Detector optimisation for the ShiP Experiment

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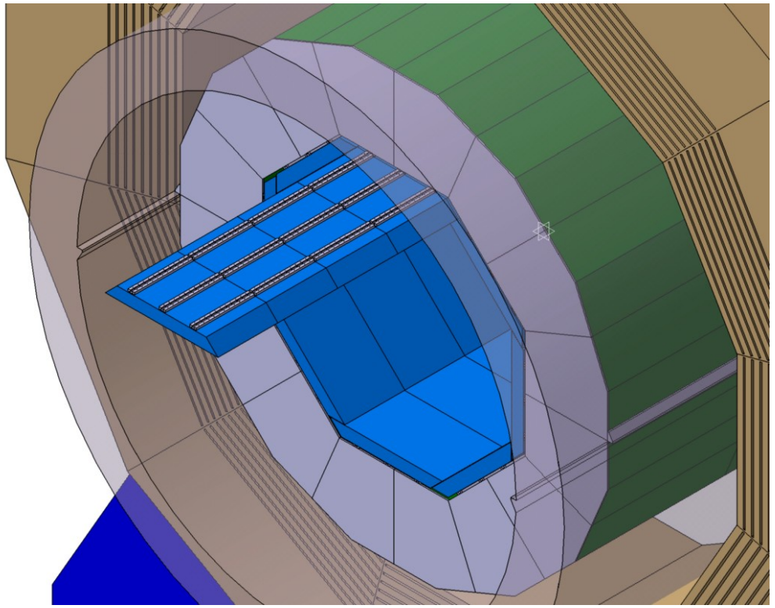
Prologue

- SHiP is an approved CERN experiment
  - “Approved” means that CERN agreed to refurbish the Beam Dump Facility in the ECN3 experimental hall
- Now formation of detector collaboration
- Many components in very preliminary state in many aspects
  - This concerns in particular layout of Scattering and Neutrino Detector (SND, see later)
- So far IJCLab gives technical help through IT staff (“historical” connection through LHCb)
- Possible application of our SiW ECAL R&D in real experiment
- Relevant physics case

Silicon Tungsten electromagnetic calorimeter

DRD Calo

- Optimized for Particle Flow: Jet energy resolution 3-4%, Excellent photon-hadron separation



The SiW ECAL in the ILD Detector

- O(108) cells
- “No space”
=> Large integration effort

Basic Requirements:

- Extreme high granularity
- Compact and hermetic
- (inside magnetic coil)

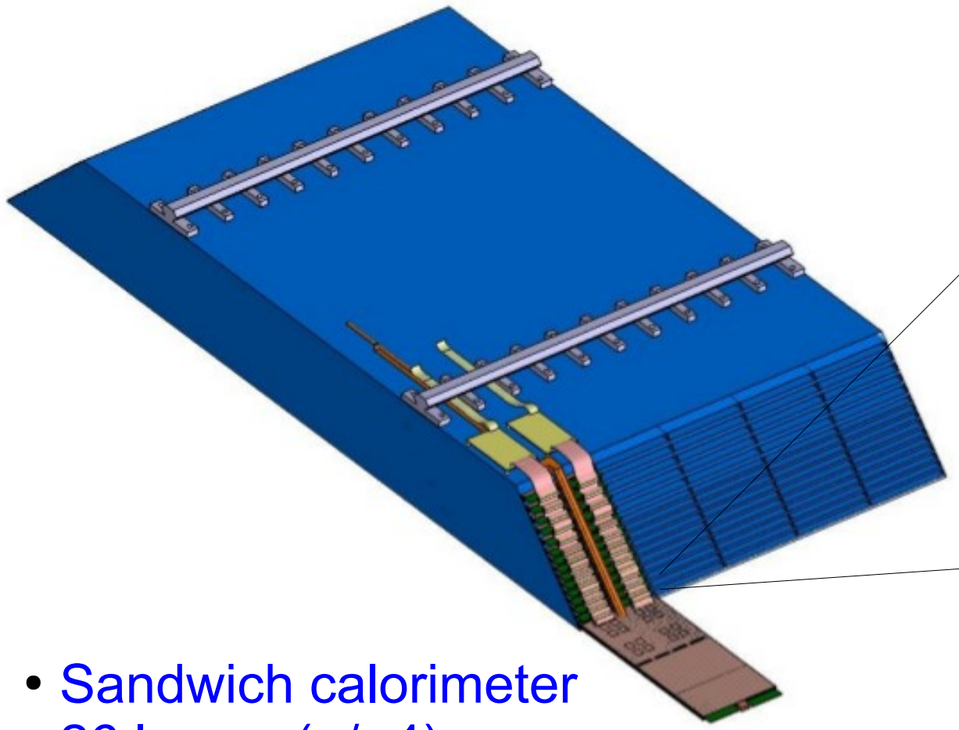
Basic Choices:

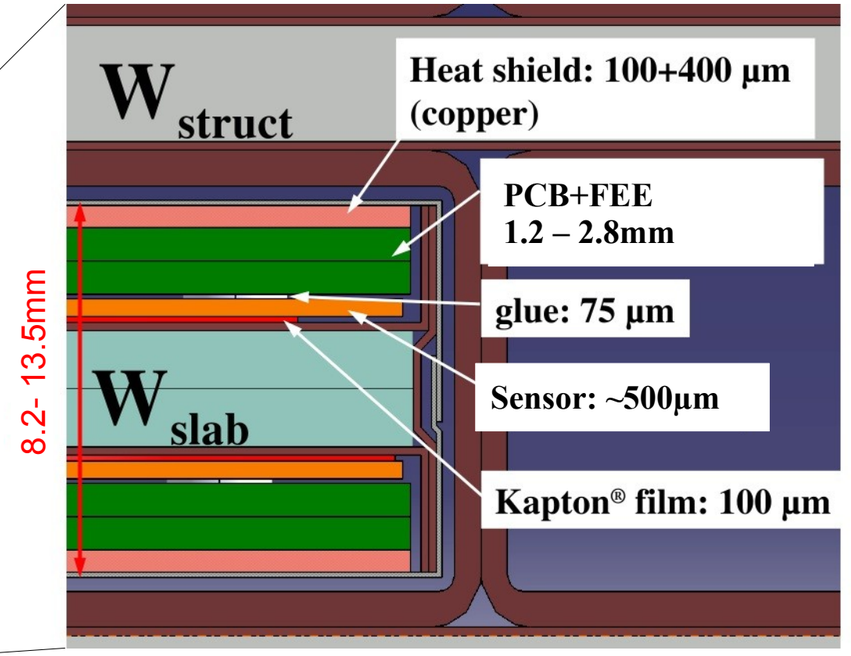
- Tungsten as absorber material
  - X_0=3.5mm, R_M=9mm, λ_I=96mm
  - Narrow showers
  - Assures compact design
- Silicon as active material
  - Support compact design
  - Allows for pixelisationRobust technology
  - Excellent signal/noise ratio: 10 as design value

- All future e+e- collider projects feature at least one detector concept with this technology
  - Decision for CMS HGCAL based on CALICE/ILD prototypes

Silicon Tungsten electromagnetic calorimeter – Example ILD *DRD Calo*

Ecal alveolar structure





- Sandwich calorimeter
- 26 layers (+/- 4)
- Thickness: ~20cm, 24 $X_0/1\lambda_I$
- Pixel size ~5x5 mm^2
- Expected elm. energy resolution 15-20%/$\sqrt{E}$

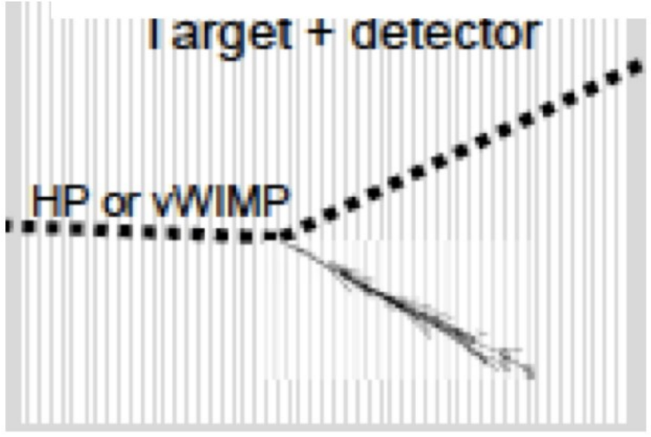
SHiP Physics case

The SHiP experiment will search for a broad range of feebly interacting particles such as:
- Light Dark Matter
- Heavy Neutral Leptons (HNLs)
- Dark photons
- Dark Scalar Higgs-like particles
- Axion-like particles (ALPs)

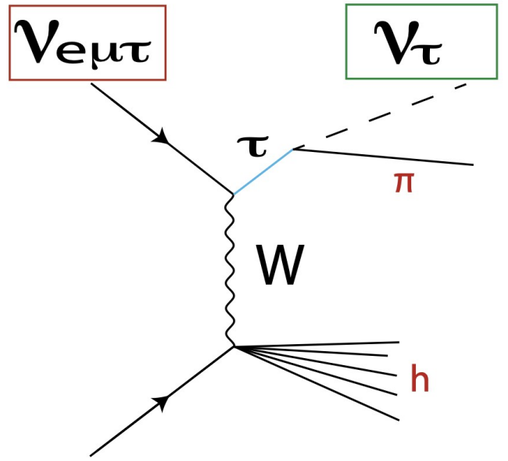
In addition SHiP will allow for a rich set of tests of Standard Model physics in with neutrinos

Relevsnt for today:

LDM



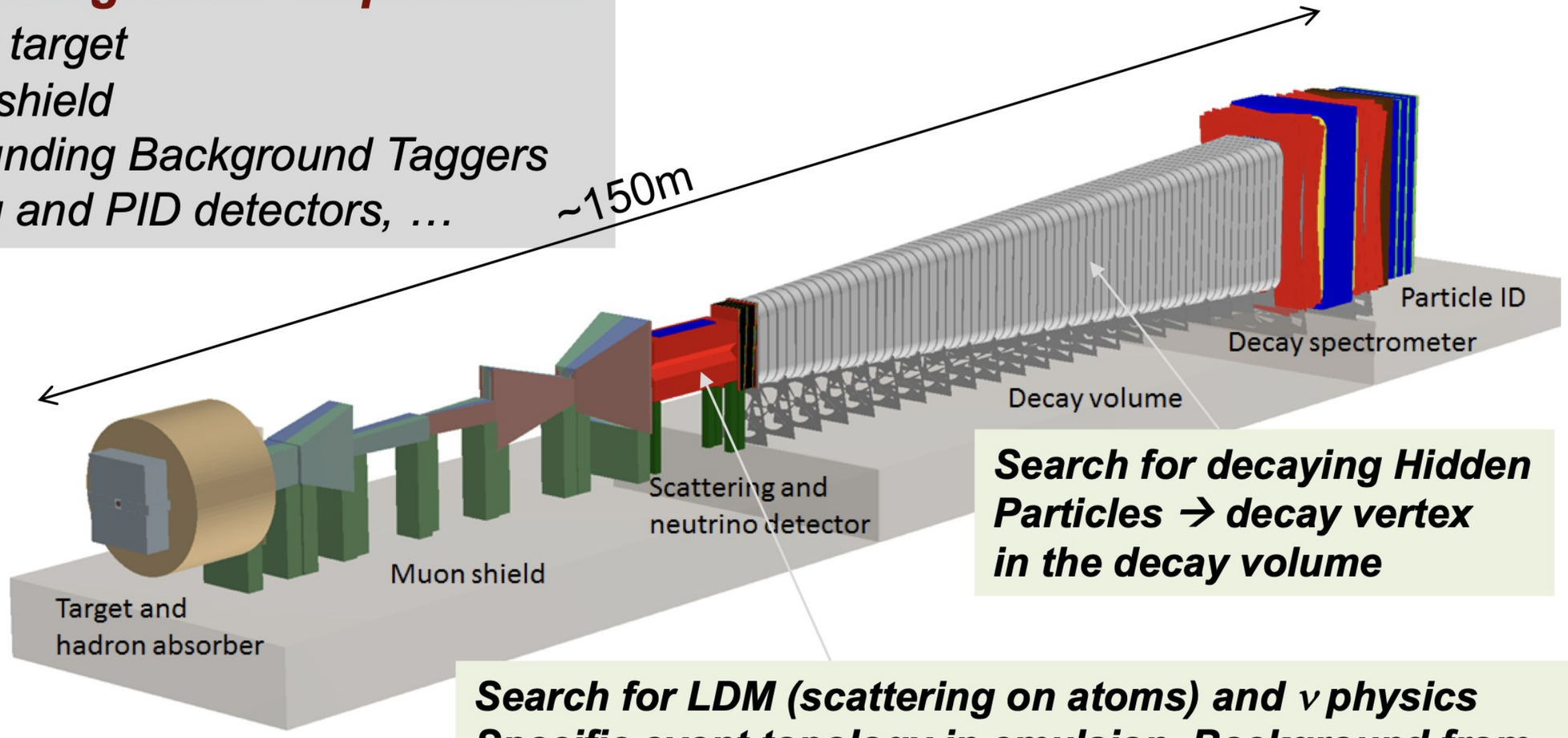
Neutrino Physics



SHiP Schematic Layout

"Zero background" experiment

- *Heavy target*
- *Muon shield*
- *Surrounding Background Taggers*
- *Timing and PID detectors, …*



Search for decaying Hidden Particles → decay vertex in the decay volume

Search for LDM (scattering on atoms) and ν physics Specific event topology in emulsion. Background from neutrino interaction for LDM searches can be reduced to a manageable level

Andrei Golutvin
ShiP Spokesperson

Calorimetry in SHiP

Two types of calorimeters:

- Neutrino physics and search for LDM scattering:
  - LDM and ν_e → Si/W
  - ν_μ and ν_τ → **M**agnetised **T**racking **C**alorimeter (MTC)

  Both are integrated to the muon shield
- Searches for FIPs and PID
  - Sampling ECAL with pointing capabilities (e.g. ALP→$\gamma\gamma$)
  - HCAL to discriminate between muons and hadrons in wide momentum range

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SHiP Schmatics

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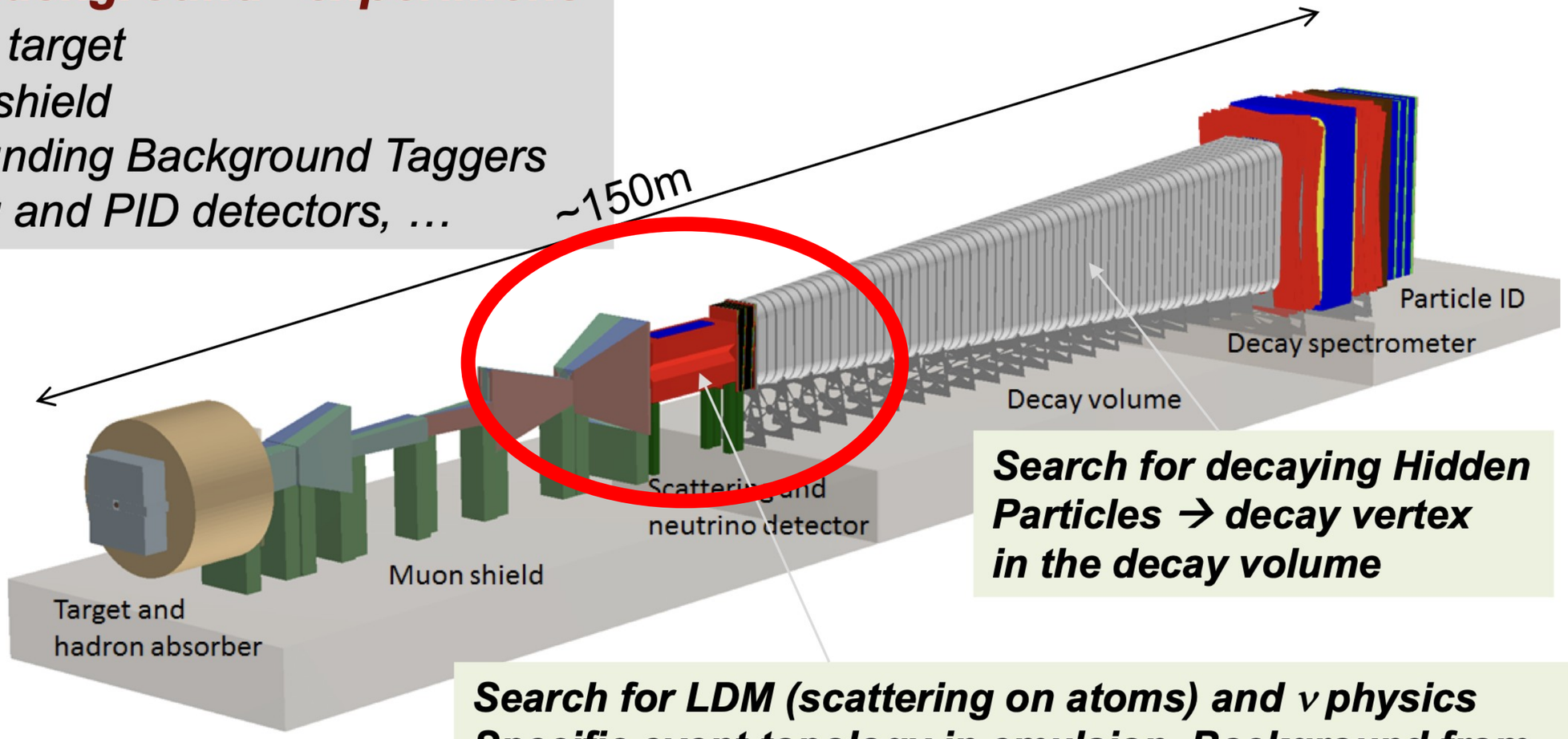

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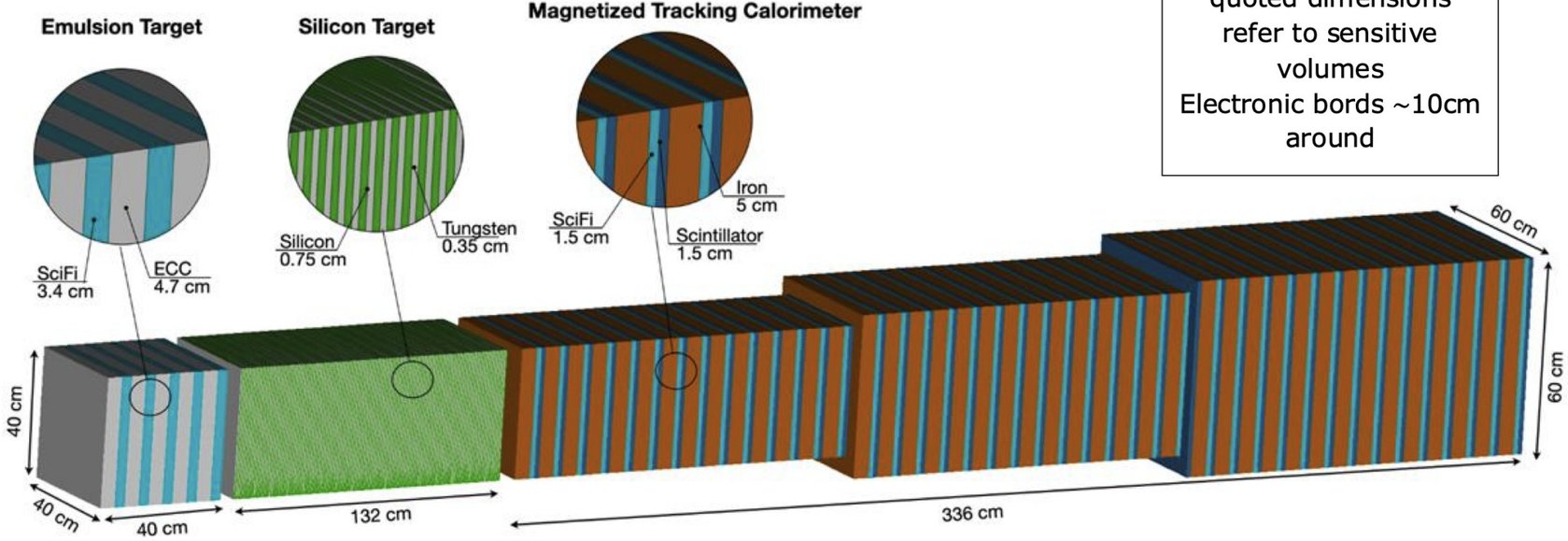
Scattering and Neutrino Detector (SND)?

DRD Calo



quoted dimensions refer to sensitive volumes
Electronic bords ~10cm around

EMULSION TARGET			
ECC	5	Tungsten	180
		Emulsion	180
SciFi	5		
Weight	0.5 ton		

SILICON TARGET	
Tungsten	120
Silicon	120
Weight	1.2 ton

MAGNETIZED TRACKING CAL	
Iron	42
Scintillator	42
SciFi	42
Weight	2.5 ton

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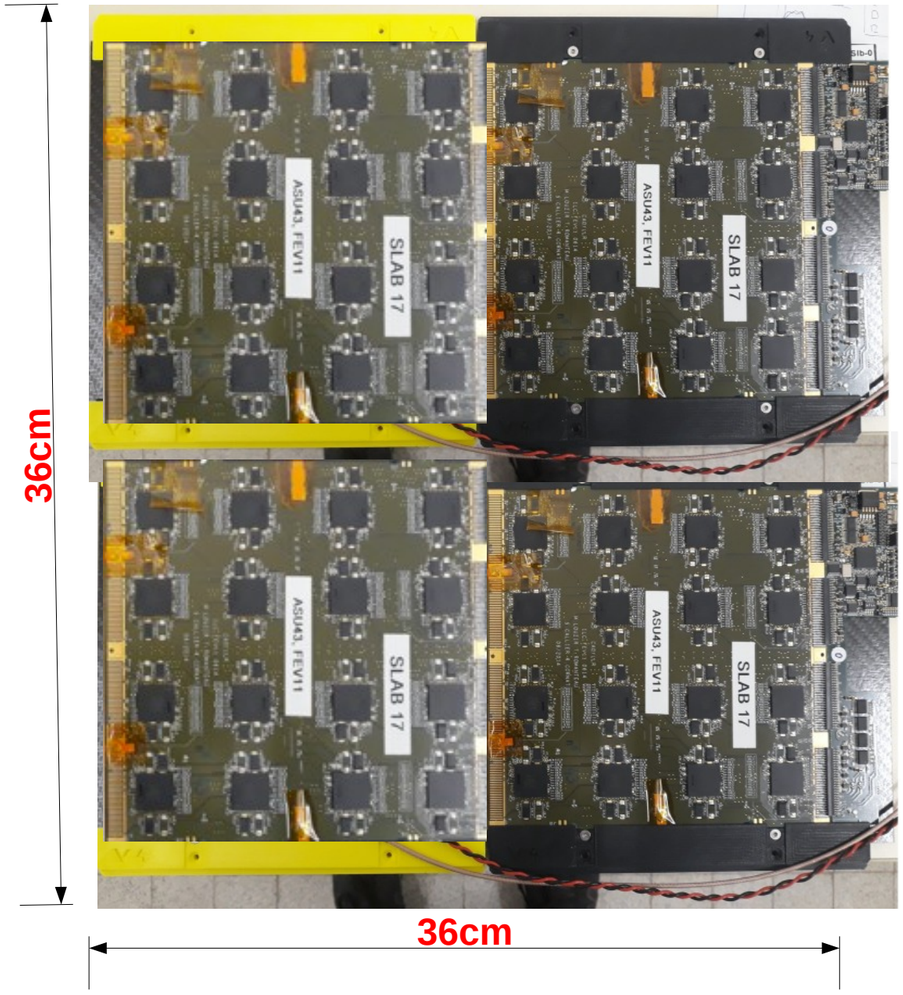
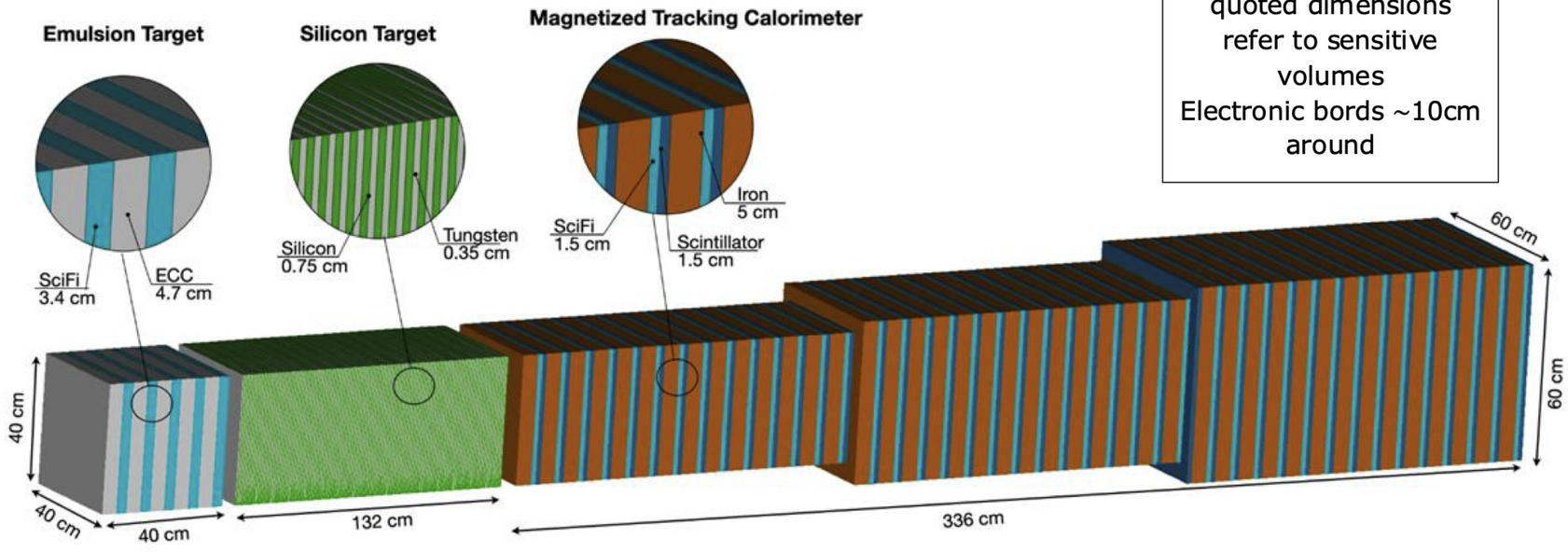
A SHiP Layer?

DRD Calo



- Should be straightforward to arrange SiW ECAL ASUs
- Modularity inherent to detector design
- N.B.: 18x18 cm^2 is not a canonical number but many tools are or will be developed for this size
- Cleary would need dedicated study on mechanical housing
- “Long layer” tests will be part of the 2025/26 test programme

A SiW Ecal for SND?



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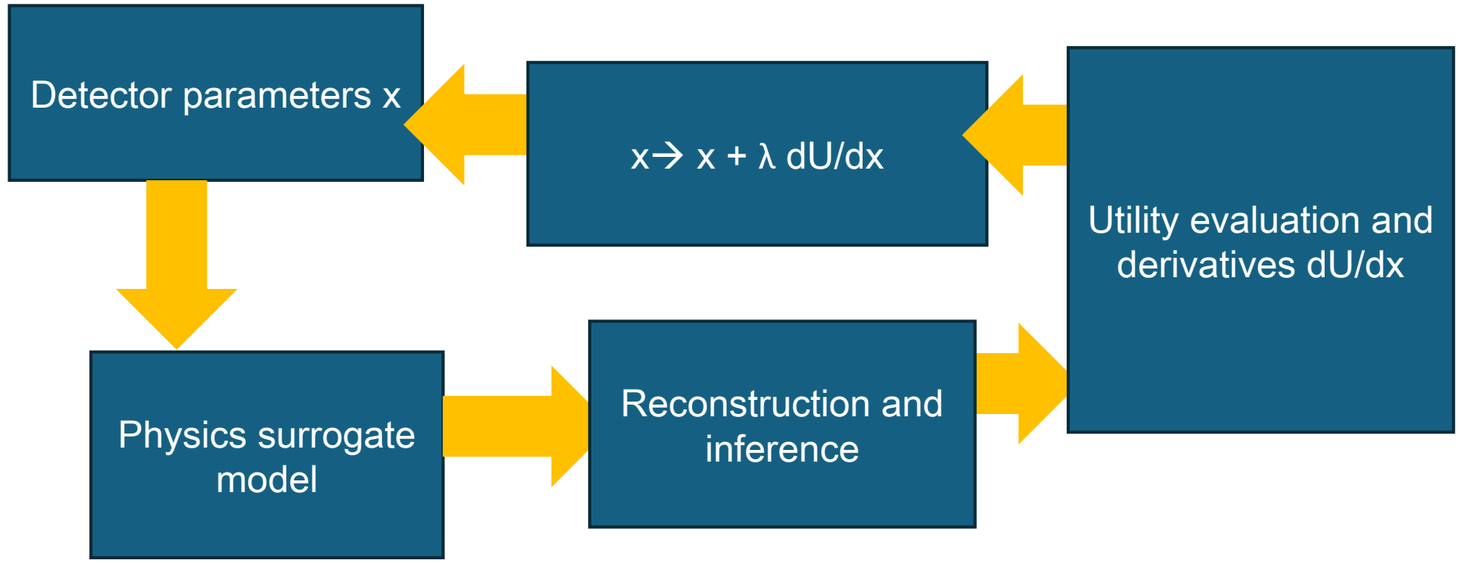
- Questions
  - How many SiW Ecal layers and where?
  - Rear part of target or MTC or both
  - Knowing that an SiW Ecal layer is not cheap
- Require serious optimisation study

What does it mean in practice?

It means creating a full parametric model of the detector, plugging in a surrogate model of the physics, and a differentiable model of the data reconstruction and inference extraction

Then you can iteratively modify the detector parameters following the gradient of the utility function – like in a NN



Dumbed down version of an optimization pipeline

Tommaso Dorigo, DRD Calo Meeting, April 2025

A fiirst proposal for P2I in April worked out with the help of Tommaso and Andrei was not supported by IJCLab Direction (“too early”)

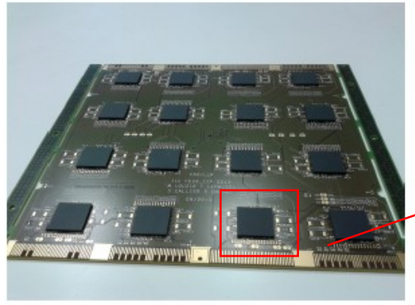
Summary

- SHiP covers relevant questions of particle physics and is (among) most powerful experiment(s) for feebly interacting particles for decades to come (at least in the low mas range < 10 GeV)
- SHiP as potential application of SiW ECAL
- Detector optimisation for SHiP would have to start soon, i.e. now!
  - In our case how many Ecal layers and where it's best to place them
  - A nice use case to learn/apply the principle of Co-design?
  - We would however start exactly from zero!
- Development for SHiP could/should leverage on R&D in DRD Calo
  - Building up on R&D for Linear Colliders, synergies with hardware development for FCCee
- Synergies with other similar experiments (that may take data before SHiP)!?
- IJCLab direction in favor of joining SHiP
  - Despite "rejection" of P2I proposal in April
  - CODEC in December 2025
  - Pre-discussions with direction before

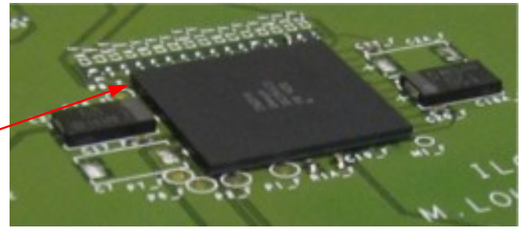
Backup

SiW Ecal Technological prototype – Elements of (long) layer *DRD Calo*

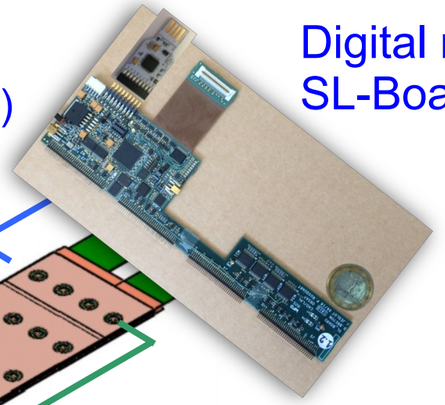
ASIC+PCB+SiWafer
=ASU
Size 18x18 cm²
(IJCLab, U Tokyo, OMEGA, LLR, SKKU)



ASIC SKIROC2(a)
(OMEGA)
Wire Bonded or
In BGA package
(IJCLab, U Tokya, LLR)

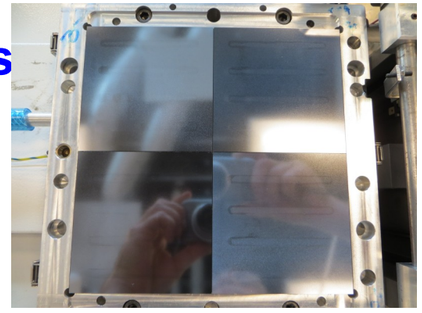


Interconnection
(IJCLab)
HV Supply
(IJCLab, LLR)



Digital readout
SL-Board (IJCLab)

Si Sensors glued onto PCB
Pixel size
5.5x5.5 mm²
(IFIC, CERN)



- The beam test set ups comprised mainly **short layers** consisting of one ASU and a readout card each