(Vector) Meson Production at H1

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Contents of this Talk

Exclusive Vector Meson Production

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

Something completely different:

- Inclusive production of η, ρ°, 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 Please do not quote it without permission from H1.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 ($\rho, \omega, \phi, J/\psi, \psi', ...$)
  - have same quantum numbers $J^{PC}=1^{--}$ as photon
  - can be produced by colorless exchange ("Pomeron") with proton
- Are a challenge to 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


- $t$: 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!
$e p \rightarrow e p \, \Psi'$

$\rightarrow J/\psi \, \pi^+ \pi^-$

$\rightarrow \mu^+ \mu^-$ 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 $J/\psi$ Cross Section

- Data from 1999/2000, $\mathcal{L} = 54.8 \text{ pb}^{-1}$
- More precise measurement of $\sigma(W_{\gamma p})$
- $W$ dependence: $W^{0.70 \pm 0.08}$

![Graph showing the relationship between $\sigma_{\gamma p \rightarrow J/\psi p}$ and $W$]
Integrated $J/\psi$ Cross Section

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

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:
  \[ \frac{d\sigma}{dt} (W_{\gamma p}) \propto W^4[\alpha(t) - 1] \]

- Measuring \( W \) dependence in bins of \( t \) is a direct measurement of the Pomeron’s trajectory

- Good agreement with ZEUS data

- \( \alpha' = 0.15 \pm 0.06 \text{GeV}^2 \): Shrinkage observed with 2.5σ!
W Dependence of $\psi'$ Production

- Ratio $R = \sigma(\psi')/\sigma(J/\psi)$ measured
- $R$ rises with $W$: $R \propto W^{0.24 \pm 0.17}$
- 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:
W Rise in $\rho^0$ Electroproduction

- Preliminary result, 2000 data, $L=42.4\,\text{pb}^{-1}$
- $W$ 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 $\rho^0$ photoproduction triggers
- More than 13000 events taken
- $W$ range 25–85GeV
- $|t|$ range up to 2GeV$^2$
- Enough data for double–differential measurement of $\rho^0$ 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
  $\Rightarrow$ 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: $\mathcal{L}=78\text{pb}^{-1}$
- $2 < |t| < 30\text{GeV}^2$: 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 $\alpha_s$.
- Power law: $n=3.00\pm0.08(\text{stat})\pm0.05(\text{syst})$

$t$ Dependence of $W$ Rise

- 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
$\rho^0$ Electroproduction

- $r_{0400}^0$ measures fraction of longitudinally polarized vector mesons:
- Rises with $Q^2$, as expected
- no $t$ dependence observed

**s–Channel Helicity Non–Conservation**

- H1 preliminary
  \( <Q^2> = 15.9 \text{ GeV}^2 \)
- H1 97 diffractive
  \( <Q^2> = 5 \text{ GeV}^2 \)
- H1 96 elastic
  \( <Q^2> = 5 \text{ GeV}^2 \)
- ZEUS 95
  \( <Q^2> = 6.3 \text{ GeV}^2 \)

\[
W(\Phi) \propto 1 + \sqrt{2\epsilon(1 + \epsilon)}(r_{00}^5 + 2r_{11}^5) \cos \Phi - \epsilon(r_{00}^1 + 2r_{11}^1) \cos 2\Phi
\]

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

Fit 2–dimensional cross section:
\[
\frac{1}{\sigma} \frac{d^2\sigma}{d\cos \theta^* d\phi^*} = \frac{3}{4\pi} \left( \frac{1}{2} \left( 1 + r_{00}^{04} \right) - \frac{1}{2} (3r_{10}^{04} - 1) \cos^2 \theta^* + \sqrt{2} \text{Re}\{r_{10}^{04}\} \sin 2\theta^* \cos \phi^* + r_{1\bar{1}}^{02} \sin^2 \theta^* \cos 2\phi^* \right)
\]

S–channel helicity conservation: all \( r \) are 0 in photoproduction
\[
\frac{1}{\sigma} \frac{d^2\sigma}{d\cos \theta^* d\phi^*} = \frac{3}{4\pi} \left( \frac{1}{2} + \frac{1}{2} \cos^2 \theta^* \right)
\]

Result: all values consistent with 0, no violation of SCHC seen
AND NOW
FOR SOMETHING
COMPLETELY
DIFFERENT
Inclusive Meson Production

Inclusive particle production in fragmentation

- Universal plateau
- Here: Photoproduction,
  2000 data, $L = 38.7\text{pb}^{-1}$
- Electron tagged, $174 < W < 256\text{GeV}$
- $3.7 \cdot 10^6$ events
- Resonance production:
  $\eta, p^0, f_0, f_2$
- $p_t$ behaviour similar to stable particles?
The Data
Universal Scaling?

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

✧ Many new results on $\rho^0$, $J/\psi$, $\psi'$ 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 $\eta$, $\rho^0$, $f_0$, $f_2$ has been measured and shows a universal behavior in $p_t+m$

✧ (Vector) meson production will stay a fruitful subject at HERA–II
New Measurement of $\psi'$ Photoproduction

- Full 1996–2000 statistics, $L=77\text{pb}^{-1}$
- Direct decays $\psi'\rightarrow\mu^+\mu^-, e^+e^-$, +cascade decays $\psi'\rightarrow J/\psi \pi^+\pi^-$
- $40<W<150\text{GeV}$, $|t|<5\text{GeV}^2$
- First differential measurements of $\psi'$ photoproduction

New J/ψ Measurement (preliminary)

- Large dataset 1999/2000
- \( \mathcal{L} = 54.8 \text{pb}^{-1} \)
- \( \sim 7000 \) events: allow double–differential measurements \( d\sigma/dt (W_{\gamma p}) \)
s–Channel Helicity Non–Conservation

\[ W(\cos \theta^*) \propto 1 - r_{00}^{04} + (3 r_{00}^{04} - 1) \cos^2 \theta^* \]

\[ W(\Phi) \propto 1 + \sqrt{2\epsilon(1 + \epsilon)(r_{00}^5 + 2r_{11}^5)} \cos \Phi - \epsilon(r_{00}^1 + 2r_{11}^1) \cos 2\Phi \]

- \( r_{00}^{04} \): helicity conserving
- \( r_{00}^5 + 2r_{11}^5 \): helicity non–conserving
- Clear SCHNC observed

s–Channel Helicity Non–Conservation

- $r_0^5 + 2r_{11}^5$: 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

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. $\alpha_\Omega=1$.

- Look for final states that are not possible for natural parity exchange, e.g. $\pi^0$ with $J^{PC}=0^{-+}$. 
How to Find a Single $\pi^0$

⚠️ Problem: Only $\pi^0$ in detector, i.e. $2\gamma$.

⚠️ Scattered electron in e–Tagger, neutron from proton dissociation in neutron calorimeter

⚠️ Gammas from $\pi^0$ decay have energy ~6GeV, very close to beampipe. Use special calorimeter (VLQ) to detect them.

⚠️ 1999/2000 data, $\mathcal{L}=30.6\text{pb}^{-1}$

Inclusive $M_{\gamma\gamma}$ spectrum for events with 2 photons in backward calorimeters:

Do We See It?

Not yet!

- No signal above background observed

- Derive limit:
  \[ \sigma(\gamma p \rightarrow N^*) < 49 \text{nb (95\% CL)} \]
  for \(0.02 < |t| < 0.3 \text{GeV}^2\)
  at \(W=215\text{GeV}\)

- Theoretical expectation*:
  \(>200\text{nb}\)

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