Stydy of soft photons at SPD/NICA

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On behalf of SPD
9JINR & GSTU0

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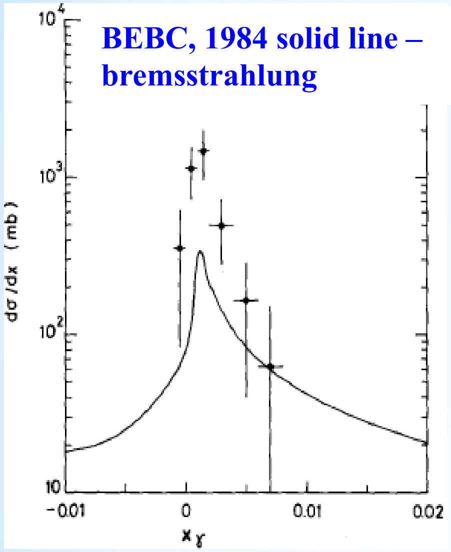
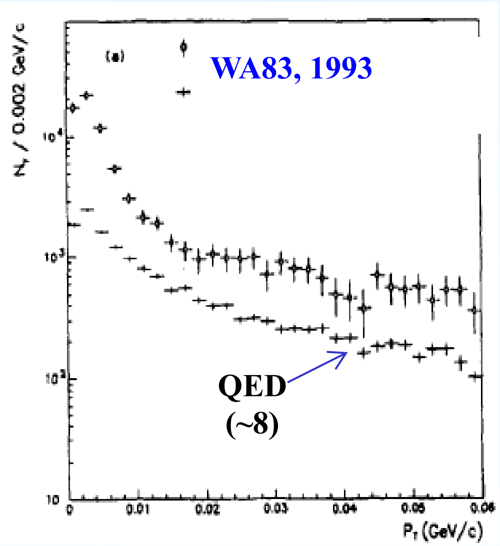
Why are we interested in Soft Photons (SP)?

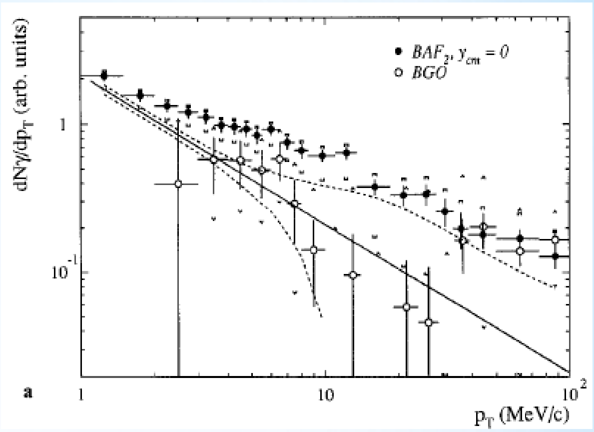
($10 < p_T < 50$ MeV)

1. Excess of SP yield is observed in hadron & nuclear interactions in a wide energy region.
2. SP are direct photons, they are not decay products of other particles.
3. Soft gluons can be sources of SP (GDM).
4. The region of SP formation lies outside pQCD.
5. The relevance of a gluon component for nucleon structure.
6. ECal pure crystals – expensive \$50/cm^3
   "spaghetti" or "shashlik" ("sandwich') - possible way for SP study

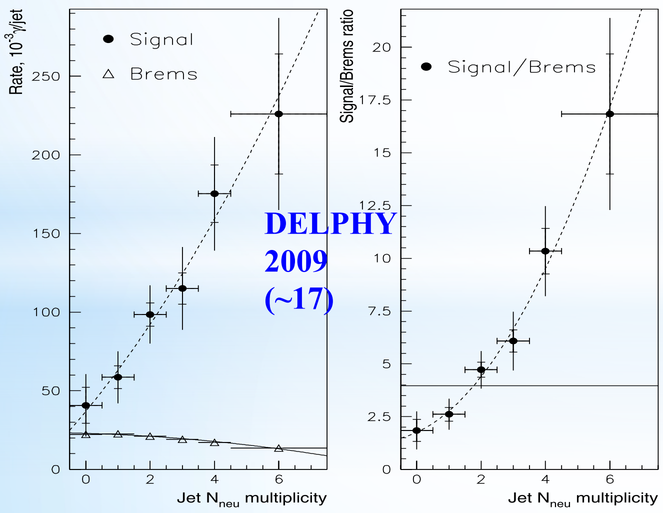
Experiments corroborating SP excess

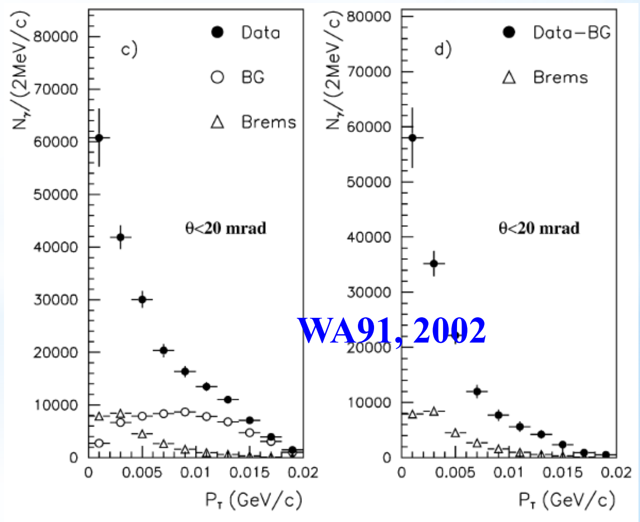






HELIOS, 1989





Gluon Dominance Model:

the main sources of secondary hadrons are active gluons (AG), and valence quarks are staying in leading particles. The rest of gluons, ~ 50%, can't turn into hadrons - not enough energy. [Part.Nucl.Let.,2015]

They are picked up by newly born quarks with following dropping of energy by emission of SP:

$g + q \to \gamma + q$.

We can estimate SP's emission region in the case of almost equilibrium state using the black body emission spectrum for *pp*->hadrons+γ (SP) at U70:

To structure of the proton:

From Xiangdong Jin, 13th Confinement & hadron spectrum (2018):

"Gluons are carriers of the strong force, bind quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleon and nuclei."

Estimation of SP's emission region

$$\sigma_\gamma \approx 4mb, \quad \sigma_{in} \approx 40mb;$$

$$\sigma_\gamma \approx n_\gamma(T)\cdot\sigma_{in} \to n_\gamma \approx 0.1;$$

Black body emission spectrum:

$$\frac{dn_\gamma}{d\nu} = \frac{8\pi}{c^3}\frac{\nu^3}{e^{\frac{h\nu}{T}}-1}.$$

$$n_\gamma(T) = 0.244\cdot V\left(\frac{2\pi kT}{hc}\right)^3, T_r = 2.725K(MVB) \to n_\gamma(T_r)/V = 4.112\cdot 10^8 m^{-3},$$

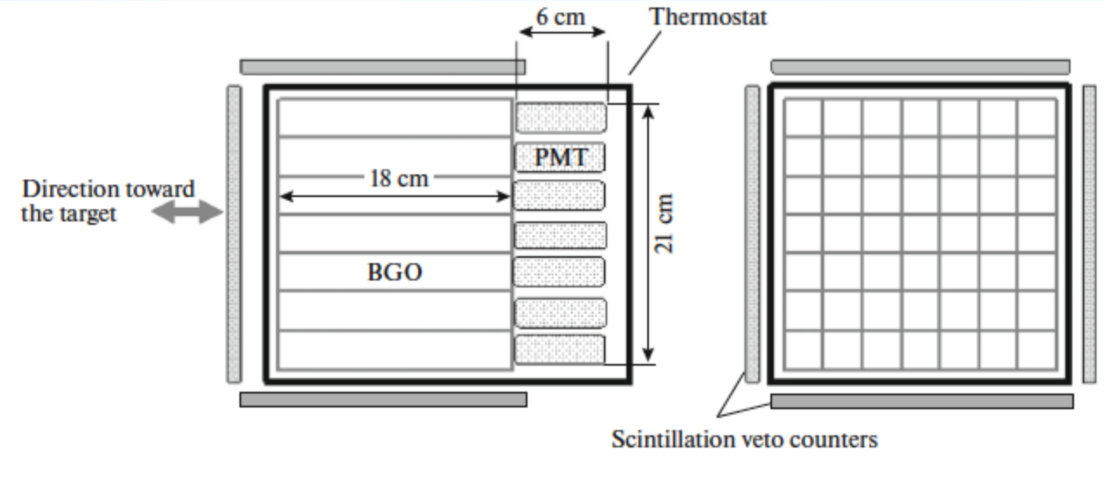
$$n_\gamma(T) = n_\gamma(T_r)\cdot\left(\frac{T}{T_r}\right)^3, \rho(T) = n_\gamma(T)/V = 4.112\cdot 10^8\cdot 10^{-6}\cdot 10^{-39}\left(\frac{T}{T_r}\right)^3 fm^{-3}.$$

$$T = p \approx p_t\cdot\sqrt{2} \qquad L^3\cdot\rho(T) \approx n_\gamma \to L(T),$$

[Part.Nucl.Let., 2004]

L ~ 4-6 fm – hadronization region?

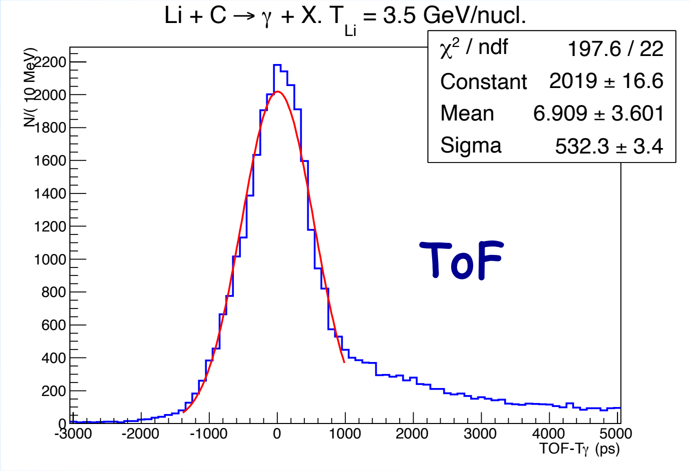
SP registration by ECal at Nuclotron



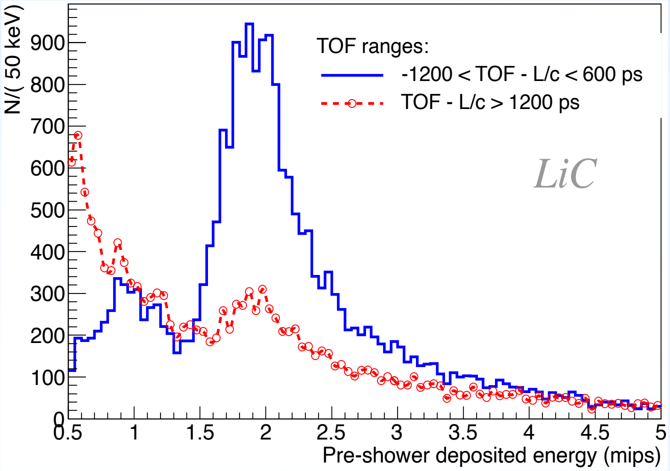
ECal scheme

A general view of ECal based on BGO crystals with veto-detectors at NIS-GIBS setup (Nuclotron, JINR)

SP registration at Nuclotron



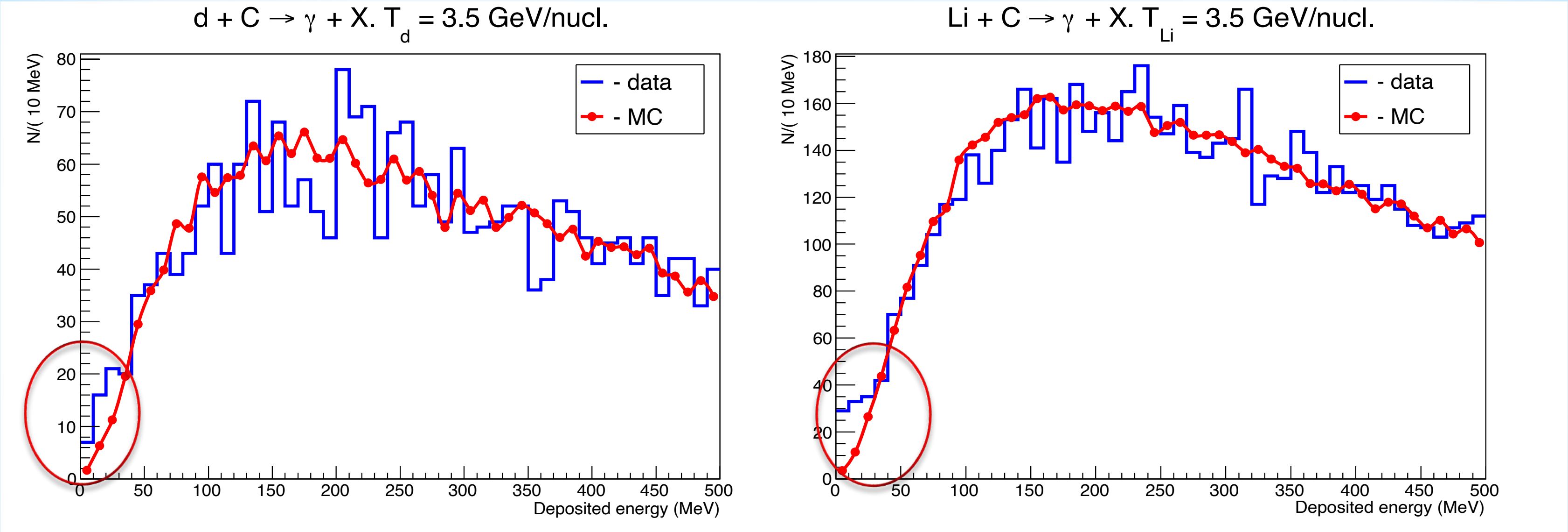
beamcounter – pre-shower



neutral particle spectra with temporal selection

<u>Criterions of selection</u>: 1) E in the front veto-counter < 0.3 MIPs; 2) E in the pre-shower 0.5 < *E* < 4 MIPs; 3) ToF: -1200 < $t - t_\gamma$ < 600 ps; 4) E of more than 2 MeV is registered in one BGO crystal; 5) location of shower in crystal must overlay throughout vertical with the triggered pre-shower counter; 6) Energy deposition in the outer BGO layer should be ≤ 1/3 of a total to prevent significant leakages.

SP yield at Nuclotron



Experimental and MC spectra of energy release in ECal + a pre-shower with 3.5A GeV/*c* beams of D (left) and Li (right) (50th + 51st runs) .

Measurement of Soft Photons (SP)

($10 < p_T < 50$ MeV)

ECal can be made of crystals or present heterogeneous structure: "shashlik", "spaghetti"...
The first type: expensive,~ $50/cm³;
The second one: cheaper, ~ $5-$30/cm³.
Threshold for "shashlik" from 100 MeV, not enough for SP registration.

Expect parameters of ECal's

We would like to fill a niche between heterogeneous structures “shashlik” for region 10-50 MeV (SP) with light yield ~ 3-6 ph/MeV and crystal detectors - light yield ~10,000 -40,000 ph/MeV.

We’re aimed at creation of “heavy” ECal’s:

- scintillation decay time ~ 90 ns;
- light yield ~ 2000-3000 ph/MeV;
- price about \$25-35/cm^3 of volume;
- radiation resistance.

"Spaghetti" calorimeter (SPACAL)

We manufactured two prototypes of SpaCals, which consists of:

1) W+Cu composite (absorber);
2) gallium-gadolinium-garnet (scintillator) $Gd_3Al_2Ga_3O_{12}$:Ce (GaGG) monocrystals

and arranged them in a beam.

Comparison of scintillator properties

Parameters	$Gd_3Al_2Ga_3O_{12}$	$Bi_4Ge_3O_{12}$	NaI:Tl
light yield, 10^3ph/MeV	57	8	38
energy resolution, (%@662кeV)	5,2	12	7,1
decay time, ns	88	300	250
hygroscopicity	-	-	+
Density, g/cm^3	6,63	7,13	3,67
Radiation peak, nm	520	480	415

Preferences of $Gd_3Al_2Ga_3O_{12}$:

- ✓fast-acting scintillator;
- ✓high light yield;
- ✓lack of hygroscopicity;
- ✓maximum of luminescence coincides well with peak SiPM's;
- ✓crystal doped with B and Ba have a higher light yield - 50,000 ph/MeV, and decay time ~ 56 ns;

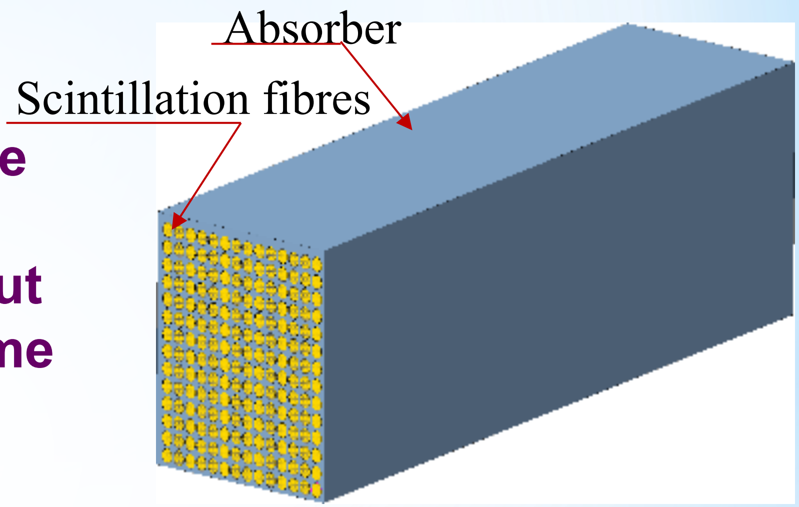
Expected principal advantages:

- ✓ timing at the level of 90 ps. Separating of neutron fluxes from the recording SP that's difficult for slower BGO crystals.
- ✓ Light yield in GaGG is 4 times more than in BGO.
- ✓ Compactness (space-saving). Integral density of this material is higher than light plastic density.
- ✓ Irradiation tests demonstrate good radiation resistance of GaGG.

SPACAL technology is a type of the sampling calorimeter with scintillation fibers running along shower direction.

This type of module makes possible reducing active material by ~30% compared to “shashlik” type without worsening of ER and even with some improvement of it.

Granularity of module is defined by the granularity of read-out system.



SPACAL module

Optimization of scheme. Questions

How does the energy loss in the absorber and energy resolution (ER) depend on the the fiber-to-fiber distance?

We should make clear what is more important - ER or compactness of shower, and then, choose sensible configuration.

Expectation of ER: < 10%/E +1%

Manufacture of SpaCal prototype

Our activities is aimed at:

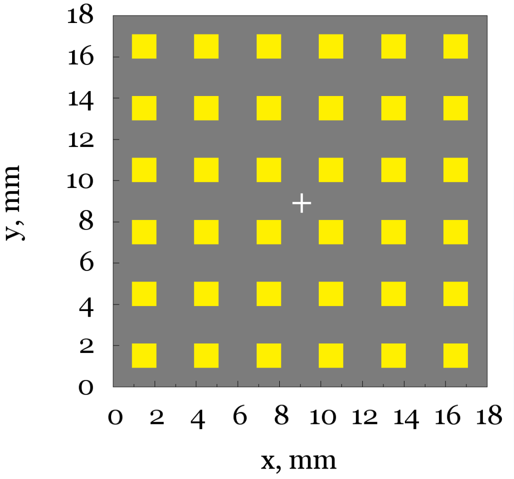
- ✓ design and manufacture prototypes of a detector cell based on W/Cu and GaGG: Ce;
- ✓ investigate and optimize the efficiency of collecting of scintillation light;
- ✓ simulate the development of an electromagnetic shower profile in SpaCal;
- ✓ study the possibilities to use the W/Cu/Pb + GaGG: Ce detector cells as SpaCal for the SP study.

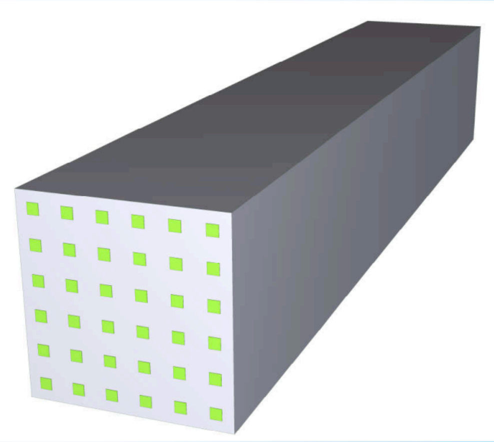
Everything's in progress.

SpaCal scheme

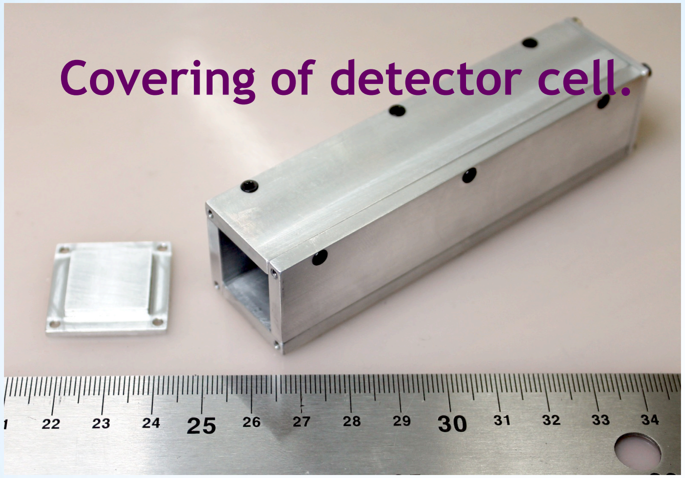
The prototype detector cell is an assembly of W+Cu composite plates and rods, and GaGG: Ce rods, with shape of a rectangular parallelepiped: 18 × 18 × 100 mm^3. It has of 6x6 (1×1×100 mm^3) scintillator rods surrounded by absorber. The surfaces of plates and absorber rods are coated with a 10 μm polymer dim white reflector. We test 2 such assemblies.

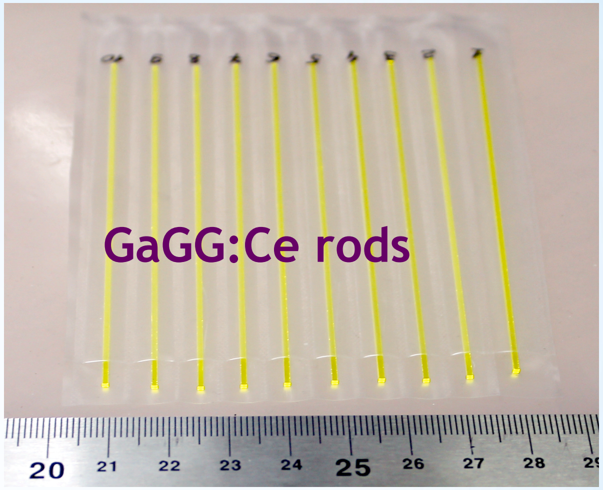
Detector cell with yellow/green rods, and grey plates.

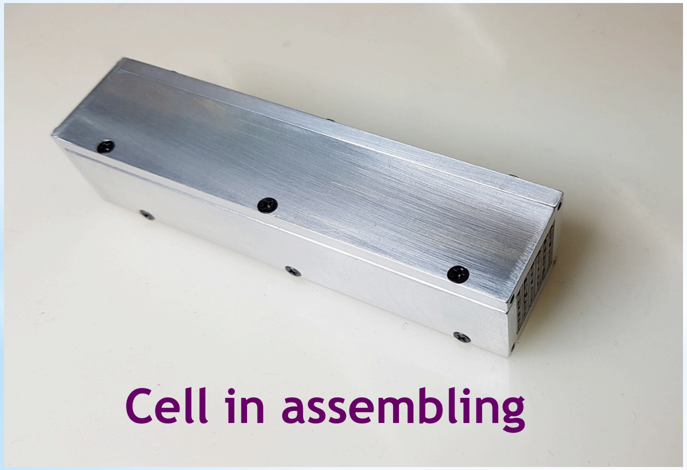


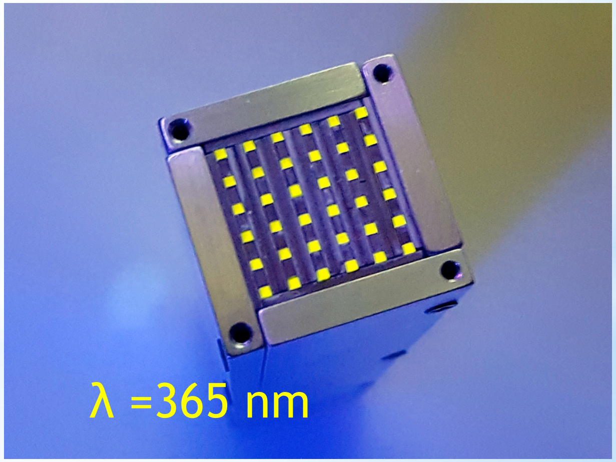


SpaCal assembly

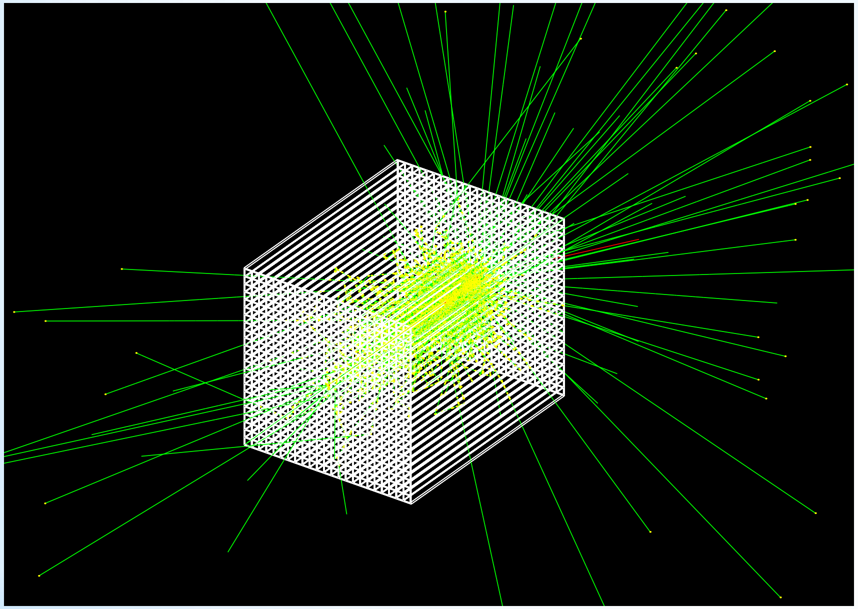




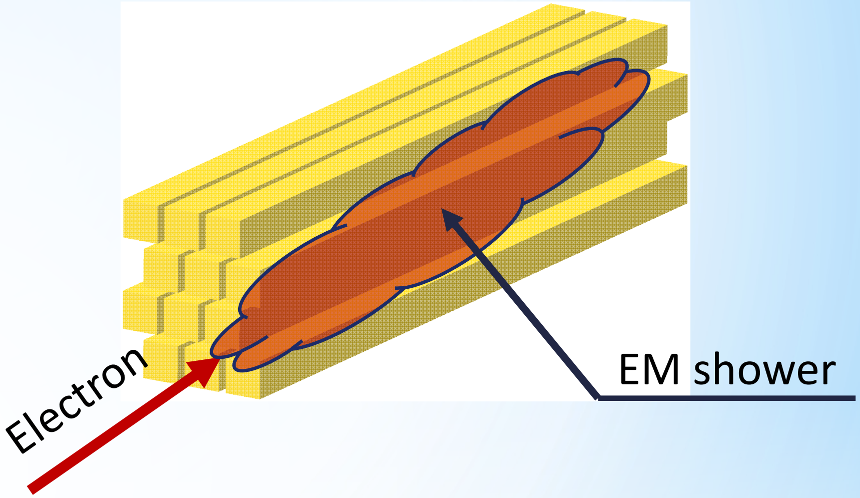




Simulation of SpaCal

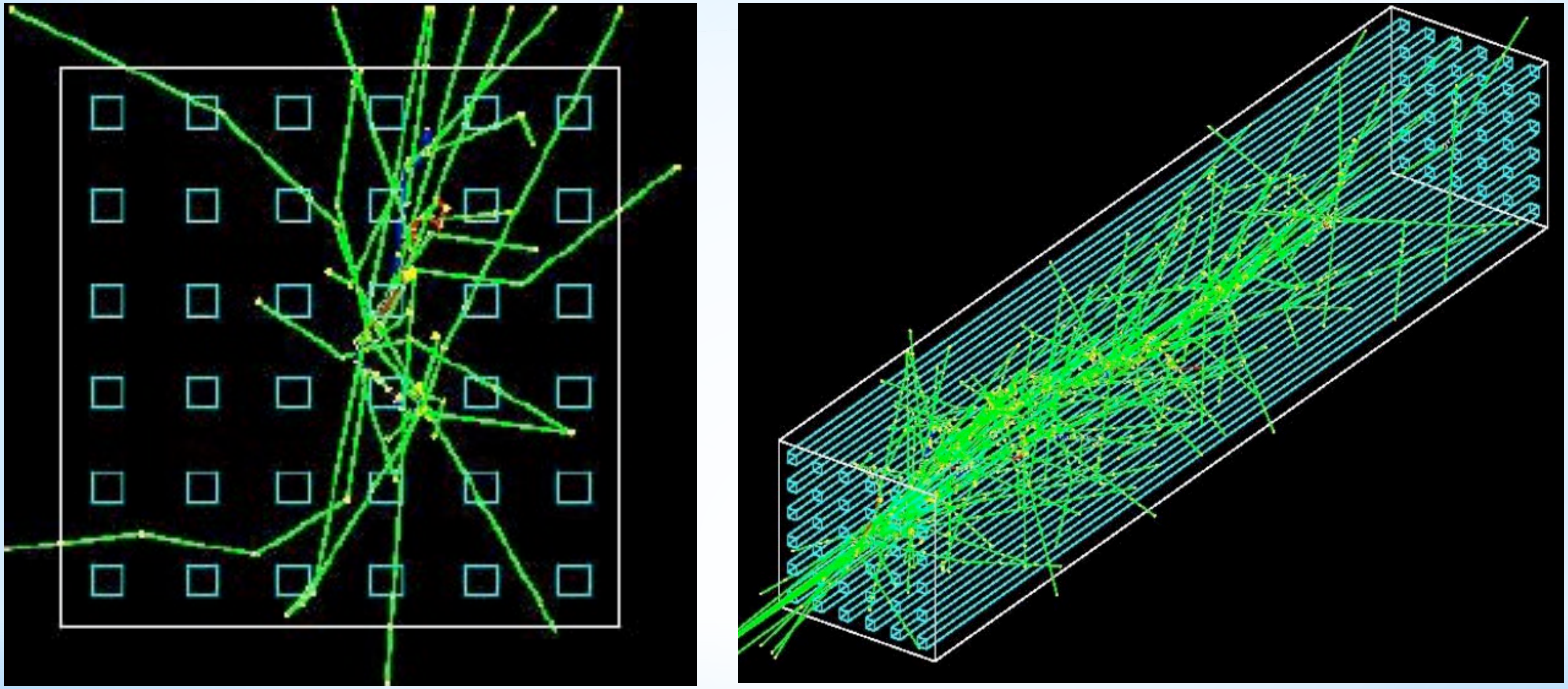


Spatial development of a shower at irradiation of assembly with 23x23 GaGG rods, $6x6x210mm^3$, 1mm gap by 10^3 photons with E_γ = 5 MeV, absorber – W+Cu.



Increasing the angle entails more fibers crossed by shower, but decreases the energy deposit in each of them.

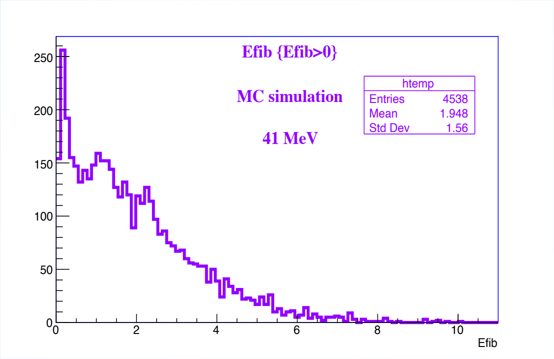
Simulation of SpaCal

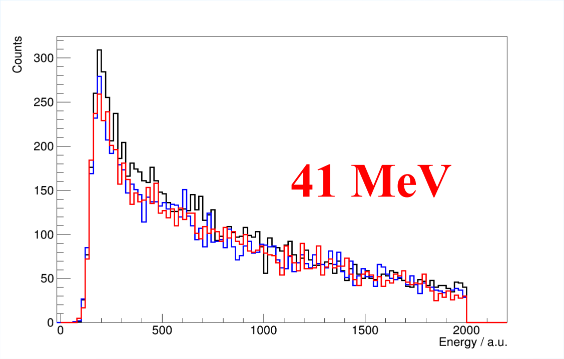


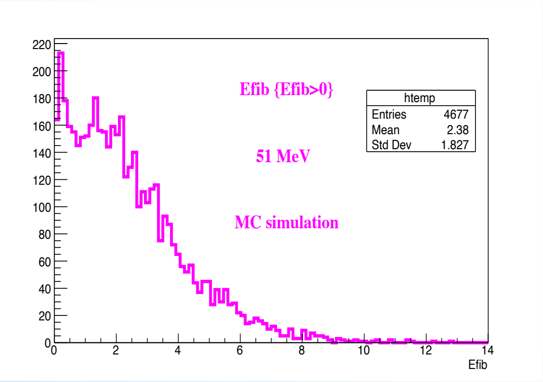
Spatial development of a shower at irradiation of assembly with 6x6 rods by single (left) and 10 photons (right) with E_γ = 100 MeV, absorber – Pb+Cu

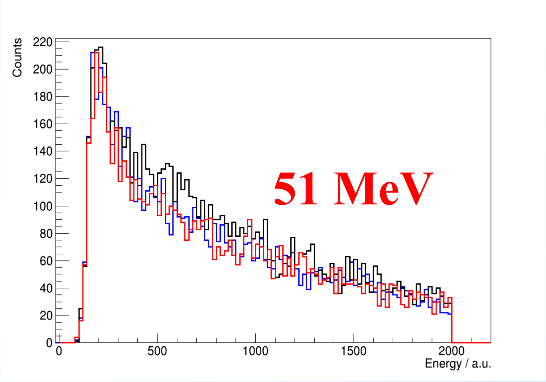
MC simulation

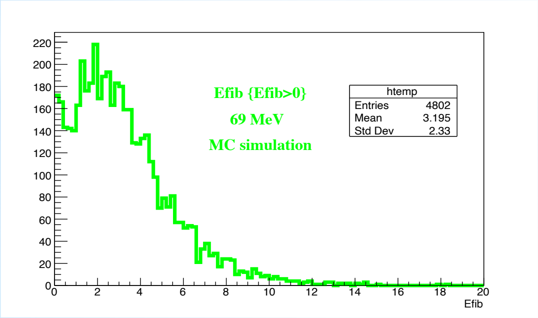
Data, Jun-2019

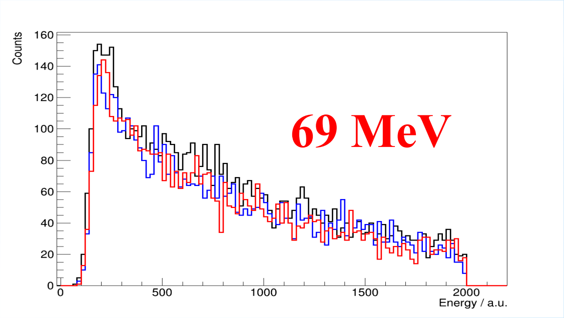






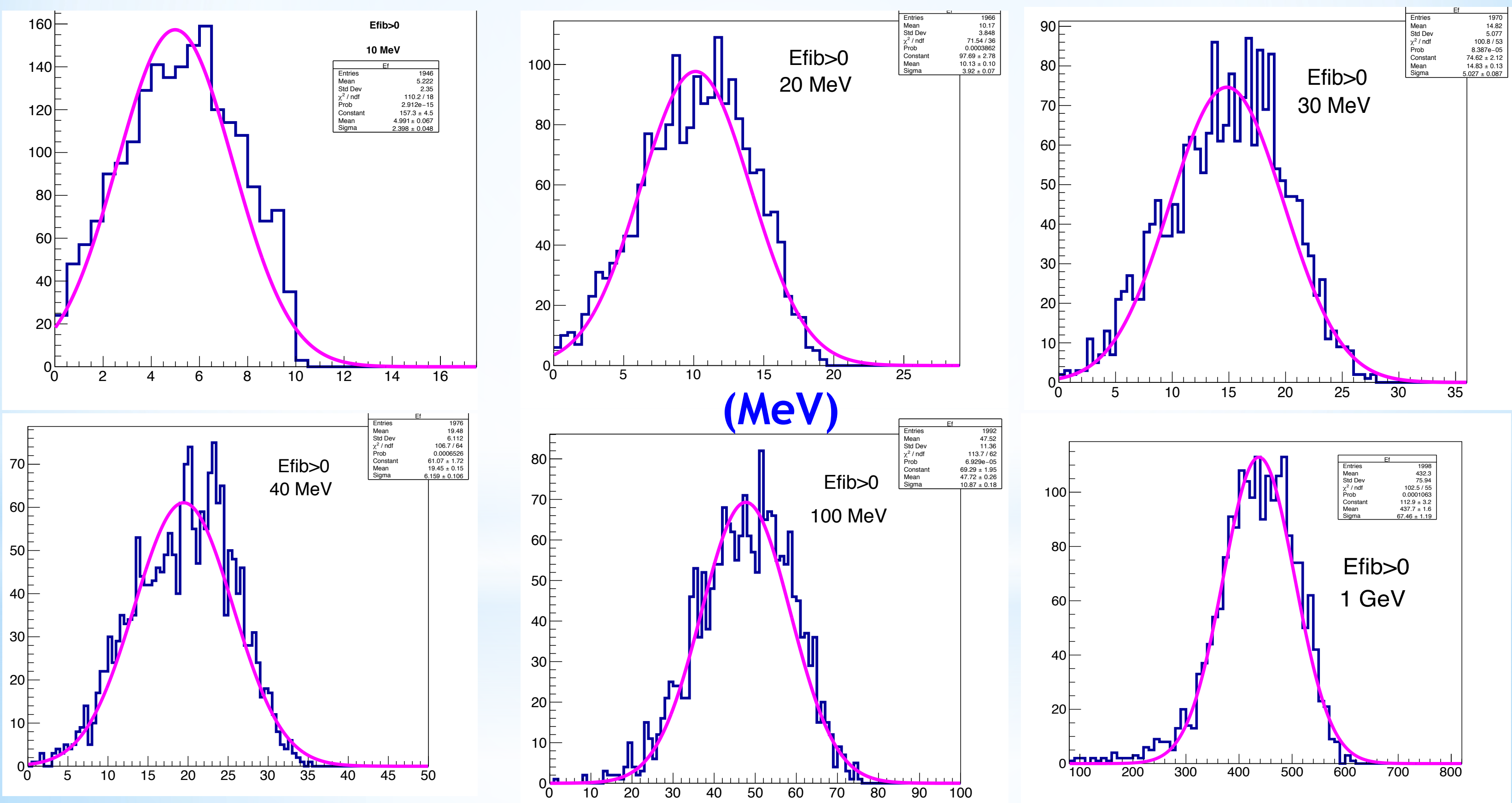






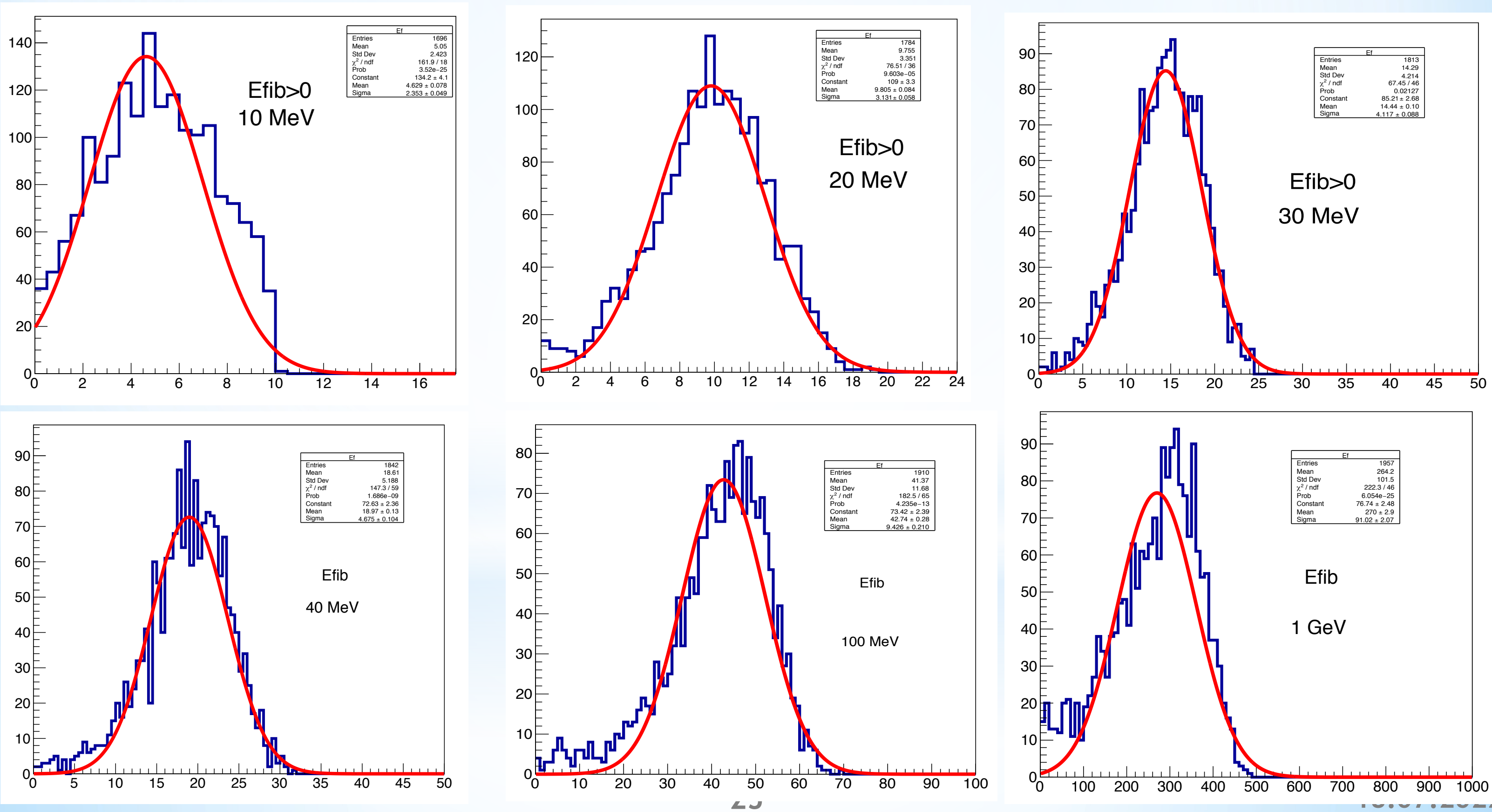
MC simulation of SpaCal

WCu(1/19),25x25 rods GaGG (3x3 mm^2), 1mm-gape, 101x101x150 mm^3

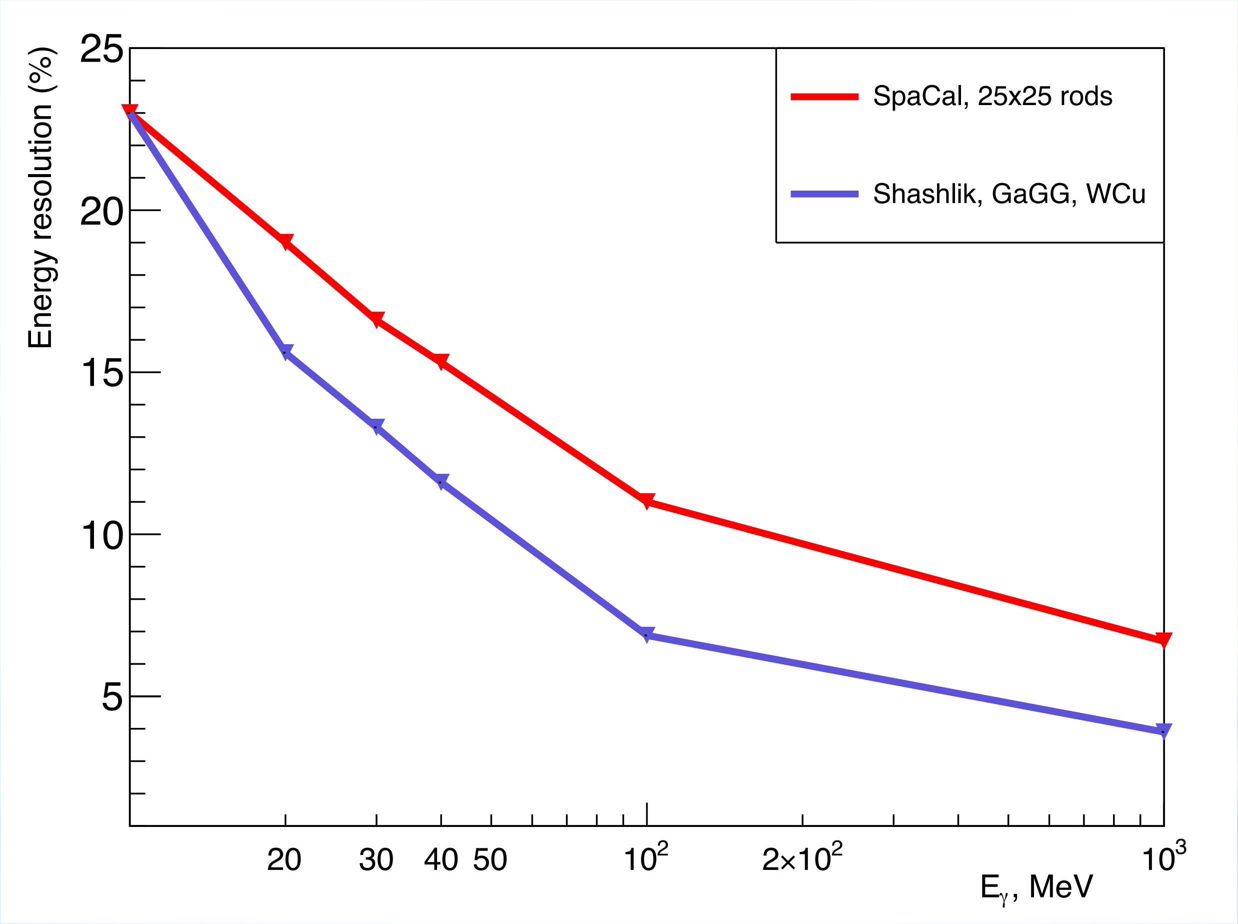


MC simulation of Shashlik

16 plates GaGG (100x100x3 mm^3), 15 plates of 2mm-absorber WCu(1/19), thickness - 78mm



Energy resolution SpaCal vs Shashlik



Energy release of EM shower in cell

GEANT4: SpaCal is irradiated by narrow beam (~0.2 mm) of photons with energy 100 MeV - 10 GeV hit in the center of assembly. The energy release in GaGG rods to total energy release is $\eta = 100\% \cdot E_{GaGG}/E_{tot}$.

Results:

$\langle\eta_W\rangle = 2.83\% \pm .01\%$, $\langle\eta_{Pb}\rangle = 5.25\% \pm .01\%$,
$\langle\eta_{Cu}\rangle = 6.49\% \pm .01\%$ -> choice of W/Cu composition.

Scintillation yield at irradiation with 662 keV γ-rays is 3940 phe/MeV if the source is located at the bottom face of the cell to the photo-receiver, 3300 phe/MeV - for top face of it.

Our plans

For SpaSal ER will be 10 % and better for photons with E_γ above 50 MeV with SiPMs and the correct scheme for transporting of light to a photo detector.

MC simulation and experiment with prototype of Shashlik with GaGG scintillator and W/Cu absorber to demonstrate better ER at low energy then with SpaCal's. In progress.

We also learn possibilities of using of Glass and Glass Ceramic Stoichiometric and Gd^{3+} heavy loaded BaO*2SiO2:Ce(DSB:Ce) scintillation material for ECal application.

Conclusions

1. The unique physical program of SP study is proposed. It can be carried out at accelerator setups of JINR and others.
2. Simulation of SpaCal and “Shashlik” is evidence this program are quite reasonable and feasible.
3. SpaCal’s parameters can be improved by changing of the section of crystal rods, adjusting the absorber density, and optimizing the length of SpaCal for a certain energy range of photons.

Thank you for attention