Studies for an electro-magnetic calorimeter for the SHiP experiment at CERN with shower direction reconstruction capability

by Walter M. Bonivento

INFN Sezione di Cagliari, Italy

on behalf of the Collaboration of 250 authors belonging to 49 institutions in 17 countries

Calorimetry for the High Energy Frontier

Lyon, France

2 - 6 October 2017

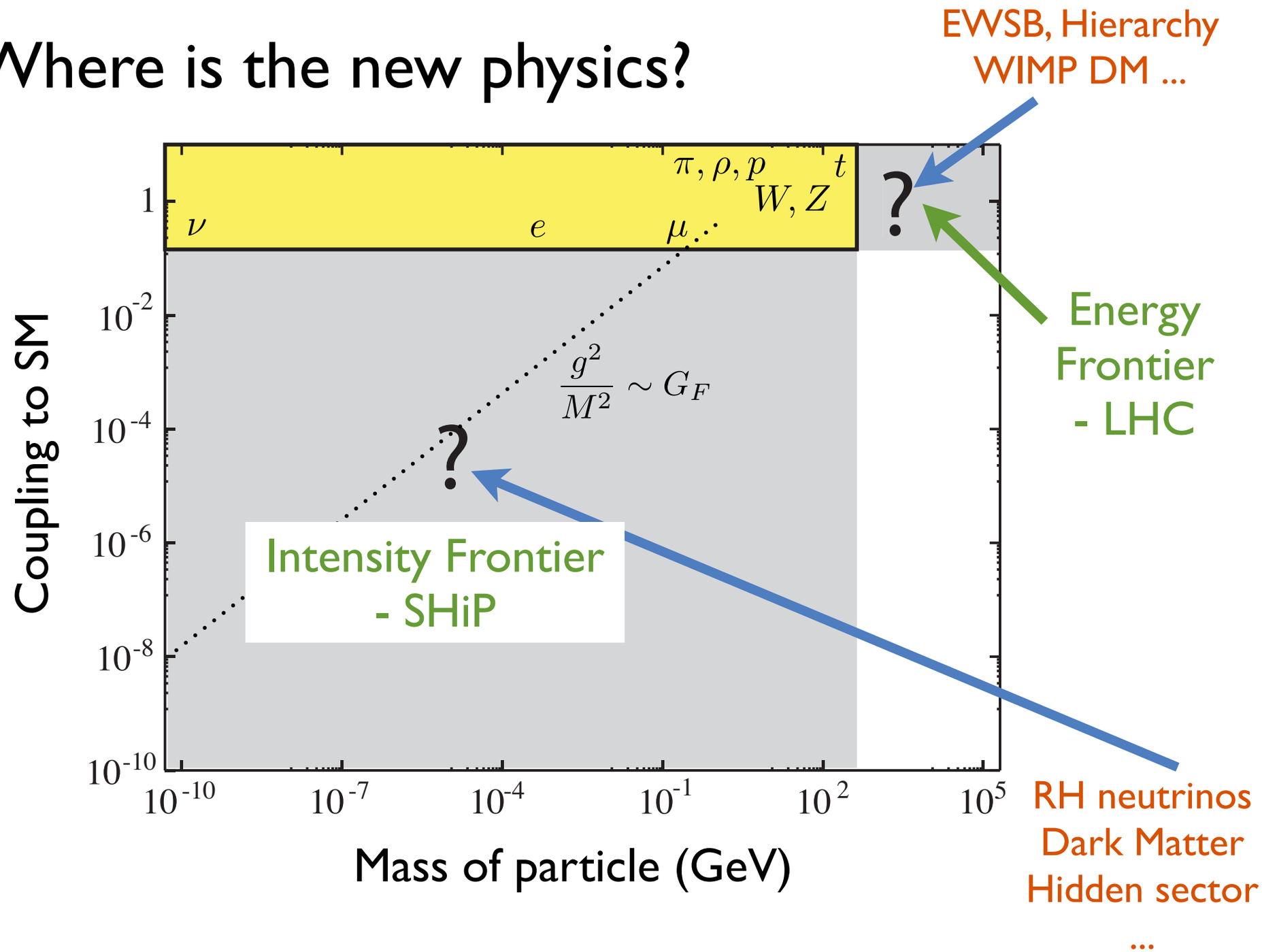
- what is SHiP

- the design of the electro-magnetic calorimeter of the Technical Proposal

- potential for a detection of axion-like particles (ALP) decaying to two photons

- ideas for a new design

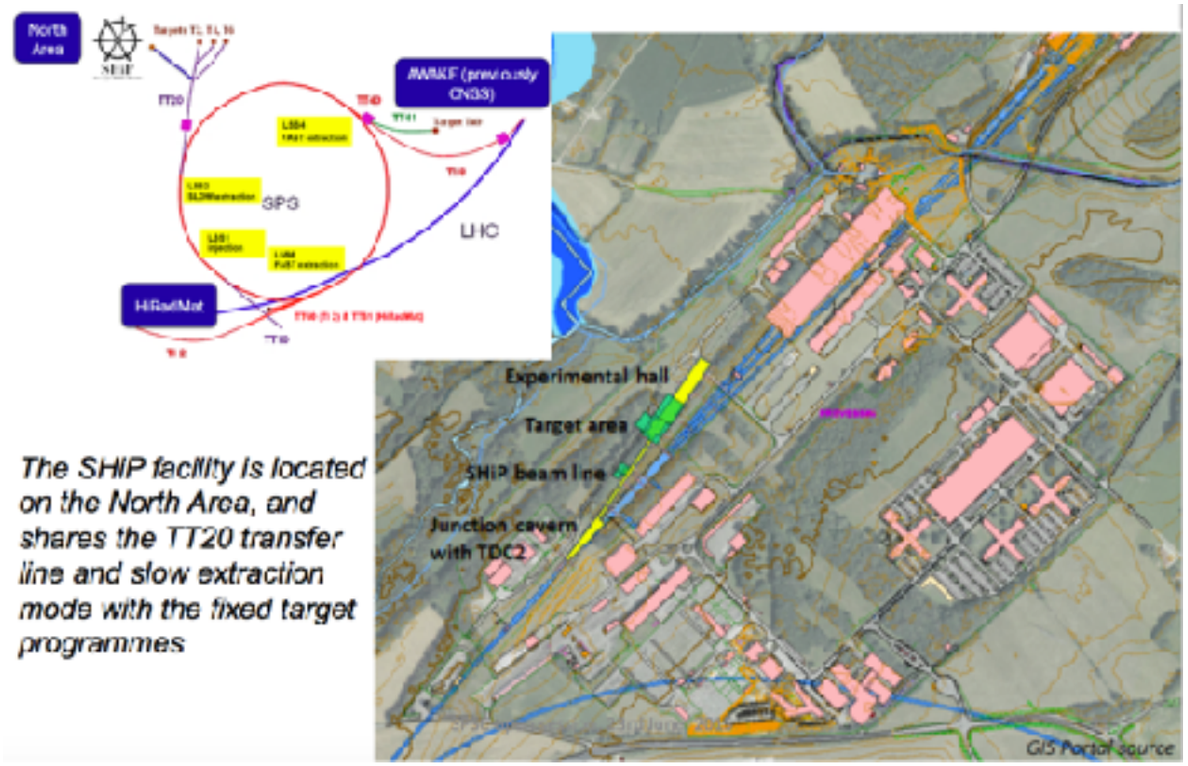
Where is the new physics?



—> long lifetimes

What is SHiP?

SHiP is a PROTON BEAM DUMP experiment proposed at CERN with the SPS p beam of 400GeV with $2x10^{20}$pot/5 years

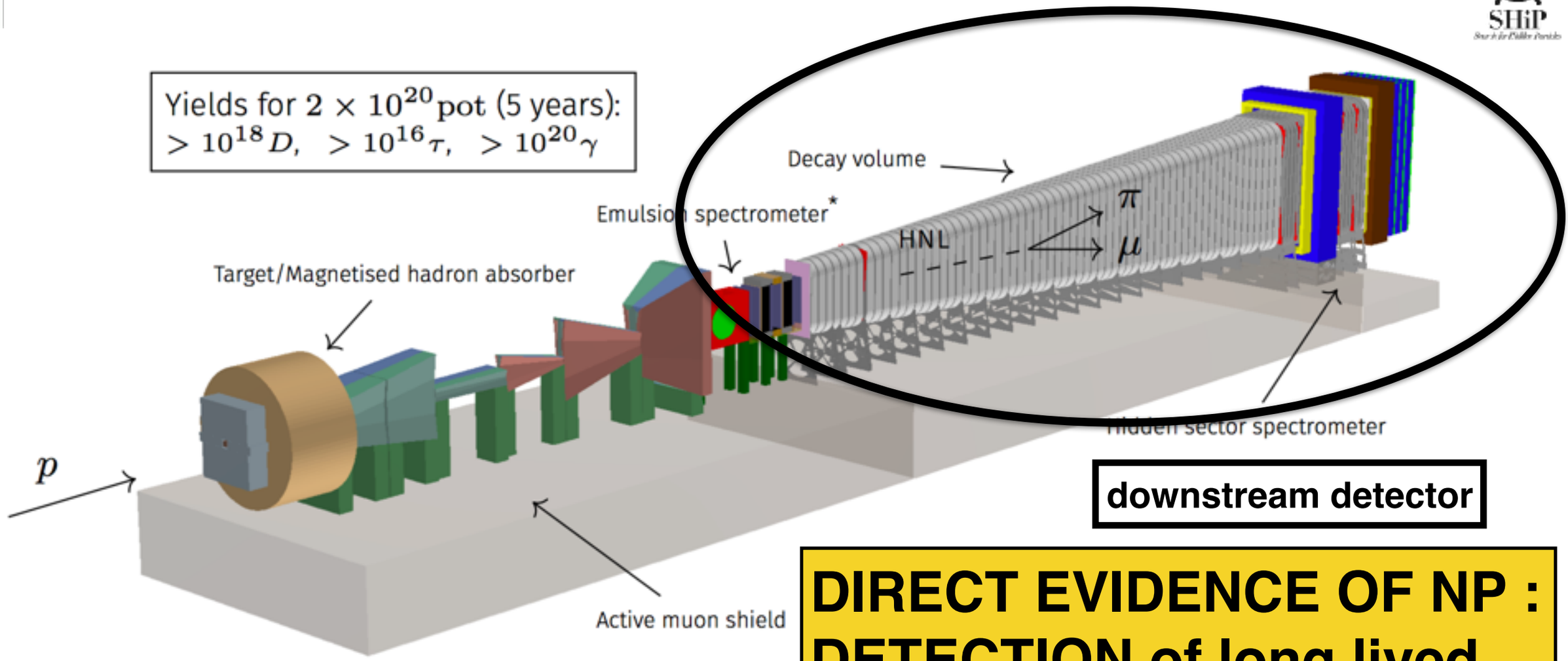


The SHiP facility is located on the North Area, and shares the TT20 transfer line and slow extraction mode with the fixed target programmes

It would make good use of the full SPS intensity that, apart from the ~2fills/day of the LHC, is not exploited

Data taking: 2026 (after LS3)

Yields for 2×10^{20} pot (5 years):
$> 10^{18} D, \quad > 10^{16} \tau, \quad > 10^{20} \gamma$

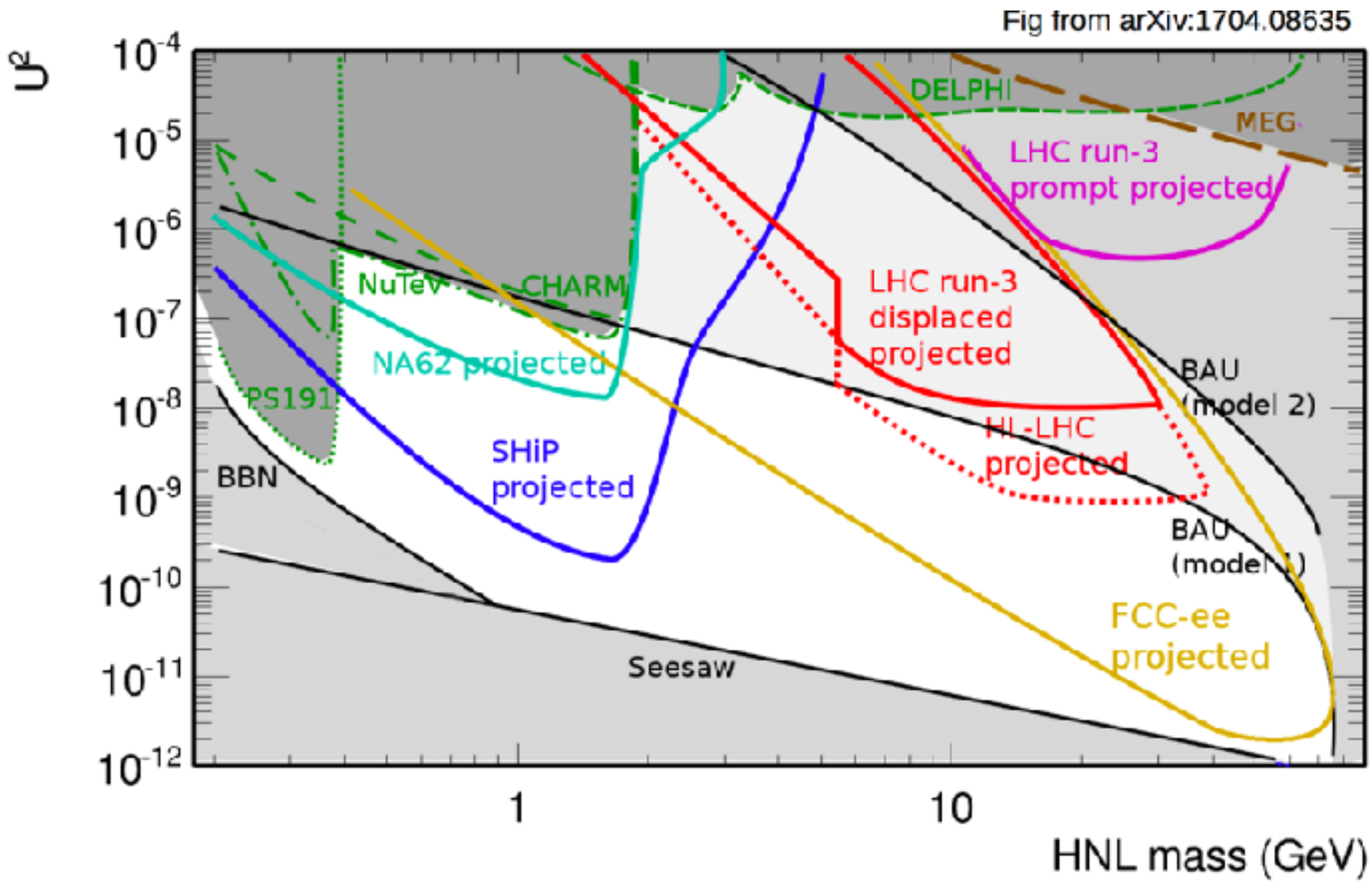


downstream detector

DIRECT EVIDENCE OF NP : DETECTION of long lived particles with masses below few GeV

signature: a ≥ 2 track vertex in the decay vessel

Sensitivity to HNL



long list of models that we can test in unexplored parameter domains

CERN's Scientific Strategy

Fabiola Gianotti

ECFA HL-LHC Experiments Workshop, Aix-Les-Bains, 3/10/2016

CERN scientific strategy (based on ESPP): three pillars

Full exploitation of the LHC:

- ❑ successful operation of the nominal LHC (Run 2, LS2, Run 3)
- ❑ construction and installation of LHC upgrades: LIU (LHC Injectors Upgrade) and HL-LHC

Scientific diversity programme serving a broad community:

- ❑ ongoing experiments and facilities at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE)
- ❑ participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through CERN Neutrino Platform

Preparation of CERN's future:

- ❑ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ❑ design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- ❑ future opportunities of diversity programme (new): "Physics Beyond Colliders" Study Group

Important milestone: update of the European Strategy for Particle Physics (ESPP): ~ 2019-2020

"Physics Beyond Colliders" Study Group established in March 2016

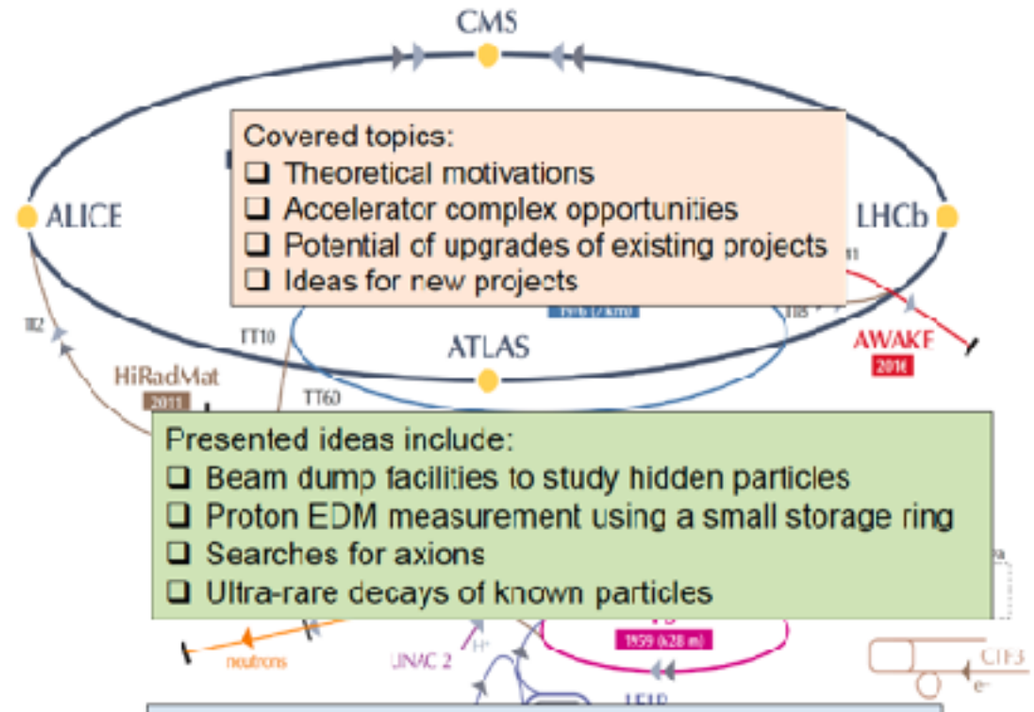
Mandate
Explore opportunities offered by the (very rich) CERN accelerator complex to address outstanding questions in particle physics through projects:

- complementary to high-energy colliders (HL-LHC, HE-LHC, CLIC, FCC, etc.)
  → we know there is new physics, we don't know where it is → we need to be as broad as possible in our exploratory approach
- exploiting the unique capabilities of CERN accelerator complex and infrastructure and complementary to other efforts in the world:
  → optimise the resources of the discipline globally

Report by end 2018 → in time for update of European Strategy

Goal is also to enrich and diversify CERN's future scientific programme.
Study Group will involve interested worldwide community, and create synergies with other laboratories and institutions in Europe (and beyond).

- Overall coordinators: Joerg Jaeckel (Heidelberg; theory), Mike Lamont (CERN; accelerator), Claude Vallée (CPPM and DESY; experimental physics)

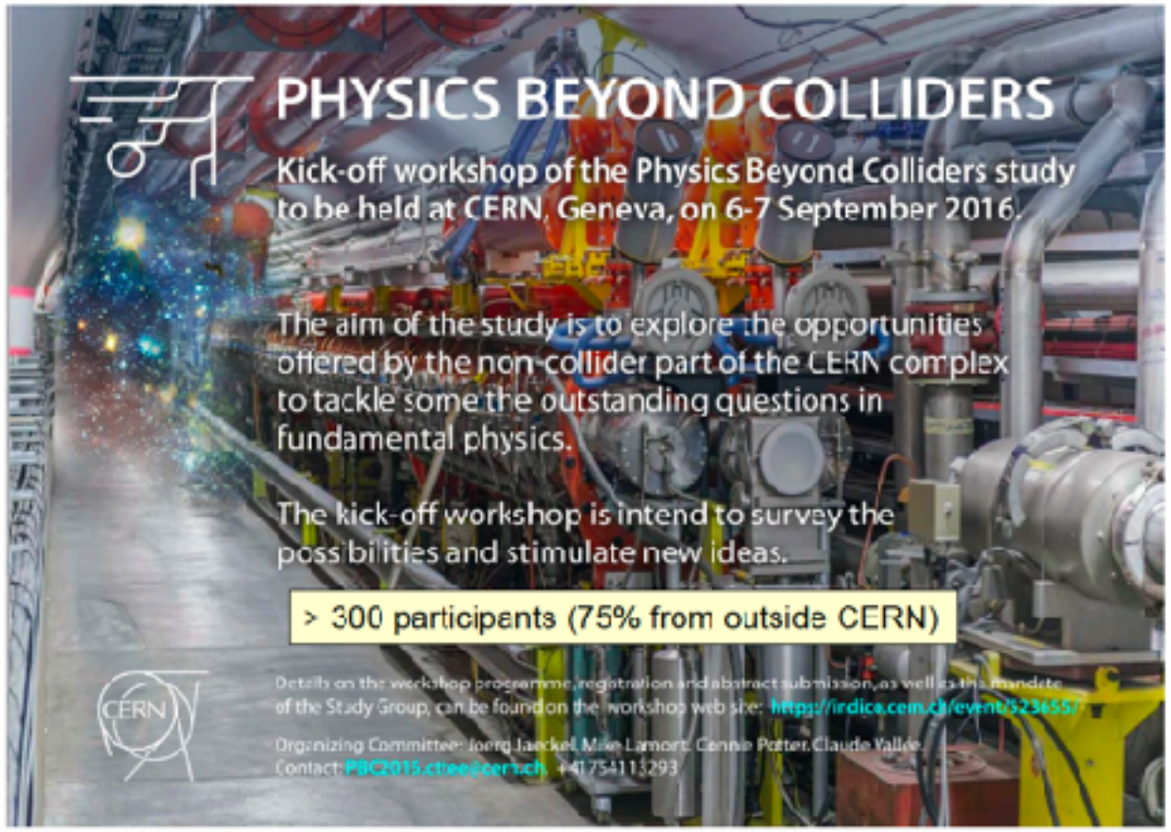


Covered topics:
- Theoretical motivations
- Accelerator complex opportunities
- Potential of upgrades of existing projects
- Ideas for new projects

Presented ideas include:
- Beam dump facilities to study hidden particles
- Proton EDM measurement using a small storage ring
- Searches for axions
- Ultra-rare decays of known particles

Emphasis on extremely-weakly-coupled, light particles

6-7 September 2016: kick-off meeting

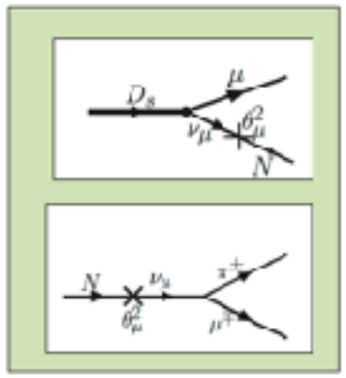


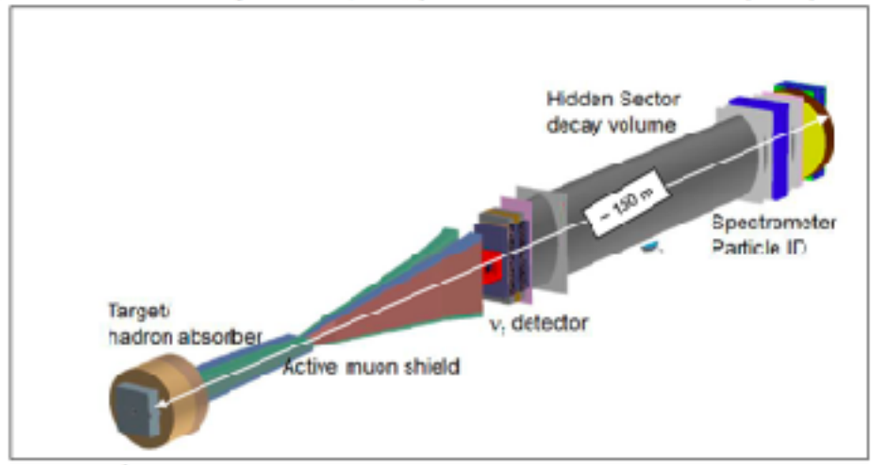
SHiP = Search for Hidden Particles

- Goal: comprehensive investigation of "dark sector" particles in the few GeV energy range: scalar (e.g. Higgs singlets), fermions (e.g. heavy neutral leptons), vectors (e.g. dark photons).

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{PORTAL} + \mathcal{L}_{DS}$$

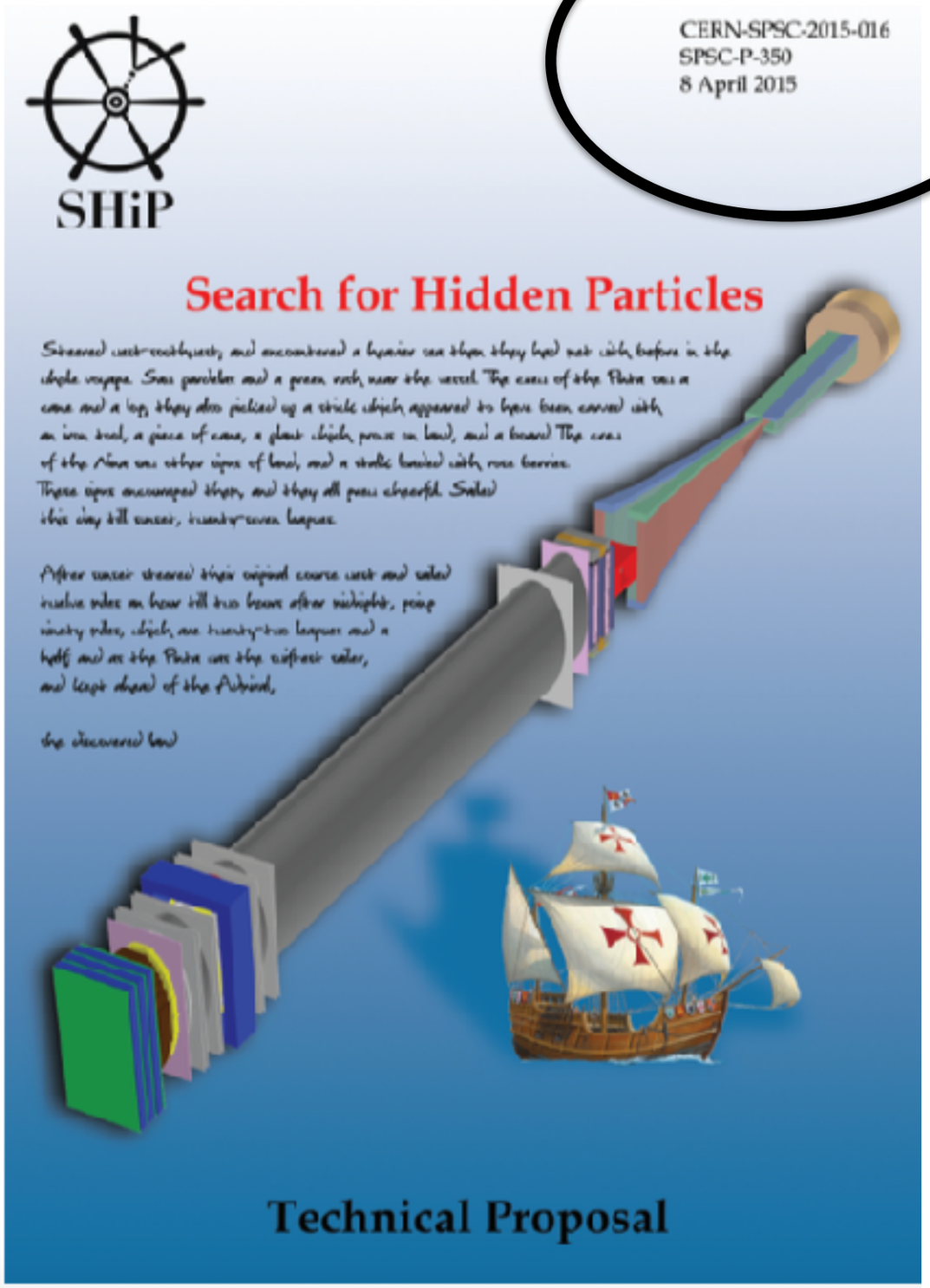
Present in several BSM scenarios addressing DM, neutrino masses, baryogenesis problems
- Beam dump facility: 400 GeV protons from SPS on target → ~2×10^{20} POT in 5 years
- Produced e.g. in D decays; detected via decays into lepton, photon, hadron, hadron-lepton pairs





- Long (50 m) evacuated decay vessel
- Most crucial experimental issue is to reject huge backgrounds → heavy target, hadron absorber, active muon shield, veto and time detectors, particle ID, etc.

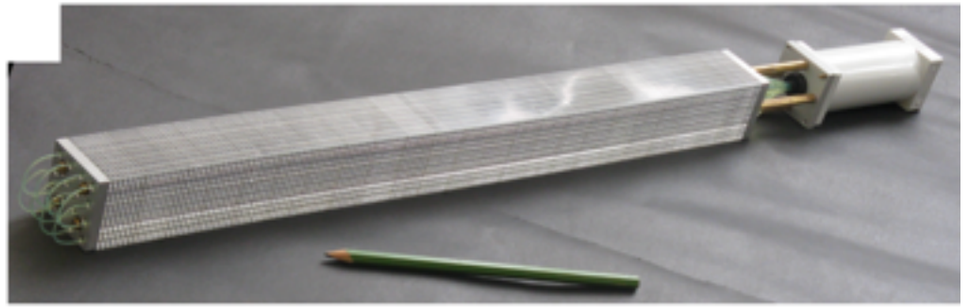

CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015
SHiP
Search for Hidden Particles
Physics Proposal


CERN-SPSC-2015-016
SPSC-P-350
8 April 2015
SHiP
Search for Hidden Particles
Technical Proposal

The EM calorimeter in the Technical Proposal

Physics: HNL—>$\pi\pi^0$l, DP—> $\pi\pi\pi^0$, e-/π separation in HNL—>πe

Particle rate —> low



Shashlik (a la LHCb)

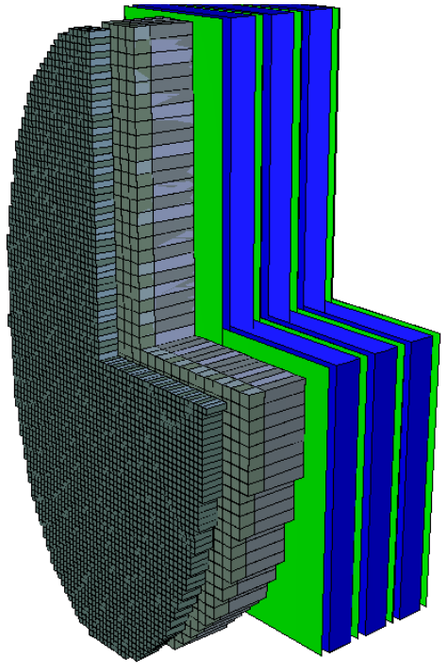
Cells of 6×6 cm^2 cross section

with 140 alternating layers of

1 mm lead and 2 mm scintillator.

Total depth of ~50 cm = 25 X_0

$\sigma(E)/E \approx 5.7\%/\sqrt{E}$



Why evolving compared to TP?

1) **reduce possibly cost of Shashlik**

2) **add the measurement of shower direction for neutral final states (need few mrad resolution for ALP—>γγ) and possibly suppress background**

3) **improve e/π separation**

of course it is a 5x10 m² guy (or lady)…

REC → GEN ↓	μ-μ	e-e	π-π	μ-π	π-e	μ-e
μ-μ 2 body	324/328 98.78%			4/328 1.22%		
e-e 2 body		280/281 99.64%			1/281 0.36%	
π-π 2 body			278/294 94.56%	4/294 1.36%	12/294 4.08%	
μ-π 2 body	4/273 1.47%		1/273 0.36%	266/273 97.44%		2/273 0.73%
π-e 2 body		1/296 0.33%	2/296 0.67%		287/296 97%	6/296 2%

REC → GEN ↓	μ-μ	e-e	π-π	μ-π	π-e	μ-e
μ-μ 2 body	287/291 98.63%			4/291 1.37%		
e-e 2 body		266/267 99.63%			1/267 0.37%	
π-π 2 body		3/297 1%	268/297 90.24%	5/297 1.68%	20/297 6.73%	1/297 0.34%
μ-π 2 body	23/296 7.77%		2/296 0.68%	259/296 87.5%	1/296 0.34%	11/296 3.72%
π-e 2 body		12/236 5.08%			221/236 93.64%	3/236 1.27%

REC → GEN ↓	μ-μ	e-e	μ-e	μ-π	π-e
μ-μ 3 body	283/287 98.61%			4/287 1.39%	
e-e 3 body		269/275 98.91%			3/275 1.09%
μ-e 3 body		3/279 1.08%	275/279 98.56%		1/279 0.36%

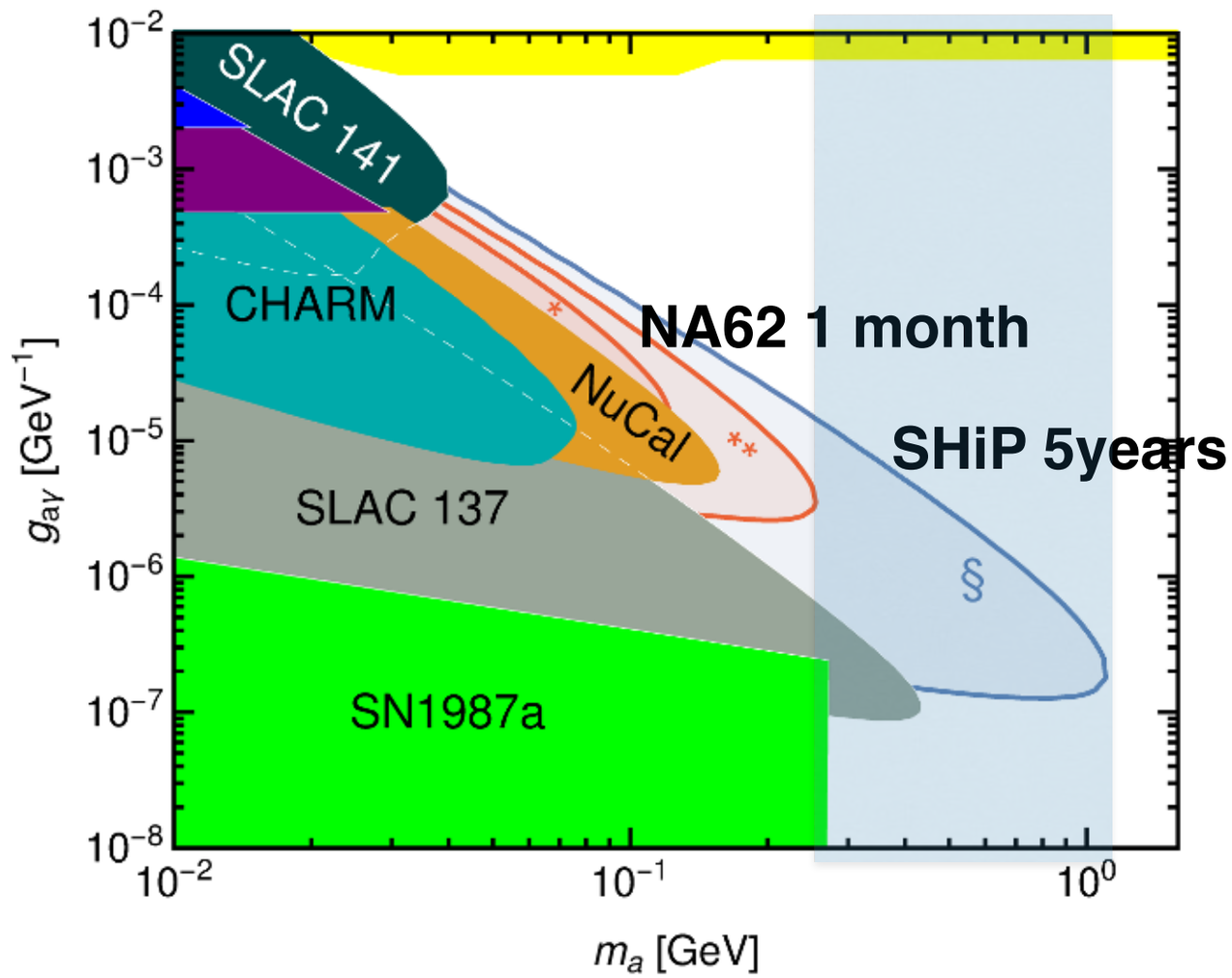
REC → GEN ↓	μ-μ	e-e	μ-e	μ-π	π-e
μ-μ 3 body	312/317 98.42%			5/317 1.58%	
e-e 3 body		230/231 99.57%			1/231 0.43%
μ-e 3 body		12/240 5%	223/240 92.92%		5/240 2.08%

Performance of PID on signal channels —> misidentification of pions into electrons

Search for

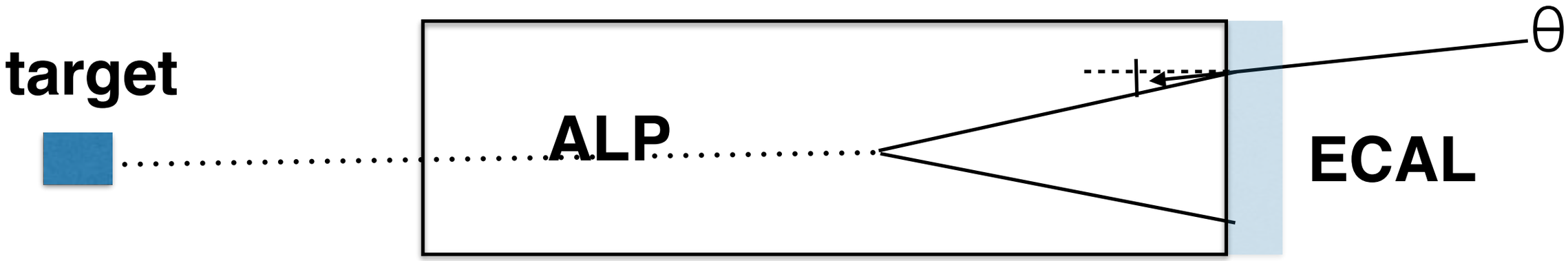
ALP—>γγ

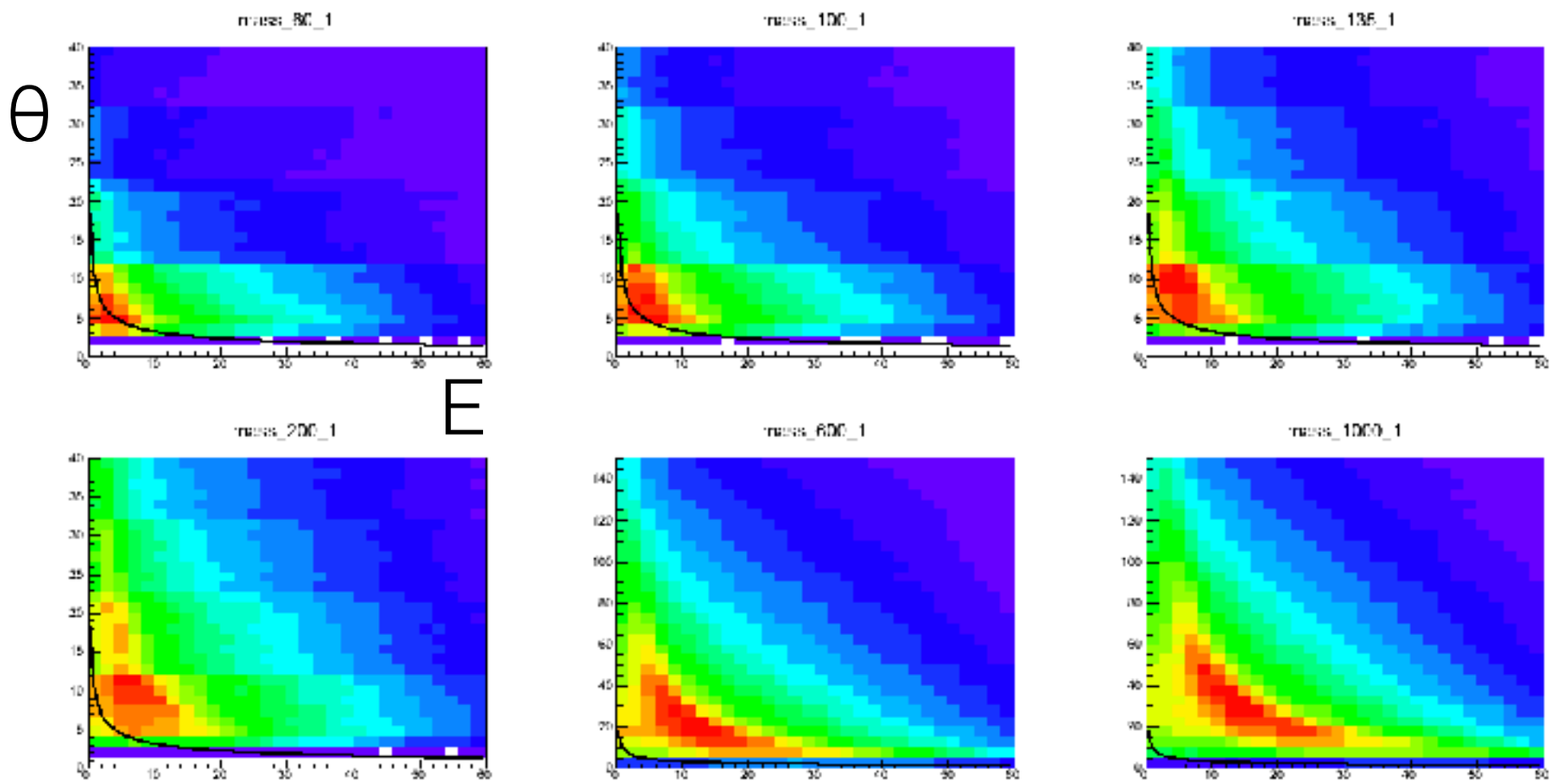
JHEP 1602 (2016) 018



300MeV-1GeV

ANGLES

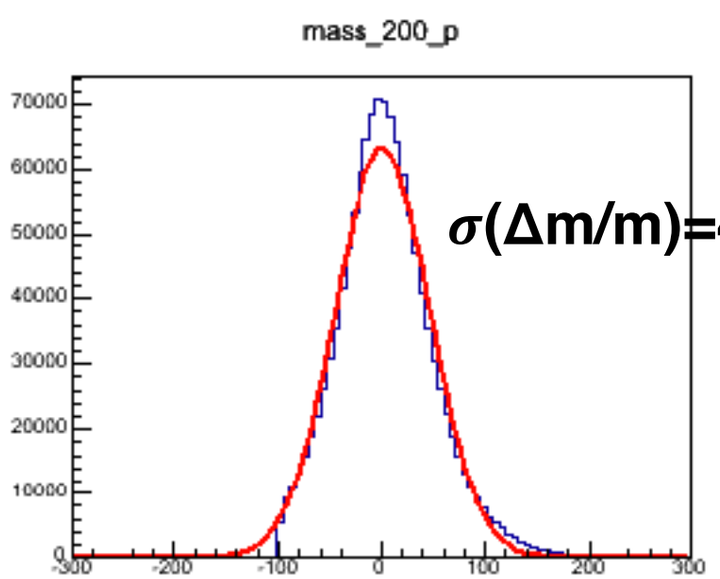




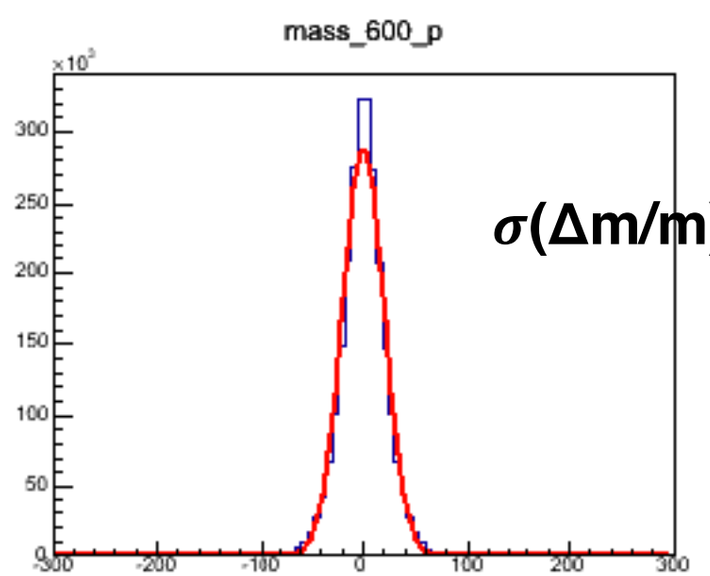
σ(θ)=10mrad/√E ->black curve

invariant mass reconstruction

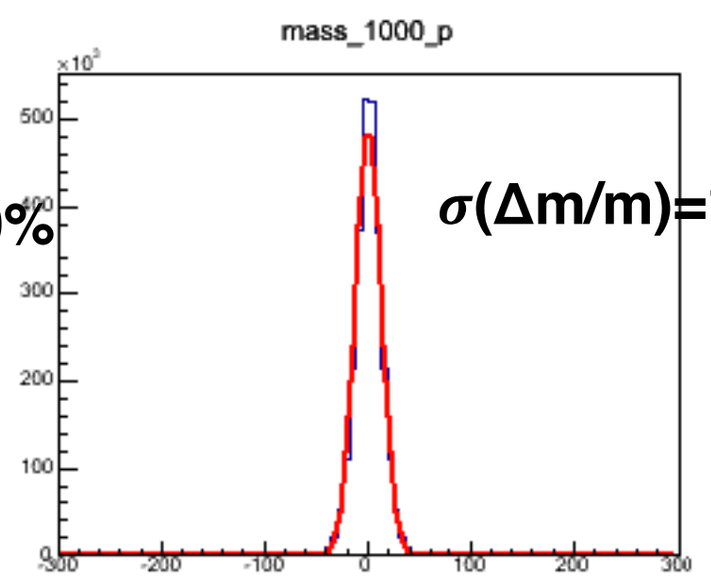
Why to care about mass reconstruction? imagine we find 10 two-photon only events. Wouldn't you like to see an accumulation of a mass peak to claim we have a discovery (and not some background)?



$\sigma(\Delta m/m)$=46%



$\sigma(\Delta m/m)$=20%



$\sigma(\Delta m/m)$=12%

the mass region which is only for us (not for NA62)

The measurement of the shower direction

This is not a completely new subject:

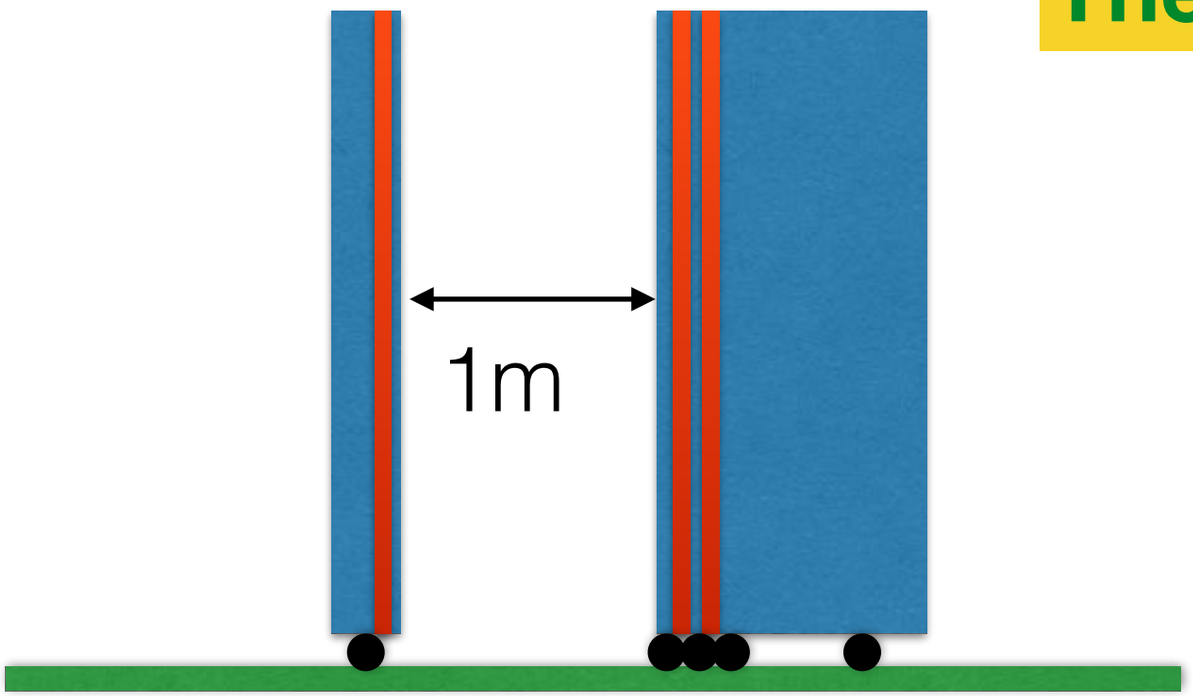
- e.g. ATLAS, though in one direction only (η)

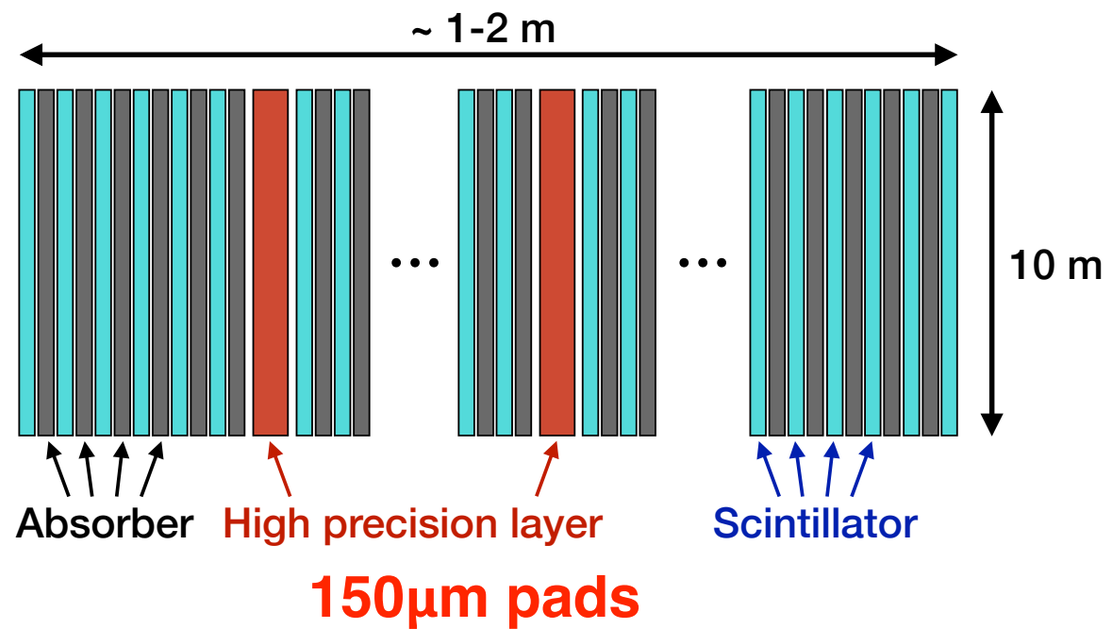
- γ-ray experiments (e.g. FERMI) in space can measure it with high precision but very low efficiency (here we need full efficiency)

In SHiP we can take advantage of the fixed target configuration that leaves some room in the longitudinal direction —> increase the lever arm

I show here some new ideas supported by GEANT simulation but work is not finished!

The SplitCal



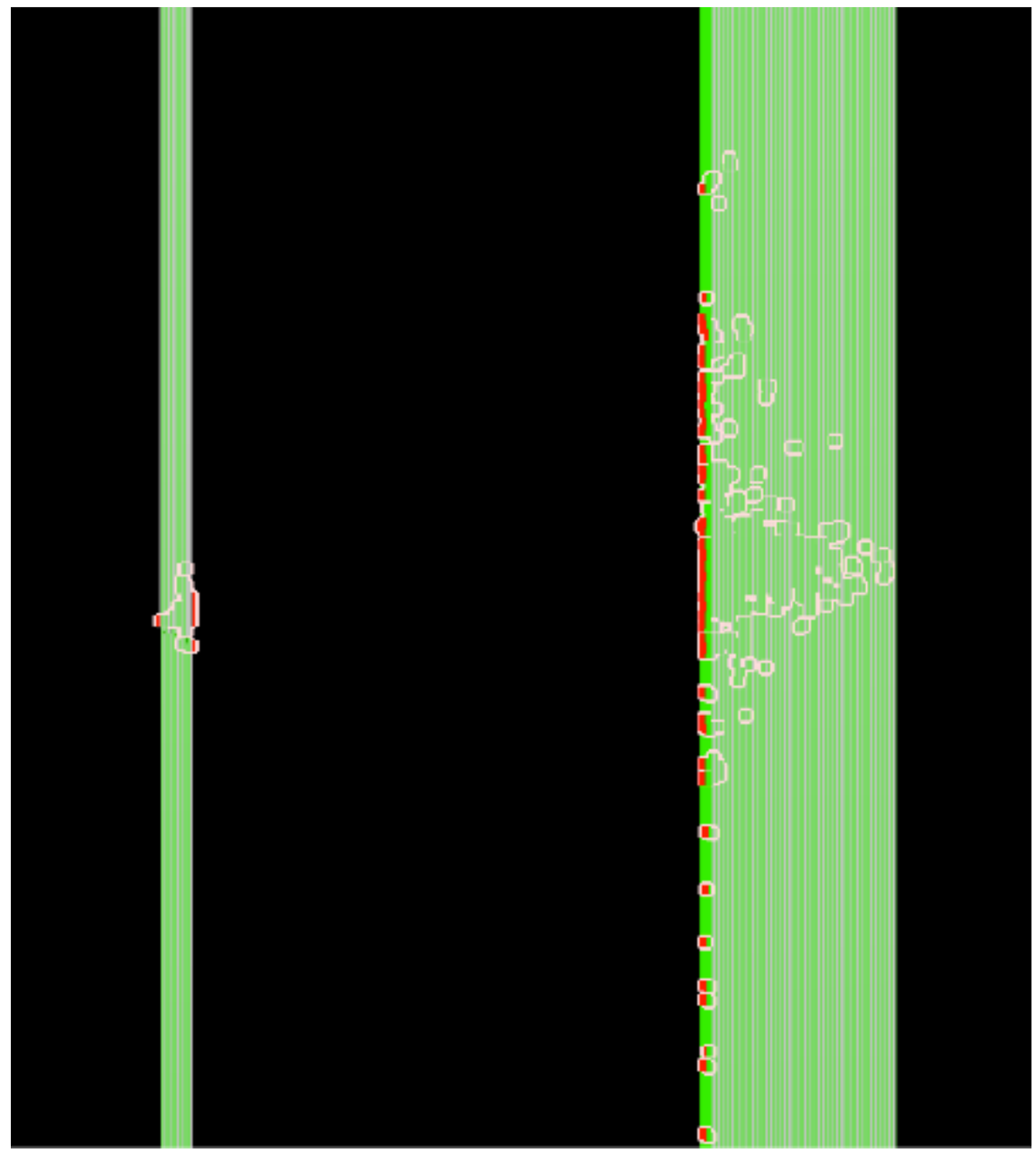


Implemented in GEANT-based simulation with some simplifying assumptions

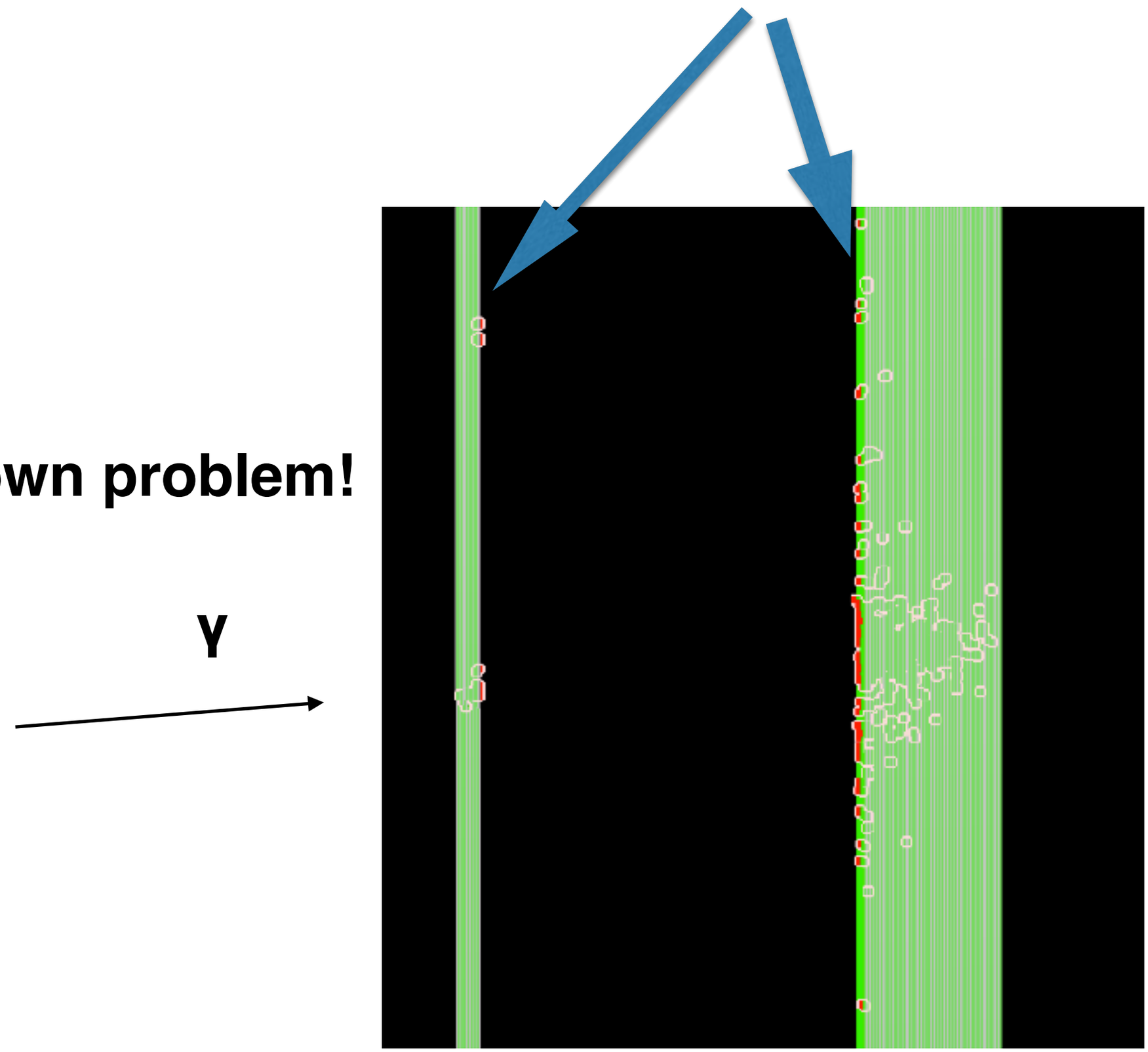
in blue a sampling ECAL with X-Y plastic scintillator bars readout via WLS fibres from the sides, coarse granularity

in red the high precision layers at $3X_0$, $5X_0$ and $6.5\ X_0$ (µ-pattern gas detectors with pad readout with digital readout) that could also be staged

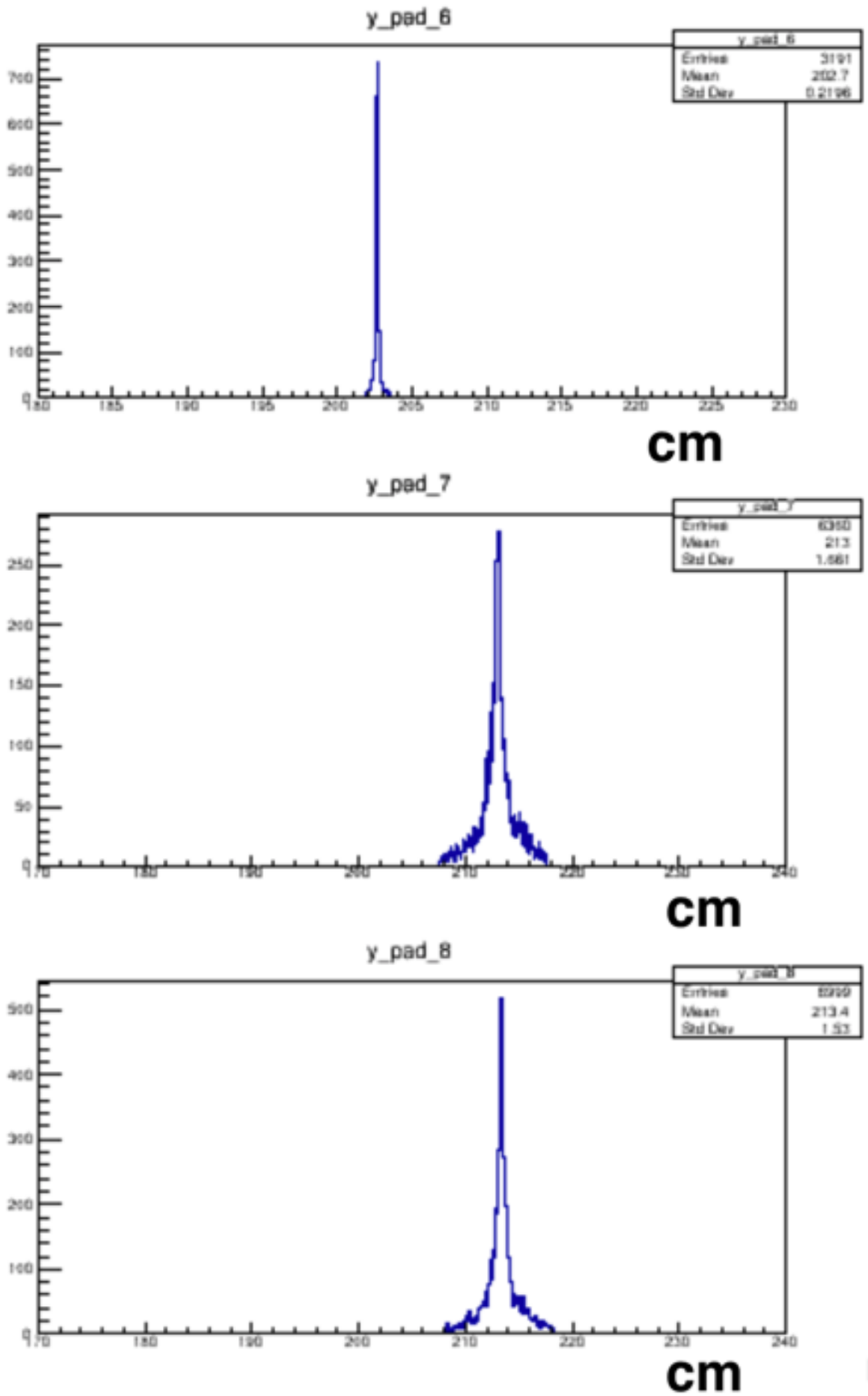
20 GeV γ generated in the yz plane with 100mrad angle and z=20m upstream of the ECAL surface



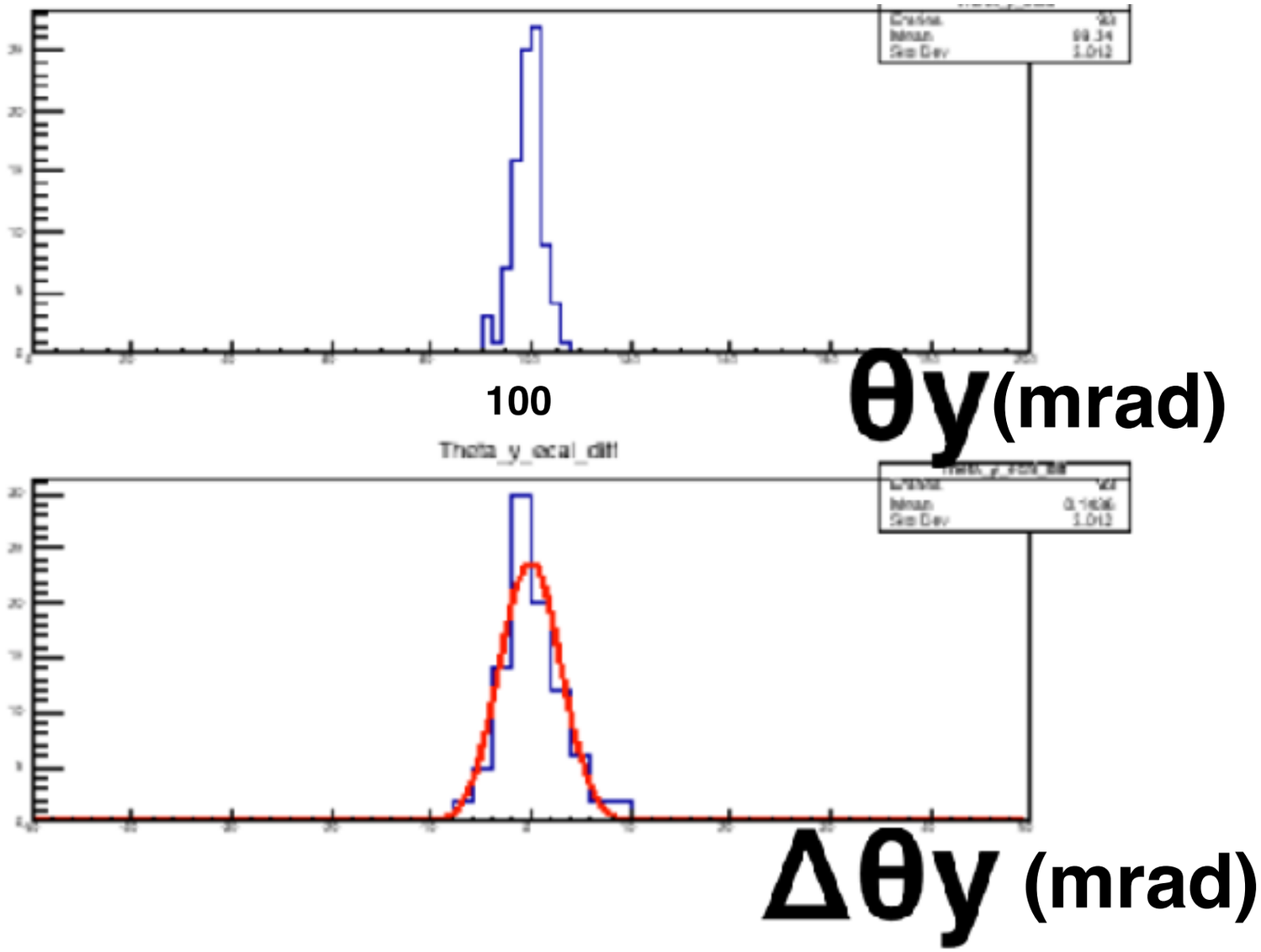
satellites



a well-known problem!

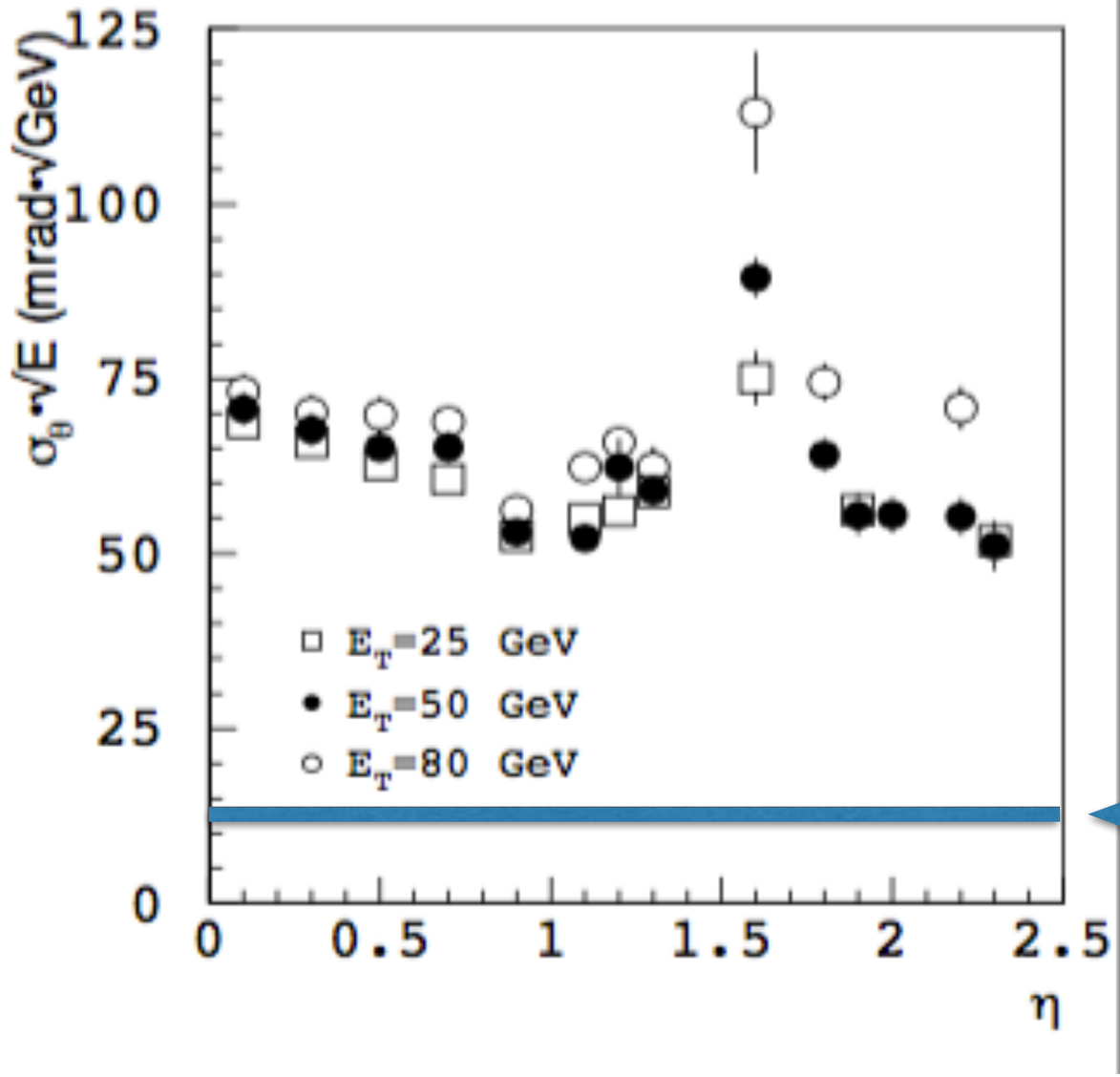


cumulative shower profiles in the three high precision layers



the shower direction reconstructed from linear fit to the reconstructed median distribution in each of the tree high precision layers

angular resolution—>3.0mrad (about 2.5mm position resolution at shower maximum)



SplitCal

as a comparison: ATLAS ECAL performance TDR: in blue our result at 20GeV ; large improvement but cost of high precision layers?

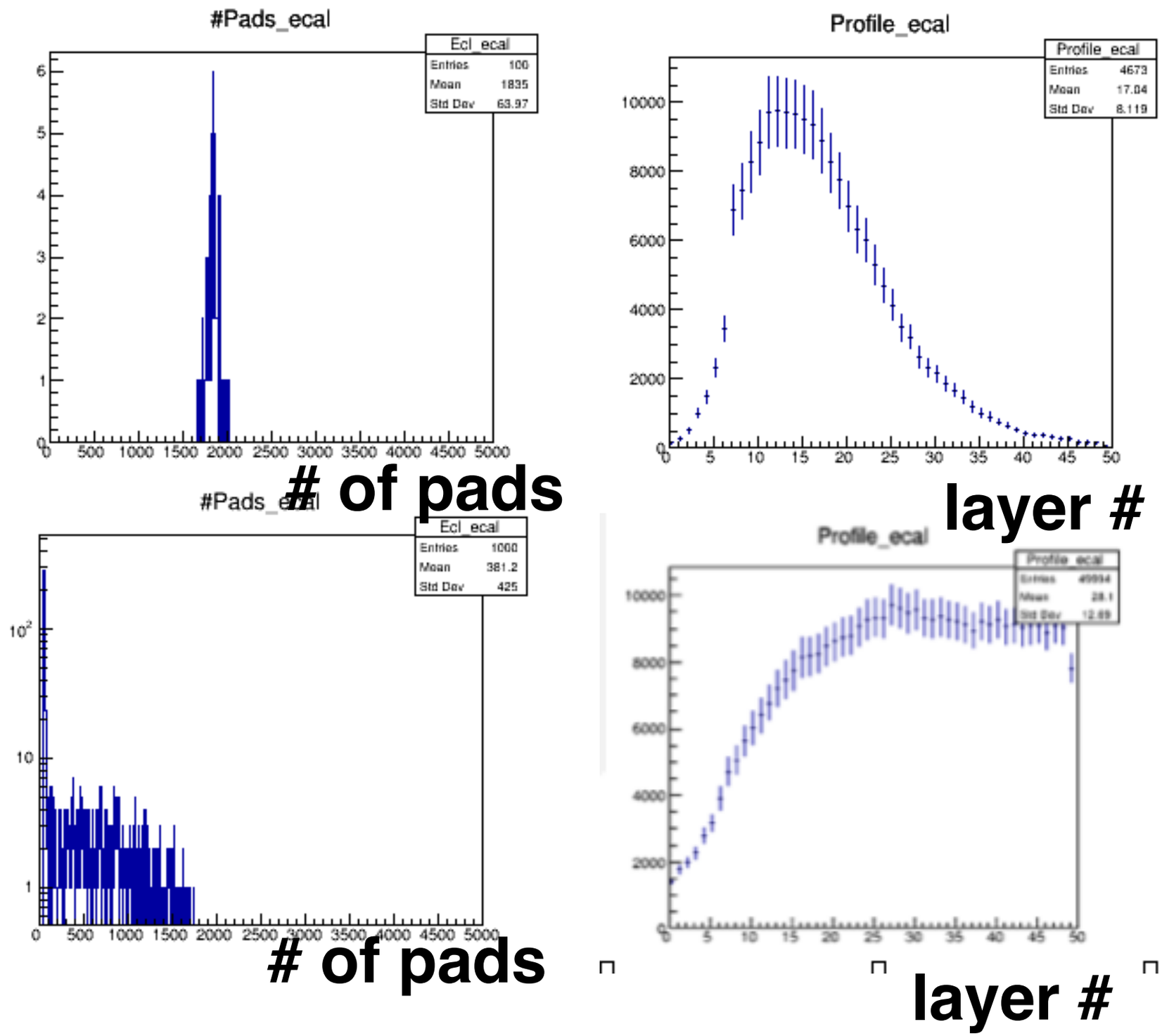
A recent estimate for 140m² (similar to our requirements) to be used in CMS of μWELLS was about 1M€ (detector only); readout to be added!

Energy resolution about 15%/√E

Electron/pion separation

20GeV e-

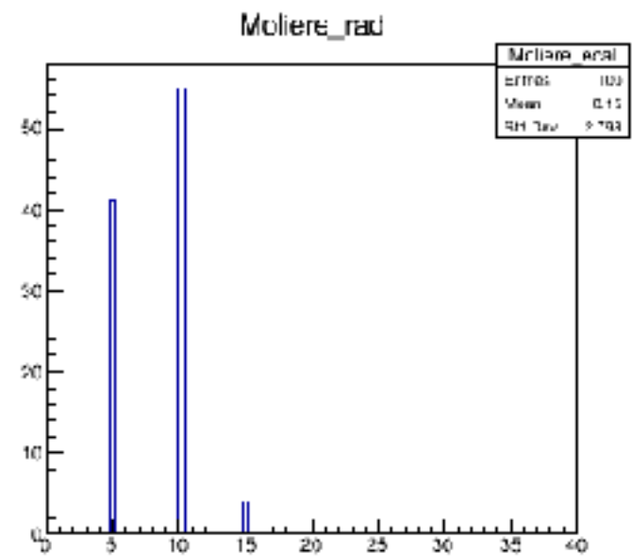
20GeV π-



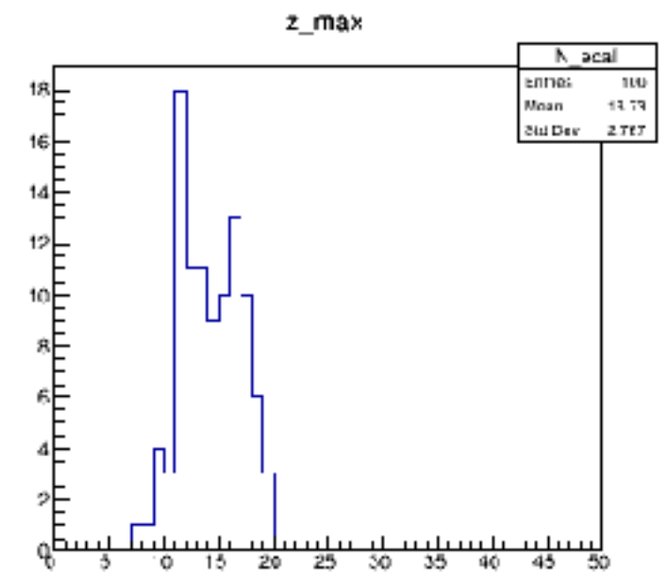
Effective Moliere radius

postion of shower max

20GeV e-

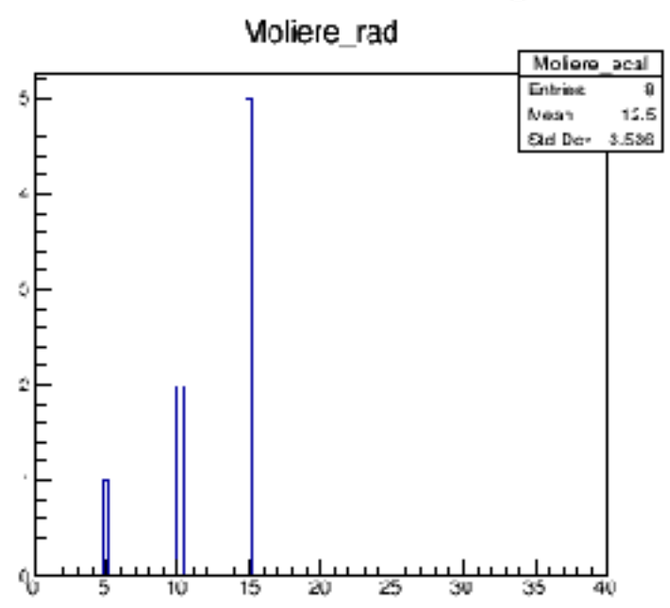


cm

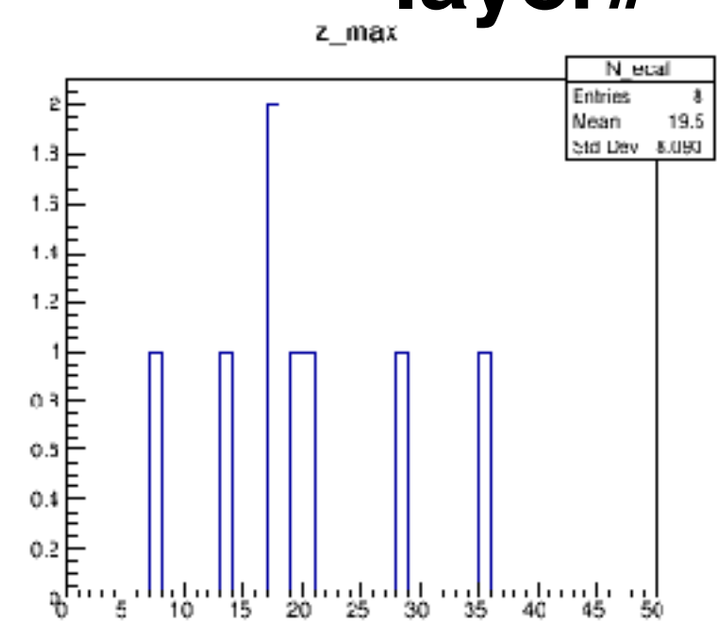


layer#

20GeV π-



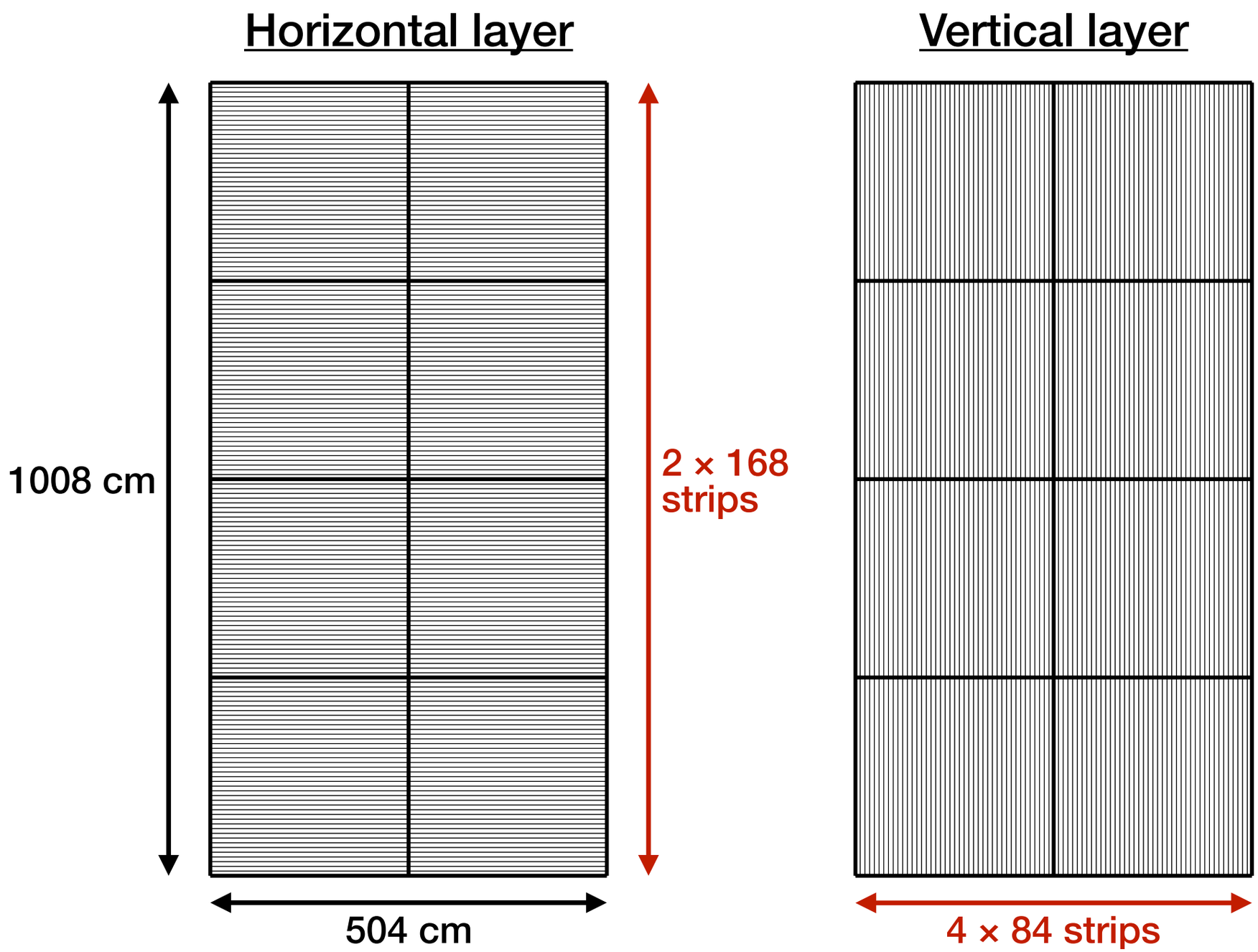
cm



layer#

no problem to go below 1% of mis-identification!

Possible layout of scintillator layers



R&D

Still, even for the scintillation section many technical issues to be solved:

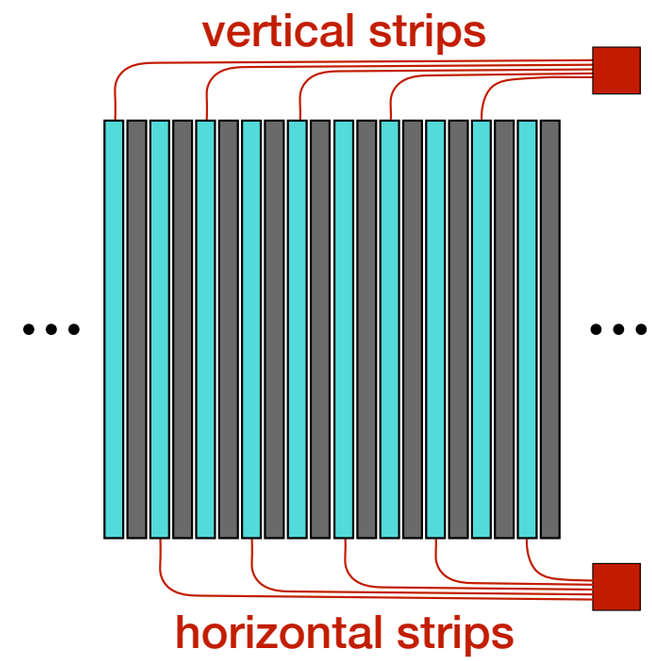
Readout with SiPMs:

fiber bundling within a plane

(minimum # of SiPM's 33600)

longitudinal fiber bundling

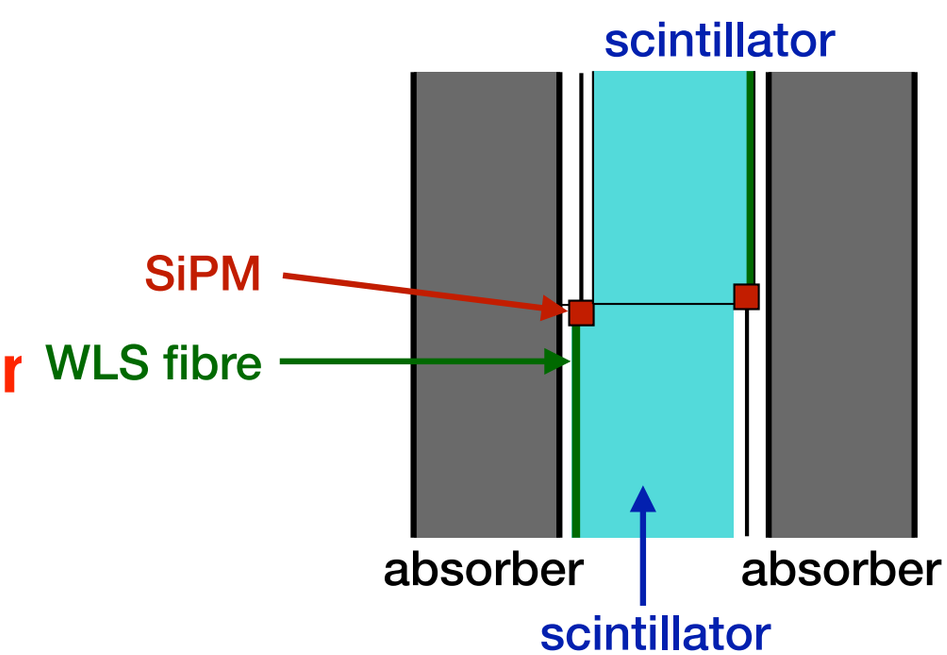
dynamic range



Mechanical assembly:

huge detector: how to decompose it ir

scintillator plane staggering



Conclusions

The SHiP project is getting momentum at CERN and the collaboration is preparing a detailed report for the European Strategy meeting in the context of the Beyond Collider Physics WG at CERN

Some new ideas for a calorimeter measuring the shower direction under study

Performance looks great, but on paper!

A lot of work ahead of us !

<u>Ideas and new collaborators welcome!</u>

Journée SHiP/Physique du secteur caché

11 October 2017
LPNHE Univ. Pierre et Marie Curie Paris-6

Welcome *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*		10:30 - 11:00
Welcome by the LPNHE director *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Gregorio Bernardi*	11:00 - 11:05
The GDR-InF, Physics at the Intensity Frontier *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Aoife Bharucha*	11:05 - 11:15
Status of the Physics Beyond Colliders workshop *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Claude Vallée*	11:15 - 11:50
SHiP Overview *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Andrei Golutvin*	11:50 - 12:25
BSM Physics with Light Particles (title to be confirmed) *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Mikhail Shaposhnikov*	12:25 - 13:00

	Leptogenesis, recent progress (title to be confirmed) *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Pilar Hernandez*	14:30 - 15:00
15:00	**The U boson as a generalized dark photon** *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Pierre Fayet*	15:00 - 15:30
	SHiP sensitivity (title to be confirmed) *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Nicola Serra*	15:30 - 16:00
16:00	**Coffee** *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*		16:00 - 16:30
	The SHiP Project *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Richard Jacobsson*	16:30 - 17:00
17:00	**SHiP Calorimetry and Particle Identification (title to be confirmed)** *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Dr. Walter Marcello Bonivento*	17:00 - 17:30
	Prospects in France *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*	*Maxim Titov and Jacques Chauveau*	17:30 - 18:00
18:00	**Discussion** *Amphithéâtre Georges Charpak, LPNHE Univ. Pierre et Marie Curie Paris-6*		18:00 - 18:30
	Closed session *T12+22 2.28 salle Higgs, LPNHE Univ. P&M Curie*		18:30 - 19:00