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on behalf of the
ZEUS Collaboration

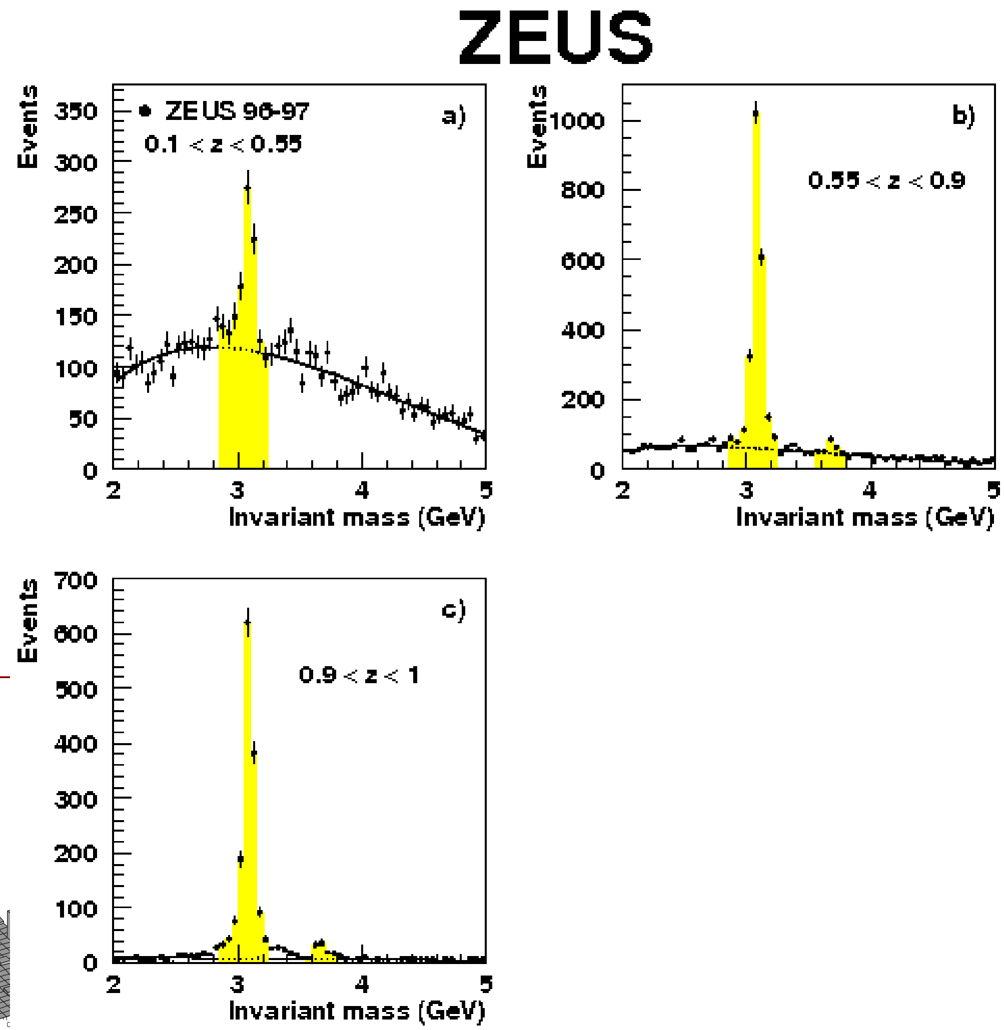
Measurement of the J/ψ helicity at ZEUS

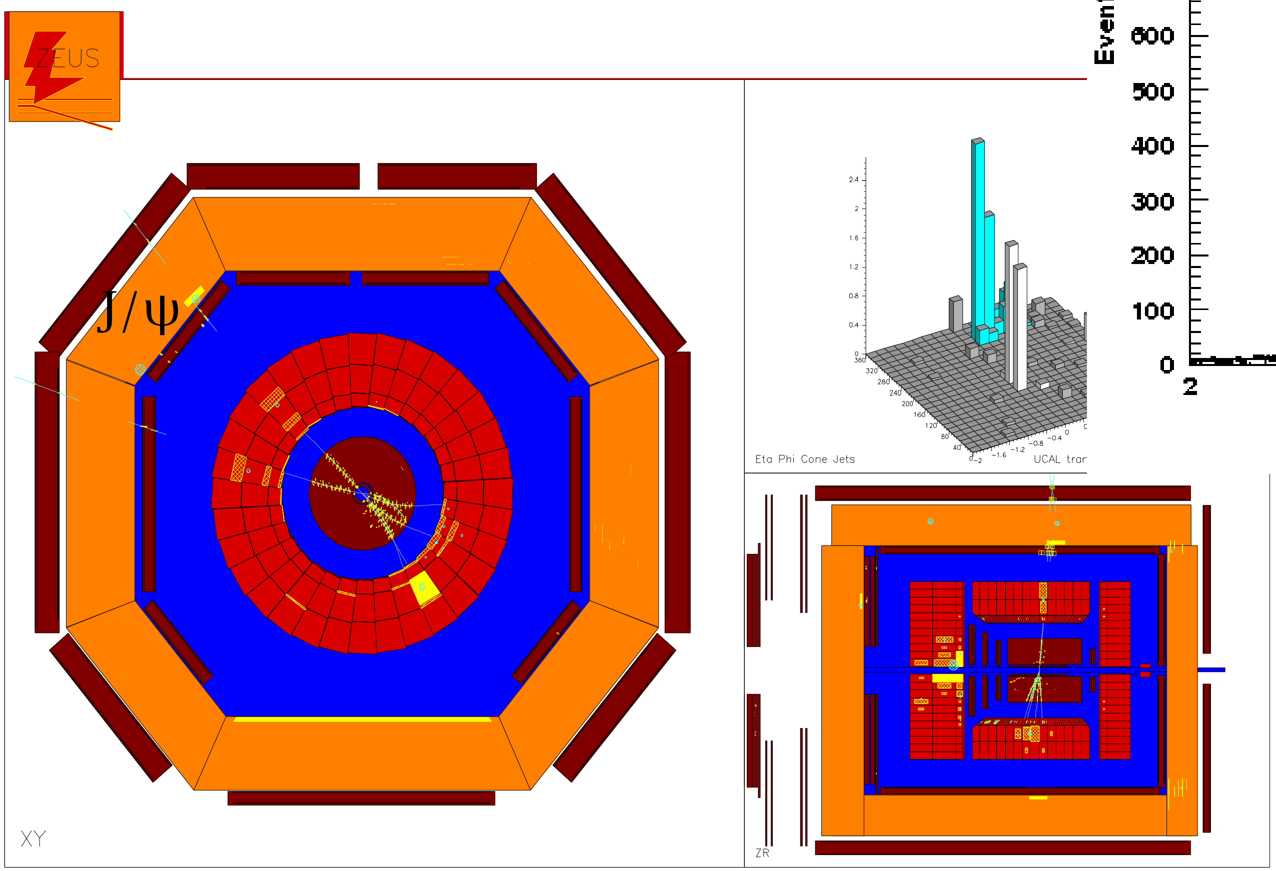
Outline:

- inelastic quarkonium at HERA
- polarization measurements in PHP
- comparisons between data and various theoretical predictions
- conclusions

inelastic quarkonium at HERA

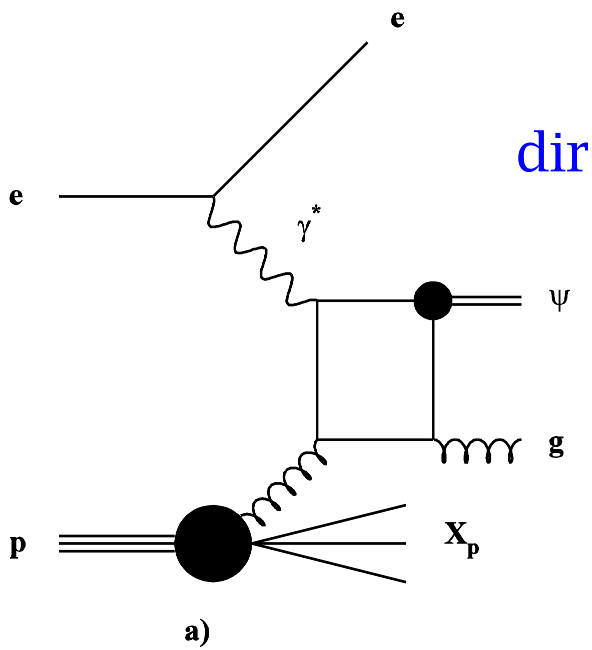
- PHP ⇔ low Q^2 ⇔ electron escape undetected
- inelastic ⇔ accompanying final state hadrons



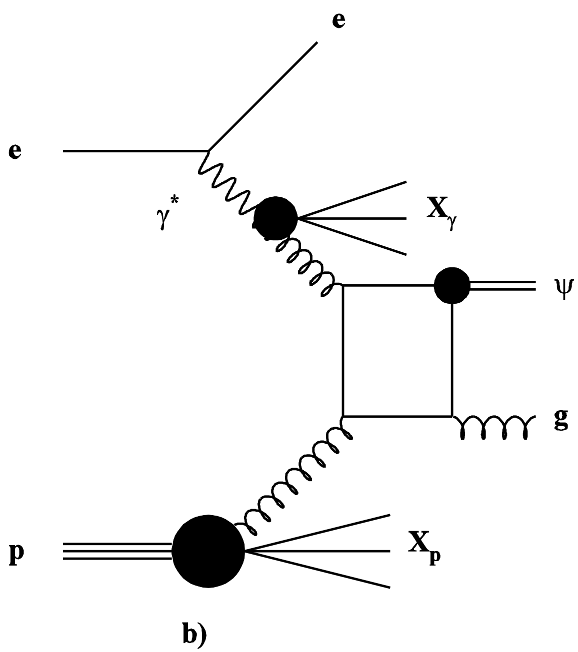


inelastic quarkonium at HERA

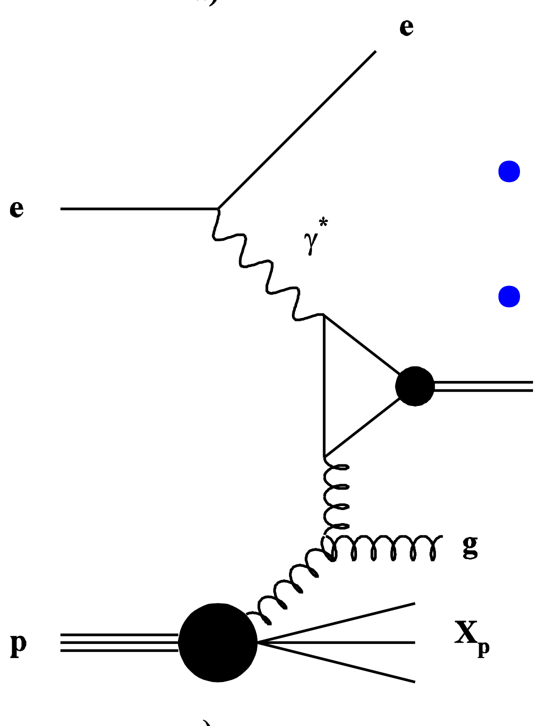
$z = E(J/\psi)/E(\gamma)$
p rest frame



direct γ, “CS model”
$0.2 < z < 0.9$



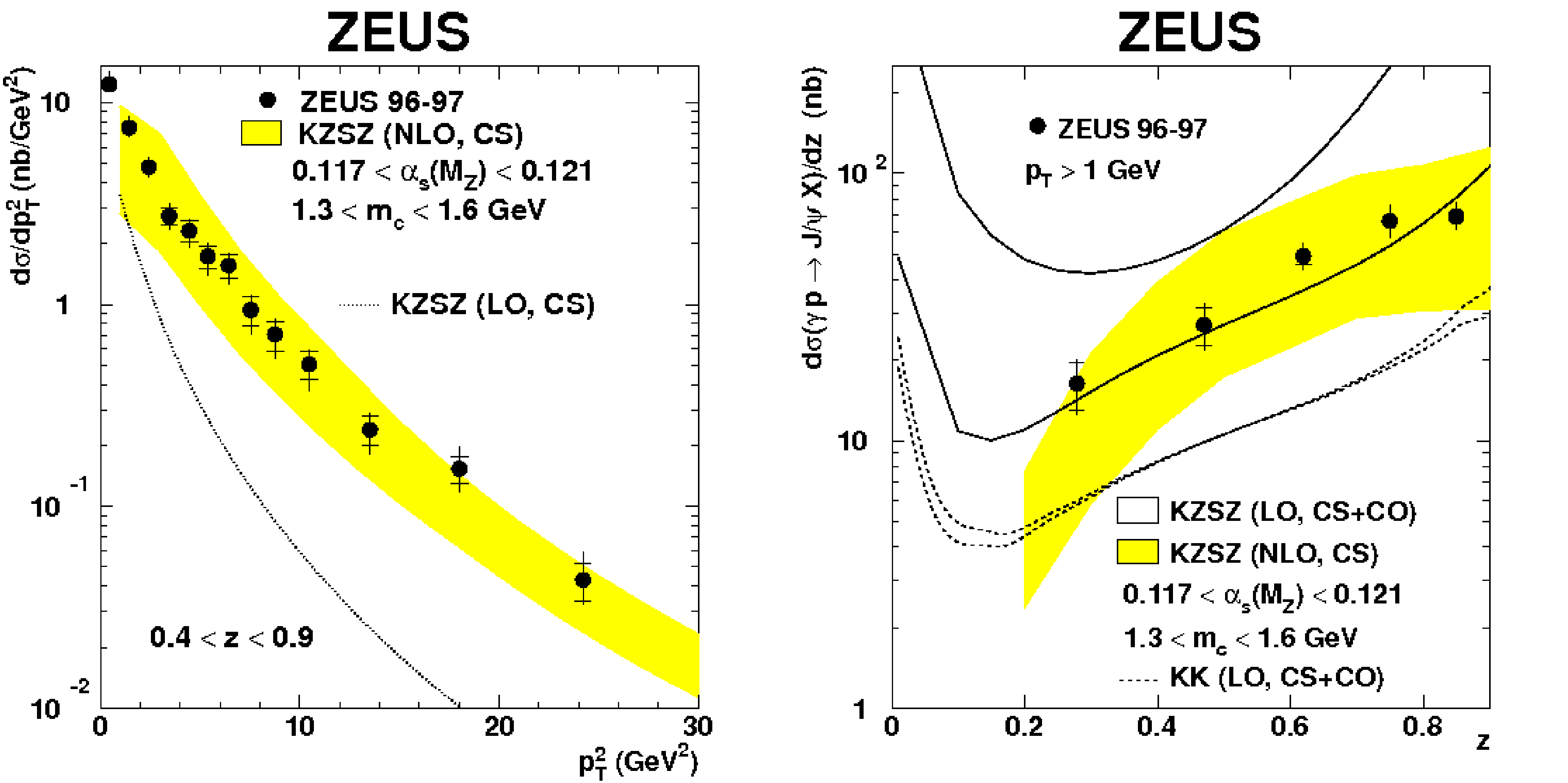
resolved γ, “CS model”
$z < 0.2$



direct γ, “CO model”
- this particular diagram $0.2 < z < 0.9$
- more “typical” ones: $z > 0.9$

+ diffractive contributions: suppressed by cuts on the main kinematic quantities

cross section measurements in PHP



- NLO CS in good agreement but large normalization uncertainties of the theoretical predictions ...
- space for CO contributions.

polarization measurements (helicity parameters)

Main advantages:

- Since the decay angular distributions are **normalized quantities** → **largely independent** from normalization uncertainties.

- They are observables **sensible** to the different production mechanisms.
- The resummation necessary in the endpoint region, important for $d\sigma/dz$ at z close to 1, affects the decay angular distributions to a lesser degree.

Main disadvantages:

- The decay angular distributions require the use of **large data sample**.

polarization measurements (helicity parameters)

The polarization of the J/ψ can be determined by measuring the angular distribution of the leptonic decay $J/\psi \rightarrow l^+ l^-$

In general the l^+ decay angular distribution in the J/ψ rest frame is parameterized as:

(M. Beneke, M. Krämer and M. Vänttinen, Phys. Rev. **D 57**, 4258 (1998)):

$$\frac{d^2\sigma}{d\,\Omega\,dy} \propto 1 + \lambda(y)\cos^2\theta + \mu(y)\sin 2\theta\cos\phi + \frac{1}{2}\nu(y)\sin^2\theta\cos 2\phi$$

where y stands for a set of variables (z and p_t(J/ψ) are good candidates)

- λ, μ, ν are related to the different color–octet matrix elements involved
- λ, μ, ν also depend on the definition of a coordinate system

polarization measurements (helicity parameters)

integrate the "helicity" master formula

in φ $$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta\, d y} \propto 1+\lambda(y)\cos^2\theta$$

in cosθ $$\frac{1}{\sigma}\frac{d^2\sigma}{d\phi\, d y} \propto 1+\frac{\lambda(y)}{3}+\frac{\nu(y)}{3}\cos^2\phi$$

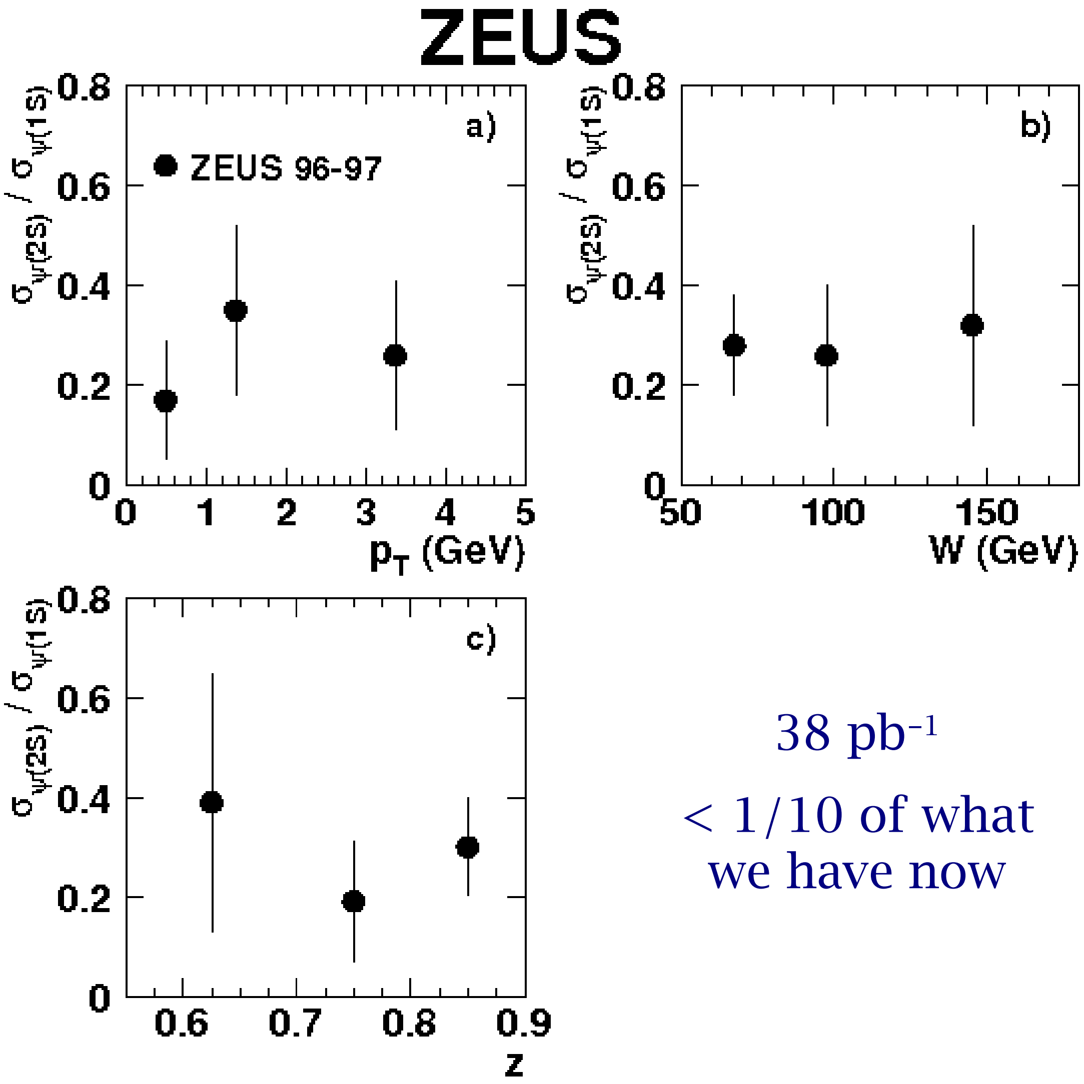
- which frame ? frame accessible experimentally using PHP events: **target frame:**
  - *z* axis (quantization axis): along the opposite direction of the incoming proton in the J/ψ rest frame
  - *x* and *y* axis: chosen to complete a right-handed coordinate system in the J/ψ rest frame.

- θ : angle between the μ^+ vector in the J/ψ rest frame and the *z* axis
- φ: azimuthal angle in the *x*-*y* plane of the μ^+ vector in the J/ψ rest frame

polarization measurements (helicity parameters)

data **NOT** corrected for:

- $B \to J/\psi(\to \mu^+\mu^-)$ anything
  (very small contribution at HERA)
- $\psi(2S) \to J/\psi(\to \mu^+\mu^-)$ anything



$$\frac{\sigma(2S)}{\sigma(1S)} = 0.33 \pm 0.01(\text{stat.})^{+0.01}_{-0.02}(\text{sys.})$$

$$BR(2S \to 1S + X) = (55.7 \pm 2.6)\% \quad \text{[PDG]}$$

38 pb^{-1}

< 1/10 of what we have now

$\psi(2S) \to J/\psi$ anything / $J/\psi \sim 15\%$

"dilute" the polarization

➢ experimentally it is **very difficult** to perform reliably these corrections

comparison between pol. measurements in PHP and NRQCD (CS +CO) calculations

- Theoretical curves from: M. Beneke, M. Krämer and M. Vänttinen, Phys. Rev. **D 57**, 4258 (1998).
- The calculations are made following the nonrelativistic QCD (NRQCD) approach:

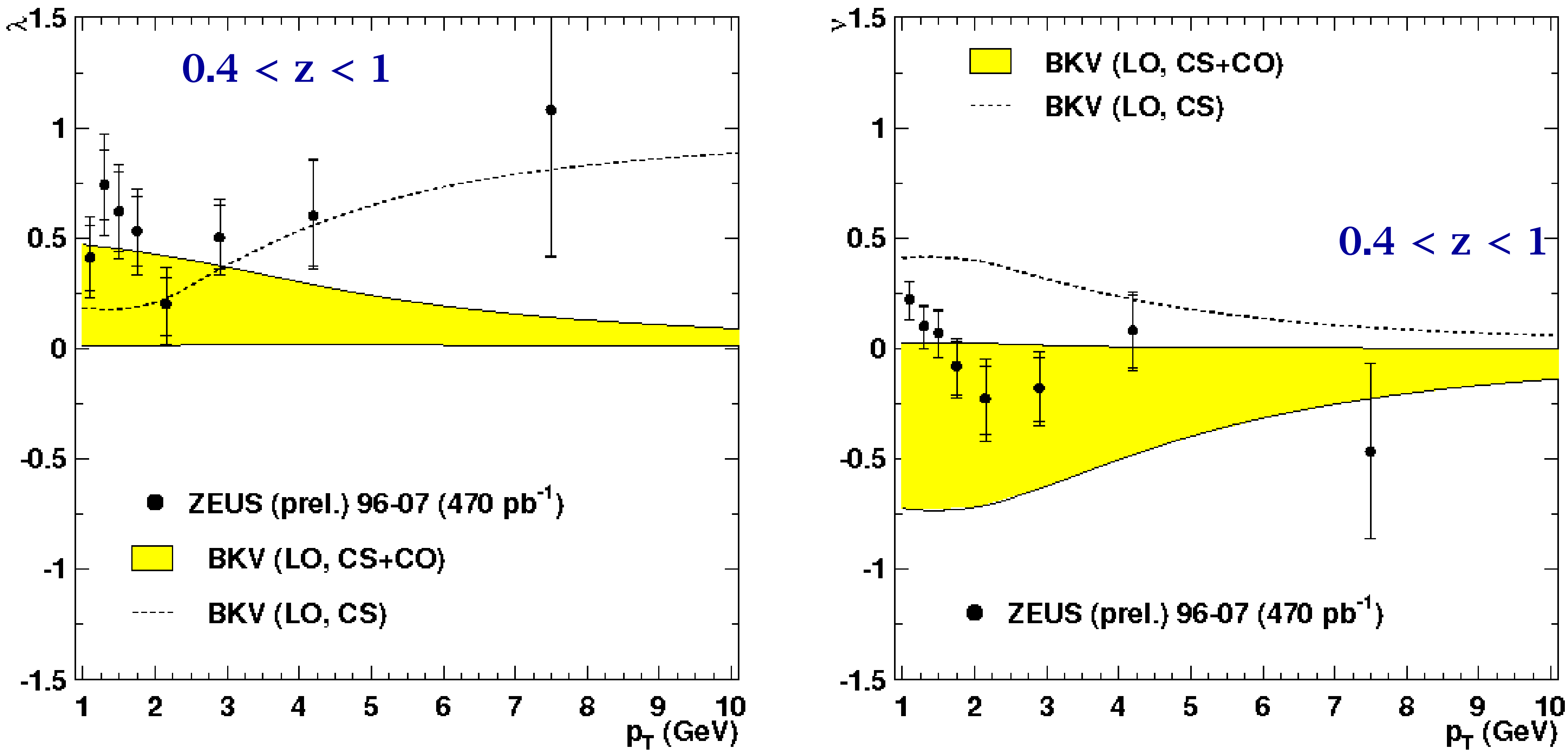
$$d\sigma(H+X) = \sum_n \hat{\sigma}(c\bar{c}[n]+X)\langle O^H[n]\rangle$$

$\hat{\sigma}(c\bar{c}[n]+X)$ ≡ short–distance cross sections calculable pert. in α_s

$\langle O^H[n]\rangle$ ≡ matrix elements, non–pert. trans. probabilities from the ccbar state n into the charmonium *H*. Their size depends on the intrinsic velocity v of the bound state.

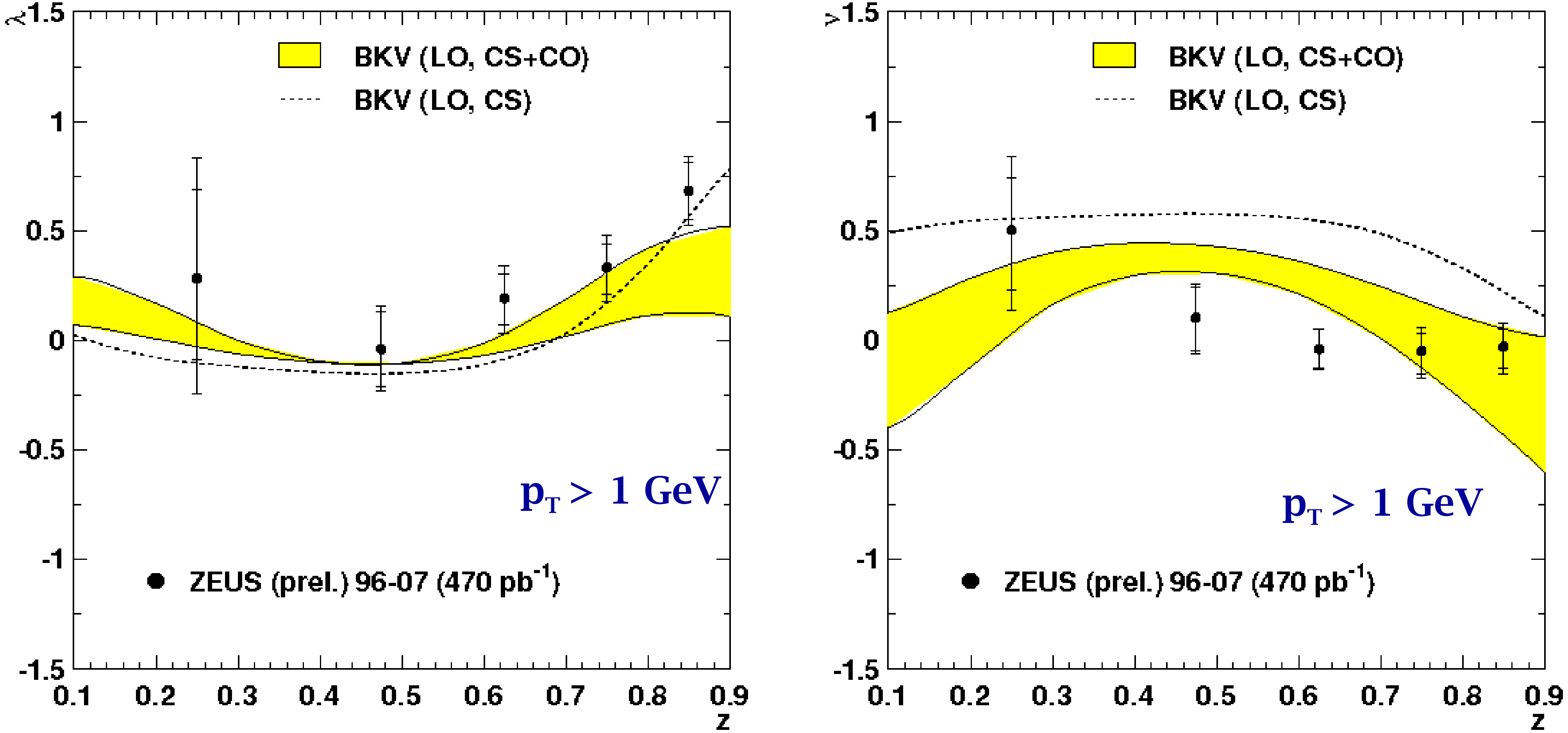
- The leading term in v coincides with the CS model.
- The calculations are made at LO
- The values and uncertainties of the matrix elements (which are universal functions) are extracted from experiments (TEVATRON, fixed target hadroproduction, $B \rightarrow J/\psi\ X$)

polarization measurements in PHP



- full data sample (HERA–I + HERA–II) ⇨ stat. uncertainties dominate.
- high p_T region difficult to access at HERA.
- λ: the data seem to prefer transverse polarization (λ = +1) as CS model predicts.
- ν: rough agreement between data and CS+CO predictions.

polarization measurements in PHP

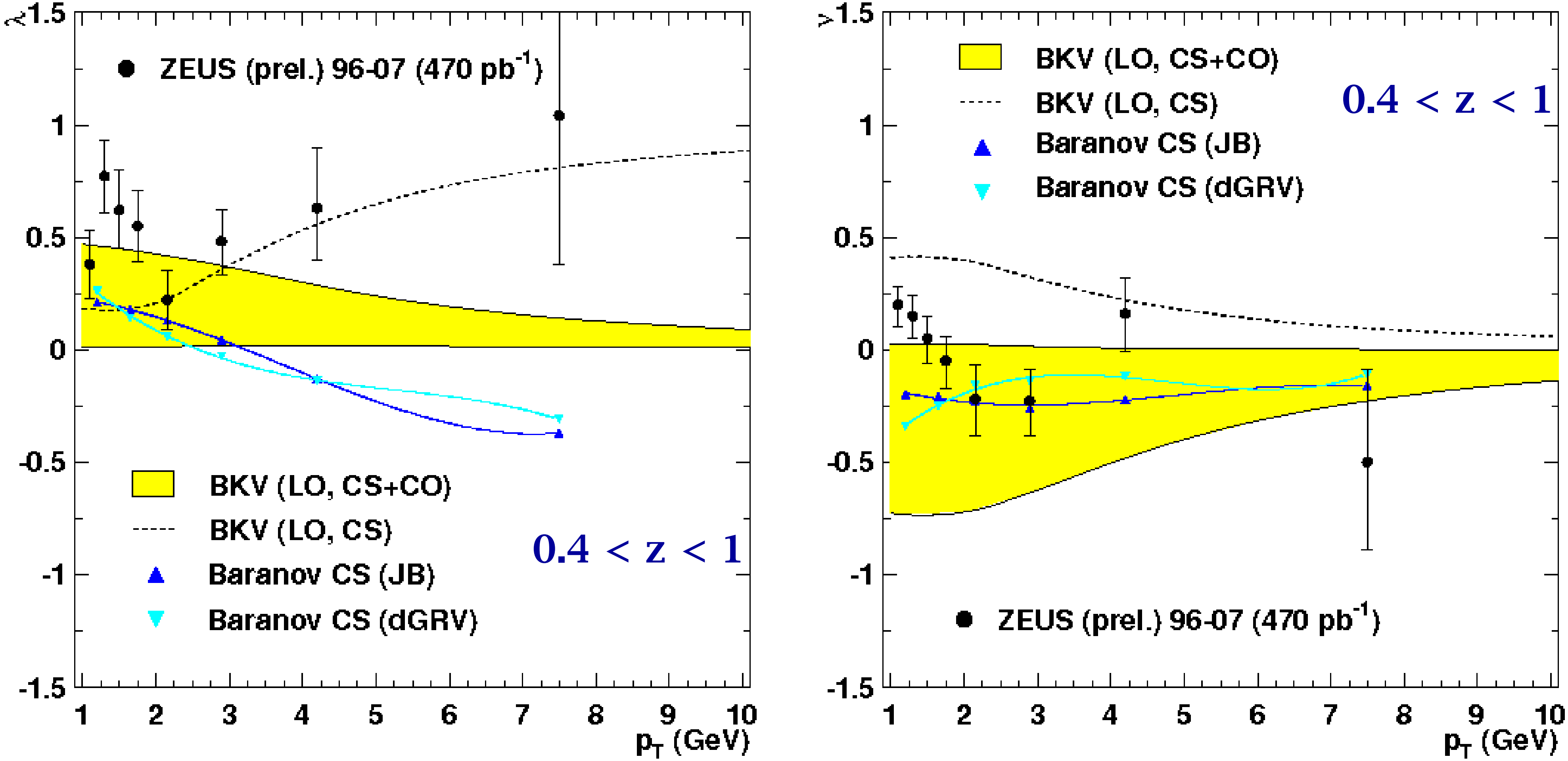


- λ: good agreement between data and theory (but poor discrimination power between CS and CO components).
- ν: do not see the positive values expected in the CS model.

comparison between pol. measurements in PHP and k_t factorization calculations

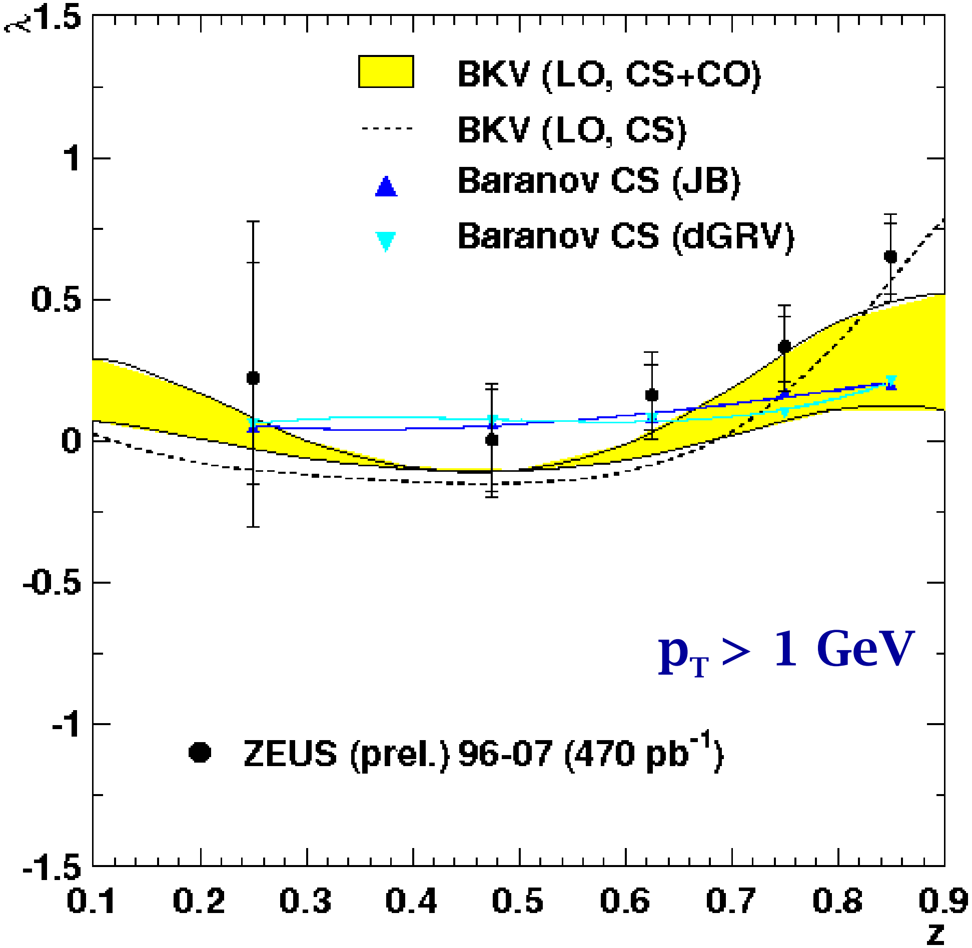
- Theoretical calculations by S.P. Baranov (private communication).
- Only CS contribution taken into account. (S.P.Baranov, Phys. Lett. B428, 377 (1998)).
- Two different parametrizations of unintegrated gluon distributions (GRV collinear gluon density as starting point):
  - **JB**: represents a solution to the leading-order BFKL equation obtained in the double-logarithm approximation (J.Bluemlein, J.Phys. G19, 1623 (1993); DESY report 95-121 (1995)).
  - **dGRV**: is derived from the collinear gluon density $G(x,\mu^2)$ by differentiating it with respect to μ^2 and setting $\mu^2 = k^2_t$.

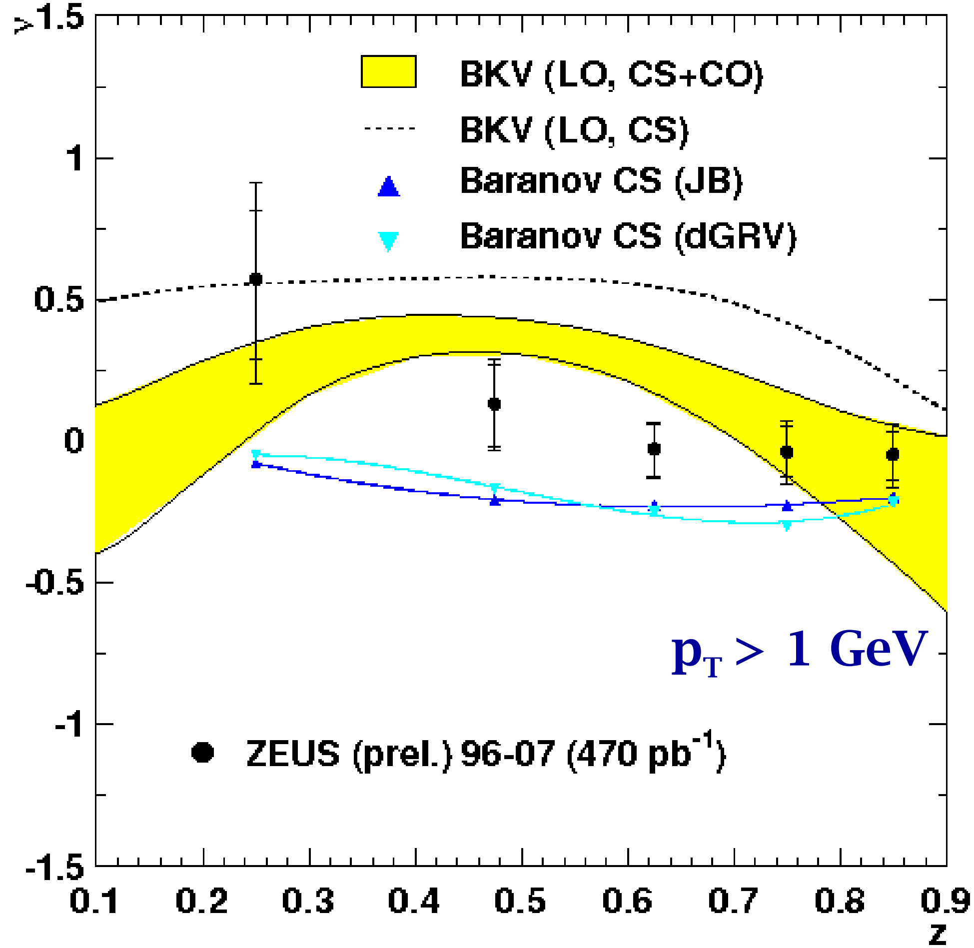
new polarization measurements in PHP and k_t factorization calculations



- λ: the model predicts substantial longitudinal polarization (λ ⇨ −1), in disagreement with the data.
- ν: rough agreement with the data.

new polarization measurements in PHP and k_t factorization calculations





- λ: good agreement between data and k_t factorization predictions.
- ν: k_t factorization always below the data.

Conclusions

- the ZEUS helicity measurement has been updated with all the HERA available statistics (470 pb^{-1}).
- the comparison of these data with the available theoretical predictions (CS at LO, CS+CO at LO, CS in the k_t framework) is not completely satisfactory.
  - CS at LO describes λ parameter both vs. p_t^2 and vs. z, but doesn't describes ν parameter.
  - CS+CO at LO describes ν parameter both vs. p_t^2 and vs. z and λ vs. z but doesn't describe λ parameter vs. p_t^2
  - CS with k_t factorization gives predictions similar to CS+CO at LO.
- ZEUS helicity data are compared to LO predictions … can the theory be improved in this respect ?