# $K^+\Lambda(1405)$ photoproduction at the BGO-OD experiment

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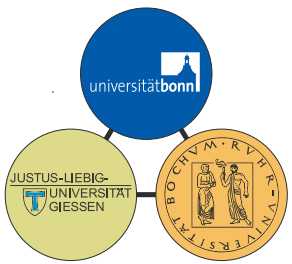
for the BGO-OD-Collaboration

Physikalisches Institut
Universität Bonn


NSTAR 2019

Bonn, 13. June 2019

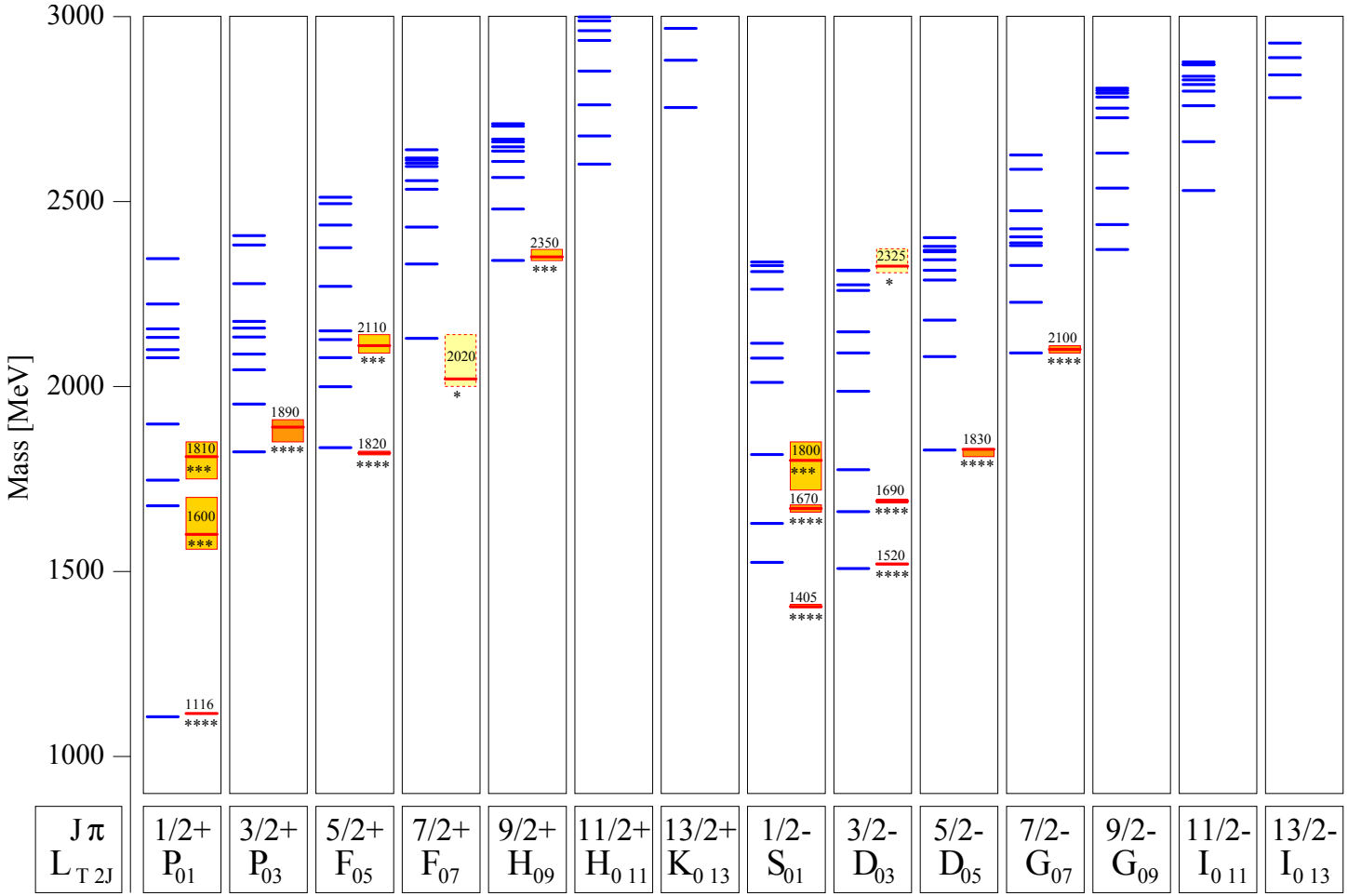
Supported by the DFG (PN 50165297)



1. **Motivation for** Λ(1405)
2. **BGO-OD experiment**
3. Λ(1405) **identification**
   - forward spectrometer (f.spec)
   - full topology (full top.)
4. **Preliminary results**
5. **Summary & outlook**

# Unconventional states in the strangeness sector?

## Quark Model predictions for $\Lambda^*(uds)$ states




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

# Unconventional states in the strangeness sector?

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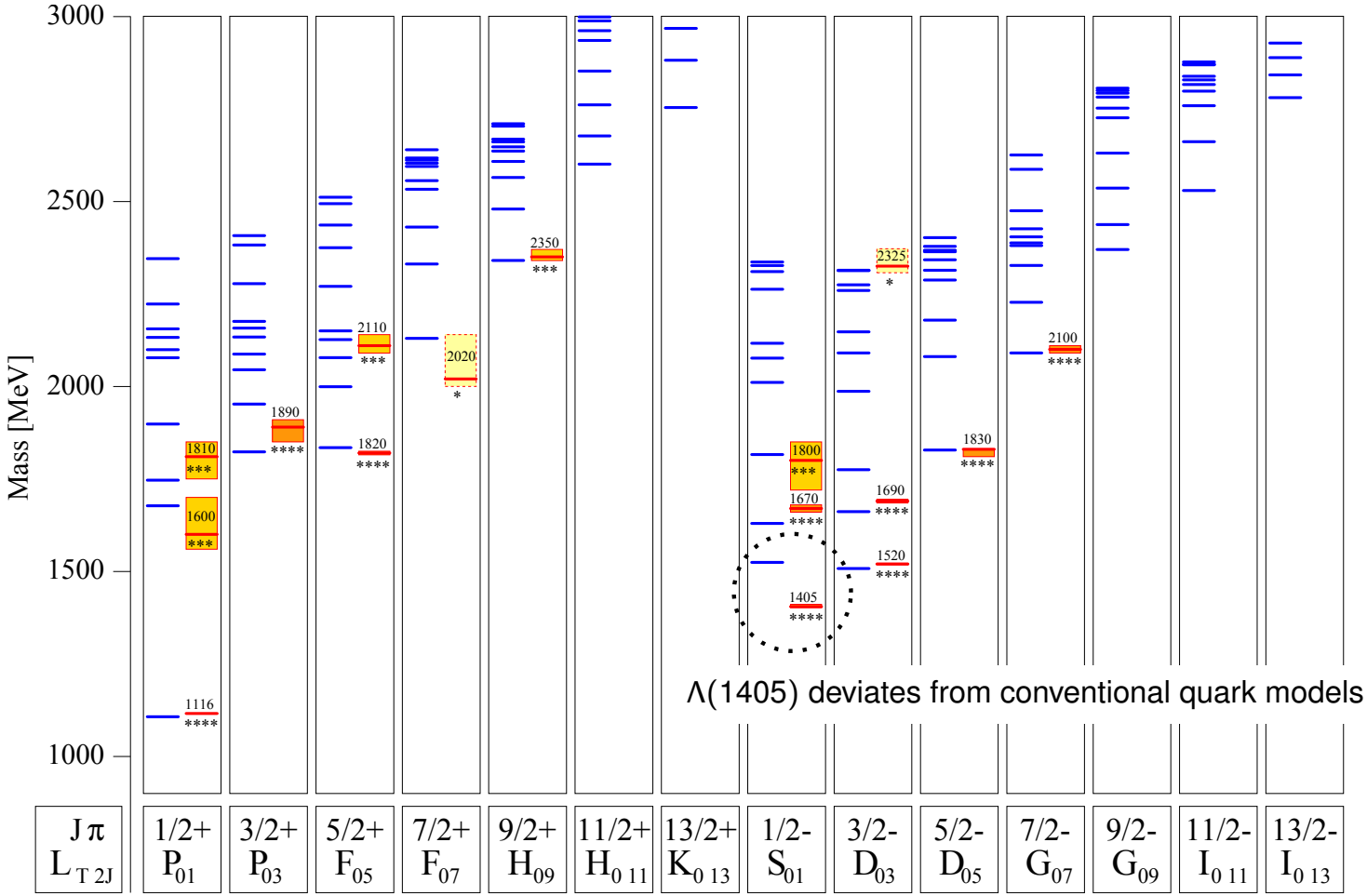


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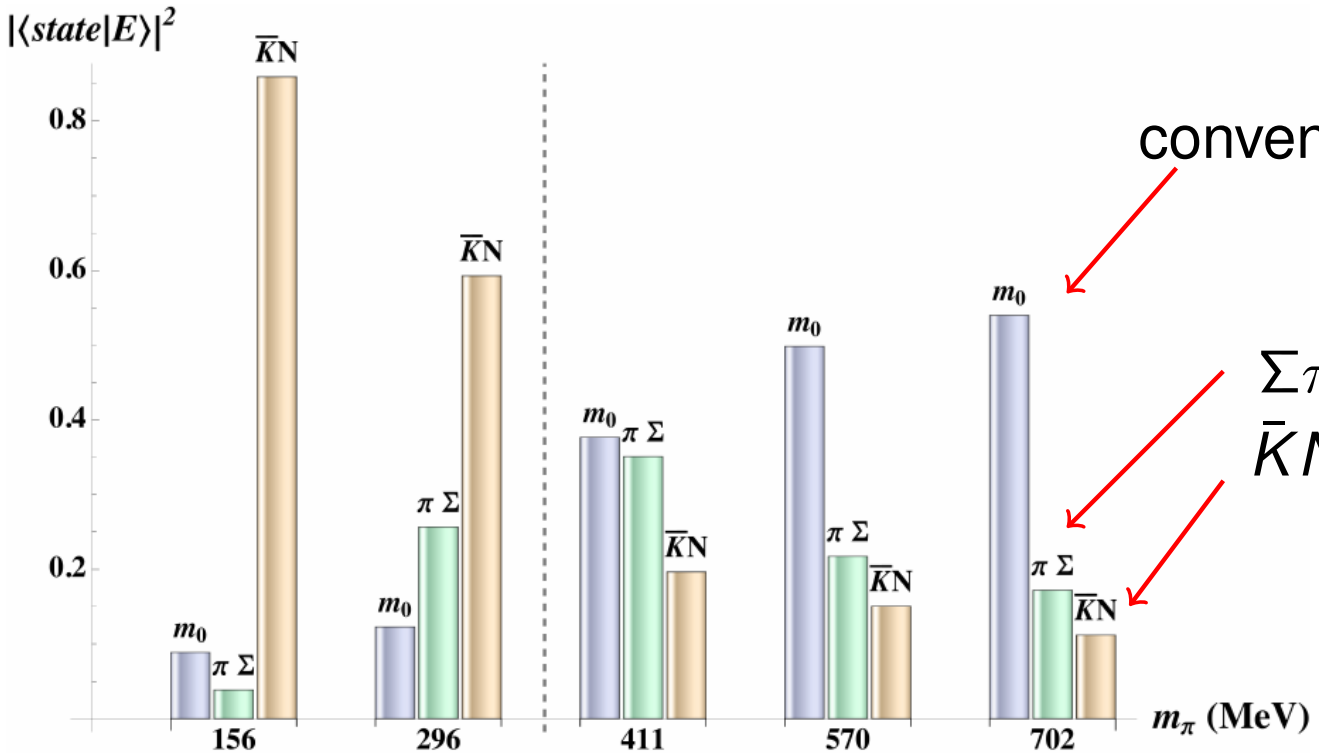
# Λ(1405) Lattice QCD



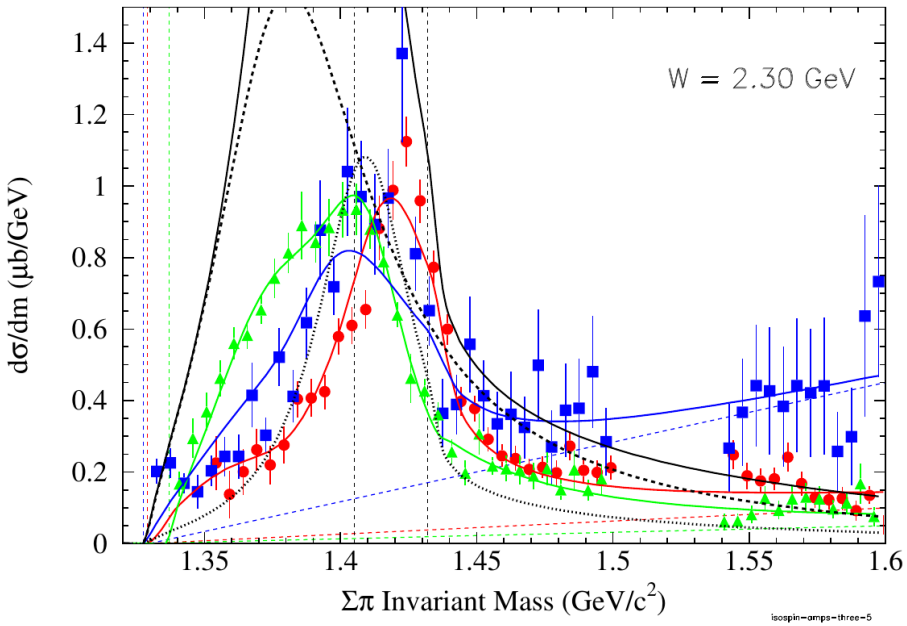

J.M.M.Hall et al. DOI: 10.1103/PhysRevLett.114.132002(2014)

$N\bar{K}$ appears as main component going to realistic pion/-quark masses

also see: R. Molina and M. Döring, Phys. Rev. D 94, 056010 (2016)

# Λ(1405) line shape

## Results at CLAS:




K.Moriya, R.A.Schumacher et al. Phys. Rev. C 88, 045201 (2013)
see also K.Moriya, R.A.Schumacher et al. Phys. Rev. C 87, 035206 (2013)

$\Lambda(1405) \rightarrow \Sigma^0\pi^0$
$\Sigma^+\pi^-$
$\Sigma^-\pi^+$

BGO-OD Experiment $\Rightarrow$ complementary setup
$\Rightarrow$ access unexplored kin. regions

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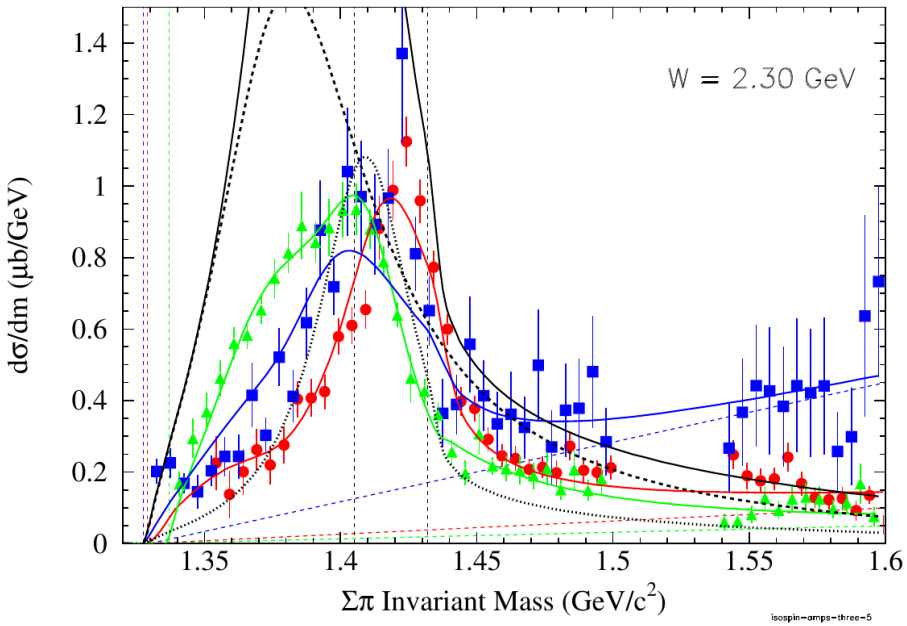


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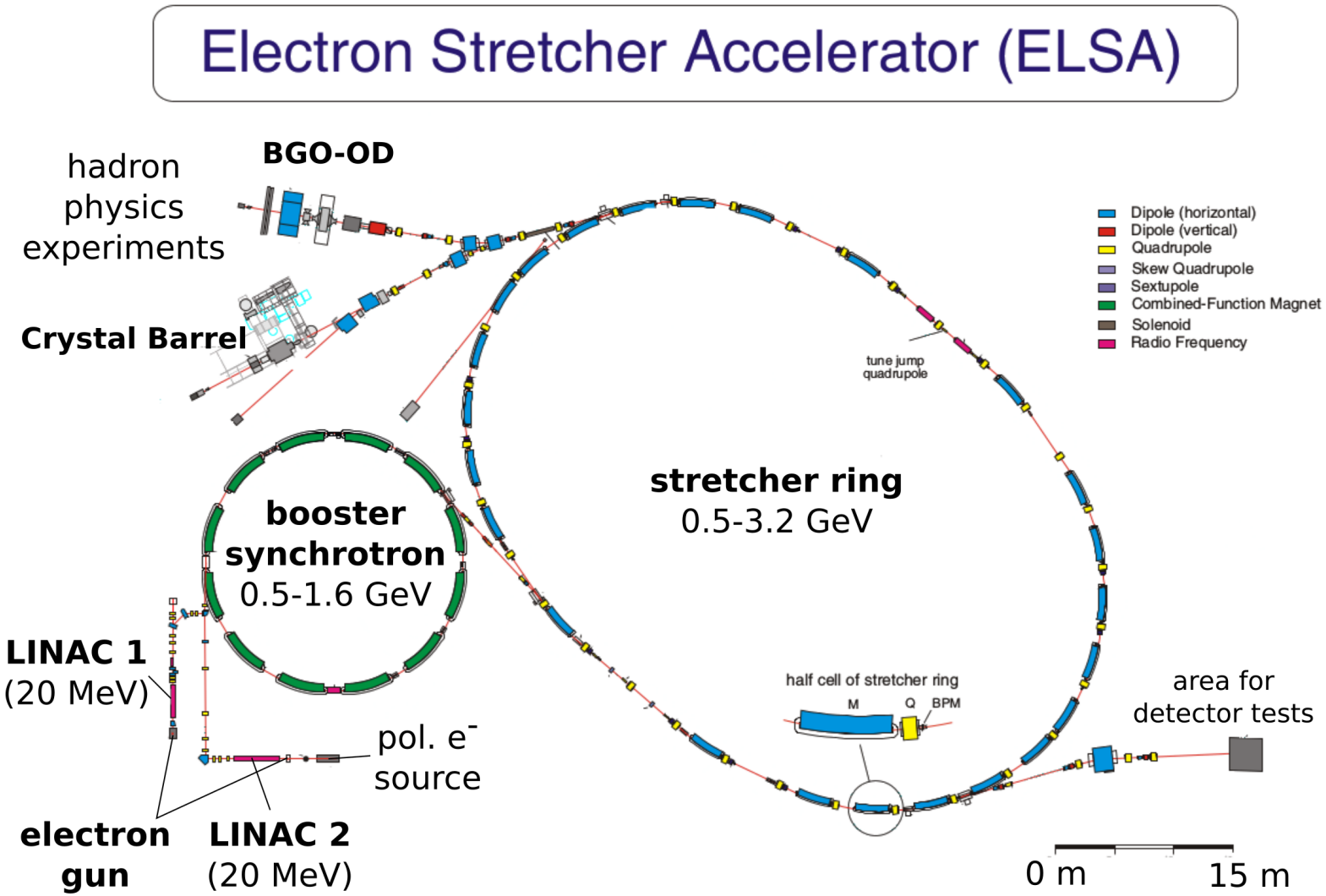
# Elektronen-Stretcher-Anlage ELSA in Bonn



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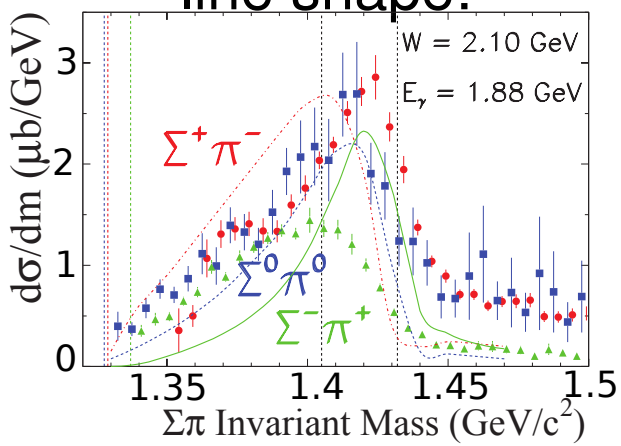
# Experimental requirements

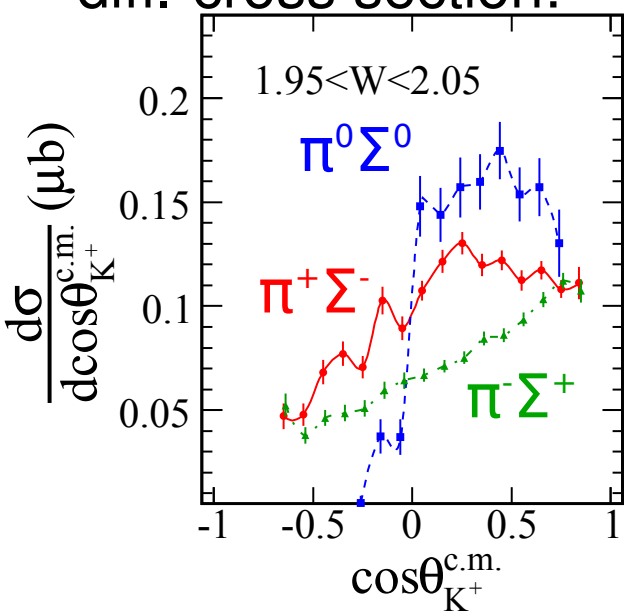
## photoproduction

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

line shape:




diff. cross section:




CLAS Collaboration, Phys. Rev. C 88 (2013)

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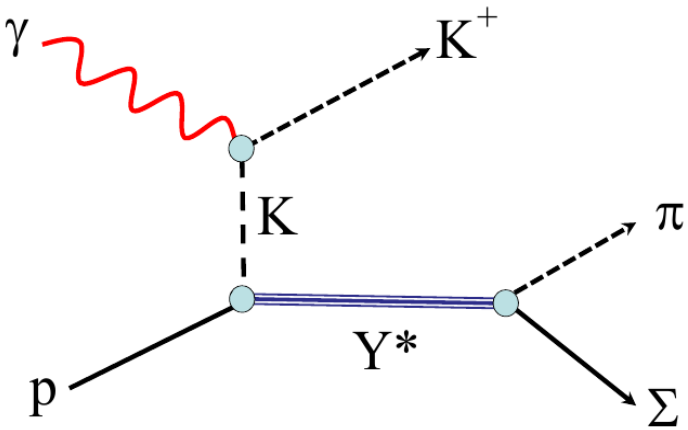
$\Lambda(1405)$


T. Hyodo et al.
DOI:10.1016/j.ppnp.2011.07.002(2011)




R.A.Schumacher et al.
DOI:10.1016/jnuclphysa.2013.03.003 (2013)

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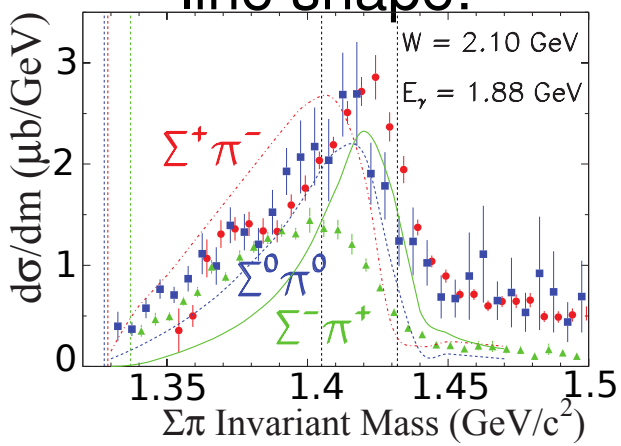


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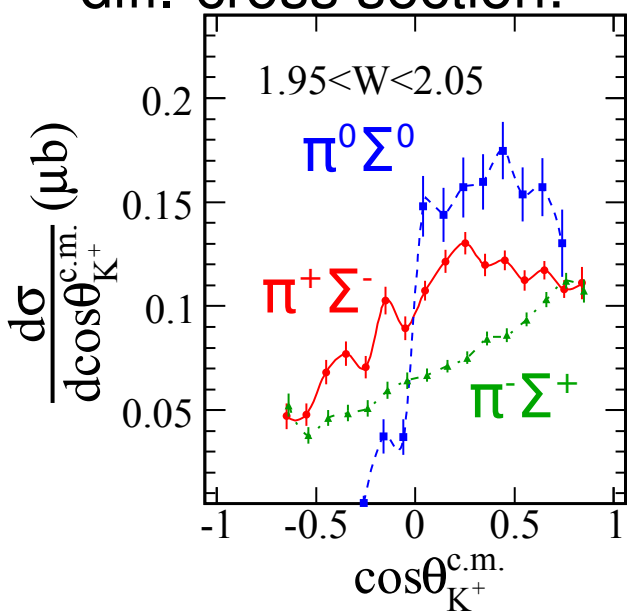
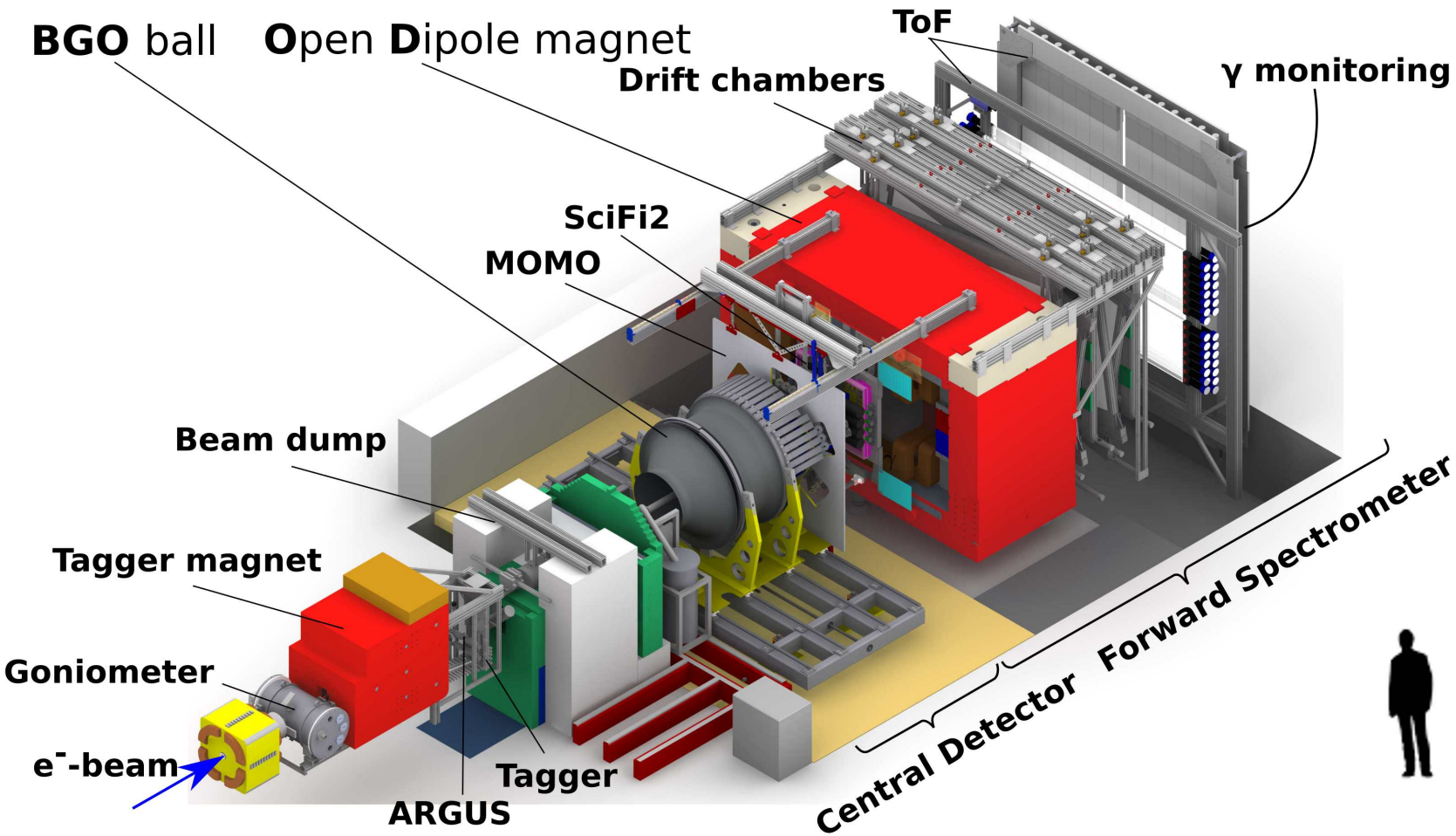



CLAS Collaboration, Phys. Rev. C 88 (2013)

# BGO-OD




Spokesperson: P. Levi Sandri, H. Schmieden

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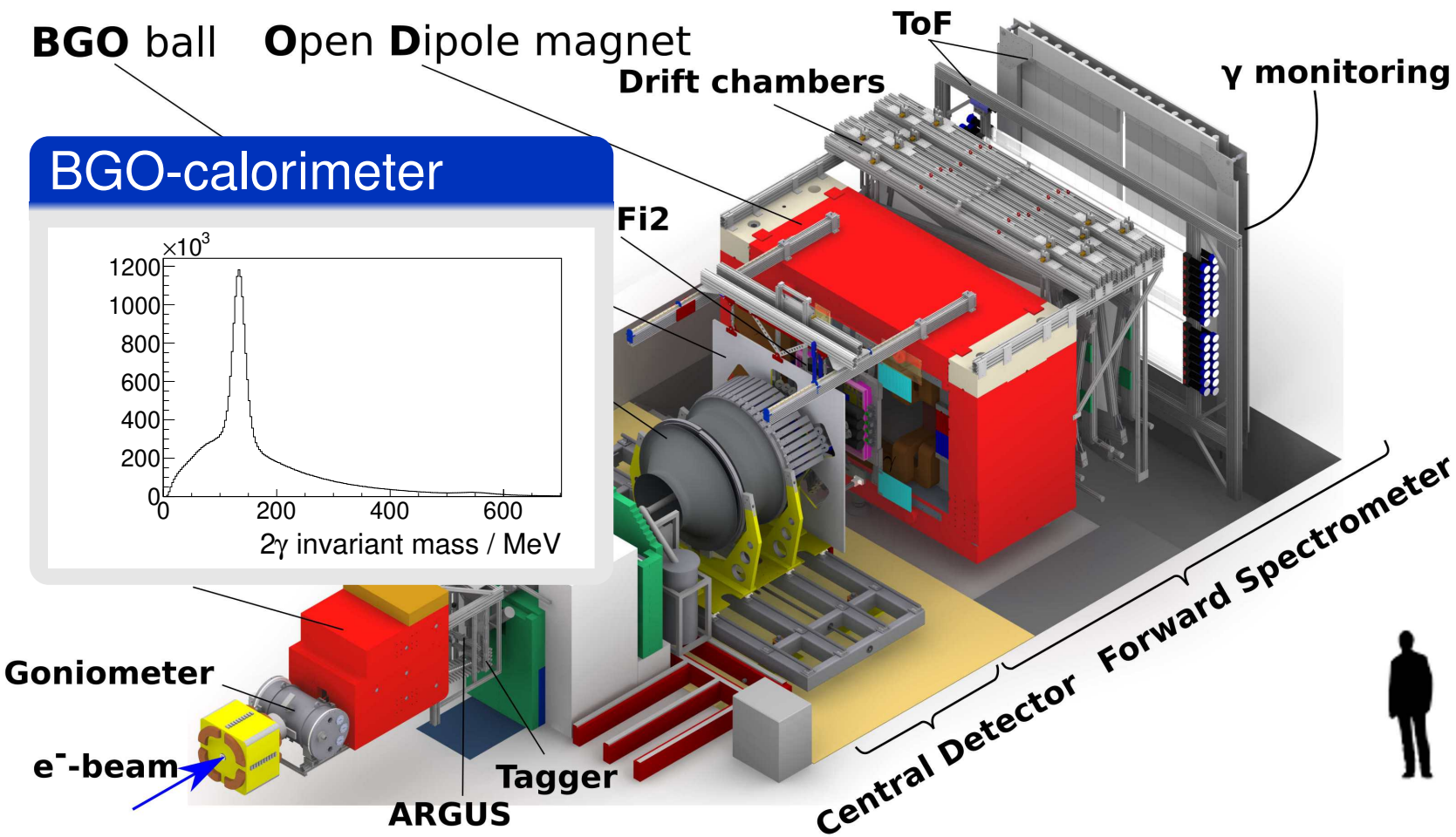


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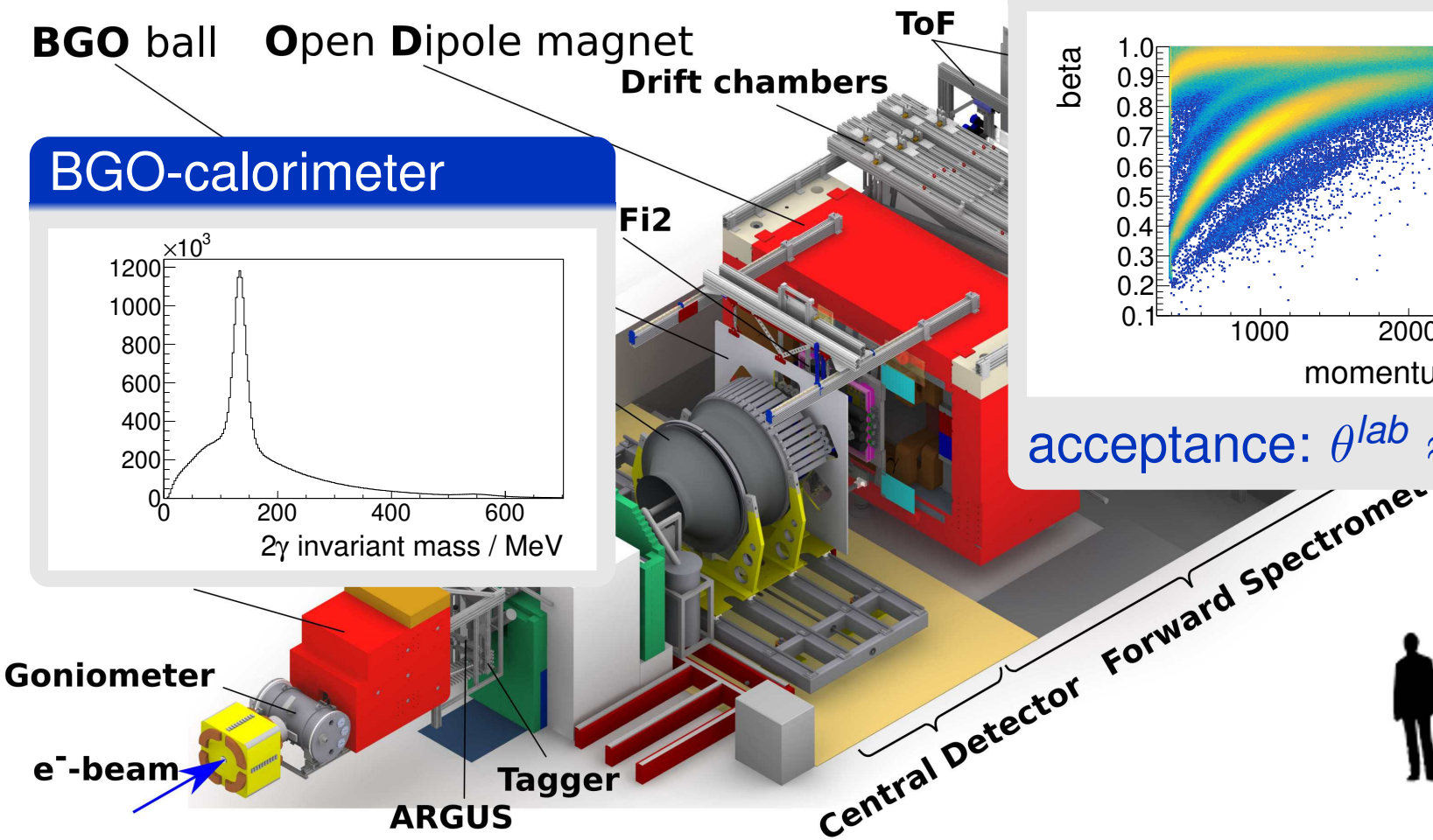


## BGO-calorimeter




## Forward Detector




acceptance: $\theta^{lab} \approx 2..10°$

Spokesperson: P. Levi Sandri, H. Schmieden



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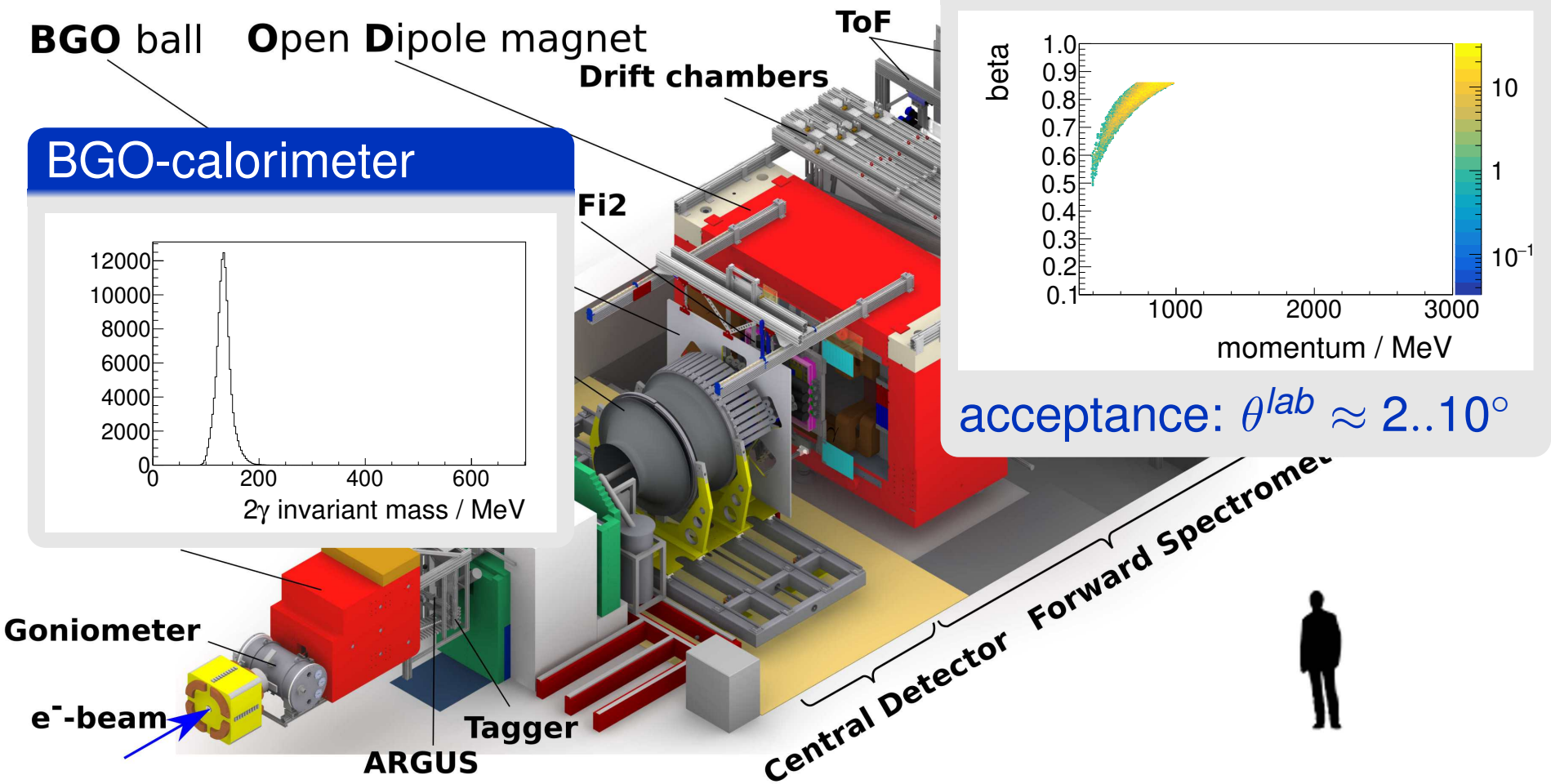
# $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$

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$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$ (33 %)

- $K^+$ in Forward Detector
- $\pi^0 \rightarrow 2\gamma$ in Central Detector
- $\Sigma^0$ missing

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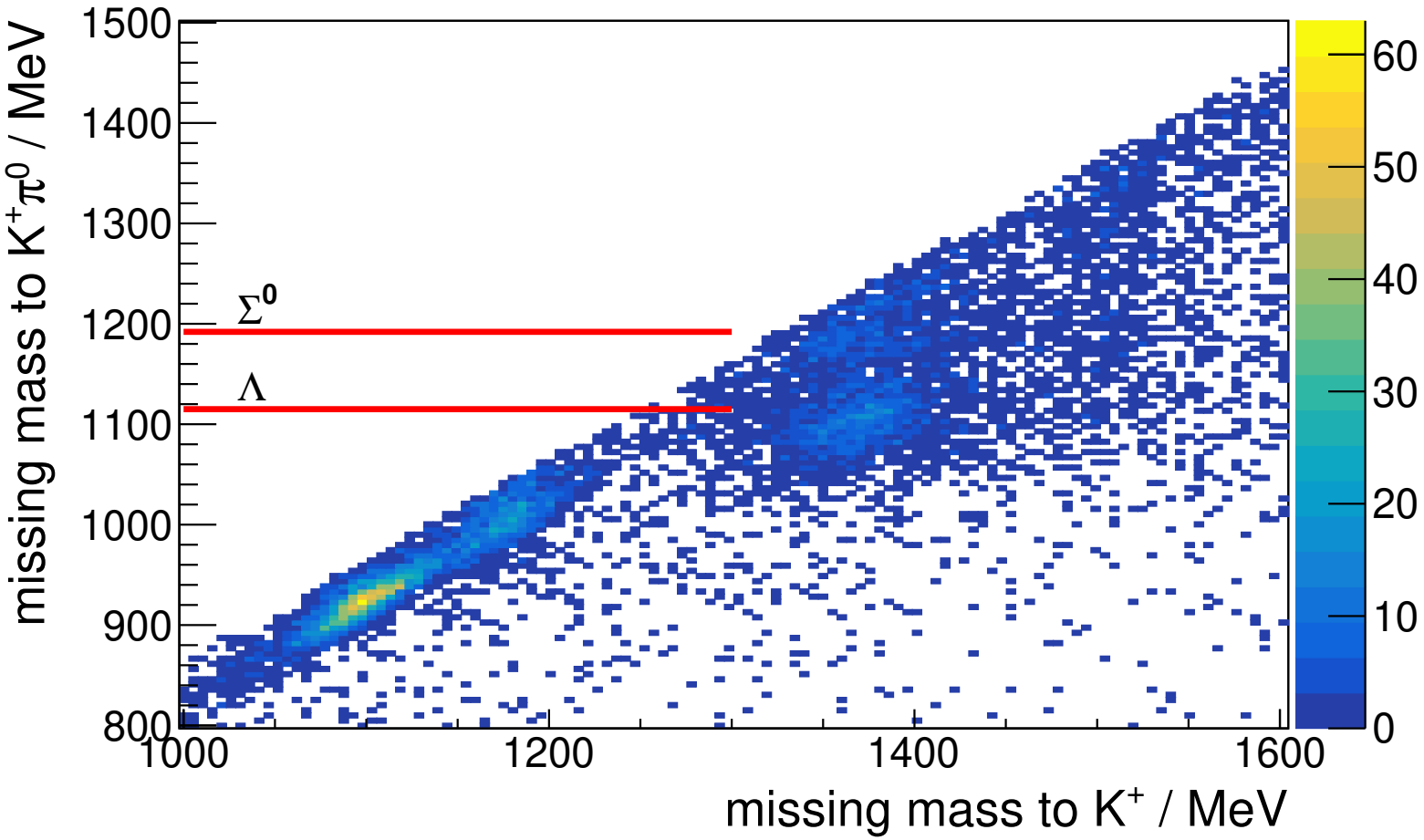
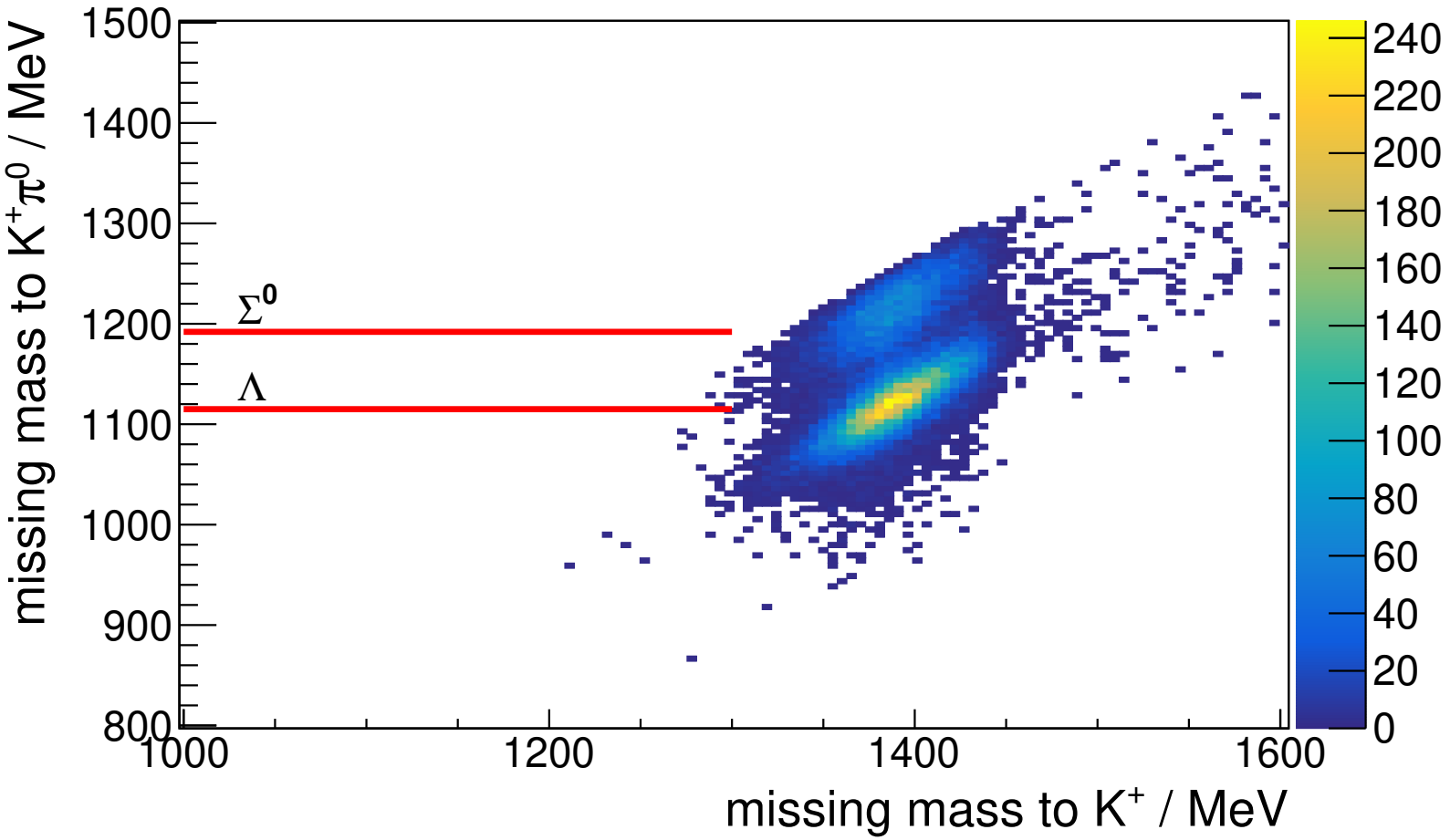
# $K^+\Lambda(1405) \rightarrow K^+\pi^0 X$ (real data, $K^+$ forward)




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

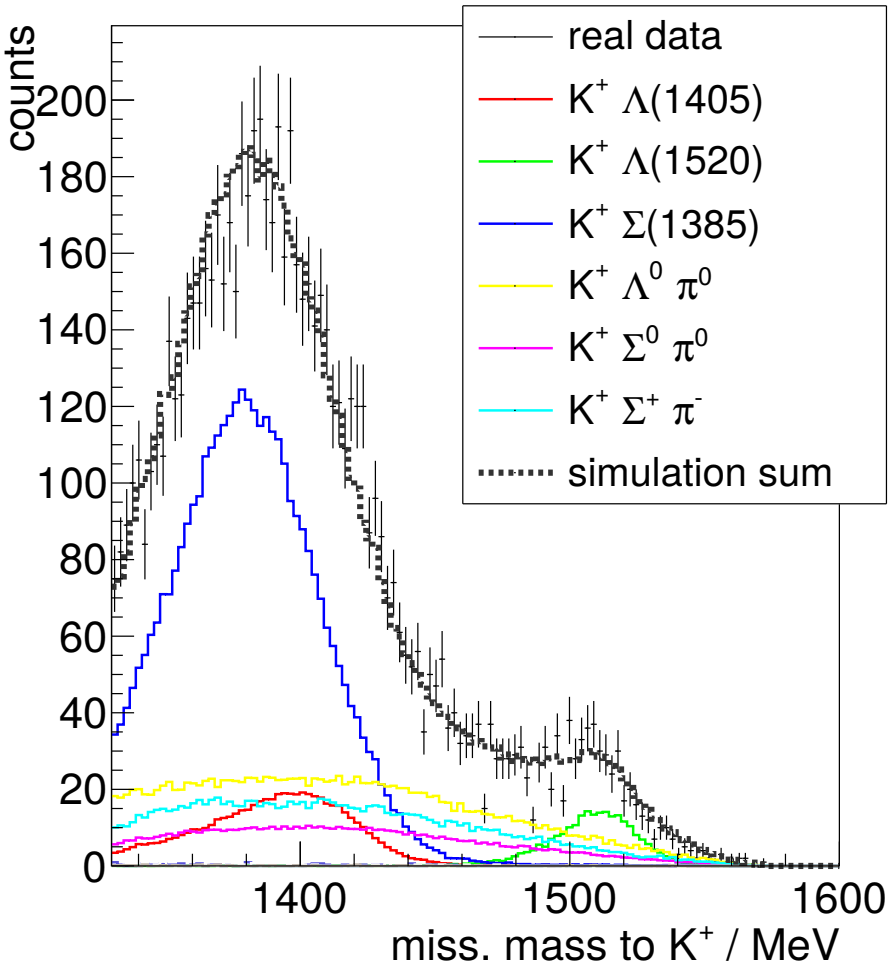
# $K^+\Lambda(1405) \rightarrow K^+\pi^0 X$ (sim. $\Sigma(1385)$, $K^+$ forward)

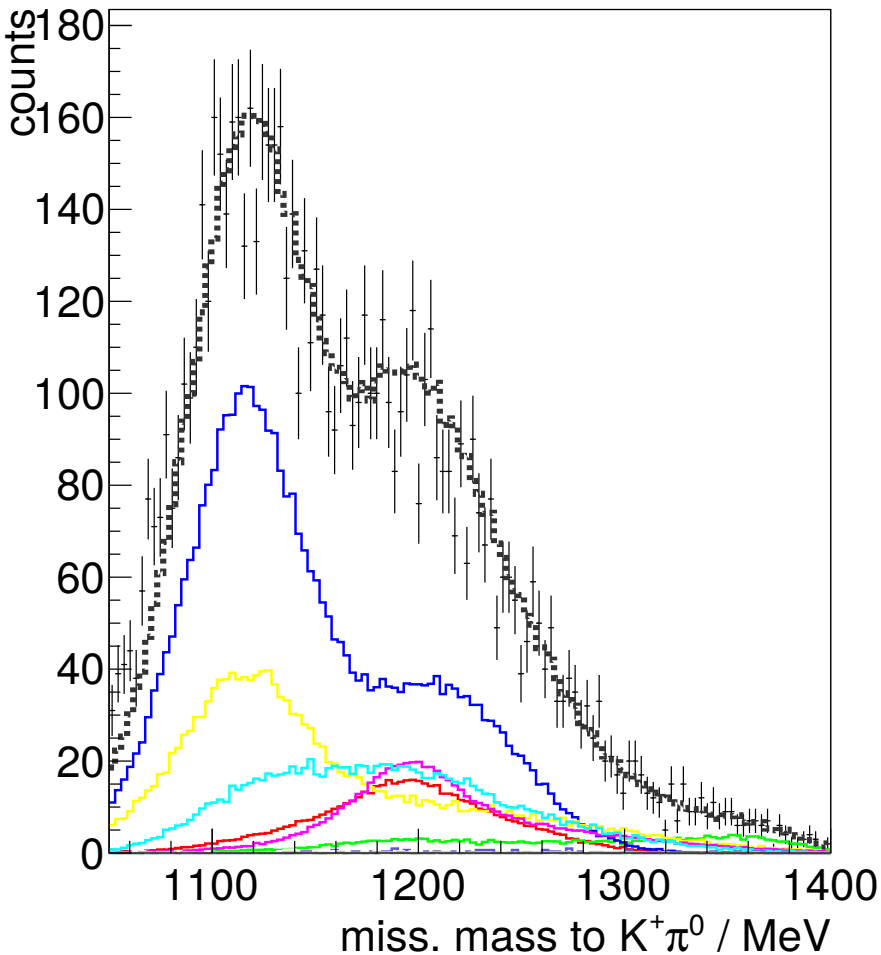



$K^+\Sigma(1385) \rightarrow K^+\pi^0\Lambda$

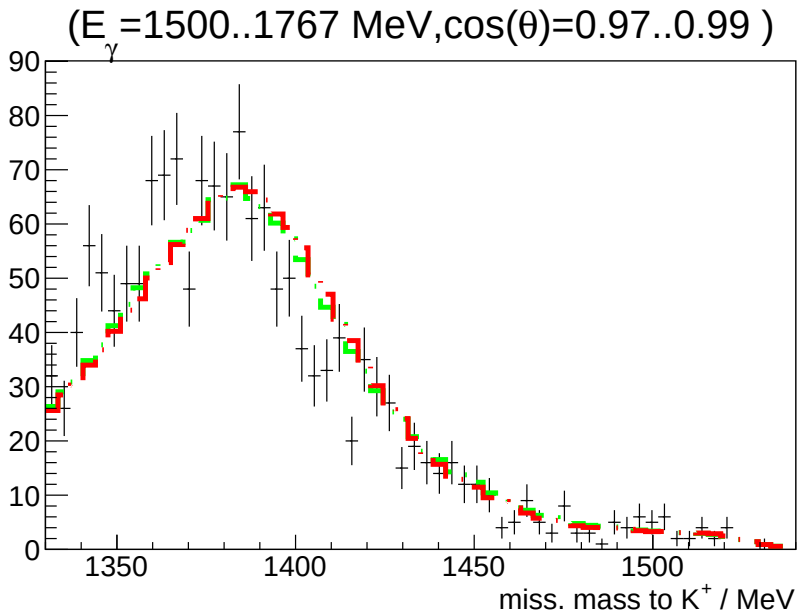
$K^+\Sigma(1385) \rightarrow K^+\pi^-\Sigma^+ \rightarrow K^+\pi^0\pi^- p$

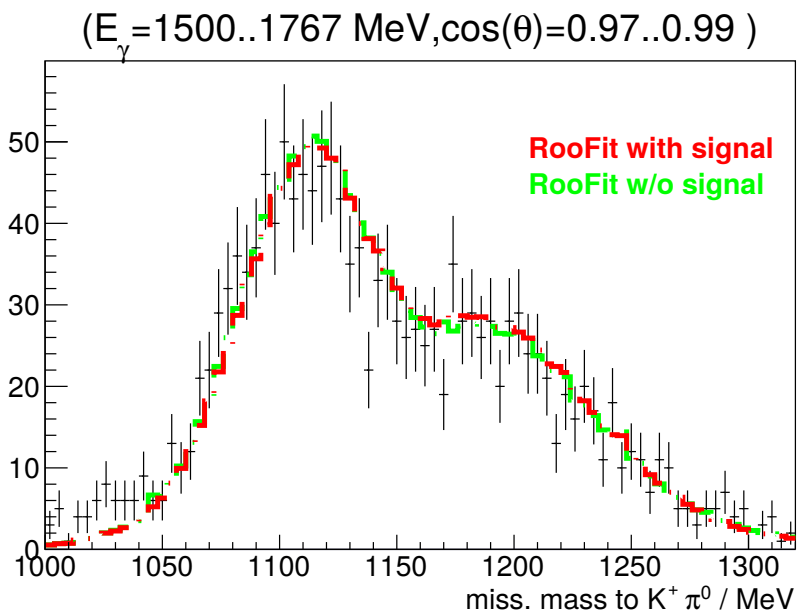
# 2D RooFit example



# RooFit reliability




⇒ Results very preliminary

# $K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$ (33 %)

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- $\Sigma^0$ missing

$\rightarrow$ f. spec.

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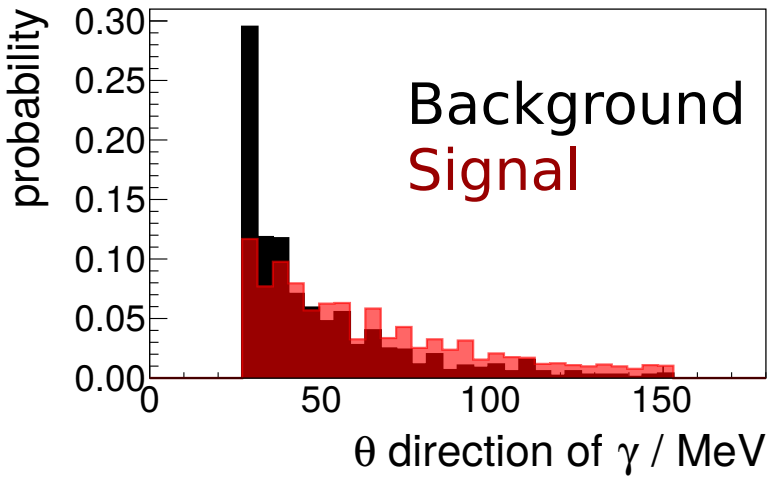
$K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma\Lambda$
$\rightarrow K^+\pi^0\gamma\pi^-p$ (21%)

- $\pi^0\gamma$ in BGO calorimeter ($\theta^{lab} = 25..155°$)
- $K^+\pi^-p$ with direction only ($\theta^{lab} = 2..155°$)
  $\rightarrow$ recalculated momentum
  $\rightarrow$ no particle identification
- kinematic fit

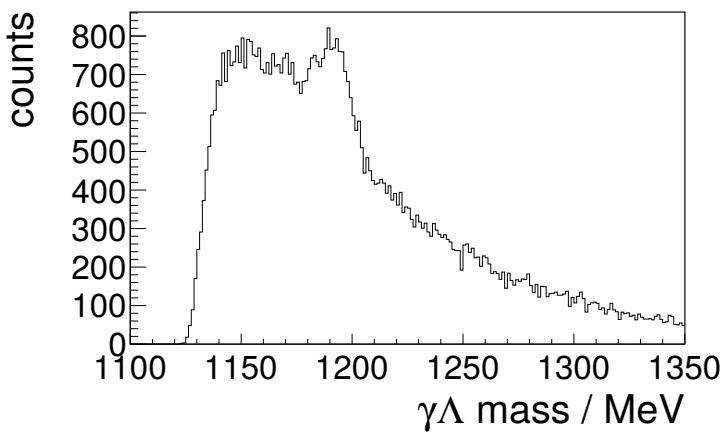
$\rightarrow$ full top.

# Removing combinatorial background

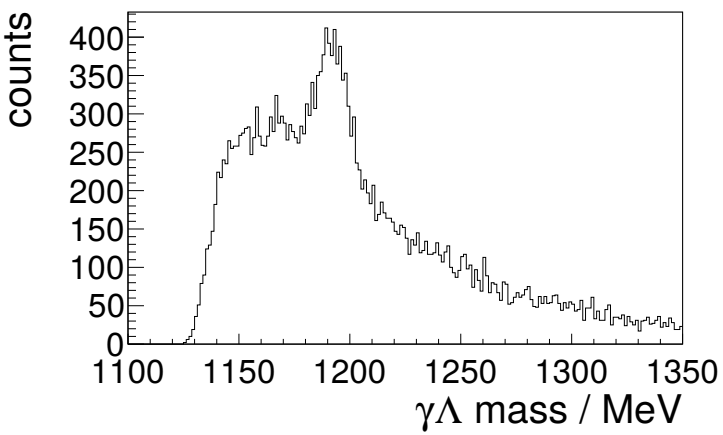
Angle distribution of $\gamma$ from the $\Sigma \rightarrow \gamma\Lambda$ decay



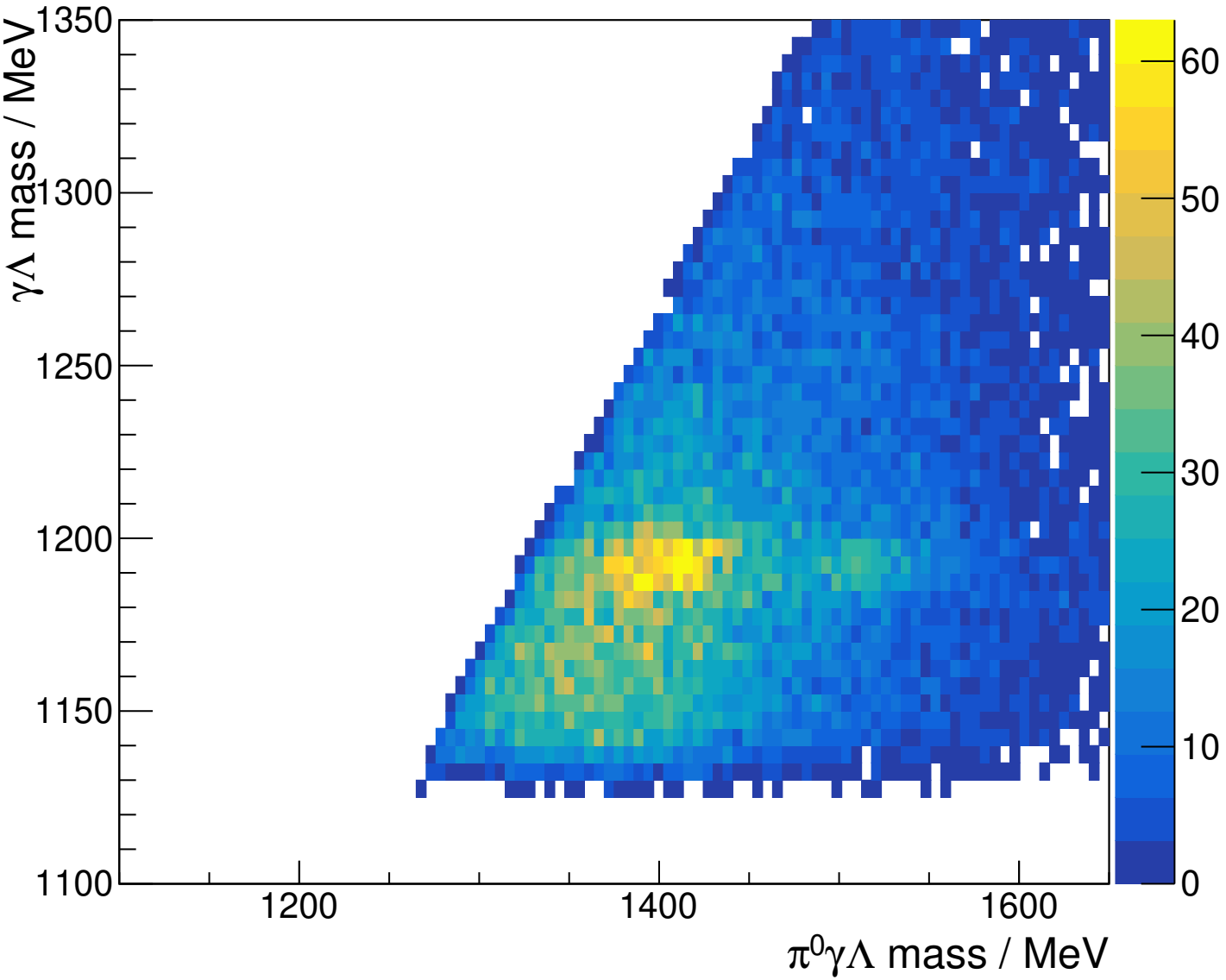

All $\theta$ allowed



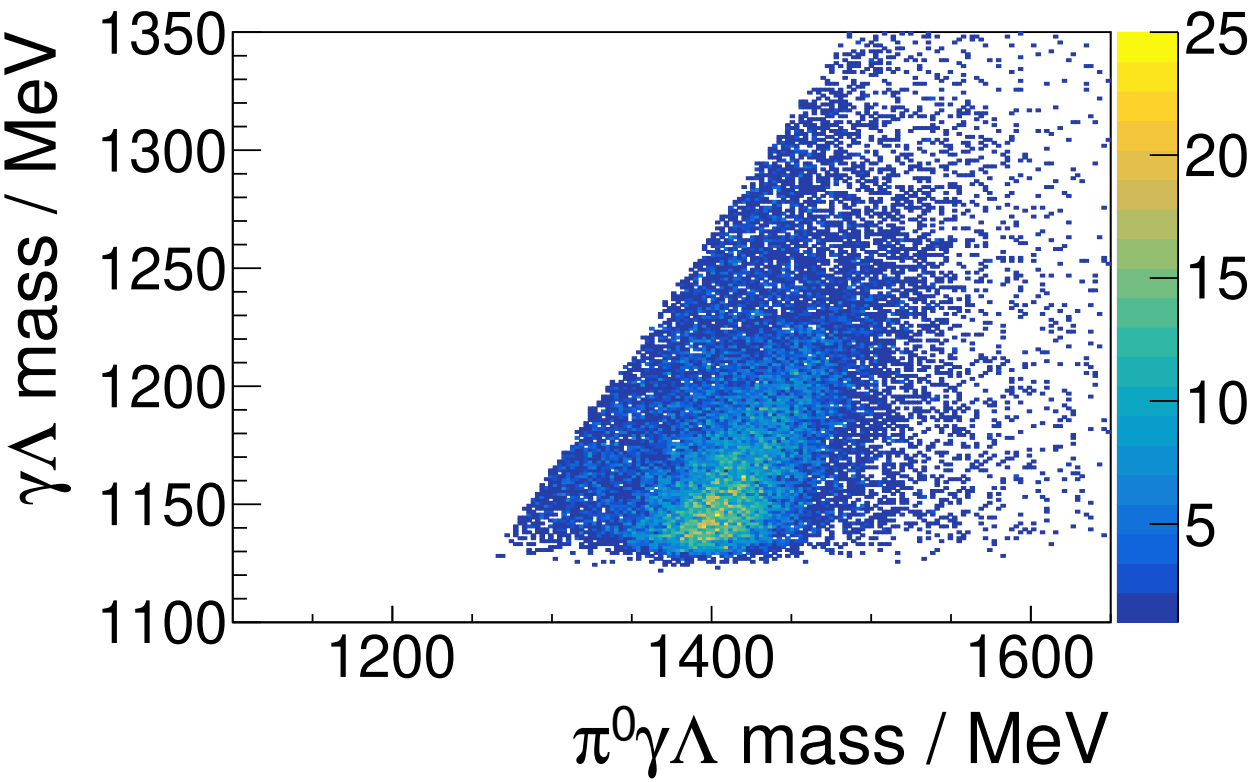

$\theta > 30°$



# Real data $\gamma p \to K^+\Lambda(1405) \to K^+\Sigma^0\pi^0 \to K^+\gamma\Lambda^0\pi^0$

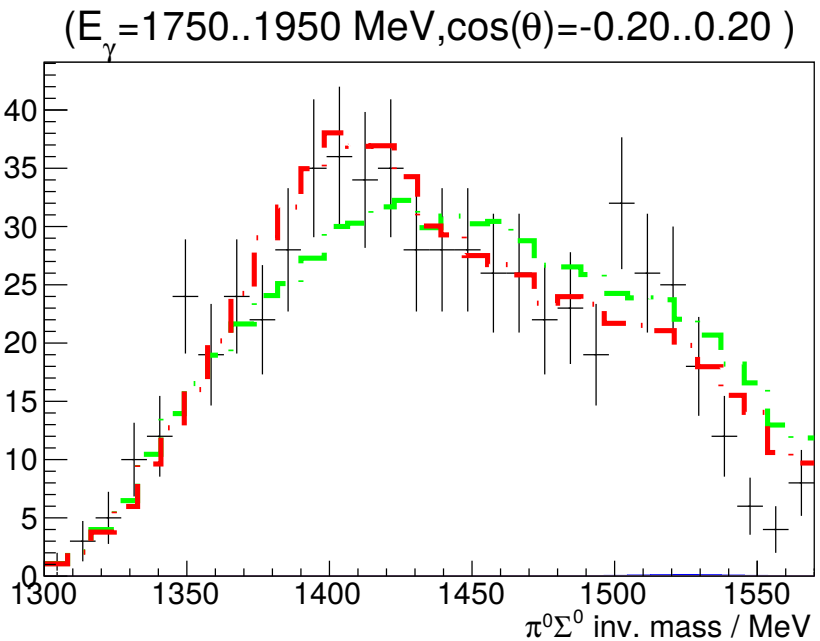


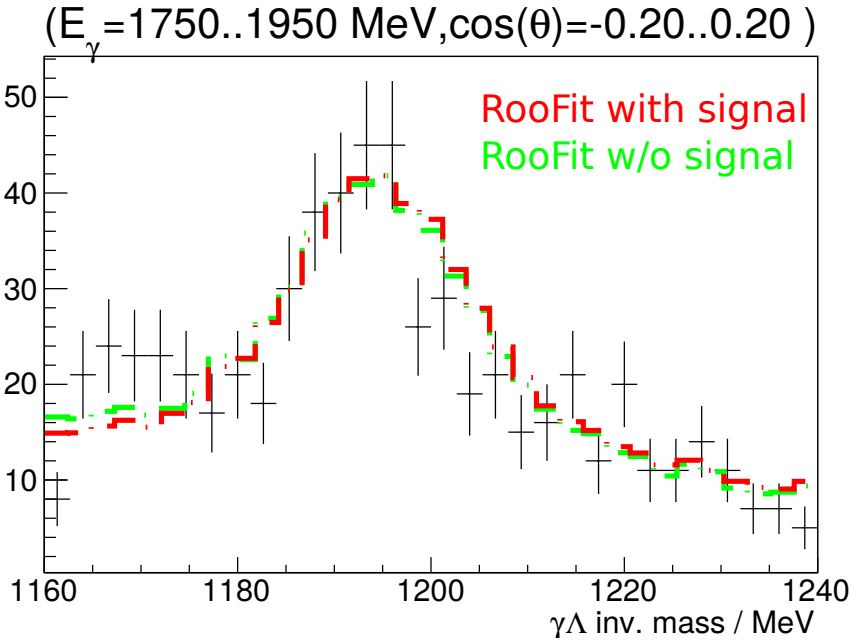
# Simulation studies of background: Σ(1385)




$$\Sigma(1385) \to \pi^0\Lambda(87\%) \to \pi^0\pi^- p$$
$$\to \pi^-\Sigma^+(4\%) \to \pi^0\pi^- p$$

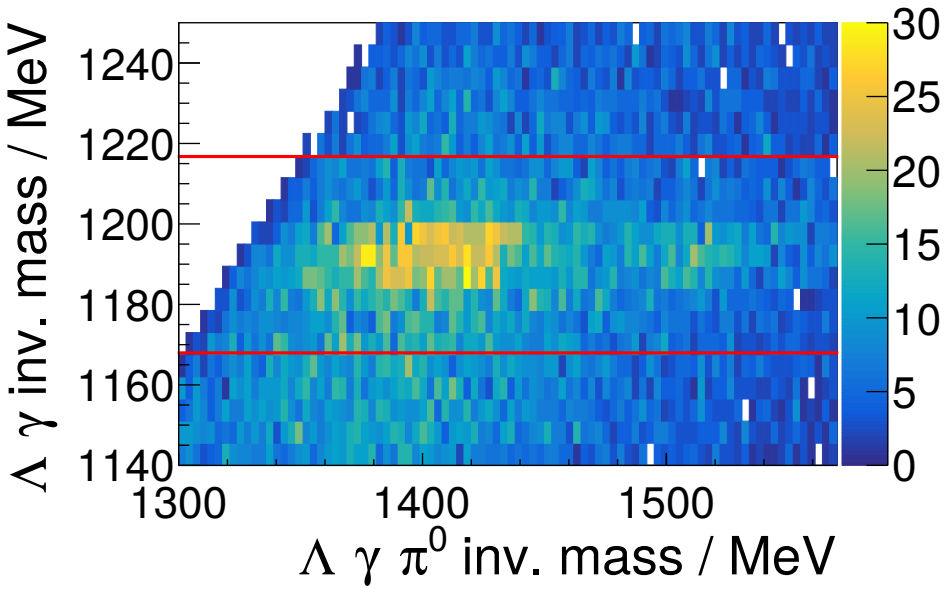
# RooFit



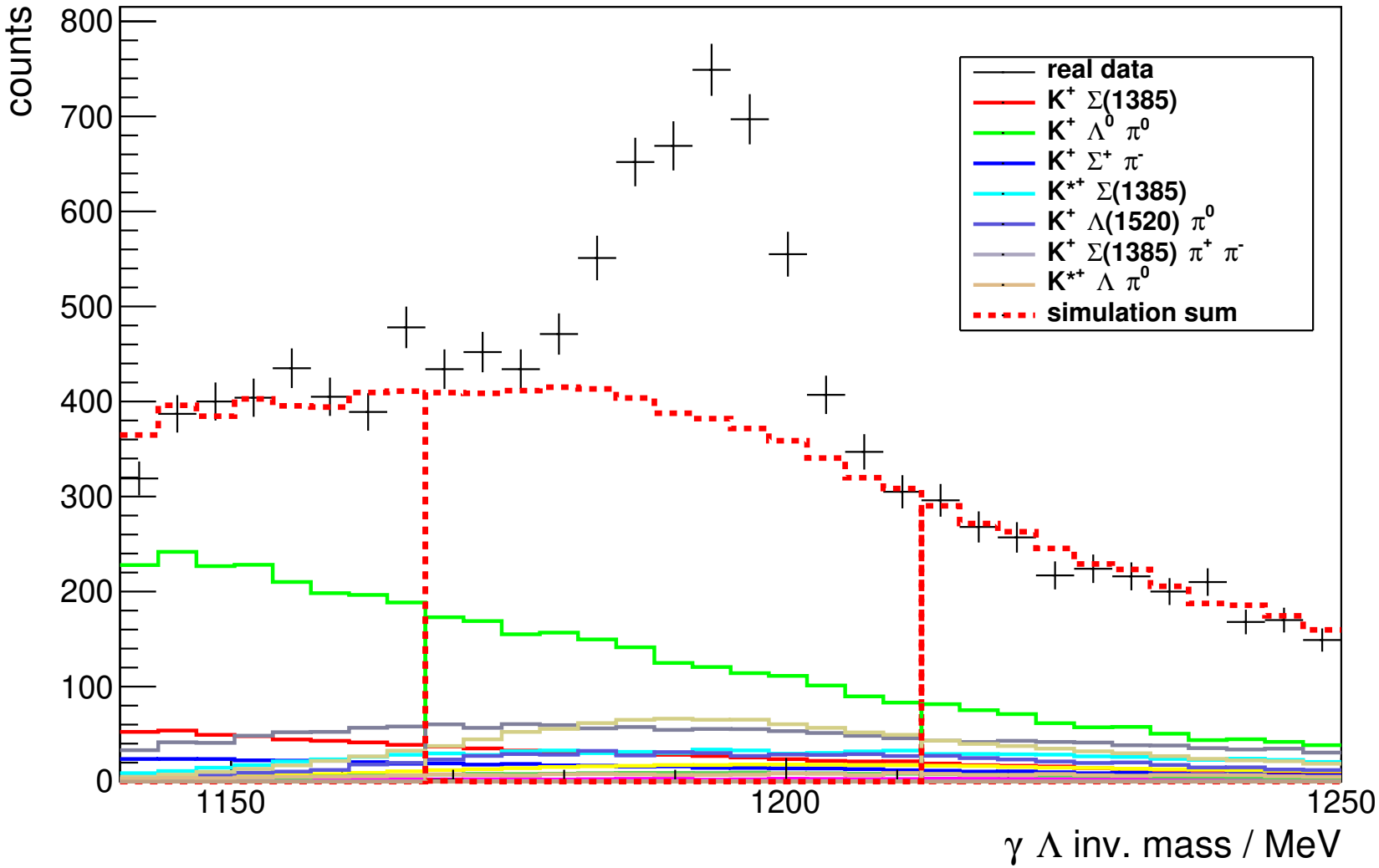

$K^+\Lambda(1405)$ events can be extracted with RooFit

# Line shape extraction with RooFit



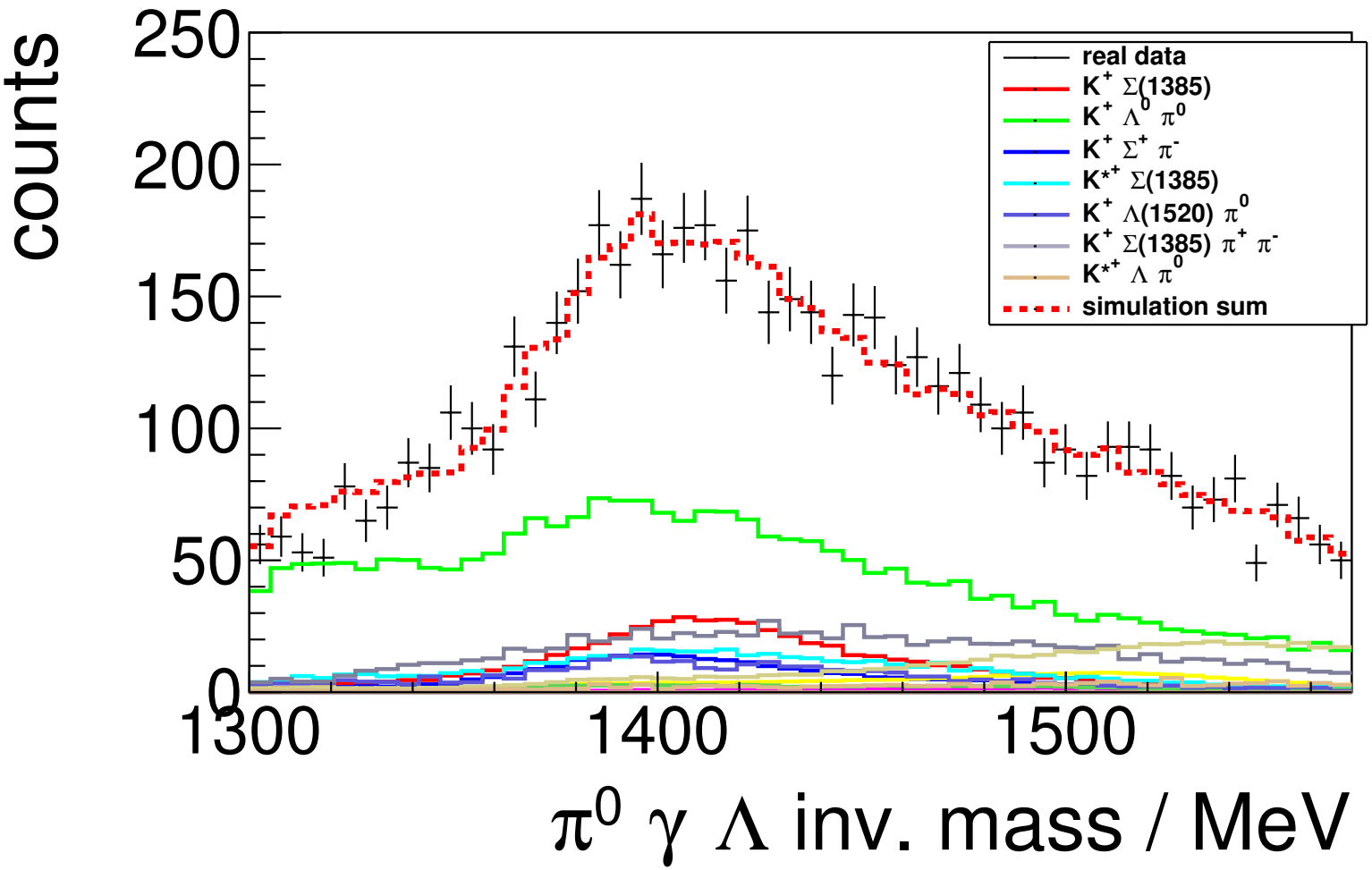

1. exclude events with $|\gamma\Lambda| \approx |\Sigma^0|$
2. fit background channels
   (excluding: $K^+\Sigma^0\pi^0, K^+\Lambda(1405/1520), K^{*+}\Sigma^0$)
3. subtract fitted background distribution from data

# Line shape extraction, RooFit results, $\gamma\Lambda$ projection



# Line shape extraction, RooFit results, $\pi^0\gamma\Lambda$ projection

background region: $|\gamma\Lambda| < 1167$ MeV or $|\gamma\Lambda| > 1212$ MeV



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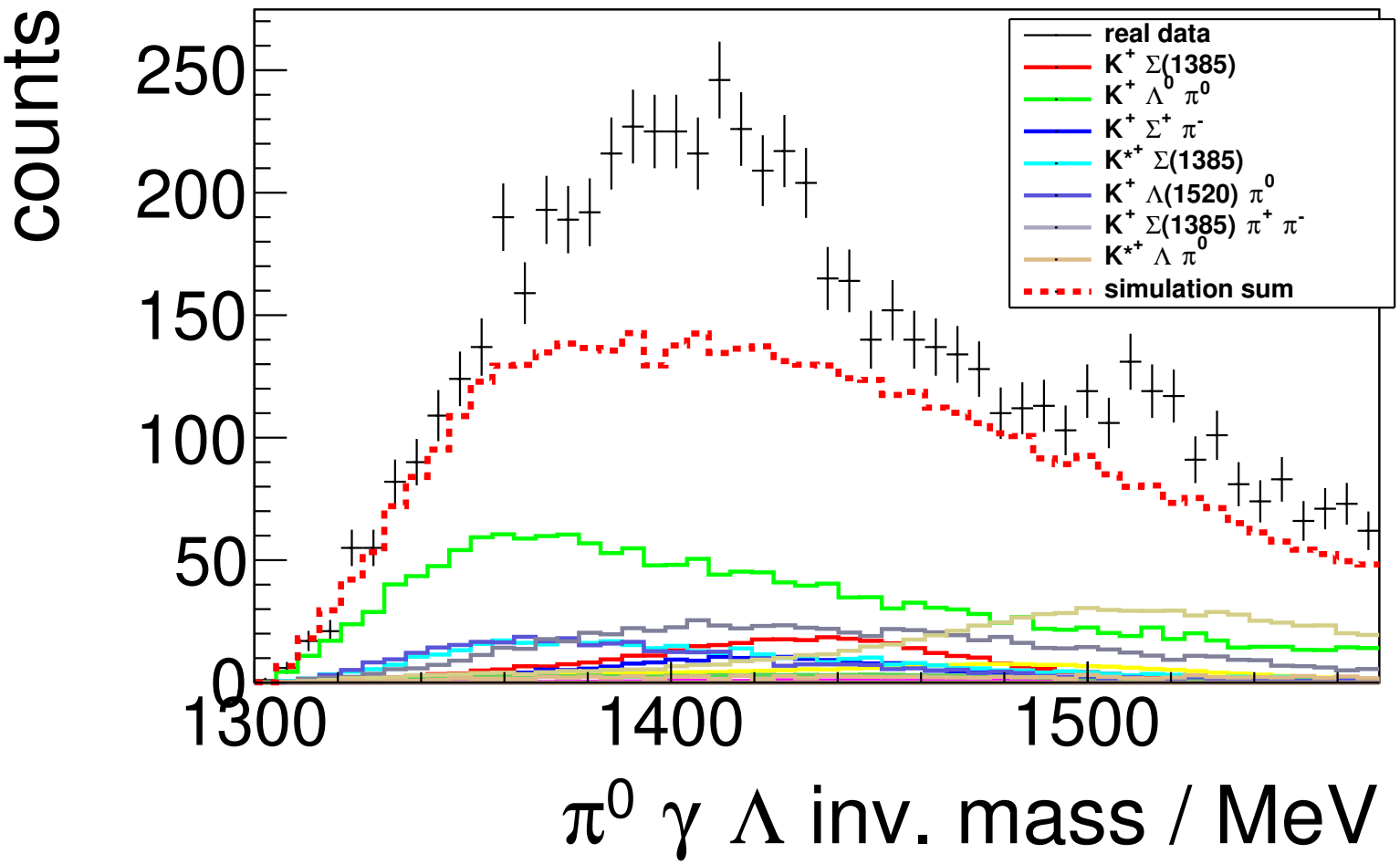
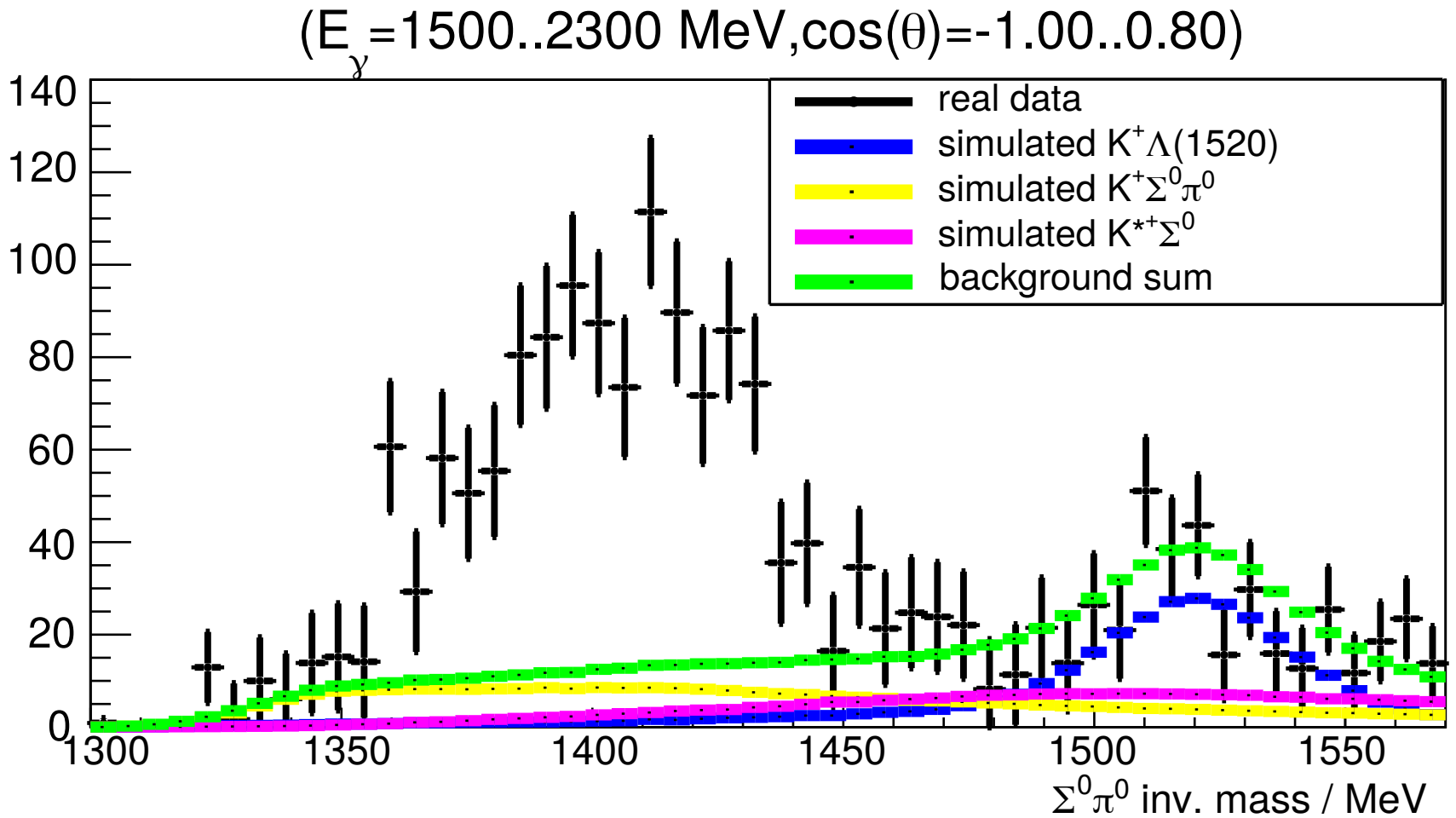
signal region: 1167 MeV $< |\gamma\Lambda| <$ 1212 MeV

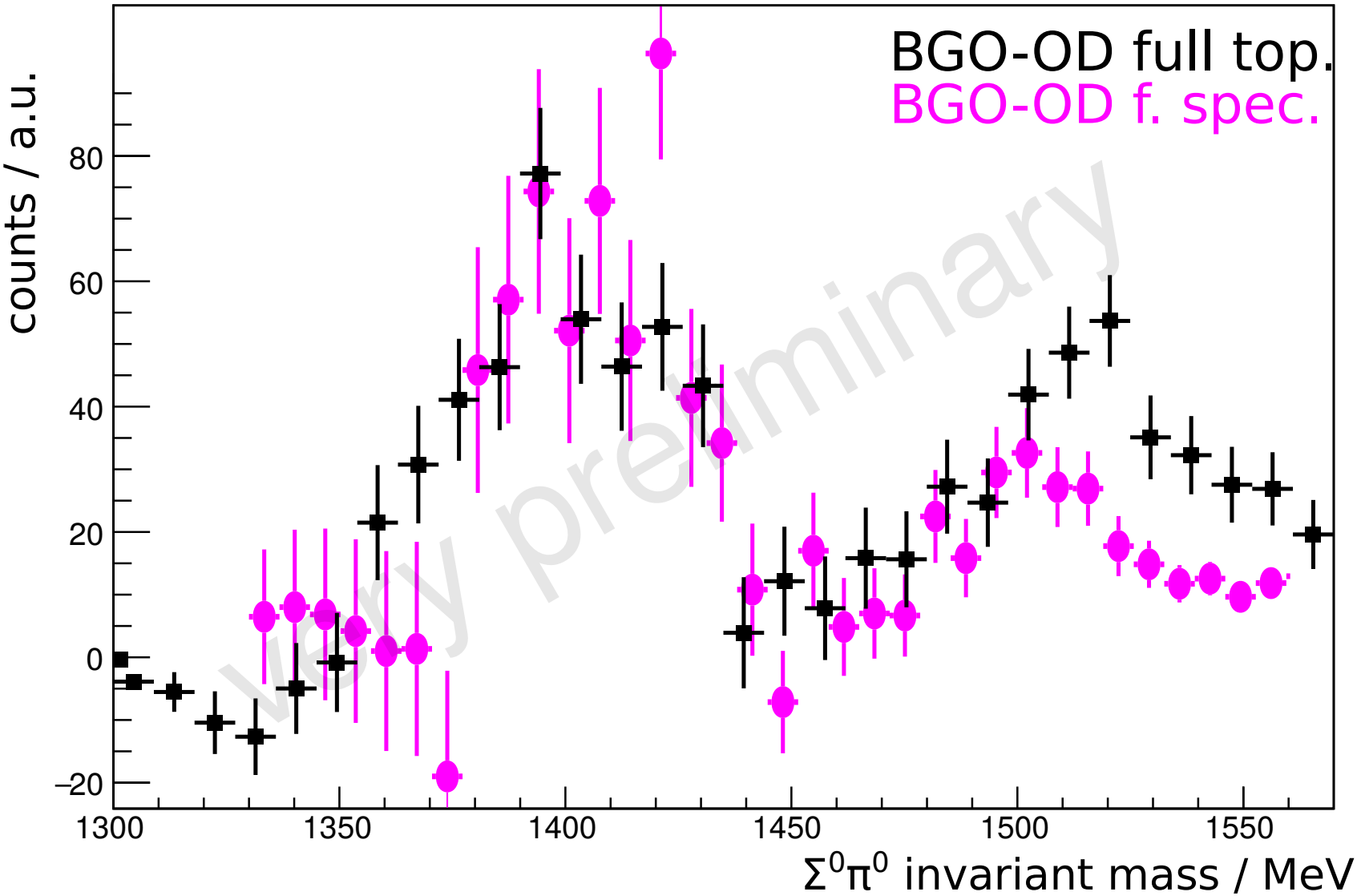


# Line shape extracted

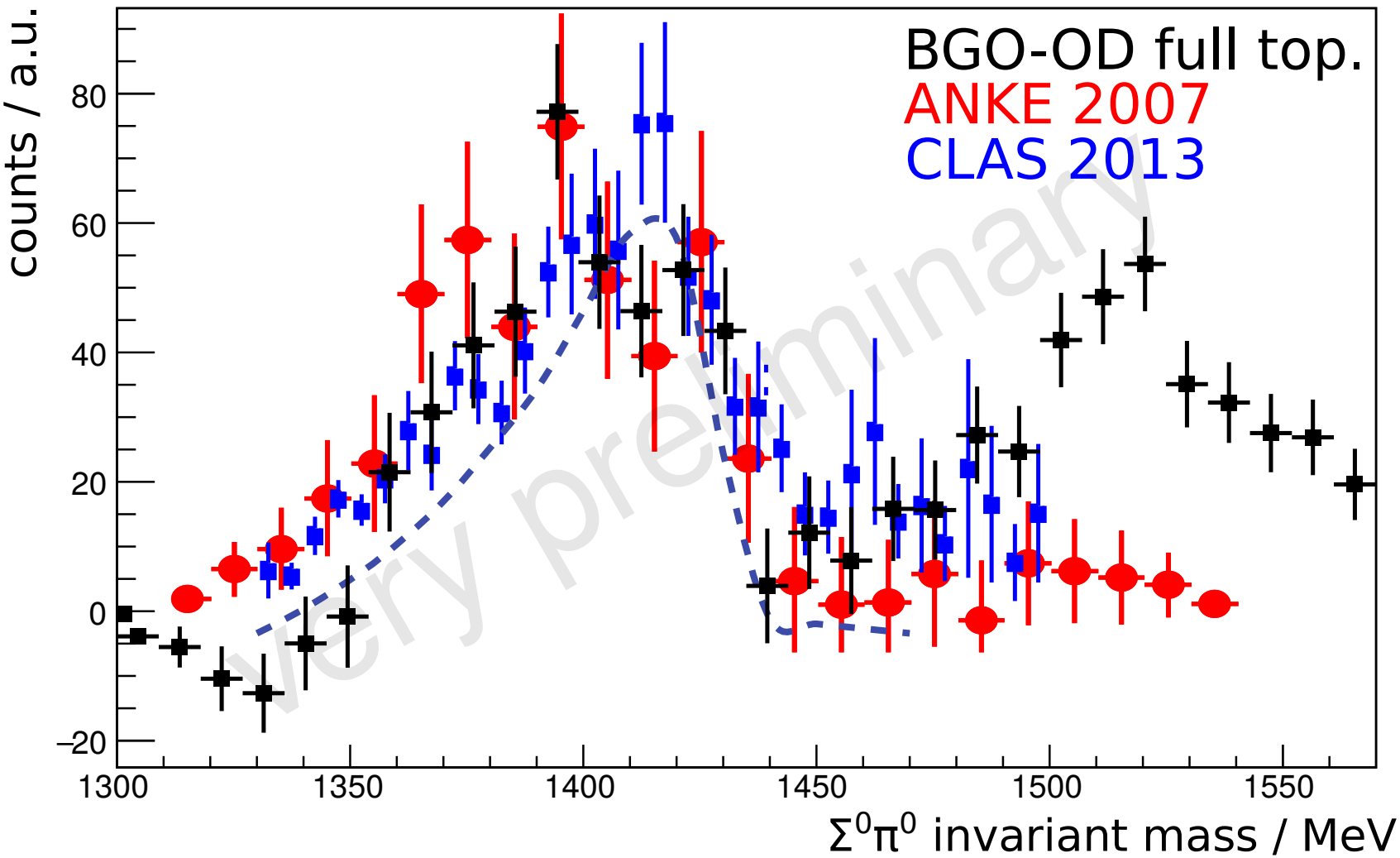



Mass resolution $\sigma = 13.0 \pm 0.1$MeV

# Line shape at BGO-OD

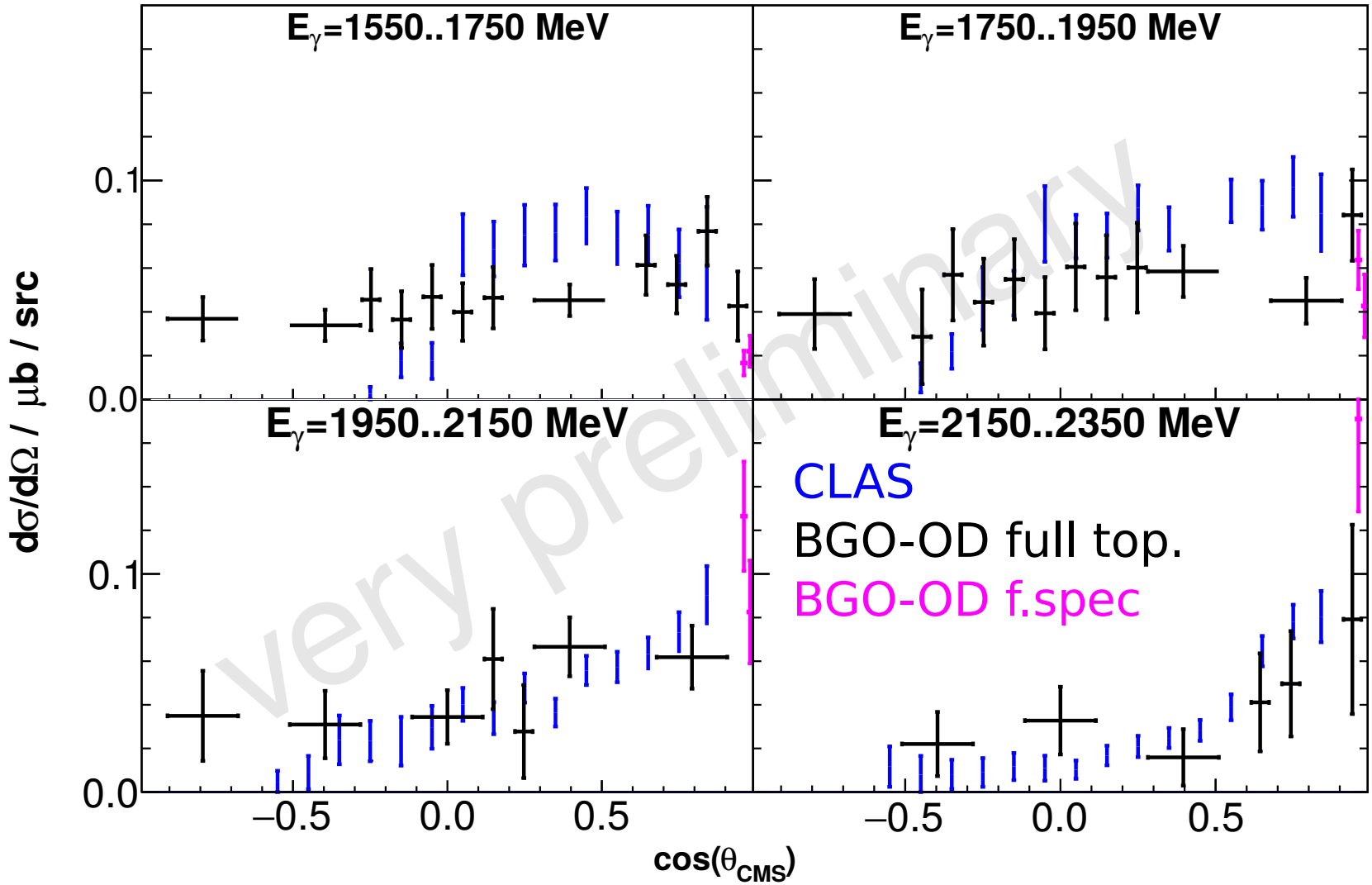


# Line shape compared to other experiments




ANKE: I. Zychor et al. Phys.Lett.B660:167-171 (2008)
dashed line: J.C.Nacher et al. Phys.Lett. B455, 55-61 (1999)

# Differential cross section $\gamma p \to K^+\Lambda(1405) \to K^+\Sigma^0\pi^0$



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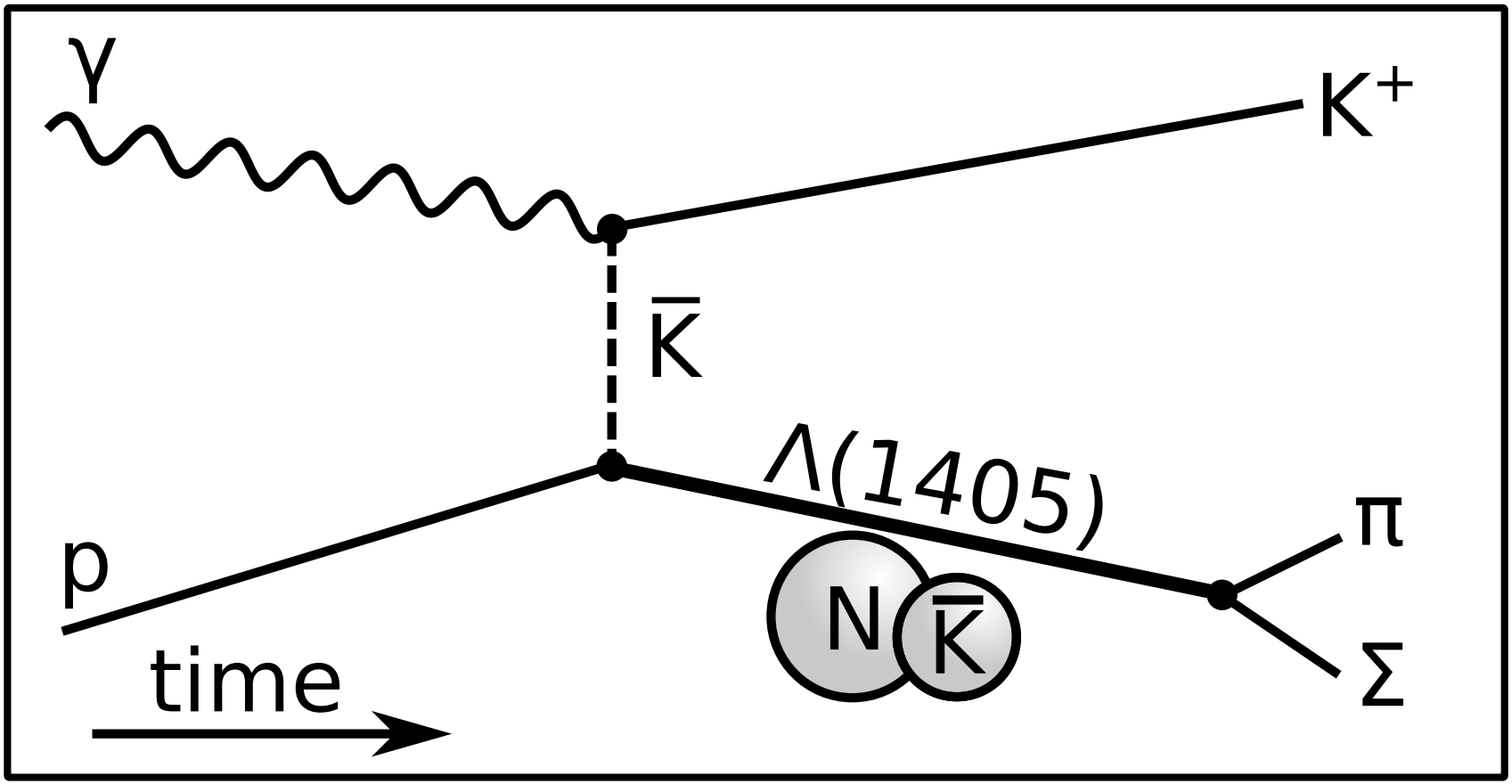
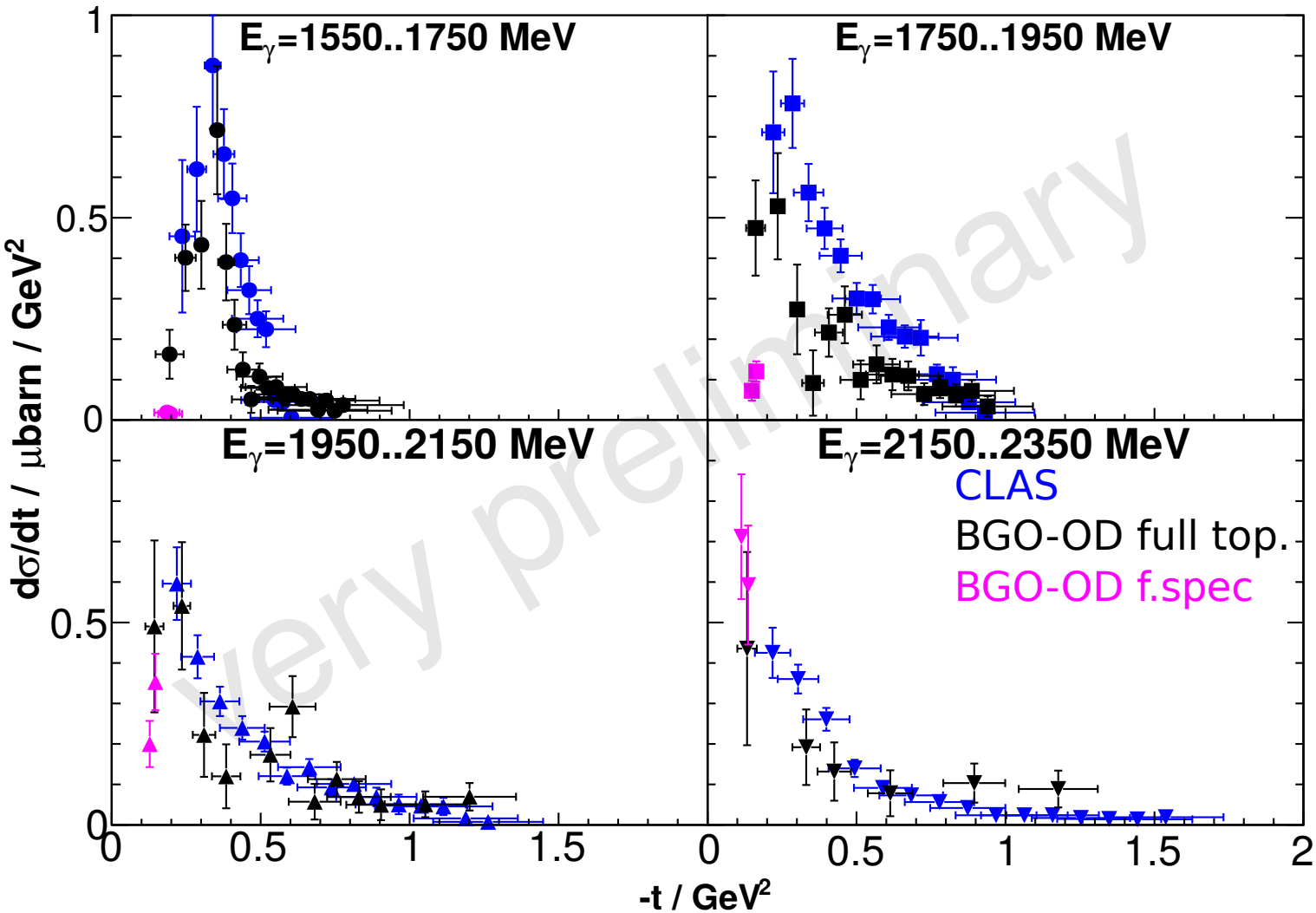



Mandelstam variable $t = (\gamma - K^+)^2$

transfer momentum $\vec{q} = \vec{\gamma} - \vec{K^+}$

# Differential cross section against *t*



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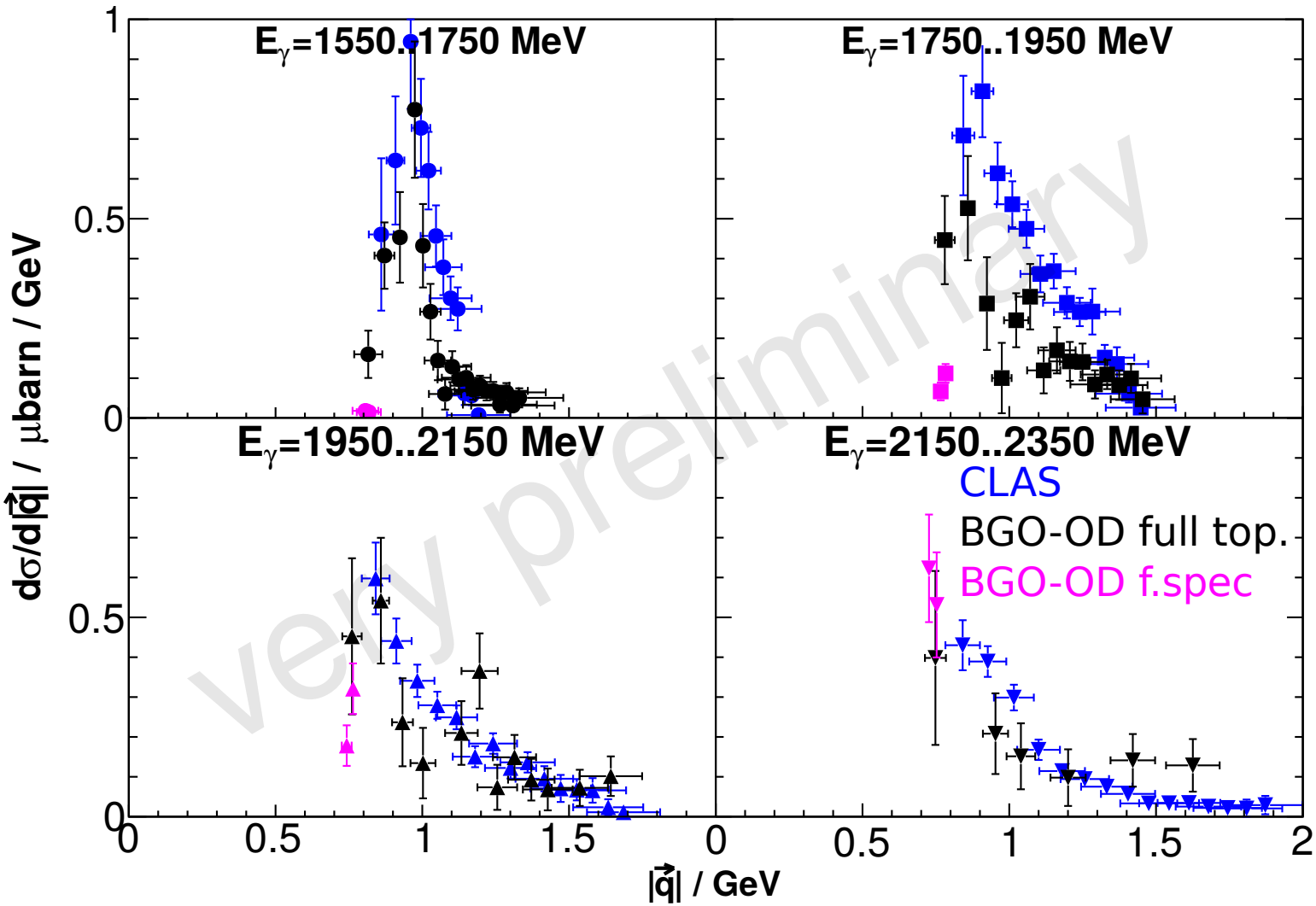
# Differential cross section against $|\vec{q}|$



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# Summary & outlook

- Motivation: unconventional states in s-sector
  - Λ(1405) molecule-like structure?

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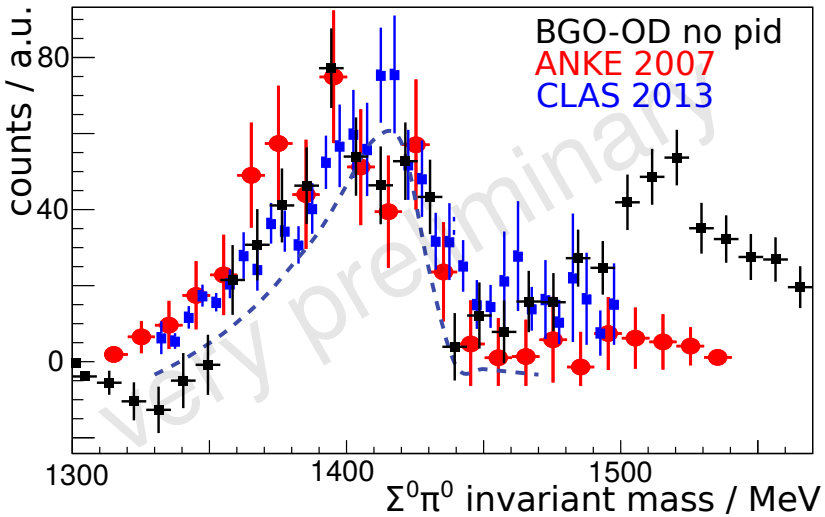
  - Line shape
    - good agreement
    - other decay modes
      $\rightarrow$ more data taking

line shape:



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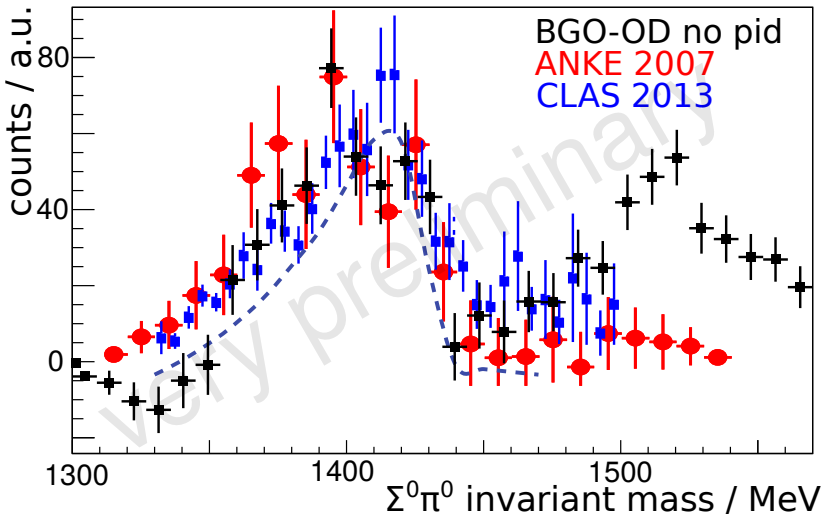
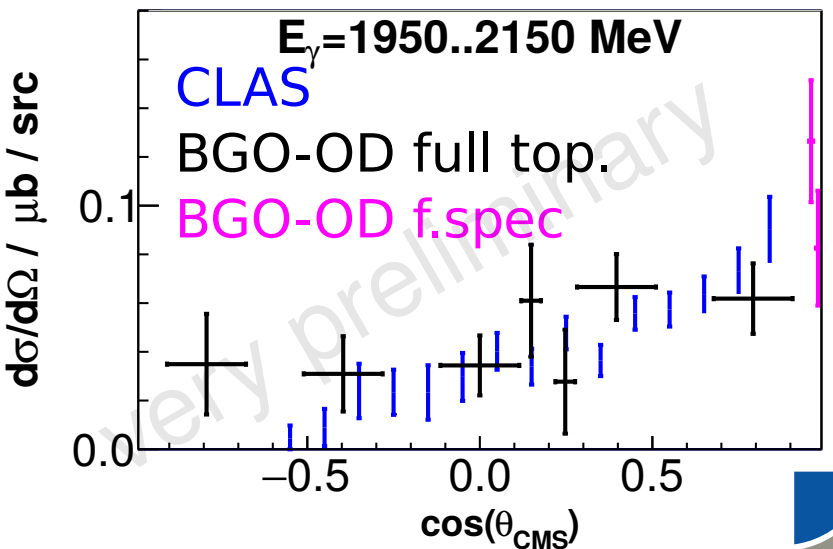
  - Λ(1405) molecule-like structure?
- Results for $\Lambda(1405) \rightarrow \Sigma^0\pi^0$
  - Line shape
    - good agreement
    - other decay modes $\rightarrow$ more data taking
  - Differential cross section
    - extreme forward angles accessible
    - agreement with CLAS

line shape:




diff. cross section:



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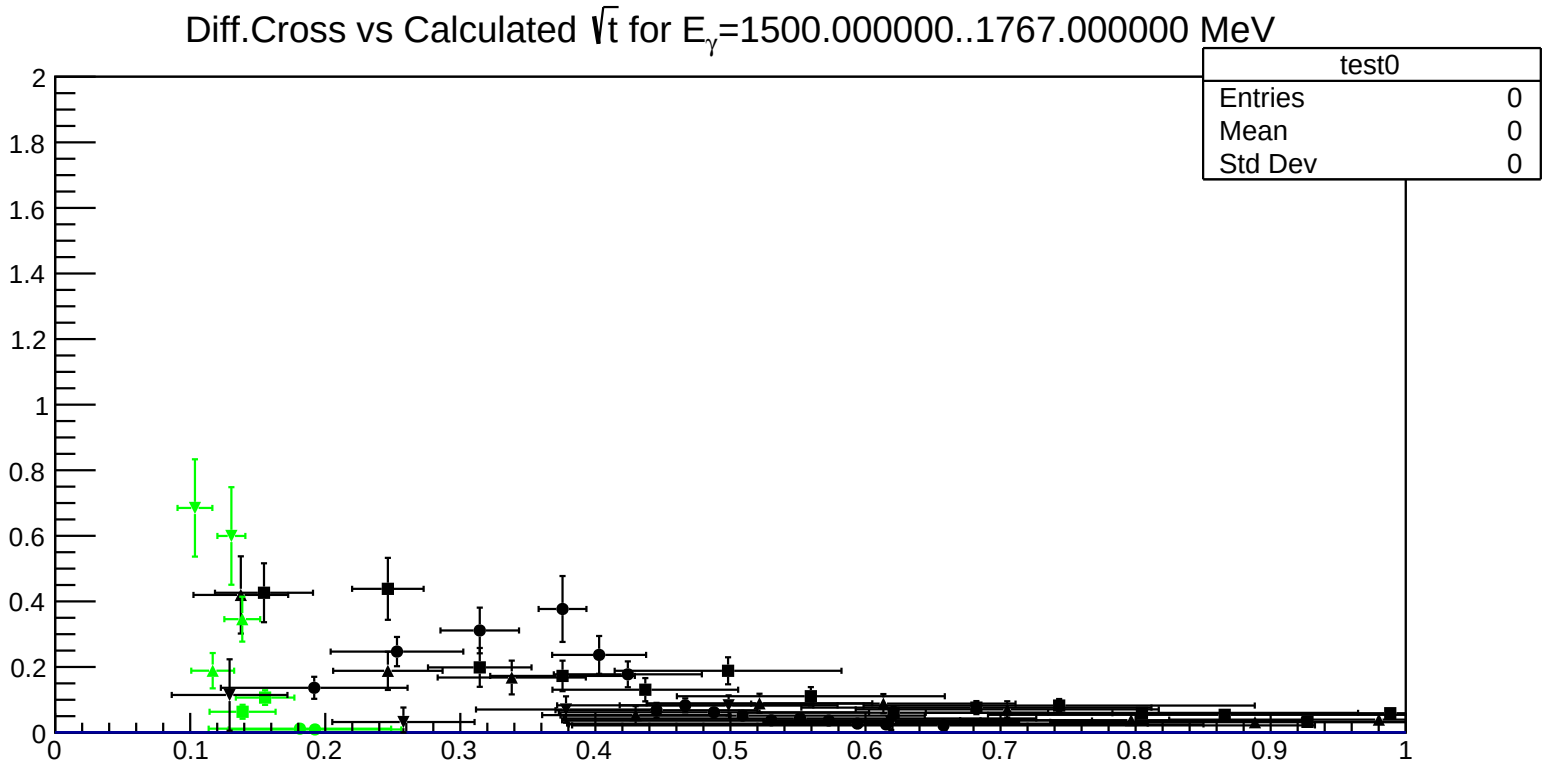
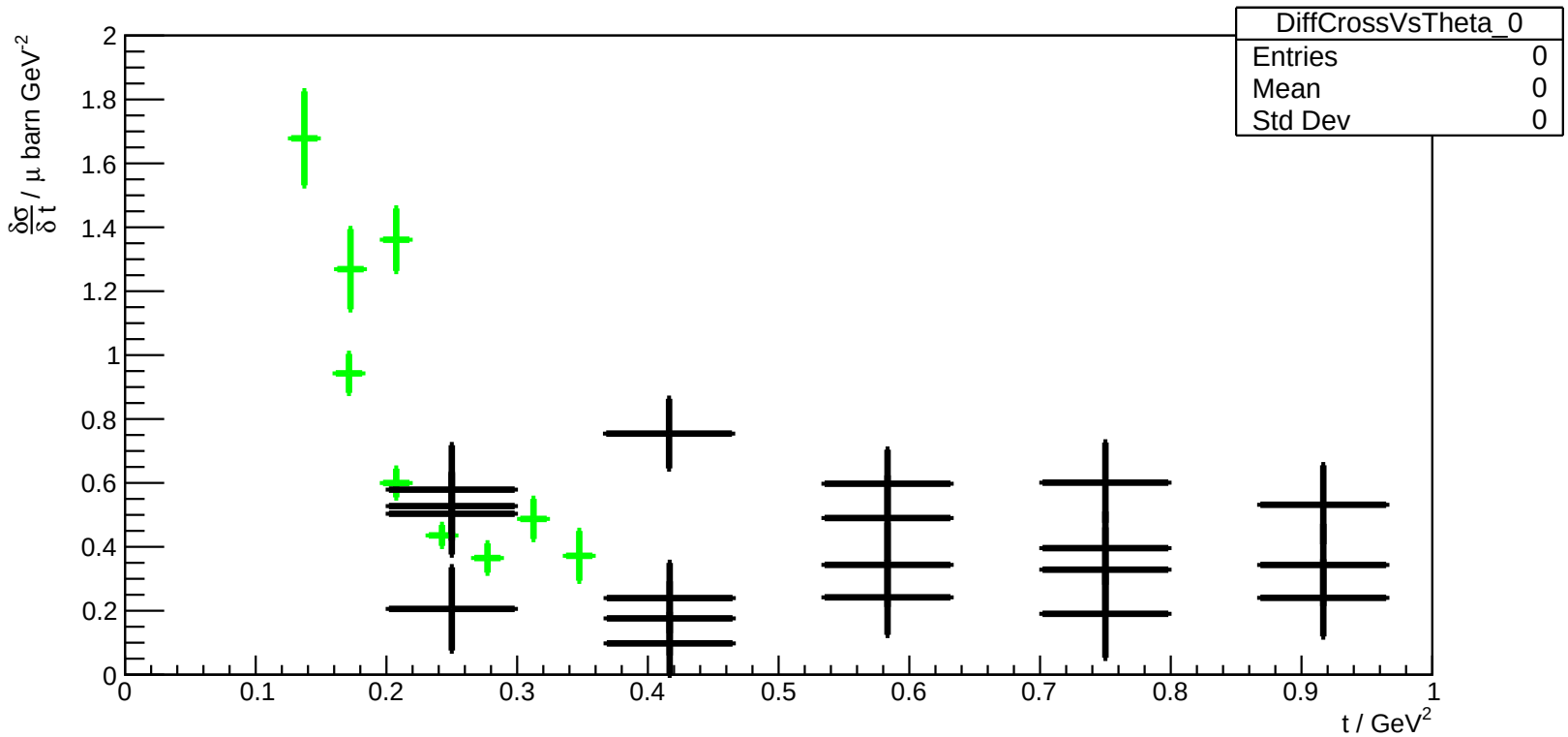
Thank you for your attention!

# new t correlation results



# new t correlation direct results



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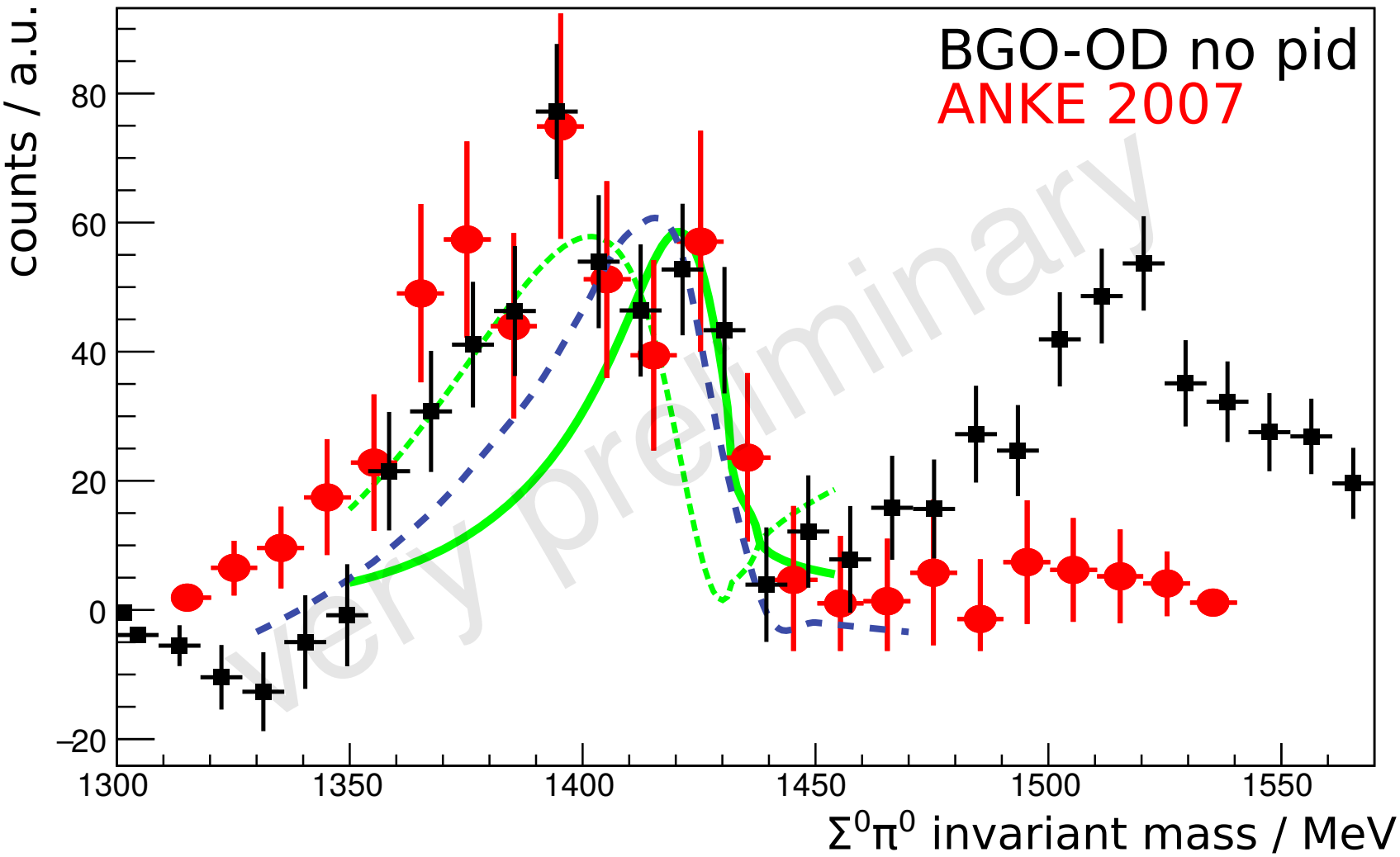
# Doppel peak structure in line shape?



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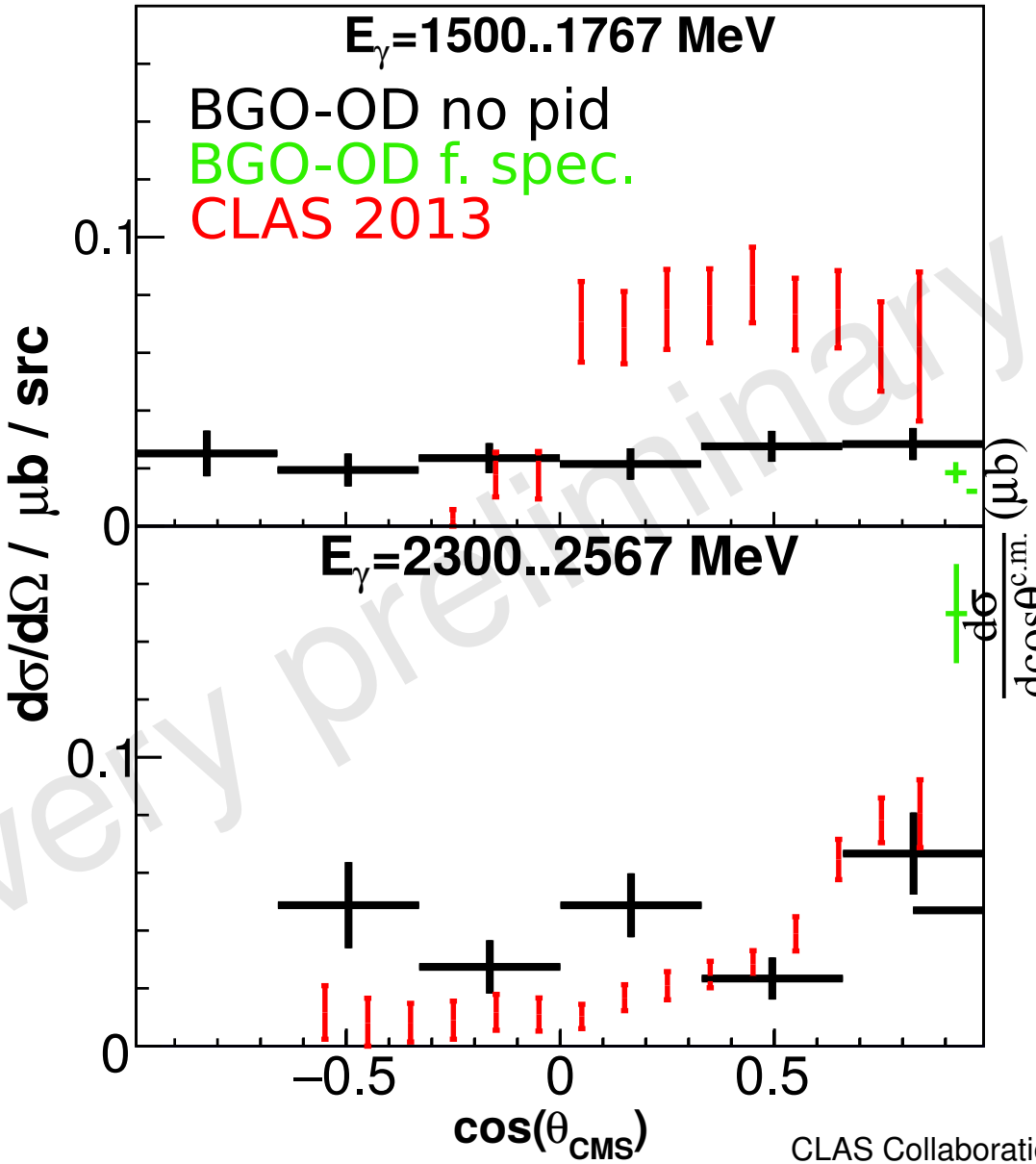
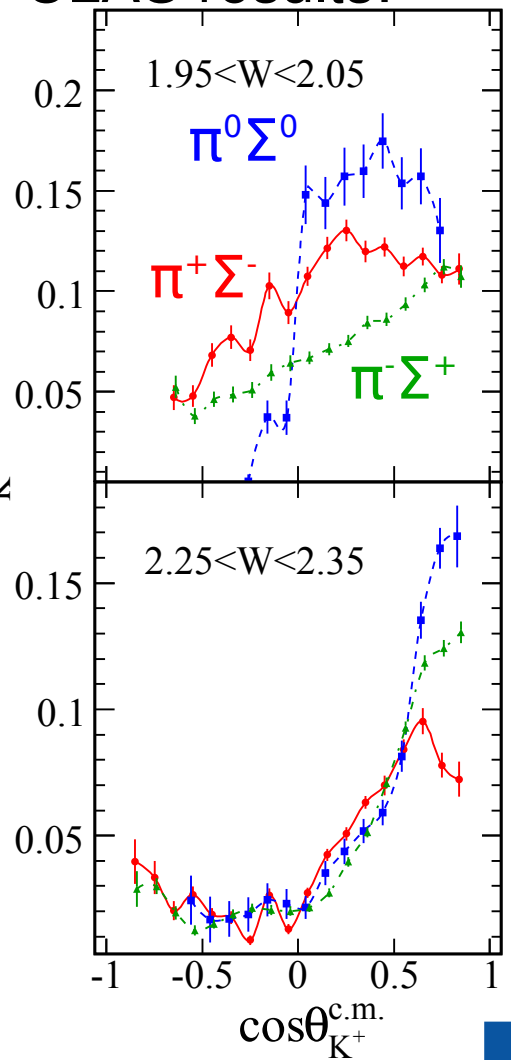
# Comparing cross section to other decay modes

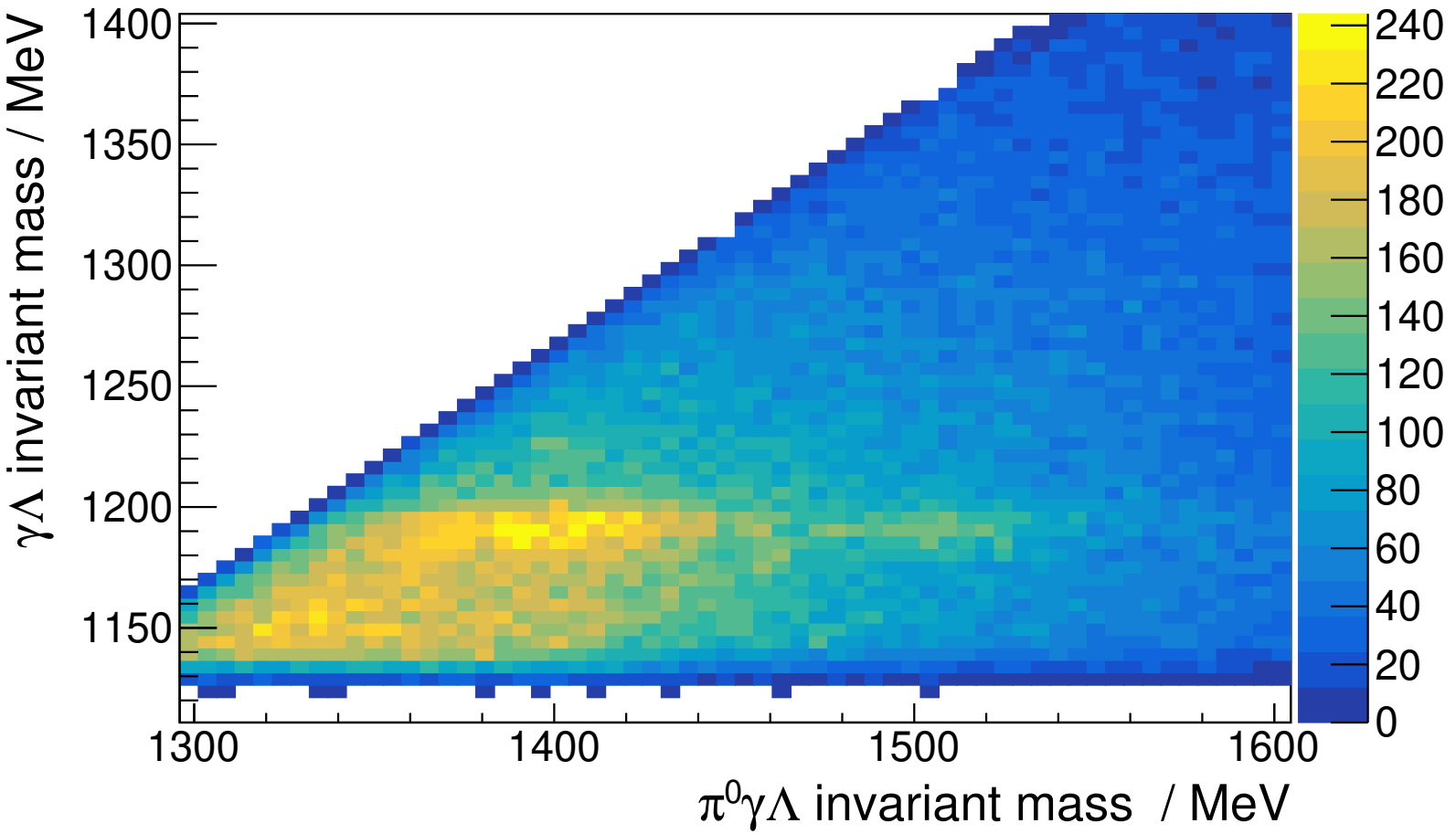



CLAS results:



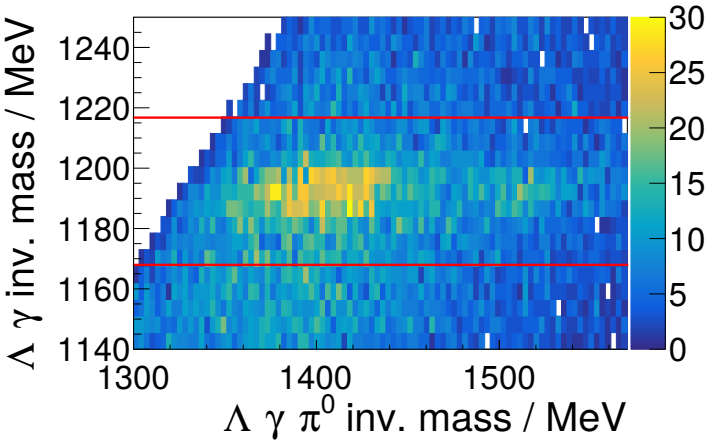

CLAS Collaboration, Phys. Rev. C 88 (2013)

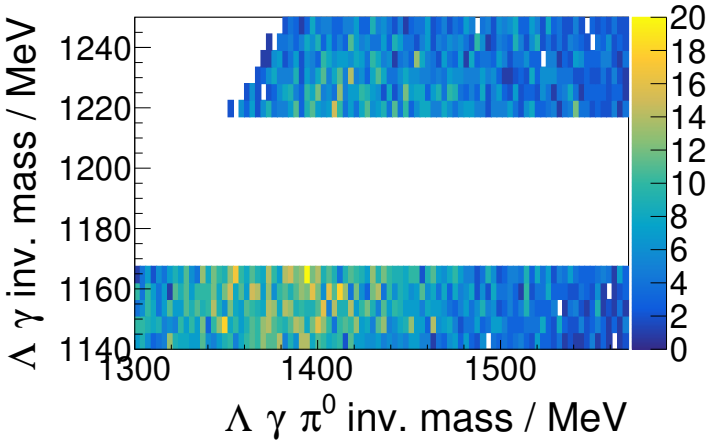
# $K^+\pi^0\Sigma^0 \rightarrow K^+3\gamma\pi^-p$ (real data)

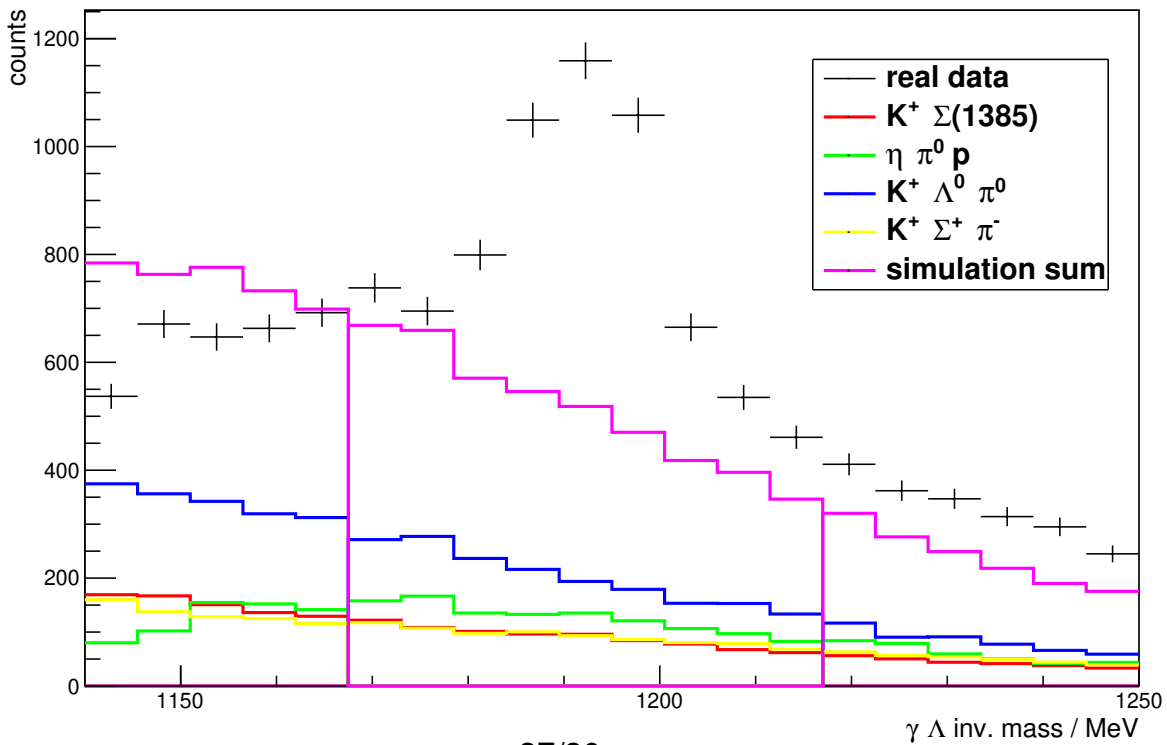



$\Sigma^0 \rightarrow \gamma\Lambda \rightarrow \gamma\pi^-p$(64%). No particle identification of $K^+$.

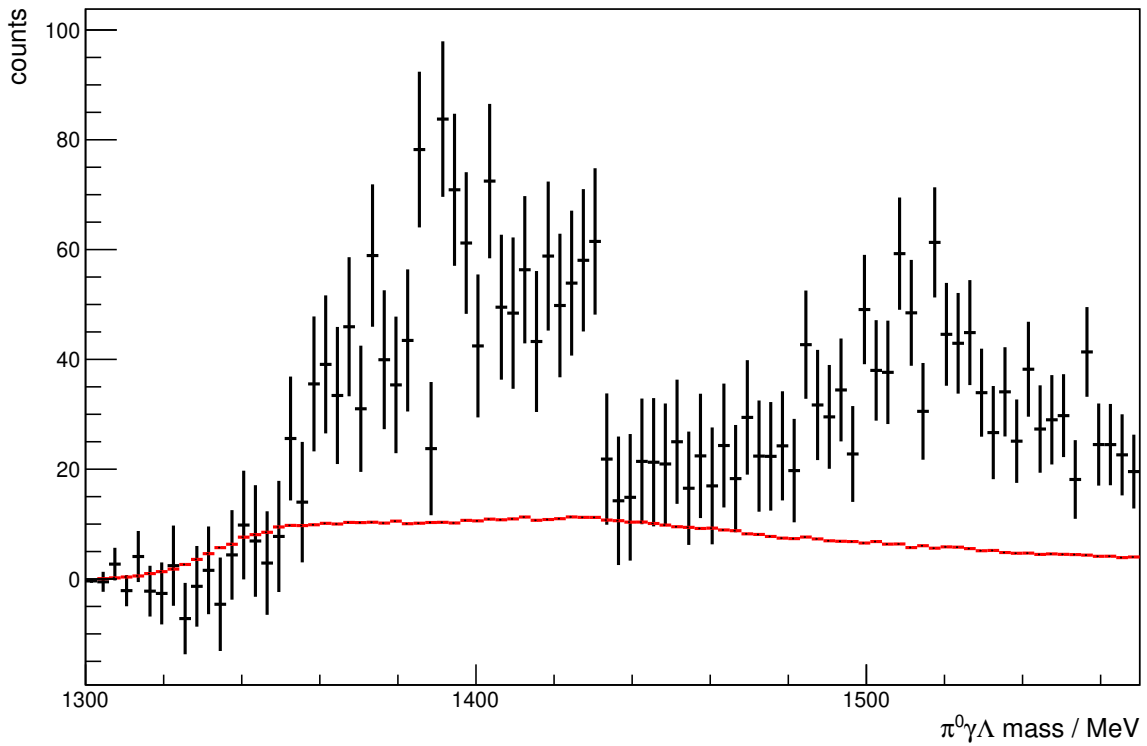
# nopid



# nopid

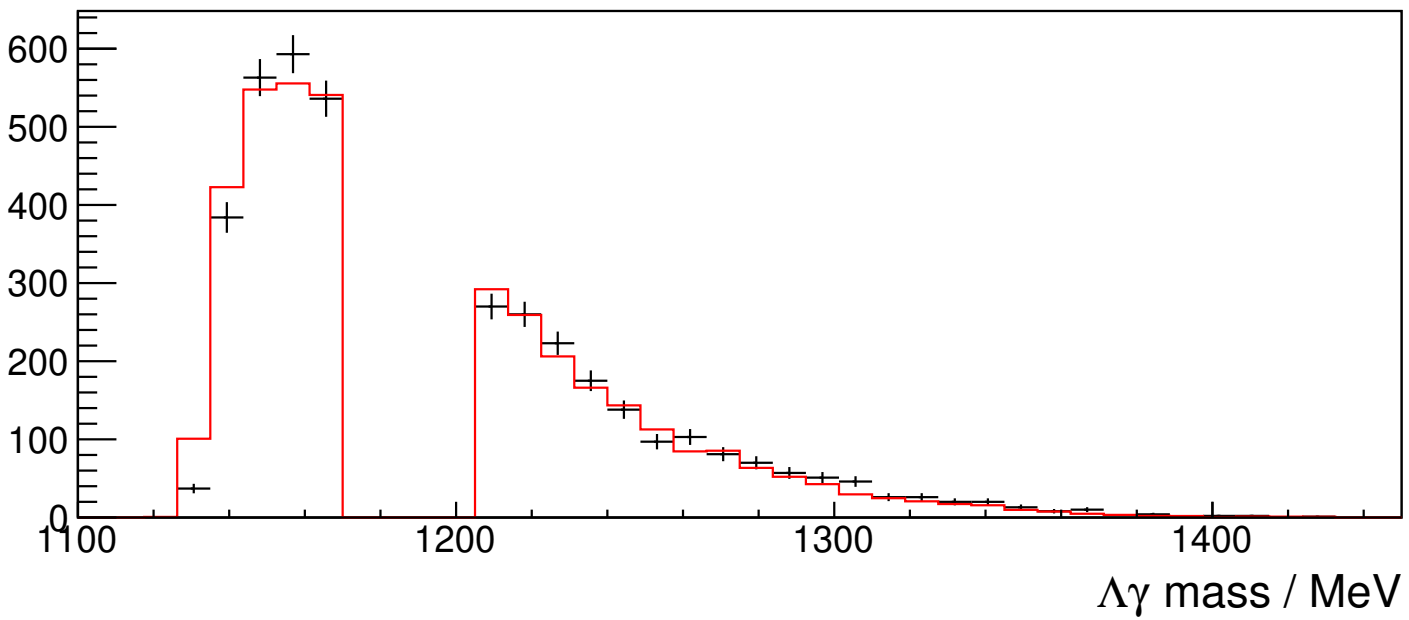

counts
100
80
60
40
20
0
1300
1400
1500
$\pi^0\gamma\Lambda$ mass / MeV

# 2D RooFit to background

- simulate background channels ($\Sigma(1385)$,$\Sigma^0$,$\pi^+\pi^-\pi^0$,...)

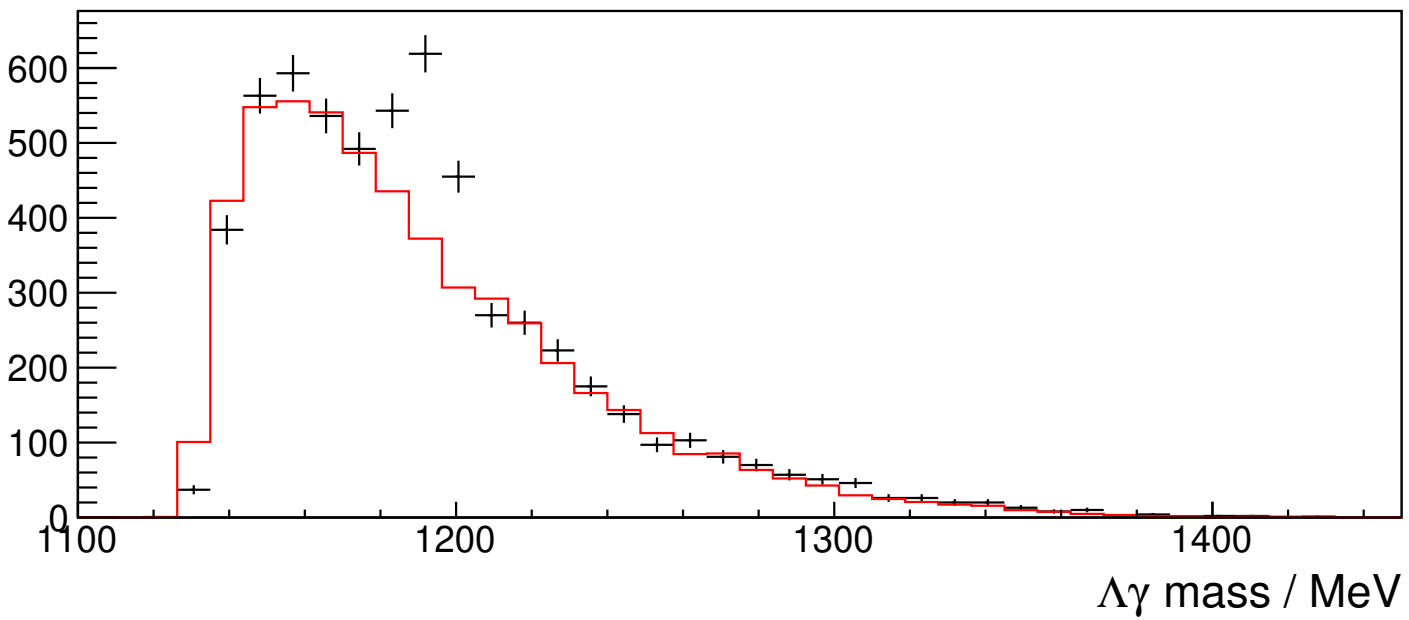
# 2D RooFit to background

- simulate background channels ($\Sigma(1385)$,$\Sigma^0$,$\pi^+\pi^-\pi^0$,...)
- data around $\Sigma^0$ mass removed
- background contribution is modulated to describe data (2D)



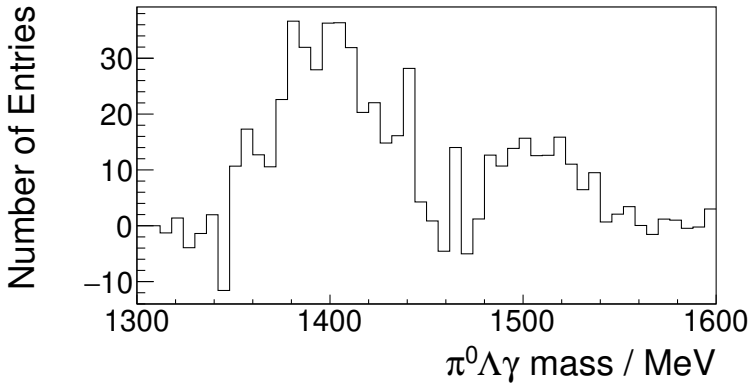
# 2D RooFit to background

- simulate background channels ($\Sigma(1385)$,$\Sigma^0$,$\pi^+\pi^-\pi^0$,...)
- data around $\Sigma^0$ mass removed
- background contribution is modulated to describe data (2D)
- found contributions subtracted from all data

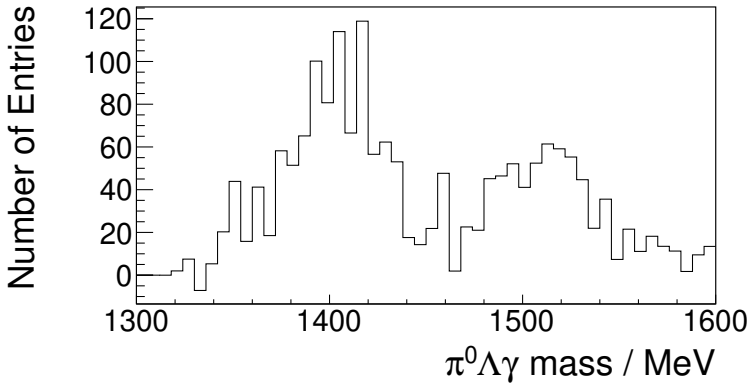


# $K^+\pi^0\Sigma^0$ background subtracted ($E_\gamma$ =1.6..2.0 GeV)

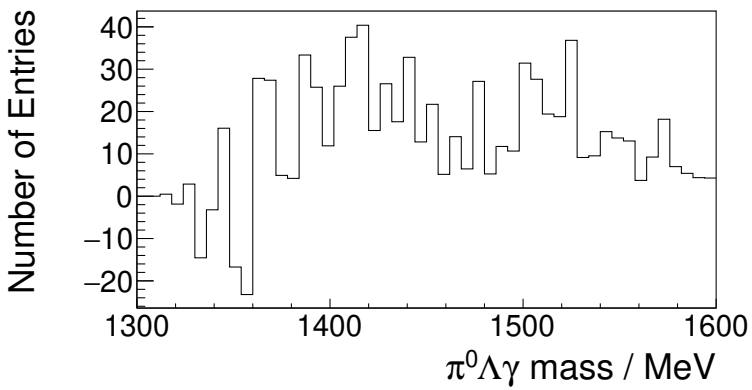
$\theta^{c.m.}_{K^+} = 0..45°$



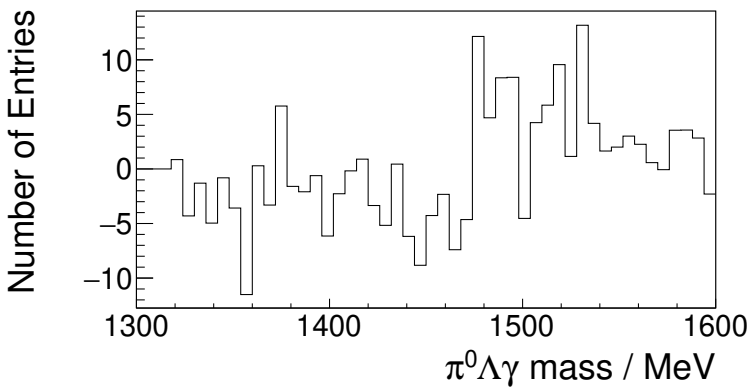

$\theta^{c.m.}_{K^+} = 45..90°$




$\theta^{c.m.}_{K^+} = 90..135°$

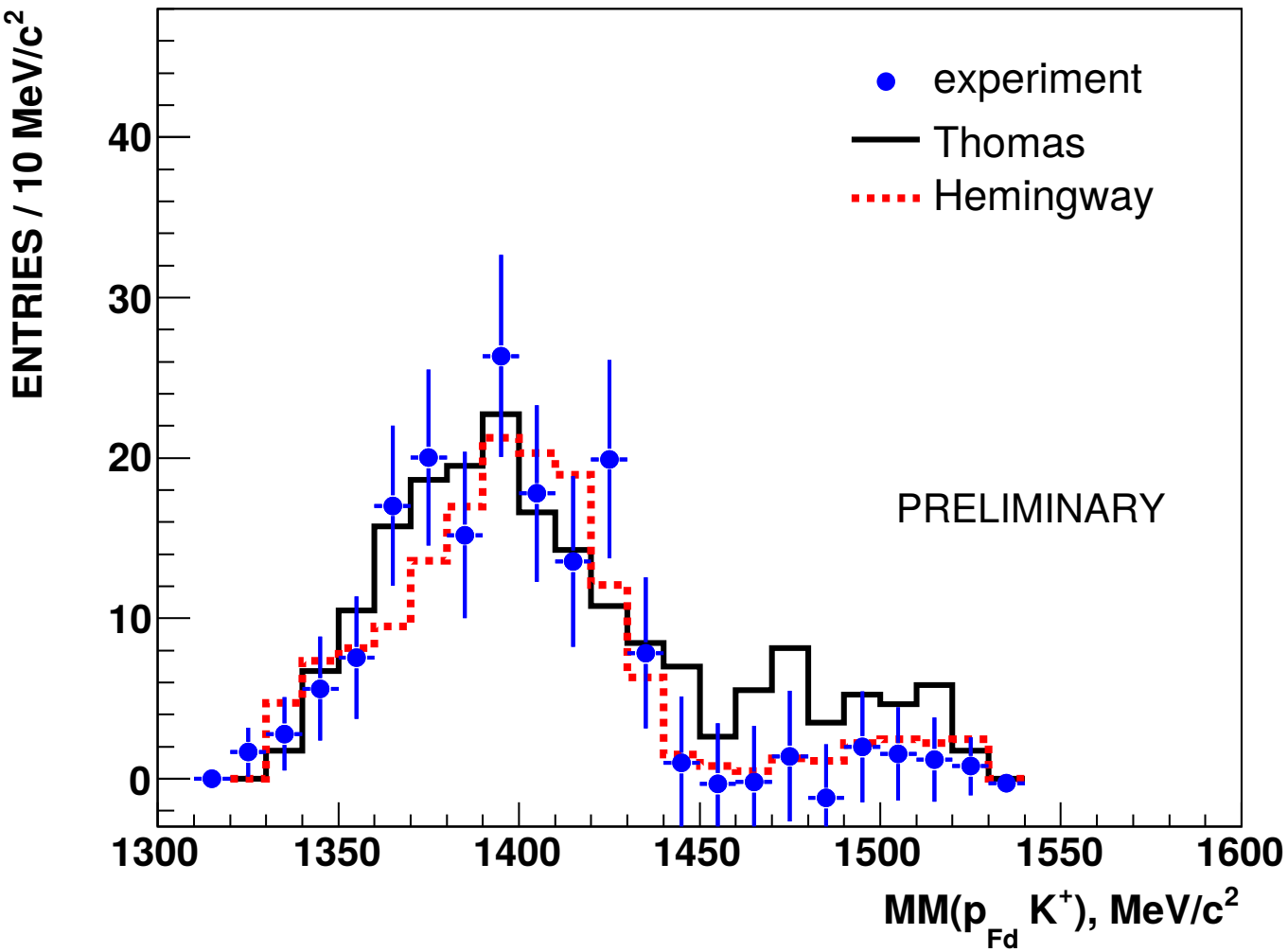



$\theta^{c.m.}_{K^+} = 135..180°$




Extraction of differential cross section possible

# Line shape Λ(1405)

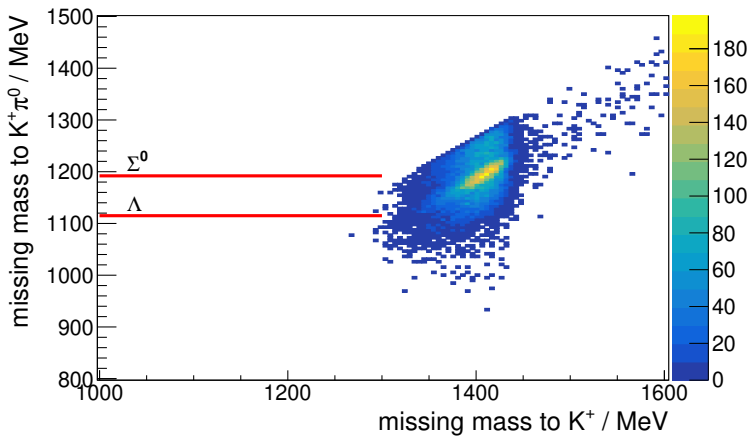



I.Zychor et al. (ANKE Collaboration) ECONFC070910:310,2007 (2007)

# Beam time durations

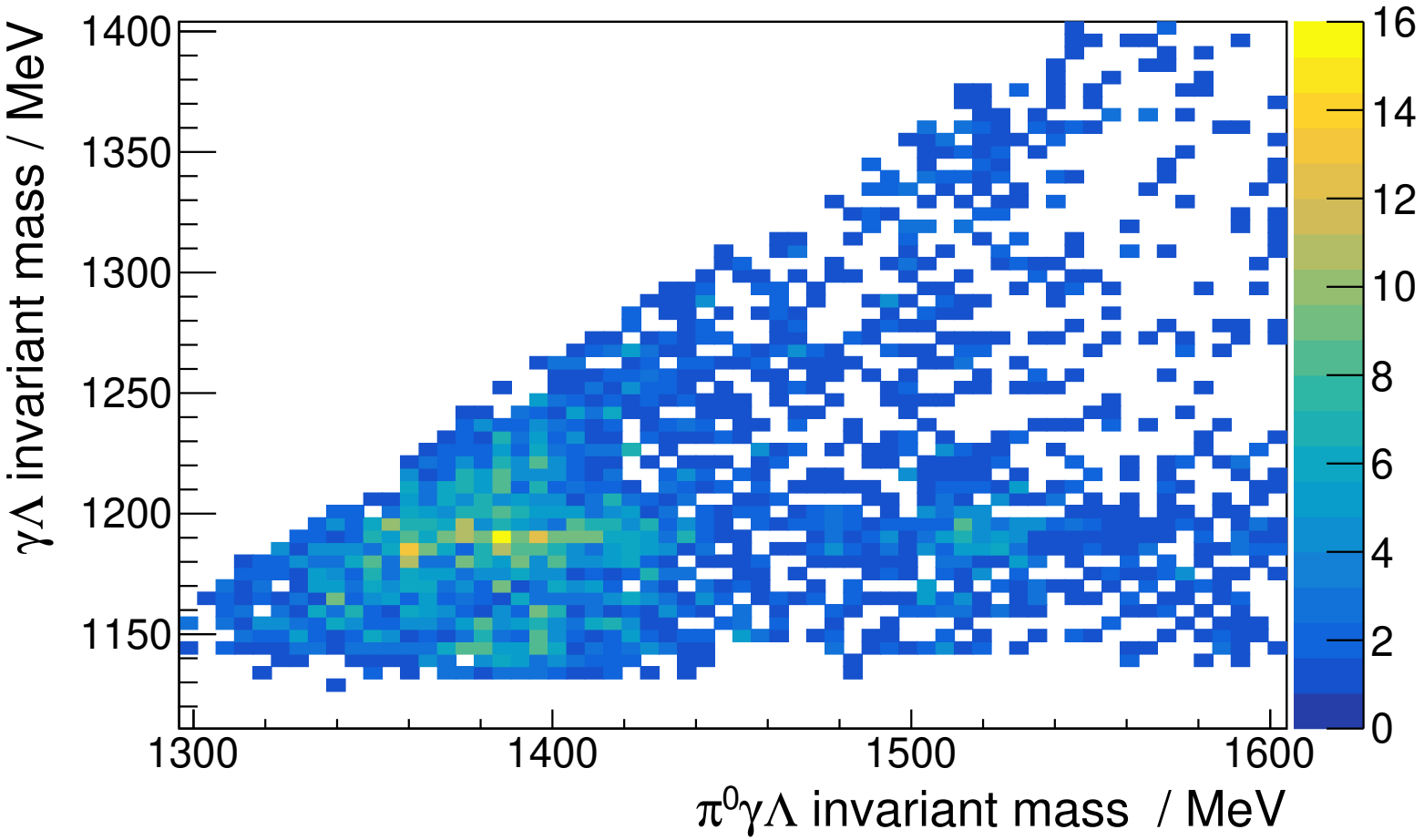
| Beamtime | datataking / days | $P_\gamma$ / % | e-Beamcurrent / pA |
|---|---|---|---|
| 6/2015 | 11 | $\approx$25 | 1300 |
| 10/2015 | 16 | $\approx$25 | 1190 |
| 2/2017 | 3 | $\approx$75 | 1300-1700 |
| 5/2017 | (15) | (75) | (1300) |

# $K^+\Lambda(1405) \rightarrow K^+\pi^0 X$ (sim. $\Lambda(1405)$, $K^+$ forward)




Knowledge about line shape of $\Lambda(1405)$ and $\Sigma(1385)$ needed!

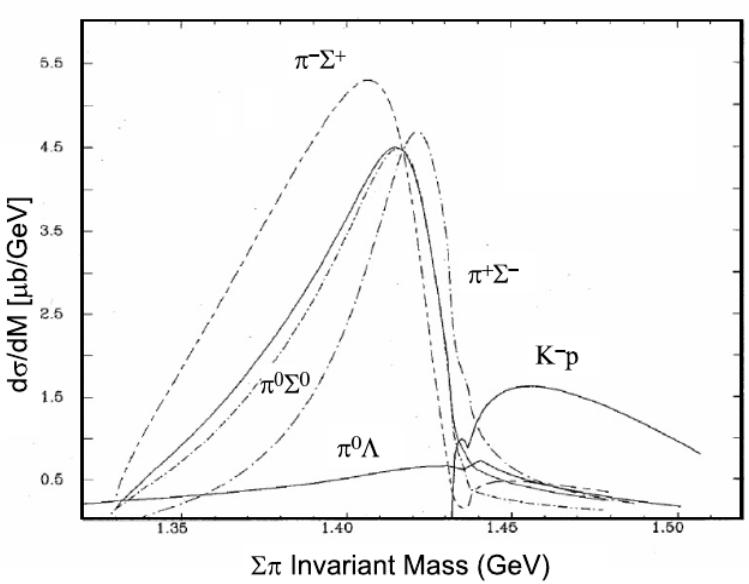
# $K^+\pi^0\Sigma^0 \rightarrow K^+\pi^0\gamma + \Lambda(\text{missing})$ (real data)




$\Sigma^0 \rightarrow \gamma\Lambda(100\%)$. After a kinematic fit to the missing $\Lambda$ mass.

# Λ(1405) line shape

**Prediction:**




J.C.Nacher et al. Phys.Lett. B455, 55-61 (1999)
see also: D.Jido et al. Nucl.Phys.A. 725,181 (2003)

$$\Lambda(1405) \rightarrow \Sigma^0\pi^0$$
$$\Sigma^{\pm}\pi^{\mp}$$

Free $N\bar{K}$ threshold at 1432 MeV $\rightarrow$ distorted mass line shape

$\rightarrow$ different for decay channels

# BGO-OD slice view