Intermediate $\pi^0\pi^\pm$ production channels off nucleons in the Deuteron with the A2 Experiment

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University of Basel

QNP2022 - The 9th International Conference on Quarks and Nuclear Physics

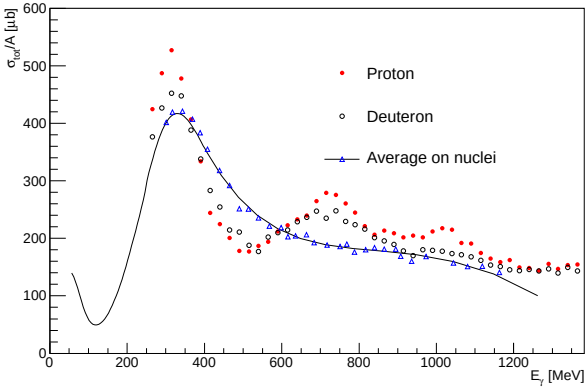
September 06, 2022

This talk is dedicated to Bernd Krusche (1956 - 2022).

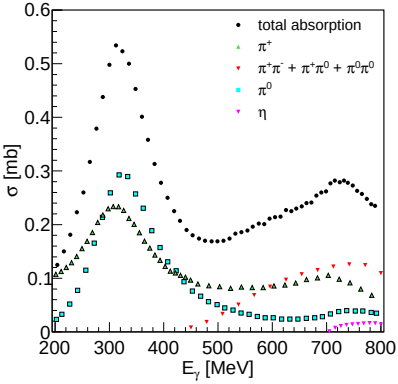
Thank you for everything!

Overview

Results from Photoabsorption Experiments



(Source: Proton, Deuteron: Armstrong et al., Average: Bianchi et al., MacCormick et al., photoabsorption at INFN)



(Source: B. Krusche, P. Pedroni et al., various publications)

Reaction Branches

$\gamma p(n) \longrightarrow \pi^+\pi^0 n(n)$

$\gamma n(p) \longrightarrow \pi^-\pi^0 p(p)$

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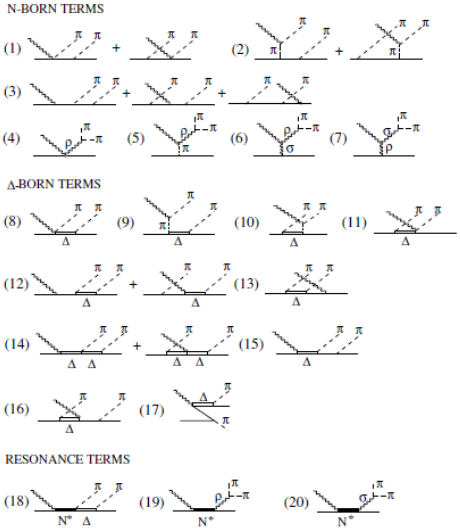
The ρ channel is present for the $\pi^\pm\pi^0$ final state, *not* for $\pi^0\pi^0$ (isospin conservation).

The MAID Model



Mainz Unitary Isobar Model

- ↪ Common background
- ↪ Born terms
- ↪ Resonances (****)

simulated up to 1.5 GeV

(Source: H. Arenhövel and A. Fix, Eur. Phys. J. A, vol. 25, pp. 115135, 2008)

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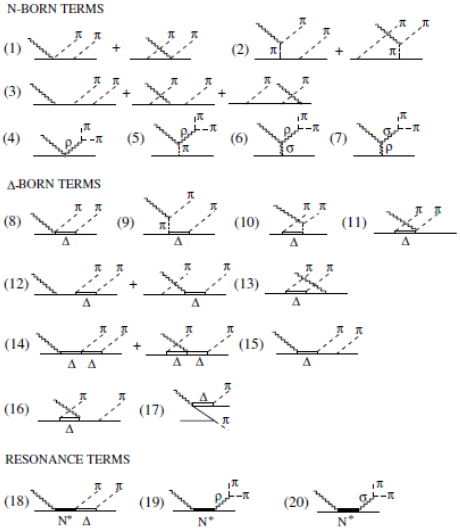

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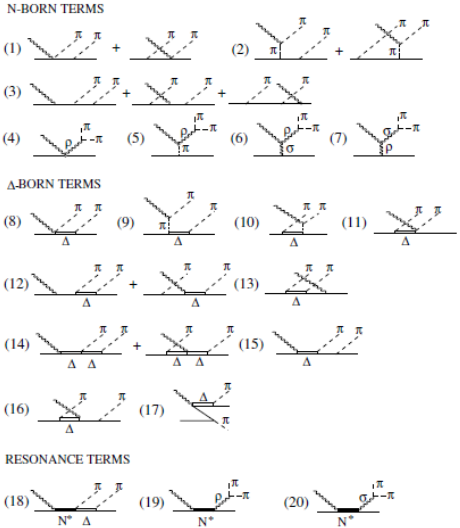

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- ↪ $\gamma N \longrightarrow \pi\pi N$
- ↪ (6), (7) and (20) forbidden for $\pi^0\pi^\pm$

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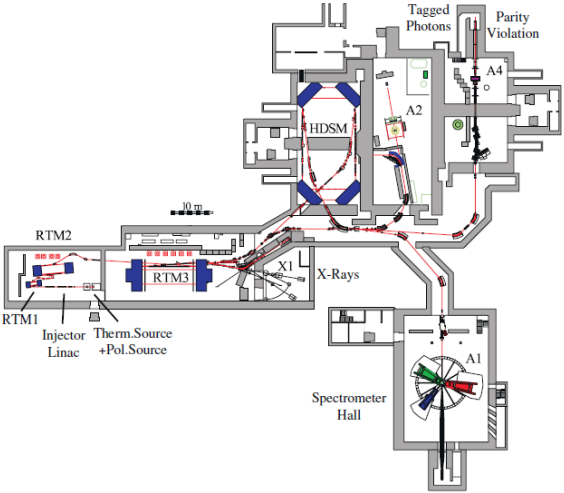
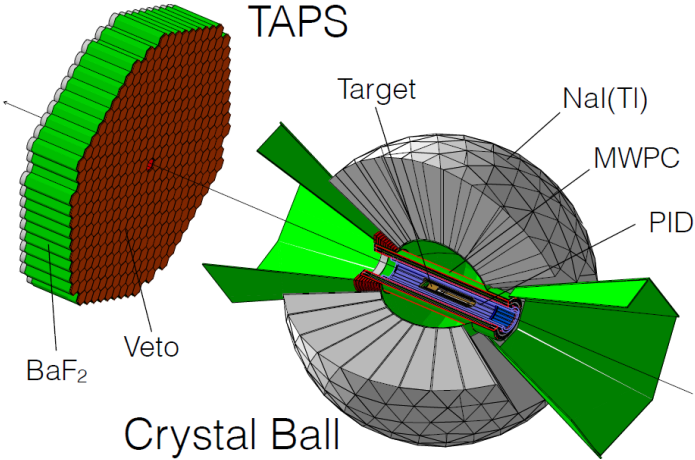
Experimental Set-up - MAMI



(Source: A2 Collaboration)

Experimental Set-up - Crystal Ball/TAPS



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Not enough information for full kinematic reconstruction!

Minimal Fermi Momentum Reconstruction

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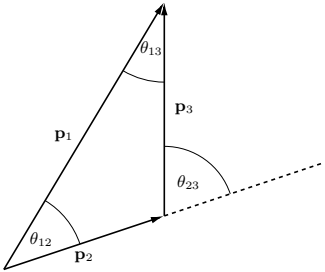

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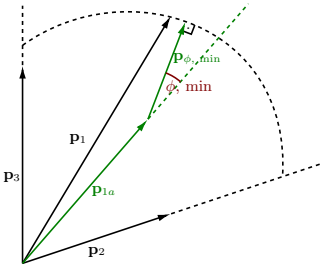

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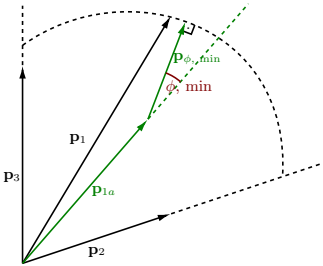

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$$m_0^2 + m_T^2 - m_2^2 - m_3^2 + 2p_0^2 + 2p_2p_3\cos\theta_{23} - 2p_2p_{1a}\cos\theta_{1a2} - 2p_3p_{1a}\cos\theta_{1a3} = 2\sqrt{{p_2}^2{p_3}^2 + m_3^2{p_2}^2 + m_2^2{p_3}^2 + m_2^2m_3^2}$$
$$- 2E_0\sqrt{{p_2}^2 + 2p_2p_3\cos\theta_{23} + {p_3}^2 - 2p_2p_{1a}\cos\theta_{1a2} - 2p_3p_{1a}\cos\theta_{1a3} + m_T^2 + p_0^2}$$

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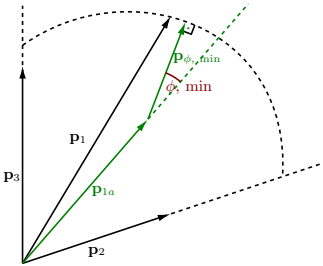

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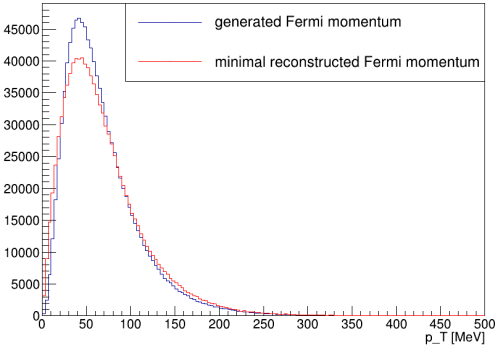
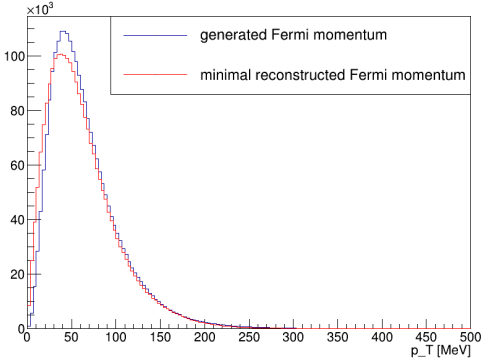
Reconstructed Fermi Momentum Average

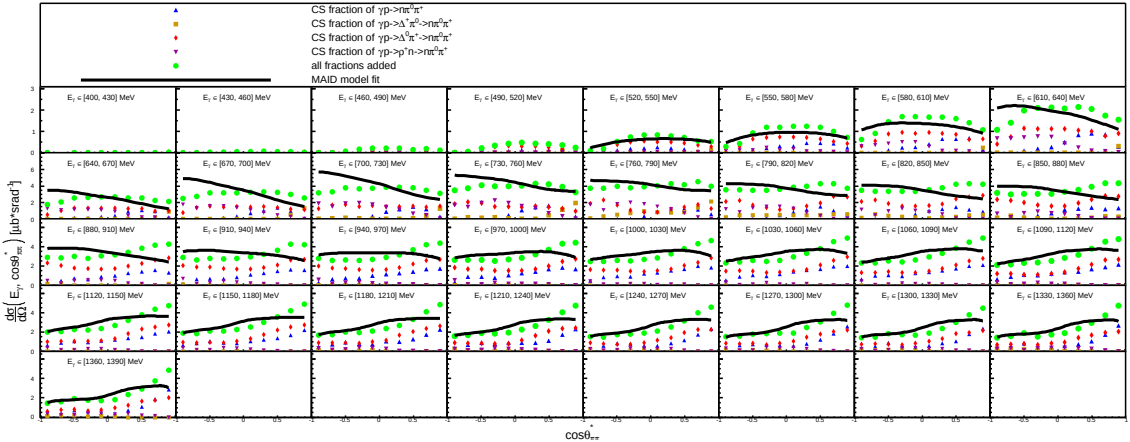
Magnitude of target momentum:
π^+ channel, phase space simulation:



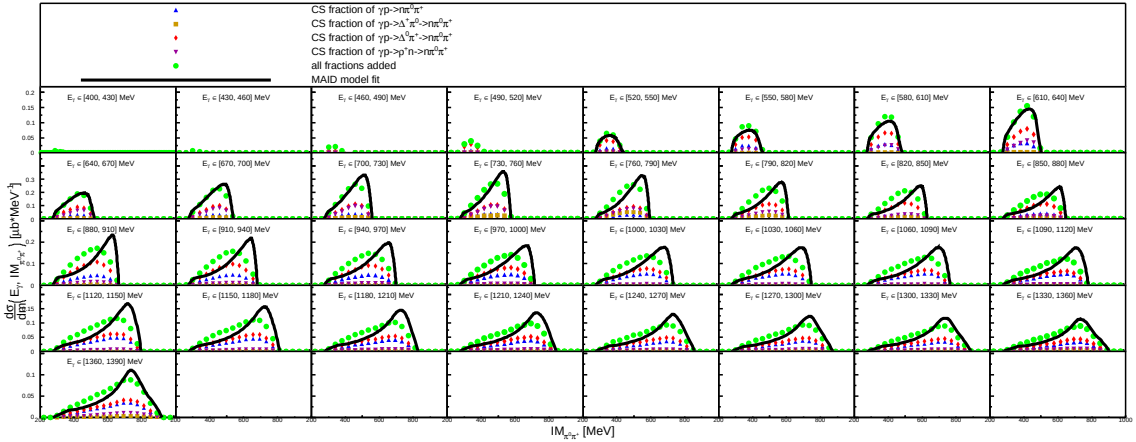
Magnitude of target momentum:
π^- channel, phase space simulation:



Results - Angular Differential Cross Sections - π^+ channel (preliminary)

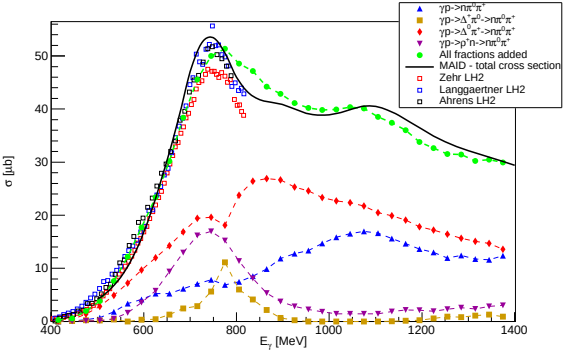


Results - Mass Differential Cross Sections - $\pi^0\pi^+$ (preliminary)



Results - Total Cross Sections - π^+ channel (preliminary)

Invariant Mass Analysis



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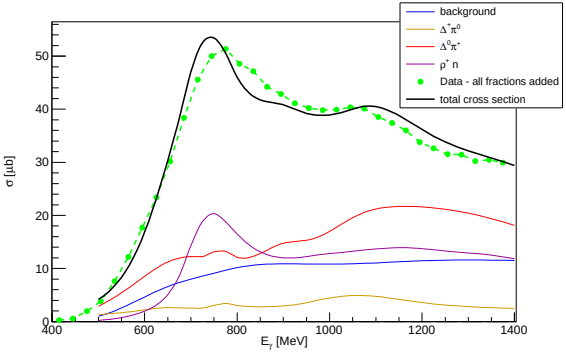
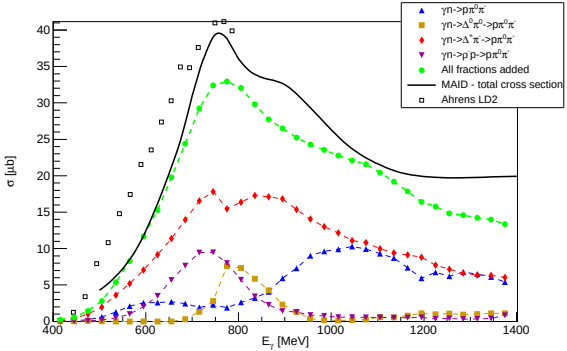


Results - Total Cross Sections - π^- channel (preliminary)

Invariant Mass Analysis



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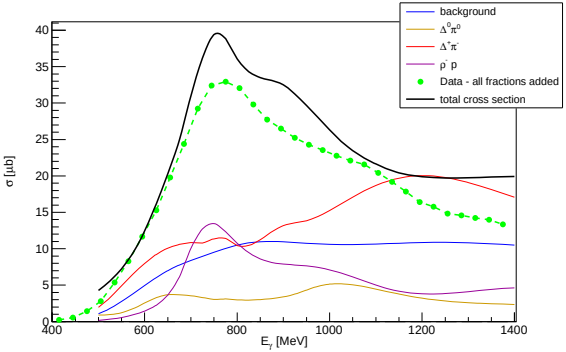
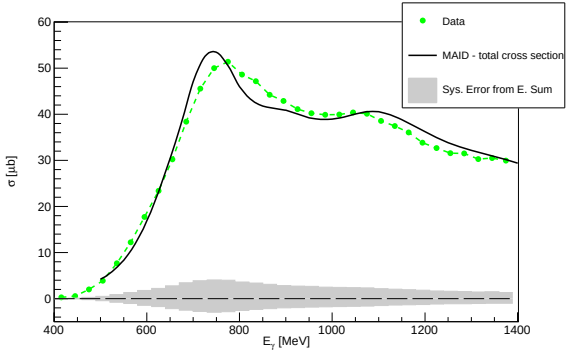


Results - Total Cross Sections - Systematic Errors (preliminary)

$\pi^+\pi^0$



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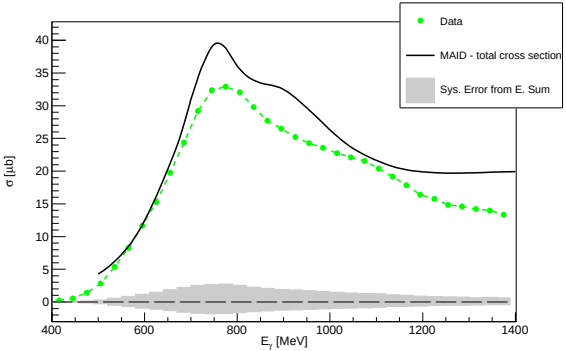

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- ↪ MAID model agrees well with total cross section for $\pi^+\pi^0$
- ↪ Full partial wave analysis may offer further insights
- ↪ A further experiment should focus on reconstruction of full kinematics
- ↪ Demonstrated minimal Fermi momentum method successful with incomplete information

Thank you for your attention!

Motivation

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Nucleons: make up atomic nucleus (protons, neutrons)

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$\hookrightarrow$ Insight into low energy QCD (scales > 1 fm)

$\hookrightarrow$ (Quasi-)free resonances of nucleons $\longleftrightarrow$ in-medium

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Photoproduction: photon induced reactions that produce new particles

Nucleons: make up atomic nucleus (protons, neutrons)

$\hookrightarrow$ Insight into low energy QCD (scales > 1 fm)

$\hookrightarrow$ (Quasi-)free resonances of nucleons $\longleftrightarrow$ in-medium

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Photoproduction of **pion pairs** off **nucleons**

Photoproduction: photon induced reactions that produce new particles

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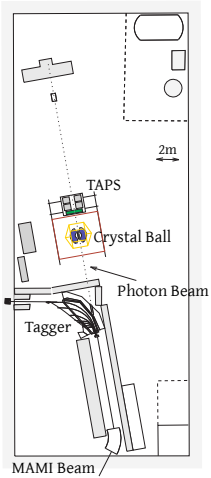
$\hookrightarrow$ Particularly: intermediate ρ-meson production

Beamtime Information

Beamtime	I	II
Date	May 09	December 07
Duration	27 days	16 days
Target	LD_2	LD_2
Target length	(30.2 ± 0.3) mm	(47.2 ± 0.5) mm
Radiator	10 μm Cu	Møller foil
CB Sum	300 MeV	300 MeV
Trigger	M2+ OR TAPS M2	M2+
Electron beam	(1557.5 ± 0.5) MeV	(1508.4 ± 0.5) MeV
Collimator ø	4mm	4mm
Tagger Magnet	1.89601 T	1.8321770 T
Data	414 GB	423 GB

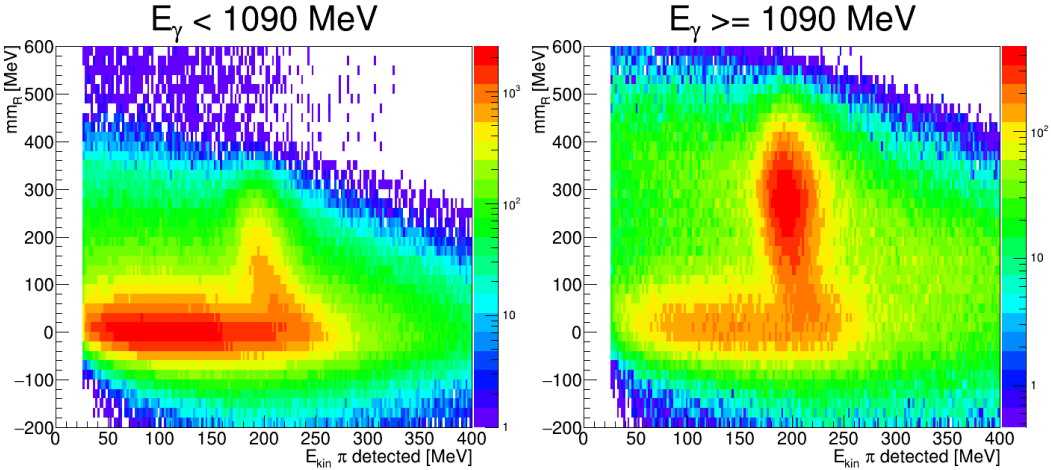
Experimental Set-up - A2 Hall



(Source: A2 Collaboration)

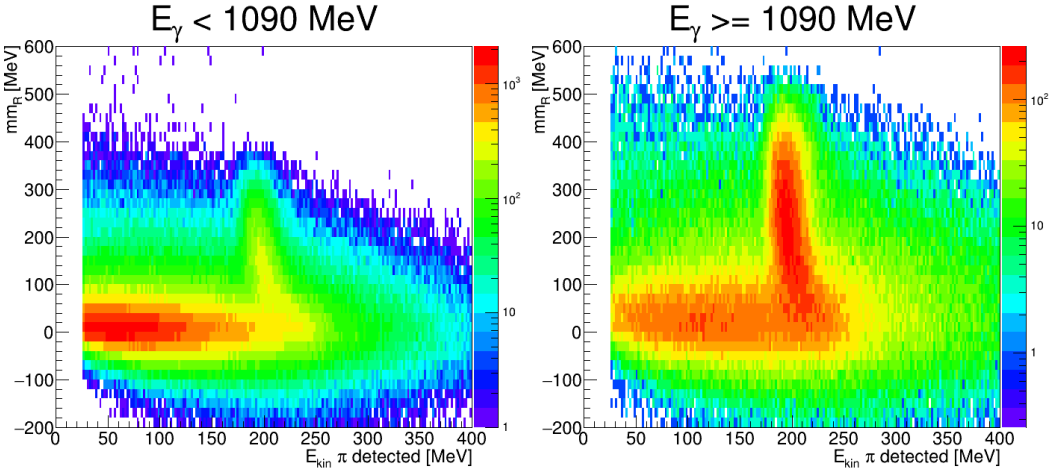
Charged Particle Energy Reconstruction - "punch-through particles"

Data from beamtime I, CB, recoil missing mass versus π^+ kinetic energy:



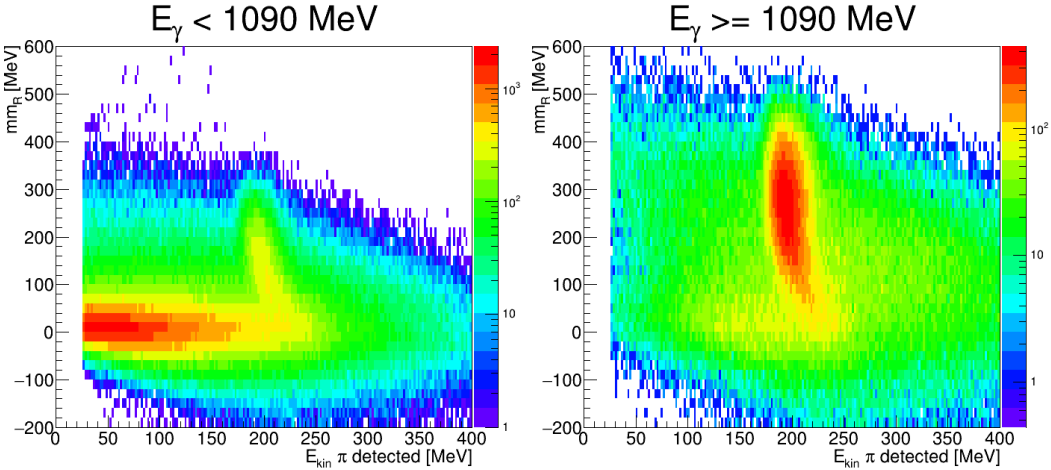
Charged Particle Energy Reconstruction - "punch-through particles"

Simulated phase space channel for π^+:

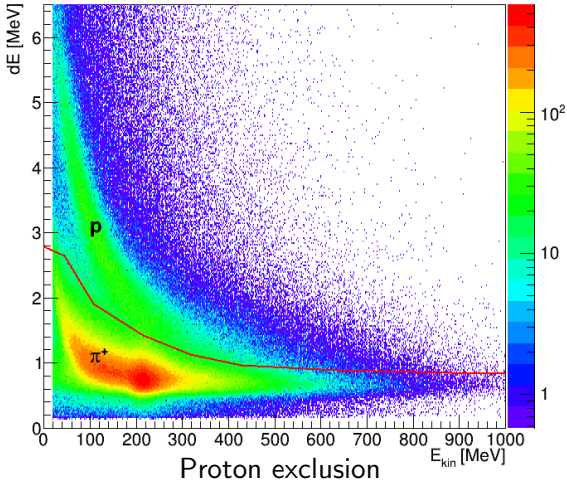


Charged Particle Energy Reconstruction - "punch-through particles"

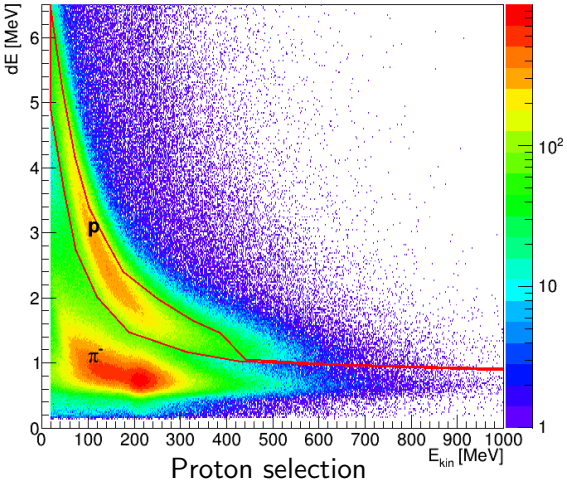
Simulated Δ^0 channel for π^+:



Charged Particle Identification - CB

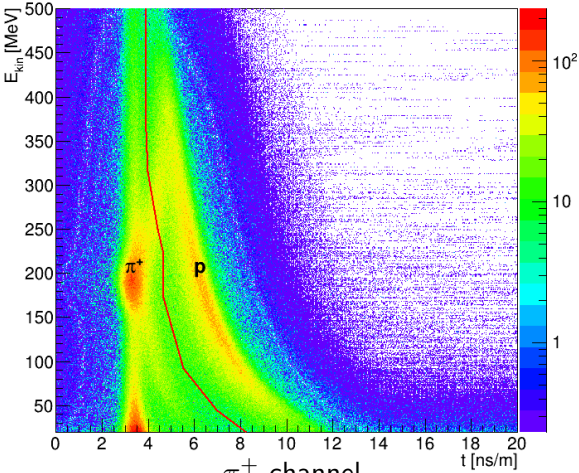


Proton exclusion

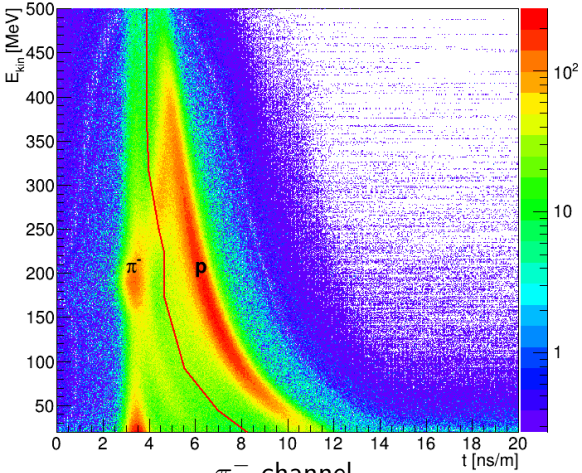


Proton selection

Charged Particle Identification - TAPS

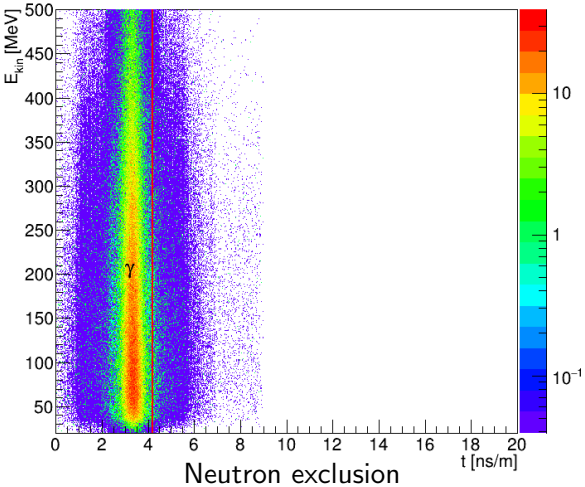


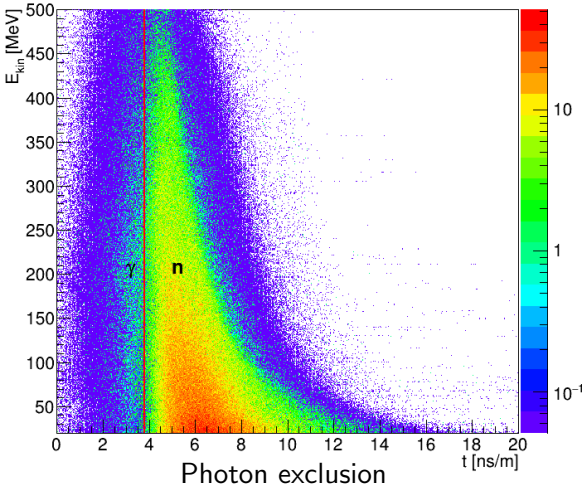
π^+ channel



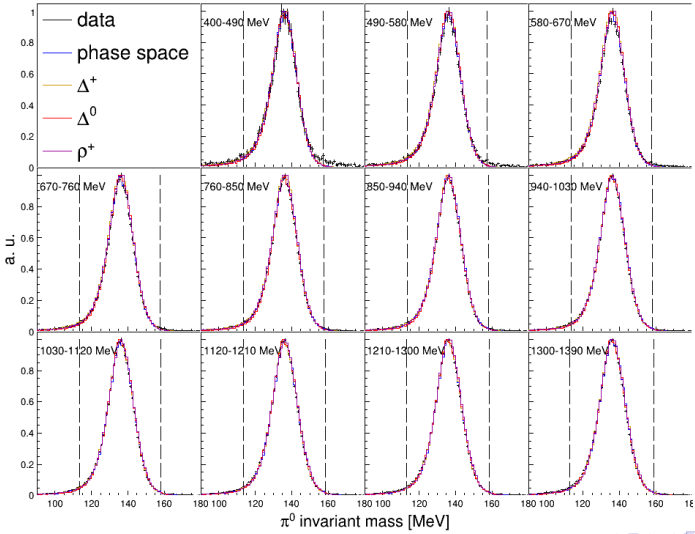
π^- channel

Neutral Particle Identification - TAPS

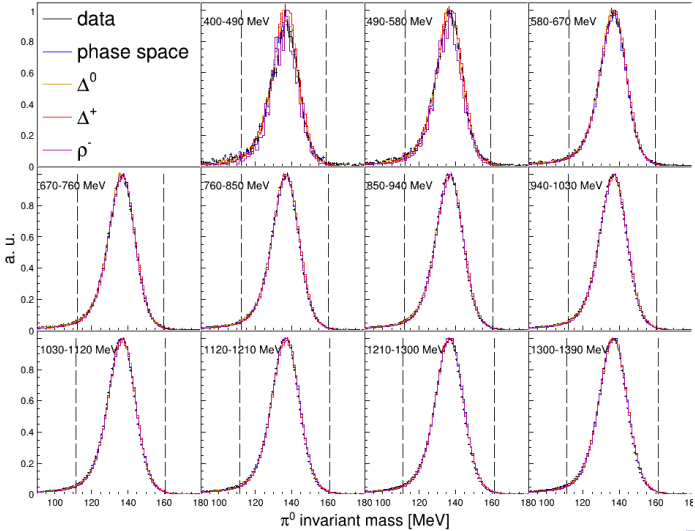




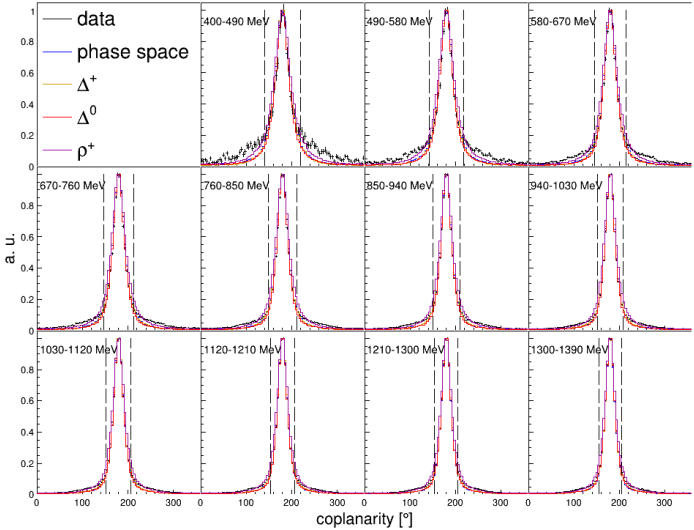
Cut Ranges - π^0 mass - π^+ channel



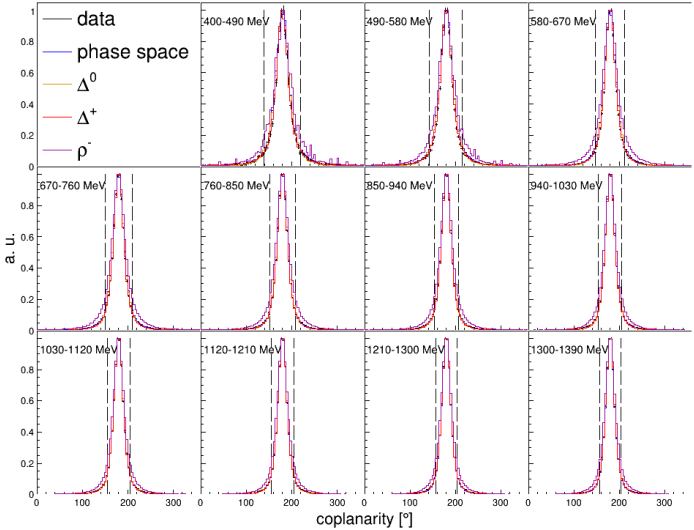
Cut Ranges - π^0 mass - π^- channel



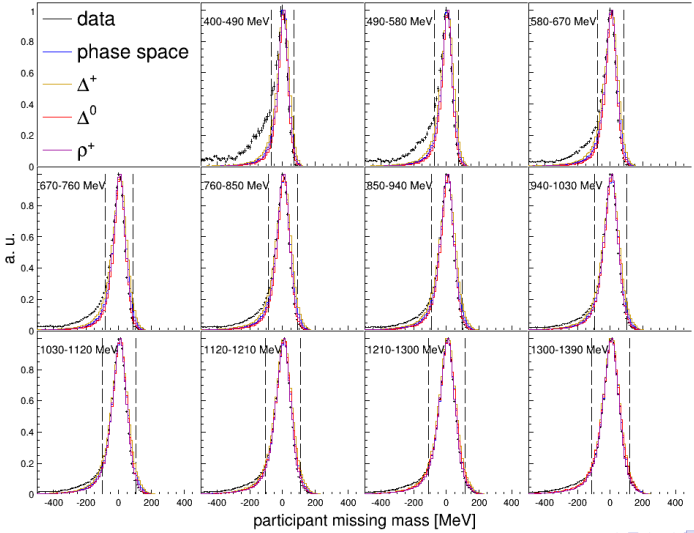
Cut Ranges - coplanarity - π^+ channel



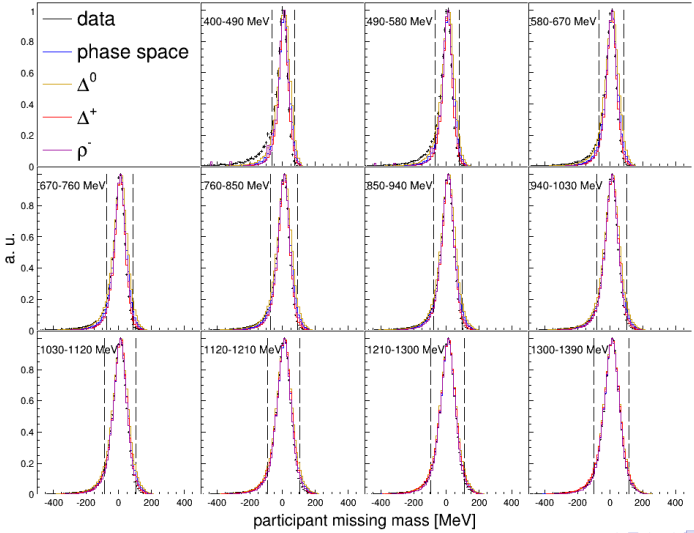
Cut Ranges - coplanarity - π^- channel



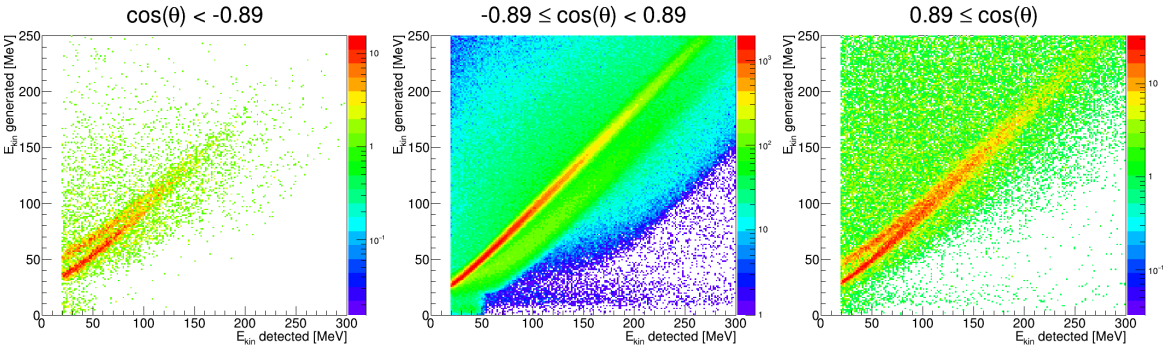
Cut Ranges - recoil missing mass - π^+ channel



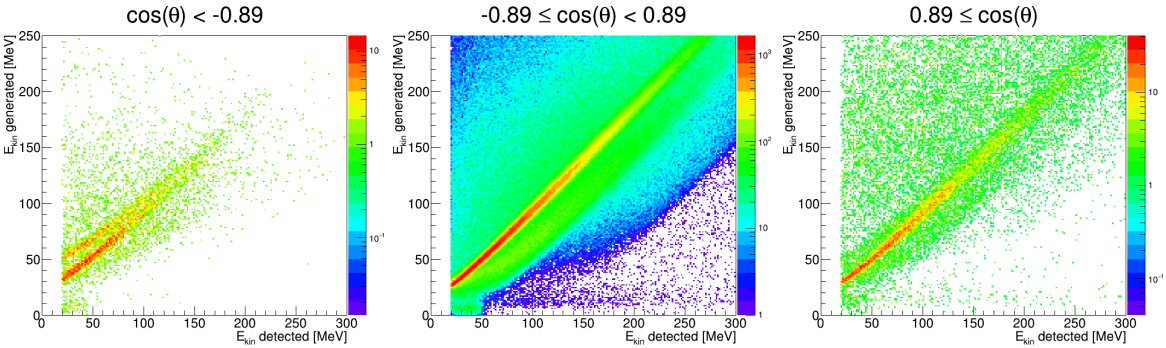
Cut Ranges - recoil missing mass - π^- channel



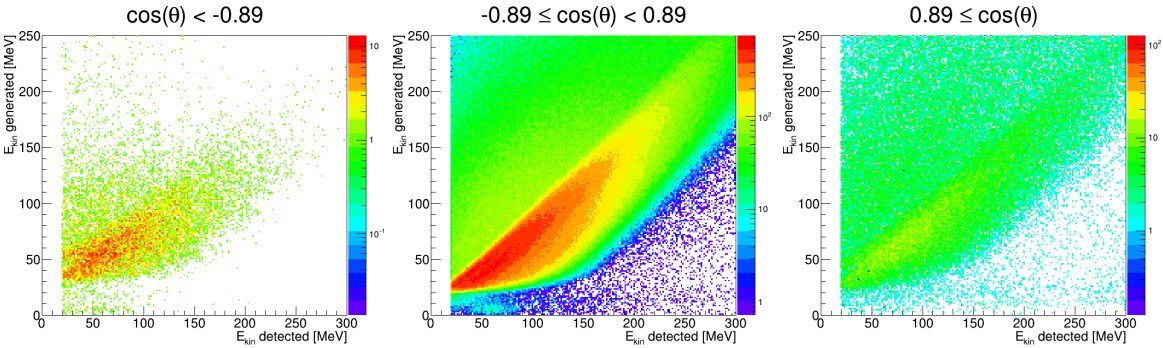
Charged Particle Energy - CB π^+ band structure



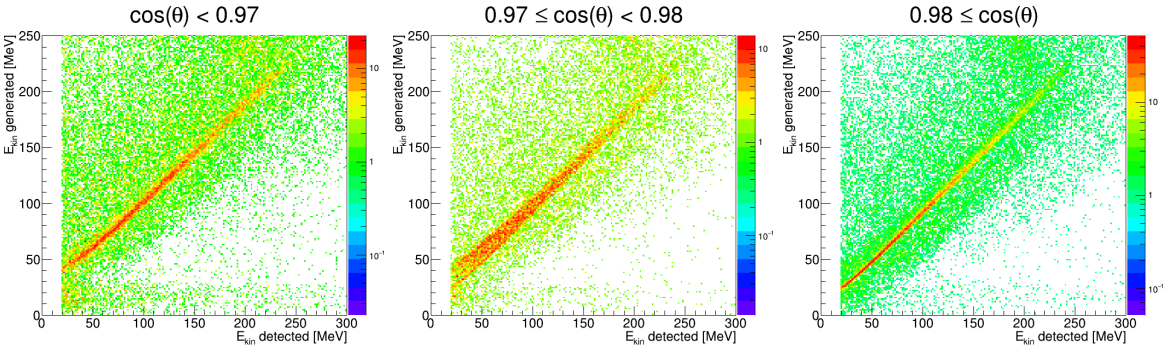
Charged Particle Energy - CB π^+ band structure - shifted PID



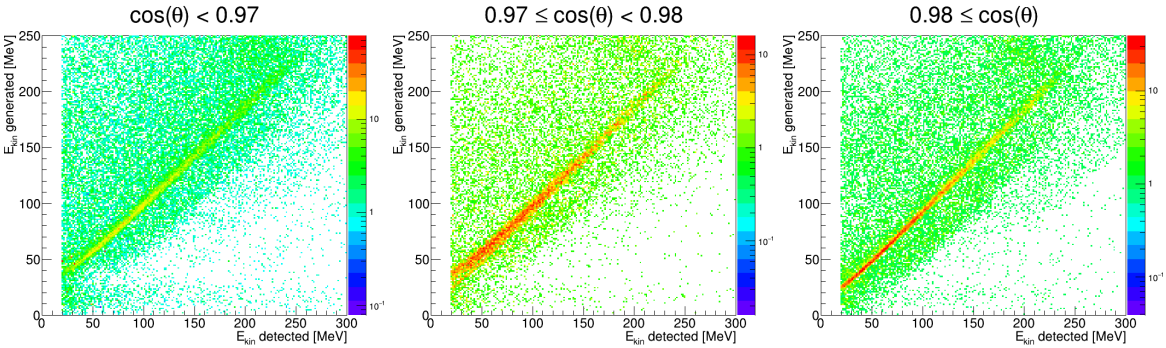
Charged Particle Energy - CB π^- smeared energy



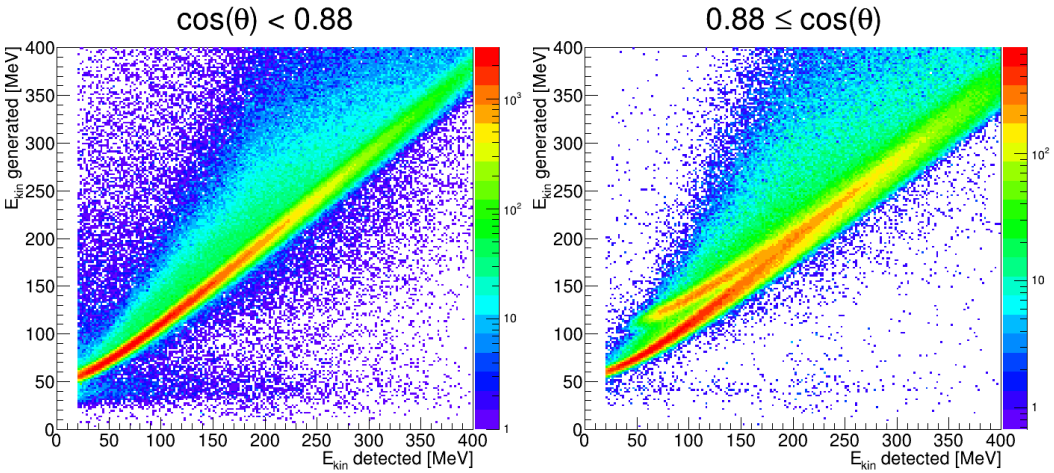
Charged Particle Energy - TAPS π^+ band structure



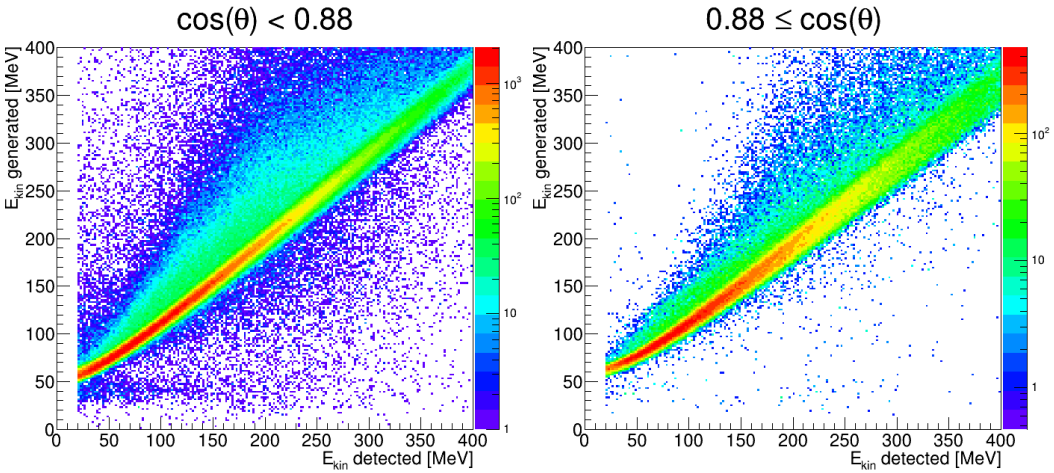
Charged Particle Energy - TAPS π^+ band structure - shifted PID



Charged Particle Energy - CB proton band structure



Charged Particle Energy - CB proton band structure - shifted PID



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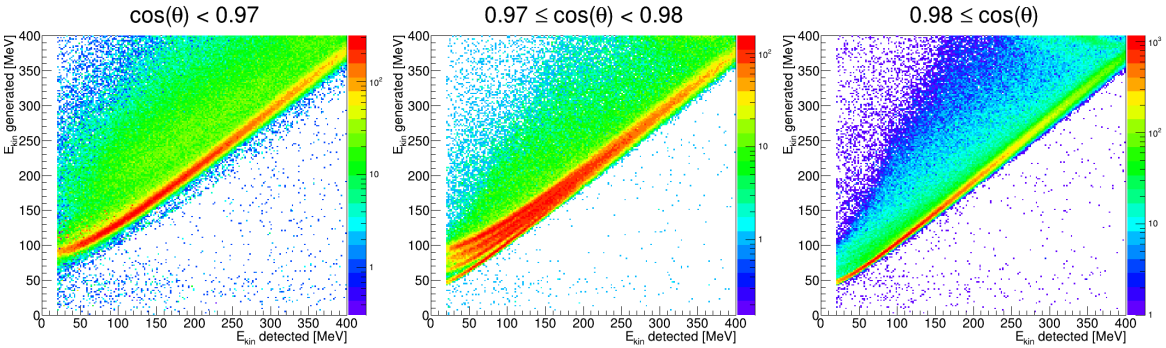

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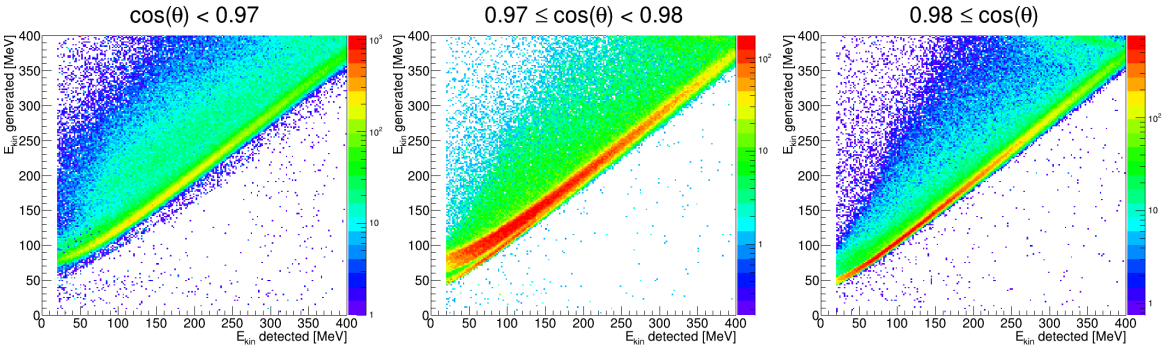
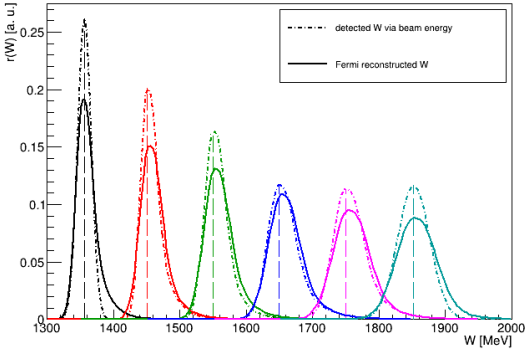
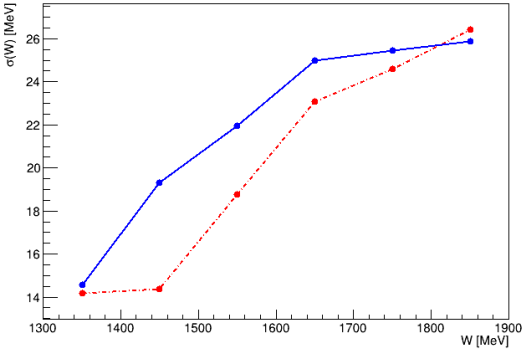
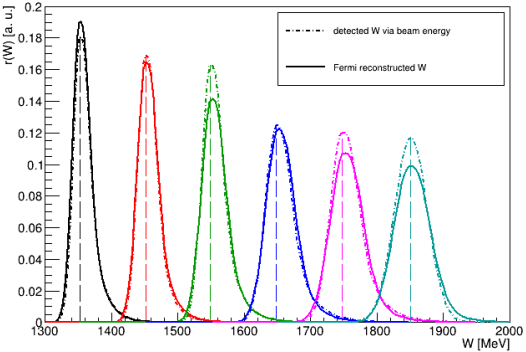


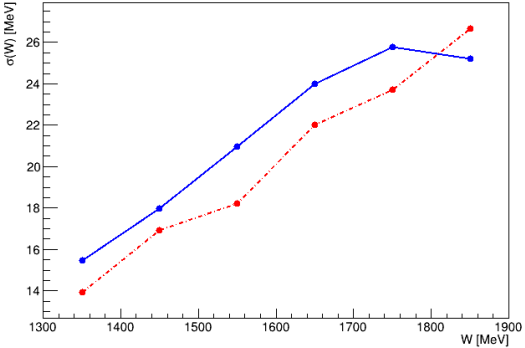
W Reconstruction - resolution for π^+



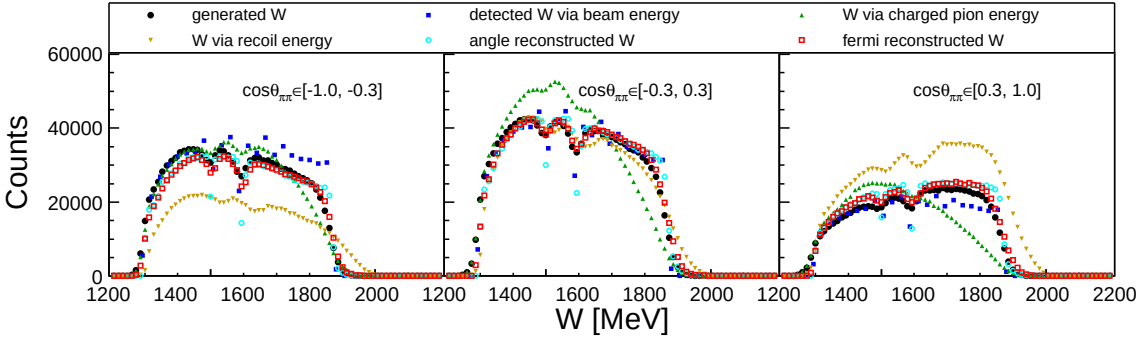


W Reconstruction - resolution for π^-

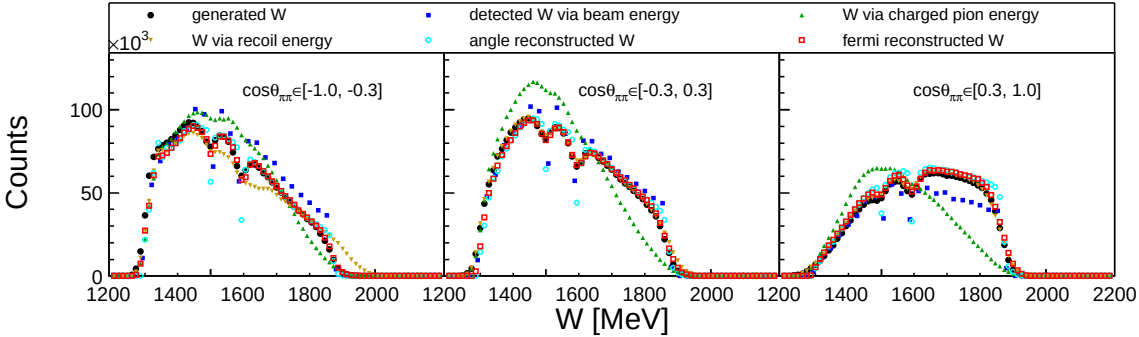




W Reconstruction - compare methods for π^+



W Reconstruction - compare methods for π^-



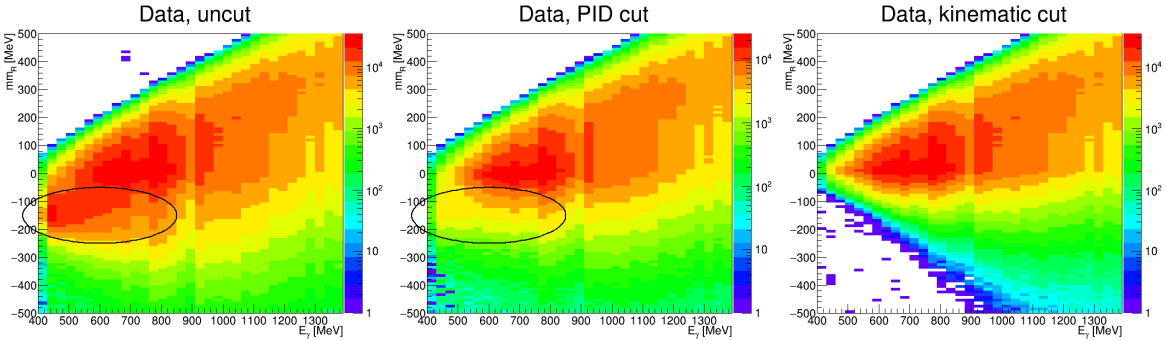
Kinematic Reconstruction Feasibility Cut

$$\Delta := 16E_1^2[(m_3^2 - m_1^2 - m_2^2)^2 - 4m_2^2(E_1^2 - p_1^2\cos^2\theta_{12})] \geq 0$$

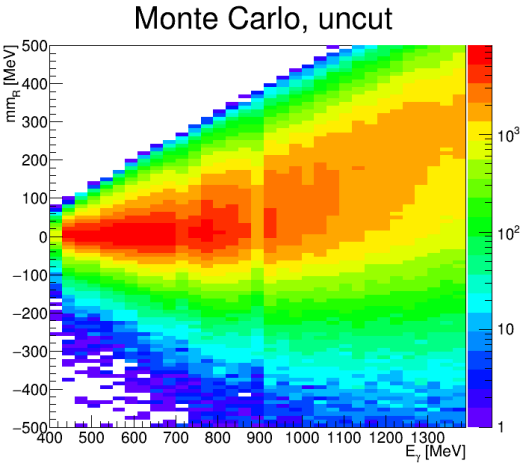
with

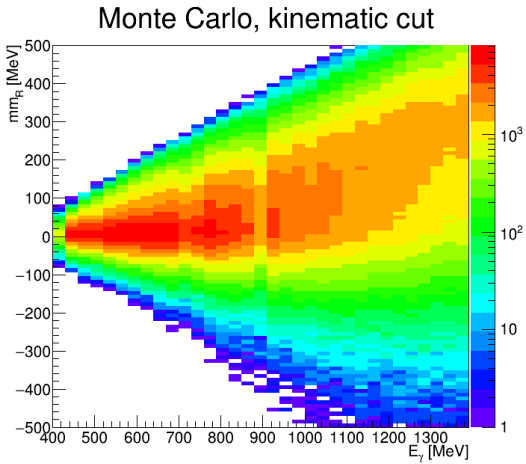
$$\mathbf{P}_1 := \mathbf{P}_\gamma + \mathbf{P}_D - \mathbf{P}_{\pi^0} - \mathbf{P}_{\pi^\pm}$$
$$\mathbf{P}_2 := \mathbf{P}_R$$
$$\mathbf{P}_3 := \mathbf{P}_S$$

Kinematic Reconstruction Feasibility Cut - π^+ data

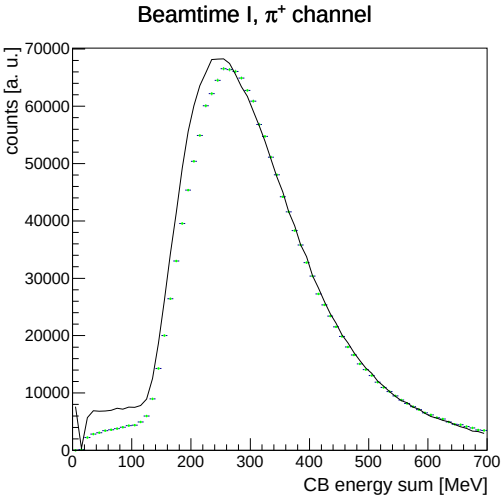


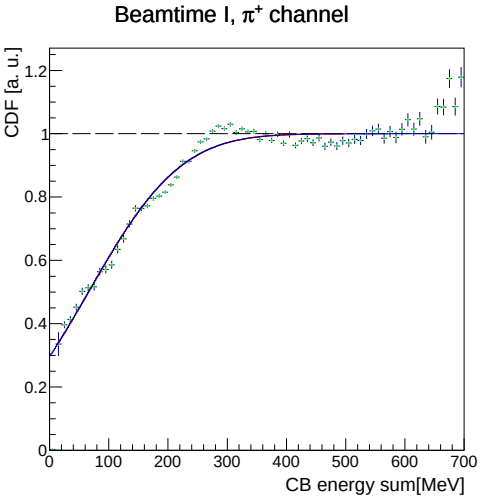
Kinematic Reconstruction Feasibility Cut - MC - Δ^0





Energy Sum Correction

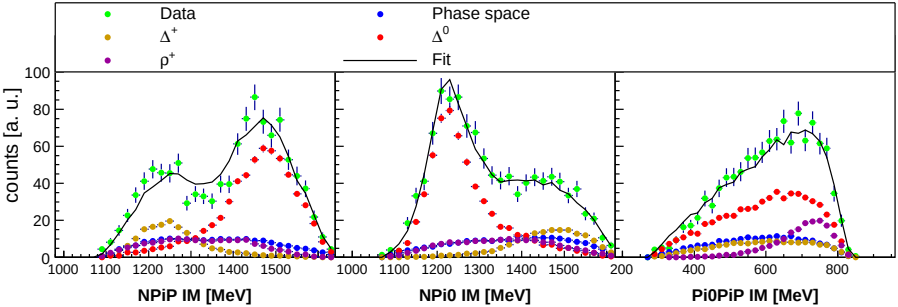




Invariant Mass Fits

Example for π^+:

$\hookrightarrow$ Fit on $n\pi^+$, $n\pi^0$ and $\pi^+\pi^0$ invariant masses



$E_\gamma \in$ [1210 MeV, 1240 MeV], $\cos(\theta) \in$ [-1.0, -0.8]

Cross sections

Angular differential cross section:

$$\frac{d\sigma^{br}}{d\Omega}(E, \cos\theta^*_{\pi\pi}) = \frac{N(E, \cos\theta^*_{\pi\pi})}{N_\gamma(E) \cdot \Delta\Omega \cdot \epsilon^{br}_{det}(E, \cos\theta^*_{\pi\pi}) \cdot \rho_t \cdot \left(\frac{\Gamma_{\pi^0\to\gamma\gamma}}{\Gamma_{\pi^0}}\right)}$$

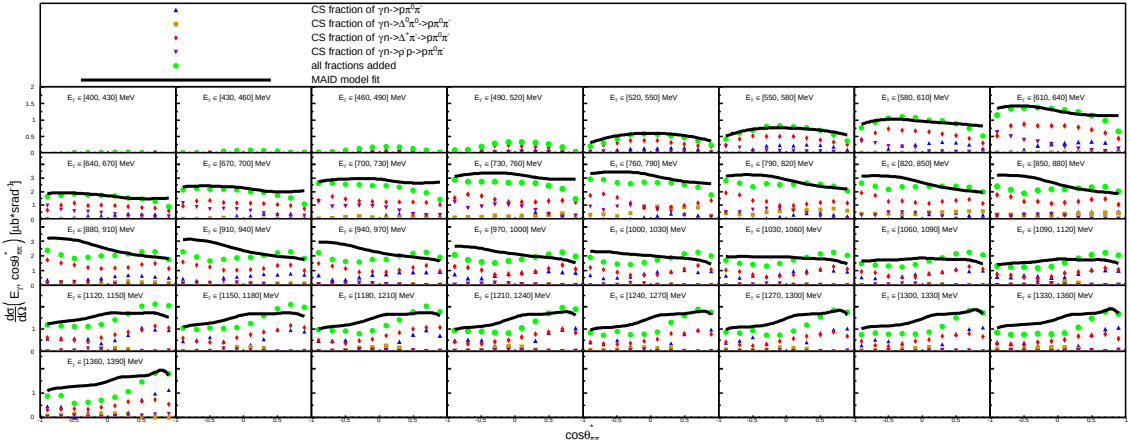
Mass differential cross section:

$$\frac{d\sigma^{br}}{dm_{pp'}}(E, m_{pp'}) = \sum_{\cos\theta^*_{\pi\pi}} \frac{N(E, \cos\theta^*_{\pi\pi}, m_{pp'})}{N_\gamma(E) \cdot \Delta m_{pp'} \cdot \epsilon^{br}_{det}(E, \cos\theta^*_{\pi\pi}) \cdot \rho_t \cdot \left(\frac{\Gamma_{\pi^0\to\gamma\gamma}}{\Gamma_{\pi^0}}\right)}$$

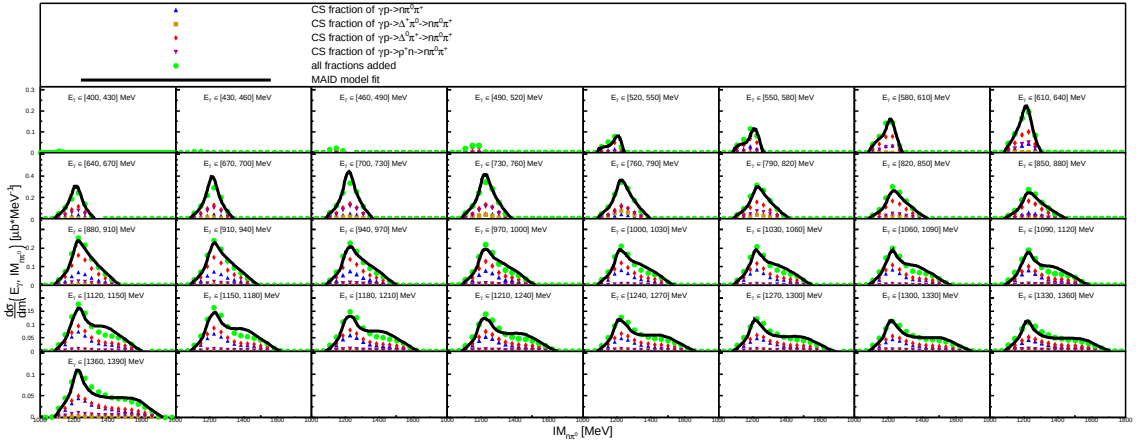
Total cross section (of branch br):

$$\sigma^{br}(E) = \sum_{\cos\theta^*_{\pi\pi}} \frac{d\sigma^{br}}{d\Omega}(E, \cos\theta^*_{\pi\pi}) \cdot \Delta\Omega$$

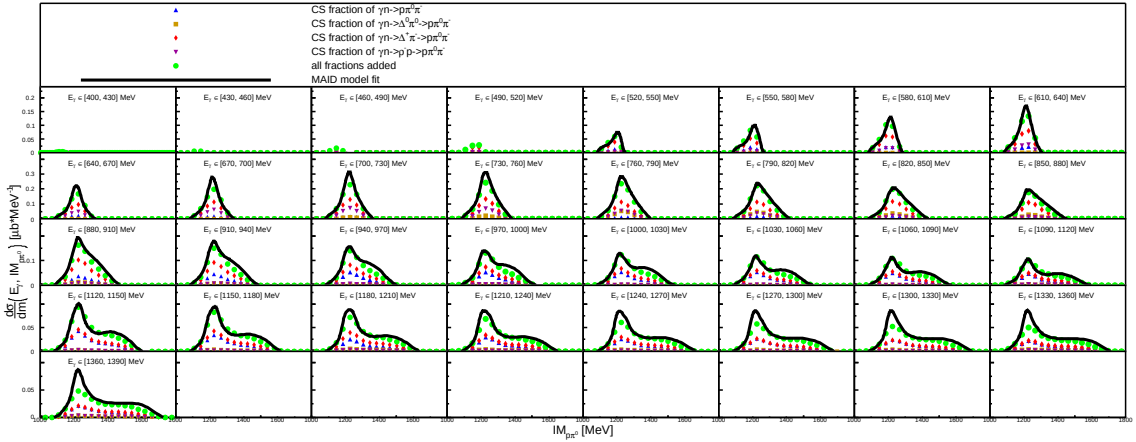
Results - Angular Differential Cross Sections - π^- channel (preliminary)



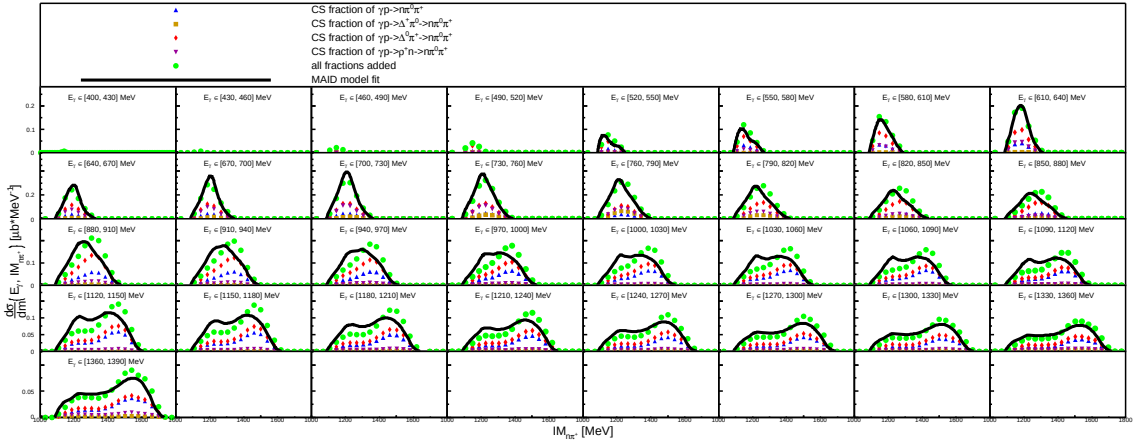
Results - Mass Differential Cross Sections - $N\pi^0$ - π^+ channel (preliminary)



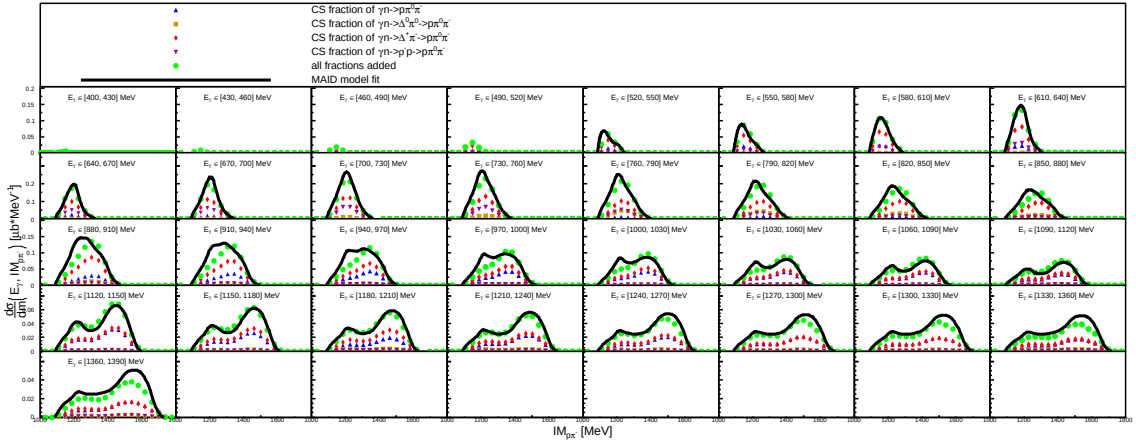
Results - Mass Differential Cross Sections - $N\pi^0$ - π^- channel (preliminary)



Results - Mass Differential Cross Sections - $N\pi^+$ (preliminary)



Results - Mass Differential Cross Sections - $N\pi^-$ (preliminary)



Results - Mass Differential Cross Sections - $\pi^0\pi^-$ (preliminary)