SHiP calorimetry

W. Bonivento INFN Sezione di Cagliari

Status, ideas, people, open areas

Journée SHiP/Physique du secteur caché

11 October 2017
LPNHE Univ. Pierre et Marie Curie Paris-6
Europe/Zurich timezone

- physics motivation

- the TP design

- the TP performance for particle identification

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

- ideas for a new design

Motivations for a good particle identification in SHiP

1) measure the mass of final states from hidden sector particle decays, with and without neutrals

2) distinguishing between models: HNLs, dark scalar, dark vector, SUSY etc.

3) distinguishing final states so to extract the parameters of the νMSM —> together with the measurement of the Dirac phase δ by DUNE/HyperK, information on lepto-genesis (e.g. JHEP 1708 (2017) 018)

As a by-product we will get further suppression of ν induced background

The TP design (1)

requirements considered for ECAL design:

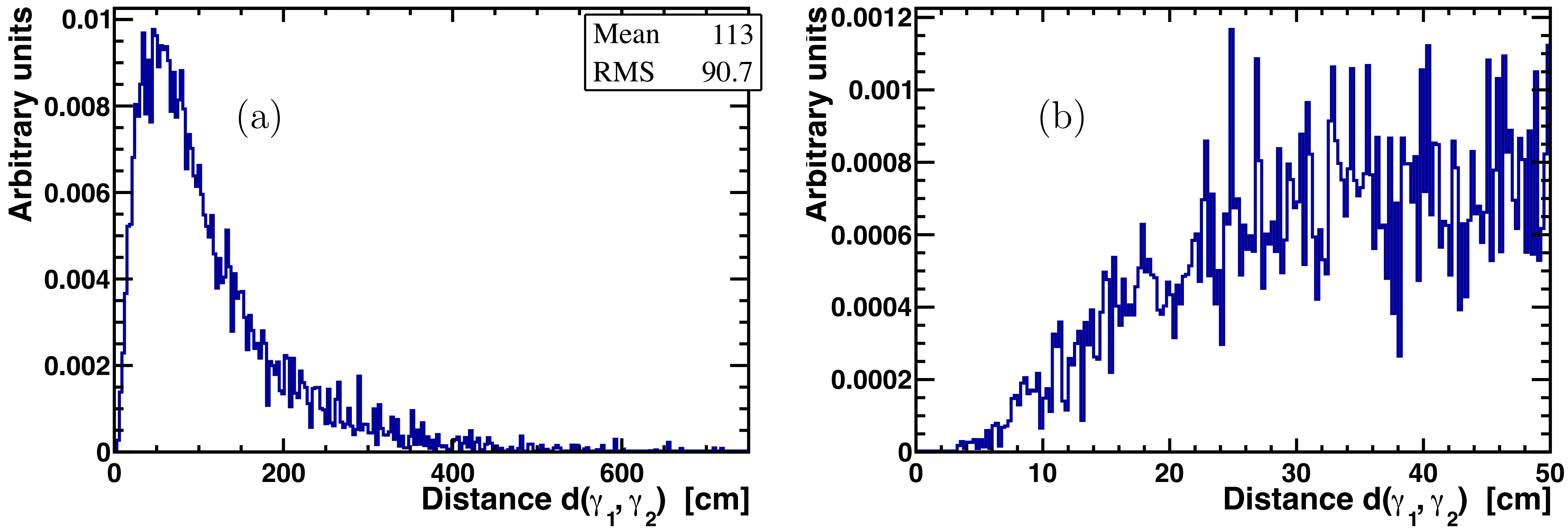
e- and γ reconstruction, energy and position measurement, e-/π separation

- large size

- known technologies

- e-/π separation as good as possible from 1 to 100Gev

- moderate $\sigma(E)$, granularity to see the two photons from the π^0 from HNL—>ρl



distance of photons in ECAL from π^0's in HNL—>ρ l

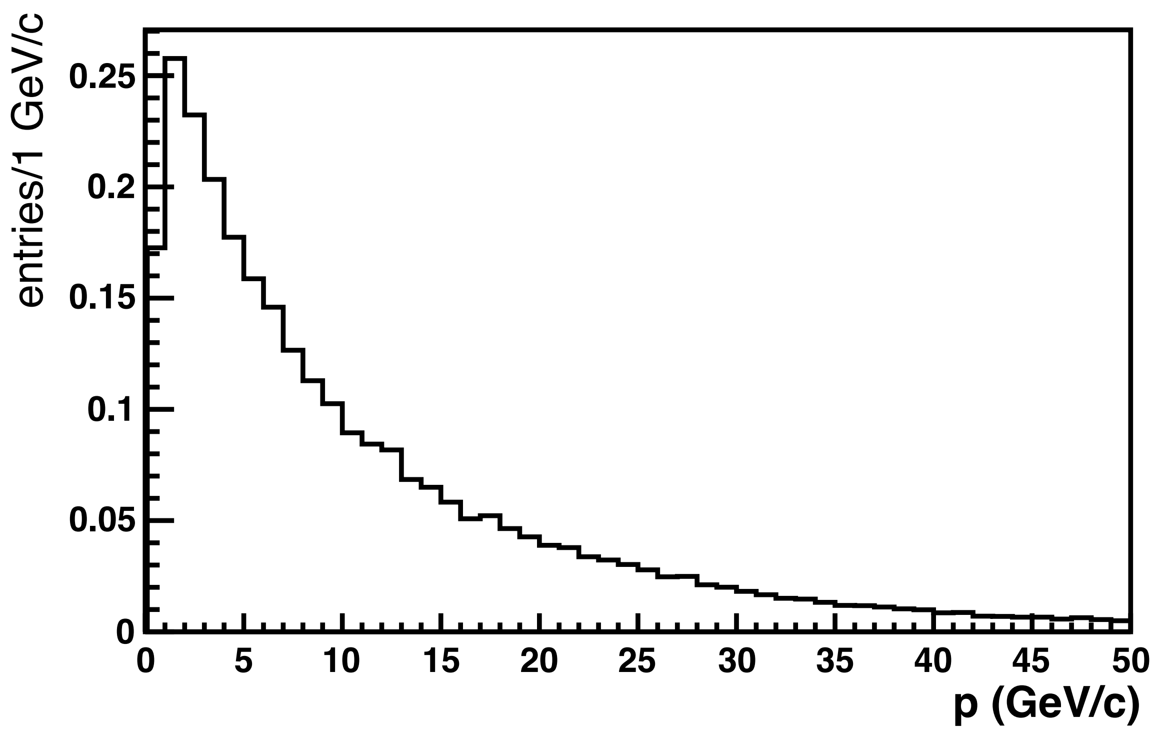
need to see separate two photons to distinguish $\pi^0\pi^0$ from ALP—>γγ

The TP design (2)

requirements considered on HCAL/MUON detector design: μ/π separation (including also ECAL!)

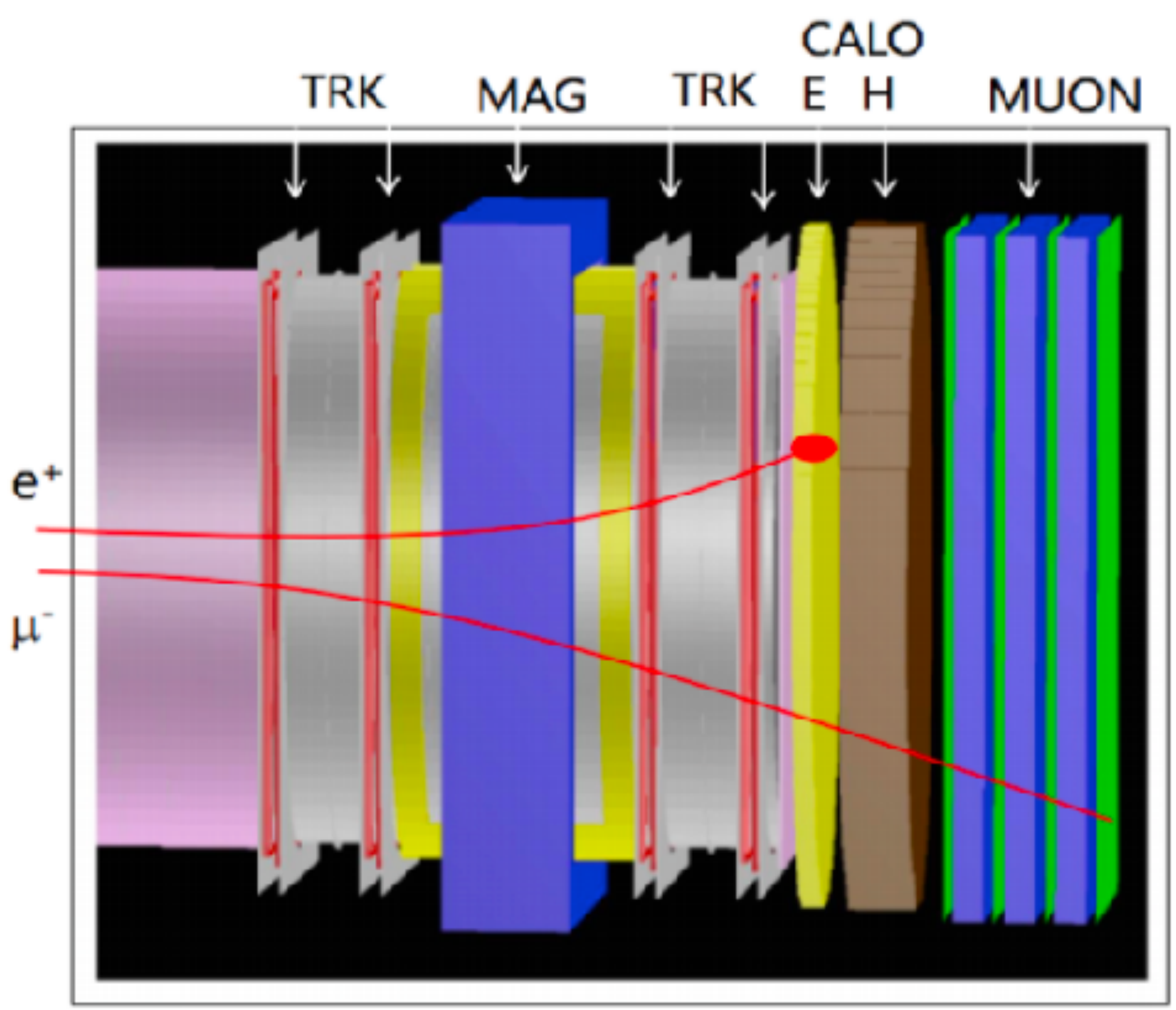
- large size
- known technologies
- tag neutral particles such a K^0_L for background rejection (but at the time no practical example)
- μ/π separation for non decaying pions as good as possible from 1 to 100GeV

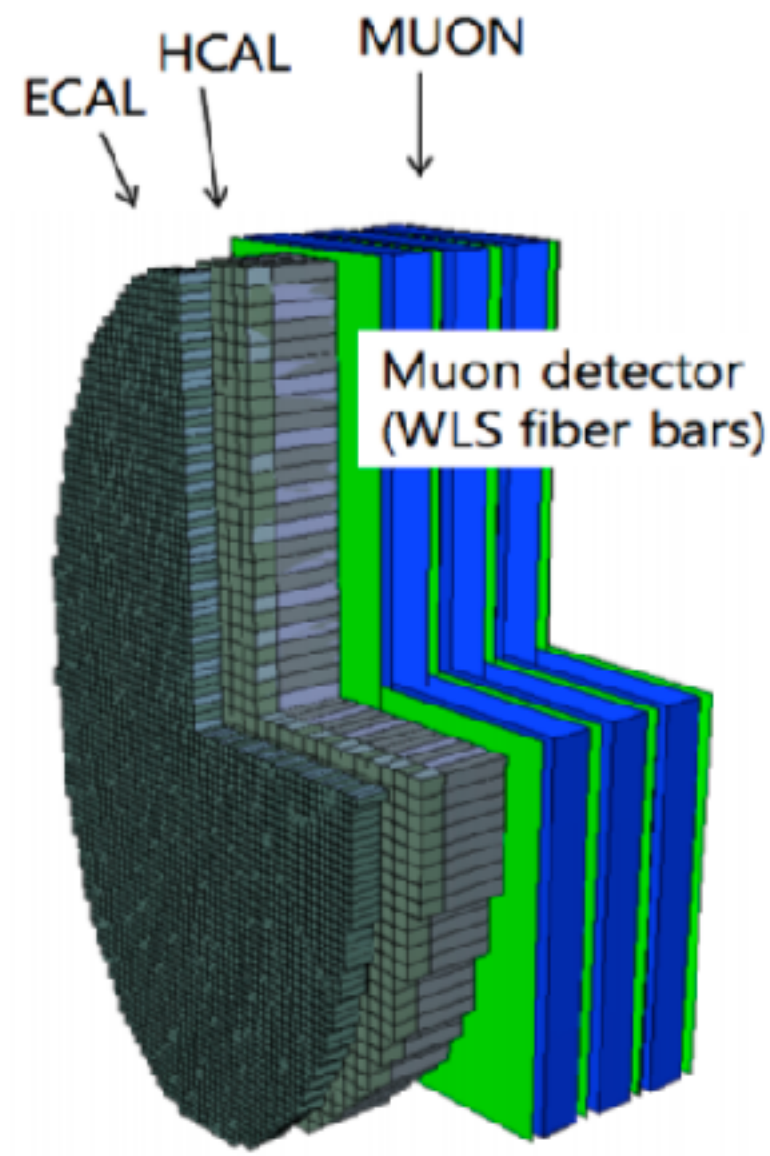
HNL decay product spectrum (DP harder)



The TP Design

Calorimeter and Muon detector





ECAL : e/γ id, π^0 and η reconstruction
(Shashlik technique, LHCb)

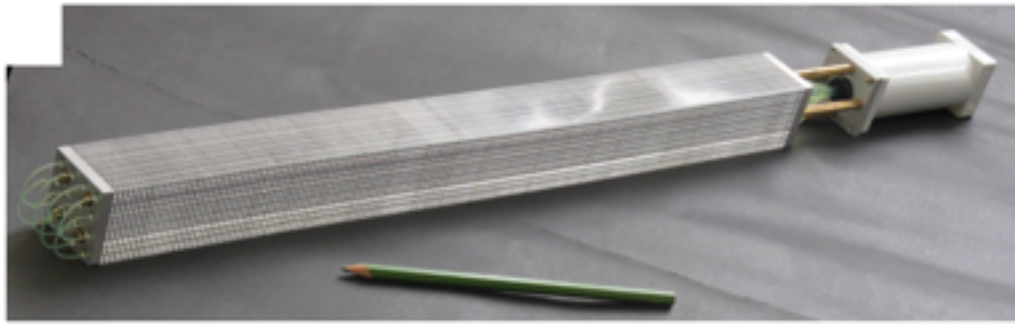
HCAL : π/μ separation
(similar technology as ECAL)

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

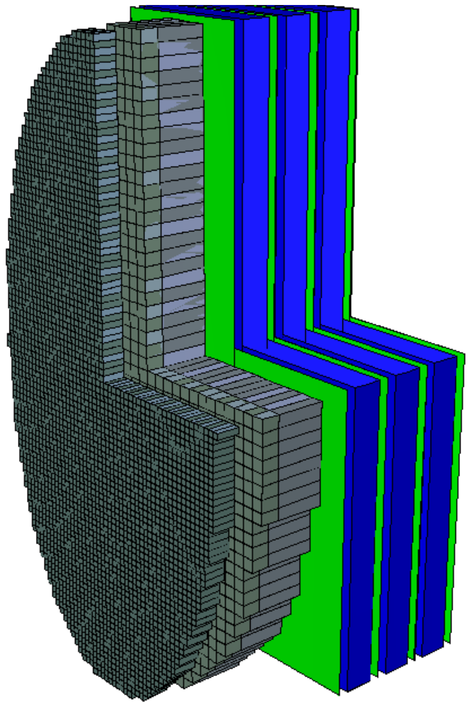
Shashlik (a la LHCb)



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

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

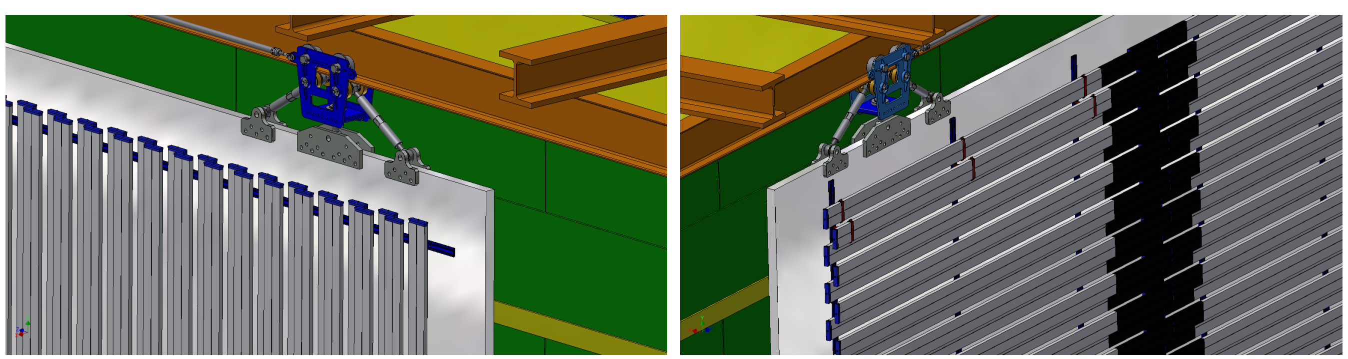


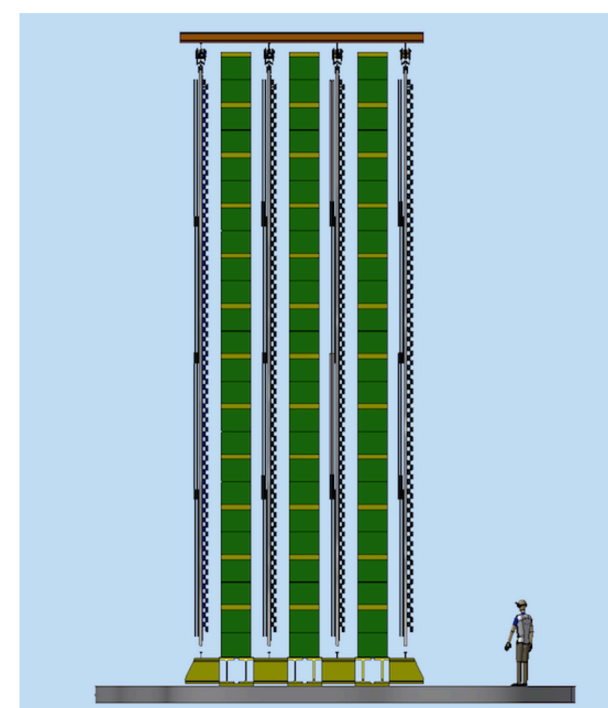
The HCAL and MUON detector in the Technical Proposal

The TP design (2)

Design:

cover μ/π separation above few GeV's <threshold> with "MUON" detector (4 layers of plastic extruded scintillator read out by WLS fibres and SiPMS's and digital readout alternated with 3.4 λ_I iron absorbers) —> a "topological" detector





The TP design (2)

and cover the low momentum region <4GeV with iron Shashlik HCAL with 24x24cm^2 cells with 6.2 λ_I first thin section (H1) with 18 sampling layers followed by a second section (H2) of 48 layers

(Shashlik was chosen just for conceptual simulation)

Of course the MUON detector threshold depends on what is in front in terms of λ_I

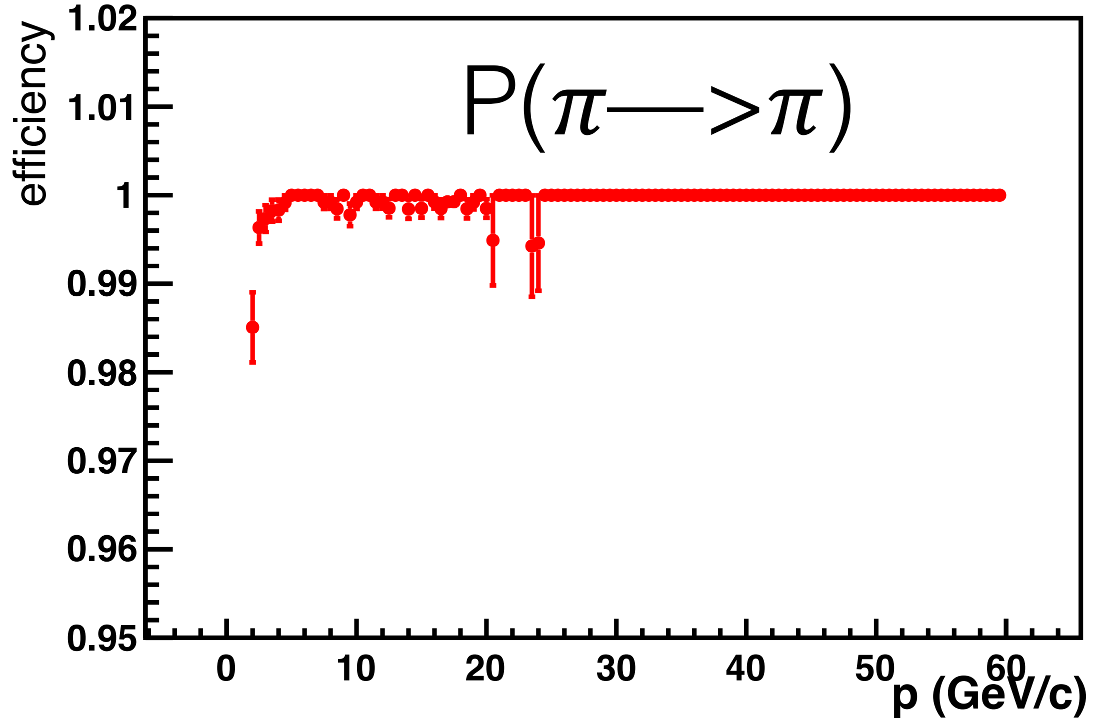
Performance studies already in the TP

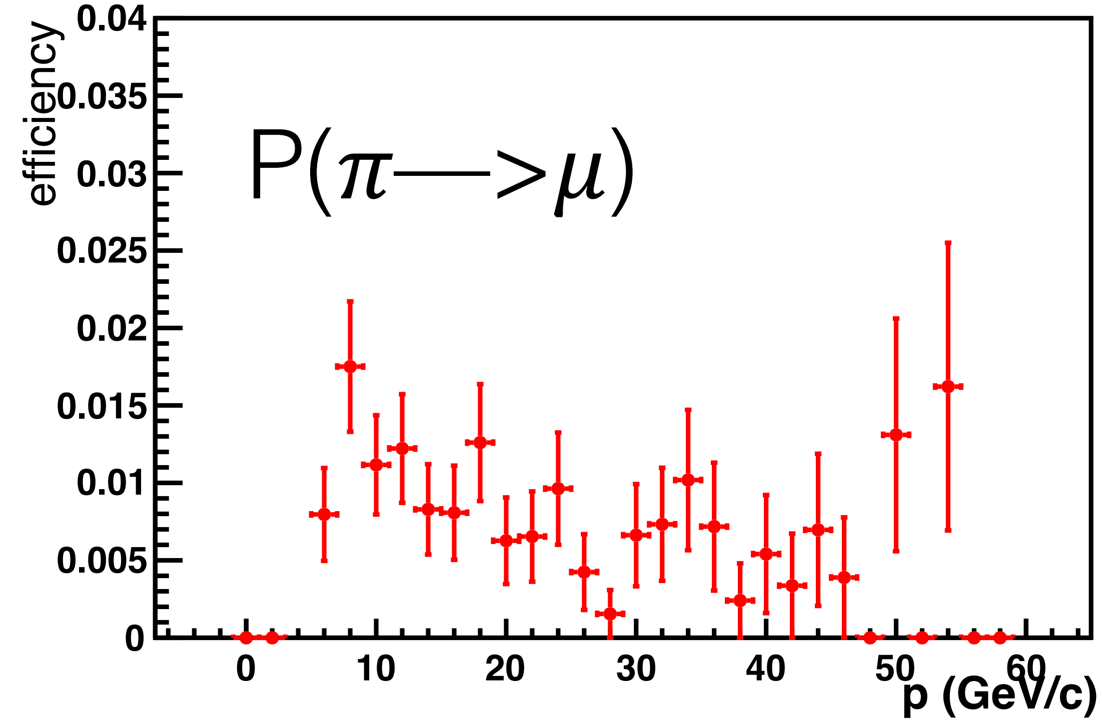
ECAL response studied with FairSHiP MC

HCAL detector optimised stand-alone (not in FairSHiP)

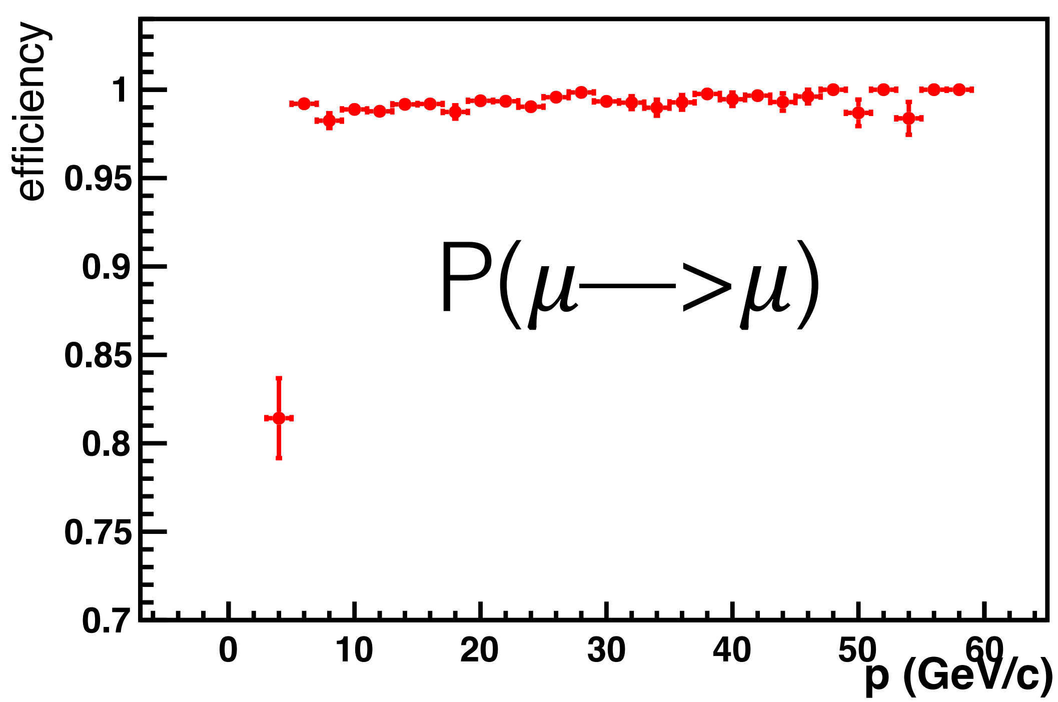
MUON detector NOT optimised but simulated in FairSHiP with HCAL in front ($6.2\lambda_I$)

Beware: hadronic shower response in MC not completely reliable





Performance on non-decaying pions of the MUON detector



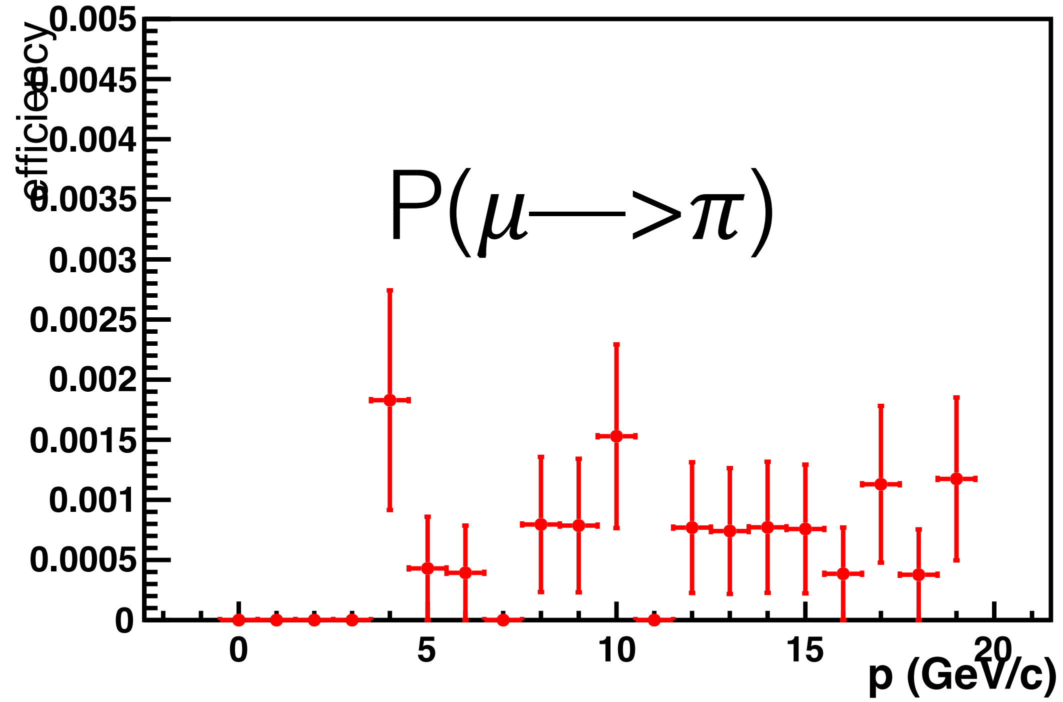


Table 4.8: Pion suppression factors and pion misidentification probabilities at 95% muon identification efficiency, achieved by ECAL $\oplus$ H1$\oplus$H2 in the current geometry.

Track momentum (GeV/c)	1	1.5	2	2.7	3	5	10
π suppression factor	23	32	50	120	160	210	250
π misidentification probability (%)	4.3	3.1	0.20	0.83	0.63	0.48	0.40

HCAL and ECAL combined

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-SHiP-NOTE-2016-CDS number
July 23, 2017

Particle Identification tools and performance in the SHiP Experiment

Behzad Hosseini[1] and Walter Bonivento[1]

[1] INFN Cagliari

Abstract

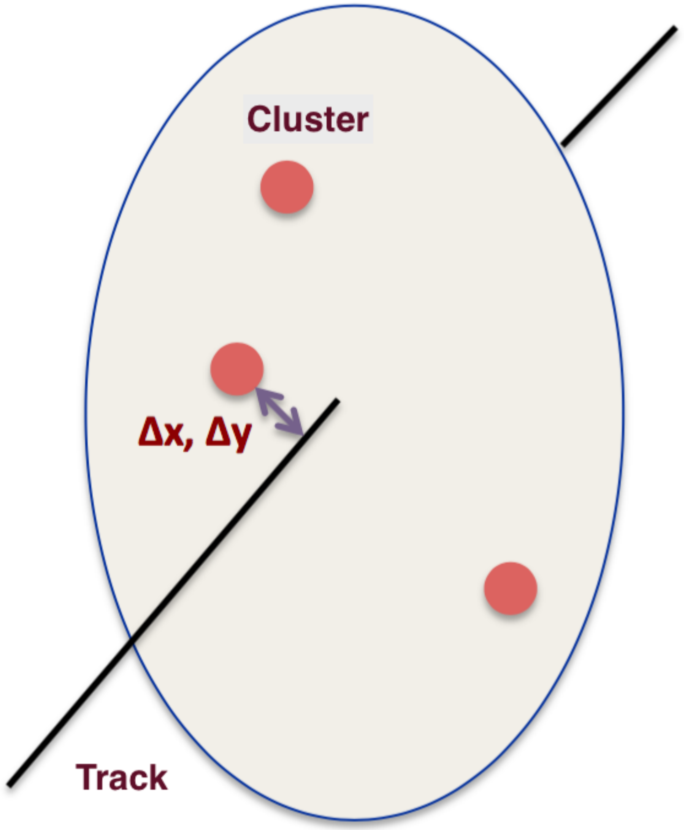
This note describes in detail the implementation and performance of the PID algorithm in the FairSHiP simulation.

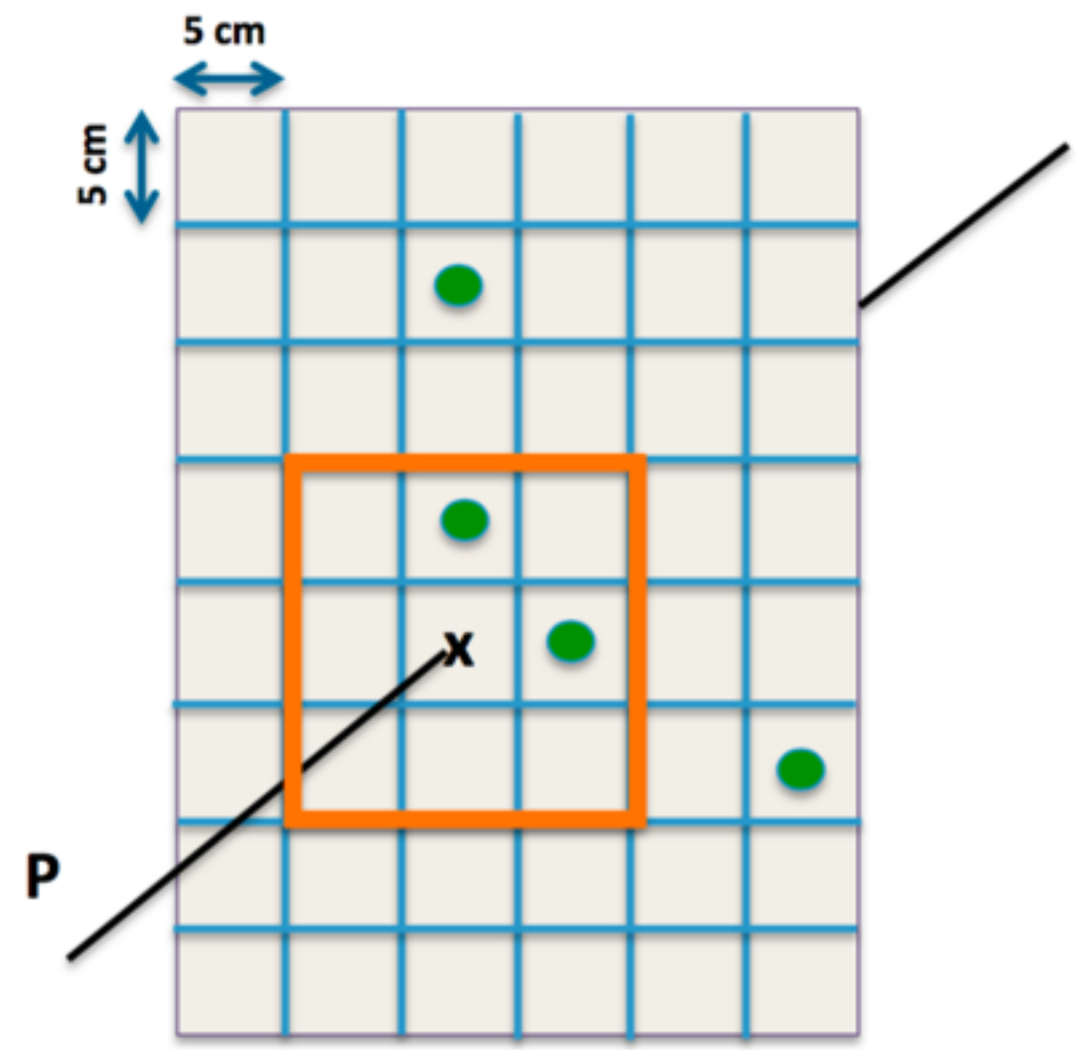
Post-TP performance studies with FairSHiP

PID software implemented in FairSHiP

- A new 30000 events are generated with the last updated FairShip using pythia8.
  - μμ, ee, ππ, μπ, πe, μμυ, eeυ, μeυ
- Following cuts aplied:
  - 1 HNL candidate
  - Vertex and tracks are in the fiducial volume
  - N.d.f > 25
  - DOCA < 1 cm
  - X^2 / n.d.f < 5
  - $P_{\text{Daughters}}$ > 1 GeV
  - IP cut: 2boddy (<10), 3boddy (>10 & <250)
  - No particle out of the acceptance of the PID detectors

24/11/2016 9th SHiP Collaboration Meeting - Behzad





ECAL/HCAL cuts (position extrapolated at shower max)

Δx,Δy and E/p (for e- should be around 1)

MUON detector cuts: Δx,Δy ,#hits, penetration

All cuts momentum dependent

for p<5 Gev check HCAL penetration and consistency with mip

PID with signal channels: HNL, Dark Photon

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
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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%**

1GeV

400MeV

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pion decays in flight

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charge exchange reaction (can occur at any depth) et al. (in MC they are seen as true e-)

the other mis-id's depend are due to overlapping tracks in CALO's

Why evolving compared to TP?

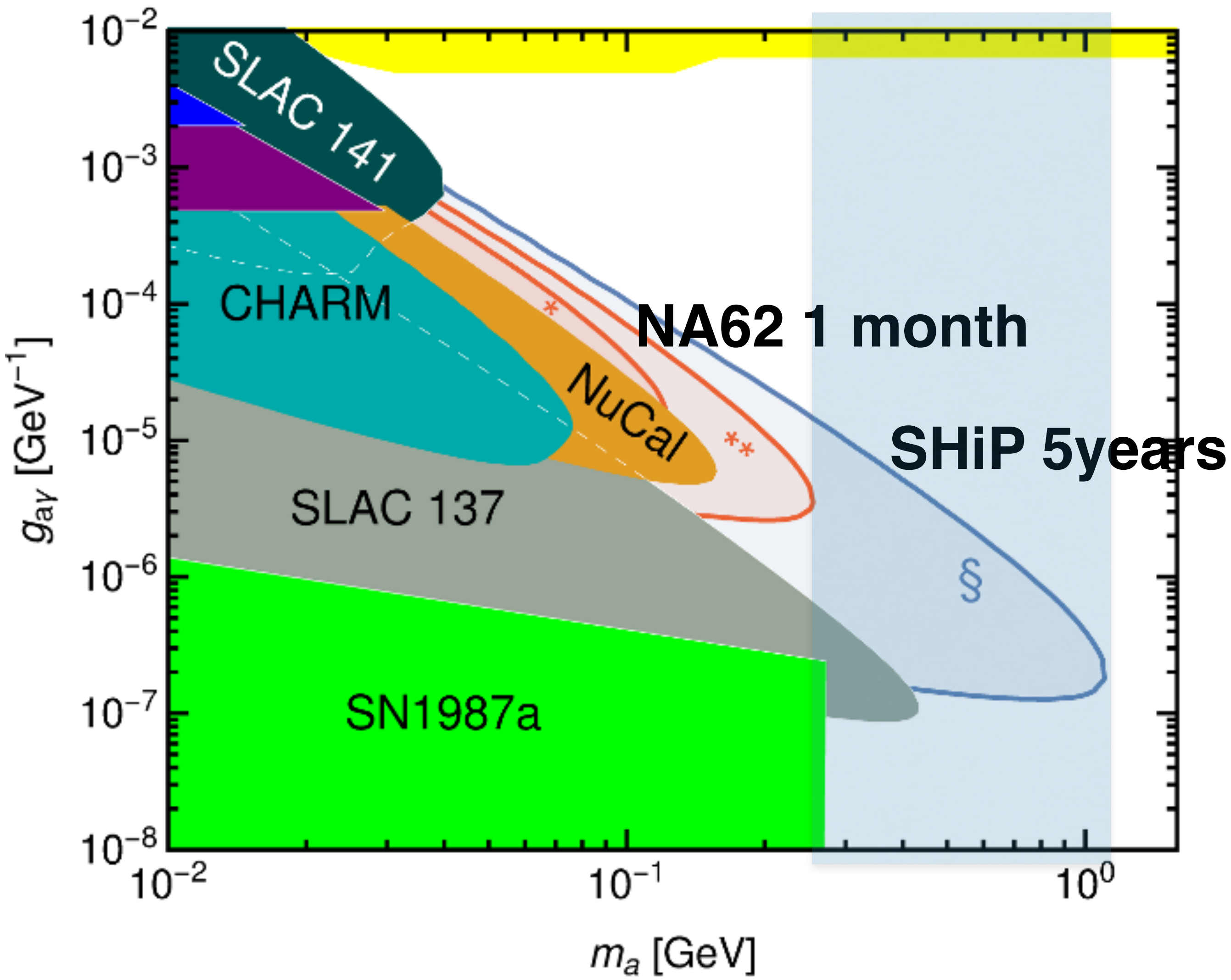
1) reduce possibly cost of Shashlik
2) add the measurement of shower direction for neutral final states (need few mrad resolution for ALP—>γγ) and possibly suppress background
3) improve e/π separation

of course it is a 5x10 m^2 guy (or lady)…

Search for

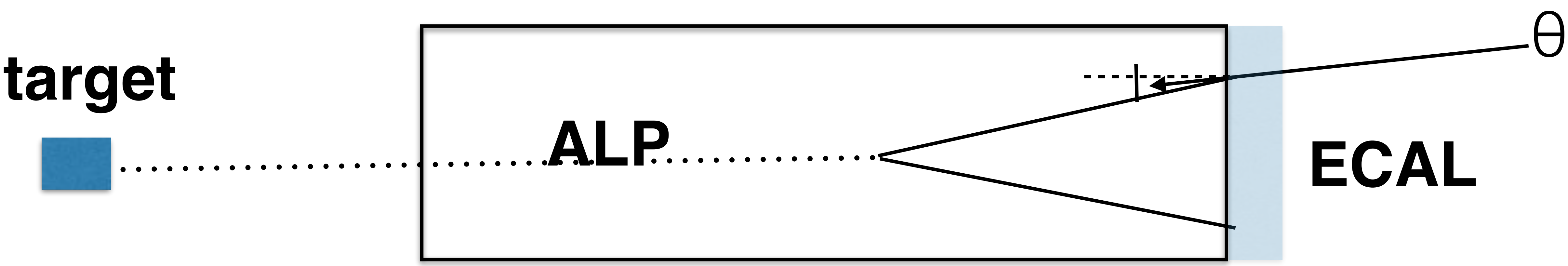
ALP—>γγ

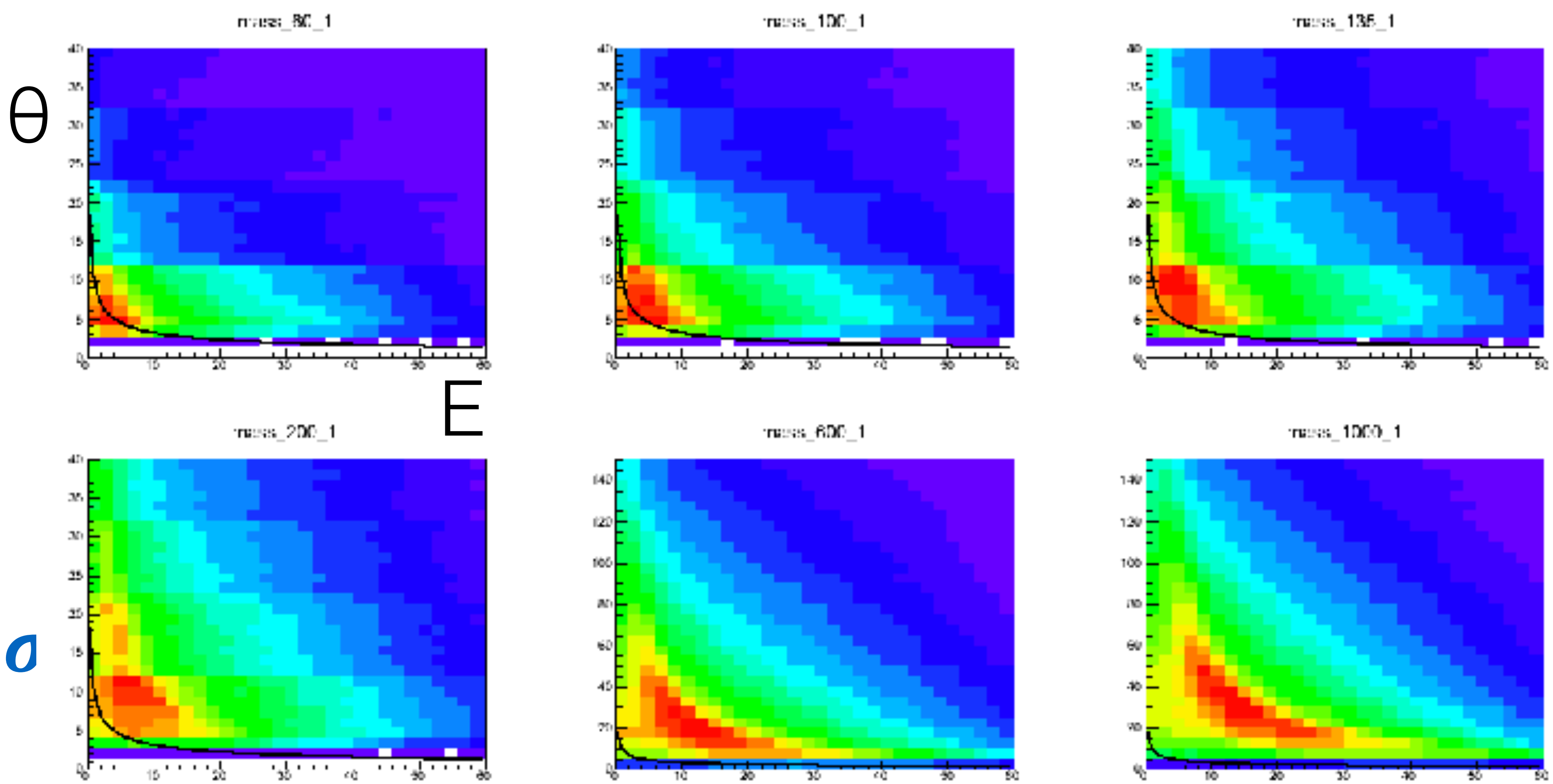
JHEP 1602 (2016) 018



300MeV-1GeV

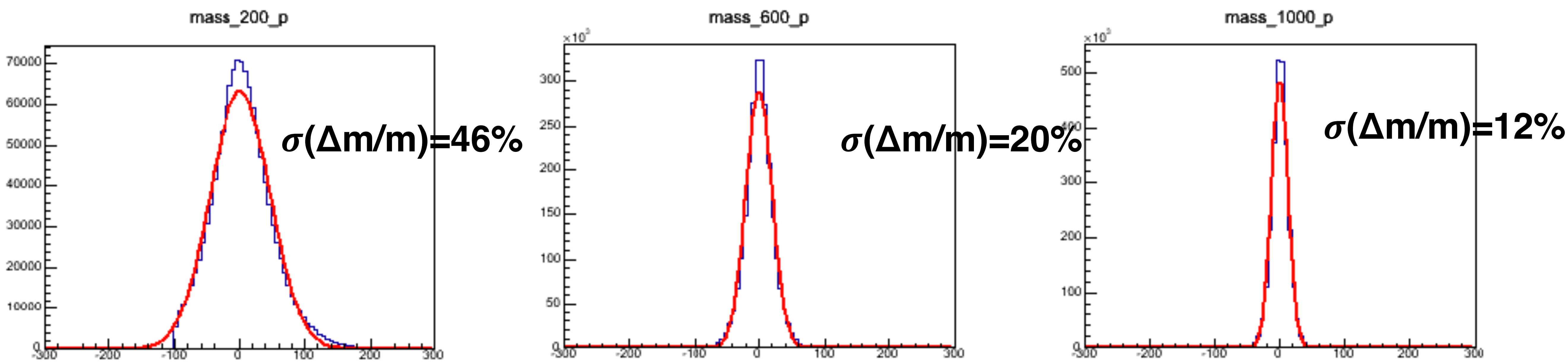
ANGLES


target
ALP
ECAL
θ


mass_80_1
mass_100_1
mass_135_1
mass_200_1
mass_600_1
mass_1000_1
θ
E
σ

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)?



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

The measurement of the shower direction

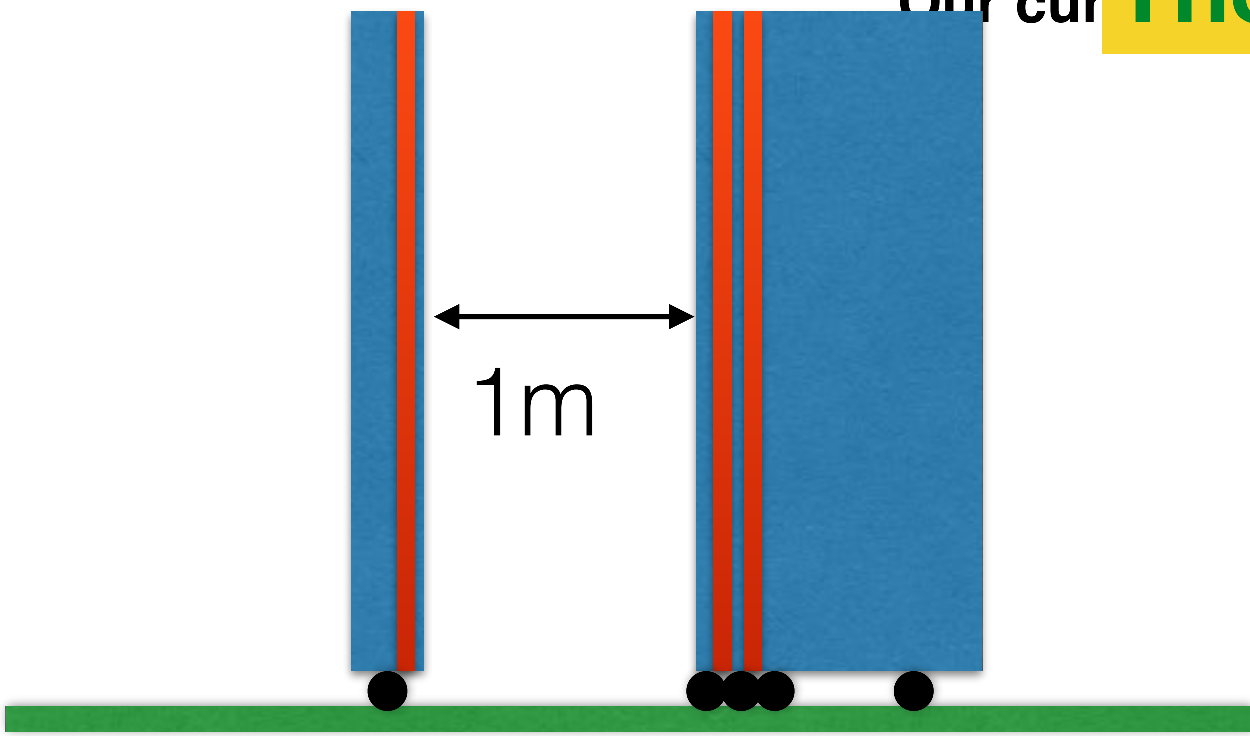
This is not a completely new subject:

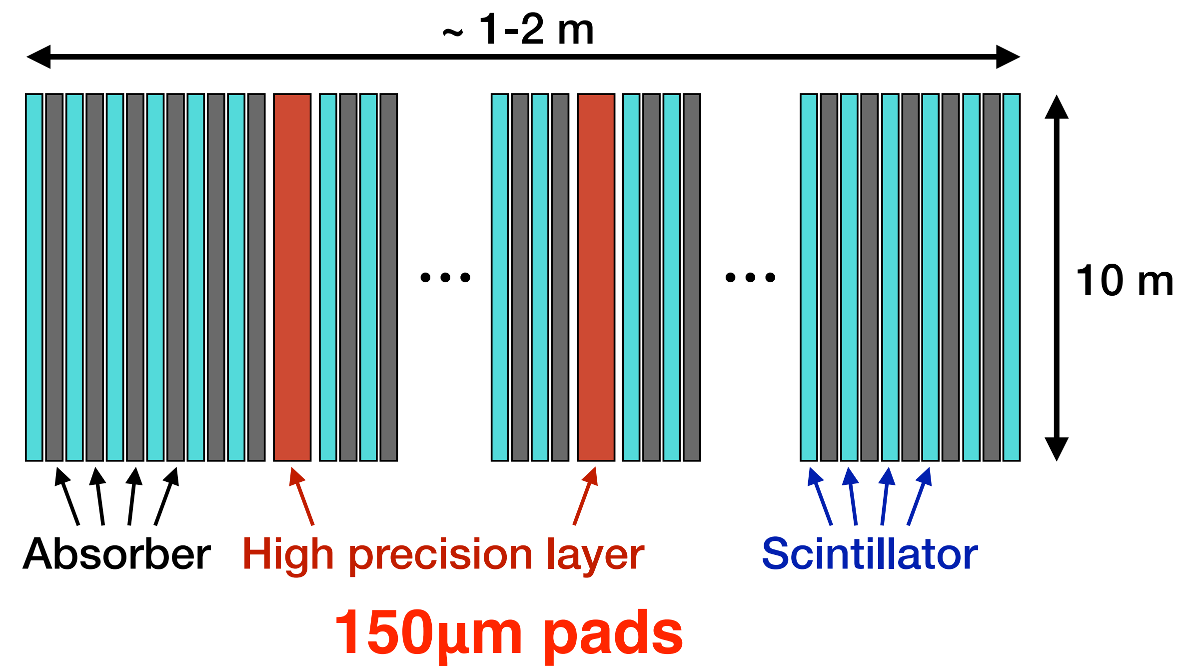
- e.g. ATLAS, though in one direction only (η)
- γ-ray experiments (e.g. FERMI) in space can measure it with high precision but very low efficiency (here we need full efficiency)

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

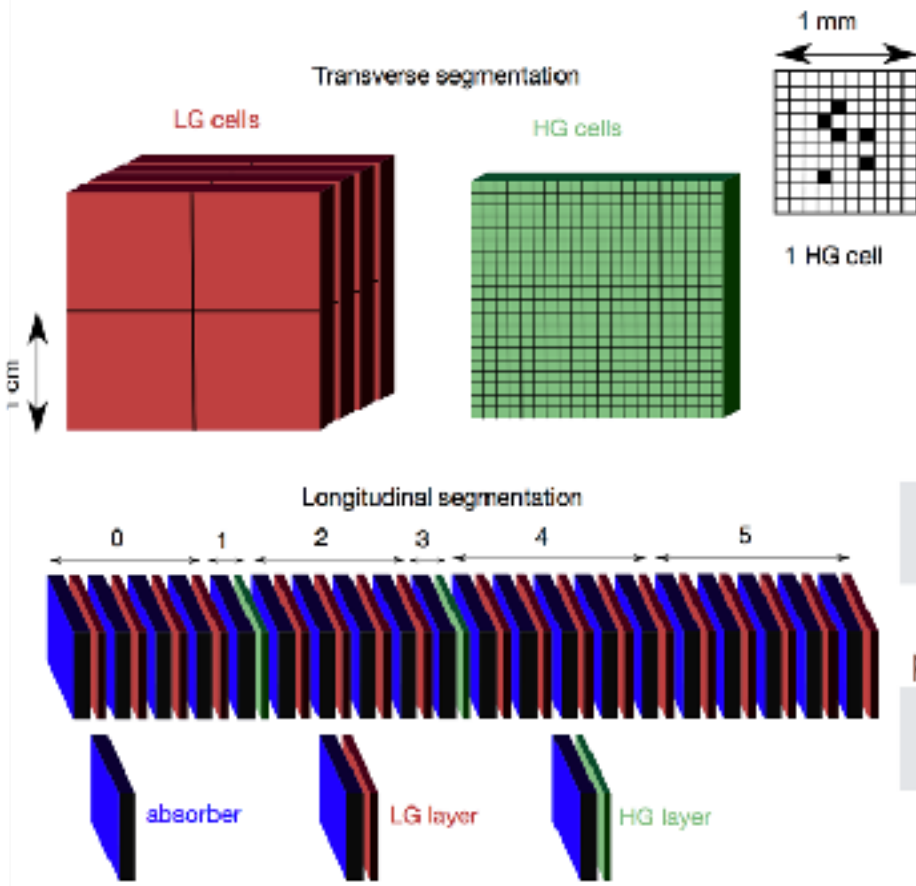
in blue a sampling ECAL with X-Y plastic scintillator bars readout via WLS fibres from the sides, coarse granularity

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

Some analogy: an ECAL with high precision layers

FoCal Strawman Design

T.Peitzmann, CHEF 17



studied in performance simulations:

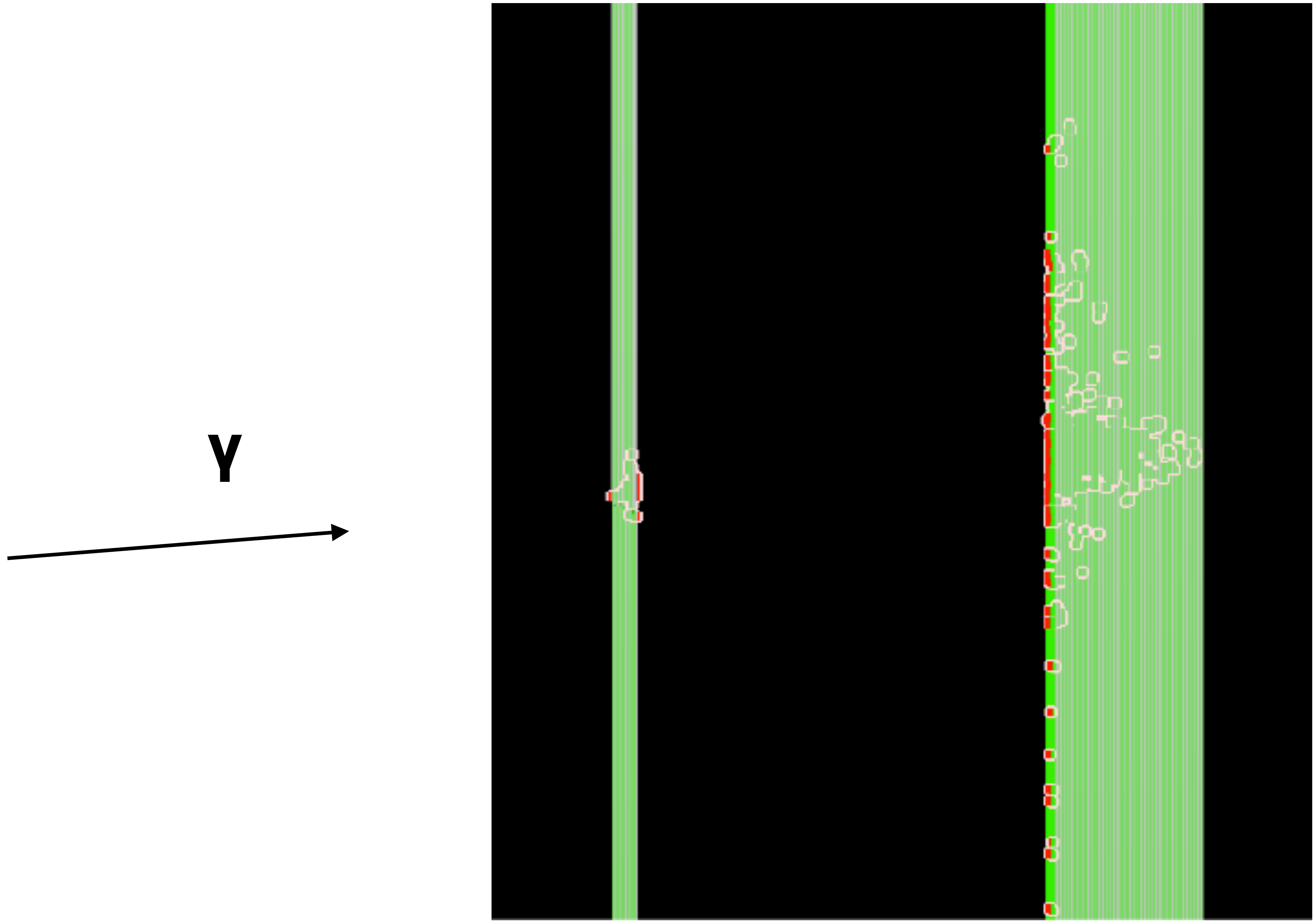
20 layers: W (3.5mm ≈ 1 X0) + Si-sensors (2 types)
low granularity (LG), Si-pads
high granularity (HG), pixels
(e.g. CMOS-MAPS)

	LG	HG
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9
readout channels	≈ 5 x 10^4	≈ 2 x 10^6

assuming ≈ 1m^2 detector surface

ALICE upgrade proposal

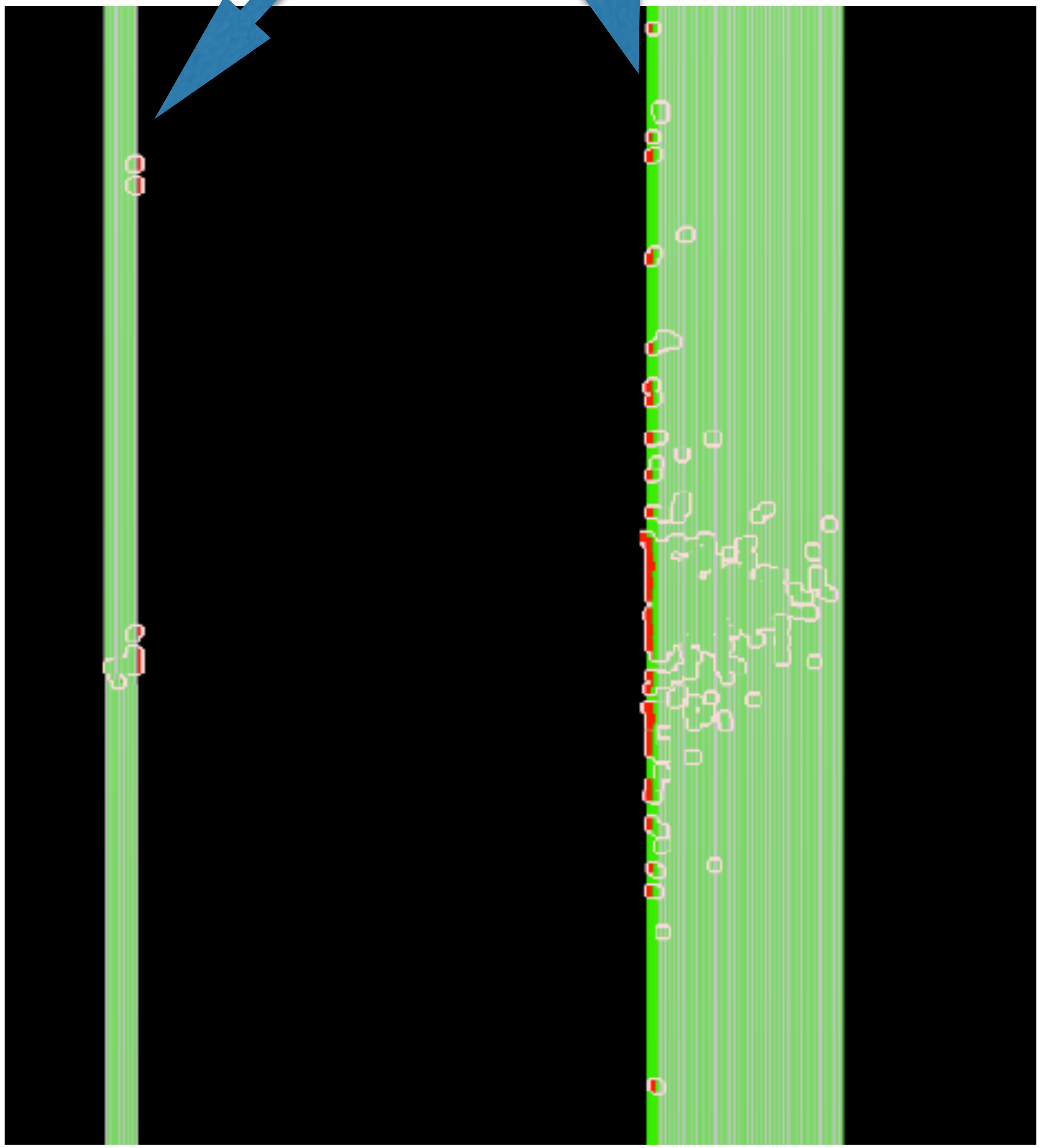
20 GeV γ generated in the yz plane with 100mrad angle and z=20m upstream of the ECAL surface

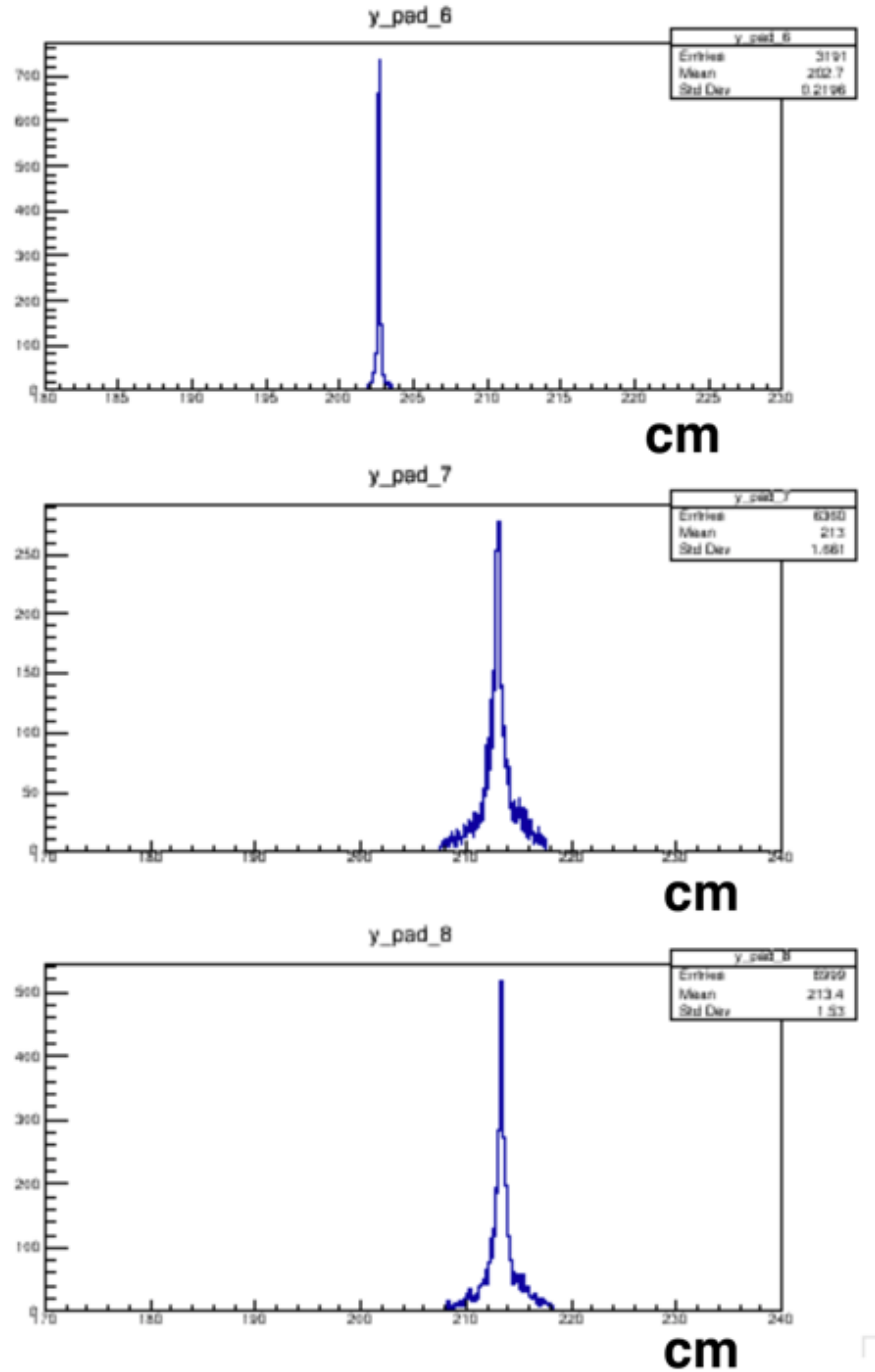


satellites

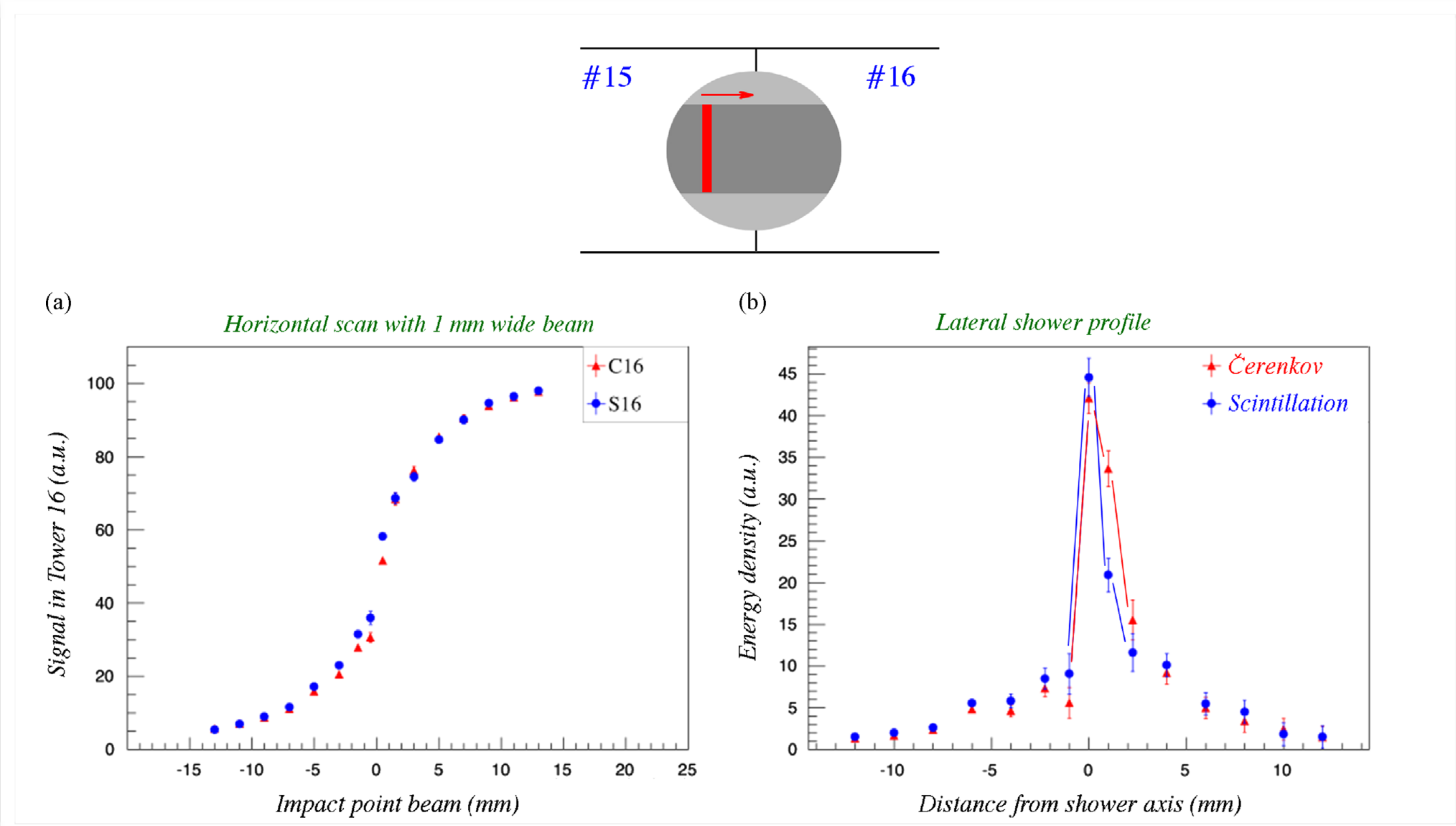
a well-known problem!

γ





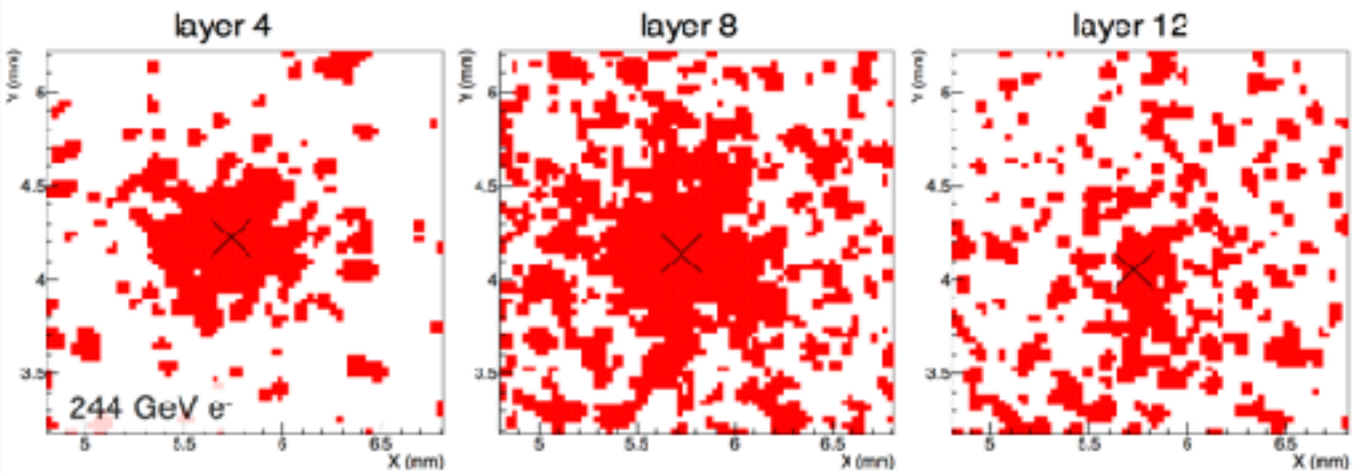
cumulative shower profiles in the three high precision layers (after a iterative cut on satellites)



DREAM ECAL
N. Akchurin et al. / Nuclear Instruments and Methods in Physics Research A 735 (2014) 130–144

wide band 100GeV beam with 1mm sliver
exploit narrow core for angular resolution!

Single Event Hit Distribution

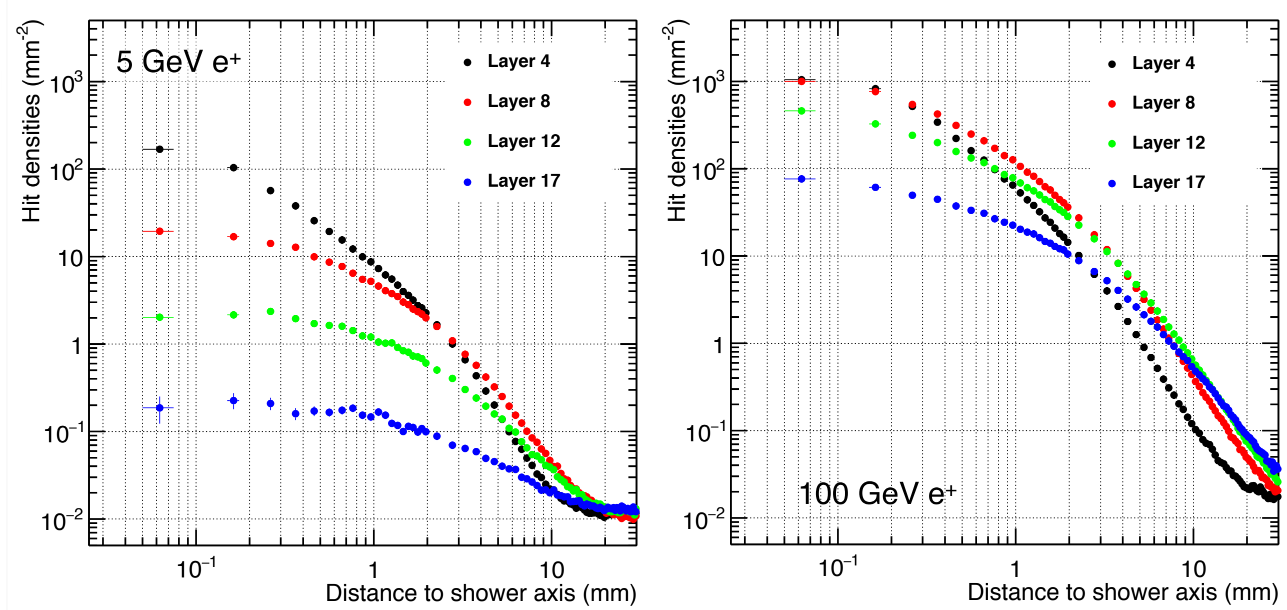


very high hit density in shower core

- not possible to reconstruct single shower particles from pixel clusters
- have to use number of hits as response (not number of clusters)
- saturation (overlap of clusters) likely for very high energy

T.Peitzmann, CHEF 17
ALICE

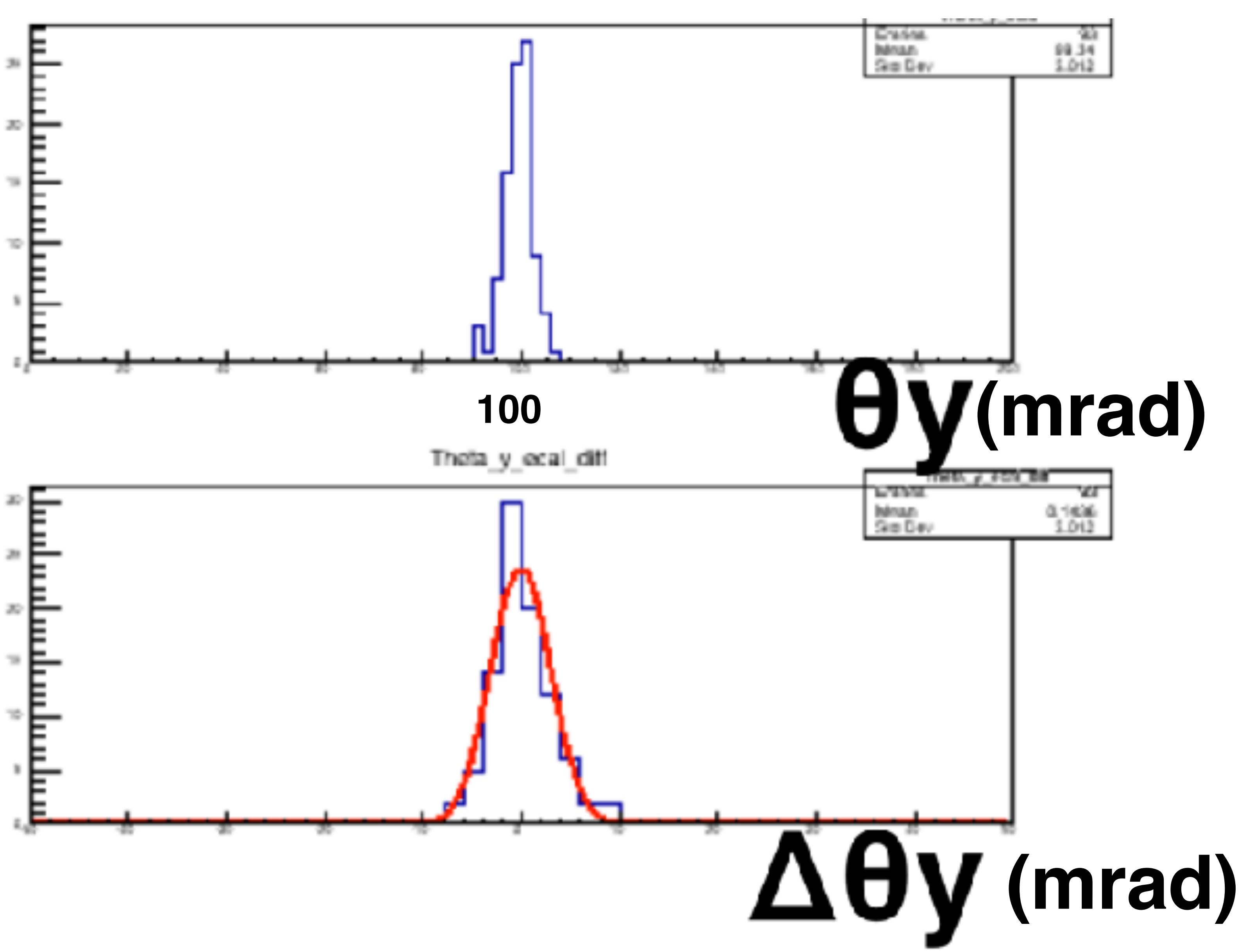
R&D - Lateral Profiles



average hit densities as a function of radius $\frac{dN_{\mathrm{hit}}}{dA}(r)$ for different layers

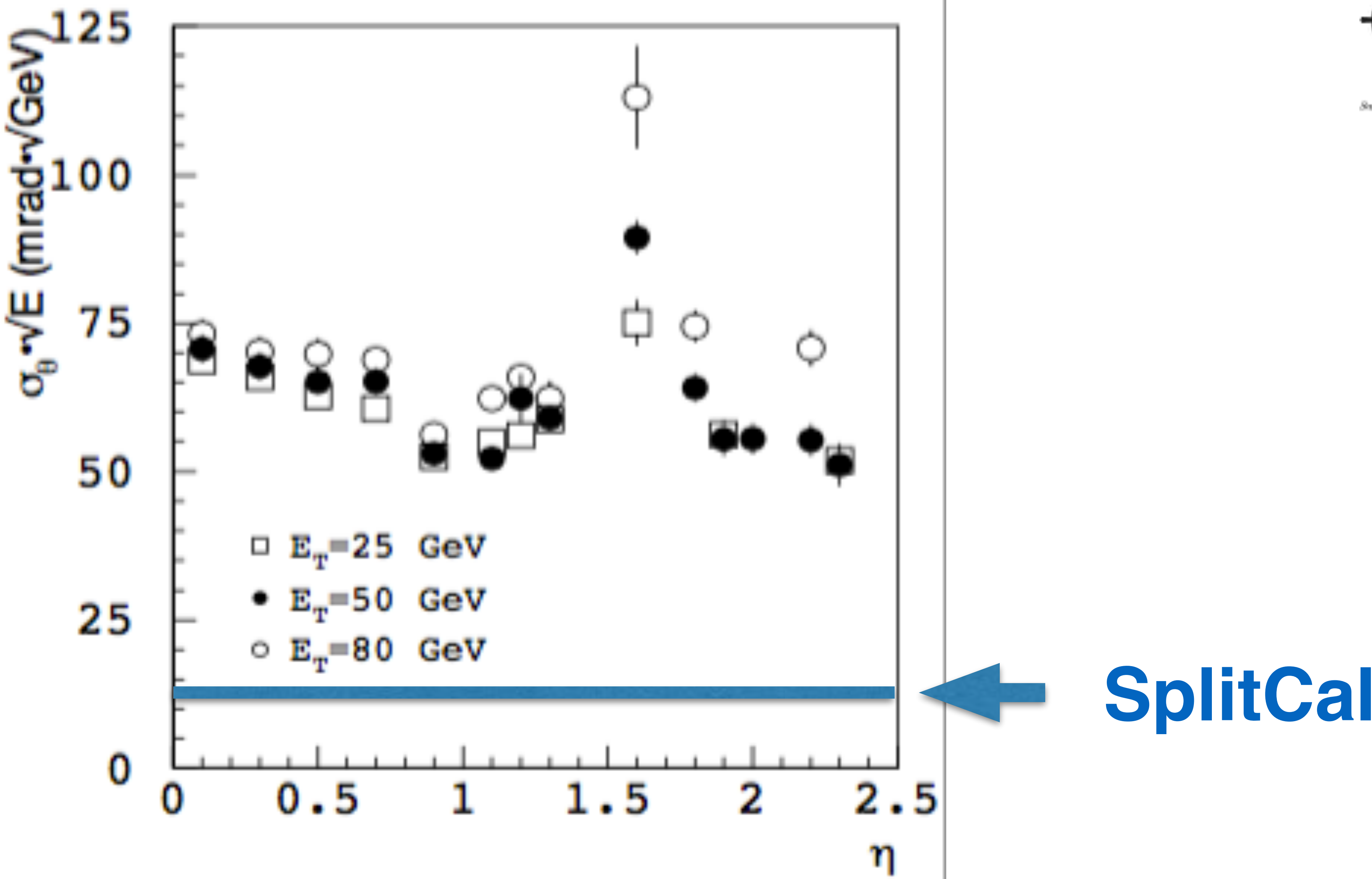
- low energy: early shower maximum, profiles broaden and decay with depth
- high energy: profiles broaden with depth, increase up to shower maximum

shower measurements with unprecedented detail!



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)



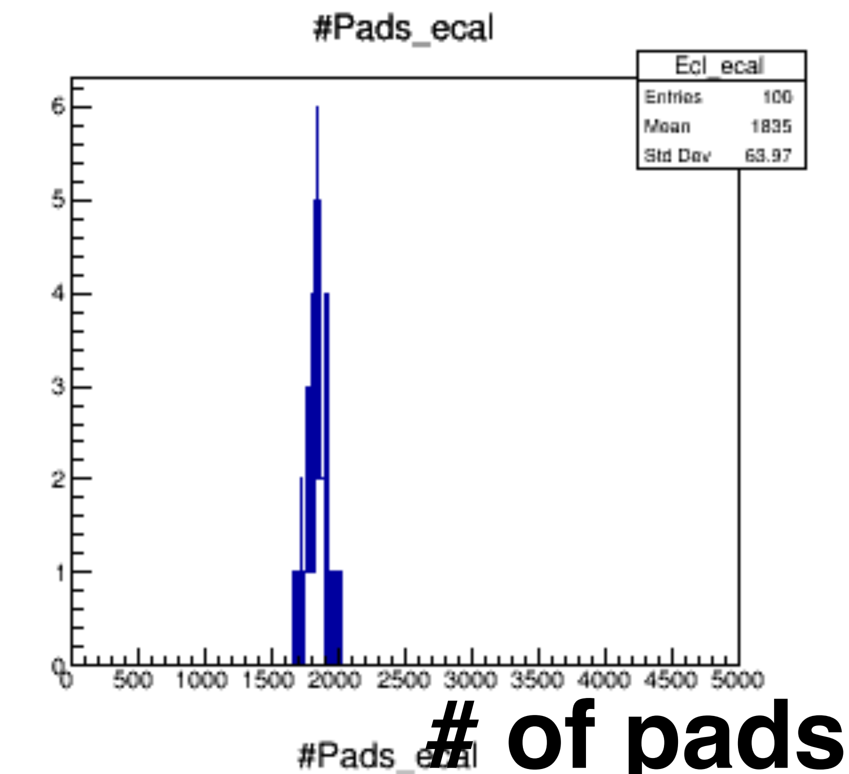
as a comparison: ATLAS ECAL performance TDR: in blue our result at 20GeV ; large improvement but cost of high precision layers?

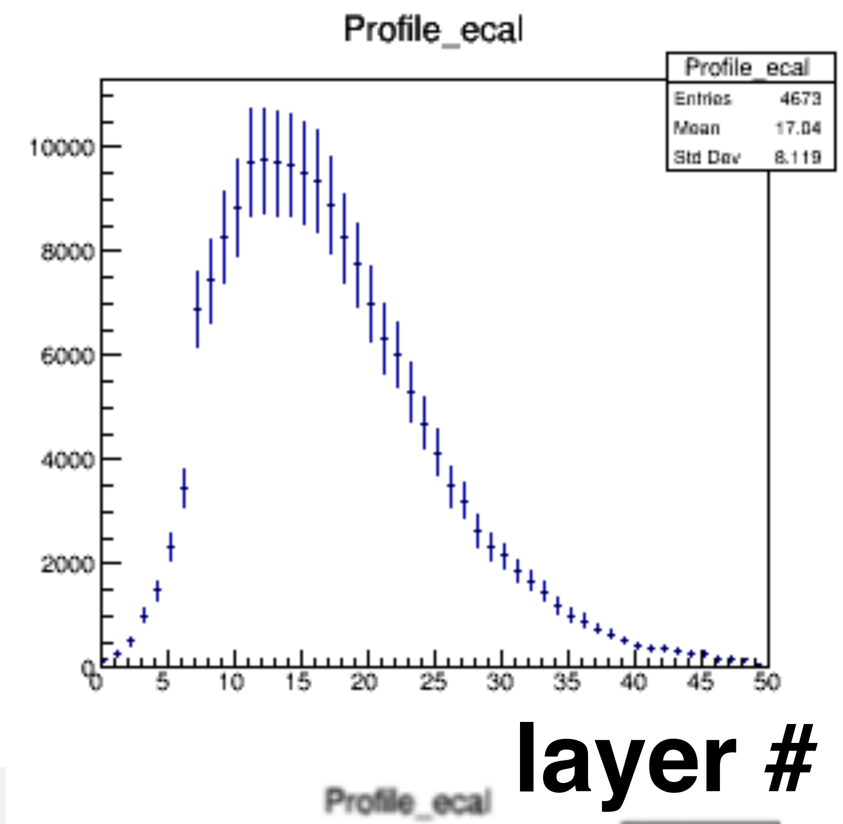
A recent estimate for 140m² (similar to our requirements) to be used in CMS of μWELLS was about 1M€ (<u>detector only</u>); readout to be added!

Energy resolution about 15%/√E

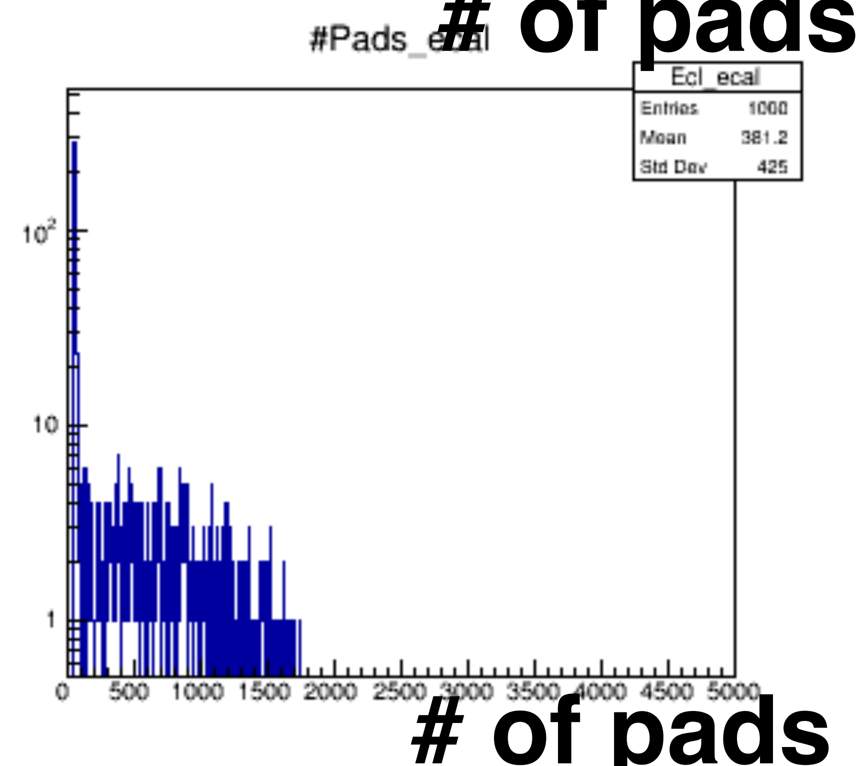
Electron/pion separation

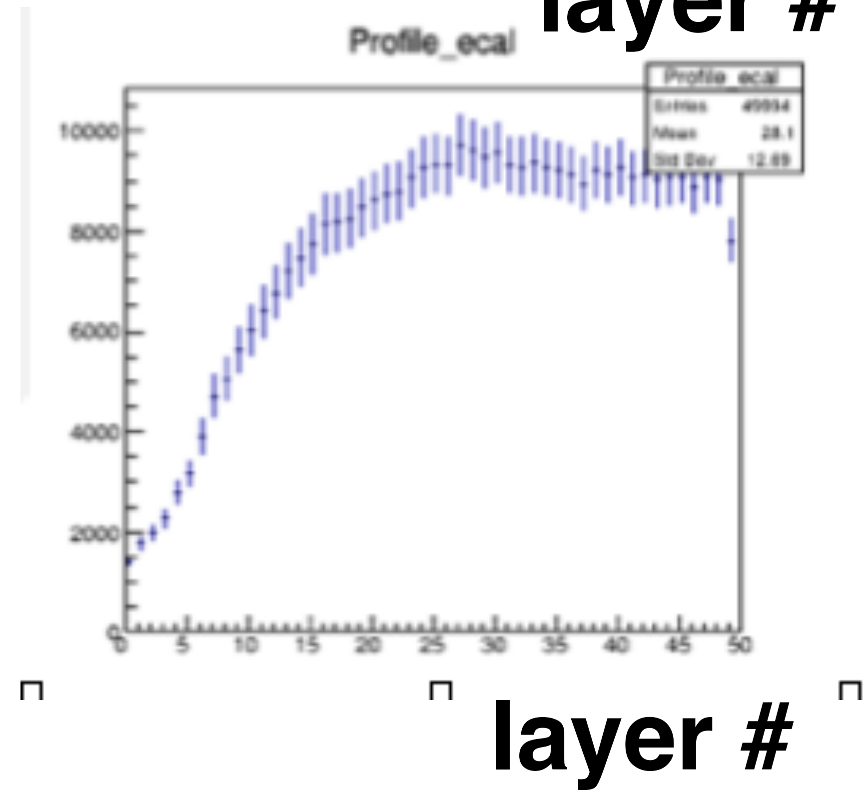
20GeV e-





20GeV π-

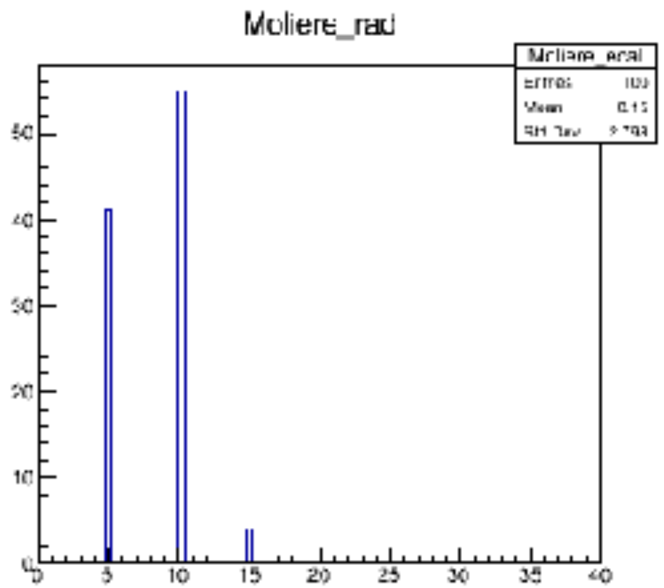




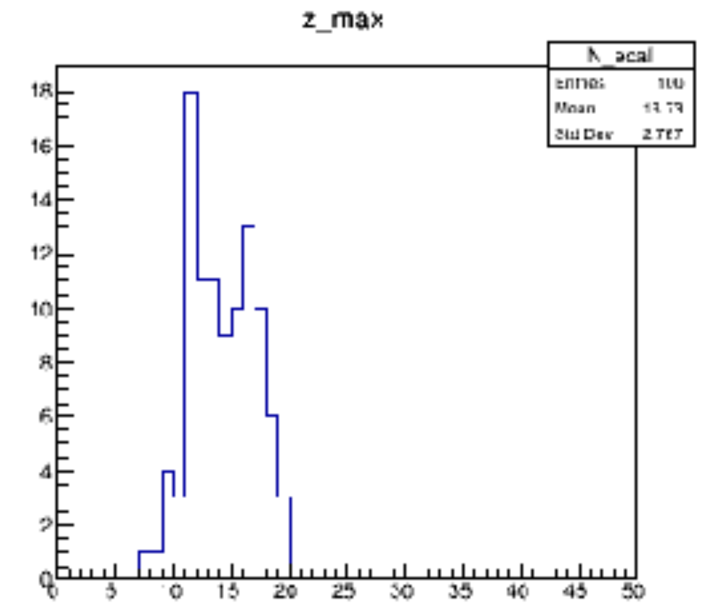
Shapes

Effective Moliere radius | postion of shower max

20GeV e-

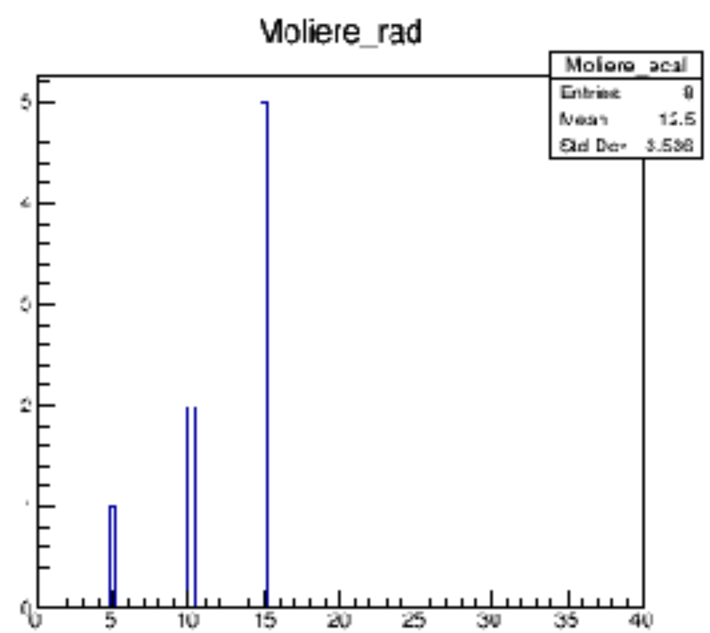


cm

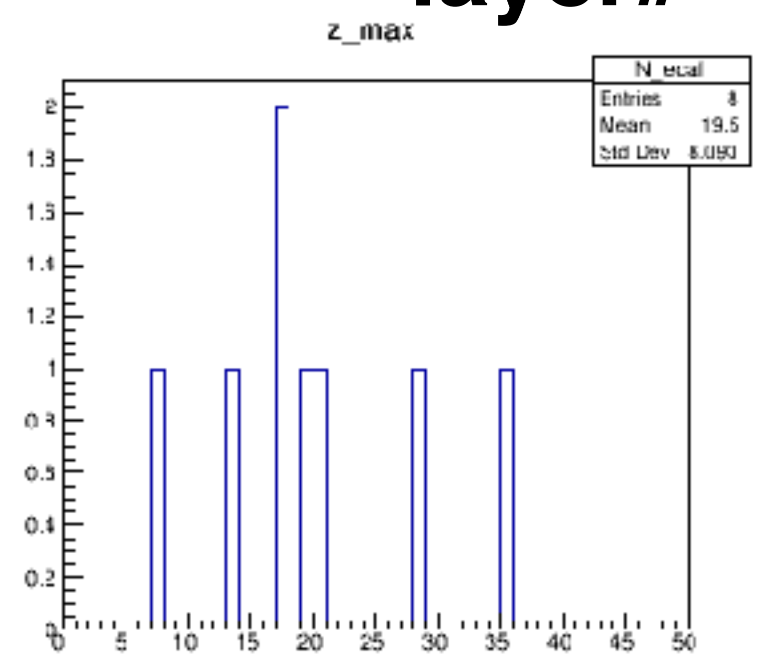


layer#

20GeV π-



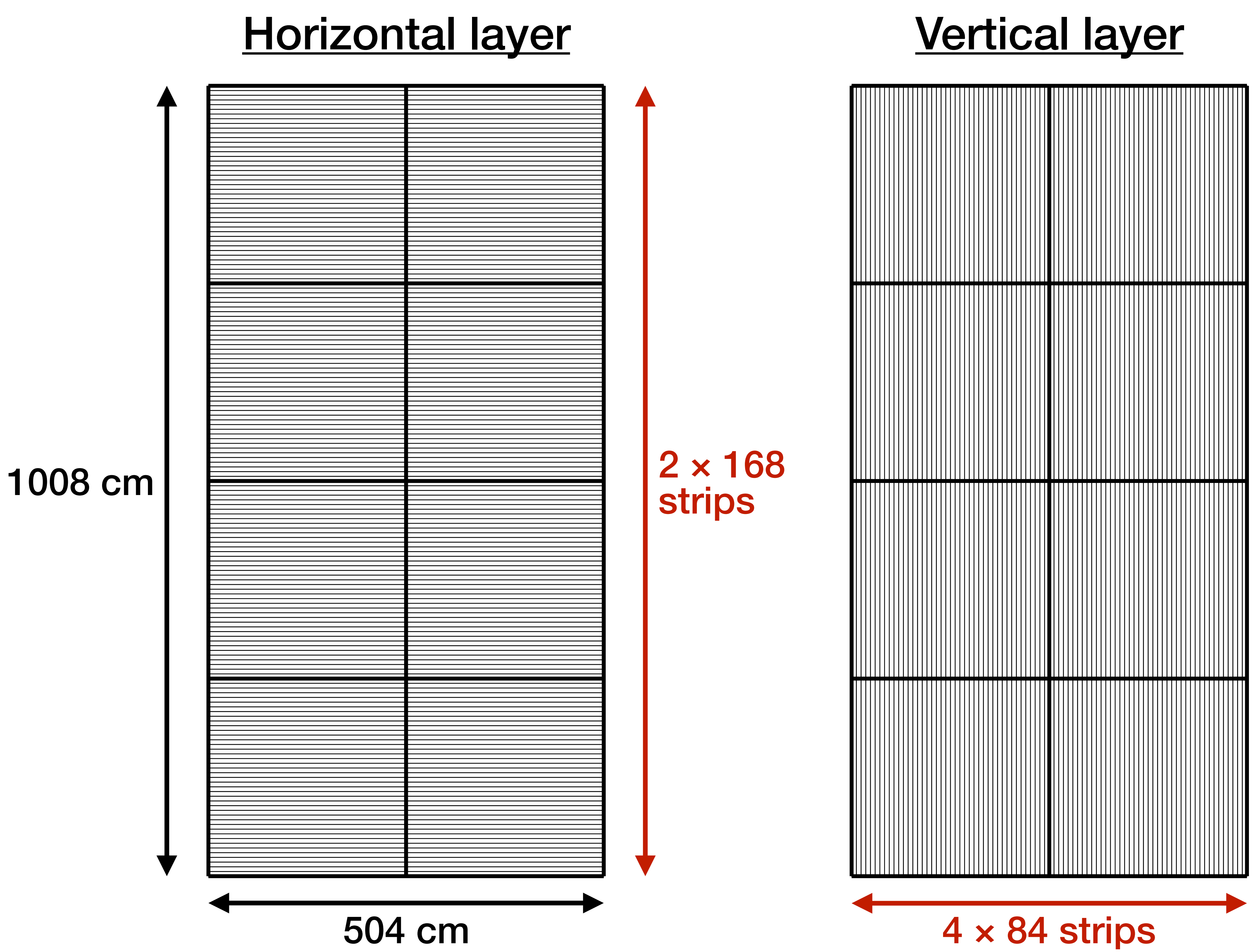
cm



layer#

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

Possible layout of scintillator layers

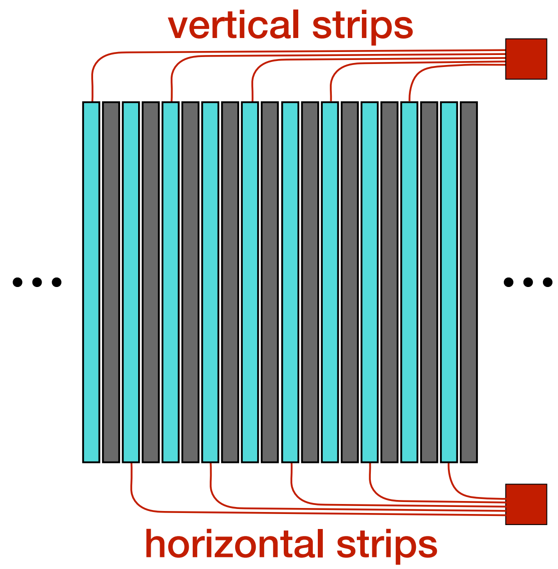


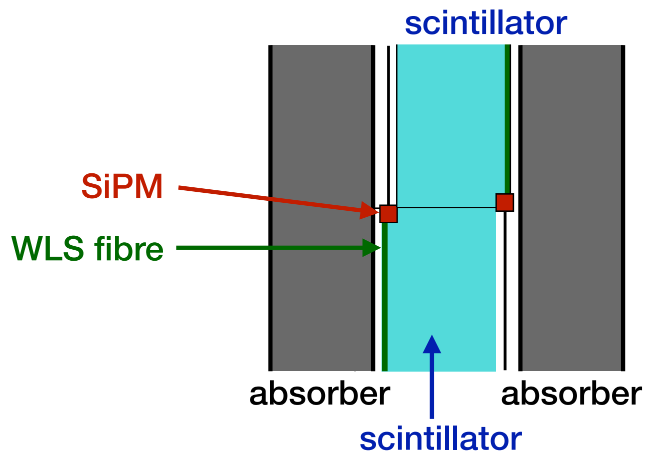
R&D

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 in plates?
- scintillator plane staggering

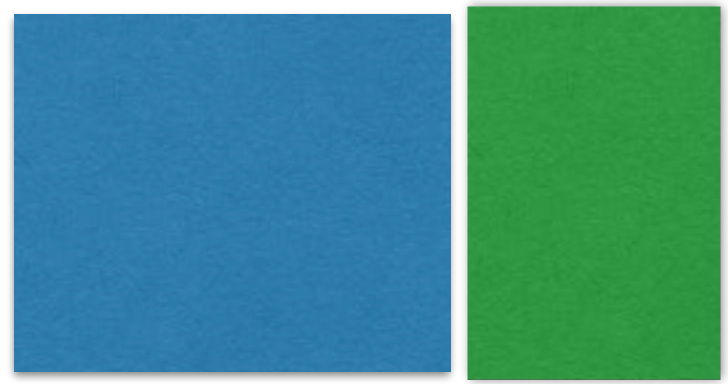
HCAL/MUON part

- detection of small deposits of hadronic energy important for suppressing background in ALP—>γγ

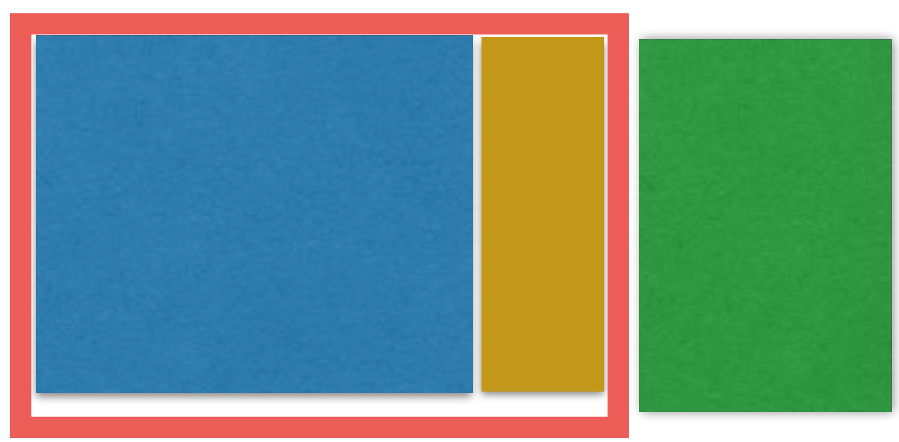
- pion id to low momentum

need to study this in the next 2 months

Either



or to instrument the first absorber ($6\lambda_I$) of the MUON detector in a similar way, with a sampling structure, with Iron but coarser sampling fraction than the MUON detector



need simulation to validate it

The choice may also depend on ECAL choice (if segmented longitudinally or not)—> optimised together

Conclusions

A lot of simulation and technical design work ahead of us

—> decision of HCAL feasible in a couple of months <u>of work</u>

—> new ECAL challenging but very interesting

ν-induced background

Doca<1 & 10 < IP < 250

VETO on =SBT+upstream veto+muon detector of neutrino detector

'otal events from Iaroslava: 249
Ve remain with 128 events.

Accepted Invariant mass: **InvMass<10GeV**

To scale to 2e20 pot divide by 8.3 for Air and 66.4 for He

Most of the **μπ** events have rejected due to the IP>10

10 < IP < 250 cm
(as for N→μμυ)

	μ-μ IP>10	e-e IP>10	μ-e IP>10	μ-π IP>10	π-π IP>10
Rec	3	1	11	105	8

$N_{air} = 1.8$
$N_{helium} = 0.22$

if vacuum =10^{-3} bar, background=0.016 events even without PID; NB: these are the neutrinos only

Doca<1 & 10 < IP < 250
VETO off

Total events from Iaroslava: 2756
We remain with 1117 events.

To scale to $2e^{20}$ pot divide by 8.3 for Air and 66.4 for He

Accepted Invariant mass: **InvMass<10GeV**

Most of the **μπ** events have rejected due to the IP>10

10 < IP < 250 cm
(as for N→μμυ)

	μ-μ IP>10	e-e IP>10	μ-e IP>10	μ-π IP>10	π-π IP>10
Rec	14	14	37	746	278

$N_{air} = 7.83$
$N_{helium} = 0.98$

if vacuum =10^{-3} bar, background=0.13 events without any PID;
these are the neutrinos only—> not good enough!
a very modest PID would do the job (say factor 10 suppression)

in this no VETO situation, 10^{-4} bar would mean no background or 10^{-2} bar with factor 100 PID suppression; we are very redundant!