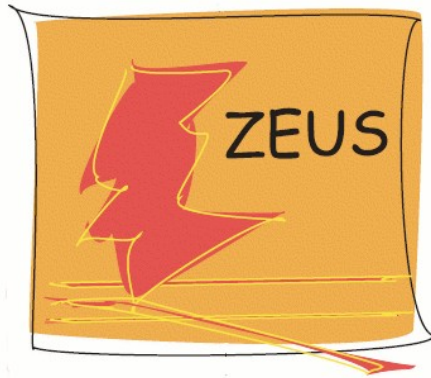


LOW X workshop

Santiago de Compostela, 3-7 June 2011

**Measurement of the energy dependence
of the total photon-proton cross section at HERA**



Vladimir Drugakov
NCPHEP and DESY

On behalf of the ZEUS collaboration

γp interaction

γ of high energy behave as hadron when interacting with other hadrons

$pp, \bar{p}p$ cross section

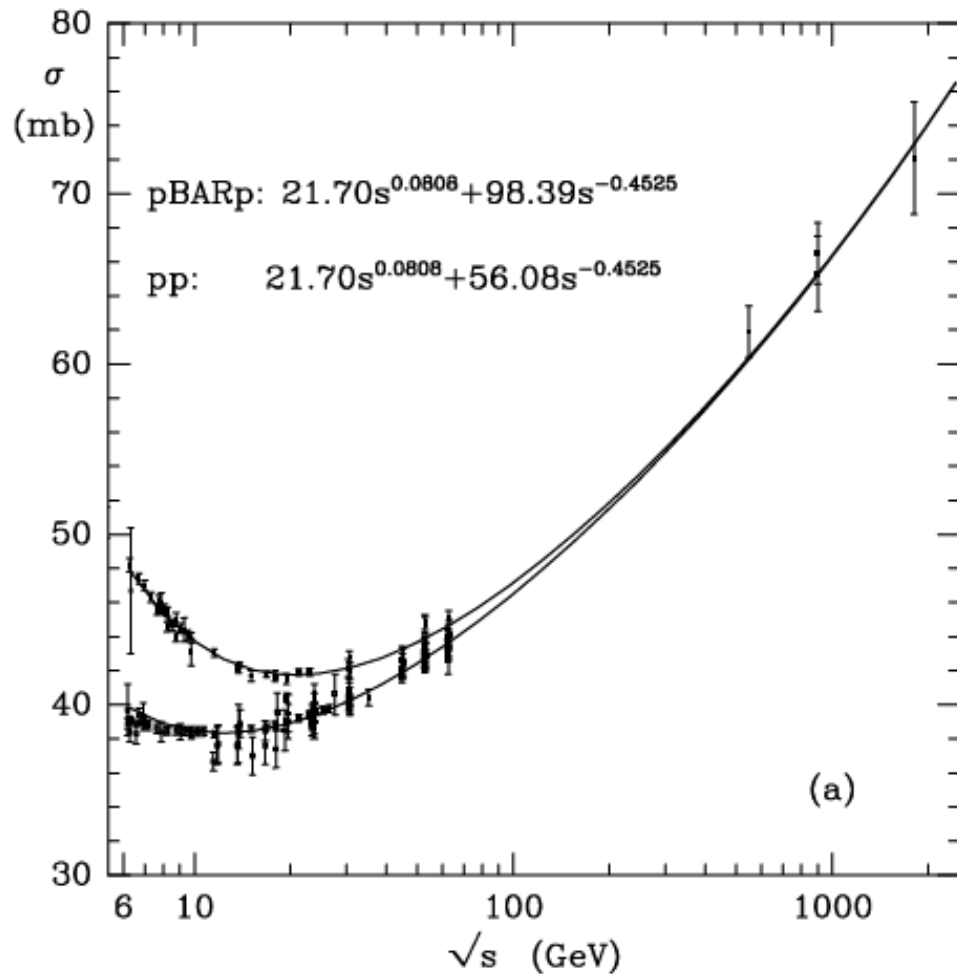


figure from *Phys. Lett. B* 296 (1992) 227

Donnachie, Landshoff:

universal behaviour of total hadron-hadron cross section

$$\sigma_{\text{tot}}(h-h) = A \cdot W^{2\epsilon} + B \cdot W^{-2\eta}$$

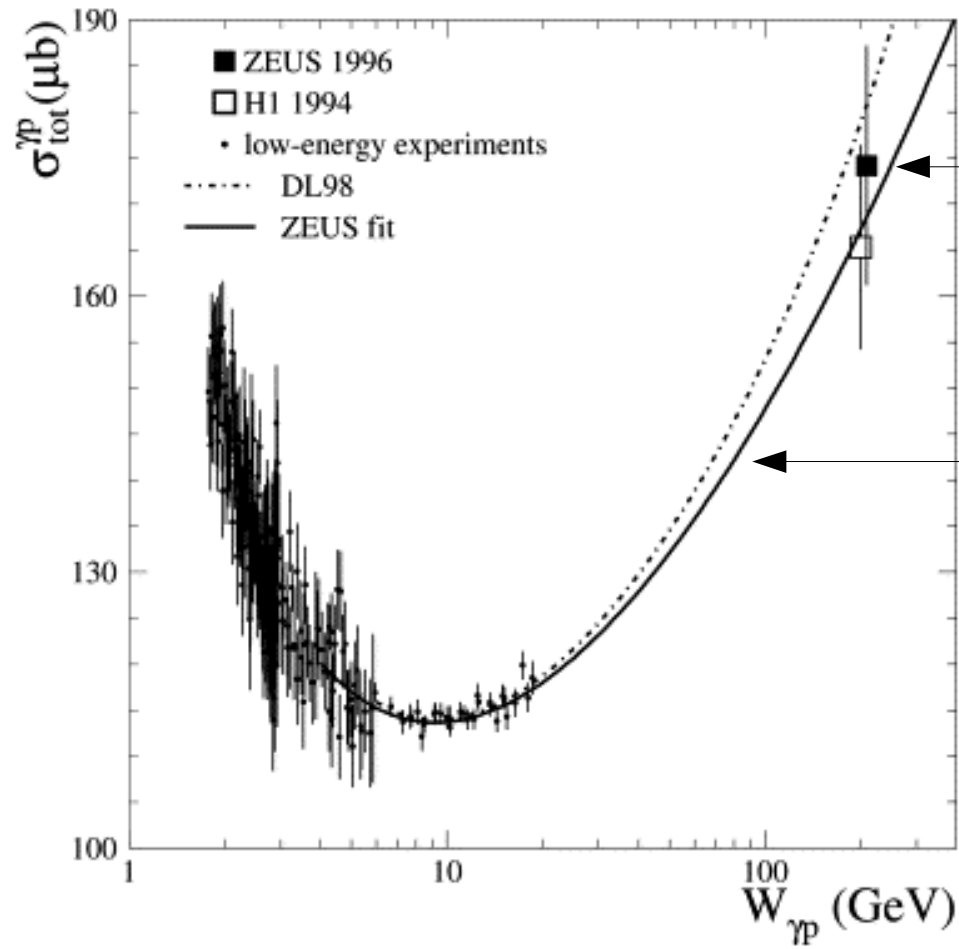
- W – $h-h$ center of mass energy
- A, B – process dependent constants
- ϵ, η – universal constants

↳ energy dependence of $\sigma_{\text{tot}}(\gamma p)$ is expected to be similar in form to σ_{tot} for $pp, \pi p, Kp$

γp interaction

$\sigma_{\text{tot}}(\gamma p)$ at high energies

γp cross section



HERA data:

- first $\sigma_{\text{tot}}(\gamma p)$ measurement at high energy

fit: $\sigma_{\text{tot}} = A \cdot W^{2\epsilon} + B \cdot W^{-2\eta}$

- combines data from many experiments

confirmed that $\sigma_{\text{tot}}(\gamma p)$ energy dependence is similar in form to $\sigma_{\text{tot}}(hh)$ one

figure from *Nucl. Phys. B* 627 (2002) 3

γp interaction

ϵ determination

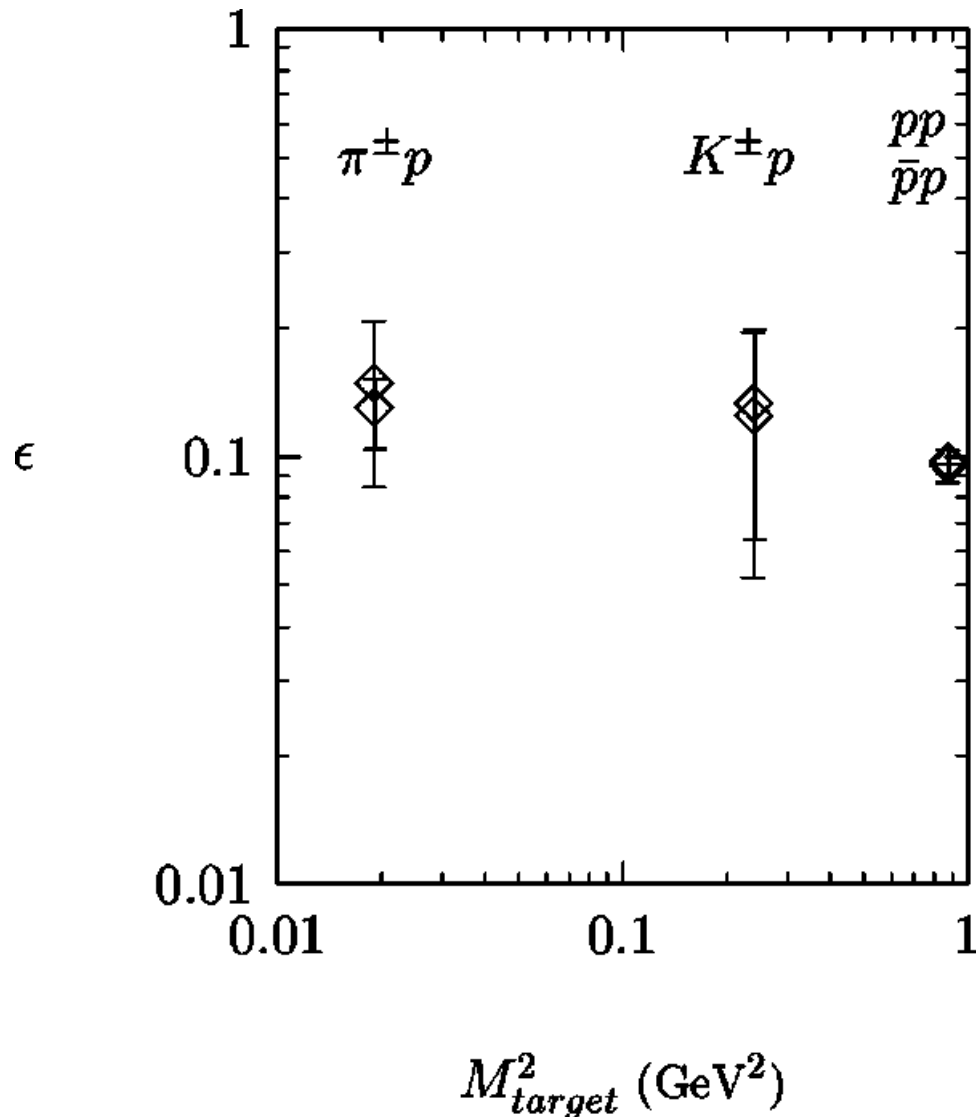


figure from *Phys. Rev. D* 61 (2000) 034019

Cudell et al.:

(*Phys. Rev. D* 61 (2000) 034019)

- $pp, \bar{p}p, \pi^\pm p, K^\pm p, \sqrt{s} \geq 9 \text{ GeV}$
- “some superseded points have been removed”

$$\epsilon = 0.093 \pm 0.003$$

“We have *not* included the γp data, as there is some uncertainty regarding these. They would lead to an intercept of order 0.075 with large error bars.”

measurement concept

$\sigma_{\text{tot}}(\gamma p)$ measured at HERA-I at one $W_{\gamma p}$

γp cross section

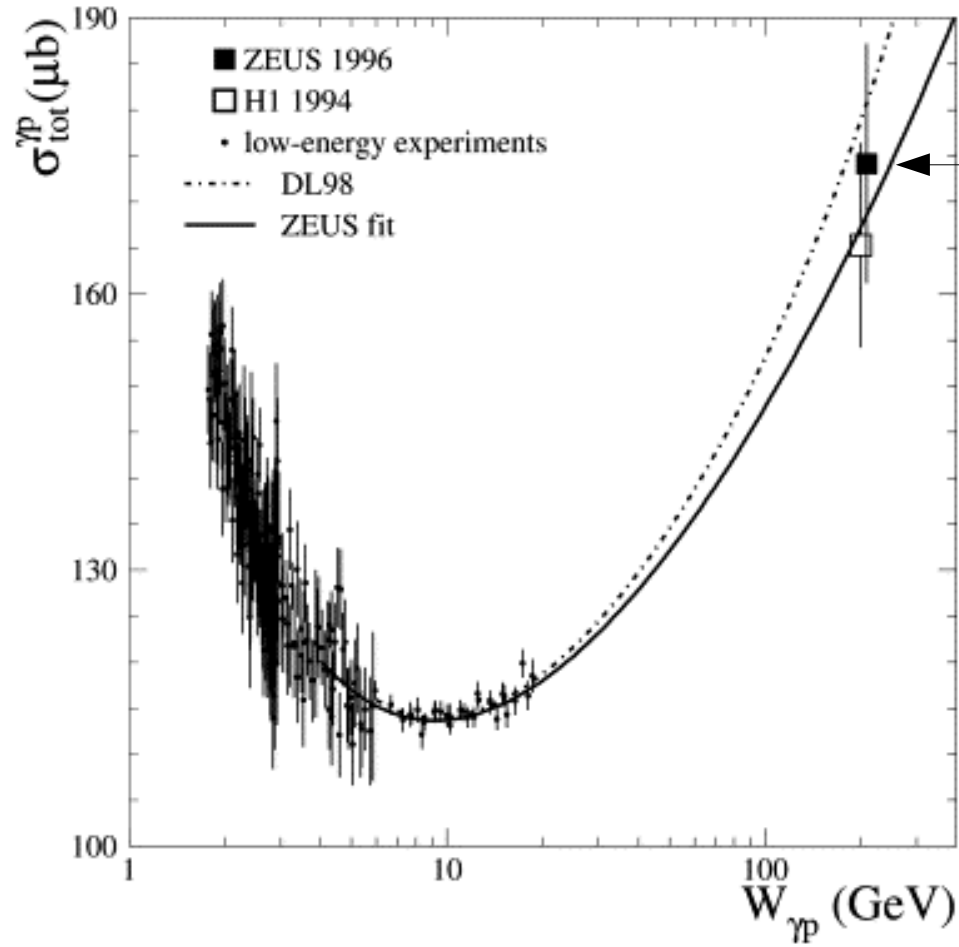


figure from *Nucl. Phys. B* 627 (2002) 3

HERA measurements:

- large systematic uncertainties
- ↳ want to reduce systematics

$$\sigma_{\text{tot}} = A \cdot W^{2\epsilon} + \cancel{B \cdot W^{-2\eta}}$$

- 2nd term is negligible at high energy

↳ ϵ can be extracted from σ_{tot} ratio:

$$R = \sigma(W_1) / \sigma(W_2) = (W_1/W_2)^{2\epsilon}$$

- any uncertainty correlated for different $W_{\gamma p}$ largely cancel

measurement concept

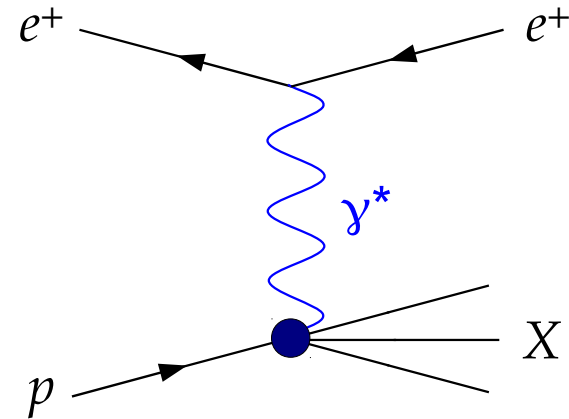
HERA-II data: 3 $W_{\gamma p}$ points with different proton energy E_p
460 GeV (LER), 575 GeV (MER), 920 GeV (HER)

$\sigma_{\text{tot}}(\gamma p)$ was measured in process $e^+p \rightarrow e^+\gamma^*p \rightarrow e^+X$ at $Q^2 \leq 10^{-3} \text{ GeV}^2$

Relation $\sigma(\gamma p) \leftrightarrow \sigma(e^+p)$:

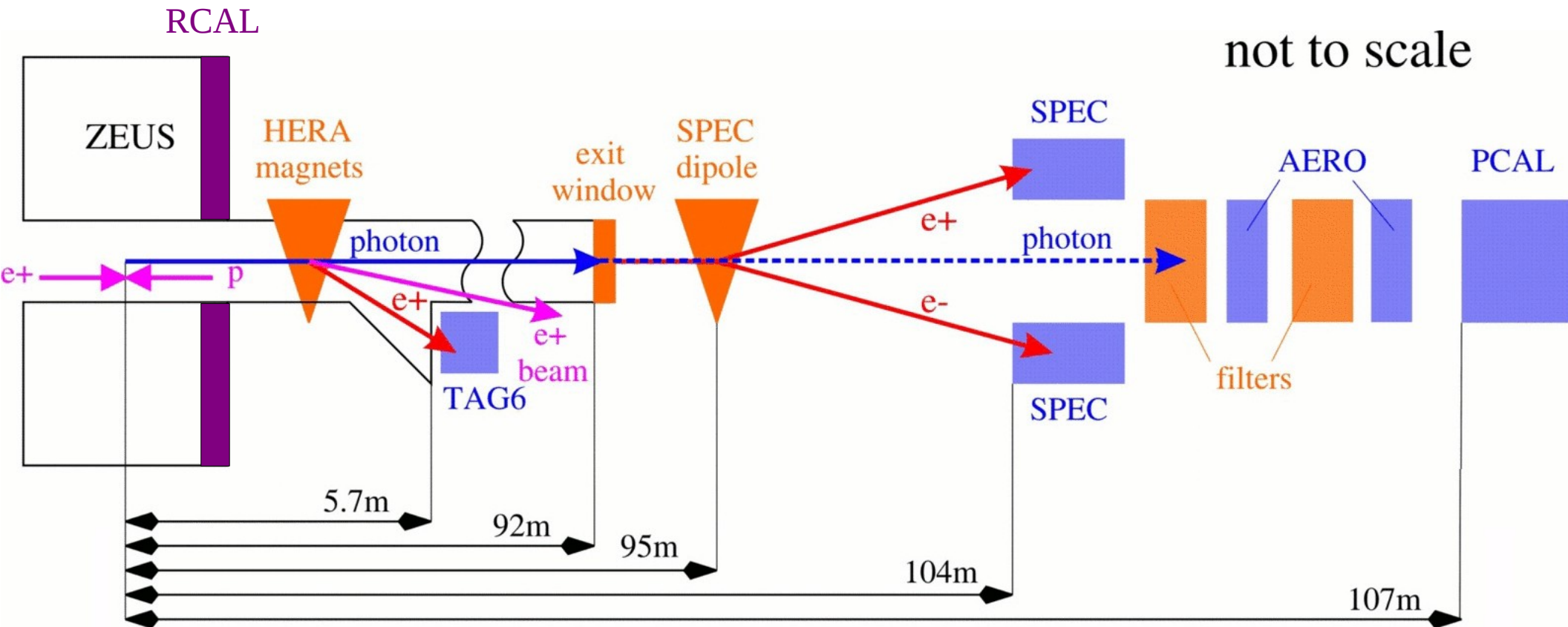
$$\frac{d^2\sigma^{ep}(y, Q^2)}{dy dQ^2} = \phi(y, Q^2)\sigma^{\gamma p}(y, Q^2)$$

- ϕ – doubly differential photon flux



↳ $\sigma_{\text{tot}}(\gamma p)$ can be extracted from $\sigma_{\text{tot}}(e^+p)$:

layout of ZEUS and luminosity systems



event signature

- 1) activity in the *RCAL*
- 2) e^+ hit in *TAG6*

- *TAG6* energy range: 3.8–7.1 GeV

PCAL

veto bremsstrahlung process:
 $e^+p \rightarrow e^+\gamma p$

SPEC

calibrate *TAG6*

from $\sigma(e^+p)$ to $\sigma(\gamma p)$

$$\frac{d^2\sigma^{ep}(y, Q^2)}{dy dQ^2} = \phi(y, Q^2)\sigma^{\gamma p}(y, Q^2)$$

$$\hookrightarrow \sigma_{\text{tot}}(e^+p) = F_\gamma \cdot \sigma_{\text{tot}}(\gamma p)$$

- photon flux $F_\gamma = \int \phi(y, Q^2)$ was measured for each $W_{\gamma p}$
- $\sigma(\gamma p)$ variation over measurement range for each $W_{\gamma p}$ is small; assumed to be constant

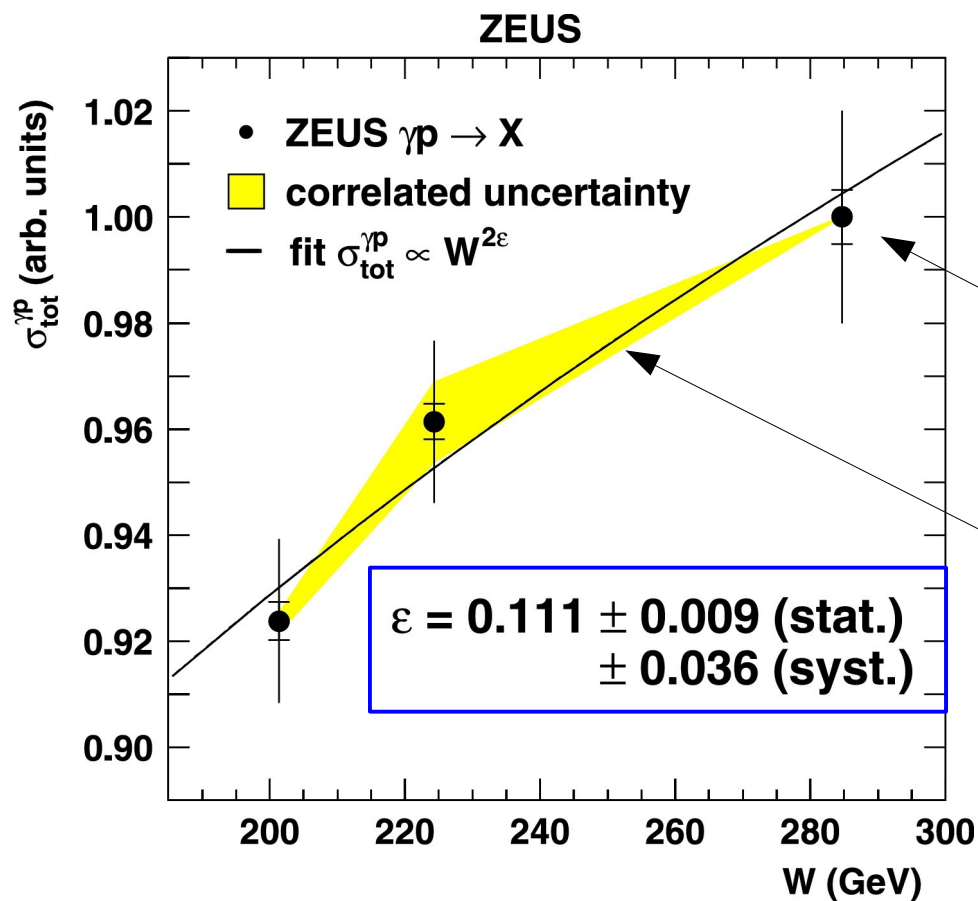
experimentally:

$$\sigma_{\text{tot}}^{\gamma p} = \frac{N}{\mathcal{L} \cdot F_\gamma^{\text{TAG6}} \cdot A_{\text{RCAL}}}$$

- A_{RCAL} is acceptance of the hadronic final state for tagged events
- A_{RCAL} is the same at different $W_{\gamma p}$ since E_e is the same; checked with *PYTHIA*

W dependence of $\sigma_{\text{tot}}(\gamma p)$

<i>data set</i>	$E_p(\text{GeV})$	$E_e(\text{GeV})$	$L(\text{nb}^{-1})$	$W_{\gamma p}(\text{GeV})$
<i>Low energy run (LER)</i>	460	27.50	912	194 – 209
<i>Medium energy run (MER)</i>	575	27.52	949	216 – 233
<i>High energy run (HER)</i>	920	27.61	567	274 – 296



$$R = \sigma_i / \sigma_{\text{HER}}$$

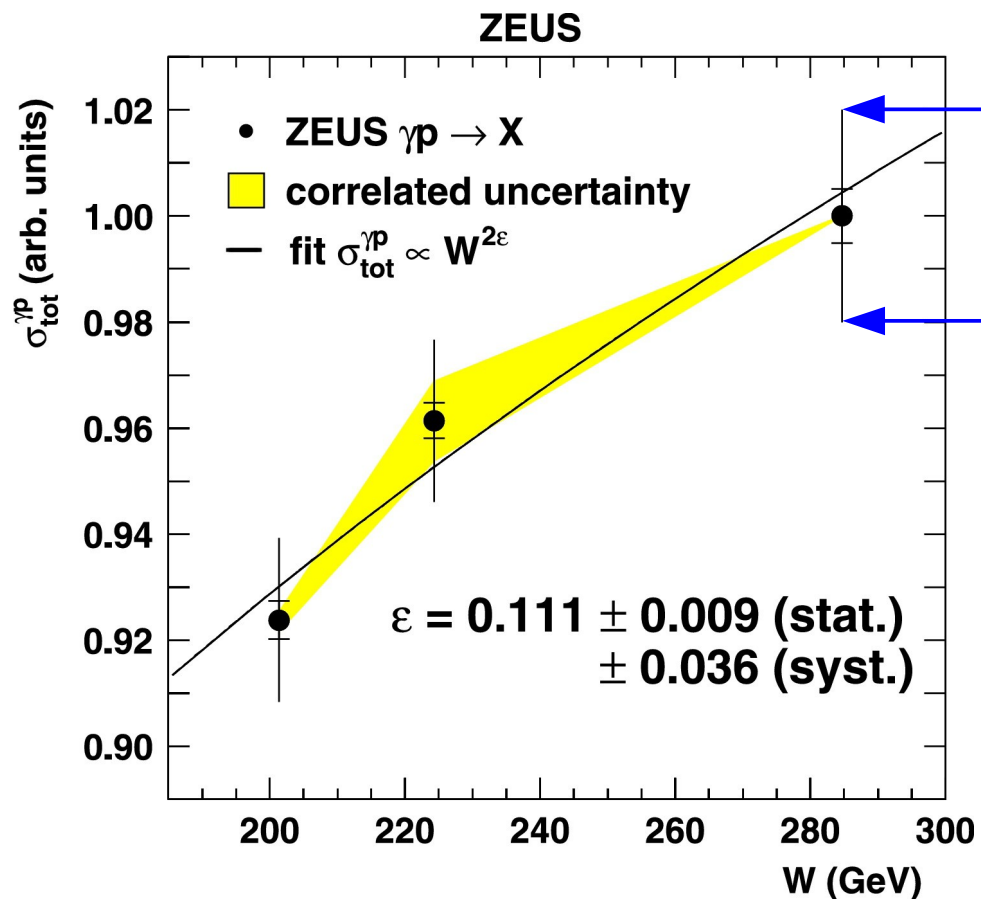
$$= (N_i / N_{\text{HER}}) \cdot (L_{\text{HER}} / L_i) \cdot (F_{\text{HER}} / F_i)$$

σ_{HER} is normalized to 1

fit $\sigma_{\text{tot}}(\gamma p) \propto W^{2\epsilon}$

systematic uncertainties

$$R = \sigma_i / \sigma_{HER}$$
$$= (N_i / N_{HER}) \cdot (L_{HER} / L_i) \cdot (F_{HER} / F_i)$$



- any uncertainty correlated for all three E_p largely cancel

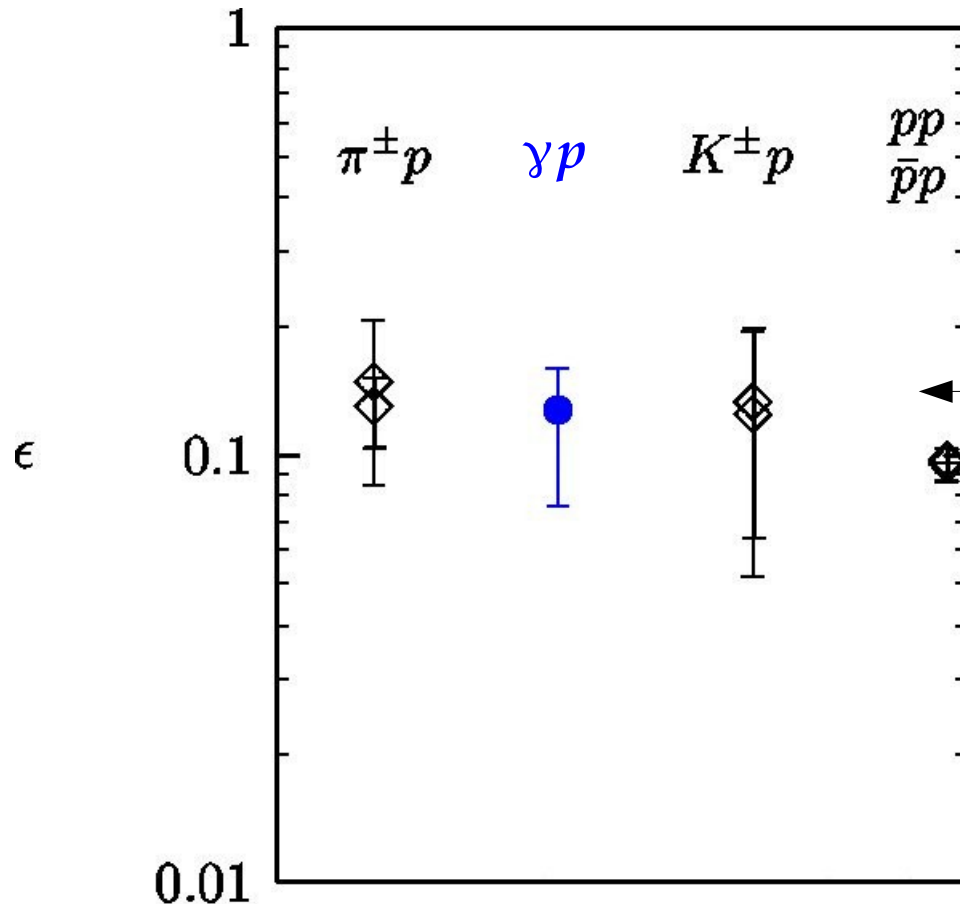
largest uncorrelated systematics:

- statistical uncertainties from event samples used for flux determination (1.1%)
- TAG6 positron energy ranges (1.1%)
- relative luminosity uncertainty between different running periods (1%)

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$$\epsilon = 0.111 \pm 0.009(\text{stat.}) \pm 0.036(\text{syst.})$$

- first determination of the high energy dependence of $\sigma_{\text{tot}}(\gamma p)$ from a single experiment



good agreement with results of hadronic cross section analysis