Hadron Physics @ ELSA

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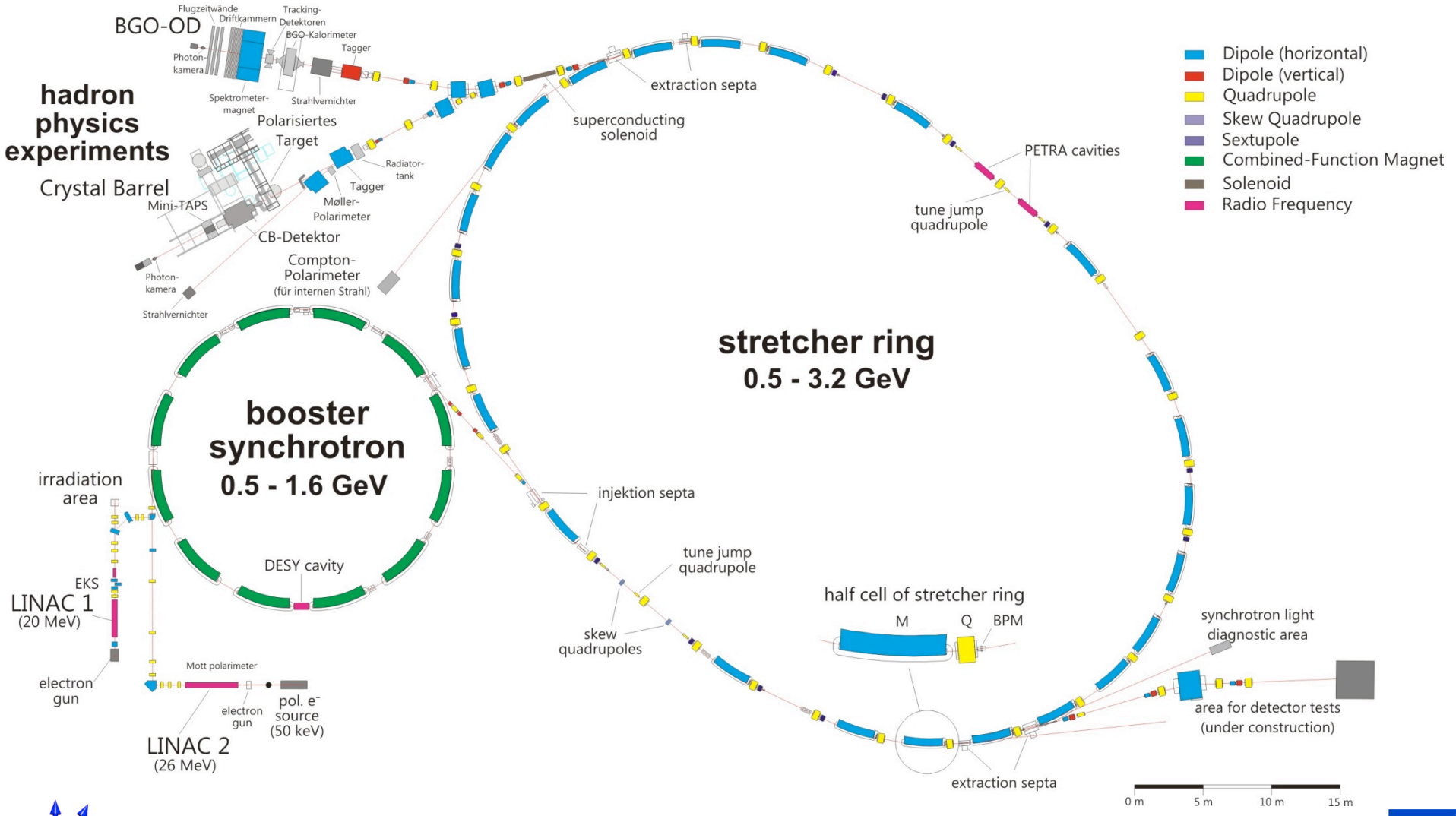
Outline

- ELSA accelerator
- Hadron Physics experiments
- recent developments
- selected results
- future plans

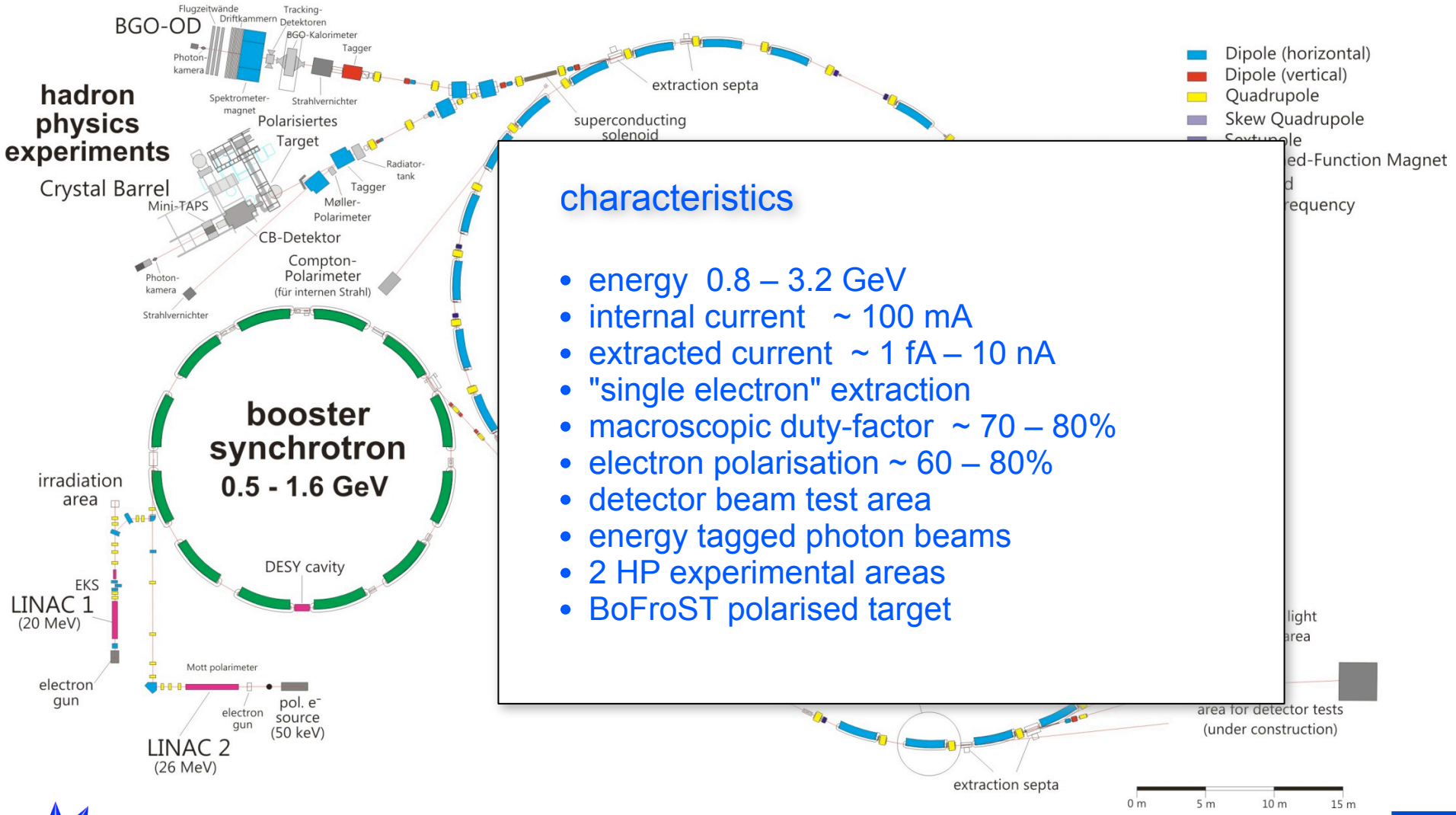
ELSA accelerator

W. Hillert, F. Klein



ELSA accelerator

W. Hillert, F. Klein



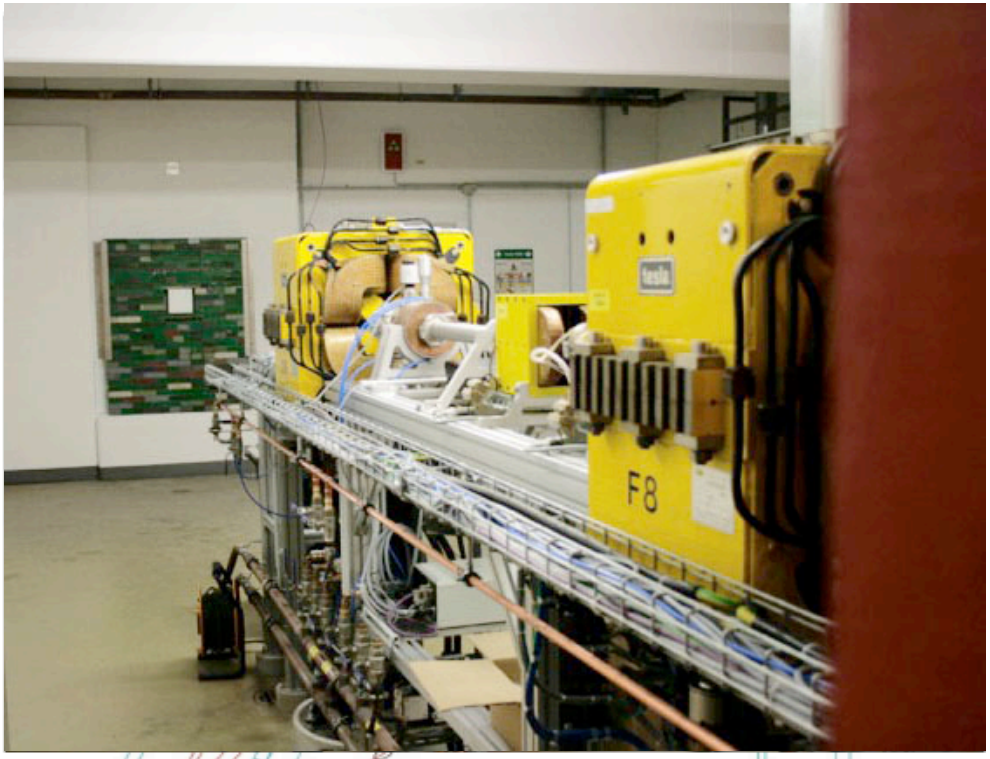
characteristics

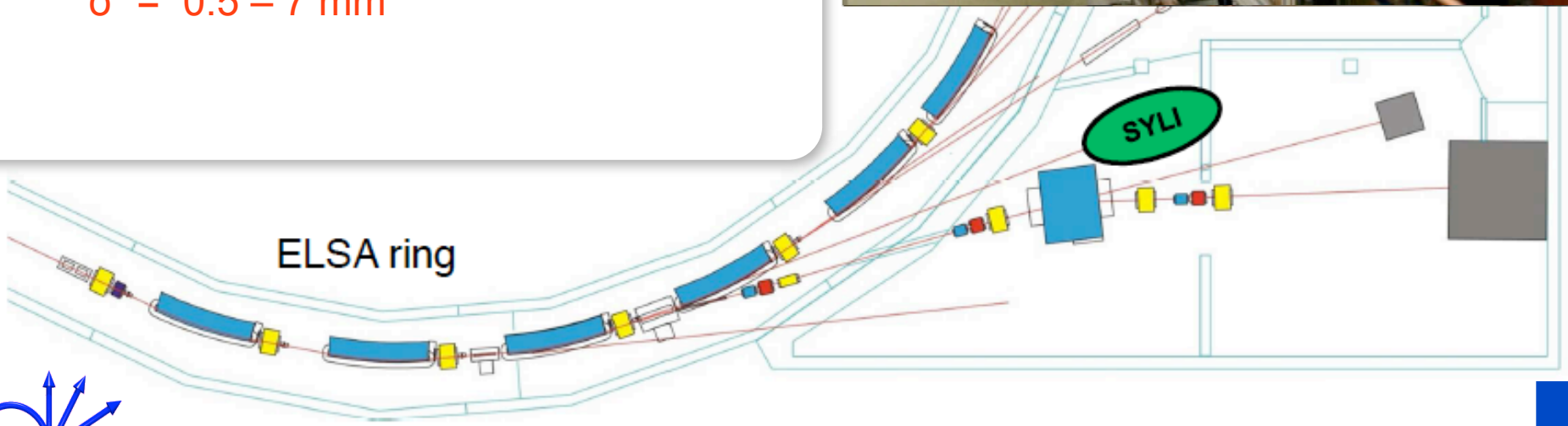
- energy 0.8 – 3.2 GeV
- internal current ~ 100 mA
- extracted current ~ 1 fA – 10 nA
- "single electron" extraction
- macroscopic duty-factor ~ 70 – 80%
- electron polarisation ~ 60 – 80%
- detector beam test area
- energy tagged photon beams
- 2 HP experimental areas
- BoFroST polarised target

Test beam area

beam parameter

- electron energy
  E = 0.8 – 3.2 GeV
- intensity
  I = 1 fA – 100 pA
  single-electron extraction
- size
  σ = 0.5 – 7 mm





ELSA

Recent developments

- Wolfgang Hillert ➔ Univ. Hamburg
  → effective Nov. 15
  → new organisational head: D. Elsner
- new ELSA directorate
  → K. Desch (speaker), J. Dingfelder, F. Klein, M. Köhl, N. Wermes
- regular end of SFB/TR-16 after 12 years
  → spokespersons: F. Klein, U.-G. Meißner, U. Thoma
  → > 450 publications in refereed journals
  → > 100 Dr. theses
  → > 20.000.000 € + PP
  → **thanks to DFG !**
- continuation of ongoing HP experiments
- FTD: "Forschungs- u. Technologiezentrum Detektorphysik"
  → spokespersons: J. Dingfelder & B. Ketzer

Experimental highlights from SFB/TR-16

→ **central theme: nucleon excitation spectrum**

E. Klempt, A. Sarantsev, U. Thoma et al.

State	PDG 2010	BnGa PWA	PDG 2012	SAID PWA
N(1860) 5/2+		*	**	
N(1875) 3/2-		***	***	
N(1880) 1/2+		**	**	
N(1895) 1/2-		**	**	
N(1900) 3/2+	**	***	***	no evidence
N(2060) 5/2-		***	**	
N(2150) 3/2-		**	**	
Δ(1940) 3/2-	*	*	**	no evidence

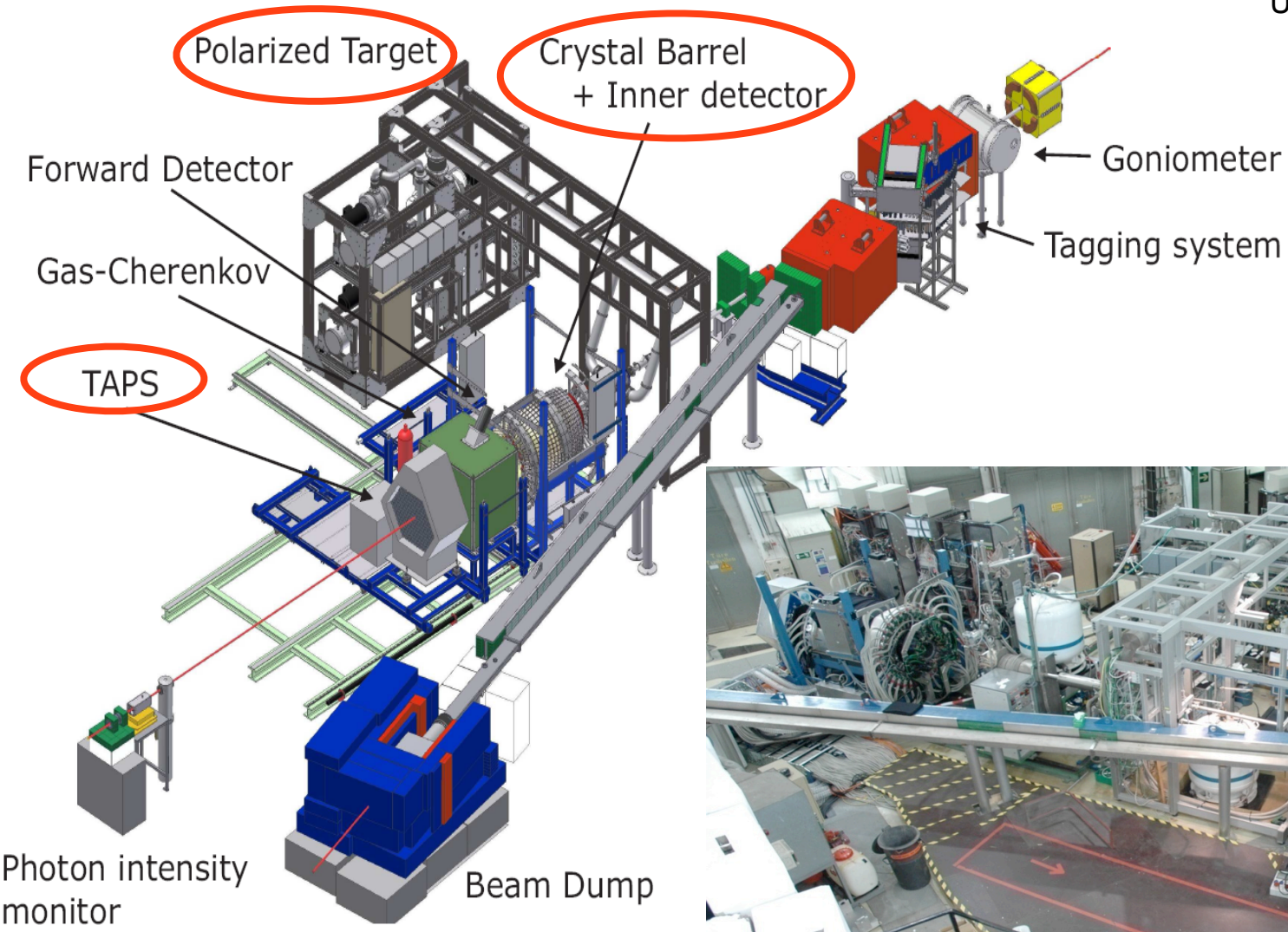
- inclusion of CLAS, MAMI, ELSA data
- confirmation of known resonances w/ improved parameters
- observation of new states

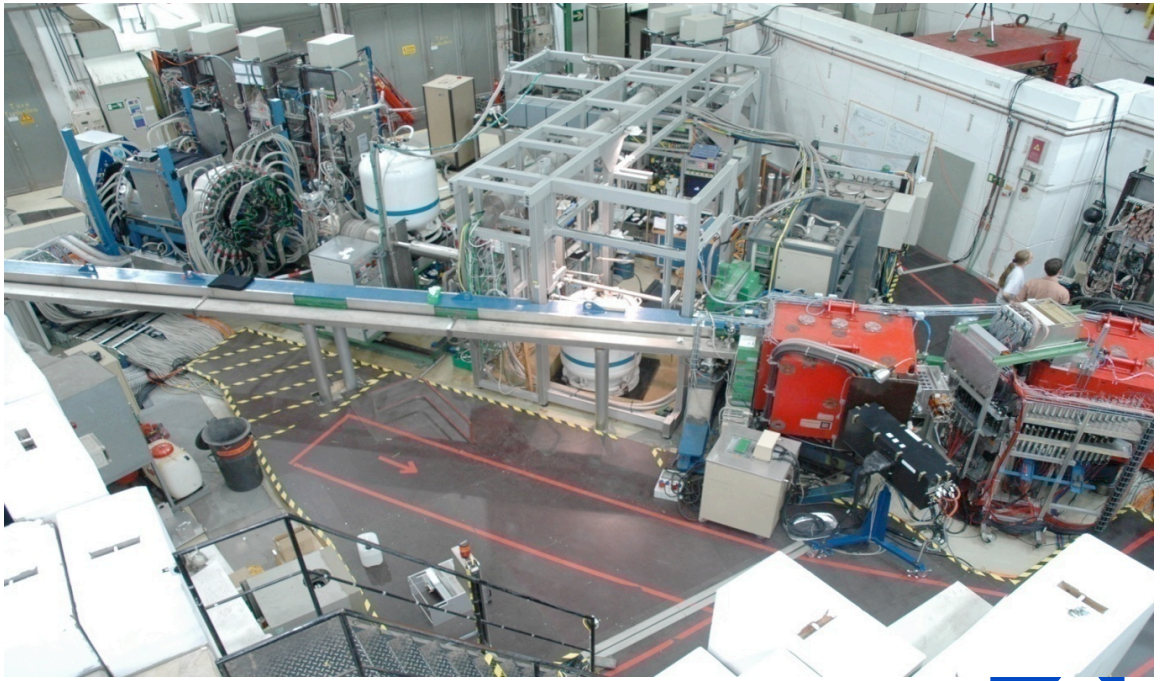
→ **few selected measurements in following**

Experimental highlights from SFB/TR-16

CBELSA/TAPS experiment w/ polarised target

spokespersons: B. Krusche (Basel)
U. Thoma (Bonn)





Experimental highlights from SFB/TR-16

CBELSA/TAPS experiment w/ polarised target

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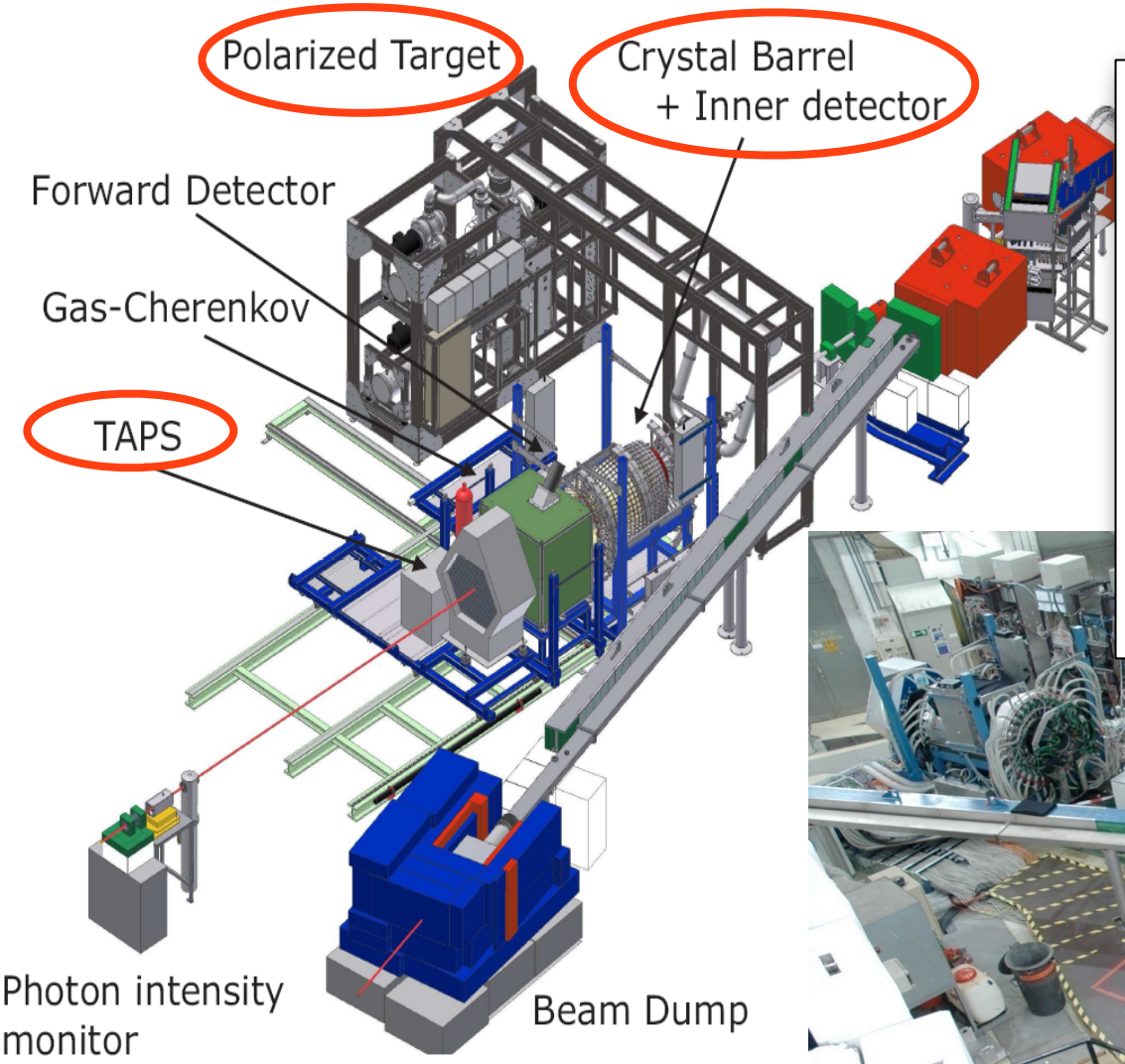
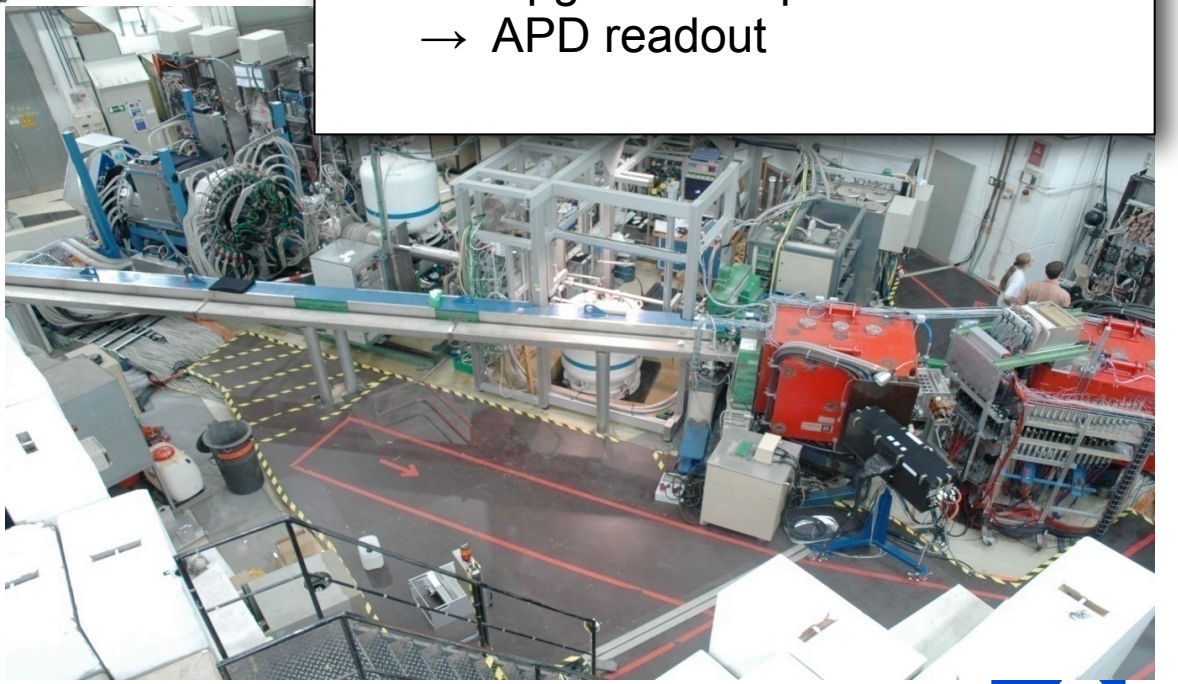


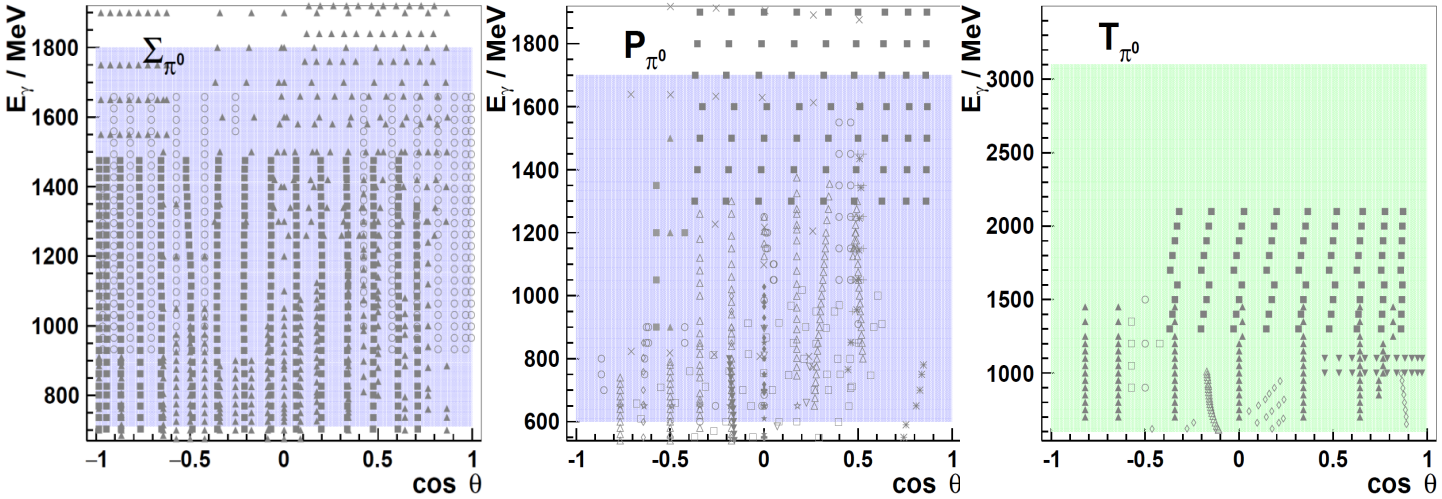
- lin./circ. polarised beam & long./transv. polarised target
- central calorimeter combined with forward calorimeter
- ideal for multi photon final states
- CB upgrade completed → APD readout

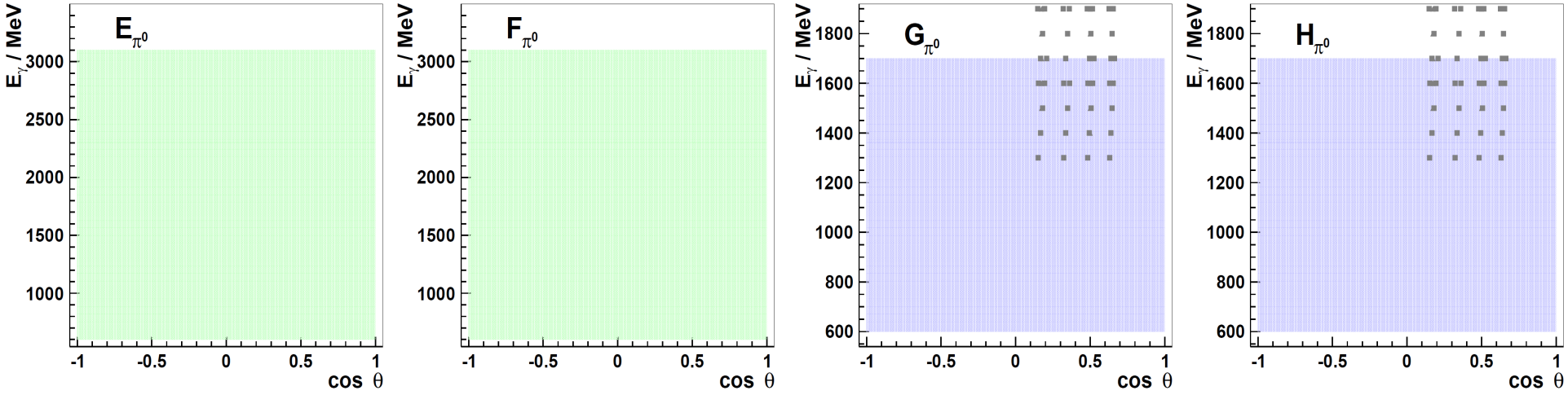


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\,\pi^0$$

data base **before** CBELSA/TAPS

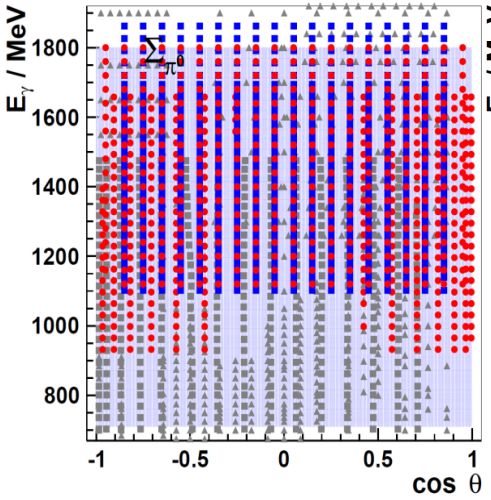


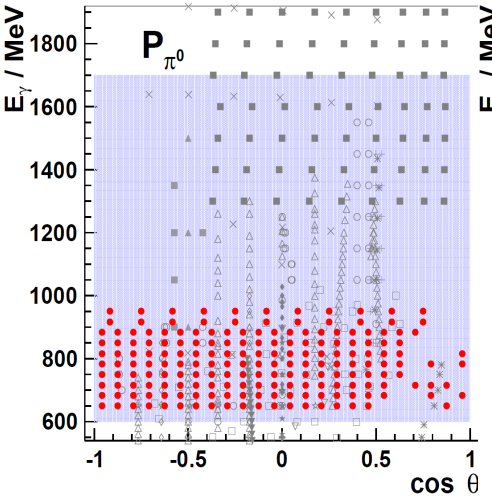


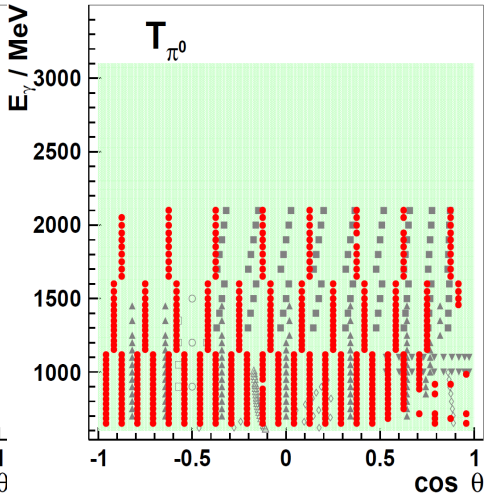
Overview measurements

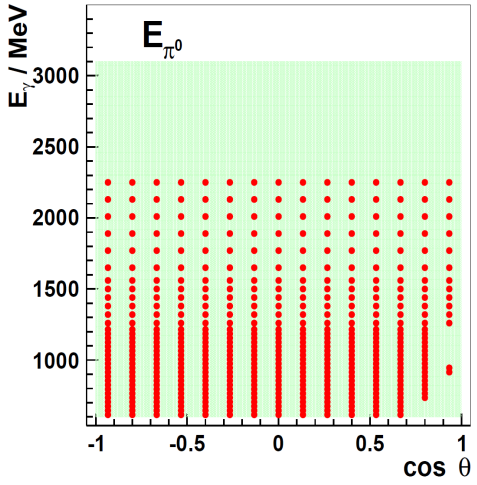
$$\vec{\gamma}\ \vec{p} \rightarrow p\,\pi^0$$

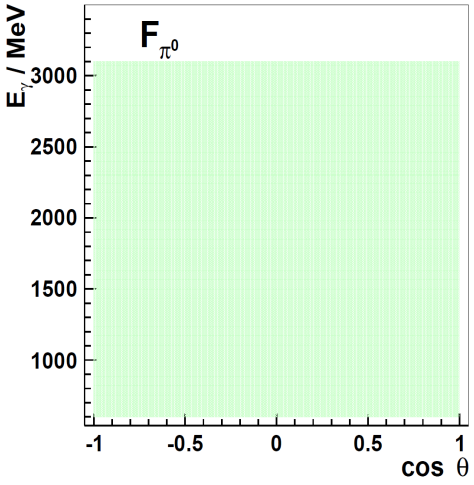
- data base **after** CBELSA/TAPS
- JLab

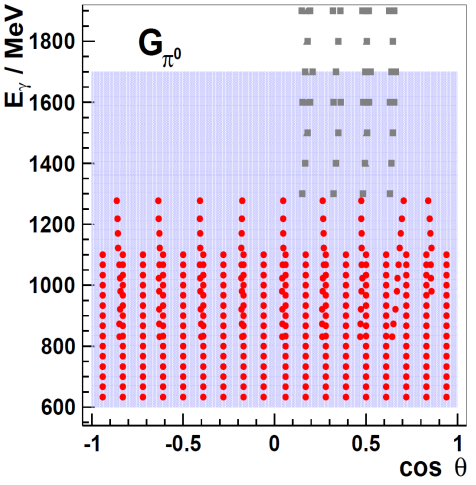


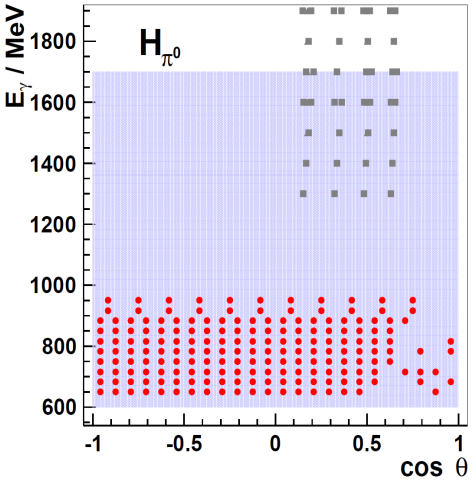








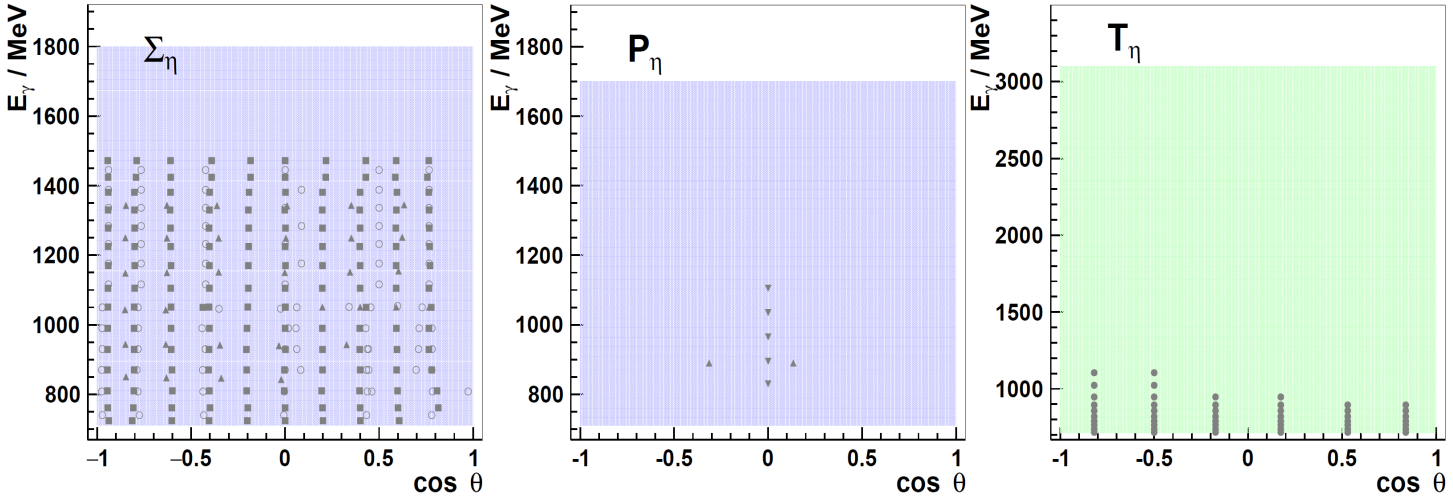


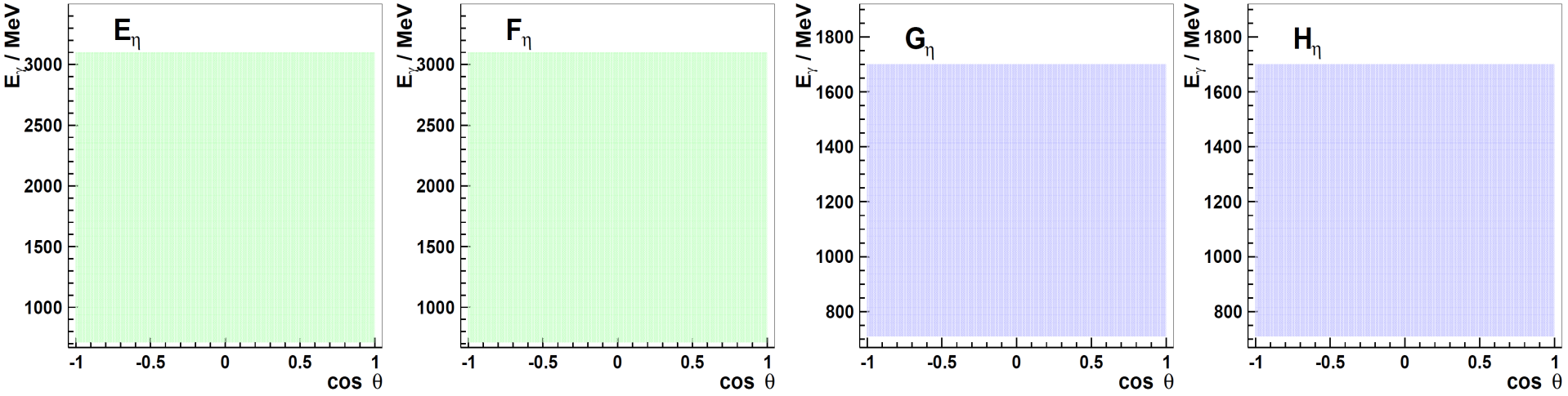


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\eta$$

data base **before**
CBELSA/TAPS

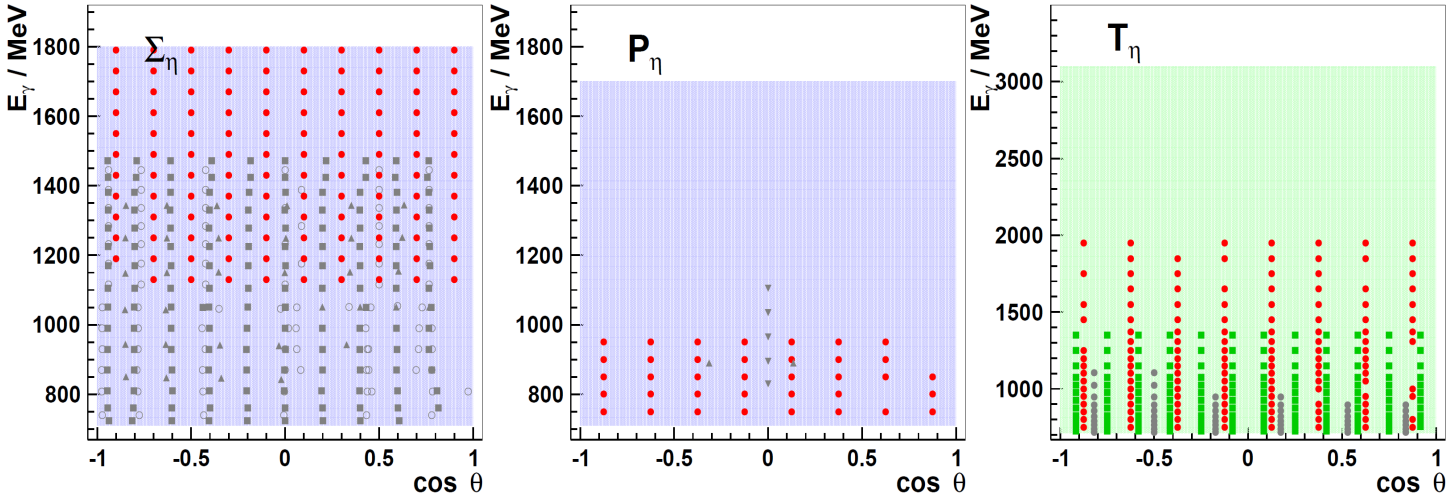


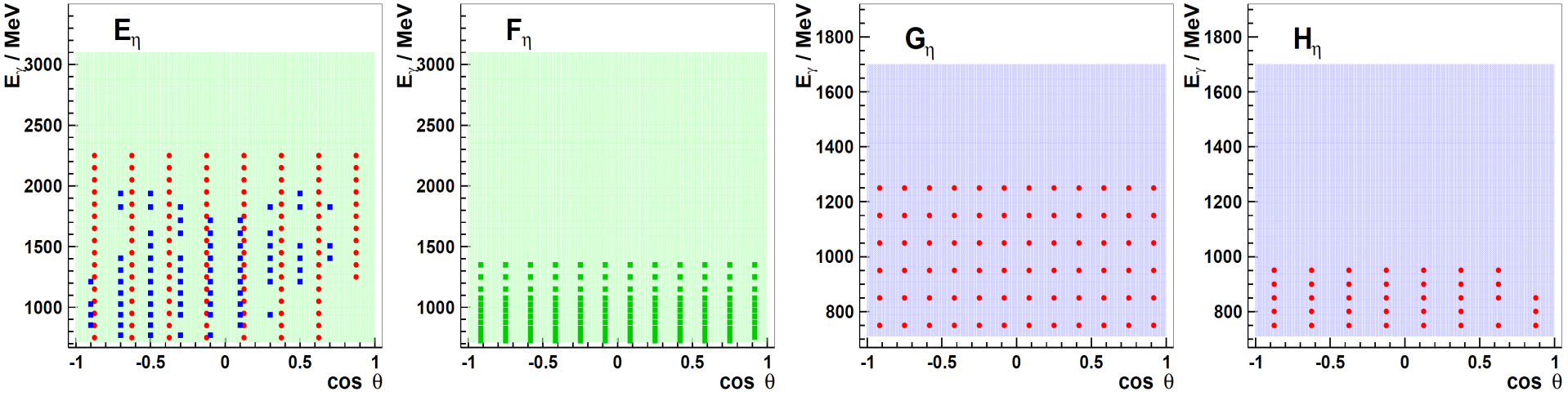


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\eta$$

- data base **after** CBELSA/TAPS
- JLab
- MAMI

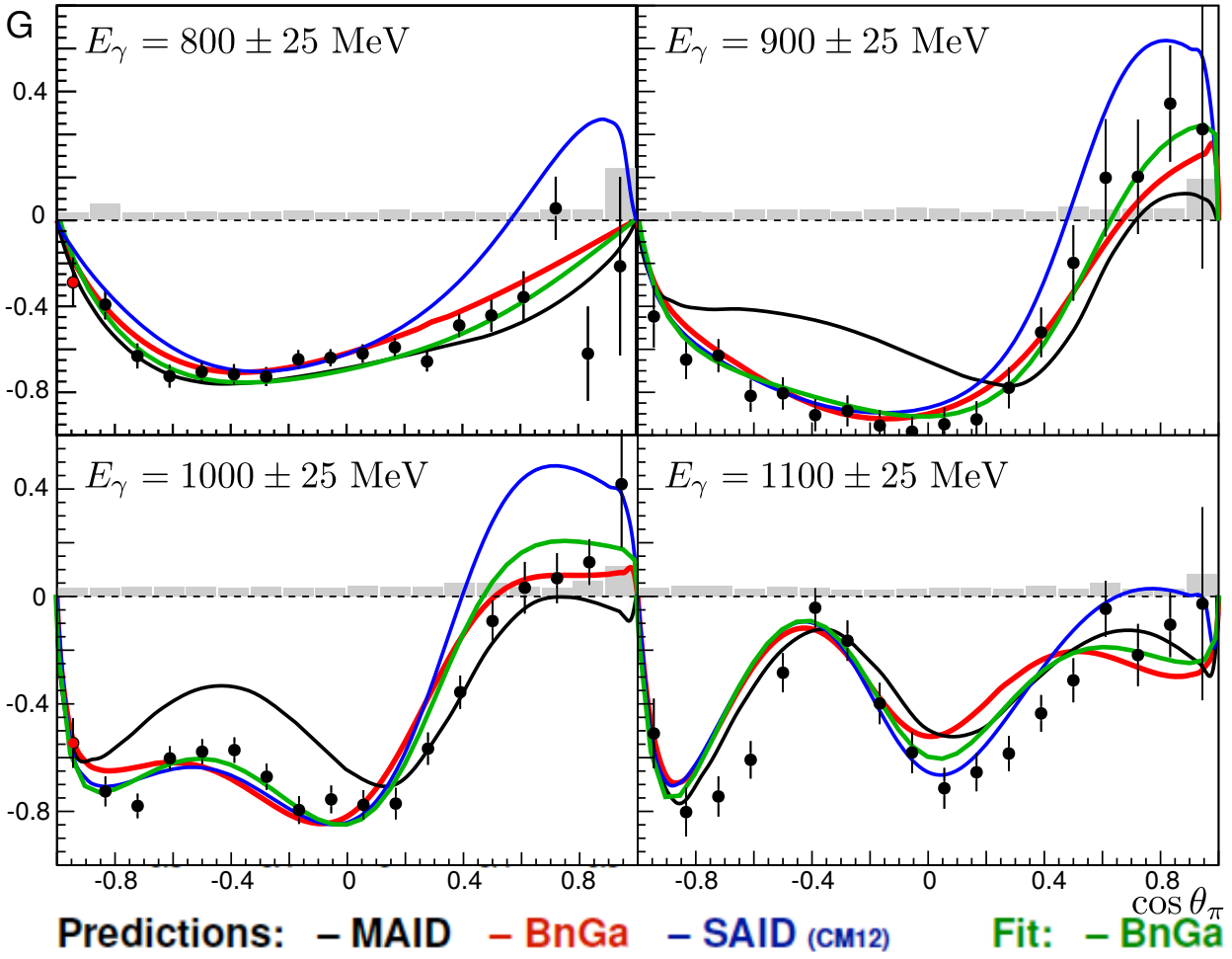




Selected results

I) π^0 photoproduction (long. pol. target & lin. pol. beam)

$$\frac{d\sigma}{d\Omega}(\Phi) = \frac{d\sigma}{d\Omega_0} \cdot \left(1 - P_\gamma^{lin} \Sigma \cos(2\phi) + P_\gamma^{lin} P_z G \sin(2\phi)\right)$$



discrepancies already in 2nd resonance region !
→ related to:

- $1/2^-$ & $3/2^-$ pw's
- E_{0+} & E_{2-} multipoles

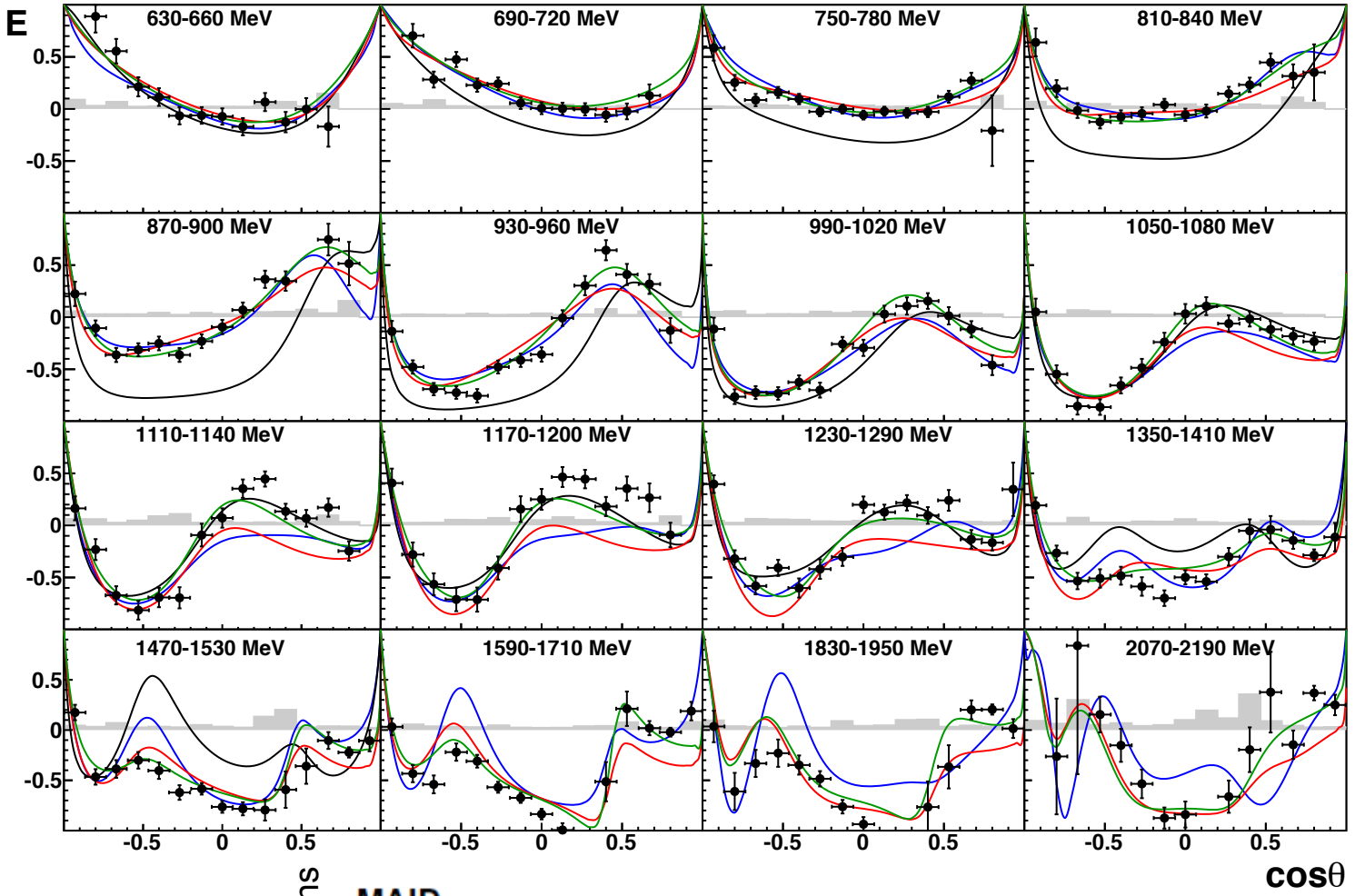
A. Thiel et al. [CBELSA/TAPS]
PRL 109 (2012) 102001

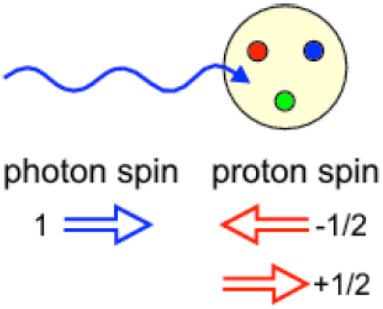
Selected results

II) π^0 photoproduction (long. pol. target & circ. pol. beam)

$\vec{\gamma}\vec{p} \rightarrow p\pi^0$

M. Gottschall et al. [CBELSA/TAPS], PRL 112 (2014) 012003





$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

discrepancies !
→ sensitive to:

- interferences with different L_π
- small resonance contributions

PWA predictions
– MAID,
– SAID (CM12),
– BnGa (2011_2)

– BnGa new fit

Selected results

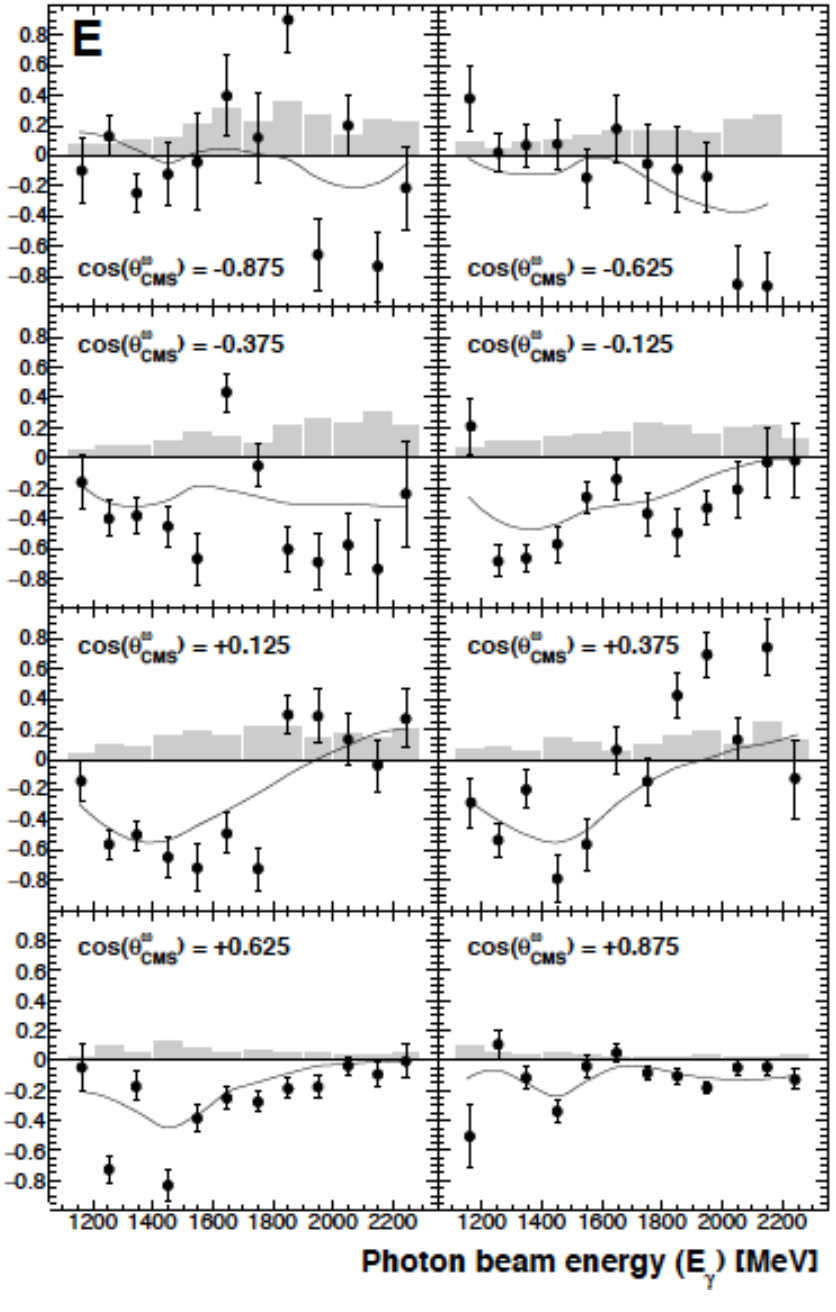
III) ω photoproduction (unpol., lin. pol. bea

H. Eberhardt et al. [CBELSA/TAPS]
Phys. Lett B748 (2015) 212

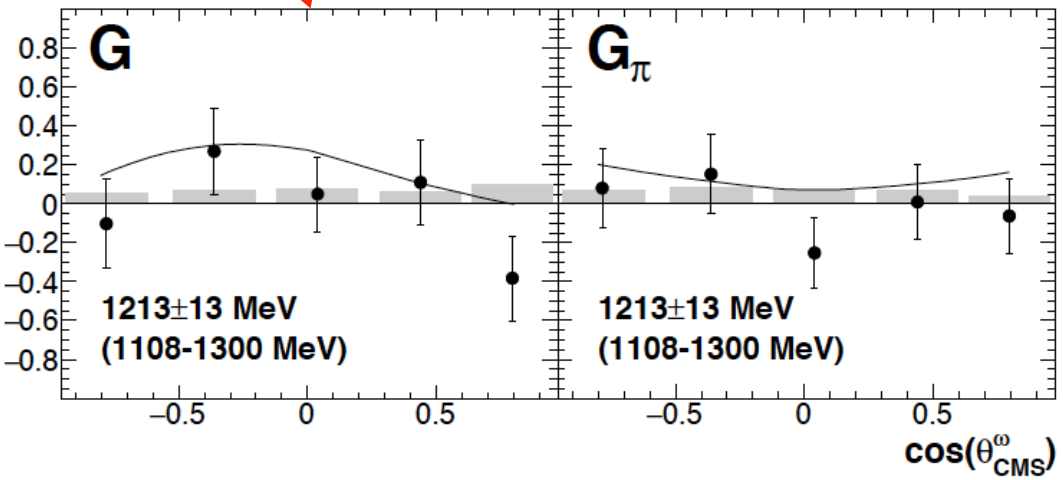
→ **beam-target double polarization**

A. Wilson et al. [CBELSA/TAPS]
Phys. Lett. B749 (2015) 407

→ **lin. polarized SDME's**



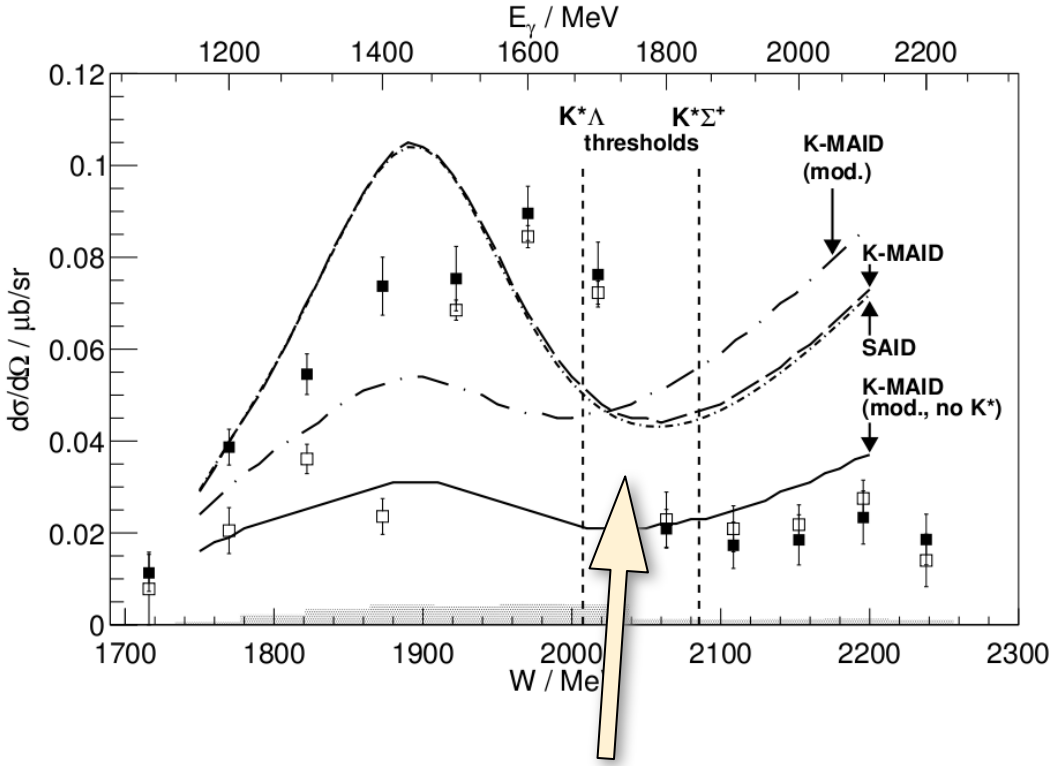
long. **polarized target** w/
circular
beam polarization
linear



curves: Bonn-Gatchina PWA

Selected results

IV) $K^0\Sigma^+$ photoproduction (unpol., lin. pol. beam)

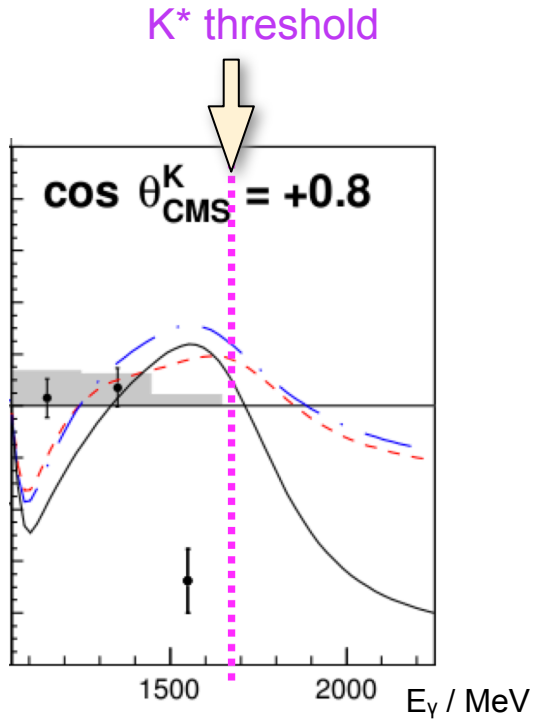


cusp-like fall-off
at K* threshold

R. Ewald et al. (CB/TAPS), PLB 713 (2012)

forward cross section

$\langle \cos \theta_K^{cm} \rangle = 0.83$



R. Ewald et al., PLB 738 (2014)

forward beam asymmetry

K^0/K^* anomaly

vectormeson – baryon "pentaquark" ??

hidden-charm

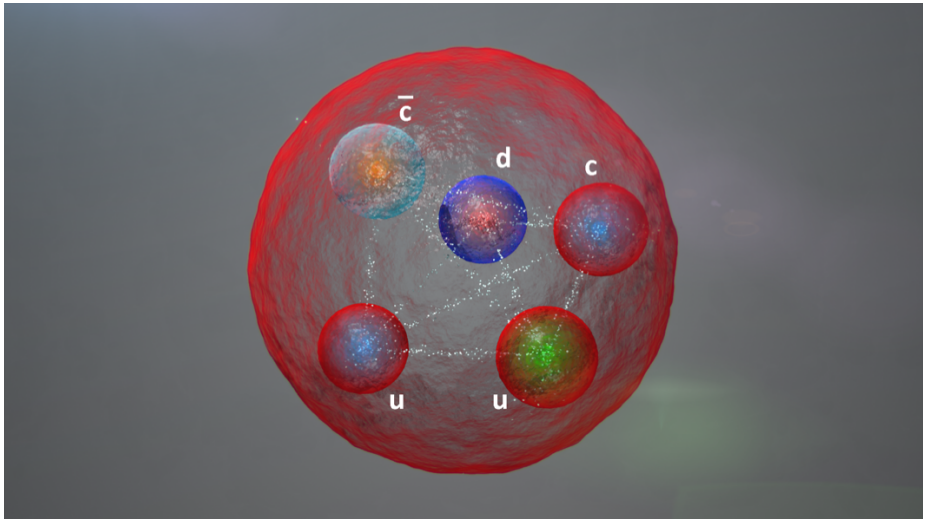
$P_c(4380/4450)$

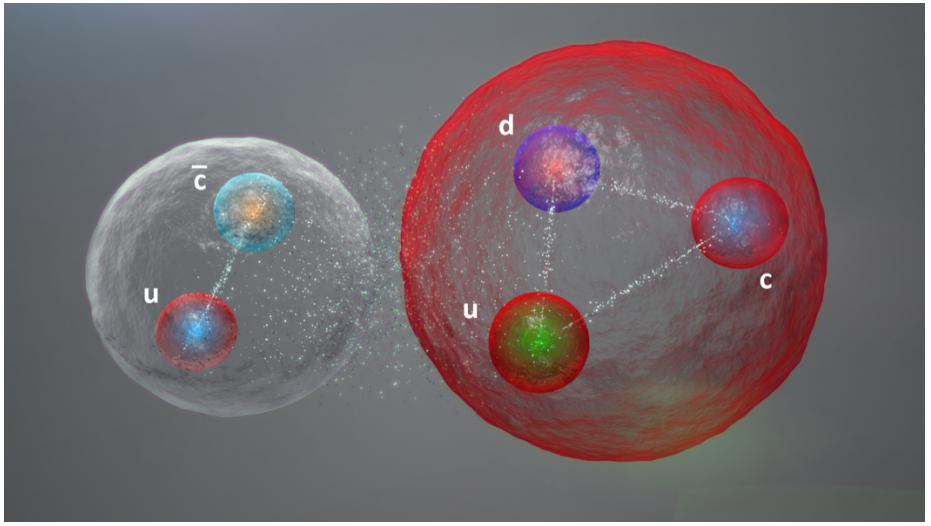
LHCb 2015

PARTICLE PHYSICS

Forsaken pentaquark particle spotted at CERN

Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.





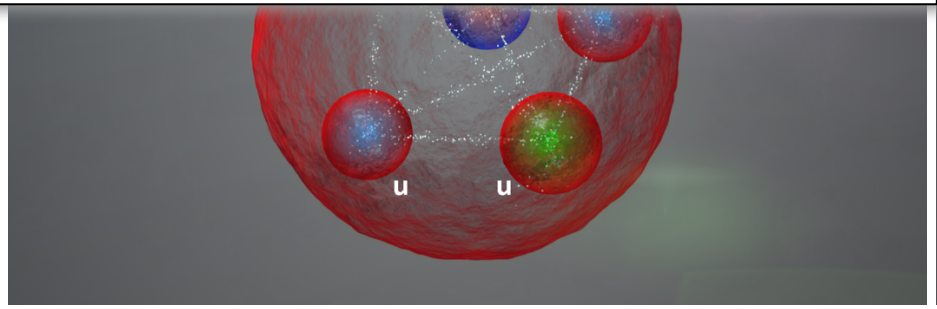
K^0/K^* anomaly

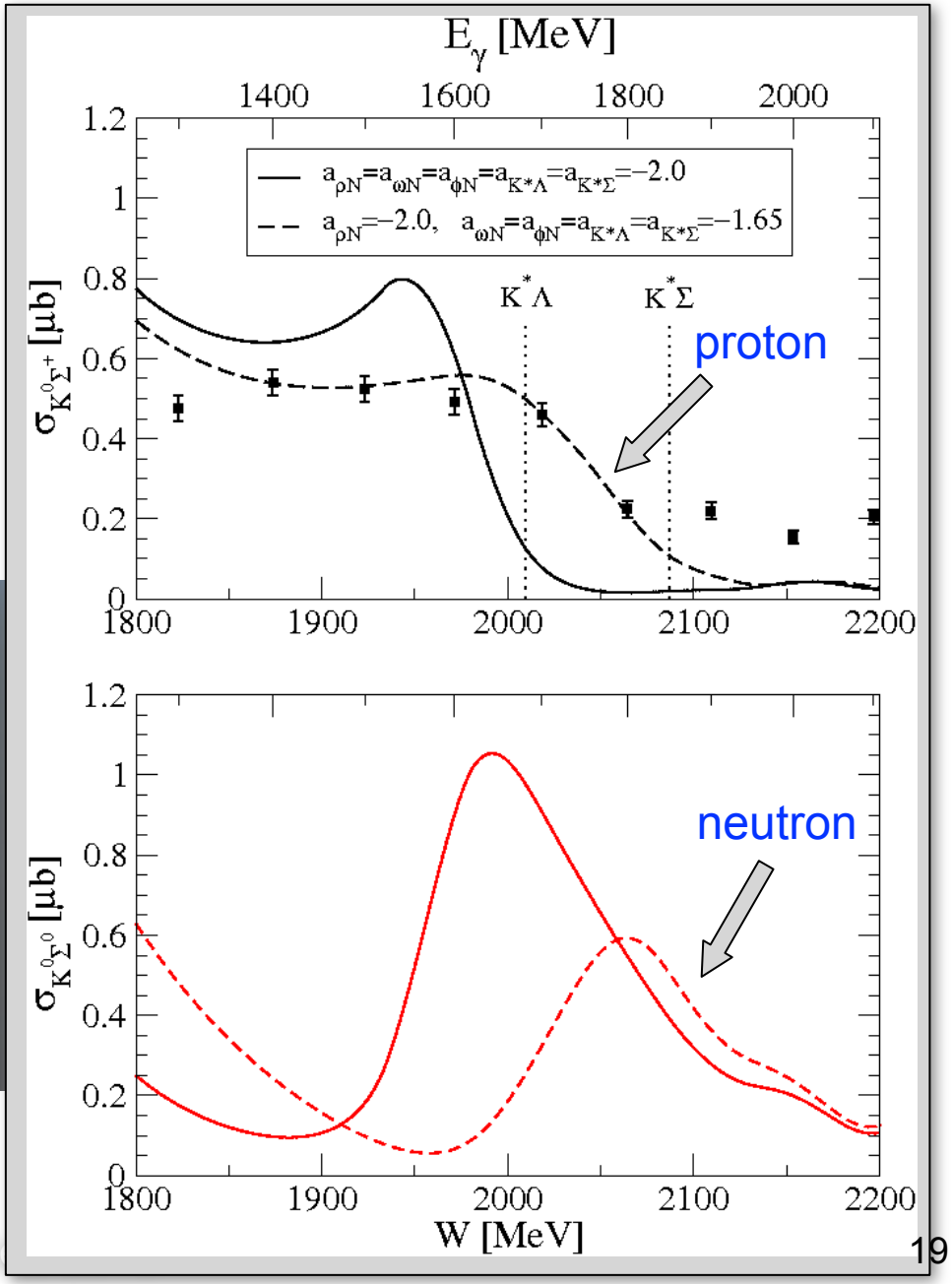
vectormeson – baryon "pentaquark" ??

hidden-strange

A. Ramos & E. Oset,
Phys. Lett. B727 (2013) 287

- vectormeson-baryon dynamics
- structure ↔ N*(2080)(3/2⁻) / N*(2090)(1/2⁻)
  [earlier removed from PDG]
- → $K^0\,\Sigma^0$ off neutron target to test

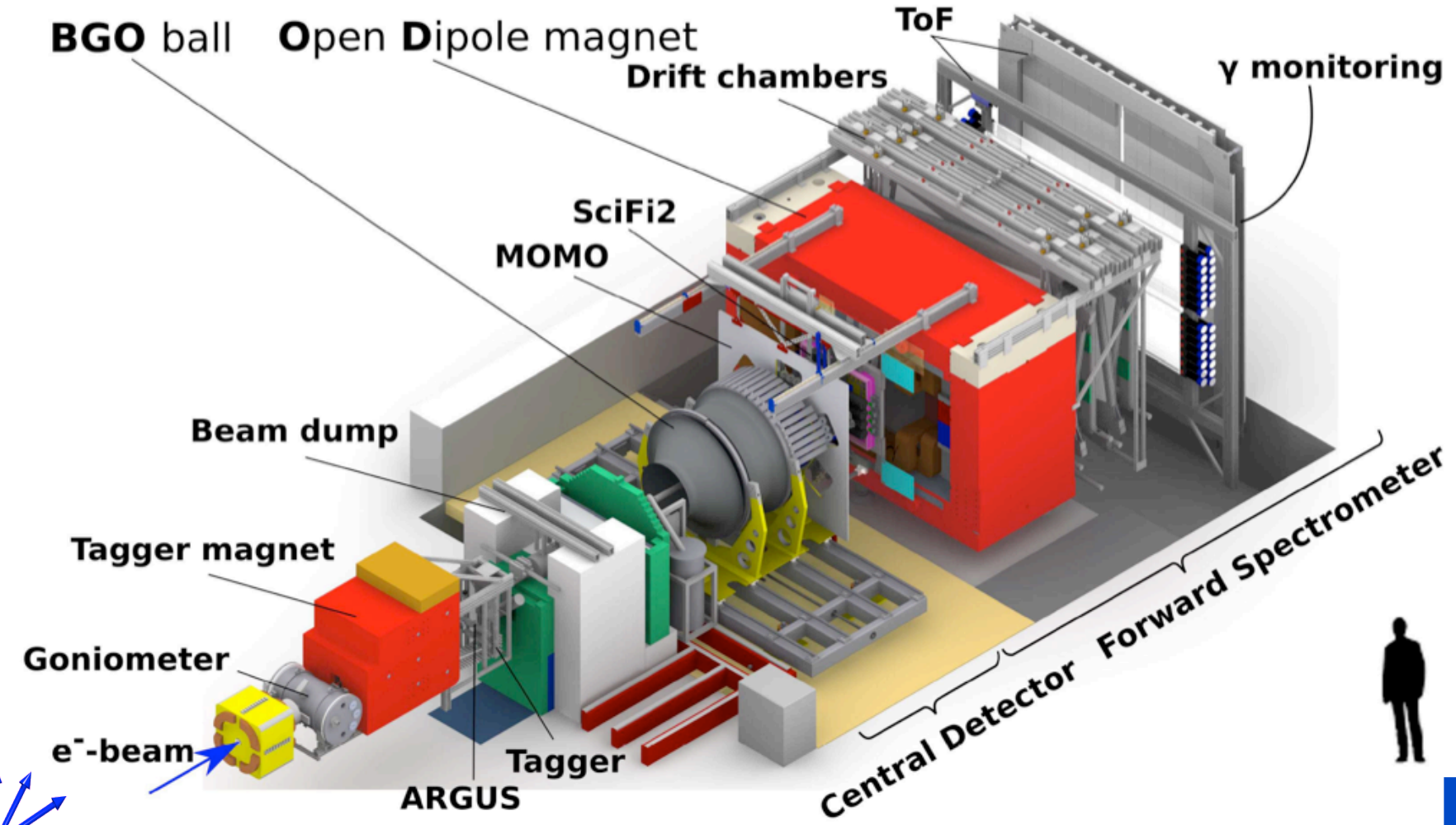




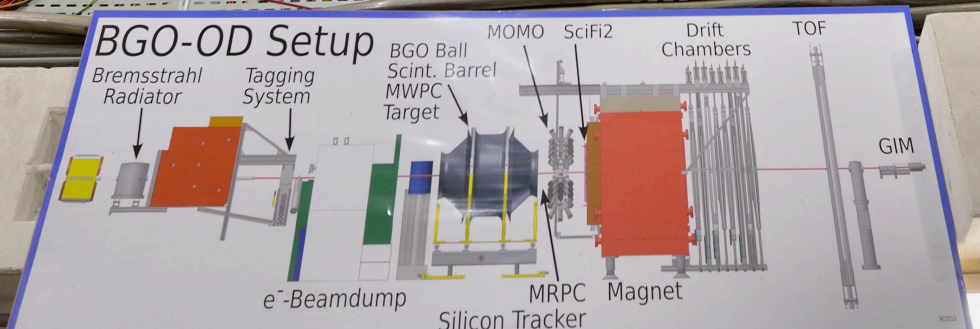
BGO-OD experiment

spokespersons: P. Levi Sandri (Frascati) & H.S. (Bonn)

- combination of BGO central calorimeter & forward spectrometer
- high momentum resolution, excellent neutral & charged particle id



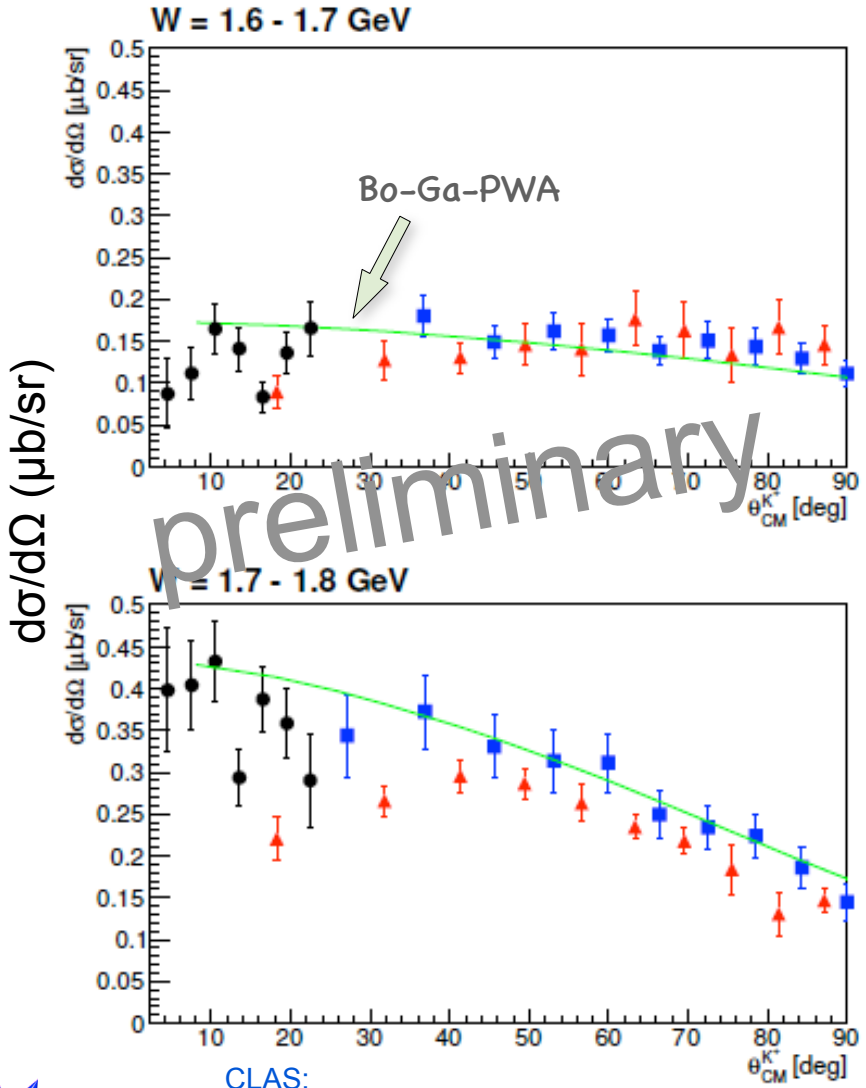
BGO-OD experiment at ELSA



BGO-OD experiment

first results: $K^+\Lambda$ @ extreme forw. angles

work of Th. Zimmermann & T. Jude

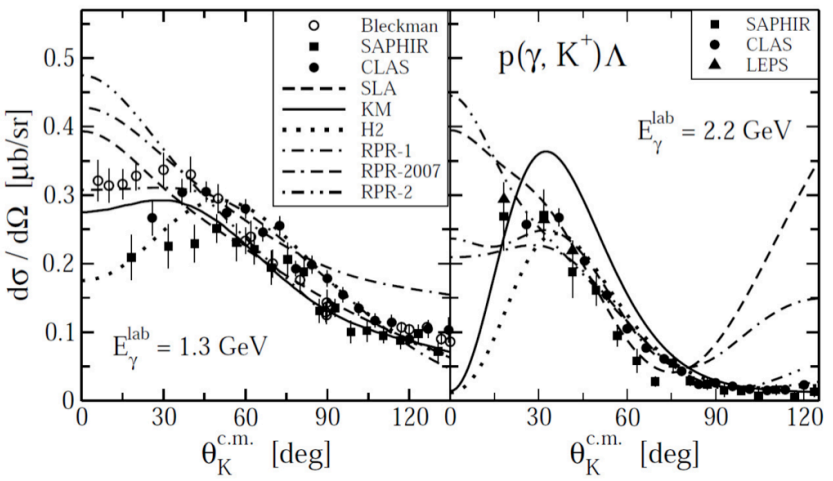


$d\sigma/d\Omega$ (μb/sr)

$\theta_{K^+}^{cm}$ (deg.)

CLAS:
M.E. McCracken 2010
PRC 81

SAPHIR:
K.H. Glander 2004
EPJA 19



Bydzovsky and Skoupil, arXiv:1211.2684
Proceedings SNP12

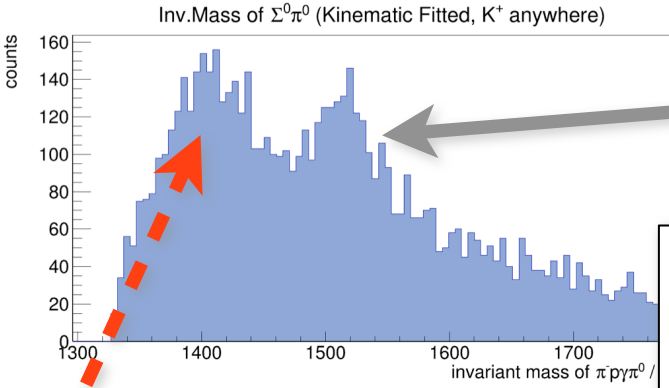
→ important constraint for hypernuclei production

- 11 days of data (more available)
- K^+ in forward spectrometer
- π^0 from Λ decay in BGO
- x4 statistics w/o π^0 requirement
- absolute flux

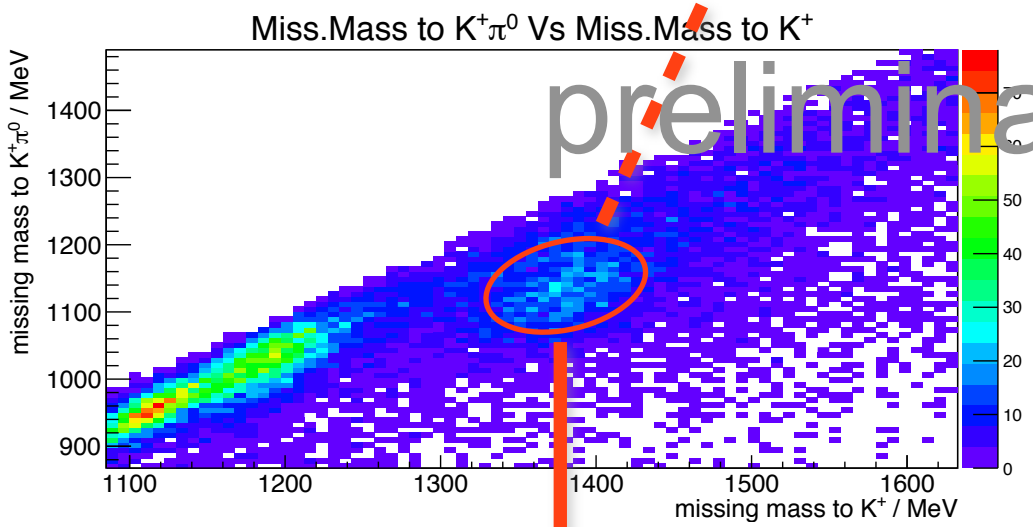
BGO-OD experiment

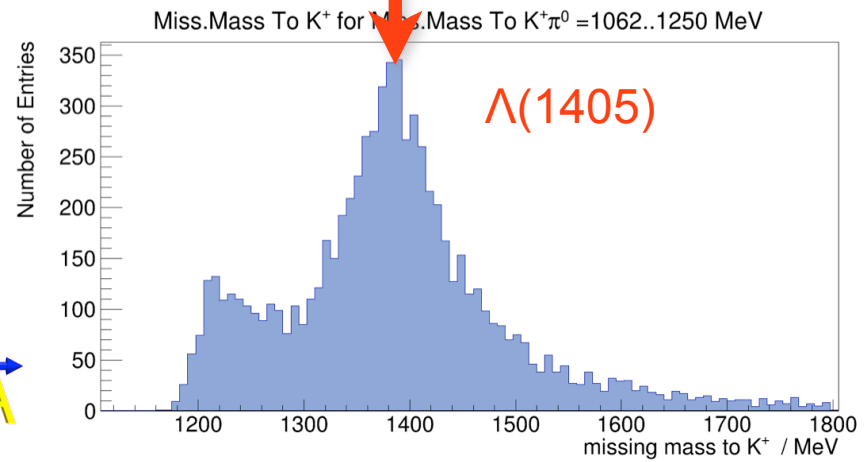
first results: $K^+\Lambda(1405)$

work of G. Scheluchin



$\Lambda(1520) \rightarrow \Sigma\pi$ [42%]
$\Lambda\pi\pi$ [10%]





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

$(\pi\Sigma)^0$

isospin forbidden for $\Sigma(1385)$

$\pi^0 \Sigma^0(1192)$

$\Lambda(1116) + \gamma$

$\pi^- p$

- production at small t
- inaccessible to previous expts

ELSA

universitätbonn

FTD Research & Technology Centre Detector Physics

Research

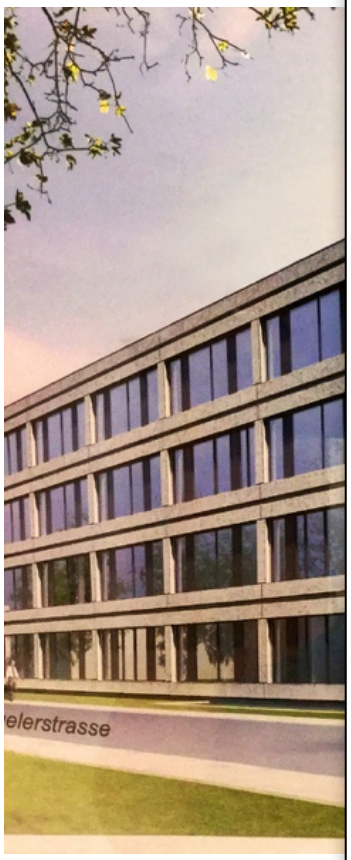
- semi-conductor pixel detectors
- gas-filled detectors
- photo sensors
- ASIC electronics
- detector characterisation at accelerator

Infrastructure

- laboratories including (2010 m^2)
  - 4 clean rooms (ISO 6/5)
  - 10 optics labs
  - assembly hangar w/ crane
- special instrumentation for
  - micro-structuring
  - interconnection
- offices & seminar room (880 m^2)

→ **2018** start of operation

ELSA



foundation stone ceremony 2. Nov. 2016

with, inter alia:
Research Minister Svenja Schulze, Lord Mayor Ashok Sridharan, Rector Michael Hoch

el detectors

ation at

g (2010 m²)
D 6/5)

w/ crane
tion for

om (880 m²)

Summary

- successful SFB/TR-16, after 12 years finished 30/6/2016
- significant new results on nucleon excitation spectrum
- ongoing experiments
  - Crystal-Barrel/TAPS w/ polarised target (CB upgraded w/ APD readout)
  - BGO-OD w/ forward spectrometer & BGO calorimeter (newly commissioned)
- detector test area
- coming:
  Research and Technology Centre Detector Physics FTD

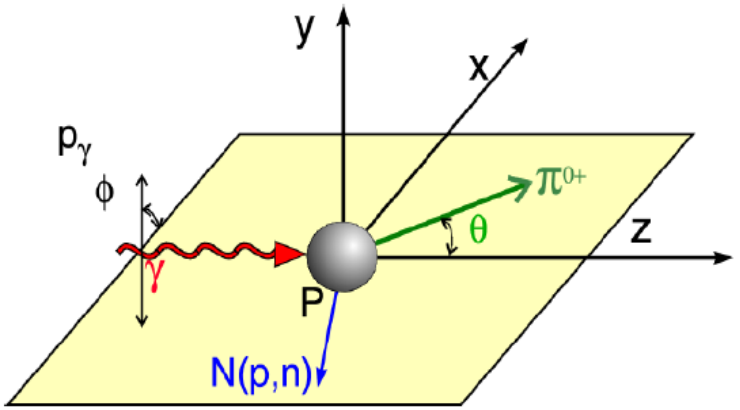
Backup

Beam-Target Polarization Observables

photoproduction of pseudoscalar mesons with polarized beam and target :

- all three single polarization observables Σ, P , T and cross section σ
- 4 double polarization observables G , E , F and H

can be measured



photon pol.		target pol. axis		
		x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

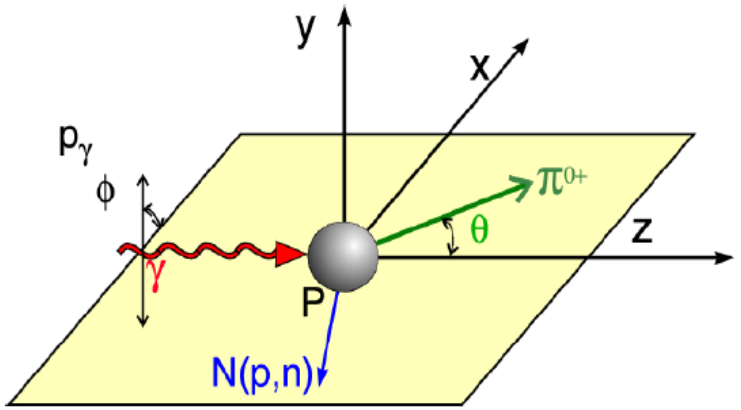
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta,\phi) = \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta) \cdot \Big[1 - P_\gamma^{\mathrm{lin}}\,\Sigma(\theta)\cos(2\phi)$$
$$+P_x \cdot \left(-P_\gamma^{\mathrm{lin}}\,H(\theta)\,\sin(2\phi) + P_\gamma^{\mathrm{circ}}\,F(\theta)\right)$$
$$+P_y \cdot \left(+P_\gamma^{\mathrm{lin}}\,P(\theta)\,\cos(2\phi) - T(\theta)\right)$$
$$-P_z \cdot \left(-P_\gamma^{\mathrm{lin}}\,G(\theta)\,\sin(2\phi) + P_\gamma^{\mathrm{circ}}\,E(\theta)\right)\Big]$$

Beam-Target Polarization Observables

photoproduction of pseudoscalar mesons with polarized beam and target :

- all three single polarization observables Σ, P , T and cross section σ
- 4 double polarization observables G , E , F and H

can be measured



photon pol.		target pol. axis		
		x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \Big[1 - P_\gamma^{lin}\,\Sigma(\theta)\cos(2\phi) + P_\gamma^{lin}\,T(\theta)\sin(2\phi) + P_\gamma^{circ}\,F(\theta)\Big)$$

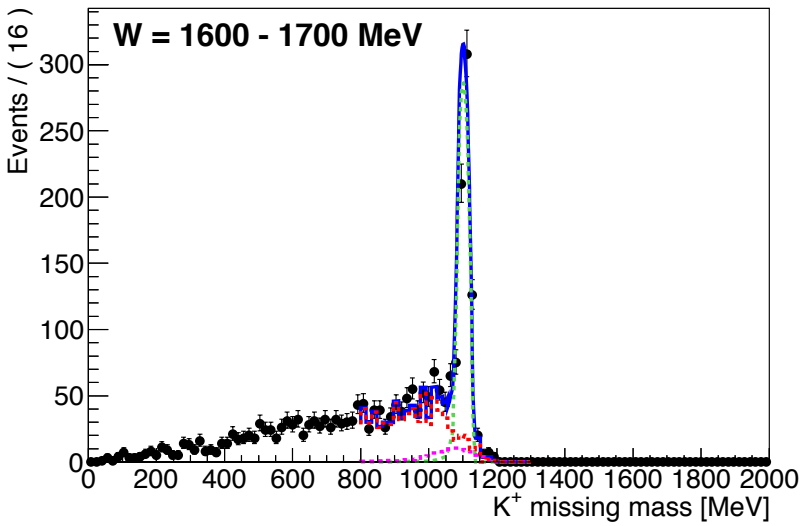
ELSA- Experiments:

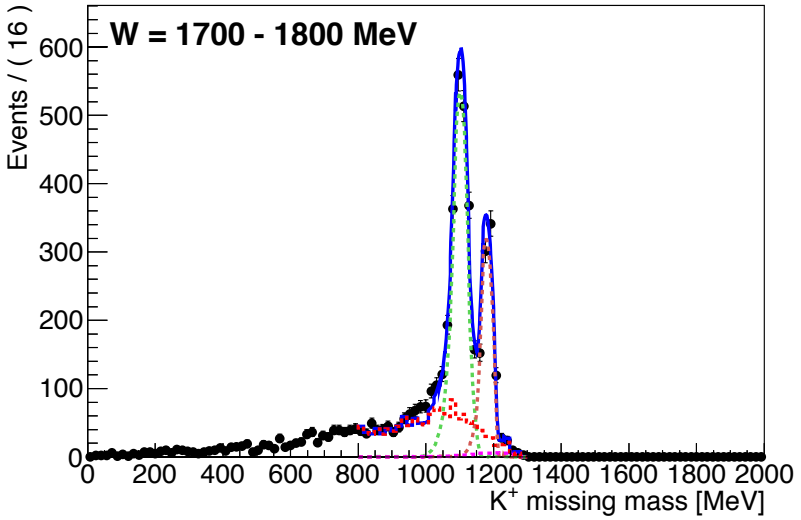
Data on all three single pol. observables Σ, P , T and diff. cross section σ

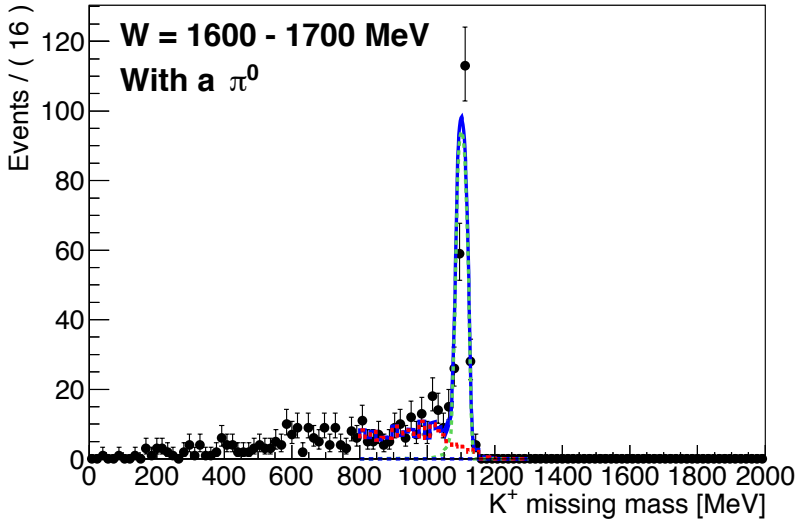
and on four double polarization observables G , E and H and (F)

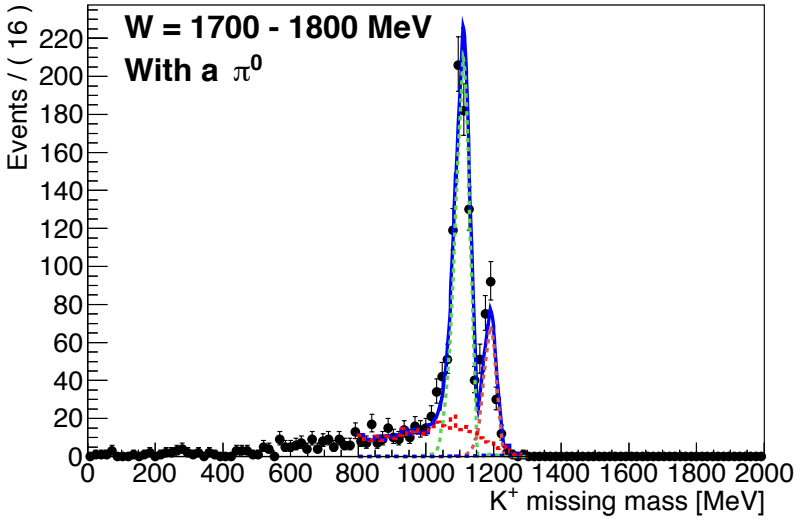
for $\vec{\gamma}\ \vec{p} \to p\pi^0$ and $p\eta$, $p\eta'$, $p\omega$, $p\pi^0\pi^0$, $p\pi^0\eta$, $K^0\Sigma^+$, ...

BGO-OD event reconstruction $K^+\Lambda$ channel

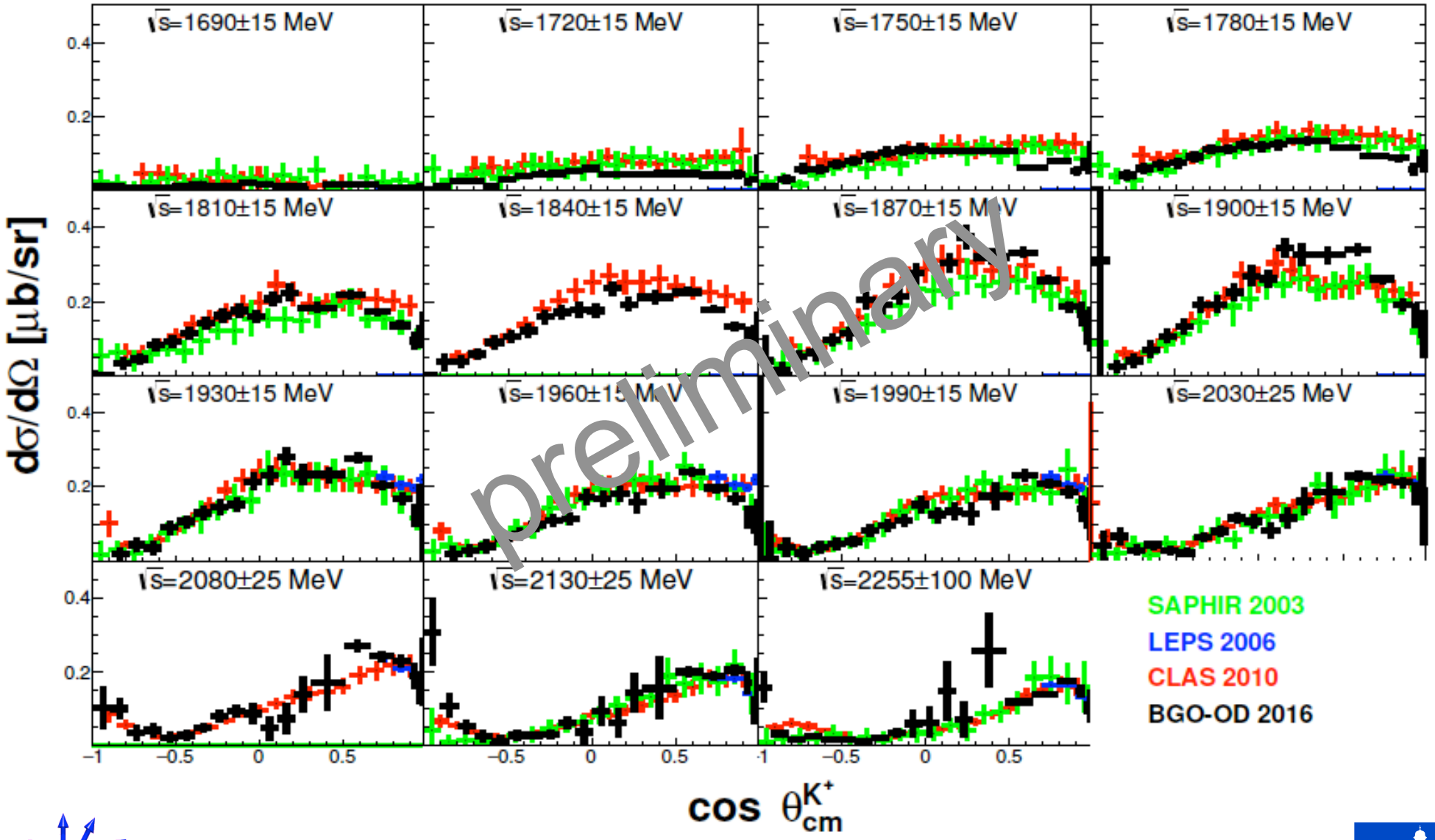








BGO-OD cross section $K^+\Sigma^0_{g.s.}$ channel



γp -> ωp PWA (Bonn-Gatchina)

I. Denisenko et al.,
Phys. Lett B755 (2016) 97

Resonance	B.R.	$\delta(\chi^2)$	Resonance	B.R.	$\delta(\chi^2)$
$N(1700)3/2^-$	22 ± 12	100	$N(1900)3/2^+$	15 ± 8	70
				13 ± 9	
$N(1710)1/2^+$	2 ± 2	26	$N(2000)5/2^+$	18 ± 8	42
	8 ± 5			1 ± 1	
$N(1720)3/2^+$	26 ± 14	105	$N(2060)5/2^-$	4 ± 3	37
$N(1875)3/2^-$	13 ± 7	98	$N(2100)1/2^+$	15 ± 10	78
	20 ± 4				
$N(1880)1/2^+$	20 ± 8	33	$N(2150)3/2^-$	12 ± 8	99
$N(1895)1/2^-$	28 ± 12	100	$N(2190)7/2^-$	14 ± 6	131

dominant CLAS PWA

suggestive CLAS PWA

GRAAL

Penner & Mosel, PR C 66

A2: new in PDG

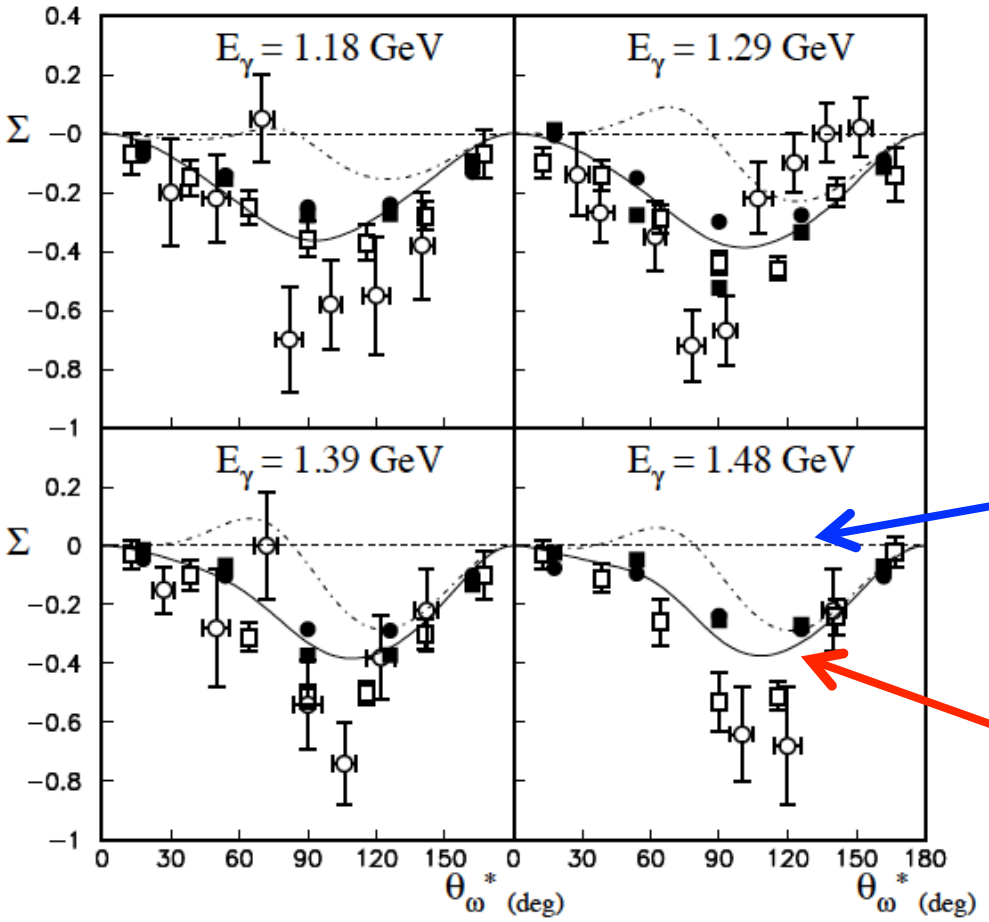
strong CLAS PWA

+ 1 new resonance > 2 GeV

dominant CLAS PWA

$N(1680)5/2^+$ — 128

γp -> ωp beam asymmetry



data

Frank Klein et al. (CBELSA)
Phys. Rev. D 78 (2008) 117101

V. Vegna et al. (GRAAL)
Phys. Rev. C 91 (2015) 065207

model

Q. Zhao et al.,
Phys. Rev. C 58 & 63

no resonances

s-channel resonances

confirms resonance contributions near threshold

Completeness in γp -> ωp

- spin-1 meson ⟹ 3 polarization states
- ⟹ determine **24 amplitudes – 1 phase**
- but: more information accessible than in pseudoscalar meson production
- ⟹ **decay angular distributions**

polarized

$$
\begin{aligned}
W^L(\Omega_d, \Phi_{pol}, \rho) &= W^0(\Omega_d, \rho) \\
&\quad + \frac{3}{8\pi} P_\gamma [\cos\Phi_{pol} W_1(\Omega_d, \rho) \\
&\quad + \sin\Phi_{pol} W_2(\Omega_d, \rho)] \\
W_1(\Omega_d, \rho) &= \sin^2\theta_d \rho^1_{00} \\
&\quad + (1+\cos^2\theta_d)\rho^1_{11} \\
&\quad + \sin^2\theta_d \cos 2\phi_d \rho^1_{1-1} \\
&\quad + \sqrt{2}\sin 2\theta_d \cos\phi_d \mathrm{Re}\rho^1_{10} \\
W_2(\Omega_d, \rho) &= \sin^2\theta_d \sin 2\phi_d \mathrm{Im}\rho^2_{1-1} \\
&\quad + \sqrt{2}\sin 2\theta_d \sin\phi_d \mathrm{Im}\rho^2_{10}
\end{aligned}
$$

unpolarized

$$
\begin{aligned}
W^0(\theta_d, \phi_d, \rho^0) &= \frac{3}{8\pi}\{\sin^2\theta_d \rho^0_{00} \\
&\quad + \frac{1}{2}(1+\cos^2\theta_d)(1-\rho^0_{00}) \\
&\quad + \sin^2\theta_d \cos 2\phi_d \rho^0_{1-1} \\
&\quad + \sqrt{2}\sin 2\theta_d \cos\phi_d \mathrm{Re}\rho^0_{10}\}
\end{aligned}
$$

⟹ $\Sigma_\omega = \rho^1_{00} + 2\rho^1_{11}$ beam asymm.

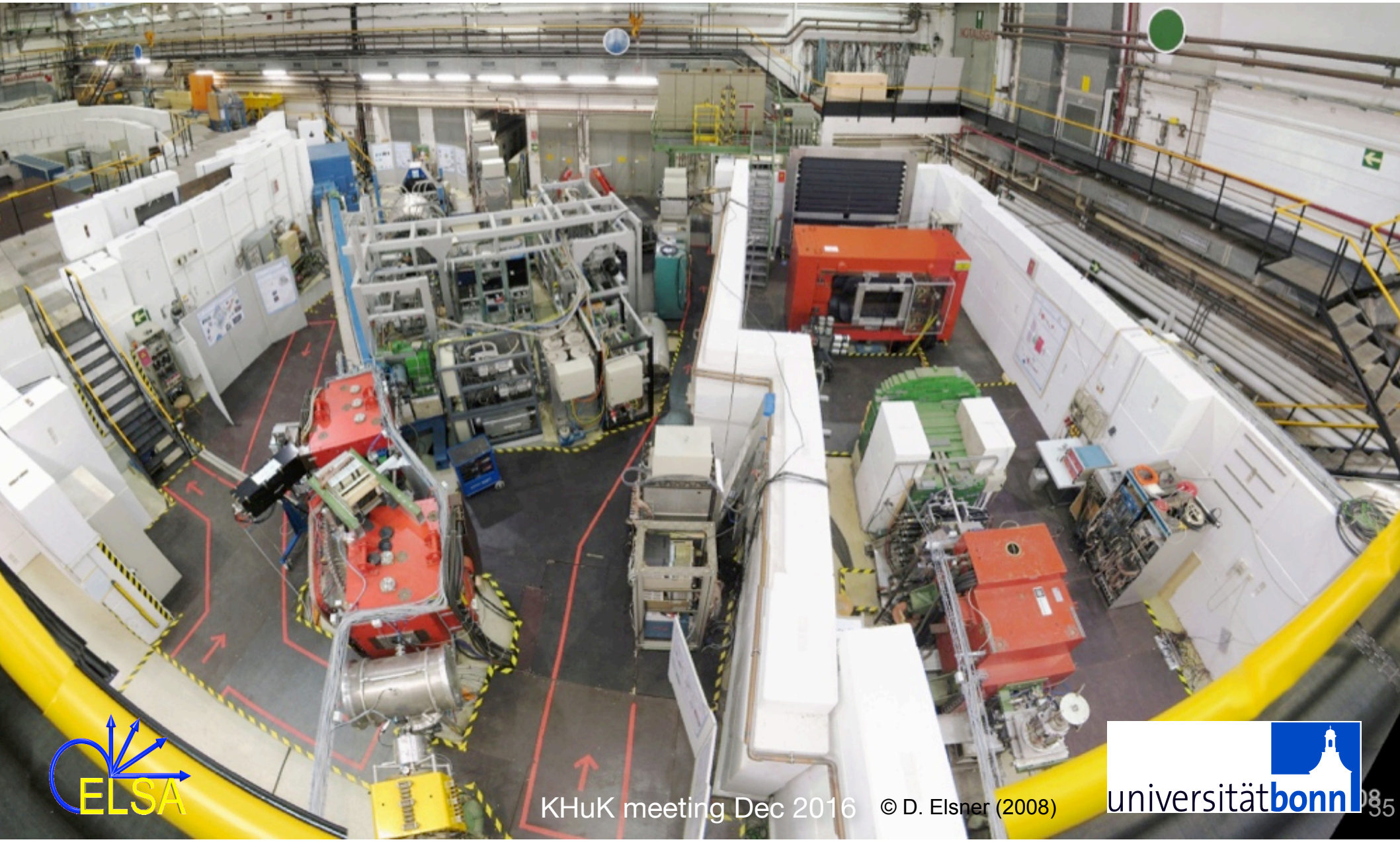
⟹ G, $G_{bachelor}$ linpol. beam-target asymm.

E beam-target helicity asymm.

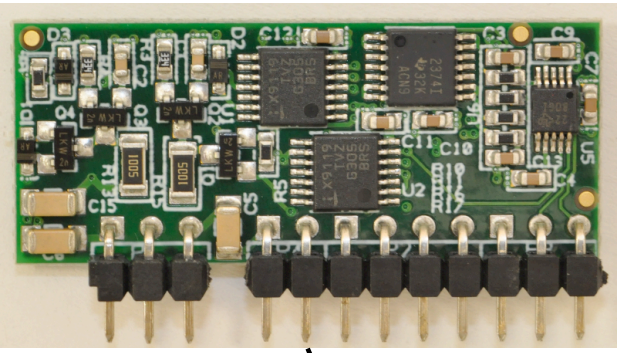
ELSA experimental areas HP

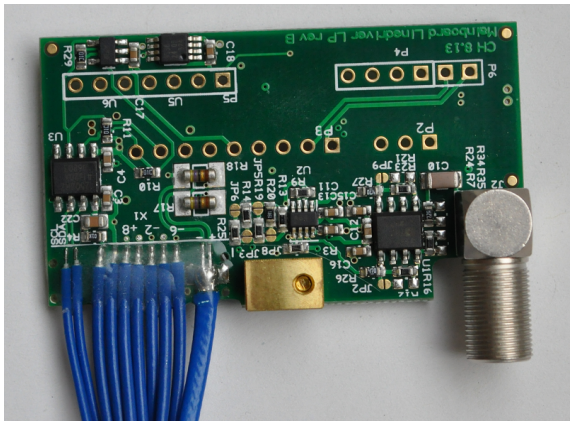
Crystal-Barrel / TAPS

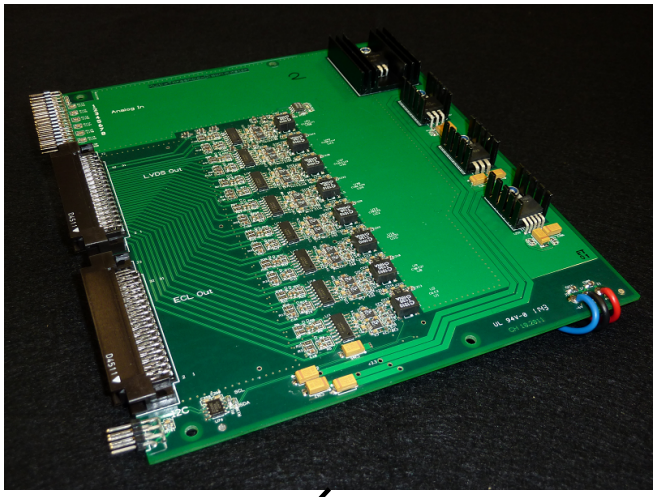
BGO-OD



New Readout for the CB-Calorimeter







High Voltage

Line Driver

Signalfilter

QDC

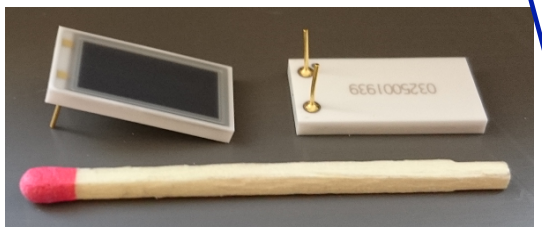
Signalfilter

Discriminator

Coincidence

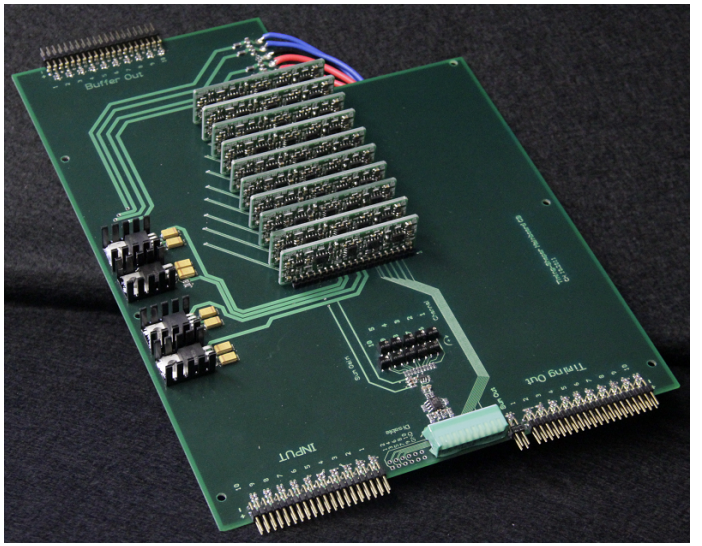
TDC

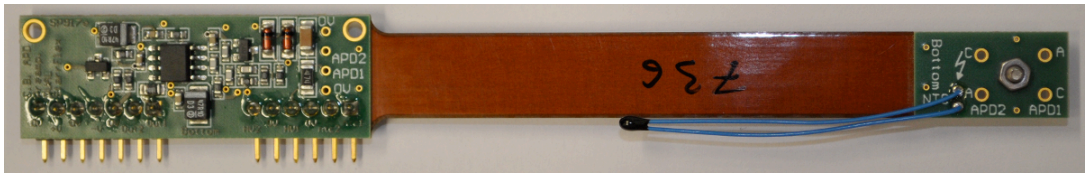
APD



[S11048: Hamamatsu Photonics]

Preamp

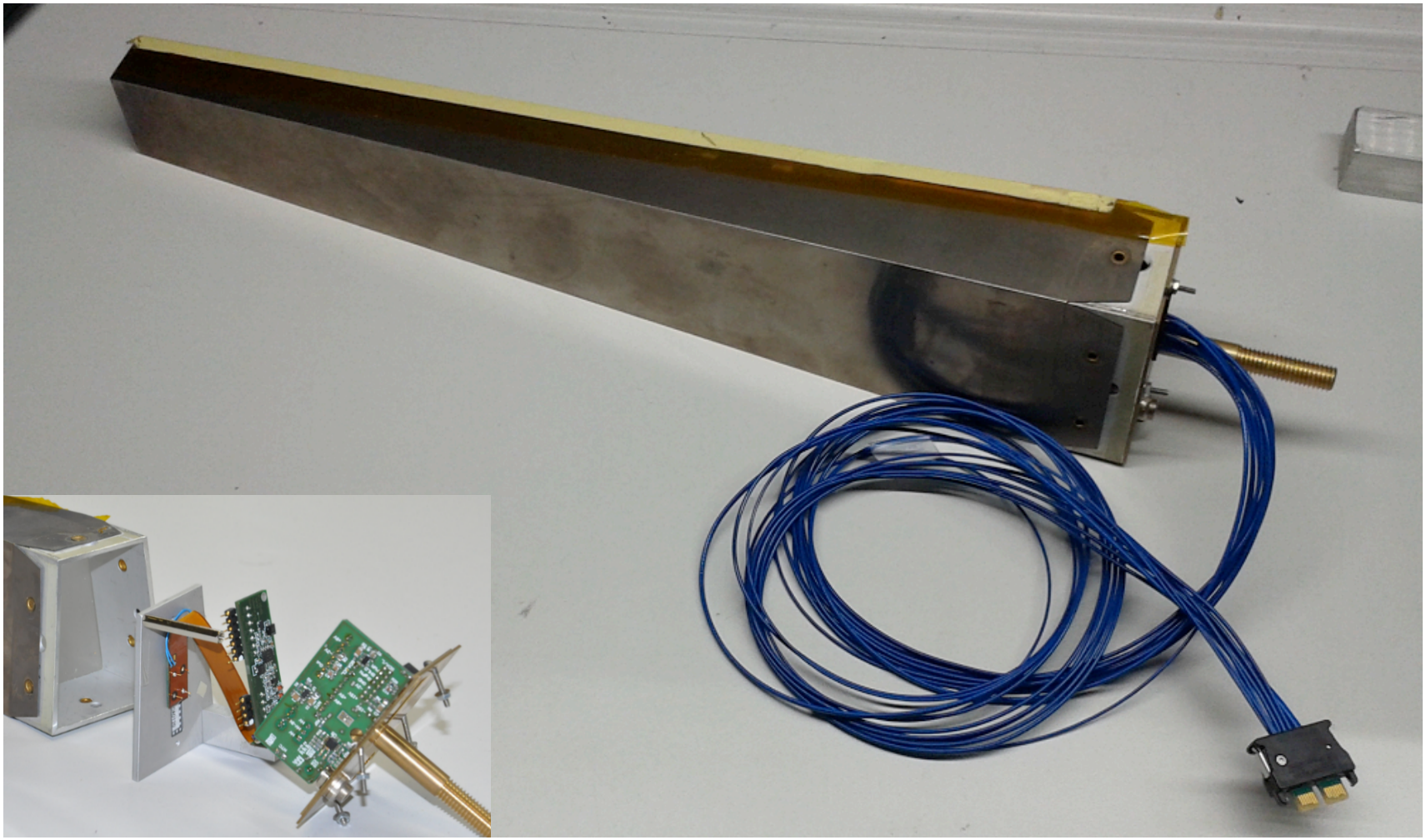




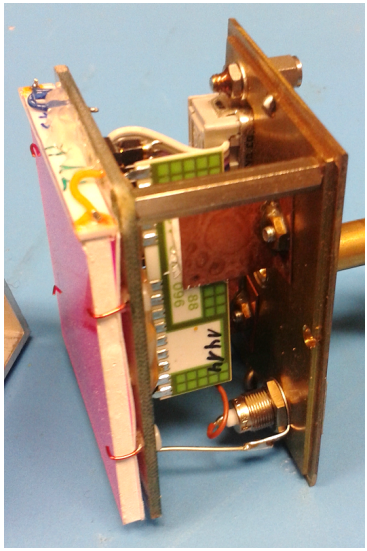
[M. Steinacher, Uni Basel]

Status Crystal Barrel Upgrade

- All1320 crystals upgraded



Old Frontend:



universitätbonn

Upgraded Upstream Half