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

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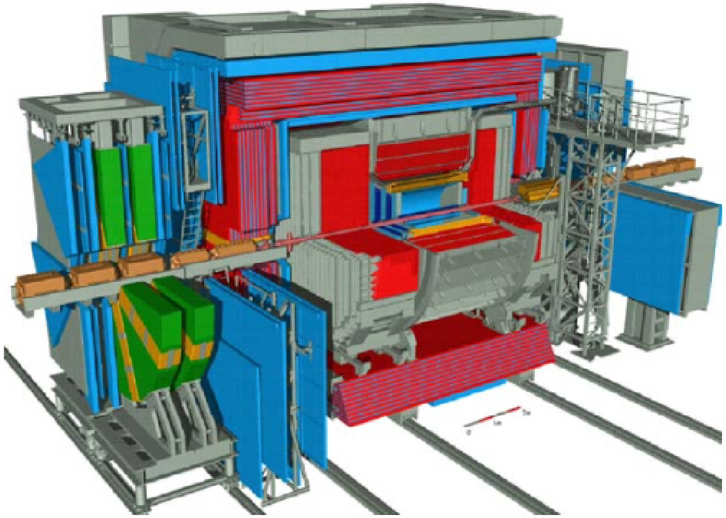
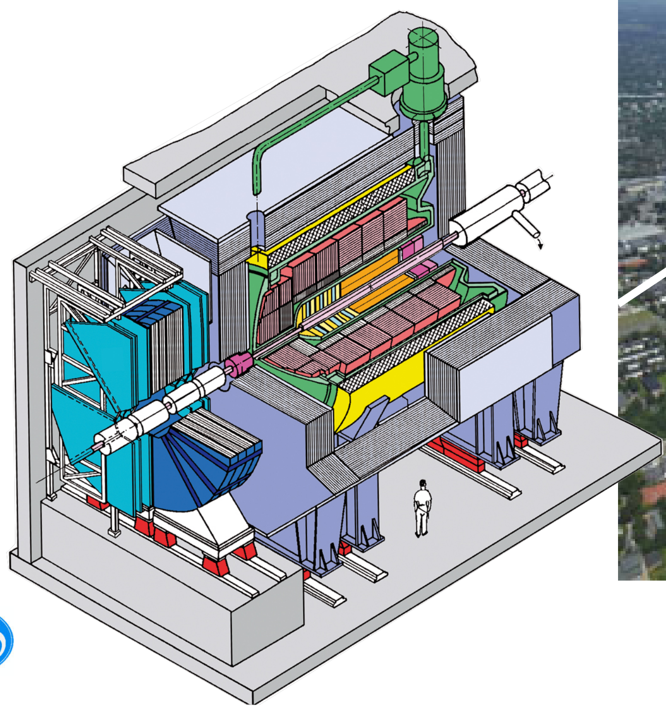
New H1 analysis, DESY-13-058 arXiv:1304.5162, (accepted by EPJC)

The HERA ep collider (1992 – 2007) at DESY in Hamburg

- ep collider:
- $e^{\pm}$ energy: 27.6 GeV
- p energy: 920 GeV, 460 GeV
- Center of mass energy: 318 GeV, 225 GeV
- 2 collider experiments: H1 and ZEUS





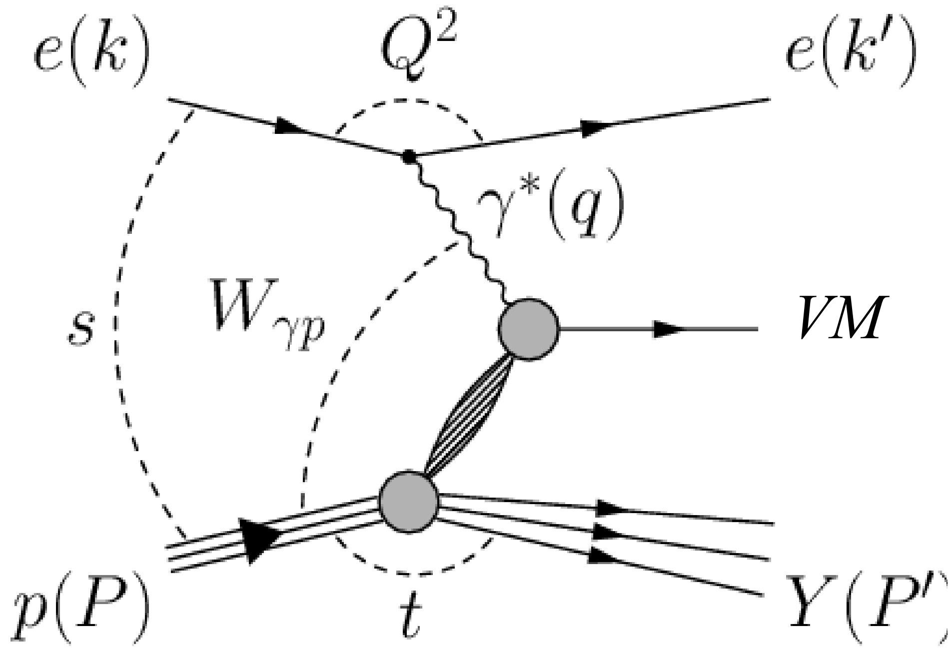
ZEUS

DESY

H1

HERA as a γ^*p collider to study VM production

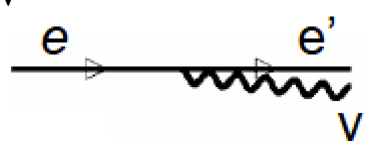
- Kinematics and scales:
  - Photon virtuality: Q^2
  - Squared cm energy of ep system: s
  - CM energy of γp system: $W_{\gamma p}$
  - (4-mom. transfer) at p vertex: t
  - Vector meson mass: M_V



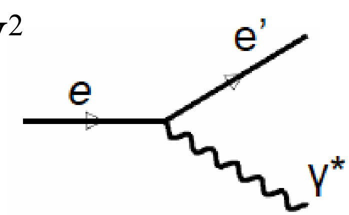
- Diffractive vector meson production can be studied at HERA as a function of several scales Q^2, M_V, t over a wide range of $W_{\gamma p}$.

$VM = (\rho, \omega, \varphi, J/\psi, \psi', \Upsilon)$

- Two kinematic regimes:
  - Photoproduction: $Q^2 \approx 0$ GeV^2



  - Deep Inelastic Scattering: $Q^2 > 1$ GeV^2 (scattered electron detected)

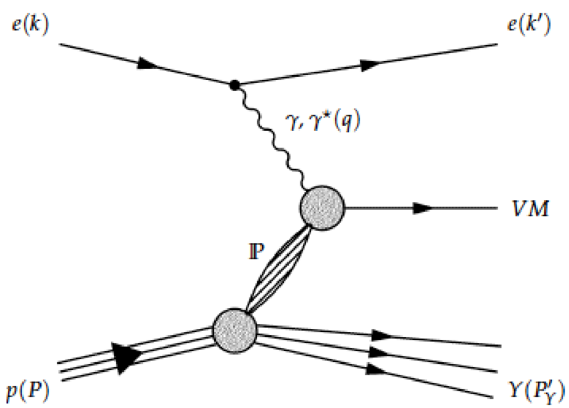


- Two ep cm mass energies:
  - $\sqrt{s} = 318$ GeV (high energy, HE)
  - $\sqrt{s} = 225$ GeV (low energy, LE) → also low $W_{\gamma p}$

Theoretical models for Vector Meson production

Regge Approach

- "soft region"



- Soft Pomeron IP exchange

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

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

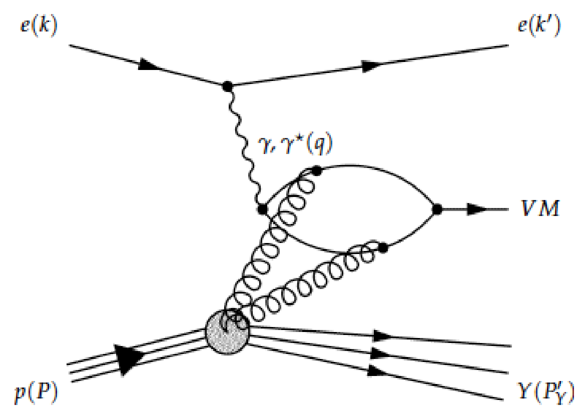
$$\frac{d\sigma}{dt} \propto e^{bt} \left(\frac{W_{\gamma p}}{W_0} \right)^{\delta} \qquad \delta = 4(\alpha_0 - 1)$$

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

- Weak energy dependence of $\sigma \propto W_{\gamma p}^{\delta}$

pQCD Approach

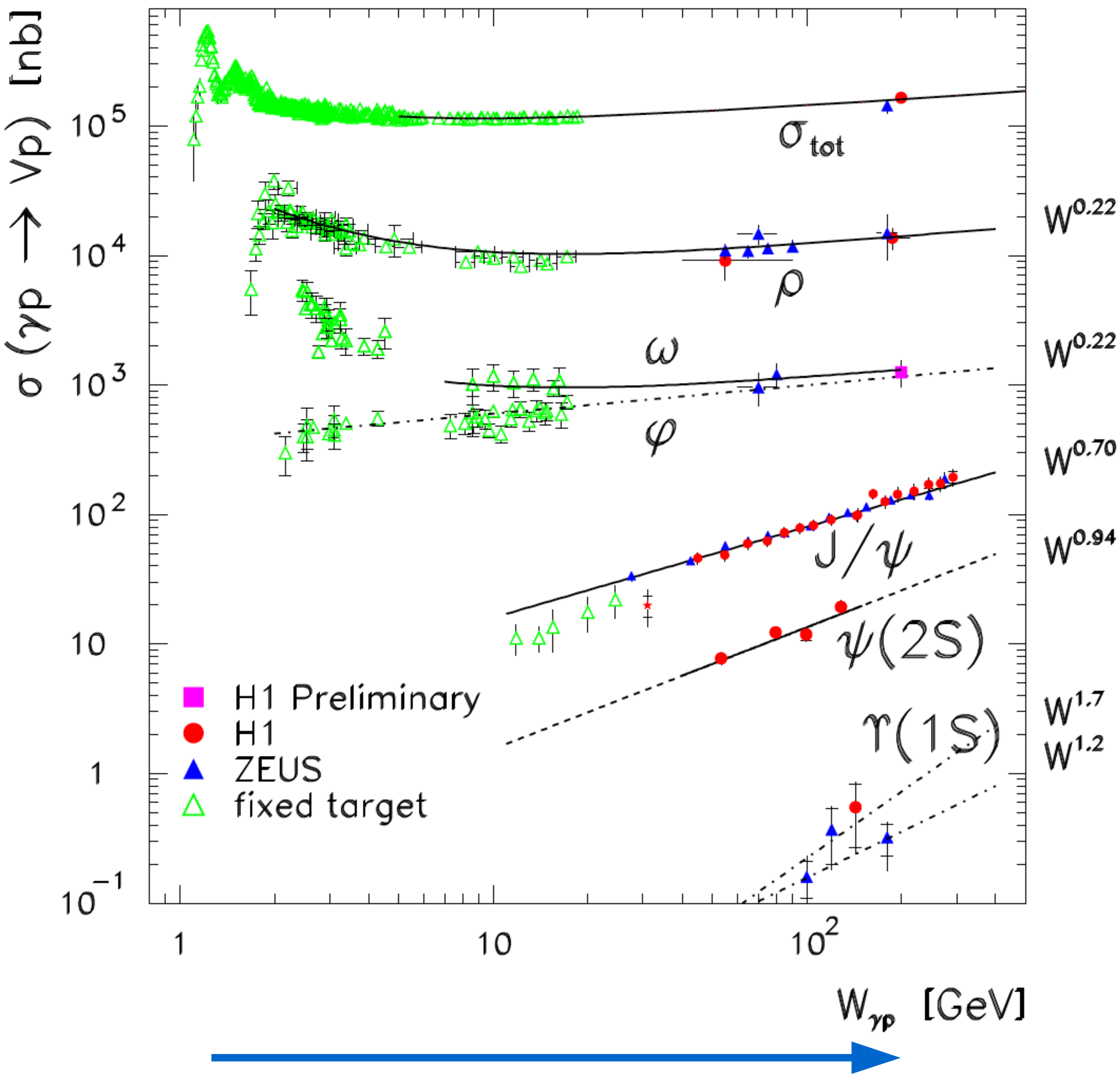
- "hard region", scales for pQCD: Q^2, M_V, t



- Exchange of ≥ 2 gluons:
  1. Virtual photon fluctuates into qq pair
  2. which interacts with the proton trough the exchange of a two gluon-ladder
  3. qq recombines into VM.
- VM cross section has sensitivity to squared gluon density in proton:

$$\begin{cases} \sigma \propto [x\, g(x, \mu^2)]^2 \\ x = \mu^2 / W^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{cases}$$

$W_{\gamma p}$ dependance of Elastic VM Photoproduction



$W_{\gamma p} \propto 1 / \sqrt{x}$

With increase of VM mass (M_V) process gets harder:

- Consistent with soft models, $\delta \sim 0.2$
- Cross section rises faster, $\delta > 0.2$
  → "hard regime"
  → sensitivity to gluon density in proton:
  $\sigma \propto [x\, g(x,M_V)]^2$

t-dependance of Vector Mesons

- Cross section approximately behaves like:

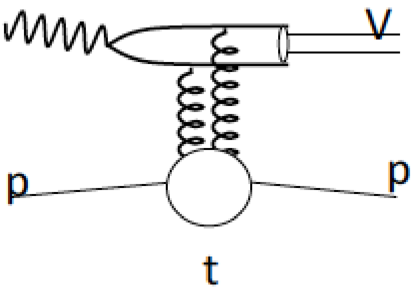
$$d\sigma / dt \propto e^{-bt}$$

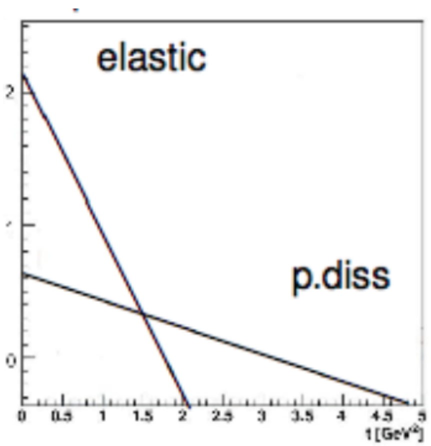
- b is related to the quadratic sum of sizes of the target and projectile:

$$b = b_V + b_P$$

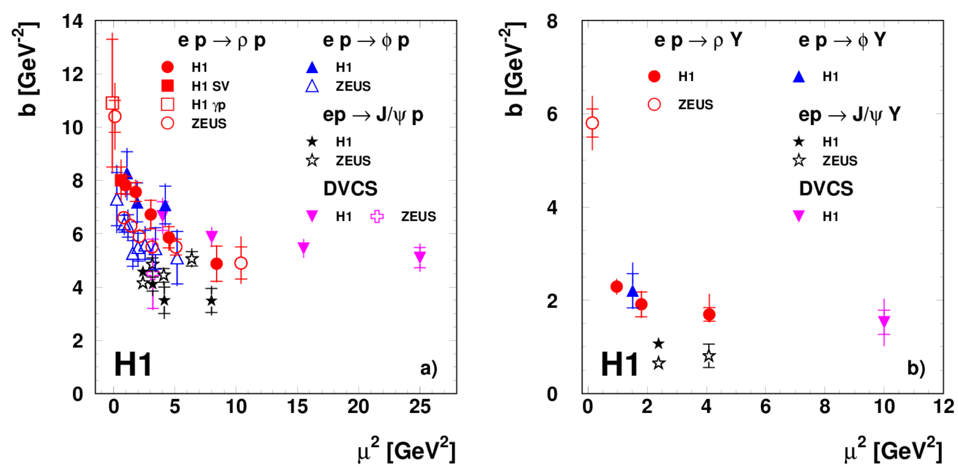
- If the target (i.e. proton) breaks, b_p does not count, i.e. b has to be smaller for p-diss. Since cross section of elas and p-diss is similar, p-diss dominates at large t.

- b decreases with the scale $\mu^2=(Q^2 + M_V^2)/4$ from ~10GeV $^{-2}$ (soft scale) ~5GeV $^{-2}$ (hard scale) for elastic and from ~3GeV $^{-2}$ (soft scale) ~1.5GeV $^{-2}$ (hard scale) for p-dis.

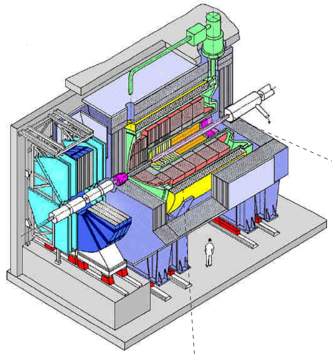




elastic p-diss.

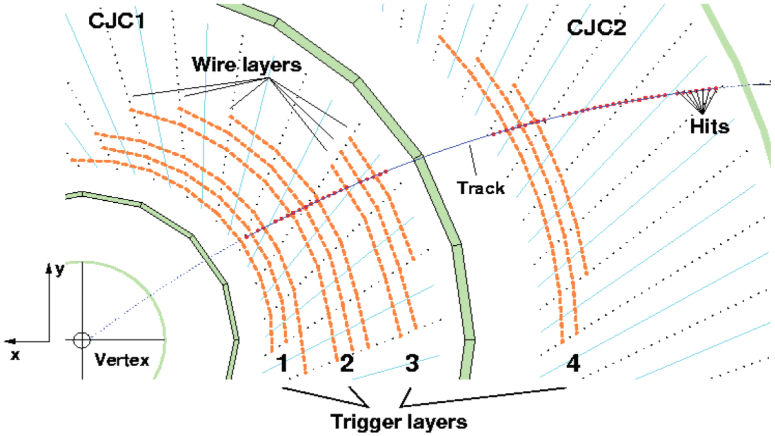


Elastic and Proton dissociative Photoproduction of J/ψ Mesons at HERA

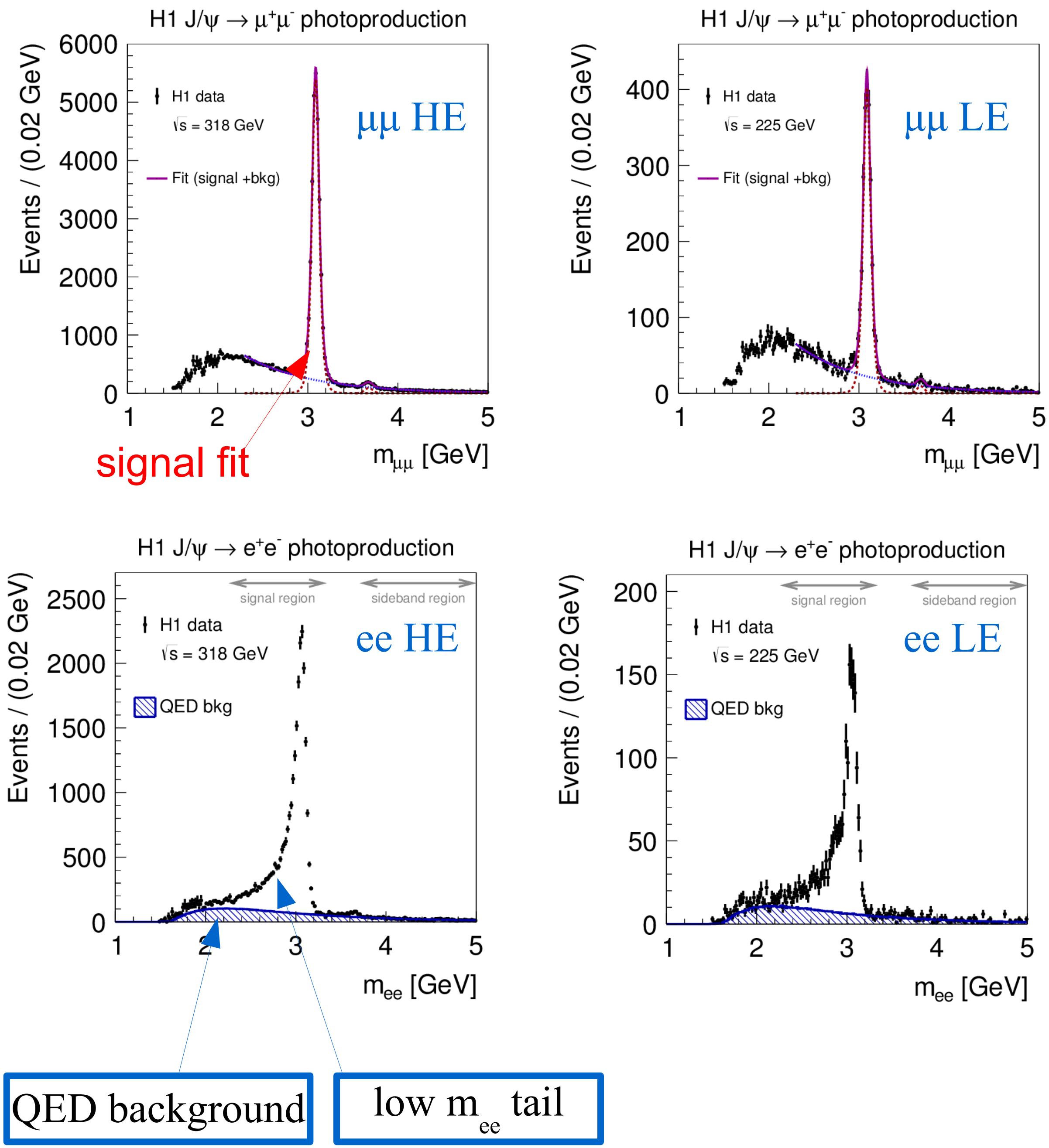


Fast Track Trigger (FTT)
Fits up to 48 **tracks**
(within 20μs) **L1-L2**

- New H1 analysis, DESY-13-058 arXiv:1304.5162, (accepted by EPJC)
- Extends the range to lower $W_{\gamma p}$
  - Use data from HERA low energy run
- Use Fast Track Trigger (FTT)
  - Purely track based information
  - Triggers on electron and muon decay channels: $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$
- Measurement of elastic and proton-dissociative process.
- Use forward detectors (FTS, Plug, LAr) to tag proton dissociative process at low |t|.
- Measure proton dissociative process to low |t| values.



Signal extraction from invariant mass distributions



$J/\psi \rightarrow \mu^{\pm}\mu^{\mp}$

- Fits to signal and non-resonant background distributions
- Functions: Student't for signal, exponential for background.
- ~30000 events for HE and ~2300 events for LE

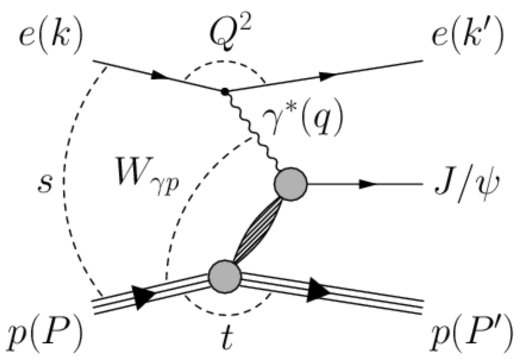
$J/\psi \rightarrow e^{\pm}e^{\mp}$

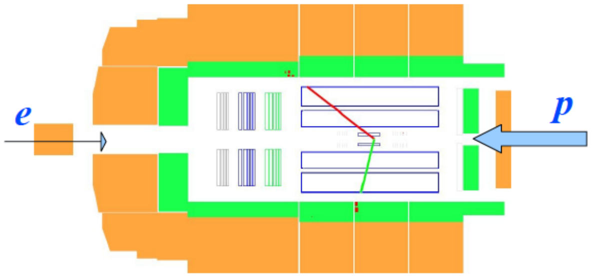
- Non-resonant background subtracted by QED simulation and counting of events in signal region.
- Procedure insensitive to low m_{ee} tail due to QED radiation losses and Bremsstrahlung.
- Possible, since no other background other than QED in selection.
- ~24000 events for HE and ~1800 for LE.

Elastic and proton dissociative J/ψ production

- Elastic

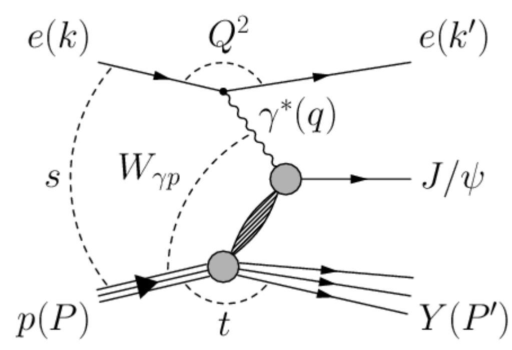
  $M_Y = m_p$

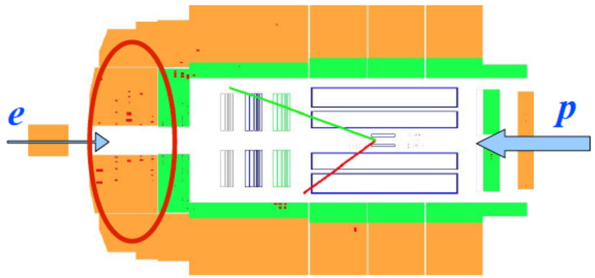


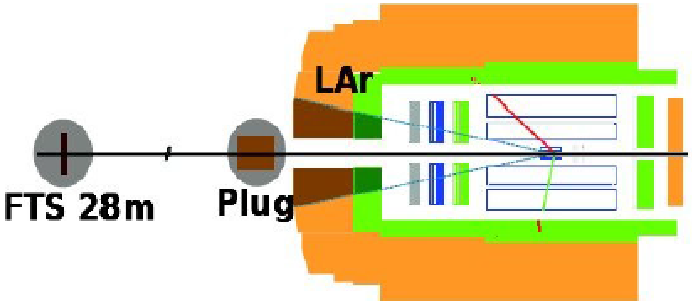


- p-diss.

  $m_p < M_Y < 10$ GeV







<u>Experimental tagging of p-diss.:</u>

- High |t| → tag
- Use forward detectors (FTS, Plug, LAr) for low |t| values.

Regularised unfolding of elastic and proton dissociative cross sections

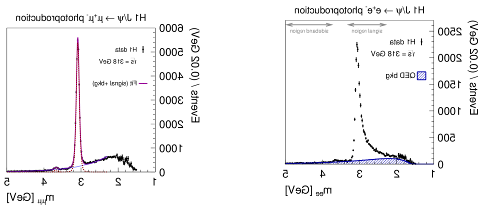
- Event-by-event distinction of the elastic and proton dissociative process is not possible, unfolded on statistical basis.
- Done by solving the matrix equation **y = A x** with a smoothness constraint.

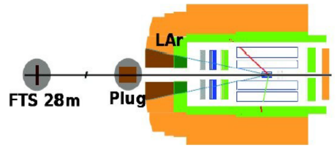
$$y = A\,x$$

Input:

Measured number of events in bins of:

- $t_{rec} = -p_{T,J/\psi}^2$, $W_{\gamma p\ rec} = s\,(E_{J/\psi} - p_{z,J/\psi}) / 2E_e$
- tagged and non-tagged

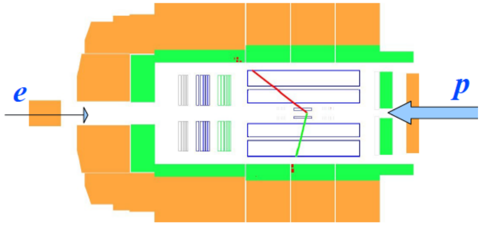




Response matrix:

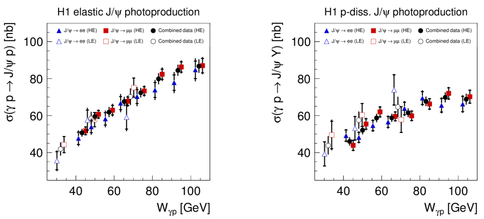
Calculated from simulation:

- physics model ⊗ detector simulation (based on GEANT)



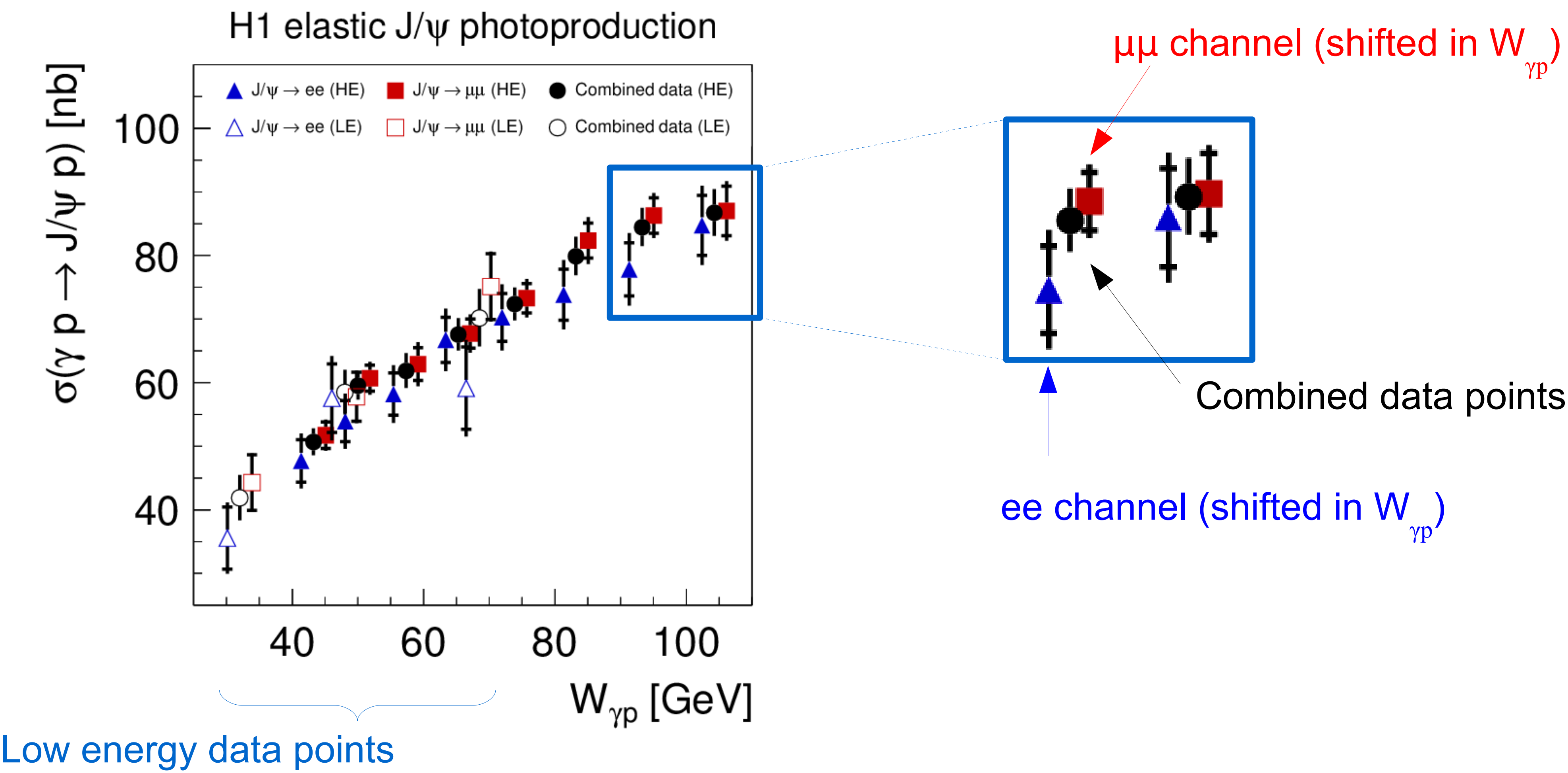
Output:

Elastic and proton dissociative cross sections

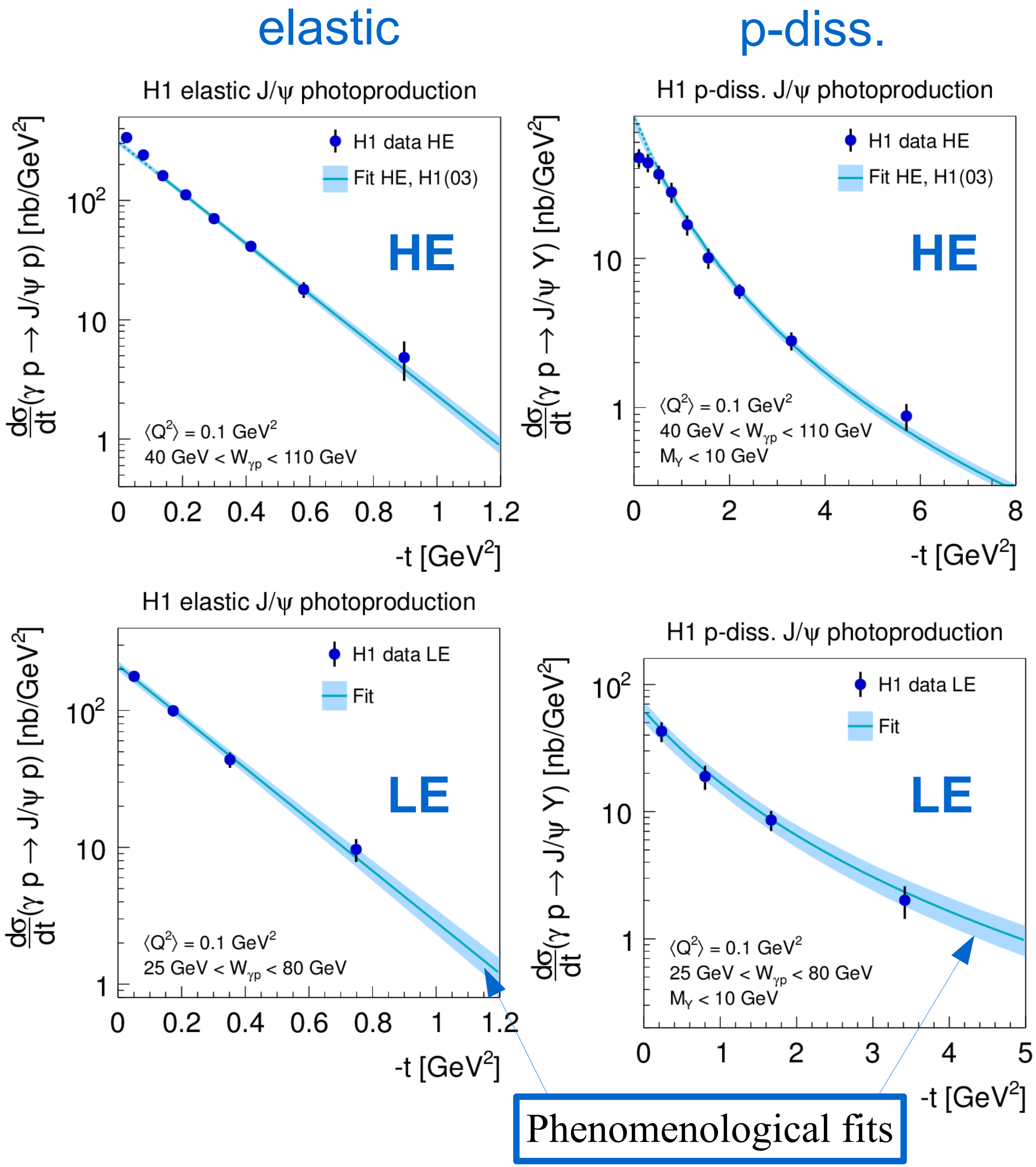


Combination of e^+e^- and $\mu^+\mu^-$ decay channels

- Done by minimizing a χ^2 function taking into account:
  - Full statistical error matrix from unfolding procedure
  - Common systematic errors
- Leads to reduced errors.
- Separately done for cross sections as a functions of t and $W_{\gamma p}$.



Elastic and proton dissociative cross sections as a function of t



Phenomenological fit model:

- Elastic:

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

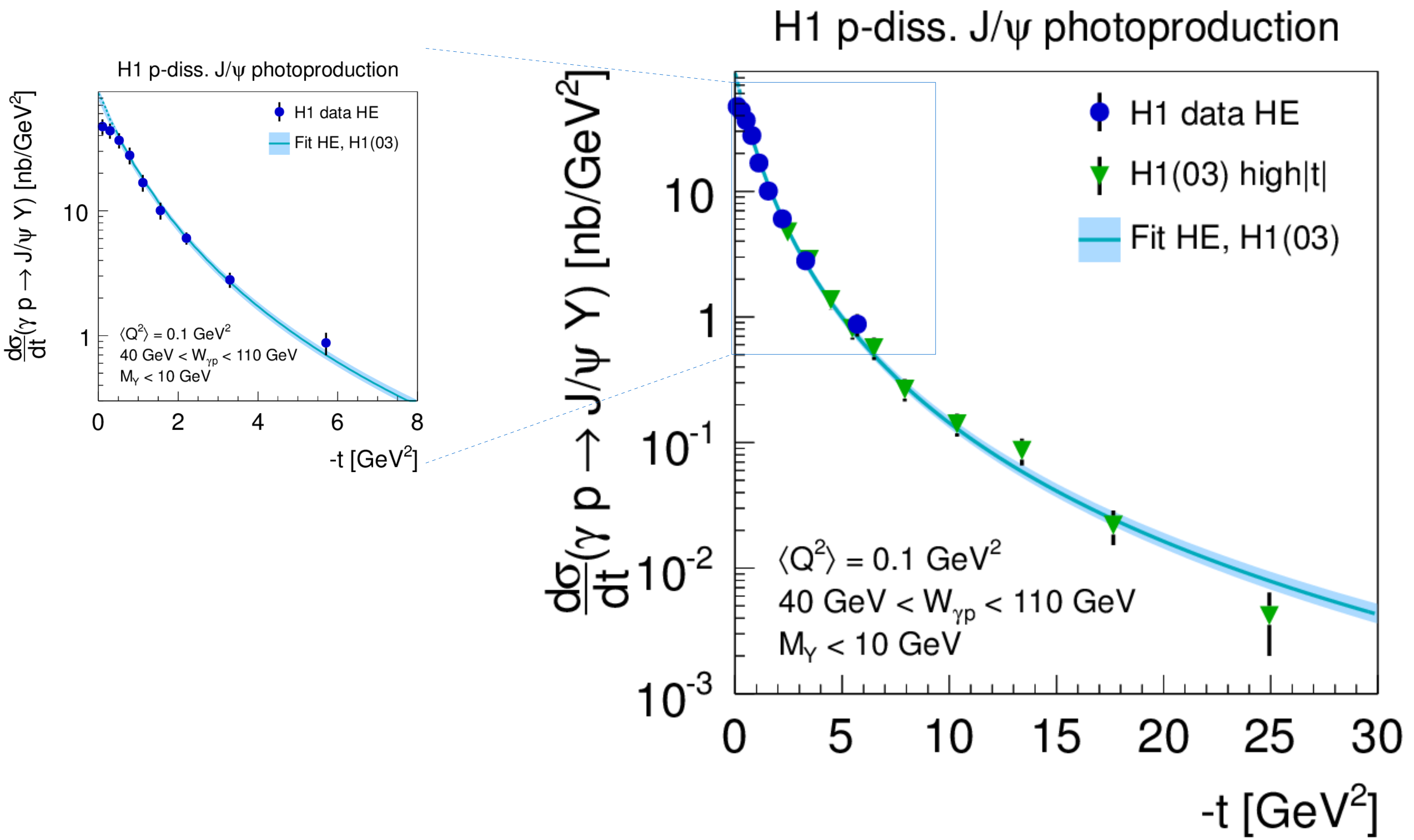
- Proton dissociative:

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

- Simultaneous χ^2 fit of elastic and p.-diss. cross sections:
  - including all correlations.
  - including previous H1 high t-data (DESY-03-061, hep-ex/0306013)
  - excluding 2 lowest |t|-points.
- Result:

Data period	Process	Parameter	Fit value	Correlation
HE	$\gamma p \to J/\psi\, p$	b_{el}	(4.88 ± 0.15) GeV^{-2}	$\rho(b_{el}, N_{el}) = 0.50$; $\rho(b_{el}, b_{pd}) = 0.49$; $\rho(b_{el}, n) = -0.21$; $\rho(b_{el}, N_{pd}) = 0.68$
		N_{el}	(305 ± 17) nb/GeV^2	$\rho(N_{el}, b_{pd}) = 0.23$; $\rho(N_{el}, n) = -0.07$; $\rho(N_{el}, N_{pd}) = 0.46$
	$\gamma p \to J/\psi\, Y$	b_{pd}	(1.79 ± 0.12) GeV^{-2}	$\rho(b_{pd}, n) = -0.78$; $\rho(b_{pd}, N_{pd}) = 0.76$
		n	3.58 ± 0.15	$\rho(n, N_{pd}) = -0.46$
		N_{pd}	(87 ± 10) nb/GeV^2	
LE	$\gamma p \to J/\psi\, p$	b_{el}	(4.3 ± 0.2) GeV^{-2}	$\rho(b_{el}, N_{el}) = 0.37$; $\rho(b_{el}, b_{pd}) = 0.10$; $\rho(b_{el}, N_{pd}) = 0.41$
		N_{el}	(213 ± 18) nb/GeV^2	$\rho(N_{el}, b_{pd}) = -0.24$; $\rho(N_{el}, N_{pd}) = -0.10$
	$\gamma p \to J/\psi\, Y$	b_{pd}	(1.6 ± 0.2) GeV^{-2}	$\rho(b_{pd}, N_{pd}) = 0.53$
		n	3.58 (fixed value)	
		N_{pd}	(62 ± 12) nb/GeV^2	

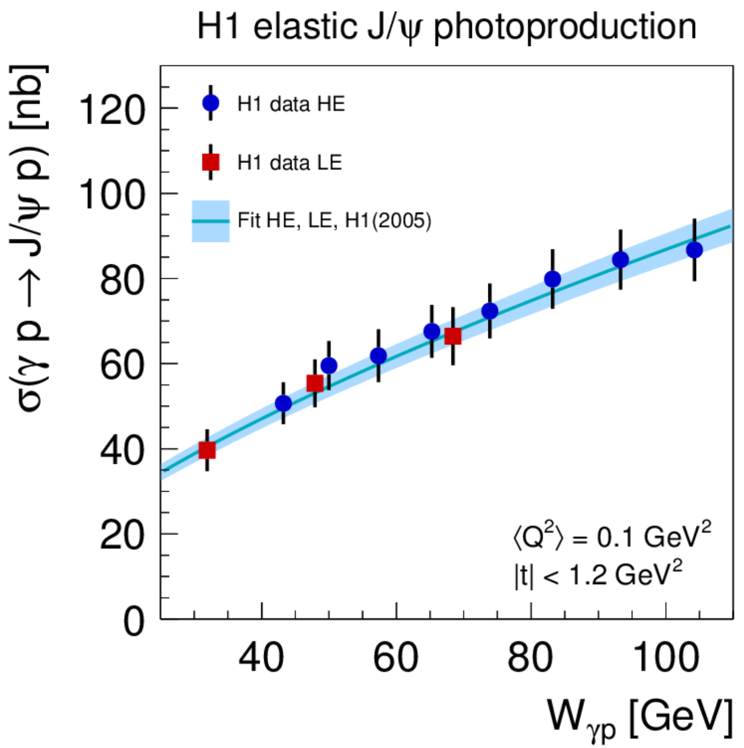
Proton dissociative cross sections as a function of t



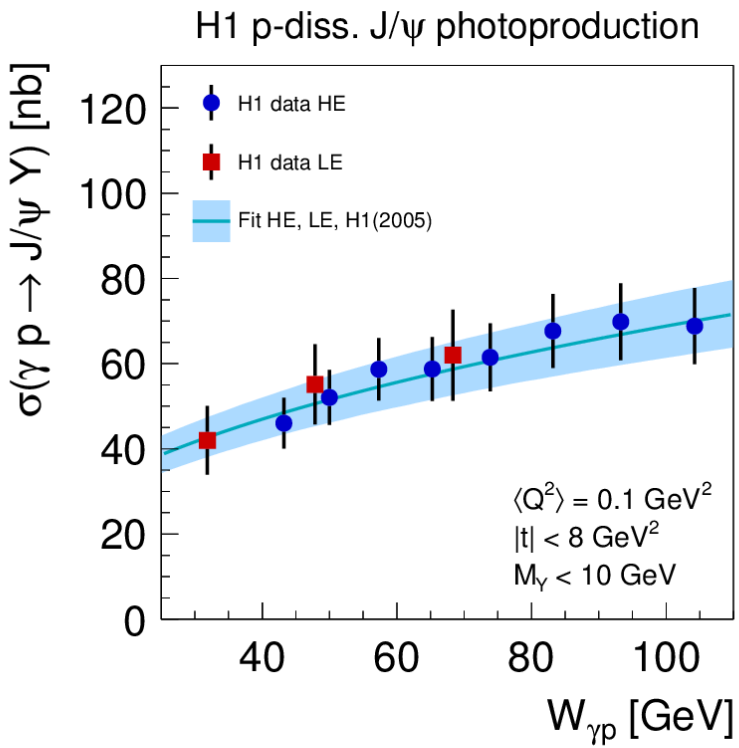
- Comparison with the previous high-|t| measurement (H1 03)
- Good agreement in overlap region.
- New proton dissociative measurement extends the reach to very low |t| values.

Elastic and proton dissociative cross sections as a function of $W_{\gamma p}$

elastic



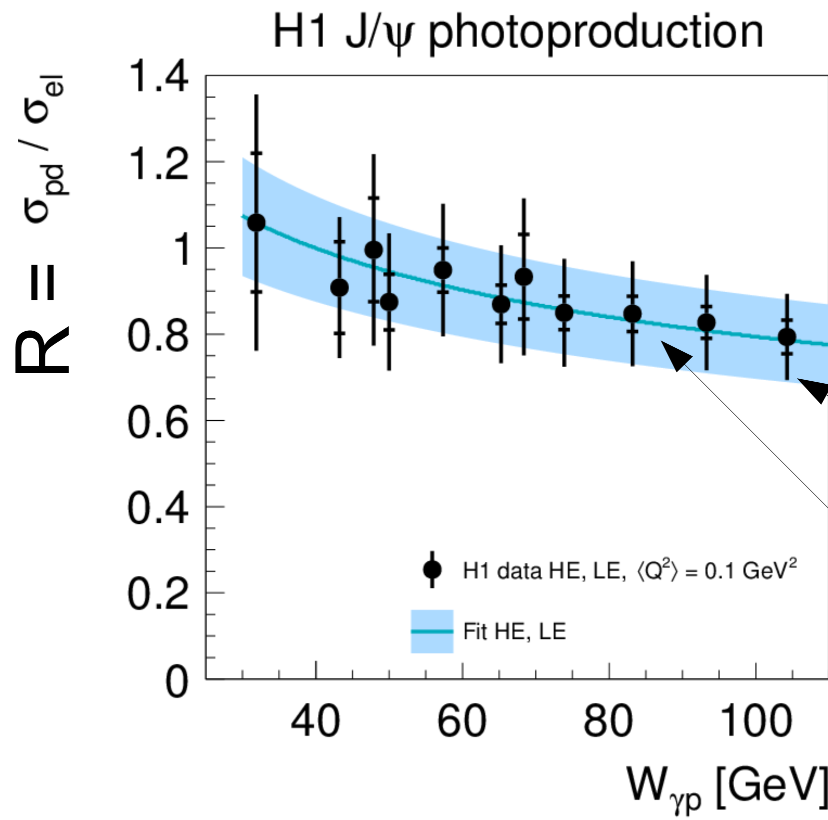
p-diss.

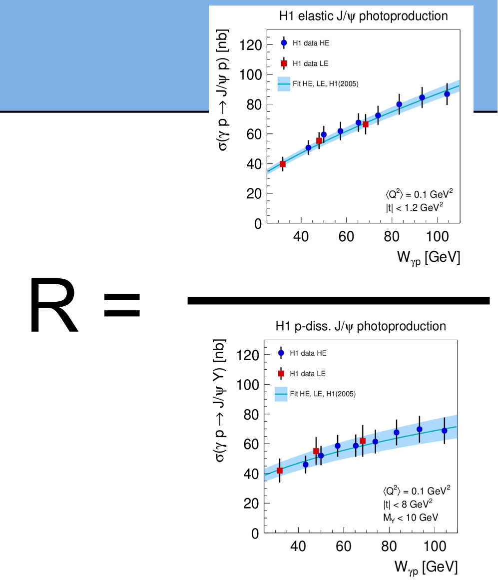


Phenomenological fit model:

- Parametrisation (for elastic and p-diss.)
  $\sigma = N\,(W_{\gamma p} / W_0)^{\delta}$ with $W_0 = 90\,\mathrm{GeV}$
- Simultaneous χ^2 fit of elastic and p.-diss. cross sections:
  - including all correlations.
  - including previous H1 data (DESY-05-161, hep-ex/0510016)

Process	Parameter	Fit value	Correlation
$\gamma p \to J/\psi\, p$	δ_{el}	0.67 ± 0.03	$\rho(\delta_{el}, N_{el})$ =-0.08 $\rho(\delta_{el}, \delta_{pd})$ = 0.01 $\rho(\delta_{el}, N_{pd})$=0.09
	N_{el}	$81 \pm 3\,\mathrm{nb}$	$\rho(N_{el}, \delta_{pd})$ = -0.27 $\rho(N_{el}, N_{pd})$=-0.18
$\gamma p \to J/\psi\, Y$	δ_{pd}	0.42 ± 0.05	$\rho(\delta_{pd}, N_{pd})$=0.09
	N_{pd}	$66 \pm 7\,\mathrm{nb}$	



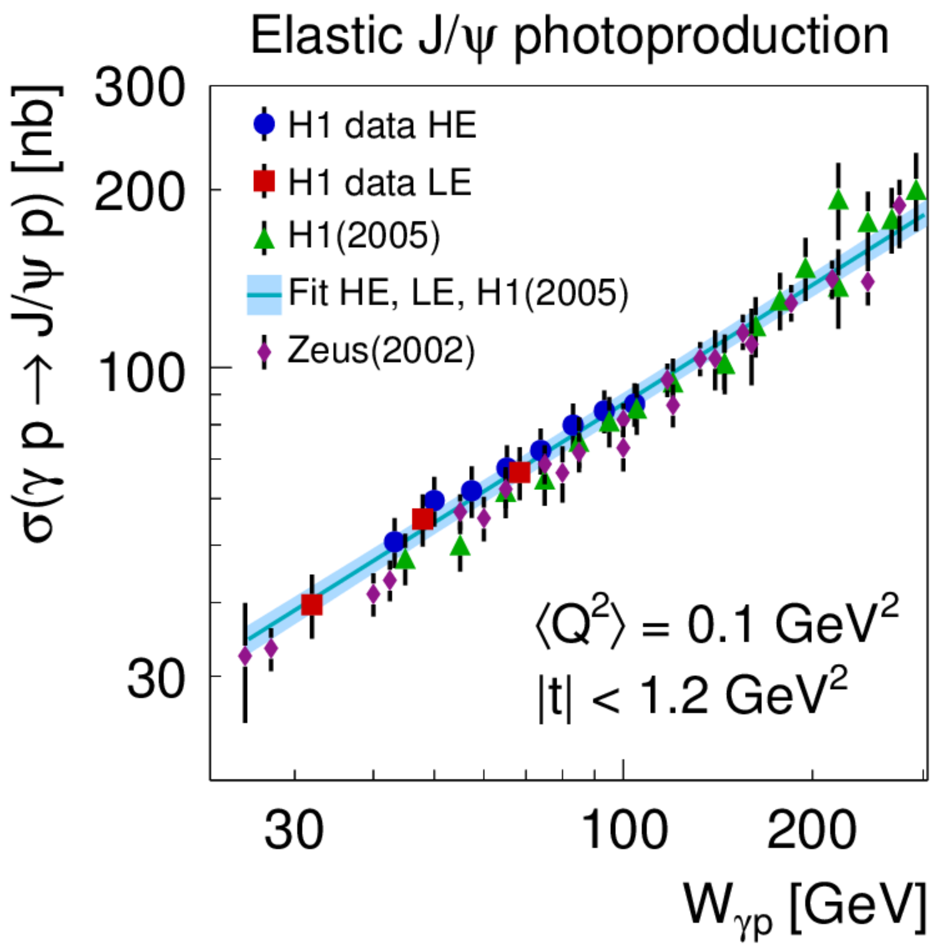


Total and uncorrelated errors (inner error bars)

Band: Ratio of fitted functions to elas and p-diss. cross sections (see slide 14).

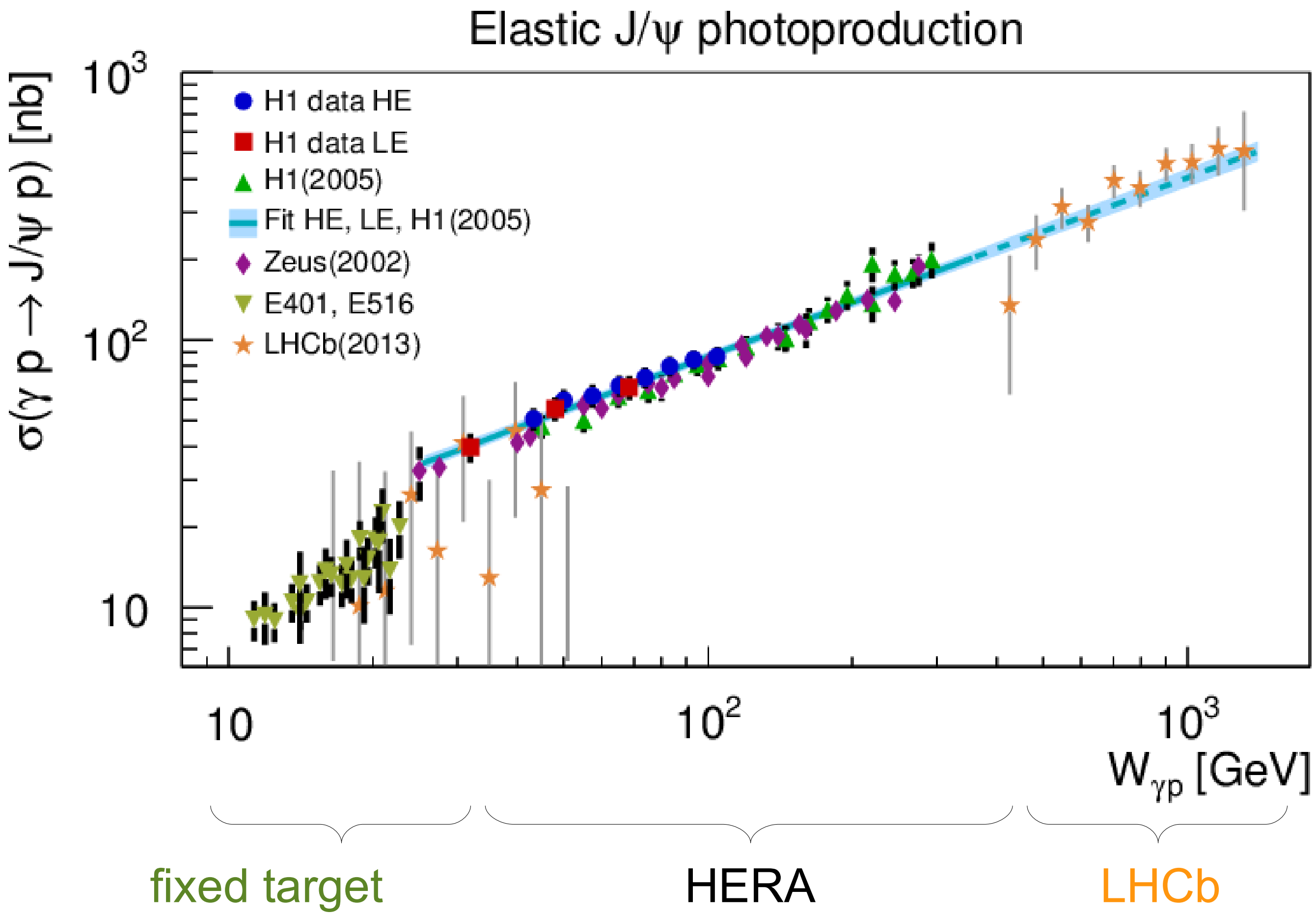
- Ratio of elastic and proton dissociative cross is approximately equal to 1.
- A slight dependence of this ratio as a function of $W_{\gamma p}$ is observed, which can be parametrized as $N_R\,(W_{\gamma p} / W_0)^{\delta R}$ with $N_R = 0.81 \pm 0.11$, δR = -0.25 ± 0.0.06

Comparison to previous H1 and ZEUS data



- Large overlap with previous H1 and ZEUS measurements.
- Similar precision in the range $30 < W_{\gamma p} < 110$ GeV. (Normalization uncertainties of ~5% are not shown).
- Good agreement of HERA measurements.

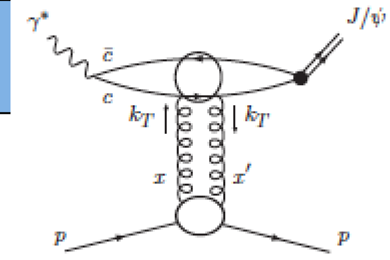
Comparison to fixed target and LHCb data

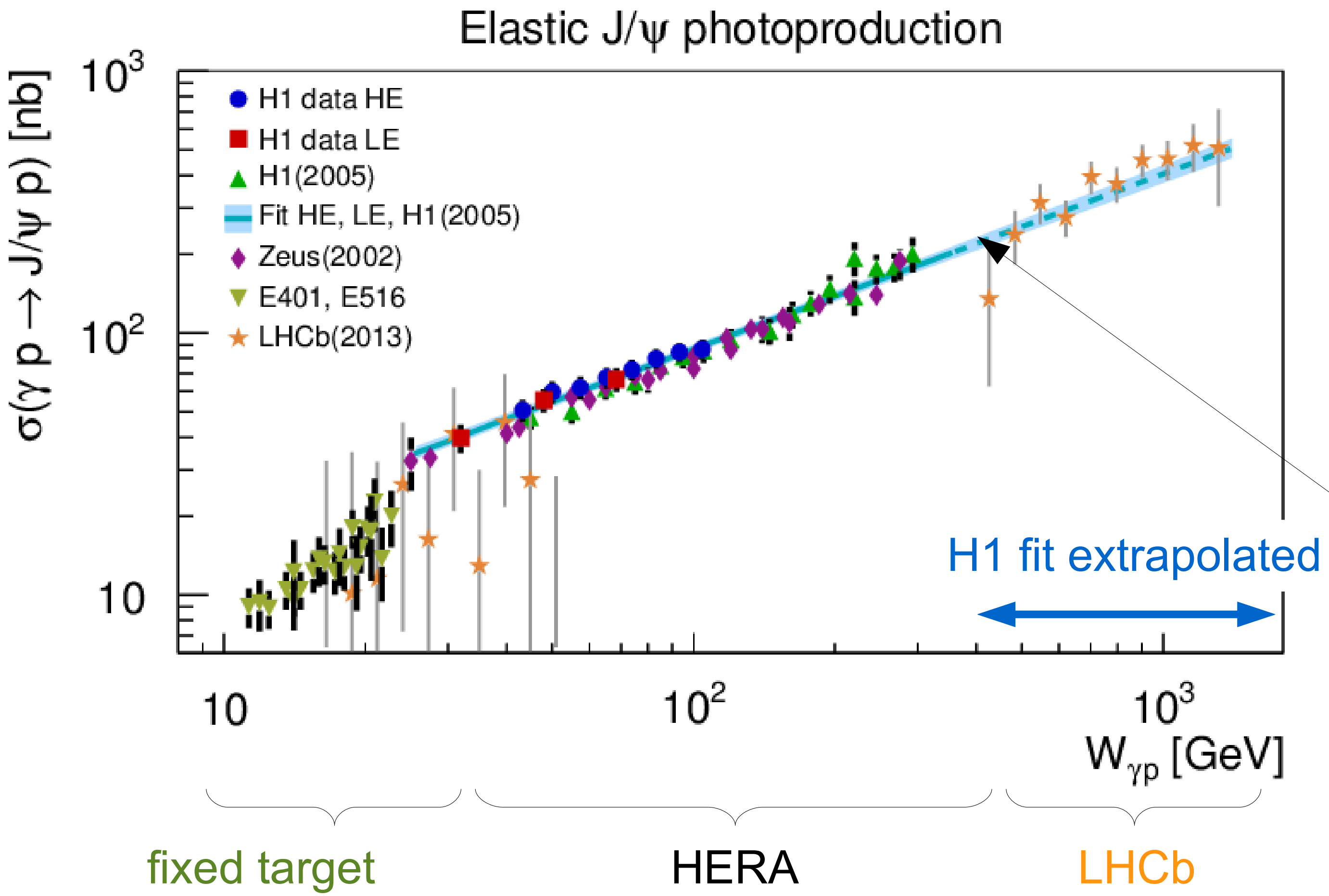


PRL 48 (1982) 73
PRL 52 (1984) 795
arXiv: 1301.7084

- New measurement in the transition region of the fixed target and the previous HERA data.
- Fixed target data: seem to have a steeper slope and lower normalization.
- Fit to H1 data extrapolated to higher $W_{\gamma p}$ values: describes the LHCb data.

Sensitivity to the gluon density





A.Martin et al., arXiv:0709.4406:

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

H1 fit:

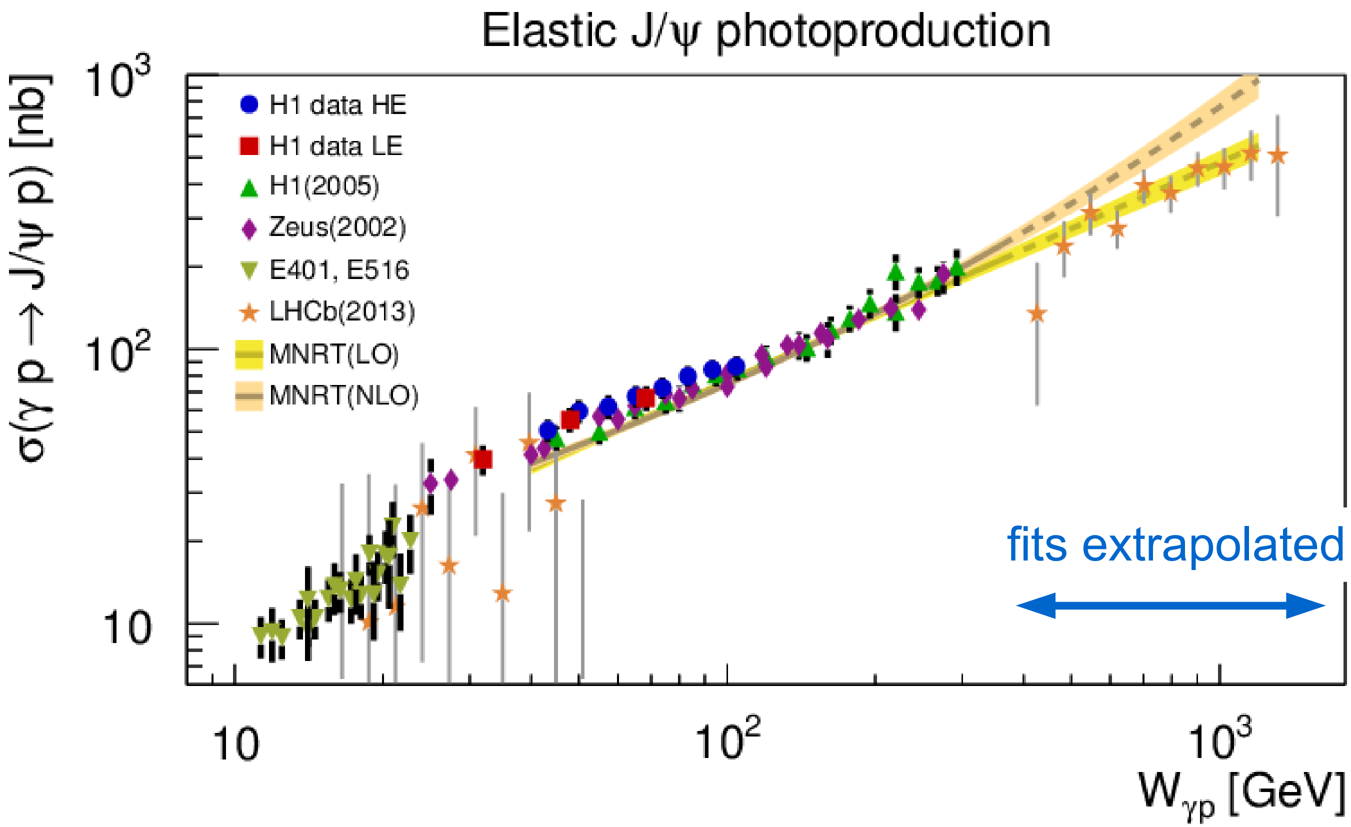
$\sigma = N\,(W_{\gamma p} / W_0)^\delta$

with $W_0 = 90\text{GeV}$

- Following A. Martin et al., δ can be related to a LO gluon density as $x^*g(x,\mu^2)=N^*x^{-\lambda}$ via $\delta \approx 4^*\lambda$, $\mu^2=(Q^2+M_{J/\psi}{}^2)/4$, $W_{\gamma p} \propto 1 / \sqrt{x}$.
- λ from this fit $\lambda_{J/\psi}(\mu^2=2.4\text{GeV}^2)=0.168\pm0.008$ agrees to previous fits to inclusive DIS data $\lambda_{J/\psi}(Q^2=2.5\text{GeV}^2)=0.166\pm0.006$.

DESY-08-171, arXiv:0904.0929

Comparison to previous fits based on QCD calculations



A.Martin et al., arXiv:0709.4406

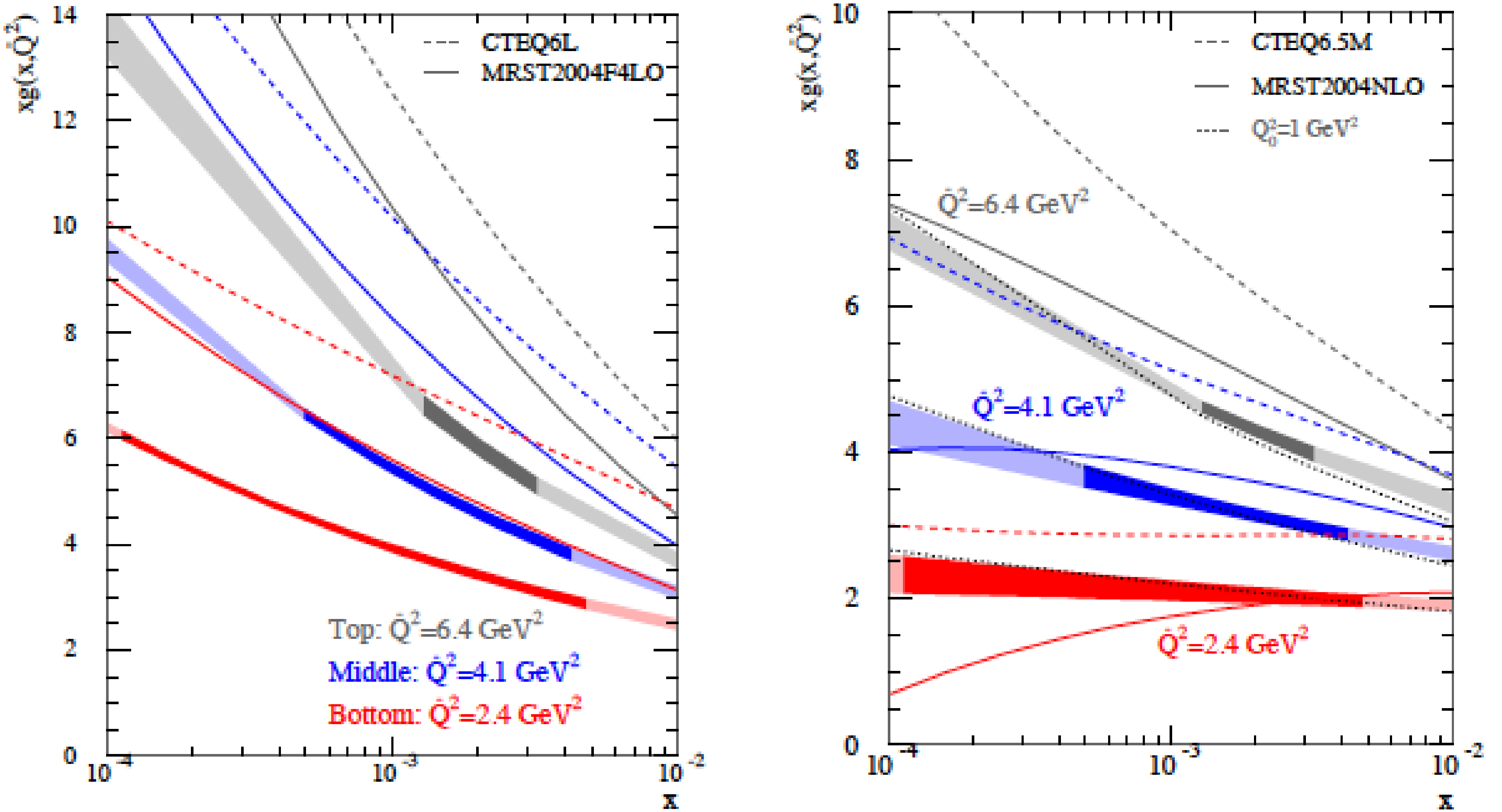
- LO and NLO fit to previous J/ψ data and extrapolated to higher $W_{\gamma p}$.
- LO fit describes the LHCb data.
- High precision J/ψ data could give important input to gluon density at low x: → with the HERA J/ψ data one could reach $x \approx 10^{-5}$, with the LHCb data $x \approx 10^{-6}$.

Summary and Conclusions

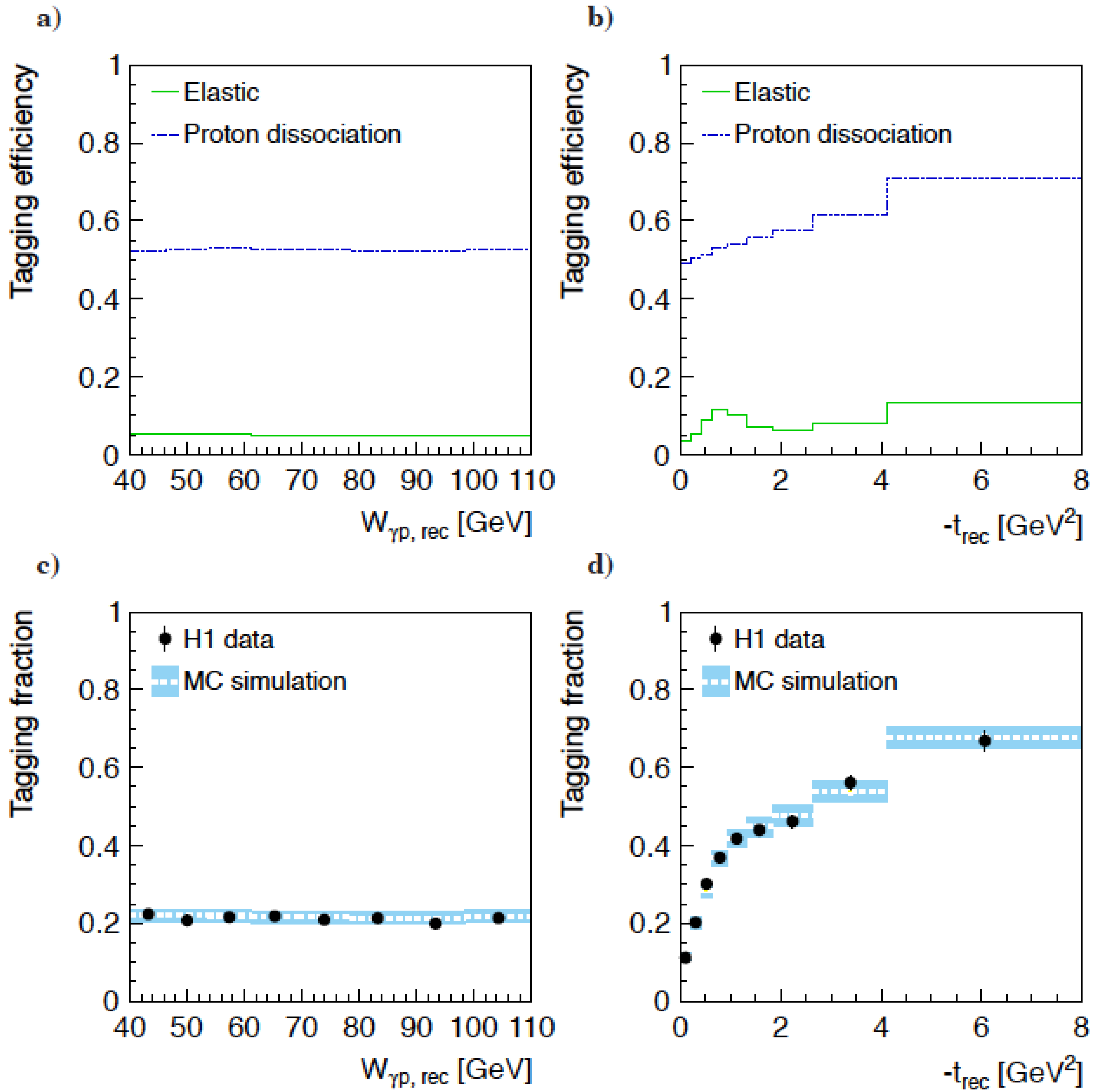
- Differential cross sections have been measured for elastic and proton dissociative J/ψ meson production:
  - using the decay channels $J/\psi \rightarrow e^+e^-$ and $J/\psi \rightarrow \mu^+\mu^-$.
  - as a functions of t and $W_{\gamma p}$ and analyzed in phenomenological fits.
- The proton dissociative cross section is measured precisely at small |t| for the first time at HERA.
- Data from the HERA low energy runs add information at low $W_{\gamma p}$.
- The ratio of the elastic to proton dissociative cross section is approximately unity, but slightly falls with $W_{\gamma p}$.
- Data from fixed target experiments differ in slope and possibly in normalization.
- This J/ψ data as sensitivity to the gluon density at low x.

backup

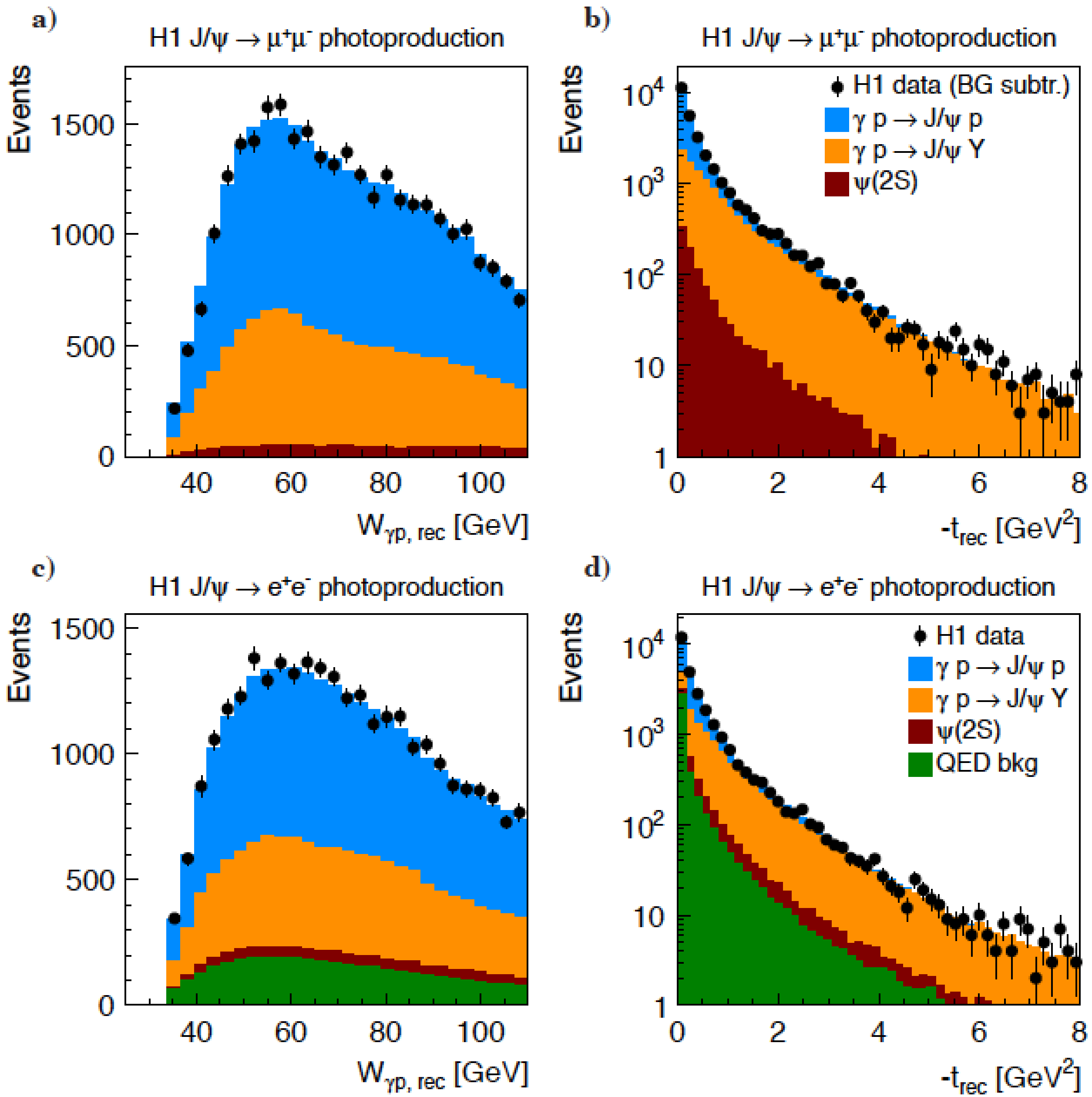
LO and NLO gluon densities from the Martin et al paper:



Tagging efficiency and fractions



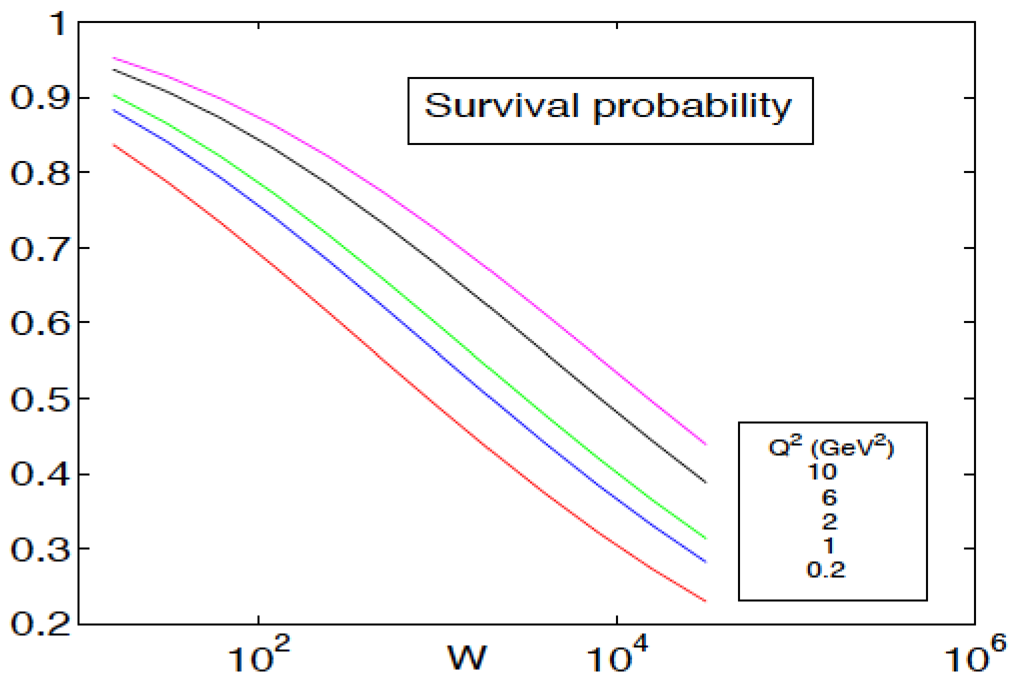
Control distributions.

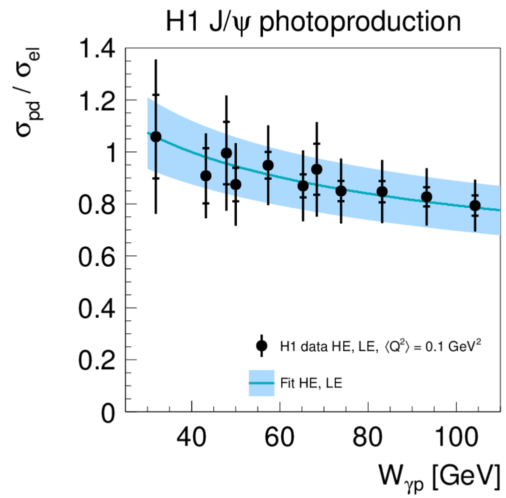


Falling ratio of p-diss. over elas cross section predicted?

E. Gotsman, A. Kormilitzin, E. Levin, U. Maor (Tel Aviv Un.), "Survival probability for high mass diffraction", arXiv:hep-ph/0702053

A large rapidity gap (LRG) process is defined as one where no hadrons are produced in a sufficiently large rapidity interval. Diffractive LRG are assumed to be produced by the exchange of a color singlet object with quantum numbers of the vacuum, which we will refer to as the Pomeron. We wish to estimate the probability that a LRG, which occurs in diffractive events, survives rescattering effects which populate the gap with secondary particles coming from the underlying event.





L. Motyka, G. Watt "Exclusive photoproduction at the Tevatron and LHC within the dipole picture", arXiv:0805.2113v2