"Secrets of the Pomeron"

Evidence for an enhanced Pomeron-Pomeron total cross section in the few GeV mass region. Glueball production ?

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What is a Pomeron ?

In hadronic collisions, there is a class of events in which an incident beam particle remains in the final state with a small $\Delta p/p$ loss, whose most likely value is near zero.

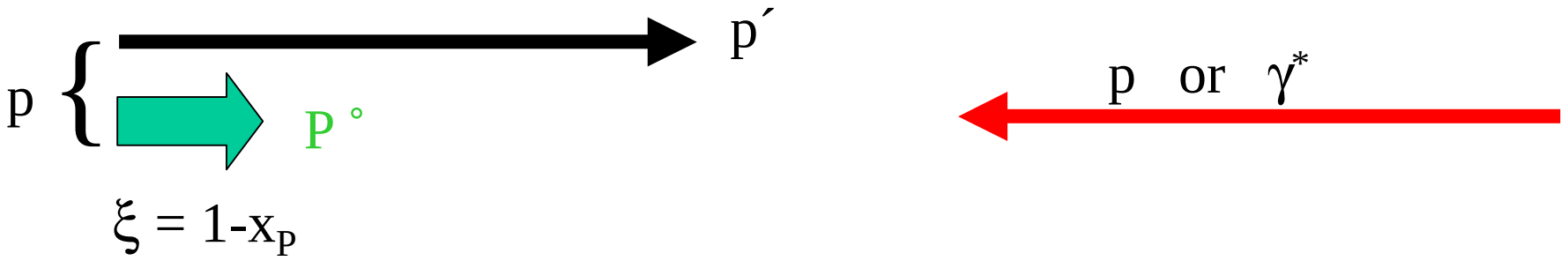
When, at high energies, this corresponds to large energy transfer to the other beam particle, hard scattering is observed (e.g. jets). Ingelman and P.S (1985); UA8, HERA

Exchanged $\Delta p/p$ system is hard, color singlet, dominantly gluonic Pomeron

What is a Pomeron ?

Look at the Pomeron from a purely observational point of view as a structure component in the proton

Scattering with Pomeron beams



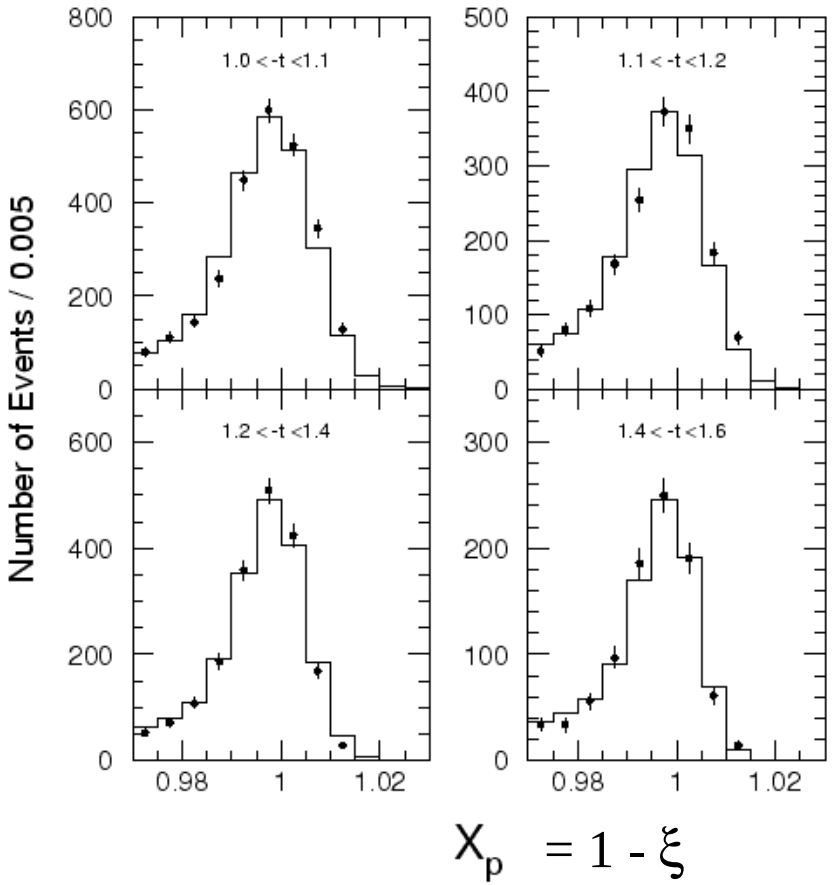
$$s' = M_X^2 = \xi s$$

Signature: p´ seen in final state with $x_P > 0.97$ (pure P exchange)
No other particles seen near p´ → "Rapidity Gap"

Analysis of data in pp, $p\bar{p}$ and ep interactions demonstrates factorization between Pomeron existence and interaction.

$$d^2\sigma / d\xi dt = F_{\mathbf{P}/p}(\xi,t) \;\; \sigma_{\mathbf{P}p}(s')$$

ξ-dependence in Flux Factor



➔ The most likely Pomeron momentum fraction is near zero.

The Regge-pole description of exchange process is:

$$F_{\mathbf{P}/p}(\xi,t) \approx \xi^{1-2\alpha(t)}$$

where: $\alpha(t) = 1 + \varepsilon + \alpha' t$

At fixed-t, $F_{\mathbf{P}/p}(\xi) \approx 1/\xi^n$

Experimentally, $\alpha(t)$ is not a fixed Regge trajectory. ε and α' depend on energy in pp interactions and are different in ep interaction. At t=0, n = 1.06 - 1.32

"Fly in the ointment"

Flux Factor, $F_{\mathbf{P}/p}(\xi,t)$, is not universal.

Reason: Pomeron's existence is non-perturbative. Multi-Pomeron-exchange effects (a.k.a. "screening", "shadowing", "damping", "absorption") increase with energy and depend on particle types. Kaidalov, Ponomarev, Ter-Martirosyan (Sov. Jour. Nucl. Phys 44 [1986] 468) showed that these effects are phenomenologically equivalent to smaller effective Pomeron trajectory intercept with energy.
Let's look at what the data say.

Single Diffractive Parametrization

Triple-Regge parametrization fits all available single-diffractive data at ISR, SPS and Tevatron.

- UA8: Nucl. Phys. B 514 (1998) 3.
- Erhan & Schlein: Phys. Lett. B 481 (2000) 177.

- $d^2\sigma / d\xi dt = F_{\mathbf{P}/p}(\xi,t)\ \ \sigma_{\mathbf{P}p}(s')$

$= 0.72\ |F_1(t)|^2\ e^{1.1t}\ \xi^{1-2\alpha(t)}\ [(s')^{0.1} + 4(s')^{-0.32}]$

$s' = M_X^2 = \xi\, s$

Working assumption: $\sigma_{\mathbf{P}p}$ like a real particle σ

Effective Pomeron Trajectory

- Effective ε and α' decrease with **s**,

  $\sqrt{s}$ = 23 Gev $\quad \alpha(t) = 1.10 + 0.22t + 0.06t^2$

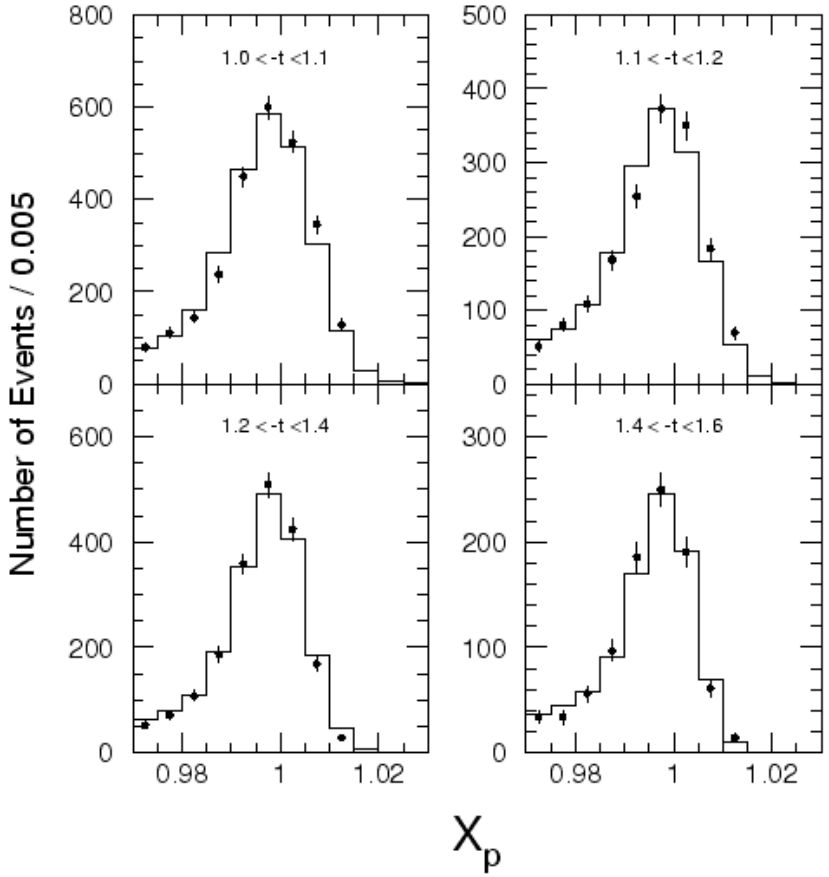
  $\sqrt{s}$ = 63 Gev $\quad \alpha(t) = 1.08 + 0.19t + 0.06t^2$

  $\sqrt{s}$ = 630 Gev $\quad \alpha(t) = 1.03 + 0.17t + 0.06t^2$

- Tevatron consistent with $\sqrt{s}$ = 630 Gev
- Trajectory flattens at high-t
- At $\sqrt{s}$ = 23 Gev, same ε as from total σ_{pp} vs. **s**,

UA8: Flattening of trajectory

No evidence that diffractive peak disappears as |t| increases, as would be expected for $\alpha(t) = 1.10+0.25t$ and $\xi^{1-2\alpha(t)}$.



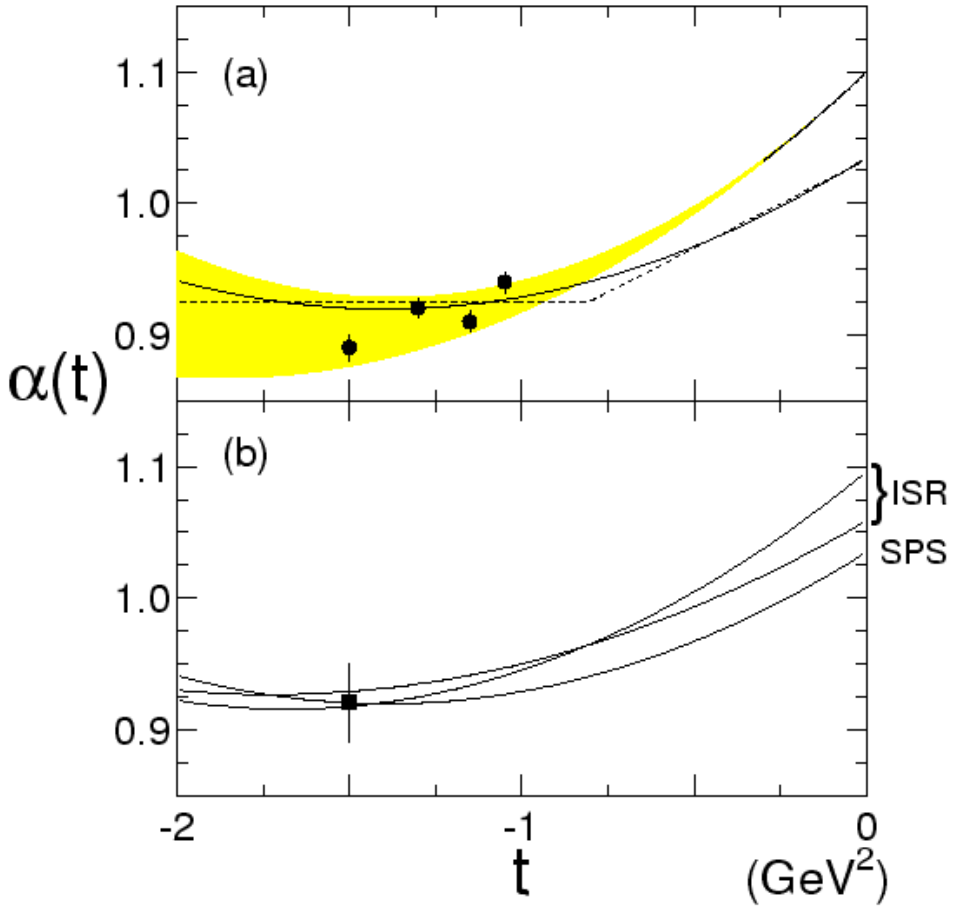
➔ Signature for flattening of trajectory

UA8 [Phys. Lett. B 514 (1998) 3.]

Fits to $dN/d\xi$ at fixed t

Fits to $d^2\sigma/d\xi dt$ at SPS / ISR

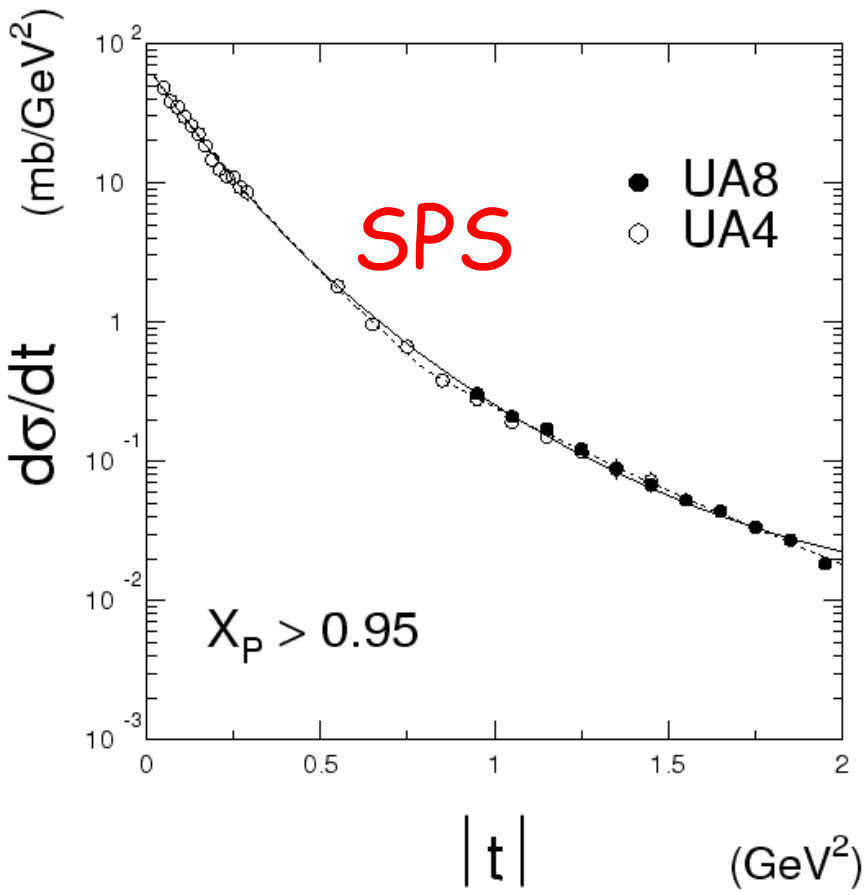
α(t) Summary



Key Results:

- No s-dependence of trajectory at high-t
- Intercept and slope exhibit s-dependence

s-dependent ε from fits to dσ/dt



$\alpha(t) = 1.035 + 0.165\ t + 0.06\ t^2$

$\chi^2/DF = 4.2$

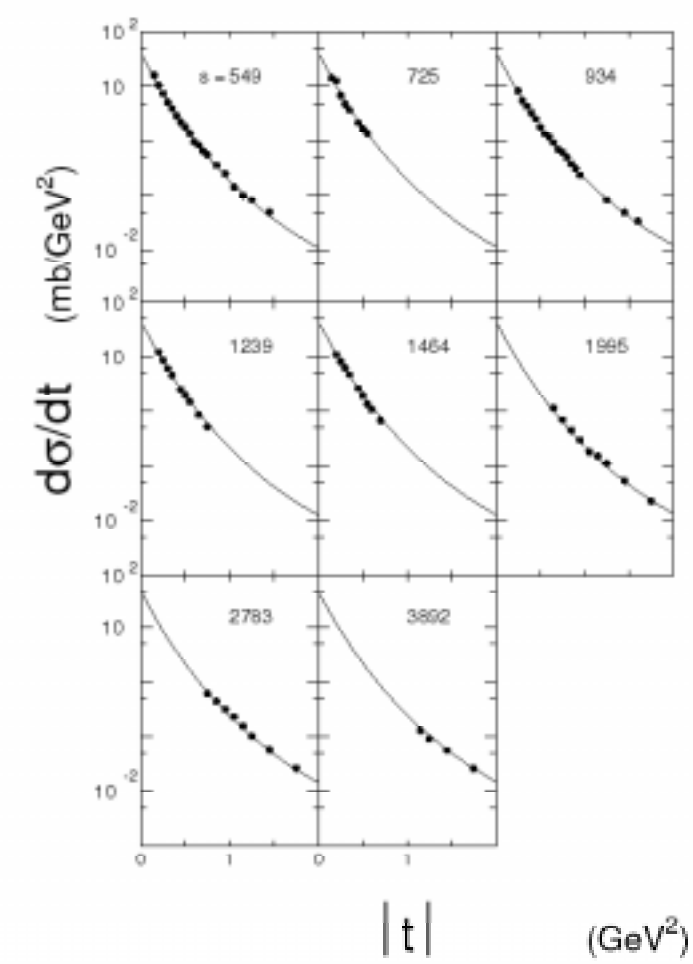
Integral is total σ_{dif}.

➔ The data require a smaller intercept and slope.

➔ Trajectory at high-t agrees with UA8 results.

s-dependent ε from fits to dσ/dt

ISR



$\alpha(t) = \varepsilon + \alpha' t + \alpha'' t^2$

6-parameter fit:

$\varepsilon = 0.10 - 0.02 \log(s/549)$

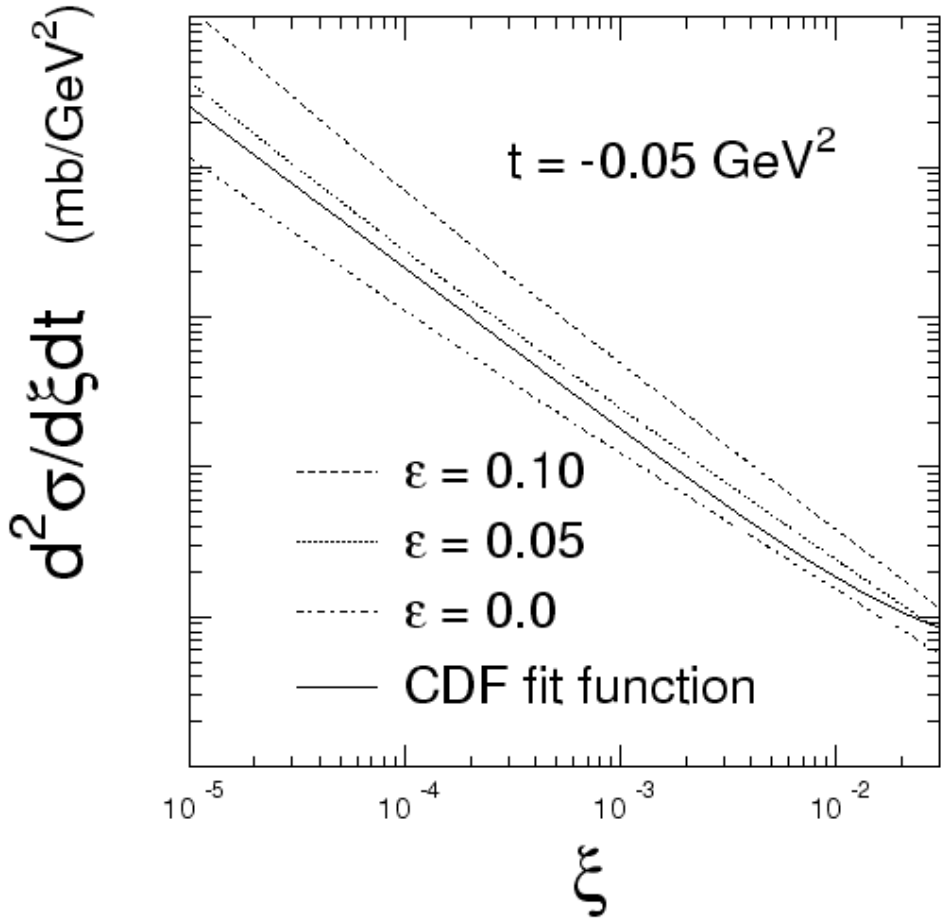
$\alpha' = 0.22 - 0.03 \log(s/549)$

$\alpha'' = 0.06 - 0.01 \log(s/549)$

s-dependent ε starts within ISR range.

α(t) flattens at high-t.

Tevatron - 1800 GeV (CDF)

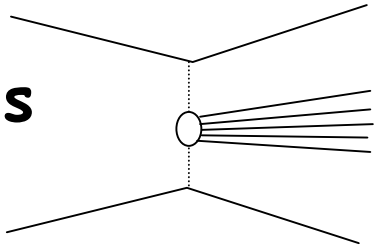


Predict $d^2\sigma/d\xi dt$ at Tevatron, using UA8 Flux Factor with different intercepts.

CDF function fit to their data agrees with a lower intercept.

F. Abe et al., Phys.Rev. D 50 (1994) 5535.

Double Pomeron Exchange (DPE)



$s' = \xi_1 \xi_2 s = M_x^2$

Monte-Carlo generation: points in 6-dimensional space, $\xi_1, t_1, \phi_1, \xi_2, t_2, \phi_2$ according to:

$$d^4\sigma / d\xi_1 dt_1 d\xi_2 dt_2 = F_{P/p}(\xi_1, t_1)\ F_{P/p}(\xi_2, t_2)\ \sigma_{PP}(s')$$

- use Flux Factors from single diffraction.
- only use physical region of $\xi_1, t_1, \phi_1, \xi_2, t_2, \phi_2$ ($s' > 0$).

Experiment UA8

In addition to the first observation of hard diffraction (its original purpose) , UA8 also measured single diffraction and double-Pomeron exchange (DPE).

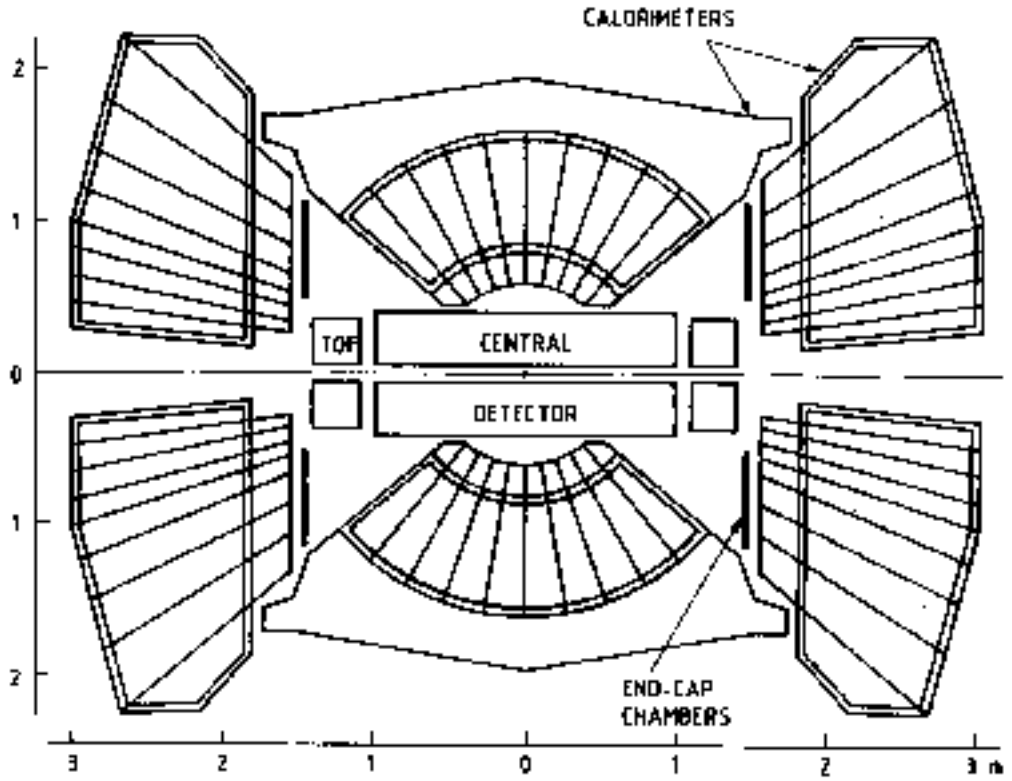
Apparatus

DPE event selection

Final results from analysis of DPE data.

Extraction of Pomeron-Pomeron total σ

UA8 = UA2 + Roman-pot spectrom.

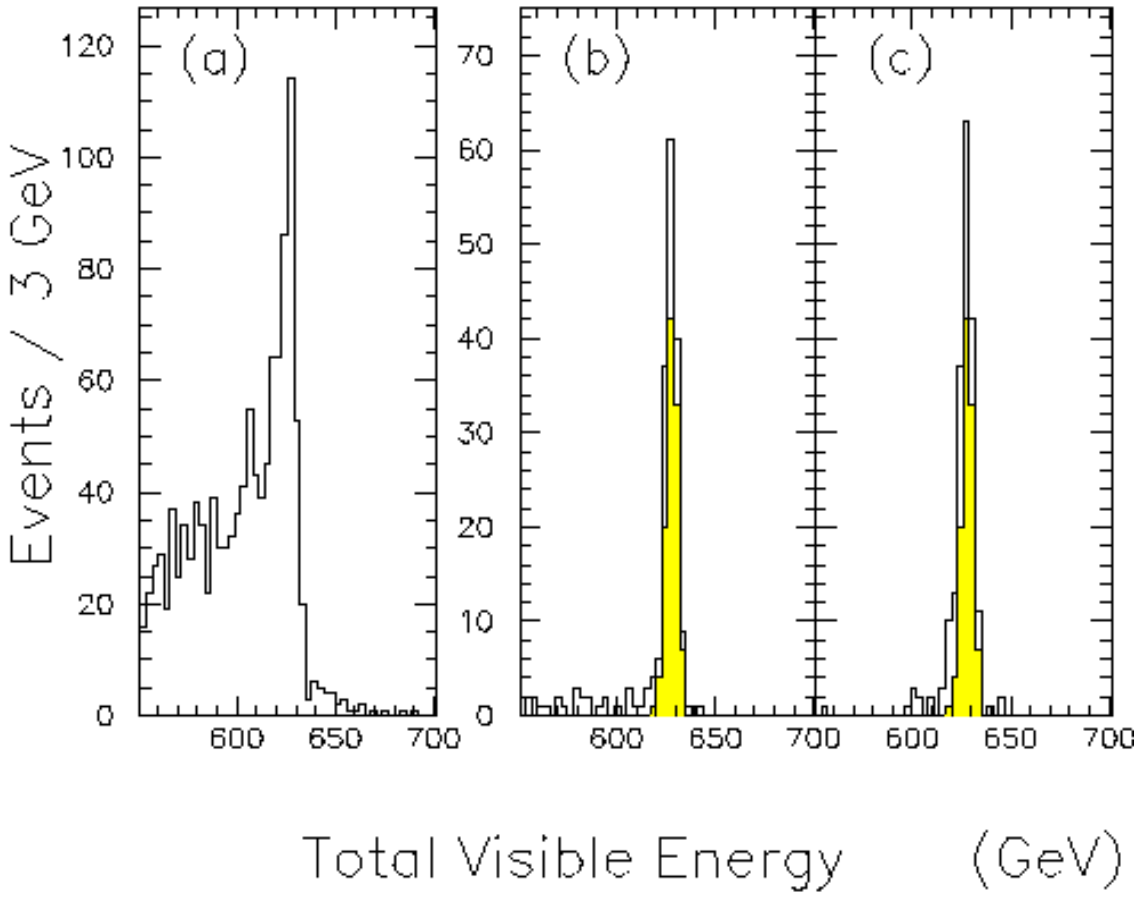


R.p. ← → R.p.

"AND" data
p and $\bar{p}$ seen.
"OR" data
p or $\bar{p}$ seen.

TOF counters had pseudorapidity 2.3-4.1

DPE "AND": Total Visible Energy



Visible Energy:

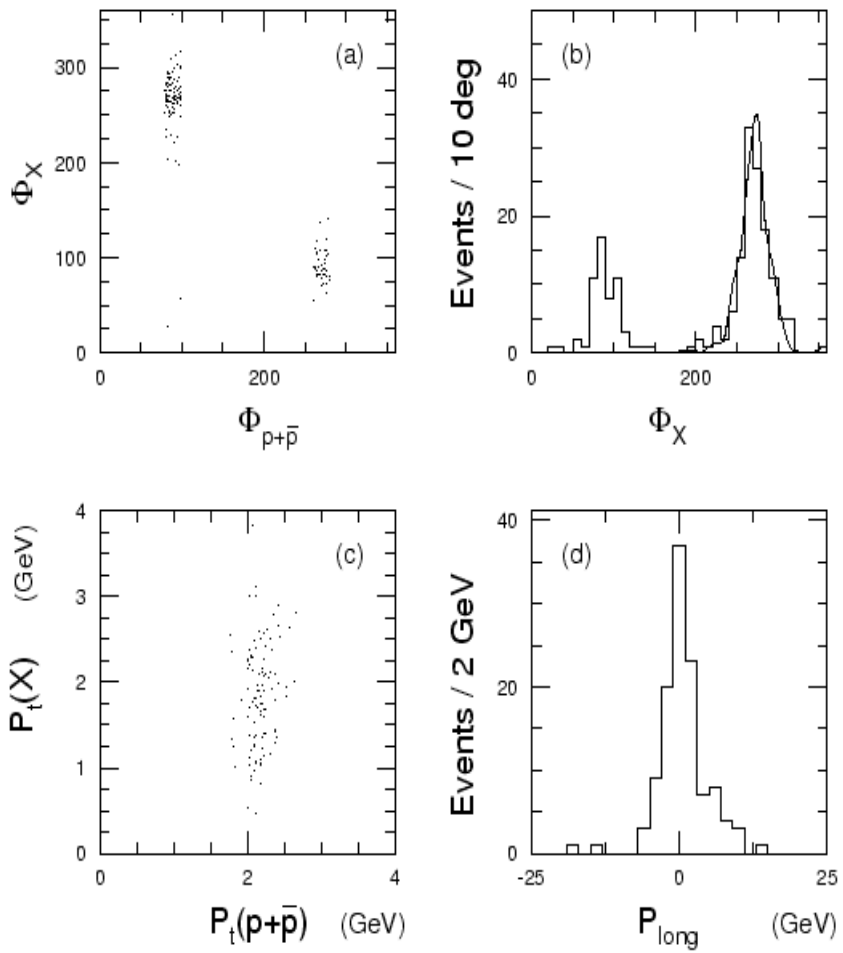
p + p + calorimetry

(b) rapidity gaps.

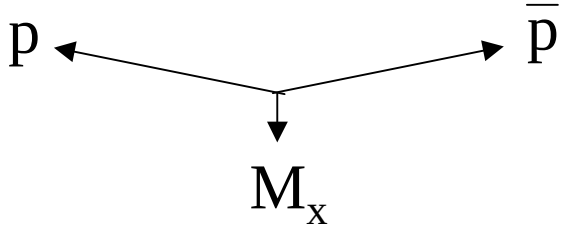
shaded: topology cuts.

(c) inverse order

DPE "AND": $\bar{}$ Event Selection



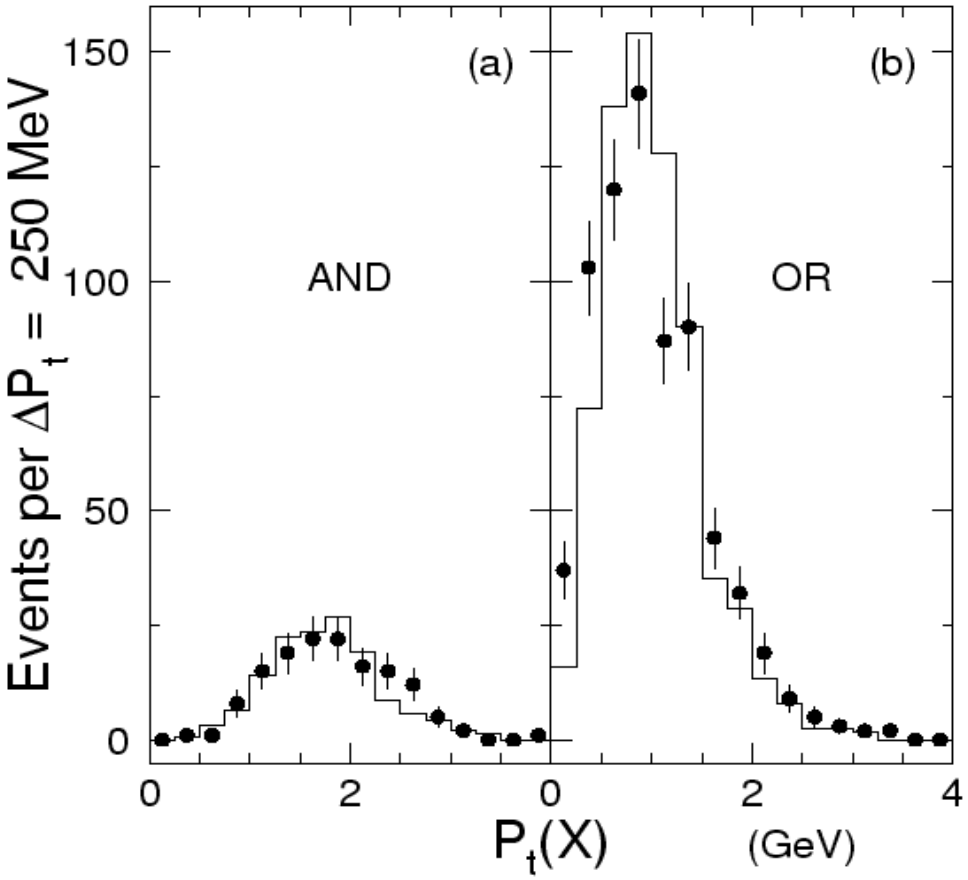
p and $\bar{p}$ Topology



p, $\bar{p}$ UP: $\phi = 90°$

Minimum P_t acceptance is 1 GeV/c.

"AND" - "OR" Calorimeter Pt

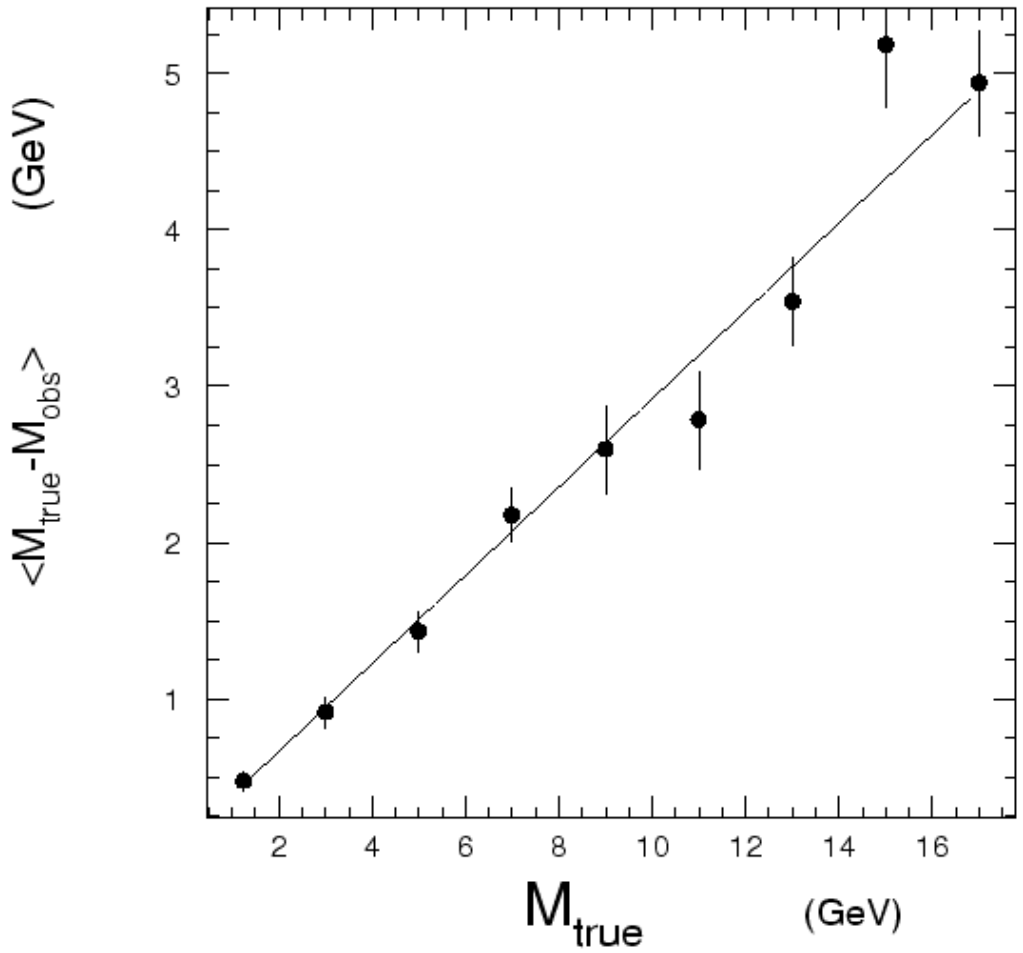


Summed transverse momentum in calorimeter

AND: $\Sigma Pt > 2$ GeV

OR: $\Sigma Pt > 1$ GeV

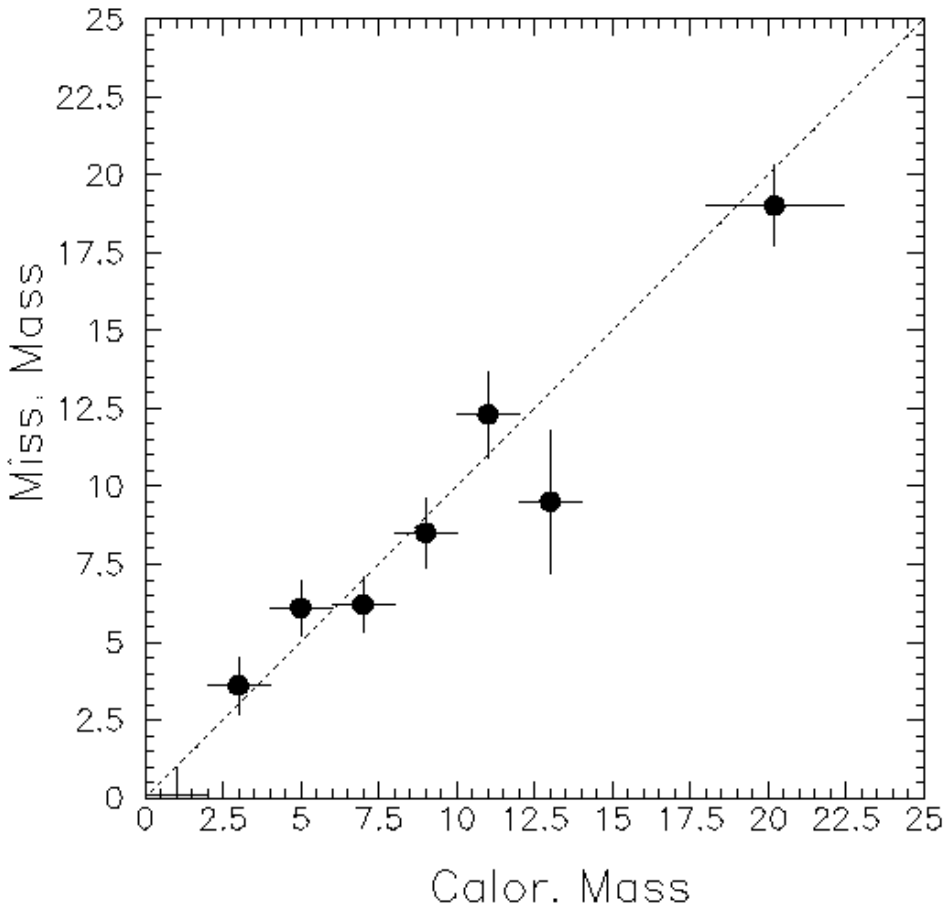
Calor. Invariant Mass Correction



$M_{true} = 0.1 + 1.4 M_{obs}$

Using UA2
Calorimeter MC

Missing Mass vs. Invariant Mass



DPE "AND" data

Average Missing Mass for bins of calorimeter invariant mass.

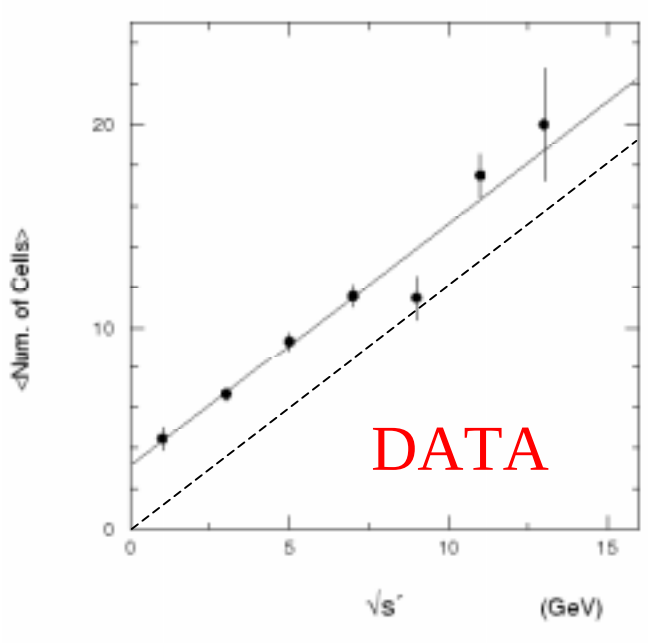
Excellent correlation !

Invariant mass resolution is 2 GeV.

DPE Monte Carlo simulation

Events generated in 6-dimensional space according to product of two Flux Factors (requiring $s' > 0$).

➔ implies $\sigma_{pp}(s')$ is independent of s'.
Central system decay multiplicity: $N_{ch} = 0.6\ Mx$

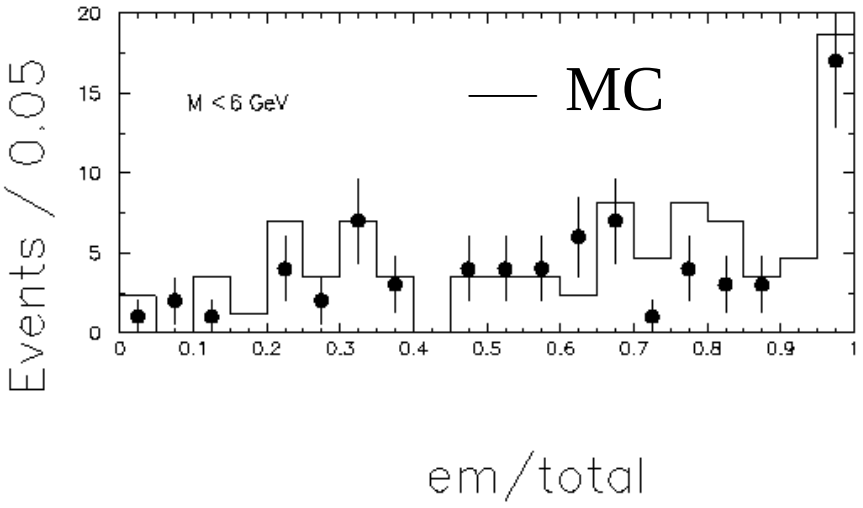


Number of hit cells in calorimeter vs. M_x

Dashed line is $N = 1.2\ M_x$

EM/Total Energy in Calorimeter

DPE "AND" data

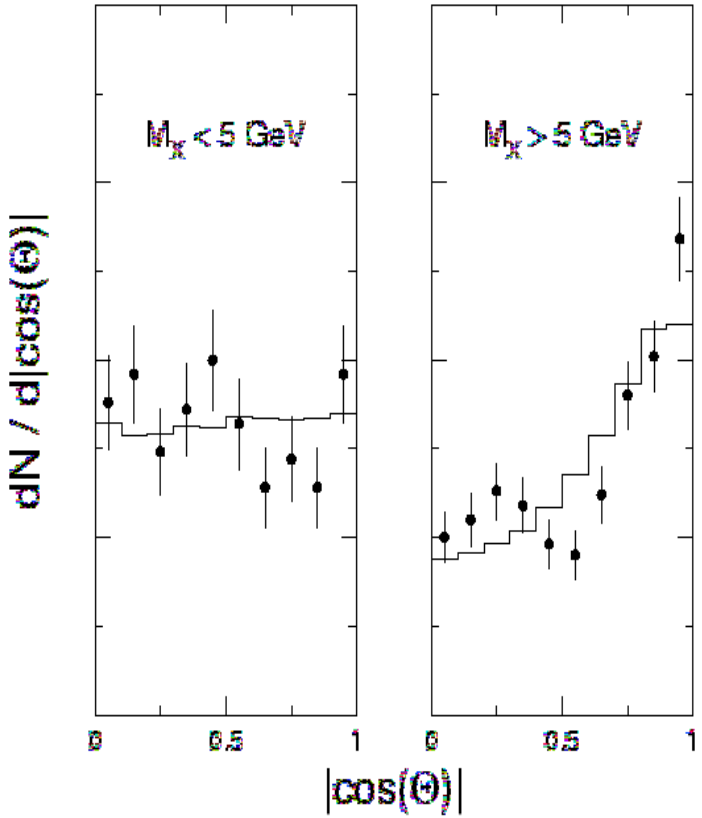


- $N\pi^0 = 0.5\ N\pi^{\pm}$

➔No anomalous behavior

Right-hand peak due to low-energy charged particles being absorbed in e.m. calorimeter

DPE "AND" Longitudinal Structure



cos θ for hit calorimeter cells in c.m. of M_x

- Mx < 5 GeV: isotropic
- Mx > 5 GeV: polar peaked

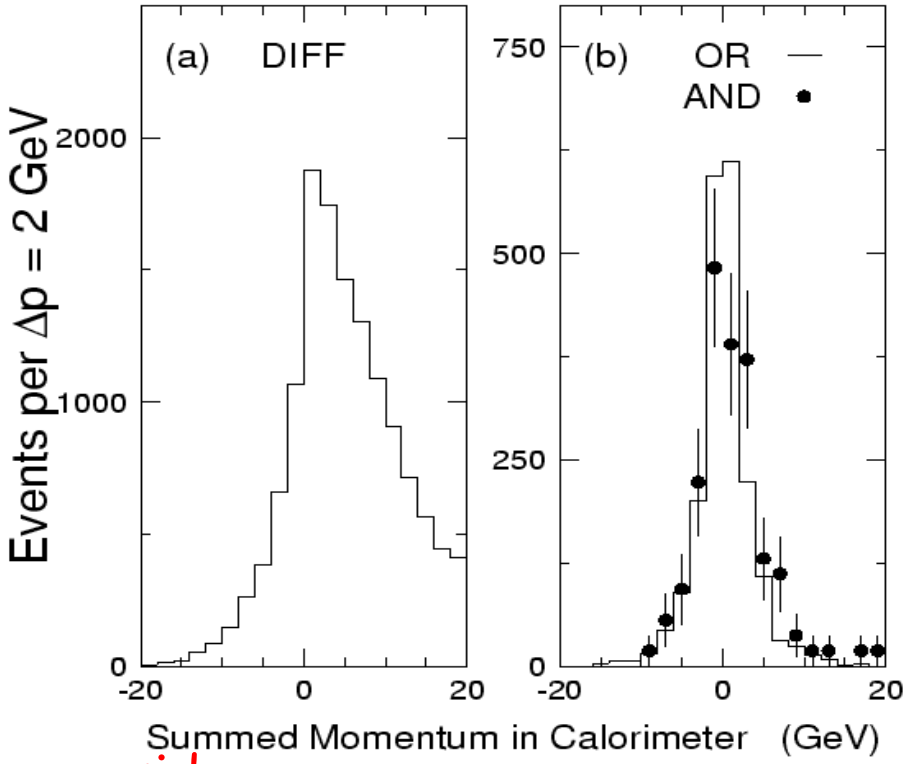
MC tuned to data by selecting isotropically-generated events which have average $\cos^2\theta$ larger than 0.375

DPE "OR" datā: Event Selection

An additional DPE data sample from DIF trigger:

- Only p OR $\bar{p}$ detected in Roman pots.
- Undetected $\bar{p}$ OR p is predominantly at $x_F = 1$ and $t = 0$.
- Offline rapidity-gap requirement in both arms isolates DPE signal

DPE "OR" Calorimeter $\Sigma P_{longitudinal}$



Trigger side

DPE "OR" Extracted from Diffractive trigger

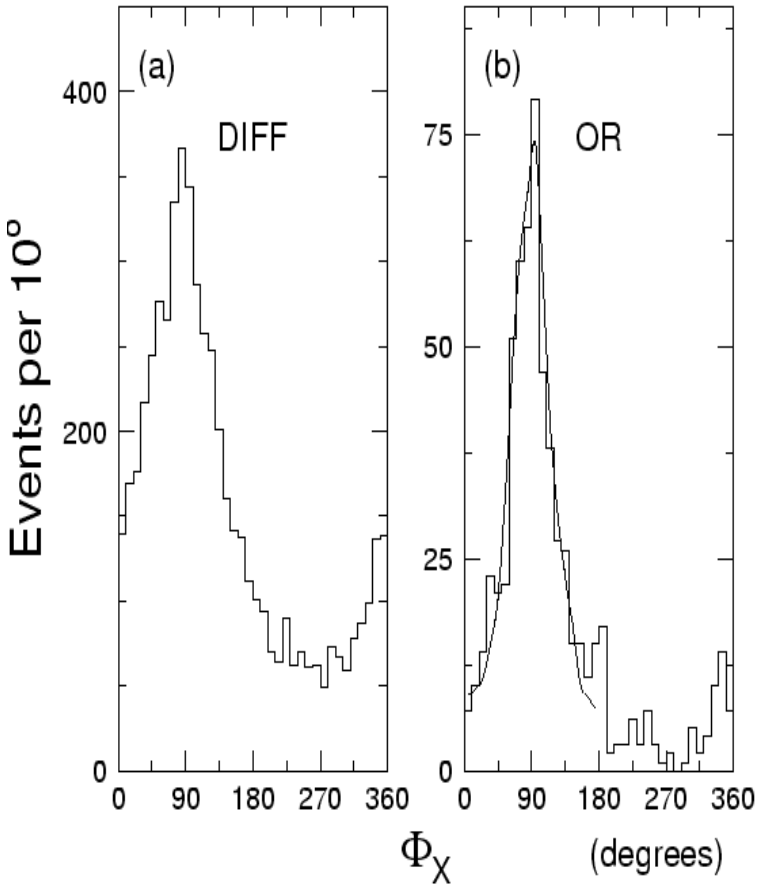
Rapidity gaps, 2.3 - 4.1

DIF ✘

DPE ✔

➔ Rap. gaps produce symmetry in calorim.

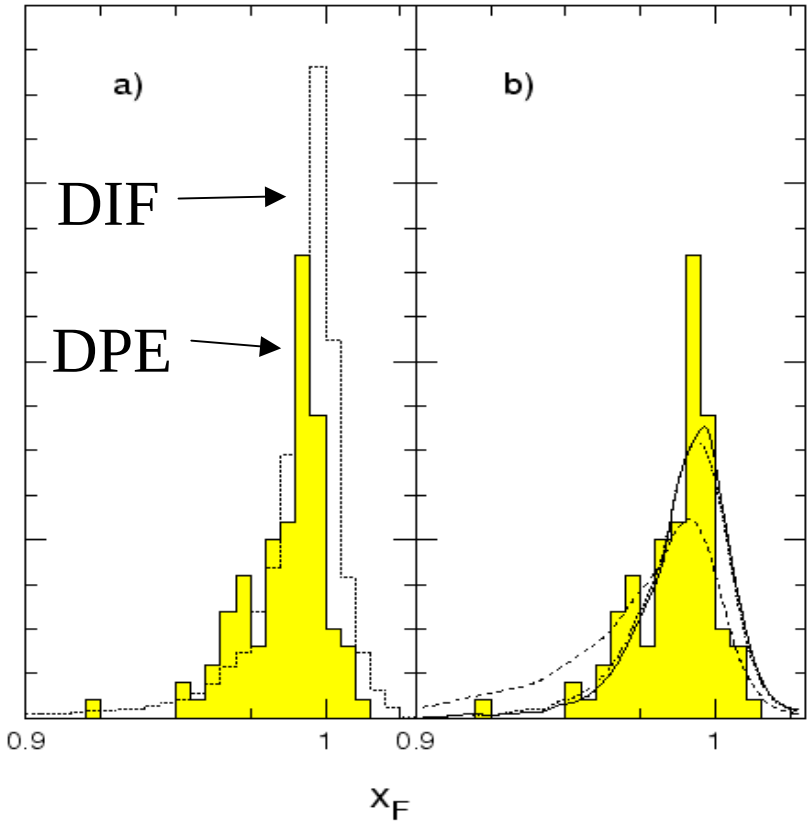
DPE "OR" vs. DIF: Calorimeter Phi



- ϕ of ΣP_t in calorimeter for events with DOWN p or $\bar{p}$. DPE has rapidity gaps:
- ϕ distribution is narrower for DPE events

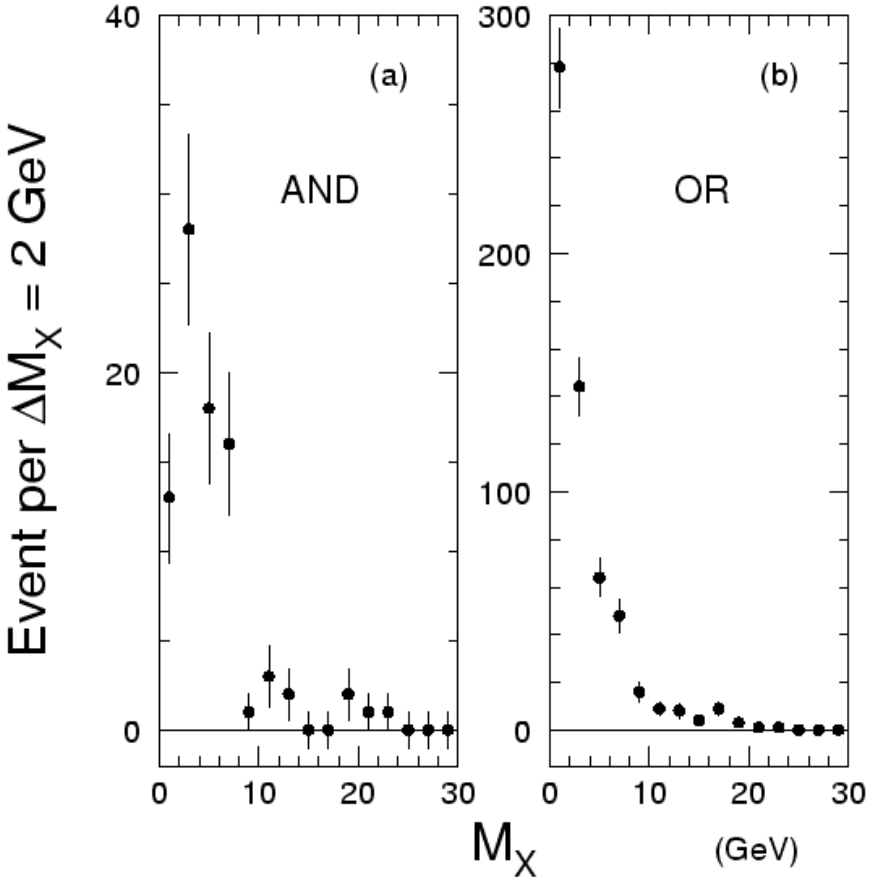
➔ entire system contained

X_F Comparison



- DPE suppressed at x = 1 due to unphysical regions in 6-dimensional space: t, ϕ, ξ for each.
- Curves in (b) are MC
  - Dashed is constant PP cross section.
  - Solid has arbitrary enhanced low-mass cross section.
- Conclude: another manifestation of low-m enhanced cross section

"AND" - "OR" Event Sample

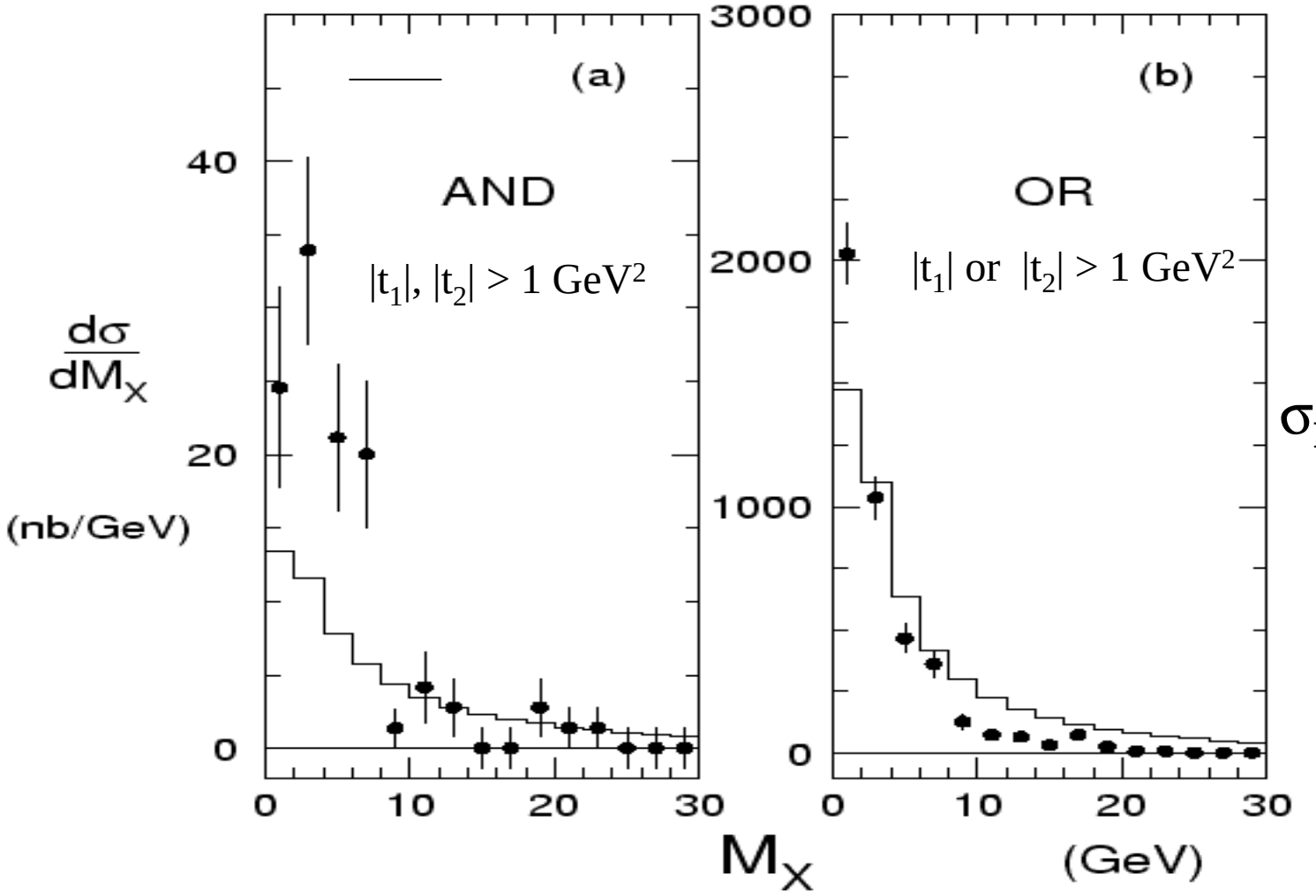


dN / dM_x

Acceptance is rather flat as a function of Mx

➔ Peaking at low mass in both "AND" and "OR" data is mostly due to Flux Factors

DPE "AND" - "OR": $d\sigma/dM_x$



MC

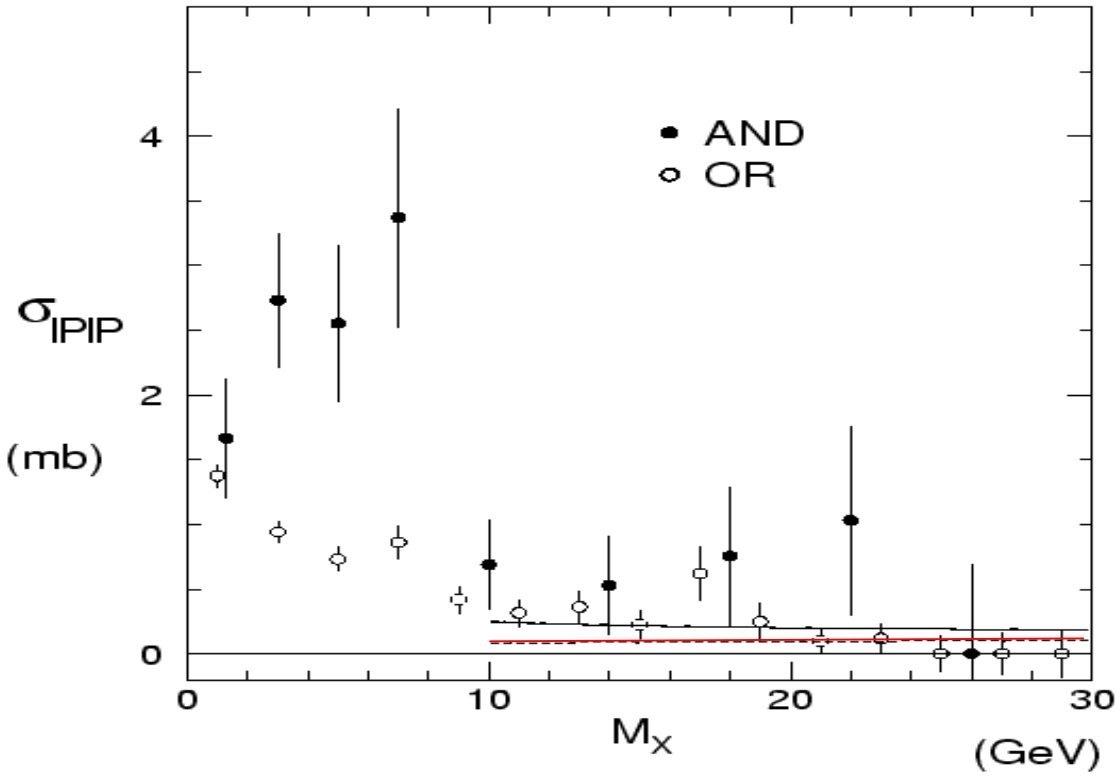
σ_{PP} = 1 mb

Pomeron-Pomeron Total Sigma

Red line is factorization prediction: about 0.1 mb.

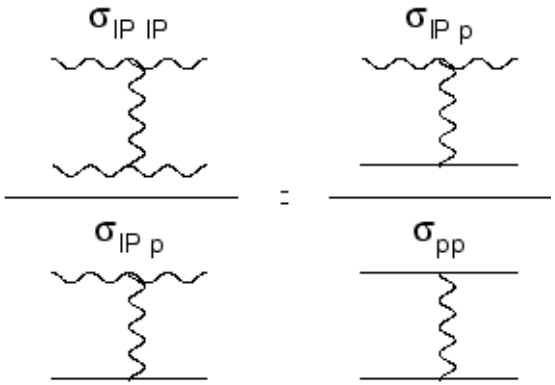
➔ High mass points appear to agree with prediction

➔ σ_{PP} low mass enhancements in both data sets.



Factorization

- Optical theorem relates σ_{total} to forward elastic amplitudes:



Factorization predicts:

$$\sigma_{PP} = \frac{[\sigma_{Pp}]^2}{\sigma_{pp}}$$

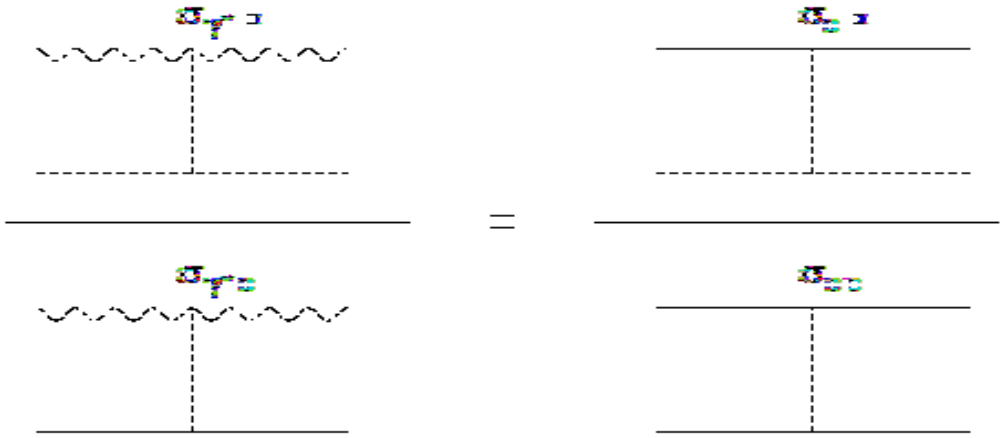
Total Cross Sections

Vertices cancel in numerator and denominator of both l.h.s. and r.h.s., thus verifying equality.

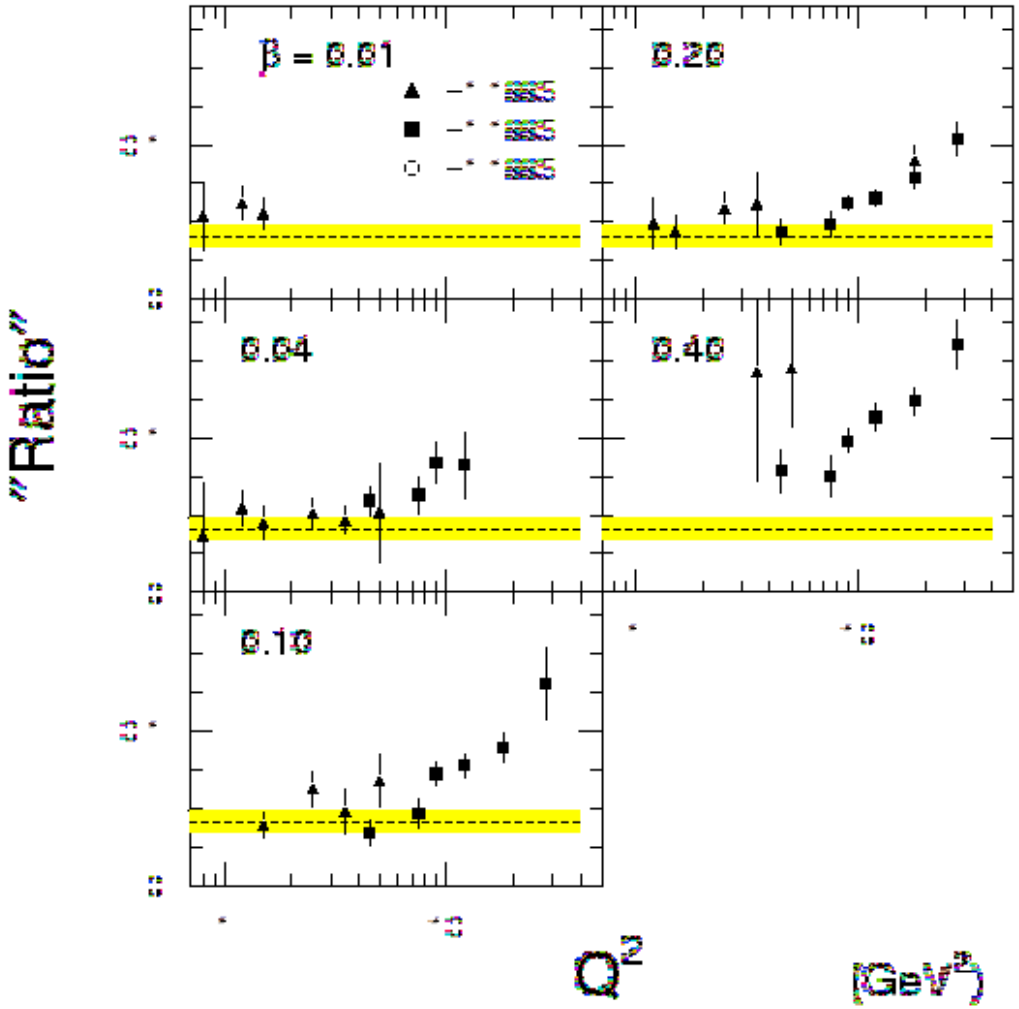
Conclusions

- Despite potential complications from multi-pomeron exchange, Regge formalism describes all data if s-dependent trajectory intercept and slope are used.
- There is large enhancement in σ_{pp} for $M_x < 6$ GeV, very pronounced in the "AND" data with $\Delta Pt = 0$.
- Factorization prediction agrees for $M_x > 10$ GeV,
- RHIC is in a good position to study multi-pomeron effects and to perform a DPE experiment with a high resolution central detector to find out if UA8 low-mass enhancement is due to glueball production.

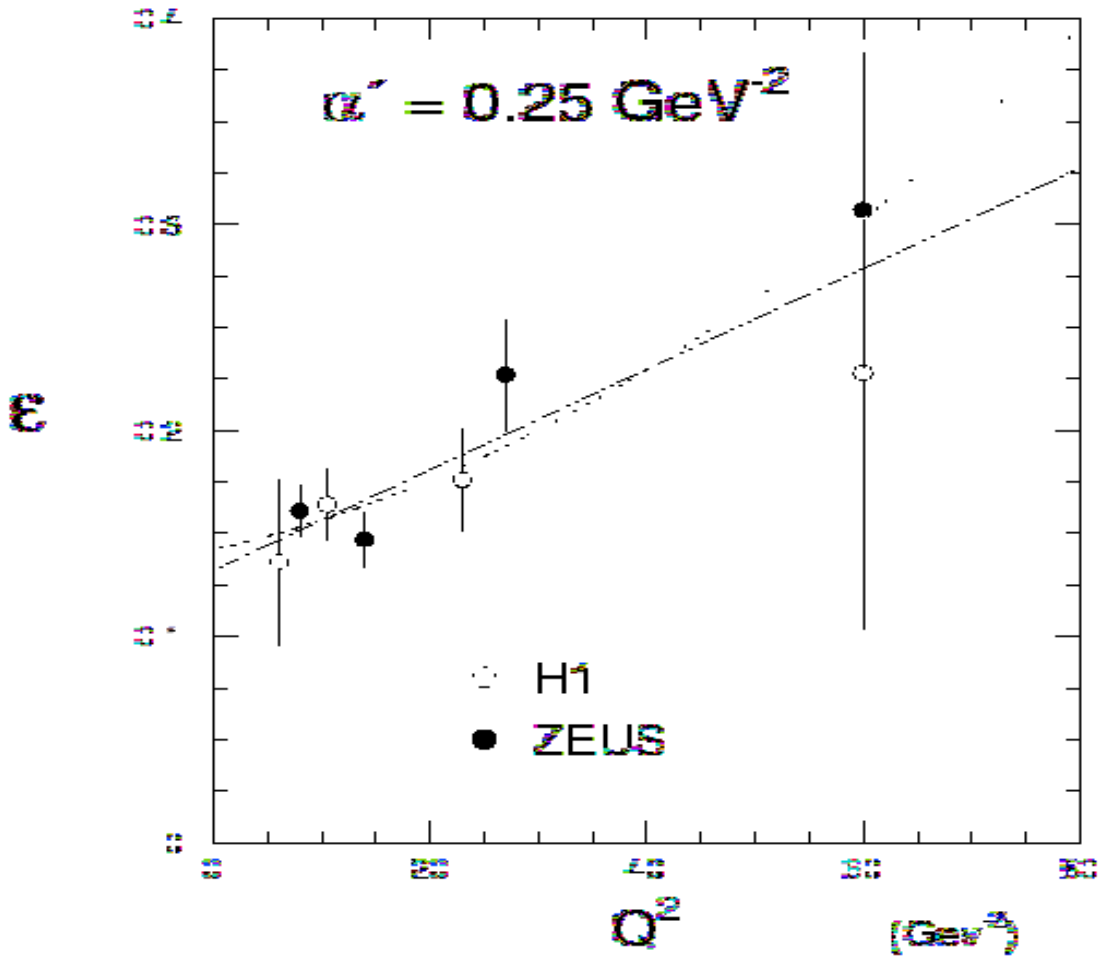
Factorization test: ep and $p\bar{p}$



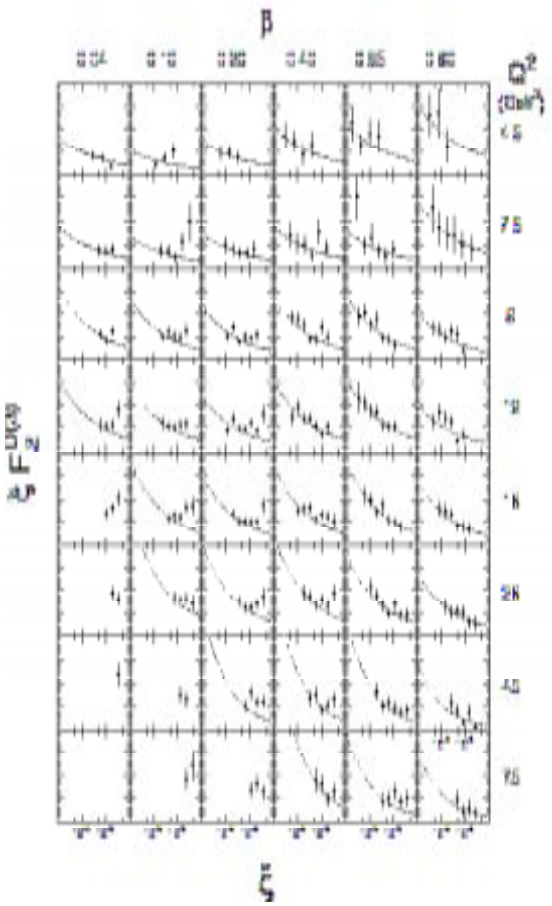
Factorization test: ep and pp



ε depends on Q^2 ; ZEUS exp.



Factorization test; H1 exp.



Factorization test; ZEUS exp.