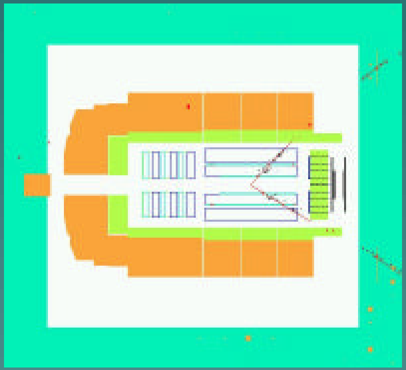
High-|*t*| Diffraction & Deeply Virtual Compton Scattering

K.Hiller, DESY Zeuthen
On behalf of the H1 Collaboration



DIFFRACTION 2004

Cala Gonone, Sardinia,ITALY
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Outline

- Introduction
  - kinematics, motivation, signature, models

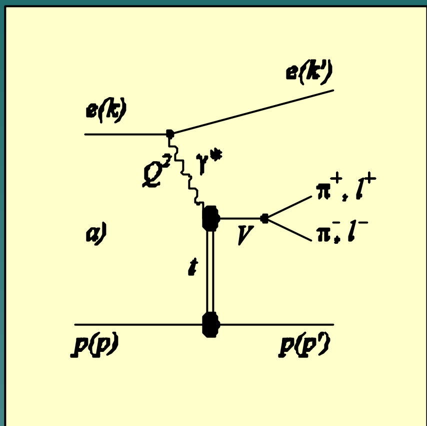
- Data - *J/y* and photons
  - luminocity, selection, backgrounds
  - cross sections versus *W*, *t* or Q^2
  - spin density matrix elements for *J/y*

- Comparisons
  - light vector mesons, low-|*t*| range
  - perturbative QCD models (BFKL, colour diople, ..)
  - ZEUS

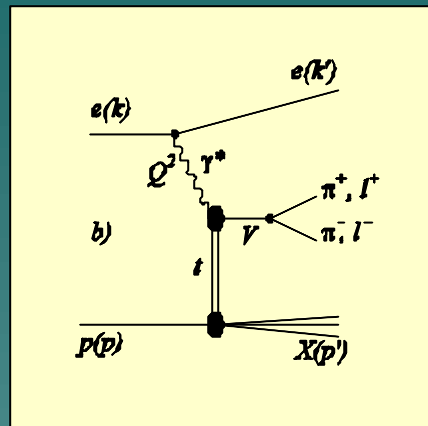
- Summary & Outlook

Kinematics of Vector Meson Production

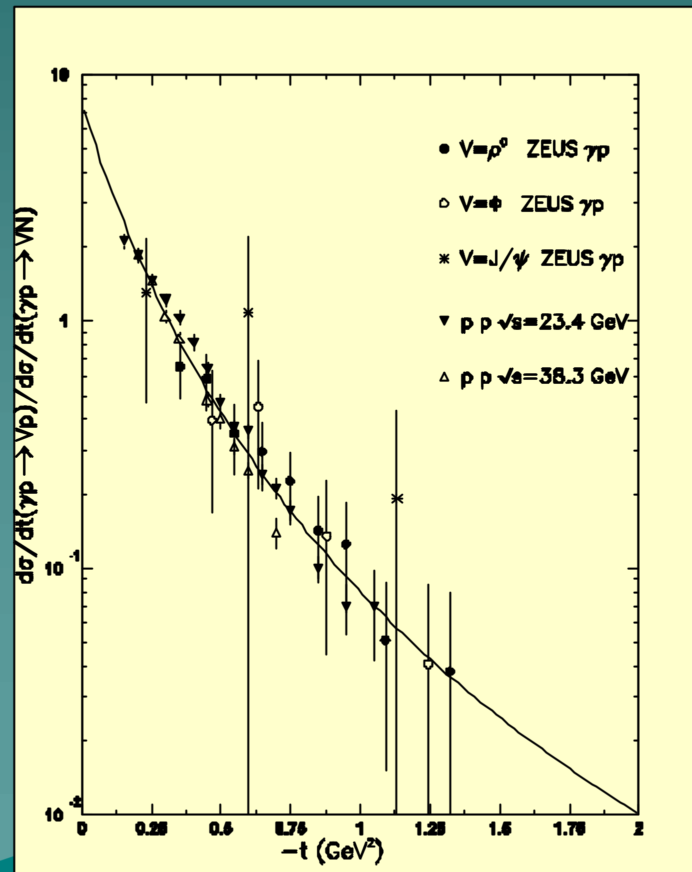
elastic at low-|*t*|



dissociative at high-|*t*|



elastic-to-dissociative
cross section ratios



Exclusive VM production described by 4 variables:

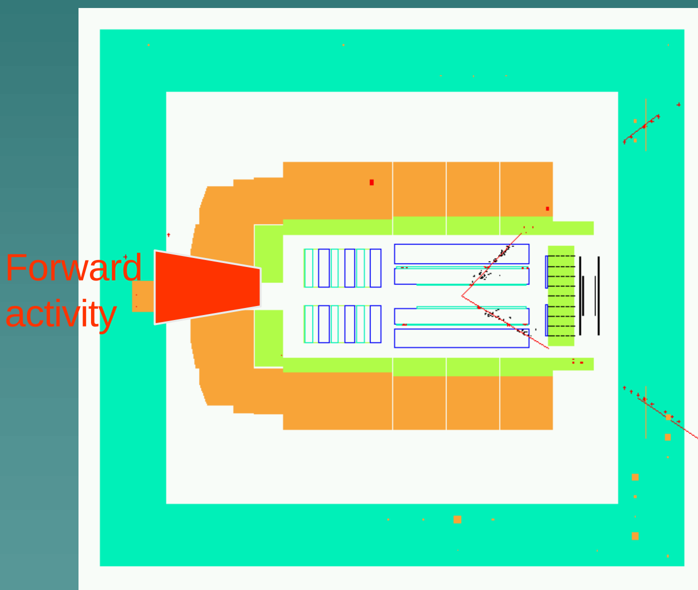
*Q*² = -(*k* – *k'*)² … photon virtuality
t = (*p* – *p'*)² … proton momentum transfer ²
W = v(*q*+*p*)² … *g p* center-of-mass energy
V = vector meson … *r, w, f, J/y, U*

For helicity studies: 3 scattering / decay angles

Event Signature

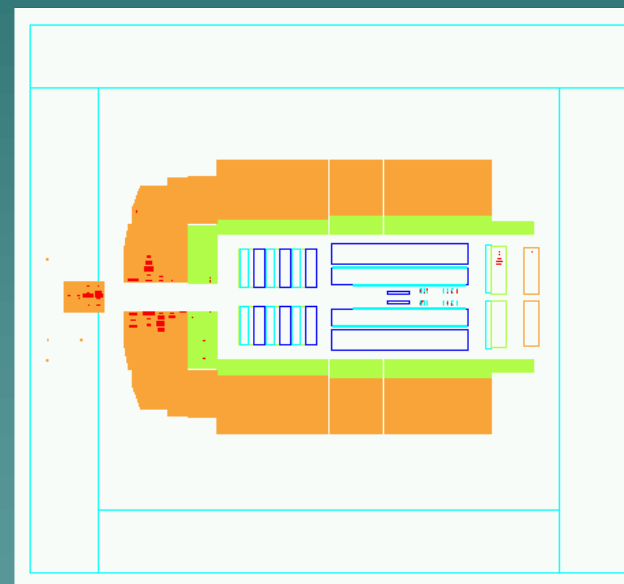
- Photoproduction: → electron scatters through small angle, mostly untagged, $Q^2 \sim 0$
- Diffractive proton dissociates → activity in forward detectors
- Only *J/y* decay particles or photon visible in H1 detector

J/y → $\mu^- \mu^+$



J/y identified by 2 high-p_T leptons

single photon



g identified by el.mag. shower

Clean / exclusive processes with less backgrounds

VM Production in pQCD

- **General picture**:
  - g* fluctuates into $q\bar{q}$, $q\bar{q}g$ colour dipole
  - exchange of colour singlet with proton
  - $q\bar{q}$ condensates in a vector meson VM
    (→ wave function needed to form VM)

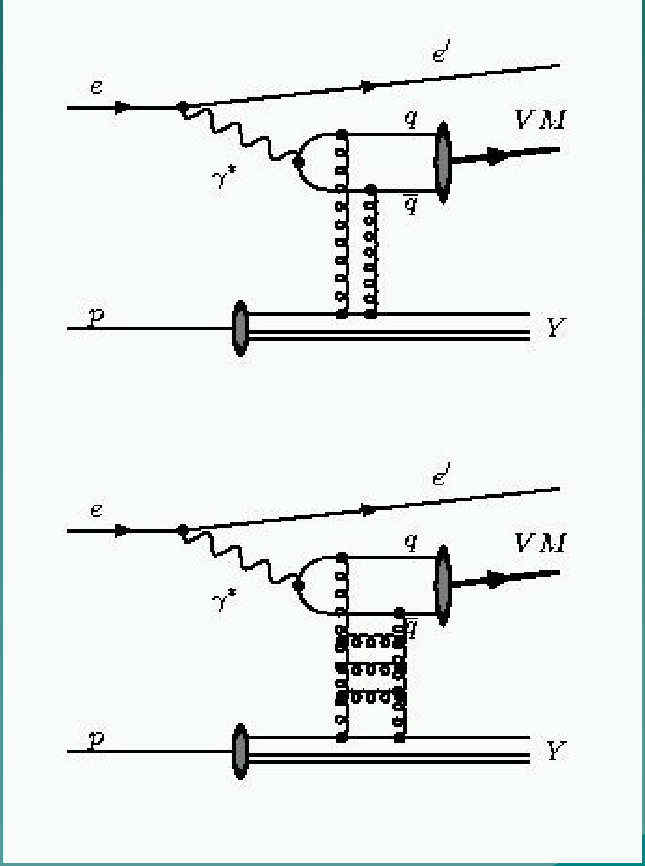
- **Colour singlet exchange**: → large rapidity gap
  - 2 gluons in lowest order ,
  - higher orders → gluon ladders
  - increasing cross section $s \sim |x\, g(x)|^2$ at low x

- **Approaches to add higher orders**:

  DGLAP:
  - ordered momenta along ladder rungs
  - valid for $|t| < M_V^2$
  - weak increase of σ with W
  - works for inclusive DIS over large Q^2-x range

  BFKL:
  - unordered momenta along ladder
  - at high-$|t|$ power law dependence $|t|^{-n}$
  - strong increase of σ with W

  CCFM:
  - angular ordering (…mixed scheme)



Test pQCD in limit of large |*t*| and small *x*

High-|*t*| *J/y* Production

e + p → e + J/y + Y

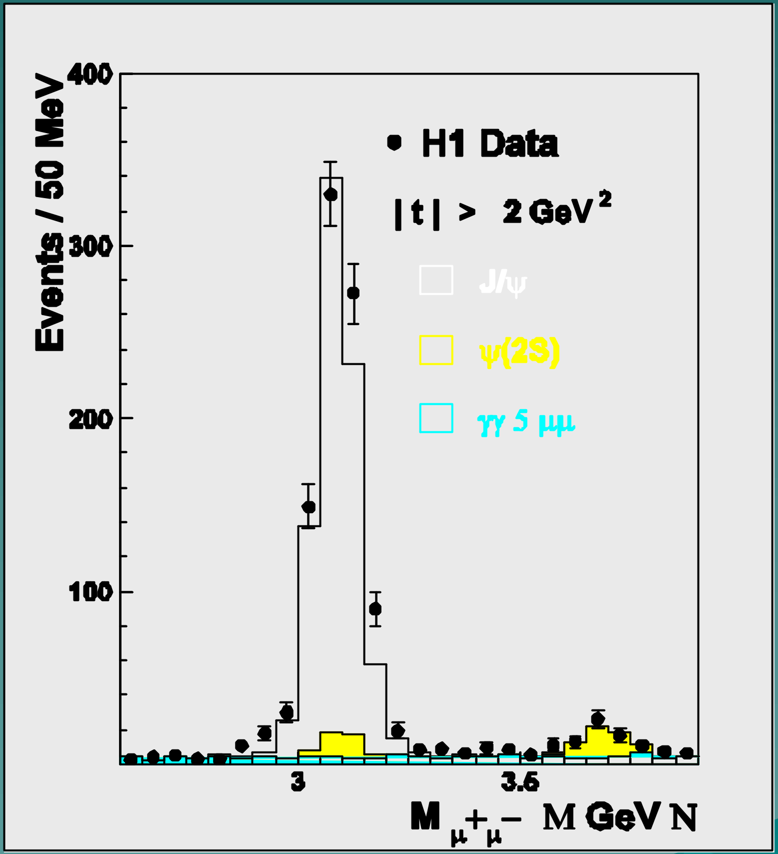
- <u>$2 < |t| < 30$ GeV²</u>
  for *g*p* energies $50 < W < 150$ GeV

- Untagged photoproduction:
  $<Q^2> \sim 0.006$ GeV²

- Diffraction : high fractional *J/y* momentum
  $z = (p_{J/y}\, p) / (p\, q) > 0.95$
  $z \sim 1 - (M_Y^2 - t) / W^2$
  → low $M_Y < 30$ GeV

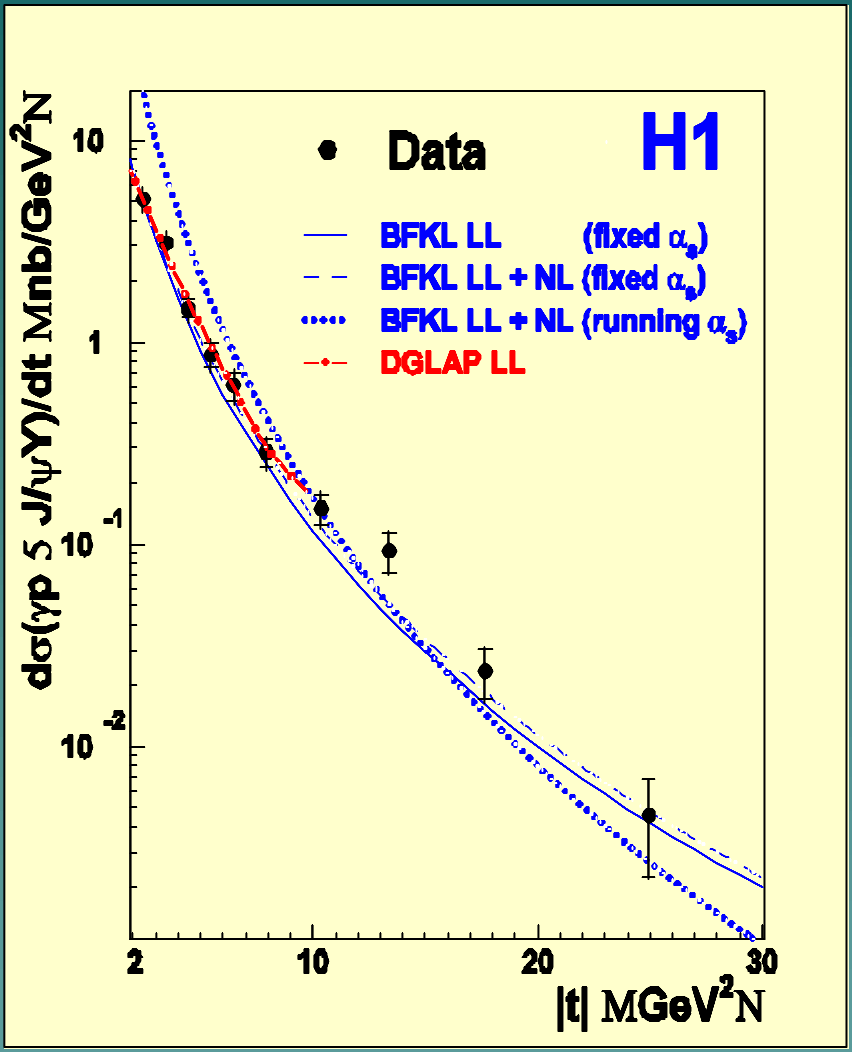
- Full HERA-I sample: $L = 78$ pb^{-1}
  → 850 decays $J/y \to \mu^+\mu^-$

- Compare with ZEUS: $L = 24$ pb^{-1}
  → 150 *J/y* at $|t| < 6$ GeV²

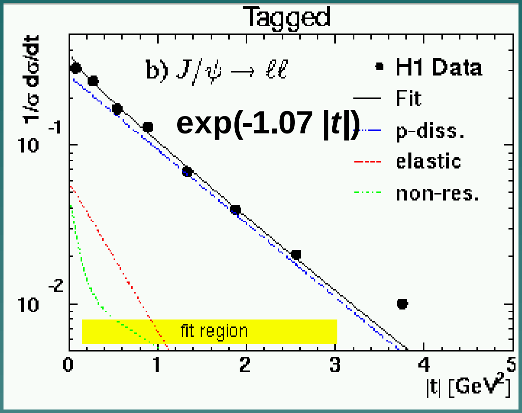


- Simulation with BFKL LL model
- Small contribution from *Y (2S)*
- Non-resonant background negligible

J/y Cross Section versus |t|



- ❑ Incompatible with exponential dependence from low-|*t*| region



- ❑ Better fit: power law $|t|^{-n}$, with n ~ 3 as expected for hard process

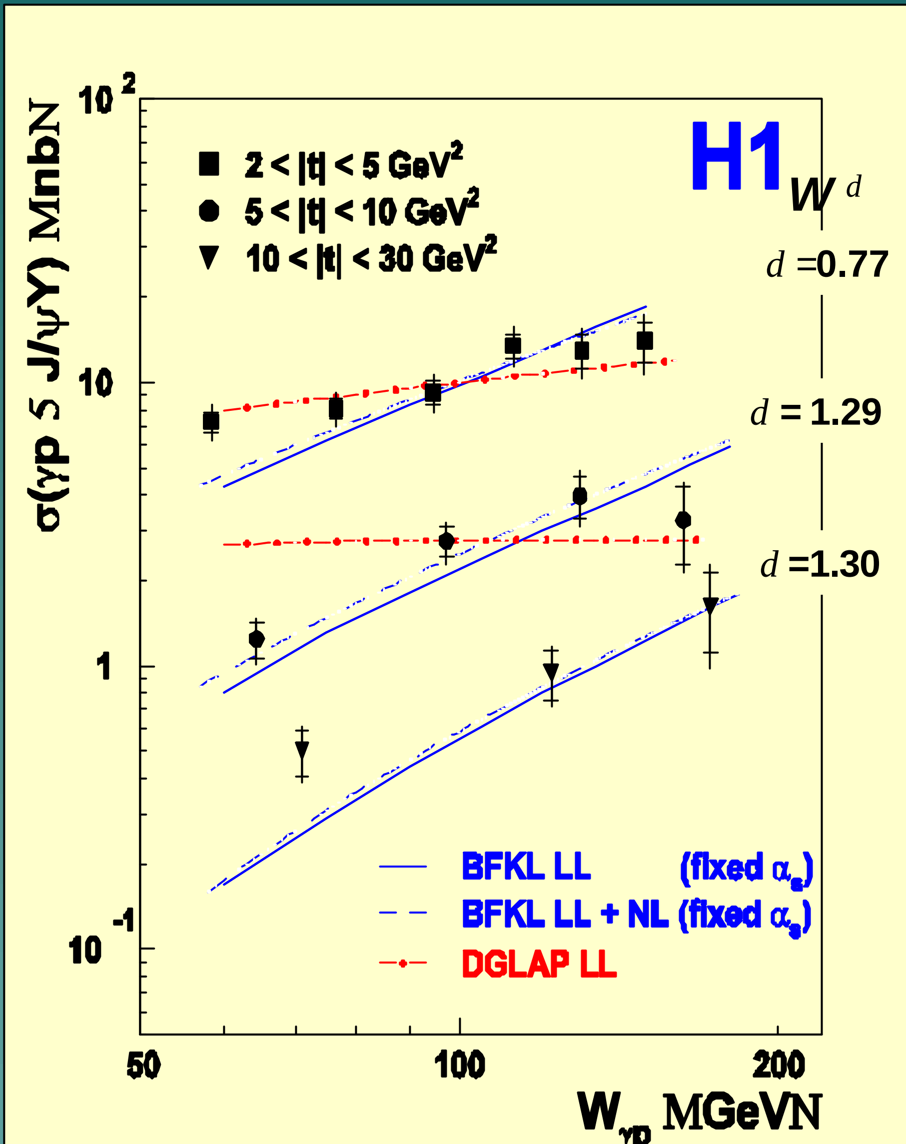
- ❑ Increase of *n* with lower |*t*| cut expected:
  - *n* ~ 1.7 for 1 < |*t*| < 6 GeV², ZEUS
  - *n* ~ 3.8 for |*t*| > 10 GeV²

- ❑ DGLAP LLA : → fine for |*t*| < M_V^2 ~ 10 GeV²
  Gotsman,Levin,Maor,Naftali

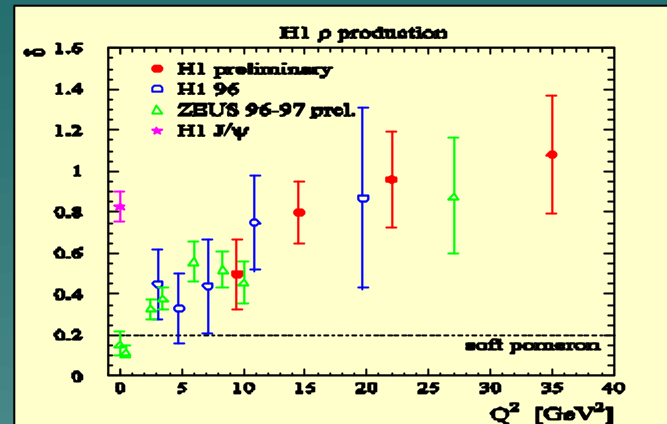
- ❑ BFKL LLA : **Enberg, Motyka, Podludniowski**
  → fixed a_s = 0.18 plus NL order fine
  → running a_s: worse at low |*t*|

pQCD models reproduce high-|*t*| dependence

J/y Cross Section versus *W*



- Power law W^d, $d \sim 1$ works well
  similar to low-|*t*| elastic *J/y* photoproduction



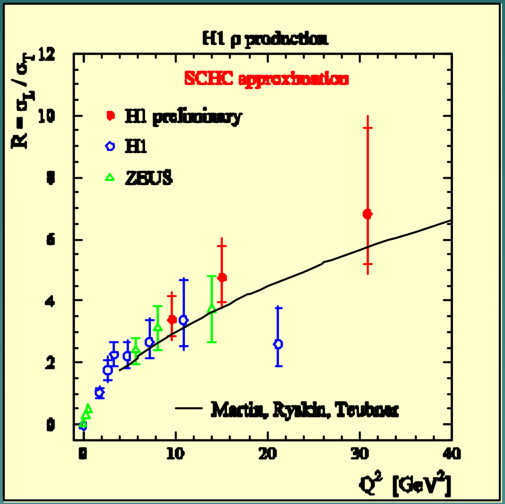
- large *d* indicates a hard process
  → see ρ at high Q^2
- Regge model: $\sigma \sim W^{4(a(t)-1)}$
  → $\alpha_0 \sim 1.17$, $\alpha' \sim 0$
  → **no universal soft Pomeron**
- DGLAP LL:
  → fails at higher $|t| > M_V^2$
- BFKL LL:
  → better, but too steep at low-|*t*|

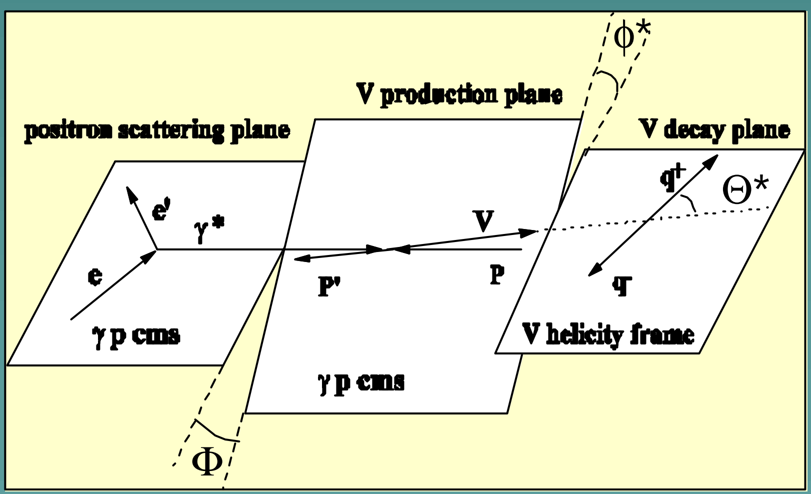
J/y – Polarization Studies

REMIND:

- ❑ Production and decay angular spectra reflect the virtual photon and VM polarization
- ❑ s-channel helicity conservation (SCHC): VM polarization = photon polarization
- ❑ Analysis scheme: 3 production / decay angles define 15 spin density matrix element (spin non-flip, single-flip, double-flip amplitudes)

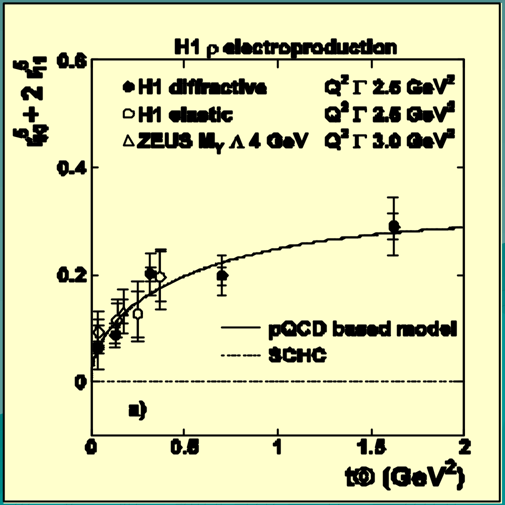
Photon with increasing Q^2 mainly longitudinal polarized





Light VM at low |*t*|:

Violation of SCHC

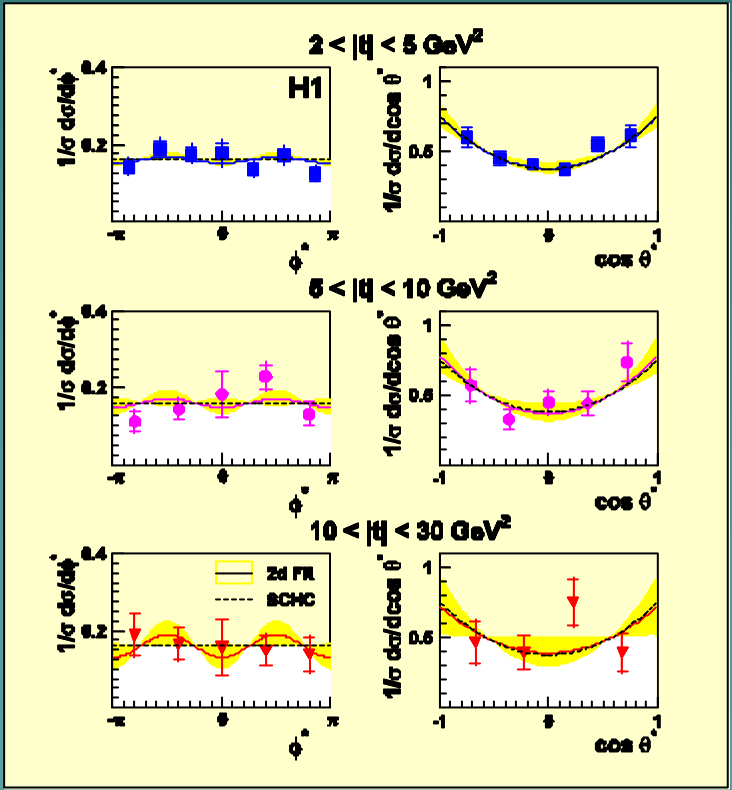


J/ψ – Decay Angular Spectra

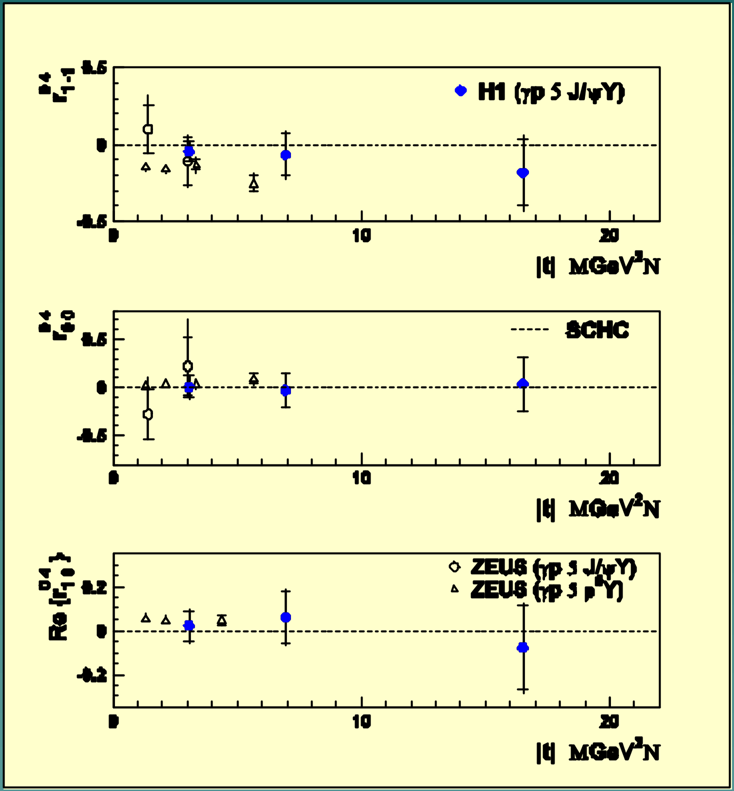
Untagged photoproduction:
→ 2 angles → 3 matrix elements:

$$d\sigma^2/d\cos\Theta^* d\phi^* \propto (1+r_{00}^{04})/2-(3r_{00}^{04}-1)\cos^2\Theta^* + \mathrm{Re}\{r_{10}^{04}\}\sin 2\Theta^* \cos\phi^* + r_{1-1}^{04}\sin^2\Theta^*\cos 2\phi^*$$

Fit 2 projections in 3 $|t|$-bins:

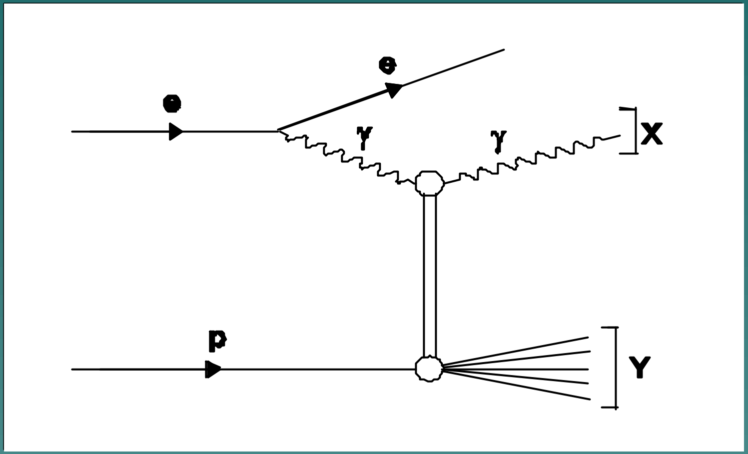


Spin density matrix elements from 2-dim. fit :



→ Data consistent with SCHC
$r_{00}^{04} = r_{1-1}^{04} = \mathrm{Re}\{r_{10}^{04}\} = 0$
in contrast to light VMs

High-|*t*| Photon Production



Motivation:

- ❑ simplest final state: no VM wave function enters
- ❑ nice test of BFKL evolution at high-|*t*|
- ❑ extended range in pseudorapidity → large gap
- ❑ complementary to high-Q^2 photons, “DVCS”

Simple & clean kinematics:

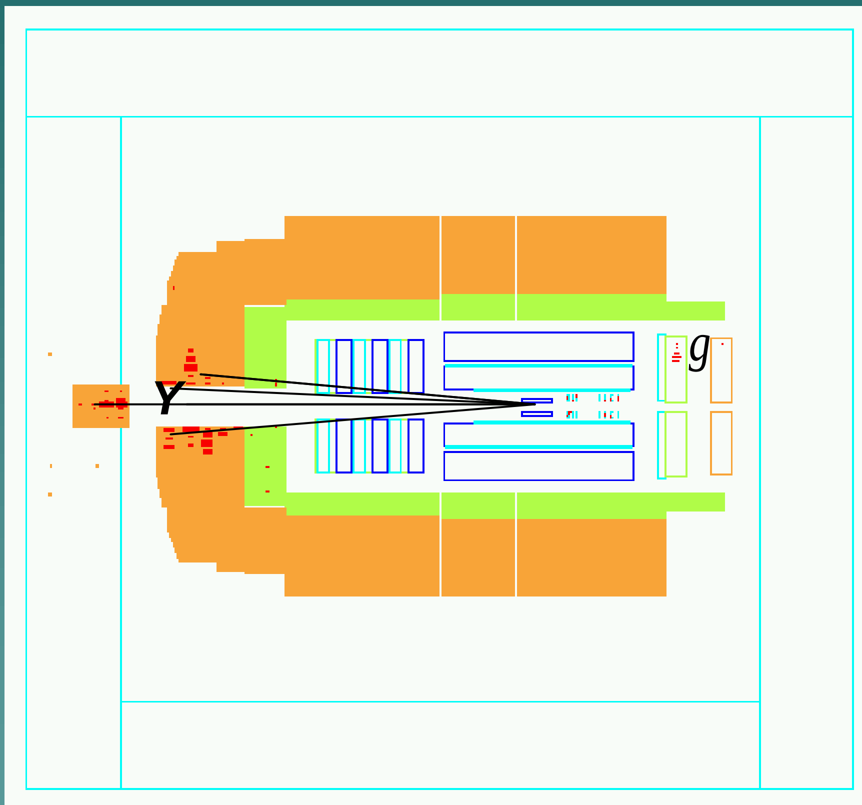
- $|t| \sim (p_T^{g})^2$

Diffractive selection: fractional Pomeron momentum

- $x_P = q\,(P-Y)\,/\,q\,P \sim (p_T^{g})^2 / W^2$
- $y_P = P\,(q-X)\,/\,q\,P \sim e^{-Dh}$

Event Selection

$e + p \rightarrow e + g + Y$



- **Tagged photoproduction**

  electrons: $Q^2 < 0.01$ GeV², $175 < W < 247$ GeV

  photons: $E_g > 8$ GeV, $p_T > 2$ GeV

- **Rapidity gap**

  $y_P \sim \Sigma(E-P_z)/\, 2E_g < 0.018$

  $\rightarrow \Delta\eta > 2$

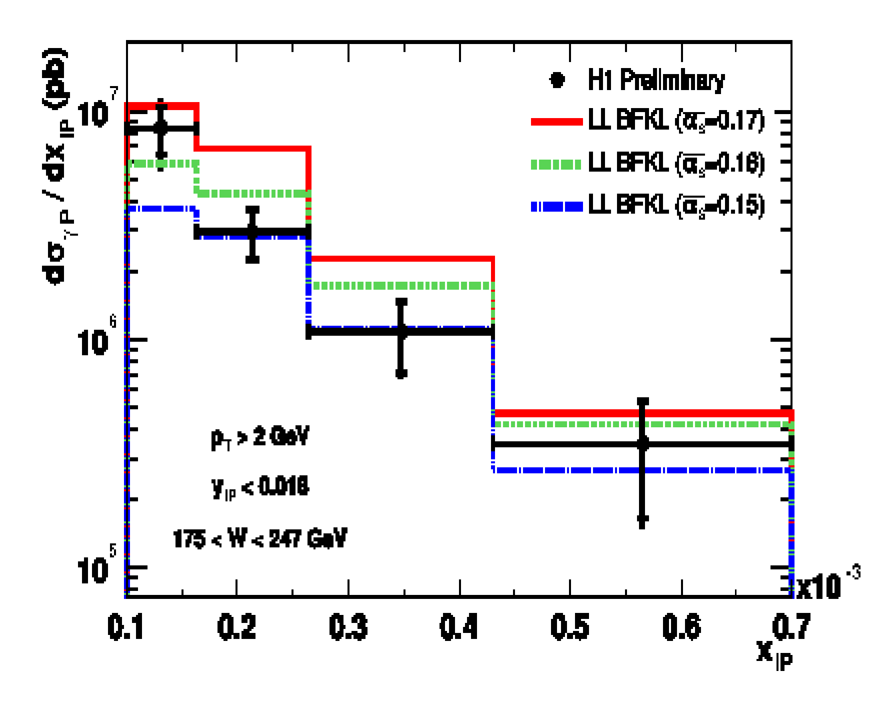
- **Backgrounds**

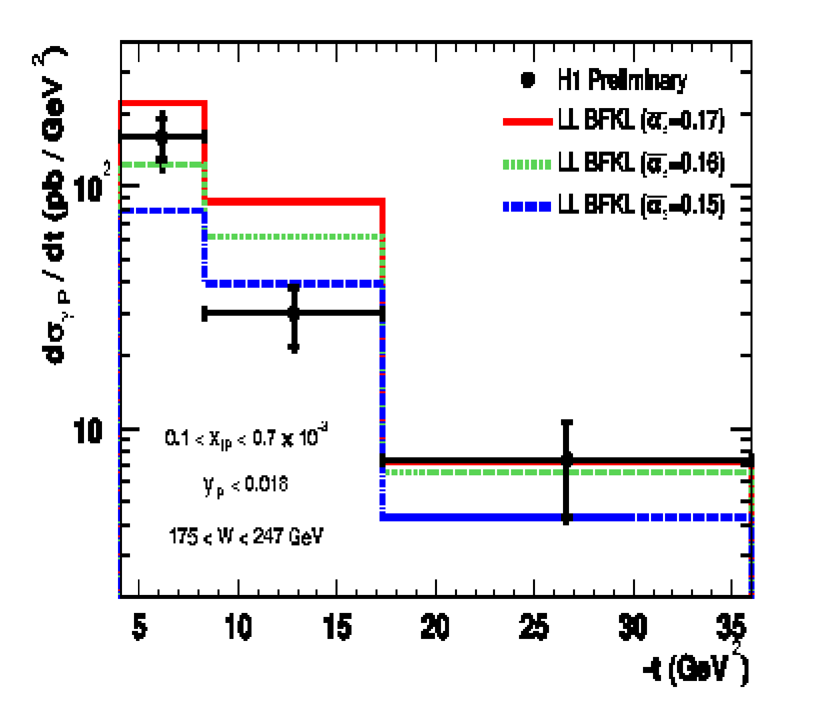
  - inclusive photoproduction < 9%, subtracted
  - hight-|t| ω production & others negligible
  - Bethe-Heitler kinematically suppressed

- **First measurement**

  1999-2000, $L = 47.6$ pb $^{-1}$

Photon Cross Section versus x_P and $|t|$





- Both spectra show typical, diffractive behaviour: steep falls …
- BFKL LLA with a_s = 0.15…0.17 reproduce the general trend
- Large errors → needs more precise data to evaluate models

Deeply Virtual Compton Scattering (DVCS)

… or high Q^2 photons

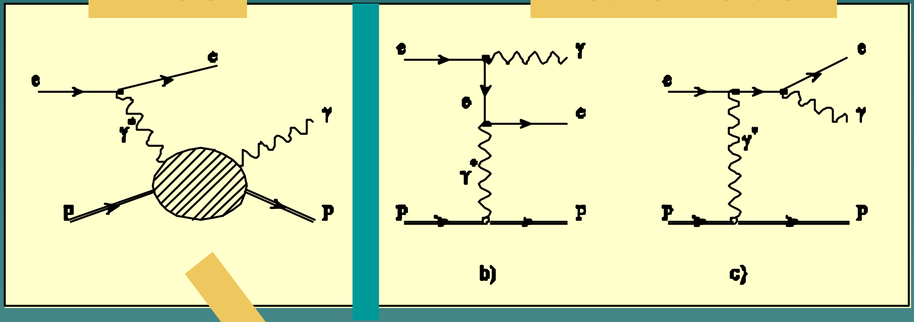
Motivation

- simple final state: similar to VM production, but no wave function needed
- at hard scale factorized ansatz : hard scattering @ proton PDFs
- unequal parton momenta give access to skewed / generalized PDFs
- Bethe-Heitler background pure el.mag. process → precisely known

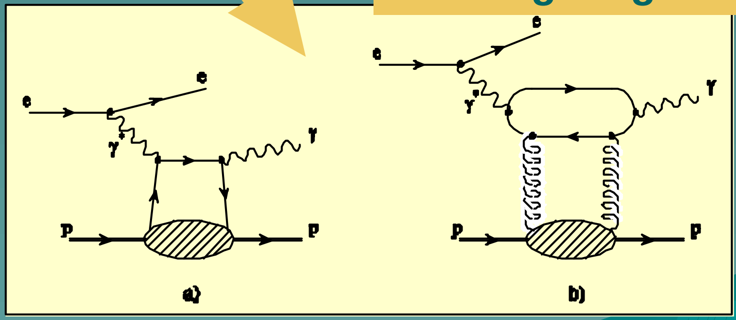
But: small cross section compared to VM production due to add. el.mag.coupling

Backgrounds

DVCS | Bethe-Heitler



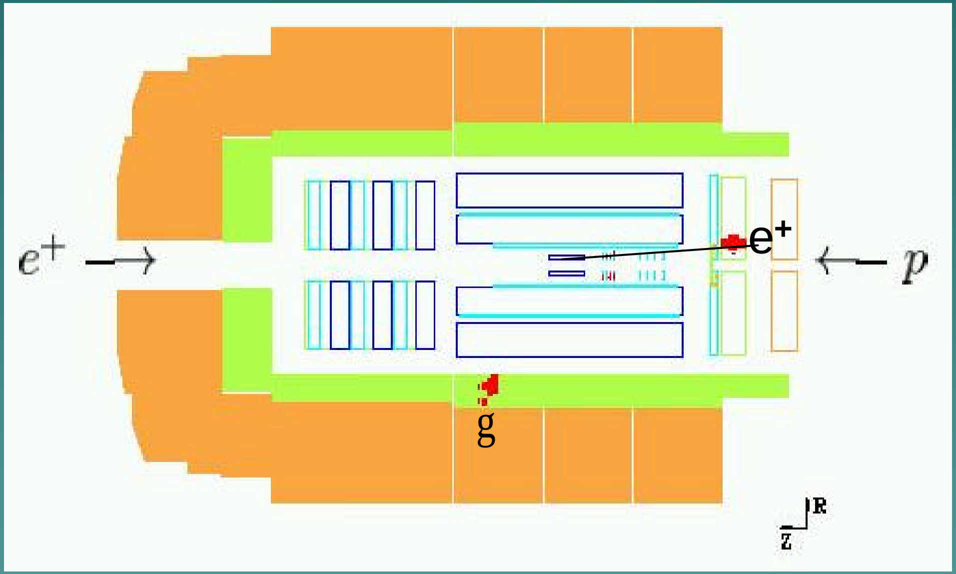
Leading diagrams



DVCS - Data Sample

$e + p \rightarrow e + g + p$

❑ **DVCS candidate sample:**
- e^+ in SpaCal E>15 GeV,
- g in LAr Calorimeter p_T>2 GeV,
- only 1 track related to e^+
- no forward activity



❑ **Kinematic range :**
- $4 < Q^2 < 80$ GeV^2,
- $30 < W < 140$ GeV,
- $|t| < 1$ GeV^2

❑ **Backgrounds:**
- Bethe-Heitler process: e^+ and g dom.backwards
- misidentified diff.electroproduction of *r*
- misidentified e^+e^- production

→ well-checked by control sample

❑ **2000 Data:** $L = 26$ pb^{-1}

DVCS – pQCD & Skewed PDFs

Model of Freund et al.:

- NLO: leading twist
- skewed PDFs:
  - q-singlet $Hq(x,x,t,m^2) = q(x,m^2)\ e^{-b|t|}$
  - gluon $Hg(x,x,t,m^2) = xg(x,m^2)\ e^{-b|t|}$

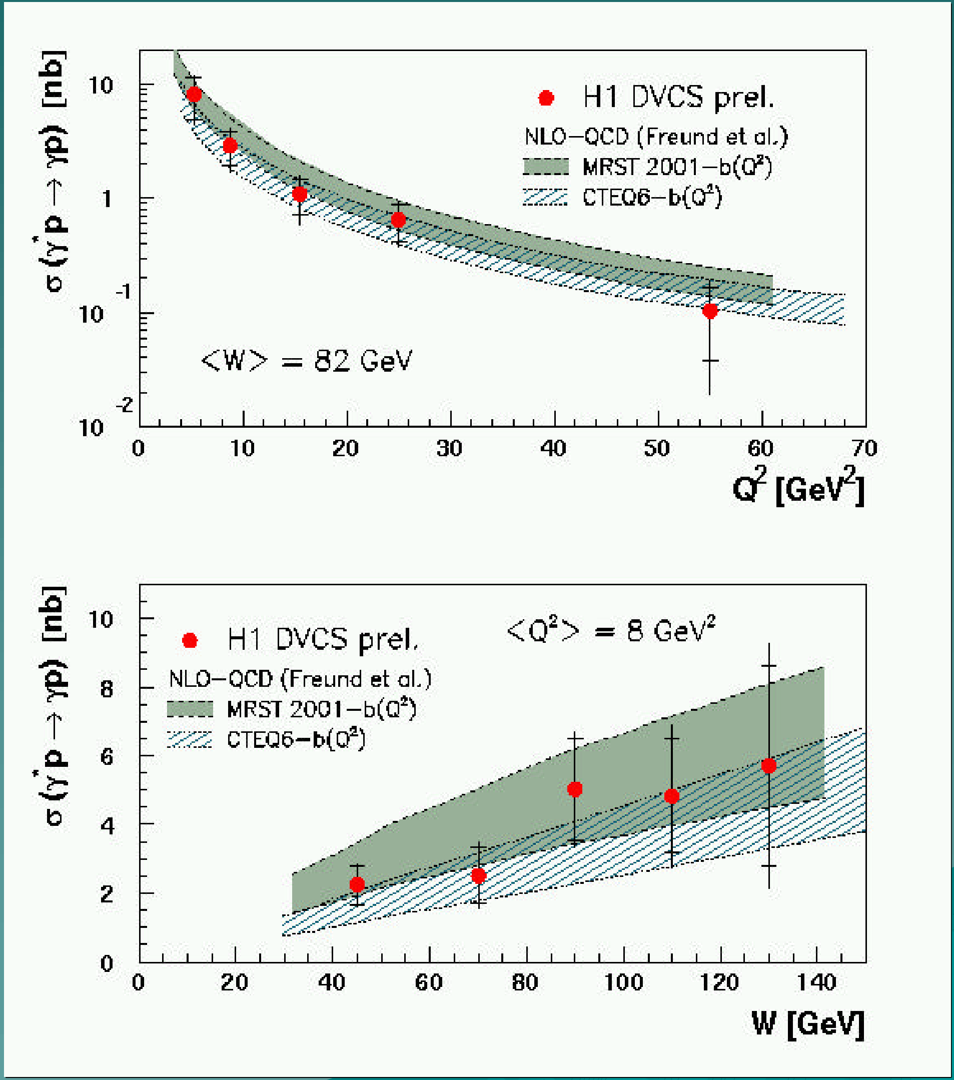
  based on MRTS2001 or CTEQ6
- unknown *t*-slope: → error bands

  $b = b_0(1 - 0.15 \log(Q^2/2))$ GeV^{-2}

  with $5 < b_0 < 9$ GeV^{-2}
- soft contribution:

  via aligned jet model

NLO QCD describes data



DVCS – Colour Dipole Models

Donnachie - Dosch:
soft + hard Pomeron

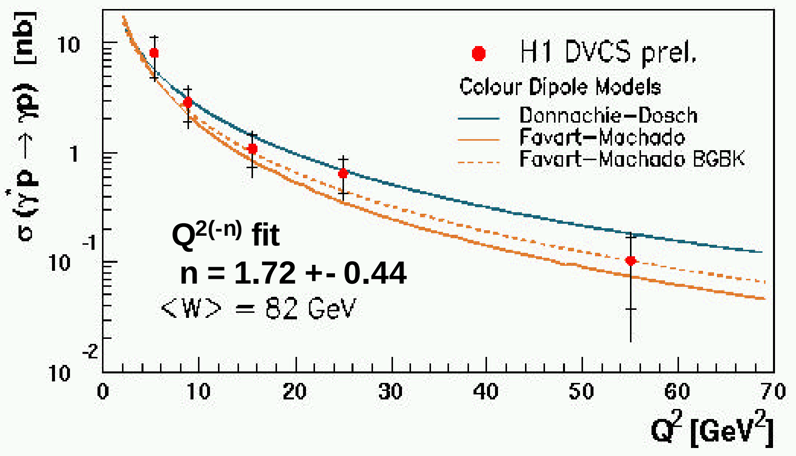
Favart - Machado:
Golec-Biernat / Wusthoff saturation model (w/out DGLAP evol.)

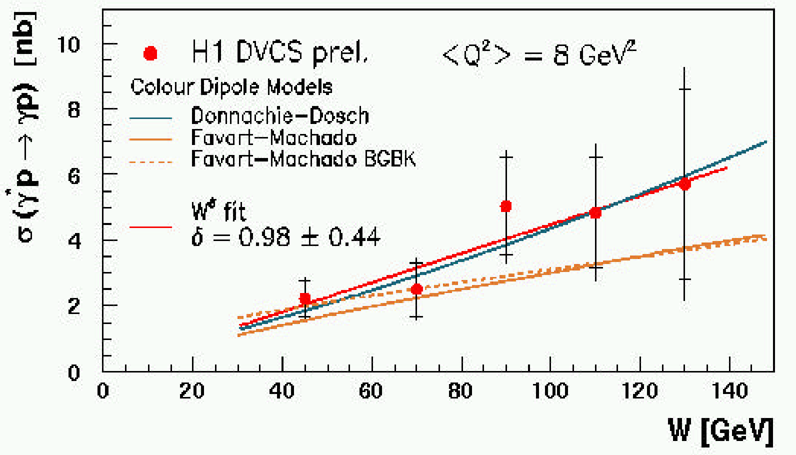
Both: |t|-slope: b = 7 GeV^{-2}

→ Q^2 dependence rather flat:
$n(r)$ = 2.60 ⟷ $n(g)$ = 1.72

→ W – dependence steep:
d ~ 1 indicates hard process

Both dipole models fit the data





Summary

❑ **high-|*t*| J/ψ :**

- observe power law in |*t*|-dependence and steep *W*-dependence expected for a hard process
- BFKL approach best candidate to describe high-|*t*| range
- angular spectra in agreement with SCHC → constrain VM wave function

❑ **high-|*t*| photons:**

- BFKL model reproduce x_P and |*t*|-spectra

❑ **DVCS / high-Q^2 photons :**

- models based on skewed PDFs and dipole models provide fair descriptions

❑ **all processes:**

- more statistics is needed to favor / rule out models
- measure |*t*|-slope in DVCS processes

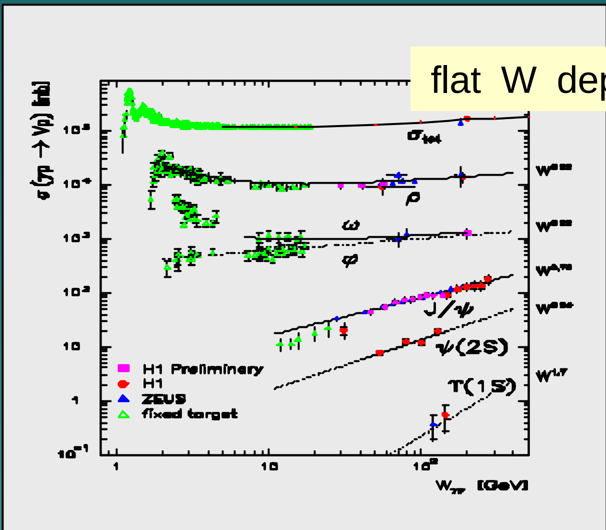
❑ **future:**

- HERA-2 started and delivers good luminocity
- H1 upgraded & new very forward proton detectors for elastic scattering
- Hope to end 2007 with 1 fb^{-1}

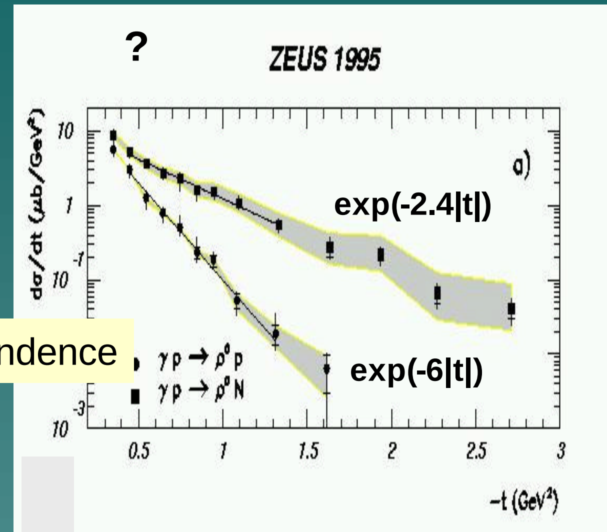
Spare Slides ….

Diffraction at soft scales

Soft means: low Q^2 / |t|, or light VM



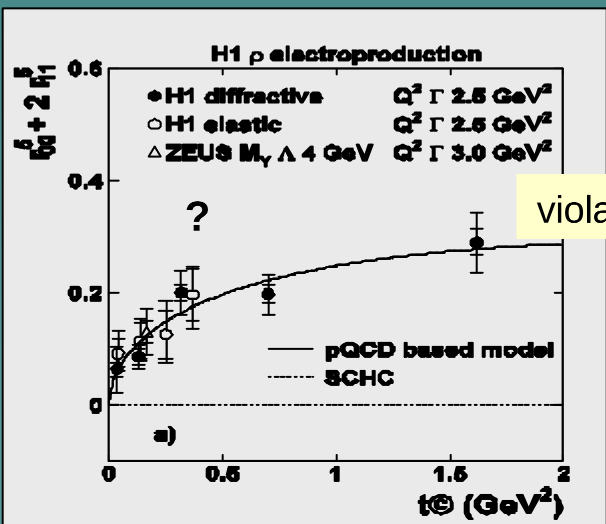
flat W dependence s ~ $W^{0.2}$



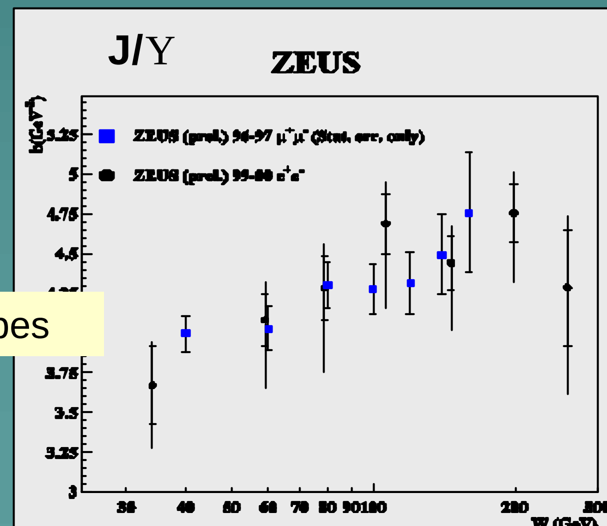
exp(-2.4|t|)

exponential |t| dependence

exp(-6|t|)



violation of SCHC



shrinkage of t-slopes

Soft processes nicely described by Soft Pomeron & Vector Dominance Model

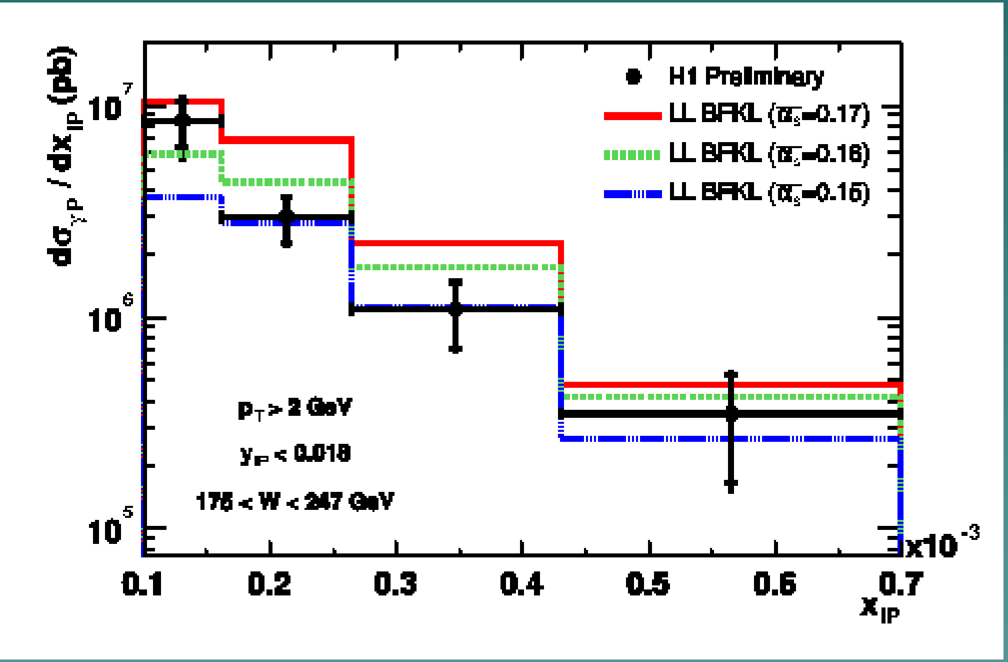
Photon Cross Section versus x_P

- Clean diffractive sample $x_P < 0.0007$ (inclusive mostly $x_P<0.05$)
- Typical steep rise at smaller x_P as described by Pomeron exchange

$$ds/dx_P \sim 1/W^2 \ \ x_P^{-2(1+\alpha 0)}$$

- BFKL LL Approximation:

$$\alpha_0 = (3\ \alpha_s / \pi)\ 4\ \ln 2$$

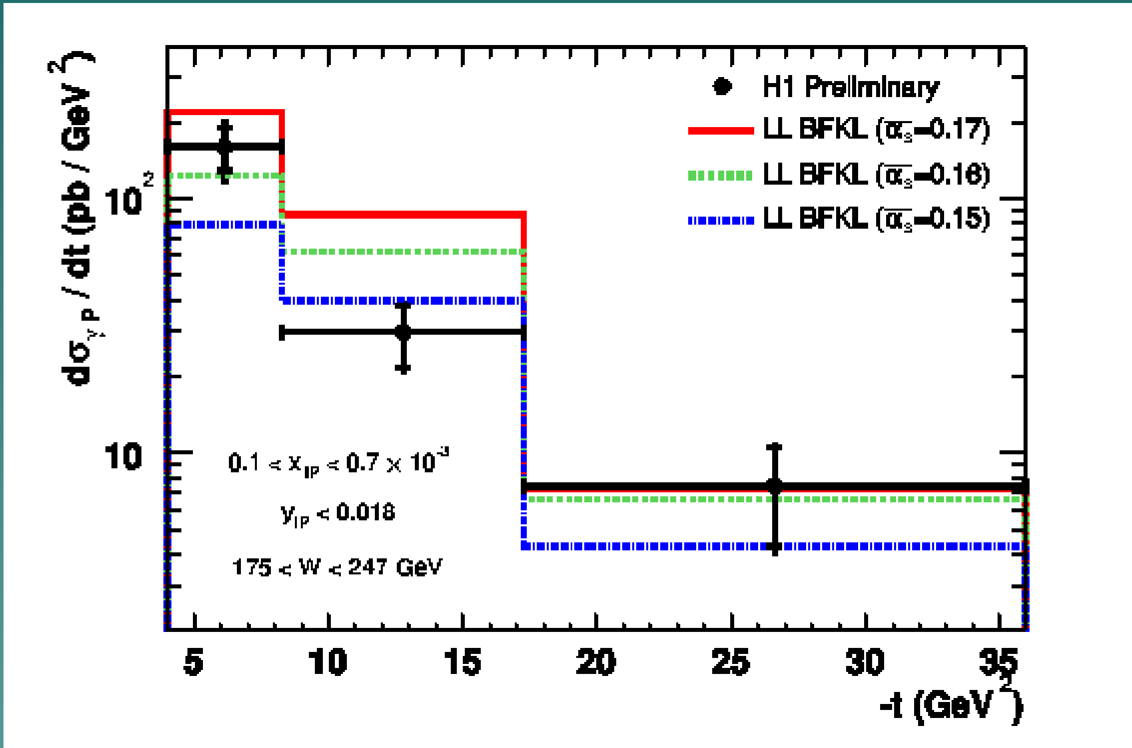


Data fairly well-described by BFKL LLA with $a_s = 0.15\ldots0.17$

Photon Cross Section versus |*t*|

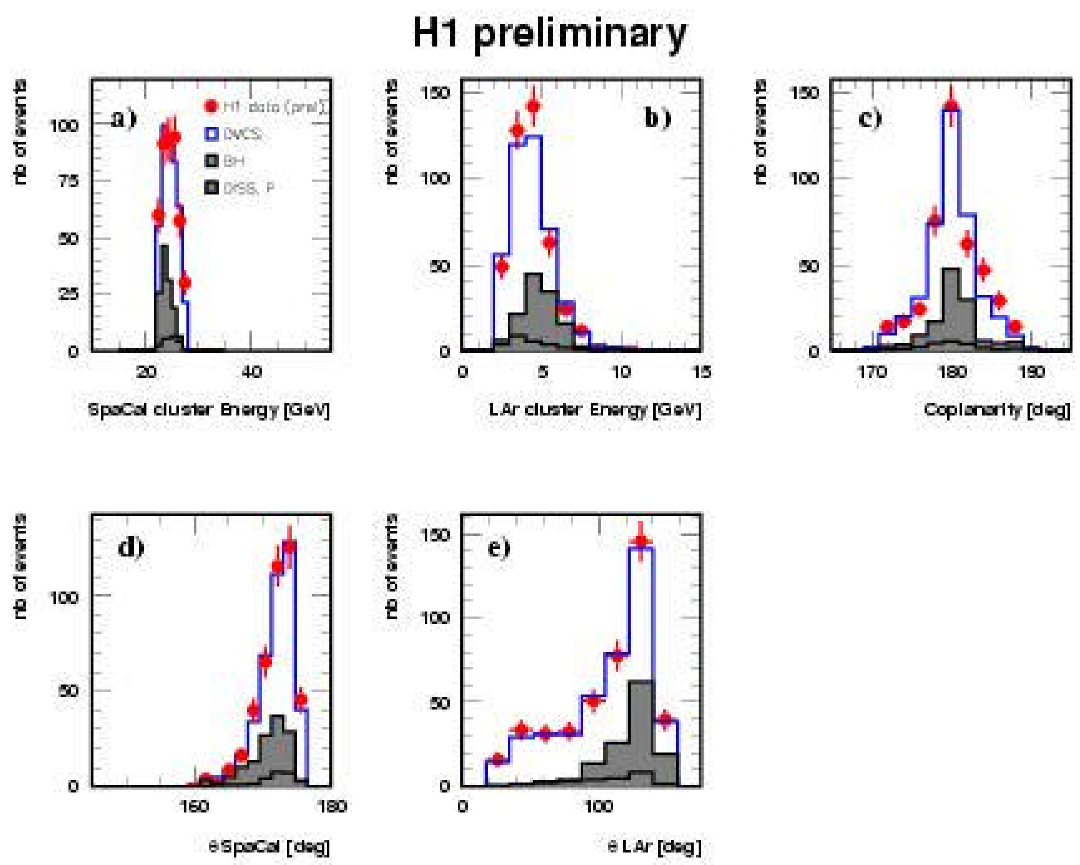
- BFKL LLA reproduce the trend
  but intrinsic normalization uncertainty
  (average / running α_s …)

- poor data at higher |t|



Needs more precise data & investigation of higher order effects

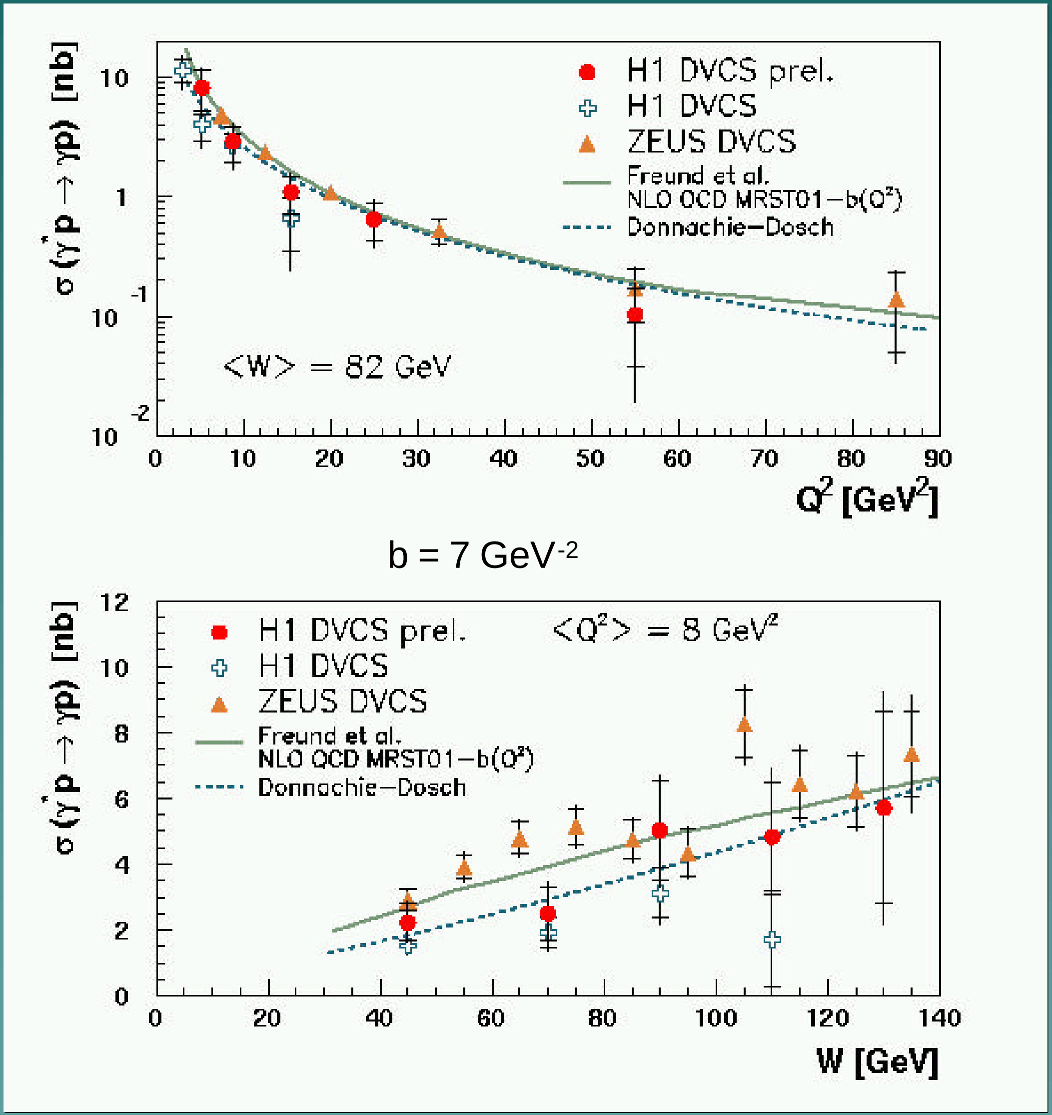
DVCS – Control Plots



- ❑ “DVCS” = ? DVCS + BH + Interference + VM
- ❑ “BH” = Bethe-Heitler process
- ❑ “DISS.P” = proton dissociation
  ~ 11 +- 6 % for M_Y < 1.6 GeV
- ❑ Other systematic errors:
  $?T_e/?T_\gamma$ = 1.3/3 mrad → 5 / 5 %
  t-slope b = 7 +- 2 GeV^{-2} → 4 %
  acceptance & bin corr. → 7 %
  energy scale uncertainty → 5%
  QED rad. Corrections → 3%

Detector response & backgrounds well-understood

DVCS – H1 versus ZEUS



- H1 results consistent
- fair agreement between H1 & ZEUS