Summary of WG2
Multi-Jet Final States and Energy Flow

HERA-LHC workshop, DESY, 13-16 March 2007

List of main topics discussed:

- Multi-Jet Topologies and Multi-Scale QCD
- Underlying Event and Minimum Bias
- Rapidity Gaps/Survival Probabilities
- Parton Shower/ME Matching

Convenors: Leif Lönnblad (Lund), Giulia Zanderighi (CERN), Claire Gwenlan (ZEUS/ATLAS), Eduardo Rodrigues (LHCb)

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Multi-Jet Topologies/Multi-Scale QCD

TALKS:

- High-E_T Forward Jets at HERA (H. PERREY)
- Prompt Photons at HERA (M. FORREST)
- Reconstruction of Top-Antitop Invariant Mass in All-Jet Top Decays using the k_T Algorithm (S. CHEKANOV)
- Jets Study and Comparison of Different Generators at LHCb (N. PUKHAEVA)

High-E_T Forward Dijets
(in Photoproduction at HERA)

H. Perrey

Motivations:

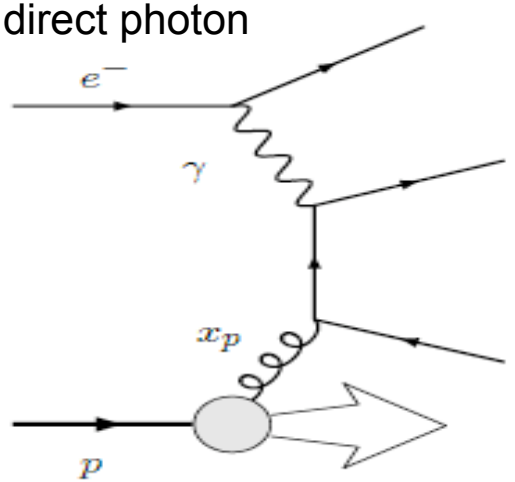
- Constrain the proton (+photon) PDFs
  (emphasis on measuring cross sections sensitive to high-x gluon PDF)
- Test NLO QCD and MC models with different implementations of parton cascade algorithms
  (measurement of azimuthal correlations
  -> sensitive to higher order effects)

kinematics

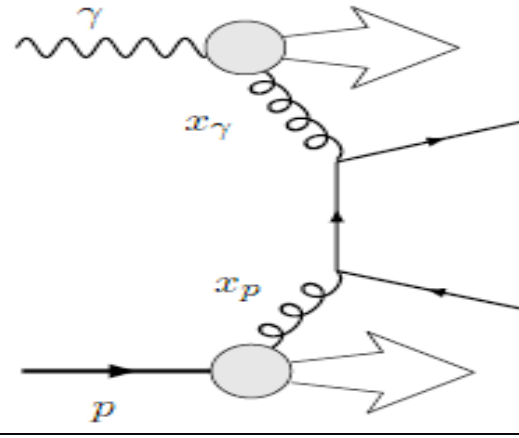
$$x_\gamma^{obs} = \frac{E_T^{jet1}\cdot\exp^{-\eta^{jet1}} + E_T^{jet2}\cdot\exp^{-\eta^{jet2}}}{2\cdot E_e\cdot y}$$

$$x_p^{obs} = \frac{E_T^{jet1}\cdot\exp^{\eta^{jet1}} + E_T^{jet2}\cdot\exp^{\eta^{jet2}}}{2\cdot E_e\cdot y}$$

direct photon



resolved photon



REMINDER: HERA Jets and the High-x Gluon

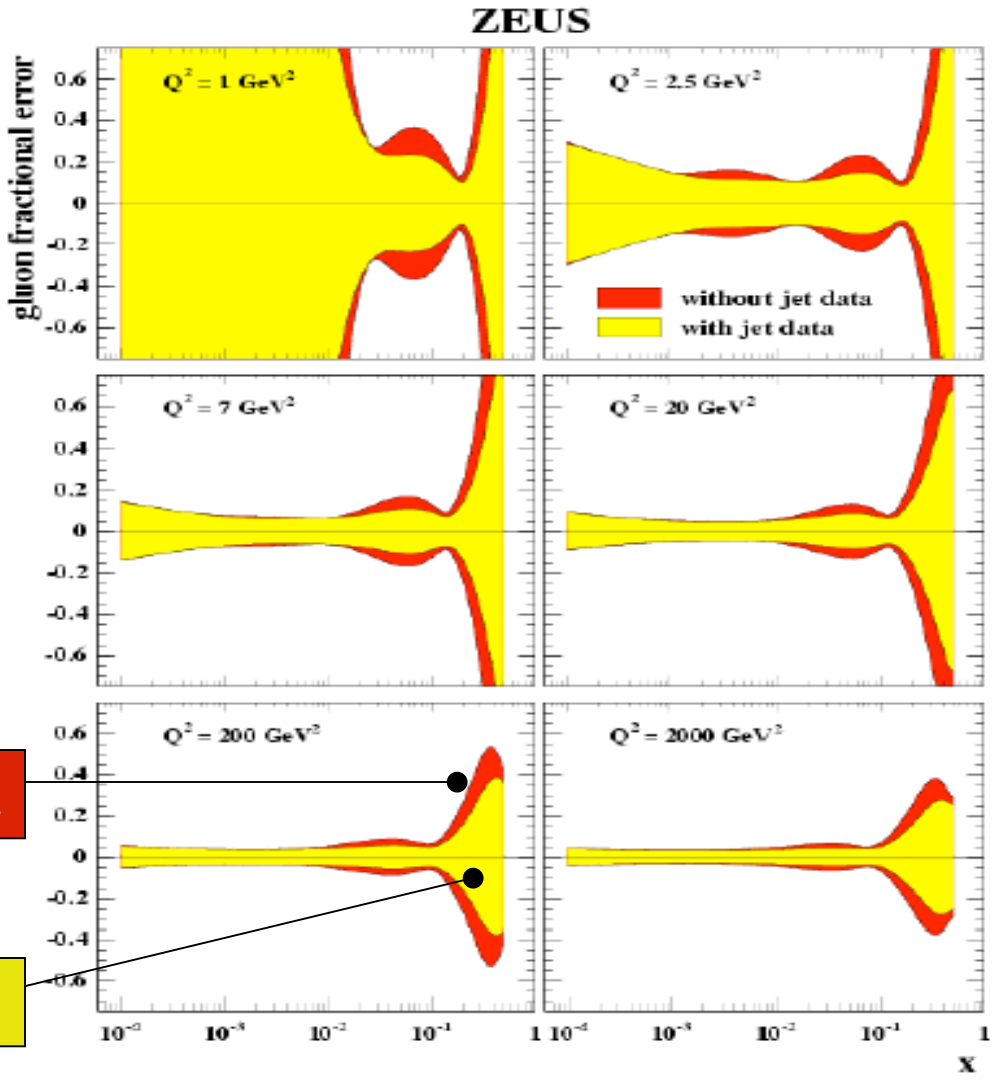
Previously:

- ZEUS PDF uses:

  NC/CC inclusive data

  + inclusive DIS jets
  + photoproduction dijets

-> Constraints on high-x gluon PDF



Without Jet Data

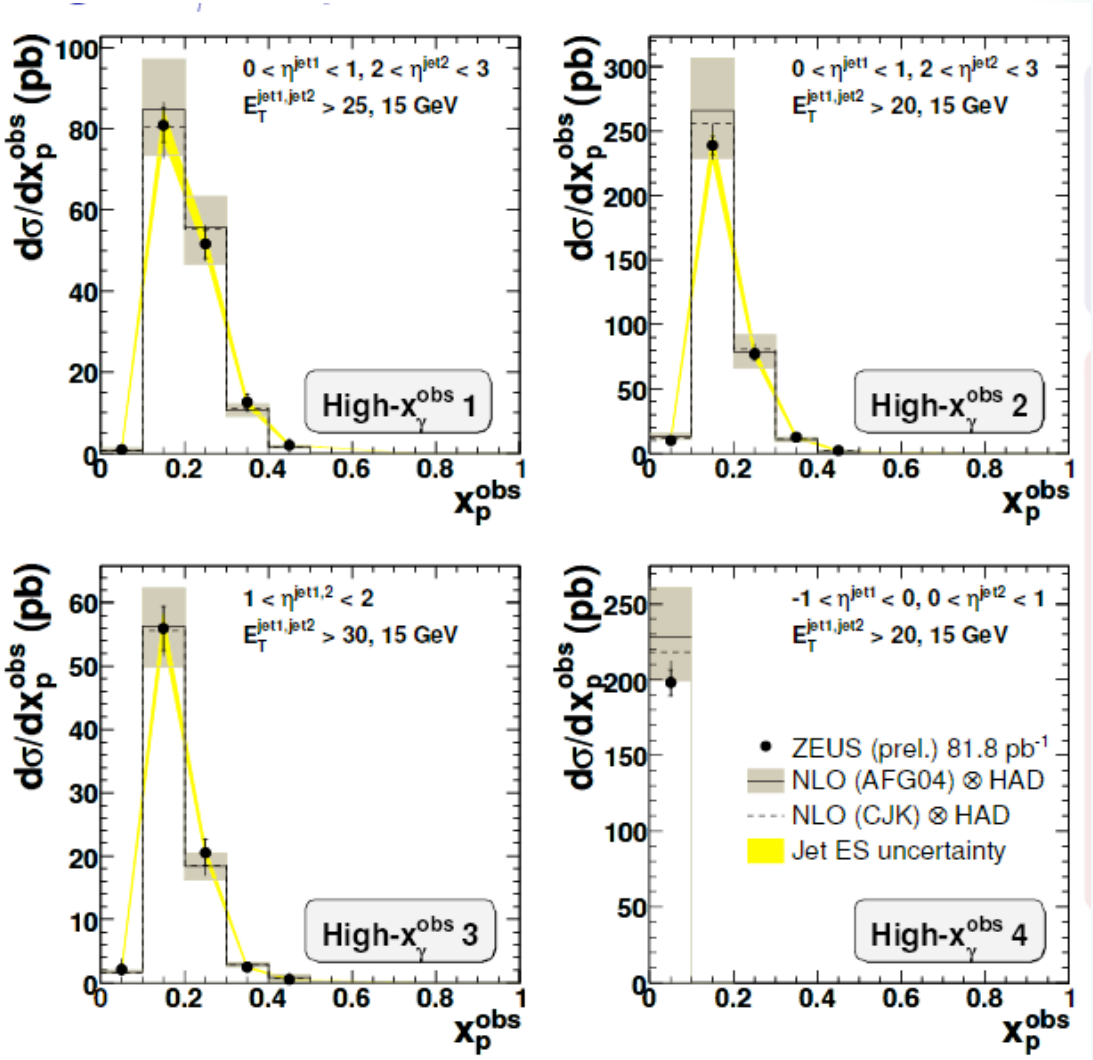
With Jet Data

High-E_T Forward Dijets
(in Photoproduction at HERA)

H. Perrey

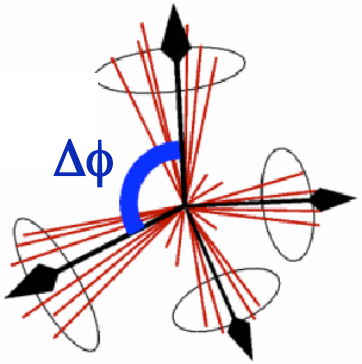
New Measurement:

- Cross sections "Optimised": for sensitivity to gluon PDF in proton
  - -> identify kinematic regions where gluon uncert. manifests itself most evidently
- Further constraints on high-x gluon in future QCD fits ?

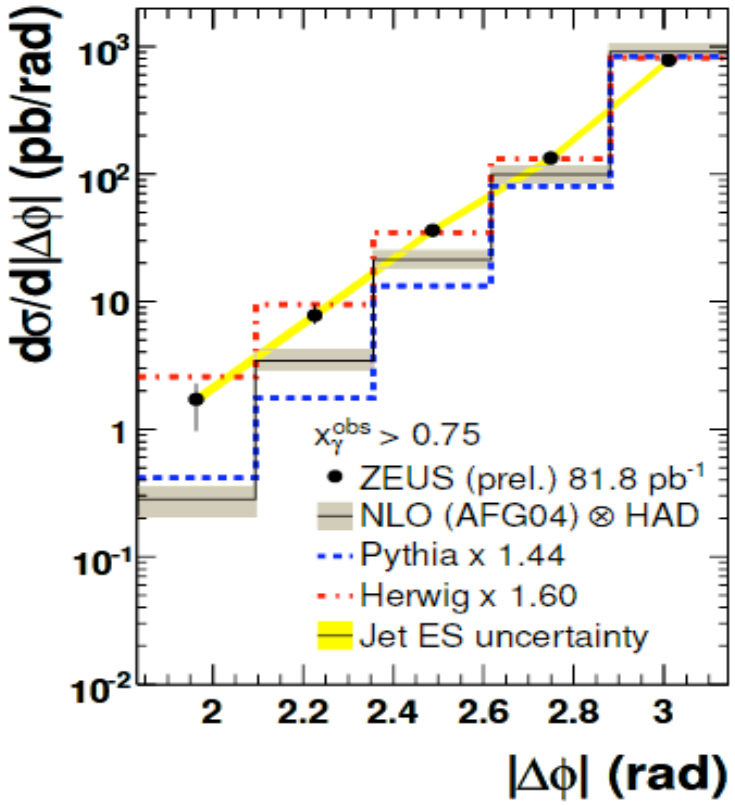


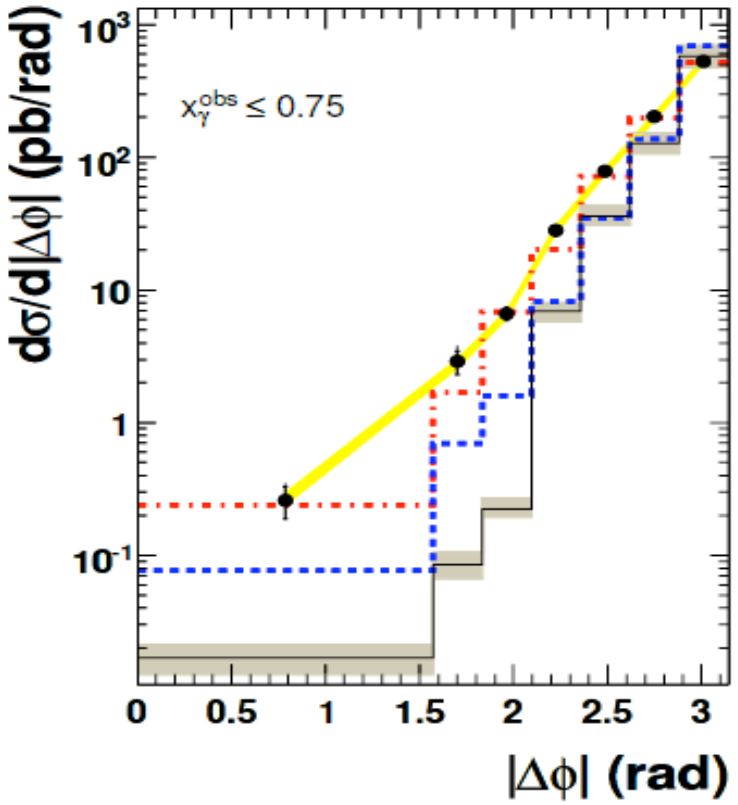
Azimuthal (de-)Correlations

H. Perrey



- $|\Delta\phi| = |\phi_1 - \phi_2|$ (LO QCD: delta function at π)
  -> Intrinsically sensitive to HO QCD
  - NLO QCD falls too steeply
  - HERWIG PS model describes shape of data well and PYTHIA less well… BUT (next slide)



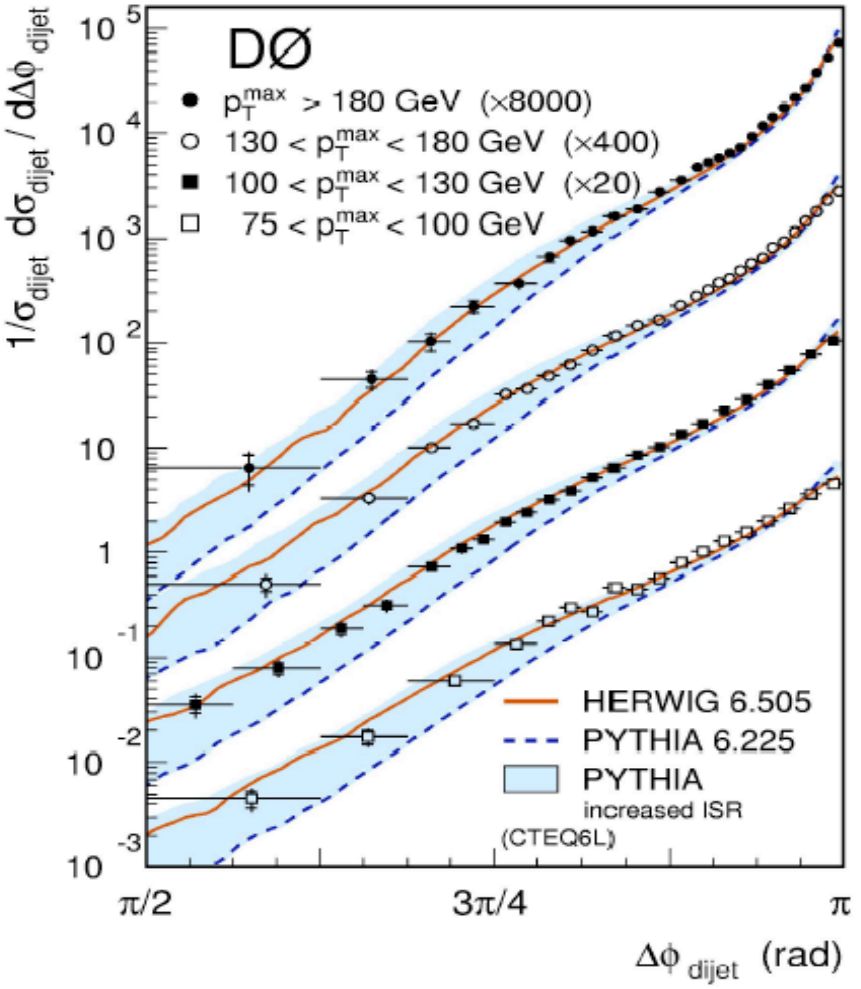


Azimuthal (de-)Correlations (cont.)

On previous slide PYTHIA used "out-of-the-box"

C.F. Tevatron measurement of azimuthal correlations
-> PYTHIA with increased ISR able to describe data
(see S. Mrenna's plenary talk)

New HERA measurement complementary to Tevatron
-> useful in future MC tunings?

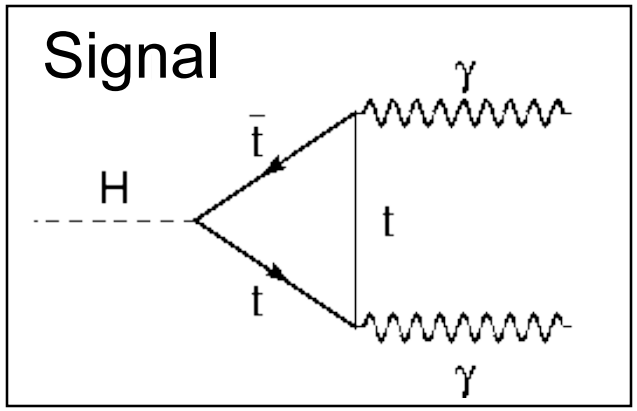


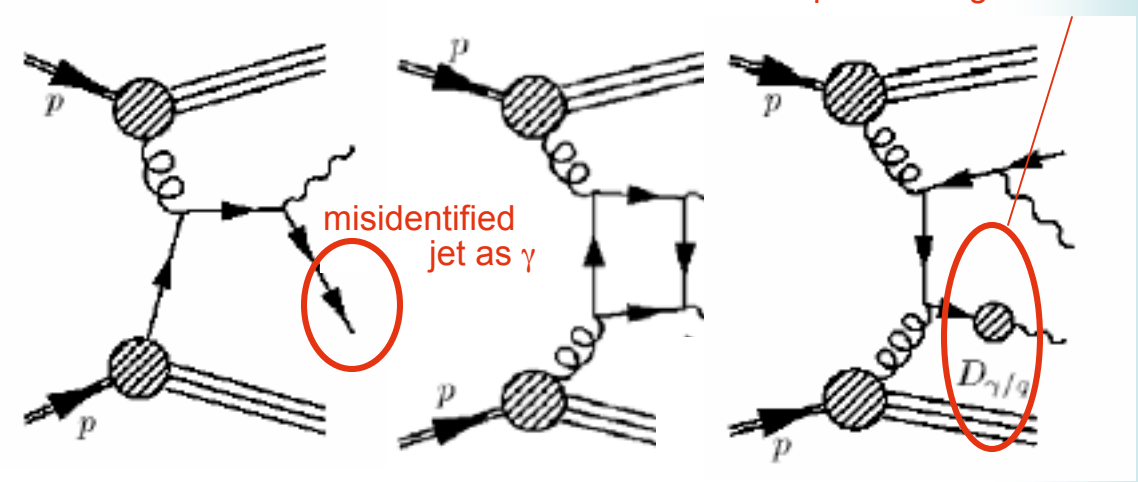
Prompt Photons

M. Forrest

- LHC motivations
  - Sensitive/clean test of QCD
  - Important background for H -> gamma gamma
    (LHC: Promising channel for 100 < m_H < 150 GeV)
  - Directly sensitive to quark and gluon PDFs
    -> reduction of high-x gluon PDF uncertainty in QCD fits?

Prompt Photons as a Background to H → γγ





example prompt photon backgrounds to H → γγ

Prompt Photons

M. Forrest

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  - Sensitive/clean test of QCD
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    (LHC: Promising channel for 100 < m_H < 150 GeV)
  - Directly sensitive to quark and gluon PDFs
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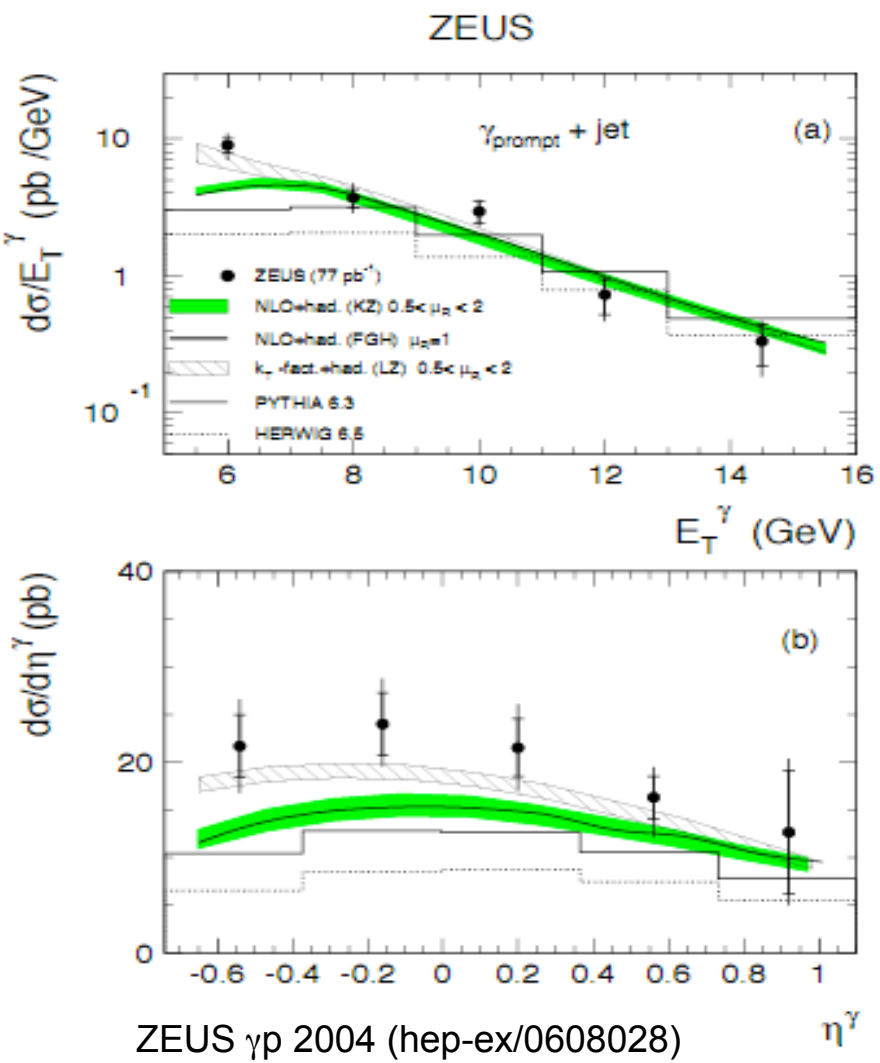
- Questions
  - How well do we know the prompt photon cross section?
  - Can prompt photons be used to constrain the gluon PDF?
  - How well do we know the quark-to-photon fragmentation function, $D_{\gamma/q}$?

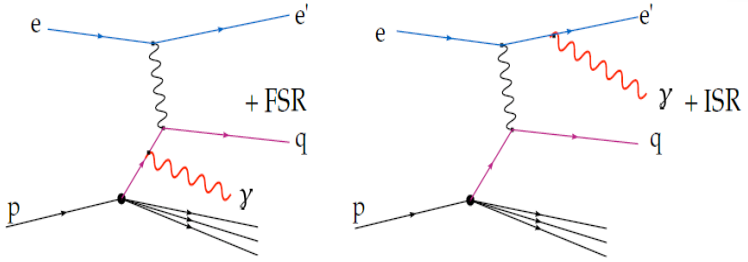
    (so far only measured at LEP - can we measure it at HERA?
    -> would require major experimental rethink)

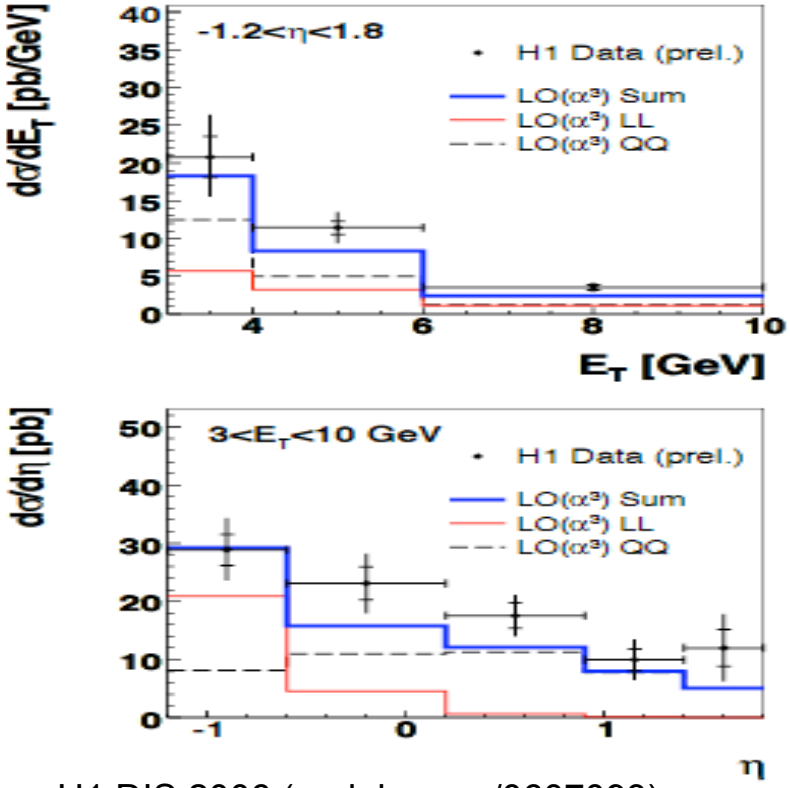
Prompt Photons
(Cross Sections at HERA)

M. Forrest



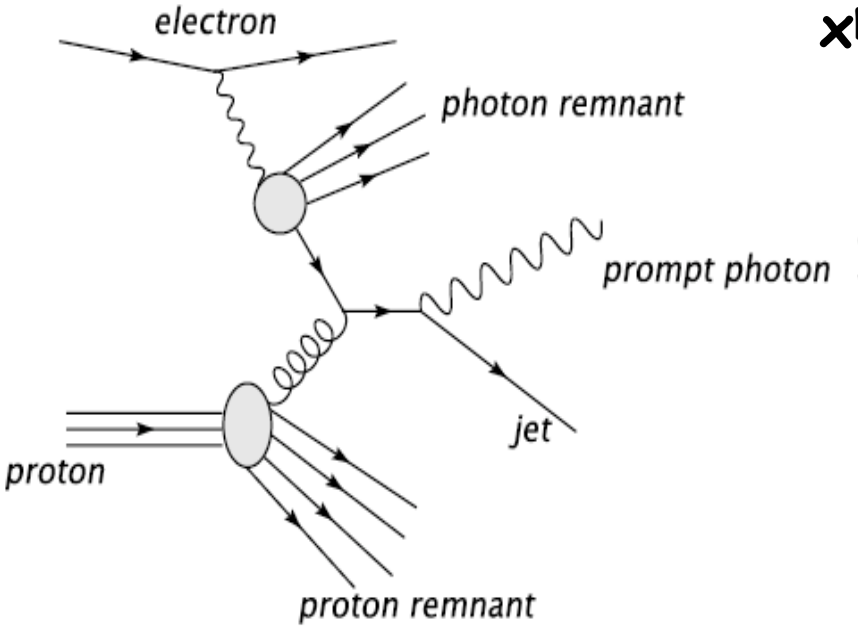
ZEUS γp 2004 (hep-ex/0608028)





H1 DIS 2006 (prel. hep-ex/0607093)

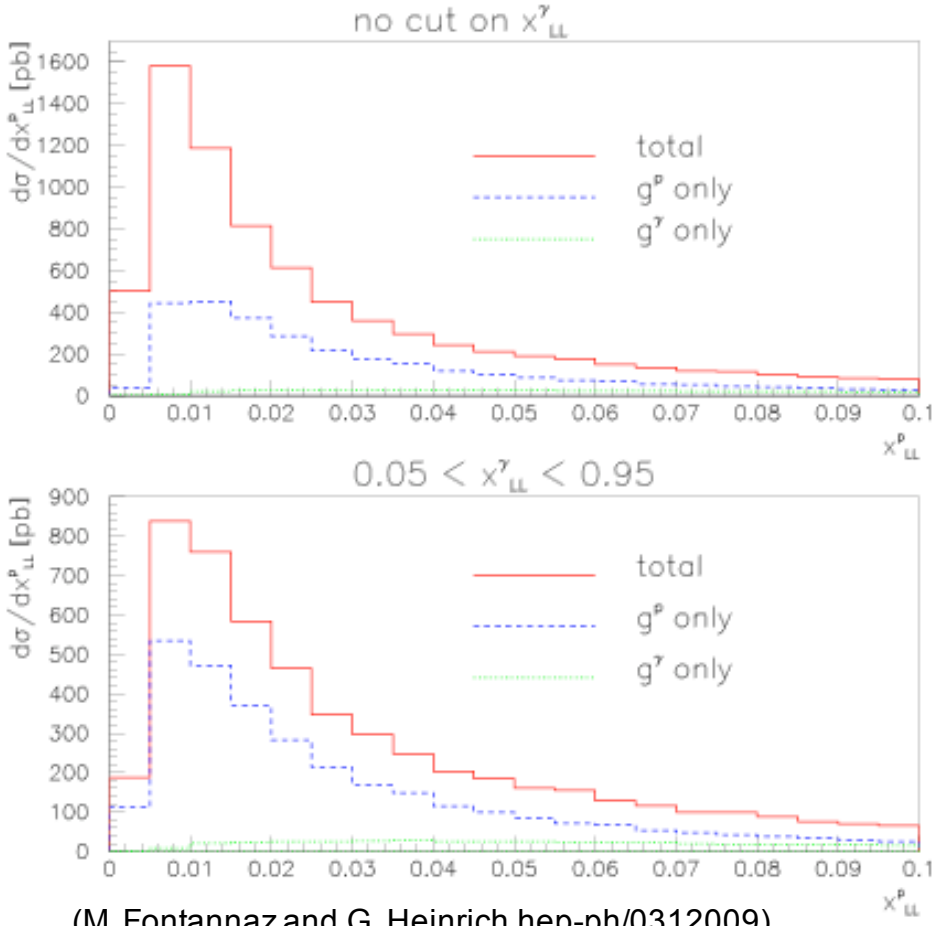
Prompt Photons
(Constraining the Gluon)



- Resolved process sensitive to gluon PDF in proton
- "Optimise" cross sections for sensitivity to high-x gluon?
  - Cuts on x^{γ}_{LL} , $\eta^{\gamma,Jet}$ promising

OBSERVABLES: (at LO: $x_{LL} \approx x_{obs}$)

$$x^{p}_{LL}: \frac{p^{\gamma}_{T}(e^{\eta^{\gamma}} + e^{\eta^{jet}})}{2E^{P}} \qquad x^{\gamma}_{LL}: \frac{p^{\gamma}_{T}(e^{-\eta^{\gamma}} + e^{-\eta^{jet}})}{2E^{\gamma}}$$



(M. Fontannaz and G. Heinrich hep-ph/0312009)

Fully Hadronic Top Decays @ LHC
(using the kT algorithm)

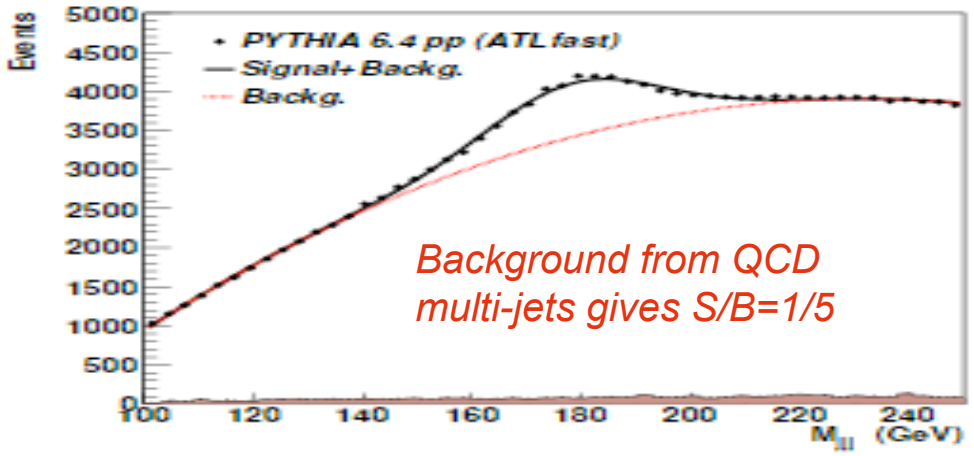
S. Chekanov

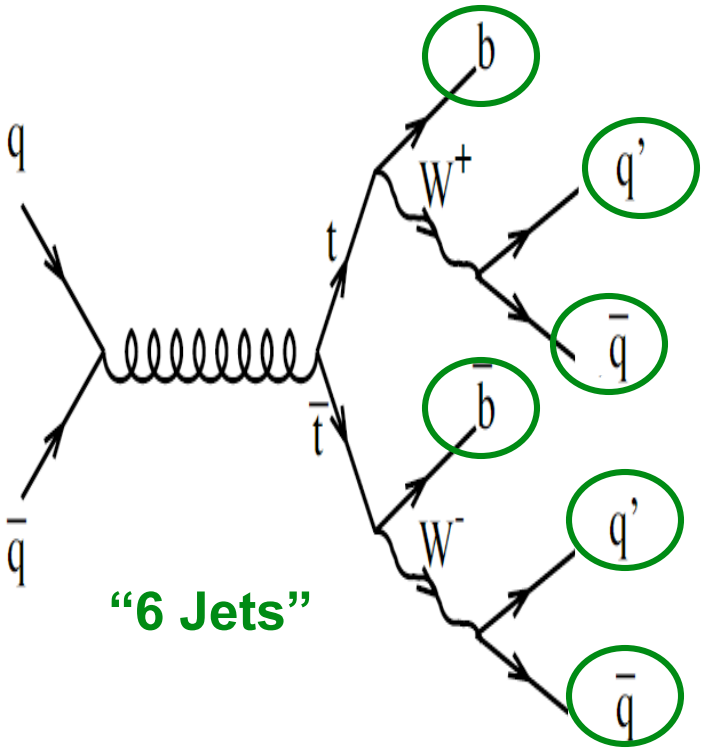
Motivation:

- Sensitive to new physics @ the TeV scale (resonant X -> ttbar)
  (XDs,CP violating Higgs sector, technicolor,…)
  -> expect narrow bump on smoothly falling M(ttbar) dist.

Fully Hadronic Top Decays:

- Kinematics can be fully reconstructed
- Largest BR=46% of all top decays
- BUT large QCD background



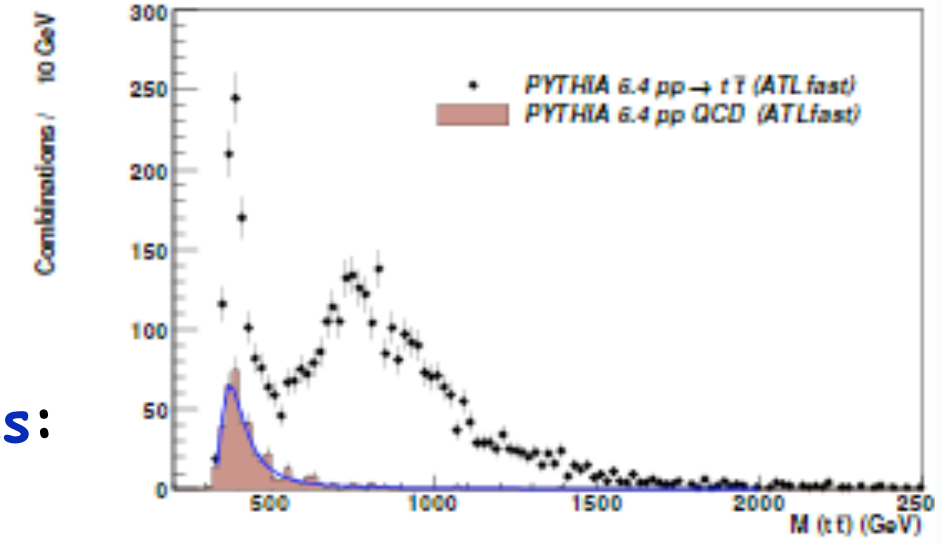


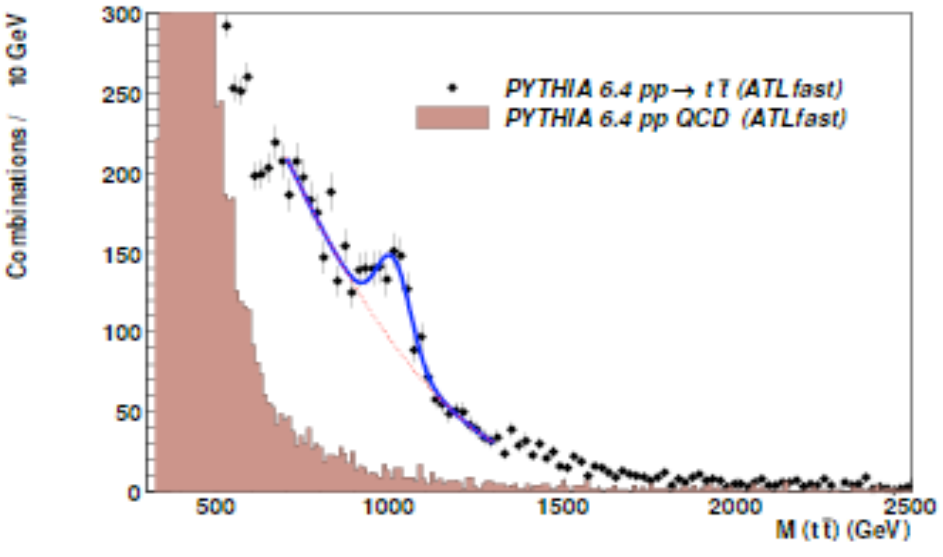
Invariant Mass Distribution

S. Chekanov

- QCD (+combinatorics) backgrounds peak at ttbar mass threshold
  - -> Small QCD background for M(ttbar) > 700 GeV
- Prospects for New Physics:
  - narrow resonance X->ttbar @ 1 TeV assumed
  - $\sigma(X)BR(X->ttbar) > 6pb$ needed for 6σ discovery (all-hadronic channel, 5 fb^{-1}) (exp. mass resolution ~ 9 GeV)
- Appears competitive with semi-leptonic channel

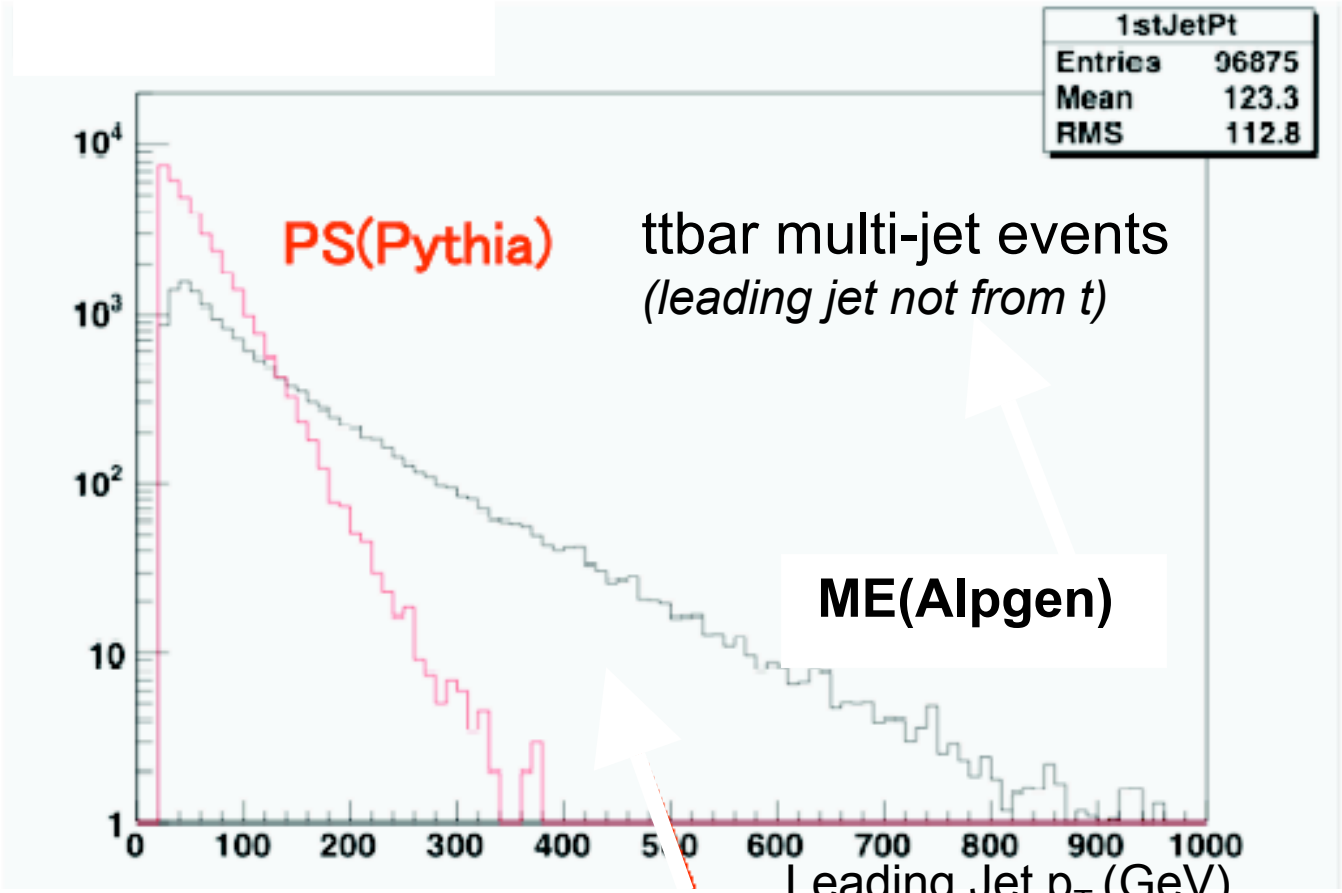
(S. Bentvelsen, hep-ph/0408111)





Matrix Element vs Parton Showers

CAVEAT: So far, study performed with PYTHIA PS MC -> six jets (is a lot!) -> ALPGEN/Sherpa MCs (using exact LO ME matched to PS) may change things significantly -> yet to be studied



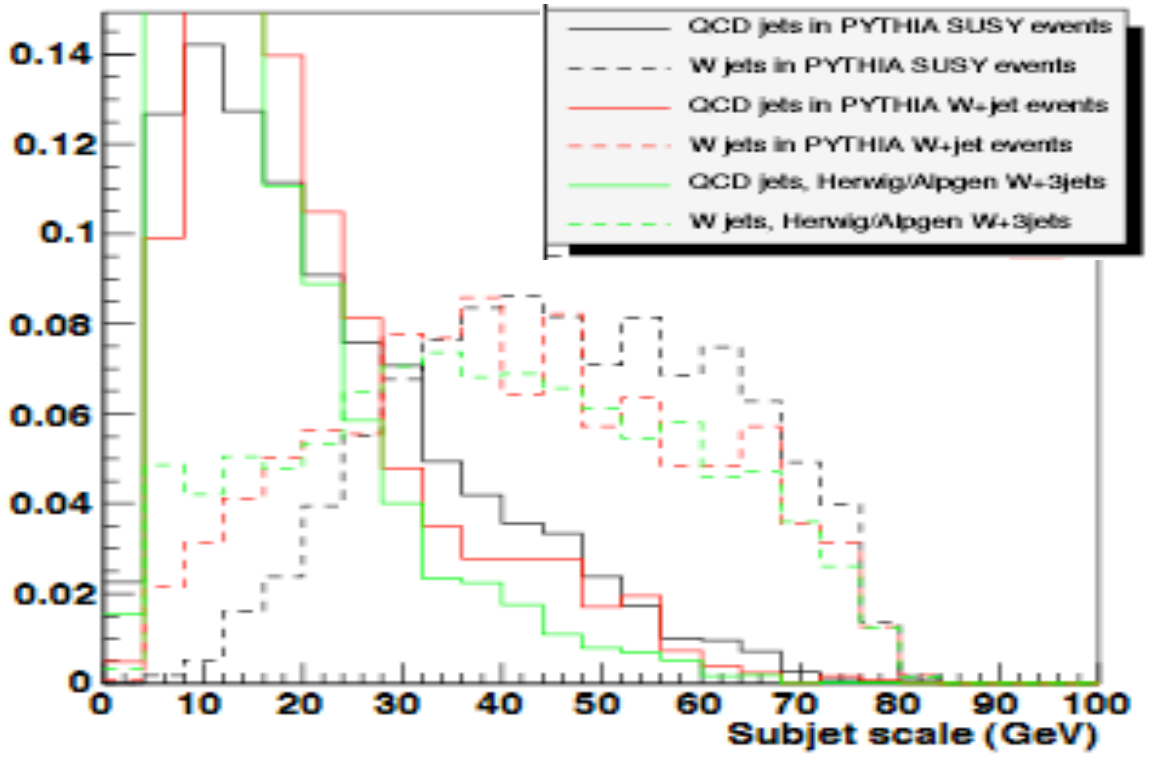
Idea?

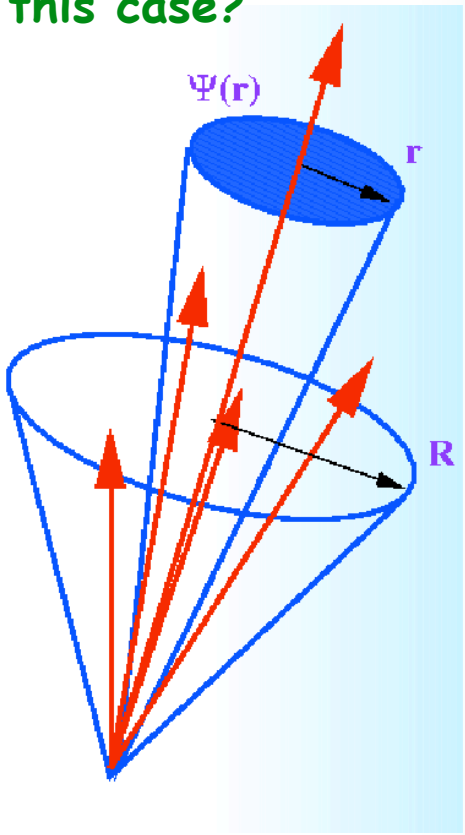
GENERAL METHOD:

Case where W (or Z,..) highly boosted (both quarks in single jet)

- **Jet MASS and SUB-STRUCTURE can discriminate between signal/QCD**
  - **-> could help with the large QCD backgrounds in this case?**

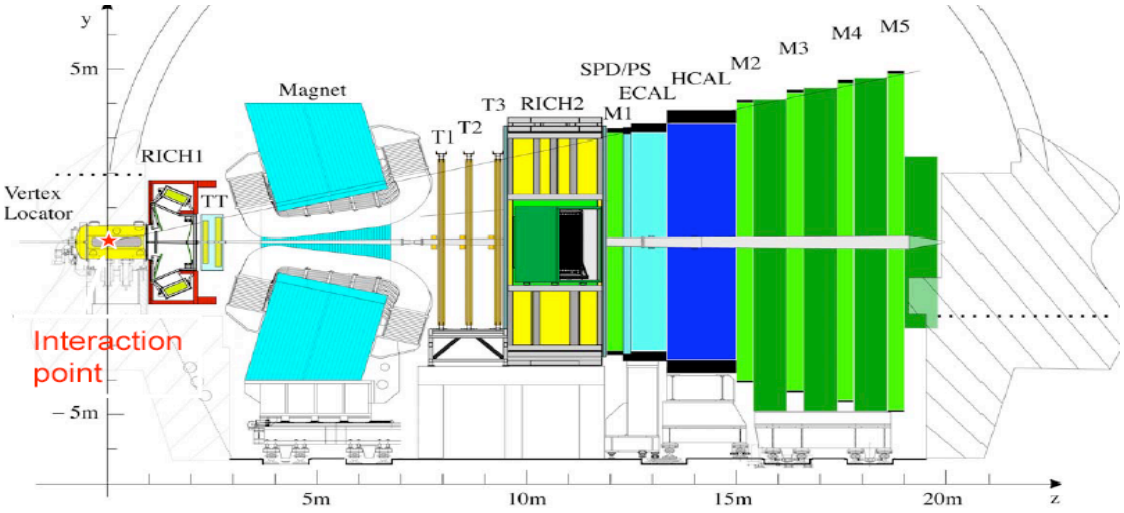
J. Butterworth, J. Ellis, A. Raklev, hep-ph/0702150





= sqrt(y)*pT

Jets Studies @ LHCb



LHCb: small acceptance forward spectrometer

- *coverage: 15-300 mrad (η = 1.9-4.9)*
- *lower luminosity than ATLAS/CMS → cleaner*

LHCb is dedicated to the Search for New Physics in CP violation and Rare B decays

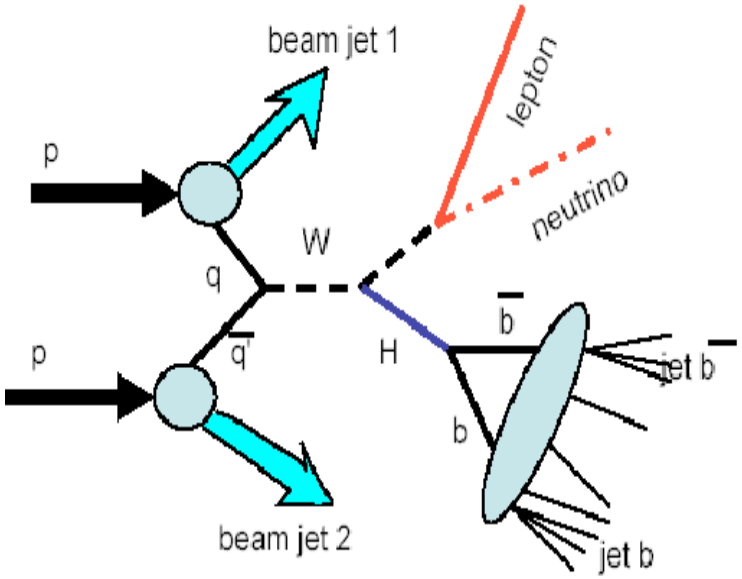
BUT smaller, parallel effort, ongoing devoted to Higgs/Jets studies

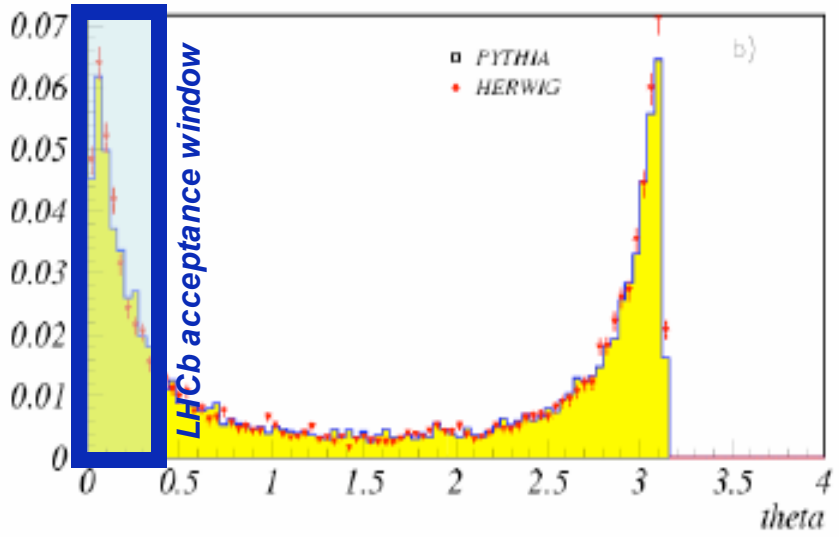
GOAL: Establish Sensitivity to SM/Light Higgs

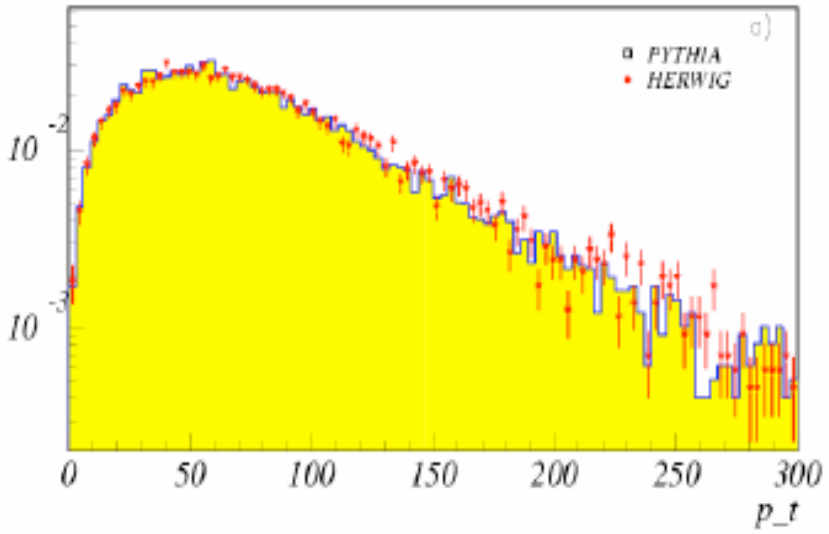
- **Understand best jet algorithms for use in forward environment** (jet definition, energy corrections, jet acceptance)
- **Study and compare the results of standard MC generators**

EG: SM Higgs @ LHCb

N. Pukhaeva







- 30% SM Higgs (m_H=125 GeV) within LHCb acceptance

STRATEGY:

- pp->WH (H->bbar,W->lv)
- So far, early studies on comparing results from standard MC generator

Underlying Event/Minimum Bias

TALKS:

- Underlying Event Tunings for the LHC (A. MORAES)
- Multiple Interactions in DIS (S. OSMAN)
- Multiple Interactions in Photoproduction (L. MARTI)
- Dipole Model with Energy Conservation and Swing (E.AVSAR)
- Multiple Interactions+Energy Loss (M. STRIKMAN)
- Parton Correlations/Multi-Parton Exclusive Cross Sections (D. TRELEANI)

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} WG5

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} WG5

- Discussion of Various Issues/Open Questions (ALL)

Discussion: Some Issues/Open Questions

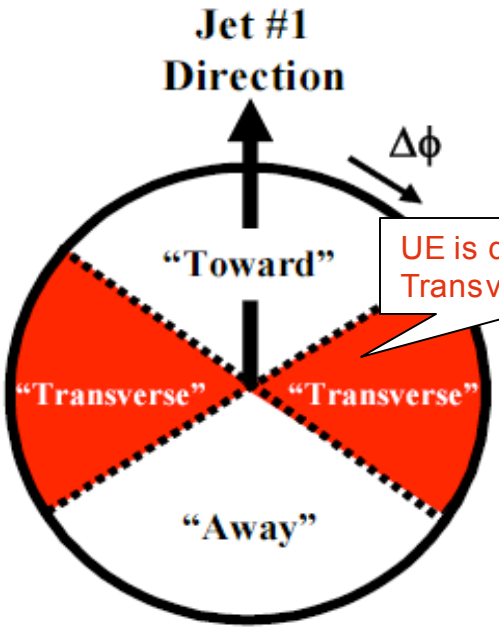
- How reliable are our present models/understanding of the UE and MI?
  - Are PYTHIA-MI/JIMMY the final answer to MI and UEs?
    Do we understand MI enough to just tune the MCs?
    What if we can't tune the models to LHC?
- Do we have the necessary measurements, tools and information to obtain the best tuned MC generators?
  - Are further investigations needed from HERA?
    Are data available in computer useable form?
- What are the prospects for the 1st LHC papers?
  (EG: underlying events - are the analysis strategies clear?)

MC Tuning for UE/MI

A. Moraes

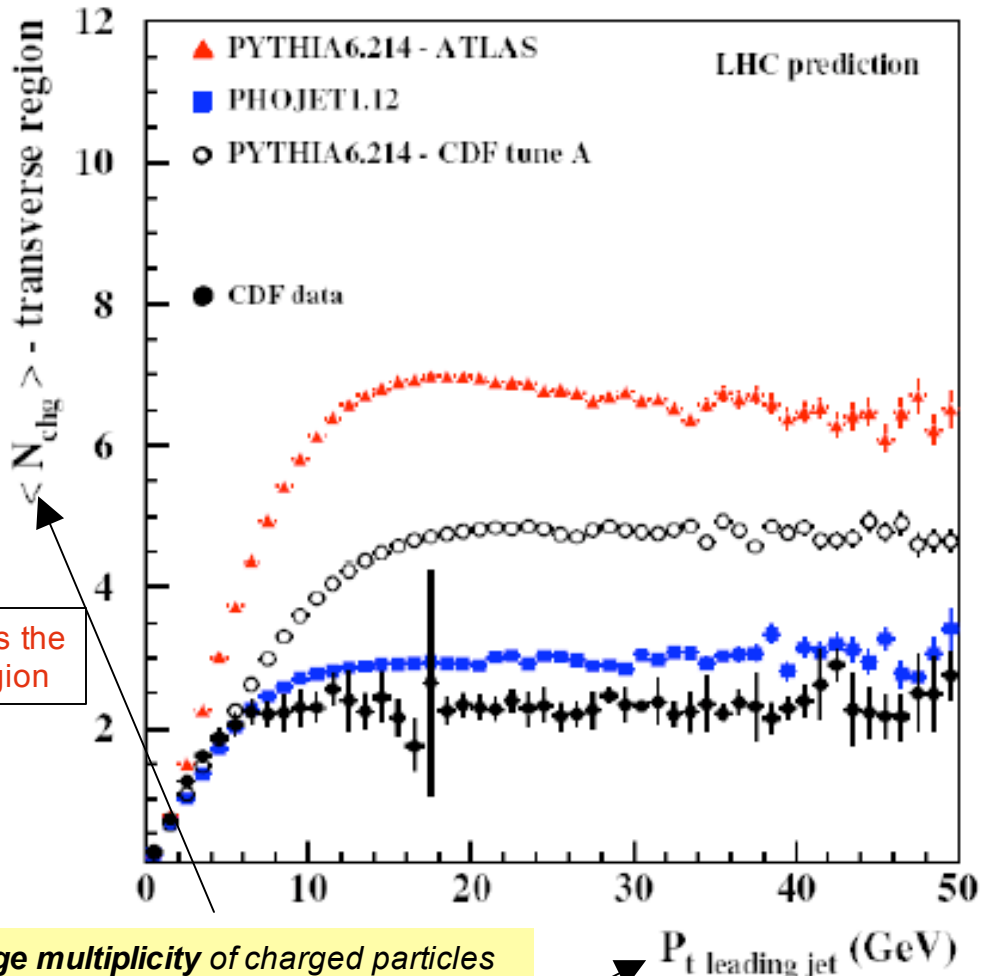
RECALL:

- MCs tuned to CDF data
- LHC predictions for transverse region differ significantly



UE is defined as the Transverse Region

Proceedings of 1st HERA-LHC Workshop

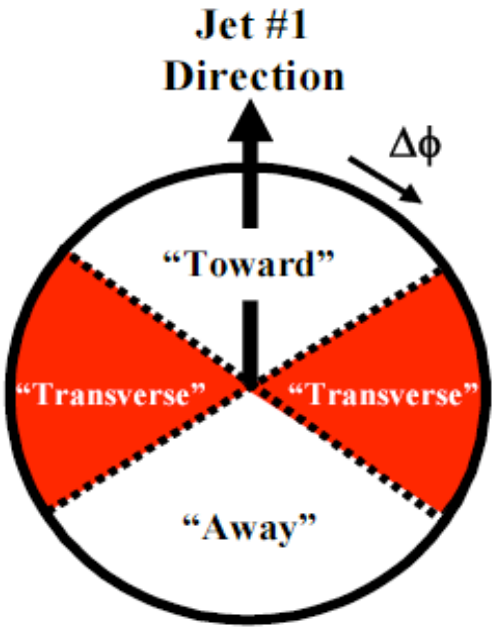


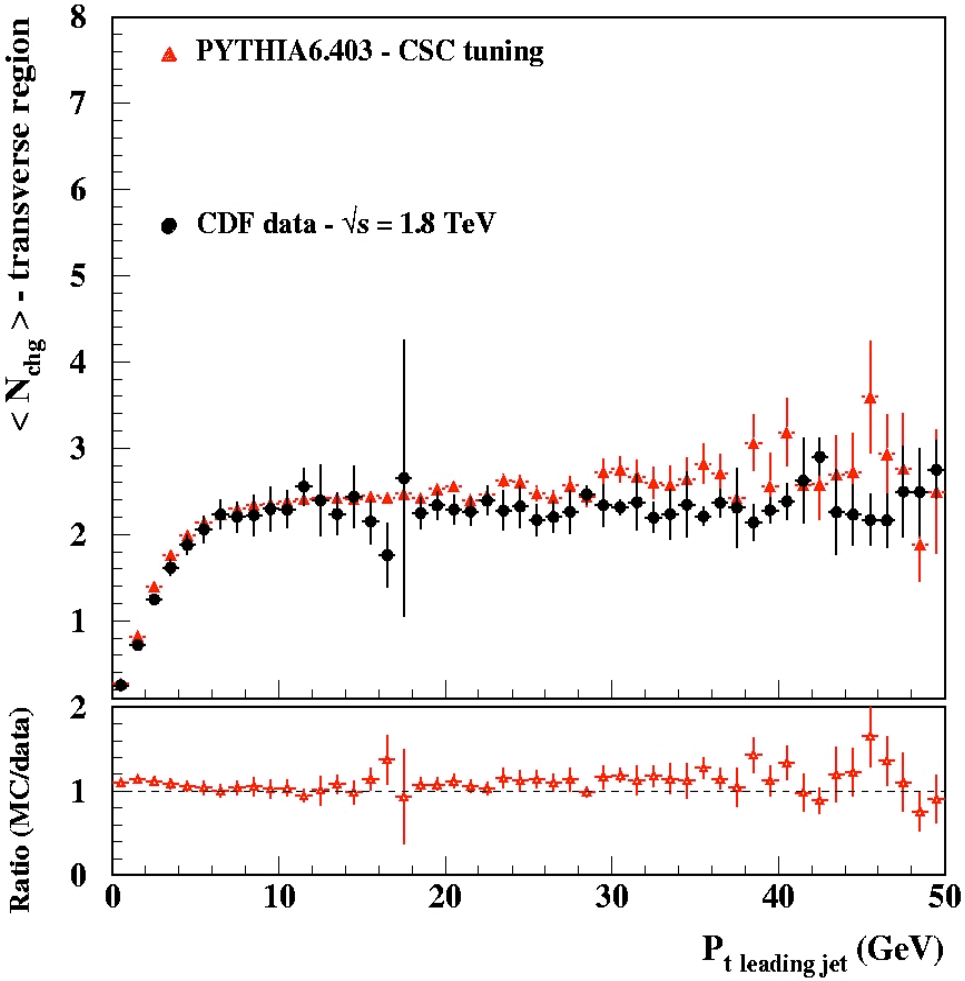
Average multiplicity *of charged particles in the underlying event associated to a leading jet with* P_t^{ljet} *(GeV).*

New MC Tuning for UE/MI

A. Moraes

- New MC Tuning:
  - PYTHIA6.403
  - CTEQ6L
- CDF Data ->



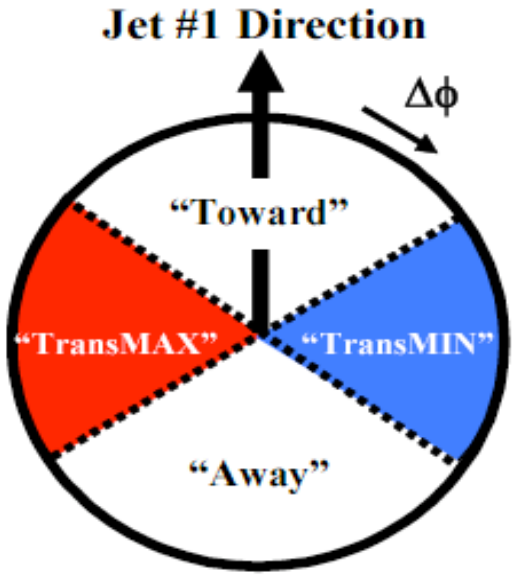


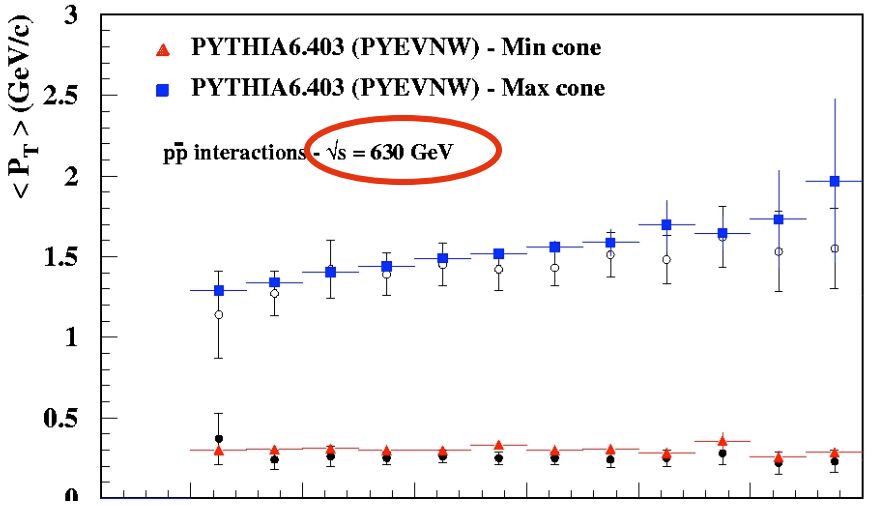
New MC Tuning for UE/MI

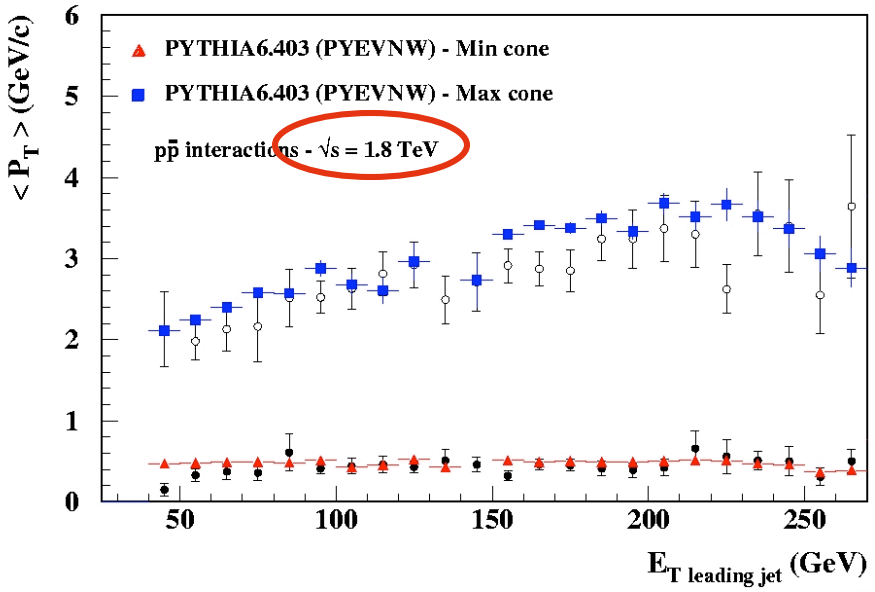
A. Moraes

- New MC Tuning:
  - PYTHIA6.403
  - CTEQ6L
- CDF Data ->
  - Including MAX/MIN data at different energies

-> info. on energy extrapolation

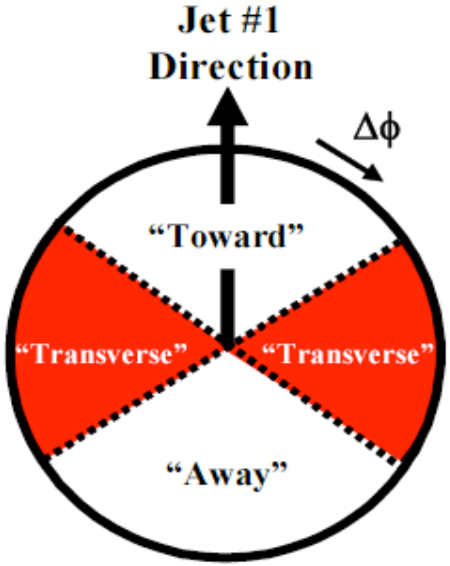


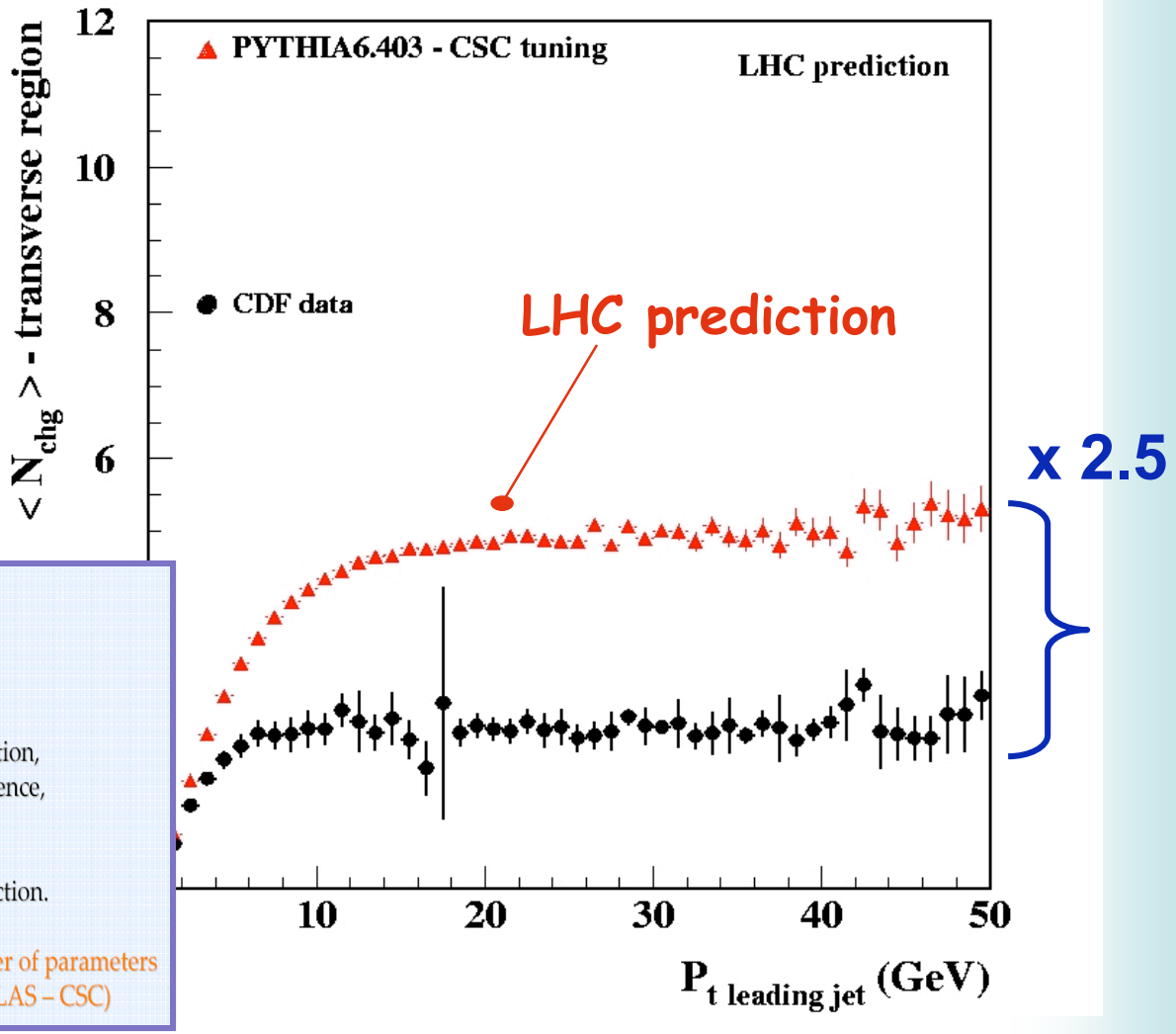




NEW LHC Prediction

A. Moraes



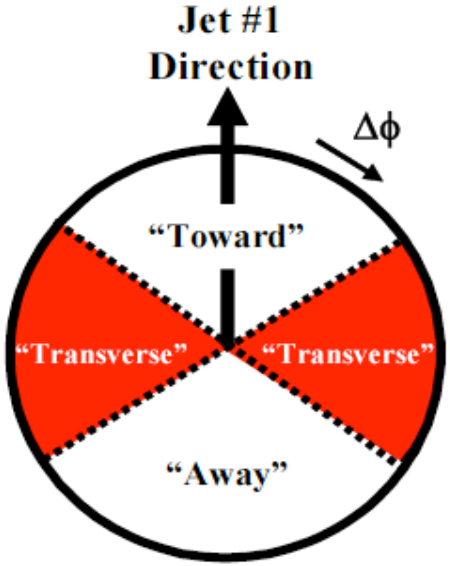


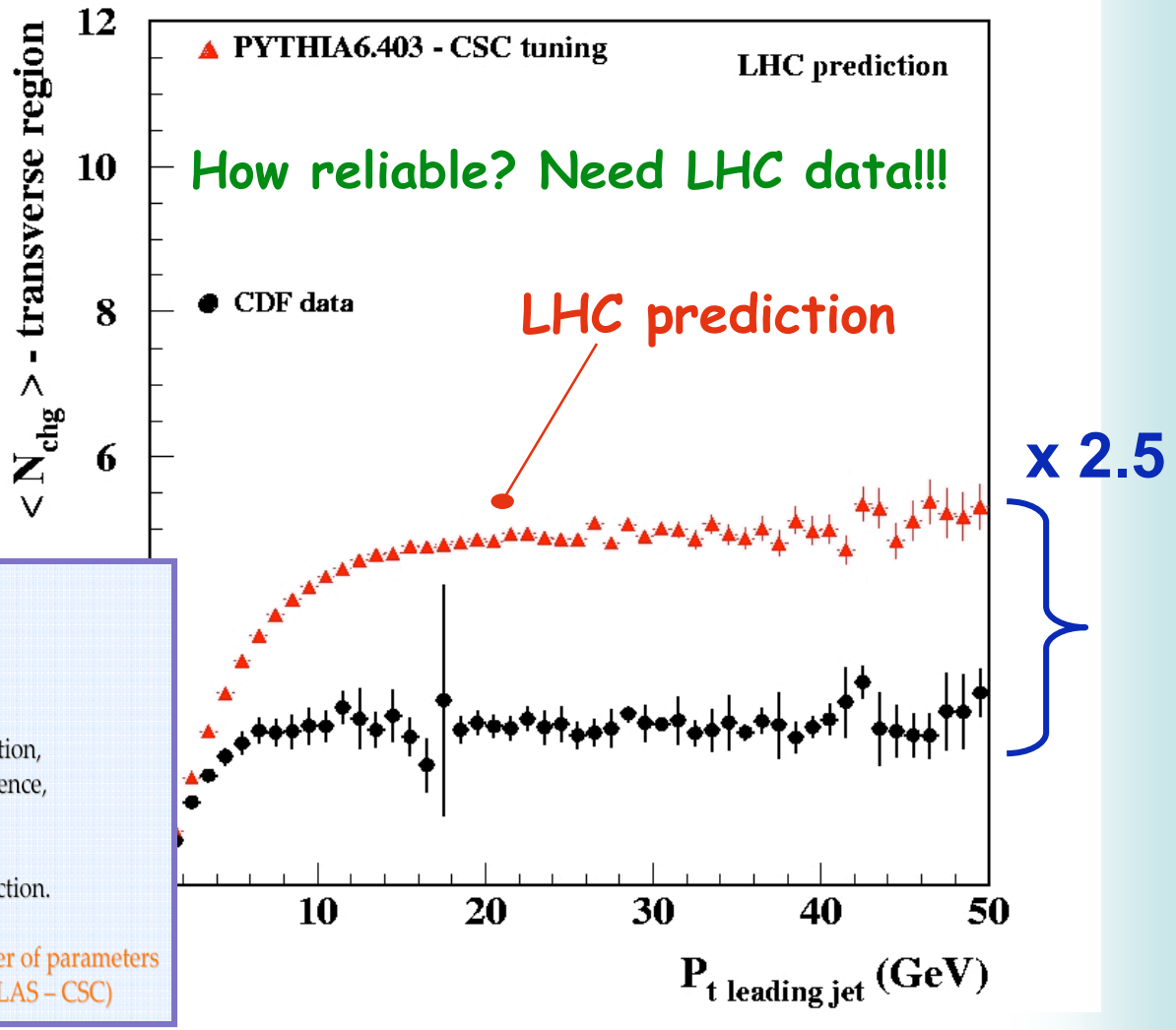
"OLD" vs. "NEW"

p_T cut-off, matter distribution, energy dependence.	p_T cut-off, matter distribution, energy dependence, ISR, FSR, colour reconnection.
Approx. number of parameters tuned: ~5 (ATLAS – DC2 & Rome) or ~8 (CDF)	Approx. number of parameters tuned: ~11 (ATLAS – CSC)

NEW LHC Prediction

A. Moraes





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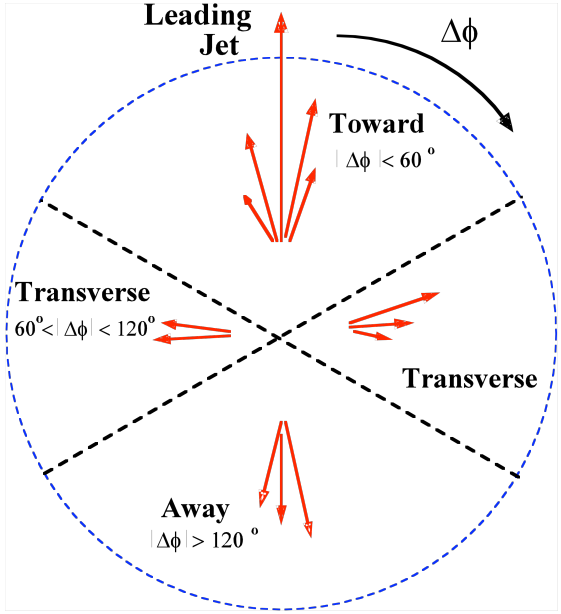
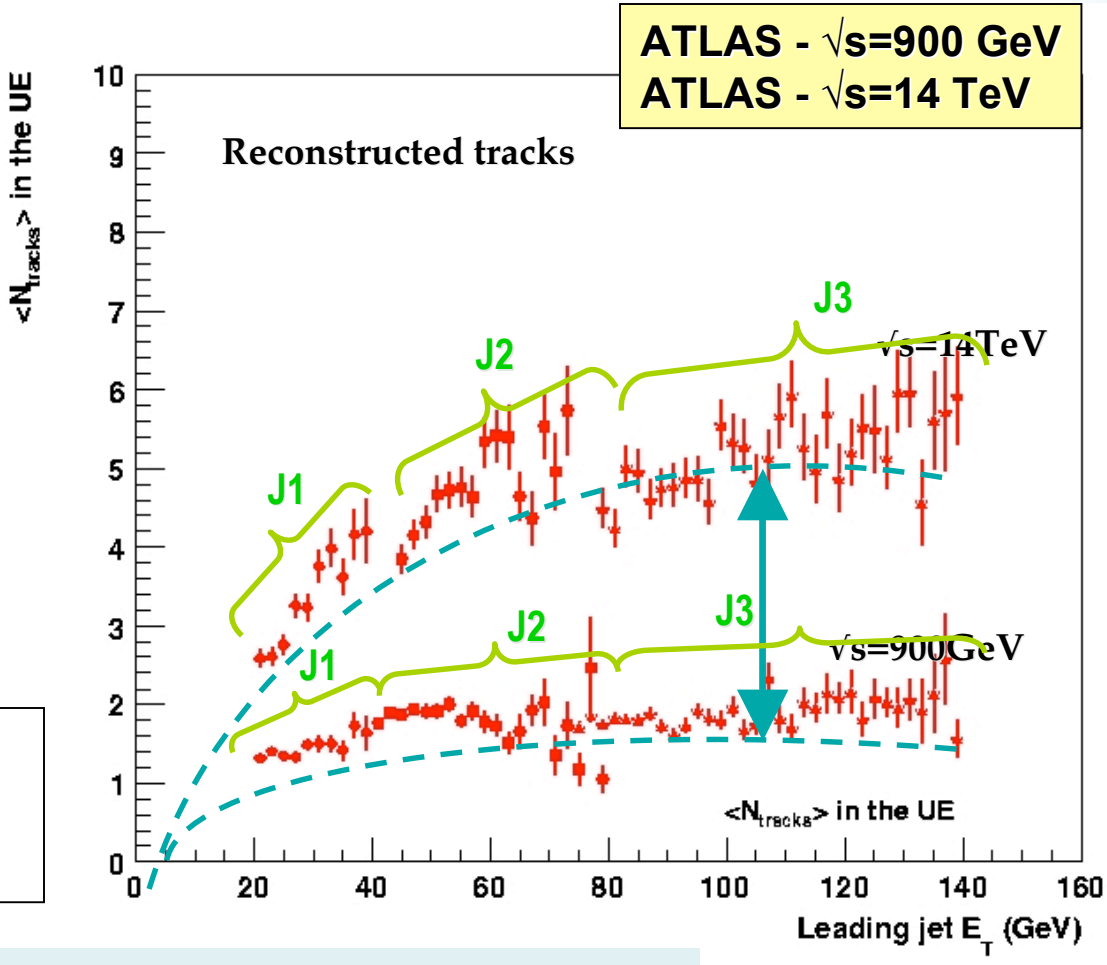
UE Measurement @ LHC

A. Moraes



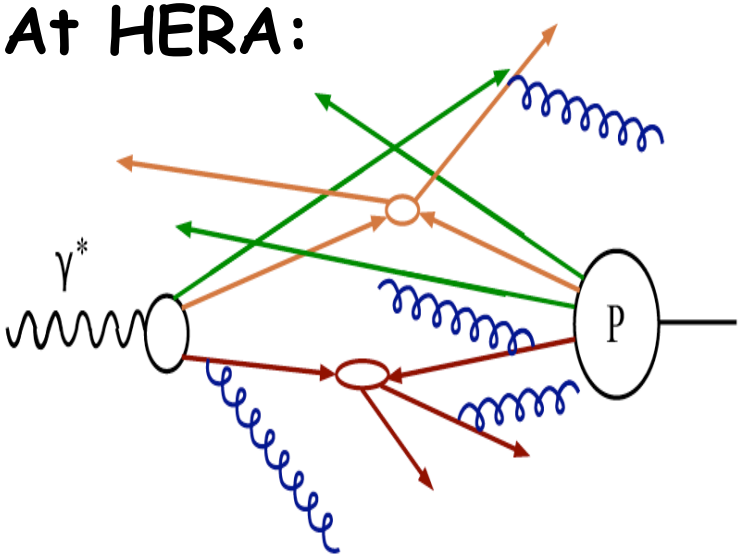
Charged particle multiplicity with $p_T > 0.5$ GeV and $|\eta| < 1$ in transverse region



15 days of data taking in 2007 enough to cover up to p_T(LJ) < 40 GeV

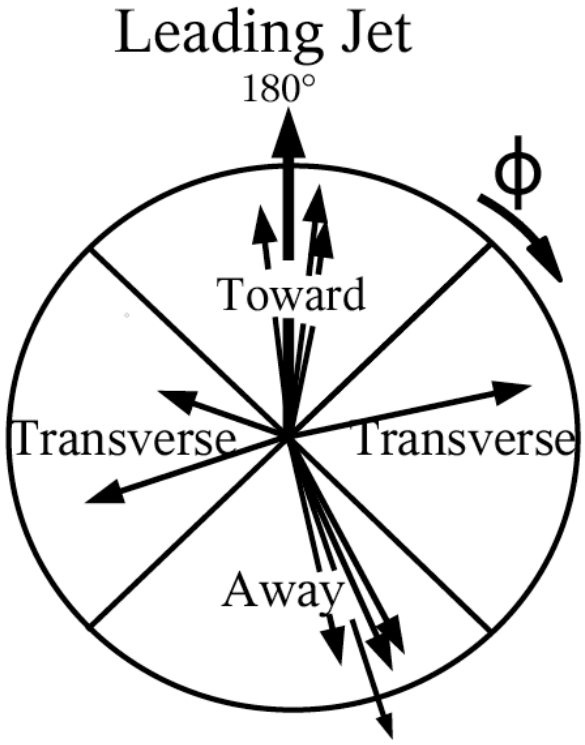
Multi-Parton Interactions @ HERA

At HERA:



* Define four regions in azimuthal:
  - Two Transverse regions:
    $60° < |\Delta\phi^*| < 120°$
  - Toward region:
    $|\Delta\phi^*| < 60°$.
  - Away region:
    $|\Delta\phi^*| > 140°$

- **Perform "CDF-like" analyses @ HERA (in DIS and photoproduction)**
  -> LONG AWAITED MEASUREMENT !!



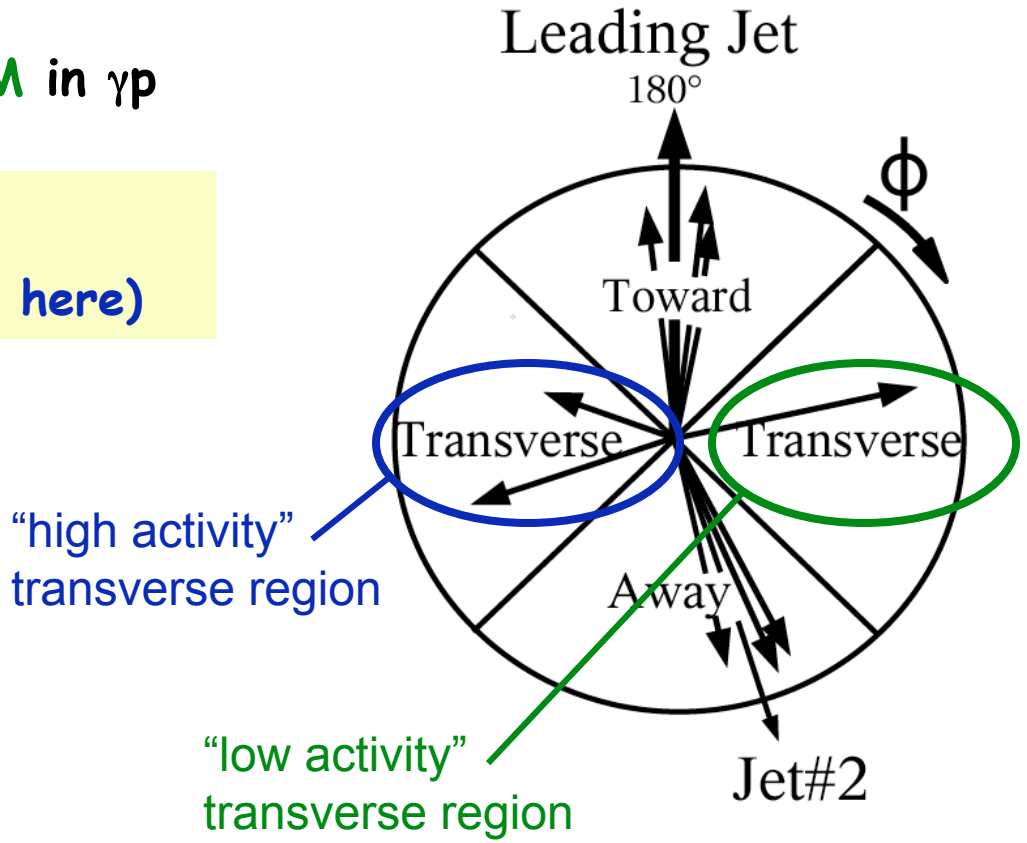
MI in γp @ HERA

L. Marti Magro

"CDF-like" analysis in γp@HERA

- measure average charged track multiplicity / p_T^{sum} in different $\Delta\phi^*$ regions for two samples:
  - DIJETS in γp
  - DIJETS with CHARM in γp

Data Unofficial
(only precision shown here)

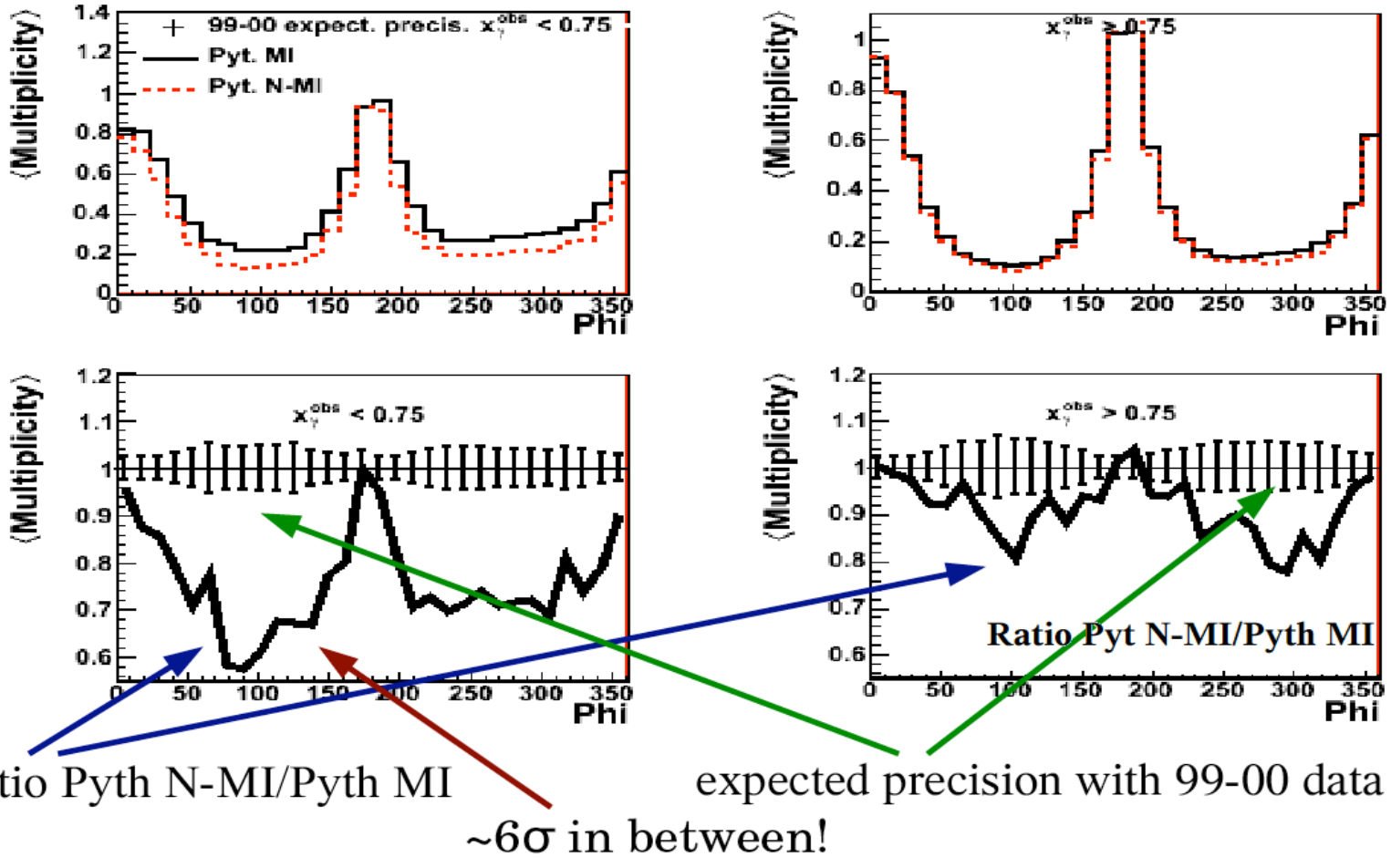


MI in γp @ HERA

L. Marti Magro

Precision Only

DIJET: large differences between models
DIJET with CHARM (not shown): smaller differences



MI in γp @ HERA

L. Marti Magro

Precision Only

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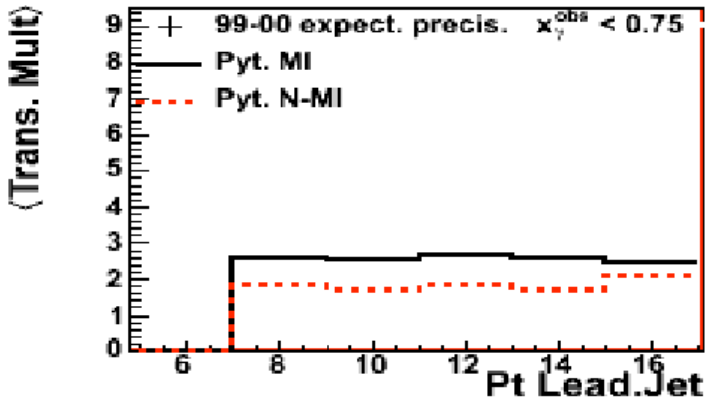
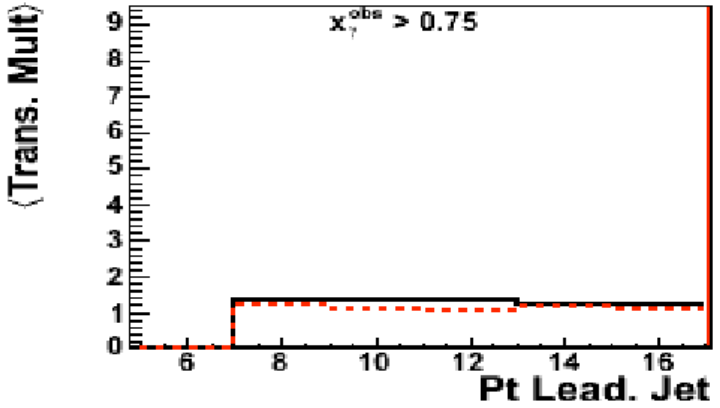
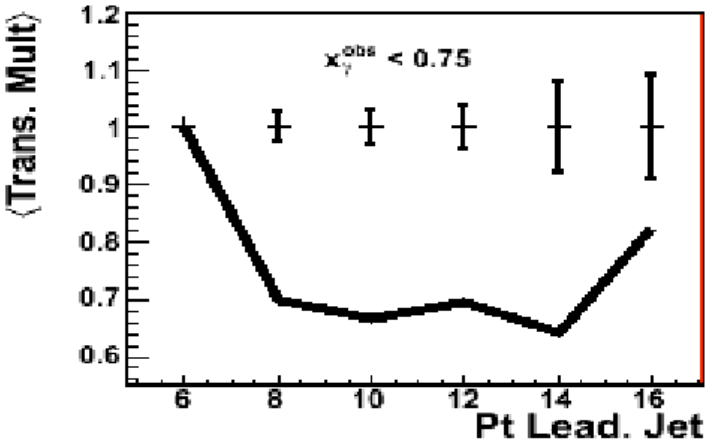
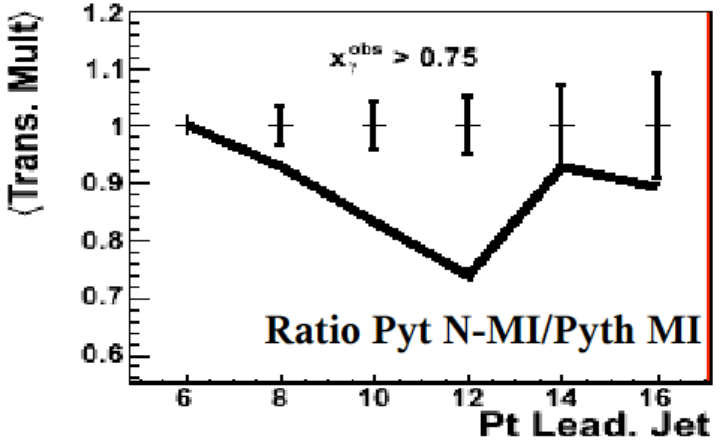








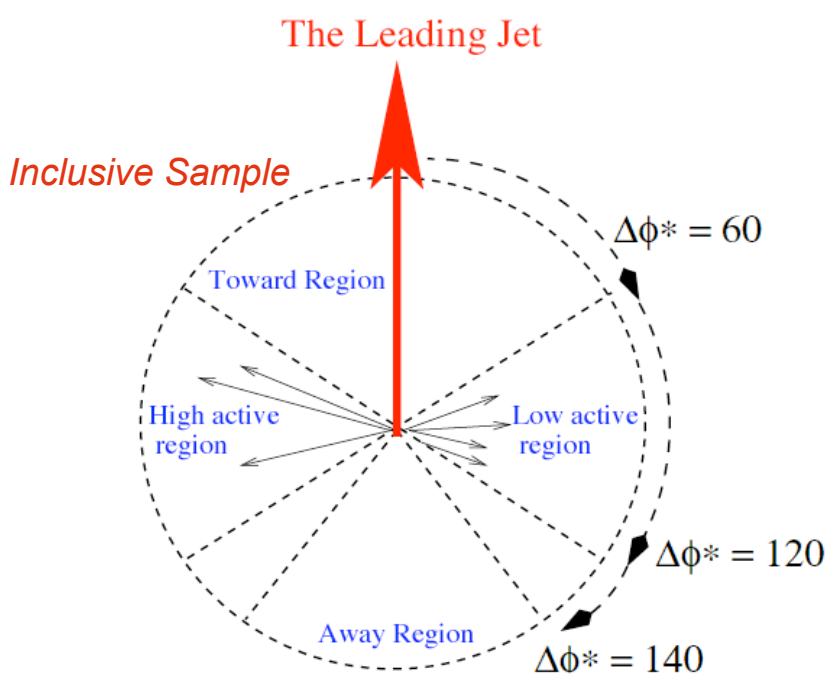
MI in DIS @ HERA

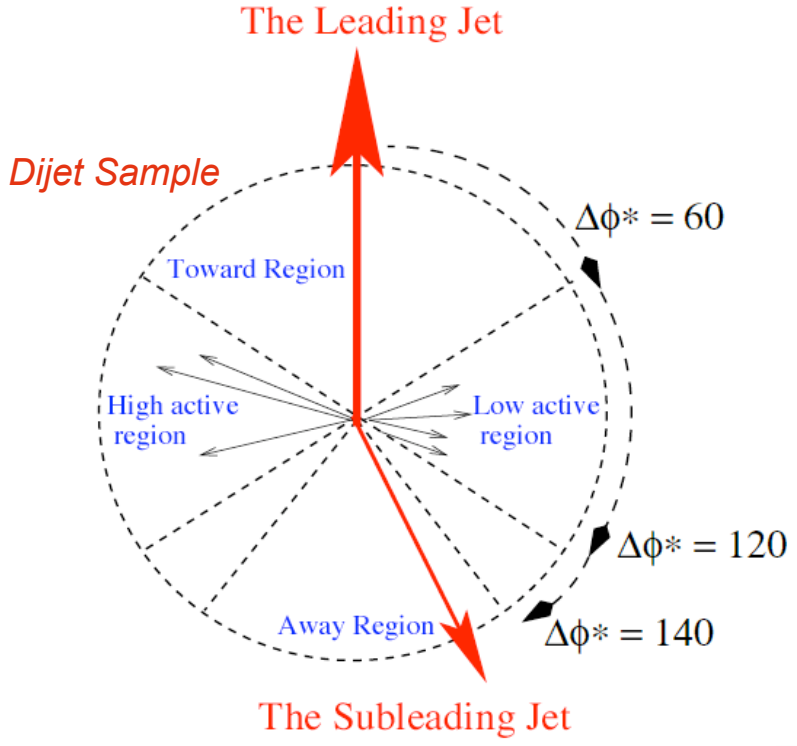
S. Osman

Can the models used to describe γp also be used in DIS?

"CDF-like" analysis in DIS@HERA

- Measurement of average minijet multiplicity (and p_T^{sum}?) using inclusive k_T algorithm as function of p_T^* of LJ in different $\Delta\phi^*$ regions in "INCLUSIVE" and "DIJET" samples:





MI in DIS @ HERA

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"CDF-like" analysis in DIS@HERA

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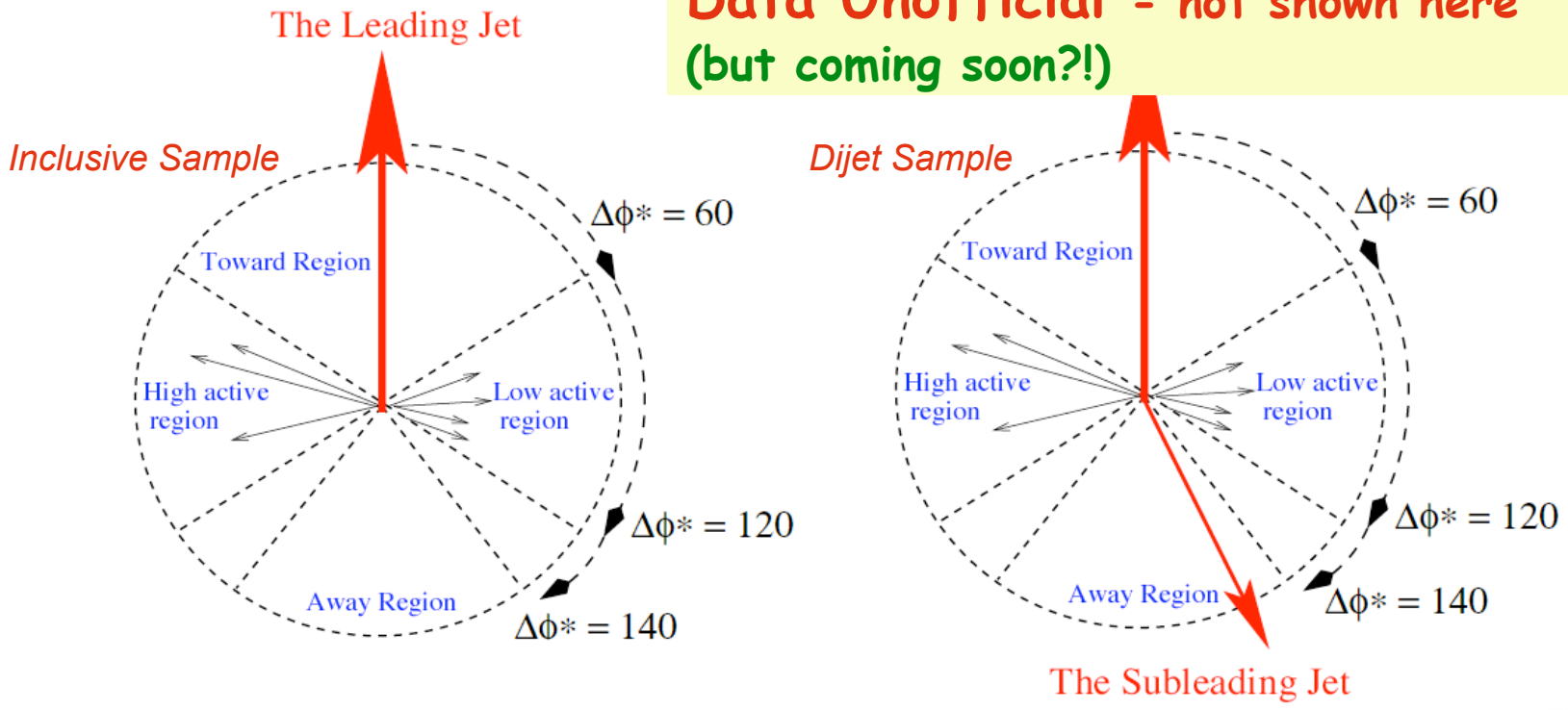
Data Unofficial - not shown here (but coming soon?!)



Discussion: Some Issues/Open Questions

- How reliable are our present models/understanding of the UE and MI?
  - Are PYTHIA-MI/JIMMY the final answer to MI and UEs?
    Do we understand MI enough to just tune the MCs?
    What if we can't tune the models to LHC?
- Do we have the necessary measurements, tools and information to obtain the best tuned MC generators?
  - Are further investigations needed from HERA?
    Are data available in computer useable form?
- What are the prospects for the 1st LHC papers?
  (EG: underlying events - are the analysis strategies clear?)

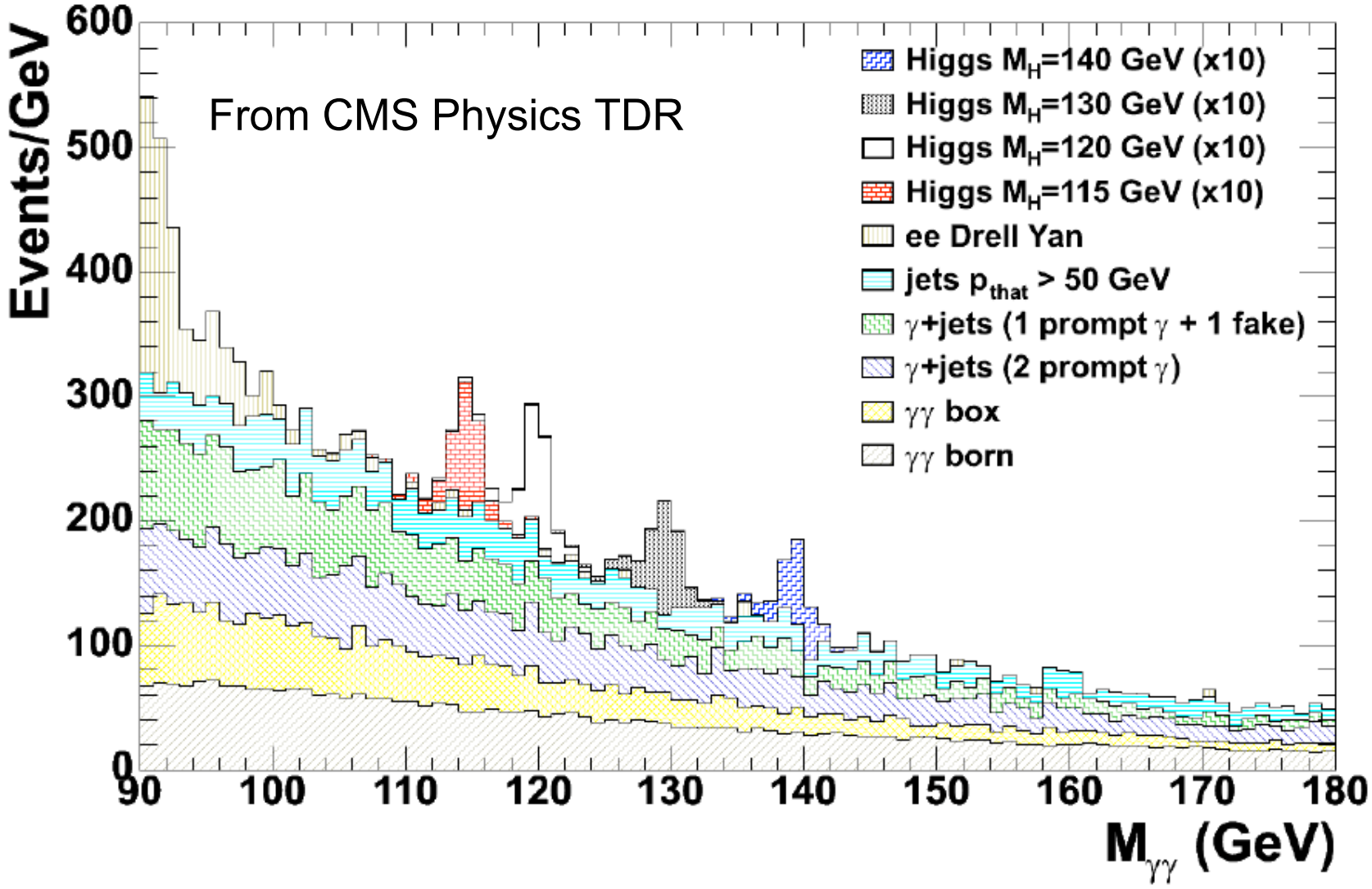
Conclusions:

- HERA: valuable measurements performed or underway
  - Potential constraints on proton PDFs
  - Potential constaints on PS/UE models
- LHC: physics studies underway in all experiments
  - Important experimental issues starting to be addressed
    e.g. background rejection/measurement, reconstruction, trigger, …
  - Studies underway for early measurement strategies (UE)
- Would Like:
  - Finalised measurements for HERA (e.g. UE)
    -> inclusion in global tuning facilities, to fully exploit information
  - MC Tunings:
    -> would like criteria to say how well models describe data?
    -> collate information (what data used? which parameters tuned? result?)

Still many open issues regarding UE/MI

Back-Ups

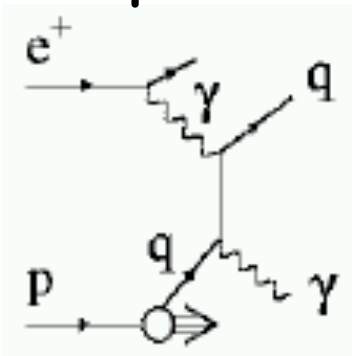
Prompt Photons and H-> gamma gamma



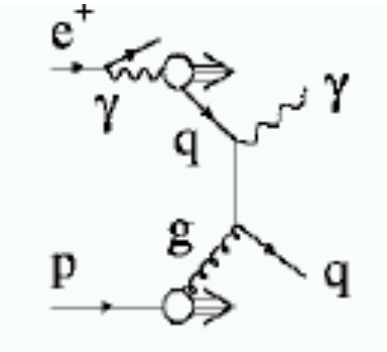
Prompt Photons at HERA

M. Forrest

Prompt Photon Production

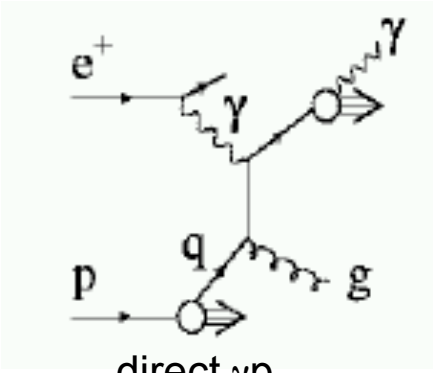


direct γp

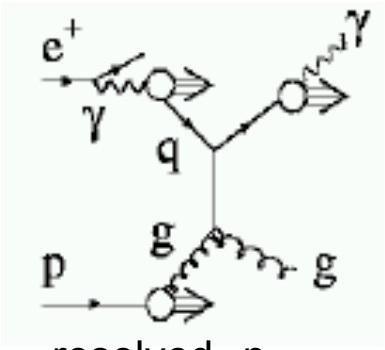


resolved γp

Radiative Photon



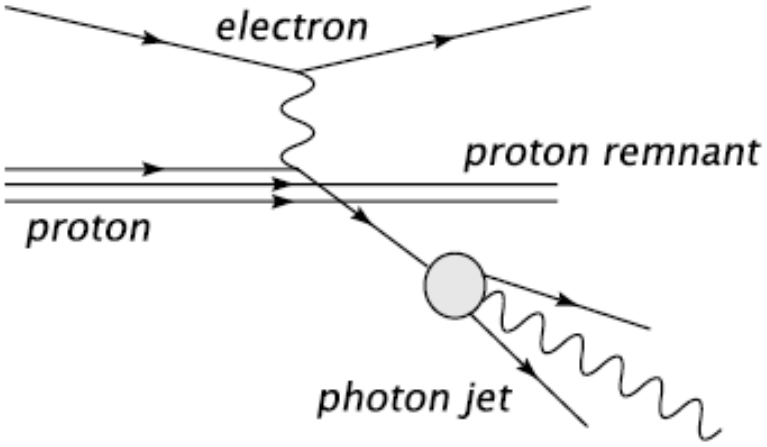
direct γp



resolved γp

M. Forrest

Prompt Photons
(Quark-to-Photon Fragmentation Function $D_{\gamma/q}$)



HERA: $z > z^{cut} = 0.9$

$$z = \frac{E_\gamma}{E_\gamma + E_{had}}$$

- Fragmentation contribution suppressed by isolation cut
  -> $D_{\gamma/q}$ could be measured at HERA by loosening cut
    - BUT will require major experimental rethink!

New MC Tuning for UE/MI

A. Moraes

"OLD" vs. "NEW"

p_T cut-off,
matter distribution,
energy dependence.

Approx. number of parameters tuned: ~5 (ATLAS – DC2 & Rome) or ~8 (CDF)

p_T cut-off,
matter distribution,
energy dependence,
ISR,
FSR,
colour reconnection.

Approx. number of parameters tuned: ~11 (ATLAS – CSC)

```
mstp(70)=2
mstp(72)=0
mstp(81)=1
mstp(82)=4
mstp(84)=1
mstp(85)=1
mstp(86)=2
mstp(87)=4
mstp(88)=0
mstp(89)=1
mstp(90)=1
mstp(95)=1

PARP(78)=0.2
PARP(80)=0.01
PARP(82)=1.9
PARP(83)=0.3
PARP(84)=0.5
PARP(89)=1800
PARP(90)=0.22

PARJ(81)=0.14
```