Determination of the polarization observables T, P and H in the reaction $\gamma p \to p\pi^0$

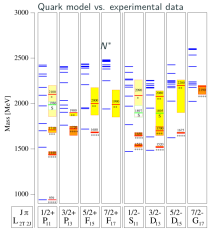
Sebastian Ciupka

University of Bonn

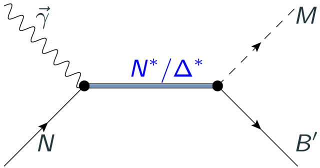
June 17, 2024

Baryon Spectroscopy

- Study exited nucleon states



U. Loering, B.C. Metsch, H.R. Petry, EPJA 10 (2001) 395-446



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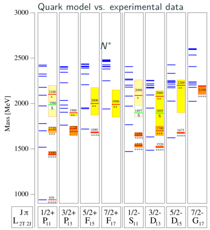
- Broad resonances with strong overlap



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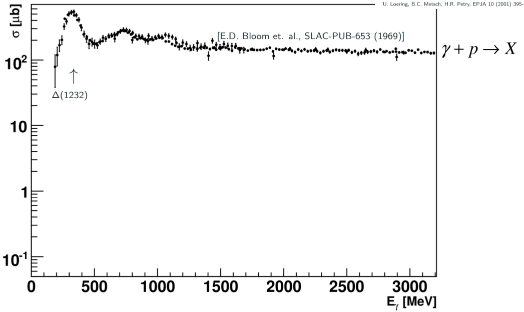

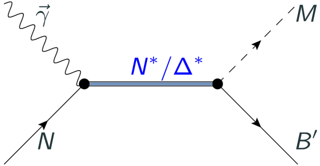

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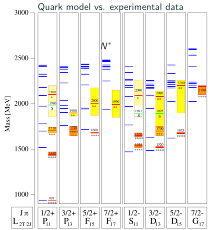

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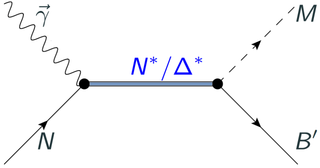

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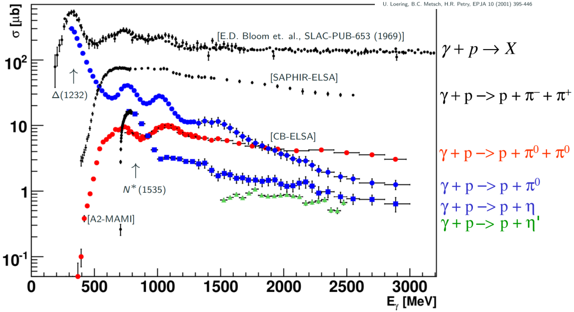
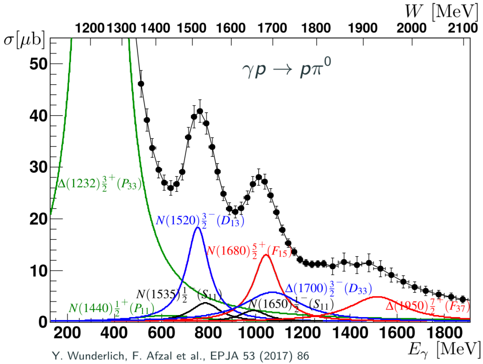
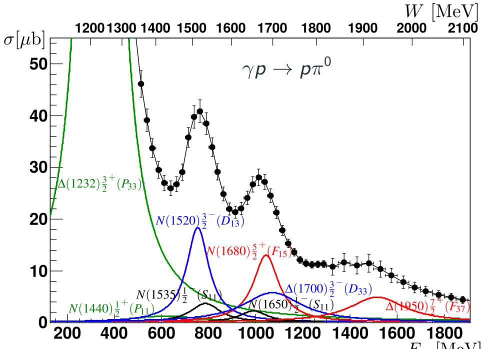


Resonances



Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

$$\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$$



Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

Photon polarization		Target polarization		
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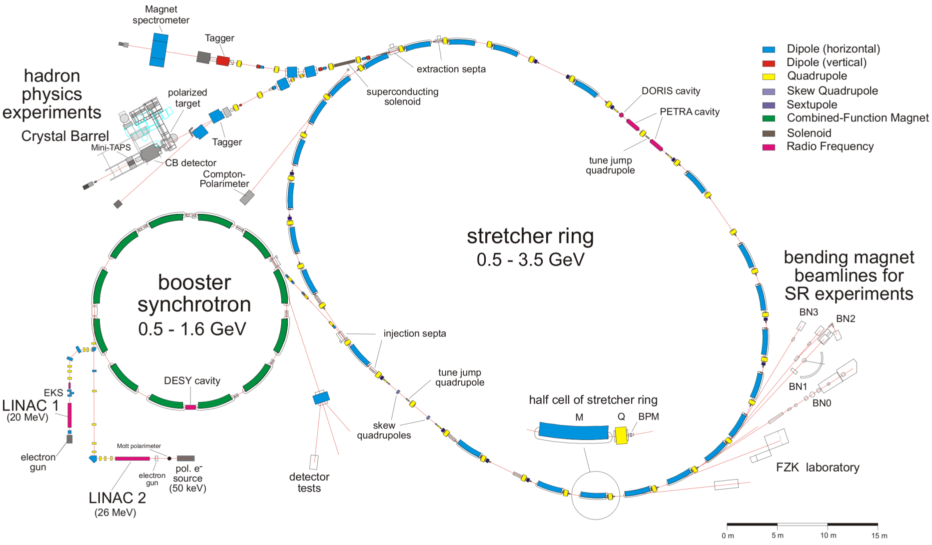
linear	$-\Sigma$	H	(-P)	-G
circular	-	F	-	-E

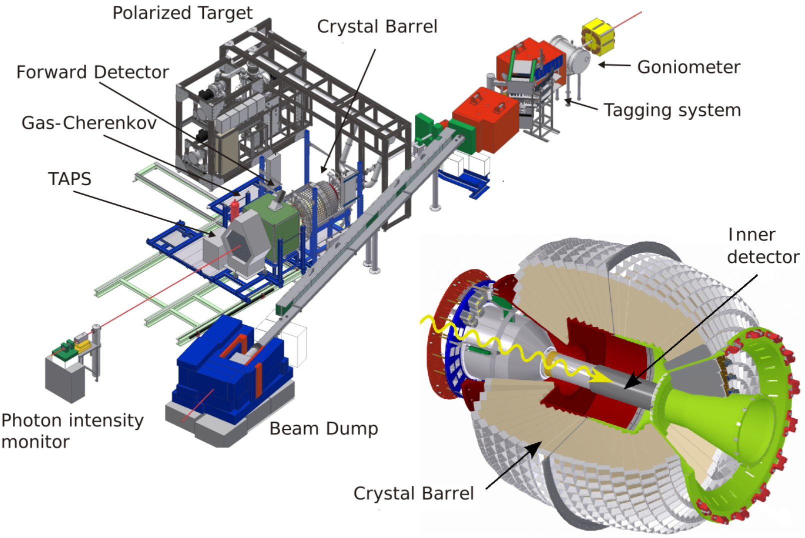
$$\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$$

$$T \sim \underbrace{-2E_{0+}^{*}E_{1+} - 2E_{0+}^{*}M_{1+}}_{\text{Interference } \Delta(1232)(P_{33}) \text{ with N}(1535)(S_{11})} + \ldots$$

ELectron Stretcher Accelerator (ELSA) Bonn



The CBELSA/TAPS experiment

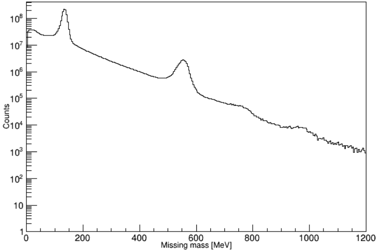


Analysis

Event selection

Only interested in: $\gamma p \rightarrow p\pi^0 \rightarrow p\gamma\gamma$

To remove background events kinematic cuts are applied:



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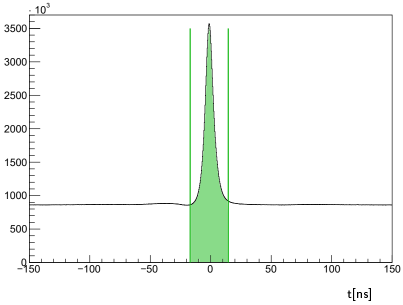

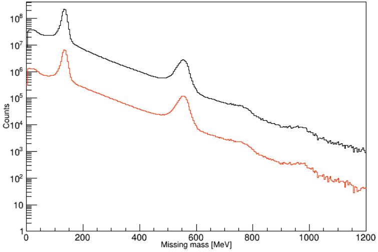

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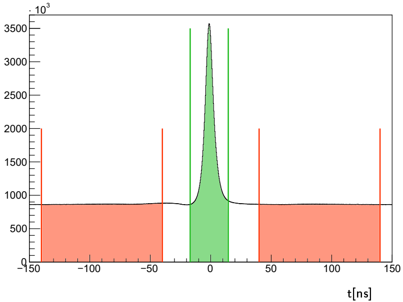

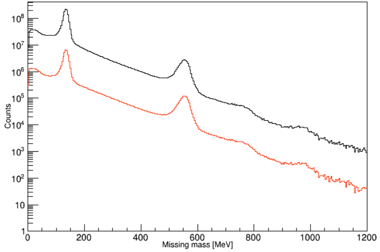

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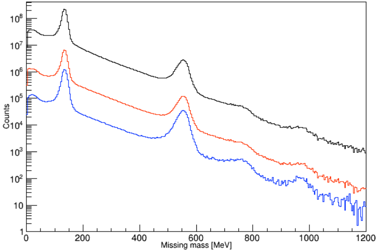

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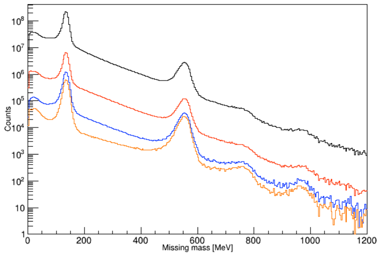

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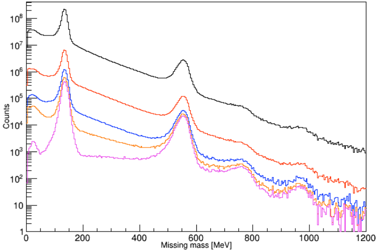

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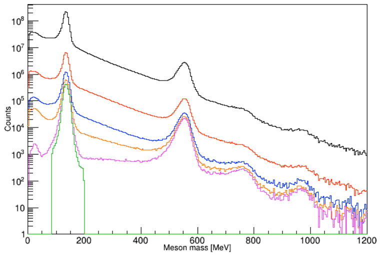
- Reconstructed invariant meson mass should be $m_{\pi^0} \pm 2\sigma$



Differential cross section

Photon polarization		Target polarization		
		X	Y	Z(beam)
unpolarized	σ	-	T	-
linear	-Σ	H	(-P)	-G
circular	-	F	-	-E

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \cdot (1 - \delta\Sigma \cos(2(\alpha - \Phi)) + \Lambda \mathbf{T} \sin(\beta - \Phi)$$
$$- \delta\Lambda \mathbf{P} \cos(2(\alpha - \Phi)) \sin(\beta - \Phi) - \delta\Lambda \mathbf{H} \sin(2(\alpha - \Phi) \cos(\beta - \Phi))$$

δ: Beam Polarization degree
α: Beam Polarization direction

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We measure:

- $\alpha_{||}$ and $\alpha_{\perp}$ with offset of 90°
- $\beta_{\uparrow}$ and $\beta_{\downarrow}$ with offset of 180°

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Differential cross section

$$N_\uparrow - N_\downarrow$$
$$\downarrow$$

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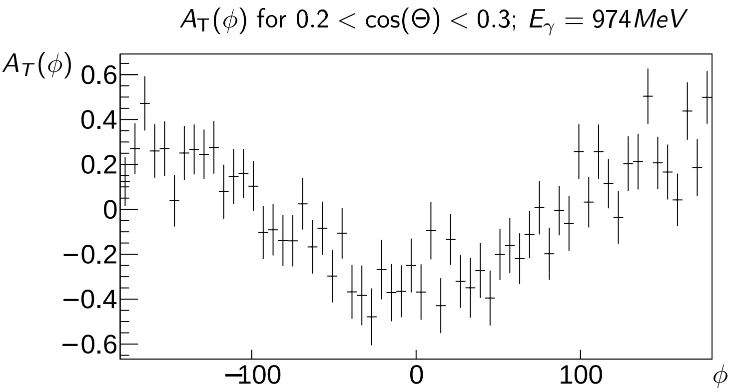
Extracting the Polarization Observables



$$A_T(\phi) = \frac{N_\uparrow - N_\downarrow}{\Lambda_\downarrow N_\uparrow + \Lambda_\uparrow N_\downarrow}$$

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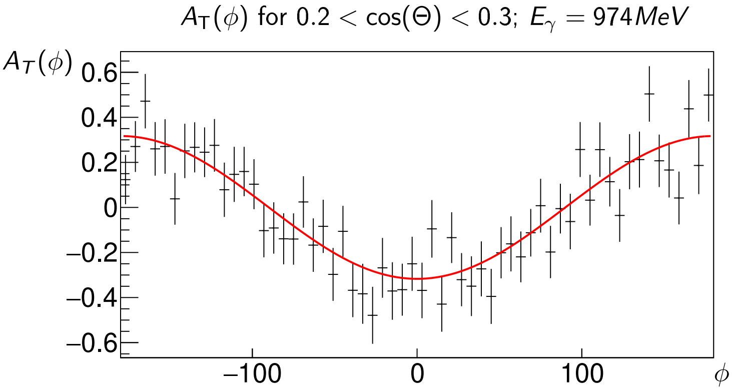

$$A_T(\phi) = \frac{N_\uparrow - N_\downarrow}{\Lambda_\downarrow N_\uparrow + \Lambda_\uparrow N_\downarrow} = d \cdot T \cdot sin(\beta - \phi)$$

Background Subtraction

Butanol Target: C_4H_9OH

$\Rightarrow$ Measure reactions off of free protons (H) and carbon (C) and oxygen (O)

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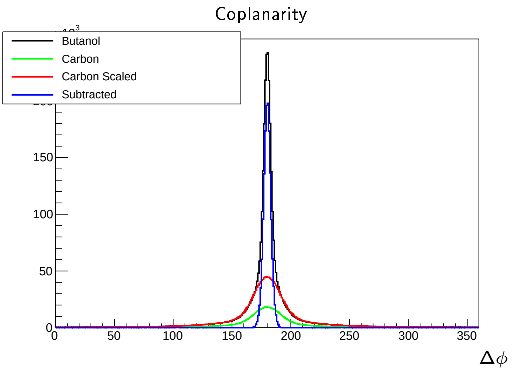
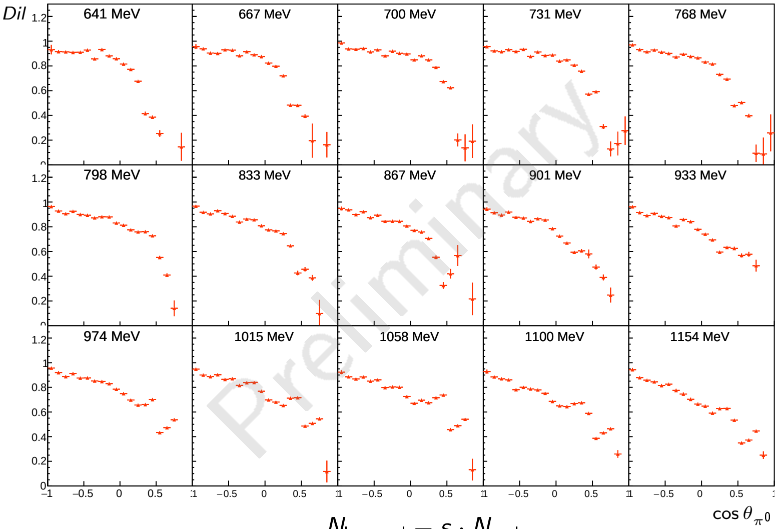
$\Rightarrow$ Measure reactions off of free protons (H) and carbon (C) and oxygen (O)

- Nuceleons in carbon and oxygen have fermi motion
  $\Rightarrow$ broader spectrum can be seperated from hydrogen spectrum
- Background is determined by measuring with a carbon foam target
- The same event selection is applied
- Carbon is then scaled to fit the butanol data



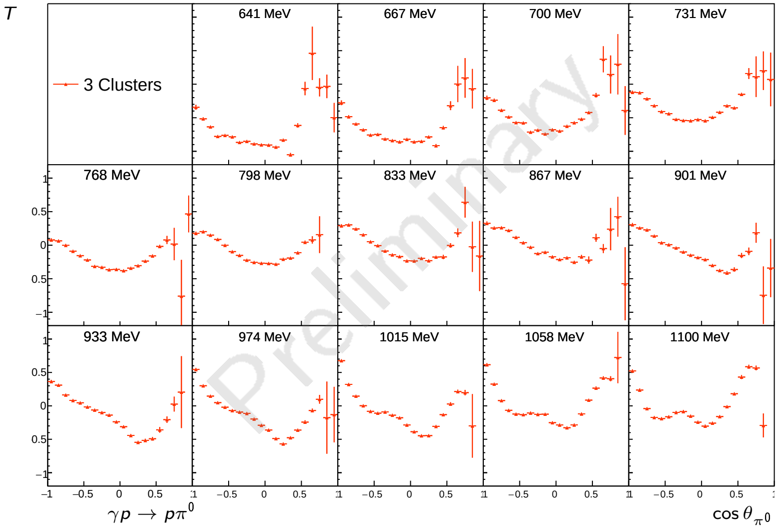
Dilution



$$d = \frac{N_{\text{butanol}} - s \cdot N_{\text{carbon}}}{N_{\text{butanol}}}$$

Results

Target polarization observable T



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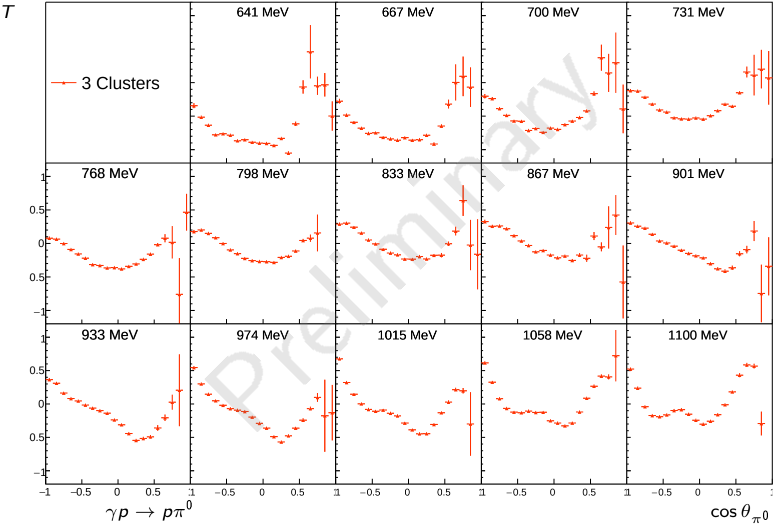

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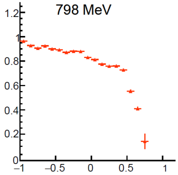

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- Measured all final state particles: two γ from the pion and the proton

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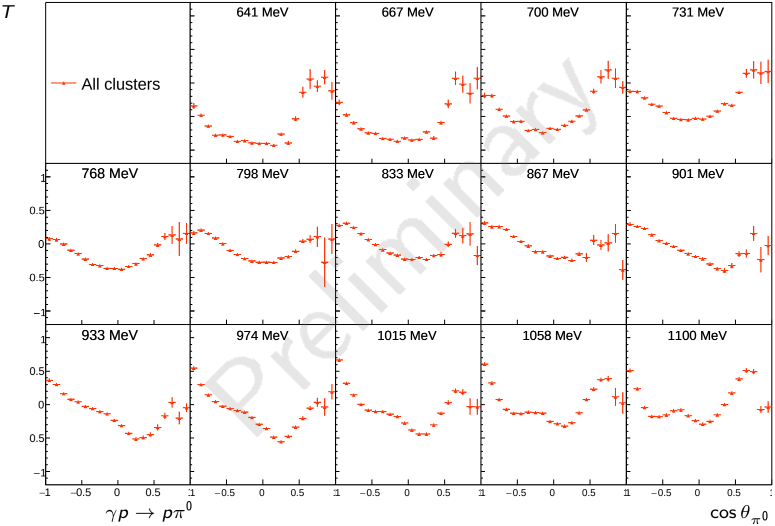
Case 2 Proton not detected:
- Direction can be reconstructed, since initial state and both decay γ are known

Determining T using all number of clusters



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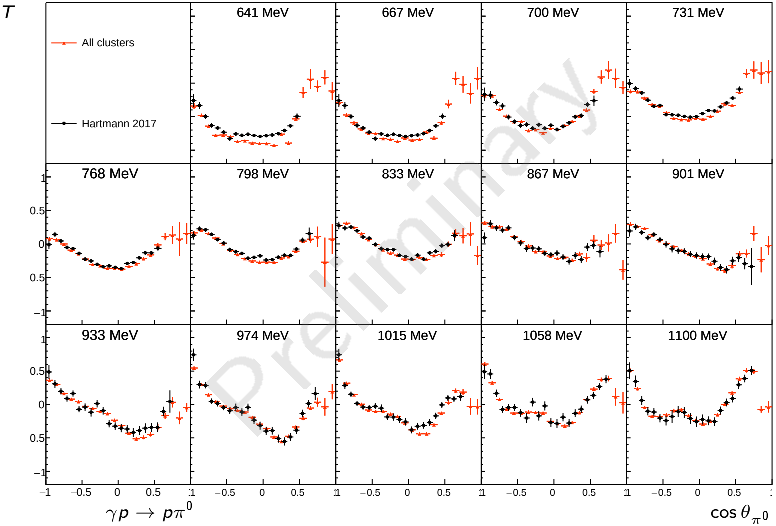
Comparing the results - Low energies



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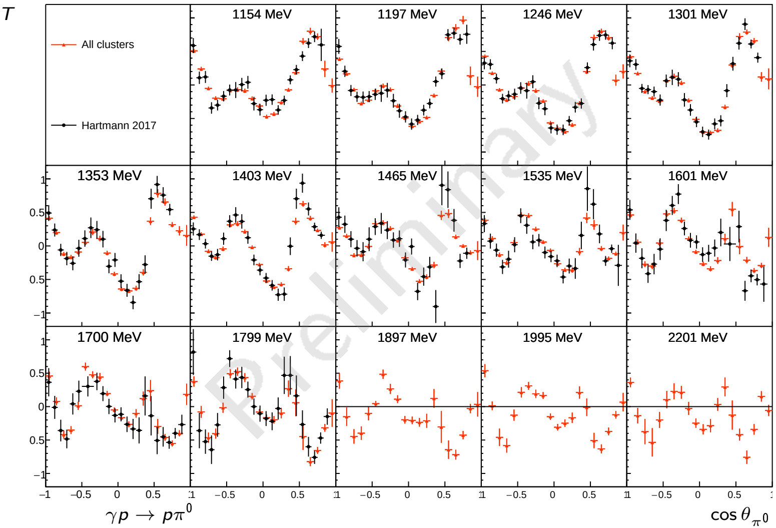

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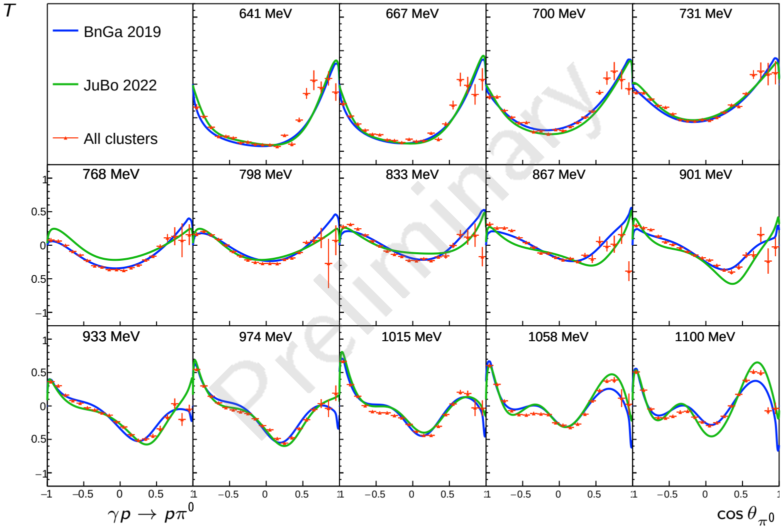

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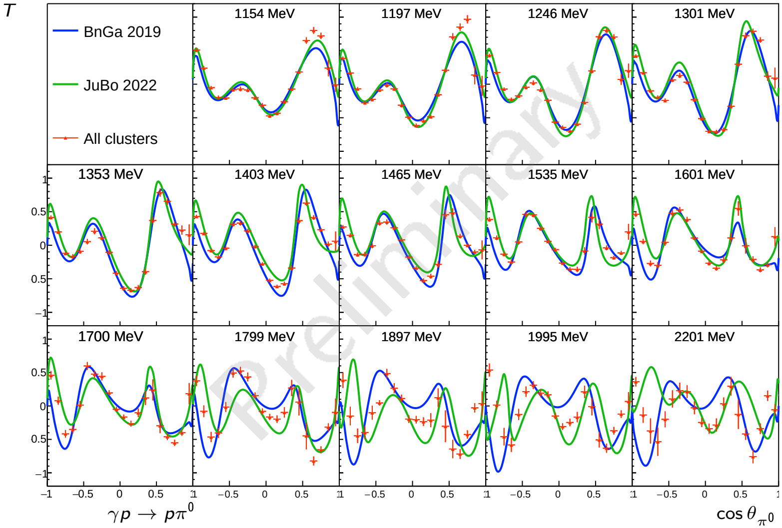

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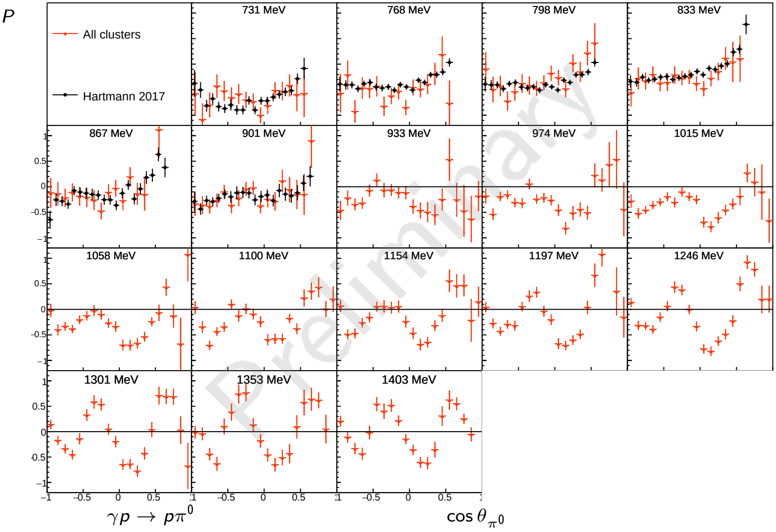
Recoil polarisation observable P



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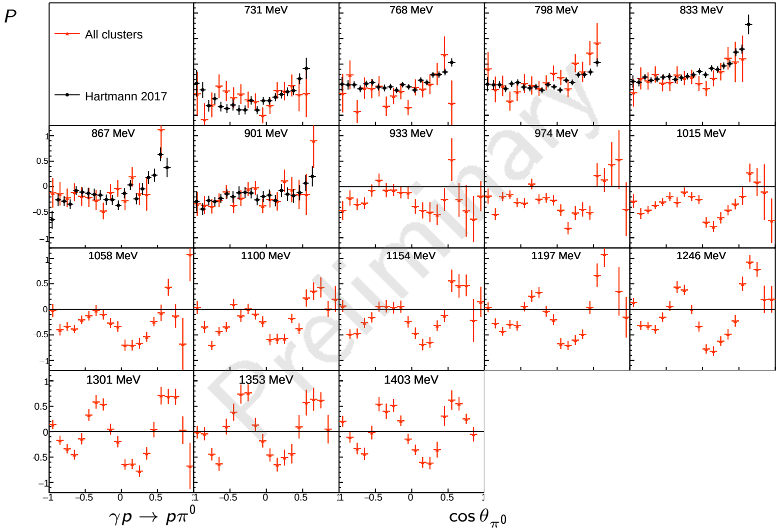

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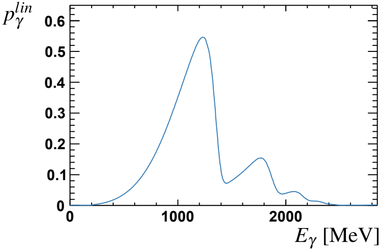
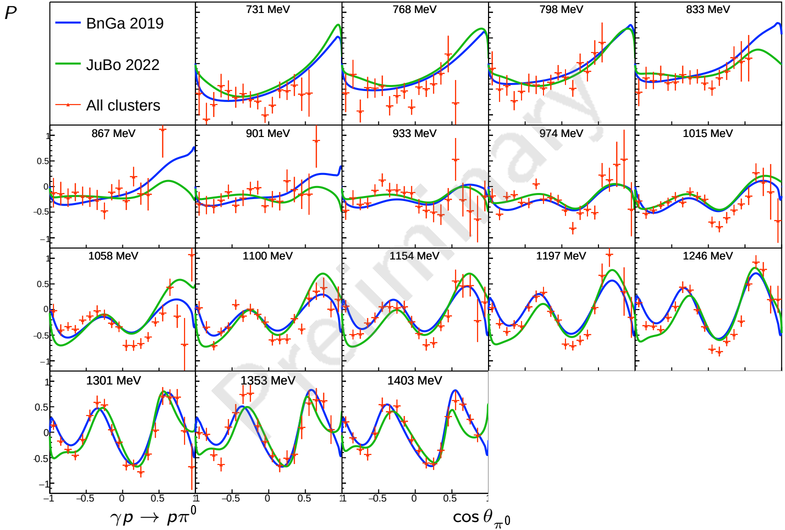


Double polarisation observable P



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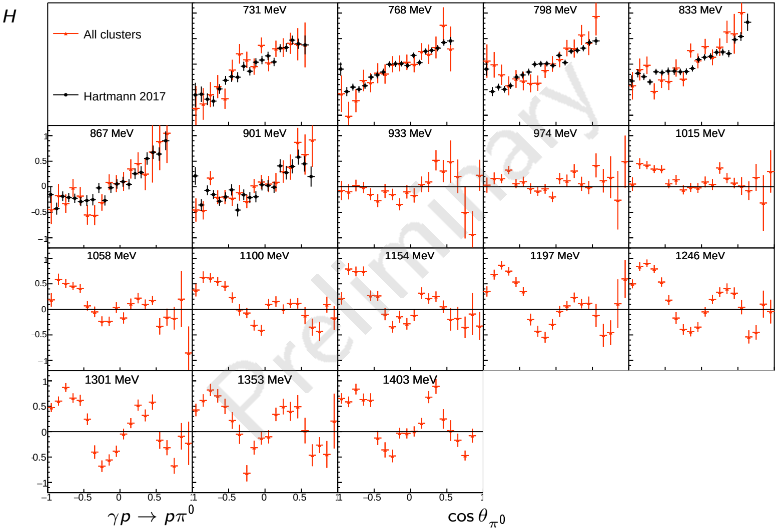
Double polarisation observable H



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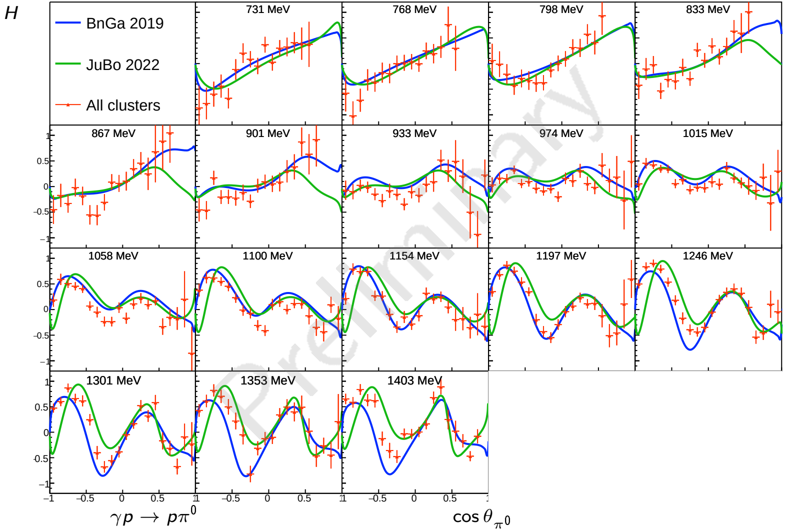
Double polarisation observable H



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Conclusion

GOAL: Better understanding of nucleon exited states

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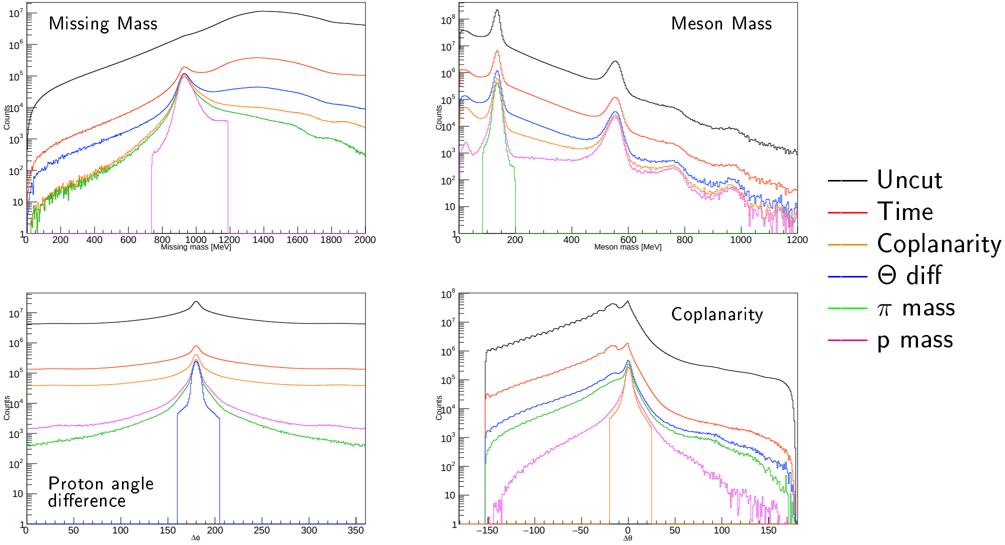
Extensive detector upgrades finished 2017
Now we are also able to trigger on neutral final states with high sensitivity
$\rightarrow$ First results for neutrons presented by Jan Hartmann tomorrow 1:30 PM

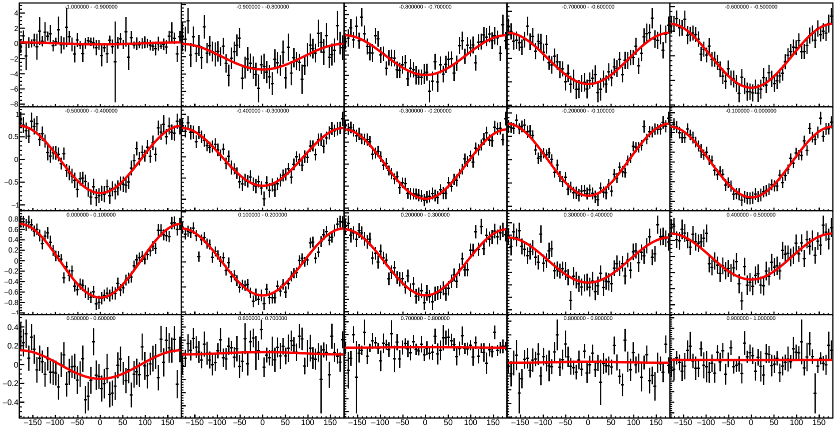
Thank you for your attention!

[1] C. Honisch et al. 'The new APD-Based Readout of the Crystal Barrel Calorimeter - An Overview' (forthcoming)

[2] J. Hartmann et al., PLB 748, 212 (2015)

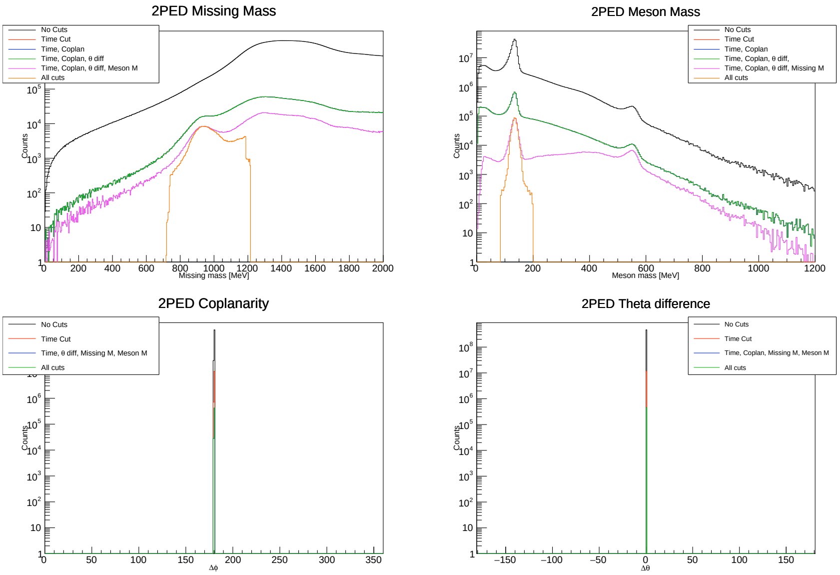
Event Selection





$$A(\phi) = \frac{1}{\Lambda} \cdot \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = d \cdot T \cdot sin(\beta - \phi)$$

Cuts 2PEDs



2PED Missing Mass
No Cuts
Time Cut
Time, Coplan
Time, Coplan, θ diff
Time, Coplan, θ diff, Meson M
All cuts
Counts
Missing mass [MeV]
2PED Meson Mass
No Cuts
Time Cut
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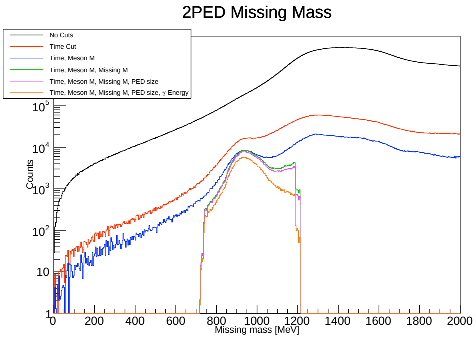
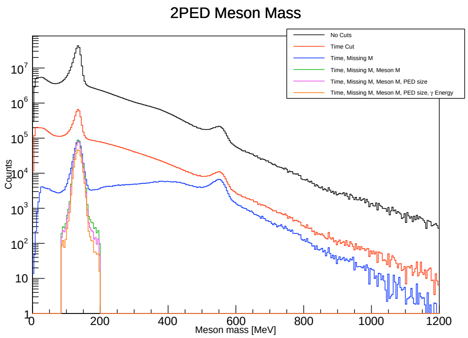
No Cuts
Time Cut
Time, θ diff, Missing M, Meson M
All cuts
Counts
Δϕ
2PED Theta difference
No Cuts
Time Cut
Time, Coplan, Missing M, Meson M
All cuts
Counts
Δθ

Cuts 2PEDs

Additional Cuts: (Preliminary)

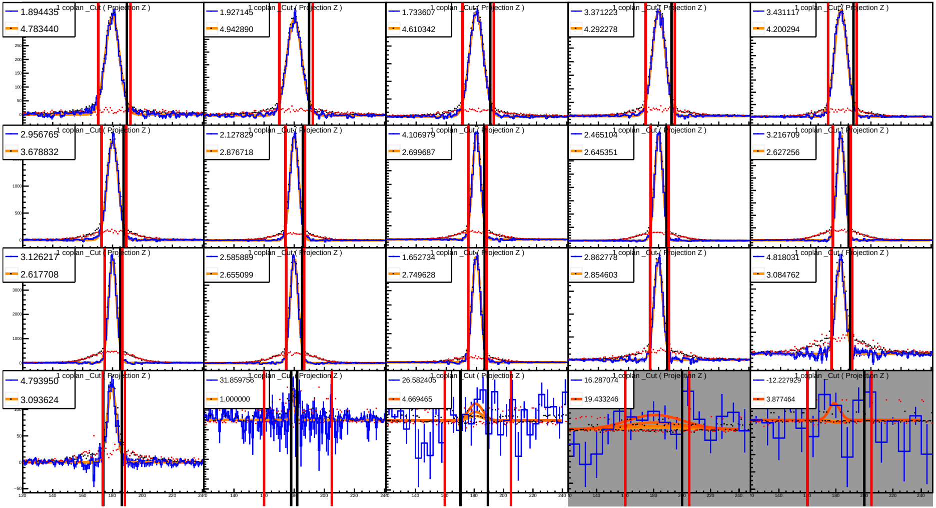
- Cluster size: > 3 (CB), > 3 (Forward plug), > 2 (Mini-Taps)
- Gamma Energy > 130 MeV



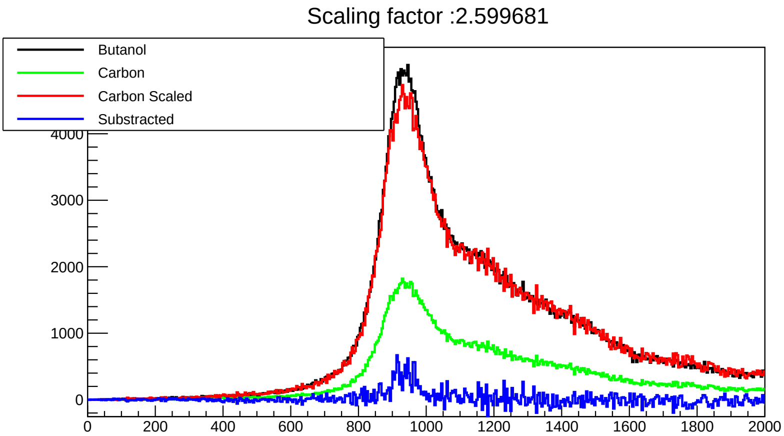


Cut Ranges

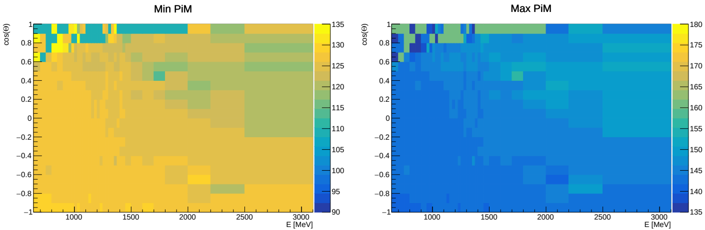
E=640MeV



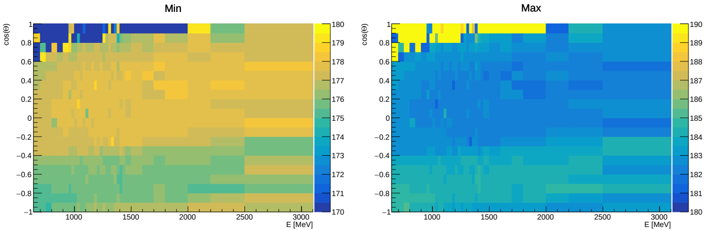
2 Ped Scaling



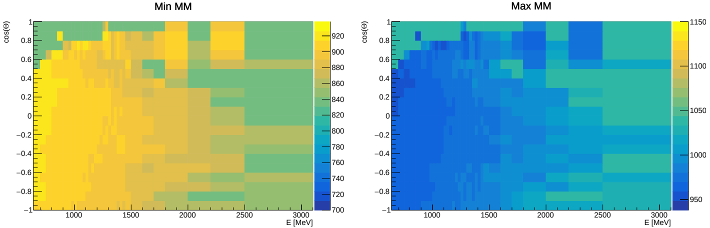
Cut-ranges



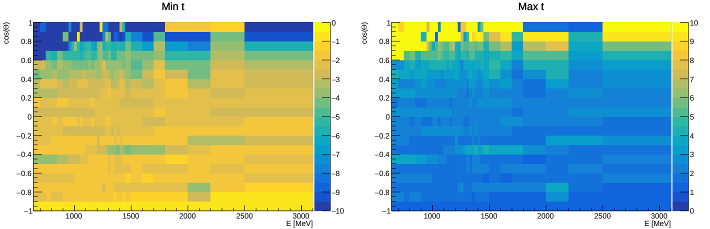
Meson Mass lower and upper cut



Coplanarity lower and upper cut



Missing Mass lower and upper cut

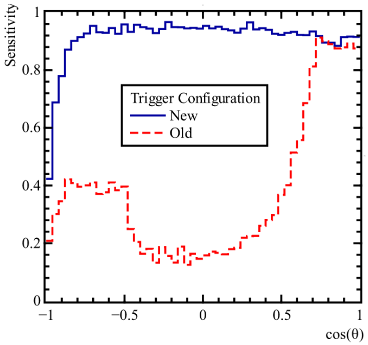


Theata difference lower and upper cut

Upgrade Motivation

- Main calorimeter was not in first level trigger
- Inner Detector is not sensitive to neutral Particles

Detector angular coverage	
Inner Detector	$23.1^\circ < \theta < 166^\circ$
Forward Plug	$11.2^\circ < \theta < 27.5^\circ$
MiniTAPS	$1^\circ < \theta < 12^\circ$



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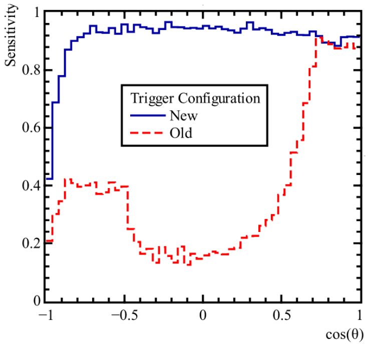

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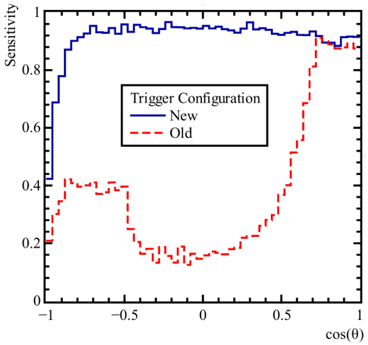

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First results for neutrons presented by Jan Hartman tomorrow 1:30 PM