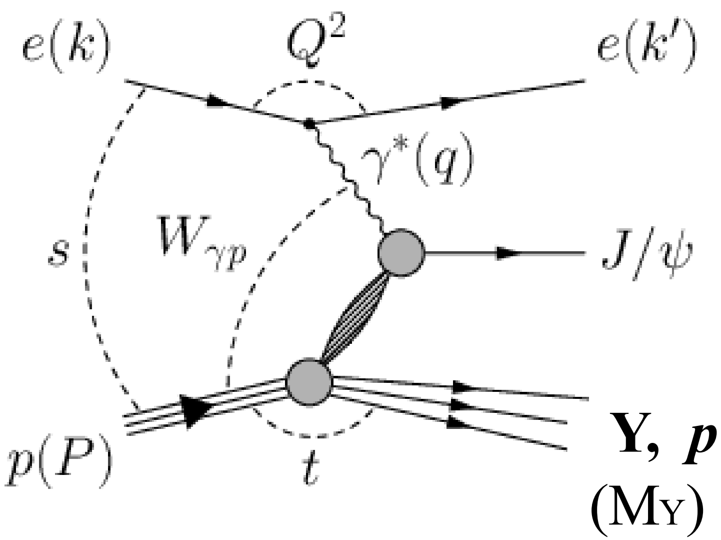
Elastic and Proton Dissociative Photoproduction of J/ψ Mesons at HERA

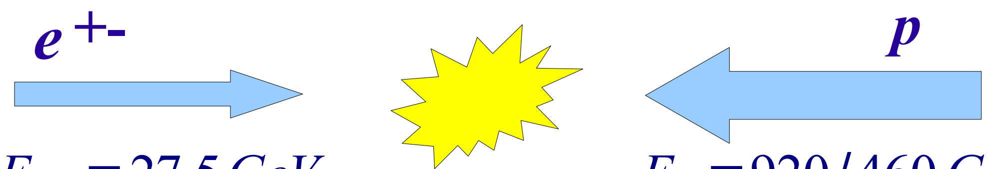
Nelly Gogitidze

LPI, Moscow & DESY, Hamburg

on behalf of the H1 Collaboration

HERA as $\gamma^* p$ Collider





$E_{e^{+-}} = 27.5\,GeV$

$E_p = 920/460\,GeV$

$\sqrt{s} = 318\,GeV$ 2006–2007

$\sqrt{s} = 225\,GeV$ 2007

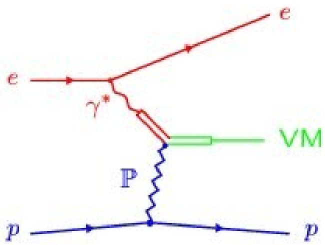
- Q^2 : Photon Virtuality
- s : Squared CM Energy of *ep* system
- $W_{\gamma p}$: CM Energy of γp system
- t : (4-mom. Transfer)^2 at proton vtx.

HERA makes it possible, within a single experiment, to study diffractive vector meson production over a large $W_{\gamma p}$ interval with a wide range of several scales:

$$Q^2, t, M_V$$ (Vector Meson Mass)

Expectations for Diffractive Vector Meson Production

- Regge Approach



Soft Pomeron exchange

$$\alpha_P(t) = \alpha_0 + \alpha' t$$

$$\alpha_0 = 1.08, \alpha' = 0.25\, GeV^{-2} \quad \text{(DL)}$$

$$\frac{d\sigma}{dt} \propto e^{bt} \left(\frac{W_{\gamma p}}{W_0} \right)^{\delta} \qquad \delta = 4(\alpha_0 - 1)$$

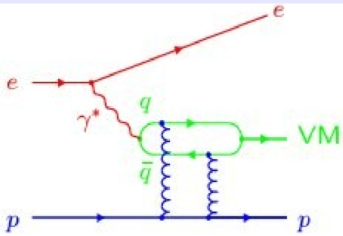
$$b = b_0 + 4\alpha' \ln \left(\frac{W_{\gamma p}}{W_0} \right)$$

For light VM at $Q^2 \approx 0, t \approx 0$ expect

Slow rise of $\sigma \propto W_{\gamma p}^{0.22 \ldots 0.32}$

Shrinkage $b = b(W_{\gamma p})$

- pQCD Approach



Exchange of ≥ 2 gluons

1. Photon fluctuates into $q\bar{q}$ dipole
2. Dipole proton interaction through a gluon ladder
3. $q\bar{q}$ recombines into VM

$$\sigma \propto [x g(x, Q^2)]^2$$

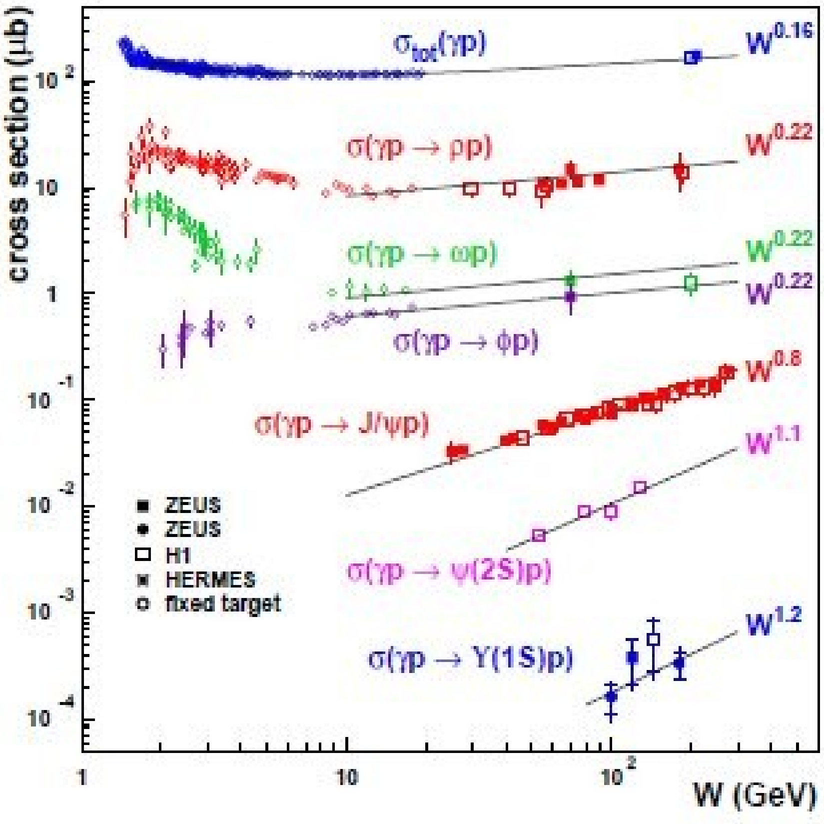
Expected to work if hard scale present

Steep rise with increasing $W_{\gamma p}$ due to gluon density increase at low x

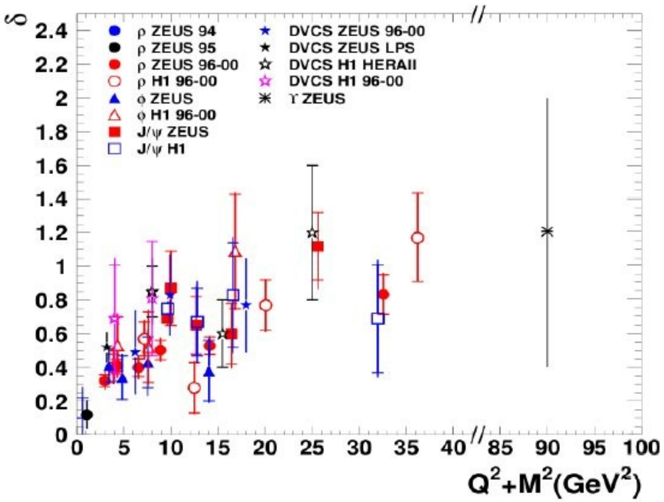
No shrinkage

Photoproduction $\gamma\, p \rightarrow V\, p$

$\sigma(\gamma\, p \rightarrow V\, p)\, vs\, W_{\gamma\, p}$



- Energy dependence $\sigma \sim W^{\delta}$
- Low mass $(\rho, \omega, \phi, M_V^2 \simeq 1\, GeV^2)$:
  no perturbative scale
  ==> weak energy dependence
  (soft regime)
- High mass $(J/\psi, \psi', \Upsilon)$:
  perturbative scale
  ==> strong energy dependence
  (hard regime, large M^2 or Q^2)

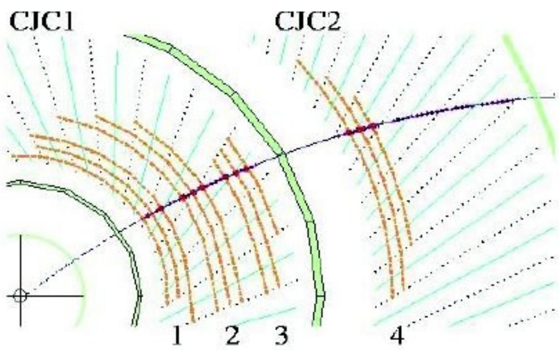


VM production at HERA:
transition between soft and hard regimes

Motivation and Experimental Technique

- New H1 analysis [arXiv:1304.5162]
- Extend energy range to lower $W_{\gamma p}$

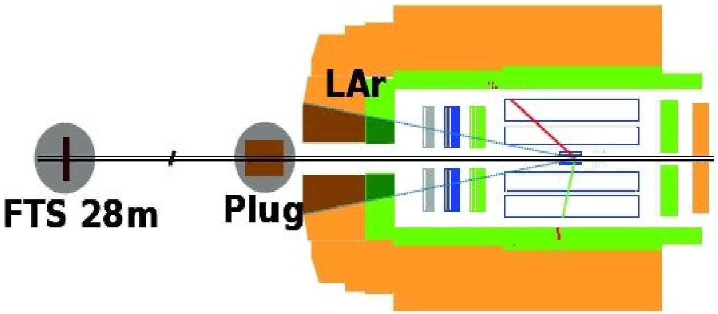
  Use data from HERA low energy run, $E_p = 460\,GeV$



- Use Fast Track Trigger (FTT)

  * purely based on track information
  * trigger both decay channels: $J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$
  * measure elastic and p-diss. processes with the same trigger

- Use forward detectors FTS, Plug, LAr to tag p-diss. process



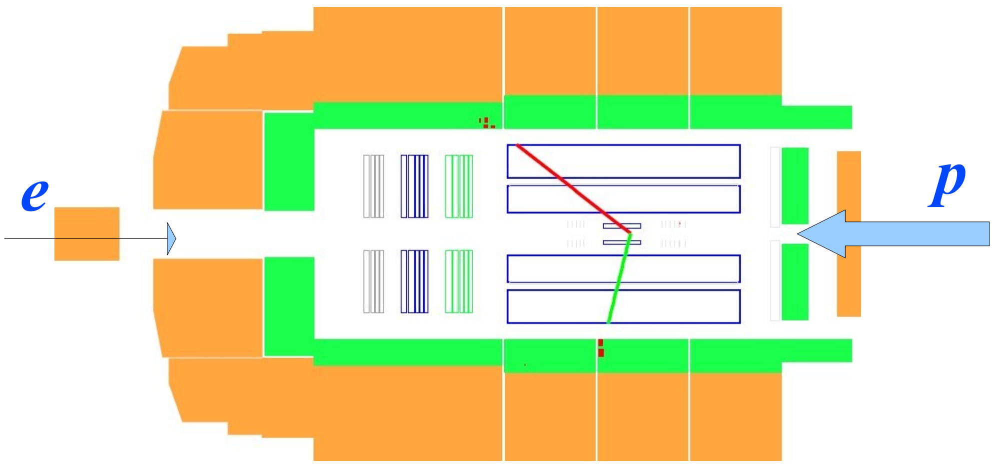
- Measure proton dissociation precisely at low |t| values :

  use Regularised Unfolding technique to disentangle elastic and p-diss. processes

Analysis Data Sets

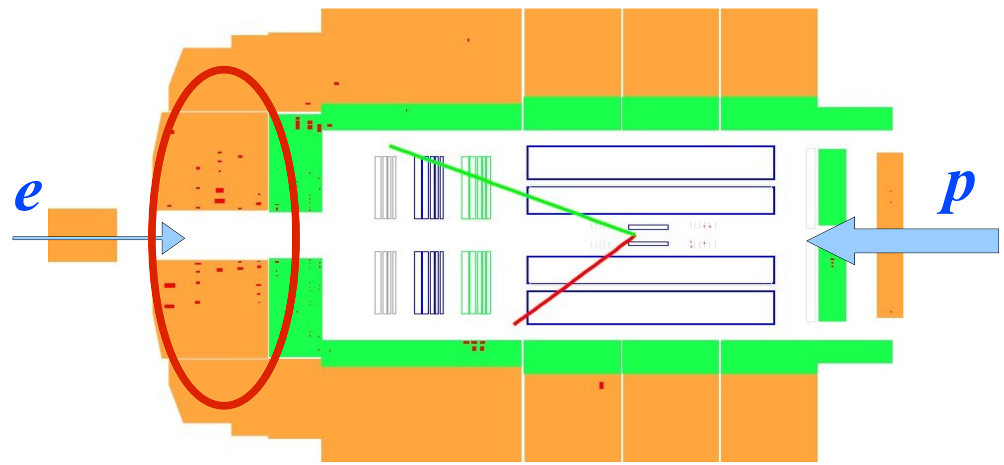
Data Set	E_p	Process	M_Y	Q^2	|t|	$W_{\gamma p}$	L
HE	920 GeV	*elastic* *p−diss*	m_p $m_p - 10\,GeV$	$< 2.5\,GeV^2$	$< 8\,GeV^2$	$40 - 110\,GeV$	$130\,pb^{-1}$
LE	460 GeV	*elastic* *p−diss*	m_p $m_p - 10\,GeV$	$< 2.5\,GeV^2$	$< 8\,GeV^2$	$25 - 80\,GeV$	$11\,pb^{-1}$

Elastic process



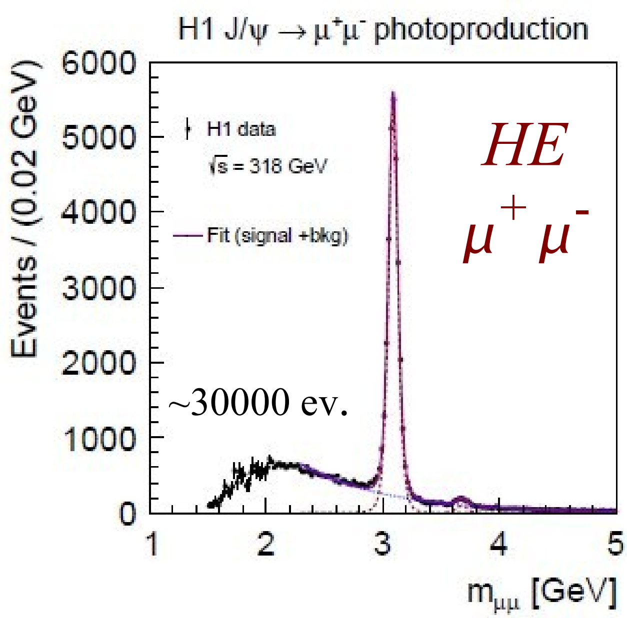
$M_Y = m_p$

Proton dissociation process



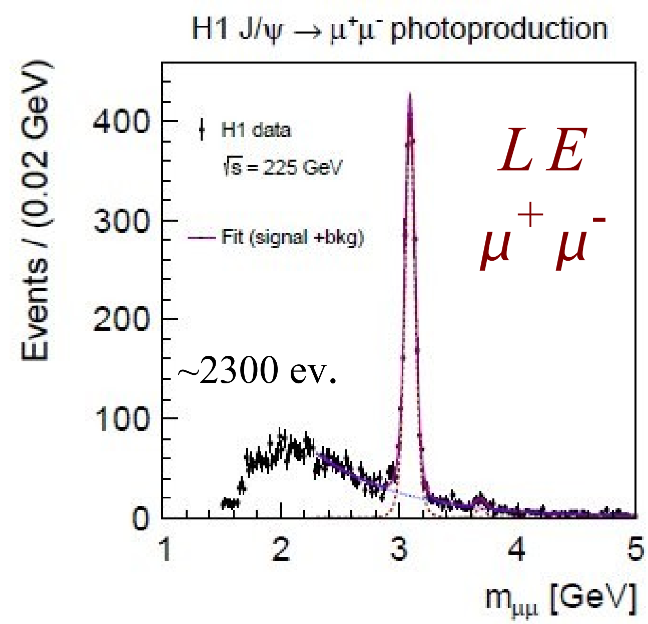
$m_p < M_Y < 10\,GeV$

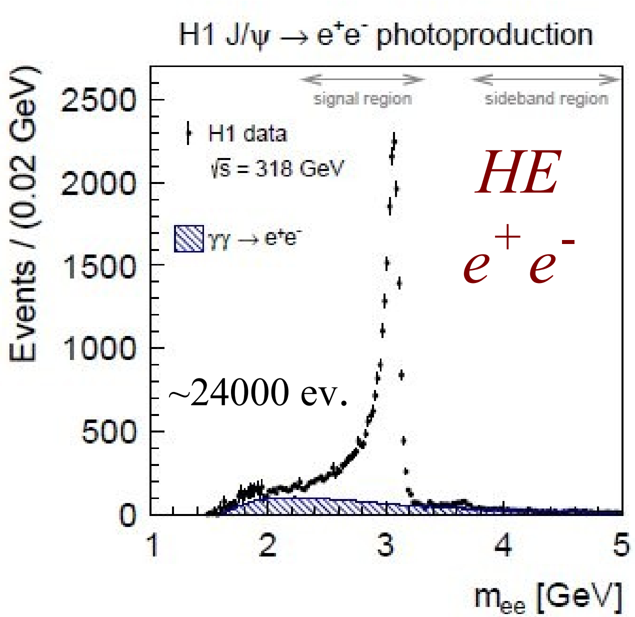
Invariant Mass Distributions



$J/\psi \rightarrow \mu^{+}\mu^{-}$

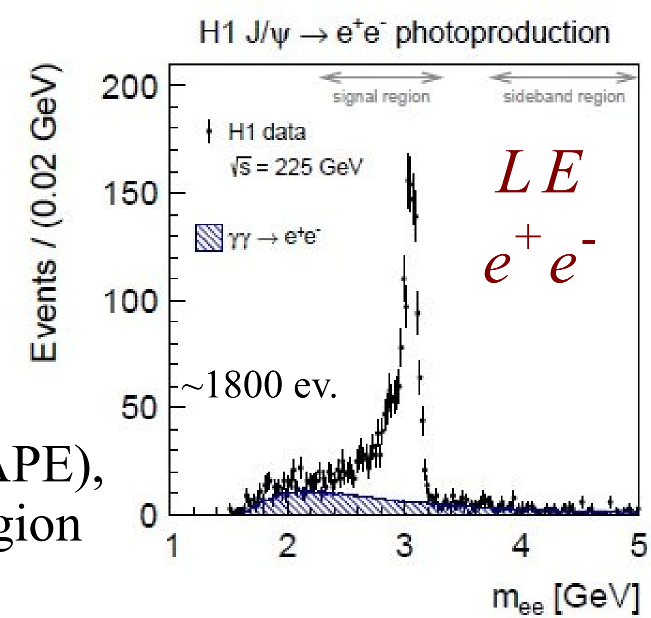
- Student's t-function for signal description
- exponential distribution for non-resonant background





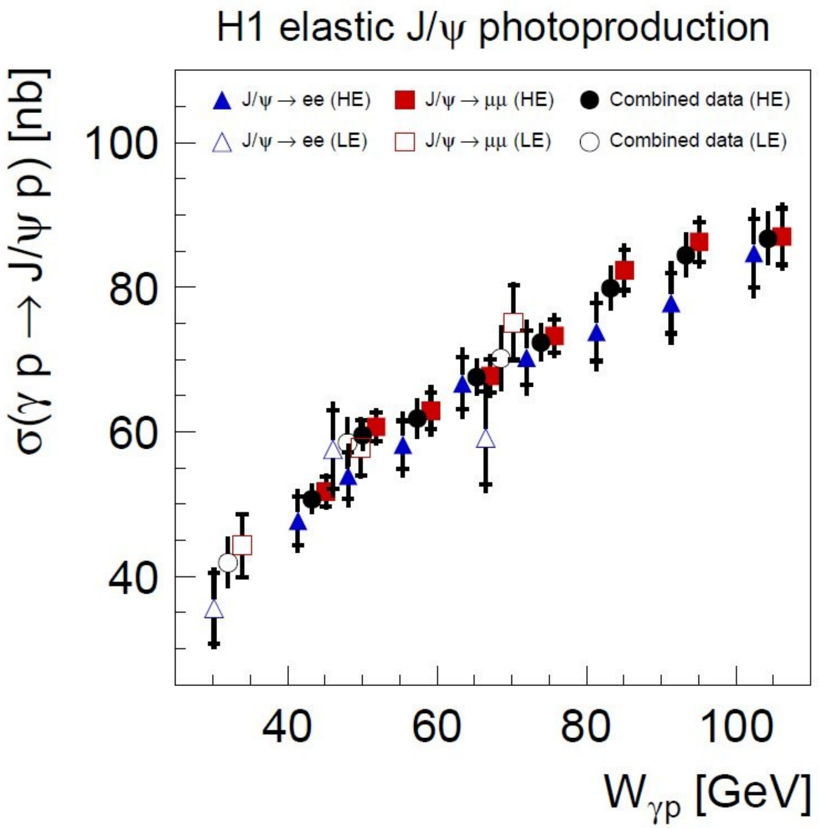
$J/\psi \rightarrow e^{+}e^{-}$

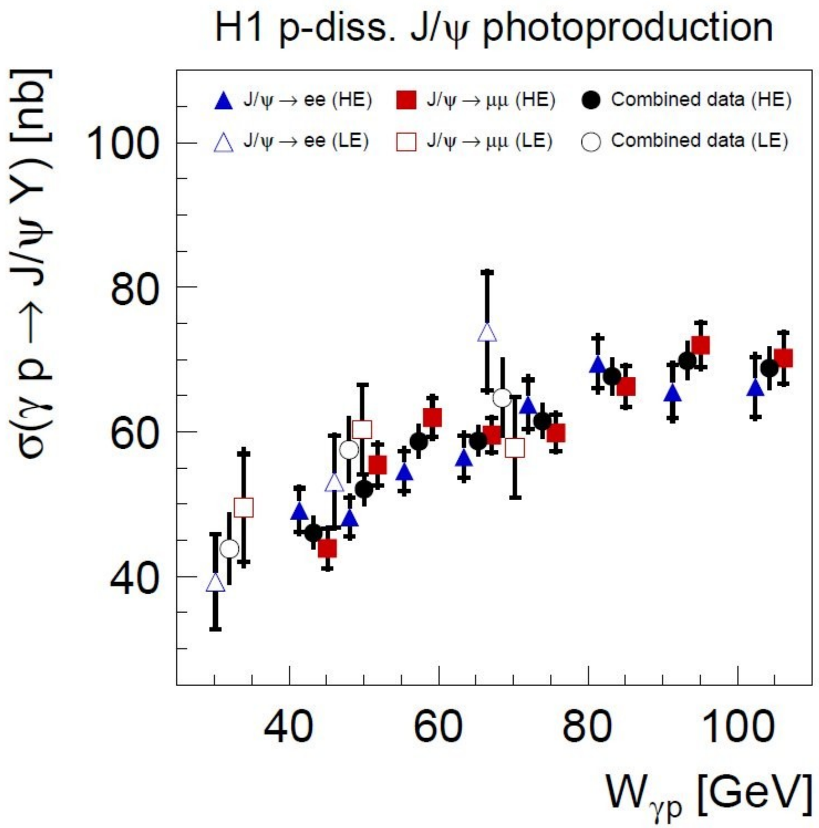
- m_{ee} low mass tail:
  - * QED radiation losses
  - * Bremsstrahlung from *e*
- Non-resonant background subtracted by simulation (GRAPE), counting of events in signal region



Combined $J/\psi \to e^+e^-, \mu^+\mu^-$ Cross Sections

Elastic and p-diss. Cross Sections measured simultaneously using Regularised Unfolding

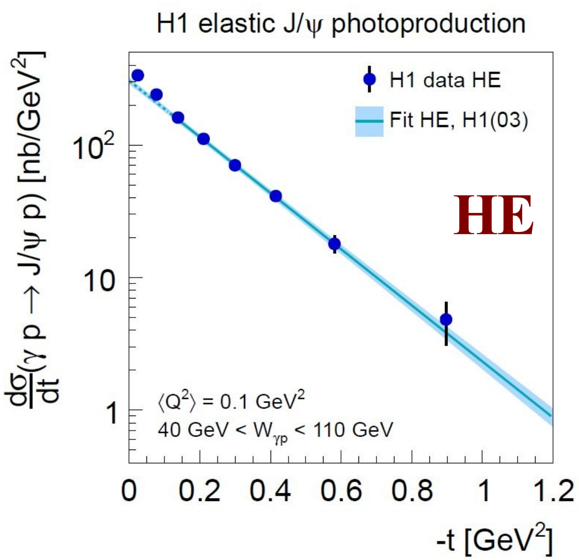


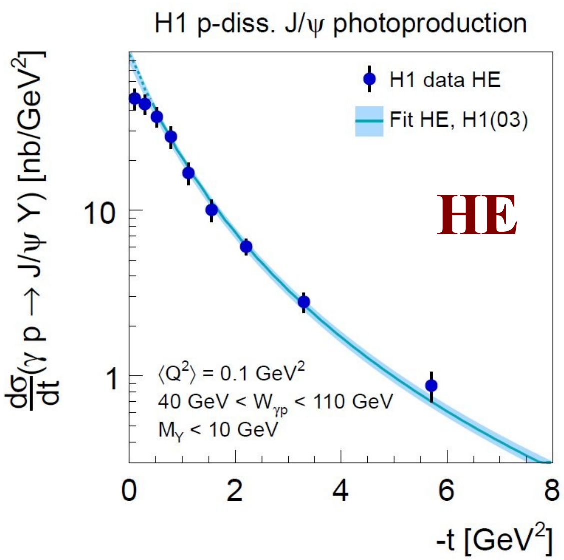


- Combination of decay channels separately for elastic and p-diss. processes by χ^2 minimisation with
  - full statistical error matrix
  - correlated systematic errors
  - applying common uncertainties after the combination

Elastic and P-diss. Cross Sections vs. |t|

Elastic **P-diss.**





Parameterisation:

- Elastic

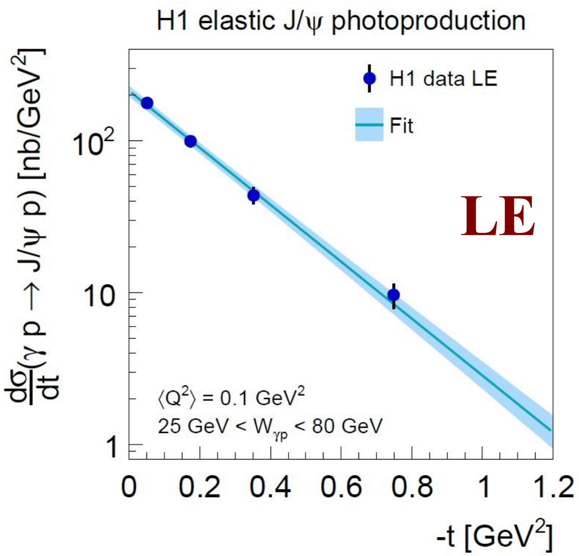
$$d\sigma/dt = N_{el}\, e^{-b_{el}|t|}$$

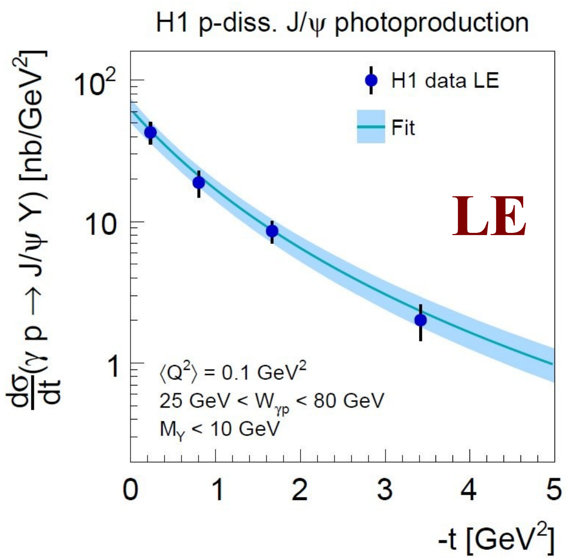
- P-diss.

$$d\sigma/dt = N_{pd}(1+(b_{pd}/n)|t|)^{-n}$$

- Simultaneous fit of elastic and p-diss. cross sections

HE: fit includes previous high |t| data H1(03) [PL B568(2003) 205]





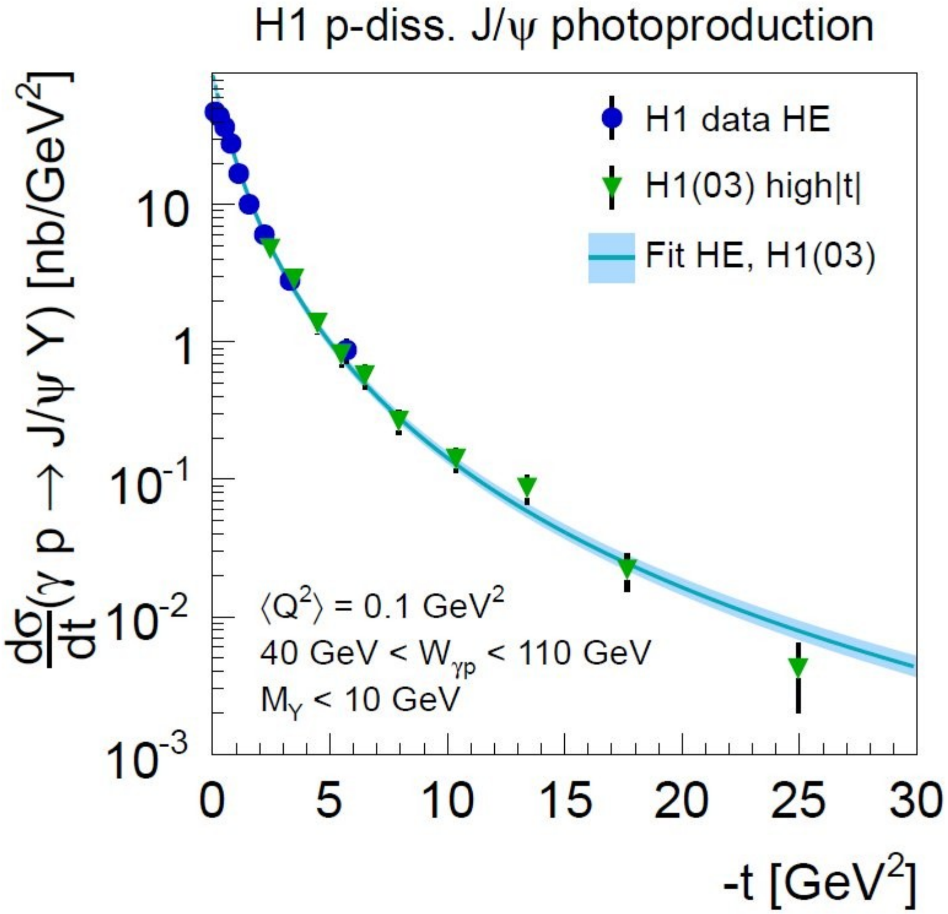
HE

$$b_{el} = 4.88 \pm 0.15\, GeV^2$$
$$b_{pd} = 1.79 \pm 0.12\, GeV^2$$
$$n = 3.58 \pm 0.15$$

LE

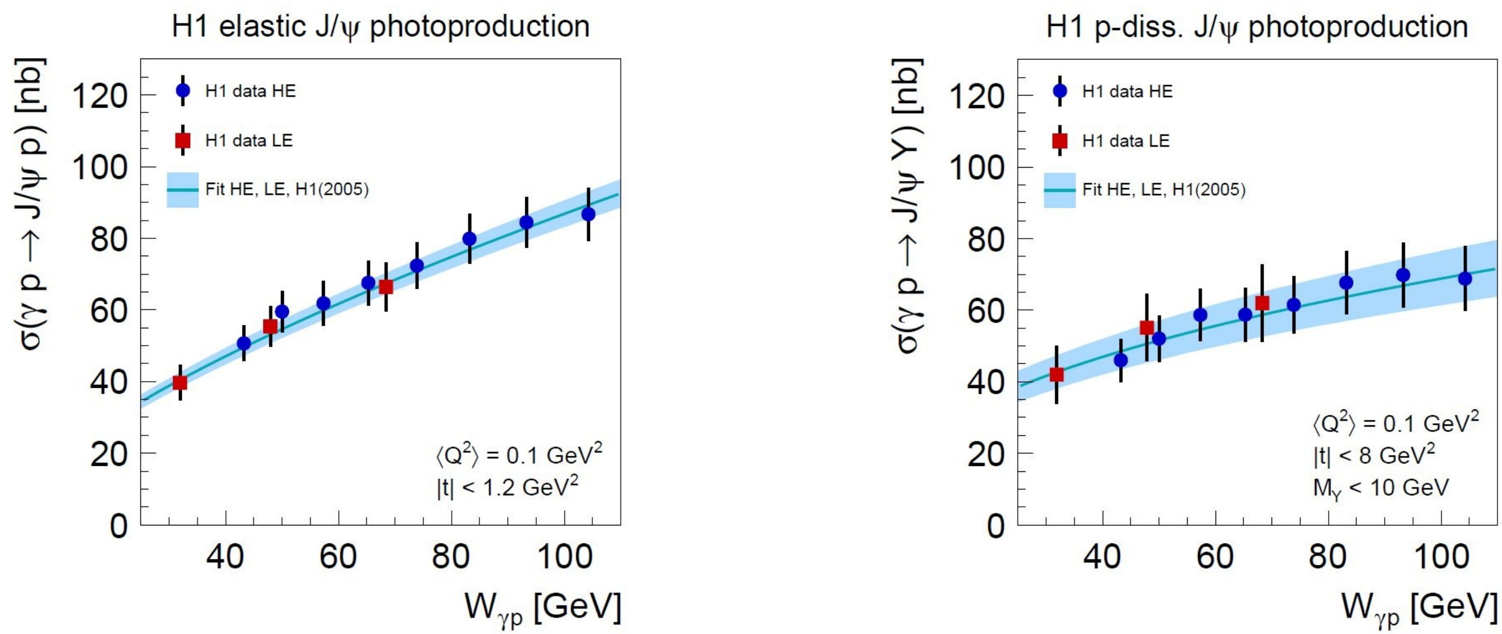
$$b_{el} = 4.3 \pm 0.2\, GeV^2$$
$$b_{pd} = 1.6 \pm 0.2\, GeV^2$$
$$n = 3.58 (\text{fixed})$$

P-diss. Cross Section vs. t



- Comparison with the previous high |t| measurement [H1(03)]
- High $|t|$ data extrapolated to match $W_{\gamma p}$, Q^2 and M_Y range of present data
- The new p-diss. measurement extends the reach to small values of |t|.
- Good agreement in the overlap region

Elastic and P-diss. Cross Sections vs. $W_{\gamma p}$

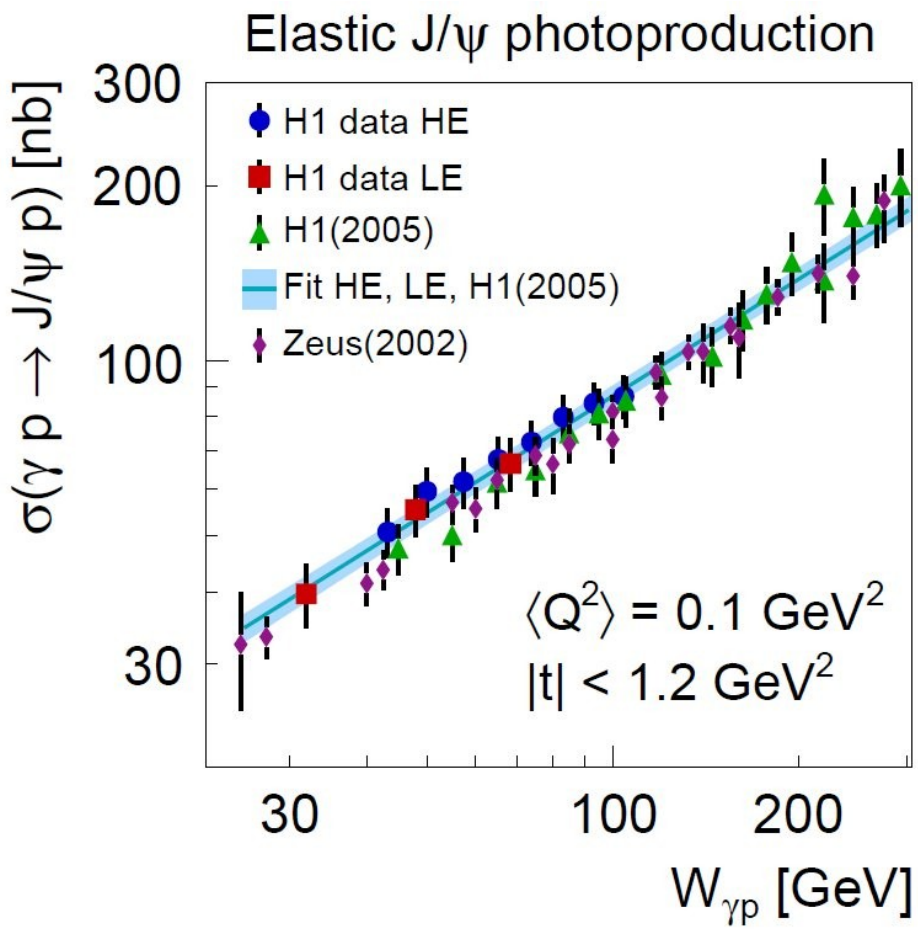


Fit includes H1(2005) [hep-ex/0510016]

- Simultaneous fit, taking into account correlations between elastic and p-diss. cross sections
- Fit function parametrised as: $\sigma = N(W_{\gamma p}/W_0)^{\delta}$

  with $W_0 = 90\, GeV$ $\delta(t) = 4(\alpha(t) - 1)$
- Results: $\delta_{el} = 0.67 \pm 0.03$ $\delta_{pd} = 0.42 \pm 0.05$
- These values are in agreement with previous H1 measurements

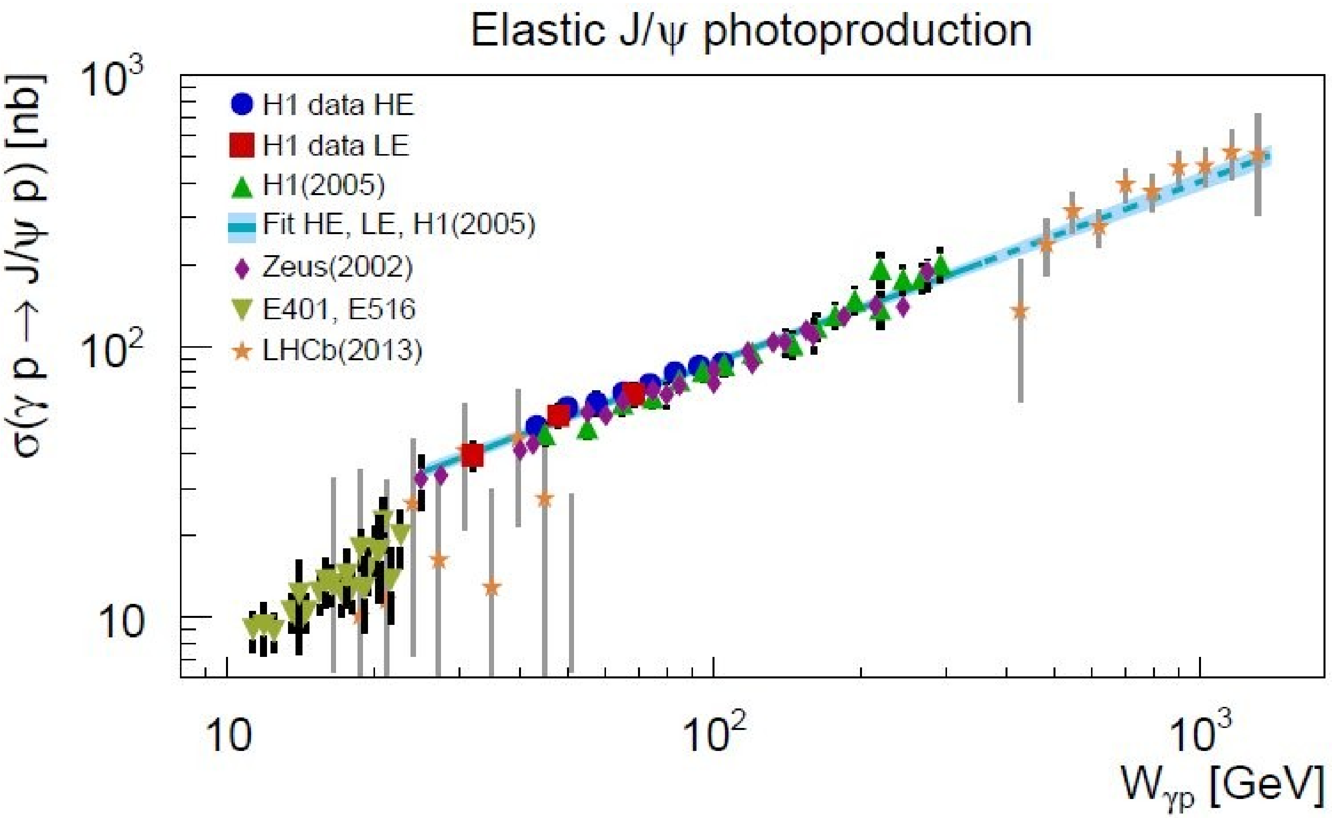
Comparison to other HERA measurements



- Large overlap with previous H1 and ZEUS [hep-ex/0201043] measurements
- Similar precision in range $30\,GeV < W_{\gamma p} < 110\,GeV$

Good agreement of HERA experiments

HERA data in comparison with fixed target and LHCb data

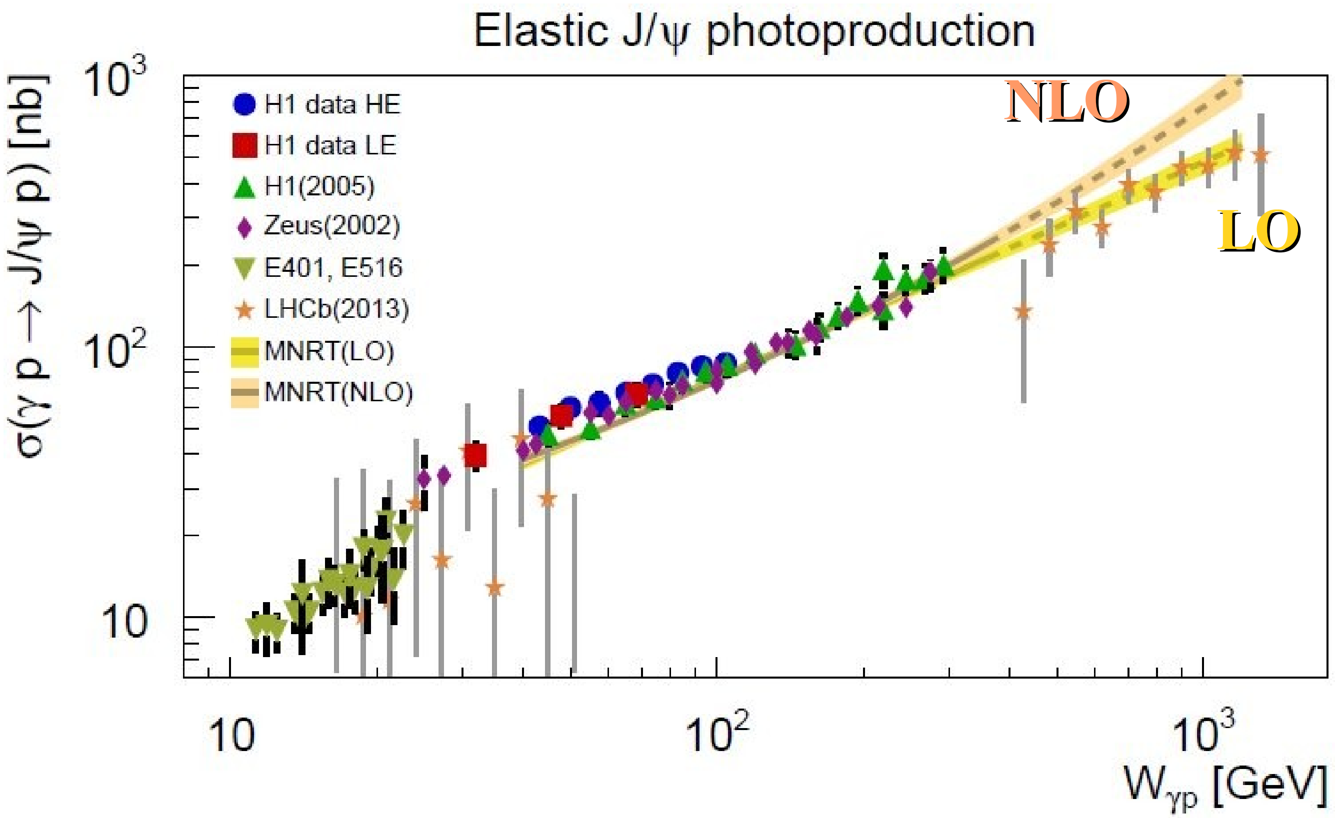


- Fixed target and LHCb data

[PRL 48(1982) 73]
[PRL 52(1984) 795]
[arXiv:1301.7084]

- New measurements in the transition region from fixed target to HERA data
- Fixed target data: steeper slope, lower normalisation ?
- Fit to H1 data, extrapolated to higher $W_{\gamma p}$, describes the LHCb data

Comparison to QCD Calculations



- LO and NLO fits to previous J/ψ measurements at HERA
  (A.Martin at al. [arXiv:0709.4406])
- Note: NLO gluon density determined from fits to J/ψ data of H1 (2005) and ZEUS (2002) (thus, agreement with data is expected)
- Both fits extrapolated to higher $W_{\gamma p}$
- LO fit describes LHCb data
- High precision J/ψ data give important input to gluon at small x

Conclusions

- Differential cross sections have been measured for elastic and proton dissociative diffractive J/ψ meson production as function of $|t|$ and $W_{\gamma p}$ in the kinematic range $|t| < 8$ GeV^2 and 25 GeV $< W_{\gamma p} <$ 110 GeV.
  The measurements in $J/\psi \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow e^+e^-$ decay channels are combined and interpreted using fits .

- The elastic and proton dissociative cross sections are extracted simultaneously using an unfolding technique.

- The cross section of p-diss. diffractive J/ψ production is measured precisely at small |t| for the first time at HERA.

- Data from HERA proton low energy run add information at lower $W_{\gamma p}$ values

- Good agreement with previous HERA measurements

- QCD inspired model is able to describe HERA and LHC data

- Fixed target data differ in slope and possibly in normalisation

Backup

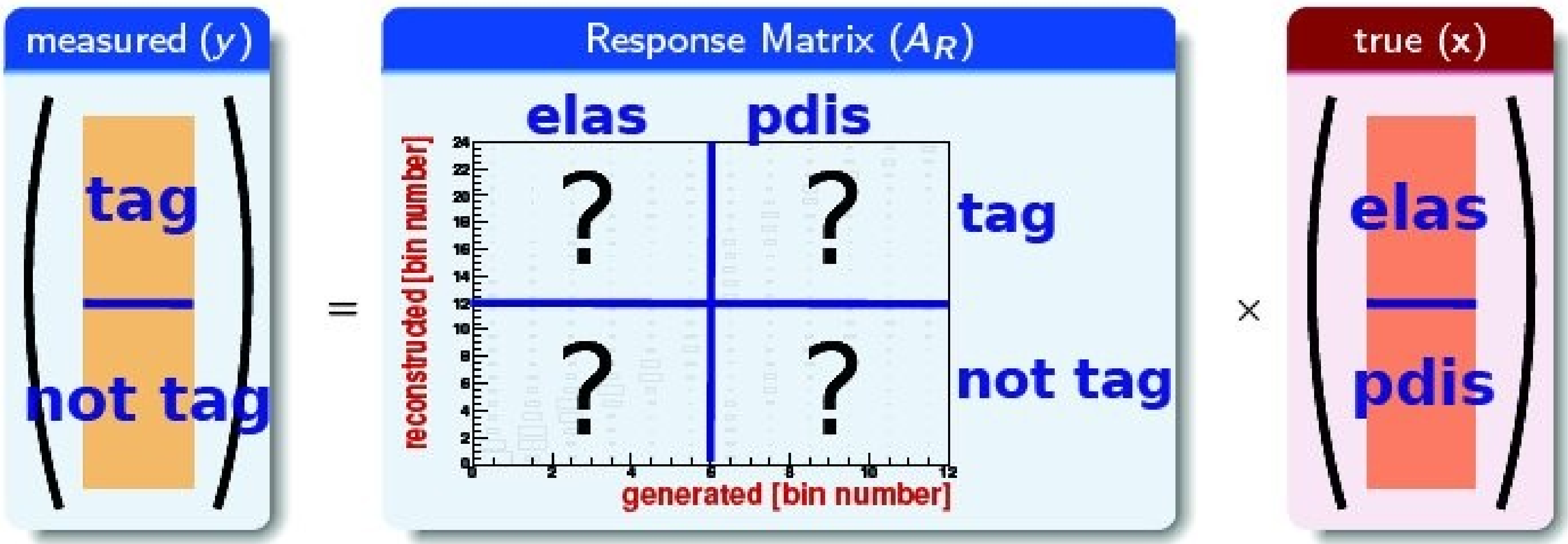
Regularised Unfolding of the Cross Sections

(F. Huber)

- Use regularised unfolding for disentangling of elastic and proton dissociative process and for taking correctly into account the migrations.
- Unfolding is done to true variables.

$$y = A_R \cdot x$$

A_R	Response matrix
x	true number of events
y	reconstructed number of events
L	regularisation matrix



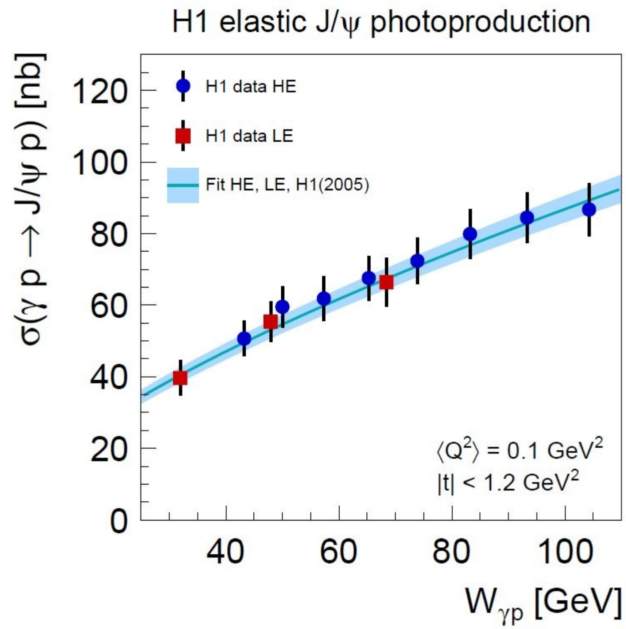
Vector filled with number of signal events from mass distribution fits.

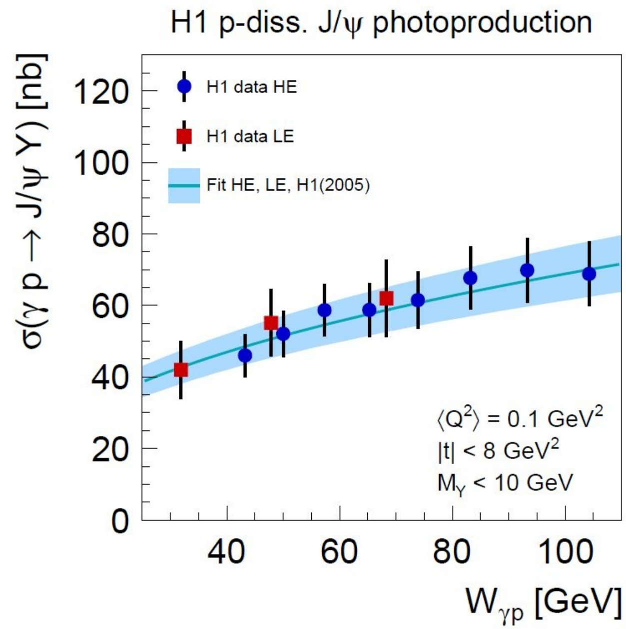
Matrix filled with MC.

Output of unfolding

Result:
- Separate measurements of σ_{el}, σ_{pd}
- First σ_{pd} measurement at low |t|

Elastic and P-diss. Cross Sections vs. $W_{\gamma p}$





Fit includes H1(2005) [hep-ex/0510016]

- Fit function parametrised as: $\sigma = N(W_{\gamma p}/W_0)^{\delta}$

  with $W_0 = 90\,GeV \quad \delta(t) = 4(\alpha(t) - 1)$

- Results: $\delta_{el} = 0.67 \pm 0.03 \quad \delta_{pd} = 0.42 \pm 0.05$

  $\alpha(0)_{el} = 1.20 \pm 0.01 \quad \alpha(0)_{pd} = 1.09 \pm 0.02$

- These values are in agreement with previous H1 measurements

$$\alpha(t) = \alpha(0) + \alpha' \cdot t$$

Note:

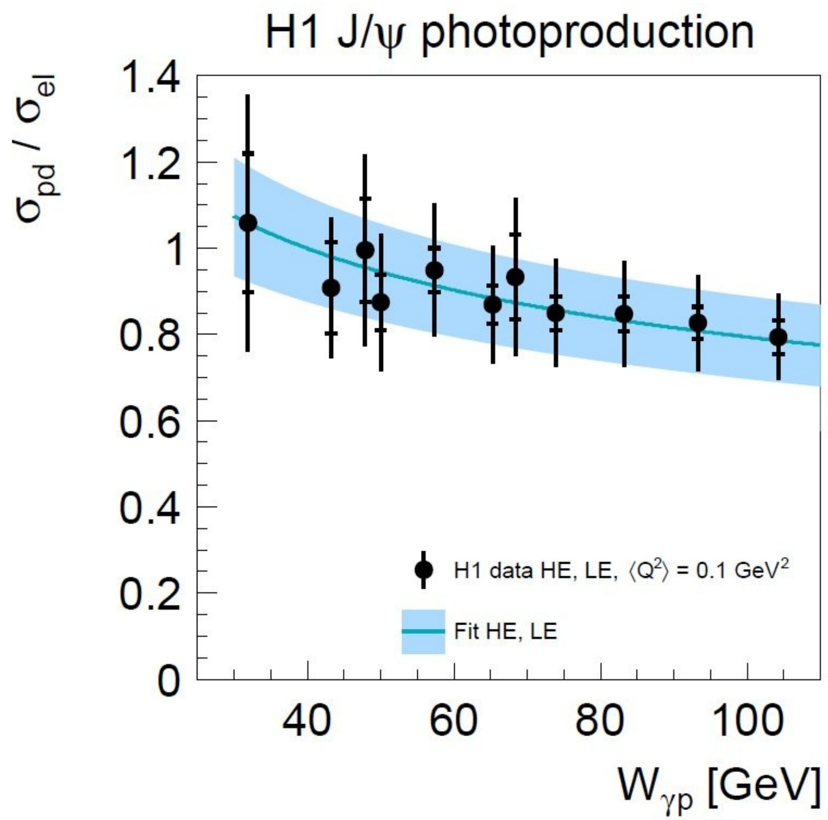
$$\alpha'_{el} = 0.164 \pm 0.028 \pm 0.030\,GeV^{-2}$$

$$\alpha'_{pd} = -0.0135 \pm 0.0074 \pm 0.0051\,GeV^{-2}$$

$$\langle t \rangle_{el} = -0.2\,GeV^2$$

$$\langle t \rangle_{pd} = -1.2\,GeV^2$$

Ratio $\sigma_{pd} / \sigma_{el}$ vs. $W_{\gamma p}$



Fit function: $N_R (W_{\gamma p} / W_0)^{\delta_R}$

with $W_0 = 90\, GeV$

$$N_R = N_{pd} / N_{el} = 0.81 \pm 0.10$$

$$\delta_R = \delta_{pd} - \delta_{el} = -0.25 \pm 0.06$$

Ratio $\sigma_{pd} / \sigma_{el}$ only slowly decreasing with increasing $W_{\gamma p}$