinematic range

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

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

Uncertainties in Heavy Quark production

A. Mitov



Leading uncertainties are:

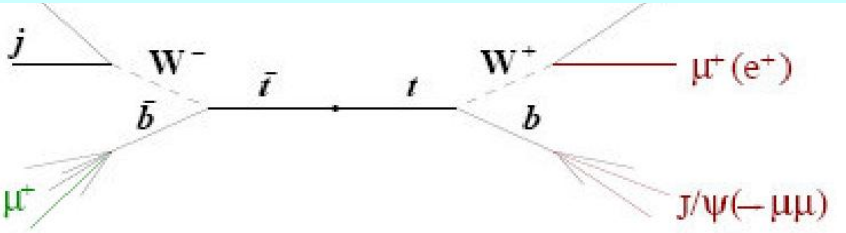
scales & fragmentation

Can these uncertainties be reduced ?

pert. corr. known to NLO. NNLO is hard, but feasible (work started...)

fragmentation is presently refined at NLL level

- Important also for top mass measure: B-meson and lepton



NON-Linear QCD effects at the LHC

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

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

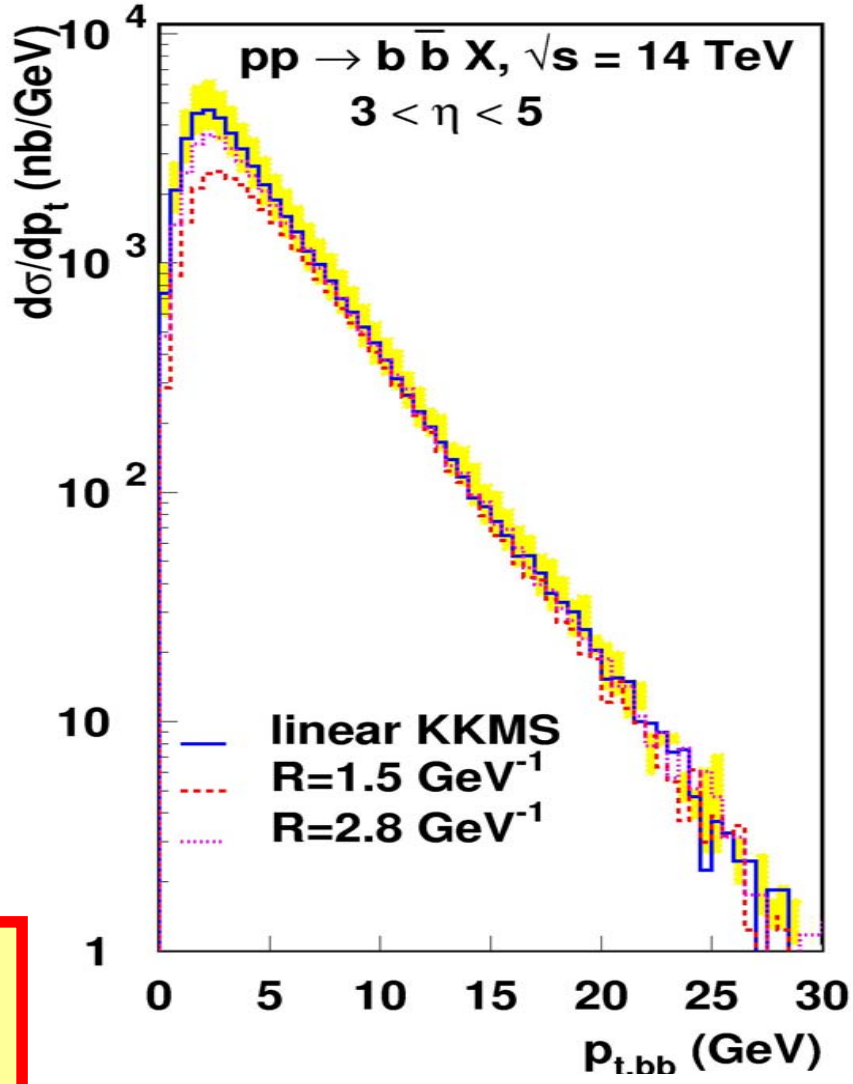
$$\tilde{f}^{(0)}(x,k^2) \longrightarrow \text{input}$$

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

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

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

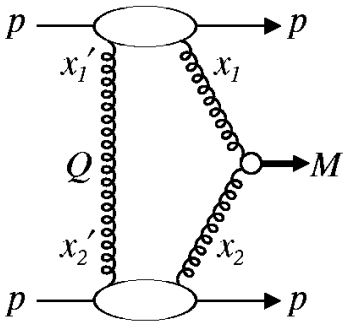
Bottom suppression due to non-linear effects in BK

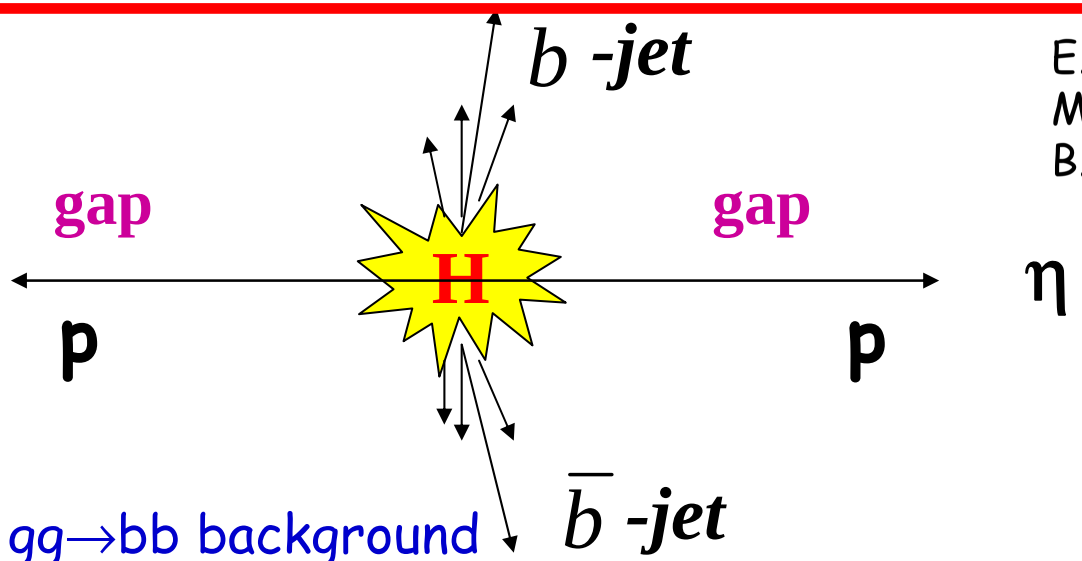


- Significant effects…
- up to factor of 2 in hot spot scenario
- factorization still ok ?

Exclusive Higgs Production

Exclusive diffractive Higgs production pp→ p +H+ p : 2-10 fb SM
Cross section 'stabelized' during the previous workshop 10-100fb MSSM



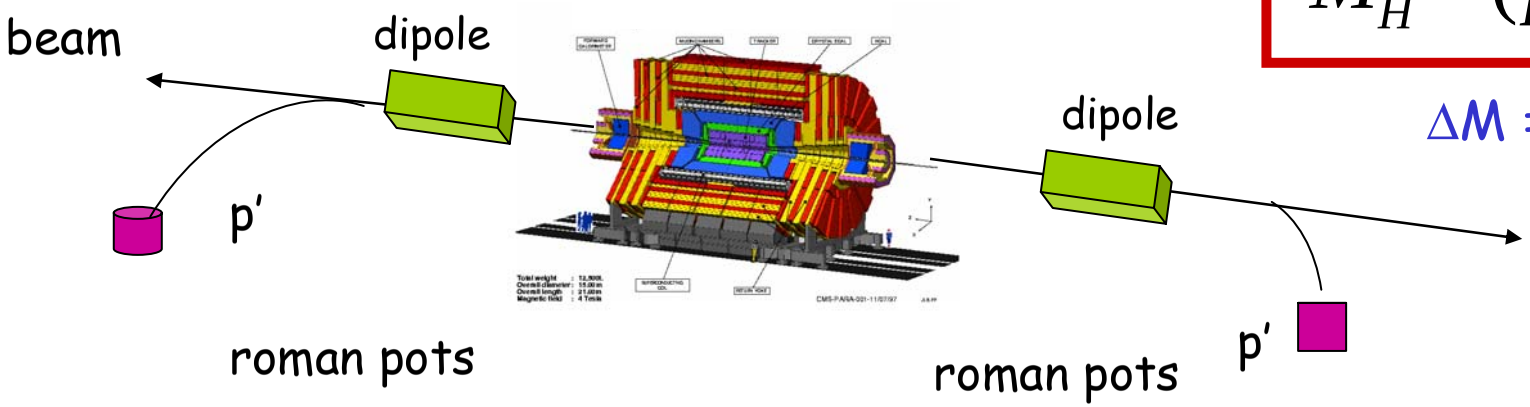


E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. ...

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

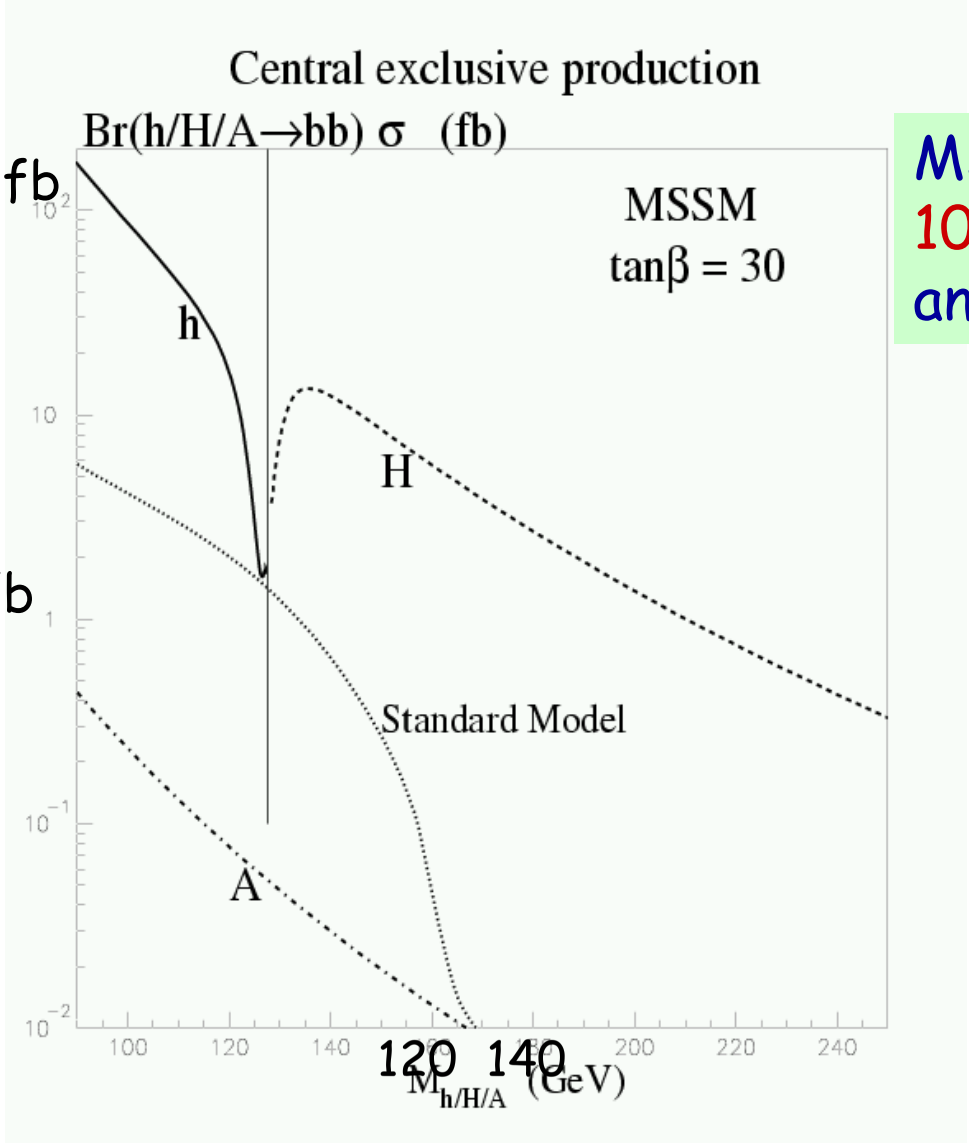
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



P. Landshof:
Cross sections
can be higher!

Central Exclusive Production



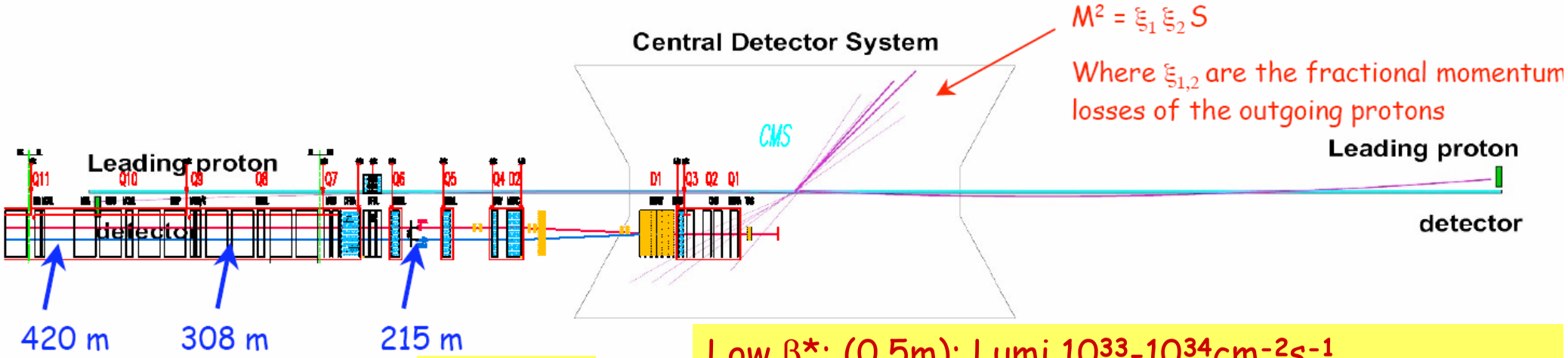
MSSM Higgs/high tanβ: (30fb^{-1}) ⇒ 100-200 signal events (after cuts) and O(10) background events

Kaidalov et al., hep-ph/0307064

⇒Study correlations between the outgoing protons to analyse the spin-parity structure of the produced boson

A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC

Detectors for Exclusive Higgs Production



$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons

FP420

TOTEM (ATLAS)

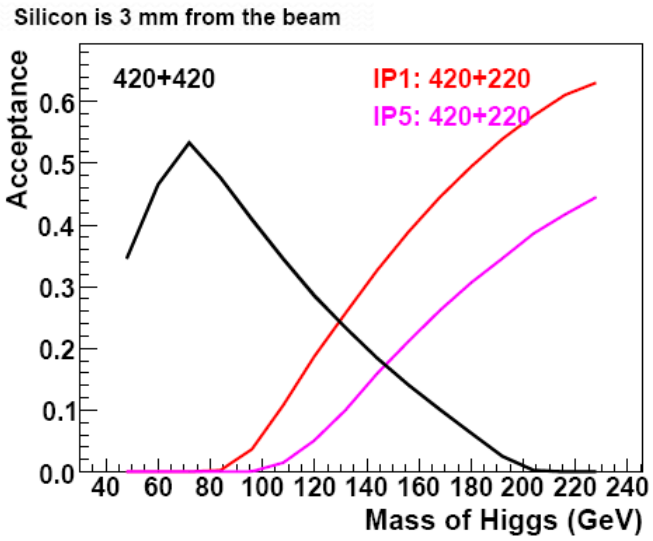
Low β^*: (0.5m): Lumi 10^{33}-10^{34}cm^{-2}s^{-1}

220m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.02$

RPs in the cold region/needs cryostat redesign

Detectors at 420 are needed to access the low ξ values for low Higgs mass acceptance



FP420 R&D Project

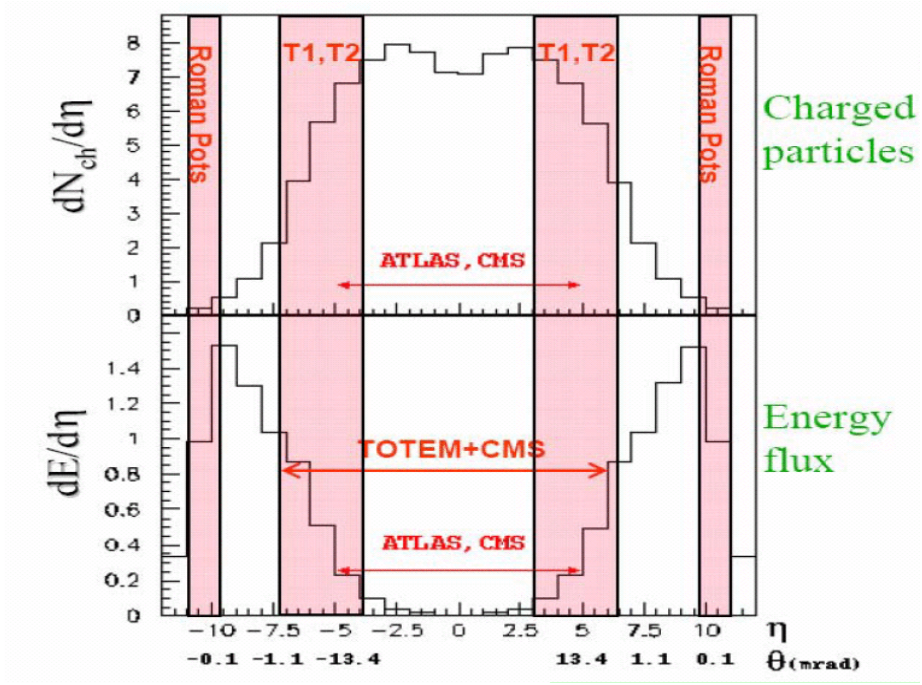
http://www.fp420.com

Contacts: A De Roeck/B. Cox

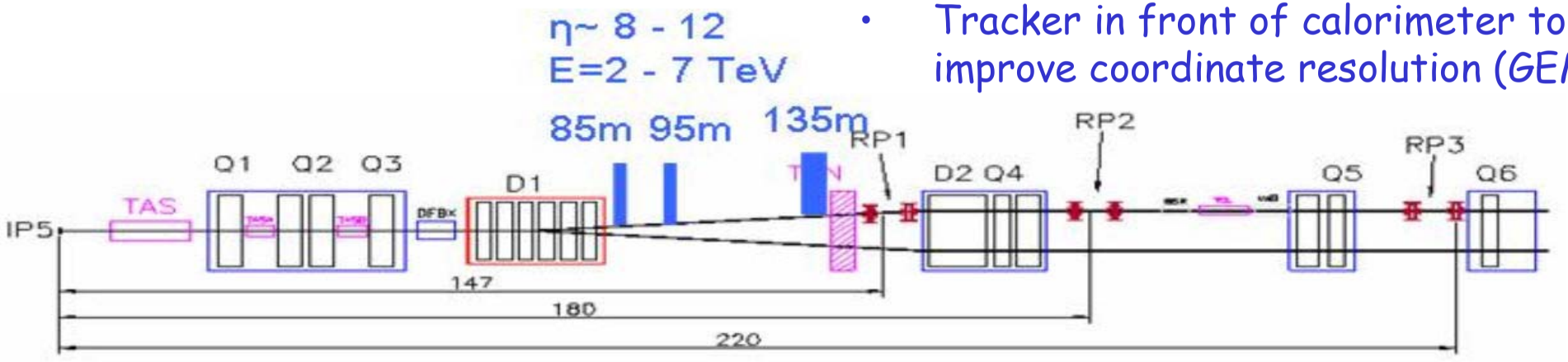
- Problem: 420m to late for CMS/ATLAS L1 trigger. Trigger on central activity

Ideas for upgrading forward region

V.Andreev, A.Bunyatyan, K.Borras, HJU, M.Kapishin, L.Lytkin
R. Orava, J. Lamsa



- Idea to fill gap in rapidity with calorimeter at 135 m in front of TAN (E ~ 2.0 - 5.5 TeV and pseudorapidity range 8 – 12)
- Beamline simulation performed
- Pseudorapidity resolution ~ 0.25-0.5 (depends on the selected energy rapidity range)
- Radiation level near the calorimeter at 135 m is reasonable (from studies of ZDC)
- Tracker in front of calorimeter to improve coordinate resolution (GEM)



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 MC4LHC 2003 workshop , concerning validation

  $\Rightarrow$A new MC4LHC workshop this summer 2006: July 17-26

Nutshell: Results from HERA/LHC I

- 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…

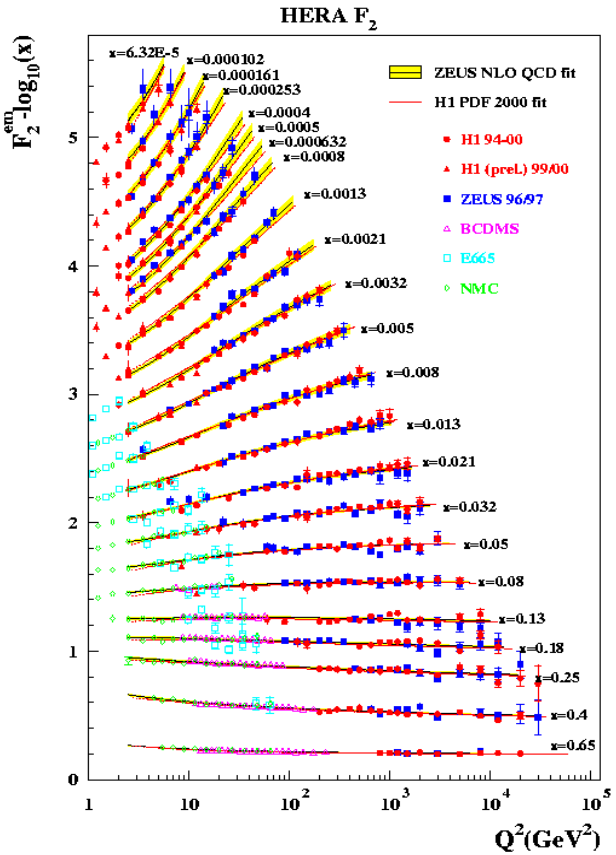
HERA/LHC II: what does LHC need?

- PDF determination:
  - Best possible PDF. Ultmate expected precision? Impact on LHC measurements?
  - Uncertainties on the PDF and QCD evolution
  - Special PDFs? Diffractive, unintegrated, generalized…
- Event topologies:
  - Multiple Interact./Underlying Events: understanding the physics/uncertainties
  - Higher Order Corrections/verified on HERA data
- Reliable Simulations/ Theory/Models
  - tuning of free parameters to many different measurements
  - improved calculations/NLO libraries
  - test alternative approaches (SCET?)

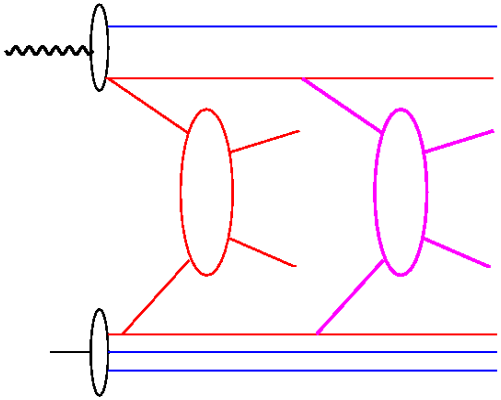
Keywords: tools, phenomenological progress, and quantitative estimate for the impact of HERA on LHC measurements

Goals for HERA/LHC II

Working Groups of the workshop

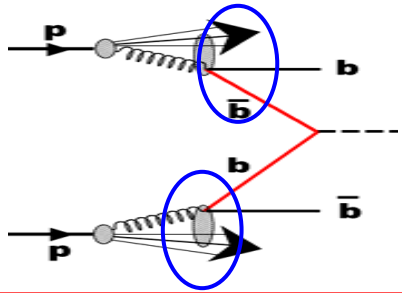


Structure functions and parton distributions
S. Forte, S. Moch,
M. Dittmar, A. Glazov
M. Botje

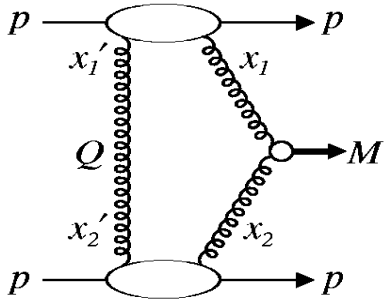


Multijets & final states
Underlying events, un-integrated pdfs
L. Lonnblad, G. Zanderighi,
C. Gwenlan, N. Tuning,
S. Banerjee, Ch. Risler, D. Traynor

MC - Tools
S. Gieseke, F. Krauss,
T. Kluge, P. Bartalini,
P. Robbe, S. Chekanov



Heavy quarks:
B quark pdfs of the proton, fragmentation fct, u-pdfs
M. Cacciari,H. Spiesberger,
A. Dainese, A. Geiser,
K. Lipka,U. Uwer

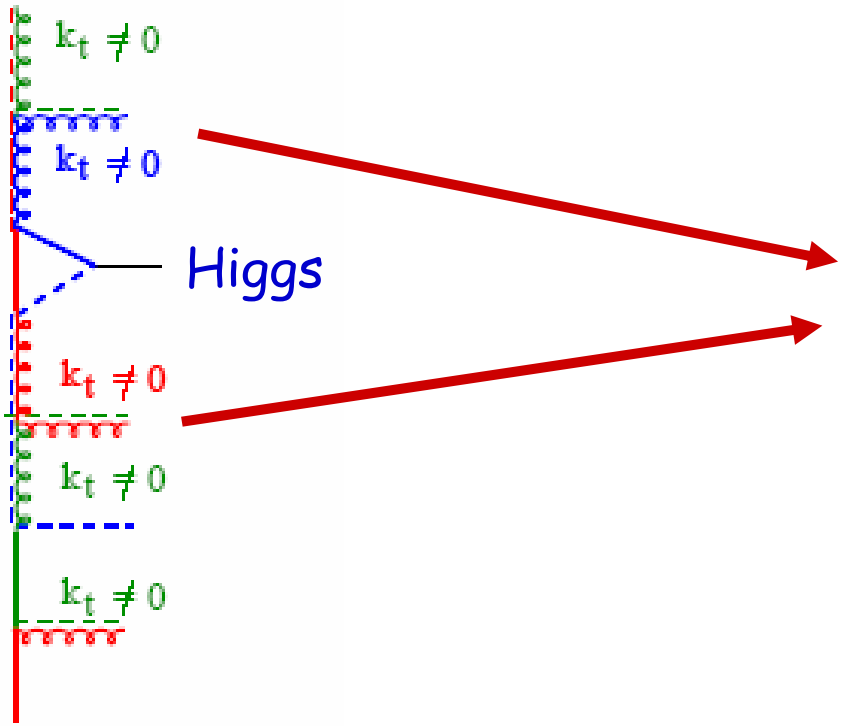


Diffraction
M. Diehl, V. Khoze
M. Arneodo, P. Newman,
A. Bruni, B. Cox, R. Orava

Backup

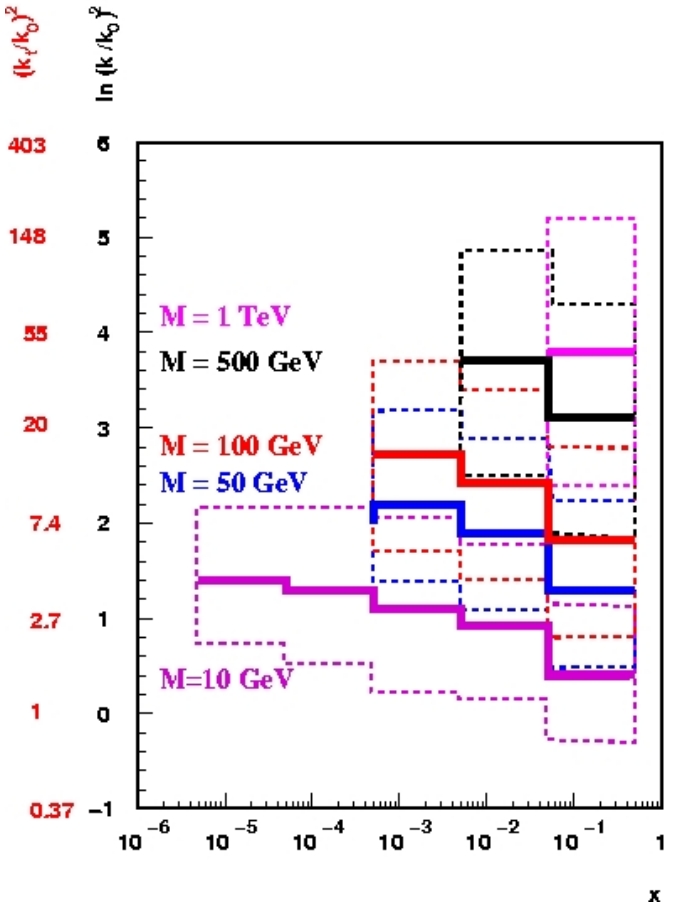
Initial k_T at HERA and LHC

Initial k_T in the hard scattering



Jung

Cascade calculation

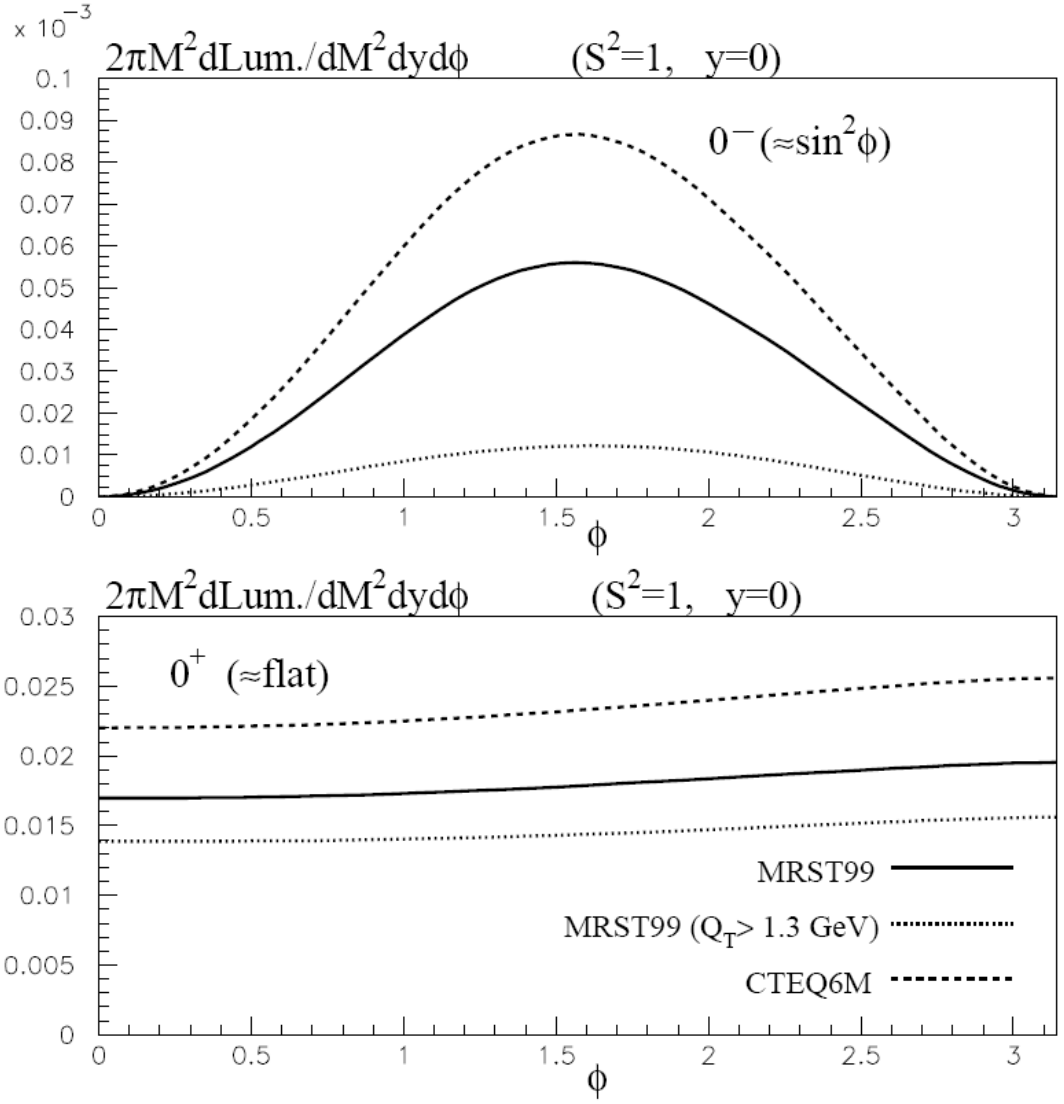


$\langle k_T \rangle$ large $\Rightarrow$ unintegrated parton PDFs will be needed

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

Measuring the Azimuthal Asymmetry



Khoze et al., hep-ph/0307064

Azimuthal correlation
Between the tagged protons

Allows to eg to differentiate O^+ from O^-

Does not include absorptive corrections (S^2), see ref above

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***

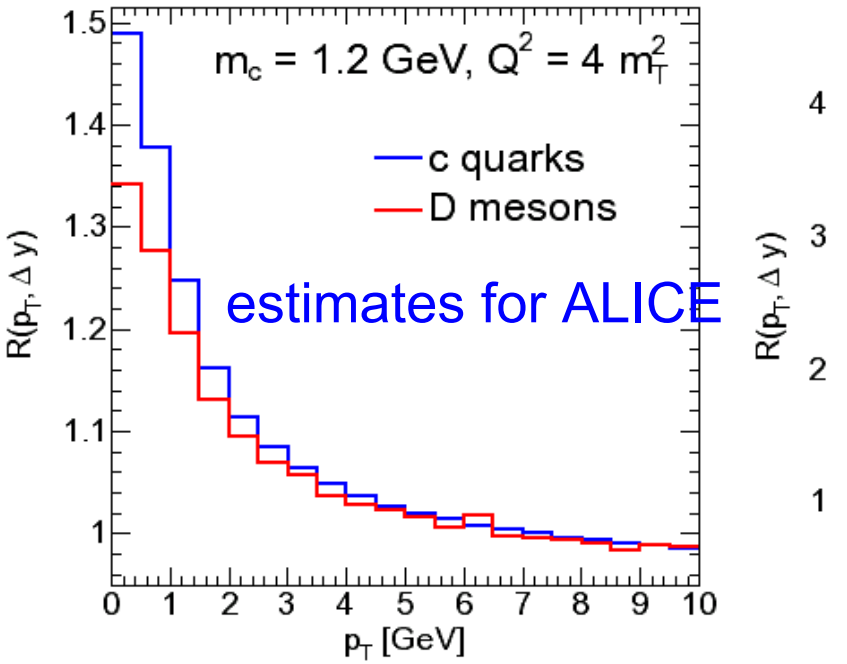
- refit HERA F_2 data, reduces F_2^{DGLAP} at

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 ...

Monte Carlo and Tools

HZtool

- calculate and compare predictions with measurements

➔ MC generators, NLOlib, MC@NLO

➔ useful for tuning of parameters

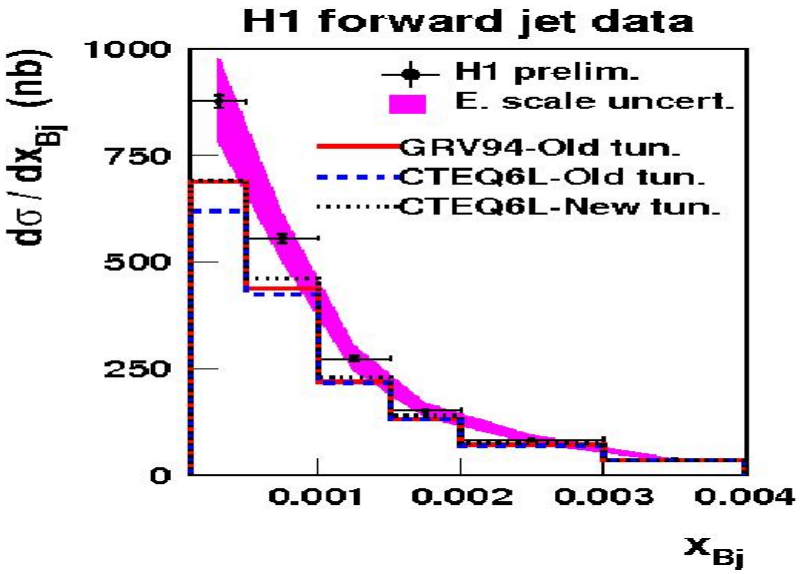
➔ useful for PDF fits with final states

- ➔ includes HERA, LEP, TeVatron data
- ➔ will be coupled to HEPDATA
- ➔ will develop into RIVET (Robust Independent Validation of Experiment and Theory) a C++ version of HZTool. Work started !
- ➔ MC/NLO validation
- ➔ compare to very different measurements

- Request by HERA & TeVatron & LHC:

C. Risler, J Butterworth

- example for tuning: ARIADNE parameters with new PDFs
- compare to fwd jet xsection (not used in tuning) (A. Knutsson, L. Joensson)



- Include also LEP data
- **Provide tuning including HERA, LEP and TeVatron data !!!**

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

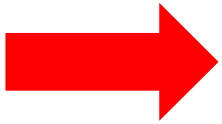
Goals and suggestions for 2nd workshop

- **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

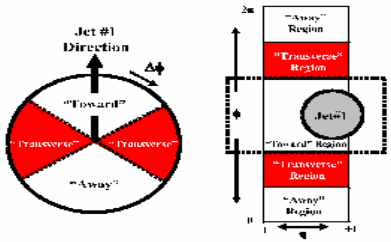
MC & Tools

- 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

Multiple Interactions at LHC



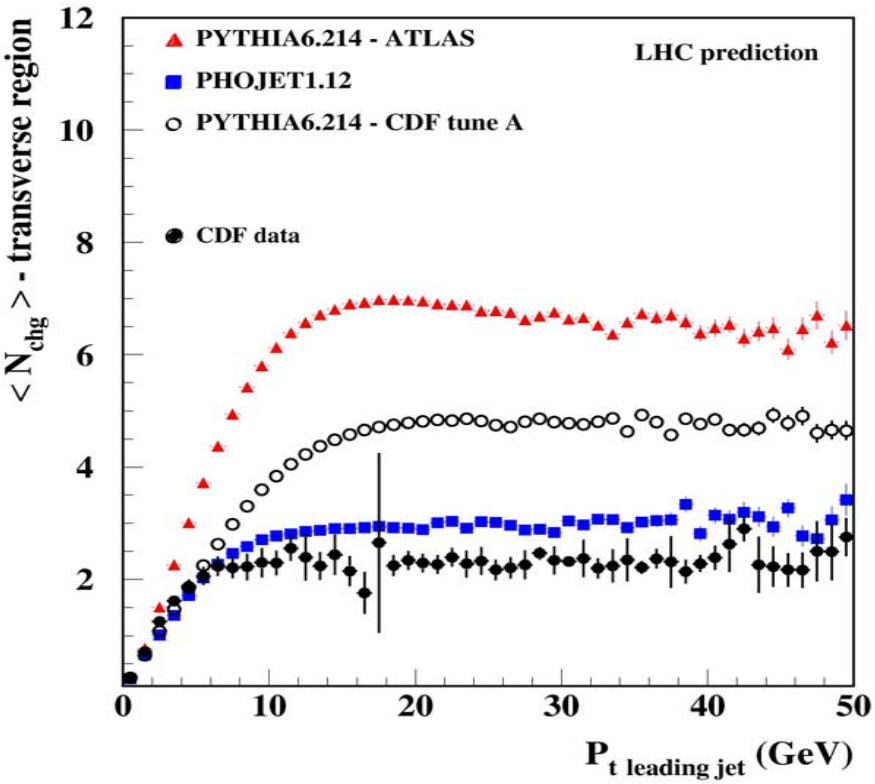
Charged multiplicities in transverse region

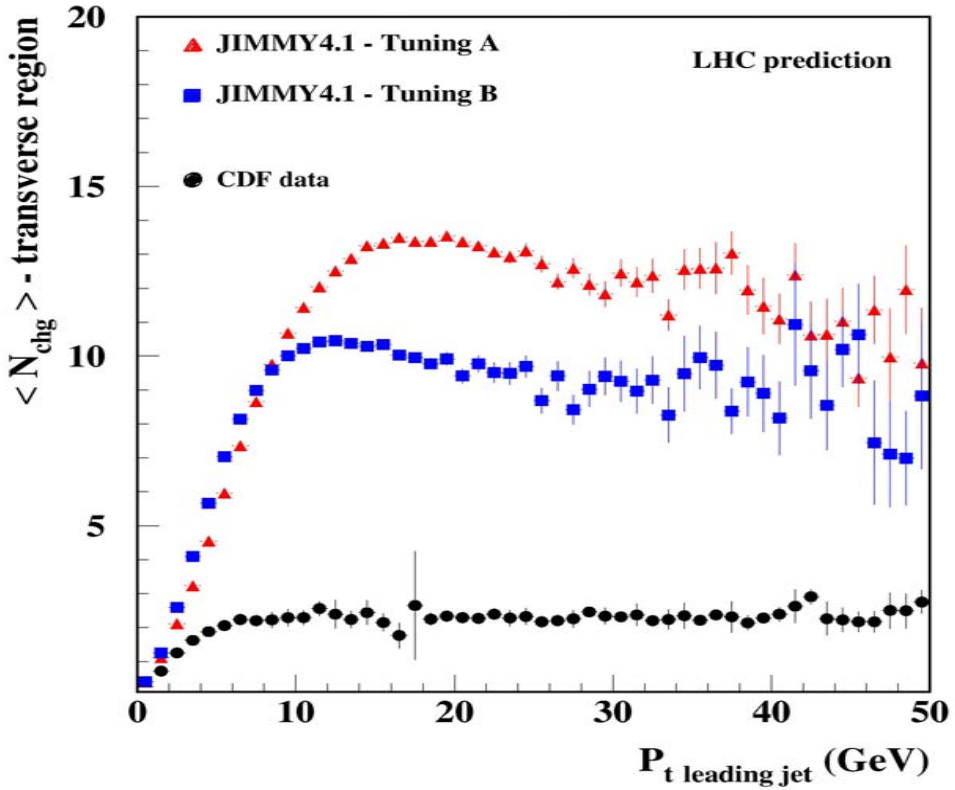
Models tuned to Tevatron data

C. Buttar et al

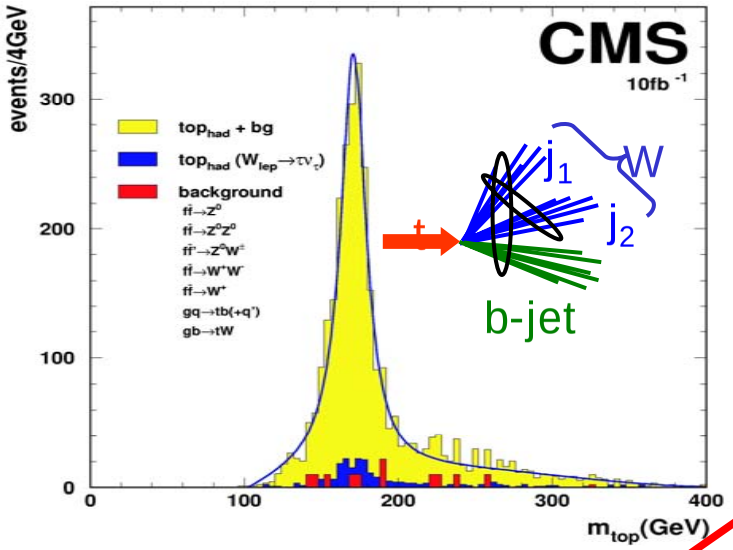
- give HUGE differences at LHC ...
- better understand multiple interactions

...





Multiple Interactions and top mass

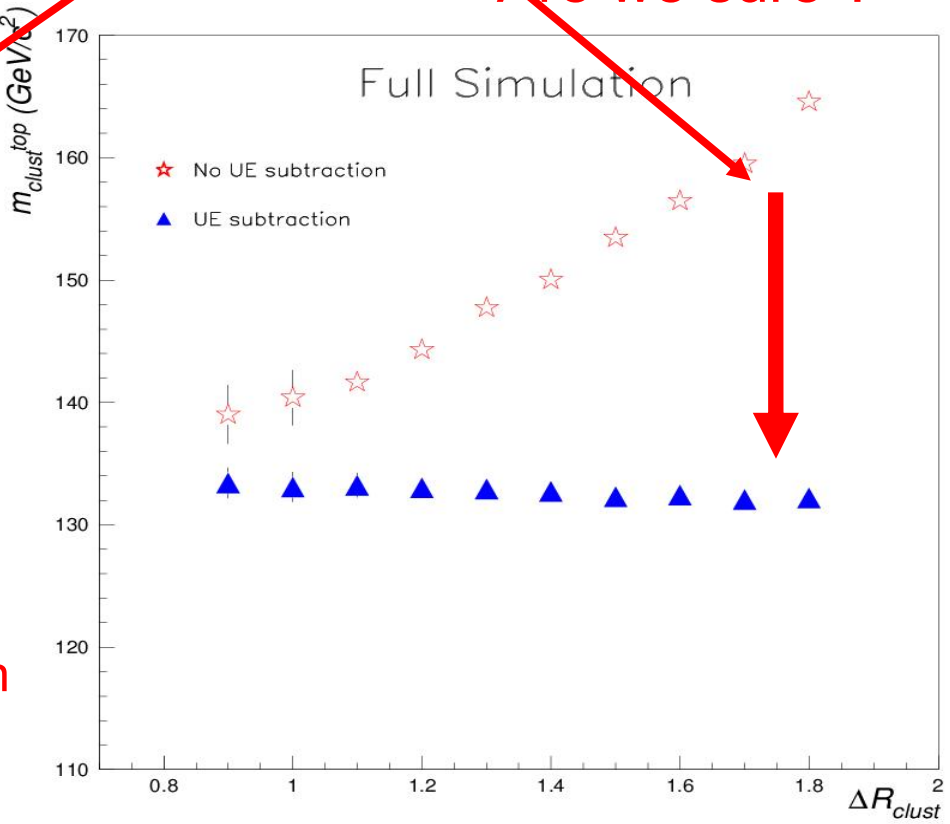


Source of error in GeV	Lepton+jets inclusive sample	Lepton+jets large clusters sample	Dilepton	All jets high pT sample
Energy scale				
Light jet energy scale	0.2	-	-	0.8
b-jet energy scale	0.7	-	0.6	0.7
Mass scale calibration	-	0.9	-	-
UE estimate	-	1.3	-	-
Physics				
Background	0.1	0.1	0.2	0.4
b-quark 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 !!!

QCD Evolution of PDFs

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

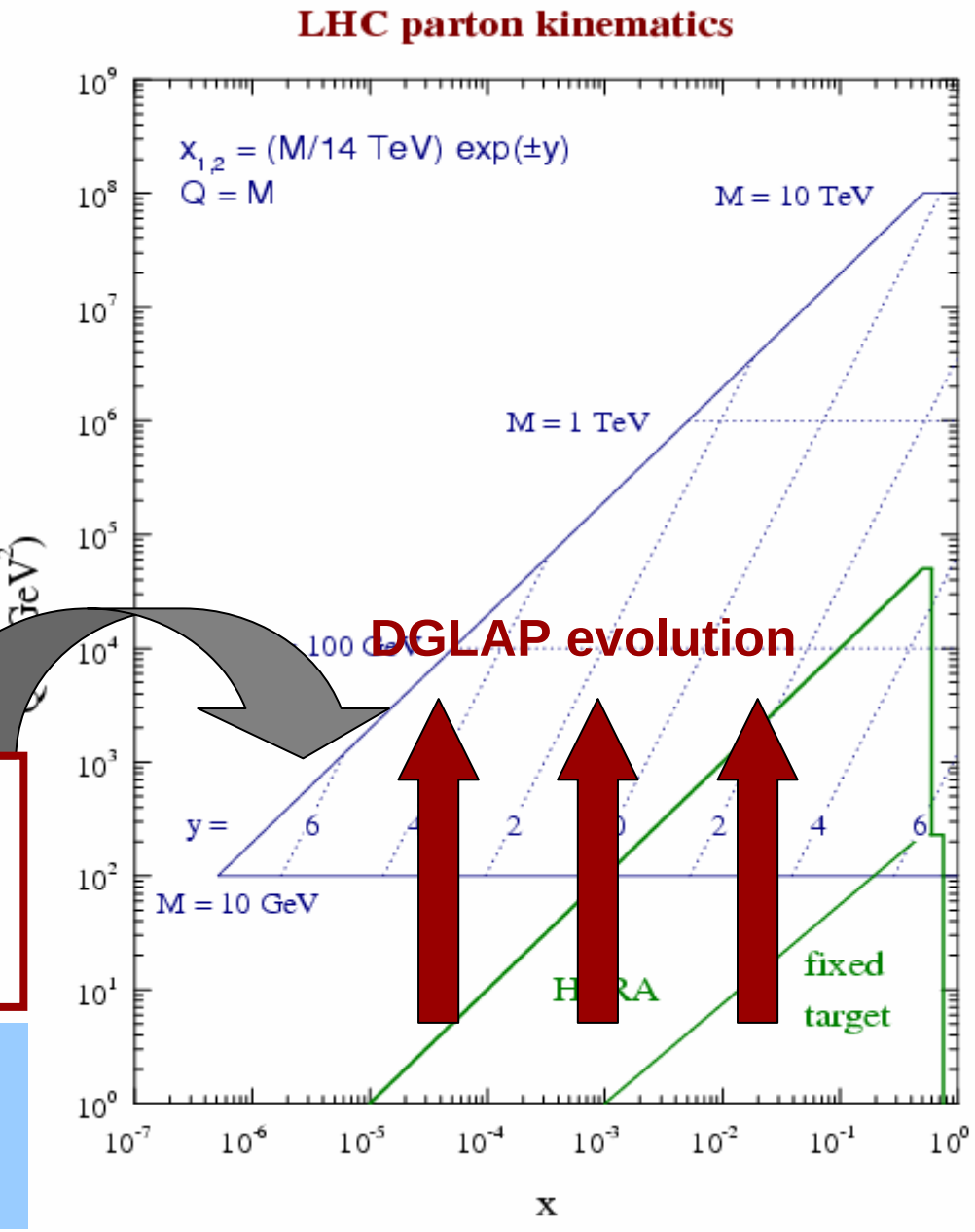
HERA measurements do not cover the LHC region, eg. for central Higgs production
$\Rightarrow$PDFs evolved via DGLAP equations from (x,Q^2_0) to (x,Q^2)

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



PDFs from quarkonia at ALICE

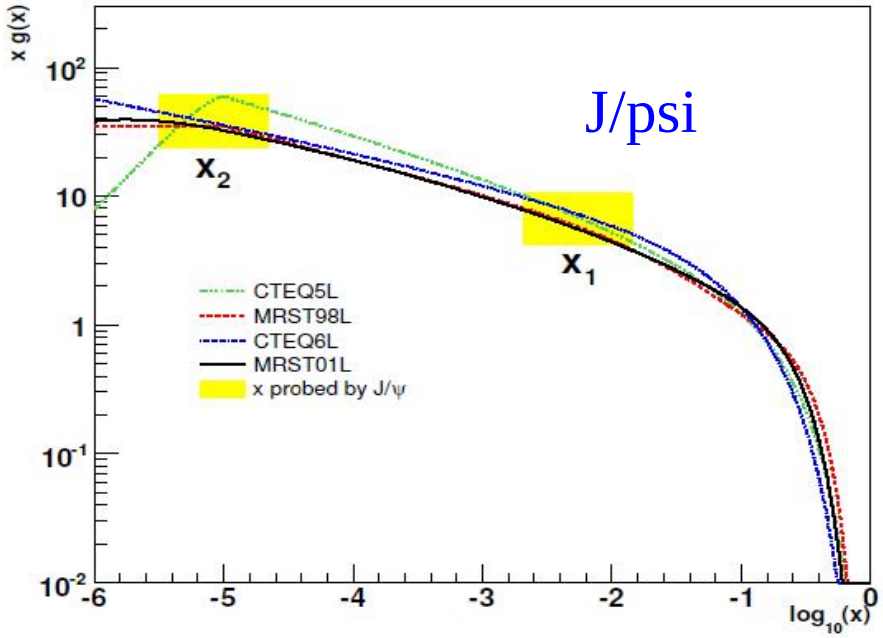
D. Stocco

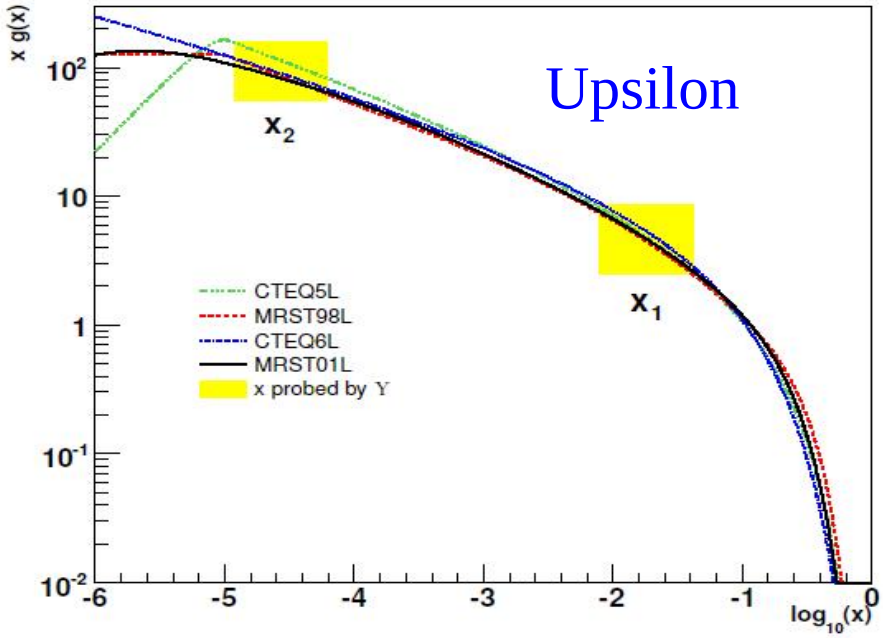
study done for ALICE

$J/\psi \Longleftarrow$ Region explored by $(2.5 < y < 4)$ $\Longrightarrow \Upsilon$

Here using ColorEvapoartionModel....

What about the other approaches (NRQCD, kt-factorization) ?





- The shape of the rapidity distribution depends on the PDFs
- Compare different PDFs...