A Measurement of the Total Photon-Proton Cross Section

Camille M. Ginsburg
The Ohio State University

on behalf of the ZEUS Collaboration

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- Motivation
- Method
- Detector acceptance
- Results
- Conclusions

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$\sigma_{TOT}^{\gamma p}$ Measurement Motivation

- HERA very high γp cm energy
- Test universality of hadronic σ_{TOT} energy dependence

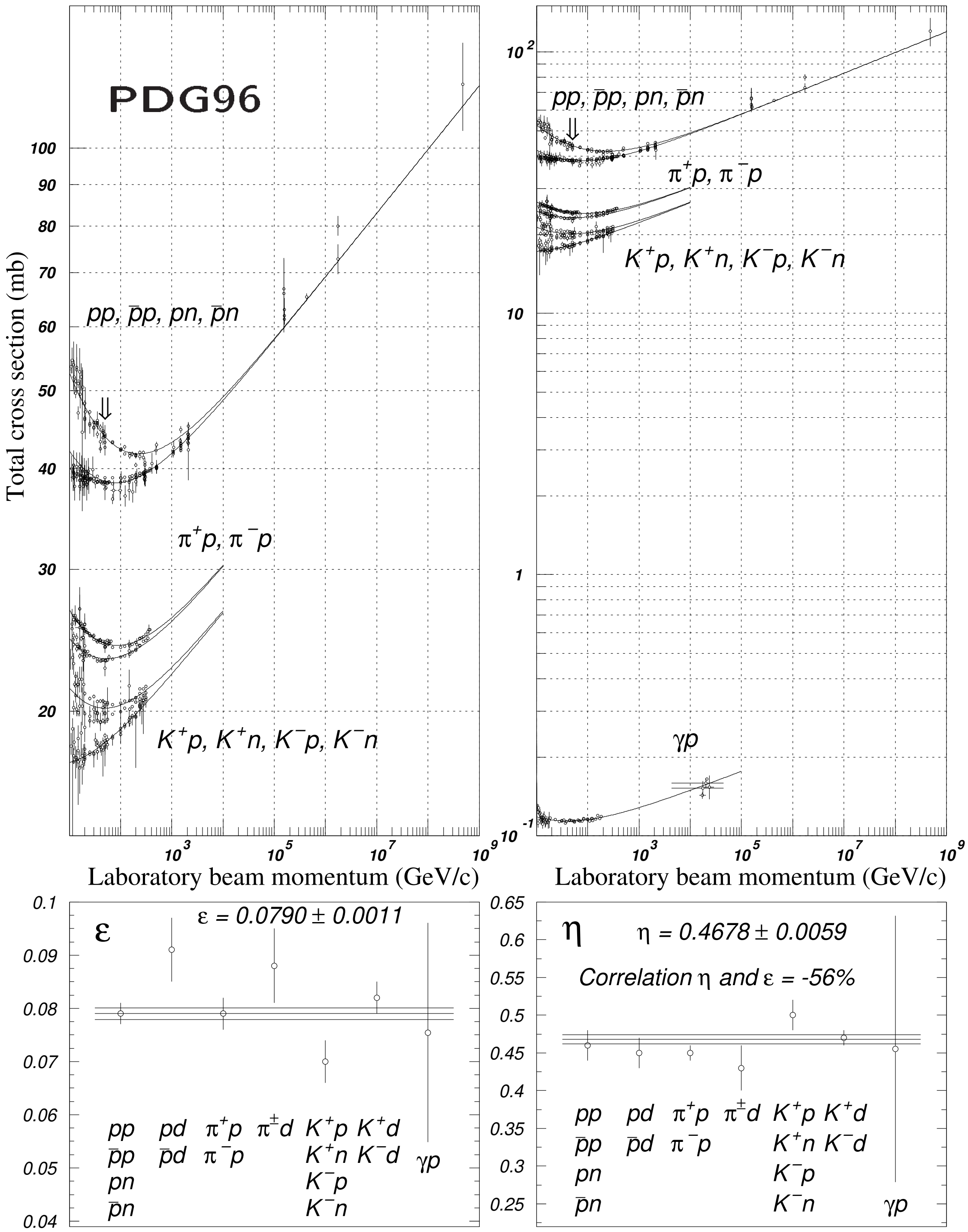
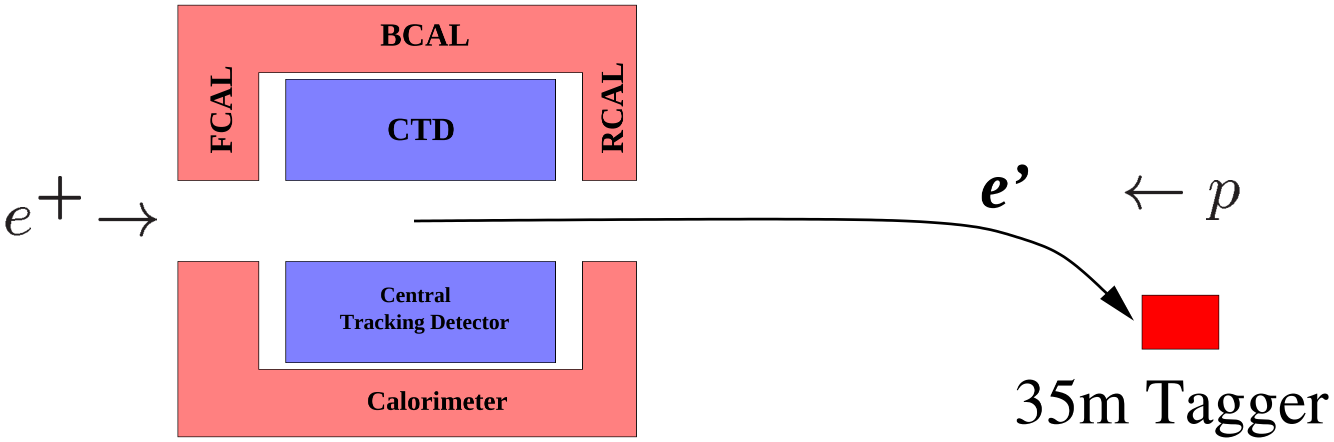


Figure 36.17: Summary of hadronic and γp total cross sections (top), and fit results to exponents for cross sections. (Courtesy of the COMPAS Group, IHEP, Protvino, Russia, 1996.)

$$\sigma_{TOT} = X s^{\varepsilon} + Y s^{-\eta}$$

$\sigma^{\gamma p}_{TOT}$ Measurement Method (1)



$$e^+p \rightarrow e^+ + \gamma^* p \rightarrow e^+ + X$$

★ e^+ tagged in 35m tagger $\Rightarrow$ photon energy
35m tagger acceptance determines kinematic range
$Q^2 < 0.02\,\mathrm{GeV}^2 \;\; \Rightarrow \;\; \langle Q^2 \rangle \simeq 10^{-3}$
$\langle W_{\gamma p} \rangle = 207$ GeV

★ hadronic system X observed in main ZEUS detector

★ Use Equivalent Photon Expression $ep \rightarrow \gamma p$

$$\frac{d\sigma^{ep}_{tot}(y)}{dy} = \frac{\alpha}{2\pi}\left[\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{\mathrm{max}}}{Q^2_{\mathrm{min}}} - \frac{2(1-y)}{y}\left(1-\frac{Q^2_{\mathrm{min}}}{Q^2_{\mathrm{max}}}\right)\right]\sigma^{\gamma p}_{TOT}(y)$$

$$= F_\gamma(y)\sigma^{\gamma p}_{TOT}(y)$$

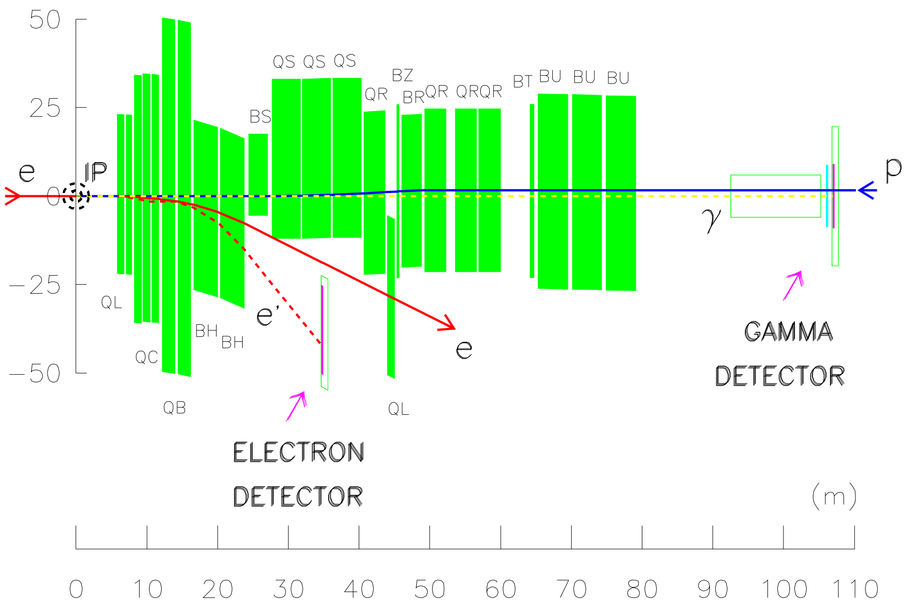
$$\sigma^{ep}_{TOT} = \int_{y_1}^{y_2} F_\gamma(y)\sigma^{\gamma p}_{TOT}(y)\,dy = f_\gamma \sigma^{\gamma p}_{TOT}$$

$$y = 1 - \frac{E'_e}{E_e}$$

★ Bremsstrahlung (BS) $e^+p \rightarrow e^+\gamma p$
primary background: BS + chance coinc with CAL trig
$\sigma_{BS} \sim 1000\ \sigma^{\gamma p}_{TOT}$
removed with $E_\gamma < 1$ GeV cut
excellent calibration tool: γ scattering angle ~ 0

$\sigma_{TOT}^{\gamma p}$ Measurement Method (2)

Improvements wrt to previous measurements



★ e^+ acceptance

- Scattered e^+ passes through quad fringe fields absolute position of magnets known to $\sim$ 1mm
  $\Rightarrow$ e^+ position detector in 35m tagger allows check of position vs. energy correlation
- e^+-beam orbit and tilt normally vary over time
  $\Rightarrow$ Dedicated run
  $\Rightarrow$ γ position detector allows control of e^+ beam tilt

★ CAL acceptance

- CAL trigger calibration different from offline
  $\Rightarrow$ Readout of CAL trigger energies to study difference
- Inclusive γp behavior unknown
  $\Rightarrow$ precise ZEUS measurements of γp subprocesses reduce reliance on MC modelling

★ General

- Calibration drifts, trigger prescales, limited statistics
  $\Rightarrow$ Dedicated run

$\sigma_{TOT}^{\gamma p}$ Measurement Method (3)

$$\sigma_{TOT}^{\gamma p} = \frac{N}{\mathcal{L}} \frac{1}{f_\gamma} \frac{\Delta(\mathrm{RAD})\,\Delta(\gamma\mathrm{acc})\,\Delta(\mathrm{BSO})}{A(\mathrm{35m})\,A(\mathrm{CAL})}$$

N	Number of γp events e+gas subtracted statistically
$\mathcal{L}$	Luminosity
f_γ	Photon flux factor
$\Delta(\mathrm{RAD})$	Correct to Born level
$\Delta(\gamma\mathrm{acc})$	Remove BS with γ lost
$\Delta(\mathrm{BSO})$	Correct removal of γp with BS overlays
$A(\mathrm{35m})$	35m tagger acceptance for γp
$A(\mathrm{CAL})$	Calorimeter acceptance for γp

$\sigma_{TOT}^{\gamma p}$ Event Selection

★ Trigger

- RCAL EM energy $>$ 0.464 GeV
- 35m tagger E_e $>$ 5 GeV
- timing consistent with ep collision

★ Offline Cuts

- RCAL EM energy $>$ 0.600 GeV (CAL trigger 100%)
- 35m tagger $12 < E_e < 16$ GeV (good accpt region)
- lumi-γ tagger E_γ $<$ 1 GeV (remove BS)

★ e^++gas BS background ($e^+N \rightarrow e^+\gamma N$)
statistically subtracted from # events & γp dists

- 1.3% correction

Correction Factors

★ **Radiative events**
$E_\gamma < 1$ GeV cut removes ISR/FSR events
$\Rightarrow$ measure $\sigma^{\gamma p}_{TOT}$ incl. radiation upto $E_\gamma = 1$GeV

- Correct by $\sigma(BORN)/\sigma(rad)$ with Heracles 4.6

  $\Delta(\text{rad}) = 0.995 \pm 0.009$

★ **BS with missing photon**
lumi-γ acceptance $\sim$ 98% leads to 1% background of not-vetoed BS overlays

- Find # BS events in γp sample after all cuts except $E_\gamma < 1$ GeV
- Multiply by lumi-γ acceptance

  $\Delta(\gamma\text{acc}) \equiv 0.99 \pm 0.01$

★ **Bremsstrahlung Overlays (BSO)**
$E_\gamma < 1$ GeV cut removes genuine γp events if BSO

- Randomly triggered data give
  E_γ distribution for ep bunches

  $\Delta(\text{BSO}) = 1.043 \pm 0.002$

35m tagger acceptance method (1)

- 35m tagger acceptance depends sensitively on e^+-beam tilt
  $\Rightarrow$ Select kin region insensitive to e^+-beam tilts

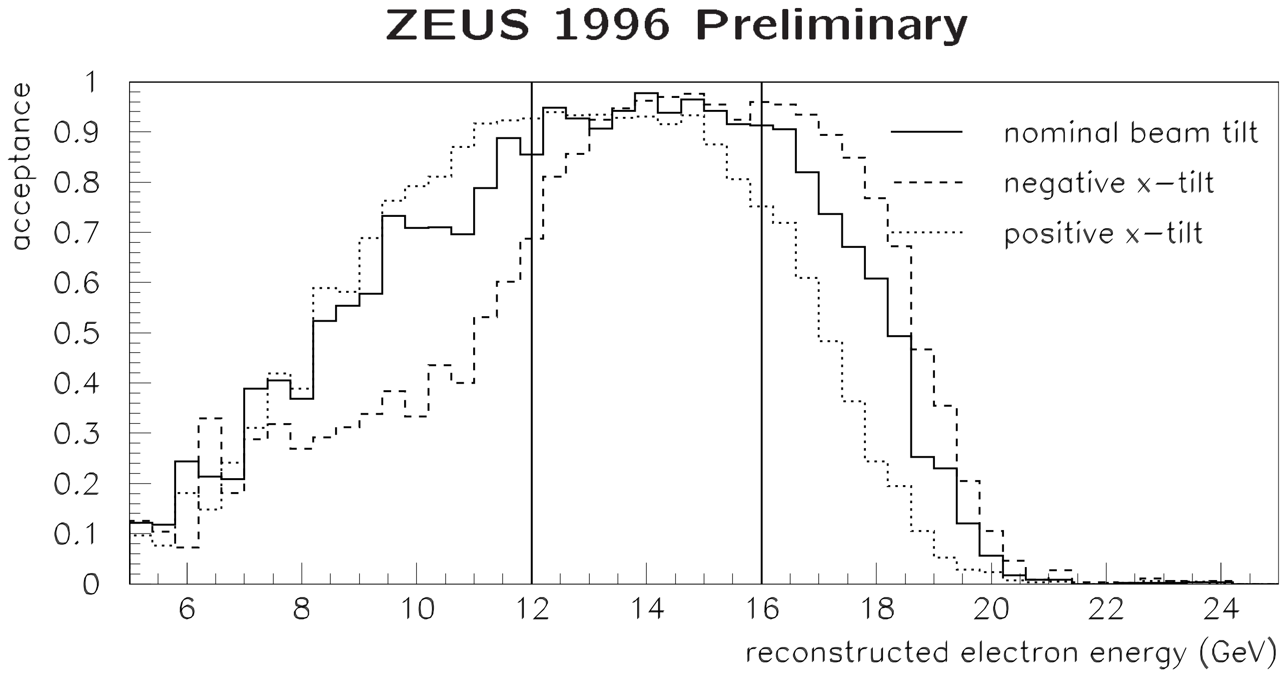
- Use BS data and MC to optimize beamline parameters
  $\Rightarrow$ x-tilt and x-vertex $\Leftarrow$
  Use three distributions, minimize χ^2
  - 35m tagger BS acceptance
  - lumi-γ energy distribution
  - $\langle x_e \rangle$ vs. E_e measured in 35m tagger

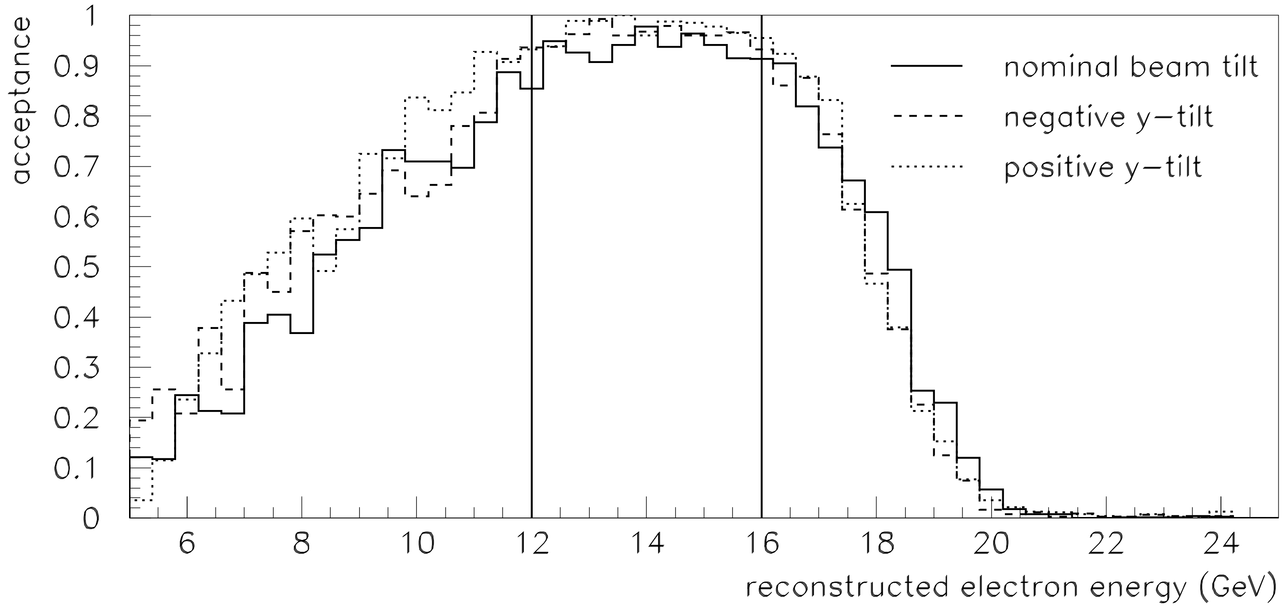
- Plug in optimized beamline parameters
  $\Rightarrow$ x-tilt and x-vertex $\Leftarrow$
  to γp MC (Heracles 4.6)

- Calculate 35m tagger acceptance for γp using γp MC

35m tagger acceptance method (2)

Bremsstrahlung e^+-beam tilt runs





$$\text{acceptance} \equiv \frac{(e \text{ in 35m) AND } (\gamma \text{ in lumi}-\gamma)}{\gamma \text{ in lumi}-\gamma}$$

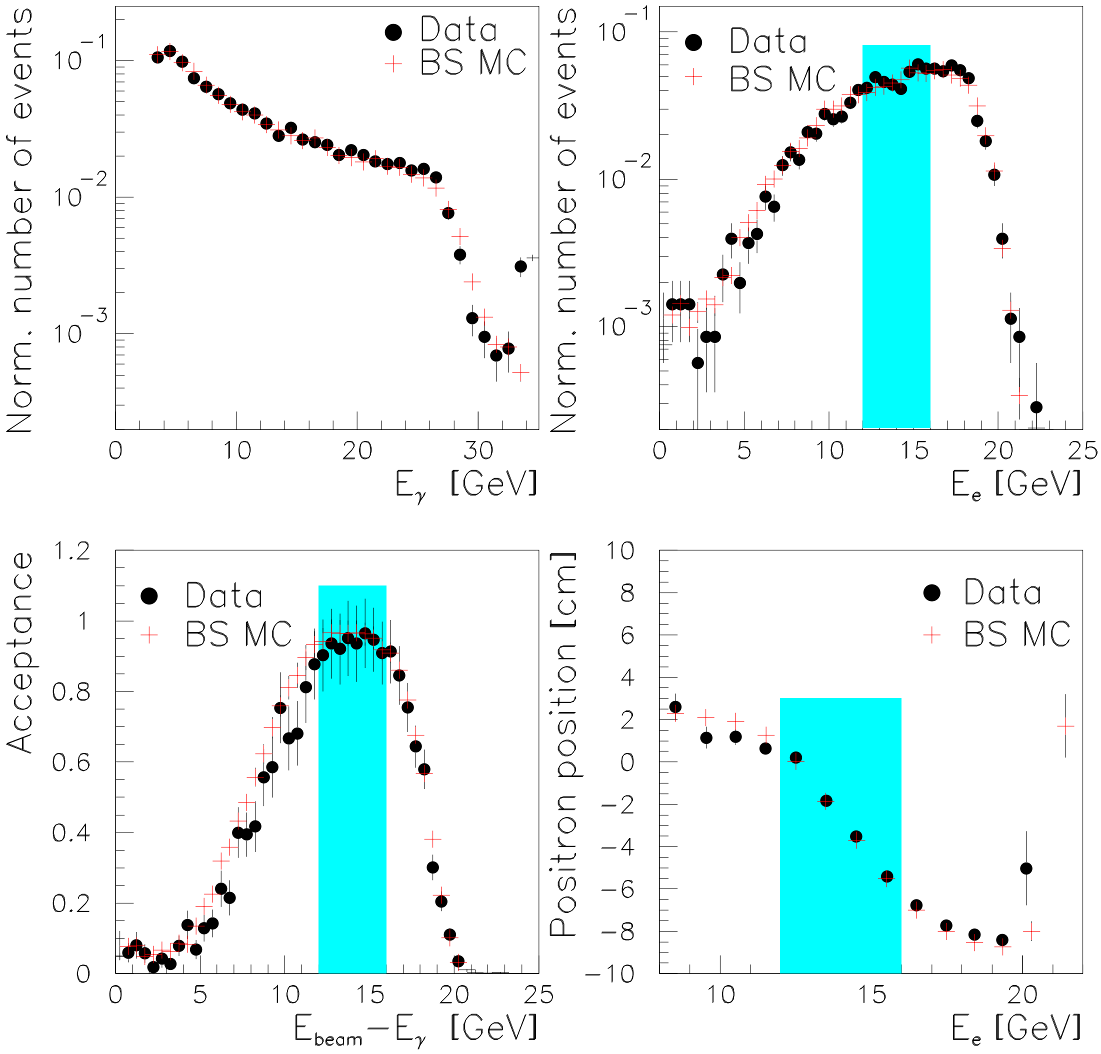
$$\text{reconstructed electron energy} \equiv E^e_{\text{beam}} - E_\gamma$$

★ Select 12-16 GeV best acceptance region

35m tagger acceptance method (3)

Compare optimized BS MC with data

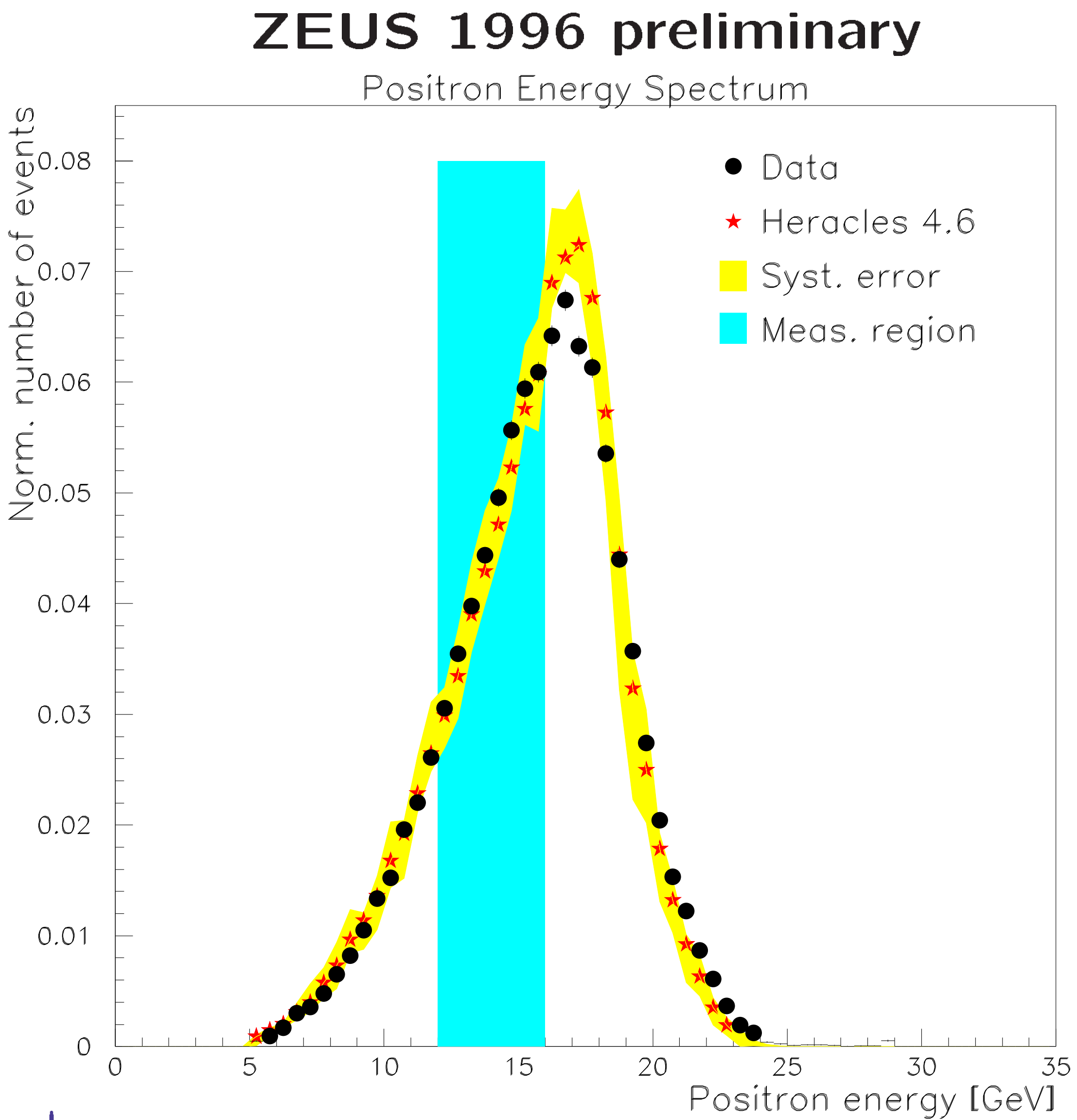
ZEUS 1996 preliminary



★ Good agreement for $12 < E_e < 16$ GeV

35m tagger acceptance method (4)

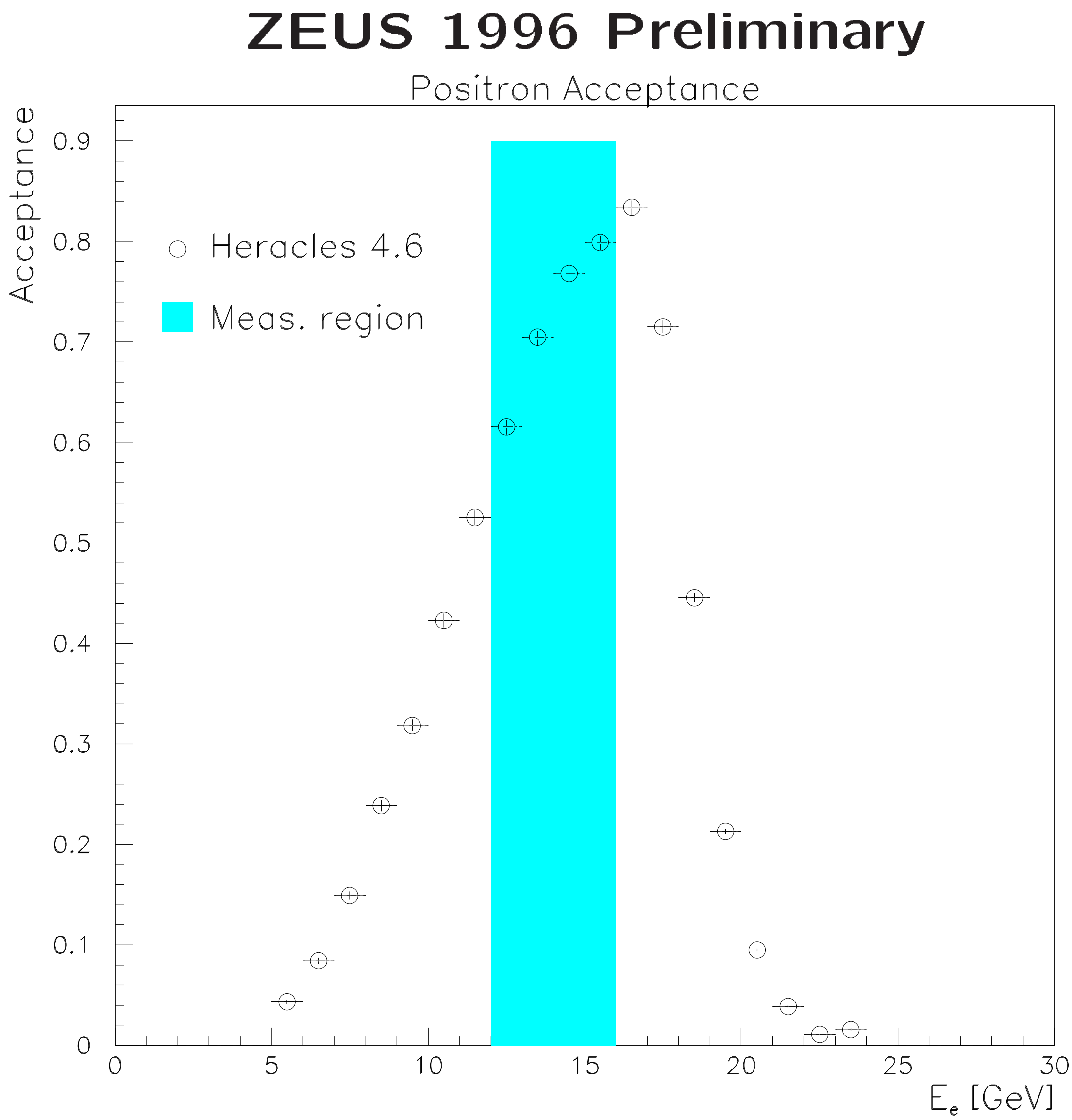
Compare optimized γp MC with data



★ Good agreement for $12 < E_e < 16$ GeV

35m tagger acceptance result

Acceptance calculated from γp MC



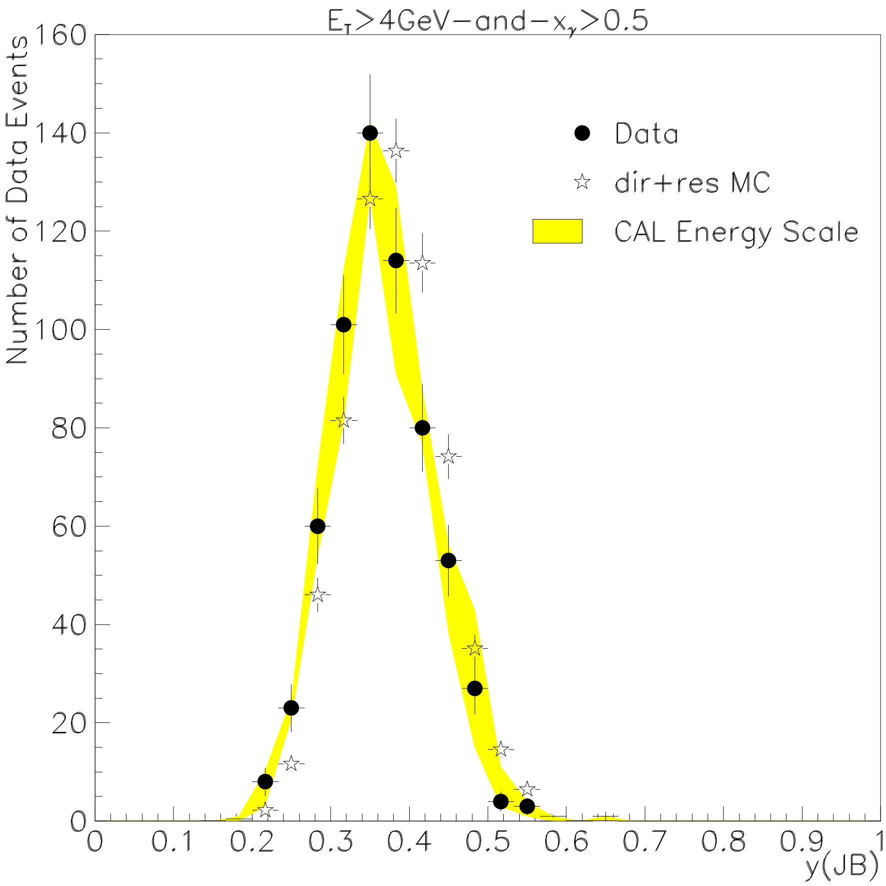
$$A(35\text{m}) = 0.731 \pm 0.050(\text{syst.})$$

$$\langle W_{\gamma p} \rangle = 207\ \text{GeV}$$

35m tagger acceptance check

Check method using independent dijet sample

ZEUS Preliminary 1996



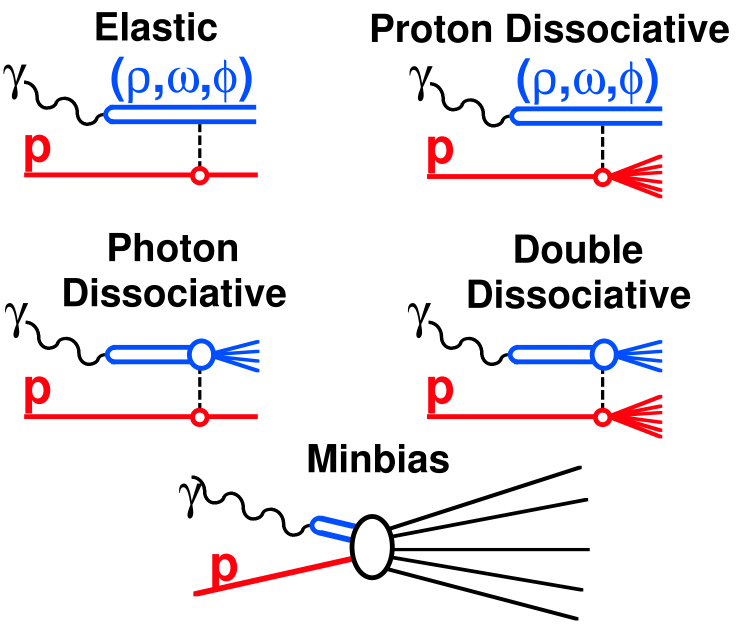
- select dijet events with "standard" dijet selection (CAL only, no 35m tagger requirement)
  + apply 35m and lumi-γ cuts
- Use standard dijet MC (Herwig 5.9 dir+res, no M.I.)
  + apply E_e weighting function from optimized γp MC
- data and MC agree
  Data/MC $= 0.945 \pm 0.053$(stat.) $\pm\, 0.023$(syst.)
  consistent with one

Note: y(JB) correlated with E_e
but depends only on dijet (CAL) reconstruction

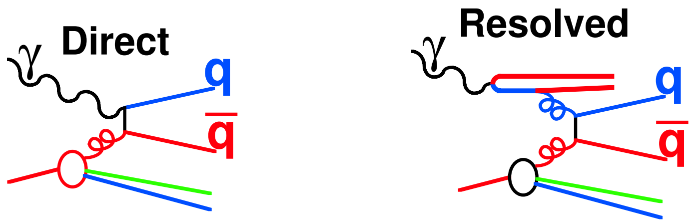
★ Assume γp described by seven basic subprocesses, modelled by Pythia 5.7 MC

Dominant processes

• Soft photoproduction via VDM



• Hard photoproduction



Measured/assumed:

elastic cross section
Phys.Lett.B377(96)259
Z.Phys.C69(95)39
Z.Phys.C73(96)73
p-diss to elastic ratio
Eur.Phys.J.C2(98)247
γ-diss fraction
Z.Phys.C75(97)421
factorization
$\sigma(W_{\gamma p})$ parametrized

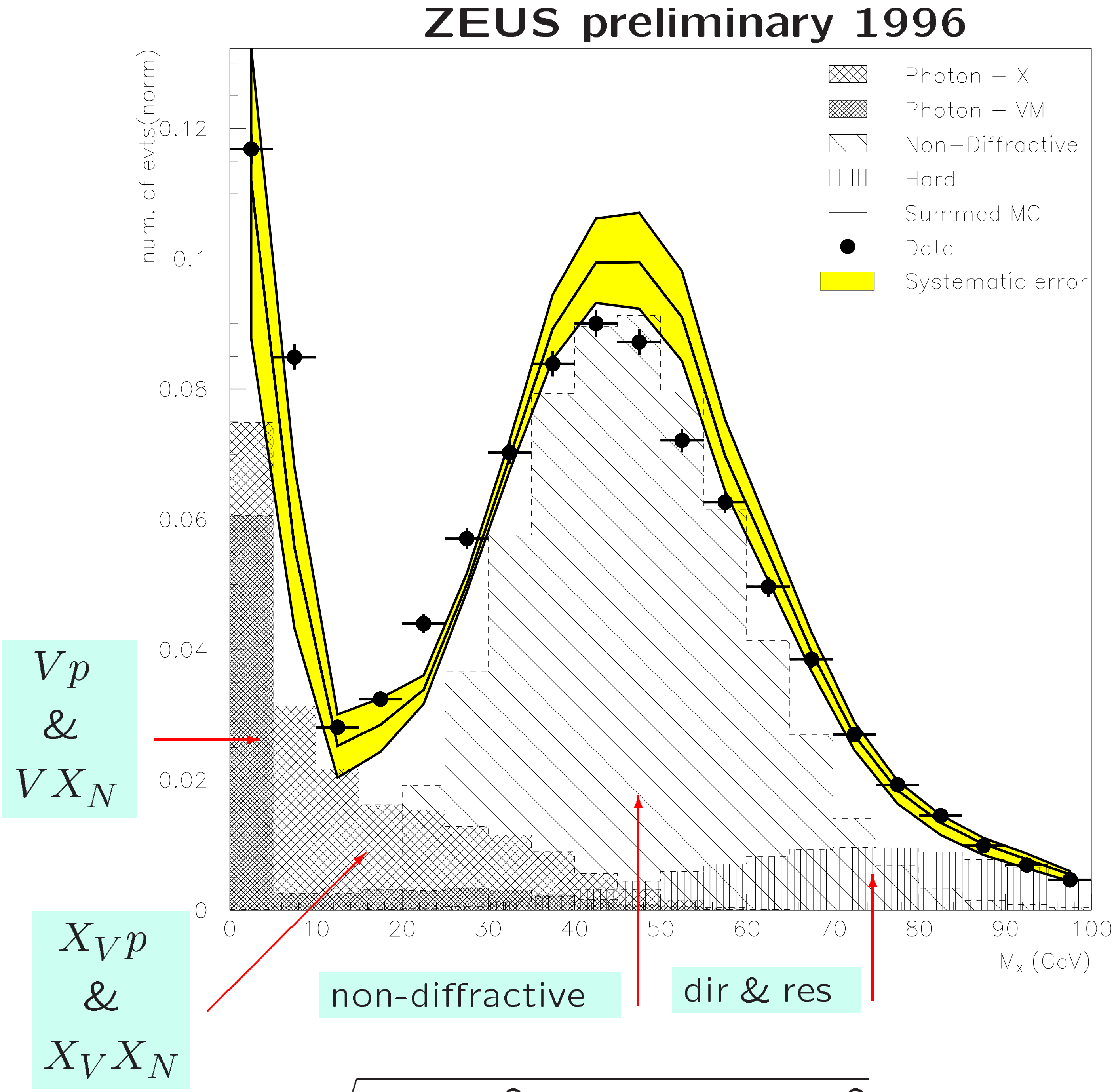
direct/resolved = 1/9
MC rept verified by data

★ Elastic and diss cross sections fixed
Fit kin dists for remaining subproc fractions:
minimum bias and direct+resolved

★ Calc CAL acceptance from MC subprocess acceptances and resulting fit fractions

CAL acceptance result

Fit kinematic distribution for subprocess fractions



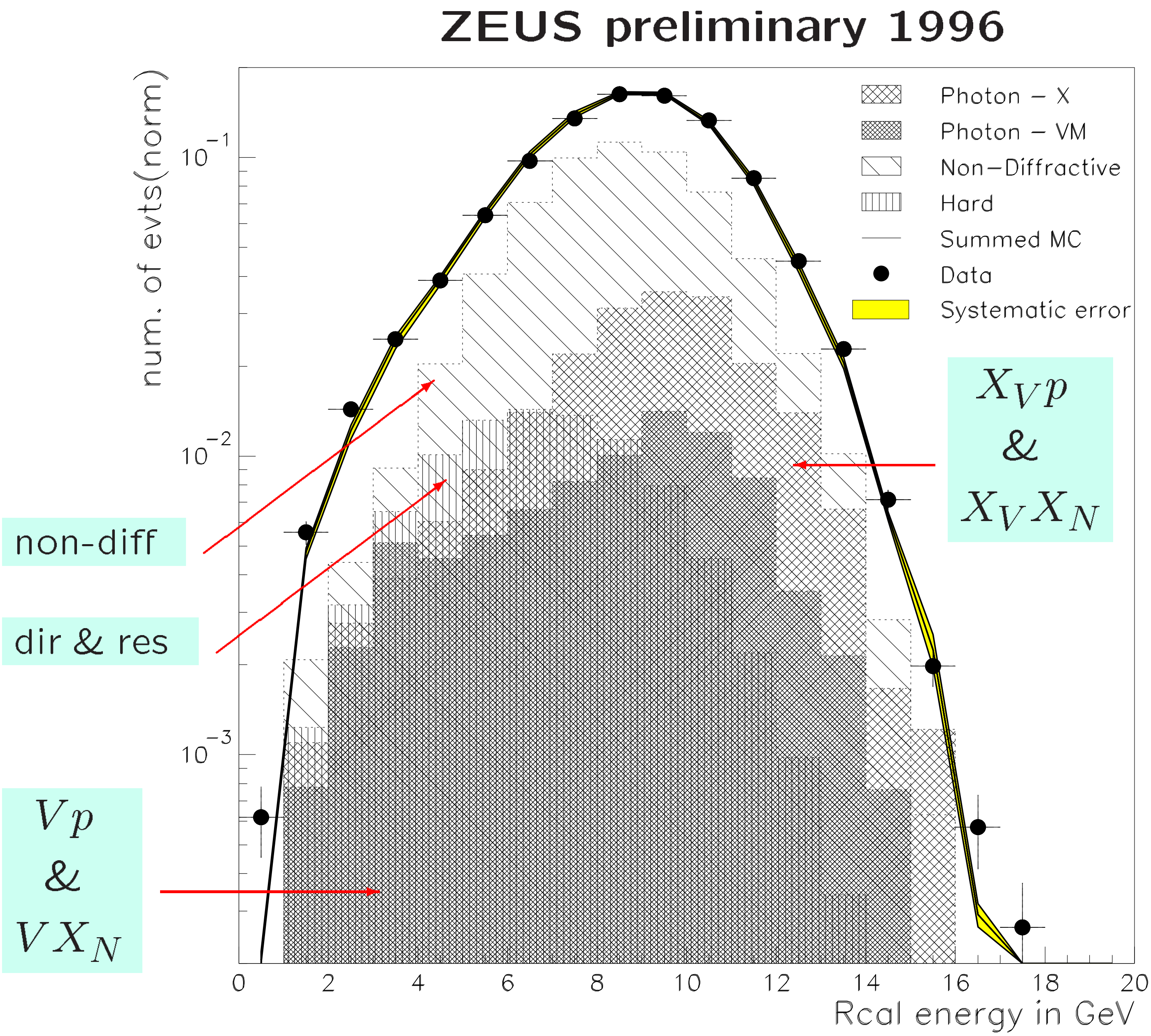
$$M_X \equiv \sqrt{(\sum_i E_i)^2 - (\sum_i E_i \cos\theta_i)^2}$$

★ Reasonable agreement data / summed MC

$$\mathrm{A(CAL)} = 0.760^{+0.041}_{-0.015}\ \mathrm{(syst.)}$$

CAL acceptance check

Check fitted fractions with RCAL energy dist



★ Subprocess fractions fit to M_X distribution

★ Resulting RCAL energy MC/data good agreement

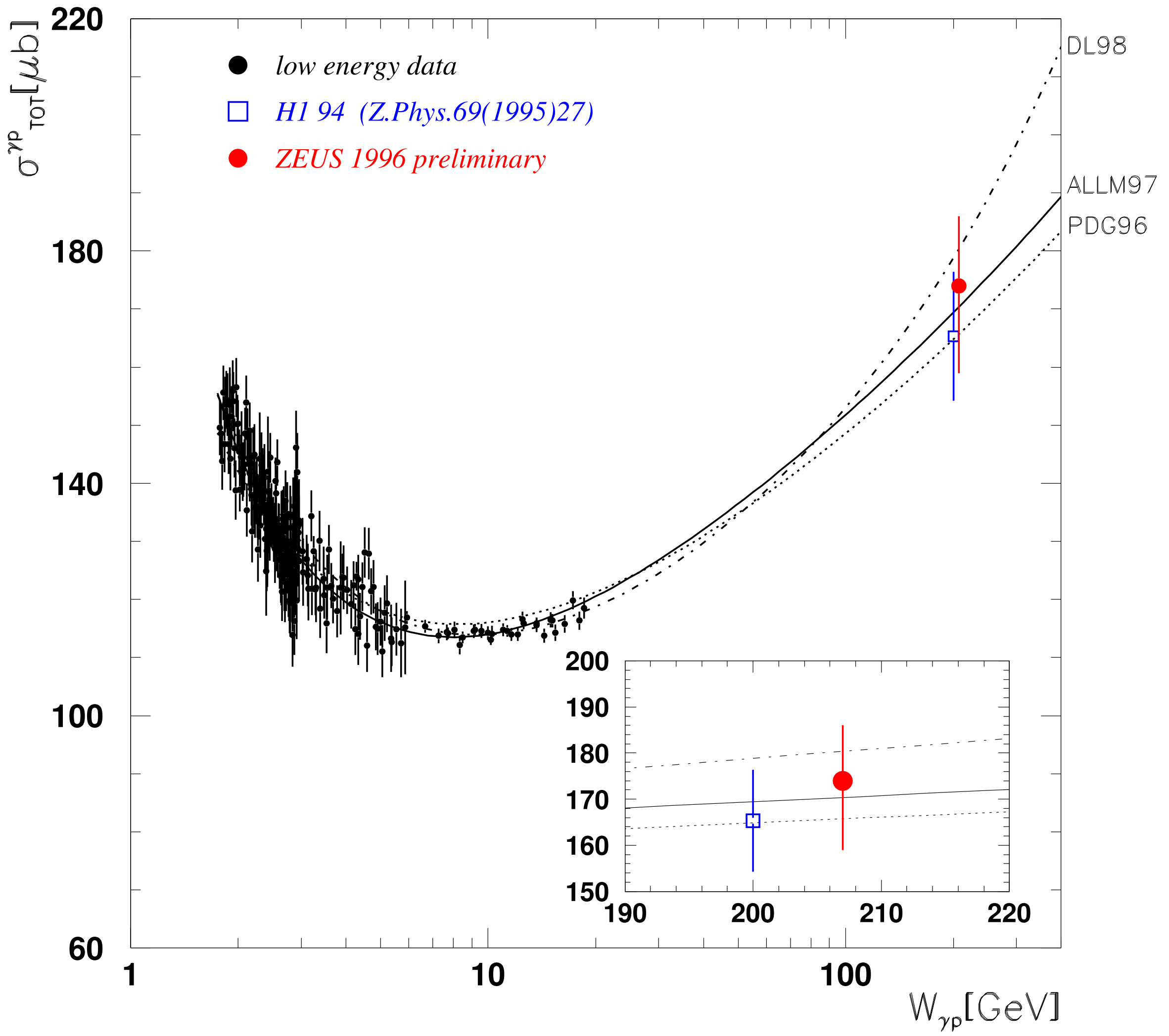
$\sigma^{\gamma p}_{TOT}$ preliminary results

$$\sigma^{\gamma p}_{TOT} = \frac{N}{\mathcal{L}} \frac{1}{f_\gamma} \frac{\Delta(\mathrm{RAD})\,\Delta(\gamma\mathrm{acc})\,\Delta(\mathrm{BSO})}{A(\mathrm{35m})\,A(\mathrm{CAL})}$$

Quantity	Value
N	$22392 \pm 162(\mathrm{stat.})$
$\mathcal{L}$ (nb)	$49.04 \pm 0.54(\mathrm{syst.})$
f_γ	0.004916
Δ_{RAD}	$0.995 \pm 0.007(\mathrm{syst.})$
$\Delta_{\gamma\mathrm{acc}}$	$0.99 \pm 0.01(\mathrm{syst.})$
Δ_{BSO}	$1.043 \pm 0.002(\mathrm{syst.})$
A_{35m}	$0.731 \pm 0.050(\mathrm{syst.})$
A_{CAL}	$0.760^{+0.041}_{-0.015}(\mathrm{syst.})$

$$\sigma^{\gamma p}_{TOT}(W_{\gamma p} = 207\mathrm{GeV}) = 172 \pm 1^{+13}_{-15}\ \mu b$$

$\sigma_{TOT}^{\gamma p}$ preliminary results



$$\sigma_{TOT}^{\gamma p}(W_{\gamma p} = 207\text{GeV}) = 172 \pm 1^{+13}_{-15}\ \mu b$$

$\sigma_{TOT}^{\gamma p}$ conclusions

★ Significant improvement of precision in ZEUS $\sigma_{TOT}^{\gamma p}$ measurement

★ Results consistent with world data

★ Results in agreement with universality of hadronic σ_{TOT} energy dependence