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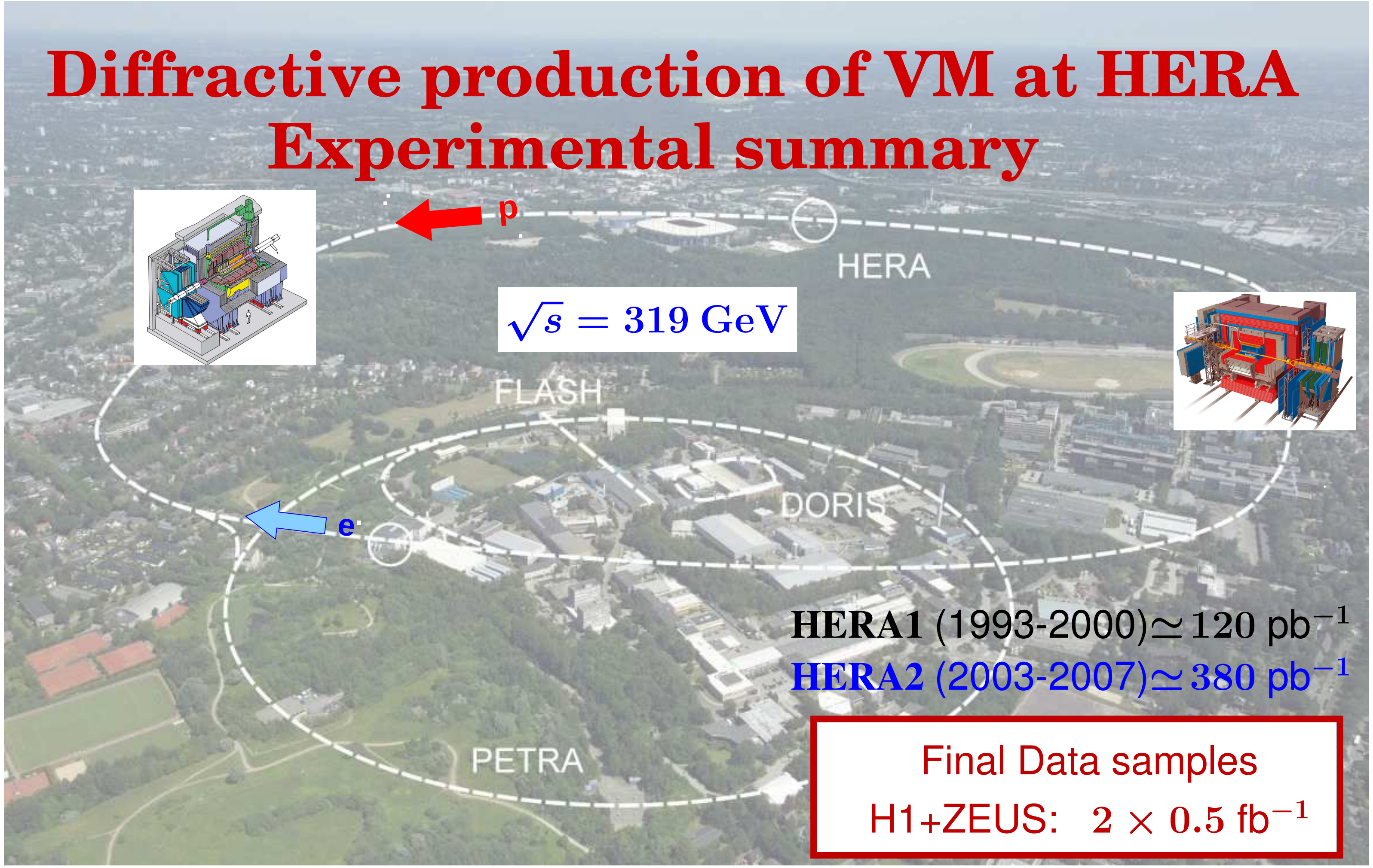
Diffractive production of VM at HERA
Experimental summary



$\sqrt{s} = 319$ GeV

HERA1 (1993-2000)$\simeq$ 120 pb^{-1}
HERA2 (2003-2007)$\simeq$ 380 pb^{-1}

Final Data samples
H1+ZEUS: 2×0.5 fb^{-1}

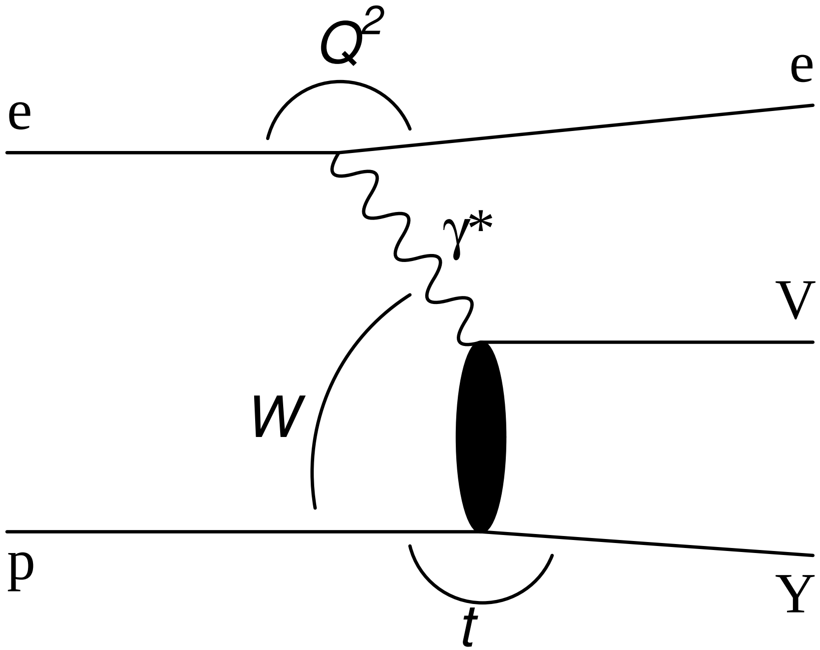
H1 and ZEUS publications on exclusive VM's (and γ) at HERA

H1 Topic	Journal	ZEUS Topic	Journal
Exclusive $\pi^+\pi^-$ and ρ^0 in PHP	Eur.Phys.J.C80 (2020), 1189	$R(\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)})$ in DIS	Nucl. Phys. B 909 (2016) 934
Exclusive ρ^0 with Leading n in PHP	Eur.Phys.J.C76 (2016) 1, 41	Exclusive Electroproduction of 2π	Eur.Phys.J. C 72 (2012) 1869
Elastic and p-diss J/ψ in PHP	Eur.Phys.J.C73 (2013) 2466	$\Upsilon(1S)$ in PHP (t-dependence)	Phys.Lett. B 708 (2012) 14
Diffractive ρ^0 and ϕ in DIS	JHEP05 (2010) 032	P-dissociative J/ψ in PHP at large t	JHEP 05 (2010) 085
Diffractive Scattering of Photons with Large t	Phys.Lett.B 672 (2009) 219	Exclusive PHP of Υ Mesons	Phys. Lett. B 680 (2009) 4
Diffractive PHP of ρ^0 with large t	Phys.Lett.B 638 (2006) 422	Exclusive ρ^0 in DIS	PMC Physics A 1, (2007) 6
Elastic J/ψ in PHP and DIS	Eur.Phys.J.C46 (2006) 585	Exclusive ϕ in DIS	Nucl. Phys. B 718 (2005) 3
Diffractive PHP of J/ψ with large t	Phys Lett B568 (2003) 205	Exclusive J/ψ in DIS	Nucl. Phys. B 695 (2004) 3
Diffractive PHP of $\psi(2S)$	Phys.Lett.B541 (2002) 251	P-dissociative VM in PHP at large t	Eur. Phys. J. C 26 (2003) 389
Helicity structure of ρ^0 in DIS	Phys.Lett.B539 (2002) 25	Exclusive PHP of J/ψ mesons	Eur. Phys. J. C 24 (2002) 345
Elastic ϕ in DIS	Phys.Lett.B483 (2000) 360	Exclusive ω in DIS	Phys. Lett. B 487 (2000) 273
Elastic J/ψ and Υ in PHP	Phys.Lett.B483 (2000) 23	Diffractive PHP of VM at large t	Eur. Phys. J. C 14 (2000) 213
Elastic ρ^0 in DIS	Eur.Phys.J.C13 (2000) 371	Spin-Density ME of Exclusive ρ^0 in DIS	Eur. Phys. J. C 12 (2000) 393
Quasi-elastic $(z > 0.95)$ $\psi(2S)$ in PHP	Phys.Lett.B421 (1998) 385	Exclusive ρ^0 and J/ψ in DIS	Eur. Phys. J. C 6 (1999) 603
P-diss. ρ^0 and Elastic ϕ in DIS	Z.Phys.C75 (1997) 607	Elastic Υ Photoproduction	Phys. Lett. B 437 (1998) 432
Elastic and Inelastic J/ψ in PHP	Nucl.Phys.B472 (1996) 3	Elastic and p-Dissociative ρ^0 in PHP	Eur. Phys. J. C 2 (1998) 247
Elastic ρ^0 and J/ψ at large Q^2	Nucl.Phys.B468 (1996) 3	Elastic J/ψ in PHP	Z. Phys. C 75 (1997) 215
Elastic Rho0 in PHP	Nucl.Phys.B463 (1996) 3	Elastic ω in PHP	Z. Phys. C 73 (1996) 73
		$\gamma^\star p \to \phi p$ in DIS	Phys. Lett. B 380 (1996) 220
		Elastic ϕ in PHP	Phys. Lett. B 377 (1996) 259
		Elastic ρ^0 in PHP	Z. Phys. C 69 (1995) 39
		Exclusive ρ^0 in DIS	Phys. Lett. B 356 (1995) 601

Measured are: $\rho, \rho', \omega, \phi, J/\psi, \psi(2S), \Upsilon$ in EL and PD channels and for $0 < Q^2 < 100\text{GeV}^2$
More than 5000 references; a couple of new "preliminary" results and ongoing analyses. $\Rightarrow$
Too much to cover in one talk.

Plan of the talk

- HERA Legacy: Overall picture and general properties
- Is that all? What still can be done with H1 data
- Some lessons: What can be improved for future experiments



$V = \rho, \omega, \phi, J/\psi, \Upsilon, ...$

Covered PS at HERA

$0 < Q^2 < 100$ GeV^2

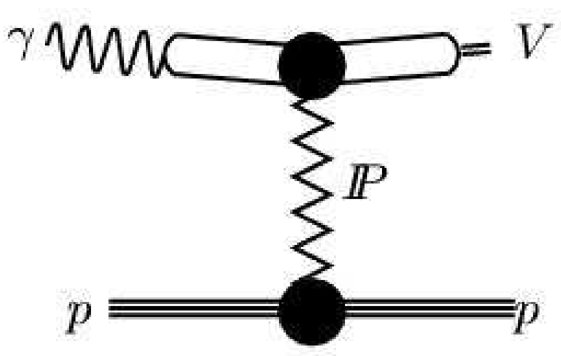
$25 < W < 305$ GeV

$0 < |t| < 30$ GeV^2

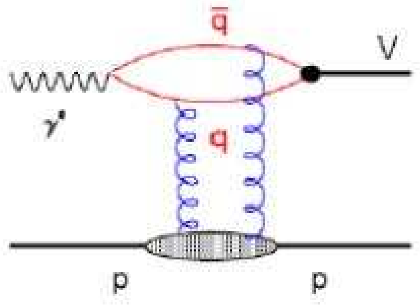
Hard scale can be provided by Q^2 and M_V^2 (at γ^* vertex) or/and by $|t|$ (at p vertex)

Modelling VM Production at HERA

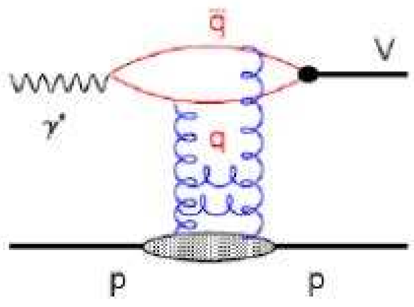
No hard scale present



Hard scale(s) present



LO 2 gluons



LL1/x ladder

VDM $\oplus$ Regge

CD picture ($\sigma \propto \Psi_{\gamma^* \to q\bar{q}} \cdot \sigma_{(q\bar{q})p} \cdot \Psi_{q\bar{q} \to V}$)

soft $I\!\!P$omeron exchange

$\alpha_{I\!\!P}(0)$=1.08; $\alpha'_{I\!\!P}$=0.25

$\sigma \propto W^{4(\alpha_{I\!\!P}-1)}$

$(\alpha_{I\!\!P}(t) = \alpha_{I\!\!P}(0) + \alpha'_{I\!\!P} t)$

hard $I\!\!P$omeron diagrams

$\alpha_{I\!\!P}(0) \simeq 1.20$; $\alpha'_{I\!\!P} \simeq 0$

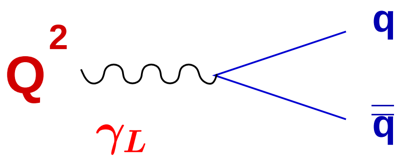
$\sigma \propto [xg(x, Q^2)]^2$

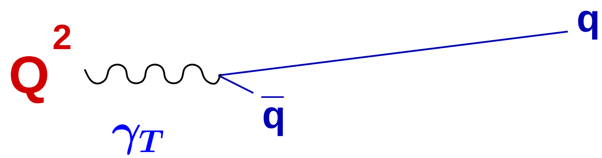
Questions of interest

- γp vs hh - is $I\!\!P$ trajectory universal?
- Is $I\!\!P$ trajectory indeed linear?
- Transition to hard regime: when and how?
- Direct access to (low x) gluons
- DGLAP vs BFKL evolution
- Confront $\sigma_{(q\bar{q})p}$ models with data

Baseline for $\gamma^* A$ physics

Interplay between soft and hard processes in DIS

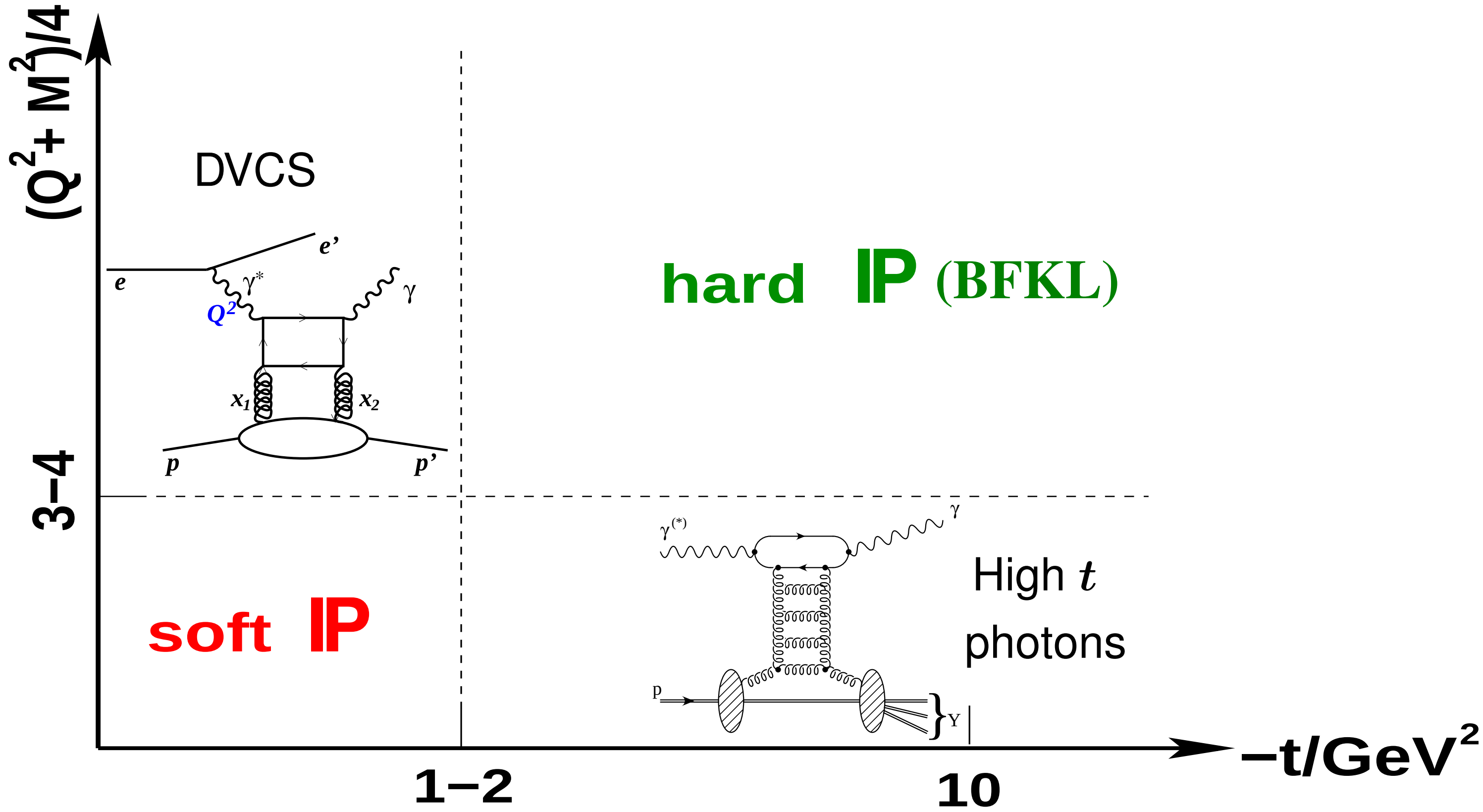




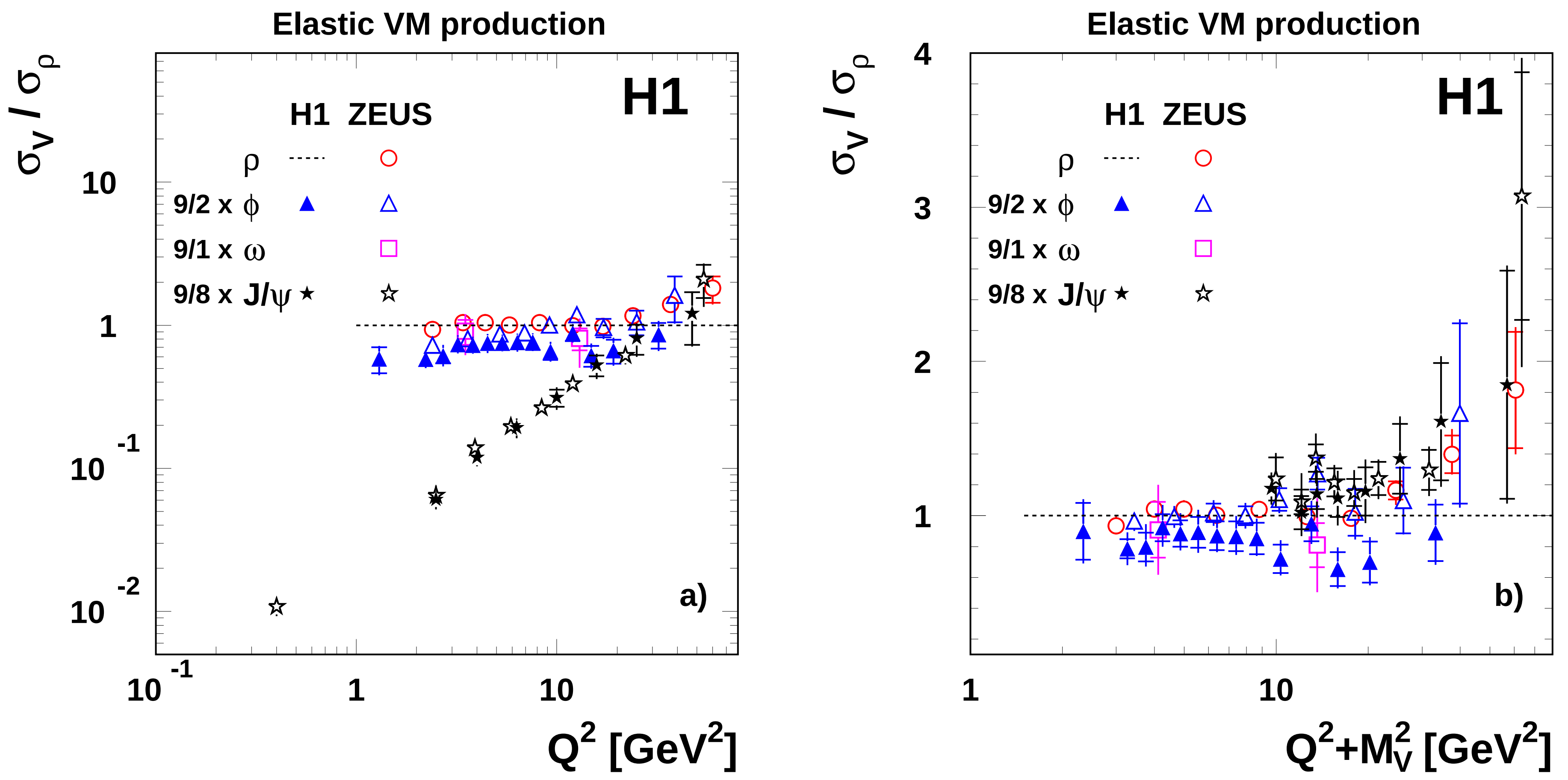
γ_L $(z \simeq 0.5)$: $\langle r_t^2 \rangle \simeq (z(1-z)Q^2 + m_q^2)^{-1} \simeq 1/[(Q/2)^2 + m_q^2]$ $(P \sim 1)$

γ_T $(z \simeq 0; 1)$: $\langle r_t^2 \rangle \simeq (z(1-z)Q^2 + m_q^2)^{-1} \simeq 1/m_q^2$ $(P \sim m_q^2/Q^2)$

Small dipole ('hard') Large dipole ('soft')



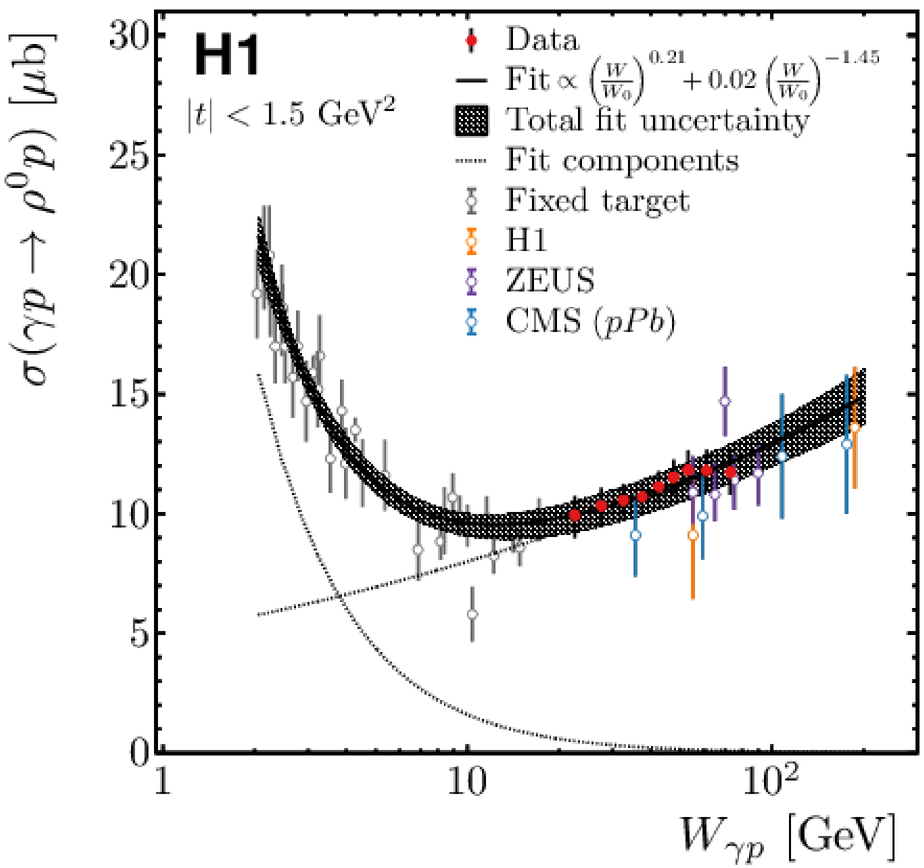
Flavour dependence. Universality

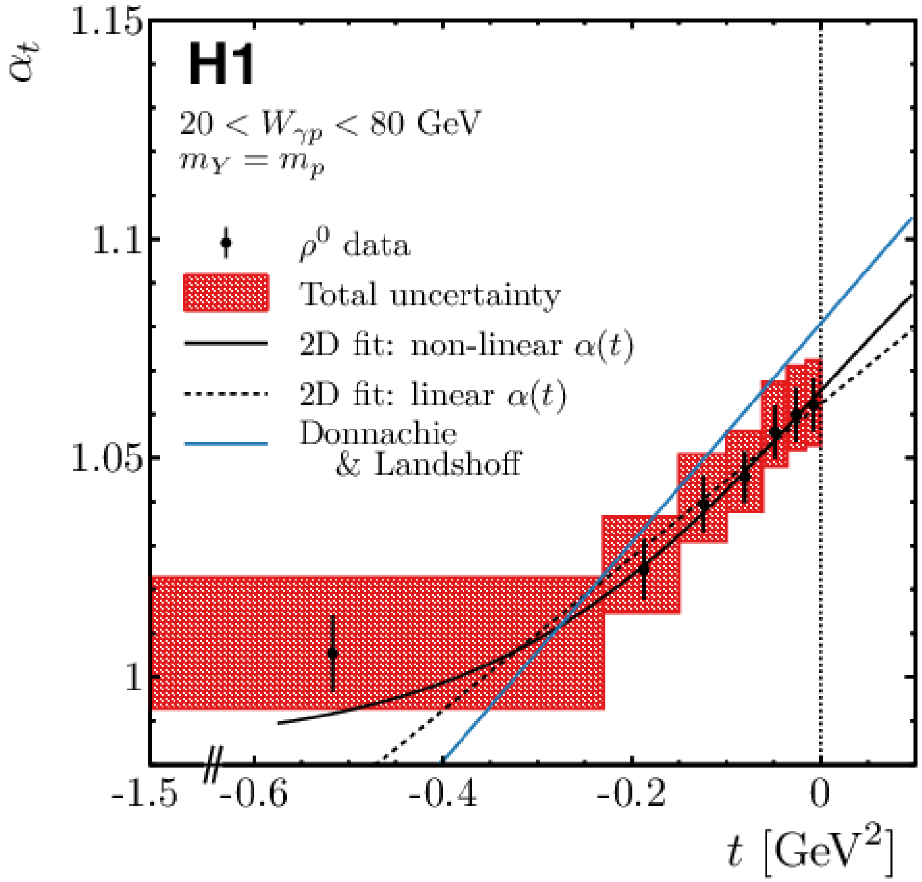


Ratios (scaled according to quark charge content) show large difference as a function of Q^2, but they become close to 1 (up to WF effects) once plotted vs scaling variable $Q^2 + M_V^2$

$\Rightarrow$ Cross sections are essentially determined by the dipole size

Soft regime. Regge in full glory



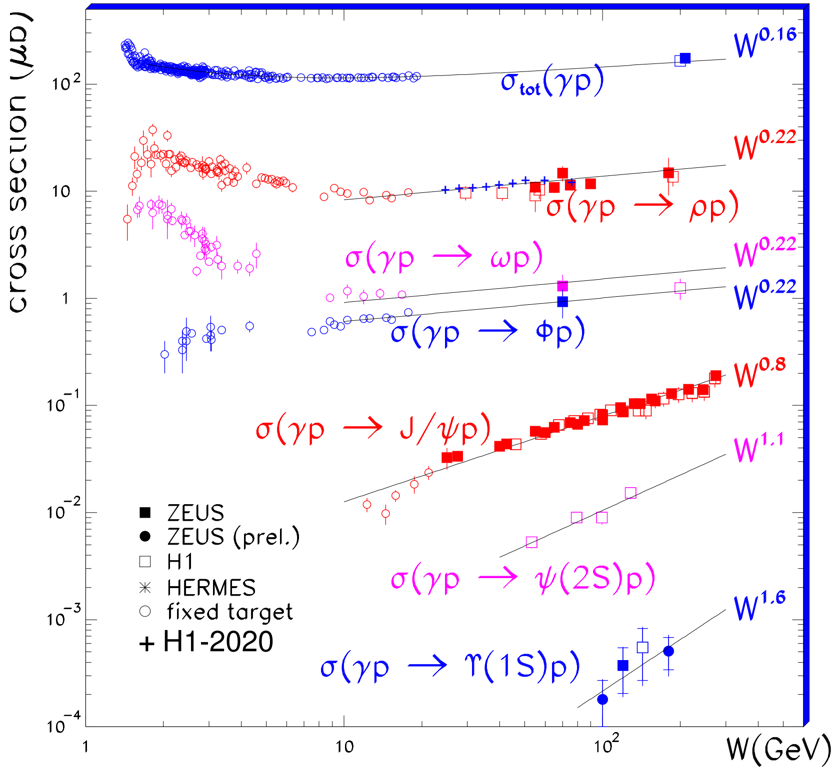


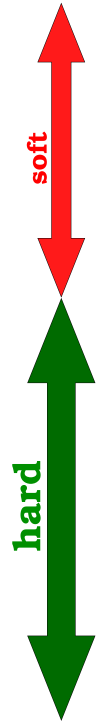
Most recent and precise measurement of elastic ρ^0 in PHP *[H1 Collab., EPJC 80 (2020), 1189]*

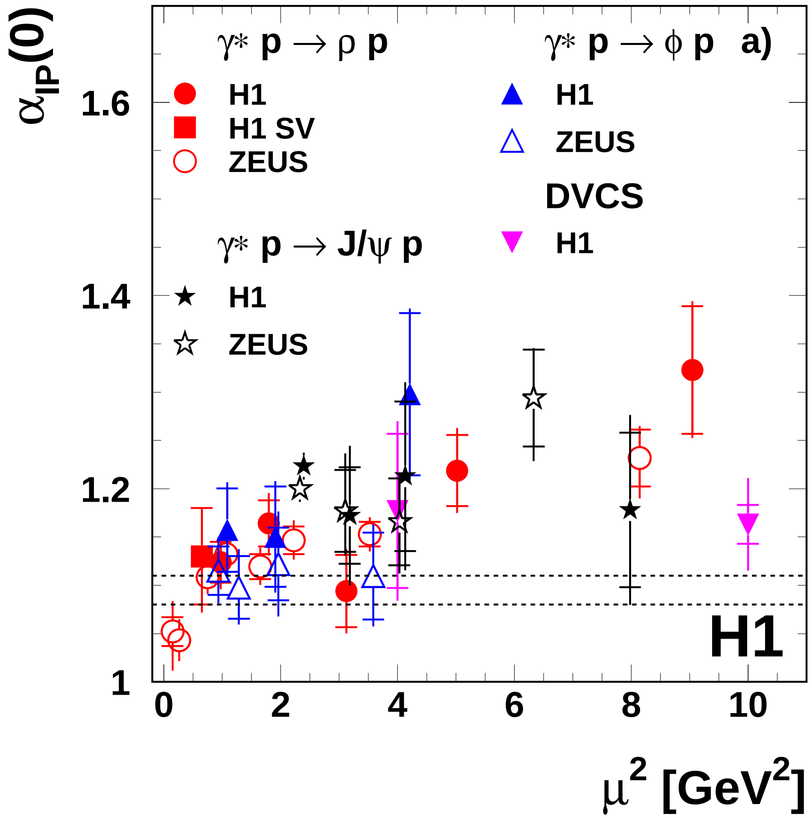
Typical soft behaviour with $\alpha_{I\!P}(0) = 1.065 \pm 0.004 \pm 0.007$

$I\!P$ trajectory is linear at small $|t|$ with possible non-linearity at $|t| > 0.2$ GeV^2

W dependence. Transition from soft to hard regime





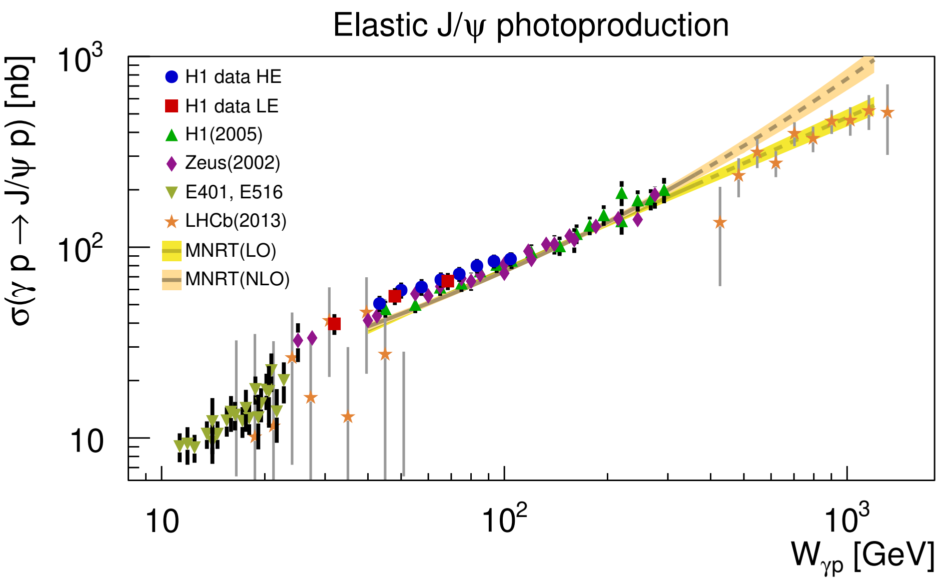


Elastic Photoproduction of VM

Elastic VM in PHP and DIS; DVCS

Transition from soft to hard regime occurs at 'universal' scale $\mu^2 = (Q^2 + M_V^2)/4 \simeq 3 \div 4$ GeV^2

Elastic Photoproduction of J/ψ mesons - Sensitivity to the g/p



- Extrapolating HERA fit describes LHCb
- Low x gluon, based on old HERA data (A. Martin et al, 2008). NLO too steep

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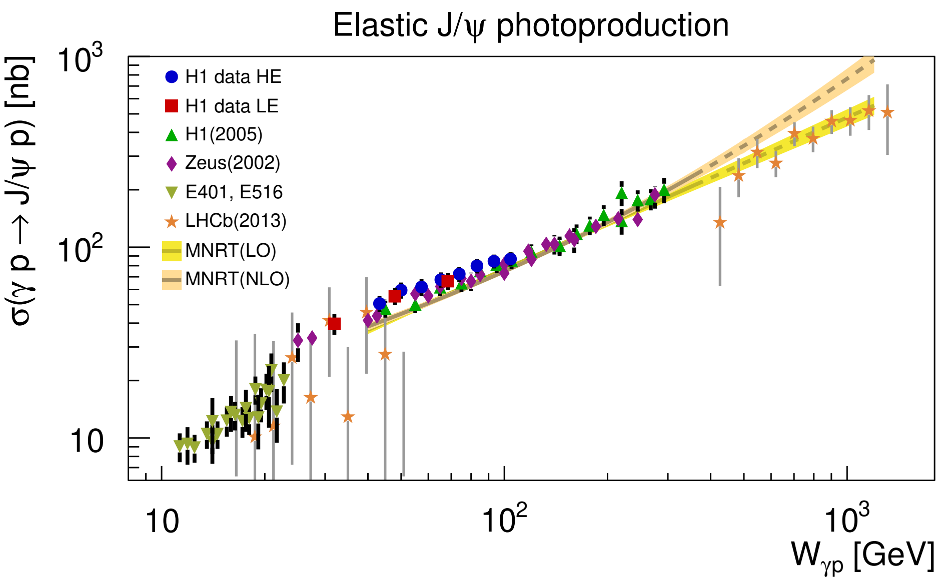
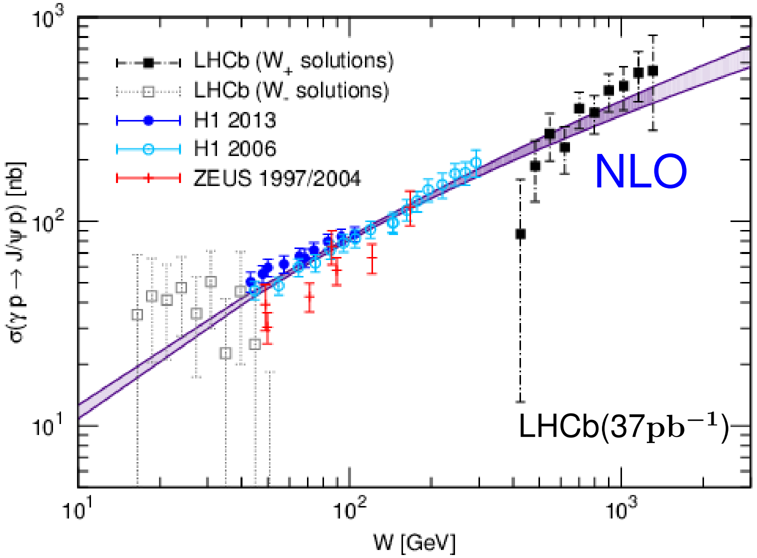
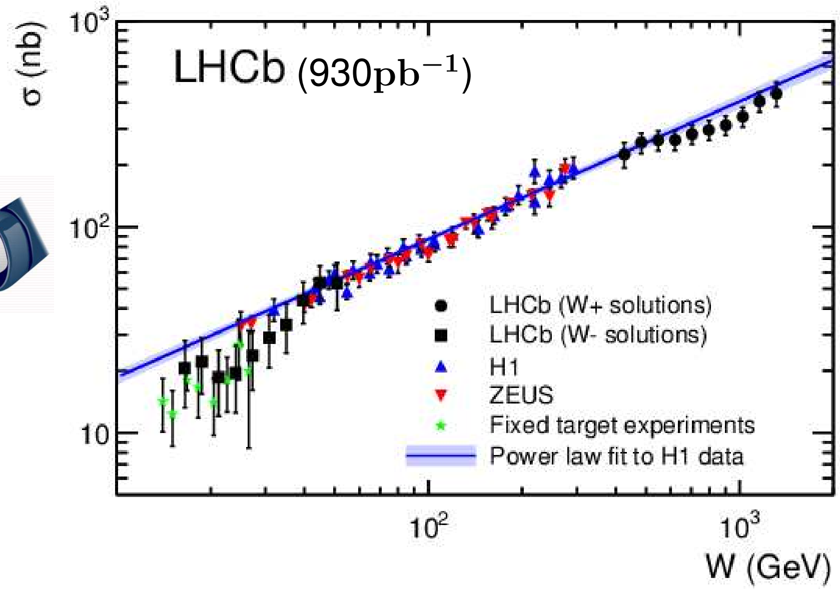
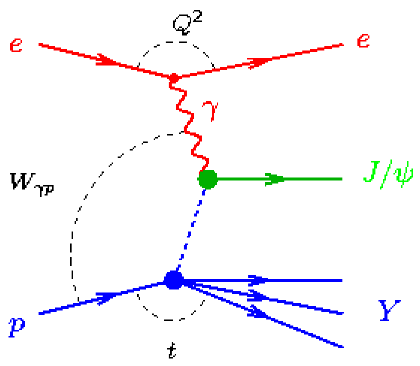


- Extrapolating HERA fit describes LHCb
- Low x gluon, based on old HERA data (A. Martin et al, 2008). NLO too steep
- New QCD analysis (A.Martin et al, 2013) skewed $g(x, x', k_T)$, abs.corr. for LHC
- New LHCb data (930pb^{-1}) [arXiv:1401.3288]





Photoproduction of J/ψ mesons with large t - BFKL $I\!P$ at work



Hard scale at both vertices

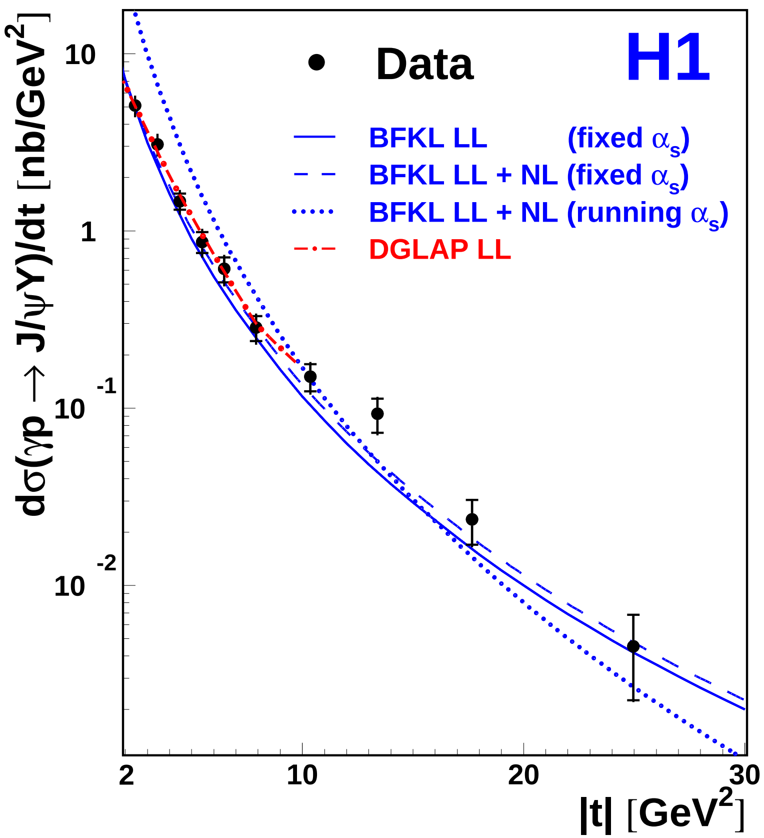
Data sample: $\mathcal{L} = 78 \text{ pb}^{-1}$

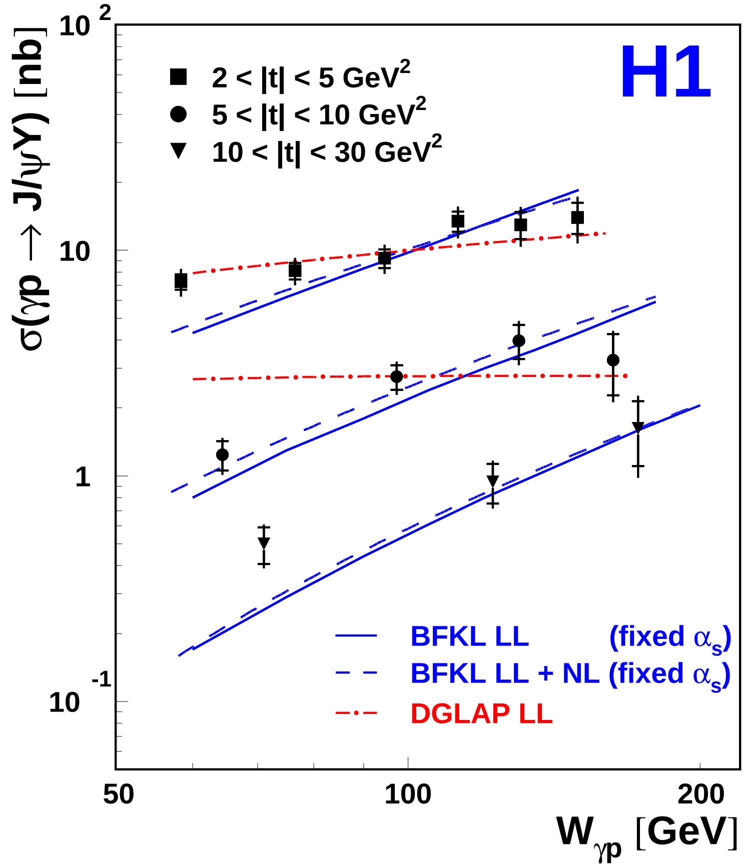
$|t| > 2,\ 50 < W < 150,\ z > 0.95$

Final statistics: 846 ± 30 events

$\alpha_{I\!P}(0) = 1.17 \pm 0.05$

$\alpha'_{I\!P} = -0.014 \pm 0.009$

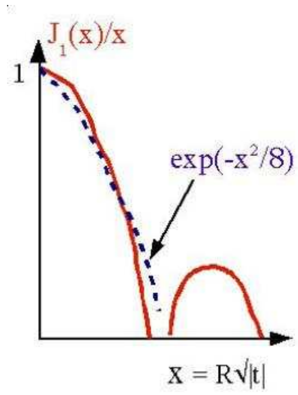




$t-$dependence. Shrinkage of diffractive peak

$d\sigma/dt \sim e^{-b|t|}$ $\rightarrow$ diffractive peak (approximated from Bessel function)

$b = (R/2)^2$ $\rightarrow$ transverse size of the target (geometric picture)



Predictions: $b = b_0 + 4\alpha'_{I\!P} \ln(W/W_0)$;

soft $I\!P$: shrinkage of diffractive peak ($\alpha'_{I\!P} = 0.25$); large $b_0 \approx 10$ GeV^{-2}

hard $I\!P$: no (or small) shrinkage ($\alpha'_{I\!P} < 0.1$); small $b_0 \approx 5$ GeV^{-2}

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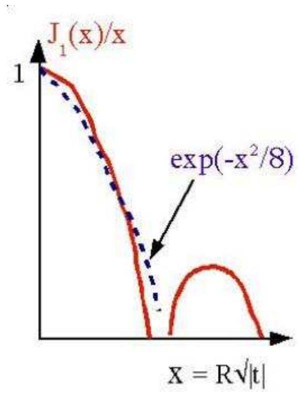

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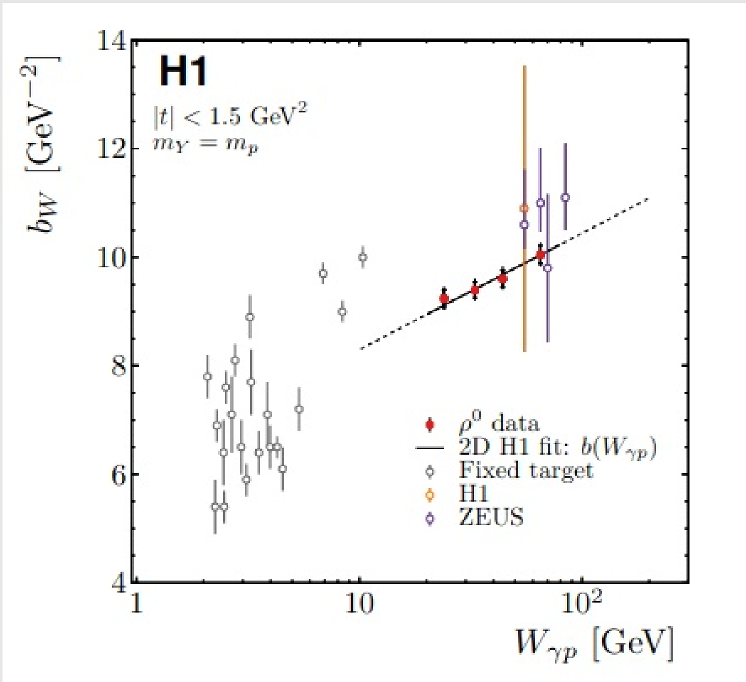
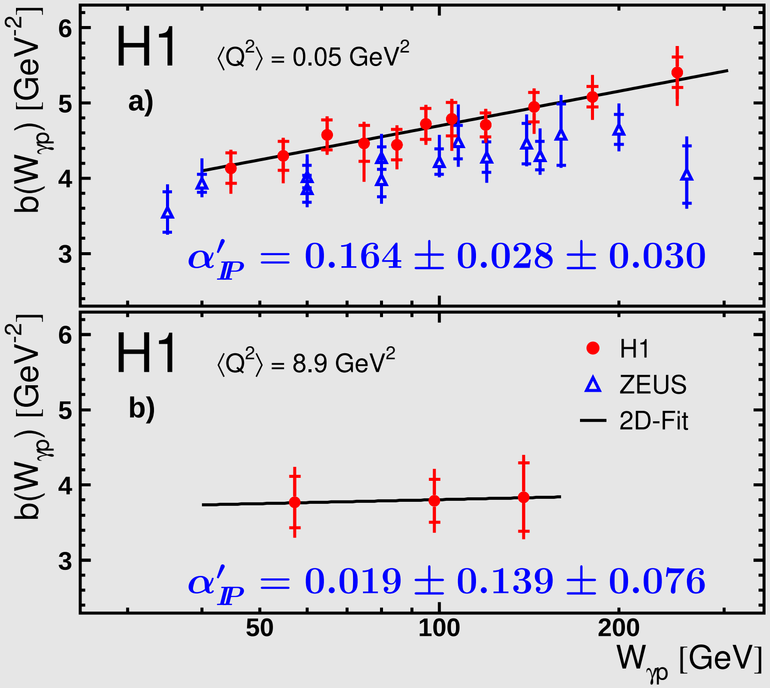


$\gamma p \to \rho^0 p$ (PHP): $\alpha'_{I\!P} = 0.233 \pm 0.064 \pm 0.029$



$\gamma^\star p \to J/\psi p$ (PHP,DIS)

$t-$dependence. Elastic slope vs Universal scale

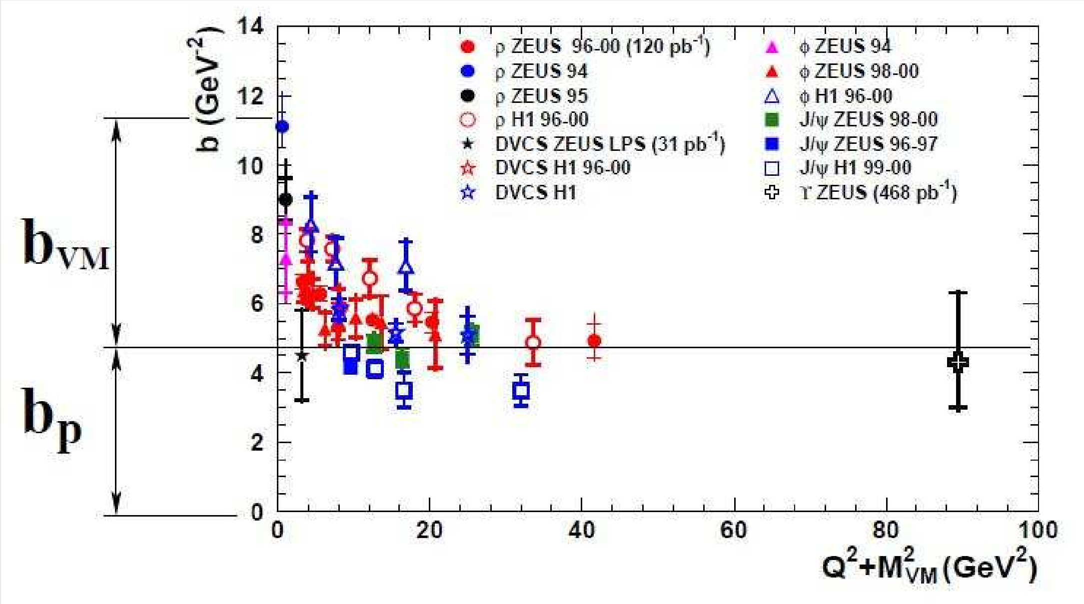
Dipole picture interpretation:

$b = b_{VM} + b_{\rm p}$

$b_{VM} \sim 1/(Q^2 + M^2_{VM})$

$b_{\rm p} \longrightarrow$ size of the gluons area:

$\langle r_g^2 \rangle = 2b_{\rm p} \cdot (\hbar c)^2 \simeq (0.6 \text{ fm})^2$



Gluons confinement area (0.6 fm) is smaller than the proton size (0.84 fm)

$t-$dependence. Elastic slope vs Universal scale

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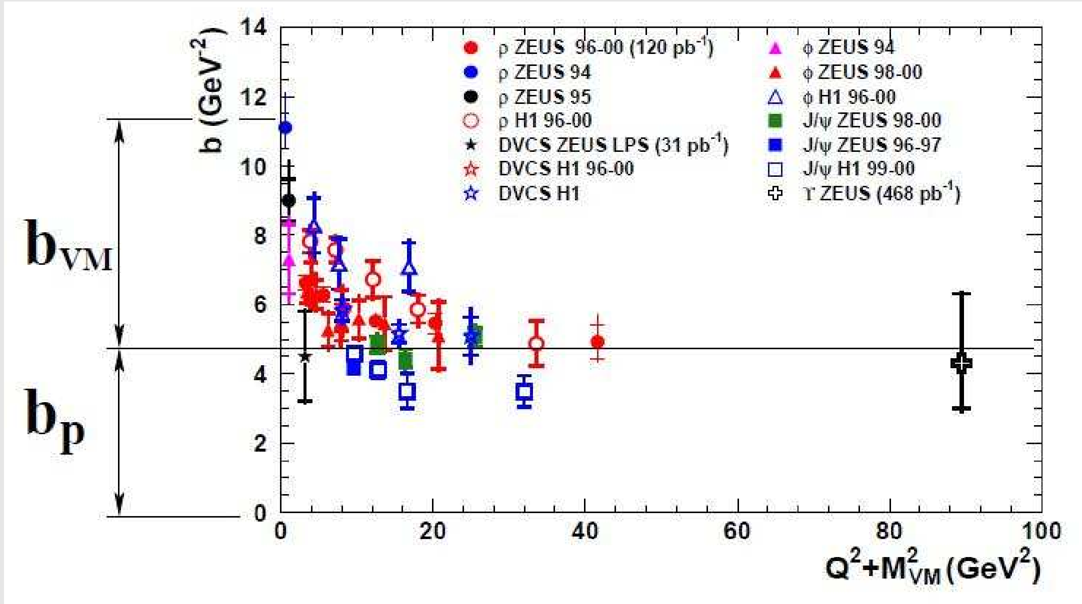
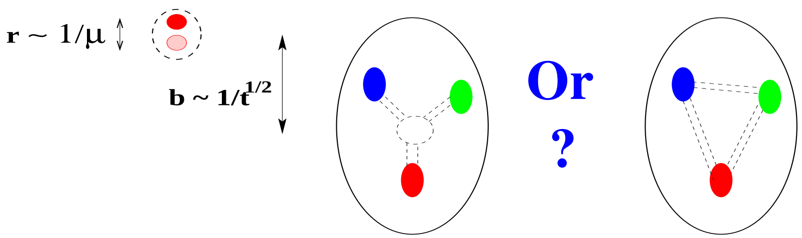


⇒ Gluons confinement area (0.6 fm) is smaller than the proton size (0.84 fm)

What is proton topology?



What is gravitational FF of the proton?

$t-$dependence. Elastic slope vs Universal scale

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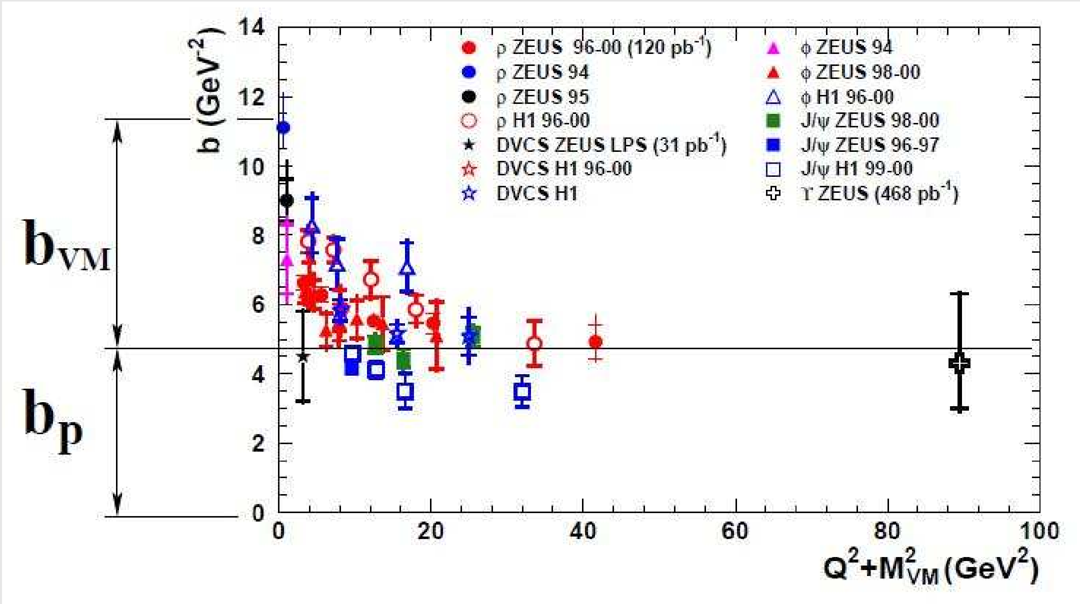

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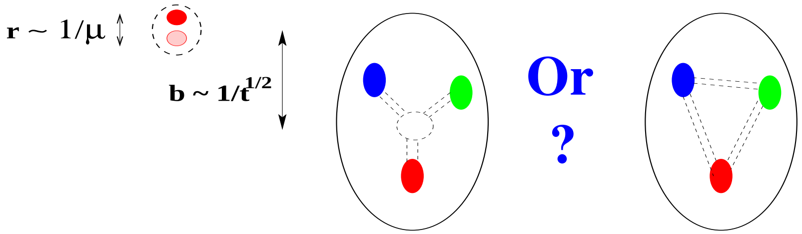

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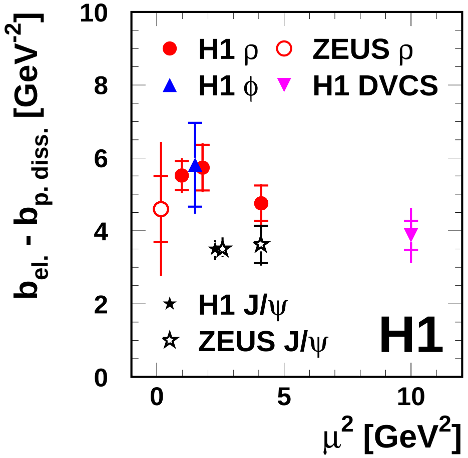


$b_{el} - b_{pd}$ data suggests even 20% smaller $\langle r_g \rangle$

HLFQCD: $\sim 0.34 \div 0.68$ fm

(HLFHS Collab, PRD **104***, 114005 (2021); D.Kharzeev, PRD* **104***, 054015 (2021); Y.Guo et al., PRD* **103***, 096010 (2021))*

Intermediate summary

- Exclusive VM production at HERA provides a rich field for the QCD understanding of diffraction over a large kinematic domain.

- Many aspects are not covered in this talk, like helicity studies, spin density ME, WF effects, comparison of elastic to proton dissociative channels etc.

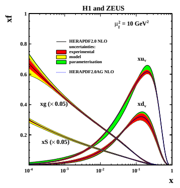
- Full list of published analyses in the field can be found in page 1.

- Several new analyses are ongoing, but we lack a manpower.
  You are welcome to join!

Now I present few selected analyses which can be improved at EIC, or still can be done with existing data, collected by the H1 experiment at HERA.

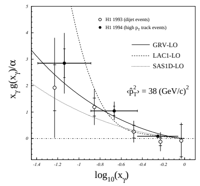
HERA as a '4P' facility

HERA enables to study structure of

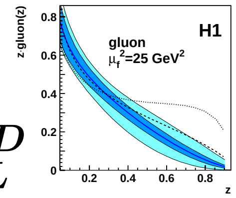


Proton – F_2, F_L, ...

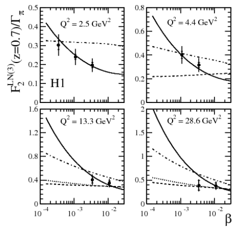
Photon – g/γ



Pomeron – F_2^D, F_L^D

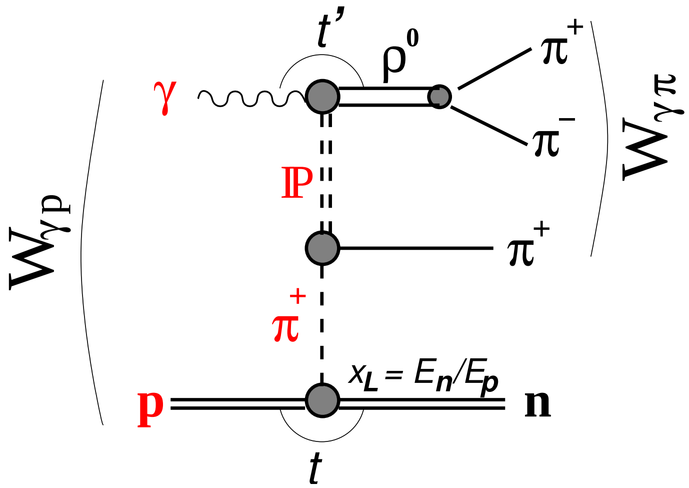


Pion – F_2^π



Here for the first time we investigate the reaction involving all these objects simultaneously:

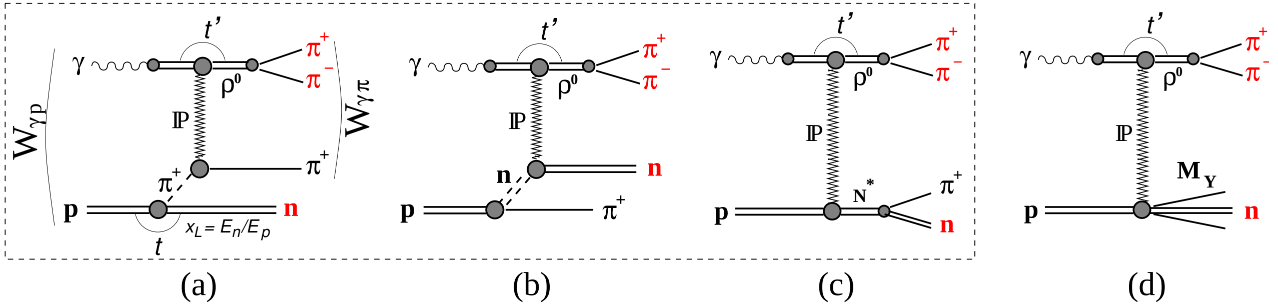
$$\gamma + \mathbf{p} \longrightarrow \rho^0 \pi^+ \mathbf{n}$$



Photoproduction:	$Q^2 < 2$ GeV^2	$(\langle Q^2\rangle = 0.04$ GeV$^2)$
Low p_t:	$\lvert t\rvert < 1$ GeV^2	$(\langle\lvert t\rvert\rangle = 0.20$ GeV$^2)$
Small mass:	$0.3 < m_{\pi\pi} < 1.5$ GeV	(m_{ρ^0})
π^+, π^- in CT:	$20 < W_{\gamma p} < 100$ GeV	$(\langle W_{\gamma p}\rangle = 45$ GeV$)$
Leading n:	$E_n > 120$ GeV;	$\theta_n < 0.75$ mrad

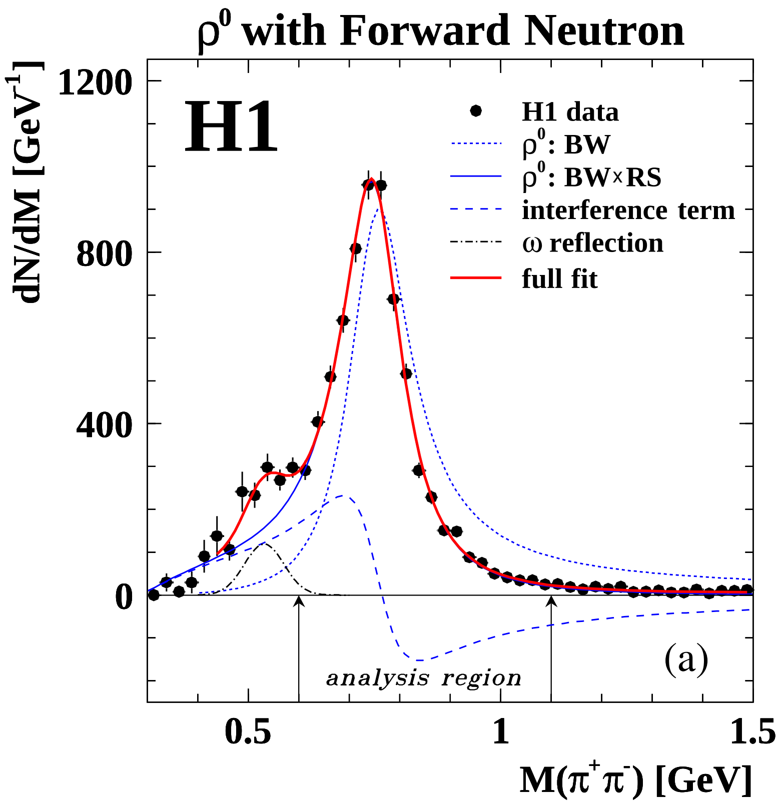
No hard scale present $\Rightarrow$ Regge framework is most appropriate

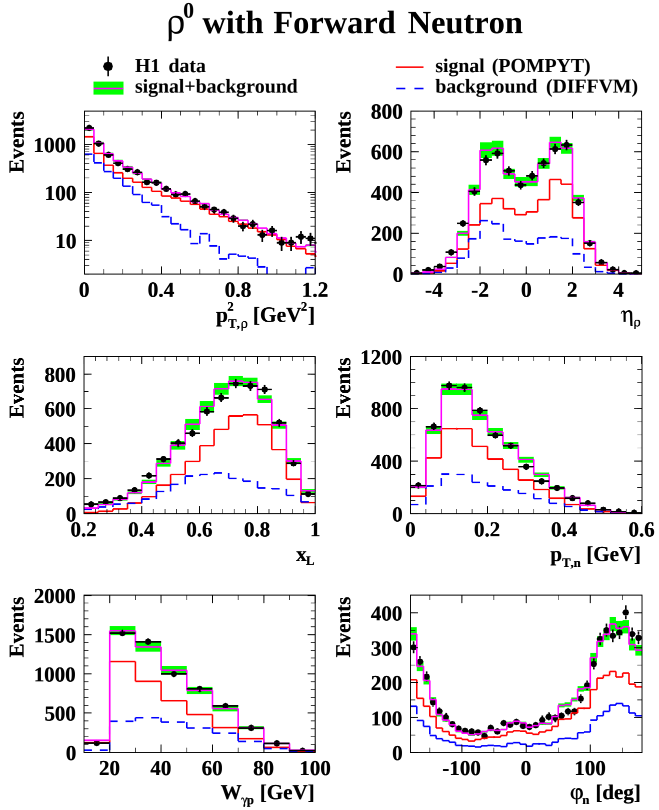
ρ^0 with Leading Neutron: Control plots



Data sample: $\mathcal{L} = 1.16\ \mathrm{pb}^{-1}$
~ 7000 events

Precision: $\delta_{\mathrm{stat}} = 2\%$
$\delta_{\mathrm{sys}} = 14\%$





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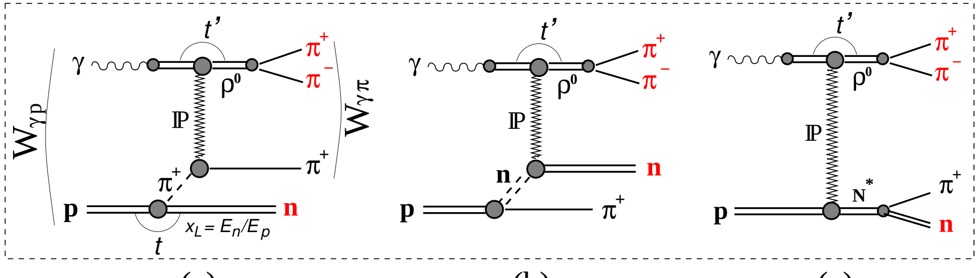


(a) (b) (c) (d)

Data sample: $\mathcal{L} = 1.16\ \mathrm{pb}^{-1}$

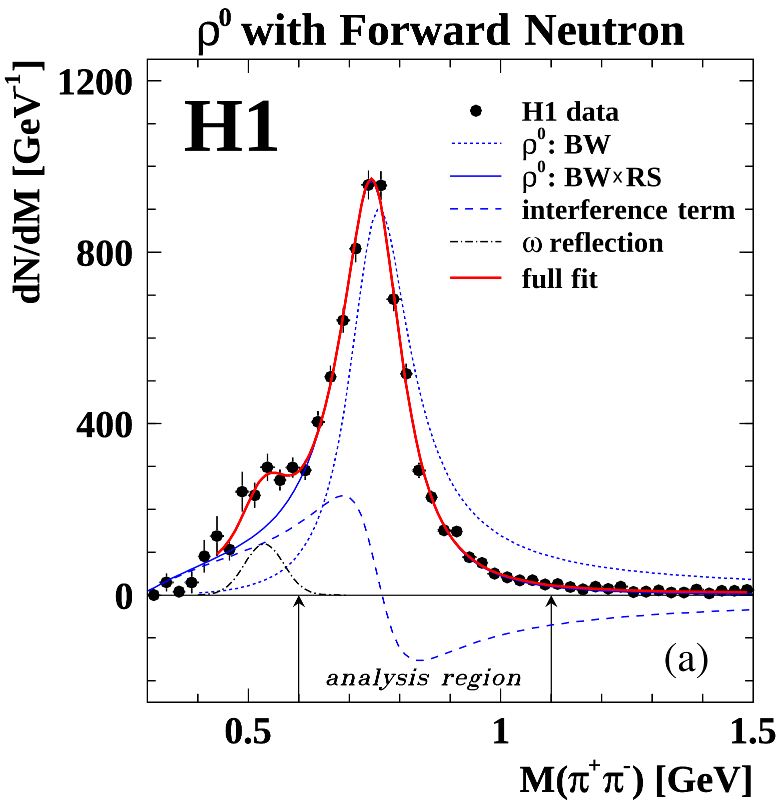
~ 7000 events

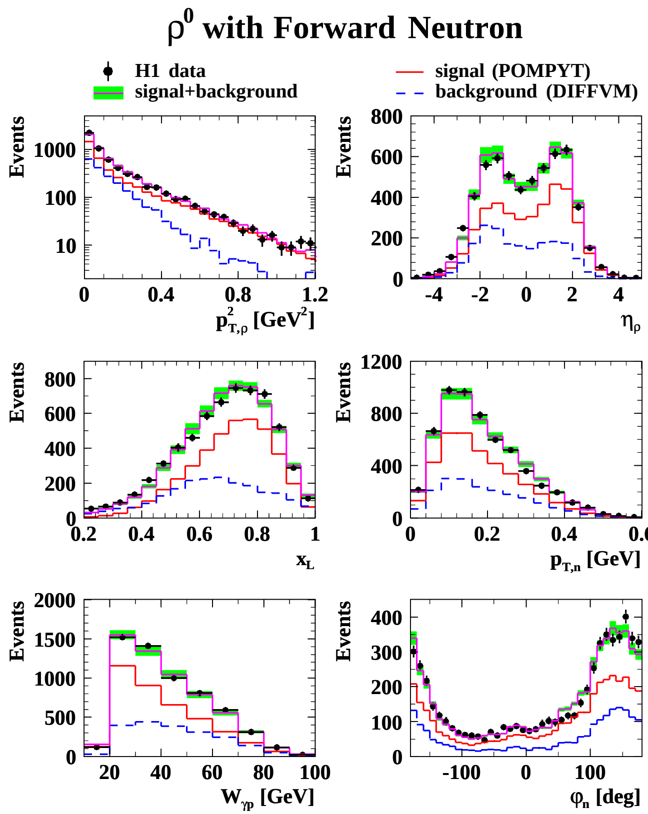
Precision: $\delta_{\mathrm{stat}} = 2\%$

$\delta_{\mathrm{sys}} = 14\%$

Dominant systematics (unobserved π^+_{fwd})

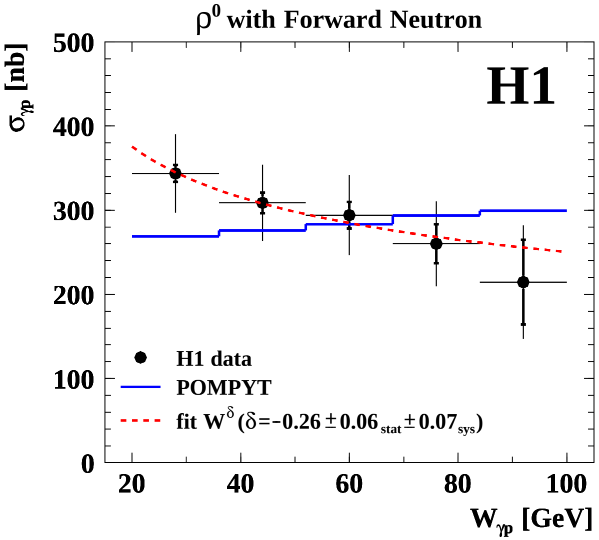
Trigger downscaling

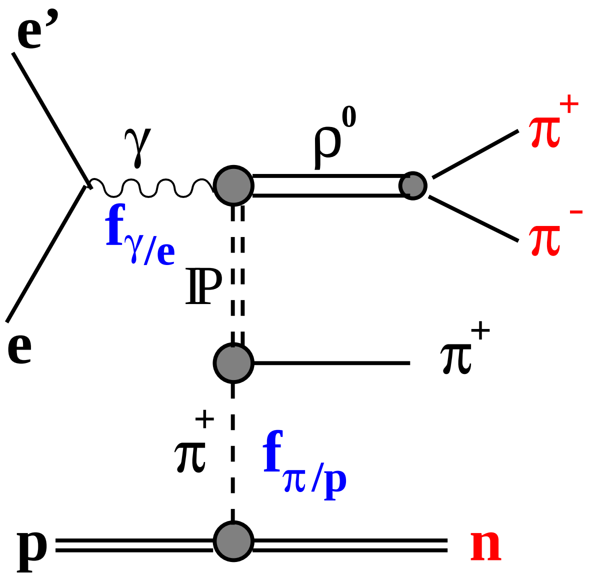




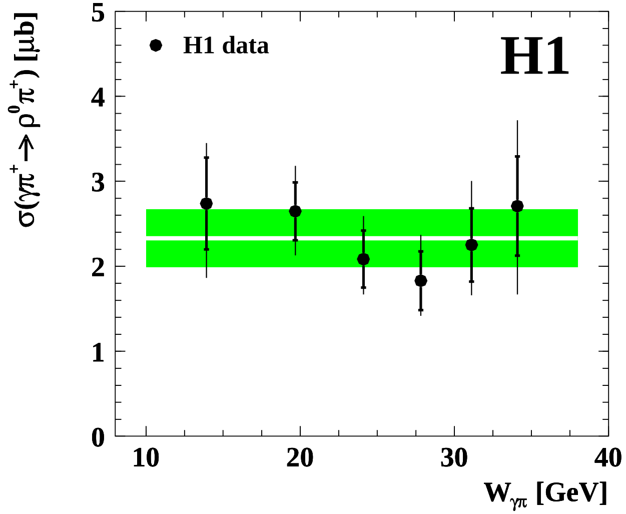
γp and $\gamma\pi$ cross sections

$$\sigma_{\gamma p} = \frac{\sigma_{ep}}{\Phi_\gamma}$$





$$\sigma_{\gamma\pi} = \frac{\sigma_{\gamma p}}{\Gamma_\pi}$$

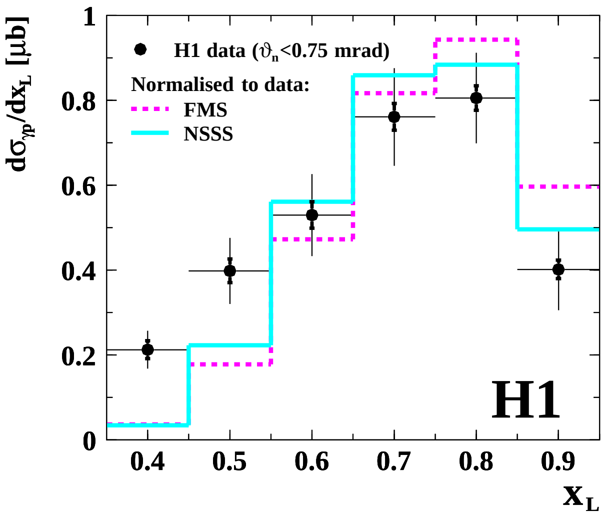


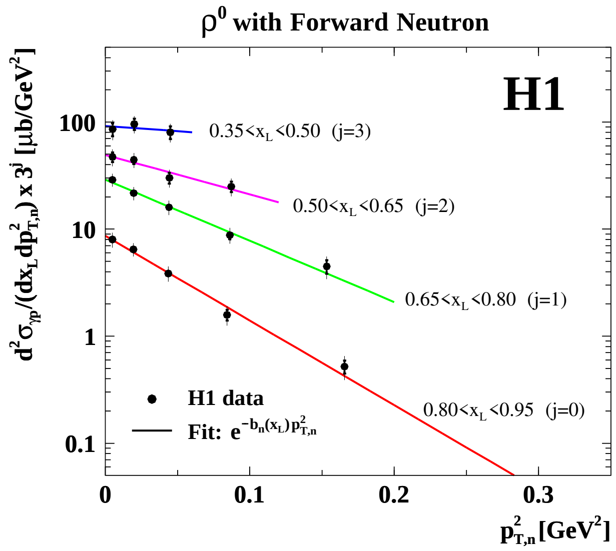
VMD: $$f_{\gamma/e}(y,Q^2) = \frac{\alpha}{2\pi Q^2 y}\left\{\left[1+(1-y)^2 - 2(1-y)\left(\frac{Q^2_{\min}}{Q^2} - \frac{Q^2}{M^2_\rho}\right)\right]\frac{1}{\left(1+\frac{Q^2}{M^2_\rho}\right)^2}\right\}$$

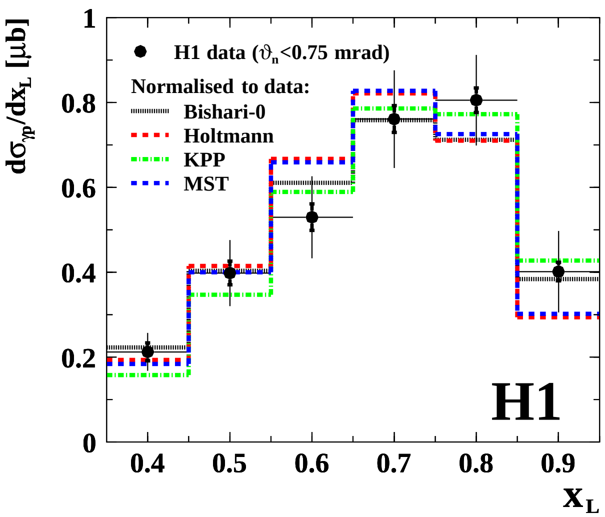
OPE: $$f_{\pi/p}(x_L,t) = \frac{1}{2\pi}\frac{g^2_{p\pi N}}{4\pi}(1-x_L)\frac{-t}{(m^2_\pi - t)^2}\exp\left[-R^2_{\pi n}\frac{m^2_\pi - t}{1-x_L}\right]$$

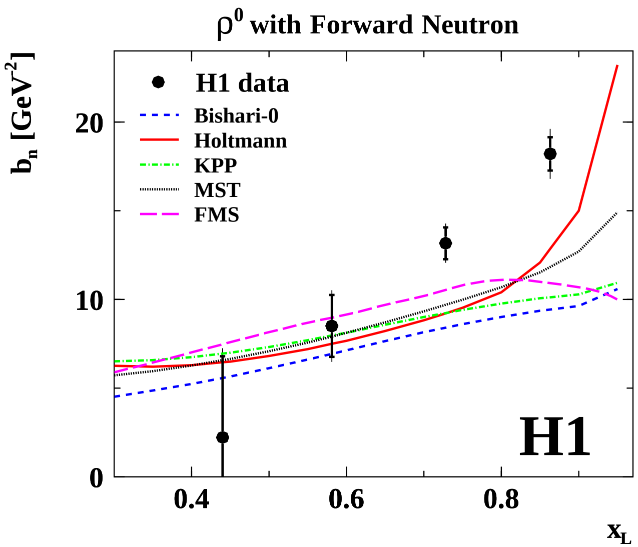
⇒ constrain pion flux by measuring x_L and $t = p^2_{t,n}$

Constraining pion flux







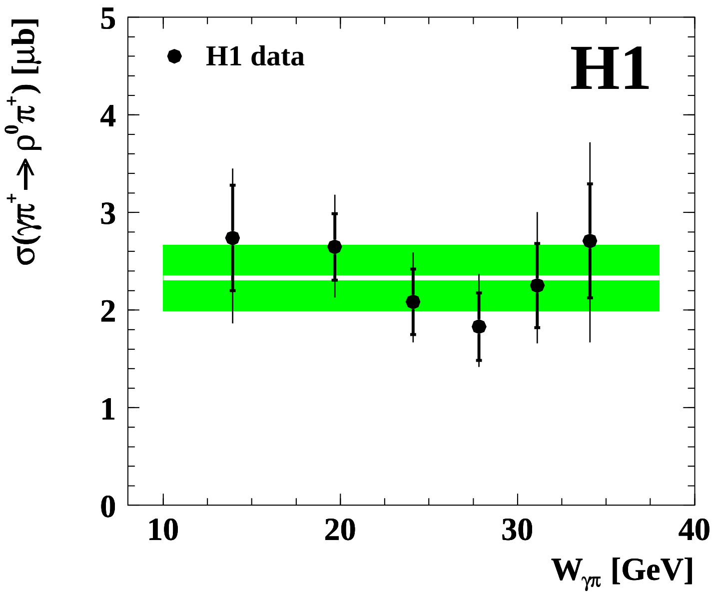


Failure to describe $b_n(x_L)$ suggests strong absorptive effects (n rescattering) $\Rightarrow$ quantify

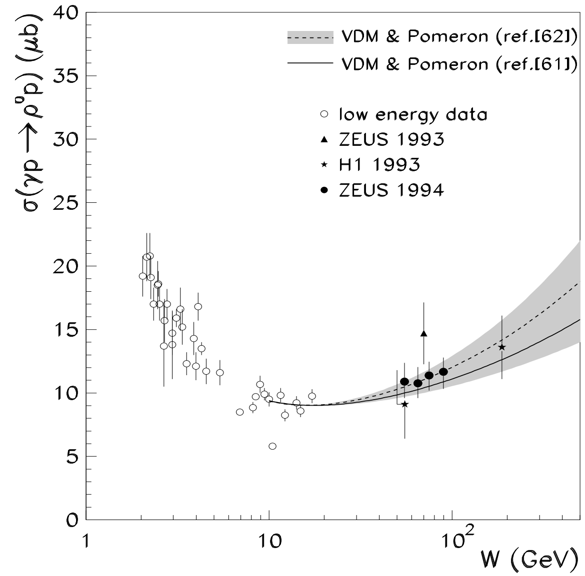
Estimate of absorption corrections

$(2.33 \pm 0.56)\mu$b

γπ



$(9.5 \pm 0.5)\mu$b



γp

$$r_{\rm el} = \frac{\sigma_{\gamma\pi\to\rho^0\pi}}{\sigma^{\gamma p\to\rho^0 p}} = \begin{cases} 0.25 \pm 0.06 & \text{(exp.extracted)} \\ 0.57 \pm 0.03 & \text{(theo.expected)} \end{cases} \Rightarrow K_{\rm abs} = 0.44 \pm 0.11$$

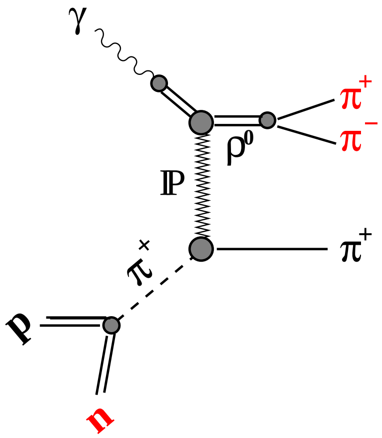
Optical Theorem: $\frac{d\sigma_{el}}{dt}\big|_{t=0} = b_{\rm el}\sigma_{\rm el} \propto \sigma^2_{\rm tot}$ ⇒ $r_{\rm el} = (\frac{b_{\gamma p}}{b_{\gamma\pi}}) \cdot (\sigma^{\gamma\pi}_{\rm tot}/\sigma^{\gamma p}_{\rm tot})^2$

Eikonal approach: $b = \langle R^2 \rangle; \quad b_{12} = b_1 + b_2$

World data: $(b_{pp} \simeq 11.7, \;\; b_{\pi^+ p} \simeq 9.6, \;\; b_{\gamma p} \simeq 9.75)$ GeV^{-2}

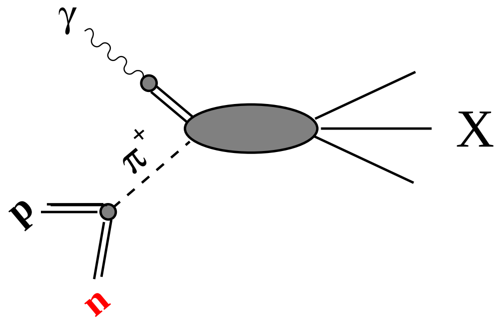
Large absorption in LN reactions

H1 (2015)



$\sigma_{el}^{\gamma\pi}$ (W=24 GeV)

ZEUS (2002)



$\sigma_{tot}^{\gamma\pi}$ (W=107 GeV)

$\sigma_{\rm el}^{\gamma\pi}/\sigma_{\rm el}^{\gamma p} = 0.25 \pm 0.06$	Exp.result	$\sigma_{\rm tot}^{\gamma\pi}/\sigma_{\rm tot}^{\gamma p} = 0.32 \pm 0.03$
OT+eikonal approach+data: $r_{\rm el} \simeq 0.57$	Theory	AQM: $r_{\rm tot} \simeq 2/3$

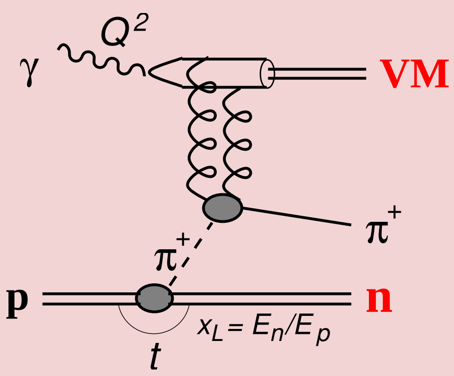
Large absorption effects!

Optical Theorem: $\frac{d\sigma_{el}}{dt}|_{t=0} = b_{\rm el}\sigma_{\rm el} \propto \sigma_{\rm tot}^2$ ⇒ $r_{\rm el} = (\frac{b_{\gamma p}}{b_{\gamma\pi}}) \cdot (\sigma_{\rm tot}^{\gamma\pi}/\sigma_{\rm tot}^{\gamma p})^2$

Eikonal approach: $b = \langle R^2 \rangle; \quad b_{12} = b_1 + b_2$

World data: $(b_{pp} \simeq 11.7, \;\; b_{\pi^+ p} \simeq 9.6, \;\; b_{\gamma p} \simeq 9.75)$ GeV^{-2}

Exclusive electroproduction of $VM + n$



VM+n in DIS

All HERA-2 data

$\mathcal{L} = 334\ \mathrm{pb}^{-1}$

(VM = $\rho^0, \phi, J/\psi$)

- Compare to PHP $\Rightarrow$ Q^2 dependence
- Compare to DIS $\Rightarrow$ (VM+n)/(VM+Y)
- Access to the g/π
- Absorption in DIS ?

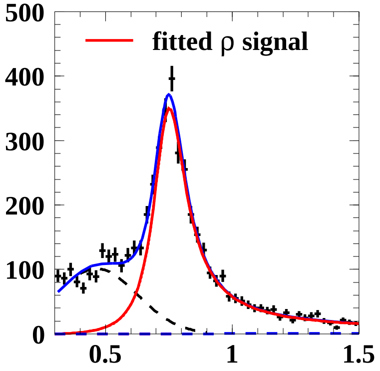


Figure 41 M(ππ) [GeV]

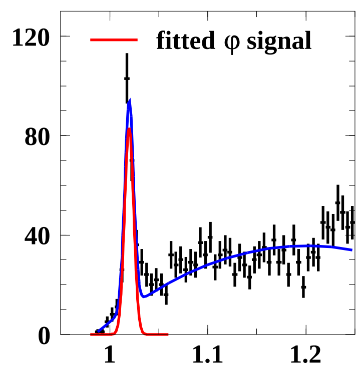


Figure 42 M(KK) [GeV]

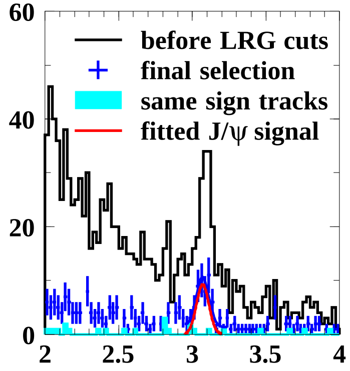
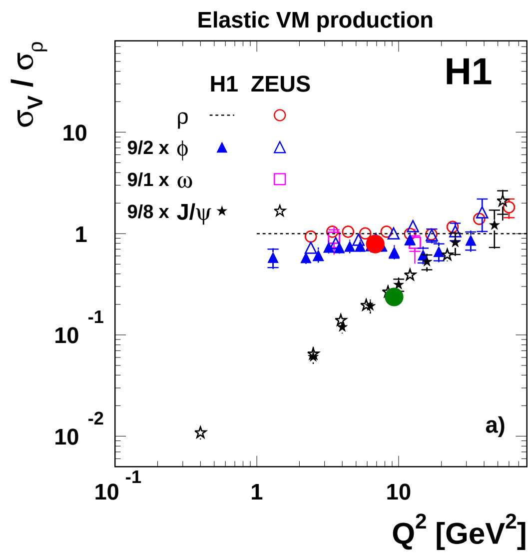


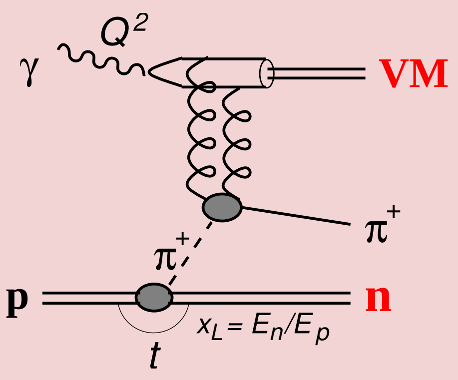
Figure 43 M [GeV]



- Signal yield for $Q^2 > 3$ GeV^2: $3000\ \rho^0,\ \ 300\ \phi,\ \ 48\ J/\psi$
- Missing: signal MC (DiffVM with π-flux); Personpower

- $\bullet - \phi : \rho$ for $VM + n$ reaction
- $\bullet - J/\psi : \rho$ for VM $+ n$ reaction

Exclusive electroproduction of $VM + n$



VM+n in DIS

All HERA-2 data

$\mathcal{L} = 334\ \mathrm{pb}^{-1}$

(VM = $\rho^0, \phi, J/\psi$)

- Compare to PHP $\Rightarrow$ Q^2 dependence
- Compare to DIS $\Rightarrow$ (VM+n)/(VM+Y)
- Access to the g/π
- Absorption in DIS ?

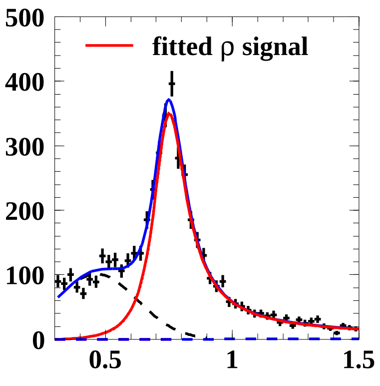


Figure 41

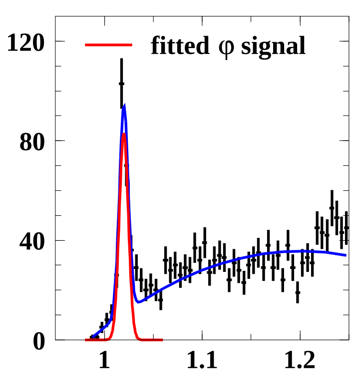


Figure 42

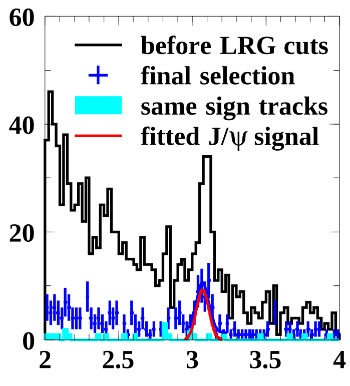
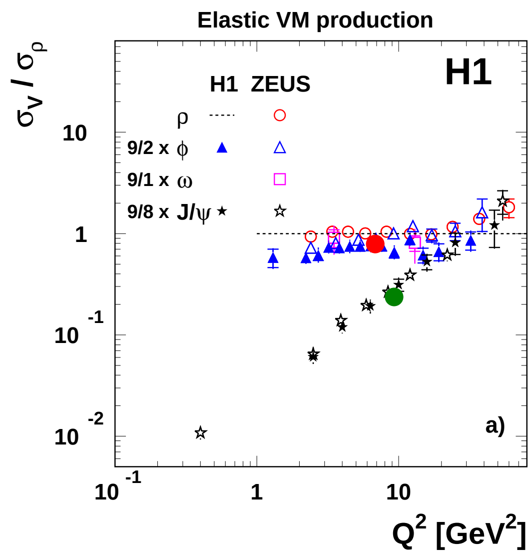


Figure 43

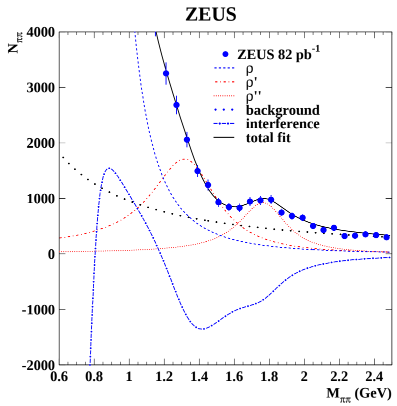


- Signal yield for $Q^2 > 3$ GeV^2: $3000\ \rho^0,\ 300\ \phi,\ 48\ J/\psi$
- Missing: signal MC (DiffVM with π-flux); Personpower

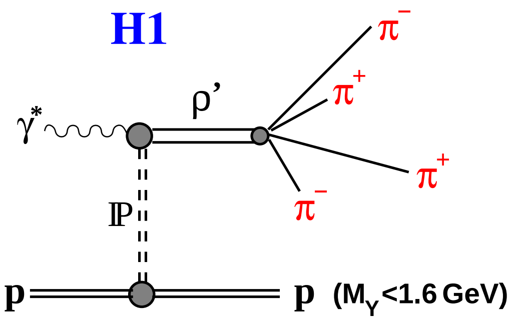
- $-\ \phi : \rho$ for $VM + n$ reaction
- $-\ J/\psi : \rho$ for $VM + n$ reaction

Disappointed by low J/ψ statistics? Try $(J/\psi + n)$ in PHP $(500 \div 1000$ events expected)

$\rho' \to 2\pi^+2\pi^-$ analyses



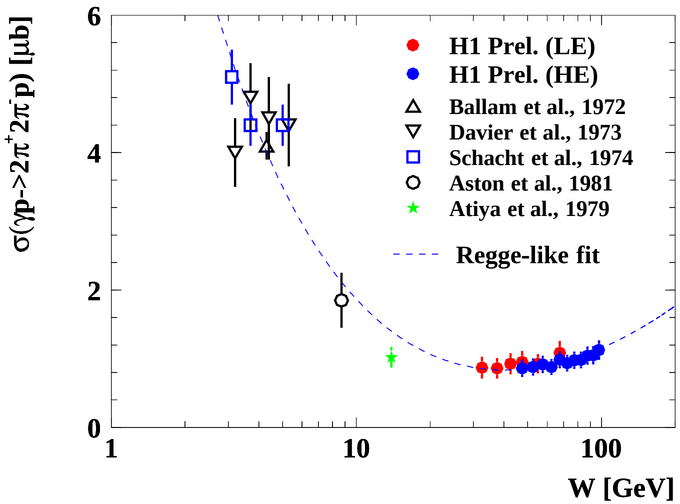
ZEUS-2012:
$\gamma^\star p \to \pi^+\pi^- p \; (Q^2 > 2)$

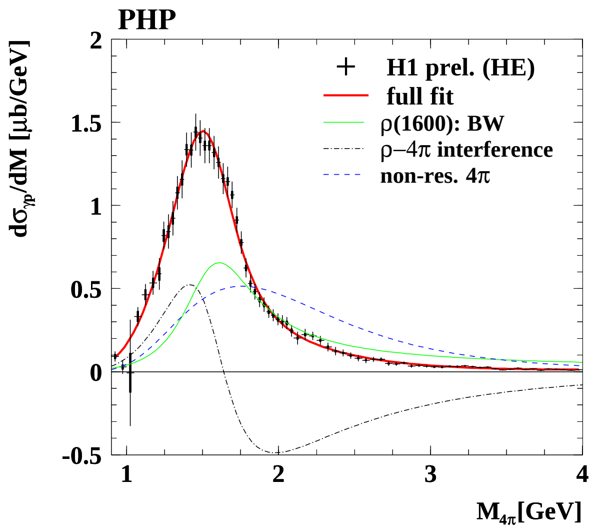


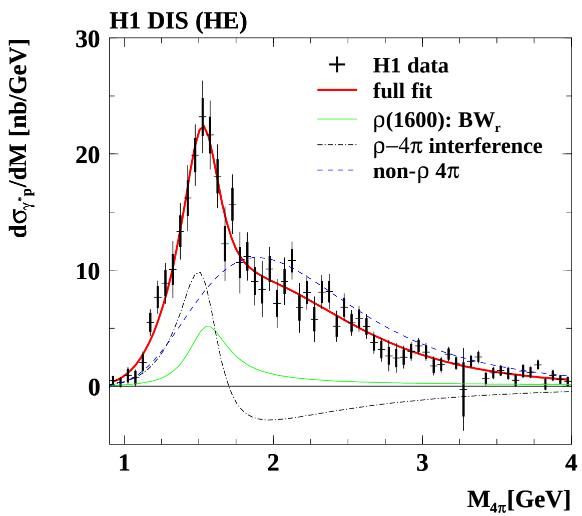
$\Rightarrow$ try $\rho' \to 4\pi$ decay channel
(PHP,DIS; HE,LE regimes)

Item / Regime	PHP HE	PHP LE	DIS HE	DIS LE
Lumi [pb-1]	7.8	1.7	136.5	9.2
Trigger	s13	s13	mix(w=1.025)	s1
Q2 cut [GeV2]	<2		>5	>3
<Q2> [GeV2]	0.04		10.1	7.4
W range [GeV]	45-100	35-75	40-150	25-100
<W> [GeV]	66	48	86	58
WWA flux	0.074382	0.069403	0.01666	0.01748
Statistics	79,776	14,411	10,410	0,851
Bgr(non-ep/PHP PHP/DIS)	1.0%	1.6%	<0.2%	2.4% (Q2<4)

Decent statistics, clean signals

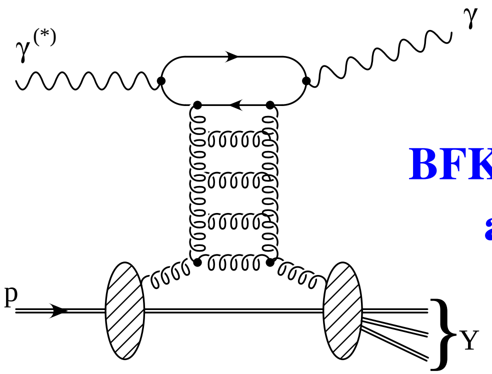




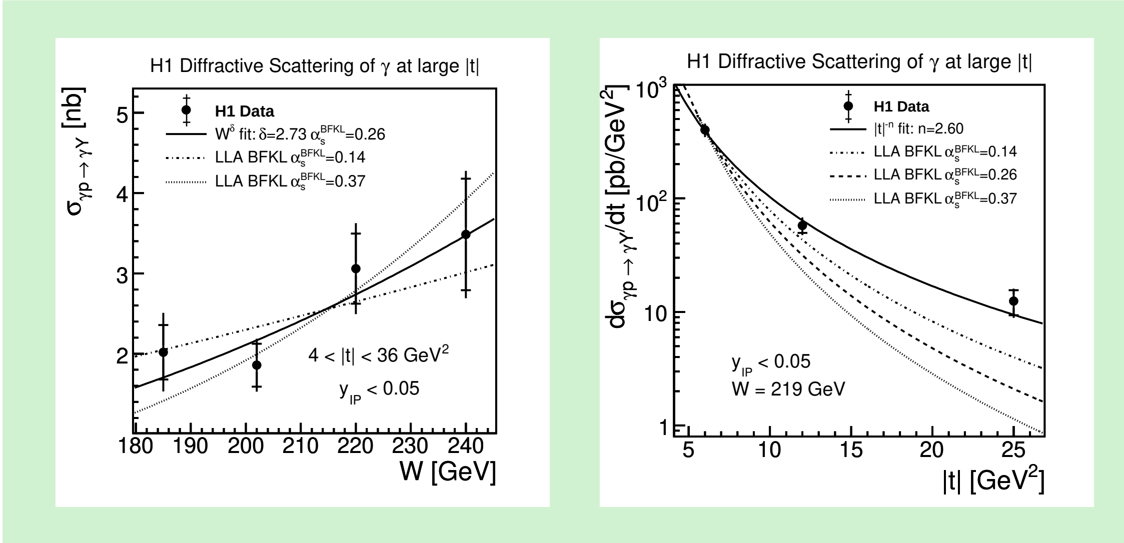


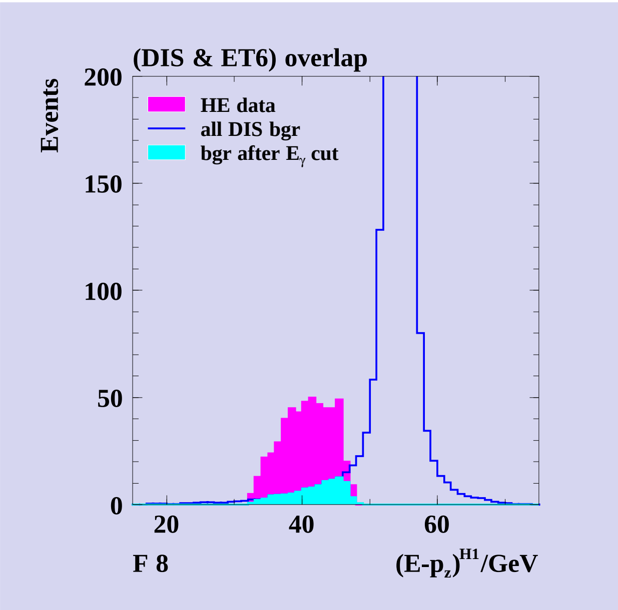
Requires more sophisticated PWA technique

Diffractive photoproduction of high-t photons



BFKL Pomeron at work





HERA1: interesting results, but statistically limited
($175 < W < 247$ GeV, $|t| > 4$ GeV², $\mathcal{L} = 46\ \mathrm{pb}^{-1}$)

HERA2: large $(18 \pm 3)\%$ DIS bgr in HE sample
($E - p_z$ cut is inefficient for ET6 range)

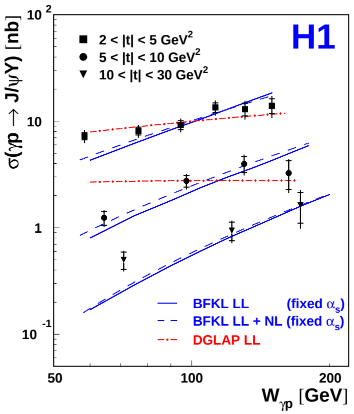
EIC: try wider E-range for e—tagger(s);
better e/γ separation down to low r (large θ_γ)

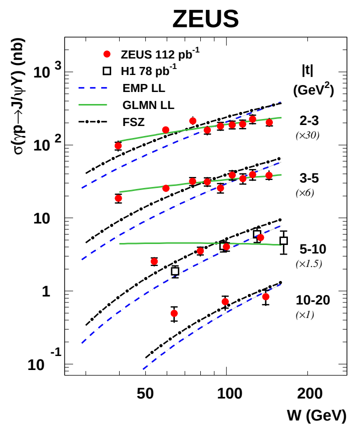
VM at HERA: published H1 results and possible new analyses

H1 Topic	Journal
Exclusive $\pi^+\pi^-$ and ρ^0 in PHP	Eur.Phys.J.C80 (2020), 1189
Exclusive ρ^0 with Leading n in PHP	Eur.Phys.J.C76 (2016) 1, 41
Elastic and p-diss J/ψ in PHP	Eur.Phys.J.C73 (2013) 2466
Diffractive ρ^0 and ϕ in DIS	JHEP05 (2010) 032
Diffractive Scattering of Photons with Large t	Phys.Lett.B 672 (2009) 219
Diffractive PHP of ρ^0 with large t	Phys.Lett.B 638 (2006) 422
Elastic J/ψ in PHP and DIS	Eur.Phys.J.C46 (2006) 585
Diffractive PHP of J/ψ with large t	Phys Lett B568 (2003) 205
Diffractive PHP of $\psi(2S)$	Phys.Lett.B541 (2002) 251
Helicity structure of ρ^0 in DIS	Phys.Lett.B539 (2002) 25
Elastic ϕ in DIS	Phys.Lett.B483 (2000) 360
Elastic J/ψ and Υ in PHP	Phys.Lett.B483 (2000) 23
Elastic ρ^0 in DIS	Eur.Phys.J.C13 (2000) 371
Quasi-elastic $(z > 0.95)$ $\psi(2S)$ in PHP	Phys.Lett.B421 (1998) 385
P-diss. ρ^0 and Elastic ϕ in DIS	Z.Phys.C75 (1997) 607
Elastic and Inelastic J/ψ in PHP	Nucl.Phys.B472 (1996) 3
Elastic ρ^0 and J/ψ at large Q^2	Nucl.Phys.B468 (1996) 3
Elastic Rho0 in PHP	Nucl.Phys.B463 (1996) 3
Exclusive $\rho' \to 2\pi^+2\pi^-$ in PHP	H1 Preliminary 2018 (manpower)
Exclusive $\rho' \to 2\pi^+2\pi^-$ in DIS	On hold (manpower)
Exclusive $VM + n$ in DIS	feasibility study: OK
Exclusive $J/\psi + n$ in PHP	proposal, to access g/π
Diffractive PHP of J/ψ with large t	HERA2 data ($4\times$HERA1 $\mathcal{L}$)

Diffractive PHP of J/ψ with large t

(complementary to diffractive PHP of γ with large t)





HERA1 data

H1: $\alpha_{I\!P}(0) = 1.167 \pm 0.054$

$\alpha'_{I\!P} = -0.014 \pm 0.009$

ZEUS: $\alpha_{I\!P}(0) = 1.084 \pm 0.038$

$\alpha'_{I\!P} = -0.014 \pm 0.009$

Open questions

- HERA limitations: missing nuclear targets; target polarisation $\Rightarrow$ Big program for EIC (gluon saturation, colour transp., spin physics, ...)

- Where is an Odderon? Direct searches [1] were negative. Try via $I\!P$-$\mathcal{O}$ interference [2,3].

- Can one observe Glueball in a double Pomeron reaction in PHP? $p - \mathrm{gap} - M_X - \mathrm{gap} - VM \quad (M_X = \sqrt{x_{I\!P1} x_{I\!P2}} W_{\gamma p} = 2 \div 6 \text{ GeV})$

- What is nucleon topology? Gluonic form factor of the proton?

[1] H1 Collaboration, Phys. Lett. B544 (2002) 35.
[2] I.F. Ginzburg, I.P. Ivanov, N.N. Nikolaev, arXiv:hep-ph/0207345
[3] C. Ewerz et al., Annals Phys. 342 (2014) 31; A. Bolz et al., JHEP 1501, (2015) 215.

Some Lessons

- Well equipped forward region, up to very large η is essential.
  Also, extend forward tracking as much as possible

- Zero degree neutron/γ(?) detector (especially in view of nuclear targets).
  Pay serious attention to its spatial resolution ($\rightarrow p_{\mathrm{t,n}}$ precision)

- LRG selection and p-tagging in Roman Pots are complementary.
  Try to exploit both methods

- Good e/γ separation in backward region is essential (High-t γ, DVCS)

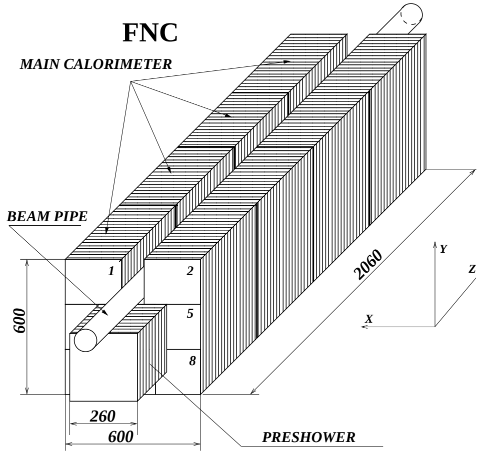
- Efficient (track based) trigger for soft events! It will pay off.
  (Low/medium W e-tagger helps in case of light VM's)

- Unfolding technique is vital (e.g. for fwd-tag/untag to EL/PD classes)

Extra slides

VM+n: Key Experimental Ingredients

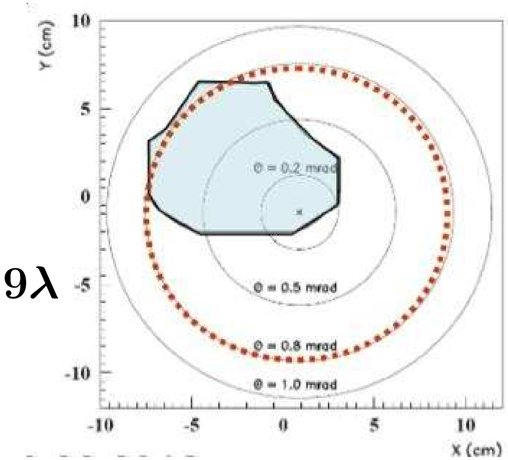
Improved H1 FNC (distinguish ($\langle P\rangle = 98\%$) and measure n and γ/π^0)

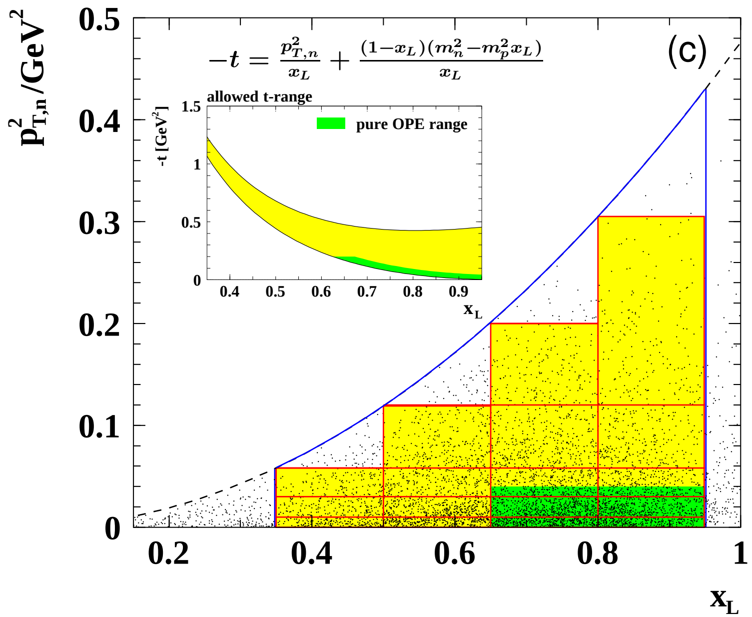


located at $z = 106$m from IP

$\langle A\rangle \simeq 30\%$ for $\theta < 0.8$ mrad

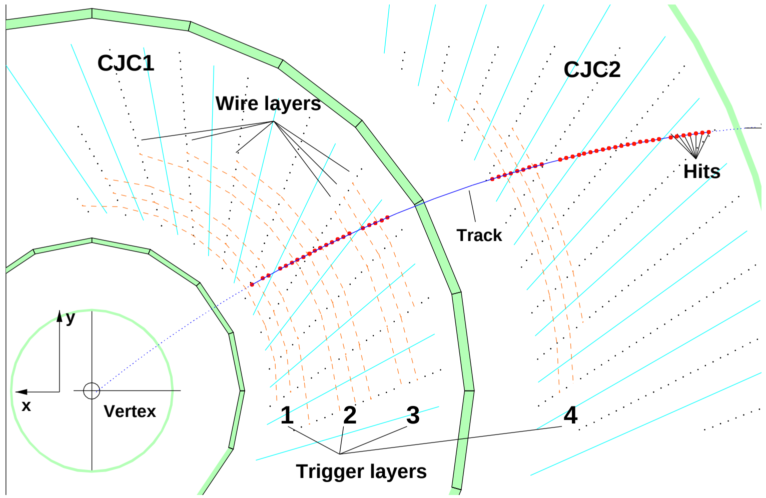
Preshower: $60X_0$, Main Calo: 8.9λ



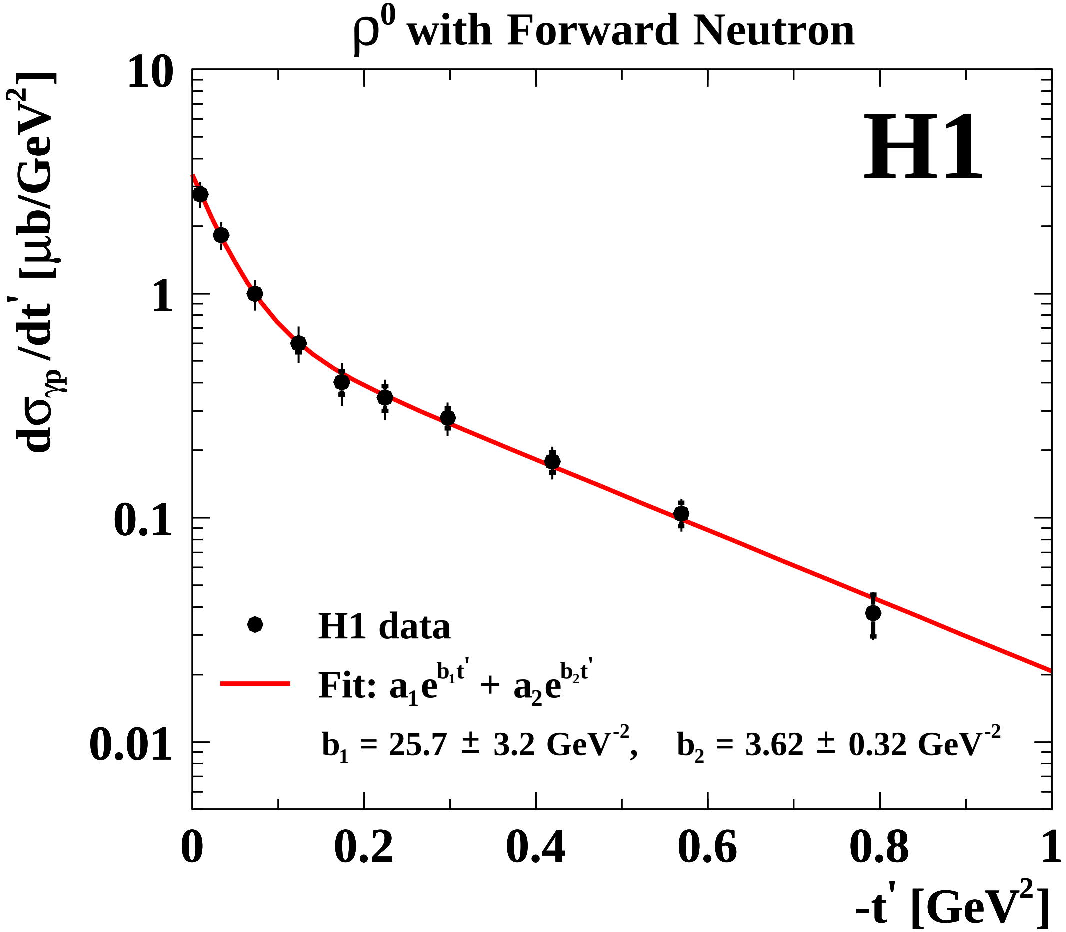


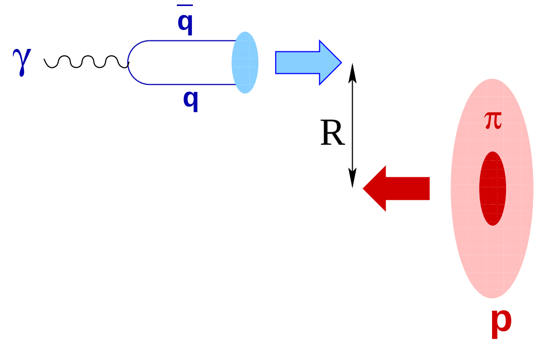
Powerful fast track trigger

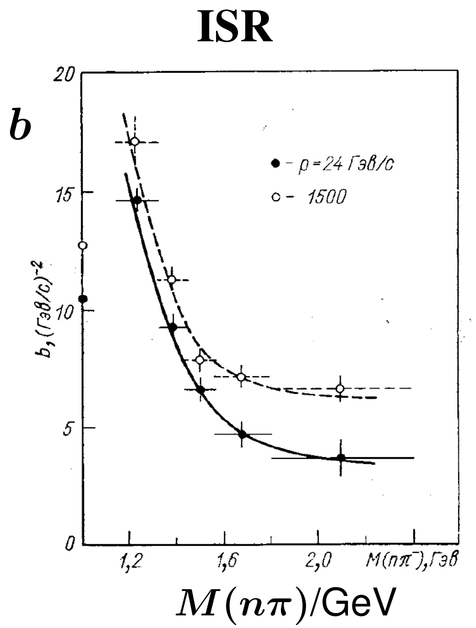
(allows untagged soft γp to be collected)



$\rho^0 + n$: Differential cross section in $p^2_{T,\rho}$



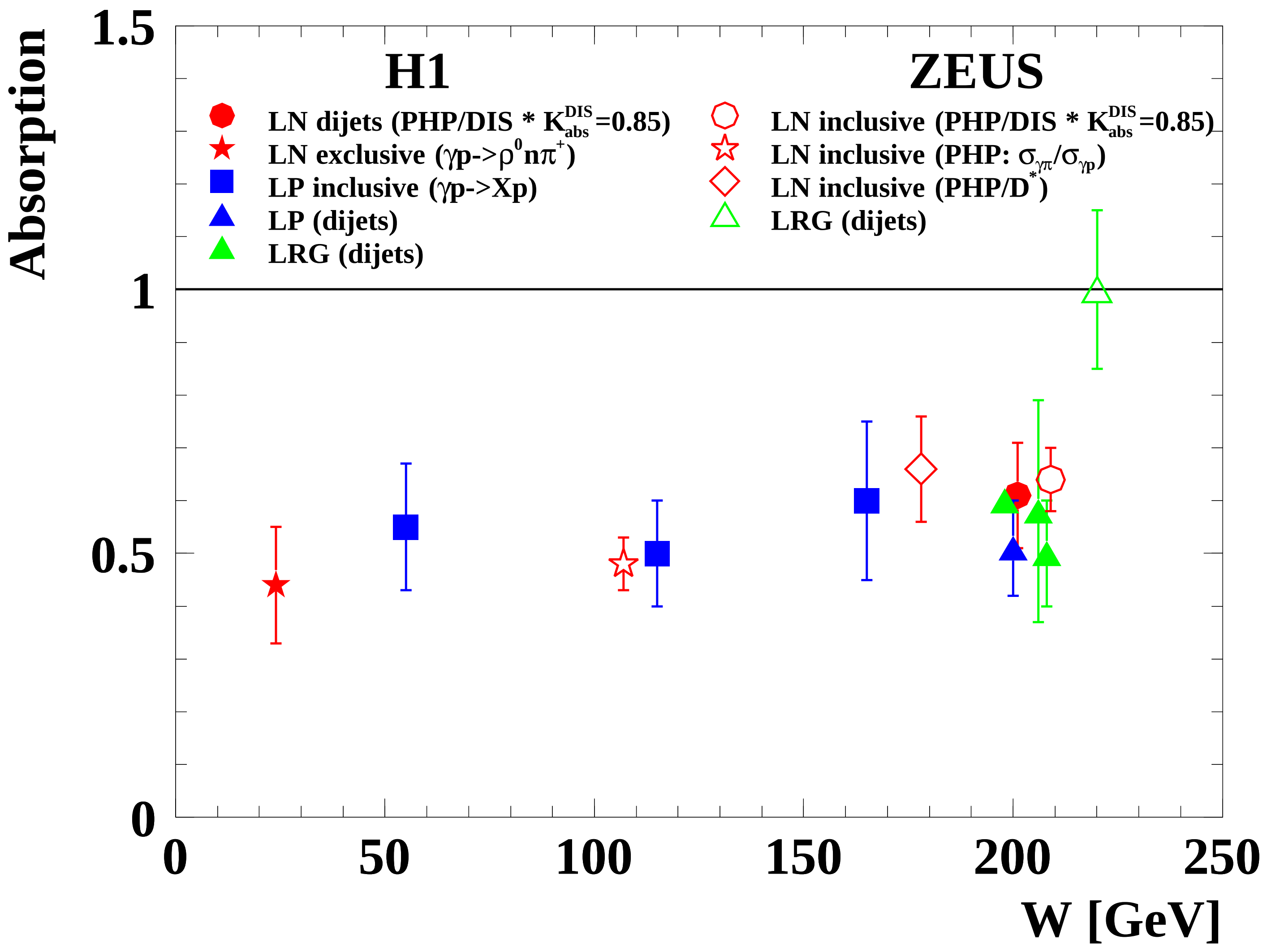




Geometric interpretation: $\langle r^2 \rangle = 2b_1 \cdot (\hbar c)^2 \simeq 2$ fm^2 $\Rightarrow (1.6 R_p)^2 \Rightarrow$ ultra-peripheral process

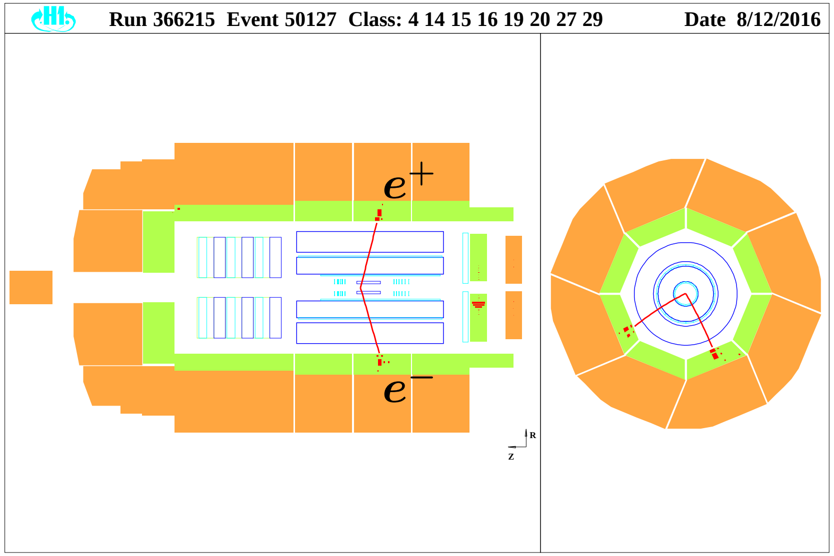
DPP explanation: low mass $\pi^+ n$ state $\rightarrow$ large slope, high masses $\rightarrow$ less steep slope

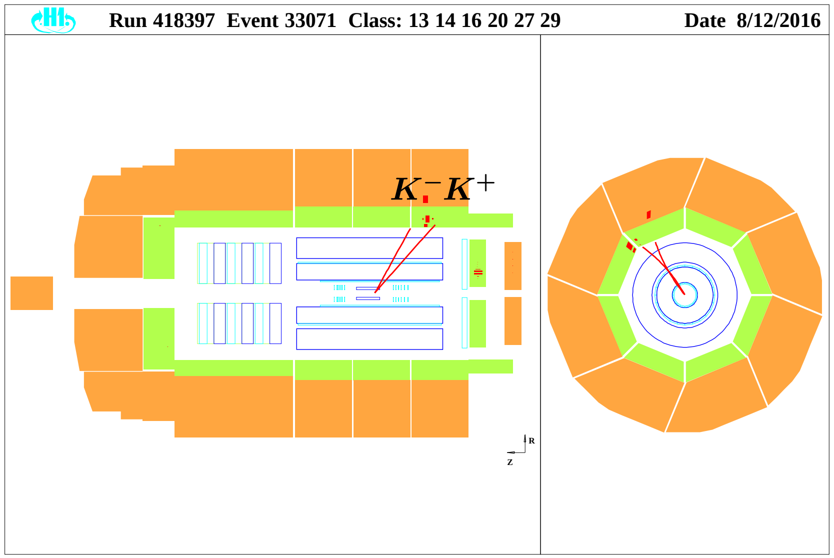
Absorptive factors, K_{abs}, in different PHP reactions



Unofficial private summary!

VM+n in DIS. Selection criteria and statistics.






```
+-------------------------------------------------------------------------------------+
|                                                                                     |
| SELECTION CRITERIA                                               EVENT STATISTICS   |
|                                                                                     |
| 1) From CDST to ntuple                                                              |
|                                                                                     |
|   -- Bad runs excluded (FNC r/o; Poor runs)                                         |
|   -- class 14 and class 20 (leading baryons, e- in Spacal)           18,008,212     |
|   -- 2 or 3 DTRA primary tracks; -50<z<100 cm                         1,541,110     |
|   -- 2 CT tracks&Q_TOT=0; or 3 CT tracks&Q_TOT=Q_beam&tet_e<165                     |
|   -- E_n > 100 GeV                                                                  |
|                                                                                     |
|                                                                                     |
| 2) From ntuple to final analysis sample                                 100,218     |
|                                                                                     |
|   -- quality:  HVOK; |zvx|<35cm; M(pipi)<4.0 GeV                                    |
|   -- trigger:  see trig.strategy (main triggers: s01, s88)                          |
|   -- tracking: 15<theta<165 && pt>100 MeV                                54,209     |
|   -- DIS:      Rcl<3.6; E_Pz>40; E_e>10; Q2_da>3; [box cut]              30,601     |
|   -- FNC:      IQ=0 (hadr.cluster) xL>0.2;  fiducial cut                 22,043     |
|   -- LRG:      Fmu<=1;  FTS28=0                                          10,651     |
|   -- NOCALO:   Erest<2 (or Nclu400(Nclu800)=0 & Espa-Ee<0.2)                        |
|                                                                    4678 (3268)     |
|                                                                                     |
| 3) VM signals (including comb.bgr)                    Exclusivity condition type    |
|                                                          0      1     2  omega     |
|   -- rho:   0.6<M(pi+pi-)<1.1 GeV; M(KK)>1.05 GeV      2190   2628  2953    895     |
|   -- phi:   M(KK) < 1.04 GeV                            271    316   303    107     |
|   -- J/psi:  2.97 < M(+-) < 3.21 GeV                     35     40    48     12     |
|   -- omega:  0.70 <M(pi+pi-pi0) < 0.86 GeV                6     41   114    120     |
+-------------------------------------------------------------------------------------+
```

Main problems:

- Yield at low R_{sp} (low Q^2) in early data samples
- MC for signal events (implement $p \to n\pi^+$ splitting)