(Vector) Meson Production at H1

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for the H1 Collaboration

Special thanks to:
Duncan Brown
Philipp Fleischmann
Xavier Janssen

Contents of this Talk

Exclusive Vector Meson Production

- J/ψ and ψ' photoproduction
  - Elastic photoproduction
  - Photoproduction at high $|t|$
- ρ^0 electroproduction
  - helicities as function of t
  - Q^2 dependence of t and W slope

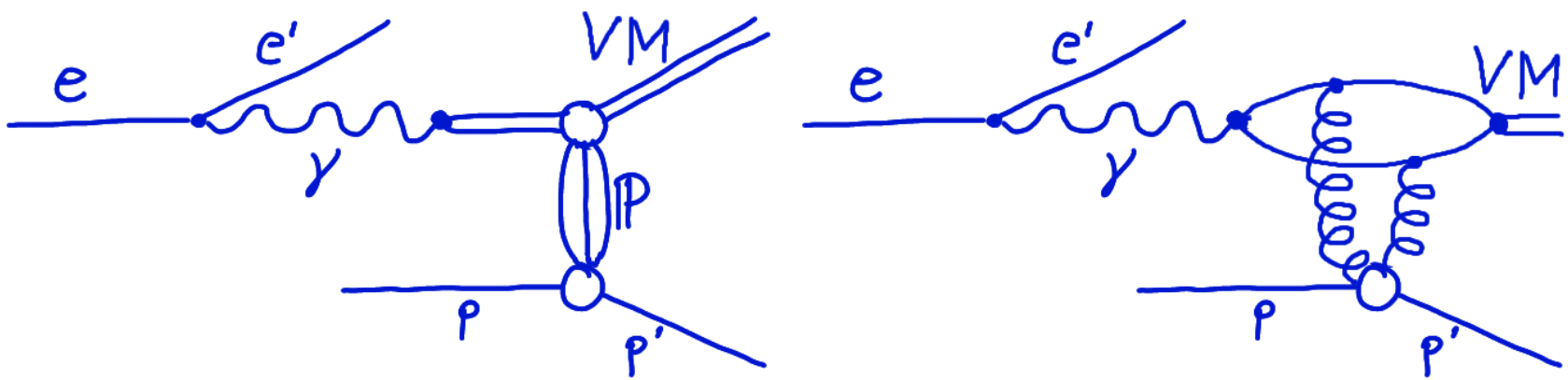
Something completely different:

- Inclusive production of η, ρ^0, f_0, f_2

Note: Data marked „H1 preliminary“ is subject to change.
Please do not quote it without permission from H1.

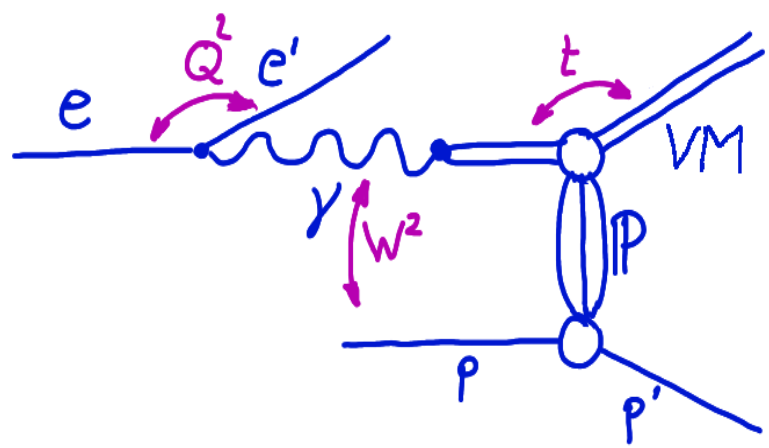
Vector Meson Photoproduction

- Vector mesons (ρ, ω, ϕ, J/ψ, ψ', ...)
  - have same quantum numbers $J^{PC}=1^{--}$ as photon
  - can be produced by colorless exchange („$\mathbb{P}$omeron“) with proton
- Are a challenge tp perturbative QCD:
  Understand cross section dependency on VM type, center−of−mass energy, momentum transfer, photon virtuality, helicity
- Closely linked to 2−gluon exchange: (Skewed) gluon density

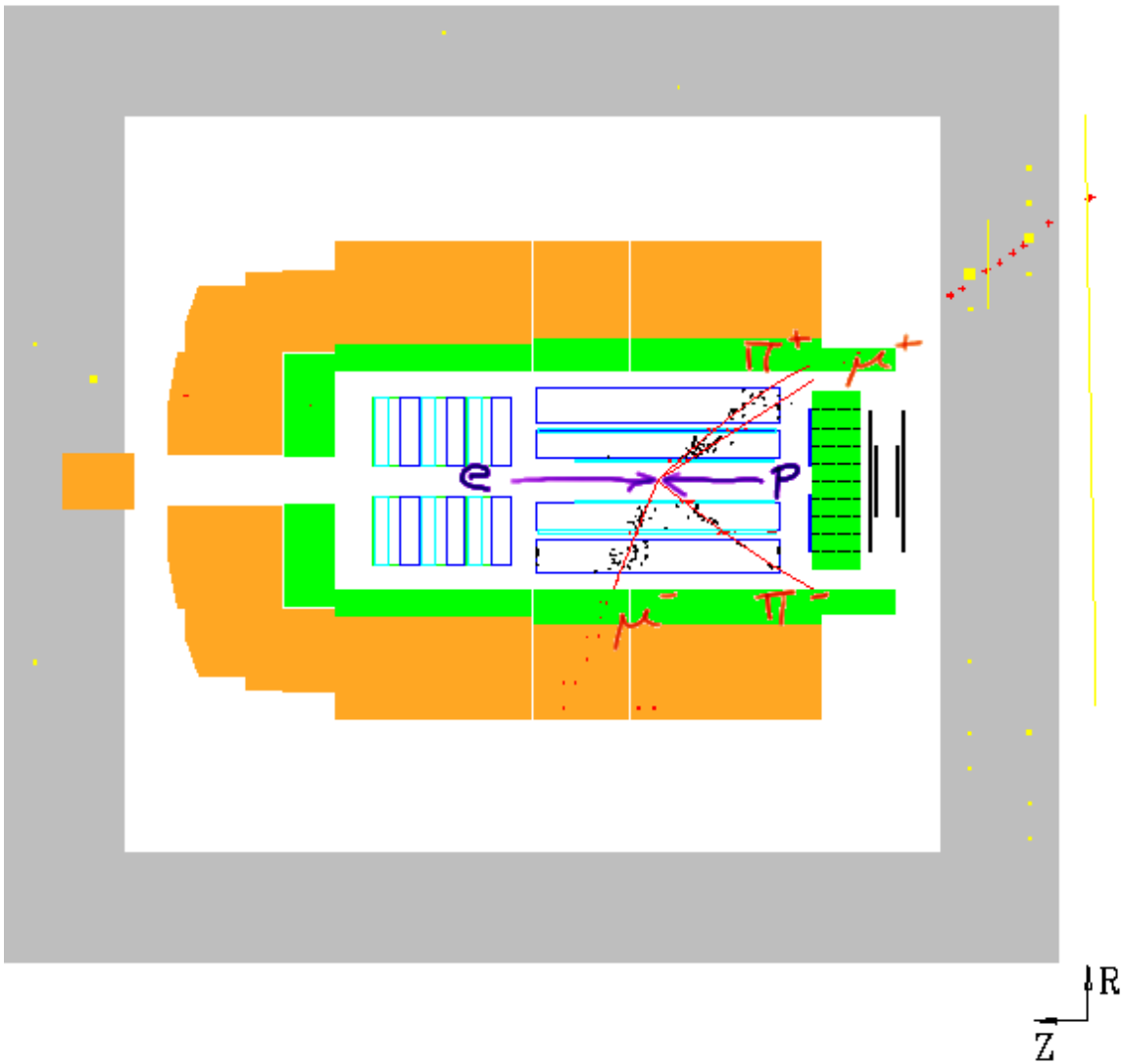


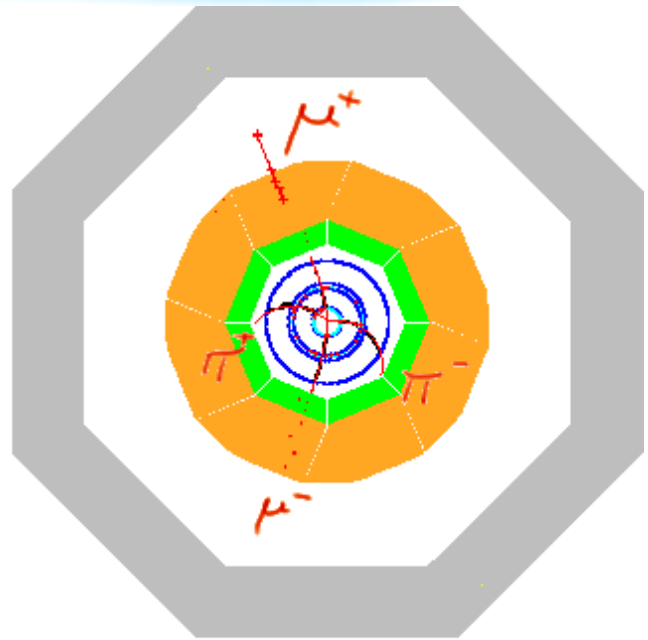
Kinematics

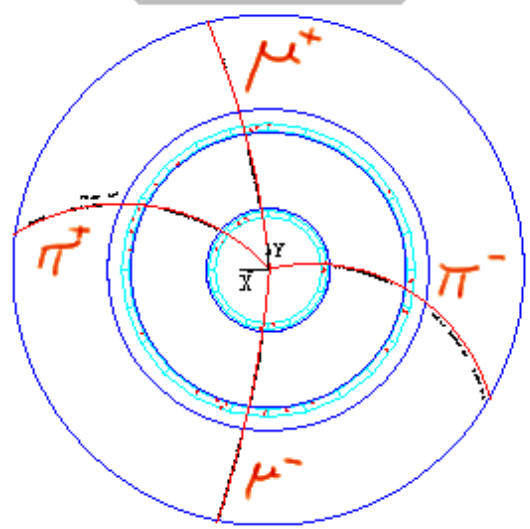
- Photon virtuality Q^2:
  - low $Q^2 < 1\text{GeV}^2$: photoproduction, electron undetected
  - $Q^2 > 1\text{GeV}^2$: electroproduction, electron in main detector
  - expect propagator term $1/(Q^2+m^2)^2$ in cross section
- W: Photon−proton center−of−mass energy; at HERA: 20−200GeV
- t: Momentum transfer squared to proton, $t \approx -p_t^2$ of proton
- M_{VM}: Vector meson mass
- All these variables can provide a hard scale for pQCD!



$ep \to ep\ \psi'$
$\hookrightarrow J/\psi\ \pi^+\pi^-$
$\hookrightarrow \mu^+\mu^-$ in H1

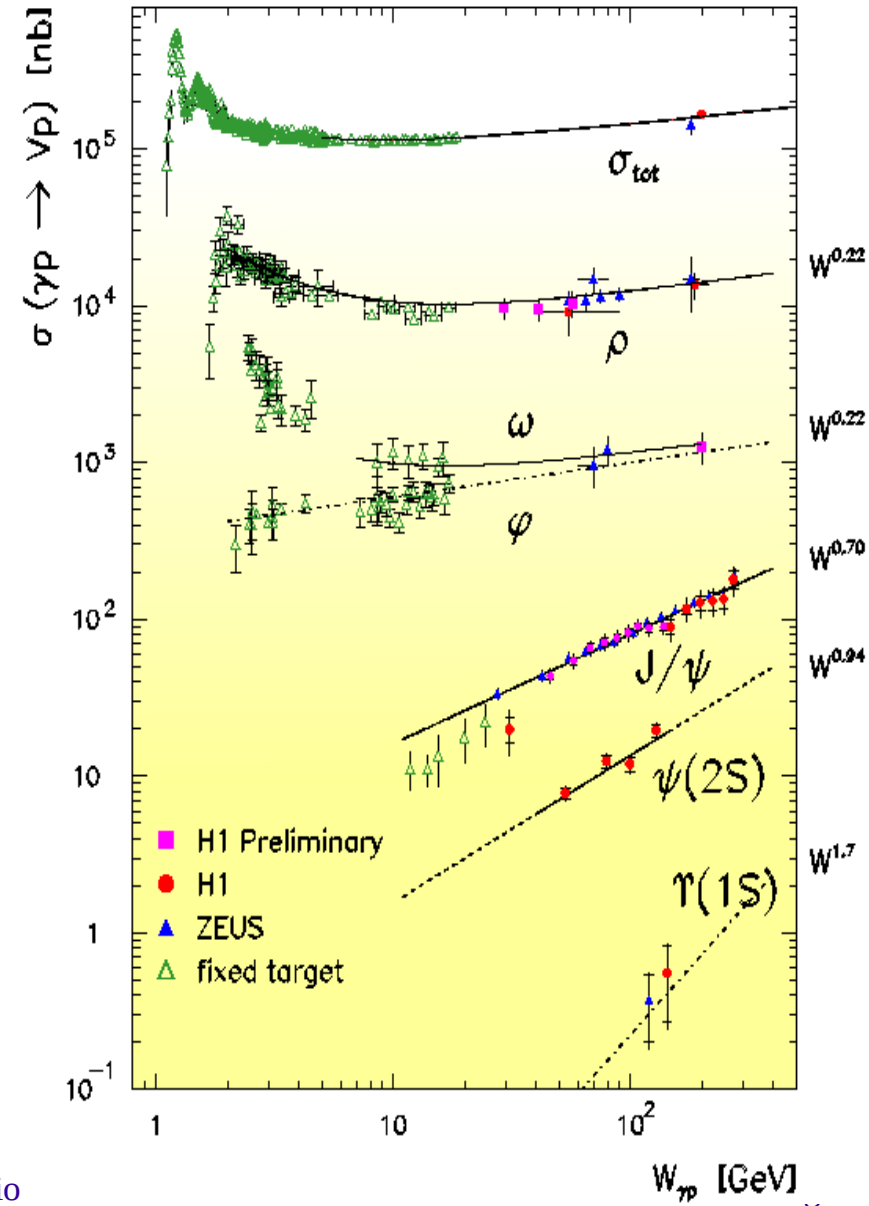




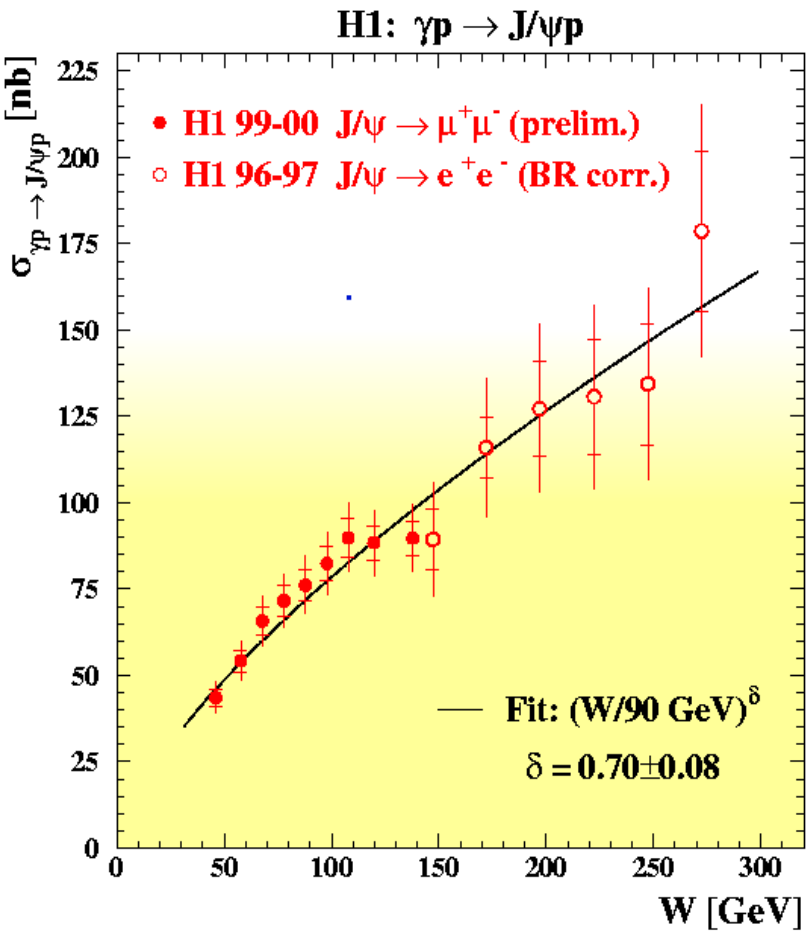


W Dependence of $\sigma_{\gamma p}$

- ℙomeron:
  $\sigma_{\gamma p} \propto W^{\delta}$,
  $\delta = 4\alpha(\langle t \rangle) - 4$
- QCD: $\sigma_{\gamma p} \propto G^2(x)$
- Rise gets steeper for:
  - higher VM mass
  - higher Q^2
  - high $|t|$?
- Can we describe that rise of the *W* slope in QCD?

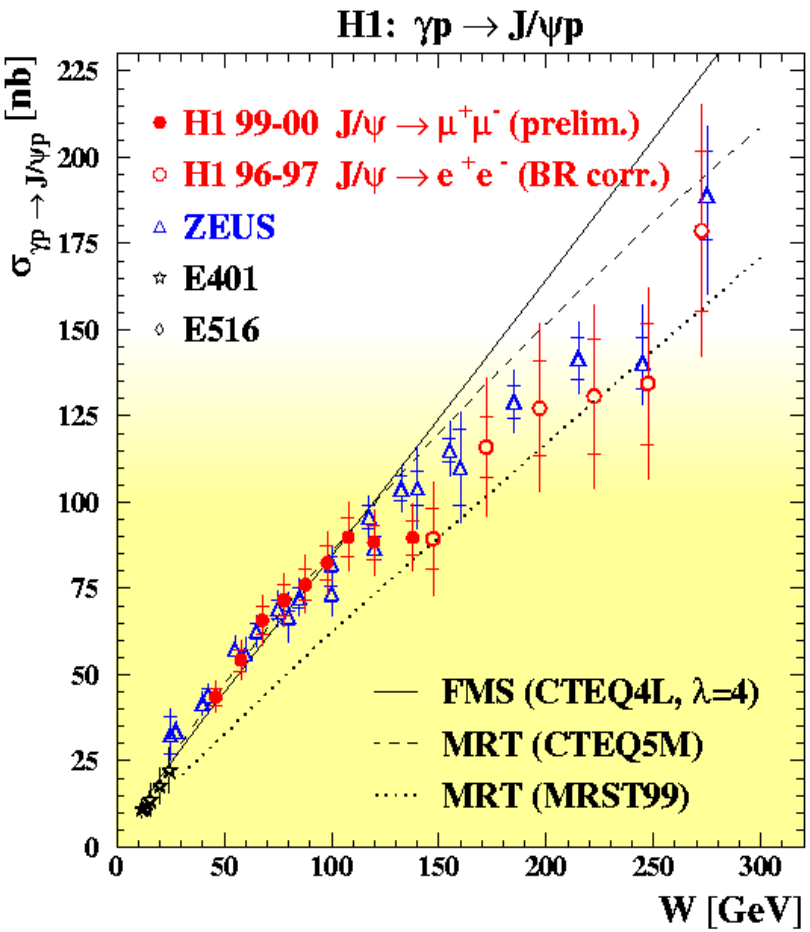


Integrated J/ψ Cross Section



- Data from 1999/2000, $\mathcal{L}$=54.8pb^{-1}
- More precise measurement of $\sigma(W_{\gamma p})$
- W dependence: $W^{0.70\pm0.08}$

Integrated J/ψ Cross Section



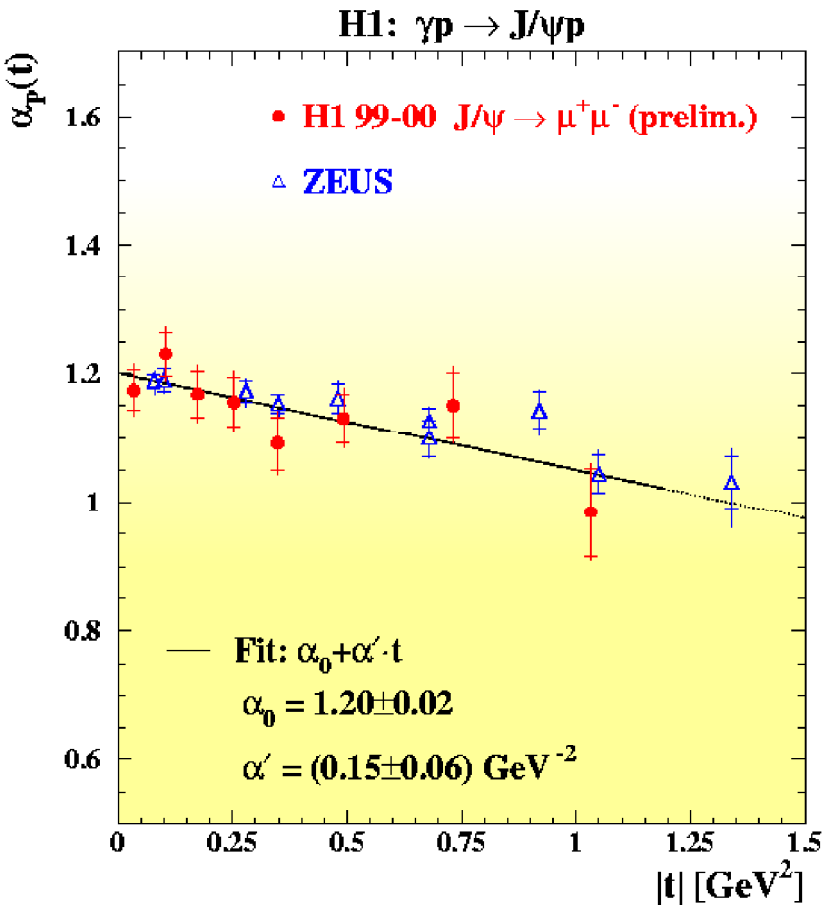
- Data from 1999/2000, $\mathcal{L}$=54.8pb^{-1}

  More precise measurement of $\sigma(W_{\gamma p})$

  W dependence: $W^{0.70\pm0.08}$

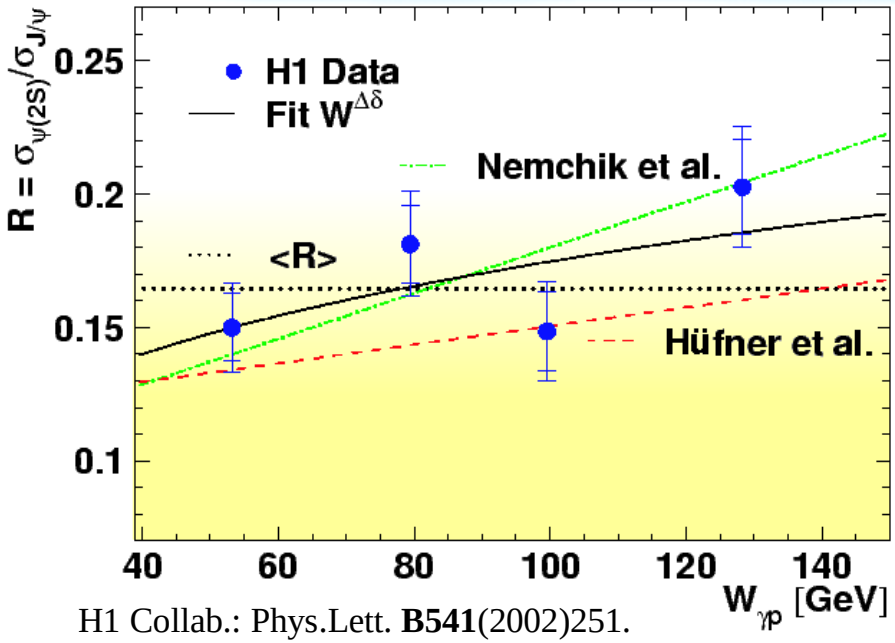
- Agreement with ZEUS and fixed target data
- Broad agreement with QCD calculations, but problems

The ℙomeron Trajectory

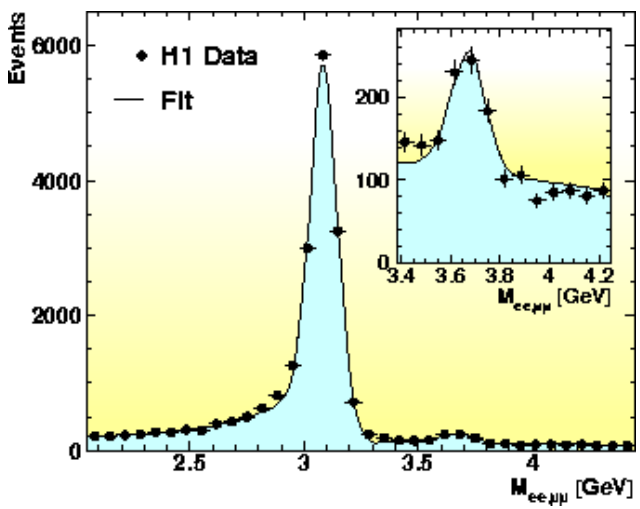


- Regge theory predicts:
  $d\sigma/dt\ (W_{\gamma p}) \propto W^{4[\alpha(t)-1]}$
- ⇨ Measuring W dependence in bins of t is a direct measurement of the ℙomeron's trajectory
- Good agreement with ZEUS data
- $\alpha' = 0.15 \pm 0.06\,\mathrm{GeV}^2$: Shrinkage observed with 2.5σ!

W Dependence of ψ' Production



H1 Collab.: Phys.Lett. **B541**(2002)251.

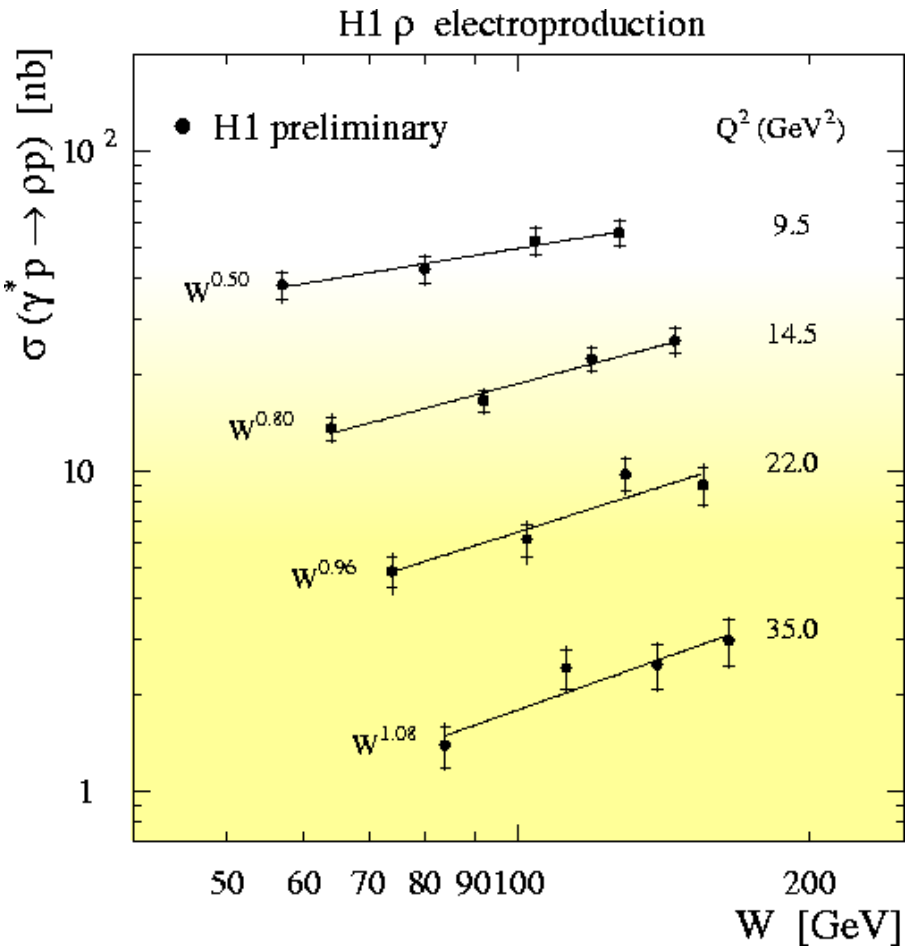


- Ratio $R=\sigma(\psi')/\sigma(J/\psi)$ measured
- R rises with W:
  $R \propto W^{0.24\pm0.17}$
- Described well by color−dipole gBFKL−based calculation from Nemchik *et al.*
- Calculation in light−cone dipole formalism from Hüfner *et al.* is a bit low

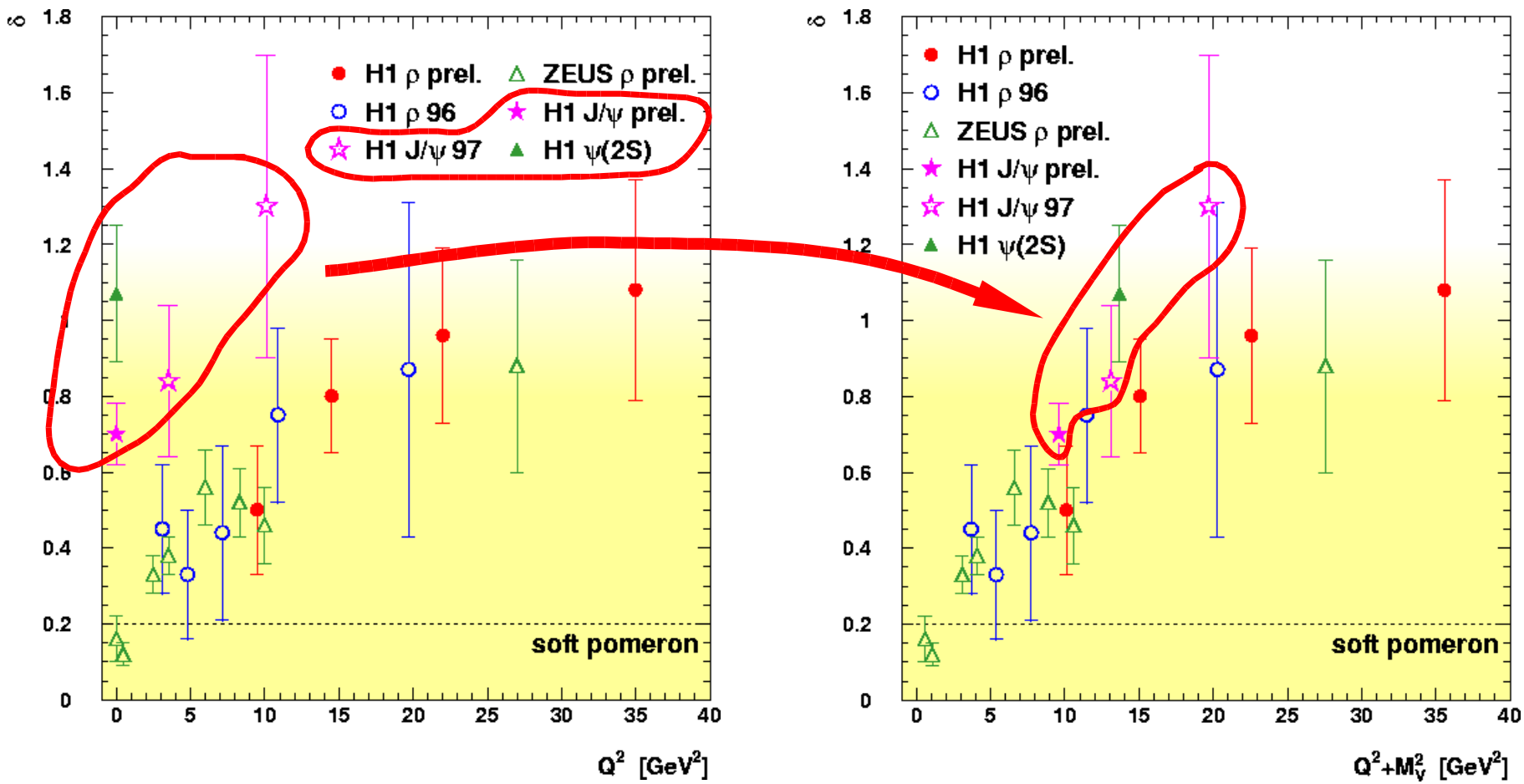
Theory:
Nemchik *et al.*, JETP **86**(1998)1054.
Hüfner *et al.*, Phys. Rev. **D62**(2000)094022.

W Rise in ρ^0 Electroproduction

- Preliminary result,
  2000 data, $\mathcal{L}$=42.4pb^{-1}
- *W* Rise gets steeper with Q^2

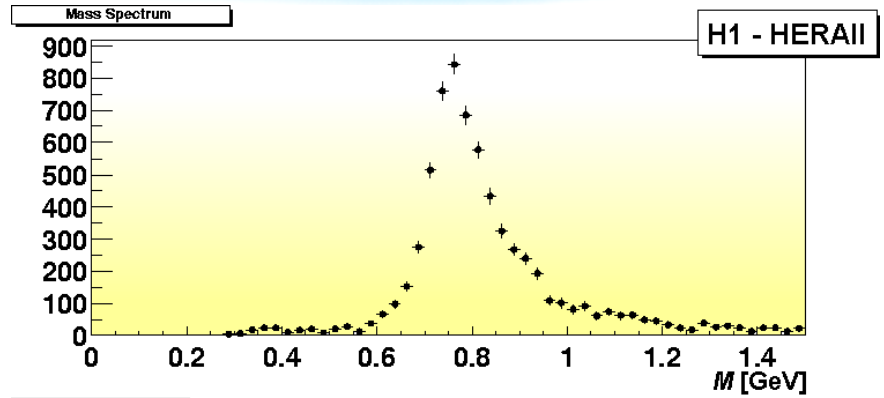


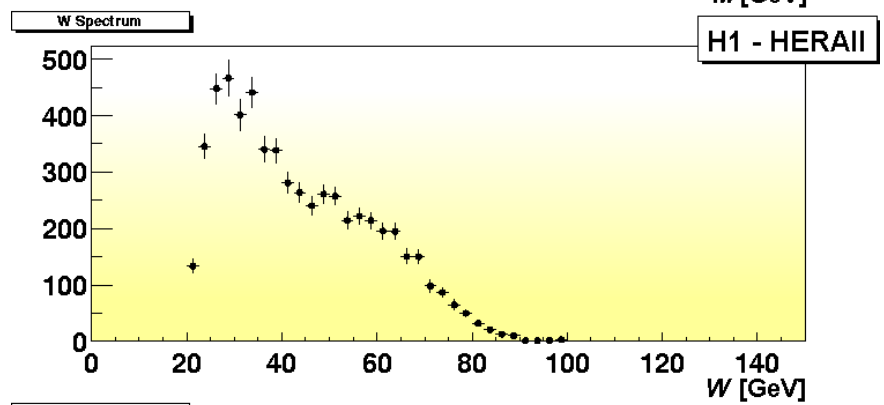
Is Q^2+m^2 a Universal Scale?

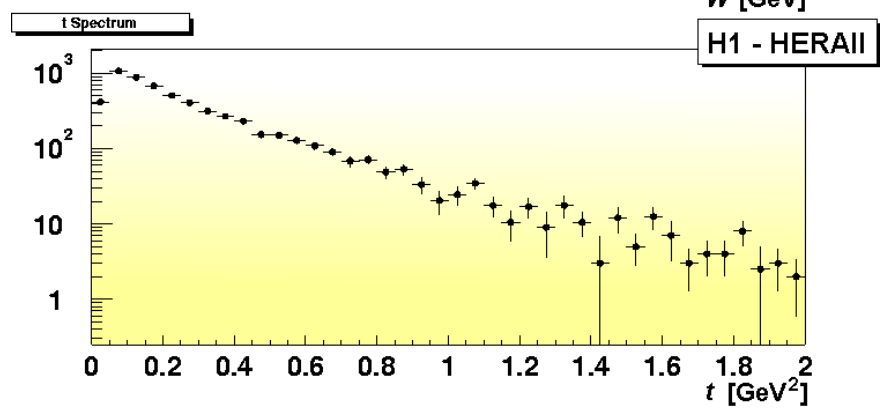


HERA−II: The Tale Continues

- Spring 2003: Special data taken with dedicated ρ^0 photoproduction triggers
- More than 13000 events taken
- W range 25−85GeV
- $|t|$ range up to 2GeV^2
- Enough data for double−differential measurement of ρ^0 photoproduction cross section





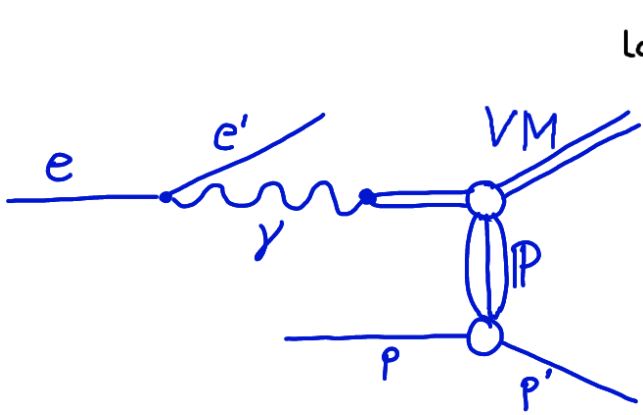


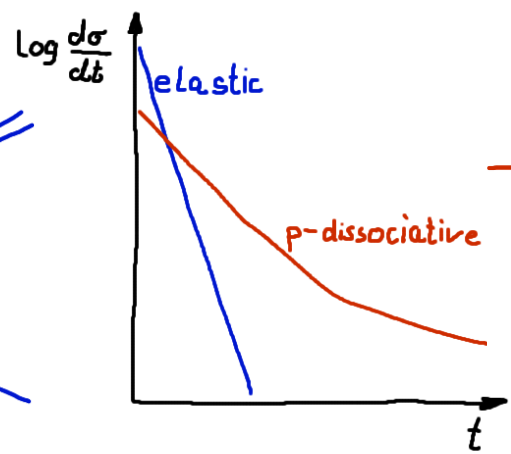
Momentum Transfer *t*

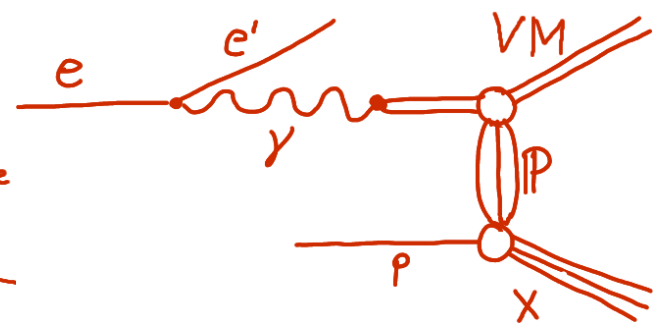
- Exponential falloff $d\sigma/dt \propto \exp(-b|t|)$
- In optical model (scattering on a black disk): $b=R^2/4$
- For proton dissociation: b smaller than for elastic production

⇒ Proton dissociation dominates at high |t|

- Slope get steeper with W: shrinkage
- High $|t|$: t becomes a hard scale for QCD calculations

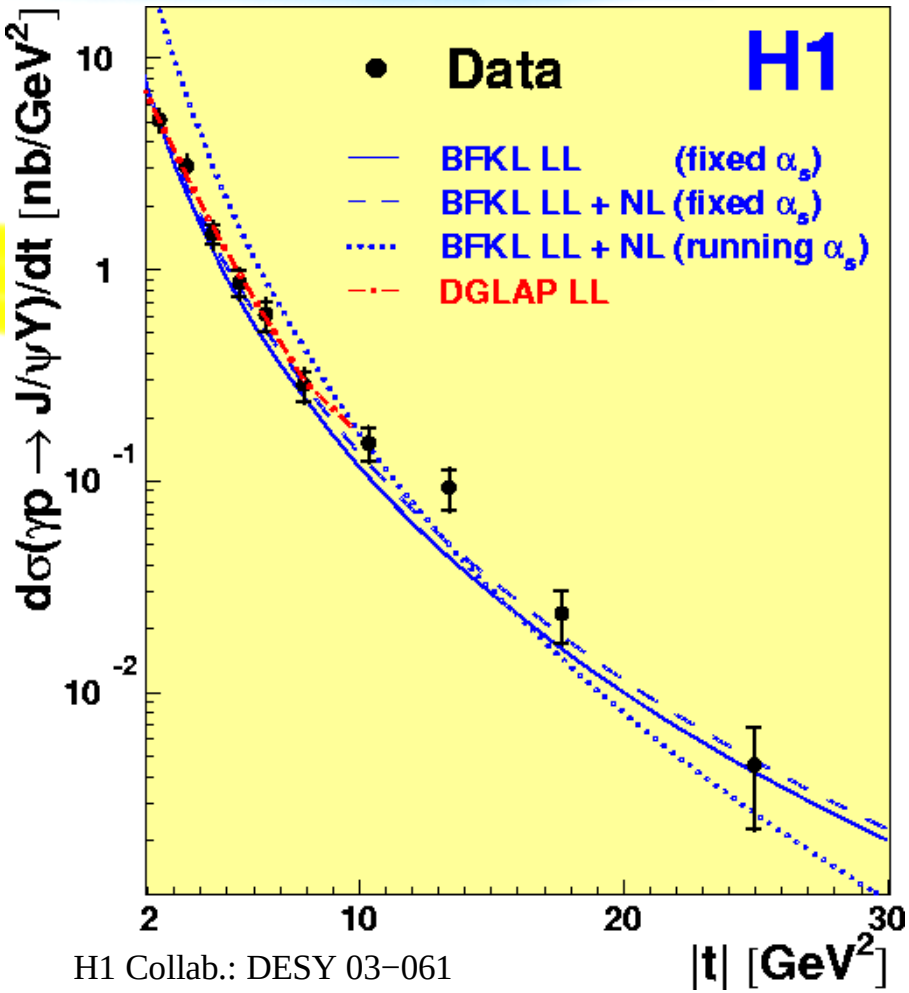






New Measurement of $\gamma p \rightarrow J/\psi X$ at High $|t|$

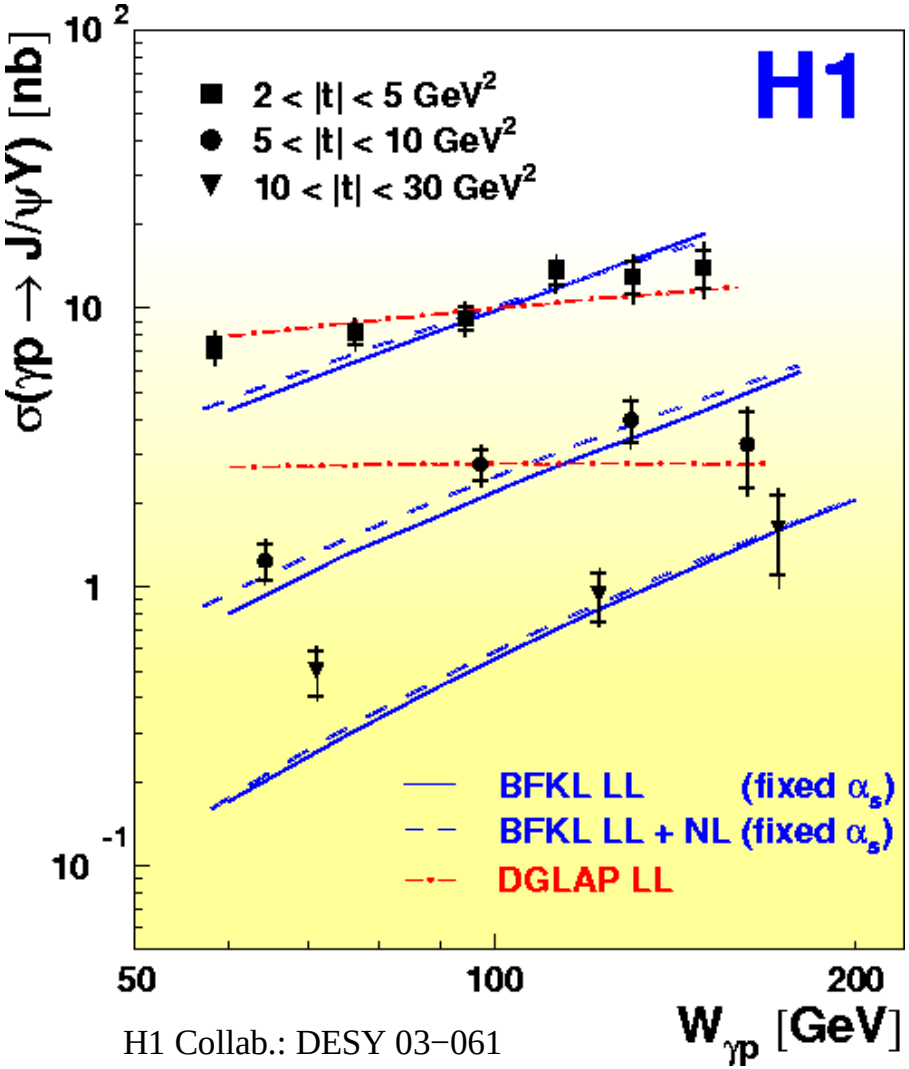
- Full statistics from 1996−2000: $\mathcal{L}=78 pb^{-1}$
- $2 < |t| < 30 GeV^2$: Probes $|t| > M^2_{J/\psi}$!
- No exponential behavior as at low $|t|$
- DGLAP* fares well up to $M^2_{J/\psi}$
- BFKL* very good, but only with fixed α_s.
- Power law: $n=3.00\pm0.08(stat)\pm0.05(syst)$



H1 Collab.: DESY 03−061 [hep−ex/0306013]

*DGLAP: Gotsman *et al.*, Phys.Lett.**B532**(2002)37.
BFKL: Enberg *et al.*, Eur.Phys.J. **C26**(2002)219.

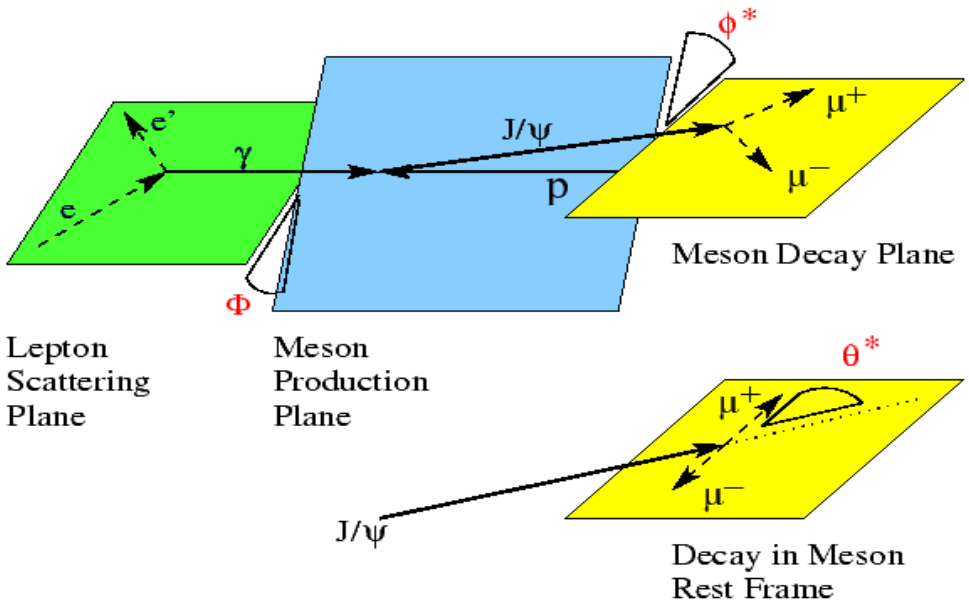
t Dependence of *W* Rise



H1 Collab.: DESY 03−061
[hep−ex/0306013]

- DGLAP too flat above $|t|>5\text{GeV}^2$, but good below
- BFKL reasonable

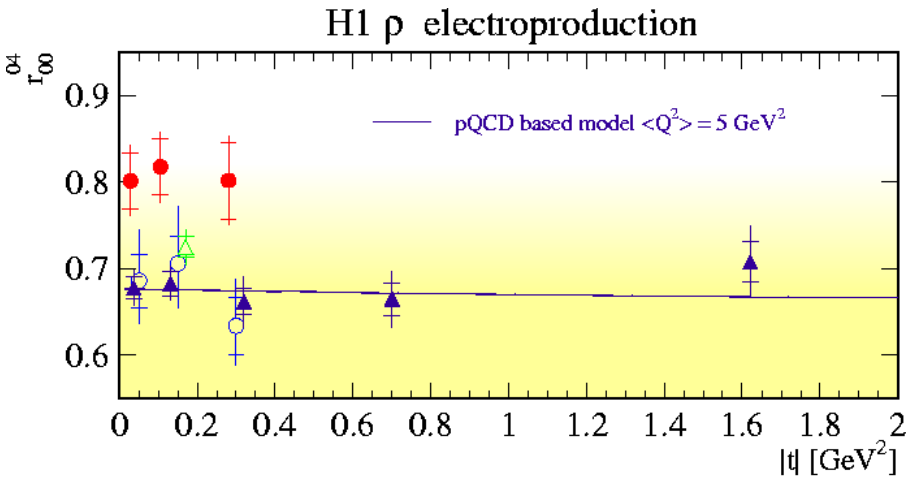
Decay Angle Distributions

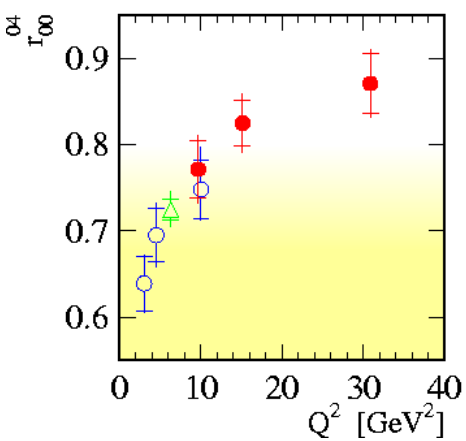


- Decay angle distributions depend on helicity state of decaying vector meson
- s−channel helicity conservation: VM keeps helicity of virtual photon

- Low Q^2: Photon behaves like real photon, VMs are transversely polarized: $\sigma^L/\sigma^T(Q^2) \propto Q^2/m_V^2$
- At higher Q^2: Longitudinal photons dominate

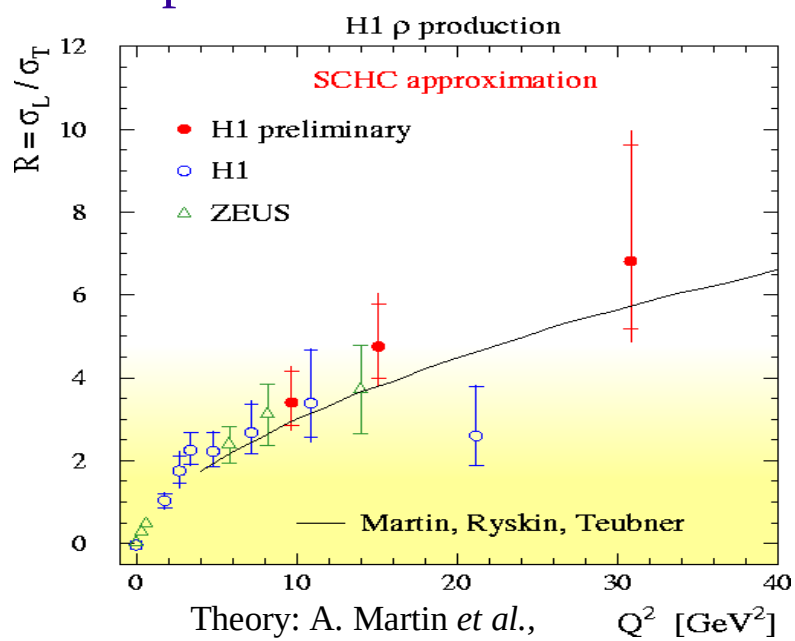
ρ^0 Electroproduction





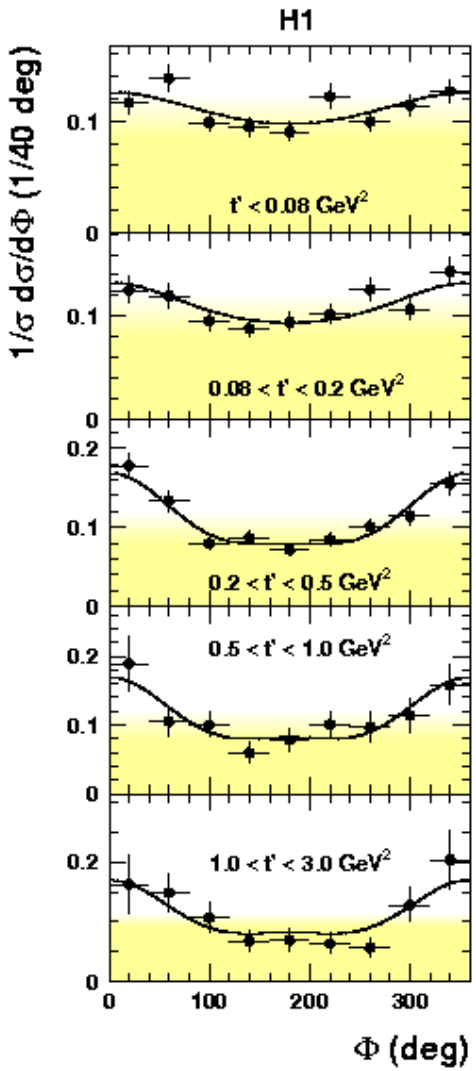
- H1 preliminary <Q^2> = 15.9 GeV^2
- H1 97 diffractive <Q^2> = 5 GeV^2
- H1 96 elastic <Q^2> = 5 GeV^2
- ZEUS 95 <Q^2> = 6.3 GeV^2

- r^{04}_{00} measures fraction of longitudinally polarized vector mesons:
  - Rises with Q^2, as expected
  - no t dependence observed



Theory: A. Martin *et al.*, Phys. Rev. **D55**(1997)4329.

s−Channel Helicity *Non*−Conservation



- H1 preliminary $\langle Q^2 \rangle = 15.9$ GeV^2
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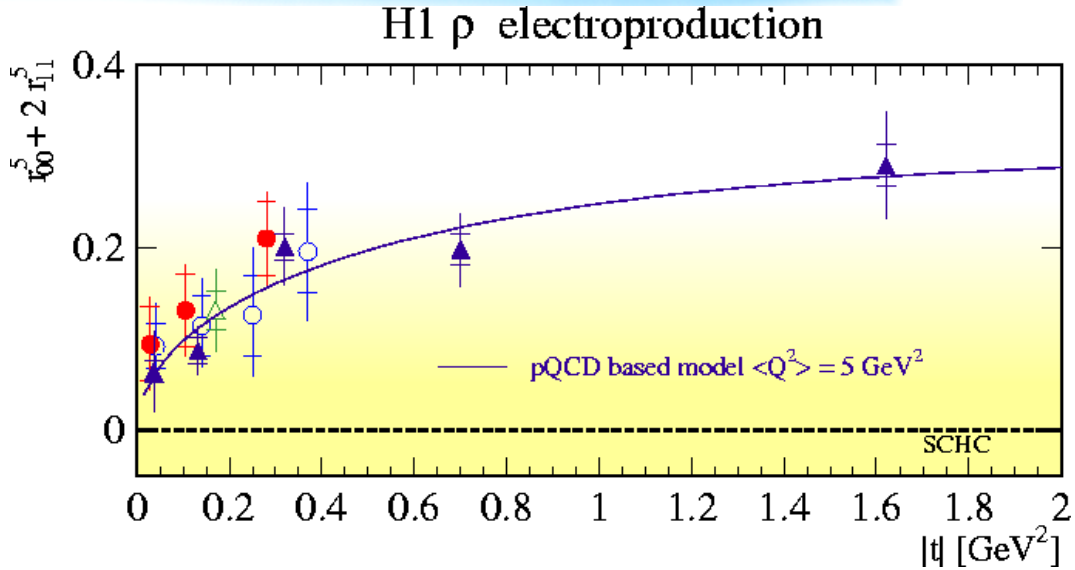


$$W(\Phi) \propto 1 + \sqrt{2\epsilon(1+\epsilon)}(r^5_{00} + 2r^5_{11})\cos\Phi - \epsilon(r^1_{00} + 2r^1_{11})\cos 2\Phi$$

- $r^5_{00}+2r^5_{11}$: helicity non−conserving (T→L transition)
- Rises with $\sqrt{|t|} \approx p_t$, as expected
- Correctly described by pQCD based model

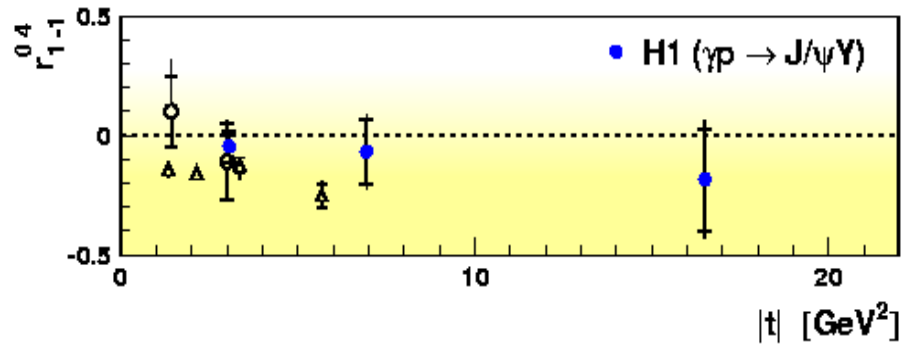
H1 Collab., Phys. Lett. **B539** (2002) 25.

Theory: Kuraev *et al.*, JETP Lett. **68**(1998)696.

J/ψ at high |*t*|: Helicity Measurement

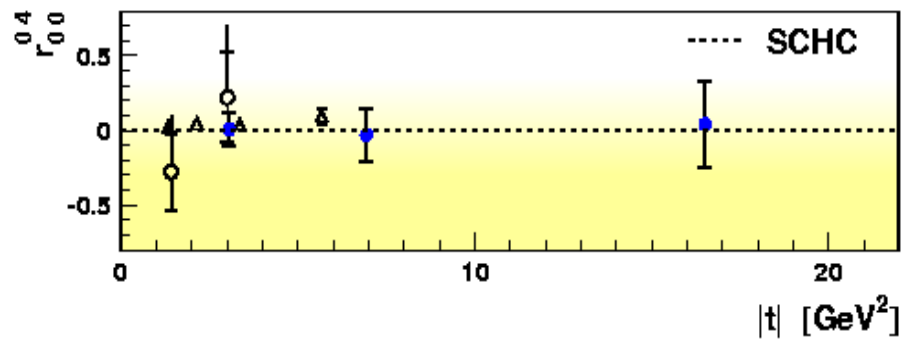
- Fit 2−dimensional cross section:

$$\frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta^*\mathrm{d}\phi^*} = \frac{3}{4\pi}\left(\frac{1}{2}(1+r_{00}^{04}) - \frac{1}{2}(3r_{00}^{04}-1)\cos^2\theta^* + \sqrt{2}\mathrm{Re}\{r_{10}^{04}\}\sin 2\theta^*\cos\phi^* + r_{1-1}^{04}\sin^2\theta^*\cos 2\phi^*\right)$$

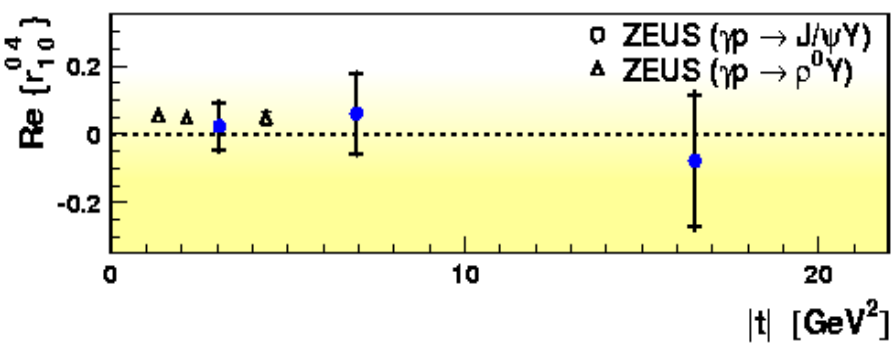


- s−channel helicity conservation:
  all *r* are 0 in photoproduction

$$\frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta^*\mathrm{d}\phi^*} = \frac{3}{4\pi}\left(\frac{1}{2} + \frac{1}{2}\cos^2\theta^*\right)$$



- Result: all values consistent with 0, no violation of SCHC seen



H1 Collab.: DESY 03−061 [hep−ex/0306013]


AND NOW
FOR SOMETHING
COMPLETELY
DIFFERENT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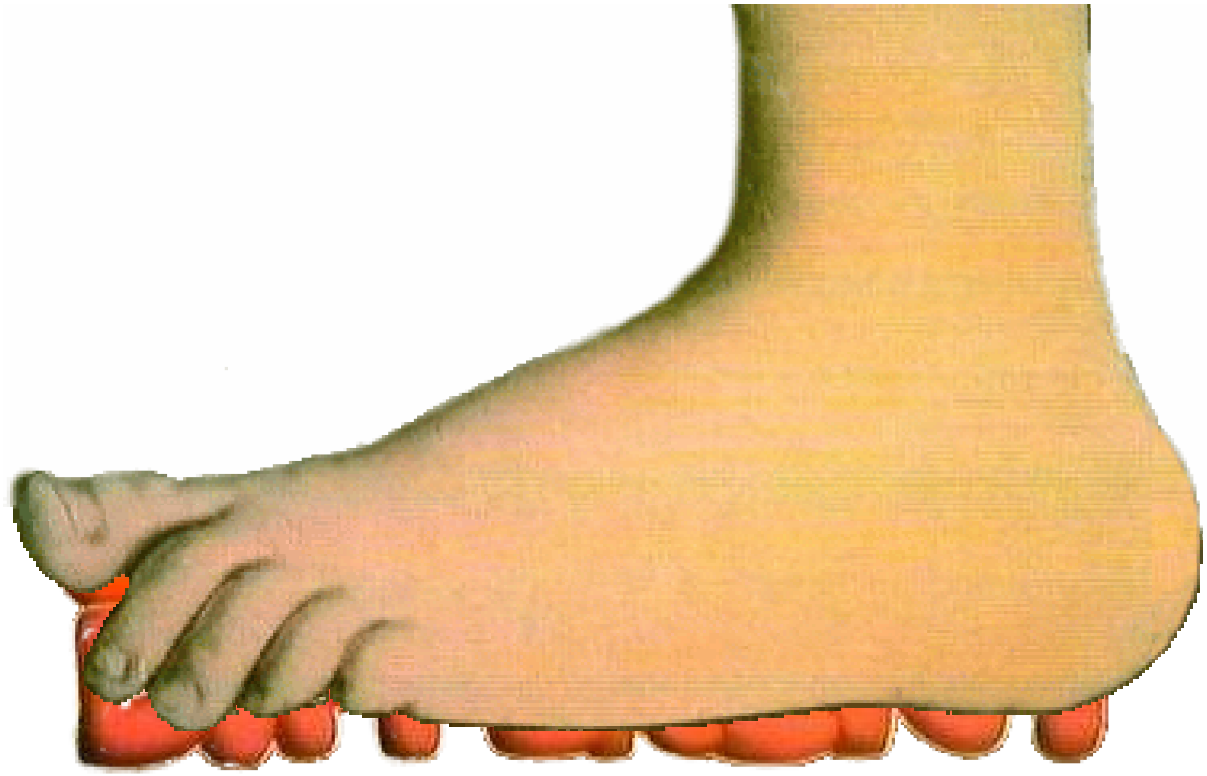
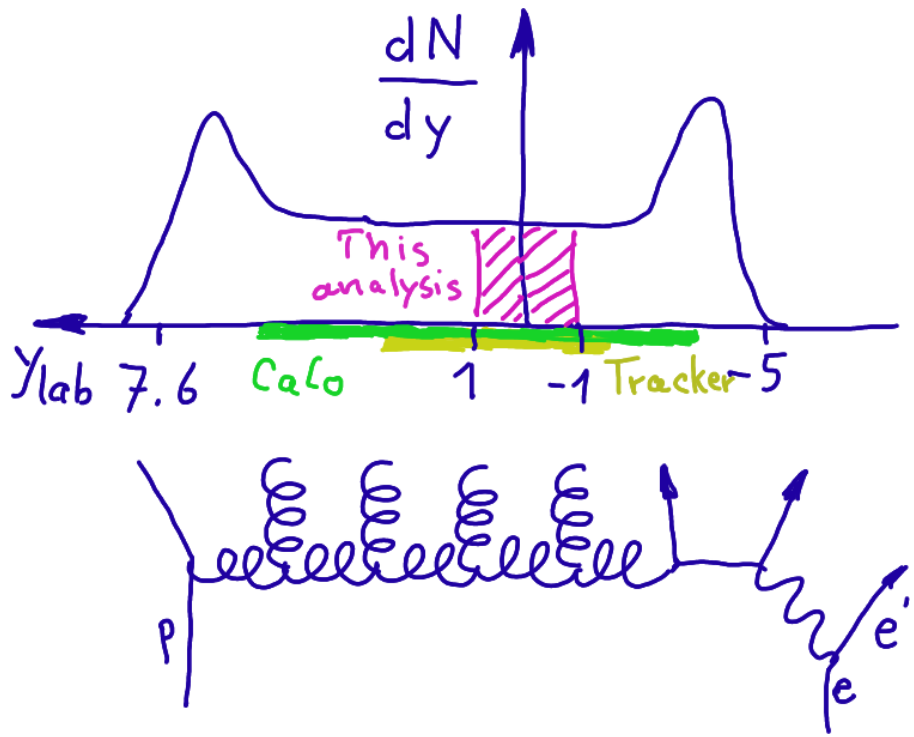


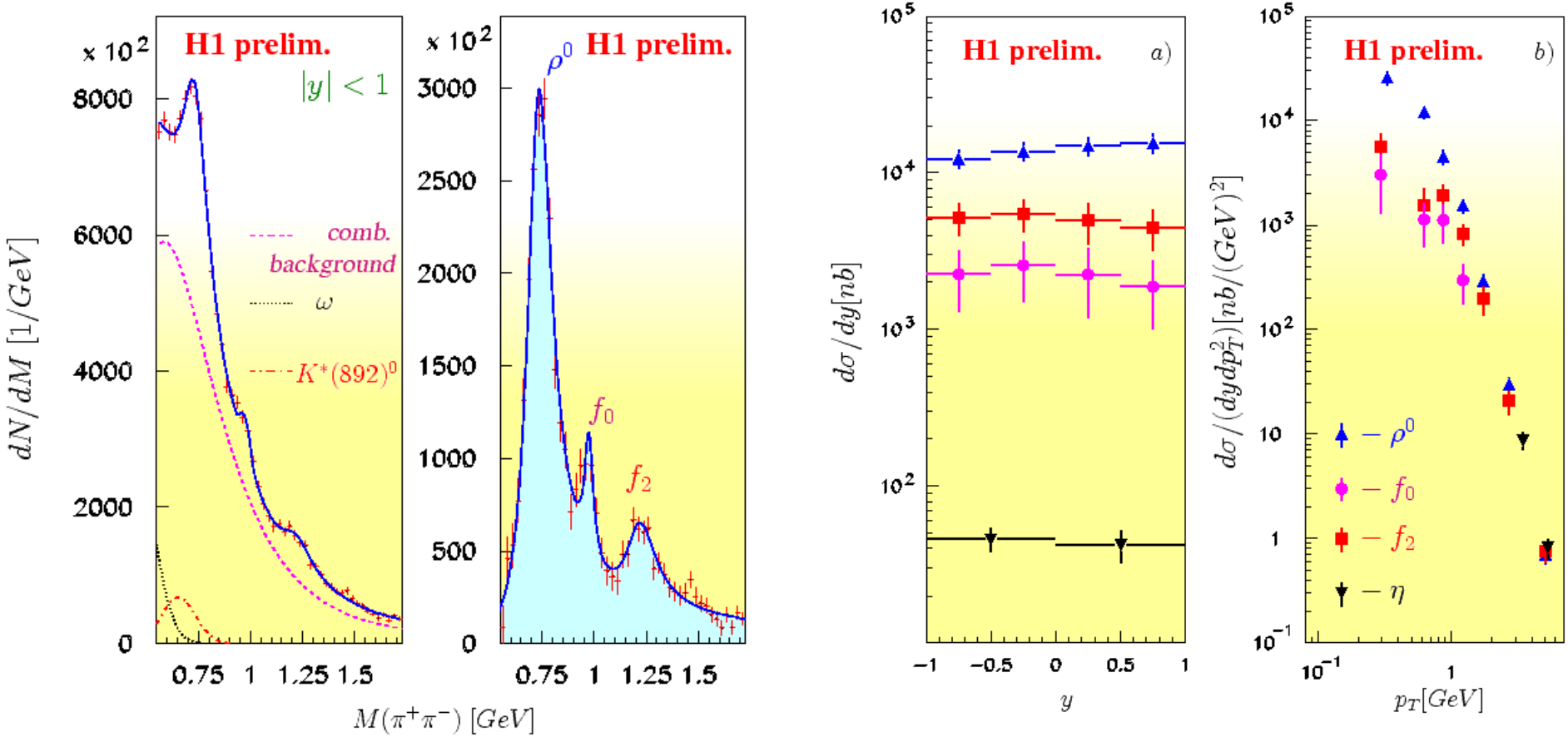
Inclusive Meson Production

Inclusive particle production in fragmentation

- Universal plateau
- Here: Photoproduction,
  2000 data, $\mathcal{L}$=38.7pb^{-1}
- Electron tagged, 174<*W*<256GeV
- 3.7·10^6 events
- Resonance production:
  η, ρ^0, f_0, f_2
- p_t behaviour similar to stable particles?

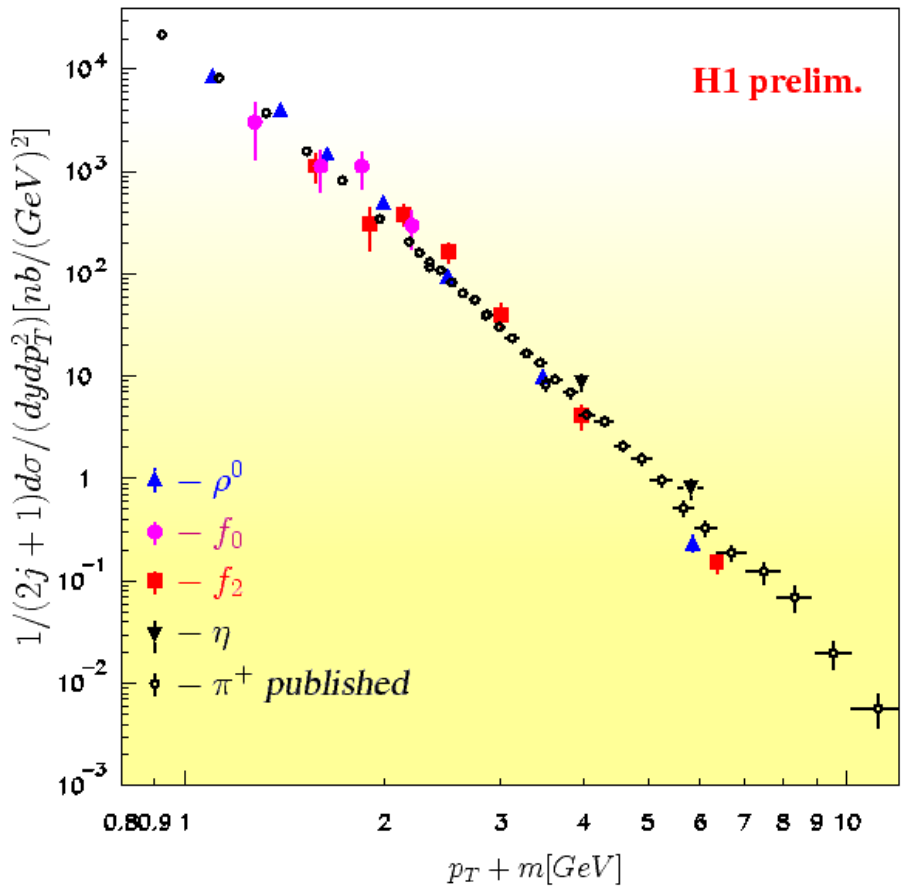


The Data


H1 prelim.
$|y| < 1$
comb. background
ω
$K^*(892)^0$
ρ^0
f_0
f_2
dN/dM [1/GeV]
$M(\pi^+\pi^-)$ [GeV]
H1 prelim. a)
$d\sigma/dy[nb]$
y
H1 prelim. b)
$d\sigma/(dydp_T^2)[nb/(GeV)^2]$
$p_T[GeV]$
η

Universal Scaling?

- After correction for spin factor:
- Resonances production lies on universal curve when plotted against p_t+m!



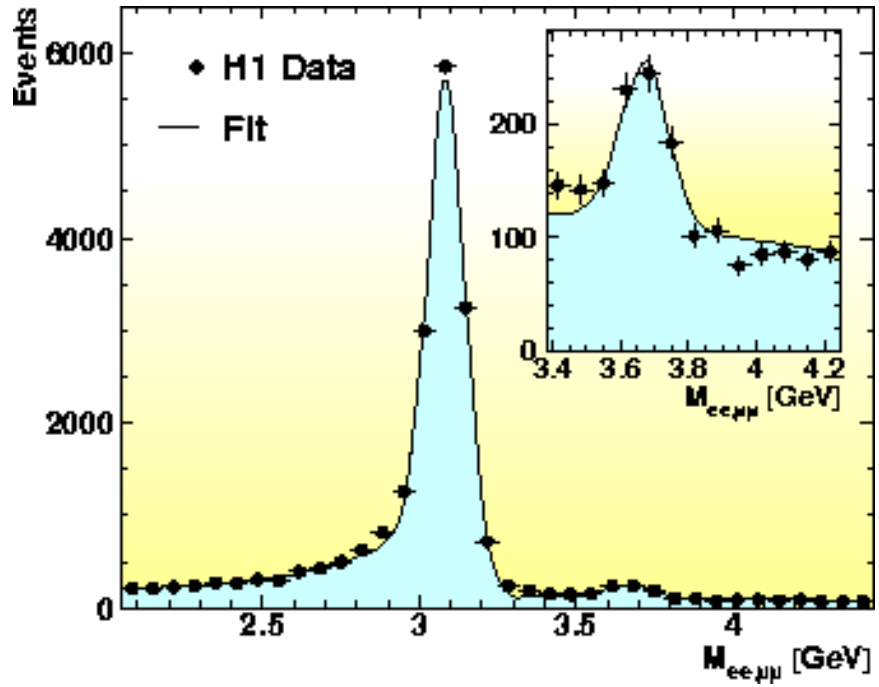
Summary

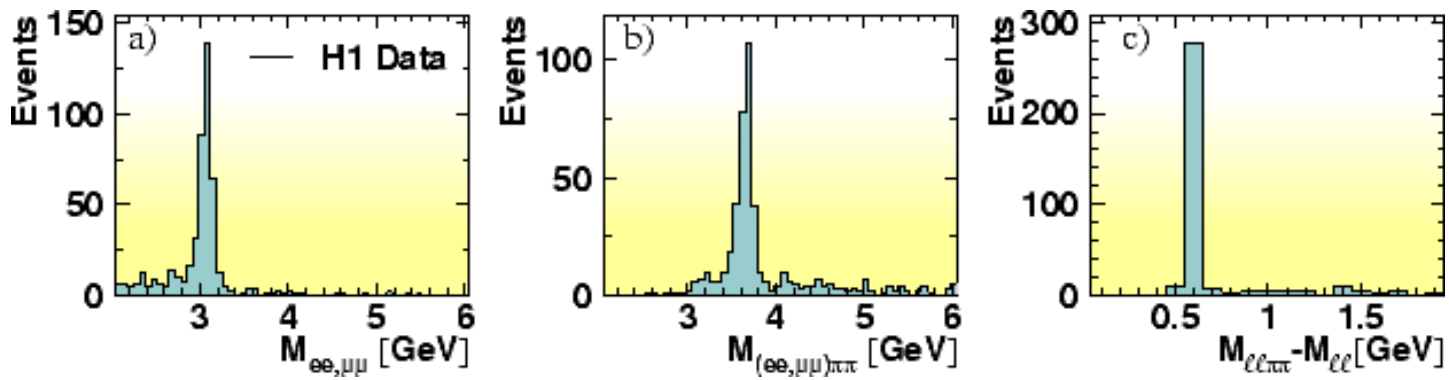
- Many new results on ρ^0, J/ψ, ψ' production, measurements become double−differential and explore new kinematic regions:
- Perturbative QCD calculations successfully describe many aspects (*W*, *t* slopes, helicity): big progress over last years
- Data continues to challenge theory
- Inclusive production of η, ρ^0, f_0, f_2 has been measured and shows a universal behavior in p_t+m
- (Vector) meson prodcution will stay a fruitful subject at HERA−II

Reserve

New Measurement of ψ' Photoproduction

- Full 1996−2000 statistics, $\mathcal{L}$=77pb^{-1}
- Direct decays ψ'→μ$^+$μ$^-$,e$^+$e$^-$ +cascade decays ψ'→J/ψ π$^+$π$^-$
- 40<*W*<150GeV, |*t*|<5GeV^2
- First differential measurements of ψ' photoproduction

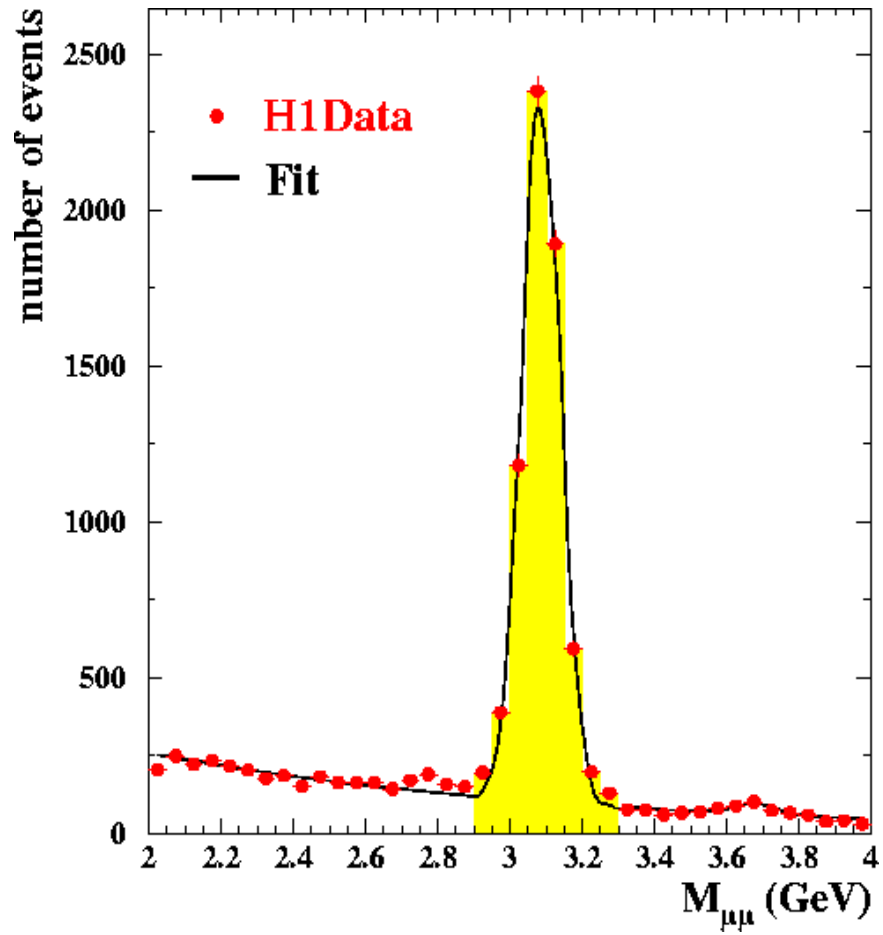




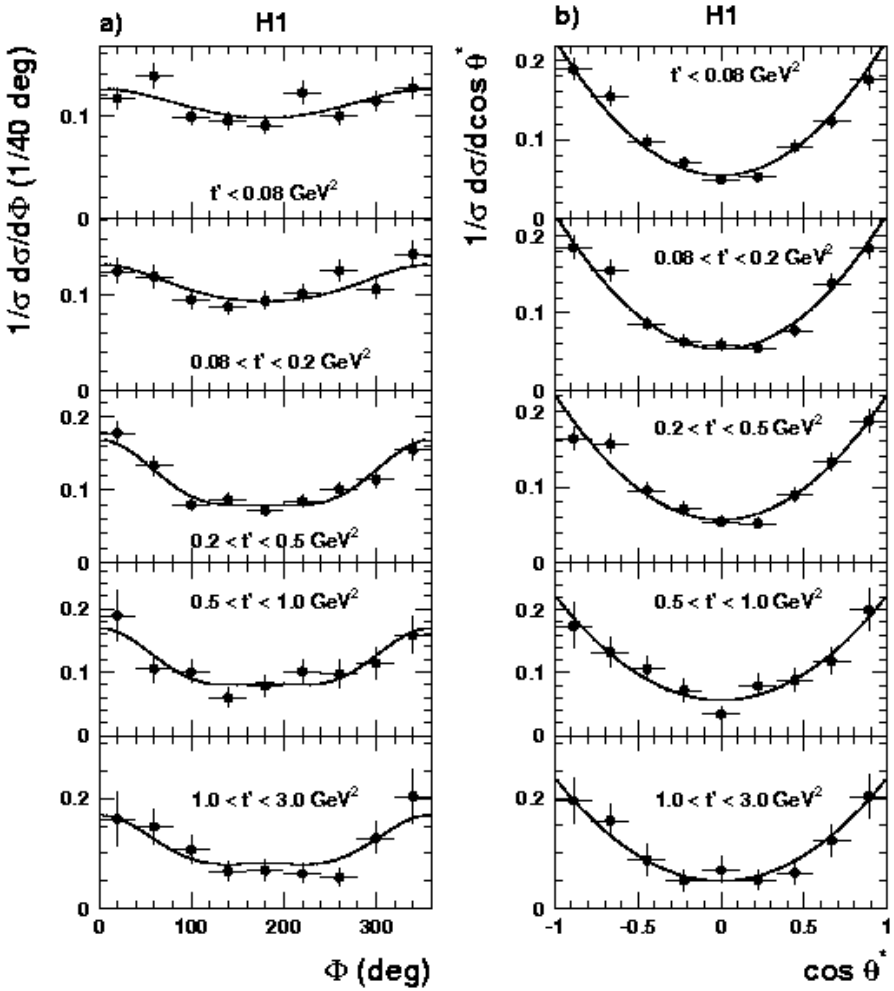
H1 Collab.: Phys.Lett. **B541**(2002)251.

New J/ψ Measurement (preliminary)

- Large dataset 1999/2000
- $\mathcal{L}$=54.8pb^{-1}
- ~7000 events: allow double−differential measurements $d\sigma/dt$ ($W_{\gamma p}$)



s−Channel Helicity *Non*−Conservation



$$W(\cos\theta^*) \propto 1 - r^{04}_{00} + (3\, r^{04}_{00} - 1)\, \cos^2\theta^*$$

$$W(\Phi) \propto 1 + \sqrt{2\epsilon(1+\epsilon)}(r^5_{00} + 2r^5_{11})\cos\Phi$$

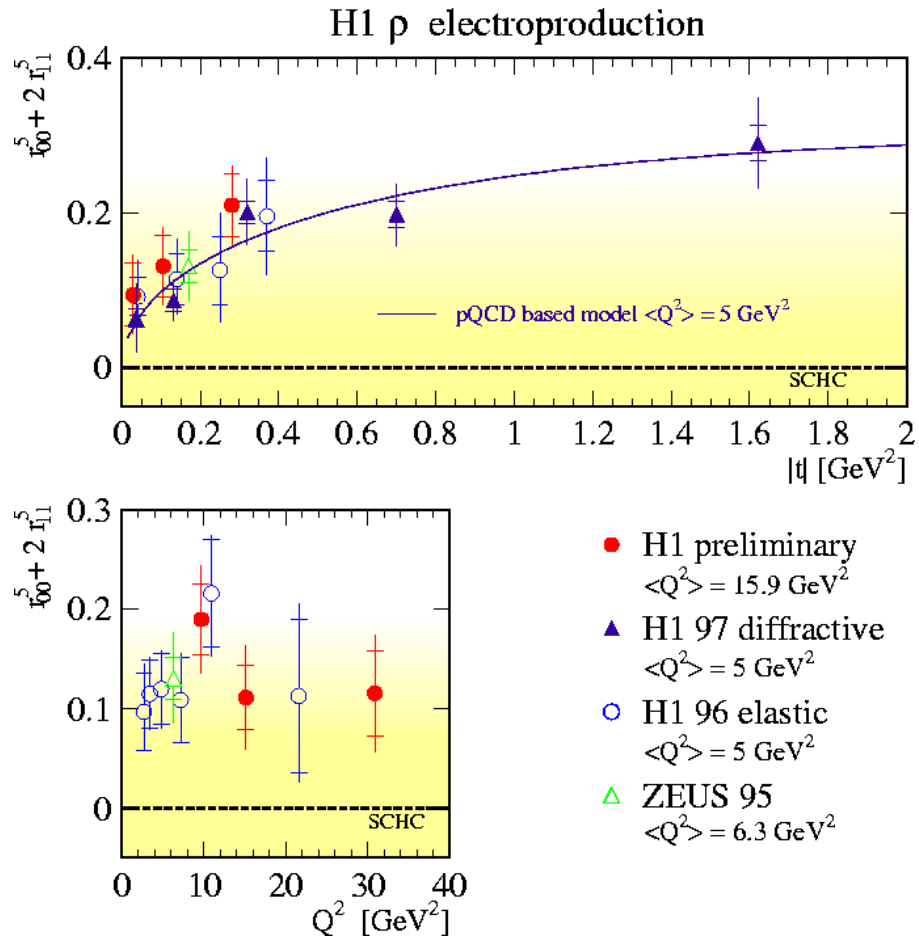
$$-\epsilon(r^1_{00} + 2r^1_{11})\cos 2\Phi$$

- r^{04}_{00}: helicity conserving
- $r^5_{00}+2r^5_{11}$: helicity non−conserving
- Clear SCHNC observed

H1 Collab., Phys. Lett. **B539** (2002) 25.

s−Channel Helicity *Non*−Conservation

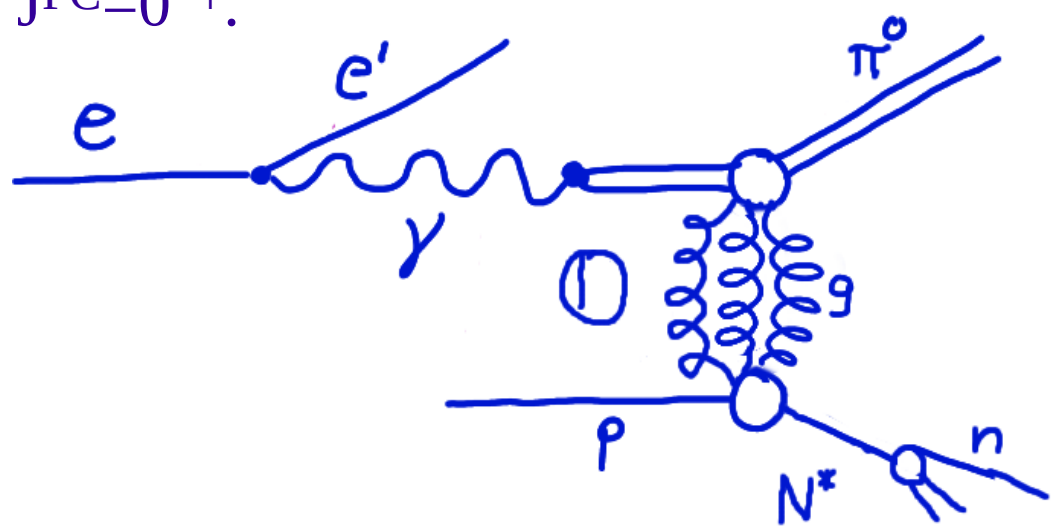
- $r^5_{00}+2r^5_{11}$: Combination of matrix elements that should vanish for SCHC
- Significant non−conservation observed
- Rises with $\sqrt{|t|} \approx p_t$, as expected
- Correctly predicted by QCD calculations



Theory: Kuraev *et al.*, JETP Lett. **68**(1998)696.

Searching the Odderon

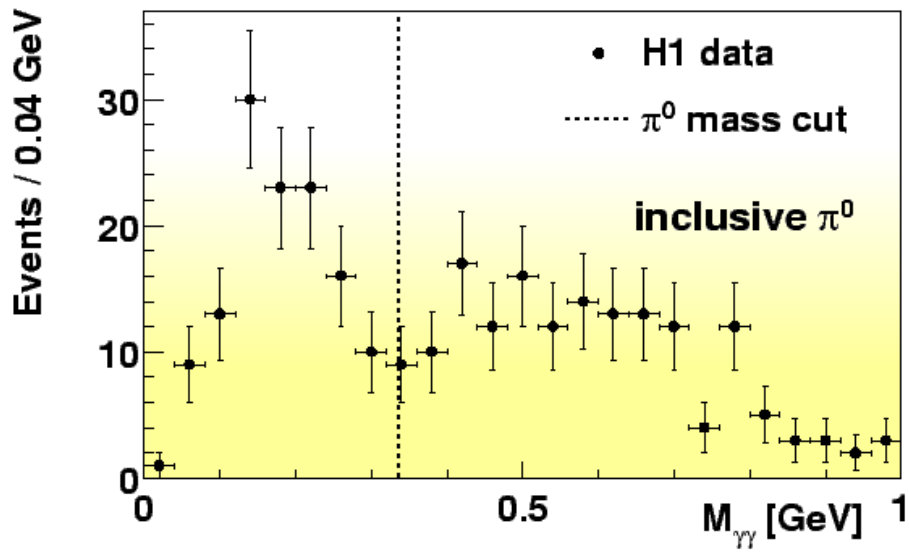
- If 2 gluons are a Pomeron,
  3 gluons are an Odderon!
- „Naive“ calculation of 3−gluon exchange shows flat energy dependence, i.e. $\alpha_{\mathbb{O}}=1$.
- Look for final states that are not possible for natural parity exchange, e.g. π^0 with $J^{PC}=0^{-+}$.



How to Find a Single π^0

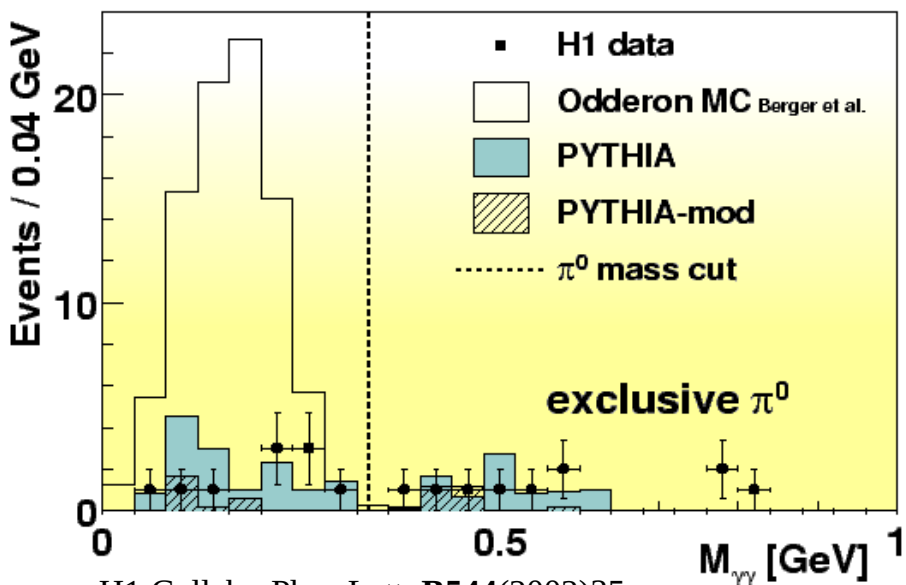
- Problem: Only π^0 in detector, i.e. 2γ.
- Scattered electron in e−Tagger, neutron from proton dissociation in neutron calorimeter
- Gammas from π^0 decay have energy ~6GeV, very close to beampipe. Use special calorimeter (VLQ) to detect them.
- 1999/2000 data, $\mathcal{L}$=30.6pb^{-1}

Inclusive M_{gg} spectrum for events with 2 photons in backward calorimeters:



H1 Collab., Phys.Lett. **B544**(2002)35.

Do We See It?



H1 Collab., Phys.Lett. **B544**(2002)35.

Not yet!

- No signal above background observed
- Derive limit:
  $\sigma(\gamma p \rightarrow N^*) < 49nb$ (95% CL)
  for $0.02<|t|<0.3GeV^2$
  at W=215GeV
- Theoretical expectation*:
  >200nb

*Berger *et al.*, Eur.Phys.J. **C9**(1999)491.