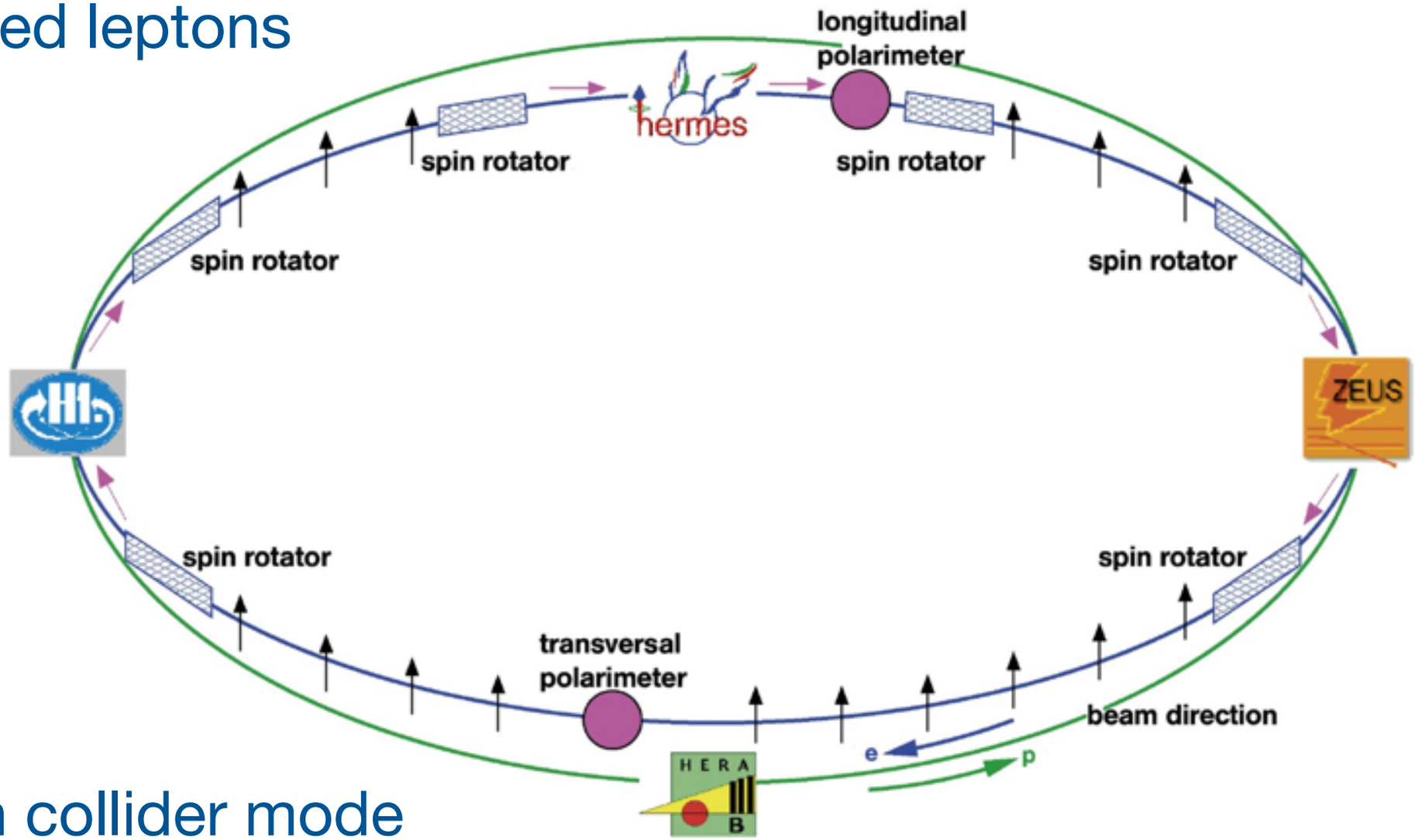
81st DESY PRC Meeting

DESY, Hamburg - April 5th, 2016

HERA

Hadron-Elektron-Ring-Anlage

- world-wide only electron/positron-proton collider, closed in 2007
- naturally polarized leptons



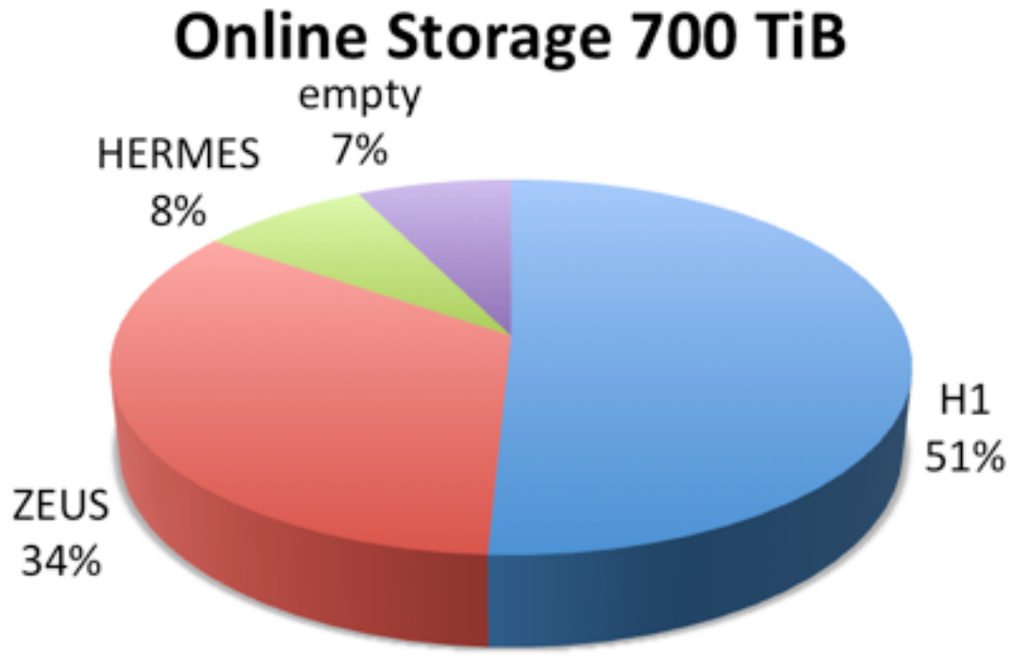
- H1 and ZEUS in collider mode
- HERMES with storage cell internal to lepton ring
  - various polarized and unpolarized target gases possible

data preservation

- fundamental for continuation of HERA analyses
- three major aspects:
  - *documentation* - preservation of experiment and analysis details as well as of all physics results
  - *software preservation* - ensuring compatibility of (reconstruction / analysis / MC) software with future operating systems
  - *bit preservation* - storage of actual (raw / processed / MC) data
- ongoing HERA analyses based on DPHEP infrastructure
- H1 already utilized raw data preserved for PID improvements

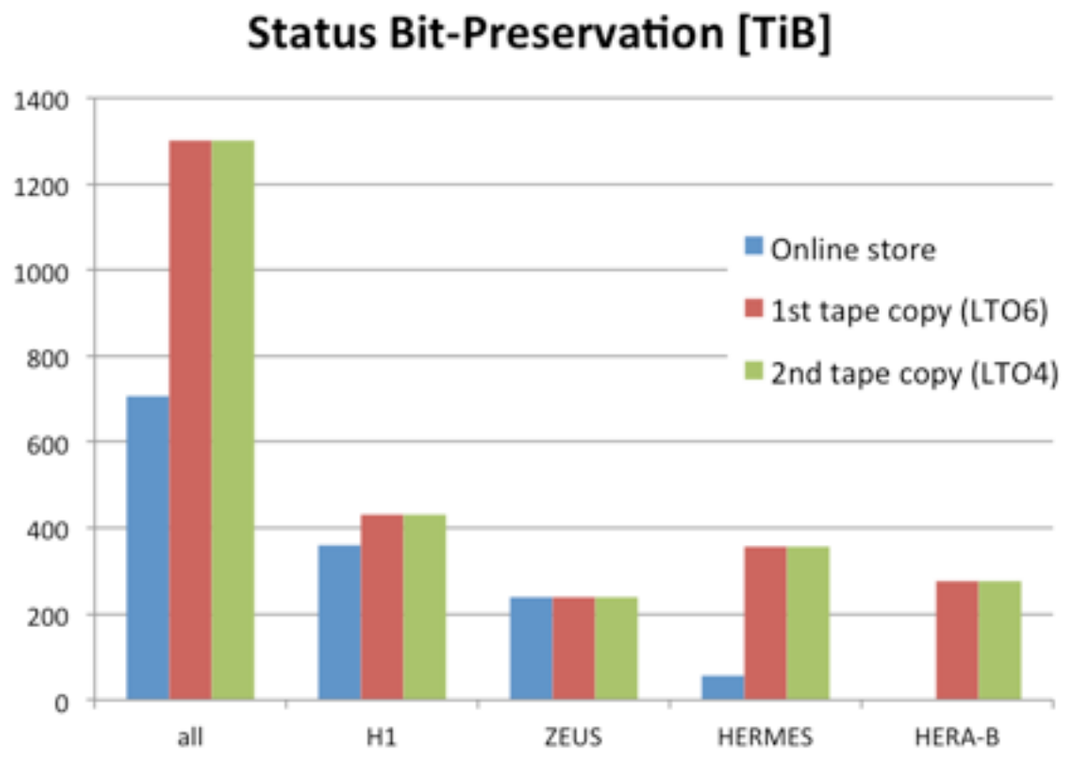
status of HERA bit-preservation

- HERA-data archive finalized
- online (disk) store filled
  - used for everyday analysis
- two tape copies*) of full archives for long-term storage
- small additions to heritage data possible



- content of archive and the procedures how to add and restore data both documented
- restoring data from tape archive to online store already successfully exercised
- HERA-data preservation effort as part of the DPHEP collaboration status report [arXiv:1512.02019v2]

*) except for the last 100TB presently written to tape



published results since last PRC report

- H1&ZEUS, *Combination of differential $D^{*\pm}$ cross-section measurements in deep-inelastic ep scattering at HERA*, JHEP09(2015)149
- H1&ZEUS, *Combination of measurements of inclusive deep inelastic $e^{\pm}$ p scattering cross sections and QCD analysis of HERA data*, EPJ C75 (2015) 580 (already 50+ citations)
- ZEUS, *Production of exclusive dijets in diffractive deep inelastic scattering at HERA*, EPJ C76 (2016) 16
- H1, *Exclusive ρ^0 meson photoproduction with a leading neutron at HERA*, EPJ C76 (2016) 41
- HERMES, *Pentaquark Θ^+ search at HERMES,* PRD 91 (2015) 057101
- HERMES, *Bose–Einstein correlations in hadron-pairs from lepto-production on nuclei ranging from hydrogen to xenon*, EPJ C75 (2015) 361
- HERMES, *Transverse-target-spin asymmetry in exclusive ω-meson electroproduction*, EPJ C75 (2015) 600
- HERMES, *Reply to "Comment on 'Reevaluation of the parton distribution of strange quarks in the nucleon'"*, PRD92 (2015) 098102

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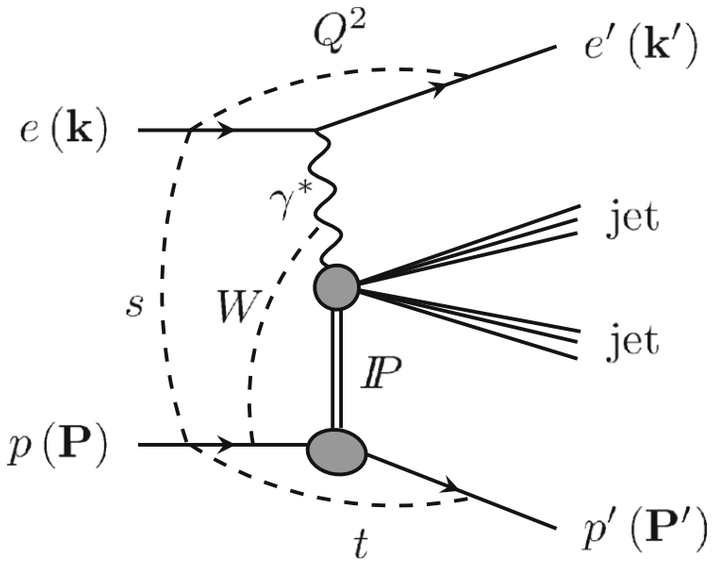
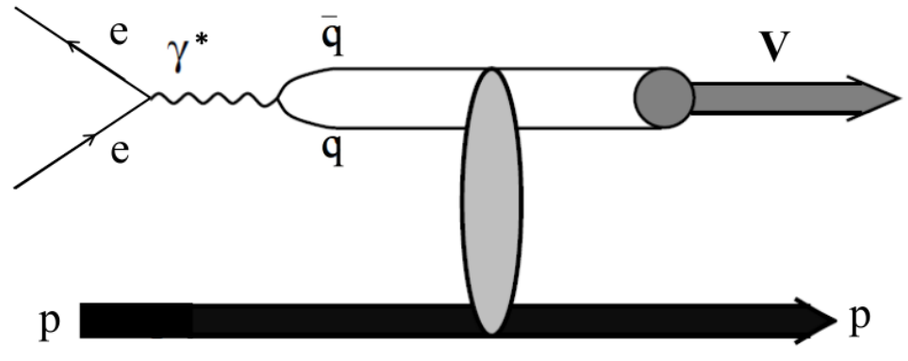
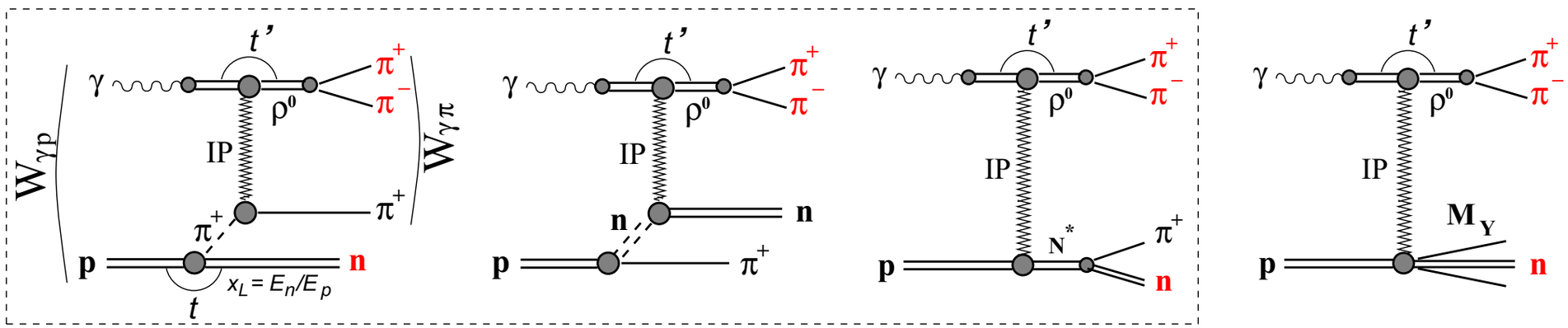
new submissions since last PRC report

- ZEUS, *Combined QCD and electroweak analysis of HERA data*, PRD (in press)
- ZEUS, *Limits on the effective quark radius from inclusive ep scattering at HERA*, submitted to PLB
- ZEUS, *Measurement of the cross-section ratio* $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ *in deep inelastic exclusive ep scattering at HERA*, submitted to NPB
- H1, *Search for QCD Instanton-Induced Processes at HERA in the High-*Q^2 *Domain,* submitted to EPJC
- ZEUS, *Search for a narrow baryonic state decaying to* pK_S^0 *and* $\bar{p}K_S^0$ *in deep inelastic scattering at HERA*, to be submitted to PLB
- … various preliminary results (e.g., for DIS'16) and in preparation for publication

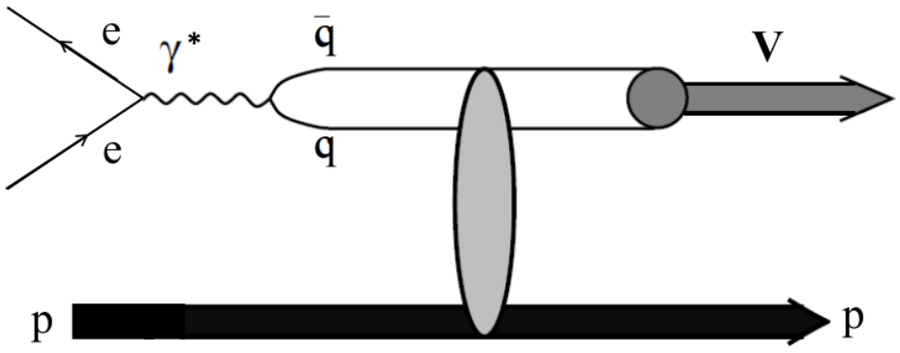




exclusive measurements



$\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ cross section ratio in DIS



V= ψ(2S) or J/ψ(1S)

→ $\mu^+\mu^-$ [also $J/\psi(1S)\pi^+\pi^-$ for ψ(2S)]

sensitive to, e.g., wave function dependence of the $c\bar{c}$–proton cross section

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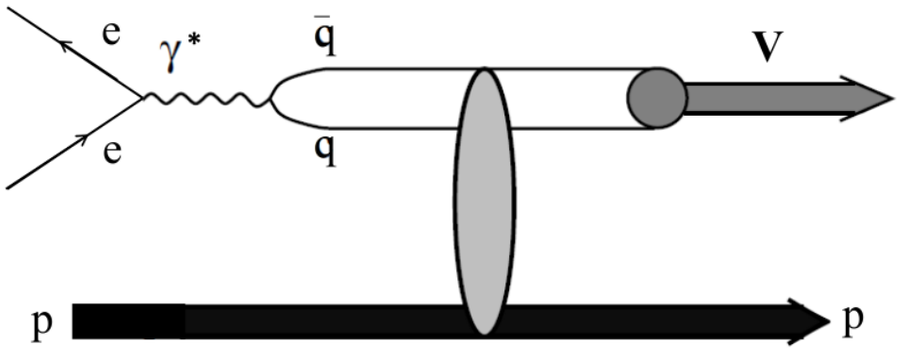

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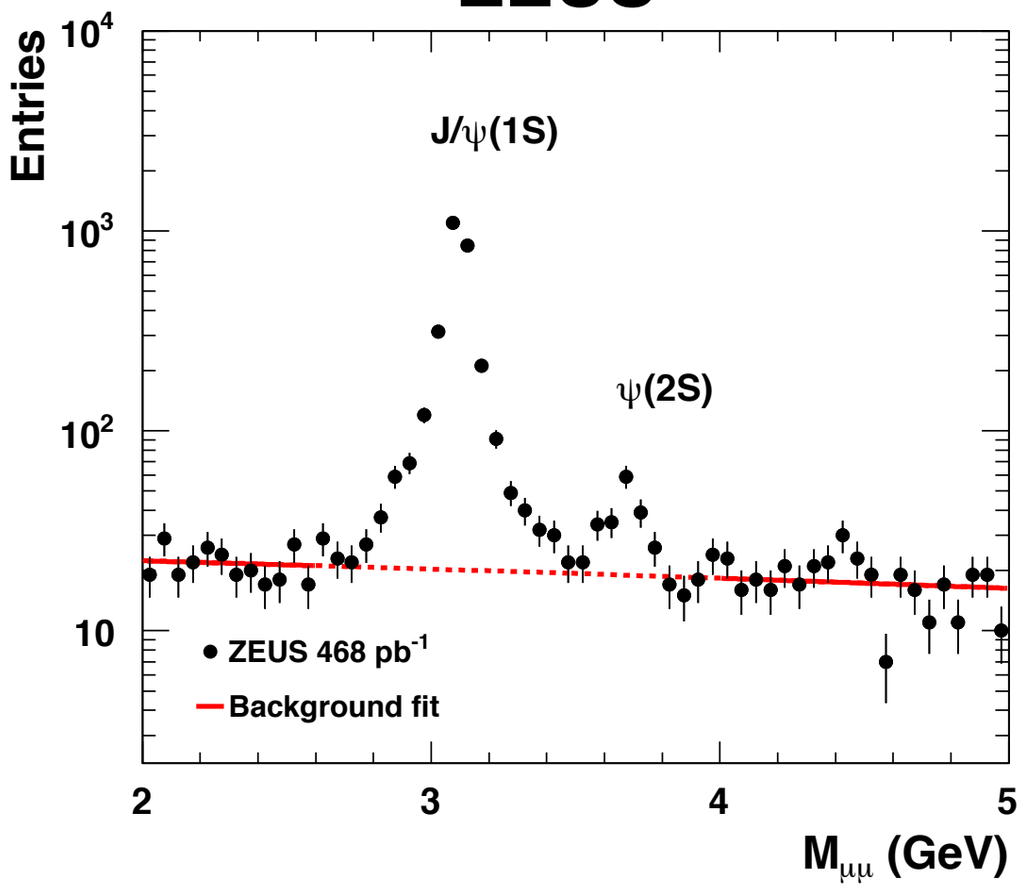
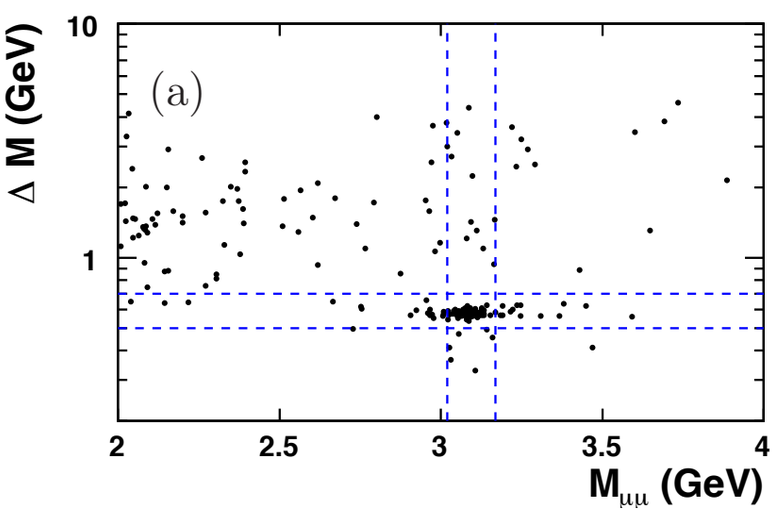
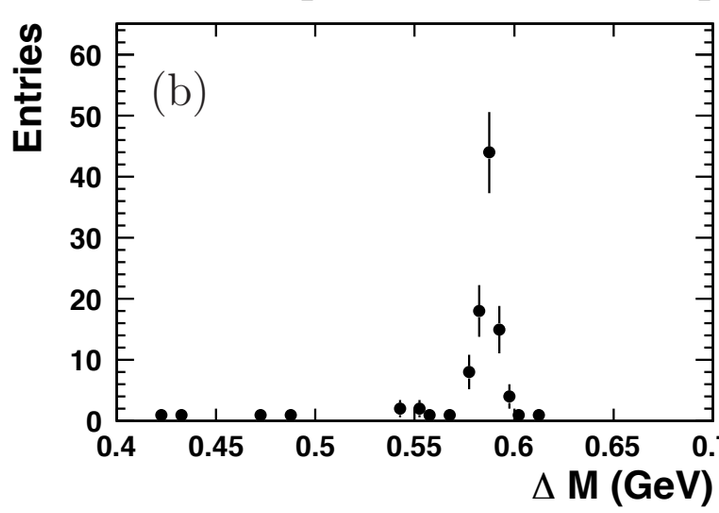
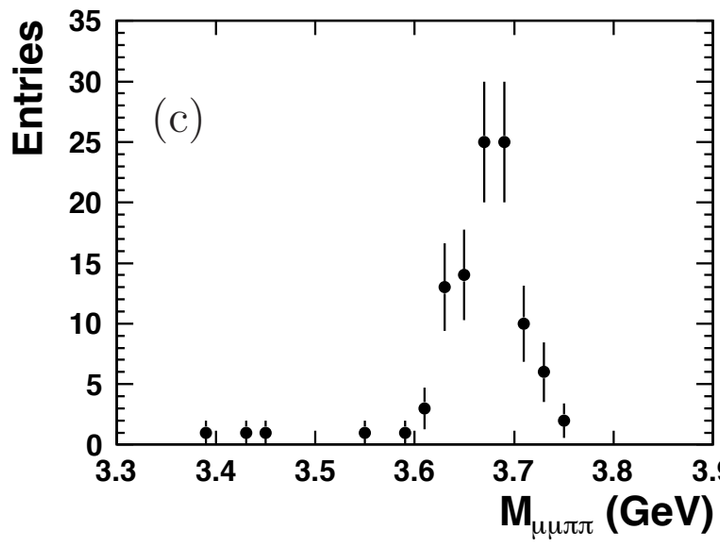




• ZEUS 468 pb^{-1}





[DESY–16–008]

gunar.schnell @ ehu.es

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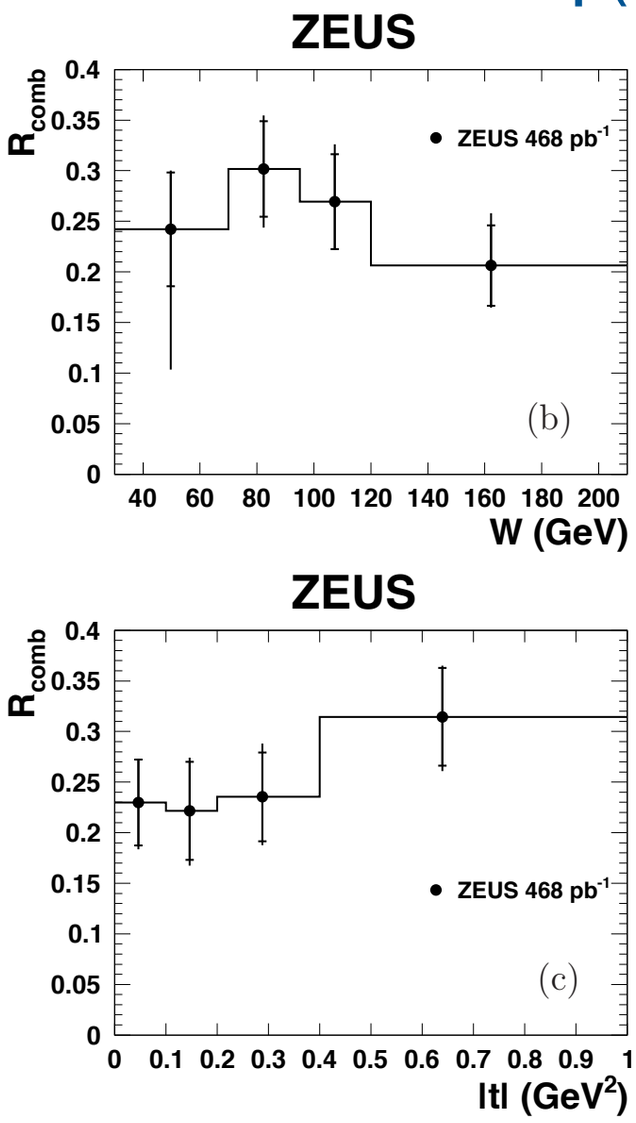
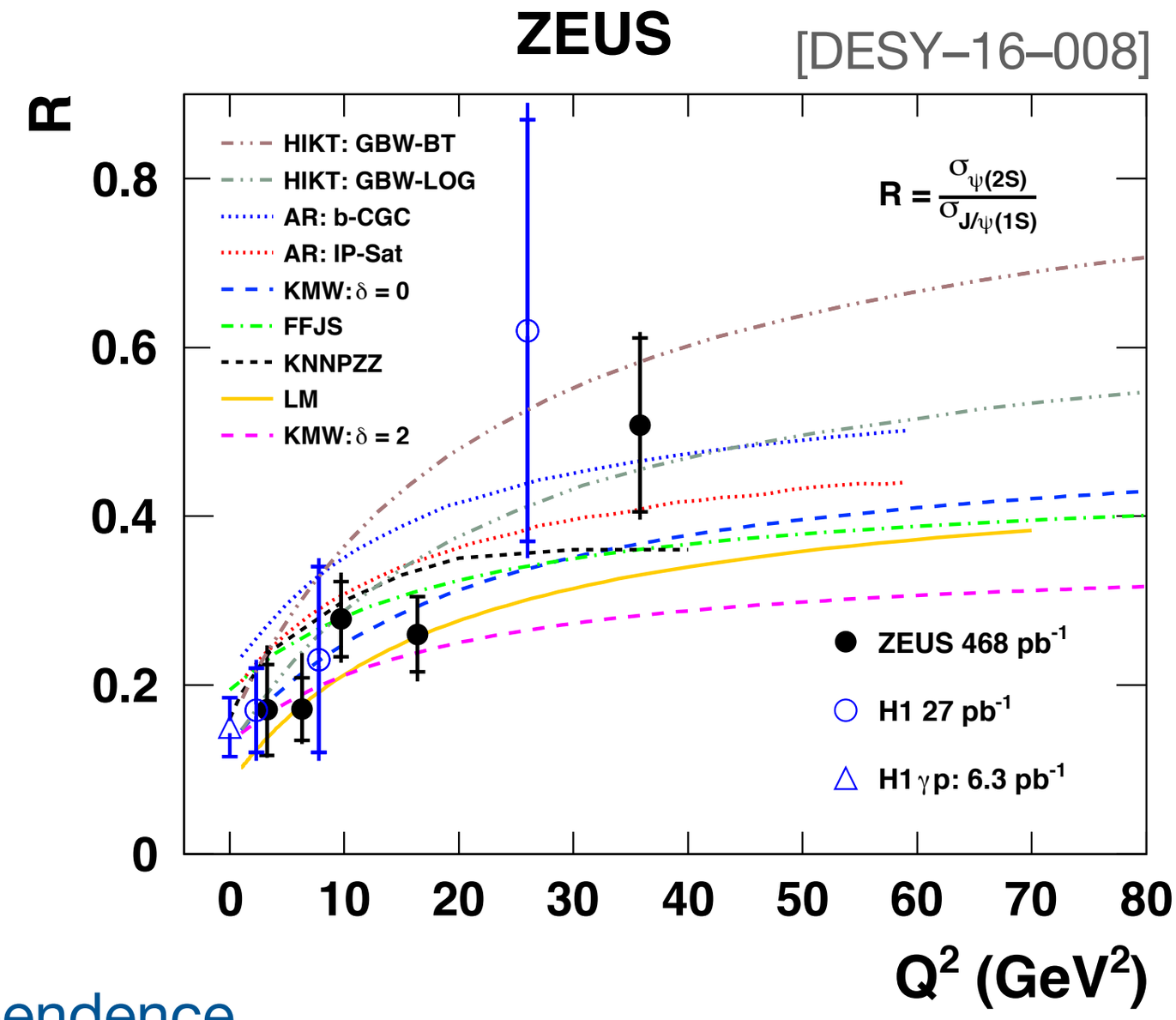
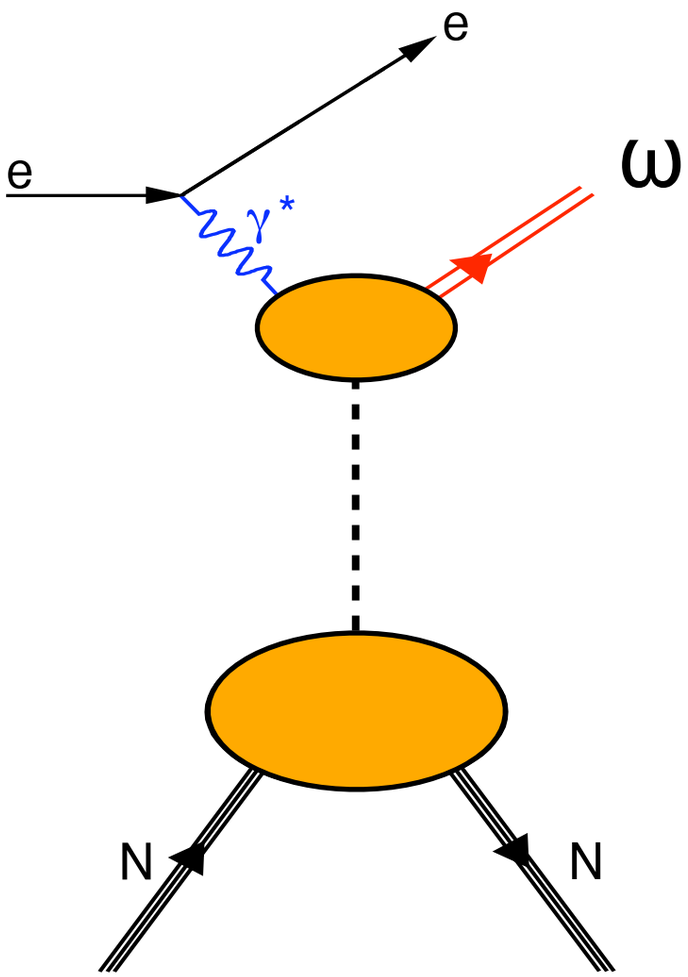




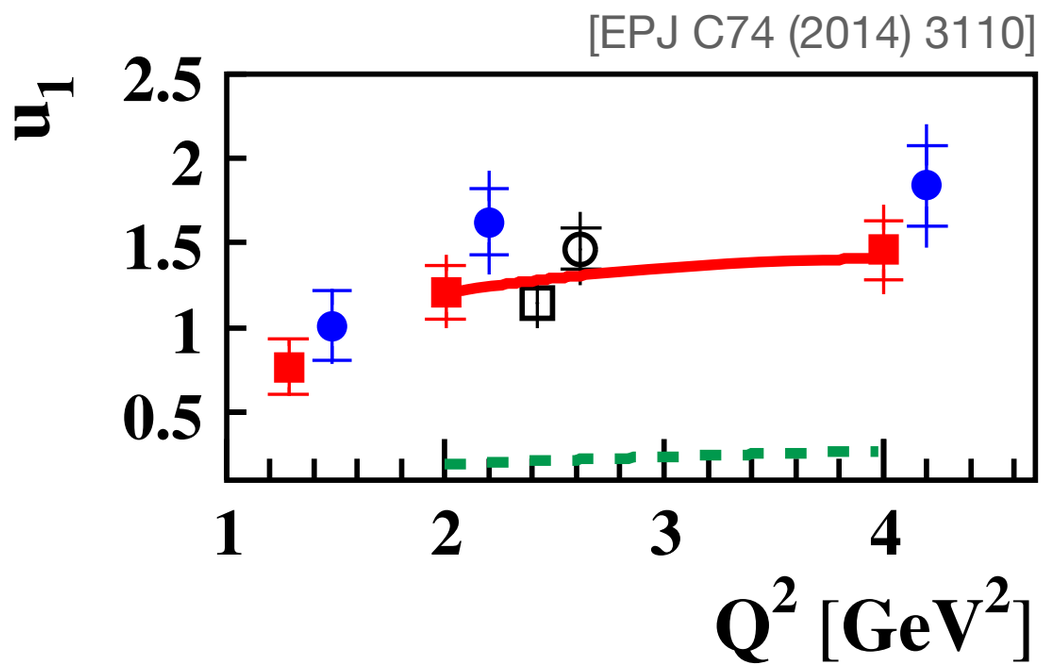
- hardly any W and |t| dependence
- increase with Q^2
  - consistent with earlier H1 result, though much improved precission
  - mostly following (widely spread) model predictions without favoring any of them (though 2-3 are disfavored)

exclusive ω production



- sensitive to nature of *particle* exchanged
- earlier HERMES data on ω spin-density matrix elements (SDMEs) highlighted role of ***π-pole*** contribution

[EPJ C74 (2014) 3110]



- sensitivity to πω transition form factor
  - SDMEs do not fix sign of πω transition form factor

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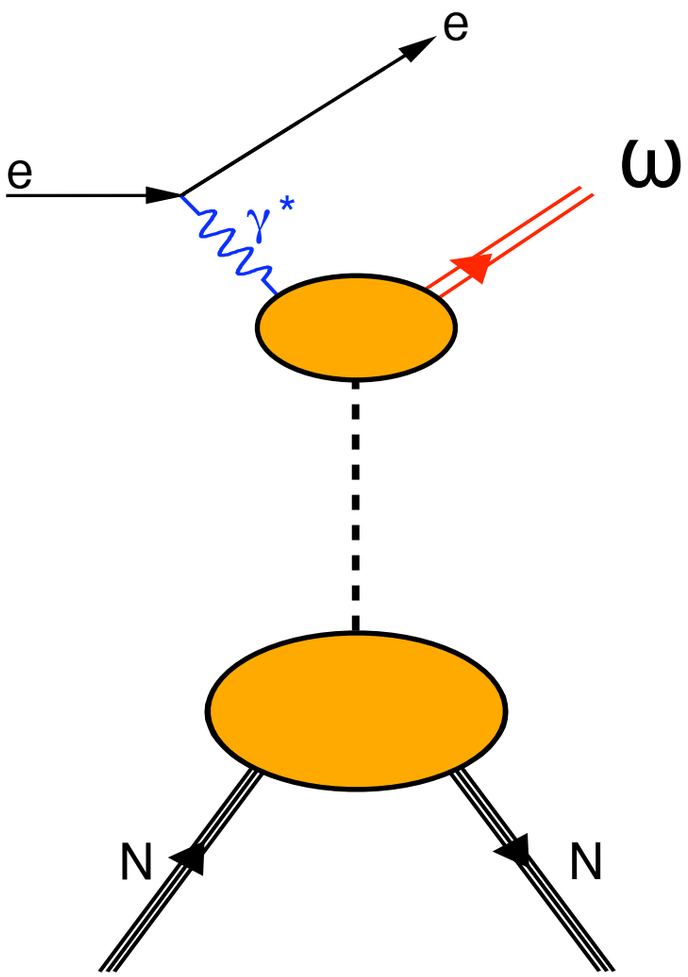

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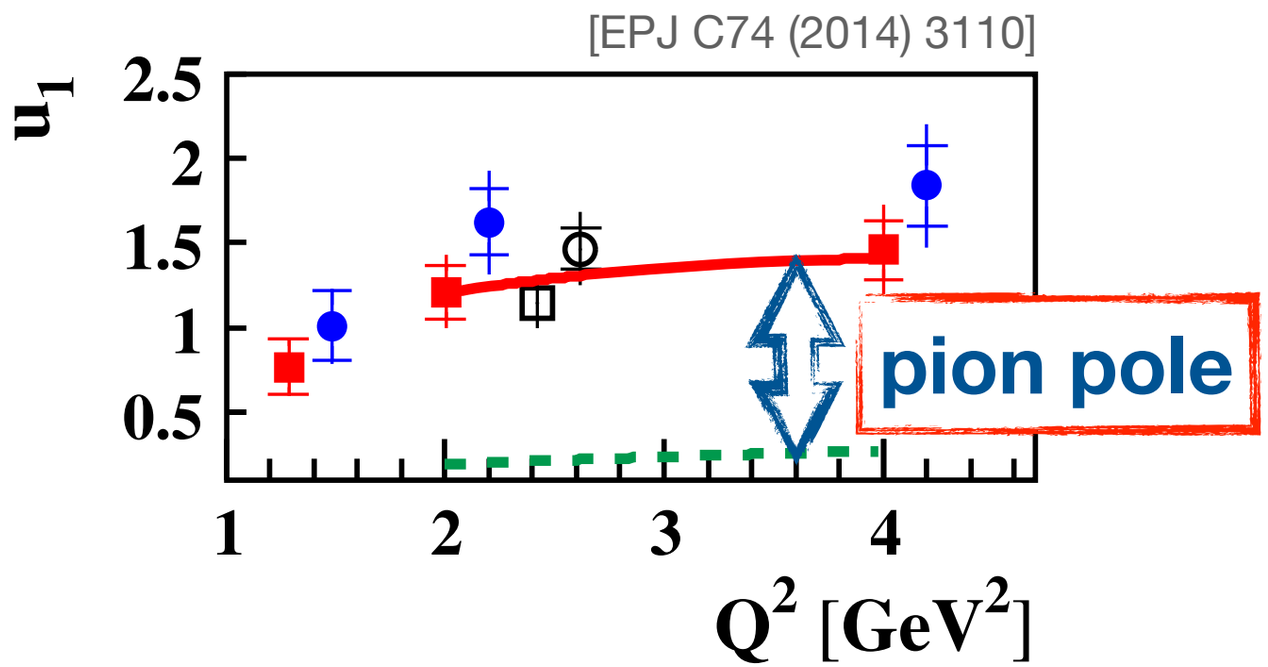

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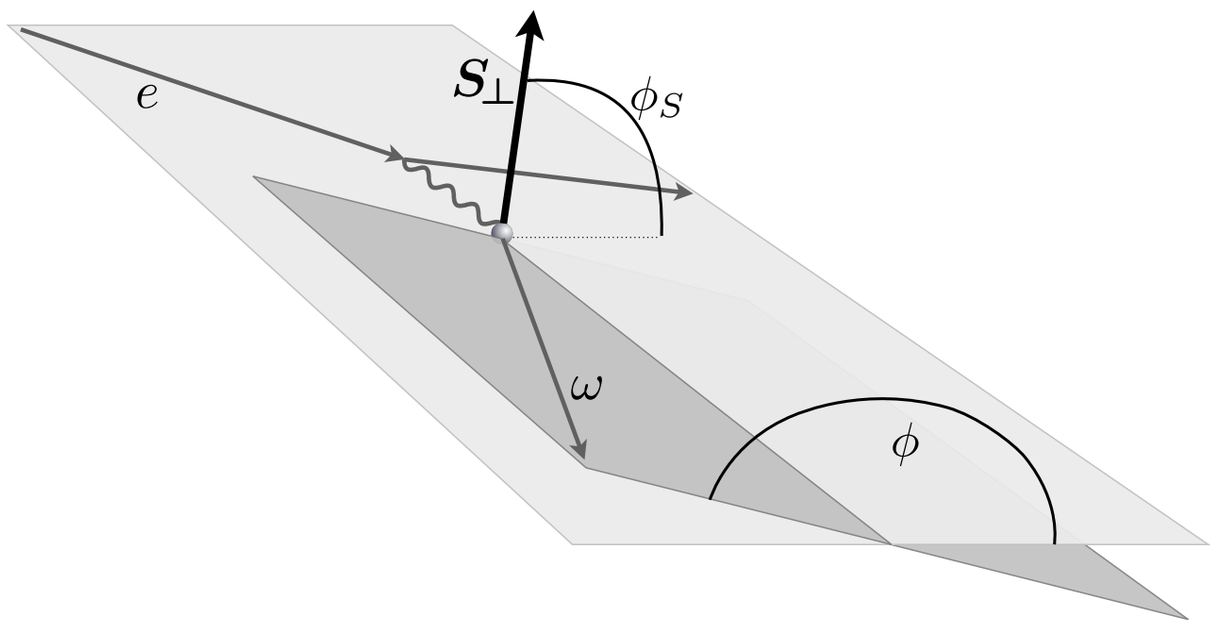
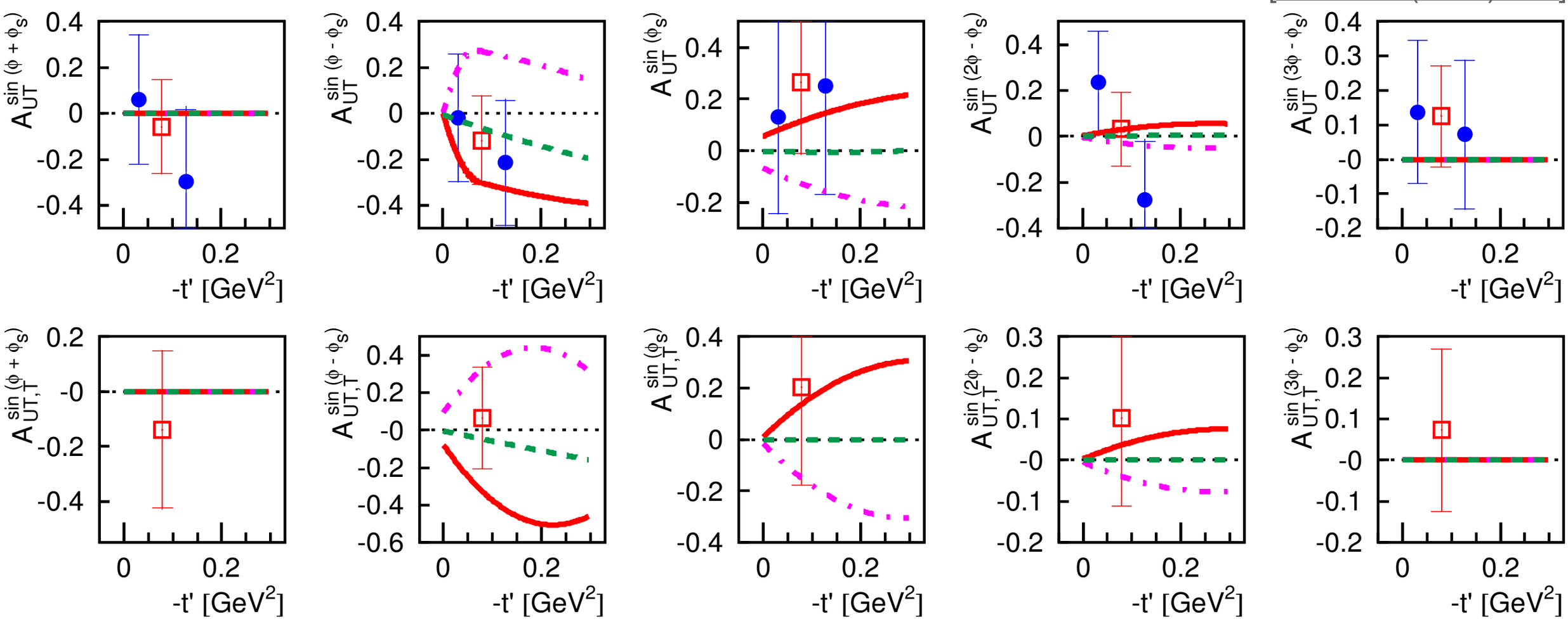


exclusive ω production

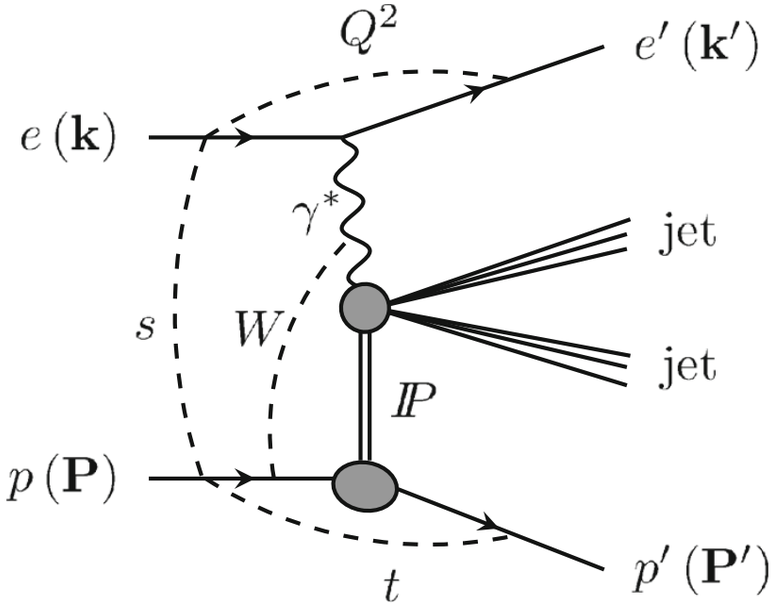
- various azimuthal dependences of transverse-target-spin asymmetry
- in principle, constrain sign of πω transition form factor

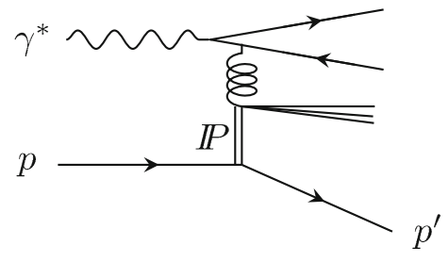
[EPJ C75 (2015) 600]



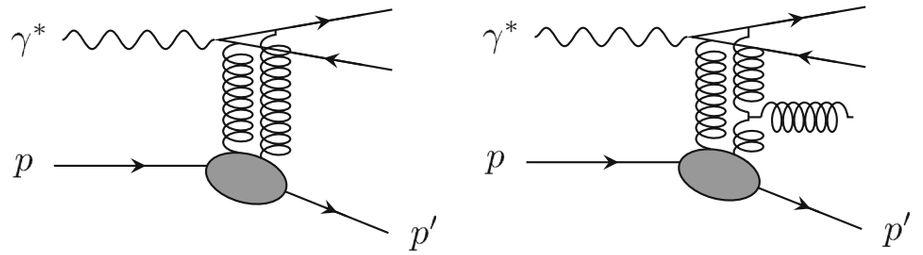
slight preference for positive $\pi\omega$ transition FF (red/full line) vs. negative one (magenta/dash-dotted line)

exclusive dijets in diffractive DIS



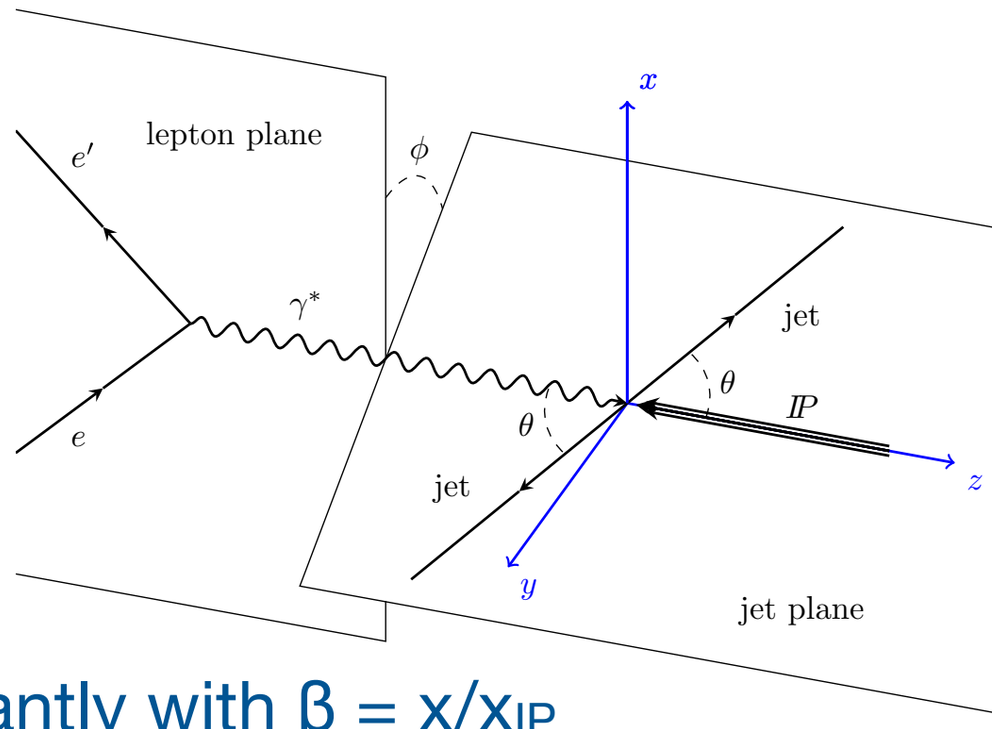


1-gluon exchange



2-gluon exchange

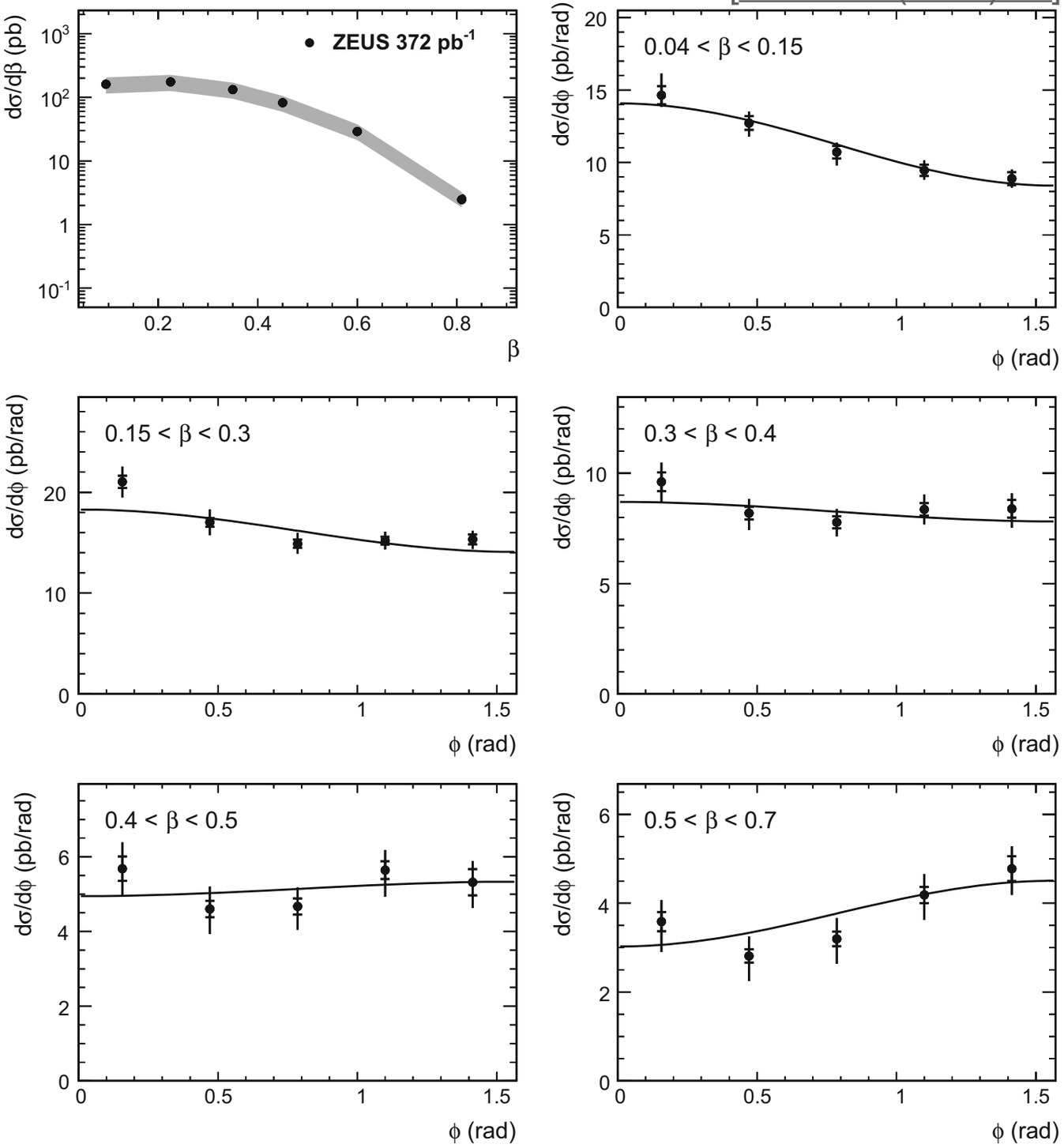
- small 4-momentum exchange at proton vertex & large rapidity gap
- complementary to exclusive production of hadrons as well as to exclusive dijets in pp and pA
- sensitive to nature of particle exchanged and gluon distr. in proton
- cross section proportional to 1+ $A(p_{T,jet})\cos 2\phi$
  - A>0 for single-gluon exchange
  - A<0 for two-gluon exchange



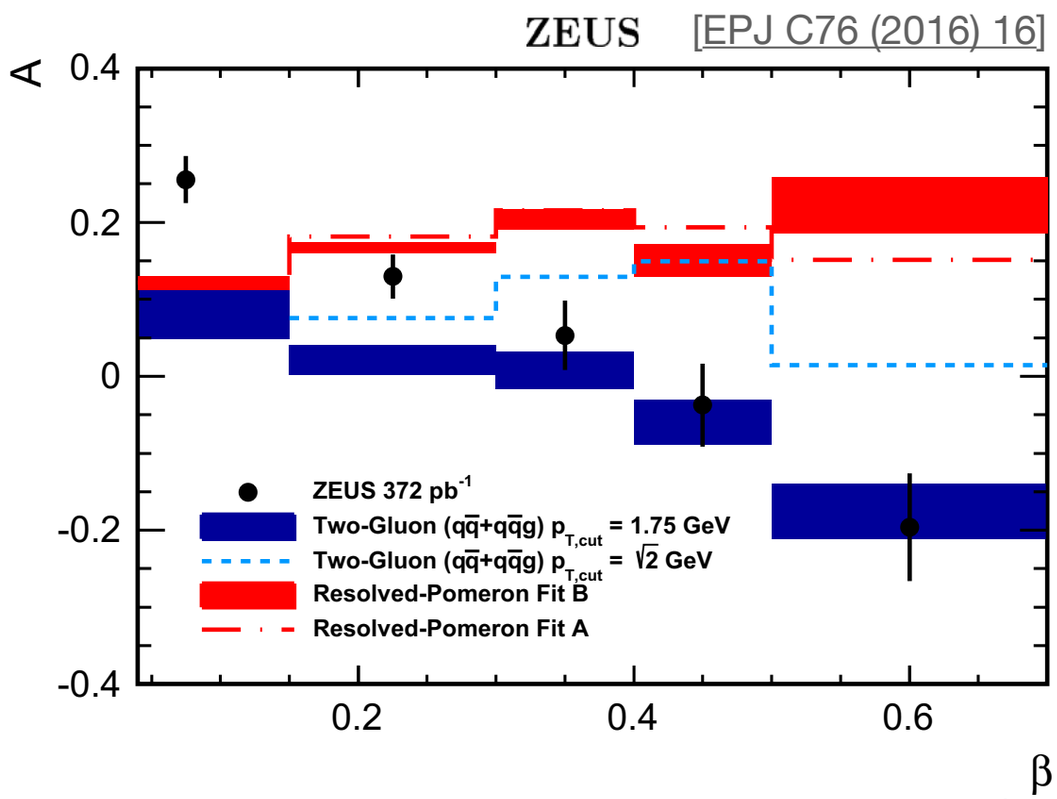
- ratio of $q\bar{q}$ to $q\bar{q}g$ production changes significantly with $\beta = x/x_{I\!P}$

exclusive dijets in diffractive DIS

[EPJ C76 (2016) 16]



- strong dependence of A on β:
  - decrease and change of sign around β = 0.4
  - qualitatively consistent with 2-gluon-exchange model
  - inconsistent with flat dependence in pomeron-exchange model



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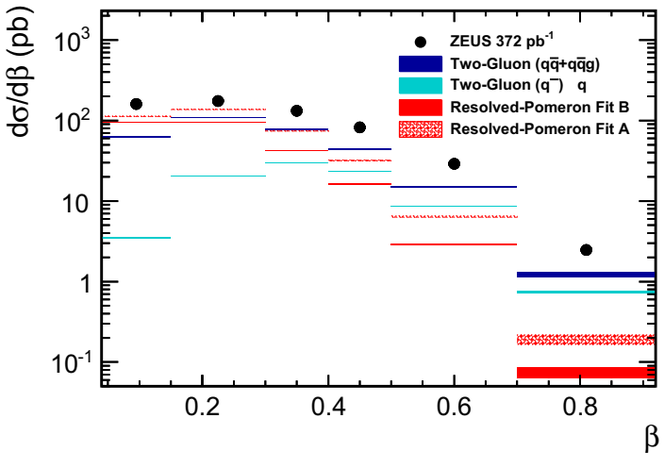

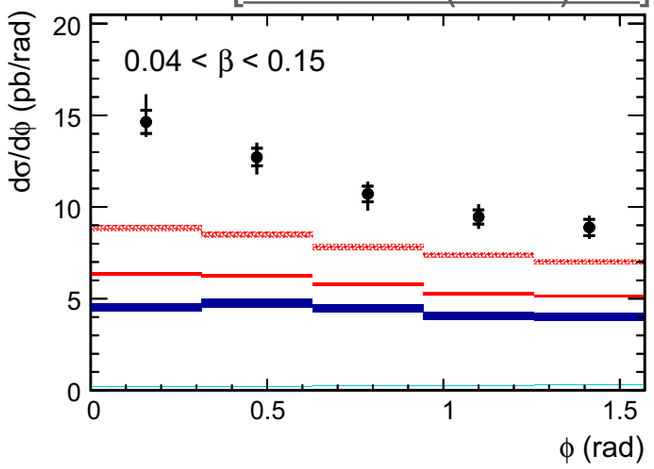

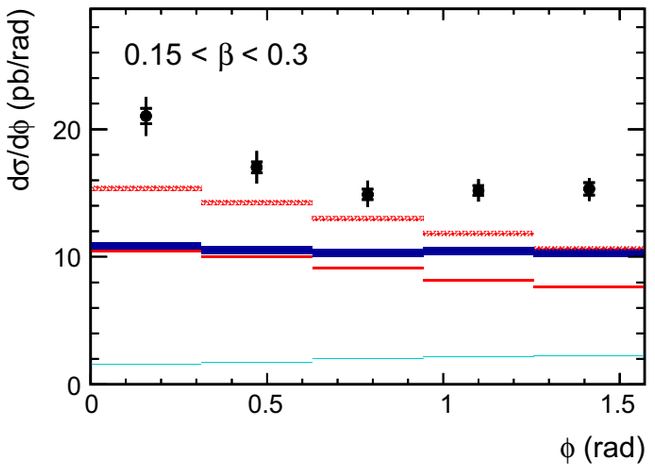

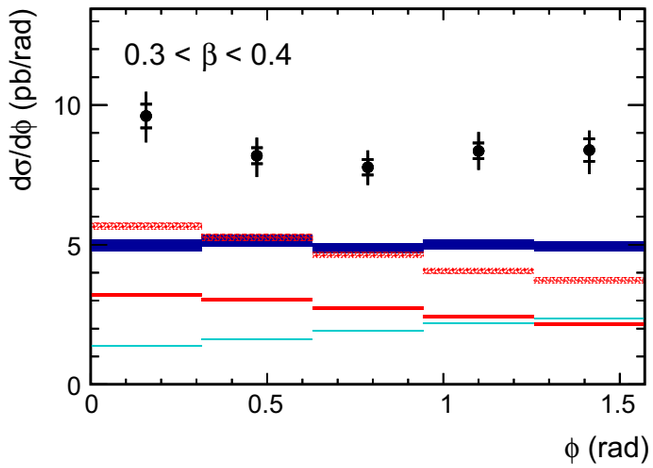

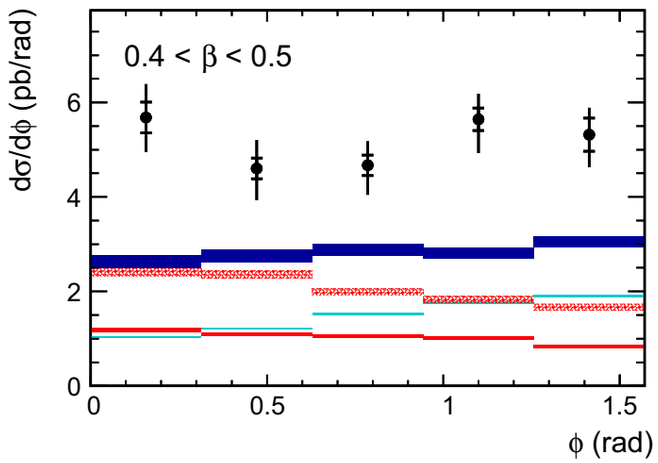

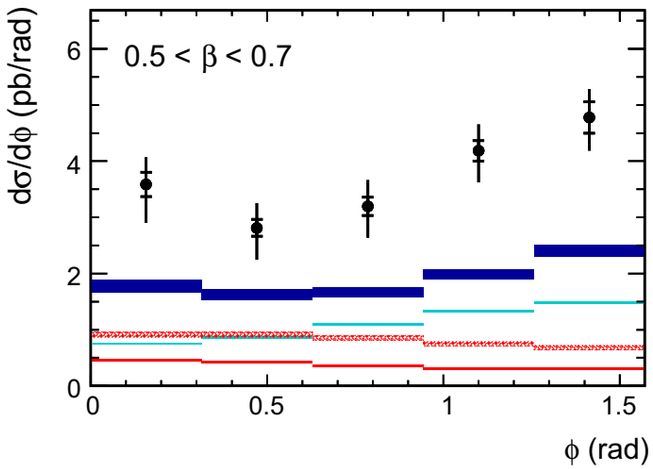

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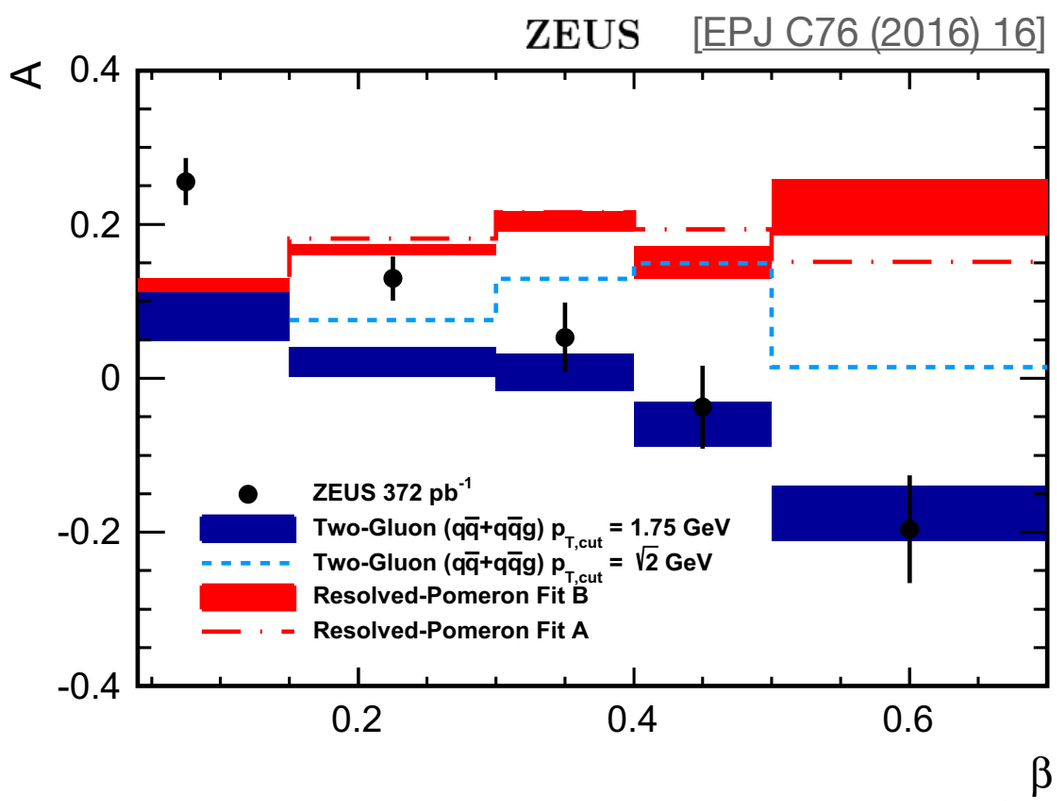
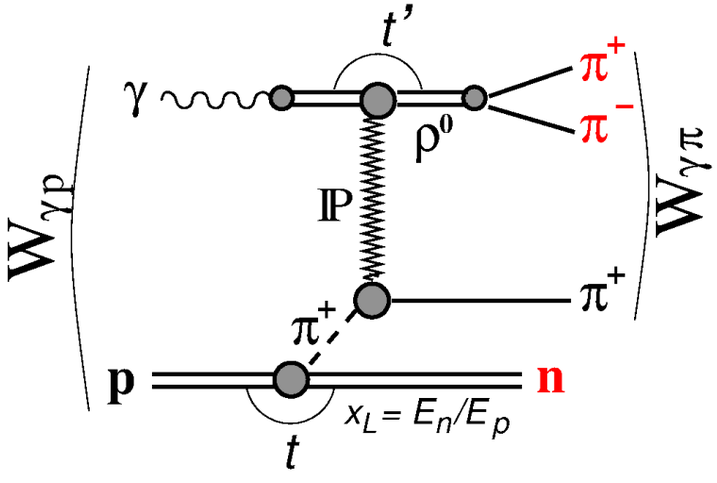
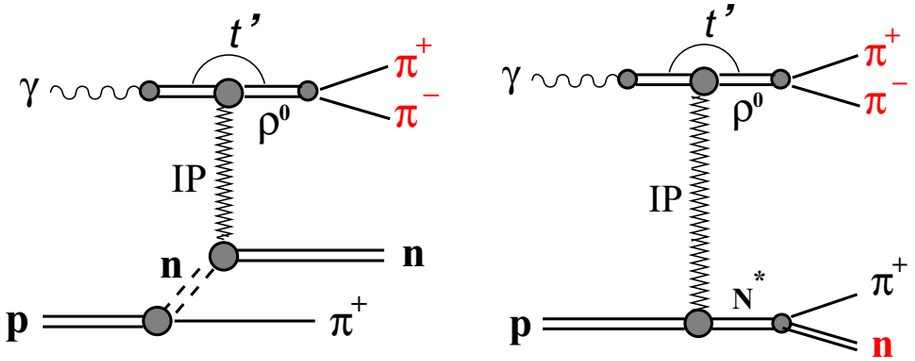


ρ^0 photoproduction with a leading neutron



dominant process



suppressed contributions

- quasi-real photon emitted from electron, momentum transfer $Q^2 \sim 0$
- soft process, no hard scale $[Q^2, t, t', m_\rho^2 \sim 0]$
- involves colorless exchange IP
- processes with same final state lead to interference effects
- dominant process also probes elastic γπ-scattering

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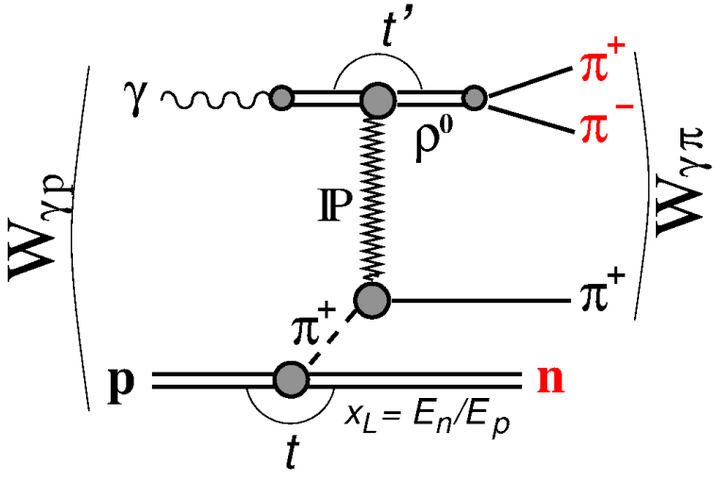

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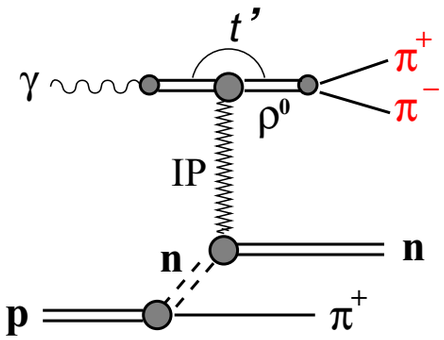

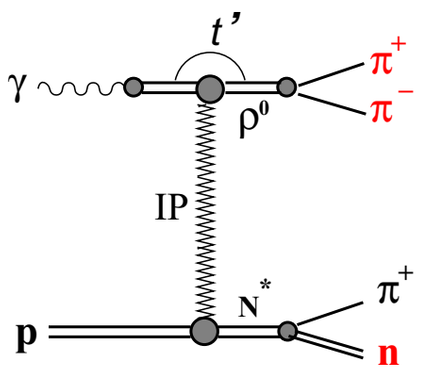

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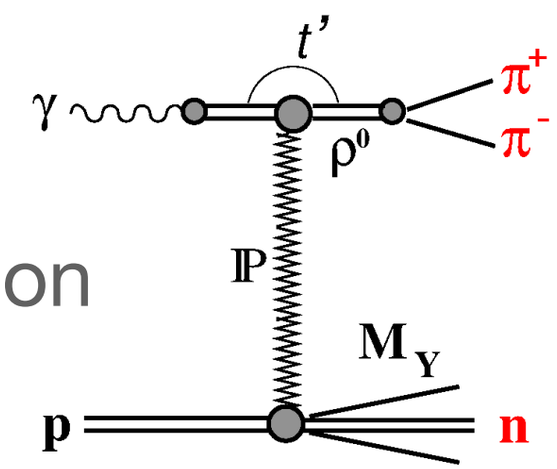
background: proton dissociation



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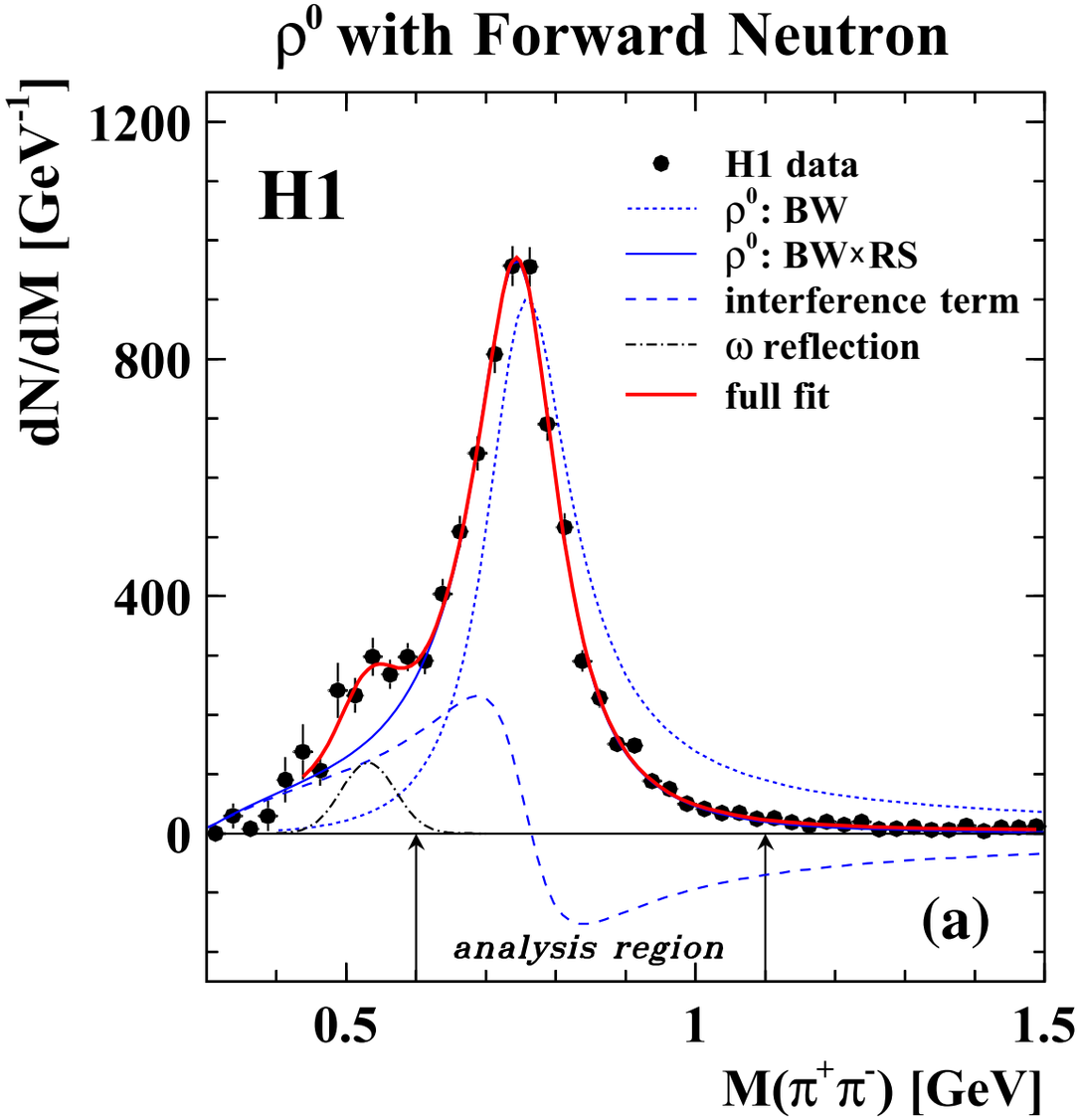
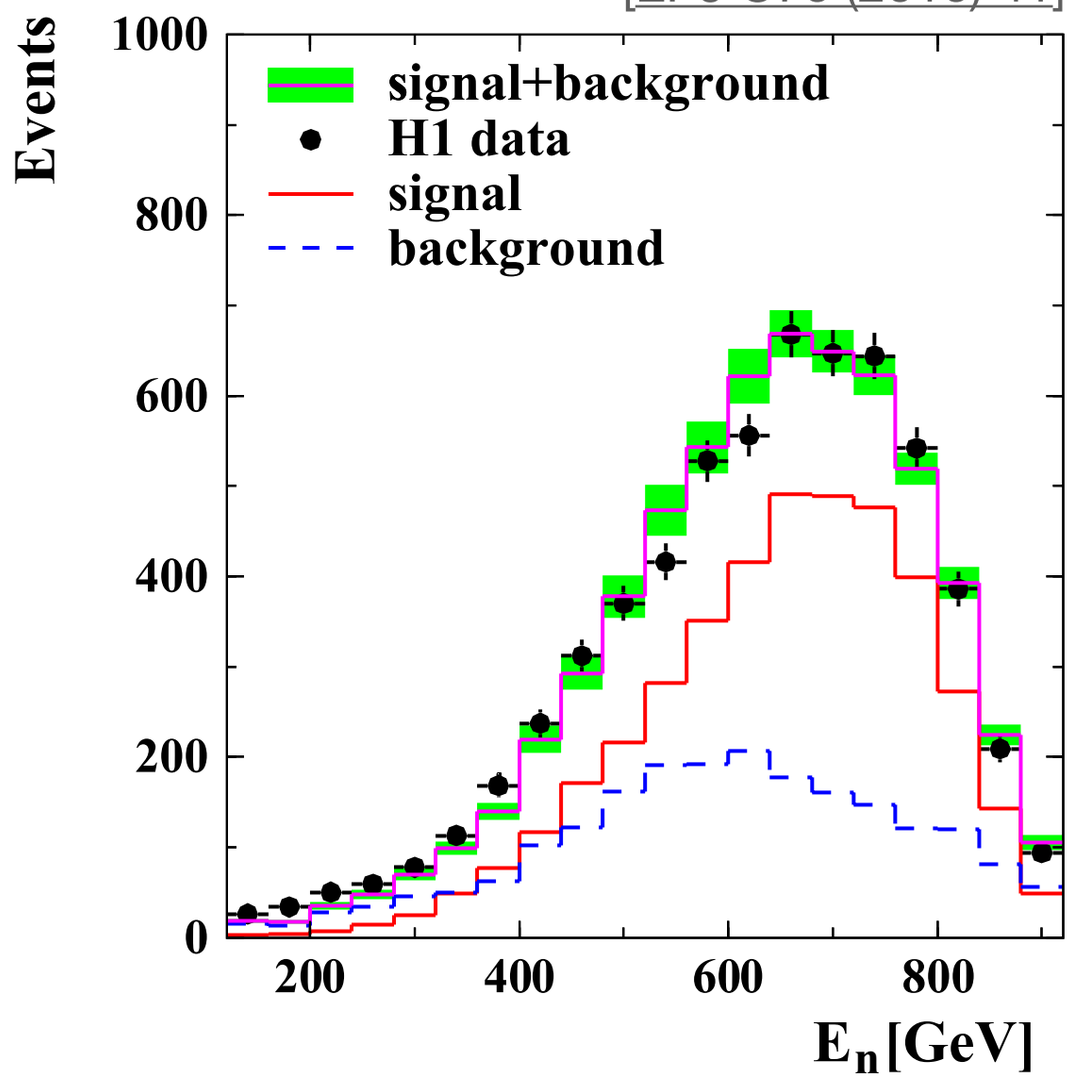


[EPJ C76 (2016) 41]



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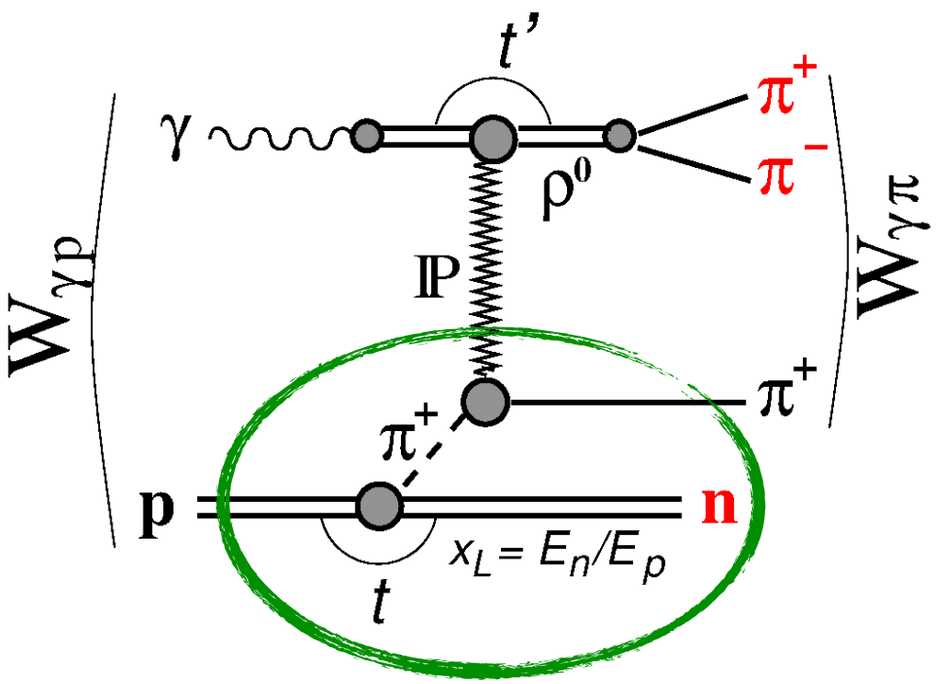
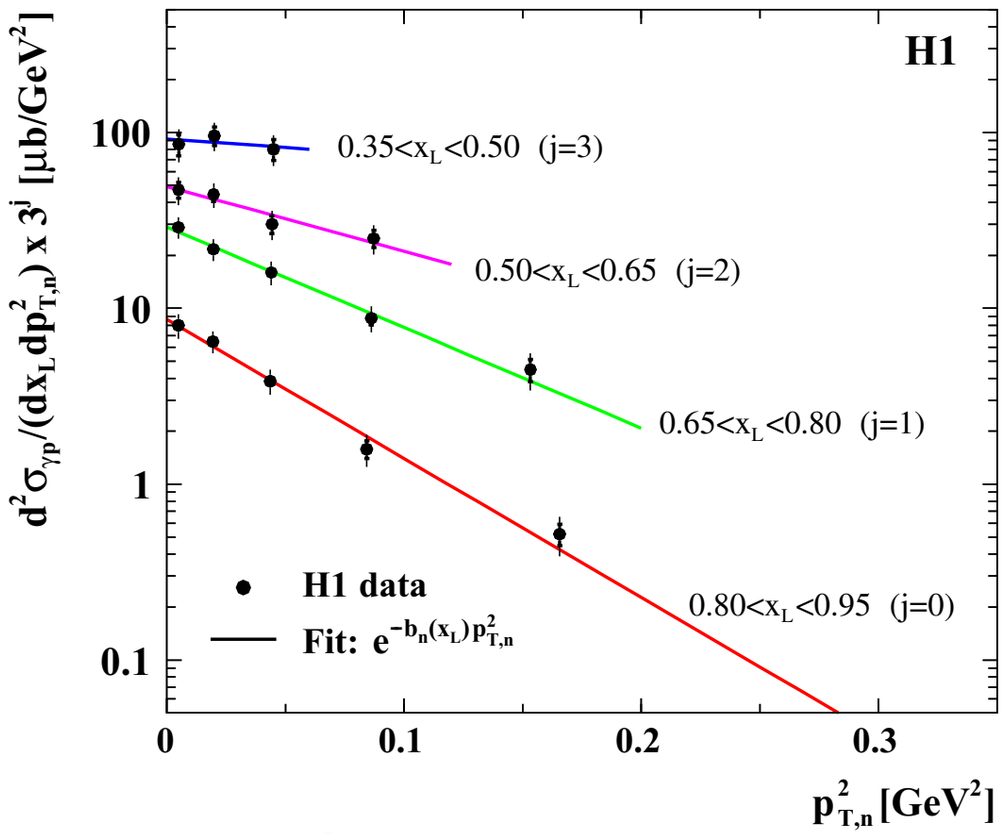


hadron-vertex kinematics:

- $p_{T,n}$ -dependence can be fit with simple exponential shape
- slope increases with x_L as predicted by the one-pion-exchange model (using different pion fluxes)



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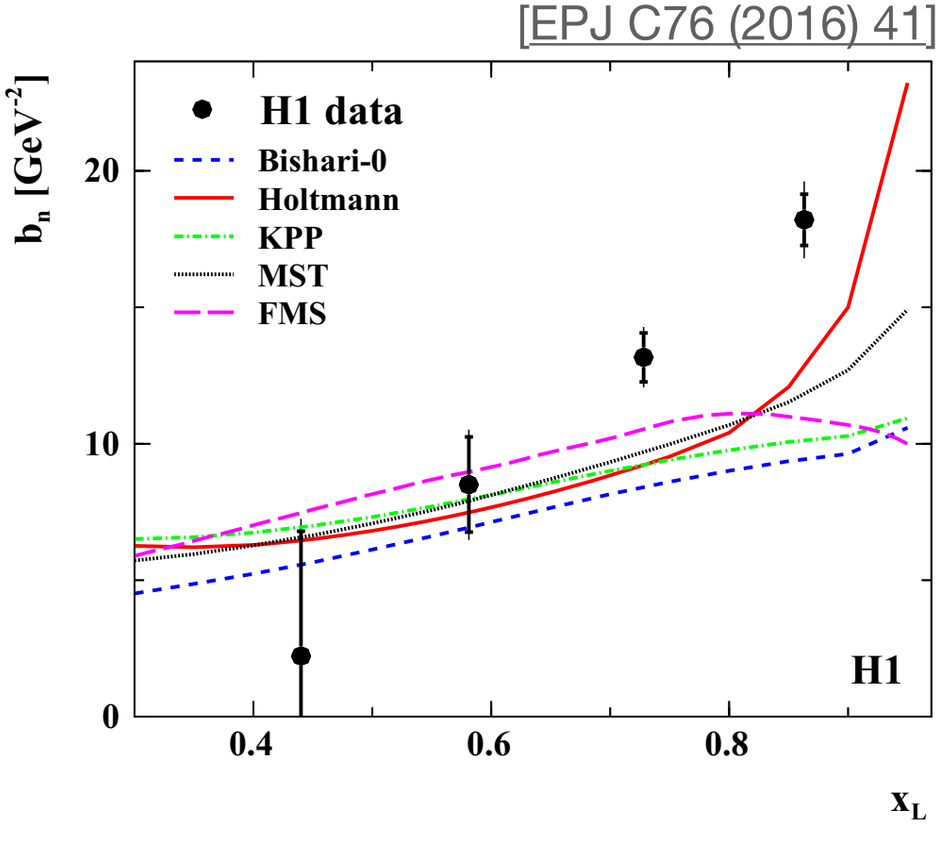
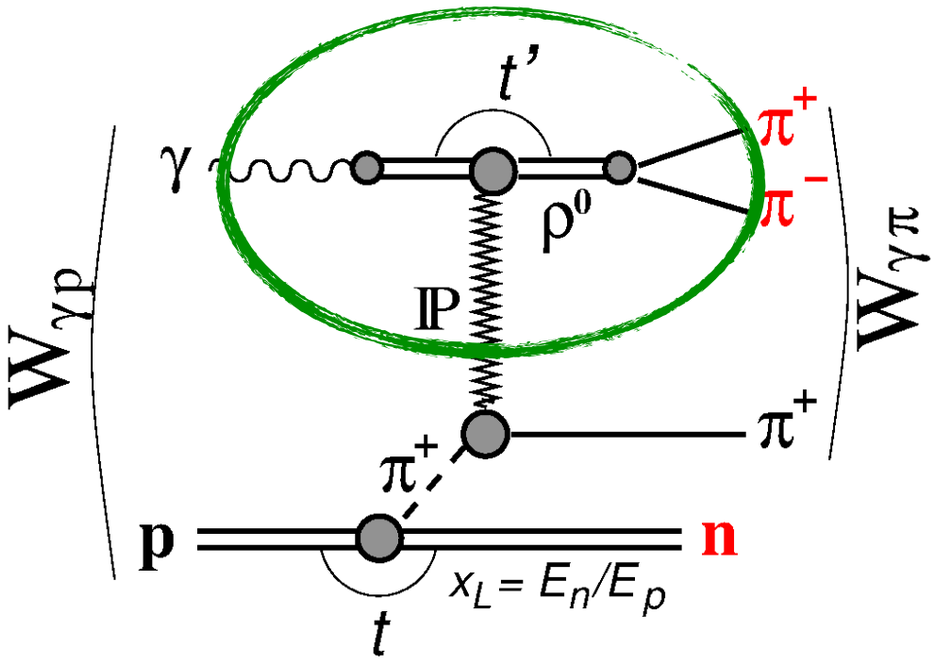
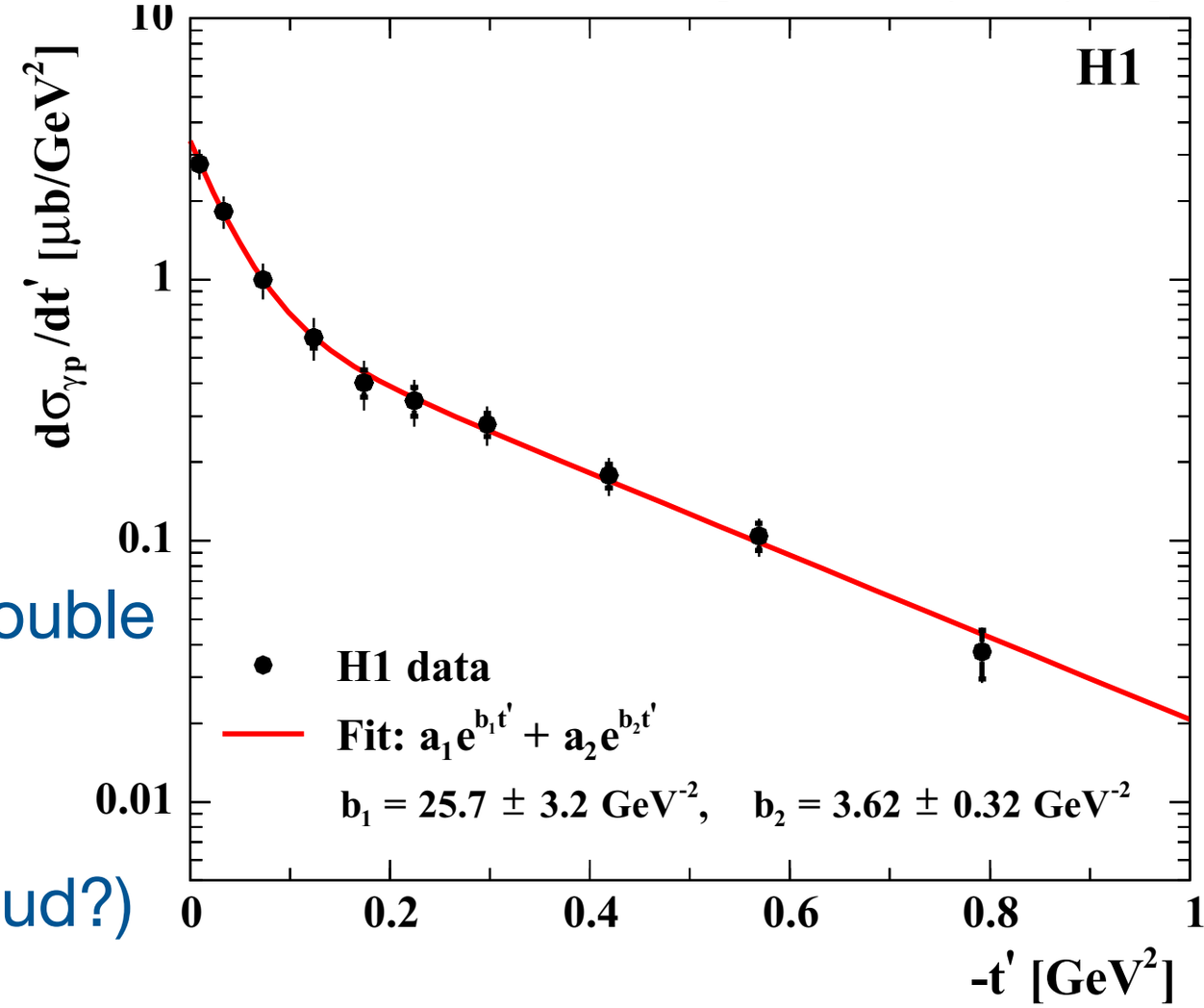


ρ^0 photoproduction with a leading neutron



[EPJ C76 (2016) 41]



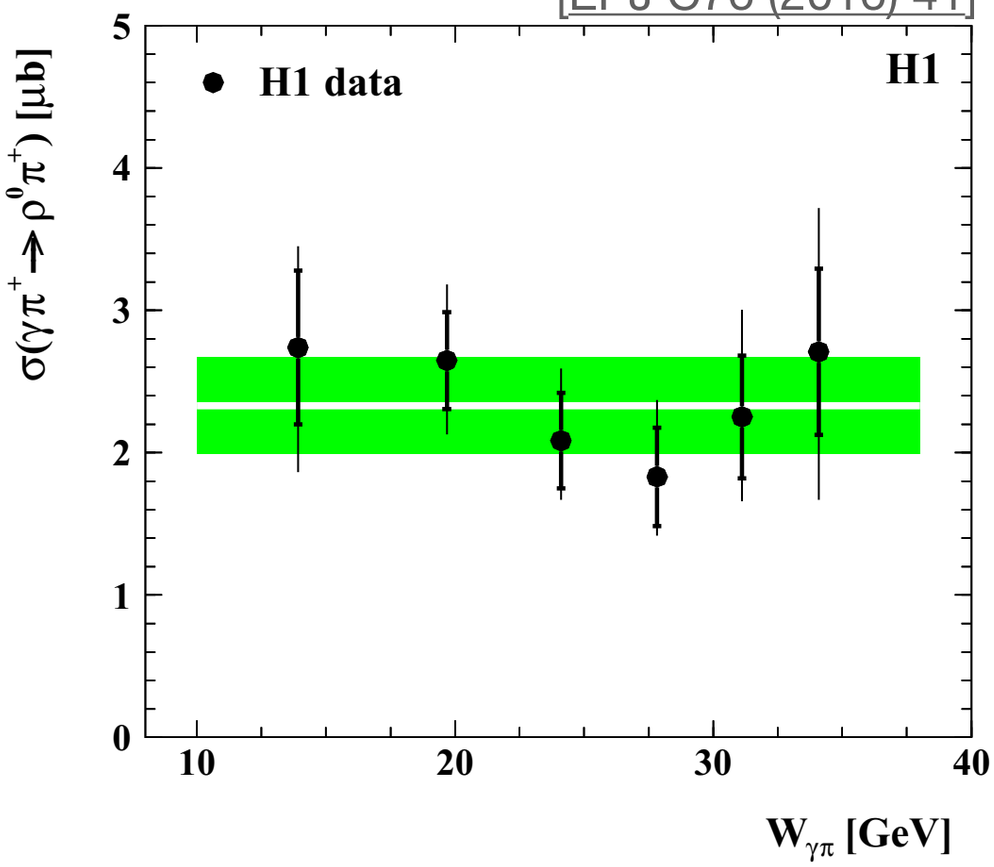
photon-vertex kinematics:

- -t' dependence typical for exclusive double peripheral exchange processes
  - b = (25.7 ± 3.2) GeV^{-2}
    → much larger than proton (pion cloud?)
  - b = (3.62 ± 0.32) GeV^{-2}
    → corresponds to target size
- interpretable also as interference effect

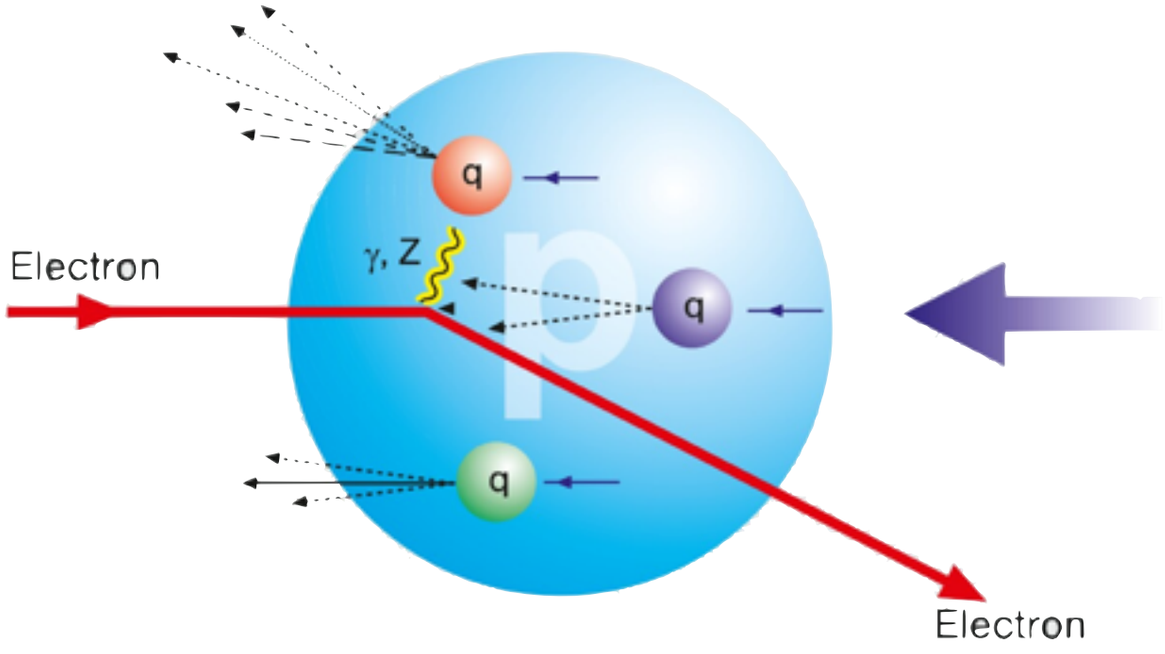
ρ^0 photoproduction with a leading neutron

- extract γπ cross section from $d\sigma/dx_L$ in the one-pion-exchange approximation

[EPJ C76 (2016) 41]



- no apparent W dependence of elastic γπ cross section (in limited range in W)
- cross section much smaller than expected - points to significant absorption corrections



inclusive measurements

$$\frac{\mathrm{d}^2\sigma^{e^\pm p}_{\mathrm{NC}}}{\mathrm{d}x\,\mathrm{d}Q^2} \propto \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3 - \frac{y^2}{Y_+}\tilde{F}_{\mathrm{L}}$$

combined QCD & EW analysis of HERA data

- recent HERAPDF2 fit to combined H1&ZEUS data does not exploit electron beam polarization available during HERA-II running

- including beam polarization in DIS structure functions:

$$\tilde{F}_2^{\pm} = F_2^{\gamma} - (v_e \pm P_e a_e)\chi_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2P_e v_e a_e)\chi_Z^2 F_2^Z$$
$$x\tilde{F}_3^{\pm} = -(a_e \pm P_e v_e)\chi_Z x F_3^{\gamma Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2)\chi_Z^2 x F_3^Z$$

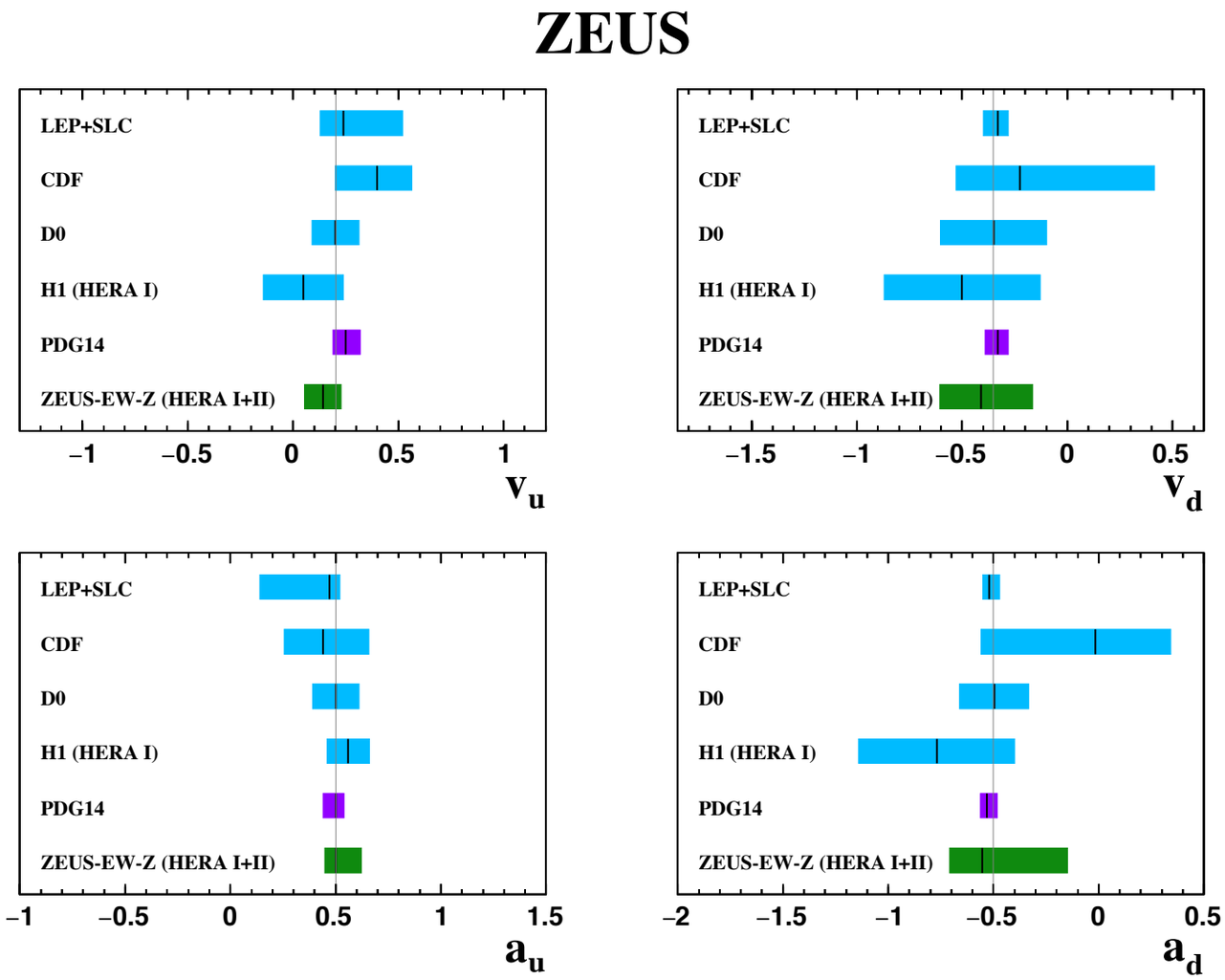
- v_e and a_e : vector and axial-vector couplings of Z boson to electron

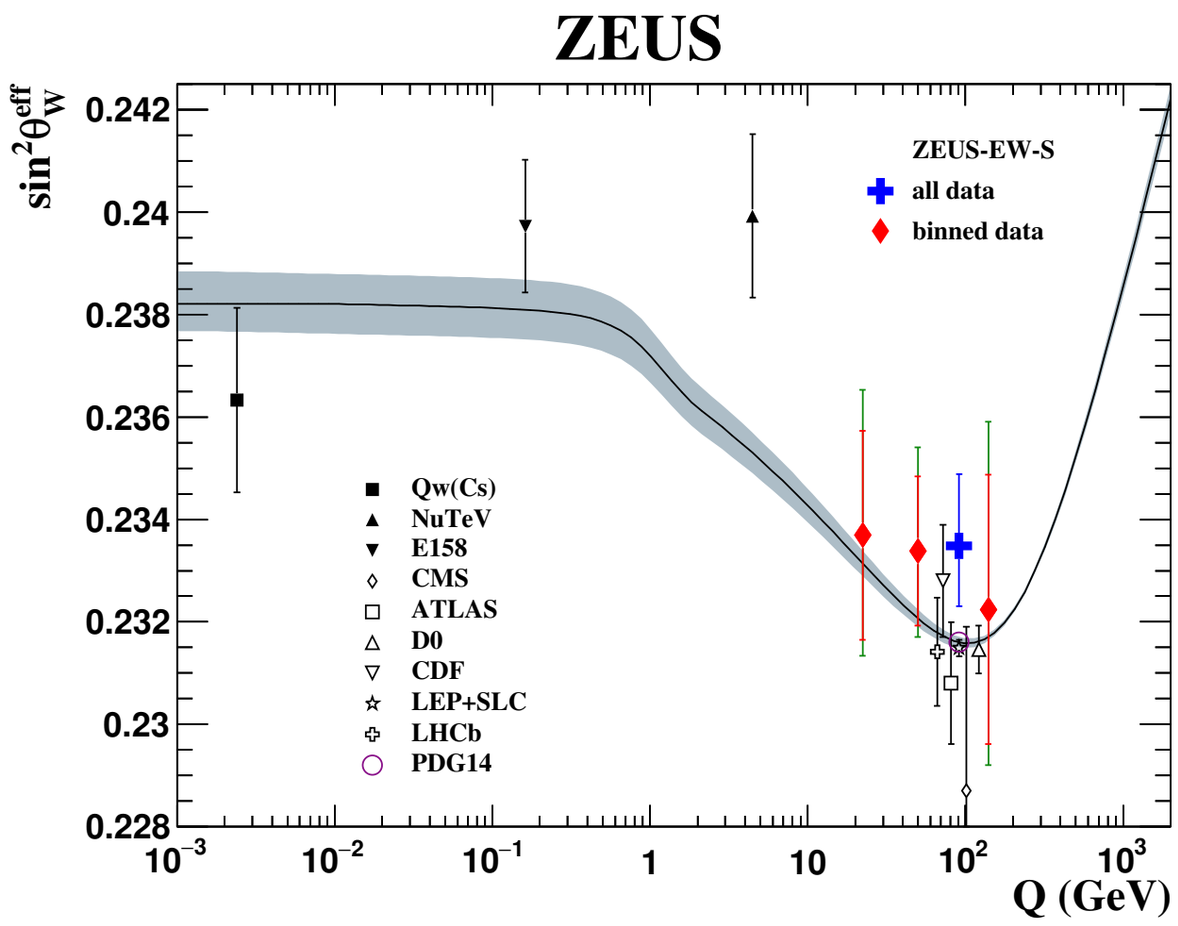
- likewise, quark-parton model expressions for structure functions include couplings a_q and v_q to quarks:

$$[F_2^{\gamma}, F_2^{\gamma Z}, F_2^Z] = \sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2] x(q + \bar{q})$$
$$[xF_3^{\gamma Z}, xF_3^Z] = \sum_q [e_q a_q, v_q a_q] 2x(q - \bar{q})$$

- exploit dependence on EW parameters in combined fit to inclusive DIS data

combined QCD & EW analysis of HERA data



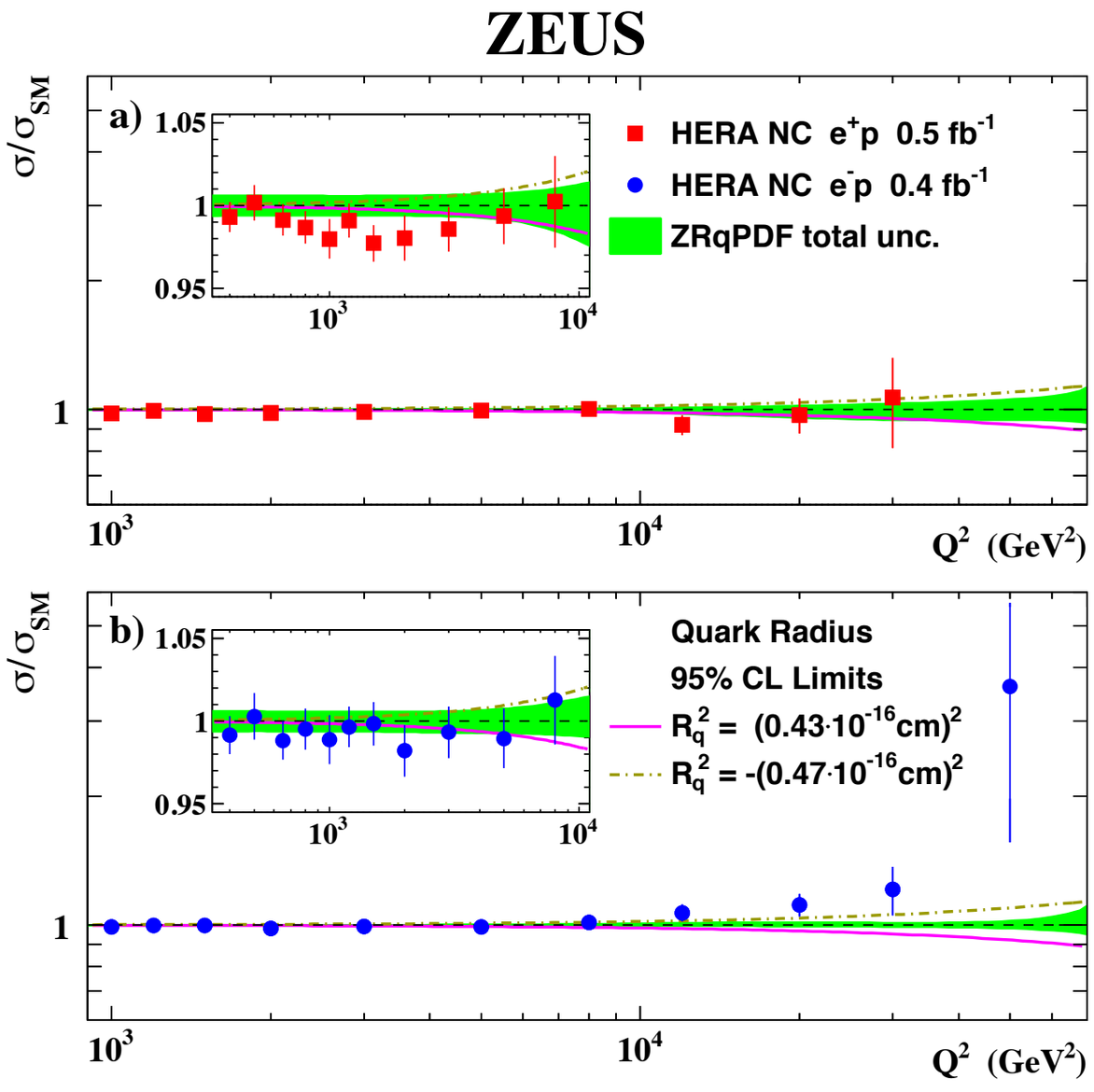


- couplings obtained well compatible with world data
  - most precise value for u quarks from single experiment
- weak mixing angle compatible with Standard Model
  - only measurement of kinematic dependence from one experiment

limits on effective quark radius

- include deviations from SM as effective quark radii (semi-classical form-factor approach) in combined fit of PDFs and *new physics*

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\mathrm{SM}}}{dQ^2}\left(1-\frac{R_e^2}{6}Q^2\right)^2\left(1-\frac{R_q^2}{6}Q^2\right)^2$$



- no deviation from SM prediction found
- limit on effective quark radii:

$-(0.47 \times 10^{-16}\ \mathrm{cm})^2 < R_q^2 < (0.43 \times 10^{-16}\ \mathrm{cm})^2$

- similar to and complementary to LEP ($R_q < 0.42 \times 10^{-16}$ cm)

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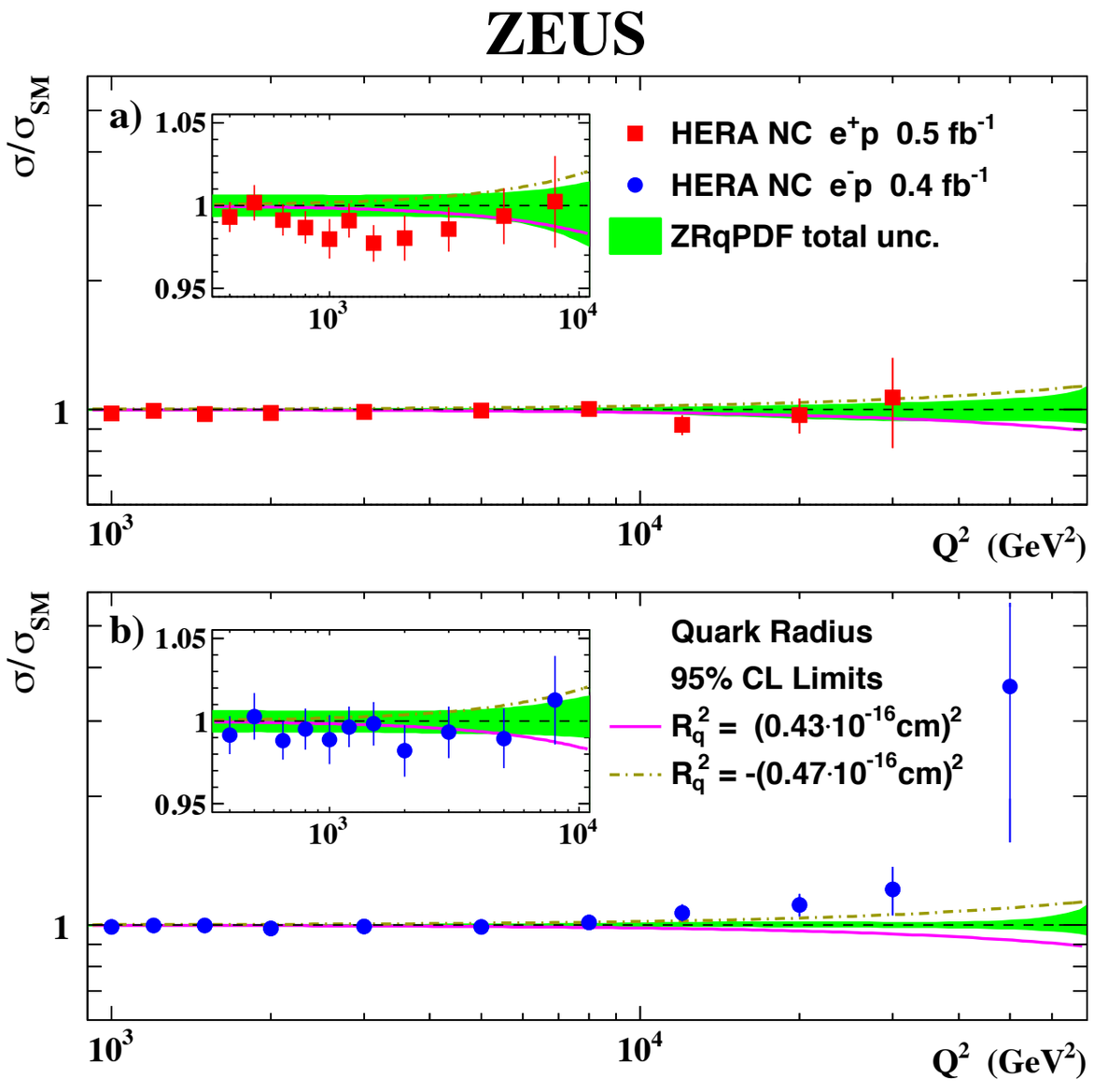

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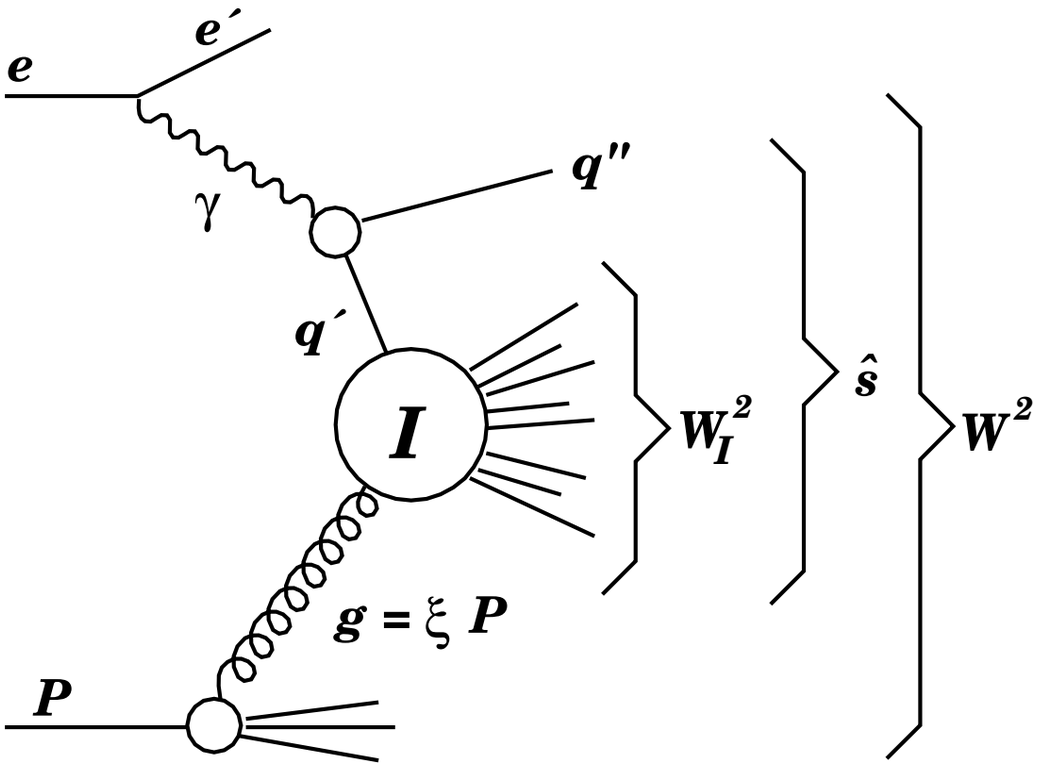
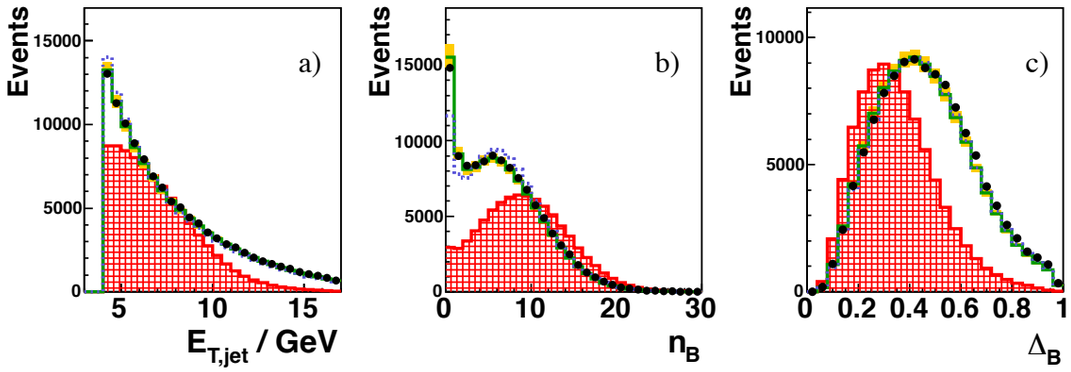
searches

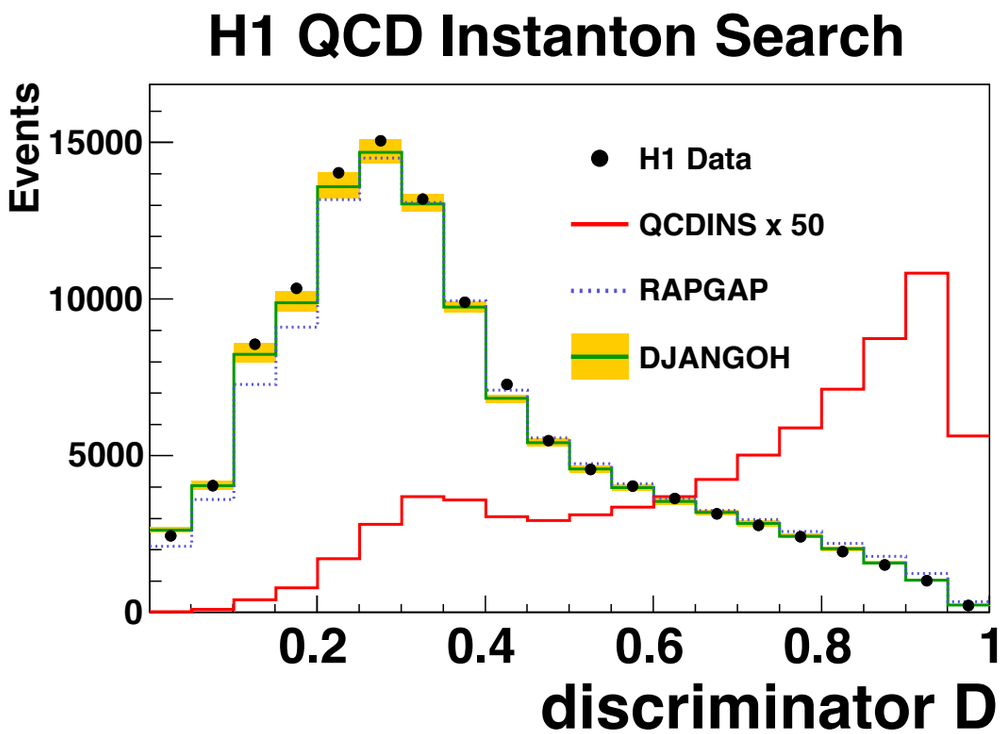
search for QCD instatons



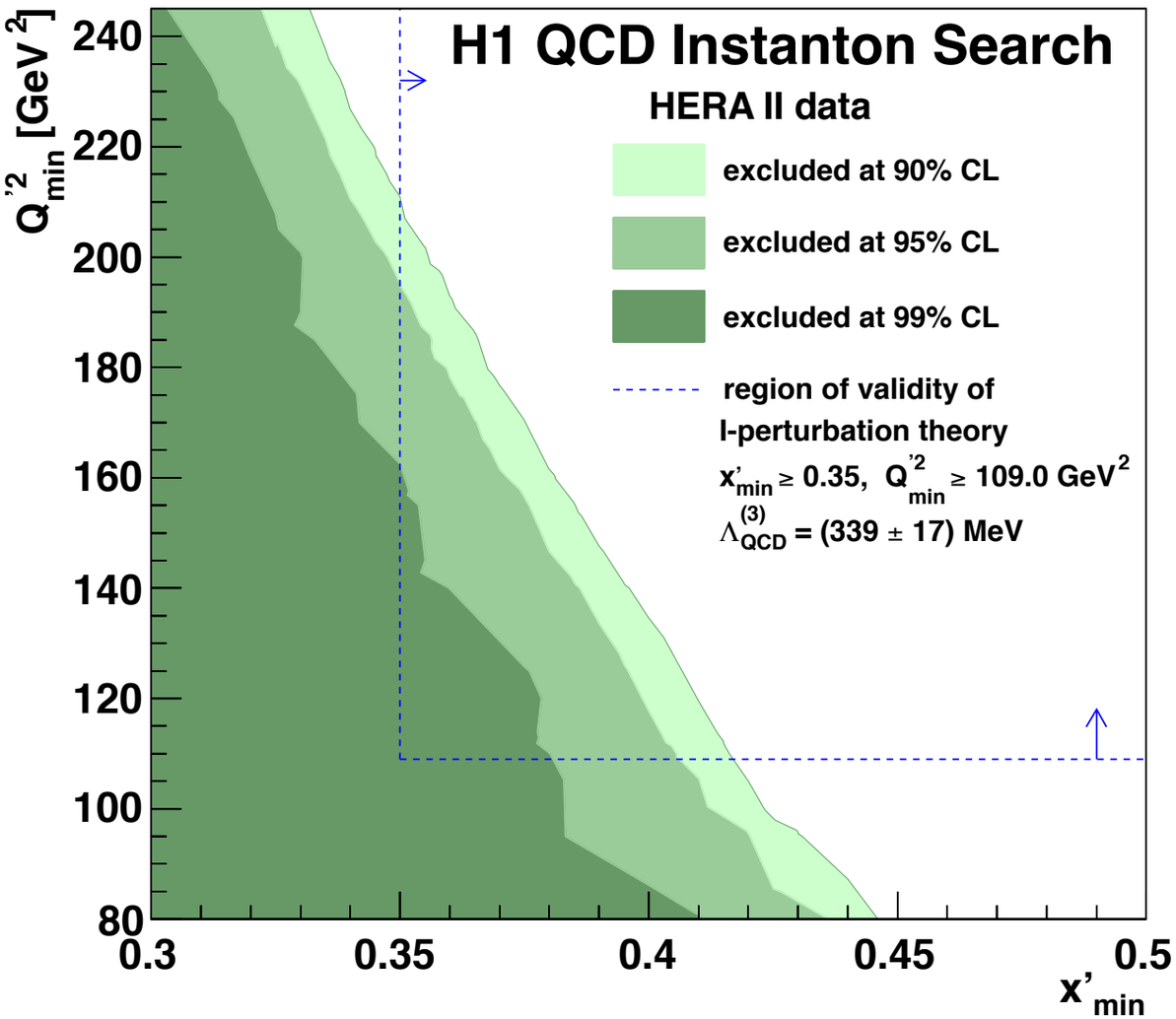
- QCD instanton: non-perturbative fluctuation of the gluon field
- interpretation: tunneling between topologically different vacua
- QCD instanton violates chirality
- at HERA: search for events with *fireball* signature
  - experimental difficulty: suppress SM QCD background
  - strategy: combine five most sensitive variables in a discriminator

search for QCD instatons





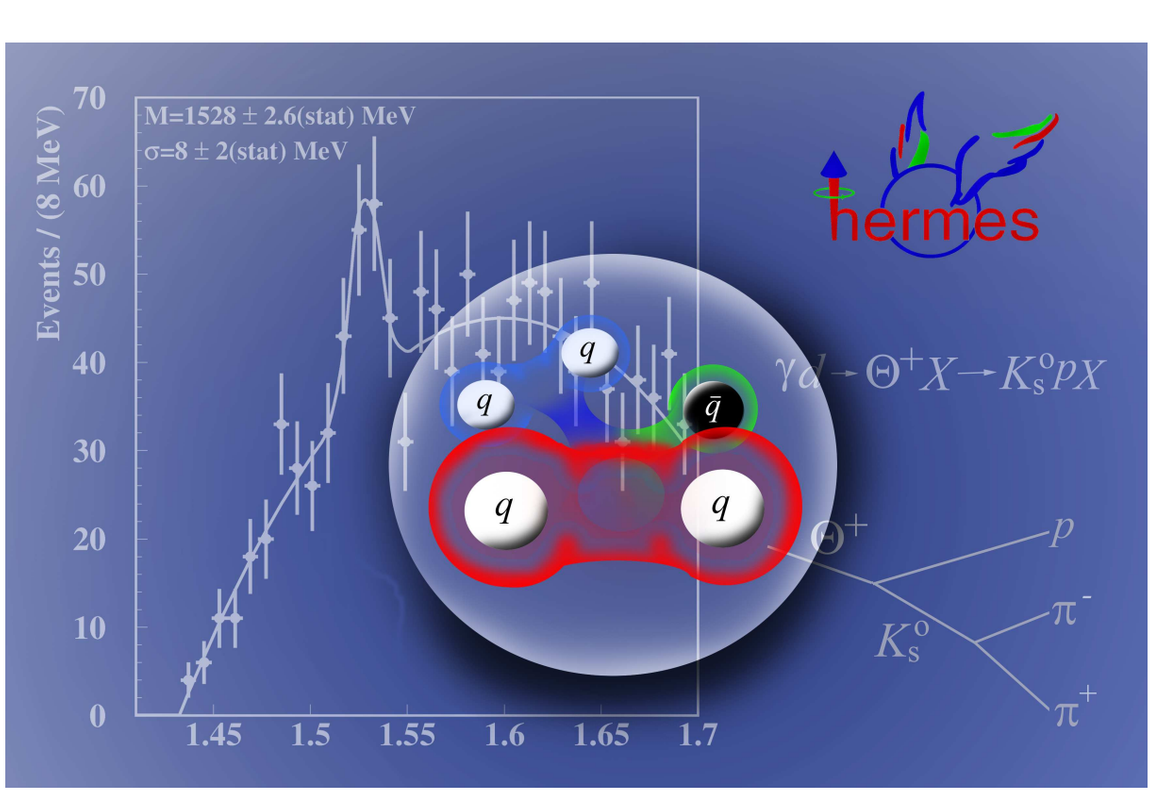
[arXiv:1603.05567]



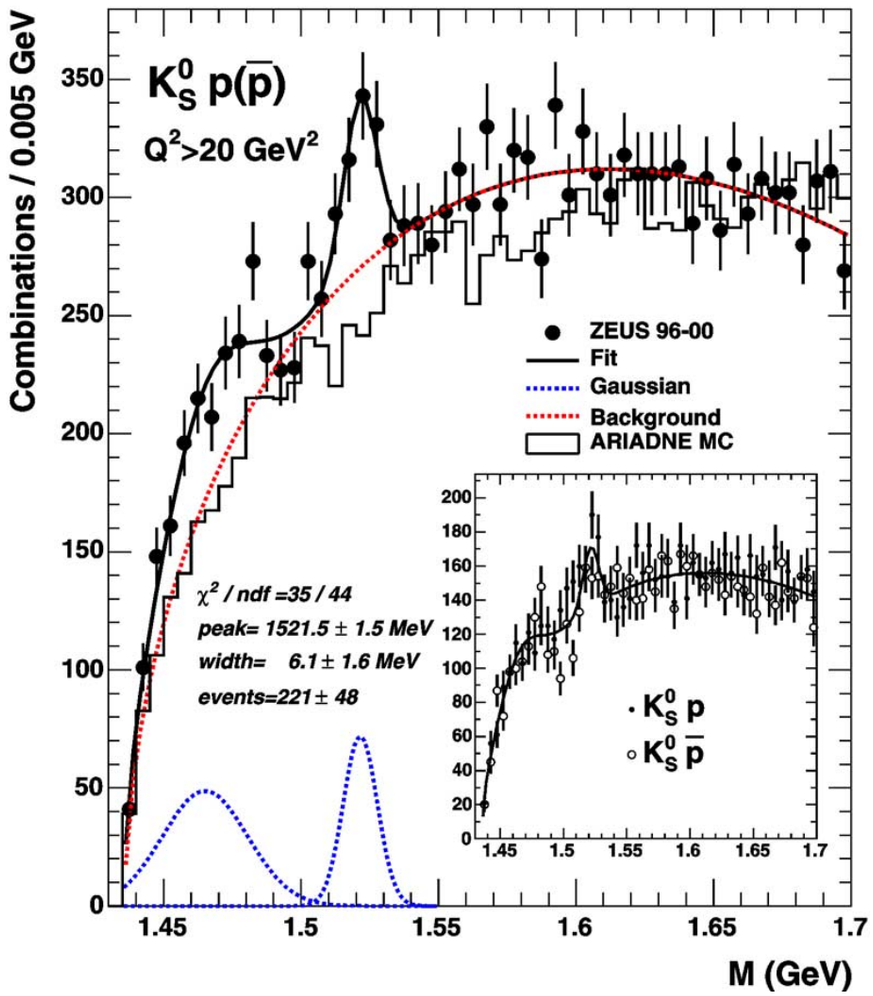
- no signal found
  - set exclusion limits
  - part of phase-space excluded

pentaquark Θ^+ search

- going beyond the familiar 2- and 3-quark states, tetra- and pentaquark states moved (again) into the center of attention after the recent findings in e^+e^-, pp, and pp
- already in early 2000s, a big *hype* after reports on the pentaquark Θ^+ state
- both ZEUS and HERMES observed clear enhancements (while H1 did not)



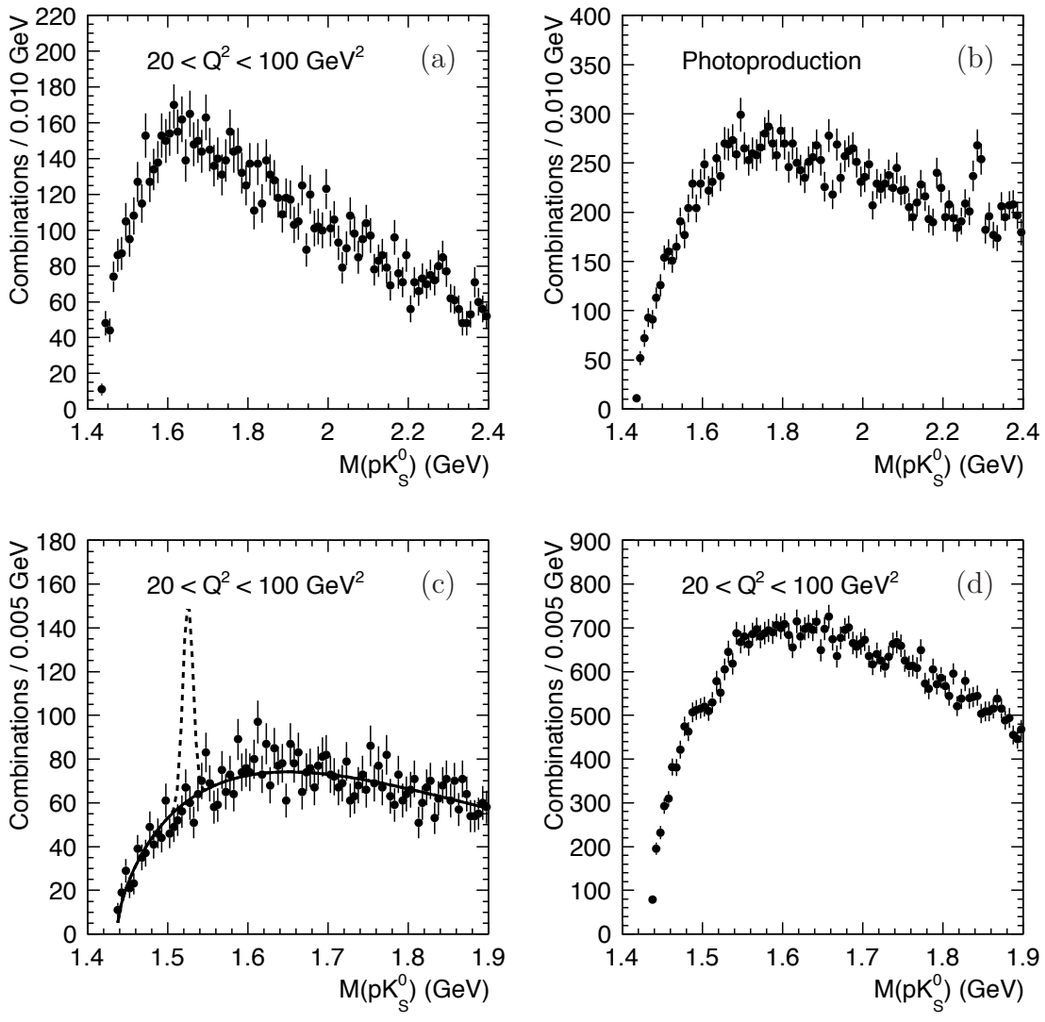
[ZEUS, PLB 591 (2004) 7]

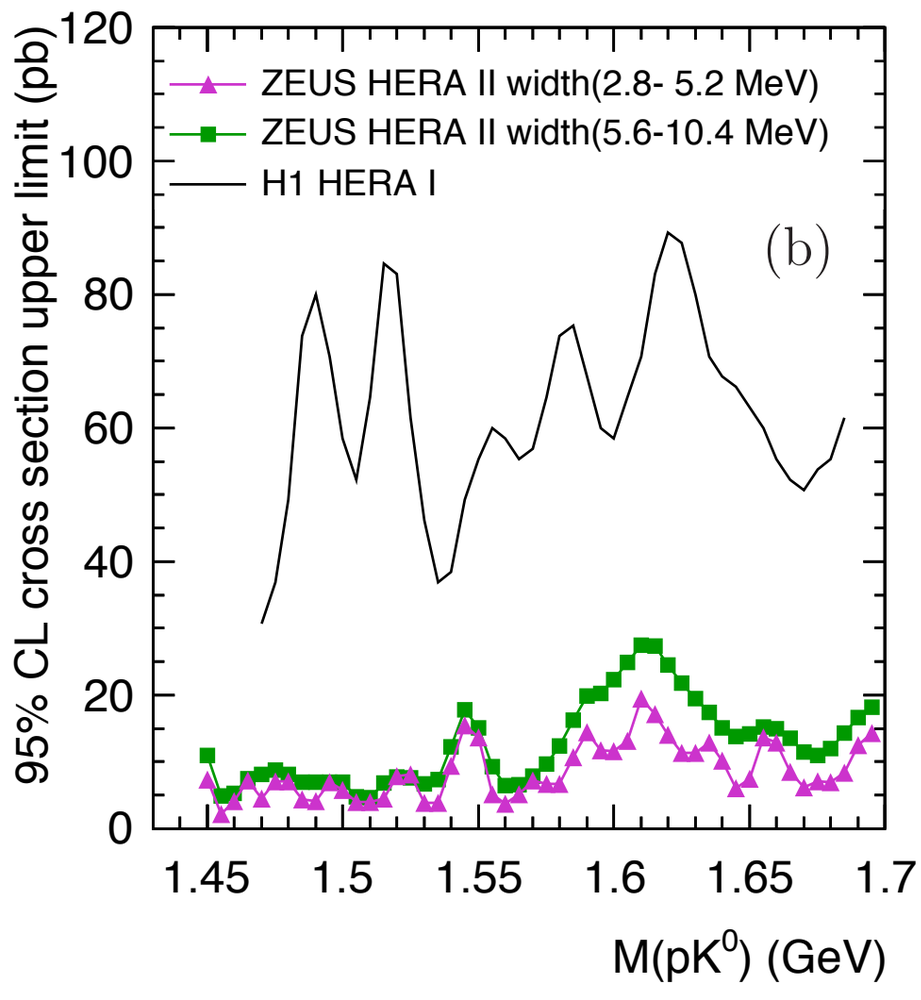


- additional HERA-II data: support/disclaim earlier results

pentaquark Θ^+ search in DIS

- 3x integrated lumi compared to earlier (HERA-I) analysis → 358pb^{-1}





- no peak structure at 1.52 GeV (26 vs. 286 events expected)
- much improved upper limit <10pb (at 95% conf. level)

conclusion

- archive of HERA data completed
  - two tape copies for complete archive
  - *online* space for direct access to subset of archive
- analysis of HERA data ongoing with many new results
- 15 HERA talks at upcoming DIS'16 conference at DESY
- large pool of analyses topics remaining
  - possibilities for future analyses both for current and new members of the HERA collaborations

backup

for the statistics enthusiasts ...

final archive storage content

H1	HERMES	ZEUS	HERA-B	Type
983398	6557725	1183157	846059	single files
11111	9179	7318	4110	archive (tar) files
810316	774032	1182941	0	files online
359	57	239	0	TiB online
~464	581	368	392	# LTO4 (800G) tapes
134	174	104	110	# LTO6 (2.4T) tapes
430	358	239	276	TiB on LTO4/LTO6 tapes

- in nuce: 1.3 PB and 10 million files
- in addition there are 10 TB data of polarimeter data/simulations included