ANOMALOUS SOFT PHOTONS AT NUCLOTRON NUCLEAR BEAMS

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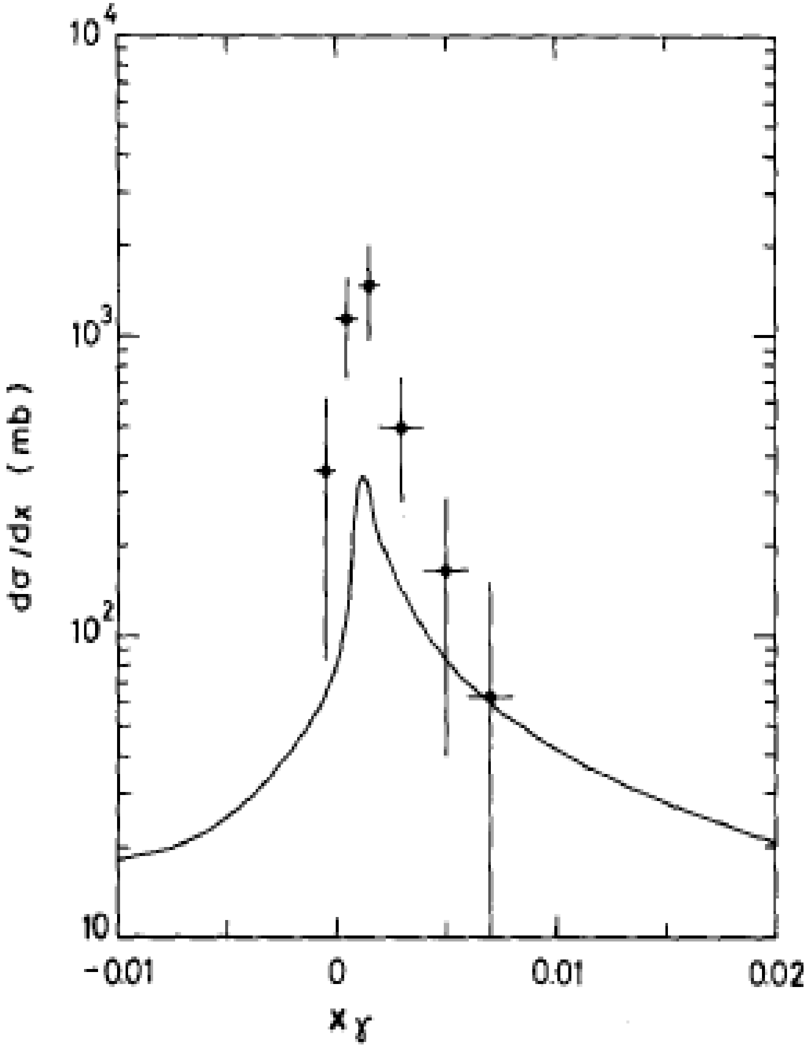
INTRODUCTION

Experimental and theoretical studies of direct photon production in hadron collisions essentially expand our insights about multiparticle production mechanisms. These photons are useful probes to investigate nuclear matter at all stages of the interaction.

Soft photons (SP) play a particular role in these studies. Until now we have no total explanation for the experimentally observed excess of SP yield.

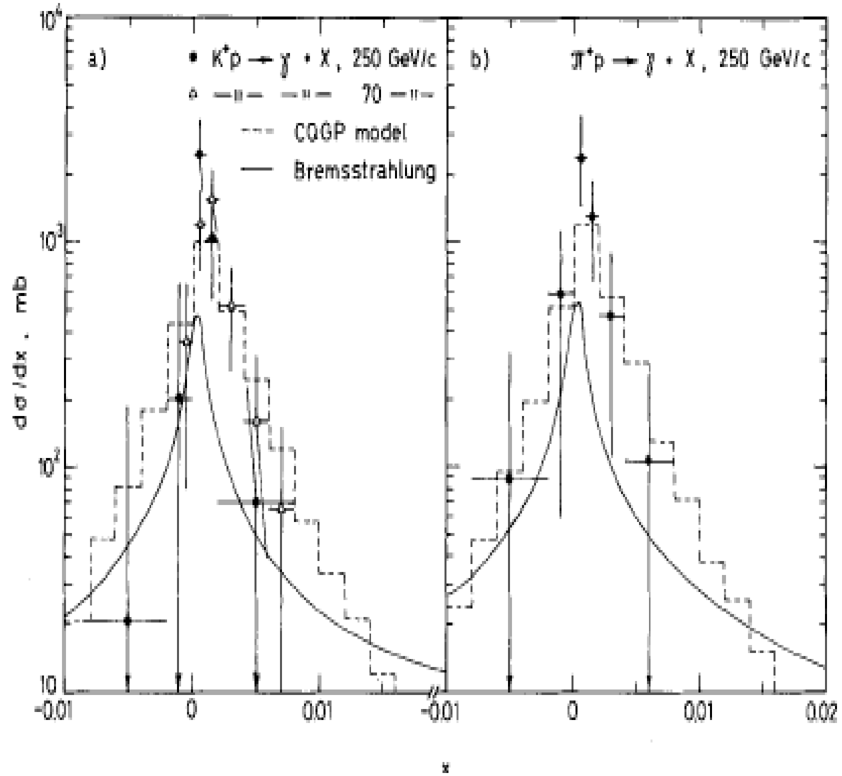
These photons have low transverse momenta $p_T < 0.1$ GeV/c, $|x| < 0.01$. In this domain their yield exceeds the theoretical estimates by 3 – 8 times.

History: In the end of 70th of the last century the anomalous phenomenon has been found: the SP yield surpasses 4 times the theoretical predictions. This effect was observed at the Big Europe Bubble Chamber (BEBC) located at the SPS accelerator, in CERN in the experiment with a 70 GeV/c K^+-meson and antiproton beams. Excess: 4.5 ± 0.9



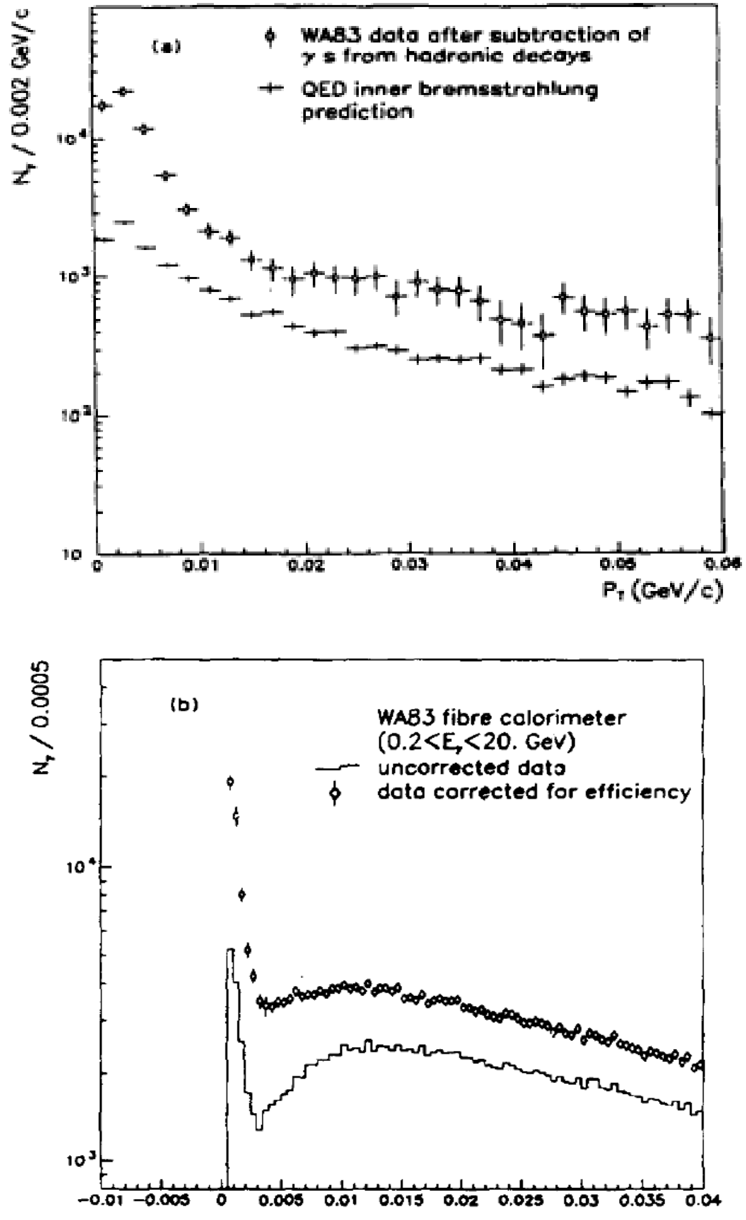
NA22 Collaboration at SPS accelerator at European hybrid spectrometer (EHS) had measured a SP yield in $K^{+} + p \rightarrow \gamma + X$ and $\pi^{+} + p \rightarrow \gamma + X$ processes with enriched 250 GeV/c meson beams.

Excess: 3.0 ± 0.25.



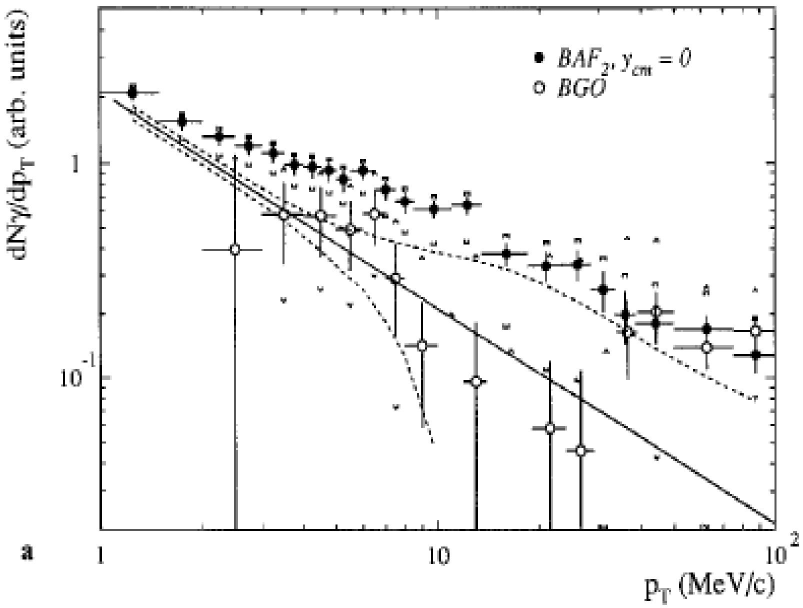
WA83 Collaboration studied direct SP yield at OMEGA spectrometer in $\pi^{-}p$ interactions at hydrogen target with 280 GeV/c π^{-}-meson. Registration of photons with small x and p_T was carried out of electromagnetic calorimeter. Its blocks have been consisted of lead plates surrounded by scintillator fibers. Light was collected by PMT array.

Excess: 7.9 ± 1.4



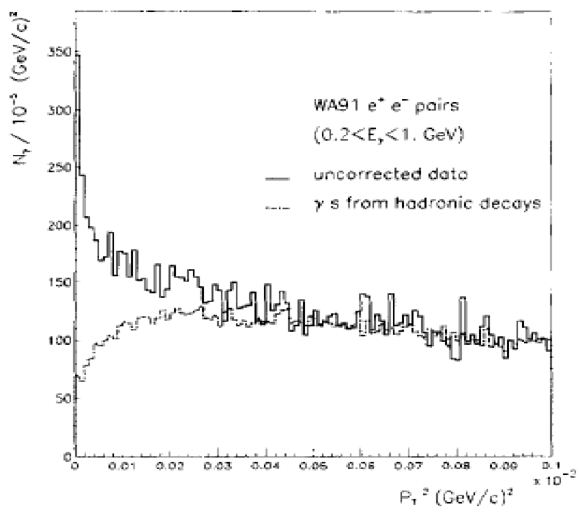
Then the SP yield measurement has been carried out in the electronic experiment HELIOS for *p*-Be interactions at 450 GeV/c proton beams at SPS accelerator, CERN. It has permitted measuring of SP spectrum in *pBe* and *pAl* scattering at 450 GeV/c.

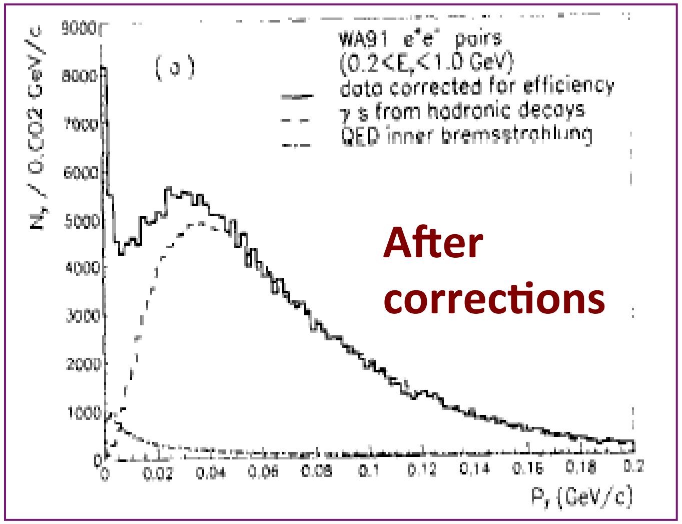
Excess (?) : 1.5 ± 0.3



SP yield has been measured at WA91 setup in $\pi^- p$, pp, 280÷ 450 GeV/c to test results of OMEGA setup . It was "clear" experiment, it was selected events: $N_{ch} \leq 8$. Photons registered by conversion pairs in lead layer.

Excess: (5.3 ÷ 9.8) ± 1,4





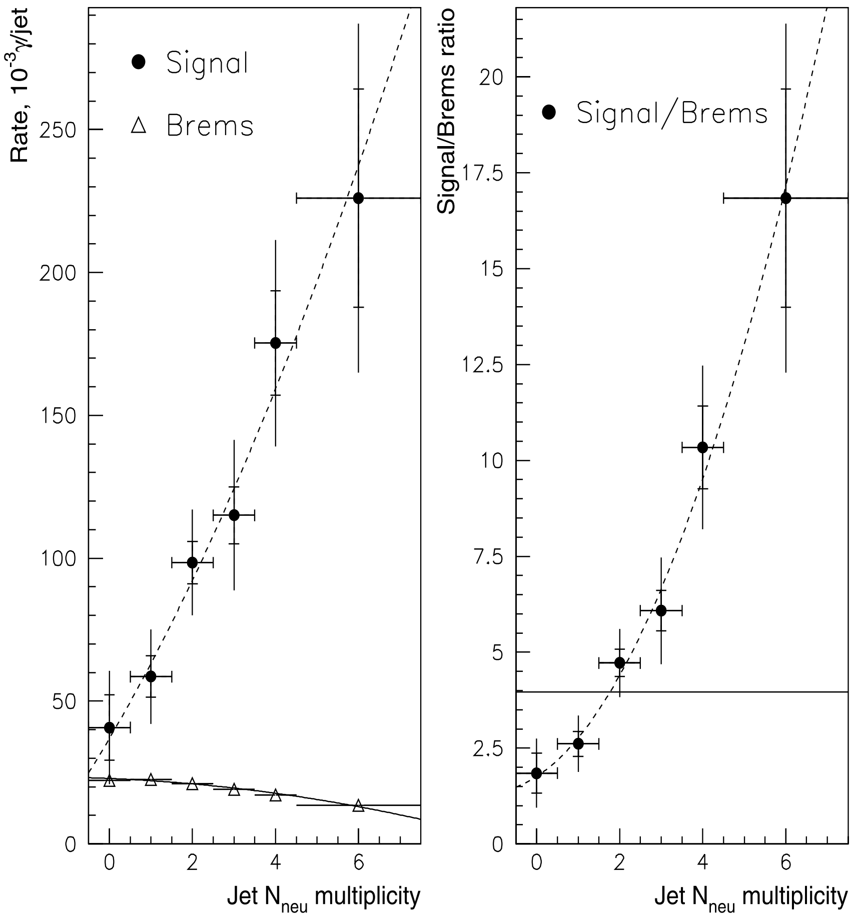
Registration of SP at DELPHI setup. The main detector registered charged particles was TPC. ECal was located after these detectors. The next processes were investigated:

$e^{+} + e^{-} \rightarrow Z^{0}$, $Z^{0} \rightarrow \mathrm{jet} + \gamma$

(excess: 3.4 ± 0.8)

for $e^{+}+e^{-} \rightarrow \mu^{+}\mu^{-}$ (no excess).

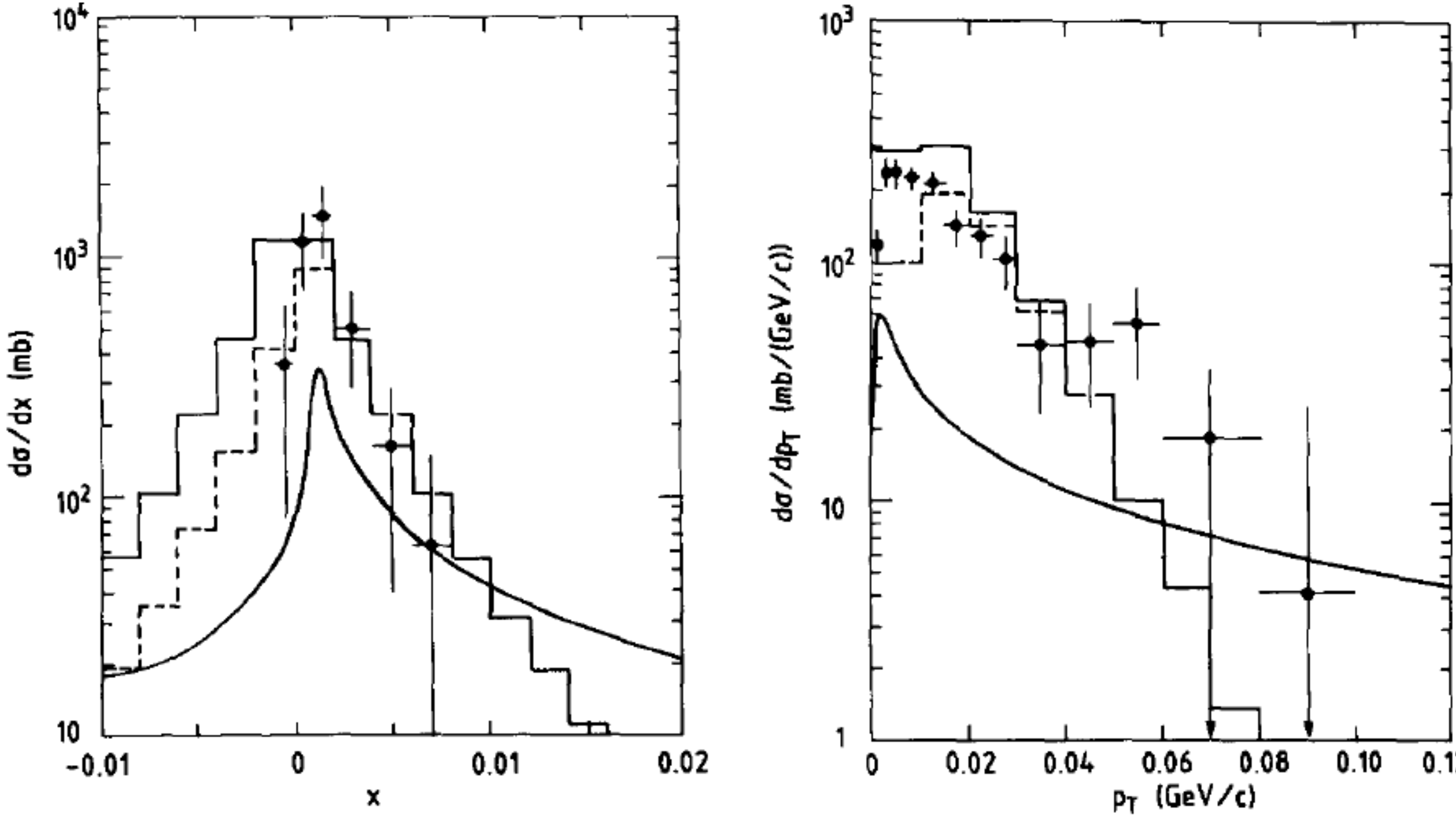
At first the excess of SP yield for neutral pions got about 17- fold excess in comparison with theoretical predictions.



Present theoretical models try to explain anomalous yield of SP but an incompleteness of data don't allow discovering of the physical essence of SP phenomenon completely

№	Author	Model	Result
1	L. Van Hove, P. Lichard. 1989	Cold spot of QGP	Numerical description of data
2	E.V.Shuryak. 1989	Drop of cold pion liquid	Qualitative statement about excess of SP yield
3	S.Barshay. 1989	Coherent state of pions - condensate	Inapplicability of bremsstrahlung Quadratic dependence of SP yield as multiplicity
4	Cheuk-Yin Wong. 2010	Oscillations in gluon string between pair of quarks	Quantitative description of data
5	D.Kharzeev, F.Loshaj. 2013-2014	Excitation of QCD vacuum	HELIOS, NA34 data description
6	E.Kokoulina et al., 2002 –2006.	Dominance of gluons in hadron and photon production	Number of gluons at the end of cascade ≥ 40. Low energy gluons ($\sim 50\%$) form γ-quanta: $q+g \rightarrow \gamma + q$.
7	M.Volkov et al. 2006	Excitation of QCD vacuum, expansion of excited system and photon emission	Estimation of emission region size of SP: $R \approx 6$ фм.

SP spectra in $\pi^+ p$, 70 GeV/c



L.Van Hove, P.Lichard (1990). Solid line – theoretical description, dashed –a cold QGP spot model. Parameters: a spot size ~ 4 fm, mass ~ 1 GeV, the number of partons in the spot ~ 40, <*p*> of parton ~ 50 MeV/c.

The size of an emission region for SP has been defined versus p_T in *pp* at 70 ГэВ/c in a gluon dominance model

p_T , MeV/c	10	15	25	30	50	100
L, fm	10.4	6.9	4.1	3.5	2.1	1.0

The smaller p_T, the larger the size of the emission region of SP → hadronization is responsible to SP formation

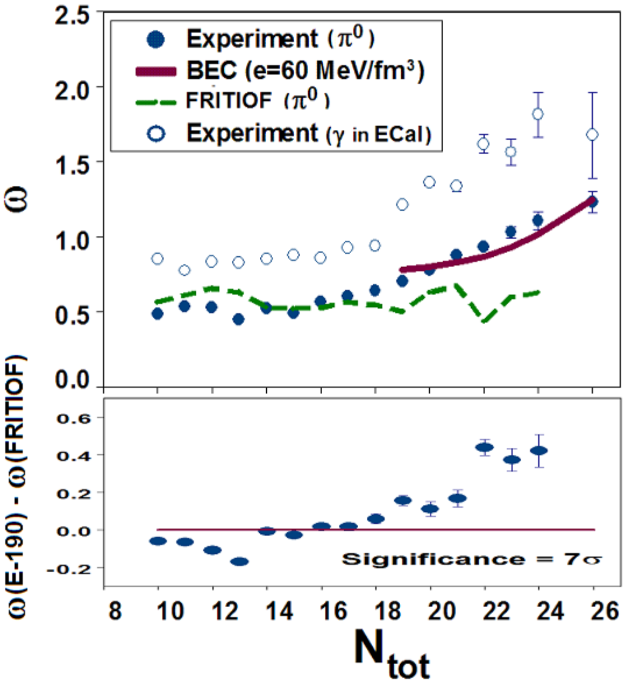
J. Schukraft, HELIOS, NA34: "The anomalous source of e.m. seen radiation in h-h interactions might be an effect of the hadronization on scales much larger than the proton radius … However, the presence of this soft radiation already in *pp* could imply that the QGP is not the only surprise to be encountered in NP QCD."

S. Barshay supposes [Phys.Lett. B227 (1989) 279] (in the model of collective particle excitation) that the excess of SP yield is connected with the pion condensate formation.

SVD Collaboration has gotten the evidence of the Bose-Einstein condensate formation in *pp* interactions in the region of high total multipl.: $N_{tot} = N_{ch} + N_0 \geq 18$.

The growth of a scaled varience:

$$\omega = D/\langle N\rangle,\ D = \langle N^2\rangle - \langle N\rangle^2.$$



The differences of experimental values from MC simulation gets 7 standard deviations at $N_{tot} \sim 27$.

EPJ, 2012; ICHEP 2012.

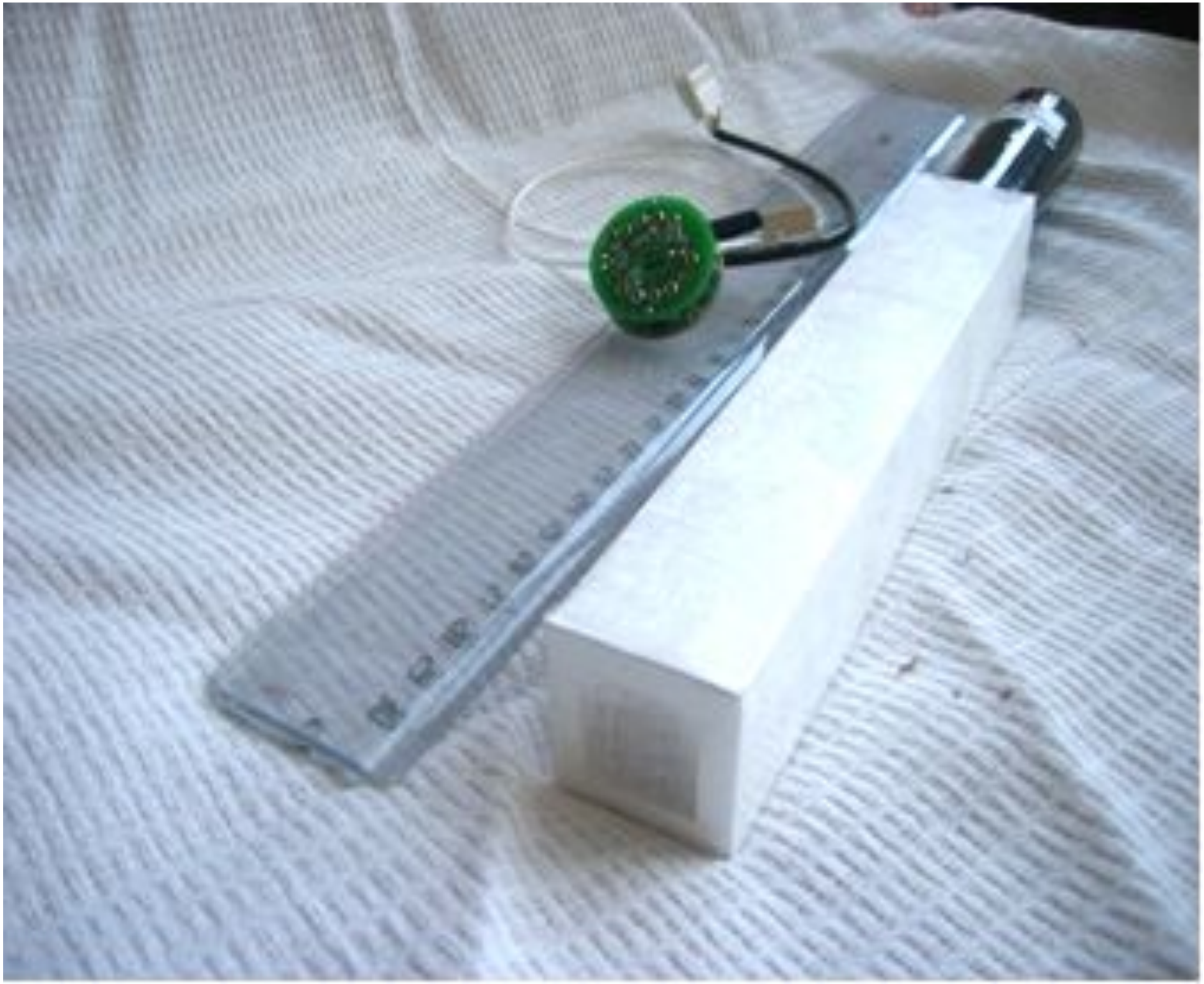
We can test prediction of Barshay at Nuclotron and U-70.

Our aims

To get the comprehensive picture of SP formation and in particular for a testing of connection between BEC and excess of SP yield, our Collaboration has manufactured the SP electromagnetic calorimeter (SPEC).

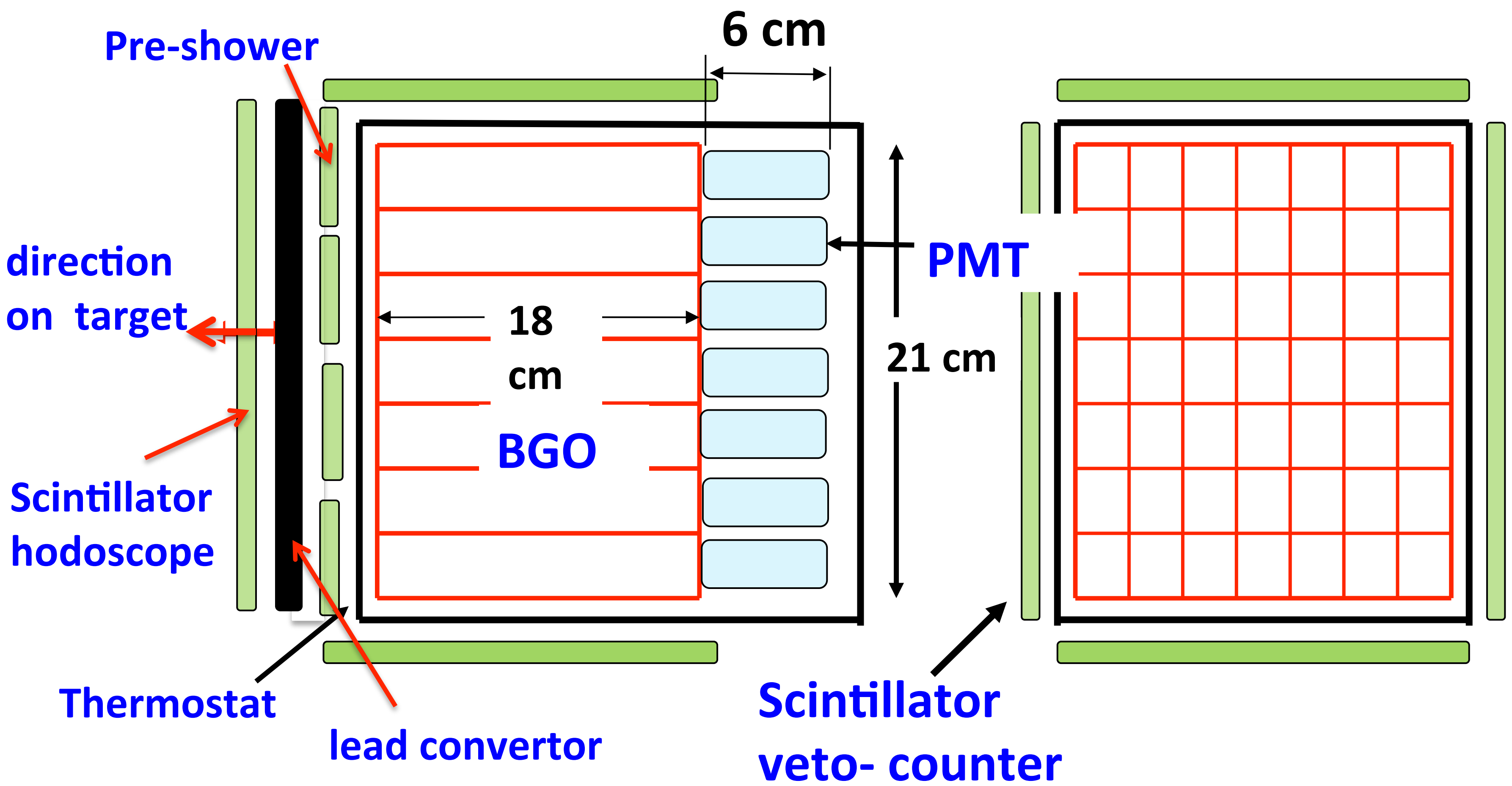
This calorimeter differs from many similar devices with a low threshold of γ-quantum registration – lower than 2 MeV. SPEC technique will allow carrying out the wide research program in *pp*, *pA* and *AA* interactions with photons.

BGO element and PMT

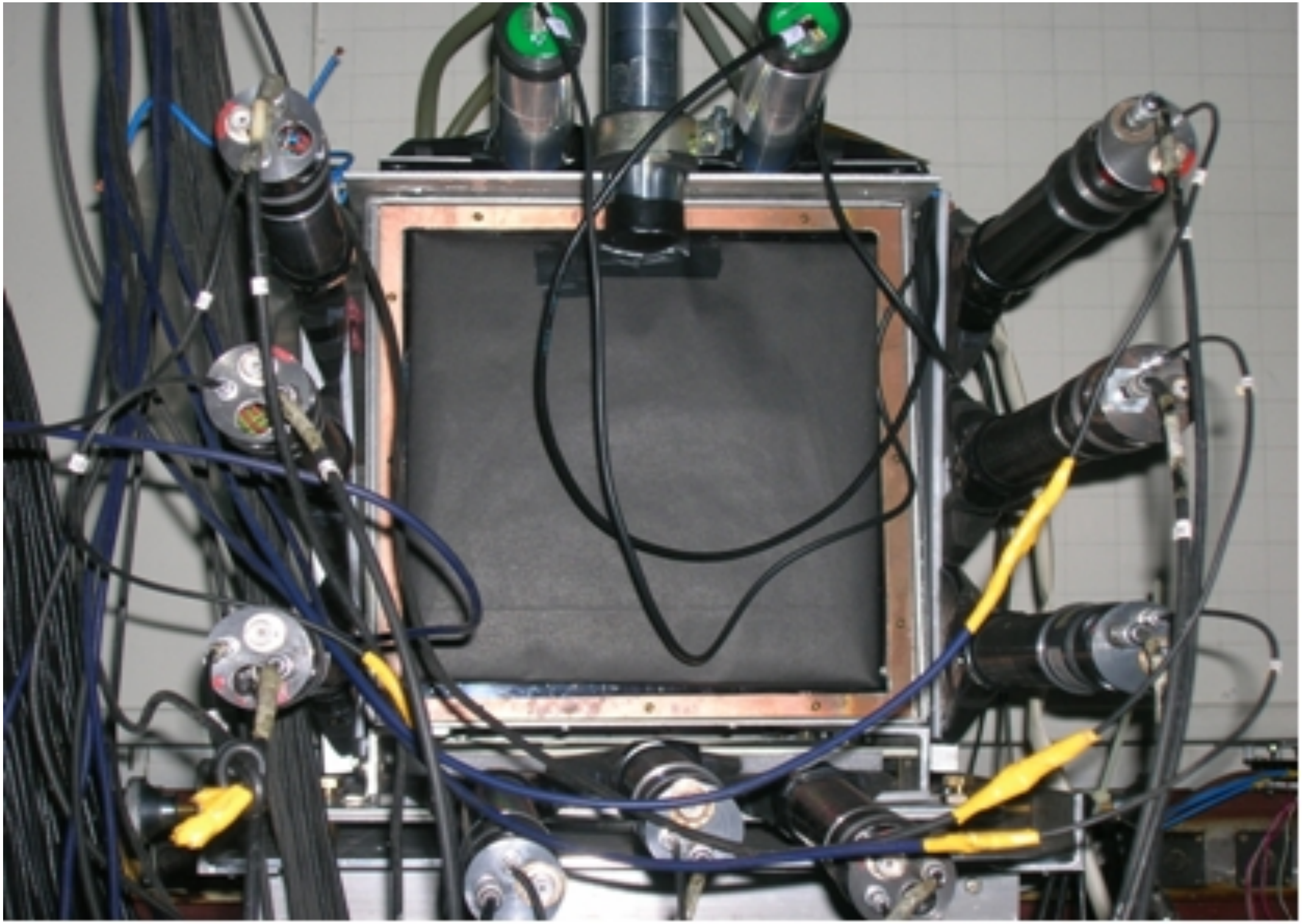


Size of crystal $3 \times 3 \times 18$ cm^3

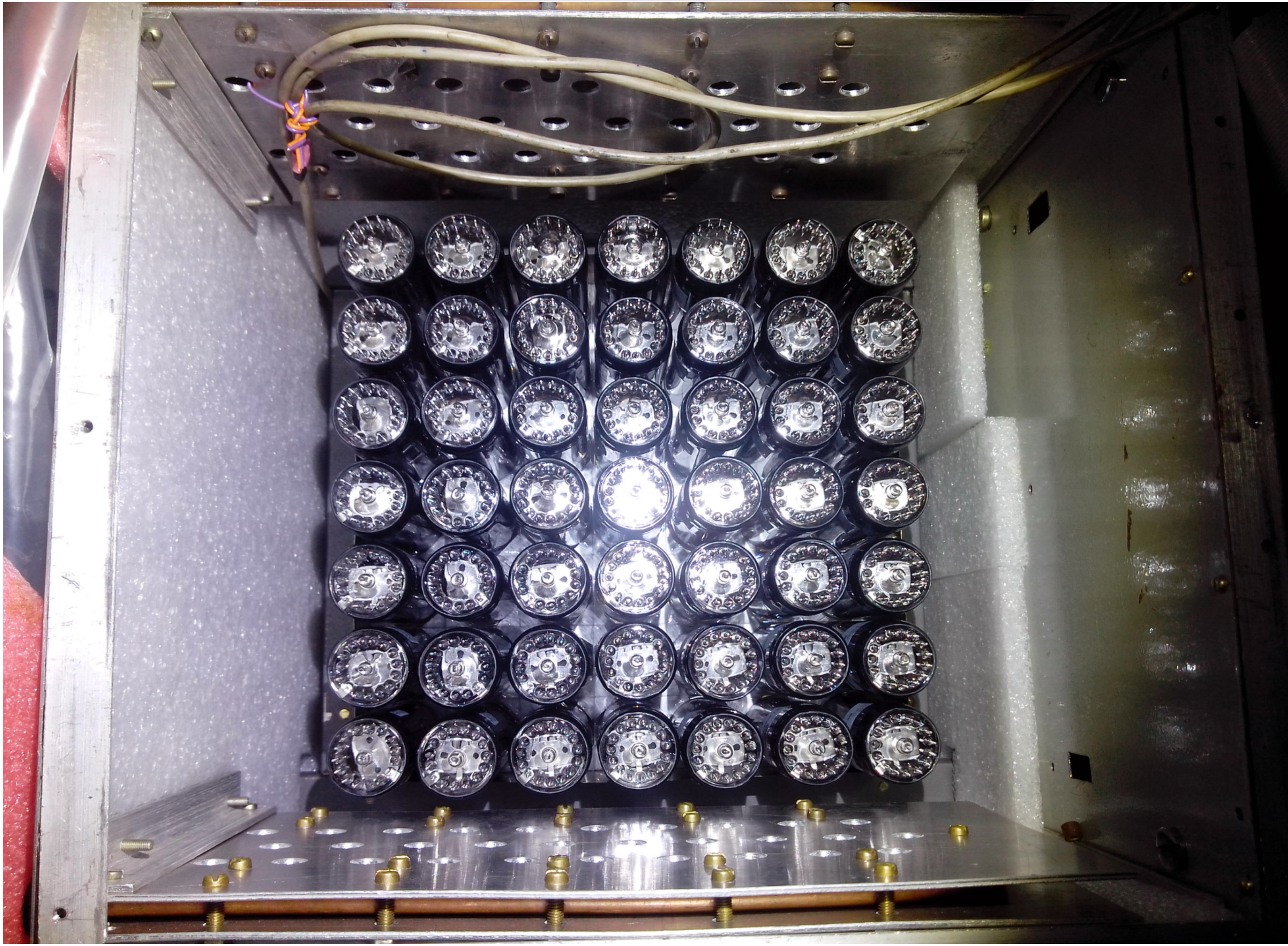
The assembly scheme of SPEC



SPEC, front view



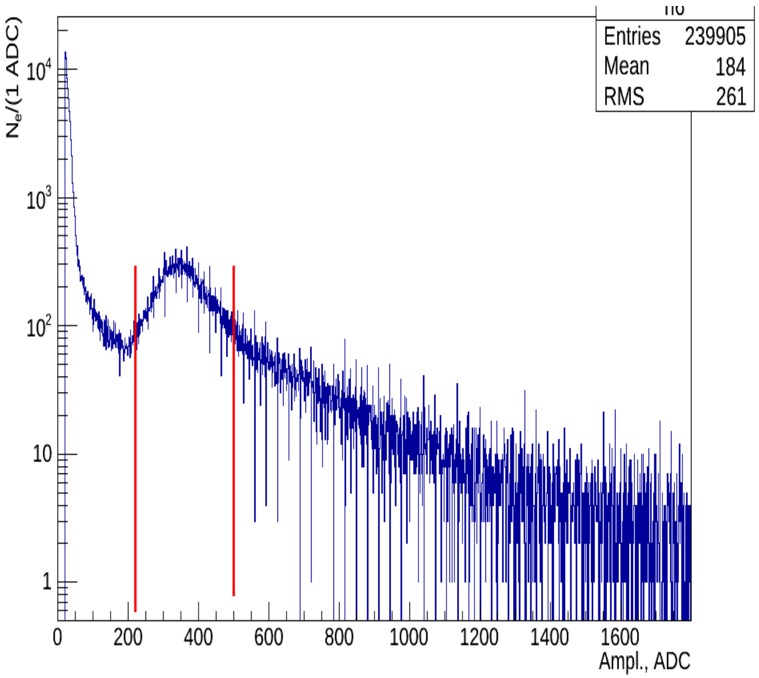
SPEC, back view – 49 PMT



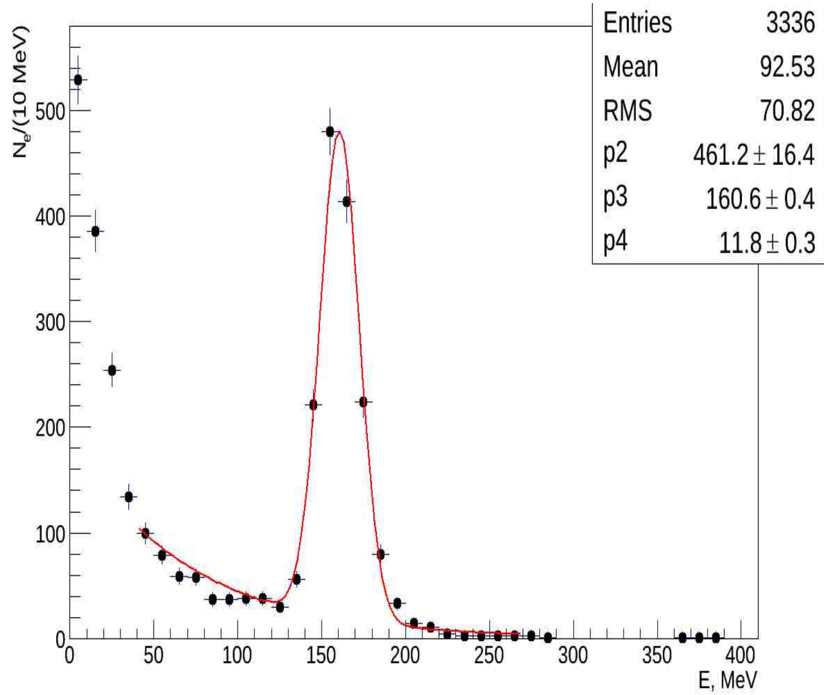
The preliminary test of SPEC has been carried out at the SVD-2 setup with 50 GeV proton beam of the U-70 at IHEP, in 2013.

SPEC was located under the angle ~ 5° and on the distance of 11 m from the H_2- target center. Signals from detectors of SPEC and the veto-system are digitized.

The photons from H_2-target are registered. These tests have confirmed the working capacity of all SPEC elements.

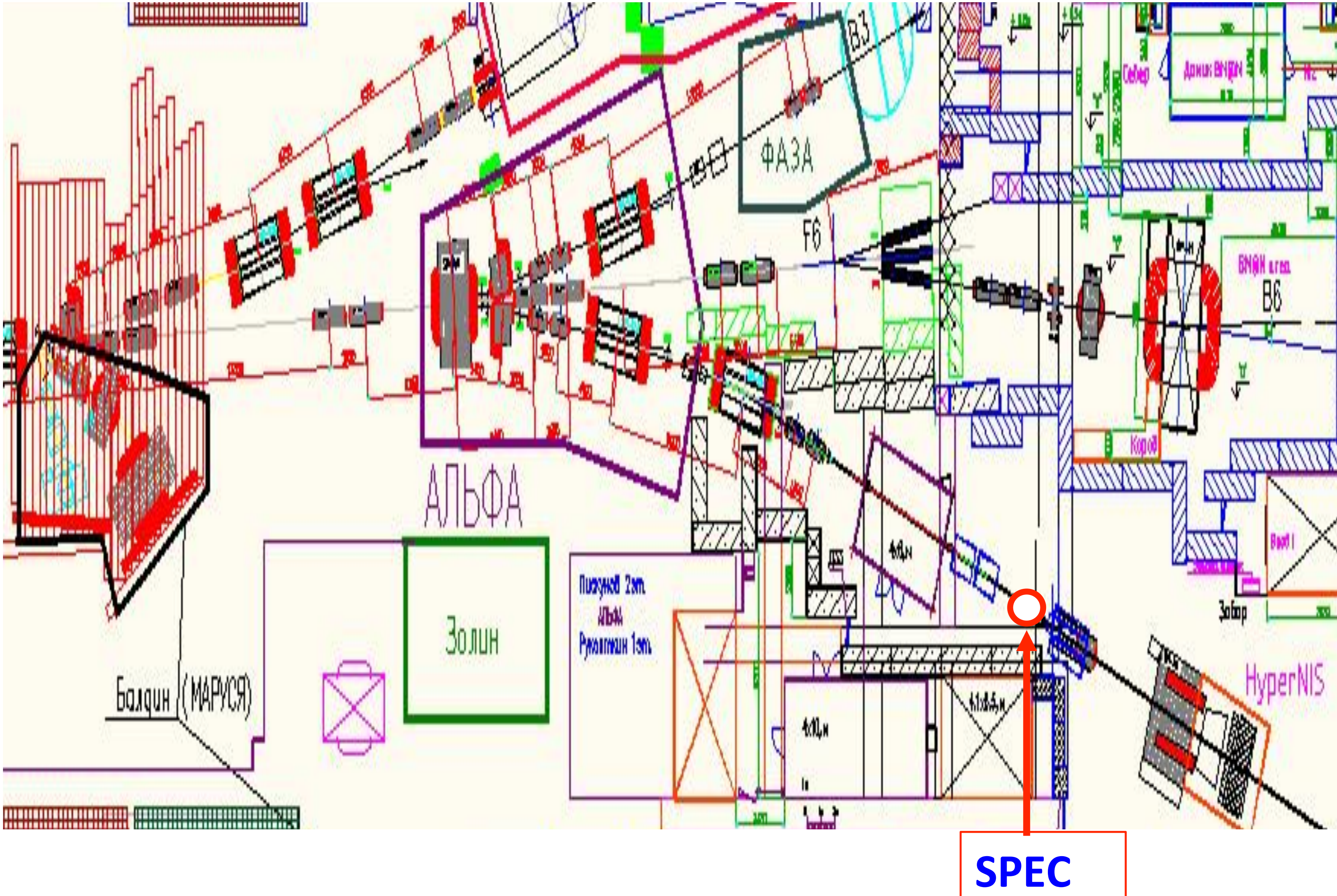


Amplitude spectrum of signals from front veto-detector of SPEC

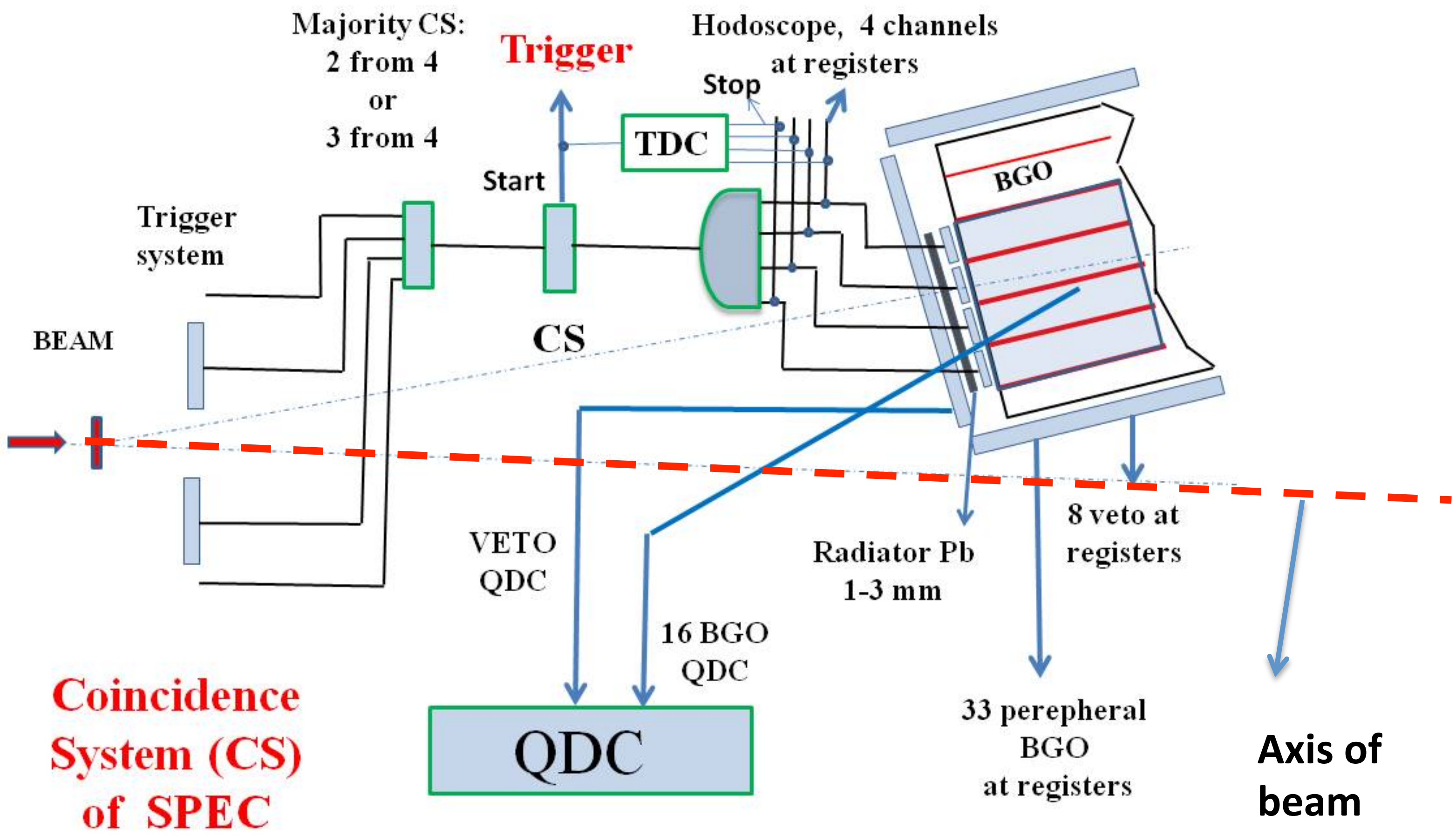


Energy spectrum of particles, registered by a single BGO element of SPEC. The peak in the region ~ 160 MeV corresponds to MIP particles

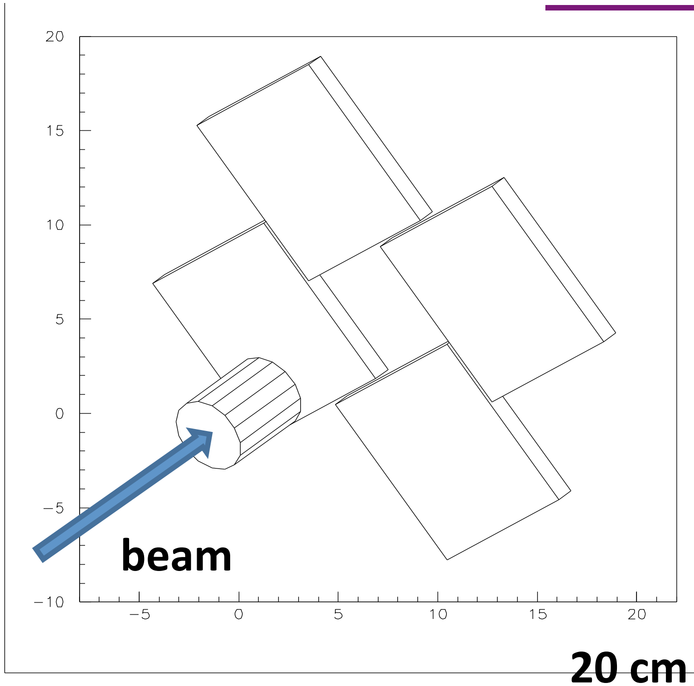
MAP of BEAMS in BUILDING 205 & SPEC LOCATION



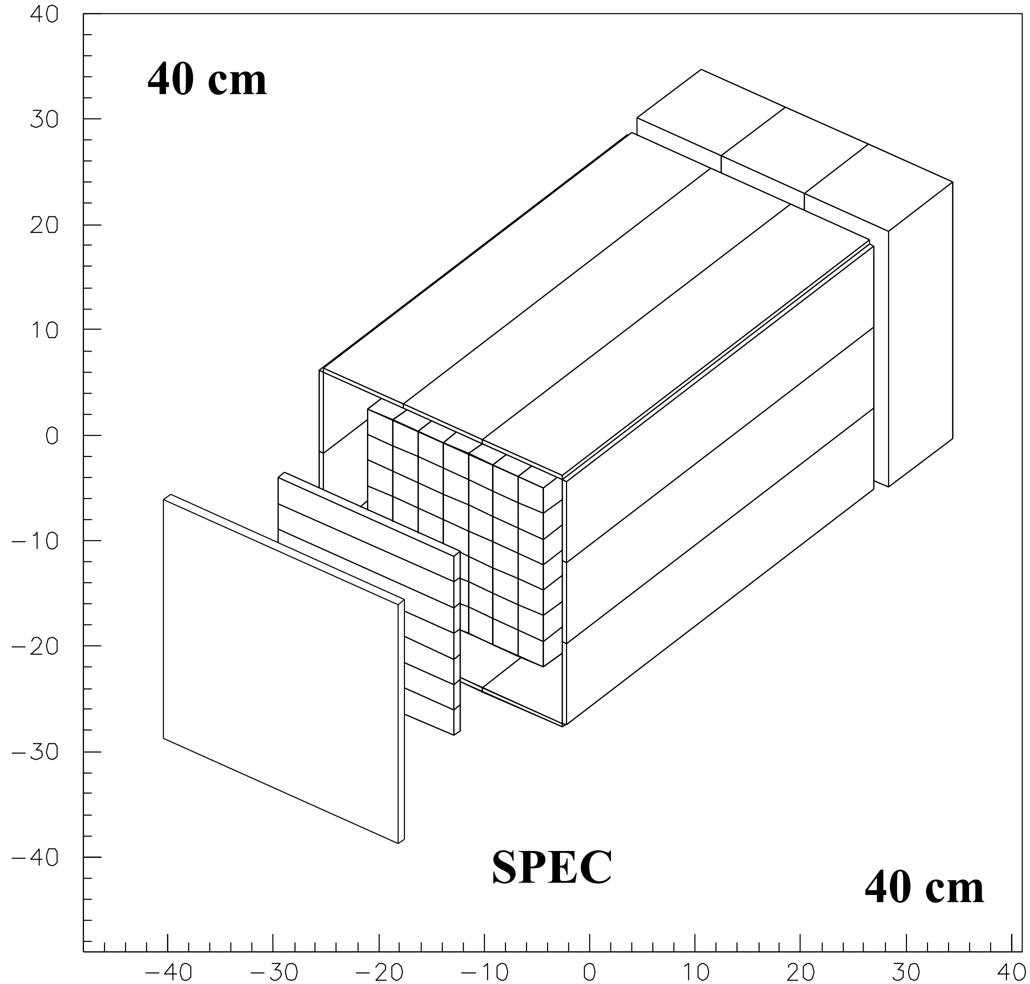
The simplified scheme of SPEC setup at Nuclotron



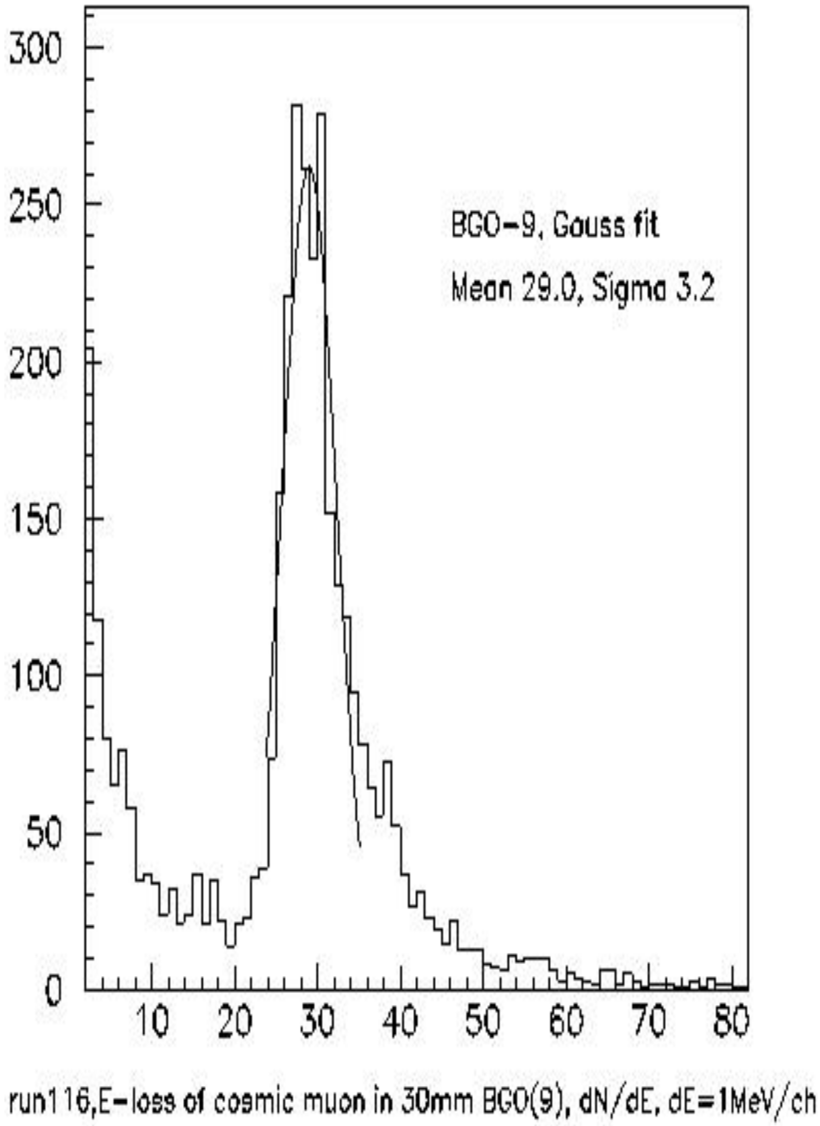
Setup elements

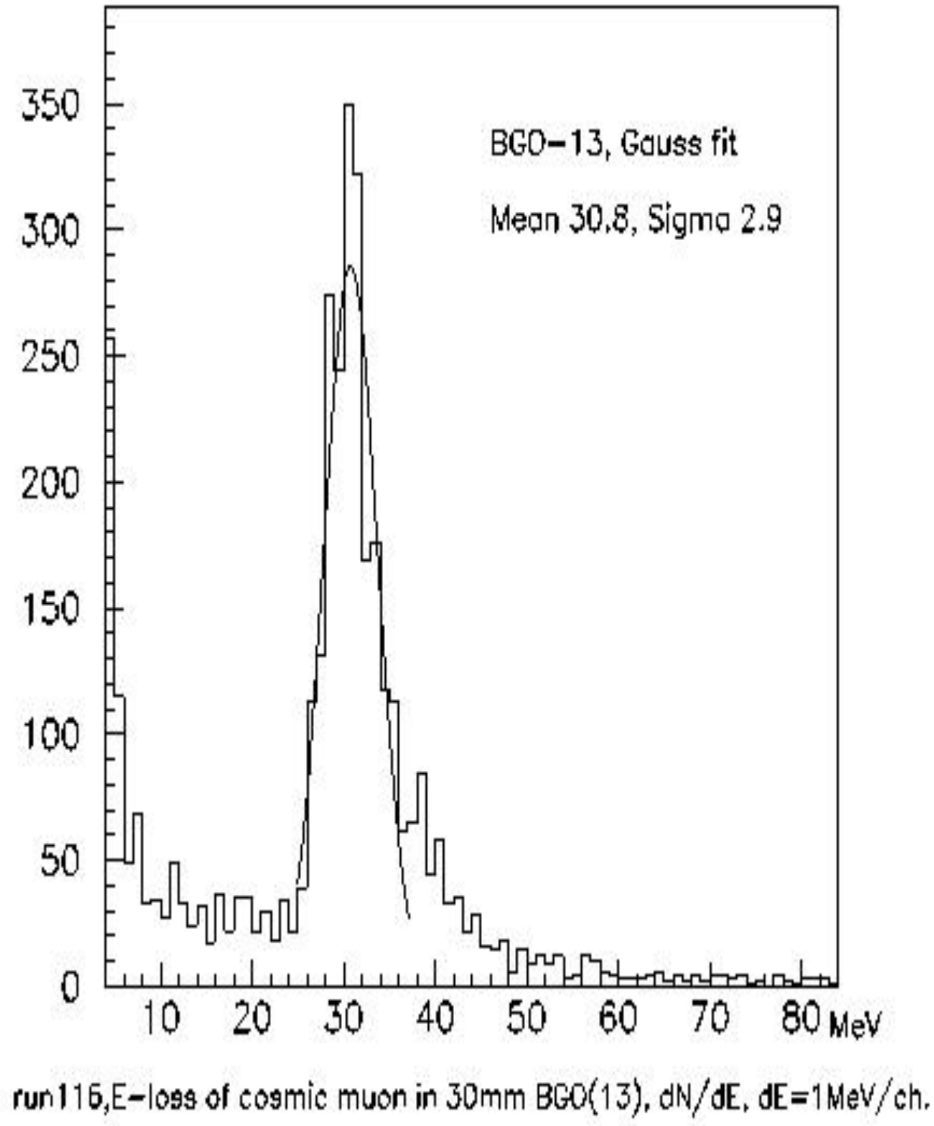


Target ^{12}C and trigger hodoscope of multiplicity

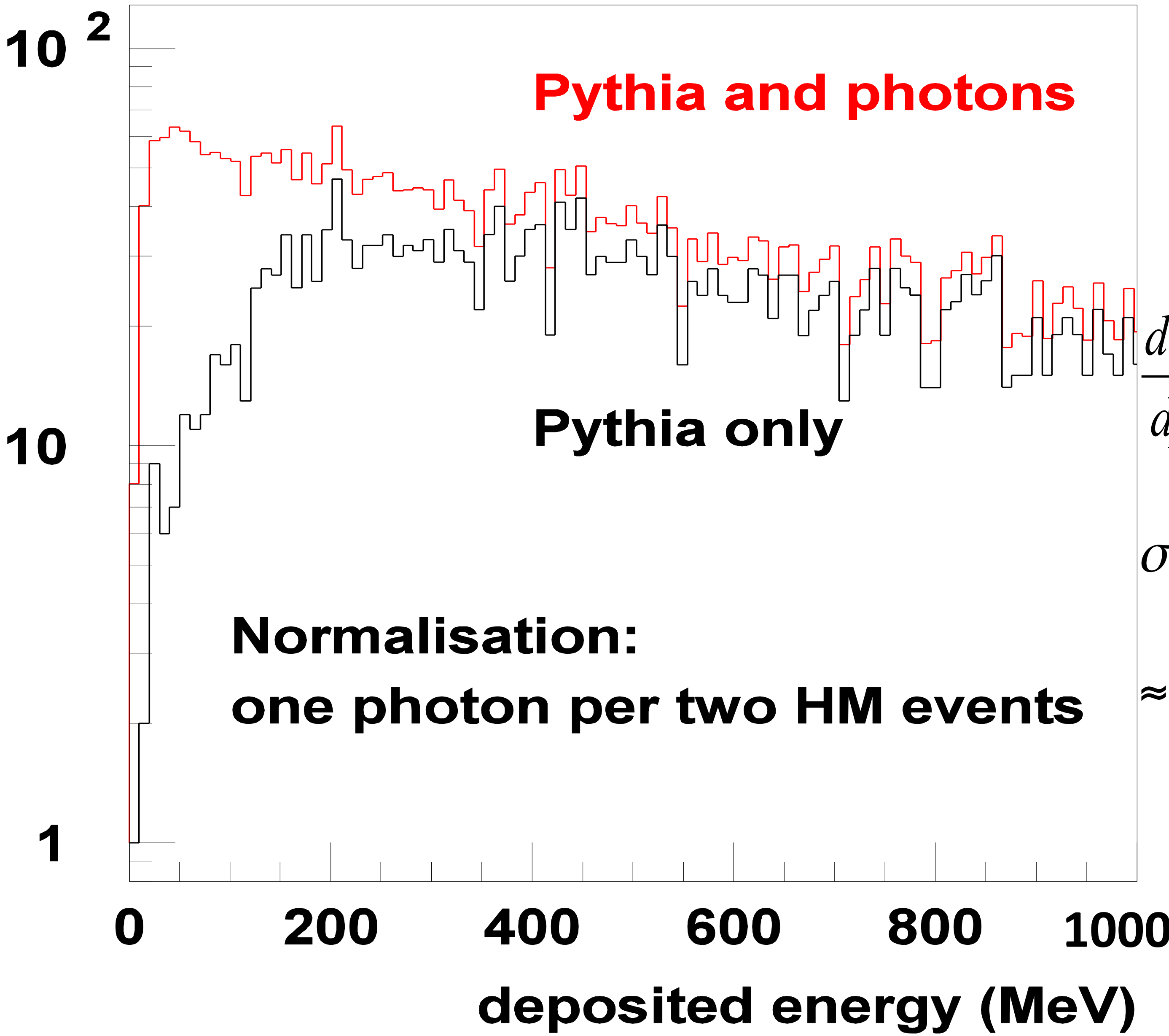


Energy calibration of SPEC by cosmic rays





Simulation of the SPEC performance

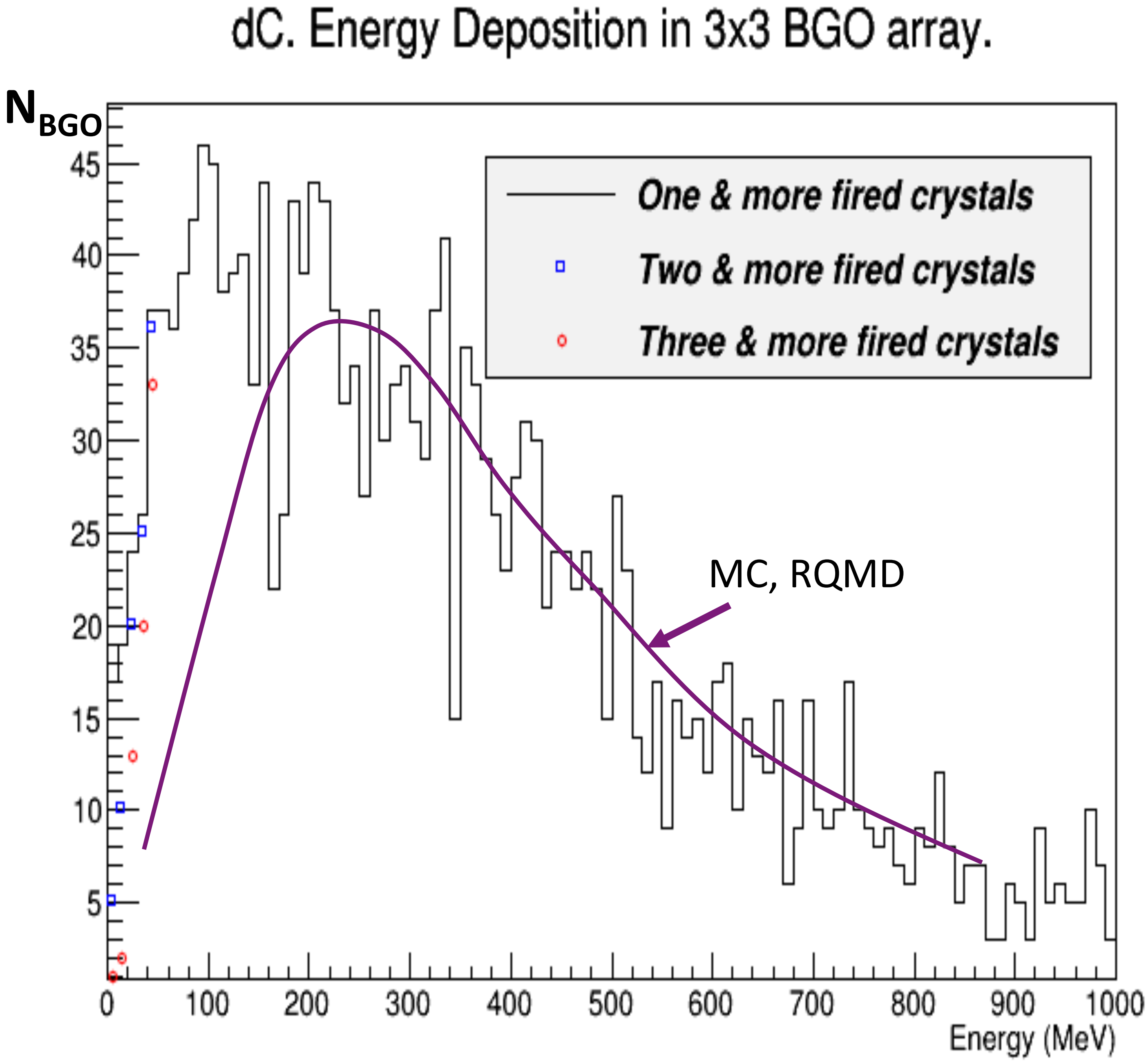


Spectrum of SP is determined by Low formula:

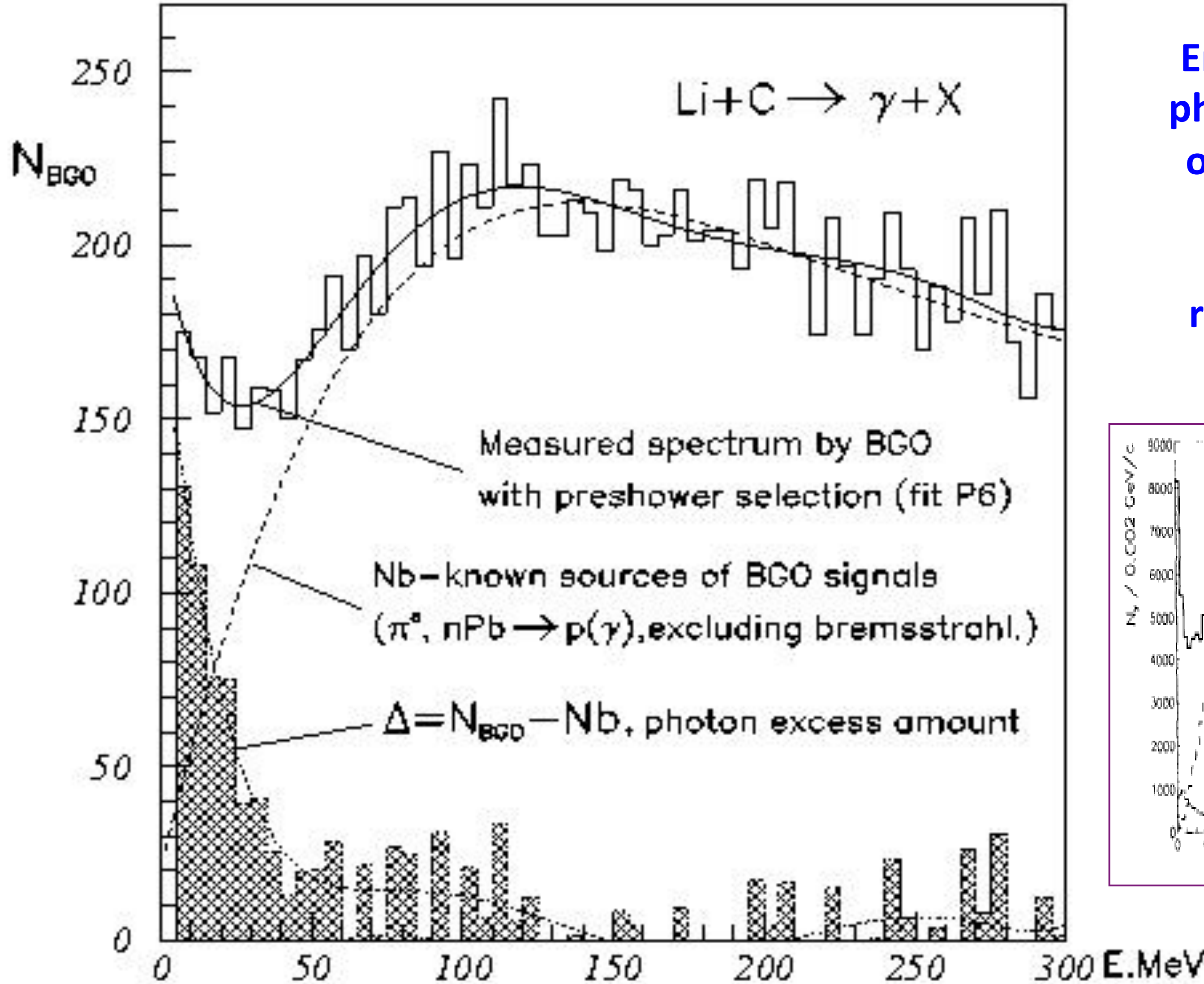
$$\frac{d\sigma}{dp} = \frac{C}{p};$$

$$\sigma_{SP} = \int_{10}^{30\ MeV/c} \frac{d\sigma}{dp} dp = $$

$$\approx 4\ mb.$$



Energy spectrum of photons at the angle of registration 17°. Nuclotron, NIS-GIBS setup, Run 49, March, 2014

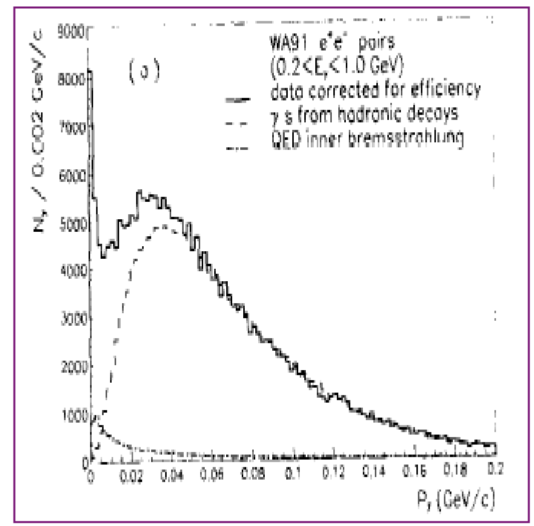


$LiC \to \gamma$, $T(Li)=3.5 GeV/nucl$, $dN\gamma/(dEd\Omega)$, $d\Omega=0.60e\text{-}02sr$, $dE=5MeV$, $\Theta=17^{\circ}$

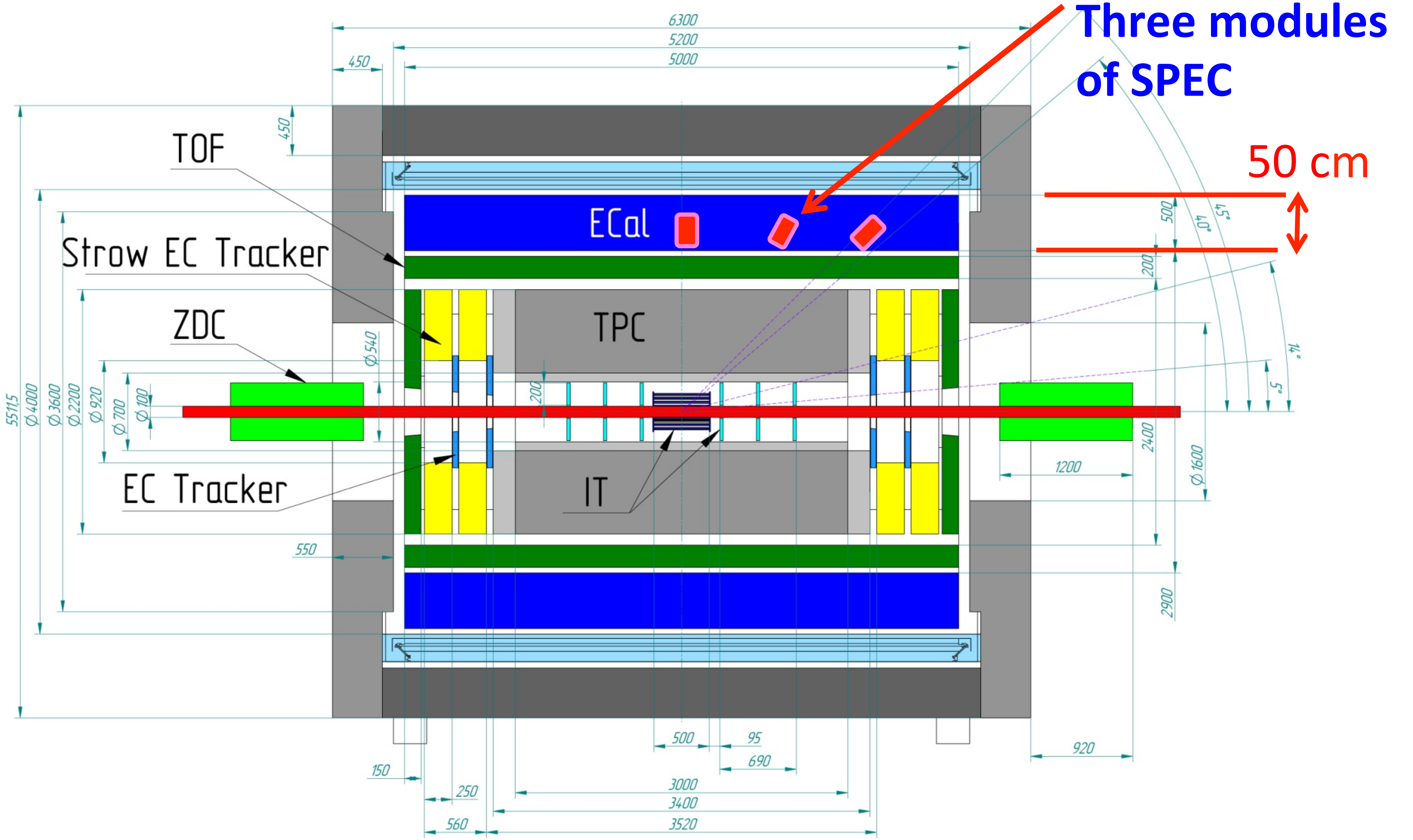
14.06.14, Runs163,165,166 BGO49 calorimeter, N300=11450 (Eγ<300MeV)

Δ/N300=0.05, Nb−approximation of sum of known γ−sources, LiCnb5M.eps

Energy spectrum of photons at the angle of registration 17˚. Nuclotron, NIS-GIBS setup, run 50, April, 2014



Possible location of few modules of SPEC at MPD setup



OUTLOOK

We are planning to carry out MC simulation of the SP calorimeter for the inclusion into BM@N setup and studying of properties of SP:

1) SP yield versus charged, neutral and total multiplicities;
2) SP yield in collisions in light (from deuterium) and heavy (up to gold) ions;
3) Angular dependence of SP yield;
4) Study of $m_{\gamma\gamma}$ spectrum with two SPEC …

Thank you for your attention