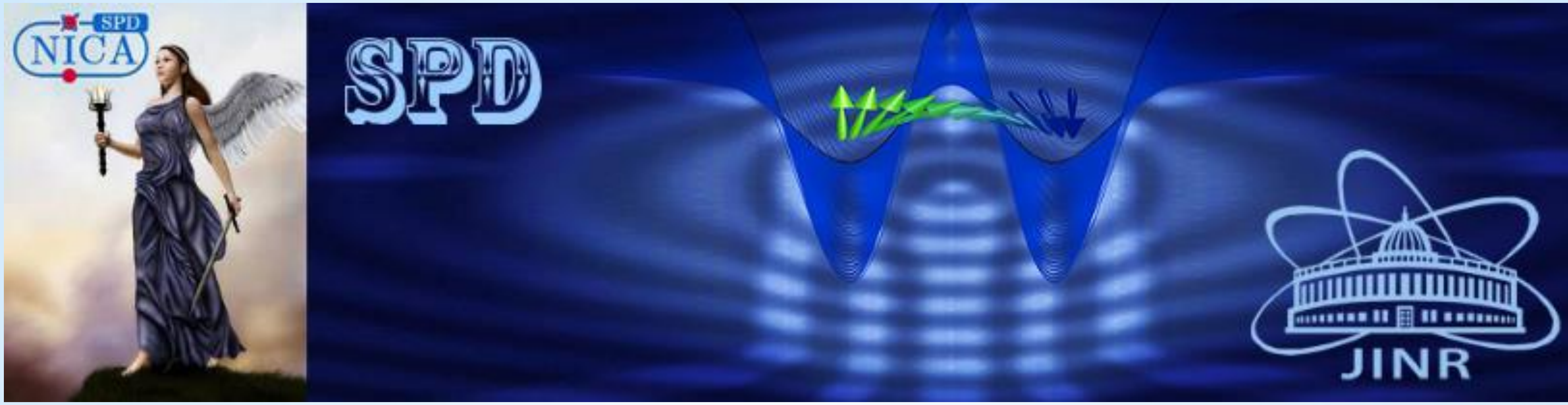


Study of soft photon yield in pp & pA interactions at JINR

V.Dunin, A.Gribowsky, E.Kokoulina, M.Korzhik, A.Kutov, E.Mosolova, V.Nikitin, V.Popov, V.Riadovikov, I.Roufanov, R.Shulyakovsky, A.Vorobiev

JINR, DM UralD RAS, SPbPU, IHEP (Russia), INP BSU, IAP NAS (Belarus)

International workshop “SPD at NICA 2019” 4-8 June 2019, Dubna

Why are we interested in Soft Photons (SP)?

(10 < p < 50 MeV)

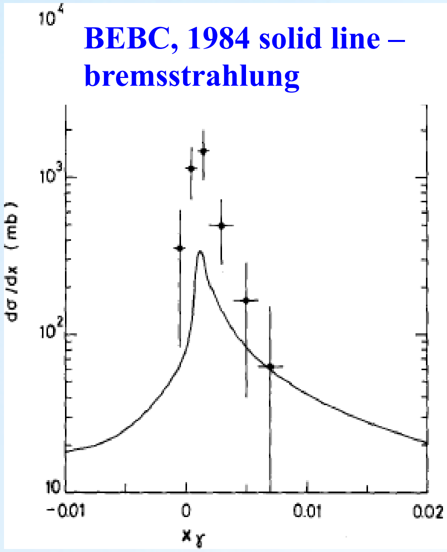
1. The observable excess of SP yield in hadron & nuclear interactions in a wide energy region.
2. SP are direct photons, not decay products of other particles.
3. Soft gluons can be sources of SP (GDM).
4. The region of SP formation lies outside pQCD.
5. The relevance of a gluon component for nucleon structure.
6. Ecal pure crystal – expensive $50/cm"spaghetti"- possible way for SP study

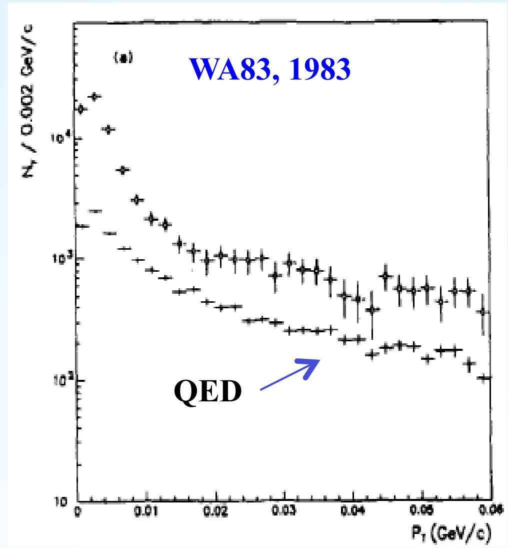
Mesurement of Soft Photons (SP)

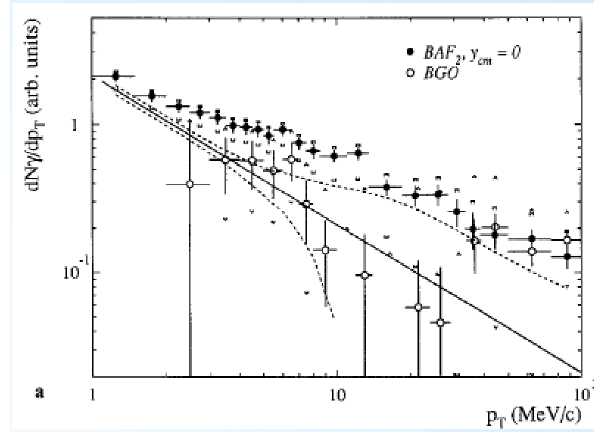
(10 < p < 50 MeV)

ECal can be made of crystals or present heterogeneous structure (“shashlik”, “spaghetti”).
The first type: expensive,~$50/cm^3;
“spaghetti”: cheaper, $25-35/cm^3.
Threshold for “shashlik” ~ from 100 MeV, not enough for SP registration.

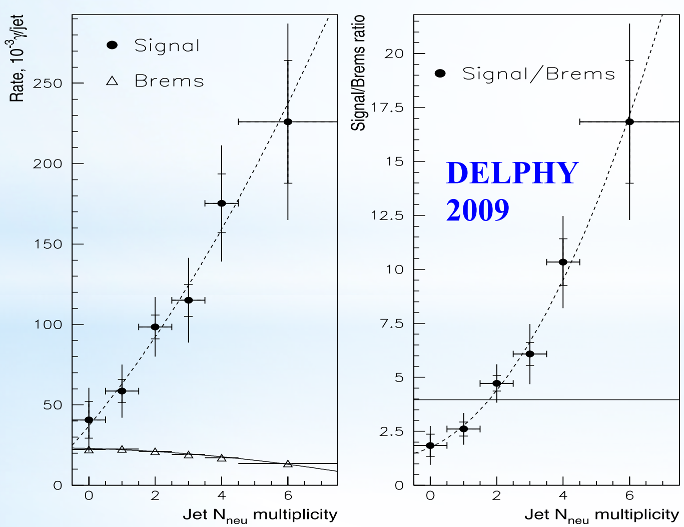
Experiments corroborating SP excess

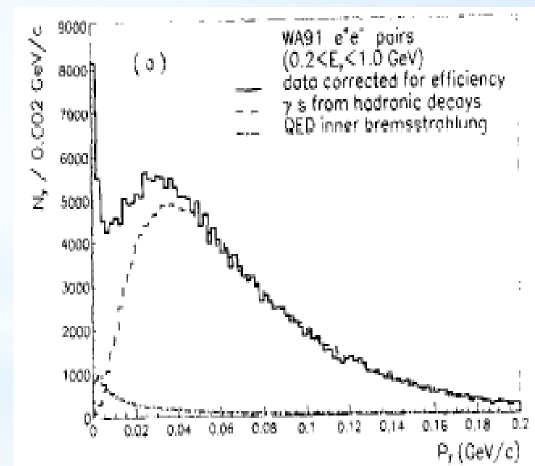






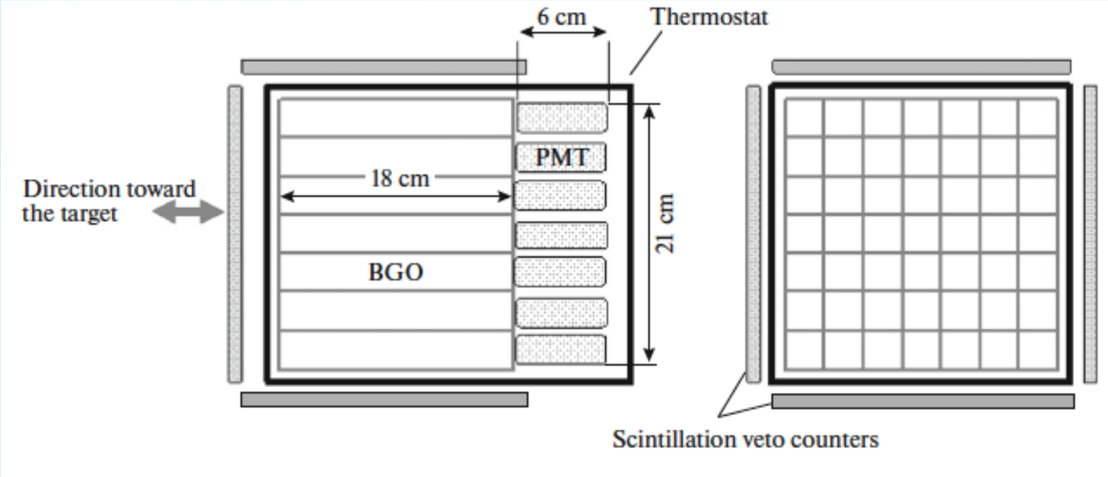
HELIOS, 1989





WA91, 2002

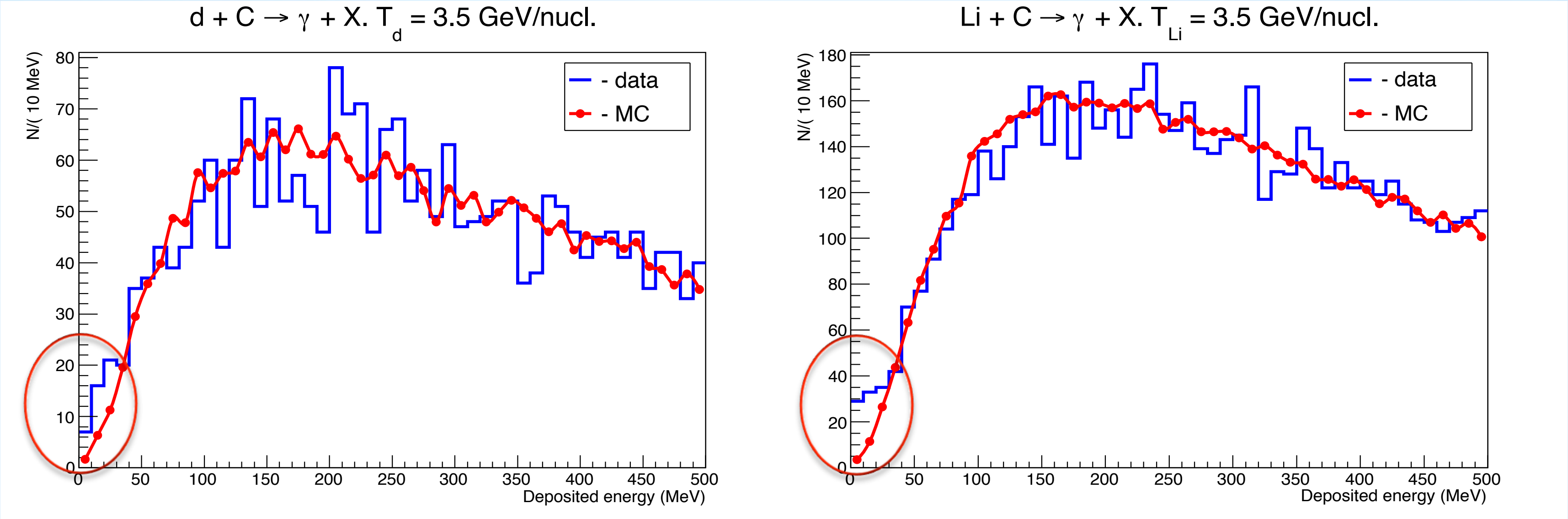
Registration of SP with ECal at Nuclotron



ECal scheme

A general view of ECal based on BGO crystals with veto-detectors at NIS-GIBS setup

Excess of 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) .

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

Proposal for extra program at SPD

1. Bose-Einstein condensate (BEC) formation in *pp* interactions at high total multiplicity.
2. Connection between the pion condensate (BEC) and excess yield of SP.
3. Search for new resonances in the system of two γ-quanta: $f_0(500)$ or σ-meson.
4. γ-femtometry for SP (WA98).
5. Search for *P*-parity violation effect in events with high p_T.
6. Anisotropy of SP in flow (v_2). Is emission of SP coherent or incoherent?

Gluon Dominance Model:

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

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 +SP at U-70:

Estimation of SP's emission region

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

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

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

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

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

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

L ~ 4-6 fm – hadronization region?

M.Volkov,E.K.,E.Kuraev. Part.Nucl.Let., 2004

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."

Expect parameters of SpaCal

We'd like to fill a niche between heterogeneous structures “shashlik” – light yield ~ 3-6 ph/MeV and monocrystal detectors – light yield ~10,000 -40,000 ph/MeV for region10-50 MeV.

Aim: an inexpensive calorimeter module with
- scintillation decay time ~ 100 ns
- light yield ~ 2000-3000 ph/MeV
- price about $25-35/cm^3$ of volume
- radiation resistance.

Our 2 prototypes (density ~ 10 g/cm^3) consists of W-Cu-Ni composite + gallium-gadolinium-garnet (GaGG) monocrystals arranged in a beam.

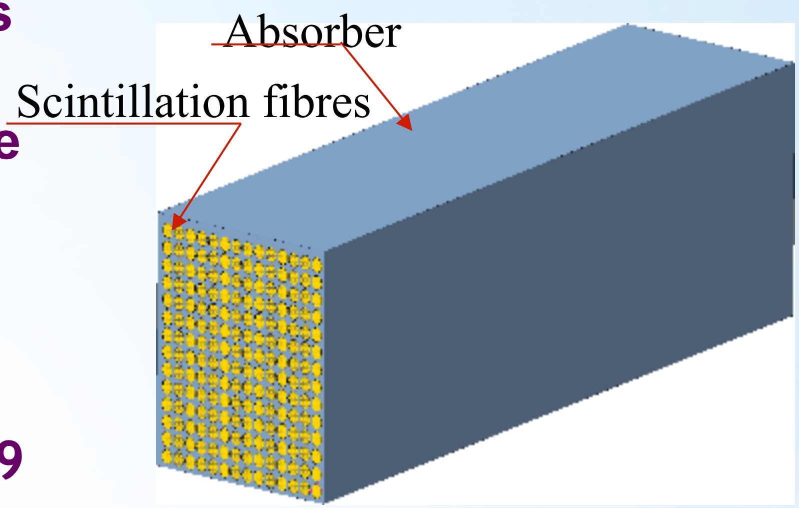
Expected principal advantages

- ✓ Energy conversion factor (transmission coefficient) ~ 3000 phe/MeV of absorbed energy.
- ✓ timing at the level of 300 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 bigger than light plastic density.
- ✓ Irradiation tests demonstrate good radiation resistance of GaGG.

Spaghetti calorimeter (SPACAL)

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

Using of that type of module makes possible reducing active material by ~30% compared to Shashlik type without worsening of energy resolution.
The constant term at 3° is 3.7%, goes down to 1.5% at larger angles, but there is no difference at 6 and 9 degrees.
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 depend on the distance between the fibres?

Energy resolution (ER) strongly depends on the fibre-to-fibre 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 module

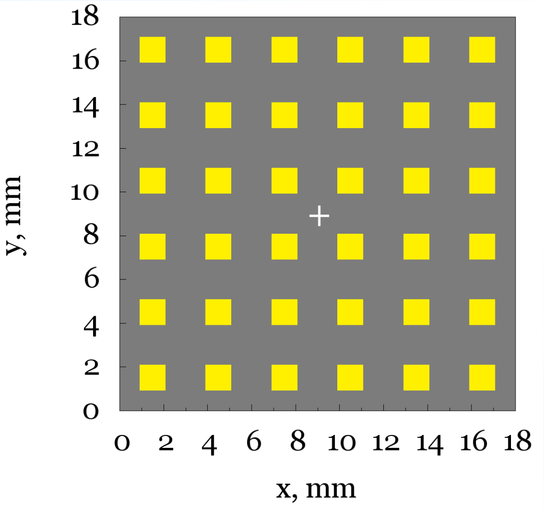
Our activities is aimed at:

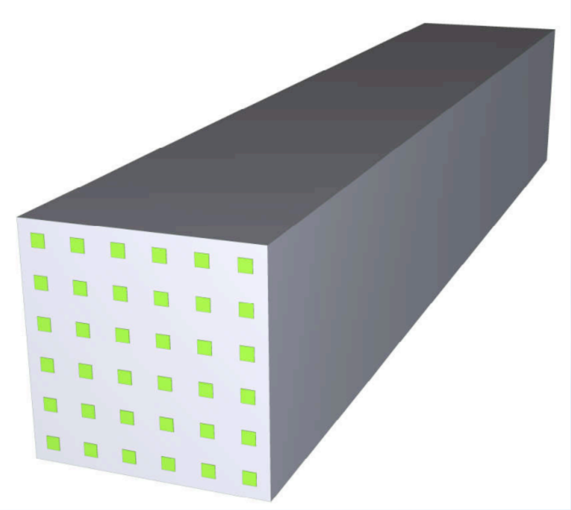
- ✓ design and manufacture 2 prototypes of a detector cell based on W and GaGG: Ce,
- ✓ investigate and optimize the efficiency of collecting of scintillation light,
- ✓ simulate the development of an electromagnetic shower profile in SpaCal.
- ✓ study the possibilities to use the W + GaGG: Ce detector cells as SpaCal for the SP study.

Everything's in progress.

SpaCal scheme

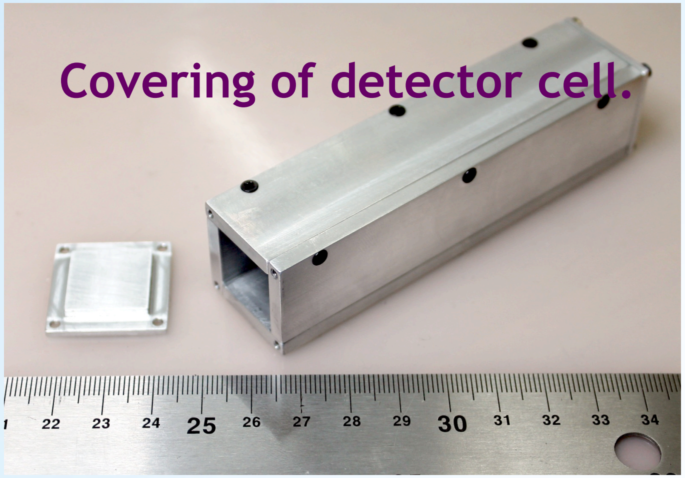
The prototype detector cell is an assembly of W+Cu composite plates and rods, and GaGG: Ce rods, with shape of a rectangular parallelepiped: 18 × 18 × 100 mm^3. It has of 6x6 (1×1×100 mm^3) scintillator rods surrounded by absorber. The surfaces of plates and absorber rods are coated with a 10 μm polymer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

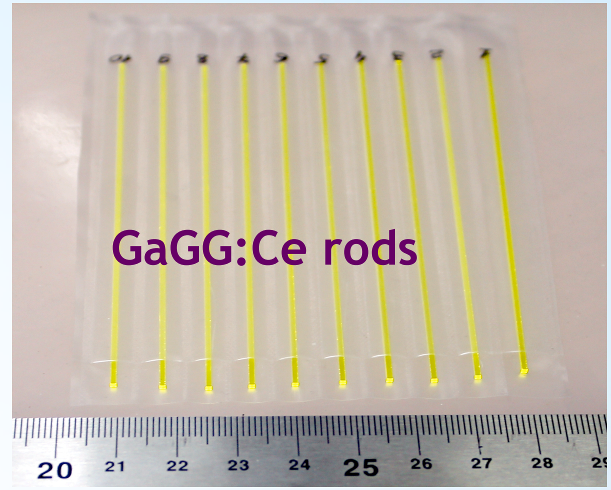


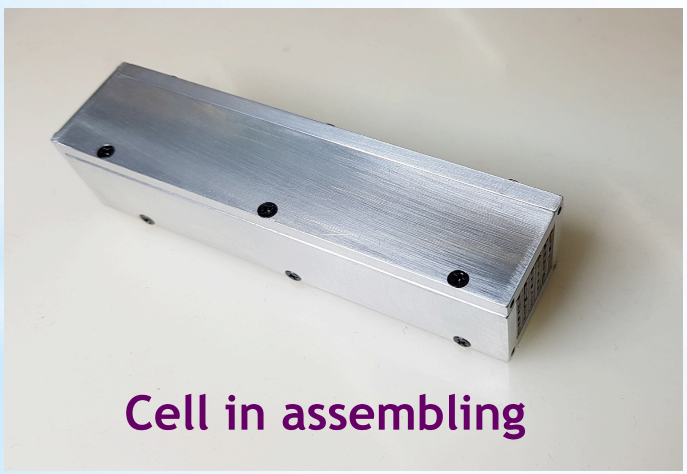


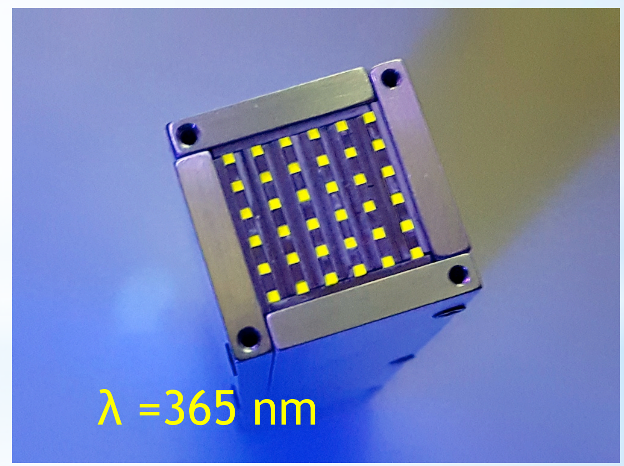
Detector cell with yellow/green rods, and grey plates.

SpaCal assembly

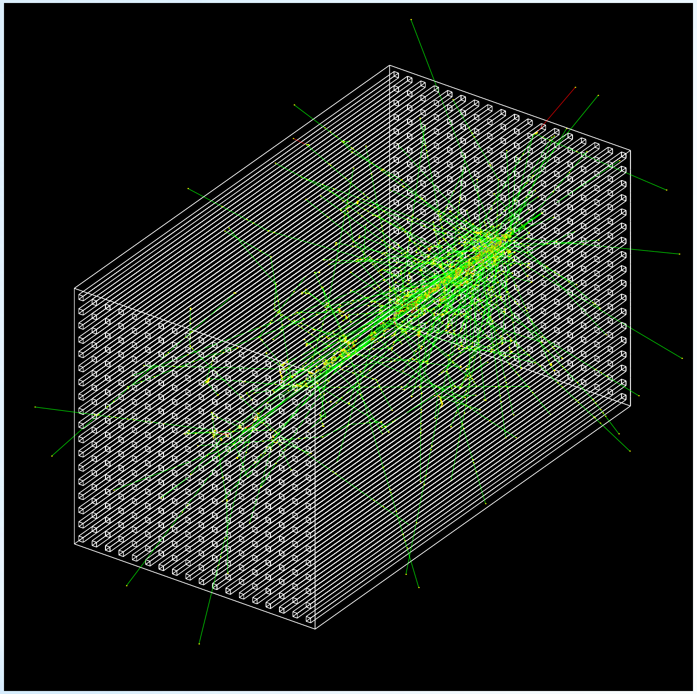




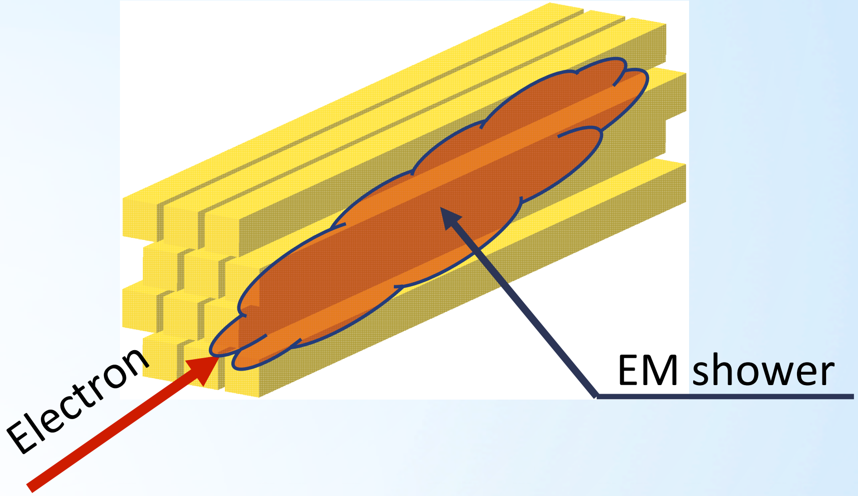




Simulation of SpaCal

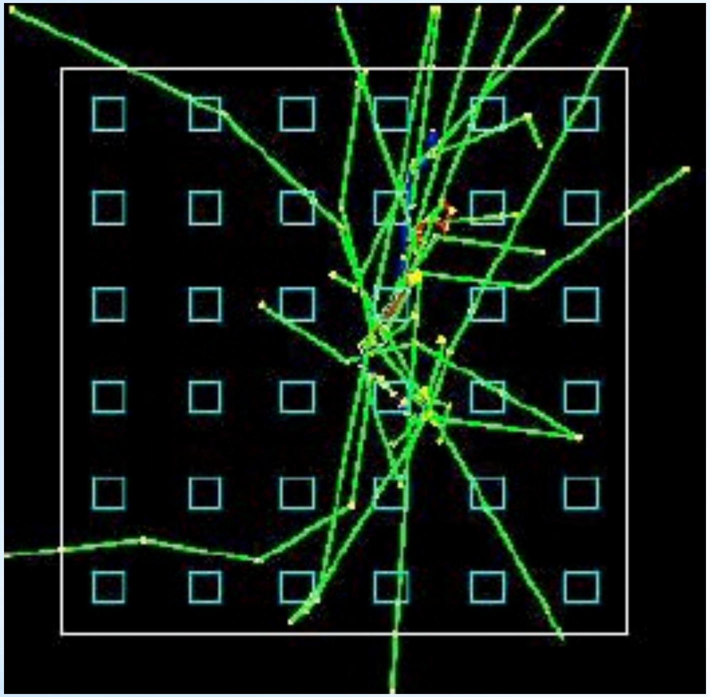


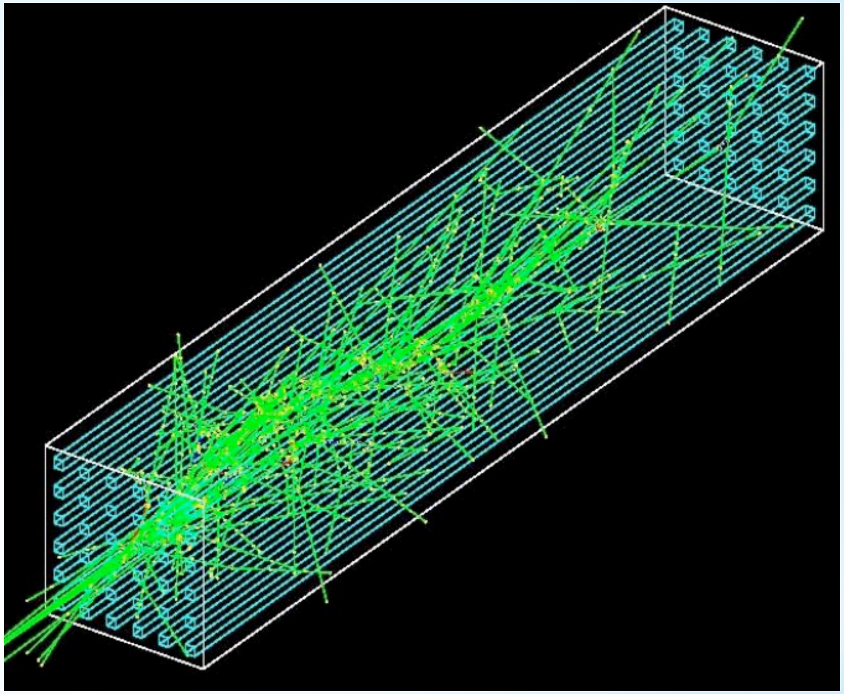
Spatial development of a shower at irradiation of assembly with 18x18 rods by 77 photons with E_γ = 15 MeV, absorber – W+Cu



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

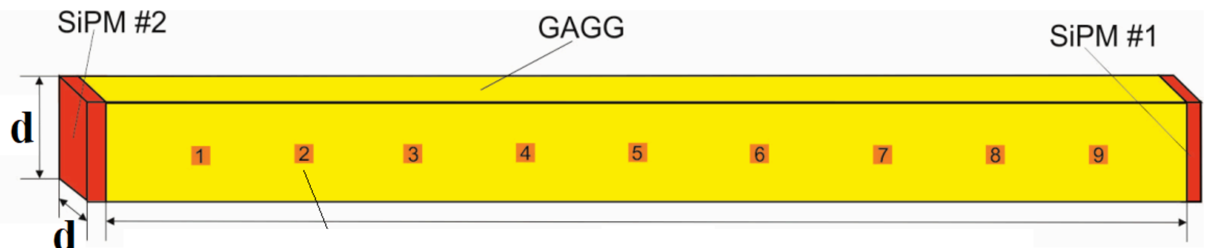
Simulation of SpaCal





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

Simulation of SpaCal



Disposition of radioactive source

Composite W+Cu with a density 12.7 g/cm^3 is chosen as absorber. The Slitrani software package is used to simulate the transport and light collection of scintillation photons in GaGG: Ce rods and investigate of heterogeneity of light collection in a cell at transverse size of rod (dxd): 1x1, 2x2 or 3x3 cm^3. Simulation: inhomogeneity doesn't depend on that d. Availability of reflector increases light gathering at a coefficient optical absorption k=1m^{-1} (k = 2m^{-1}) by 32% (17%).

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:

$<\eta_W> = 2.83\% \pm .01\%$, $<\eta_{Pb}> = 5.25\% \pm .01\%$,
$<\eta_{Cu}> = 6.49\% \pm .01\%$ -> 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.

Results

ER will be better than 10% for photons with energy above 5 MeV with SiPMs and the correct scheme for transporting of light to a photo detector.

Parameters of assembly can be improved by changing of the cross section of the crystal rods, adjusting the absorber density, and optimizing the length of SpaCal for a certain energy range of the detected gamma quanta.

Conclusions

1. The unique physical program of SP study is proposed. It can be carried out at accelerator setups of JINR.
2. Simulation of SpaCal is evidence this program are quite reasonable and feasible.
3. We invite everyone who is interested in SP study to join to this program.

Back slides

Possible effects in SPACAL module

Self-Compensating effects

✓ Particle goes through fibers leading to an increase of deposited energy in them, but shower crosses only a few fibers.

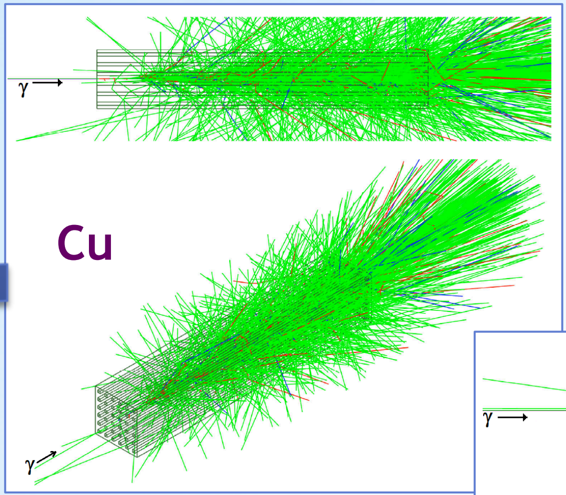
✓ Increasing the angle entails more fibers crossed by shower, but decreases the energy deposit in each of them.

Next steps: Beam test measurements of prototype and calibration MC by collected data.

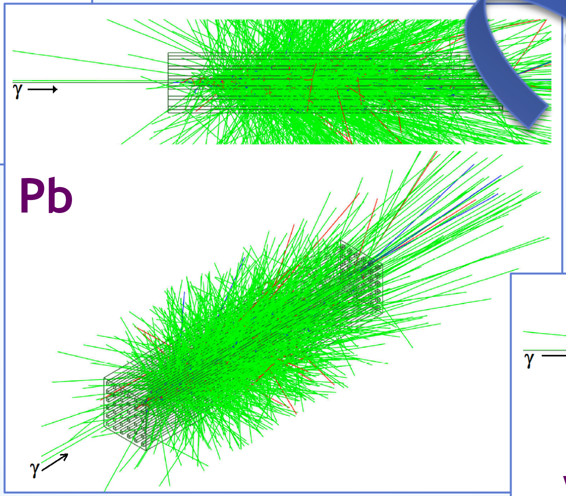
Performing simulation studies to define spatial, time and energy resolutions.

From LHCb report

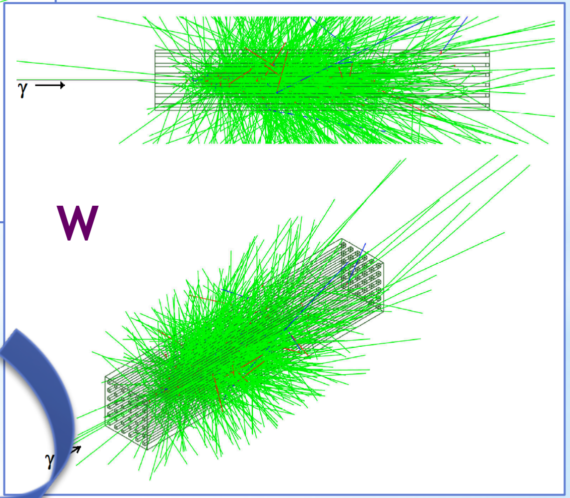
Spatial development of a shower upon irradiation of a cell with Eγ = 10 GeV, the absorber material: Cu,Pb, and W



shower extends cell boundaries, longitudinal leakage of energy is increased



Lead is inefficient in connection high flexibility at thin plate formation.



difficulties at mechanical treatment; small Molière radius leads to a decrease in energy transfer to neighboring GaGG: Ce rods in the cell.