

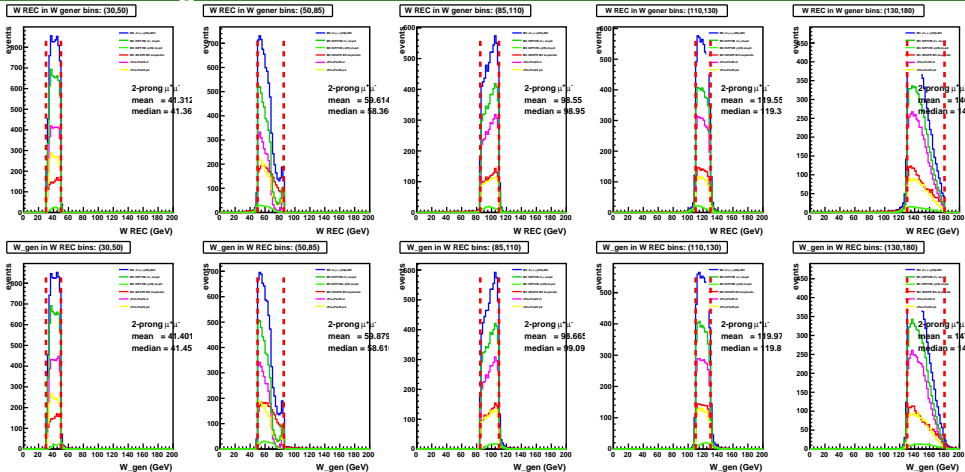
# $\psi(2S)/J/\psi(1S)$ ratio in photoproduction: towards systematics

G. Grzelak

ZEUS Analysis Forum, DESY/ZOOM meeting, 25-Nov-2020

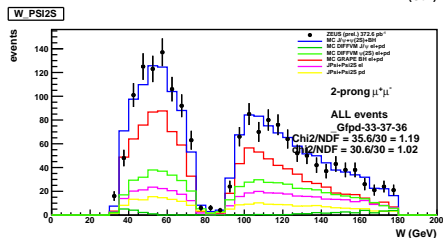
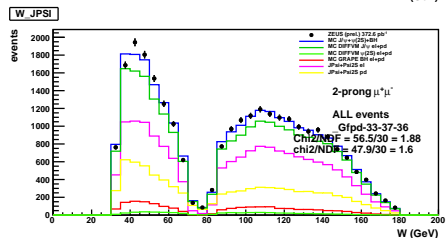
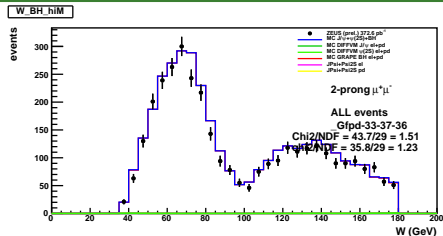
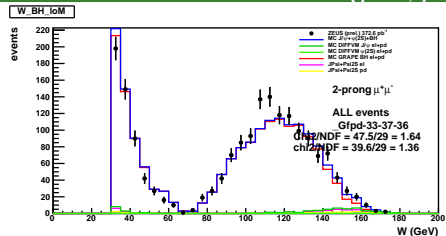
- new binning for  $R$  vs.  $W$  and  $|t|$
- systematic related to p.diss fraction (driven by  $|t|$ -slopes)
- theory predictions
- $R$  measurements from other experiments
- conclusions

# W binning



- 5  $W$  bins: (30 – 50 – 85 – 110 – 130 – 180) GeV
- almost equidistant : equal statistic, no “dip” in the middle of any bin
- $W_{REC}$  in  $W_{GEN}$  bins (upper row),  $W_{GEN}$  in  $W_{REC}$  bins (lower row)
- (almost) no leakage

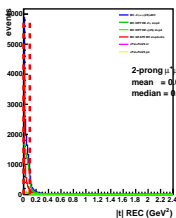
# W distribution in $M(\mu^+, \mu^-)$ bins



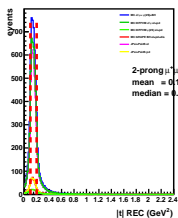
- gap between BMUO and FMUON chambers
- “dip” position differ a bit for  $J/\psi$  (lower left) and  $\psi'$  (lower right)
- very low acceptance in around the “dip”

# $|t|$ binning

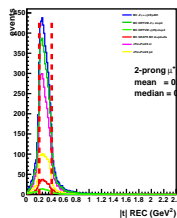
[ $|t|$  REC in  $|t|$  gener bins: (0,0,0.1)]



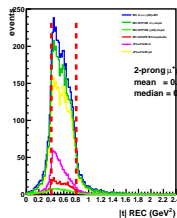
[ $|t|$  REC in  $|t|$  gener bins: (0.1,0.2)]



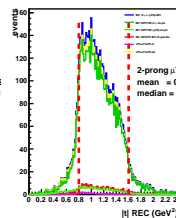
[ $|t|$  REC in  $|t|$  gener bins: (0.2,0.4)]



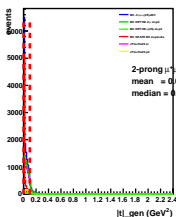
[ $|t|$  REC in  $|t|$  gener bins: (0.4,0.8)]



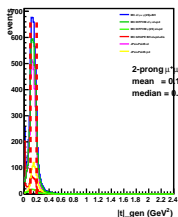
[ $|t|$  REC in  $|t|$  gener bins: (0.8,1.6)]



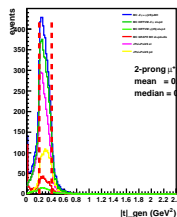
[ $|t|_{gen}$  in  $|t|$  REC bins: (0,0,0.1)]



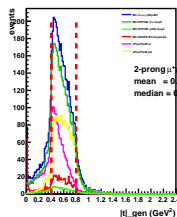
[ $|t|_{gen}$  in  $|t|$  REC bins: (0.1,0.2)]



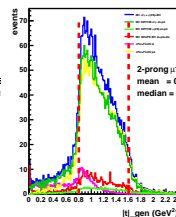
[ $|t|_{gen}$  in  $|t|$  REC bins: (0.2,0.4)]



[ $|t|_{gen}$  in  $|t|$  REC bins: (0.4,0.8)]



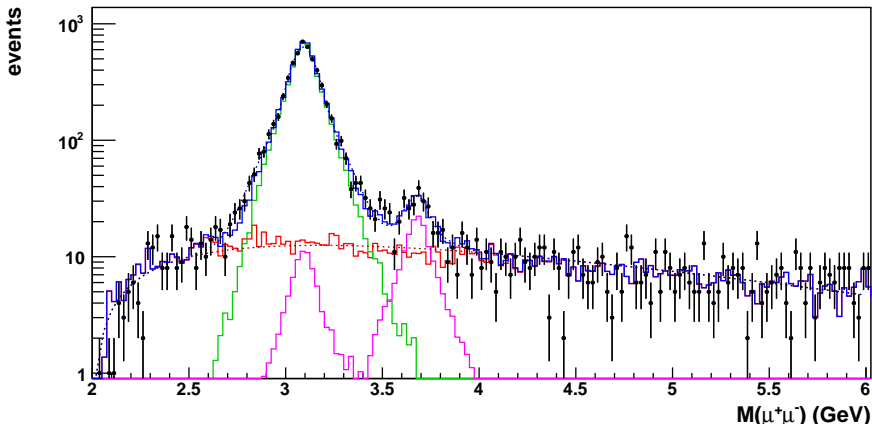
[ $|t|_{gen}$  in  $|t|$  REC bins: (0.8,1.6)]



- 5  $|t|$  bins: (0.0 – 0.1 – 0.2 – 0.4 – 0.8 = 1.6)  $\text{GeV}^2$
- non-equidistant bins :  $\rightarrow$  equal statistic for  $\sim \exp()$  distribution
- $t_{REC}$  in  $t_{GEN}$  bins (upper row),  $t_{GEN}$  in  $t_{REC}$  bins (lower row)
- significant migration to neighbor bins

# Di-muon mass in $W5$ bin

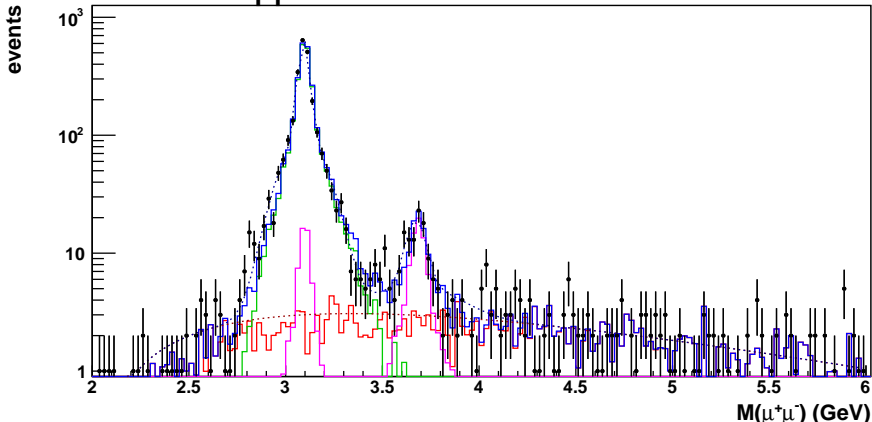
**W5:  $130 < W < 180$  GeV**



- good fits and DATA/MC agreement for all  $W$  bins
- for rest of bins see the backup plots
- bin with worst mass resolution:  $\psi'$  separation still OK

# Di-muon mass in $t5$ bin

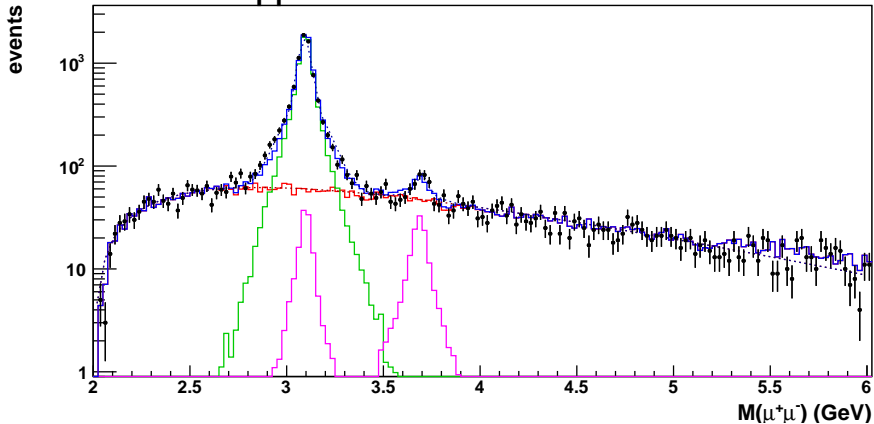
$t5: 0.8 < |t| < 1.6 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $|t|$  bins
- for rest of bins see the backup plots
- bin dominated by p.diss events

# Di-muon mass in $t1$ bin

$t1: 0.0 < |t| < 0.1 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $|t|$  bins
- for rest of bins see the backup plots
- bin dominated by BH BG events

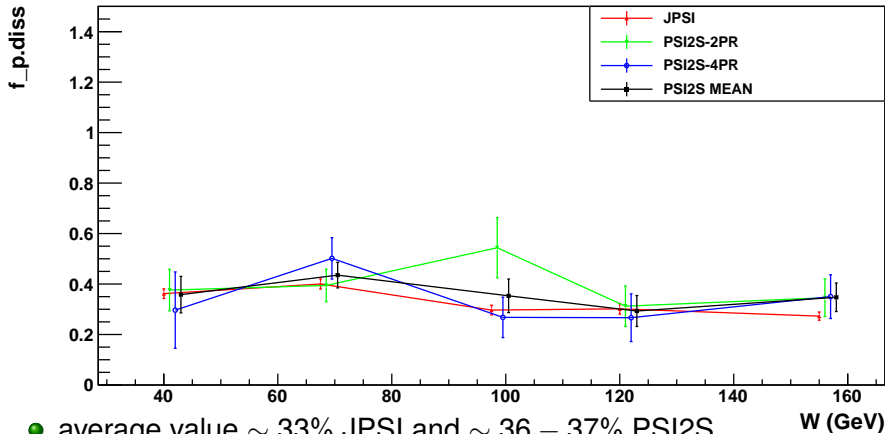


# Base-line $t$ -slopes

- MC templates for  $\frac{dN}{d|t|}$  reweighted on generator level
- (and used in `TFractionalFitter`)
- JPSI:  $b_{el} = 5.6 \pm 0.2 \text{ GeV}^{-2}$  (ZEUS HERA-I value:  $b_{el} = 4.15$ )
- JPSI:  $b_{pd} = 1.3 \pm 0.1 \text{ GeV}^{-2}$
- PSI2S:  $b_{el} = 5.0 \pm 0.5 \text{ GeV}^{-2}$
- PSI2S:  $b_{pd} = 1.0 \pm 0.2 \text{ GeV}^{-2}$
  
- obtained from best double `exp()` fits to ZEUS HERA-II data  
(see plots from last ZAF meeting)

# $f_{p.diss}$ fractions in $W$ bins

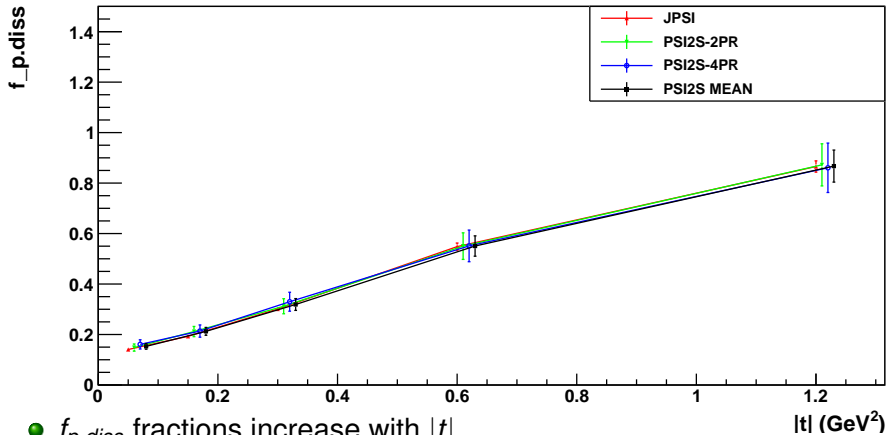
fraction  $f_{p.diss}$ : JPSI and PSI2S 2PR, 4PR vs.  $W$



- average value  $\sim 33\%$  JPSI and  $\sim 36 - 37\%$  PSI2S
- compatible results for 2- and 4-prong channels, no  $W$  dependence
- bigger stat. errors for PSI2S (fit in each  $W$  bin)
- black: weighted mean for PSI2S 2- and 4-prong (used in analysis)

# $f_{p.diss}$ fractions in $|t|$ bins

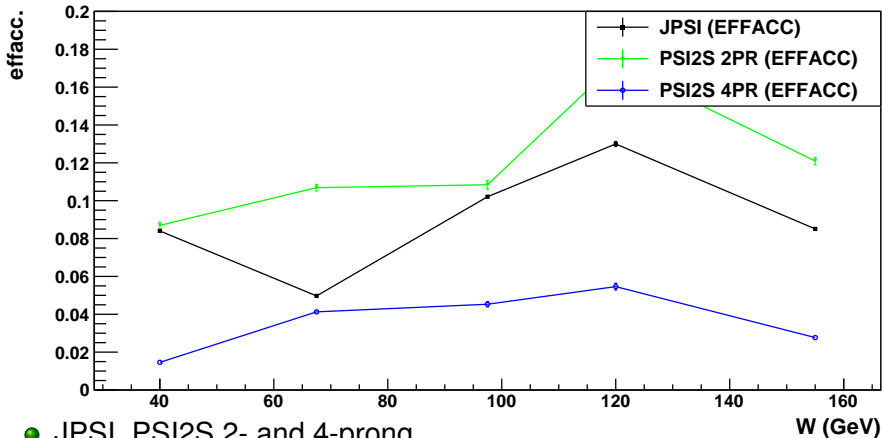
fraction  $f_{p.diss}$ : JPSI and PSI2S 2PR, 4PR vs.  $|t|$



- $f_{p.diss}$  fractions increase with  $|t|$
- compatible results for 2- and 4-prong channels
- very similar values for JPSI and PSI2S
- smaller stat. errors (fit for all  $W$ ,  $|t|$  slices)

# Acceptance\*efficiency in $W$ bins

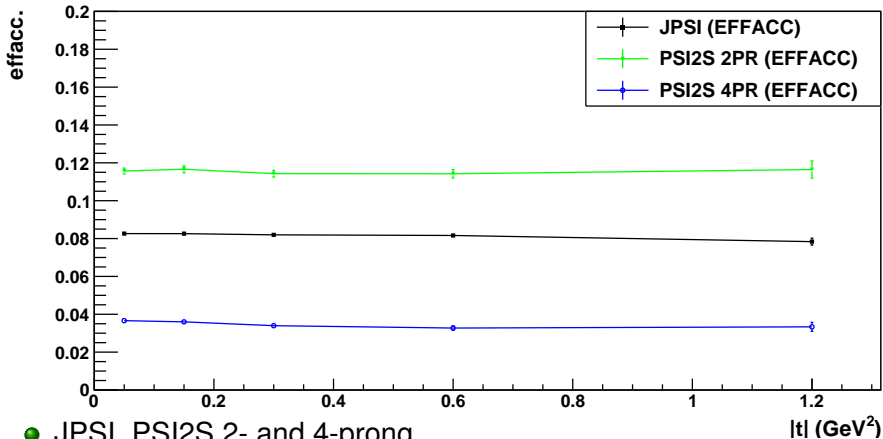
EFFACC of JPSI, PSI2S-2PR, PSI2S-4PR vs.  $W$



- JPSI, PSI2S 2- and 4-prong
- Higher di-muon acceptance for higher mass state
- different angular coverage for final muons

# Acceptance\*efficiency in $|t|$ bins

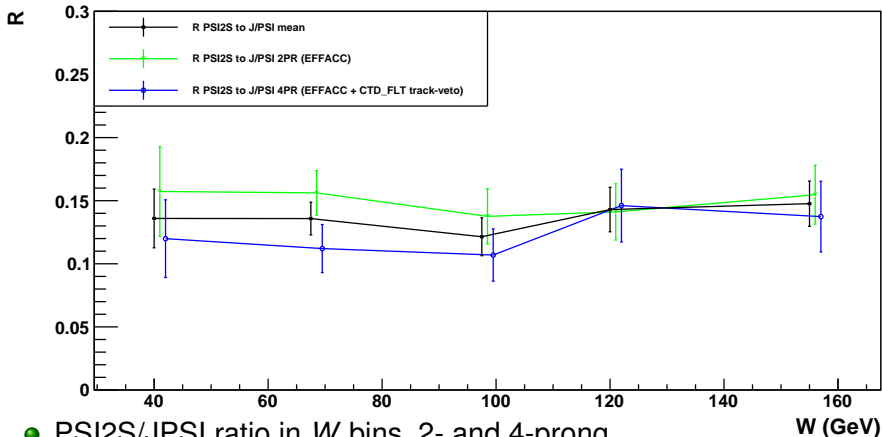
EFFACC of JPSI, PSI2S-2PR, PSI2S-4PR vs.  $|t|$



- JPSI, PSI2S 2- and 4-prong
- Higher di-muon acceptance for higher mass state
- flat in  $|t|$  (no angular correlations to  $|t|$ )

# $R$ in $W$ bins, 2- and 4-prong

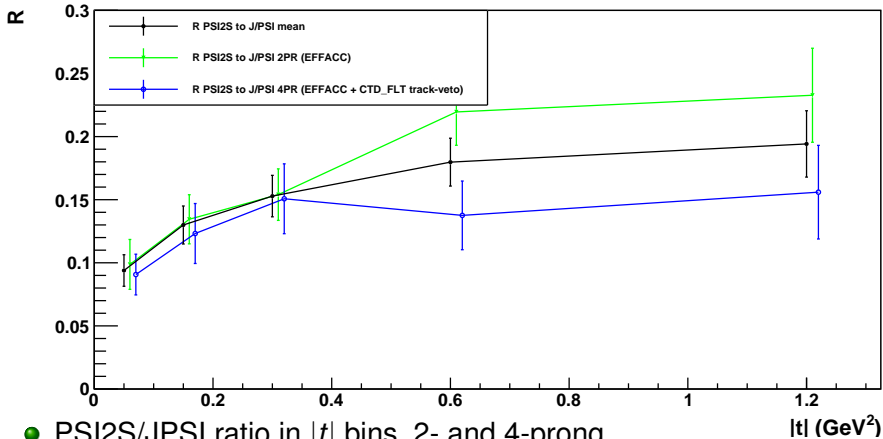
R  $\psi$ ' to J/ $\psi$  2PR, 4PR (stat err only) vs.  $W$  (EFFACC + CTD FLT track-veto corr for 4PR)



- PSI2S/JPSI ratio in  $W$  bins, 2- and 4-prong
- good agreement for 2- and 4-prong channels
- (before  $f_{p.diss}$ ) correction

# $R$ in $|t|$ bins, 2- and 4-prong

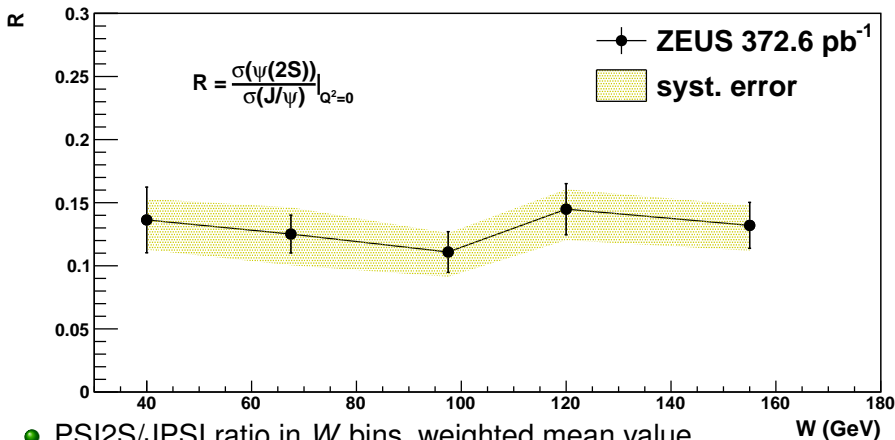
R psi' to J/psi 2PR, 4PR (stat err only) vs.  $|t|$  (EFFACC + CTD FLT track-veto corr for 4PR)



- PSI2S/JPSI ratio in  $|t|$  bins, 2- and 4-prong
- good agreement for 2- and 4-prong channels
- (before  $f_{p.diss}$ ) correction

# Mean $R$ in $W$ bins

FINAL mean  $R$   $\psi(2S)$  to  $J/\psi$  vs.  $W$

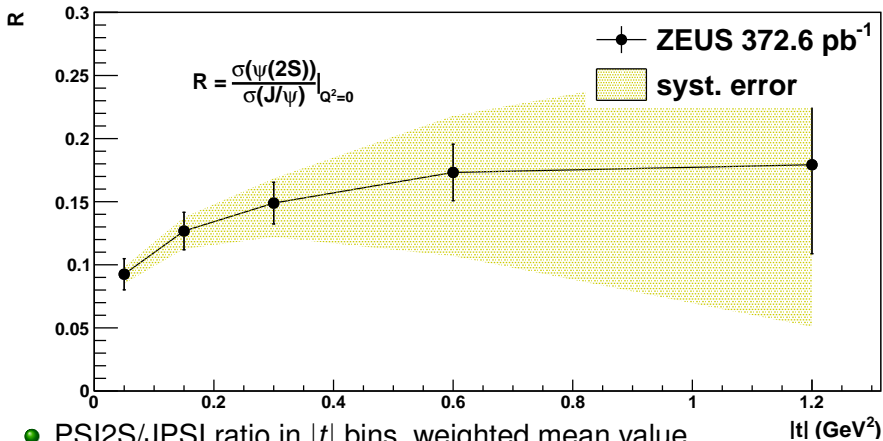


- $\psi(2S)/J/\psi$  ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation: (see next pages)  
(added in quadrature)



# Mean $R$ in $|t|$ bins

FINAL mean  $R$   $\psi(2S)$  to  $J/\psi$  vs.  $|t|$

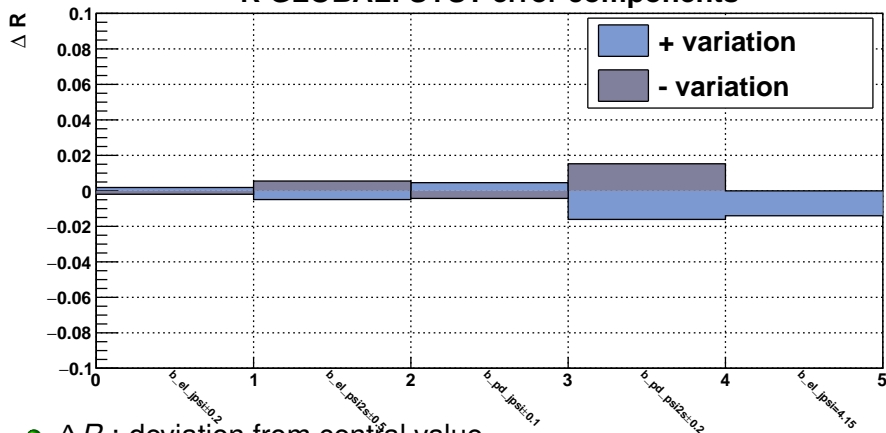


- $\psi(2S)/J/\psi$  ratio in  $|t|$  bins, weighted mean value
- after  $f_{p,diss}$  correction (common for 2- and 4- prongs)
- **exploding systematics** due to  $|t|$ -slopes variation: (see next pages) (added in quadrature)

# Contributions to syst. error (global mean R)

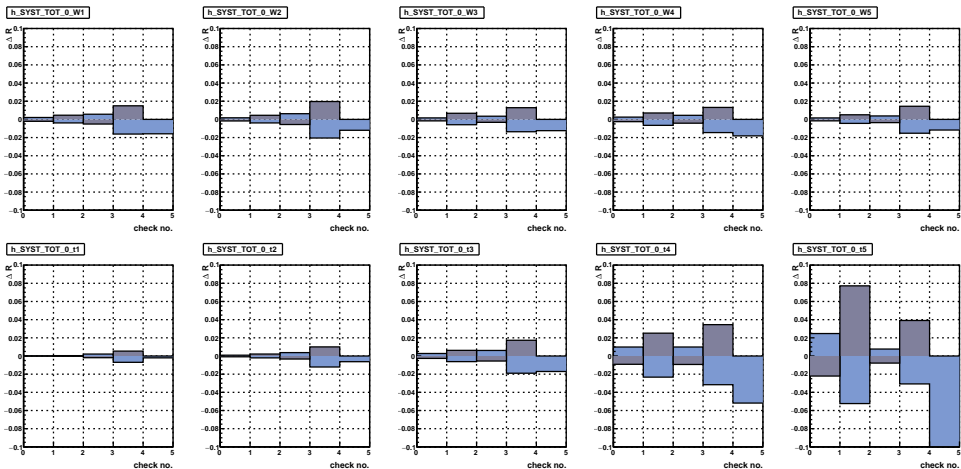
h\_SYST\_TOT\_0

## R GLOBAL: SYST error components



- $\Delta R$  : deviation from central value
- variation of  $b$ -slopes according to stat errors (plus  $b_{el}^{JPSI} = 4.15$ )
- biggest influence to  $f_{p.diss}$  fraction
- negligible influence on acceptance/efficiency

# Contributions to syst. error in $W$ and $|t|$ bins



- $\Delta R$  : deviation from central value for each  $W$ ,  $|t|$  bin (upper, lower row)
- variation of  $b$ -slopes according to stat errors
- biggest coupling to  $f_{p.diss}$  fraction for high  $|t|$  bins

# ZEUS $\psi'$ to $J/\psi$ paper in DIS

The measured  $|t|$  distributions for  $J/\psi(1S)$  and  $\psi(2S)$  have been fitted separately by single exponentials, and by the sum of two exponentials. It is found that the second exponential is not significant, and that the slopes for  $J/\psi(1S)$  and  $\psi(2S)$  agree within the statistical uncertainties. This confirms the validity of the assumptions made in Section 3 given the limited statistics of the data sample, it is neither necessary to simulate proton dissociative events nor to weight the  $|t|$  distributions of the  $J/\psi(1S)$  and  $\psi(2S)$  differently.

- DIS analysis : the same  $b$ -slope for elastic JPSI and PSI2S
- no contribution from p.diss events
- $\rightarrow f_{p.diss}$  fractions cancel out “by definition”
- no contribution to syst. errors...

# ZEUS $\psi'$ to $J/\psi$ paper in DIS

The cross-section ratios were calculated using

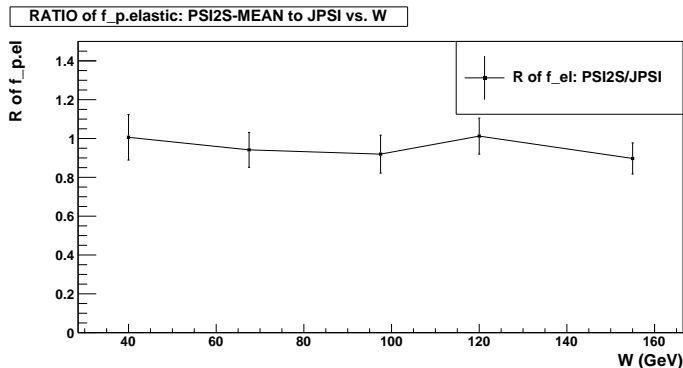
$$R_{\mu\mu} = \left( \frac{N_{\mu\mu}^{\psi(2S)}}{B(\psi(2S) \rightarrow \mu^+\mu^-) \cdot A_{\mu\mu}^{\psi(2S)}} \right) / \left( \frac{N_{\mu\mu}^{J/\psi(1S)}}{B(J/\psi(1S) \rightarrow \mu^+\mu^-) \cdot A_{\mu\mu}^{J/\psi(1S)}} \right)$$

- basic  $R$  formulae (in  $W$  and  $|t|$  bins)
- missing factor:  $\frac{f_{el}^{PSI2S}}{f_{el}^{JPSI}} = \frac{1 - f_{pd}^{PSI2S}}{1 - f_{pd}^{JPSI}}$
- sensitive to  $b$ -slopes differences when integrated over  $|t|$  bin
- 

$$\frac{d\sigma^{JPSI}}{d|t|} \sim (1 - f_{pd}^{JPSI}) \exp(-b_{el}^{JPSI}|t|) + f_{pd}^{JPSI} \exp(-b_{pd}^{JPSI}|t|)$$

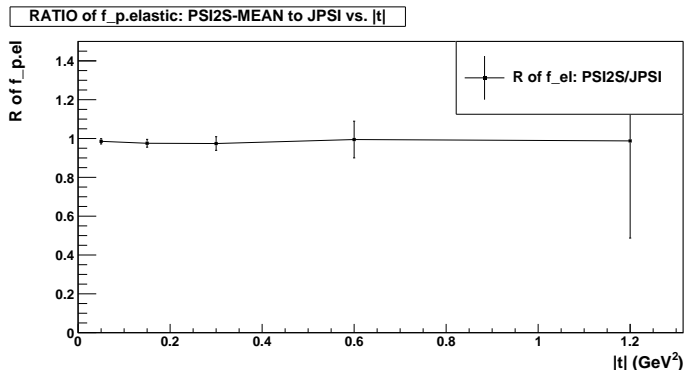
$$\frac{d\sigma^{PSI2S}}{d|t|} \sim (1 - f_{pd}^{PSI2S}) \exp(-b_{el}^{PSI2S}|t|) + f_{pd}^{PSI2S} \exp(-b_{pd}^{PSI2S}|t|)$$

# Ratio of elastic fractions vs. $W$



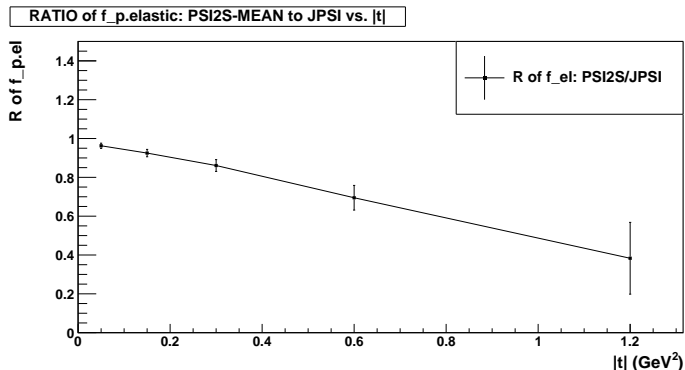
- ratio of elastic fractions vs.  $W$
- using “best” (nominal)  $b$ -slopes in this analysis
- flat and  $\sim 1.0$  (using “best”  $b$ -slopes)
- **this is not obvious relation !**

# Ratio of elastic fractions vs. $|t|$



- ratio of elastic fractions vs.  $|t|$
- using “best” (nominal)  $b$ -slopes in this analysis
- flat and  $\sim 1.0$  (using “best”  $b$ -slopes)
- **this is not obvious relation !**

# Ratio of elastic fractions vs. $|t|$

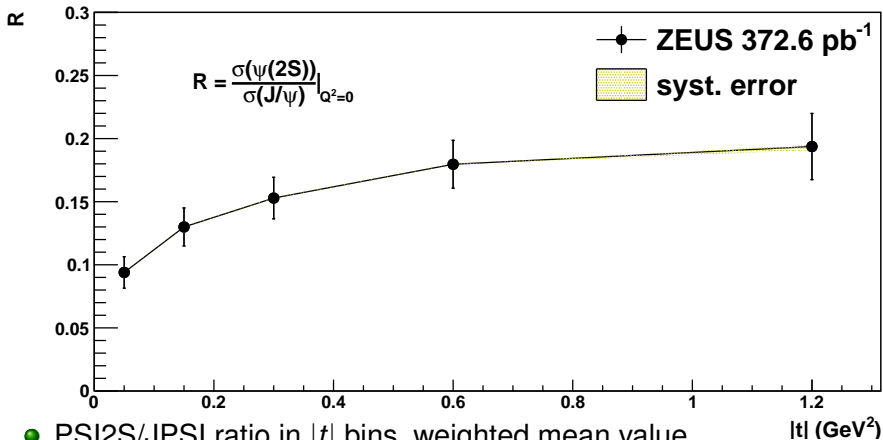


- ratio of elastic fractions vs.  $|t|$
- using  $b_{el}^{JPSI} = 4.15 \text{ GeV}^{-2}$  (ZEUS HERA-I value)
- as used for one of the syst. checks
- **easy to have non-flat dependence !**



# Mean $R$ in $|t|$ bins: assuming cancellation of $f_{p.diss}$

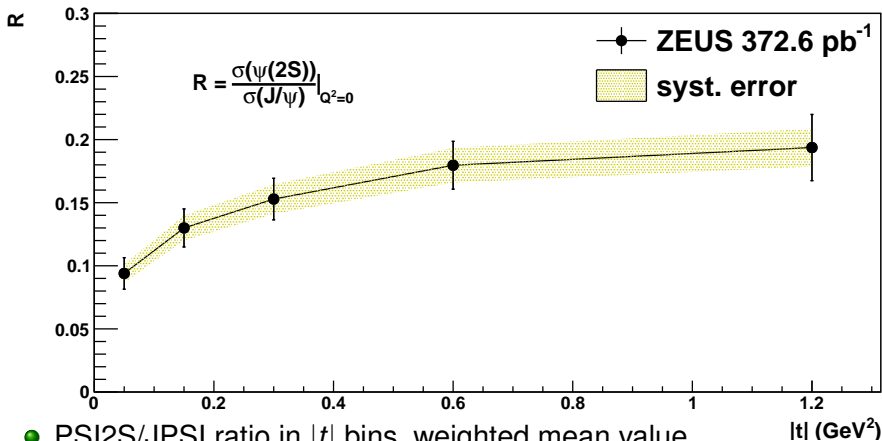
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $|t|$



- PSI2S/JPSI ratio in  $|t|$  bins, weighted mean value
- assuming cancellation of  $f_{p.diss}$  (as in DIS paper)
- systematics due to  $|t|$ -slopes variation only on acceptance  
→ negligible !

# Mean $R$ in $|t|$ bins: assuming cancellation of

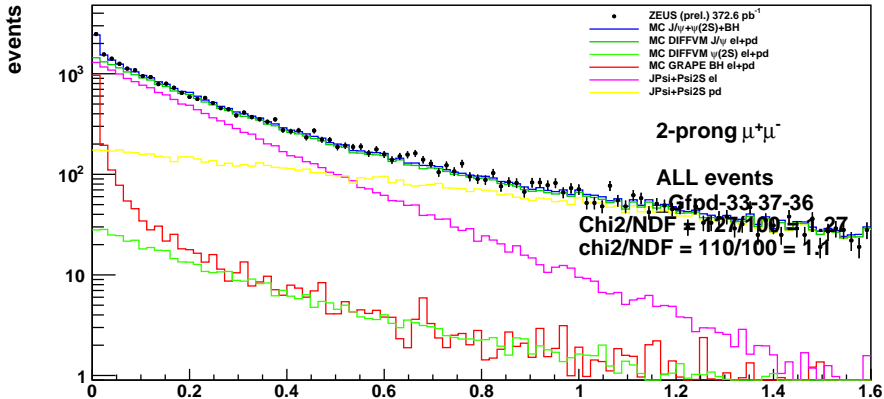
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $|t|$



- $\psi(2S)/J/\psi$  ratio in  $|t|$  bins, weighted mean value
- assuming cancellation of  $f_{p.diss}$  (as in DIS paper)
- including (arbitrary !?) systematics on  $f_{p.diss} = (35 \pm 5)\%$  (not related to  $b$ -slopes variation)

# $|t|$ distribution for JPSI

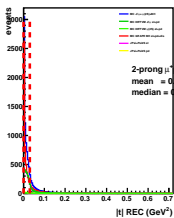
t\_JPSI\_eq



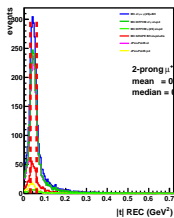
- another solution: reduce phase space to very low  $|t|$  bins
- $|t| < 0.5 \text{ GeV}^2$  : sample dominated by elastic events
- alternative  $|t|$  binning:  $(0 - 0.03 - 0.06 - 0.12 - 0.24 - 0.48) \text{ GeV}^2$
- should be much less sensitive to  $f_{p,diss}$  systematics

# alternative $|t|$ binning

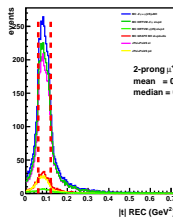
$|t|$  REC in  $|t|$  gener bins: (0.0,0.03)



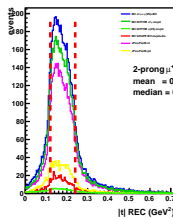
$|t|$  REC in  $|t|$  gener bins: (0.03,0.06)



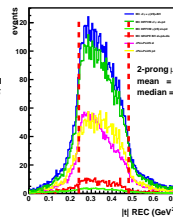
$|t|$  REC in  $|t|$  gener bins: (0.06,0.1)



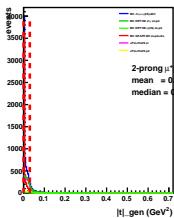
$|t|$  REC in  $|t|$  gener bins: (0.1,0.2)



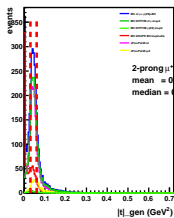
$|t|$  REC in  $|t|$  gener bins: (0.2,0.5)



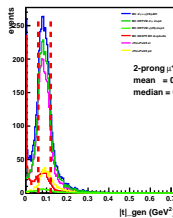
$|t|_{gen}$  in  $|t|$  REC bins: (0.0,0.03)



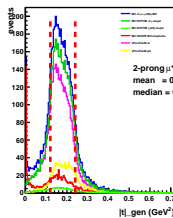
$|t|_{gen}$  in  $|t|$  REC bins: (0.03,0.06)



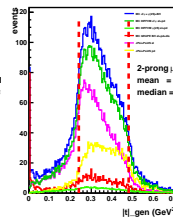
$|t|_{gen}$  in  $|t|$  REC bins: (0.06,0.1)



$|t|_{gen}$  in  $|t|$  REC bins: (0.1,0.2)

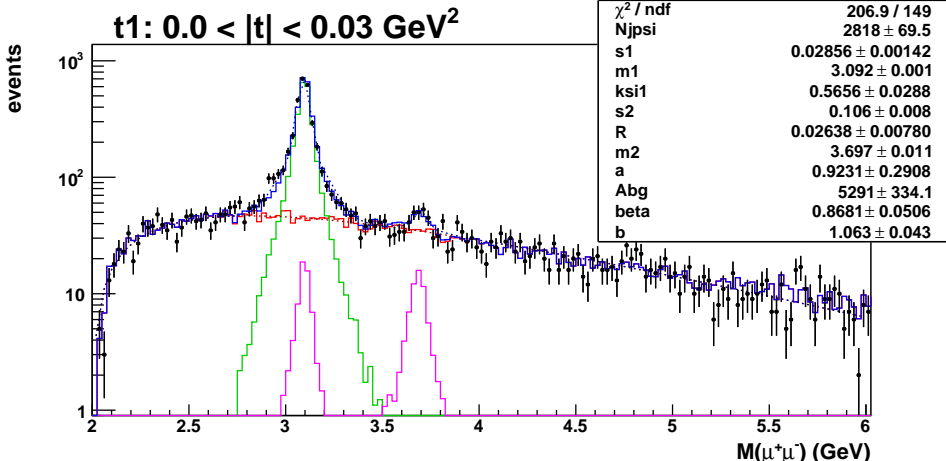


$|t|_{gen}$  in  $|t|$  REC bins: (0.2,0.5)



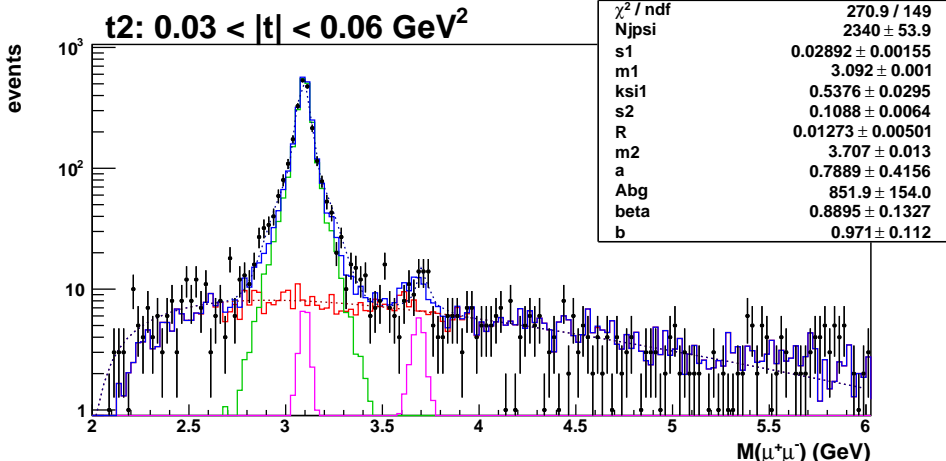
- 5  $|t|$  bins: (0 – 0.03 – 0.06 – 0.12 – 0.24 – 0.48)  $\text{GeV}^2$
- non-equidistant bins :  $\rightarrow$  equal statistic for  $\sim \exp()$  distribution
- $t_{REC}$  in  $t_{GEN}$  bins (upper row),  $t_{GEN}$  in  $t_{REC}$  bins (lower row)
- acceptable migration to neighbor bins

# alternative $|t|$ binning: $|t1|$ Mass distribution



- bin dominated by BH background
- $\psi'$  signal still visible but large stat. errors (see next pages)

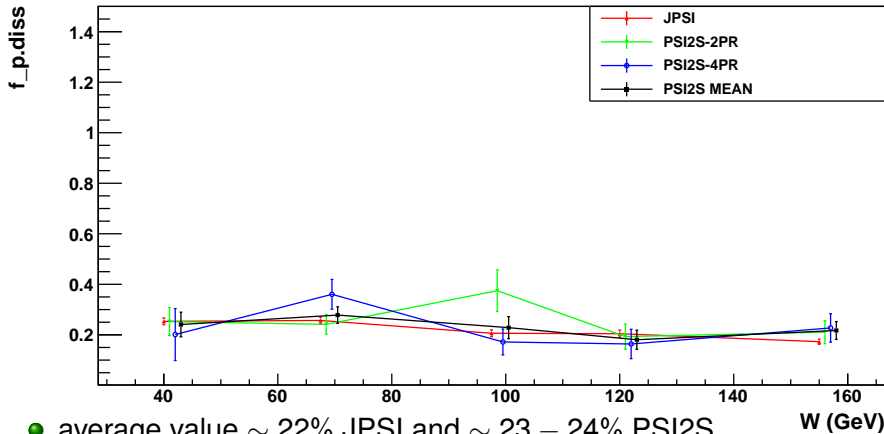
# alternative $|t|$ binning: $|t_2|$ Mass distribution



●  $\psi'$  signal still visible

# $f_{p.diss}$ fractions in $W$ bins (alternative $|t|$ range)

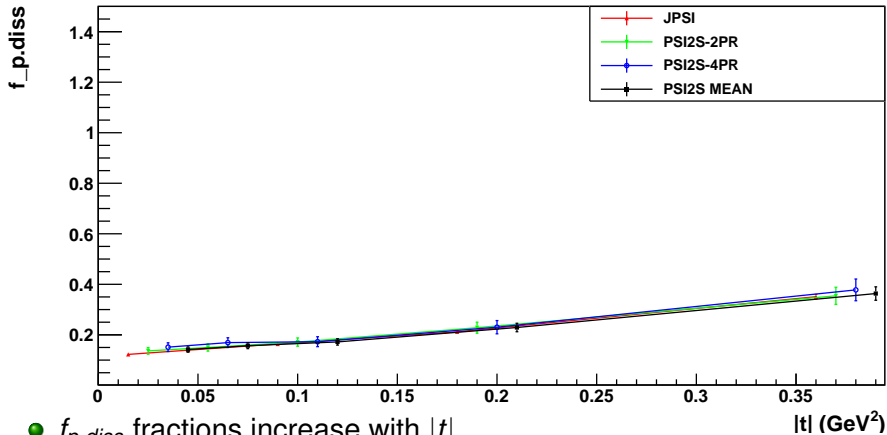
fraction  $f_{p.diss}$ : JPSI and PSI2S 2PR, 4PR vs.  $W$



- average value  $\sim 22\%$  JPSI and  $\sim 23 - 24\%$  PSI2S
- compatible results for 2- and 4-prong channels, no  $W$  dependence
- bigger stat. errors for PSI2S (fit in each  $W$  bin)
- black: weighted mean for PSI2S 2- and 4-prong (used in analysis)

# $f_{p.diss}$ fractions in $|t|$ bins

fraction  $f_{p.diss}$ : JPSI and PSI2S 2PR, 4PR vs.  $|t|$

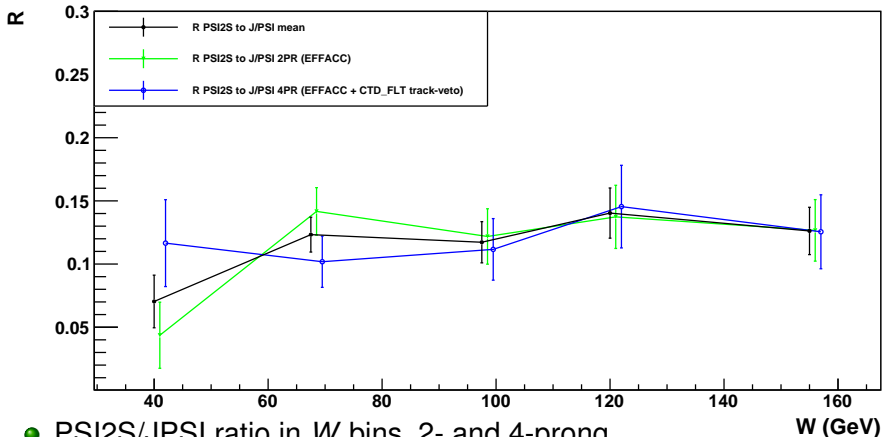


- $f_{p.diss}$  fractions increase with  $|t|$
- compatible results for 2- and 4-prong channels
- very similar values for JPSI and PSI2S
- smaller stat. errors (fit for all  $W$ ,  $|t|$  slices)



# $R$ in $W$ bins, 2- and 4-prong (alternative $|t|$ range)

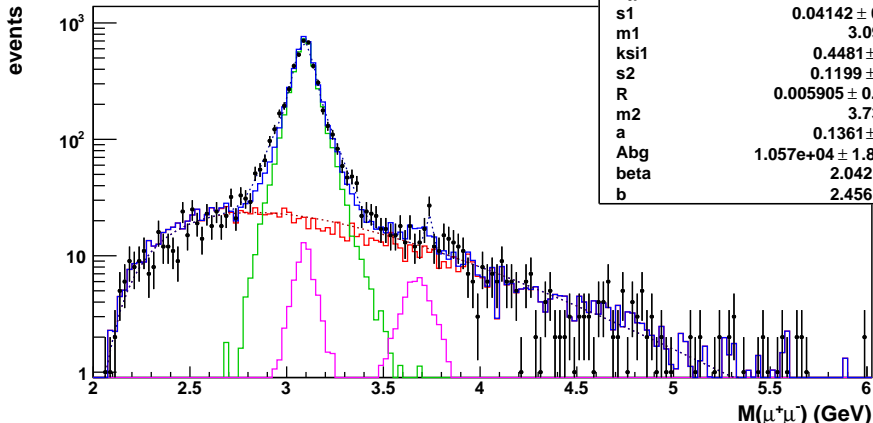
R psi' to J/psi 2PR, 4PR (stat err only) vs. W (EFFACC + CTD FLT track-veto corr for 4PR)



- PSI2S/JPSI ratio in  $W$  bins, 2- and 4-prong
- good agreement for 2- and 4-prong channels (except lower  $W$  bin ?)
- (before  $f_{p.diss}$ ) correction

# alternative $|t|$ binning: $W1$ Mass distribution

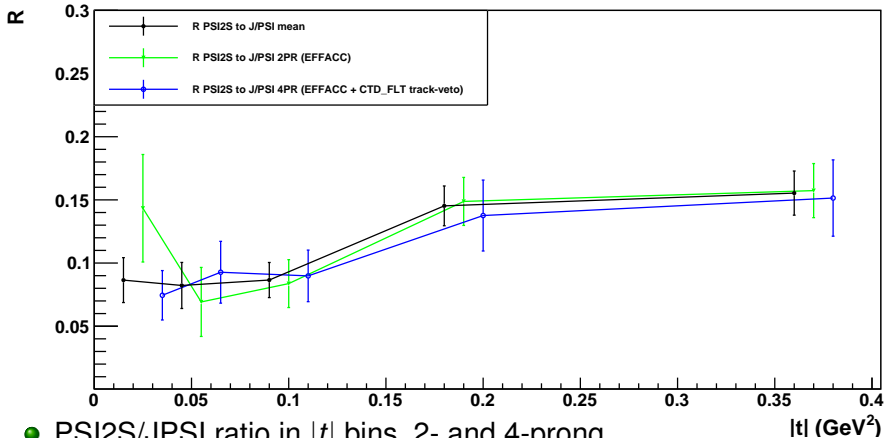
**W1:  $30 < W < 50$  GeV**



- first  $W1$  bin, reduced  $|t| < 0.48$  GeV<sup>2</sup>
- PSI2S signal not visible (?)

# $R$ in $|t|$ bins, 2- and 4-prong (alternative $|t|$ binning)

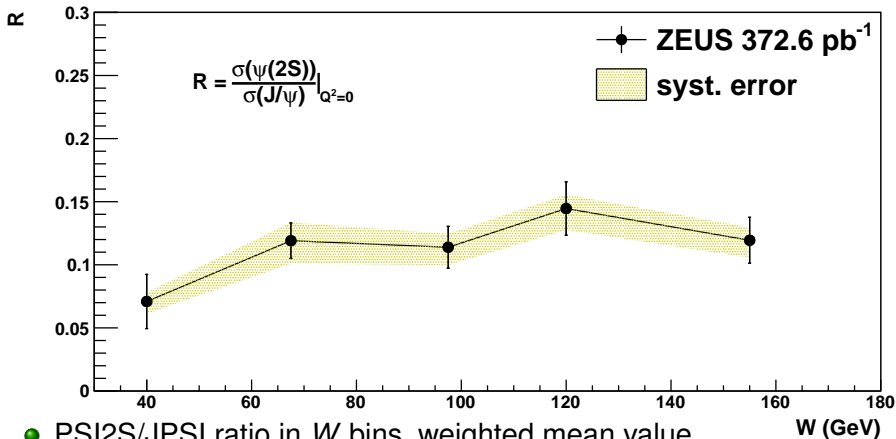
R psi' to J/psi 2PR, 4PR (stat err only) vs.  $|t|$  (EFFACC + CTD FLT track-veto corr for 4PR)



- PSI2S/JPSI ratio in  $|t|$  bins, 2- and 4-prong
- good agreement for 2- and 4-prong channels (except lower  $|t|$  bin ?)
- (before  $f_{p.diss}$ ) correction

# Mean $R$ in $W$ bins (alternative $|t|$ range)

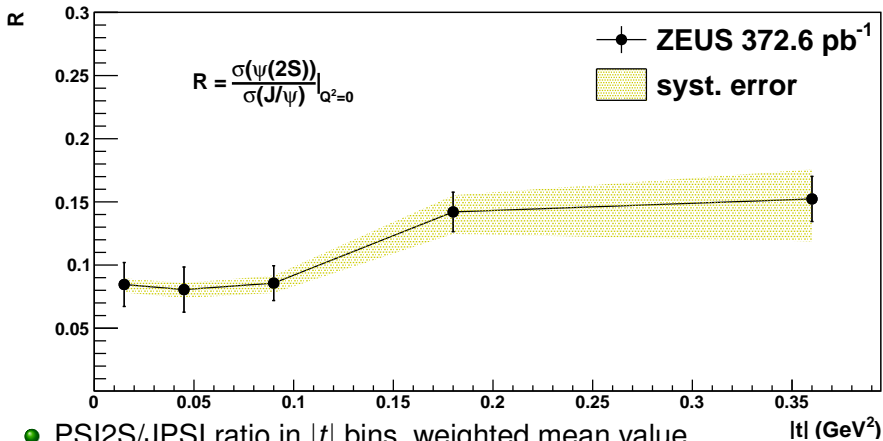
FINAL mean  $R$   $\psi(2S)$  to  $J/\psi$  vs.  $W$



- $\psi(2S)/J/\psi$  ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction

# Mean $R$ in $|t|$ bins (alternative $|t|$ binning)

FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $|t|$



- PSI2S/JPSI ratio in  $|t|$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction
- reasonable (under control) systematics

- $\psi'$  to  $J/\psi$  xsec. ratio in exclusive (elastic) PHP
  - $R$  vs.  $W$  integrated over  $t$  (“to infinity”) :  $|t| < 1.5 \text{ GeV}^2$
  - $R$  vs.  $|t|$  integrated over  $W$  : (30-180) GeV

# Theory predictions: models (so far collected...)

- **Heikki Mäntysaari (HM) :**
- 2S parameters from arXiv:1406.2877 (PoS DIS2014 (2014) 069)
- 1S parameters from hep-ph/0606272 (Phys.Rev. D74 (2006) 074016)
- Calculation described in (Phys.Rev. C83 (2011) 065202)
- IPsat dipole from fit (Phys.Rev. D87 (2013) no.3, 034002)
- Wave function: Boosted Gaussian,  $Q^2 = 0 \text{ GeV}^2$
- Skewedness and real part corrections included

# Theory predictions: models (so far collected...)

- **Jan Čepila (JC) and CO.:**

- model with hot spots randomly sampled in the transverse plane bound by the size of the proton (arXiv:1811.06479 + accepted to be published by PRD)
- The slope parameter  $b$  is  $4.72 \text{ GeV}^{-2}$  and it is fixed by the combined H1 and ZEUS data from 2013 for JPsi photoproduction  $t$ -distribution.
- the same  $b$ -slope for both JPsi and Psi2s

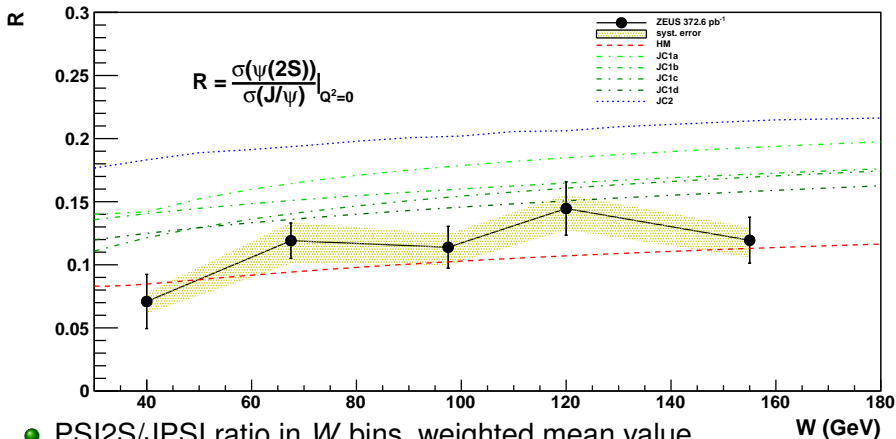


# Theory predictions: models (so far collected...)

- **Jan Nemcik (JN) and CO. (incl. JC):**
- Eur. Phys. J. C **79**, no.6, 495 (2019)
- Eur. Phys. J. C **79**, no.2, 154 (2019)
- calculations have been performed for various combinations of quarkonium wave functions:
  - **BT (Buchmueller-Tye)** ← **used on plots**
  - Cor (Cornell)
  - HO (Harmonic oscillator)
  - Log (Logarithmic) and Pow (Power-like) potentials
- and models for the dipole cross sections:
  - GBW, GBWnew, IPsat and KST.
- for simplicity, we take the same  $b$ -slope parameters for both quarkonium states.

# Mean $R$ in $W$ bins (alternative $|t|$ range) + theory

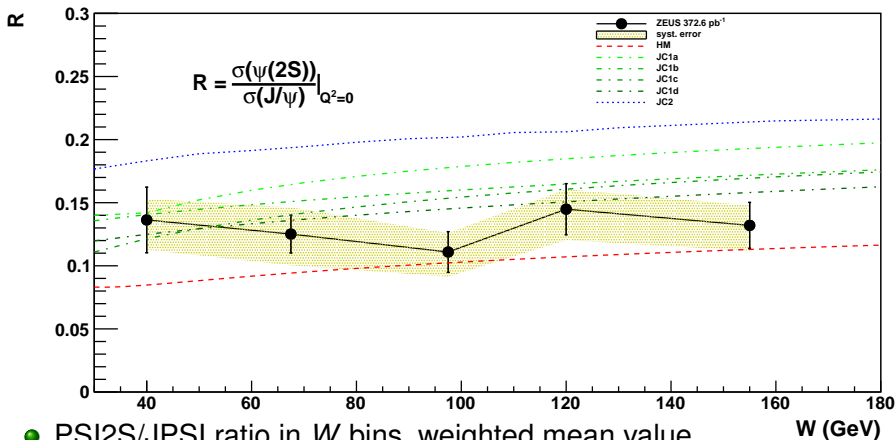
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $W$



- PSI2S/JPSI ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction

# Mean $R$ in $W$ bins (wider $|t|$ range) + theory

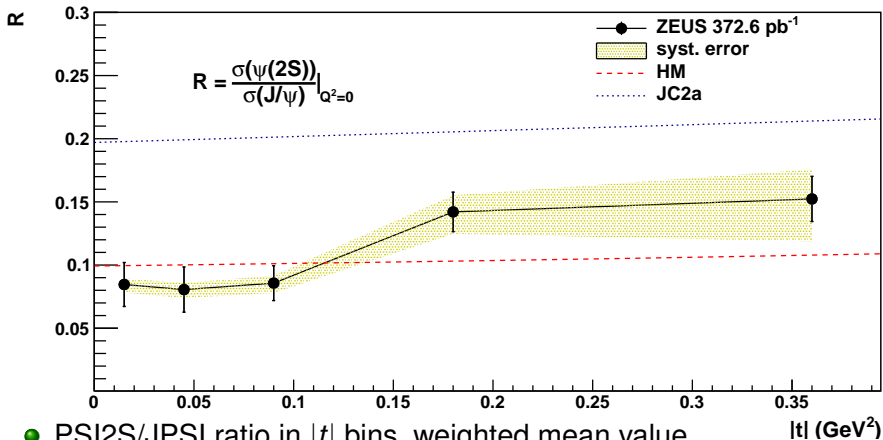
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $W$



- PSI2S/JPSI ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction

# Mean $R$ in $|t|$ bins (alternative $|t|$ range) + theory

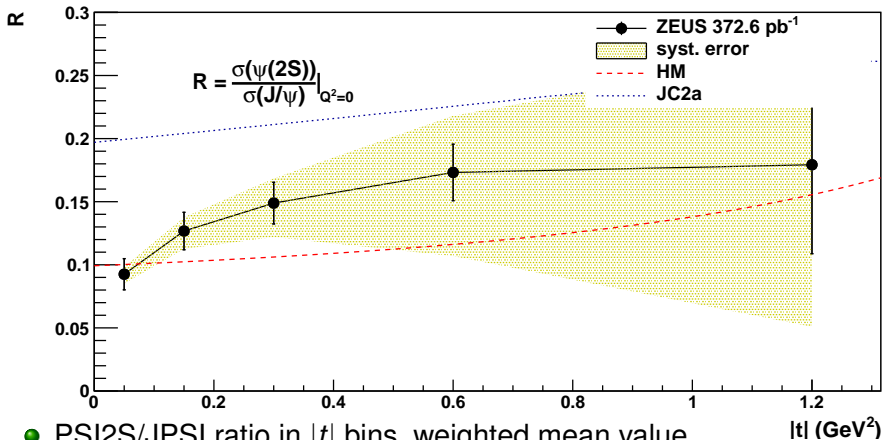
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $|t|$



- PSI2S/JPSI ratio in  $|t|$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction
- (still waiting for calculations based on JN models)

# Mean $R$ in $|t|$ bins (wider $|t|$ range) + theory

FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $|t|$



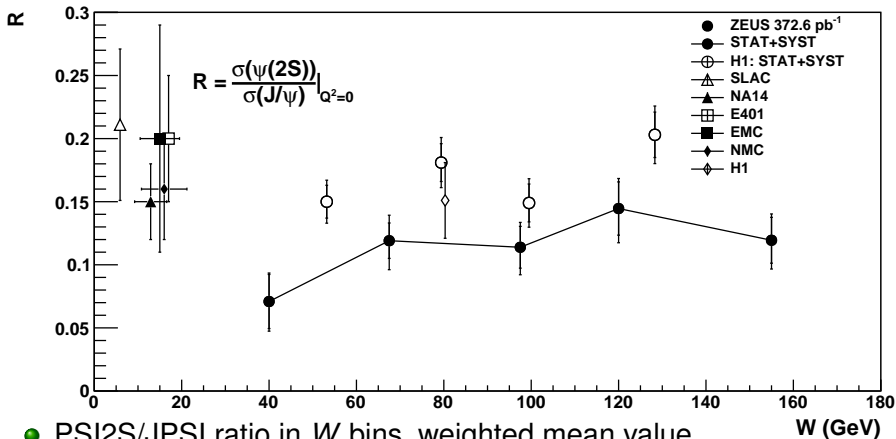
- PSI2S/JPSI ratio in  $|t|$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction
- (still waiting for calculations based on JN models)

# Comparison with other experiments

- already published ratios of  $\psi'$  to  $J/\psi$  mesons:
- **SLAC**: U. Camerini et al., Phys. Rev. Lett. 35 483 (1975).
- **NA14 Collab.**, R. Barate et al., Z. Phys. C33 505 (1987).
- **E401 Collab.**, M. Binkley et al., Phys. Rev. Lett. 50 302 (1983).
- **EMC Collab.**, J.J. Albert et al., Nucl. Phys. B213 1 (1983).
- **NMC Collab.**, P. Amaudraz et al., Nucl. Phys. B371 553 (1992).
- **H1 Collab.**, C. Adloff et al., Phys. Lett. B421 385 (1998).
- **H1 Collab.** C. Adloff, et al., Phys.Lett. B541 251-264 (2002).

# Mean $R$ in $W$ bins (alternative $|t|$ range) + other EXP

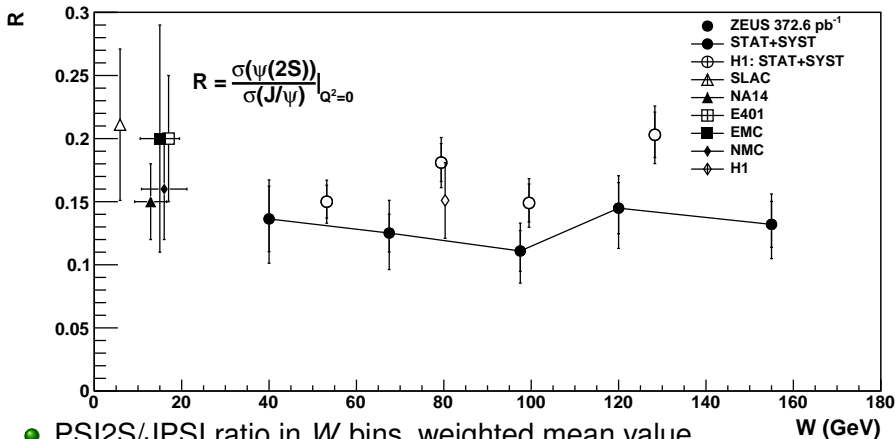
FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $W$ : STAT+SYST comb.



- PSI2S/JPSI ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction

# Mean $R$ in $W$ bins (wider $|t|$ range) + other EXP

FINAL mean  $R$   $\psi'$  to  $J/\psi$  vs.  $W$ : STAT+SYST comb.



- PSI2S/JPSI ratio in  $W$  bins, weighted mean value
- after  $f_{p.diss}$  correction (common for 2- and 4- prongs)
- systematics due to  $|t|$ -slopes variation incl. p.diss fraction



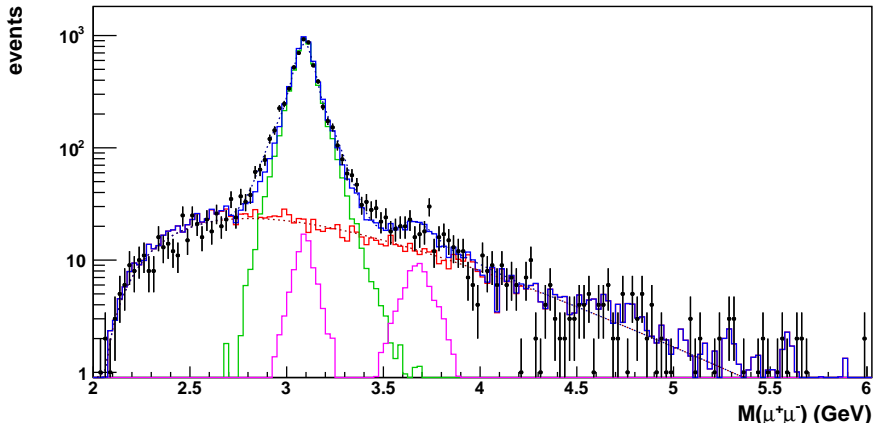
# Conclusions/plans

- first study of systematic effects was made
  - biggest contribution from p.diss fraction (via  $b$ -slopes)
  - first comparison to theoretical models:  
→ our data prefer lower  $R$  values
  - comparison with other measurements
- 
- decide on final binning: number of bins and size
  - more systematics (!)
  - paper draft

- Backup plots...

# Di-muon mass in $W1$ bin

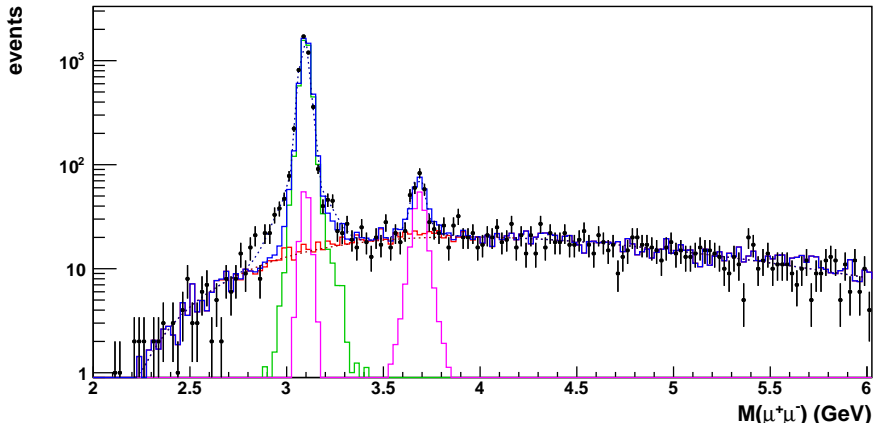
**$W1: 30 < W < 50$  GeV**



- good fits and DATA/MC agreement for all  $W$  bins

# Di-muon mass in $W2$ bin

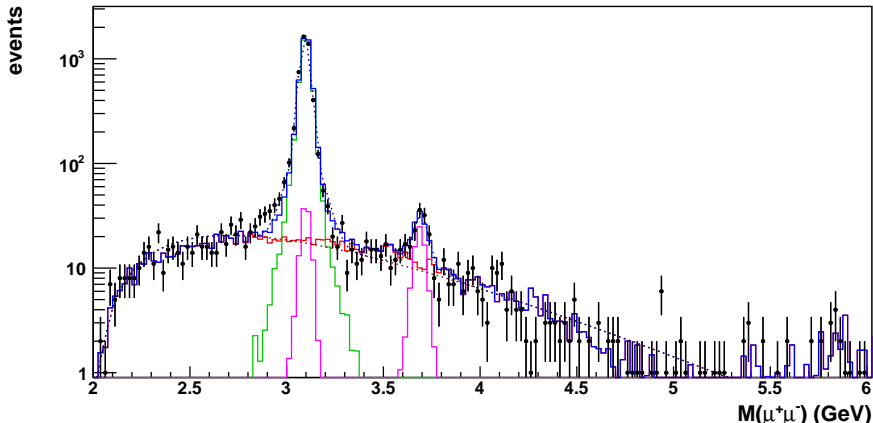
$W2: 50 < W < 85 \text{ GeV}$



- good fits and DATA/MC agreement for all  $W$  bins

# Di-muon mass in $W3$ bin

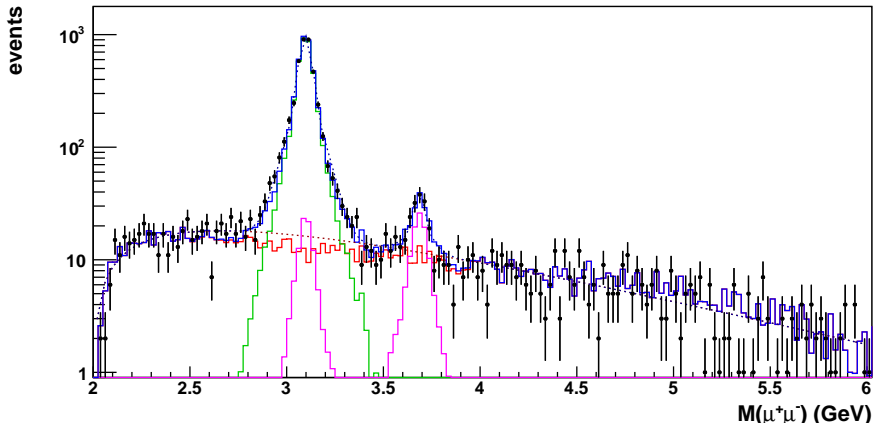
**W3:  $85 < W < 110$  GeV**



- good fits and DATA/MC agreement for all  $W$  bins

# Di-muon mass in $W4$ bin

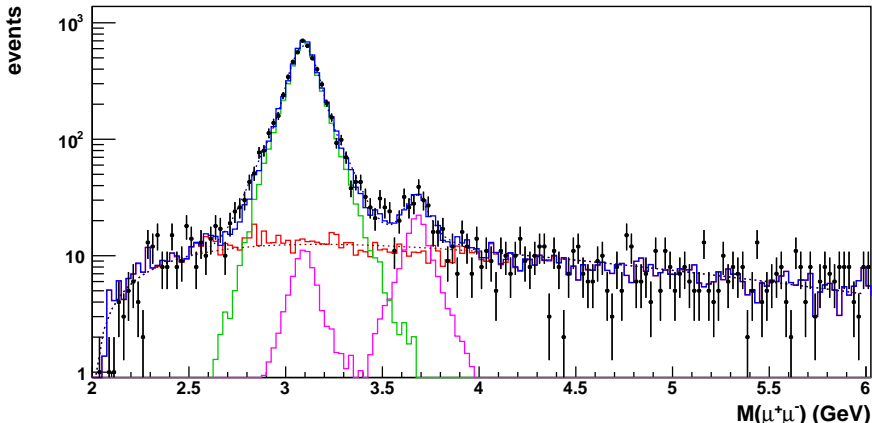
**W4:  $110 < W < 130$  GeV**



- good fits and DATA/MC agreement for all  $W$  bins

# Di-muon mass in $W5$ bin

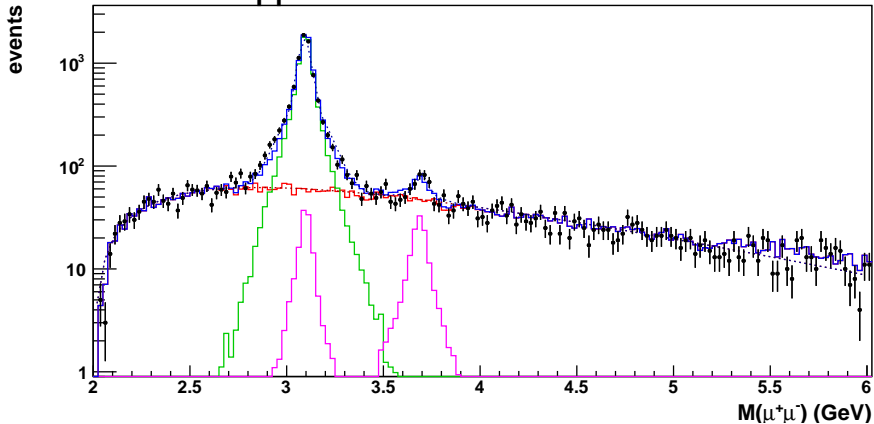
**W5:  $130 < W < 180$  GeV**



- good fits and DATA/MC agreement for all  $W$  bins

# Di-muon mass in $t_1$ bin

$t_1: 0.0 < |t| < 0.1 \text{ GeV}^2$

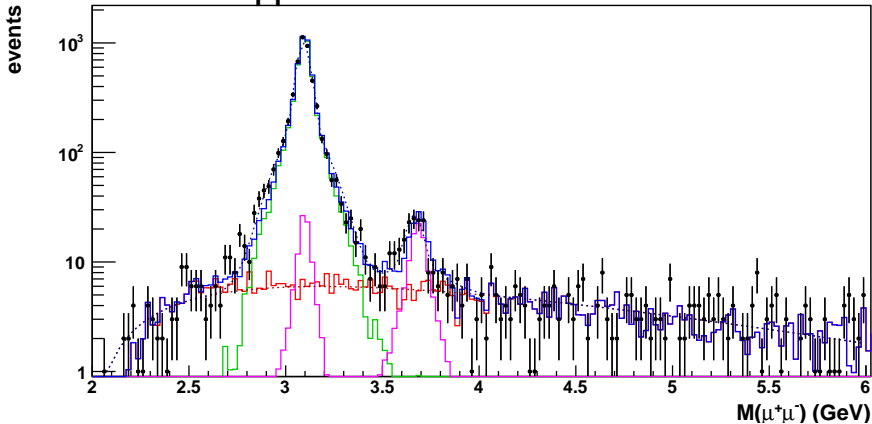


- good fits and DATA/MC agreement for all  $t$  bins



# Di-muon mass in $t2$ bin

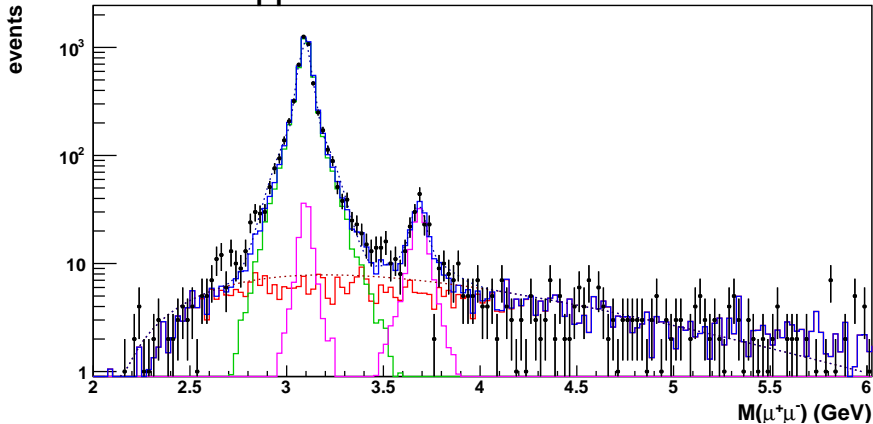
$t2: 0.1 < |t| < 0.2 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $t$  bins

# Di-muon mass in $t3$ bin

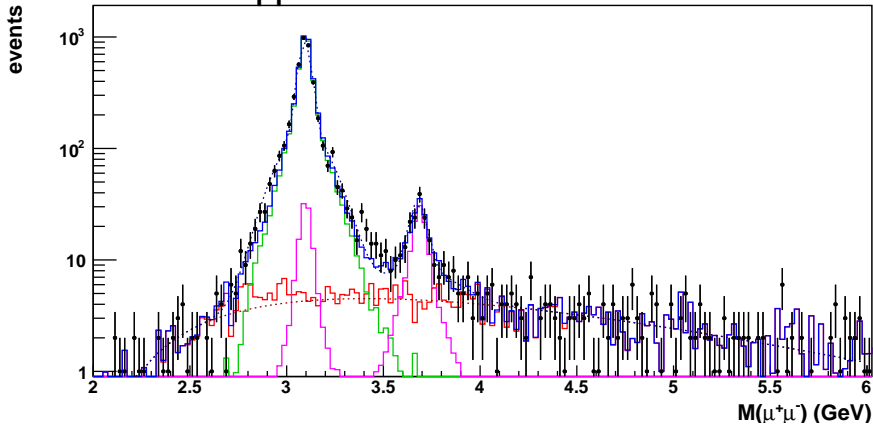
$t3: 0.2 < |t| < 0.4 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $t$  bins

# Di-muon mass in $t4$ bin

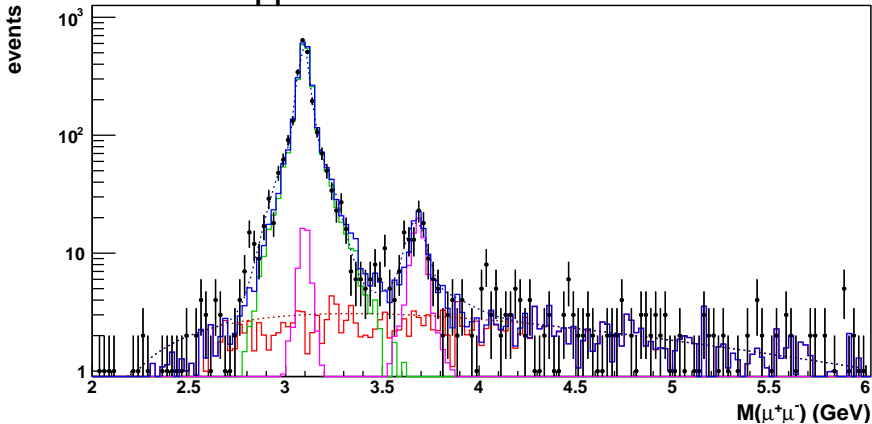
$t4: 0.4 < |t| < 0.8 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $t$  bins

# Di-muon mass in $t5$ bin

$t5: 0.8 < |t| < 1.6 \text{ GeV}^2$



- good fits and DATA/MC agreement for all  $t$  bins