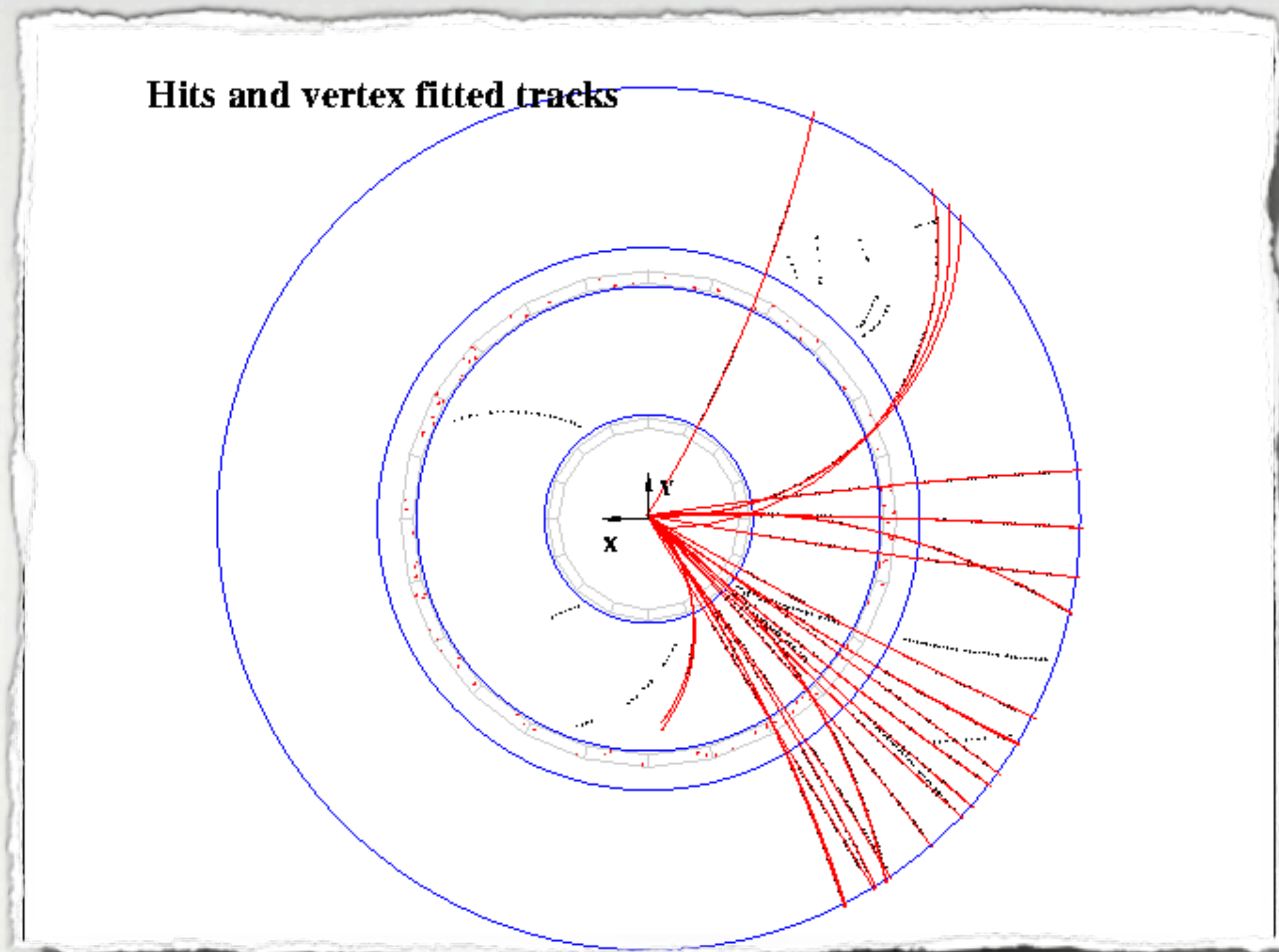


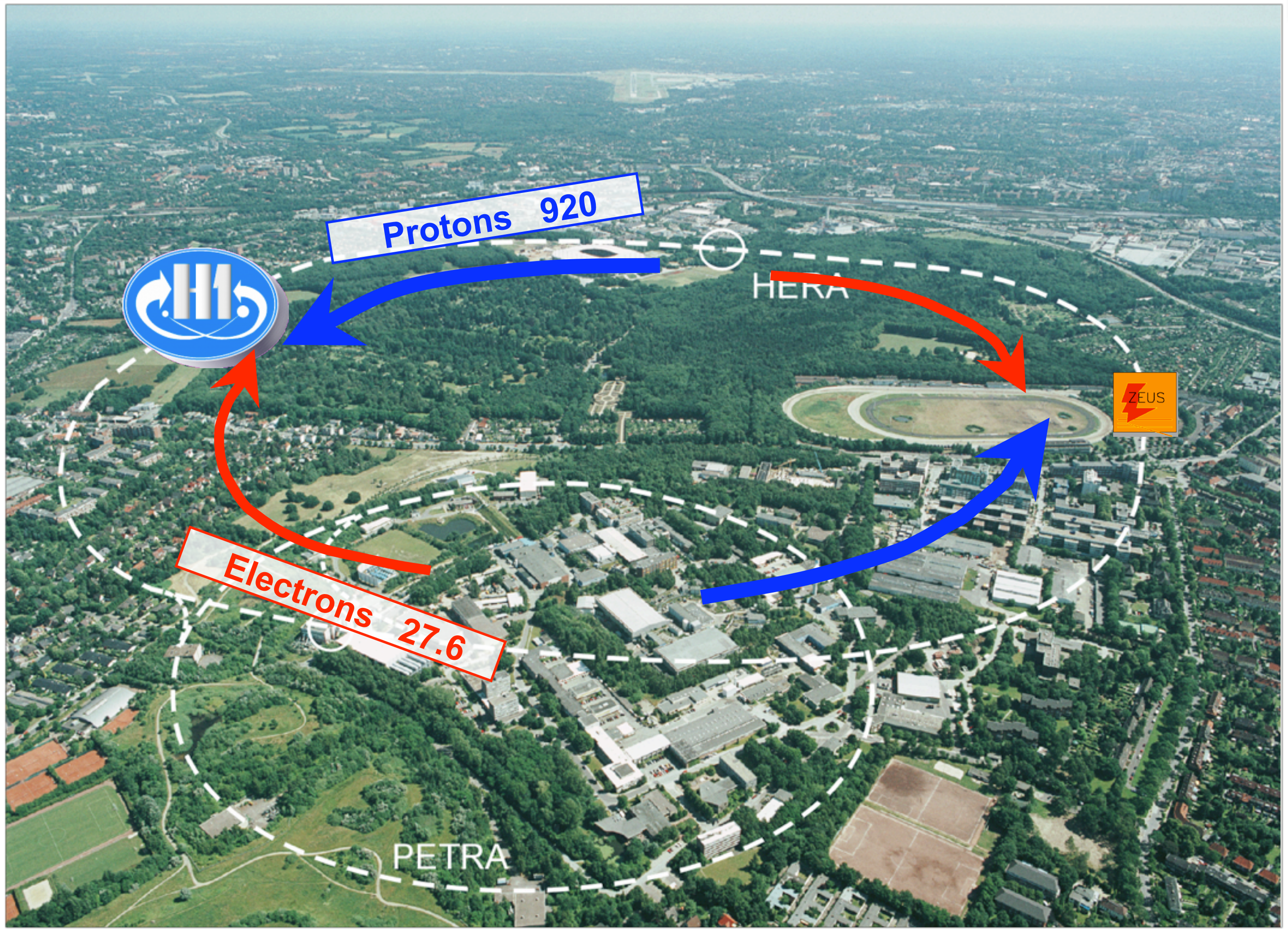
PARTICLE PRODUCTION AT H1

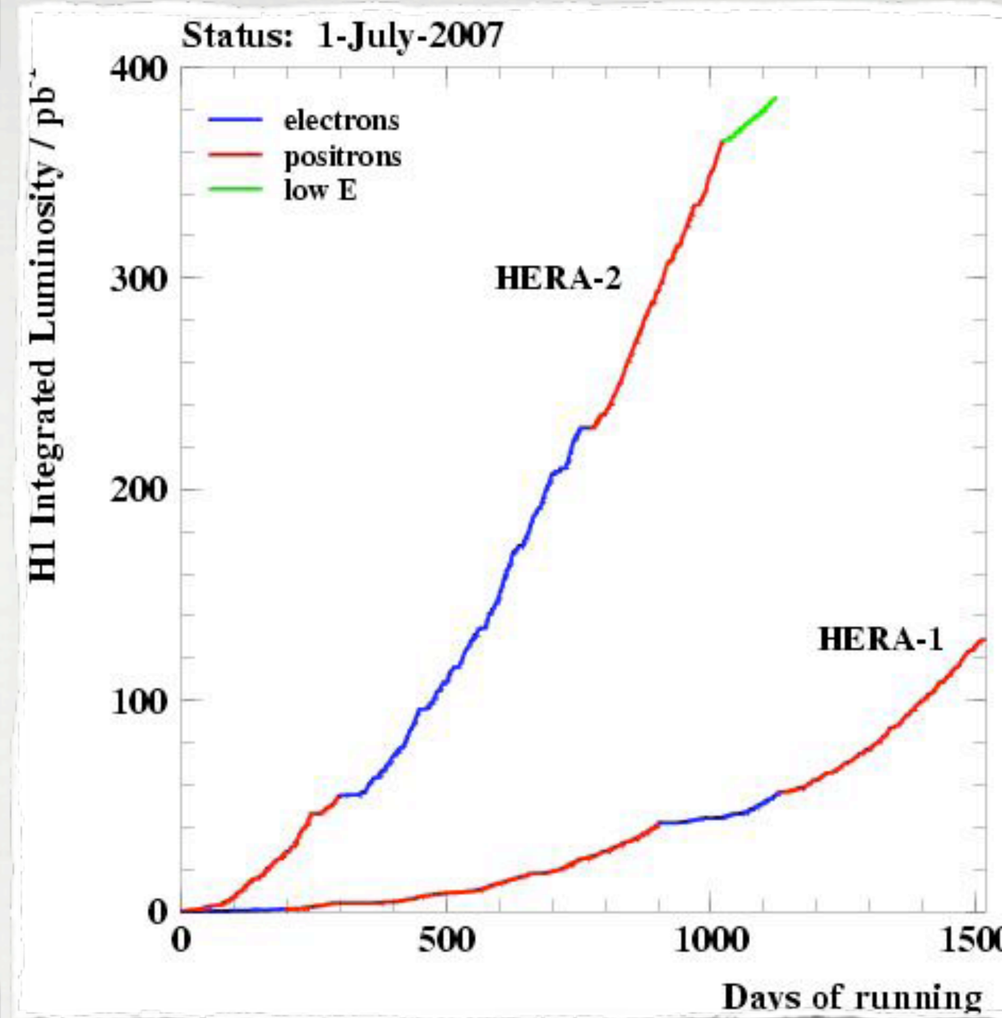
DANIEL TRAYNOR

Queen Mary University of London

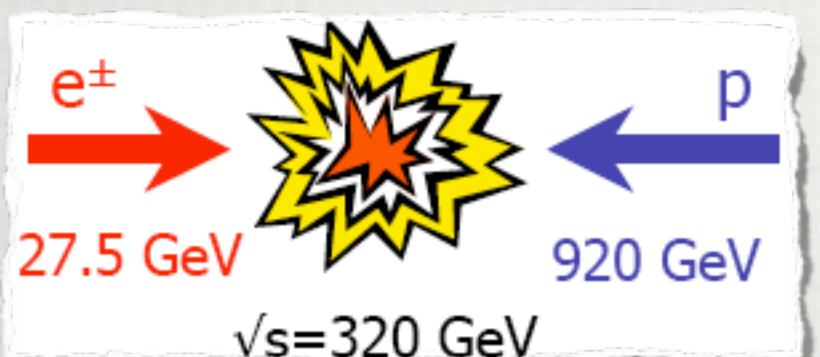
OVERVIEW

- GENERAL INTRO (HERA, H1, AND SOME THEORY)
- CHARGED PARTICLE PRODUCTION AND FRAGMENTATION
- UNDERLYING EVENT STUDIES.
- SUMMARY AND THE FUTURE





H1 PHYSICS USABLE SAMPLE ~500 pb^{-1}

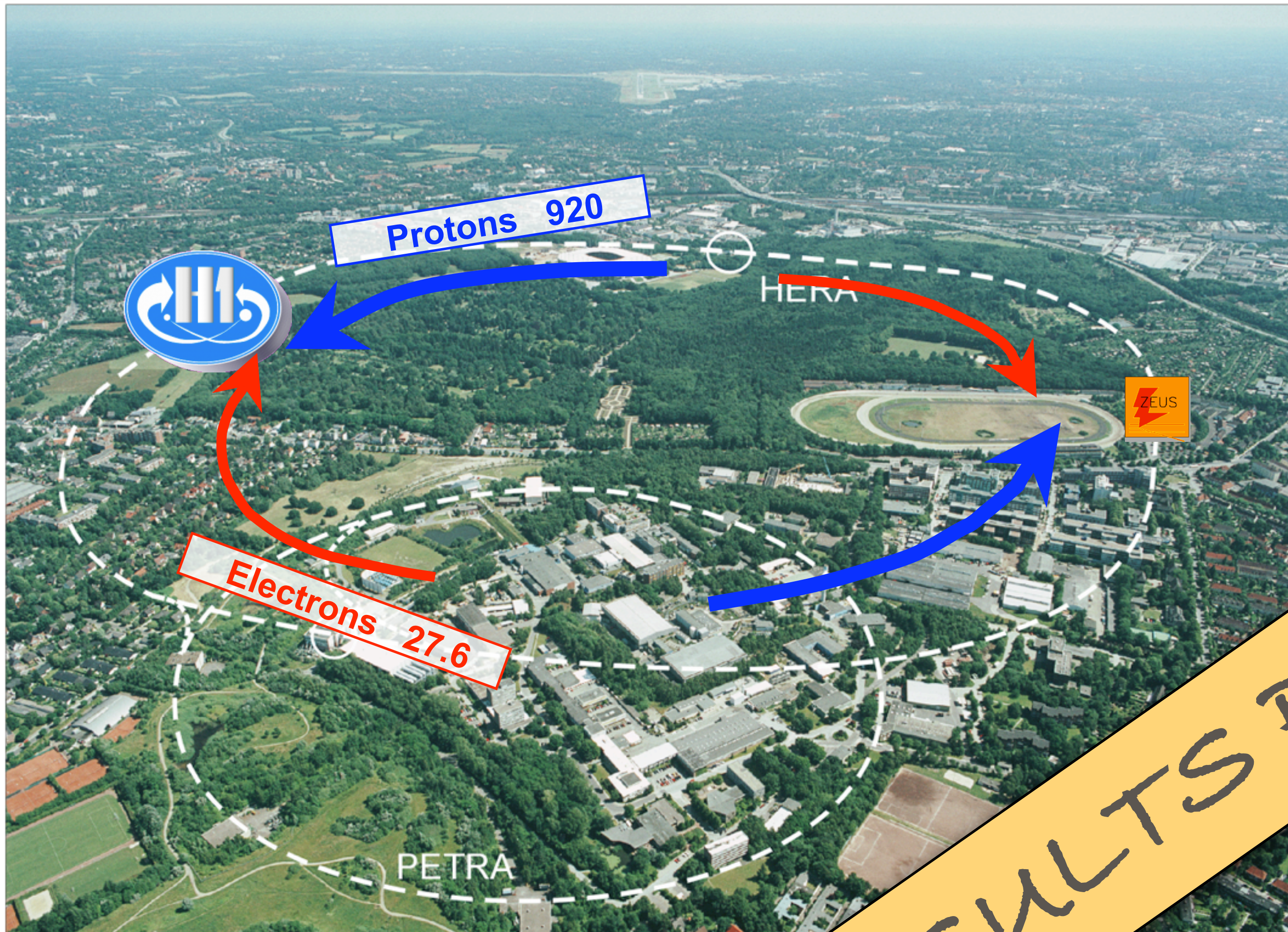


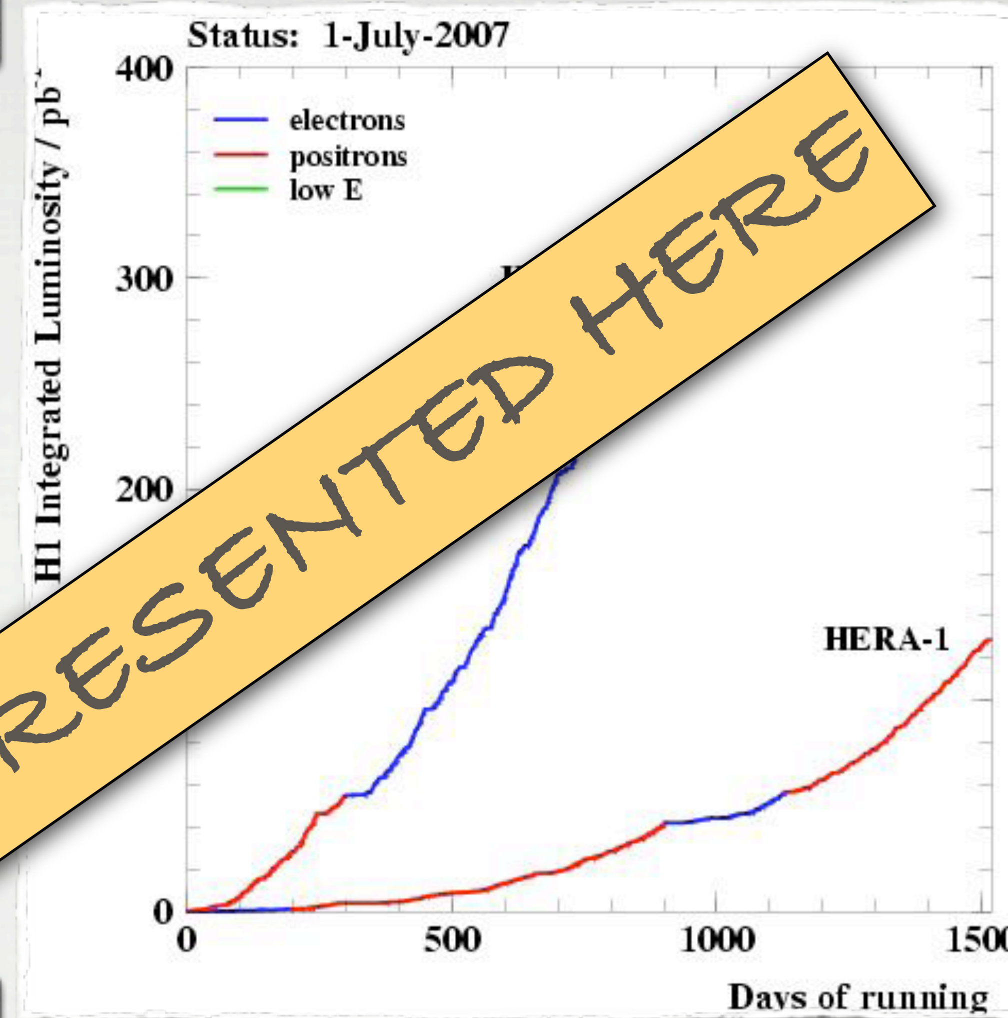
ELECTRONS OR POSITRONS

4 DIFFERENT PROTON ENERGIES

POLARISED LEPTON BEAMS

H1 AND HERA





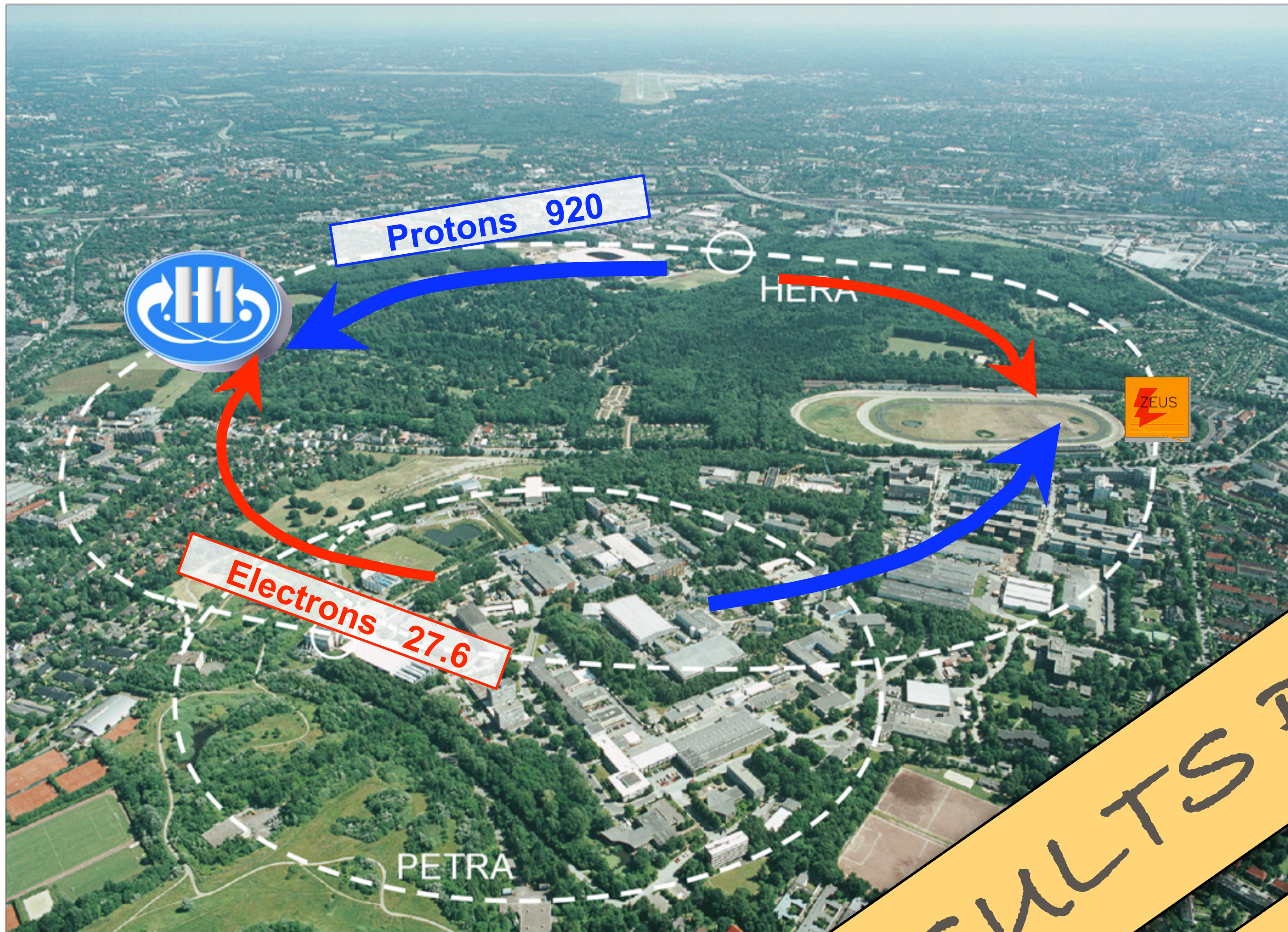
ONLY HERA I RESULTS PRESENTED HERE

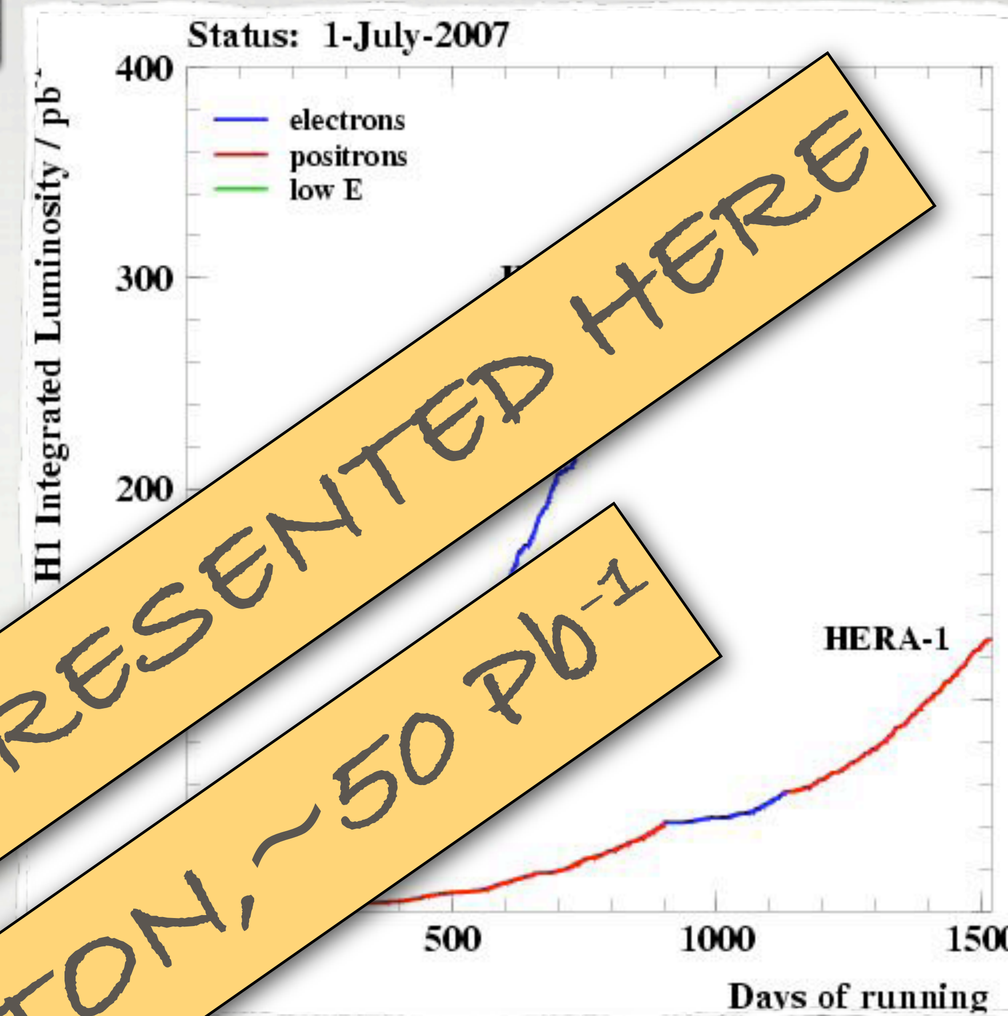
H1 P… USABLE SAMPLE ~500 pb^{-1}

ELECTRONS OR POSITRONS

4 DIFFERENT PROTON ENERGIES

POLARISED LEPTON BEAMS





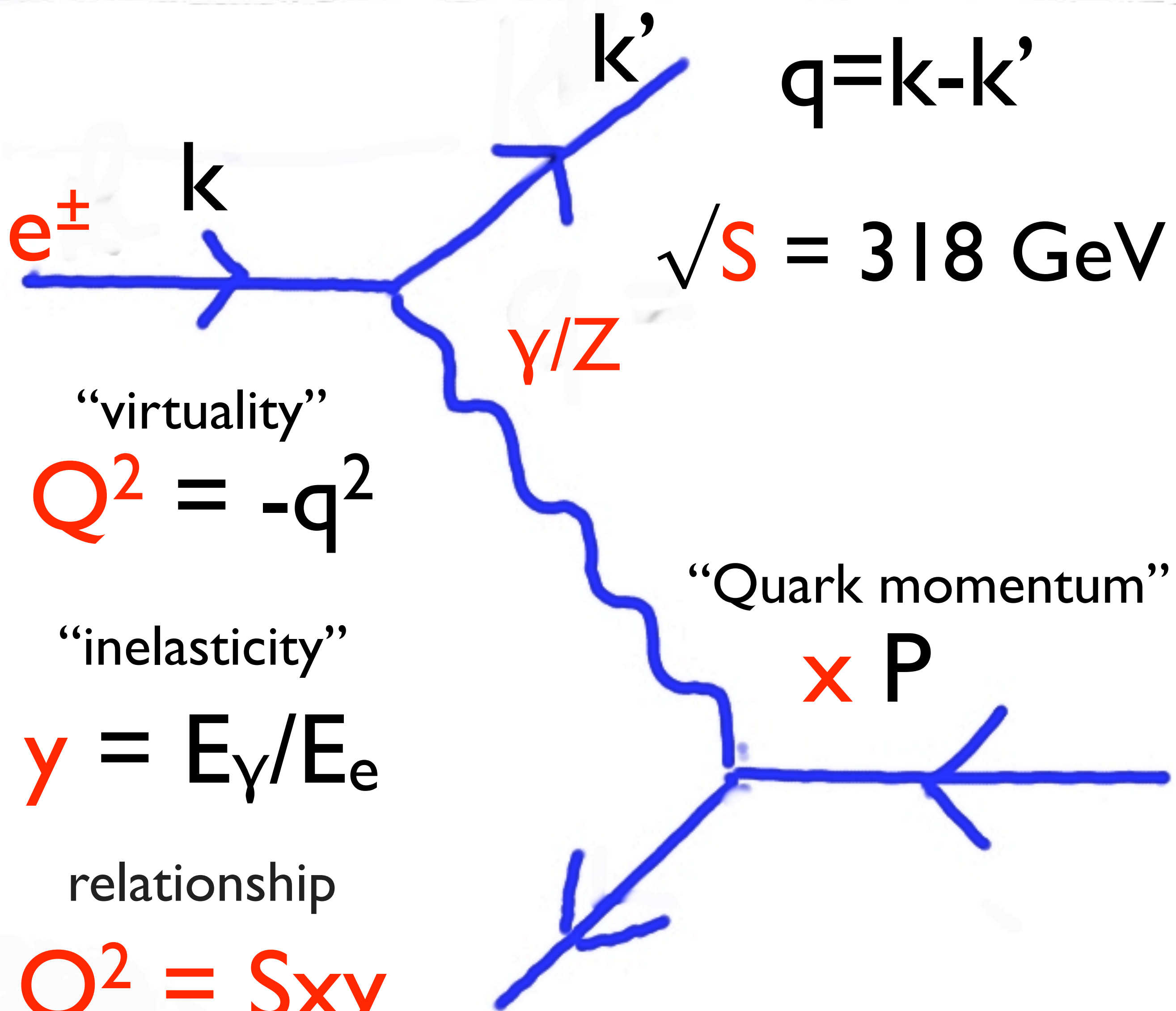
ONLY HERA I RESULTS PRESENTED HERE

POSITRON - PROTON, ~50 pb^{-1}

- H1 P… SAMPLE ~500 pb^{-1}
- …TRONS OR POSITRONS
- …ERENT PROTON ENERGIES
- POLARISED LEPTON BEAMS

H1 AND HERA

BORN LEVEL
"0TH ORDER QCD"



$q = k - k'$

$\sqrt{S} = 318$ GeV

"virtuality"

$Q^2 = -q^2$

"inelasticity"

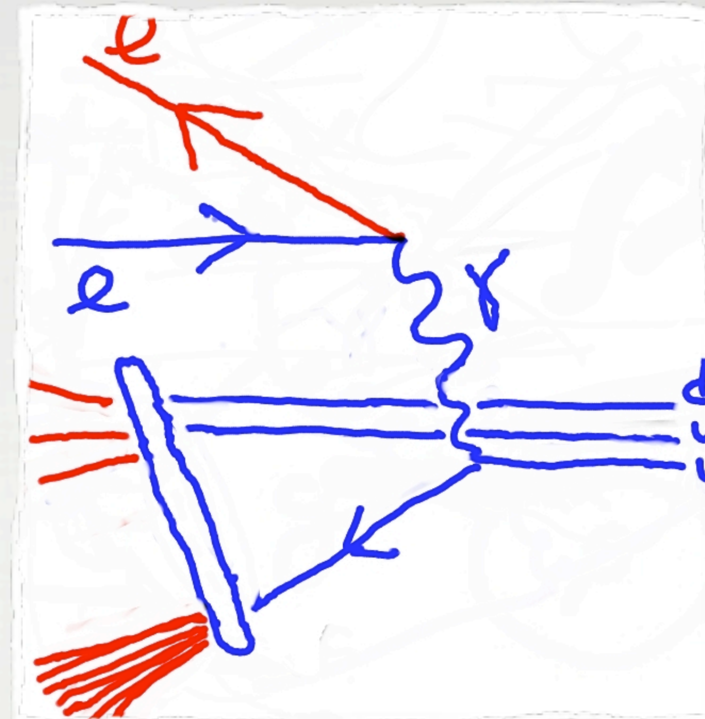
$y = E_\gamma / E_e$

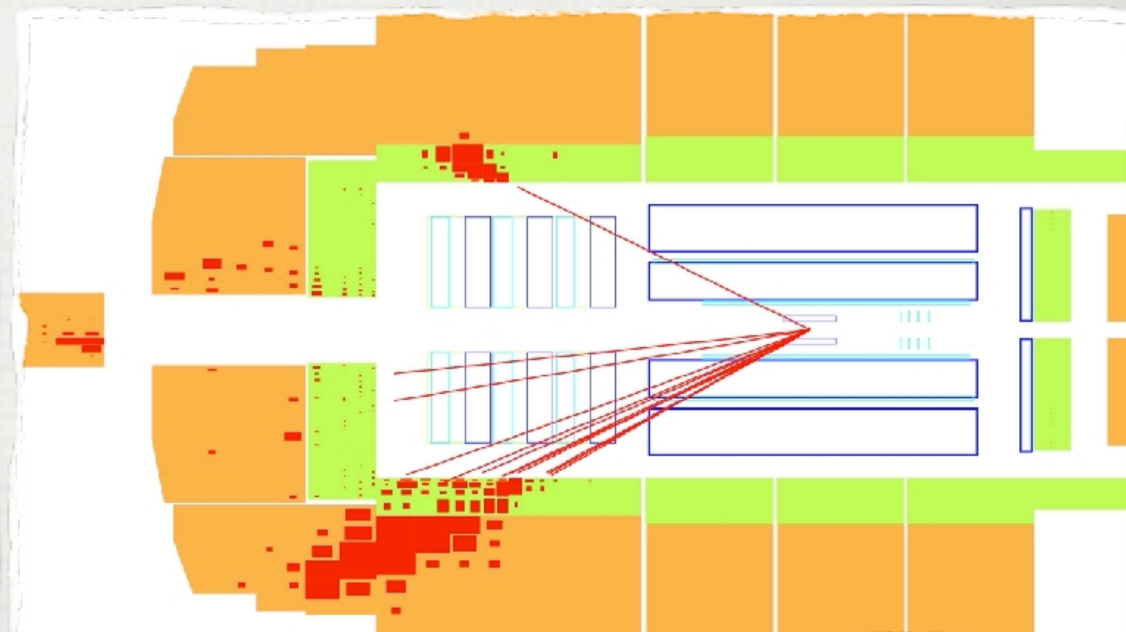
relationship

$Q^2 = Sxy$

"Quark momentum"

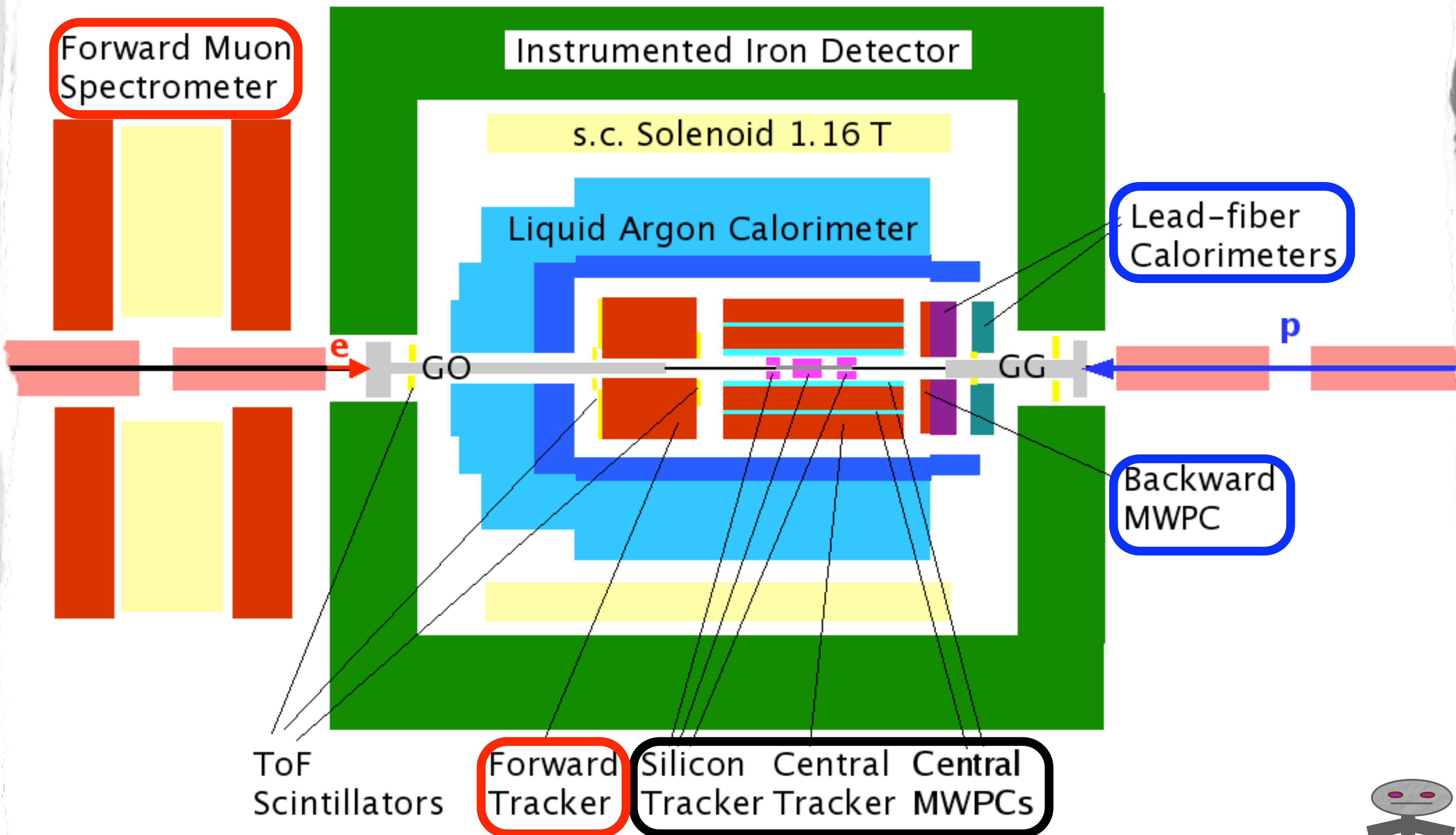
$x\,P$





DEEP INELASTIC SCATTERING

MORE


Forward Muon Spectrometer
Instrumented Iron Detector
s.c. Solenoid 1.16 T
Liquid Argon Calorimeter
Lead-fiber Calorimeters
e
GO
GG
p
Backward MWPC
ToF Scintillators
Forward Tracker
Silicon Tracker
Central Tracker
Central MWPCs

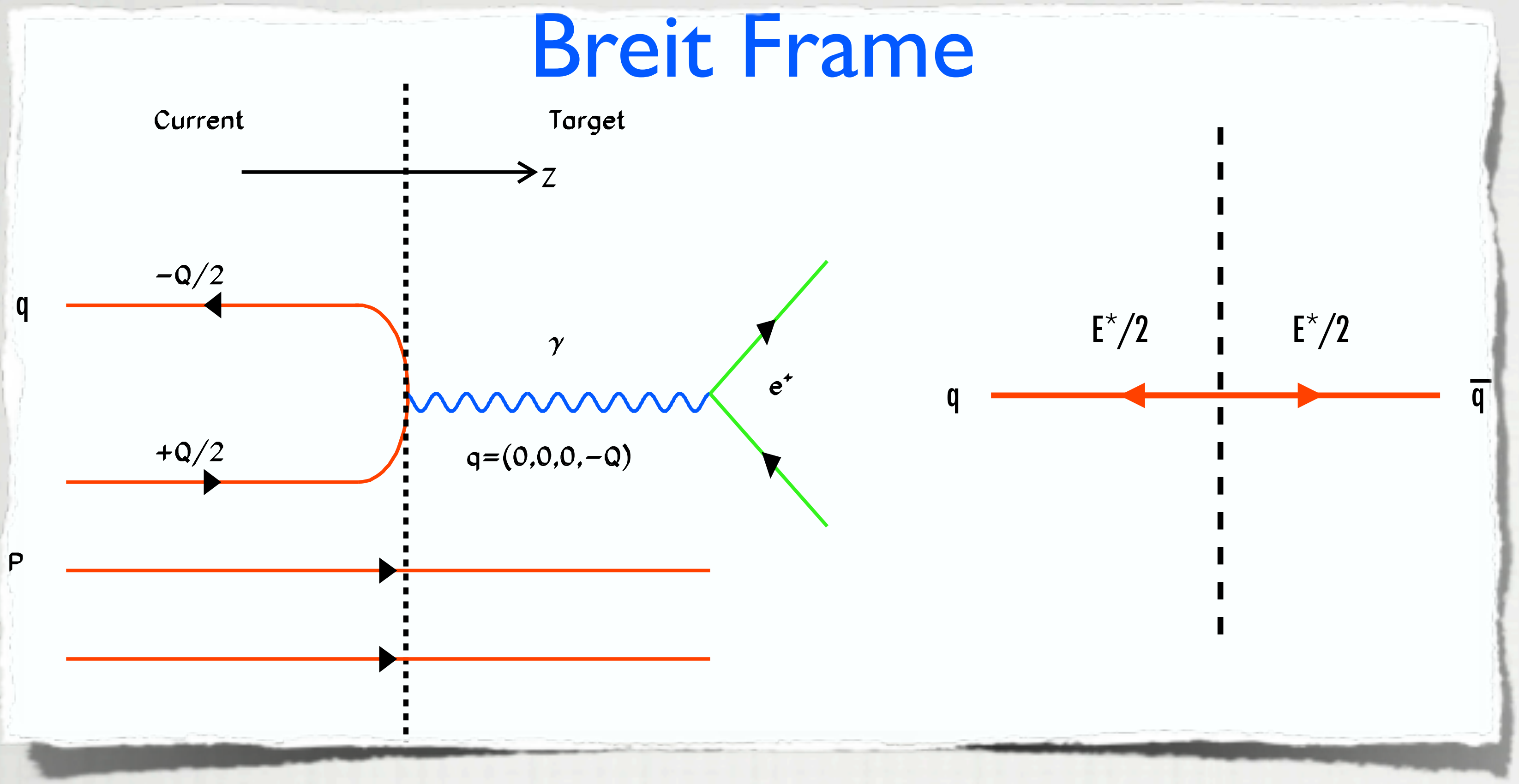
MORE

H1

CHARGED PARTICLE PRODUCTION IN HIGH Q^2 DIS

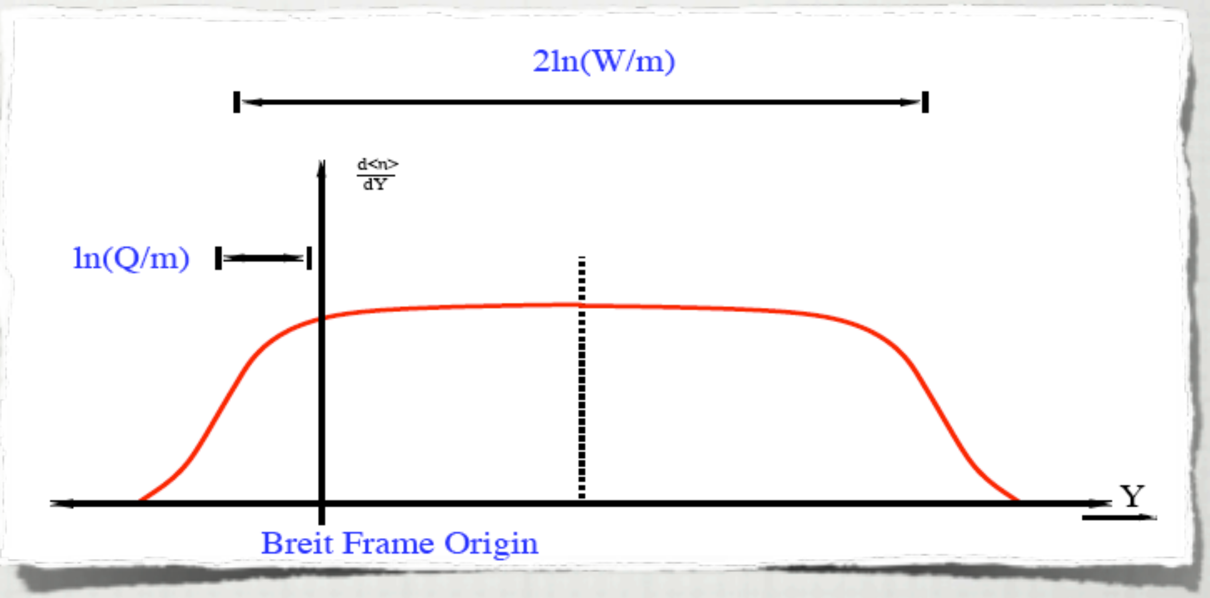
H1 COLLABORATION., F.D. AARON ET AL., PHYS.LETT.B654:148-159,2007.

ARXIV:0706.2456[HEP-EX]



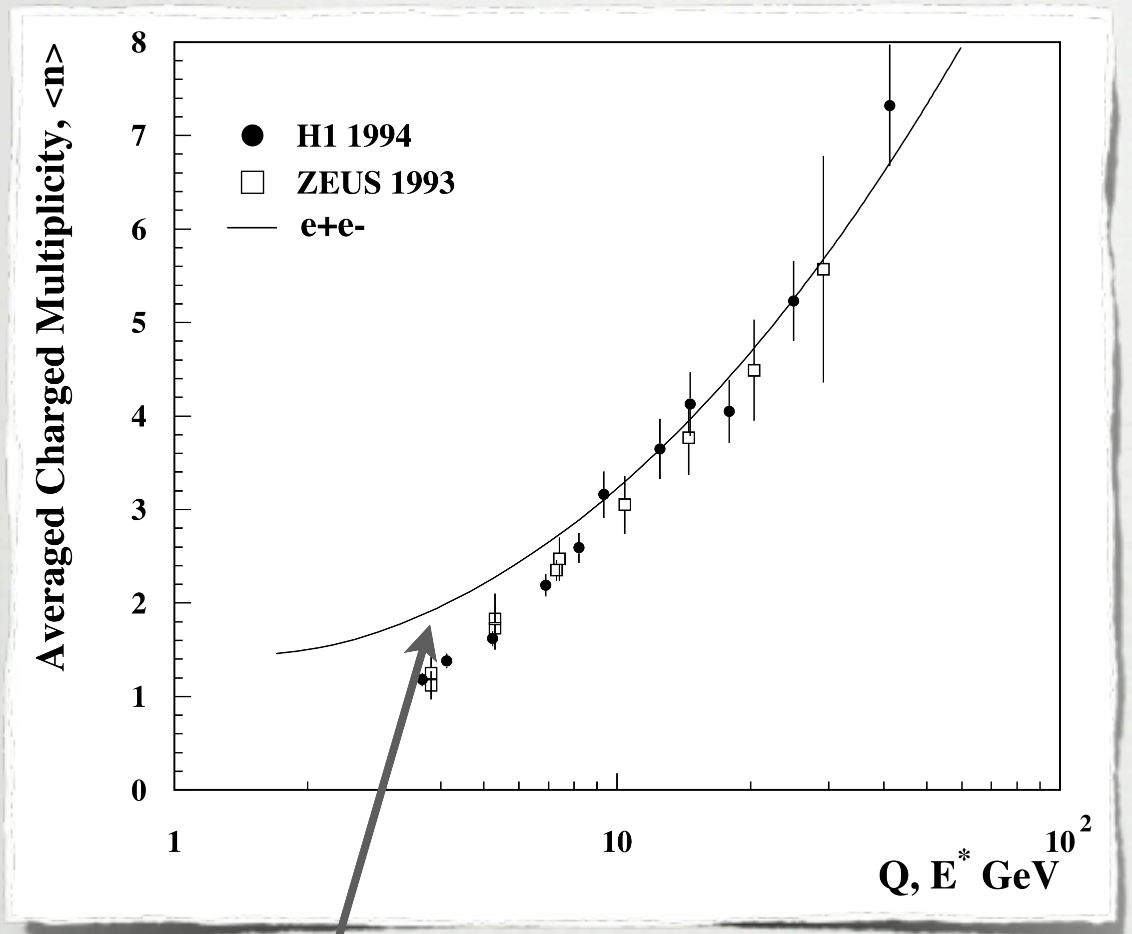
PROVIDES CLEAREST SEPARATION BETWEEN PARTICLES FROM HARD SCATTERING AND PROTON REMNANT. ALLOWS FOR EASY COMPARISON WITH e^+e^- DATA

CURRENT REGION ENERGY SCALE IS Q/2



THE BREIT FRAME

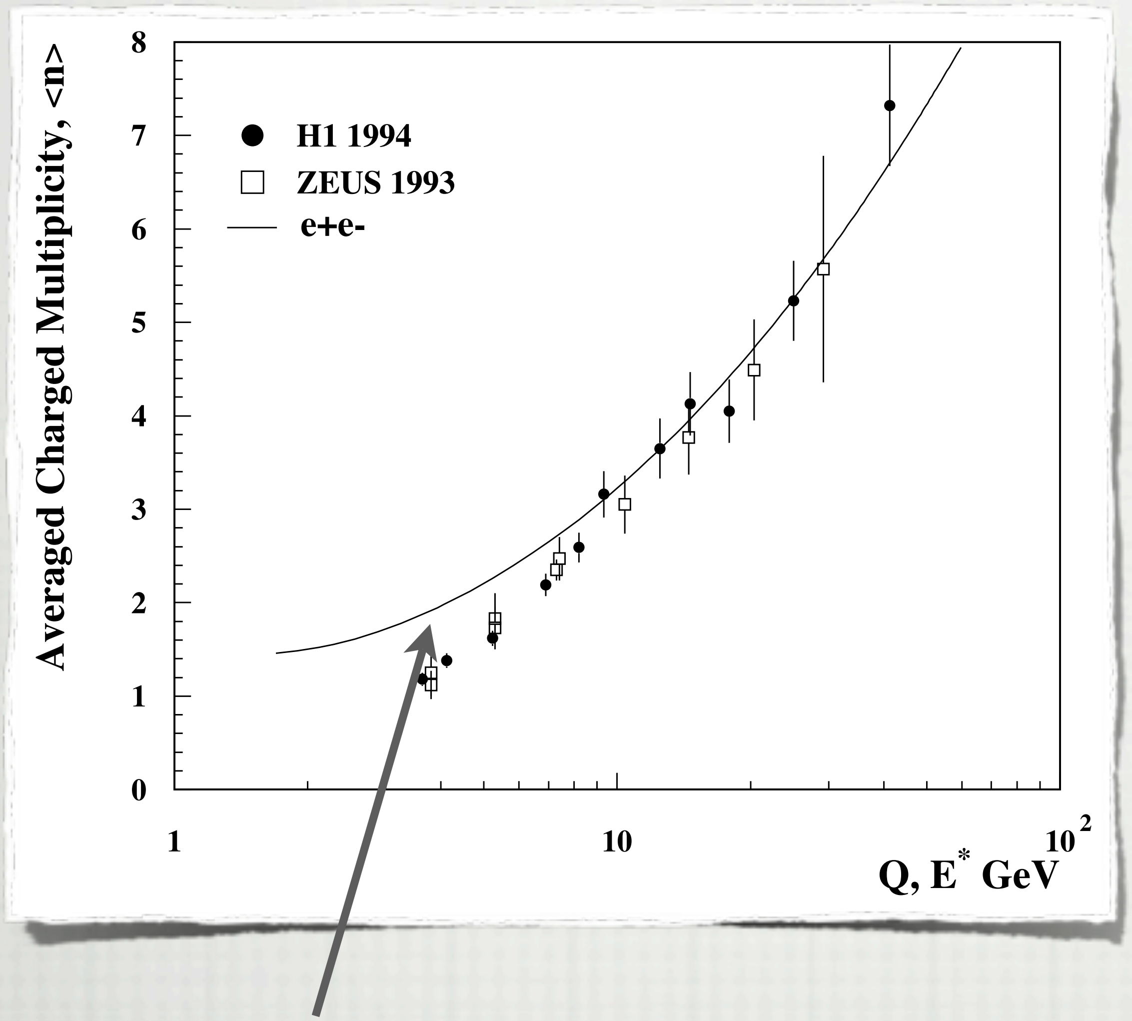
$<n^{+/-}>$



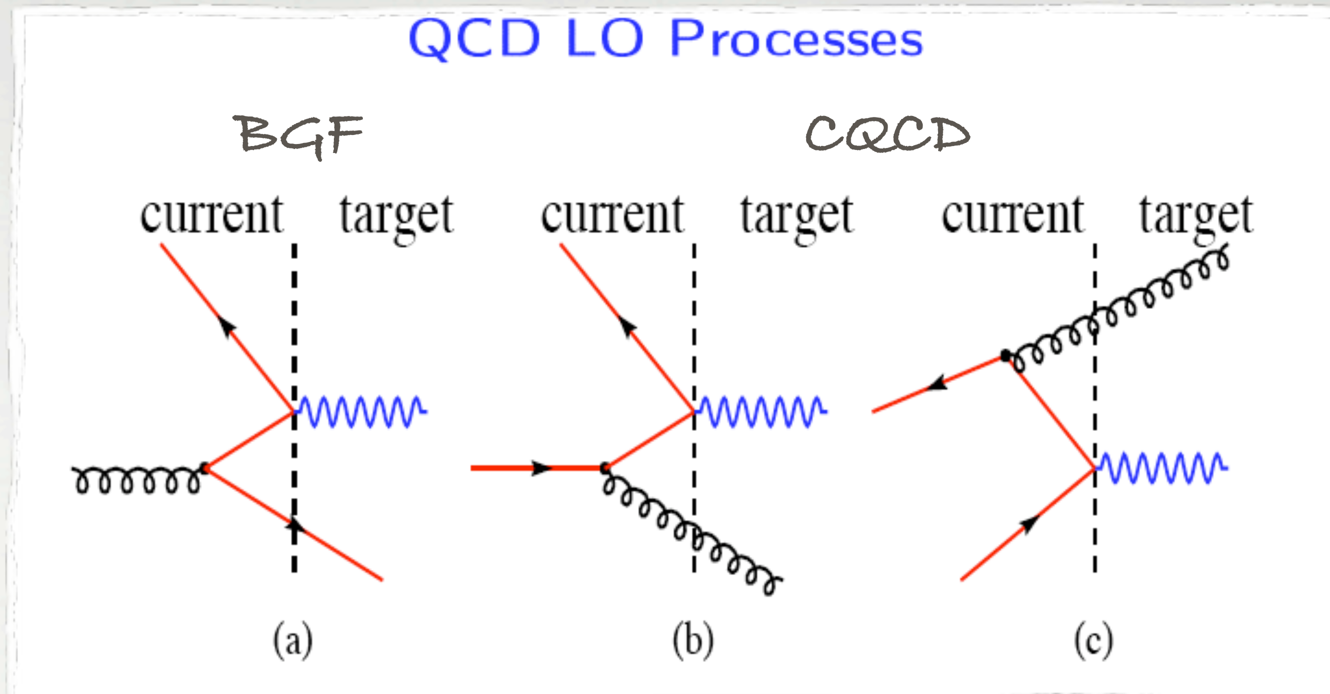
DEPOPULATION OF
CURRENT REGION

MORE

$<n^{+/-}>$



DEPOPULATION OF CURRENT REGION

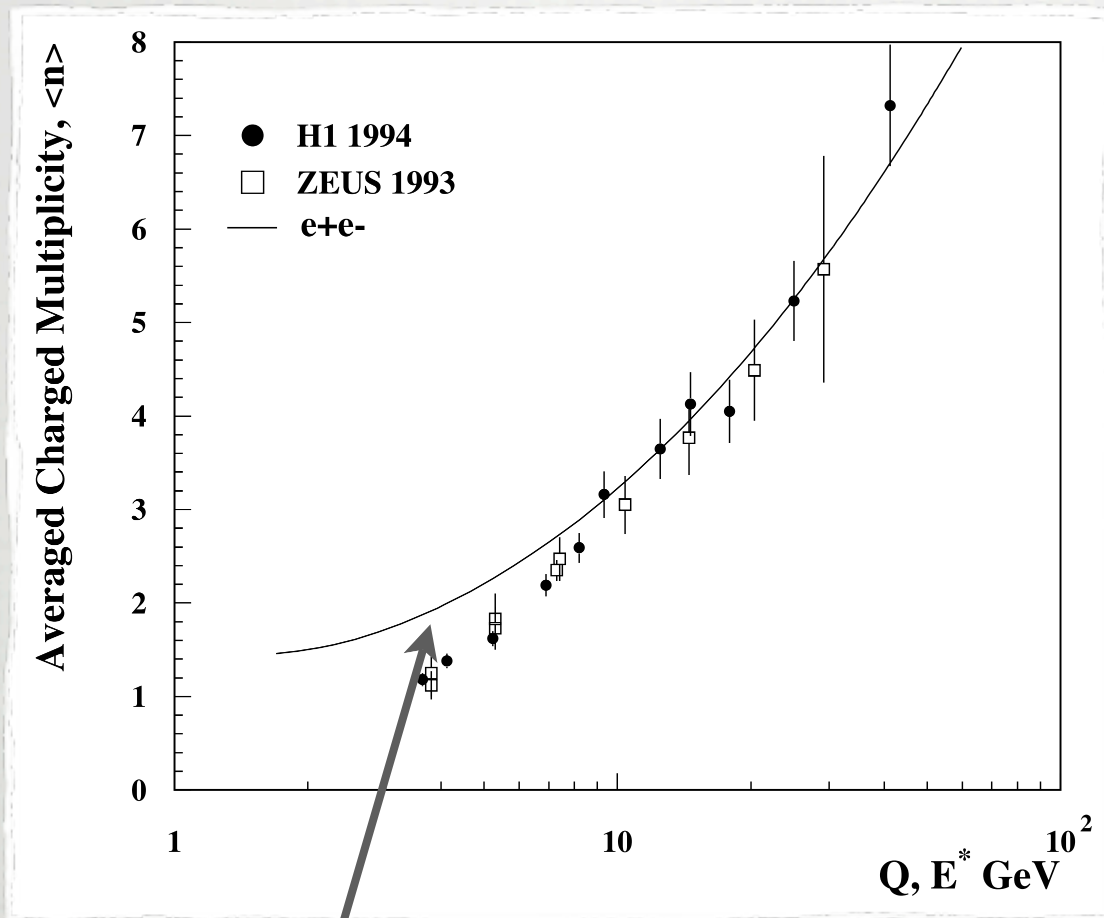


INITIAL STATE QCD NOT PRESENT IN e^+e^-

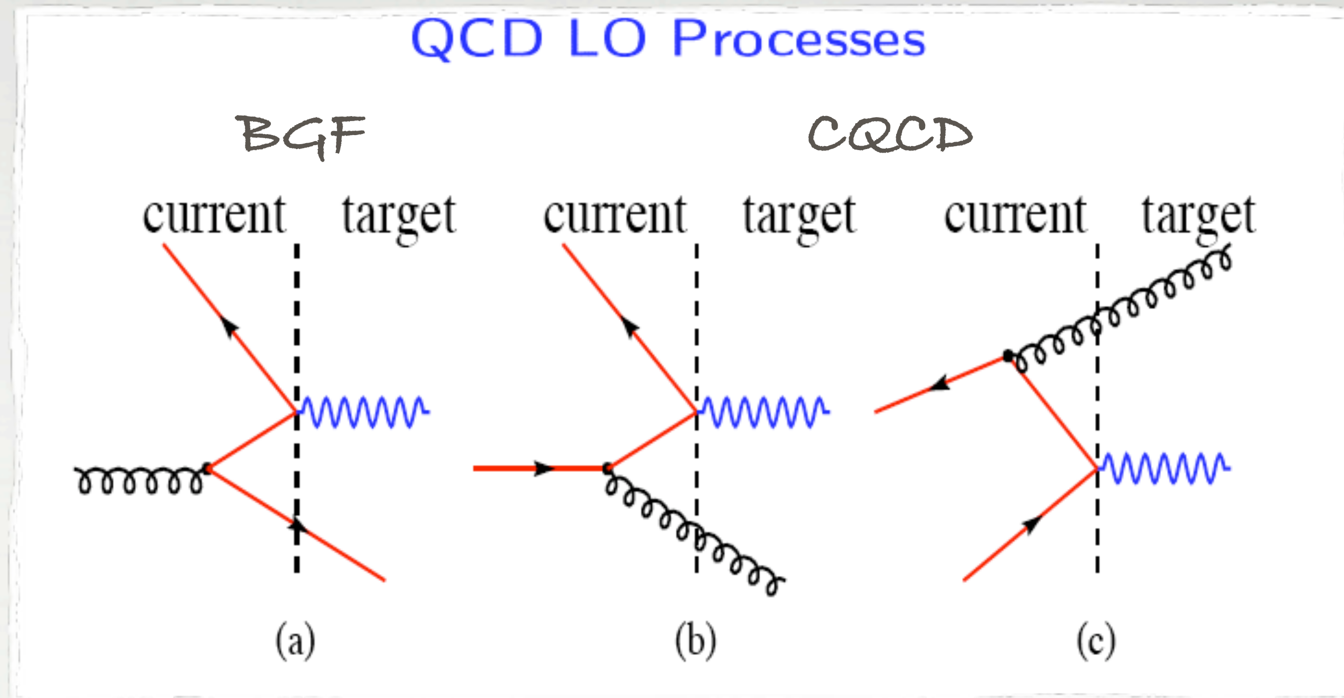
ONLY SEE 1/2 THE EVENT C.F. TO e^+e^-

MORE

$\langle n^{+/-} \rangle$



DEPOPULATION OF CURRENT REGION



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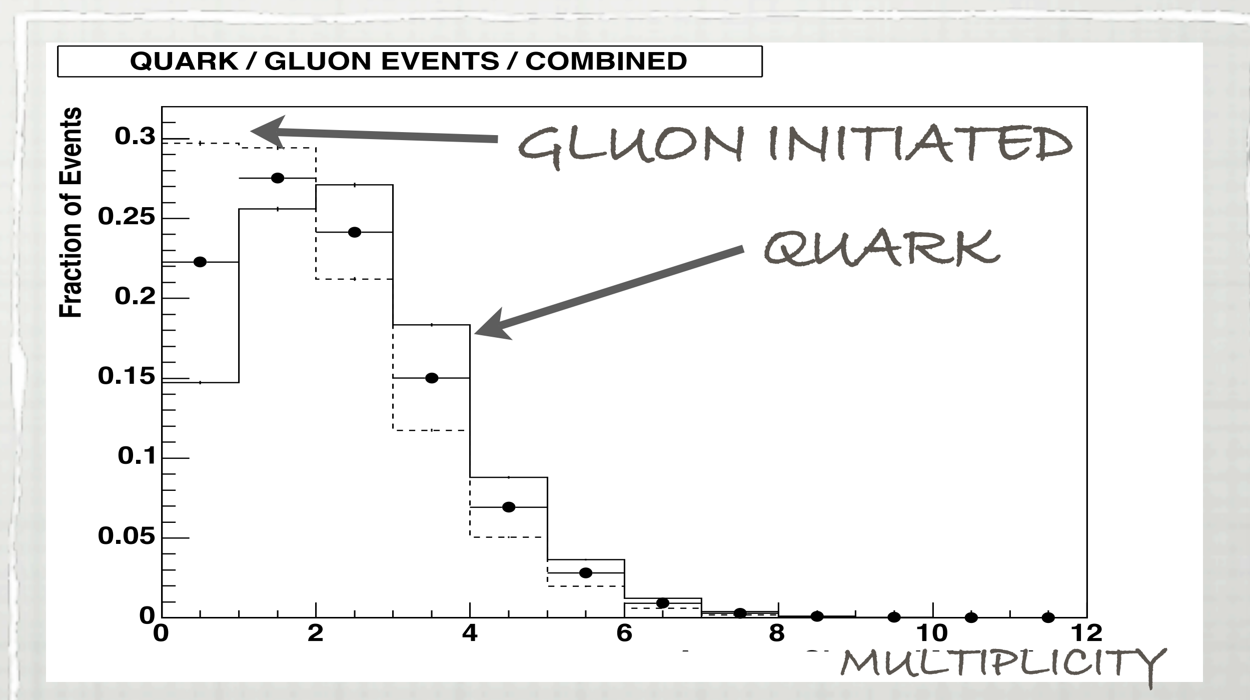


MORE

KINEMATIC PHASE SPACE

$100 < Q^2 < 20{,}000$ GEV^2

$0.05 < Y < 0.6$

$\theta_{electron} > 150°$

$30° < \theta_{q,lab} < 150°$

$\Theta_{Q,LAB}$, QUARK SCATTERING ANGLE, CALCULATED FROM KINEMATICS. ENSURES CURRENT REGION OF BREIT FRAME REMAINS WITHIN TRACKING ACCEPTANCE.

EASY TO CALCULATE IN THEORY.

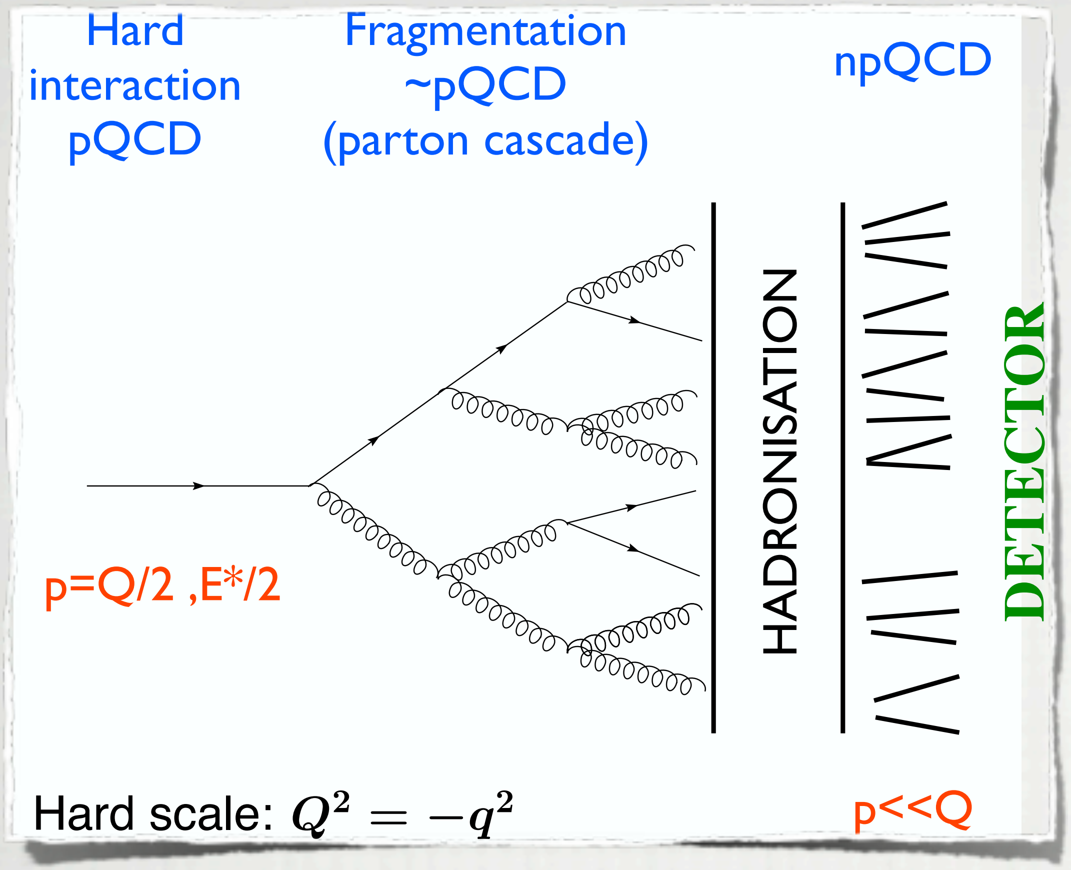
CORRECTION FACTOR < 1.2. DOMINATED BY BOOST TO BREIT FRAME. CORRECTION FOR TRACKING EFFICIENCIES FEW %

BOOST TO BREIT FRAME MEANS WE MEASURE DOWN TO $P_{BREIT} = 0$!

SYSTEMATIC ERROR ~5%

EXPERIMENTAL POINTS

MORE



$\pi^{+/-}$

$K^{+/-}$

$p^{+/-}$

~~K^0..~~

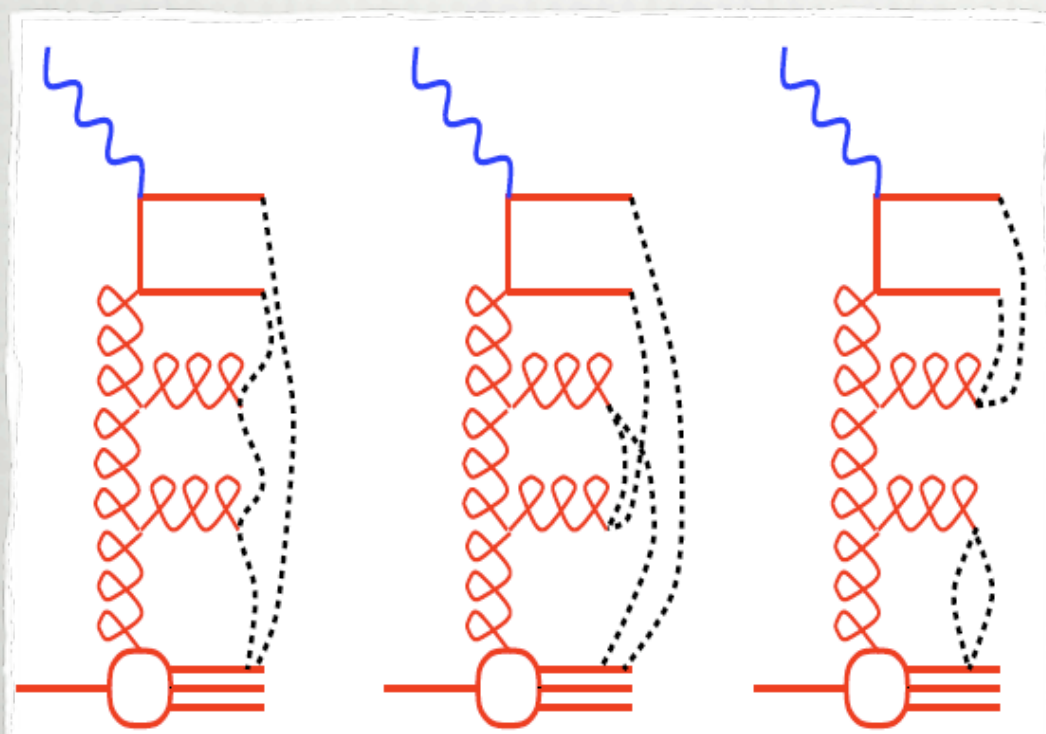
MONTE-CARLO (LO ME)

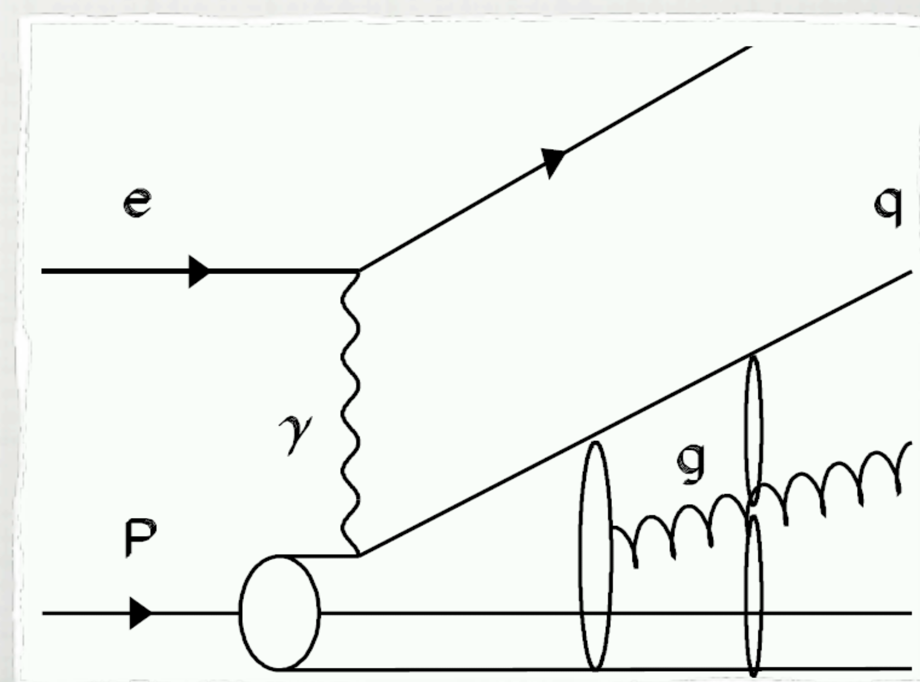
LEPTO (PARTON SHOWERS + STRING)

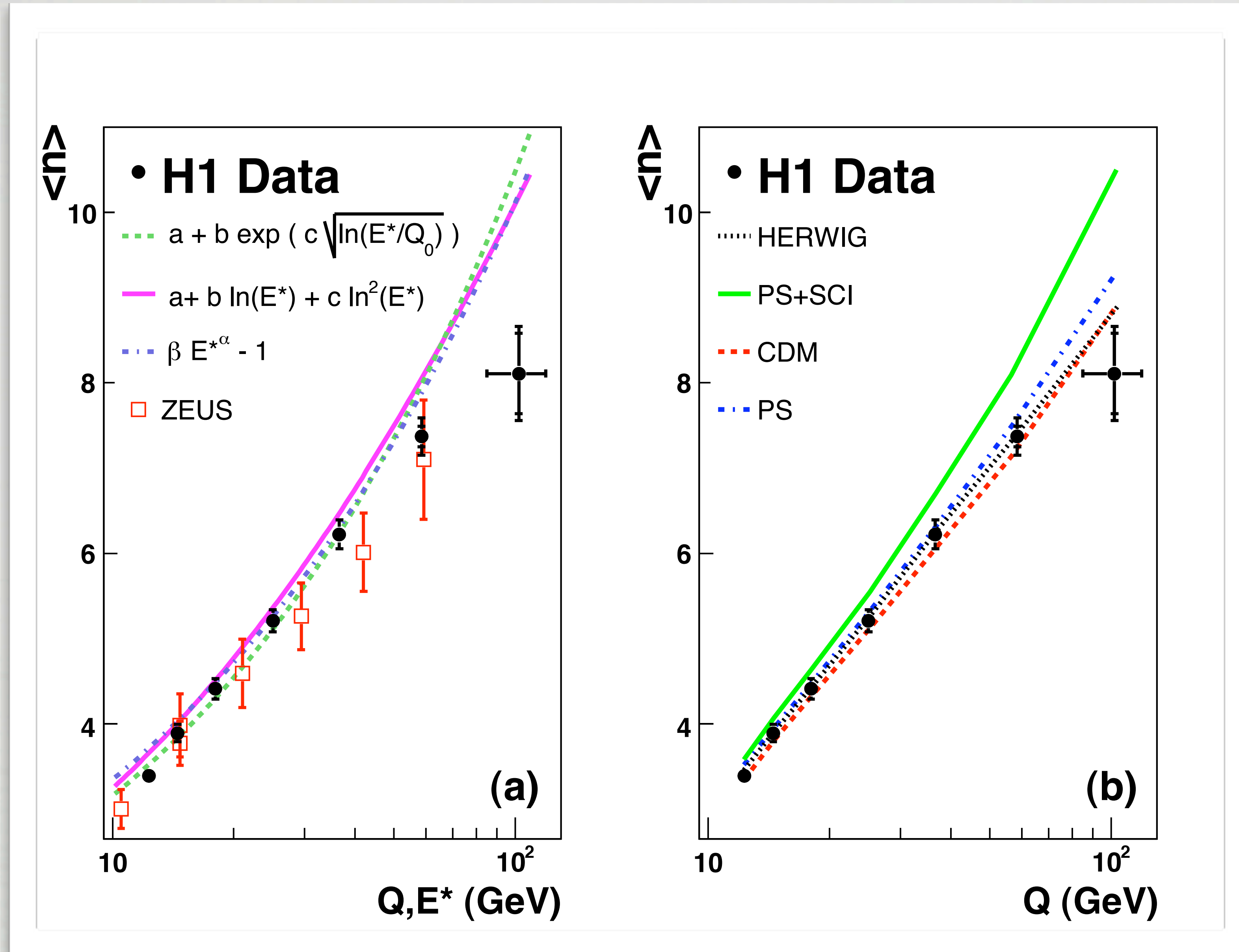
SCI (LEPTO + SOFT COLOUR INTERACTIONS)

ARIADNE (COLOUR DIPOLE MODEL + STRING)

HERWIG (PS + CLUSTER)







GOOD AGREEMENT WITH e^+e^- EXCEPT AT HIGHEST Q^2

GOOD AGREMENT WITH MODELS EXCEPT FOR SCI

e^+e^- PARAMETERISATIONS
OPEL Z. PHYS C534 539 (1992)

ZEUS RESULTS 94-97 DATA
EUR. PHYS. J. C 11, 251-270 (1999)

MONTE CARLO FRAGMENTATION MODELS TUNED USING e^+e^-

AVERAGE CHARGED PARTICLE MULTIPLICITY

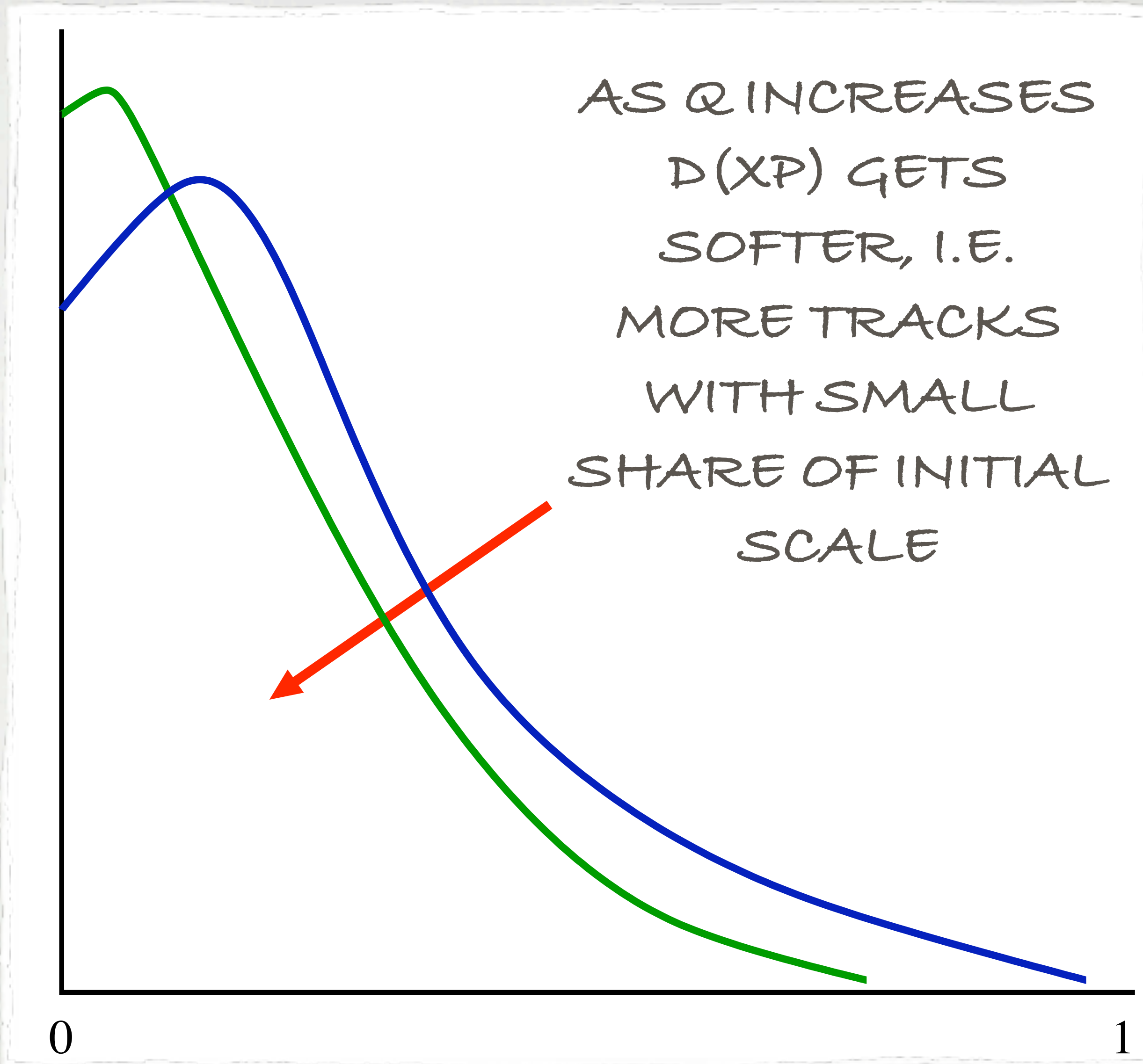
$$x_p = \frac{(2P_h)}{Q}$$

$$D(x_p) = \frac{1}{N_{event}} dn/dx_p$$

X_P = SCALED MOMENTUM VARIABLE

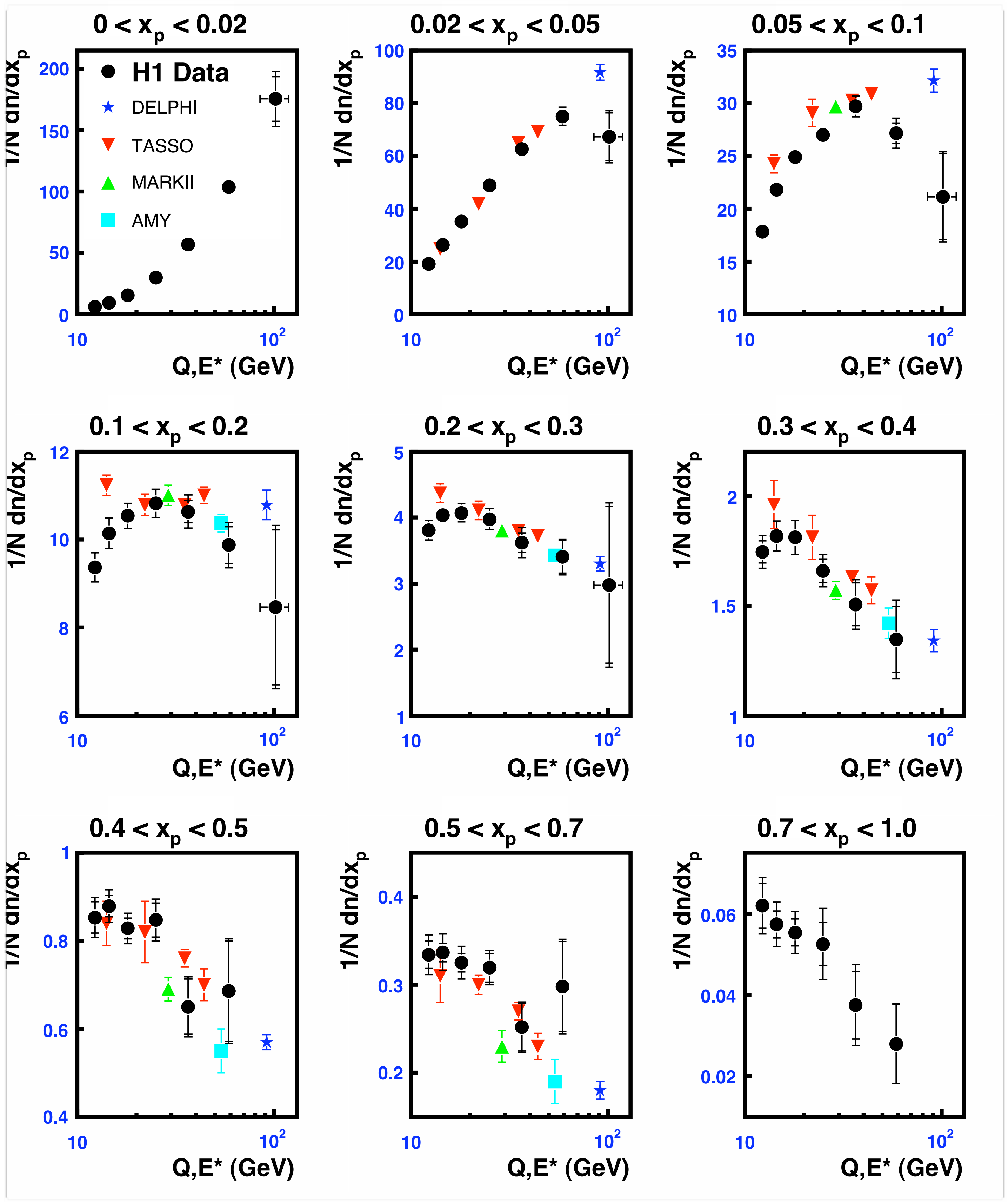
$Q/2$ = SCALE IN CURRENT REGION OF BREIT FRAME

P_h = MOMENTUM OF CHARGED PARTICLE IN CURRENT REGION OF BREIT FRAME



$D(X_P)$ = EVENT NORMALISED, CHARGED PARTICLE, SCALED MOMENTUM DISTRIBUTION

SCALED MOMENTUM DISTRIBUTION



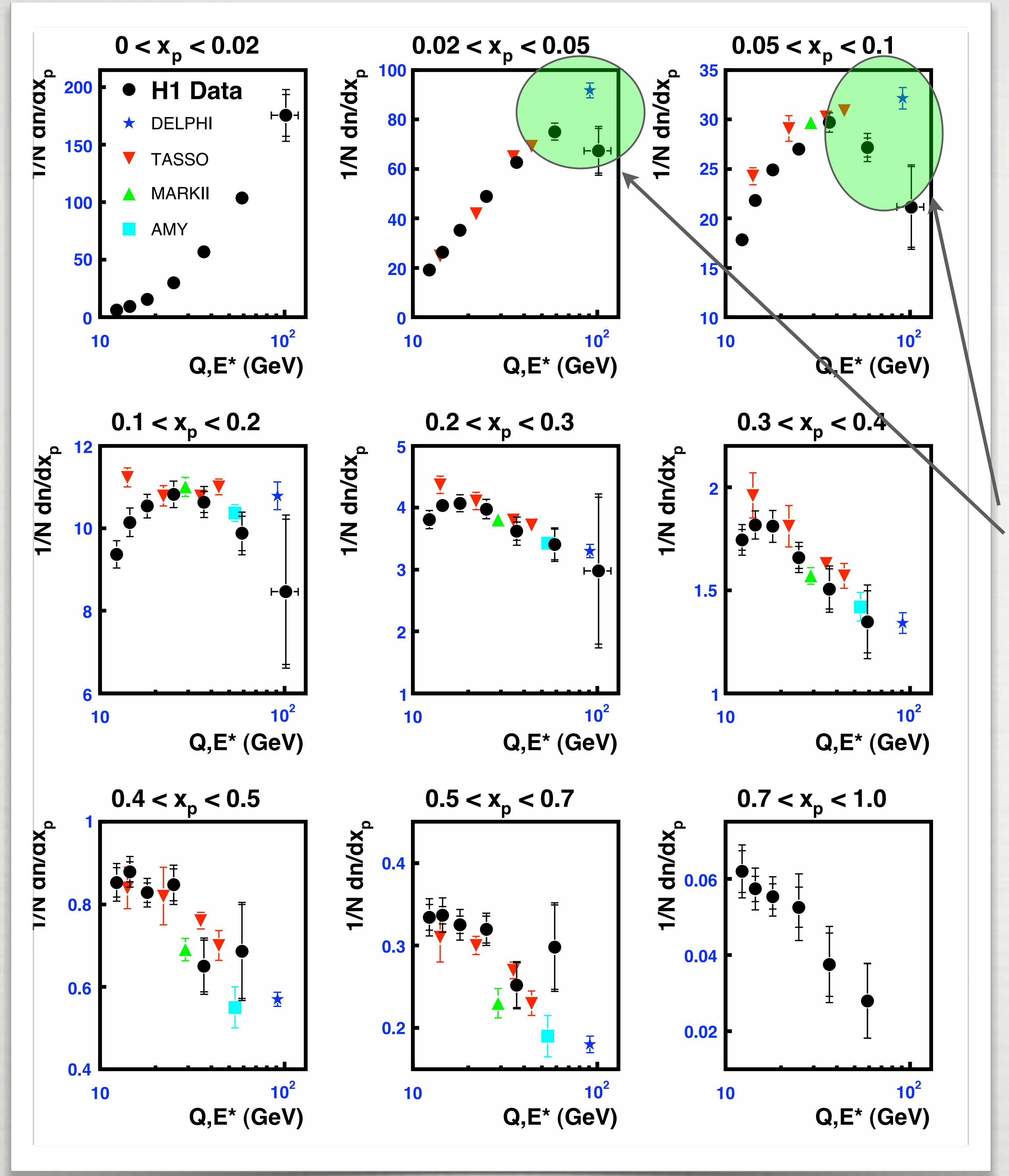
SCALED MOMENTUM

PRETTY GOOD AGREEMENT BETWEEN ep AND e^+e^- !

HIGH Q^2 AND SMALL X_P REASON UNCLEAR

LOW Q^2, MID X_P. EXPECTED TO BE DUE TO BGF KINEMATICS PRODUCING EMPTY CURRENT REGION

NB: SUPPRESSED ZEROS



SCALED MOMENTUM

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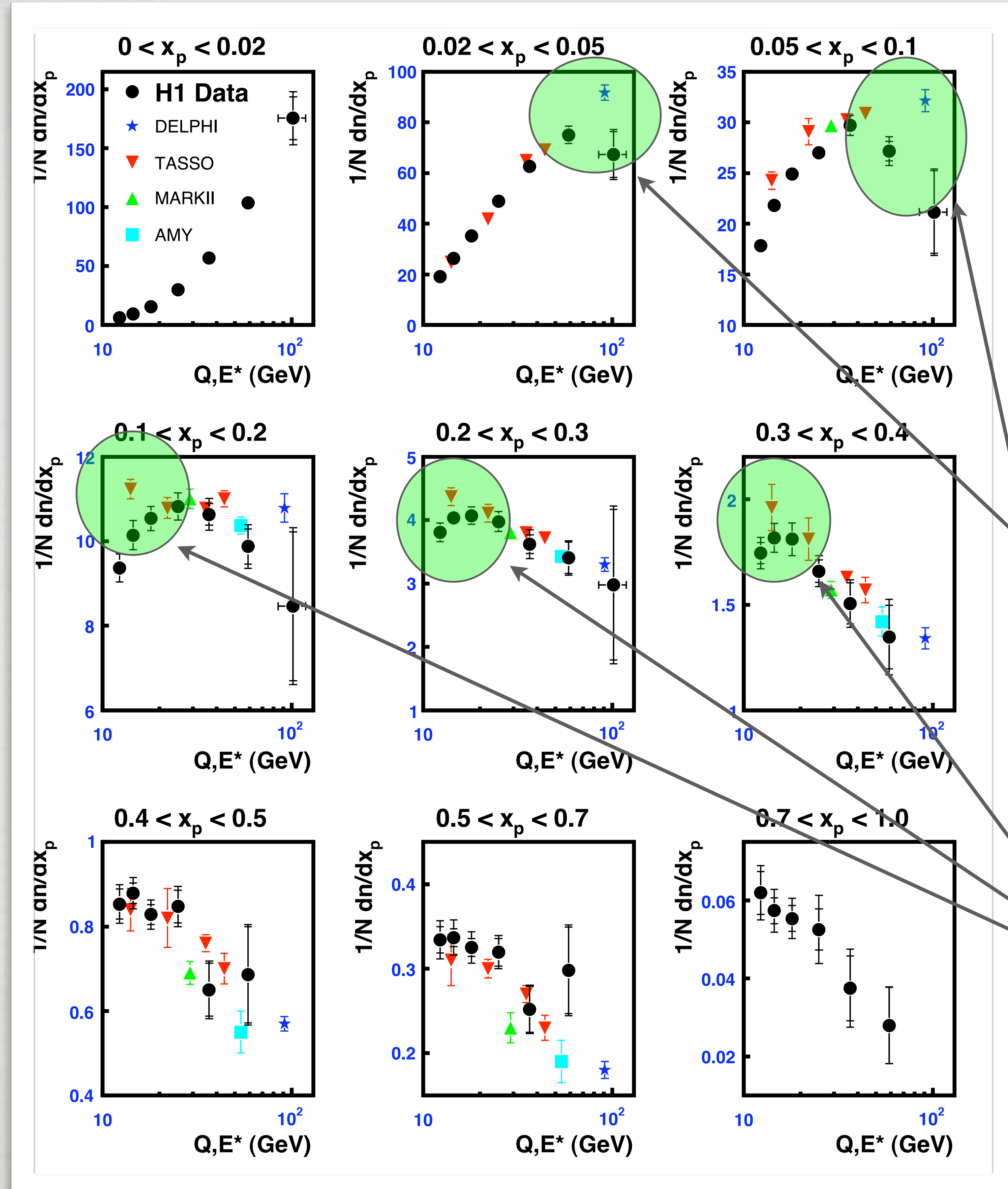
SCALED MOMENTUM



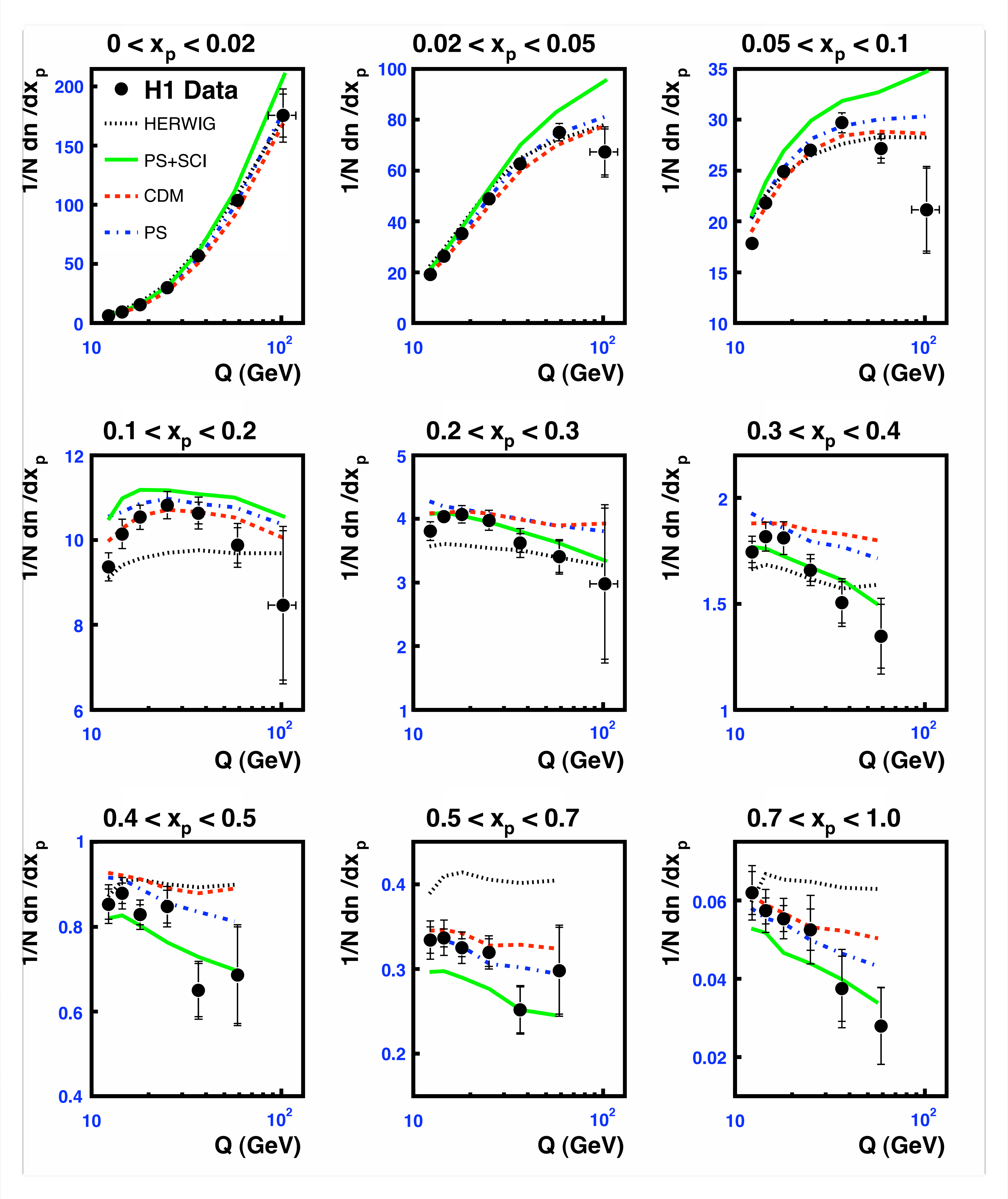
PRETTY GOOD AGREEMENT BETWEEN ep AND e^+e^- !

HIGH Q^2 AND SMALL X_P REASON UNCLEAR

LOW Q^2, MID X_P. EXPECTED TO BE DUE TO BGF KINEMATICS PRODUCING EMPTY CURRENT REGION

NB: SUPPRESSED ZEROS

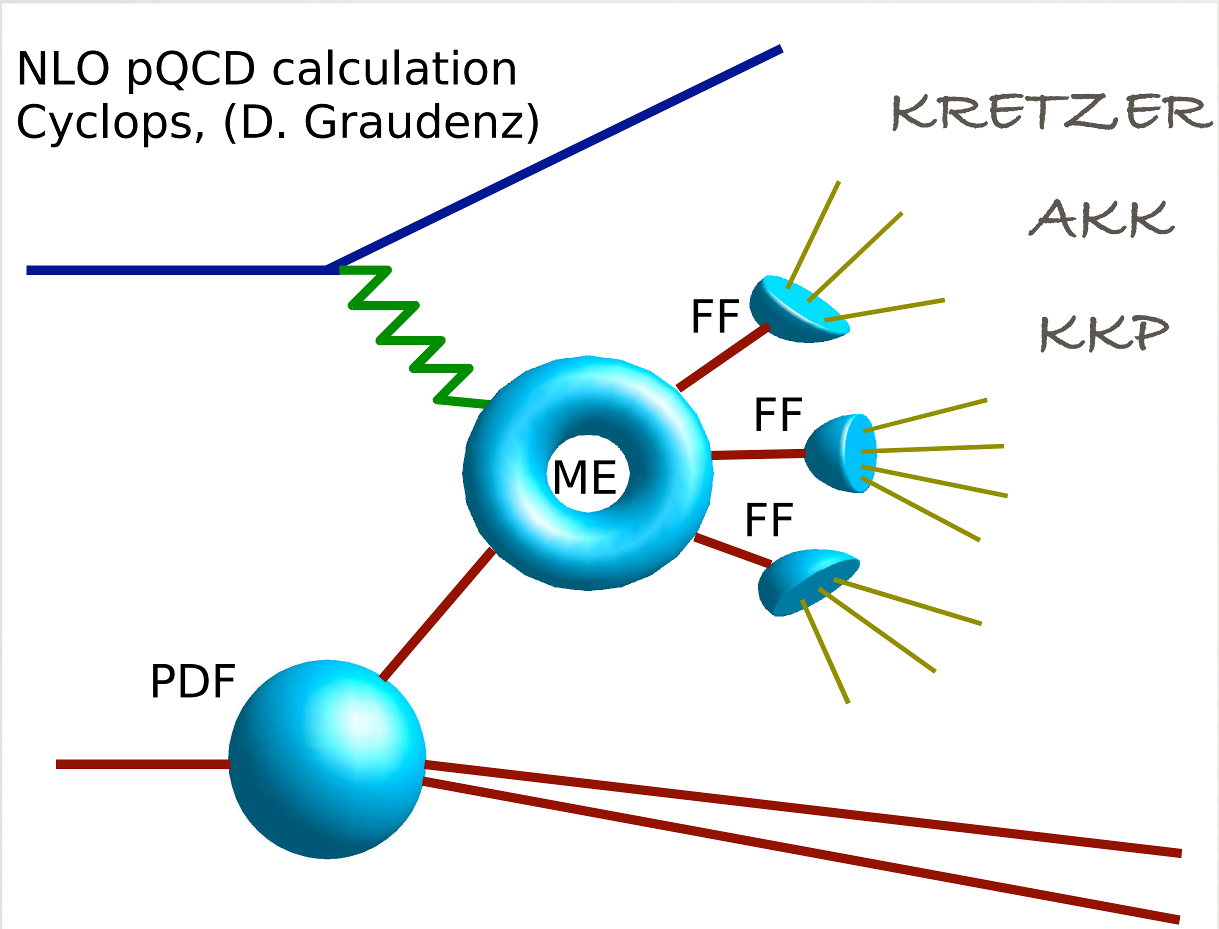
SCALED MOMENTUM



CDM AND PS ACCEPTABLE DESCRIPTION OF DATA. BOTH TEND TO OVERESTIMATE THE MULTIPLICITY AT HIGH Q^2

SCI MODEL PREDICTS TOO SOFT A SPECTRUM

HERWIG IS TOO HARD AND FAILS TO REPRODUCE SCALING VIOLATIONS SEEN IN THE DATA



KRETZER

AKK

KKP

$$\sigma_h = \text{PDF} \otimes \text{M.E.} \otimes \text{FF}$$

<u>NLO PQCD</u> CYCLOPS

FRAGMENTATION FUNCTIONS - e^+e^- FITS

INFRA RED SAFE REGION
(Q2>100), XP > 0.1

FF PARAMETERISED FROM
XP>0.1

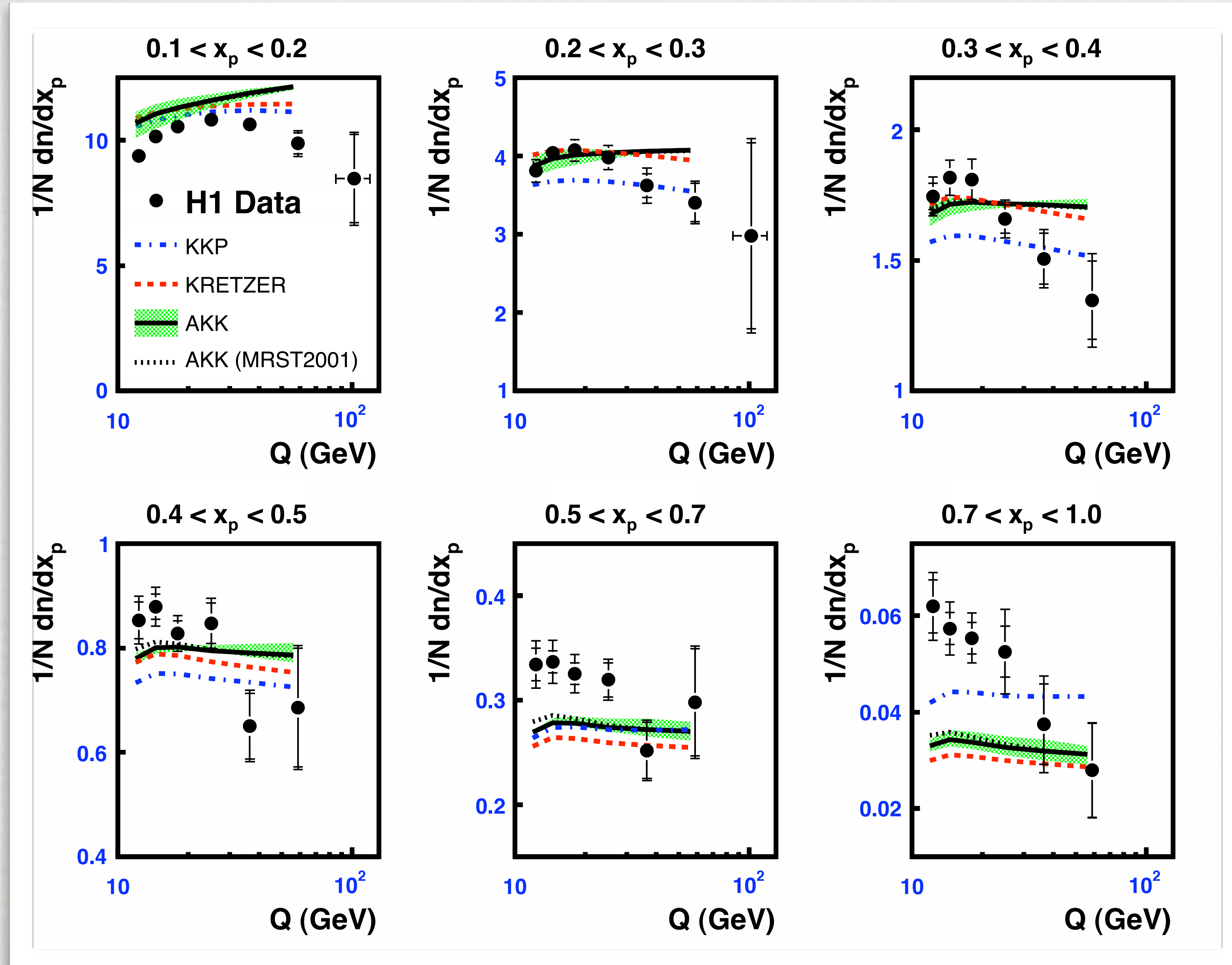
HIGHEST Q2 BIN (8,000 - 20,000)
LOW IN STATISTICS.

CTEQ6M, $\Lambda(5)$QCD = 226 MEV
(ALSO ME + FF)

PHYSICS MODELS

MORE

SCALED MOMENTUM



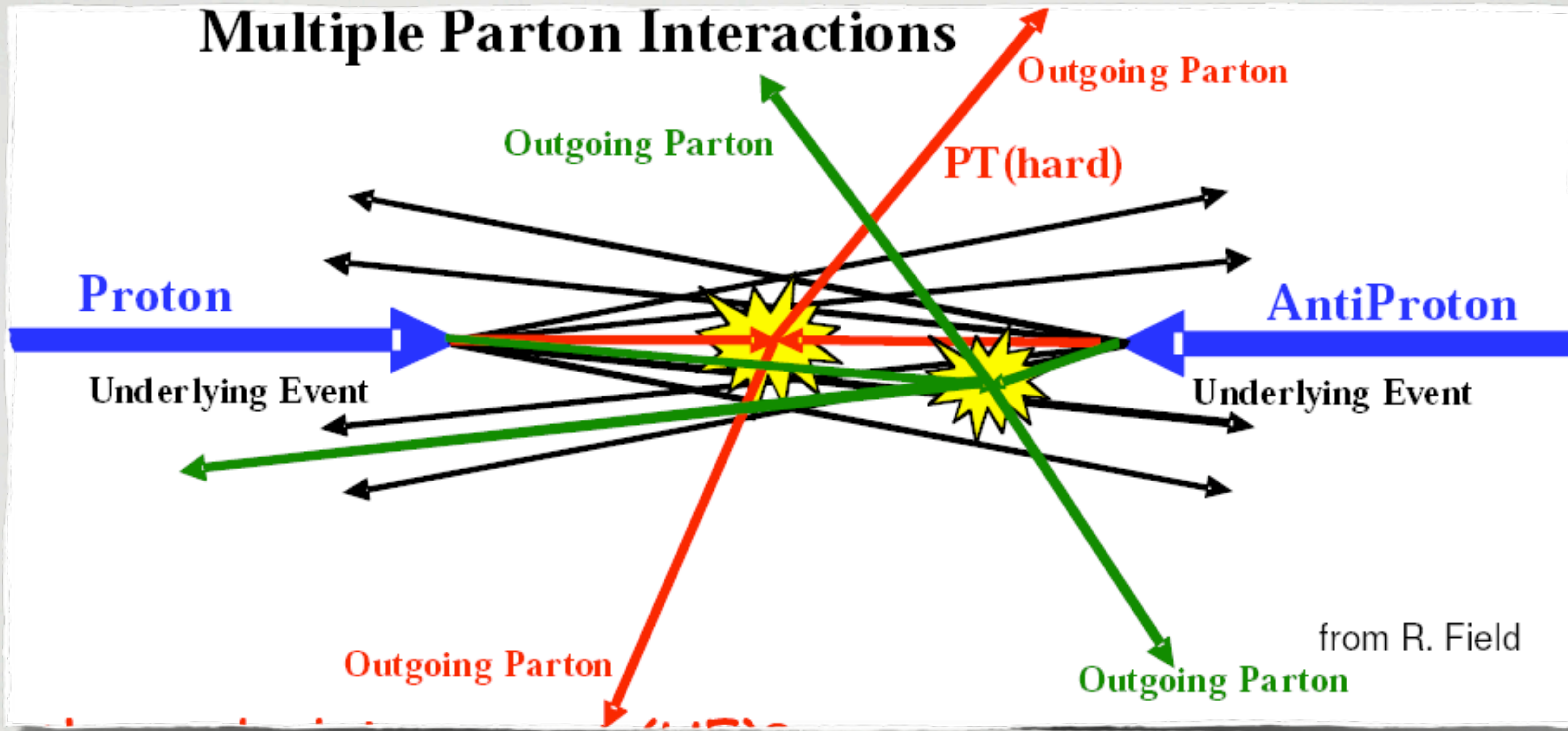
FRAGMENTATION FUNCTIONS (KKP, KRETZER, AKK) TAKEN FROM FITS TO e^+e^- DATA

SCALE AND PDF ERRORS SMALL

SENSITIVITY TO DIFFERENT FF

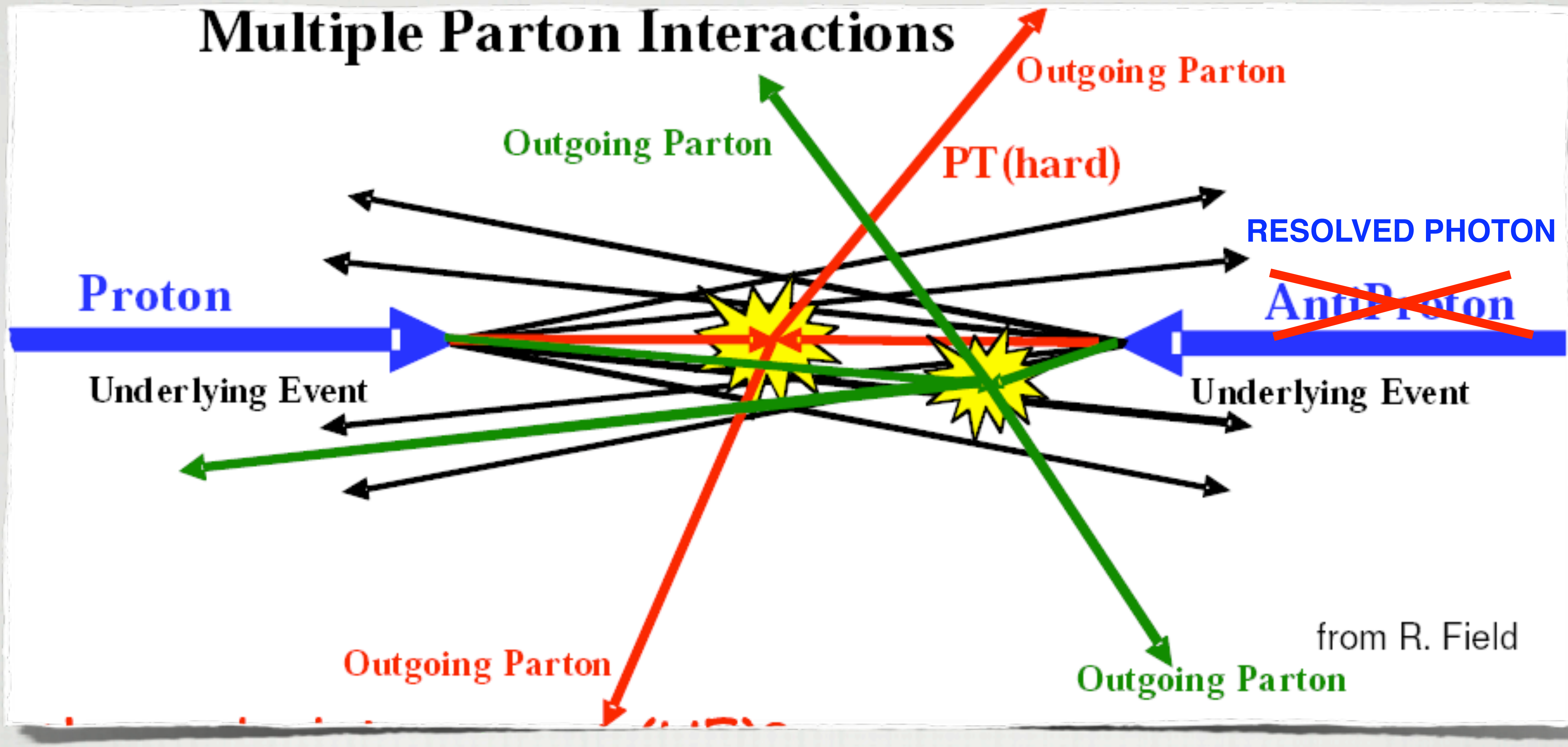
NLO THEORY DOES NOT DESCRIBE THE SCALING VIOLATIONS SEEN IN DATA

MINIJET PRODUCTION IN LOW Q^2 DIS



UNDERLYING EVENT: EVERYTHING EXCEPT THE "FIRST" HARD INTERACTION

- ADDITIONAL PARTON-REMNANT INTERACTIONS, MPI
- PARTON SHOWERS
- ...BUT NOT PILE UP

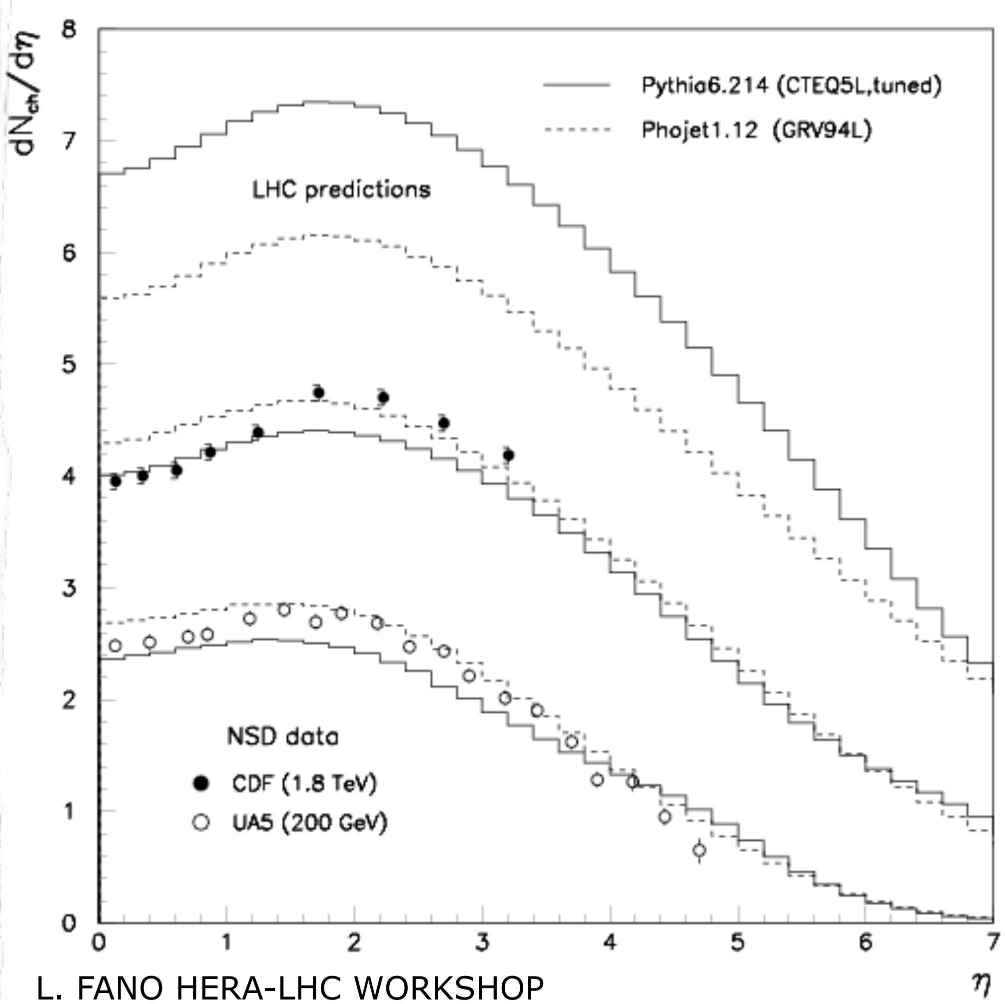


UNDERLYING EVENT: EVERYTHING EXCEPT THE "FIRST" HARD INTERACTION

- ADDITIONAL PARTON-REMNANT INTERACTIONS, MPI
- PARTON SHOWERS
- ...BUT NOT PILE UP

UI CAN INTERFERE WITH MANY TYPES OF PHYSICS ANALYSIS SO MUST BE UNDERSTOOD:

1. THEY REDUCE RAPIDITY GAP SURVIVAL PROBABILITY
2. THEY AFFECT ISOLATION CRITERIA (E.G. FOR MUONS)
3. THEY LEAD TO LARGER CHARGED/PARTICLE MULTIPLICITIES
4. AFFECT JET PROFILES/PEDESTALS AND INCREASE JET ENERGY SCALE
5. POTENTIALLY INCREASE JET RATES AND AFFECT JET ANGULAR CORRELATIONS



L. FANO HERA-LHC WORKSHOP

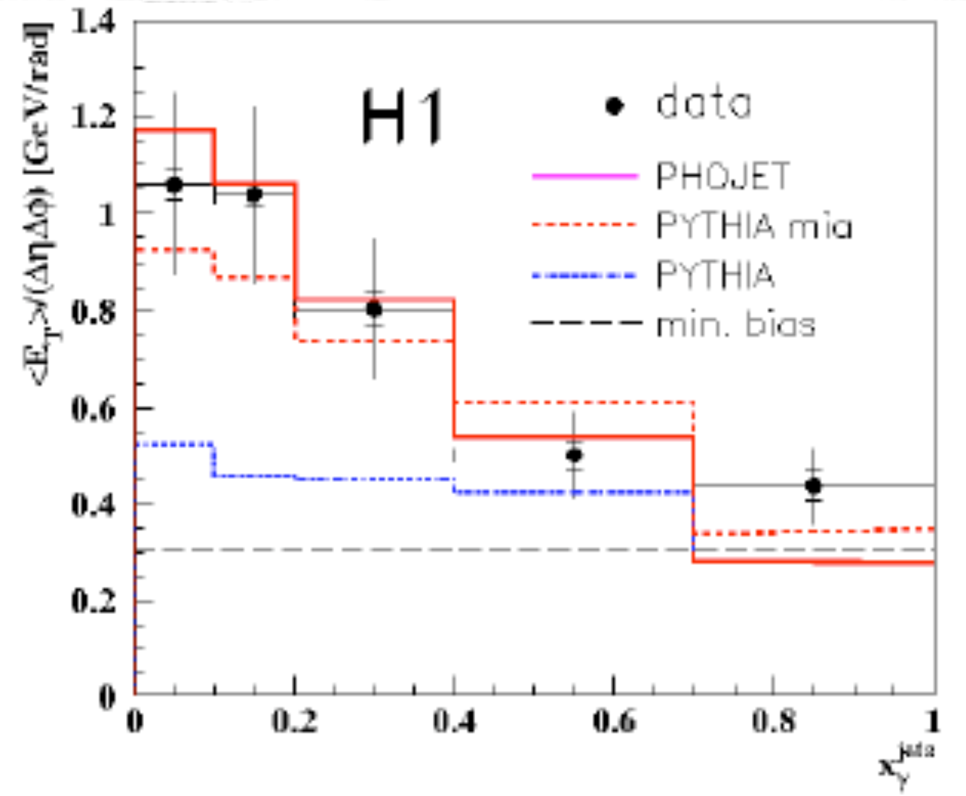
AND UI AT THE LHC WILL BE FAR MORE PREVALENT.

TO FIND (MOST) NEW PHYSICS MUST UNDERSTAND QCD BACKGROUND

UI AFFECT WHAT ANALYSES CAN BE DONE AND...
WHAT TRIGGERING STRATEGIES SHOULD BE EMPLOYED

MORE

IN PHOTOPRODUCTION ($Q^2 \sim 0$) THERE IS A LARGE RESOLVED COMPONENT. REMNANT-REMNANT INTERACTION VERY IMPORTANT (SEE RECENT ZEUS PAPER)



$$x_\gamma = \frac{E_{T,1}e^{-\eta_1} + E_{T,2}e^{-\eta_2}}{2E_\gamma}$$

IN DIS RESOLVED PROCESSES SUPPRESSED, BUT STILL PRESENT, BY VIRTUALITY (Q).

DO WE SEE ADDITIONAL INTERACTIONS ?

MORE

INCLUSIVE JET

PHASE SPACE

$5 < Q^2 < 100$ GEV^2

$0.1 < Y < 0.7$

W>200 GEV

JET SELECTION

$P_{T,1}^* > 5$ GEV

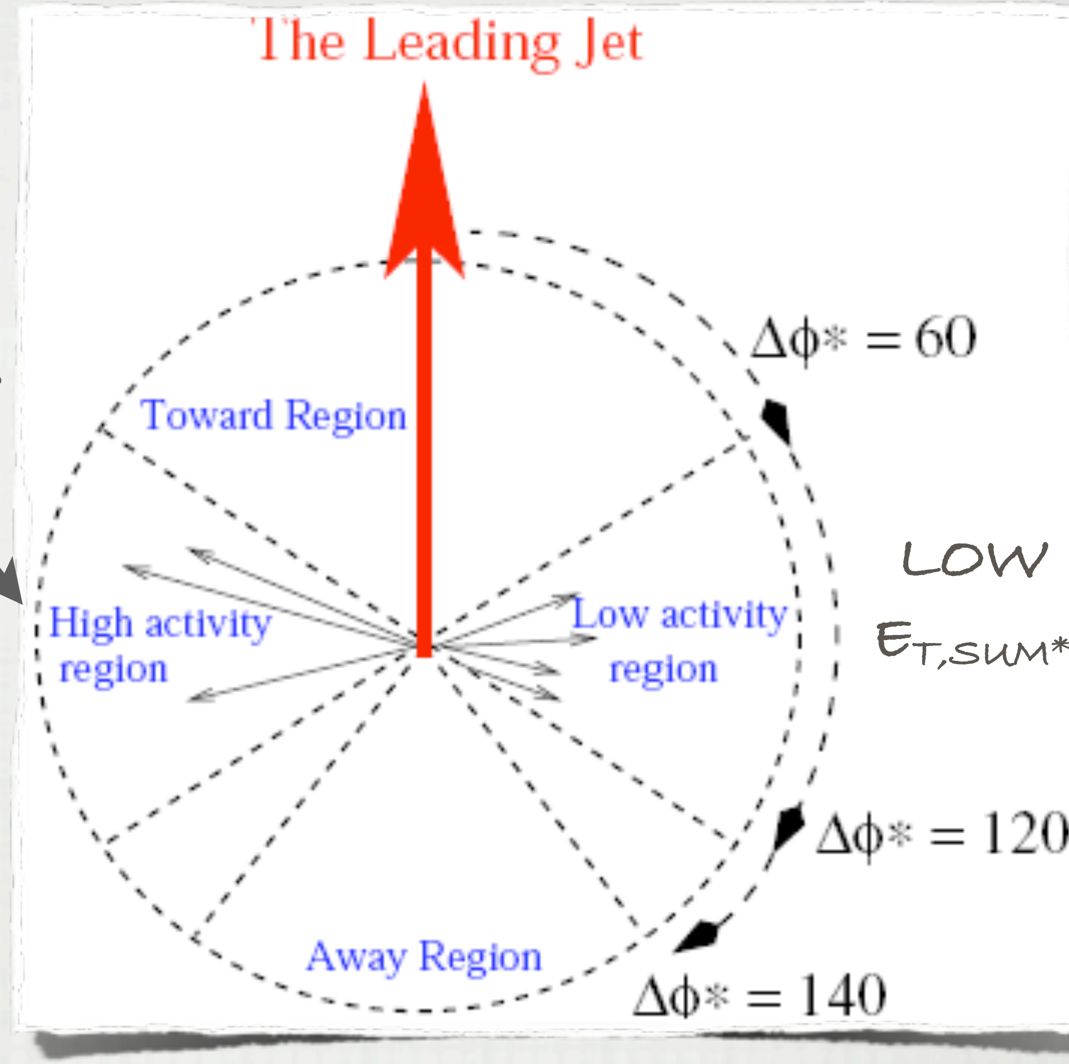
$-1.79 < \eta < 2.79$

MINJET SELECTION

$-1.79 < \eta_{minjet} < 2.79$

$P_{t,minijet} > 3$ GeV

HIGH E_{T,SUM^*}
OF MINIJETS



MEASURE

$$< N_{Minijets} >= \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$$

BINS OF Q^2, η AS FUNCTION OF P_{T1}^*

RAPGAP

LO ME + DGLAP PARTON SHOWERS (NO MPI)

RESOLVED PHOTON COMPONENT CAN BE INCLUDED.

CDM (ARIADNE)

PARTON SHOWERS FROM THE COLOR DIPOLE MODEL (NO MPI).

QPM AND BGF EVENTS FROM LO ME.

PYTHIA

LO ME + DGLAP PARTON SHOWERS

MPI: AVERAGE NUMBER OF INTERACTIONS/EVENT,

$$\sigma_{\mathrm{hard}}(p_{\mathrm{t,\ min}})/\sigma_{\mathrm{non\text{-}diff}}$$

SEVERAL FREE PARAMETERS. DIFFERENT TUNES EXIST.

HERE THE DEFAULT PARAMETERS ARE USED.

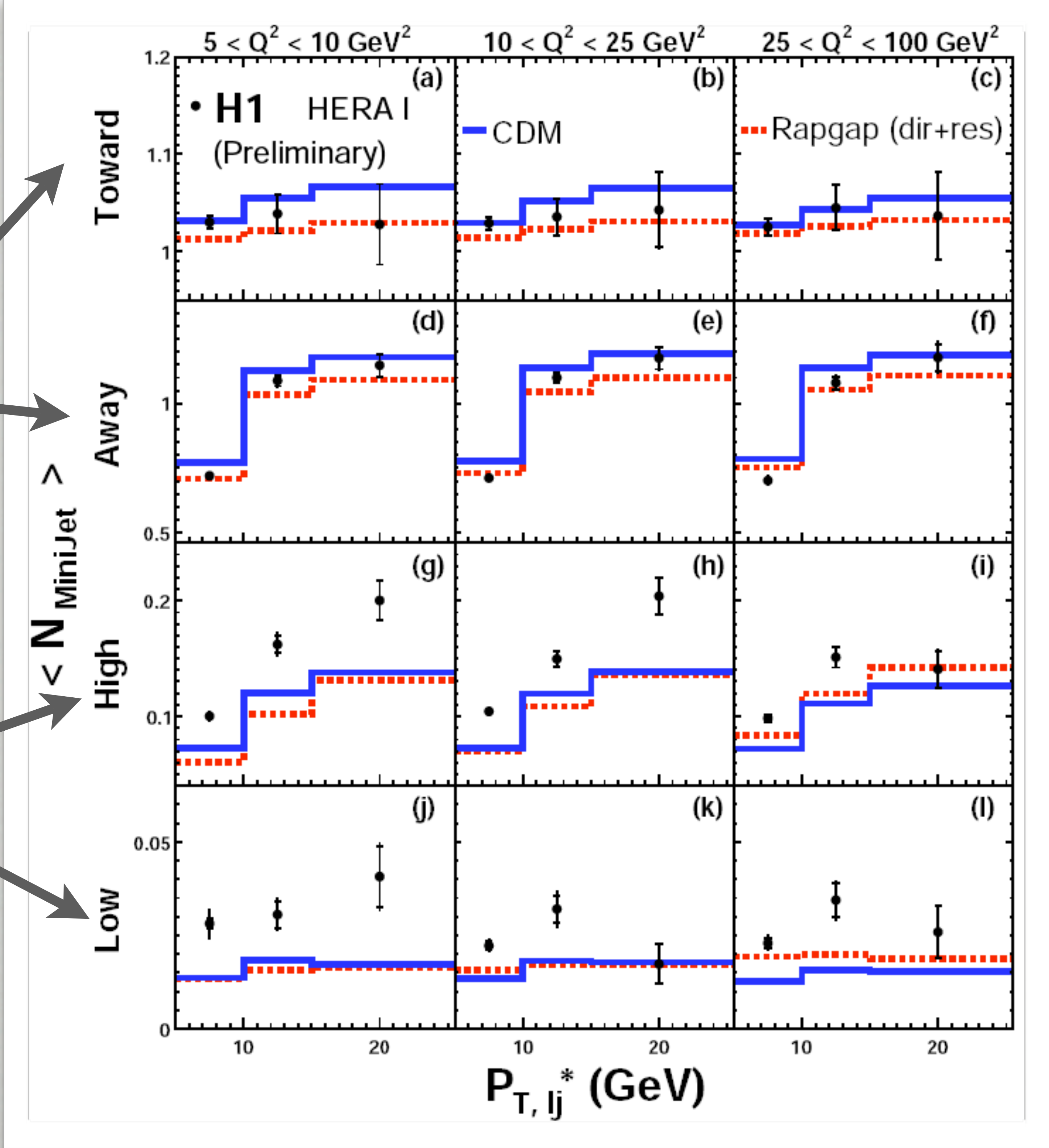
PHYSICS MODELS

INCLUSIVE JET SAMPLE

$$-1.7 < \eta^{jet} < 0.5$$

HARD REGIONS (TOWARD AND AWAY) DESCRIBED BY MONTE CARLO WITHOUT MULTIPLE INTERACTIONS

MODELS WITHOUT MULTIPLE INTERACTIONS FAILS IN TRANSVERSE REGIONS



INCLUSIVE JET SAMPLE

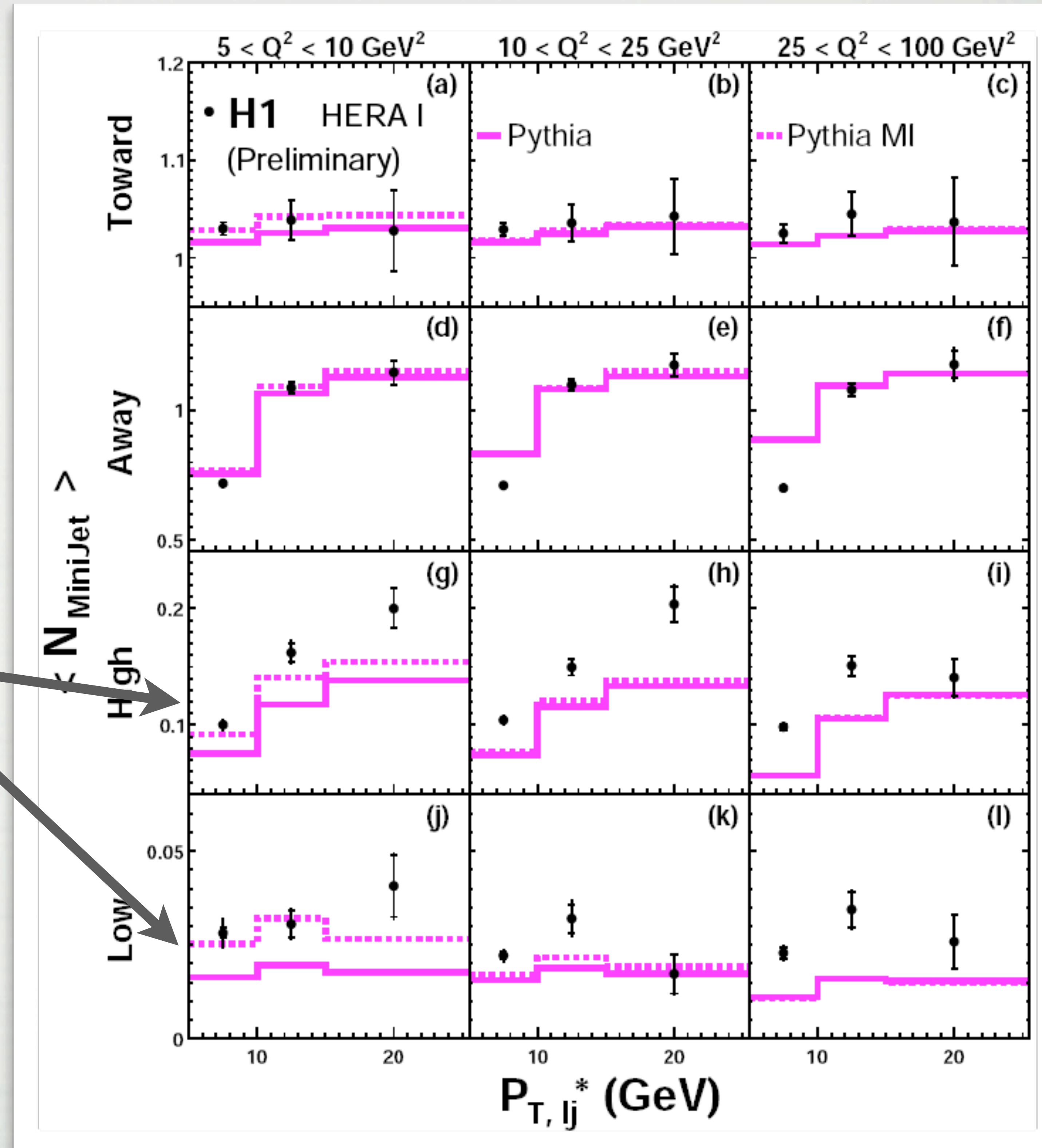
$$-1.7 < \eta^{jet} < 0.5$$

PYTHIA WITH MPI DOES SLIGHTLY BETTER AT LOW Q^2

LOWER Q^2 -> MORE RESOLVED PHOTON

SIMILAR STORY FOR

$$0.5 < \eta^{jet} < 2.79$$



DIJET SAMPLE

PHASE SPACE

$5 < Q^2 < 100$ GEV^2

$0.1 < Y < 0.7$

W>200 GEV

JET SELECTION

$P_{T,1,2}^* > 5$ GEV

$-1.79 < \eta < 2.79$

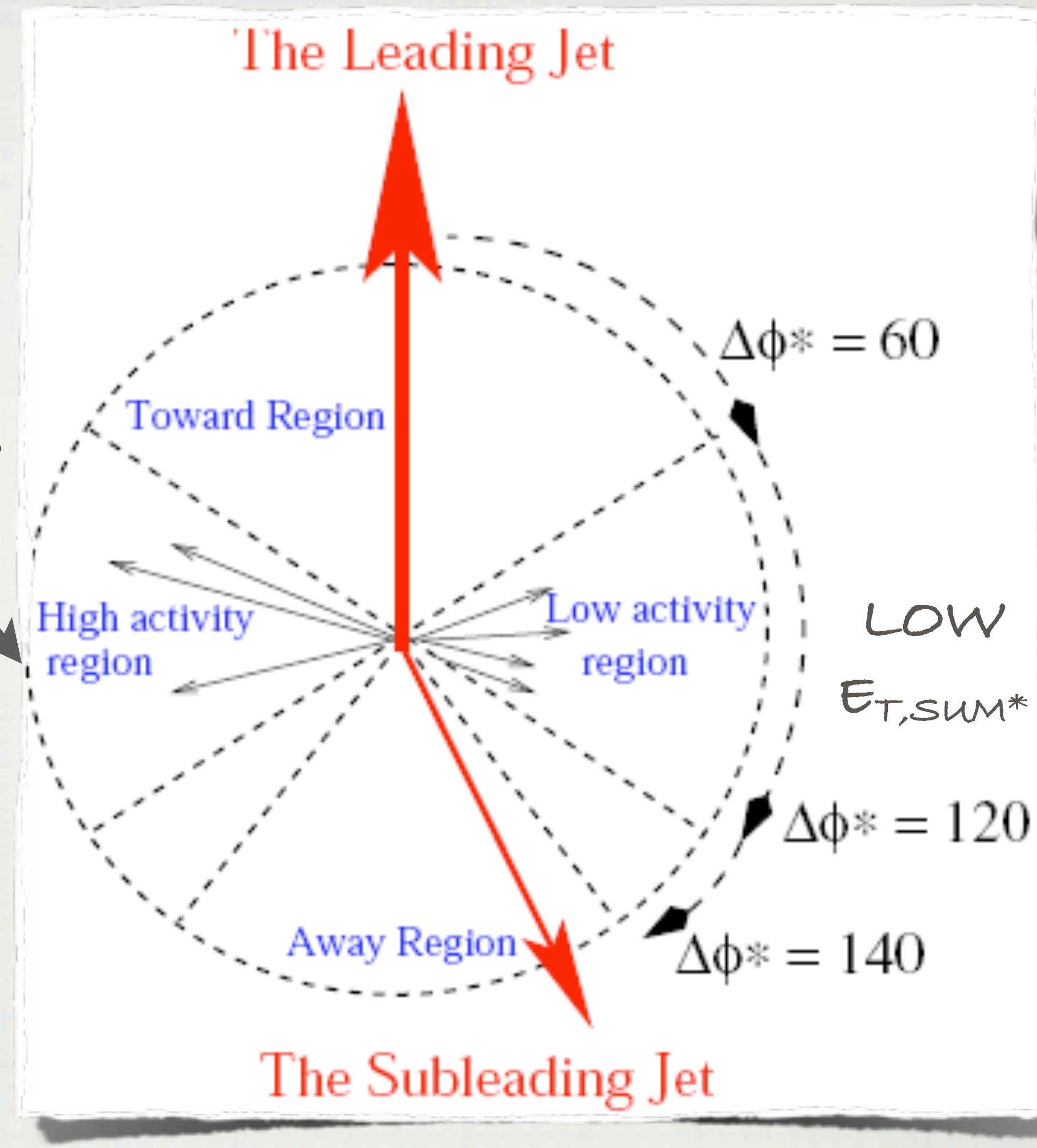
$(|\varphi_1^* - \varphi_2^*| > 140)$

MINJET SELECTION

$-1.79 < \eta_{minjet} < 2.79$

$P_{t,minijet} > 3$ GeV

HIGH $E_{T,SUM}^*$ OF MINIJETS



LOW $E_{T,SUM}^*$

MEASURE

$$< N_{Minijets} >= \frac{\sum^{N_{events}} N_{Minijet}}{N_{events}}$$

BINS OF X_γ AS FUNCTION OF P_{T1}^*

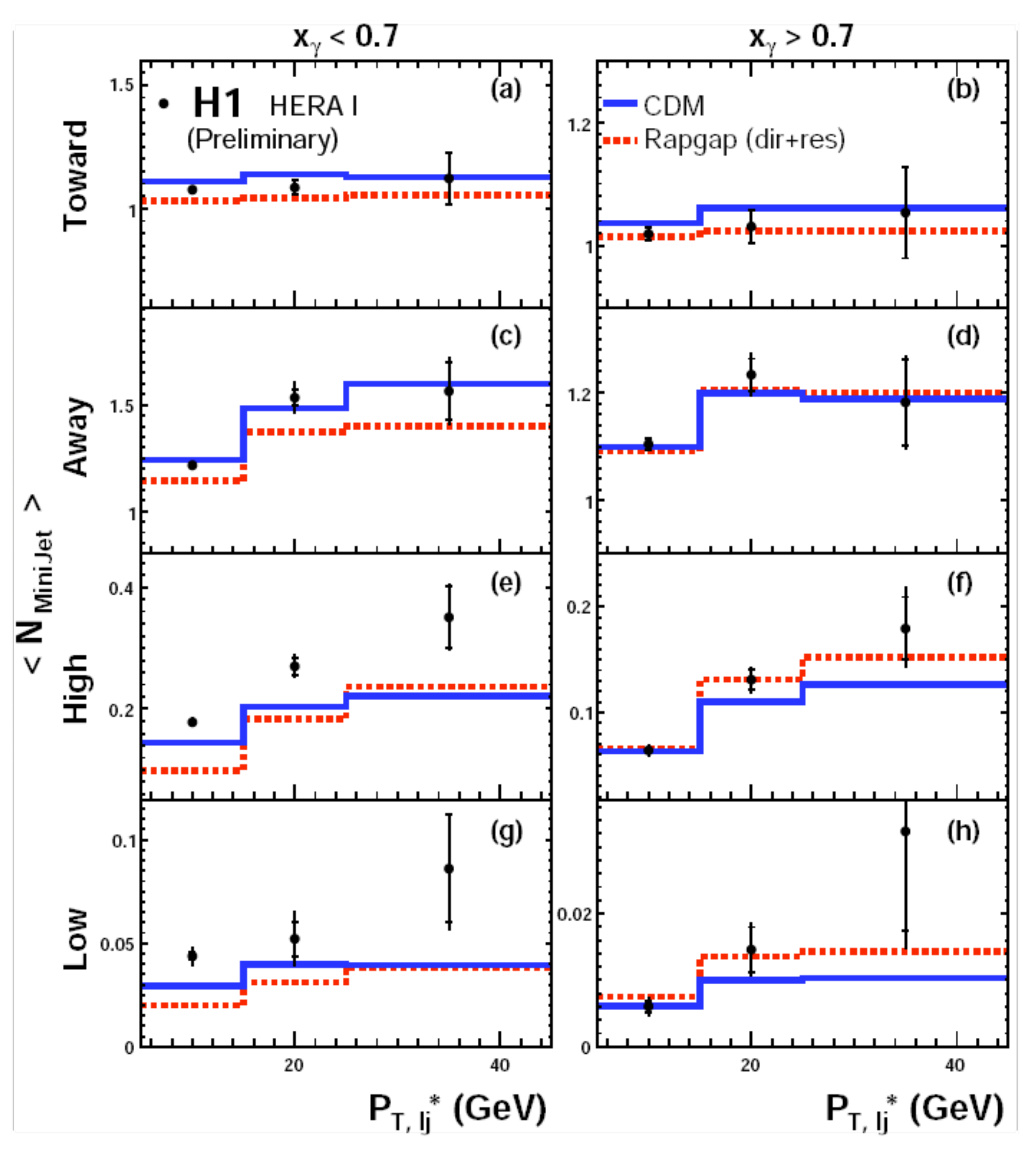
DIJETS SAMPLE

$$-1.7 < \eta^{jet} < 2.79$$

SAME BEHAVIOUR AGAIN:

HARD REGIONS OK

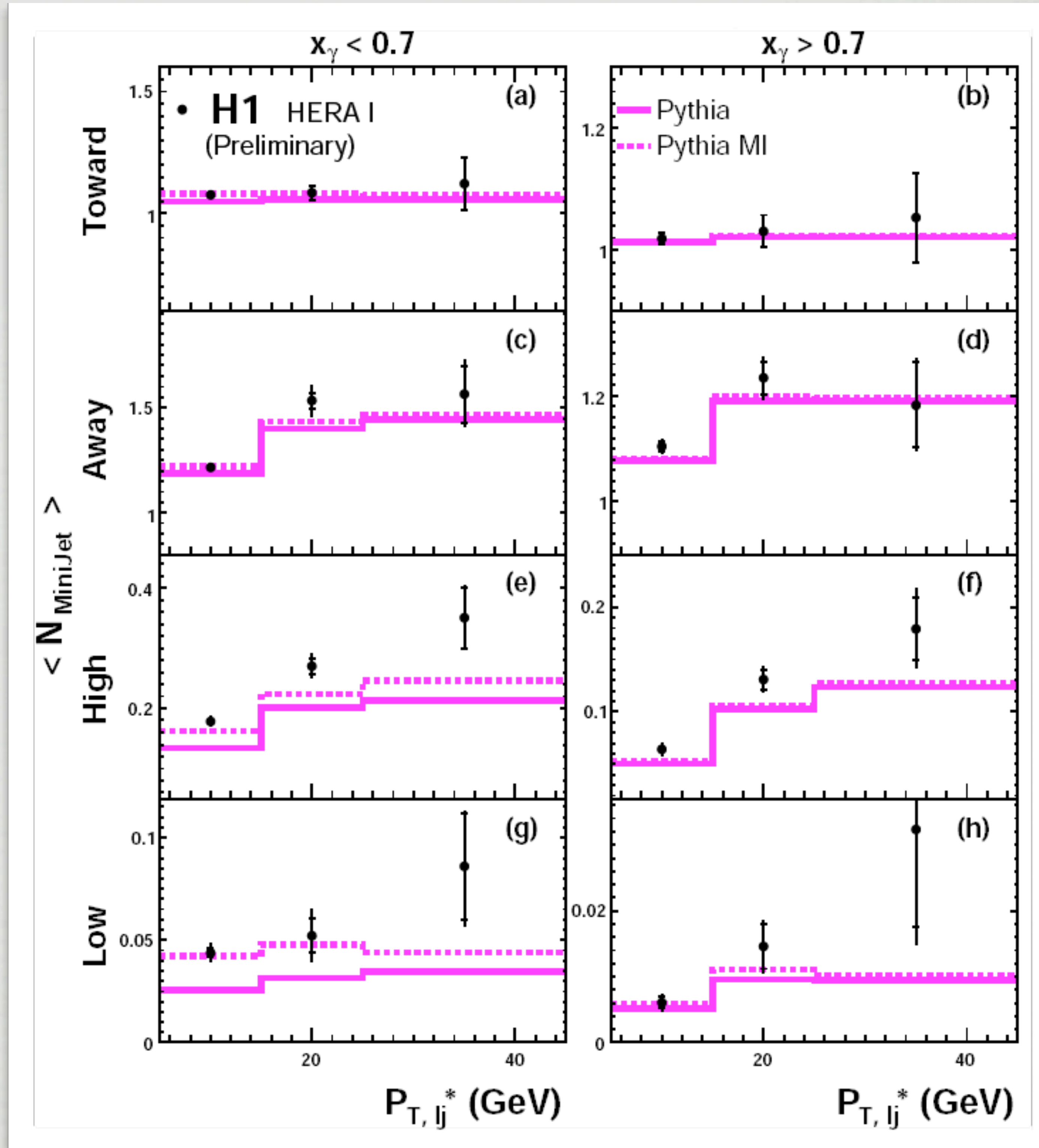
LOW x_γ:
(MORE RESOLVED PHOTON)
CDM OR RAPGAP
NOT ENOUGH ACTIVITY
IN TRANSVERSE REGIONS



DIJETS SAMPLE

$$-1.7 < \eta^{jet} < 2.79$$

AND AGAIN... MULTIPLE INTERACTIONS IMPROVES THE DESCRIPTION BUT ITS NOT SATISFACTORY

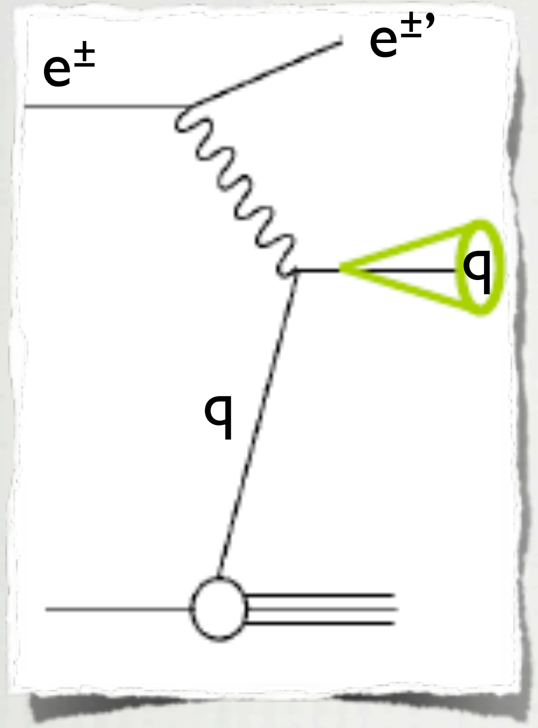


SUMMARY

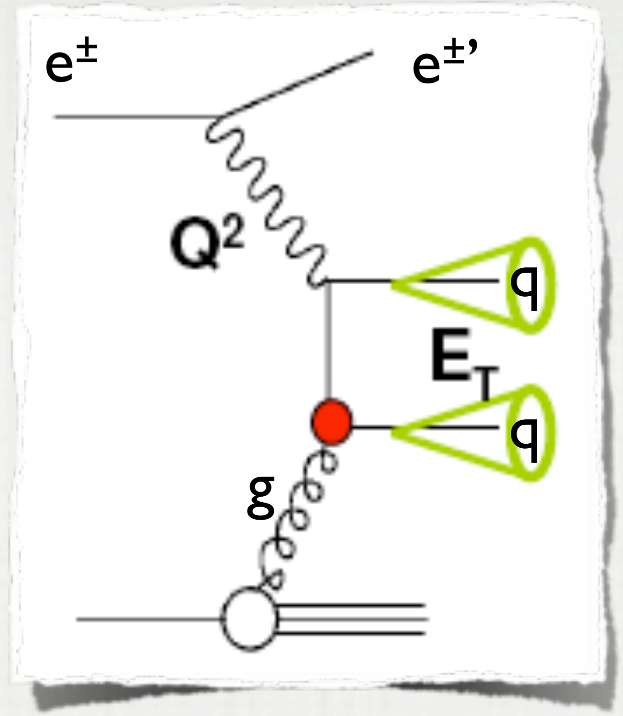
- e^+e^- TUNED MONTE CALRO MODELS AND FRAGMENTATION FUNCTIONS HAVE TROUBLE DESCRIBING HERA DATA.
  - HIGH Q2 CHARGED PARTICLE PRODUCTION
  - LOW Q^2 MINJET ANALYSIS. ETC...
- SEVERAL SUMMARY ANALYSES STILL TO COME ON PARTICLE PRODUCTION AND FRAGMENTATION.
  - ID PARTICLE PRODUCTION / SPECTRA (POSABLE EVEN PHOTON FRAGMENTATION STUDIES), UNDERLYING EVENT STUDIES... USING HIGH STATS HERA II DATA.
- STILL POSSIBLE TO INFLUENCE FINAL HERA ANALYSES

BACKUP

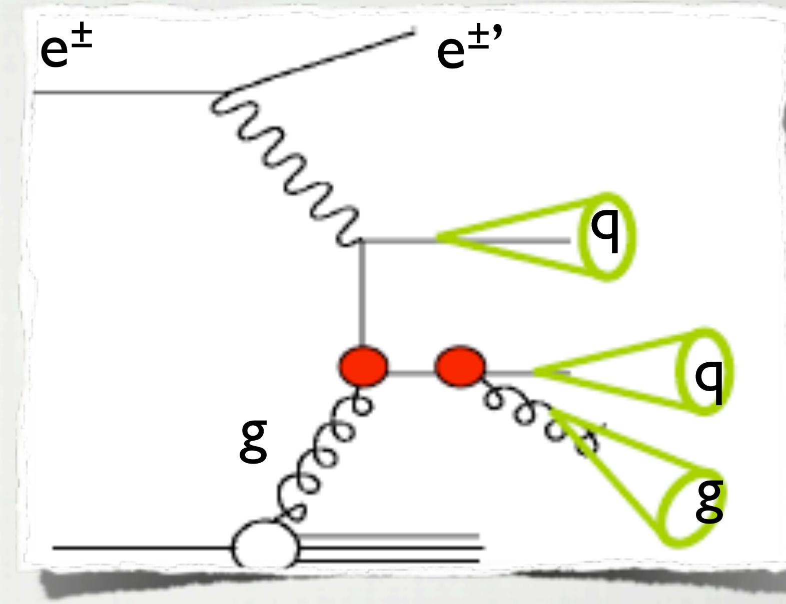
BORN



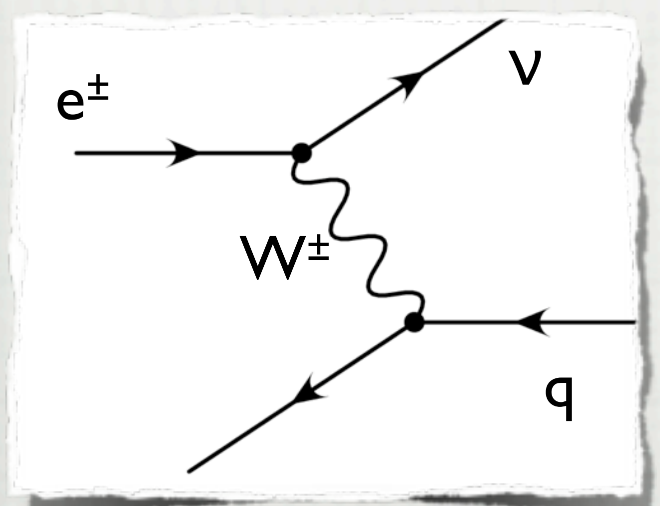
LO BGF



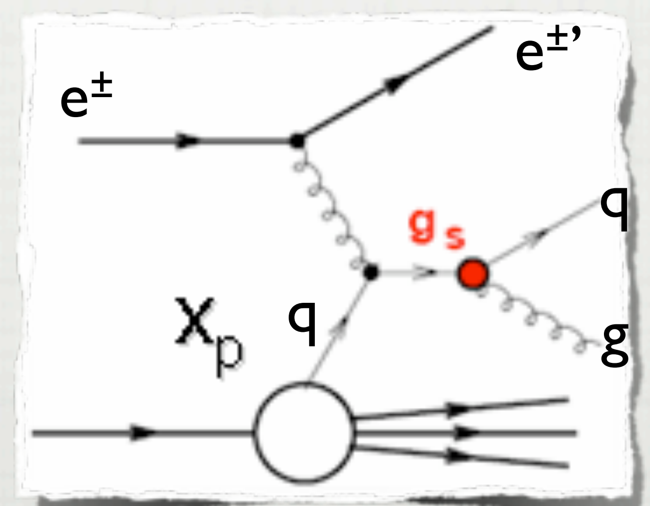
NLO



CHARGE CURRENT

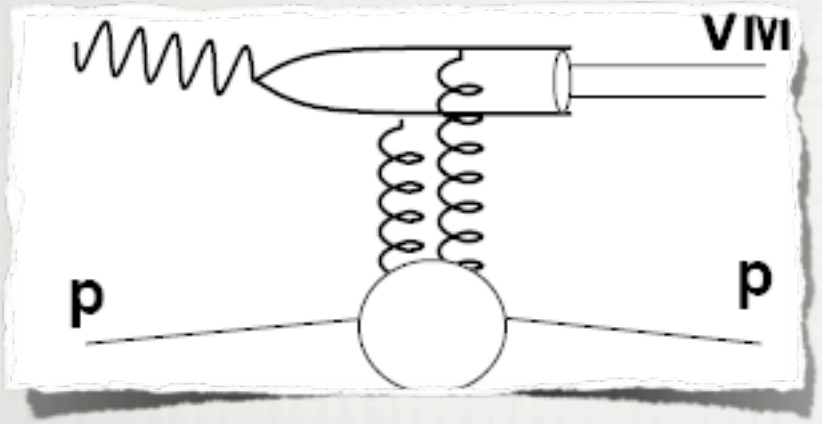


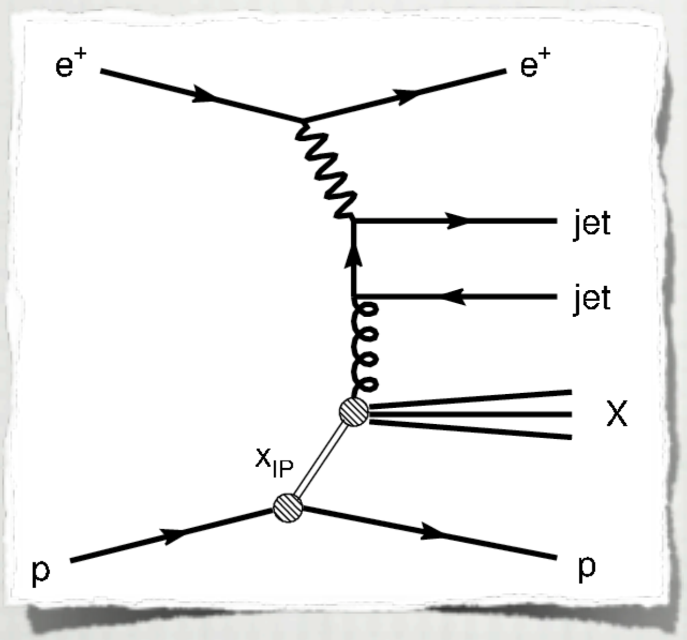
LO QCD COMPTON



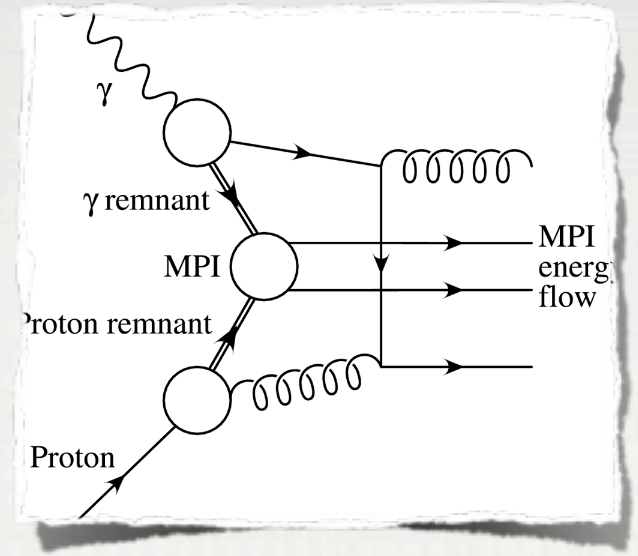
BACK

DIFFRACTION

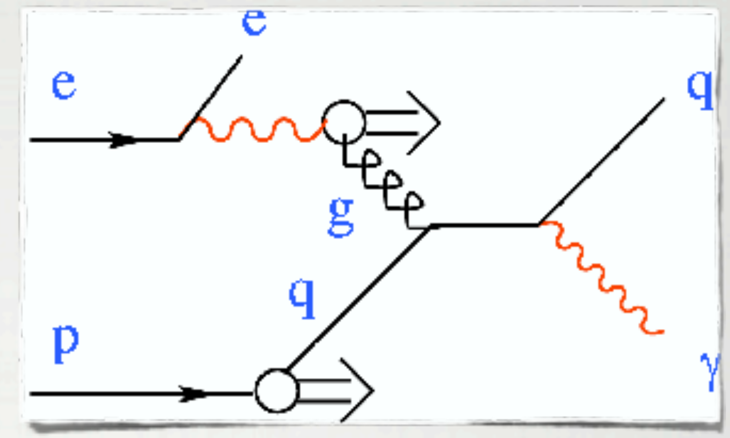




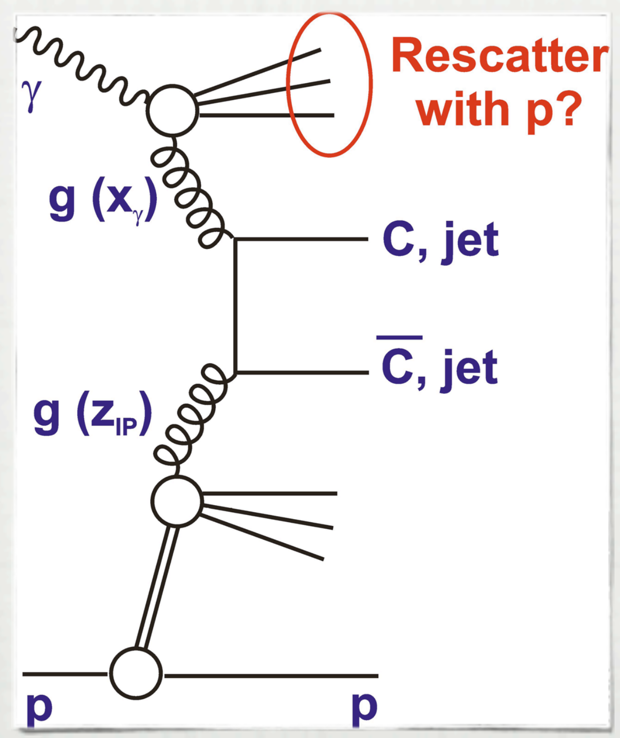
UNDERLYING EVENT



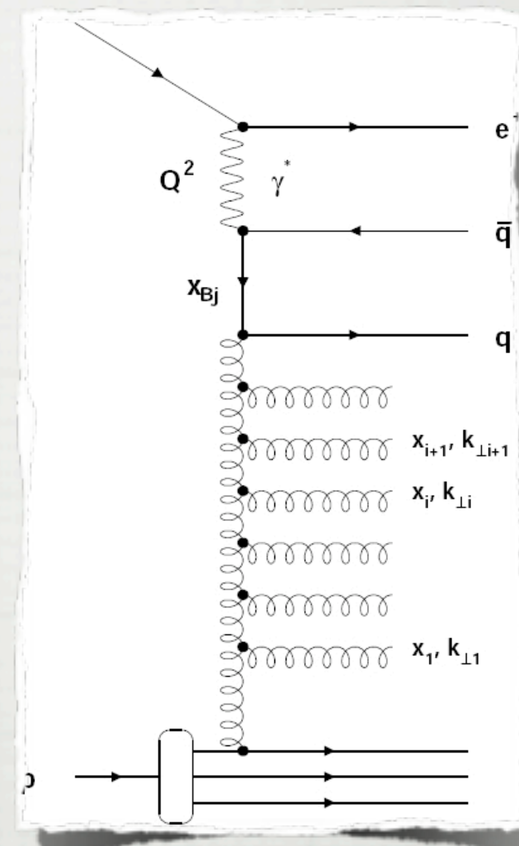
PROMPT PHOTONS



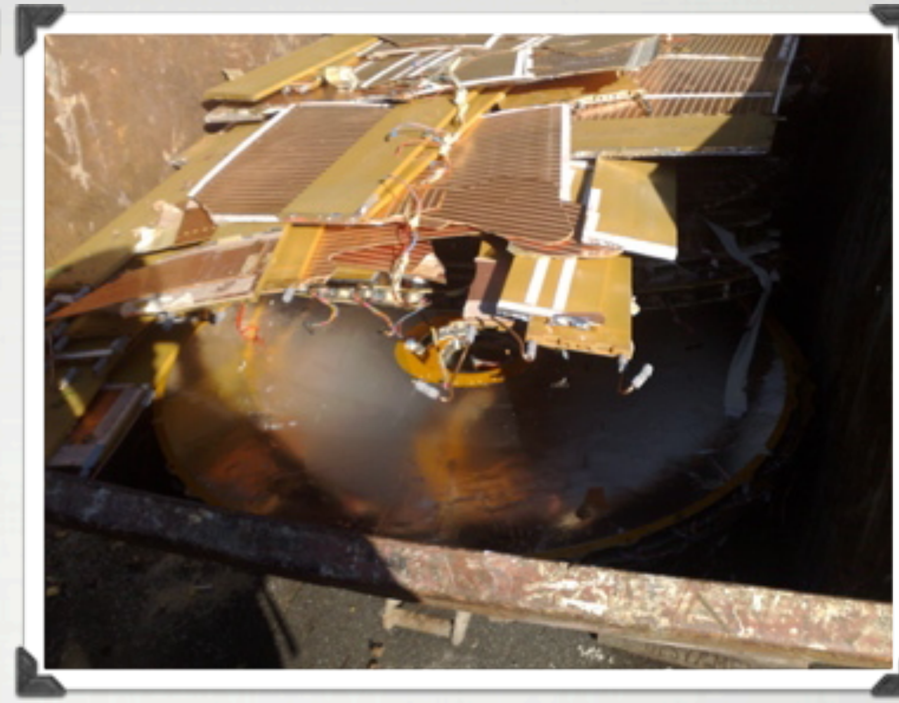
PHOTOPRODUCTION



LOW X, BFKL



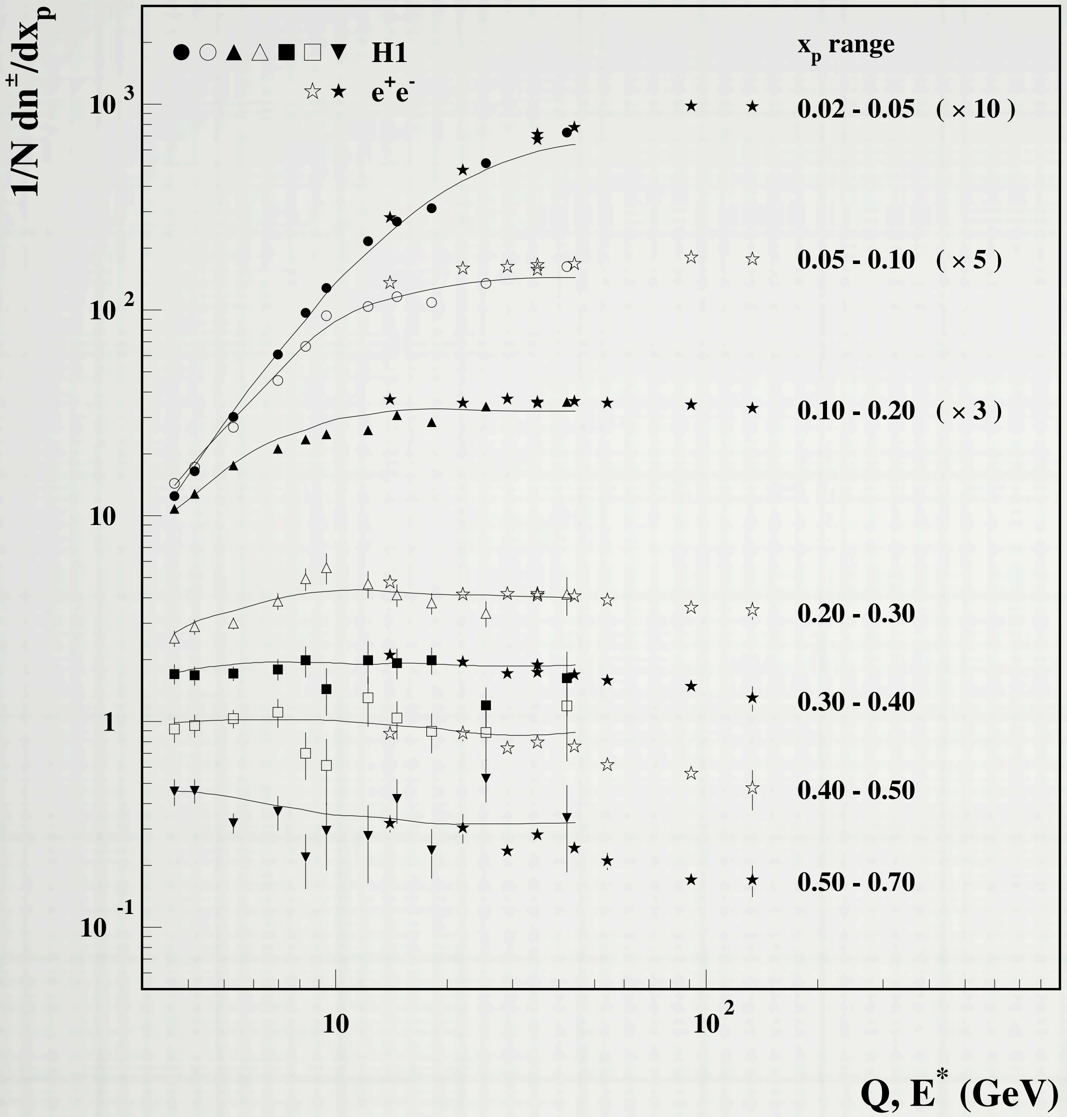
NOT ONLY BUT ALSO

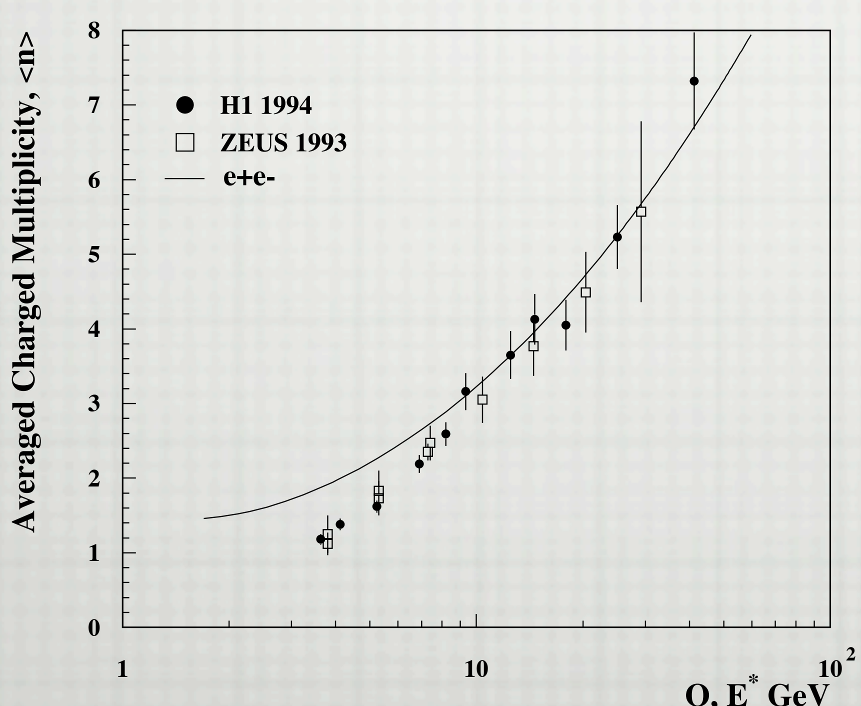


H1 DISMANTLING

BACK

PREVIOUS RESULTS





LAST PUBLISHED DATA FROM 94.
96/97 DATA ANALYSIS NEVER PUBLISHED.
(PEOPLE LEFT H1)

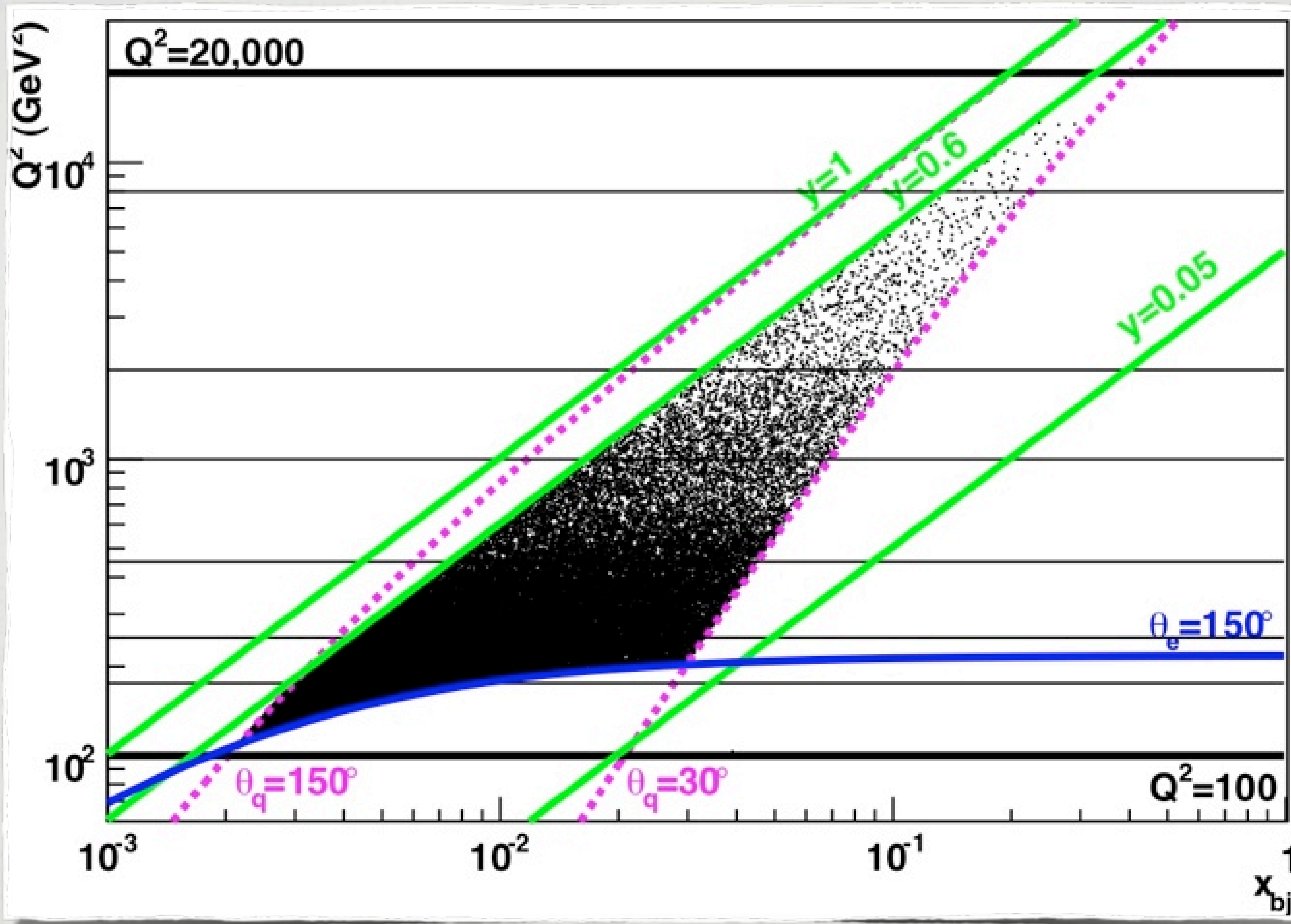
HIGH Q EP RESULTS CAN BE DIRECTLY COMPARED WITH E+E- (MOST E+E- DATA FOR E*>10GEV)

MORE DATA POINTS ARE INFRARED SAFE FOR NLO QCD CALCULATIONS AT HIGH Q

HIGH Q DATA STATISTICALLY LIMITED

COMPLICATIONS OF BGF/ISCQCD ARE SEEN TO BE LESS IMPORTANT AT HIGH Q

BACK

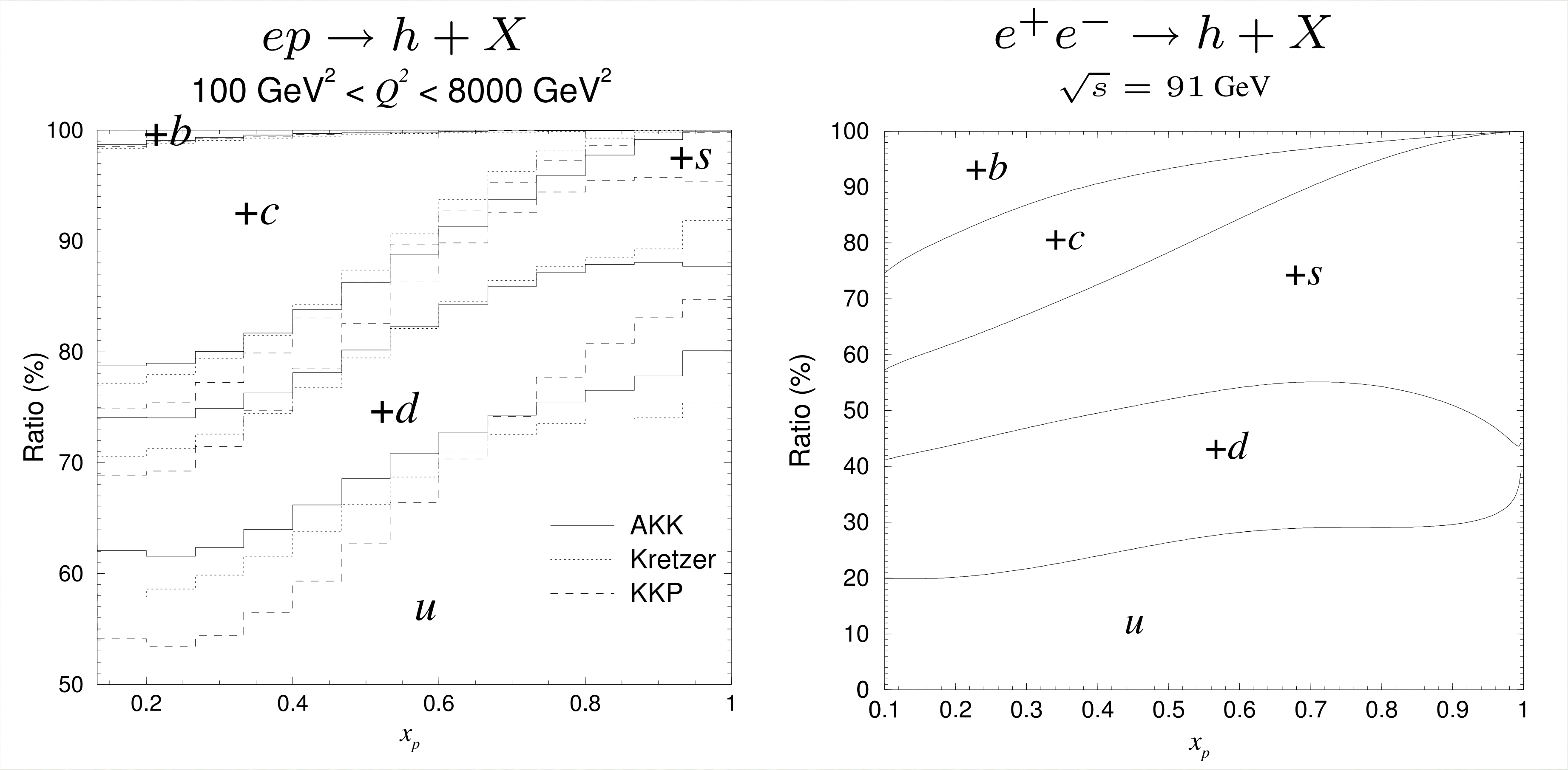


PHASE SPACE

BACK

Quark tagging (H1)

Identify quark flavour at e.w. vertex

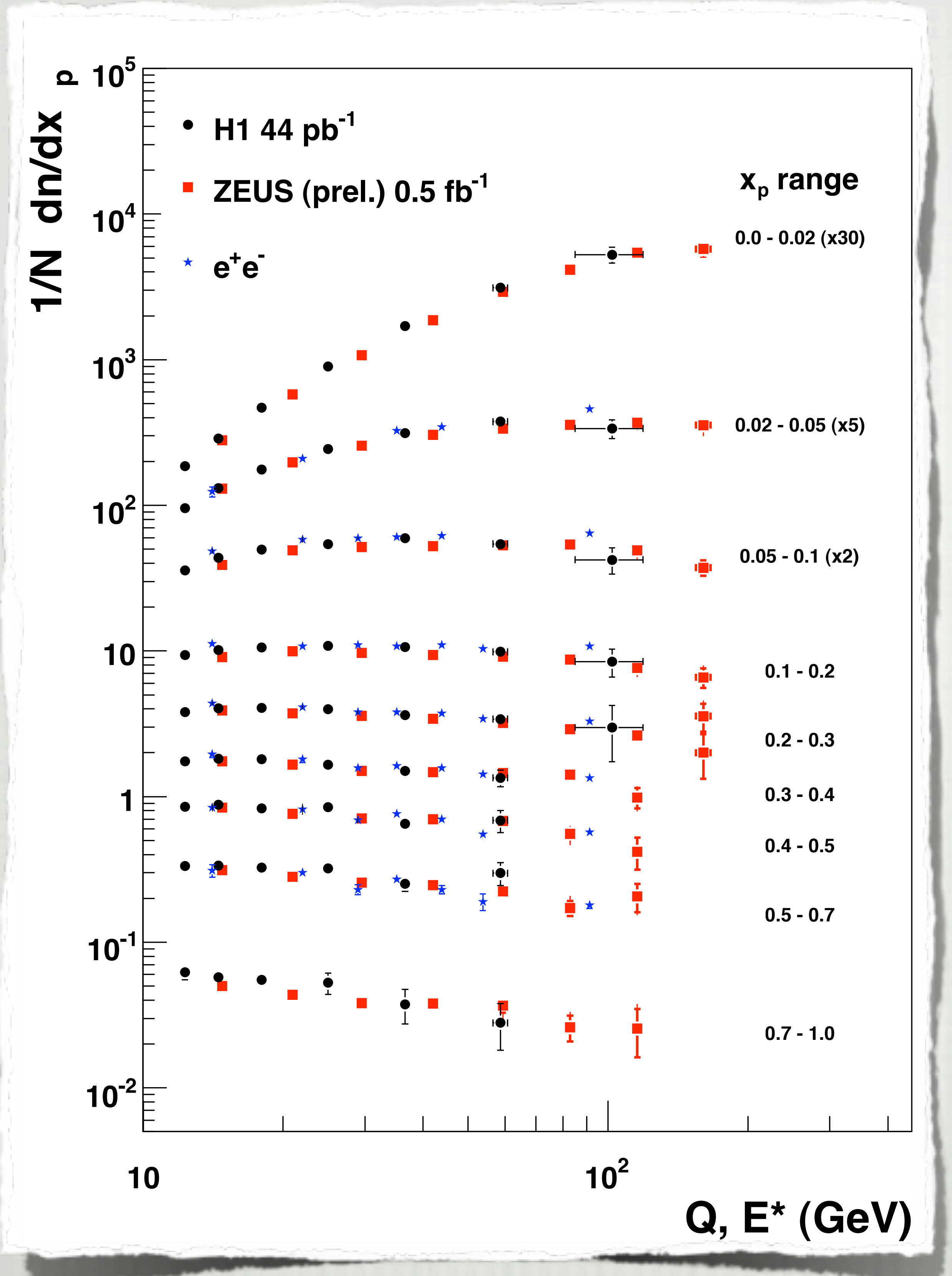


Proton is good source of u

s relatively large

In principle, ep and e^+e^- together can separate uds FFs

BACK



SCALED MOMENTUM

SUMMARY:

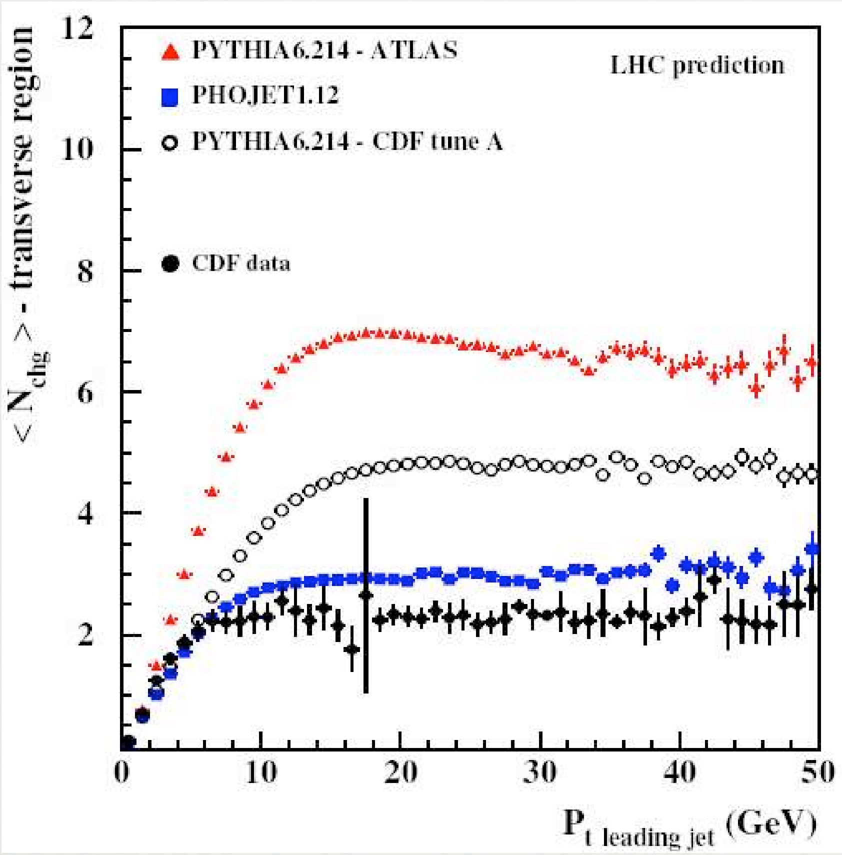
PUBLISHED H1 RESULTS

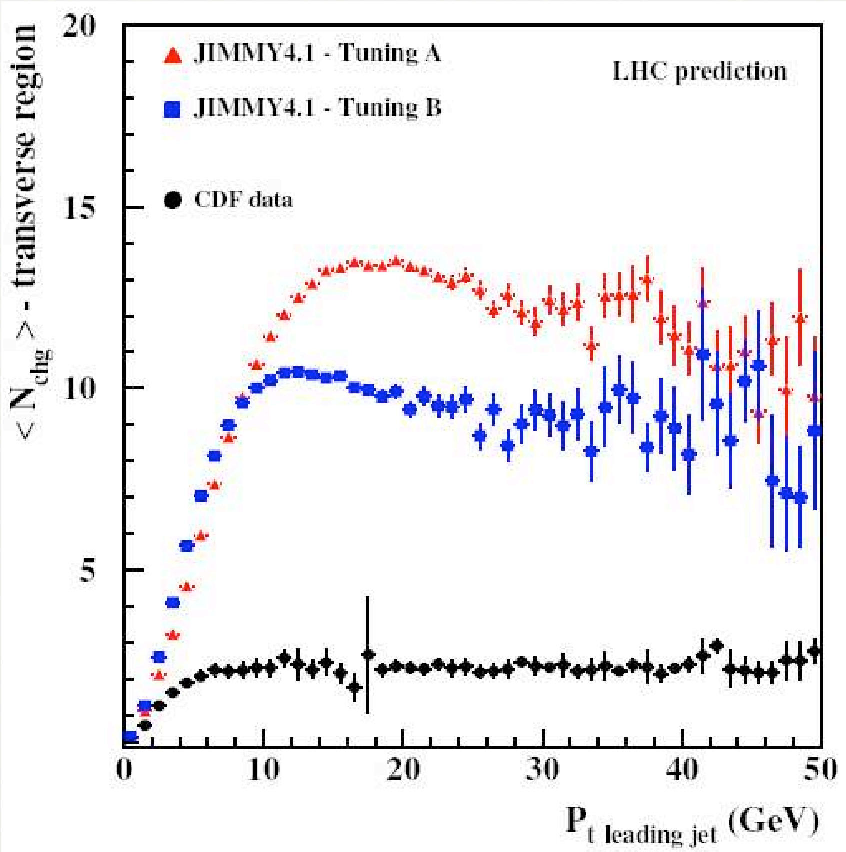
PRELIMINARY ZEUS DATA

SELECTED e^+e^- RESULTS

Underlying event at the LHC?

- What will the underlying event be like at the LHC? Can we say anything presently?





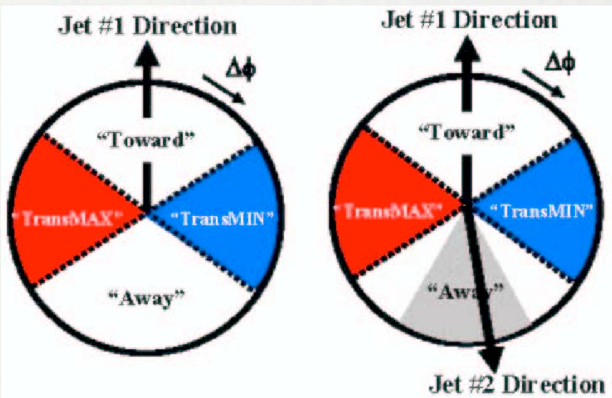
- Clearly, LHC extrapolations based on tunes to current data disagree
- certainly first LHC data will provide an interesting test for the current models
- but beyond just being a background for physics it will be interesting if MPI events can be used constructively to gain further insight into e.g. proton structure.

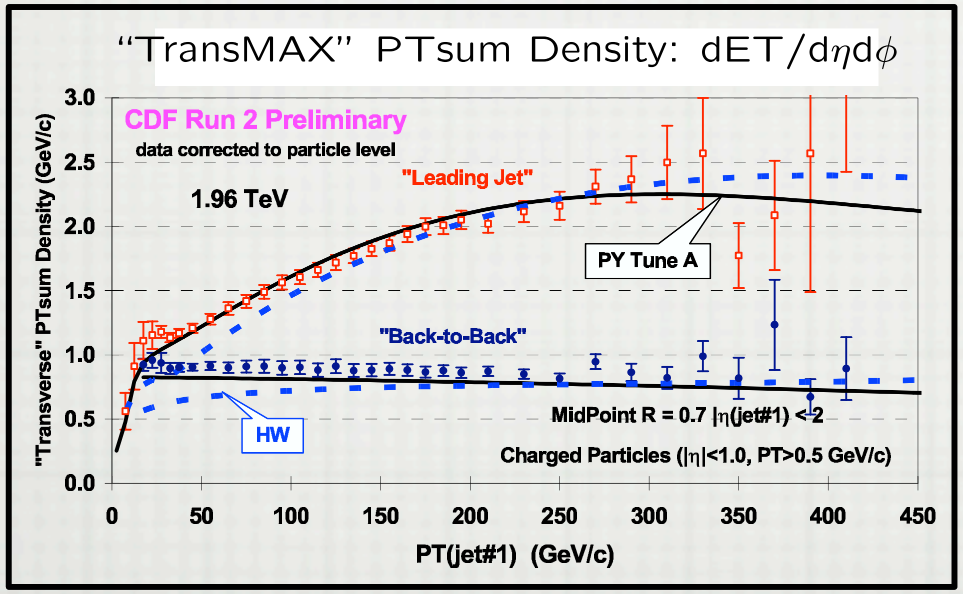
BACK

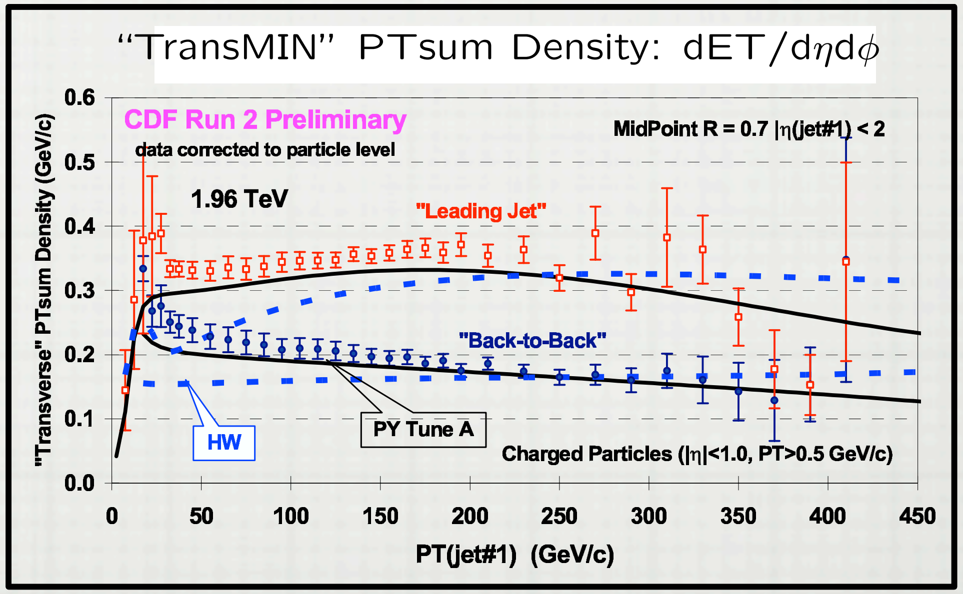
Underlying event in $p\bar{p}$ - transverse P_T

- Tevatron underlying event most relevant for LHC
- analysis of "transverse" regions (*see figure right*)
- plot hadronic P_T sums compared to MC models
- HERWIG (no MPIs) below the low-PT(jet#1) data
- best description by PYTHIA with MPIs ("Tune A")

"Leading Jet" "Back-to-Back"

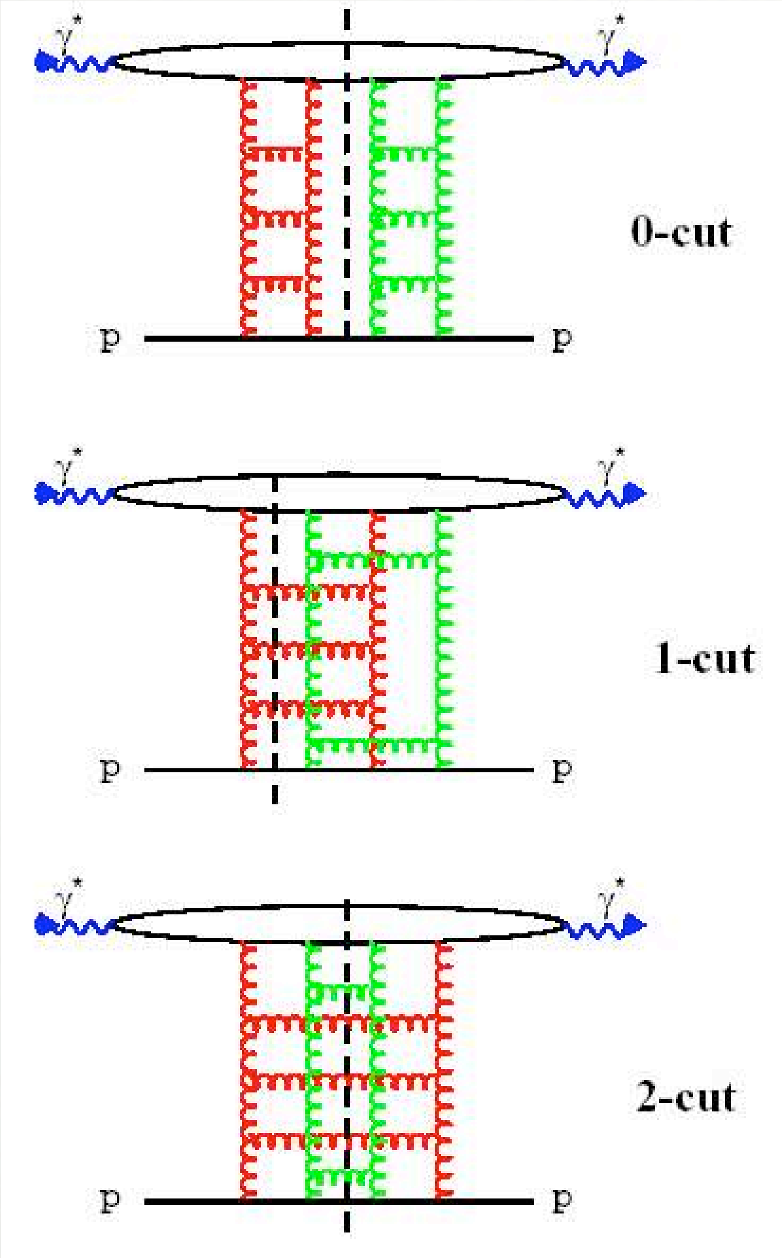






- R. Field [CDF Collab.], AIP Conf. Proc. **828** (2006) 163

BACK



AGK cutting rules developed before QCD to cut pomerons. Now we cut gluon ladders.

To leading order in $1/N_c$ the result is the same: The same amplitude for all cut with factors

+1 Diffraction

-4 Saturation

+2 Multiple interactions

But QCD cuts can be more complicated . . .

[Bartels, Kowalski, Sabio-Vera]

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

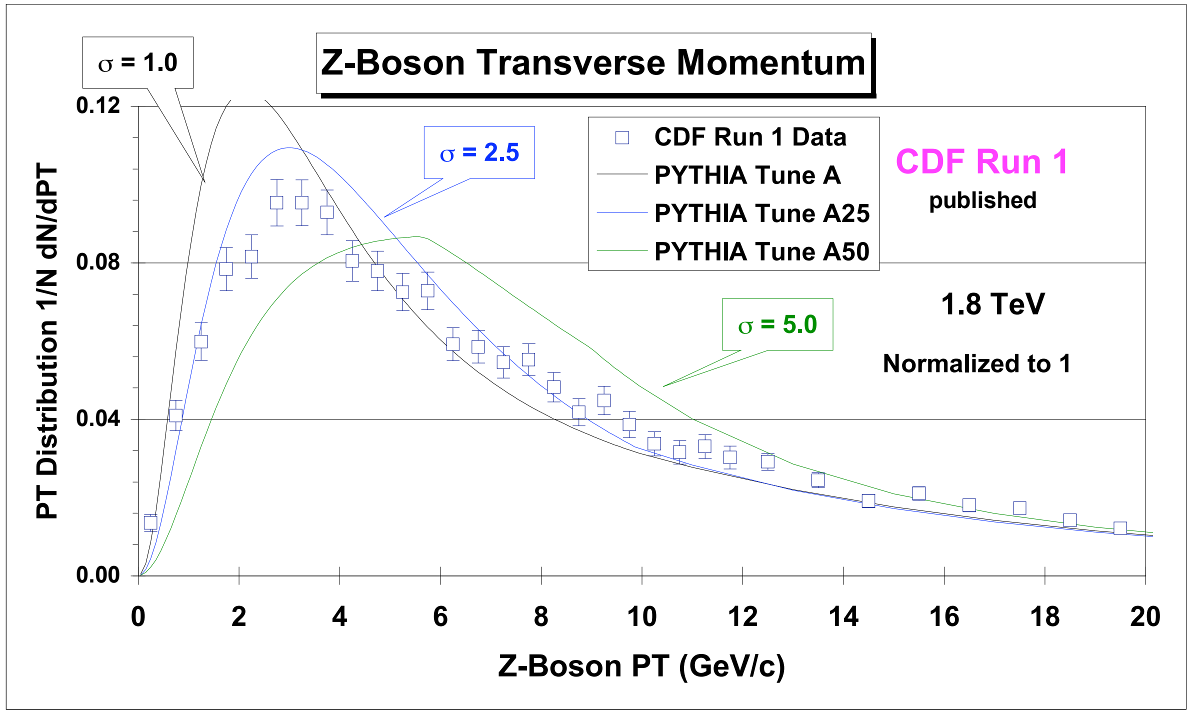
UE Parameters

Parameter	Tune A	Tune A25	Tune A50
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	0.9	0.9
PARP(86)	0.95	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(67)	4.0	4.0	4.0
MSTP(91)	1	1	1
PARP(91)	1.0	2.5	5.0
PARP(93)	5.0	15.0	25.0

ISR Parameter

Intrensic KT

Vary the intrensic KT!



Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($<p_T(Z)> = 9.7$ GeV/c), Tune A25 ($<p_T(Z)> = 10.1$ GeV/c), and Tune A50 ($<p_T(Z)> = 11.2$ GeV/c).

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

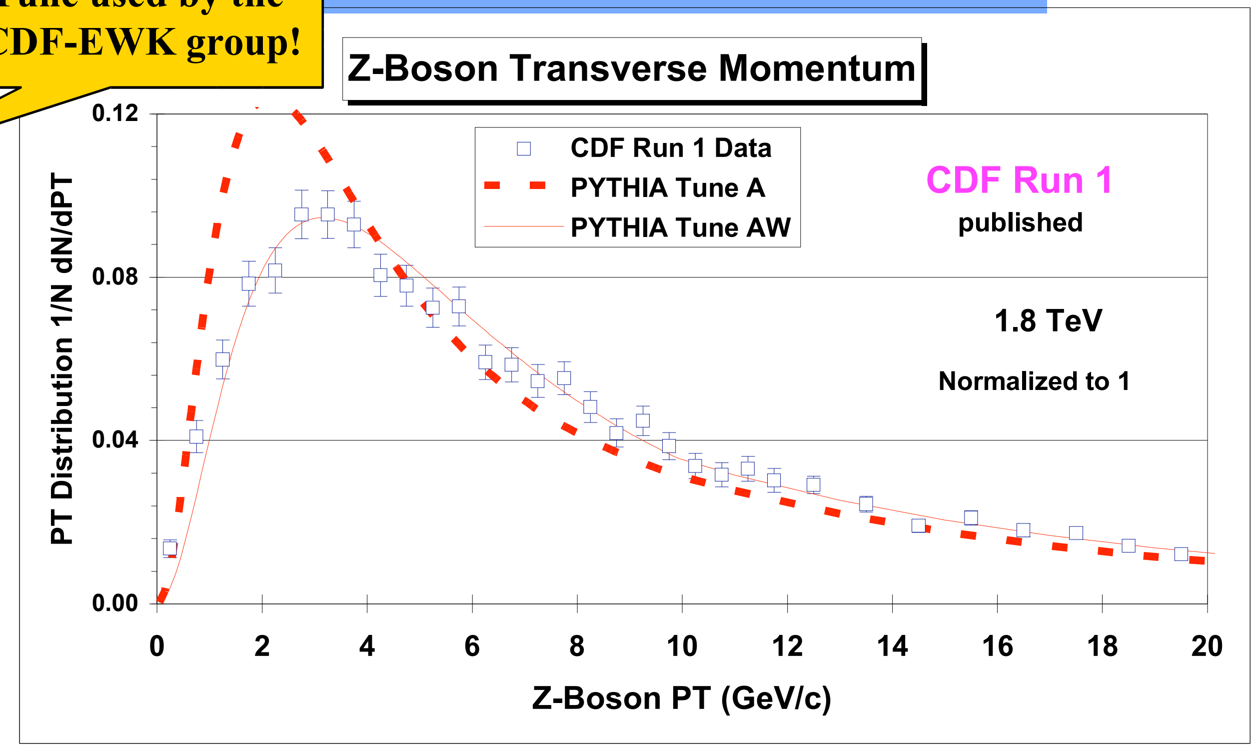
Tune used by the CDF-EWK group!

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0

UE Parameters

ISR Parameters

Intrensic KT



Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)>$ ≈ 11.5 GeV/c) compared with PYTHIA Tune A ($<p_T(Z)>$ = 9.7 GeV/c), and PYTHIA Tune AW (Z)> = 11.7 GeV/c).

Effective Q cut-off, below which space-like showers are not evolved.

The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

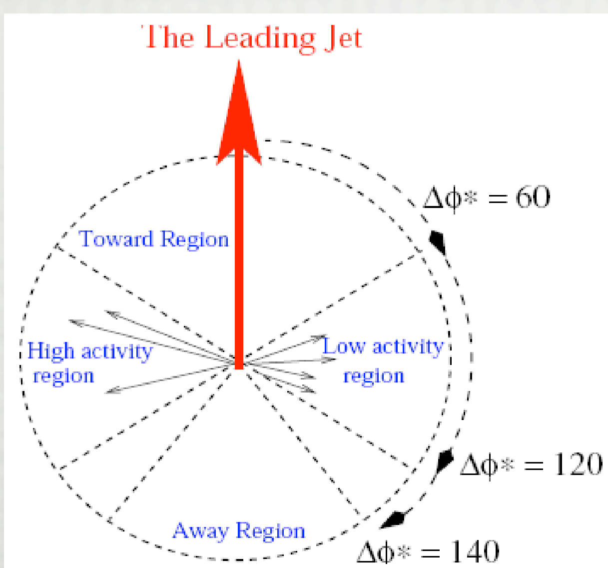
Mini jets in DIS (H1)

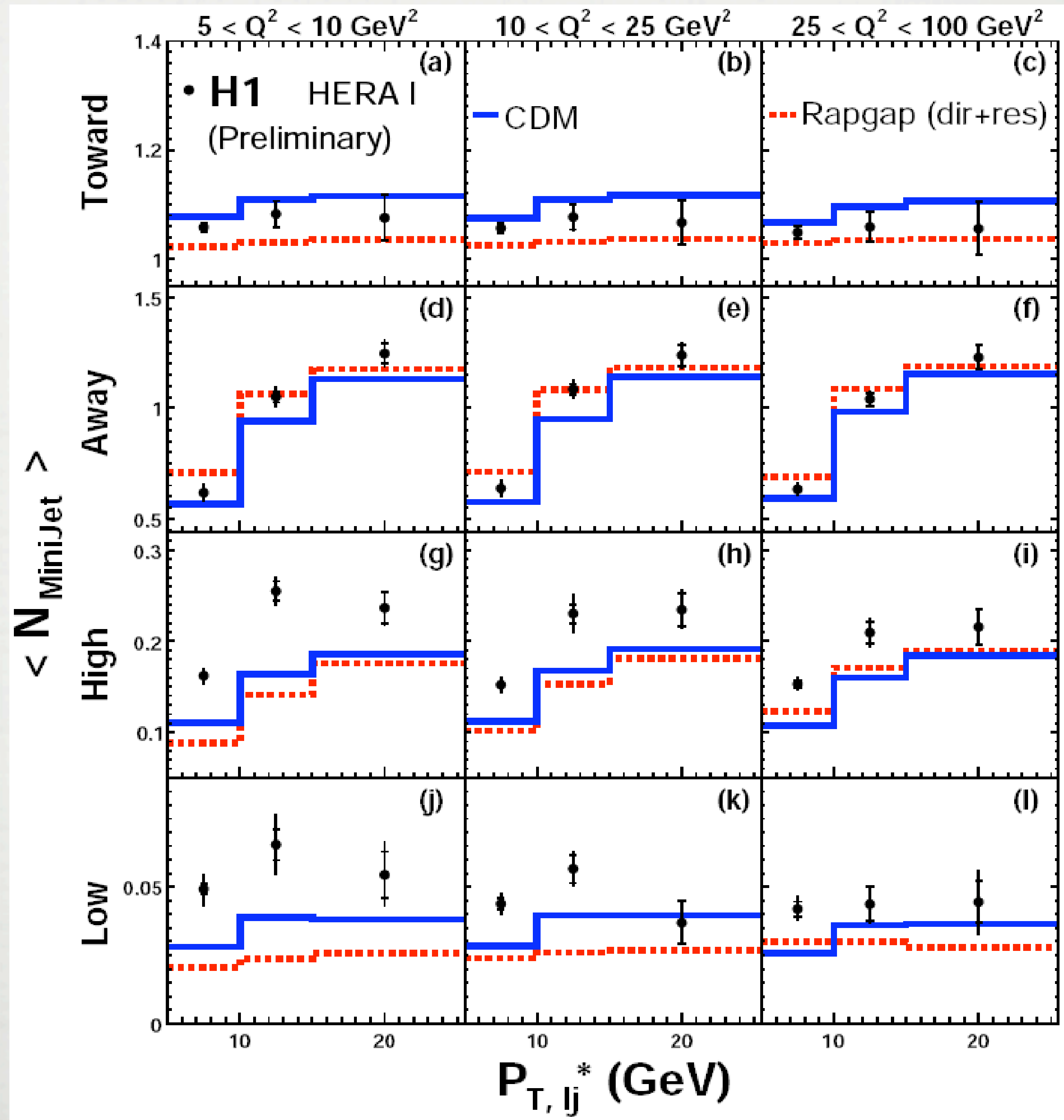
Inclusive 1 jet sample

and

$$0.5 < \eta^{jet} < 2.79$$

- More activity in transverse regions compared to event sample with leading jet in central region
- Again, more transverse activity in data compared to MC





Mini jets in DIS (H1)

Inclusive 1 jet sample

and

$$0.5 < \eta^{jet} < 2.79$$

- **Again, activity from MPI improves description of data at low Q2 in transverse regions**