ELECTROMAGNETIC CALORIMETER (SPLITCAL)

SHiP
Search for Hidden Particles

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PRiSMA+
Cluster of Excellence

JOHANNES GUTENBERG UNIVERSITÄT MAINZ
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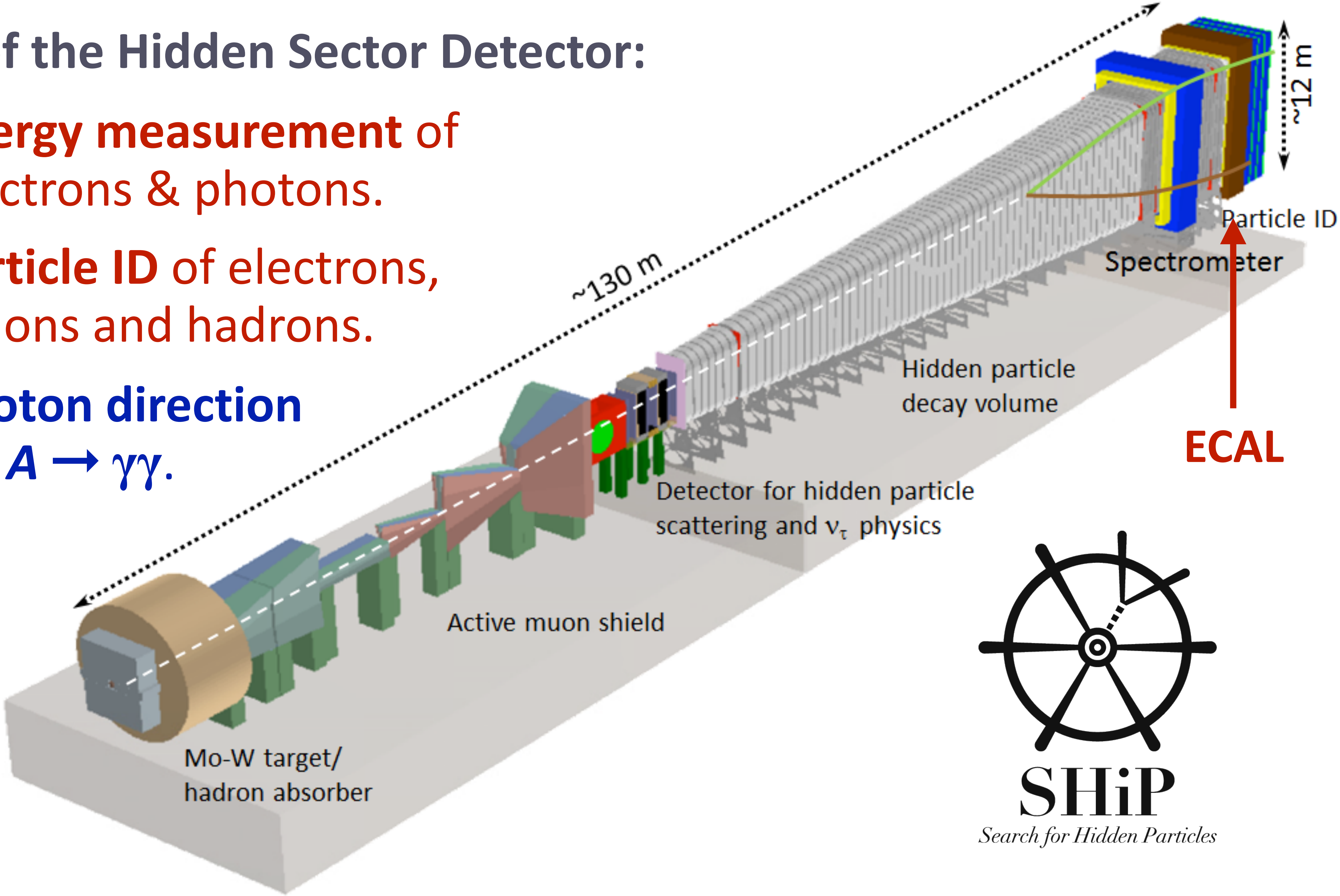
The Electromagnetic Calorimeter

ECAL of the Hidden Sector Detector:

- **Energy measurement** of electrons & photons.
- **Particle ID** of electrons, muons and hadrons.
- **Photon direction** for $A \rightarrow \gamma\gamma$.



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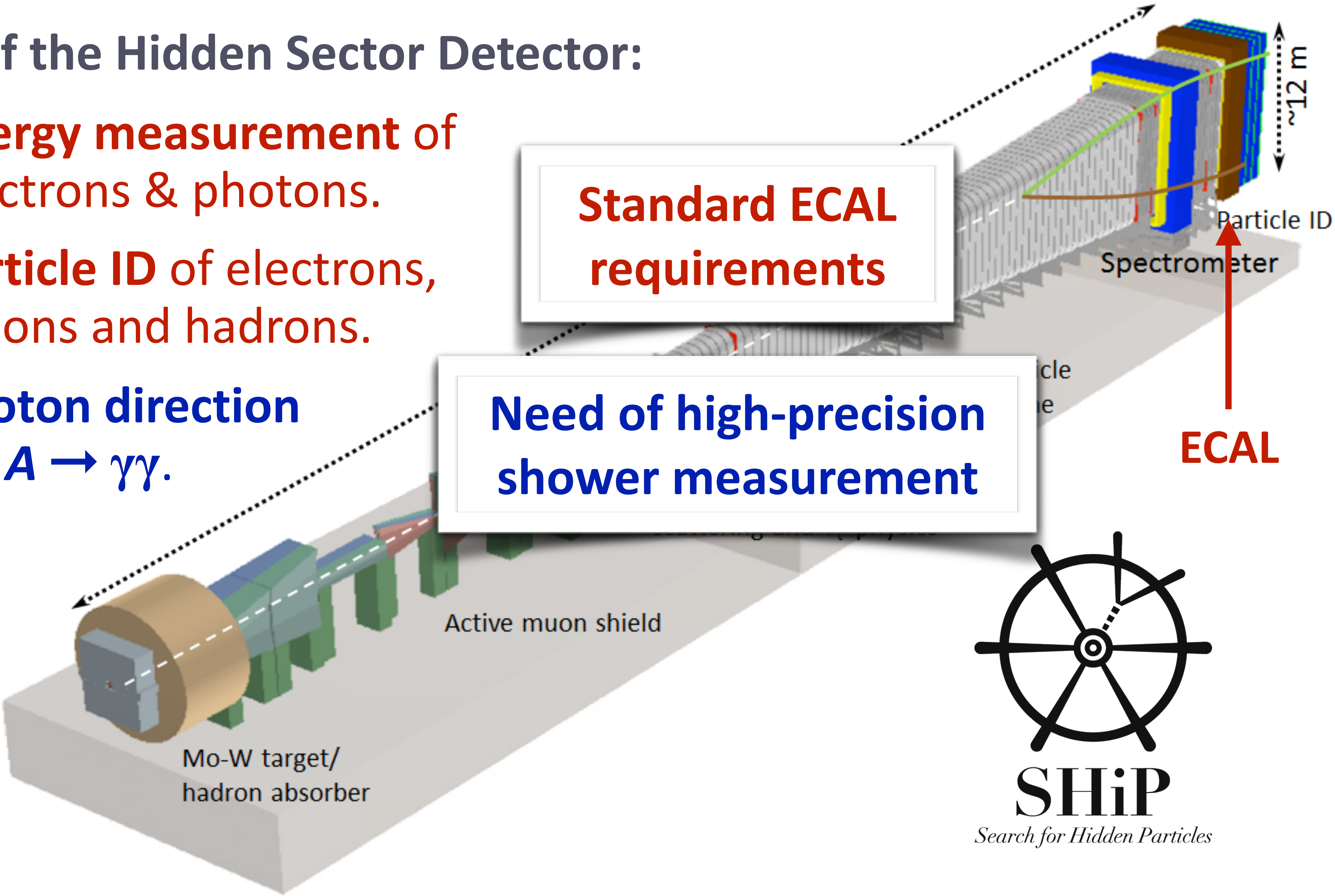

Standard ECAL requirements

Need of high-precision shower measurement

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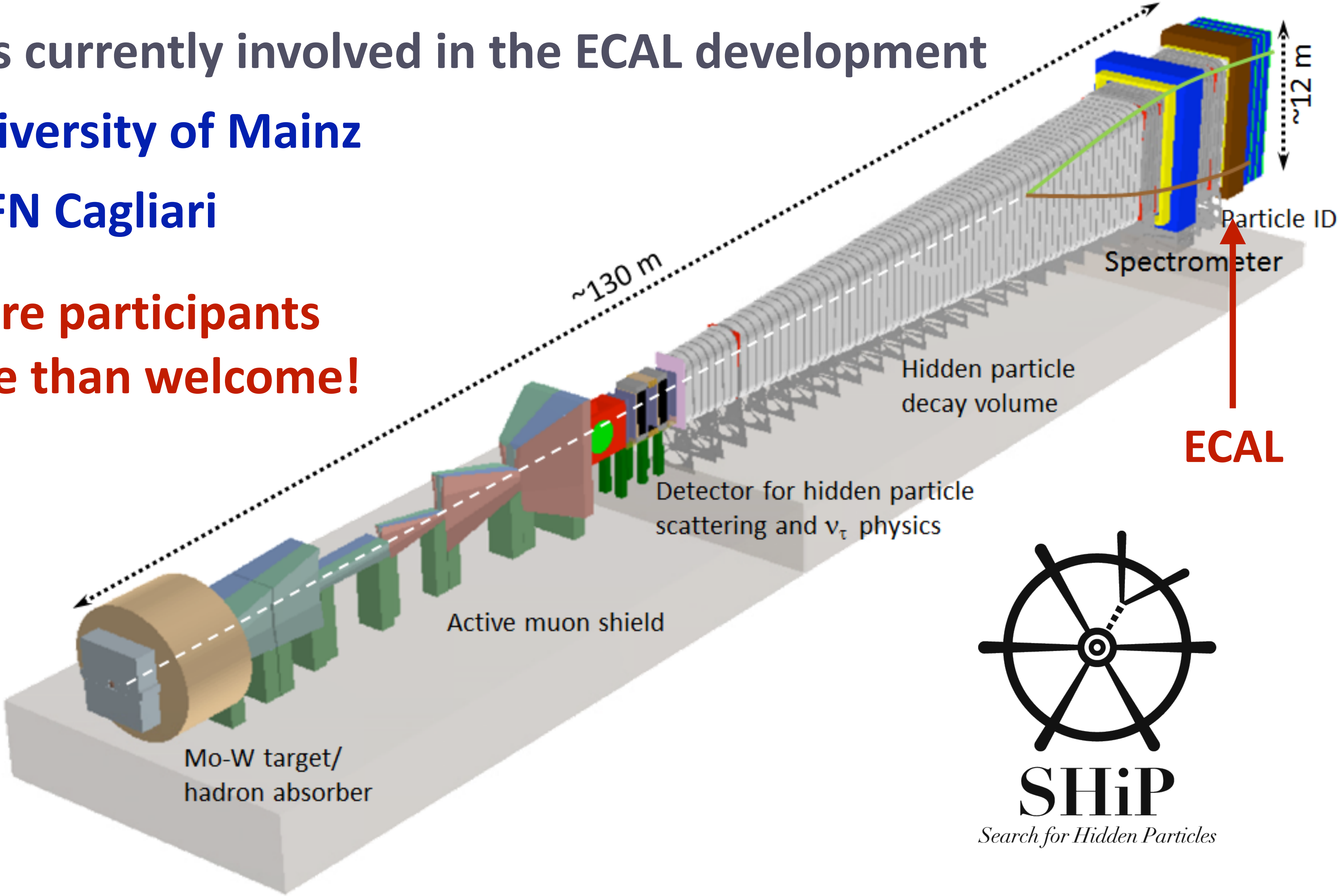
Calorimeter Groups

Groups currently involved in the ECAL development

- **University of Mainz**
- **INFN Cagliari**

More participants more than welcome!



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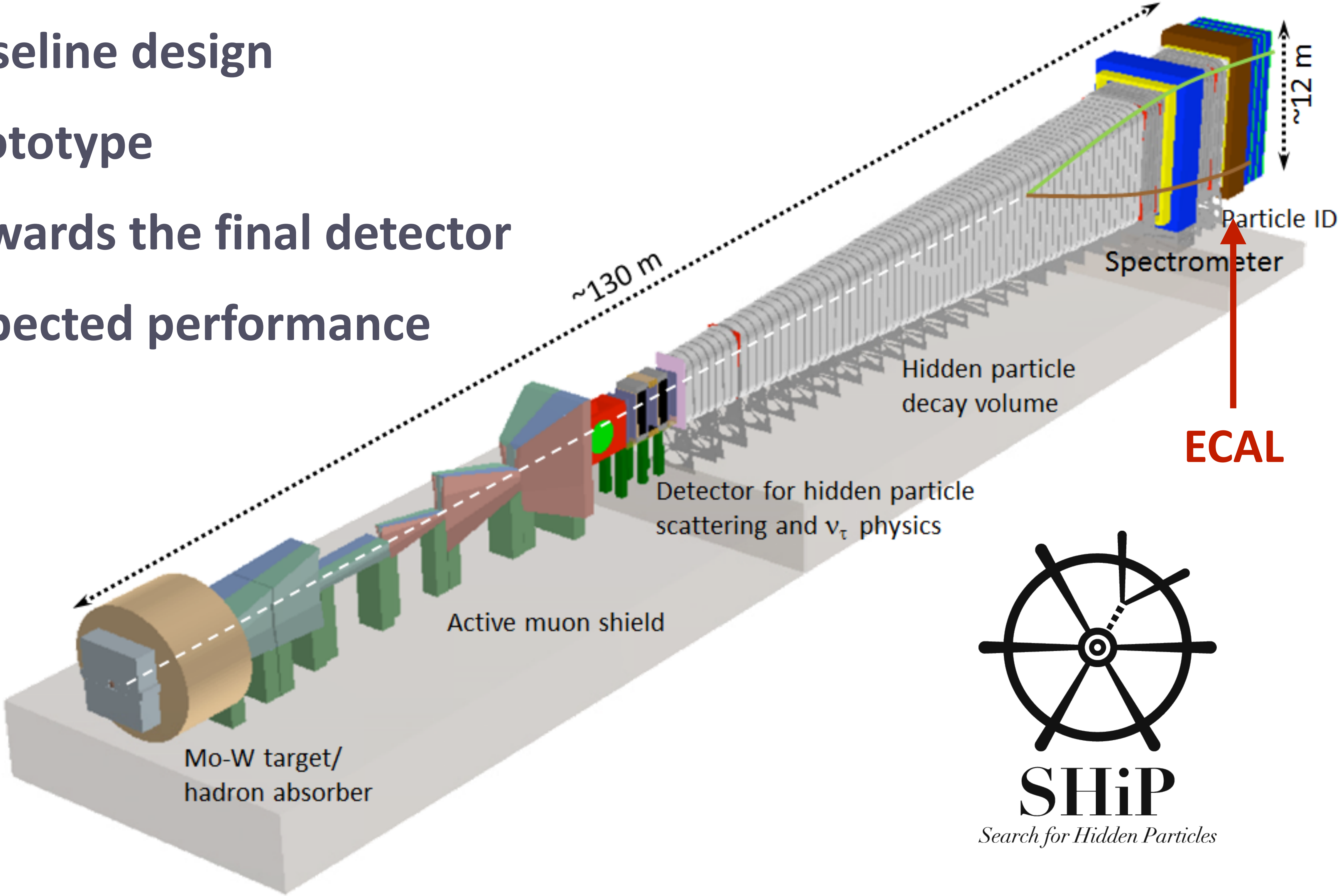
Overview

- Baseline design
- Prototype
- Towards the final detector
- Expected performance



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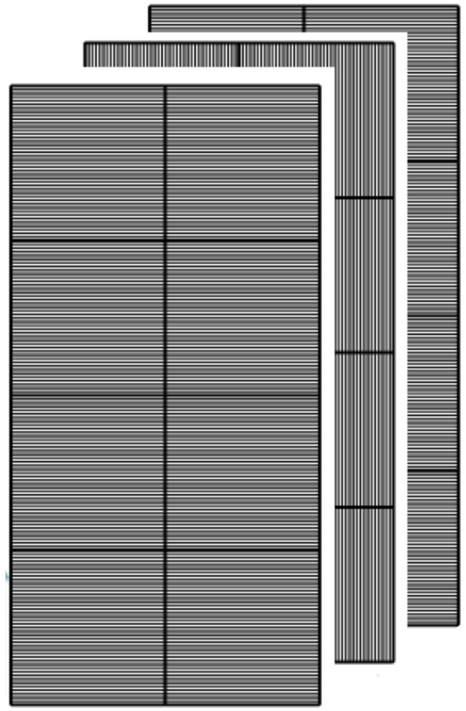
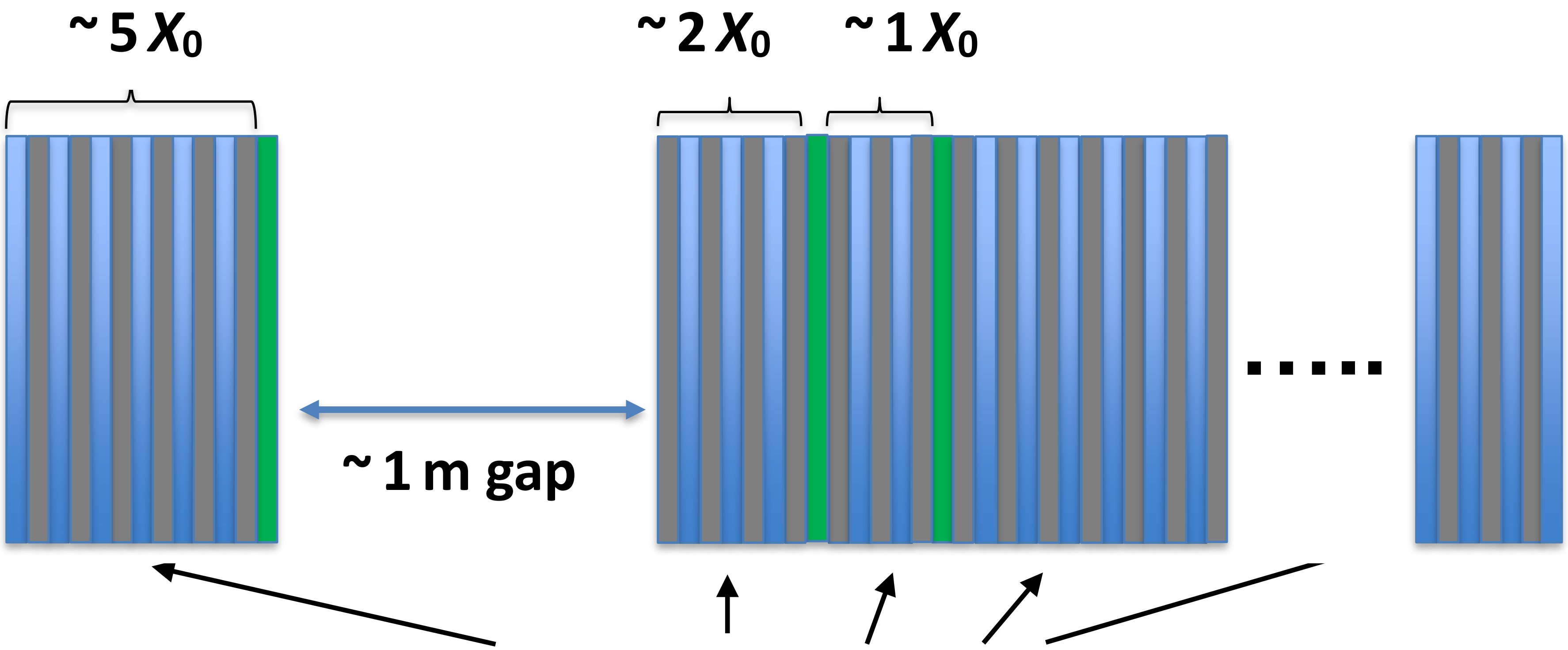
Baseline Design

Two separate and very different detectors in one:

1. **Scintillator ECAL** for shower energies.
   - **Large absorber planes** of **6 m × 12 m** cross section
   - **About 40 scintillating planes (20 X_0)** with strips alternating in x and y and **WLS fibre readout.**



Front view



~ 5 X_0

~ 2 X_0

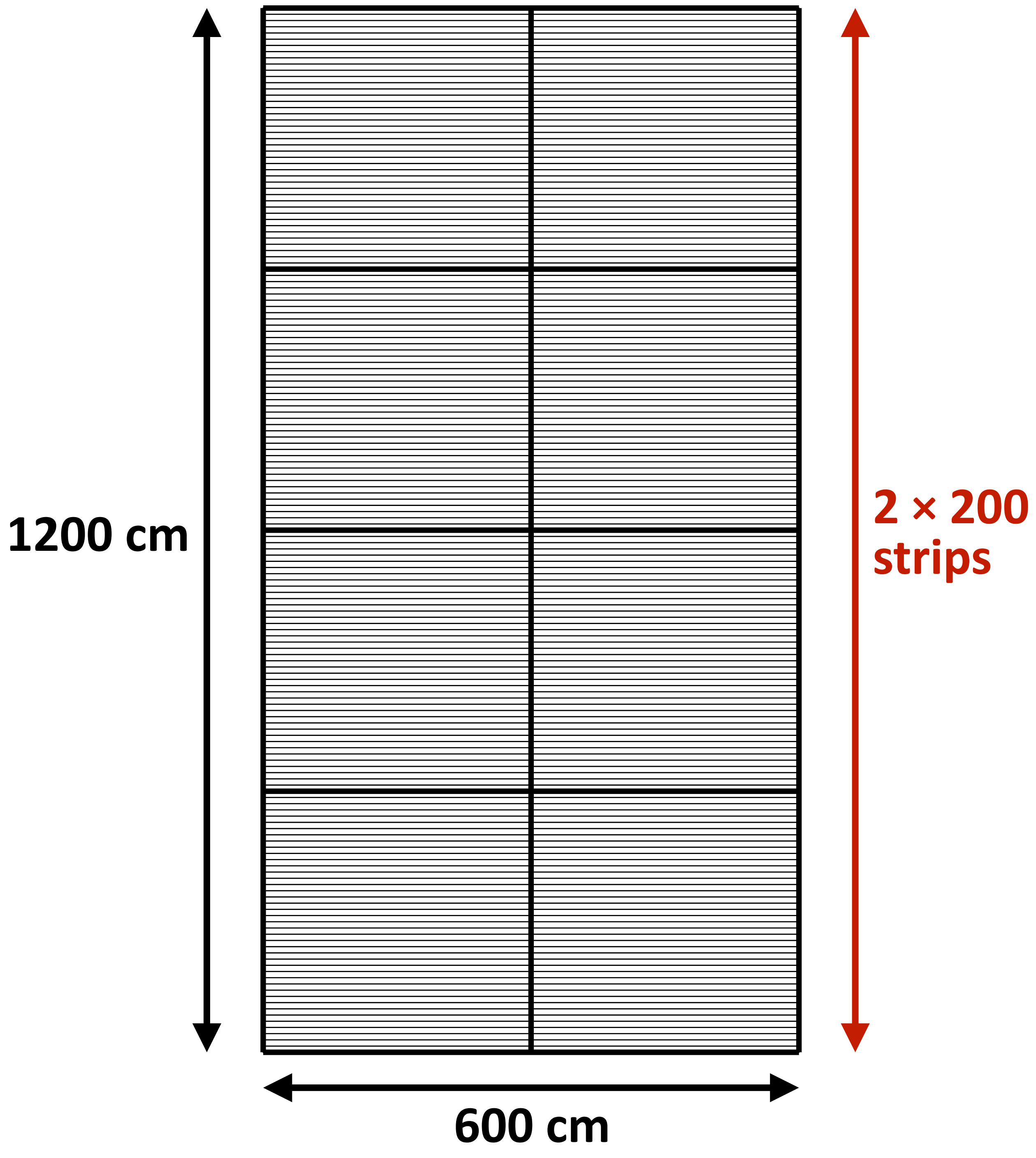
~ 1 X_0

~ 1 m gap

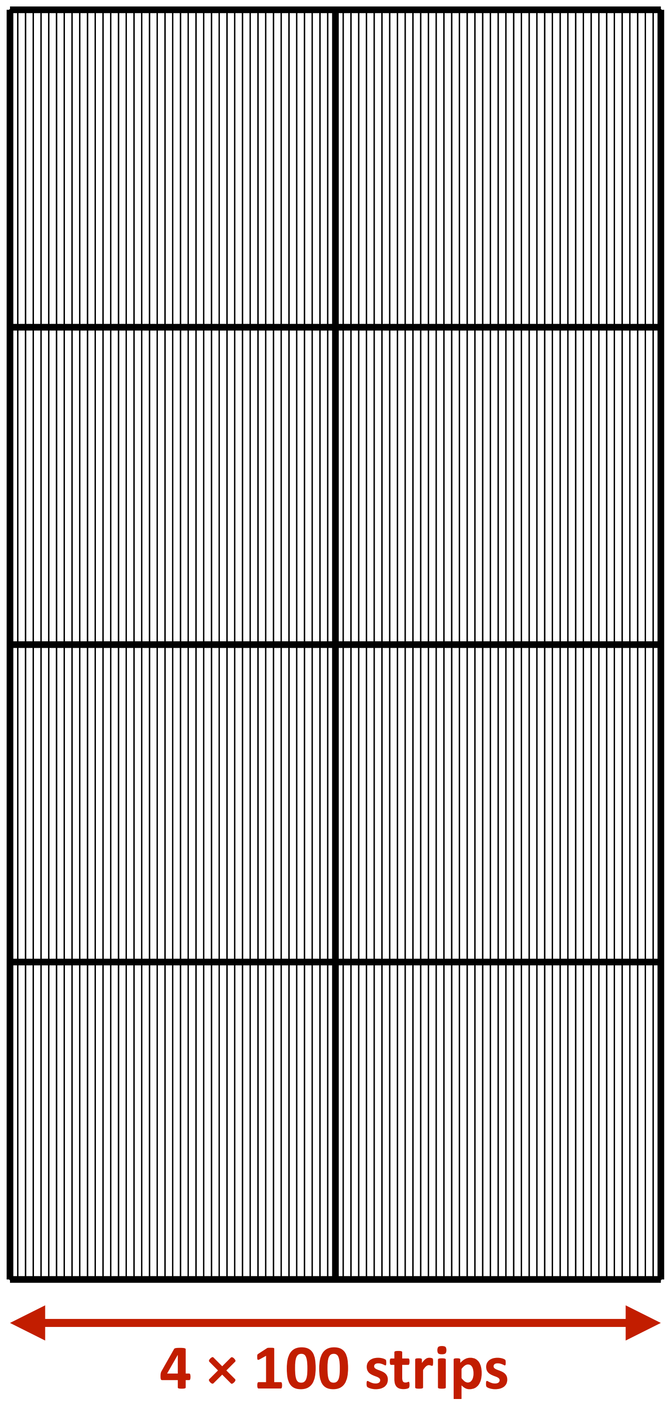
Scintillator-absorber planes

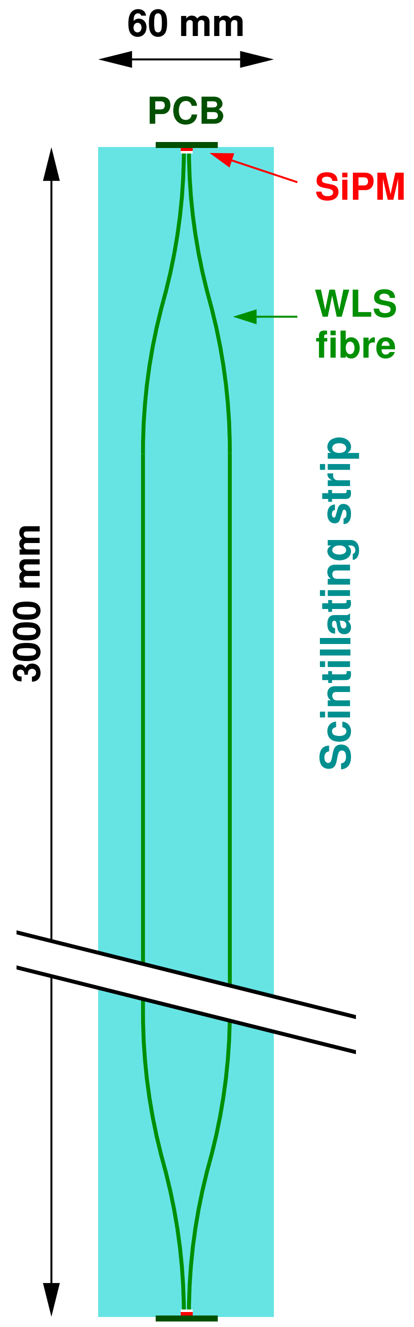
Layout of Scintillating Layers

Horizontal layer



Vertical layer



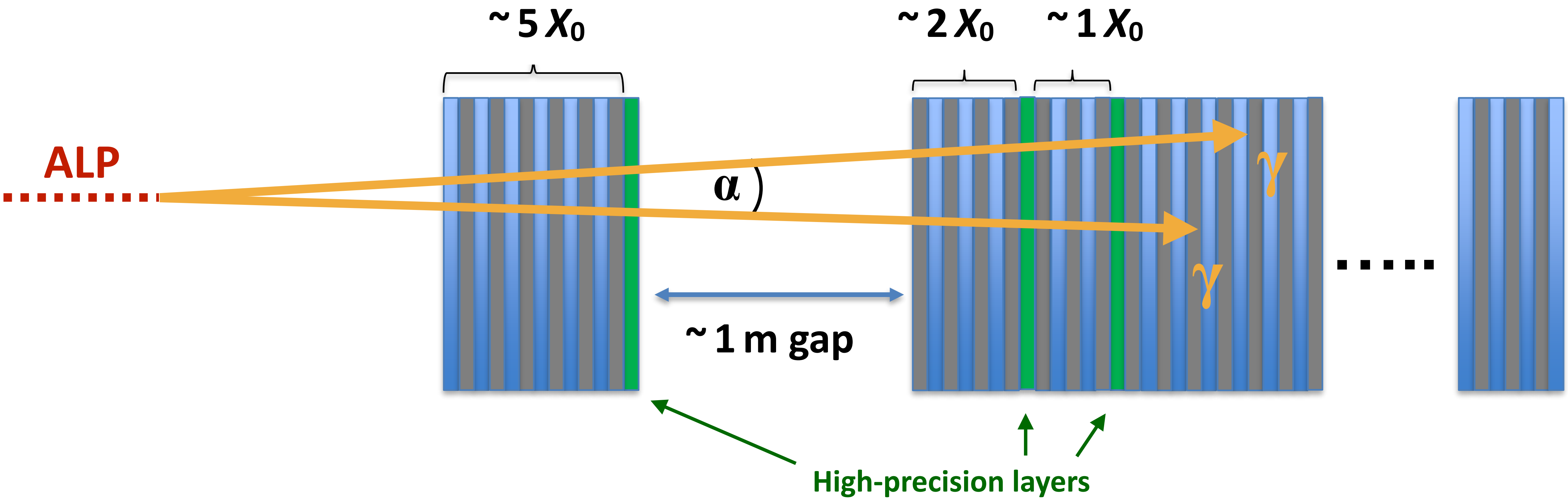


Baseline Design

Two separate and very different detectors in one:

2. **Two or three high-precision layers** for photon directions.
   - **Invariant mass of an ALP decay $A \rightarrow \gamma\gamma$** can be measured:

$$m^2 = E_{\gamma 1} \times E_{\gamma 2} \times (1 - \cos\alpha)$$



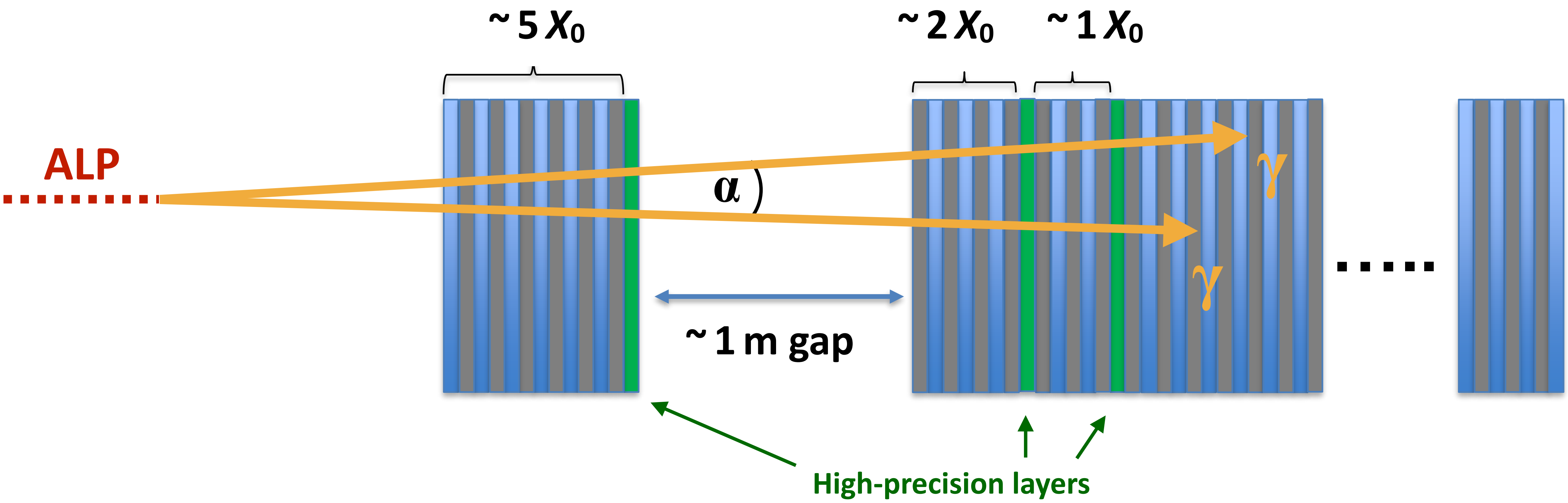
Baseline Design

Position of high-precision layers optimum between two competing inefficiencies in photon detection:

- **Conversion probability** only 56% per X_0 ➜ **First layer at ≥ 5 X_0.**
- **Shower length** for low-energy photons ➜ **Last layer at 7-8 X_0.**

➜ **Still inefficiencies of $\mathcal{O}(5\%)$.**

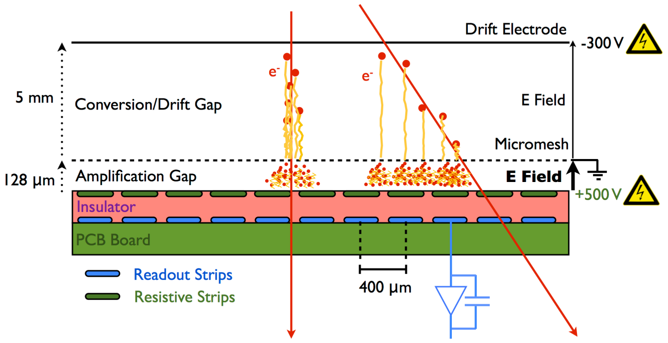
Gap of ~1 m for better lever arm ➜ **„SplitCAL“**

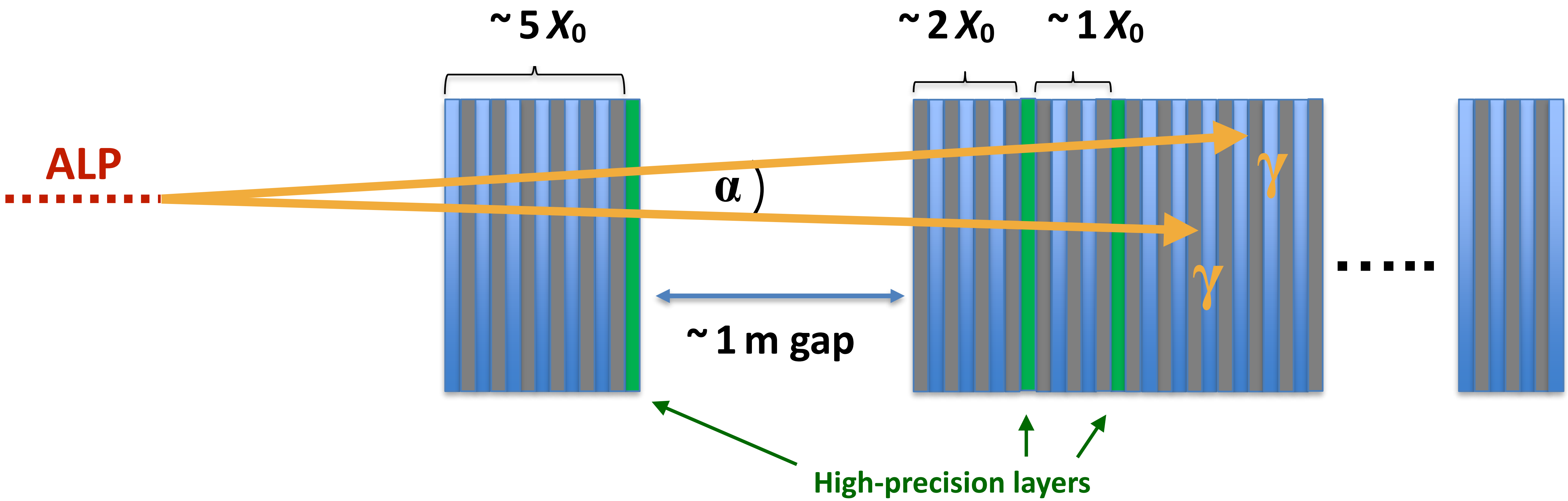


Baseline Design

Technology of high-precision layers:

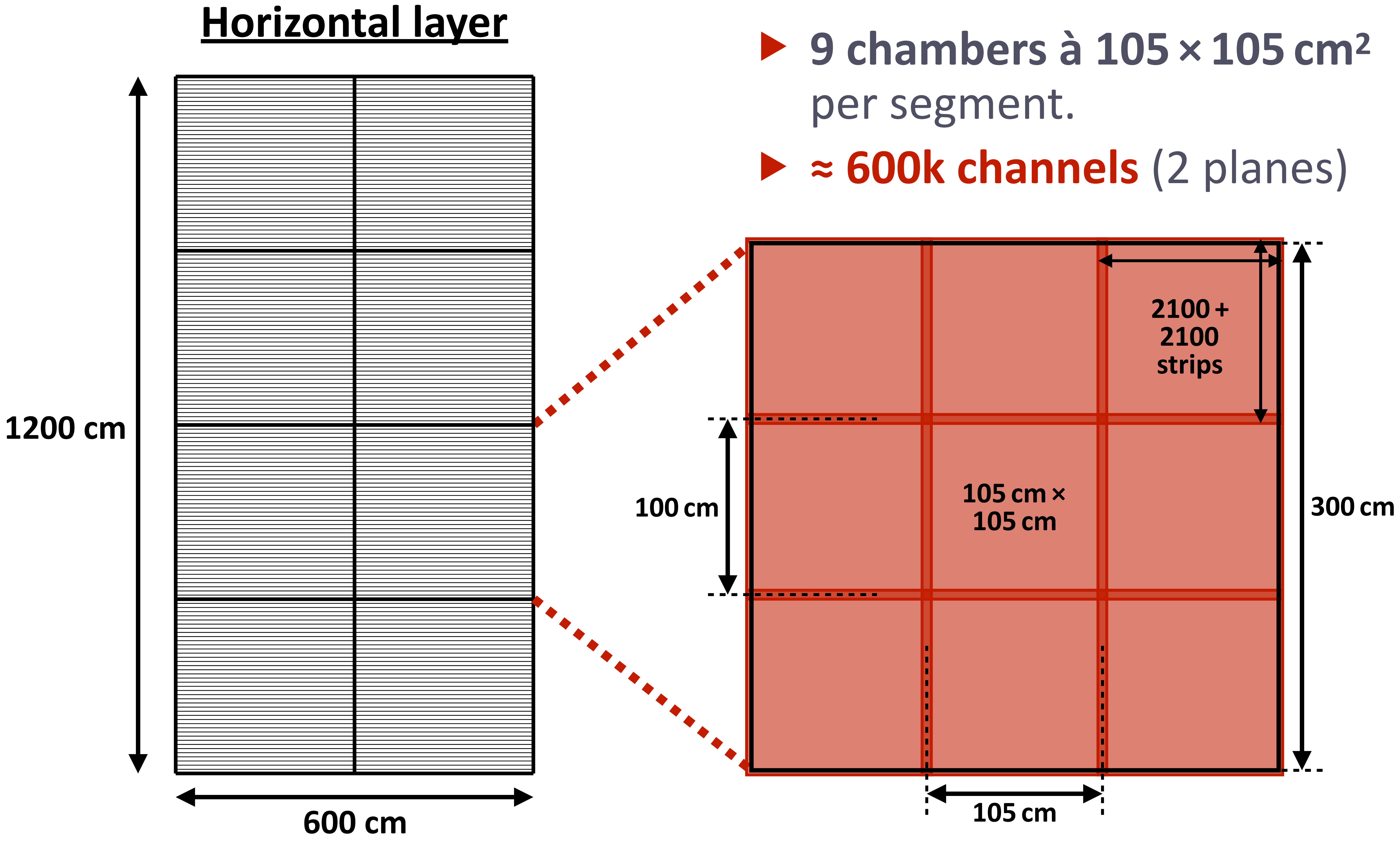
- In principle every technology with high resolution does the job.
- As baseline we use **MicroMegas** as for the ATLAS muon system upgrade.
  ➜ Known technology, available in Mainz.





Layout of MicroMegas Layers

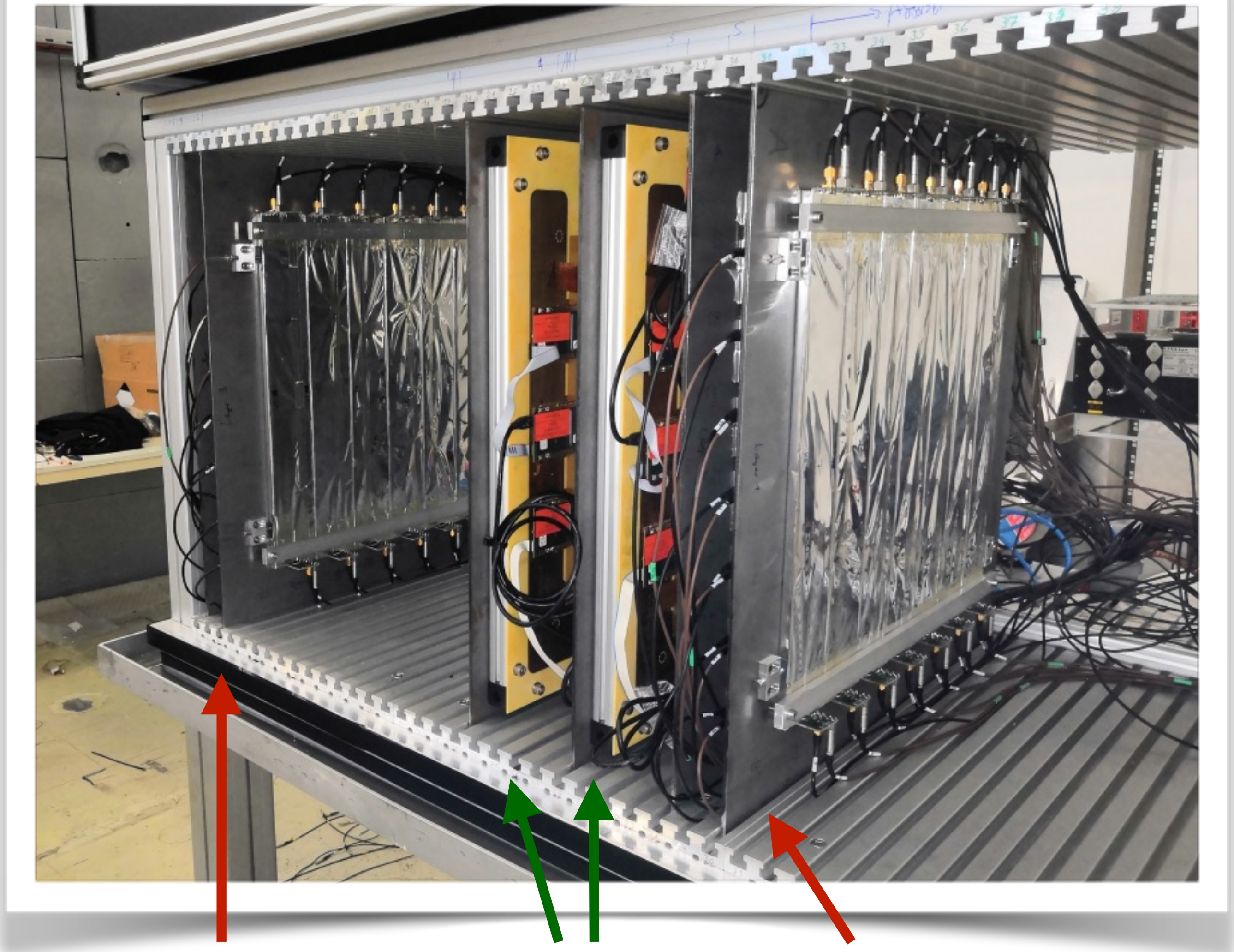
- **9 chambers à 105 × 105 cm²** per segment.
- **≈ 600k channels** (2 planes)



SplitCAL Prototype

SplitCAL Prototype

No additional absorber layers

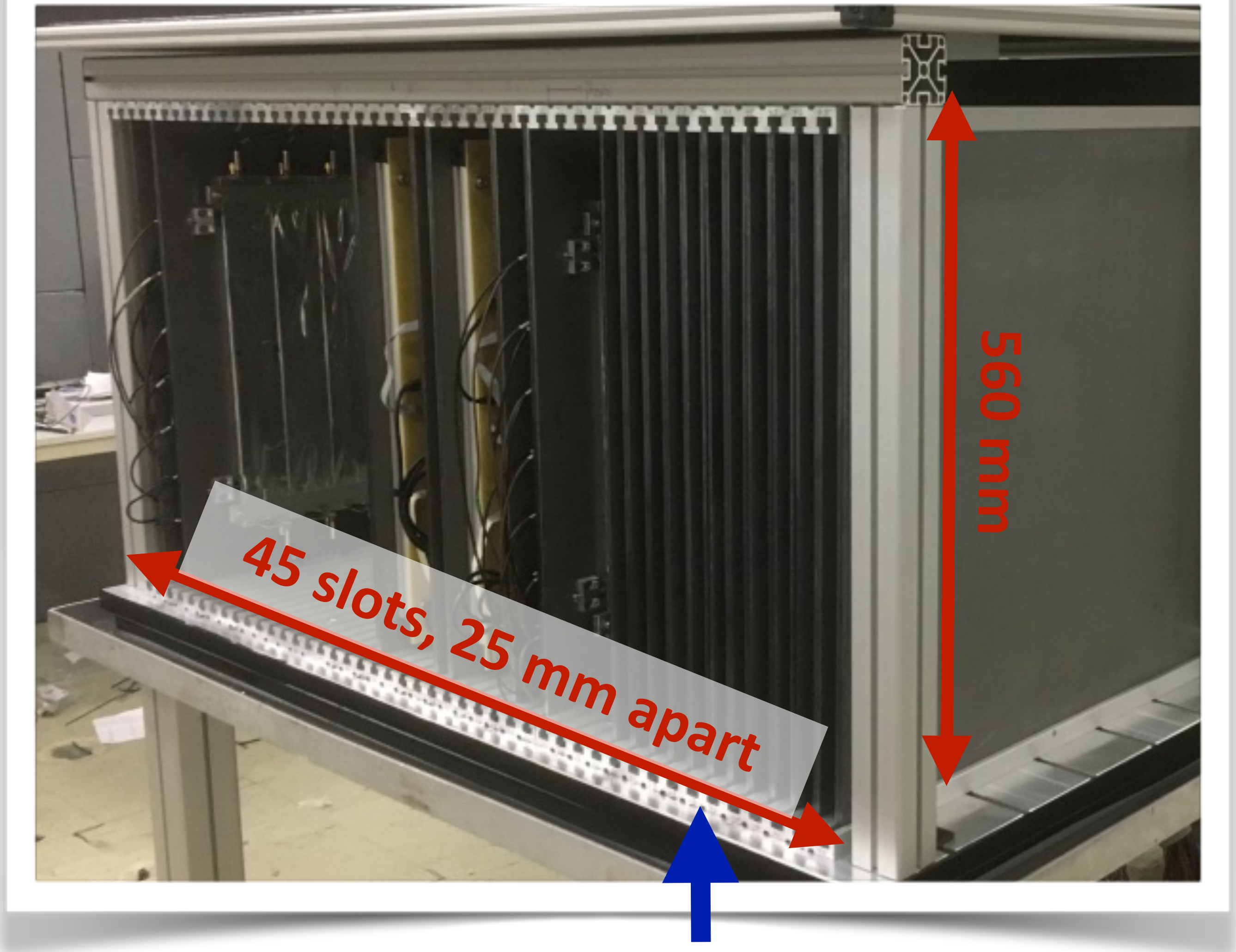


2 scintillator layers (x & y)

2 Micro-Megas

2 scintillator layers (x & y)

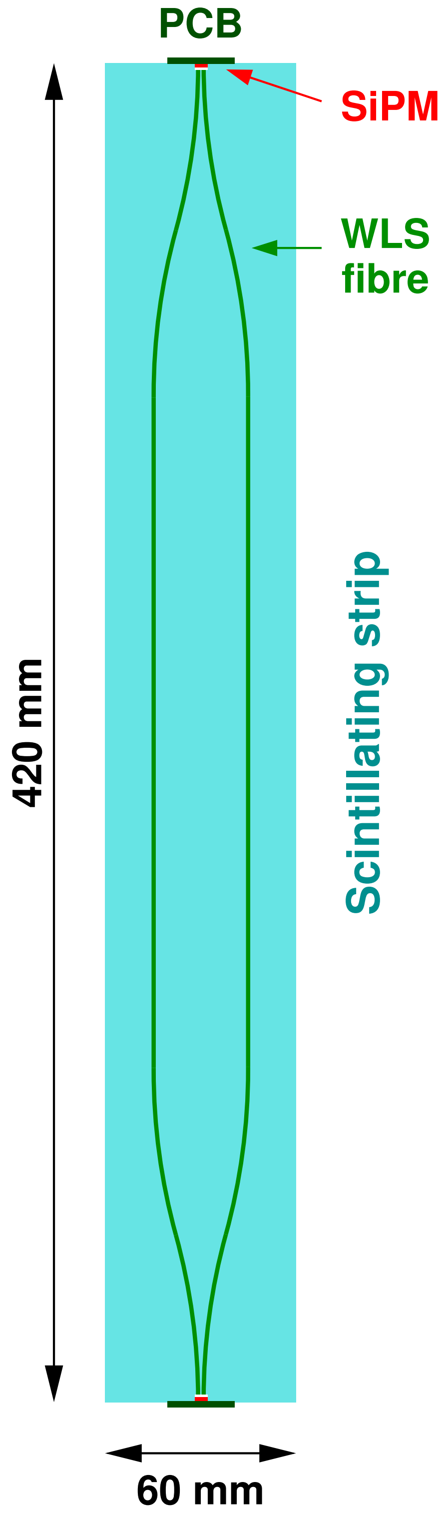
With absorber layers in front



22 absorber layers (≈ 5 X_0)

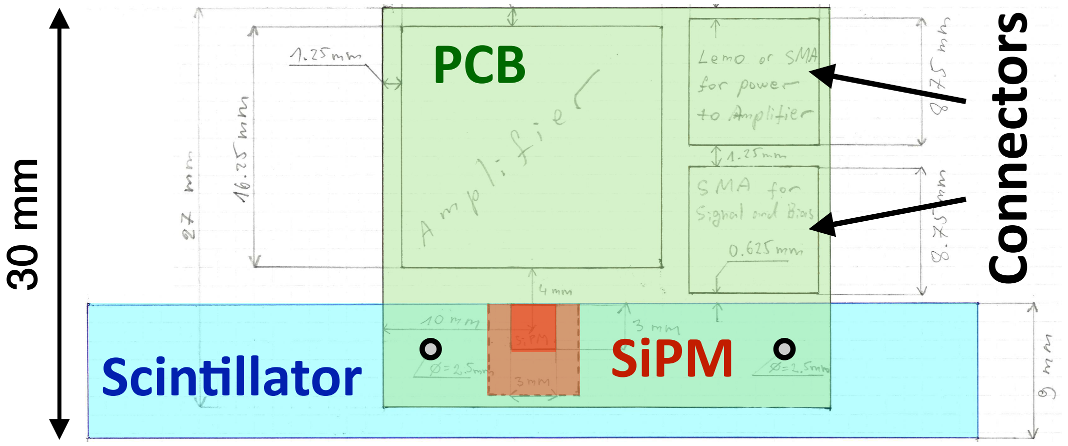
All kinds of setups easily possible.

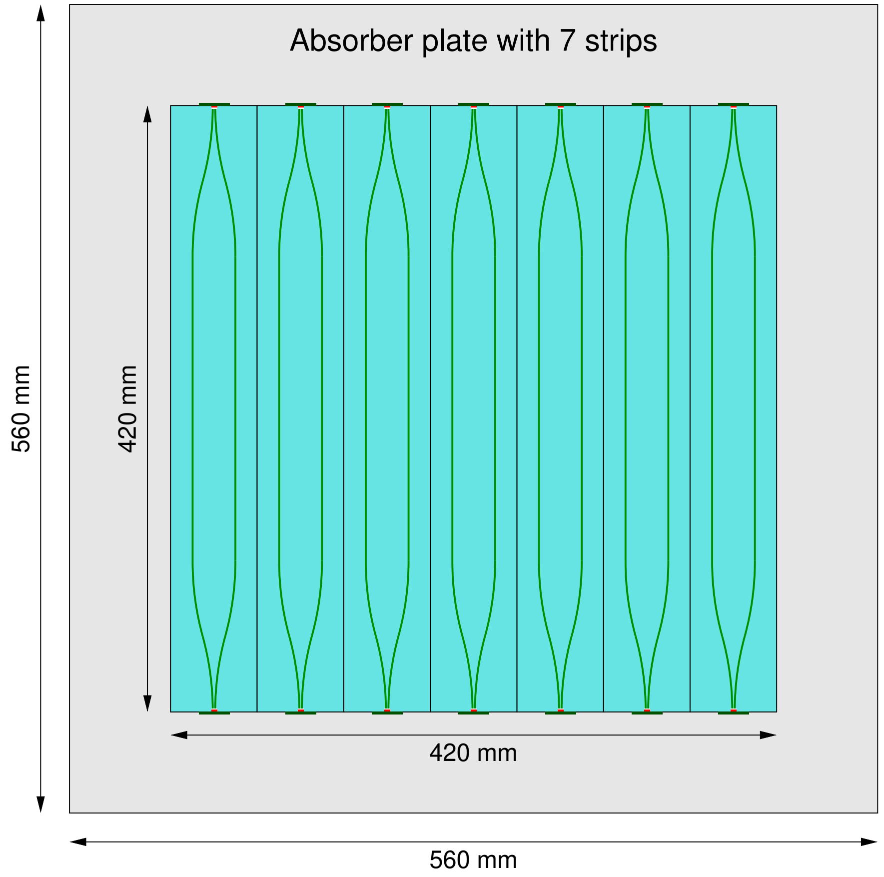
Scintillating Planes of the Prototype



Each scintillating plane consists of one absorber plate, with 7 scintillating strips mounted.

- Double-sided readout ➜ 2 × 7 = 14 chan/plane.
- 2 horizontal & 2 vertical planes.
- SiPMs, preamps, and bias voltage mounted on a single PCB on the front faces of the strips.





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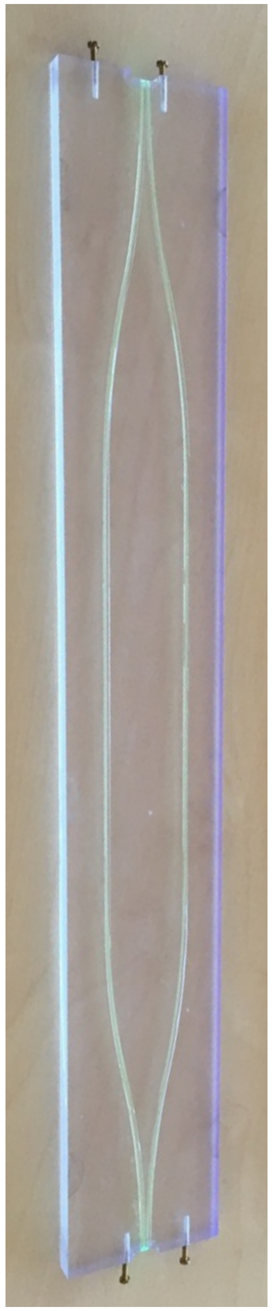
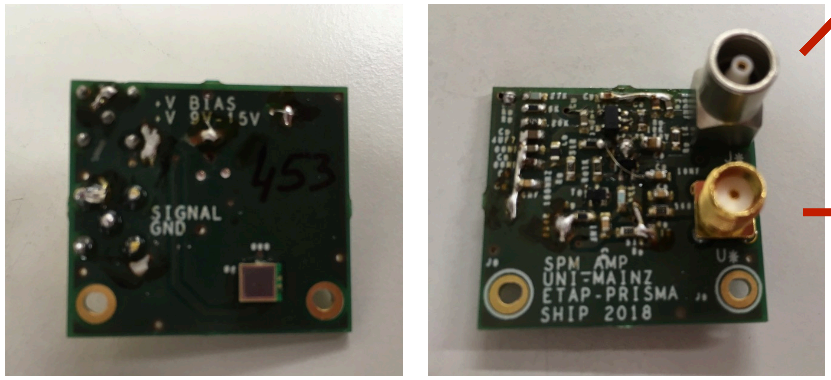
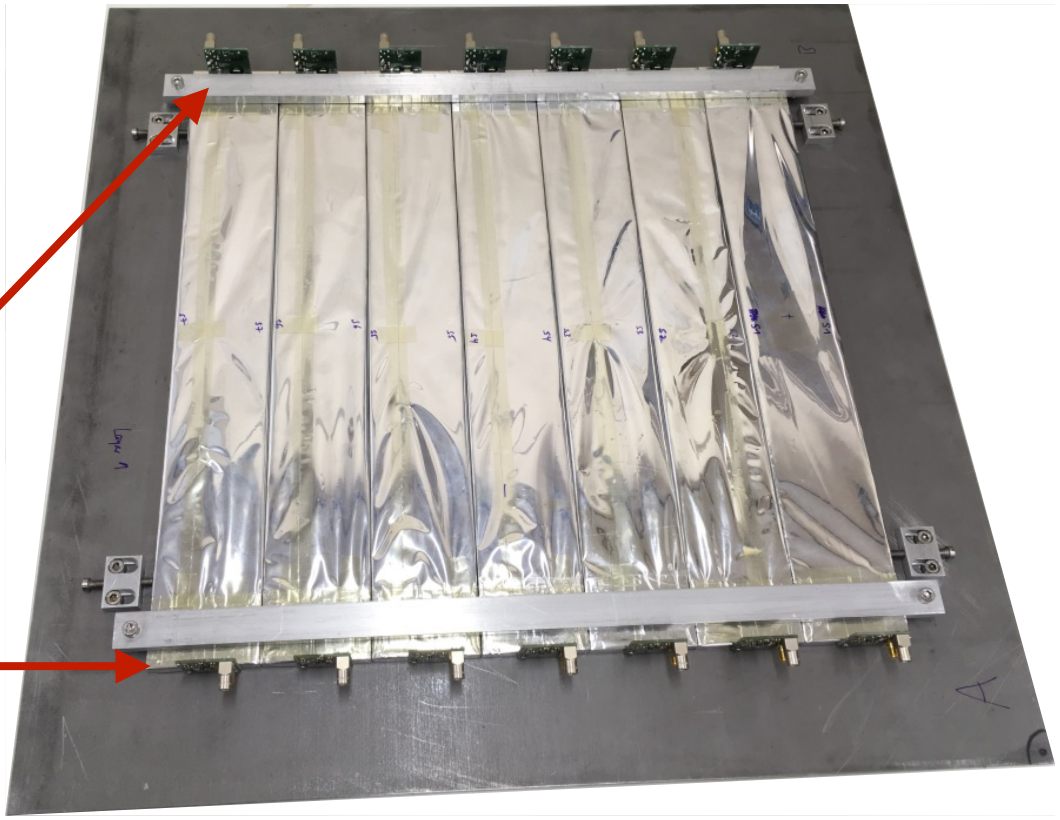


Scintillating strip



SiPM with preamplifier

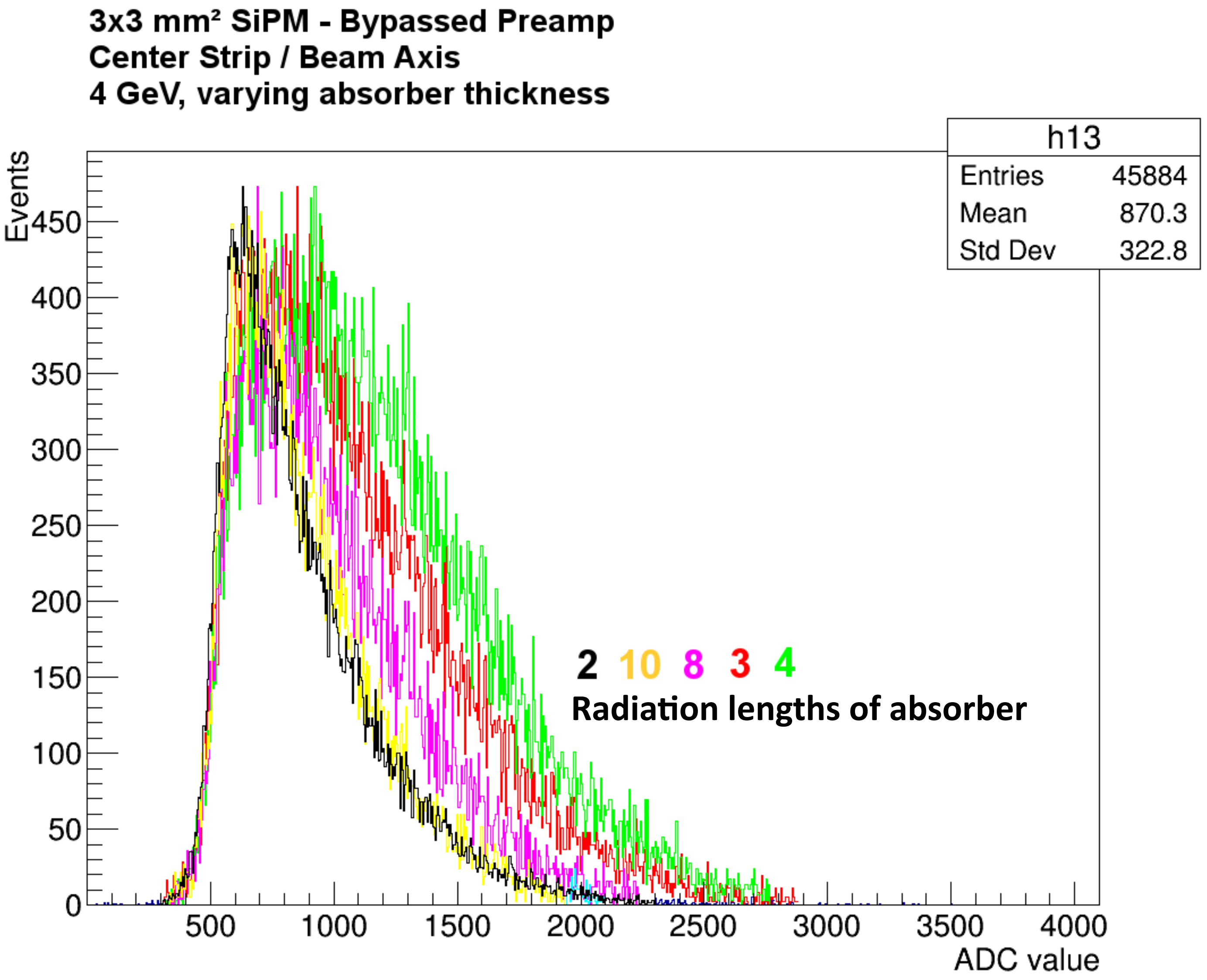


Absorber plate with 7 strips

Results of Scintillating Planes

Measurement of electron showers (test beam data):

- **Shower development through absorber layers clearly visible.**



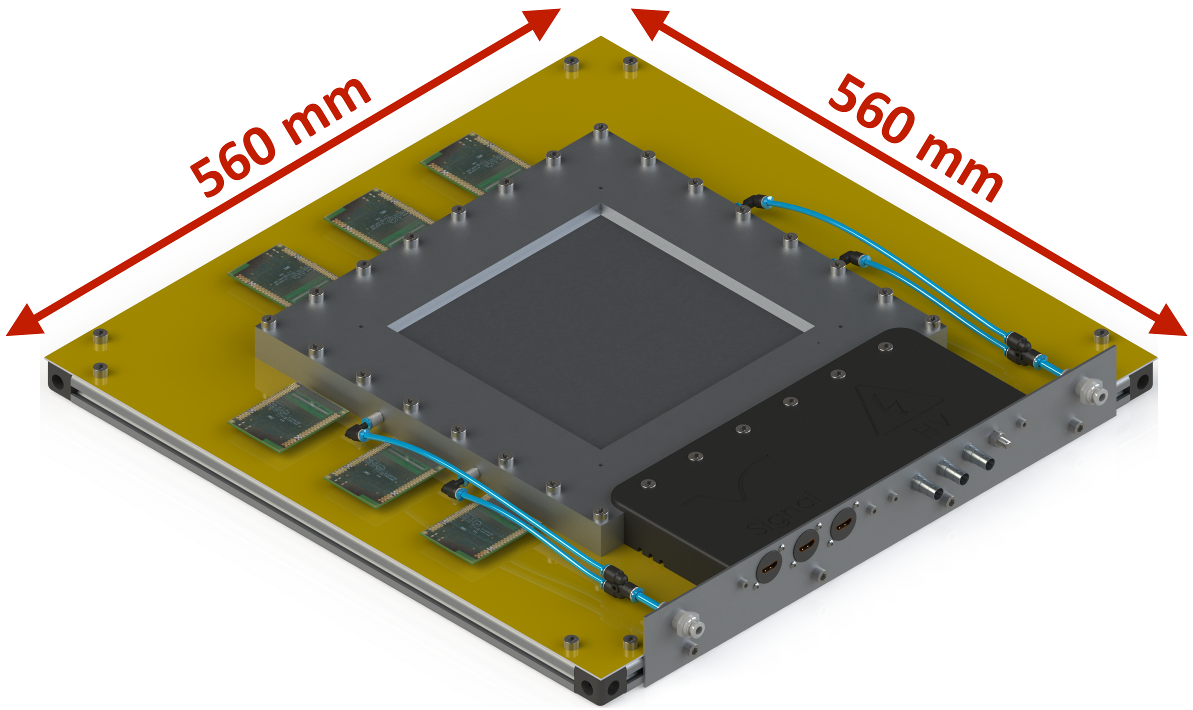
3x3 mm² SiPM - Bypassed Preamp
Center Strip / Beam Axis
4 GeV, varying absorber thickness

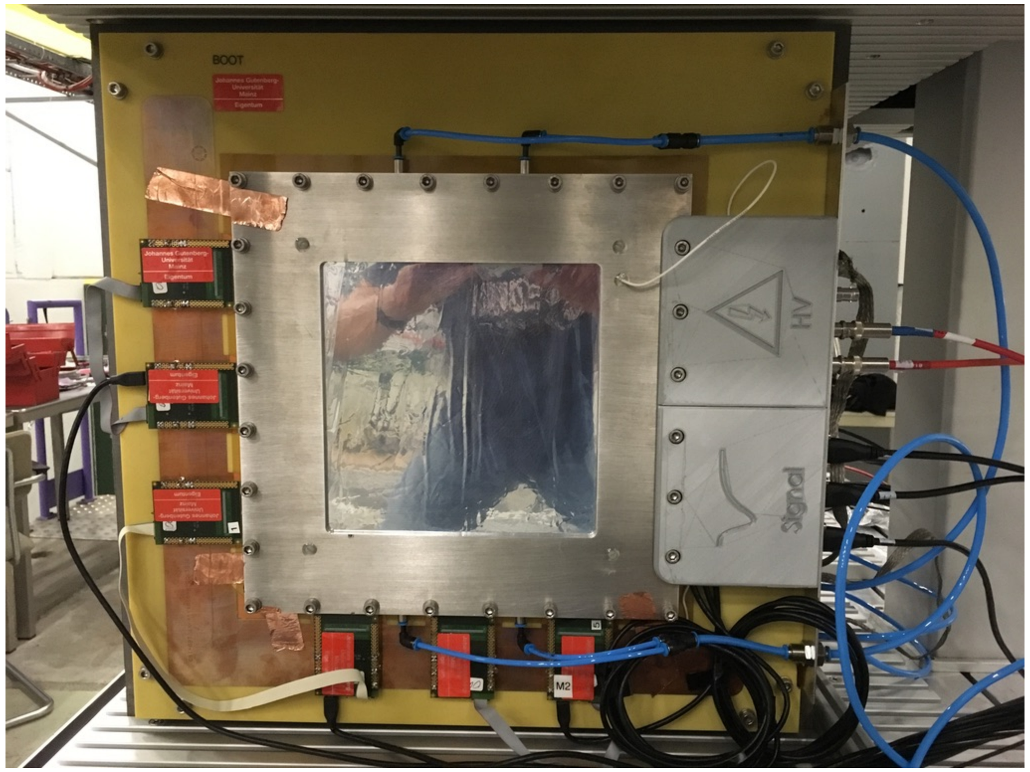
2 10 8 3 4
Radiation lengths of absorber

High-Precision Layers of the Prototype

Two MicroMegas chambers with 18 × 18 cm² active area.

- Each MicroMegas contains a double-layer with *x* and *y* strips, mounted on one absorber plate.
- Strip pitch = 500 µm ➜ 360 strips in each view.
- Readout with custom ASICs (APV) and external trigger.

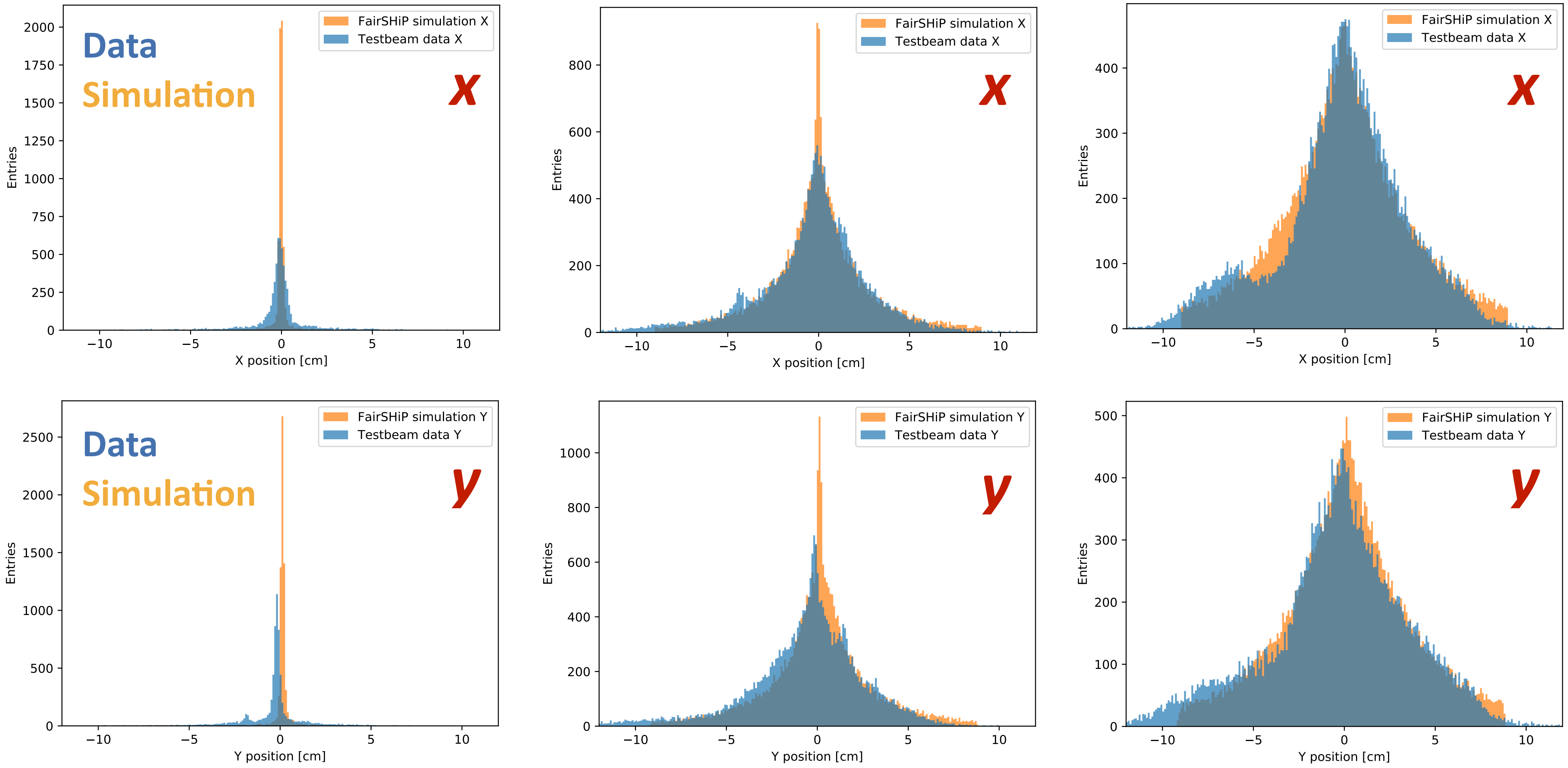




Test Beam Results for High-Precision Layers

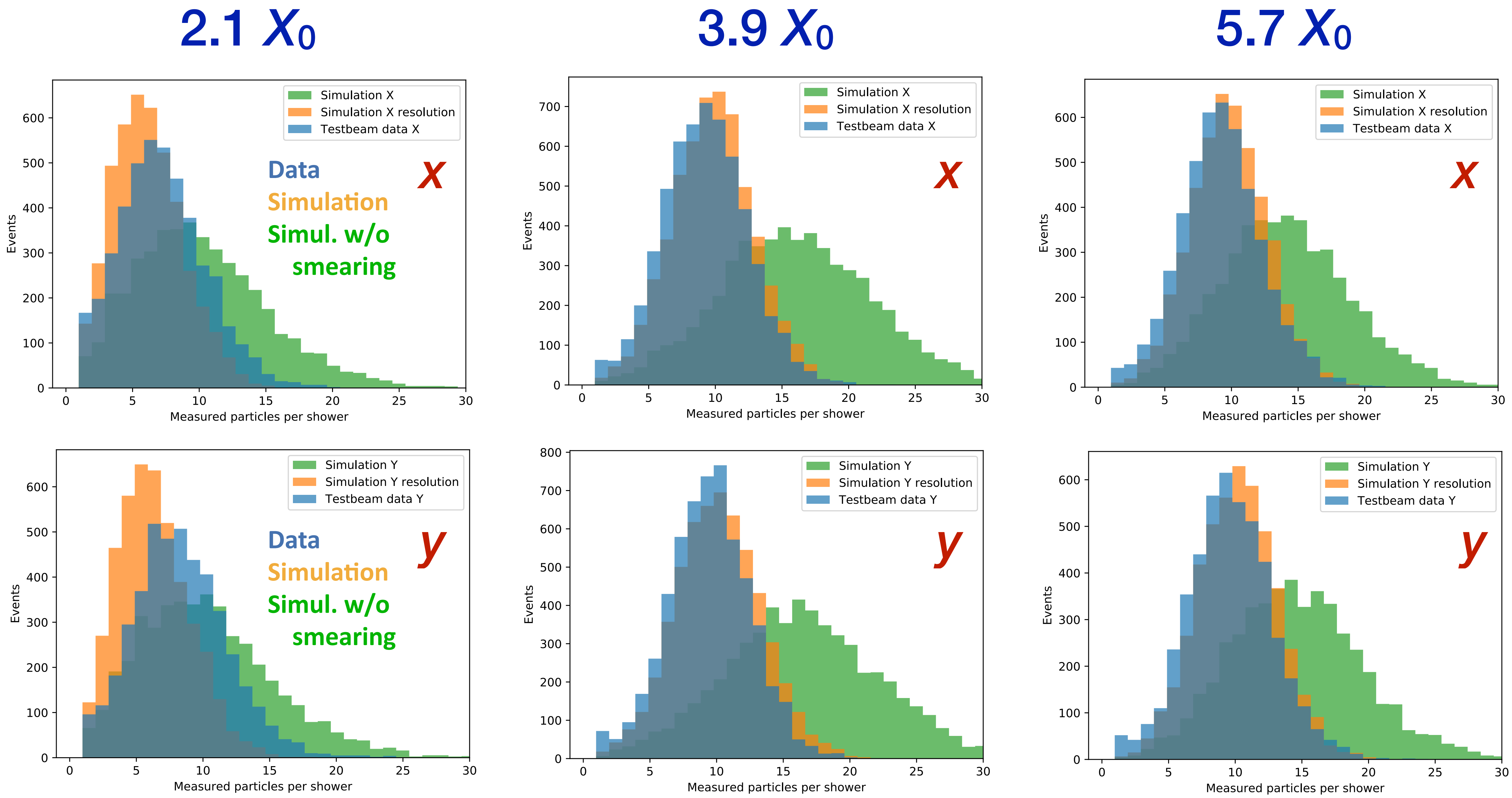
MicroMegas layers (electron test beam data):
Hit distributions for data and simulation with 2 mm hit resolution.
➜ **Very good agreement** apart from residual noise.

0.2 X_0 **2.1 X_0** **5.7 X_0**



Test Beam Results for High-Precision Layers

Average number of measured particles per shower:

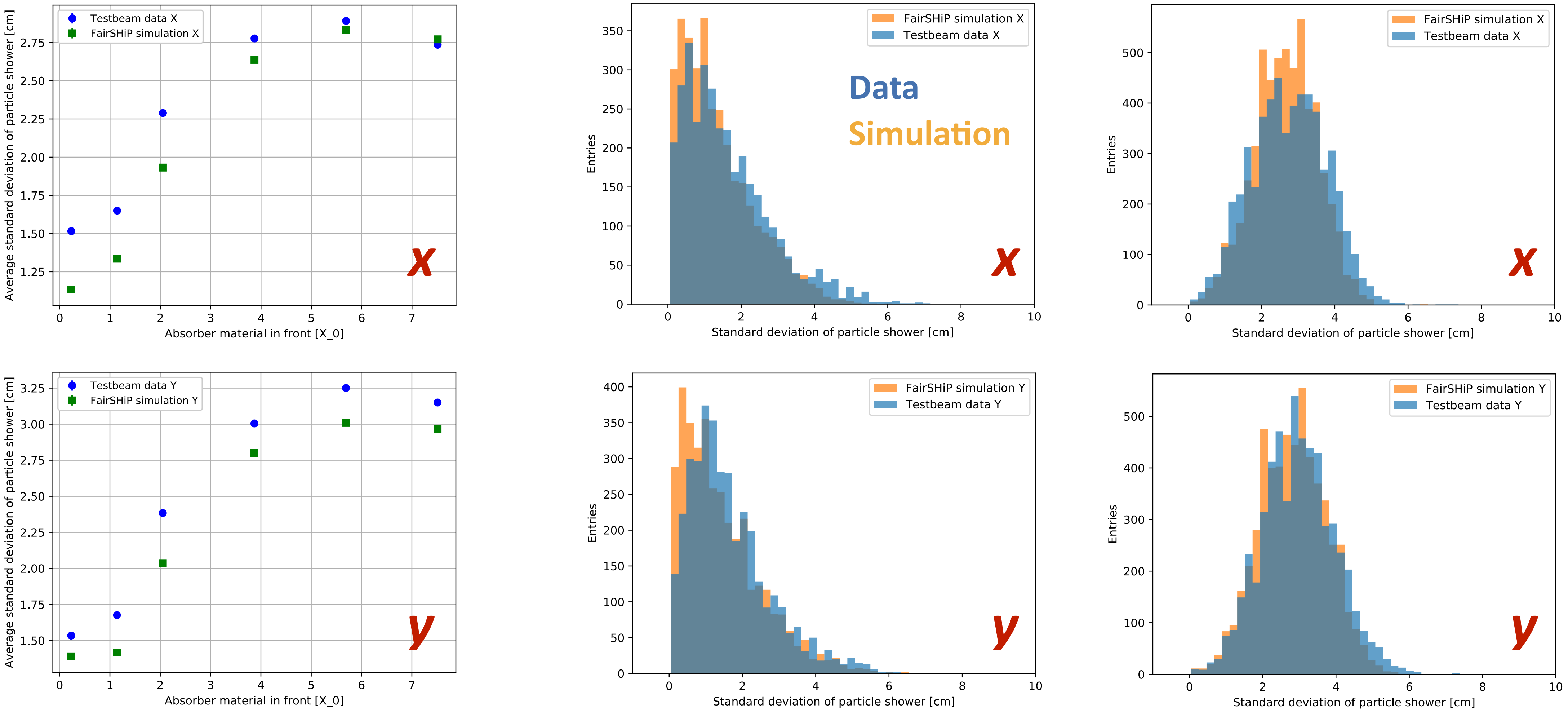


Test Beam Results for High-Precision Layers

Shower width (excluding single-particle events):

- ▶ **Good agreement between measurement and simulation.**

1.1 X_0 3.9 X_0

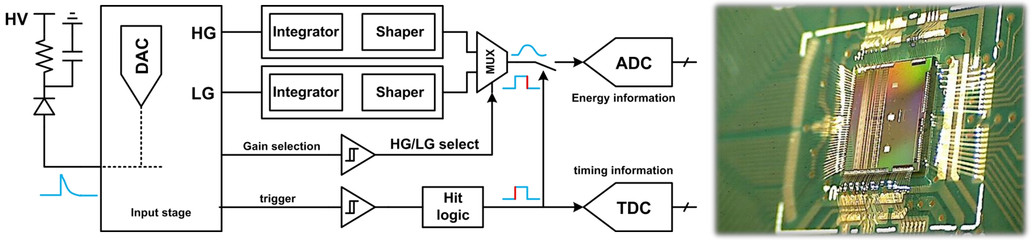


Towards the final SplitCAL

Scintillator SiPM Readout

- **Prototype readout too expensive** (and clumsy) for $\mathcal{O}$(40k) channels.
- **Better: ASICs near SiPMs** for signal collection & digitization.

  Requirements:
  - Large dynamic range (MIPs as well as e.m. showers).
  - SiPM calibration.
  - Multiplexed digital output because of high # of channels.



(Z. Yuan)

KLauS chip from Uni Heidelberg is an option

Main R&D topic at the moment.

Technological prototype

Next step: ***Technological prototype***

- **Involves all required materials and technologies and demonstrates the feasibility and functionality.**
- **Front face of about 1.5 m x 1.5 m.**
- **10 scintillating layers** (5 *x*, 5 *y*) and **2 high-precision layers.**
- **500 SiPM channels** and **25200 MicroMegas channels.**
- **Close to final Readout** with ASICs.
- **Mechanical integration.**

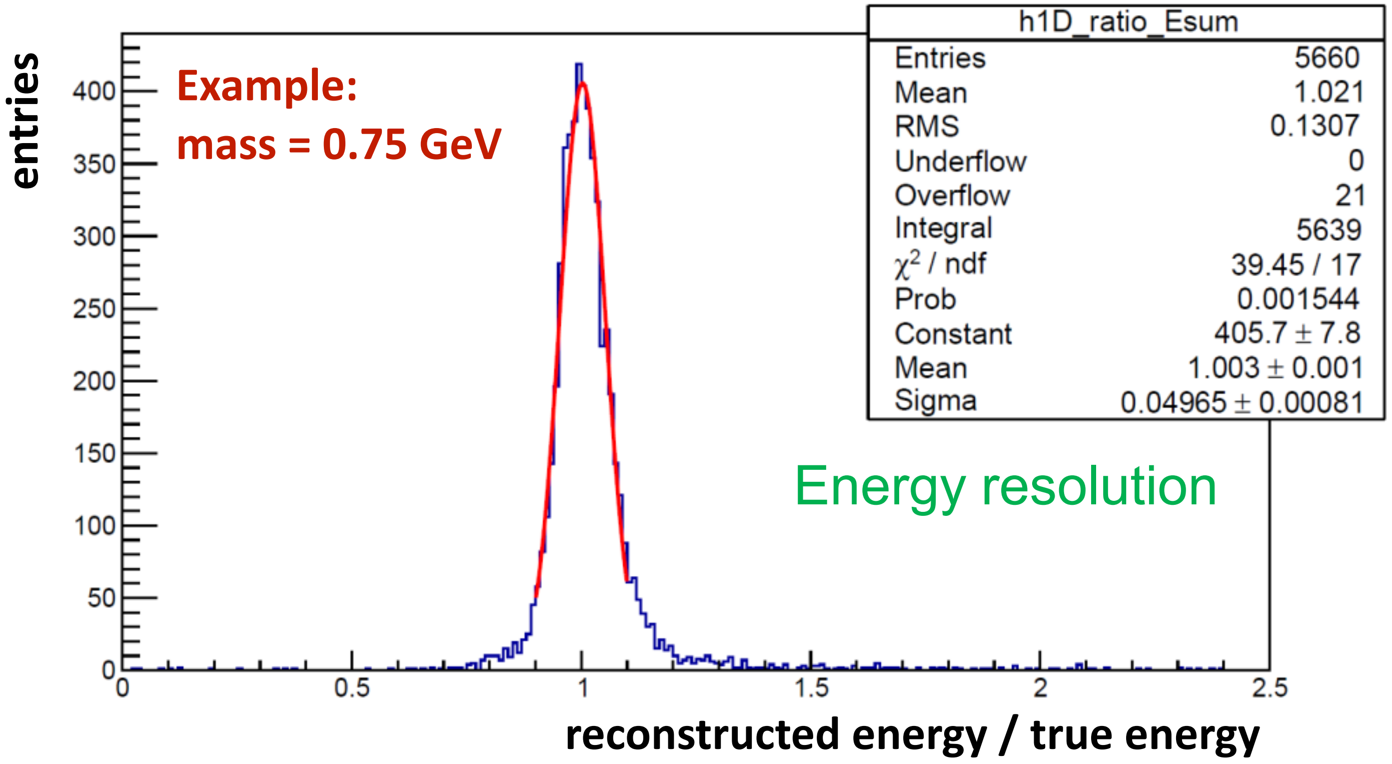
To be built for the TDR

SplitCAL Performance

Expected SplitCAL Performance

Energy resolution from scintillating layers

- Simulation of ***ALP*** **→ γγ decays** with different masses and energies.
- Full detector implementation in GEANT4 and full shower reconstruction.
- **Energy resolution (RMS) of about 15%.**



Example:
mass = 0.75 GeV

h1D_ratio_Esum	
Entries	5660
Mean	1.021
RMS	0.1307
Underflow	0
Overflow	21
Integral	5639
χ^2 / ndf	39.45 / 17
Prob	0.001544
Constant	405.7 ± 7.8
Mean	1.003 ± 0.001
Sigma	0.04965 ± 0.00081

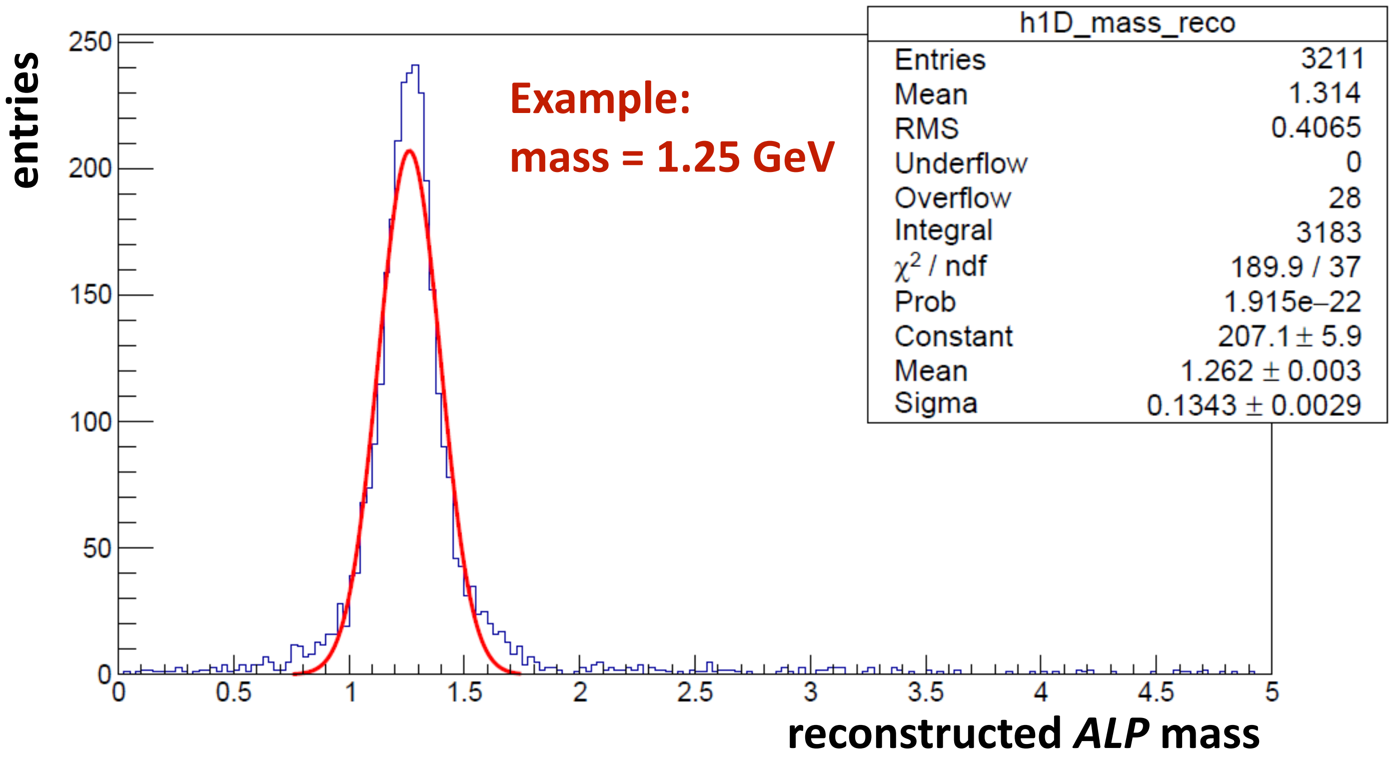
Energy resolution

Expected SplitCAL Performance

Mass resolution from high-precision layers

- No full detector MC implementation yet, but **using positions of shower particles smeared by 2 mm** (as obtained from prototype data/MC comparison).
- ***Preliminary study with ALPS between 0.25 and 1.25 GeV:*** **Mass resolutions of 70 - 130 MeV.**

Mass [GeV]	Mass (MPV ± Sigma)	Reco. Efficiency
0.25	0.27 ± 0.07	84.5 %
0.5	0.51 ± 0.10	89.5 %
0.75	0.77 ± 0.12	90.7 %
1	1.01 ± 0.13	91.3 %
1.25	1.26 ± 0.13	92.3 %



Example: mass = 1.25 GeV

Conclusions

SplitCAL — ECAL with reconstruction of shower directions

Two separate and very distinct detectors:

- **„Standard“ absorber-scintillator ECAL** with WLS fibre readout.
- **Integrated high-precision layers (MicroMegas).**
  Whole ECAL split into two parts for better lever arm.

First prototype built & running. Good agreement with simulation.

Next step: Construction of technological prototype.

Looking for additional groups to participate!

Backup

Full SplitCAL: Scintillating Layers

Baseline parameters of the SplitCAL scintillator layers:

ECAL front face	$6\,\mathrm{m} \times 12\,\mathrm{m} = 72\,\mathrm{m}^2$
ECAL depth	$20\,X_0$
Number of scintillator/absorber layers	40
Scintillator strip dimensions	$300\,\mathrm{cm} \times 6\,\mathrm{cm} \times 1\,\mathrm{cm}$
Number of strips per layer	400
Total number of strips	16 000
Length of WLS fibres	2 400 m/layer, 96 km in total
Number of readout channels	800/layer, 32 000 in total
Scintillator weight	760 kg/layer, 30.4 tons
Absorber thickness ($0.5\,X_0$)	2.8 mm (lead), 8.8 mm (iron)
Absorber weight per layer	2.3 tons (lead), 5.0 tons (iron)
Total weight (without support)	122 tons (lead), 230 tons (iron)

Full SplitCAL: High-Precision Layers

Baseline parameters of high-precision layers with MicroMegas.
Numbers are given for two (three) high-precision layers.

Active area of one MicroMegas module	80 cm × 80 cm	
Number of modules per layer	128	
Total number of modules	256	(374)
Strip pitch	500 µm	
Number of channels per module	3 200	
Total number of channels	819 200	(1 228 800)
Total number of read-out chips	6 400	(9 600)

Very preliminary Cost Evaluation

	Cost/unit (€)	Quantity	Cost (k€)
ECAL Scintillator strips (3 m)	100	16 000	1 600
ECAL WLS fibres	3 000 per km	100 km	300
ECAL SiPMs	30	32 000	960
ECAL front-end electronics	40 per channel	32 000 channels	128
ECAL cables, crates, DAQ, etc.	–	–	250
MicroMegas PCBs	4 000	256	1 024
MicroMegas Parts	2 000	256	512
MicroMegas Readout	2 per channel	800 000	1 600
MicroMegas cables, crates, DAQ, etc.	–	–	100
ECAL absorbers (20 X_0 lead)	5 per kg	92 tons	460
Mechanics	–	–	400
Total			7 340
Total including 20 % contingency			**8 800**

SiPMs

Two types of SiPMs used:

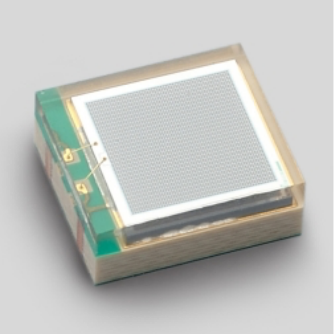
- **Hamamatsu S13360-3025PE**

  3 × 3 mm², 25 µm pitch, 14400 pixels.
  Used with WLS fibres of 1.2 mm diameter.

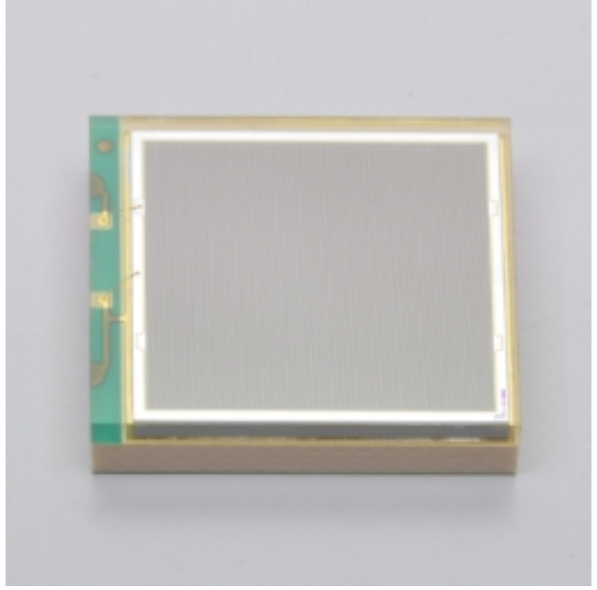
- **Hamamatsu S13360-6050PE**

  6 × 6 mm², 50 µm pitch, 14400 pixels.
  Used with WLS fibres of 2.0 mm diameter.

Large number of pixels necessary for dynamic range between MIPs and electron showers.



S13360-3025PE



S13360-3025PE