Exclusive π^- Electroproduction off the Neutron in Deuterium in the Resonance Region

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- Motivation
- Data Analysis
- Preliminary Results
- Summary and Outlook

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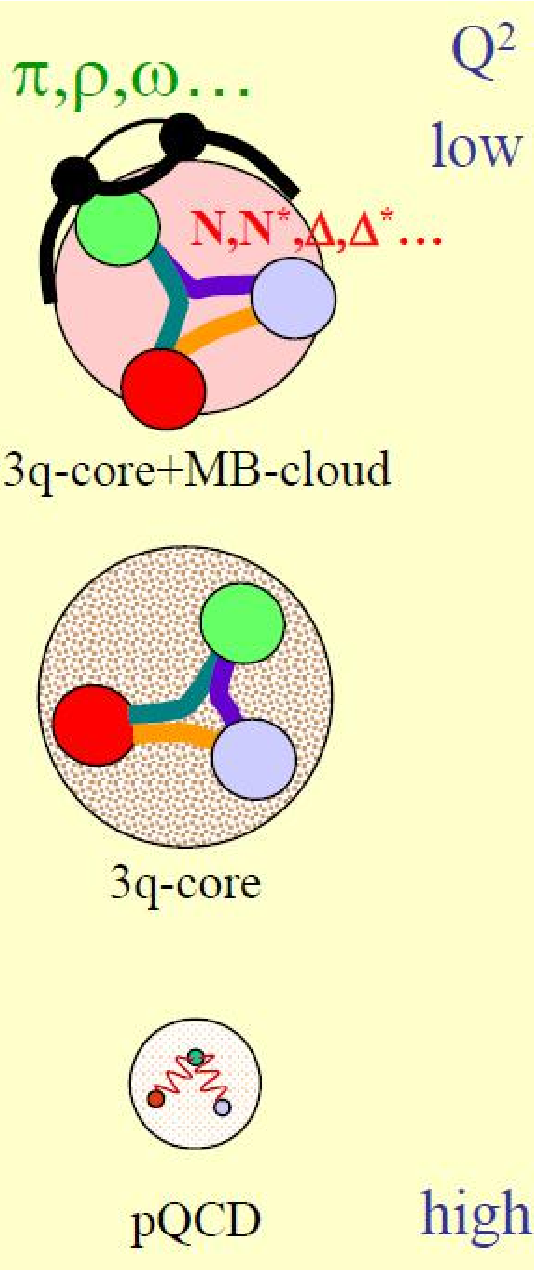
Motivation



◆ Since proton is the only stable hadron, the excited states of the free proton have been studied in great detail, there are very few data for the neutron excitations.

◆ There is no free neutron target, the deuterium target is the alternative target, because it contains the simplest and most loosely bound nucleon system.

◆ In order to extract the free neutron information, we have to deal with the final state interaction and correct it from the quasi-free process.

Single pion electroproduction reactions

$$\gamma^* + p \to \pi^0 + p$$

$$\gamma^* + p \to \pi^+ + n$$

$$\gamma^* + d(p) \to \pi^+ + n + n_s$$ (Hollis)

$$\gamma^* + d(n) \to \pi^- + p + p_s$$

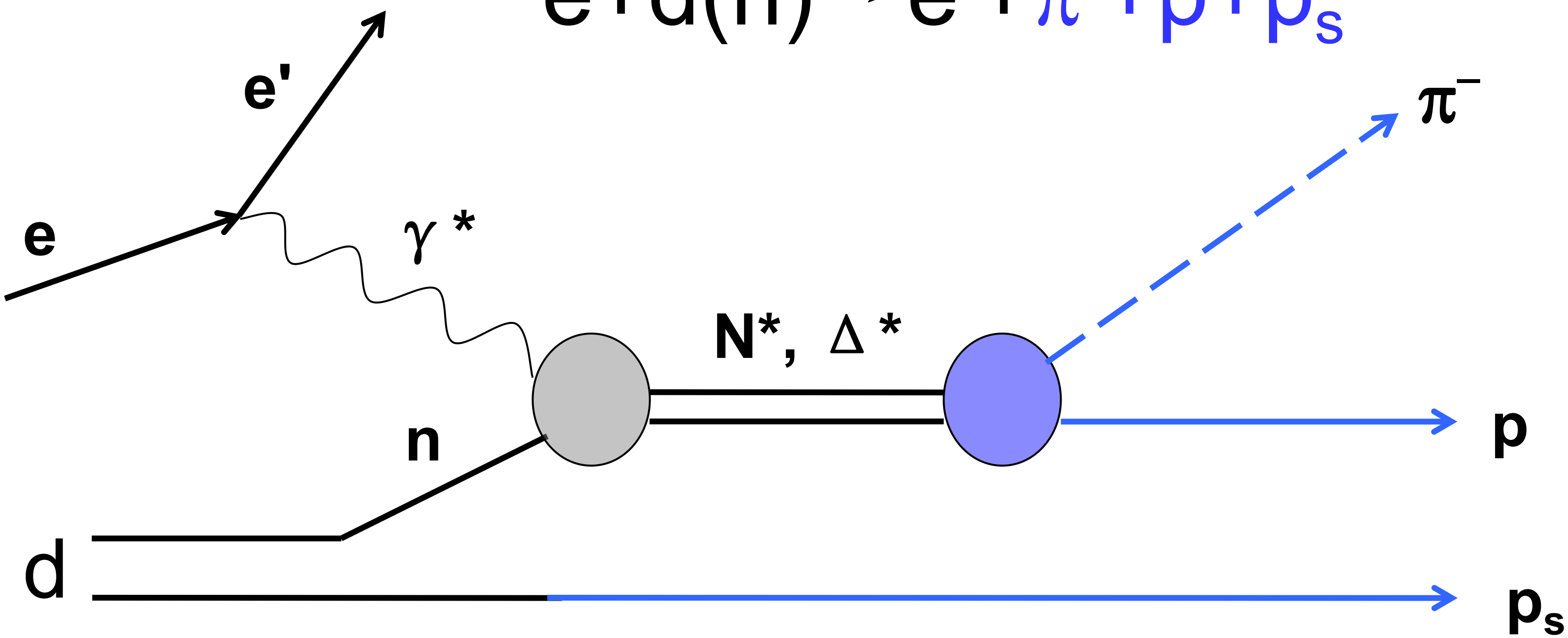
H_2 target (first two reactions)

D_2 target (last two reactions)

e1e run (all four reactions)

Exclusive π⁻ electroproduction

$e + d(n) \rightarrow e' + \pi^- + p + p_s$



Energy and momentum conservation ➡ initial state of neutron (off shell)

$$p_s^\mu + n^\mu = d^\mu \ , \quad \vec{P}_{ps} + \vec{P}_n = 0$$

Exclusive π⁻ production kinematic

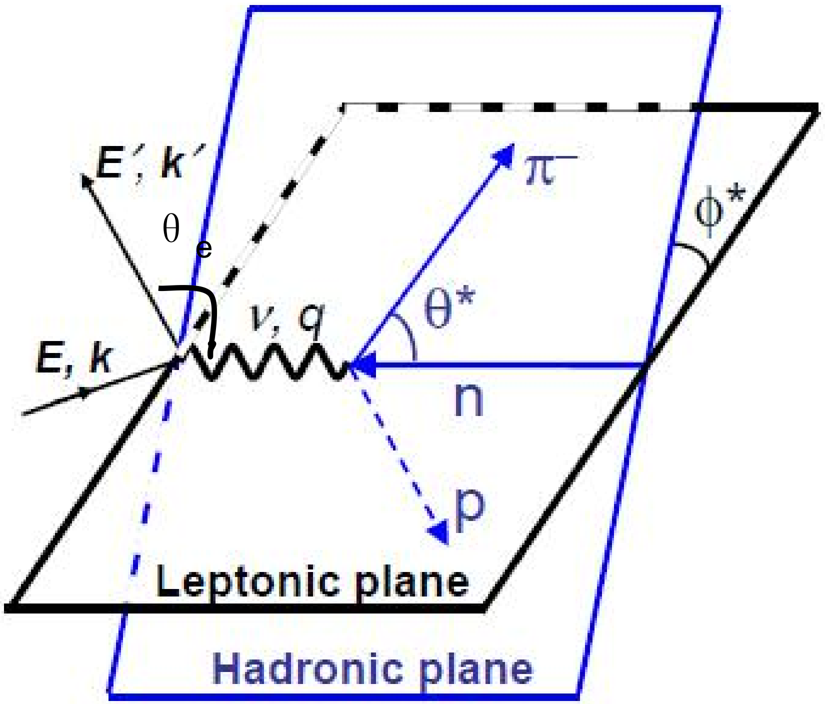
$$\nu = E - E'$$

$$q = K - K'$$

$$Q^2 = -(q^\mu)^2$$

$$= -(e^\mu - e'^\mu)^2$$

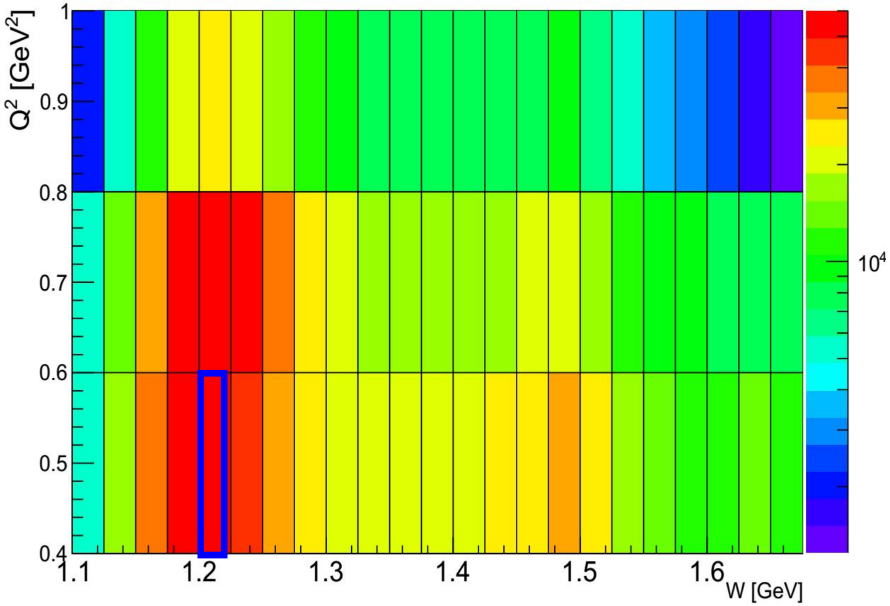
$$\approx 4EE'\sin^2\frac{\theta_e}{2}$$

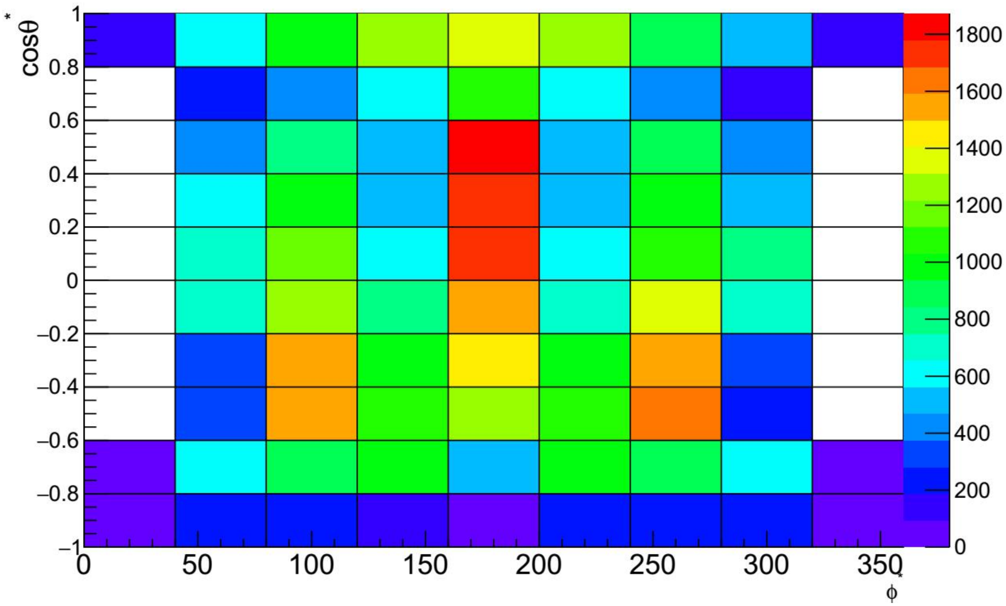


$$W^2 = (p^\mu + \pi^\mu)^2 = (q^\mu + n^\mu)^2 = (q^\mu + d^\mu - p_s^\mu)^2$$

θ^* and ϕ^*: polar and azimuthal angle of π^- in the CM frame

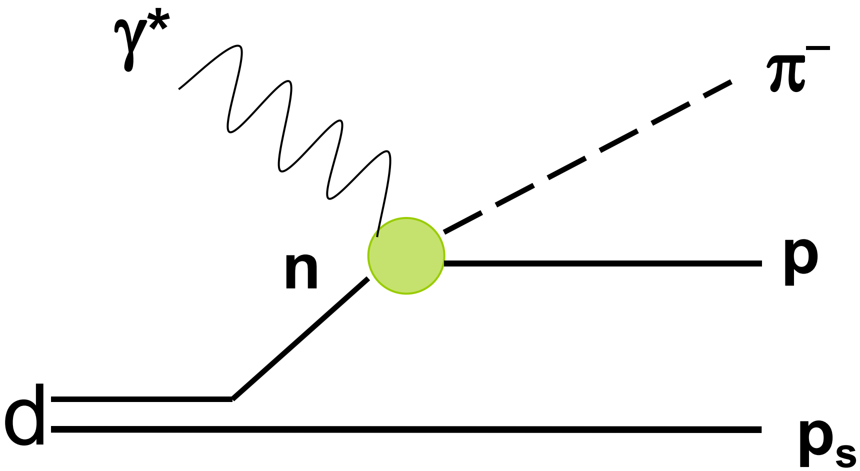
Exclusive π^- production kinematic



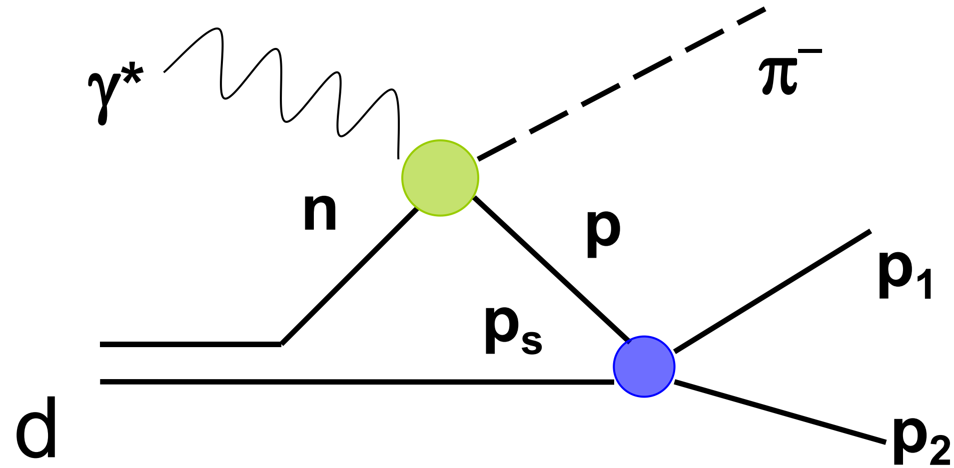


Variable	Lower limit	Upper limit	Number of bins	Bin size
W GeV	1.1	1.7	24	0.025
Q^2 GeV^2	0.4	1.0	3	0.2
cos θ*	-1	1	10	0.2
ϕ*	0 °	360°	9, 8, 6	40°, 45°, 60°

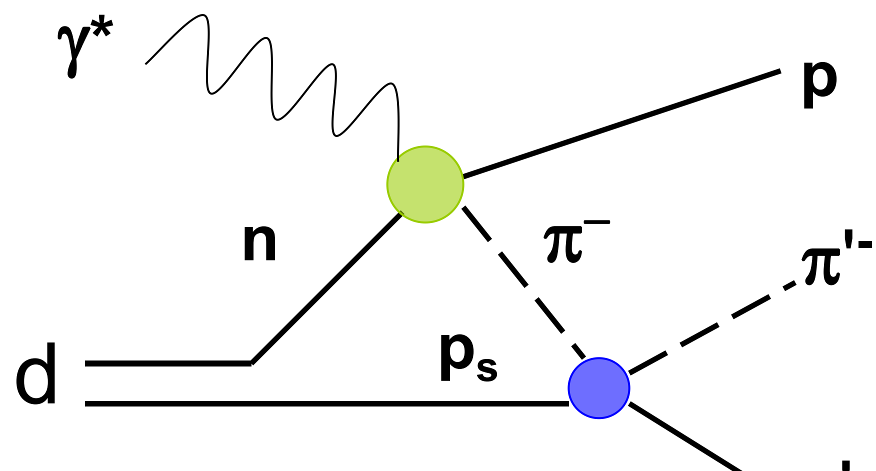
Final state interactions sketch



quasi-free

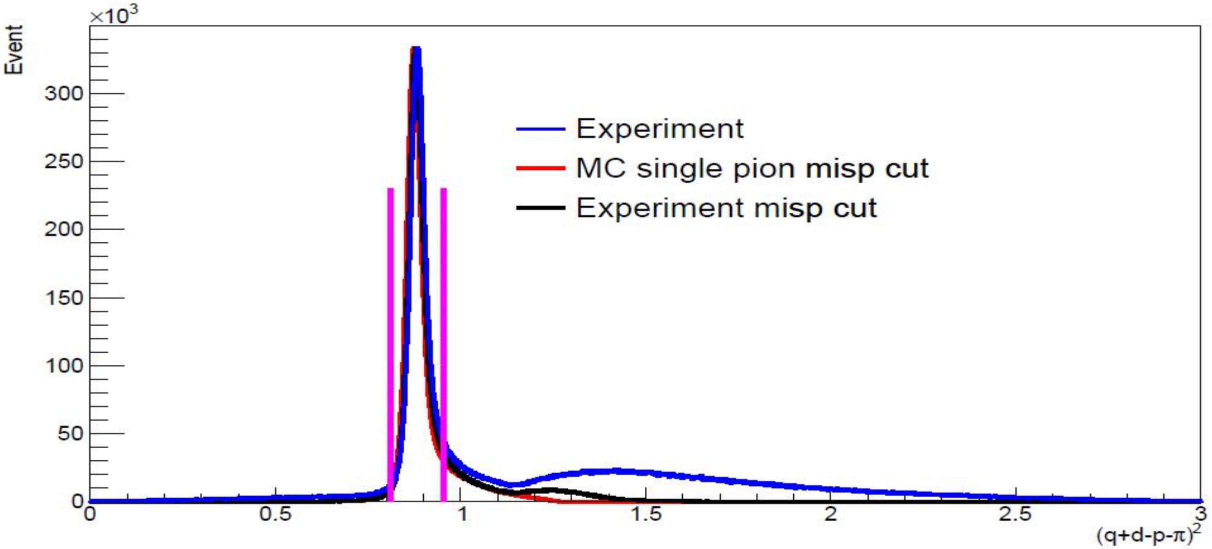


pp rescattering



pπ rescattering

Exclusive event selection

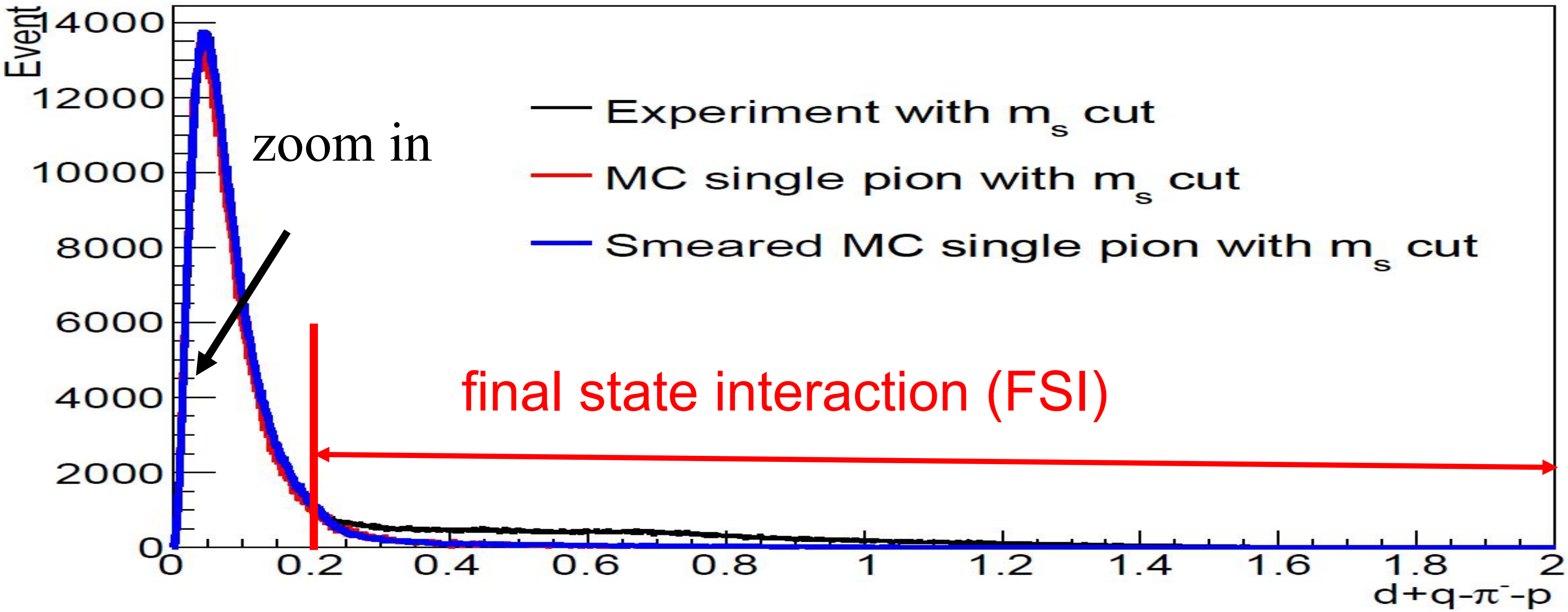


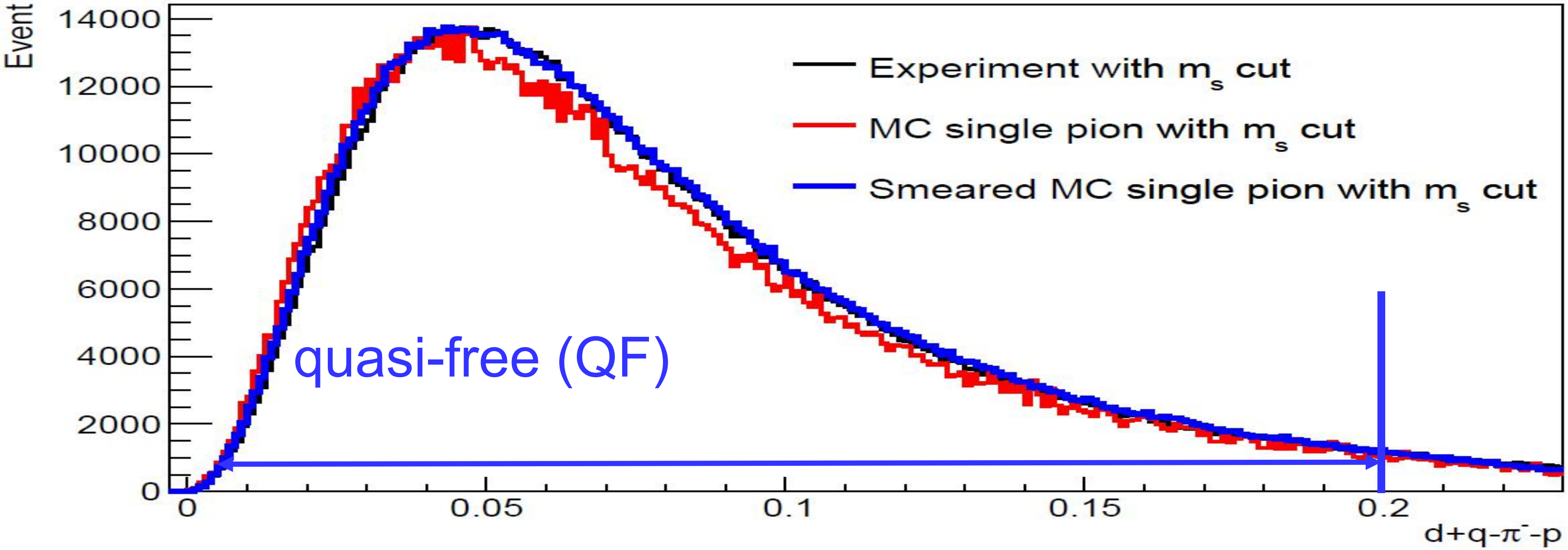
missing mass

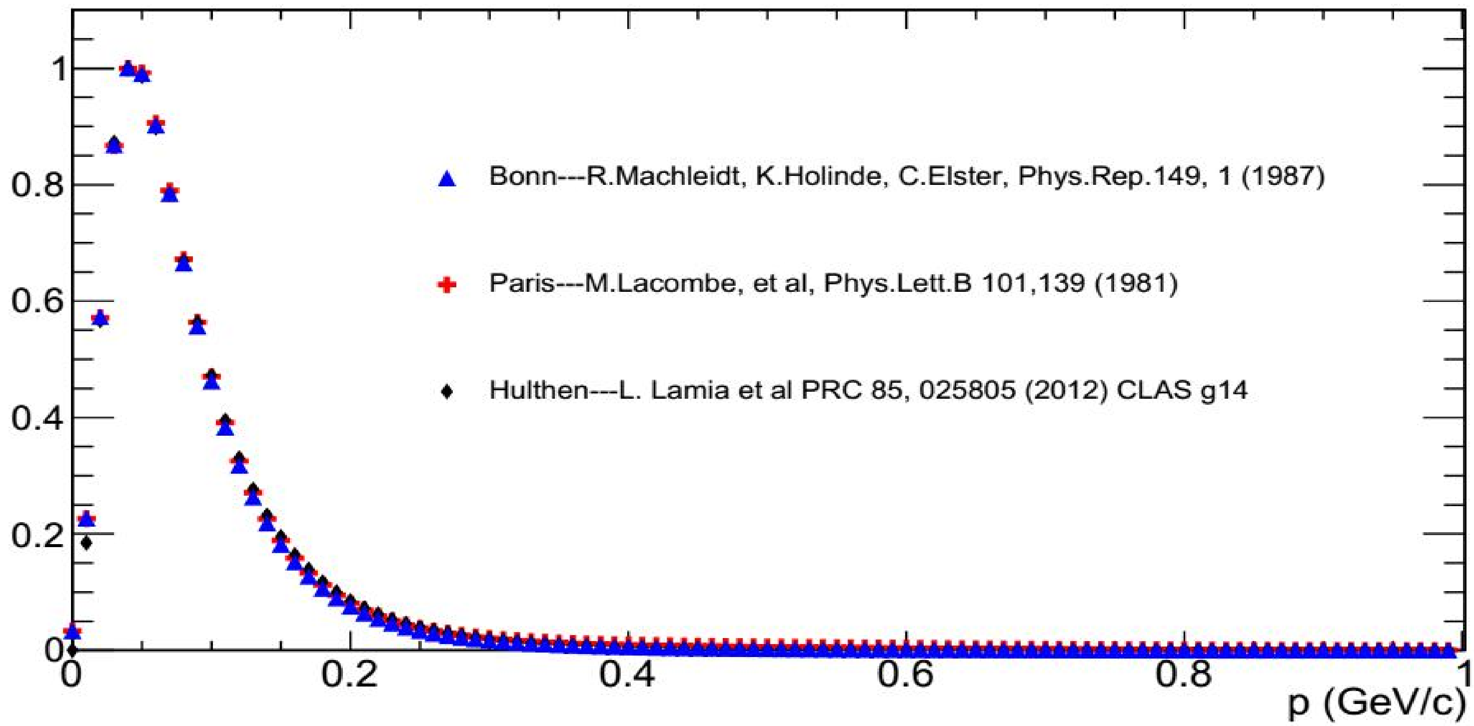
$$\left(q^{\mu}+d^{\mu}-p^{\mu}-\pi^{\mu}\right)^{2}$$

missing momentum:

$$\left|\vec{q}-\vec{p}-\vec{\pi^{-}}\right|$$

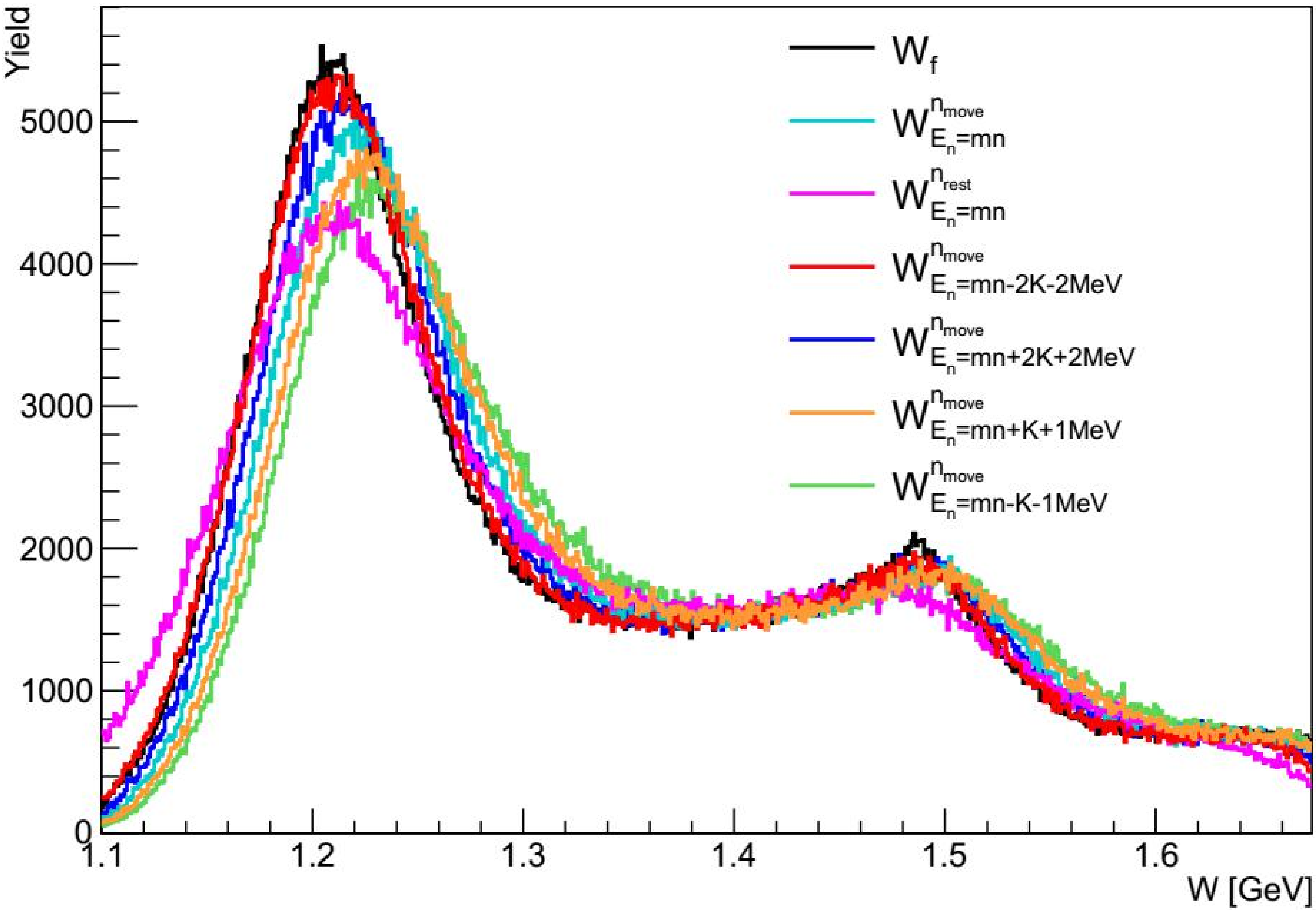






comparison data courtesy of Reinhard Schumacher

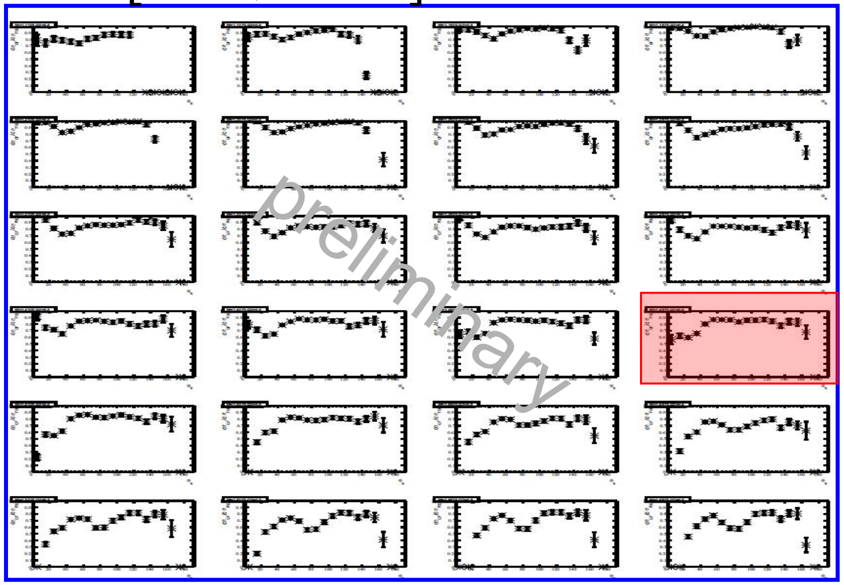
Off-shell effects

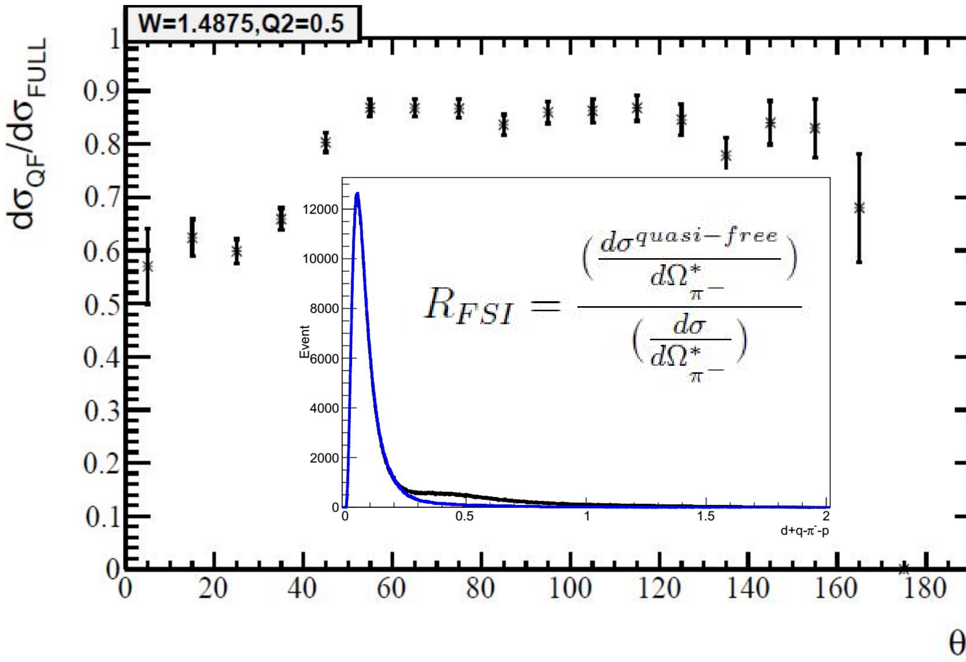


Final state interaction correction factor

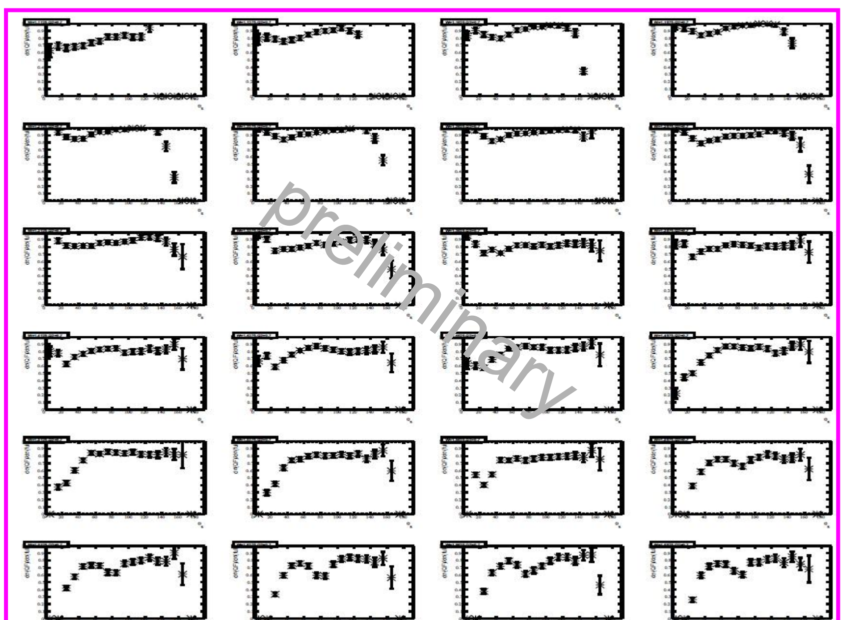
$W \in [1.125, 1.1675]\,GeV$ ΔW=25MeV

Q²=0.5GeV²

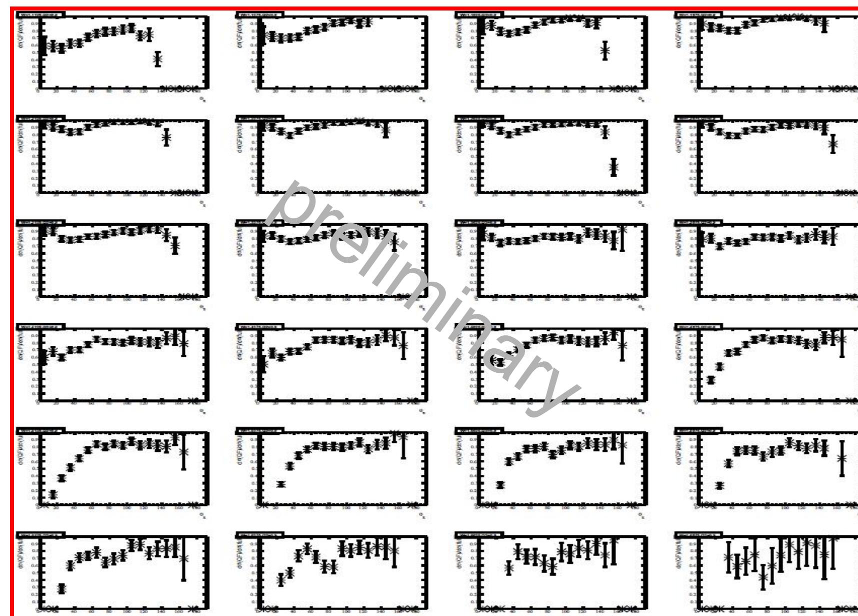




Q²=0.7GeV²



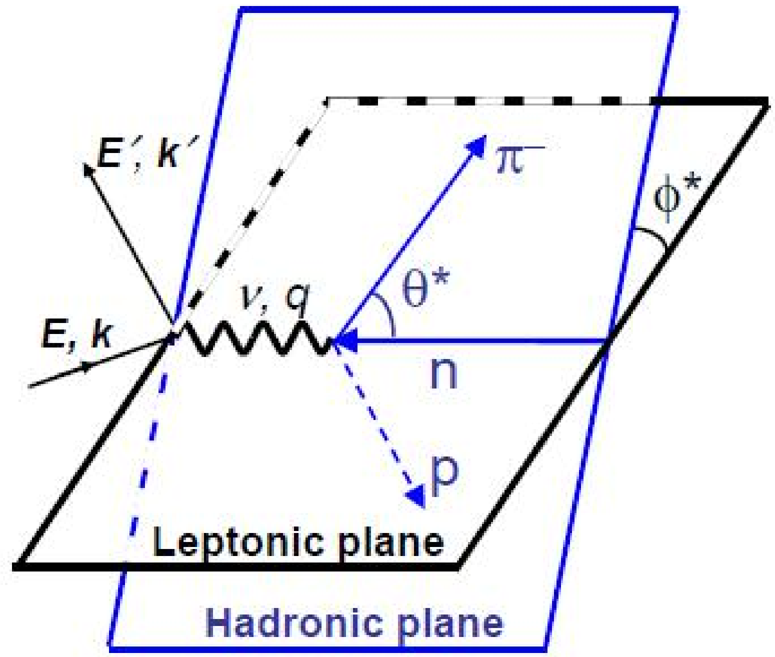
Q²=0.9GeV²



Differential cross section

$$\frac{d\sigma}{dW dQ^2 d\Omega^*_{\pi^-}} = \Gamma_\nu \frac{d^2\sigma}{d\Omega^*_\pi}$$

$$\Gamma_\nu \equiv \frac{\alpha}{4\pi}\frac{1}{E^2}\frac{W\left(W^2 - m_n^2\right)}{m_n^2 Q^2 \left(1-\varepsilon\right)}$$

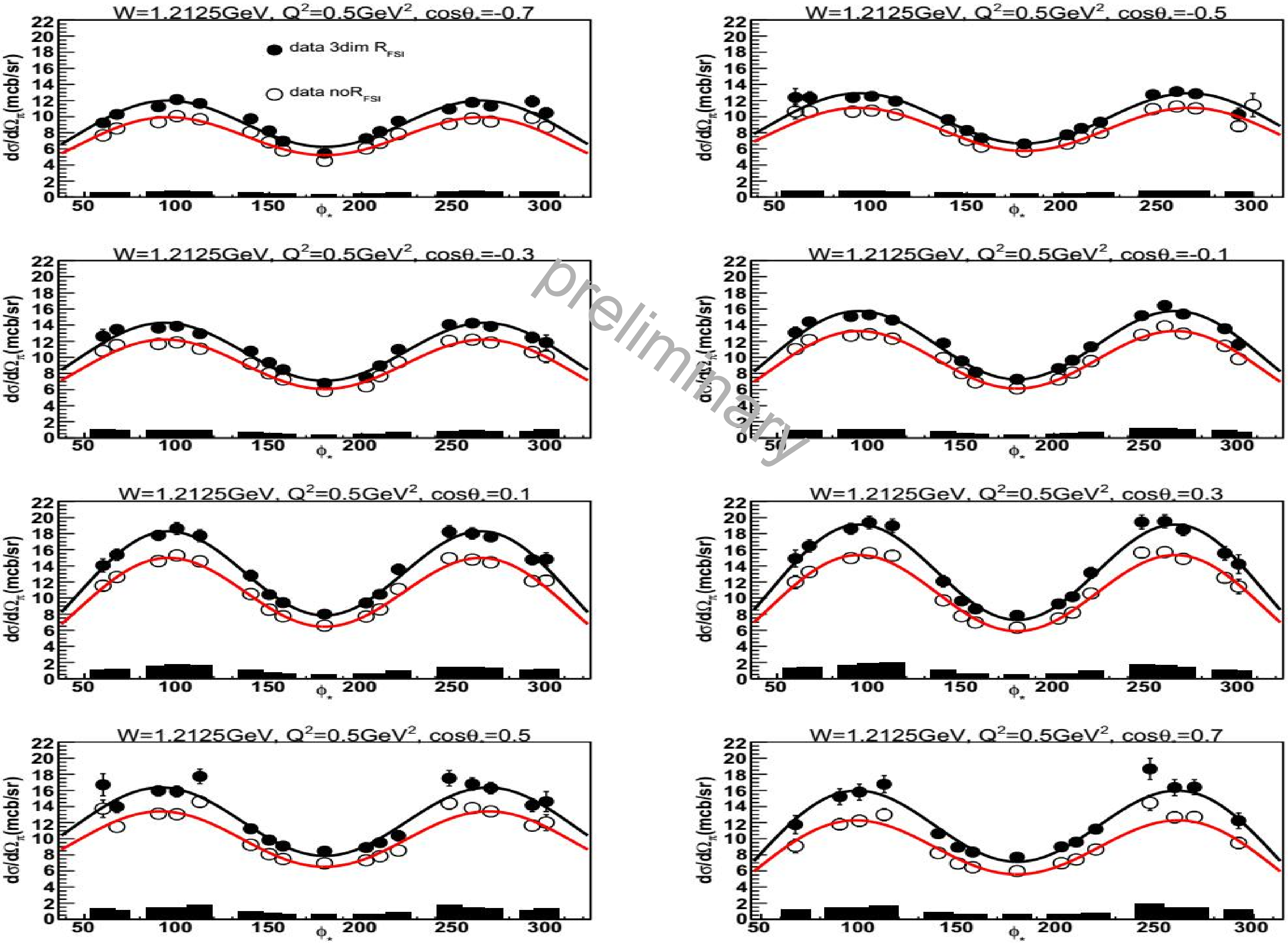


$$\frac{d^2\sigma}{d\Omega^*_\pi} = \sigma_T + \varepsilon\sigma_L + \sqrt{2\varepsilon\left(1+\varepsilon\right)}\sigma_{LT}\cos\phi^* + \varepsilon\sigma_{TT}\cos 2\phi^*$$

$$\varepsilon \equiv \left(1 + 2\frac{|q|^2}{Q^2}\tan^2\frac{\theta_e}{2}\right)^{-1}$$

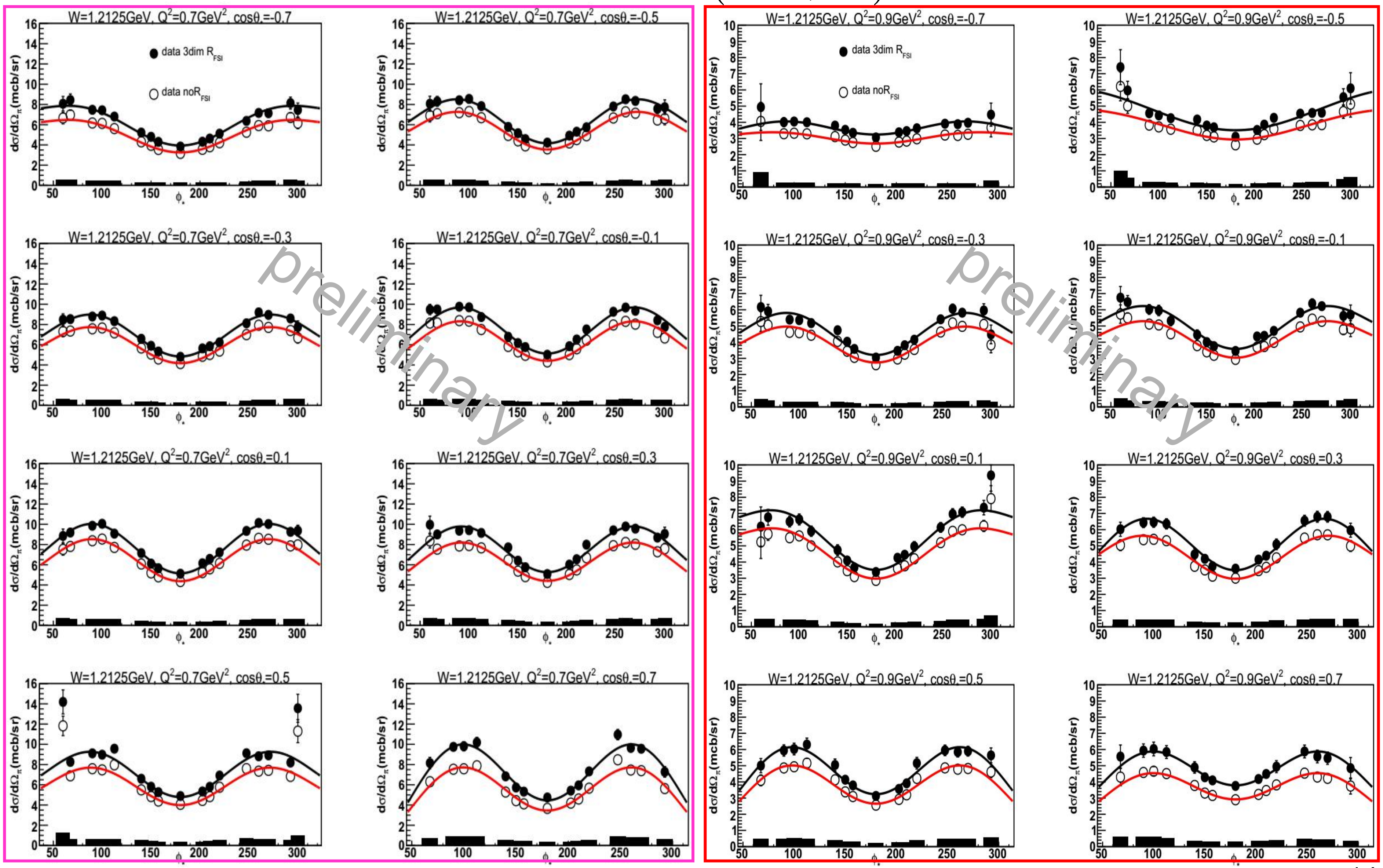
Preliminary results

Q^2=0.5GeV^2 $\cos\theta^* \in (-0.8, 0.8)$ $\Delta\cos\theta^* = 0.2$



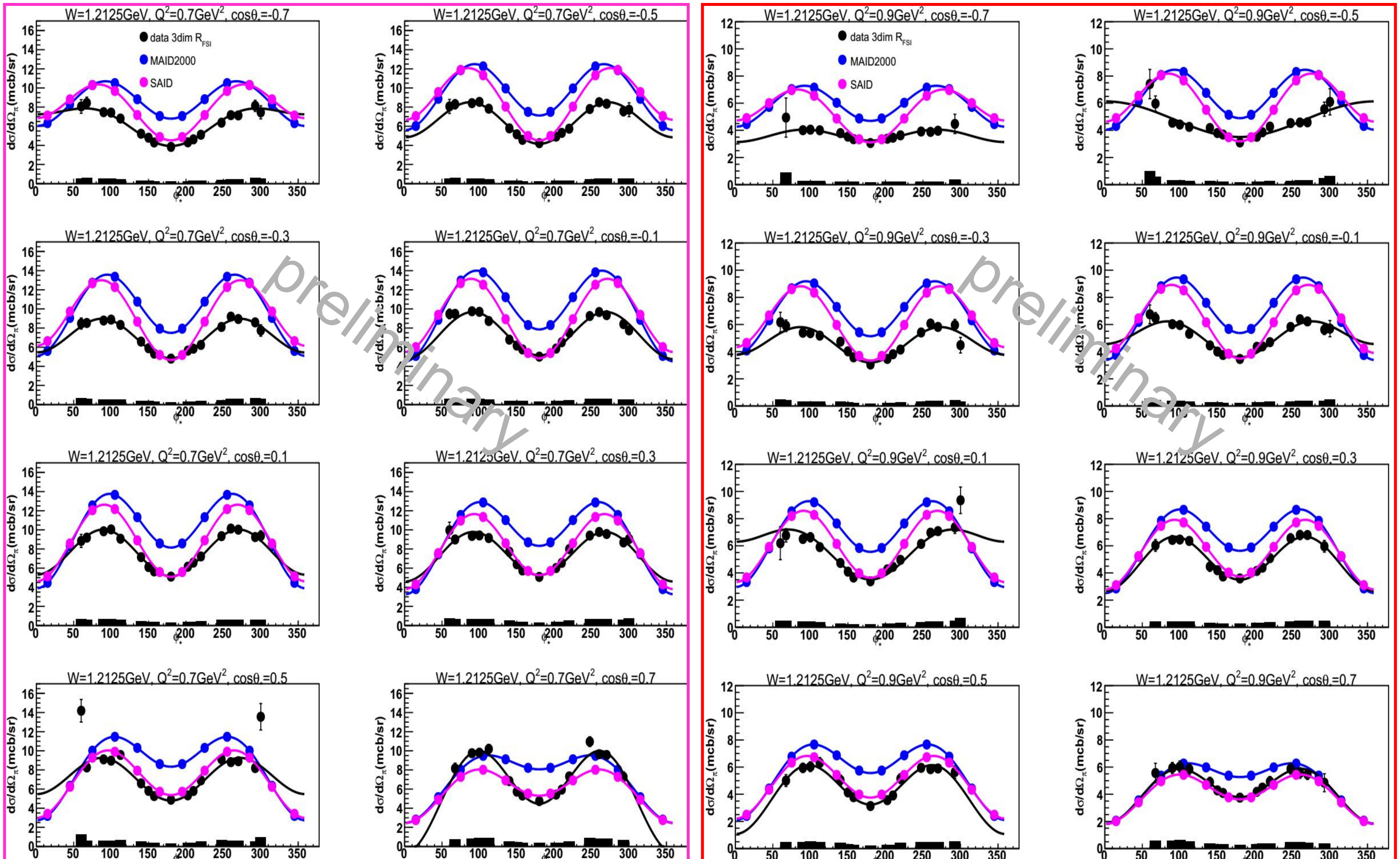
Preliminary results

Q^2=0.7GeV^2 ΔQ^2=0.2GeV^2 $\cos\theta^* \in (-0.8, 0.8)$ $\Delta\cos\theta^* = 0.2$ Q^2=0.9GeV^2



Preliminary results

Q²=0.7GeV² $\Delta Q^2 = 0.2\,\mathrm{GeV}^2$ $\cos\theta^* \in (-0.8, 0.8)$ $\Delta\cos\theta^* = 0.2$ Q²=0.9GeV²



Preliminary results

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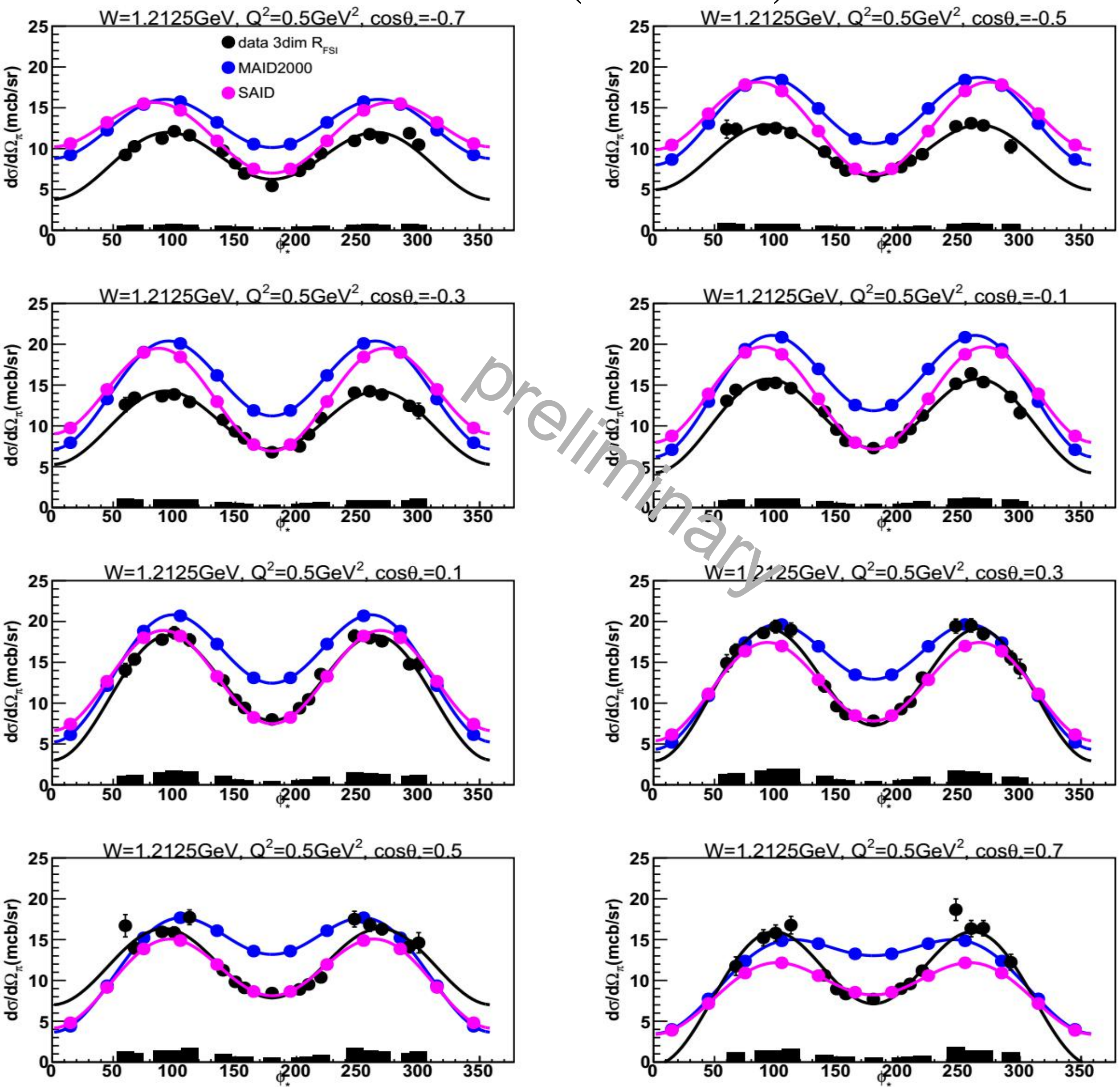


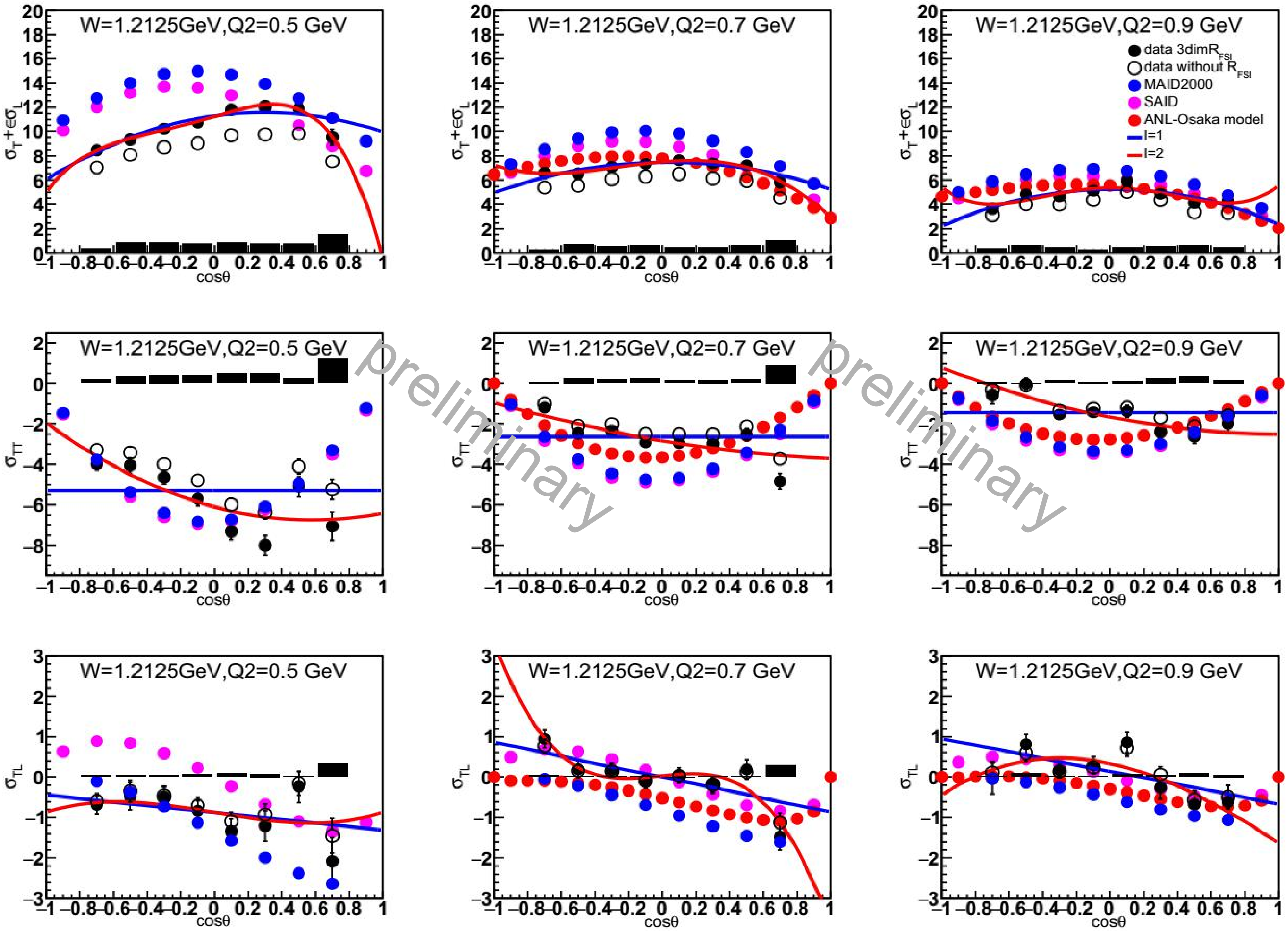
The Legendre polynomial expansion of the structure functions

$$\sigma_T + \varepsilon\sigma_L = \sum_{i=0}^{2l} A_i P_i(\cos\theta_\pi^*)$$

$$\sigma_{TT} = \sum_{i=0}^{2l-2} B_i P_i\left(\cos\theta_\pi^*\right)$$

$$\sigma_{LT} = \sum_{i=0}^{2l-1} C_i P_i\left(\cos\theta_\pi^*\right)$$

Preliminary results



Summary and outlook

- **The goal of this study is to provide the exclusive $\gamma^*(n) \rightarrow \pi^- p$ reaction cross section, from which the n-N* transition form factors will be extracted by phenomenological models.**

- **The final state interaction of the π^- electroproduction is on average about 10% to 20%, which will be used to correct the quasi-free neutron π^- electroproduction cross section off Deuterium.**

- **Next: preliminary differential cross sections with bin centering correction.**

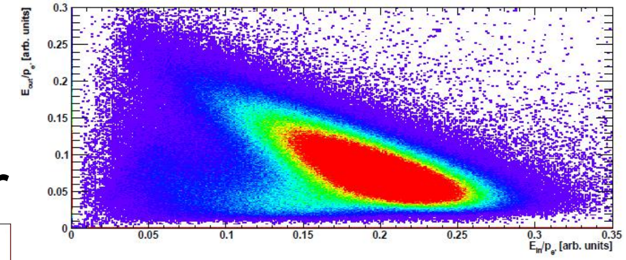
Thank you

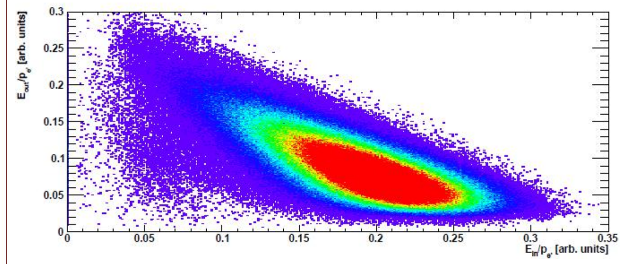
Backup

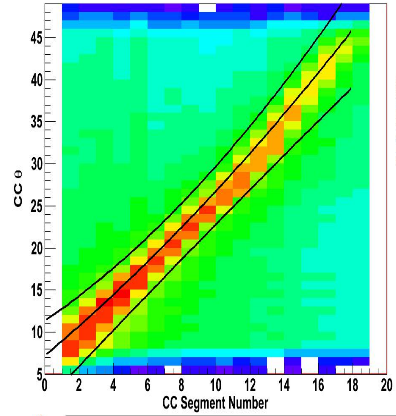
Electron identification

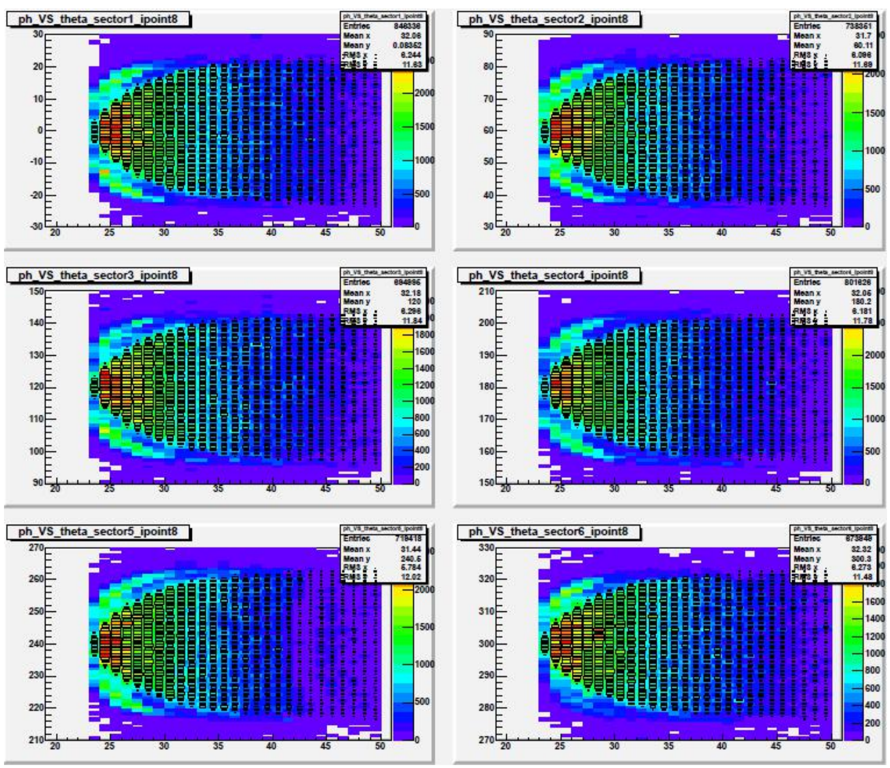
The electron identification includes the following requirements

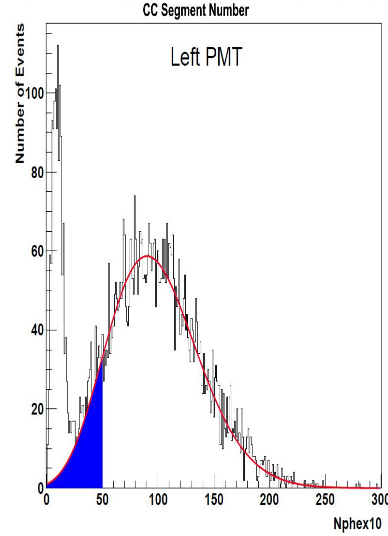
- negative track that triggered the event
- coincidence of CC and EC hit
- track in DC and SC hit in the same sector
- good geometric hit status

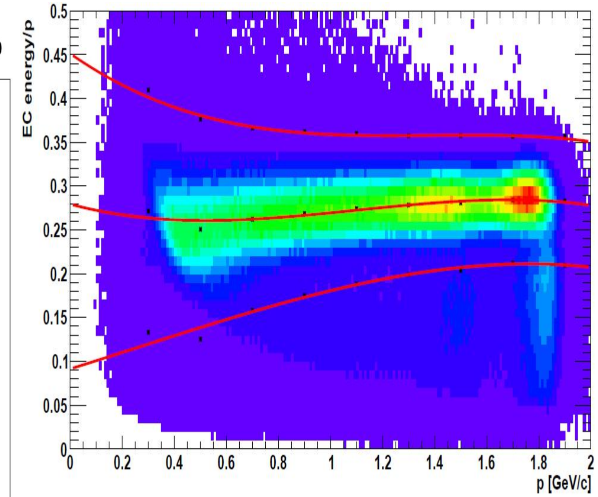












Charged hadrons identification

The charged hadrons identification requirements:

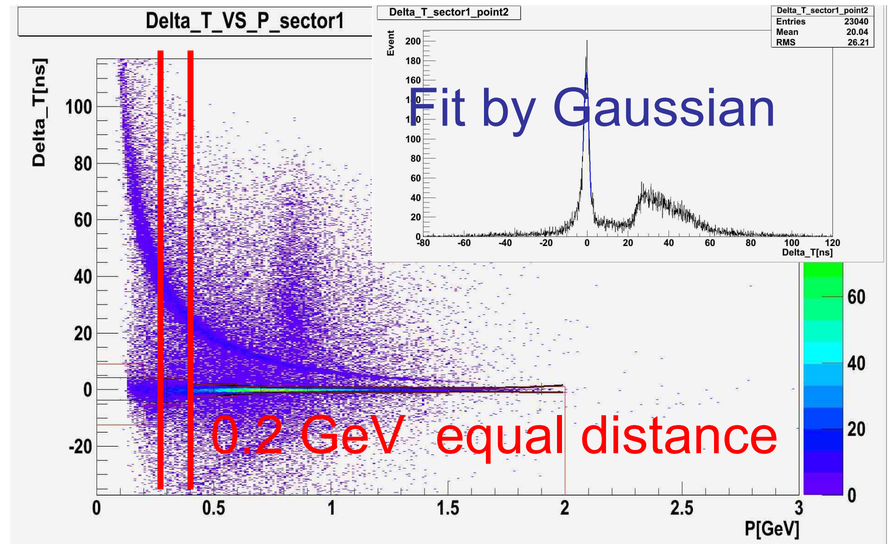
- matching charge
- SC hit
- good geometric hit status

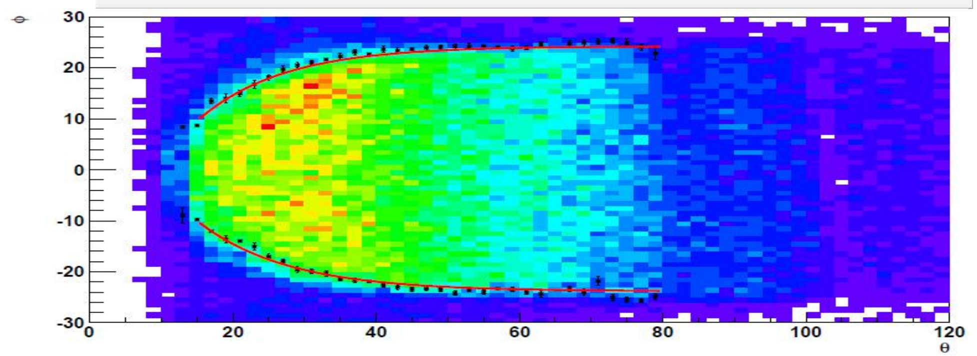
$$T_0 = T_e - \frac{l_e}{c}$$

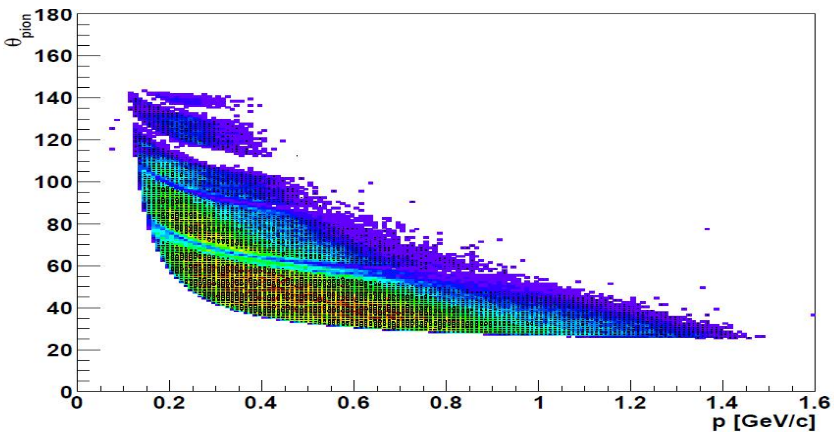
$$\beta = \frac{v}{c} = l / c(T - T_0)$$

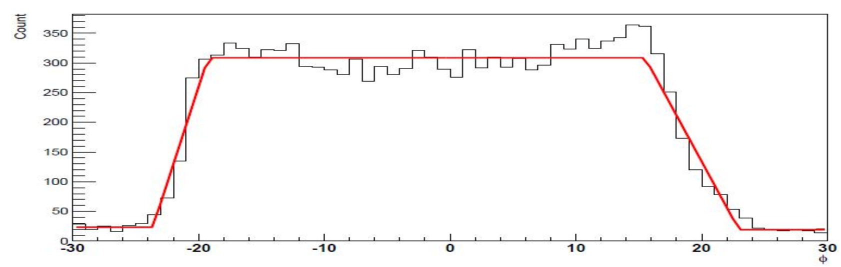
$$\Delta T = \frac{l}{\beta'} - (T - T_0)$$

$$\beta' = \sqrt{p^2/(M_p^2 + p^2)}$$



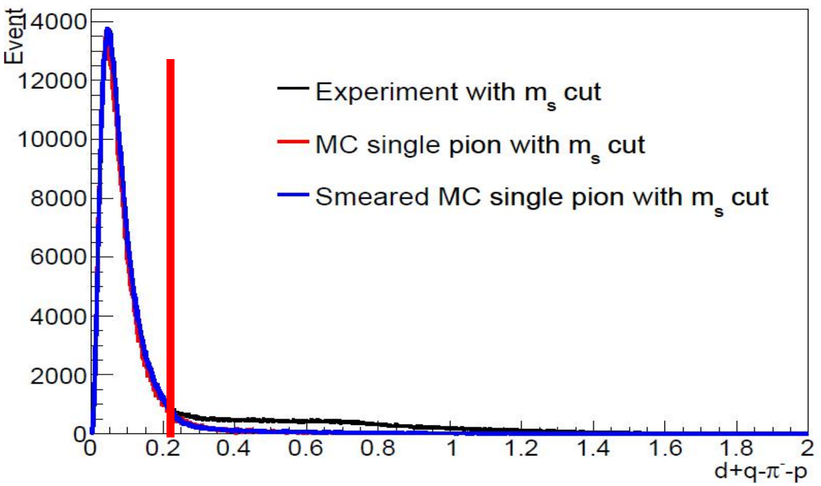






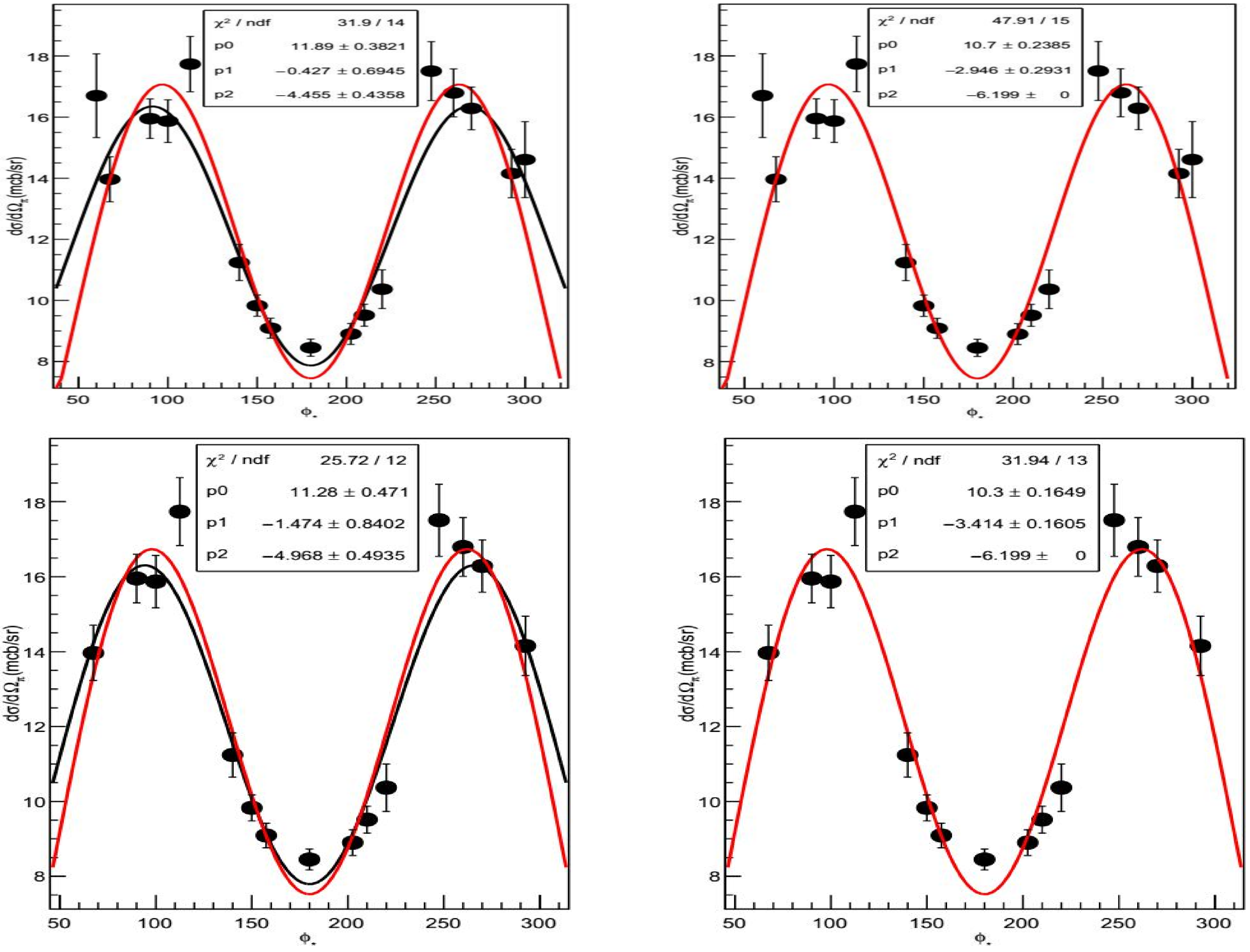
Final state interaction correction factor

$$R_{FSI} = \frac{\dfrac{d\sigma^{quasi-free}}{d\Omega^*_{\pi^-}}}{\dfrac{d\sigma^{full}}{d\Omega^*_{\pi^-}}} = \frac{\dfrac{N_{data}^{200MeV\_cut}\left(W,Q^2,\cos\theta,\phi\right)}{A^{200MeV\_cut}\left(W,Q^2,\cos\theta,\phi\right)\bullet r\left(W,Q^2,\cos\theta,\phi\right)}}{\dfrac{N_{data}^{full}\left(W,Q^2,\cos\theta,\phi\right)}{A^{full}\left(W,Q^2,\cos\theta,\phi\right)}}$$

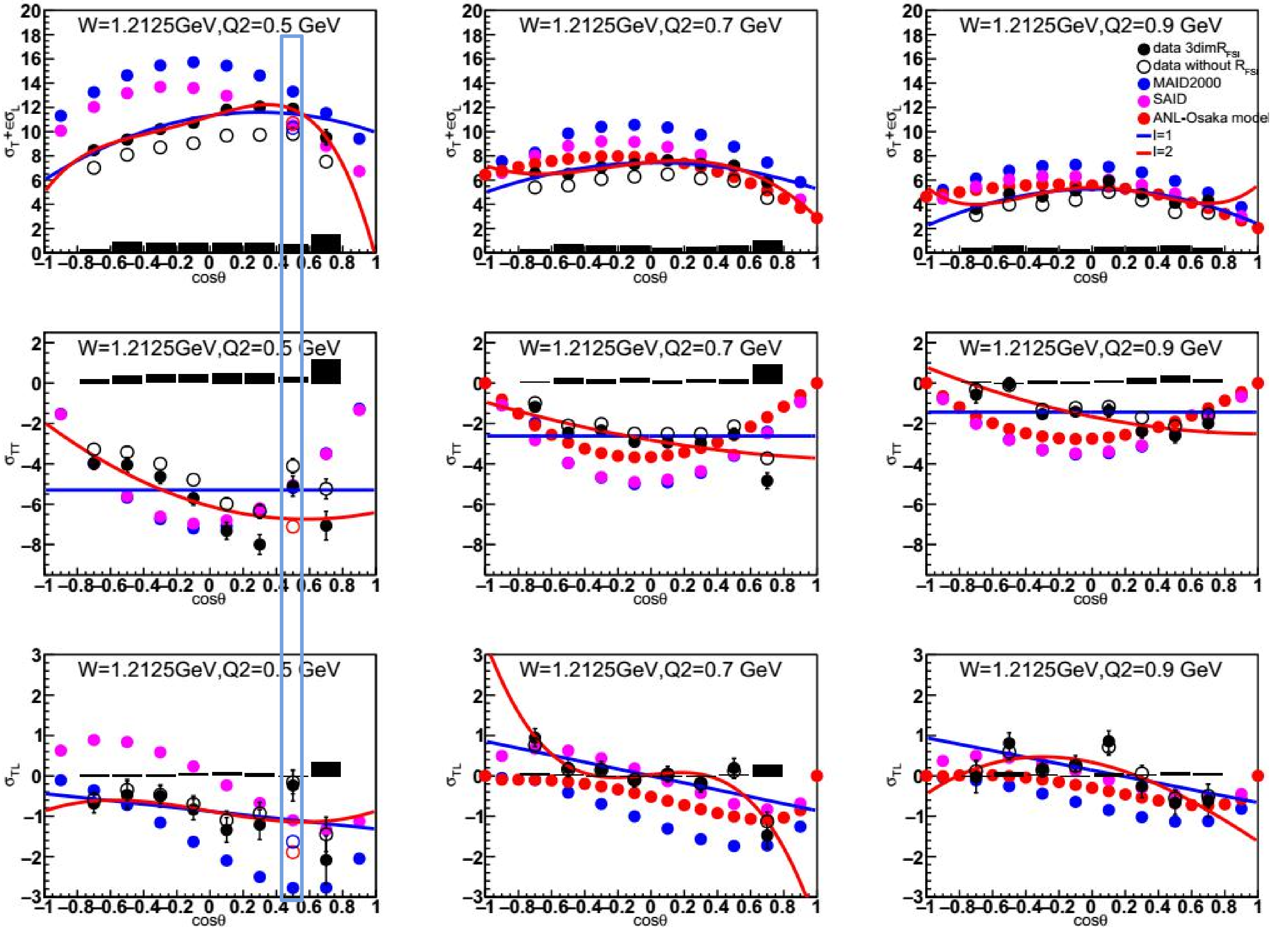


$$r\left(W,Q^2,\cos\theta,\phi\right) = \frac{N_{P_{s\_Bonn}}^{200MeV\_cut}\left(W,Q^2,\cos\theta,\phi\right)}{N_{P_{s\_Bonn}}\left(W,Q^2,\cos\theta,\phi\right)}$$

$$\frac{d^2_{\gamma^* n\_\exp}\sigma}{d\Omega^*_{\pi^-}} = R_{FSI}^{-1}\frac{d^{200MeV\_cut2}_{\gamma^* n\_\exp}\sigma}{d\Omega^*_{\pi^-}}$$

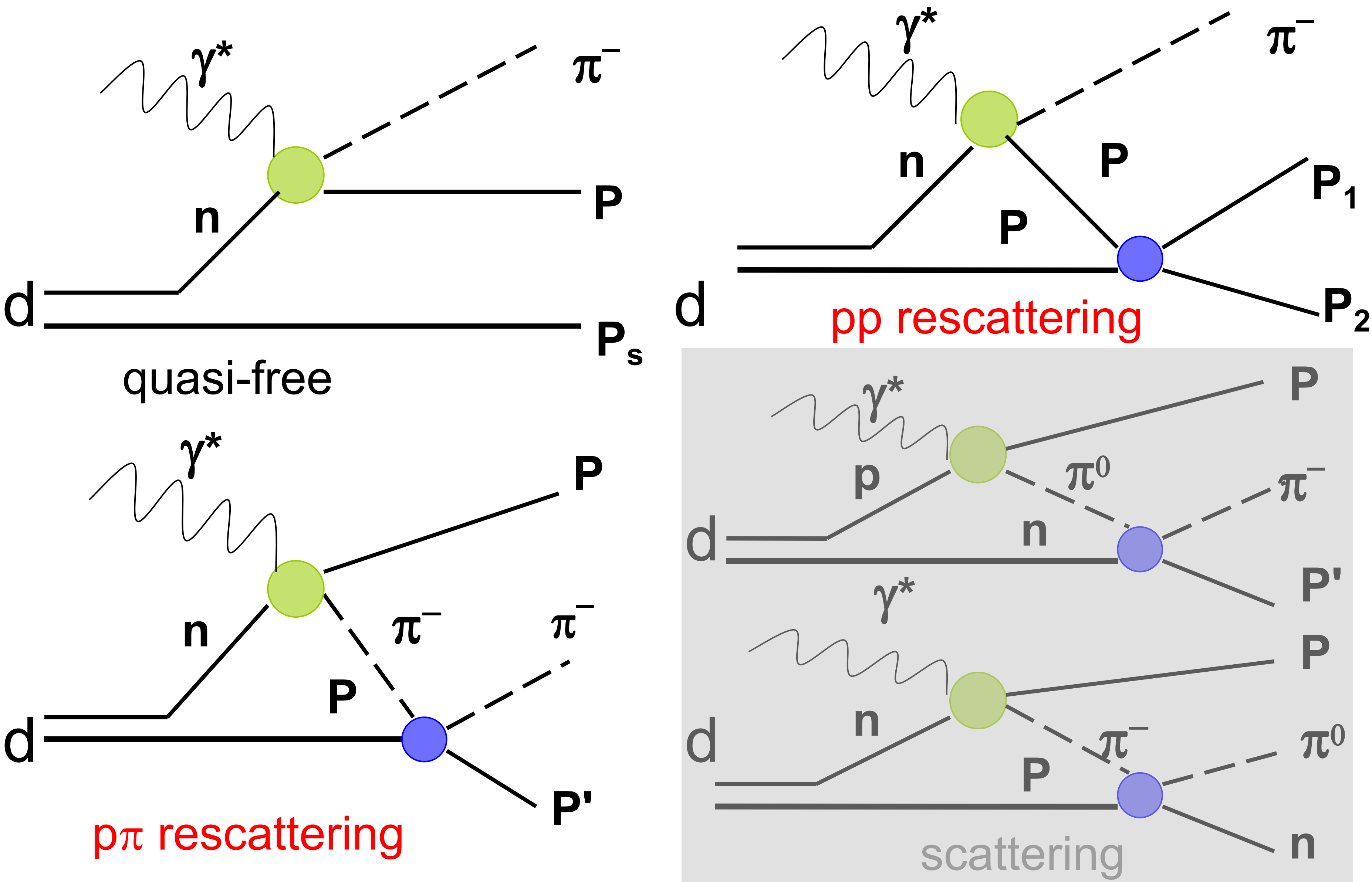


χ² / ndf 31.9 / 14
p0 11.89 ± 0.3821
p1 −0.427 ± 0.6945
p2 −4.455 ± 0.4358
χ² / ndf 47.91 / 15
p0 10.7 ± 0.2385
p1 −2.946 ± 0.2931
p2 −6.199 ± 0
χ² / ndf 25.72 / 12
p0 11.28 ± 0.471
p1 −1.474 ± 0.8402
p2 −4.968 ± 0.4935
χ² / ndf 31.94 / 13
p0 10.3 ± 0.1649
p1 −3.414 ± 0.1605
p2 −6.199 ± 0
dσ/dΩπ (mcb/sr)
φ*



W=1.2125GeV,Q2=0.5 GeV
W=1.2125GeV,Q2=0.7 GeV
W=1.2125GeV,Q2=0.9 GeV
data 3dimR_FSI
data without R_FSI
MAID2000
SAID
ANL-Osaka model
l=1
l=2
σT+εσL
σTT
σTL
cosθ

Final state interactions



Other channels

$\gamma^* p(n) \to p\ \pi^+\pi^-(n)$ main background channel

$\gamma^* p(n) \to p\ \pi^0(n) \to \pi^- p$ final state goes in channel

$\gamma^* n(p) \to p\ \pi^-(p) \to \pi^0 n$ final state goes out channel

need combined analysis channels

$$\gamma^* + p \to \pi^+ + n$$

$$\gamma^* + d(p) \to \pi^+ + n + n_s$$

$$\gamma^* + d(n) \to \pi^- + p + p_s$$