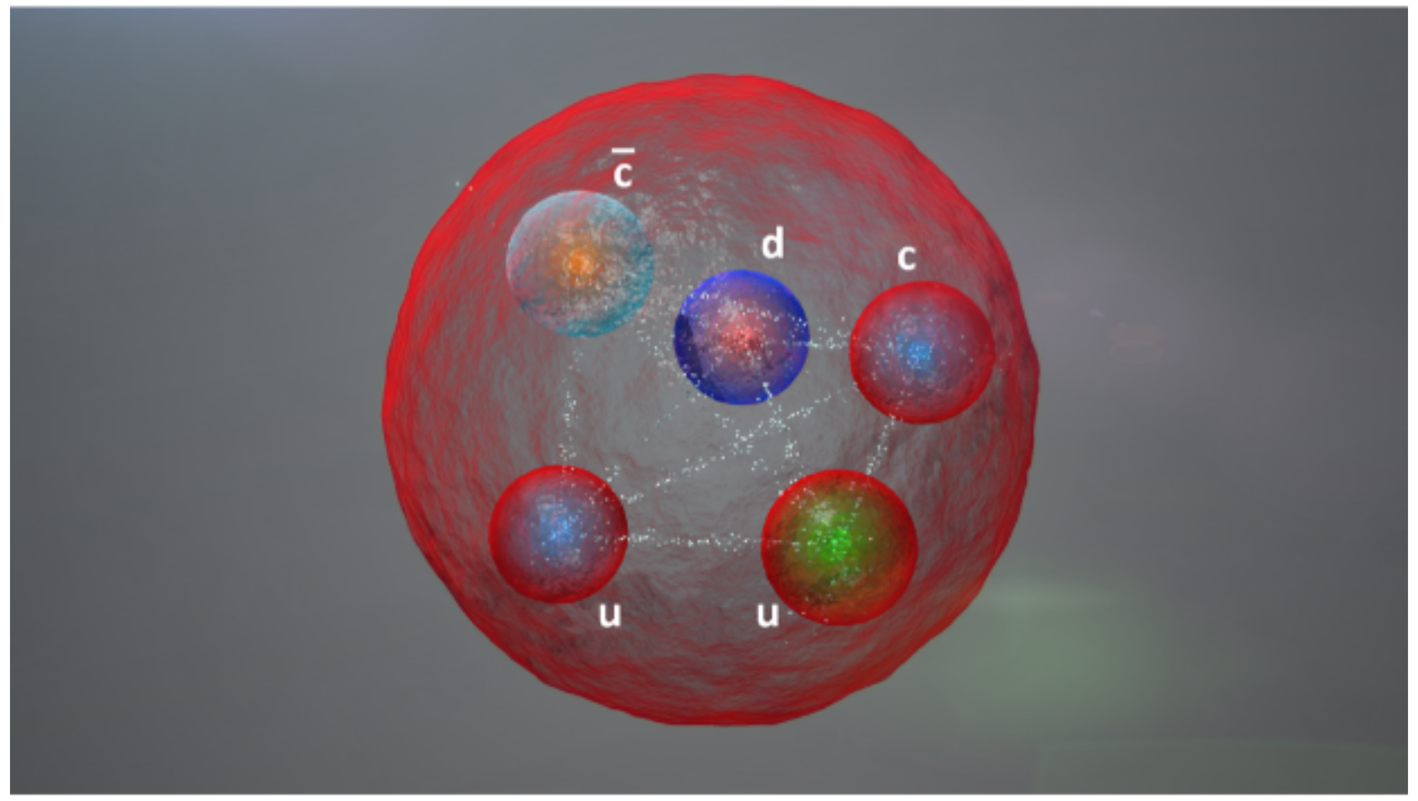
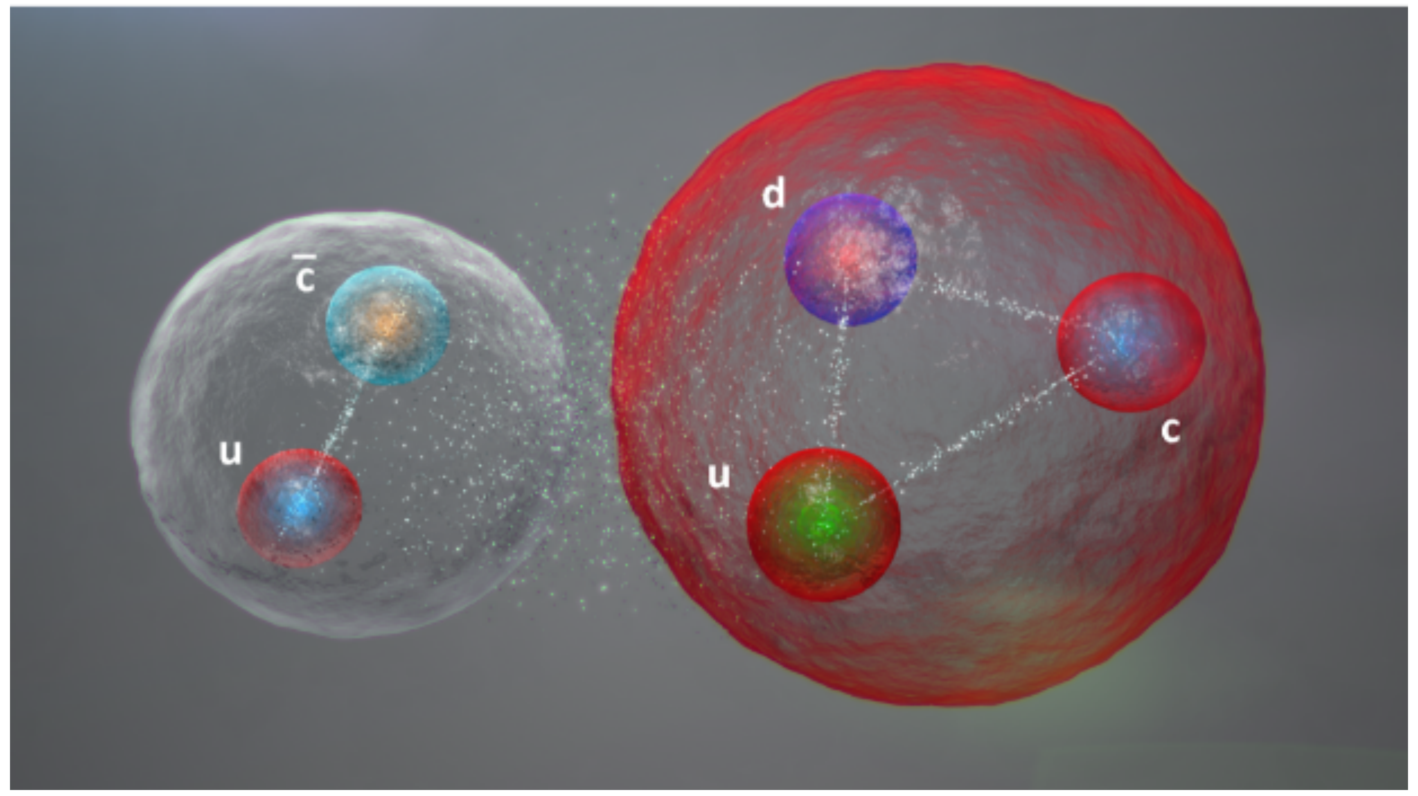
$K^0\Sigma^0$ photoproduction at the BGOOD Experiment

Physikalisches Institut der Universität Bonn

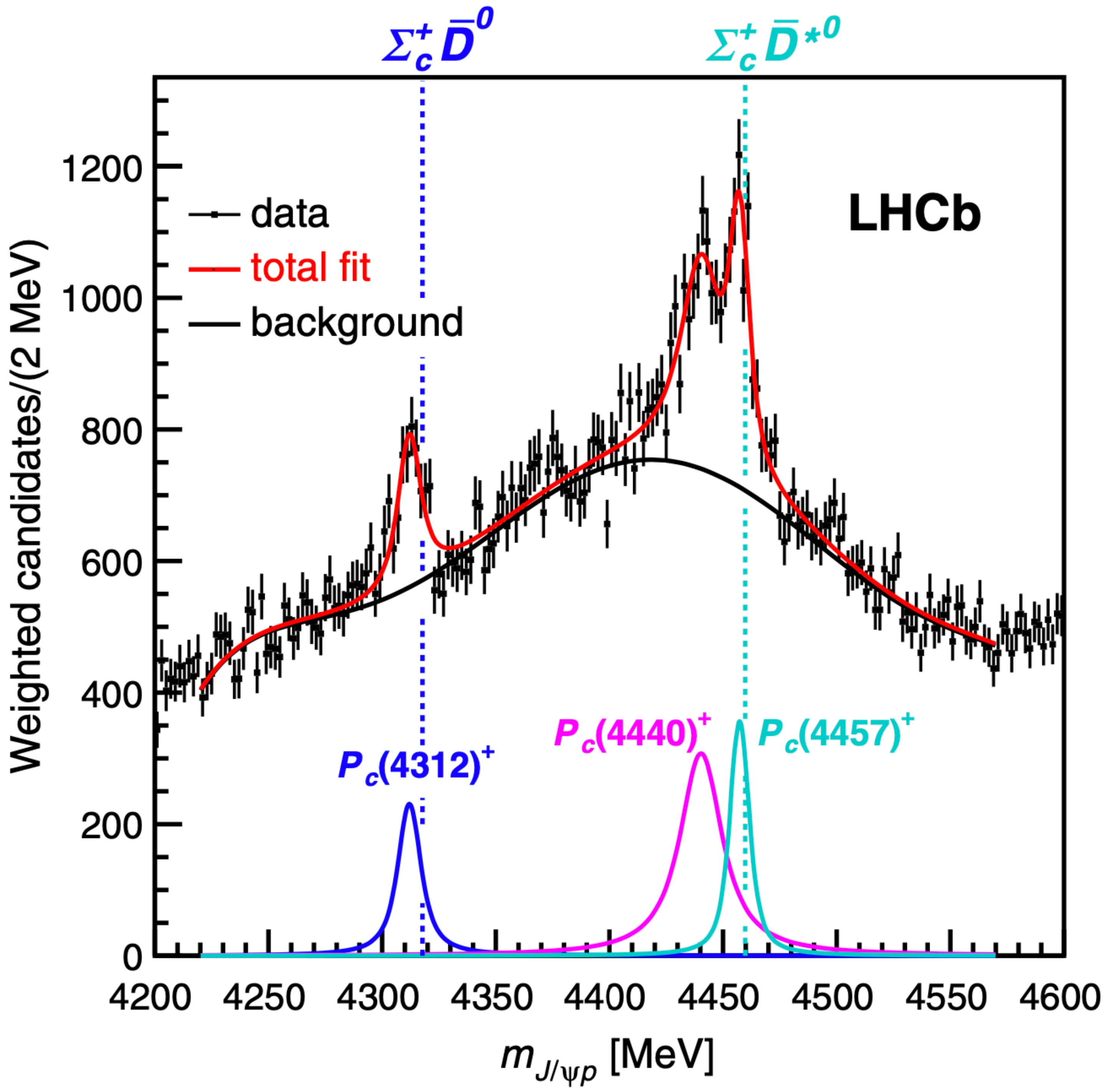
Adrian Sonnenschein, 18th June 2026

Motivation

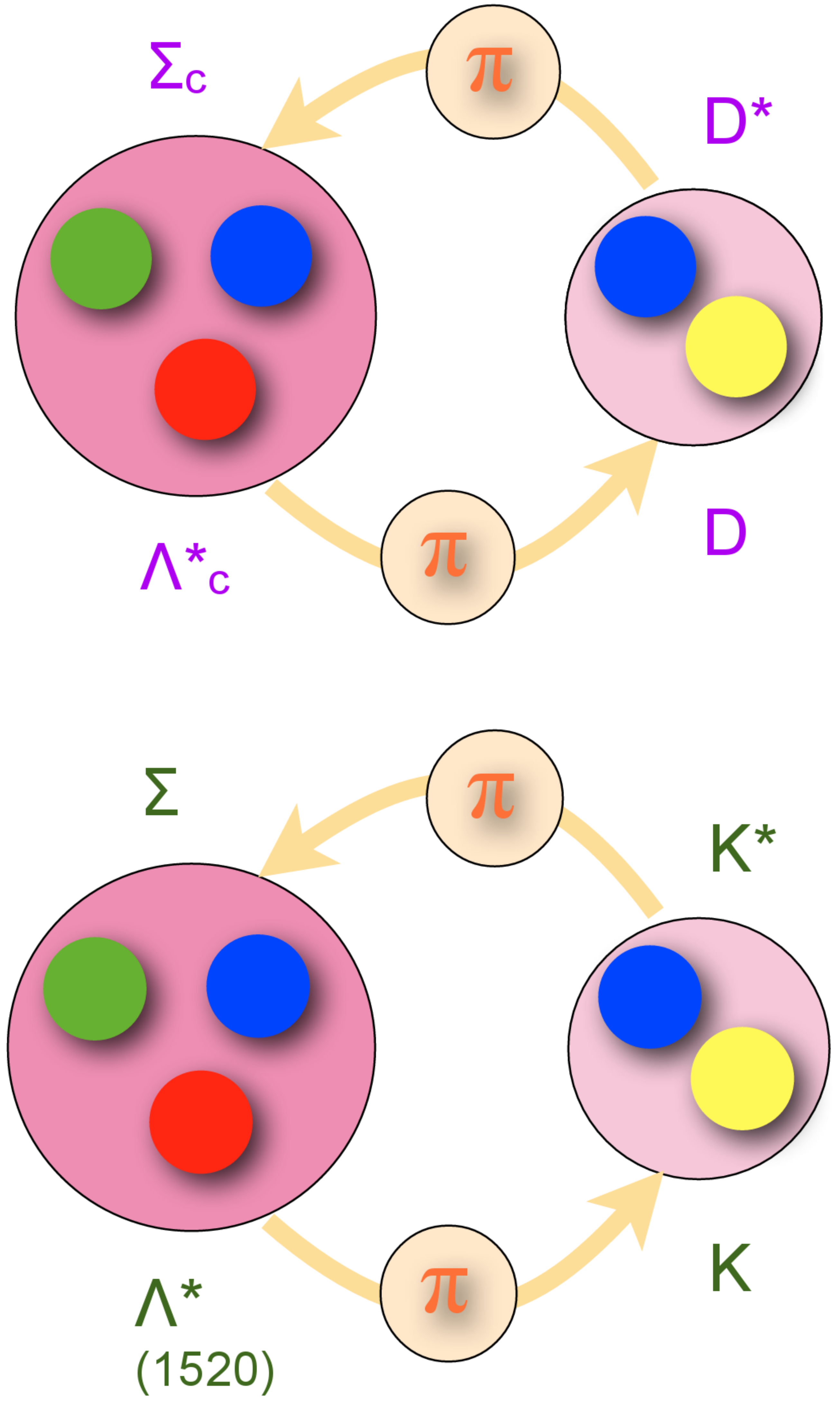




- Dynamically generated Meson-Baryon states?
- Strange sector equivalent?

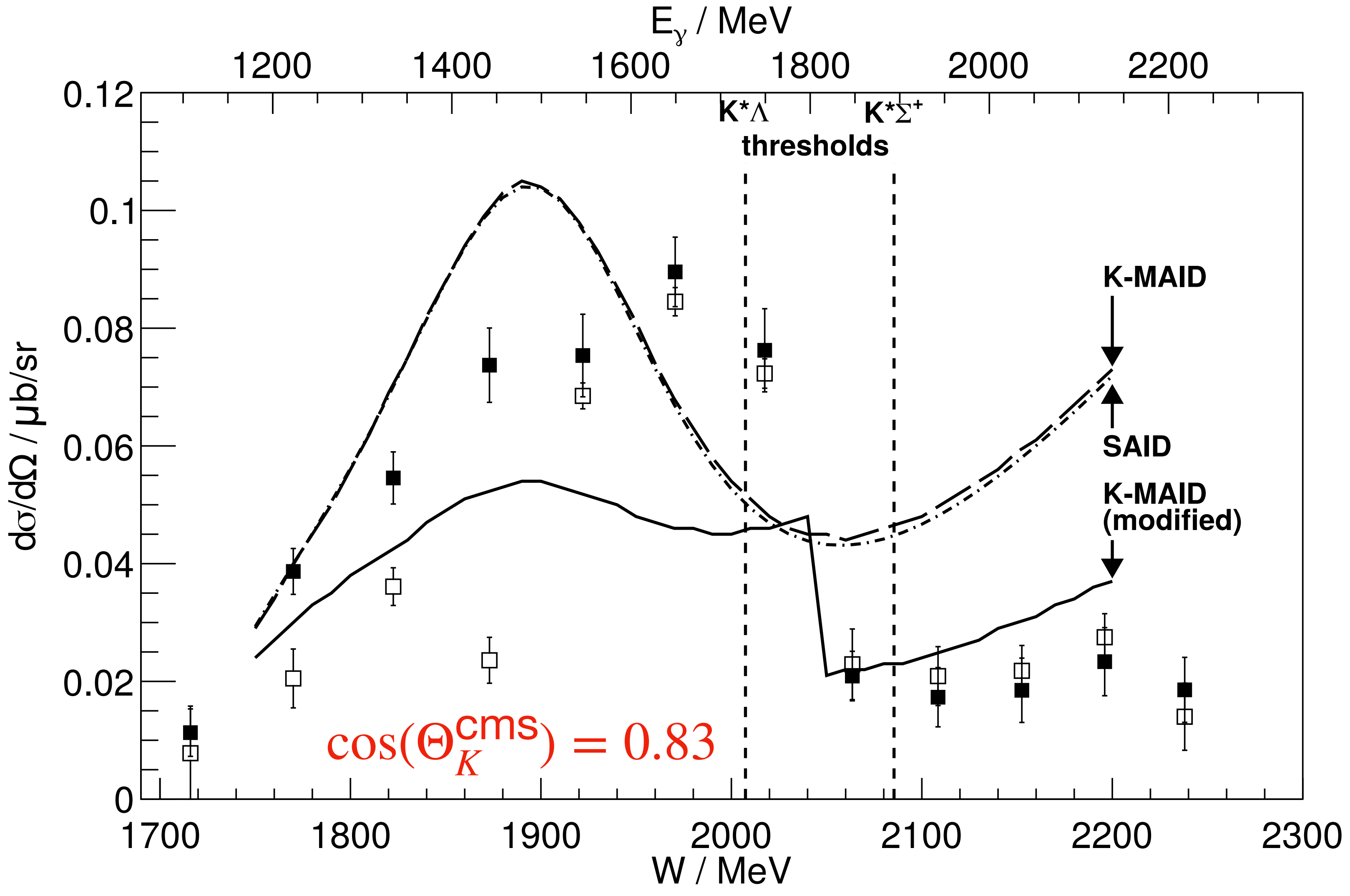


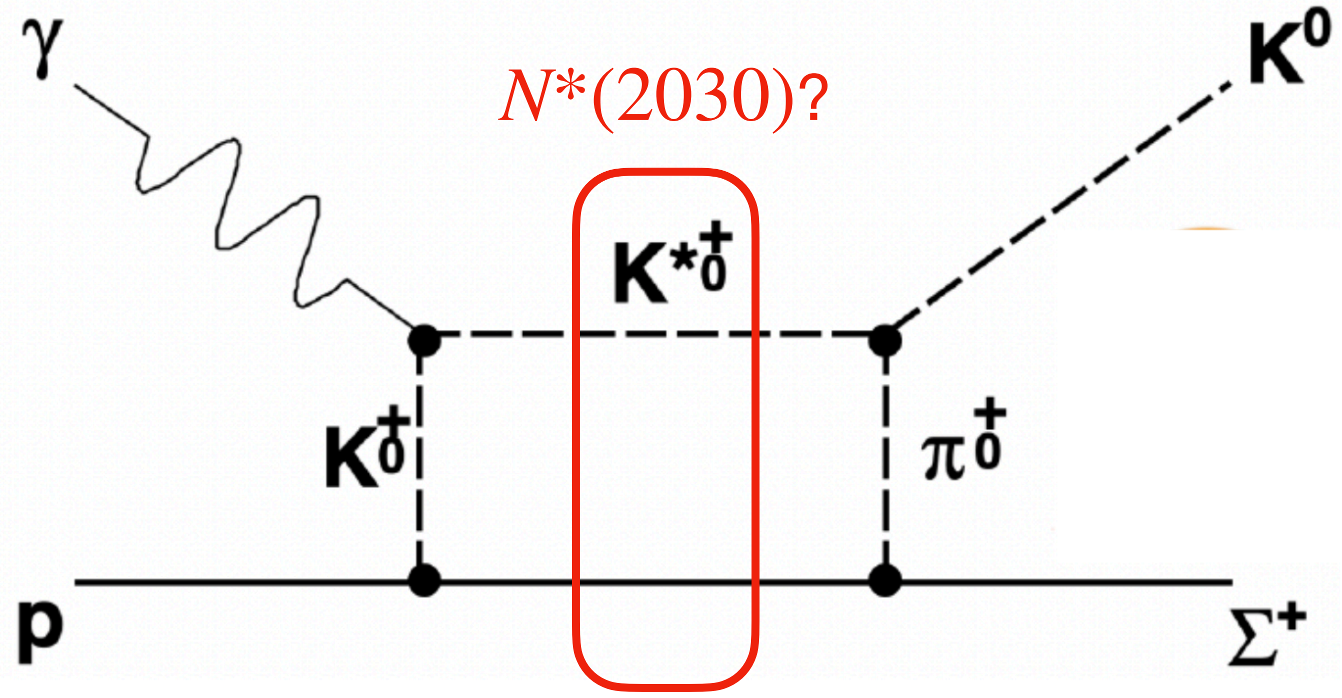
R. Aaij, et al., PRL 115, 072001 (2015) & PRL 122, 222001 (2019)

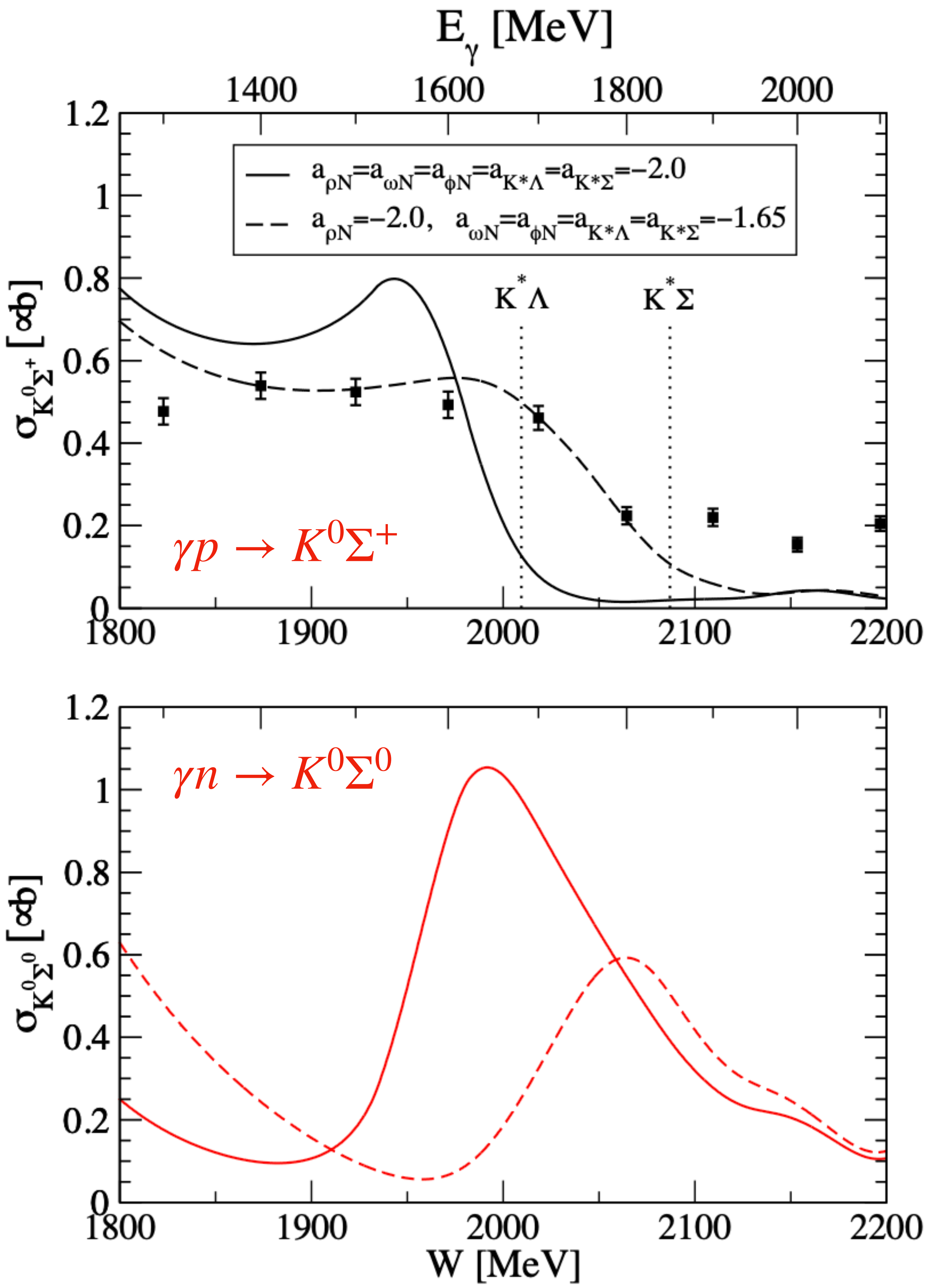


The $\gamma p \to K^0\Sigma^+$ channel

- Cusp in the $\gamma p \to K^0\Sigma^+$ cross section
- Explained by introducing $N^*(2030)$ resonance
- Same model predicts peak in the $\gamma n \to K^0\Sigma^0$ cross section







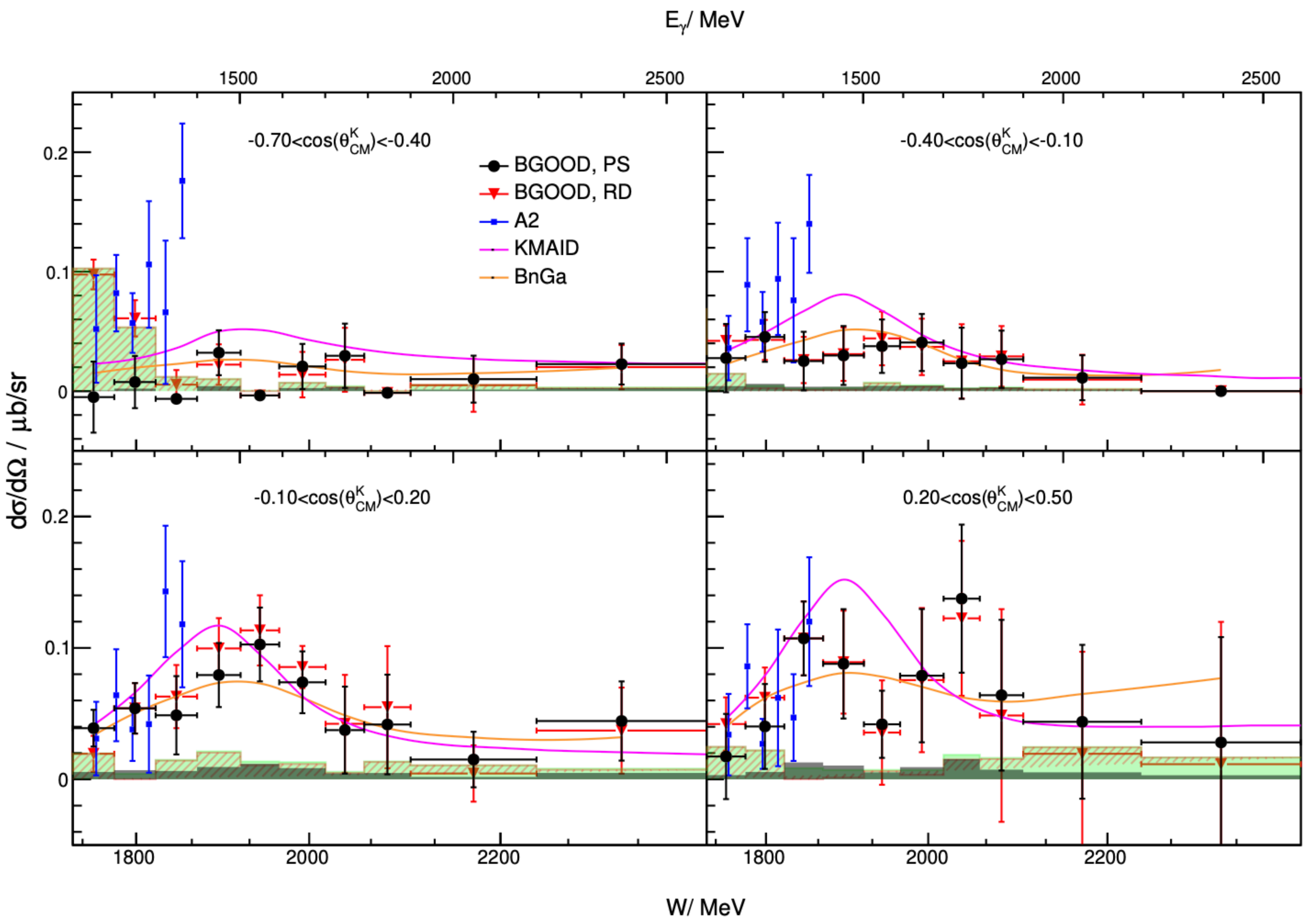
Data: R. Ewald et al. CBELSA/TAPS Collaboration, Phys. Lett. B 713 (2012)

Model: A. Ramos & E. Oset, Phys. Lett. B 727 (2013)

Previous results on the $\gamma n \rightarrow K^0\Sigma^0$ channel

Methodology:

- Yields from $2\pi^0$ inv. mass spectrum of neutral K^0 decay
- Proton background from H dataset (luminosity scaled and subtracted)
- Different methods to describe the other background
- Expected $\gamma n \rightarrow K^0\Lambda$ contribution subtracted



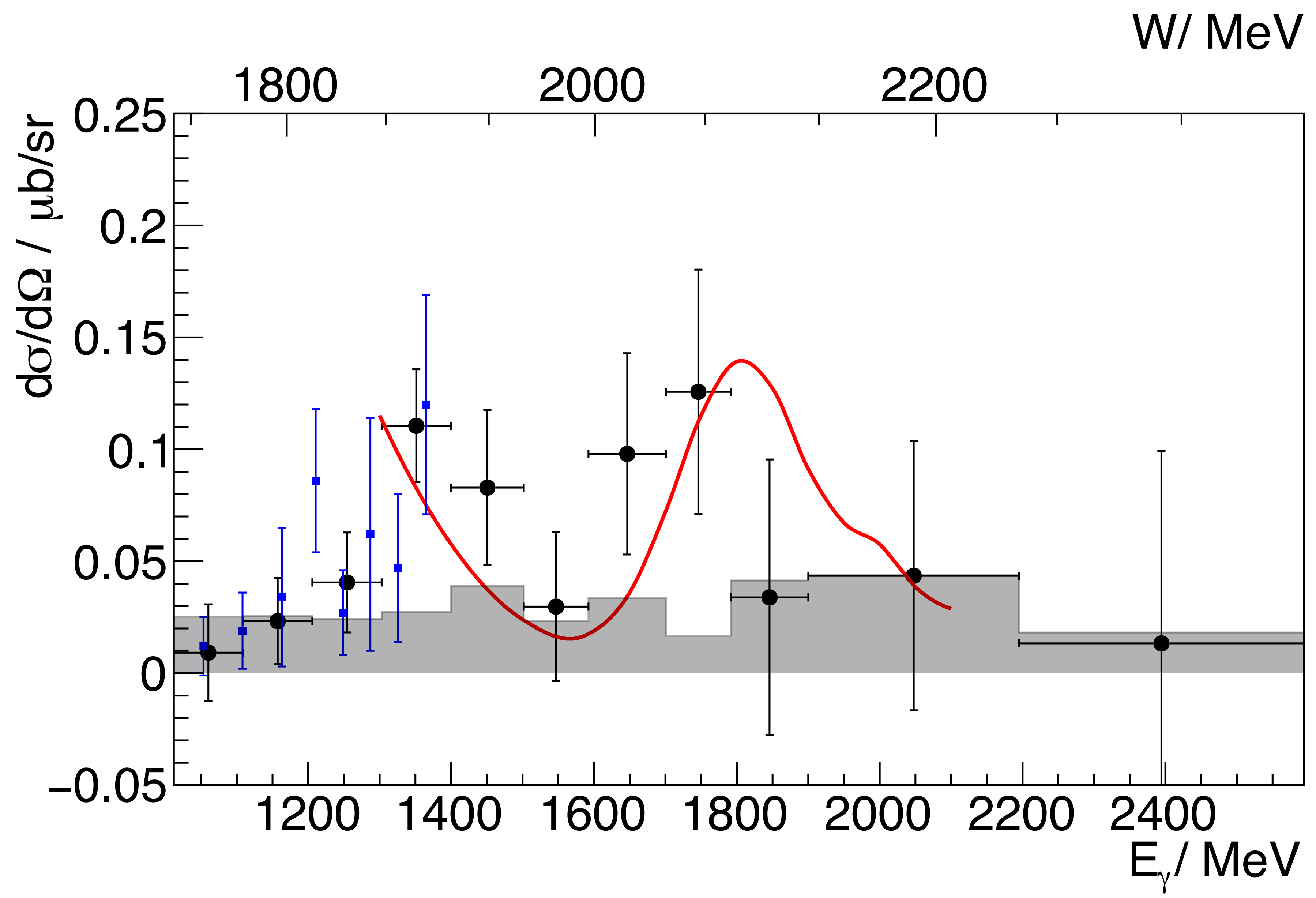
Kohl, K., Jude, T.C., Alef, S. et al. Eur. Phys. J. A 59, 254 (2023)

Previous results on the $\gamma n \to K^0\Sigma^0$ channel

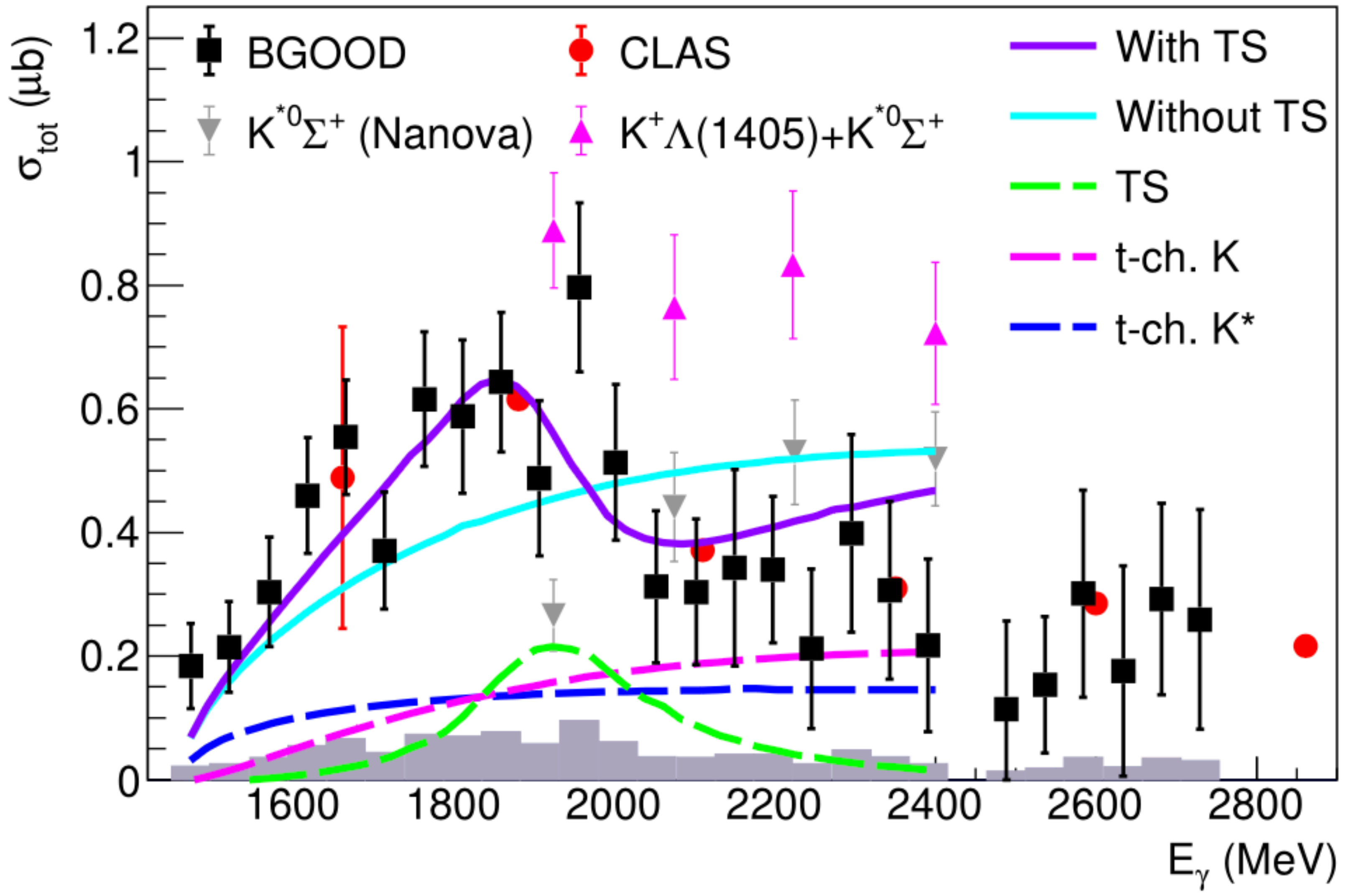
- Structure in the most forward bin consistent with prediction
- Indication for $K\Lambda$ / $K\Sigma$ type resonance $N^*(2030)$, analogue to the P_c states at LHCb

- Same resonance may explain cusp in $\gamma p \to K^+\Lambda(1405)$ cross section

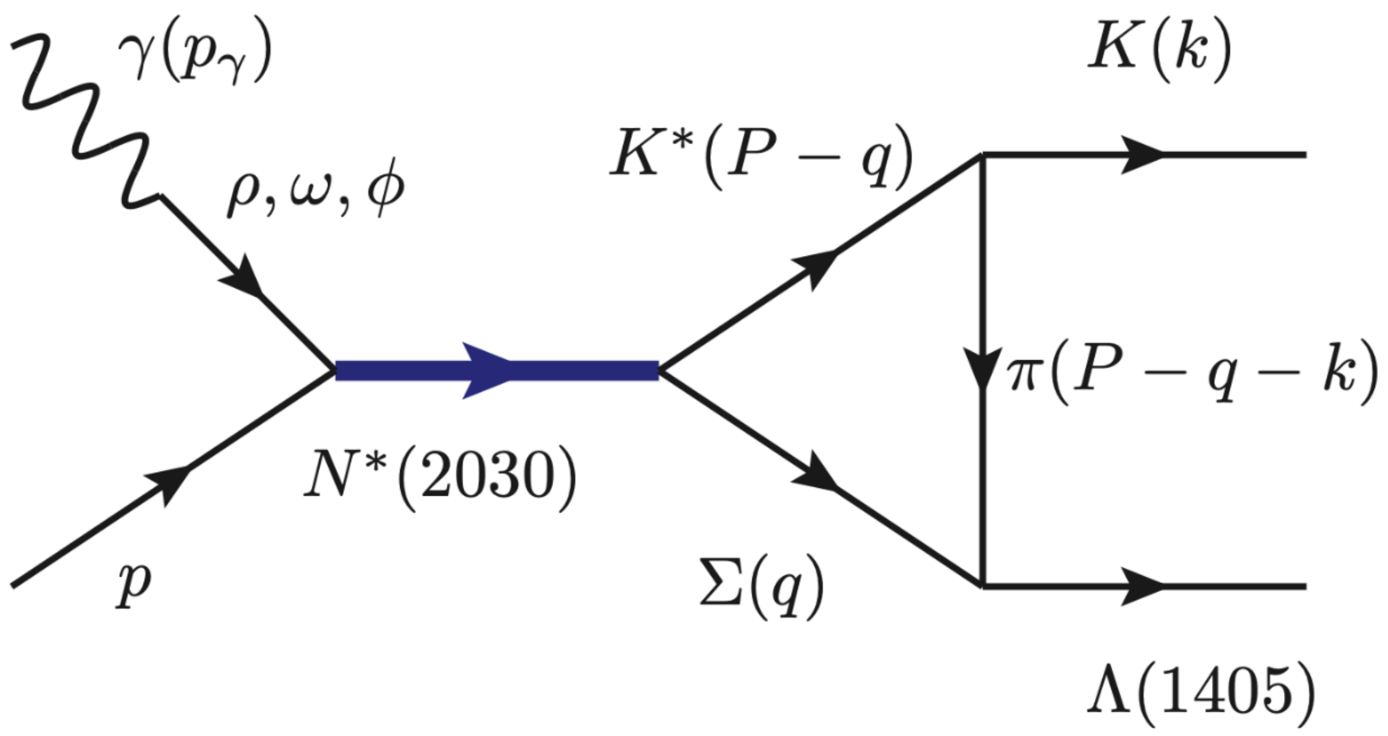
More information: Studies of $\Lambda(1405)$ at forward angles, Antonio J. Clara Figueiredo



Black: Kohl, K., Jude, T.C., Alef, S. et al. Eur. Phys. J. A 59, 254 (2023)
Blue: C. Akondi, et al A2., Eur. Phys. J. A 55, 202 (2019)
Red: A. Ramos and E. Oset, Phys. Lett. {B 727}, (2013) 287 scaled to approx. fit the height

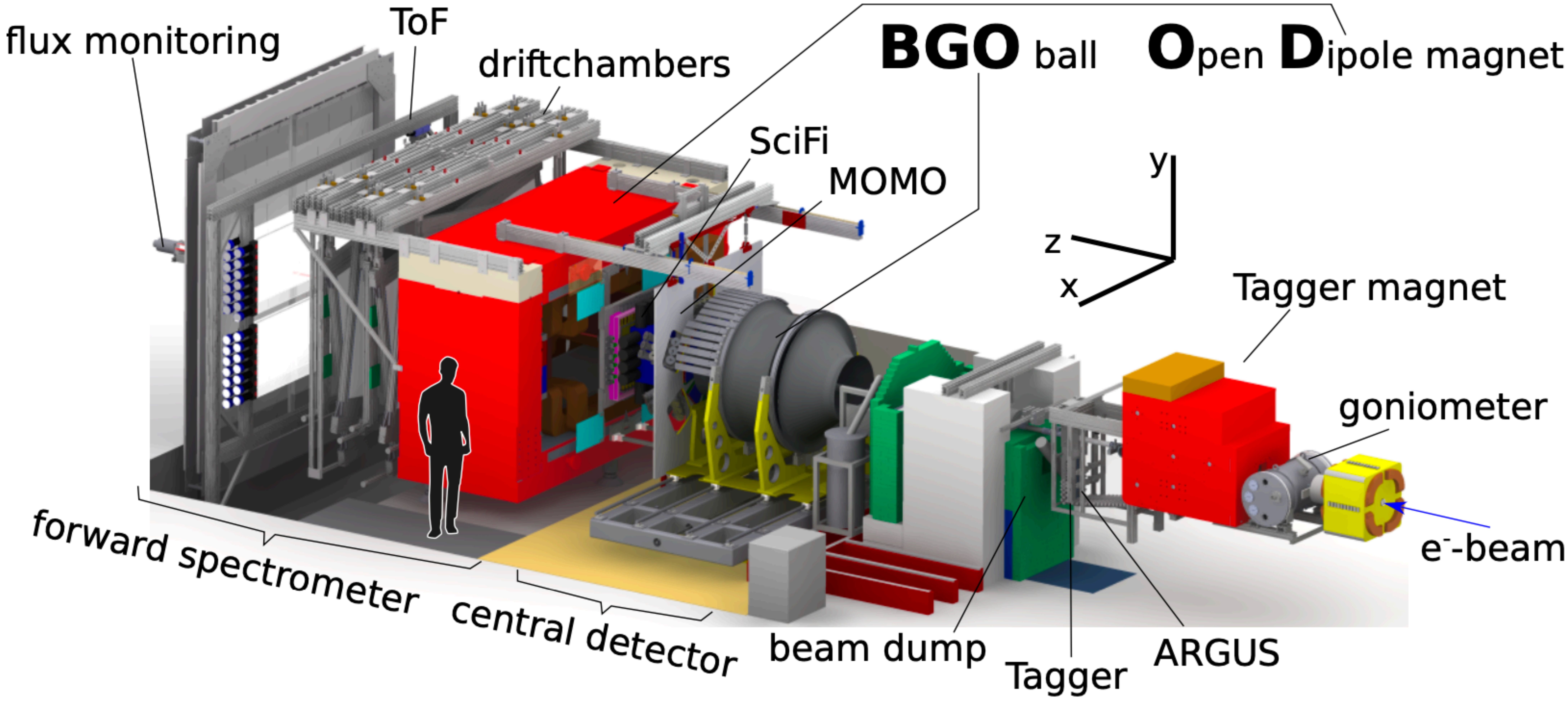


G. Scheluchin et al BGOOD, Phys. Lett. {B 833}, (2022) 137375



Wang et al. PRC 95, 015205 (2017)

The BGOOD Experiment



S. Alef et al. "The BGOOD experimental setup at ELSA", Eur. Phys. J. A 56.4 (2020)

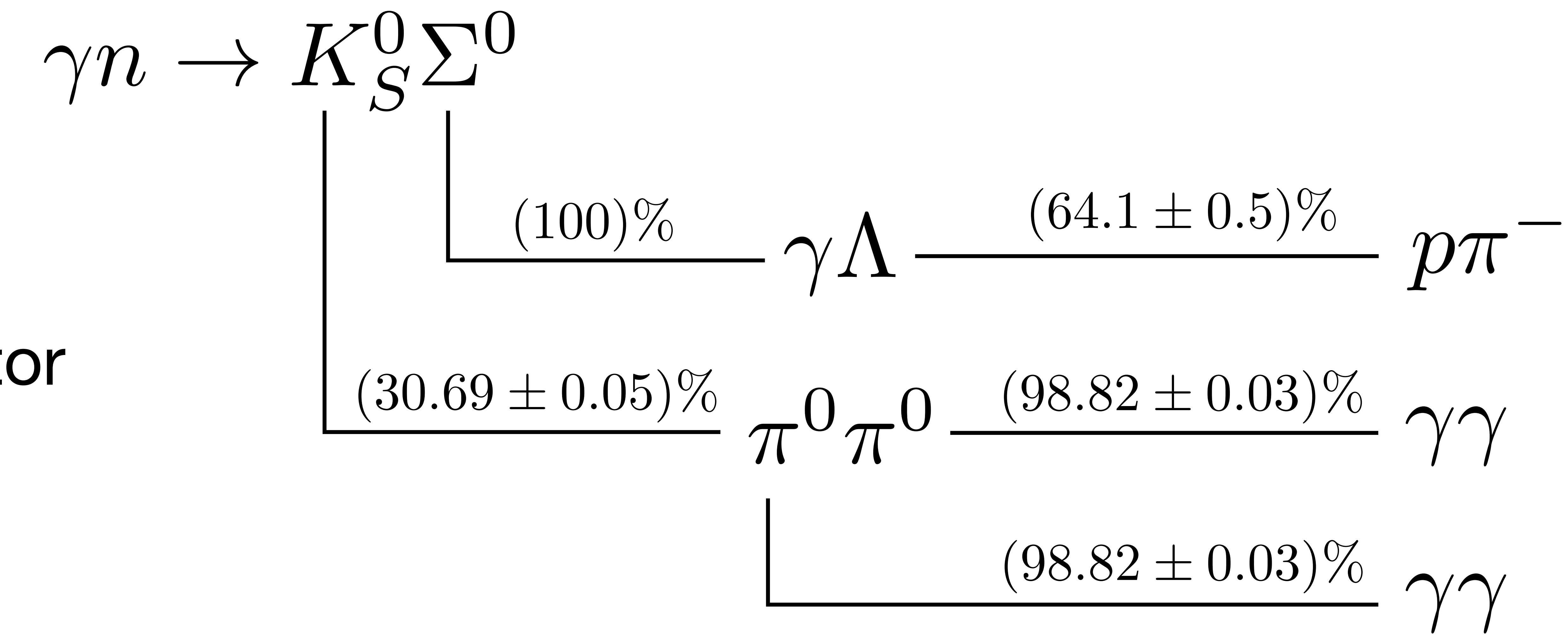
Analysis

New approach:

- Improved statistical precision → including second beamtime (2021 September)
- Apply a kinematic fitting routine to the data
- Yield is extracted from E_γ of the $\Sigma^0 \rightarrow \gamma\Lambda$ decay (74.42 MeV)

Track selection:

- 5 neutral tracks in the BGO Ball
- 2 charged tracks in any part of the detector system



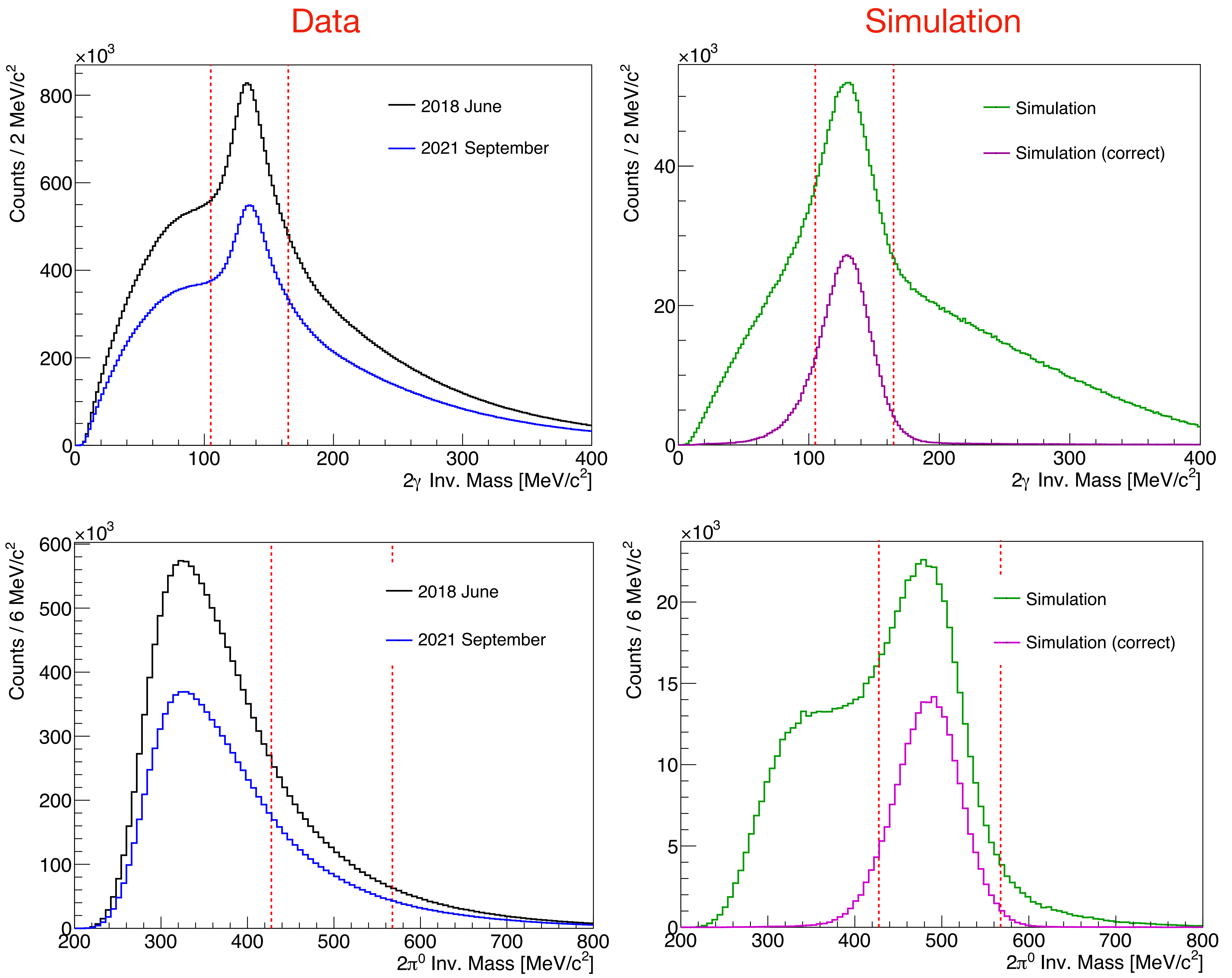
Reconstruction of the K^0

Reconstruction of π^0

- Form π^0 candidates for every $\gamma\gamma$ combination
- Discard candidates outside 2σ invariant mass range

Reconstruction of K^0

- Form K^0 candidate for every $\pi^0\pi^0$ combination
- Discard candidates outside 2σ invariant mass range



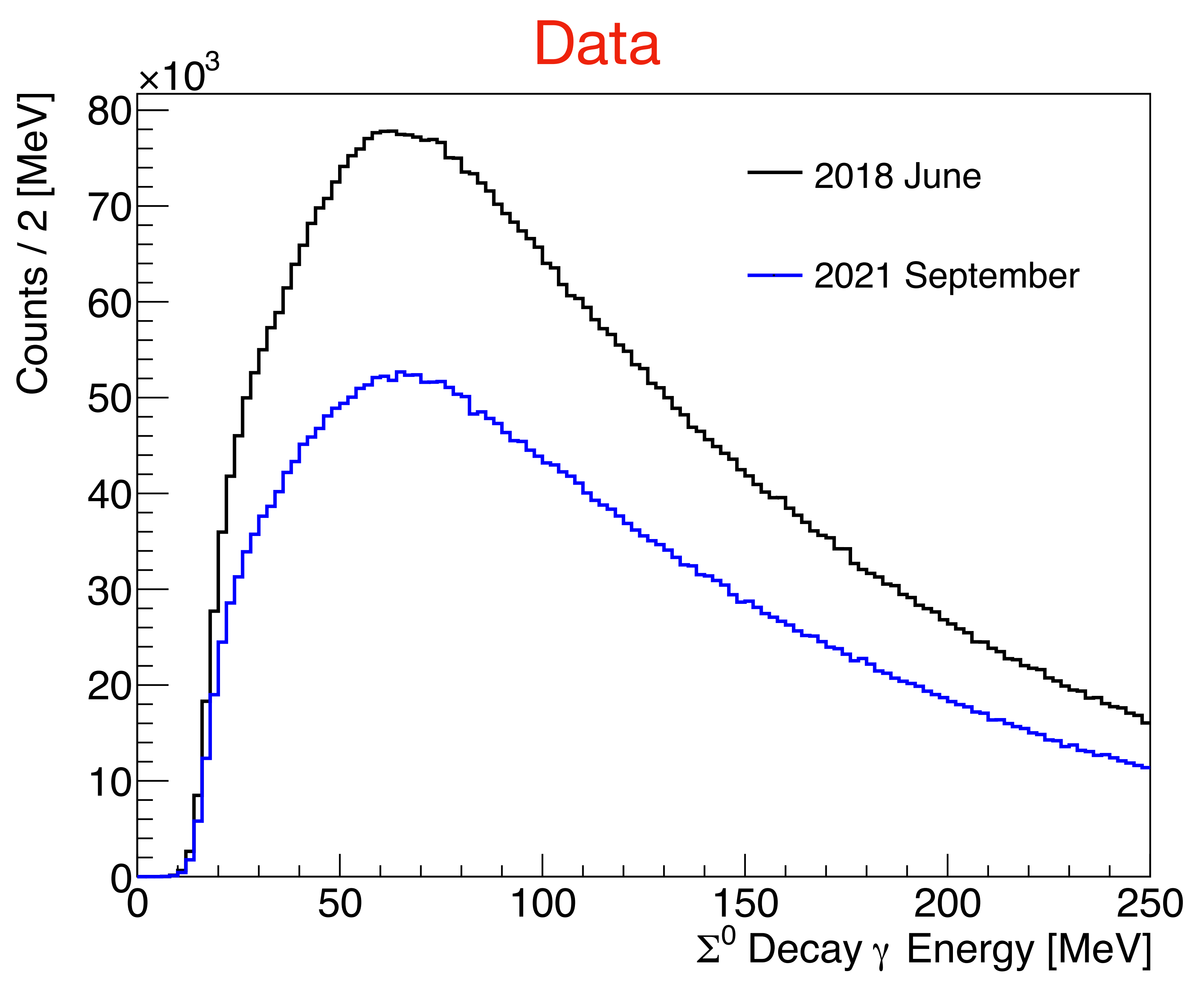
Reconstruction of Σ^0

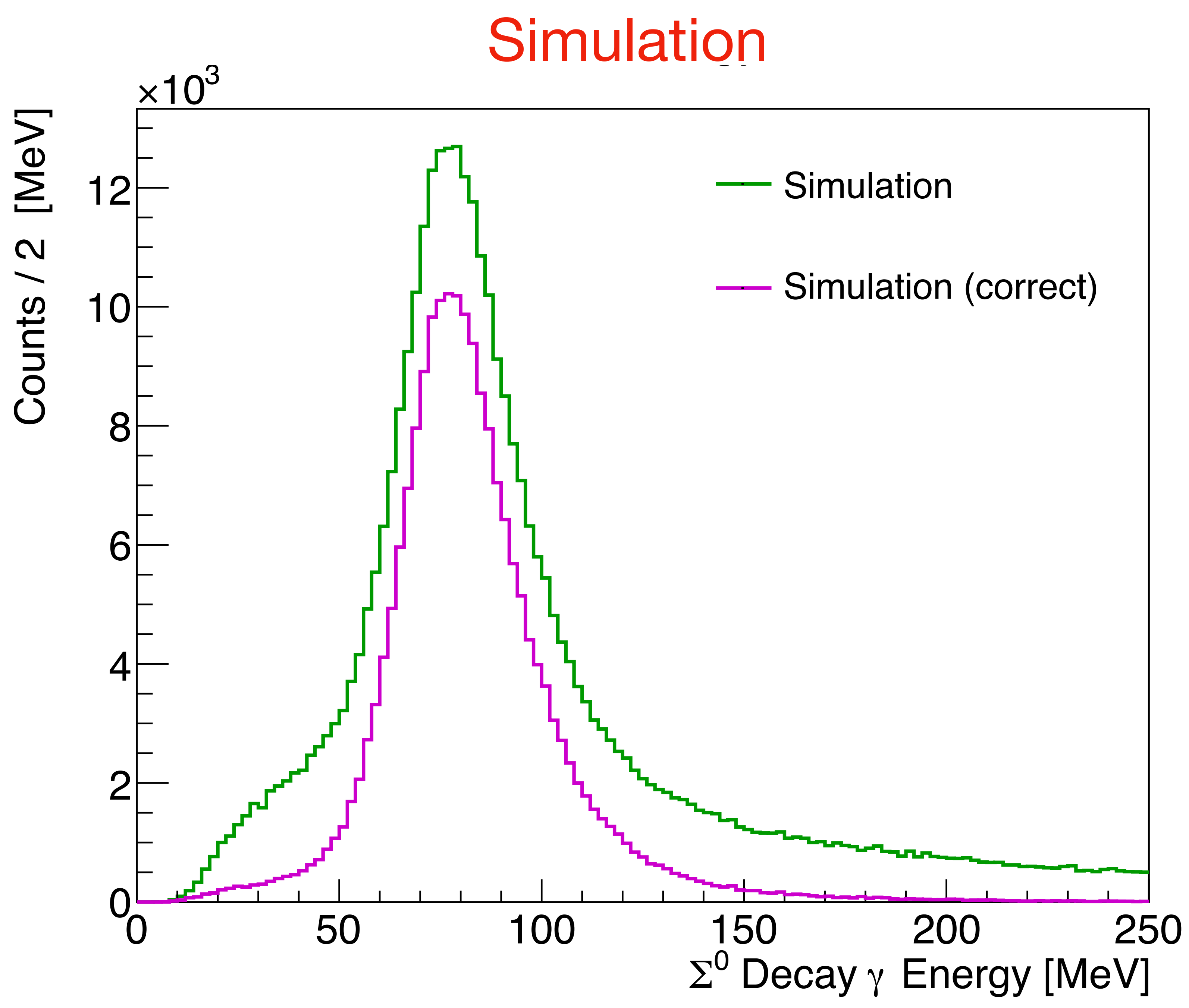
Decay photon:

- Remaining photon from K^0 reconstruction is considered to be the decay photon
- Boost into Σ^0 (from miss. mass) rest frame
- E_γ is expected to be 74.42 MeV

Yield extraction will be done based on this observable:

→ *No cuts applied*

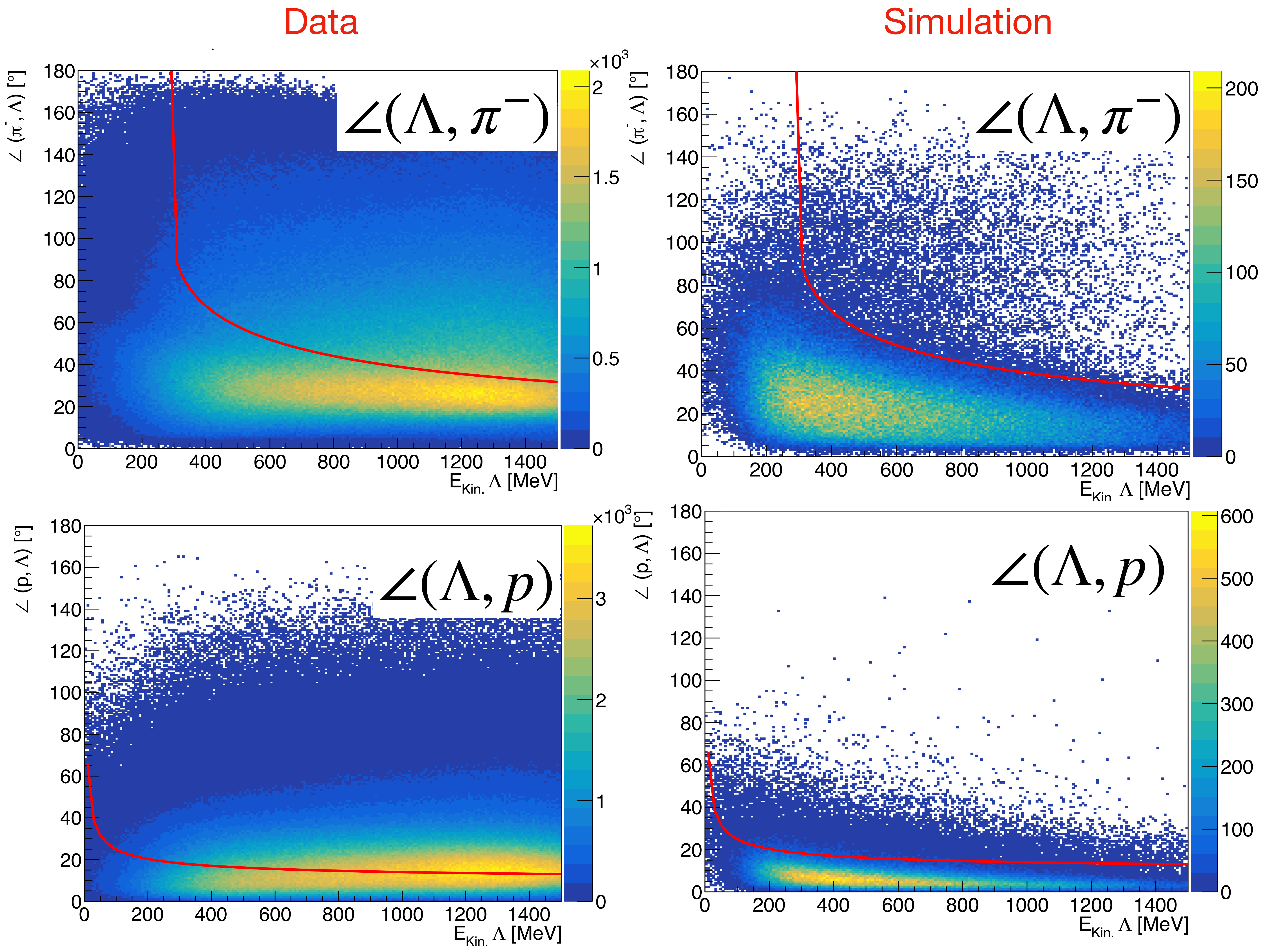


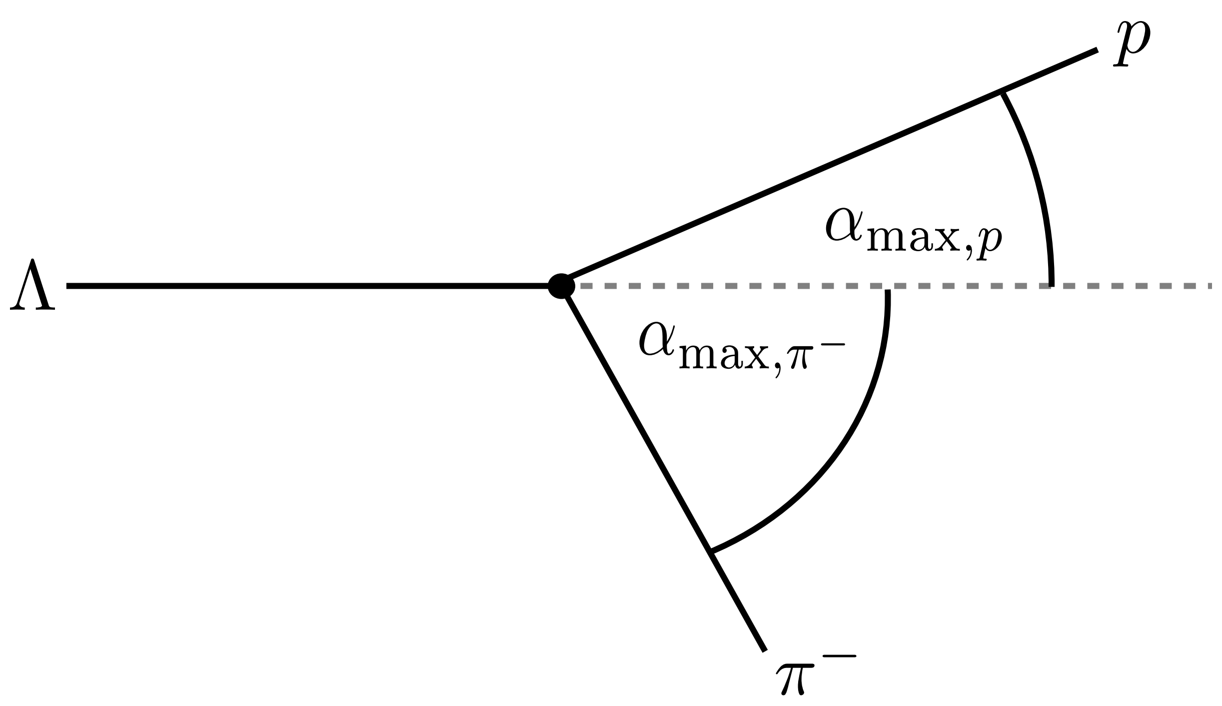


Reconstruction of Σ^0

Charged particles:

- Assignment of p and π^- based on charge signature or angle compared to Λ (from miss. mass)
- Cut based on maximum allowed angle α_{max}
- Momentum of p and π^- calculated from miss. mass (if not measured)



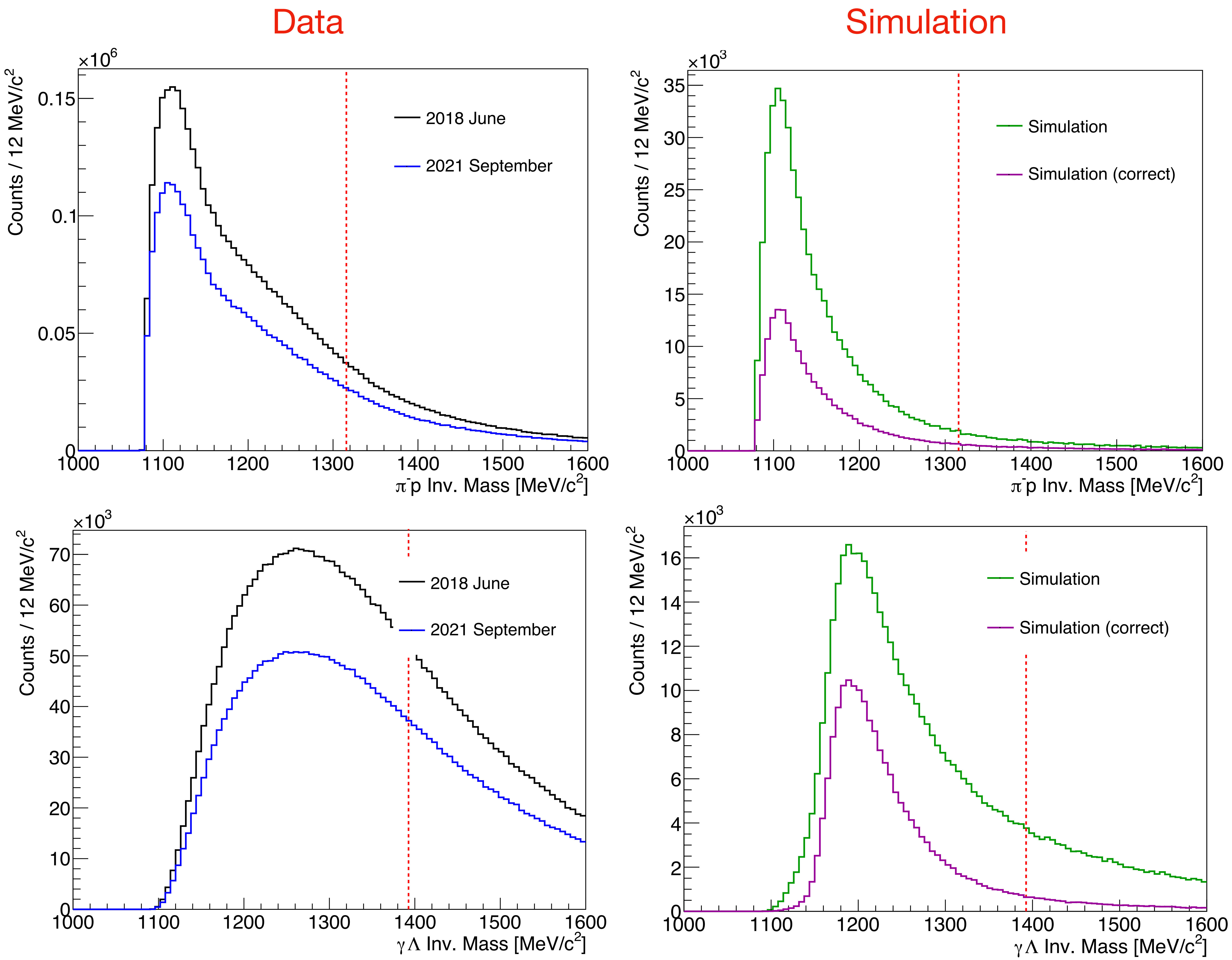


Additional selection criteria

After Reconstruction:

- Broad cuts on $p\pi^-$ inv. mass
- Broad cuts on $\Lambda\gamma$ inv. Mass
- Broad cuts on Σ^0 miss. mass
- Broad cuts on K^0 miss. Mass (asymmetric: left = 2.5σ, right = 1.25σ)

➡ Reduce number of events before kinematic fitting procedure



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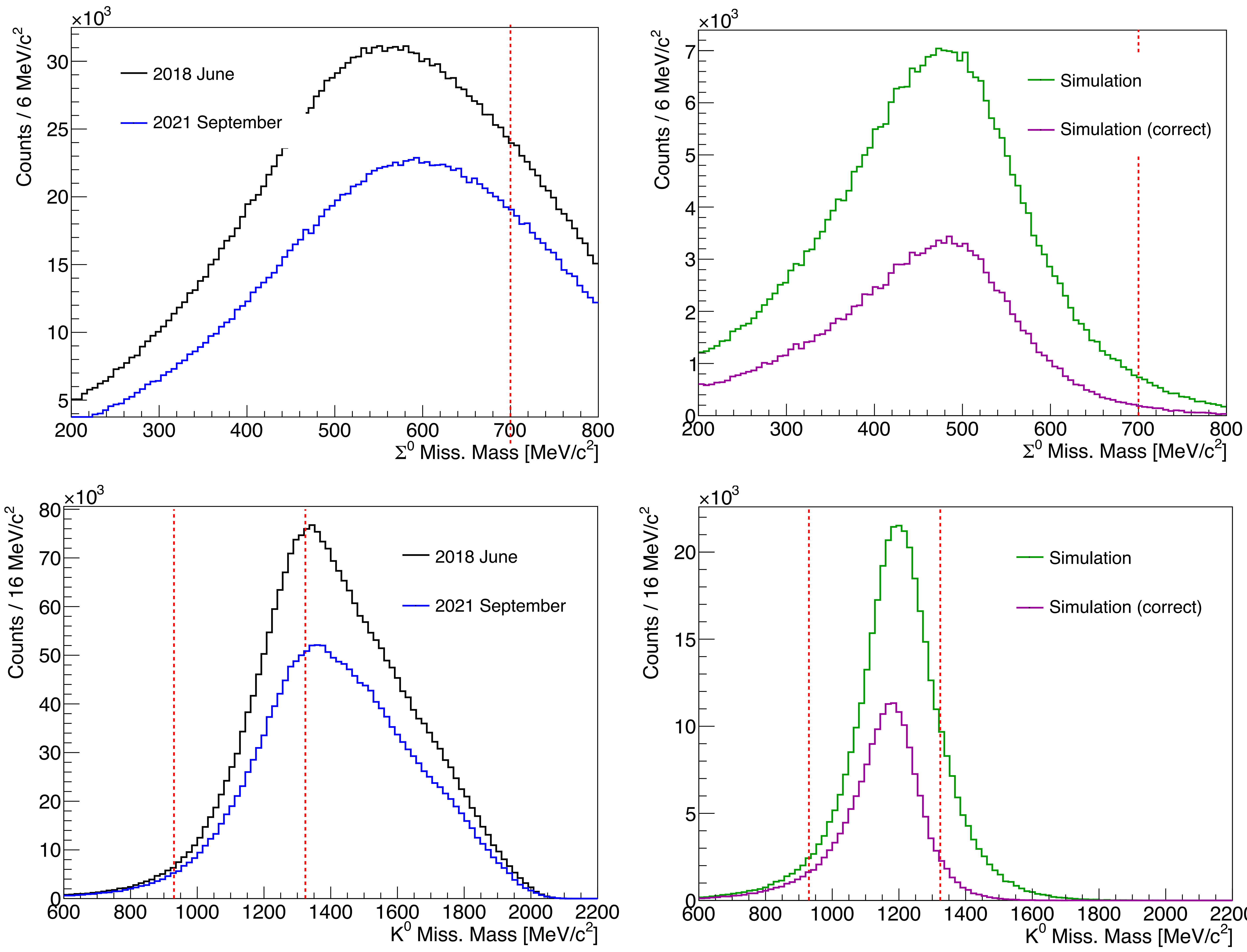
Data

Simulation

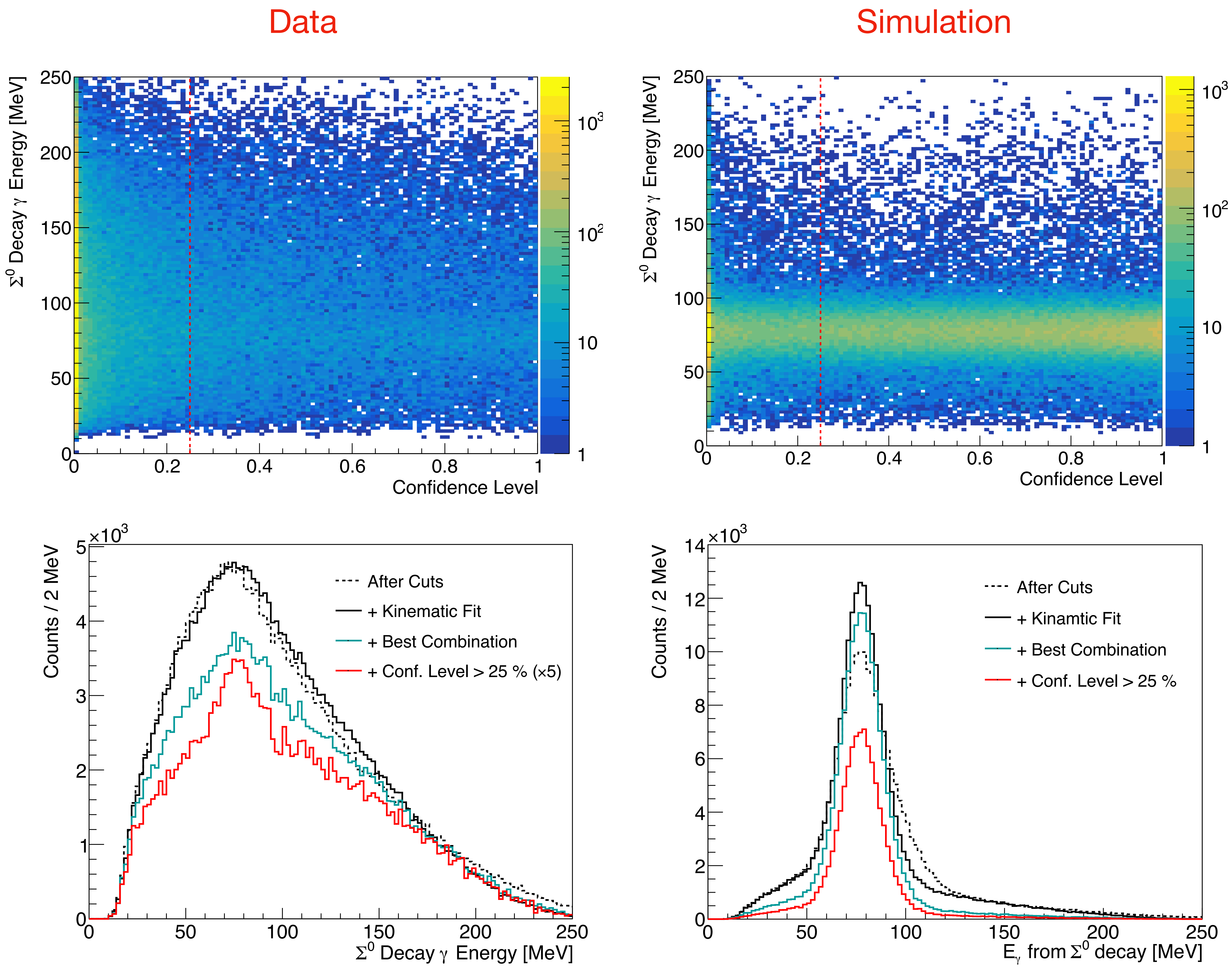


Kinematic fit

Constraints:

- Momentum conservation
- Energy conservation
- Mass of both π^0
- Mass of K^0
- Mass of Λ

Discard events with confidence level < 25%



Kinematic fit

Constraints:

- Momentum conservation
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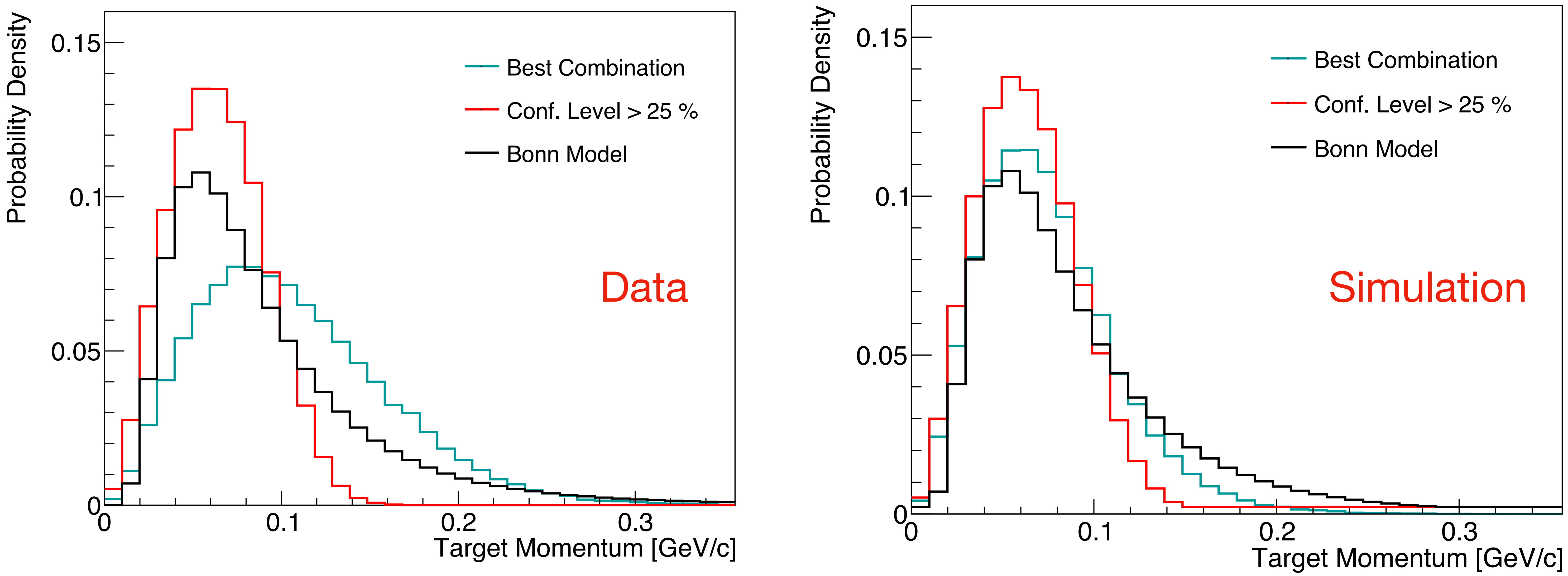
- Mass of Λ

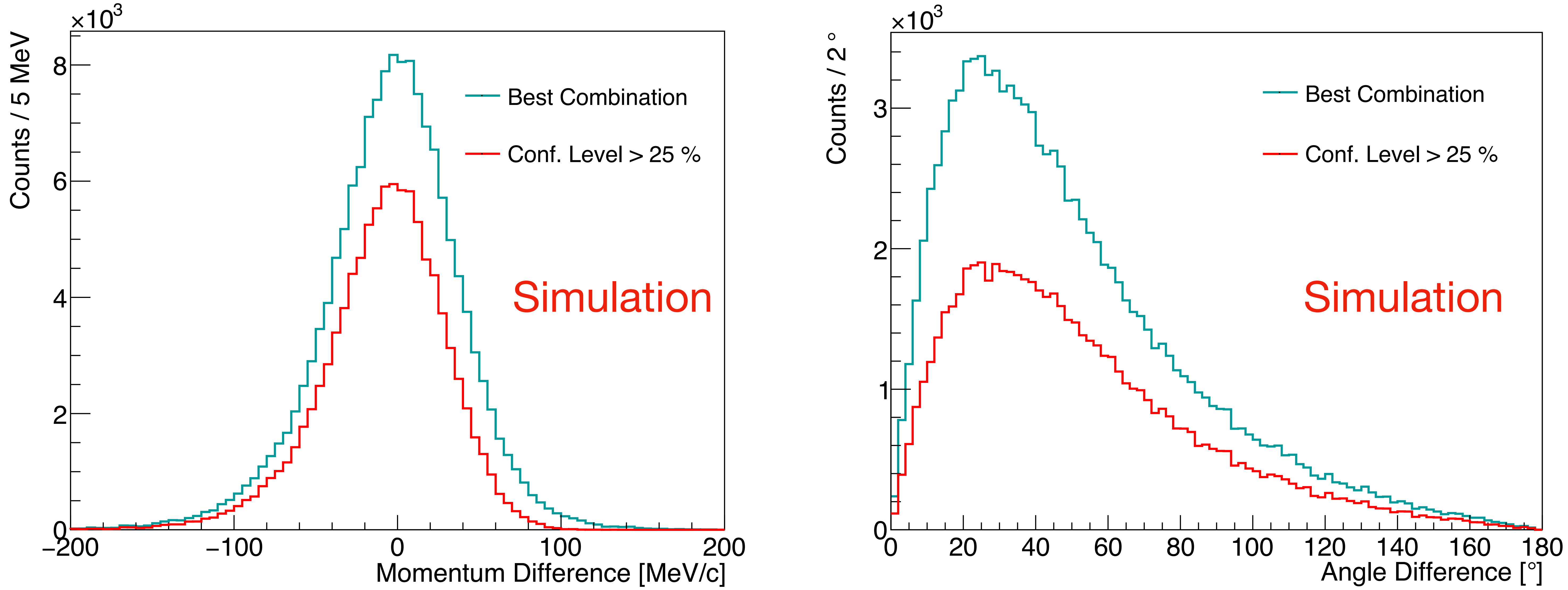
Discard events with confidence level < 25%

Model: R. Machleidt., “High-precision, charge-dependent Bonn nucleon-nucleon potential”, doi: 10.1103/PhysRevC.63.024001

Target momentum after kin. fit:



Resolution on event-by-event basis:



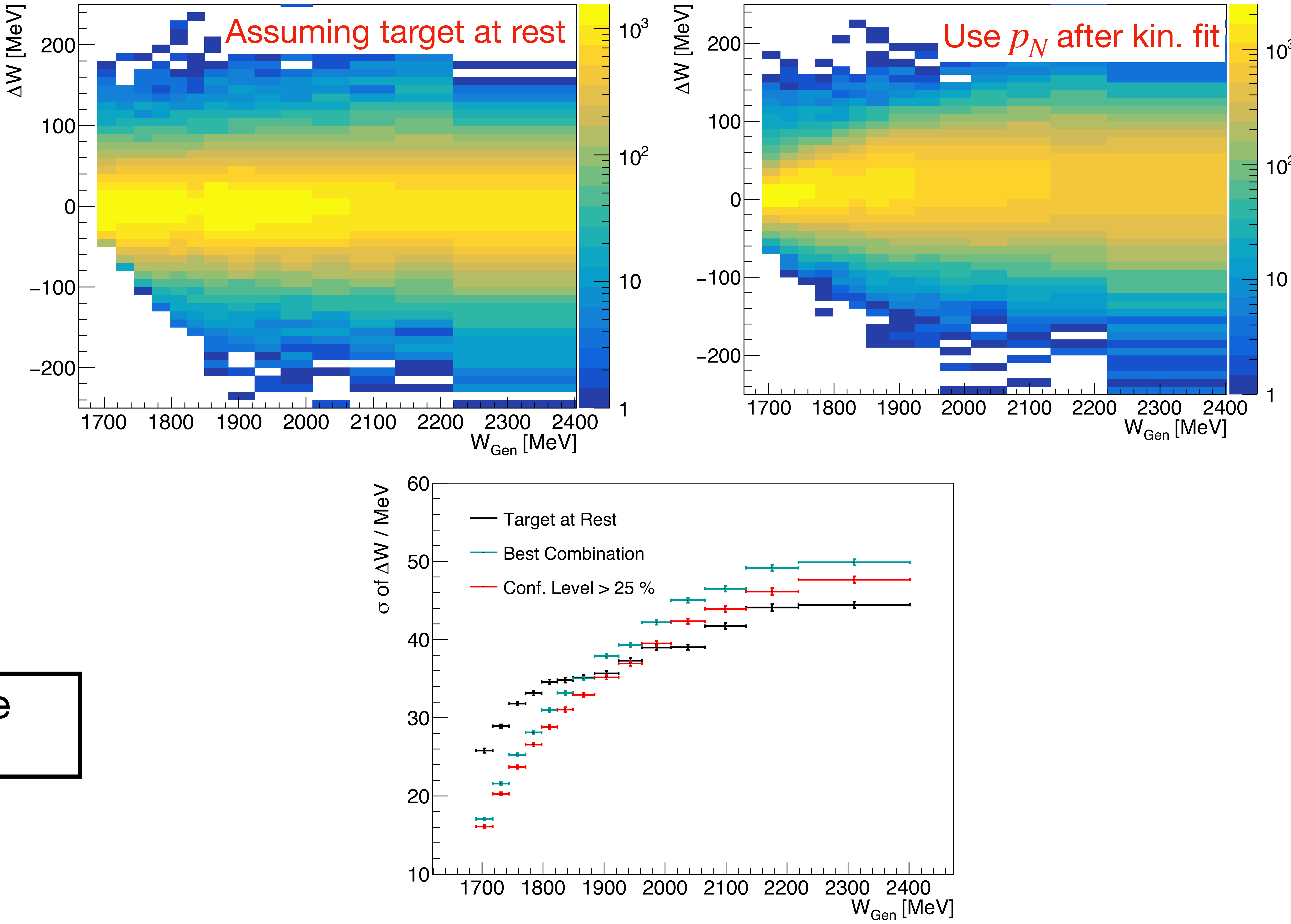
Kinematic fit

Constraints:

- Momentum conservation
- Energy conservation
- Mass of both π^0
- Mass of K^0
- Mass of Λ

Discard events with confidence level < 25%

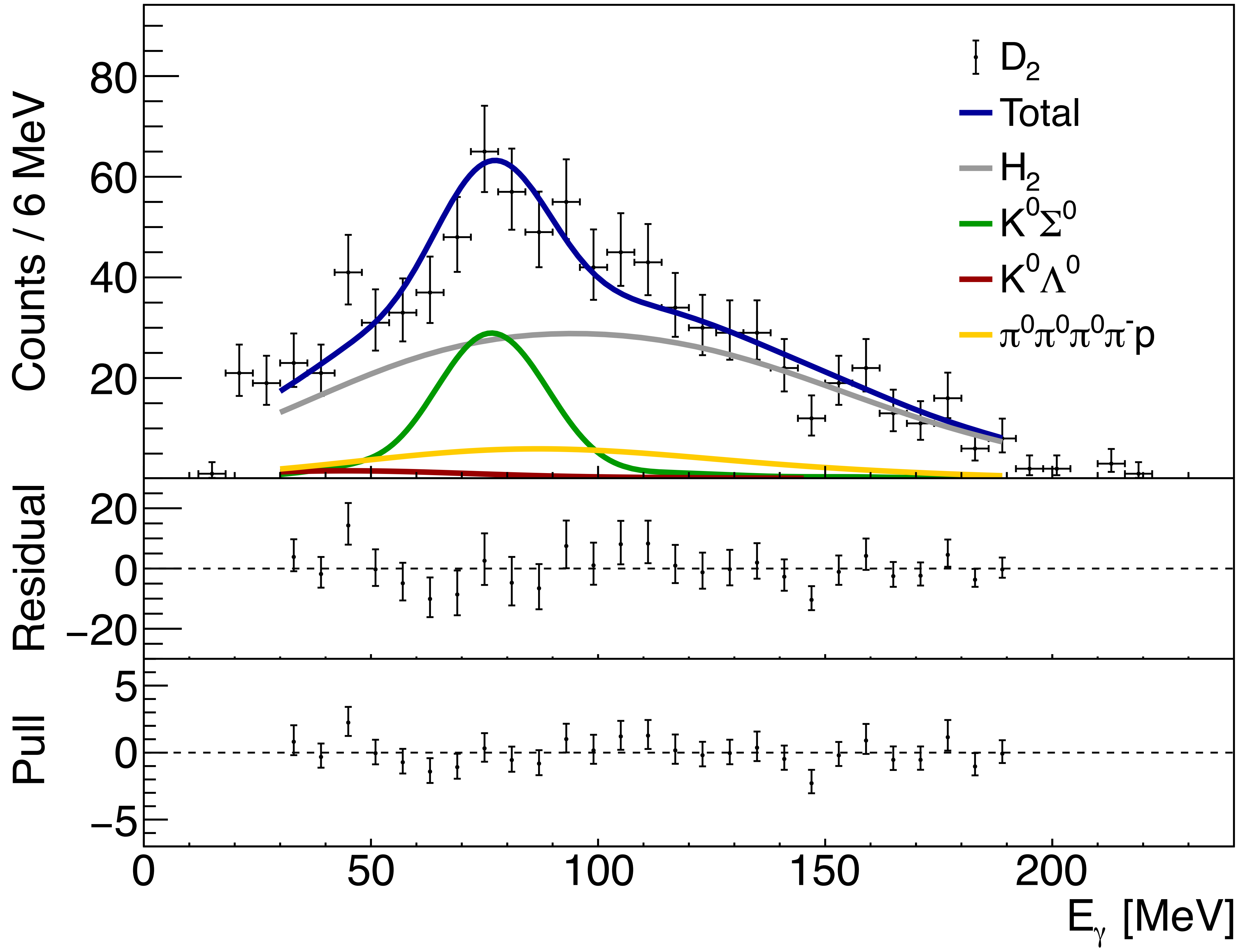
Resolution in W on event-by-event basis:



Yield extraction

Background modeling:

- Incoherent reactions on the proton
  - ➡ H dataset (+ Fermi Motion) / luminosity scaled and set as fixed component
- Incoherent reactions on the neutron
  - ➡ Phase space: $\gamma n \rightarrow K^0\Lambda, \gamma n \rightarrow \pi^0\pi^0\pi^0\pi^- p$



Fit methods:

- Kernel Density Estimates (KDE)
- Gaussian constraints on normalized background yield across neighboring bins

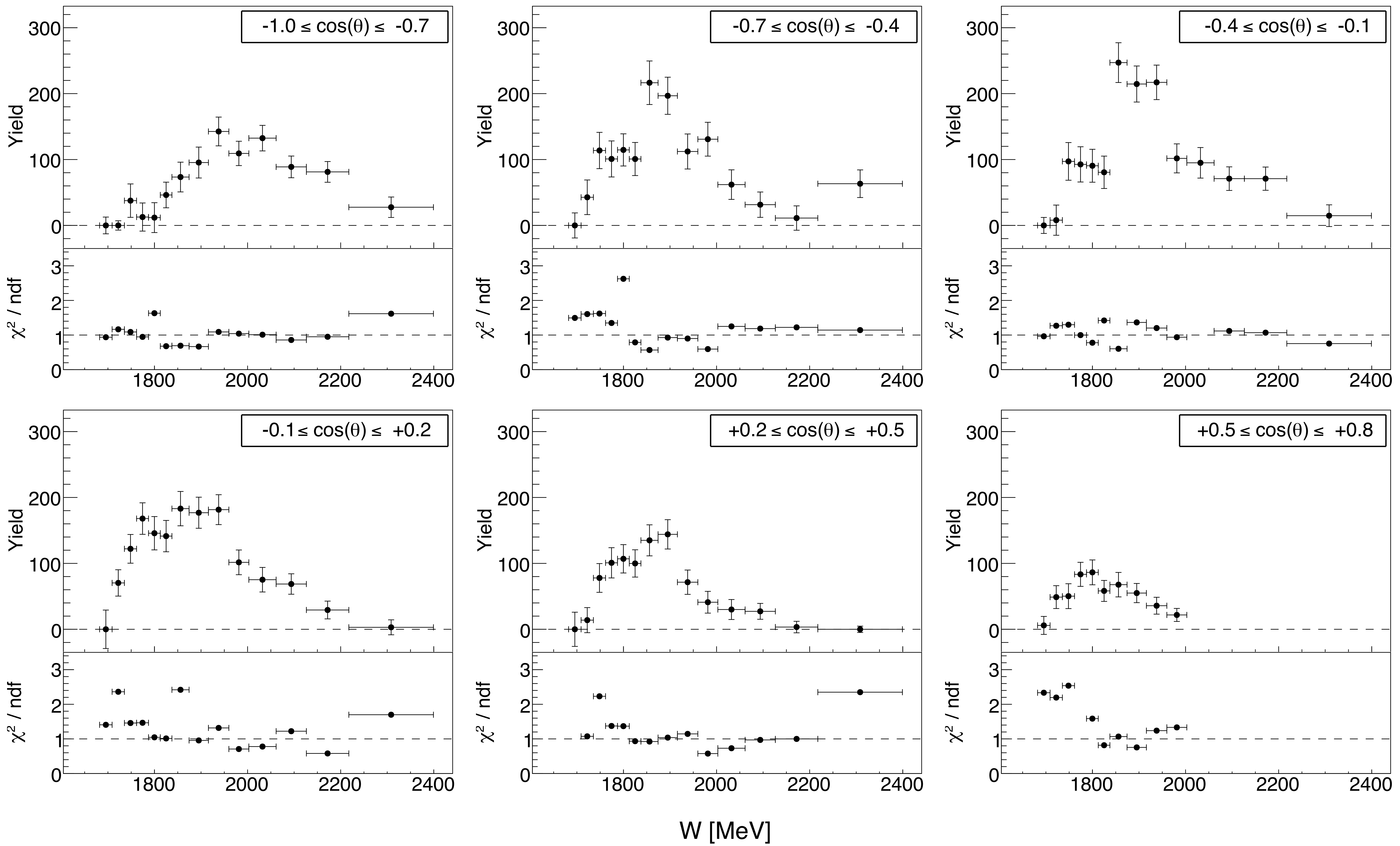
Yield extraction

Binning:

- 6 bins in $\cos(\theta^K_{CM})$
- 15 bins in W

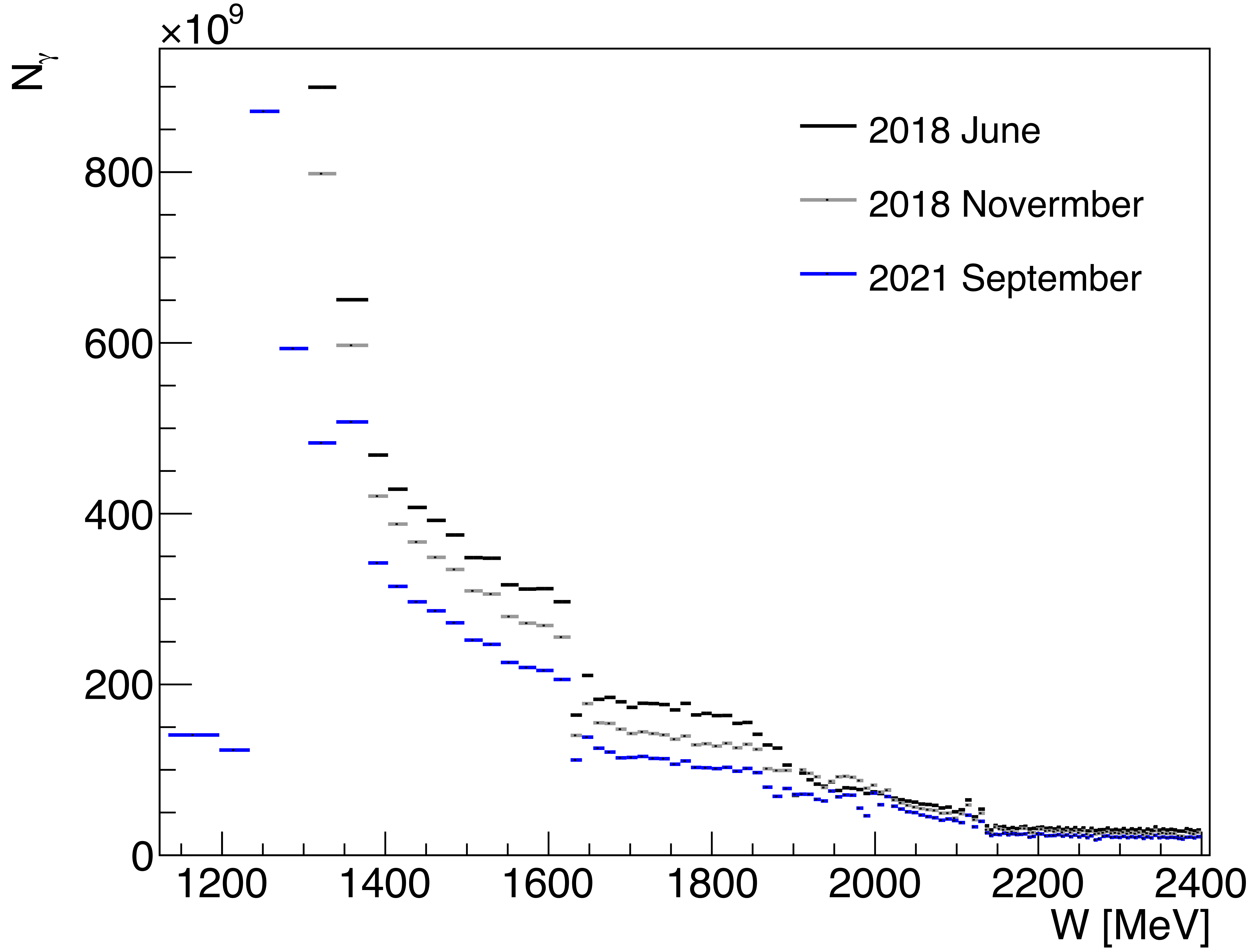
Fit quality:

- χ^2 values close to 1

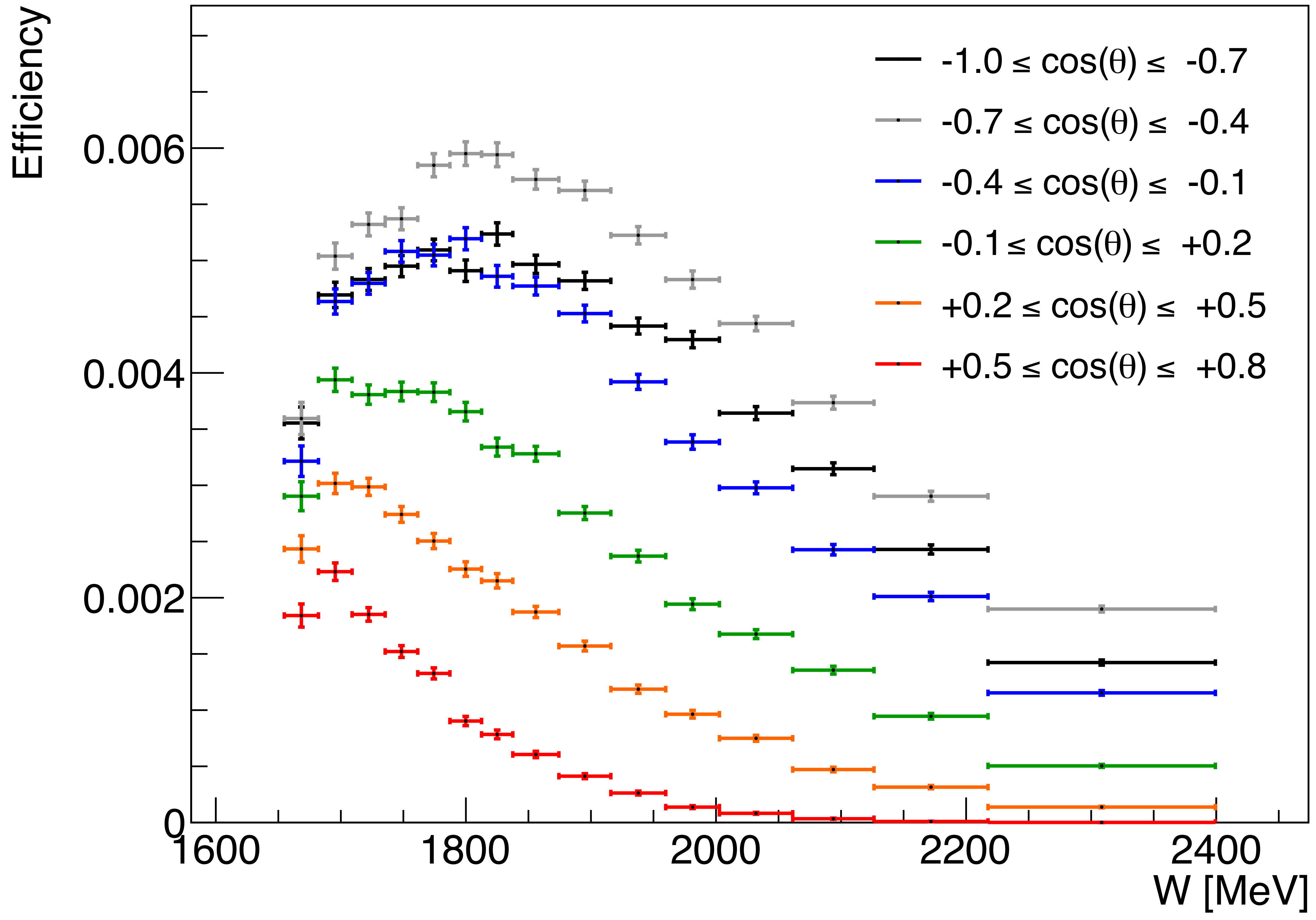


Flux and reconstruction efficiency

Flux:

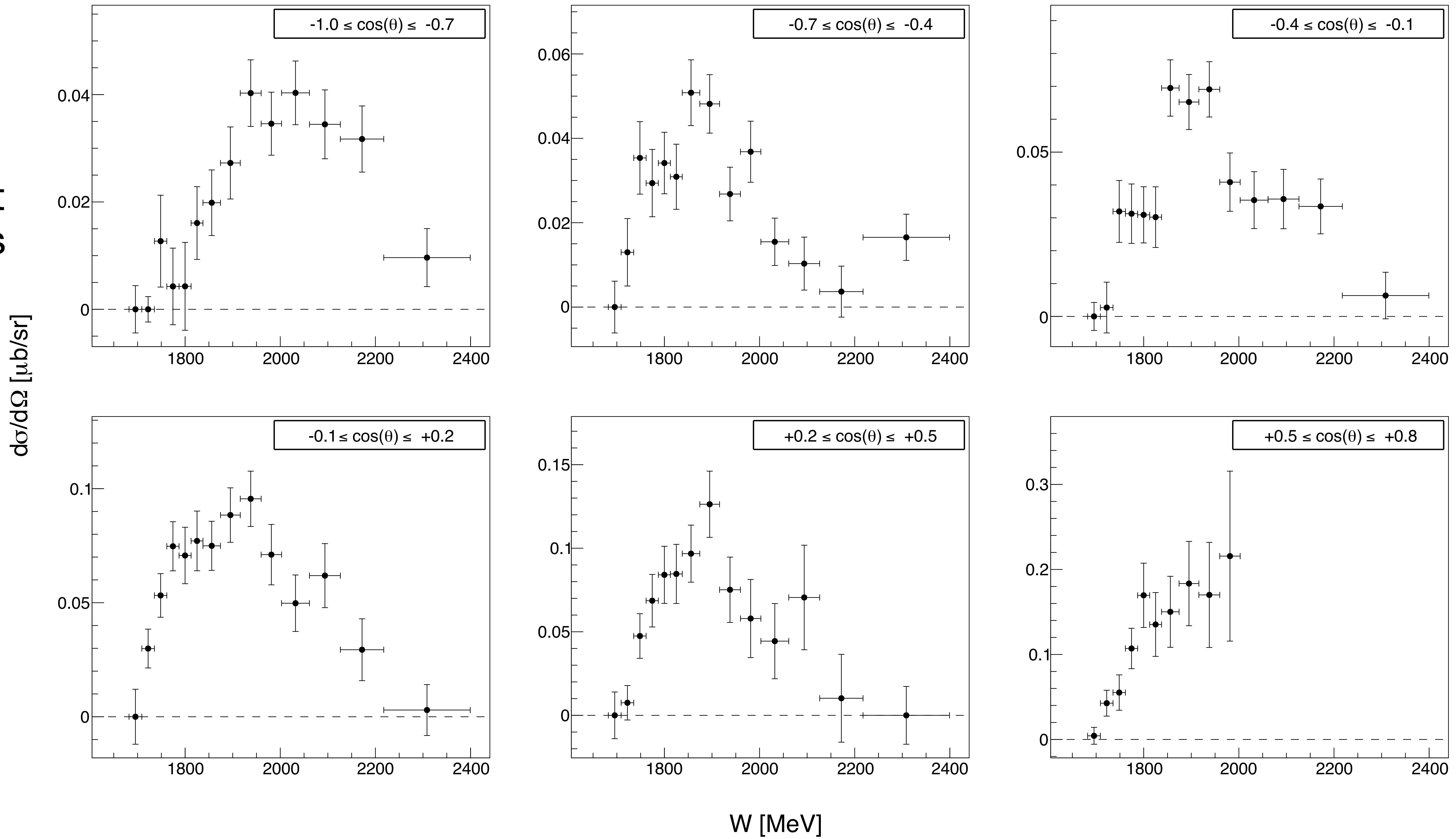


Reconstruction efficiency:



Differential cross section (DCS)

- Good statistical precision
- Strengh increases at more forward angles
- Structure at the predicted region seems to persist

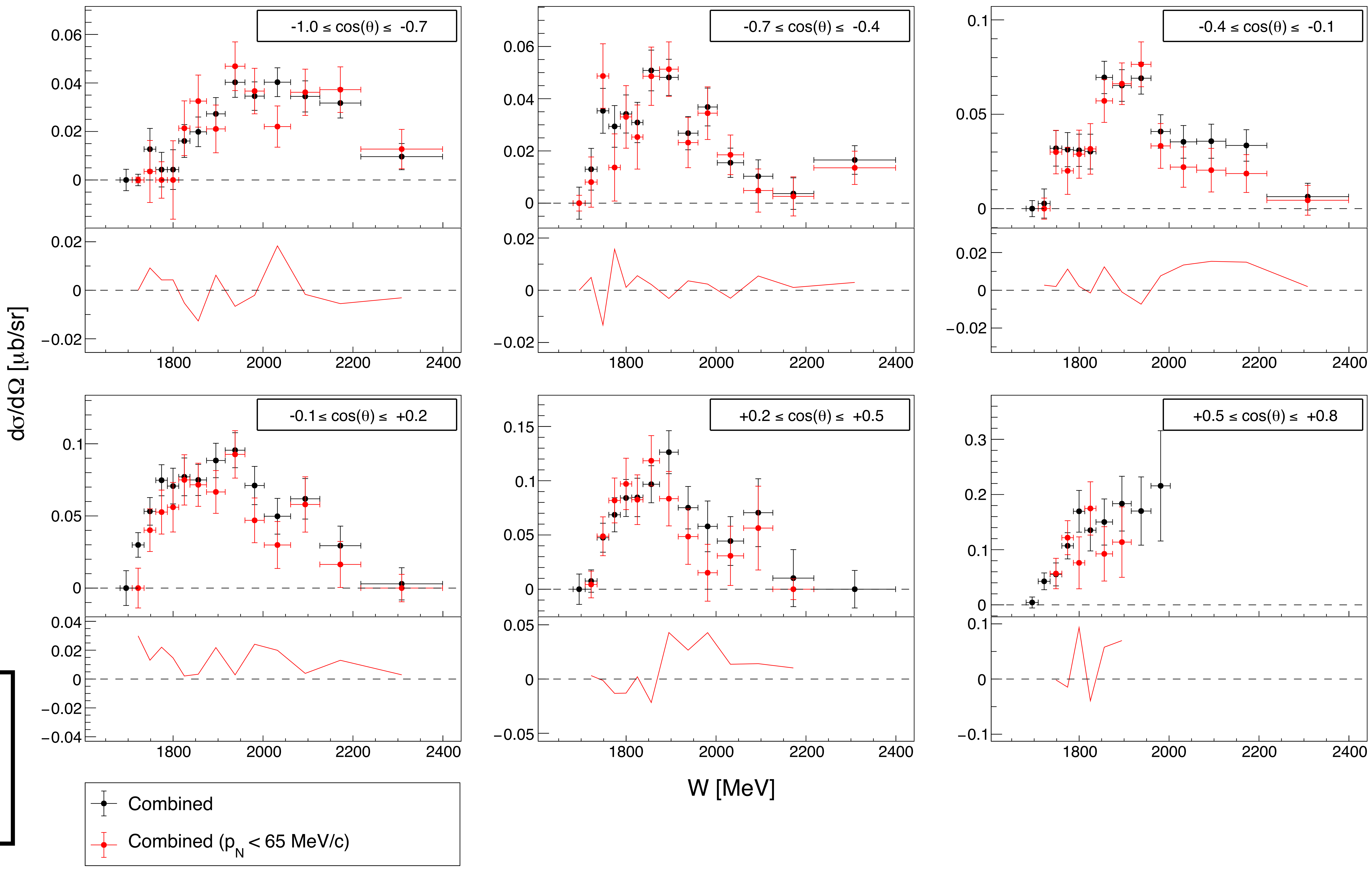


DCS: Low target momentum

- Approach quasi free production by selecting $p_N < 65$ Mev
- No big discrepancies, spectator approximation seems to be reliable
- Smaller CS at higher energies and more forward angles?

↓

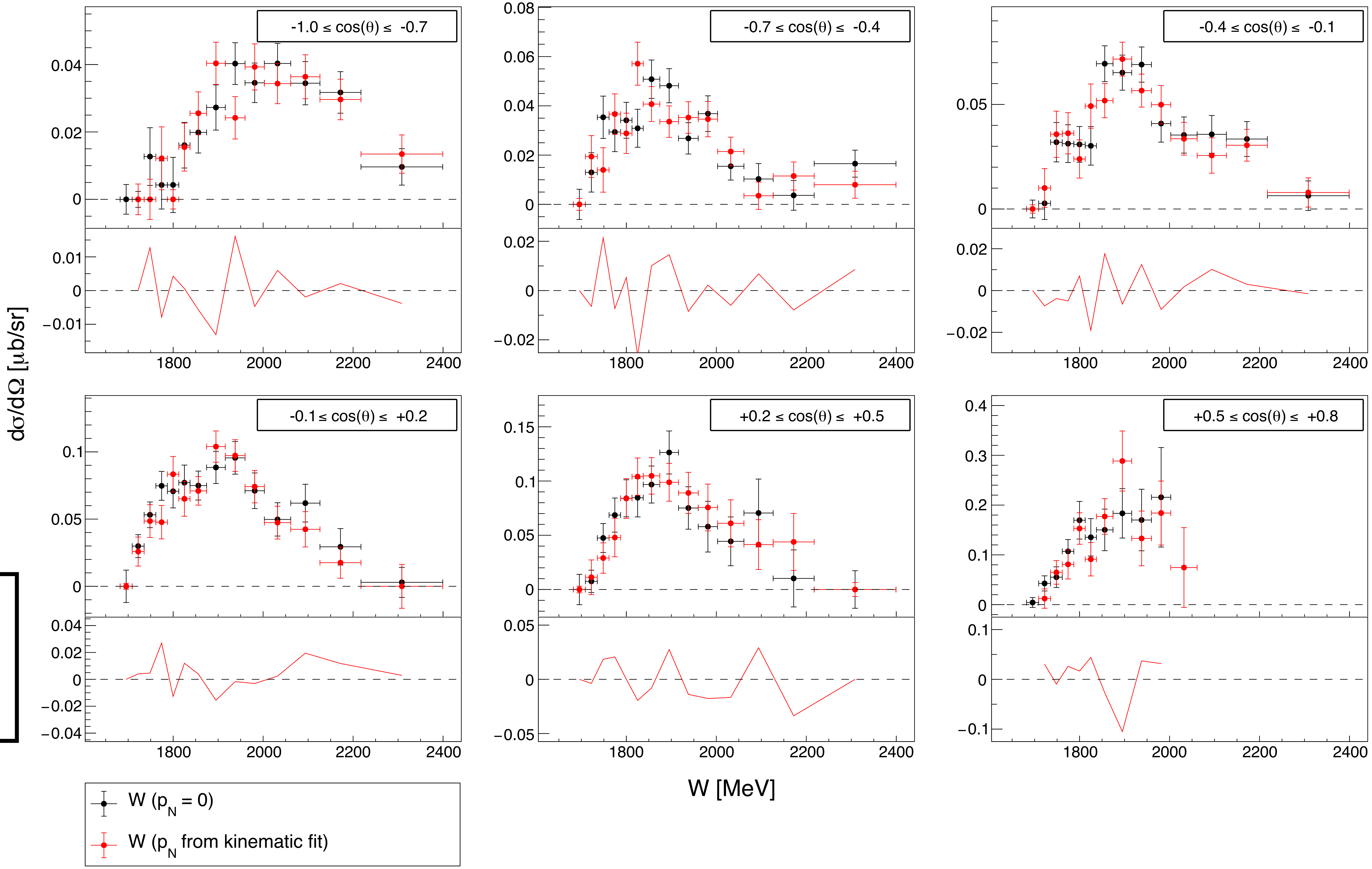
Better determination of p_N needed on event-by-event basis



DCS: Different W estimates

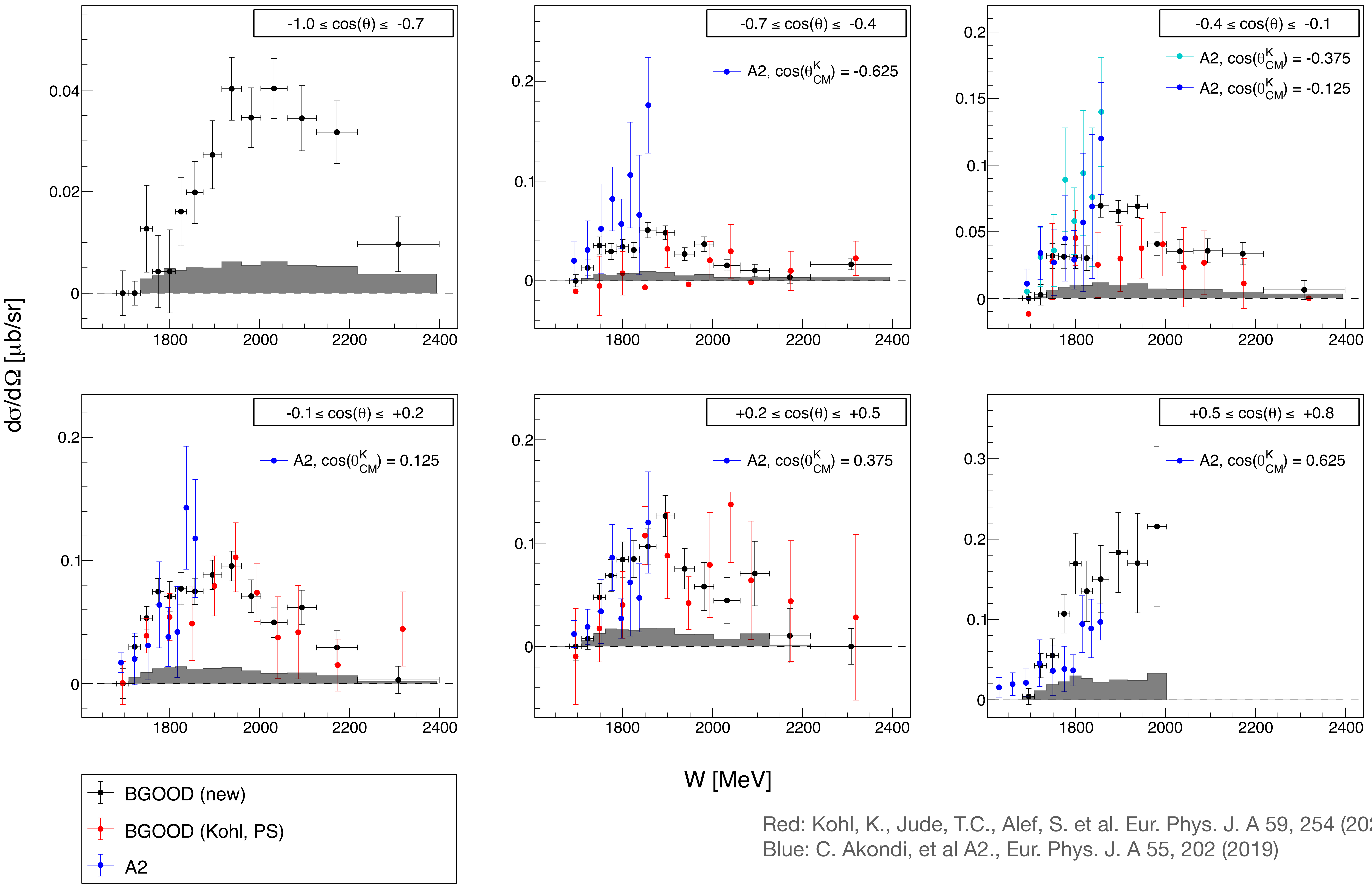
- Good agreement
- All data points consistent within statistical uncertainties
- Structure not present with different W estimate?

Better determination of p_N needed on event-by-event basis



Results: Compare to previous data

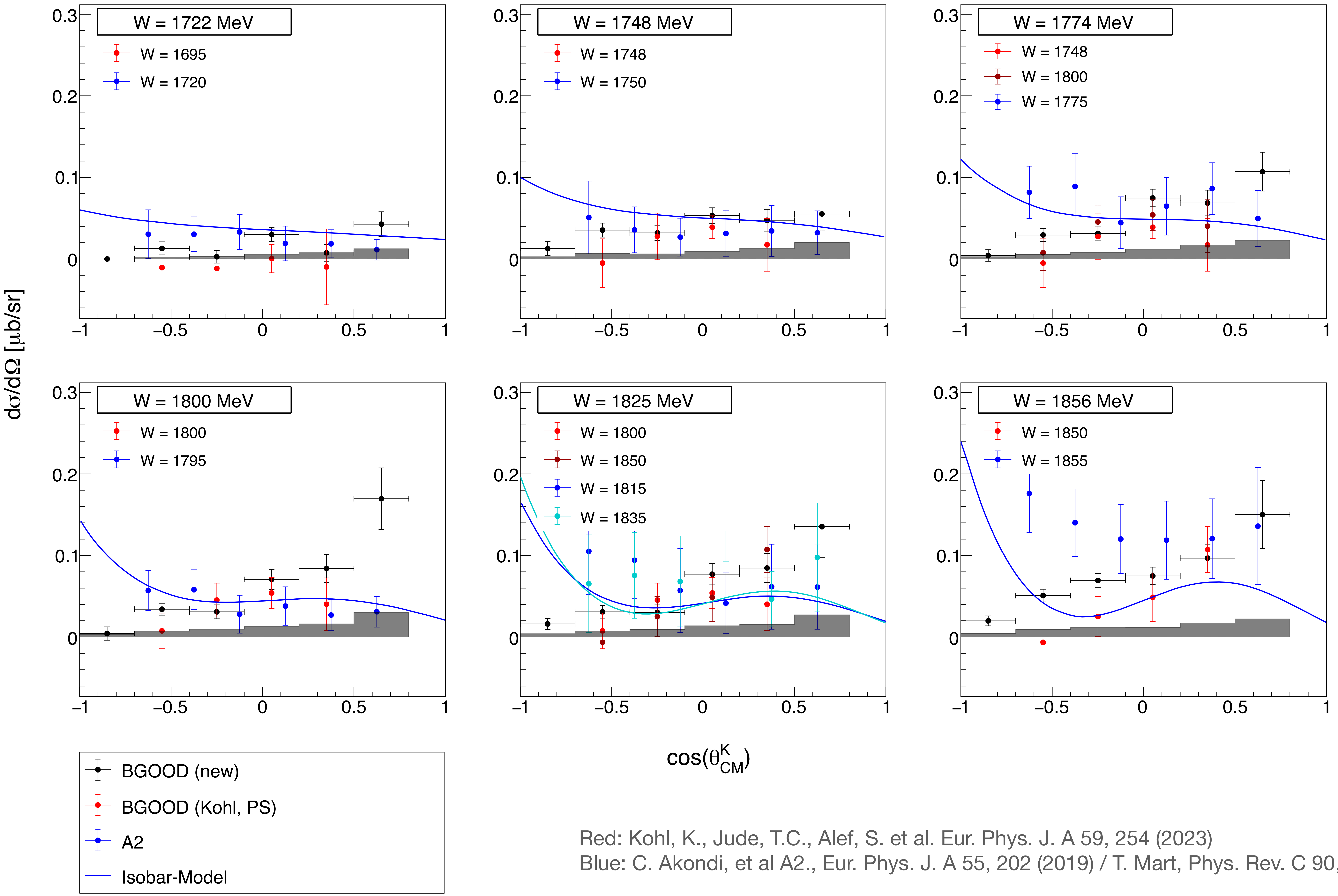
- Reasonable agreement with both datasets
- Better statistical precision



Red: Kohl, K., Jude, T.C., Alef, S. et al. Eur. Phys. J. A 59, 254 (2023)
Blue: C. Akondi, et al A2., Eur. Phys. J. A 55, 202 (2019)

Results: Compare to previous data

- Reasonable agreement with both datasets
- Better statistical precision
- Some differences at more backward angles

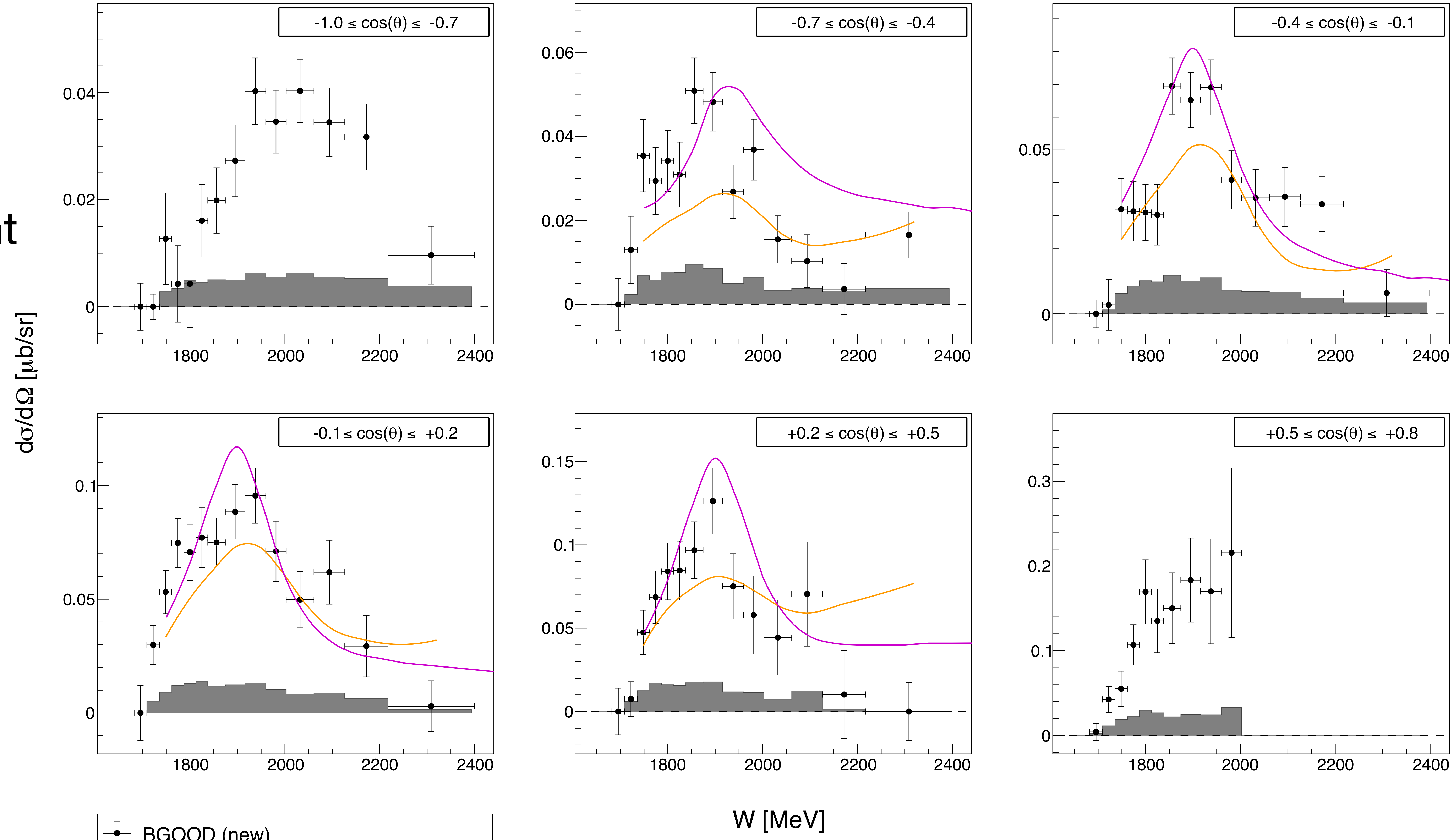


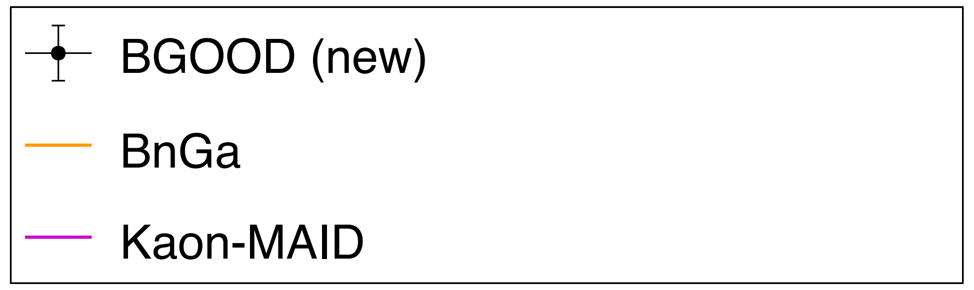
Red: Kohl, K., Jude, T.C., Alef, S. et al. Eur. Phys. J. A 59, 254 (2023)
Blue: C. Akondi, et al A2., Eur. Phys. J. A 55, 202 (2019) / T. Mart, Phys. Rev. C 90, 065202

Results: Compare to model calculations

- Good agreement with KMAID
- Reasonable agreement with BnGa

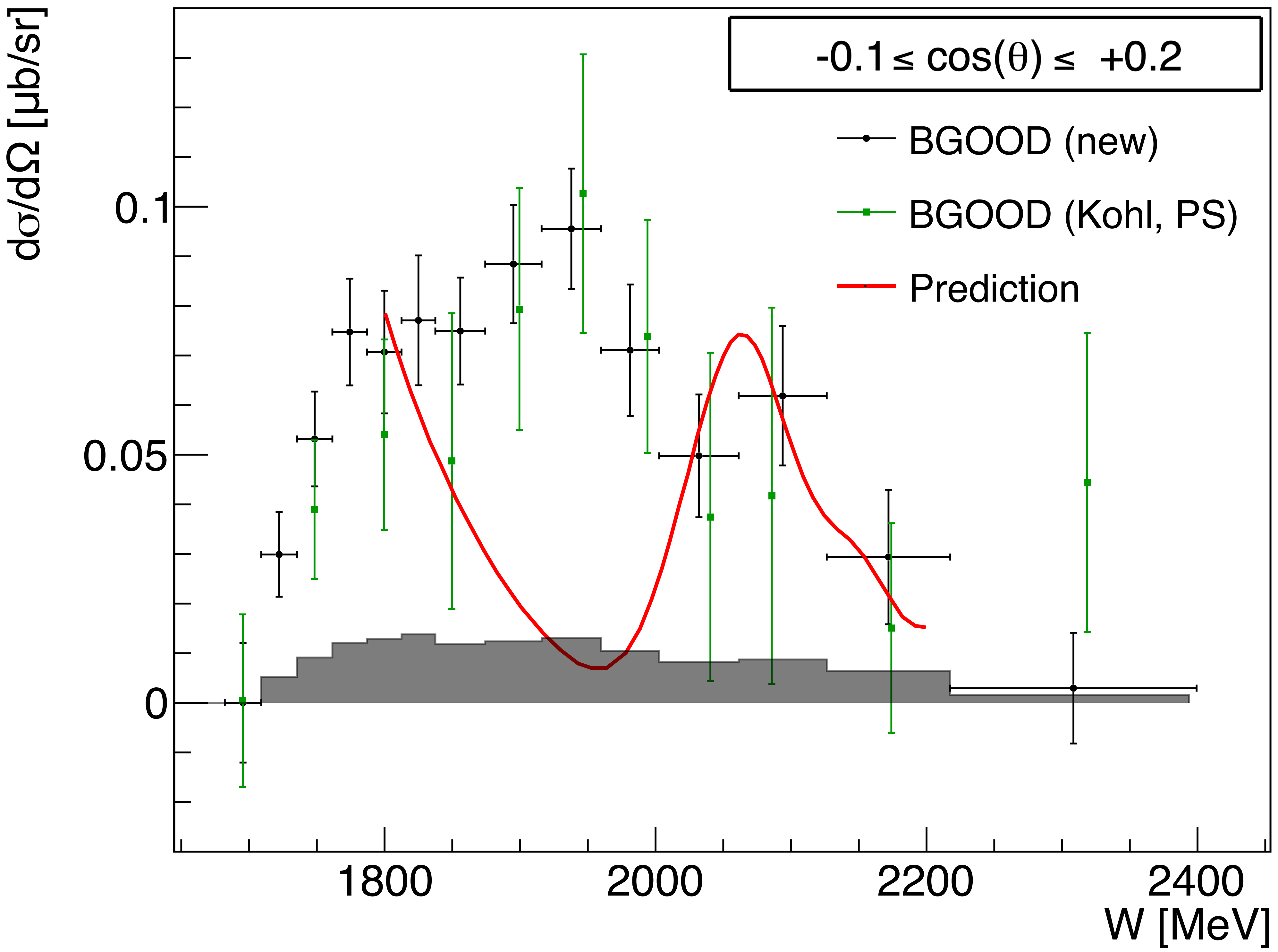
➡ Update with new data

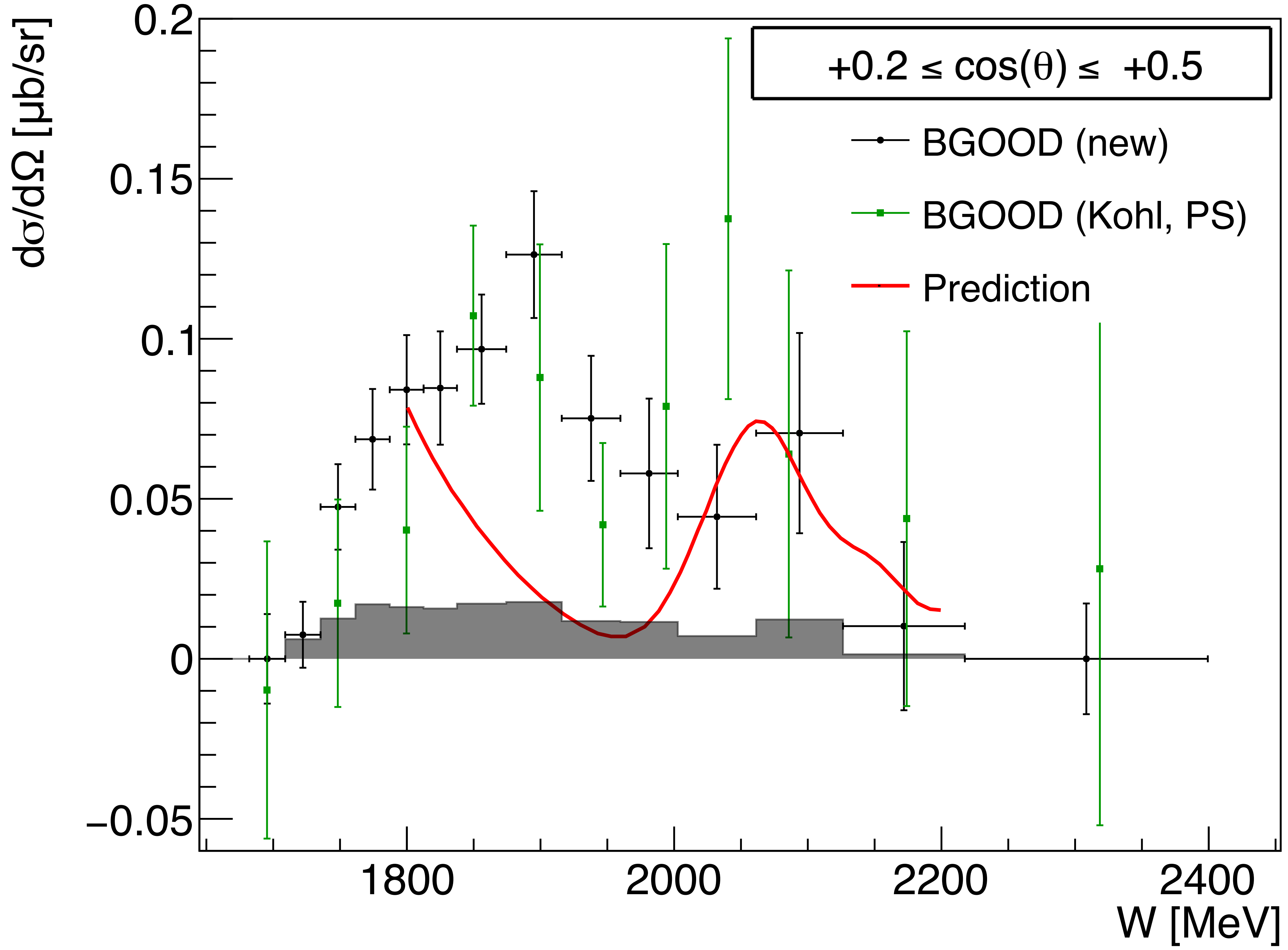




Orange: Bonn-Gatchina Partial Wave Analysis Group (url: https://pwa.hiskp.uni-bonn.de)
Magenta: Kaon-MAID (url: https://www.kernphysik.uni-mainz.de/maid/. Version: 29-03-2007)

Results





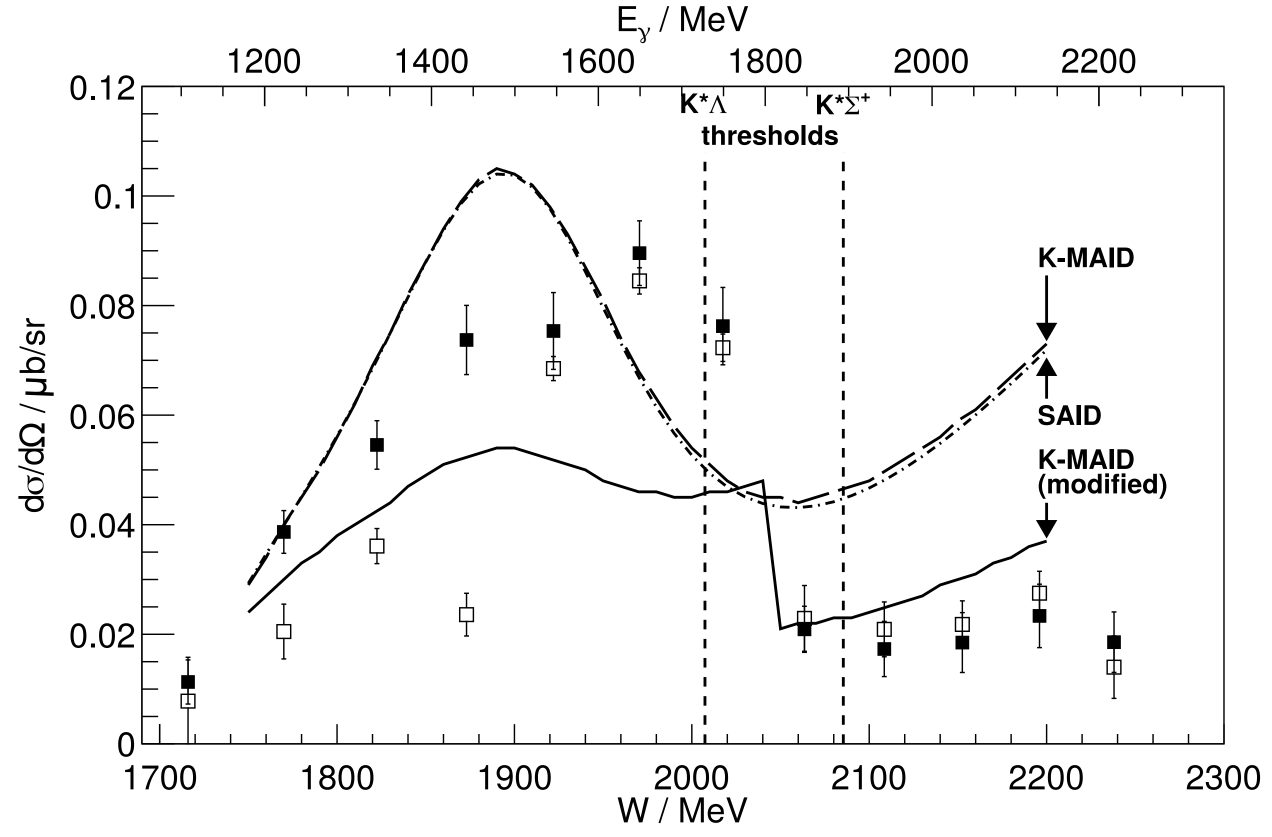
Conclusion:

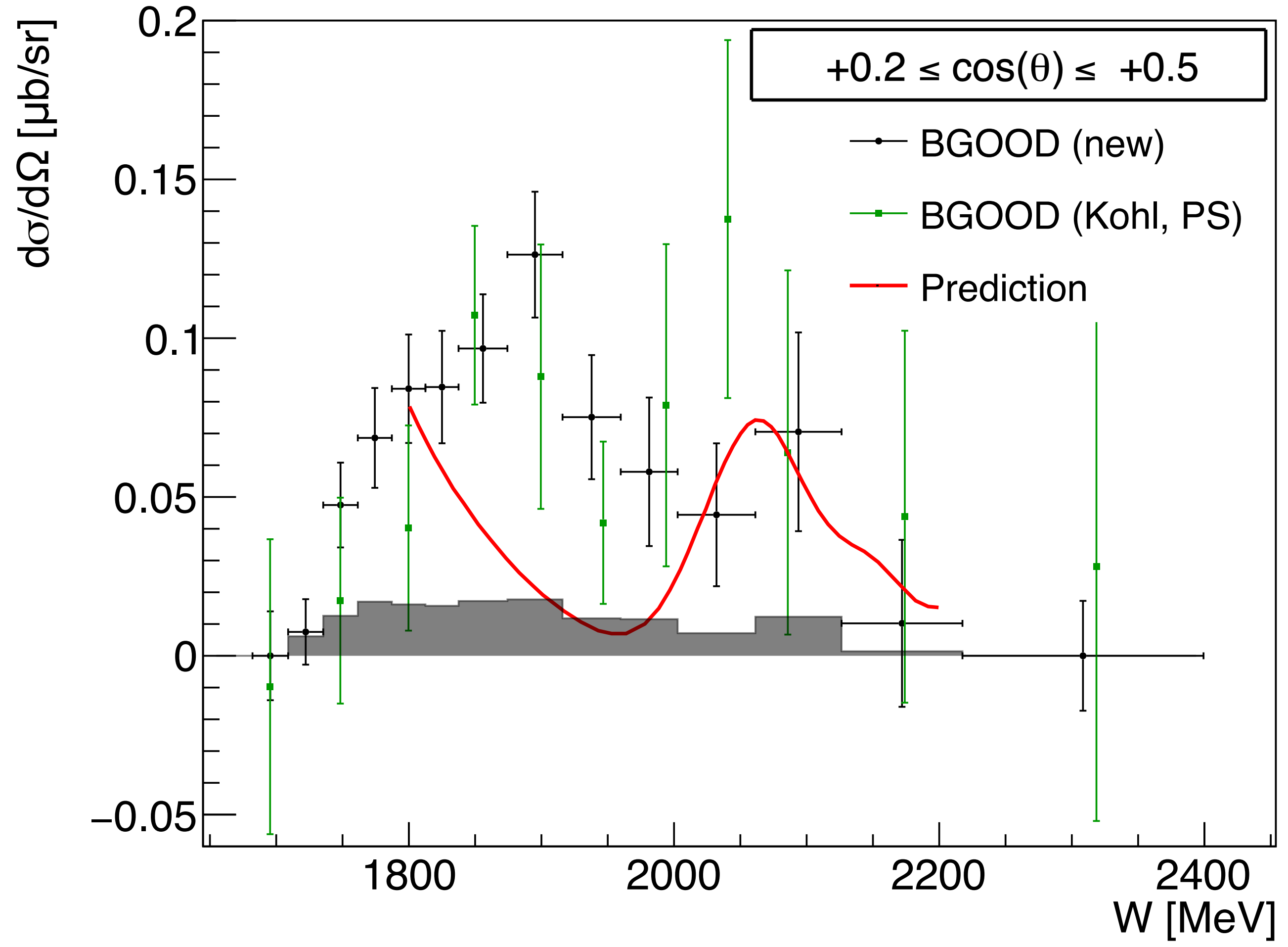
- Data shows reasonable agreement with previous measurements and models
- Improved statistical precision (2x) + extend angular range
- Structure at the predicted region seems to persist

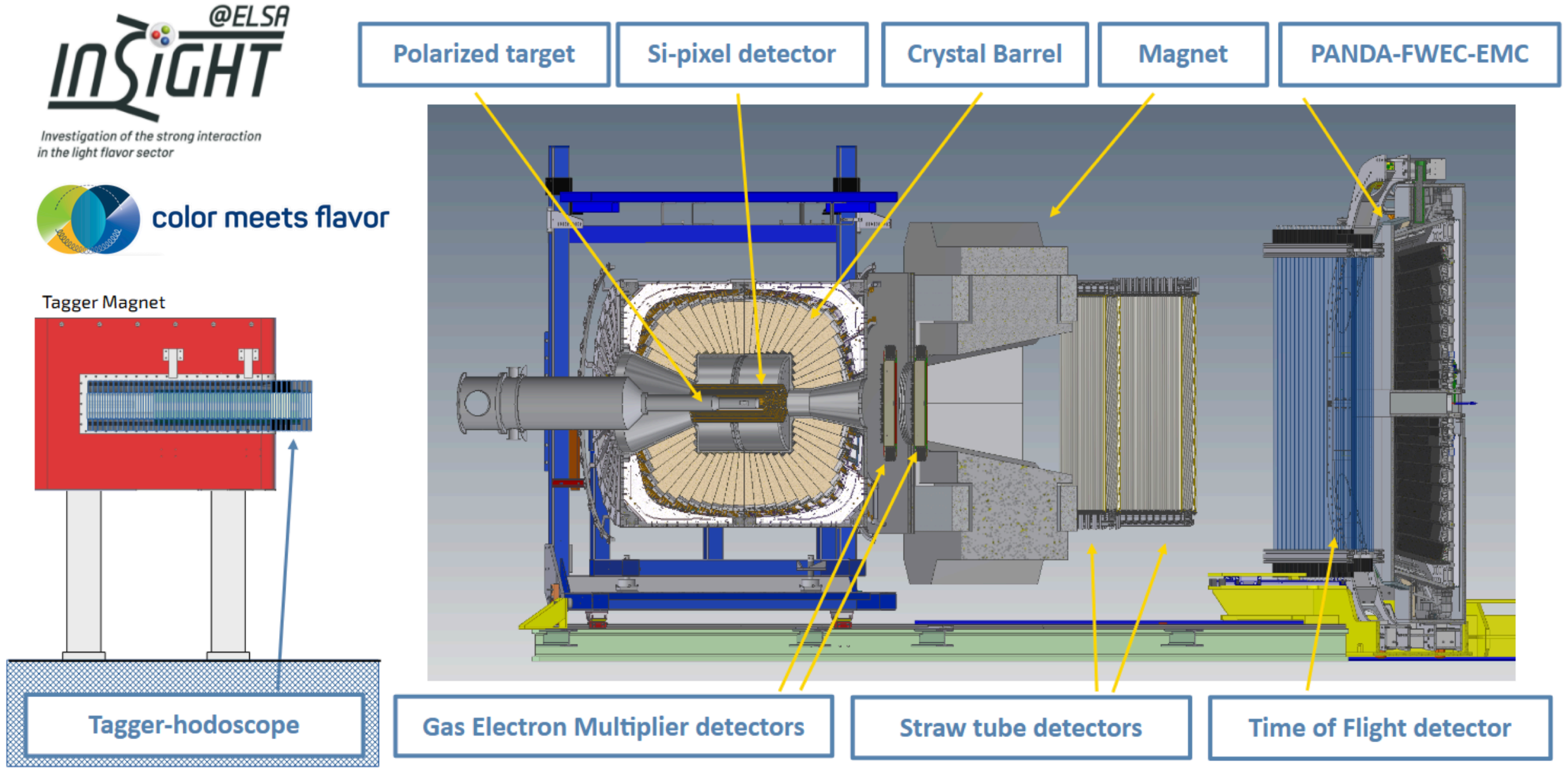
Green: Kohl, K., Jude, T.C., Alef, S. et al. Eur. Phys. J. A 59, 254 (2023)
Red: A. Ramos and E. Oset, Phys. Lett. {B 727}, (2013) 287 scaled to approx. fit the height

Summary and Outlook

- Pentaquark states observed at LHCb in charm sector
- Similar model predicts structures in $K\Sigma$ photoproduction cross section and triangle mechanism for $\Lambda(1405)$
- $K^0\Sigma^0$ differential cross section consistent with prediction (more statistics needed, especially in most forward region)







https://agthoma.hiskp.uni-bonn.de/images/Poster_SessionVorstellungAG2025_Seite1_v1.pdf

- Finetune fitting procedures, include other deuterium datasets
- Non-gaussian errors in kinematic fit
- INSIGHT Experiment (EMC in forward direction)

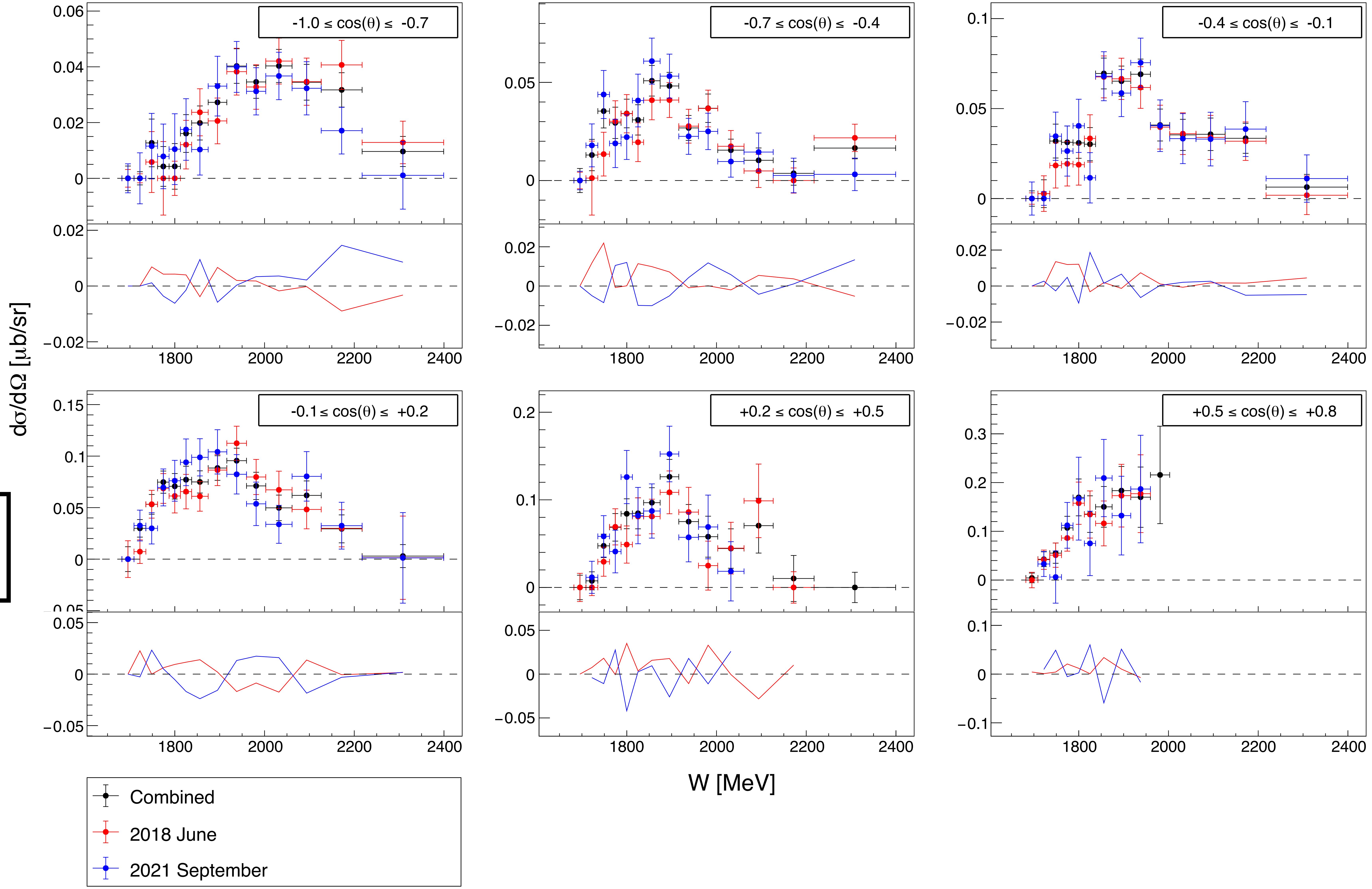
Thank you for your attention!

Backup

DCS: Beamtime comparison

- Good agreement
- Data points consistent within statistical uncertainties
- Fluctuations seems to be of statistical nature

➡ Combining datasets is ok!



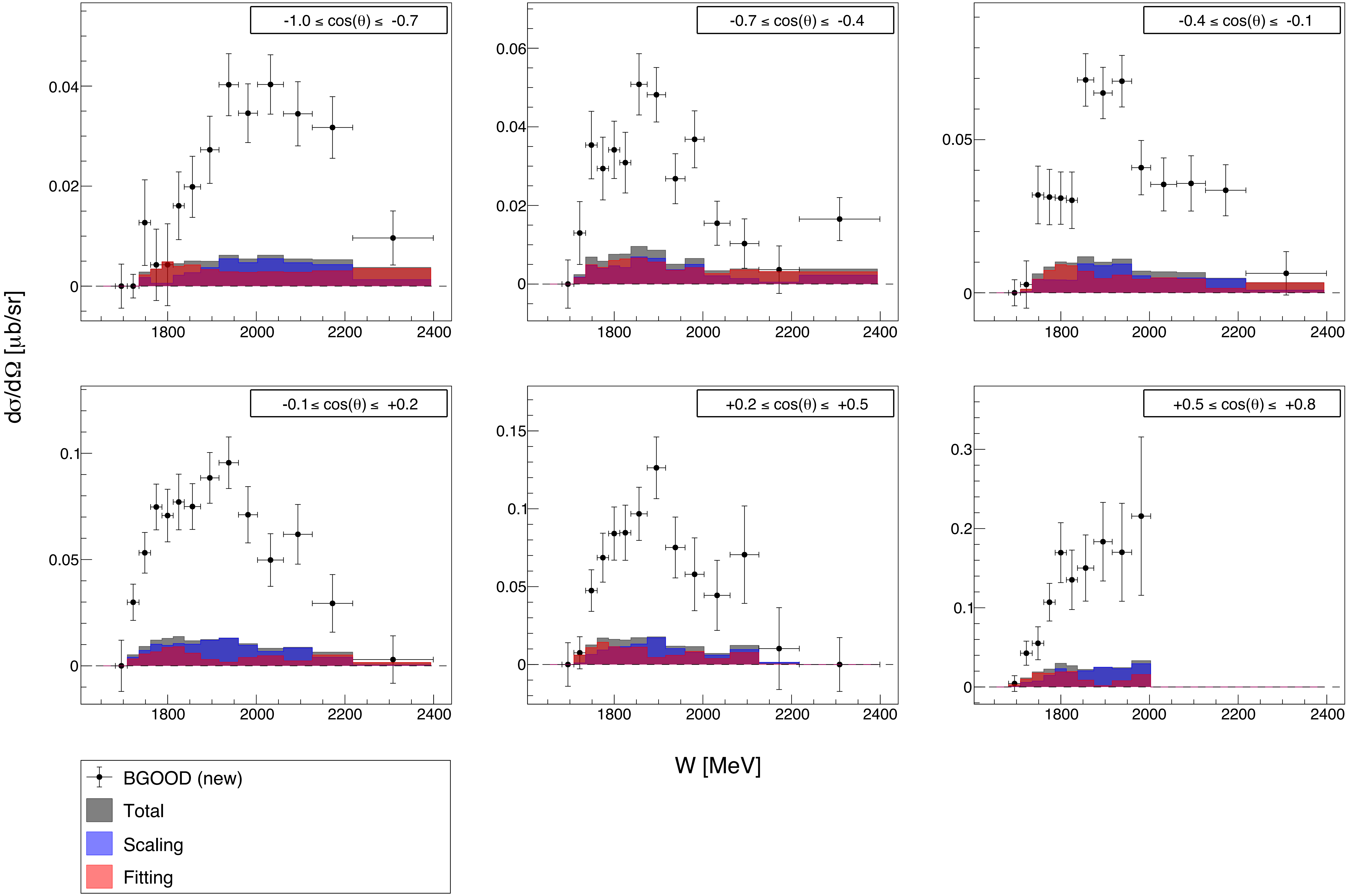
DCS: Systematic errors

Scaling Errors:

- Hardware
- Analysis

Fitting Errors:

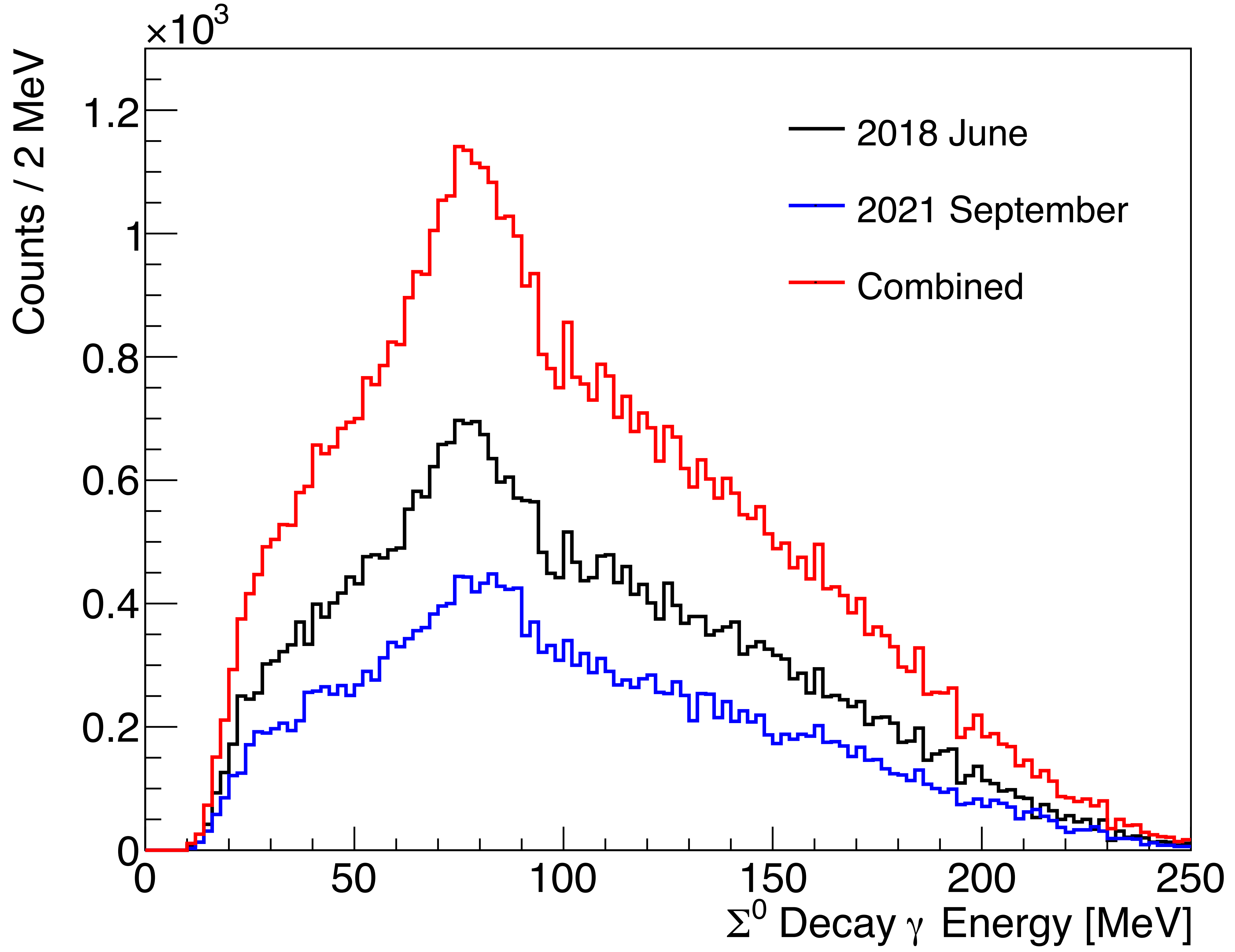
- Fits for yield extraction



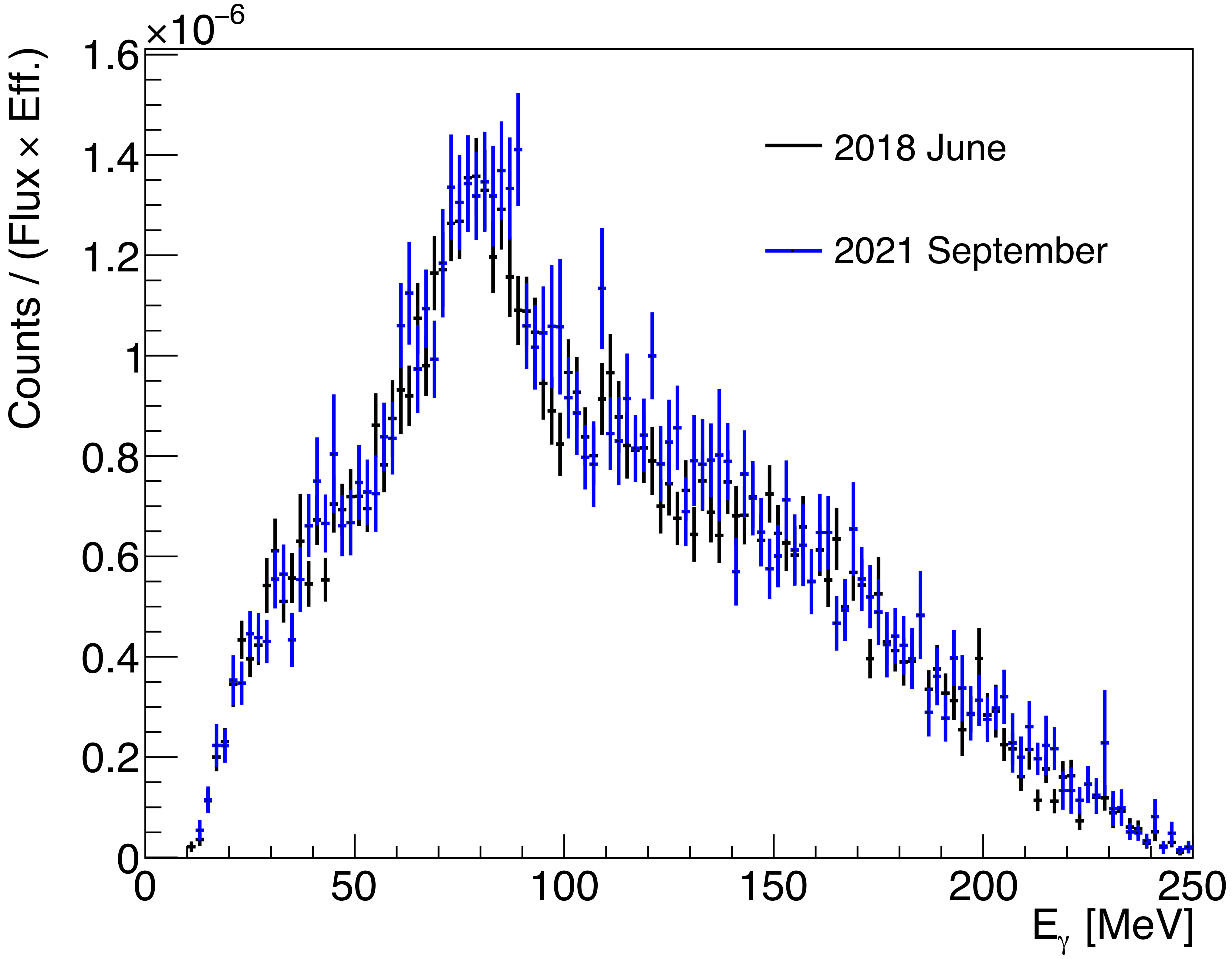
Beamtime comparison

Check if beamtimes are consistent:

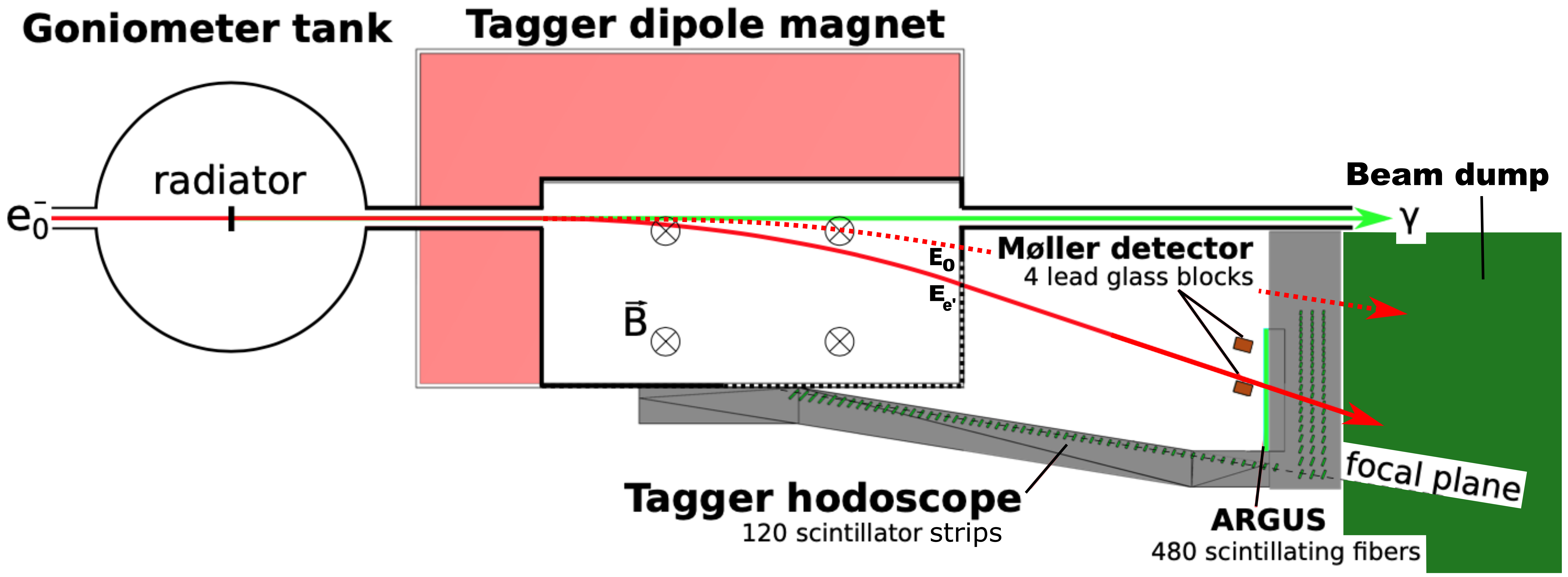
Combined Results



Individual datasets normalized by flux and efficiency



The BGOOD Experiment



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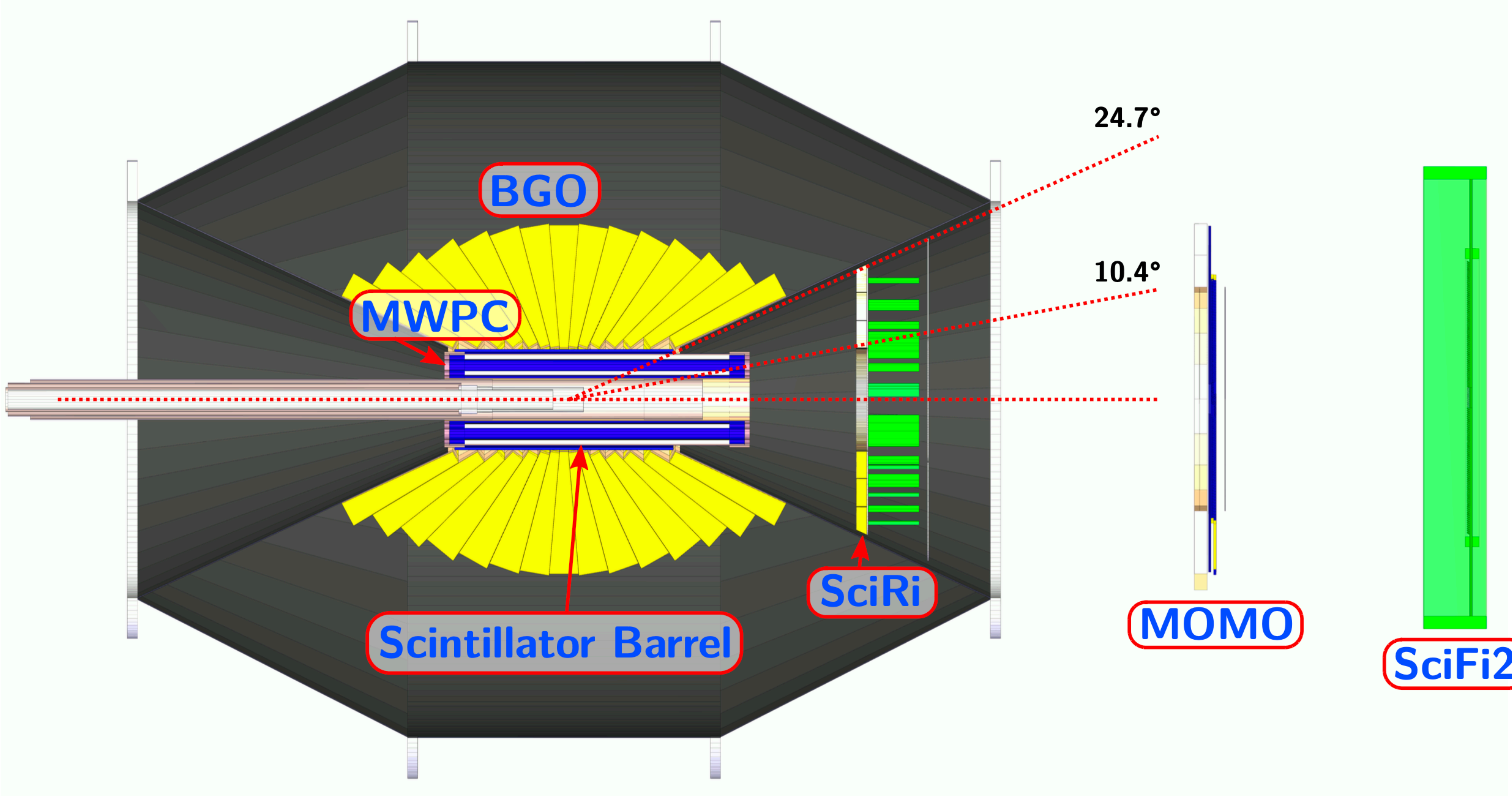

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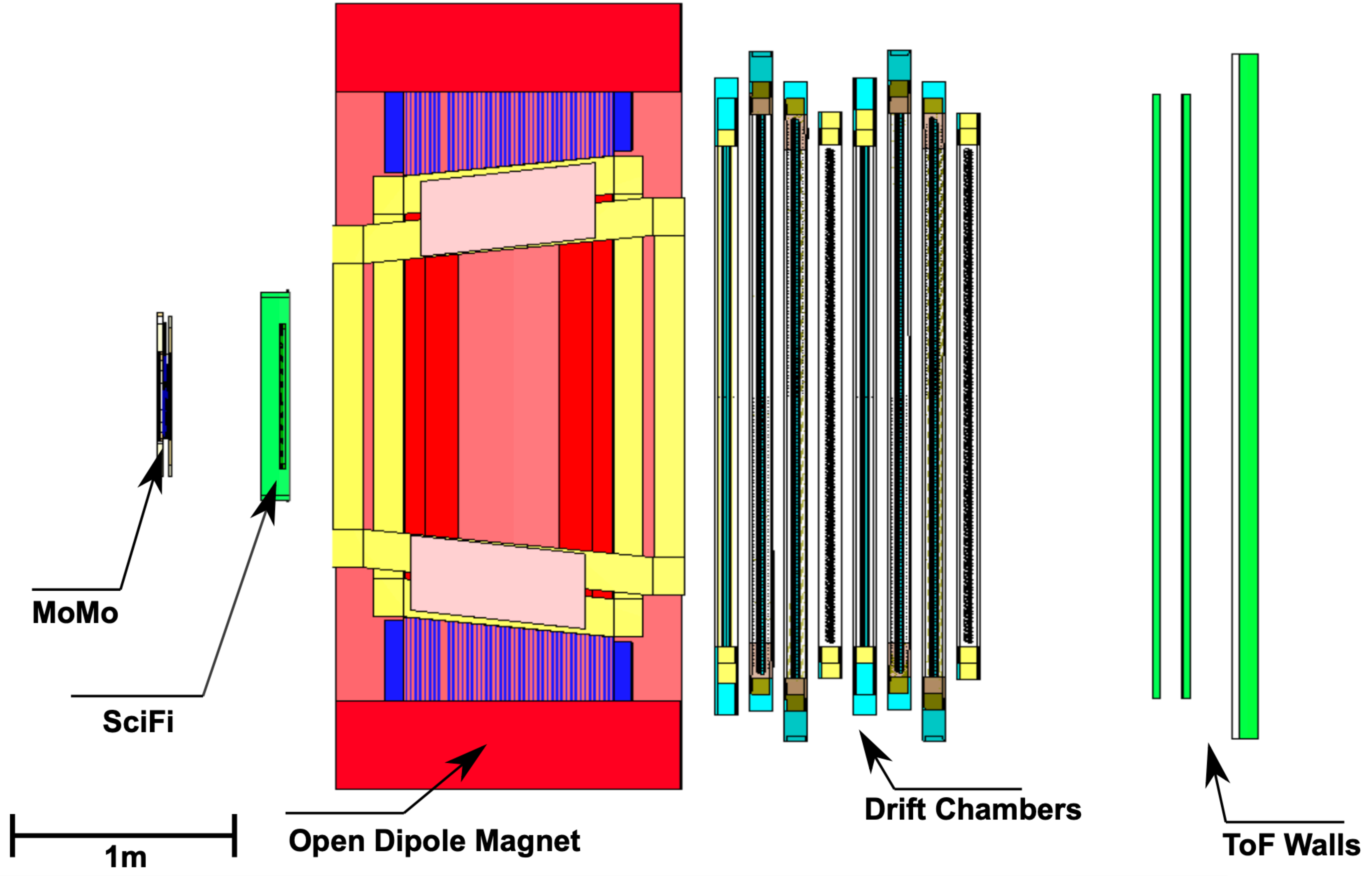
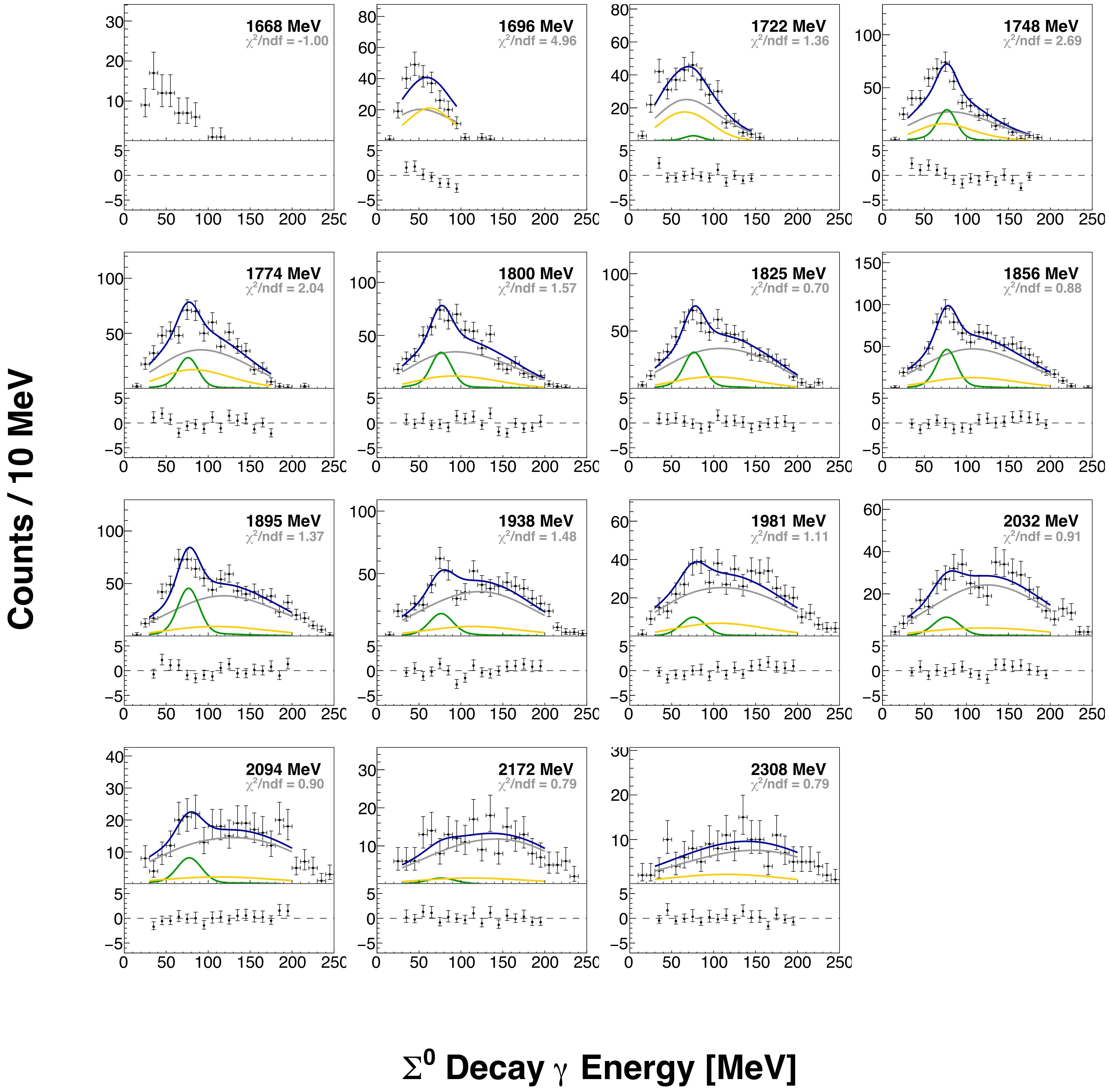


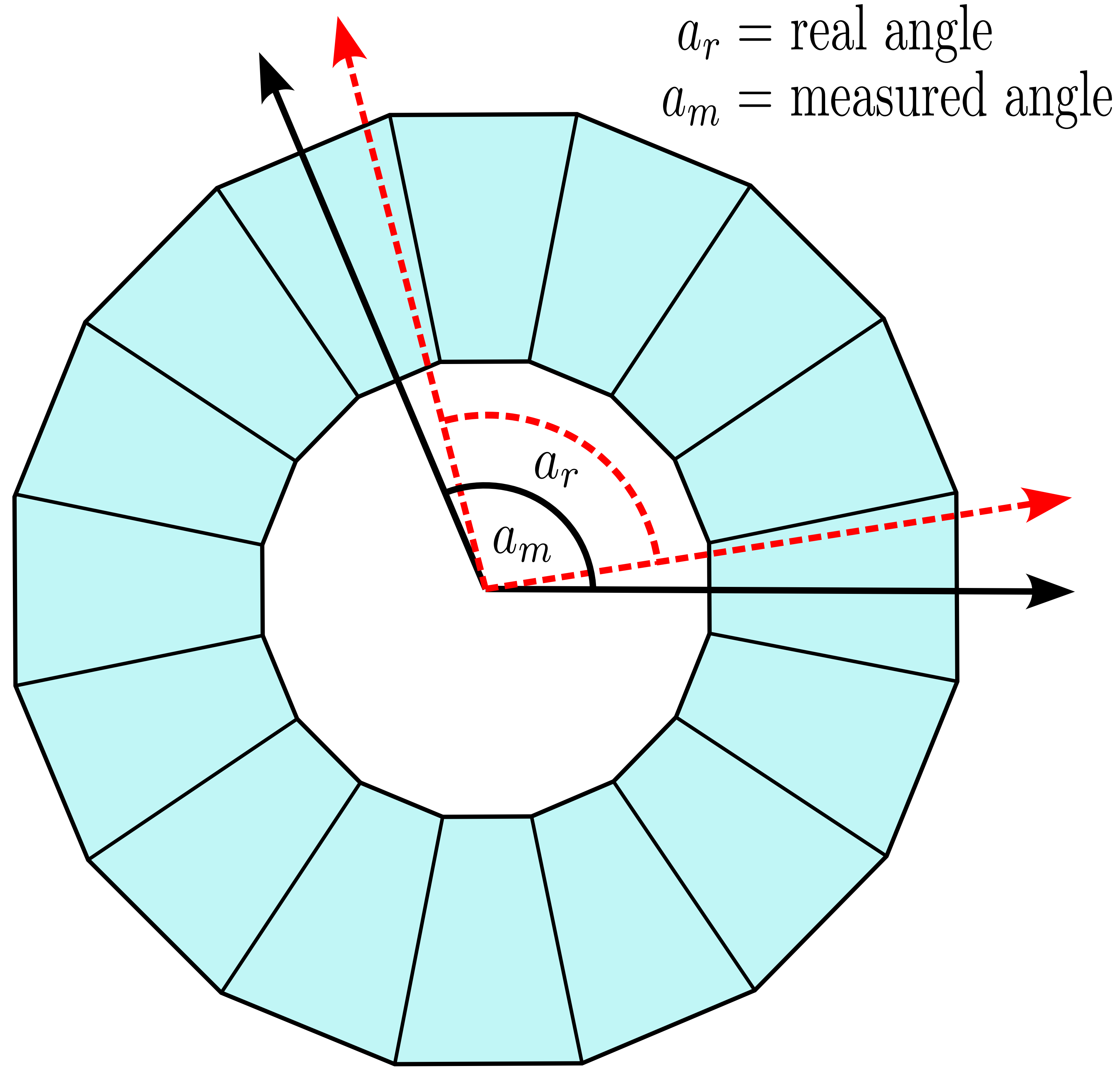
Fits

$$0.2 < \cos(\theta^K_{cms}) < 0.5$$



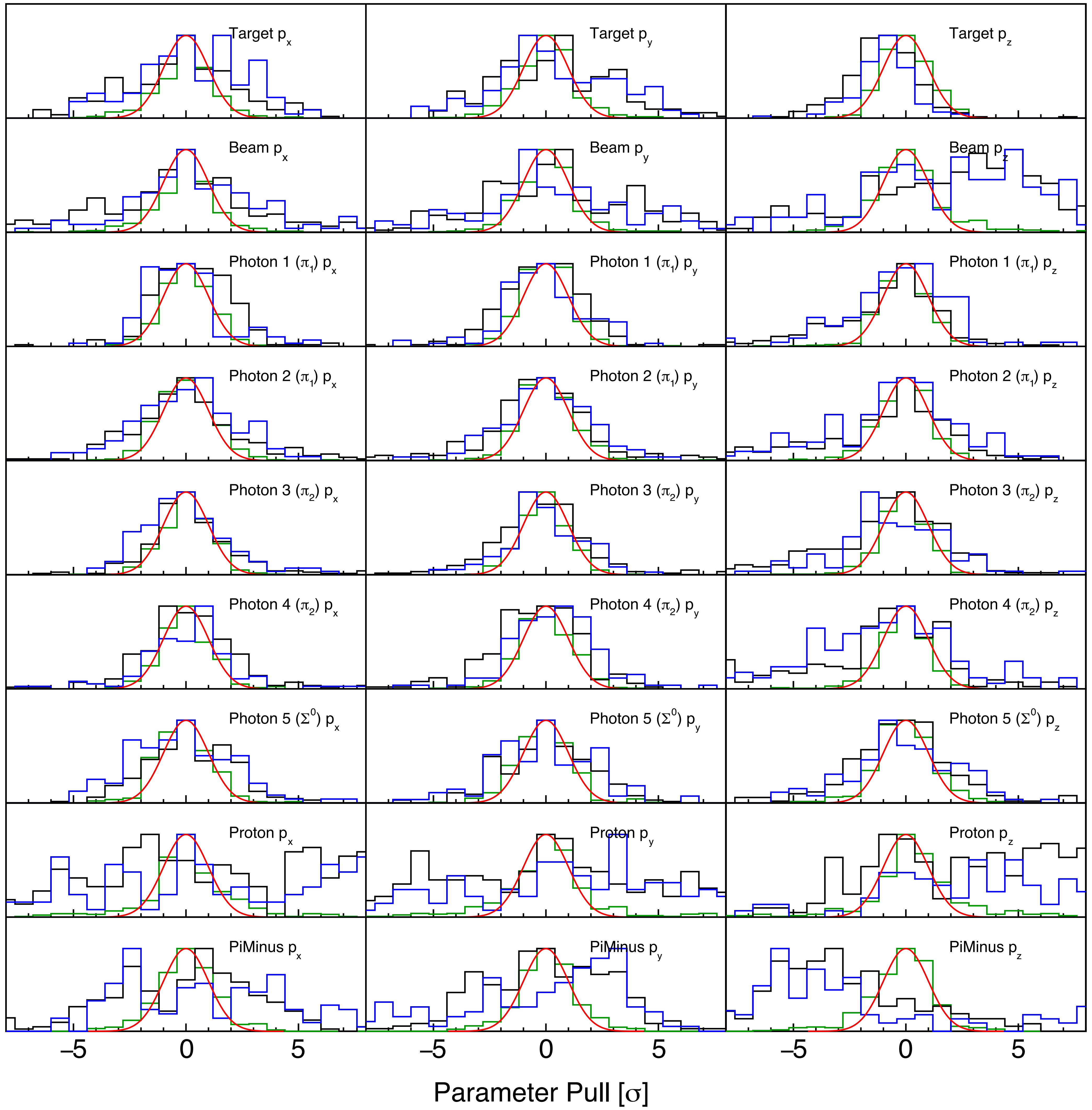
Kinematic fit

- Mathematical procedure to enhanced resolution of key variables
- Physical information is supplied via constraints (eg. energy and momentum conservation, mass, ...)
- Constraints are linearized and added to χ^2equation
- Minimizes the χ^2 simultaneously with the constraint conditions
- Tracks are "pulled" away from their unconstrained values within the range of their known uncertainties

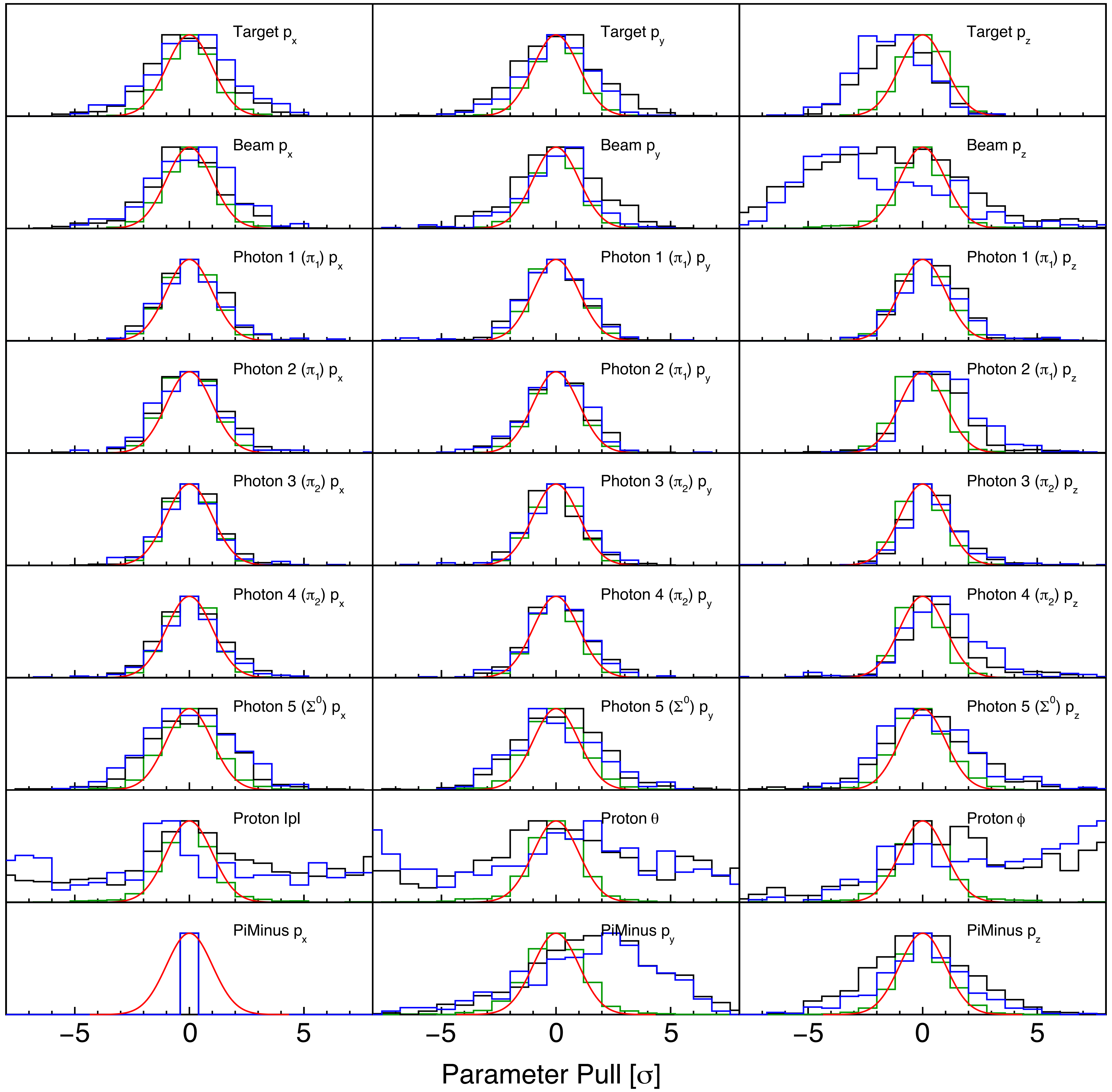


Pull distributions

No charged particles is directional

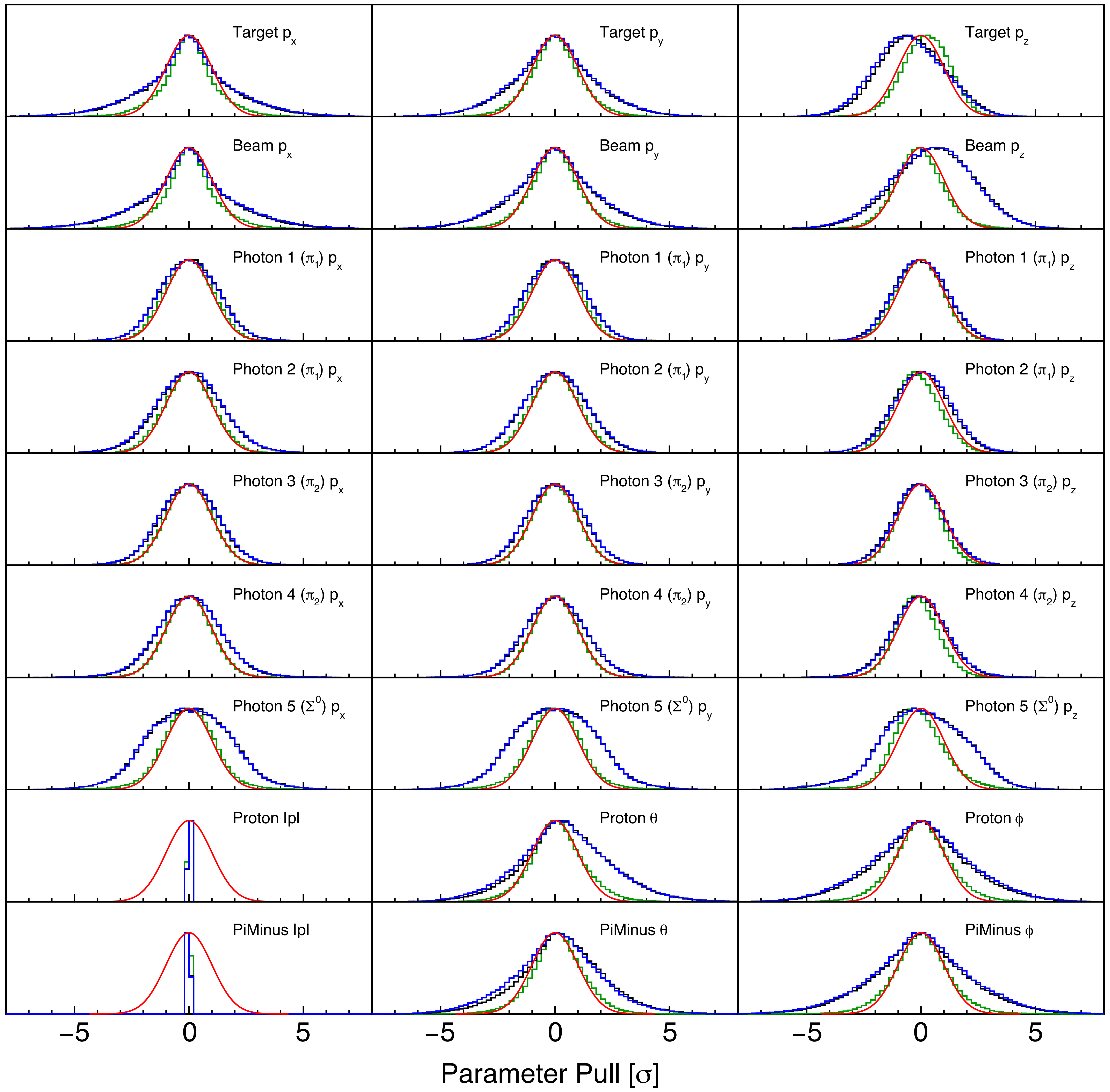


directional proton

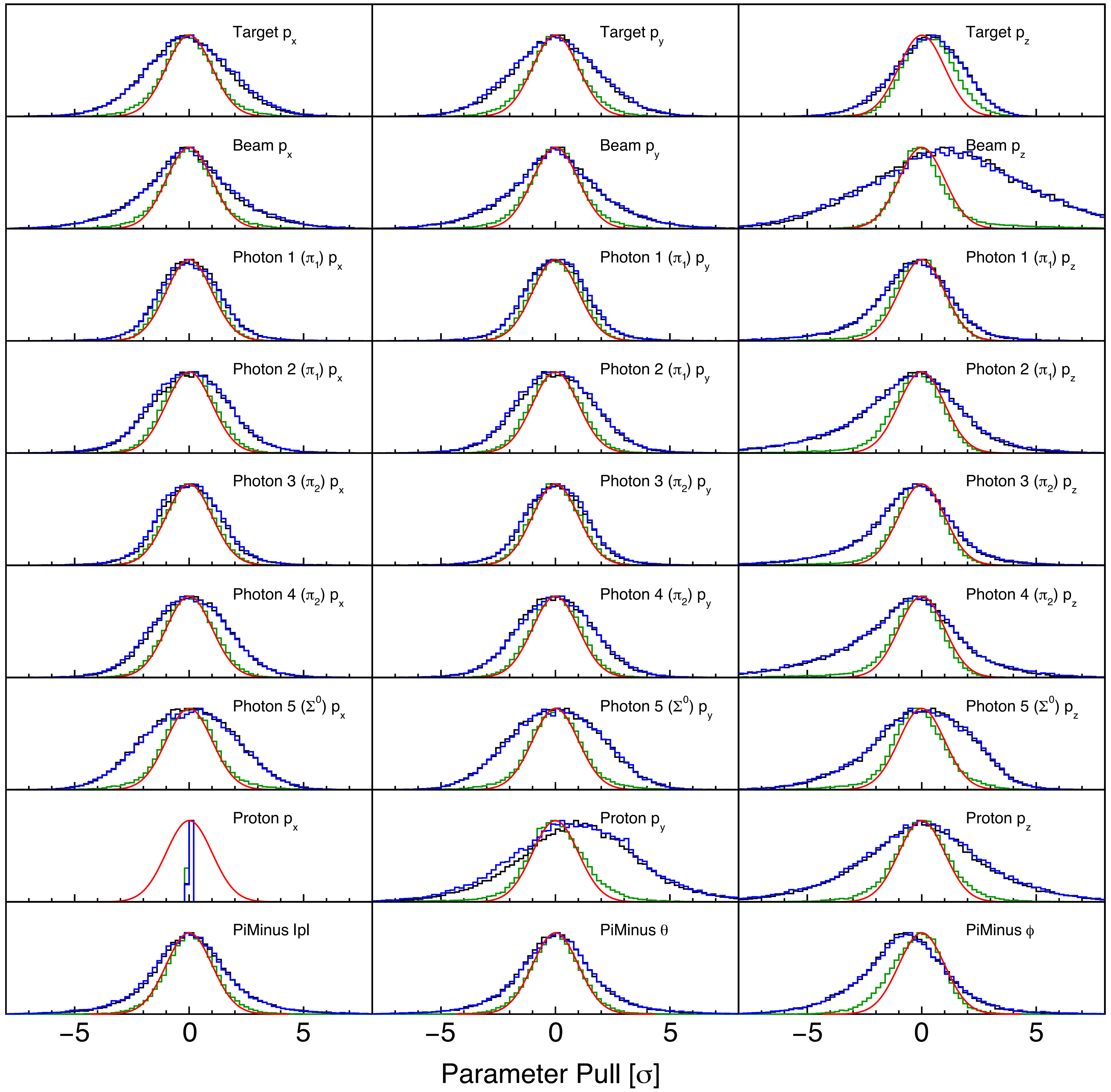


Pull distributions

Both charged particles are directional

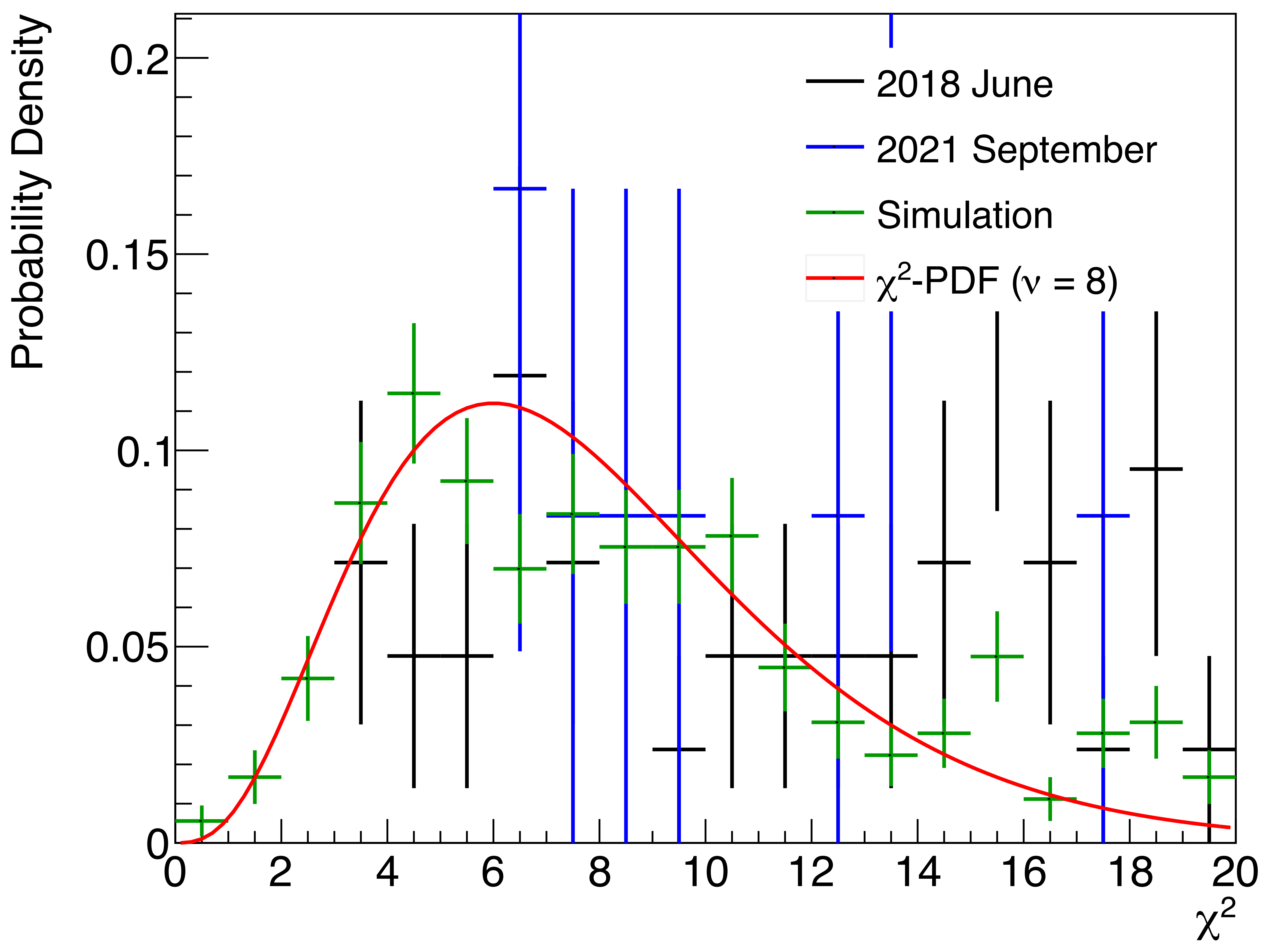


directional π^-

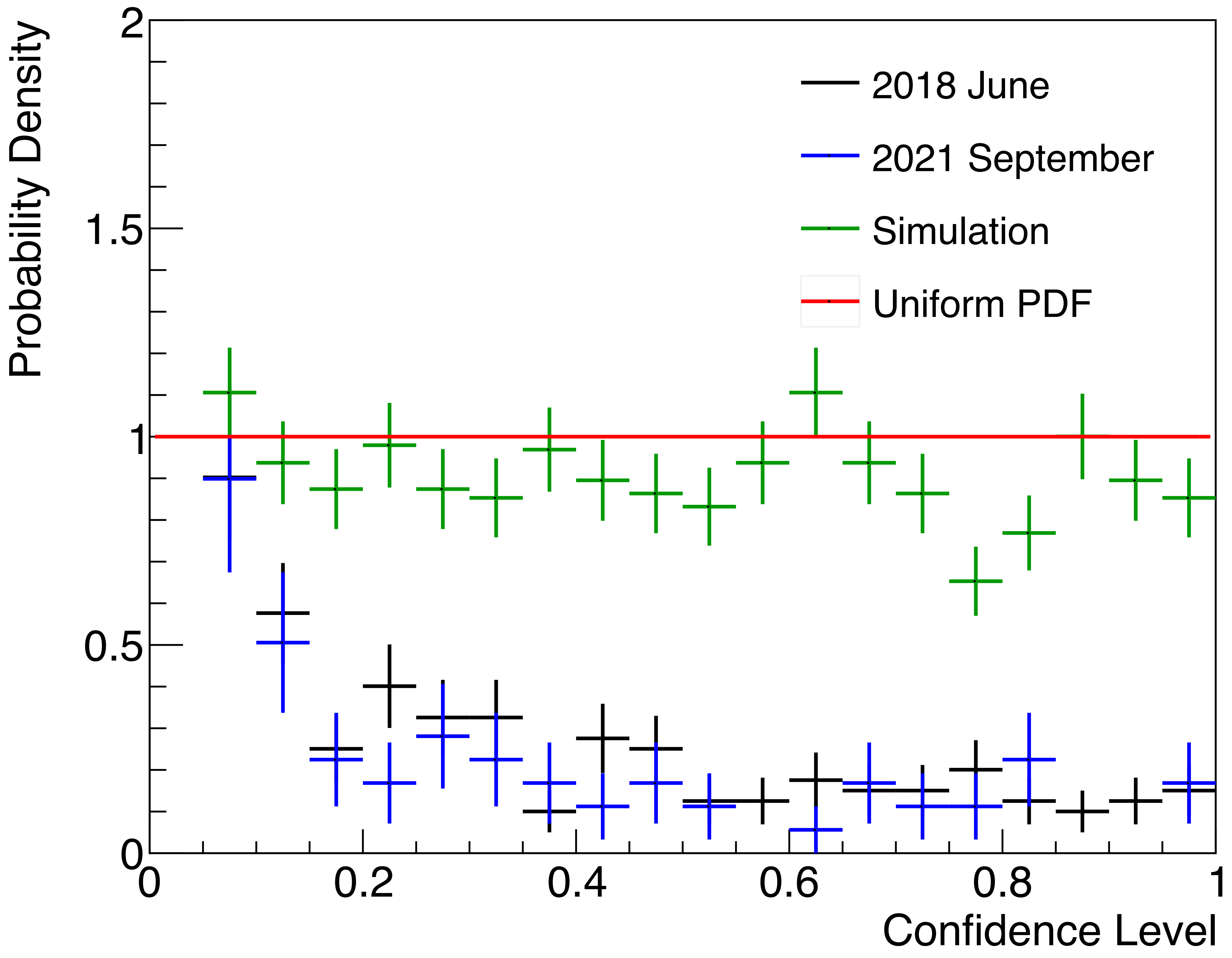


Confidence Level

No charged particles is directional

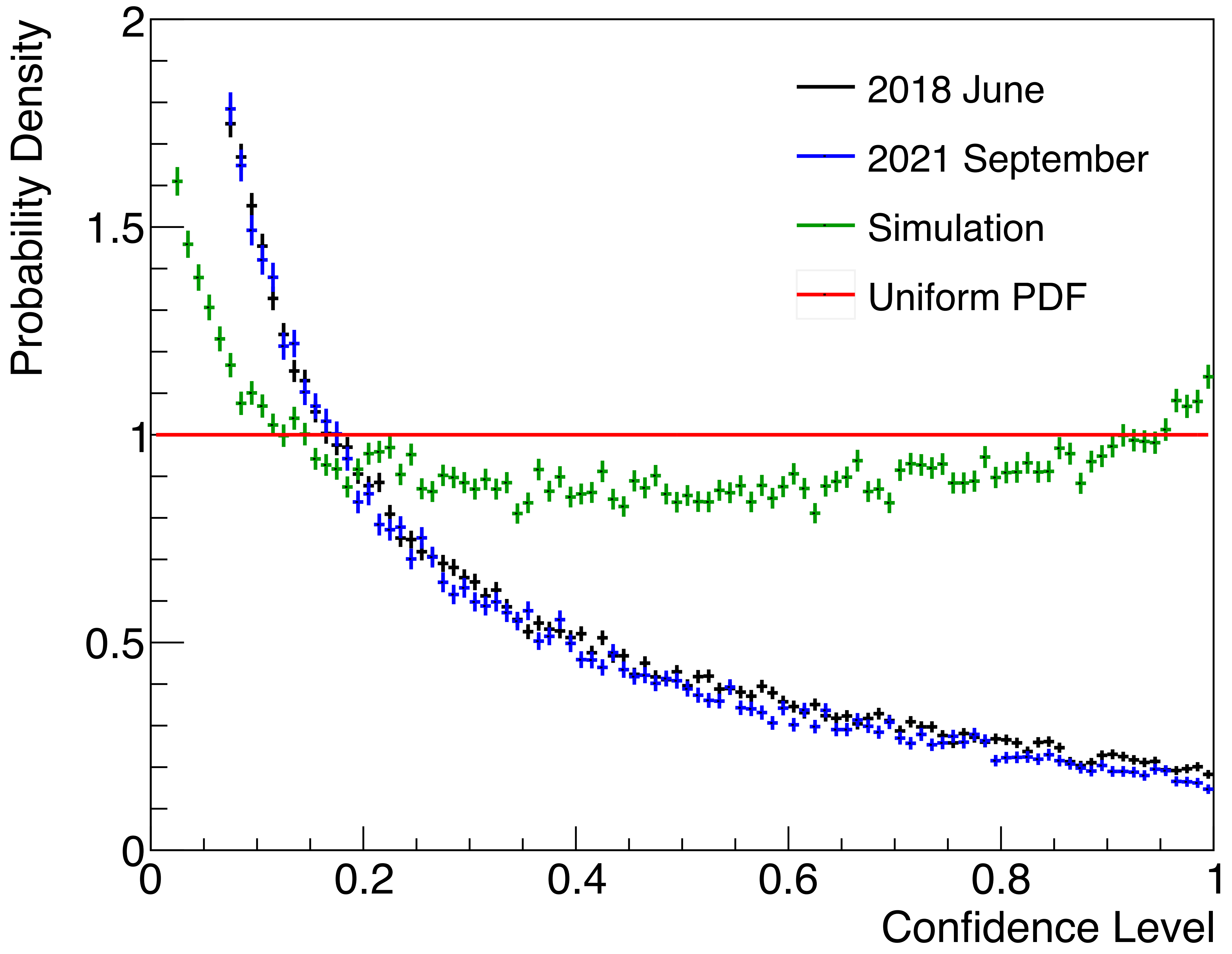


directional proton

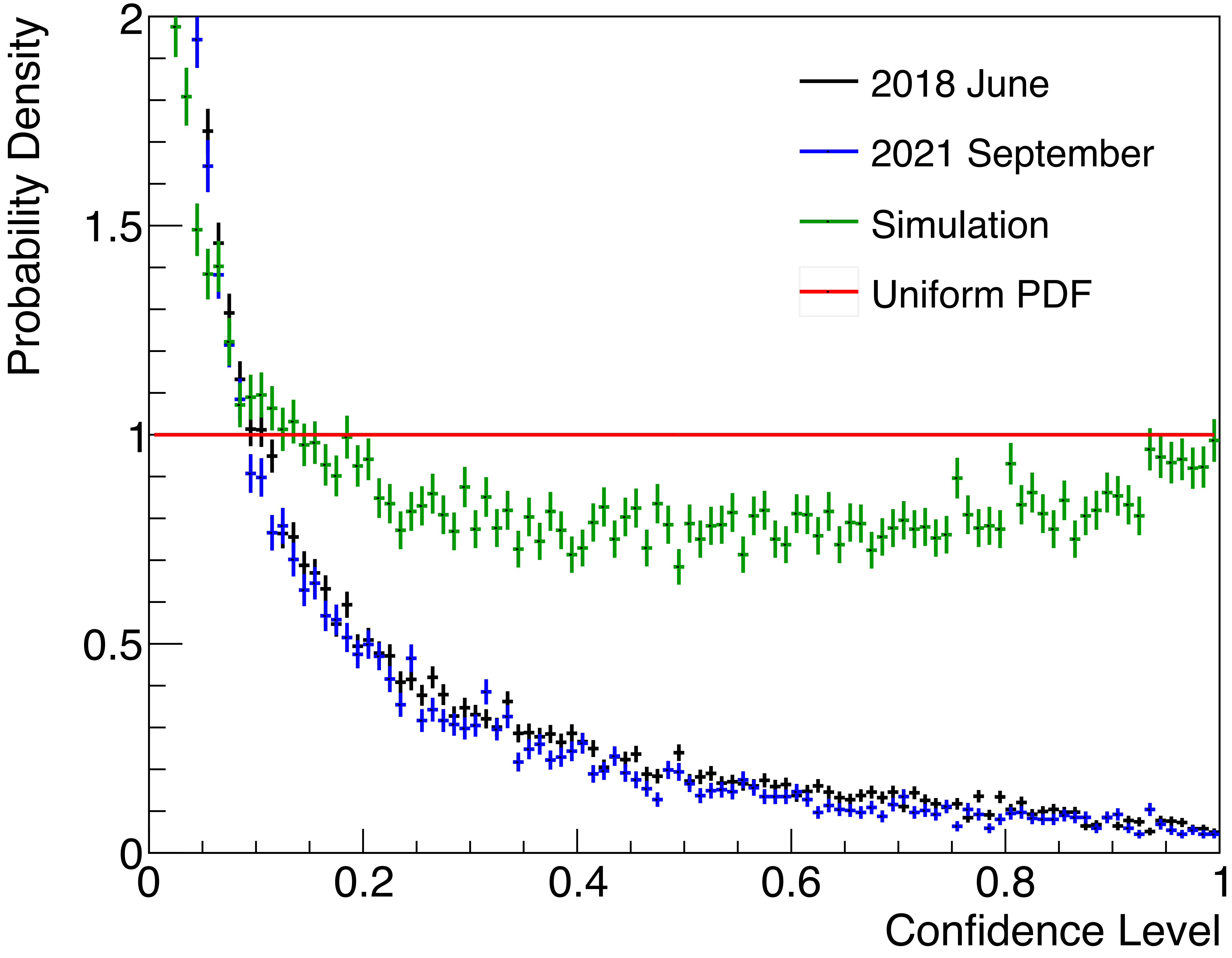


Confidence Level

Both charged particles are directional

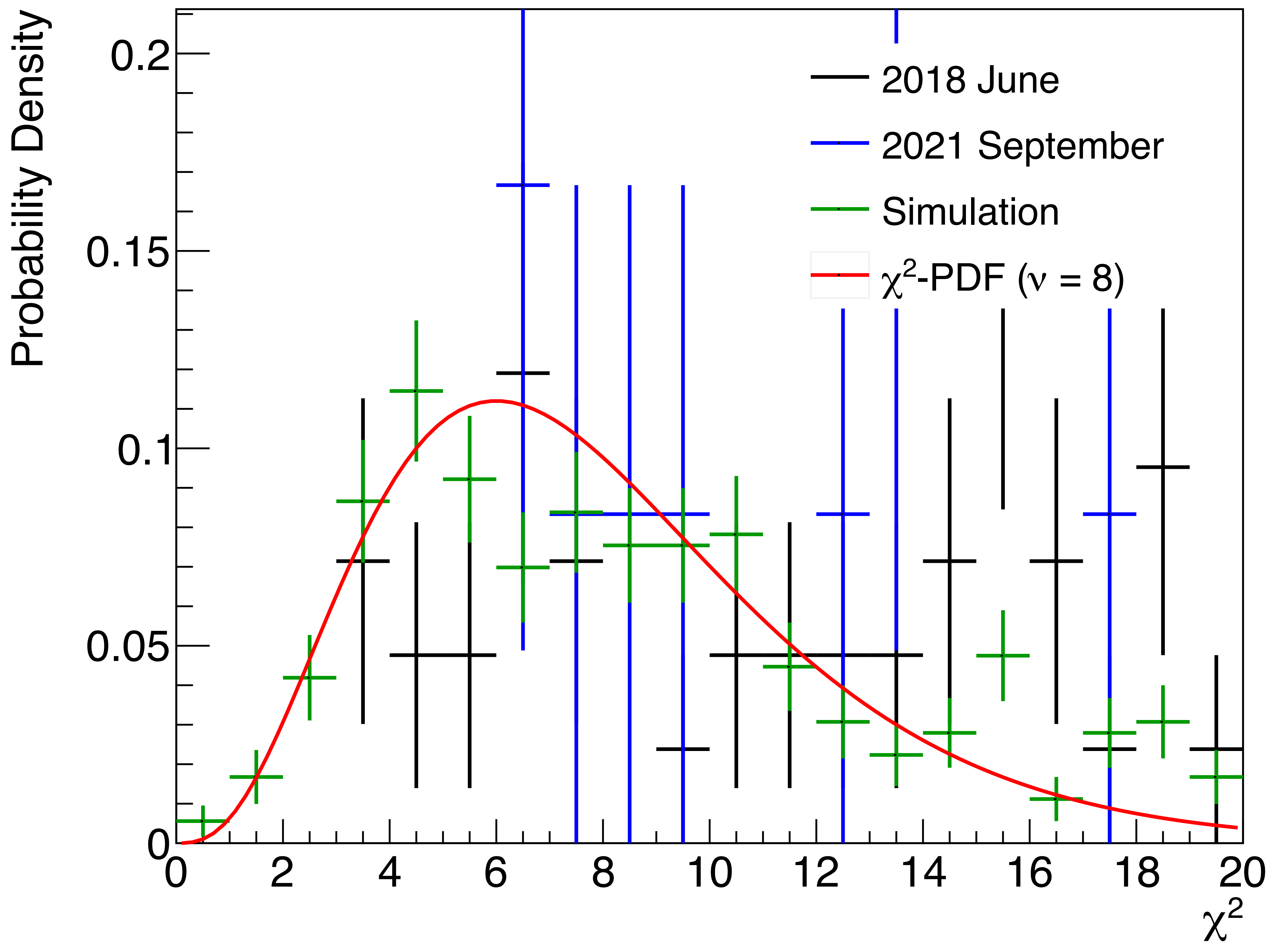


directional π^-

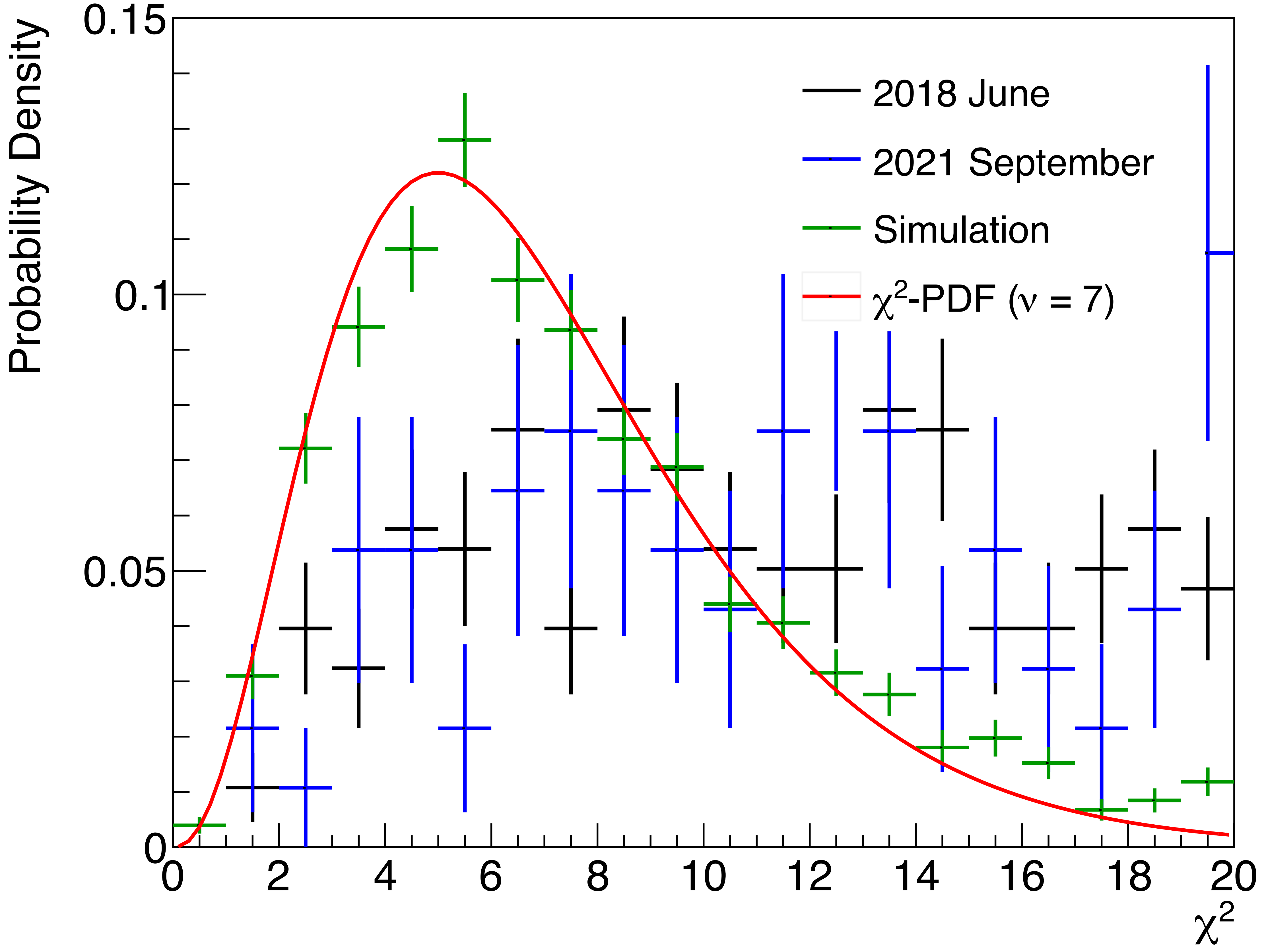


χ^2 distribution

No charged particles is directional

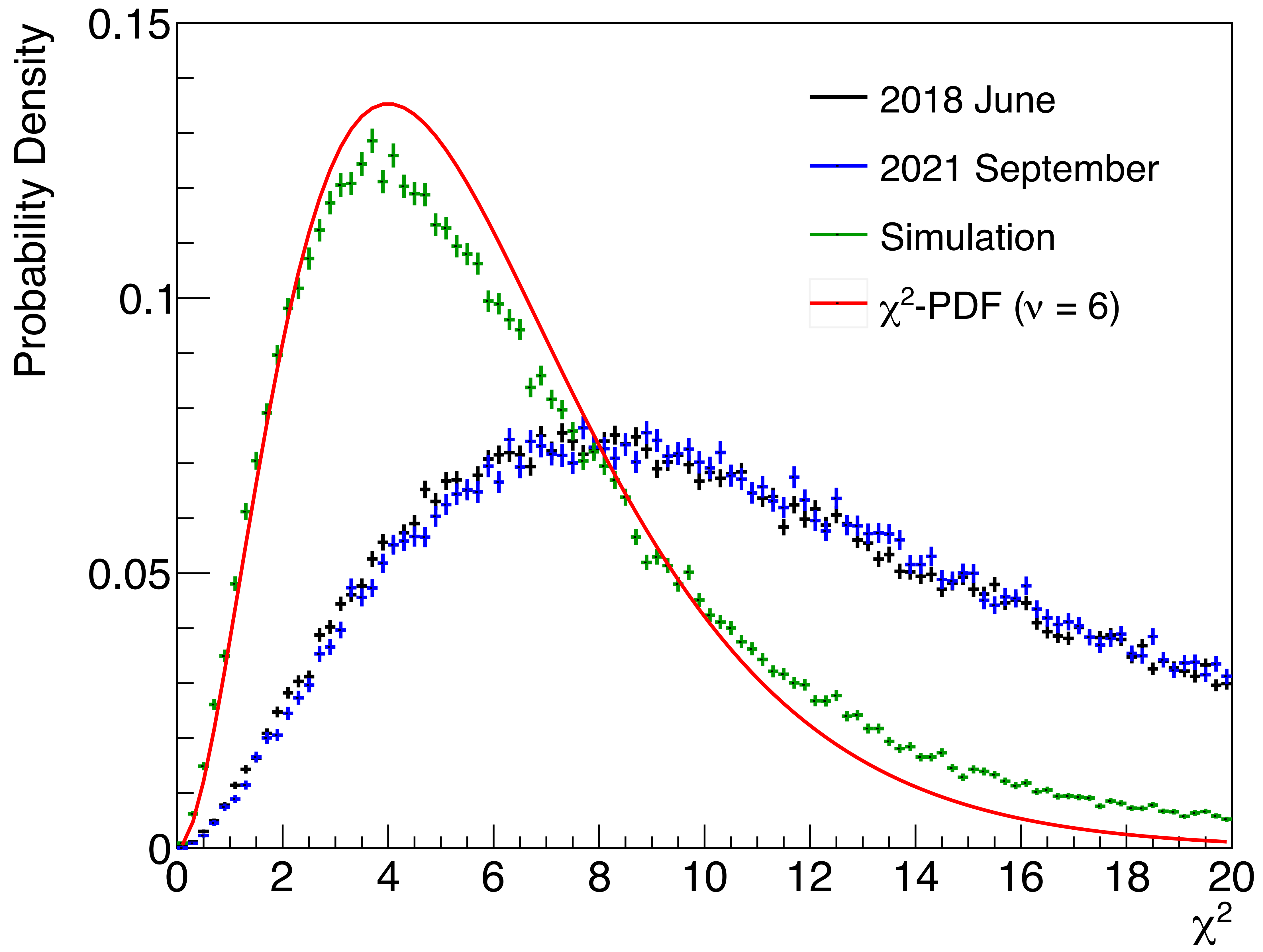


directional proton



χ^2 distribution

Both charged particles are directional



directional π^-