

Studies of $\Lambda(1405)$ photoproduction

at the BGOOD experiment

Antonio J. C. Figueiredo, June 18th 2026

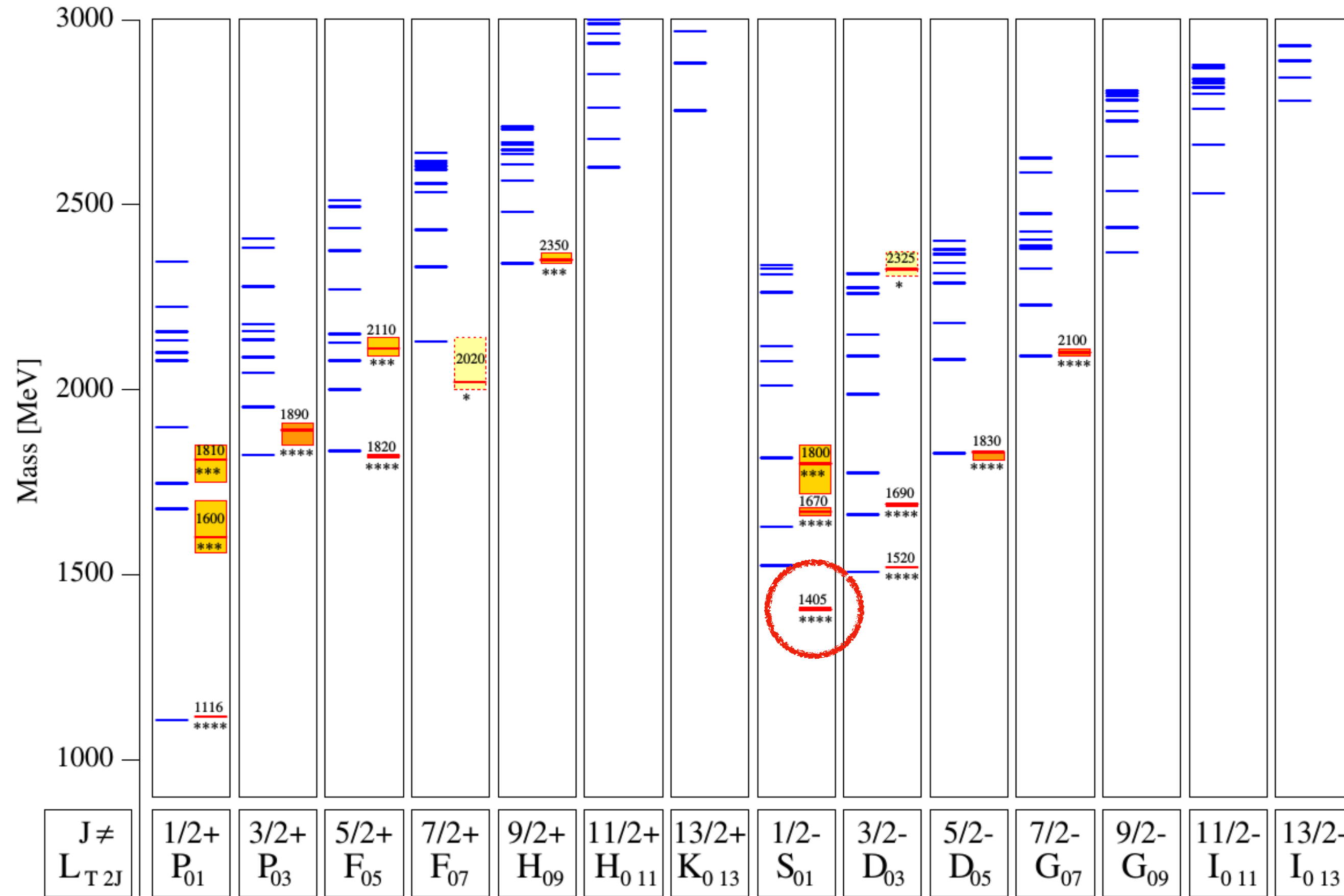


Overview

- **Motivation**
- **The BGOOD experiment at ELSA, Bonn**
- $\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^+ \pi^-)$
- $\gamma p \rightarrow K^+ \Sigma(1385)$
- $\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$
- **Summary and Outlook**

Motivation - status of Λ^* spectroscopy

CQM vs. experiment

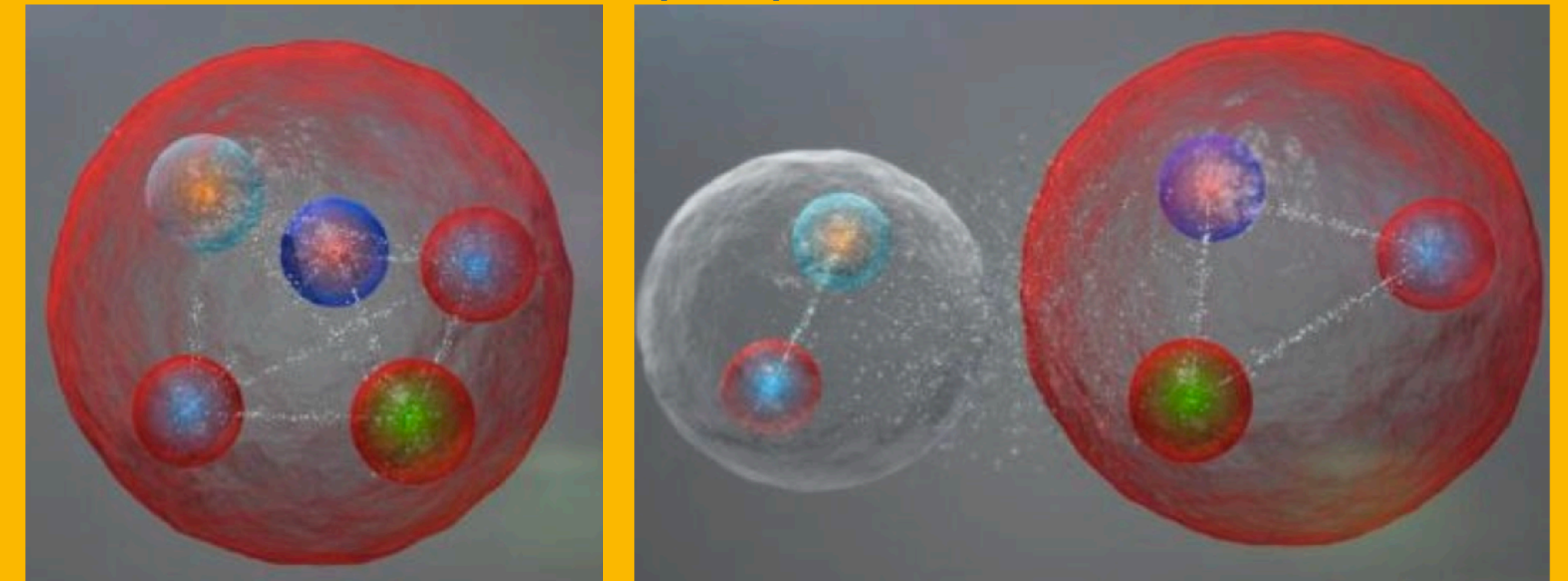


U. Löring, B. C. Metsch and H. R. Petry, Eur. Phys. J. A10, 447-486 (2001)

Relevant degrees of freedom?

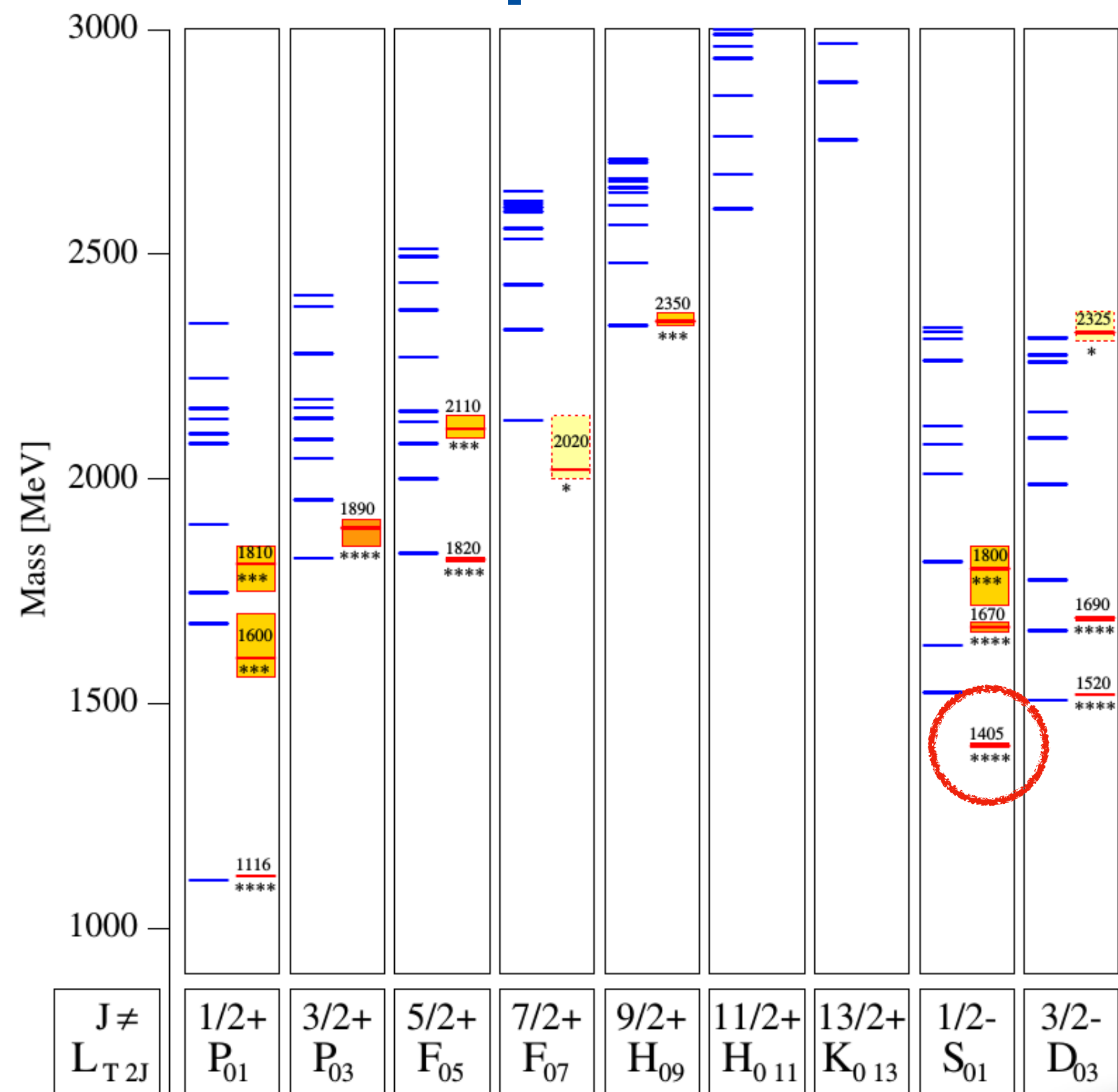
- 3 quark states only?
- Molecule-like states, meson-baryon degrees of freedom?

Glozman & Riska, Phys. Rep. 268 (1996) 263,
 Garcia-Recio et al., PLB 582 (2004) 49,
 Lutz & Kolomeitsev, PLB 585 (2004) 243

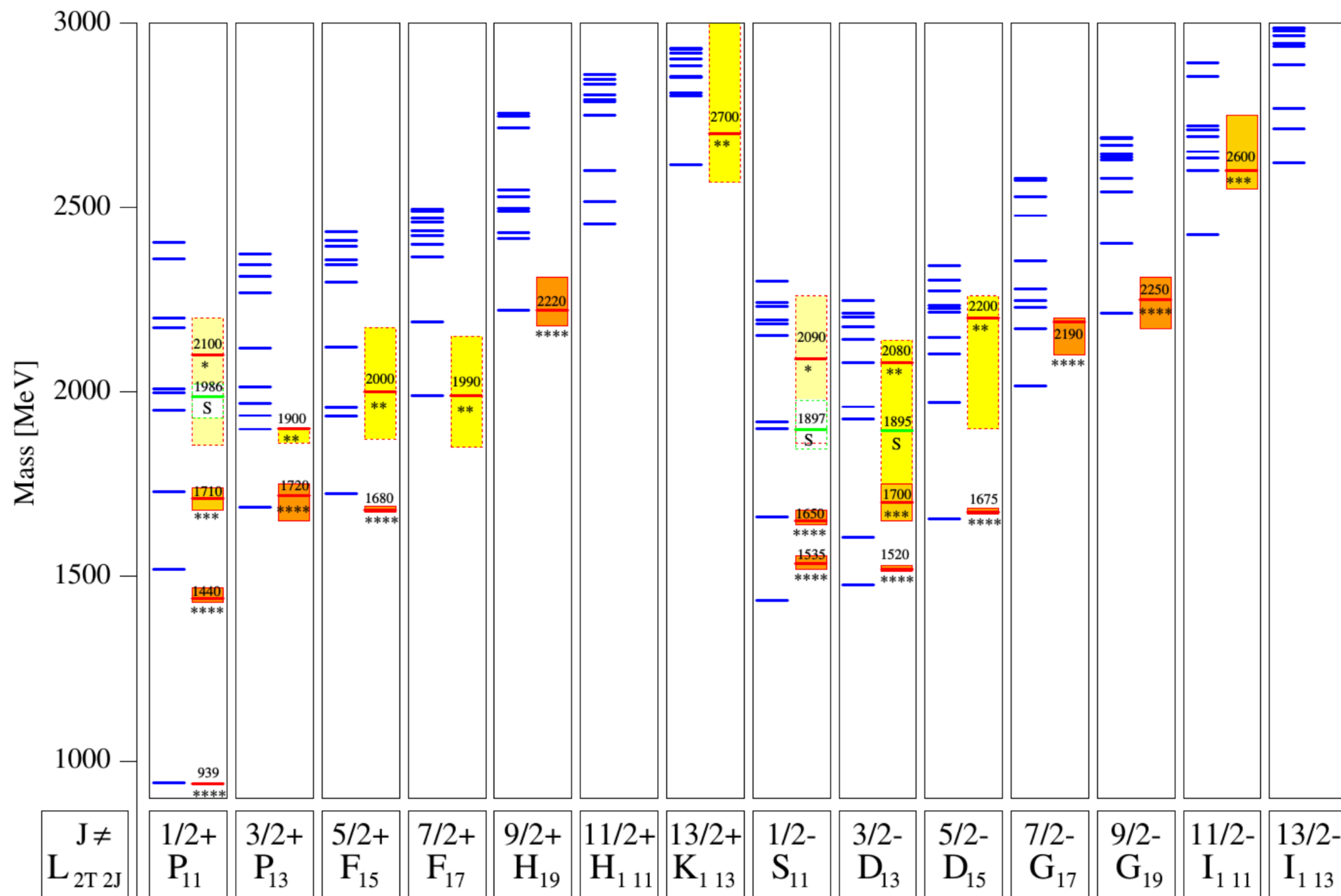


Motivation - status of Λ

CQM vs. experiment



N^* Spectrum

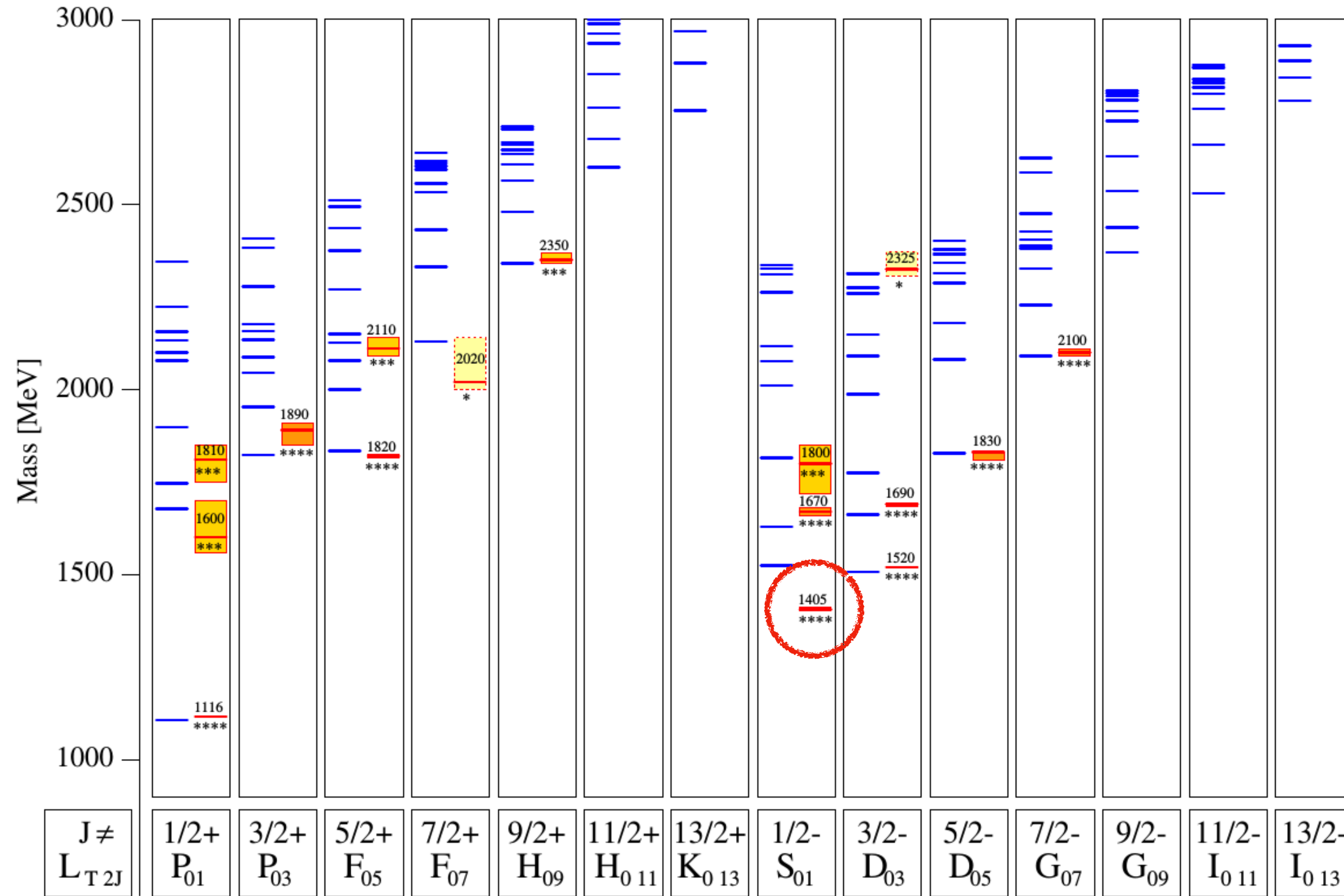


U. Löring, B. C. Metsch and H. R. Petry, Eur. Phys. J. A10, 395 (2001)

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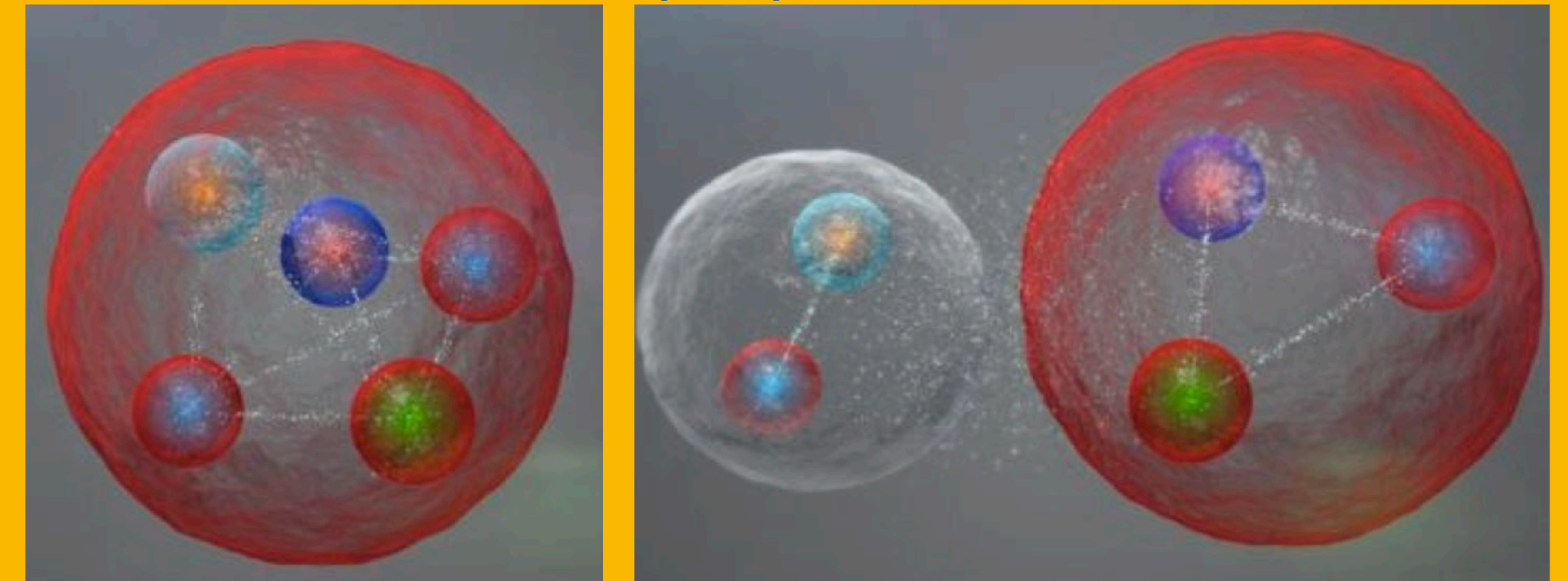


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82. Pole Structure of the $\Lambda(1405)$ Region

Revised Feb. 2025 by T. Hyodo (RCNP, Osaka U.; Tokyo Metropolitan U.) and U.-G. Meißner (Bonn U.; FZ Jülich).

The $\Lambda(1405)$ resonance emerges in the meson-baryon scattering amplitude with the strangeness $S = -1$ and isospin $I = 0$. It is the archetype of what is called a dynamically generated resonance, as pioneered by Dalitz and Tuan [1]. The most powerful and systematic approach for the low-energy regime of the strong interactions is chiral perturbation theory (ChPT), see e.g. Ref. [2]. A perturbative calculation is, however, not applicable to this sector because of the existence of the $\Lambda(1405)$ just below the $\bar{K}N$ threshold. In this case, ChPT has to be combined with a non-perturbative re-

S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024) and 2025 update

L_{T2J} P_{01} P_{03} F_{05} F_{07} H_{09} H_{011} K_{013} S_{01} D_{03} D_{05} G_{07} G_{09} I_{011} I_{013}

U. Löring, B. C. Metsch and H. R. Petry, Eur. Phys. J. A10, 447-486 (2001)

Motivation - structure of the $\Lambda(1405)$

- Considered a $\bar{K}N$ molecule prior to the quark model

Dalitz & Tuan, PRL 2 (1959) 425

- Between $\pi\Sigma$ & $\bar{K}N$ thresholds & difficult to reconcile with a CQM:

- Mass too low compared to $N^*(1535)$
- Large spin orbit splitting to $\Lambda(1520)$

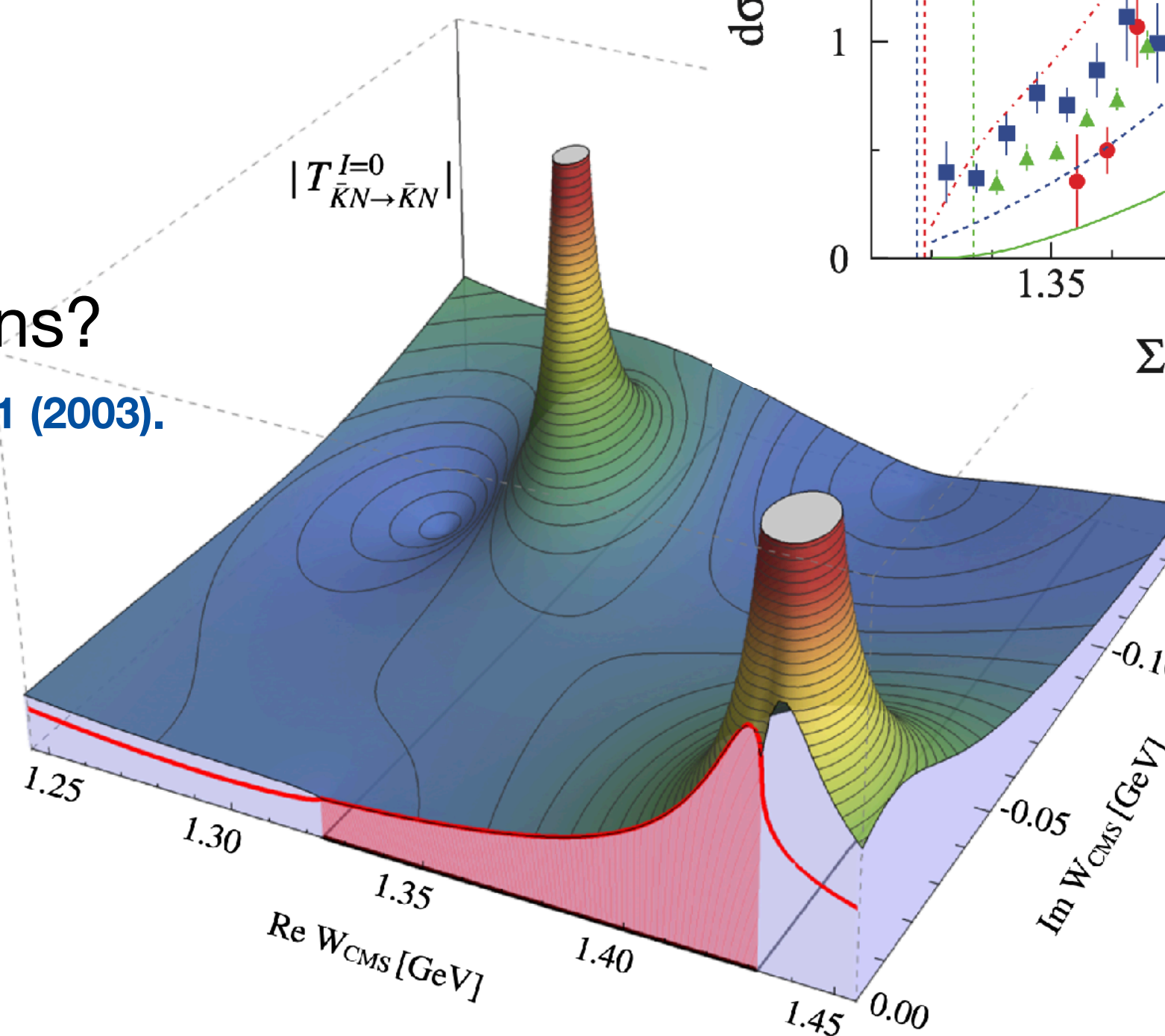
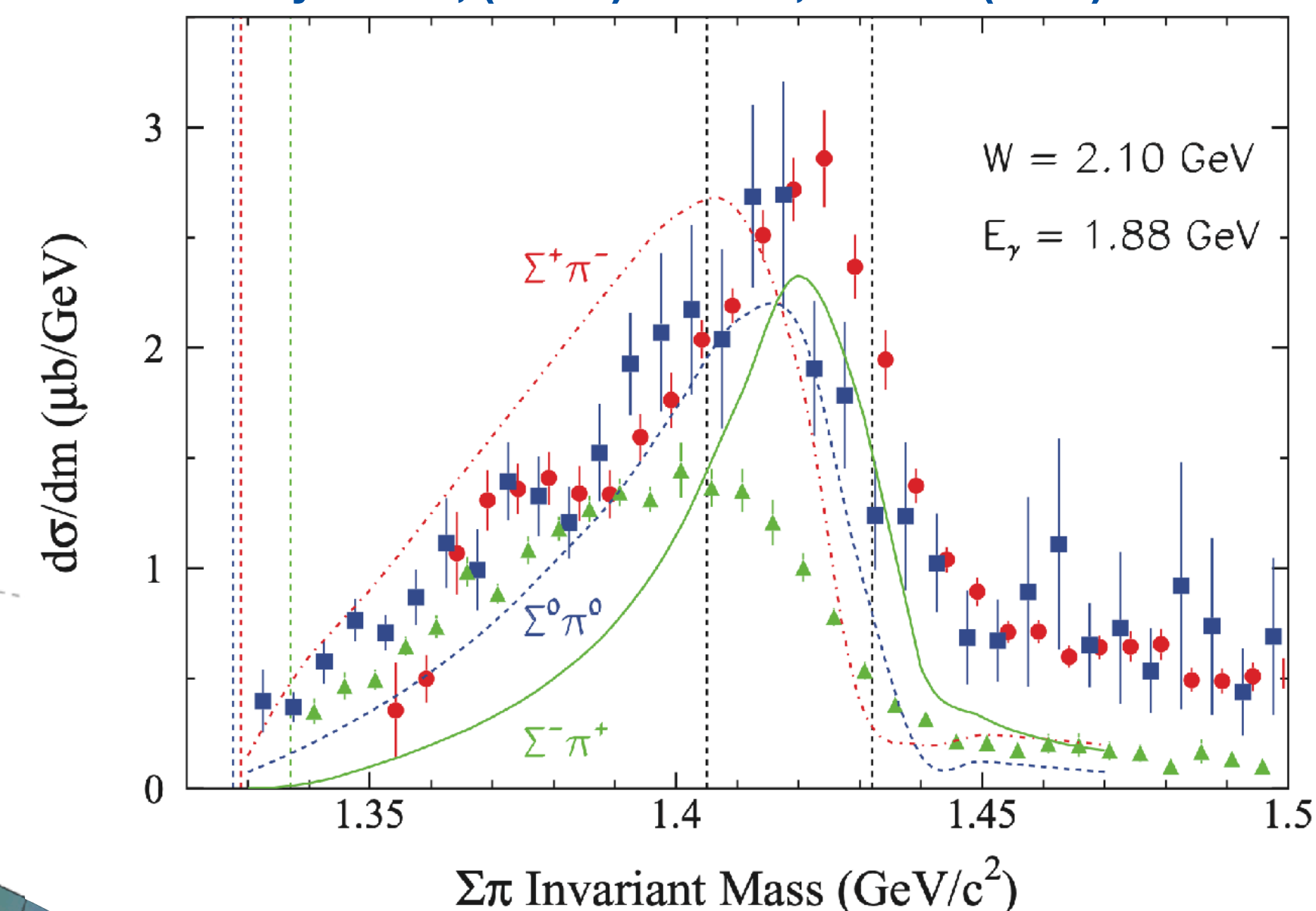
- Dynamically generated, meson-baryon interactions?

D. Jido, J. A. Oller, E. Oset, A. Ramos, U.G. Meissner. Nucl Phys. A 725:181 (2003).
Molina & Döring, PRD 94, 056010 & 079901 (2016)

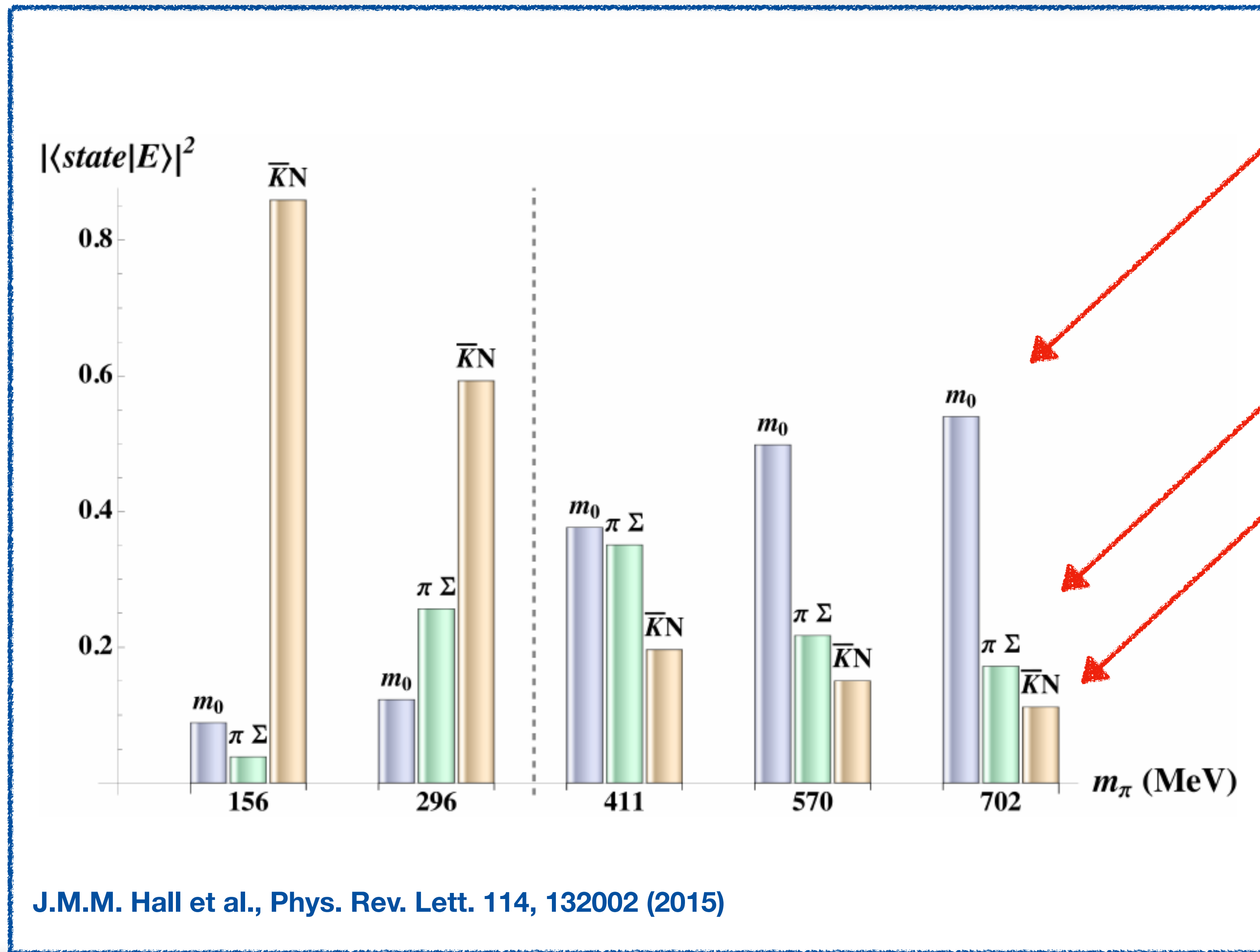
- 2-pole structure in χ PT based models

M. Mai, EPJ Spec. Top. (2021) 230, 1593
M. Mai, U.-G. Meißner, EPJA 51, 30 (2015)

Moriya et al., (CLAS) PRC 87, 035206 (2013)



Motivation - $\Lambda(1405)$ Lattice QCD



Conventional state

$\Sigma\pi$ molecule

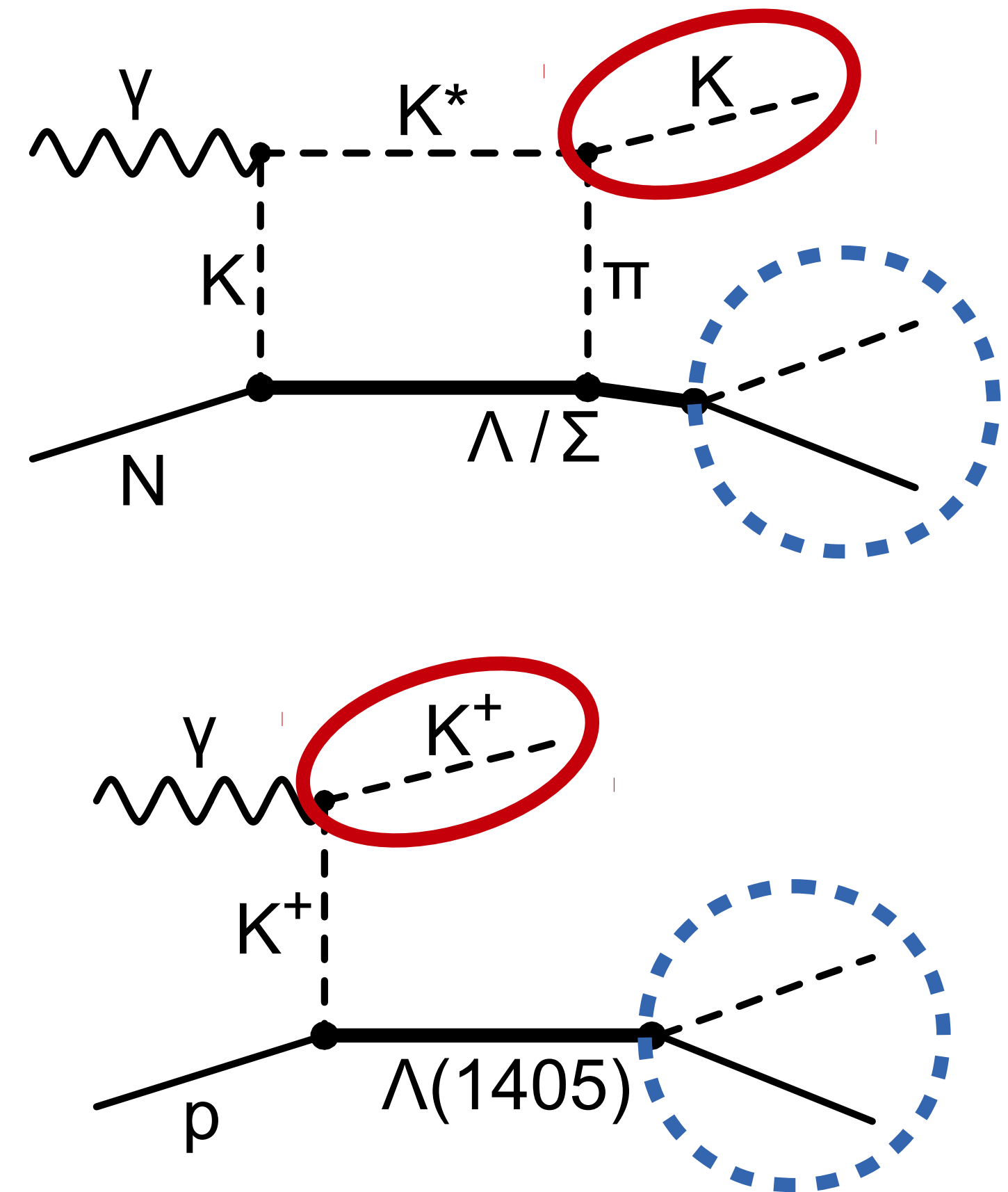
$\bar{K}N$ molecule

- Going towards realistic π -masses $\bar{K}N$ component dominates

➔ Support for the molecular-like structure of $\Lambda(1405)$

Motivation - Experimental requirements

- Reaction dynamics at low momentum exchange
 - Charged particle identification at forward angles
- Reconstruction of mixed charged final states
 - $\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ \Sigma^0 \pi^0 \rightarrow K^+ 3\gamma p \pi^-$

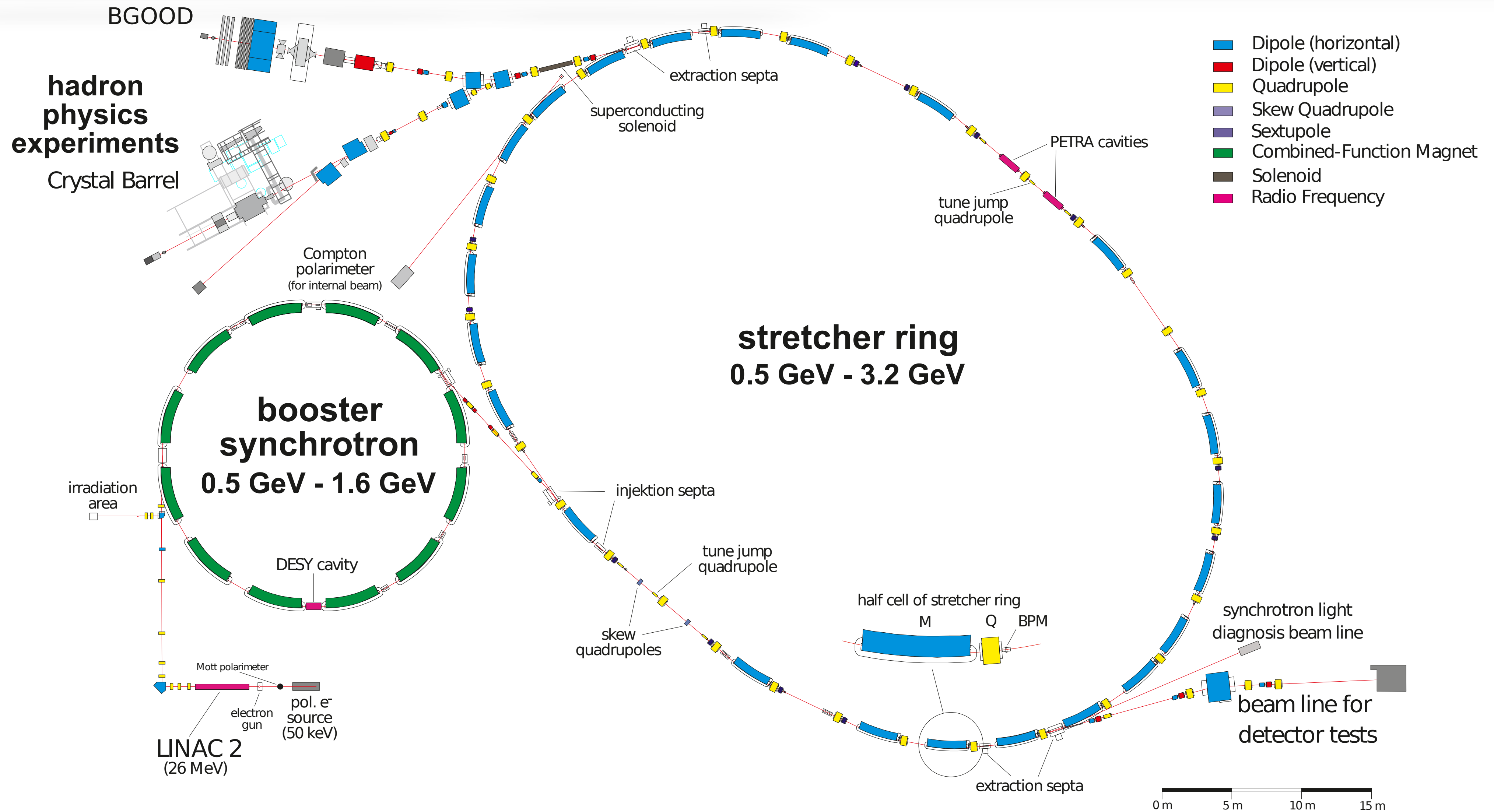


BGOOD at the ELSA facility, Bonn

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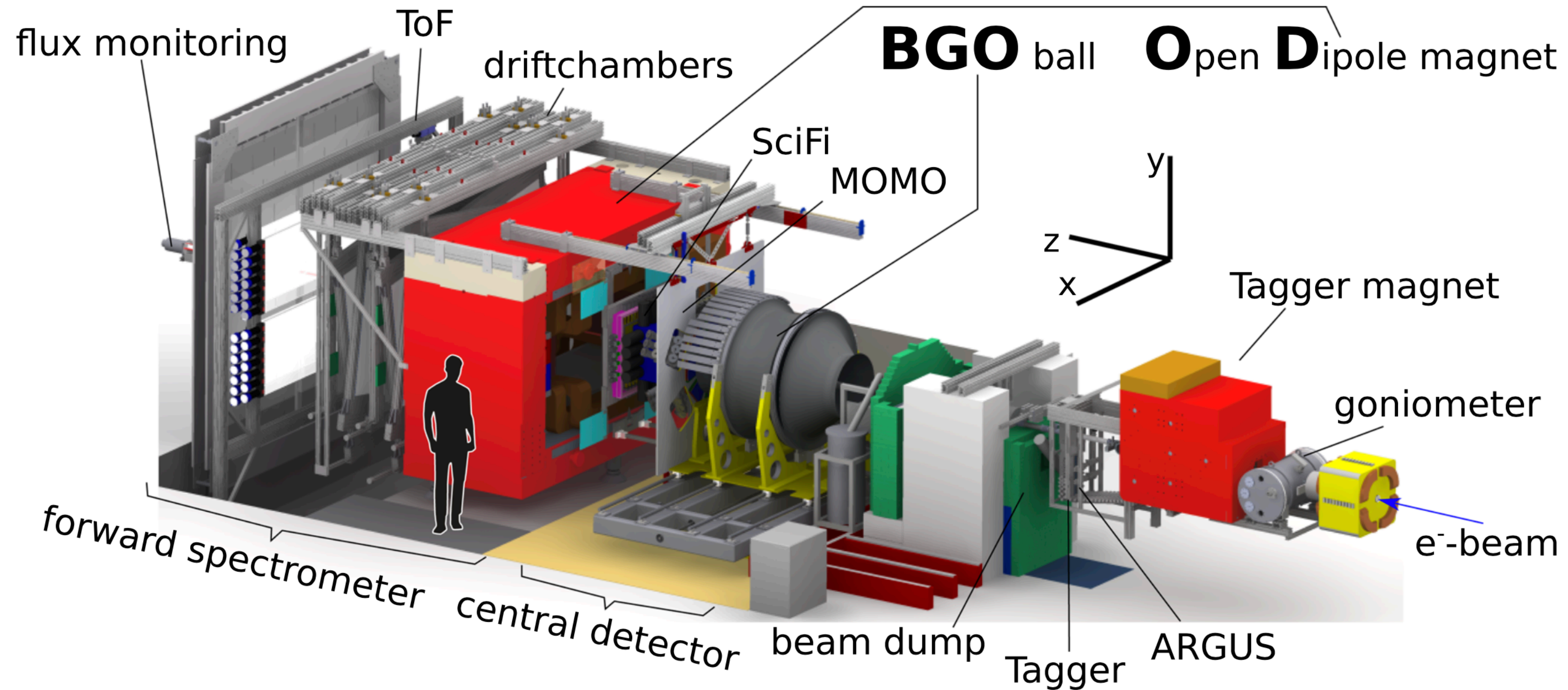
The Electron Stretcher Accelerator



The BGOOD photoproduction experiment

BGO Calorimeter (central region) & Forward Spectrometer combination

Spokespersons: T.C. Jude (Bonn) & P. Levi Sandri (Frascati)

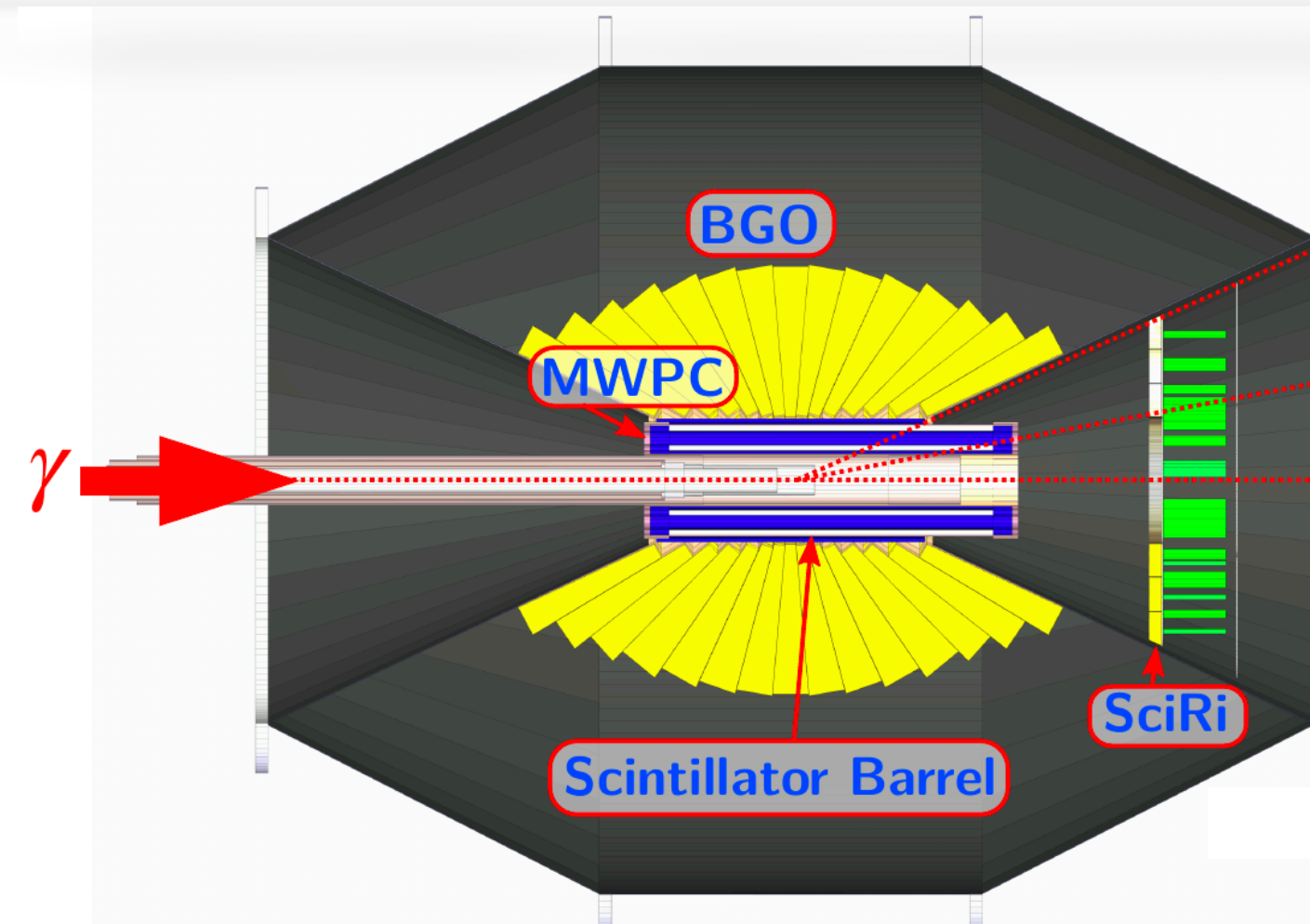


The BGOOD setup at ELSA, Eur. Phys. J. A 56 (2020) 104

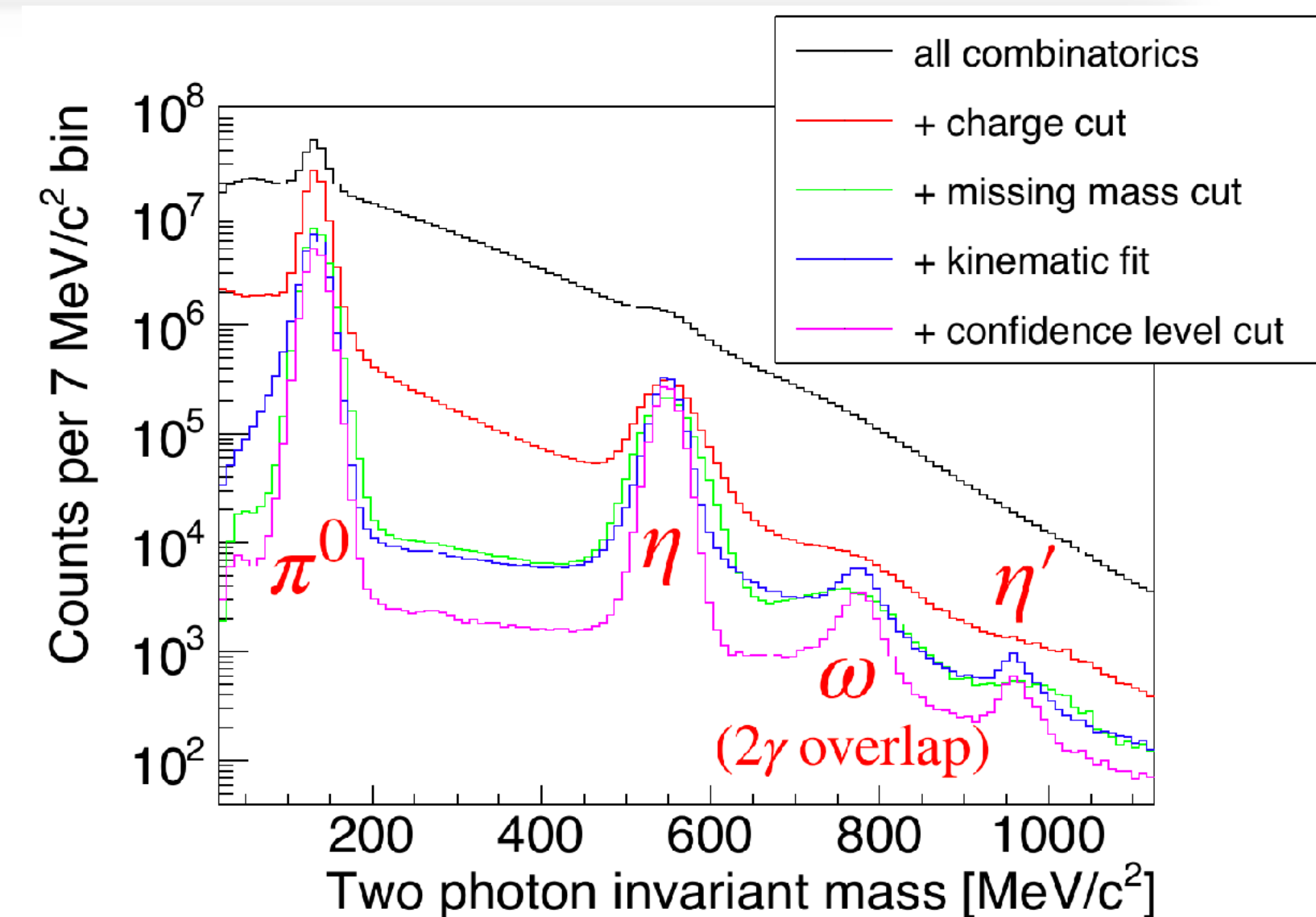
BGOOD - particle identification



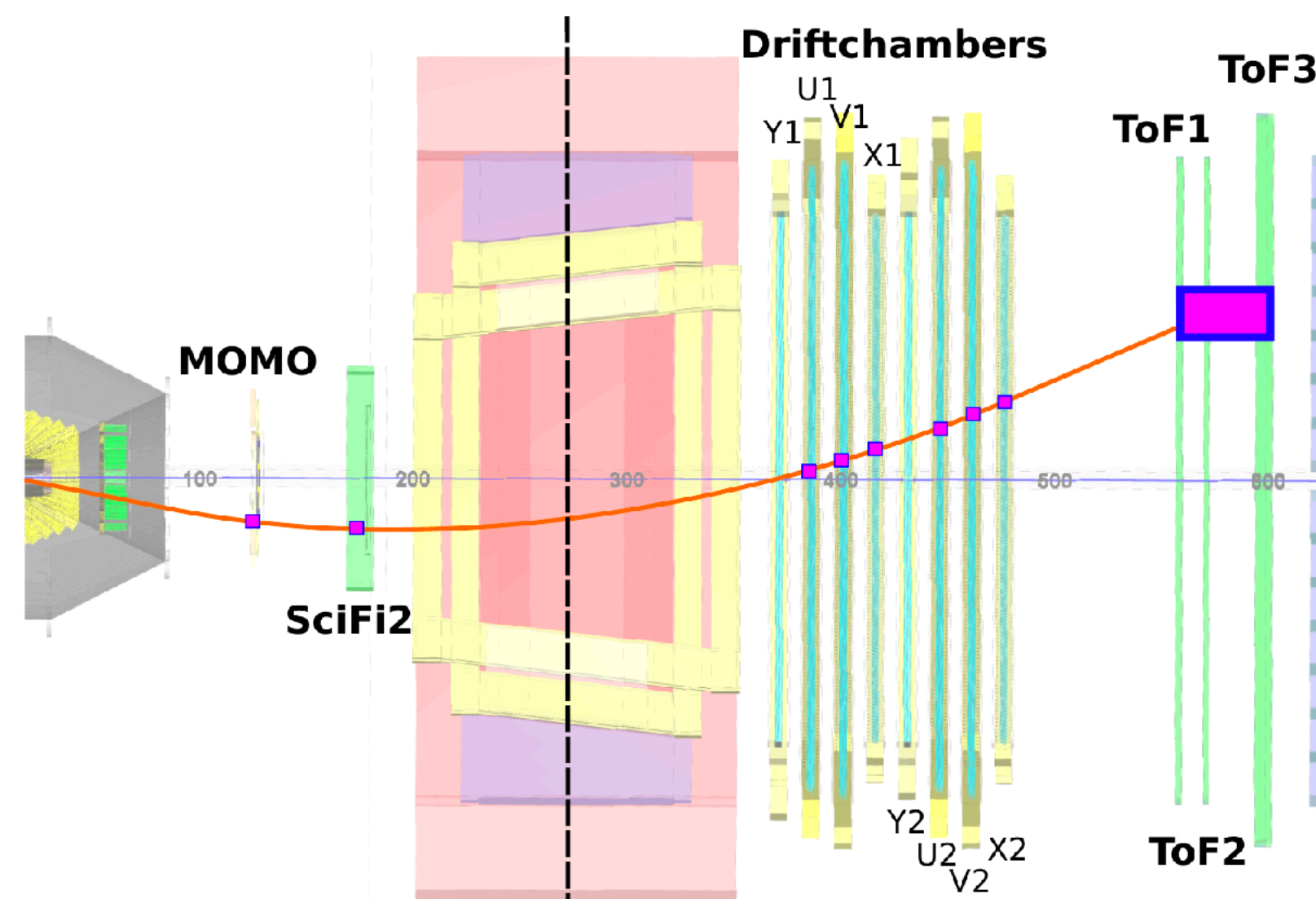
Central region



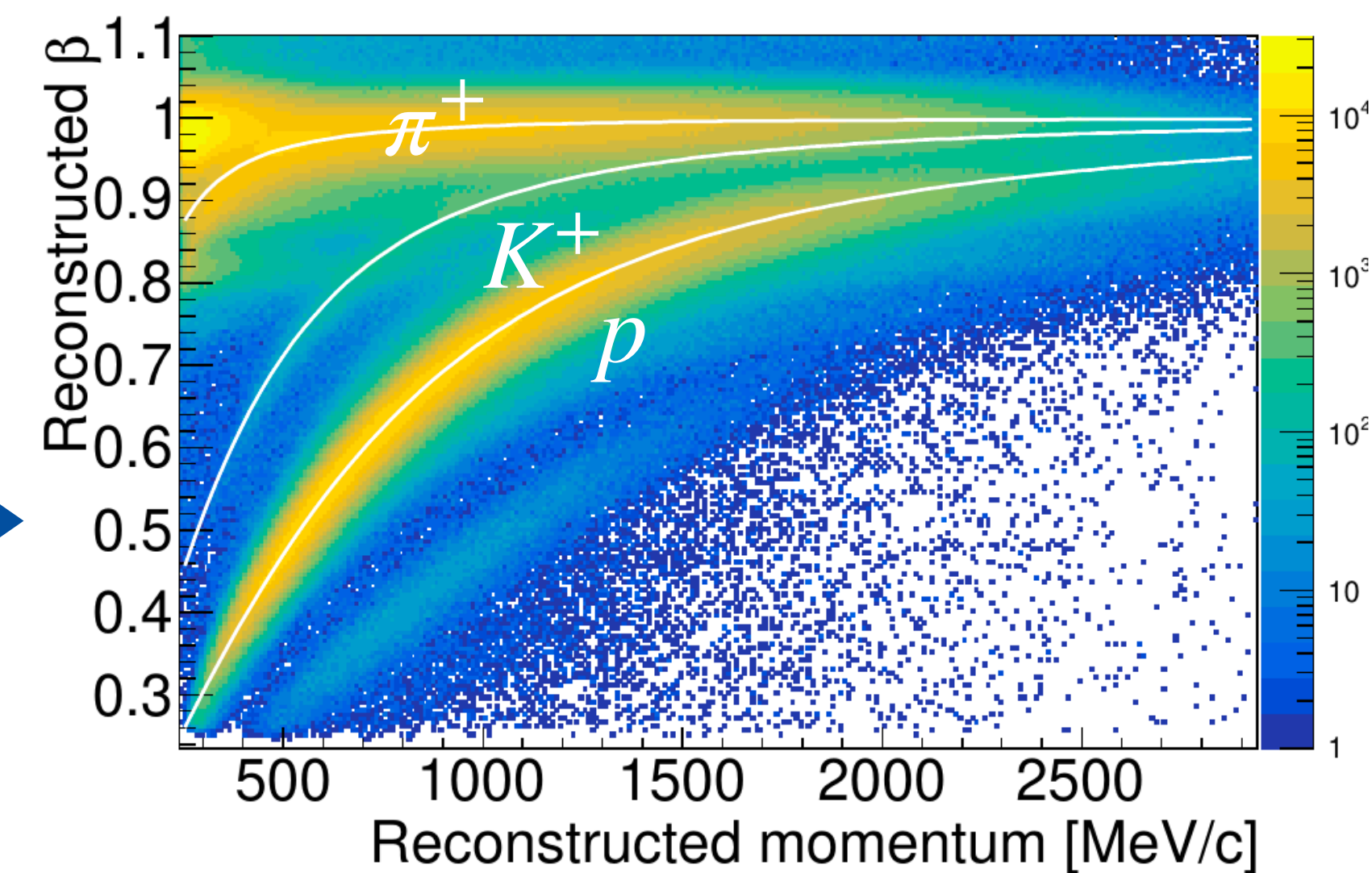
Neutral meson identification



Forward region

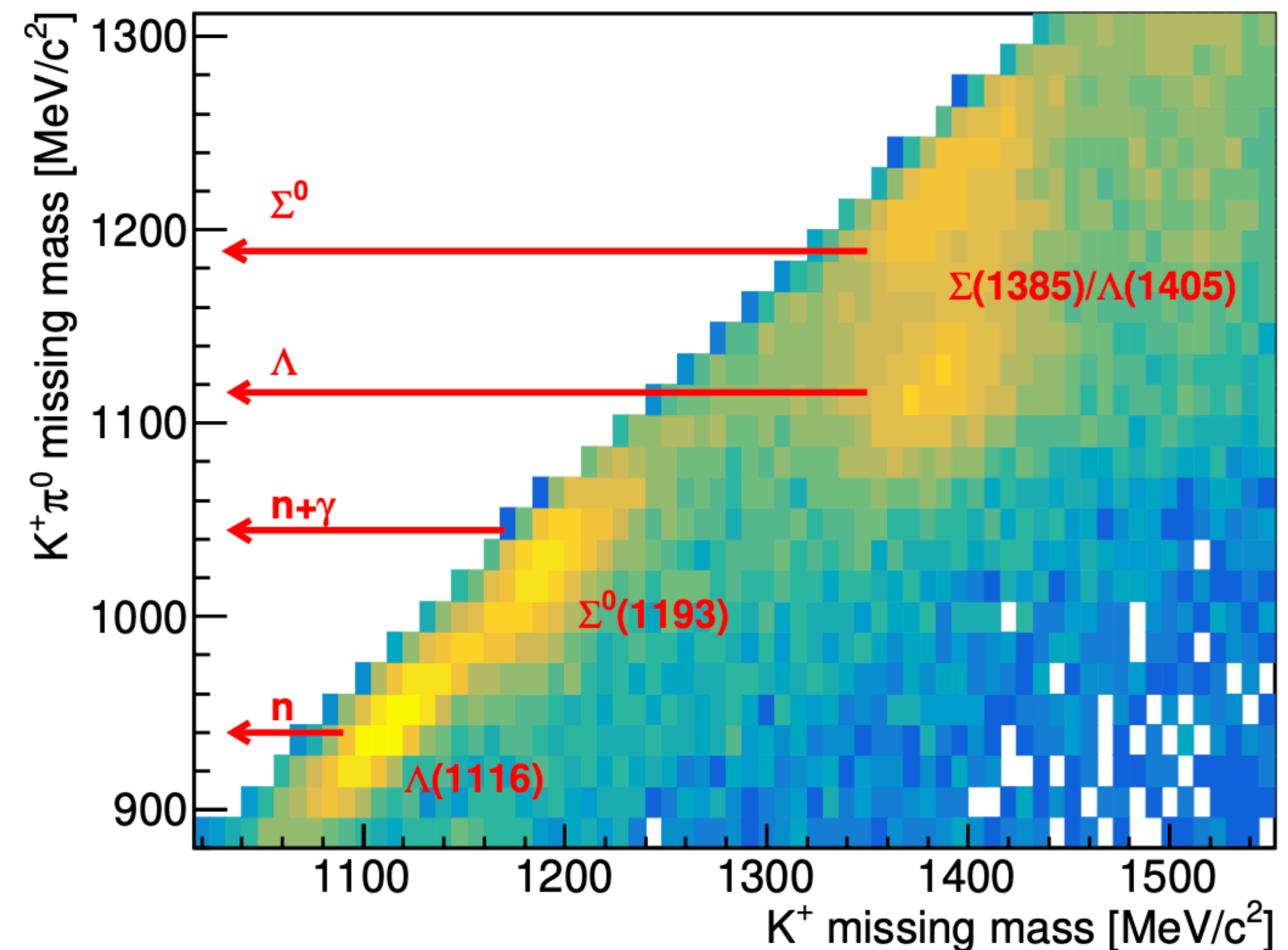
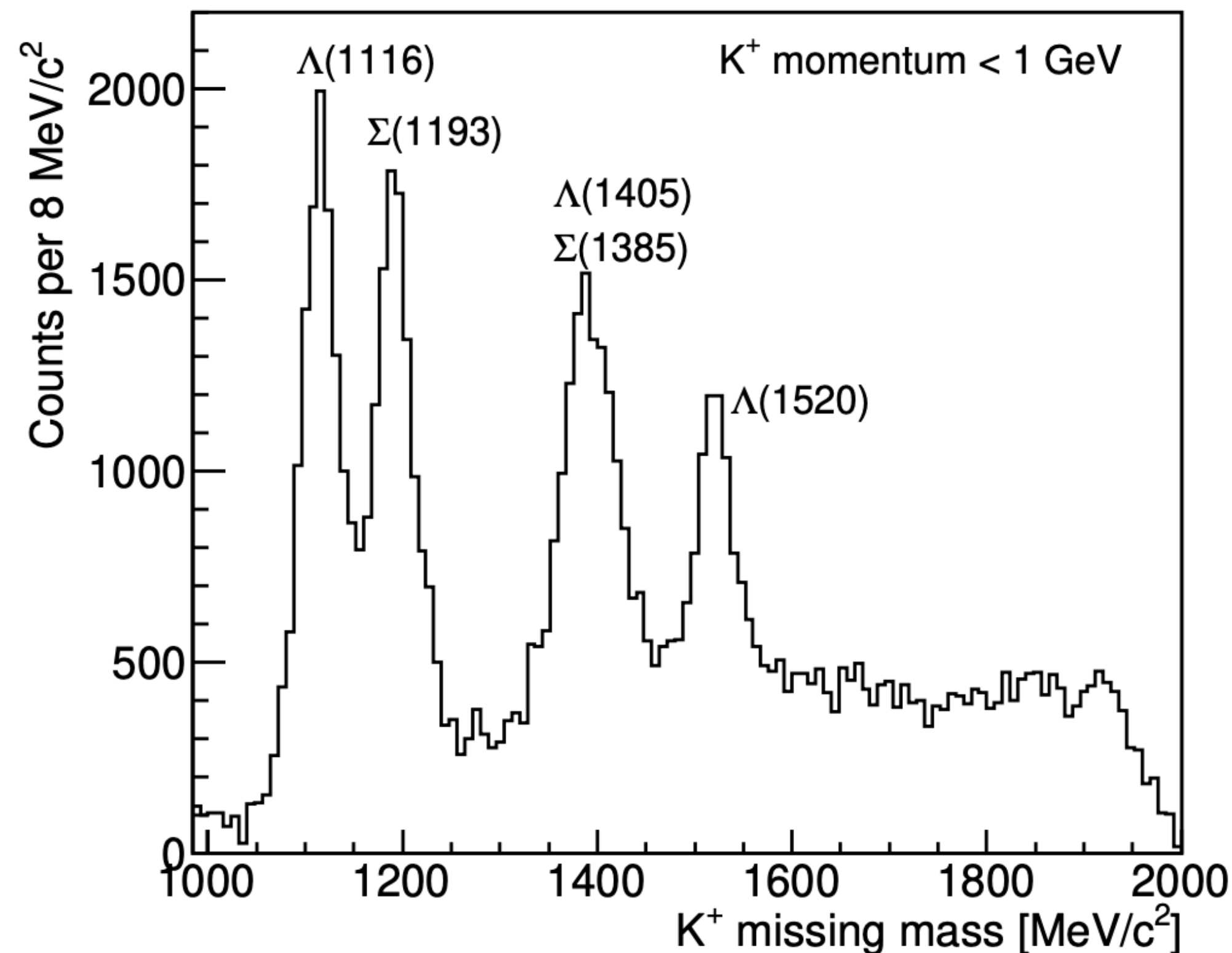


Charged particle identification



Identification of open strangeness final states

- K^+ identified in the forward spectrometer, $\cos \theta_{CM}^K > 0.9$
- The study of Y^* in an extremely low momentum transfer region

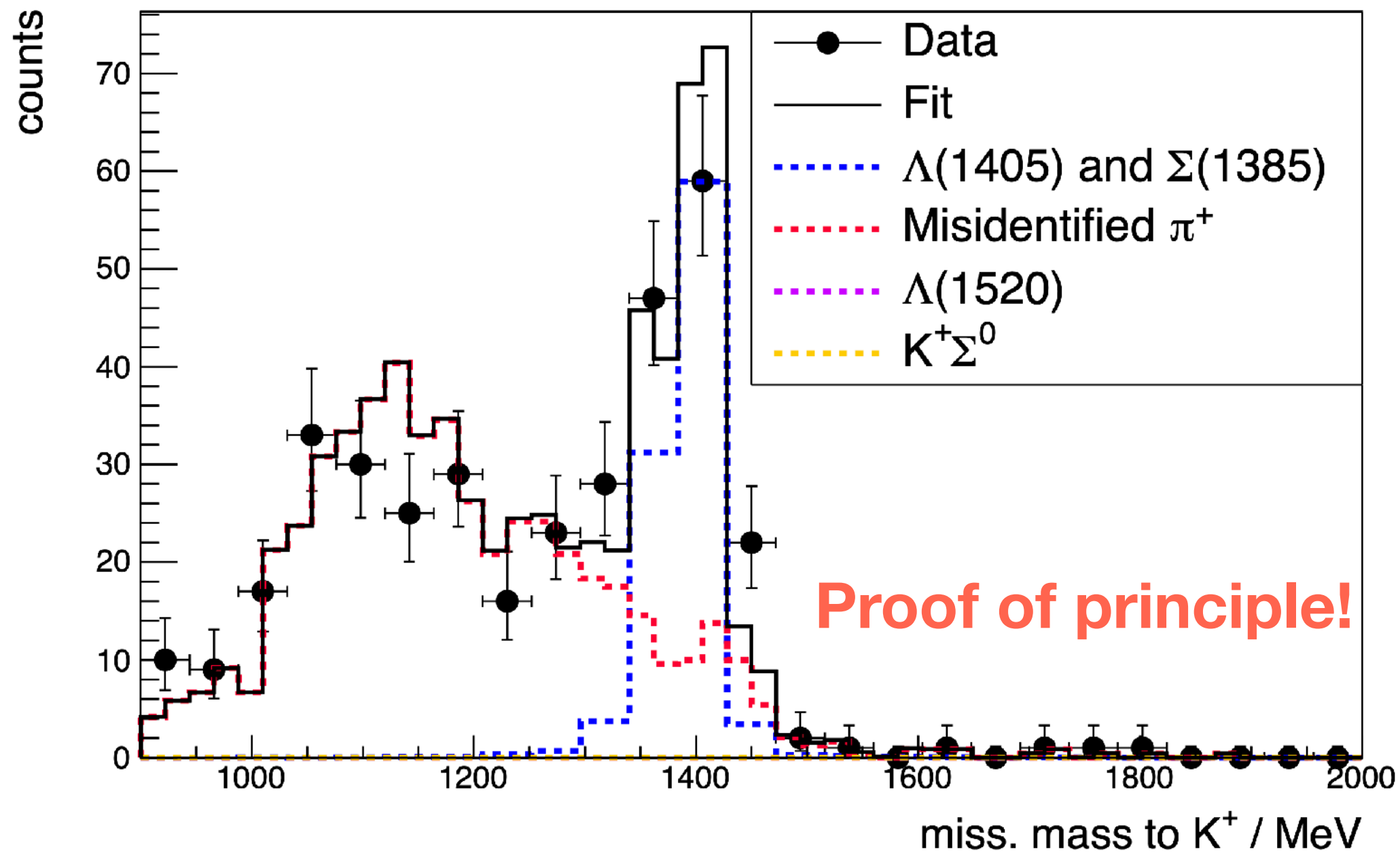


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- $\gamma p \rightarrow K^+\Sigma(1385)$
- $\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0\pi^0)$
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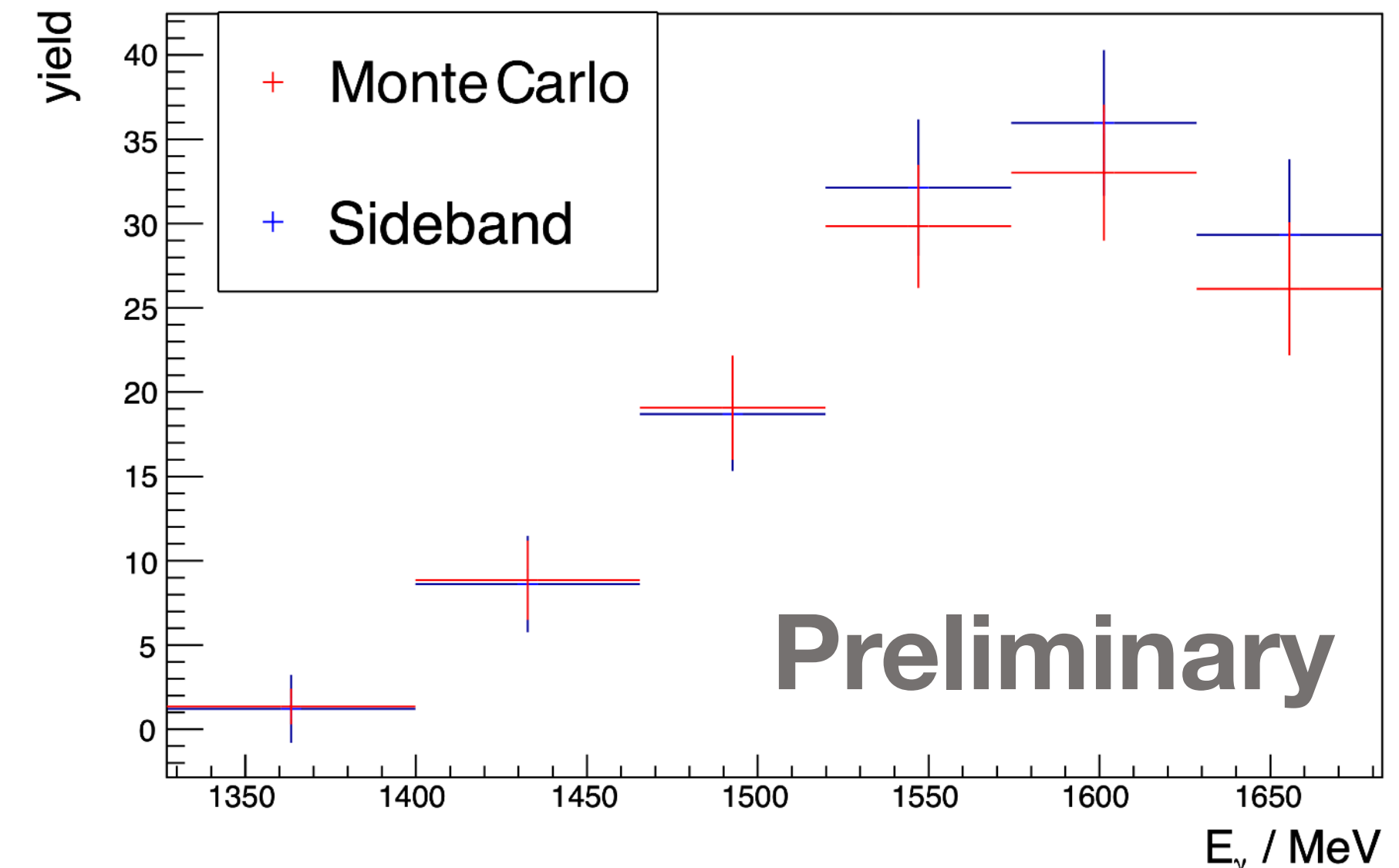
$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^+\pi^-)$

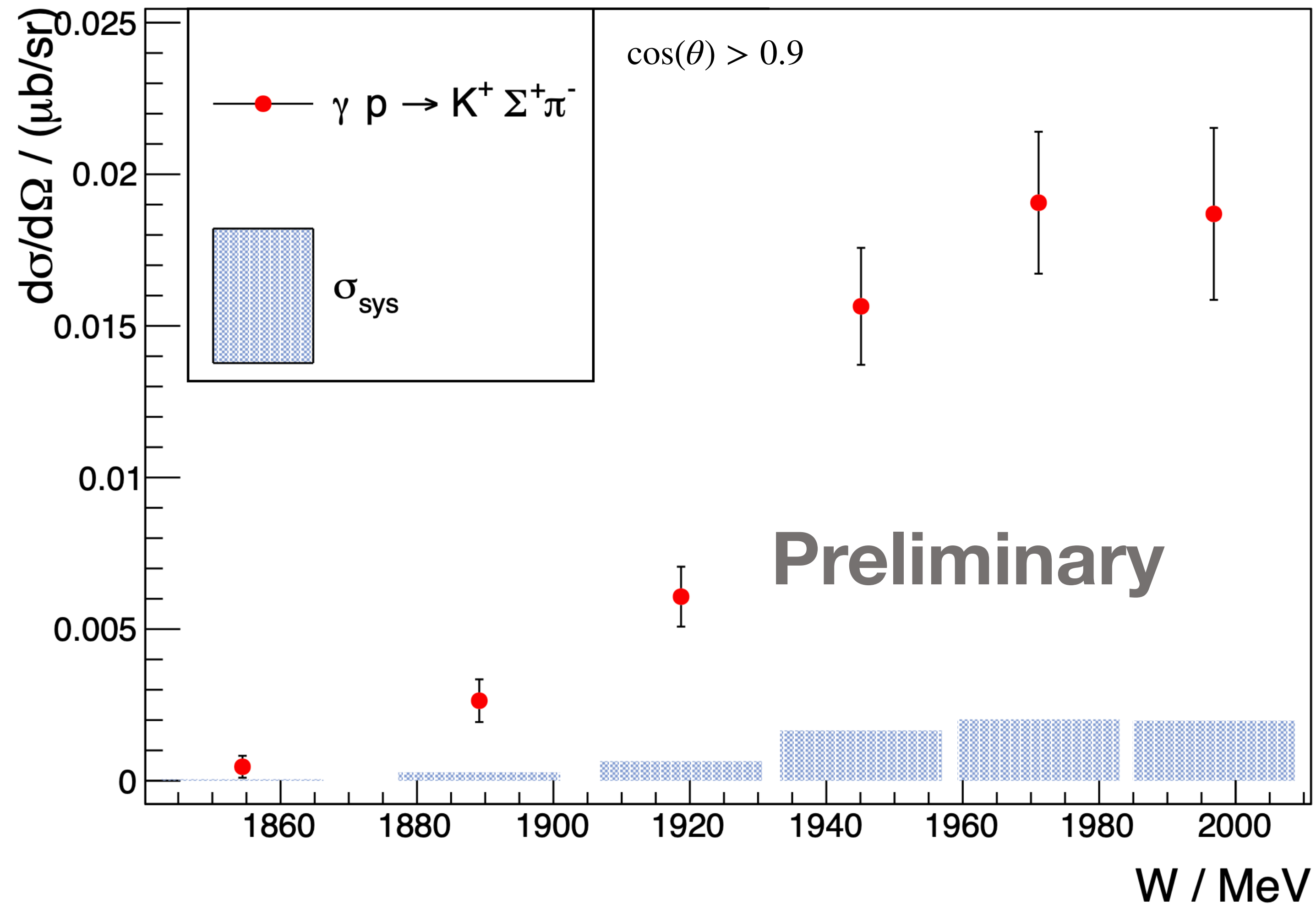
L. Plagens, Masters thesis, Uni Bonn 2024



- Yield extraction using two independent methods
 - Monte Carlo template fits
 - Sideband subtraction only considering pionic background

- K^+ identified in the forward spectrometer
 - $\cos \theta_{CM}^K > 0.9$
- Reconstructed via the decay $\Sigma^+\pi^- \rightarrow p\pi^0\pi^-$
 - π^0 identified in the central detector via the decay into 2γ
 - p and π^- identified via kinematic constraints



Differential Cross Section for $\gamma p \rightarrow K^+ \Sigma^+ \pi^-$ 

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$\gamma p \rightarrow K^+ \Sigma^0(1385)$

M. Jena, Masters thesis, Uni Bonn 2024

A. J. C. Figueiredo, PhD thesis (in preparation), Uni Bonn



- K^+ identified in the forward spectrometer

- $\cos \theta_{CM}^K > 0.9$

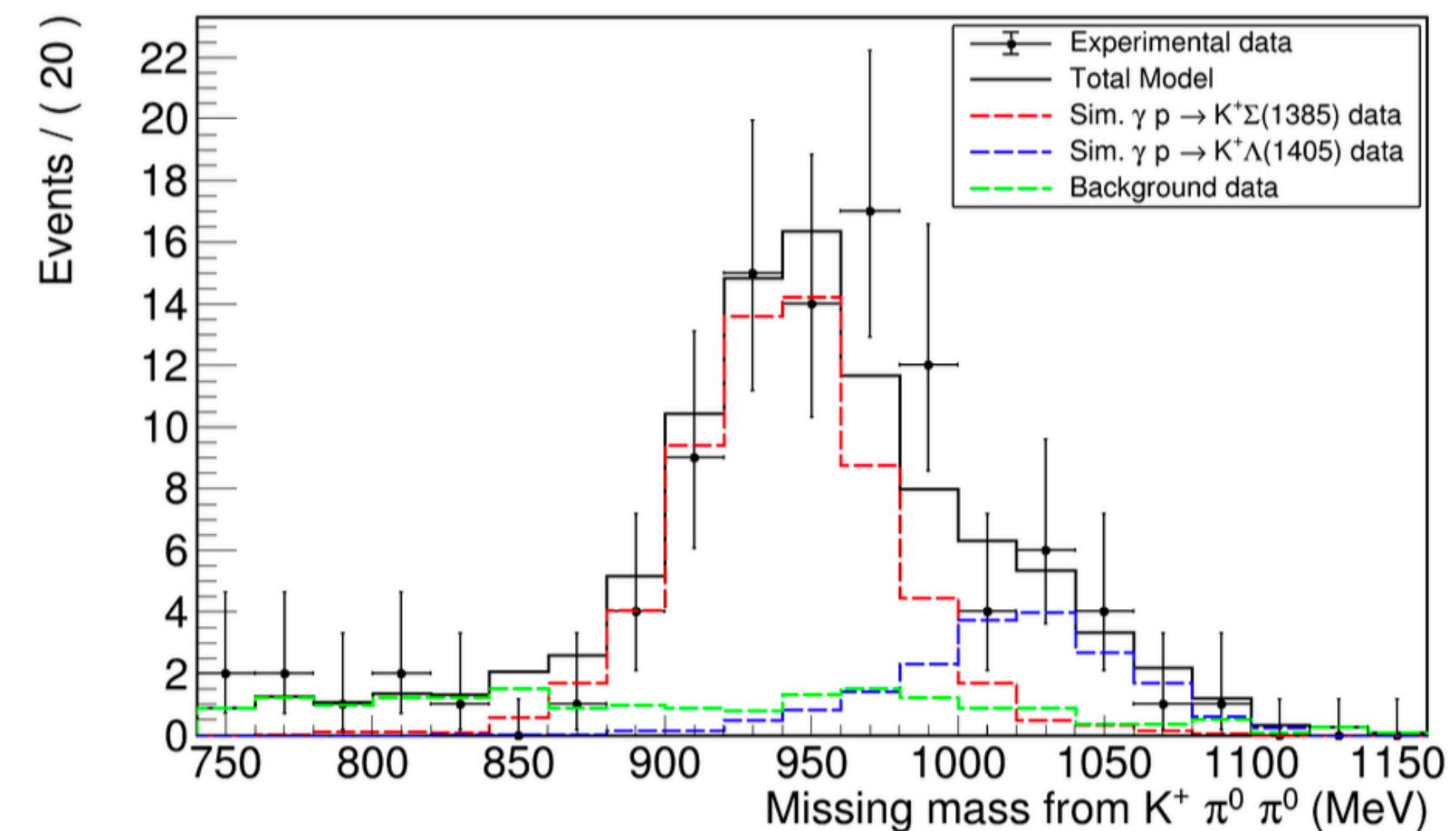
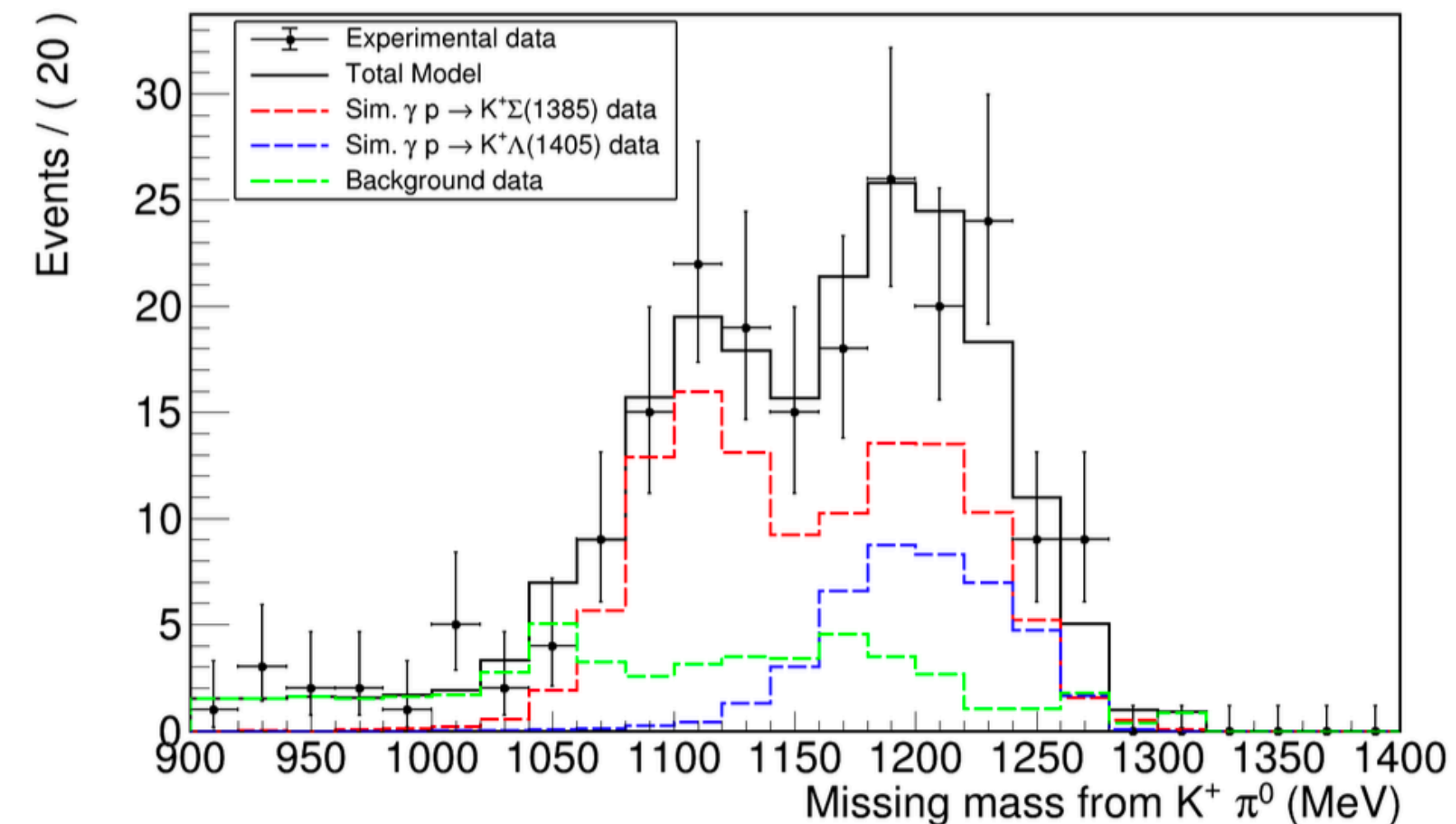
- 2 independent analysis methods ...

- ... with 2 independent fitting procedures

- $\Sigma^0(1385) \rightarrow \pi^0 \Lambda \rightarrow \pi^0(n\pi^0)$

- $\Sigma^0(1385) \rightarrow \pi^0 \Lambda \rightarrow \pi^0(p\pi^-)$

- Example separation of $\Sigma^0(1385)$ and $\Lambda(1405)$



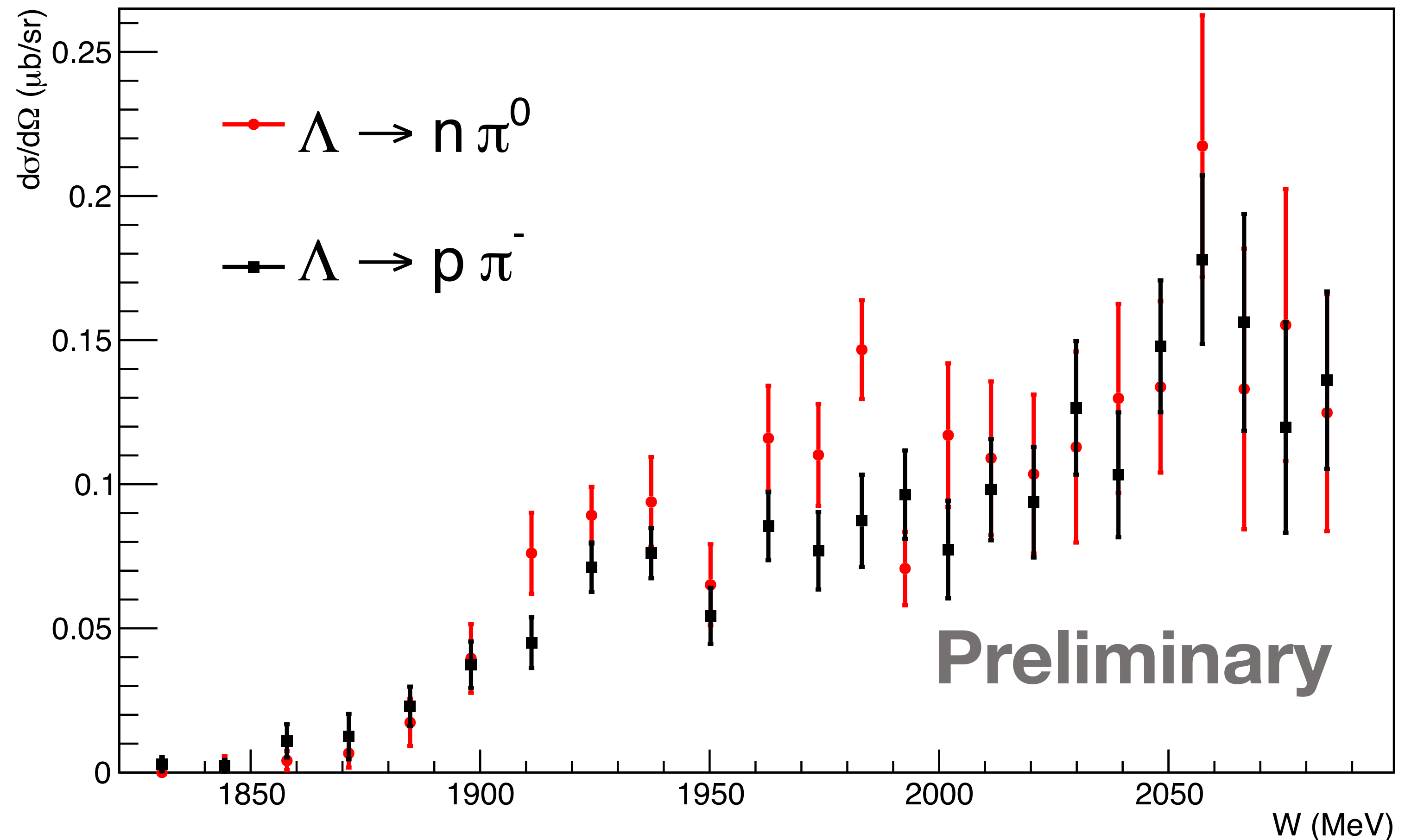
$\gamma p \rightarrow K^+ \Sigma^0(1385)$

M. Jena, Masters thesis, Uni Bonn 2024

A. J. C. Figueiredo, PhD thesis (in preparation), Uni Bonn



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 - $\cos \theta_{CM}^K > 0.9$
- 2 independent analysis methods ...
- ... with 2 independent fitting procedures
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Preliminary

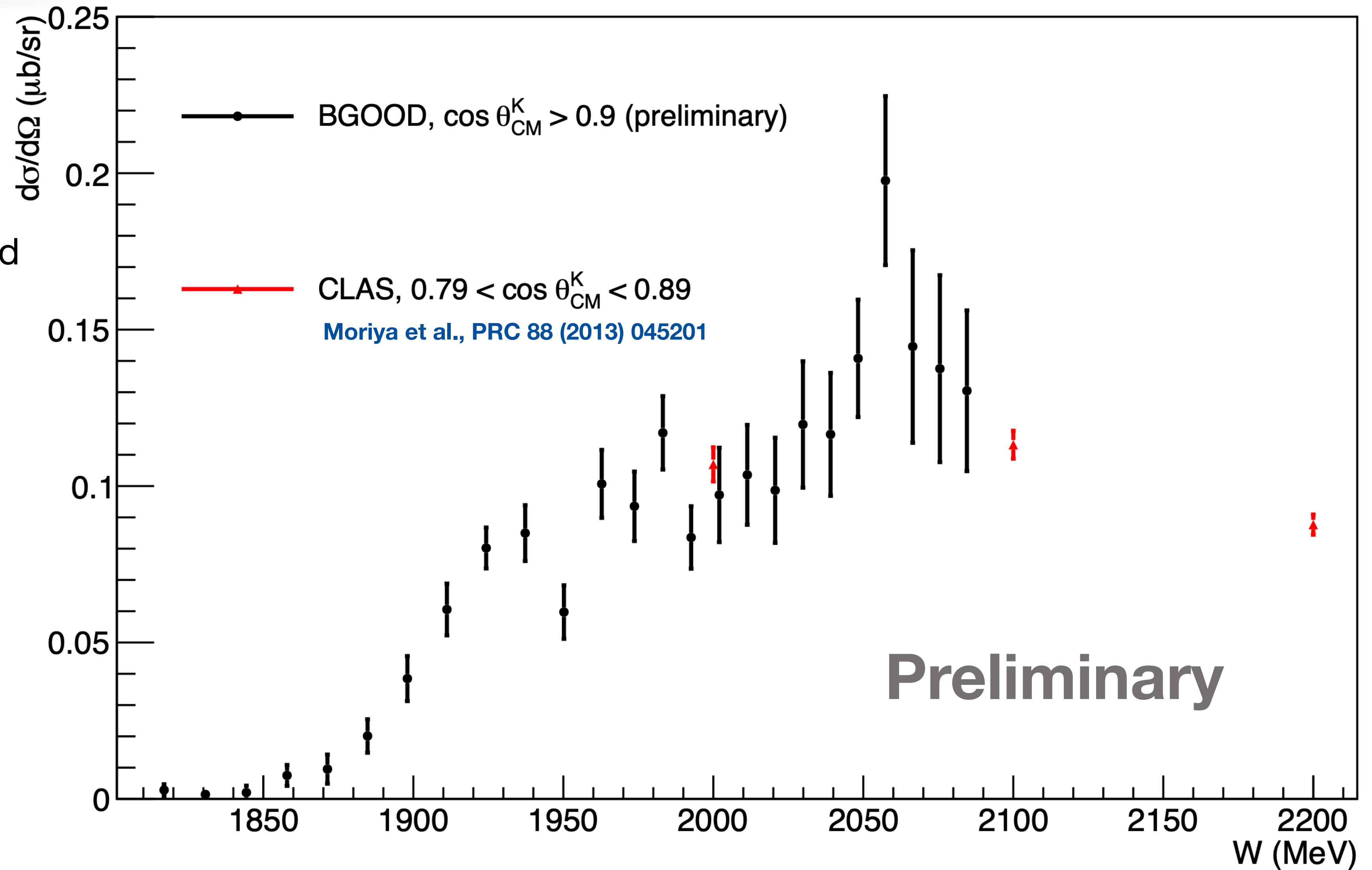
$\gamma p \rightarrow K^+ \Sigma^0(1385)$

M. Jena, Masters thesis, Uni Bonn 2024

A. J. Clara Figueiredo, PhD thesis (in preparation), Uni Bonn



- 1st measurement from threshold
- At $\cos(\theta) > 0.9$
- High W resolution



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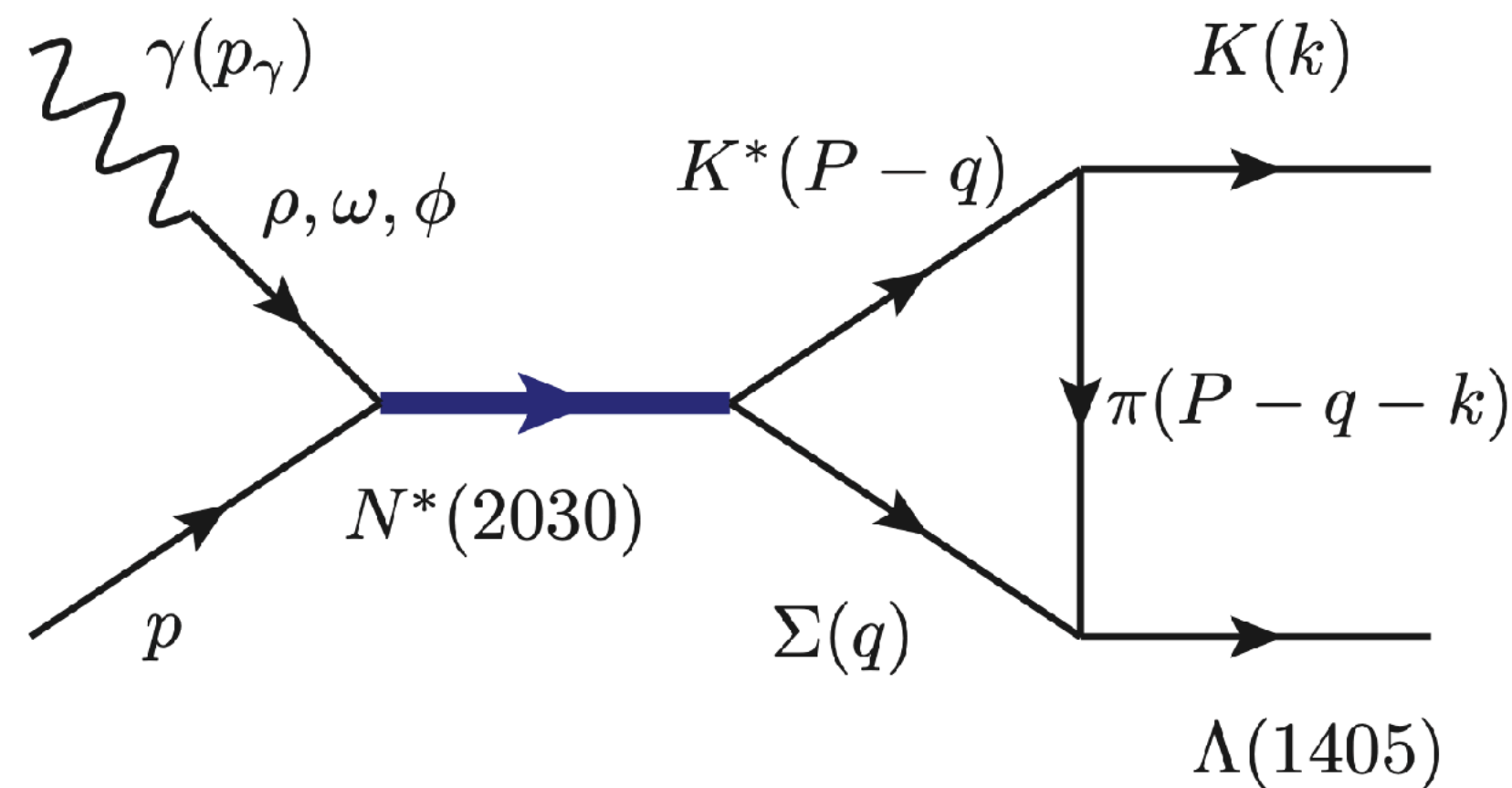
$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$

G. Scheluchin, T.C Jude *et al.*
PLB 833 (2022) 137375

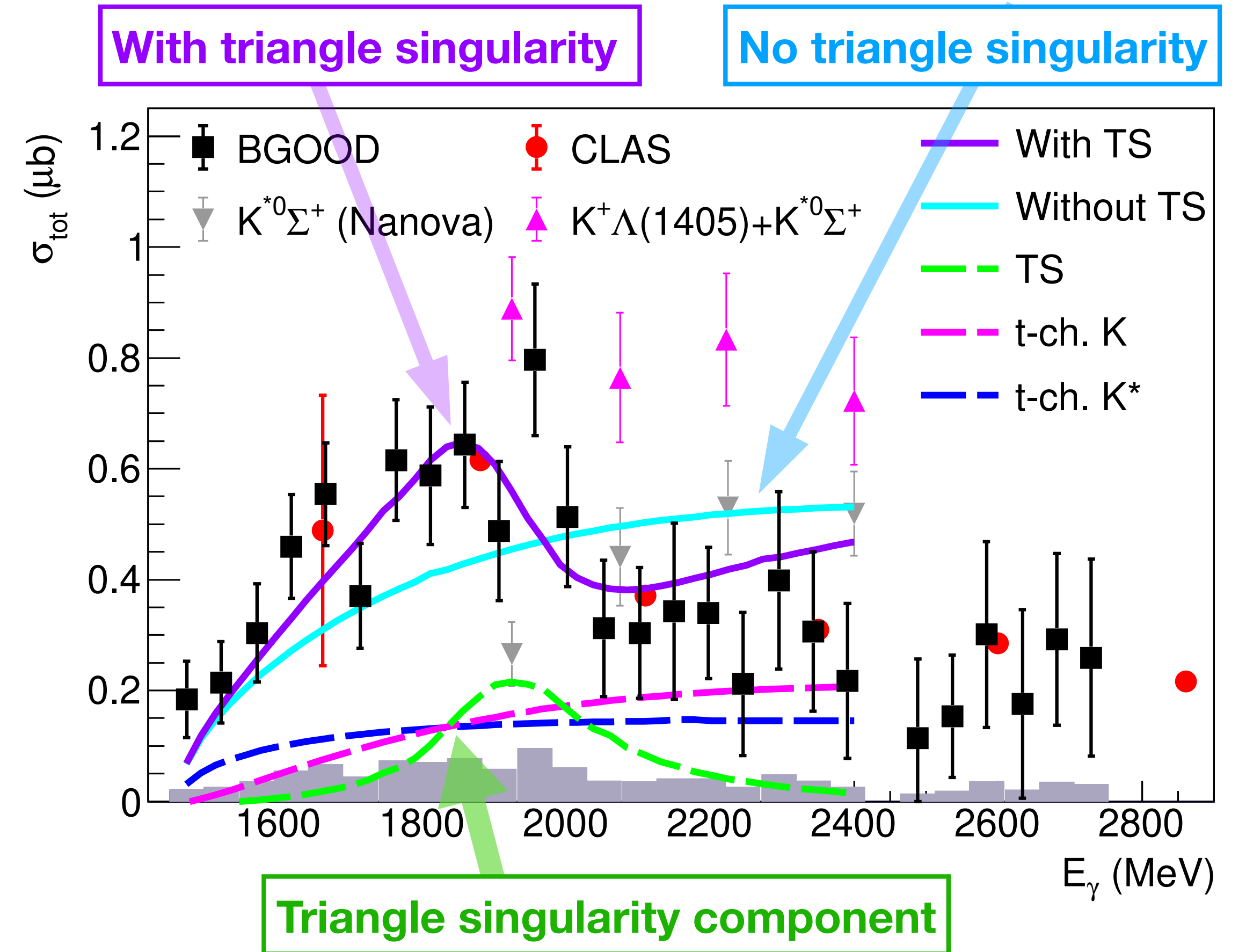


$\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ \Sigma^0 \pi^0 \rightarrow K^+ 3\gamma p \pi^-$ & kinematic fit

- Proposed triangle singularity:
- The same dynamically generated $N^*(2030)$ proposed for cusp in $K^0 \Sigma^+$



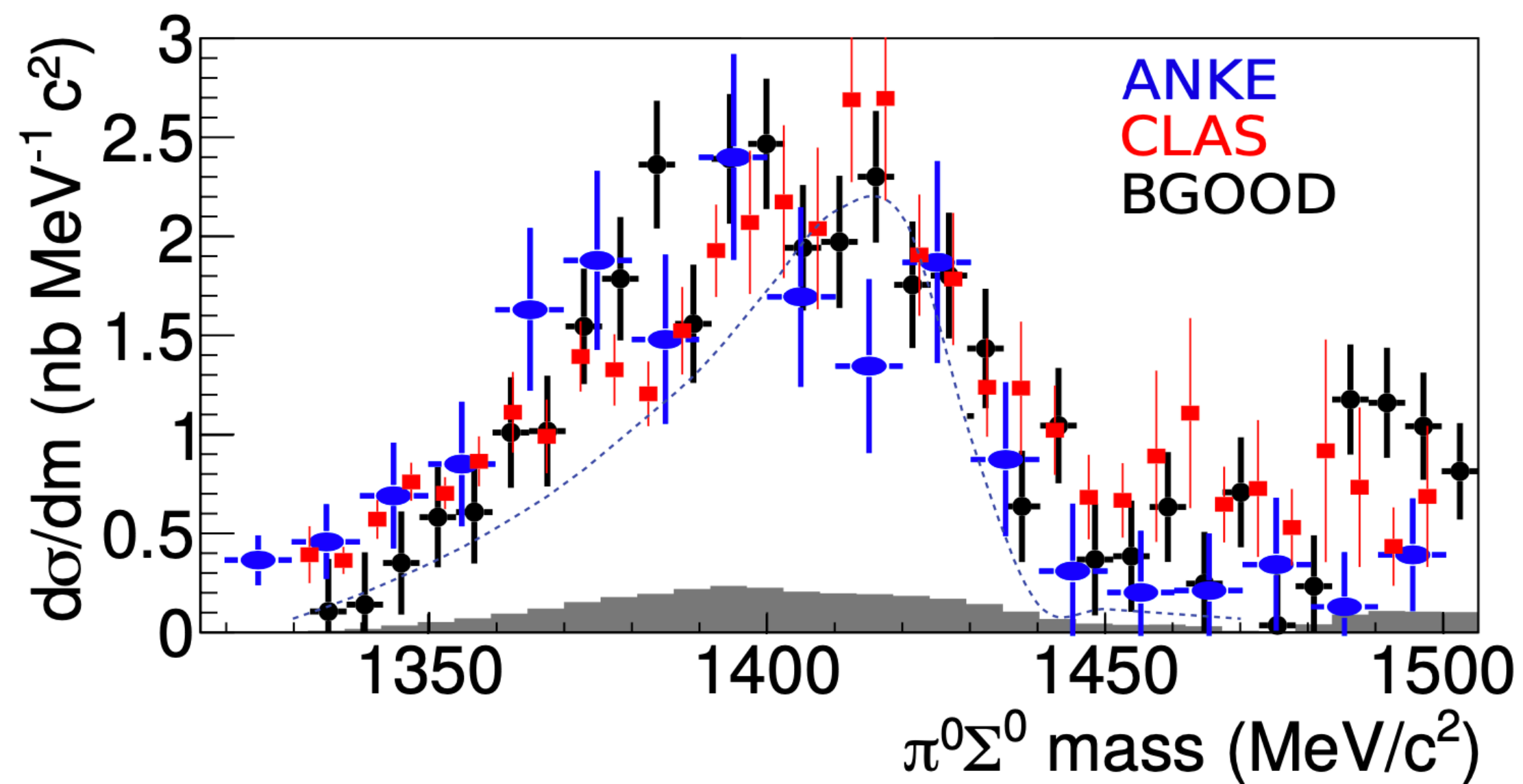
Wang *et al.*, PRC 95, 015205 (2017)



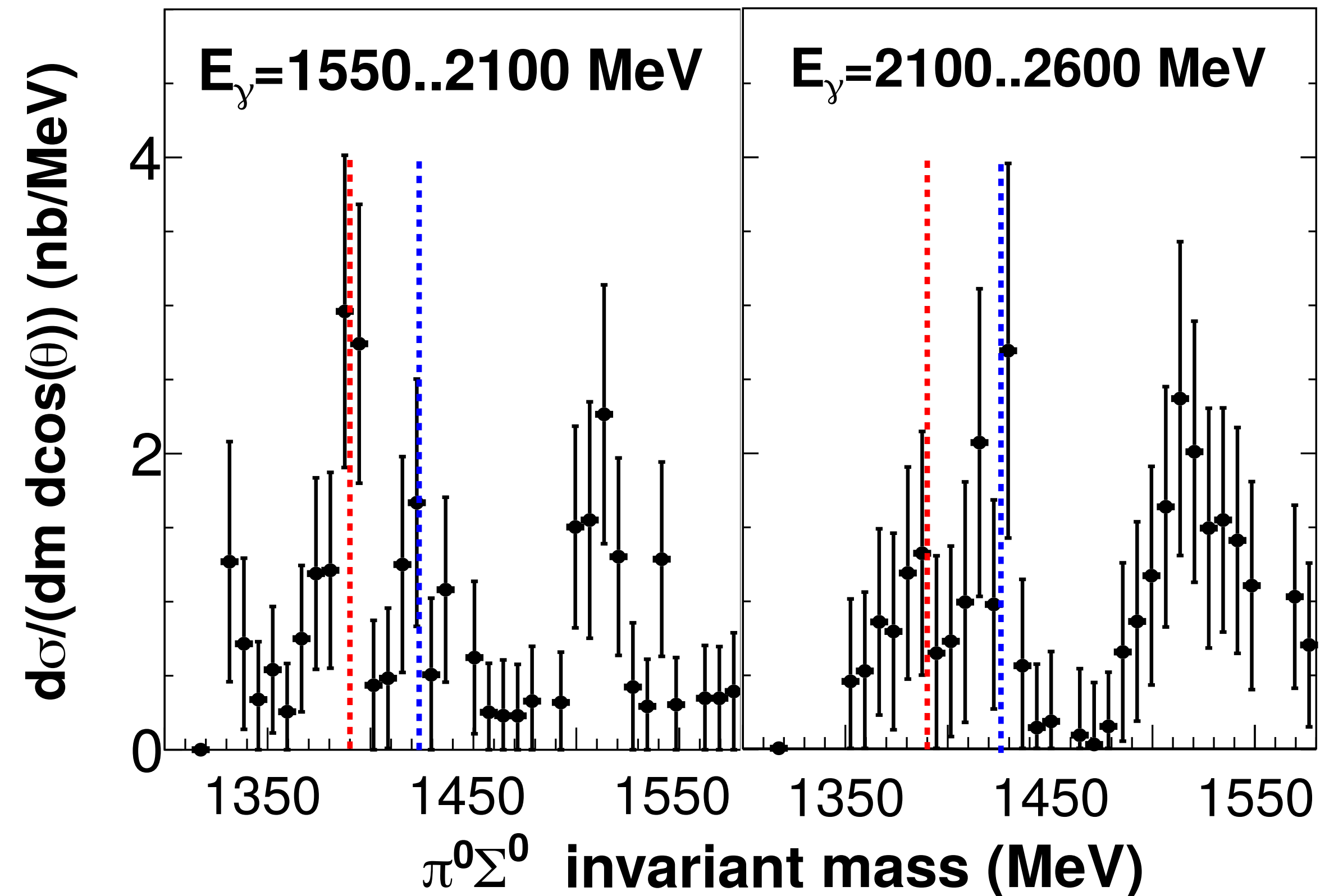
$$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$$

$\Lambda(1405)$ line shape measurements

- 2 peak structure at 1395 & 1425 MeV/c²?
- Integrated over all $\cos \theta_{\text{CM}}^K$:

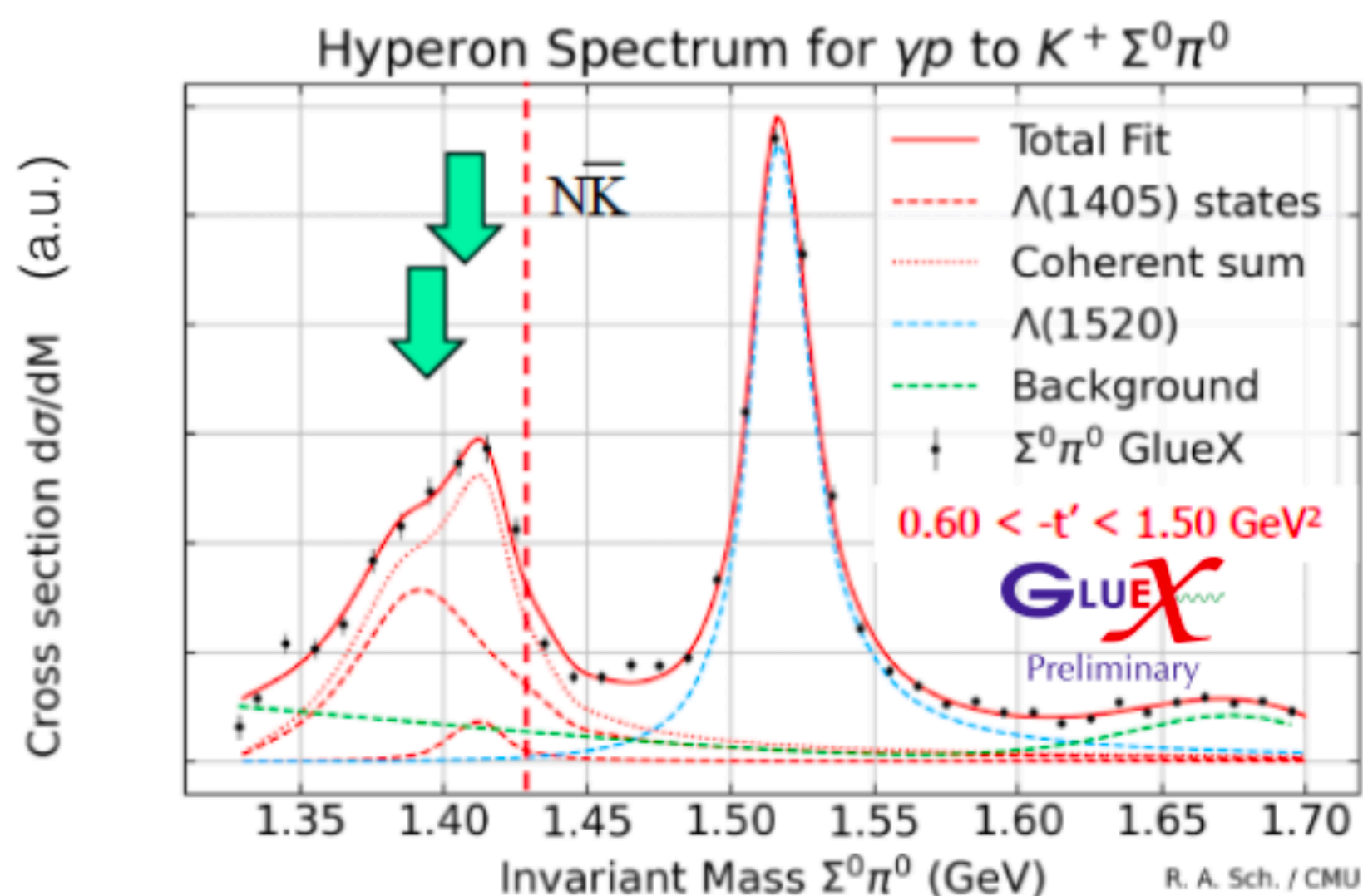
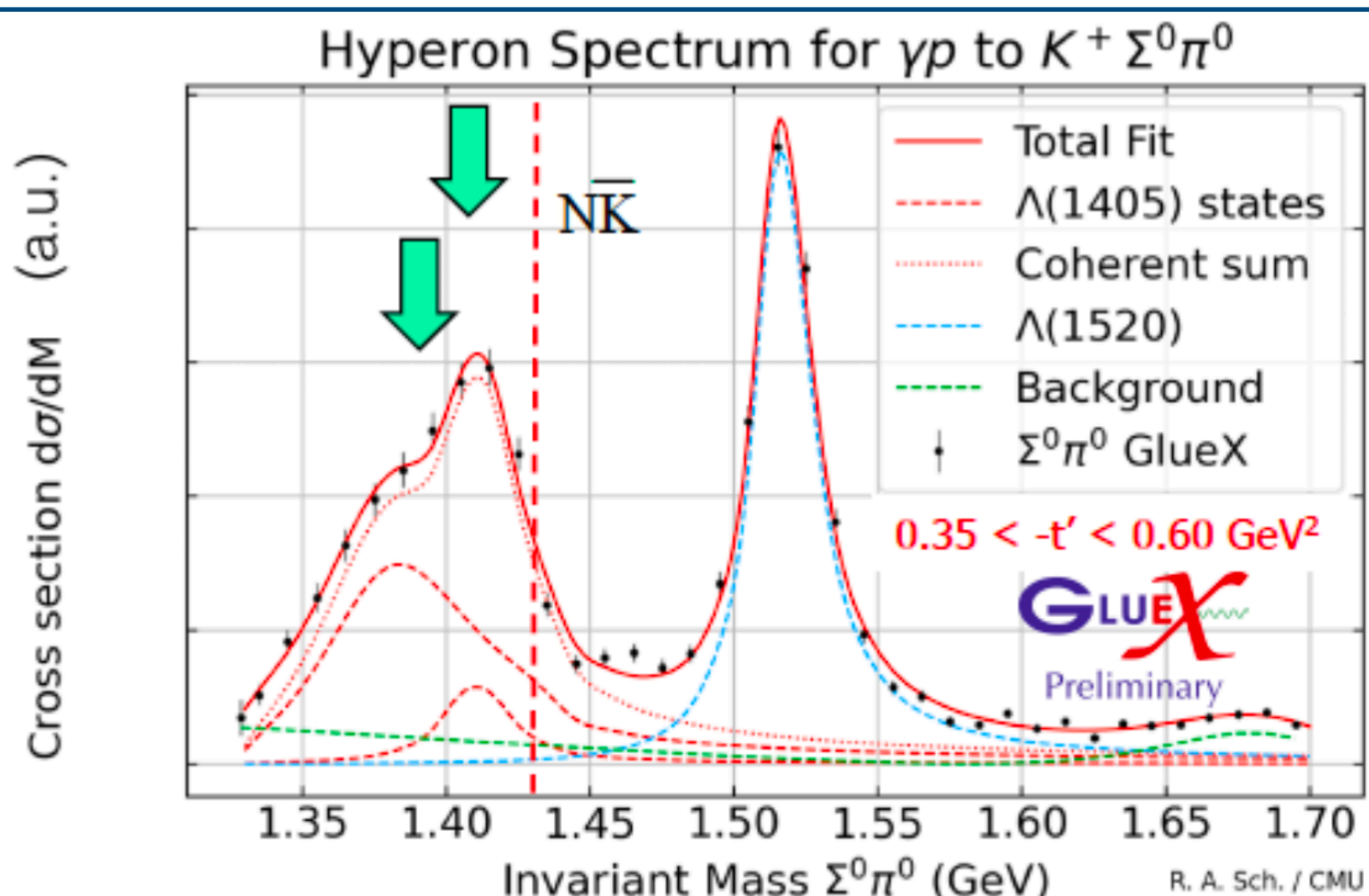
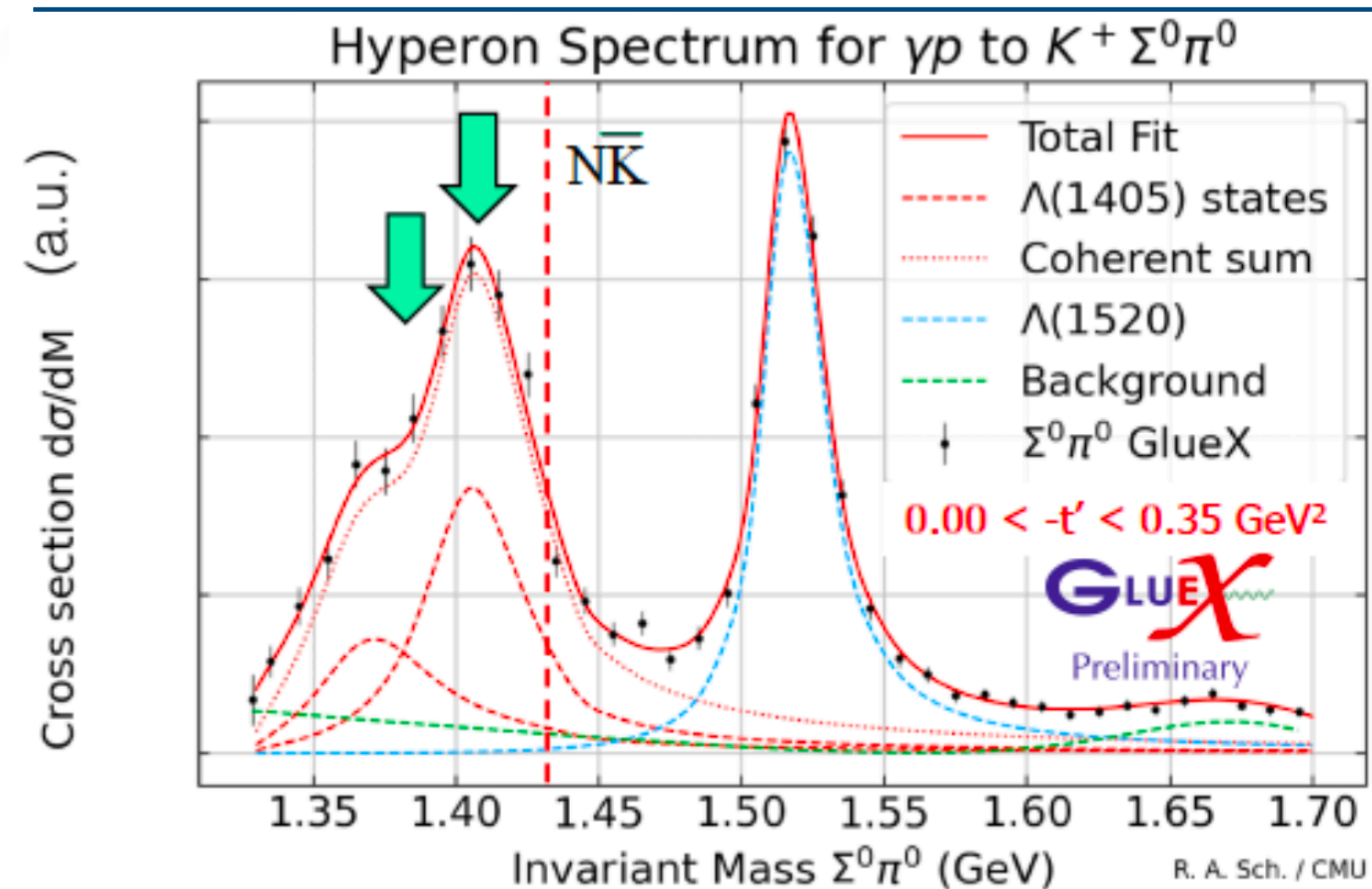


- At forward K^+ angles: $\cos \theta_{\text{CM}}^K > 0.86$:



- Relative amplitudes of “poles” appear to vary

Comparison – GlueX Results



Preliminary

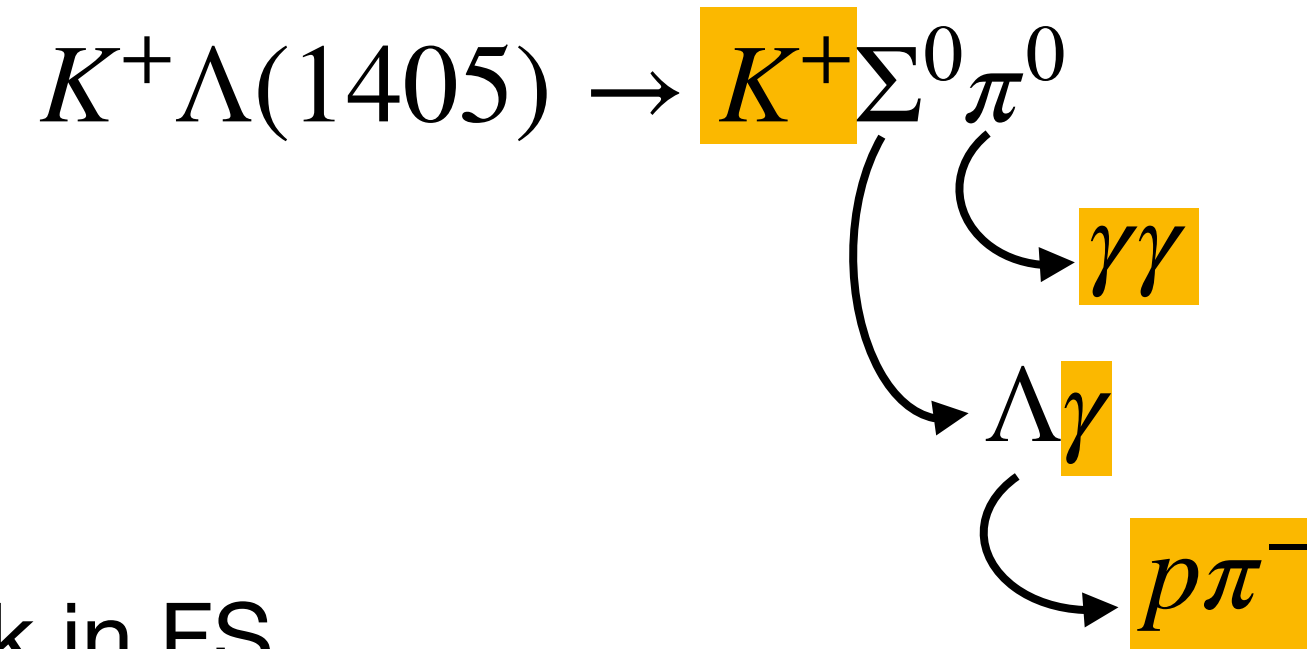
- Inv. Mass distribution shows deviation from a single Flatté-type Breit-Wigner
- Fit in favour of two amplitudes
- Indication of possible t -dependency

arXiv:2209.06230 [nucl-ex]

$$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$$

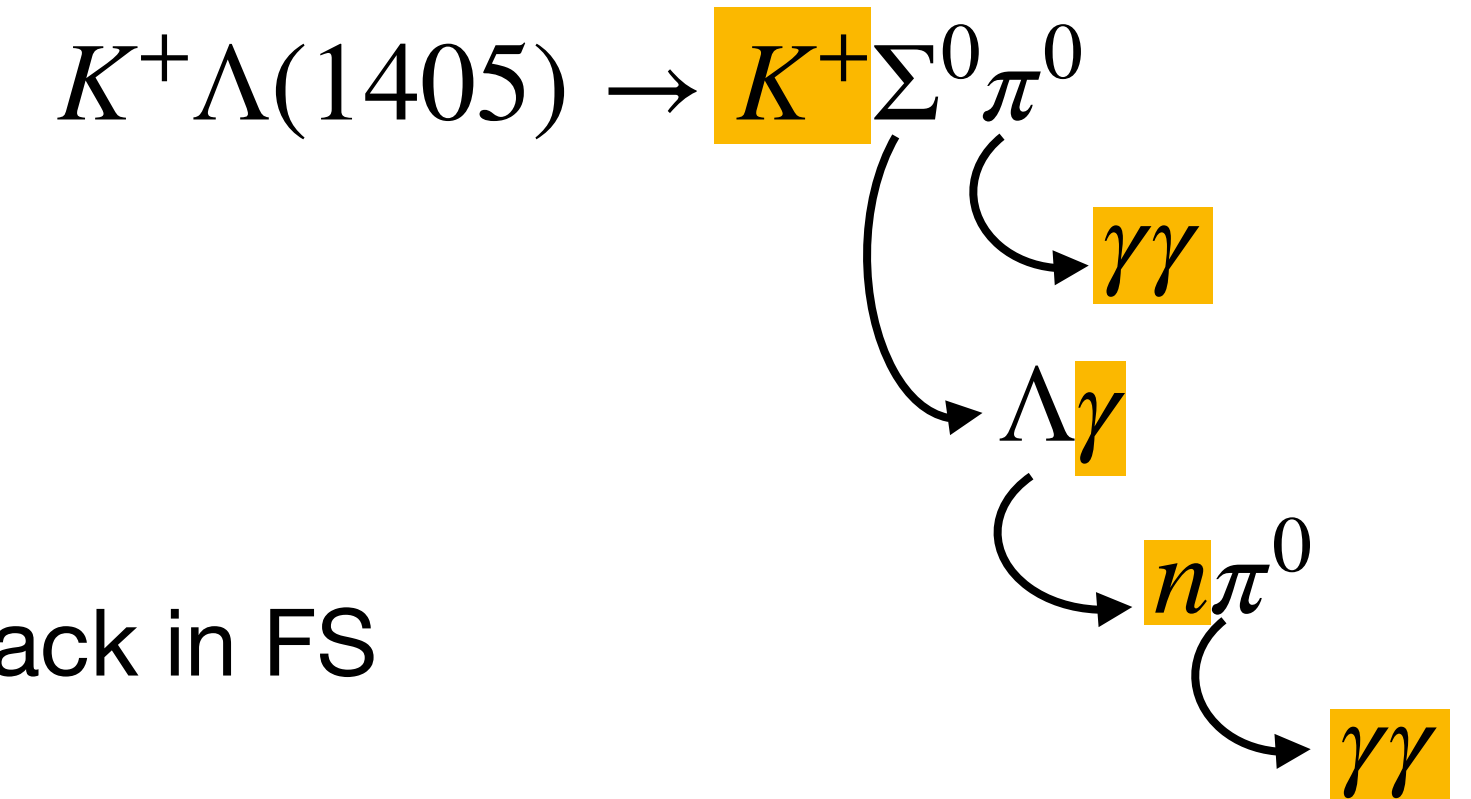
Event Selection

$$\Lambda \rightarrow p\pi^-:$$



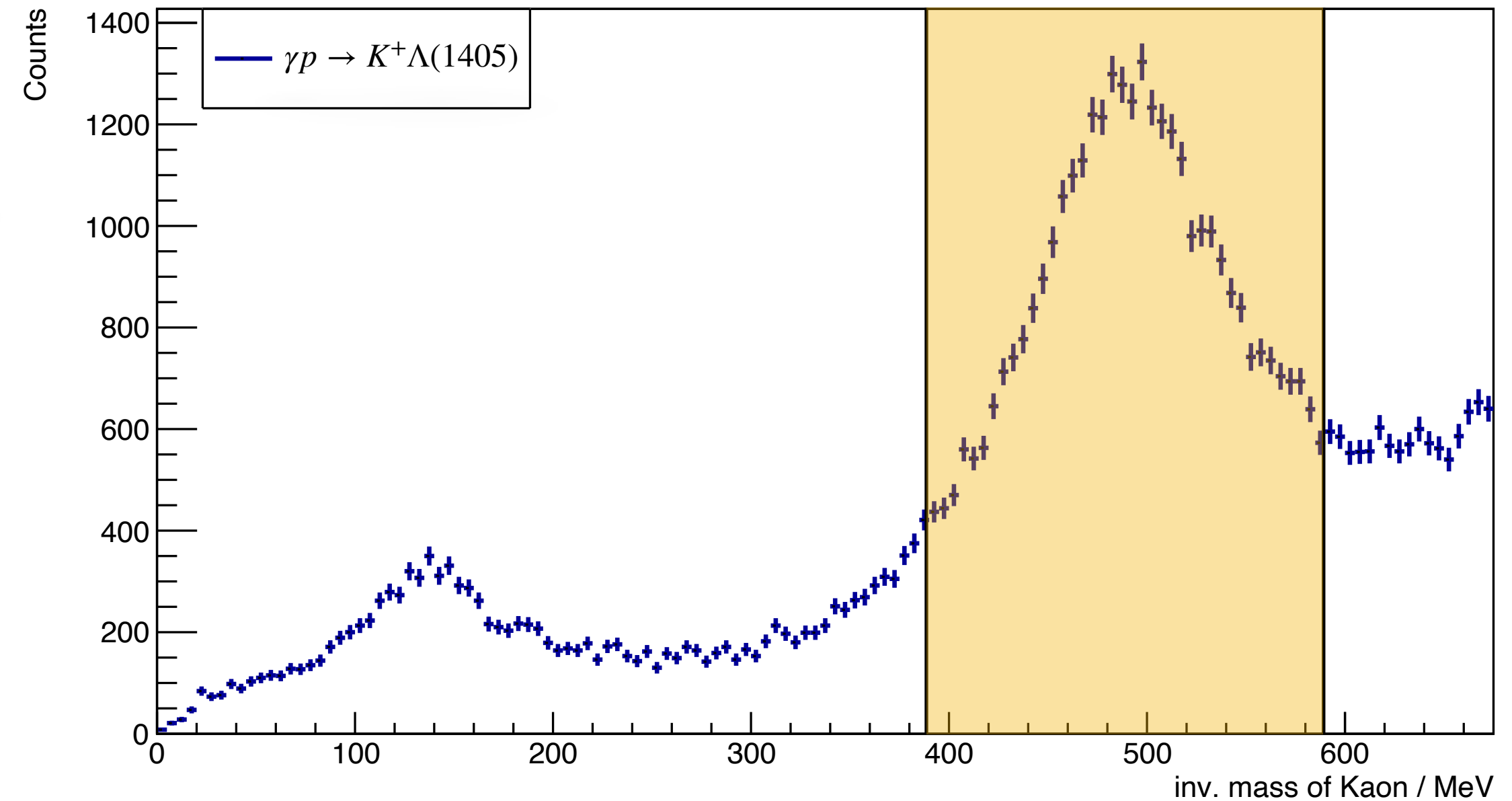
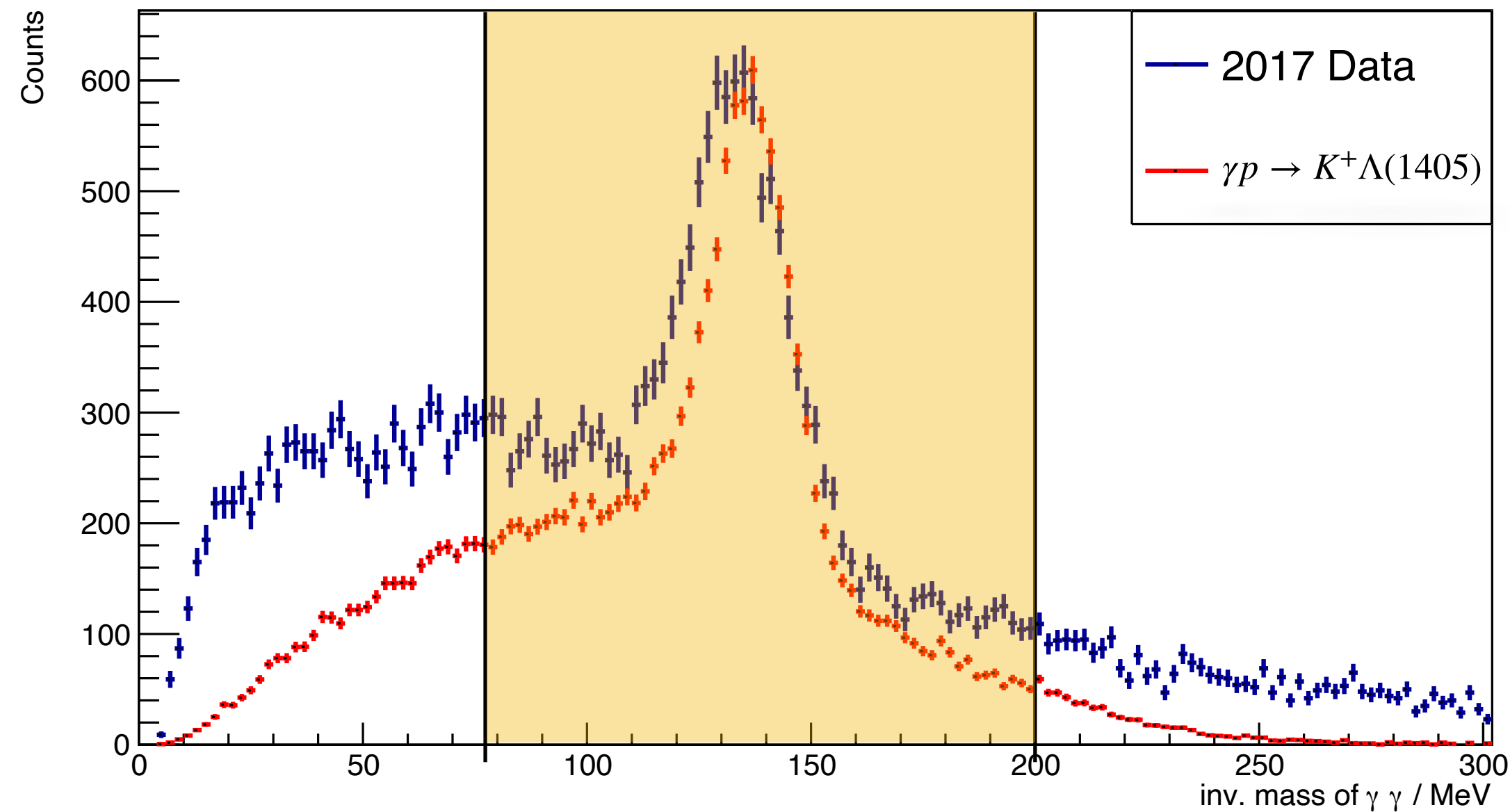
- 1 charged track in FS
- 2 charged tracks in BGO + SciRi
- 3 neutral tracks in BGO

$$\Lambda \rightarrow n\pi^0:$$



- 1 charged track in FS
- 0 charged tracks in BGO + SciRi
- 5-6 neutral tracks in BGO

$$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$$



Charged topology:

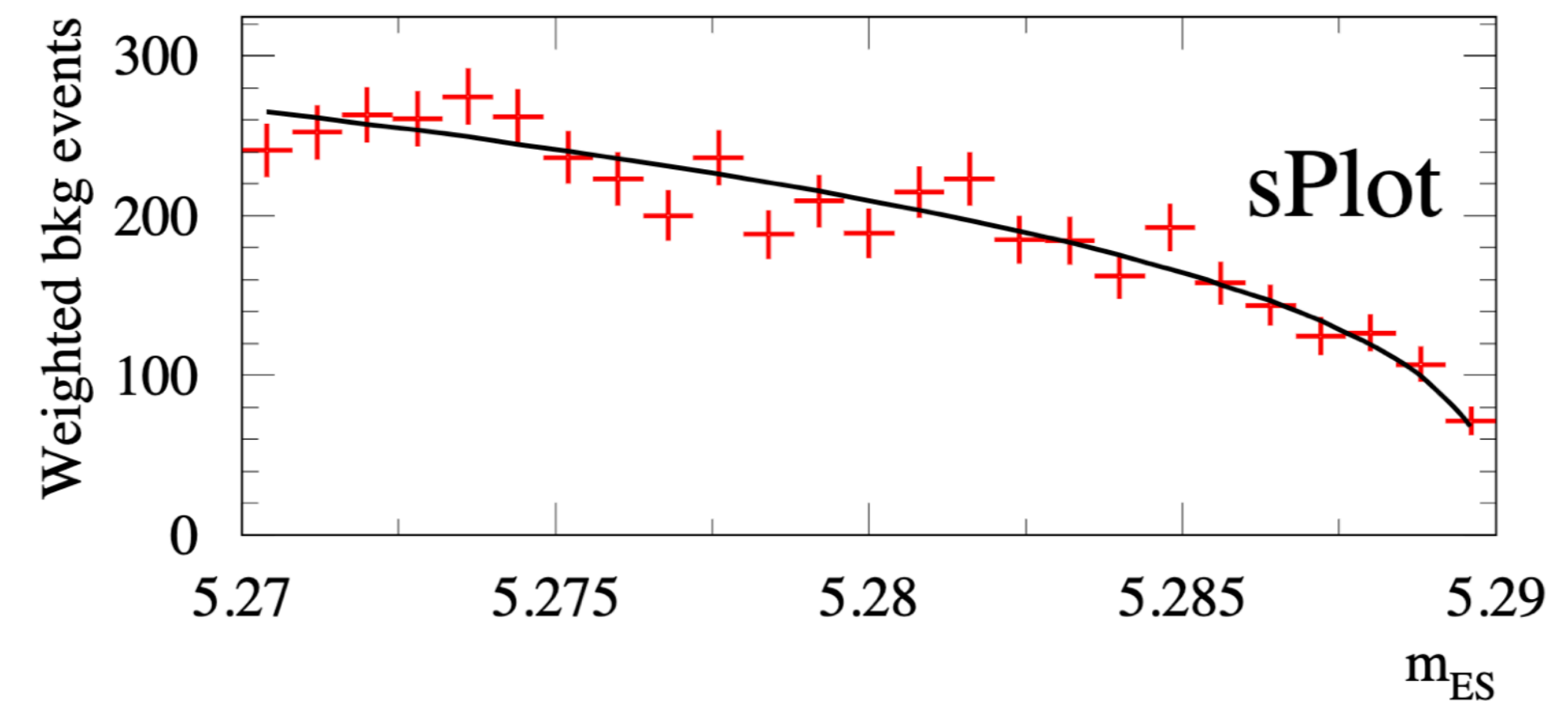
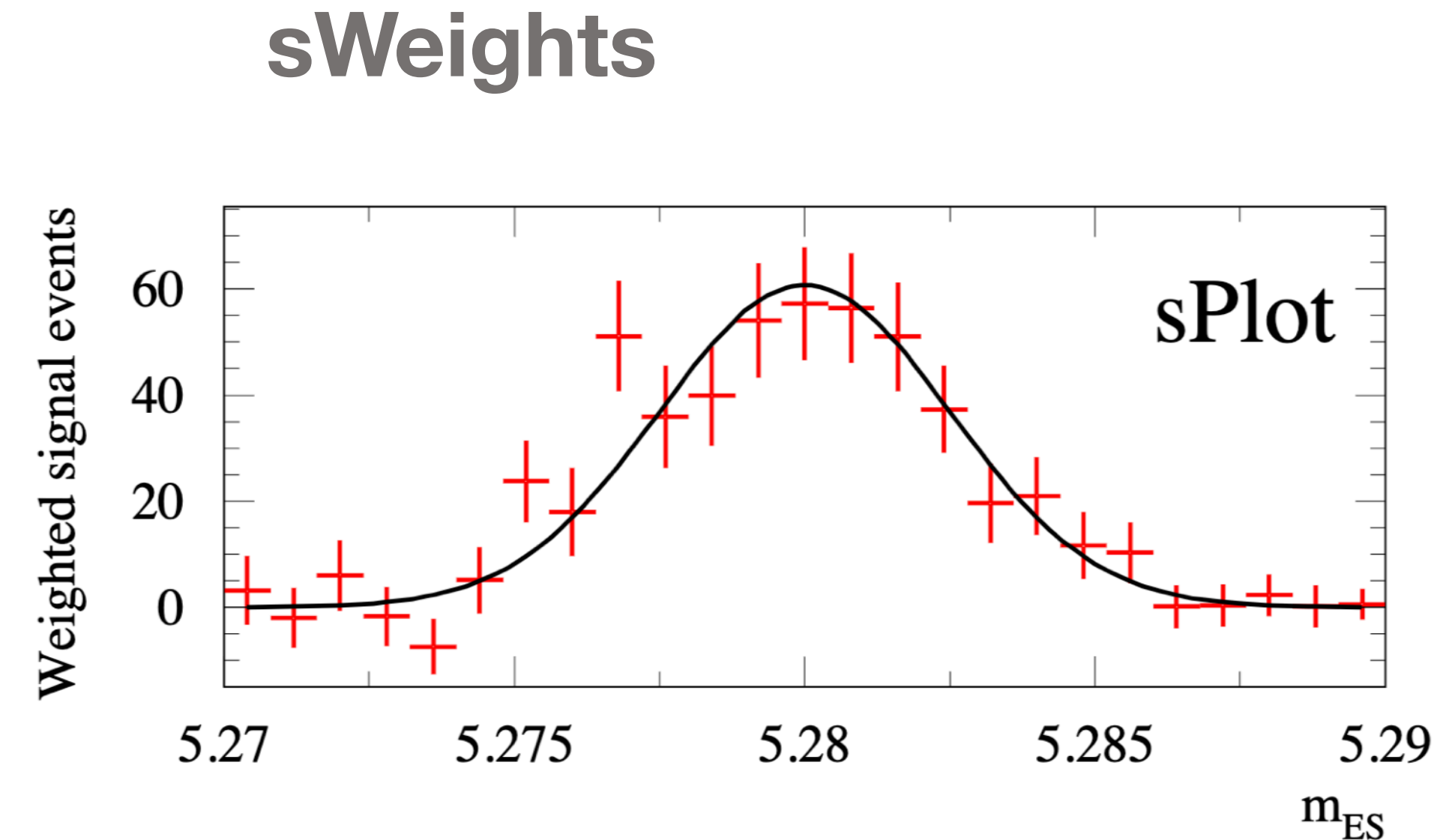
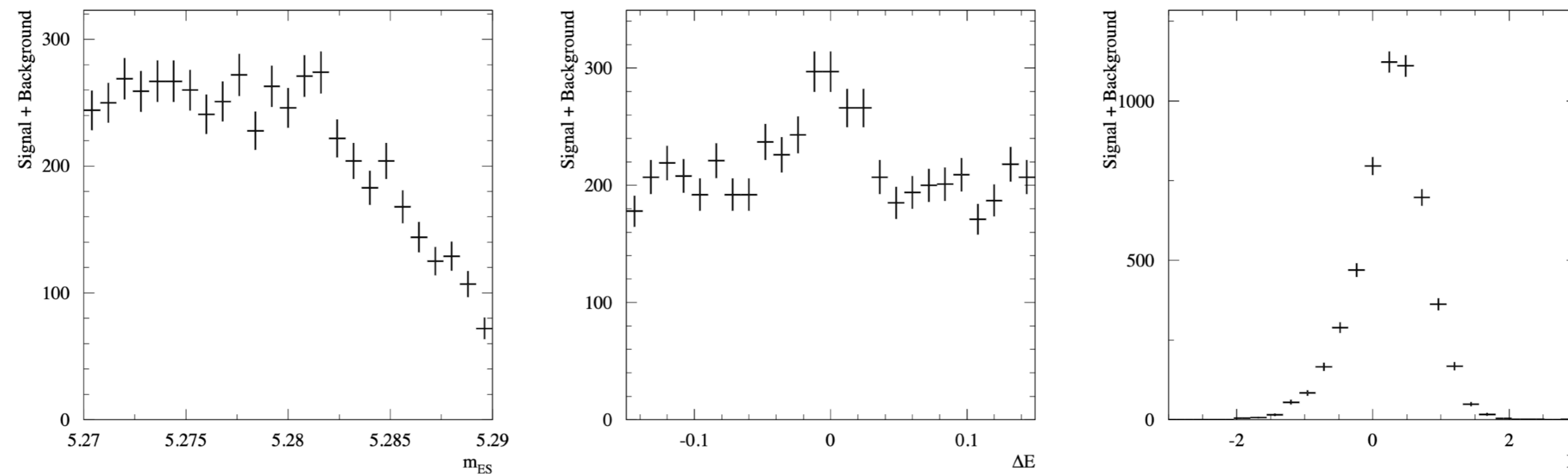
- Reconstruct Σ^0 candidate from $K^+ \pi^0$ missing momentum
- Reconstruct Λ candidate from Σ^0 and decay γ_{Σ^0}
- Treat closest track to Λ as p

Neutral topology:

- Reconstruct n candidate from $K^+ \pi^0 \pi^0 \gamma_{\Sigma^0}$ missing momentum

$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$

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- Data sample containing multiple contributions/species (signal/background)
- Likelihood fit performed for discriminating variables
- Fitted yield and covariance matrix used to compute species-specific sWeights
- Projection on control variable without hard cuts

[arXiv:physics/0402083 \[physics.data-an\]](https://arxiv.org/abs/physics/0402083)

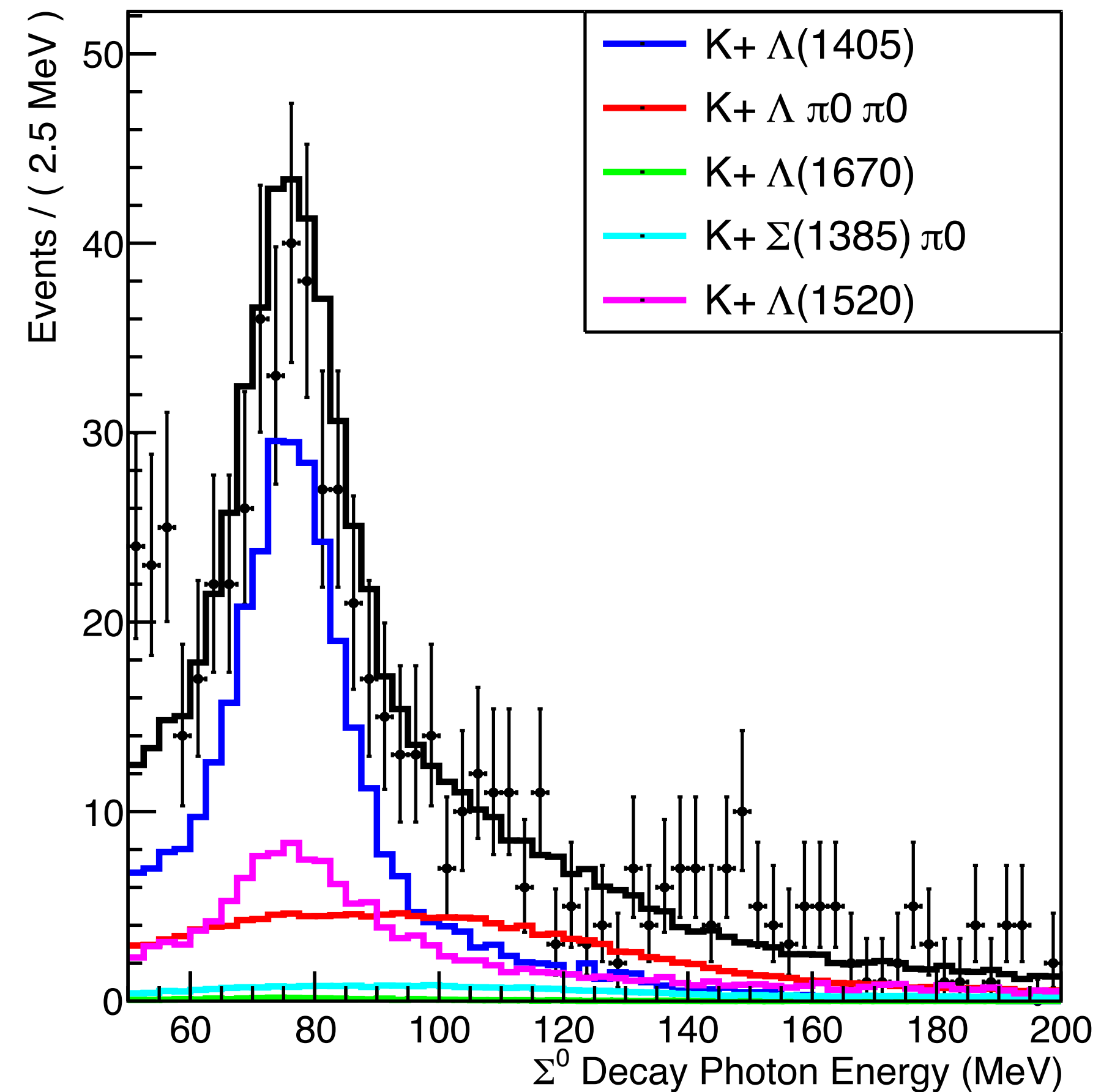
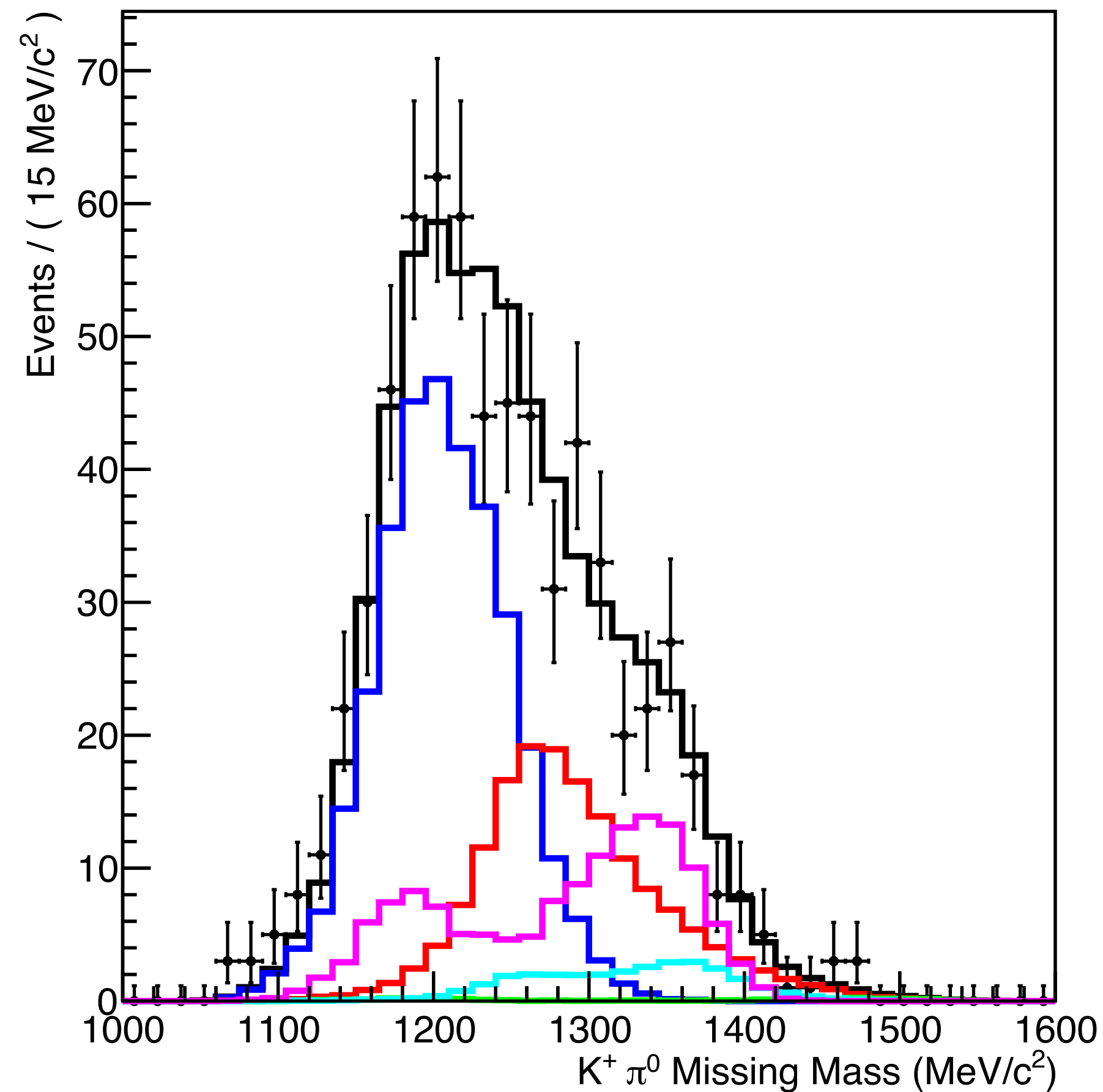
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$\Lambda(1405)$ line shape extraction – neutral topology

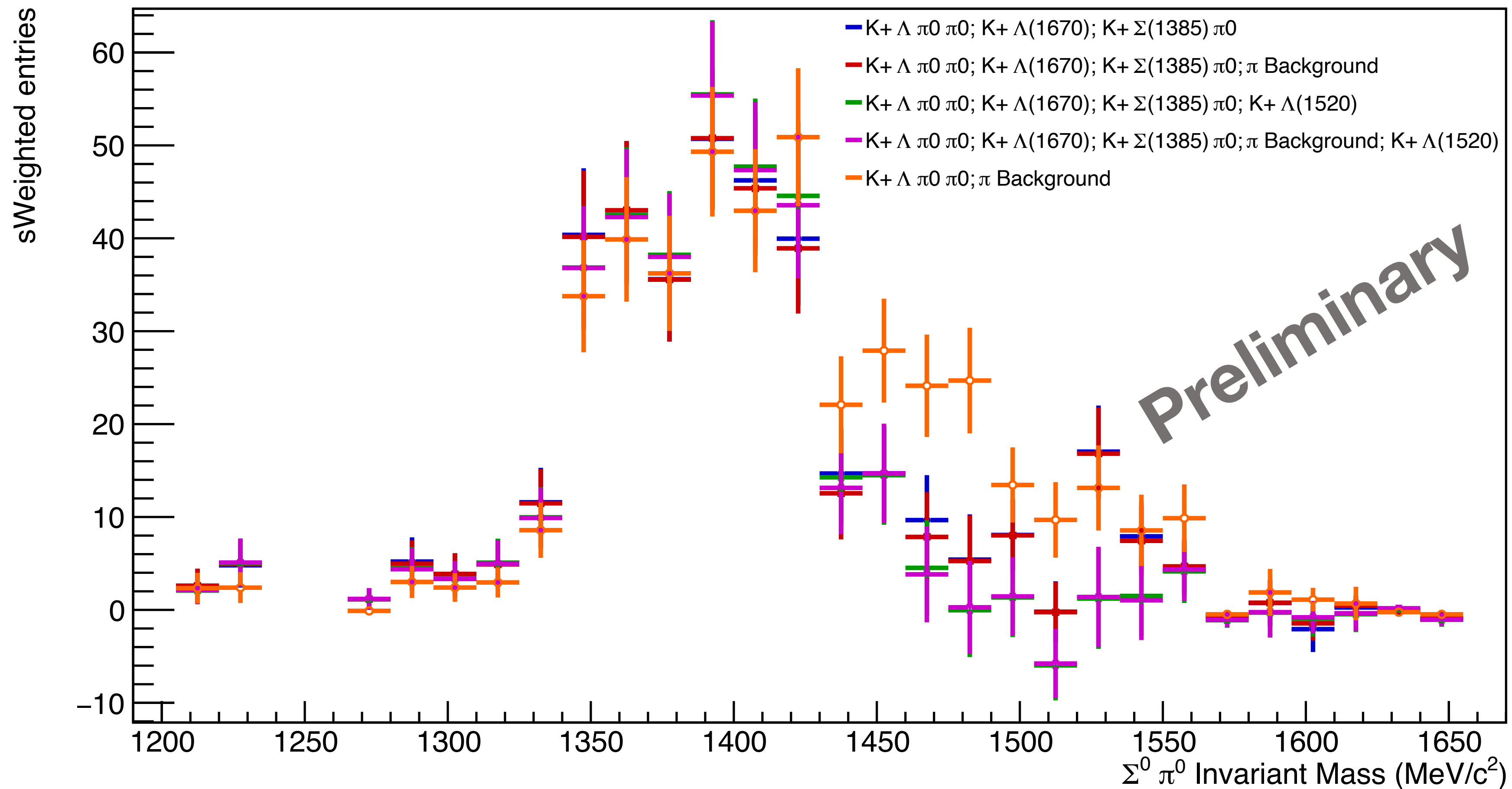
$$E_\gamma = 1544\text{MeV} - 2096\text{MeV}$$





$\Lambda(1405)$ line shape extraction – neutral topology

$$E_\gamma = 1544\text{MeV} - 2096\text{MeV}$$



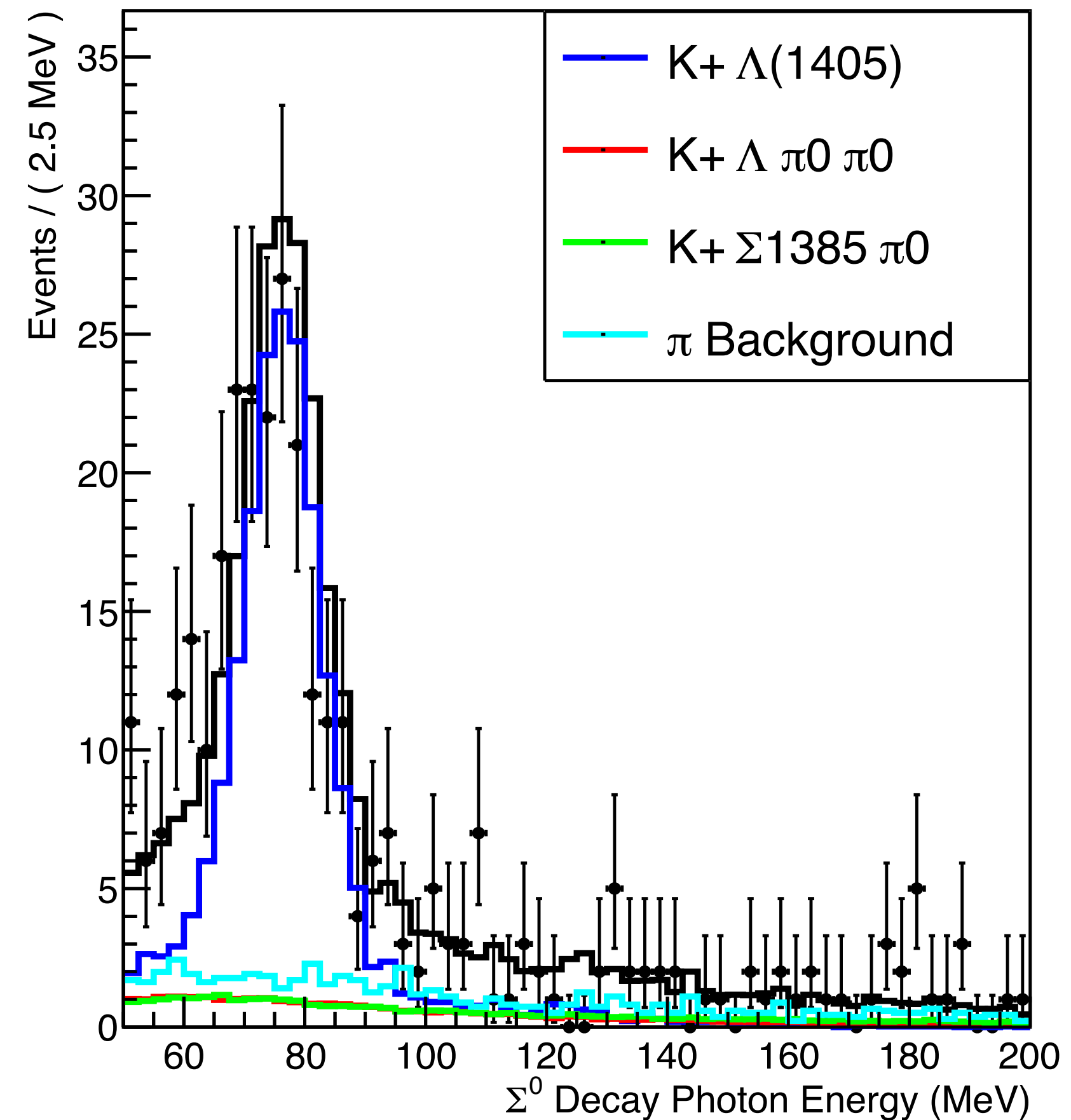
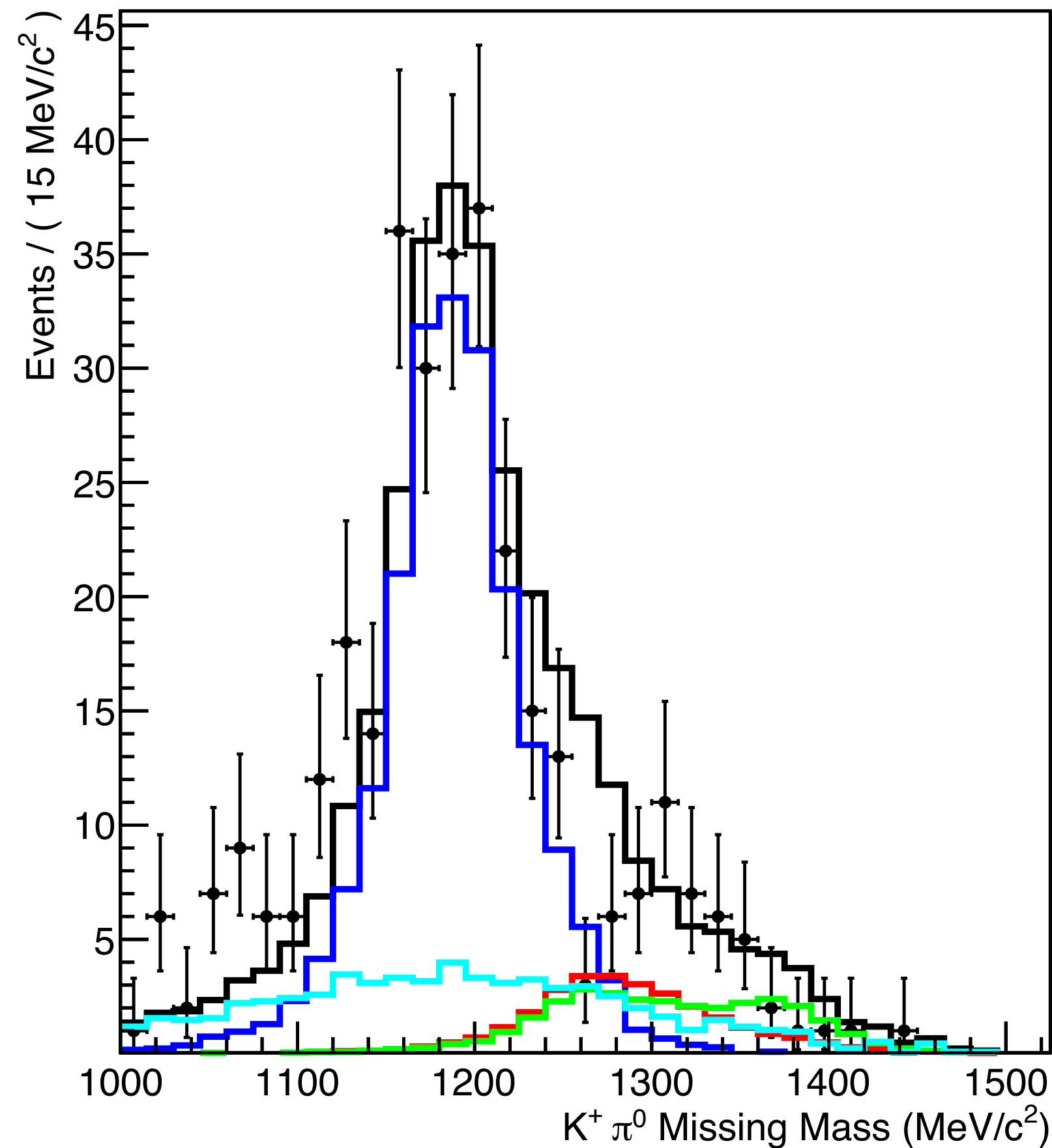
$$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$$

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$\Lambda(1405)$ line shape extraction – charged topology

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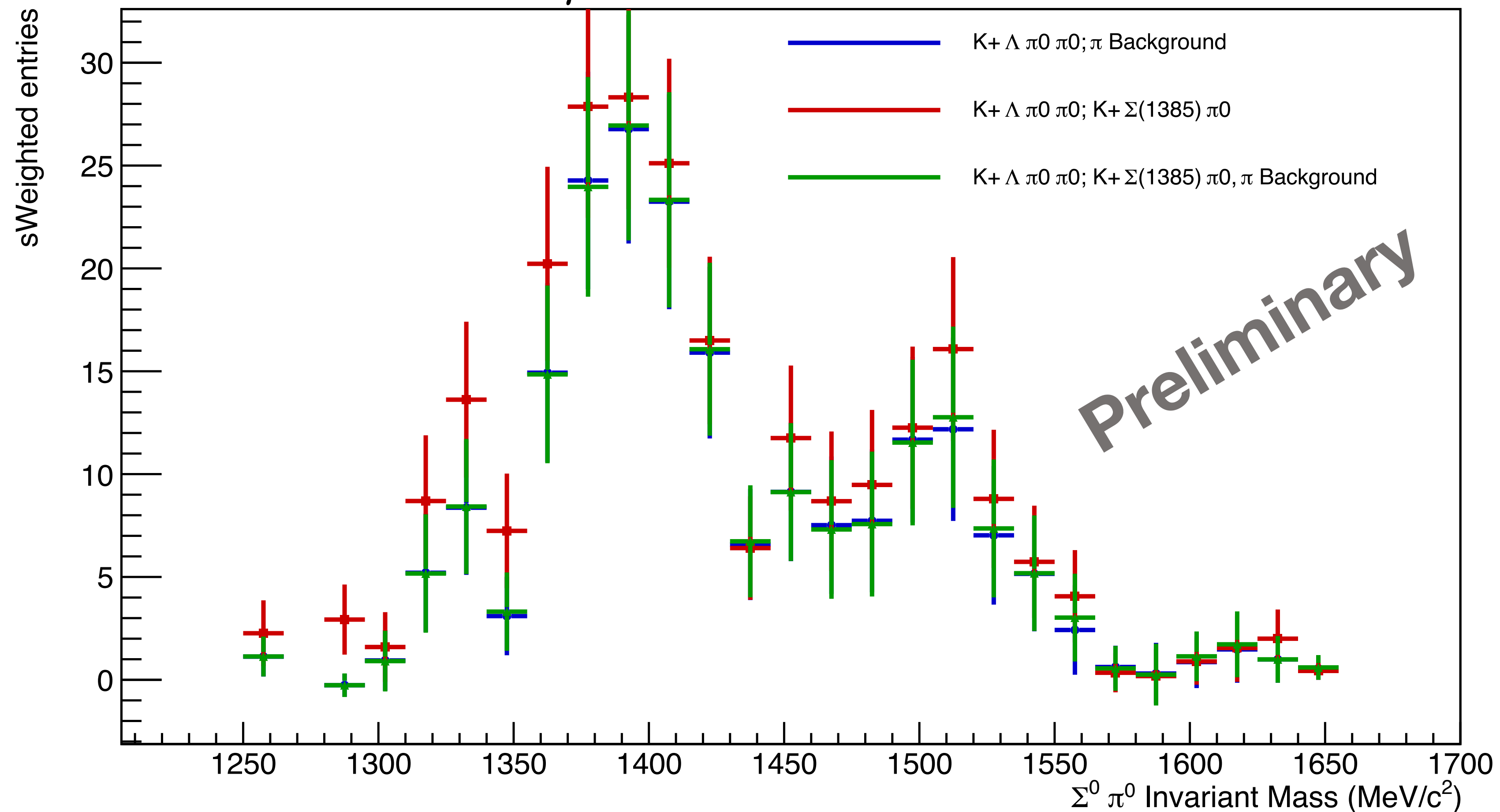
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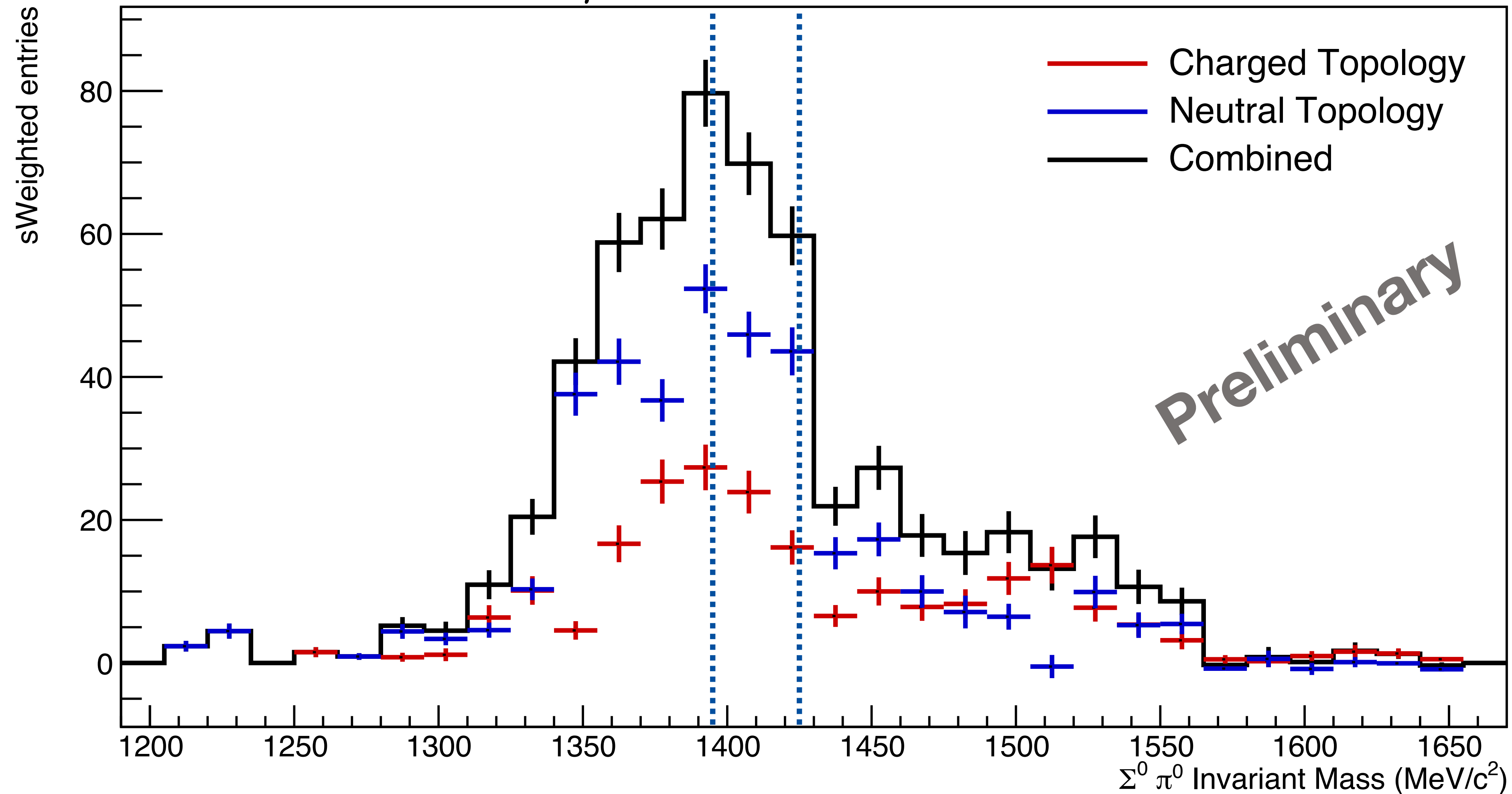


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$E_\gamma = 1544\text{MeV} - 2096\text{MeV}$

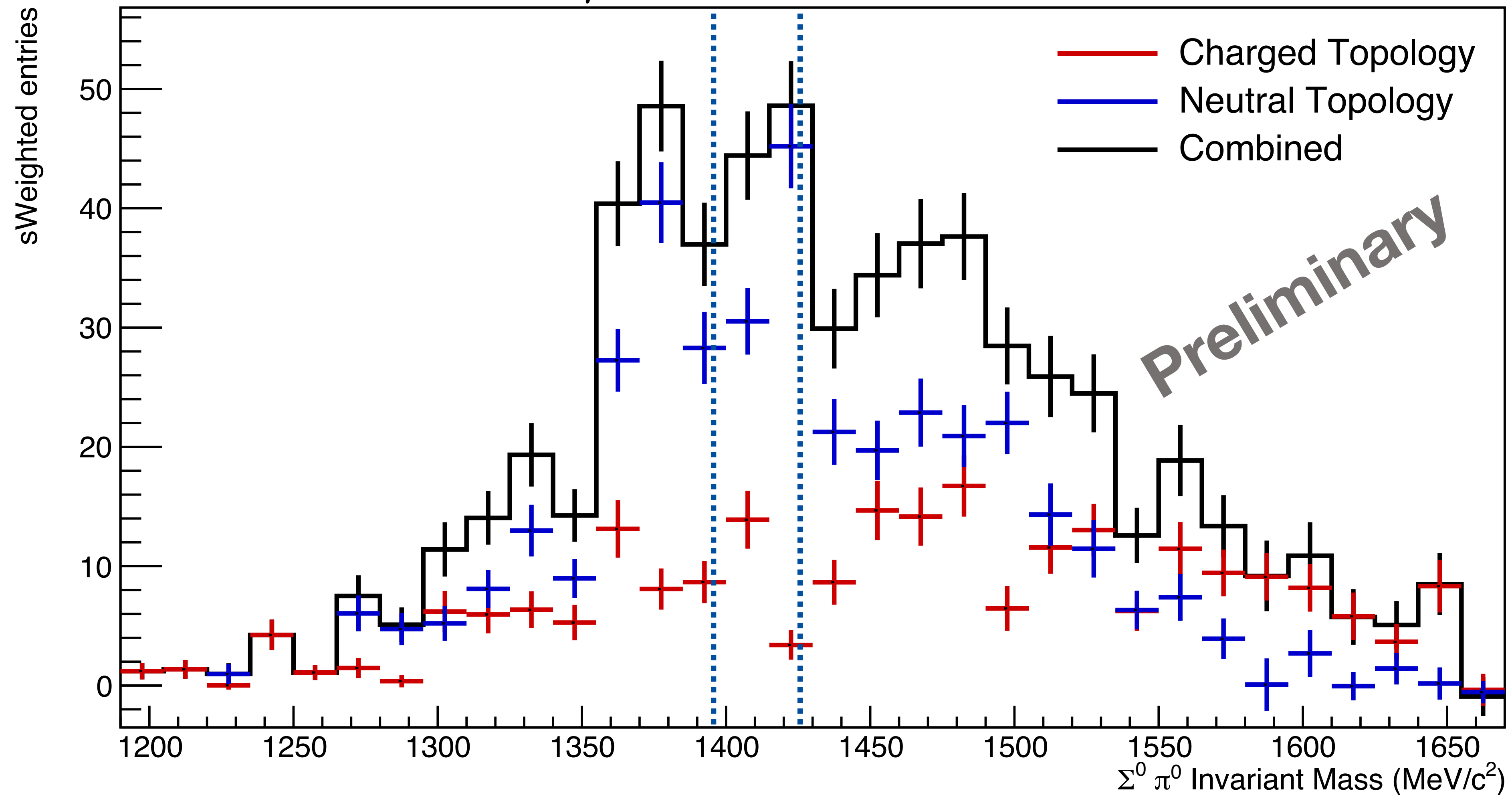


$\gamma p \rightarrow K^+(\Lambda(1405) \rightarrow \Sigma^0 \pi^0)$

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$E_\gamma = 2096\text{MeV} - 2607\text{MeV}$



Overview

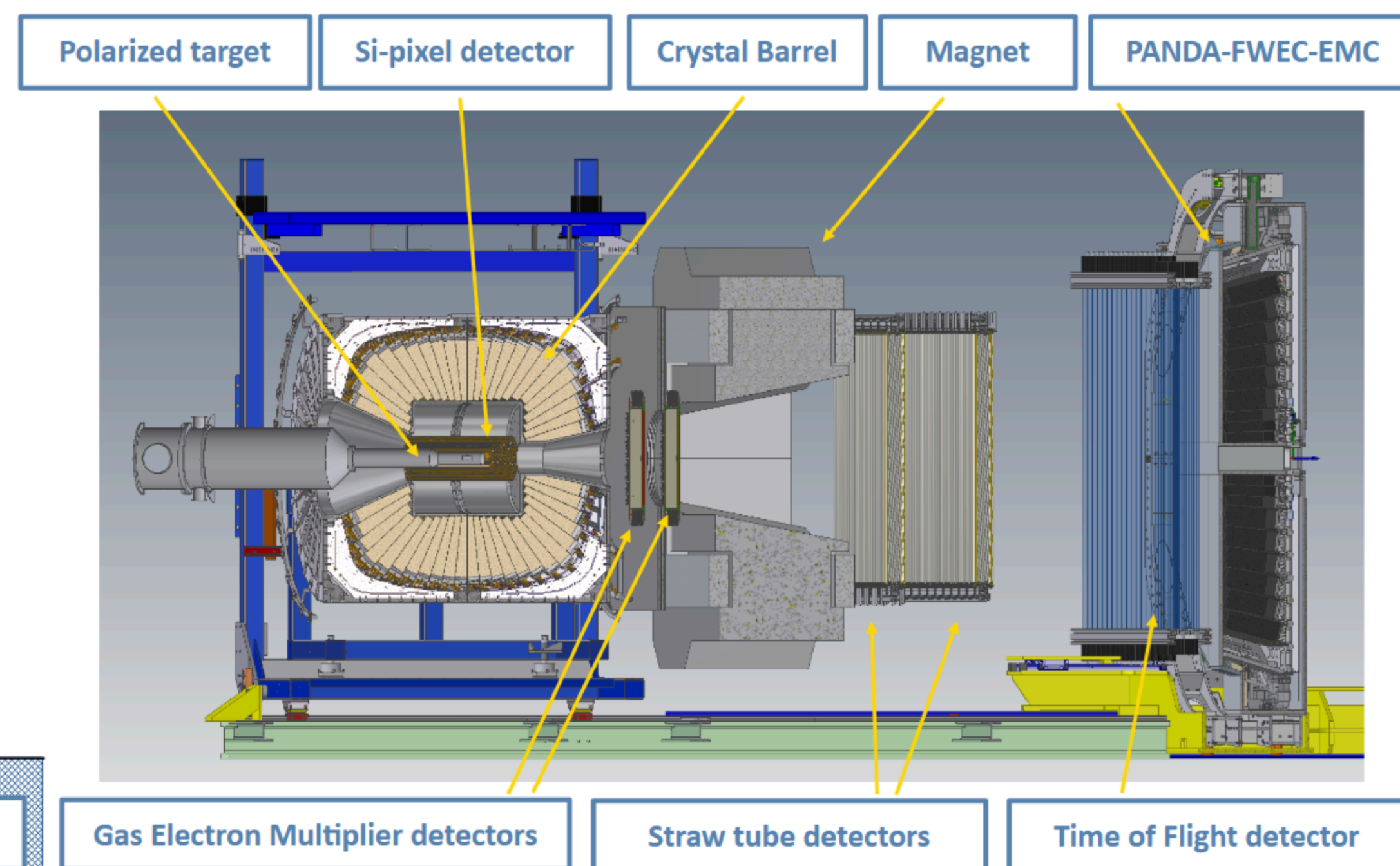
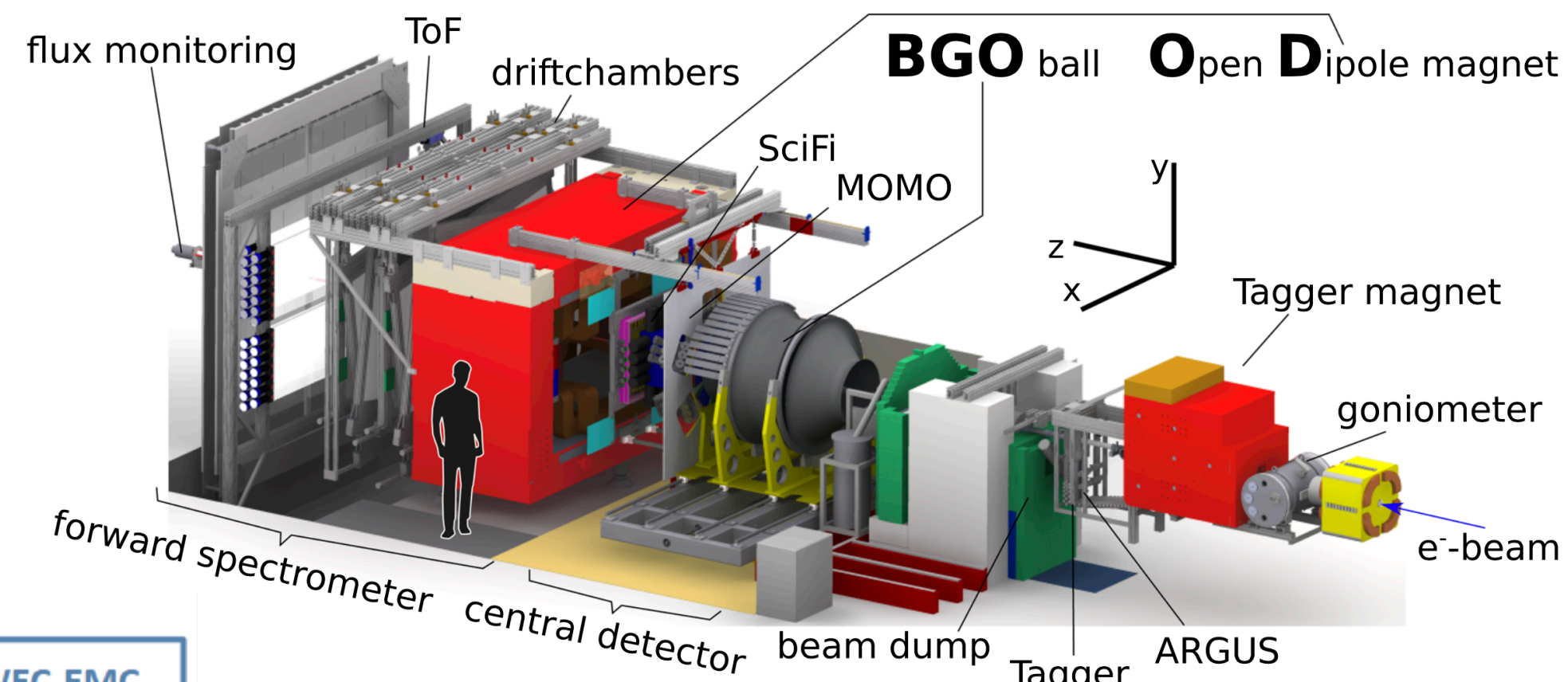
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- **Summary and Outlook**

... the story so far

- Molecular structure of $\Lambda(1405)$ supported by recent developments in CPT based models and LQCD calculations
- BGOOD provides low t kinematics
 - Sensitive to molecular-like structures
- Exploratory analysis on $\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ (\Sigma^+ \pi^-)$
- First measurements of $\gamma p \rightarrow K^+ \Sigma(1385)$ from threshold at low t
- $\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ (\Sigma^0 \pi^0)$:
 - Total cross section measurement
 - $\Sigma^0 \pi^0$ lineshape measurement
 - First indication of 2 pole structure at forward K^+ angles

Outlook

- Further investigation of $\Sigma(1385)$
- Ongoing analysis on the 2-pole structure of $\Lambda(1405)$
- Energy dependent $\Lambda(1405) \rightarrow \Sigma^0 \pi^0$ line shape
- Combination of multiple data sets



- $\sim 4\pi$ solid angle:
 - High resolution photon measurements
 - Precise charged particle detection
- Polarised beam & polarised target



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