Hadronic Final States in Diffractive ep Scattering

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representing the

ZEUS and **H1** Collaborations

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Outline of the Talk

- Introduction
- Energy Flow
- Event Shapes: Thrust, Sphericity
- Particle Spectra
- Jets in Diffraction:
  - H1: cone algorithm, 2– and 3–jet events
  - ZEUS: k_t algorithm, 3–jet events
- Not in this talk: Charm (see next talk)

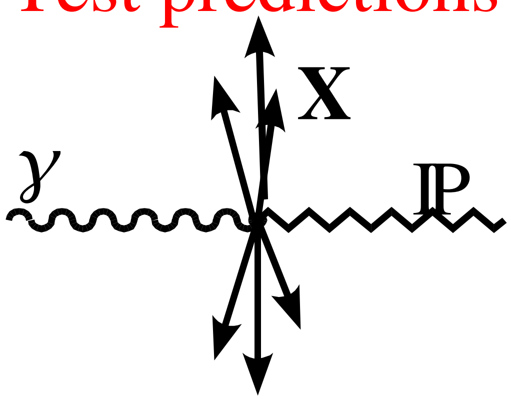
Introduction

Inclusive measurements of diffraction provide information about parton content of the pomeron.

Studying the hadronic final state in the rest frame of the hadronic system X ($\gamma \mathbb{P}$–CMS) provides additional information on the underlying dynamics.

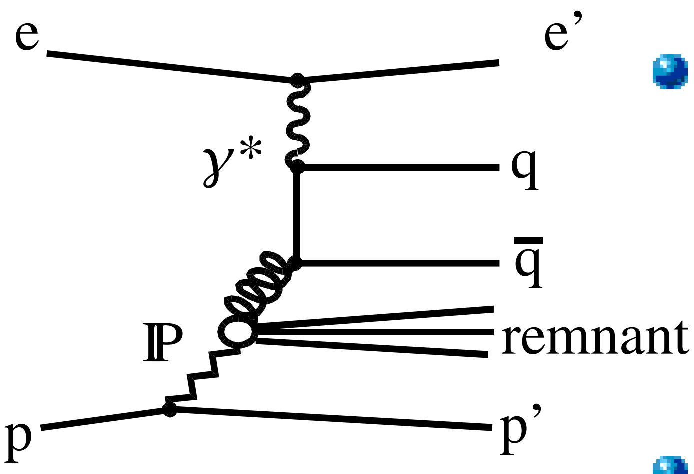
The pomeron is known to be gluon–dominated. Now:

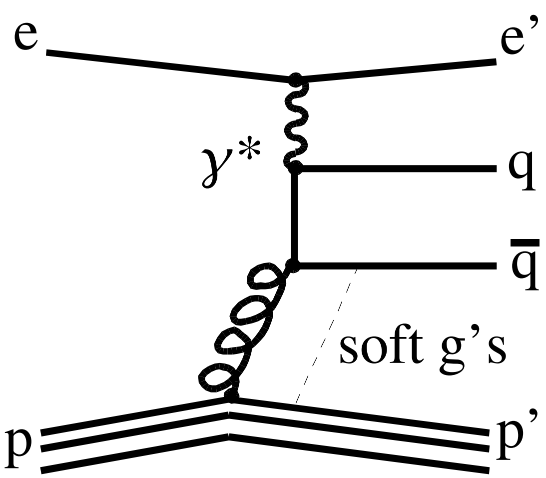
Test predictions of different models for...



- Energy Flow, Particle p_t
- Event Shapes: Thrust, Sphericity
- Jets

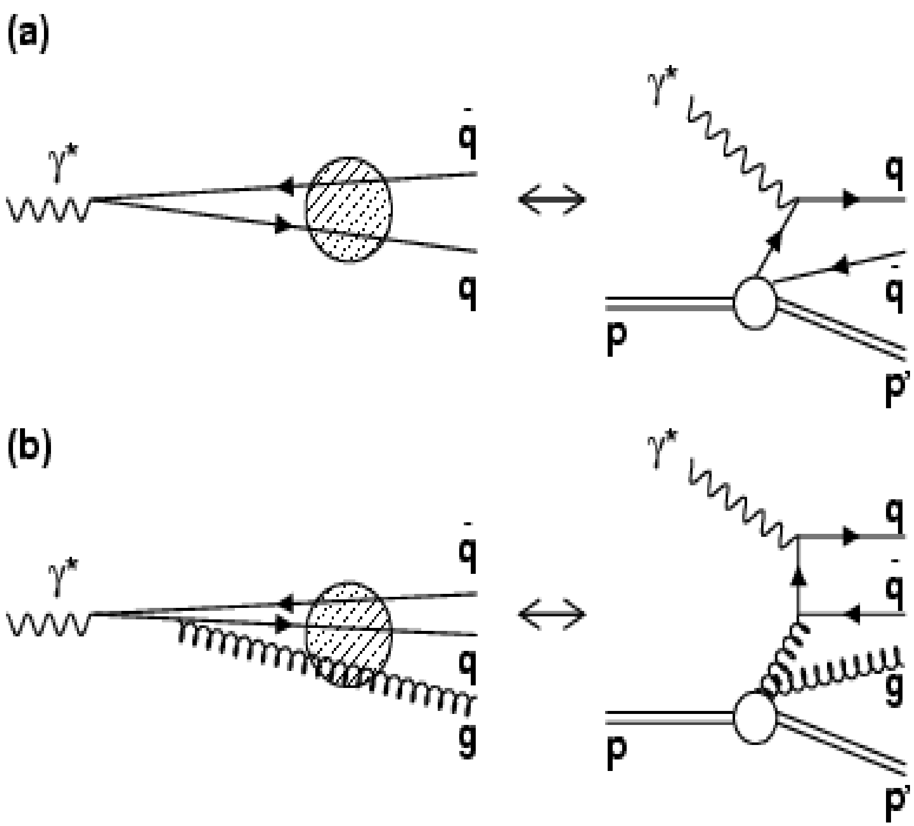
Models: Resolved Pomeron and SCI





- Resolved Pomeron:Ingelman & Schlein
  - Treat Pomeron as hadron within proton: flux factor x pomeron parton densities
  - MC: RAPGAP
- Soft Color Interactions: Ingelman, Edin, Rathsman
  - Diffractive ep scattering = »normal« ep scattering + color neutralization through soft gluons
  - MC: LEPTO

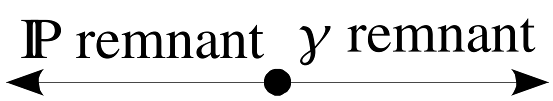
Color Dipole and Two Gluon Models

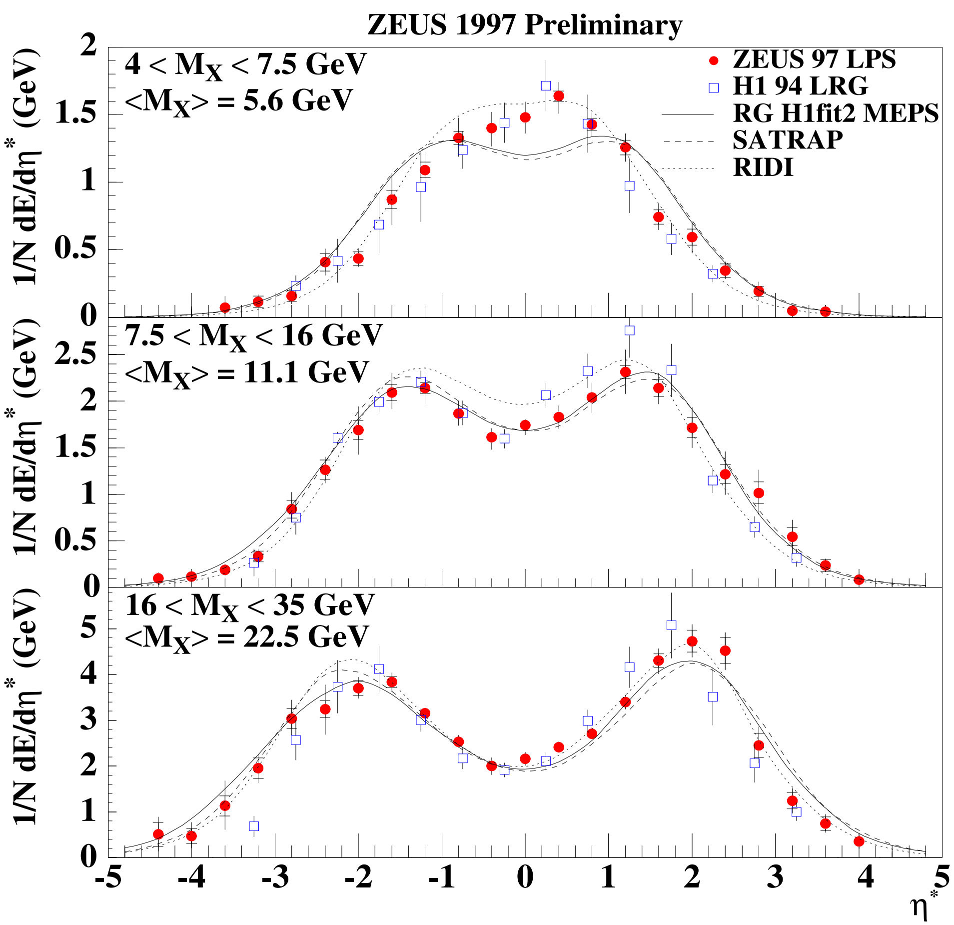


Low & Nussinow 1975: ℙ=2g

- Golec–Biernat & Wüsthoff:
  - Saturation model
  - MC SATRAP
- Bartels, Jung, Lotter, Wüsthoff:
  - Non–k_t–ordered contributions
  - implemented within RAPGAP
- Ryskin *et al.*:
  - MC RIDI

Energy Flow





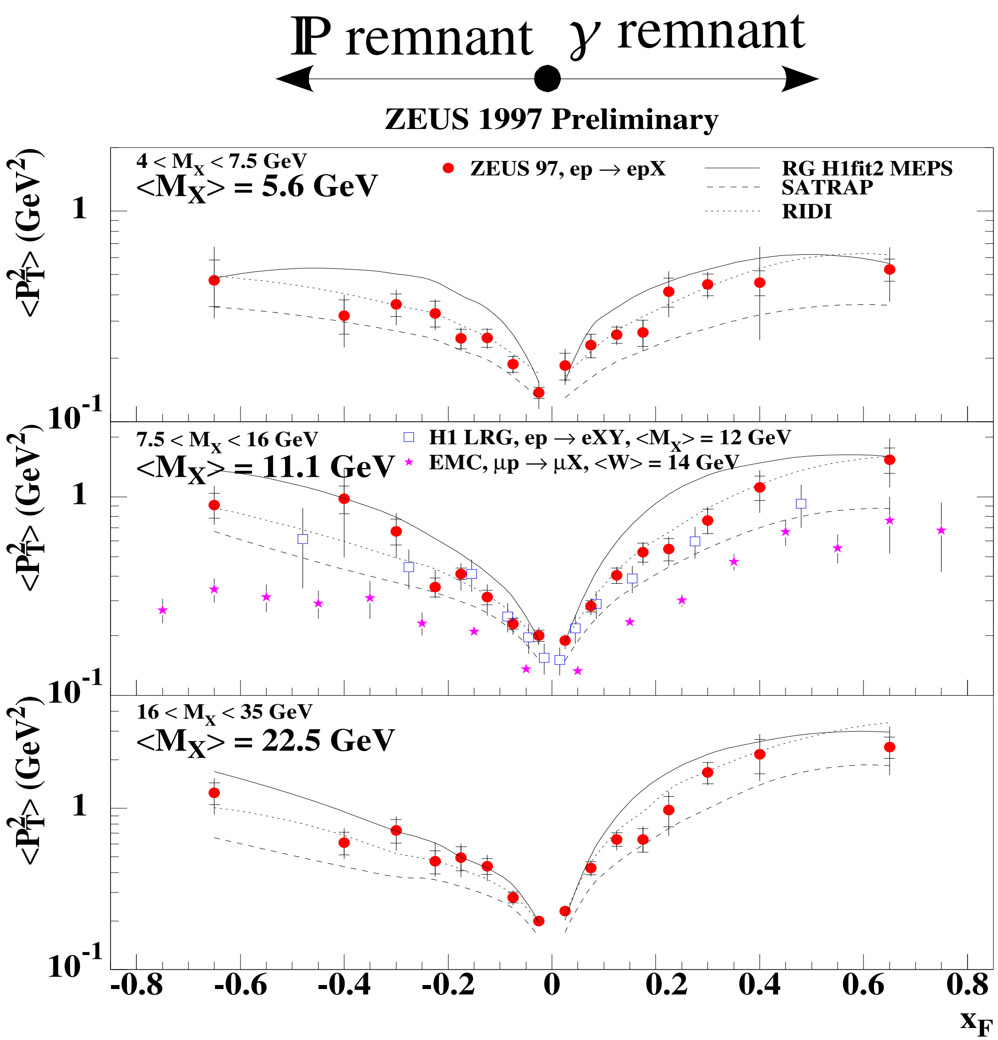
- ZEUS 1997 data, LPS tagged, $\int \mathscr{L} dt = 13.8\mathrm{pb}^{-1}$
- Agrees with 1994 H1 data
- As M_X goes up: two–jet structure emerges

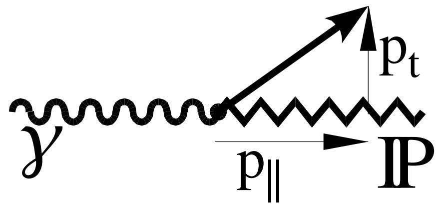
✓ Resolved IP (RAPGAP) and 2–gluon models (RIDI, SATRAP) fit: Confirms gluon dominance

✗ Sensitivity to hadronisation model at low M_X

ZEUS, contributed paper 876 to ICHEP 2000, Osaka. H1, Phys. Lett. B428(1998)206.

Seagull Plot





$$\langle p_t \rangle^2 \quad vs \quad x_F = \frac{p_\parallel}{\frac{1}{2} M_X}$$

Particle p_t: Sensitivity to parton k_T, different for remnant of extended objects (proton, pomeron)

- ZEUS 1997 data, LPS tagged
- μp data from EMC: more p_t suppression on proton side
- At high M_X: increasing asymmetry

✓ Resolved IP and 2−gluon models fit qualitatively

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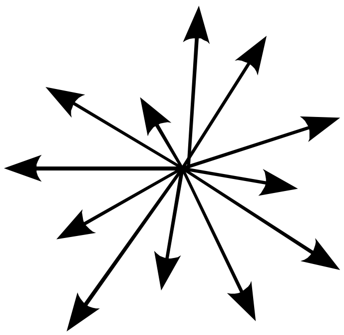
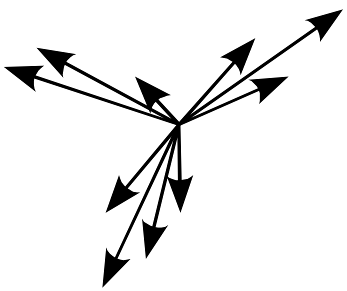
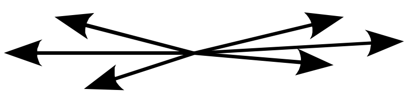
Event Shape Variables



$T \to \frac{1}{2}$ $\quad S \to 1$



$T \to \frac{3}{4}$ $\quad S \to \frac{1}{2}$



$T \to 1$ $\quad S \to 0$

Thrust: $T = max \frac{\sum_i |\vec{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}$

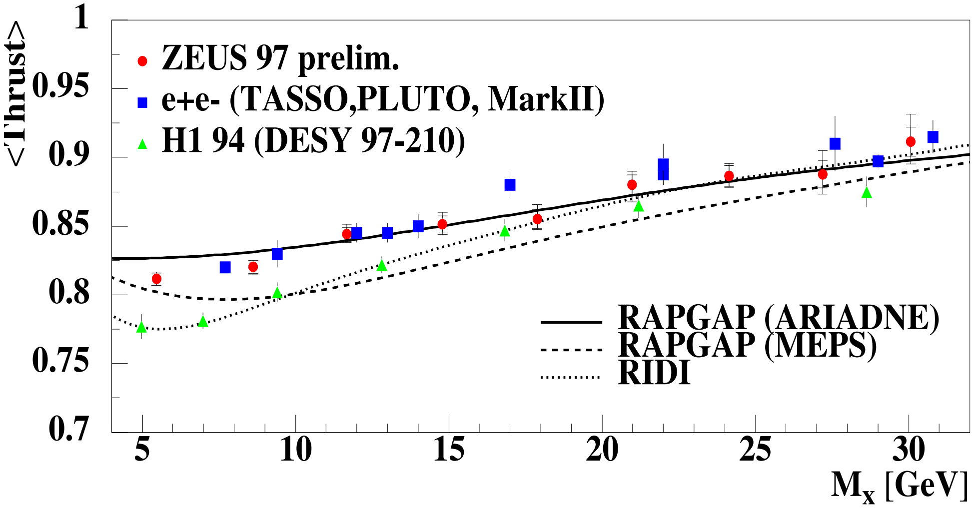
Sphericity: $S = \frac{3}{2}(\lambda_2 + \lambda_3)$

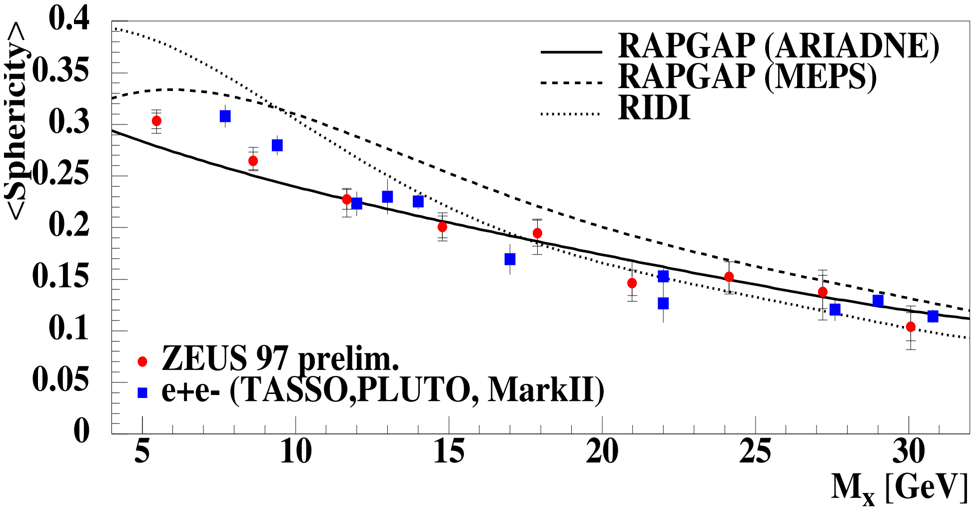
λ_i are the eigenvalues of the

sphericity tensor: $S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |\vec{p}_i|^2}$

$\lambda_1 > \lambda_2 > \lambda_3$

Thrust and Sphericity





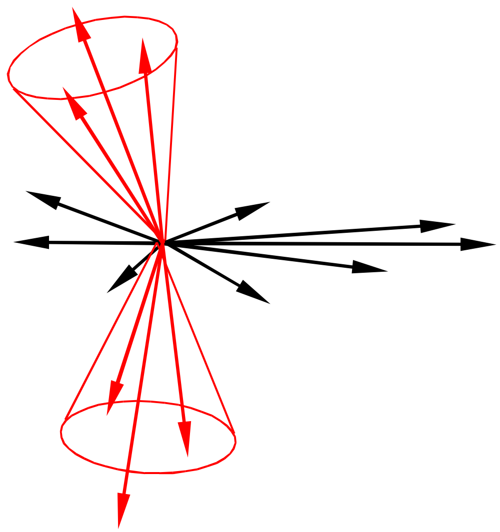
- ZEUS 1997 data, LPS tagged
- Thrust and sphericity are independent of Q^2, $x_{\mathbb{P}}$, W
- Thrust distribution: Discrepancy ZEUS–H1
- ZEUS: Similar shapes as in $e^+e^- \rightarrow qq$, but not identical
- ✗ Again: hadronisation important at low M_X

ZEUS, contributed paper 876 to ICHEP 2000, Osaka. H1, Eur.Phys.J. C1(1998)495.

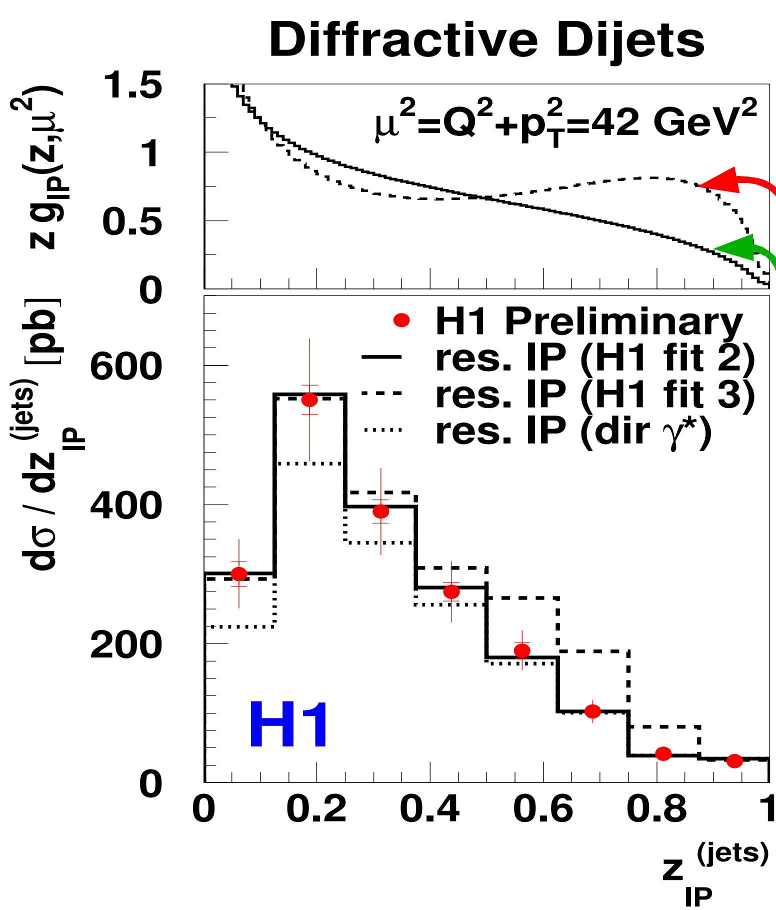
Jets in Diffraction: H1

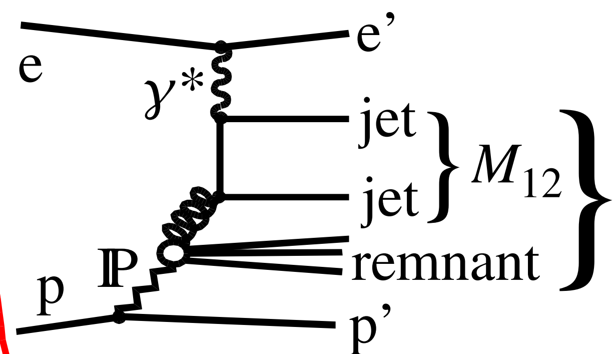
H1: Analyse 2– and 3–jet events in $\gamma^* I\!P$ CMS

- Cone algorithm, E_T>4 GeV, $R = 1$
- $4 < Q^2 < 80$ GeV^2, $x_{I\!P} < 0.05$, $0.1 < y < 0.7$
- Diffraction tag: $\eta_{max} < 3.2$, forward detectors
- 1996+1997 data, $\int \mathscr{L} dt = 18 \mathrm{pb}^{-1}$
- 2500 dijet events, 130 three–jet events



Dijets: Gluon in the Pomeron





$$z_{IP} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2}$$

$z_{\mathbb{P}}$: fractional momentum of pomeron entering hard process

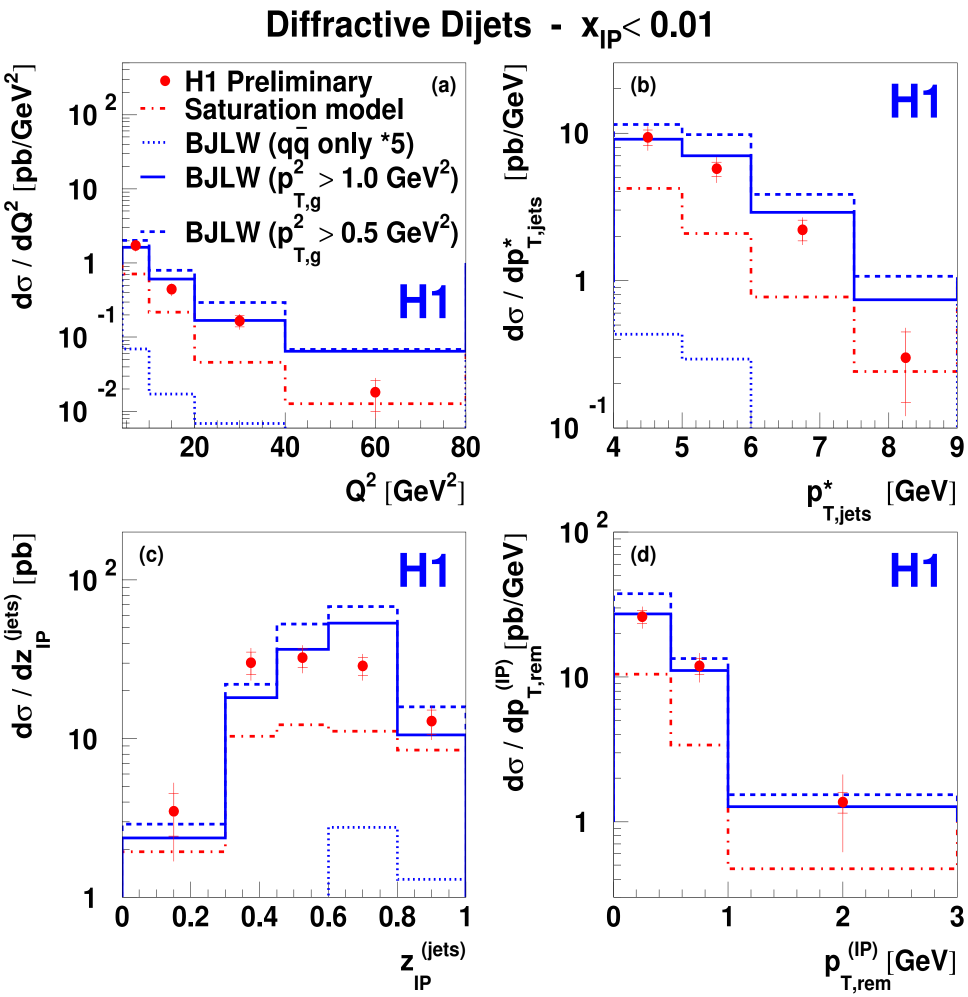
✗ H1 fit 3: »hard« gluon: too hard

✓ H1 fit 2: »flat« gluon: OK

$\Rightarrow$ $z_{\mathbb{P}}$ distribution is sensitive to gluon distribution in the pomeron

H1, contributed paper 960 to ICHEP 2000, Osaka.

Dijets: Two–Gluon Models



For applicability of models:

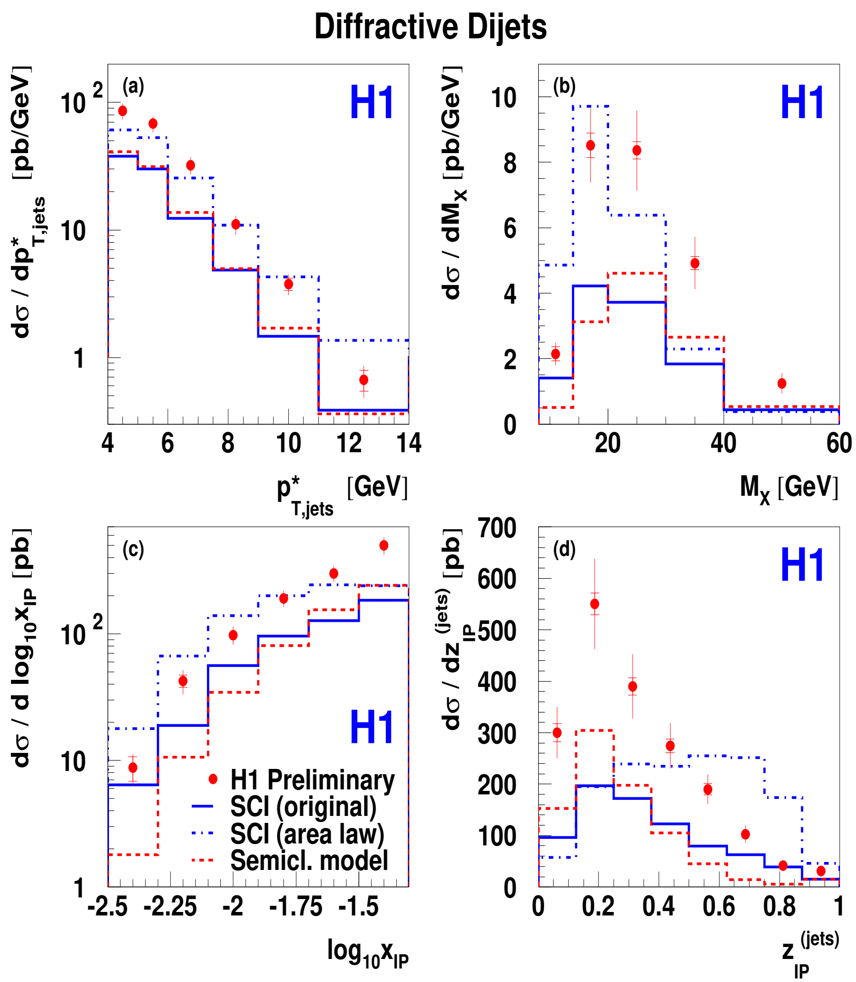
Restricted kinematical range: $x_{\mathbb{P}} < 0.01$

✓ 2–Gluon model of Bartels, Jung, Lotter, Wüsthoff (BJLW): OK!

✗ Saturation model (SATRAP): too low, but shapes OK!

H1, contributed paper 960 to ICHEP 2000, Osaka.

Dijets and SCI Models

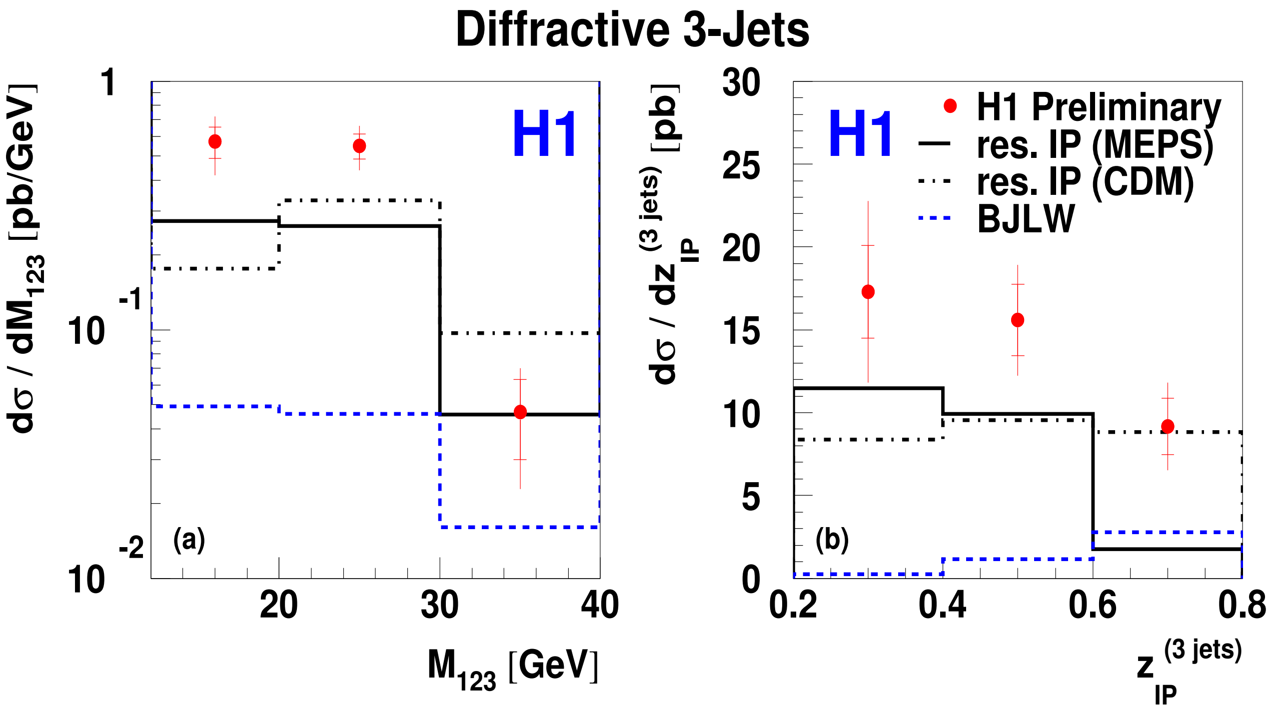


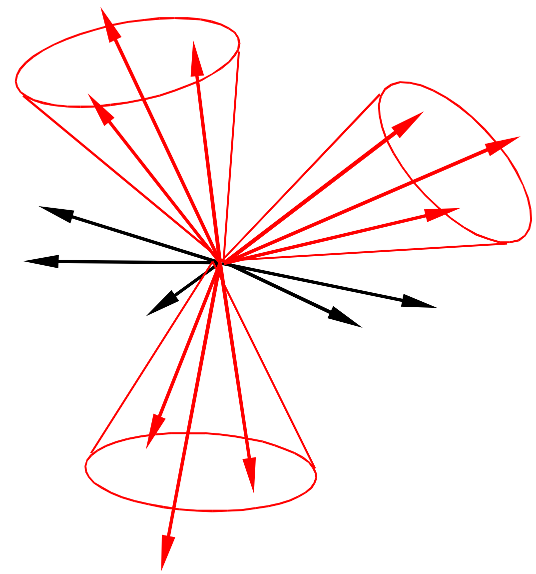
H1, contributed paper 960 to ICHEP 2000, Osaka.

Different incarnations of Soft Color Interactions:

- SCI: Ingelman, Edin, Rathsman
  - Original version
  - New version: generalized area law
- Semiclassical Model: Buchmüller, Hebecker, Gehrmann
- All models have problems, either with normalization or with shape of z_{IP} distribution

Three–Jet Events





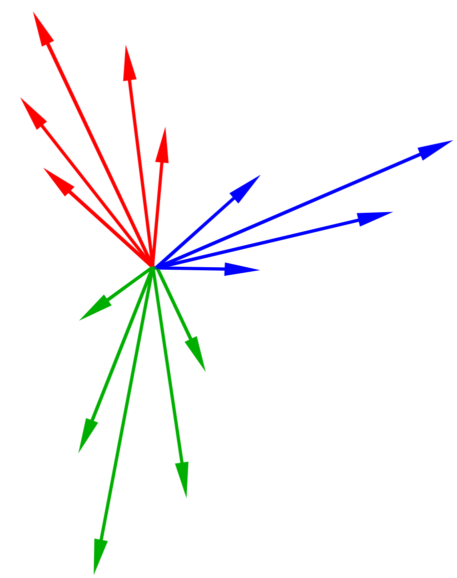
H1, contributed paper 960 to ICHEP 2000, Osaka..

- ✗ Resolved Pomeron with either parton showers (MEPS) or color dipole radiation (CDM) too low
- ✗ Two–gluon model (BJLW) much too low

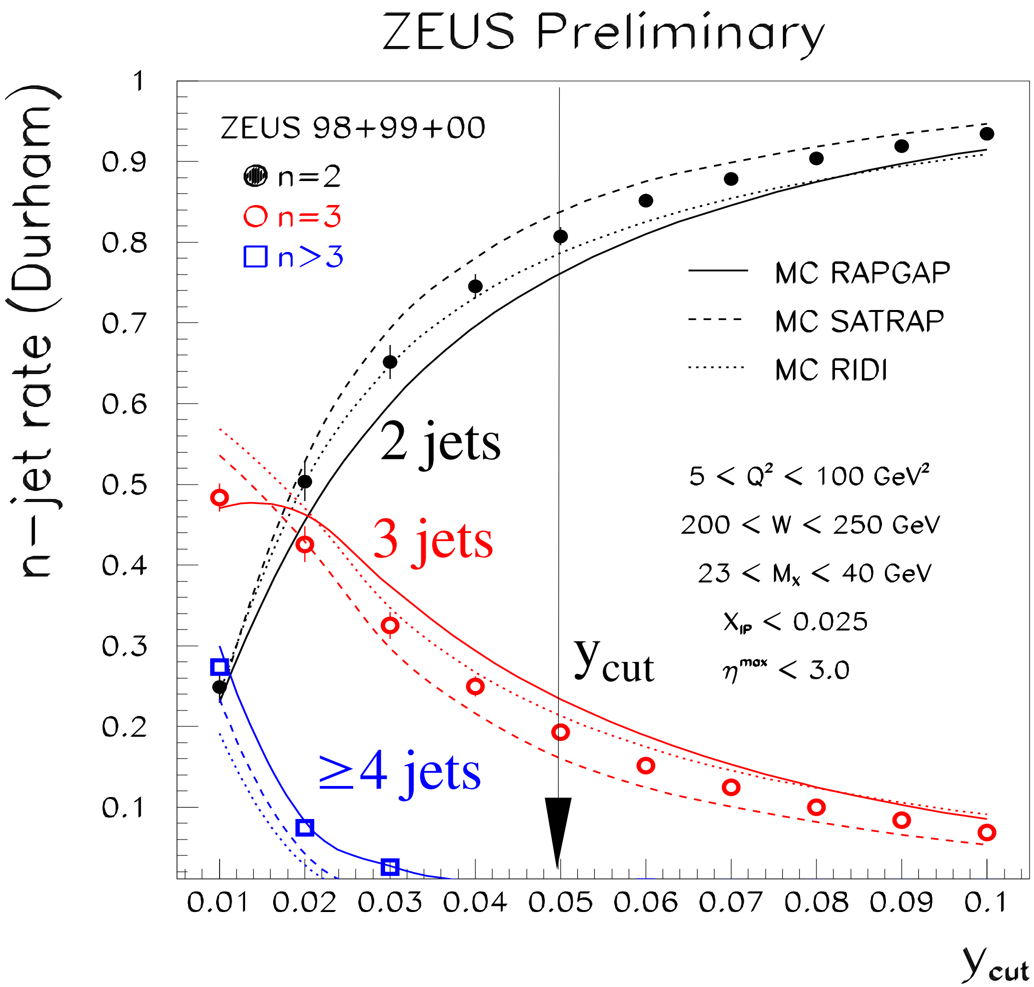
Jets in Diffraction: ZEUS

ZEUS:Analyses three–jet events in $\gamma^* \mathrm{I\!P}$ CMS

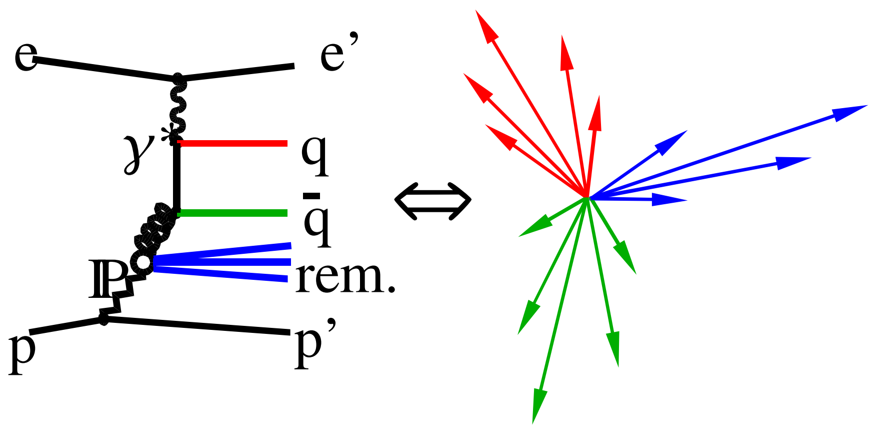
- Durham (k_T) algorithm, $y_{cut} = 0.05$
  (each particle is clustered into a jet)
- $5 < Q^2 < 80\ \mathrm{GeV}^2$, $x_{\mathrm{I\!P}} < 0.025$, $200 < W < 250$ GeV,
  $23 < M_X < 40$ GeV
- Diffraction tag: $\eta_{max} < 3.0$
- 1998–2000 data, $\int \mathscr{L} dt = 39 \mathrm{pb}^{-1}$
- 678 three–jet events ($\simeq$20% of events)



Jet Rates



- ✓ Jet rates qualitatively described by MC models
- $y_{cut} = 0.05$ gives best parton–hadron correlation

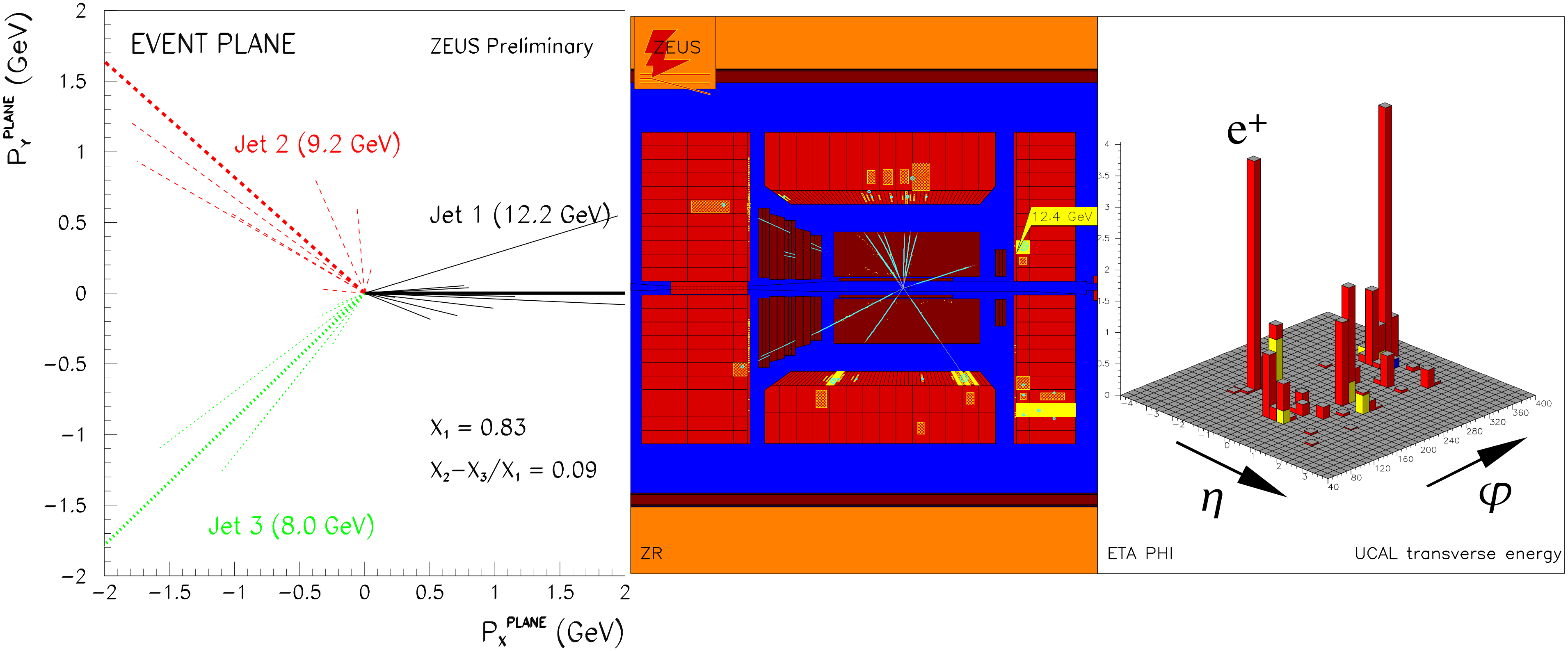


ZEUS, contributed paper 872 to ICHEP 2000, Osaka..

Example Three–Jet Event

Jets in center–of–mass system of hadronic final state:

Jets in laboratory system:



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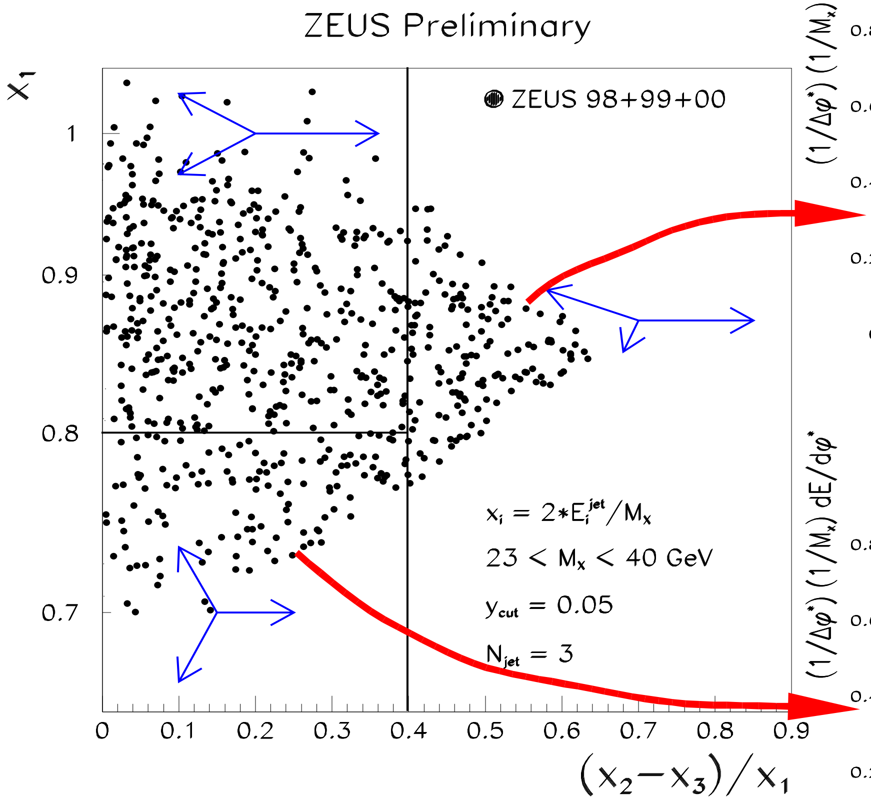
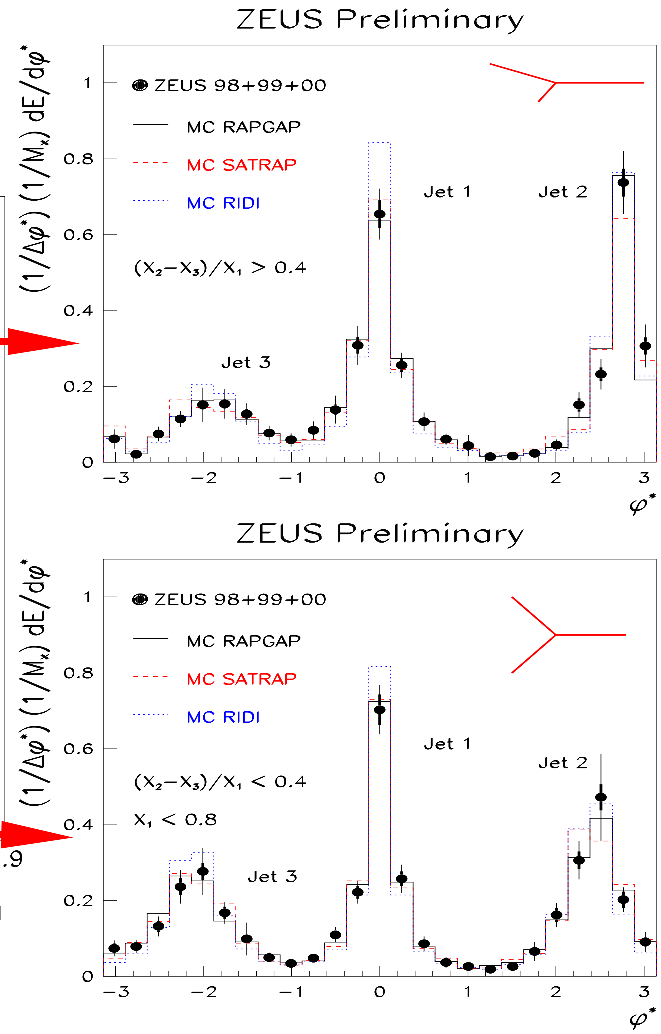
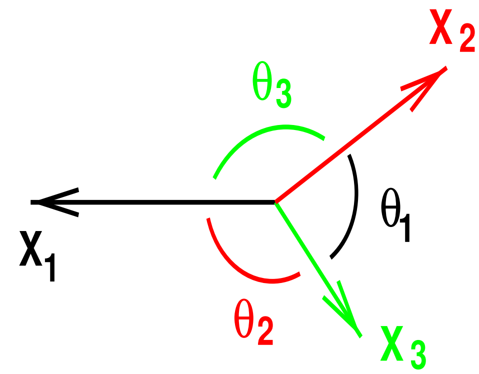
Three–Jet Events: Jet Topologies

Clear 3–Jet topologies







$$x_i = \frac{2\,E_i^{jet}}{M_X}$$

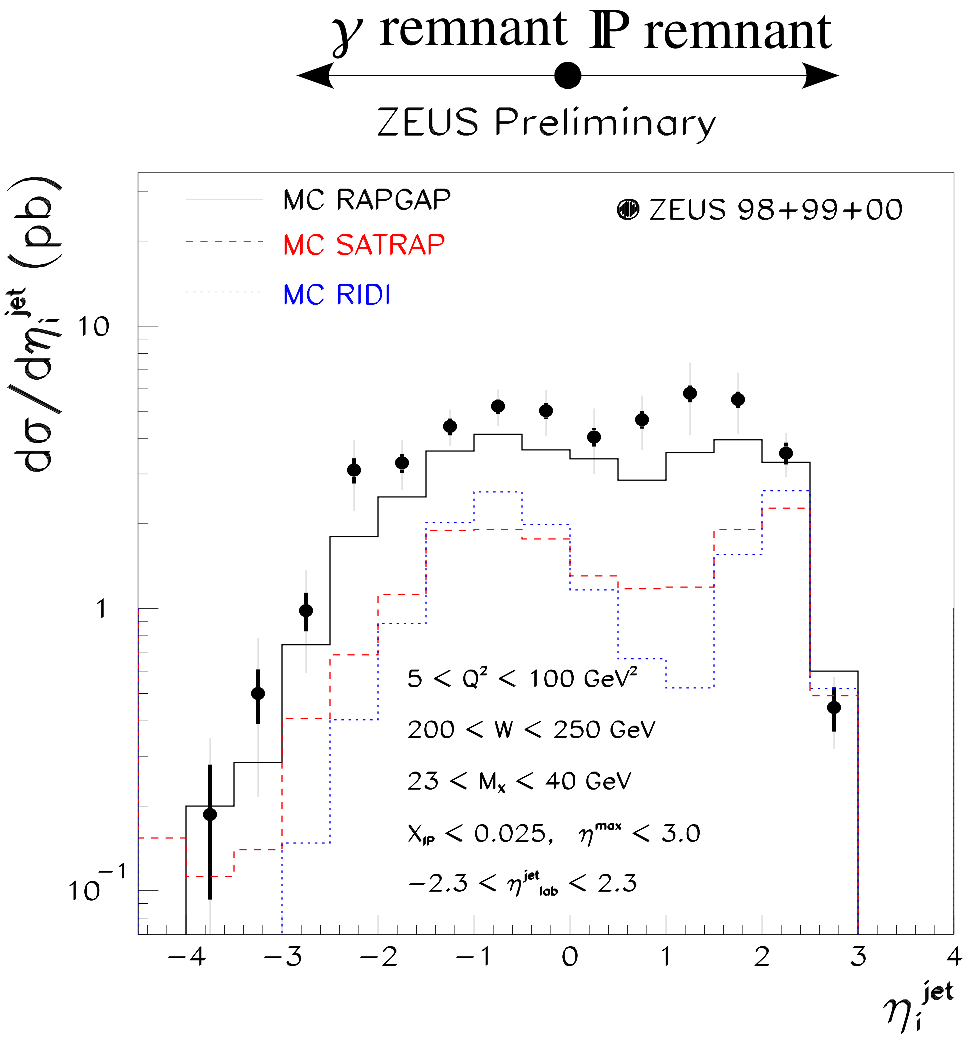
$$x_1 \geq x_2 \geq x_3$$

$$x_1 + x_2 + x_3 = 2$$

All topologies present

ZEUS, contributed paper 872 to ICHEP 2000, Osaka..

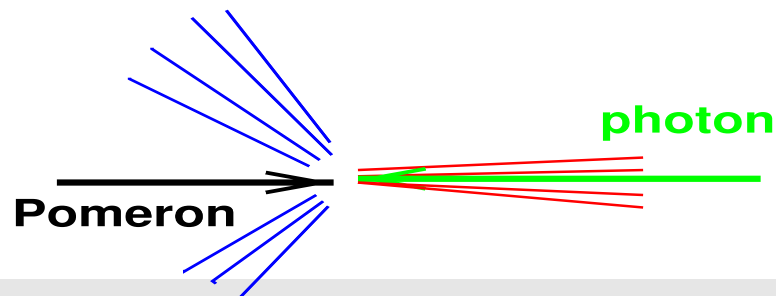
Three–Jet Events: Rapidity



ZEUS, contributed paper 872 to ICHEP 2000, Osaka..

Plot η in center–of–mass system for each jet

- ✓ Resolved $\mathbb{P}$ (RAPGAP) describes data well
- ✗ Saturation model (SATRAP) too low, shape OK
- ✗ RIDI much too low, wrong shape
- Photon and pomeron remnant very similar, gluon k_T important!



Summary

New results on

- Energy flow, event shapes, particle spectra
- Jets in Diffraction:
  - 2– and 3–jet events with cone algorithm
  - 3–jet events with Durham algorithm

Conclusions

- **Models that derived from inclusive measurements describe data remarkably well**
- **But: No single model fits all the data!**

✓ Resolved Pomeron (RAPGAP) does generally well and is still the model to beat, but:

  ✗ Hadronization effects neep more tuning

✓ Color dipole / two gluon models catch up!

  ✗ valid only in limited $x_{\mathbb{P}}$ range, jet rates too low

✗ Soft color interactions, semiclassical model:

  ✗ Cannot describe H1 dijet data