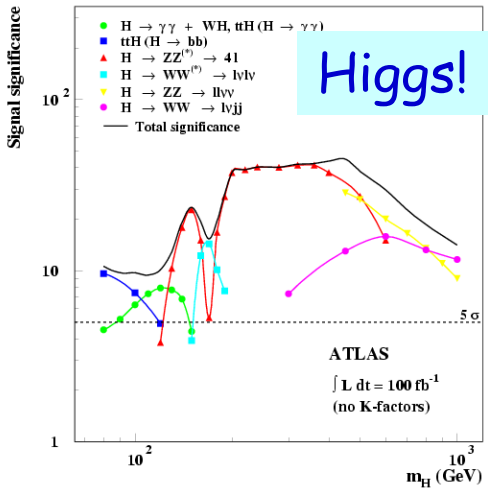
Summary the HERA/LHC Workshop

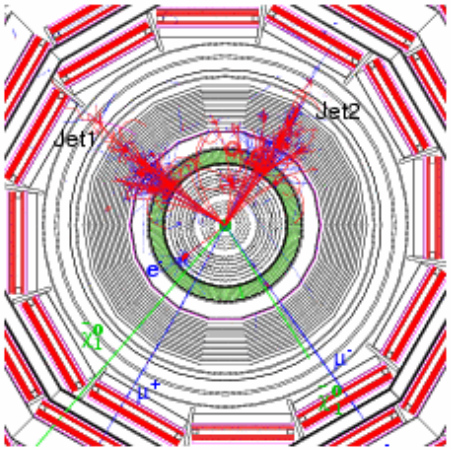
A. De Roeck/CERN

- Introduction and Goals of the Workshop
- Overview & Highlights
- The end of phase I and the continuation of the Workshop

Physics at the LHC: pp @ 14 TeV

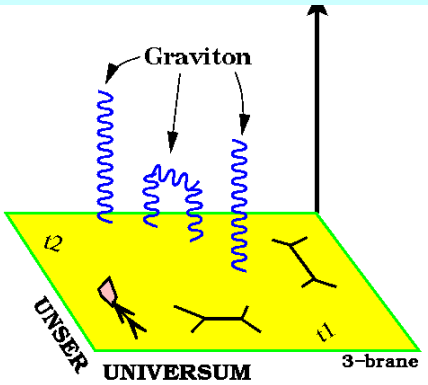


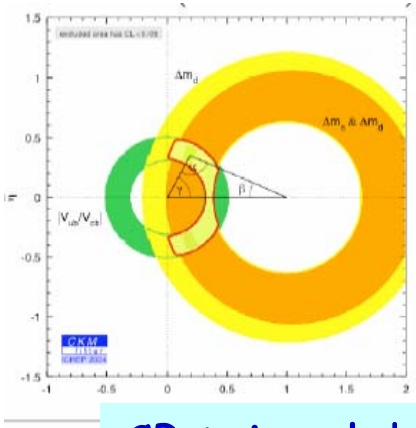
Higgs!



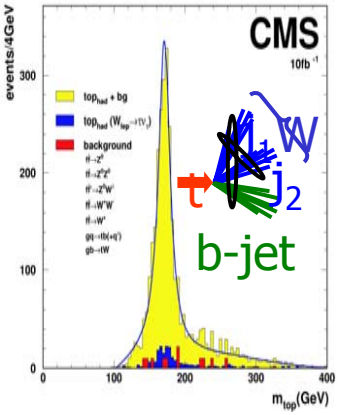
Supersymmetry?

Extra Dimensions?



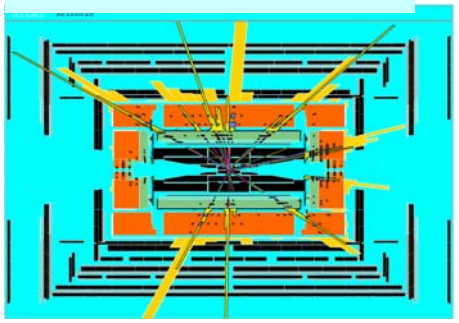


CP triangle!

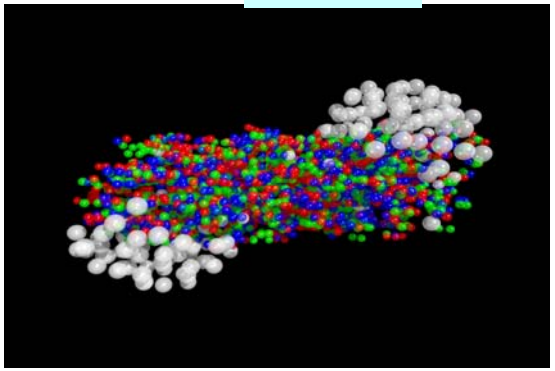


Precision measurements e.g top!

Black Holes???

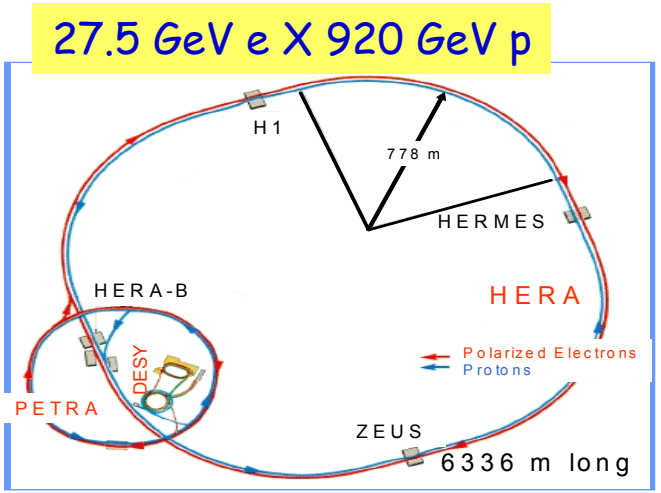


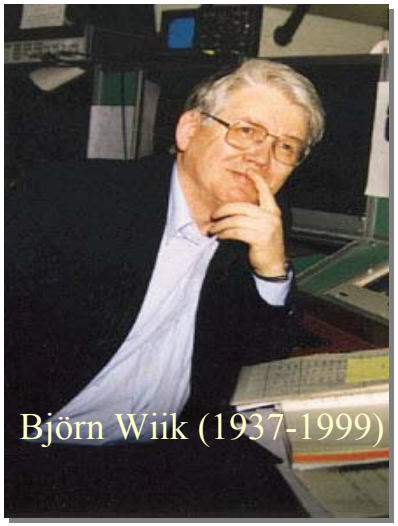
QGP?



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

The HERA Collider





ep collisions
$\sqrt{s}$ = 318 GeV
$\Delta r \geq 0.001$ fm

HERA:

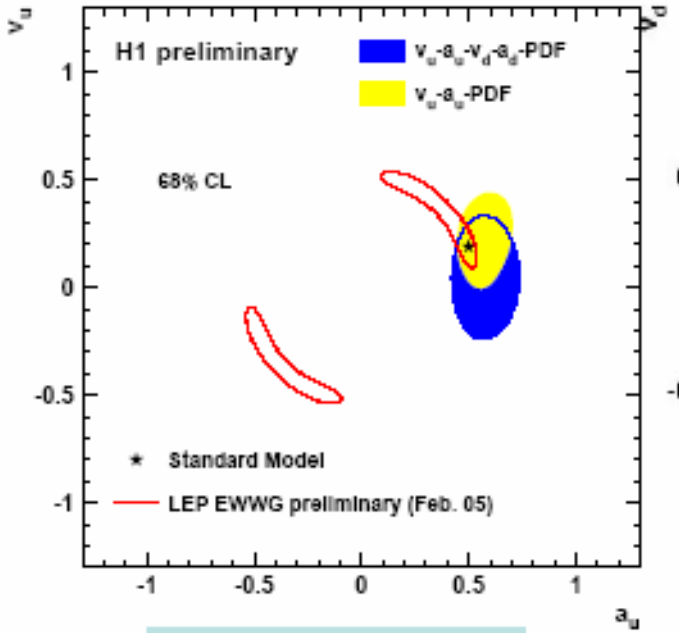
- Structure of the proton (and photon)
- Detailed study of QCD
- Heavy flavour studies
- Diffraction
- …EW, BSM

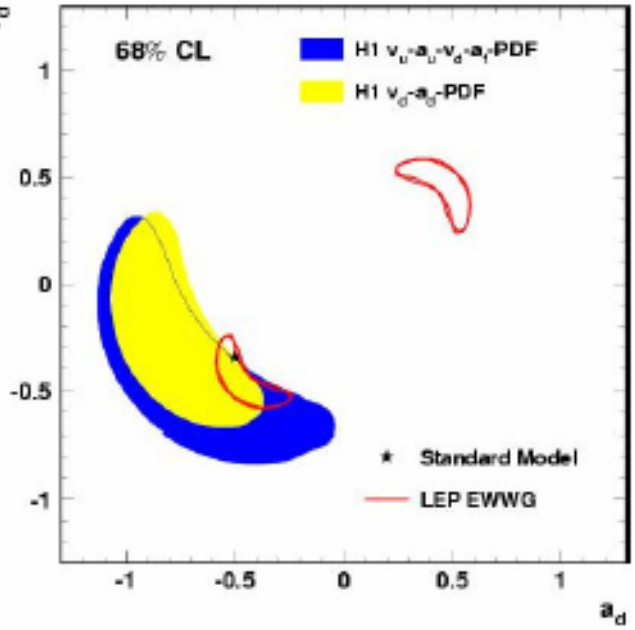
- HERA collected 100 pb^{-1} in phase HERA-I (1992-2000)
- Luminosity upgrade started 2002
- HERA will terminate summer 2007

HERA: Not just QCD

Fit of electroweak parameters:

O. Behnke
DIS05
Madison





First HERA results on a_q, v_q

Further results:

- $M_{prop} = 82.87 \pm 1.82$ GeV [exp]
- $\sin^2\theta_w = 0.2151 \pm 0.0040$ [exp]
- $M_{top} = 125 \pm 42$ GeV

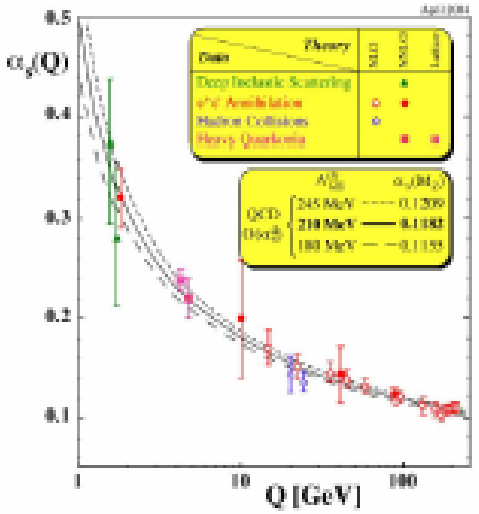
However QCD IS important

Not a recent development, but …

2004 Nobel Prize in Physics

D. Gross, H. D. Politzer, F. Wilczek

"for the discovery of asymptotic freedom in the theory of the strong interaction"



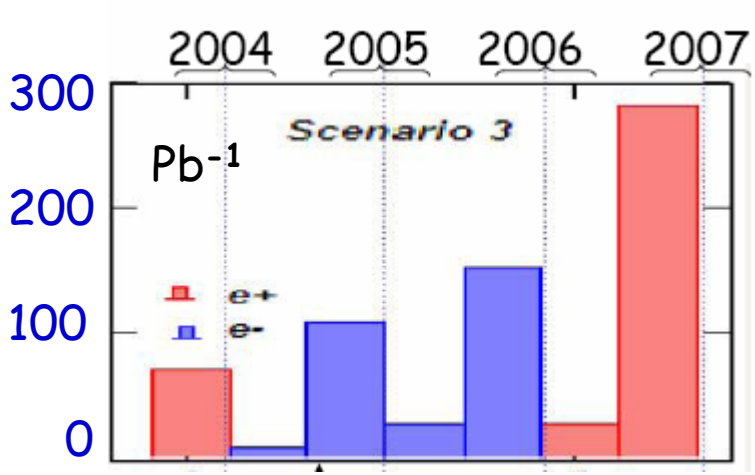
… without it there would be no perturbative QCD

HERA-II running

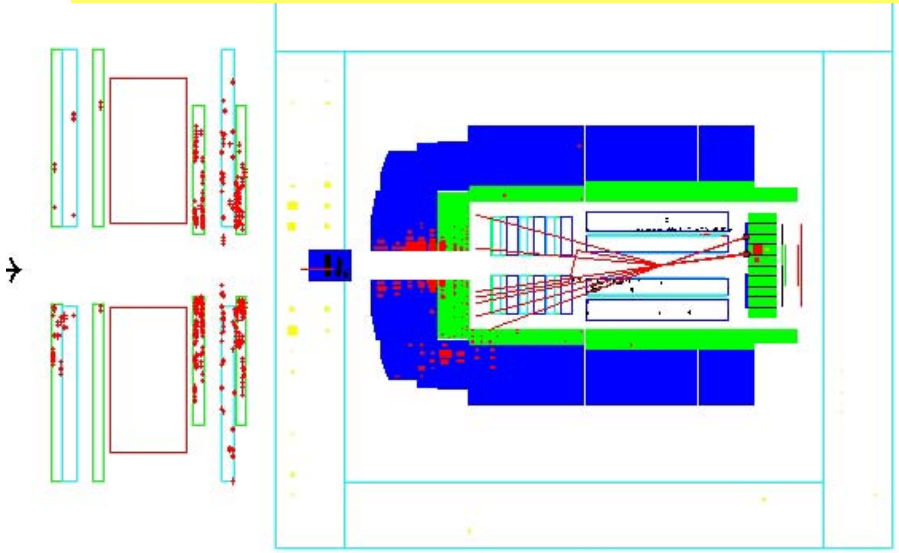
HERA-II increasing luminosity

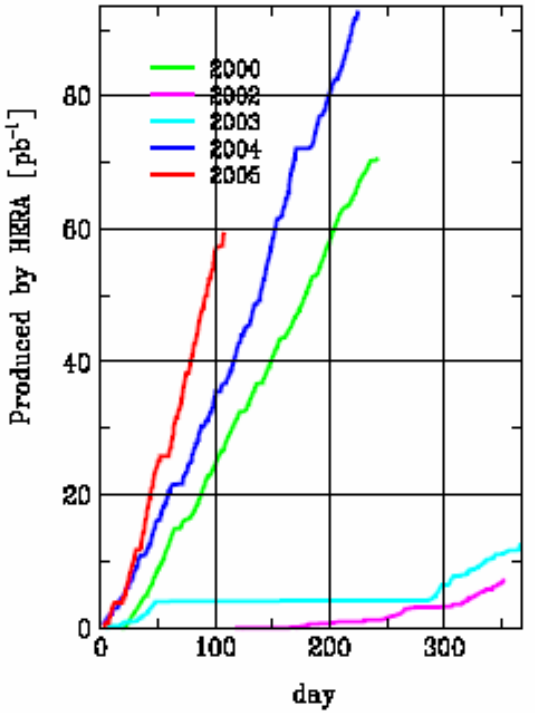
Peak luminosity so far 4.5 10^{31} cm^{-2} sec^{-2}

Expect to accumulate ~ 700 pb^{-1}



A deep inelastic scattering event





Workshop Aims

- 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.

⇒ Five Working Groups

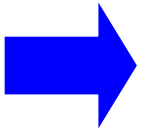
- Parton density functions
- Multi-jet final states
- Heavy quarks (charm and beauty)
- Diffraction
- MC-tools

Workshop Chairs
H. Jung, ADR

Meetings

First meeting:	26-27 March CERN (~ 250-300 participants)
Intermediate meeting:	1-4 June/ DESY
Second meeting:	11-13 October CERN
Intermediate meeting:	15-19 November/ DESY
Intermediate meeting	17-21 January 2005/ CERN
Final meeting:	21-24 March 2005/ DESY (~150 particpants)

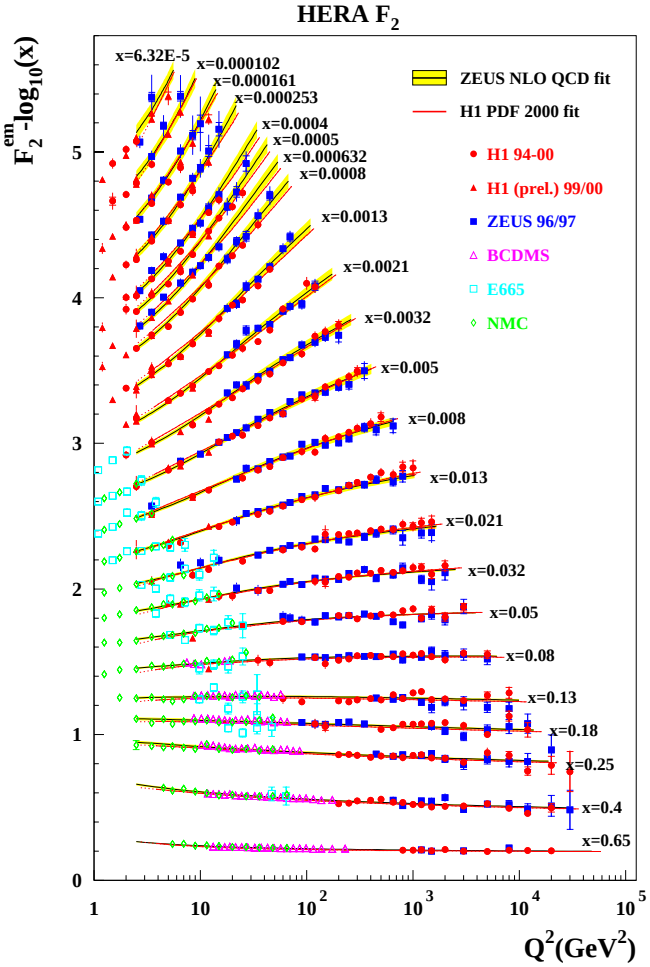
http://www.desy.de/~heralhc

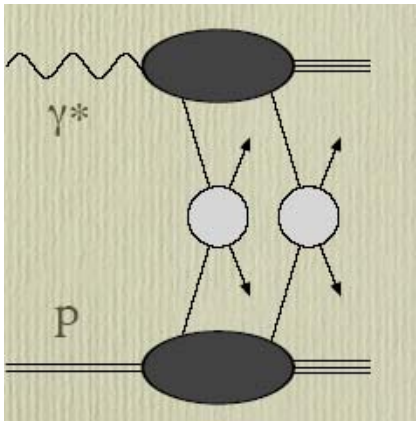


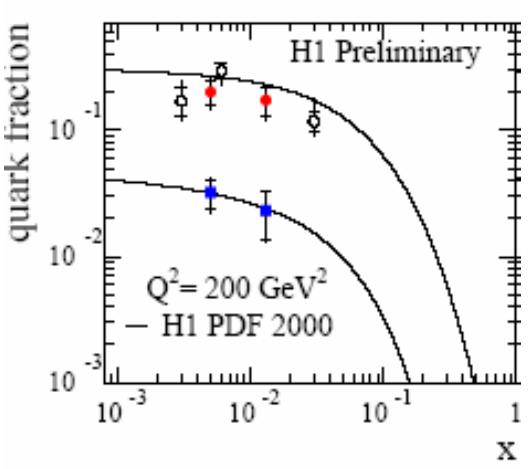
Joint DESY/CERN Report in 2005

So, how well did we do?

Examples: HERA→ LHC





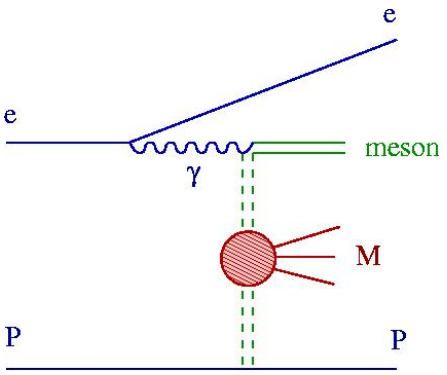


Underlying event:
tunable elementarity
of one beam particle
γp ↔γ*p collisions
LHC: event complexity

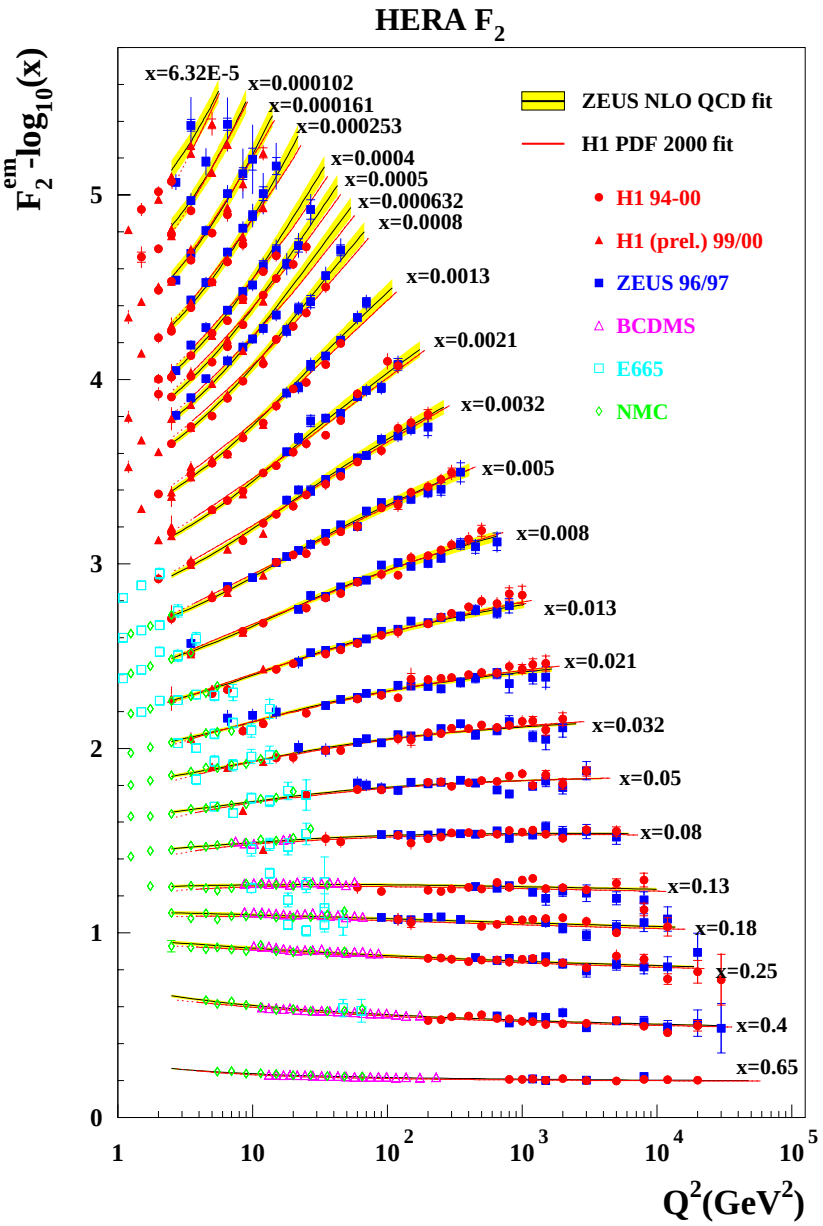
B-production: B quark
PDFs of the proton
LHC: Higgs production

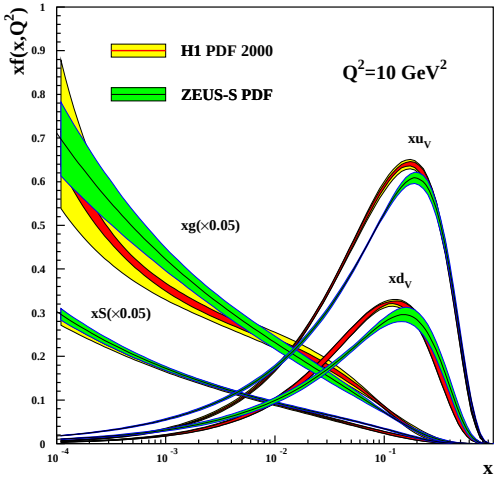
Structure functions and
parton distributions
LHC: cross sections/precision

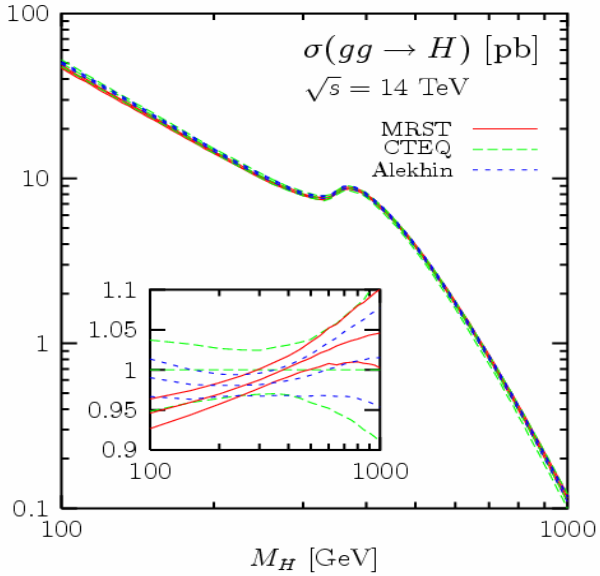
Diffraction
LHC: diffractive
scalar production



WG1: PDFs





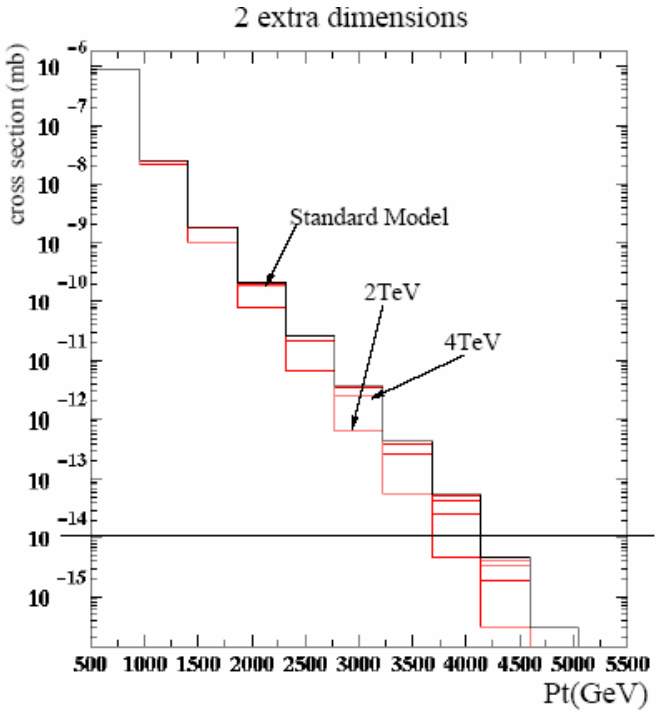


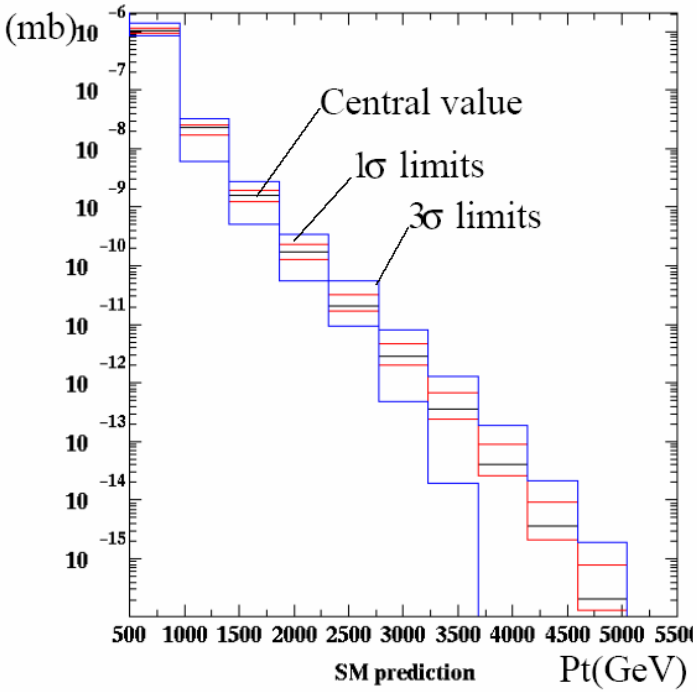
Simple spread of existing PDFs gives up to 10% uncertainty on Higgs cross section

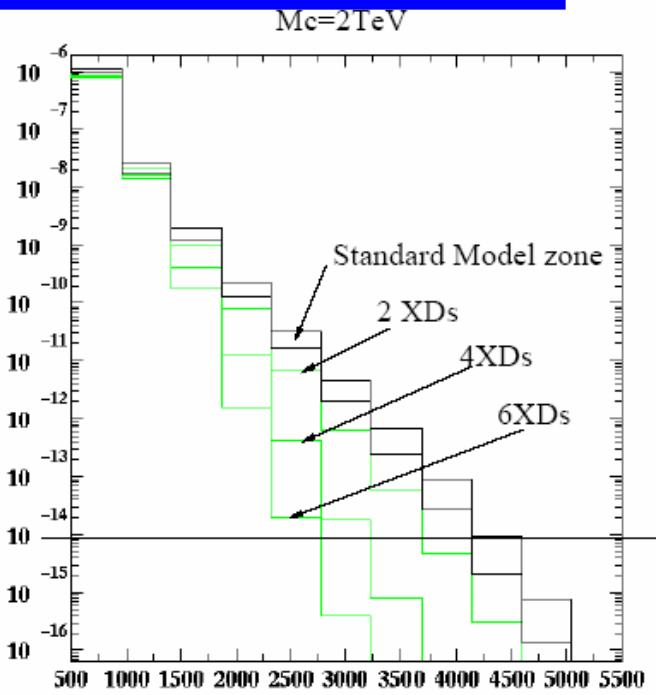
⇒ we have to do better than that!

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)

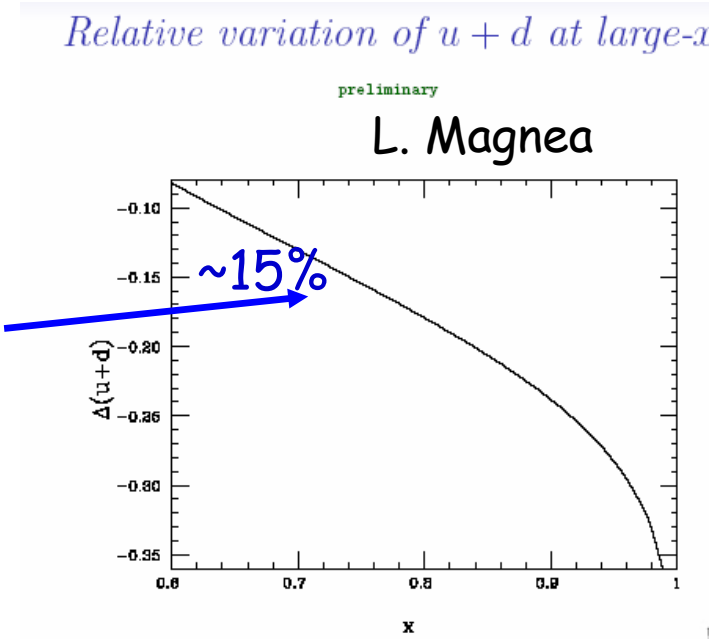
	2 extra-dimensions	4 extra-dimensions	6 extra-dimensions
Theoretically	5 TeV	5 TeV	5 TeV
including PDF uncertainties	< 2 TeV	< 3 TeV	< 4 TeV

WG1: Structure Functions

- Potential experimental and theoretical accuracy for various LHC processes (DY,W,Z,WW,γ+jet…)

  Precision measurements at LHC/luminosity determination?
  - Cross sections and distributions
  - Benchmark with LHC detector simulation
- Impact of PDF's on LHC measurements
  - Making the most of HERA data
  - Need for F_L or eD scattering?
  - Can we judge which PDF is "preferred"?

    $\Rightarrow$Most precise PDFs + errors
- Impact of small x and large x resumations and saturation corrections on pdfs. QCD evolution validation (DGLAP,…)
  - Impact for LHC?
  - Verify with HERA data.



WG1

Precision physics at the LHC!!

- List of interesting LHC reactions and assessment of their theoretical and experimental accuracy, including ratios. Document in progress

Towards a list of well measurable LHC final states and their potential experimental and theoretical accuracies

contributers:

Abstract

Cross section calculations for a large number of Standard Model LHC reactions have been performed during the last 20 years. Many experimental simulations demonstrate how various final states might eventually be selected. These studies indicate how large the potential signals and backgrounds might be and the results can be found at various places in the literature. We attempt to give a comprehensive summary for these different cross sections and their potential statistical errors. Furthermore, we try to provide some consistent estimates for potential systematic errors of these future LHC measurements. Obviously, many experimental and theoretical uncertainties can only be estimated or guessed today. Nevertheless, such a list might not only become useful during the coming years, but will eventually be proven to be too pessimistic or optimistic once real measurements can be performed at the LHC.

Contact M. Dittmar

example

Conclusions

- study of WW,WZ and ZZ production with experimental cuts
- differential distributions (rapidity, P_T, m_{inv})
- systematic uncertainties:
  - PDF : 3.5-4%
  - Perturbative 3.6 – 4.1 %
- Systematics for VV and V is uncorrelated, does not cancel in the VV/V ratio

Summary of uncertainties

	W/Z	W/Z + jet	WW/ZZ
Δ_{PDF}[%]	± 5.3	± 4.3	± 3.7
Δ_{Pert}[%]	± 5.4	± 9.1	± 3.8

HERA-LHC Workshop March 21-24, 2005 H. Stenzel - W/Z pair production at LHC 14

Includes Drell-Yan, Z,W production
γ-final states, di-boson event,
top quarks, multi-jet events…

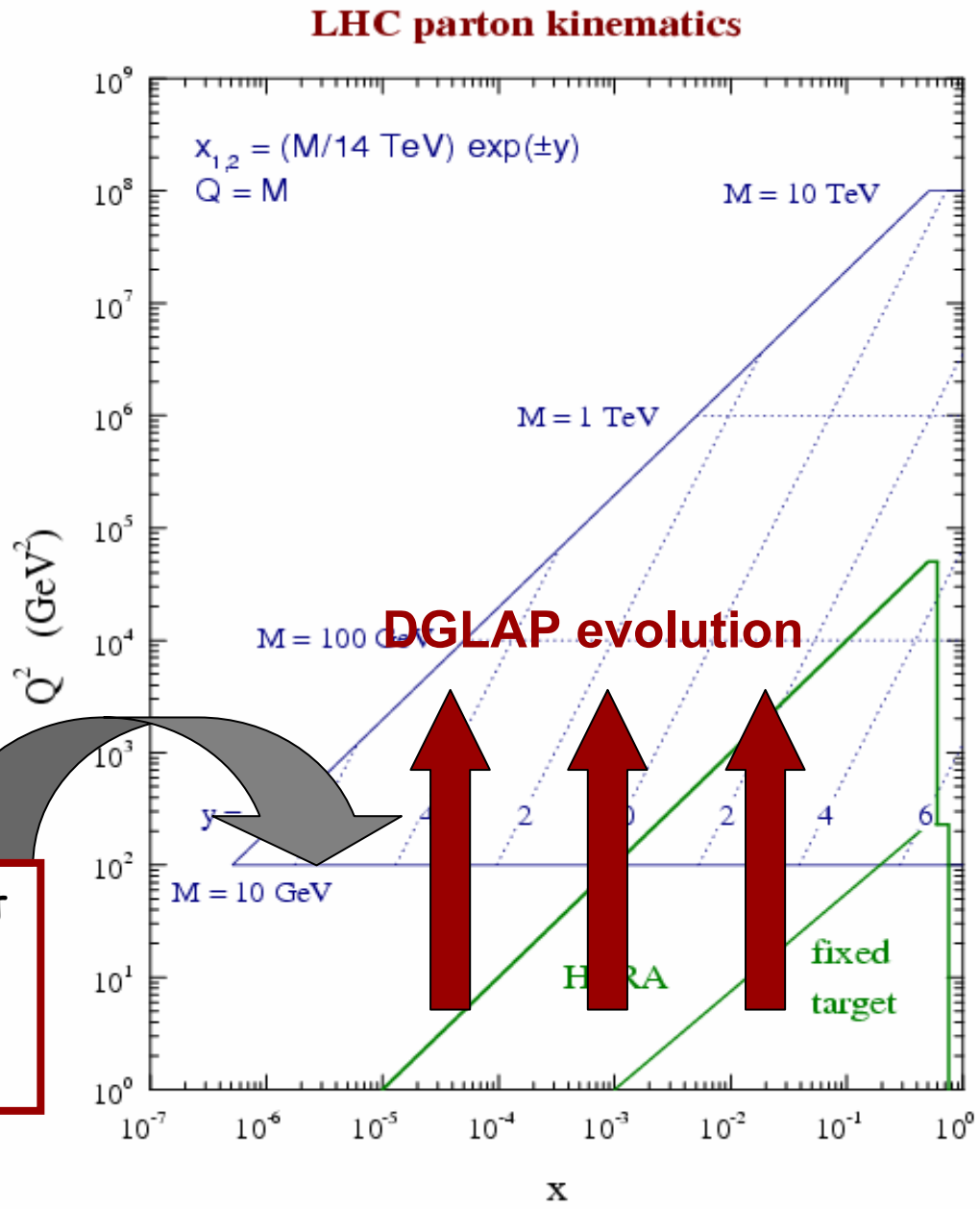
Use LHC data for PDF determination?

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

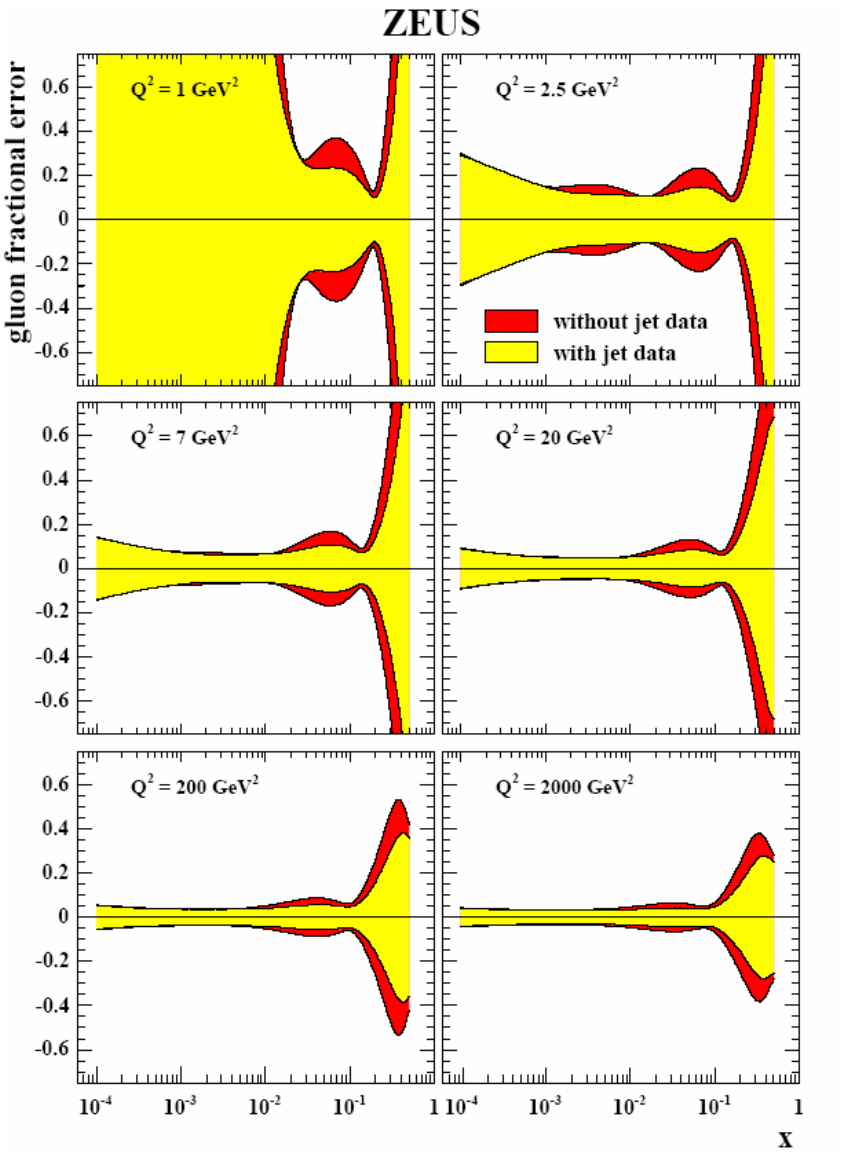
⇒ PDFs evolved via DGLAP equations from (x,Q^2_0) to (x,Q^2)



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?

Making the most of HERA data…

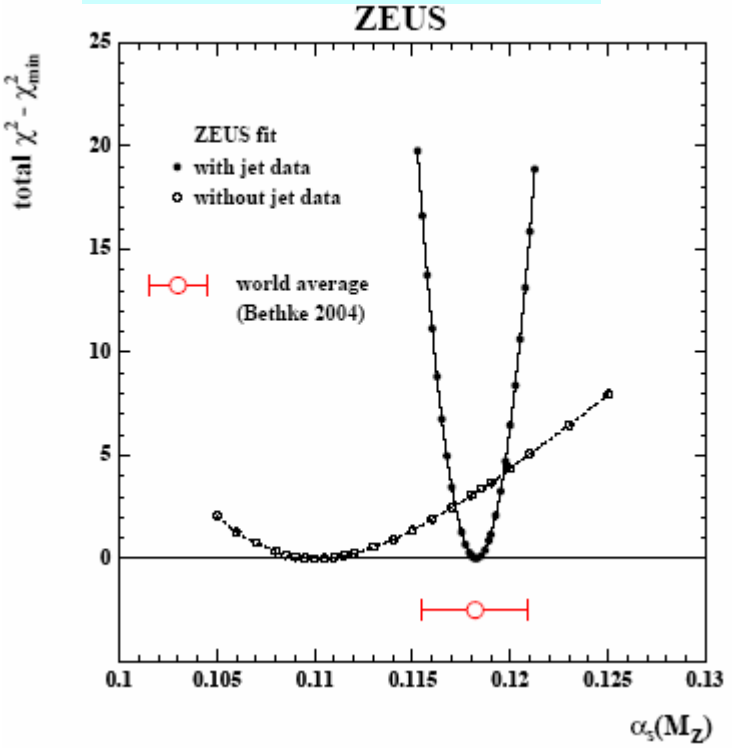
Improvement on g(x)



Global fits do have the problem of consistent treatment (errors) and sometimes 'tensions'
⇒Fits of inclusive cross + jets (+..) within one "experiment"

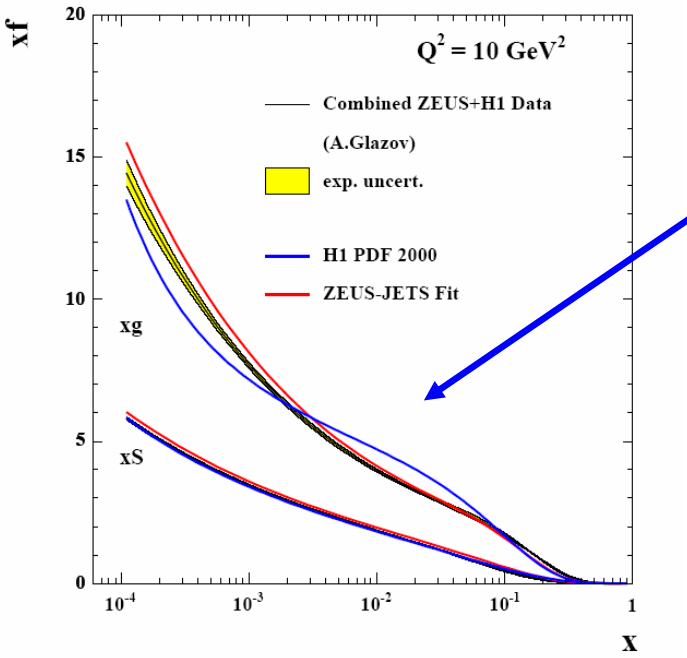
C. Gwenlan et al.

Improvement on αs



Combined Data Sets from HERA?

I think the World wants it (like we want one top mass etc…)
⇒ HERA PDFs will be THE standard for a long time to come
An effort is starting ⇒ Averaged data set… (A. Glazov et al.)



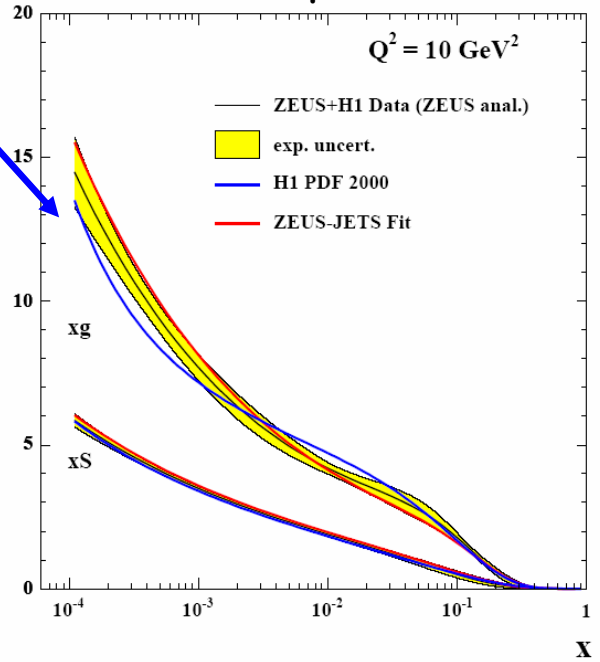
Compare PDF fit to H1+ZEUS data sets, and to the 'average data set.

Improved error?

Caution!

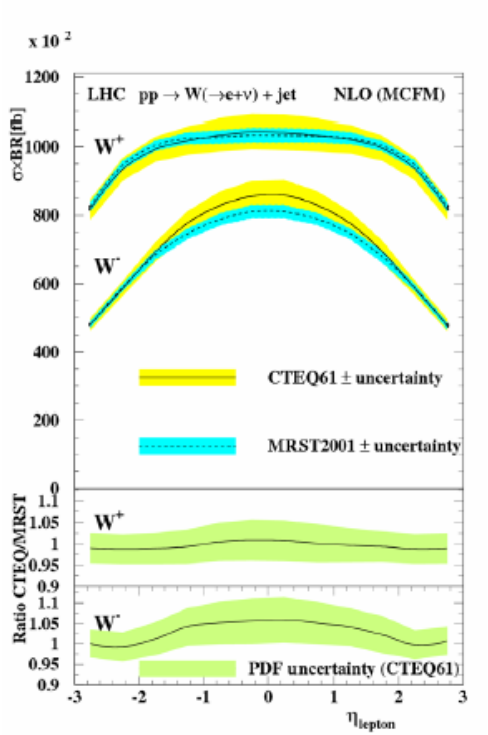
- Averaging procedure still very preliminary
- Some disagreements between the data set at low Q^2

M. Cooper et al.

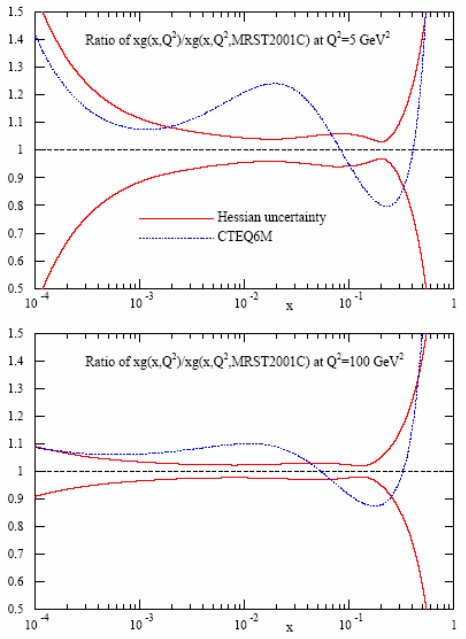


Feel encouraged to pursue this!

Need for F_L? Deuterons?



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)

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

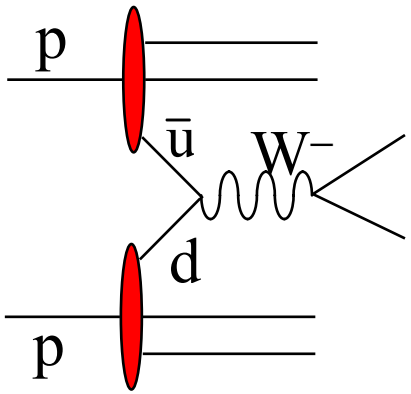
Deuterons: good for flavour separation, non-singlet SF extraction

HERA is unique: looks to me that you would want to do that!!

⇒ MUST make a strong quantitative argument! For Proceedings?

Deuterons

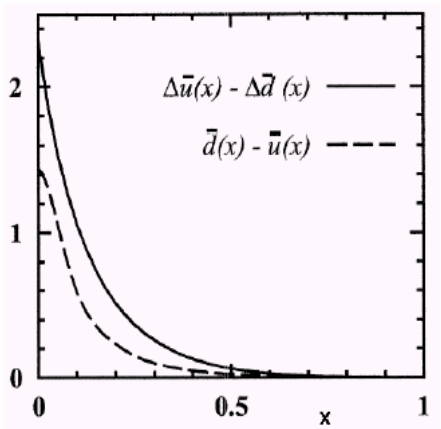
Global fits assume $\bar{u}=\bar{d}$ at small x

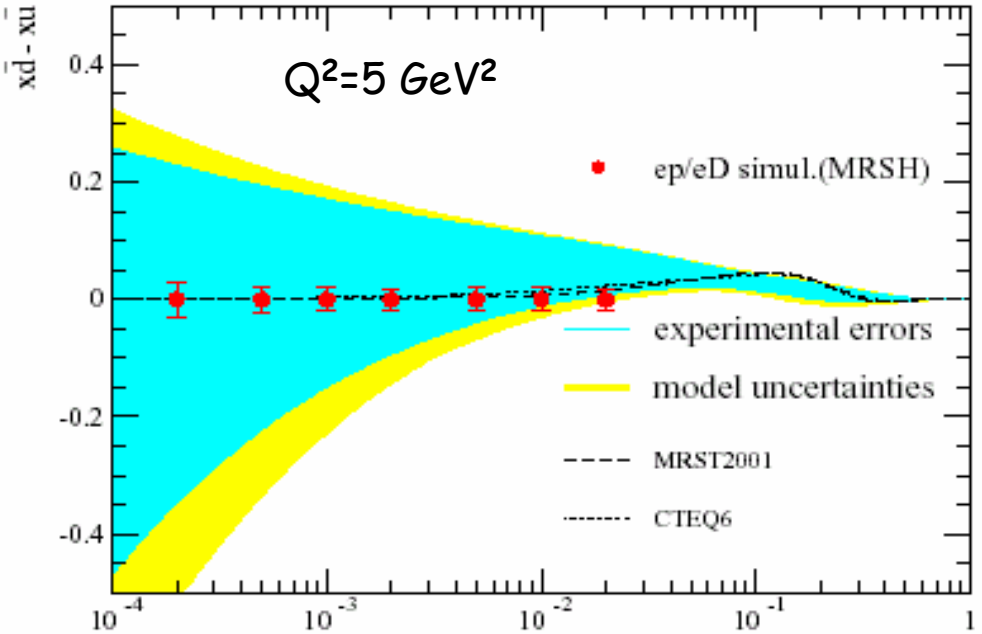


$$\tfrac{1}{2}\left(F_2^{\,p}+F_2^{\,n}\right)-F_2^{\,p}$$
$$=x\left(\tfrac{1}{6}d_v-\tfrac{1}{6}u_v+\tfrac{1}{3}\bar{d}-\tfrac{1}{3}\bar{u}\right)$$
$$\approx\tfrac{1}{3}x\left(\bar{d}-\bar{u}\right)\ \text{at low x.}$$

Needs electron-Deuteron runs

Eg. Chiral Soliton model





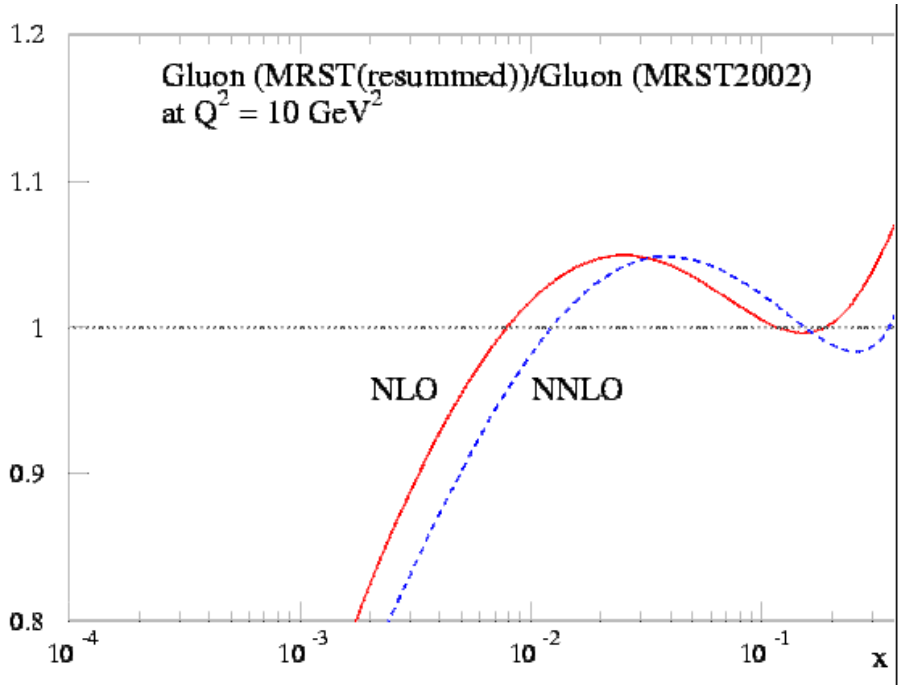
simulated accuracy (20pb-1 eD, 40 ep)

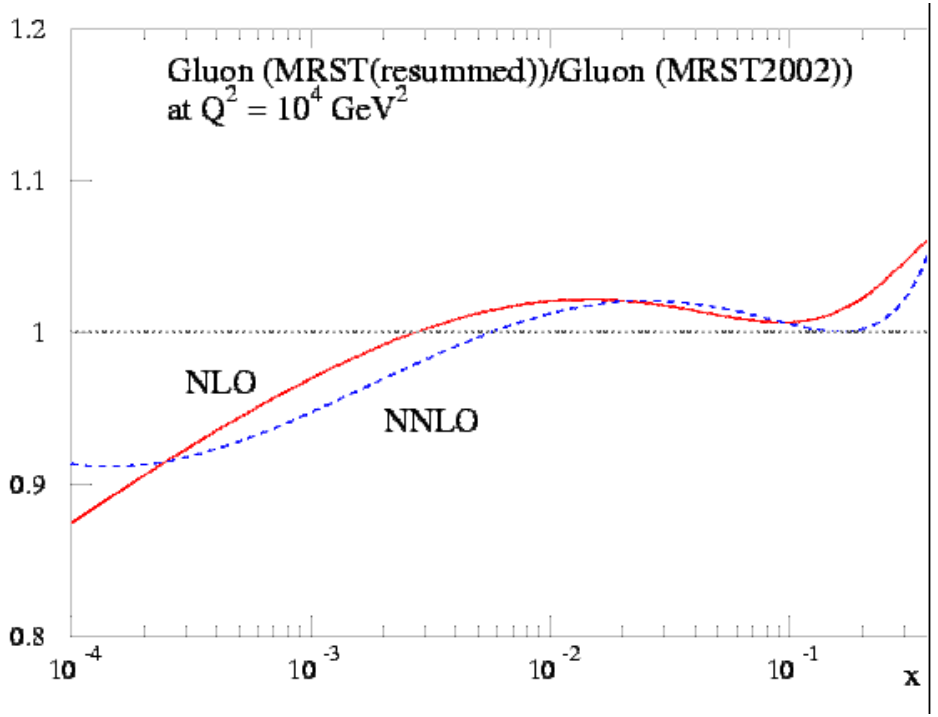
Parton luminosity problem at the LHC?

Low-x Resummation

Global fits: effects of including low x resummation (R.Thorne)

Differences can be larger than 20% at $x \sim 10^{-3}$, low Q^2





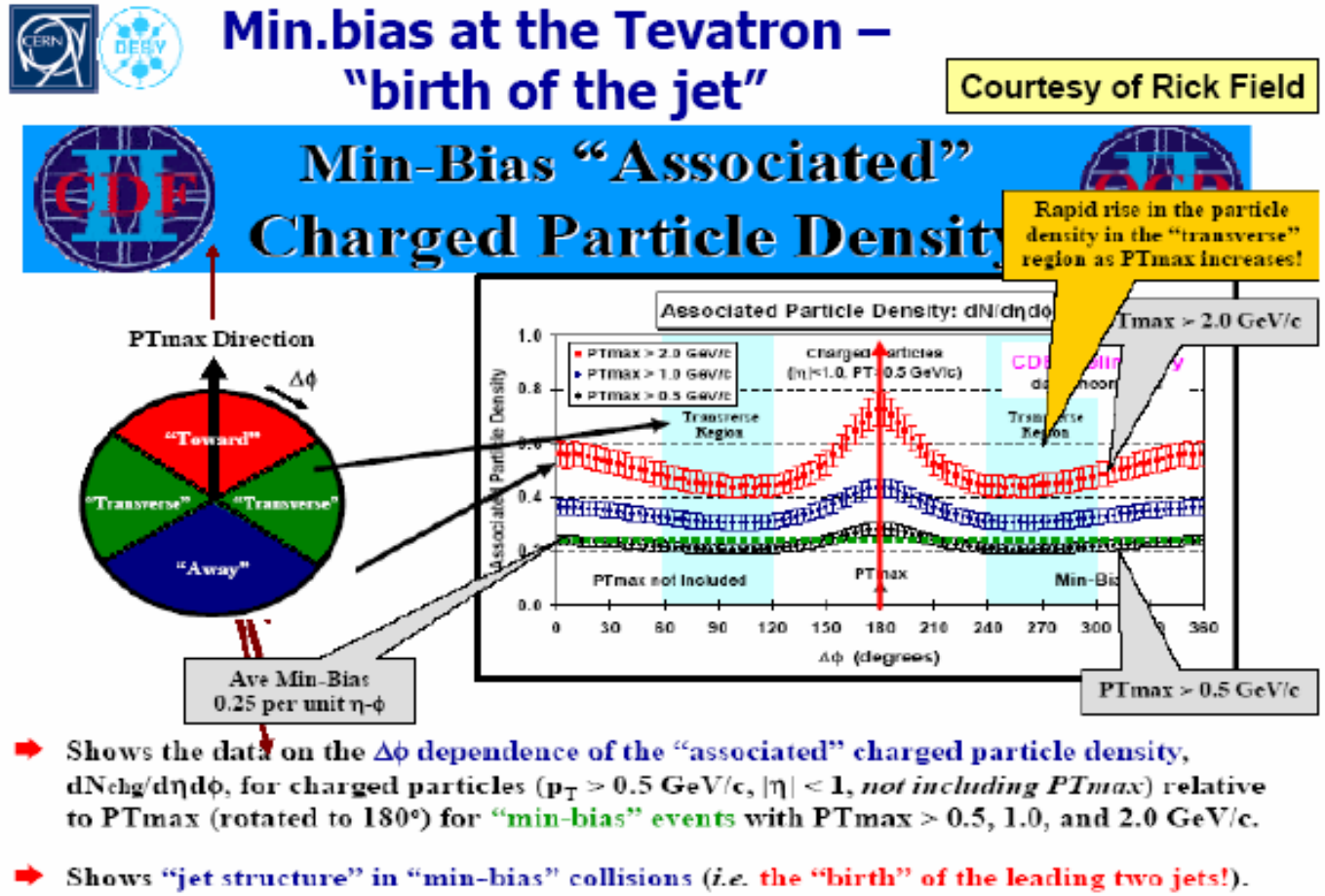
Need for other methods to extract the gluon or verify the QCD evolution/corrections

WG2: Multi-jet Final States & Eflows

- Underlying event/minimum bias events
  - New models appeared during the workshop
  - Tunes to pp data validated
  - Study similar observables in ep as in pp

    $\Rightarrow$Task force in action
- Gap survival
  - Still not sufficiently understood/ Consequences for the LHC!
  - New measurements like effects in leading neutron spectra in ep?
- Cascade, based on CCFM (contrary to DGLAP)
  - Shows effects at the LHC at low x
- Unintegrated pdfs and their importance e.g for pt of the Higgs
- ME-PS matching
- Resummations for event shape variables
- Future parton shower developments
  - Unintegrated parton correlation functions and QEDxQCD exponentiation

Underlying events/minimum bias



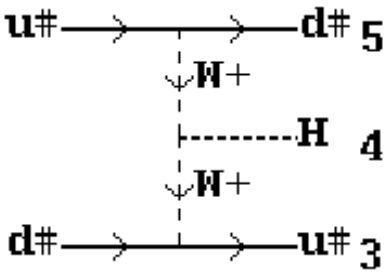
R. Field

➡ Shows the data on the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.

➡ Shows "jet structure" in "min-bias" collisions (*i.e.* the "birth" of the leading two jets!).

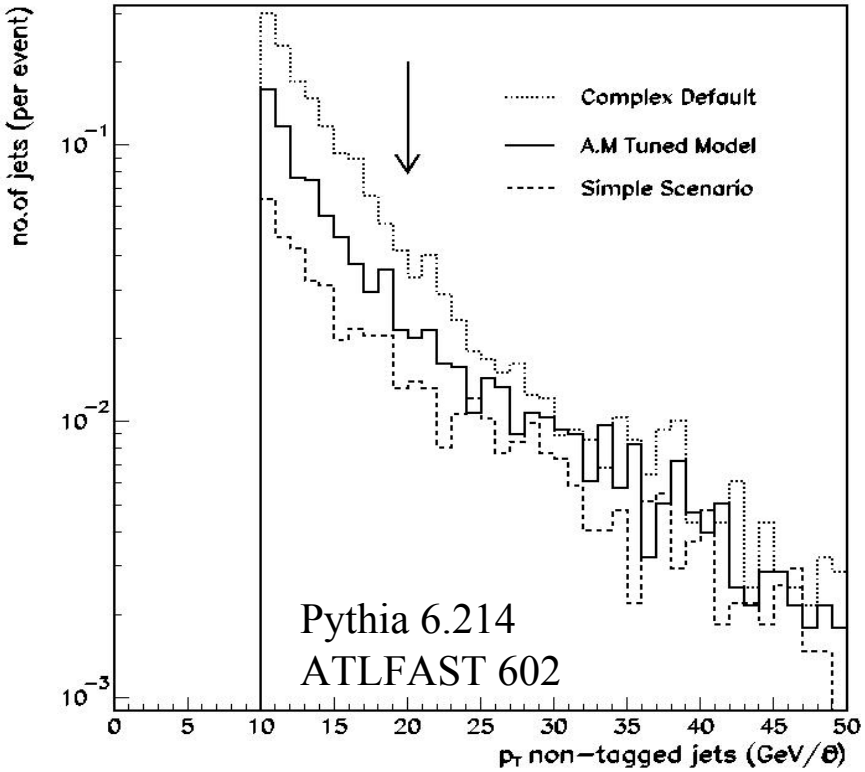
- Studies and tunes made on Tevatron/lower energy data
- These tunes should be validated on HERA data ⇒ work in progress
  Similar studies should be made as for the Tevatron data
- New models on the market that should be tested (new Pythia, Jimmy, Sherpa)

Effect of underlying event on central jet veto in VBF Higgs

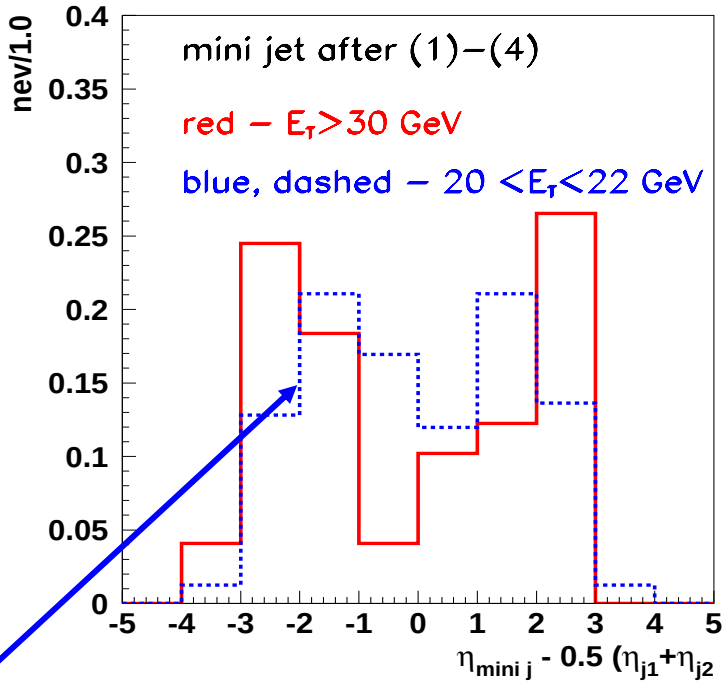


H->WW*->2l in qqH prod.

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



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

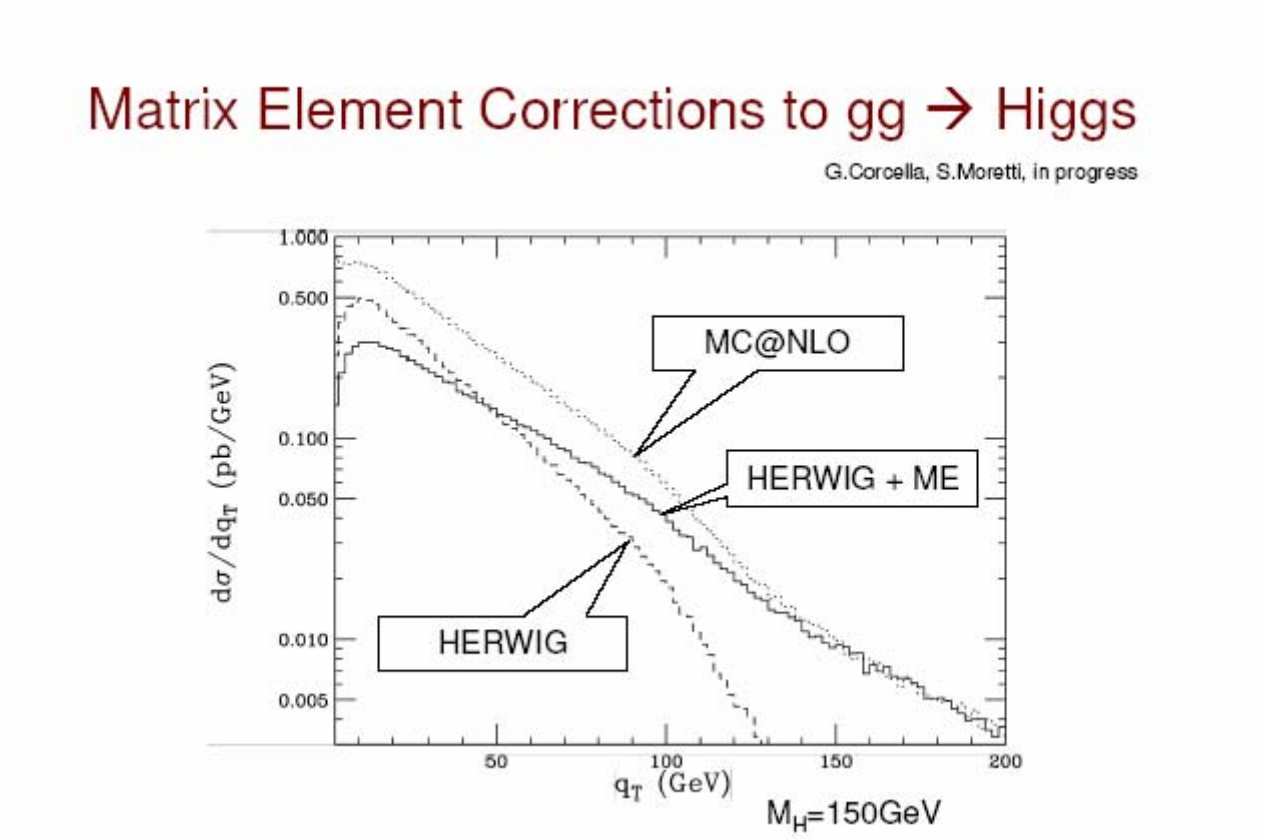


Model	CJV efficiency	Significance
Default pythia	85%	8.2
Default DG	75%	7.7
AM tuning	79%	7.9

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

S. Nikitenko

Matrix elements and parton showers

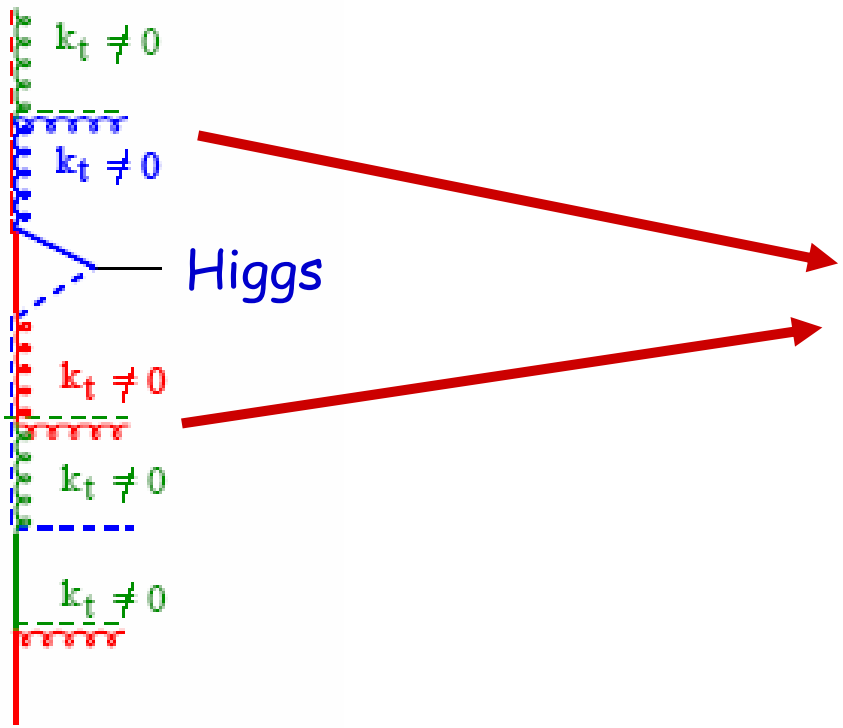


- Will be very important at the LHC
- Need to understand jet topologies of up to 8 jets (and more)
- Matching algorithms now also being implemented for ep scattering
- Can be benchmarked to HERA multi-jet data.

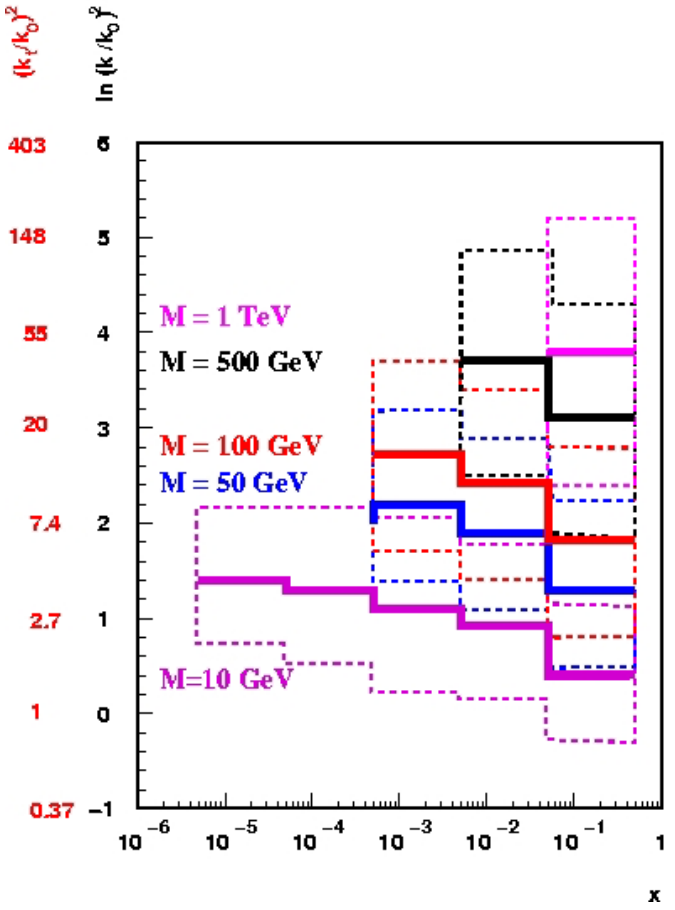
Initial k_t at HERA and LHC

Jung

Initial K_t in the hard scattering



Cascade calculation



$\langle K_t \rangle$ large $\Rightarrow$ unintegrated parton PDFs will be needed
Test predictions at HERA
Measure unintegrated PDFs at HERA via final states

WG3: Heavy Flavours

List of measurements of measurements to be made at LHC (need > 400 pb^{-1})

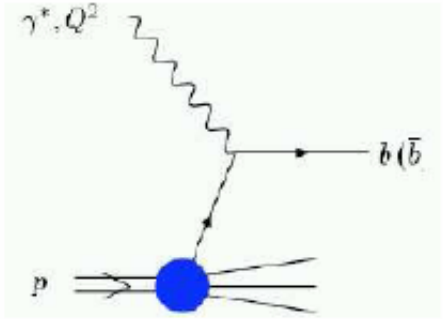
- $F_2^{cc/bb}$
- Charm exclusive final states (γp and DIS)
  - Cross sections
  - Fragmentation universality
  - Contribution from higher charm resonances
- Charm exclusive final states with jets (γp and DIS)
- Beauty exclusive final states (γp and DIS)
- Double quark tag
- Charm and beauty in charged current events
- Quarkonia
- Diffraction

Several of these have direct impact on the LHC

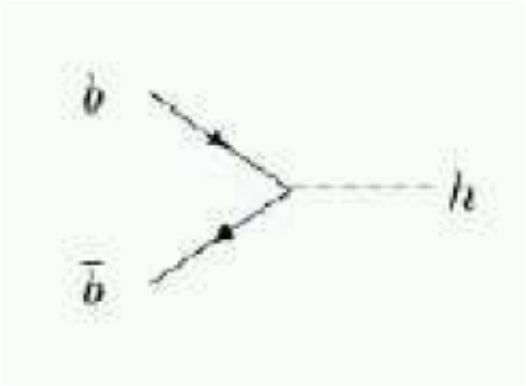
F2b at large Q2

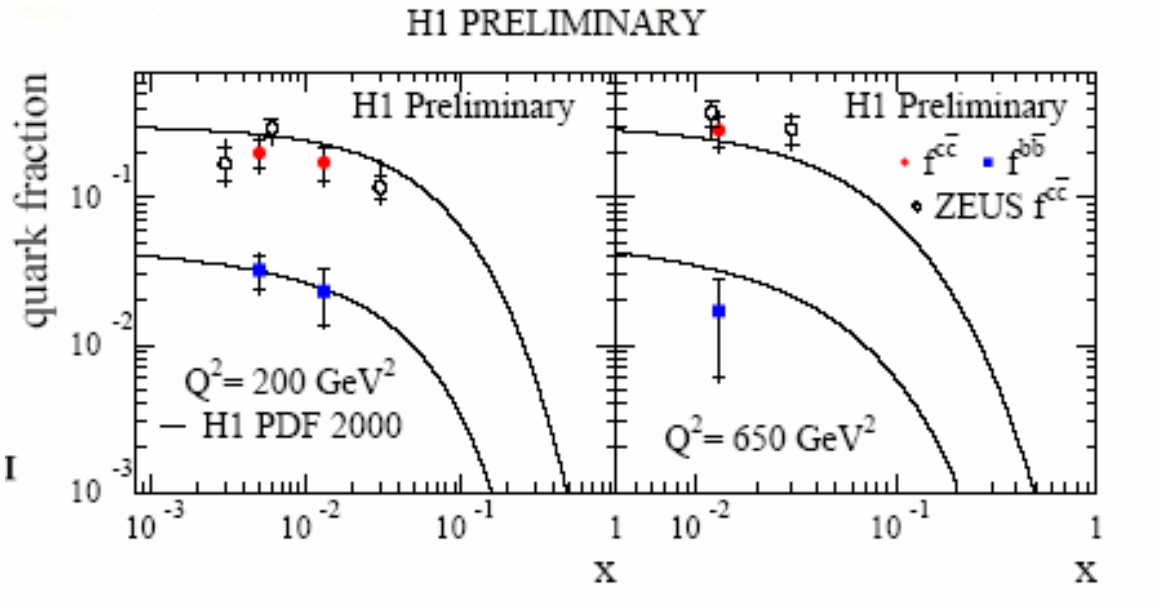
b-pdf at HERA goes to LHC

Beauty at HERA



Higgs at LHC



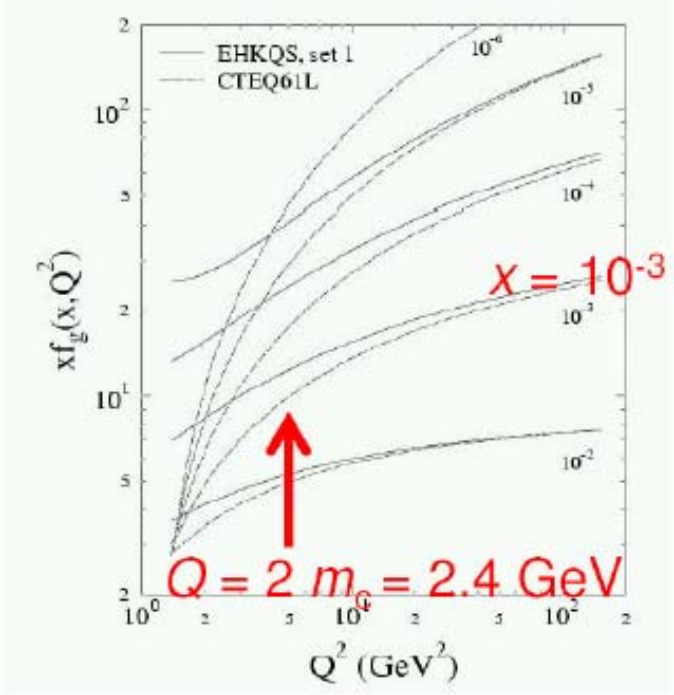


Need to measure the F_2^b at the same scale as ~$M_H/2$

Possibly reduce error by a factor of 4 at HERA-II

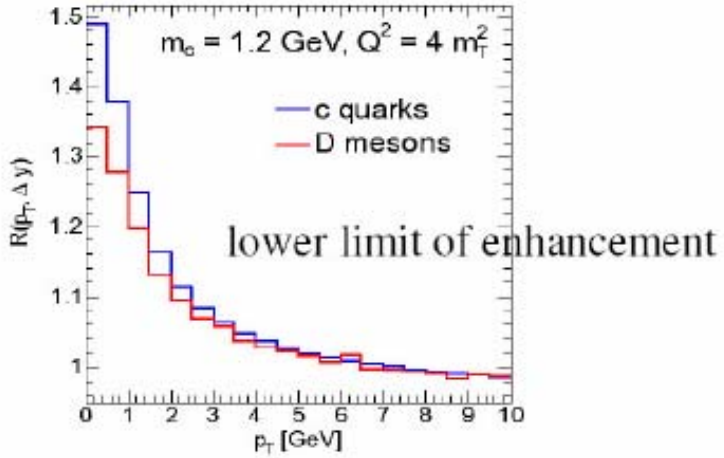
Charm production

Charm enhancement at LHC due to nonlinear gluon evolution



- Fits to HERA F_2 data at small x, small Q^2 improved by adding nonlinear terms (nonDGLAP) to gluon evol. [hep-ph/0211239]
- At LO, implies higher xf_g in x region probed by LHC

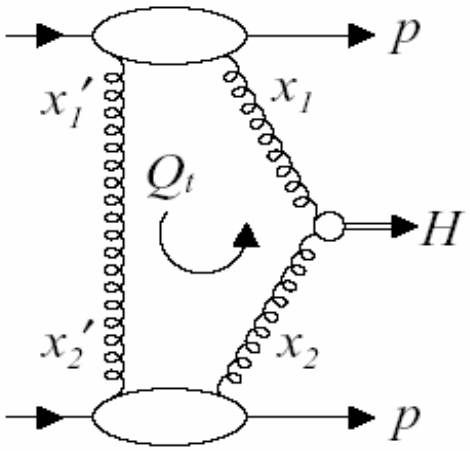
→ more charm at low p_T [hep-ph/0310111]



- ALICE can reconstruct D mesons down to $p_T \approx 0$ and look for the effect [hep-ph/0403098]

WG4: Diffraction

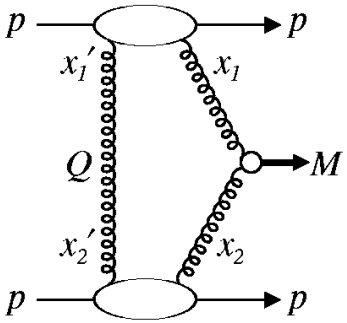
- Diffractive Higgs production
- Backgrounds to diffractive Higgs
- Diffractive factorization breaking
  - Dijet production
  - Charm production
  - Leading neutrons
- Rapidity gap survival (with WG2)
- New measurements e.g F_L^D
- Exclusive diffractive dijets
- Saturation effects and relation to MI/gap survival

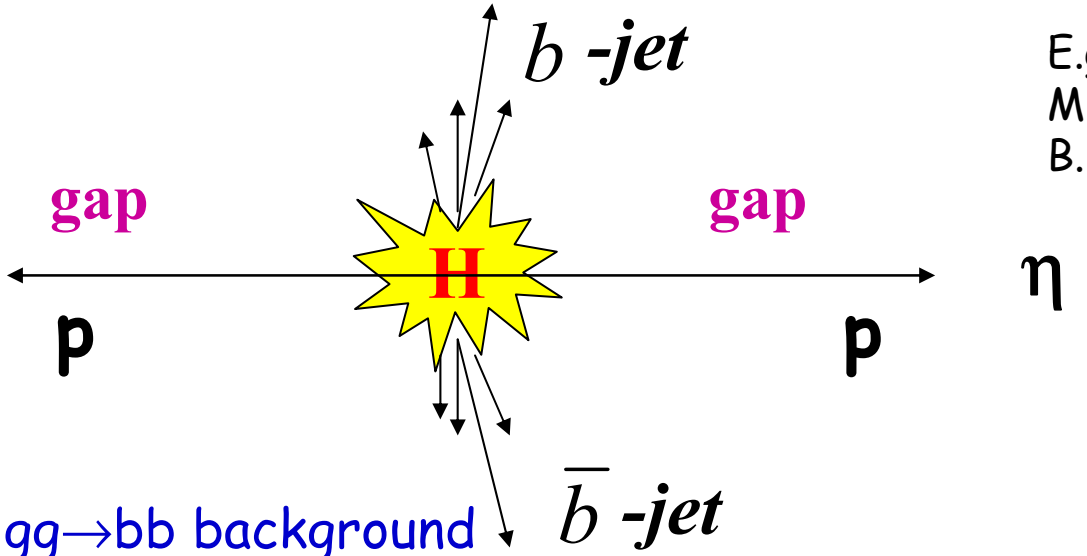


- Large part of the activities was transfer of experience of the knowledge and design and operation of detectors for forward physics from HERA to the LHC

Diffractive Higgs Production

Exclusive diffractive Higgs production pp→ p H p : 2-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : O(100) fb



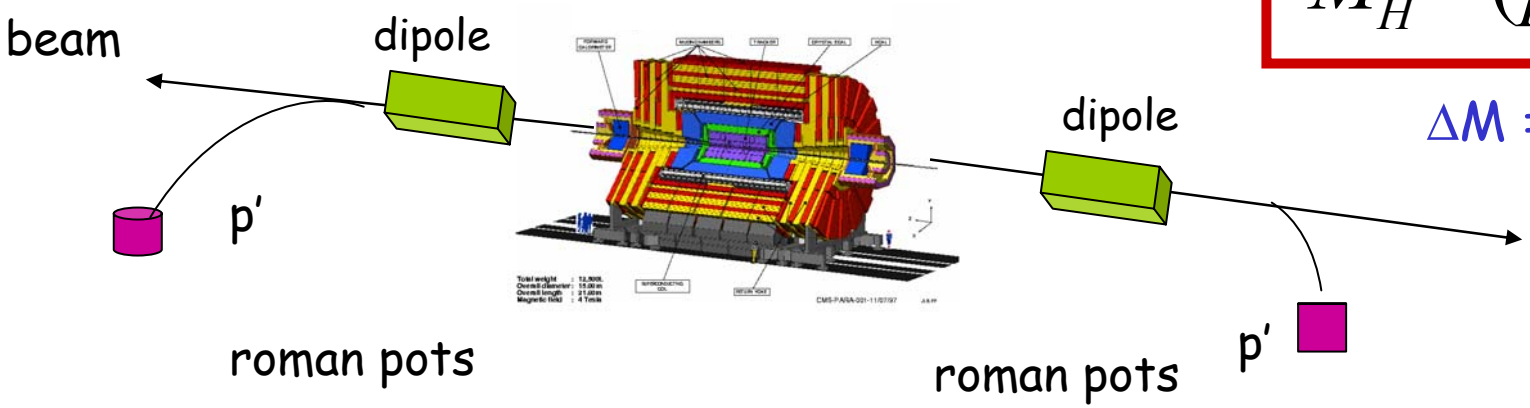


E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. …

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

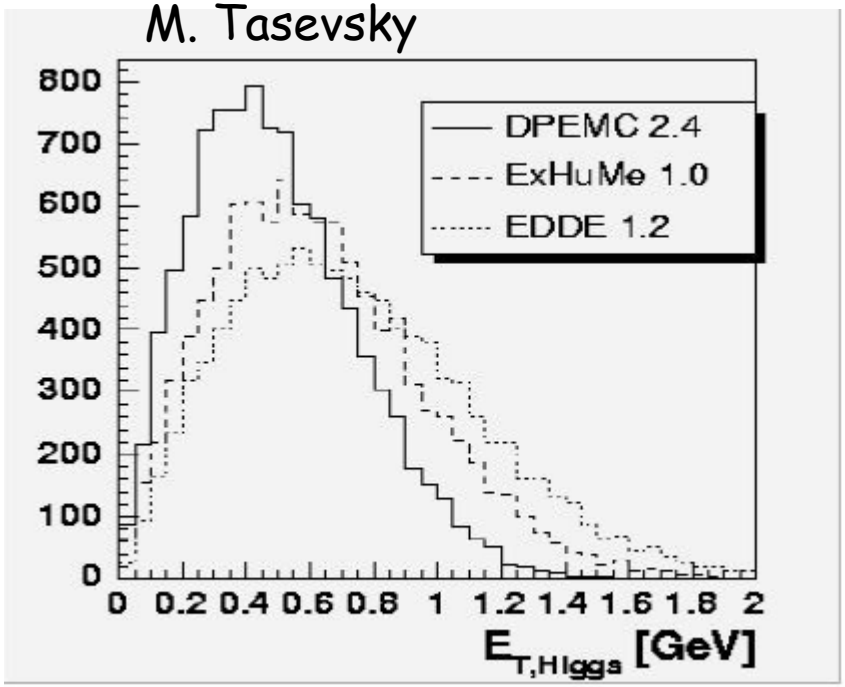


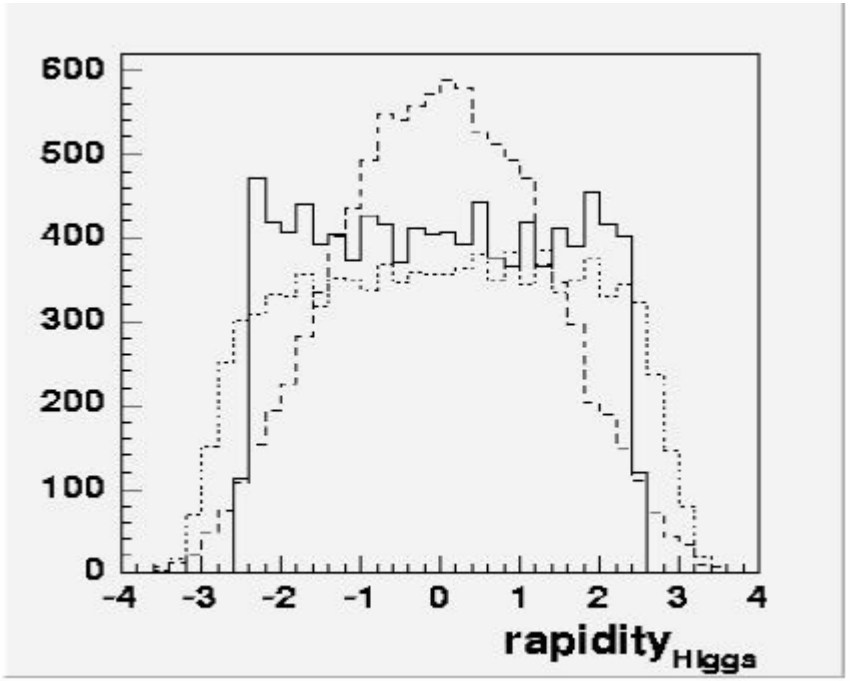
Diffractive Higgs production

A lot of useful and necessary discussion during this workshop on

- Different models
- Realism of such measurement

M. Tasevsky

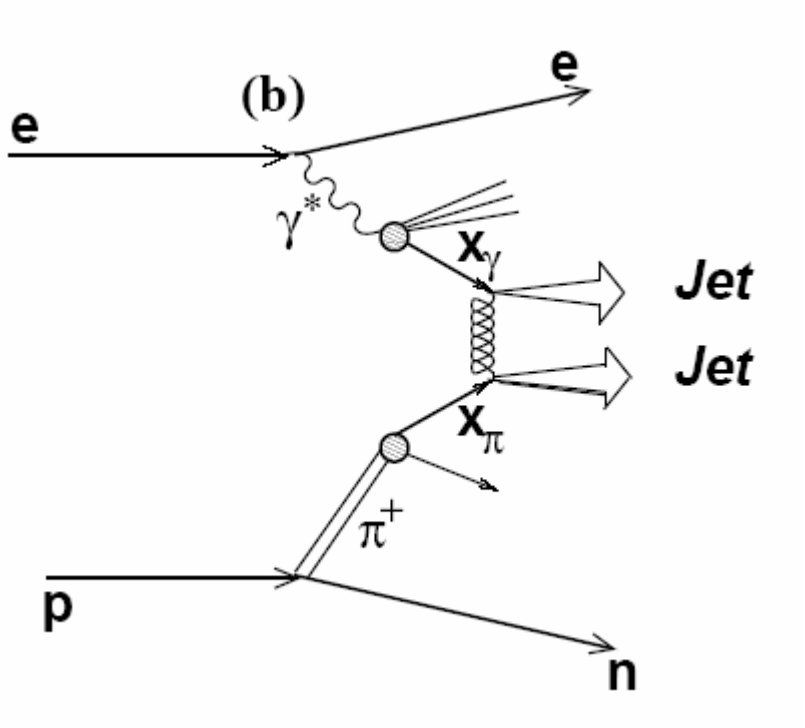


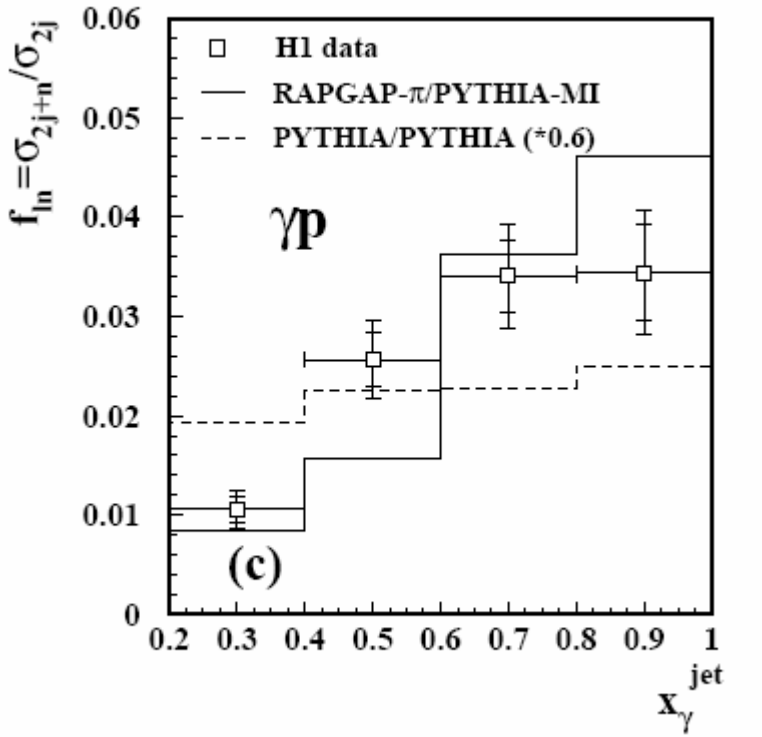


- Differences understood (Sudakov factors, parton distributions…)
- Exhume gives the more natural expected η behavior
- Khoze-Martin-Ryskin calculations checked by independent group ⇒ ok

Understanding the Gap Survival

A complementary way to study re-scattering effects in collisions
⇒ suggest to look at events with a leading neutron





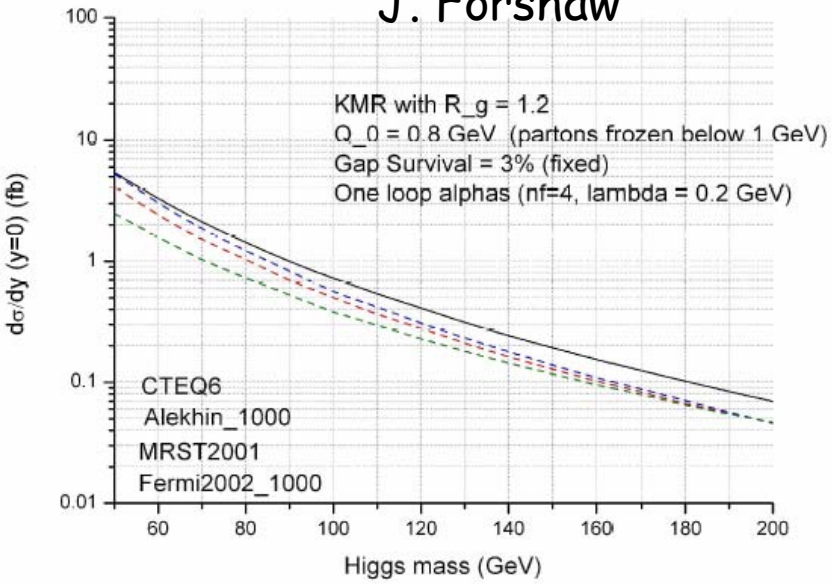
- Can be an ideal laboratory to study the dynamics of gap survival probability
- Effects can be calculated, x-pt correlations etc. (A. Kadialov et al. to appear)
- More measurements like the one shown here will be very usefull

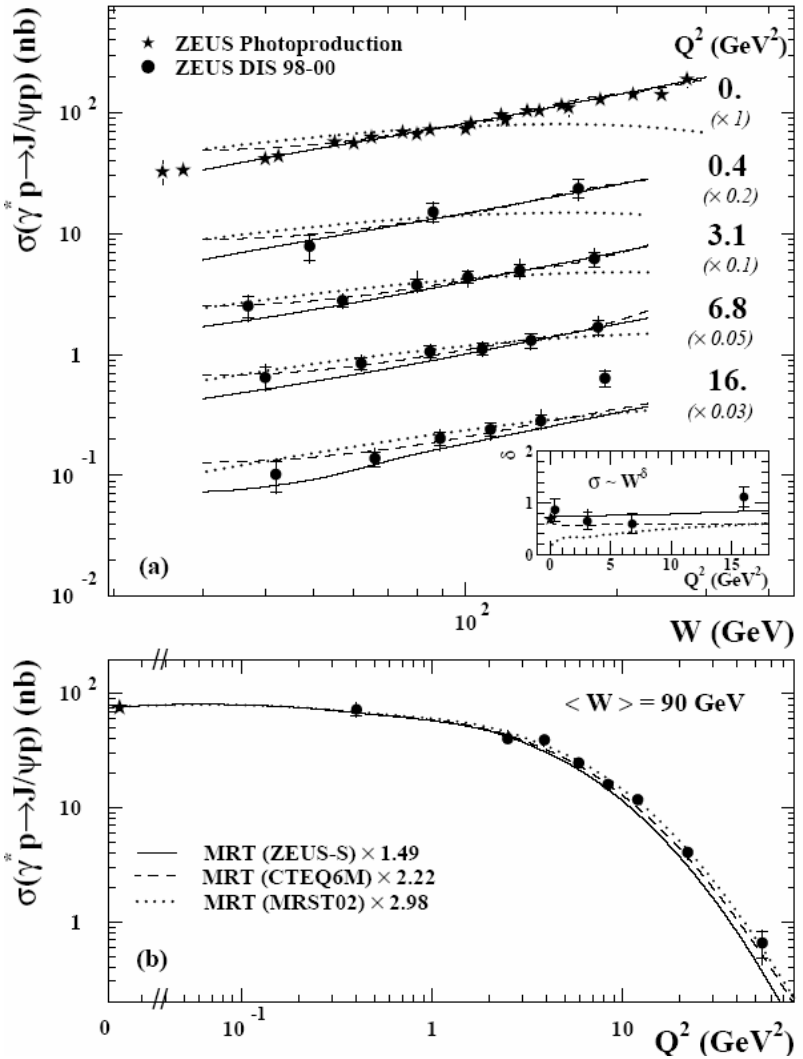
Generalized Parton Distributions

Generalized parton distributions affect the predictions for diffractive Higgs production

Can be measured at HERA eg. in exclusive J/ψ production

J. Forshaw

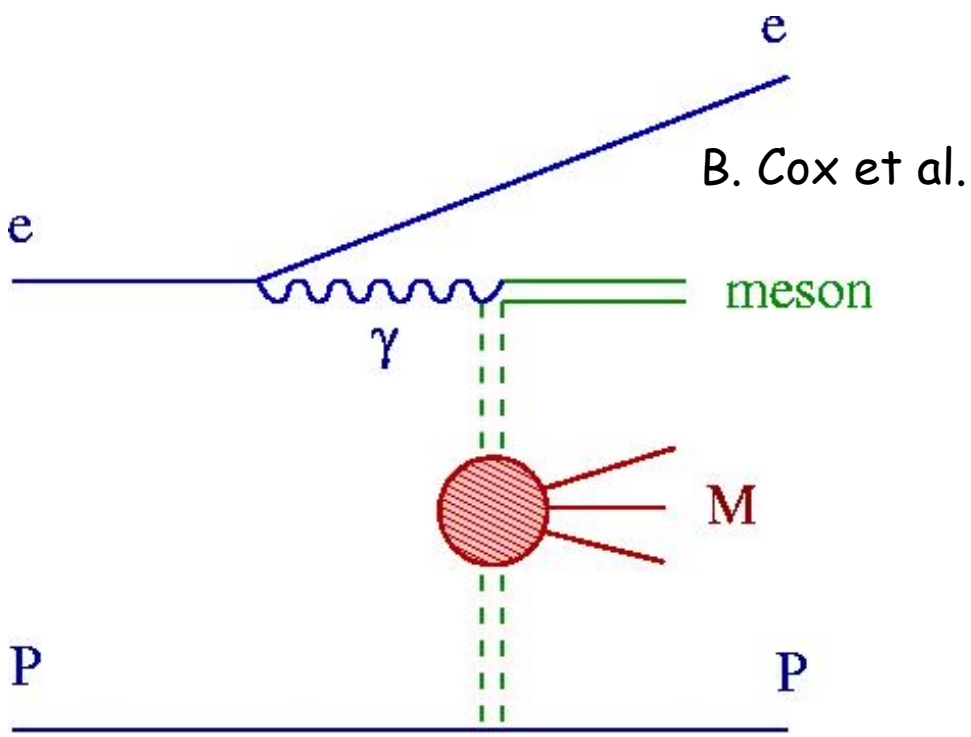




Upsilon production measurement would be even better!

Information from HERA

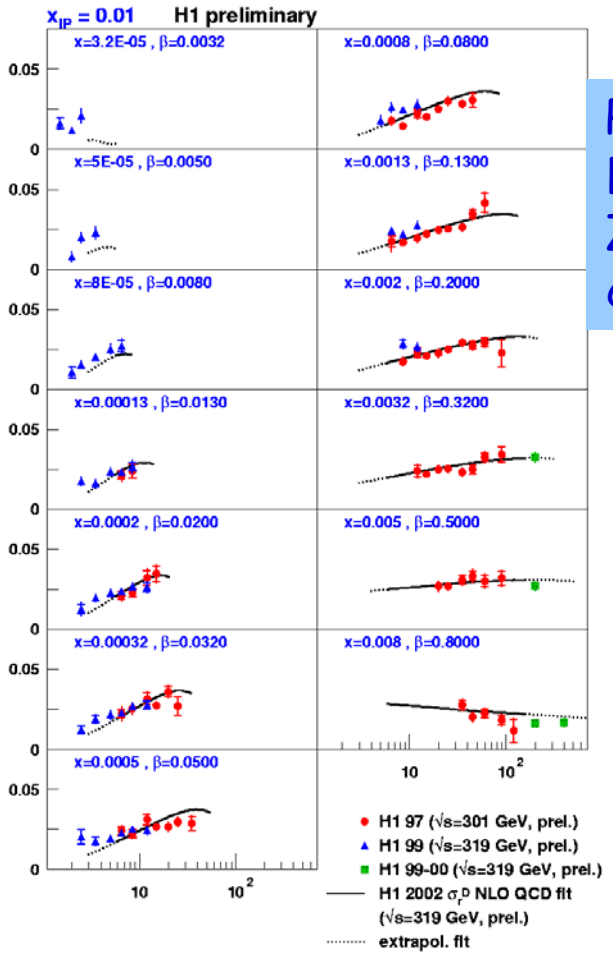
Study the process of $\gamma p \rightarrow VM + X + p$



Double pomeron exchange @ HERA

Measurable cross section at HERAII

Diffractive structure functions



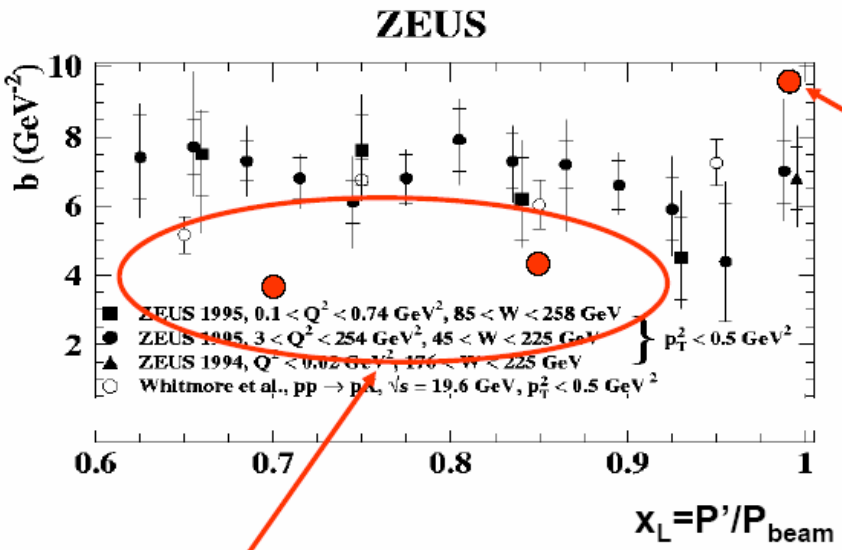
Planned:
F_2^D H1 and ZEUS data combination

+ Future F_L^D measurements to constrain the gluon further

Leading proton spectra in generators

M. Ruspa

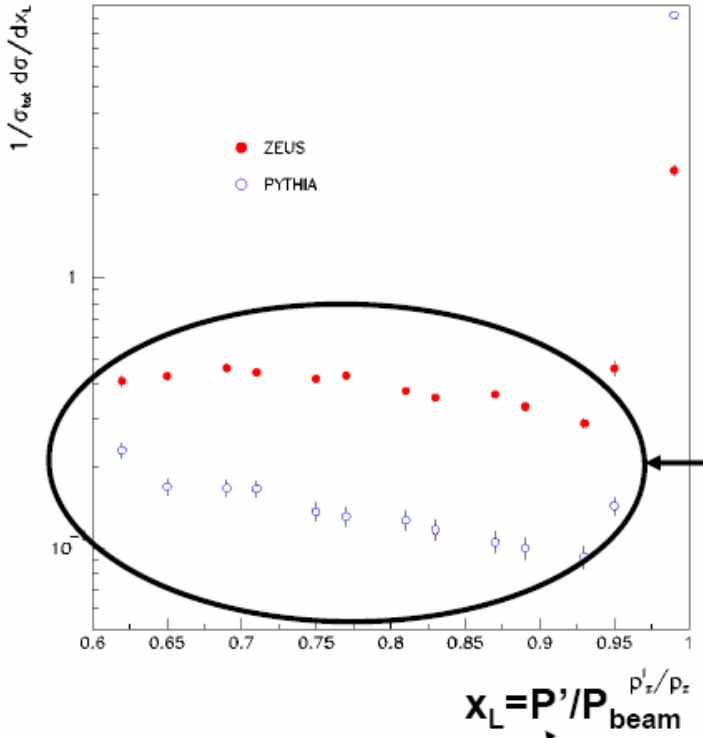
PYTHIA used for pile-up background studies at LHC!
How good is it when compared to data, e.g. from HERA??



Pythia approx OK in diffractive Peak, after taking shrinkage ($b = b_0 + 4\alpha' \ln s$) into account

Pythia too low outside diffractive peak

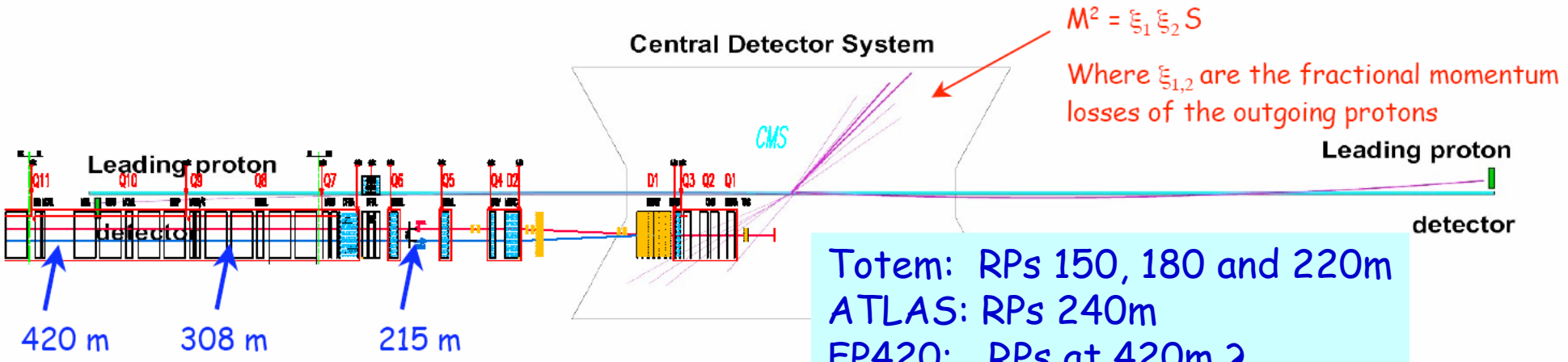
b-slope



Pythia wrong in shape and normalisation outside diffractive peak (approx factor 2-3)

Leading proton spectra

TOTEM/CMS Forward Detectors



$M^2 = \xi_1 \xi_2 S$

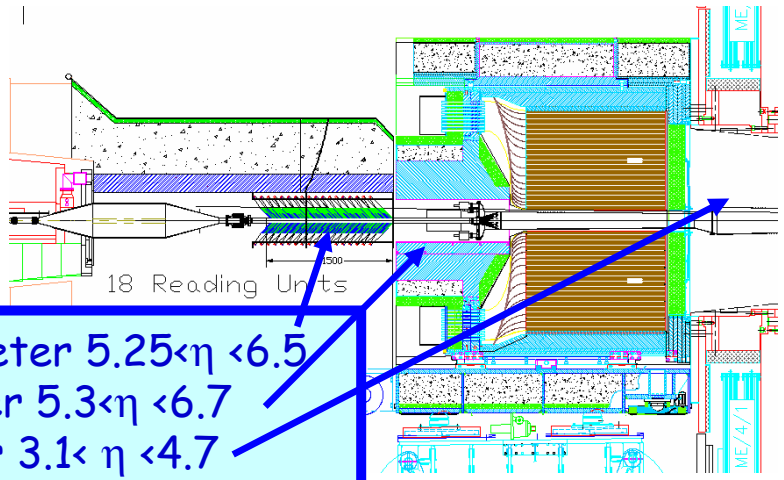
Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons

Totem: RPs 150, 180 and 220m
ATLAS: RPs 240m
FP420: RPs at 420m ?

Diffraction/Low-x is part of the LHC physics program (EOI)

CMS/TOTEM work on common LOI for diffraction+lowx

ATLAS starting…



- Castor calorimeter $5.25<\eta<6.5$
- T2 GEM tracker $5.3<\eta<6.7$
- T1 CSC tracker $3.1<\eta<4.7$
- ZDC calorimeter
- Region $7<\eta<9$ needs study

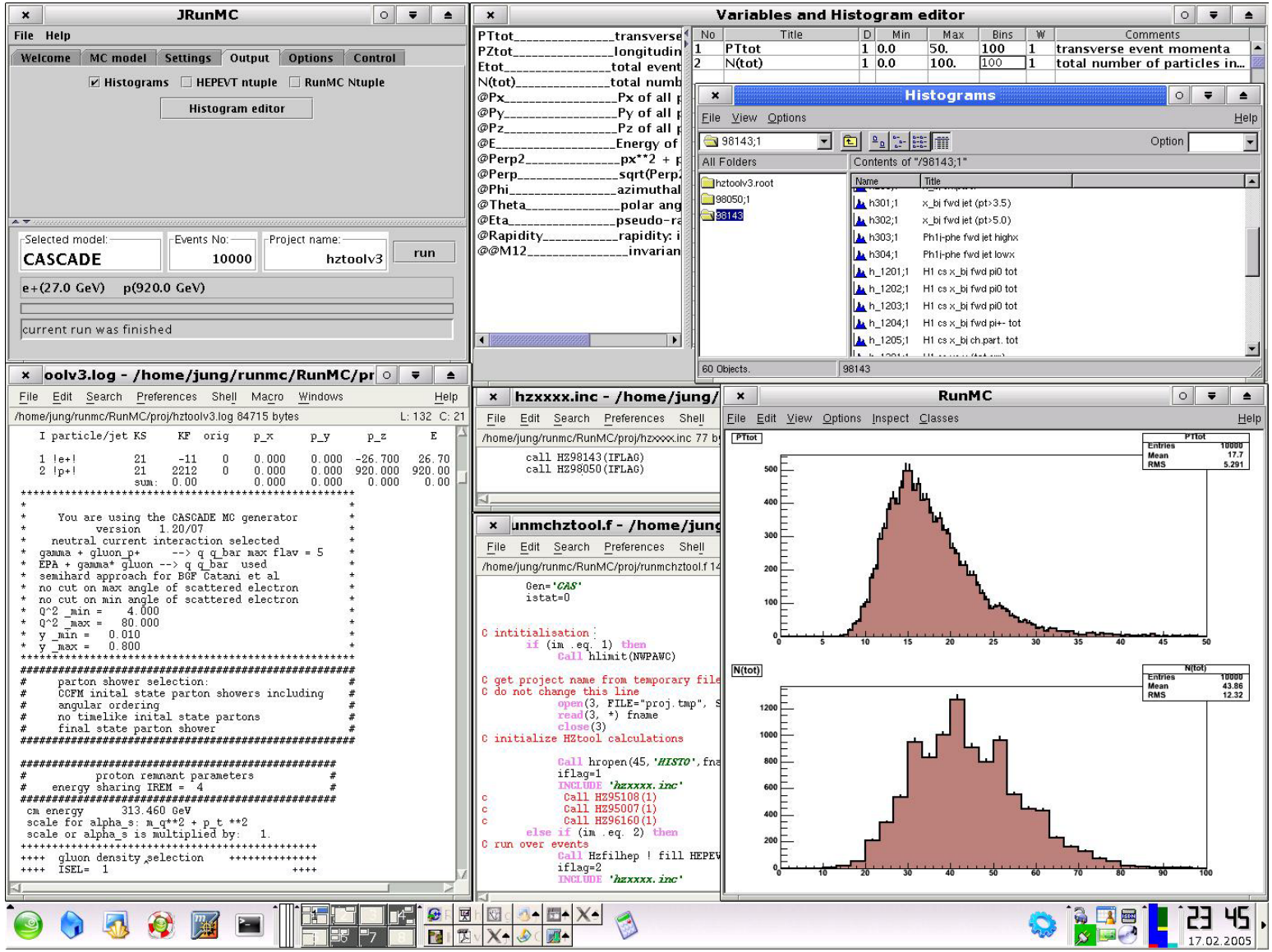
Opportunities for new groups to join or contribute to the LOI !!

WG5: 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 (but not done yet?)
- 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 other MC tools and comparisons with ep where possible
- Continuation of the MC@LHC workshop, concerning validation

Screen shot of RUNMC session

S. Chekanov



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 due to new measurements. Fits with 1-σ bands will be available.
  - Quantitative techniques 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 2-3? (personal guess)
- 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…

The Verdict

- 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.

Many studies still ongoing
⇒ Quantitative results for Proceedings and Beyond

I think we are not doing so bad!

Wait… did he say "beyond"?

- Phase I of this workshop is over and will be concluded with the proceedings
- However an important link between communities has been established.
- We should not just let it fade away, but strongly exploit it, to the benefit of both communities.

  ⇒ Therefore this is not THE END
- Keep momentum with one plenary HERA/LHC meeting per year

March	2006	CERN
March	2007	DESY
March	2008	CERN… (first physics @ LHC!?!)

- Keep also good contacts with TeV4LHC (a common meeting some time?)


DESY
HERA and the LHC
CERN
This will be the beginning of a
beautiful friendship !