Measurement of New Observables from the $p\pi^+\pi^-$ Electroproduction off the Proton

Reaction: $ep \to e'p'\pi^+\pi^-$

$Q^2 = [2.0, 5.0] GeV^2$

$W = [1.400, 2.125] GeV$

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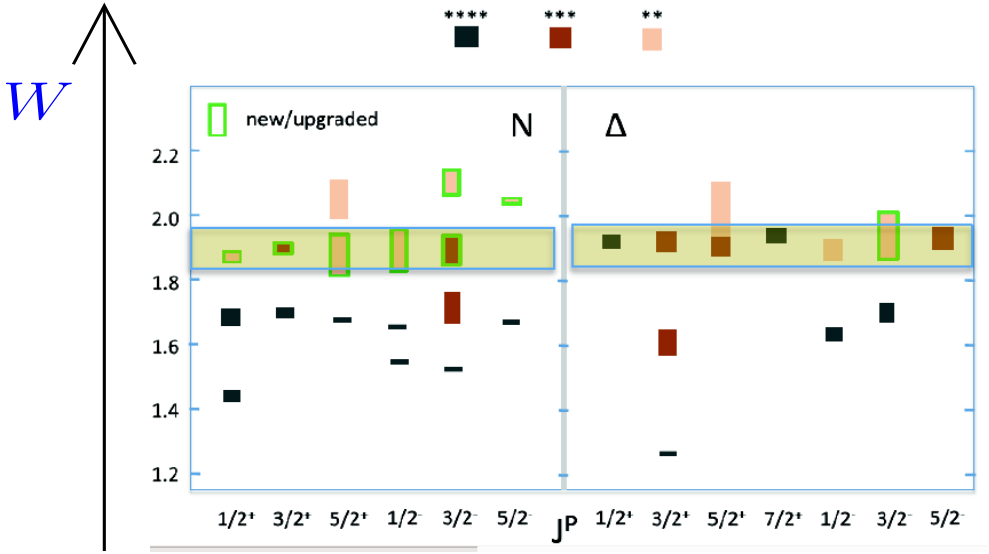
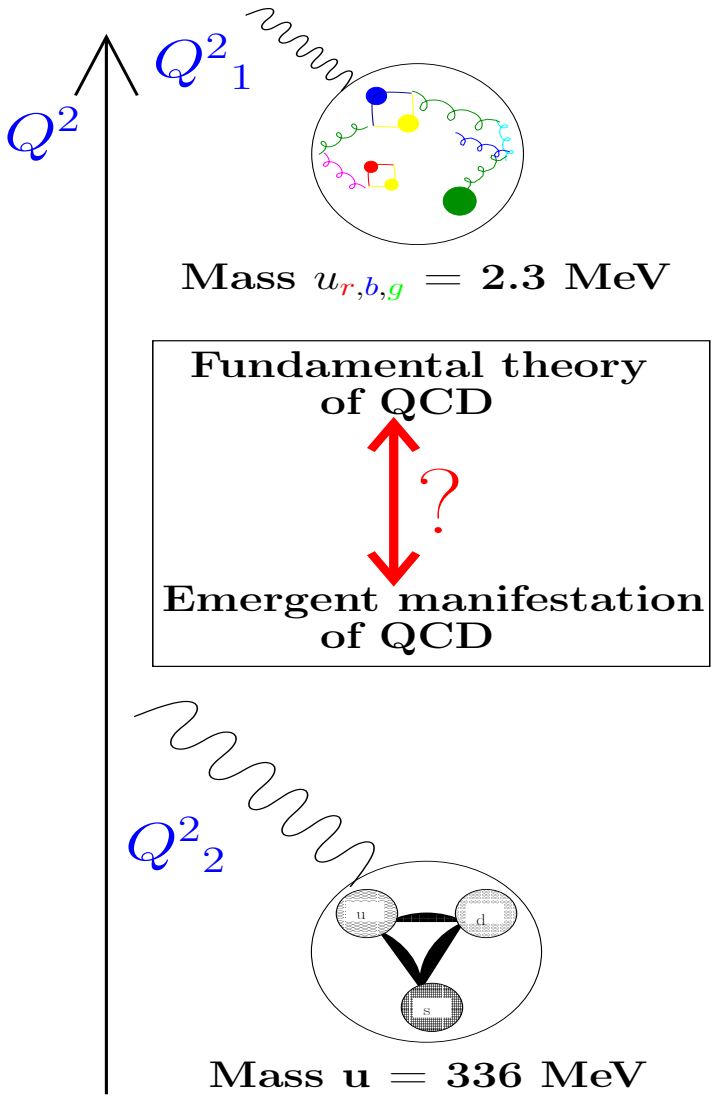
Outline

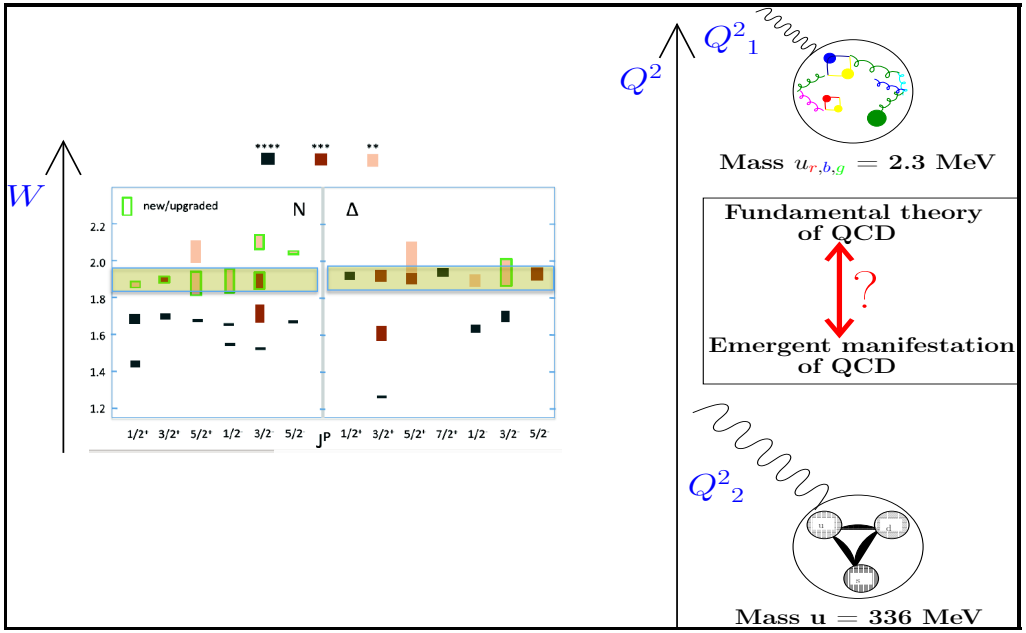
In the Physics Perspective

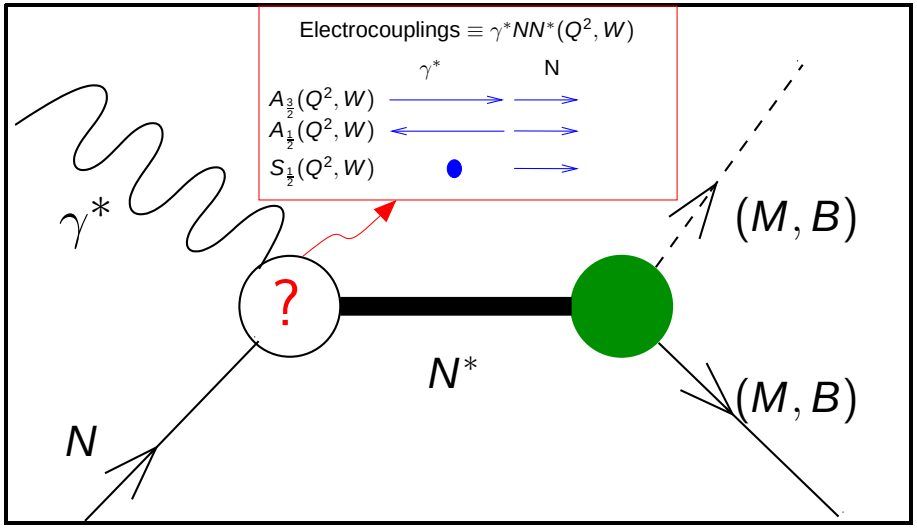
Photoproduction → Spectroscopy



Electroproduction → Transition Form Factors (TFF)



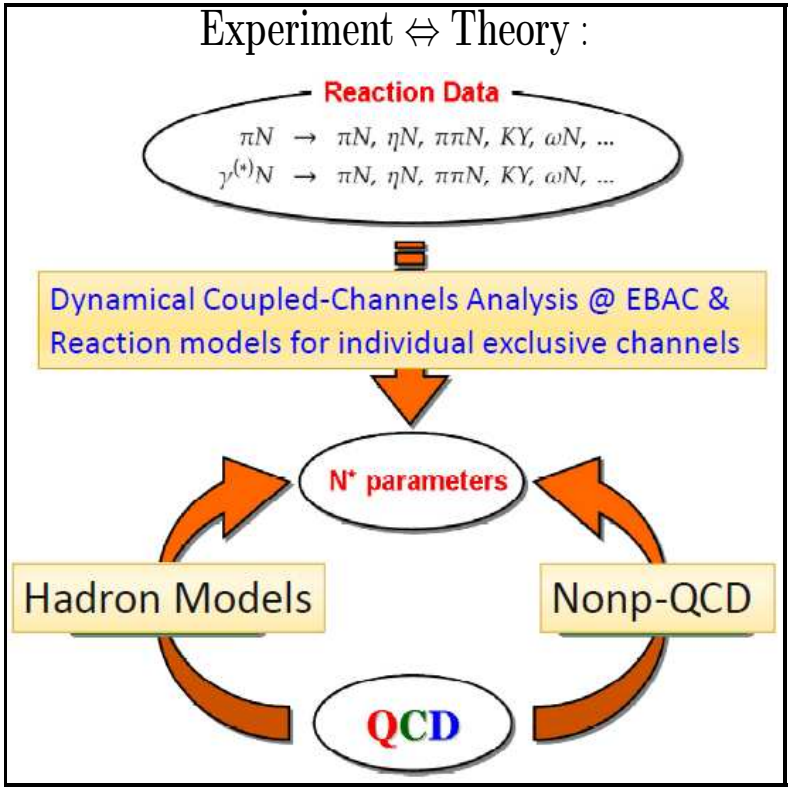


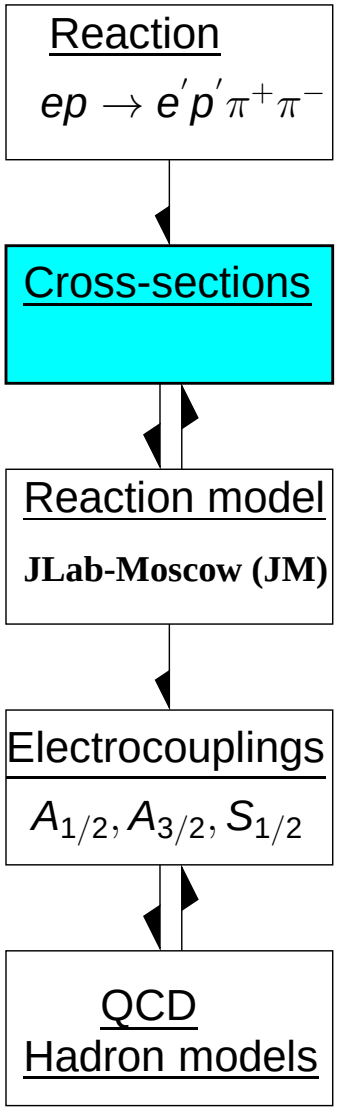


- $A_{\frac{1}{2}}(W), A_{\frac{3}{2}}(W) \rightarrow A_{\frac{1}{2}}(Q^2, W), A_{\frac{3}{2}}(Q^2, W), S_{\frac{1}{2}}(Q^2, W) :=$ TFF

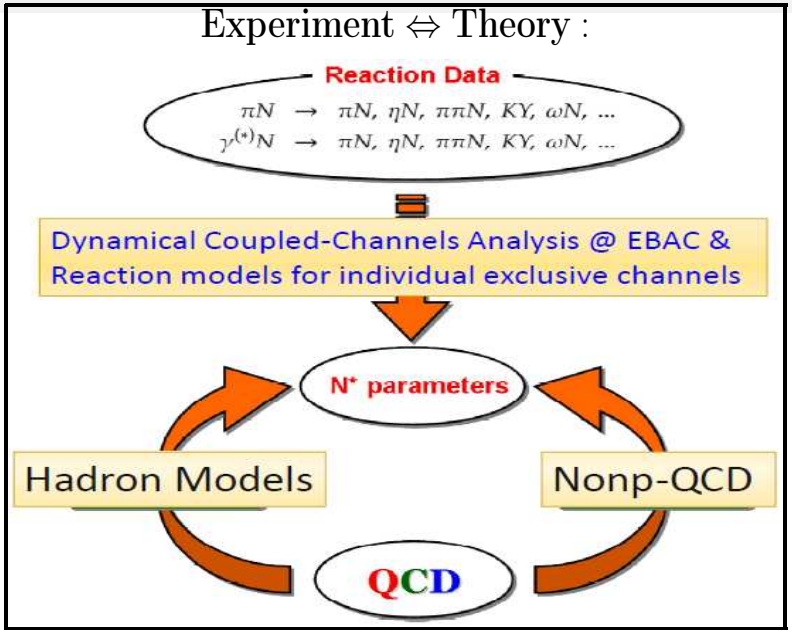
In the N* Program Perspective

Epistemological structure of the N* program



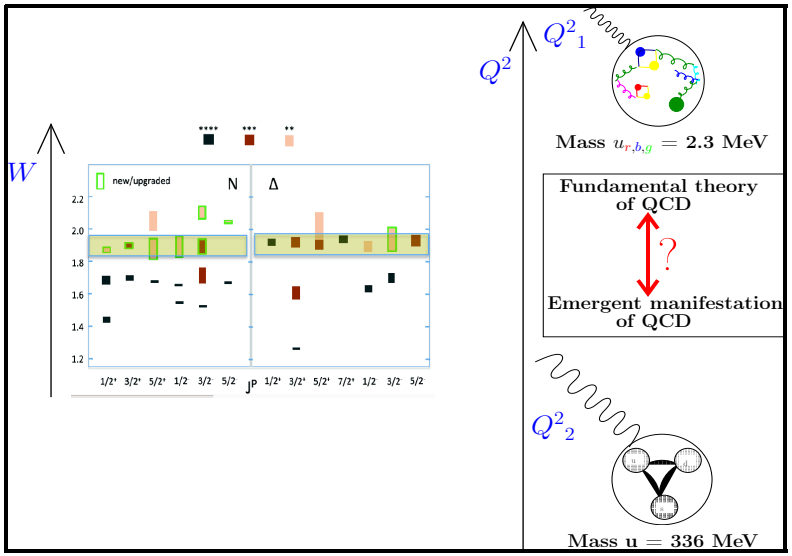


Reaction and its kinematic coverage



Results from the N* Program at Jefferson Lab.
(Journal of Physics: Conference Series 299 (2011) 012008)

$p(\gamma,K)X$	[3]	$p(e,e'K^+K^-)p, p(e,e'K^+\pi^-)X$	[17]
$p(\gamma,\eta,\eta')p$	[4]	$p(e,e'\pi)N$	[18]
$D(\gamma,\eta),\ D(\gamma,\eta')$	[5]	$\vec{p}(\vec{e},e'p)\pi^0$	[19]
$p(\gamma,\pi)N$	[6]	$p(e,e'\omega)p$	[20]
$p(\vec{\gamma},\omega)p$	[7]	$p(e,e'\pi^+\pi^-)p$	[21]
$\vec{\gamma}\vec{p}\to K^+\Lambda, K^+\Sigma, K^0\Sigma^+$	[8]	$\vec{p}(\vec{e},e'\pi)n$	[22]
$\vec{p}(\vec{\gamma},\pi^+)n, \vec{p}(\vec{\gamma},p)\pi^0$	[9]	$p(\vec{e},e'p)\pi^0,\ p(\vec{e},e'\pi^+)n$	[23]
$\vec{p}(\vec{\gamma},\eta)p$	[10]	$p(e,e'p)\pi^0$	[24]
$\vec{p}(\vec{\gamma},\pi^+\pi^-p)$	[11]	$p(e,e'K^+)\Lambda,\Sigma$	[25]
$n(\vec{\gamma},K\Lambda)$	[12]	$p(e,e'\pi^0)p, p(e,e'\pi^+)n$	[26]
$p(e,e'\pi)N$	[13]	$p(e,e'\pi^+\pi^-p)$	[27]
$p(e,e'\pi^+)n,\ p(e,e'p)\pi^0,\ n(e,e'\pi^-)p$	[14]	$p(\vec{e},e'K,\vec{\Lambda},\vec{\Sigma})$	[28]
$p(e,e'p)\eta$	[15]	$p(e,e'p)\pi^0,\eta$	[29]
$p(\vec{e},e'p)\pi^0,\ p(\vec{e},e'\pi^+)n$	[16]		



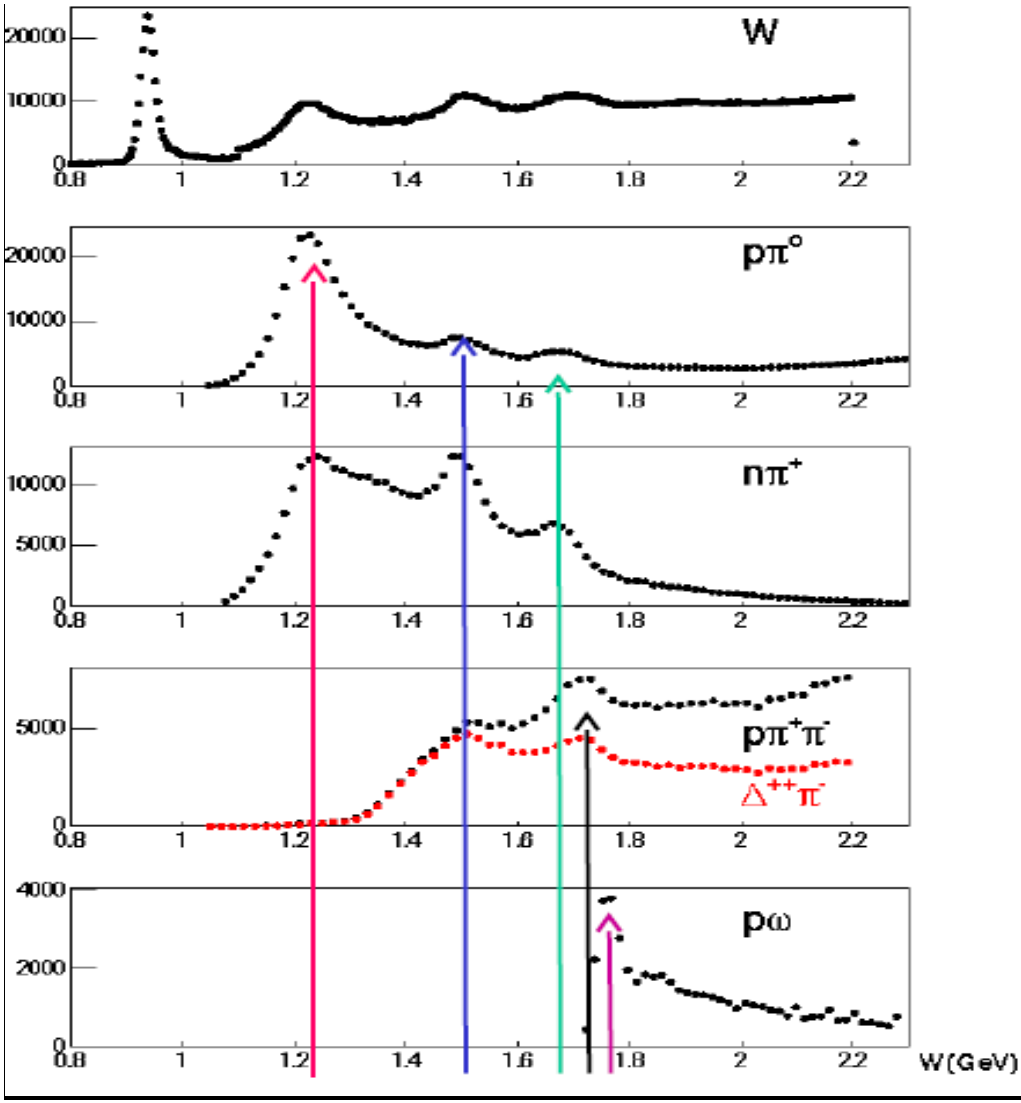
Q^2 coverage, GeV^2	W coverage, GeV	Bin size over W/Q^2, GeV/GeV^2	Data status
0.20-0.60	1.30-1.57	0.025/0.050	Completed [69]
0.50-1.50	1.40-2.10	0.025/0.3-0.4	Completed [70]
2.0-5.0	1.40-2.00	0.025/0.5	In progress
0.	1.60-2.80	0.025	In progress

Evgeny Isupov, arXiv:1705.01901 (Accepted: Phys. Rev. C)

Significance of $p\pi^+\pi^-$ channel

In relation to π channel

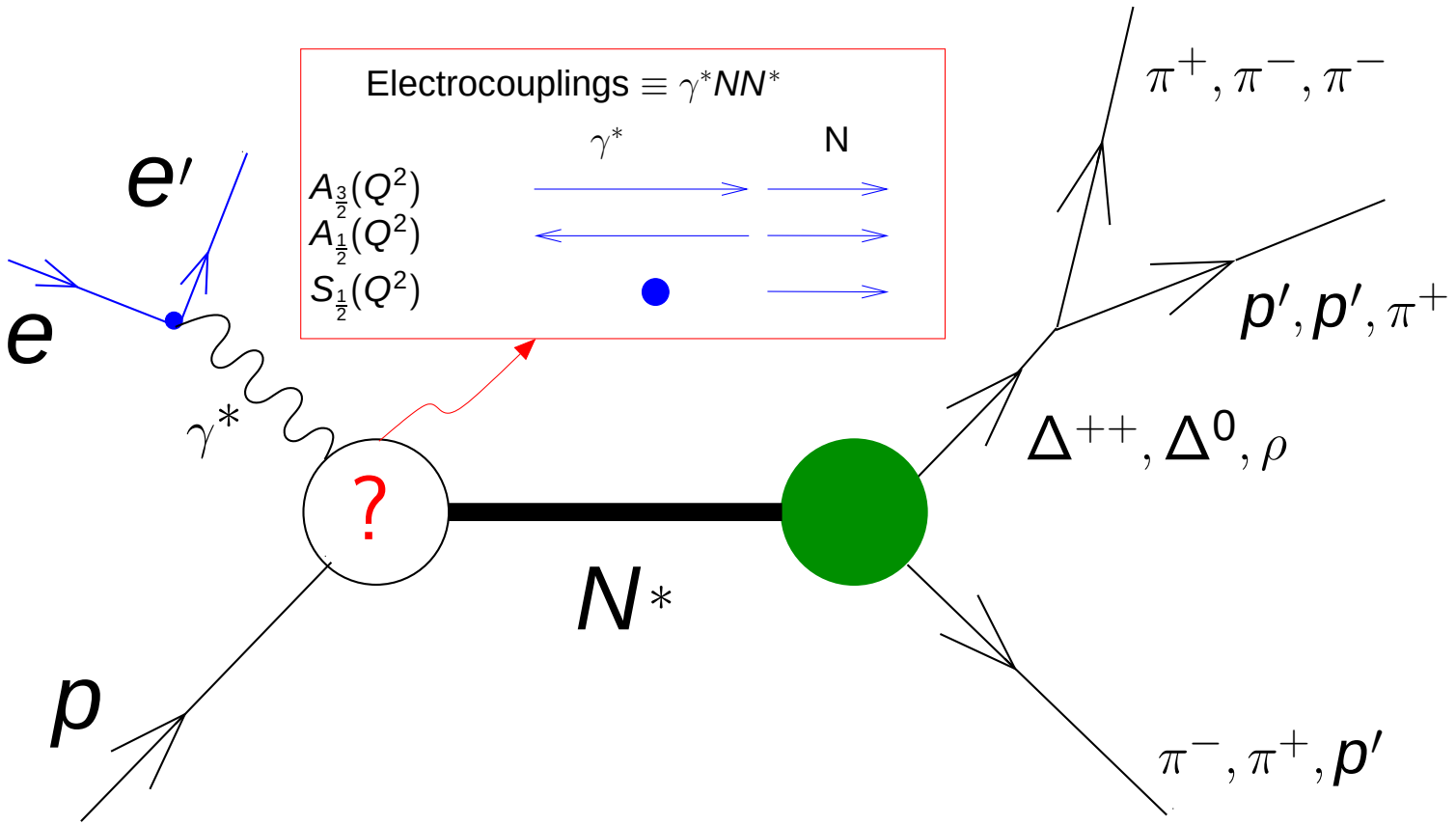
- Access to higher W
- Cross-check for extracted TFFs
  - Has different background contributions



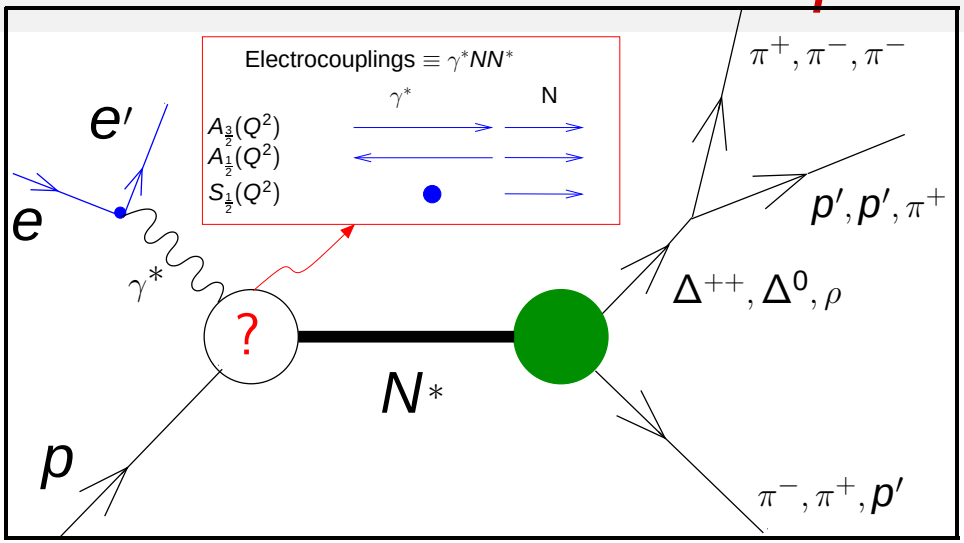
Measurements

Cross-sections from $ep \to e'p'\pi^+\pi^-$

A Mnemonic Introduction



Cross-sections from $ep \to e'p'\pi^+\pi^-$



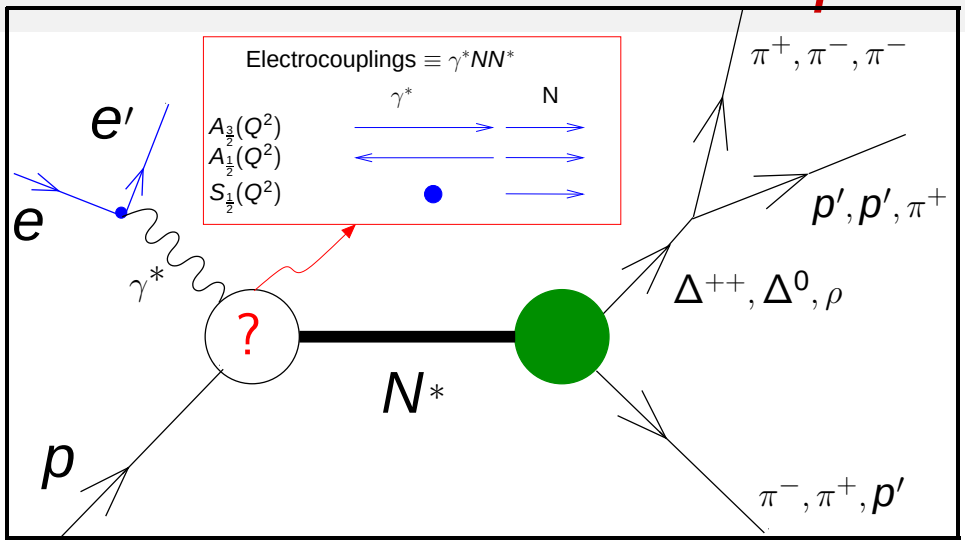
Variable sets

Δ^{++} : $M_{p\pi^+}, \theta^*_{\pi^-}, \phi^*_{\pi^-}, \alpha^*_{[p'\pi^+][p\pi^-]}, M_{\pi^+\pi^-}$

Δ^0 : $M_{p\pi^-}, \theta^*_{\pi^+}, \phi^*_{\pi^+}, \alpha^*_{[p'\pi^-][p\pi^+]}, M_{p\pi^+}$

ρ : $M_{\pi^+\pi^-}, \theta^*_p, \phi^*_p, \alpha^*_{[\pi^+\pi^-][p'p]}, M_{p\pi^+}$

Cross-sections from $ep \to e'p'\pi^+\pi^-$



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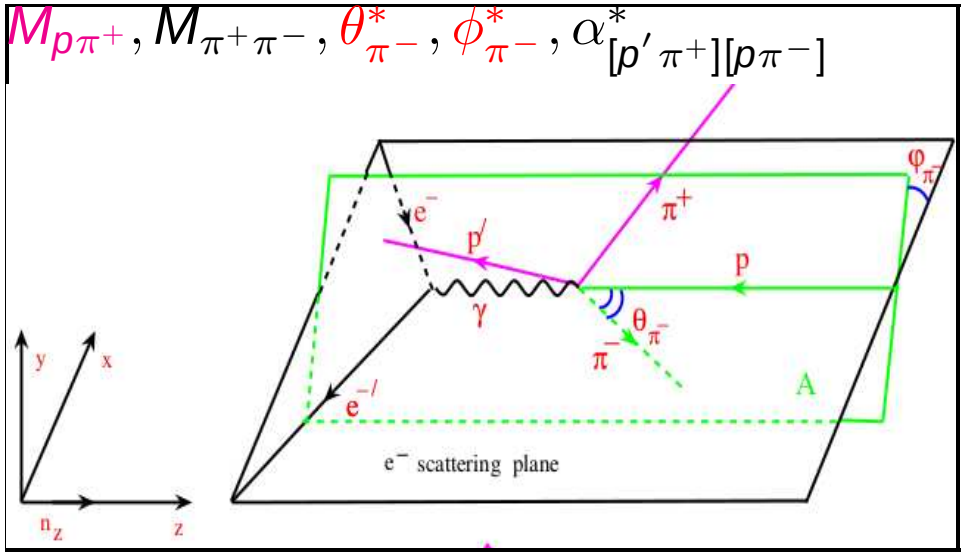

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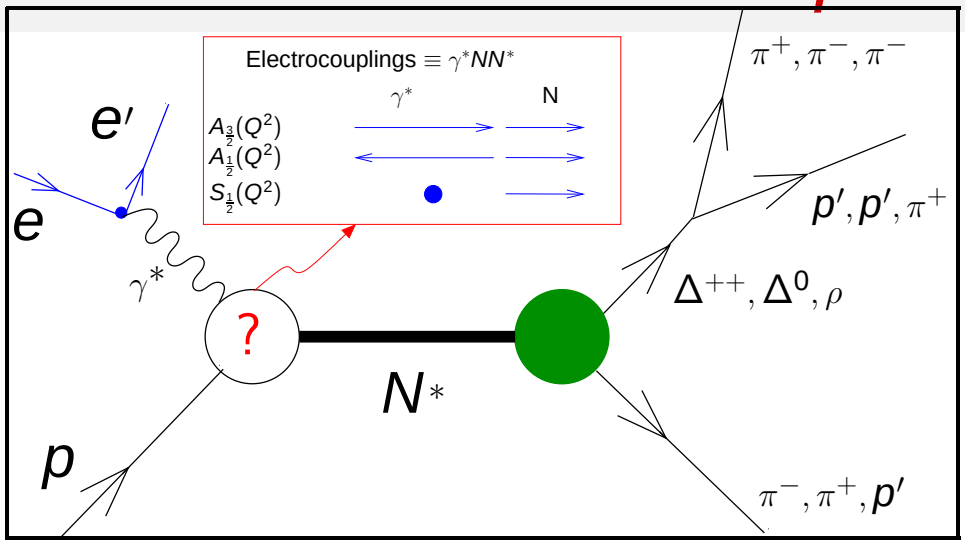

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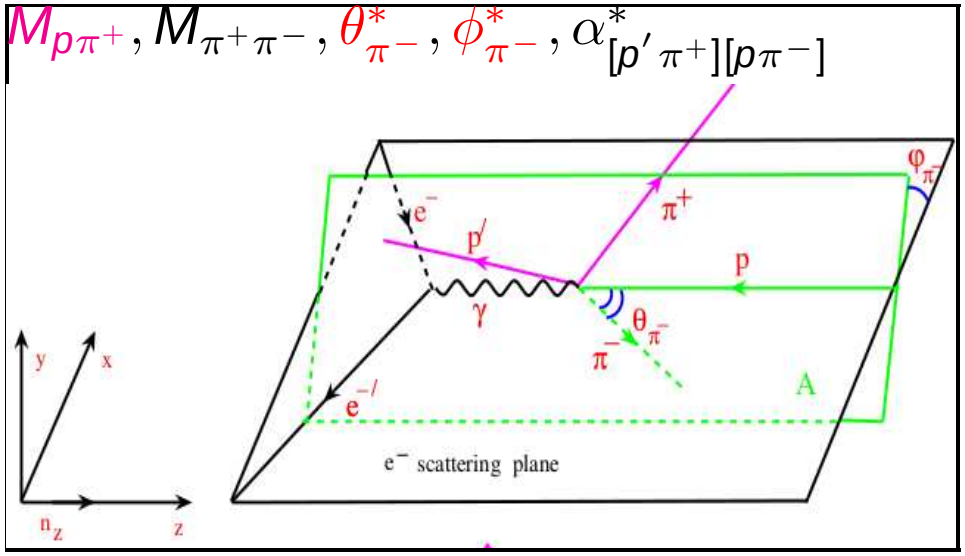
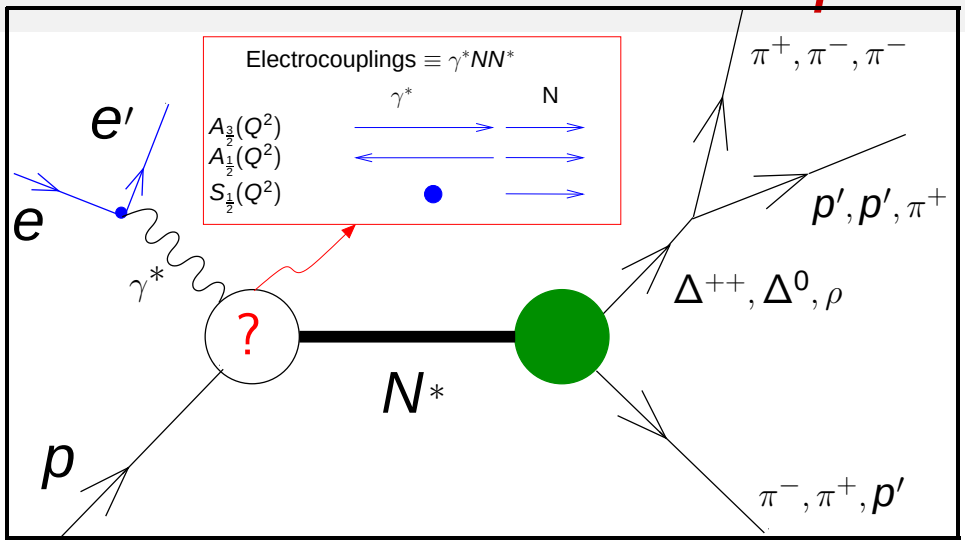


Cross-sections

Independent of γ^* polarization:

1 $\frac{d^5\sigma}{d\tau^5} \to \frac{d\sigma}{dX_{ij}}$

Cross-sections from $ep \to e'p'\pi^+\pi^-$



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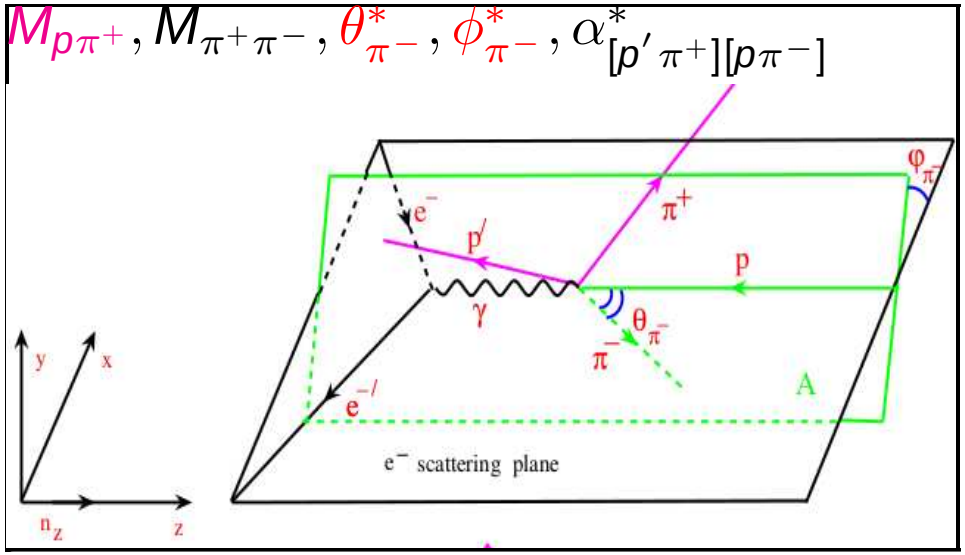


Cross-sections

1. Independent of γ^* polarization:

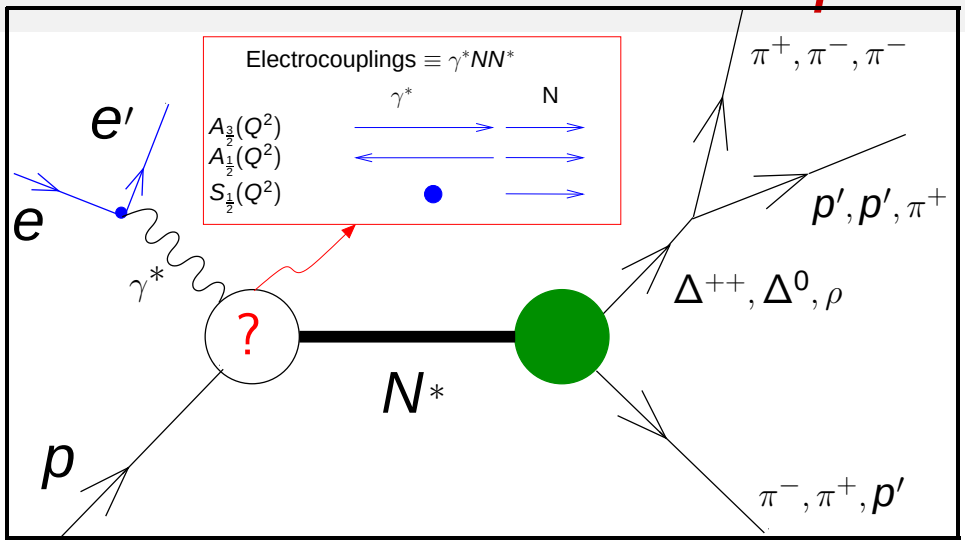
$$\frac{d^5\sigma}{d\tau^5} \to \frac{d\sigma}{dX_{ij}}$$

2. Sensitive to γ^* polarization:

(Iu. A. Skorodumina et al., Moscow University Physics Bulletin, 2015, Vol. 70, No. 6, pp. 429-447)

$$\left(\frac{d^2\sigma}{dX_{ij}d\phi_i}\right) = R2_T{}^{X_{ij}} + R2_L{}^{X_{ij}} + R2_{LT}{}^{c,X_{ij}}\cos\phi_i + R2_{TT}{}^{c,X_{ij}}\cos 2\phi_i + \delta_{X_{ij}\alpha_i}\left(R2_{LT}{}^{s,\alpha_i}\sin\phi_i + R2_{TT}{}^{s,\alpha_i}\sin 2\phi_i\right)$$

Cross-sections from $ep \to e'p'\pi^+\pi^-$



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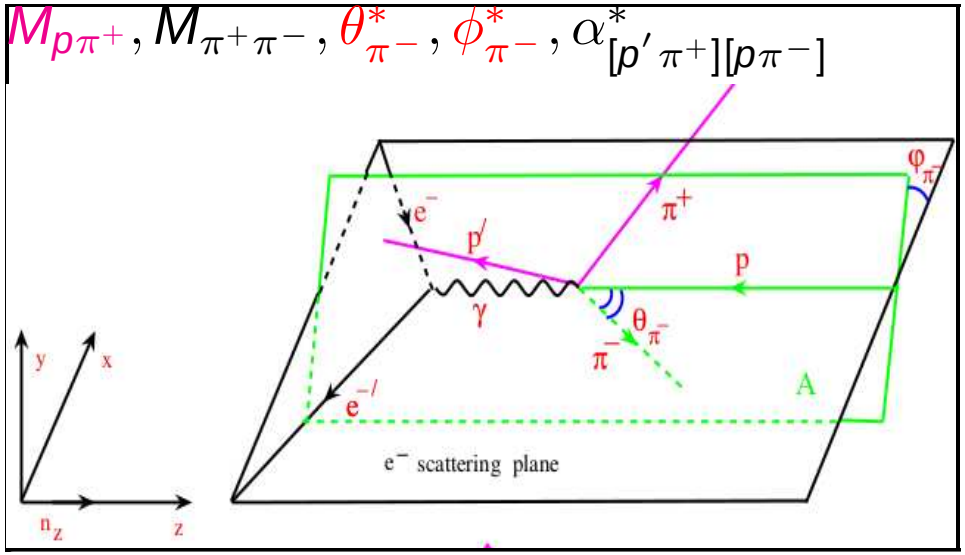

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All possible observables: A glimpse

Polarization Observables for Electroproduction

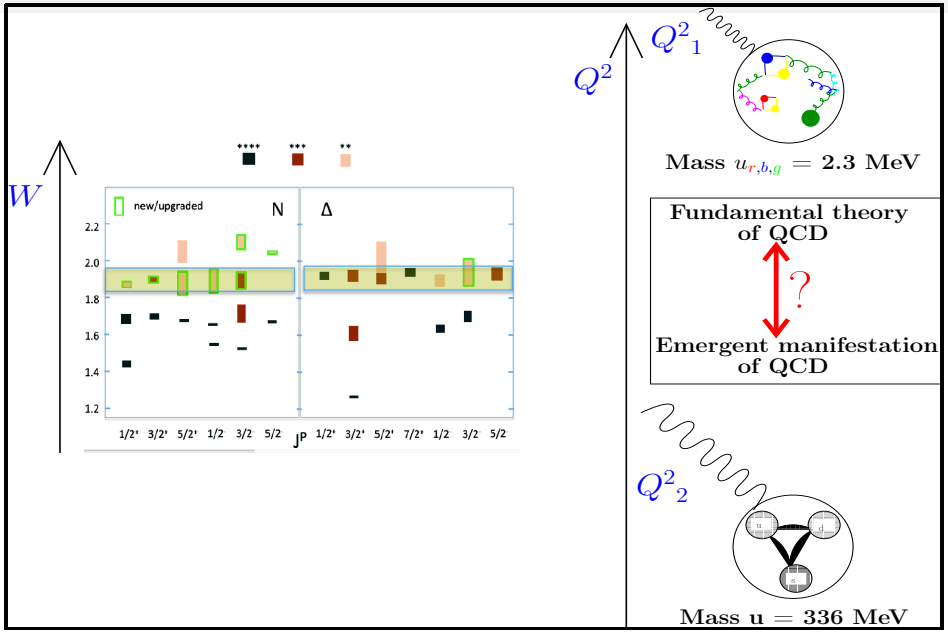
(arXiv:nucl-th/9506029v1)

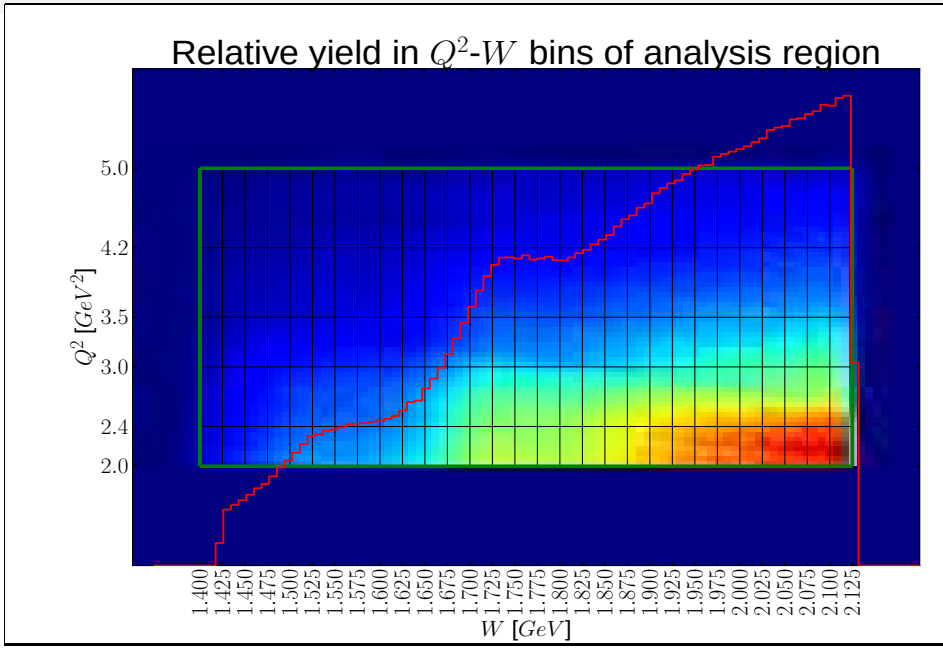
	Target				Recoil			Target + Recoil								
β	–	–	–	–	x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
α	–	x	y	z	–	–	–	x	y	z	x	y	z	x	y	z
T	R_T^{00}	0	R_T^{0y}	0	0	$R_T^{y'0}$	0	$R_T^{x'x}$	0	$R_T^{x'z}$	0	*	0	$R_T^{z'x}$	0	$R_T^{z'z}$
L	R_L	0	R_L^{0y}	0	0	*	0	$R_L^{x'x}$	0	$R_L^{x'z}$	0	*	0	*	0	*
${}^cTL$	${}^cR_{TL}^{00}$	0	${}^cR_{TL}^{0y}$	0	0	*	0	${}^cR_{TL}^{x'x}$	0	*	0	*	0	${}^cR_{TL}^{z'x}$	0	*
${}^sTL$	0	${}^sR_{TL}^{0x}$	0	${}^sR_{TL}^{0z}$	${}^sR_{TL}^{x'0}$	0	${}^sR_{TL}^{z'0}$	0	*	0	*	0	*	0	*	0
${}^cTT$	${}^cR_{TT}^{00}$	0	*	0	0	*	0	*	0	*	0	*	0	*	0	*
${}^sTT$	0	${}^sR_{TT}^{0x}$	0	${}^sR_{TT}^{0z}$	${}^sR_{TT}^{x'0}$	0	${}^sR_{TT}^{z'0}$	0	*	0	*	0	*	0	*	0
${}^cTL'$	0	${}^cR_{TL'}^{0x}$	0	${}^cR_{TL'}^{0z}$	${}^cR_{TL'}^{x'0}$	0	${}^cR_{TL'}^{z'0}$	0	*	0	*	0	*	0	*	0
${}^sTL'$	${}^sR_{TL'}^{00}$	0	${}^sR_{TL'}^{0y}$	0	0	*	0	${}^sR_{TL'}^{x'x}$	0	*	0	*	0	${}^sR_{TL'}^{z'x}$	0	*
TT'	0	$R_{TT'}^{0x}$	0	$R_{TT'}^{0z}$	$R_{TT'}^{x'0}$	0	$R_{TT'}^{z'0}$	0	*	0	*	0	*	0	*	0

- Note that this table is applicable for single pseudoscalar electroproduction
- In case of double (charged) pseudoscalar electroproduction, in addition to ${}^cR2_{LT}^{00}$ and ${}^cR2_{TT}^{00}$, ${}^sR2_{LT}^{00}$ and ${}^sR2_{TT}^{00}$ can be also be measured:

$$\left(\frac{d^2\sigma}{dX_{ij}\,d\phi_i}\right) = R2_T{}^{X_{ij}} + R2_L{}^{X_{ij}} + R2_{LT}{}^{c,X_{ij}}\cos\phi_i + R2_{TT}{}^{c,X_{ij}}\cos 2\phi_i + \delta_{X_{ij}\alpha_i}\left(R2_{LT}{}^{s,\alpha_i}\sin\phi_i + R2_{TT}{}^{s,\alpha_i}\sin 2\phi_i\right)$$

Summary





51 (30 new)1D Cross-sections per Q^2, W bin

1. $\frac{d\sigma}{dX_{ij}}$ (3x3=9)
2. γ^* polarization dependent
   - i $R2_T^{X_{ij}} + R2_L^{X_{ij}}$ (3x4=12)
   - ii $R2_{LT}^{c,X_{ij}}$ (3x4=12)
   - iii $R2_{TT}^{c,X_{ij}}$ (3x4=12)
   - iv $R2_{LT}^{s,\alpha_i}$ (3x1=3)
   - v $R2_{LT}^{s,\alpha_i}$ (3x1=3)

X_{ij} := Variable sets

1. $M_{p\pi^+}, \theta^*_{\pi^-}, \phi^*_{\pi^-}, \alpha^*_{[p'\pi^+][p\pi^-]}, M_{\pi^+\pi^-}$
2. $M_{p\pi^-}, \theta^*_{\pi^+}, \phi^*_{\pi^+}, \alpha^*_{[p'\pi^-][p\pi^+]}, M_{p\pi^+}$
3. $M_{\pi^+\pi^-}, \theta^*_{p}, \phi^*_{p}, \alpha^*_{[\pi^+\pi^-][p'p]}, M_{p\pi^+}$

Core Tasks

Experiment: $ep \to e'X$

1. Reconstruct $ep \to e'p'\pi^+\pi^-$
   - I Particle identification
   - II Fiducial cuts
   - III Momentum corrections
   - IV Energy loss corrections
   - V Event selection
   - VI Bin events $\Rightarrow N_R^i$
2. A^i from Simulation
3. $N_T^i = N_R^i / A^i$
4. Radiative effects correction
5. $\sigma(Q^2, W) = \frac{\sum N_T^i}{L\Gamma(Q^2, W)}$

Experiment: $ep \to e'X$
Natural process

1. Reconstruct $ep \to e'p'\pi^+\pi^-$
   - I Particle identification
   - II Fiducial cuts
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   - V Event selection
   - VI Bin events $\Rightarrow N_R^i$
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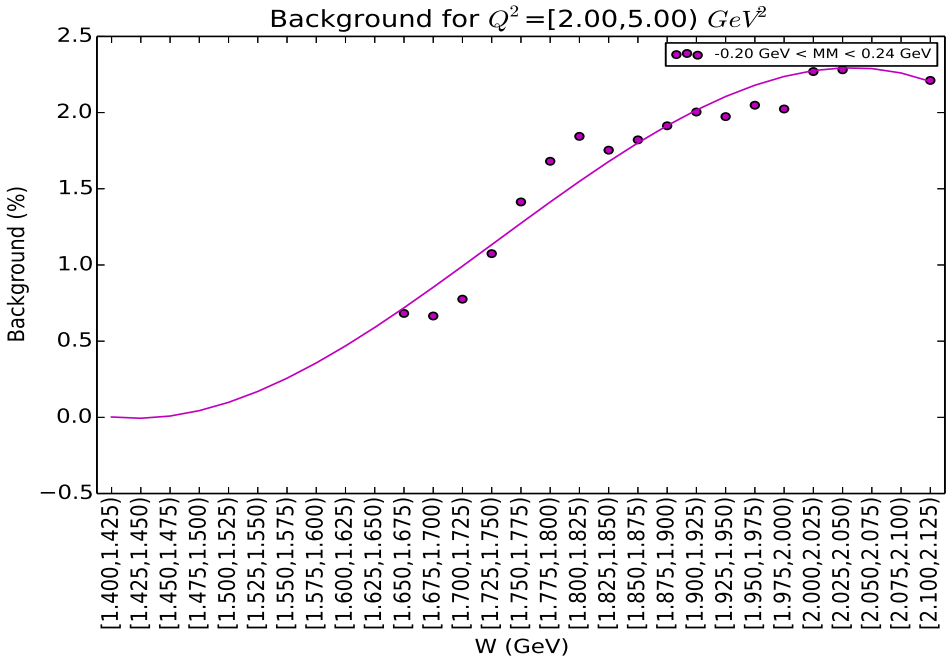
5. $\sigma(Q^2, W) = \frac{\sum N_T^i}{L\Gamma(Q^2, W)}$

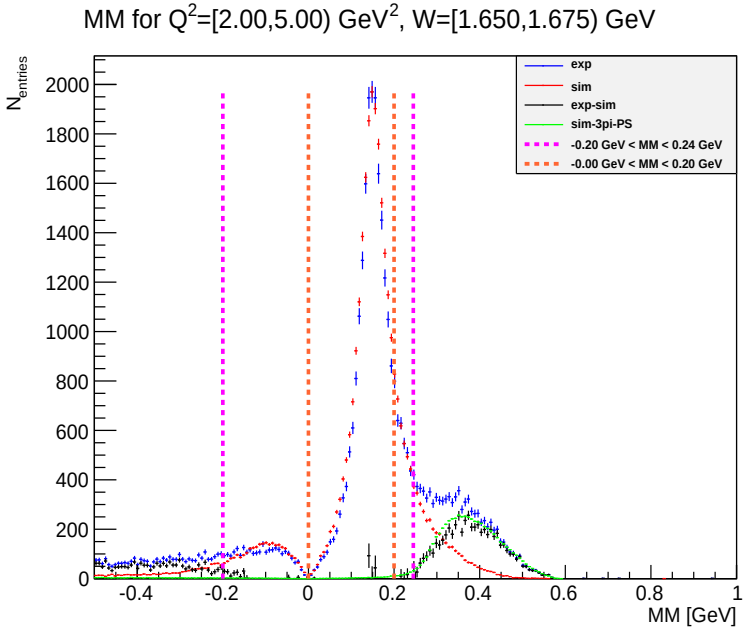
Simulation: $ep \to e'p'\pi^+\pi^-$
Model(JM) based process

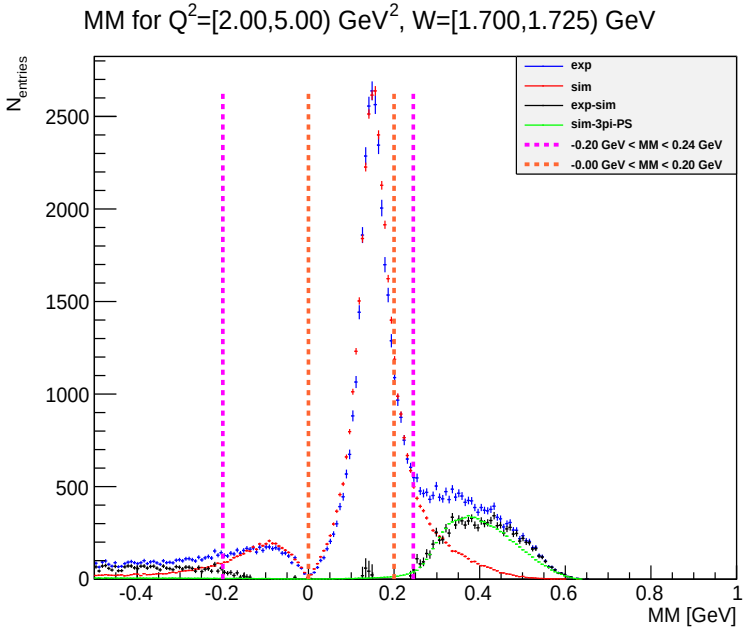
1. Reconstruct $ep \to e'p'\pi^+\pi^-$
   - I similar
   - II similar
   - III N.A.
   - IV similar
   - V similar
   - VI similar
2. $A^i = N_R^i / N_T^i$
3. $N_T^i = N_R^i / A^i$
4. N.A.
5. N.A.

Event Selection

- $ep \rightarrow e'p'\pi^+\pi^-$
- $ep \rightarrow e'p'\pi^+X$
- $MM_X = \sqrt{(\gamma^{*\mu} + p^\mu - p'^\mu - \pi^{+\mu}) \cdot (\gamma^*{}_\mu + p_\mu - p'_\mu - \pi^+{}_\mu)}$

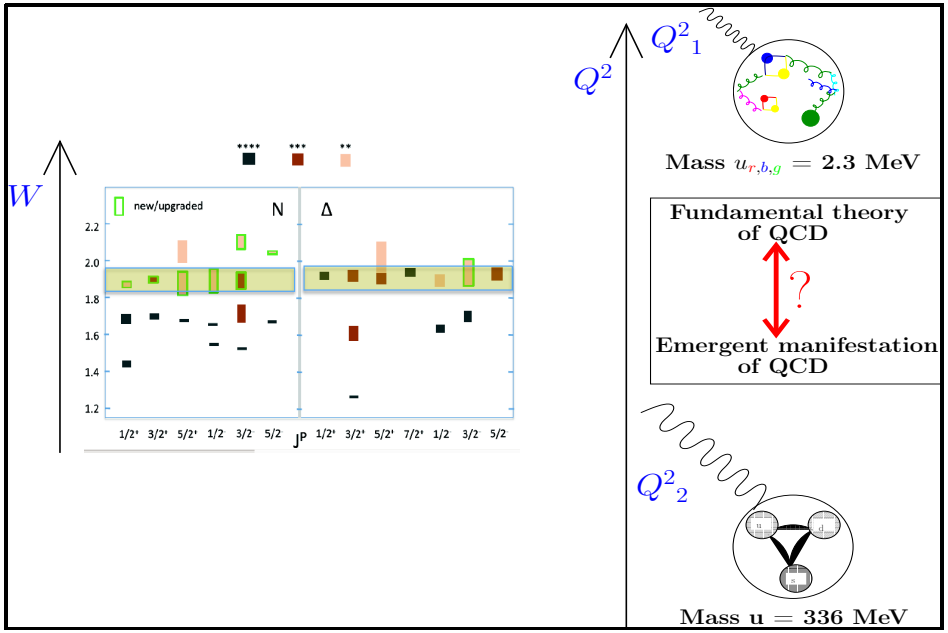


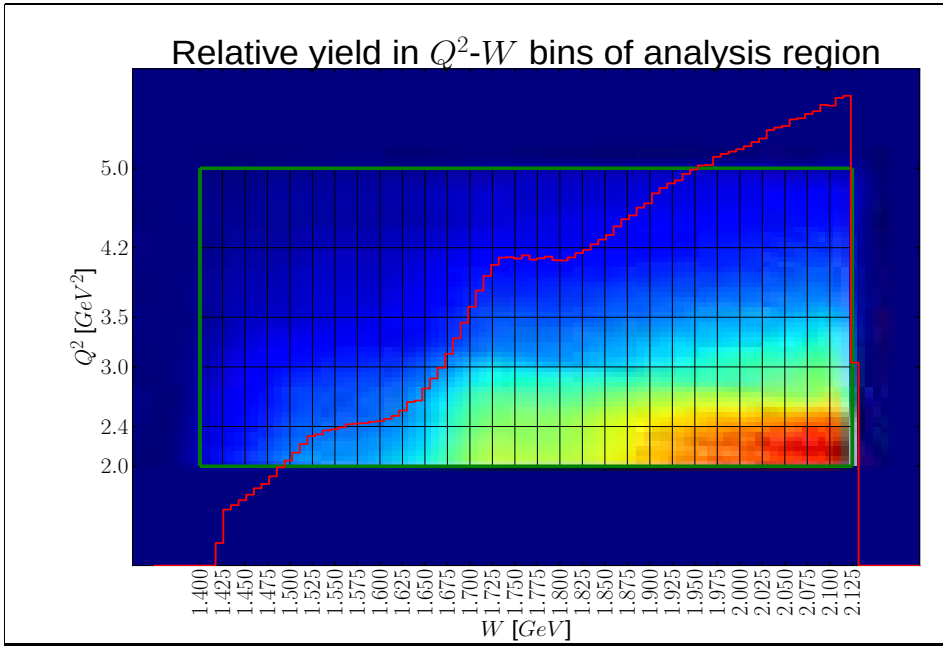




Preliminary Results

E16 experiment conducted in Hall B





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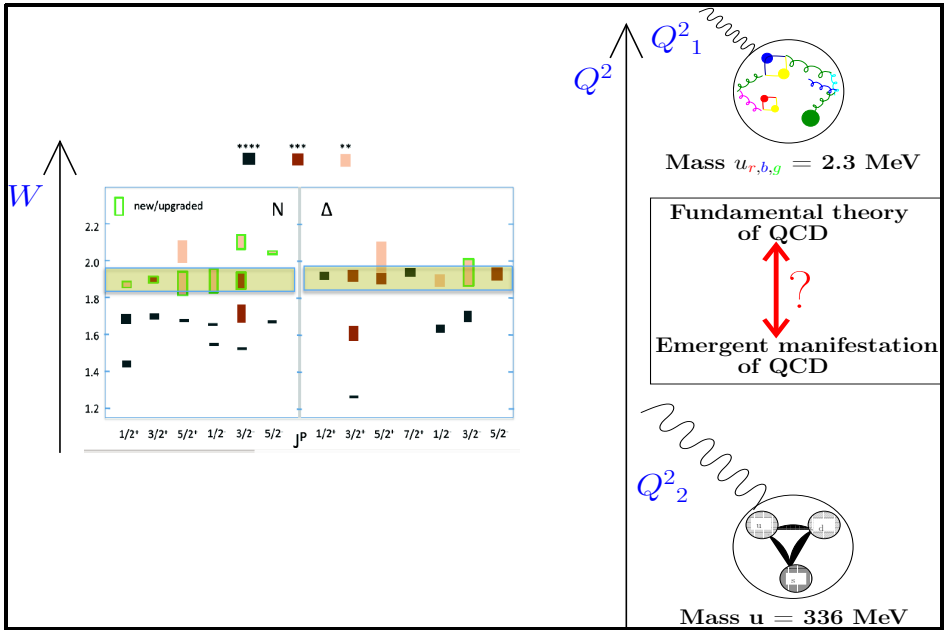
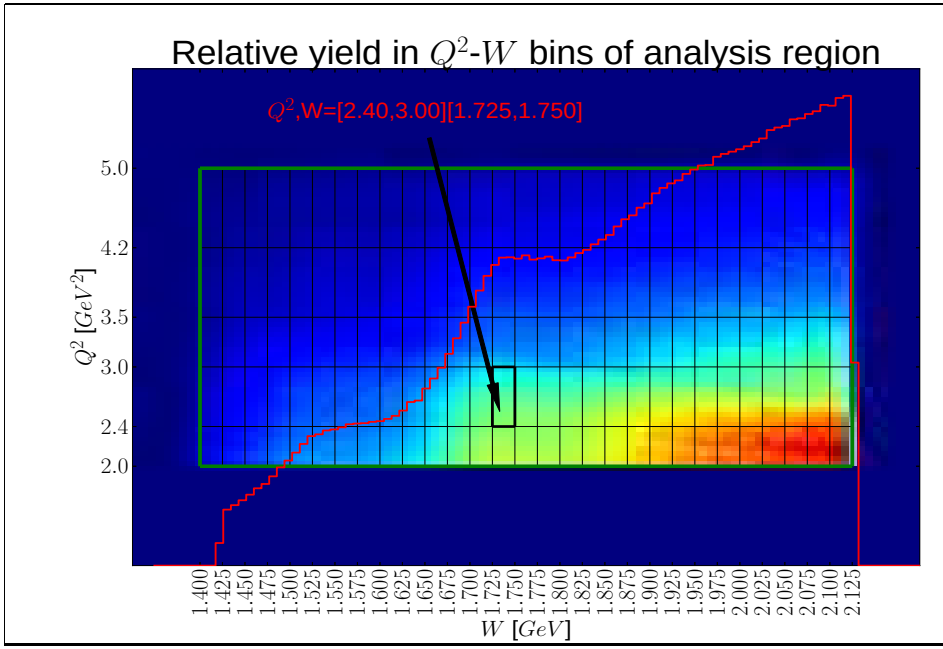
3. $M_{\pi^+\pi^-}, \theta^*_{p}, \phi^*_{p}, \alpha^*_{[\pi^+\pi^-][p'p]}, M_{p\pi^+}$

E16 experiment conducted in Hall B





51 (30 new)1D Cross-sections per Q^2, W bin

1. $\frac{d\sigma}{dX_{ij}}$ (3x3=9)
2. γ^* polarization dependent
   - i $R2_T^{X_{ij}} + R2_L^{X_{ij}}$ (3x4=12)
   - ii $R2_{LT}^{c,X_{ij}}$ (3x4=12)
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   - iv $R2_{LT}^{s,\alpha_i}$ (3x1=3)
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X_{ij} := Variable sets

1. $M_{p\pi^+}, \theta^*_{\pi^-}, \phi^*_{\pi^-}, \alpha^*_{[p'\pi^+][p\pi^-]}, M_{\pi^+\pi^-}$
2. $M_{p\pi^-}, \theta^*_{\pi^+}, \phi^*_{\pi^+}, \alpha^*_{[p'\pi^-][p\pi^+]}, M_{p\pi^+}$
3. $M_{\pi^+\pi^-}, \theta^*_{p}, \phi^*_{p}, \alpha^*_{[\pi^+\pi^-][p'p]}, M_{p\pi^+}$

Single-differential cross-sections

Q^2, W bin $= [2.4, 3.0) GeV^2, [1.725, 1.750) GeV$

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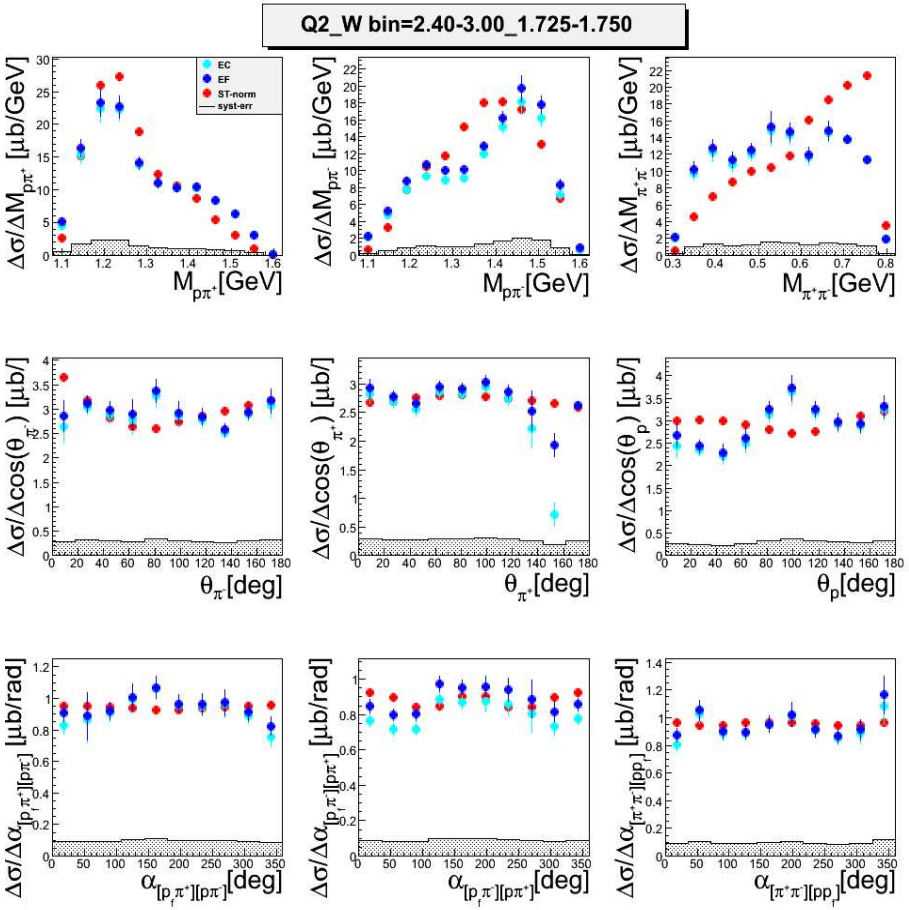

γ^* polarization dependent cross-sections

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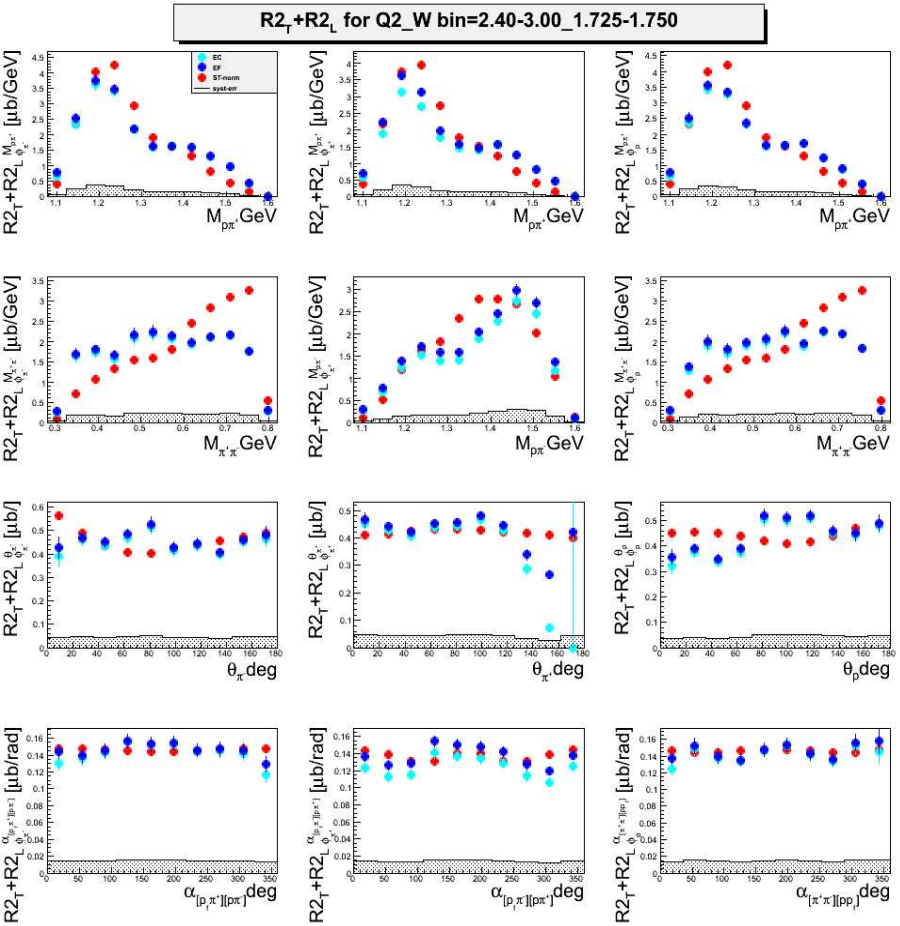

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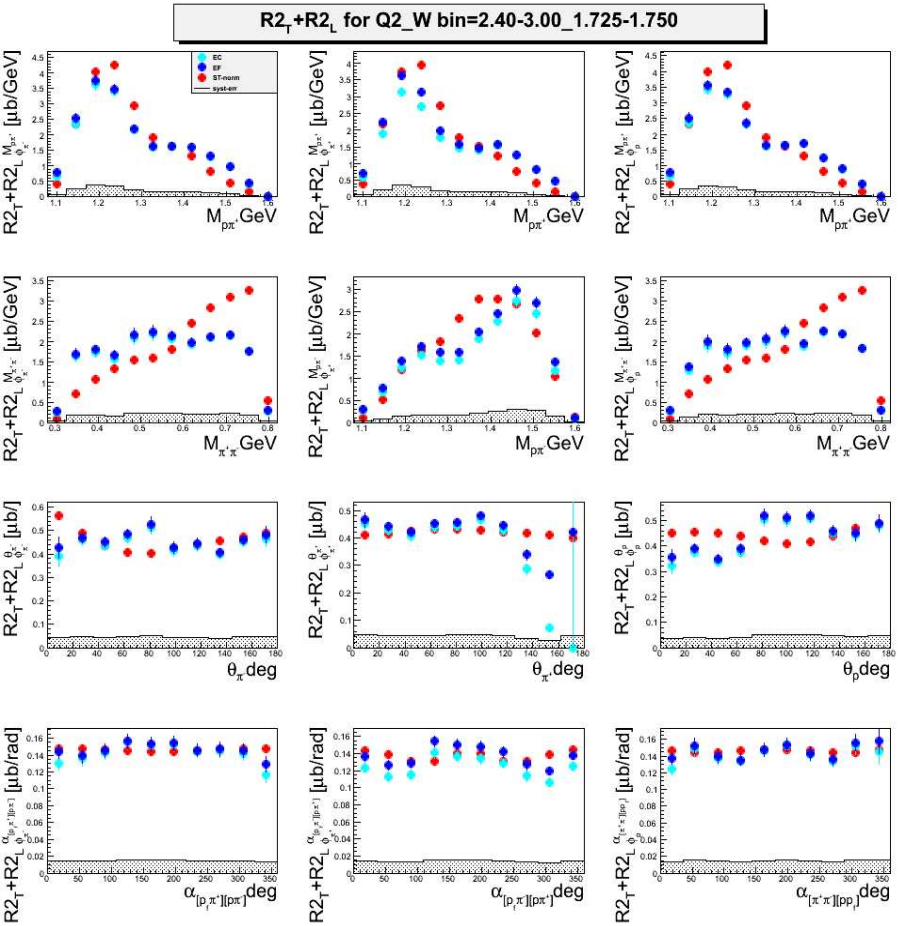

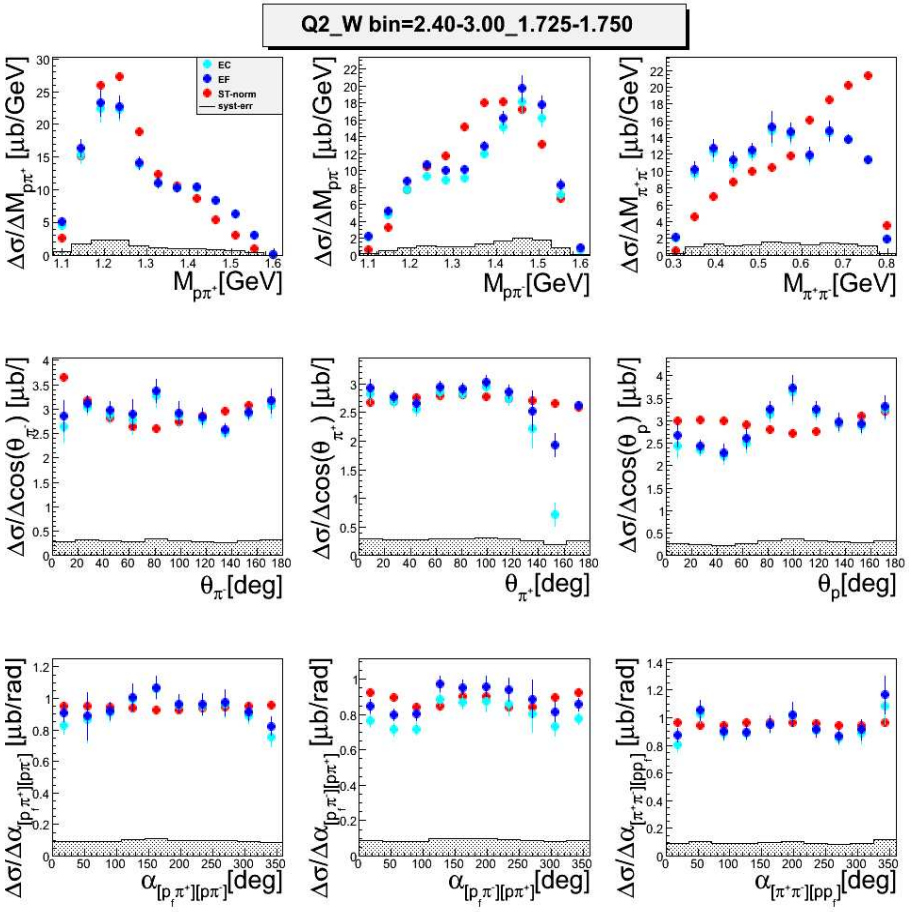

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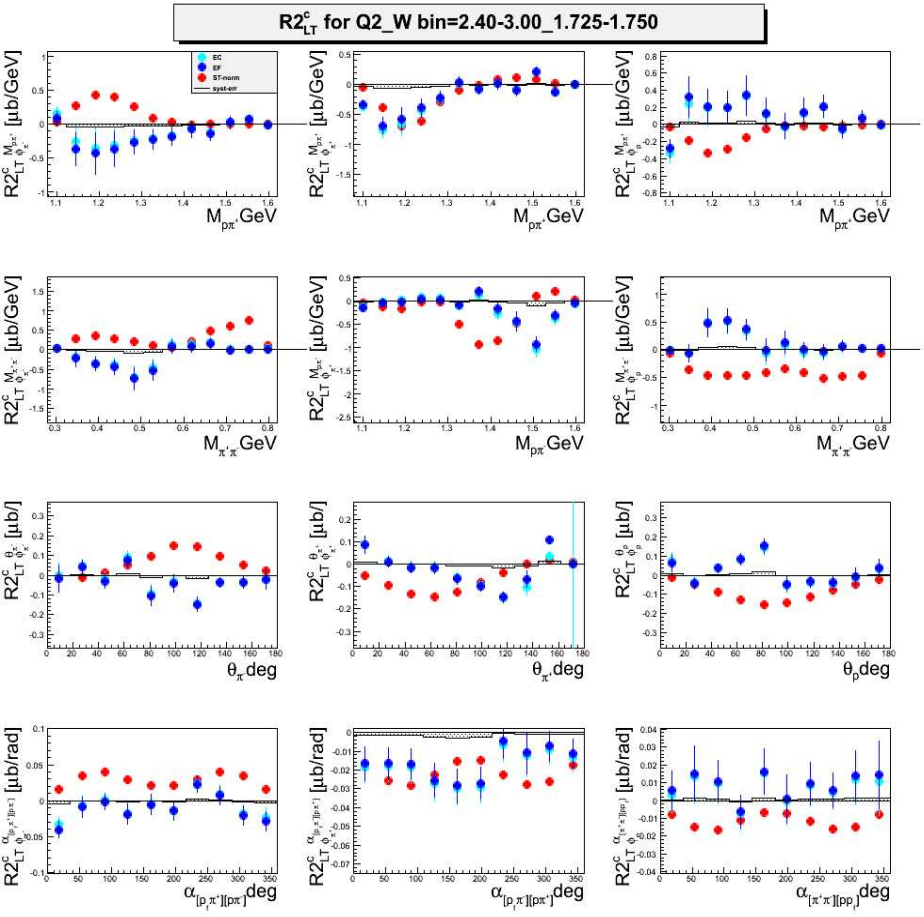

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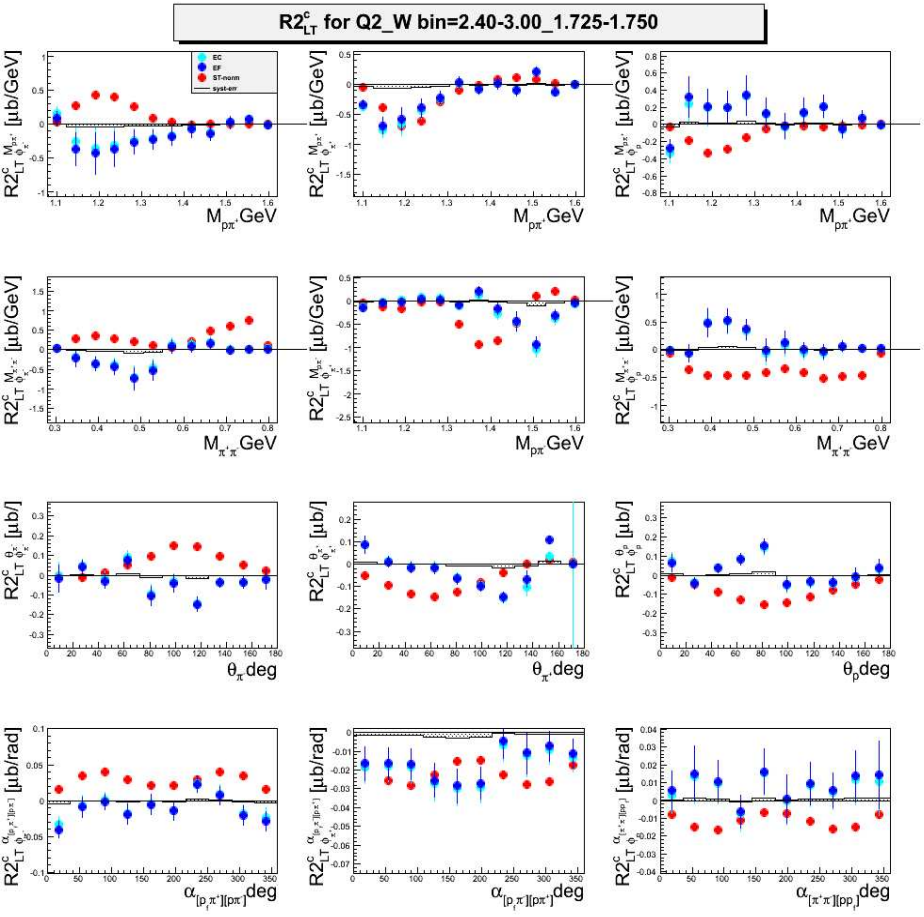

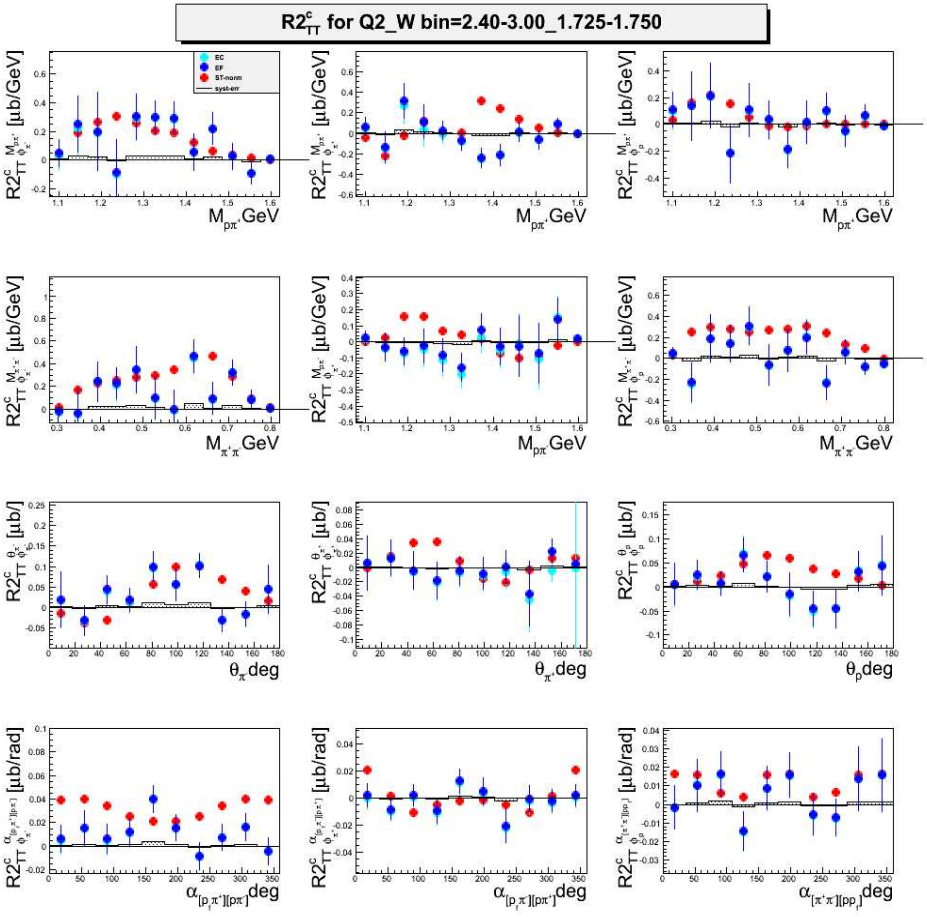

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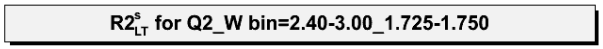

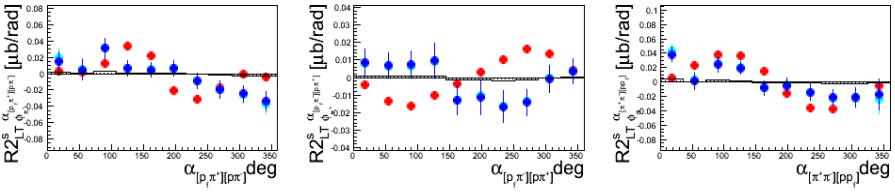

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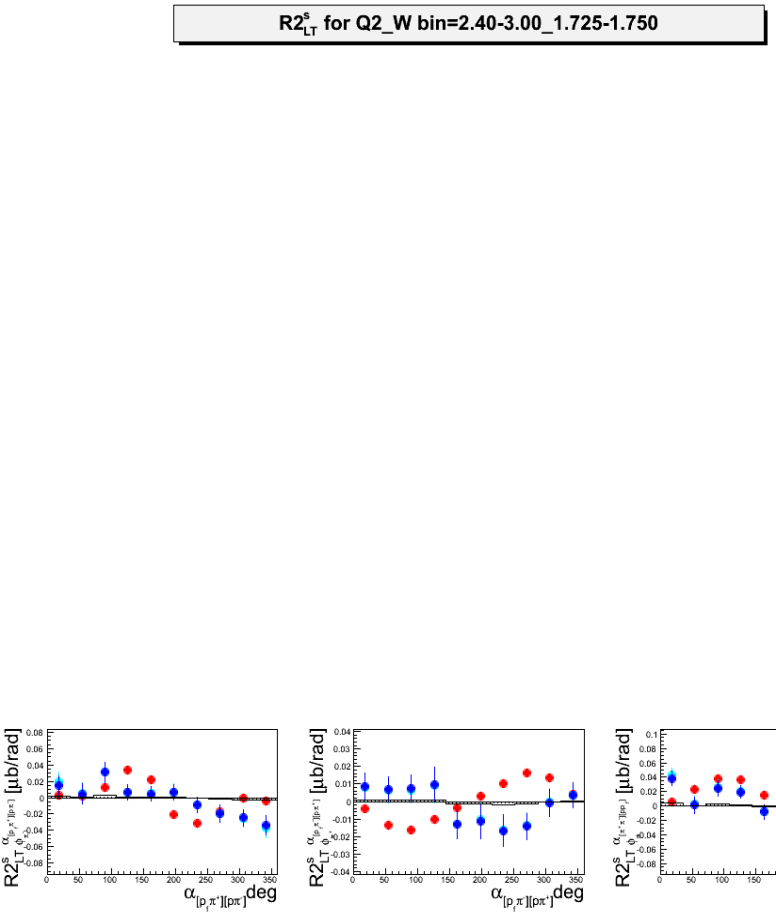

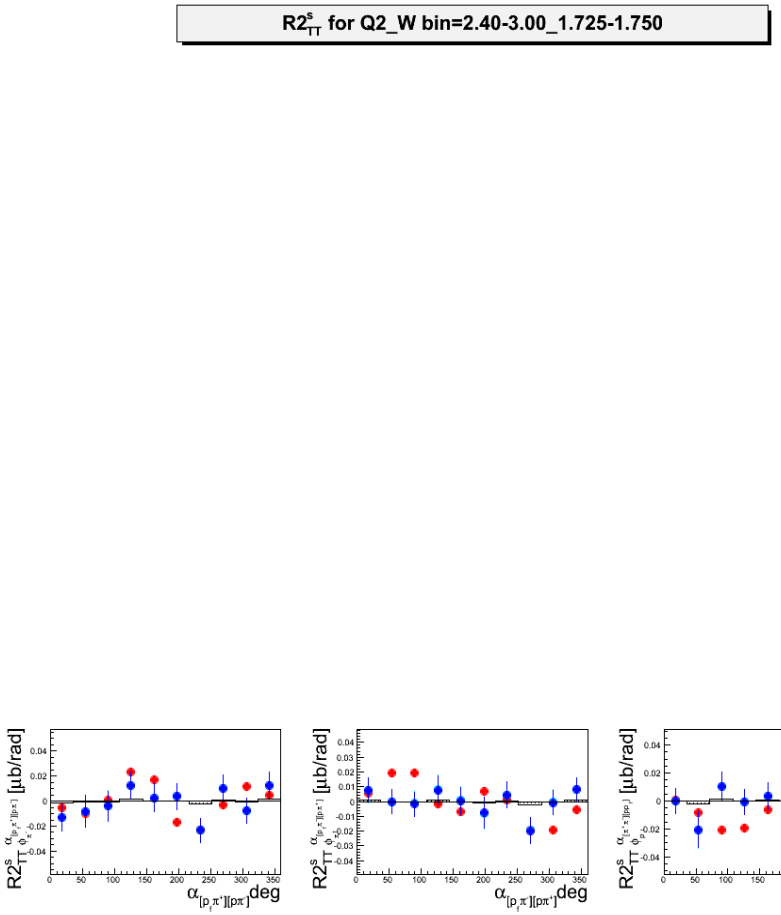

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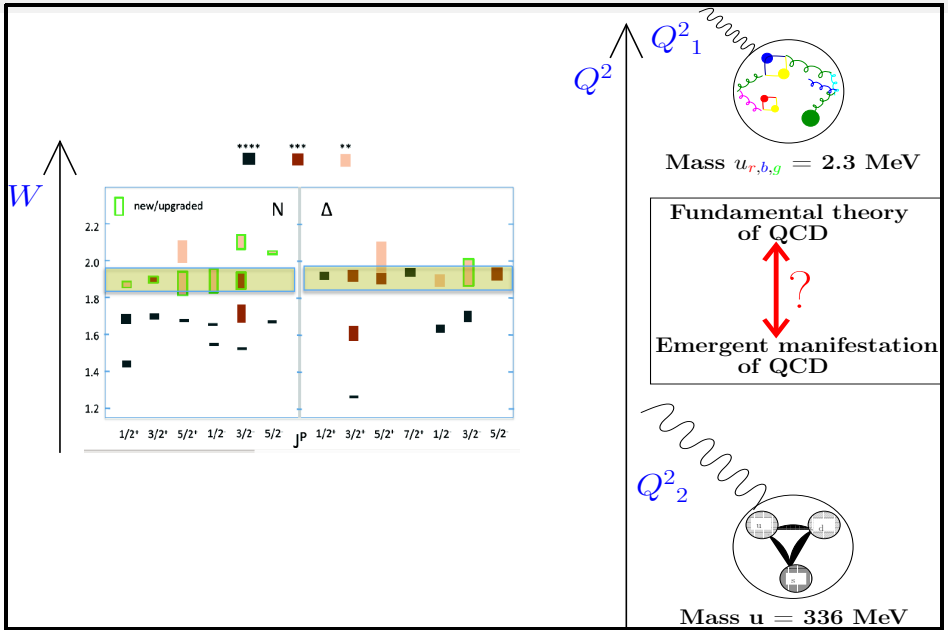
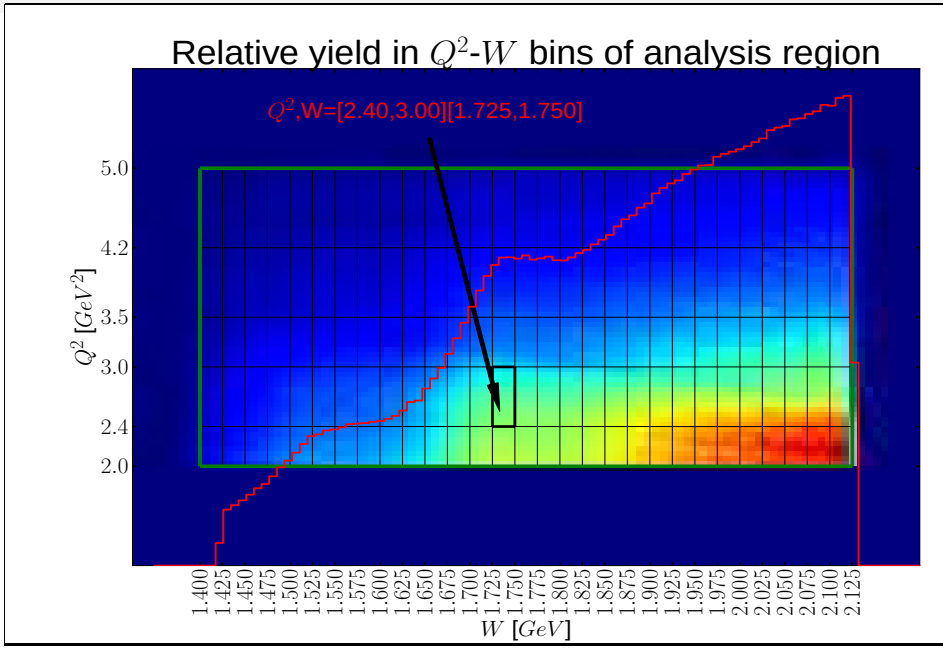
Overview of measurements





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51 sets of cross-sections measured in every Q^2-W bin, of which 30 are new

Summary and Outlook

- Summary
  - 51 sets of cross-sections measured in each bin of Q^2-W region.
    - This region covering $Q^2, W = [2.0, 5.0]\ GeV^2, [1.400, 2.125]\ GeV$ is newly charted by Evgeny Isupov (arXiv:1705.01901. Accepted: Phys. Rev. C).
  - Of these 51:
    - 21 are already measured by Evgeny Isupov.
    - 30 are measured for the first time.
- Outlook
  - Working on analysis note and finalizing data studies.
  - Analysis note expected to be submitted for review in September 2017.

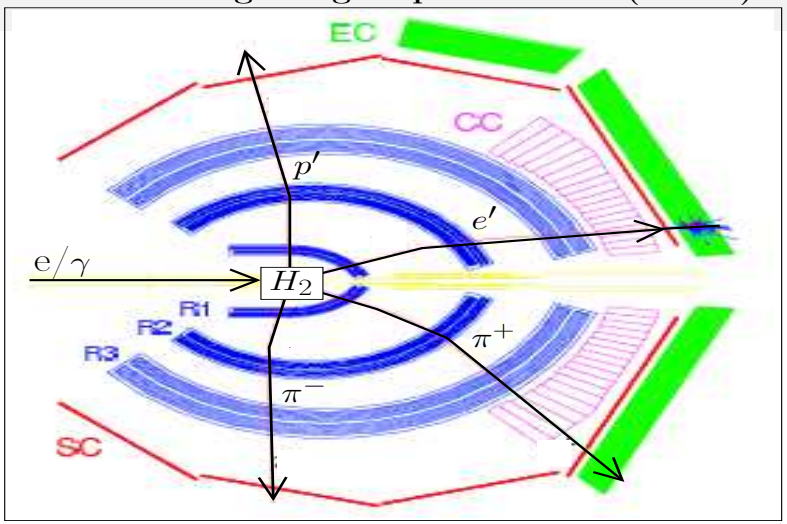
Backup Slides

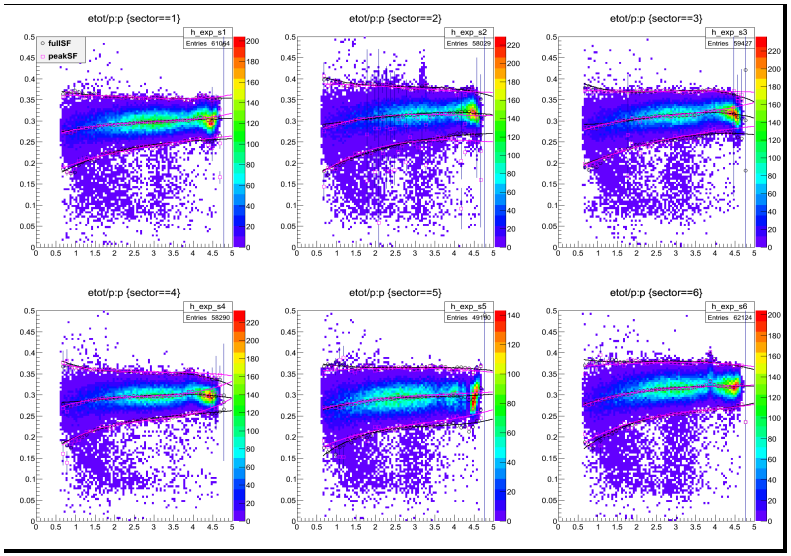
Particle Identification

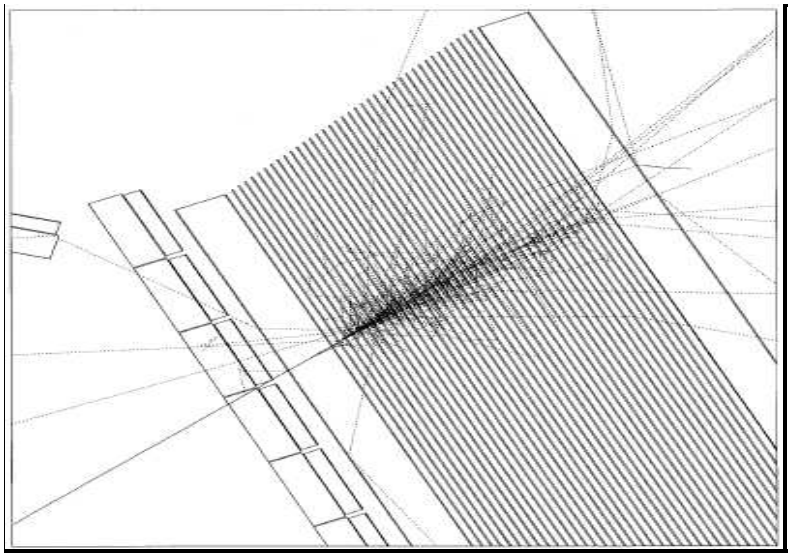
Electrons

- Coincident track in DC,CC,SC,EC
  - Only electrons trigger CC
- Additionally, use the EC
  - SF = $\frac{E_{EC}}{p}$ = constant

CEBAF Large Angle Spectrometer (CLAS)





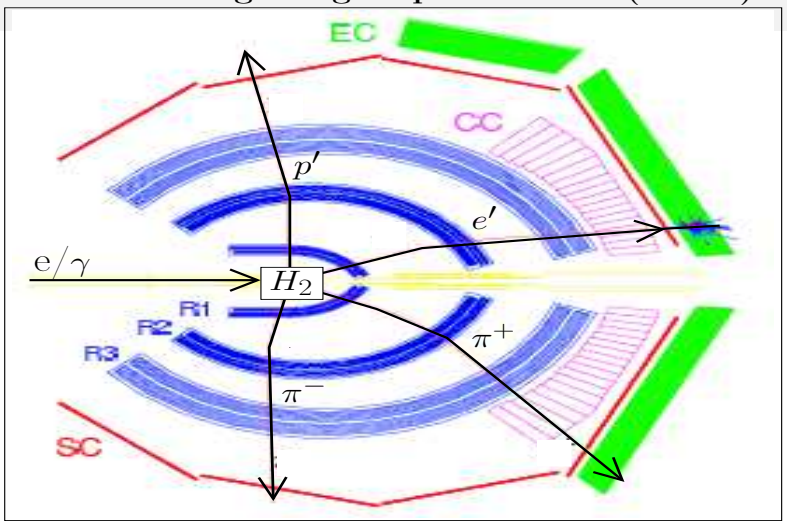


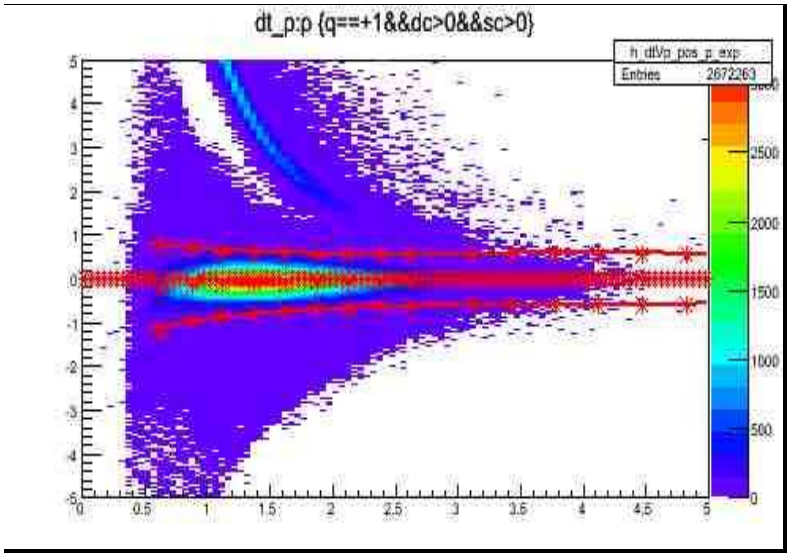
Particle Identification

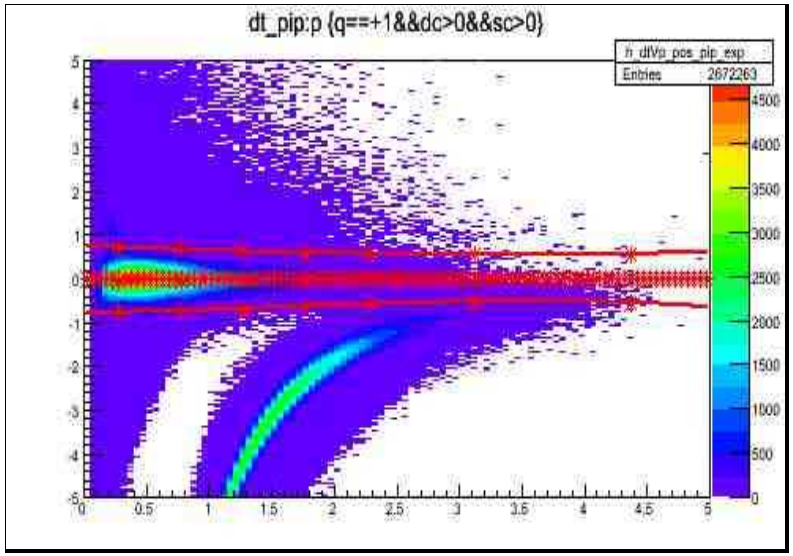
Protons & pions

- Coincident track in DC & SC
- Use independent meausure of time of flight from DC and SC:
  - t_{SC}: Direct measure of time of flight
  - $t_{DC} = f(L_{DC}, p_{DC})$

CEBAF Large Angle Spectrometer (CLAS)







Fiducial cuts

Electron, protons and pions

- Remove if detected at and beyond edges of fiducial volume