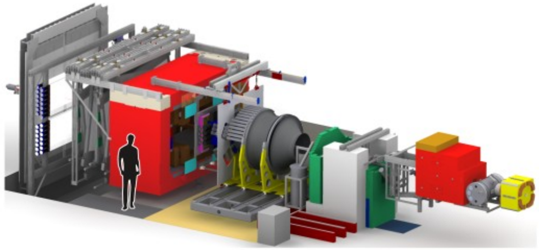
RECENT RESULTS FROM BGOOD

Rachele Di Salvo

INFN Roma "Tor Vergata"

- **Photoproduction off nucleons and physics motivations**
- **The BGOOD Detector**
- **Overview of analysis and results**



BARYON RESONANCES AND MESON PHOTOPRODUCTION OFF NUCLEONS

Physics motivation for the study of photon-induced meson production off nucleons is the investigation of the **excitation spectrum of the nucleon**.

→ Static and dynamical properties of baryon resonances are the testing ground for our "understanding" of the quark structure of the matter.

Baryon resonances have been first observed in πN scattering and most states listed in PDG and their properties have been extracted from πN data.

BUT

in the last 30 years large efforts have been done to perform experiments with real and virtual photons at high duty-cycle facilities and dedicated apparata for detection.

Particle	J^P	Year	Overall status	$N\gamma$	$N\pi$
$N(1860)$	$5/2^+$	1996 2018	– **	– *	– **
$N(1875)$	$3/2^-$	1996 2018	– ***	– **	– **
$N(1880)$	$1/2^+$	1996 2018	– ***	– **	– *
$N(1895)$	$1/2^-$	1996 2018	– ****	– ****	– *
$N(1900)$	$3/2^+$	1996 2018	** ****	 ****	** **

Strakovski, Progress in Particle and Nuclear Physics 111 (2020) 103752

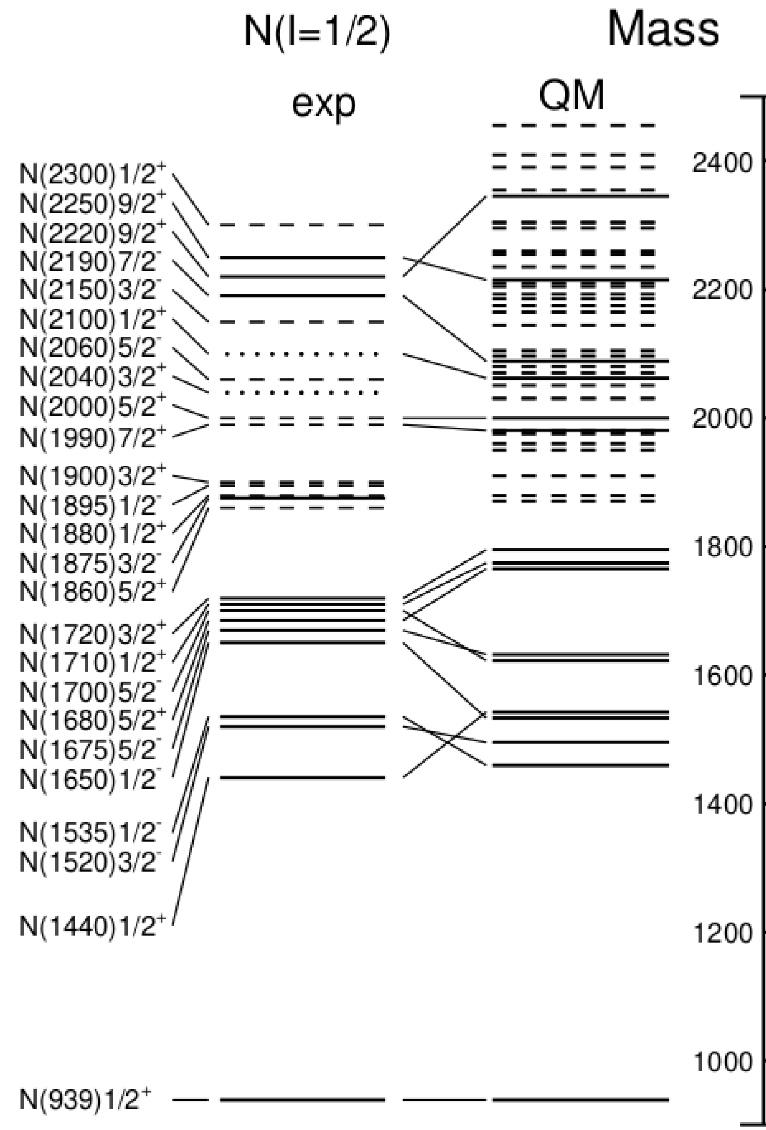
BARYON RESONANCES AND MESON PHOTOPRODUCTION OFF NUCLEONS

OPEN PROBLEMS

“MISSING RESONANCES”

→ effective degrees of freedom inside the nucleon

NATURE OF CERTAIN RESONANCES
(not well explained by conventional models)
→ meson-baryon molecular states



Particle Data Group, Phys. Rev. D 98, 030001 (2018)

Meson photoproduction allows:

+ access to resonance states coupled to photons → **ACCESS TO FINAL STATES DIFFERENT FROM πN → "MISSING RESONANCES"?**

+ polarization observables are accessibles → **SEPARATION OF OVERLAPPING RESONANCES**

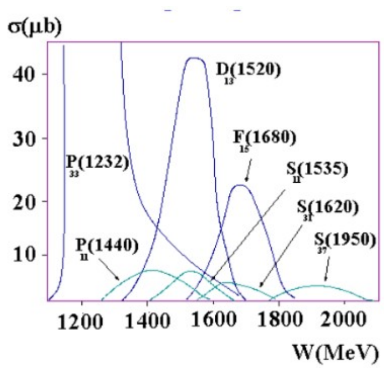
+ decay amplitudes extraction → **STUDY OF RESONANCE NATURE**

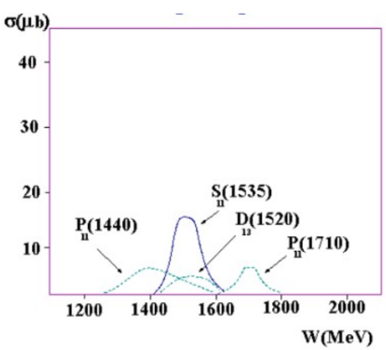
- low e.m. cross-sections → **Overcome thanks to technological developments**

- non-resonant contributions are significant → **Disentagled with polarization observables**

N.B. isospin filters (η, η', ω) → **ACCESS TO *N** RESONANCES**

$\gamma\, p \to \pi^0\, p$





$\gamma\, p \to \eta\, p$

From B.Krusche, Prog. Part. Nucl. Phys. 51 (2003), 399-485

N.B. Photoproduction amplitudes on **proton** and **neutron** of the same meson (in its different charge states) can be decomposed in terms if isospin aamplitudes.

→ **NEED FOR EXPERIMENTS ON NEUTRONS AND PROTONS**

AN EXAMPLE: THE η PHOTOPRODUCTION

Let us see the expressions for unpolarized cross section and beam asymmetry in terms of multipoles for η photoproduction case, obtained after truncation at the first orders:

$$\left(\frac{d\sigma}{d\Omega}\right)_{UNP} = \frac{q^{CM}}{2\,k_\gamma^{CM}}\Big\{ |E_{0+}|^2 - Re\left[E_{0+}^*(E_{2-} - 3M_{2-})\right] +$$

$$+ 2\cos\theta\ Re\left[E_{0+}^*(3E_{1+} + M_{1+} - M_{1-})\right] + 3\cos^2\theta\ Re\left[E_{0+}^*(E_{2-} - 3M_{2-})\right]\Big\}$$

$$\Sigma = -\frac{q^{CM}}{2\,k_\gamma^{CM}} \frac{1}{\left(\frac{d\sigma}{d\Omega}\right)_{UNP}} 3\,\sin^2\theta\ Re\left[E_{0+}^*(E_{2-} + M_{2-})\right]$$

$E_{0+} \rightarrow S_{11}$

$M_{1-} \rightarrow P_{11}$

$E_{1+}, M_{1+} \rightarrow P_{13}$

$E_{2-}, M_{2-} \rightarrow D_{13}$

Further term is: ($g\sin^2\theta\cos\theta$)
(interference S_{11}-F_{51})

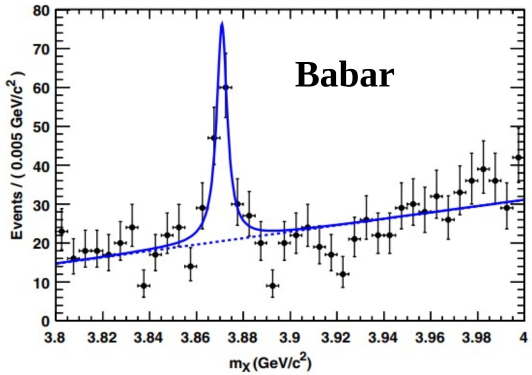
Since the E_{0+} multipole dominates at threshold, in the differential cross-section it is hard to distinguish the contribution of other resonances.

In beam asymmetry, on the contrary, this contribution is amplified in the interference with the dominating multipole E_{0+}.

NEED FOR POLARIZED BEAMS AND/OR TARGETS EXPERIMENTS

STRANGENESS PHOTOPRODUCTION

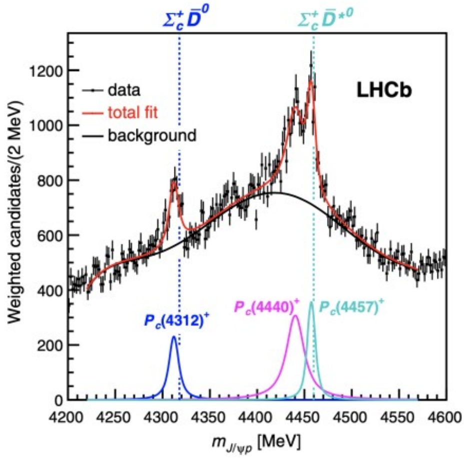
In the last years focus has been put on the investigation of unconventional multi-quark states.

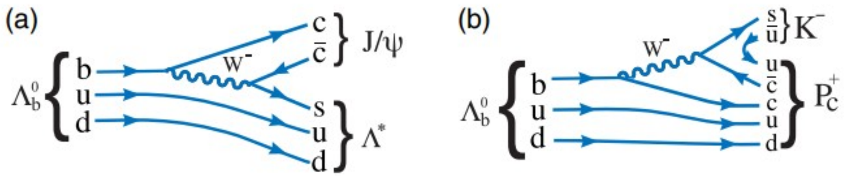


Interest has been fueled by discoveries, in the (hidden) charm sector, of:

X(3872) @ BELLE (**PRL91, 262001, 2003**)
X(3872) @ Babar (**PRD77 091101, 2008**)
$B^+ \rightarrow K^+\pi^+\pi^- J/\psi$ very close to $D^0\bar{D}^{*0}$ threshold
interpreted as a tetraquark state

***P_c* (4380/4450) states @** LHCb (**PRL 115, 072001, 2015**)
observed in M(J/ψ p) distributions
predicted in **Wu et al., PRL 105, 232001 (2010)**
interpreted as pentaquark states





Parallels between the charm and strange sectors are possible and predictions for lighter multi-quark states can be done (exchanging a $c \rightarrow s$), that can be interpreted as meson-baryon molecular-type structures.

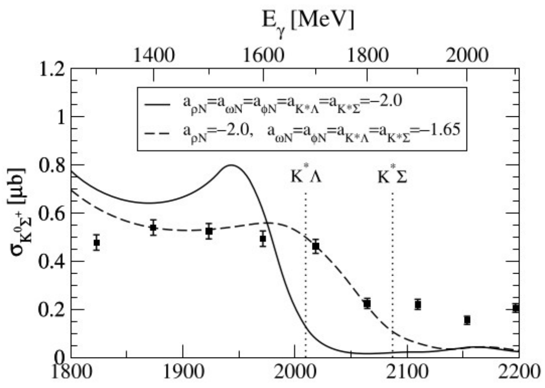
→ **See Katrin Kohl's talk (Oct. 18th @ 15:00)**
→ **See Johannes Groβ' talk (Oct 19th@ 15:40)**

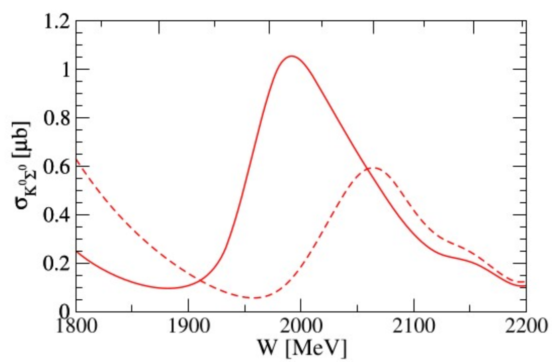
The same model that predicts P_C states (**A. Ramos and E. Oset, Phys. Lett. B 727, (2013) 287**):

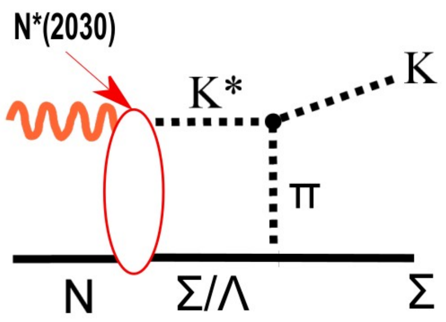
- explains the cusp observed in $K^0\Sigma^+$ (**CBELSA/TAPS Phys. Lett. B 713 (2012) 180**)
- predicts an enhancement in $K^0\Sigma^0$ on the neutron

due to destructive/constructive interference between $K^*\Lambda$ and $K^*\Sigma$ states magnified by a same resonance $N^*(2030)$, a loosely bound $K^*\Sigma$ state.

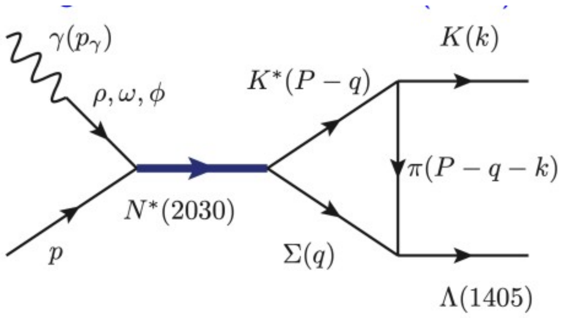
$\gamma p \rightarrow K^0\Sigma^+$ **$\gamma n \rightarrow K^0\Sigma^0$**







Same resonance $N^*(2030)$ could be responsible for $\Lambda(1405)$ photoproduction via the triangle singularity (**E. Wang, et al., Phys. Rev. C 95 (2017) 015205**)



BGOball**O**pen**D**ipole magnet **Collaboration**

⇒ A collaboration has been established in 2009 (~ 50 collaborators, **Germany**, **Italy**, **Great Britain**, **Russia**, **Switzerland, Ukraine**)

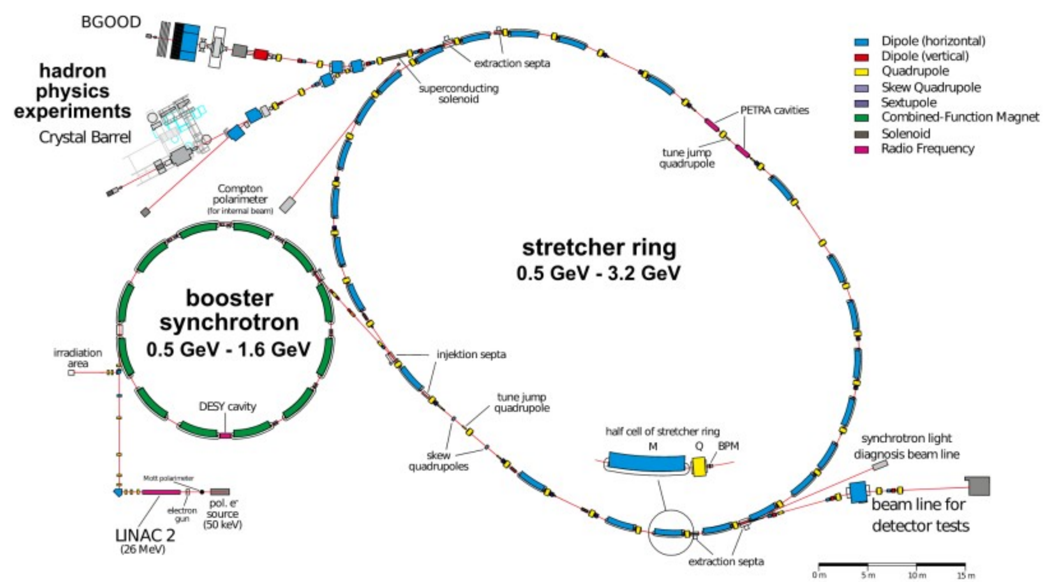
- **LoI** signed and accepted at the PAC Mainz-Bonn 2009, June 25th-26th
- **MoU** signed on 2010, March 9th

Location:
S-Beamline
ELSA Accelerator in Bonn

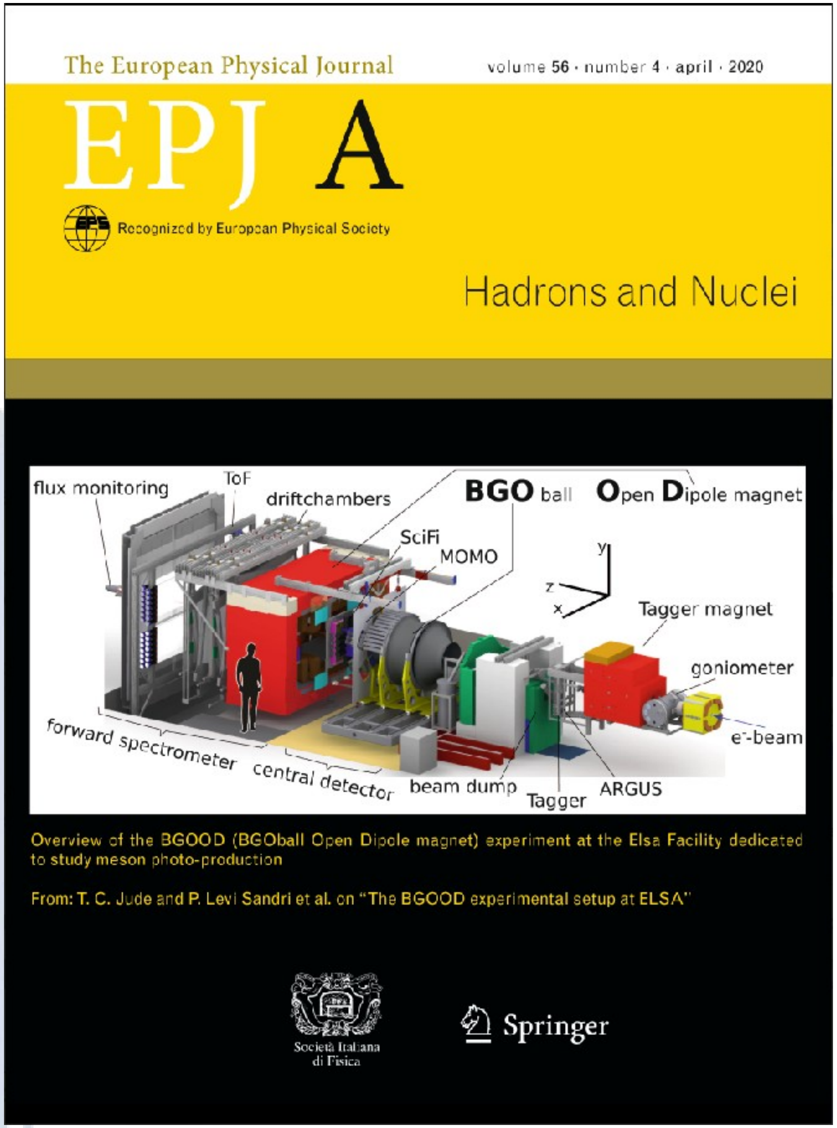
Beam:
polarized and tagged photon beam in the energy range 0.2-3. GeV

Spokespersons:
H. Schmieden, **P. Levi Sandri**

Italian Responsible:
P. Levi Sandri (2015 → today)
R. Di Salvo (2008 → 2015)



The BGOOD experiment, Eur. Phys. J. A 56:104 (2020)
Spokespersons: H. Schmieden (Bonn University) & P. Levi Sandri (INFN, Frascati)



Eur. Phys. J. A (2020) 56:104
https://doi.org/10.1140/epja/s10050-020-00107-x

THE EUROPEAN PHYSICAL JOURNAL A

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Regular Article - Experimental Physics

The BGOOD experimental setup at ELSA

S. Alef[1], P. Bauer[1] , D. Bayadilov[2,3] , R. Beck[2], M. Becker[2], A. Bella[1], J. Bieling[2], S. Böse[2], A. Braghieri[4], K.-Th. Brinkmann[5], P. L. Cole[6], R. Di Salvo[7], D. Elsner[1], A. Fantini[7,8], O. Freyermuth[1], F. Frommberger[1], G. Gervino[9,10], F. Ghio[11,12], S. Goertz[1], A. Gridnev[3], E. Gutz[5], D. Hammann[1], J. Hannappel[1,19], W. Hillert[1,19], O. Jahn[1], R. Jahn[2], J. R. Johnstone[1], R. Joosten[2], T. C. Jude[1,a], H. Kalinowsky[2], V. Kleber[1,20], F. Klein[1], K. Kohl[1], K. Koop[2], N. Kozlenko[3], B. Krusche[13], A. Lapik[14], P. Levi Sandri[15,b], V. Lisin[14], I. Lopatin[3], G. Mandaglio[16,17], M. Manganaro[16,17,21], F. Messi[1,22], R. Messi[7,8], D. Moricciani[7], A. Mushkarenkov[14], V. Nedorezov[14], D. Novinskiy[3], P. Pedroni[4], A. Polonskiy[14], B.-E. Reitz[1], M. Romaniuk[7,18], T. Rostomyan[13], G. Scheluchin[1], H. Schmieden[1], A. Stugelev[3], V. Sumachev[3], V. Tarakanov[3], V. Vegna[1], D. Walther[2], H.-G. Zaunick[2,5], T. Zimmermann[1]

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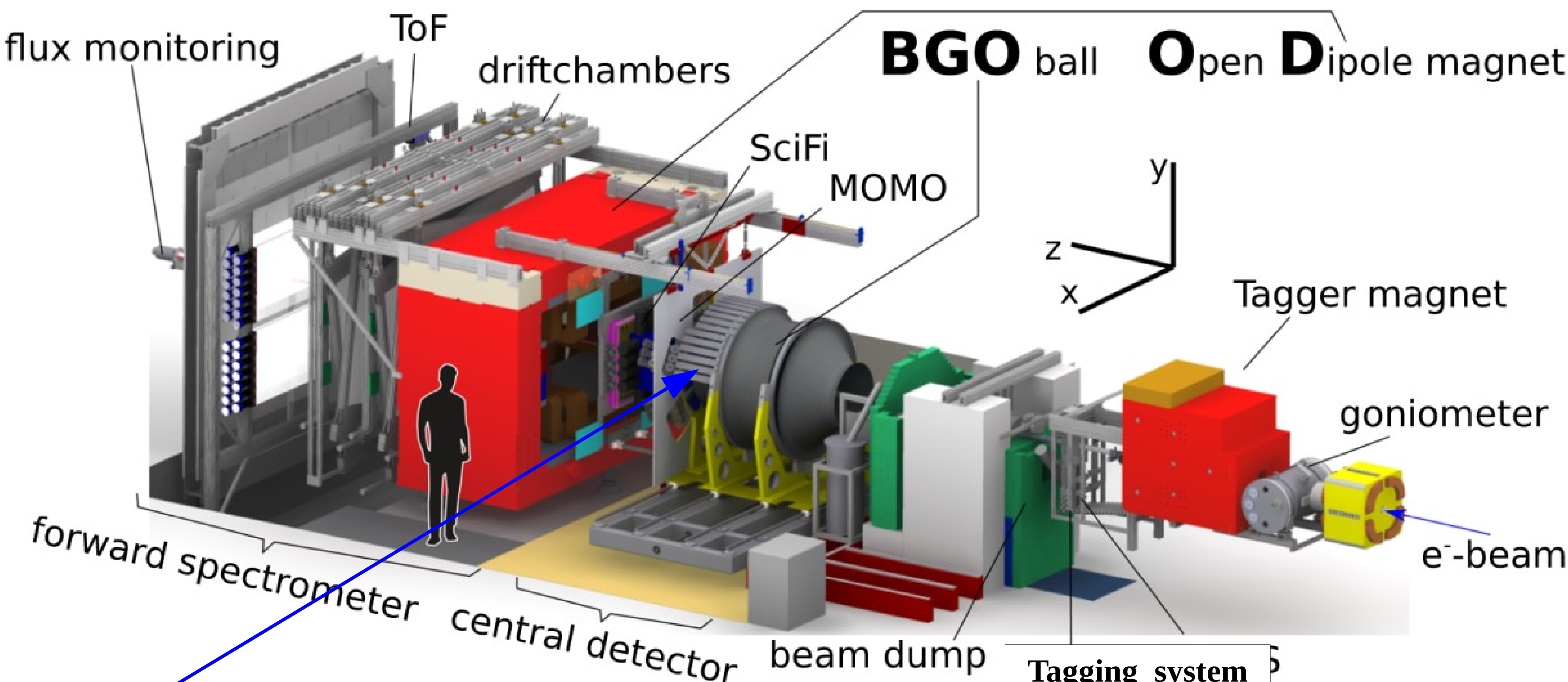
BGOOD – The Detector



Scintillating Ring Detector

BGO Calorimeter 480 Crystals

Plastic Scintillator Barrel

2 MWPCs

Target system LH2 LD2

Tagging system 120 scint. bars+ARGUS

GENERAL FEATURES OF BGOOD

Setup is a **unique combination of:**

- central region: large solid angle calorimeter with excellent energy resolution for photons and good detection efficiency for neutrons; charged particle tracking and identification; neutron/photon discrimination

- high momentum resolution forward tracking of charged particles

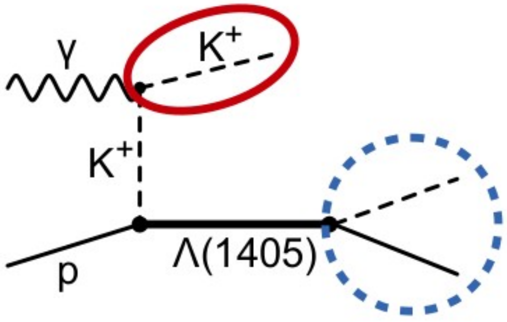
and has trigger capabilities (trigger on the released energy in BGO)

→ Ideally suited for:

- **mixed charged and neutral final state detection** (reconstruction of the complete kinematics of complex final states. both charged and neutrals)

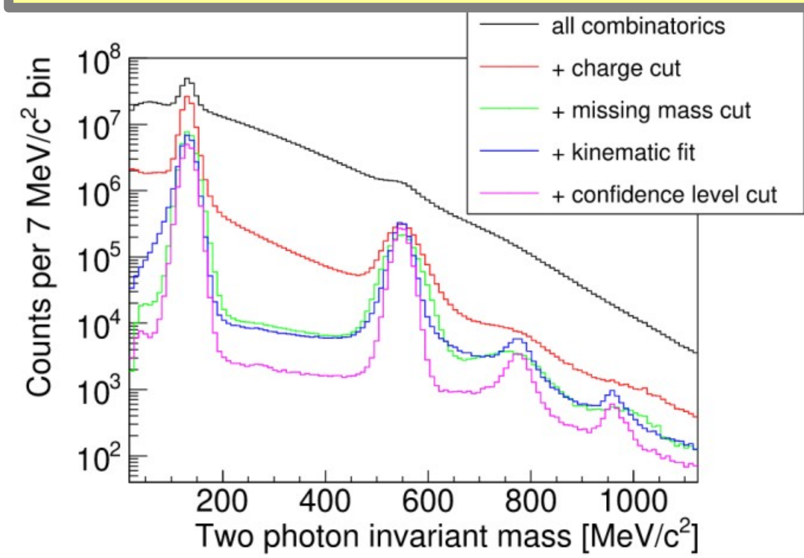
- **investigation of kinematical regimes with minimal momentum transfer**

- **open trigger**

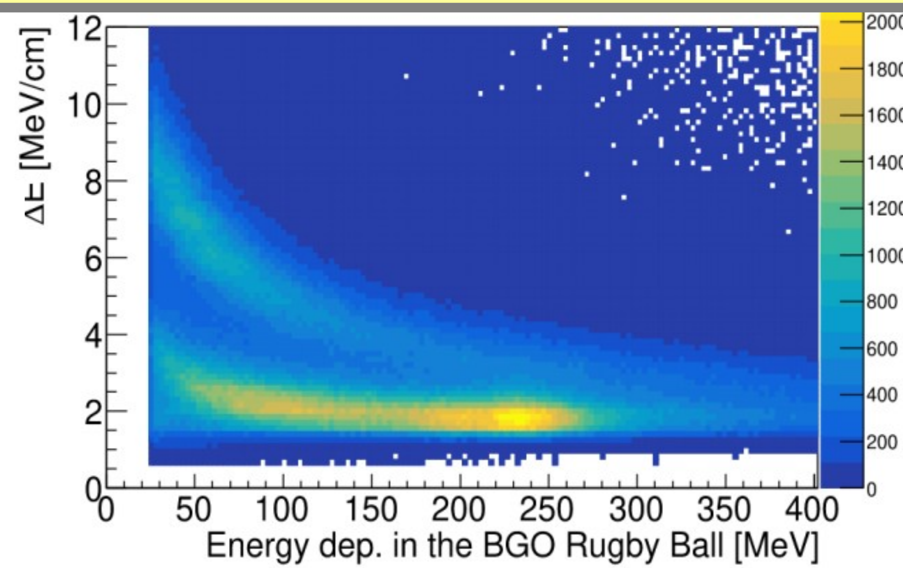


BGOOD Detector Performances

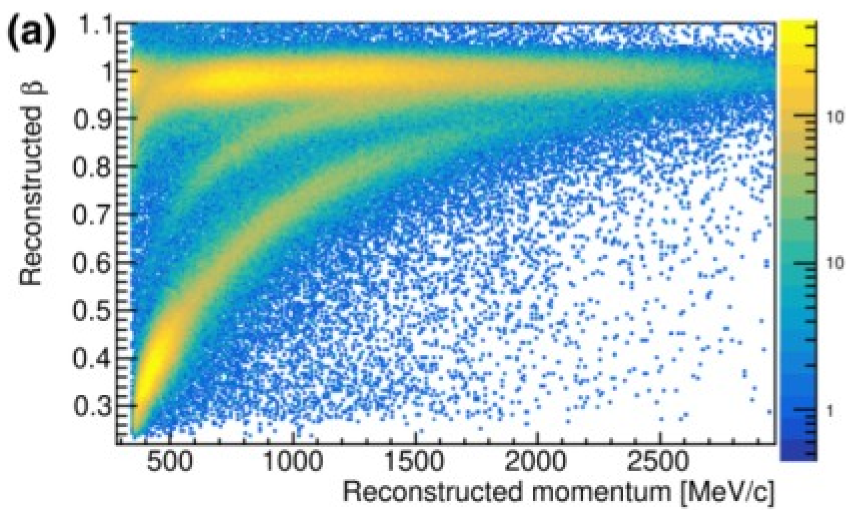
Photons in BGO Rugby Ball



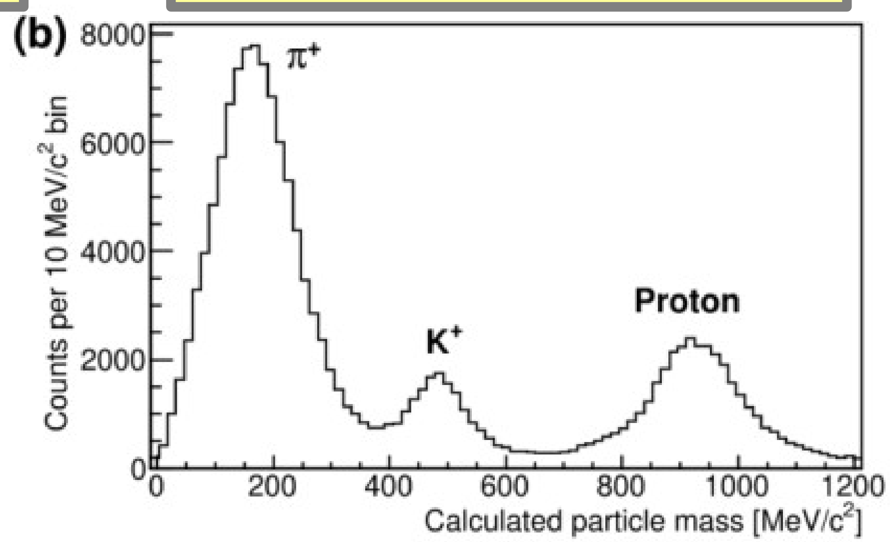
Pid BGORugbyBall-Plastic Scint. Barrel



β vs Momentum in Forw Spectr



Mass From ToF Walls



EXPERIMENTAL PROGRAM AT BGOOD

Extensive program for:

- strangeness photoproduction → CROSS SECTIONS

- **$\gamma\, p \rightarrow K^+\Lambda$**
- **$\gamma\, p \rightarrow K^+\Sigma^0$** → **See Johannes Groβ' talk (Oct 19th @ 15:40)**
- **$\gamma\, p \rightarrow K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$**
- **$\gamma n \rightarrow K^0\Sigma^0$**

} → **See Katrin Kohl's talk (Oct 18th @ 15:00)**

- **$\gamma n \rightarrow K^+\Sigma^-$ (preliminary)** → **See Johannes Groβ' talk (Oct 19th @ 15:40)**

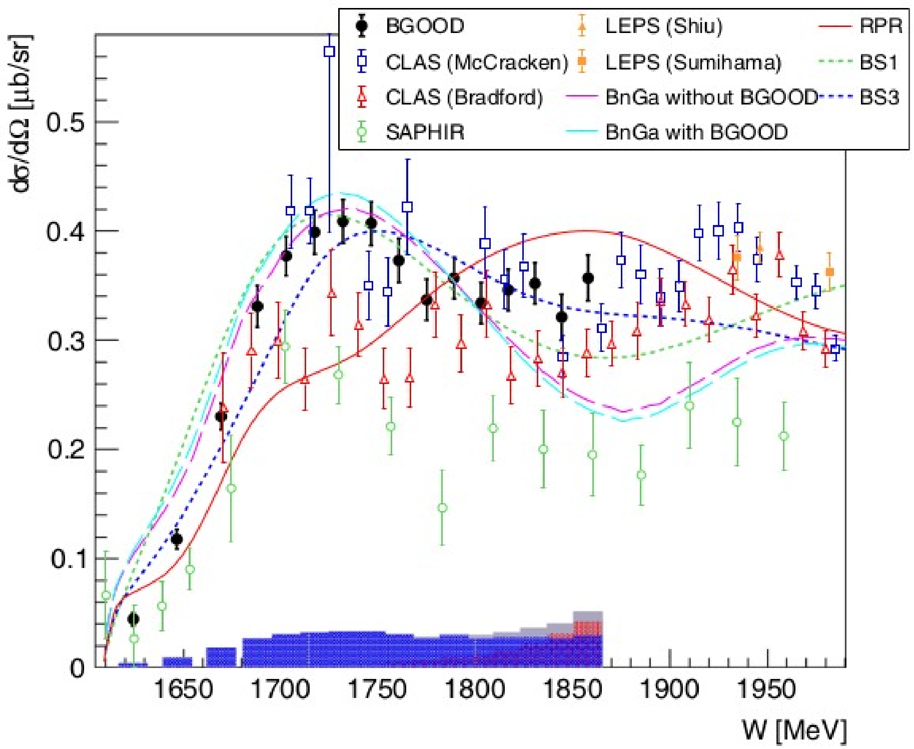
- baryon-baryon dynamics in the ud sector

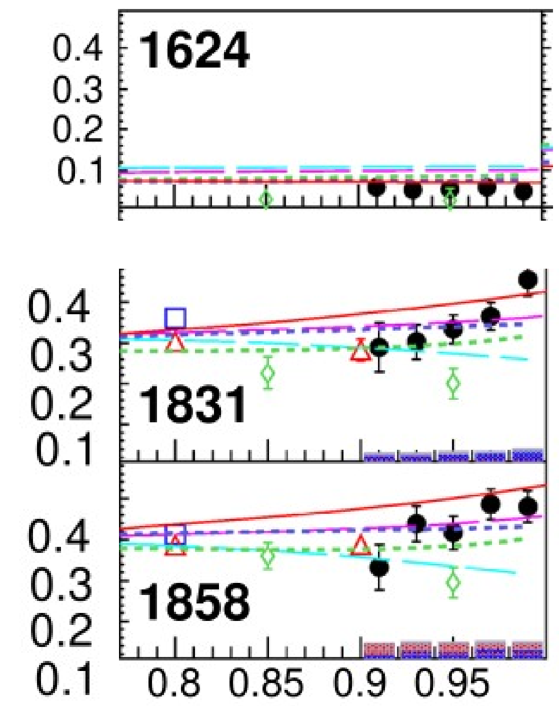
- **$\gamma d \rightarrow \pi^0\pi^0 d$** → **See Tom Jude's talk (Oct 18th @ 15:40)**

- pseudoscalar meson photoproduction → BEAM ASYMMETRIES

- **$\gamma\, p \rightarrow \pi^0 p$ $\quad$ $\gamma\, n \rightarrow \pi^0 n$**
- **$\gamma\, p \rightarrow \eta\, p$ $\quad$ $\gamma\, n \rightarrow \eta\, n$**
- **$\gamma\, p \rightarrow \eta'\, p$**

$\gamma p \rightarrow K^+\Lambda$
S. Alef *et al.*
Eur. Phys. J. A (2021) 57:80





K^+ detected in forward spectrometer and $\Lambda \rightarrow \pi^0 n$ with 2γ in BGO **$\cos\theta^{K^+}_{CM} > 0.9$**

- **VERY HIGH STATISTICS**

→ Diff x-section vs. $\cos\theta_{CM}$ in W bins is flat at threshold and more forward peaked for higher W, consisting with increasing t-channel *K* and *K** exchange processes.

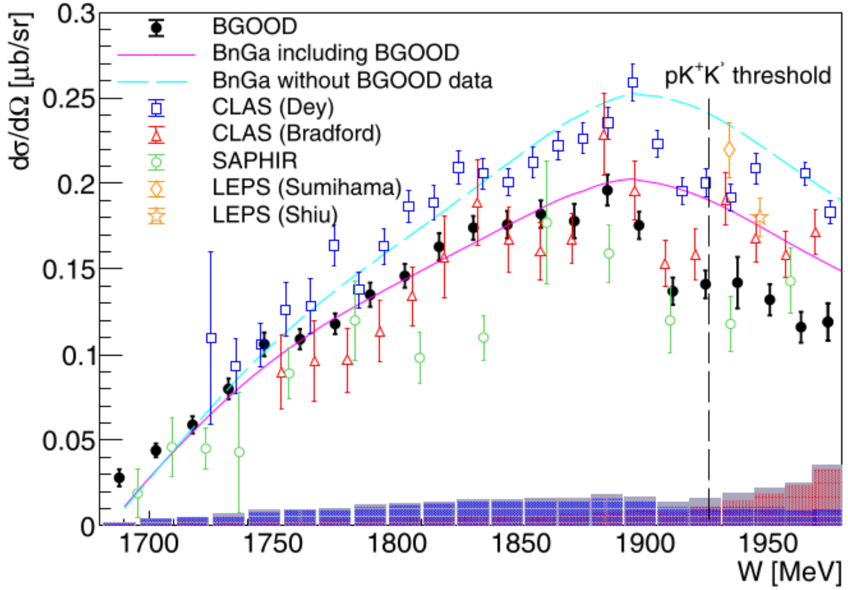
- **VERY GOOD ANGULAR RESOLUTION IN THE FORWARD DIRECTION**

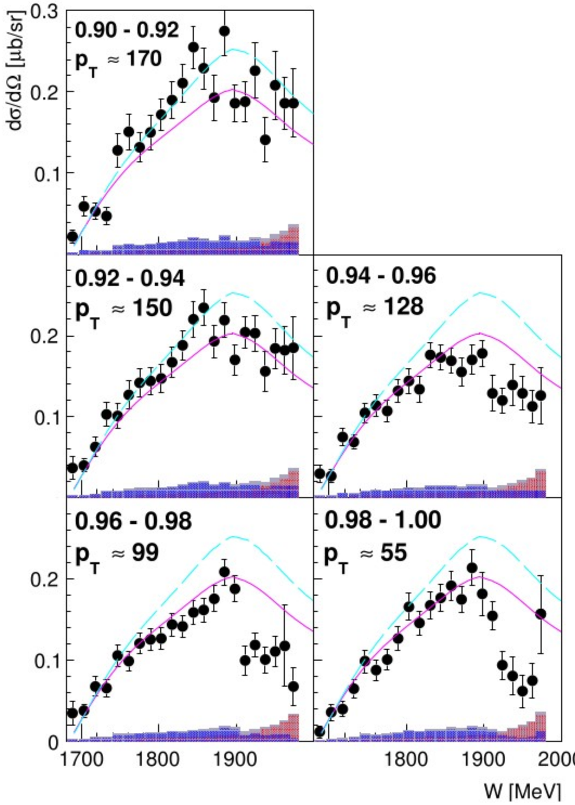
→ sensitivity to high spin states (3^{rd} resonance region, only access to *N**)

- **Structure visible at 1720 MeV** then data are more flat for energies above 1800 MeV.

Helpful in constraining elementary reaction mechanism for hypernuclei electroproduction at very low Q^2, an important prerequisite to study hypernuclei.

$\gamma p \rightarrow K^+\Sigma^0$
T.C. Jude *et al.*
Phys. Lett. B 820 (2021), 136559





See Johannes Groβ' talk (Oct 19th@ 15:40)

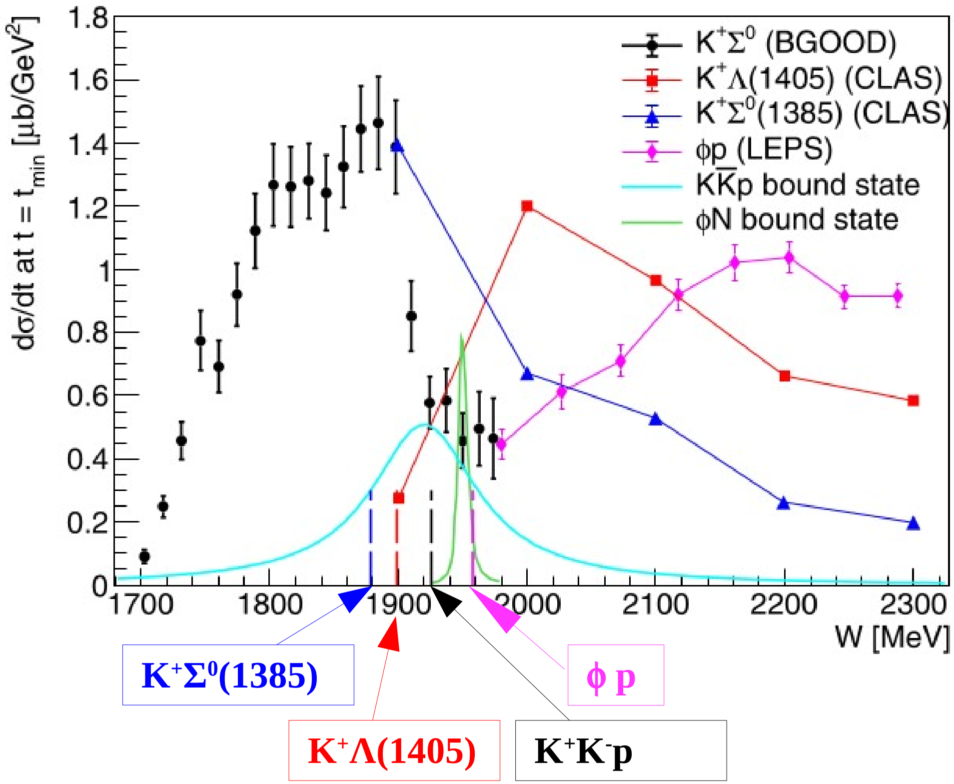
K^+ detected in forward spectrometer and $\Sigma \rightarrow \Lambda\ \gamma$ with γ's in BGO **$\cos\theta^{K^+}_{CM} > 0.9$**

- **VERY GOOD ANGULAR RESOLUTION IN THE FORWARD DIRECTION**

- **Cusp at W=1900 MeV where the x-sections drops by 1/3 over a 20 MeV range.**

Structure nicely resolved in bins of θ_{CM}, (visible for $0.94 < \cos\theta_{CM} < 0.96$, pronounced for $\cos\theta > 0.98$).

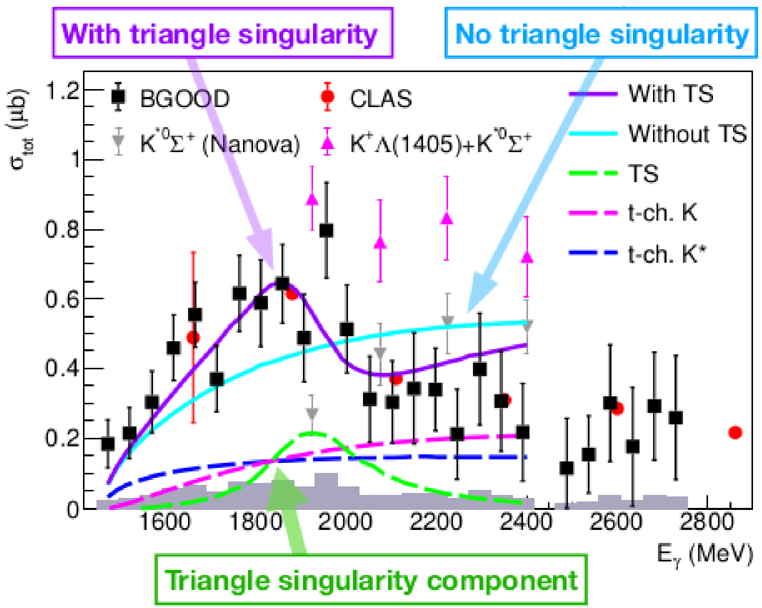
- **ALMOST NO EXTRAPOLATION NEEDED TO *$t=t_{min}$***



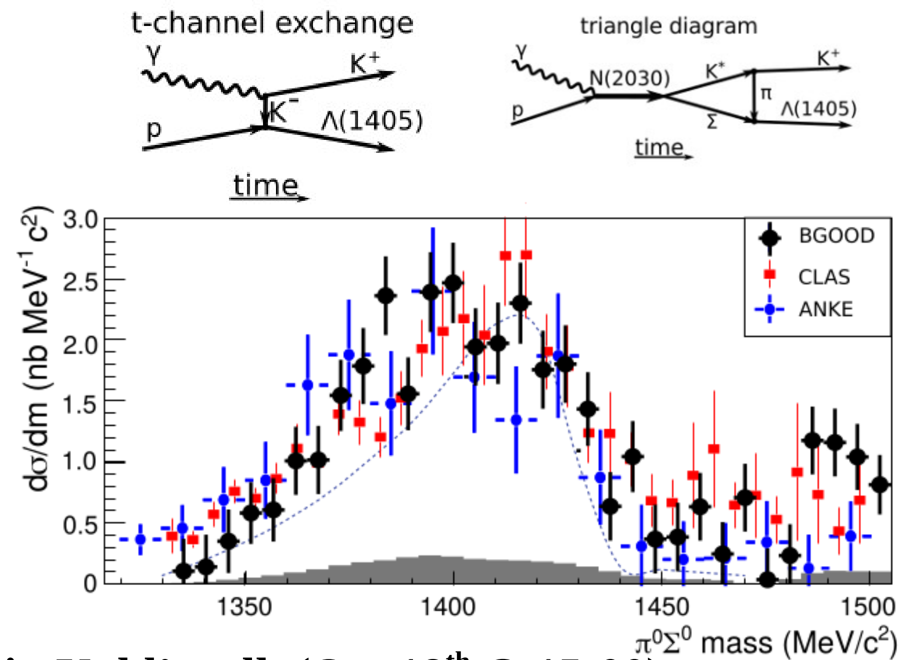
$K^+\Sigma^0(1385)$ (mass 1873)
$K^+\Lambda(1405)$
ϕ p
K^+K^-p (threshold)
$K\bar{K}p$ (mass 1920MeV)
ϕ p (mass 1950MeV)

- **In *dσ/dt* drop very pronounced at W=1900 MeV.**
- **Drop due to pentaquark X(2000)? (proposed by the Sphinx Collaboration (for p_T <141 MeV)** in diffractive $p+C \rightarrow [K^+\Sigma^0] + C$, *Z. Phys. C 68 (1995) 585)* **)**
- **But also compatible with re-scattering effects close to open and hidden strange thresholds in a region with various hadronic bound states.**

$\gamma p \rightarrow K^+\Lambda(1405) \rightarrow K^+\pi^0\Sigma^0$
G. Scheluchin, T.C. Jude *et al.*
Phys. Lett. B 833 (2022), 137375



[CLAS: Moriya, PRC 87, 035206 (2013)]
[M. Nanova et al., EPJA 35 (2008) 333]



See Katrin Kohl's talk (Oct 18th @ 15:00)

K^+ detected in forward spectrometer and $\Lambda(1405) \rightarrow \Sigma^0\pi^0 \rightarrow (\gamma\Lambda)(\gamma\gamma) \rightarrow (\gamma\pi^-p)(\gamma\gamma)$ with 3γ's in BGO
3 charged p.

- **HERMETIC COVERAGE** → allows detection of all final state particles
- **EXTENSION TO VERY FORWARD ANGLES WITH UNPRECEDENTED ENERGY RESOLUTION**

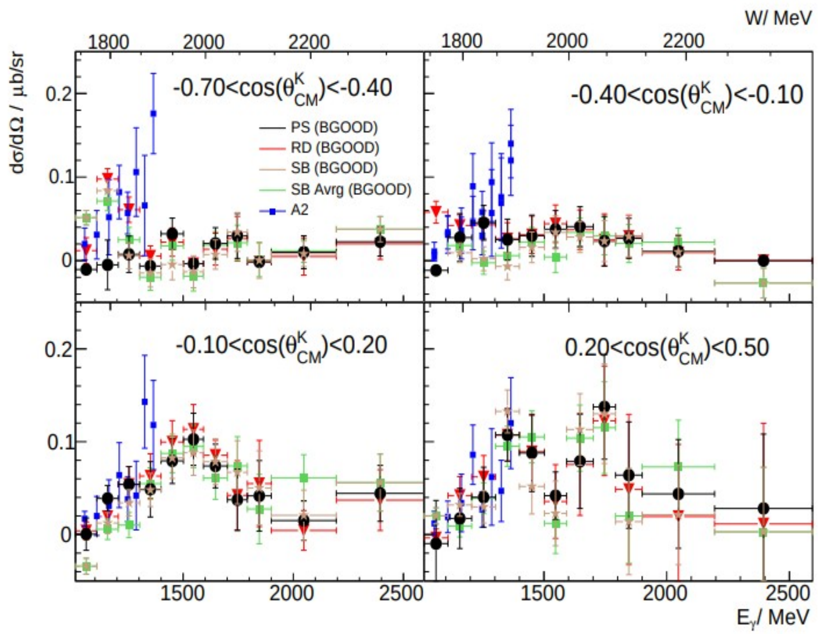
→Λ(1405) is assumed to mainly proceed via the kaon t-channel exchange dominated by small momentum transfer, *t*, in particular if it has a relatively loosely bound molecular structure.

→ Another proposed mechanism (**PRC 95 (2017) 015205**) is a triangle singularity driven by the ***N**(2030) (bound *K**Σ)** which is expected to vanish once the threshold of free *K**Σ production is exceeded.

Cross-section data support the triangle mechanism with *N(2030) (bound *K**Σ)**

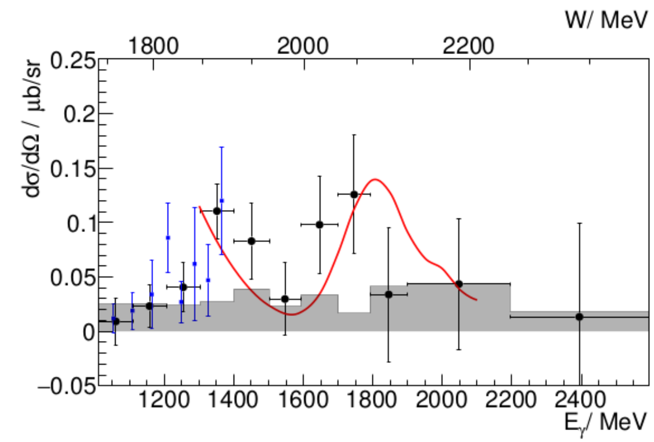
- **Measured line-shape of $\Lambda(1405) \rightarrow \Sigma^0\pi^0$**

γn → $K^0\Sigma^0$
K. Kohl *et al.*
arXiv: 2108.13319 and Submitted to EPJA



blue squares:
C. Akondi, et al. A2,
Eur. Phys. J. A 55,
202 (2019)

See Katrin Kohl's talk (Oct. 18th @ 15:00)



γn → $K^0\Sigma^0$ → ($\pi^0\pi^0$) (γΛ) → (γγ γγ) (γπ^-p) with all γ's in BGO and most of charged part in BGO/SciRi

- **HERMETIC COVERAGE** → allows detection of all final state particles
- **Structure may become visible @ 0.2<cosθ_{CM}<0.5,**

→ could be interpreted as due to N^*(2030) (dinamically generated $K^*\Sigma$ state) **(Phys. Lett. B 727, (2013) 287)** causing constructive interference between $K^*\Sigma$ and $K^*\Lambda$ states.
N.B. N^*(2030) could also explain the **cusp observed in $K^0\Sigma^+$** and be responsible for **Λ(1405)** photoproduction **(supported by BGOOD data)**

In principle other interpretations in terms of conventional states cannot be ruled out.

- **Peak at W = 1900 MeV @ −0.10 <cos θ_{CM} < 0.20 → Δ(1900)1/2$^-$**

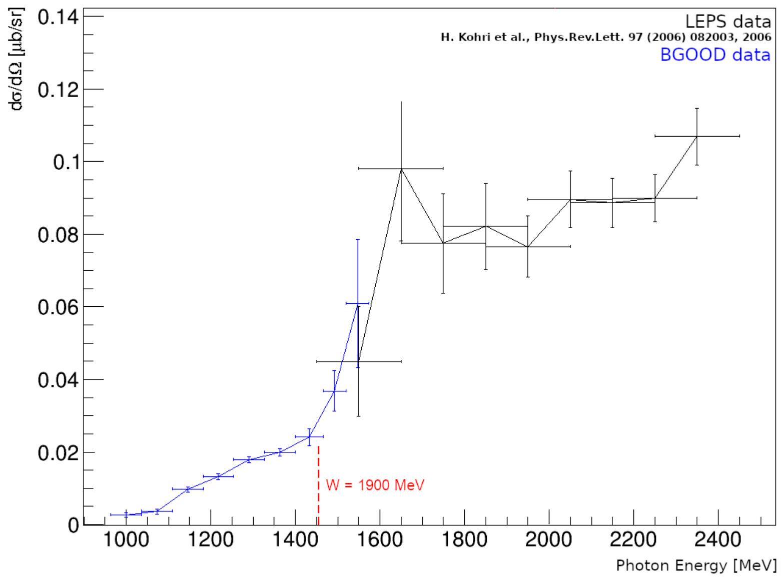
Preliminary Analysis on $\gamma n \rightarrow K^+\Sigma^- \rightarrow K^+ (\pi^- n)$
Johannes Groβ

See Johannes Groβ' talk (Oct 19th @ 15:40)

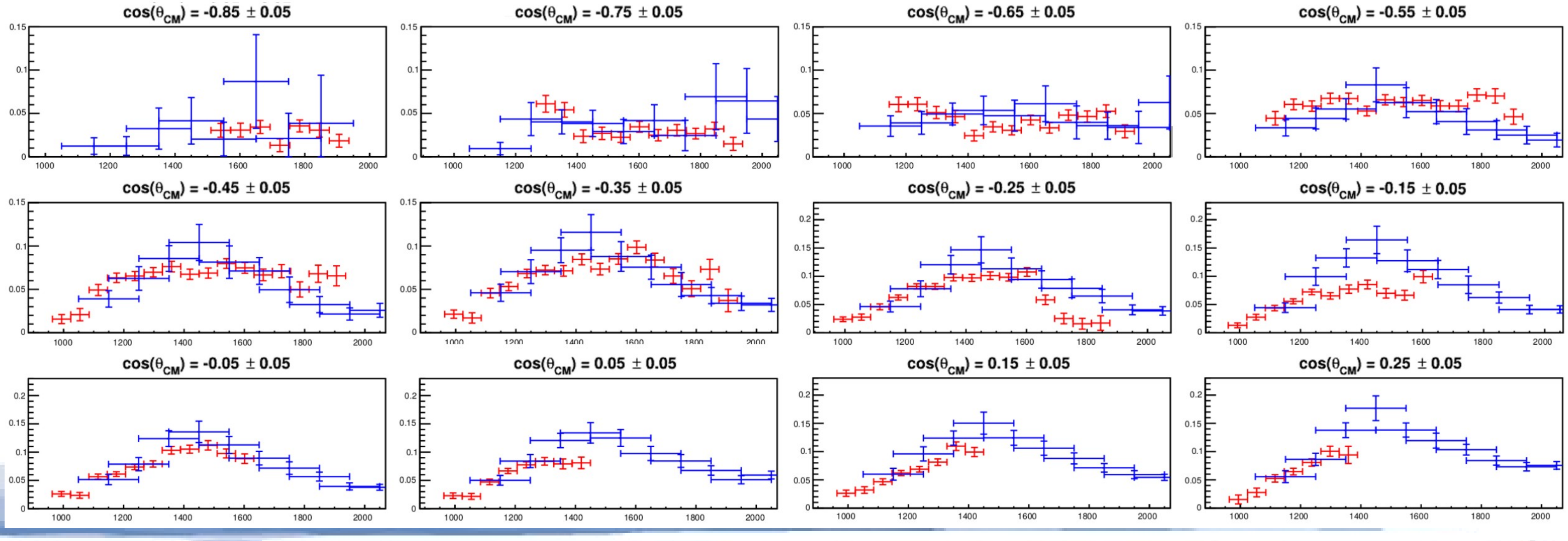
K^+ detected in forward spectrometer
π^- in BGO
n not required

Measured Missing Mass From K^+
Background from proton subtracted with Hydrogen target data

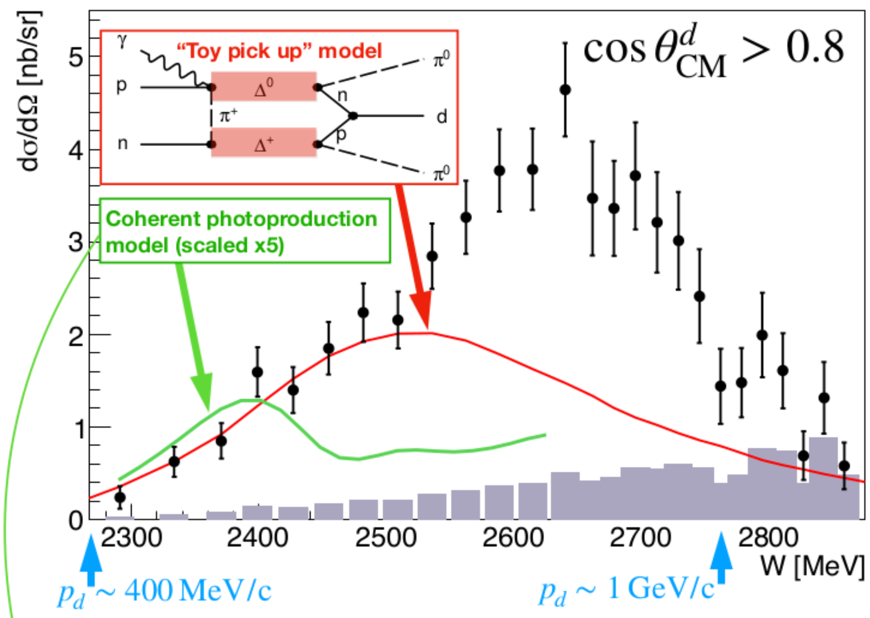
$\cos\theta^{K+}_{CM} > 0.9$



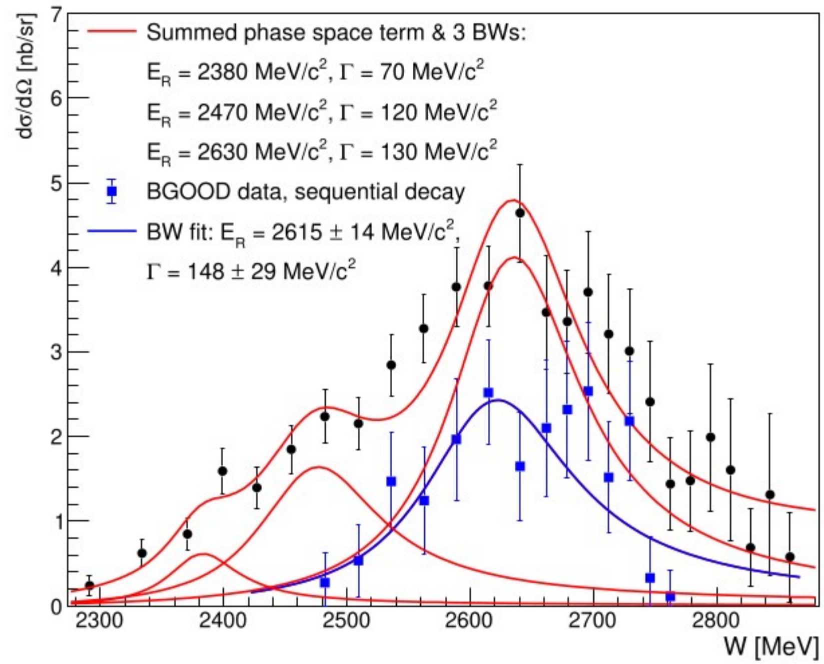
Preliminary data available for K^+ detected in BGO
$-0.85 < \cos\theta^{K+}_{CM} < 0.35$



$\gamma\, d \rightarrow \pi^0\pi^0 d$
T.C. Jude *et al.*
Phys. Lett. B 832 (2022) 137277



Egorov & Fix, NPA, 933 (2015) 104 - Fix & Arenhövel, EPJA, 25 (2005) 115



→ **See Tom Jude's talk (Oct 18th @ 15:40)**

d detected in forward spectrometer and $\pi^0\pi^0 \rightarrow$ 4γ's in BGO **$\cos\theta^d_{CM} > 0.8$**

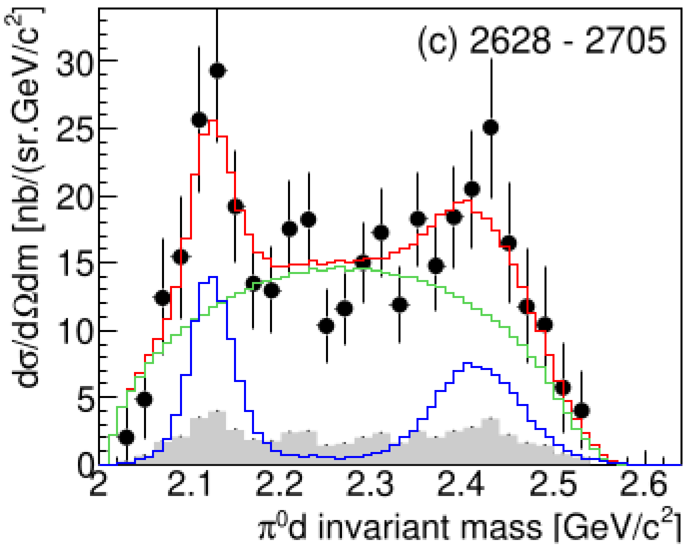
- **X-section peaks at 2650MeV around 4nb/sr**

→ not compatible with coherent photoproduction (**green curve**),"Toy pick-up" models (**red curve**)
→ **compatible** with a 3-isoscalar dibaryon scenario, *d**(2380), 2470 and 2630 MeV/c² reported by ELPH collaboration (PLB 789 (2019) 413) (**red curve, right picture)**, but statistics not sufficient to draw conclusions**.**

- Evidence of $d^*(2380)$ is also supported by the $2\pi^0$ inv. mass confirming the so-called "ABC" effect.

  Extracted:

$$\gamma\, d \rightarrow d^*(2380) \rightarrow \pi^0\pi^0 d \qquad \text{cross section} = (\, 11.3\pm3.2\text{stat}\pm2\,.7 \text{ sys})\text{ nb}$$



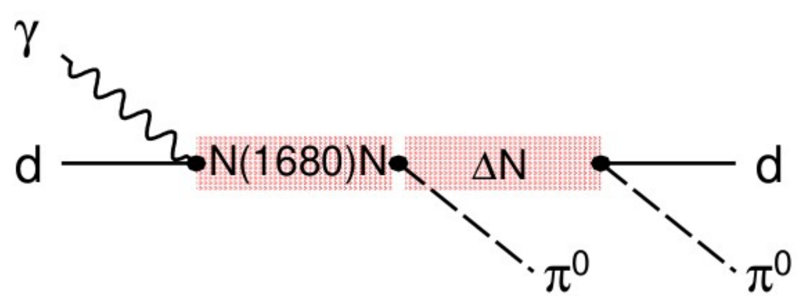
- Double peak structure for W>2500 MeV for $\pi^0 d$ invariant mass, compatible with observations at ELPH of an isovector dibaryon with:

  M = 2140MeV/c^2 Width = 91 MeV/c^{2}.

  BGOOD:

  M = 2117 MeV/c^2 Width = 20MeV/c

The isovector is produced via a sequential decay mechanism isoscalar-isovetor.



BEAM ASYMMETRY IN MESON PHOTOPRODUCTION

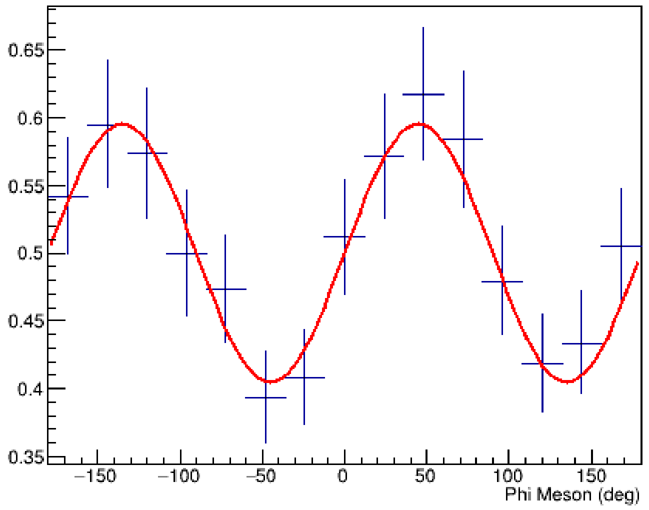
With two polarization states → systematical errors not depending on the polarization cancel:

$\mathbf{N_{1,2}}(E_\gamma,\theta_{C.M.})$ = # events in pol 1/2

$\mathbf{F_{1,2}}(E_\gamma)$ = flux of photons in pol 1/2

$$\frac{\frac{N_{1,2}}{F_1}}{\frac{N_1}{F_1}+\frac{N_2}{F_2}}=\frac{1}{2}\left(1\pm P_\gamma\left(E_\gamma\right)\Sigma\cos\left(2\varphi\right)\right)$$

$$\Sigma=\Sigma\left(E_\gamma,\theta_{c.m.}\right)$$



Extraction of the asymmetry

In the hypothesis that the two polarizaton states have different degrees of polarization, we have:

$$N^{P}_{Pol+}=F^{P}_{Pol+}\left(\frac{d\sigma}{d\Omega}\right)_{UNP}\varepsilon(\varphi)\,N_{SC}\left(1+P^{P}_{Pol+}\Sigma\cdot\cos(2\varphi)\right) \qquad (1)$$

P = period

$$N^{P}_{Pol-}=F^{P}_{Pol-}\left(\frac{d\sigma}{d\Omega}\right)_{UNP}\varepsilon(\varphi)\,N_{SC}\left(1-P^{P}_{Pol-}\Sigma\cdot\cos(2\varphi)\right) \qquad (2)$$

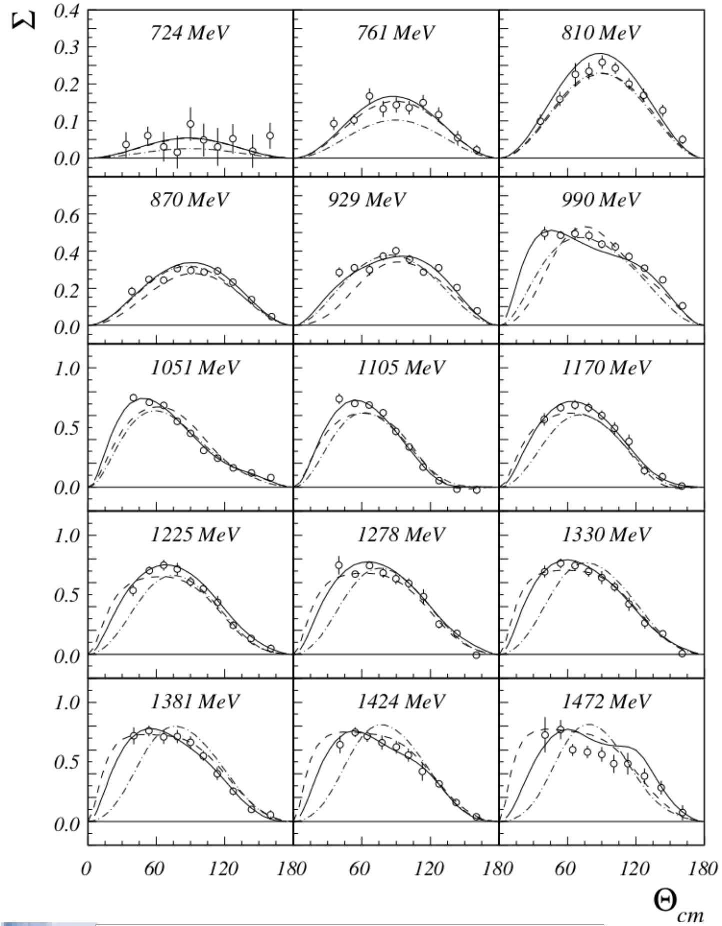
If we extract the asymmetry from the usual ratio:

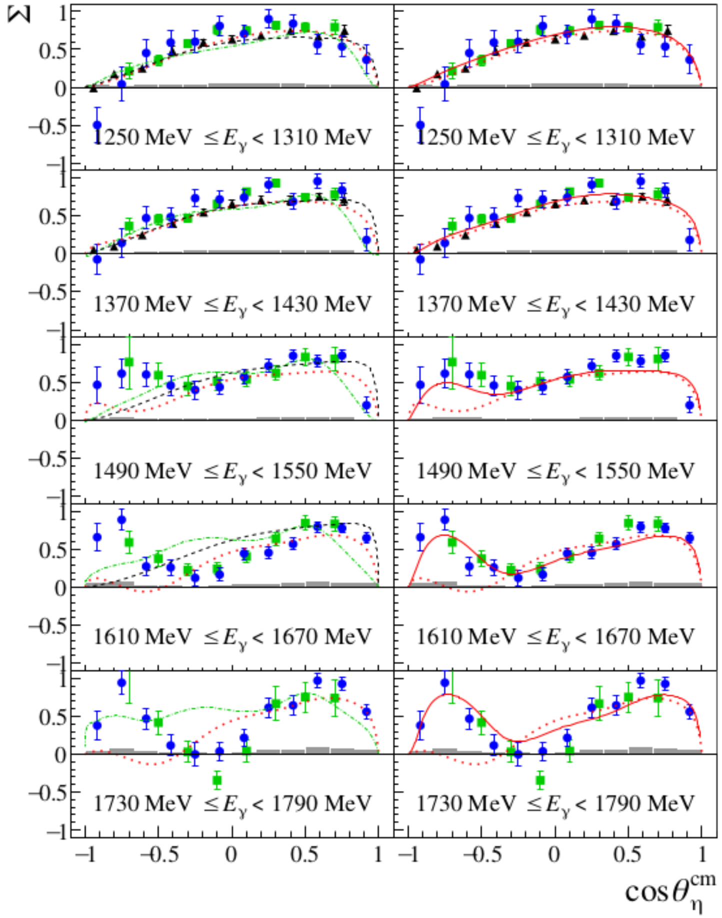
$$\frac{\dfrac{N^{P}_{Pol+}}{F^{P}_{Pol+}}}{\dfrac{N^{P}_{Pol+}}{F^{P}_{Pol+}}+\dfrac{N^{P}_{Pol-}}{F^{P}_{Pol-}}}=\frac{1+P^{P}_{Pol+}\Sigma\cdot\cos(2\varphi)}{2+\left(P^{P}_{Pol+}-P^{P}_{Pol-}\right)\Sigma\cdot\cos(2\varphi)} \qquad (3)$$

We get a behaviour which depends on phi also in the denominator. This depends on the fact that the denominator is not proportional to the unpolarized cross section.

The unpolarized can be defined as:

$$\frac{N^{P}_{UNP}}{F^{P}_{UNP}}=\frac{1}{2}\frac{1}{P^{P}_{Pol+}+P^{P}_{Pol-}}\left(P^{P}_{Pol-}\frac{N^{P}_{Pol+}}{F^{P}_{Pol+}}+P^{P}_{Pol+}\frac{N^{P}_{Pol-}}{F^{P}_{Pol-}}\right) \qquad (4)$$





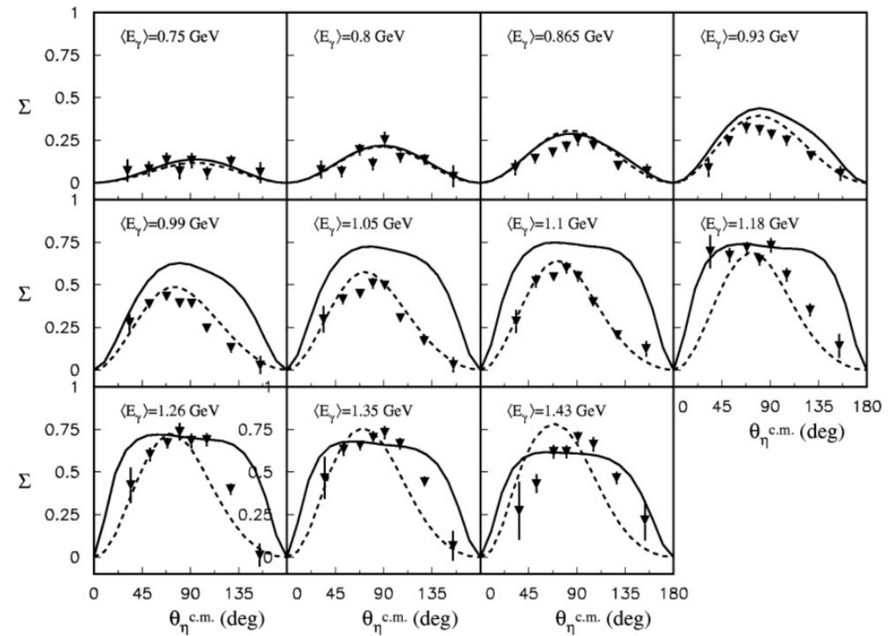
γ p → η p
Blue circles
PRL 125 (2020) 15, 152002
Green squares
PLB 771, 213 (2017)

γ p → η p
EPJA 33, 169–184 (2007)

Low energy:
Interf S_{11}(1535)-D_{13}(1520) ($\sin^2 \theta_\eta^{cm}$ behav.)

High energy: interference S_{11}(1535)-F_{15}(1680)
(peak at forward angles)

γ n → η n
Full triangles
PRC78 (2008) 015203



$\gamma\, p \rightarrow \eta\, p$

Preliminary

R. Di Salvo, A. Fantini, P. Levi Sandri

Analysed reactions

1) **$\eta \rightarrow 2\,\gamma$**

with: 2 γ in BGO + 1 proton in all detector

2) **$\eta \rightarrow 3\pi^0 \rightarrow 6\,\gamma$**

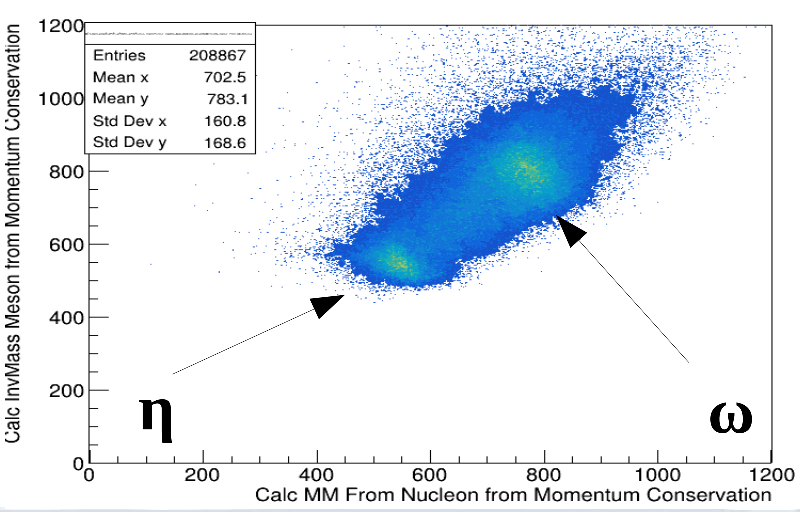
with: 6 γ in BGO + 1 proton in all detector

3) **$\eta \rightarrow \pi^+\pi^-\pi^0$**

with2 γ in BGO + 1 proton in all detector + $\pi^+\pi^-$ in BGO

→ **proton and charged pions momenta reconstructed from momentum conservation between initial and final state particles with no hypothesis on the decaying meson**

Reconstructed Inv. Mass ($\pi^+\pi^-\pi^0$)

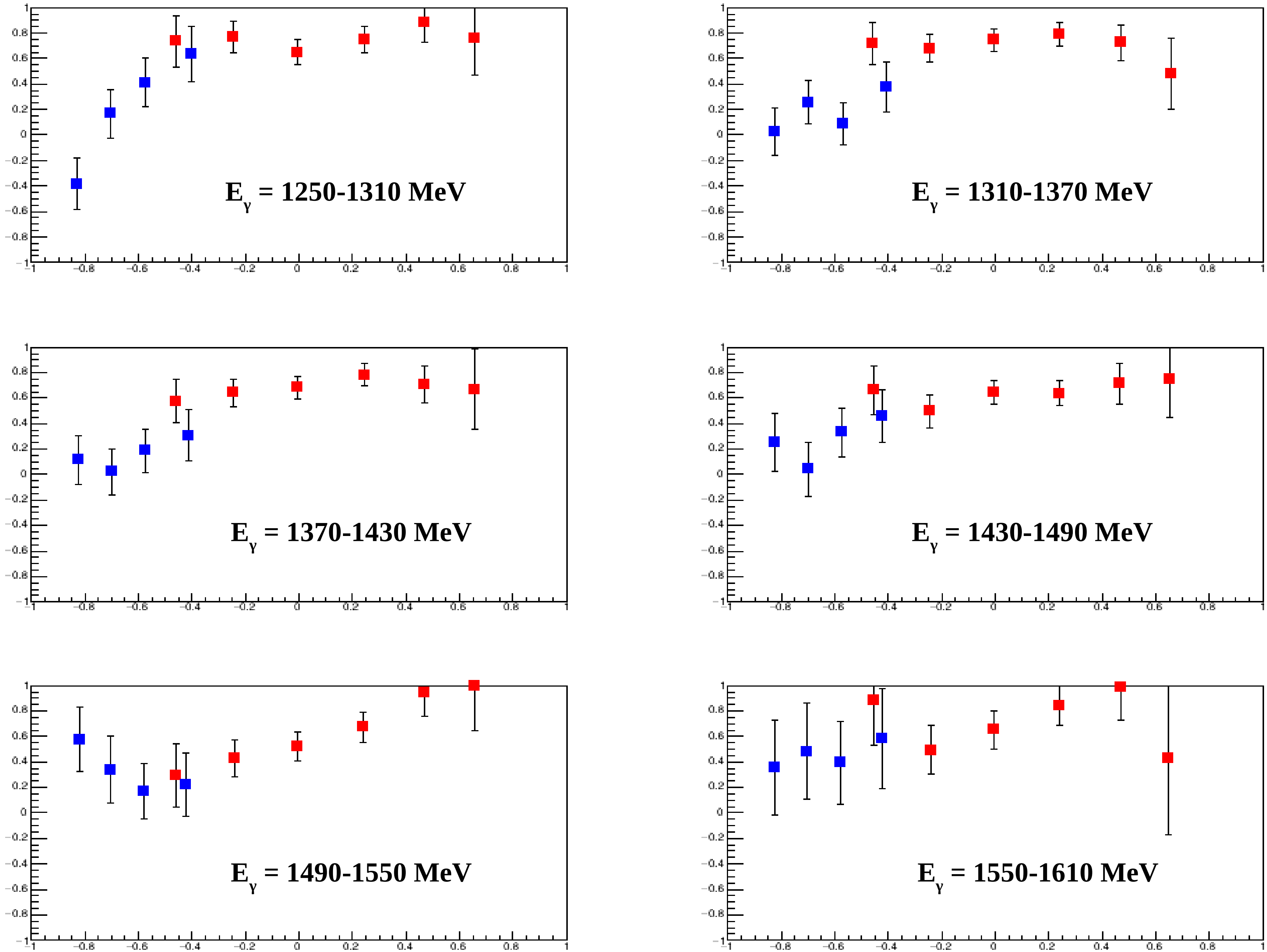


Reconstructed Miss Mass from Proton

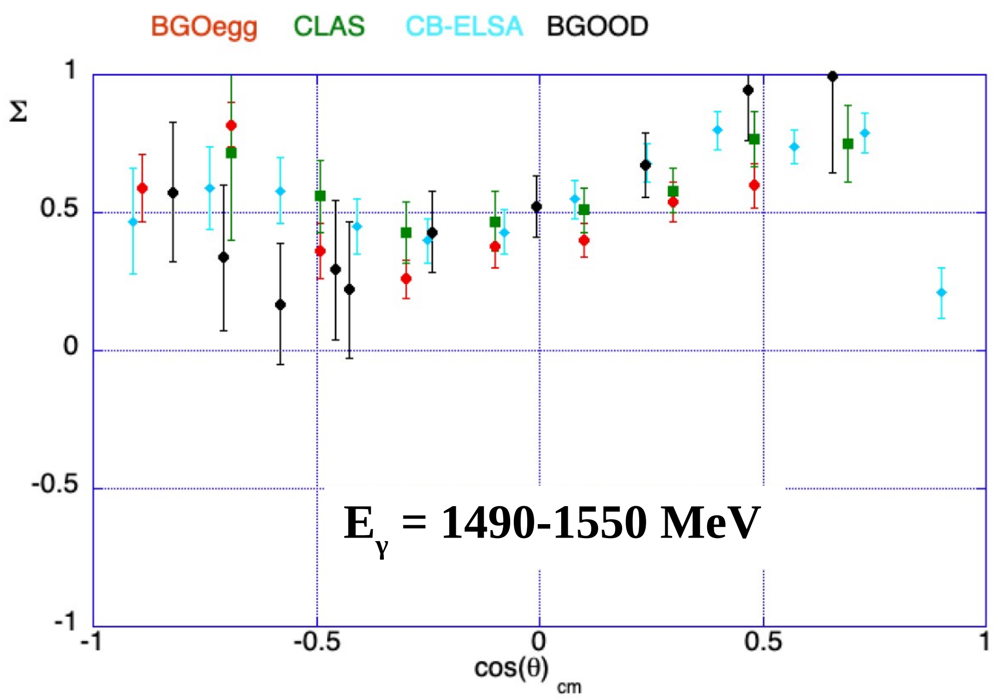
AprMay2017+NovDec2018 $\eta \rightarrow 2\gamma, 6\gamma, \pi^+\pi^-\pi^0$

Blue Points = Proton in SciRi | **Squares = PolPlus** | **15 Bins in φ**

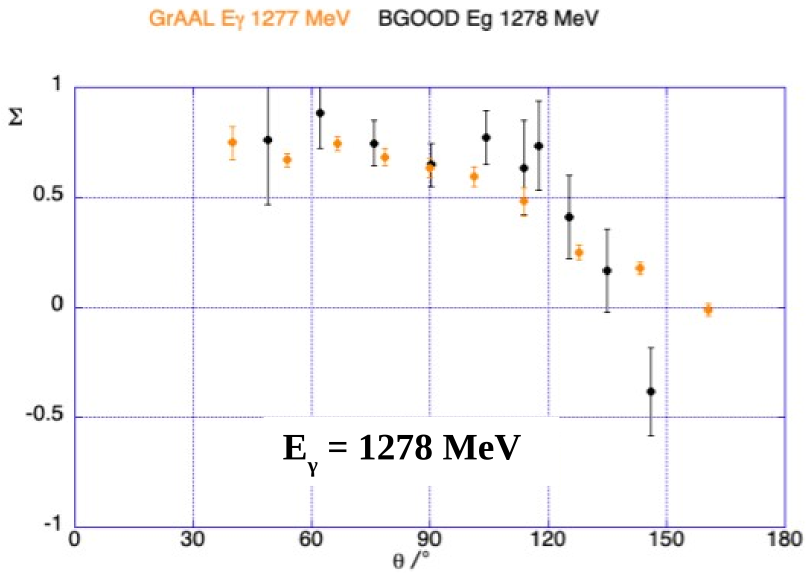
Red Points = Proton in BGO

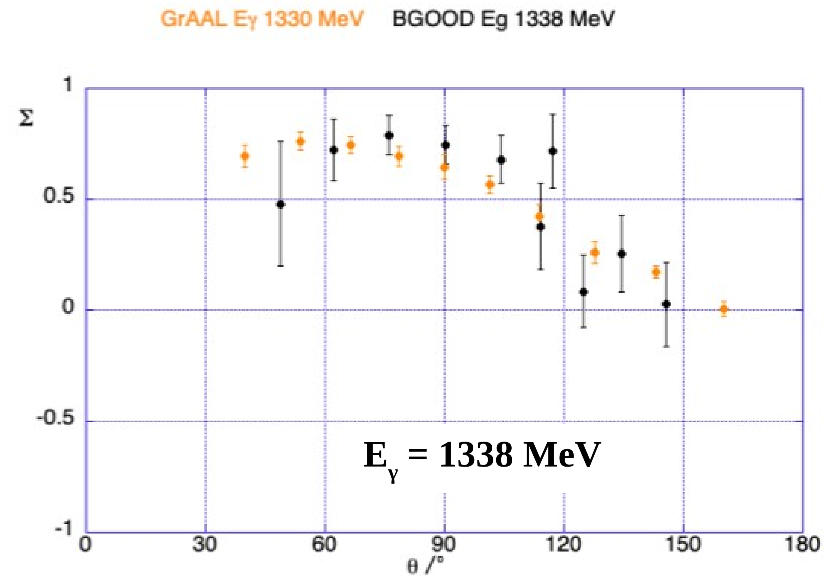


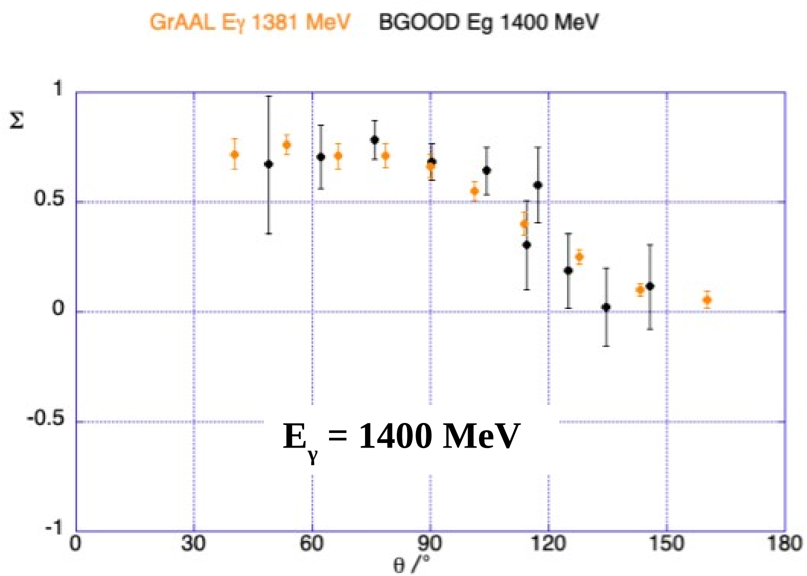
$\gamma\, p \rightarrow \eta\, p$

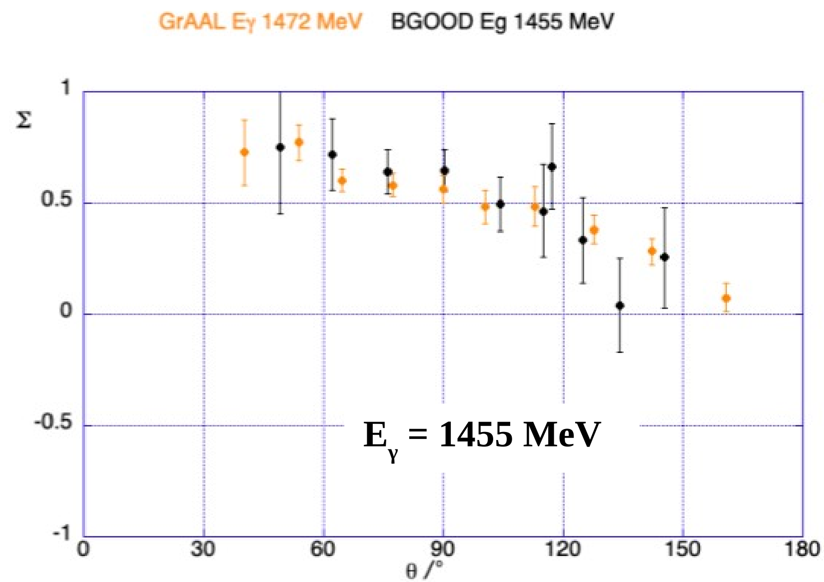


$\gamma p \rightarrow \eta p$



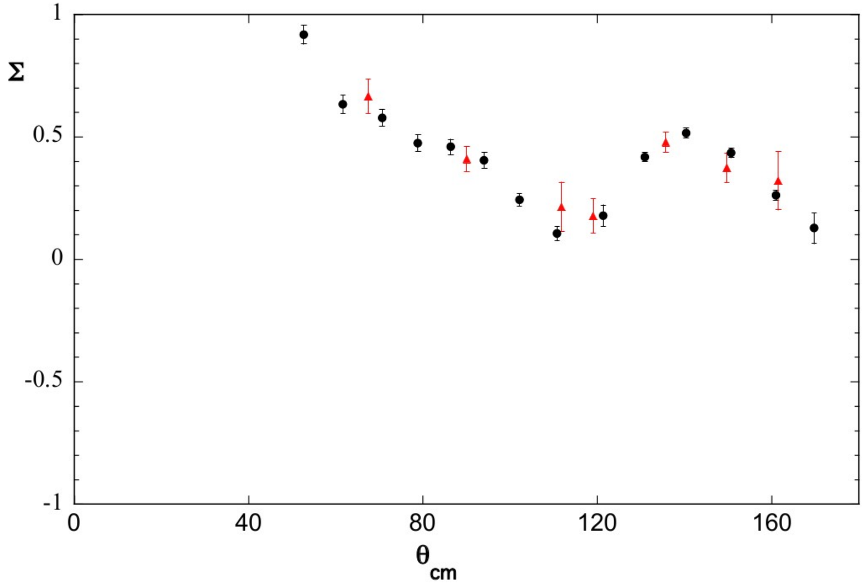




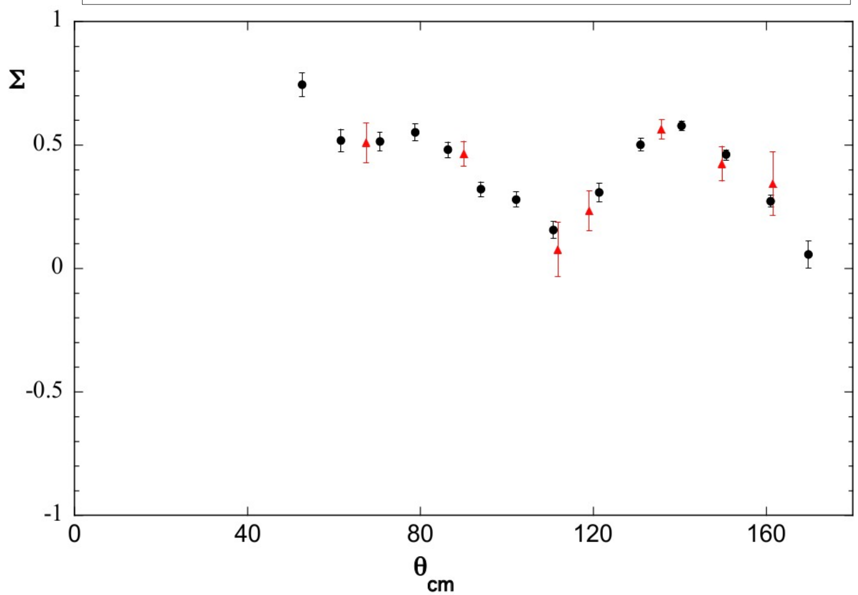


$\gamma\, p \rightarrow \pi^0\, p$

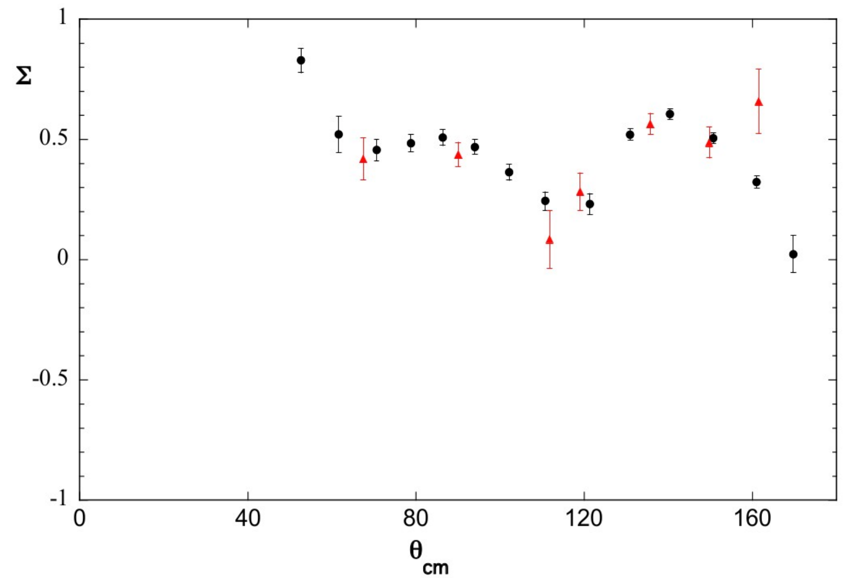
Black Points **GRAAL E_γ = 1425 MeV**
Red Triangles **BGOOD E_γ = 1425 MeV**



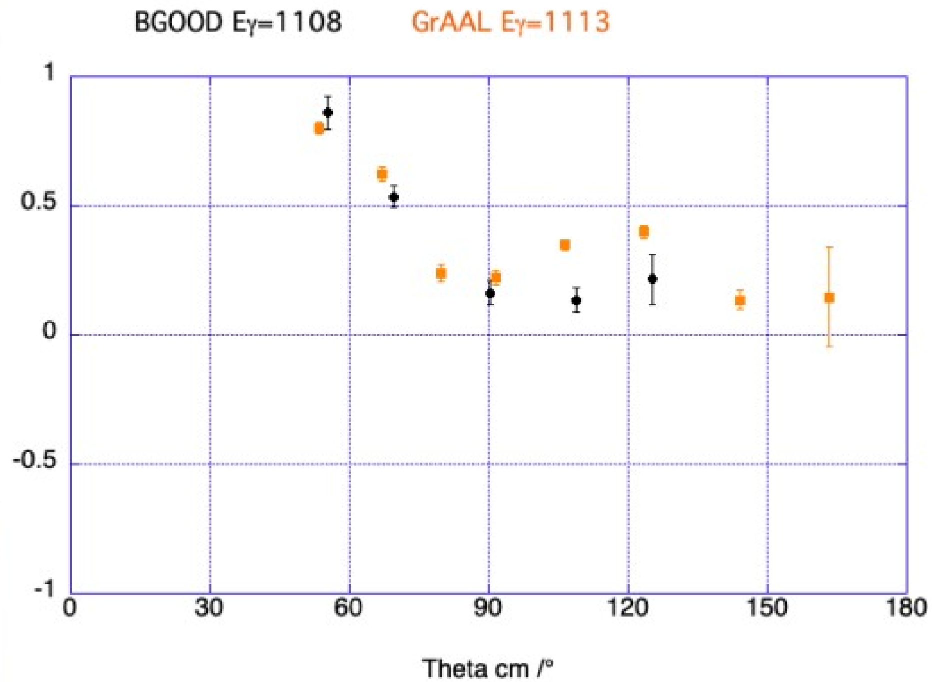
Black Points **GRAAL E_γ = 1450 MeV**
Red Triangles **BGOOD E_γ = 1450 MeV**

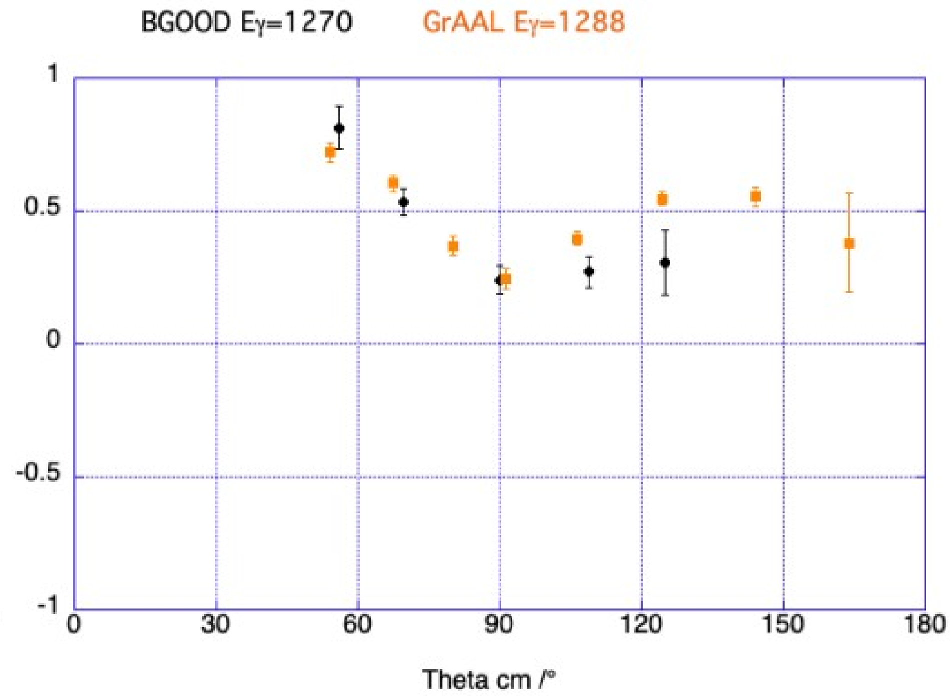


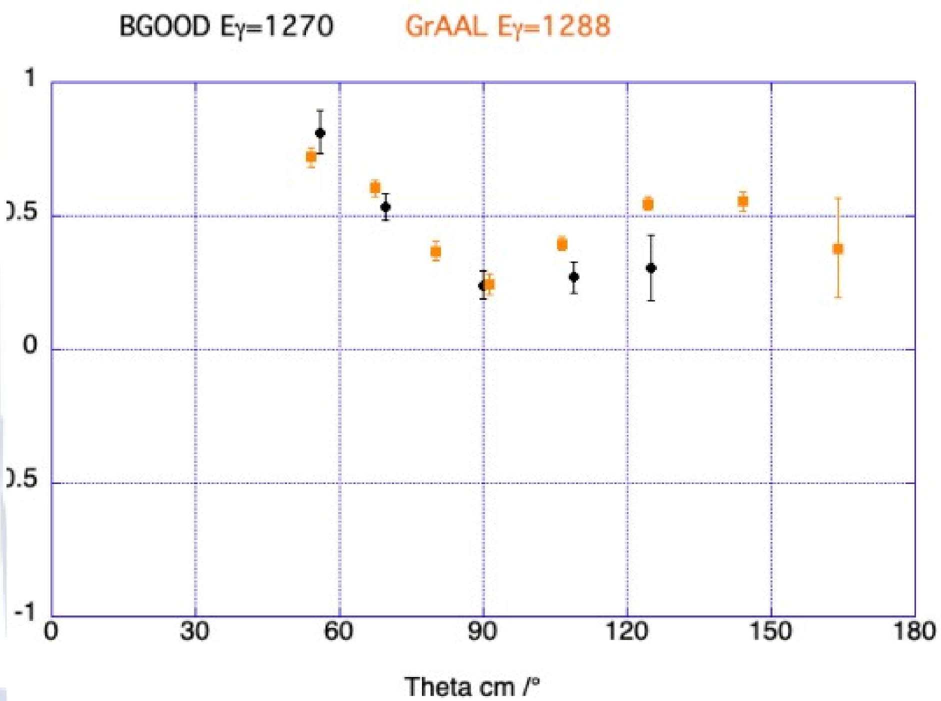
Black Points **GRAAL E_γ = 1475 MeV**
Red Triangles **BGOOD E_γ = 1475 MeV**

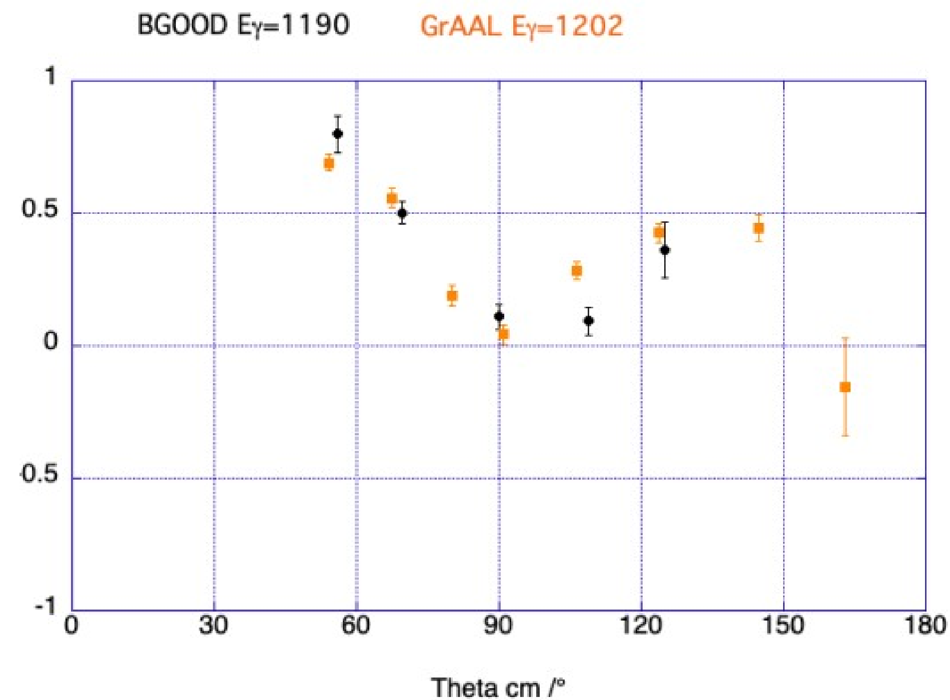


$\gamma\, n \rightarrow \pi^0\, n$









SUMMARY AND CONCLUSIONS

- BGOOD is a unique detector for forward acceptance and hermetic coverage working in the 3rd resonance region.

- An extensive program in progress at BGOOD on:

  strangeness photoproduction focused on forward angles and low momentum transfer → potential to investigate unconventional states

  $\gamma\, p \rightarrow K^+\Lambda, K^+\Sigma^0, K^+\Lambda(1405)$
  $\gamma\, n \rightarrow K^0\Sigma^0, K^+\Sigma^-$

  baryon-baryon dynamics in the ud sector
  $\gamma\, p \rightarrow d\, \pi^0\pi^0\, , d\, \pi^0\pi^0\, \pi^0, d\, \eta\, \pi^0$

  pseudoscalar meson photoproduction on proton and neutron (and also vector mesons ω in the future)

- Improving the statistics of some channels (also already published) is possible.
  Statistics to be analyzed is already available on tapes.

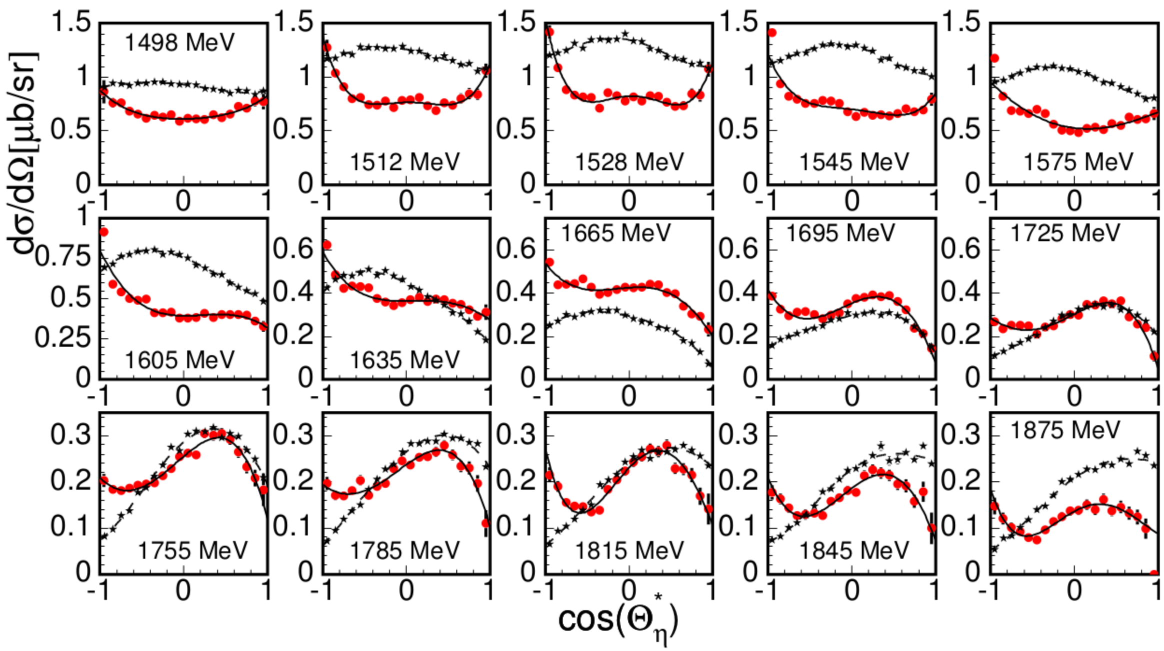
THANK YOU!!

BACKUP SLIDES

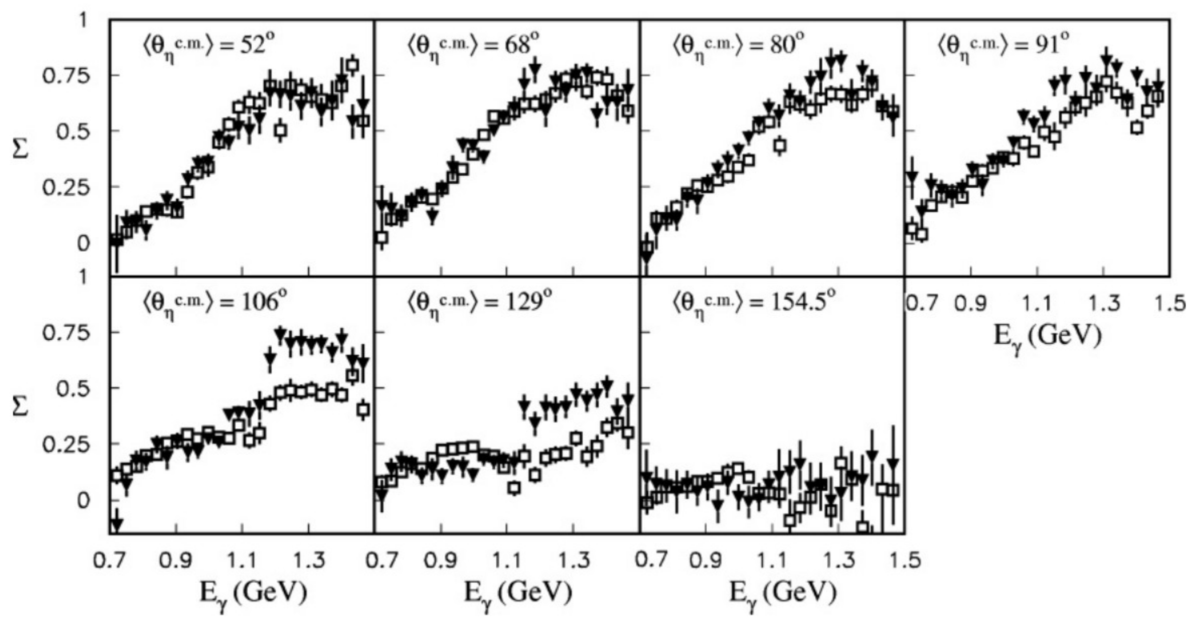
EXPERIMENTAL SITUATION FOR η PHOTOPRODUCTION

γ p → η p
Black Pts
PRC82 (2010) 035208

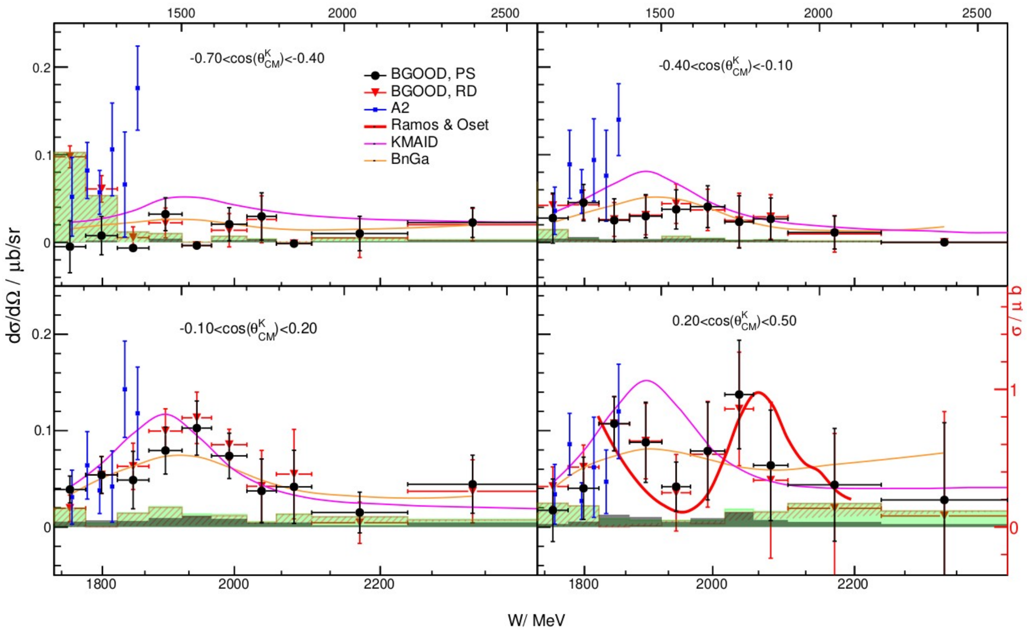
γ n → η n
Red Pts
PRL111 (2013) 232001



γ p → η p
Open Squares
γ n → η n
Full triangles
PRC78 (2008) 015203



Measurement of the $\gamma n \rightarrow K^0\Sigma^0$ differential cross section over the K^* threshold
K. Kohl *et al.*
arXiv: 2108.13319 and Submitted to EPJA



See Katrin Kohl's talk (Oct. 18th @ 15:00)

$\gamma n \rightarrow K^0\Sigma^0 \rightarrow (\pi^0\pi^0)\ (\gamma\Lambda) \rightarrow (\gamma\gamma\ \gamma\gamma)\ (\gamma\pi^- p)$ with all γ's in BGO and most of charged part in BGO/SciRi

HERMETIC COVERAGE

→ allows detection of all final state particles

Structure may become visible at $0.2<\cos\theta_{CM}<0.5$,

→ could be interpreted as due to a vector meson-baryon dynamically generated $K^*\Sigma$ resonance, the $N^*(2030)$ (**Phys. Lett. B 727, (2013) 287**) causing the constructive interference between $K^*\Sigma$ and $K^*\Lambda$ states.

N.B.

- In the same model $N^*(2030)$ could explain a **cusp observed in $K^0\Sigma^+$** (destructive interference between $K^*\Lambda$ and $K^*\Sigma$ states amplified by $N^*(2030)$).
- **$N^*(2030)$** is supported by BGOOD data in **Λ(1405)** photoproduction

In principle other interpretations in terms of conventional states cannot be ruled out.

La Rivista del Nuovo Cimento (2022) 45:189–276
https://doi.org/10.1007/s40766-021-00028-5

REVIEW PAPER

Check for updates

Trends in particle and nuclei identification techniques in nuclear physics experiments

7.3 BGOOD (MAMBO): neutral particles discrimination with BGO

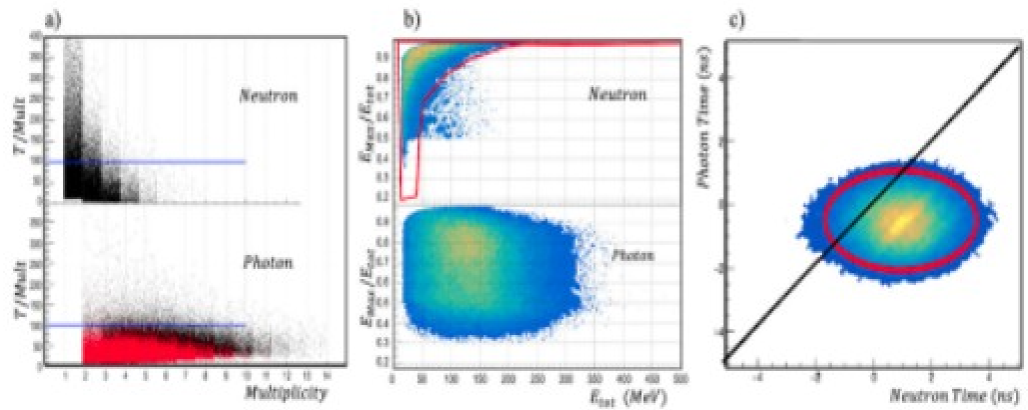


Fig. 35 MAMBO. **a** Ratio between the total cluster energy and the cluster multiplicity for neutrons and photons (in black and red the more and less energetic π^0 decay photons, respectively). **b** Ratio between the maximum energy released in a crystal and the total cluster energy for neutrons with multiplicity $>$ 2 and photons (sum of red and black distributions from **a**).The applied graphical cut is the red contour. **c** photon TOF versus neutron TOF distribution for selected events, the applied cut is presented in red. Ambiguity between two neutral signals with the same multiplicity is solved assigning the neutron tag to the signal with larger TOF (see 45° black line in the picture)

NEUTRON/PHOTON DISCRIMINATION IN BGO

GOAL OF THE JOB

Find criteria for identification and separation neutron/photon in BGO

N.B. Sampling ADC used for BGO crystals readout allow also time measurement with 1.5ns resolution.

TECHNIQUE

Start from a clean sample of selected events with a neutron and a photon in the final state.

The selection is based only on kinematical criteria.

Derive criteria for neutron/photon discrimination from this clean sample.

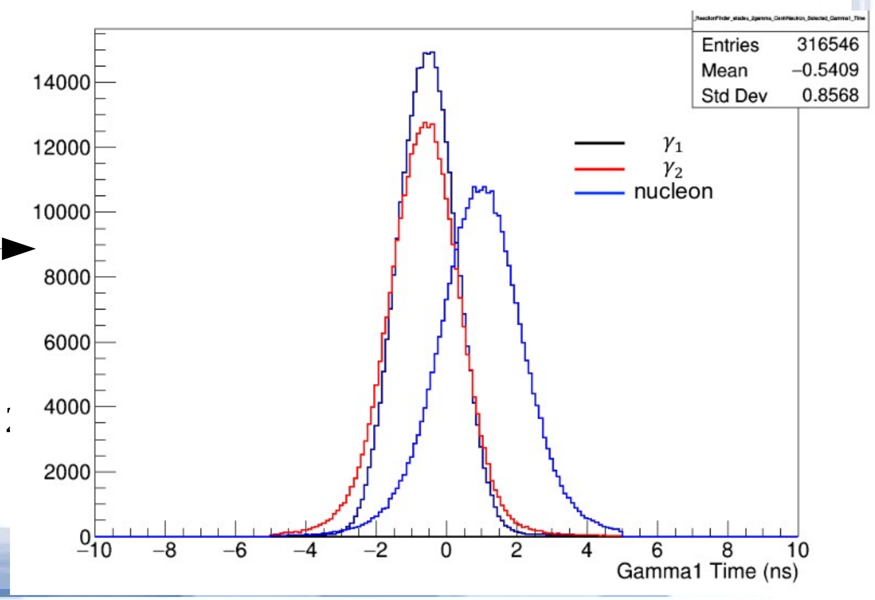
CHOSEN REACTION: $\gamma\, n \rightarrow \pi^0\, n$

SELECTION CRITERIA:

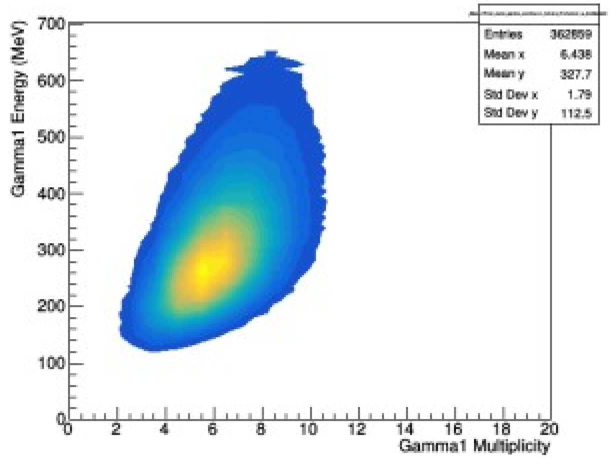
- 3 "neutral" clusters in BGO (i.e. with no signal in barrel/mwpc in geometrical coincidence), arranged into 3 possible combinations

- Choose the combination for which neutron cluster has the lowest multiplicity Mult or, being Mult equal, the largest ToF
(in average nucleon tof > γ ToF)

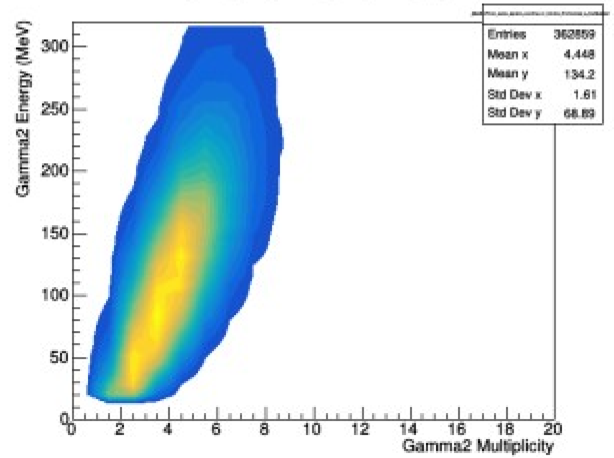
- Kinematical cuts on the 2-body reaction



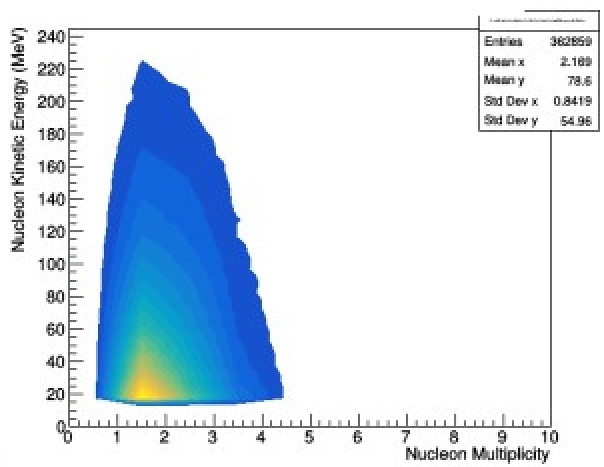
HIGH ENERGY PHOTONS



LOW ENERGY PHOTONS



NEUTRONS



PID CRITERIA:

1) Ratio between the cluster total energy and cluster multipl:

$$R = \frac{ETOT_{Clus}}{Mult_{Clus}}$$

R vs. Mult.

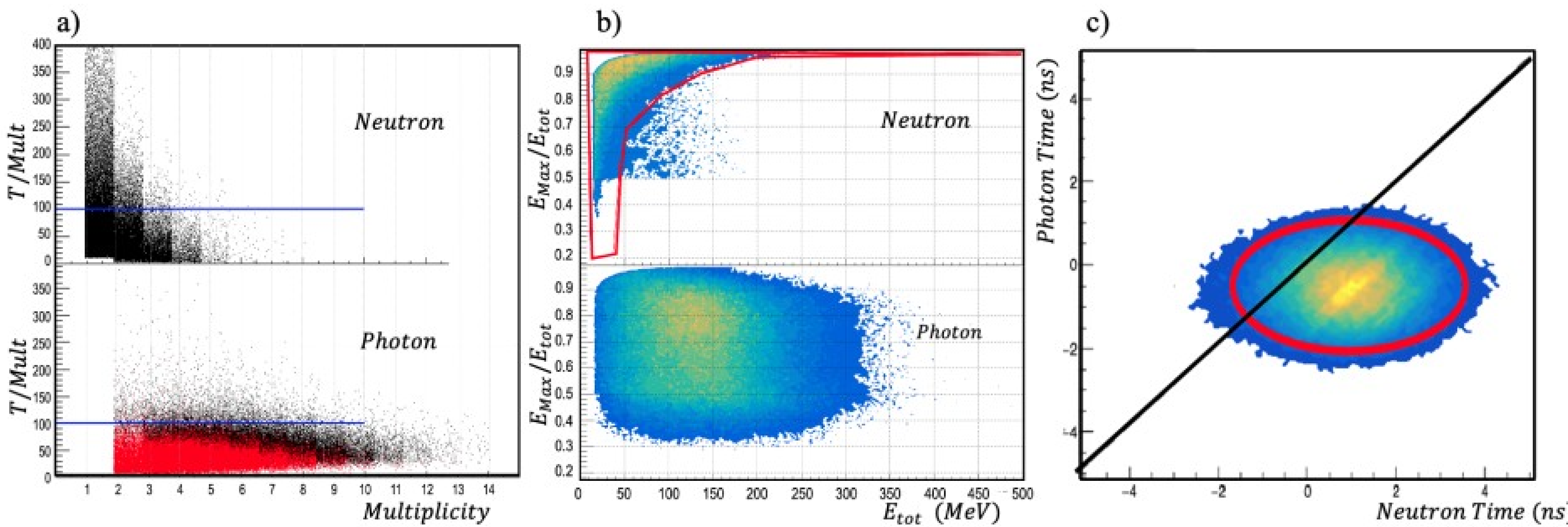
Photons: R<100 MeV/crystal
Neutrons:R<400 MeV/crystal

2) Ratio between the max energy in a crystal of a cluster and the total cluster energy:

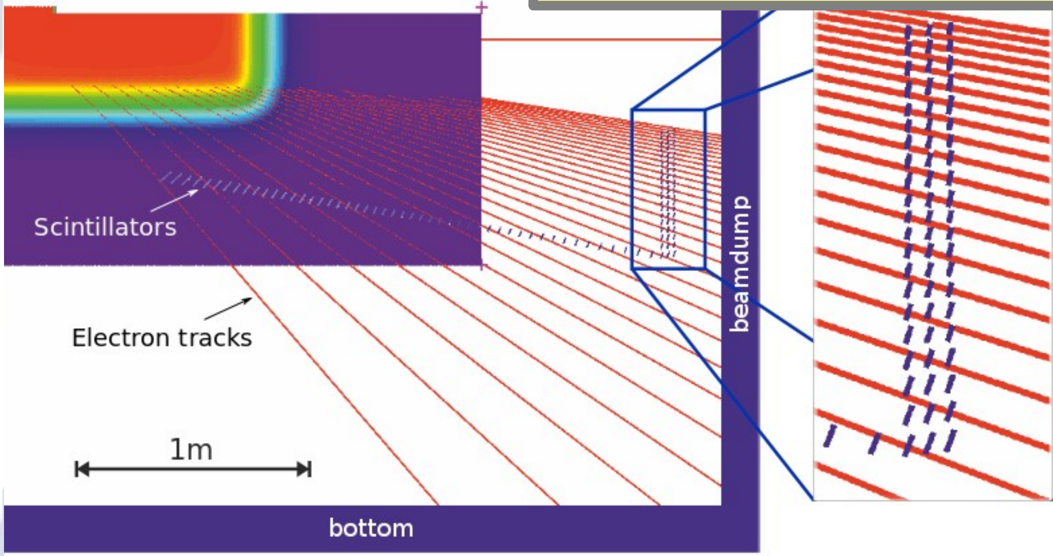
$$R' = \frac{E_{Cryst,MAX}}{ETOT_{Clus}}$$

R' vs. $ETOT_{Clus}$

3) neutron tof (≈1ns) is in average higher than γ (≈ −0.5ns)

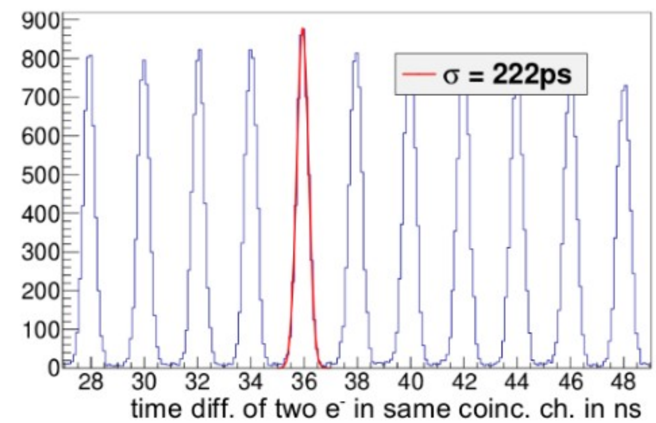


TAGGER DESIGN



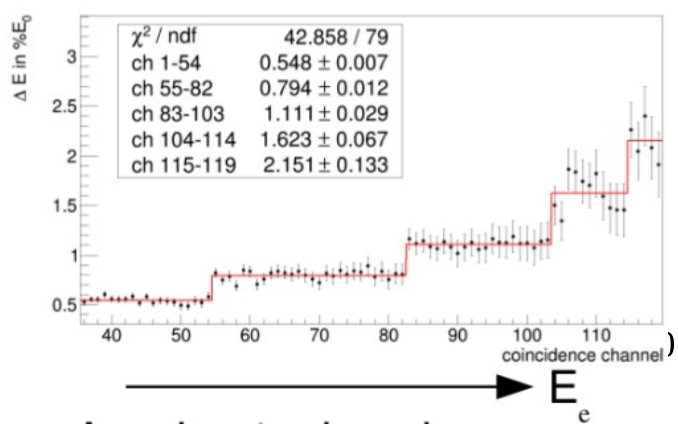
Siebke, G.

- **120 Channels (covering 0.1-0.9 E_0)**
- **Energy resolution: 10-40 MeV ($0.55\%E_0$-$2.15\%E_0$)**
- **Beam Intensity: $5 \cdot 10^7\,s^{-1}$**



- High energy e^- ($\rightarrow$ low en. γ): focal plane is not accessible split into 54 horizontal scint. (10-32% E_0) and 66 vertical ones (32-90% E_0)

- **trigger on double and triple coincidences**

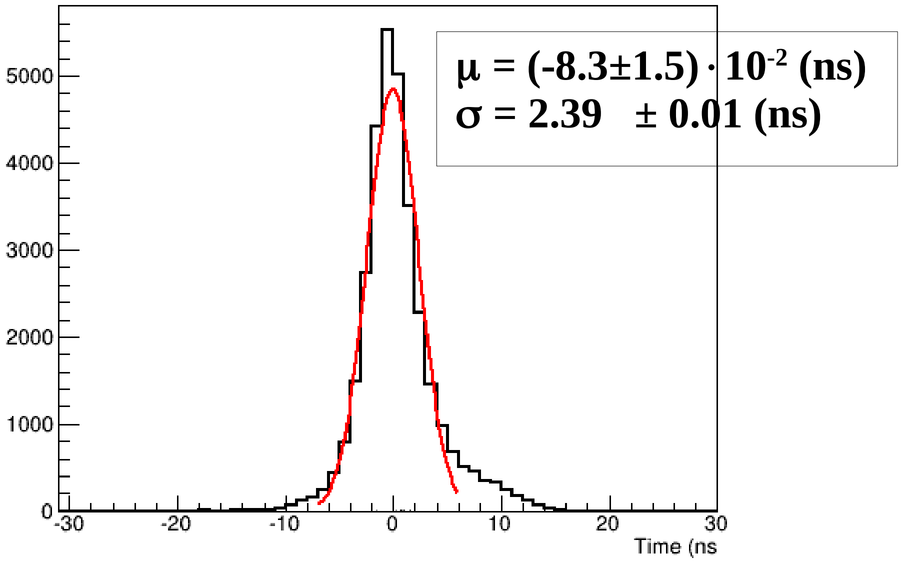


A. Bella-F. Messi

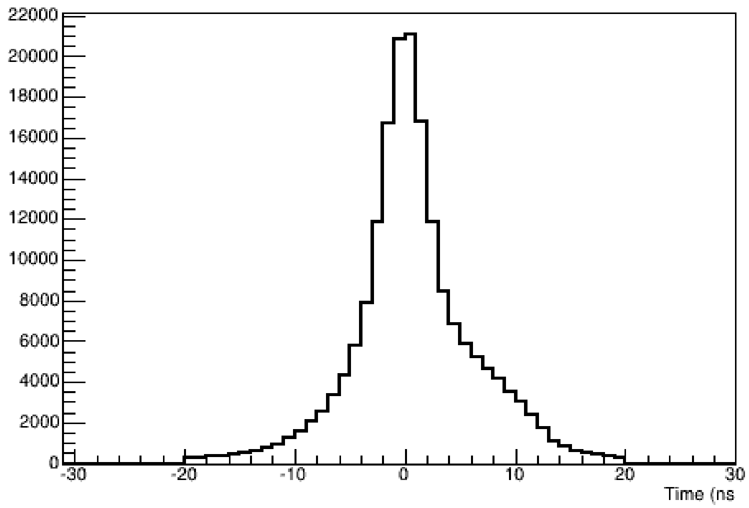
Time Distribution of clusters in BGO

Clusters from a photon

For selected π^0 events

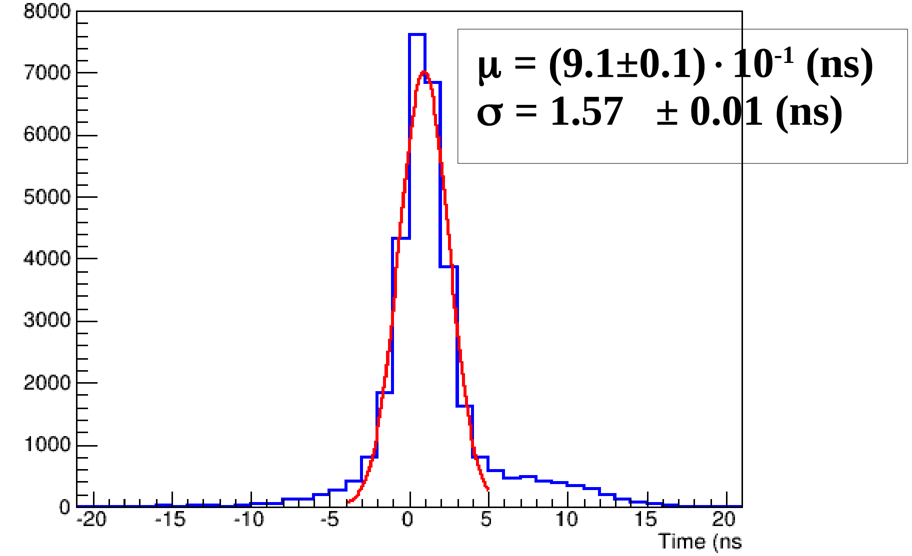


For not selected events

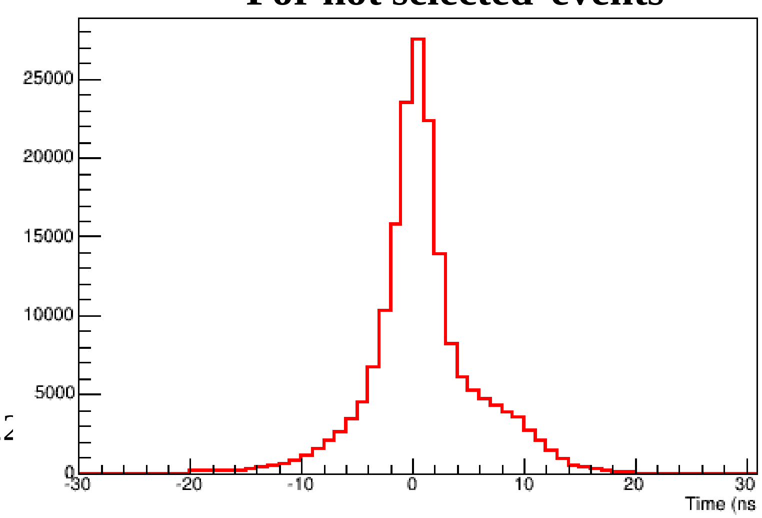


Clusters from a proton

For selected π^0 events



For not selected events

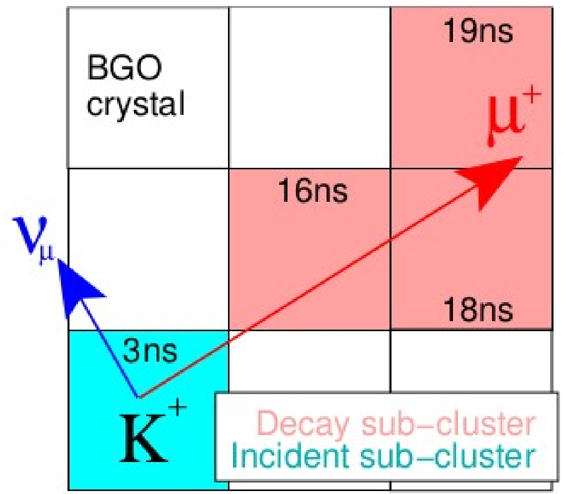


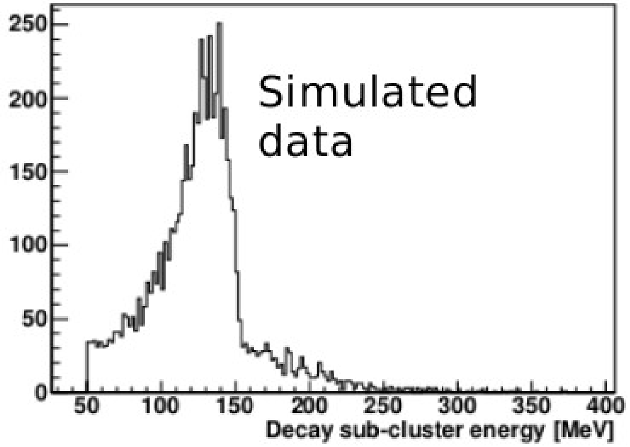
K^+ identification with the BGO ball

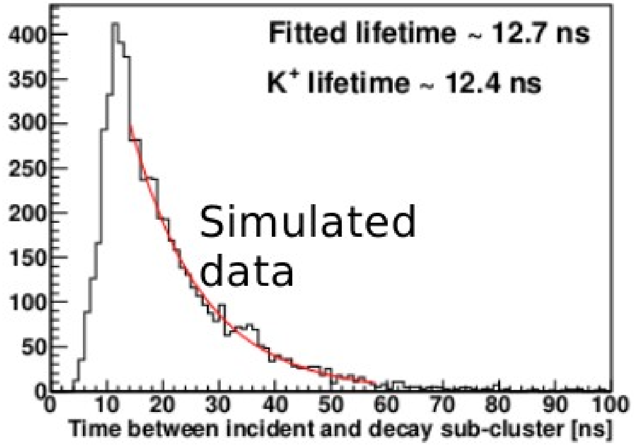
- Time delayed, K^+ weak decay within the crystals of the BGO ball
- Technique proven with the Crystal Ball, Mainz

Lifetime 12 ns,
2 main decay modes:

$$K^+ \rightarrow \mu^+ \nu_\mu$$
$$K^+ \rightarrow \pi^+ \pi^0$$

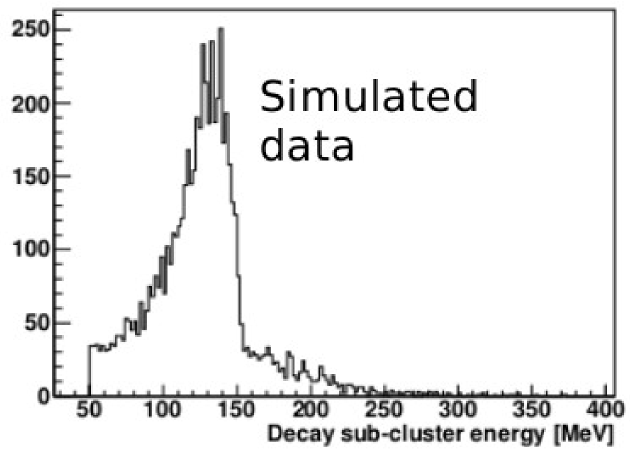


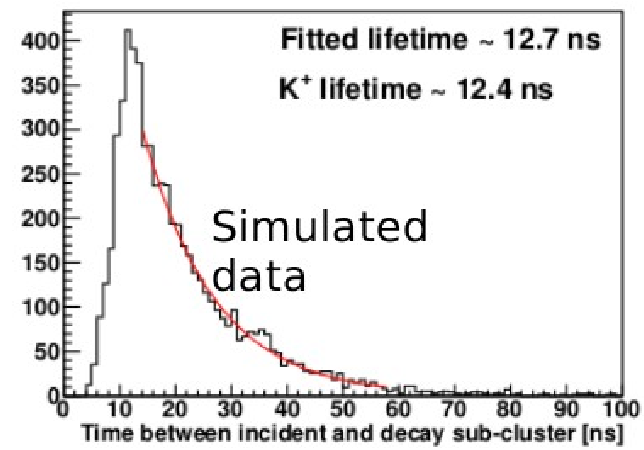




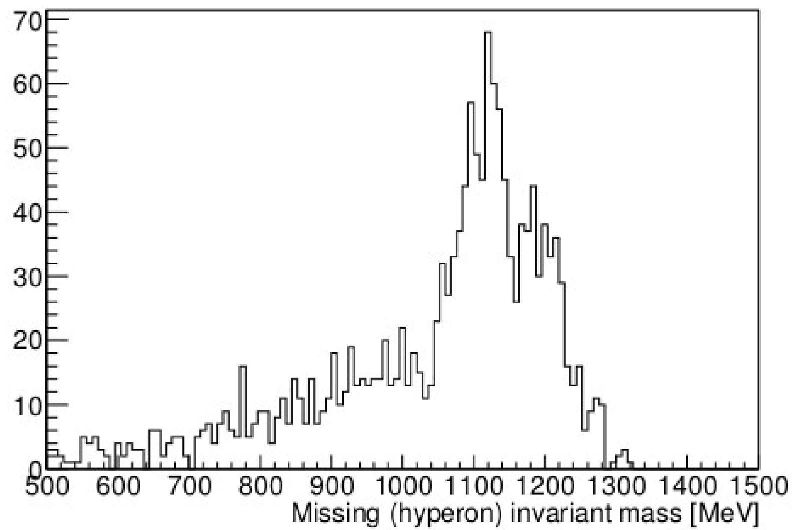
2

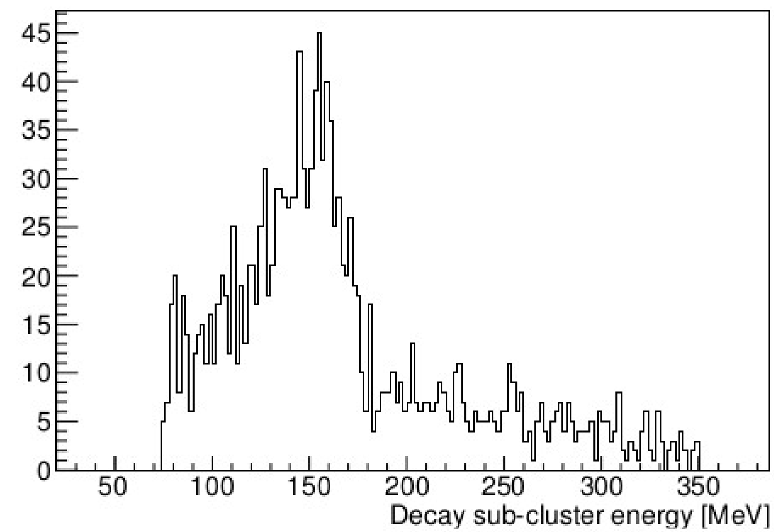
K^+ identification with the BGO ball





- Preliminary experimental data (no charged particle ID used):





FORWARD SPECTROMETER: BEFORE DIPOLE

MOMO

SciFi2

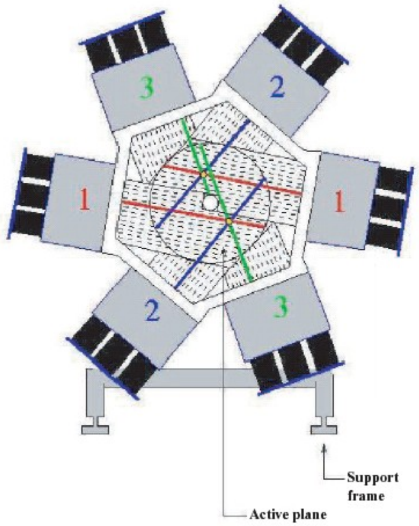
Successful commissioning with beam tests in Feb.-March 2012 and June 2012

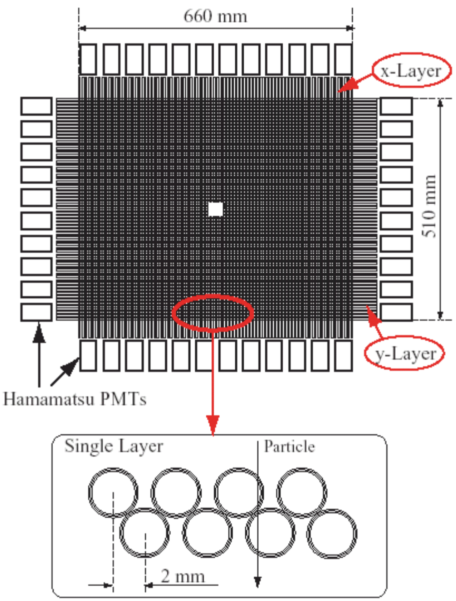
MOMO

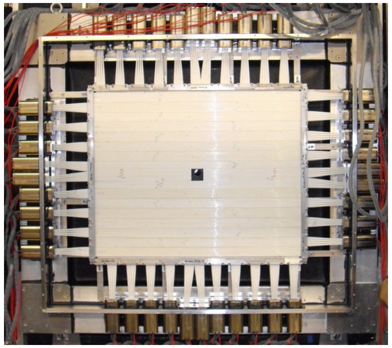
Scintillation fiber detector (⊘44cm)
672 total channels
3 layers of 2x112 parallel fibers
(⊘2.5mm, Δx=1.5mm)
Each layer rotated of 60° w.r.t. each other
Read-out 16 channel PM
Central hole (⊘5cm) for the passage of beam

SciFi2

Scintillation fiber detector (66cmx51cm)
640 total channels
2 double layers x/y (352 and 288 rot. 90°)
Each single layer consists of two fiber arrays
(2.0mm track length for crossing particles)
Read-out 16 channel PM
Central hole (⊘4cm) for the passage of beam





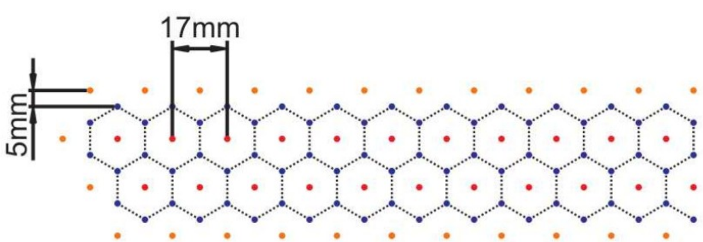


D. Bayalov-S. Boese

FORWARD SPECTROMETER: AFTER DIPOLE

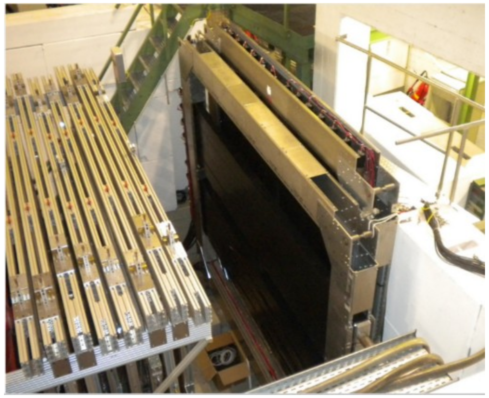
DRIFT CHAMBERS

Two sets of 4 double layers
X(vert.), Y(90°), U(+9°), V(-9°)
Sensitive area 1.2 x 2.4 m^2
X = horizontal
Y = vertical
U = 99° w.r.t. X
V = 81° w.r.t. X
Hexagonally shaped drift cells (inner radius 8.5mm)
Distance from target = 3.8 m÷4.5 m
Gas mixture: 70% Ar, 30% Co_2
Central insensitivity spot (5x5cm^2)

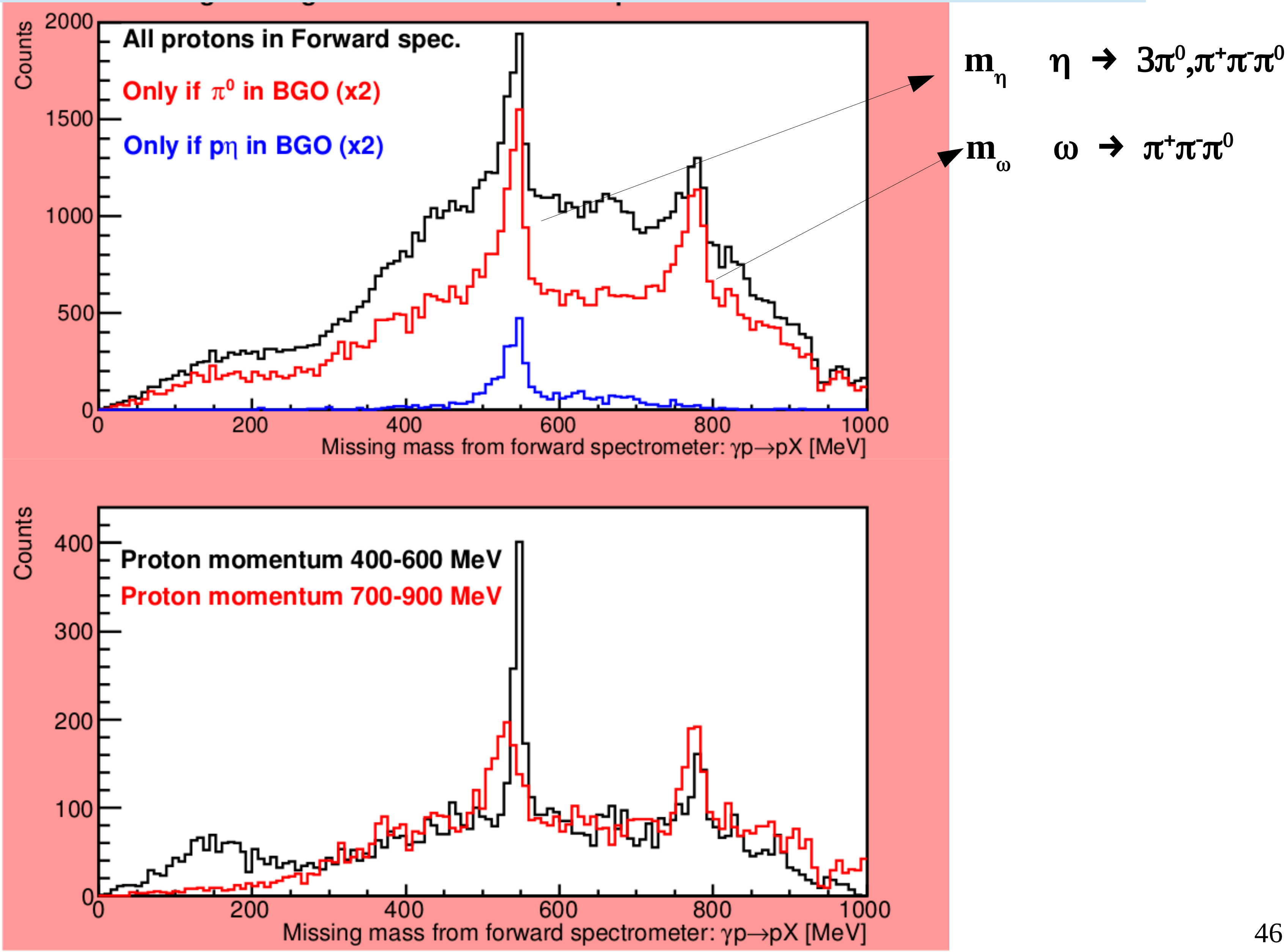


TOF WALLS

- 2 walls
- 14 bars vert., 8 bars hor.
- Scintillator dimensions:
- 3400mm x 210mm x 60mm (horizontal bars)
- 2700mm x 200mm x 45mm (vertical bars)
- Time resolution ~500ps
- Upgrade using former GRAAL ToF detectors (time resolution ~200ps) **JUNE 2014**



Missing Mass from Protons Detected in the Forward Spectrometer



N.B. p_{proton} > 400 MeV/c in order to suppress π^0 photoproduction

FLUX MONITORS

Two flux monitors:

GIM (Gamma Intensity Monitor): efficiency close to 100%
Lead Glass
Uses the Cerenkov effect to separate charged particles from the e.m. showers generated by photons
One single lead block
2" PM

FLUMO (Flux Monitor)
Three scintillators + a Copper foil between the first and second scintillators
Low intensity runs to extract the efficiency of the FluMo