

## Эксперимент VGO-OD (Бонн)

«Спектроскопия барионов и мезонов»  
Бонн, VGO-OD



## **B1-коллаборация на ускорителе ELSA (Бонн), 2006 – н.в.**

*University of Bonn, Physikalisches Institut, Germany*

University of Bonn, Helmholtz Institut für Strahlen- und Kernphysik, Germany

**Petersburg Nuclear Physics Institute, Gatchina, Russia**

INFN sezione Roma “Tor Vergata”, Italy

University of Roma Tor Vergata and INFN sezione Roma “Tor Vergata”, Italy

Istituto Superiore di Sanit`a and INFN sezione Roma1, Italy

INFN Laboratori Nazionali di Frascati, Italy

INFN sezione Pavia, Italy

University of Messina and INFN sezione Catania, Italy

University of Torino, Italy

University of Edinburgh, UK

National Science Center Kharkov Institution of Physics & Technnology, Ukraine

University of Moscow, Russia

University of Basel, Switzerland

**Участники от ПИЯФ**

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В.В. Сумачев, Е.А. Филимонов

В.С. Козлов, Г. Макаренков, В.В. Голубев, В.И. Тараканов

В.Л. Головцов, Л.Н. Уваров, В.И. Яцюра, Э.М. Спириденков, Н.Ф. Бондарь

Производство и настройка 9 дрейфовых камер

*(8+прототип), CROS-3*

*Расчет, дизайн и установка защитной системы от м.п. магнитного  
диполя для входного детектора (Sci-Fi2) форвардного  
спектрометра*

*Изготовление счетчиков и световодов для системы мечения  
фотонов (~ 50%)*

- Проблема недостающих резонансов
- Барионная спектроскопия (массы, ширины, моды распада)
  - ❖ Измерение сечений ( $\sigma$ ,  $d\sigma/d\Omega$ )
  - ❖ Измерение поляризационных наблюдаемых (pol.  $P_{\text{em}} + H_2, D_2$ )
  - ❖ Измерение двойных поляризационных наблюдаемых
  - ❖ Изучение «узких структур»

Baryon multiplets: octet, dekaplet, 56-plet, 70-plet...

In total hundreds of resonances composed of u, d, and s quarks.

**PDG 1998:** Total number of well established in experiment resonances is 49 (the so-called problem of missing resonances).

→ **Need for more experimental data?**

## Photon factories

- **GRAAL (Grenoble) (1996 -2007)**
- **CLAS/HallB@Jlab (1996 --~2014)**
- **CBELSA/TAPS (Bonn) (~1999 -)**
- **A2@MaMiC (Mainz) ( ~2009 -)**
- **BGO-OD (Bonn) (~2017 -)**
- **LEPS (Tohoku) (~2000 --~2010)**

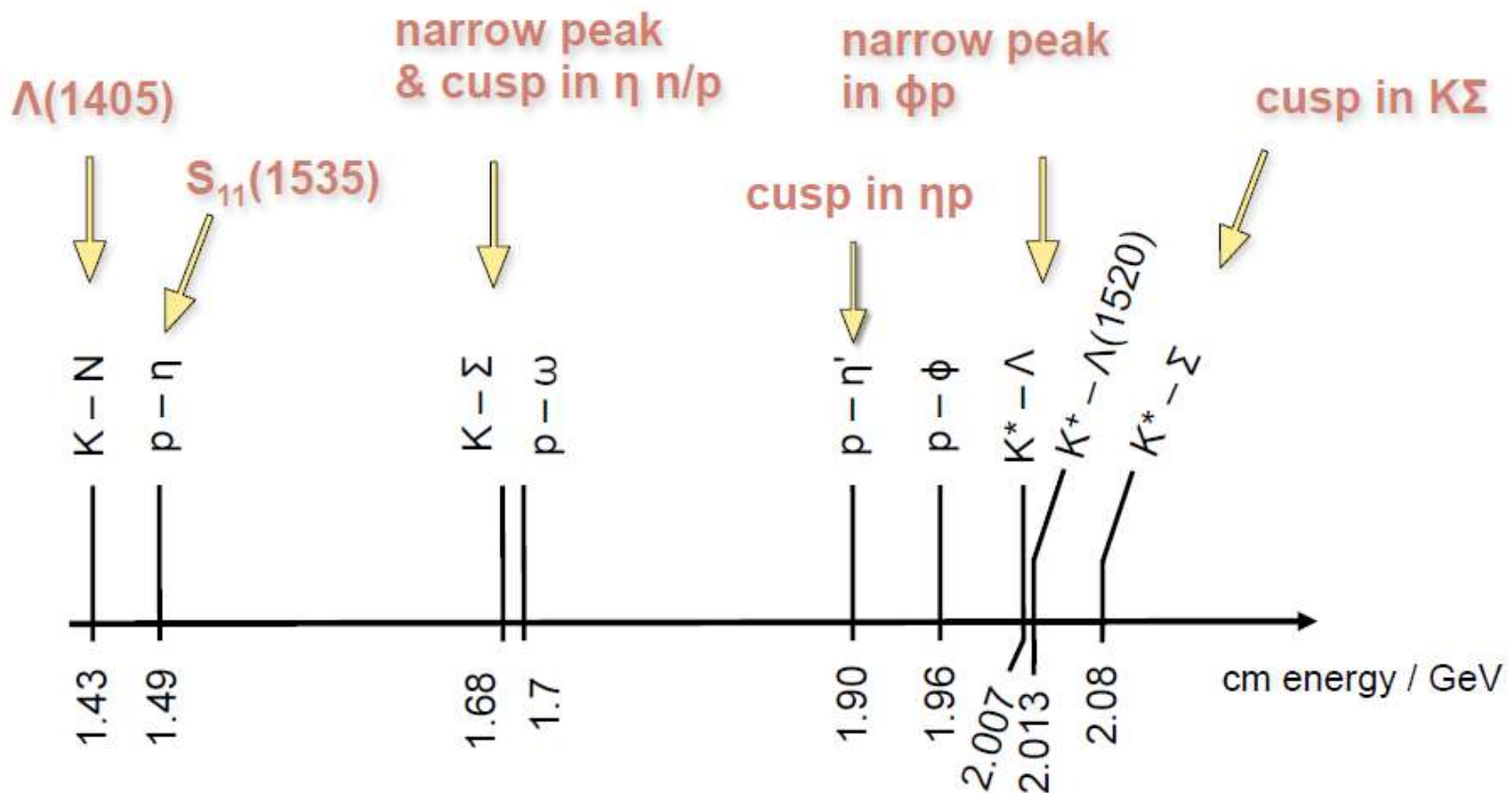
## The partial wave analysis groups

- **SAID (GWU,USA)**
- **MAID (Mainz)**
- **Bonn-Gatchina**
- **Juelich group**
- **ANL-OSAKA**
- **M. Manley (Kent Uni)**

# Physics program, $E_\gamma = 0,53 \div 2,85$ GeV

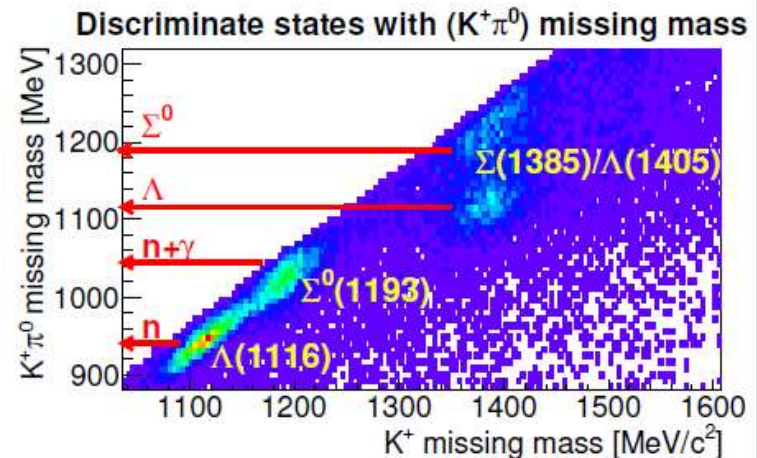
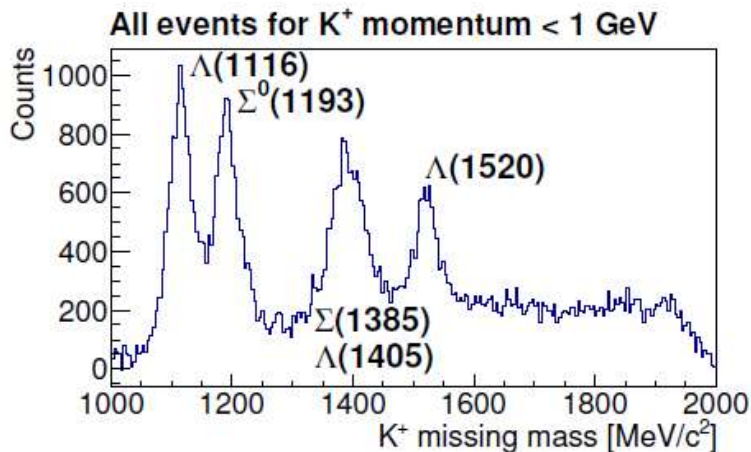
Изучение пороговых аномалий, мод распада, «молекулярных структур» и т.д.

Изучение рождения странных частиц



# Experimental data (Strangeness photoproduction)

$$d\sigma/d\Omega: \gamma + p \rightarrow K^+ + \Lambda$$



## Identify $Y^*$ states from $K^+\pi^0$ recoiling mass

- $K^+\Lambda \rightarrow K^+\pi^0 n$  (Missing neutron mass from  $K^+\pi^0$  system)
- $K^+\Lambda(1405) \rightarrow K^+\pi^0 \Sigma^0$  (Missing  $\Sigma^0$  mass from  $K^+\pi^0$  system)
- $K^+\Sigma(1385) \rightarrow K^+\pi^0 \Lambda$  (Missing  $\Lambda$  mass from  $K^+\pi^0$  system)

# Physics program, $E_\gamma = 0,53 \div 2,85$ GeV

Comparison Kuznetsov et al.  $\longleftrightarrow$  CBELSA/TAPS

+EPECUR

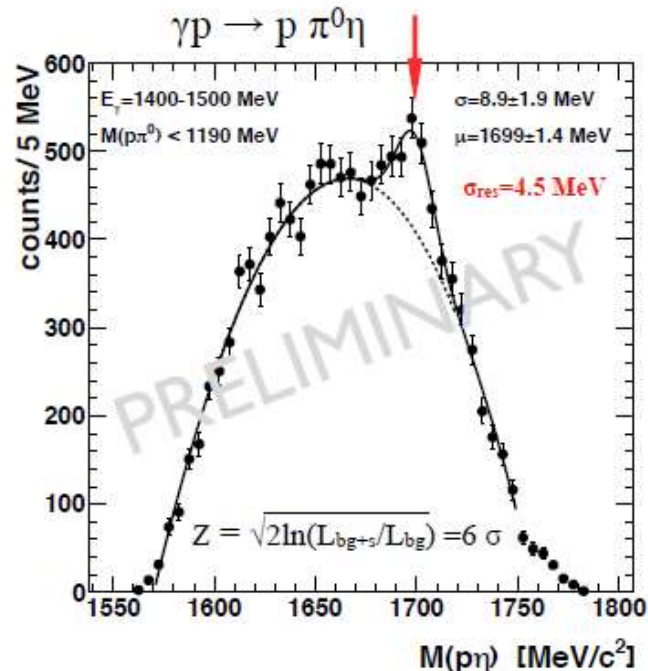
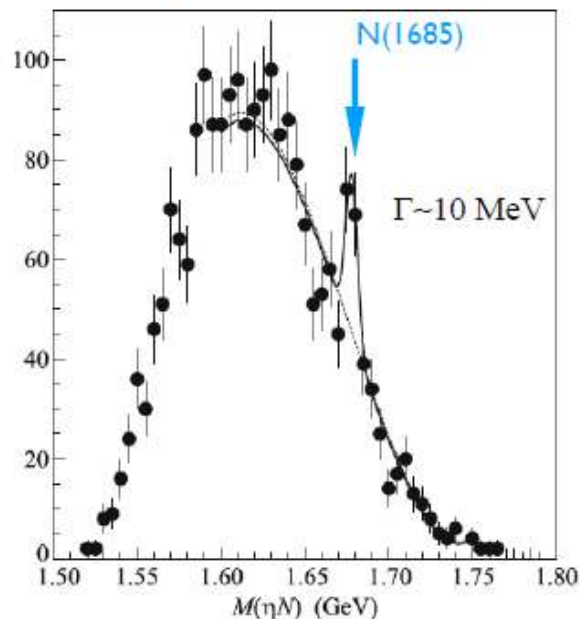
$E_\gamma = 1400 - 1500$  MeV

cut used by Kuznetsov:  $1120 \text{ MeV} \leq m_{p\pi} \leq 1220 \text{ MeV}$

to suppress  $\gamma p \rightarrow \Delta^* \rightarrow \eta \Delta(1232) \rightarrow p\pi\eta$

Kuznetsov et al., JETP 106 (2017) 693

$\gamma N \rightarrow \pi \eta N$  - sum of all channels



cut applied to CBELSA/TAPS data:  $m_{p\pi} \leq 1190$  MeV



# ELectron Stretcher Accelerator (ELSA)

„Elektronen Stretcher Anlage“

duty factor  $\leq 90\%$

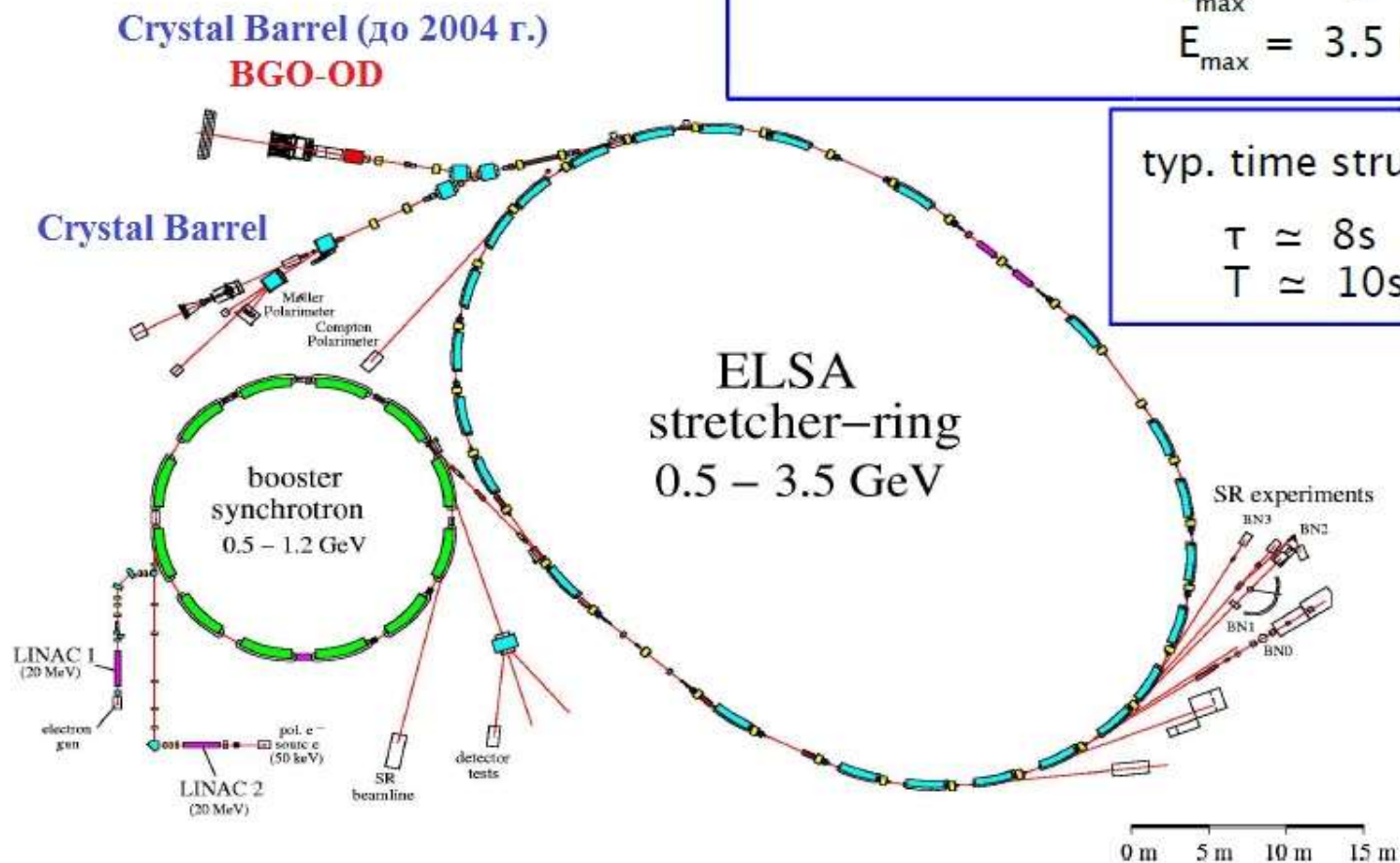
$I_{\max} \approx 3\text{ nA}$

$E_{\max} = 3.5\text{ GeV}$

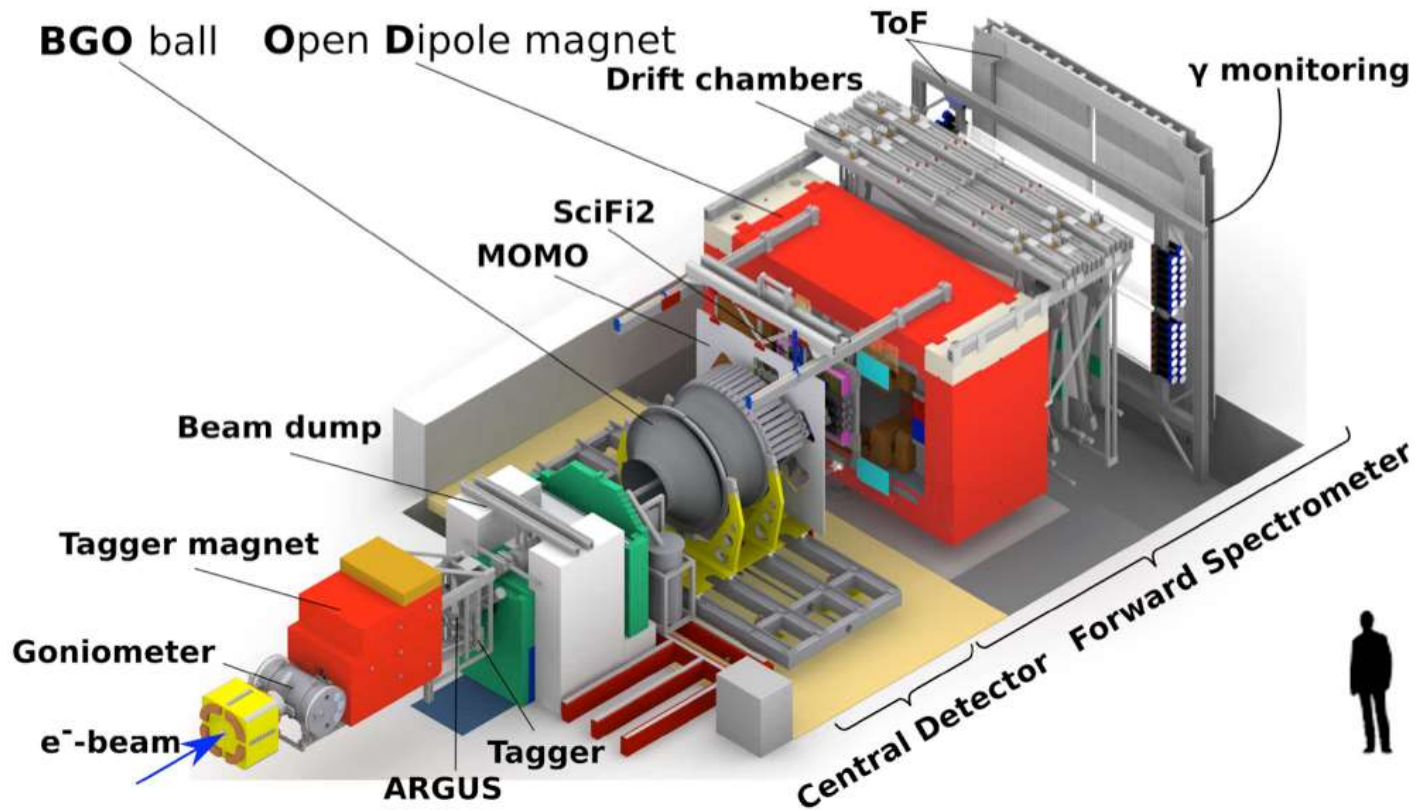
typ. time structure

$\tau \approx 8\text{ s}$

$T \approx 10\text{ s}$

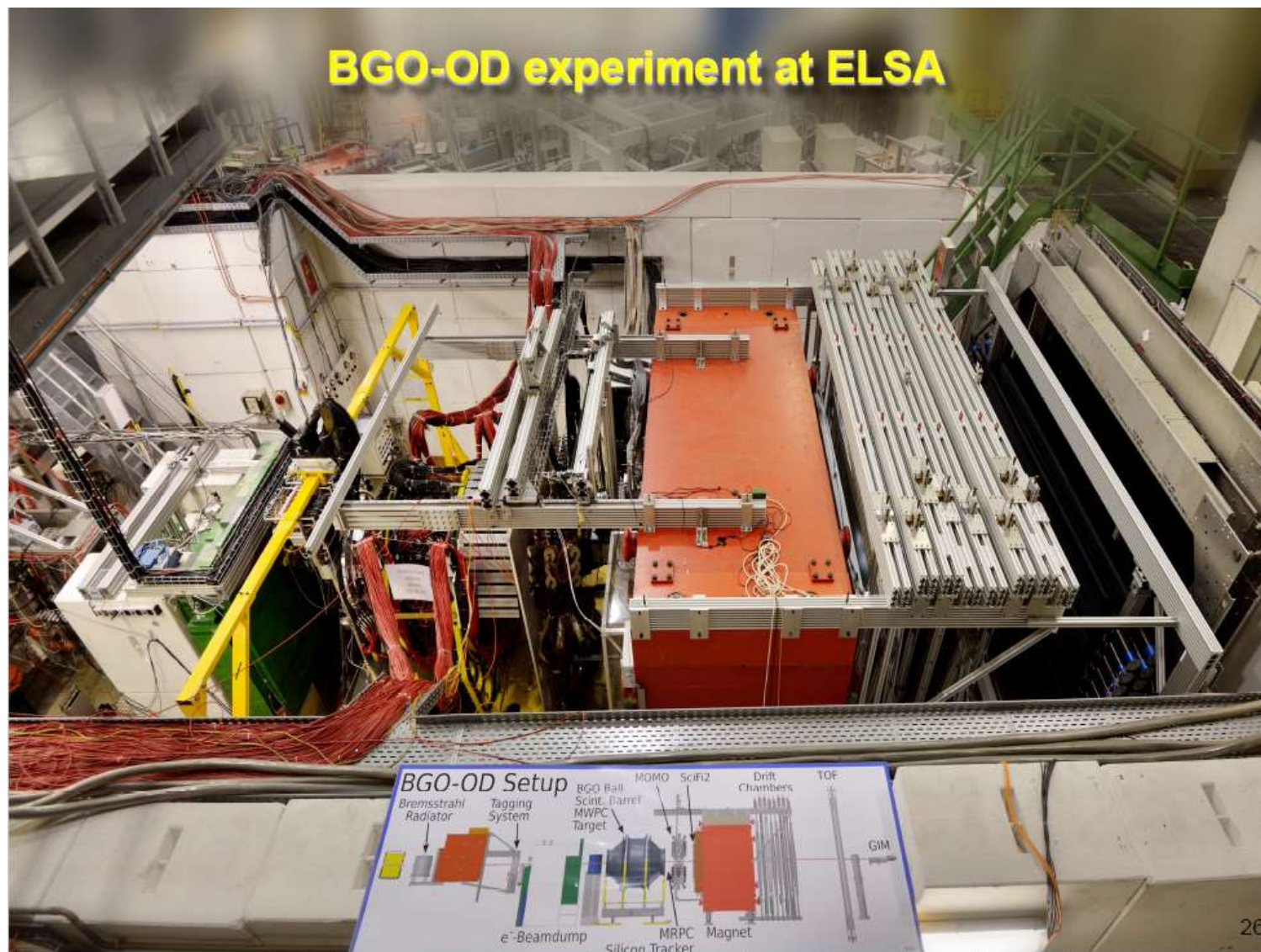


# BGO-OD Experimental setup



beam polarization up to 60%;  
High-resolution and high-efficiency detection of photons  
High-resolution measurement of the energy of final-state charged particles. TOF for neutrons.

# BGO-OD Experimental setup

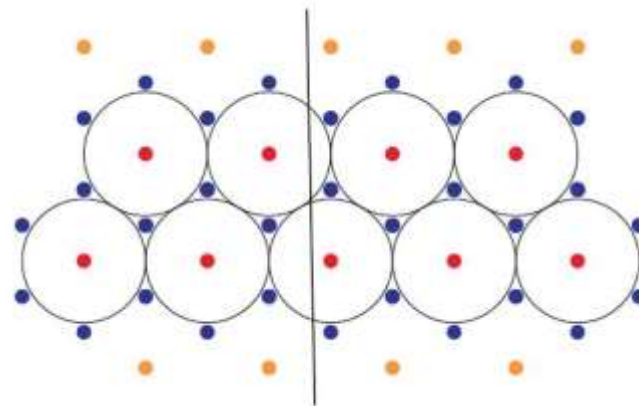


# Drift Chamber

- ✧ Точность позиции горизонтали 30 мкм
- ✧ Точность по вертикали 60 мкм
- ✧ Усредненная точность 32 мкм
- ✧ Размер рабочей области ~ 1,2\*2,4 м<sup>2</sup>

- ✧ Гексагональная структура ДК
- ✧ Радиус ячейки 10 мм
- ✧ Расстояние между сигнальными проволочками ~ 17 мм

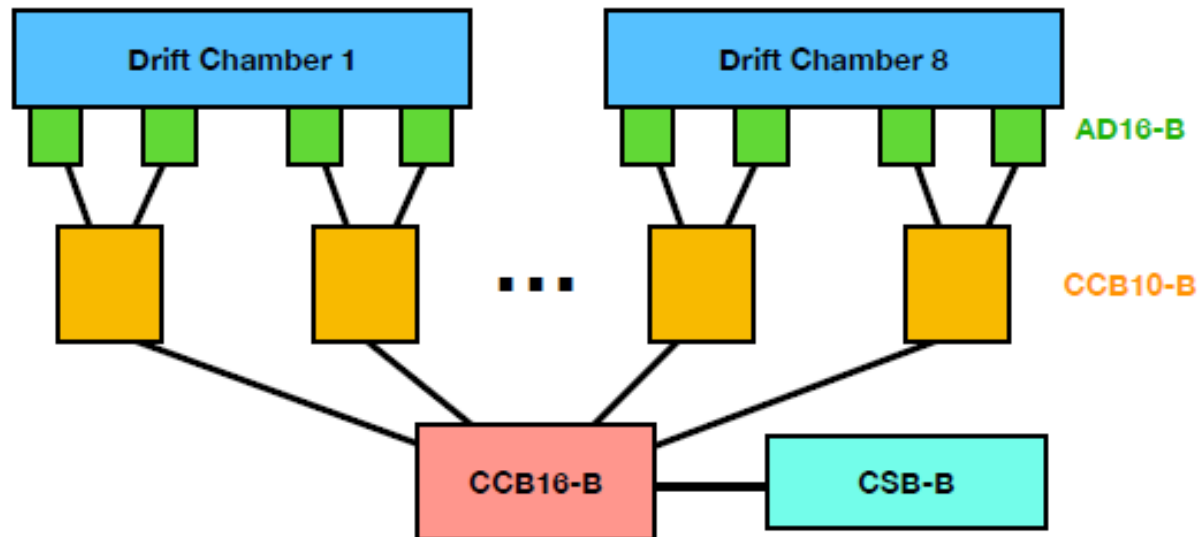
Разрешение ~ 0,2 мм  
(ИТЭФ, Бонн)



# CROS3-B for DC

The Coordinate Readout System (CROS3-DC) consists of the following boards:

- ✓ AD16-B – a 16-channel Amplifier/ Discriminator – Front-End;
- ✓ CCB10 – a 10-channel Concentrator;
- ✓ CCB16 – a 16-channel Concentrator;
- ✓ CSB – a System Buffer PCI-Interface.



# Physics program, $E_\gamma = 0,53 \div 2,85$ GeV

**B. Bantes et al. The BGO-OD Experiment at ELSA.  
Int. J. Mod. Phys. Conf. Ser. 26 (2014) 1460093-1**

## experimental program

$\eta$	p, d	lin. pol./unpol.	3.2 GeV	5000 h
$\eta'$	p	lin. pol.	3.2 GeV	1000h
$\omega, \phi$	p, d	lin. pol./unpol.	3.2 GeV	3200 h
$K^+\Lambda, K^+\Sigma^0, K^0\Sigma^+$	p	lin. pol./unpol.	3.2 GeV	3000 h
$\eta'$ mesic nuclei	$^{12}\text{C}$	unpol.	3.2 GeV	1200 h

**2019**

**The BGO-OD experimental setup at ELSA e-Print: arXiv:1910.11939  
<http://inspirehep.net/record/1761554> <https://arxiv.org/abs/1910.11939>**

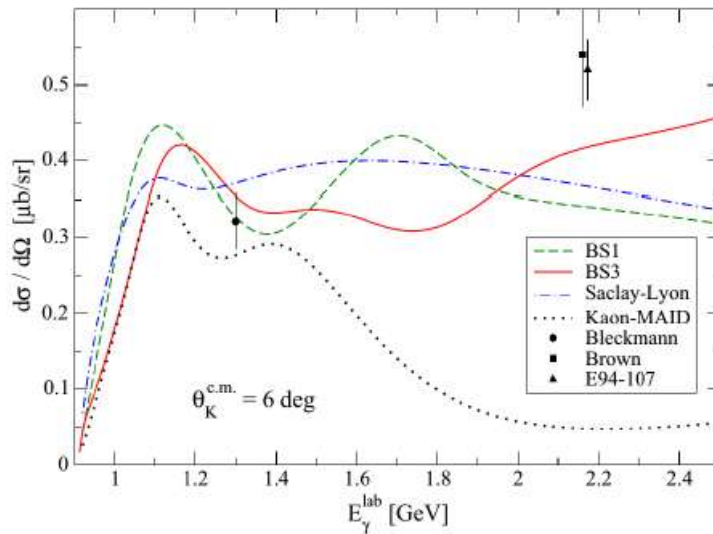
**Strangeness Photoproduction at the BGO-OD Experiment  
Phys.Part.Nucl. 50 (2019) no.5, 493-500  
(2019-09-04)**

**Aspects of baryon spectroscopy at ELSA EPJ Web Conf. 199 (2019) 01017**

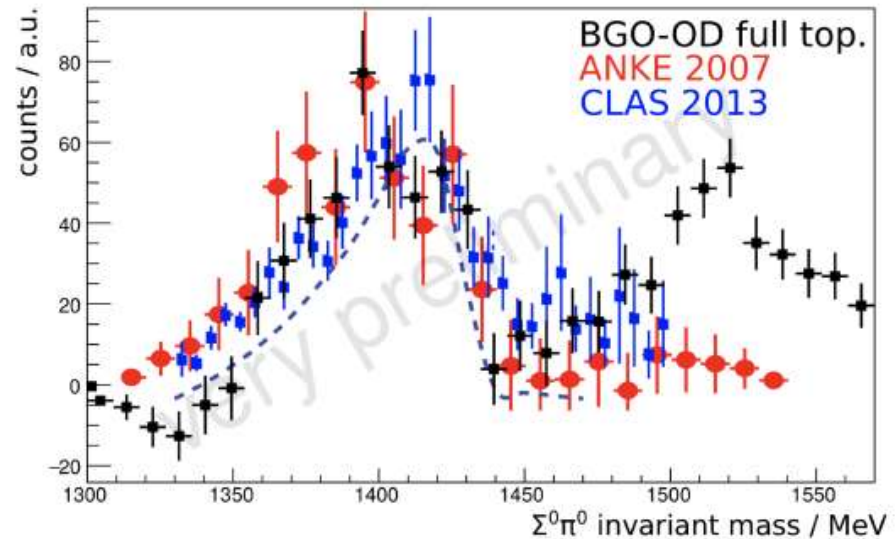
**Forward  $K^+\Lambda$  and  $K^+\Sigma^0$  photoproduction**

# Experimental data

## Forward $K^+\Lambda$ photoproduction



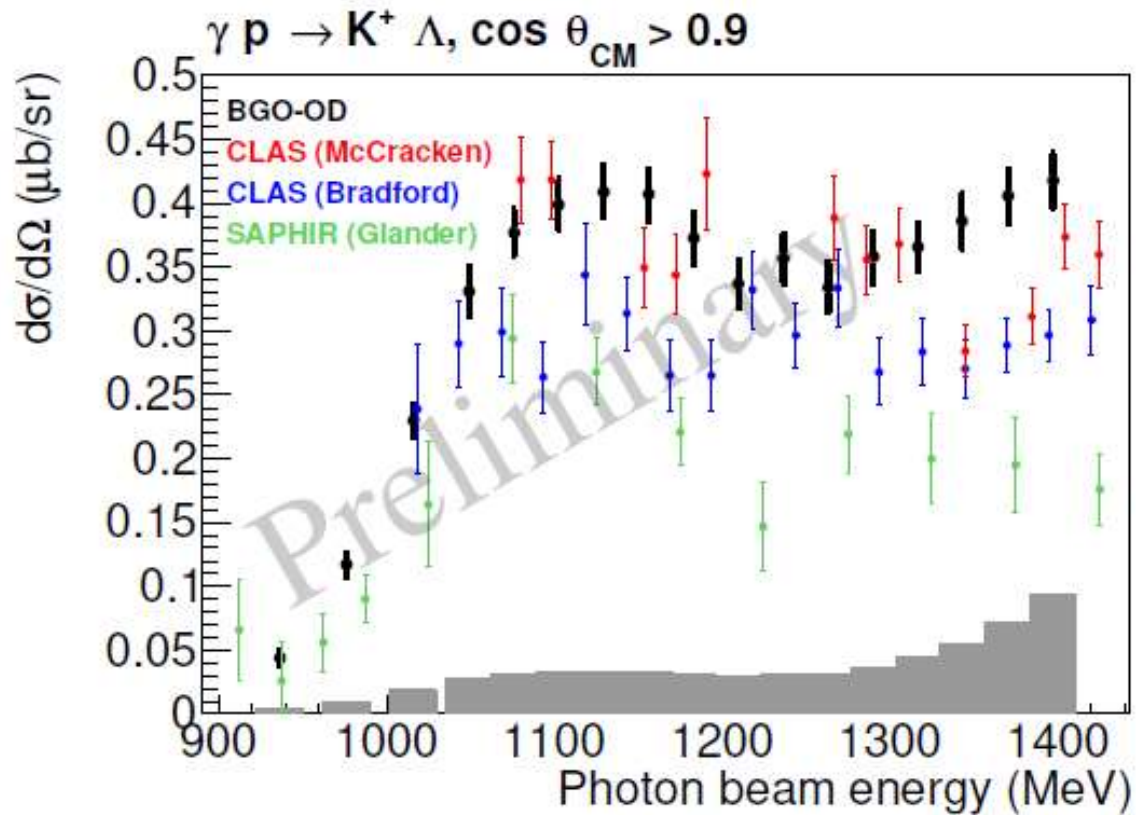
## $\Lambda(1405) \rightarrow \pi^0 \Sigma^0$





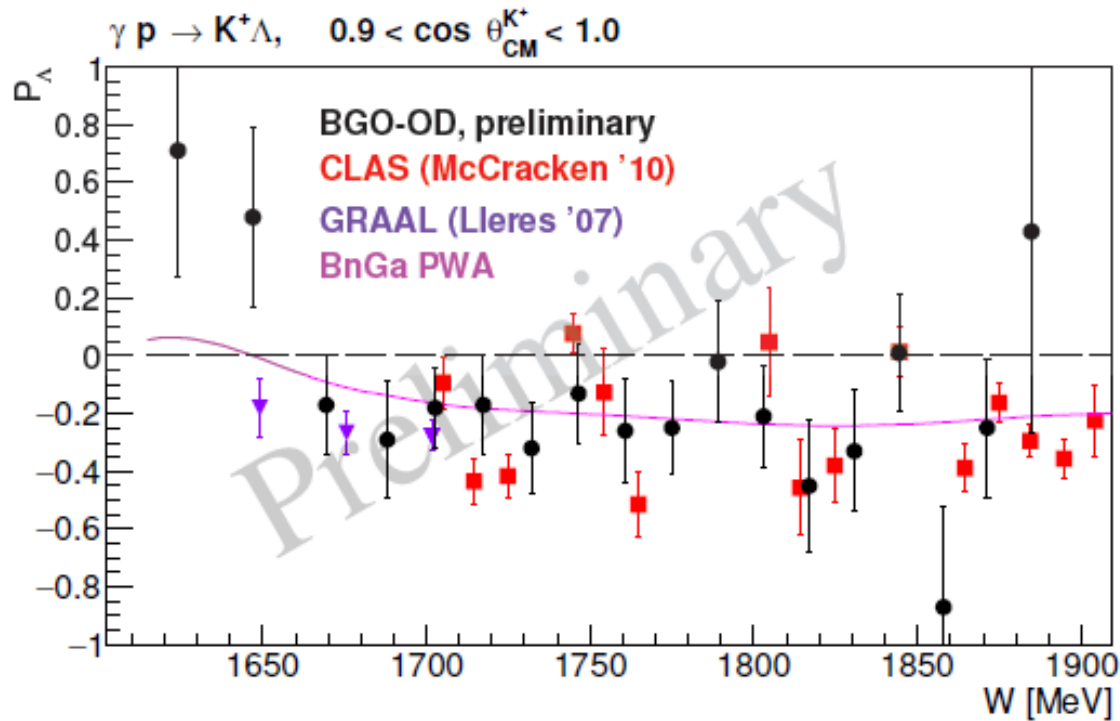
# Experimental data

## Forward $K^+\Lambda$ photoproduction



# Experimental data

## Forward $K^+\Lambda$

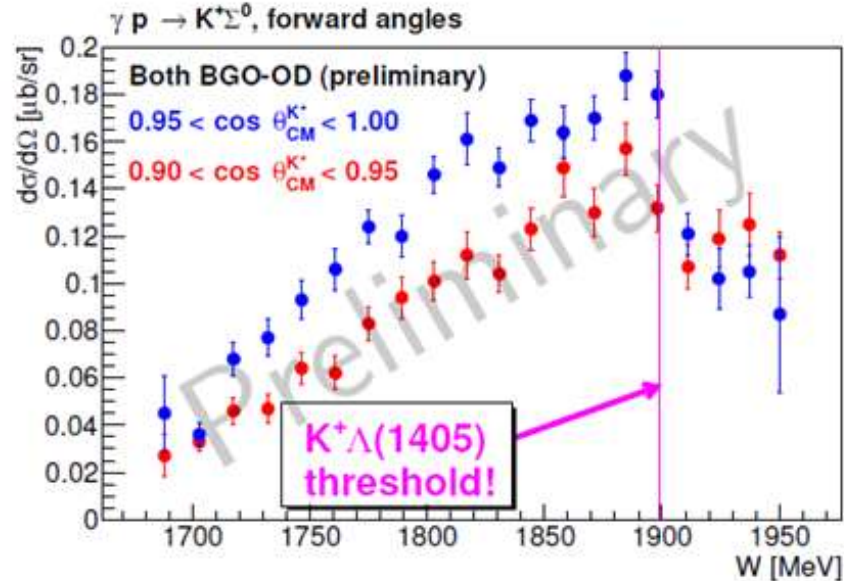


$$\alpha = 0.642$$
$$P_\Lambda = \frac{2 N_\uparrow - N_\downarrow}{\alpha N_\uparrow + N_\downarrow}$$

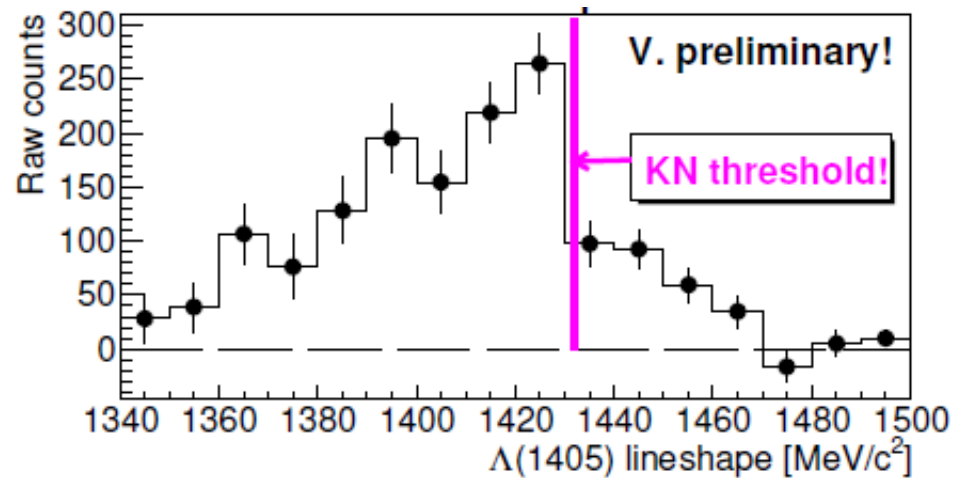
$\cos \theta_{CM}^{K^+} > 0.9.$

# Experimental data ( $K\Lambda$ , $K\Sigma$ )

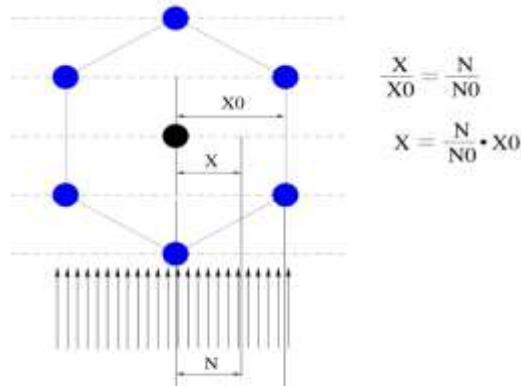
$$\gamma p \rightarrow K^+ \Sigma^0$$



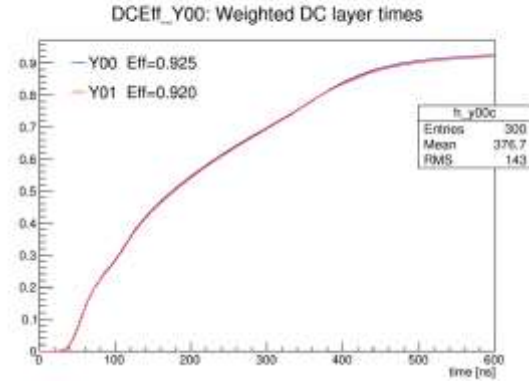
$$\Lambda(1405) \rightarrow \Sigma^0 \pi^0$$



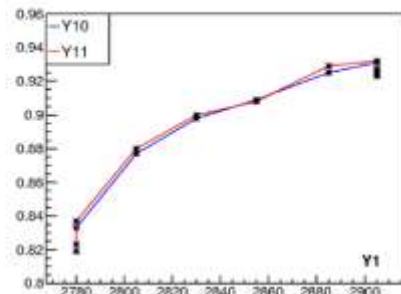
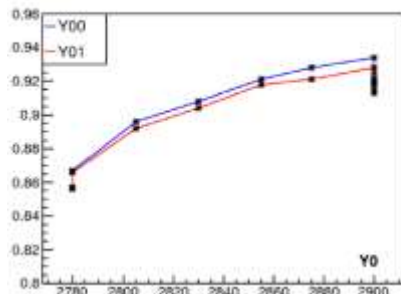
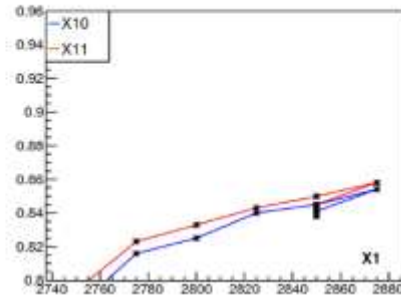
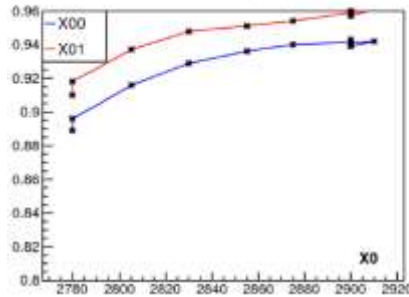
# Калибровка дрейфовых камер offline (Козленко)



## Cumulative Sum DT Histogram



## Efficiency X0 X1 Y0 Y1 chambers



**Н.Г. Козленко**

## Ближайшие планы (2020-2022)

$$\gamma p \rightarrow K^+\Lambda \text{ and } K^+\Sigma^0$$

$$\gamma n (\mathbf{D}) \rightarrow K^+\Sigma^-$$

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

$$\gamma d \rightarrow K^+\Lambda + (n), \dots$$

$$\gamma {}^{12}\text{C} \rightarrow K^+ {}^{12}\text{C}_\Lambda$$

$$\gamma {}^{12}\text{C} \rightarrow \pi^0 {}^{12}\text{C}^* \rightarrow \pi^0 {}^{12}\text{C}^* + \gamma (4,4 \text{ МэВ})$$

## Summary

- **BGO-OD: публикация «The BGO-OD experimental setup»**
- **Начато систематическое изучение реакций со странными частицами в конечном состоянии:**  
 $\gamma p \rightarrow K^+ \Sigma^0, \Lambda(1405) \rightarrow \Sigma^0 \pi^0$
- **... и много на будущее**

**С наступающим Новым годом.**

**Всем здоровья и научных успехов в 2020 году!**

# Summary

❖ Доп. слайды

## Prediction of Baryon resonances

**Baryon multiplets: octet, deкупlet, 56-plet, 70-plet...**

**PDG2014:** The  $N = 0$  band, which contains the nucleon and  $\Delta(1232)$ , consists only of the  $(56, 0^+)$  supermultiplet. The  $N = 1$  band consists only of the  $(70, 1^-)$  multiplet and contains the negative-parity baryons with masses below about 1.9 GeV. The  $N = 2$  band contains five supermultiplets:  $(56, 0^+)$ ,  $(70, 0^+)$ ,  $(56, 2^+)$ ,  $(70, 2^+)$  and  $(20, 1^+)$ .

In total hundreds of resonances composed of u, d, and s quarks. **PDG 1998:** Total number of well established in experiment resonances is 49 (the so-called problem of missing resonances).

→ **Need for more experimental data?**



# Experimental setup, BGO Rugby Ball



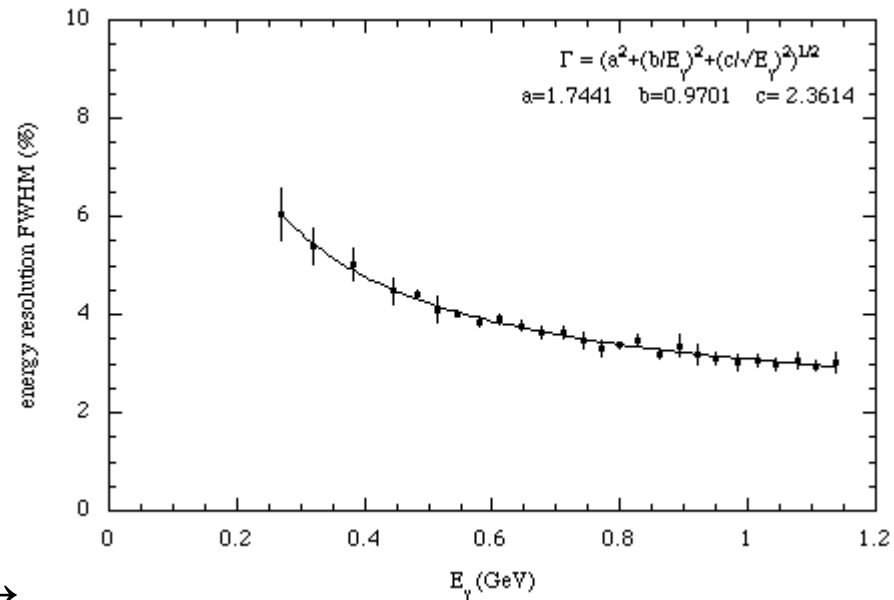
GRAAL (В.А.Кузнецов) →  
ELSA

**480 crystals**

24 cm length (~ 21 R.L.)

15 sectors of  $\theta \in [25^\circ; 155^\circ]$

32 sectors of  $\varphi \in [0; 1360^\circ]$

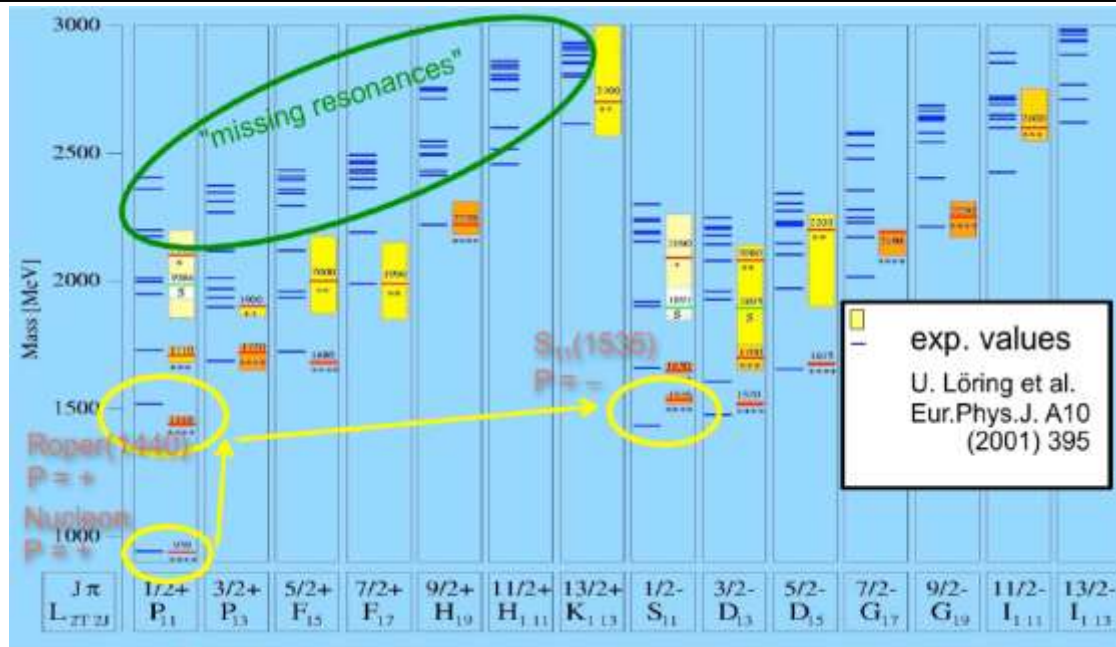


$\Delta\theta \sim 6^\circ \div 10^\circ$

$\Delta\varphi \sim 11,5^\circ$

$\Omega = 0,9 \times 4\pi$

# Physics



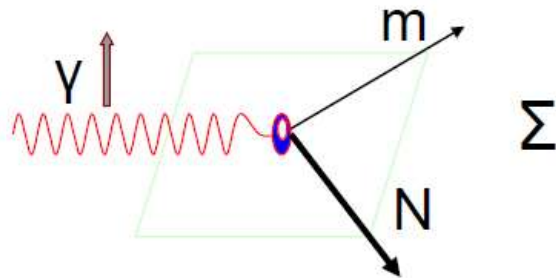
	PDG (2010)	BnGa PWA	PDG (2018)
N(1860)5/2 <sup>+</sup>		*	**
N(1875)3/2 <sup>-</sup>		***	***
N(1880)1/2 <sup>+</sup>		**	**
N(1895)1/2 <sup>-</sup>		****	****
N(1900)3/2 <sup>+</sup>	**	***	***
N(2060)5/2 <sup>-</sup>		***	**
N(2150)3/2 <sup>-</sup>		**	**
$\Delta(1900)1/2^-$	*	*	**
$\Delta(1940)3/2^-$	*	**	**

Bonn-Gatchina partial wave analysis

## Observables in meson photoproduction

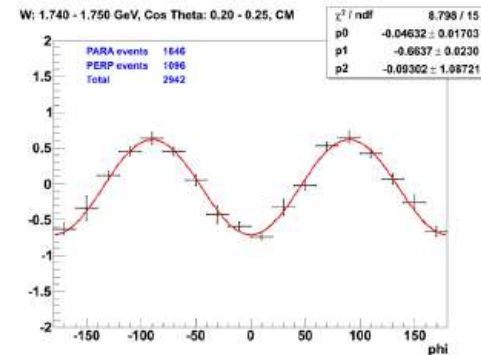
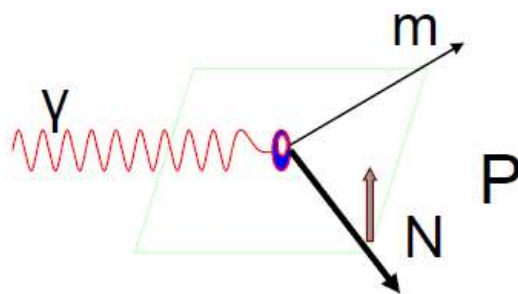
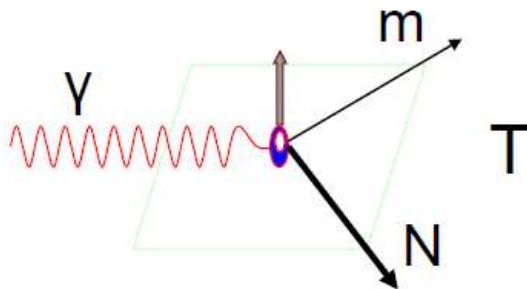
- **Unpolarised Cross section** ( $\sigma_0$ )
- **Single-polarization observables**
  - Recoil polarization ( $P$ )
  - Beam asymmetry ( $\Sigma$ )
  - Target asymmetry ( $T$ )
- **Double-polarization observables**
  - Beam + Recoil ( $C_{x'z'}, C_{z'x'}, O_{x'z'}, O_{z'x'}$ )
  - Beam + Target ( $E, F, G, H$ )
  - Recoil + Target ( $T_{x'z'}, T_{z'x'}, L_{x'z'}, L_{z'x'}$ )

## Single Polarization observables



$$\frac{d\sigma}{d\Omega} = \sigma_0(1 + P\Sigma \cos(2\varphi))$$

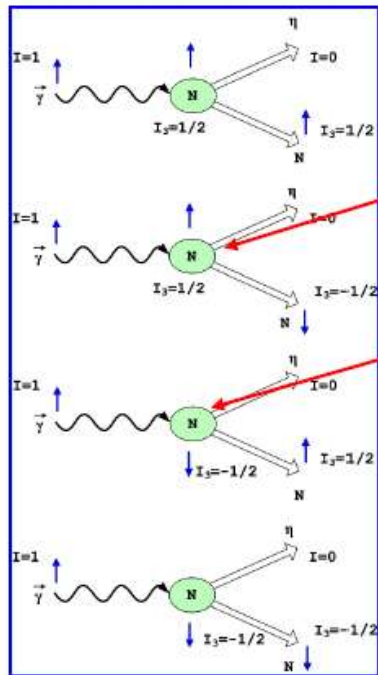
$$\frac{n_V - n_H}{n_V + n_H} = P_\gamma \Sigma \cos(2\varphi)$$



## Role of polarization observables

Helicity amplitudes

$$H_{\uparrow\uparrow} \quad H_{\downarrow\downarrow} \quad H_{\downarrow\uparrow} \quad H_{\uparrow\downarrow}$$



$H_{\uparrow\uparrow}$

$H_{\uparrow\downarrow}$

$H_{\downarrow\uparrow}$

$H_{\downarrow\downarrow}$

$$\sigma \sim |H_{\uparrow\uparrow}|^2 + |H_{\downarrow\downarrow}|^2 + |H_{\downarrow\uparrow}|^2 + |H_{\uparrow\downarrow}|^2$$

Dominates in cross section

S-P interference

$$\Sigma \sim \text{Re}\{H_{\uparrow\uparrow}H_{\downarrow\downarrow}^* - H_{\downarrow\uparrow}H_{\uparrow\downarrow}^*\}$$

$$T \sim -\text{Im}\{H_{\downarrow\uparrow}H_{\uparrow\uparrow}^* + H_{\downarrow\downarrow}H_{\downarrow\downarrow}^*\}$$

$$P \sim -\text{Im}\{H_{\uparrow\uparrow}H_{\downarrow\downarrow}^* + H_{\downarrow\uparrow}H_{\uparrow\downarrow}^*\}$$

The signal of a weakly photoexcited P11 resonance may not be seen in the cross section, but might be well seen in the  $\Sigma$  beam asymmetry data through the interference with S11(1535)