A Pointing Electromagnetic Calorimeter for FIP Experiments leveraging $X \rightarrow \gamma\gamma$ decays

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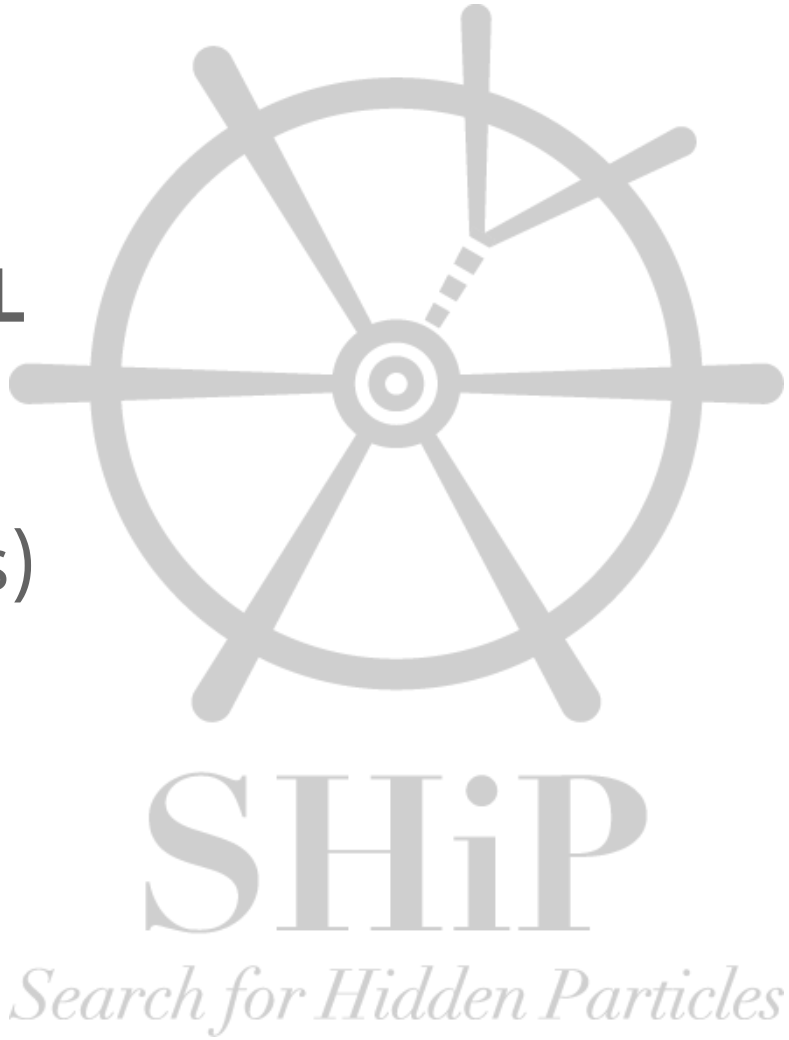
OUTLINE

- Motivation
- ECAL Concept – two Options
- Baseline Design
- Simulation Results
- Conceptual Prototype
- Test Beam Results
- Summary + Outlook

Tom Gauld

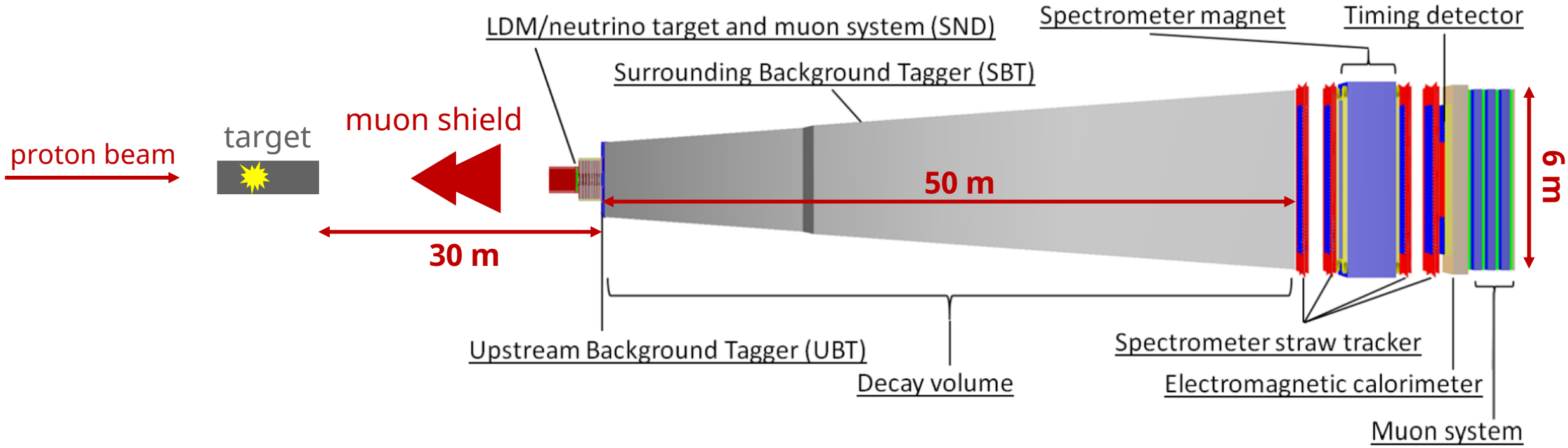
MOTIVATION

- **SHiP is approved and needs a pointing ECAL**
- BDF/SHiP offers advanced experimental setup dedicated to neutrino physics and searching for feebly interacting particles (FIPs)
- FIPs considered a good DM candidate
- To be built at CERN SPS in the **next 5 years**



EXPERIMENTAL SETUP

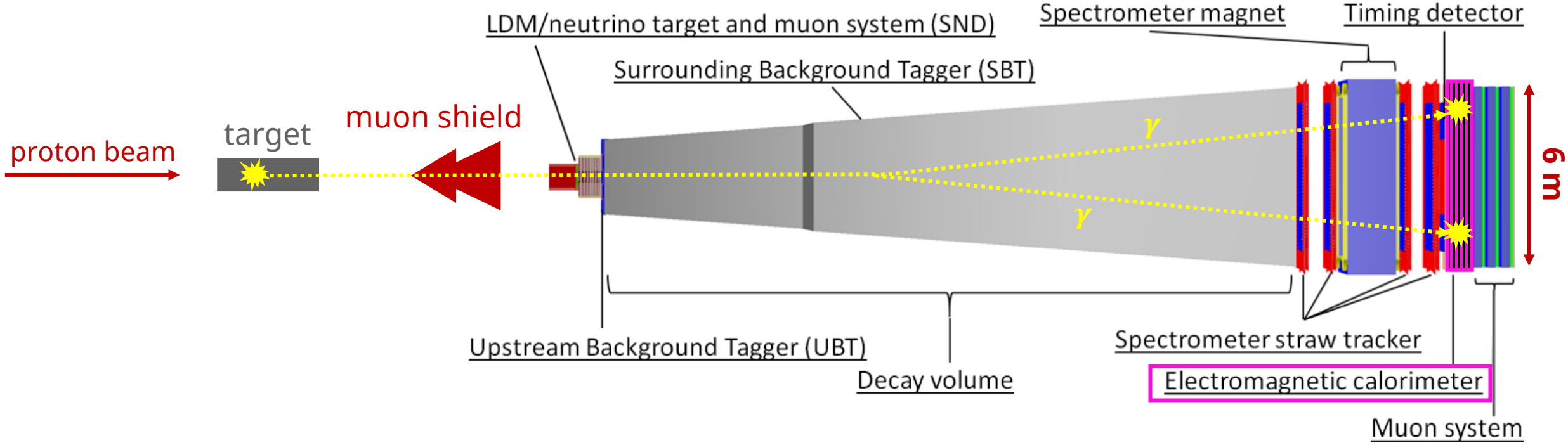
- Fixed target experiment
- Long fiducial volume → ideal for studies of long-lived particles
- ECAL part of larger spectrometer



ECAL REQUIREMENTS

- Energy resolution: 10-15%/$\sqrt{E(GeV)}$
- Particle ID with E/p measurements

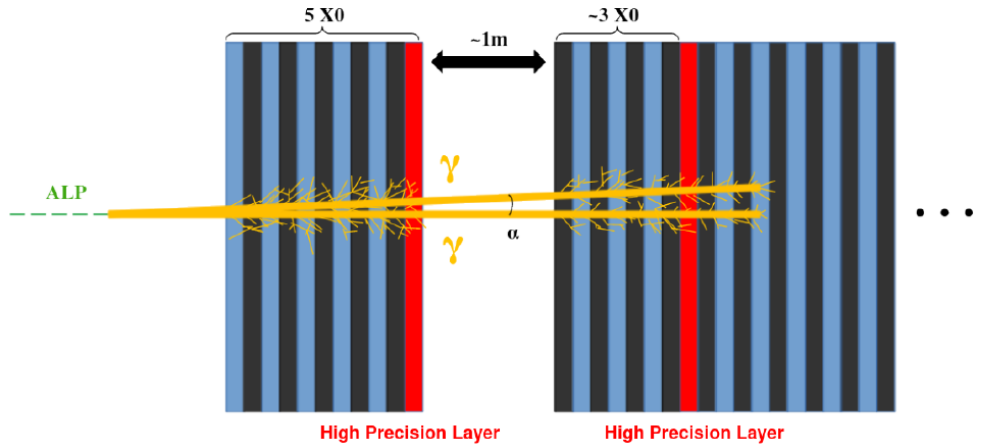
- **Pointing capabilities required** for
  - reconstruction of FIP decays into two photons ($X \rightarrow \gamma\gamma$)
  - background rejection



TWO OPTIONS EVALUATED IN MAINZ

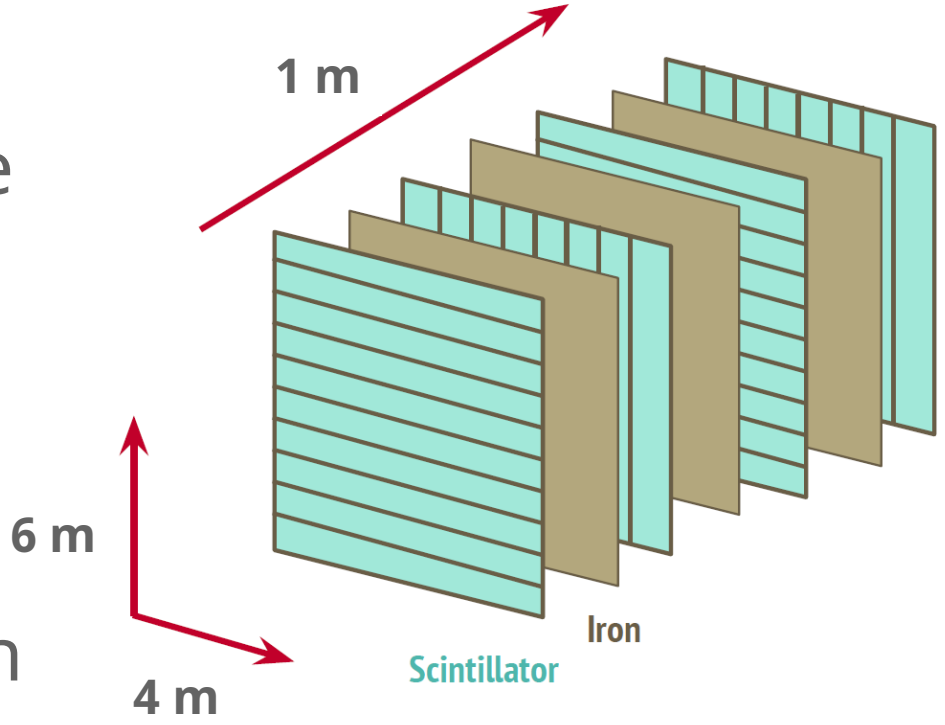
- SplitCAL:
  - Plastic scintillator-based sampling calorimeter with 6 cm strips
  - Split into two parts to increase lever arm for pointing
  - 2-3 high precision layers (eg MicroMegas) for pointing accuracy

- **StripCAL** (focus of this talk)
  - Pointing capability through smaller strips
  - Single technology → simplified design
  - Split design will be considered



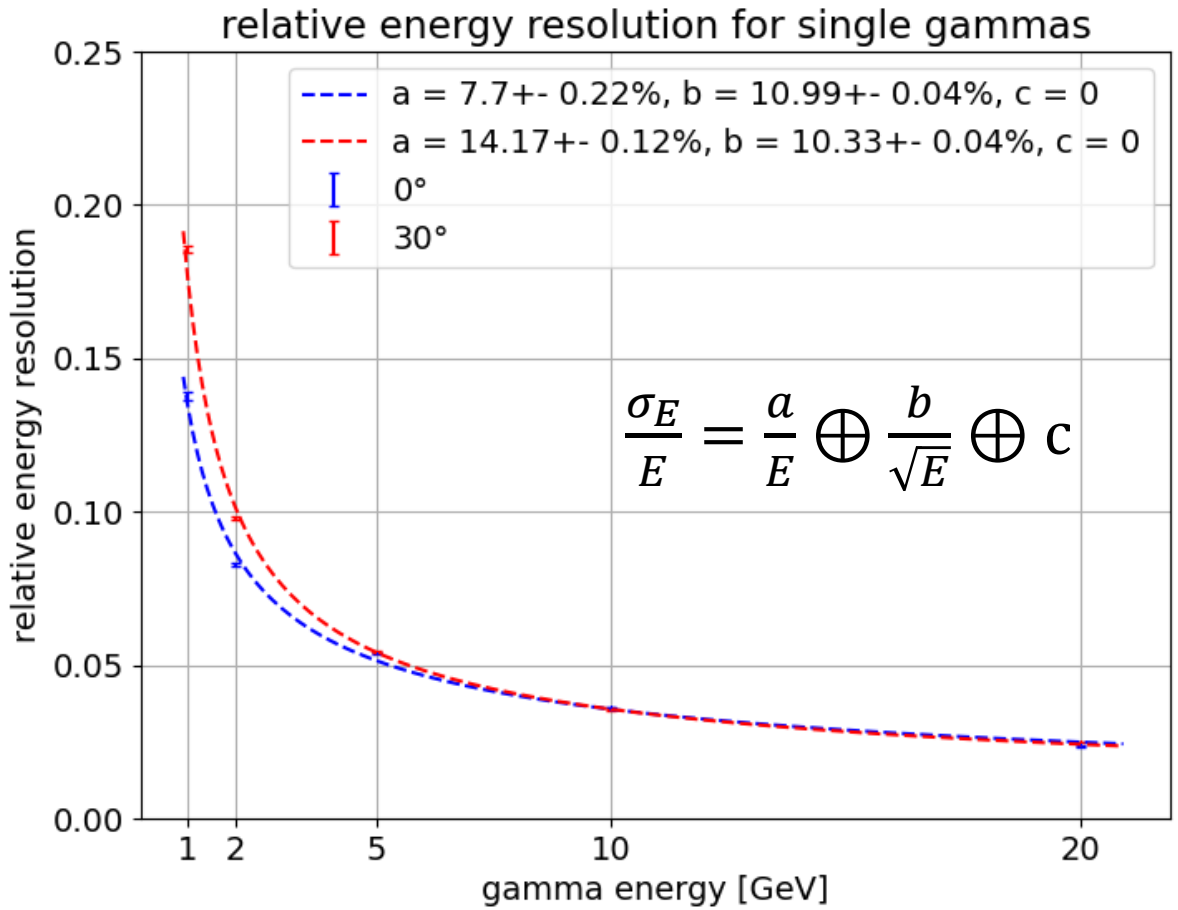
BASELINE DESIGN

- Sampling calorimeter
- 20 X_0 deep ECAL to avoid shower leakage
- About 1 m (for 9 mm iron absorbers)
- 40 layers of scintillating strips
  - 1x1 cm² strip cross-section
  - Alternating horizontal/vertical orientation
- Double-sided readout of scintillators with WLS fibers and SiPMs



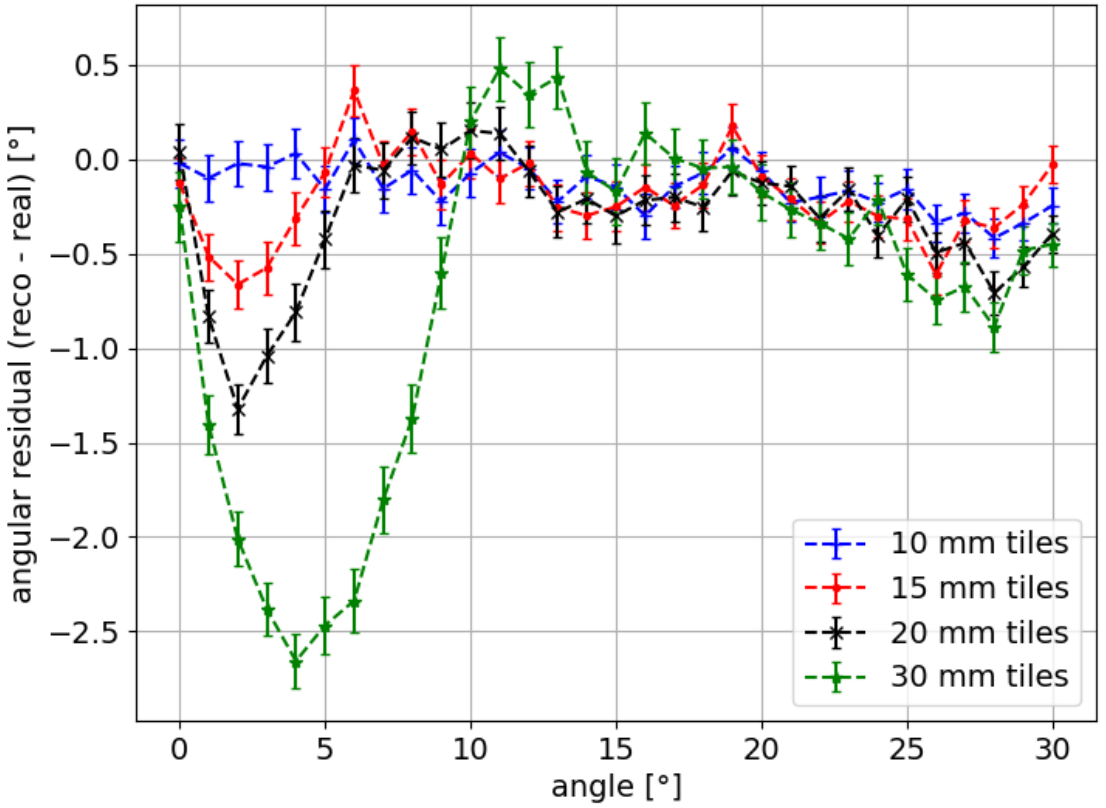
GEANT4 SIMULATION

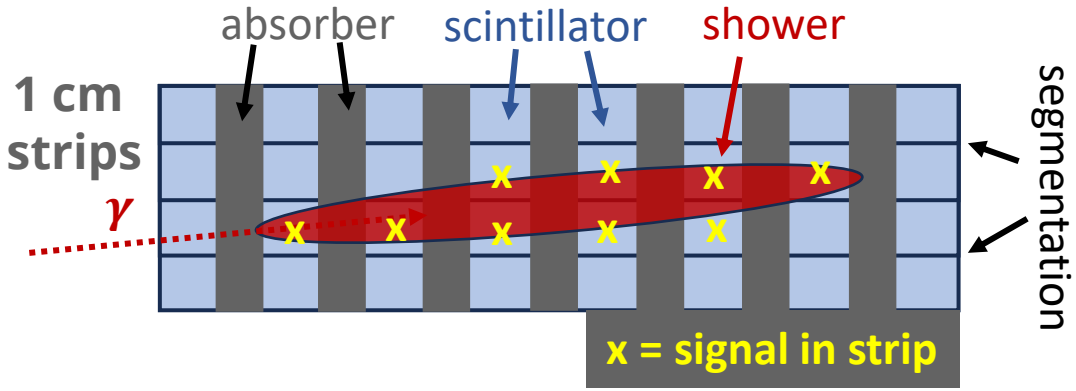
- Single photons hitting ECAL at various angles
- Energy range from 1-20 GeV
- Energy resolution of about $10\%/\sqrt{E(GeV)}$ within requirements
- Largely independent of incident angle



GEANT4 SIMULATION

- Strip width choice determines angular reconstruction bias
- Mainly affects smaller energies due to low shower depth
- Lack of angular resolution at small incident angles with wider strips
- **Ideal scintillator strip width** for shower direction reconstruction **– 1 cm**





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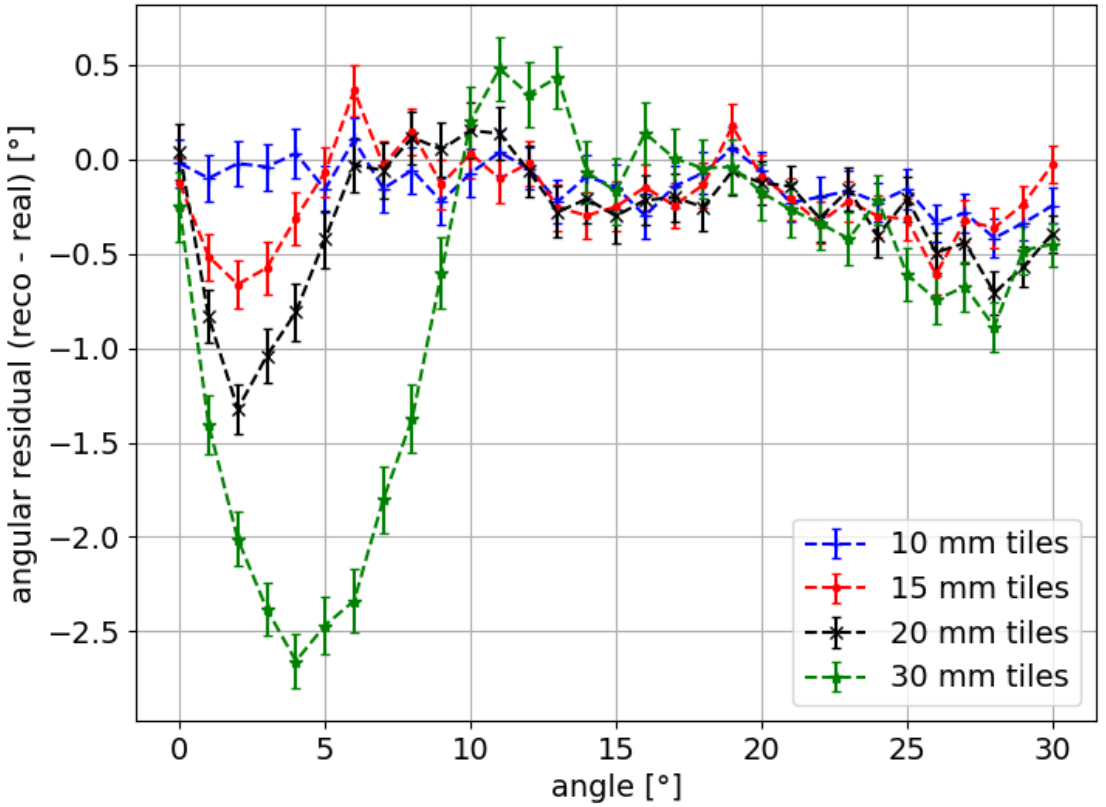
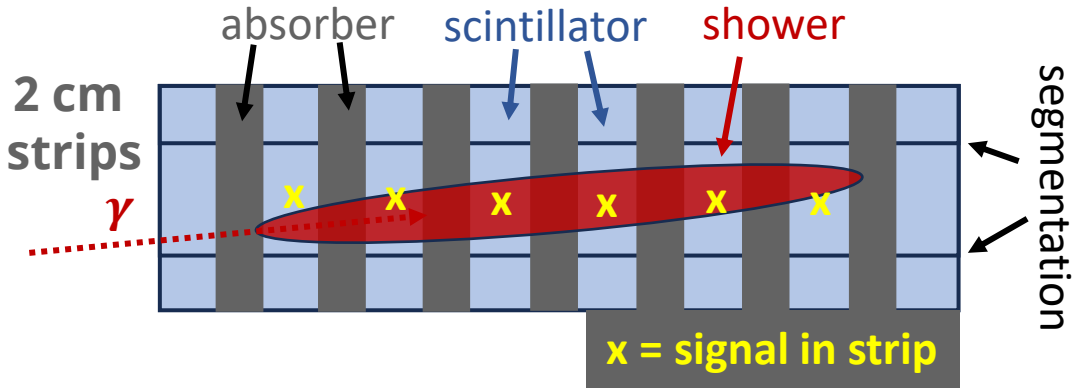
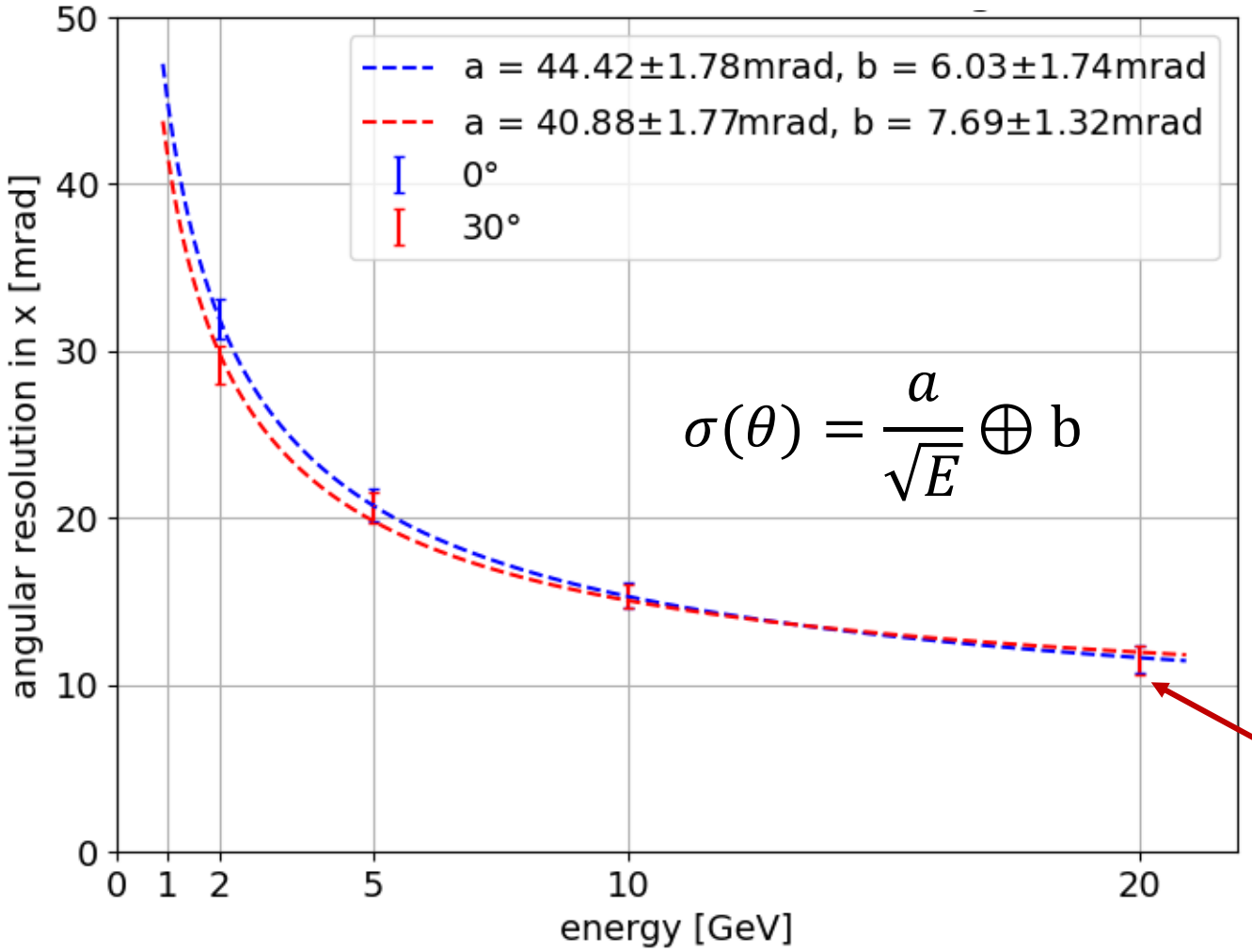




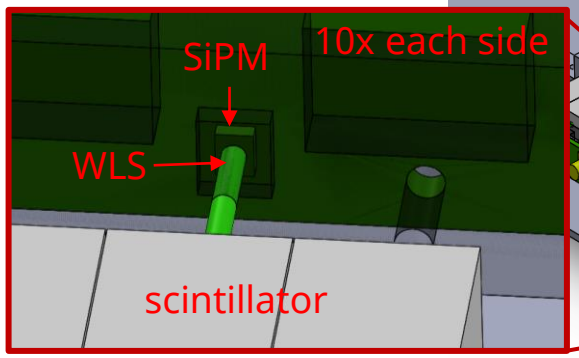
POINTING RESOLUTION FOR 1 CM STRIPS

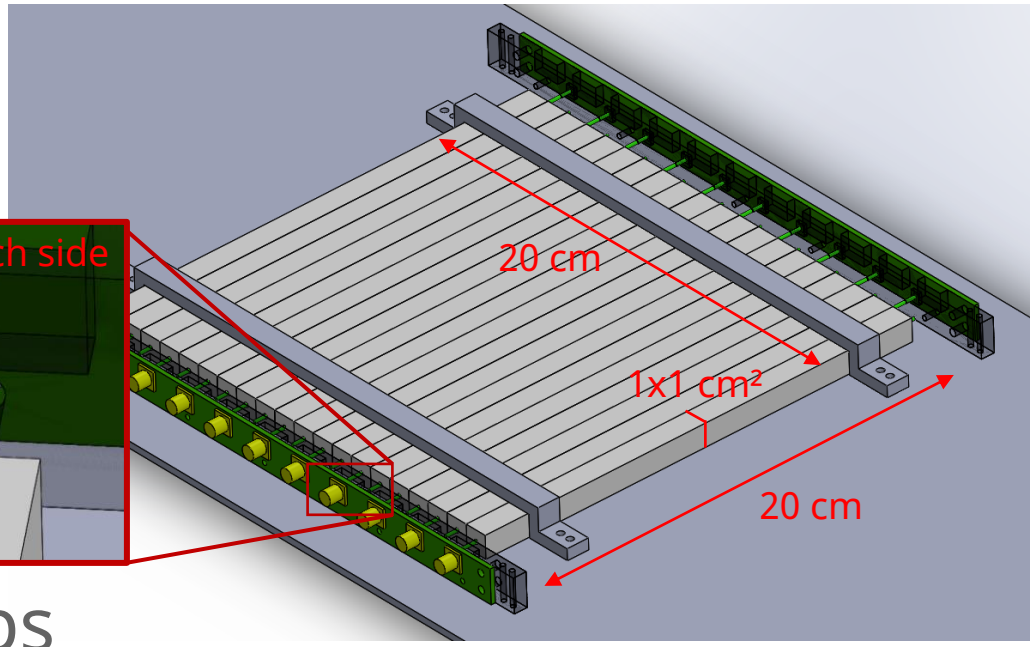


- Very promising result
- Design not jet optimized
- No dependence on the incident angle

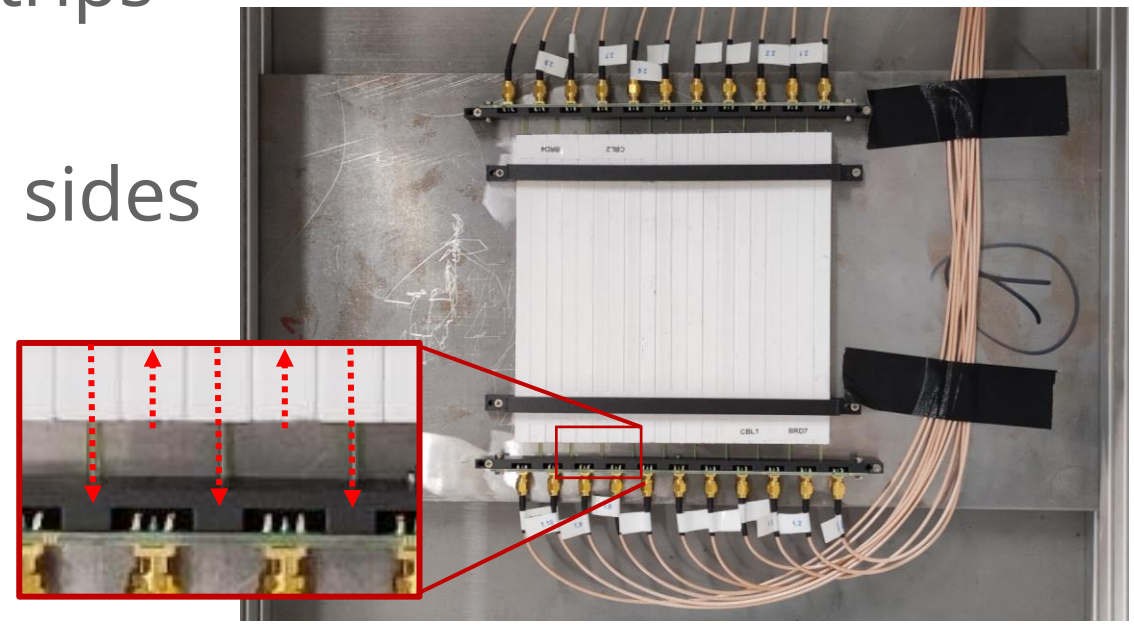
12 mrad (0.7°) @20 GeV

CONCEPTUAL PROTOTYPE





- 9 layers – 180 channels
- 20x20 cm² active area
- 1x1x20 cm³ coextruded scintillator strips
- Modular 4 mm iron absorbers
- Single-sided readout on alternating sides



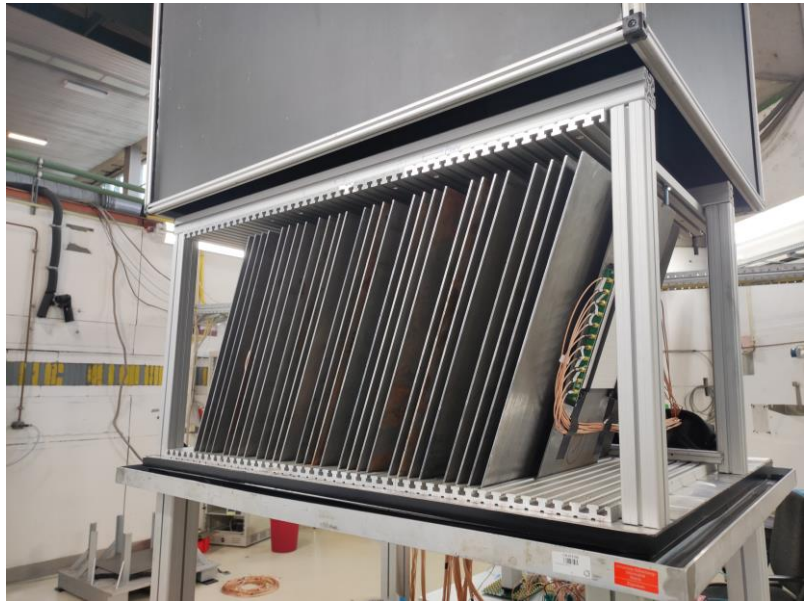
- S13360-1325PE HAMAMATSU SiPMs
- Kuraray YS2 fibers

TEST BEAM @DESY

- Electron energies from 1 to 5 GeV
- 5 angles from 0 to 20°
- Different absorber configurations

- Main goals:
  - Validate simulation
  - **Verify pointing resolution**

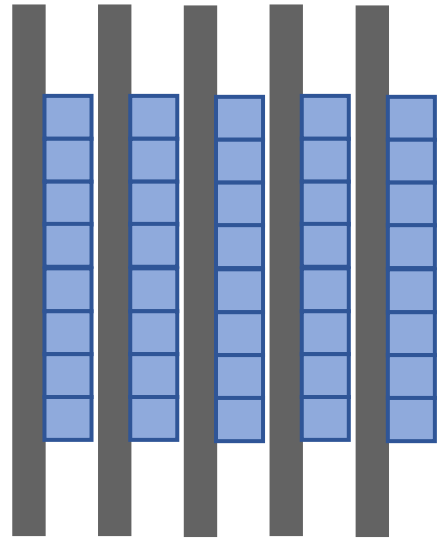
- Very simple detector concept
  → 6 months from design to test beam



DESIGN ADAPTATIONS FOR CONCEPTUAL PROTOTYPE

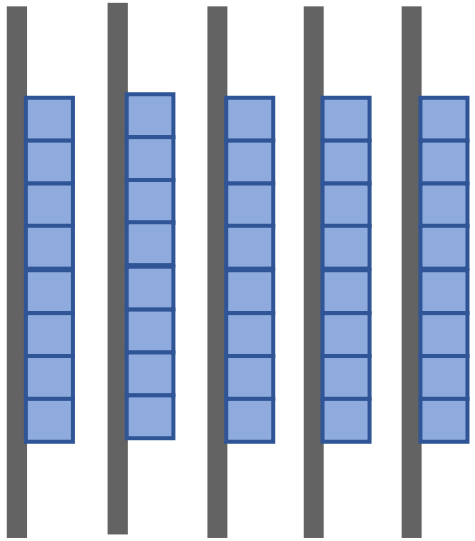
- Small design changes from baseline design to conceptual prototype
- Necessary due to external constraints

baseline design



- 9 mm → 4 mm absorbers
- 1 mm → 12 mm air gap between layers

conceptual prototype

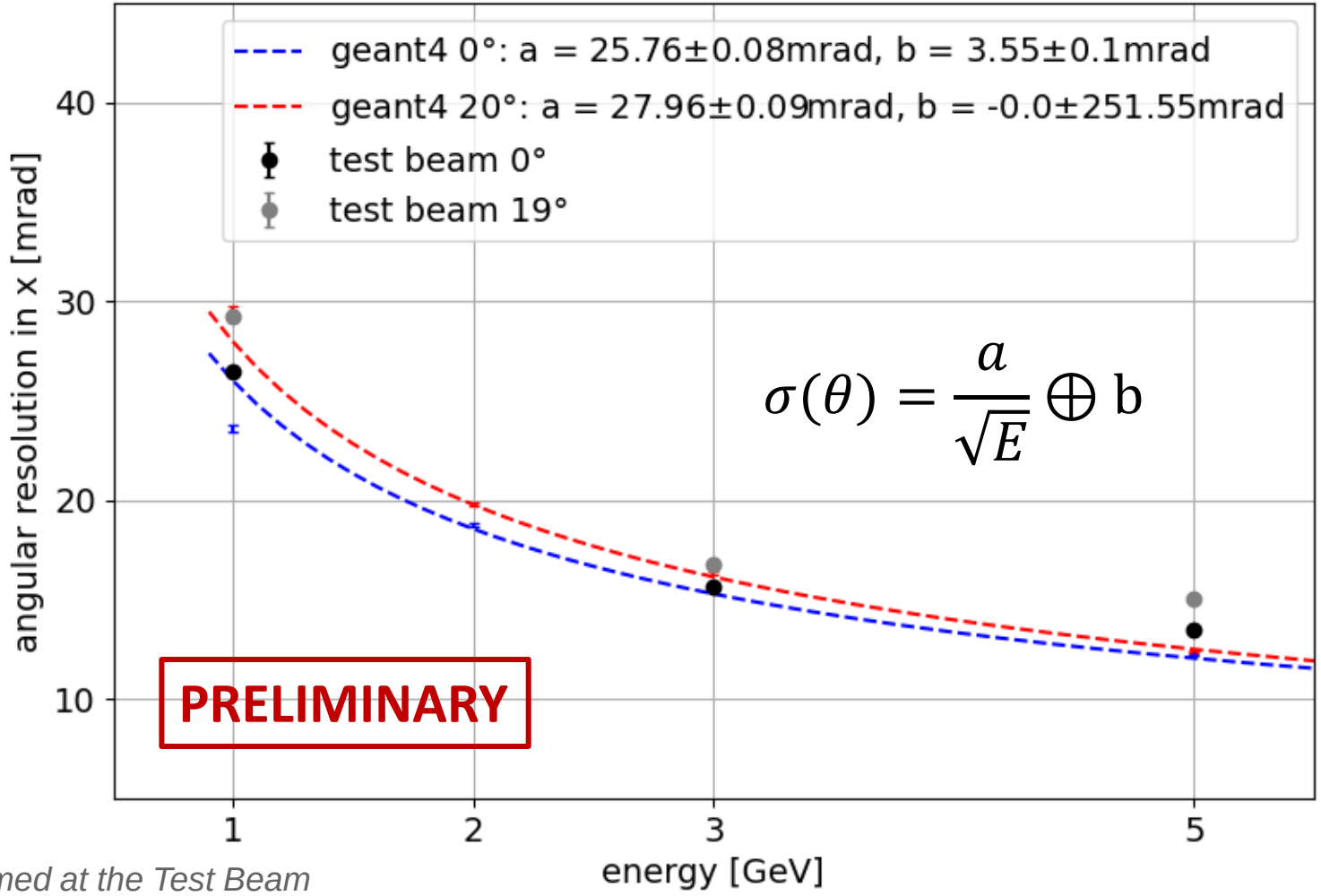


➢ **Better sampling fraction**

➢ **Larger lever arm for angular reconstruction**

CONCEPTUAL PROTOTYPE VS SIMULATIONS

- **Simulation and TB data in good agreement**
- 9 layers in prototype (65 cm)
- 40 layers in simulation (90 cm)

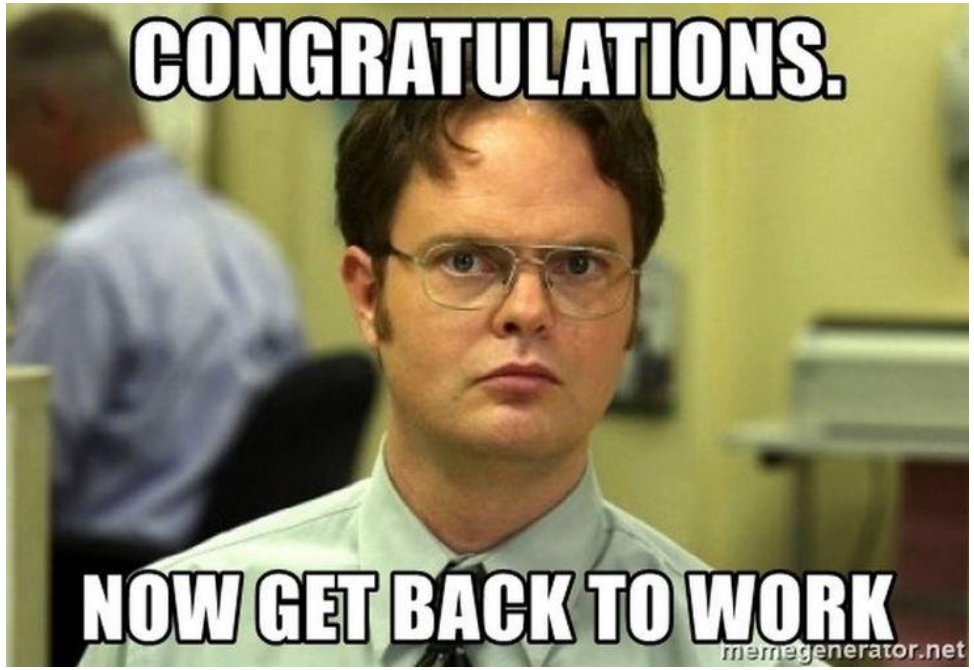


The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

SUMMARY + OUTLOOK

- StripCAL shows **very promising performance**
- **Test beam results match simulation**

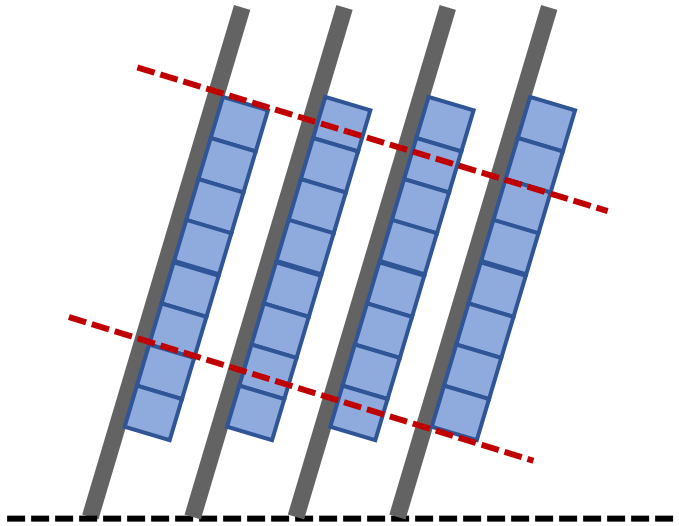
- Further optimization of both ECAL designs
- Studies towards full-size detector
- **Consolidation into one design proposal**



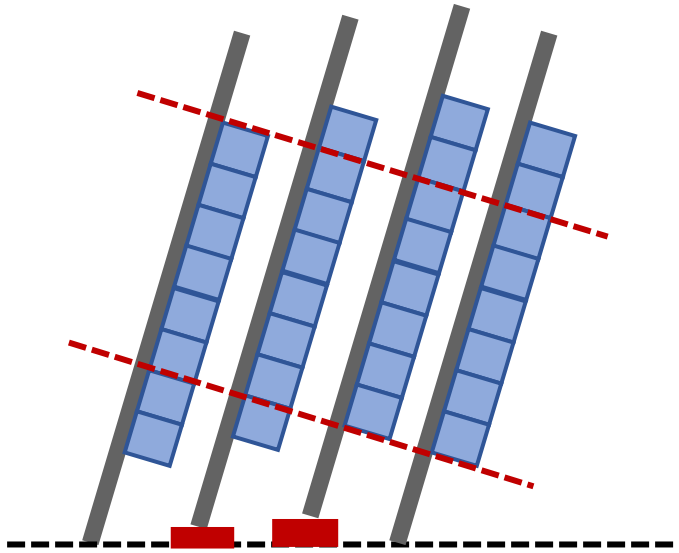
BACKUP

LAYER WISE OFFSET

- In angled setup channels are not aligned between layers



- Individual physical offset for each horizontal layer
- Alignment achieved to $\pm$1 mm



POINTING: SplitCAL vs StripCAL

- **Fair comparison difficult at this stage**

- StripCAL:
  - 12 mrad @20 GeV with current baseline design (can be improved)
  - 99% efficiency in shower direction reconstruction

- SplitCAL:
  - 2 mrad (0.12°) @20 GeV resolution **if** high-precision layers are fully utilized
  - Efficiency of event reconstruction about 90% (http://doi.org/10.25358/openscience-7043)

BASELINE DESIGN VS CONCEPTUAL PROTOTYPE PERFORMANCE