華南師範大學
SOUTH CHINA NORMAL UNIVERSITY

PicoCal

LHCb

Studies on Light Guide for LHCb ECAL Upgrade II

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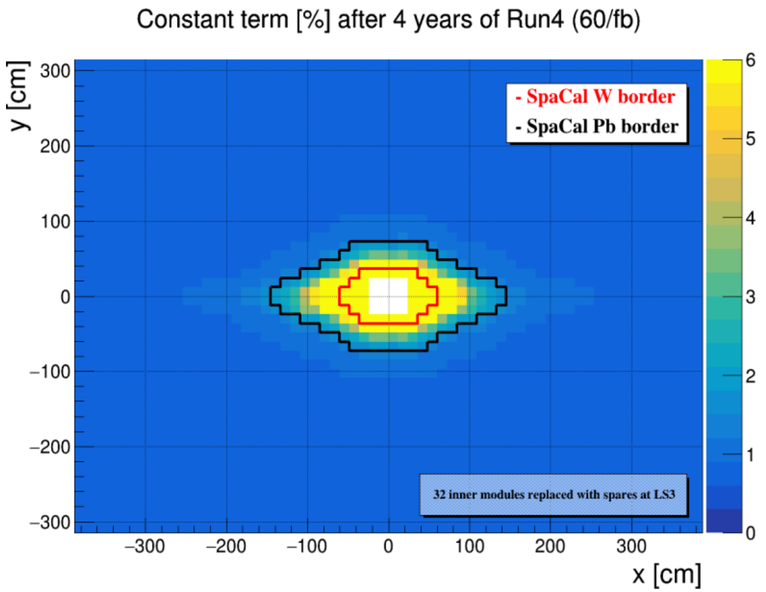
14 -17 Nov. 2024

Outline

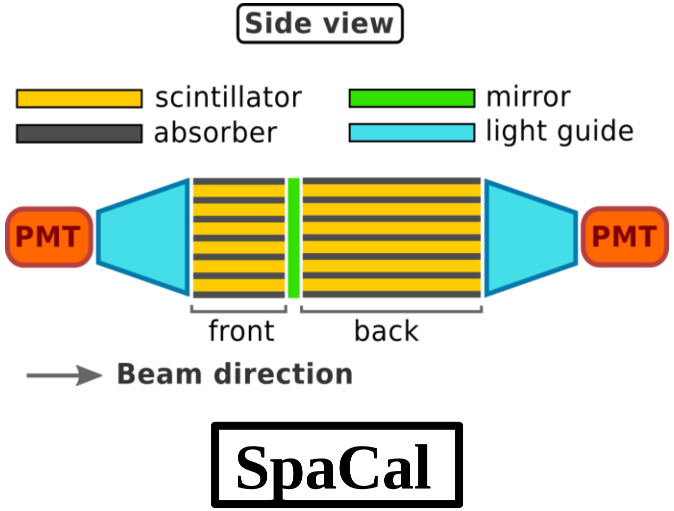
01 Introduction to light guide

- LHCb ECAL Upgrade Plan
- Light Guide R&D Design for W Absorber Module
- Evaluation Criteria



- **LS3 enhancement in 2026-2028:**
  - ✓ Construct an ECAL structure with a rhombic distribution, introduce single readout models of SpaCal with sizes of 2 × 2 cm² and 3 × 3 cm², to enhance ECAL performance at a luminosity $\mathcal{L} = 2(4) \times 10^{33}$ $cm^{-2}s^{-1}$.
  - ✓ 32 SpaCal-W & 144 SpaCal-Pb modules with plastic fibres compliant with Upgrade II conditions.

- **LS4 Upgrade II in 2033/2034:**
  - ✓ Introduce double-section radiation hard SpaCal (1.5 × 1.5, 3 × 3 and 4 × 4 cm² cells) and improve timing of Shashlik modules for a luminosity of up to $\mathcal{L} = 1.5 \times 10^{34}$ $cm^{-2}s^{-1}$.
  - ✓ Innermost SpaCal-W modules equipped with crystal fibres.
  - ✓ Include timing information and double-sided readout to full ECAL for pile-up mitigation.

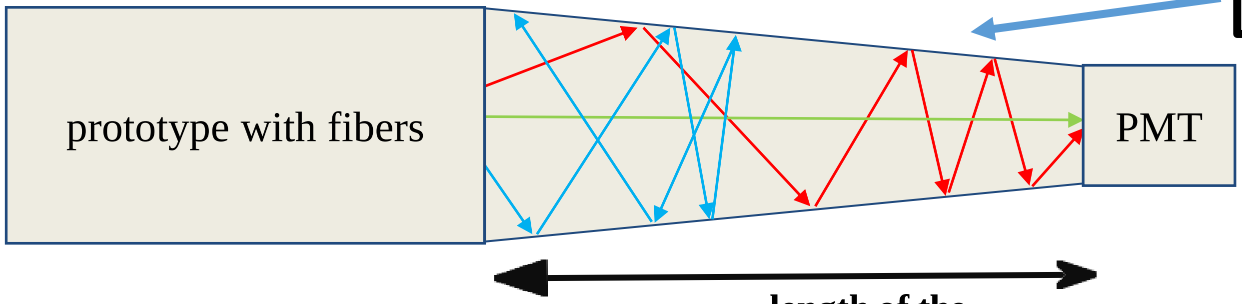


PicoCal Workshop at Beijing, Philipp

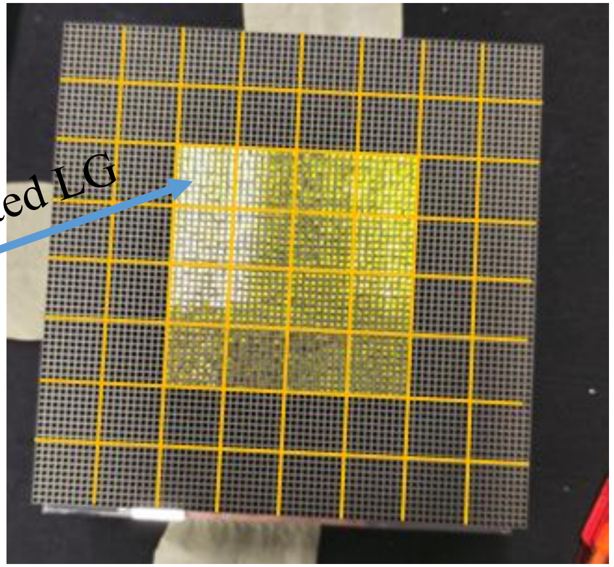
Introduction – Light Guides for Tungsten Absorber

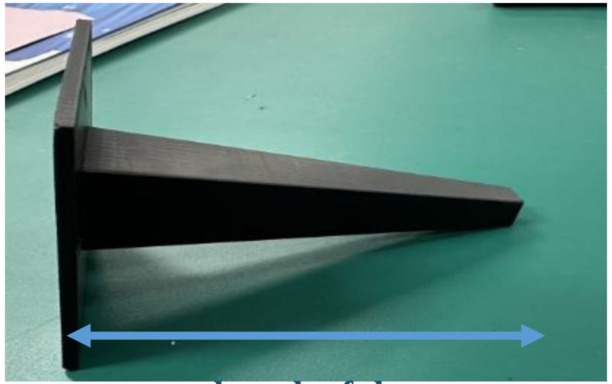
- Why we need the light guide?
  - ✓ Enhances light collection efficiency by guiding photons to PMTs.
  - ✓ Reduces the transit time spread effect (TTS).
  - ✓ Overcomes spatial constraints for effective photon transmission.

Light Guide



Fiber connected LG





- Cell size 20 ×20 mm², 15 ×15 mm².
- ⌀8 mm, 18 ×18 mm²
- Octagon, circler, square

- Scintillating photon hits the PMT directly.
- Scintillating photon reflects many times and then hits the PMT.
- Scintillating photon reflects many times and go back to the prototype.

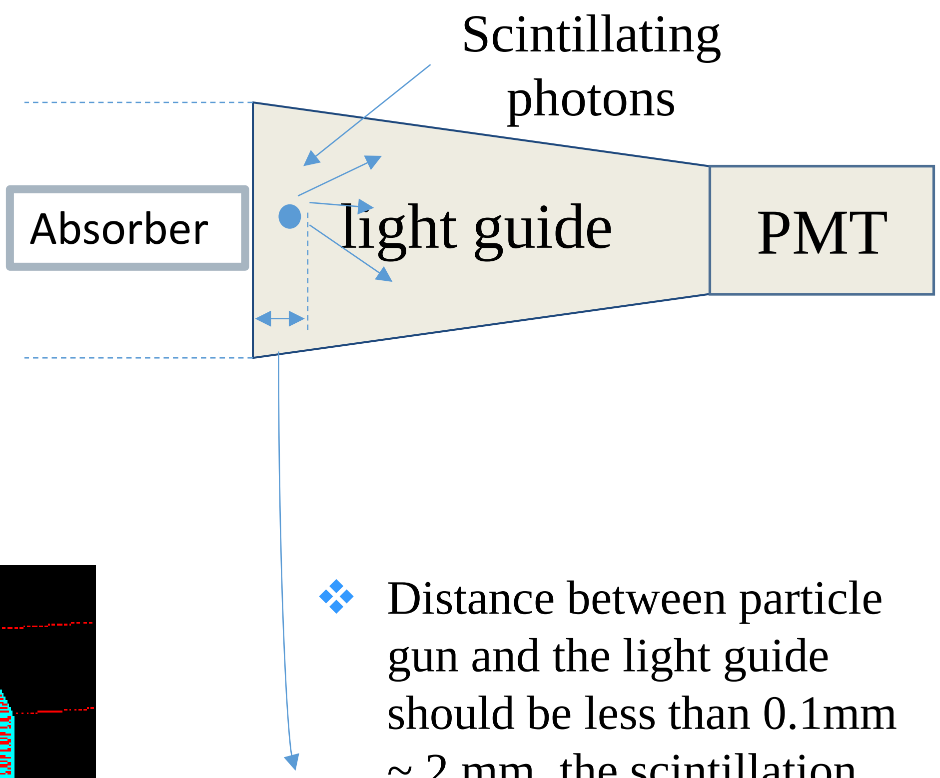
Should be optimize the time resolution.

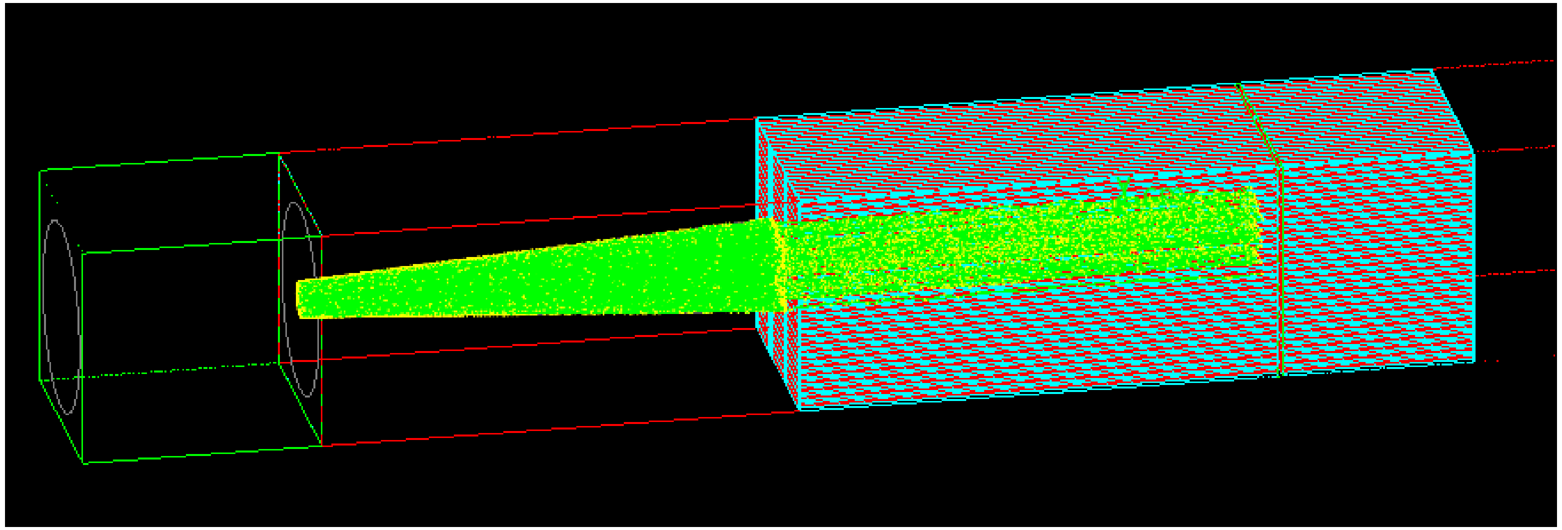
02 Light Guide R&D Methodologies

- Tungsten-Poly Module and Tungsten-GAGG Module
- Full-ray Tracing Simulation
- Measurement at Lab
- Hybrid-MC Simulation
- Analysis
- Material Mechanical Test

Strategies – Full Ray Tracing Simulation

- Use CAD software to model a light guide and import it as an ***OBJ** file into the Geant4 simulation program.
  - ✓ Simulated the scintillation photons within the light guide.
  - ✓ 15 mm square to 8 mm octagon with 100 mm long.
  - ✓ Maximum Emission Angle: The maximum angle allowed for scintillating photons to be emitted.

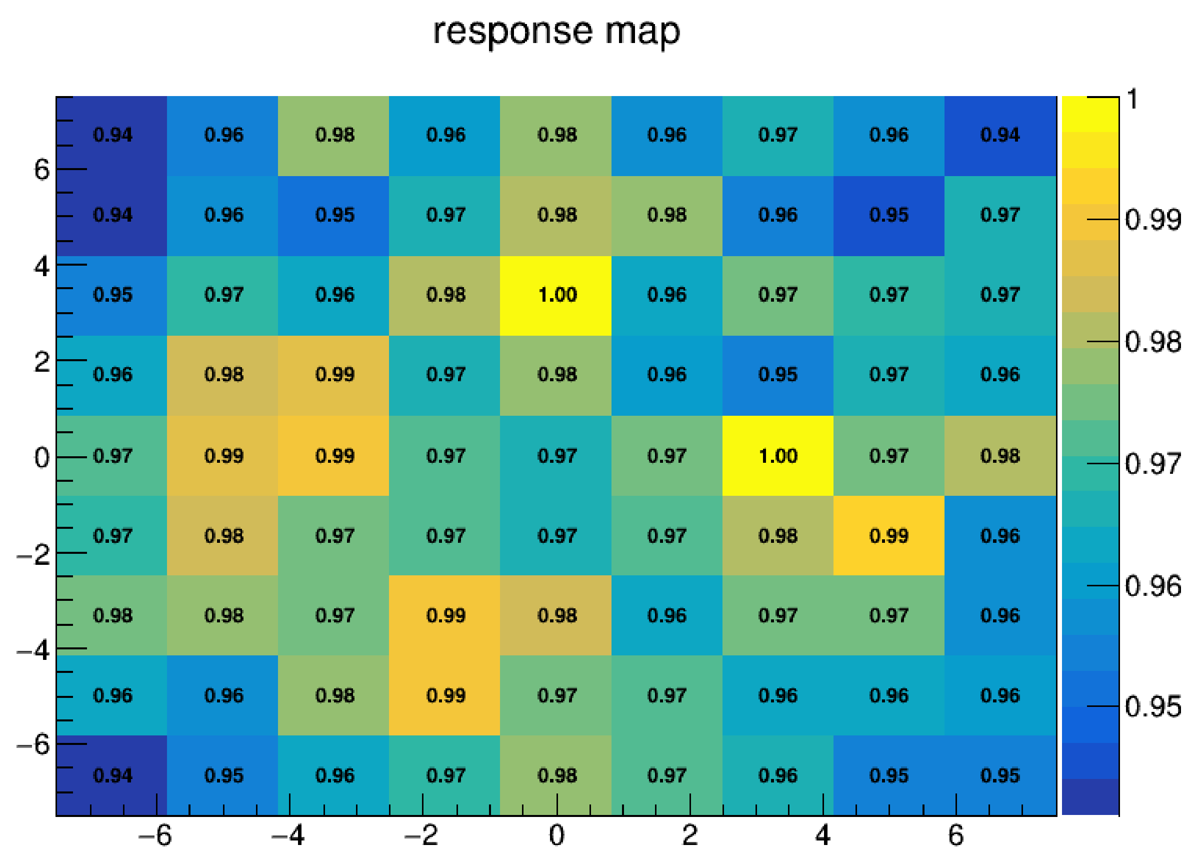




- Distance between particle gun and the light guide should be less than 0.1mm ~ 2 mm, the scintillation photons are emitted closely along the light guide surface.

- Calculate the light collection efficiency:

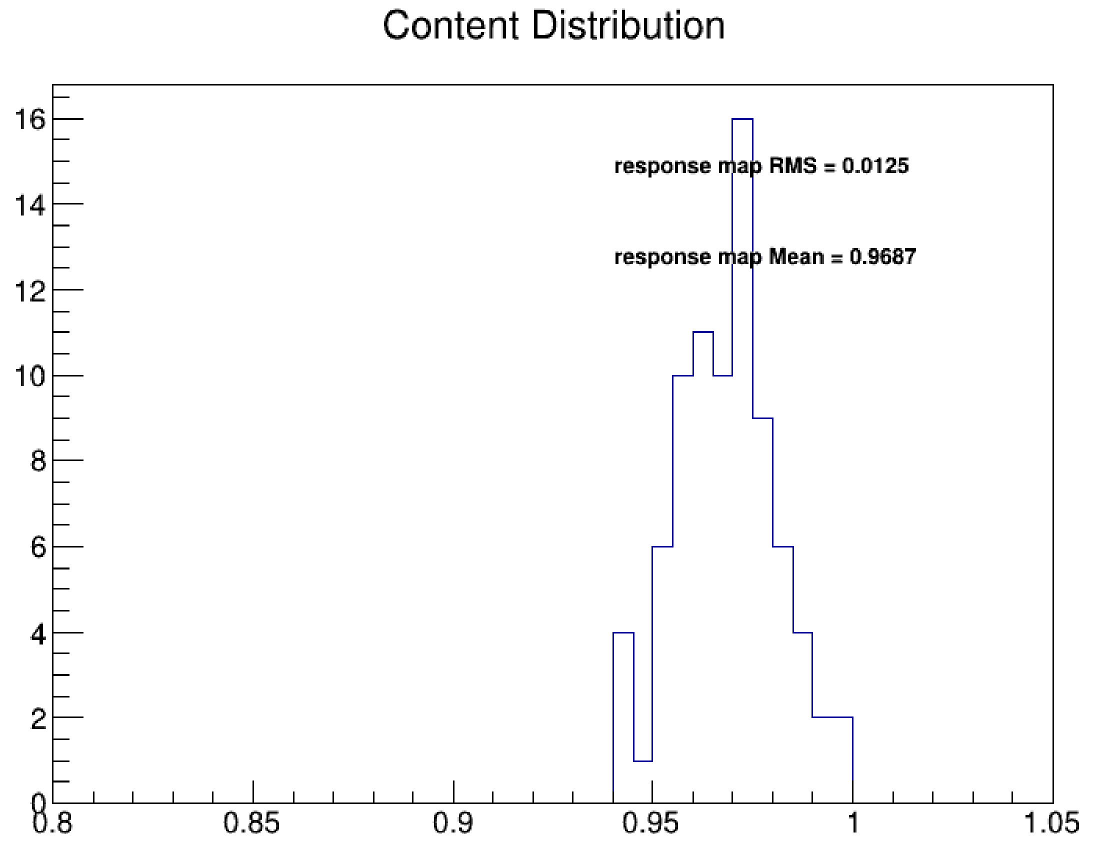
$$\varepsilon = \frac{\text{Number of photons are detected by PMTs}}{\text{Number of total photons}}$$



Uniformity response map: described by RMS index, less than 3%.

Important!!!

- Full tracing simulation results:
  - ✓ RMS = 1.25% < 3%, then move on Lab measurement.



Strategies – Prototype Bench Design

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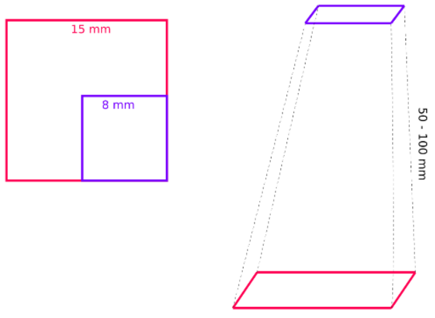
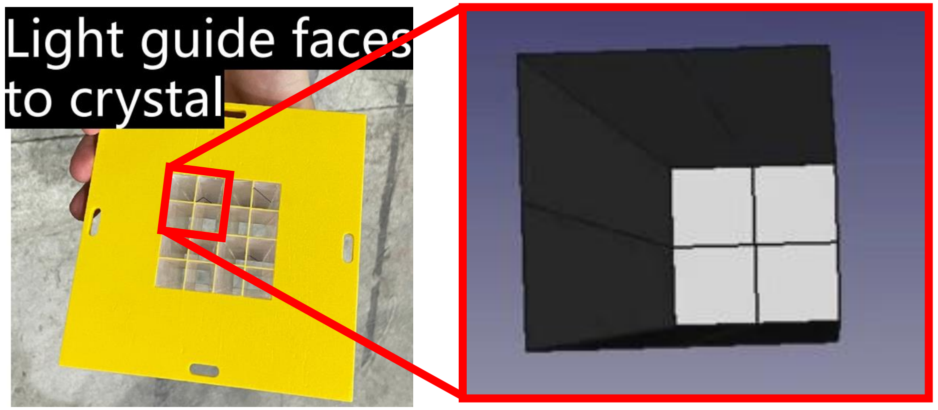
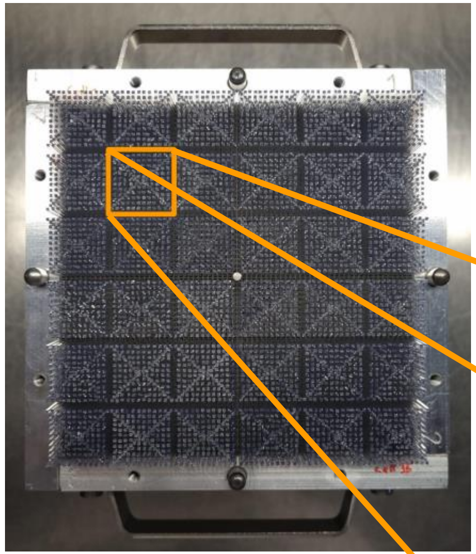
According to the different LS period to design prototype bench.

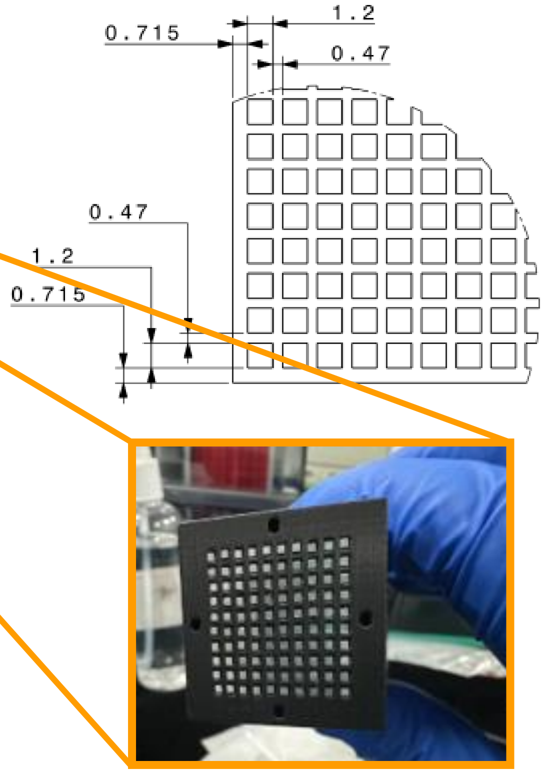
- **LS3 enhancement in 2026-2028 (Tungsten-Plastic fiber):**
  - ✓ The size of a module 121 × 121 mm^2 will be divided by 6 × 6 cells.
  - ✓ Each cell size of 20 × 20 mm^2 size with insert 12 × 12 plastic fibers.
  - ✓ Single signal readout by Hamamatsu PMT R9880U.
  - ✓ The cross section size of fibers are 1.0 ×1.0 mm^2 and100 mm long.

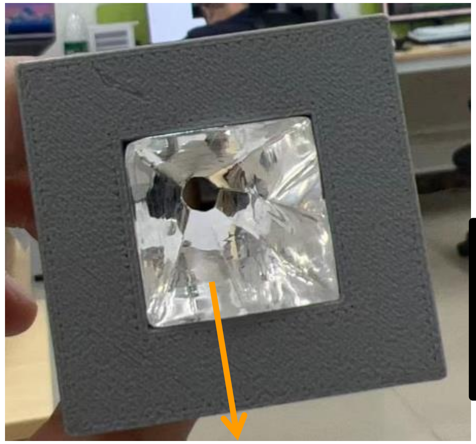
- **LS4 Upgrade II in 2033/2034 (Tungsten-GAGG) :**
  - ✓ The size of a module 121 × 121 mm^2 will be divided by 8 × 8 cells.
  - ✓ Each cell size of 15 × 15 mm^2 size with insert 9 ×9 GAGG crystals.
  - ✓ Single signal readout by Hamamatsu MaPMT R7600U (4 channels).
  - ✓ The cross section size of GAGG are 1.0 ×1.0 mm^2 and100 mm long.









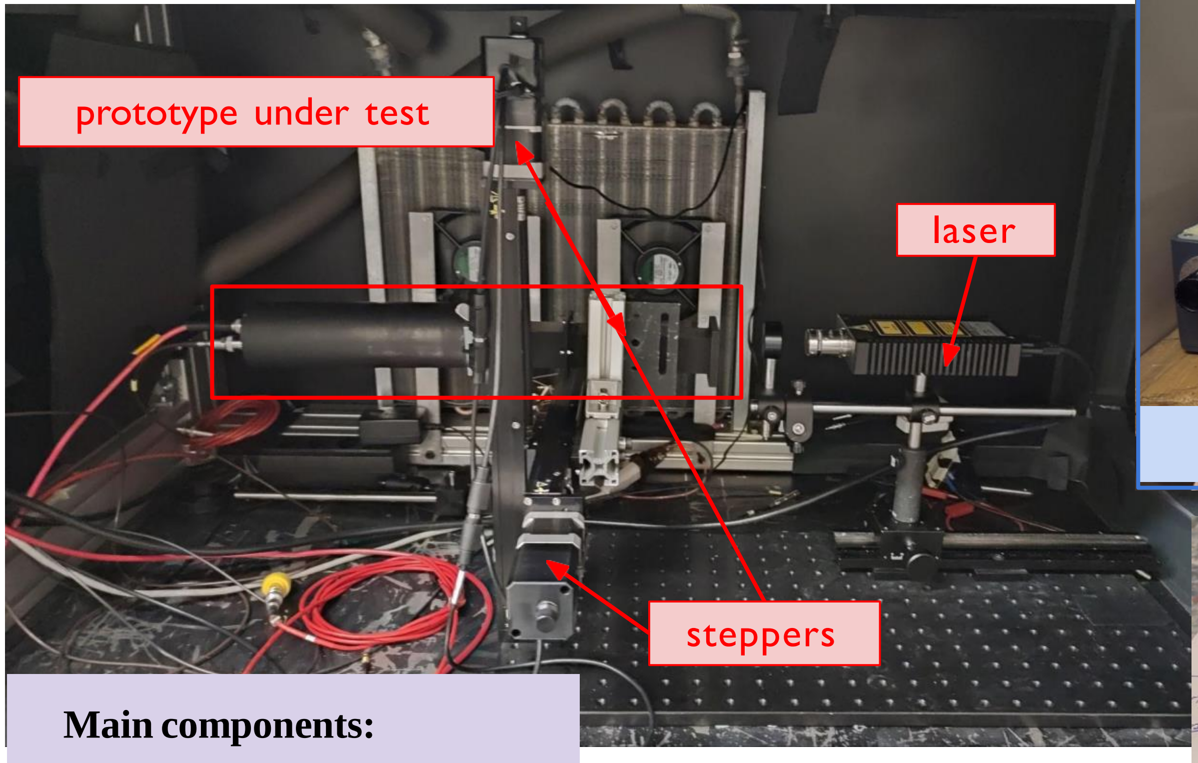


ESR reflector

A prototype bench for Tungsten-Poly

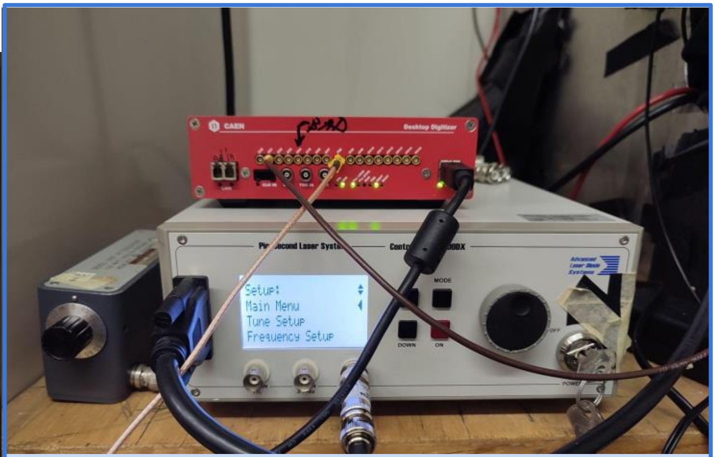
Strategies – Laboratory Setup

- Use a laser as the excitation source to scan the cross-section of the entire prototype, and the scintillator part will produce a signal in the PMT.



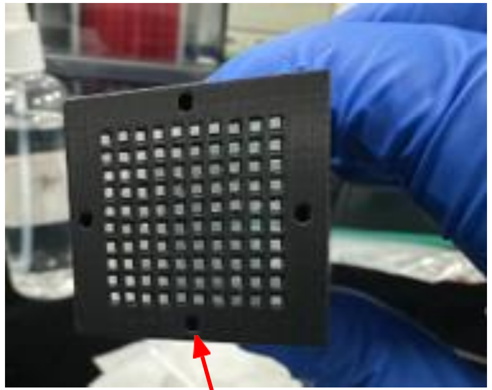
Main components:

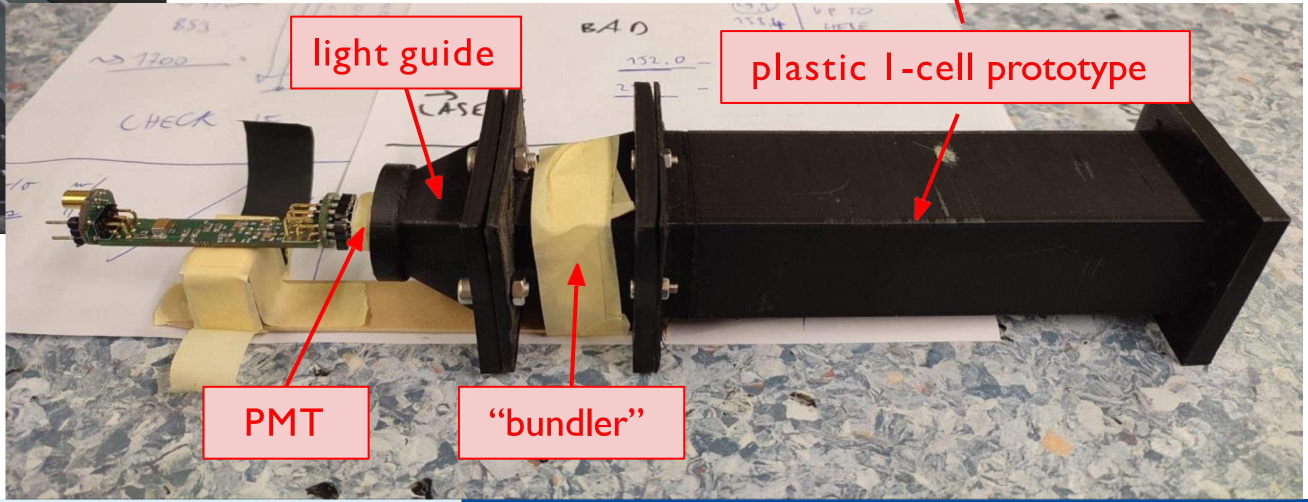
1. Laser
2. Steppers
3. Prototype
4. Electronics



Digitizer CAEN DT5742

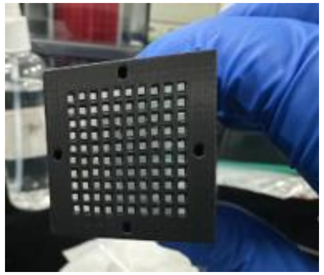
- Laser scan front cross section





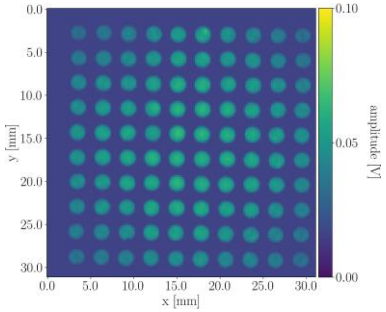
[PicoCal Workshop at Beijing, Alex]

Strategies – Laboratory Results



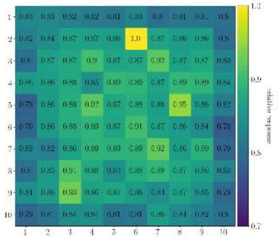
prototype

scan…



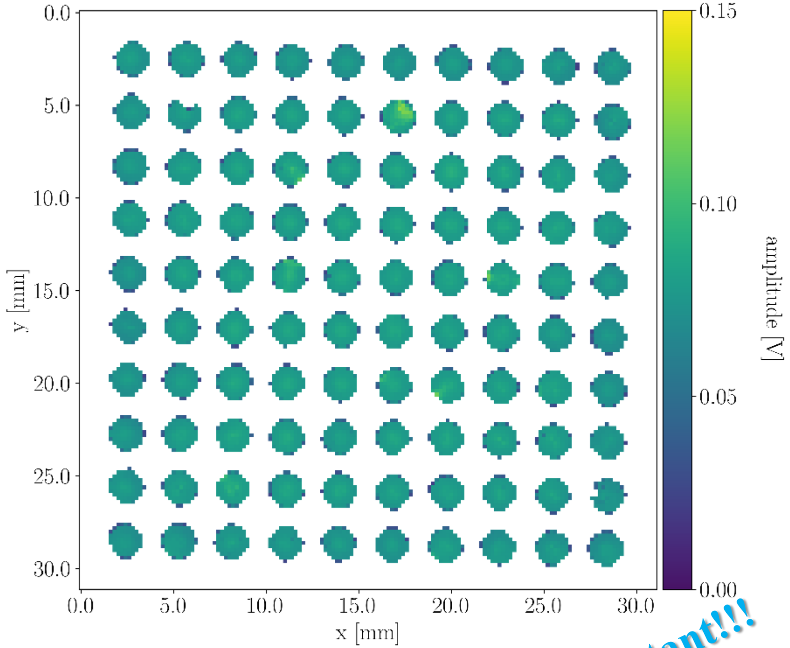
measurement

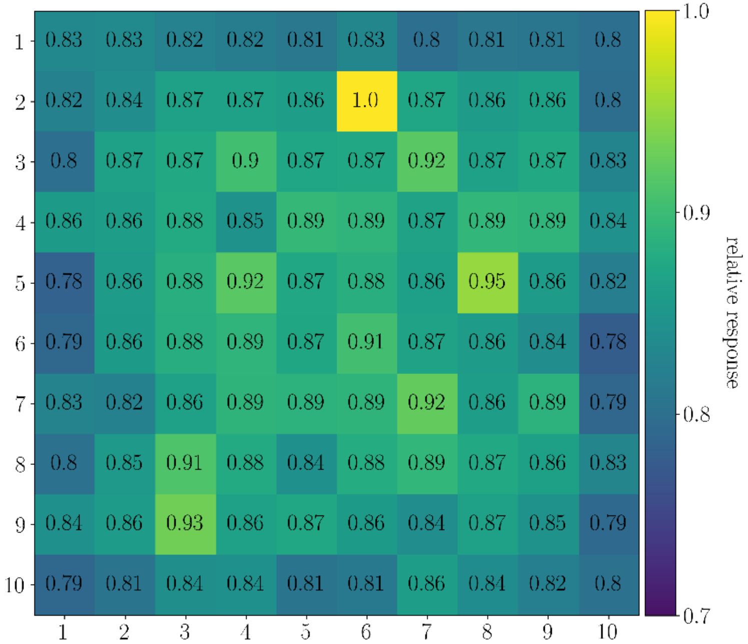
analysis…

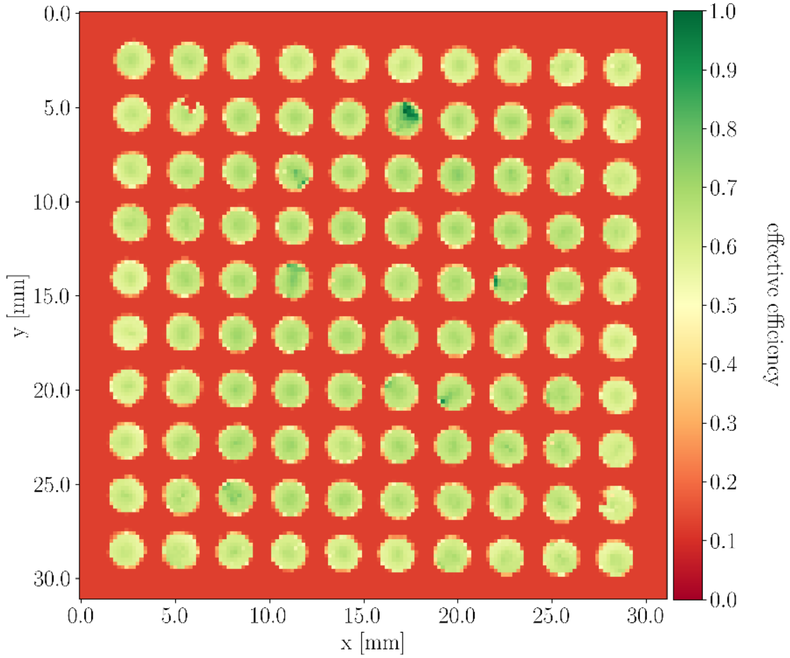


response map

❖ RMS: 4.52 ± 0.32 %







Important!!!

Uniformity response map: described by RMS index, less than 3%.

Strategies – Laboratory Setup at SCNU

- The main components are ready. Prepare for assembly, complete data collection, and finally reproduce CERN's results.

- Clean room

- PMT

- Laser

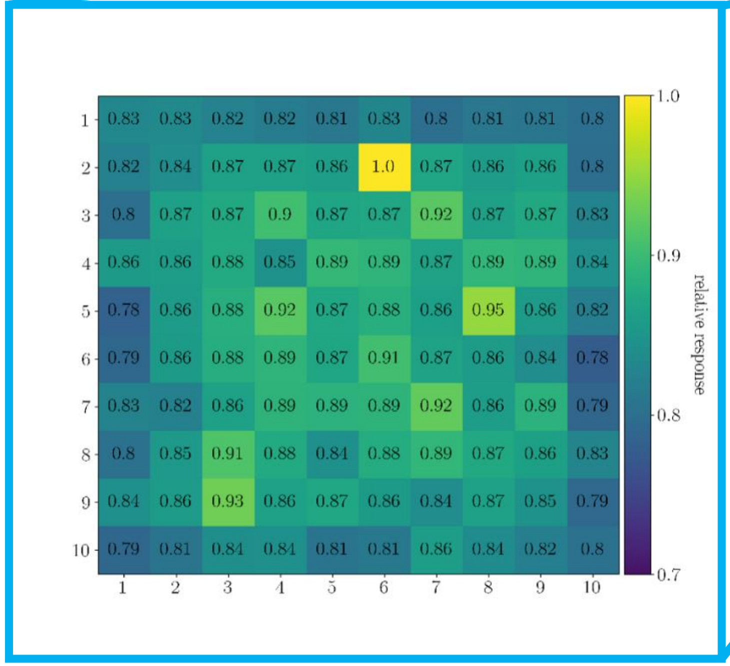
- Steppers

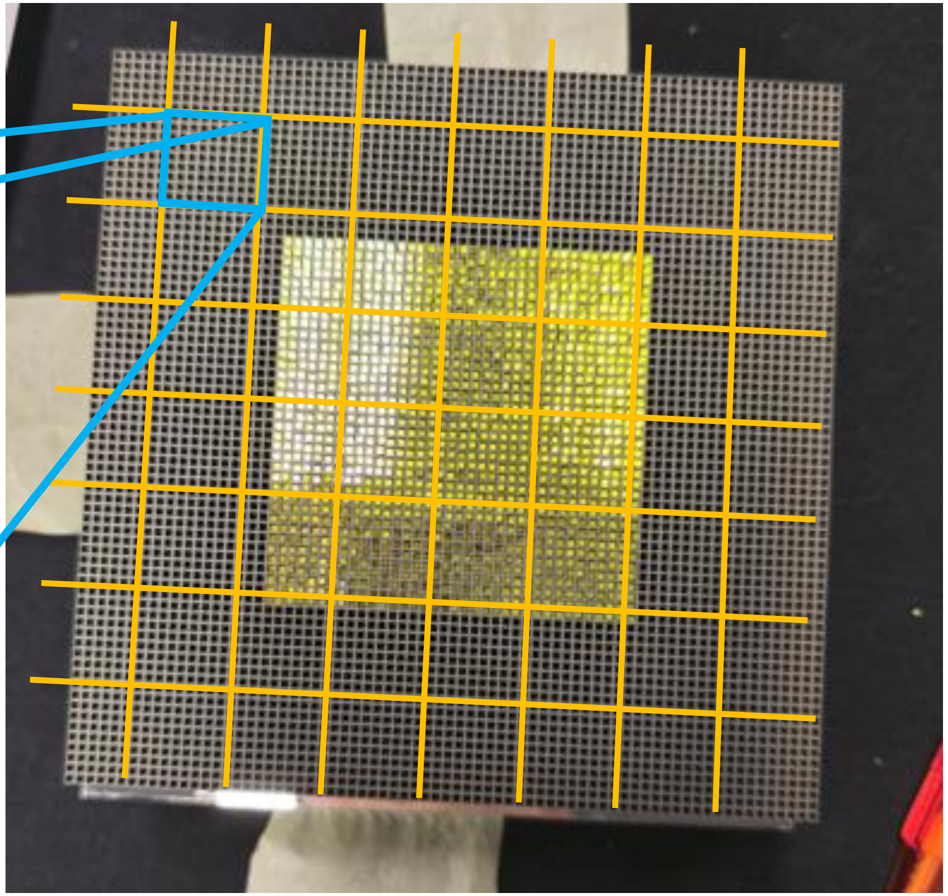
- Black box

Strategies – Hybrid-MC Simulation

- The response map measured in the laboratory will be applied to the hybrid-MC simulation of the full module.
- Each number represents the collection efficiency of an optical fiber.
- The constant term obtained from the mixed simulation is reflected in the energy resolution. **(constant term ~ 1%)**

Important!!!





Strategies – Plastic Materials Mechanical Test

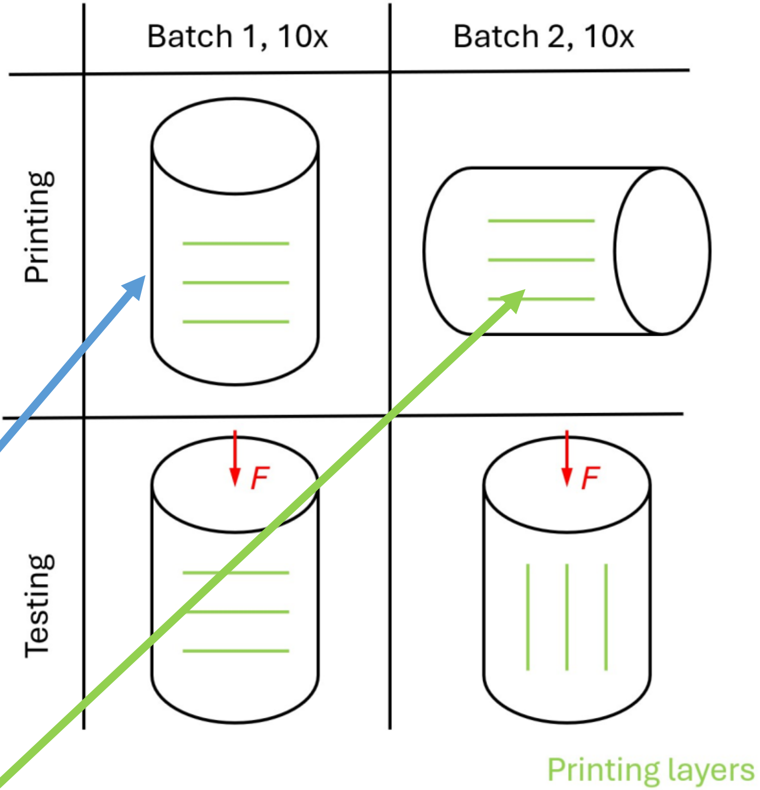
- The plastic installed on the LHCb detector should meet the specified requirements. → see LHCb Underground Safety Regulations.

- The plastic material needs to meet the following requirements:
  - ✓ Radiation-resistant.
  - ✓ High temperature tolerance.
  - ✓ High compressive strength.
  - ✓ Resistant to oxidation and deformation.

- Candidate plastics:
  - ✓ PEEK
  - ✓ PEI
  - ✓ PPSU
  - ✓ PA 12
  - ✓ …

- Candidate technology:
  - ✓ FDM
  - ✓ SLS
  - ✓ SLA
  - ✓ …

- Testing method:
  - ✓ Printing the cylinders with diameter of 10 mm and length of 20 mm.
  - ✓ 10 pieces of compression test sample in standing build up orientation, using finest definition possible **(aim for 0.5mm wall thickness)**
  - ✓ 10 pieces of compression test samples in lying build up orientation, using finest definition possible **(aim for 0.5mm wall thickness)**



- Aim:
  - ✓ Get the pressure-strain curve
  - ✓ Yang's modulus

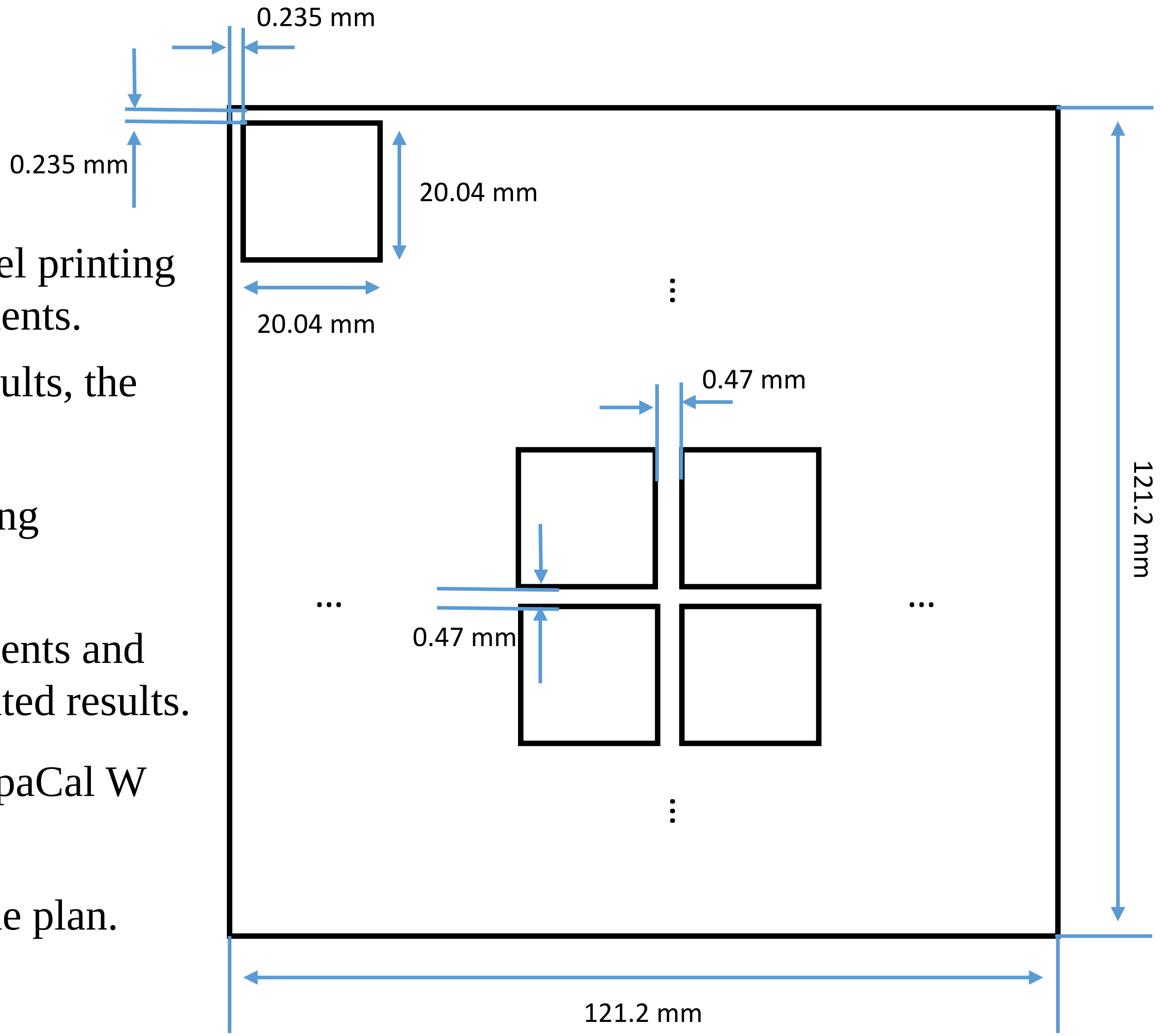
Important!!!

03 Outlook and Next steps

- Refine the simulation framework.
- Setup the laboratory.
- Perform pressure testing on plastic materials.
- Time information.

Conclusion – Outlook and Next Steps

- Setup the laboratory as soon as possible.
  - ✓ Build the framework required for light guide testing.
  - ✓ Complete a series of processes, from light guide model printing and ESR reflector processing to laboratory measurements.
  - ✓ Collecting the experimental data and calculate the results, the respond map.
- Complete the light guide simulation from the full-ray tracing simulation to hybrid-MC simulation.
- Calculate the time information in the laboratory measurements and optimize the time resolution to bring it closer to the simulated results.
- Prepare a full-size (6 × 6 cells) mirror with a pattern for SpaCal W absorber.
- Following mechanical testing of the plastic according to the plan.



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THANK YOU!