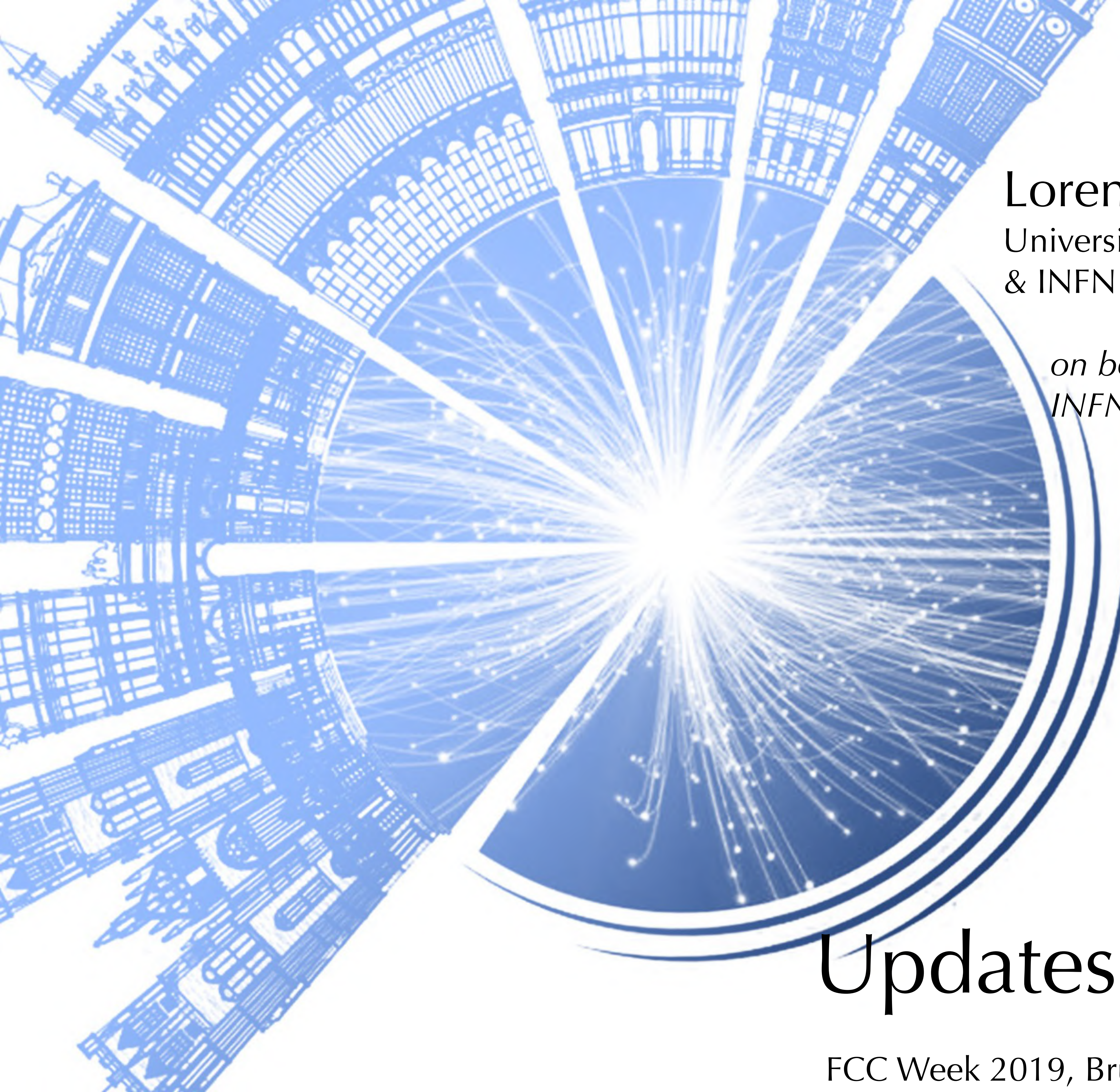


Lorenzo Pezzotti
Università degli Studi di Pavia
& INFN

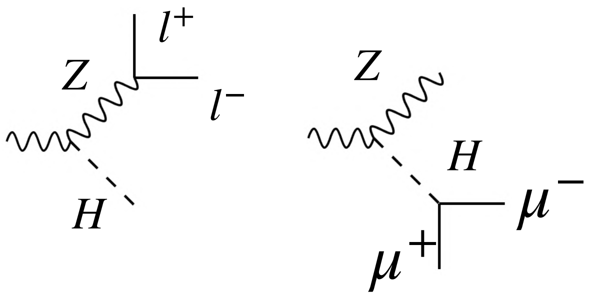
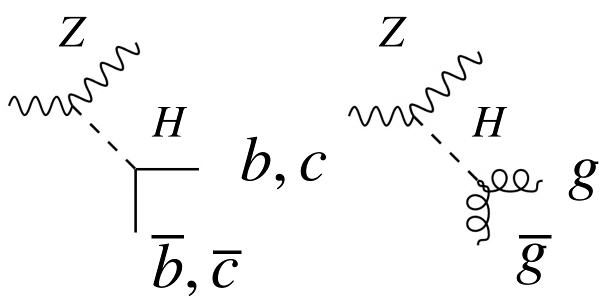
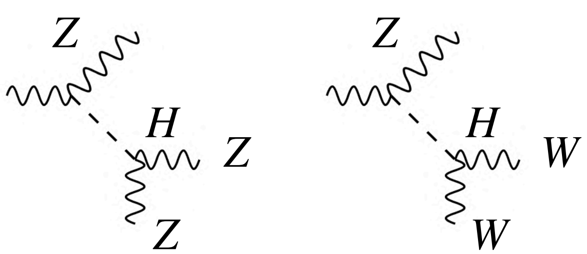
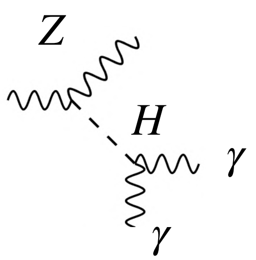
on behalf of the
INFN RD_FA Collaboration

Updates on IDEA

FCC Week 2019, Bruxelles 26/6/2019

FCCee physics drivers

- Higgs physics

	To measure	Critical Detector	Required Performance
	Higgs mass, Cross section	Tracker	$\Delta(1/p_T) \simeq 2 \times 10^{-5} \pm 1 \times 10^{-3}/(p_T \sin\theta)$
	Branching ratios	Vertex	$\sigma_{r\phi} \simeq 5 \pm 10/(p \sin^{3/2}\theta)\mu m$
	Branching ratios	Calorimeter (ecal + hcal)	$\sigma/E_{jet} \simeq (30-40)\,\%/\sqrt{E}$
	Branching ratio	Calorimeter (ecal)	$\sigma/E_{\gamma} \simeq 16\,\%/\sqrt{E} \pm 1\,\%$

- Z, W, top physics mostly covered with the above requirements

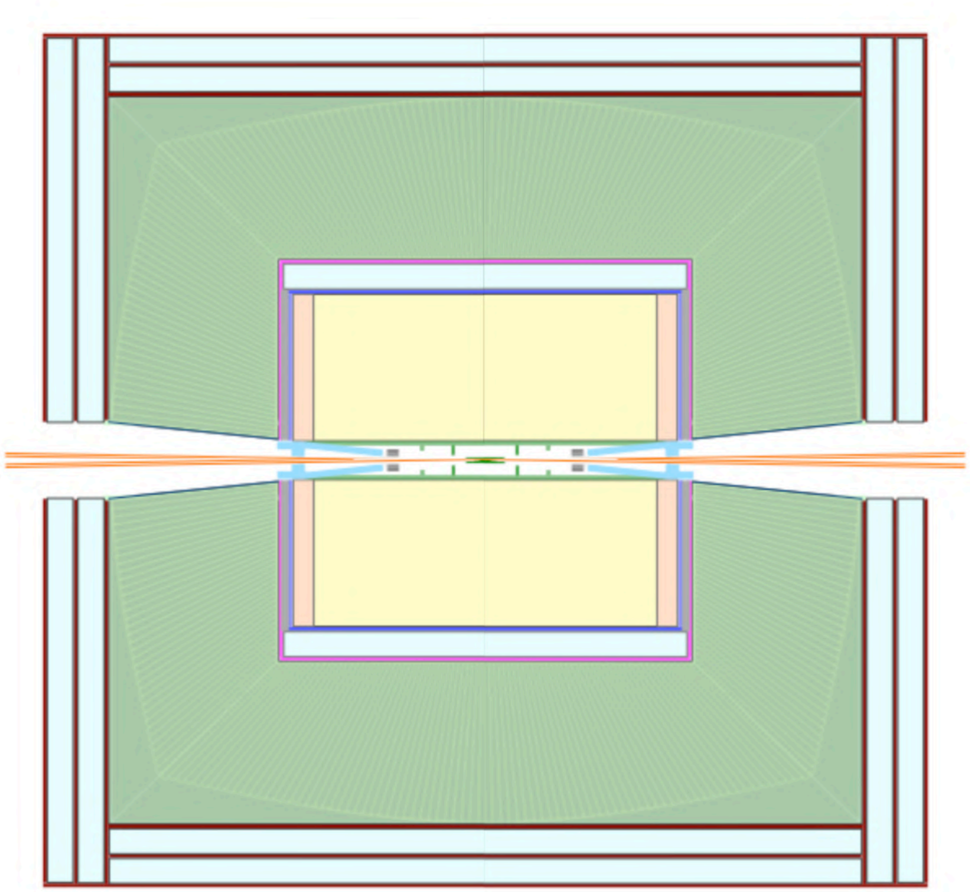
FCCee IDEA Detector

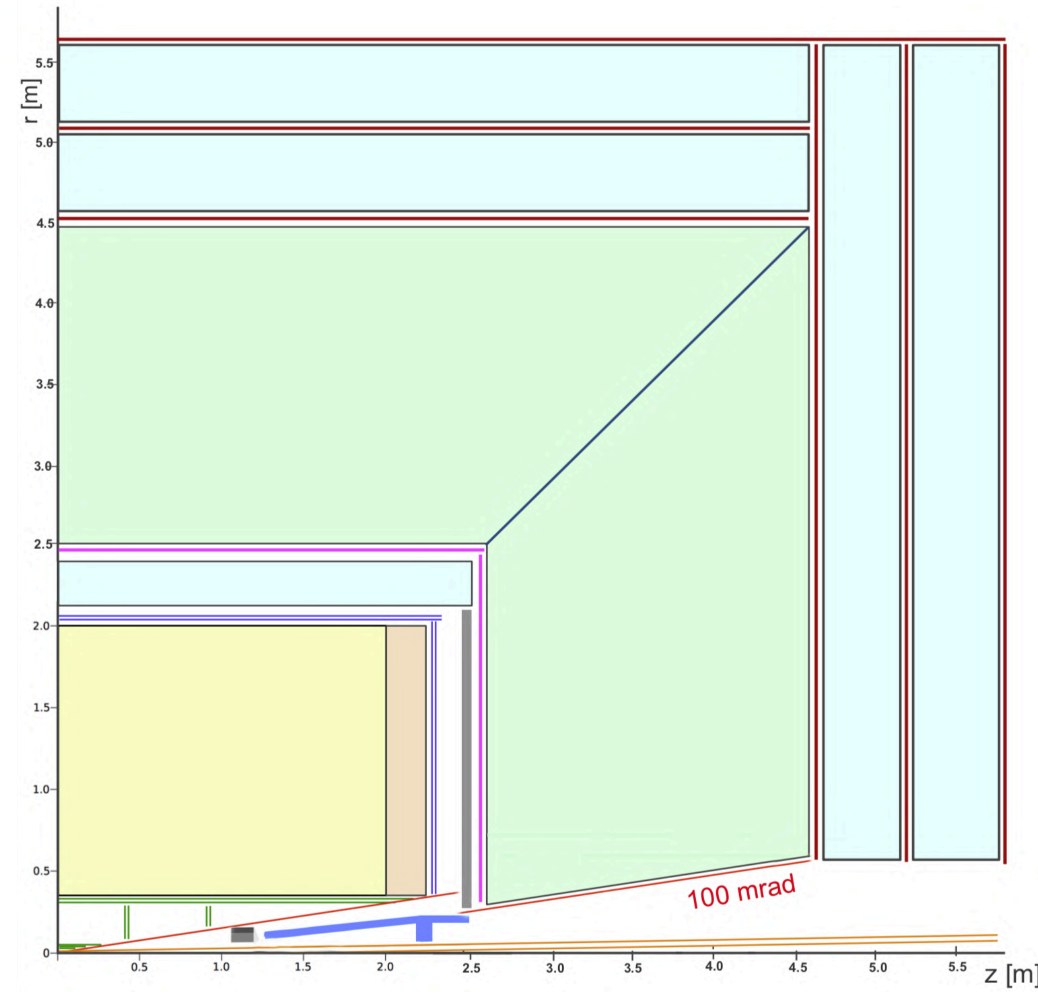
Beam pipe: r ~1.5 cm

Vertex: 5 MAPS layers
r = 1.7-34 cm

Drift Chamber: 4 m long, r = 35-200 cm

Outer Silicon Layers: strips





Superconducting solenoid coil: 2 T, r ~ 2.1-2.4 m
$0.74\ X_0$, $0.16\ \lambda$ @ 90°

Preshower: ~1 X_0 μ-RWELL MPGD

Dual-Readout Calorimeter: 2 m / 8 λ_{int}

Yoke + Muon chamber: μ-RWELL MPGD

Muon chambers

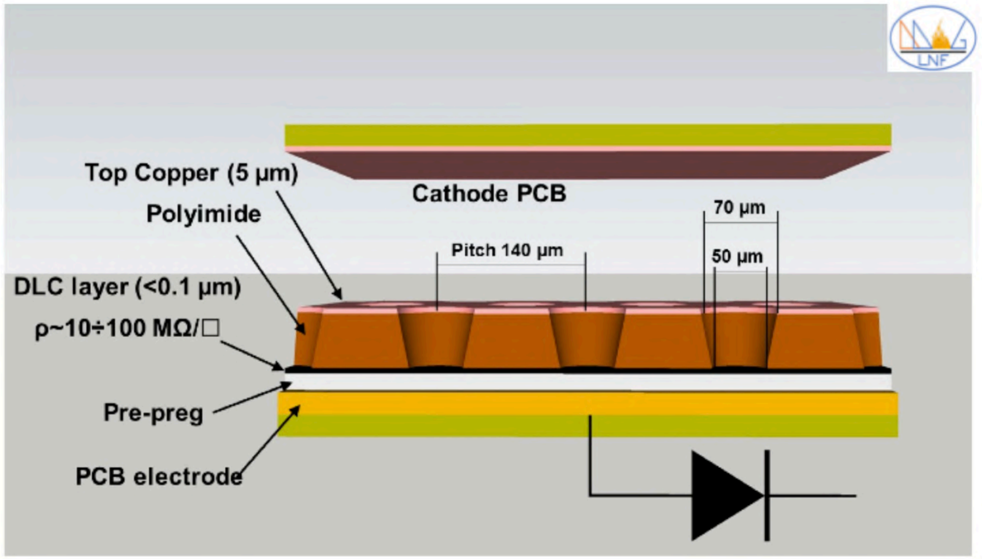
Features

- Large areas: ~77 m^2 in the barrel region, ~37 m^2 in the endcap and ~900 m^2 divided in 3 stations for the muon spectrometer (assuming 2-dimensional readout).
- High granularity preshower (for π^0 ID near charged hadrons and acceptance definition for γ @ level of μm).

MPGD Detector

- High rate capability > 1 MHz/cm^2, space resolution easily < 200 μm, signal creation time ~100 ns.

… how to deal with spikes?



The micro-Resistive WELL,
made of

- Cathode
- u-RWELL PCB: a Well patterned Apical foil acting as amplification stage, a resistive layer for discharge suppression, a readout PCB

2D spatial resolution tunable for muon chambers and preshower up to 40 μm

IDEA Dual-Readout Calorimeter

Features

Jet energy resolution of 3-4% for jets of 100 GeV, good particle ID capability (ε(e) ~99%, ~2% π^- mis-ID) and electromagnetic energy resolution of $\simeq 11\,\%/\sqrt{E} \oplus 1\,\%$

… in a single calorimeter calibrated at the electromagnetic scale.

Excellent 2D spatial resolution by reading out each fiber with a dedicated SiPM.

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… in a single calorimeter calibrated at the electromagnetic scale.

Excellent 2D spatial resolution by reading out each fiber with a dedicated SiPM.

Concept: Do not reach h/e=1 by construction, but measure both components in each event.

Cherenkov signal

$$C = E[fem + \left(\frac{h}{e}\right)_c (1 - fem)]$$

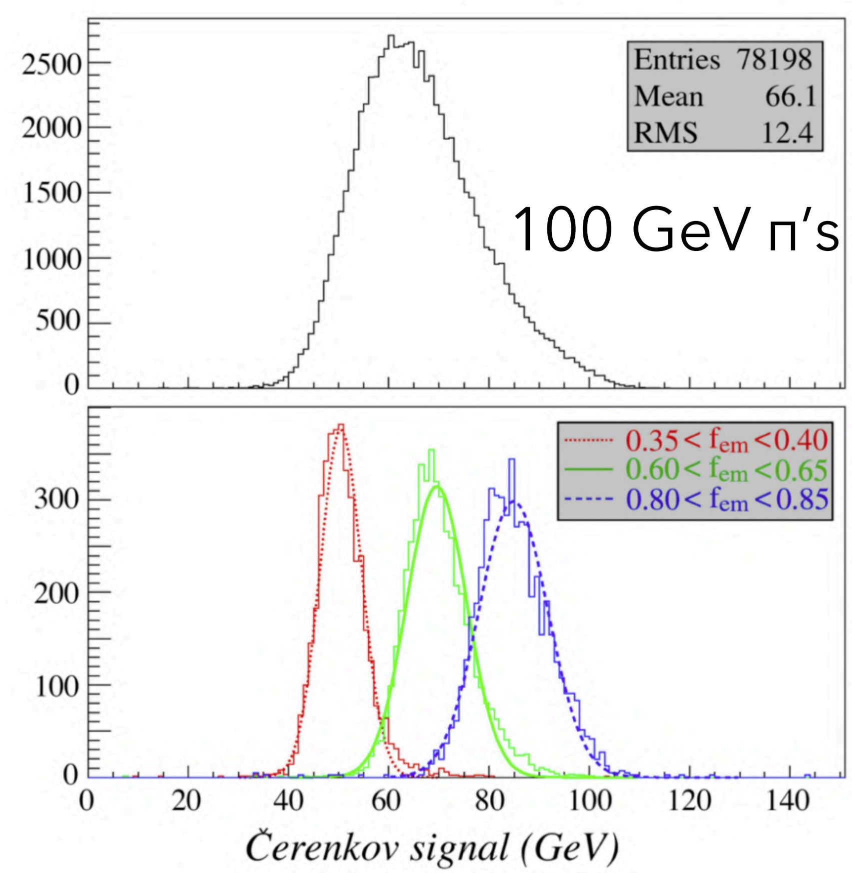
Scintillation signal

$$S = E[fem + \left(\frac{h}{e}\right)_s (1 - fem)]$$

The correct energy value is given by

$$E = \frac{S - \chi C}{1 - \chi} \qquad \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}$$

Data from RD52 Collaboration



EM resolution,

measured

$$\sigma/E = 11\%/\sqrt{E} \oplus 1\%$$

Had resolution,

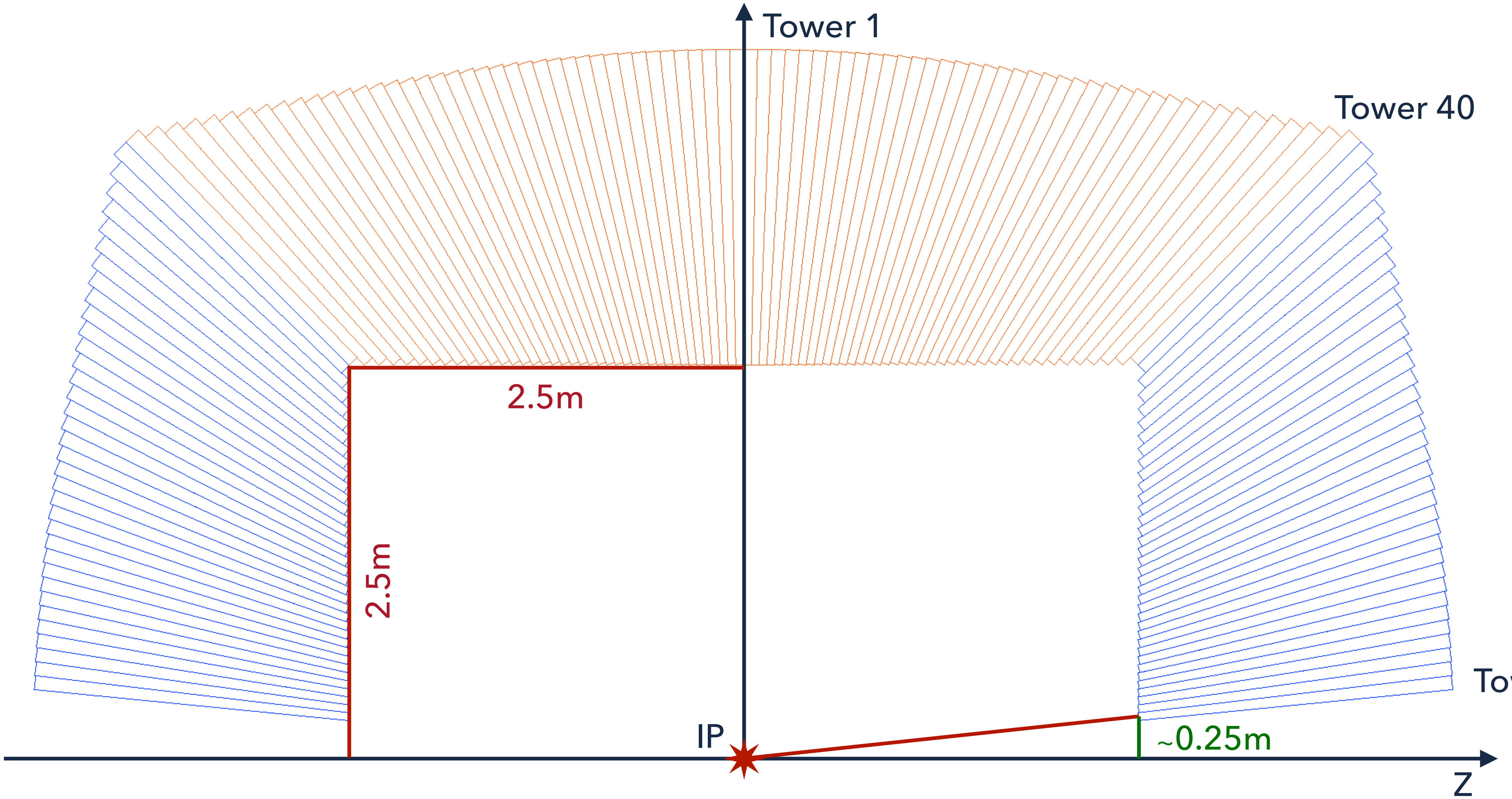
Geant4 expected

$$\sigma/E = (30 - 40\%)/\sqrt{E}$$

Updates on IDEA DR Calorimeter

Design of the fully projective fiber solution

Tower segmentation: $\Delta\vartheta = 1.125°$, $\Delta\phi = 10.0°$
Total number of towers in barrel: 40*2*36 = 2880
Total number of towers per endcap: 35*36 = 1260
Theta coverage up to ~0.100 rad

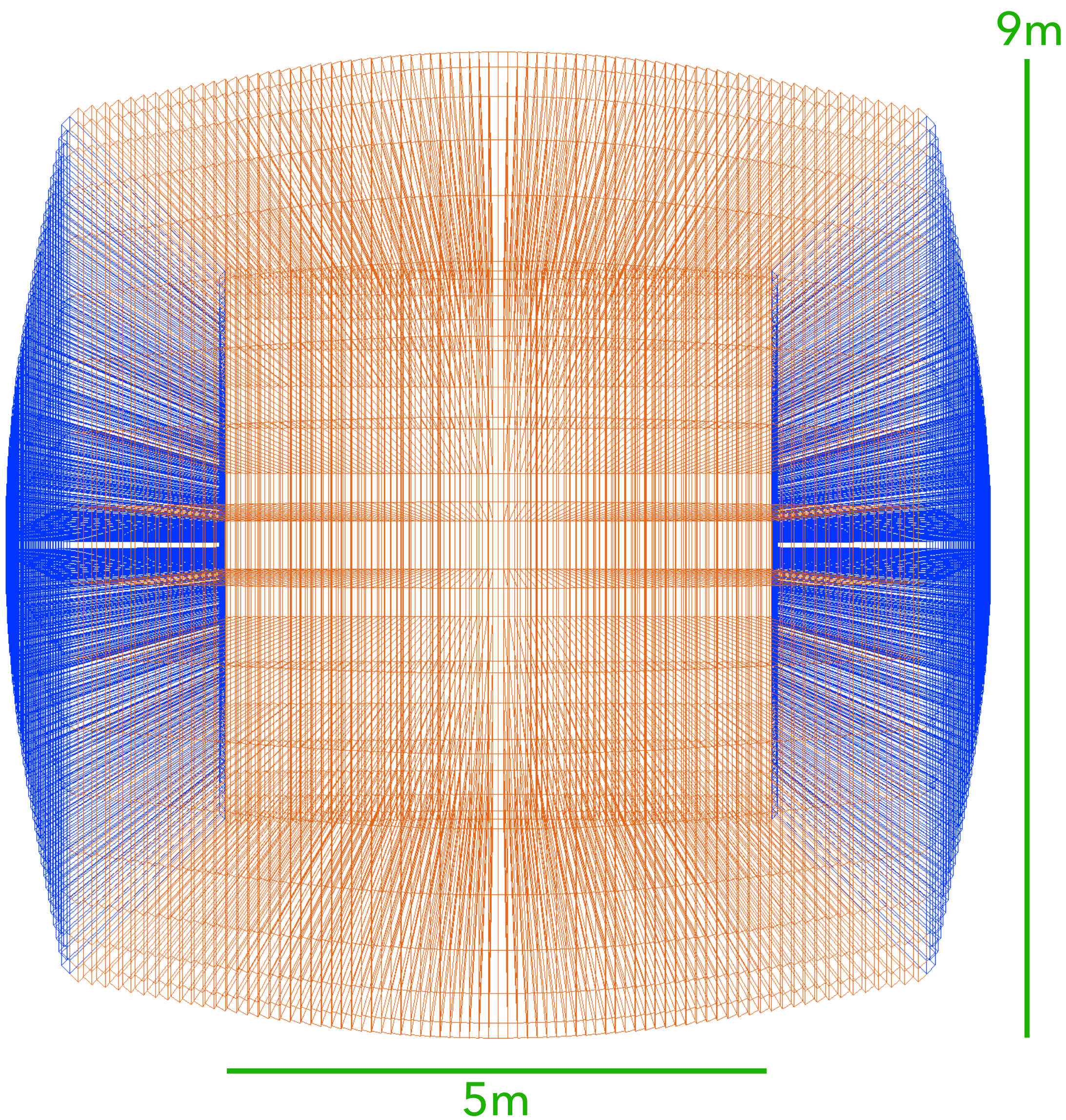


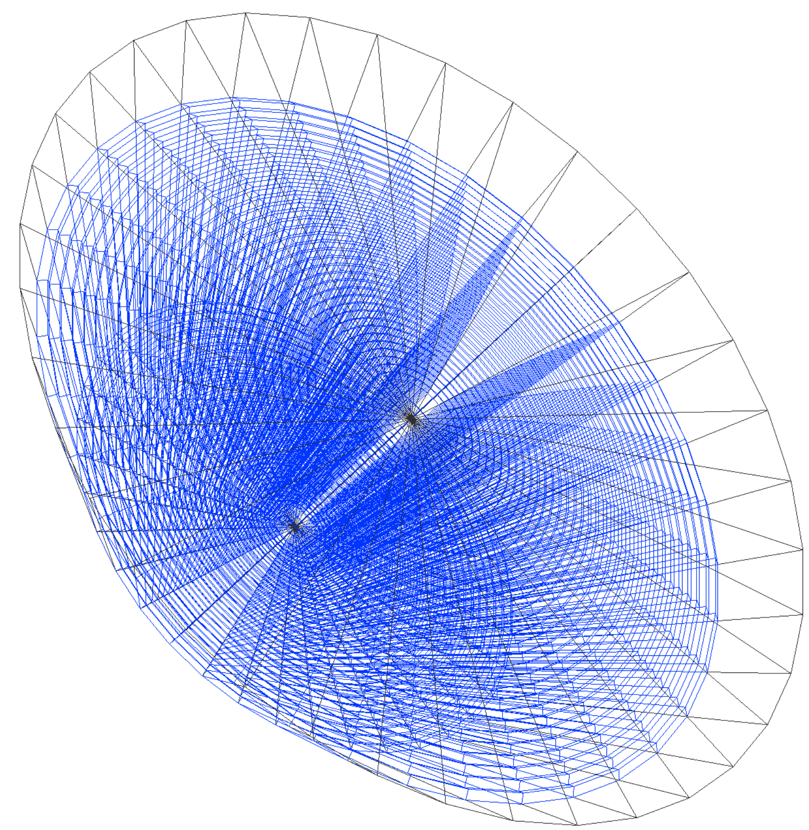
Implemented in Geant4 simulation

Updates on IDEA DR Calorimeter

Design of the fully projective fiber solution

Barrel: Inner length: 5m - Outer diameter: 9 m @ 90°
2 m long copper based towers: ~ 8.2 λ
36 rotation around z axis





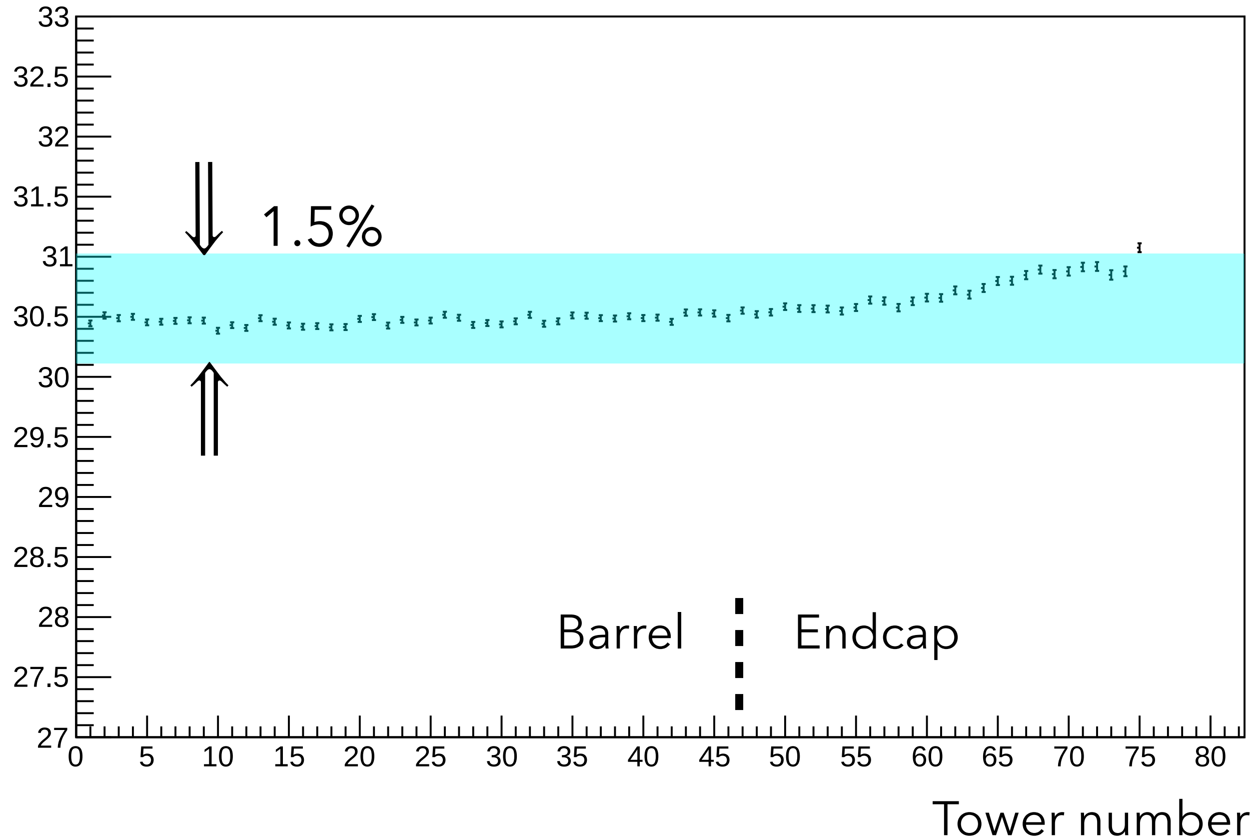
Implemented in Geant4 simulation

Updates on IDEA DR Calorimeter

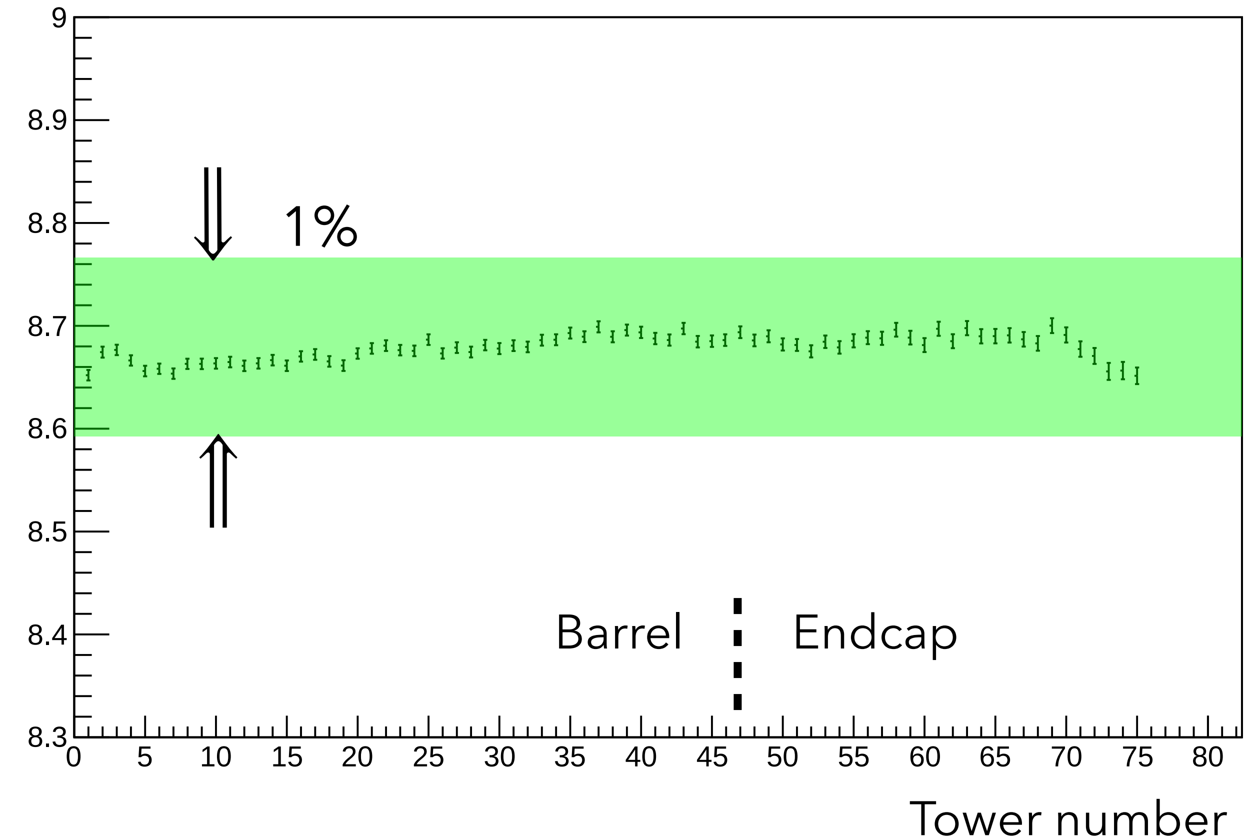
Calorimeter response

Main advantage of keeping the sampling fraction constant:
Scintillation response uniform within 1.5% from θ=90° to θ=5.7°
Cherenkov response uniform better than 1.0% from θ=90° to θ=5.7°

Scintillation - Response vs. tower #



Cherenkov - Response vs. tower #



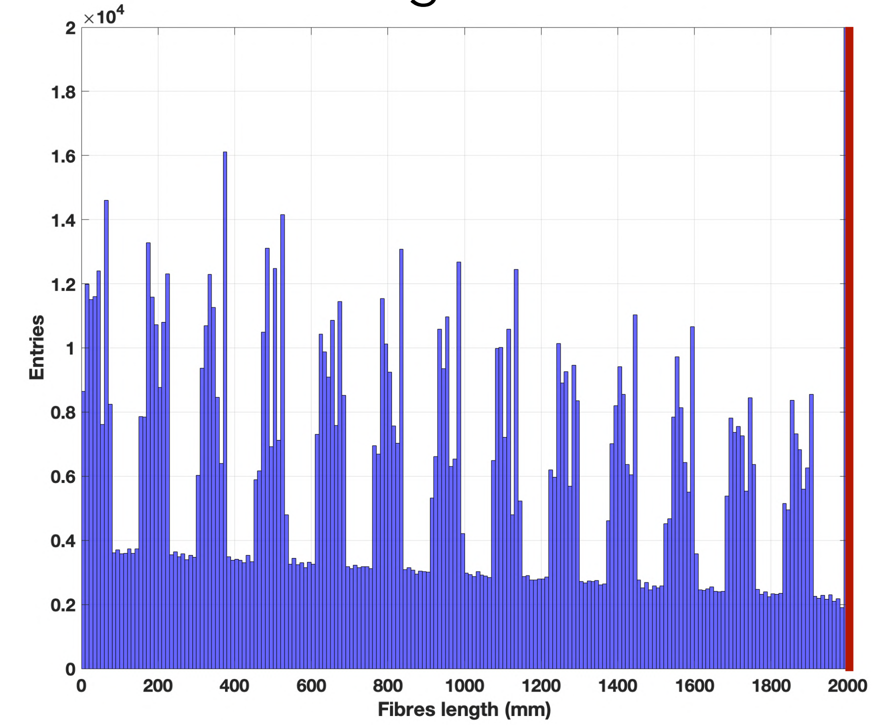
Updates on IDEA DR Calorimeter

Calorimeter event displays

For both C/S fibers: 1 mm diameter, 0.5 mm absorber in between.
Total number of fibers: ~131 M.

Fibers starting at different depths
to keep the sampling fraction constant.

Fiber length distribution



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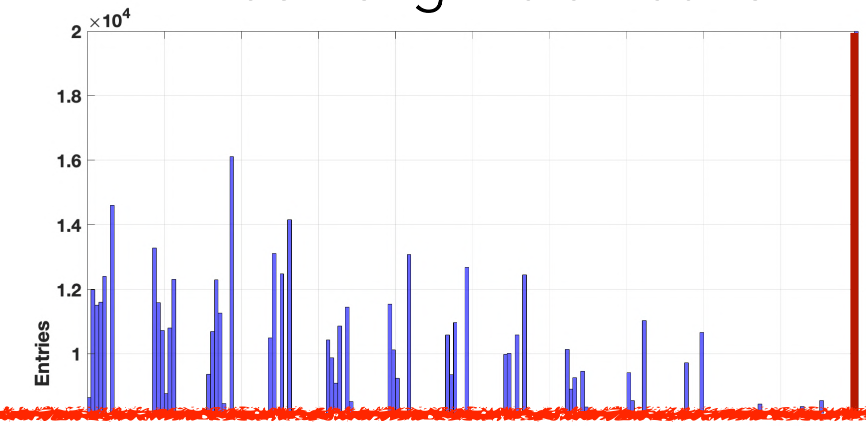
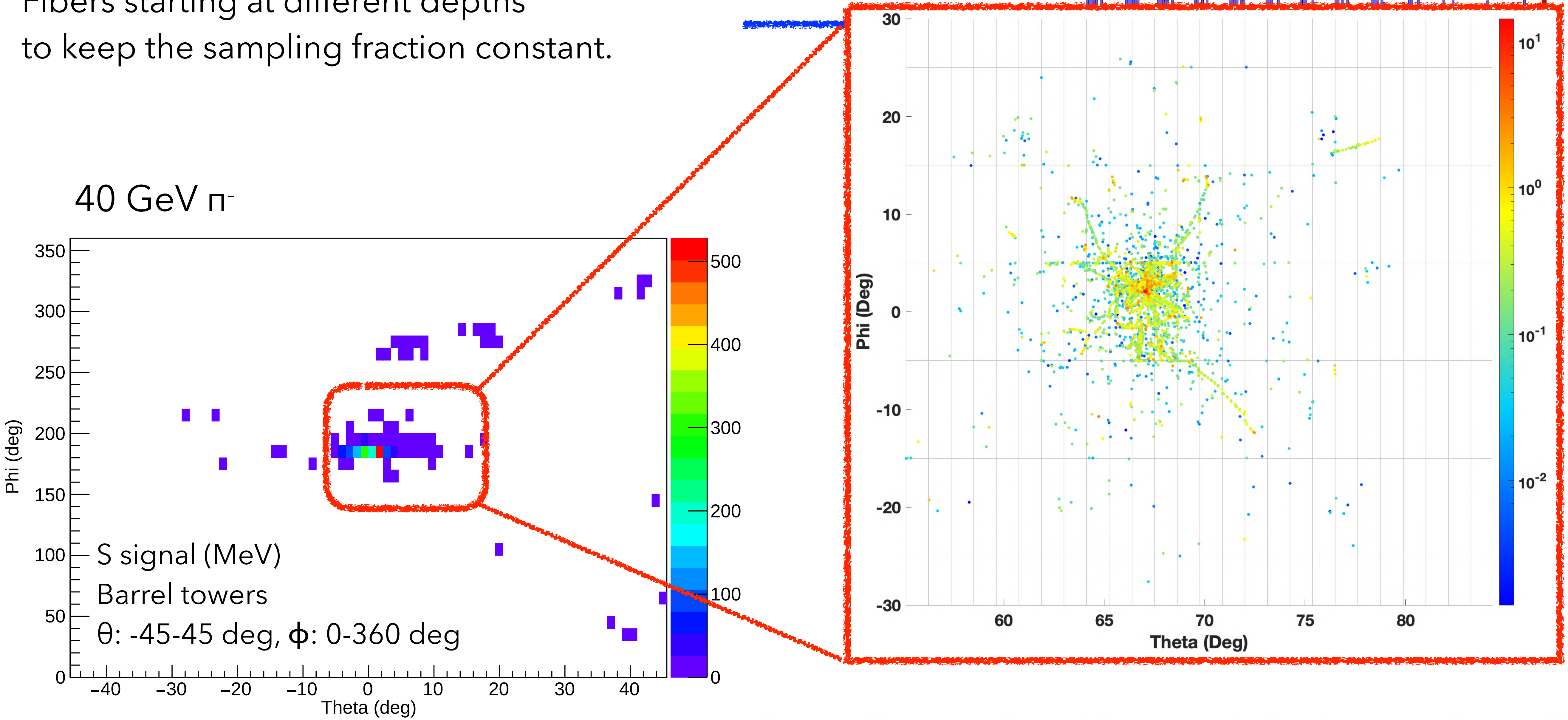


For both C/S fibers: 1 mm diameter, 0.5 mm absorber in between.
Total number of fibers: ~131 M.

Fibers starting at different depths
to keep the sampling fraction constant.

40 GeV π⁻



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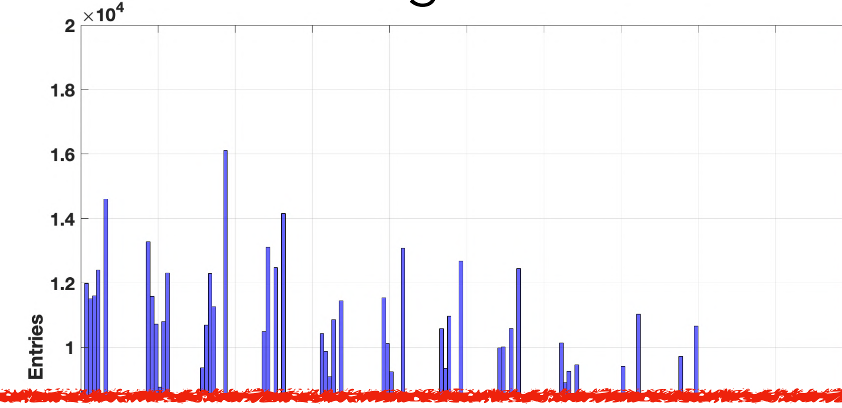

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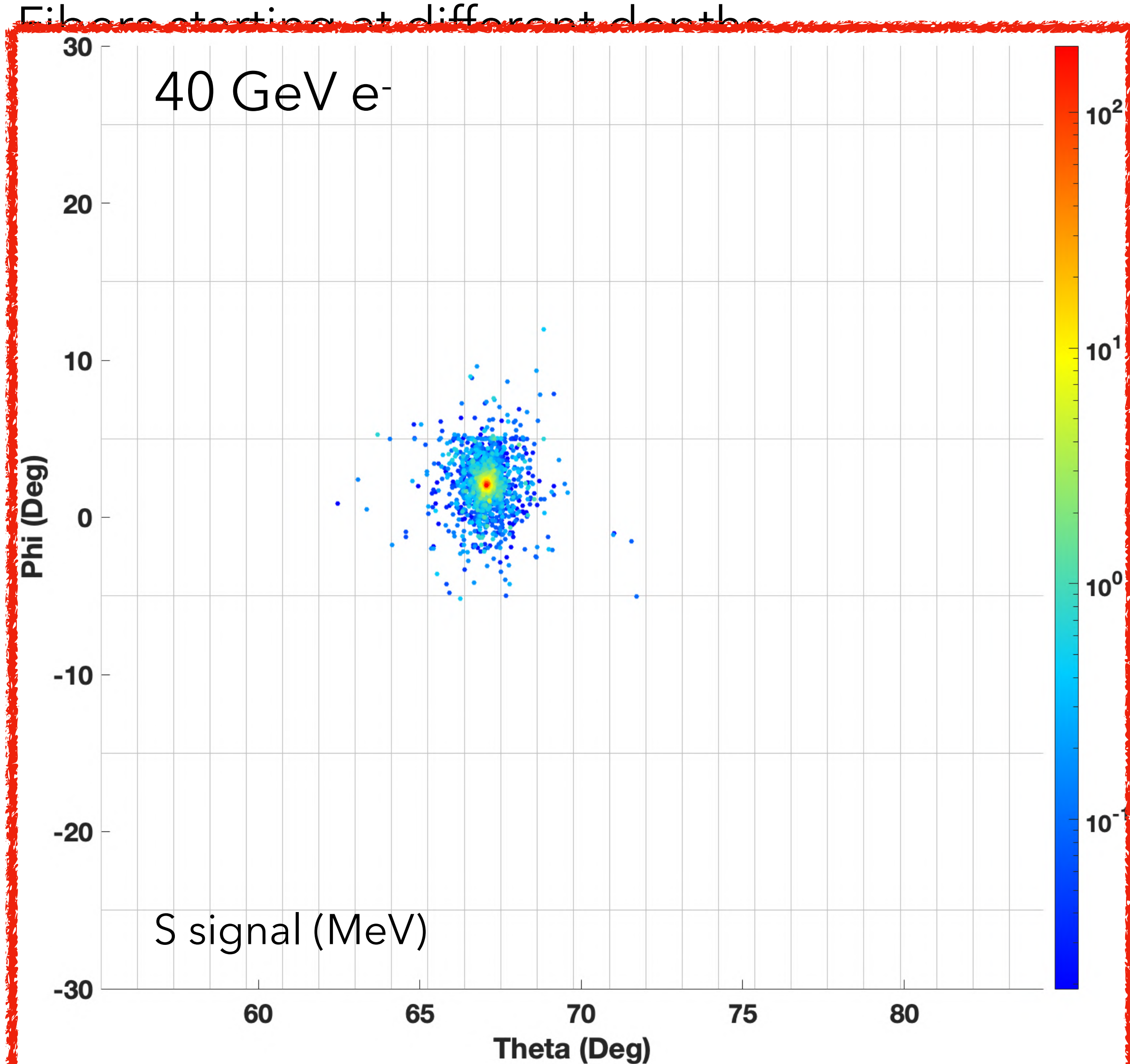
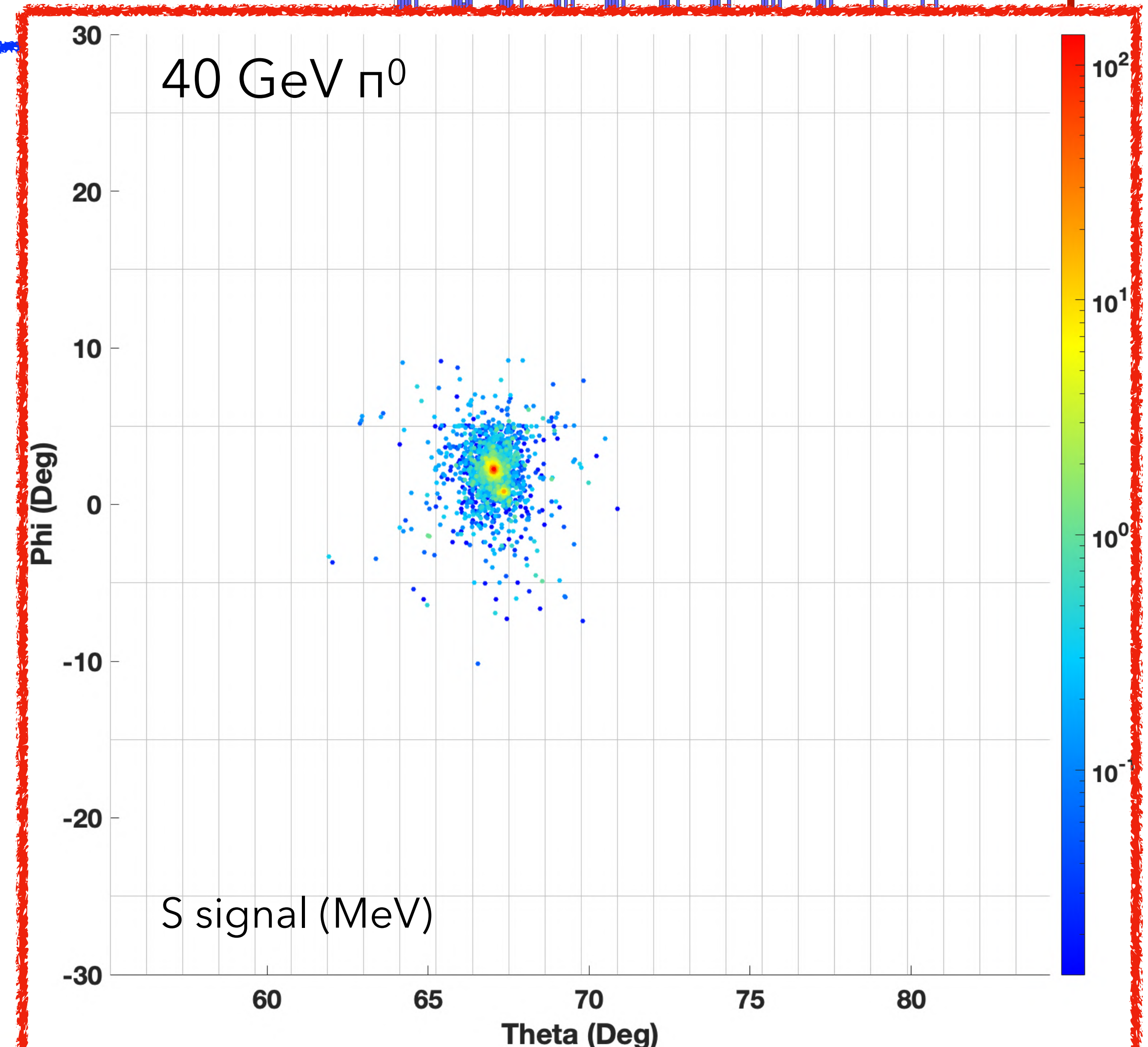




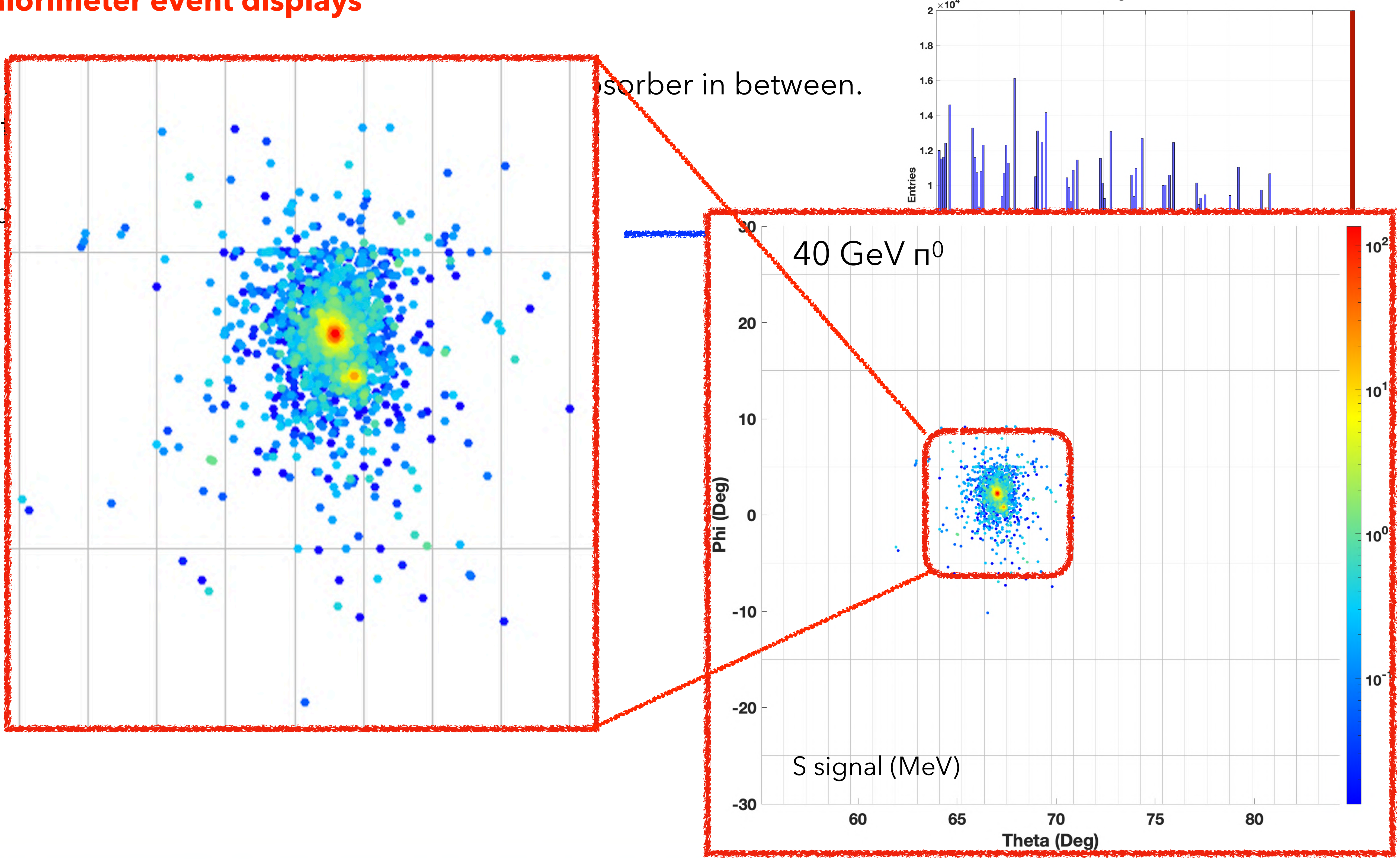
Updates on IDEA DR Calorimeter

Calorimeter event displays

Fo[...] ...sorber in between.
Tot[...]

Fib[...]
to[...]

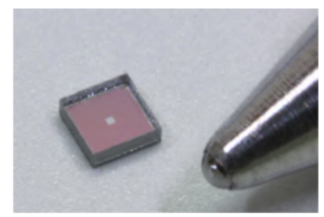
Fiber length distribution

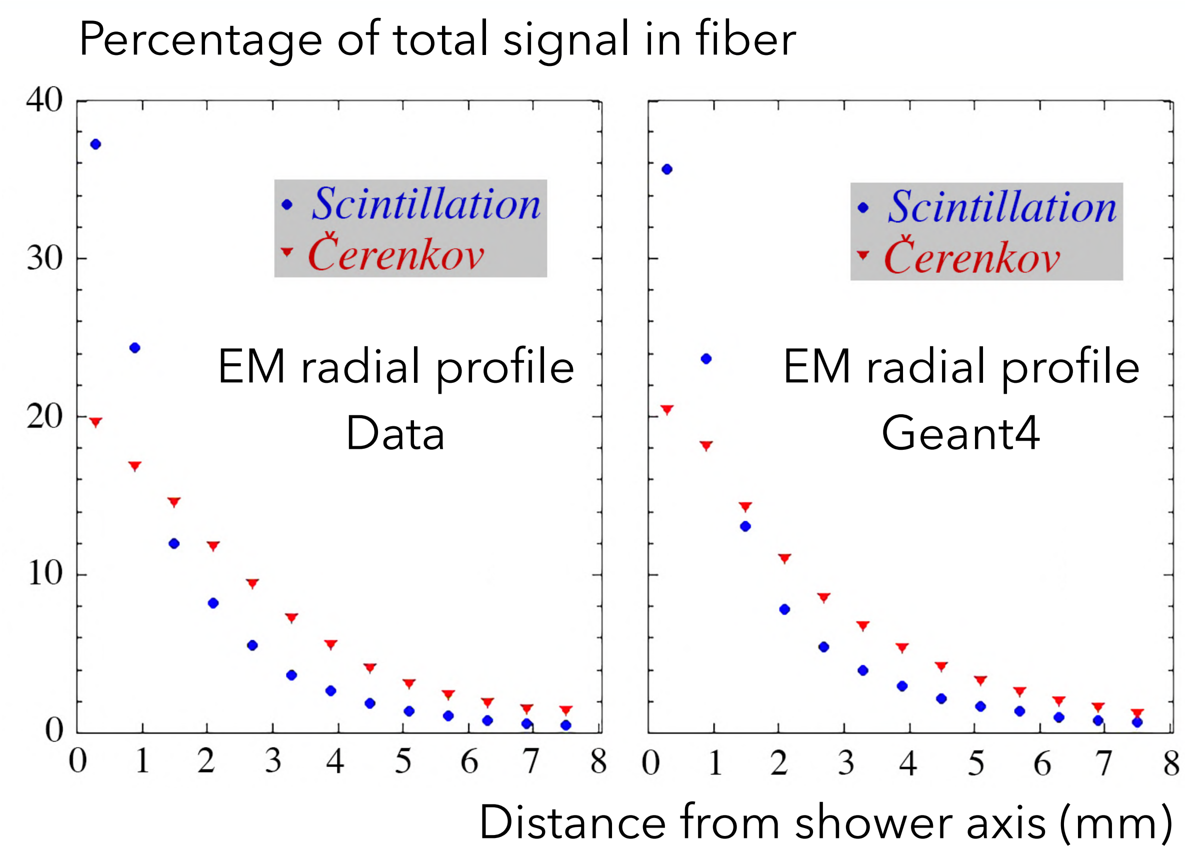


Updates on IDEA 2018 test beam

SiPM readout

SiPMs enable an unprecedented 2D spatial resolution but…
a single fiber can carry up to 10% of the total signal!



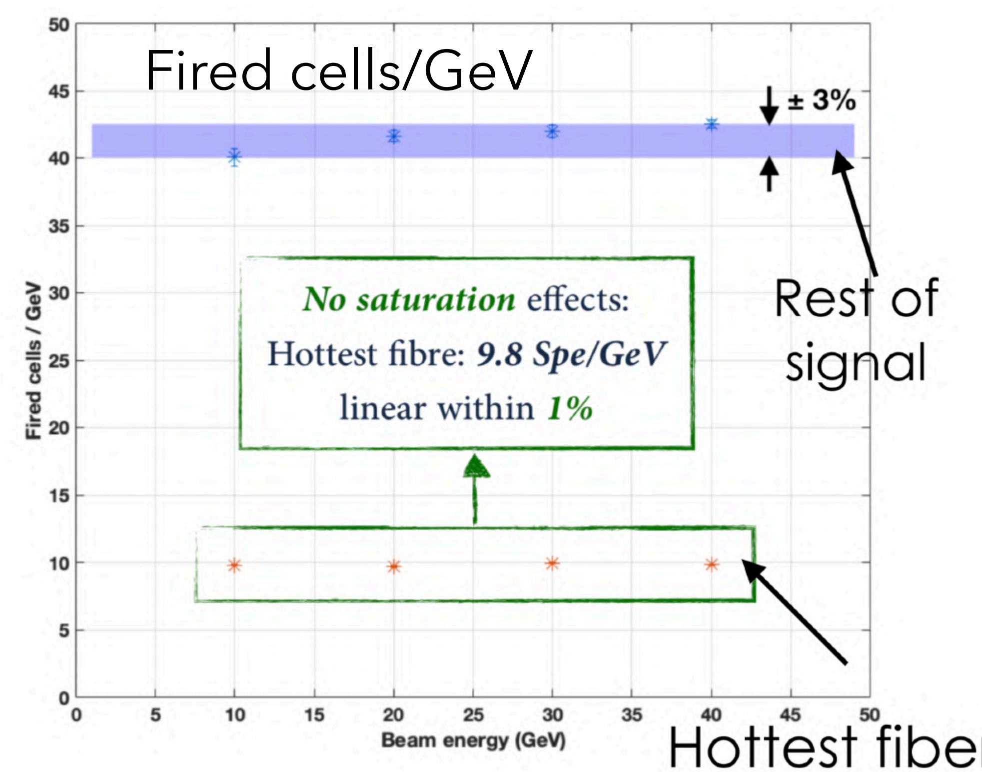


Achieved SiPM response linearity

By filtering the scintillation light

- it is possible to operate at 22% PDE and a light yield of 93 Spe/GeV with no saturation effects, with 25 μm pixel sensors.

Photon statistics fluctuations will become negligible going to 10 μm pixels.

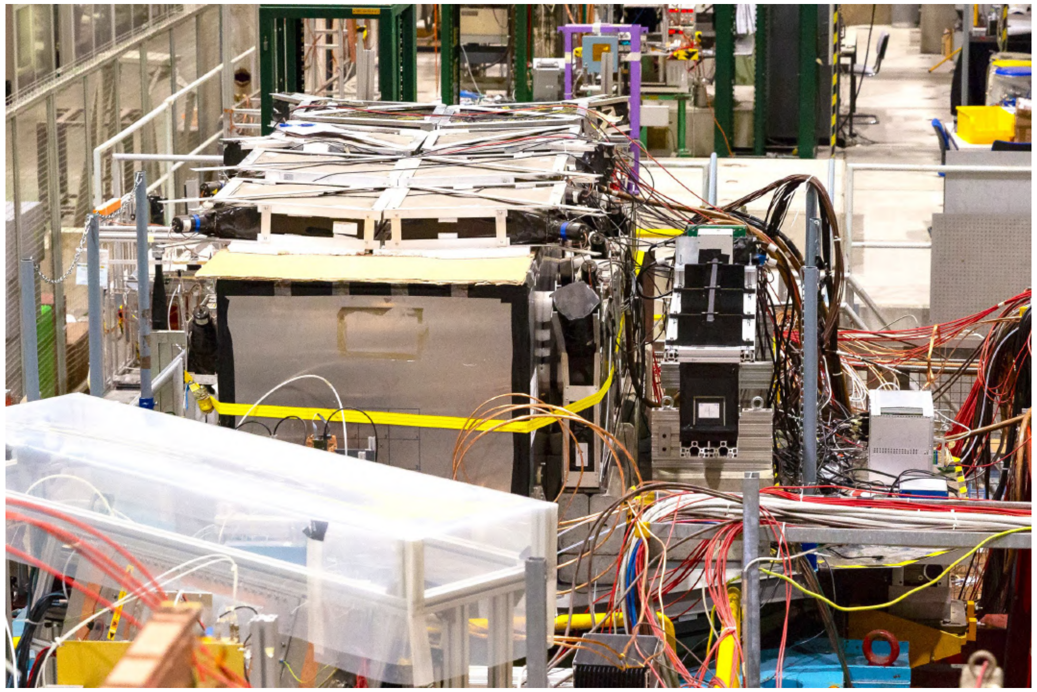


Updates on IDEA 2018 test beam

What about longitudinal segmentation?

For a better separation of em and hadronic clusters a longitudinal segmentation might be needed.
The first DR staggered module was tested at the CERN SPS beam line:

- 9.2 x 9.2 x 230 cm^3
- Half fibers (C and S) start at ~ 20 X_0 from the front face
- Short fibers only sensitive to hadrons
- Long - Short fibers' signals define an em compartment



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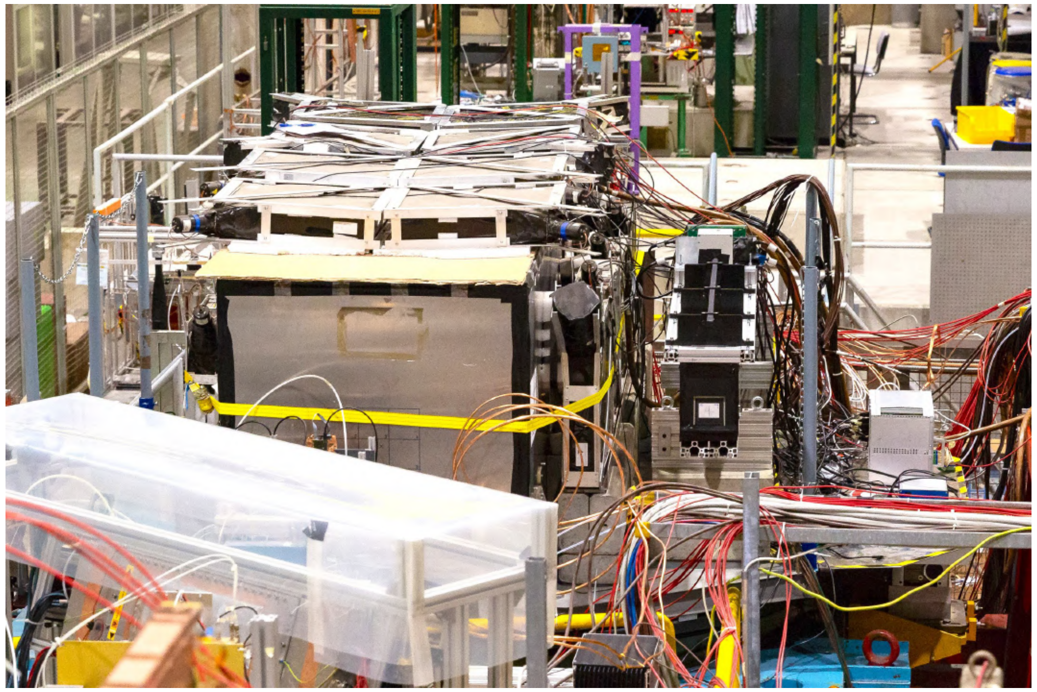
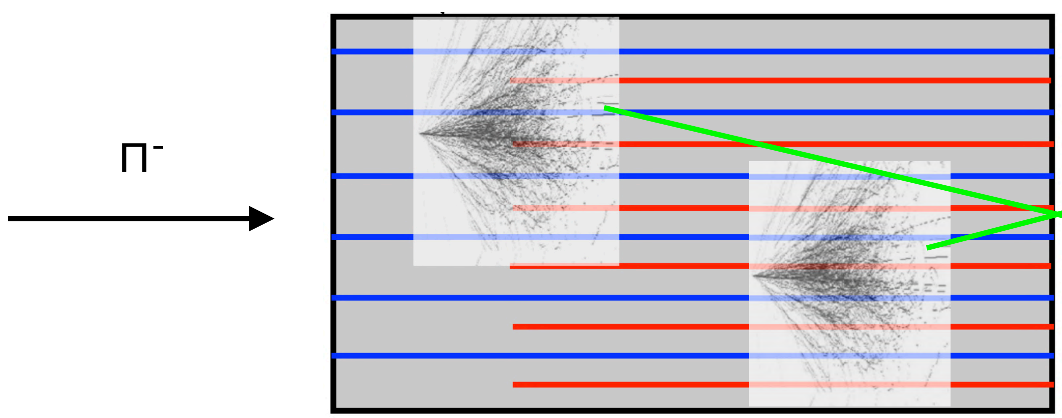
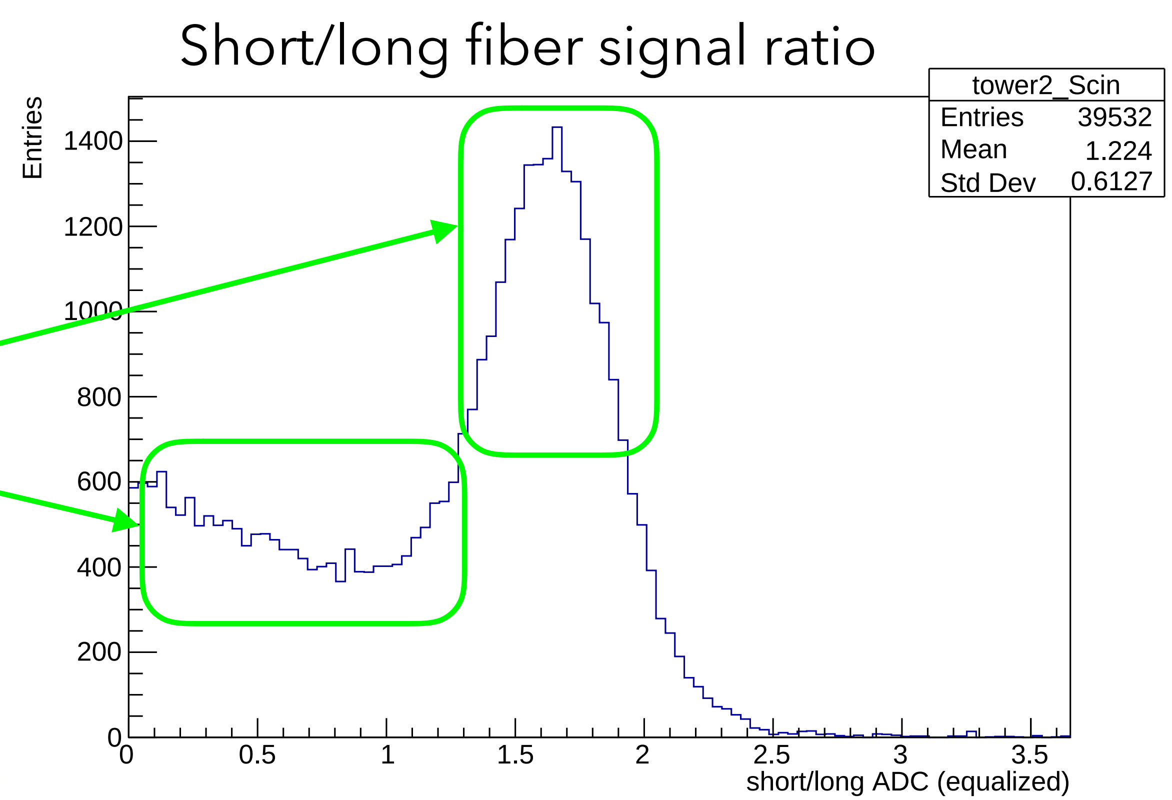






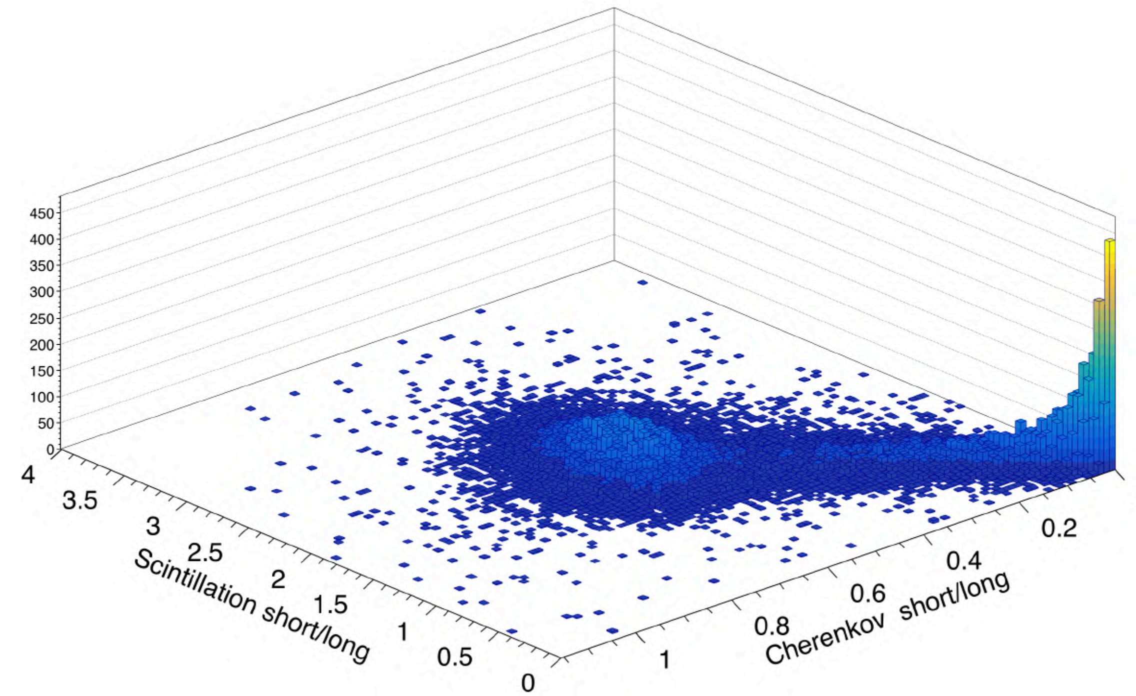
Updates on IDEA 2018 test beam

Scintillation and Cherenkov channel - 60 GeV π⁻

As it is possible to estimate the difference in the responses between short and long fibers,

↓

- it is possible to use the dual-readout principle in a longitudinally segmented fiber calorimeter.



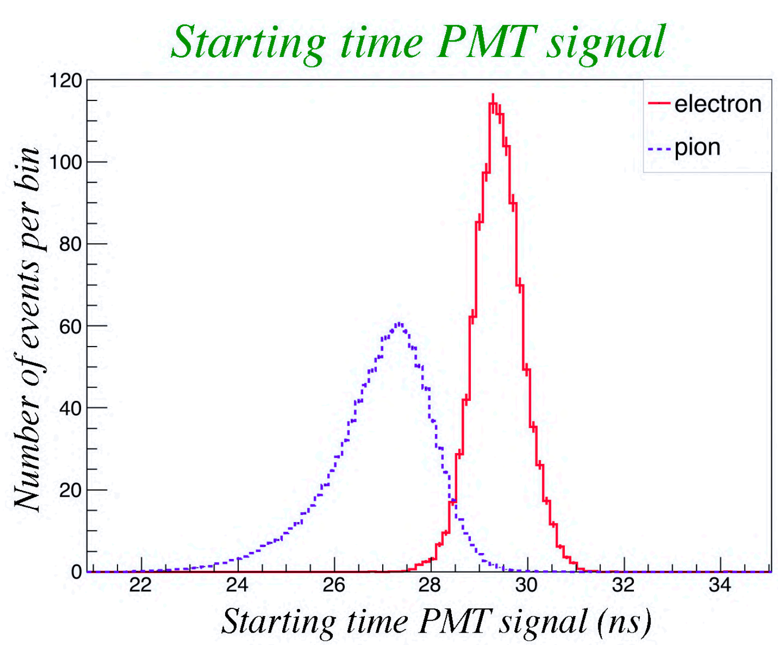
… what about timing?

As light in fibers travels at c/n, it is possible to discriminated between electrons and hadrons with the signals' time of arrival.

↓

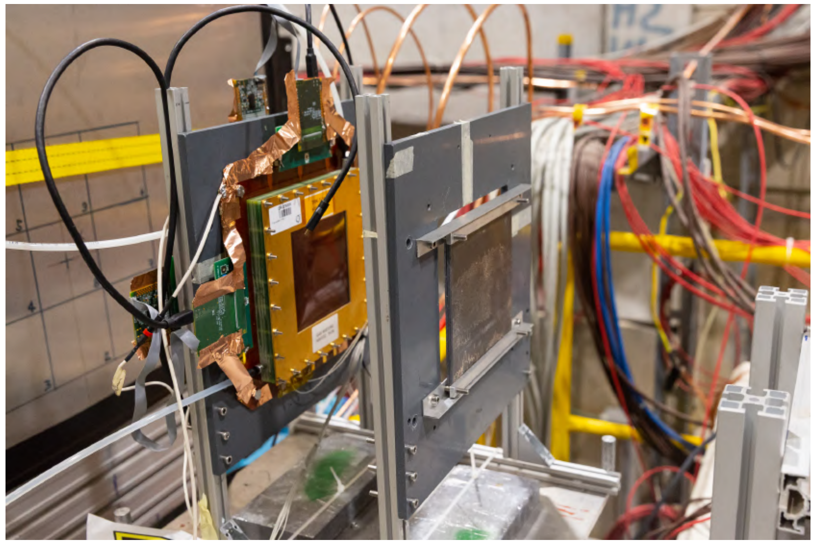
- to be studied with SiPMs!

Data from RD52 Collaboration, PMTs readout fiber calorimeter



Updates on IDEA 2018 test beam

The IDEA vertical slice combined test beam



To study the combined performances of IDEA we tested in series:

- a drift chamber
- two GEM detectors (+ lead slabs as preshower)
- the RD52 lead Dual Readout calorimeter
- 2 GEM detectors (muon trackers)

Updates on IDEA 2018 test beam

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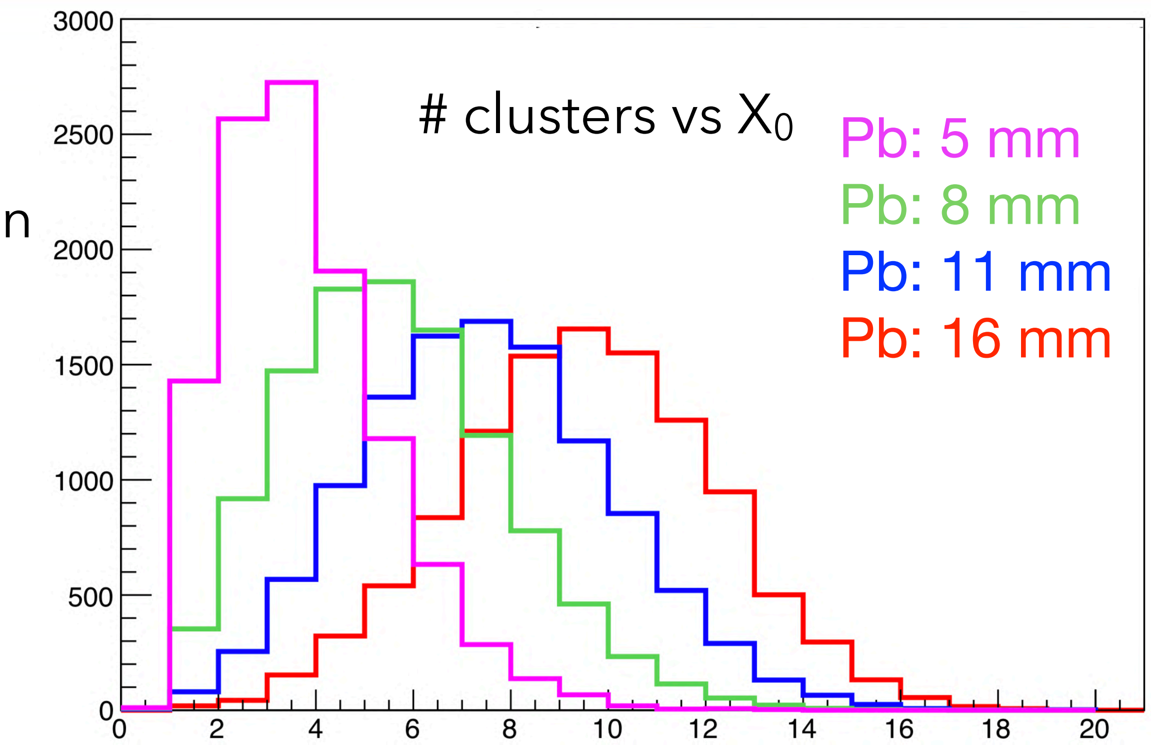
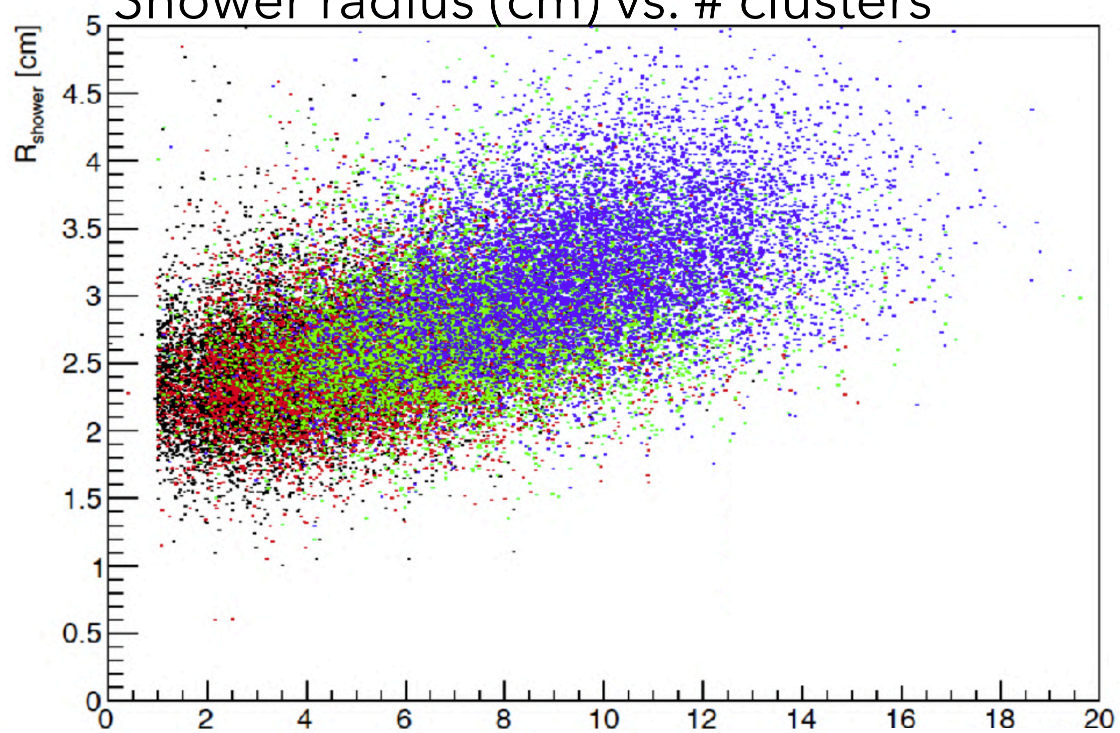


Effect of budget material on the electromagnetic performances

GEM detectors clearly indicate the effect of upstream radiation in front of the calorimeter, however

↓

- The electromagnetic energy resolution was not spoiled.
  Strong point for having the coil inside the calorimeter!



IDEA Drift Chamber

Features

Large solid angle coverage (|cosϑ| = 0.99), high granularity and high transparency detector.

Good momentum resolution at level of $\sigma_{p_t}/p_t \simeq 10^{-5} p_t$ (a factor 10 better than LEP).

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Caveat

Emittance preservation at the IR constraints the B field to be at the 2T level

… but $\frac{\Delta p_t}{p_t} = \frac{8\sqrt{5}\sigma_{xy}}{0.3BR_{out}^2\sqrt{N}} p_t \oplus \frac{0.0523}{\beta BL} \sin\theta \sqrt{\frac{L}{X_0}}$ → stay light and large!

Short bunch spacing @ Z-pole (20-30 ns) → stay fast!

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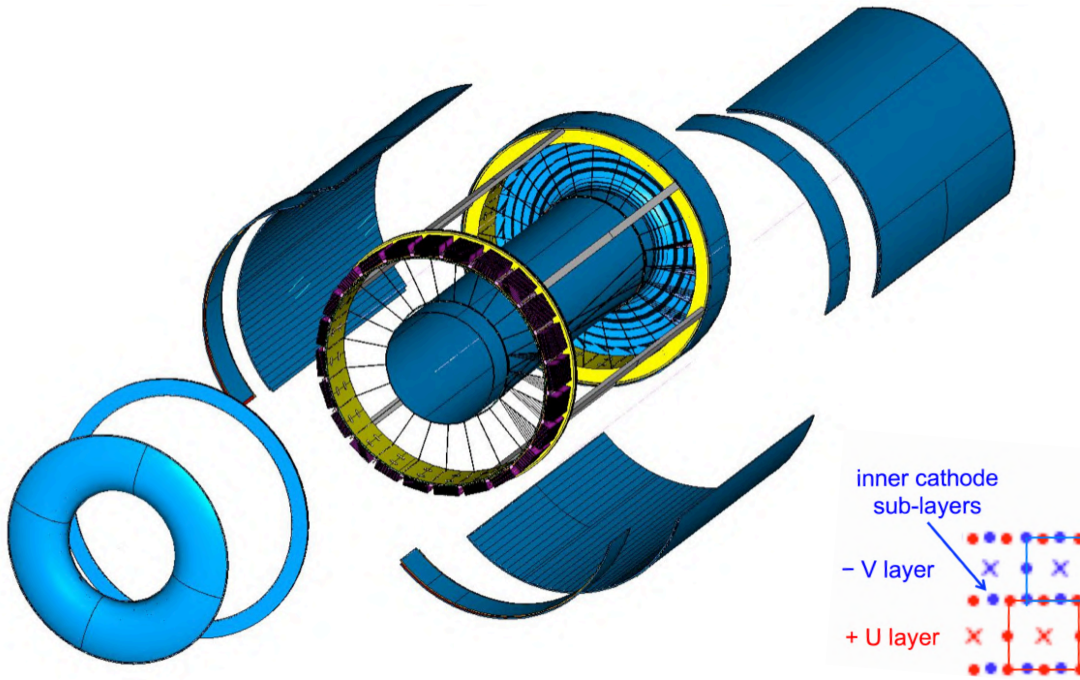
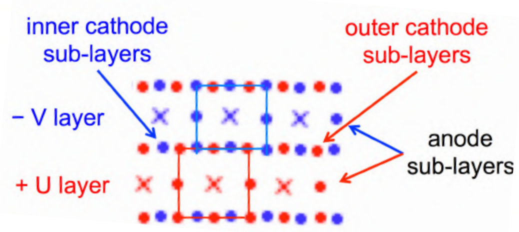




L = 400 cm, R = 35-200
Gas: 90% He - 10% iC_4H_{10}
Drift length: 1 cm → drift time: 350 ns

Spatial res: $\sigma_{xy} < 100$ μm, $\sigma_z < 1000$ μm
56448 squared drift cells of 12 - 13.5 mm
Layers: 112

Vertex

Boundary conditions

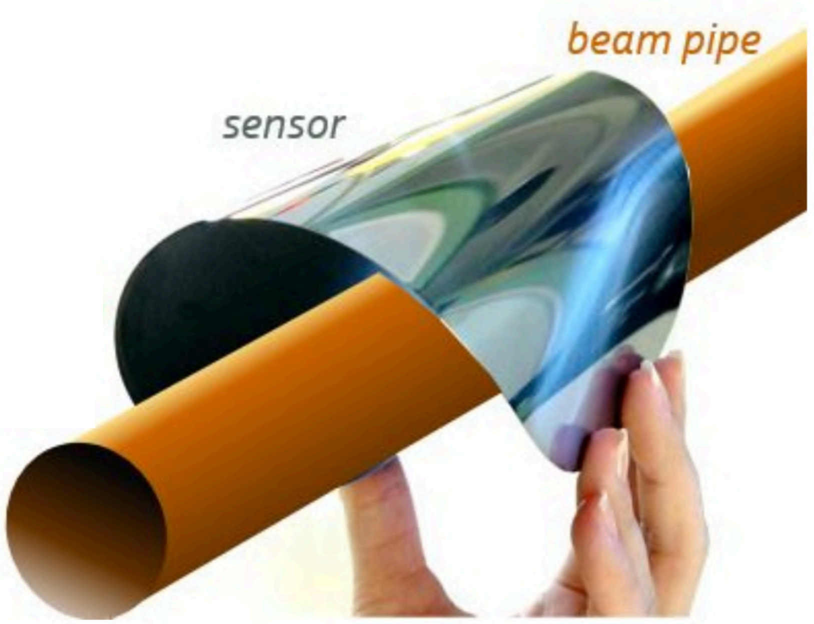
- Detector specific: $\sigma_{ip} = a \oplus \frac{b}{p \sin^{3/2}\theta}$ towards $\sigma_{ip} \simeq 5 \oplus \frac{10}{p \sin^{3/2}\theta}\ \mu m$
- Beam induced background: @ H pole 1-10 hits/cm^2/BX

to limit the occupancy at 1% level → readout Δt < 80 μs → "burn" energy and "grow in mass"

… but air cooling namely works up to a power density of ~ 20 mW/cm^2

But, as of today, there is NO SENSOR featuring:

- single point resolution at the 3 μm
- level thickness at the 0.1% X_0 level
- power dissipation not exceeding 20 mW/cm^2
- being read-out in less than 80 μs/cm^2
- scaled-up to "reticle size" areas



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ARCADIA (Advanced CMOS Architectures with Depleted Integrated sensor Arrays)

- INFN CSNV Call Project targeting a full-size system-ready demonstrator of a low-power high-density pixel matrix CMOS monolithic sensor featuring

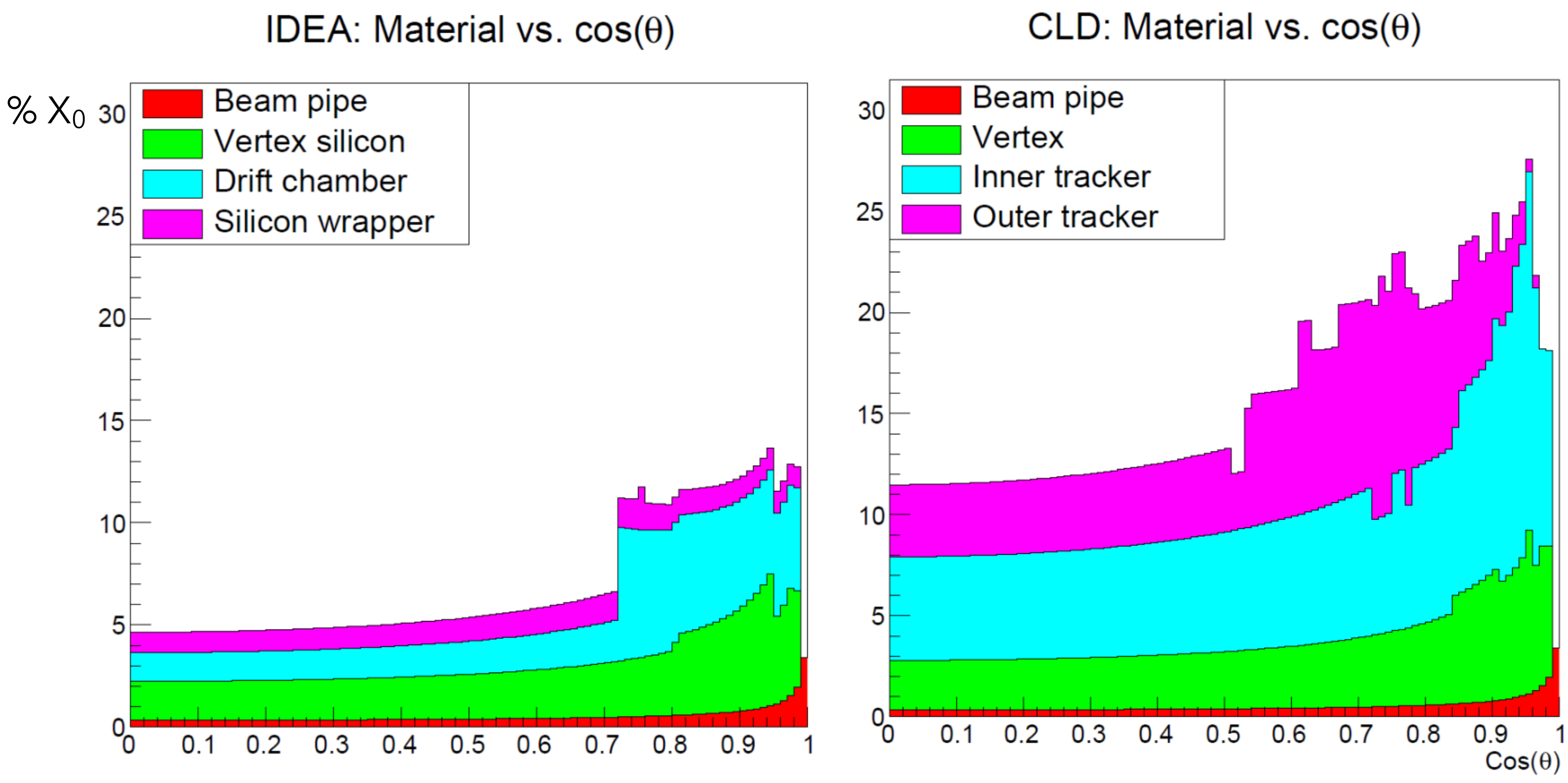
1. Active sensor thickness in the 50-500 μm range
2. Operating in full depletion fast charge collection by drift
3. Scalable readout architecture with ultra-low power capability O(10 mW/cm^2)

Updates on the IDEA Drift Chamber

Estimates of the full tracker material budget

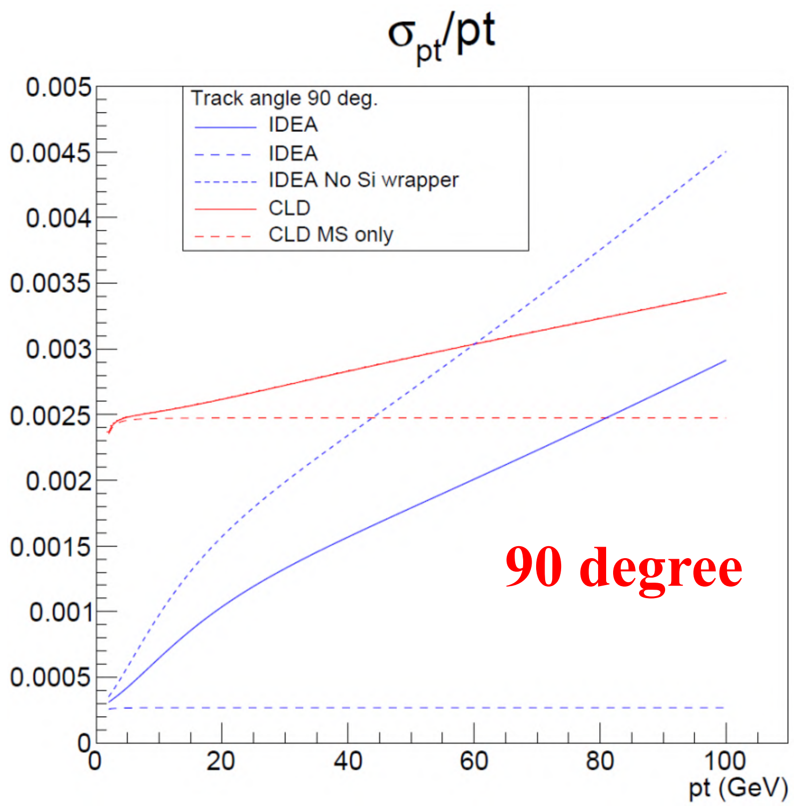
5% X_0 - barrel region

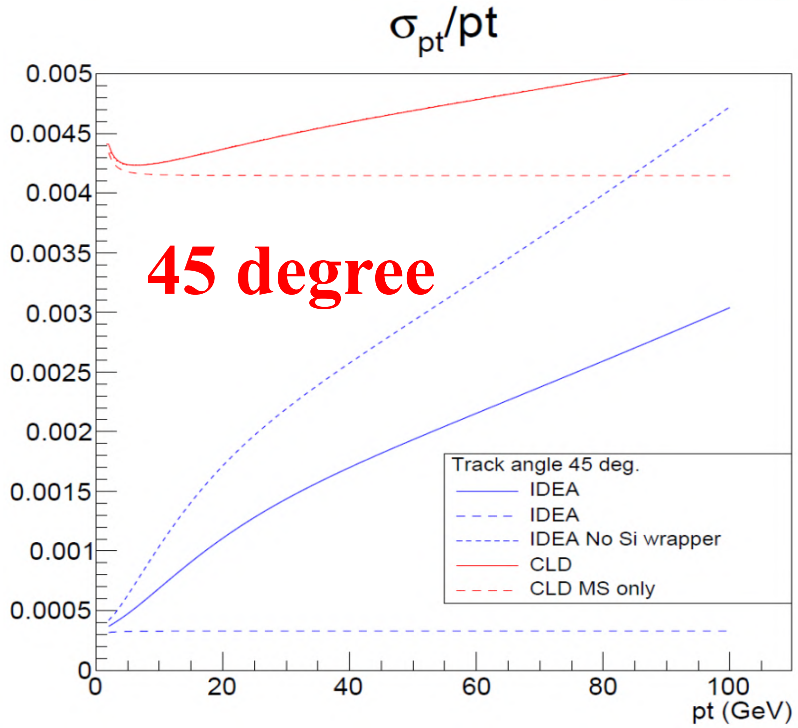
< 15% X_0 - forward and backward regions



Updates on the IDEA Drift Chamber

Full tracking performances (vertex + drift chamber + Si wrapper)





@ 90°, asymptotic behavior

IDEA

$$\sigma_{p_t}/p_t \simeq 2.2 \times 10^{-5} p_t$$

IDEA no Si wrapper

$$\sigma_{p_t}/p_t \simeq 5.7 \times 10^{-5} p_t$$

+

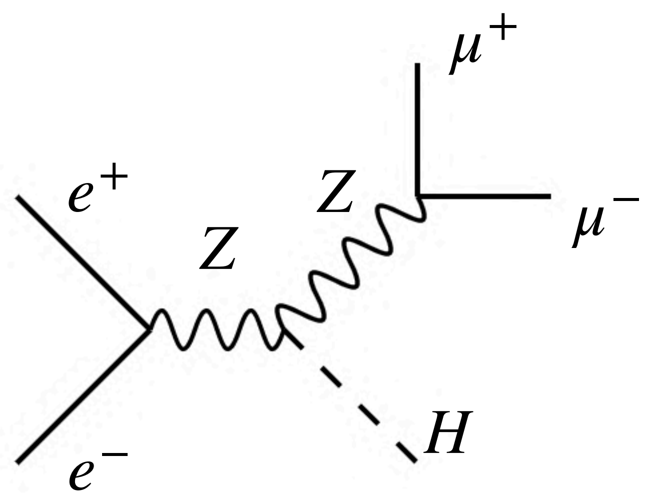
Cluster counting
for improved particle identification:
$dN_{cl}/dx \sim 2\%$ vs $dE/dx \sim 4\%$

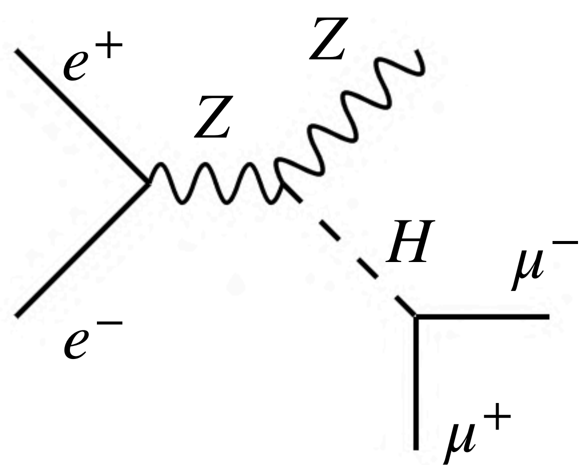
No ion back-flow & short drifting time.

Updates on the IDEA Drift Chamber

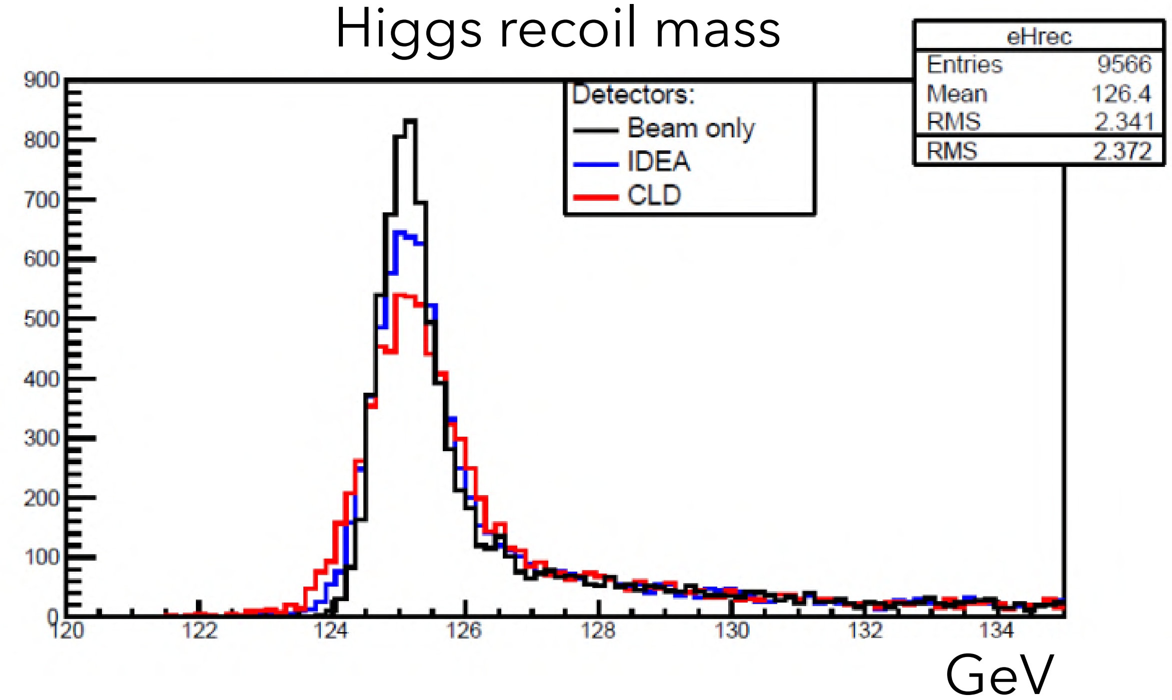
IDEA/CLD Comparison

Run @Higgs pole, assuming 0.136% beam spread

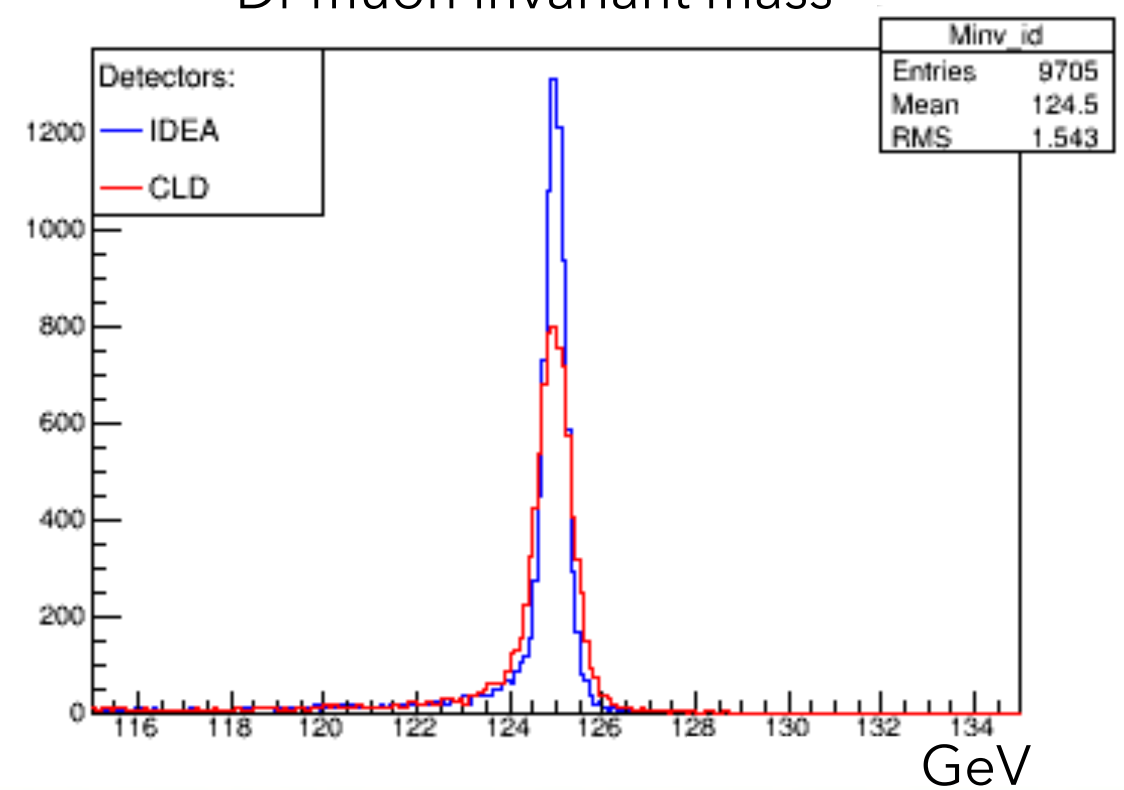




Higgs recoil mass

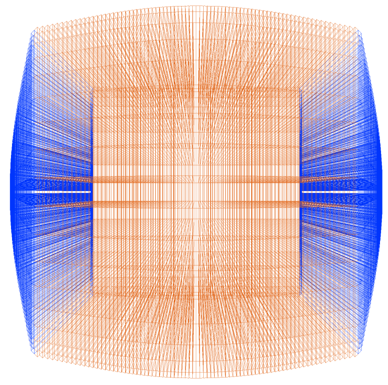


Di-muon invariant mass

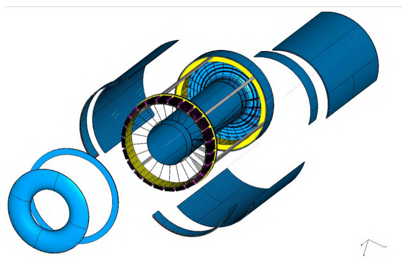


Conclusions

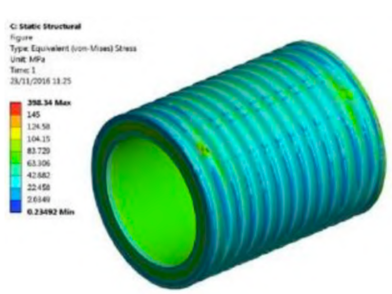
The IDEA Detector is specifically intended for e^+e^- high luminosity circular colliders, featuring:



A Dual-readout calorimeter for excellent hadronic and jet energy resolution



An ultra-light drift chamber for superior momentum resolution in the envisaged energy range and excellent particle identification capabilities



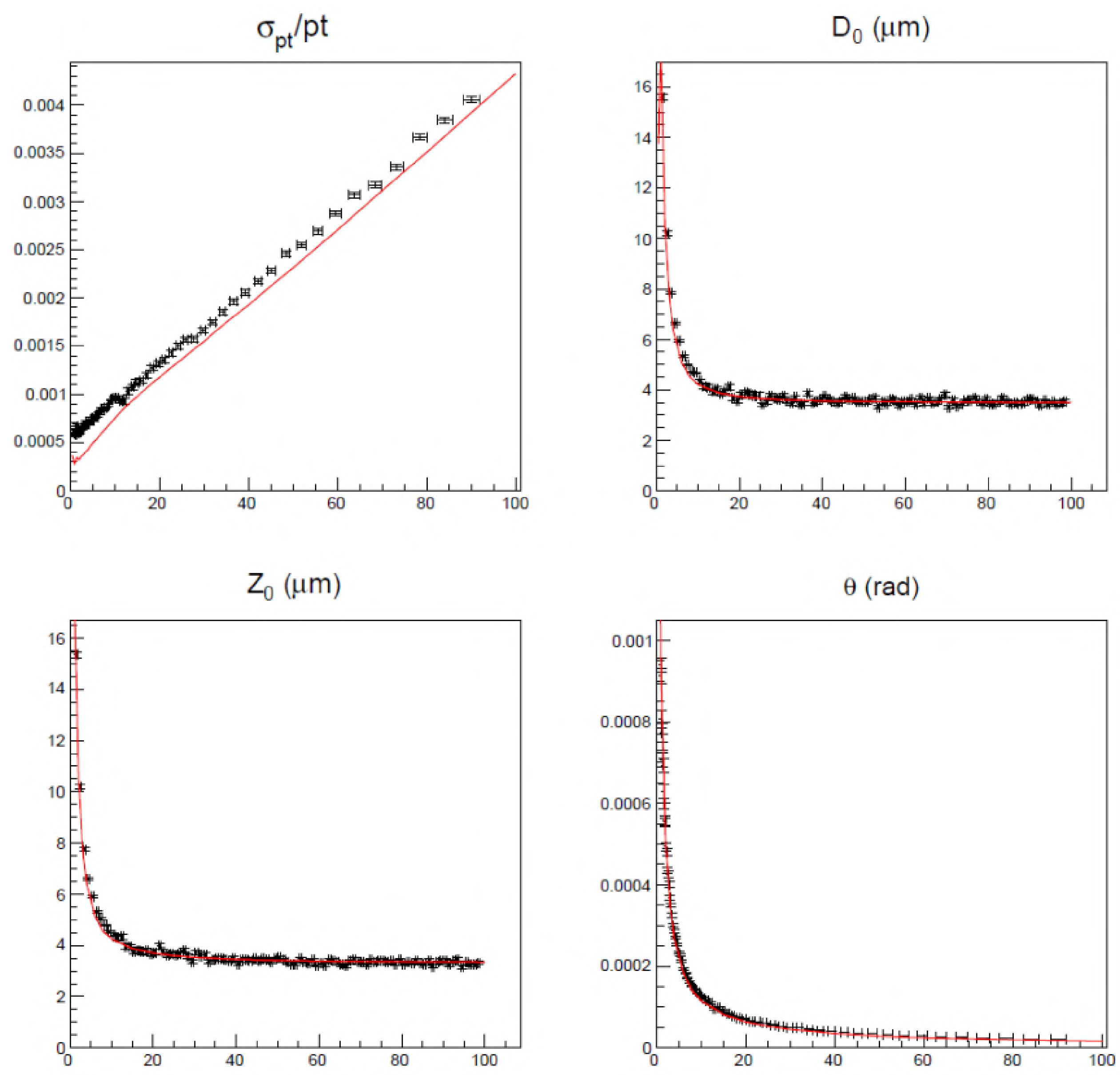
and an ultra-light solenoid coil inside the calorimeter.

Several AIDA++ EOI's to be submitted both on hardware and software sides.

THANK YOU!

Backup

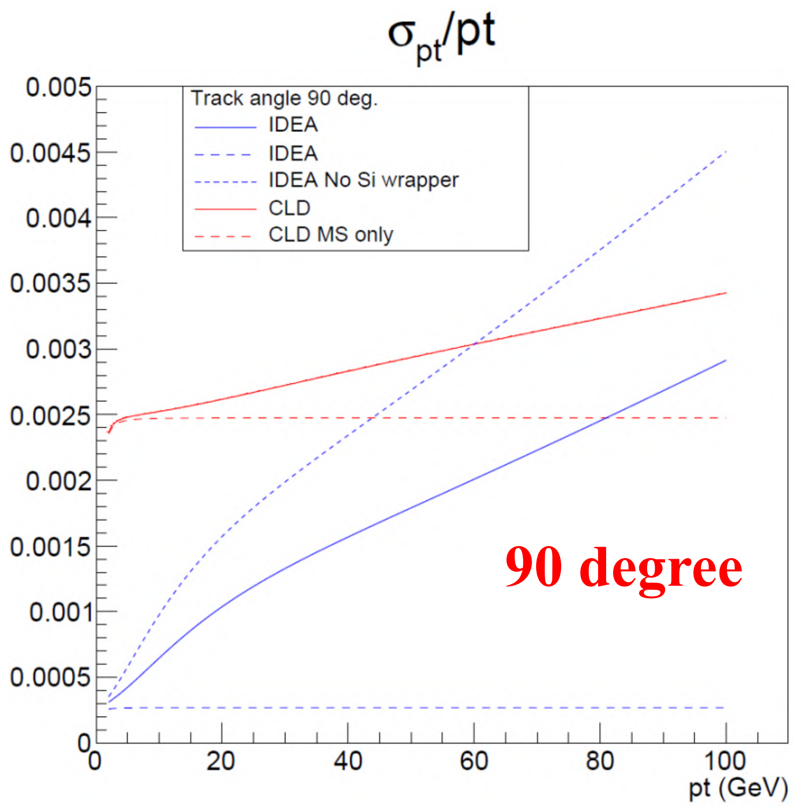
Drift chamber tracking performances

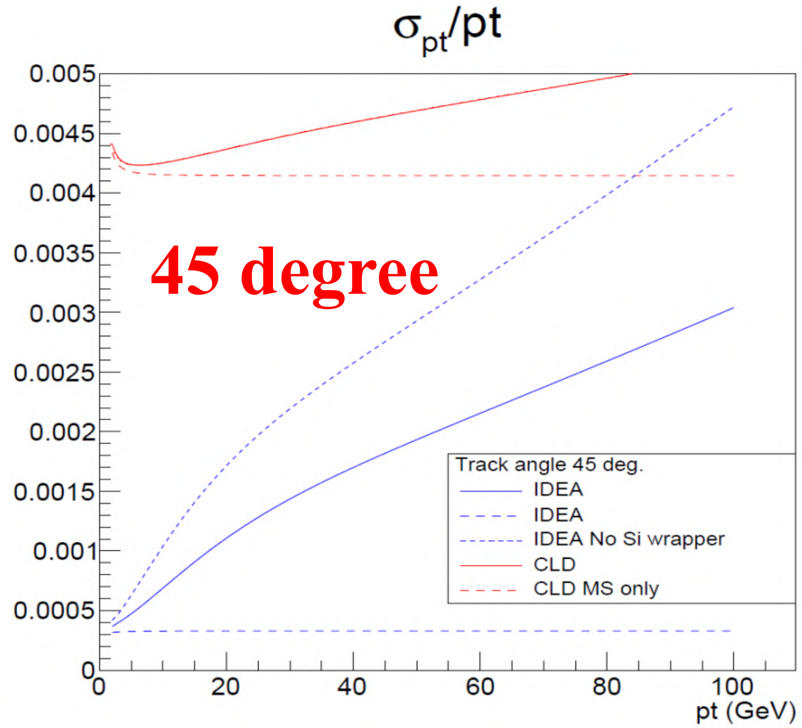


- **Geant4**
- **ROOT based simulation**

Updates on the IDEA Drift Chamber

Tracking performances





@ 90°, $p_t > 30$ GeV

IDEA

$$\sigma_{p_t}/p_t = 0.7 \times 10^{-3} + 2.2 \times 10^{-5} p_t$$

IDEA no Si wrapper

$$\sigma_{p_t}/p_t = 0.5 \times 10^{-3} + 5.7 \times 10^{-5} p_t$$

IDEA, Multiple Scattering only

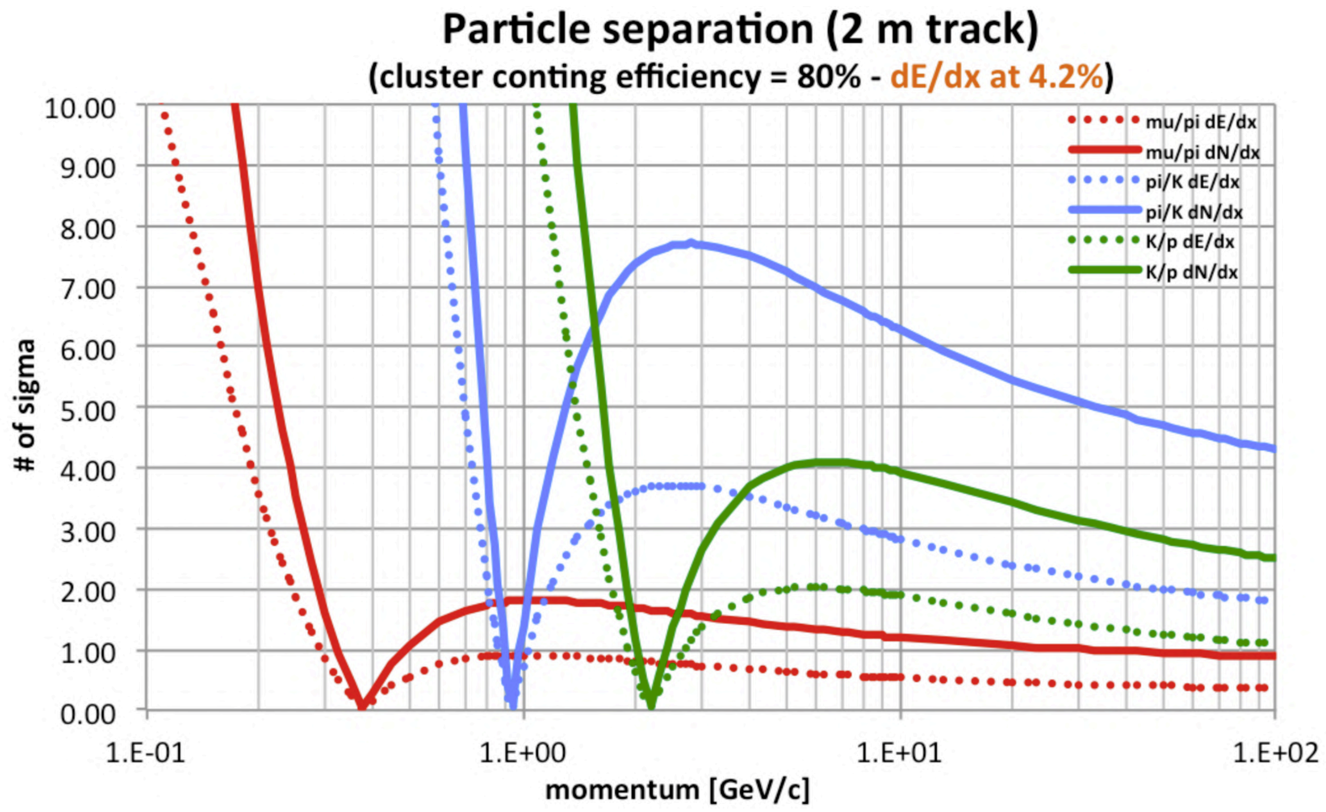
$$\sigma_{p_t}/p_t = 0.25 \times 10^{-3}$$

CLD, Multiple Scattering only

$$\sigma_{p_t}/p_t = 2.5 \times 10^{-3}$$

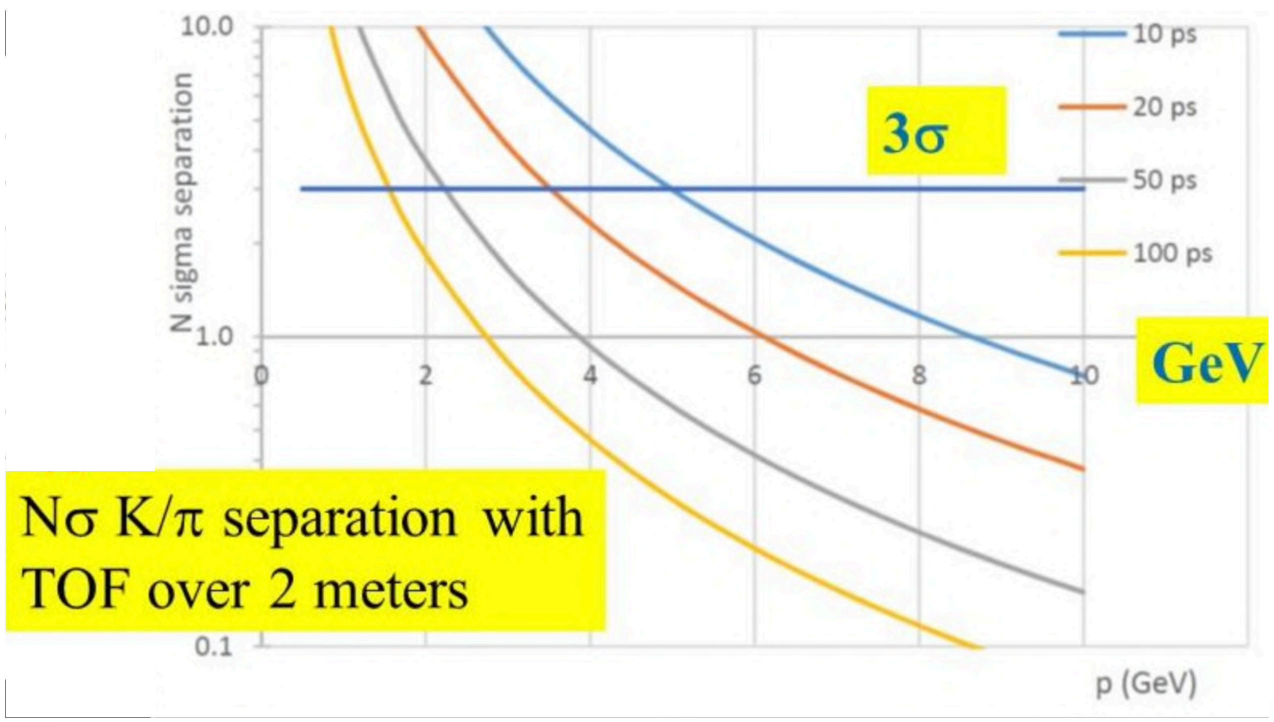
Updates on the IDEA Drift Chamber

Particle Identification



Excellent K/π separation

except 0.8<p<1.5 GeV

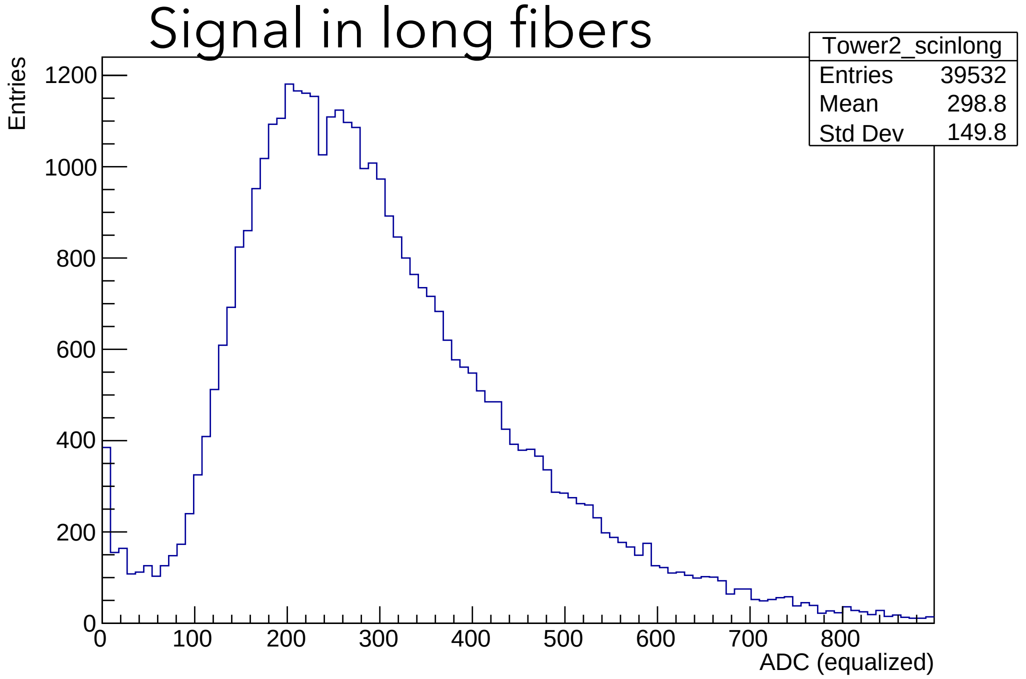


PID with TOF might become marginal,
if not needed at all..

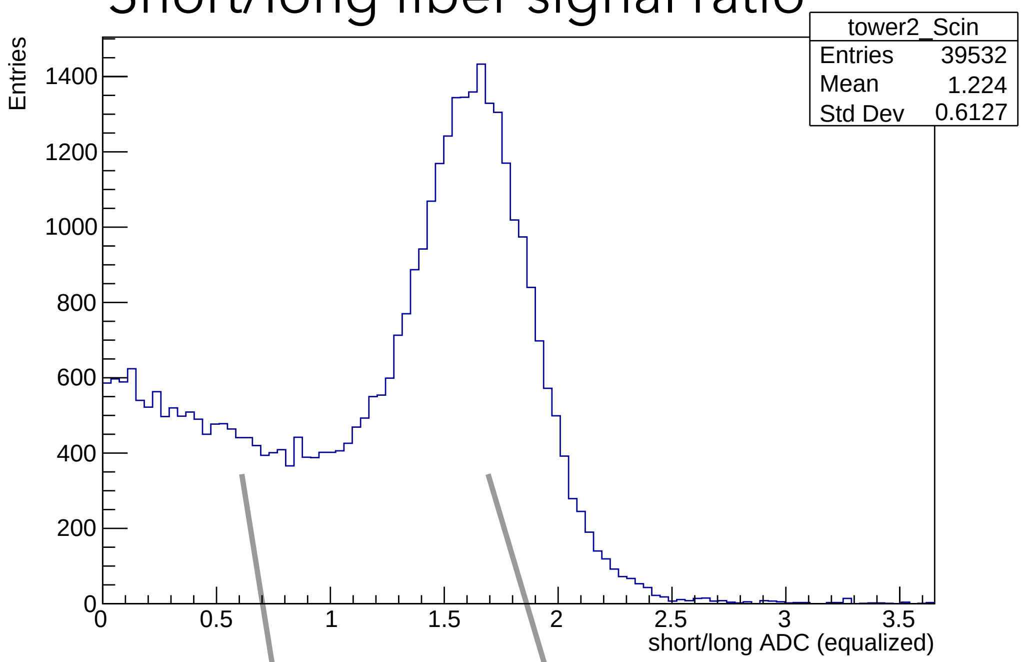
Updates on IDEA 2018 test beam

Scintillation channel - 60 GeV π⁻

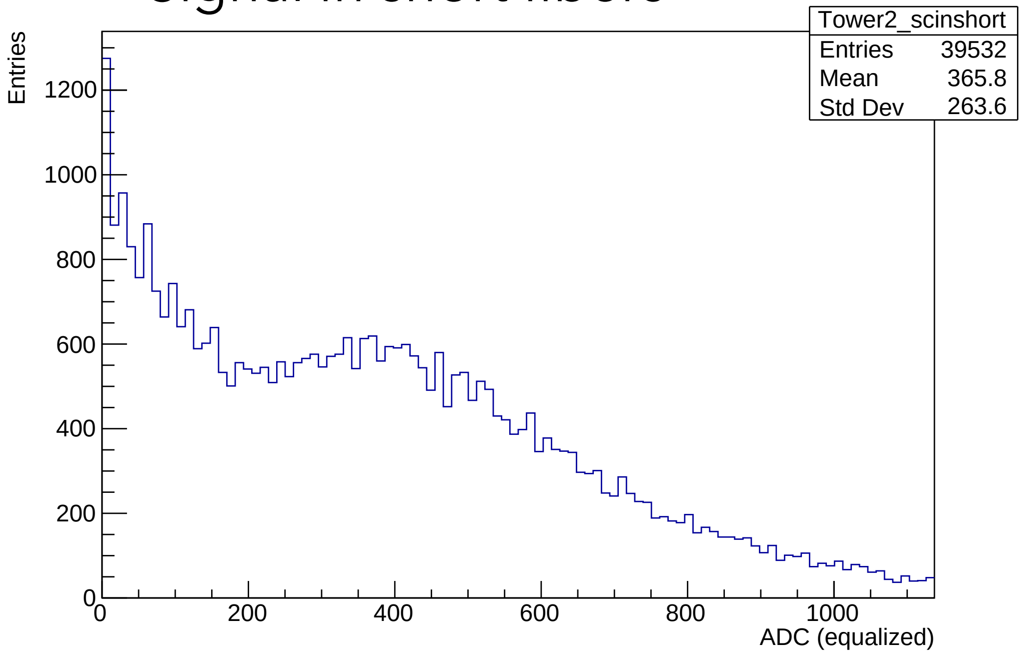
Signal in long fibers

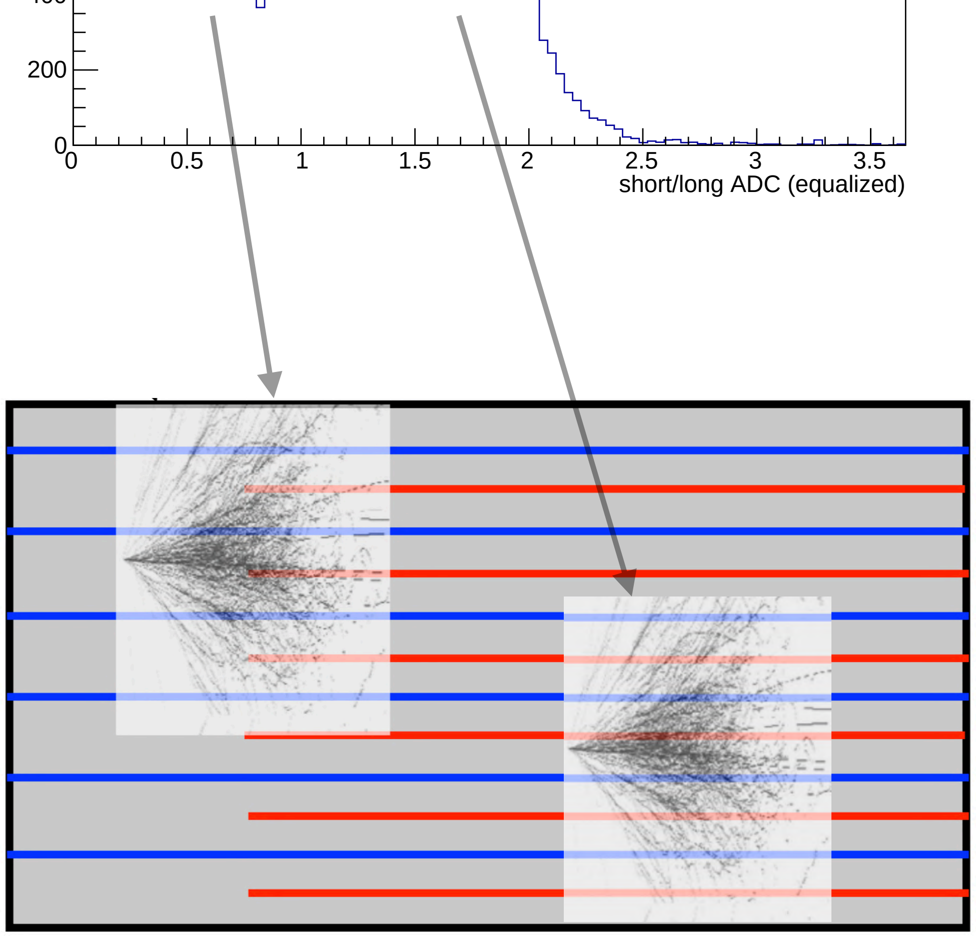


Short/long fiber signal ratio



Signal in short fibers



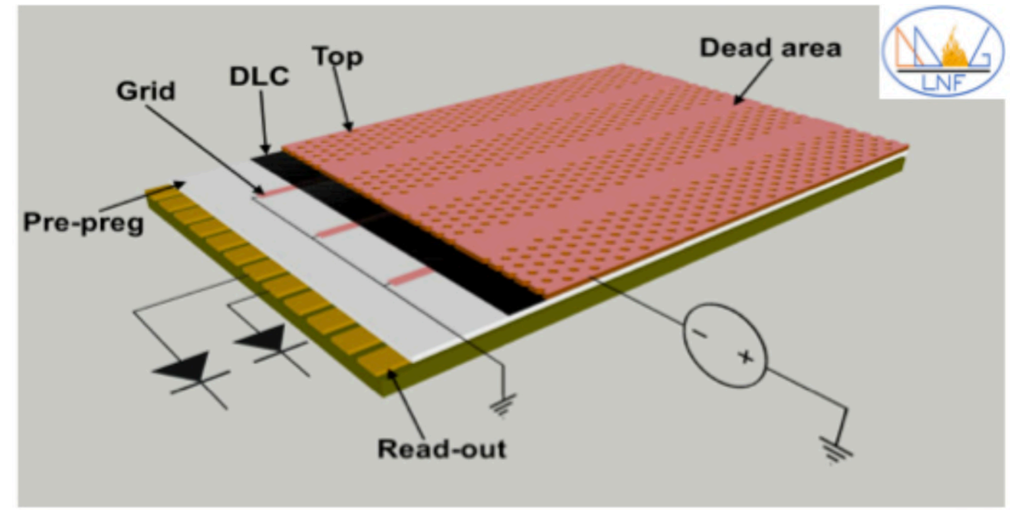


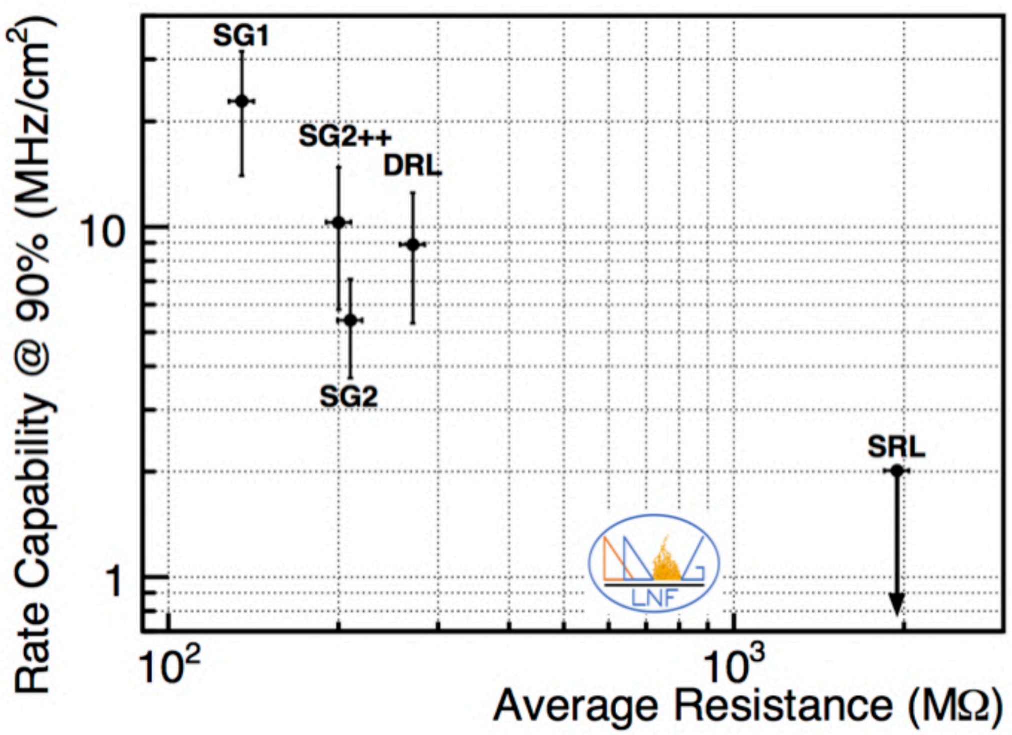
Updates on u-RWELL

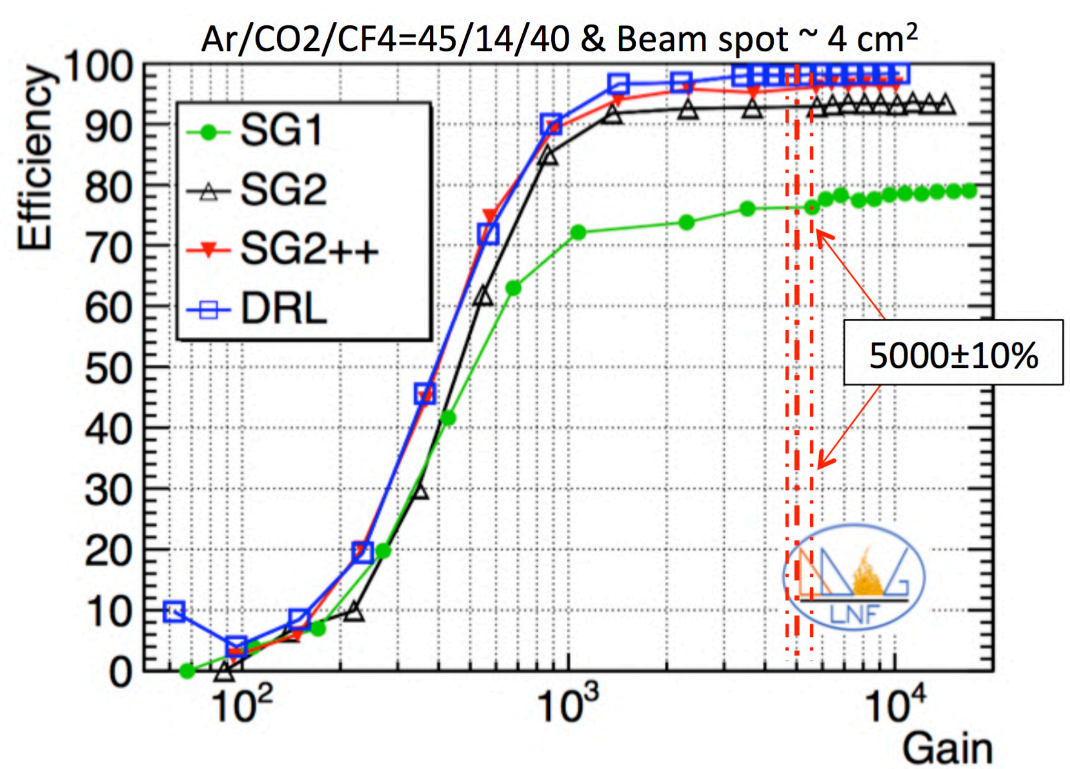
From low rates to high rates: the silver grid solution

Single Resistive Layer (SRL): 2-D current evacuation scheme based on a single resistive layer with a conductive grounding all around the perimeter.

A simplified high rate scheme on a single resistive layer with the implementation of a 2-D grounding based on conductive strip lines realized on the DLC layer.







	Pitch (um)	Dead area (um)
SG1	6	2
SG2	12	1.2
SG2++	12	0.6