Simulation studies of a SPACAL calorimeter module

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Preconditions of studies

Current calorimeter – Shashlik technology

The main problem – non radiation hard scintillator and light guides made from plastic

Possible candidates for new scintillator are:

•$Y_3Al_5O_{12}$:Ce (YAG)

•$Gd_3Al_2Ga_3O_{12}$:Ce (GAGG)

Density – YAG - 4.57, (GAGG - 6.63) g/cm^3

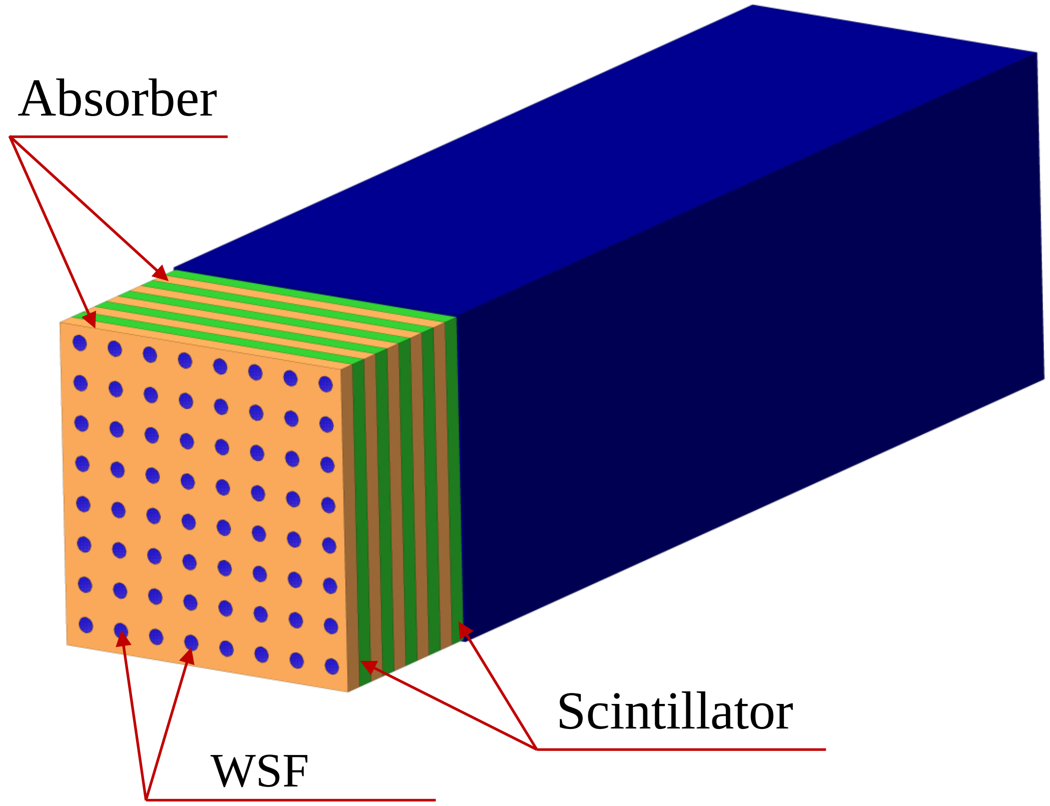
Light yield – 11 000 (60 000) ph/MeV

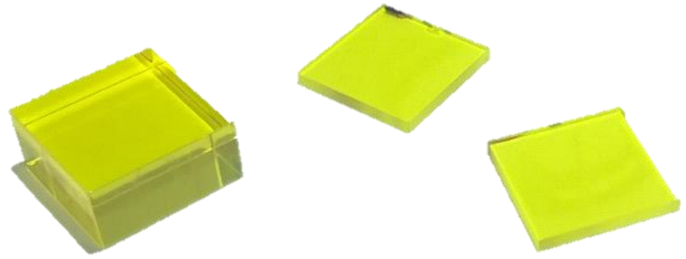
Decay time – 70 (60) ns

Wavelength of emission max – 550 (520) nm

Irradiation tests demonstrate good radiation hardness of GAGG:Ce

Shashlik module

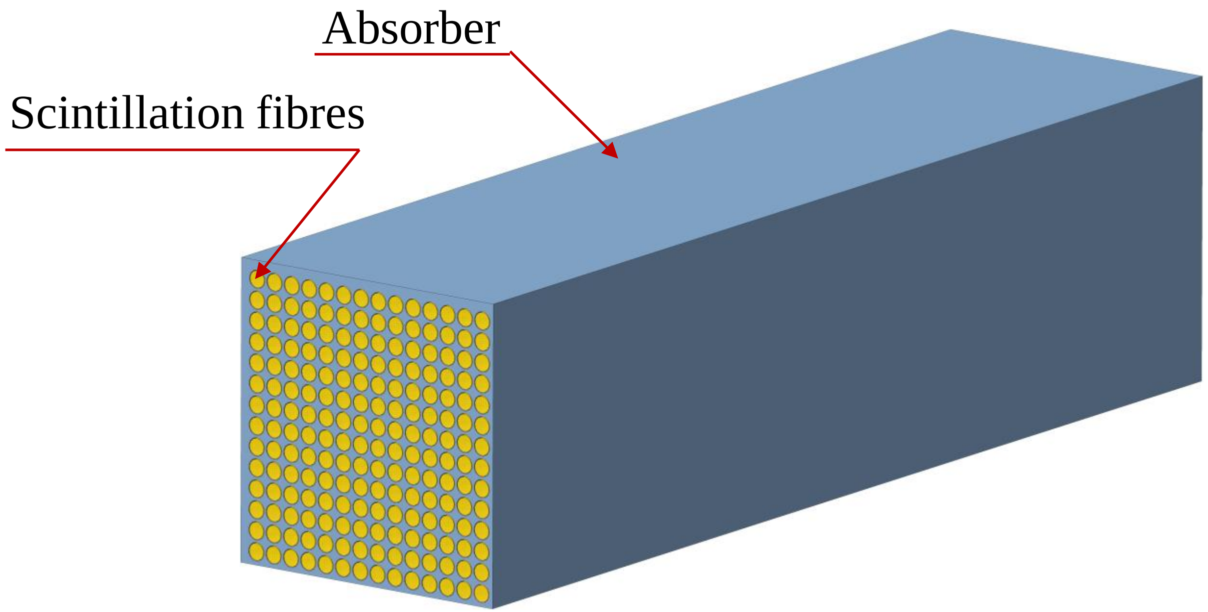




GAGG: Ce

Spaghetti calorimeter (SPACAL)

SPACAL technology is a type of the sampling calorimeter with scintillation fibers running along shower direction. Hence scintillating fibers transport the light to the rear of the module



SPACAL module

Expectation:

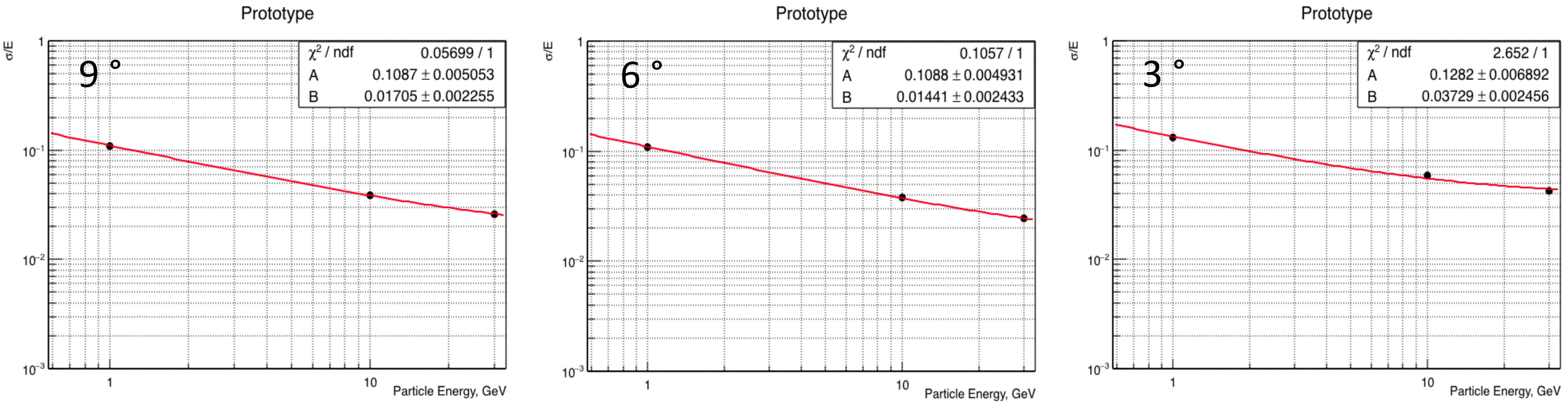
✓Using this type of module makes possible reducing an active material by ~30% compared to Shashlik type without worsening of energy resolution

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

Simulations of SPACAL module

Configuration:
Size of module 210x180x400 mm
Square fibers with side 1 mm
Distance between fibers 1.8 mm
Scintillator – GAGG:Ce
Absorber – Tungsten-Copper alloy (75:25)

The first step of simulation was to estimate the energy resolution dependence on the angle of primary particle.

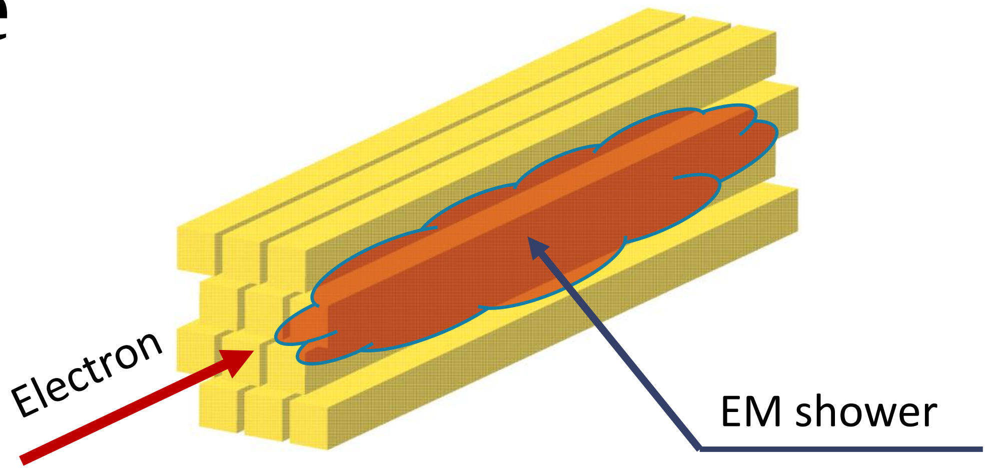


The constant term at 3° is 3.7%, goes down to 1.5% at larger angles, but no difference at 6 and 9 degrees.

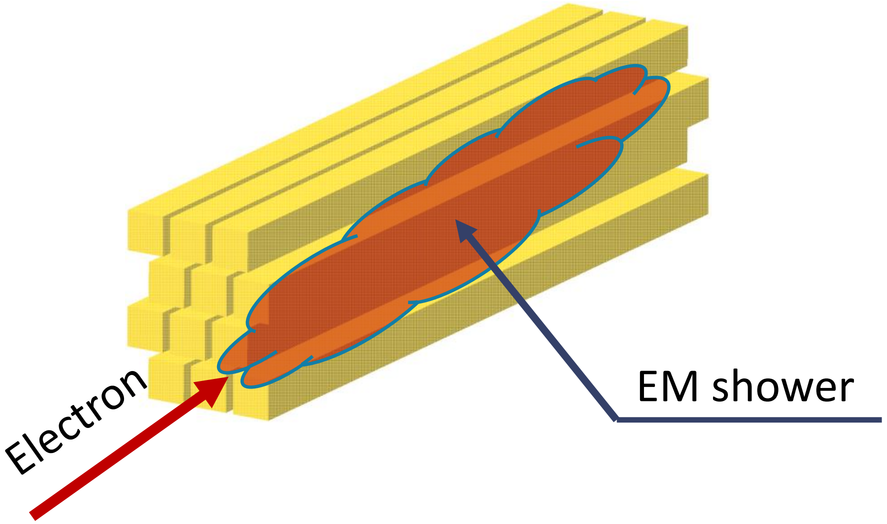
Simulations of SPACAL module

Two possible effects:

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



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

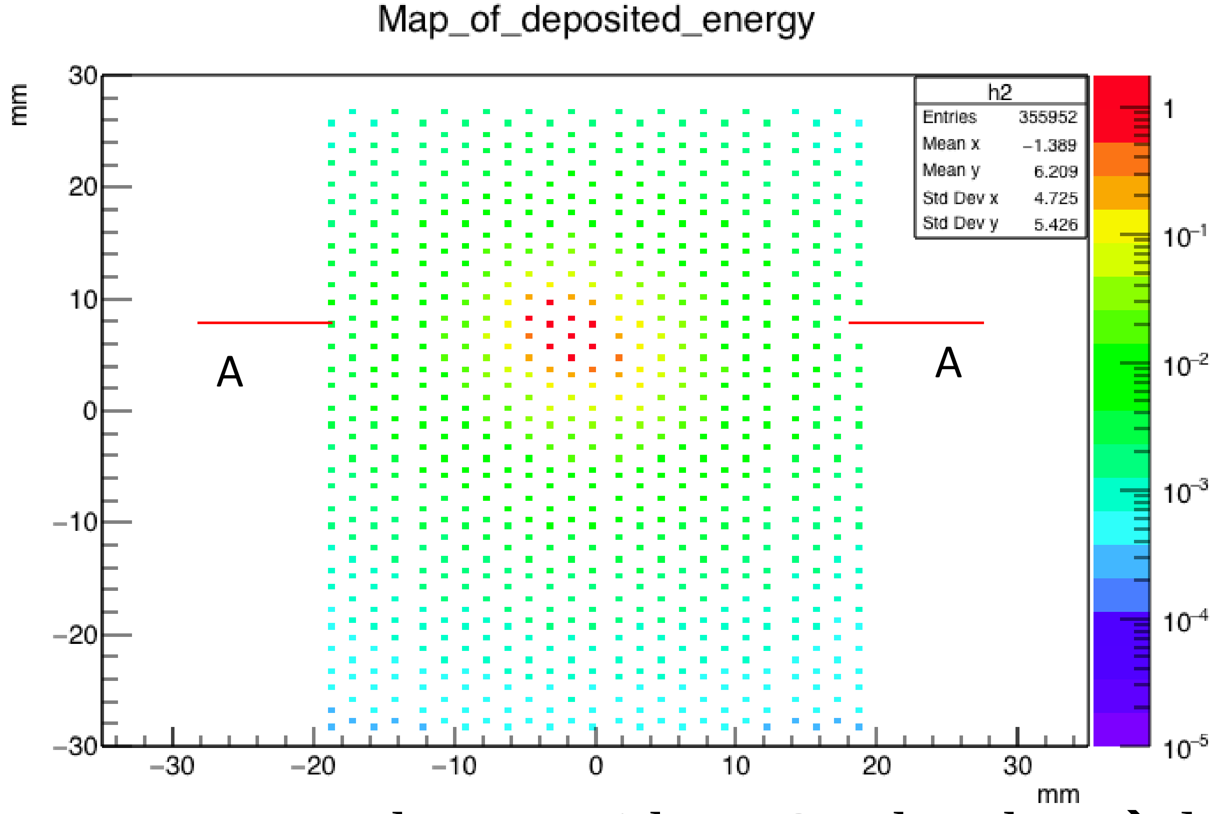


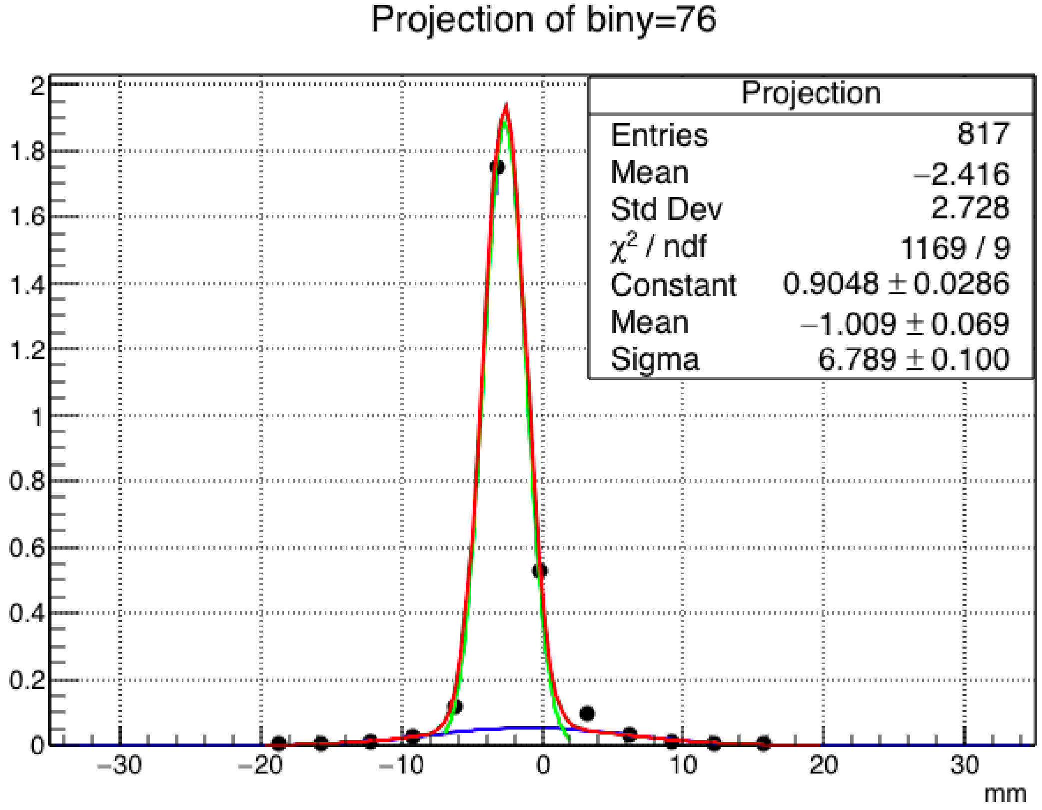
✓ Self-Compensating effects

Map of deposited energy

10 GeV Prototype (60x70x200 mm). GAGG square fibers (1 mm) with distance 1.8 mm. Absorber – Tungsten-Copper alloy (75:25).

Center of the beam was shifted by 5 mm to the left side and 10 mm to the up side.





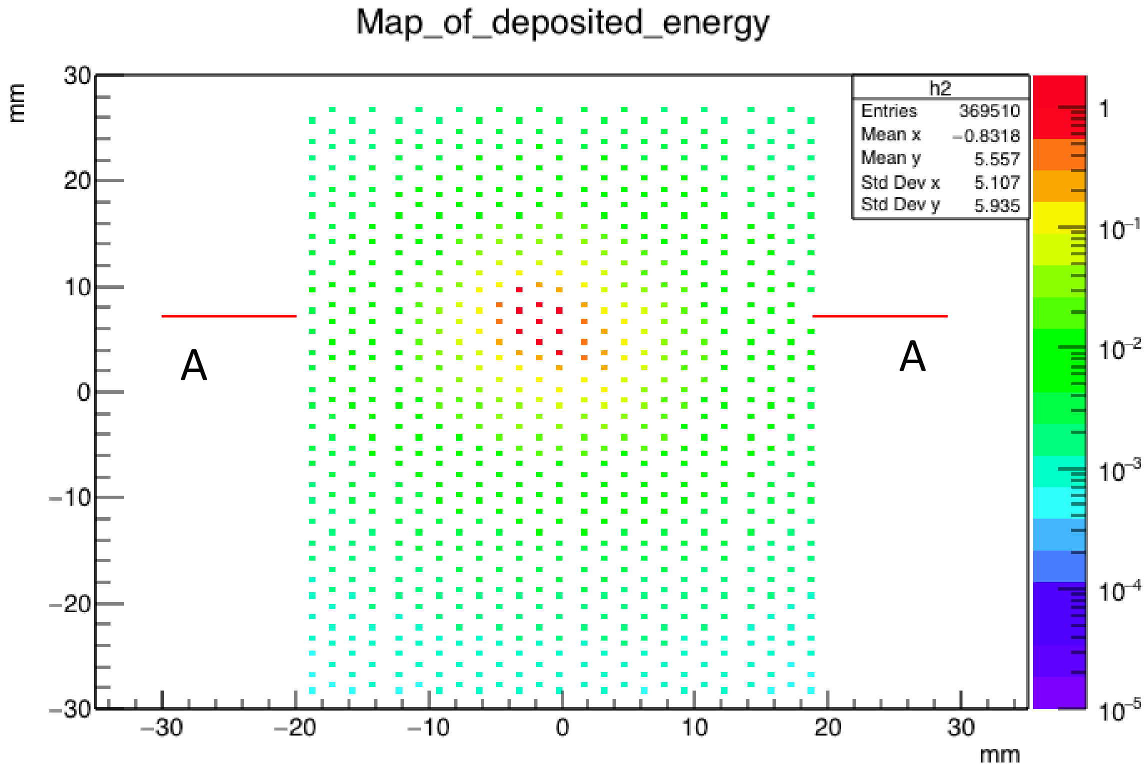
Very narrow shower with W-Cu absorber → large fluctuation in energy deposited to fibres

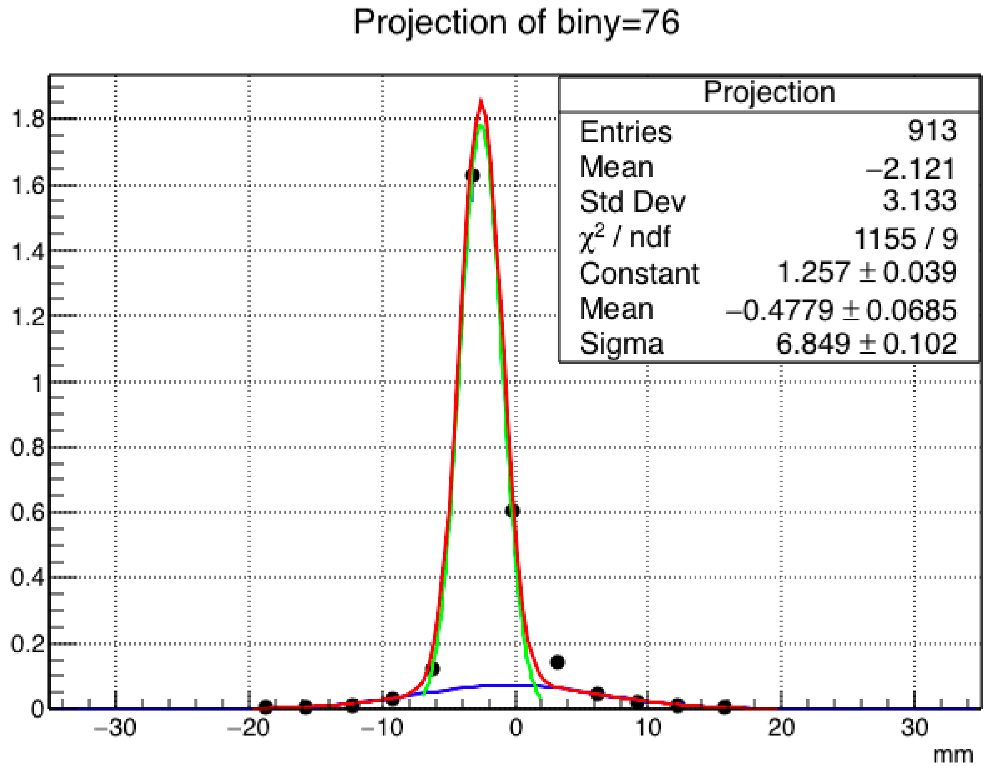
Possible solution could be using other absorber with larger Mollier radius or decreasing the distance between fibers.

Map of deposited energy

10 GeV Prototype (60x70x200 mm) with GAGG square fibers (1 mm), distance between fibers - 1.8 mm. Absorber – Lead.

Center of the beam was shifted by 5 mm to the left side and 10 mm to the up side.





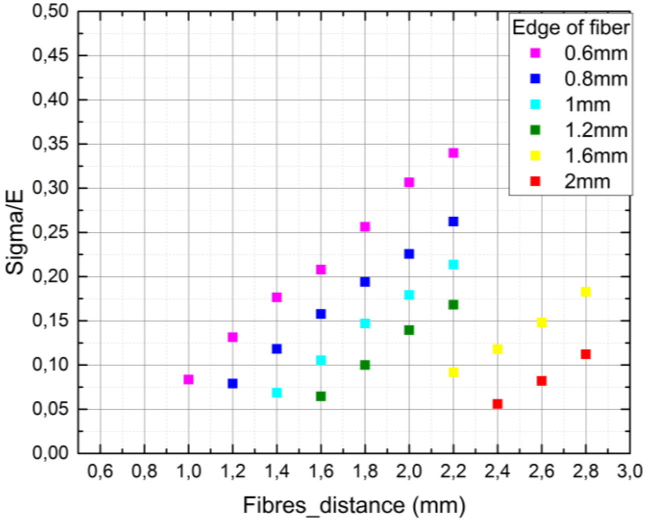
Slightly wider shower with Lead absorber

→ Optimize distance between fibres to minimize losses of energy in absorber between fibres.

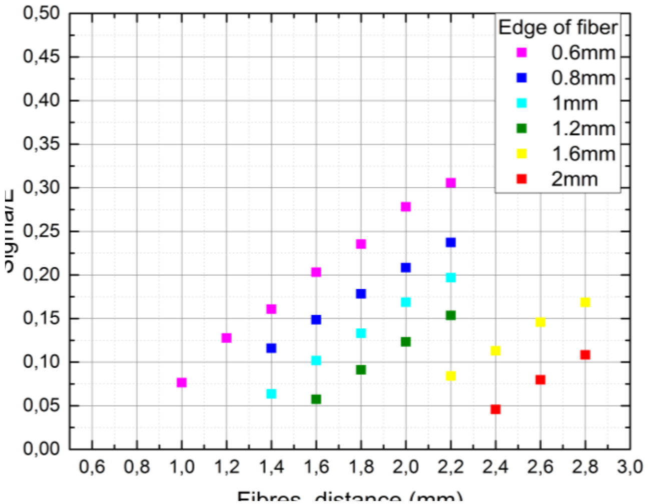
Simulations of SPACAL module

How energy resolution depends on fibres's size and distance between fibres?

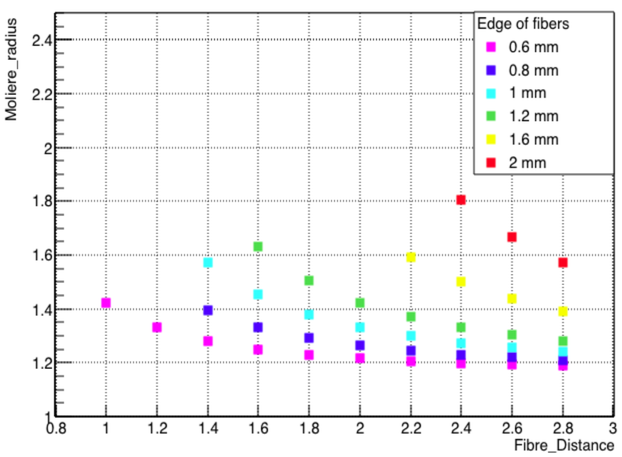
YAG:Ce



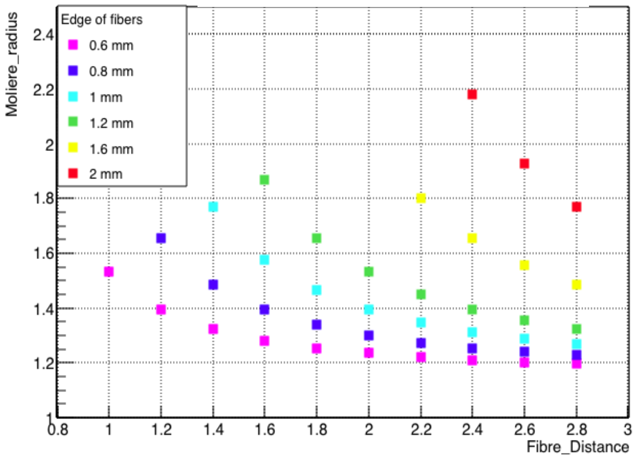
GAGG:Ce



Moliere_radius (GAGG:Ce)



Moliere radius (YAG: Ce)



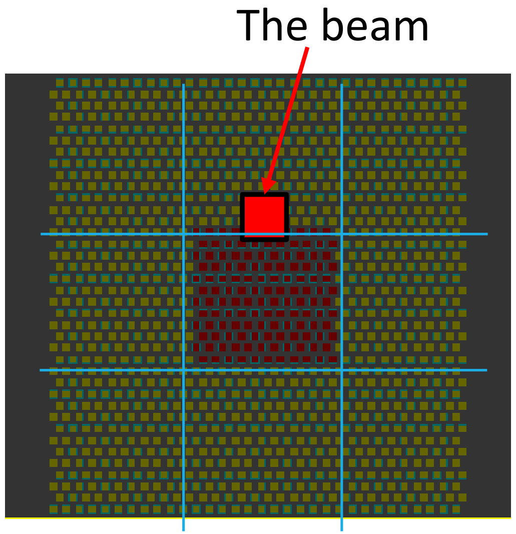
Particle energy: 1GeV
The size of module: 210x180x400 mm^3
Absorber: Tungsten – Cooper alloy (75:25%)
Angle of primary particle: 3°

➢ Energy resolution strongly depends on the fibre-to-fibre distance!

Must be optimized

✓ When it become clear what is more important – energy resolution or compact shower, we can choose needed configuration.

Simulations of SPACAL prototype module



For testing there was a SPACAL module (60x70x200 mm^3) from Tungsten-Copper alloy (75:25% mass fraction) with holes for 1 mm square fibers and distance between center of fibers 1.8 mm.

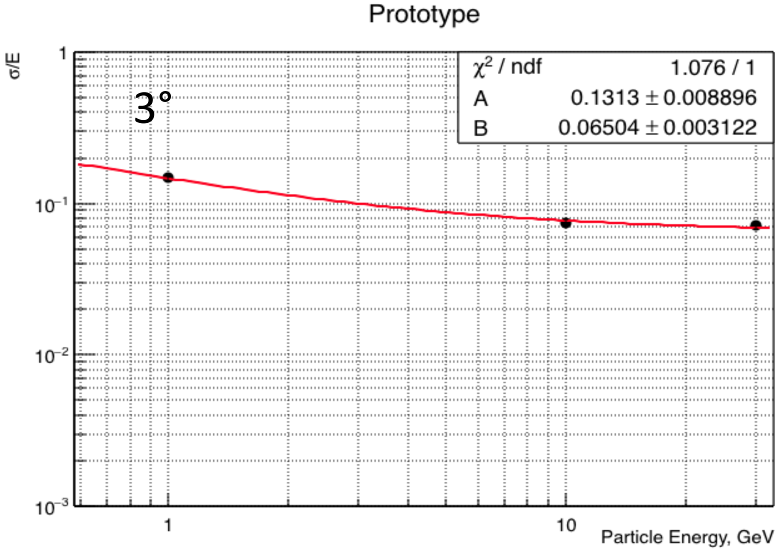
First prototype's simulation configuration was:

Two sections – 100 mm each.

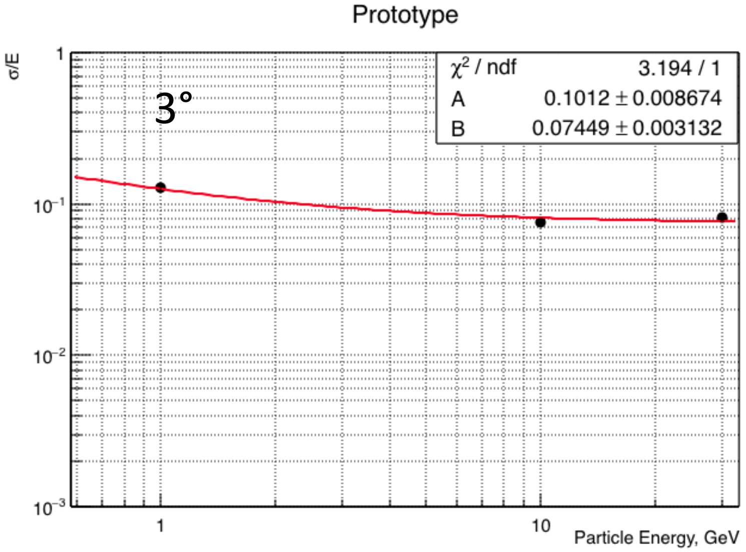
The first section 1 Cell GAGG:Ce – Red (20x20 mm^2) + 8 Cell (YAG:Ce) – Yellow

The second section 1 Cell GAGG:Ce (20x20 mm^2) + 8 Cell (Polystyrene)

Additionally the lead absorber was simulated



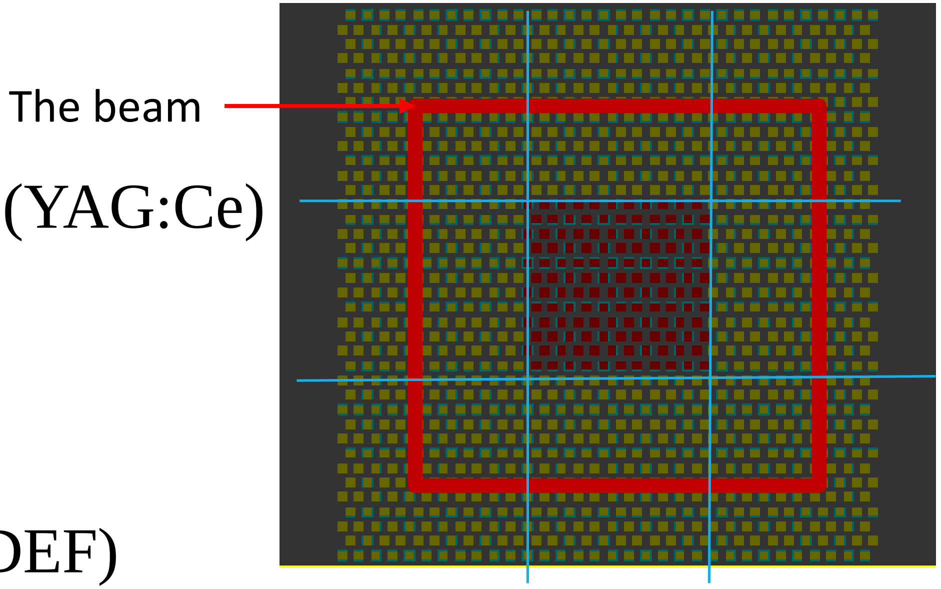
No calibration -> Big Constant term



Must be calibrated for precise estimate.

Calibration

Size of module 70x60x100 mm^3 (Two Section)
The first section 1 Cell GAGG:Ce (20x20 mm^2) + 8 Cell (YAG:Ce)
The second section 1 Cell GAGG:Ce (20x20) + 8 Cell (Polystyrene)
Absorber: W-Cu alloy (75:25) and lead.



Definition of dependence of Energy deposited in fibres (DEF) by Energy deposited in cell where is the fibres located (DC).

$$\frac{1}{C(YAG)} = \frac{1}{N} * \sum_{i=1}^{i=N} \frac{DEF(YAG)[i]}{DC[i]}$$

$$\frac{1}{C(GAGG)} = \frac{1}{N} * \sum_{i=1}^{i=N} \frac{DEF(GAGG)[i]}{DC[i]}$$

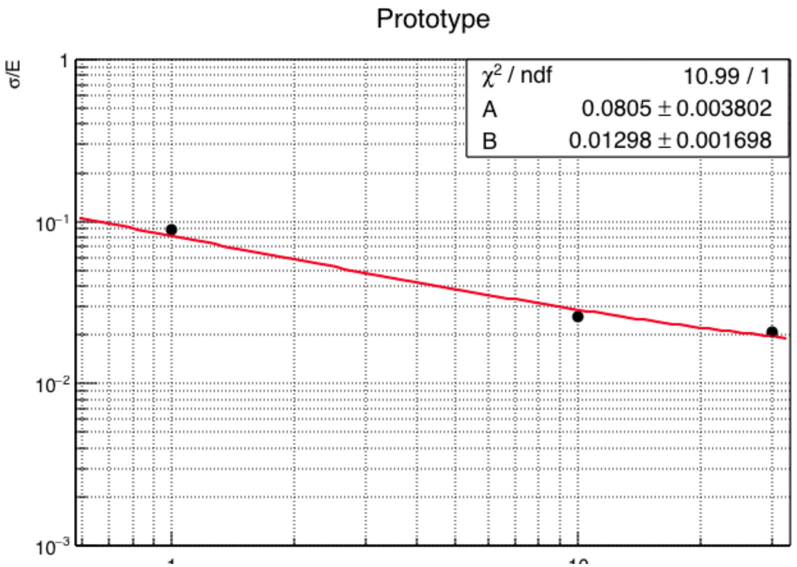
$$\frac{1}{C(GAGG1)} = \frac{1}{N} * \sum_{i=1}^{i=N} \frac{DEF(GAGG)[i]}{DC[i]}$$

$$\frac{1}{C(Pl)} = \frac{1}{N} * \sum_{i=1}^{i=N} \frac{DEF(Pl)[i]}{DC[i]}$$

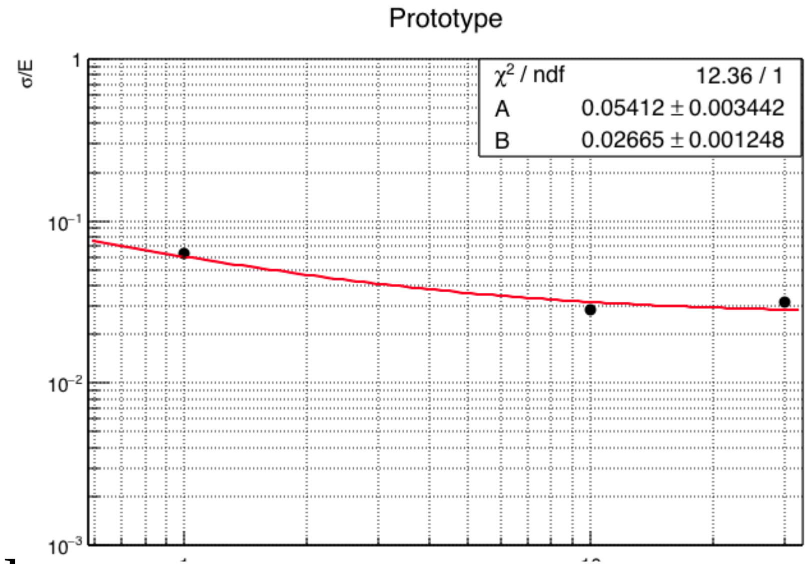
$$E(reconstr)[i] = DEF(YAG)[i] * C(YAG) + DEF(GAGG)[i] * C(GAGG) + DEF(GAGG1)[i] * C(GAGG1) + DEF(Pl)[i] * C(Pl)$$

Results after calibrations

Absorber: Cooper-Tungsten Alloy (25:75) – left
Lead - right

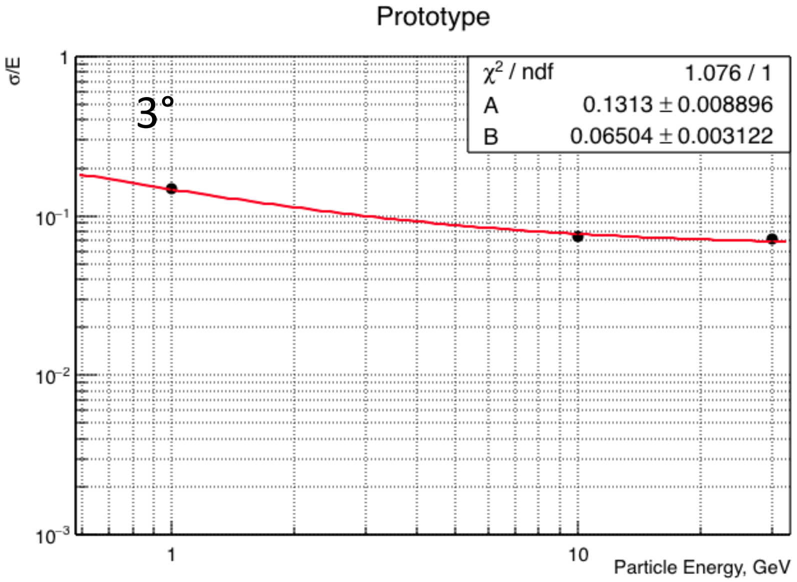


3° angle of primary particle

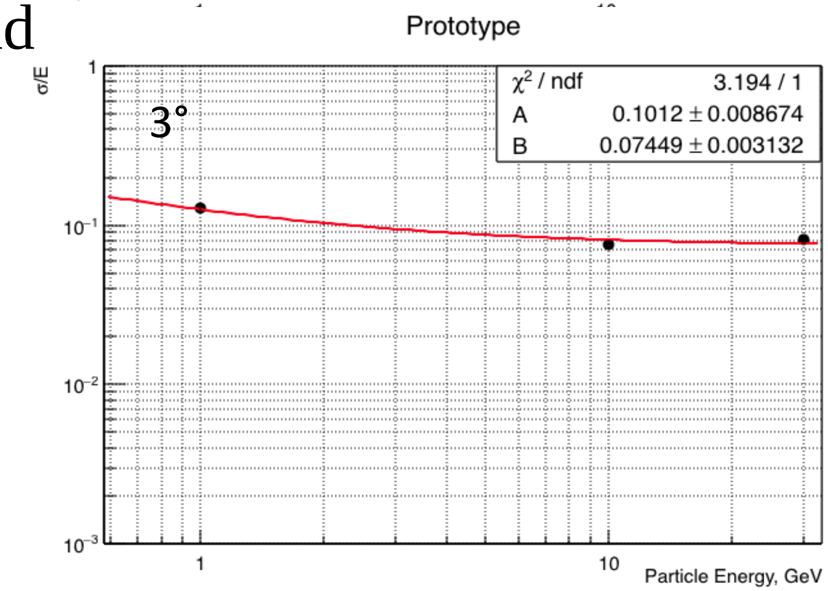


C-T Alloy

Lead

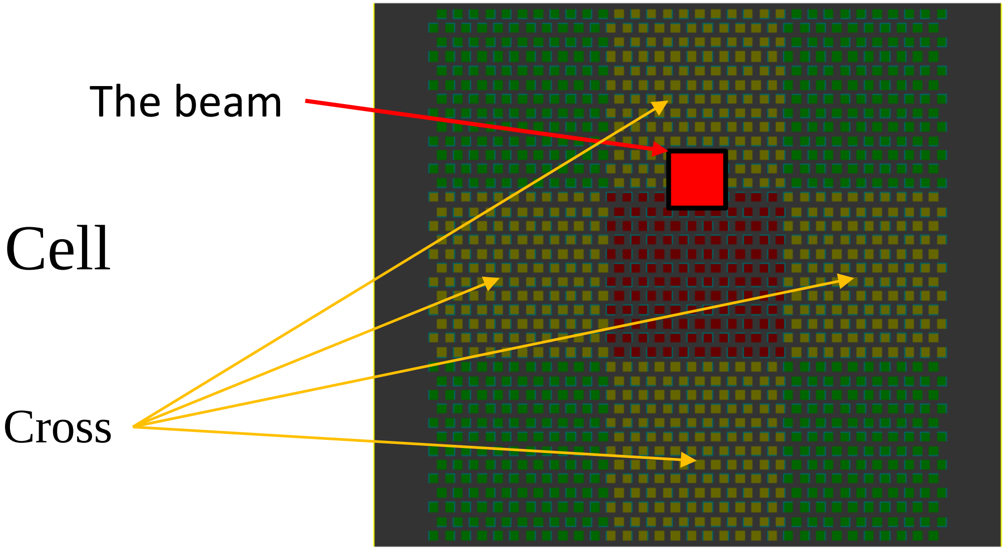


– Without calibration –



Prototype "Cross from YAG"

Size of module 70x60x100 mm^3 (Two Section)
The first section 1 Cell GAGG:Ce (20x20 mm^2) + 4 Cell YAG:Ce (Yellow) + 4 Cell Polystyrene (Green)
Second section – the same
Absorber: W-Cu alloy (75:25).



Deposited energy in fibres:
•Cross – 1.76% of total
•Center – 14.53% of total
•Corners – 0.07% of total

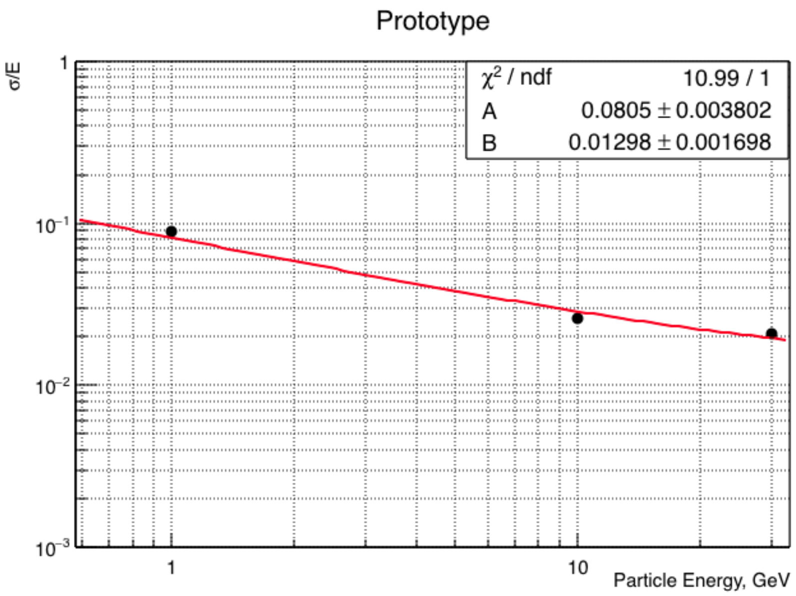
- Significant part of shower in Corners (First Section) ~ 0.6% of total
- In second section more important central and Cross (YAG) side

Comparison of two prototypes

Absorber – Cooper-Tungsten Alloy (25:75)

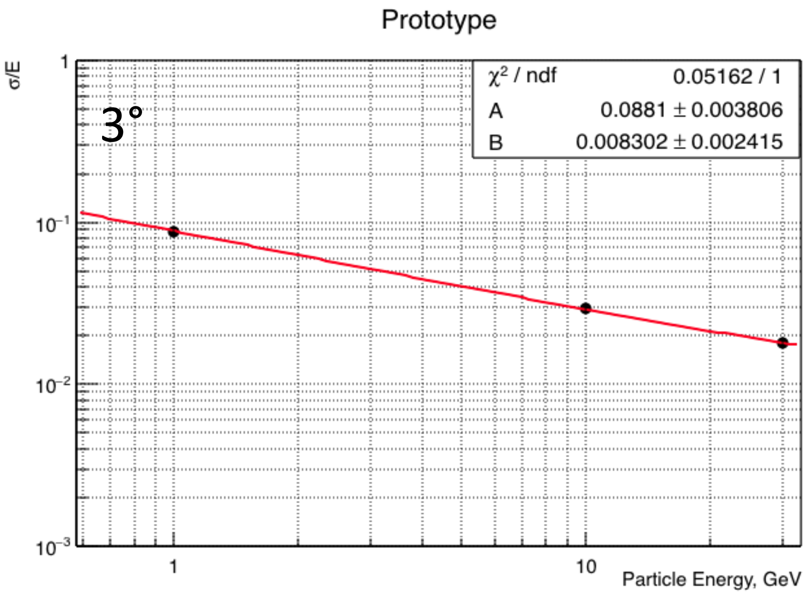
3° angle of primary particle

GAGG + YAG around and GAGG + Polystyrene around



Worse stochastic term because polystyrene instead YAG in corners

Cross from YAG



Conclusion

- ✓ First steps of SPACAL module simulation was completed

- ✓ The prototype of SPACAL module was built and ready for beam test now

Expectations of energy resolutions: $\sim \frac{10\%}{E} + 1\%$

Next steps:

- ➢ Beam test measurements of prototype and calibration MC by collected data.
- ➢ Performing simulation studies to define spatial, time and energy resolutions.