CLAS12: inbending vs outbending

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CLAS Collaboration Meeting, April 29, 2020

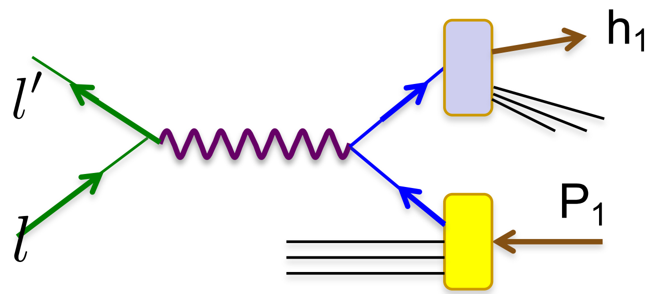
- DIS with inbending and outbending
- RGA vs RGB
- SIDIS: inbending vs outbending
- DIS and SIDIS systematics
  - Charge symmetric background
  - Radiative events and low energy electrons
- Summary & Conclusions

DIS & SIDIS

The inclusive ($d\sigma(lN \to lX)$) cross sections could be obtained from semi-inclusive one ($d\sigma(lN \to lhX)$) by integration over $z = E_h/\nu$, and summing over all hadrons h:

$$\frac{d\sigma(lN \to lX)}{dx\, dQ^2\, d\psi} = \frac{1}{\nu + M} \sum_h \int E_h\, dE_h \frac{d\sigma(lN \to lhX)}{dx\, dQ^2\, d\psi\, dE_h} = \frac{\nu}{\nu + M} \sum_h \int z\, dz \frac{d\sigma(lN \to lhX)}{dx\, dQ^2\, d\psi\, dz}$$

with $\frac{\nu+M}{\nu} = 1 + \gamma^2/(2x)$



$$\frac{d\sigma}{dx\, dQ^2\, d\psi} = \frac{2\alpha^2}{xQ^4} \frac{y^2}{2(1-\varepsilon)} \left\{ F_{UU,T}(x,Q^2) + \varepsilon F_{UU,L}(x,Q^2) \right\}.$$

where

$$F_{UU,T}(x,Q^2) = F_T(x,Q^2) = 2xF_1(x,Q^2) = \sum_h \int z\, dz F_{UU,T}(x,z,Q^2)$$

$$F_{UU,L}(x,Q^2) = F_L(x,Q^2) = (1+\gamma^2)F_2(x,Q^2) - 2xF_1(x,Q^2) = \sum_h \int z\, dz F_{UU,L}(x,z,Q^2)$$

$$\boxed{\frac{d\sigma}{dx\, dQ^2\, d\psi} = \frac{2\alpha^2}{xQ^4} \frac{y^2}{2(1-\varepsilon)} \left\{ 2(1-\varepsilon)xF_1(x,Q^2) + \varepsilon(1+\gamma^2)F_2(x,Q^2) \right\}.}$$

$y^2\varepsilon(1+\gamma^2)/2(1-\varepsilon) = 1 - y - 0.25y^2\gamma^2$ and $\cos^2\theta/2E'/E = 1 - y - 0.25y^2\gamma^2$

DIS ep→e'X

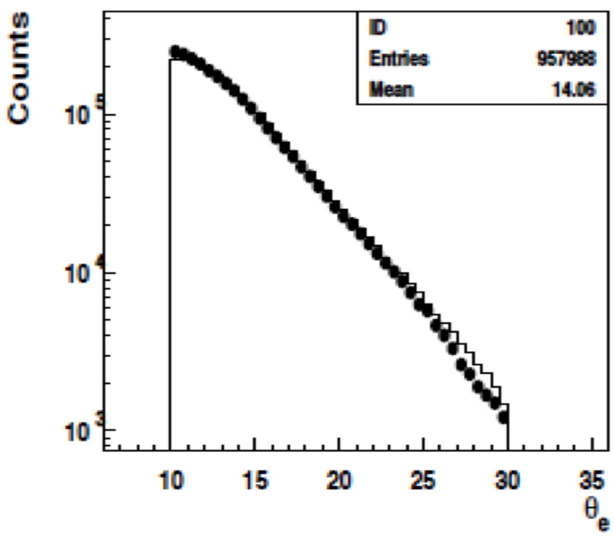
ep→e'X (Inclusive SFs relatively well known)

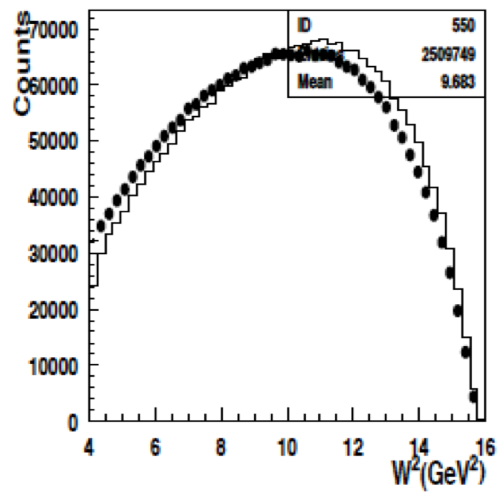
<u>Full event generator (LUND-MC)</u>

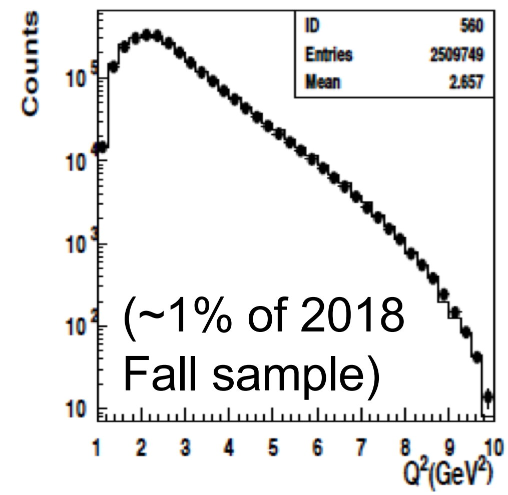
$$\frac{d\sigma}{dx\,dy\,d\psi} = \frac{2\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\varepsilon)}\left\{F_T + \varepsilon F_L + S_{\|}\lambda_e\sqrt{1-\varepsilon^2}\,2x\,(g_1 - \gamma^2 g_2) - |S_\perp|\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,2x\gamma\,(g_1+g_2)\right\}$$

$$y = (qP)/(kP)$$
$$x = Q^2/2(qP)$$

CLAS12 data vs MC

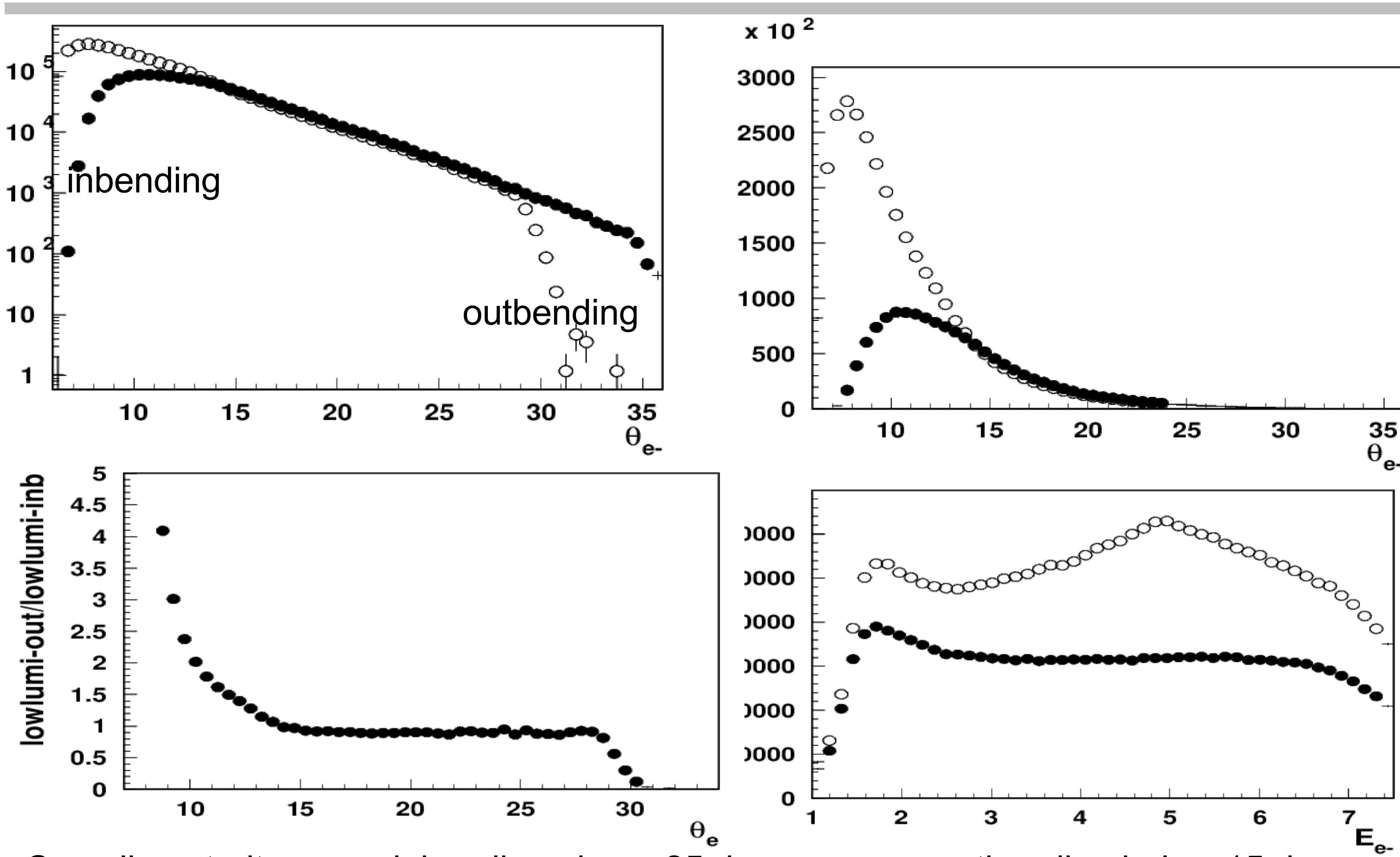






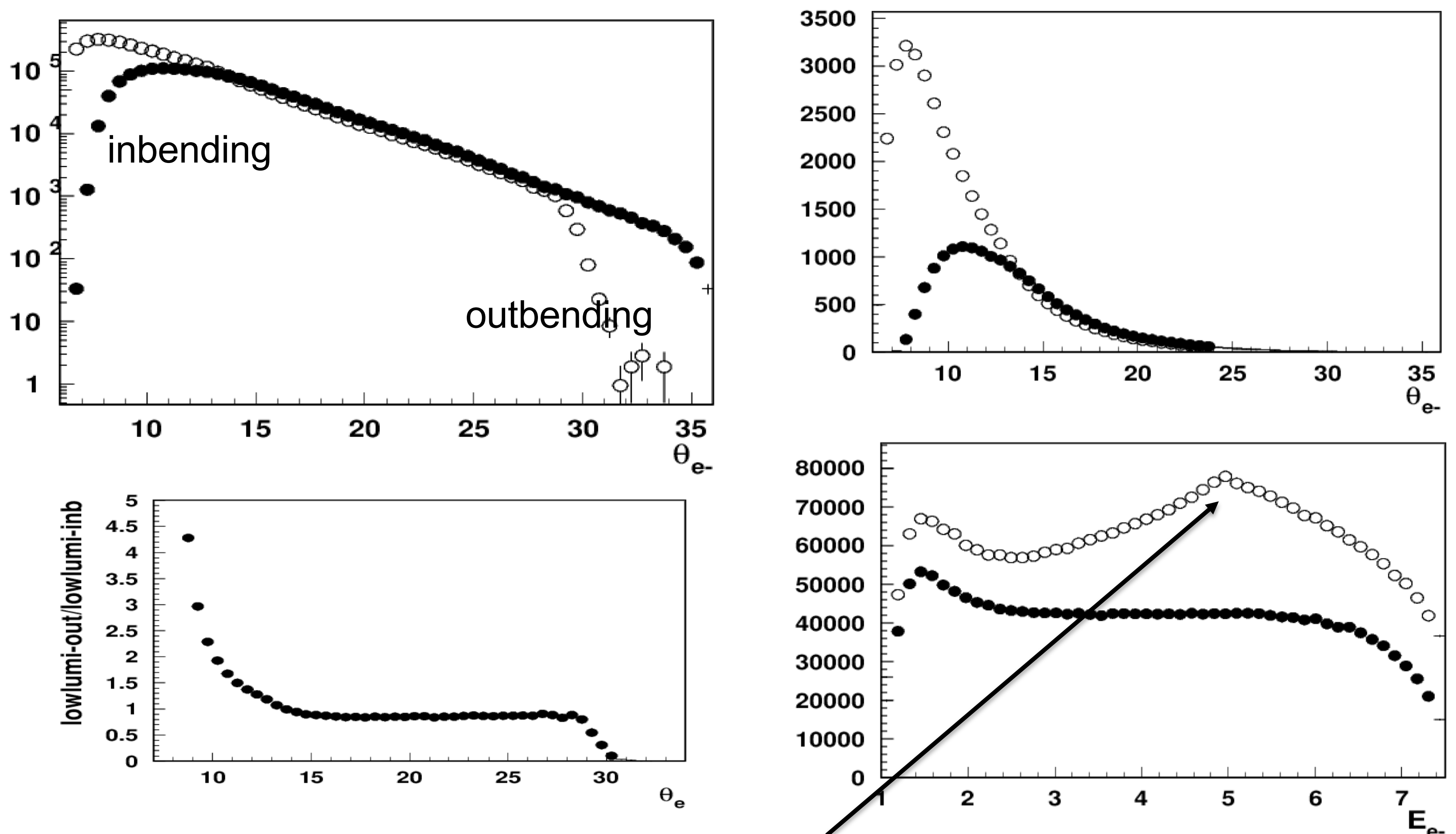
- Kinematic dependences of e- counts for normalized e'X events (uncorrected for acceptance) are consistent with clas12 LUND MC

DIS: inbending vs outbending (RGA 5nA)



Complimentarity: more inbending above 25 degree, more outbending below 15 degree

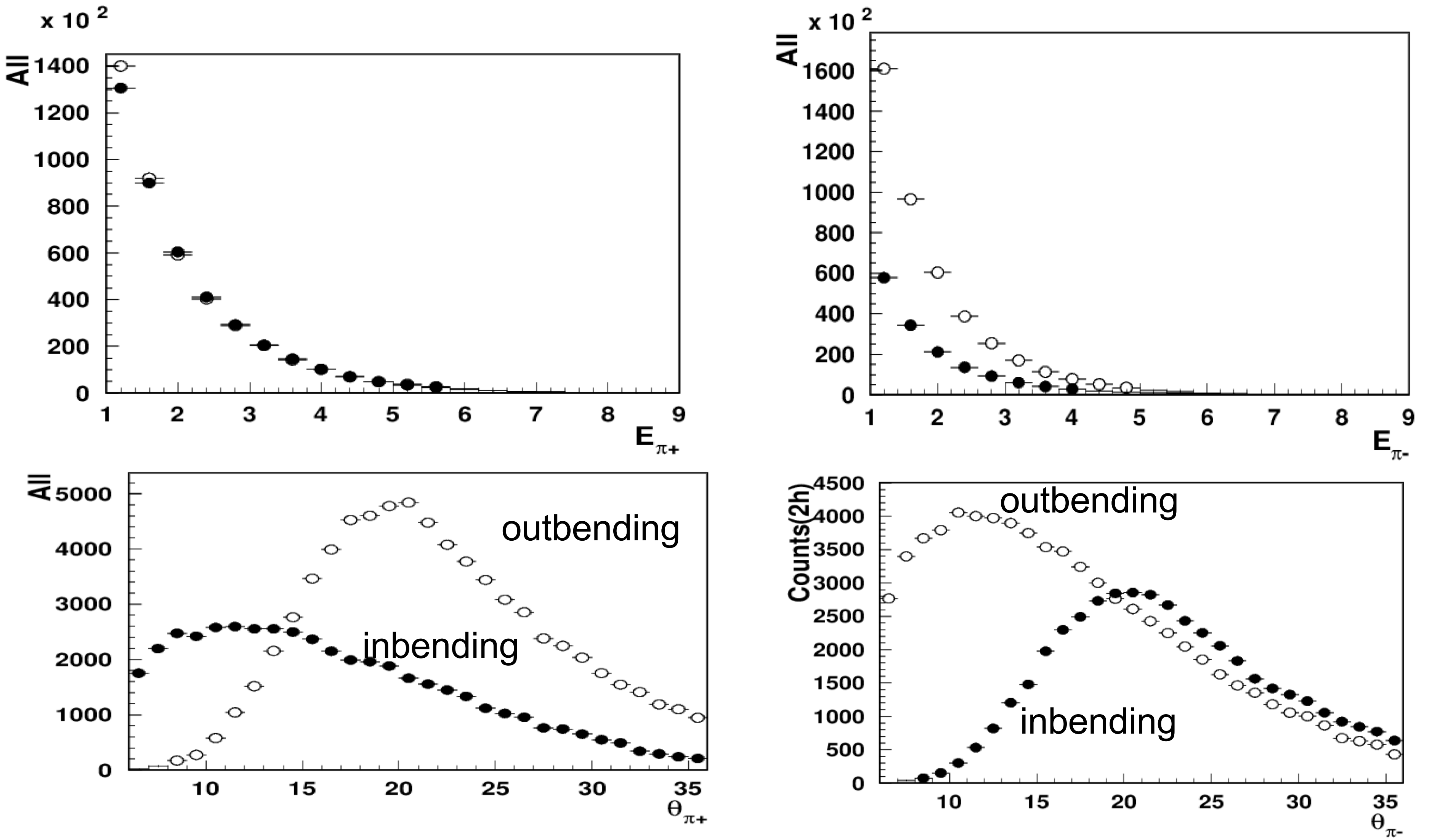
DIS: inbending vs outbending (RGB 6447-inb vs 11120-out)



Fraction of misidentified π- may be higher with deuteron

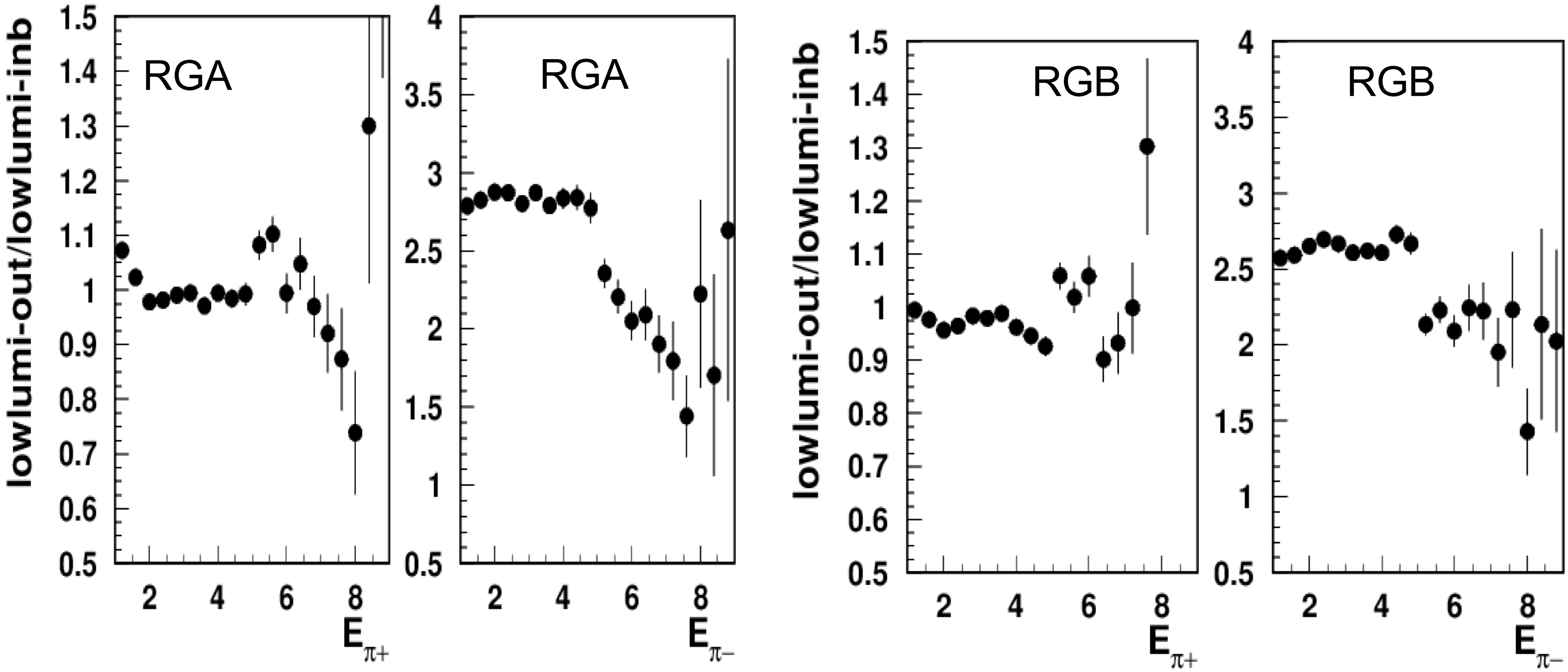
Complimentarity: more inbending above 27 degree, more outbending below 15 degree

SIDIS: inbending vs outbending



Inbending and outbending complementary, cover very different kinematical ranges

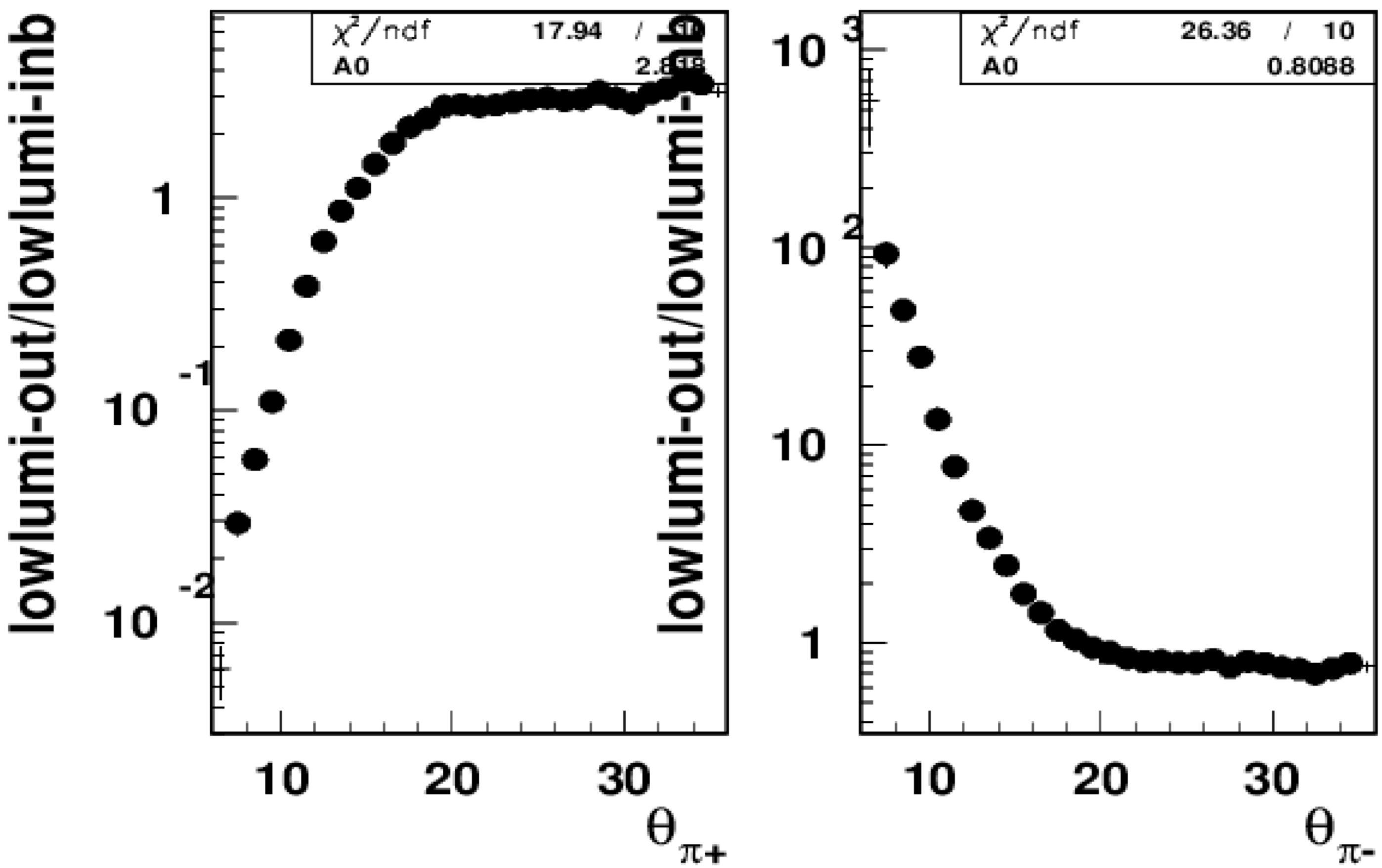
SIDIS: inbending vs outbending (RGA vs RGB)



Similar behavior in RGA and RGB

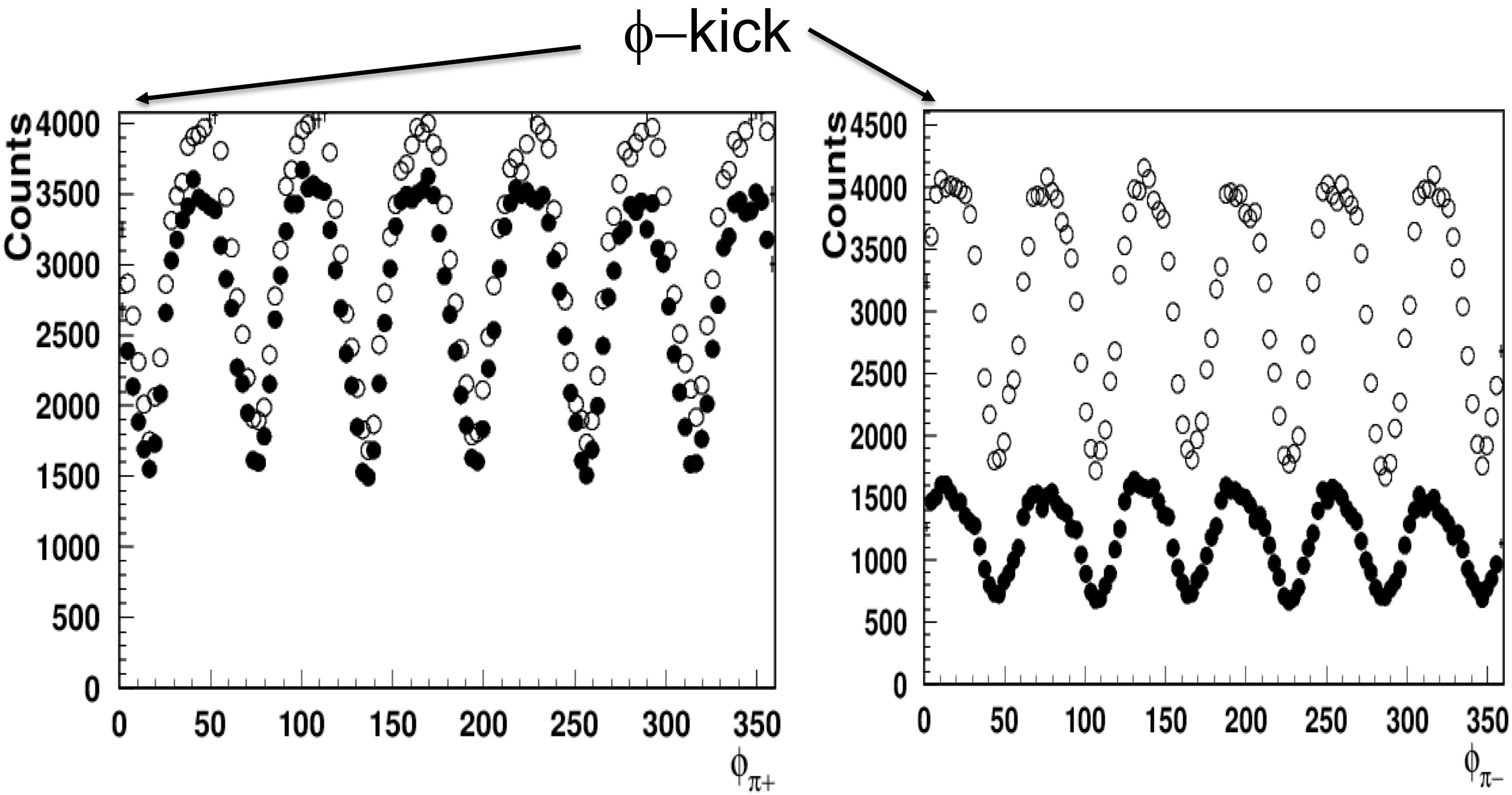
- Roughly equal number of e-π+ and ~2.5 times more e-π-

SIDIS: inbending vs outbending (RGB)



Acceptance for positive and negative pions very different at small angles/high energies (need both configurations for completeness)

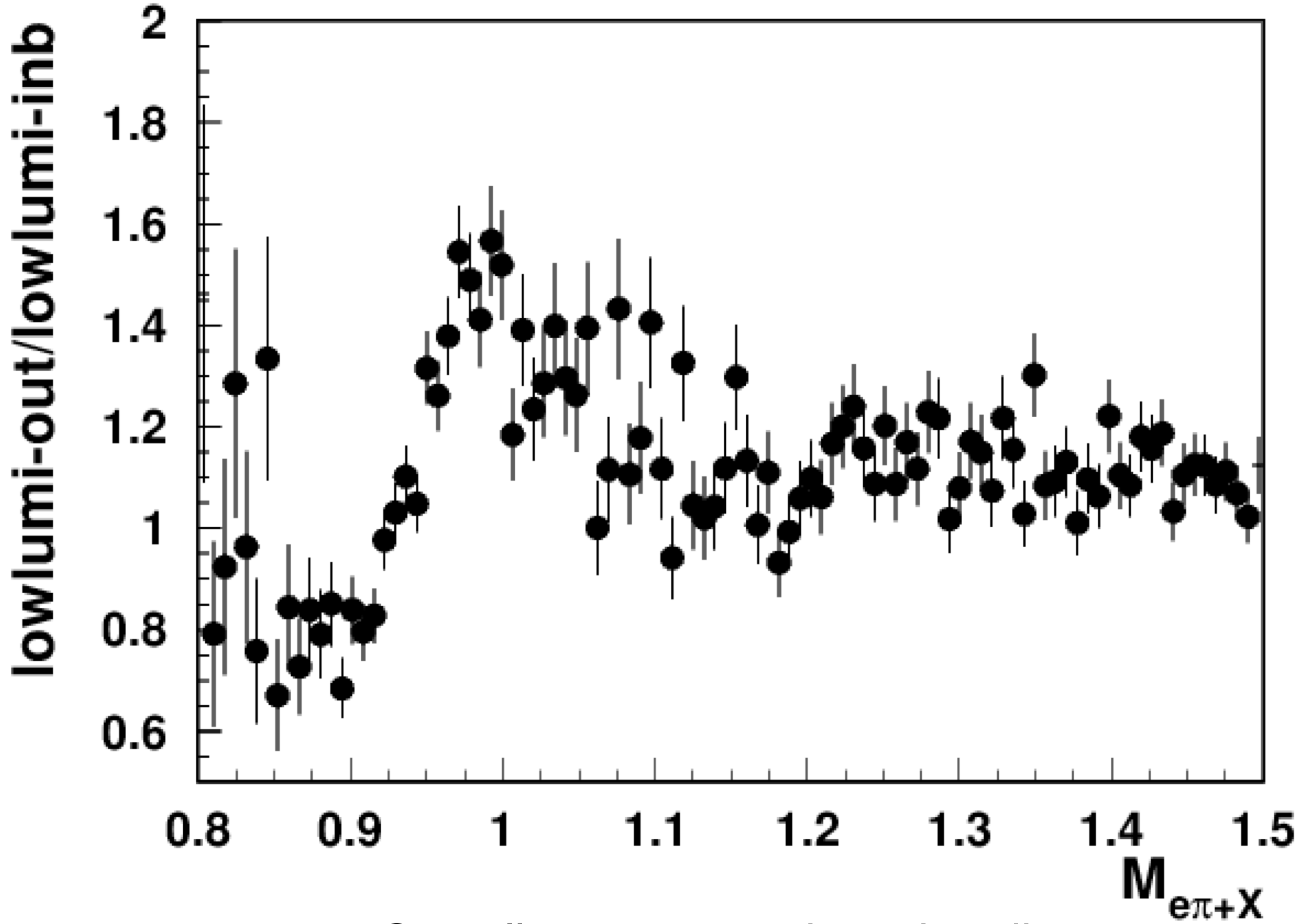
SIDIS: inbending vs outbending



Comparable number of π+, but significantly more π- in outbending configuration

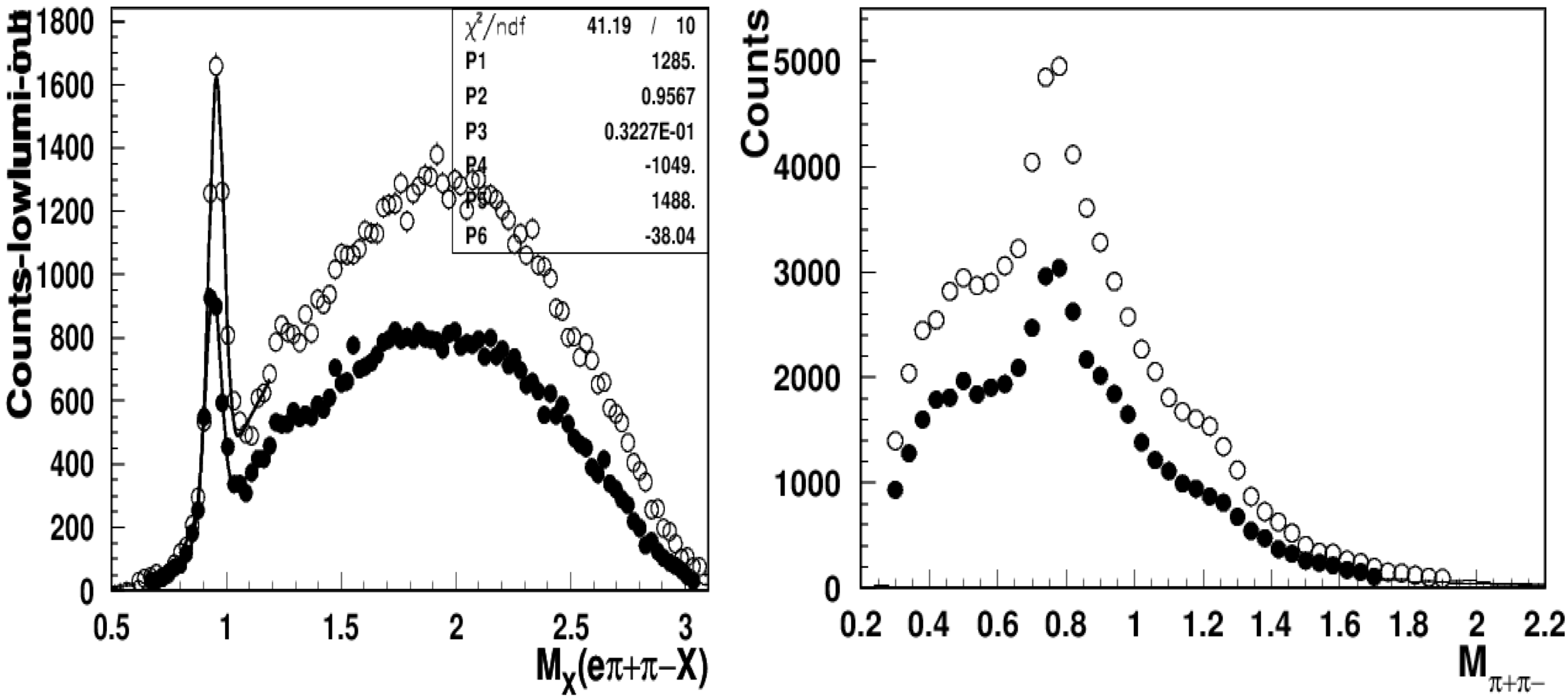
SIDIS: inbending vs outbending (RGA)

Comparable counts for e-pi+



Overall counts more in outbending
Peak slightly shifted in outbending

2h SIDIS: inbending vs outbending (RGA)



Significantly more counts for e-pi+pi- in outbending configuration (open symbols)

Sources of DIS and SIDIS systematics

Main sources of systematics in DIS and SIDIS include

Detector:
1) Misidentification of e- (more at E_{lepton}>4.5 GeV)
2) Misindetification of pions (more E_{pion}>4 GeV)
3) Acceptance and efficiency calculations

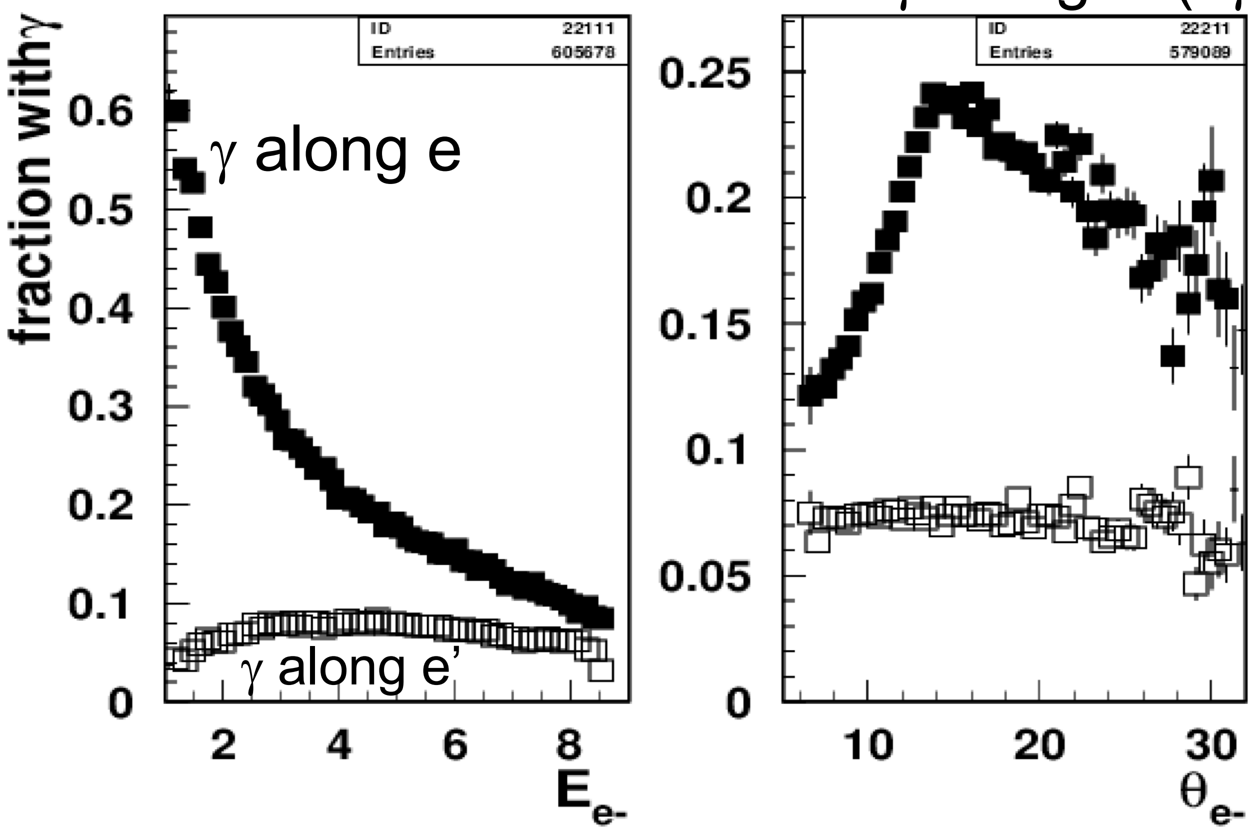
Physics:
1) Charge symmetric background: “Non DIS” electrons from decays of quasi-real production of hadrons and e+e- pairs.
2) Radiative effects

………

Radiative DIS

Radiative DIS MC (internal) ($E\gamma > 0.1$GeV)

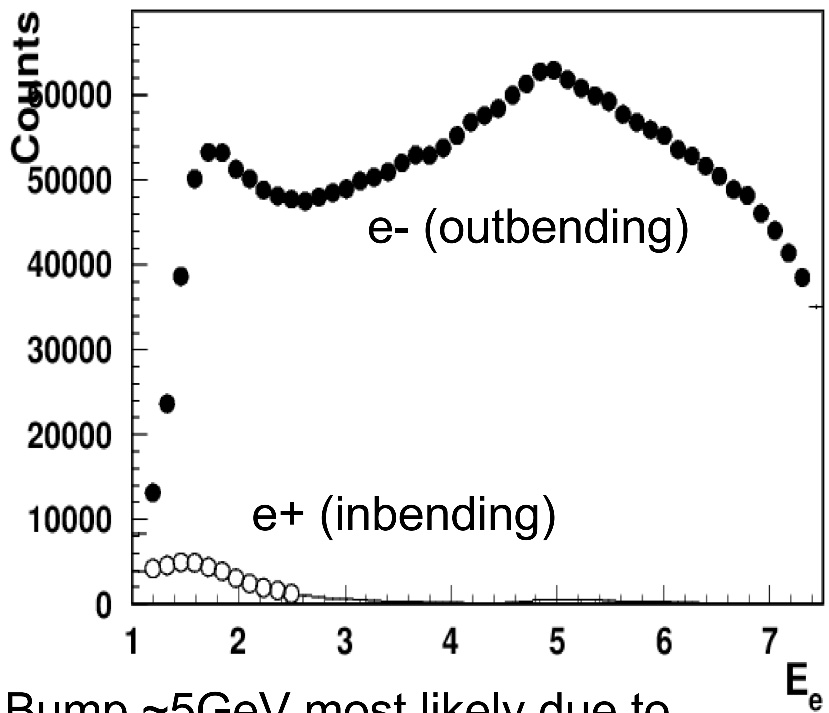
2 samples γ along e ($\theta\gamma<5^o$), γ along e' ($\theta\gamma>5^o$)

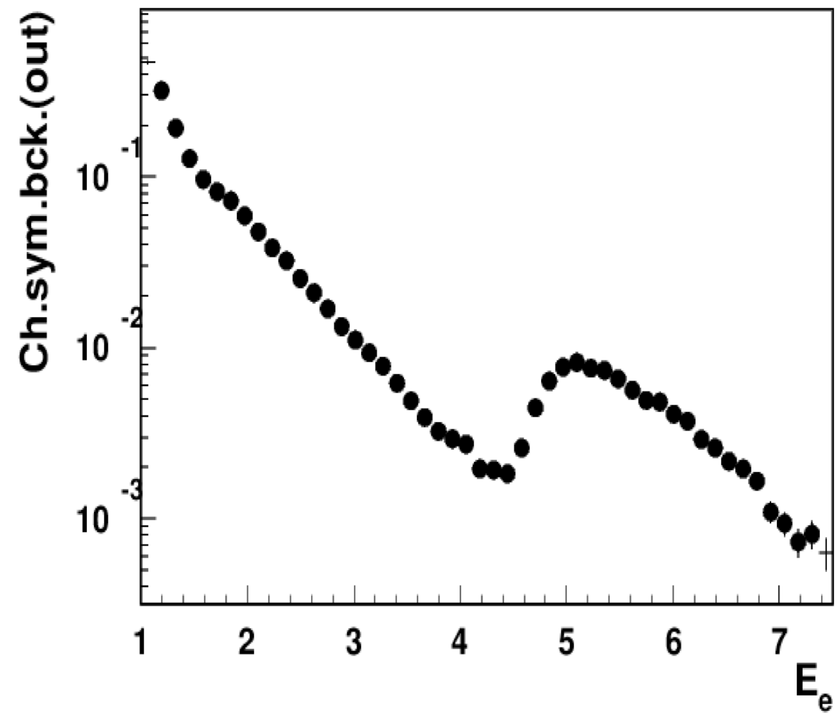


- Significant fraction of inclusive events in reconstructed sample comes with photon
- Most affected the sample of electrons with E_e < 2GeV

Sources of systematics: charge symmetric background

W>2 GeV outbending background

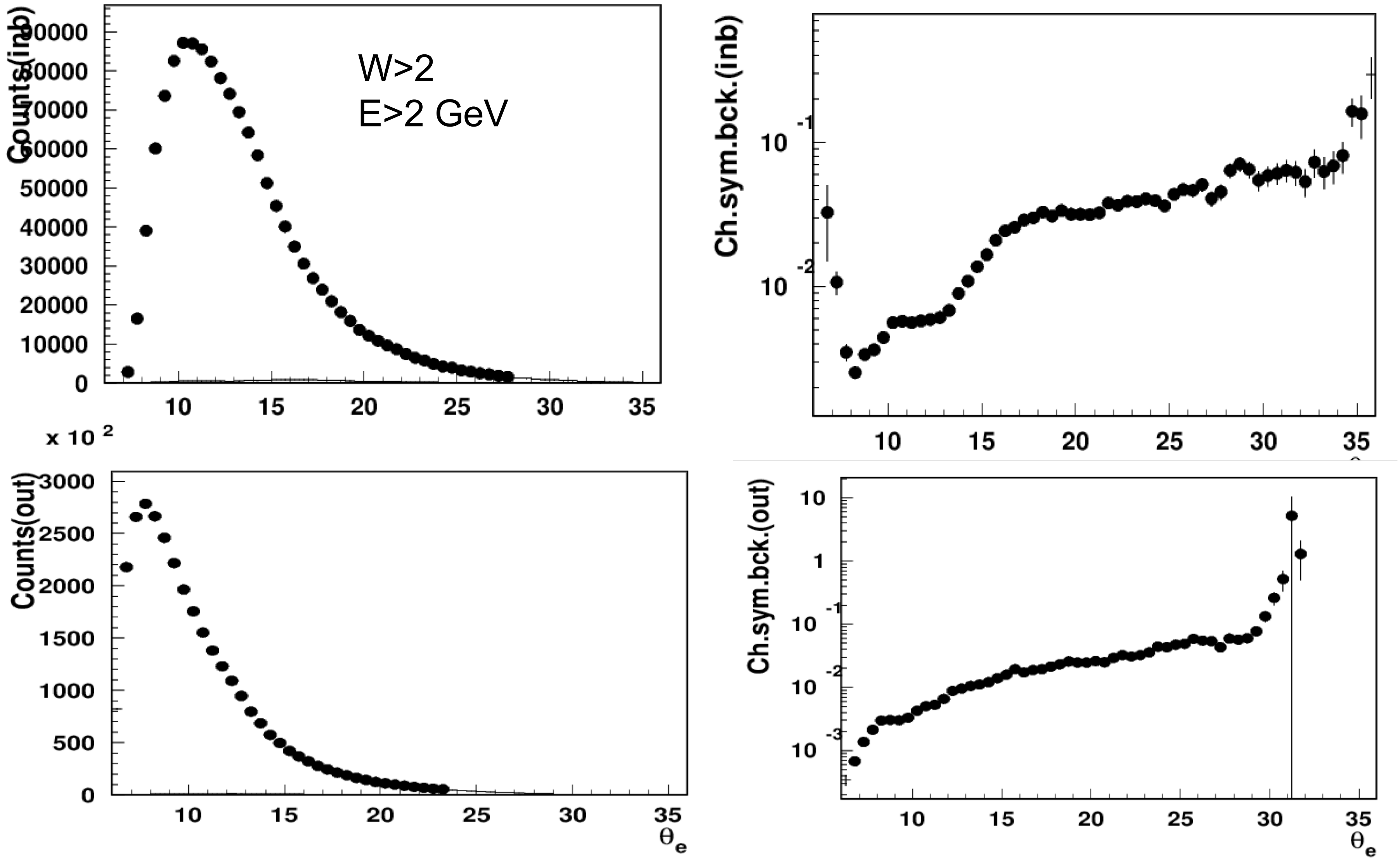




Bump ~5GeV most likely due to misidentification of leptons

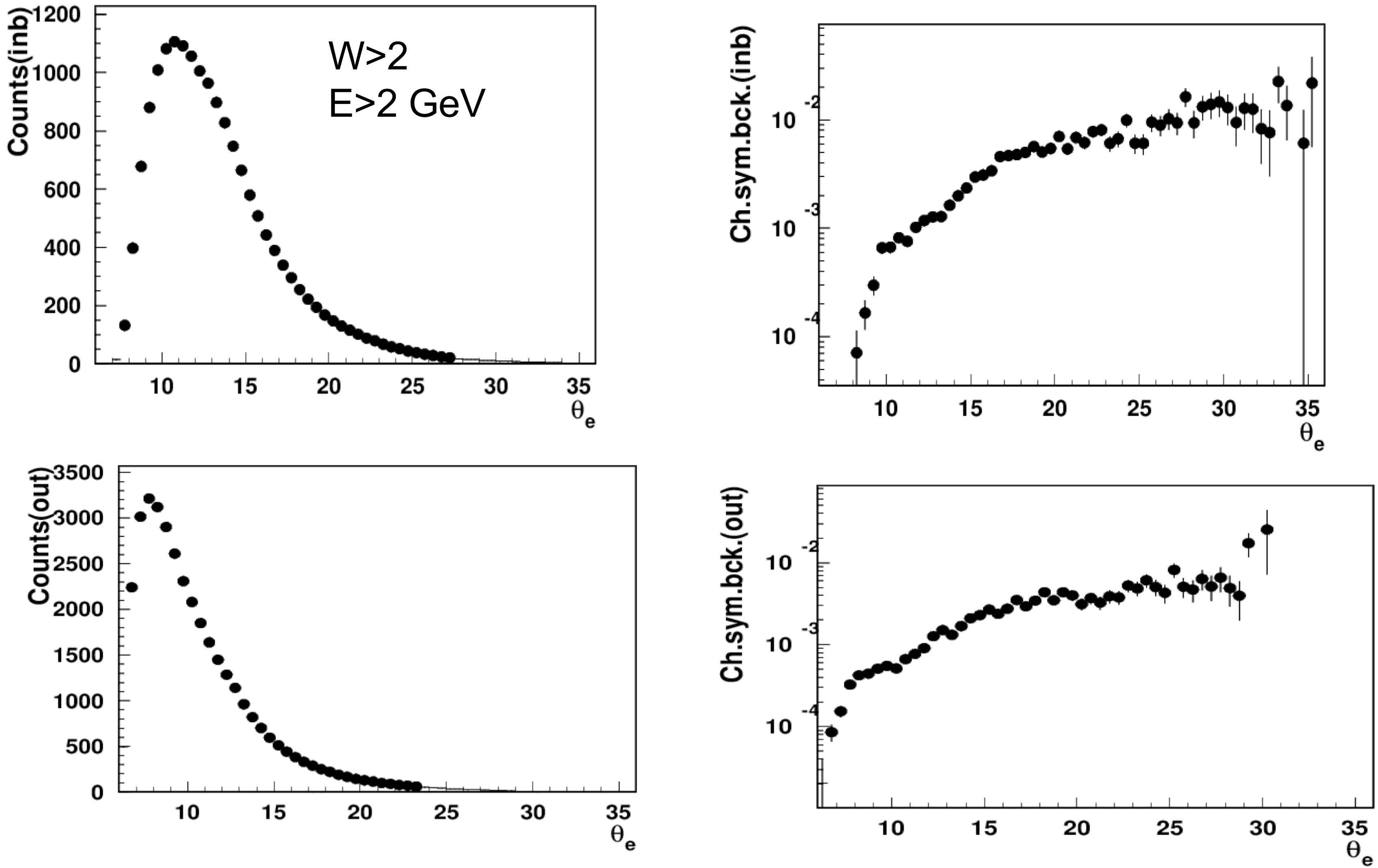
Positrons in the inbending configuration provide an estimate for "non-DIS" electrons in outbending and vice a versa

Sources of systematics: charge symmetric background (RGA)



Contamination at large angles may be significant

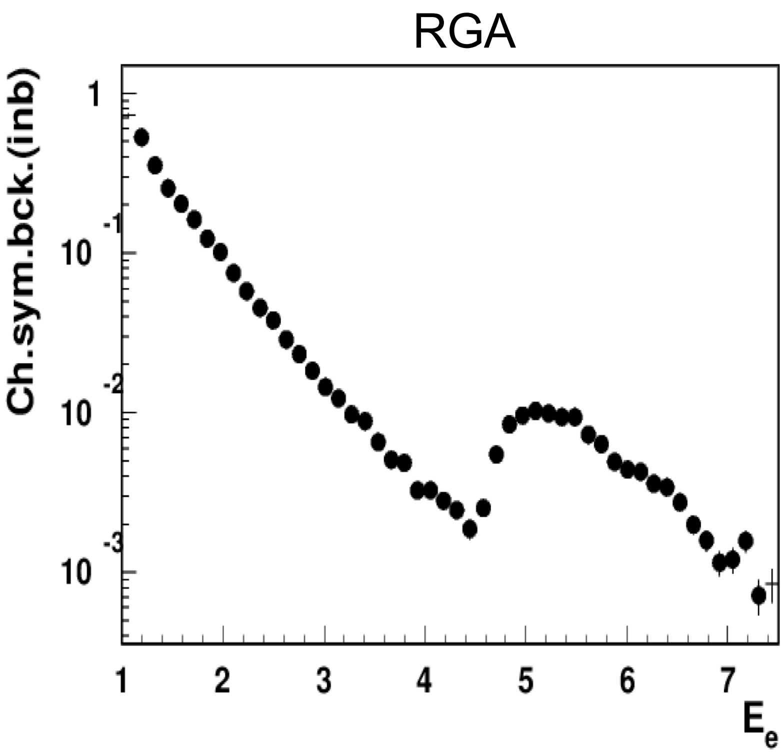
Sources of systematics: charge symmetric background(RGB)

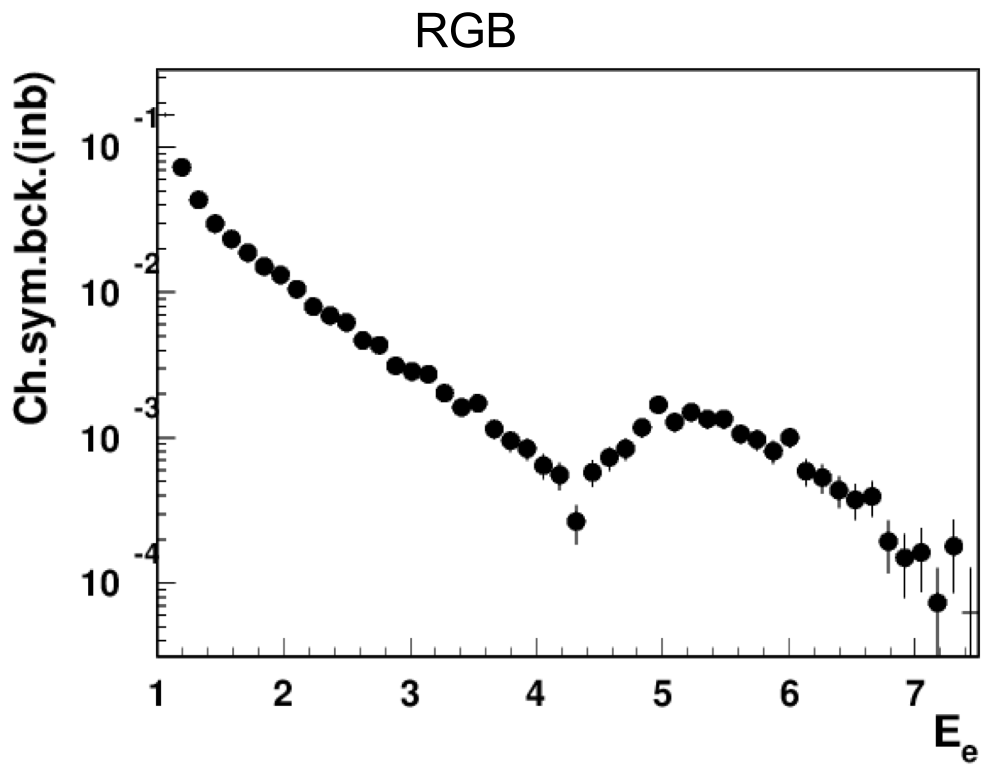


Contamination at large angles is more significant, but less than in RGA

Sources of systematics: charge symmetric background

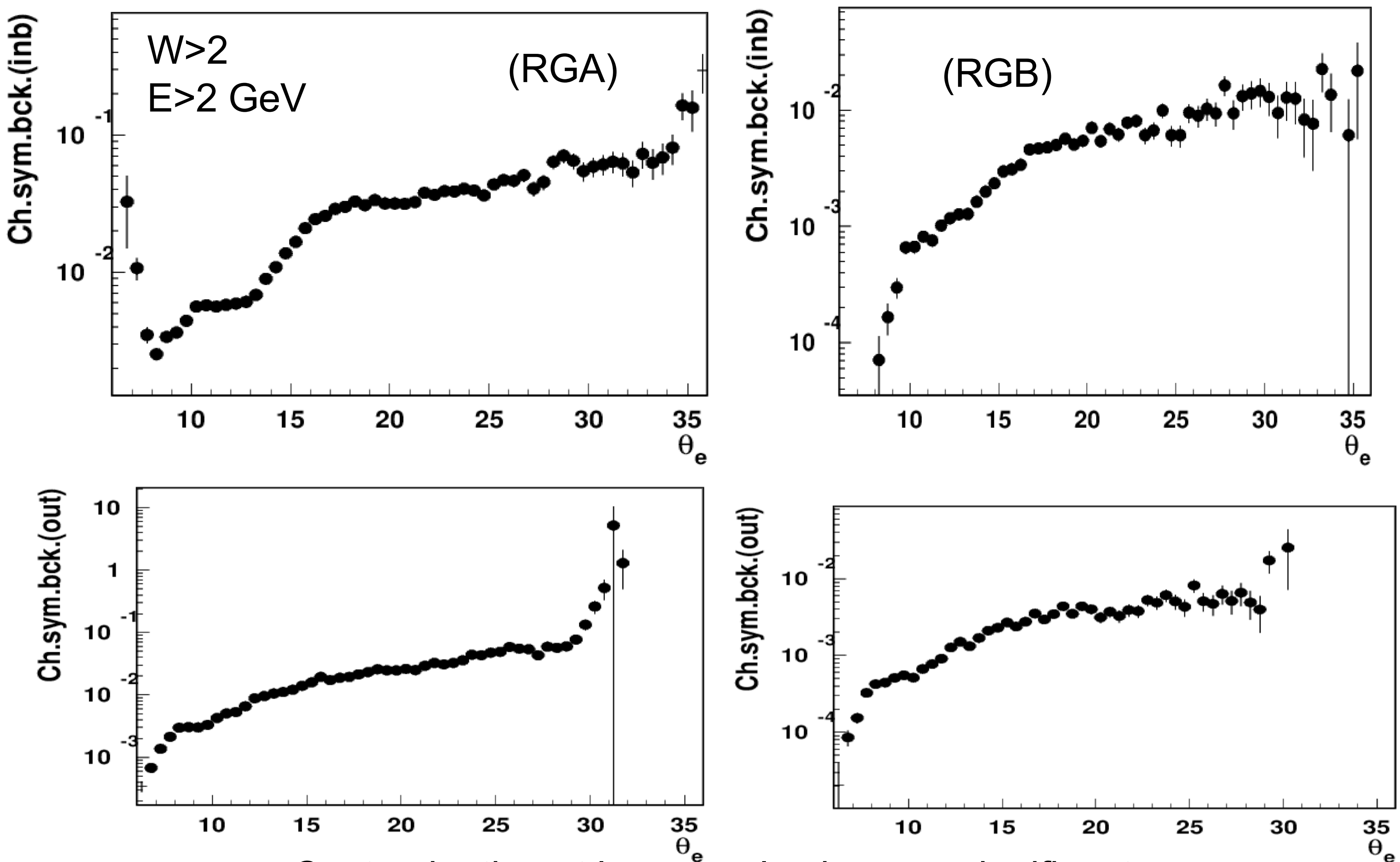
W>2 inbending background





e+ in outbending used for estimate of inbending e-, and vice a versa
Main contribution at small energies of electrons
Bump ~5GeV most likely due to misidentification of leptons

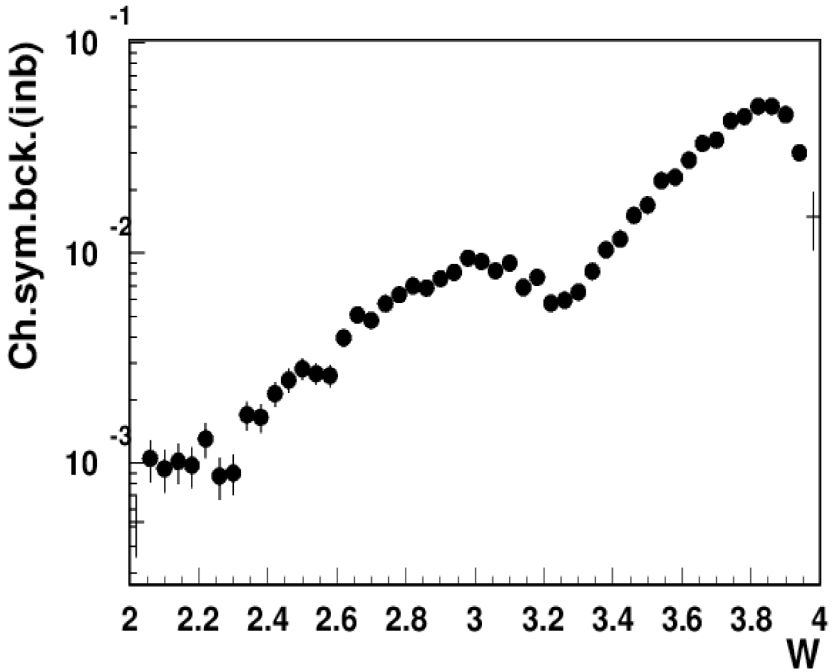
Sources of systematics: charge symmetric background



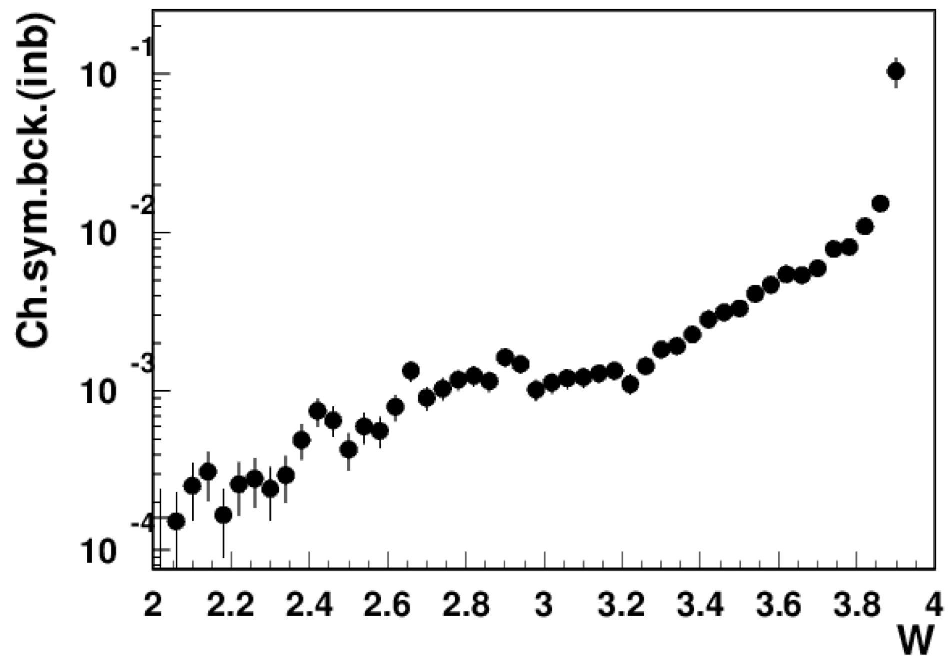
- Contamination at large angles is more significant
- Significantly less background in RGB than in RGA

Sources of systematics: charge symmetric background

RGA



RGB



Contamination in kinematical variables may be very significant

SUMMARY & CONCLUSIONS

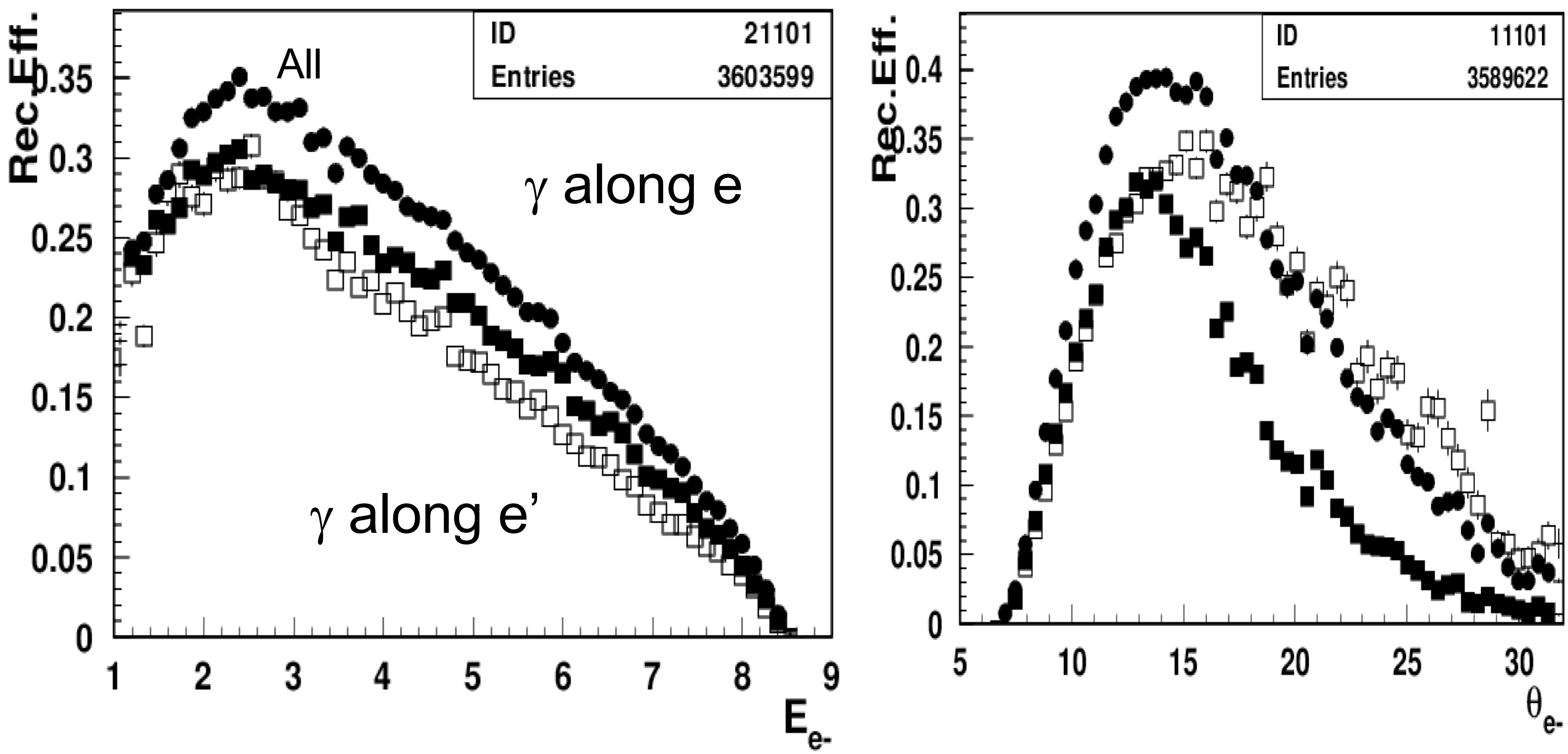
- CLAS12 outbending samples complementary to inbending and crucial for estimates of systematics (physics, detector,..)
- Contribution of ”non-DIS” electron events from charge symmetric background estimated using the positrons in the same kinematics
- Systematics due to contamination of “non-DIS” electrons should be accounted in measurements of kinematical distributions in DIS and SIDIS ($x,Q^2,W,\ldots$)
- The fraction of low energy electrons in CLAS12 has significant contribution from photoproduction and radiative DIS

In most of the kinematics, outbending configuration provides significantly higher statistics, complementary to inbending coverage <u>(50/50 configuration should be considered in future)</u>

- Support slides

Radiative DIS

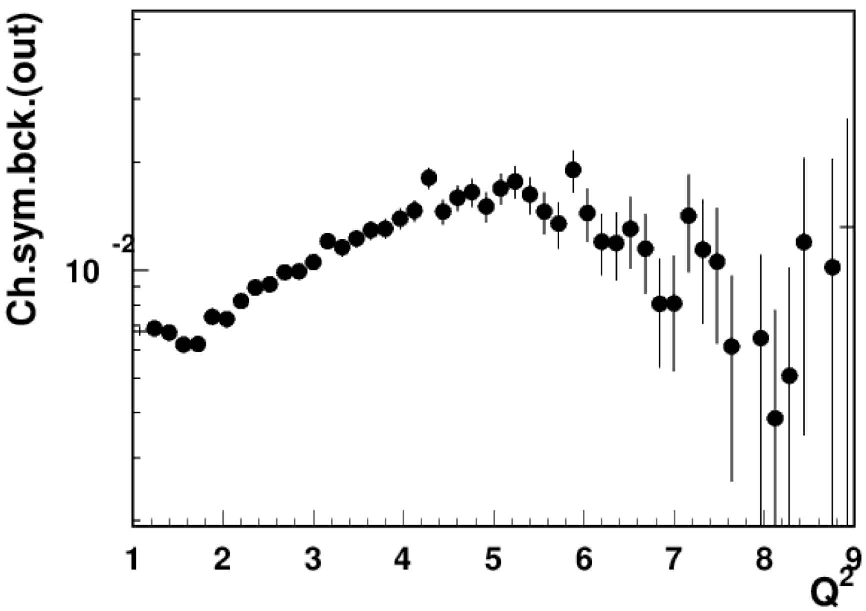
Radiative DIS MC (internal)

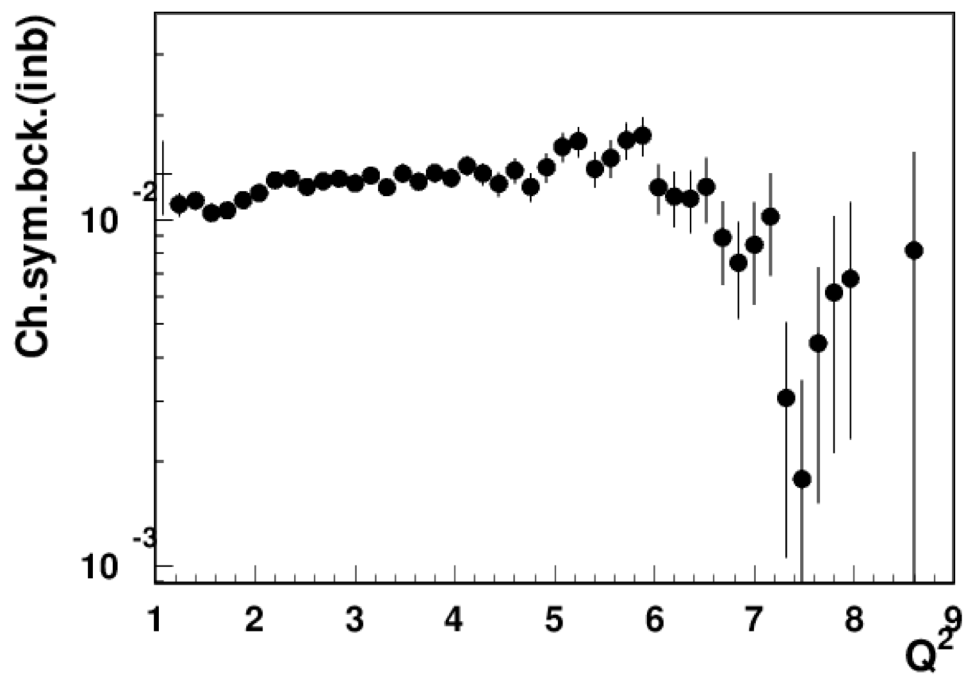


Lower energies and large angles reconstructed better with photon (quality to be checked)

Sources of systematics: charge symmetric background

E>2 GeV

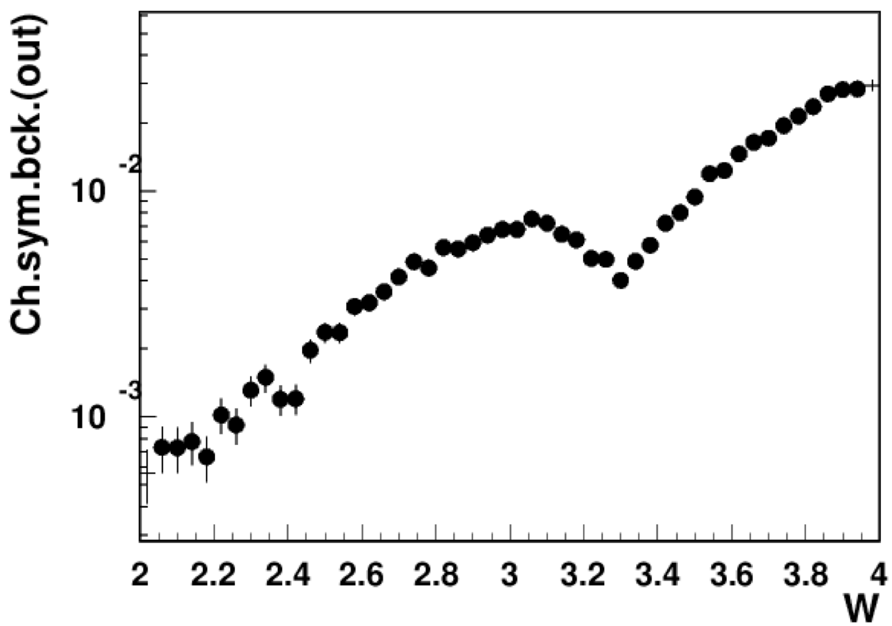


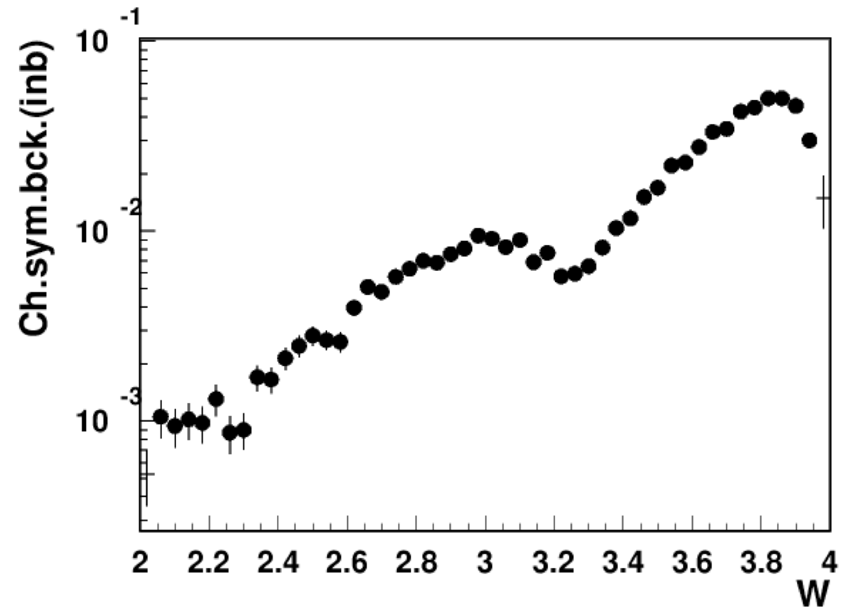


Contamination in kinematical variables with E>2 GeV, 1-5%

Sources of systematics: charge symmetric background

E>2 GeV





Contamination in kinematical variables with E>2 GeV, 1-5%

Sources of systematics: charge symmetric background

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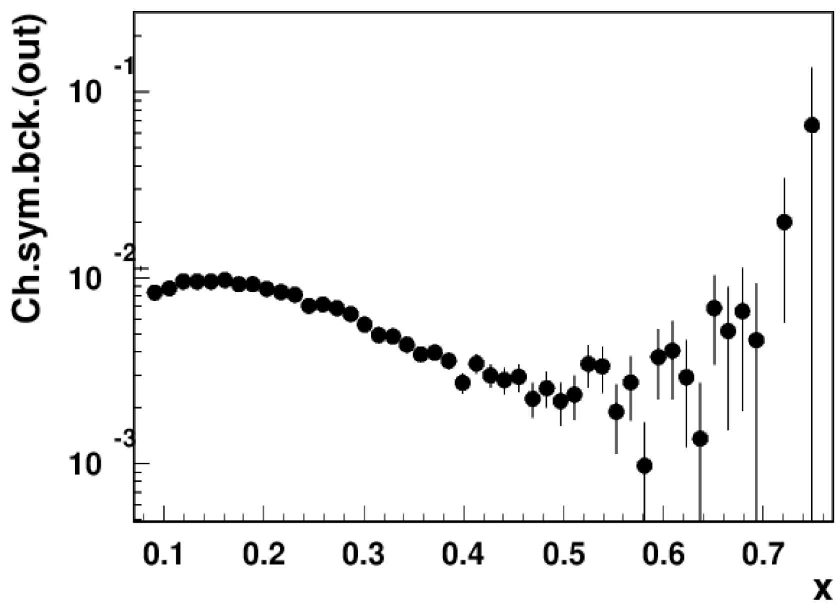
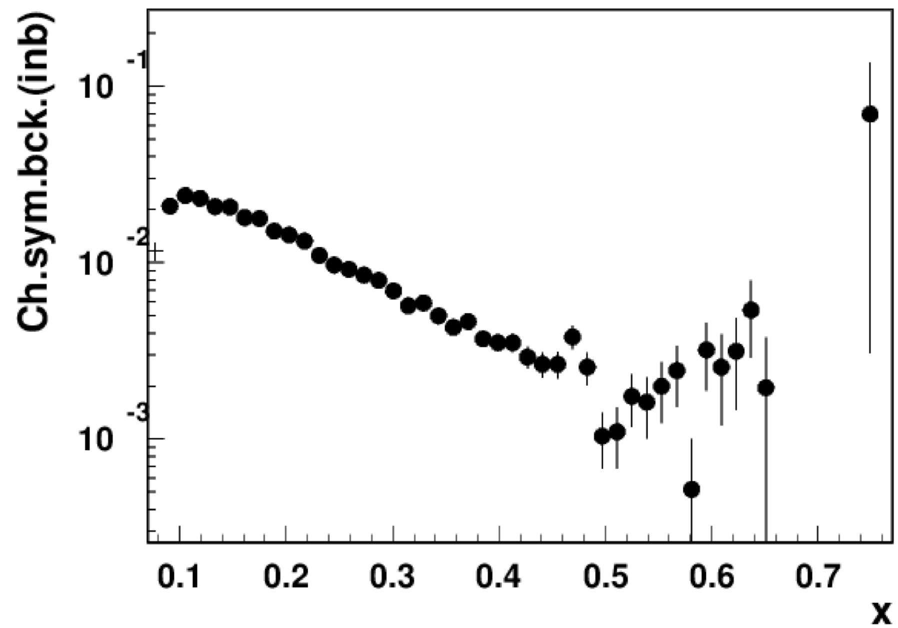
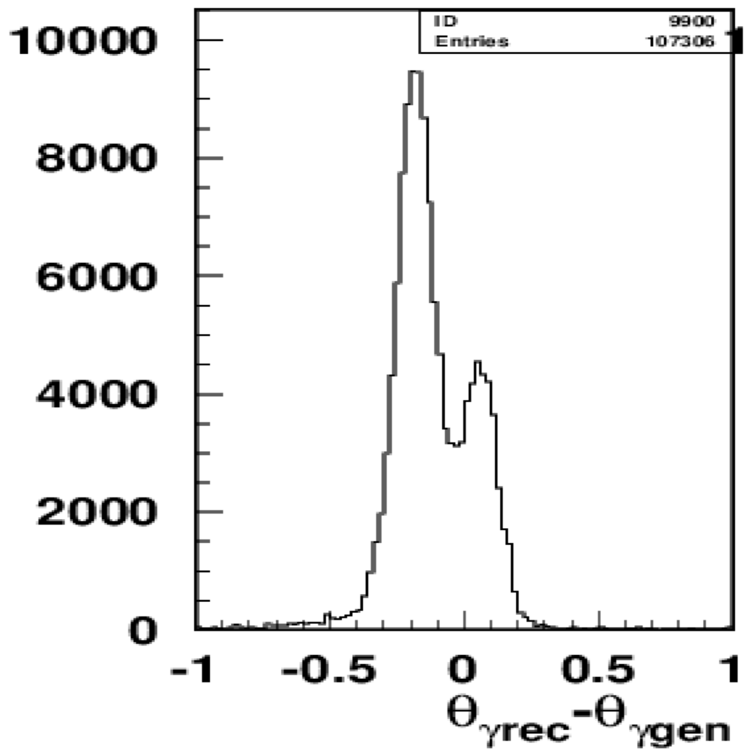


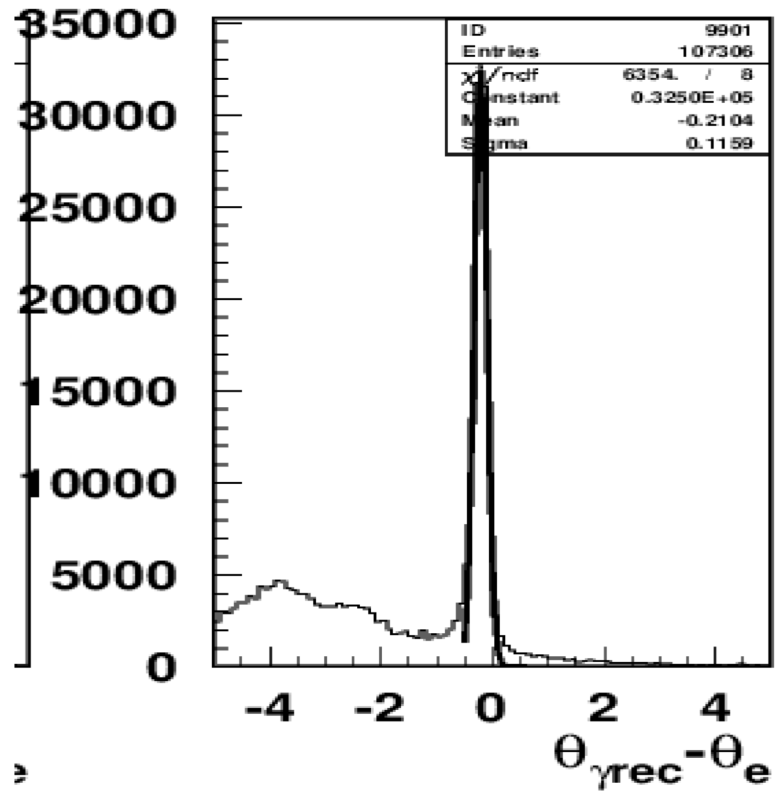


Contamination in kinematical variables with E>2 GeV, 1-3%

Radiative DIS: photons in CLAS12

Radiative DIS MC (internal)



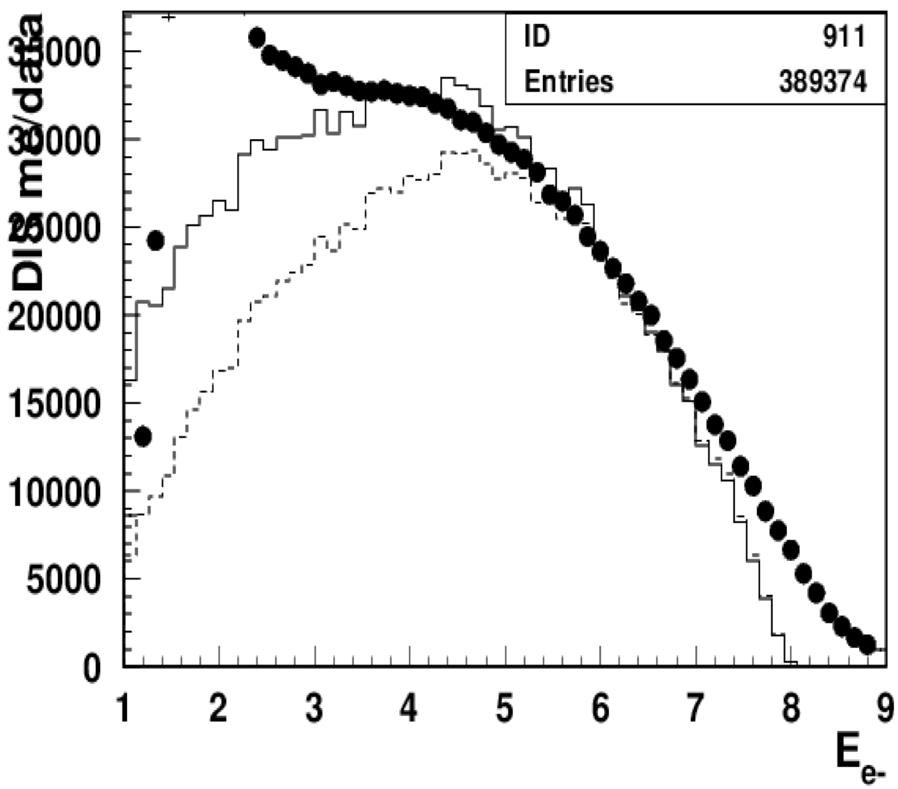


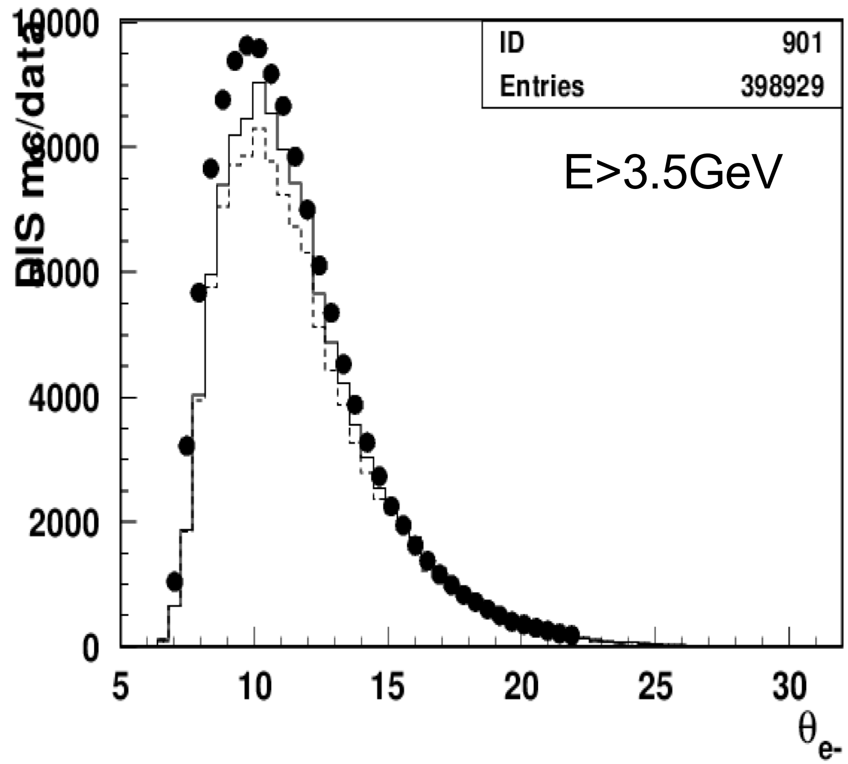
Double peak in reconstructed photon angles

All photons along the e' within 1 degree

Radiative DIS

Radiative DIS studied using radgen based clas12-DIS MC
https://github.com/JeffersonLab/inclusive-dis-rad

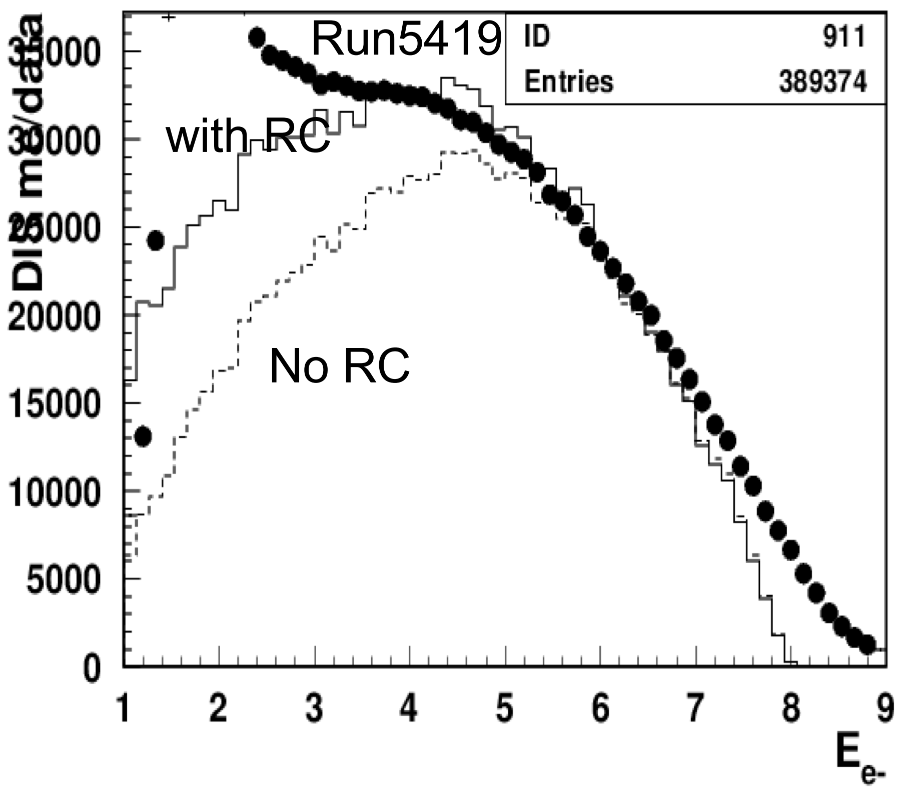


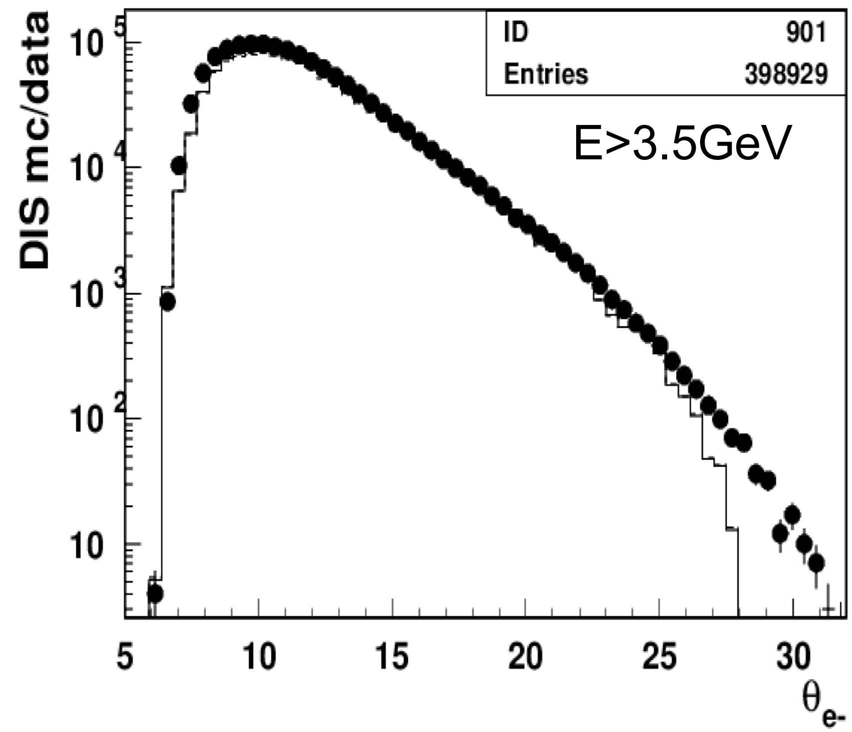


Radiative effects increase the fraction of low energy electrons
Comparison indicates more Radiation in data (possibly external)

Radiative DIS

Radiative DIS MC (internal)





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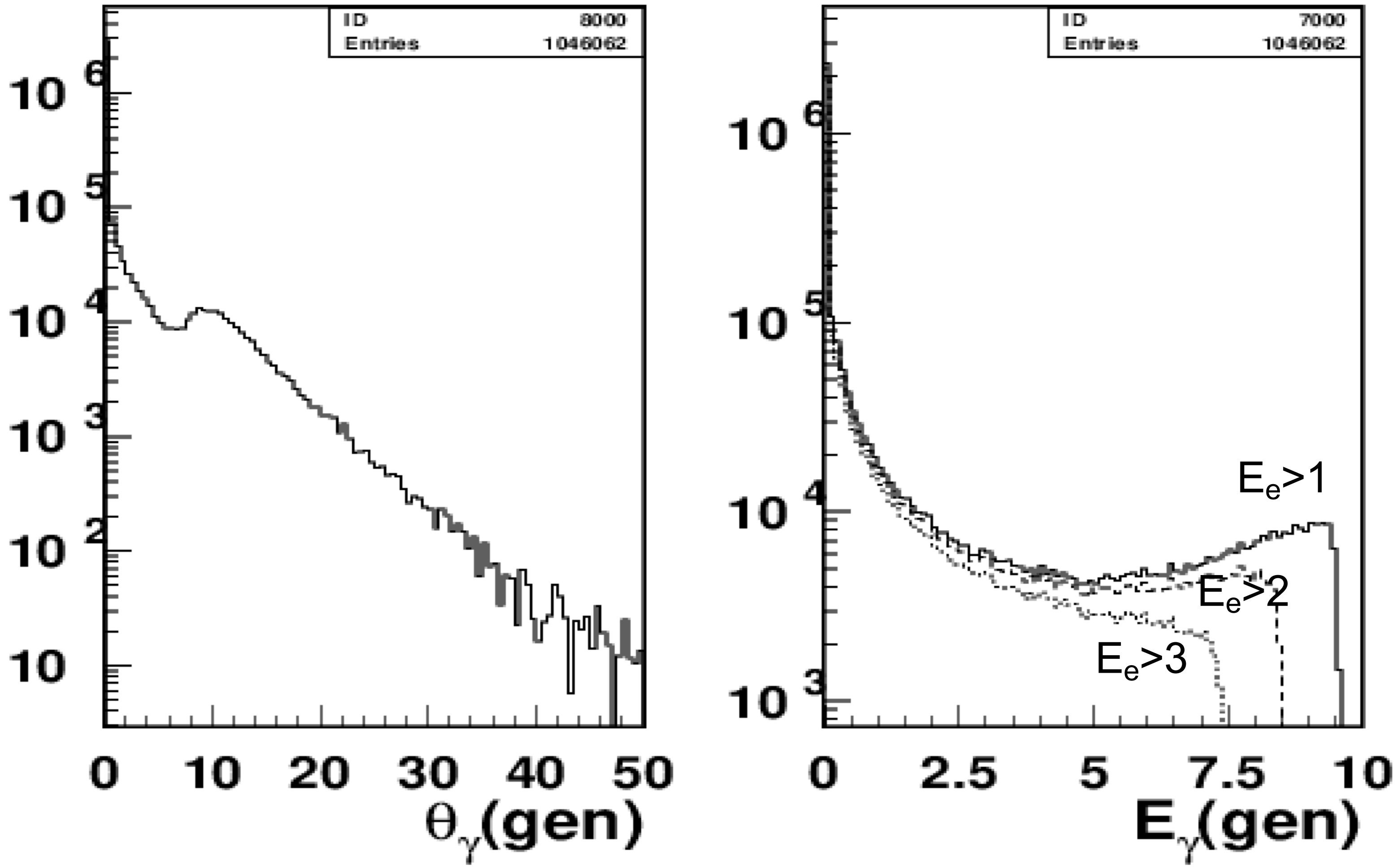
Radiative DIS: photons in CLAS12

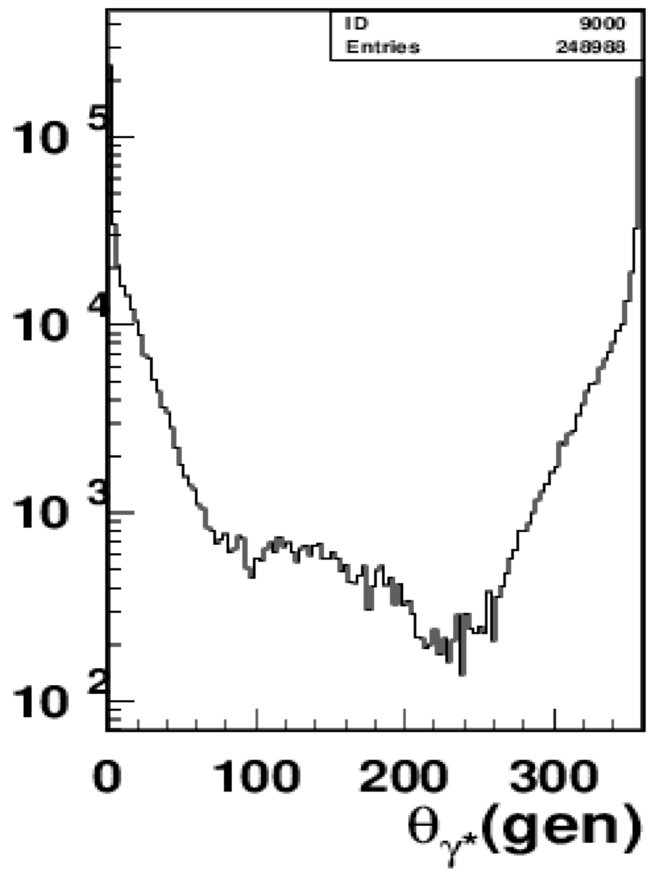
Radiative DIS MC (internal)

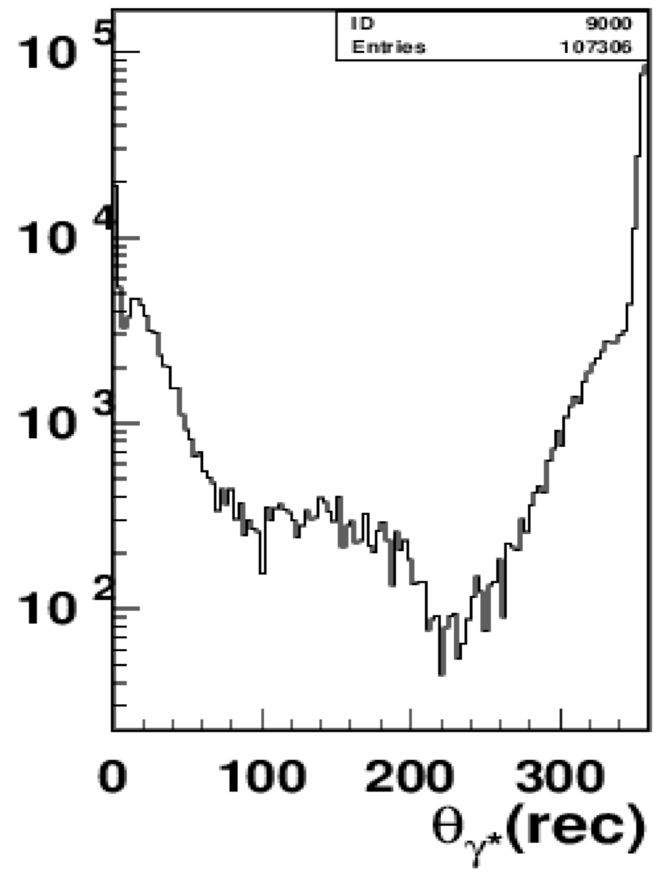


Dominating directions for photons, along the incoming and scattered electrons
Higher the energy cut for e' less phase space for hard photons

Radiative DIS: photons in CLAS12

Radiative DIS MC (internal)



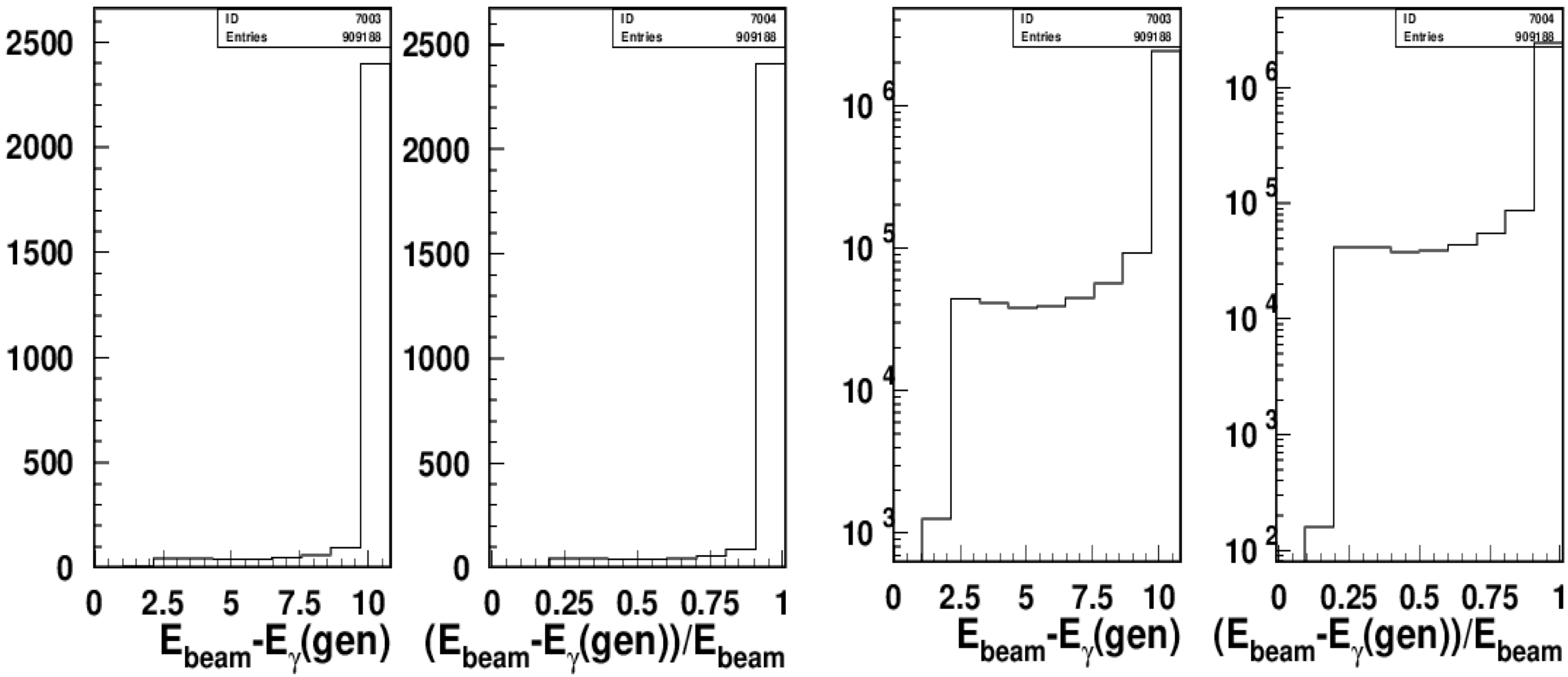


BH photons mainly at 0 and 360, and due to kick of e' have also non-zero sin moment

Radiative DIS: modification of beam energy

Radiative DIS MC (internal)

Log scale

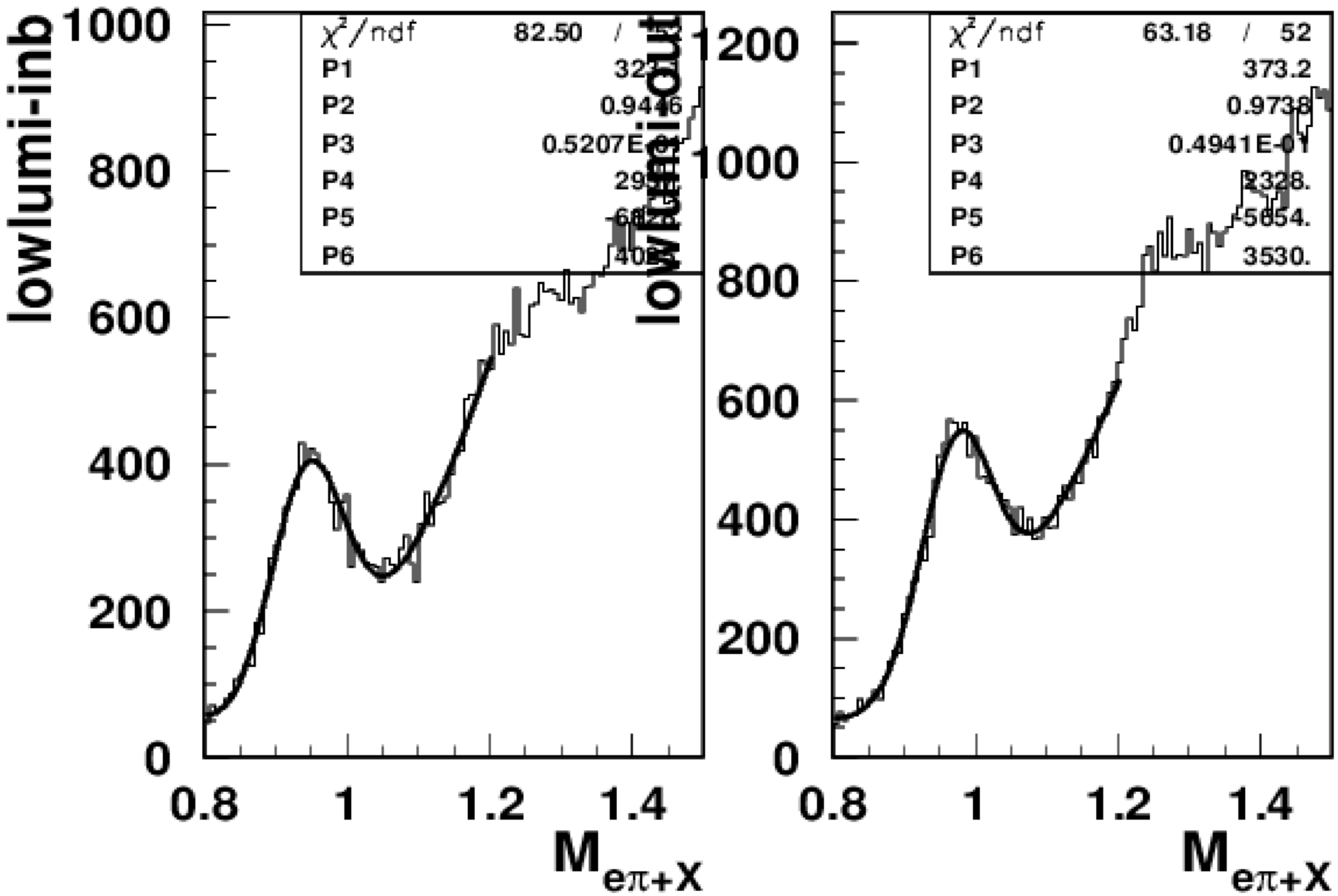


Significant fraction of electrons scatter with lower beam energies

Summary on Radiative DIS

- RC modify the kinematics, effectively reducing the beam energy for a fraction of events
- About 20% of events have a photon along the beam, and ~7% along the scattered electron
- Events with photon radiation, mainly along the beam, have different reconstruction efficiencies
- At lower energies the fraction of events with additional photon radiated very significant
- Most of the photons radiated by scattered electron are within 1 degree
- Photon reconstruction may be improved (shows double peak)
- ……

RGB missing masses

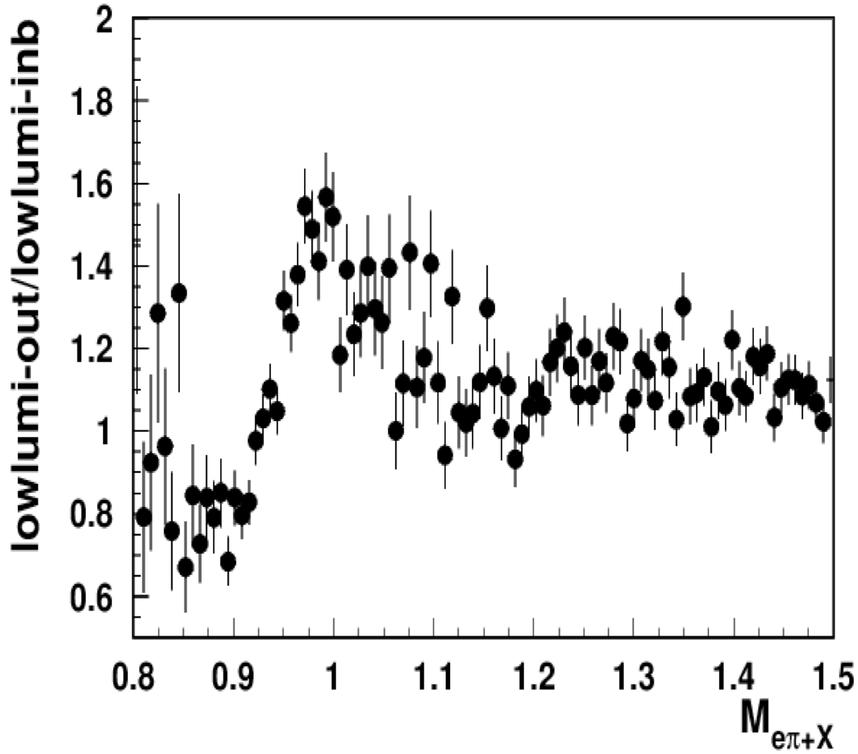


Peak shifted in outbending

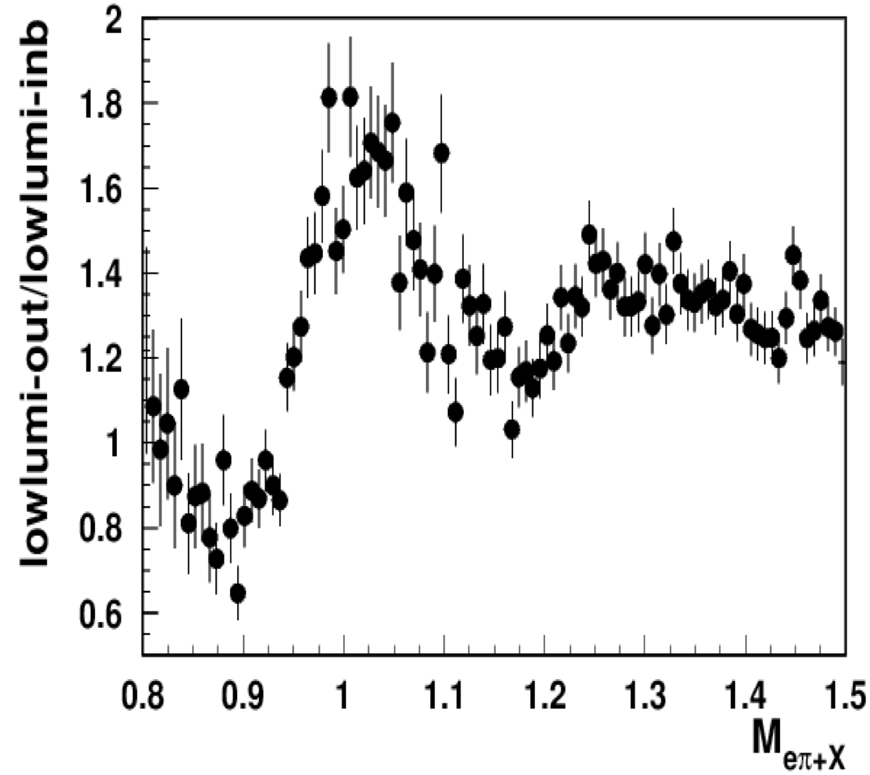
2h SIDIS: inbending vs outbending

Comparable counts for e-pi+

(RGA)

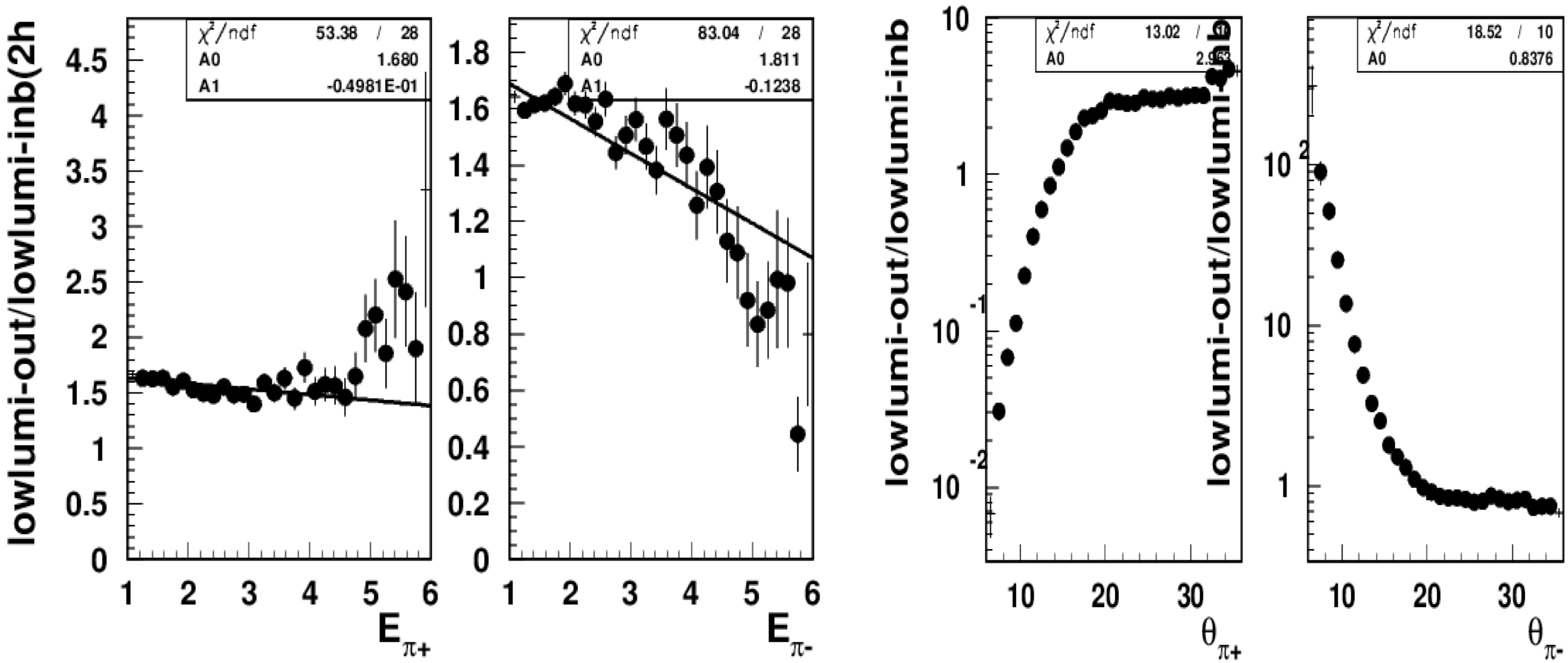


(RGB)



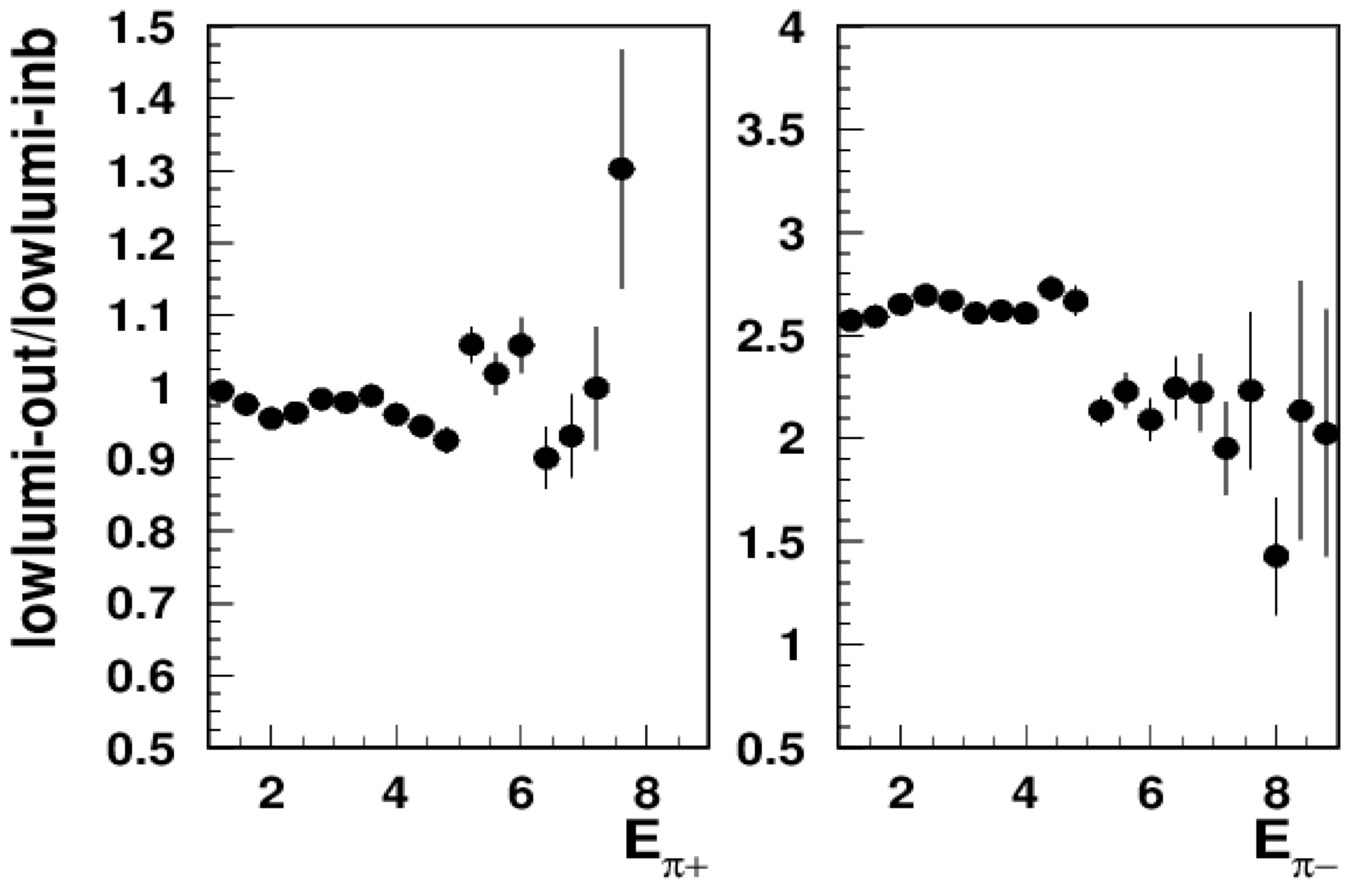
Similar shift of the peaks in RGA and RGB for inb vs outbending

2h SIDIS: inbending vs outbending



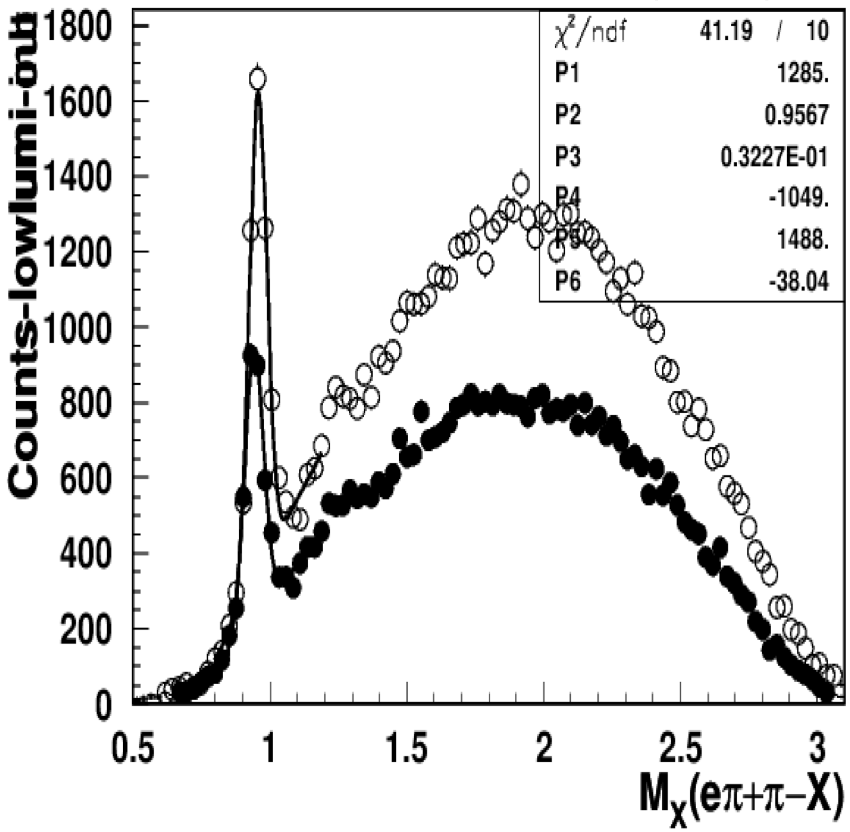
In the angular range from 15-30 degrees ratios flat

SIDIS: inbending vs outbending (RGB)

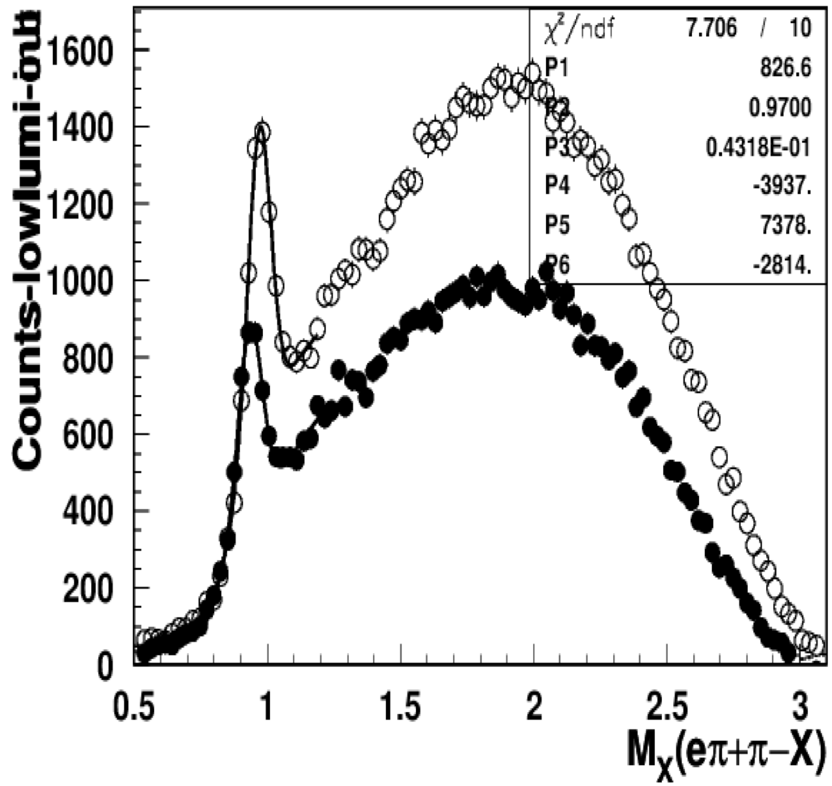


2h SIDIS: inbending vs outbending

(RGA)

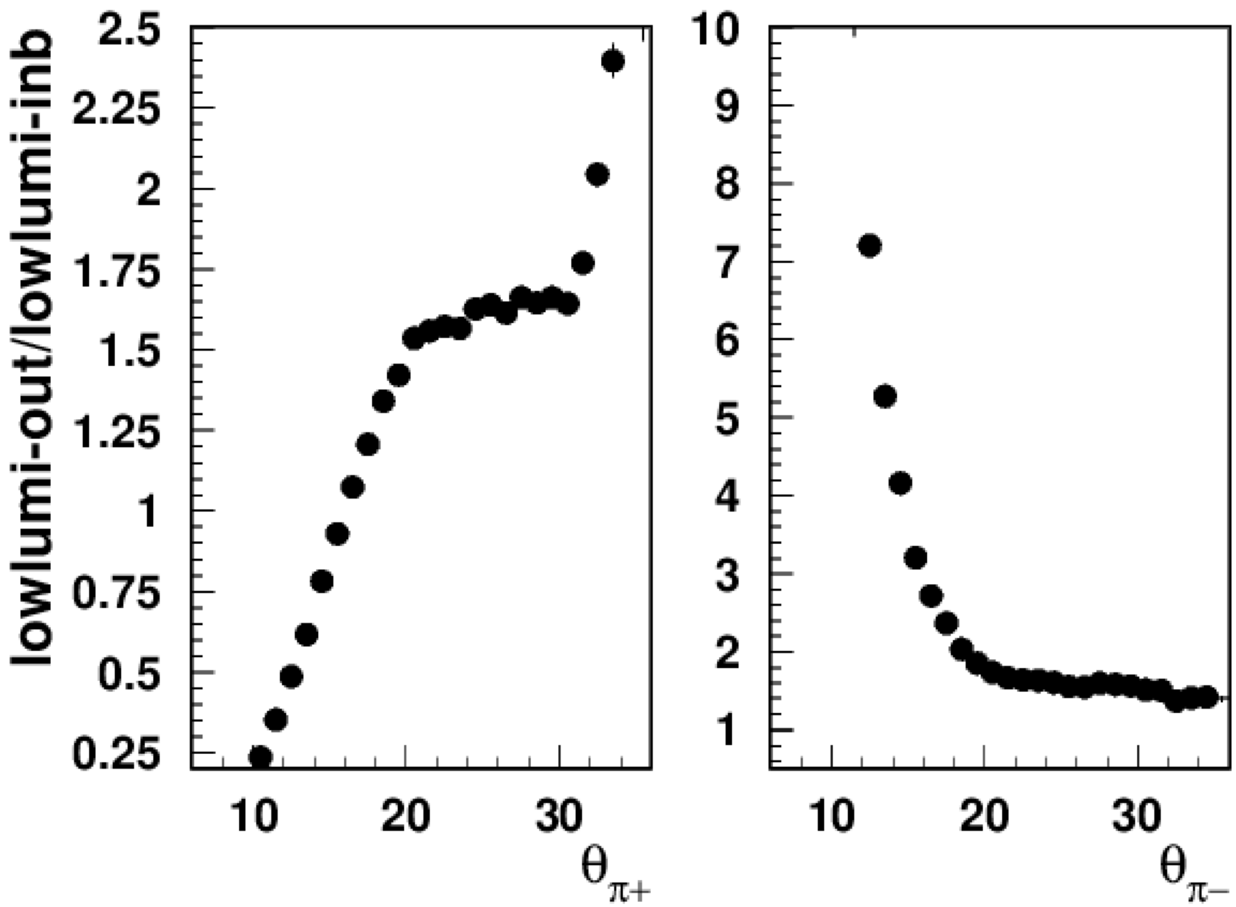


(RGB)



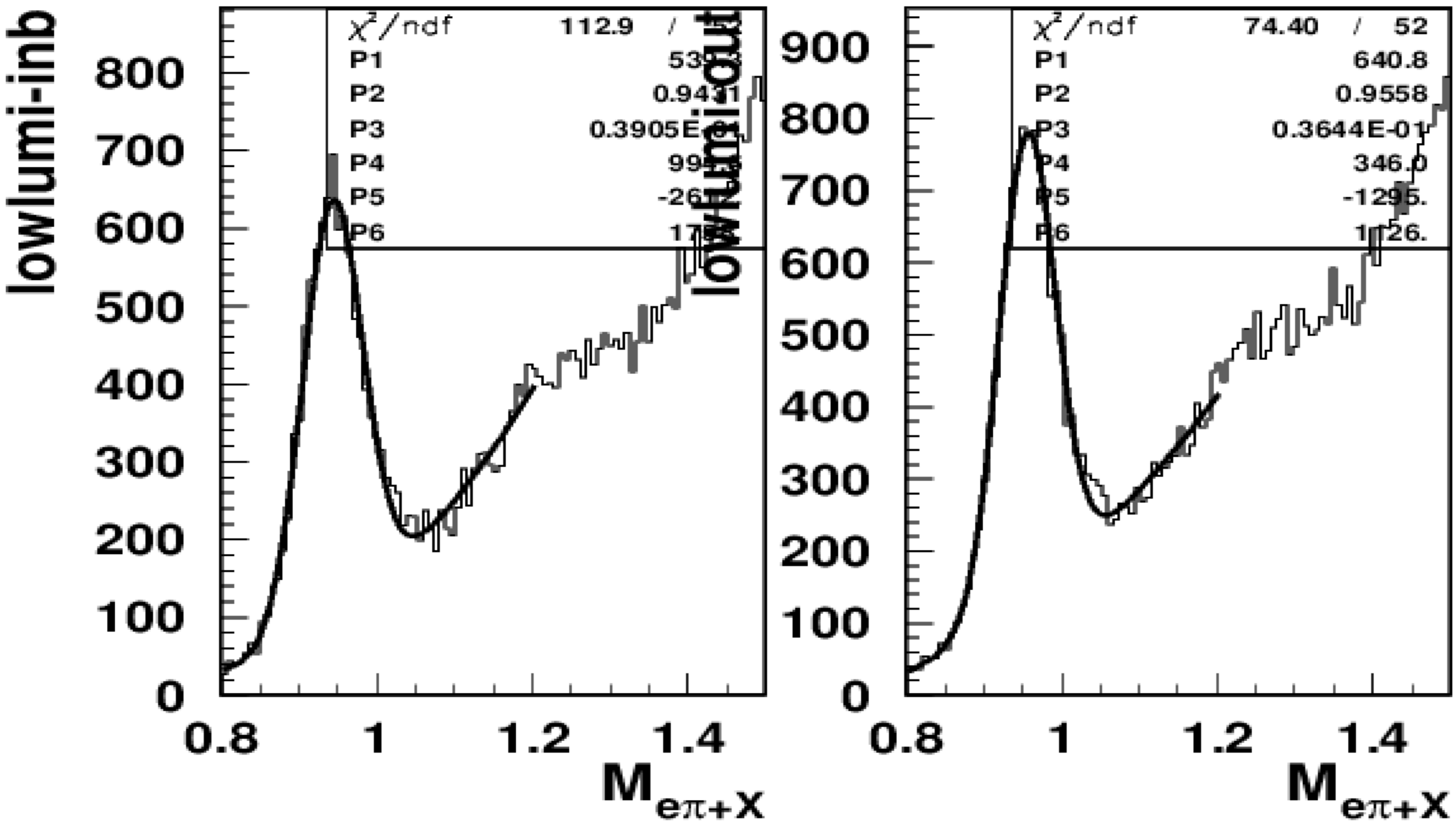
Significantly more counts for e-pi+pi- in outbending configuration (open symbols)

SIDIS: inbending vs outbending



Inbending and outbending complementary, cover very different kinematical ranges

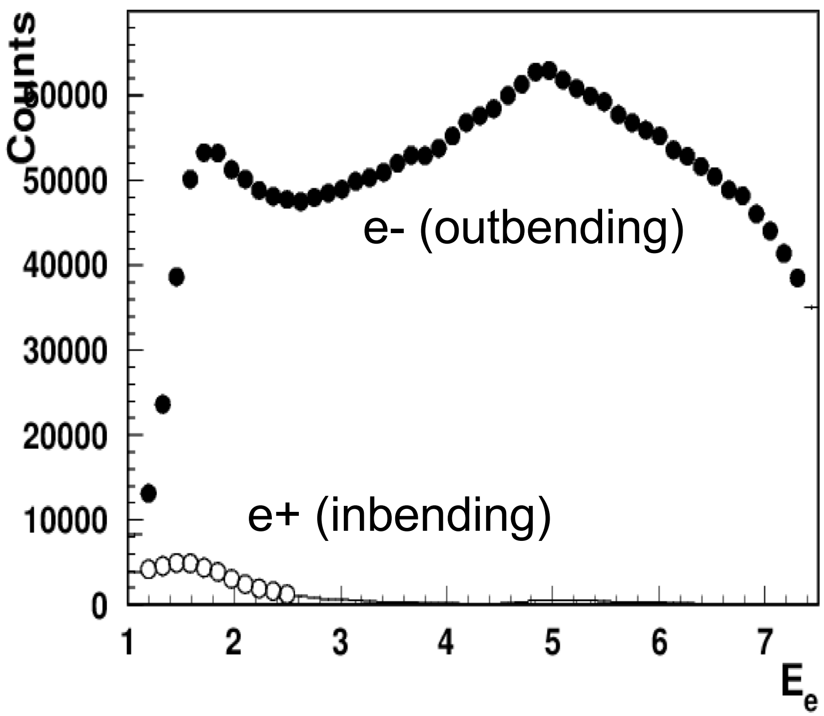
2h SIDIS: inbending vs outbending

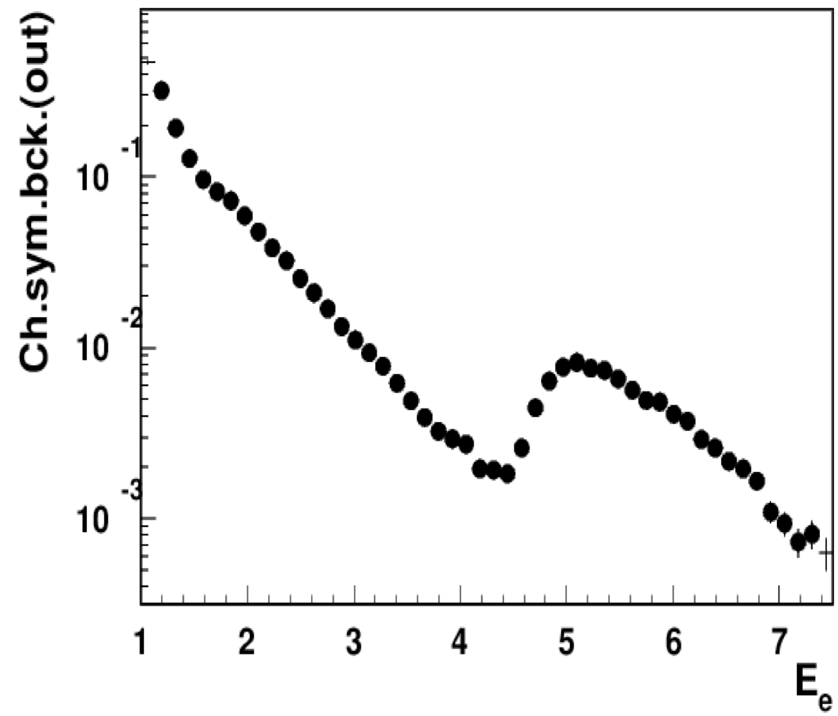


Comparable counts for e-pi+, slightly better resolution for outbending + more shift

Sources of systematics: charge symmetric background

W>2 GeV outbending background





Bump ~5GeV most likely due to misidentification of leptons

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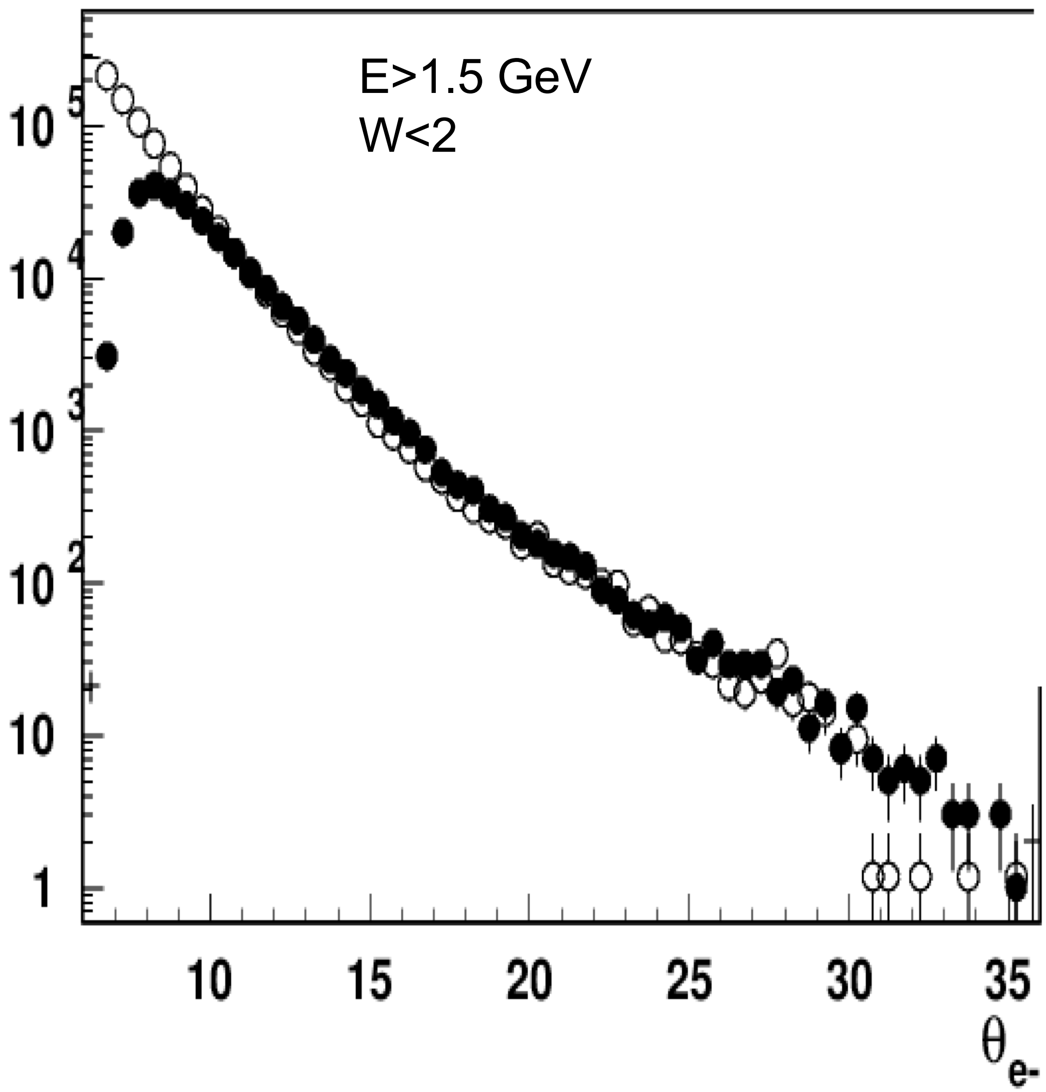
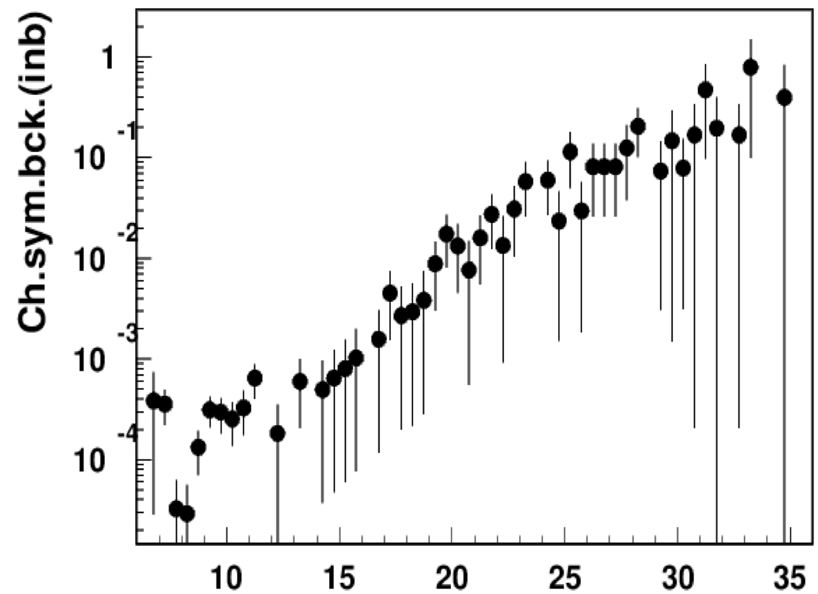
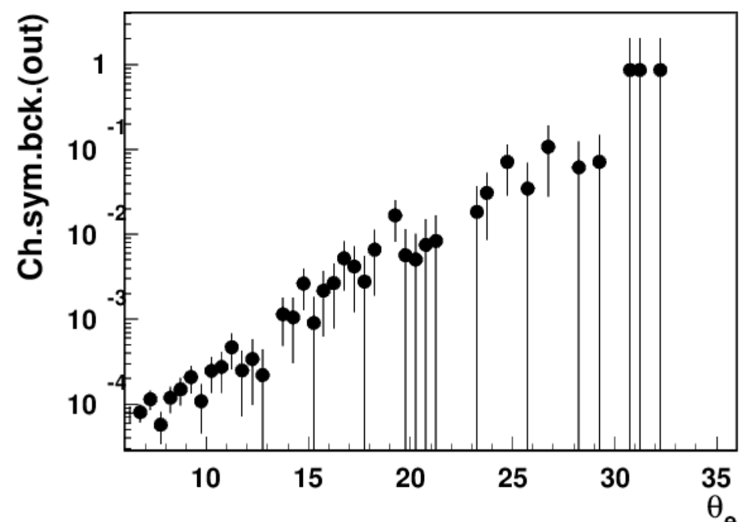
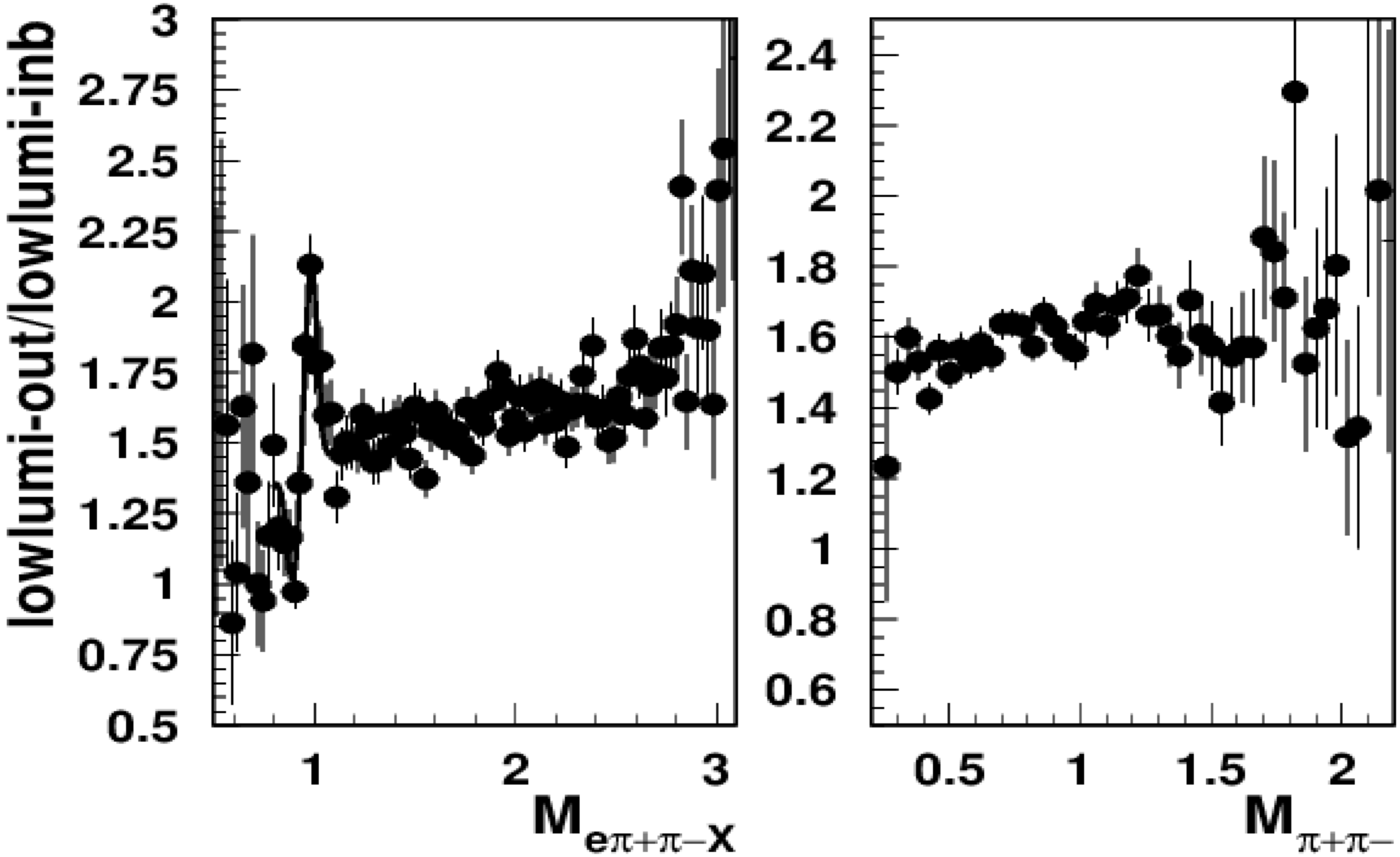




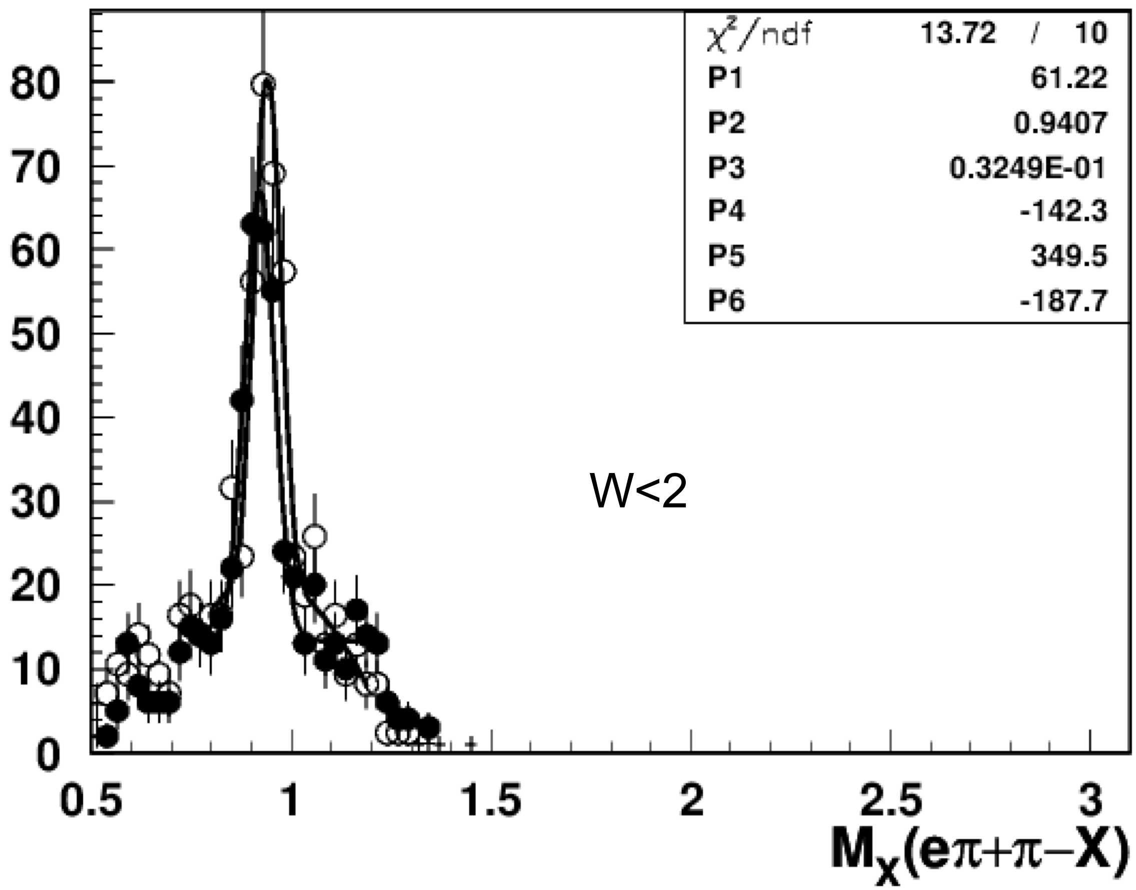


2h SIDIS: inbending vs outbending



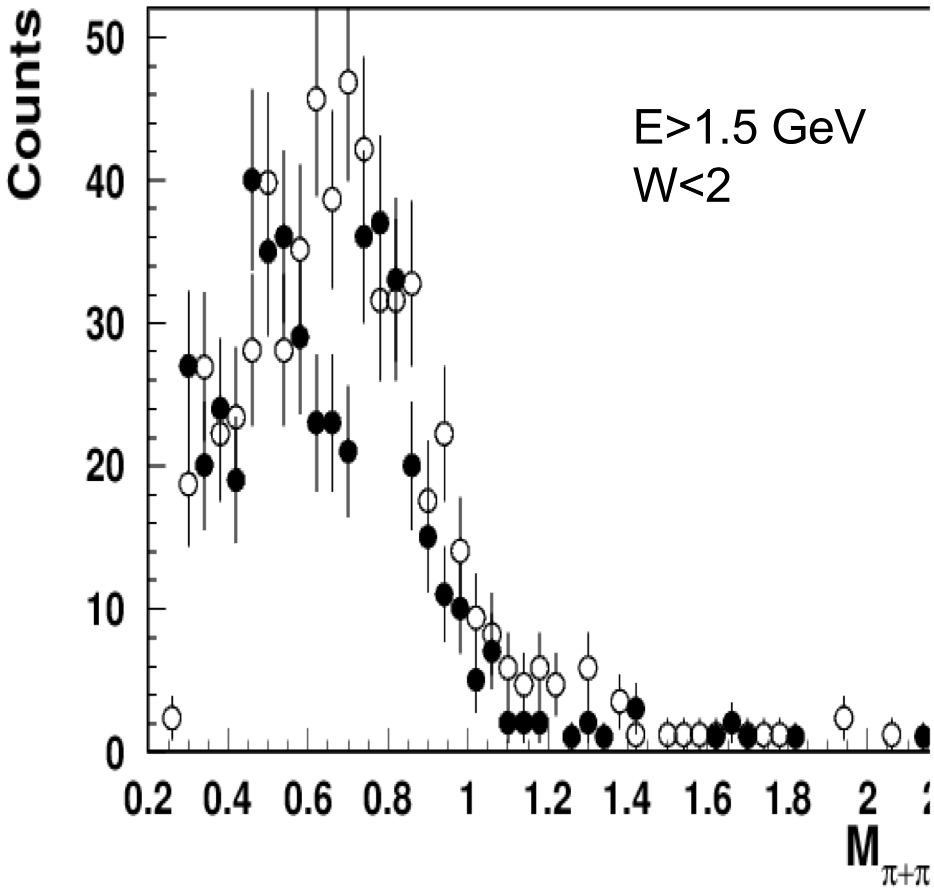
Significantly more counts for e-pi+pi- in outending configuration

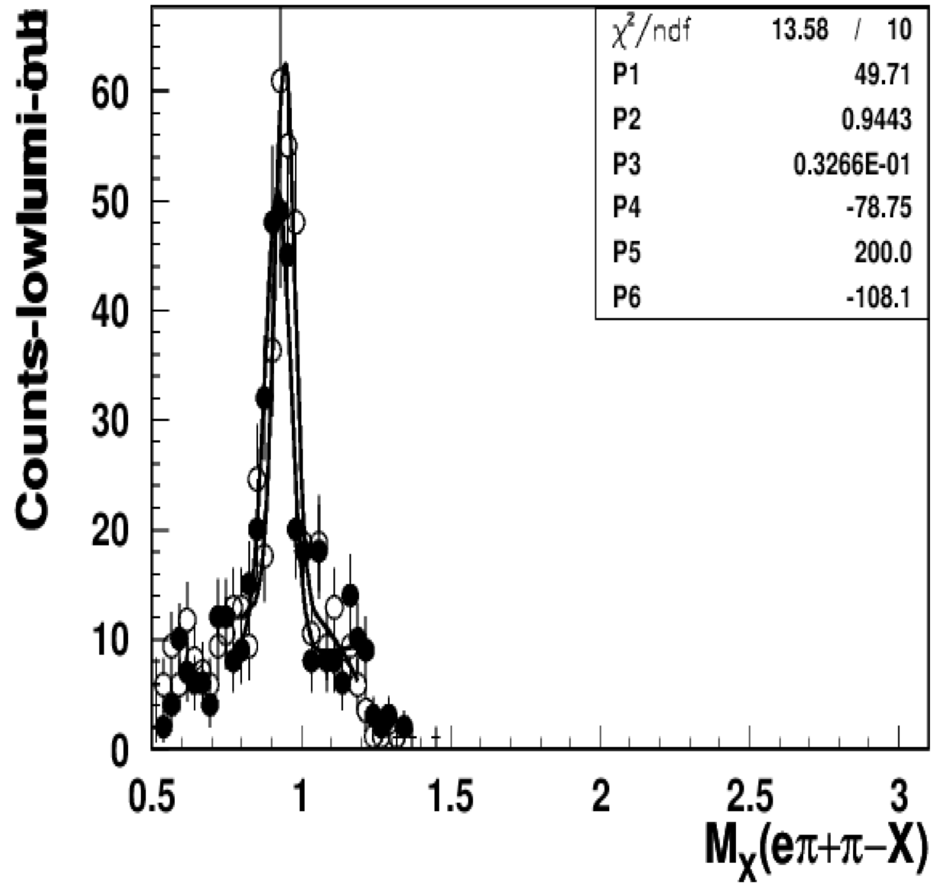
2h SIDIS: inbending vs outbending



At small w no much phase space to generate non-exclusive states
Resolution ~30 MeV, slightly better (and more shifted) for outbending

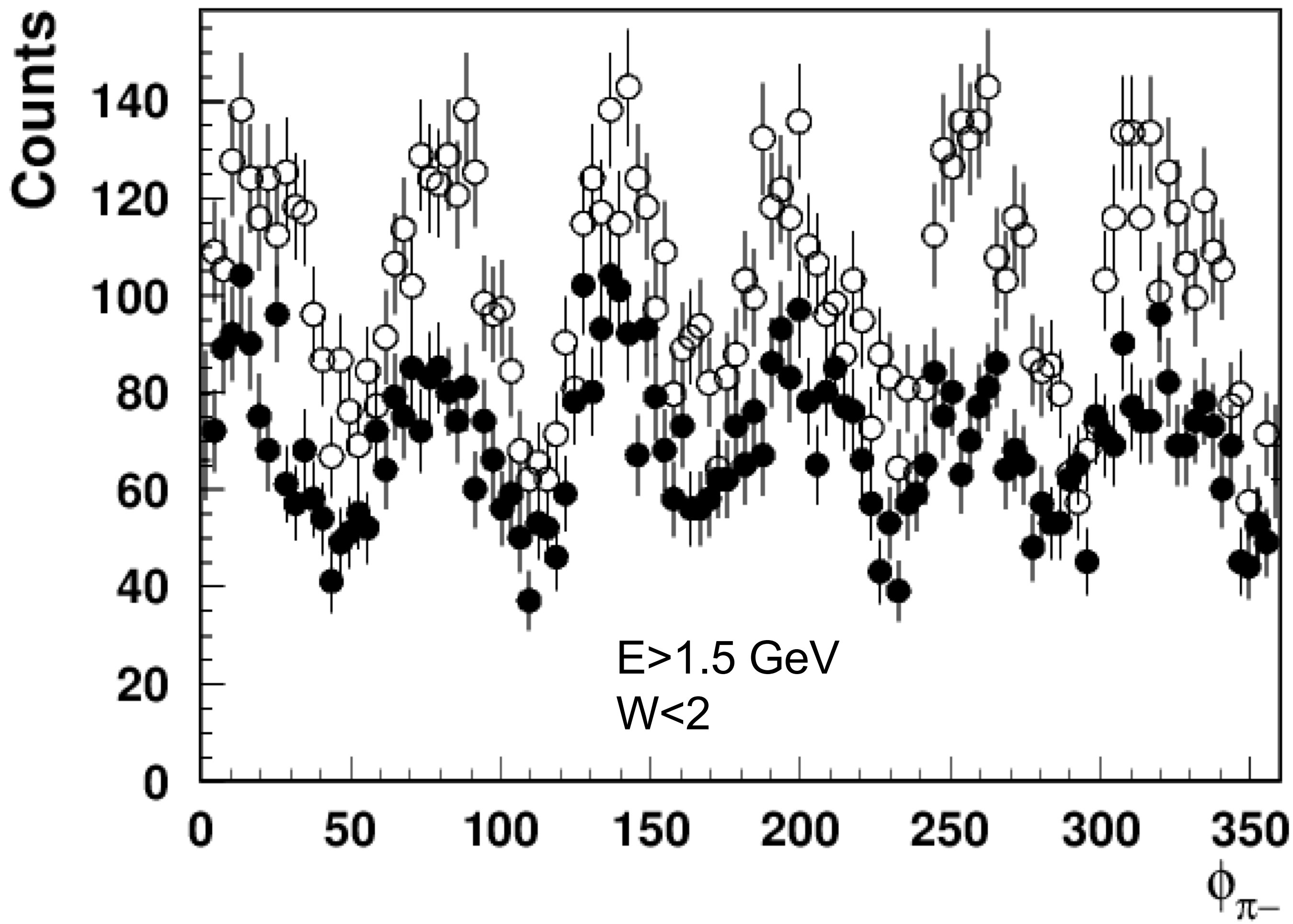
Sources of systematics: charge symmetric background





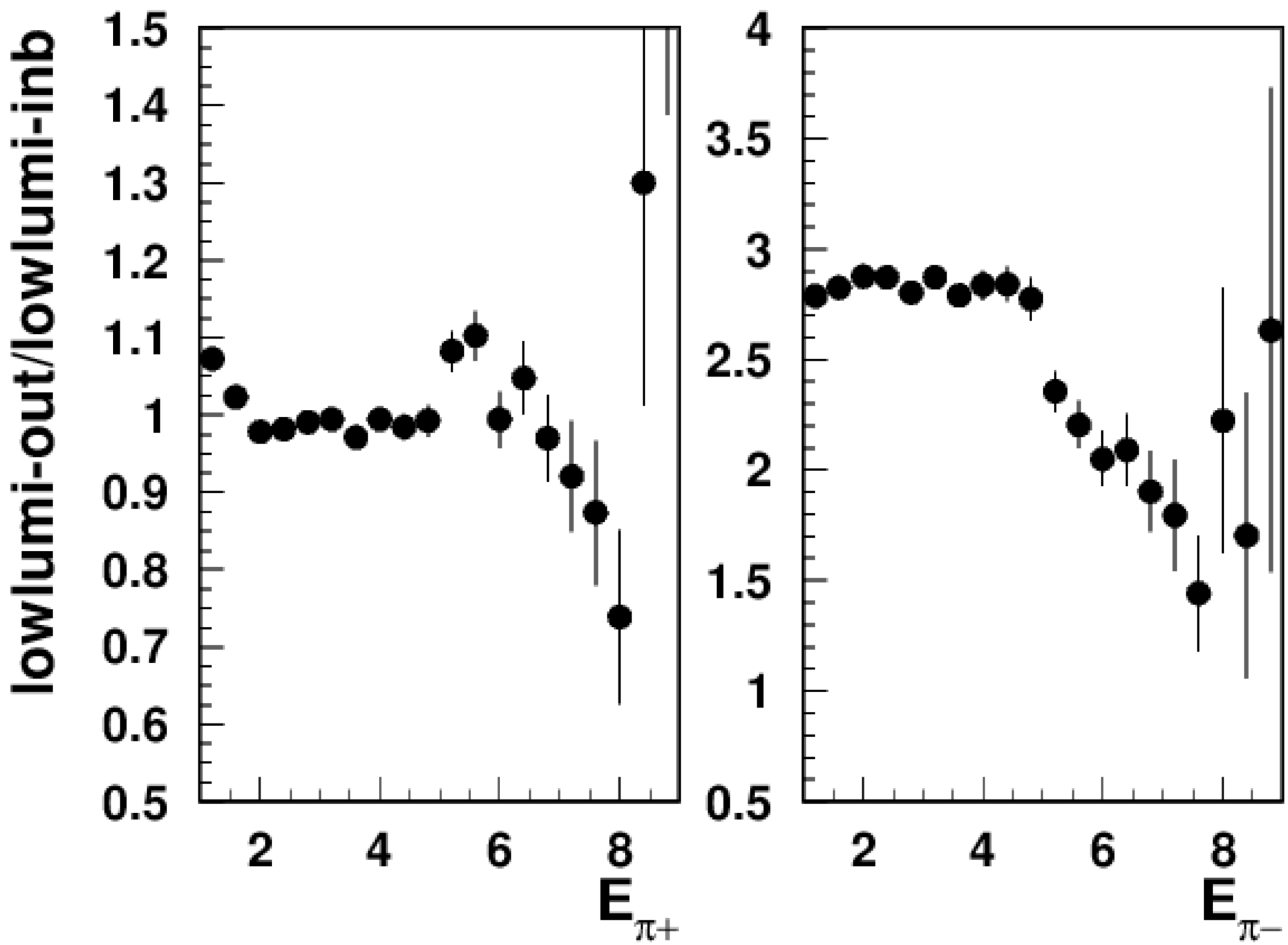
Mainly exclusive VMs at low W

Sources of systematics: charge symmetric background

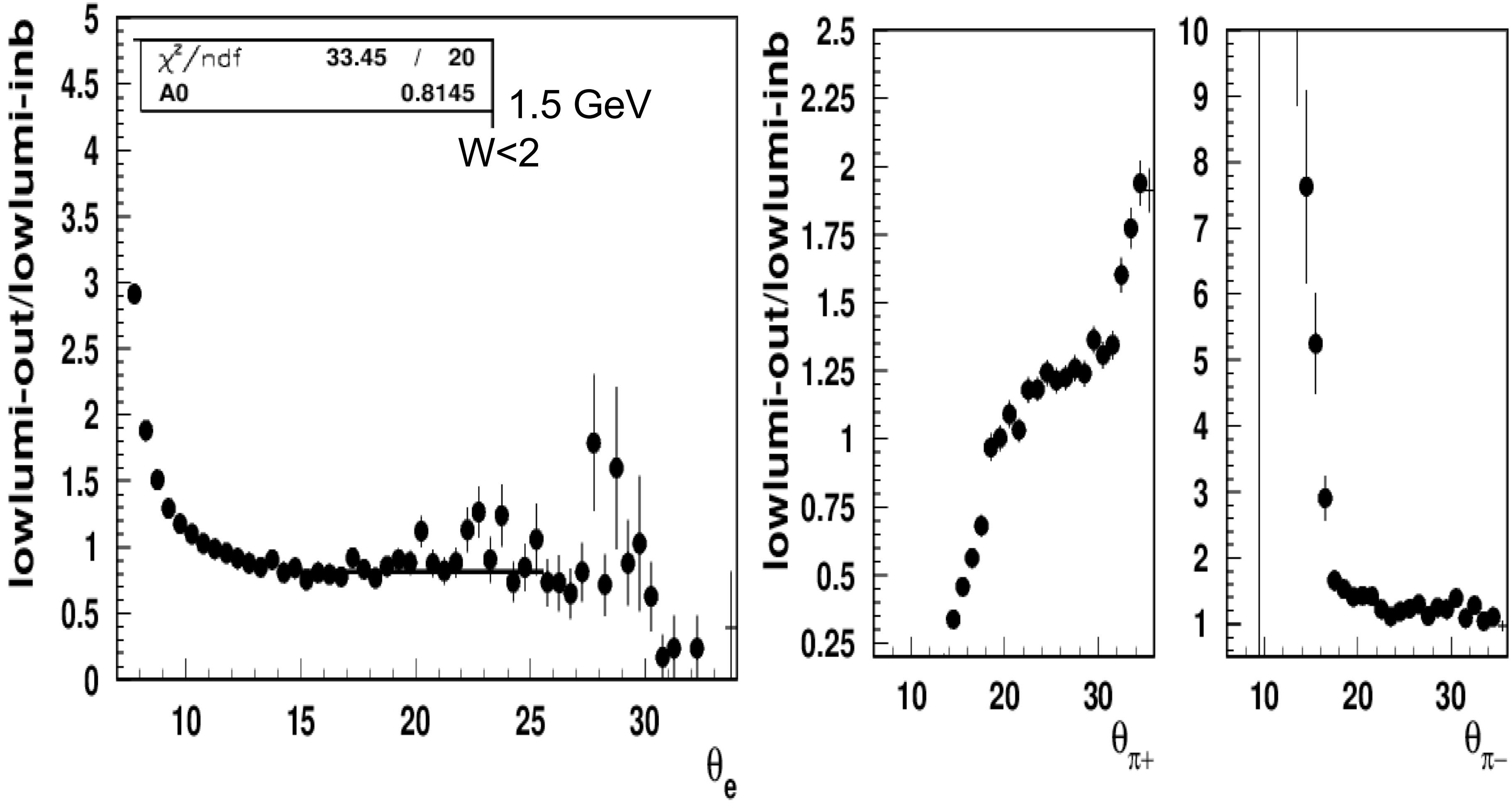


Pi- mainly from exclusive VMs at low W

SIDIS: inbending vs outbending

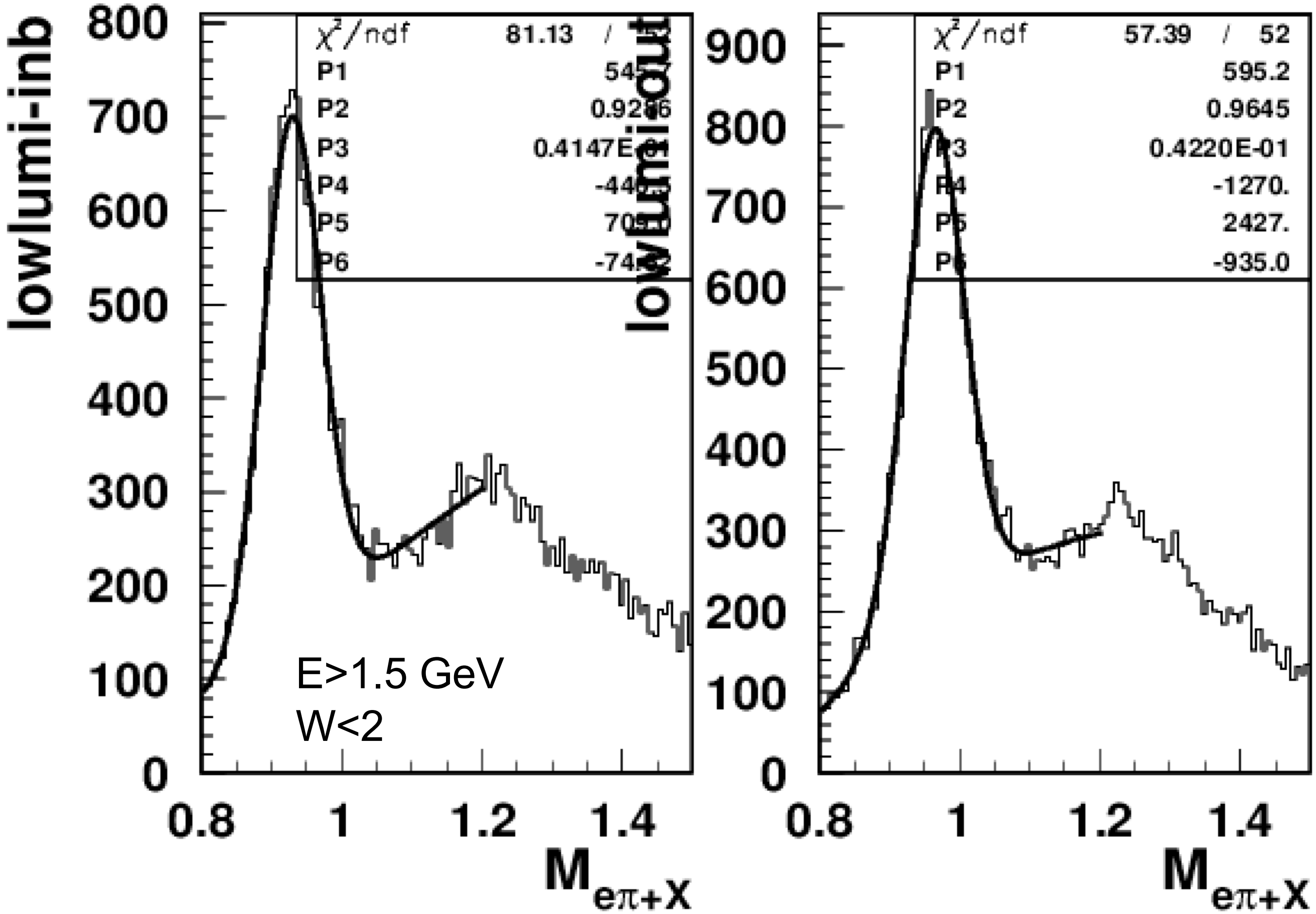


Sources of systematics: charge symmetric background



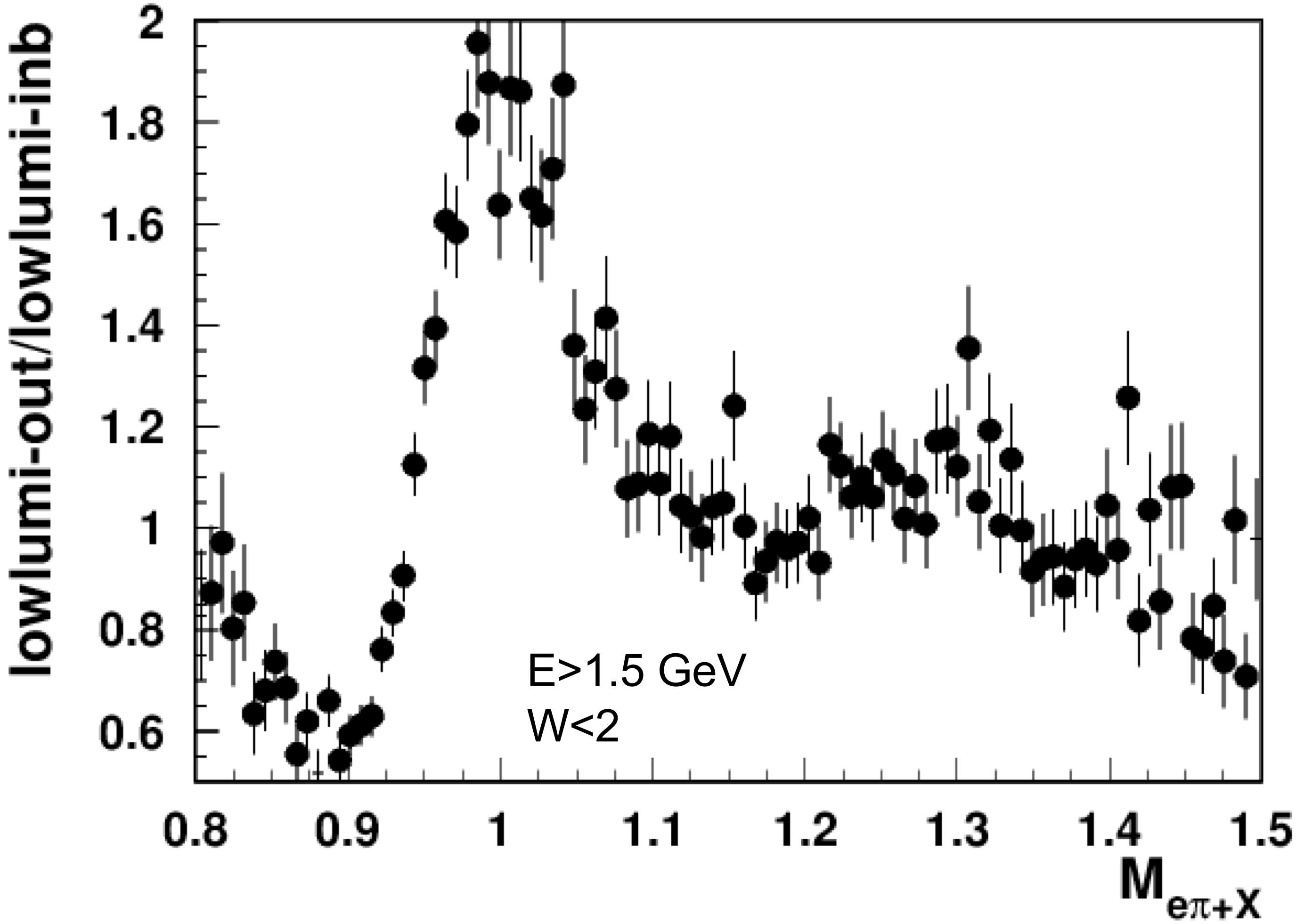
Normalization diff for 20%

Sources of systematics: charge symmetric background



Outbending shifted more

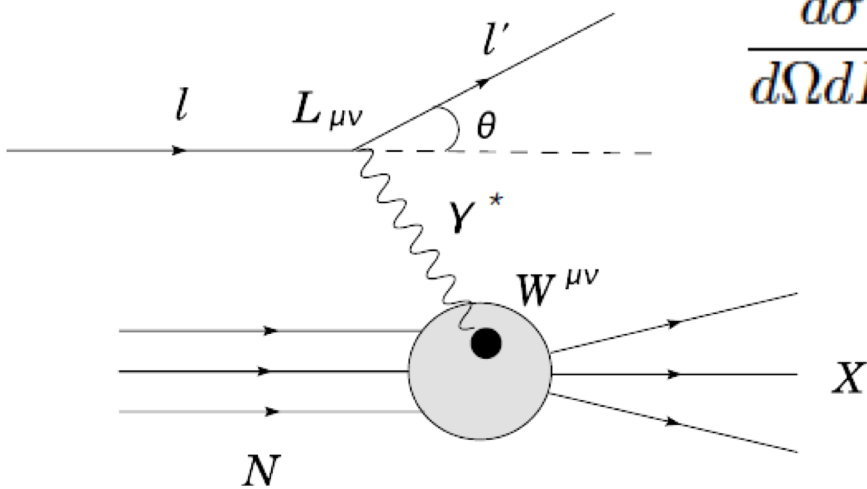
Sources of systematics: charge symmetric background



Outbending shifted more

DIS

$L_{\mu\nu}$ and $W^{\mu\nu}$ the lepton and hadron tensors



$$\frac{d\sigma}{d\Omega dE'} = \frac{d\sigma}{d\Omega}^{Mott}\left[\frac{F_2}{\nu} + \frac{F_1}{M}\tan^2(\theta/2)\right]$$

$$\frac{d\sigma}{d\Omega}^{Mott} = \frac{\alpha^2}{4E^2\sin^4(\theta/2)}\cos^2(\theta/2)$$

$$W^{(S)}_{\mu\nu} = 2\left(-g_{\mu\nu} - \frac{q_\mu q_\nu}{Q^2}\right)F_1(x,Q^2) + \left(P_\mu + \frac{P\cdot q}{Q^2}q_\mu\right)\left(P_\nu + \frac{P\cdot q}{Q^2}q_\nu\right)\frac{F_2(x,Q^2)}{P\cdot q},$$

$F_1(x,Q^2)$ and $F_2(x,Q^2)$ are dimensionless unpolarized structure functions

$$\boxed{\frac{d\sigma}{dx dQ^2 d\psi} = \frac{d\sigma}{d\Omega}^{Mott}\frac{\nu}{2xEE'}\left[\frac{F_2}{\nu} + \frac{F_1}{M}\tan^2(\theta/2)\right]}$$

In parton model → $F_2(x) = x\sum_q e_q^2 q(x)$

$$F_1(x,Q^2) = \frac{1+\gamma^2}{2x(1+R(x,Q^2))}F_2(x,Q^2)$$

Radiative DIS

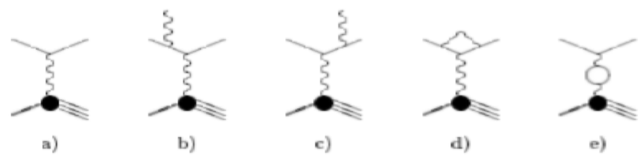


Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

Akushevich et al. http://www.jlab.org/RC/radgen/

SIDIS version: JLAB-PHY-19-2938

For RC we need x-sections (or SFs) in the full W range, including exclusive part

generate a single kinematical point at E_b=10.6 GeV with e'=2.0 GeV, θ=0.3
→ **x,y,Q^2,W^2(0.12,0.8,1.9,15.1)**
Integrated over all **Eγ** **$\sigma_{Rad}/\sigma_{Born}$=1.24**

original Q^2,W^2(1.9,15.1)