New Trends
in
High Energy Physics
Jalta, Crimea
22-29 September, 2001

Search for Odderon Induced Contributions to Exclusive Meson Photoproduction at HERA

Jan Olsson, DESY, Hamburg
On behalf of the H1 Collaboration

- Introduction
- Experimental Procedure
- Exclusive π° production
- Multi-Photon Final States
- Summary, Conclusions and Outlook

The Odderon: What is it?

1973-75: **Discuss possibility of a $C = -1$ contribution in hadron–hadron scattering at high energies**

L. Łukaszuk, B. Nicolescu, Lett.Nuov.Cim. 8 (73) 405

K. Kang, B. Nicolescu, Phys.Rev.D 11 (75) 2461

G. Białkowski, K. Kang, B. Nicolescu, Lett.Nuov.Cim. 13 (75) 401

1975: **Name–giving!** **Odd–under–crossing–Pomeron**

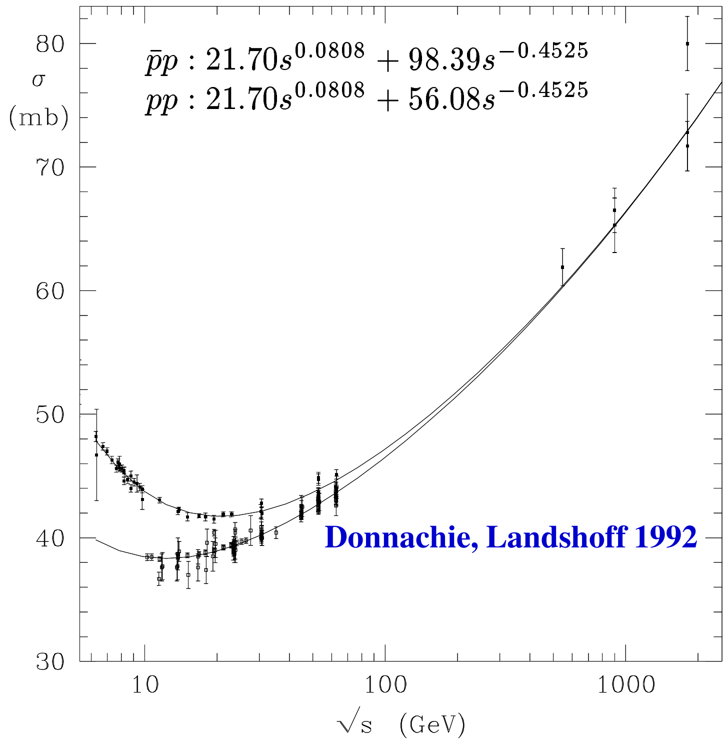
D. Joynson, E. Leader, B. Nicolescu, C. Lopez, Nuov.Cim. 30A (75) 345

Odderon (C=P=-1) and Pomeron (C=P=$+1$)
Companions in High Energy Scattering
Similar Intercepts, i.e. $\alpha_{\mathbb{O}}(0) \approx 1$

Presence of Odderon leads to the prediction that, e.g.

$$\Delta\sigma = \sigma_{\bar{A}B} - \sigma_{AB} \not\rightarrow 0, \quad s \longrightarrow \infty$$

Violation of Pomeranchuk's Theorem



- **No evidence for Odderon**
- **All hadron-hadron data excellently fitted, using only Pomeron and Reggeon terms**
- $\alpha_{\mathbb{P}}(0) = 1.0808$
  $\alpha_{R}(0) = 0.5475$

The perturbative Odderon

QCD developments 1980's, 1990's

- Pomeron interpreted as exchange of 2 gluons
  Odderon interpreted as exchange of 3 gluons
- Meanwhile Odderon is recognized as
  important and basic prediction of QCD
- Odderon solutions have been found

  L.N. Lipatov 1997

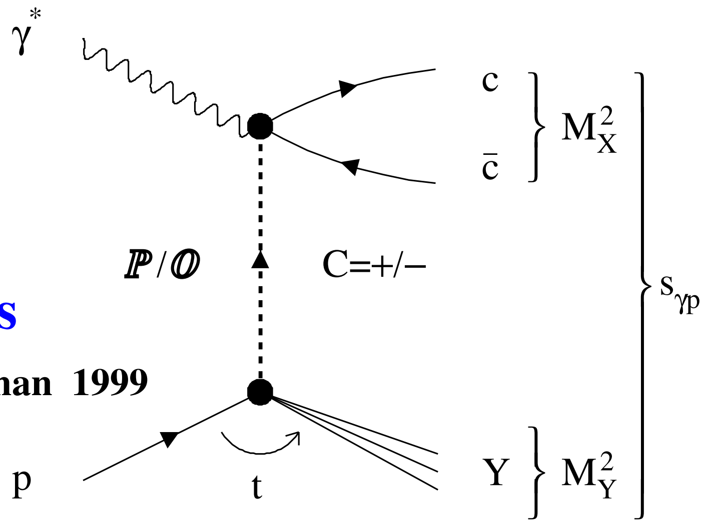
  R.A. Janik and J. Wosiek, 1999
- Predictions for experimental searches,
  based on perturbative calculations,
  using hard scales Q^2, m_c, etc., e.g.:

▷ $$\sigma(\gamma p \xrightarrow{\mathbb{O}} \eta_c p) = 50 \text{ pb at } Q^2 = 0$$
$$= 1.3\text{pb at } Q^2 = 25\,\text{GeV}^2$$

J. Bartels et al., 2001

▷ Asymmetry in fractional energy in $c - \bar{c}$ jets, due to interference of exchange amplitudes

S.J.Brodsky, C.Merino, J.Rathsman 1999



Challenge to the HERA experiments !

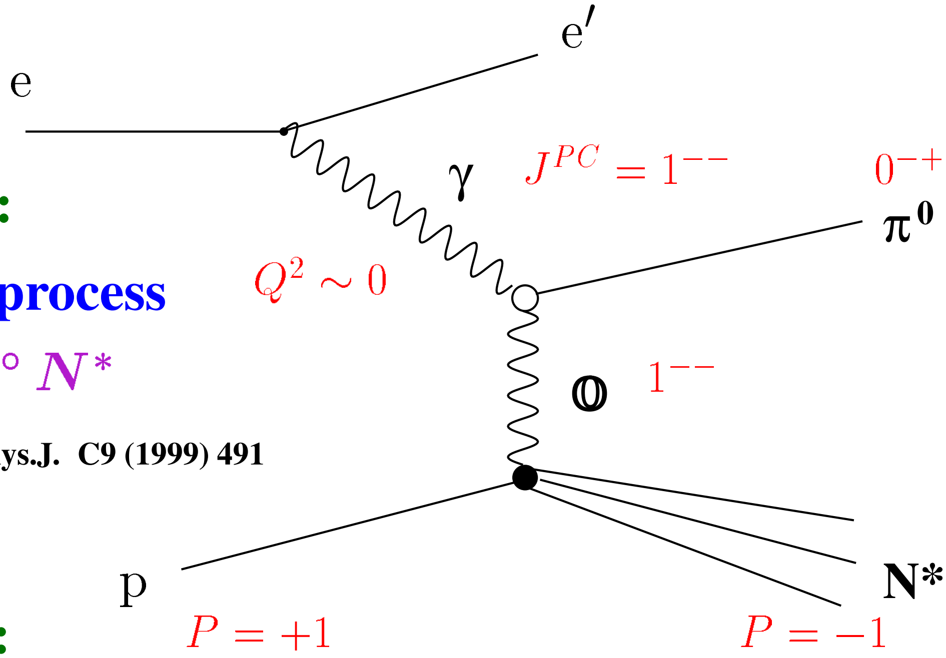
The non–perturbative Odderon

Heidelberg Group:

Prediction for the process

$$\gamma\, p \xrightarrow{\mathbb{O}} \pi^\circ\, N^*$$

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



Model ingredients:

- Non-perturbative QCD, using Functional Integral techniques
- ”Stochastic Vacuum Model”, Dosch & Simenov 1987-88, Nachtmann 1991
- Diquark model of the proton Reuter & Dosch, 1996
- Tuned for Pomeron Exchange reactions
- Extended to Odderon Exchange
- Diquark–quark Symmetry arguments:
  - ▷ Explain suppression of Odderon exchange in pp and $\bar{p}p$ data !
  - ▷ Predict suppression of process $\gamma\, p \xrightarrow{\mathbb{O}} \pi^\circ\, p$
  - ▷ But: Large Cross Section if proton excited to N^* with P$= -1$!

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) = 294 \text{ nb} \quad \text{at} \quad W_{\gamma p} = 20 \text{ GeV}$$

Prediction at HERA energies: $\sim$ 300 nb !
$\sim$ 1 event / minute !!

The expected (and trivial) Background:

- **Diffraction, i.e. $\mathbb{P}$omeron exchange**
  - ▷ $\gamma p \longrightarrow \omega N^*, \quad \omega \longrightarrow \gamma\pi^\circ$
  - ▷ $\gamma p \longrightarrow \rho^\circ N^*, \quad \rho^\circ \longrightarrow \gamma\pi^\circ$ **B.R.** $= (6.8 \pm 1.7)10^{-4}$
  - ▷ $\gamma p \longrightarrow \pi^\circ X N^*$ **Inclusive π° production**
- **$\gamma\gamma$ processes, i.e. Primakoff Effect**
  - ▷ **Negligible**
- **Reggeon (ω) exchange, i.e.** $\gamma p \xrightarrow{\omega} \pi^\circ N^*$
  - ▷ **Negligible**

Use PYTHIA for Simulation of Background*

* PYTHIA-mod:

**With permission of the author, T. Sjöstrand,
the Diffractive part of PYTHIA was modified,
in order to exclude the** isospin violating decay $\rho^\circ \longrightarrow \pi^\circ\pi^\circ$

**This decay does not disturb the PYTHIA description of inclusive,
high–multiplicty diffractive events, but is an important effect
in exclusive, low–multiplicity studies**

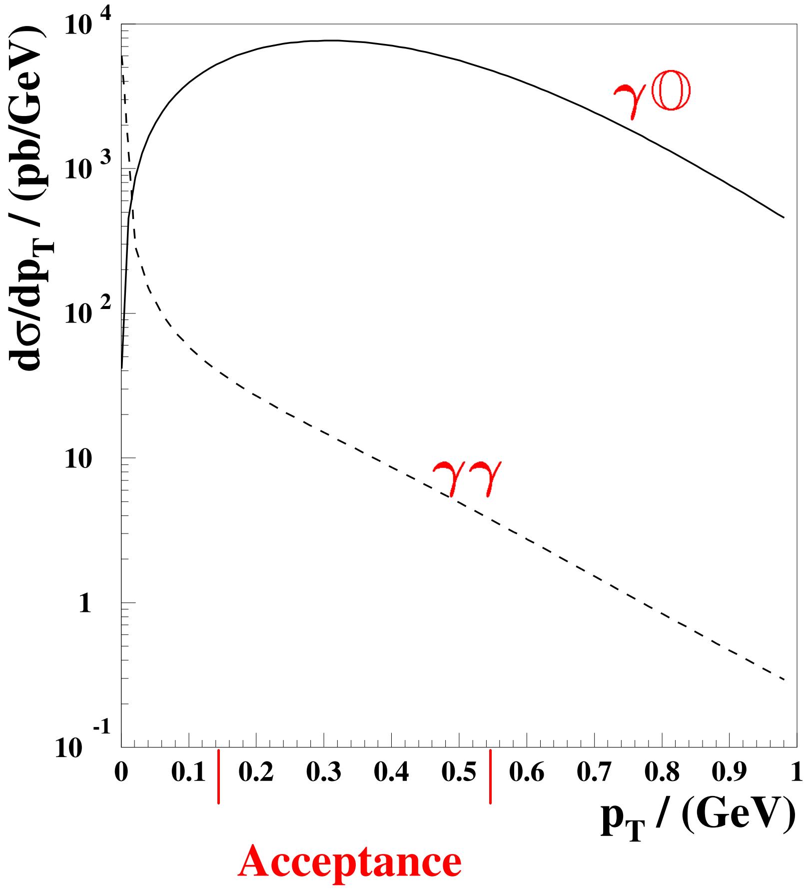
$\mathbb{O}\,\mathbb{P}$IUM*

- **Simulates the process** $\gamma\, p \xrightarrow{\mathbb{O}} \pi^\circ\, N^*$
- **is an extension of DIFFVM** (B. List, A. Mastroberardino)
- **Considers the baryon states** $(I = \frac{1}{2},\ J^P = \frac{1}{2}^-,\ \frac{3}{2}^-)$

$$N^*(1520),\ N^*(1535),\ N^*(1650),\ N^*(1700)$$

$N^*(1520)$	$N^*(1535)$	$N^*(1650)$	$N^*(1700)$
45%	45%	5%	5%

- **Final State Neutron in 42% of the N^* decays**
- **π° transverse momentum distribution from MSV**



$\gamma\gamma$ exchange important only at very low π° p_T

Acceptance
$0.02 < |t| < 0.3$ GeV^2

t: squared momentum transfer at proton vertex

$(t \sim -p_T^2)$

* $\mathbb{O}$dderon and $\mathbb{P}$omeron Induced Unified Meson maker (W. Kornelis)

THE SIGNATURE

$$ep \longrightarrow e\,\pi^{o}\,N^{*}$$

$$N^{*} \longrightarrow n\,X \qquad \pi^{o} \longrightarrow \gamma\gamma$$

TRIGGER:

Neutron Energy $>$ 200 GeV

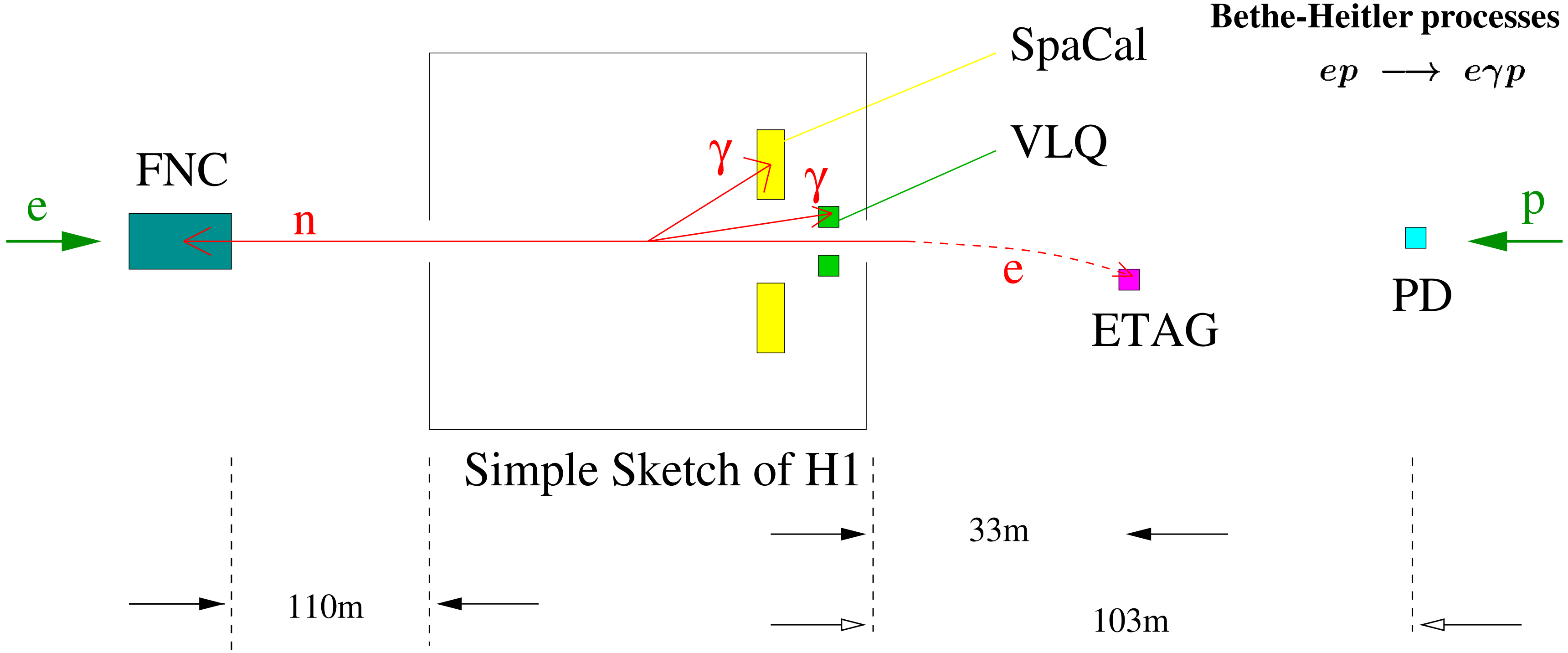
VLQ Energy $>$ 6 GeV

Electron Energy $>$ 6 GeV

PD Energy $<$ 2 GeV

Rejection of background from overlapping Bethe-Heitler processes

$$ep \longrightarrow e\gamma p$$

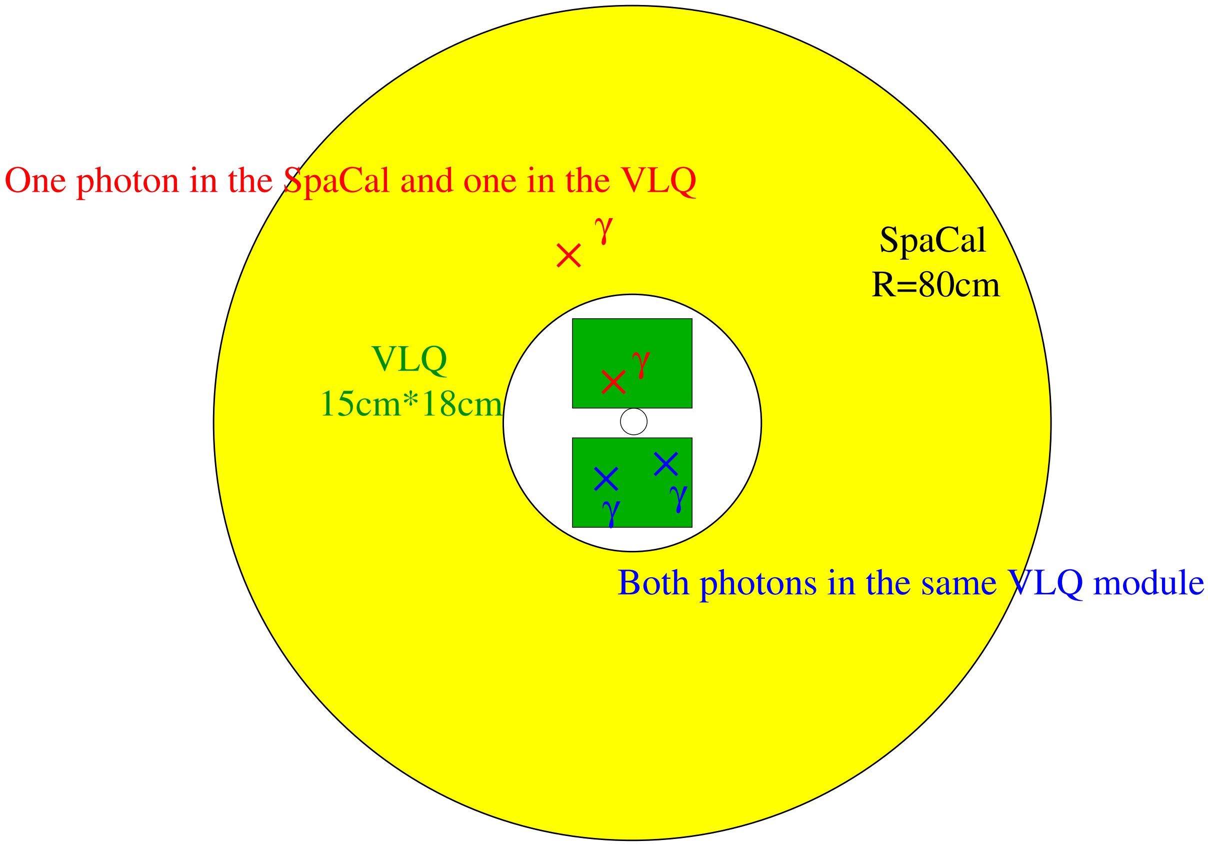


Data Sample: **30.6 pb^{-1}, collected 1999-2000**

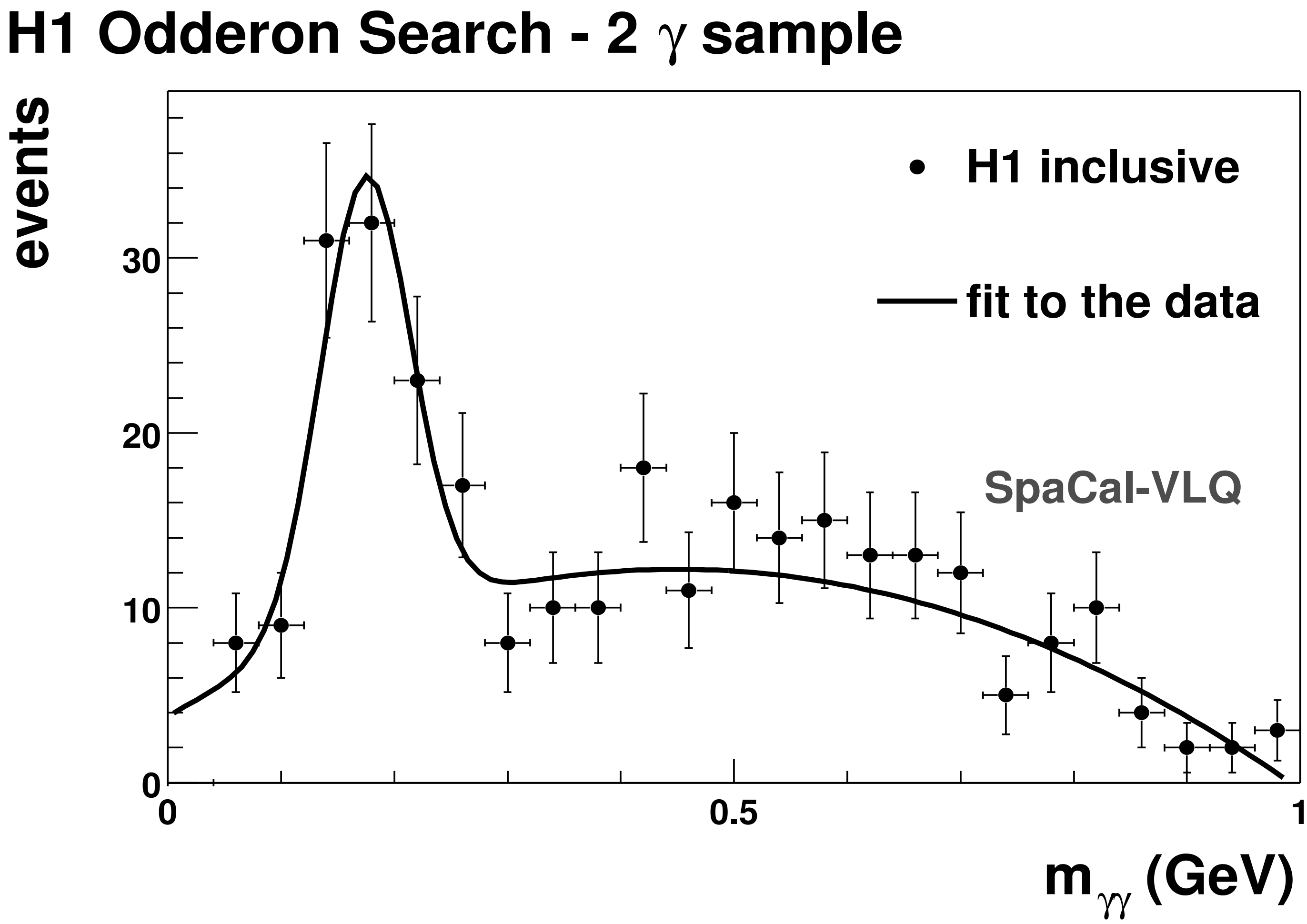
Trigger: **Electron Tag, Neutron tag, VLQ energy**

Event Selection:

- **Exactly 2 ”Good” Photons**
  - ▷ **”SpaCal–VLQ” or ”VLQ–VLQ” Topology**
  - ▷ $E_\gamma > 2$ **GeV (VLQ)**
    $E_\gamma > 60$ **MeV (SpaCal)**
  - ▷ **Cluster Shapes compatible with Photons**
  - ▷ **Locations well within Fiducial Volumes (no shower leakage)**



Inclusive (but not yet exclusive !) $\gamma\gamma$ events



Proof of π° Detection Sensitivity

Is there an Odderon signal ?

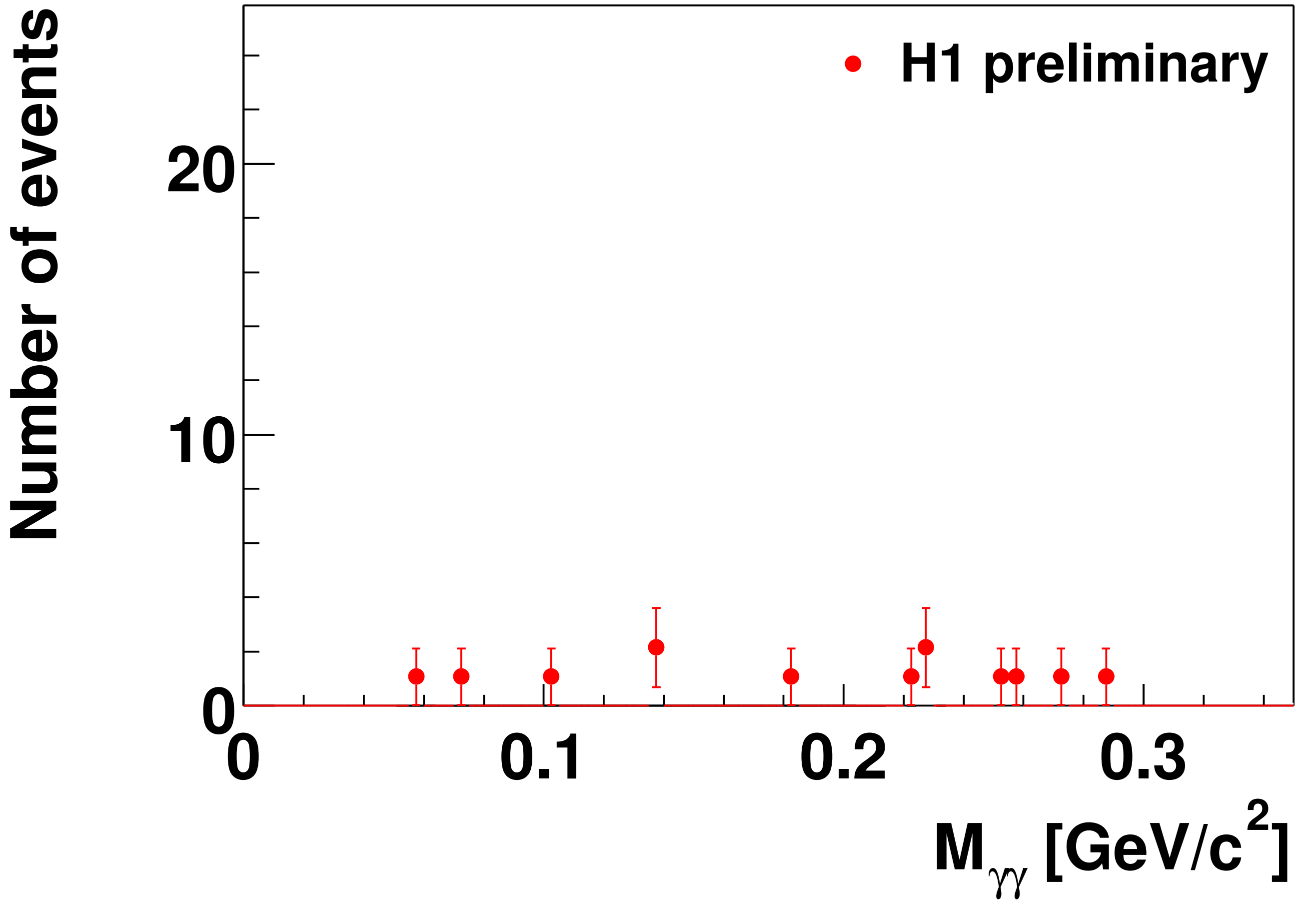
Event Selection, continued:

- **Electron**
  - ▷ **Well measured,**
    $\Longrightarrow$ **Electron energy cluster well within fiducial volume**
  - ▷ **Inelasticity** $0.3 < y = 1 - E'_e/E_e < 0.7$
    $\Longrightarrow$ $8 \leq E_{\pi^\circ} \leq 19$ GeV
  - ▷ $E_{PD} < 2$ GeV
    $\Longrightarrow$ **Reduce background from Bethe–Heitler processes.**
- **Neutron**
  - ▷ **Well measured,**
    $\Longrightarrow$ **Neutron energy cluster well within fiducial volume**
  - ▷ $E_n > 200$ GeV **(nominal trigger threshold)**
- **Exclusive events**
  - ▷ **No track vertex reconstructed (No charged particles)**
  - ▷ **Energy – Momentum Balance**

$$49 < (E - p_z)_{e\gamma\gamma} < 60 \text{ GeV}$$

Reject non-exclusive events

After all Selection Cuts:

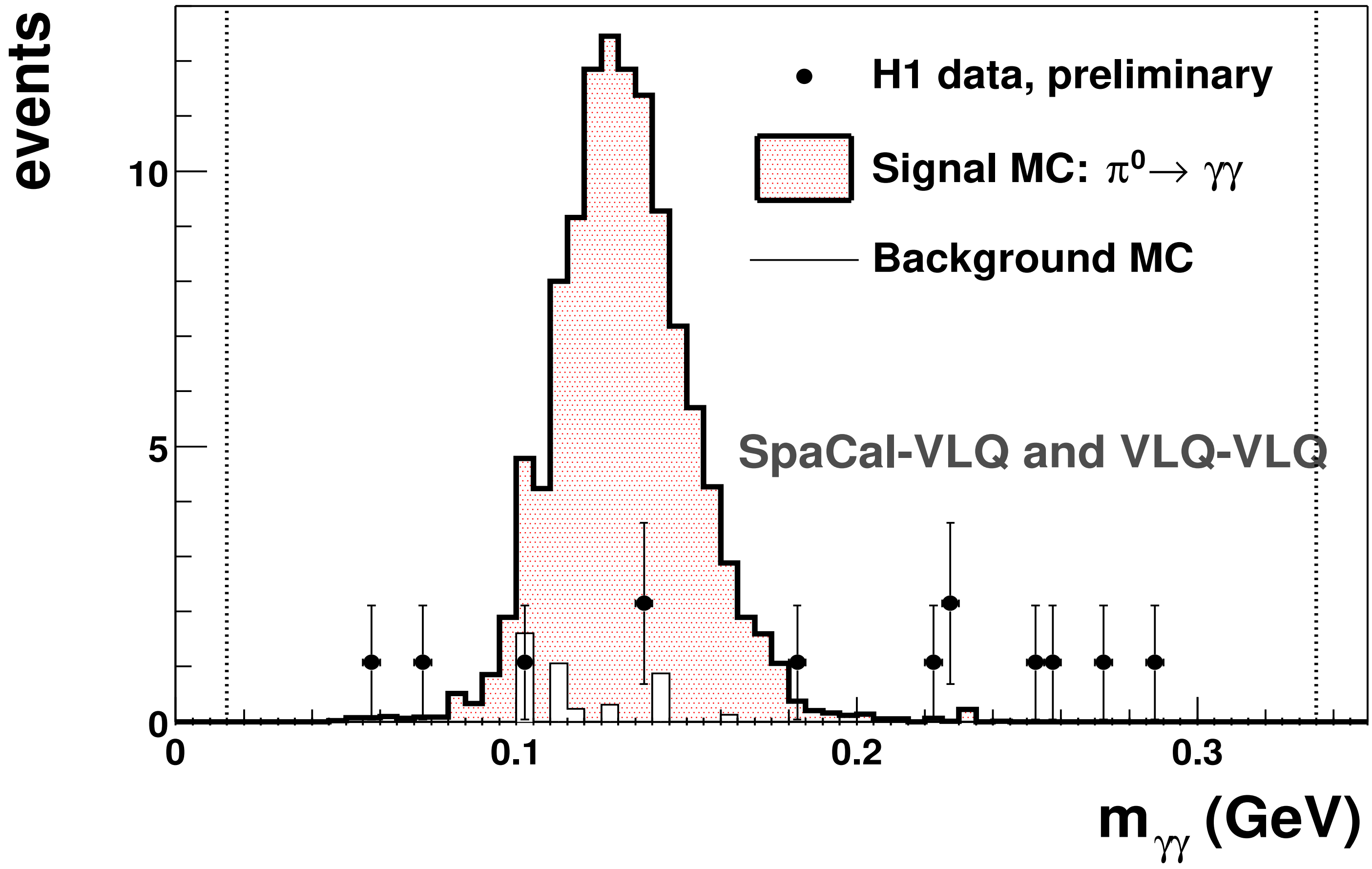


No Signal !

What do we expect to see?

MC Calculations: $\Longrightarrow$

H1 Odderon Search - 2 γ sample



Few events in Signal Region

Consistent with PYTHIA estimate of trivial background

Theory expects $>$ 100 events !

("Uncertainty at least a factor 2")
E.R. Berger et al.

No Odderon Signal

$\Longrightarrow$ **Upper Limit on Cross Section**

- **Observe 13 Events in π° window 30–350 MeV**
- **PYTHIA predicts 4 Events background**
- **Systematic Uncertainty 25 %**

$\Longrightarrow$ **22 events** (for Limit at 95% C.L.)*

H1 Preliminary 95% C.L.

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) < 39 \text{ nb}$$

For $\langle W_{\gamma p} \rangle = 210$ GeV
and $0.02 < |t| < 0.3$ GeV^2
(visible t range)

Prediction from E.R. Berger et al.:

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) = 200 \text{ nb}$$

* R.D. Cousins and G.J. Feldman, Phys.Rev. D57 (1998) 3873
R.D. Cousins and V.L. Highland, Nucl.Instr.Meth. A320 (1992) 331

No Odderon seen! What can be the Reason ?

- **Cross Section correctly estimated ?**

Model prediction at $W_{\gamma p} = 20$ GeV
Extrapolation to HERA energies, assuming

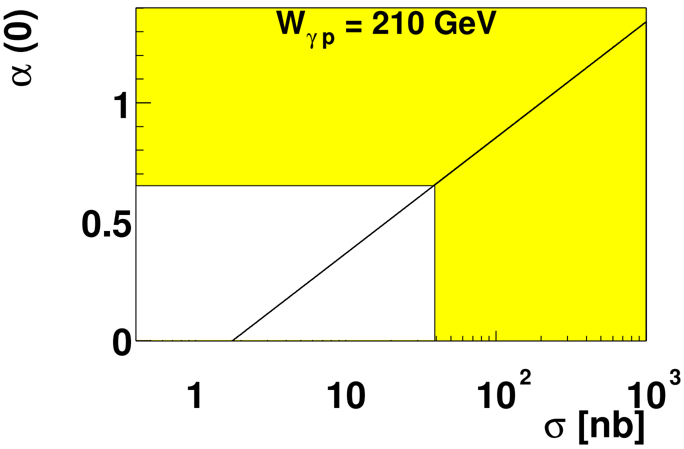
$$\sigma = \sigma_\circ \, (W_{\gamma p}^2/400)^{\,\alpha_{\mathbb{O}}(0)-1}$$

E.R. Berger et al. estimate $\alpha_{\mathbb{O}}(0) = 1$
Other authors also estimate $\alpha_{\mathbb{O}}(0)$ **close to 1**

The H1 non-observation can be interpreted as

Upper Limit on the intercept:

$$\alpha_{\mathbb{O}}(0) < 0.65$$



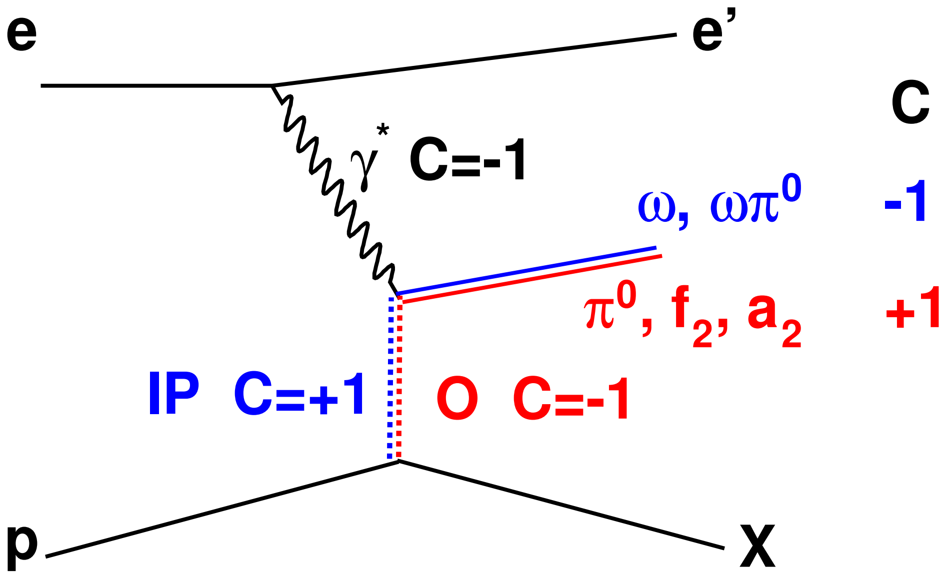
- **Small $\gamma\pi^\circ\mathbb{O}$ coupling ?**

Coupling could be small,
due to Goldstone Boson nature of π
(coupling $\propto m_q \approx 0.005$ GeV)

$\Longrightarrow$ **Look for heavier Mesons !**

$$\gamma p \rightarrow f_2(1270)\, N^*$$
$$\gamma p \rightarrow a_2(1320)\, N^*$$

Odderon or Pomeron exchange



Odderon exchange

Final States with $C = +1$ Even number of photons

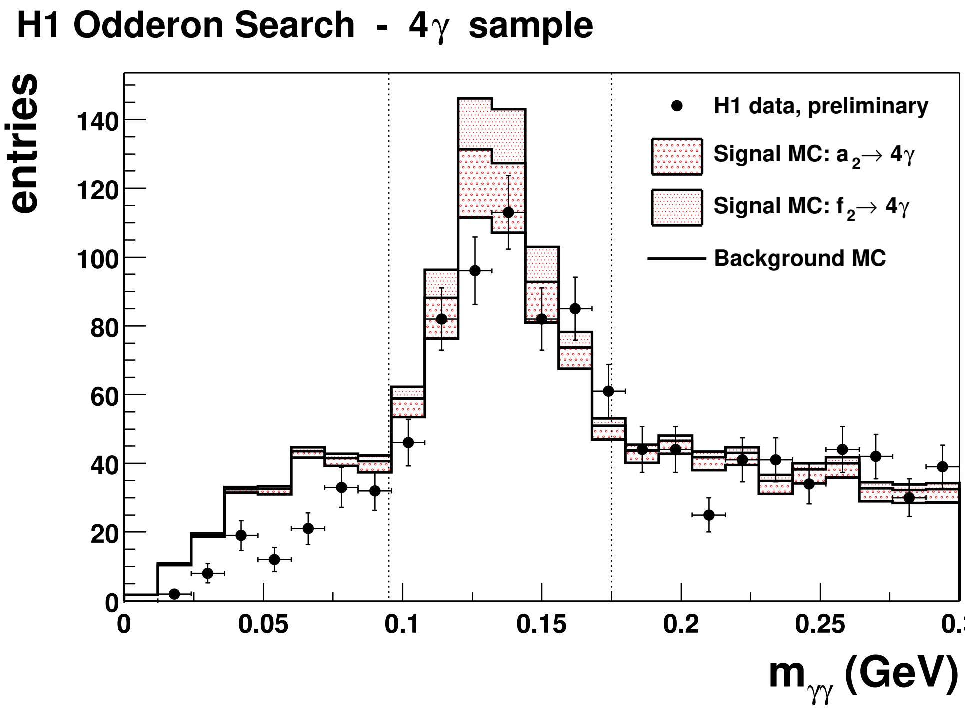
$$
\begin{array}{rcccl}
 & & \pi^\circ & \longrightarrow & 2\gamma \\
f_2(1270) & \longrightarrow & \pi^\circ\pi^\circ & \longrightarrow & 4\gamma \\
a_2(1320) & \longrightarrow & \pi^\circ\eta & \longrightarrow & 4\gamma
\end{array}
$$

Pomeron exchange

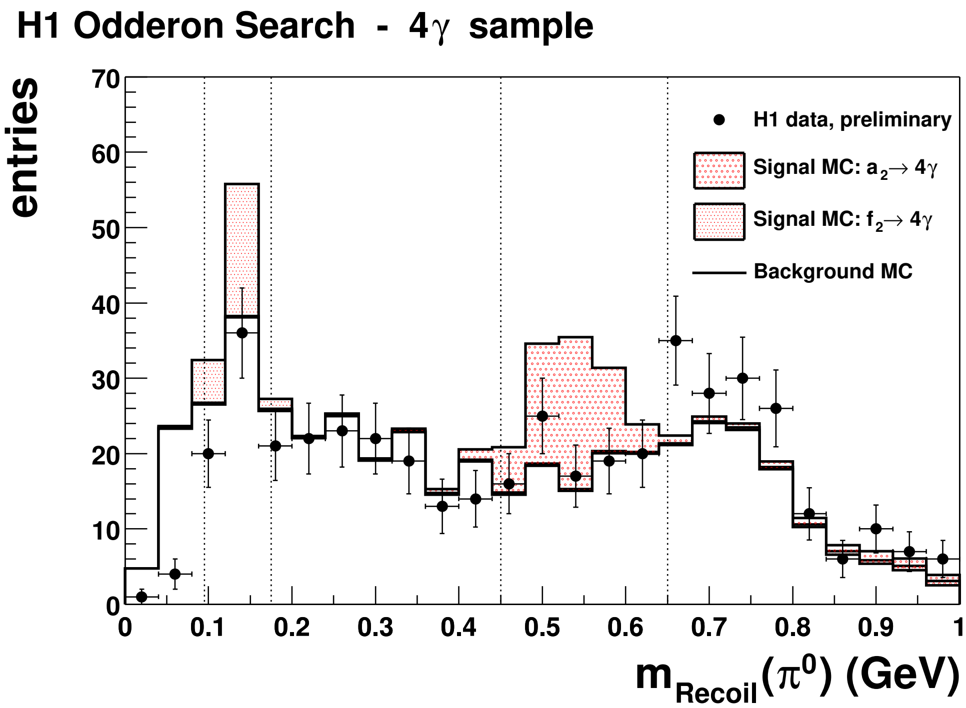
Final States with $C = -1$ Odd number of photons

$$
\begin{array}{rcccl}
\omega & \longrightarrow & \gamma\pi^\circ & \longrightarrow & 3\gamma \\
b_1(1235) & \longrightarrow & \omega\pi^\circ & \longrightarrow & 5\gamma
\end{array}
$$

6 $\gamma\gamma$ combinations / event



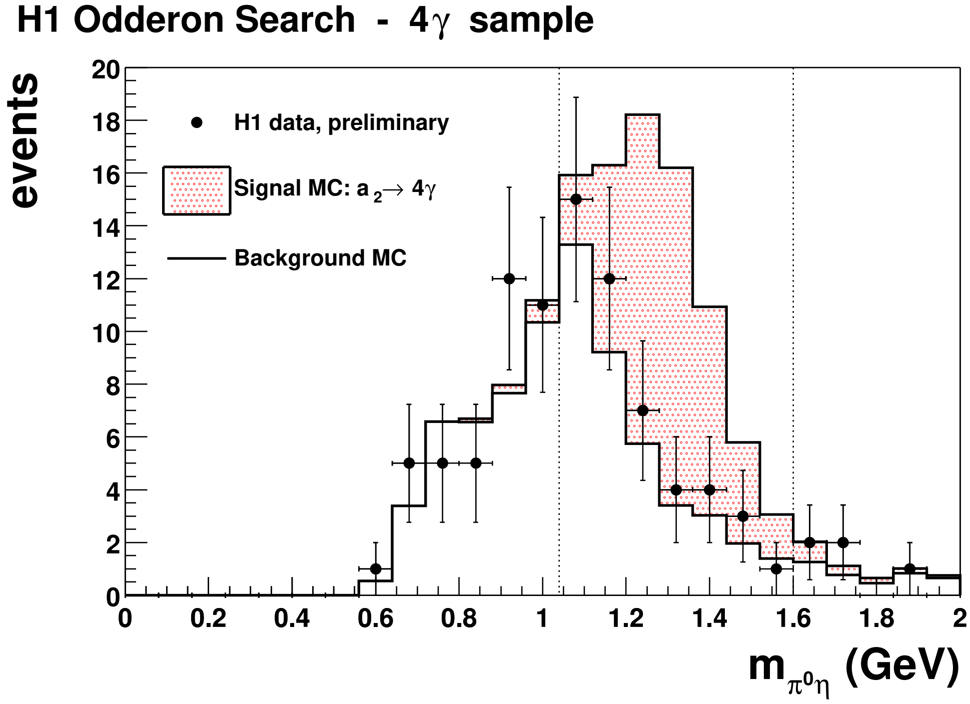
Select π° band, plot recoiling $\gamma\gamma$ mass



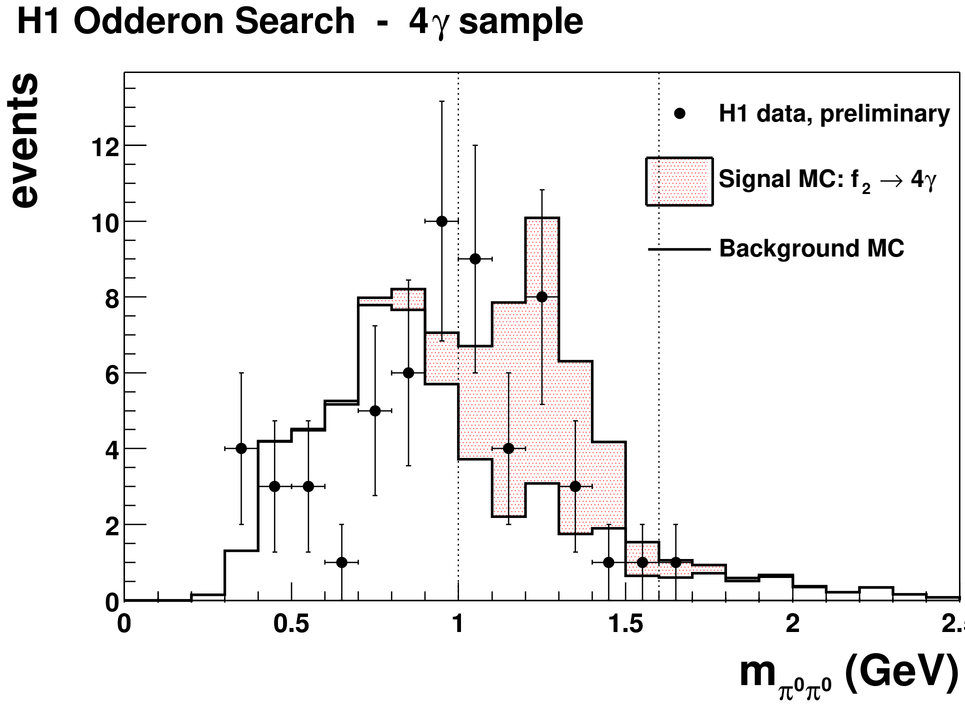
$\pi^\circ\pi^\circ$ or $\pi^\circ\eta$ production ?

Nothing above (trivial) background...

Select π°, η bands, plot 4γ mass



Select π°, π° bands, plot 4γ mass



No signals above background

$\Longrightarrow$ **Upper limits for cross sections**

No Odderon Signals

$\Longrightarrow$ **Upper Limits on Cross Sections**

H1 Preliminary 95% C.L.

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2(1270)X) < 16 \text{ nb}$$

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} a_2(1320)X) < 96 \text{ nb}$$

For $\langle W_{\gamma p} \rangle = 200$ **GeV**

Predictions from E.R. Berger et al.★:

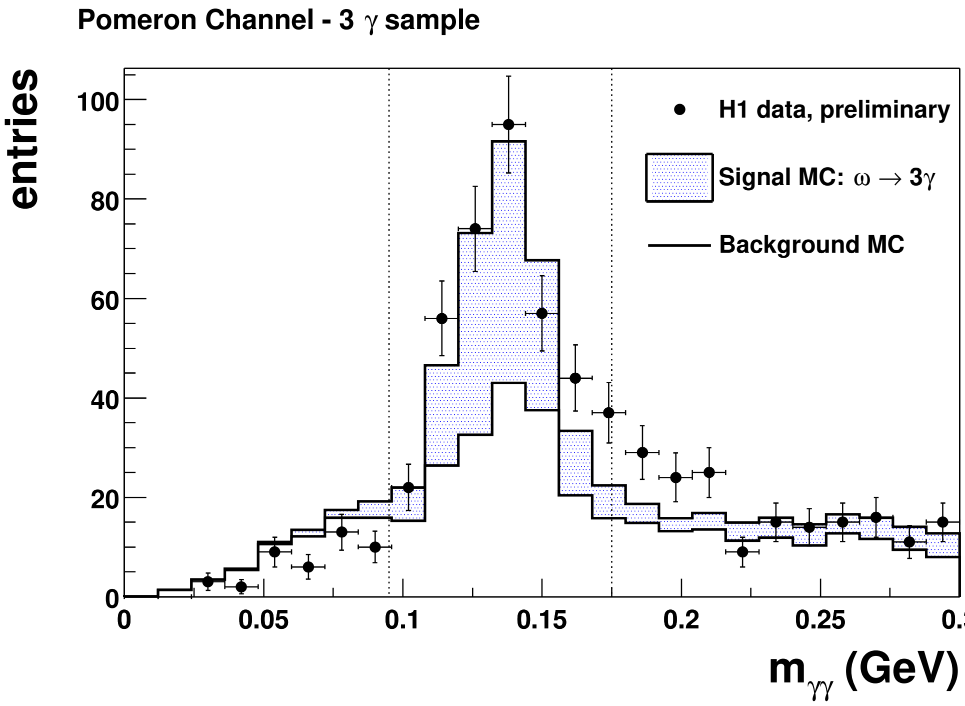
$$\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2(1270)N^*) = 21 \text{ nb}$$

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} a_2(1320)N^*) = 190 \text{ nb}$$

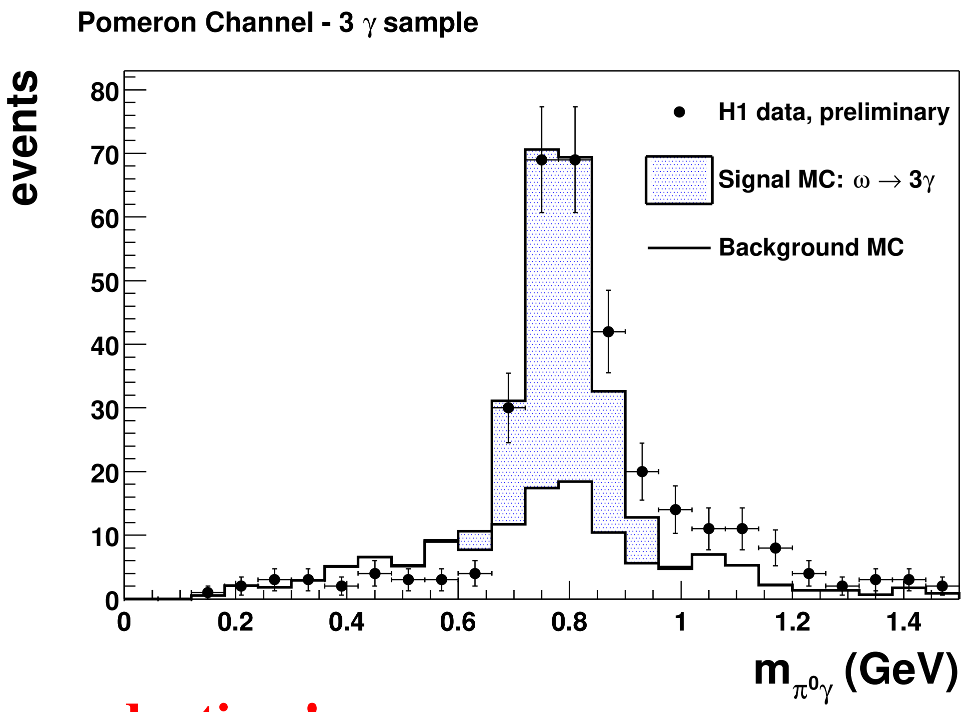
★ **E.R. Berger et al., Eur.Phys.J. C14 (2000) 673** ($f_2(1270)$)
E.R. Berger et al., private communication ($a_2(1320)$)

(”Uncertainty at least a factor 2”)

3 $\gamma\gamma$ combinations / event



Select π° band, plot 3γ mass

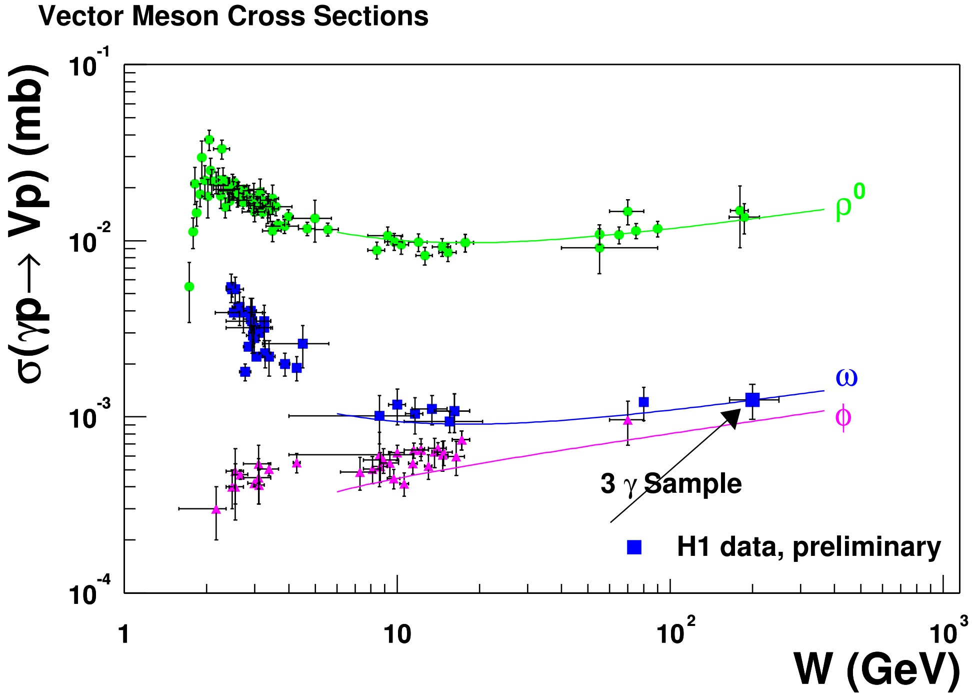


Clear ω production !

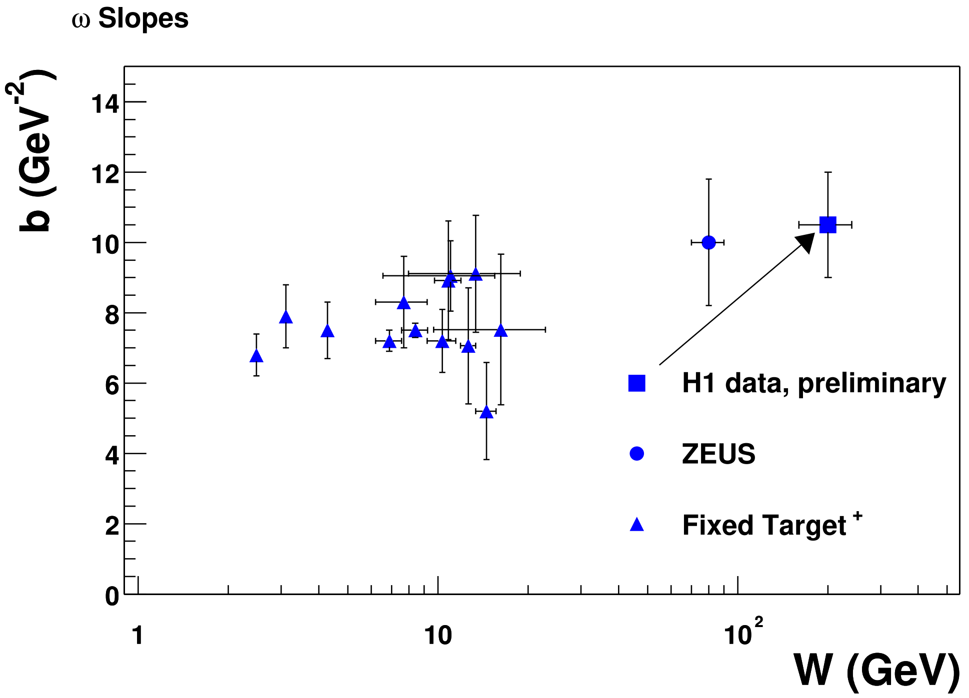
$$\sigma(\gamma p \longrightarrow \omega p) = (1.25 \pm 0.17 \pm 0.22)\ \mu\mathrm{b}$$

H1 Preliminary

W dependence of the cross section

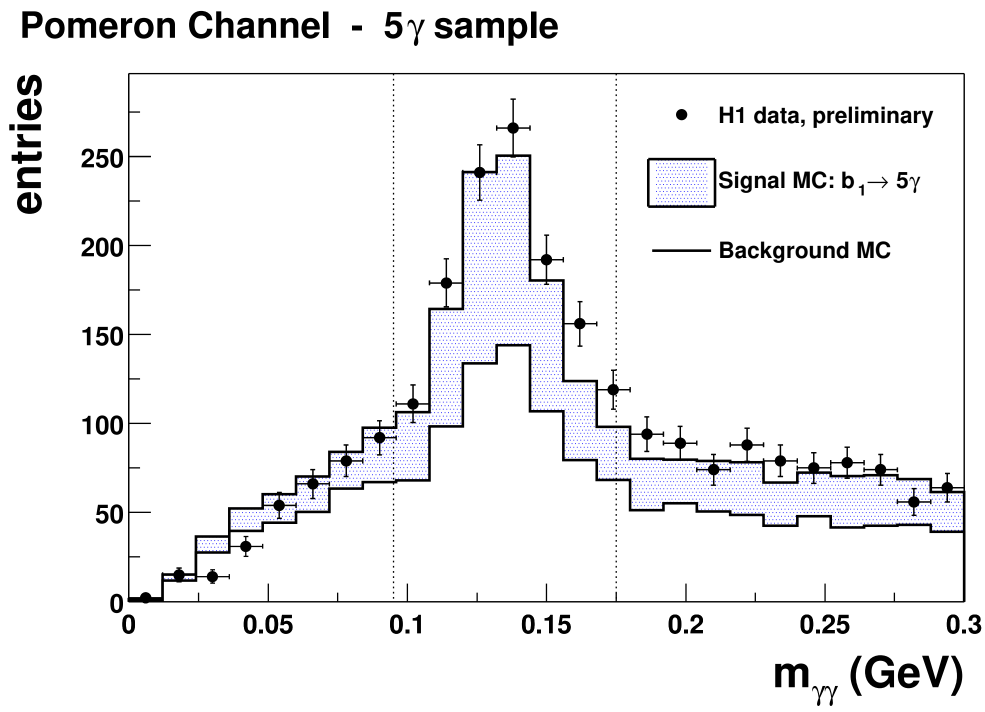


W dependence of the b-slope $\quad (dN/dt \propto e^{-b|t|})$

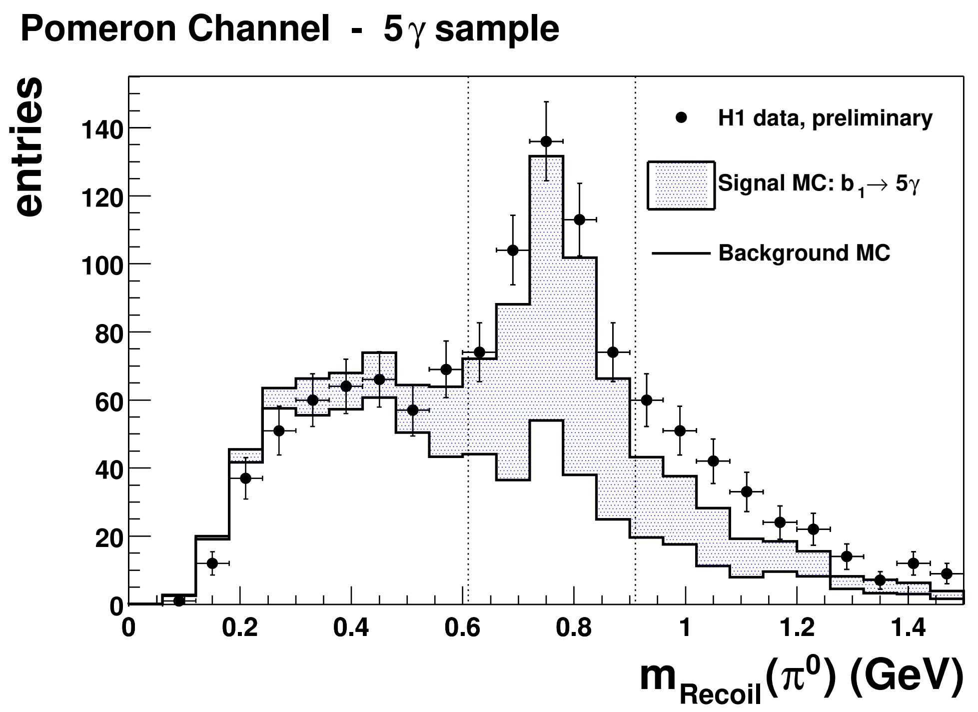


Consistent with previous observations
of Vector Meson production via $\mathbb{P}$omeron exchange

10 $\gamma\gamma$ combinations / event

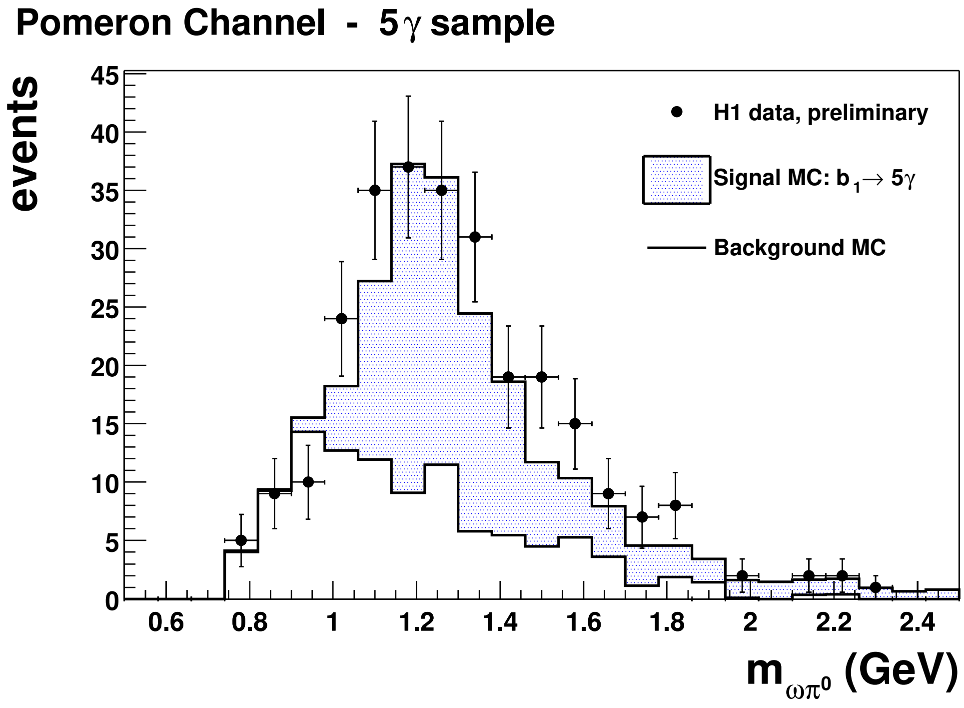


Select π°, π° bands, plot recoiling 3γ mass



Clear signal of ω, recoiling against π°!

Select $\pi^\circ, \pi^\circ, \omega$ bands, plot 5γ mass



$$\sigma(\gamma p \longrightarrow \omega\pi^\circ X) = (980 \pm 200 \pm 200) \text{ nb}$$

H1 Preliminary

PYTHIA (background) expectation 190 nb

$\omega\pi^\circ$ excess due to $b_1(1235)$???

$b_1(1235)$ ($J^{PC} = 1^{+-}$) photoproduction previously observed at CERN[*]

Extrapolate Cross Section to HERA energies $\Longrightarrow$

$$\sigma(\gamma p \longrightarrow \omega\pi^\circ X) = 660 \text{ nb}$$

Nice Agreement !!!

[*] **M. Atkinson et al., Omega Photon Coll., Nucl.Phys. B243 (1984) 1**

SUMMARY

- A Search for **Odderon** exchange was performed, using Exclusive Meson Photoproduction reactions with Multi-Photon Decay modes
- No Odderon Signal found above trivial Background in 2γ and 4γ final states. Upper Limits of cross sections below Predictions of E.R. Berger et al.

  (Non-perturbative QCD, Stochastic Vacuum Model)
- Exclusive ω and $\omega\pi^\circ$ photoproduction observed in 3γ and 5γ final states, consistent with expectations from $\mathbb{P}$omeron exchange and consistent with other observations of Exclusive Vector Meson photoproduction

H1 Preliminary 95% C.L.

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) < 39 \text{ nb}$$

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2(1270)X) < 16 \text{ nb}$$

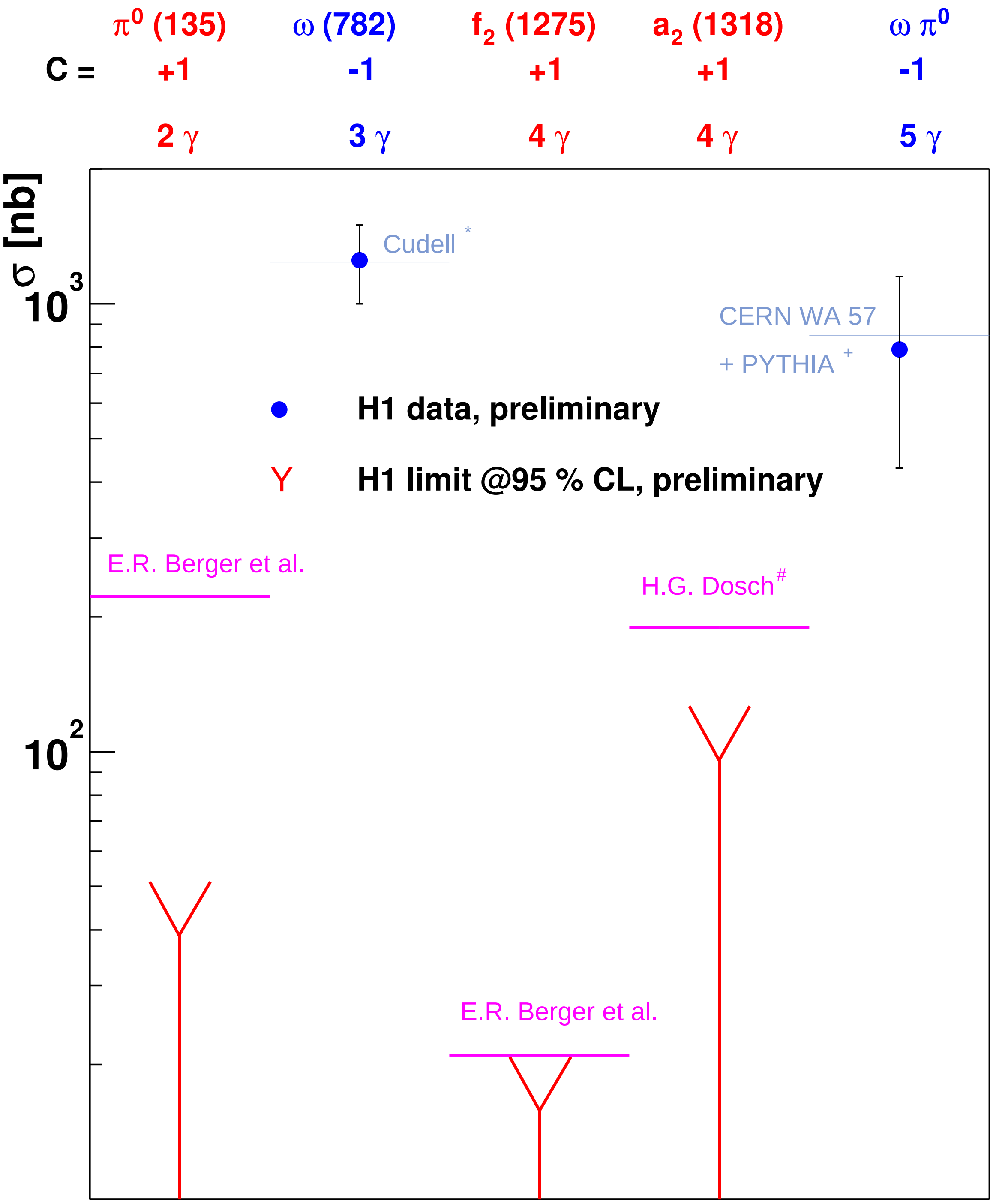
$$\sigma(\gamma p \xrightarrow{\mathbb{O}} a_2(1320)X) < 96 \text{ nb}$$

$$\sigma(\gamma p \longrightarrow \omega p) = (1.25 \pm 0.17 \pm 0.22)\ \mu\text{b}$$

$$\sigma(\gamma p \longrightarrow \omega\pi^\circ X) = (980 \pm 200 \pm 200) \text{ nb}$$

For $\langle W_{\gamma p}\rangle \sim$ 200 GeV

SUMMARY



* Cudell et al.: Phys.Rev. D61 (00), 034019; Schuler, Sjoestrand: Nucl.Phys. B407 (93), 539

\+ CERN WA 57: Nucl.Phys. B243 (84), 1; extrapolated to HERA energies

\# private communication

O U T L O O K

- Interest in the Odderon is an Order of Magnitude below interest in the Pomeron.

  A Search in WWW reveals:
  Odderon: $\sim$ 150 hits Pomeron: $\sim$ 1500 hits
  This may change in the future

- Odderon physics
  now becoming an interesting field of research also for the HERA experiments

- In particular,
  Diffractive, Exclusive Production of Pseudoscalars and Tensors should in future attract much more interest, similar to the interest Diffractive Vector Meson Production enjoys today.

- Will there be a Signal ??

"The real problem with the Odderon is the paradoxical scarcity of the high–energy data in hadron–hadron scattering, leading to an excessive focus on the pp and $\bar{p}p$ data ... The recent shift in attention from pp and $\bar{p}p$ scattering towards ep scattering is, in this context, very positive."

B. Nicolescu, EDS 1999, Protvino

Wait for the HERA II data !