The IDEA detector concept performance

Roberto Ferrari

on behalf of the INFN RD_FA collaboration

Oxford, April 16th, 2019

Requirements

Higgs physics:

recoil mass → tracking
b/c separation → vertex
2j, 4j, 2γ → calorimetry
τ → ρν → preshower / high-granularity calorimeter

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3 - 4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

Z, WW, tt → mostly covered by above
(Z → excellent acceptance determination)

More inputs

High luminosity:

→ low magnetic field (~2T) for beam emittance preservation

→ fast detector

Extremely high statistics at Z pole:

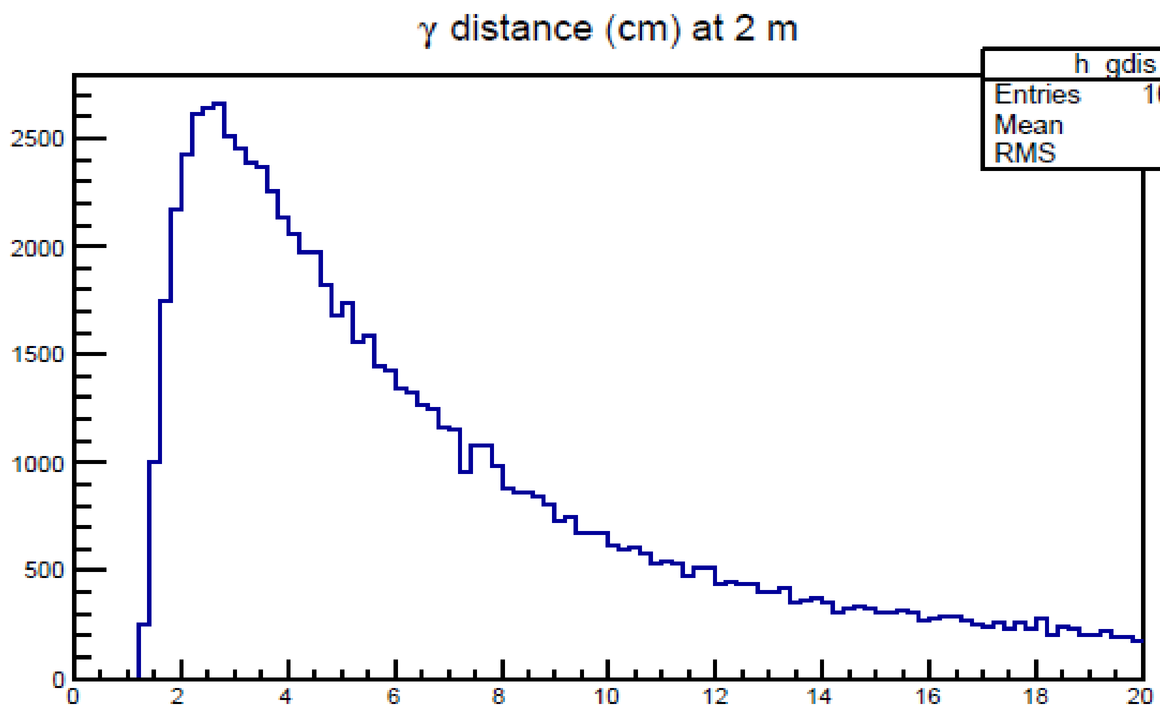
→ systematics on acceptance determination are critical

→ silicon layer after DCH for charged acceptance and resolution

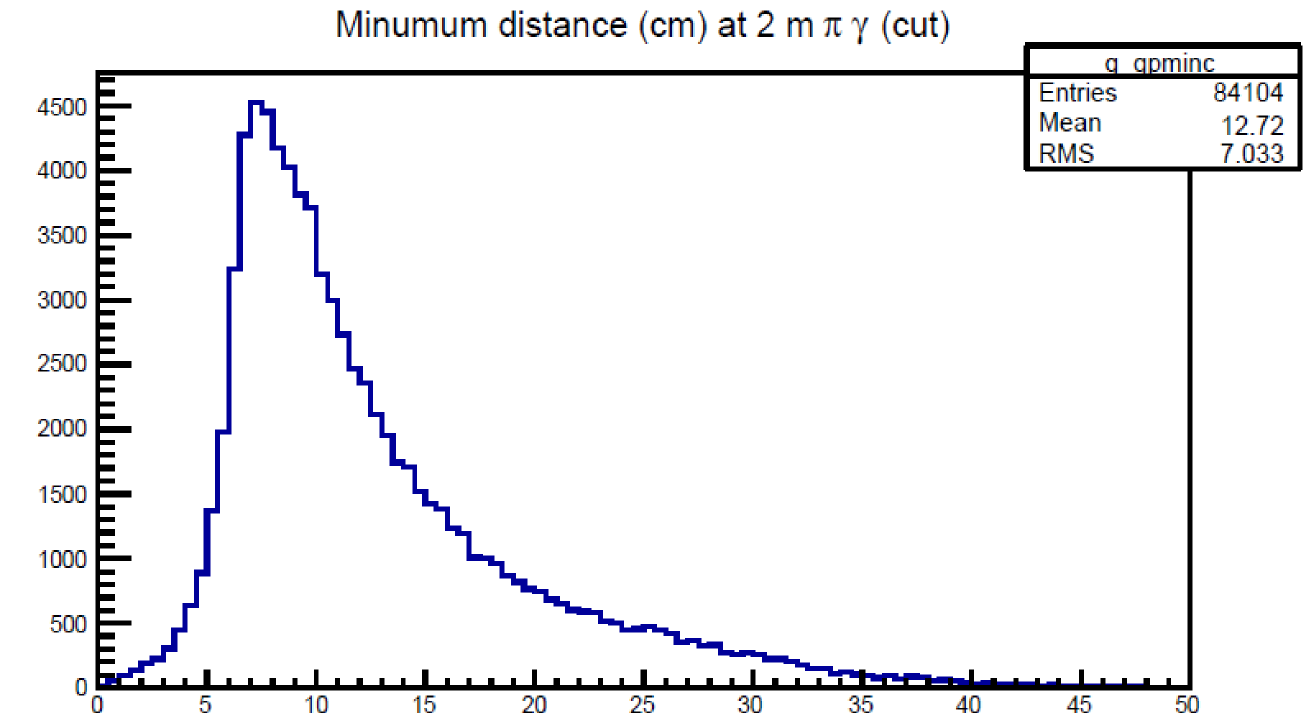
→ preshower for μm-level acceptance definition for γ.s

the $\tau^{\pm} \rightarrow \rho^{\pm}\upsilon \rightarrow \pi^{\pm}\pi^{0}\upsilon$ case

$$[\, Z \rightarrow \tau^{+}\tau^{-} \,] \rightarrow [\, \tau^{+} \rightarrow \rho^{+}\upsilon \rightarrow \pi^{+}\pi^{0}\upsilon \,]$$



2γ separation (cm) @ 2 m



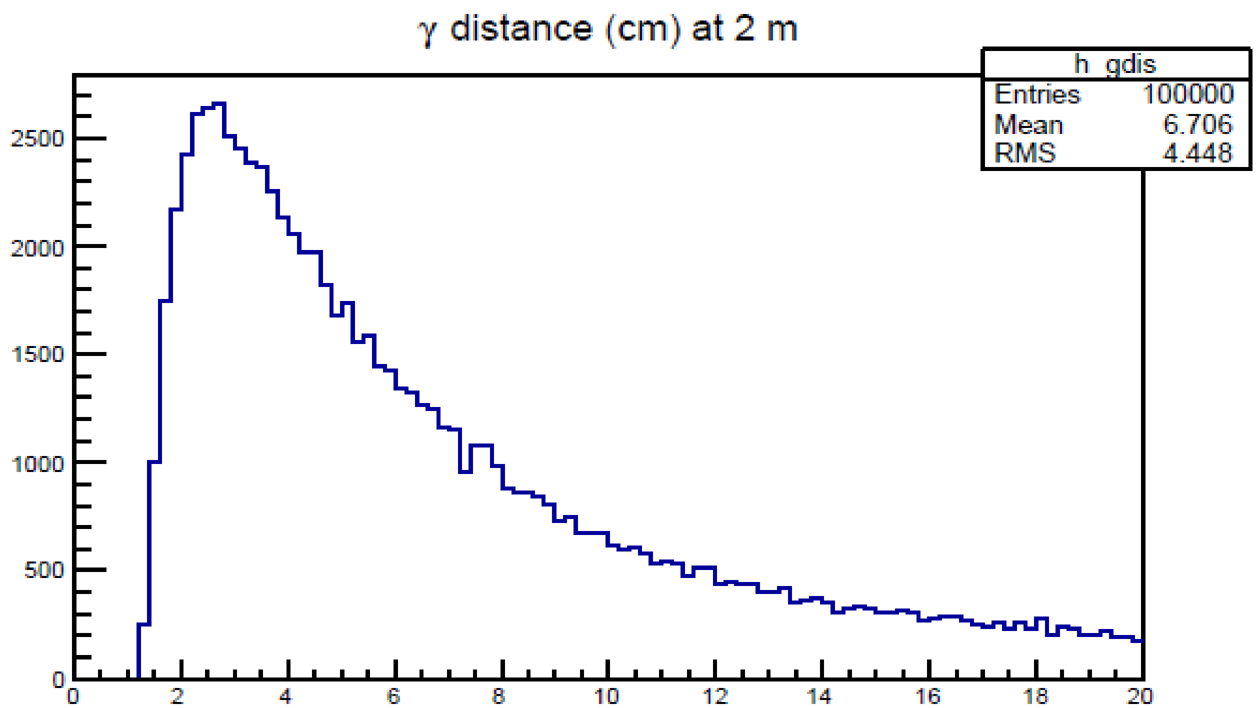
Min(γ, π^{+}) separation (cm) @ 2 m

High-granularity calorimetry + preshower
→ π^{0} identification and direction

Q: does require longitudinal segmentation ?

the $\tau^{\pm} \rightarrow \rho^{\pm}\upsilon \rightarrow \pi^{\pm}\pi^{0}\upsilon$ case

$$[\, Z \rightarrow \tau^{+}\tau^{-} \,] \rightarrow [\, \tau^{+} \rightarrow \rho^{+}\upsilon \rightarrow \pi^{+}\pi^{0}\upsilon \,]$$



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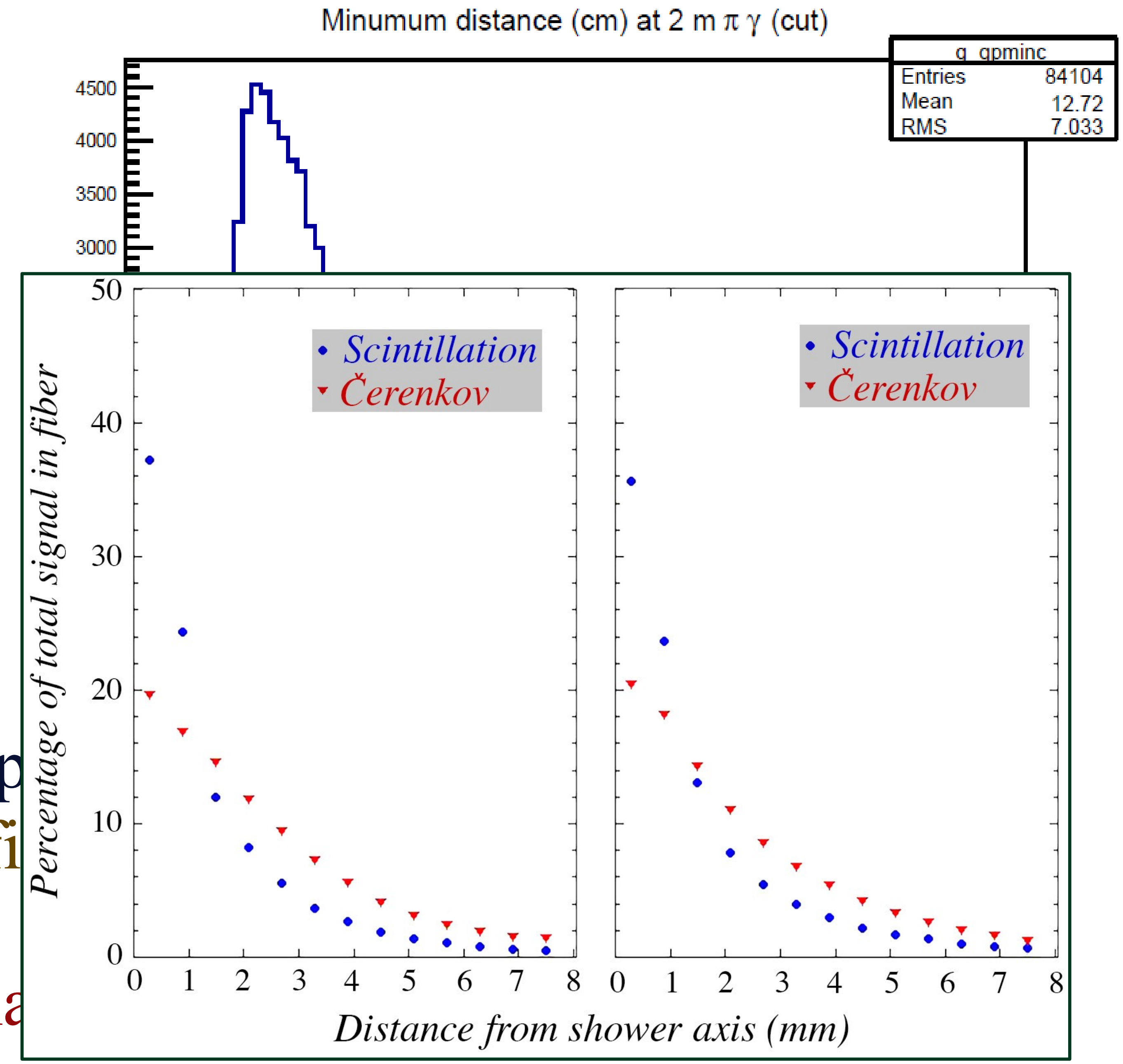
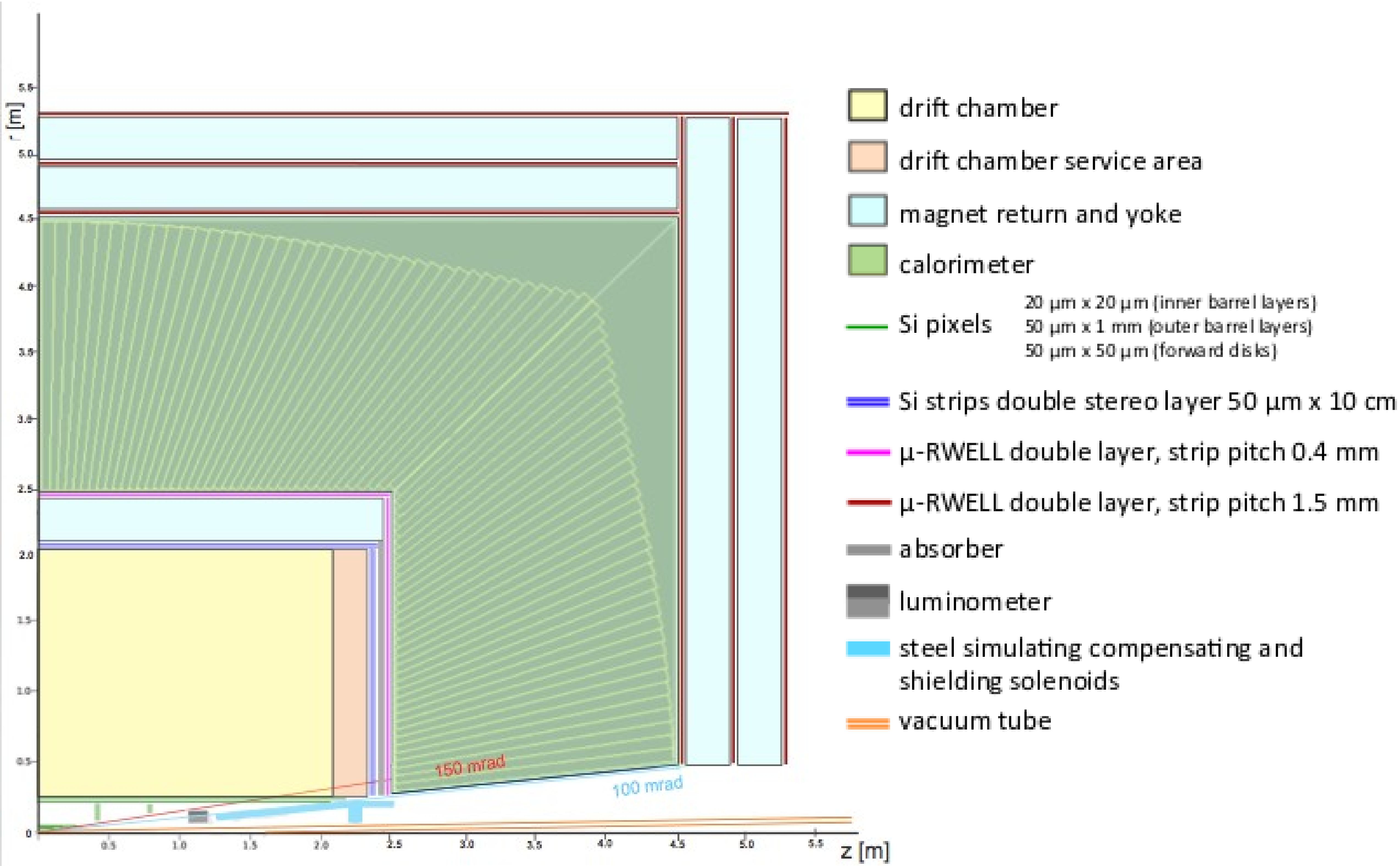


High-granularity calorimetry + p

$\rightarrow \pi^{0}$ identifi

Q: does require longitudina

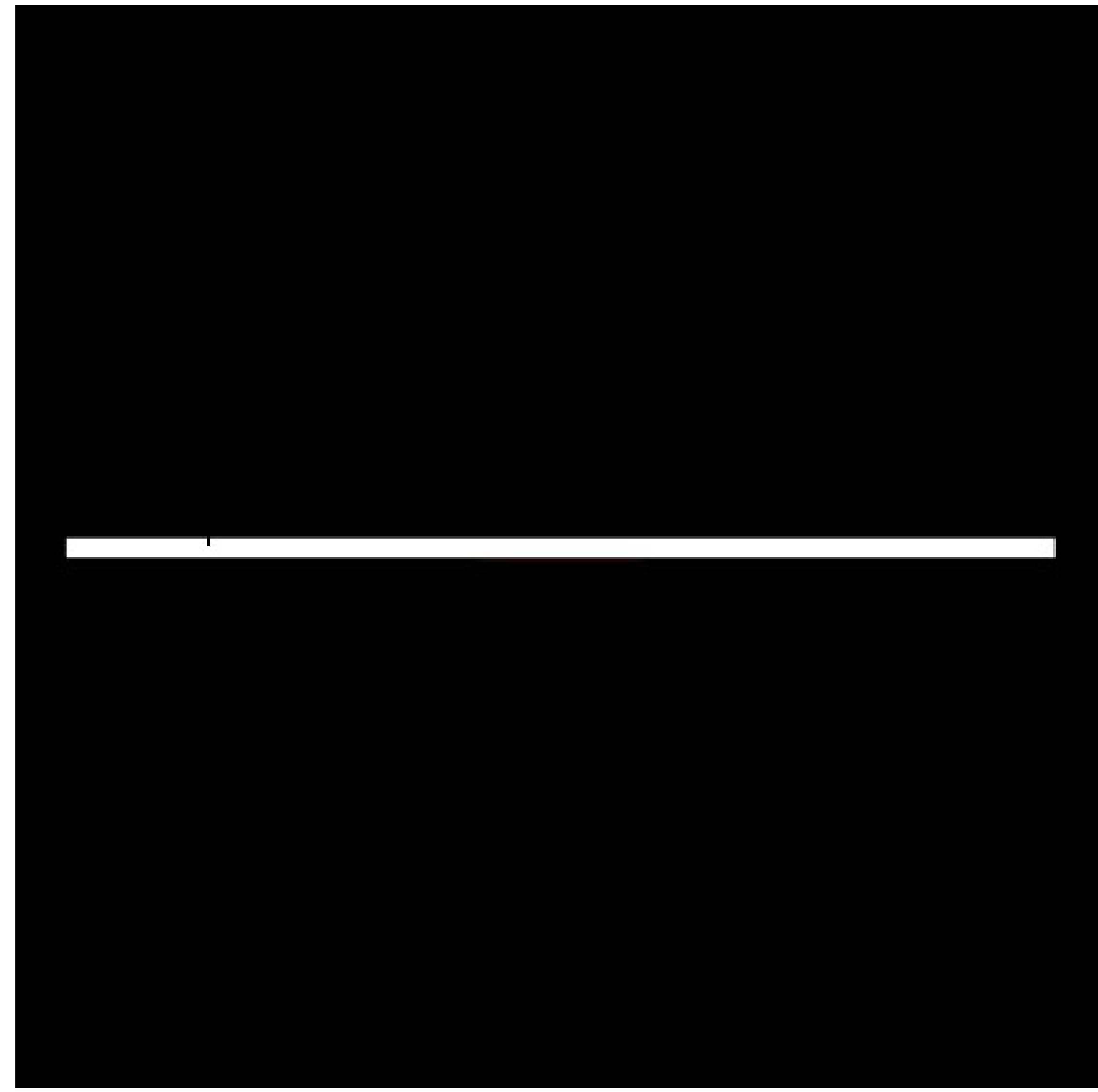
IDEA layout



drift chamber
drift chamber service area
magnet return and yoke
calorimeter
Si pixels
20 μm x 20 μm (inner barrel layers)
50 μm x 1 mm (outer barrel layers)
50 μm x 50 μm (forward disks)
Si strips double stereo layer 50 μm x 10 cm
μ-RWELL double layer, strip pitch 0.4 mm
μ-RWELL double layer, strip pitch 1.5 mm
absorber
luminometer
steel simulating compensating and shielding solenoids
vacuum tube
150 mrad
100 mrad
r [m]
z [m]

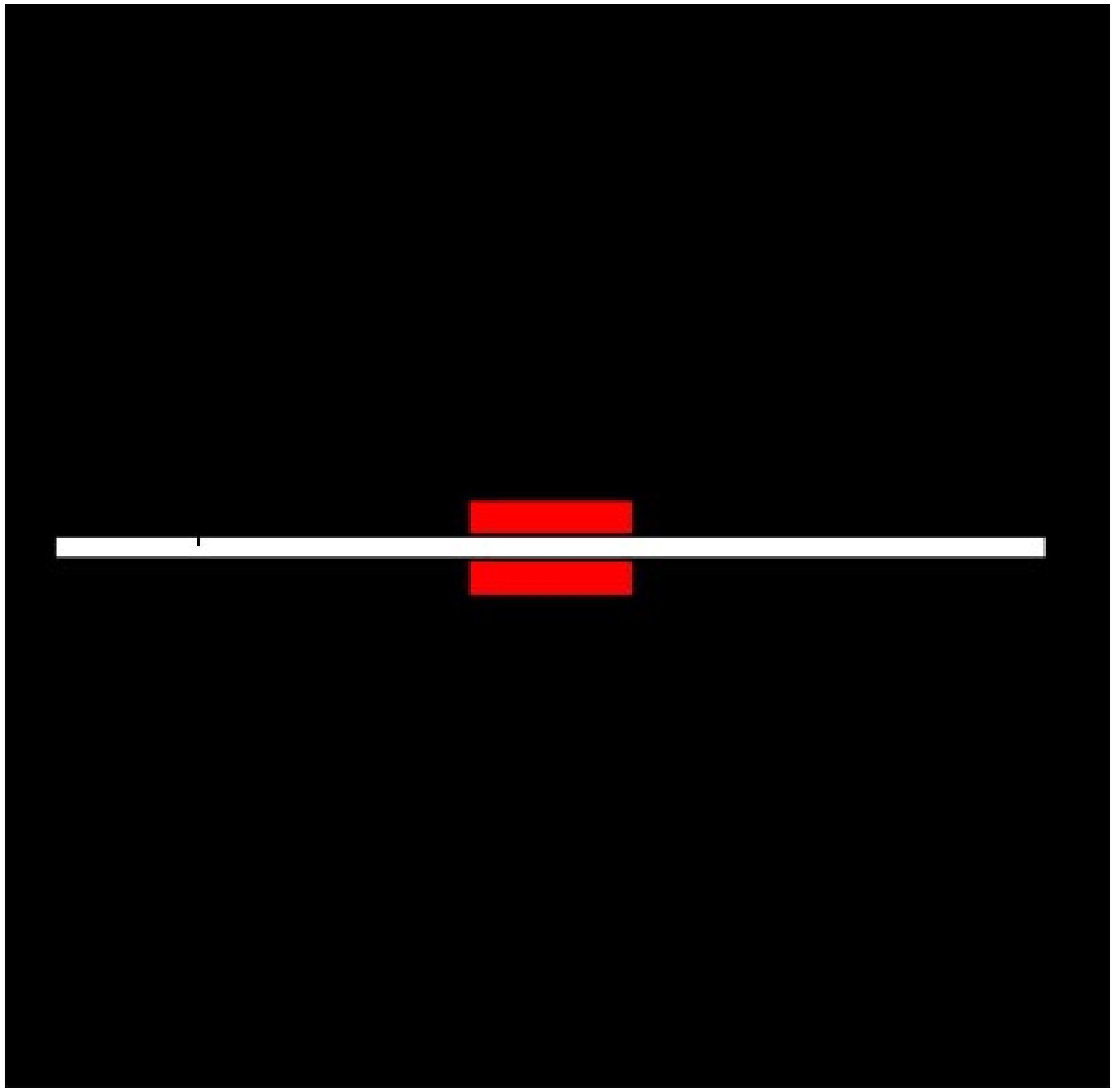
IDEA layout

1) Beam pipe (R ~ 1.5 cm)



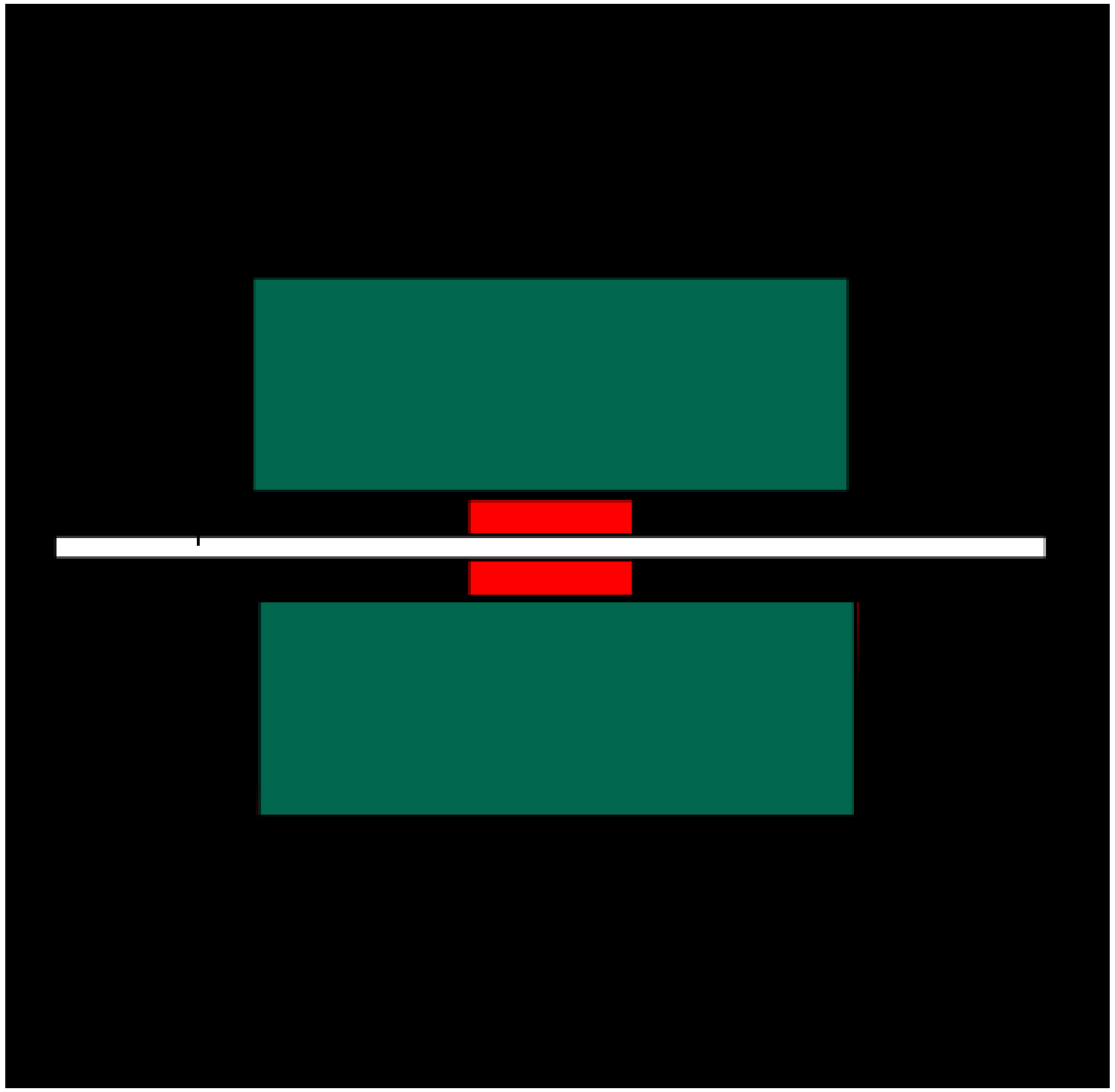
IDEA layout

1) Beam pipe (R ~ 1.5 cm)
2) VTX: 4-7 MAPS layers



IDEA layout

1) Beam pipe (R ~ 1.5 cm)
2) VTX: 4-7 MAPS layers
3) DCH: 4 m long, R ~ 30-200 cm



IDEA layout

1) Beam pipe (R ~ 1.5 cm)
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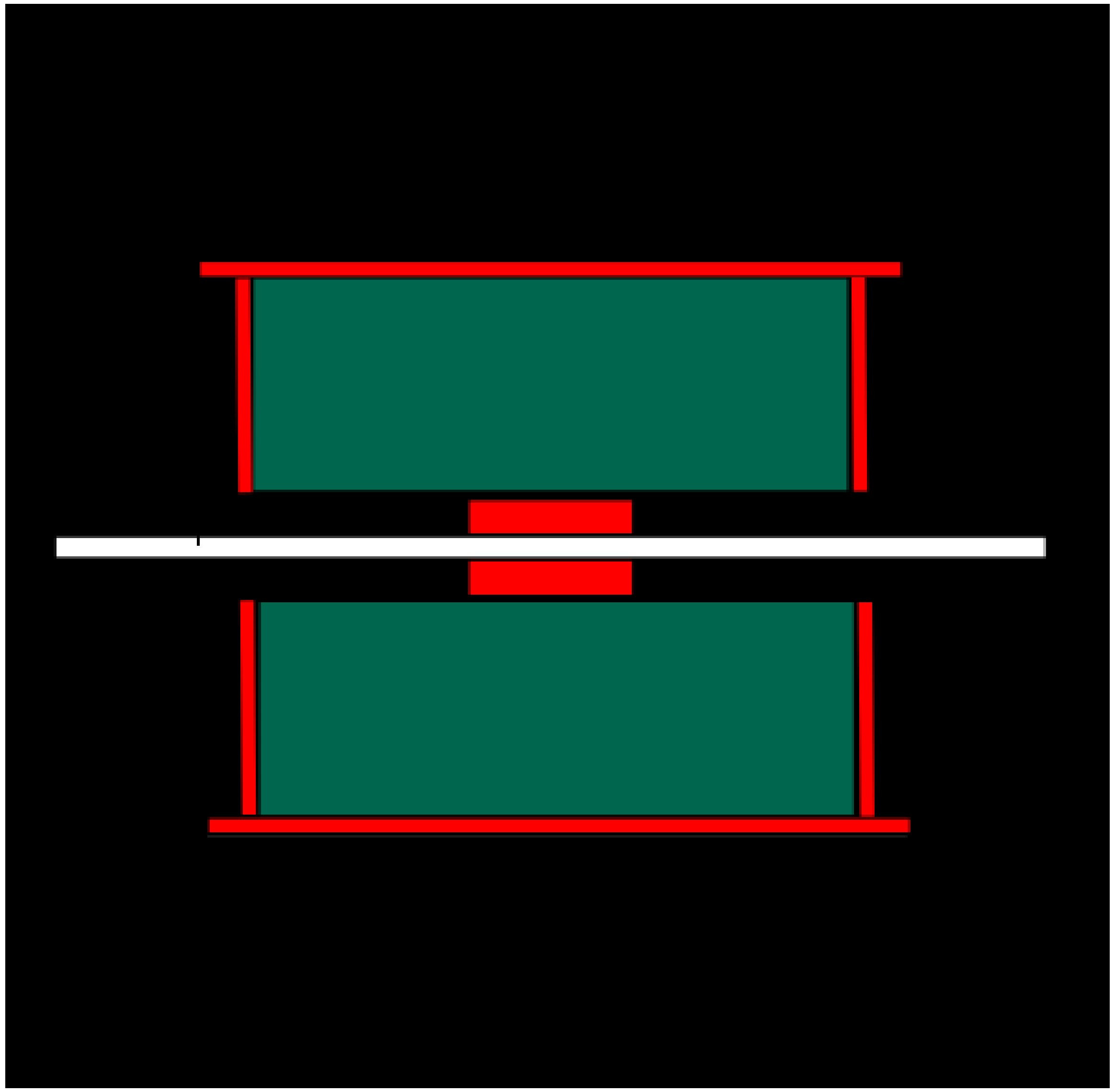
4) Outer Silicon Layer



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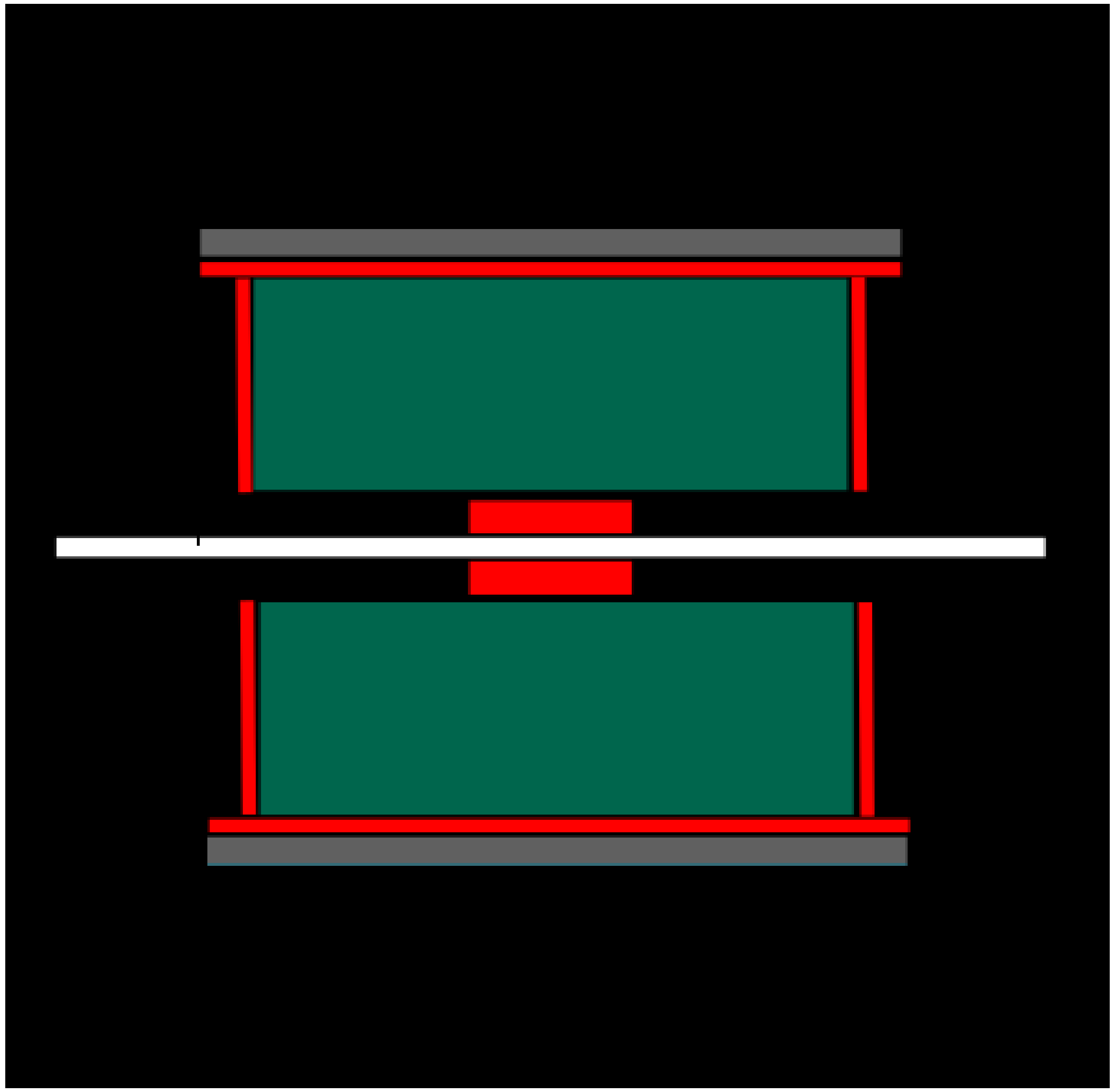
5) SC coil: R ~ 210 cm



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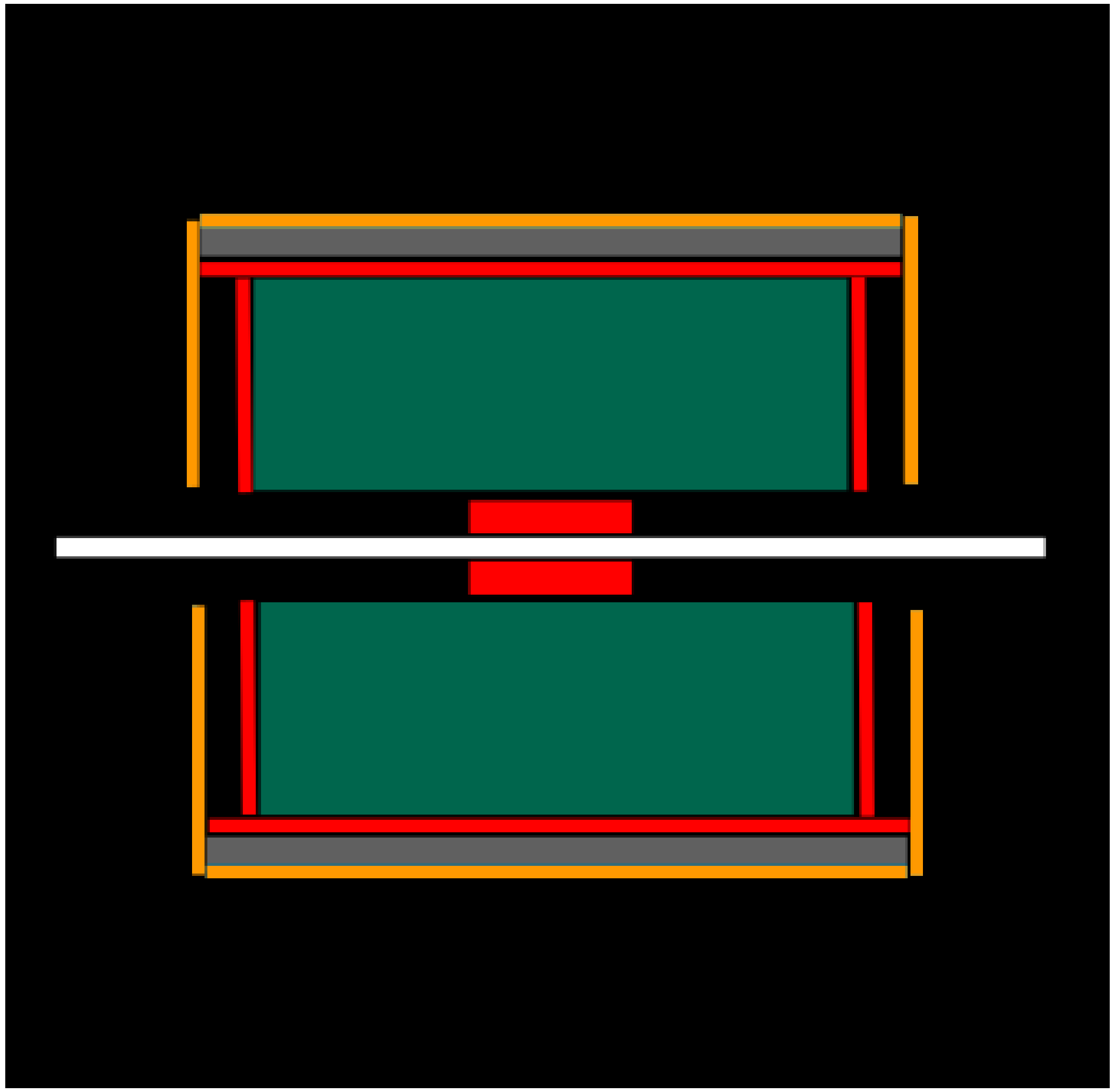
6) Preshower: ~ 1 X_0



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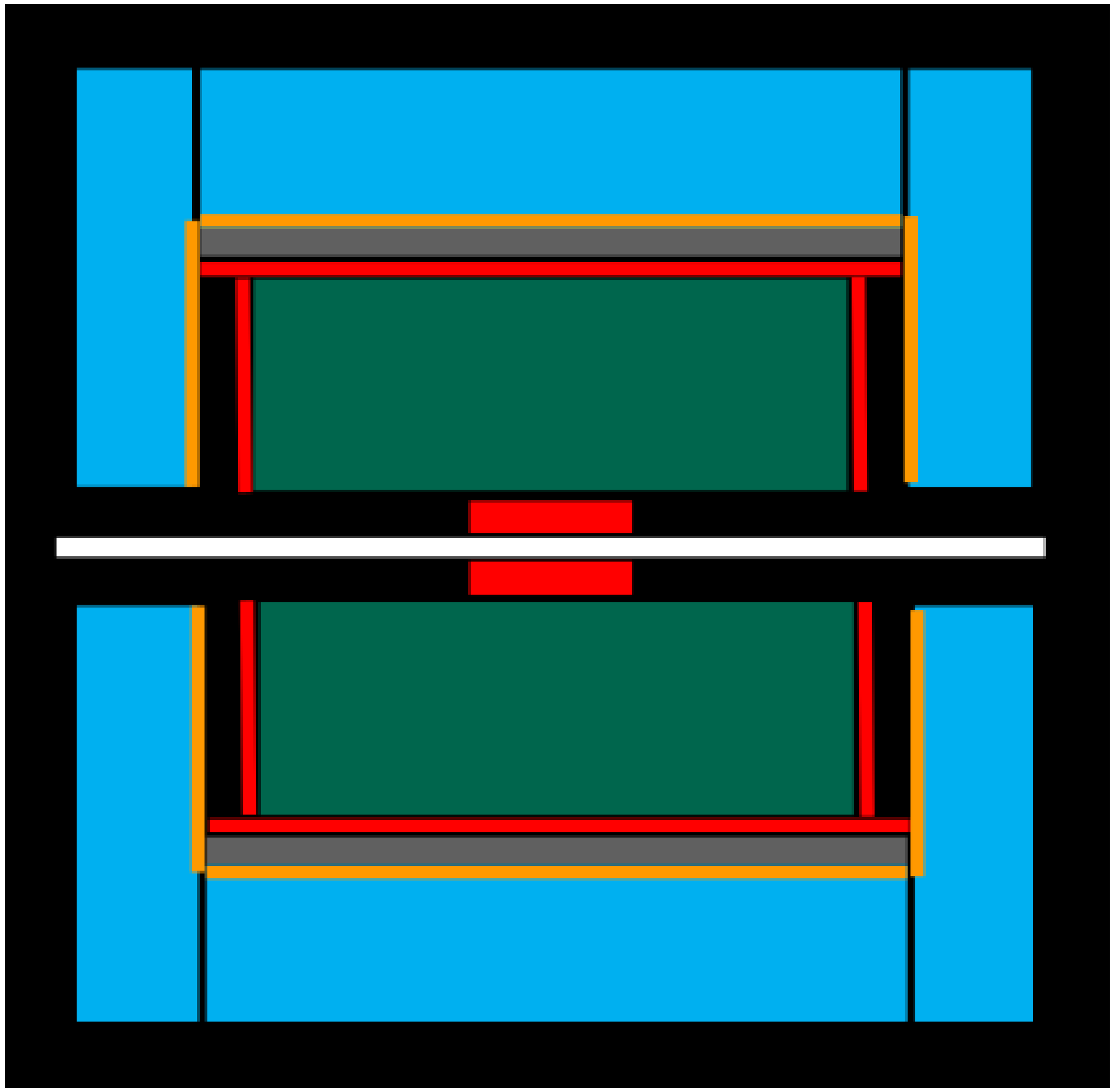
7) DR calorimeter: ~ 2 m / 7 λ_{int}



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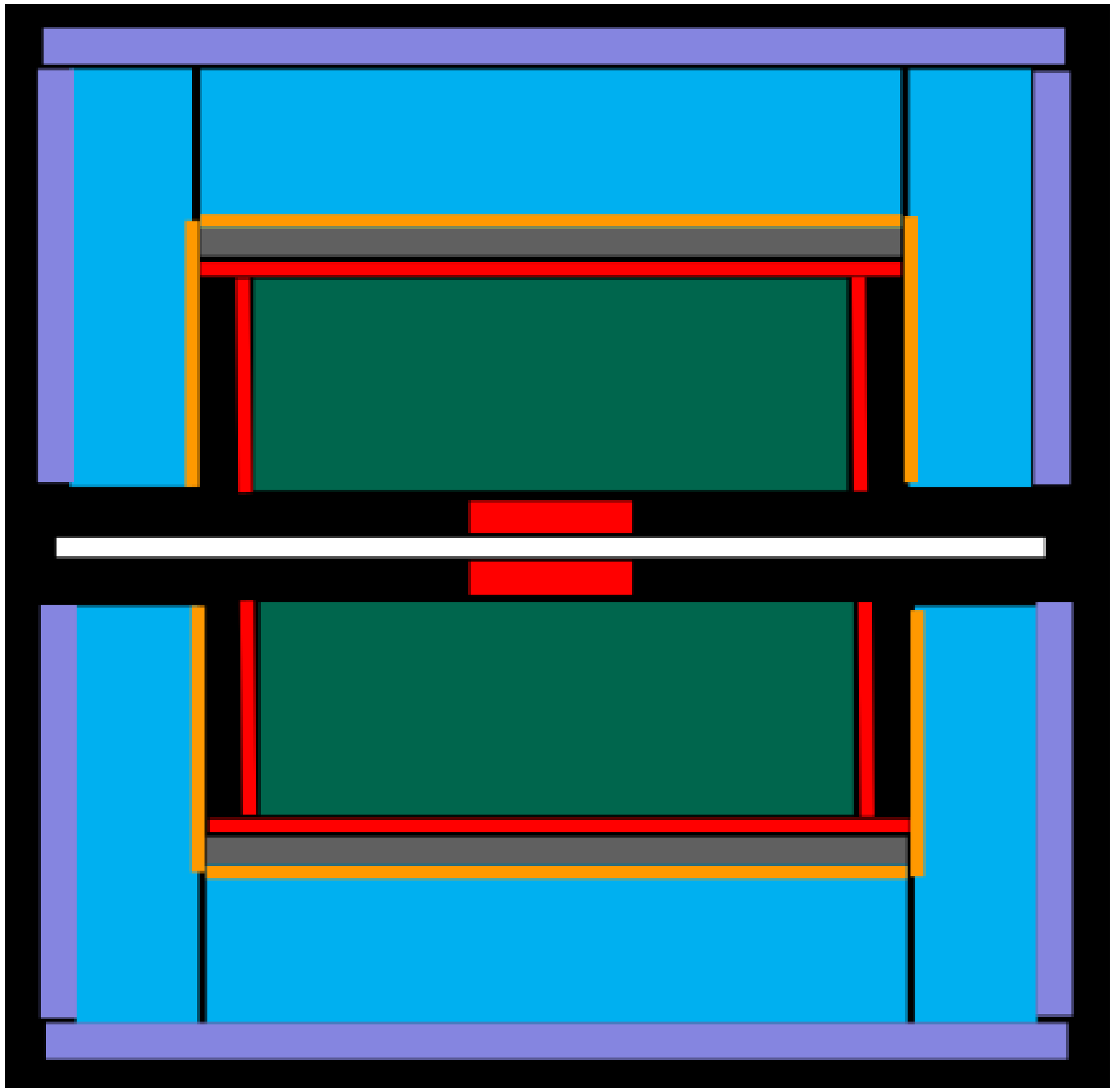
8) Yoke + muon spectrometer



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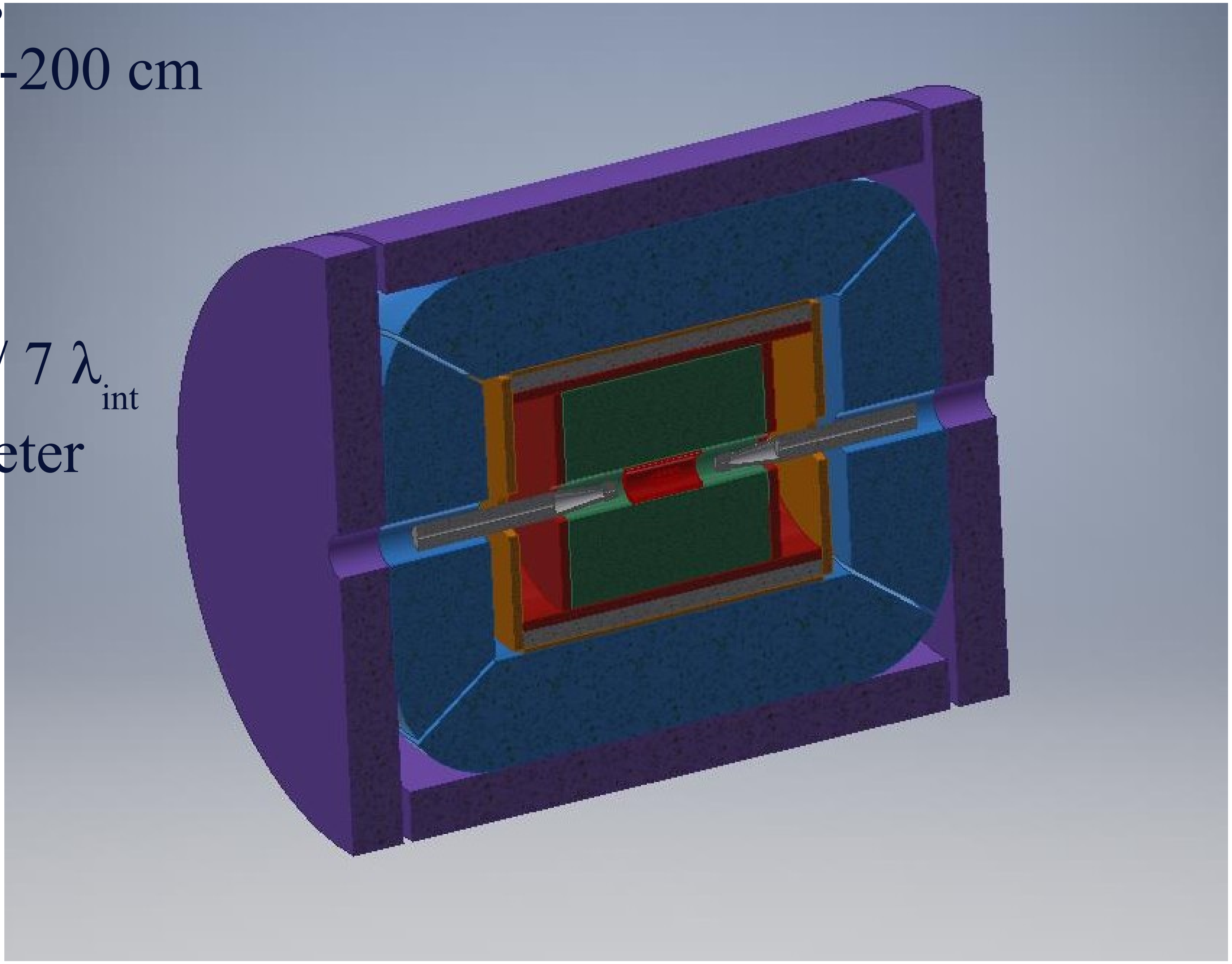
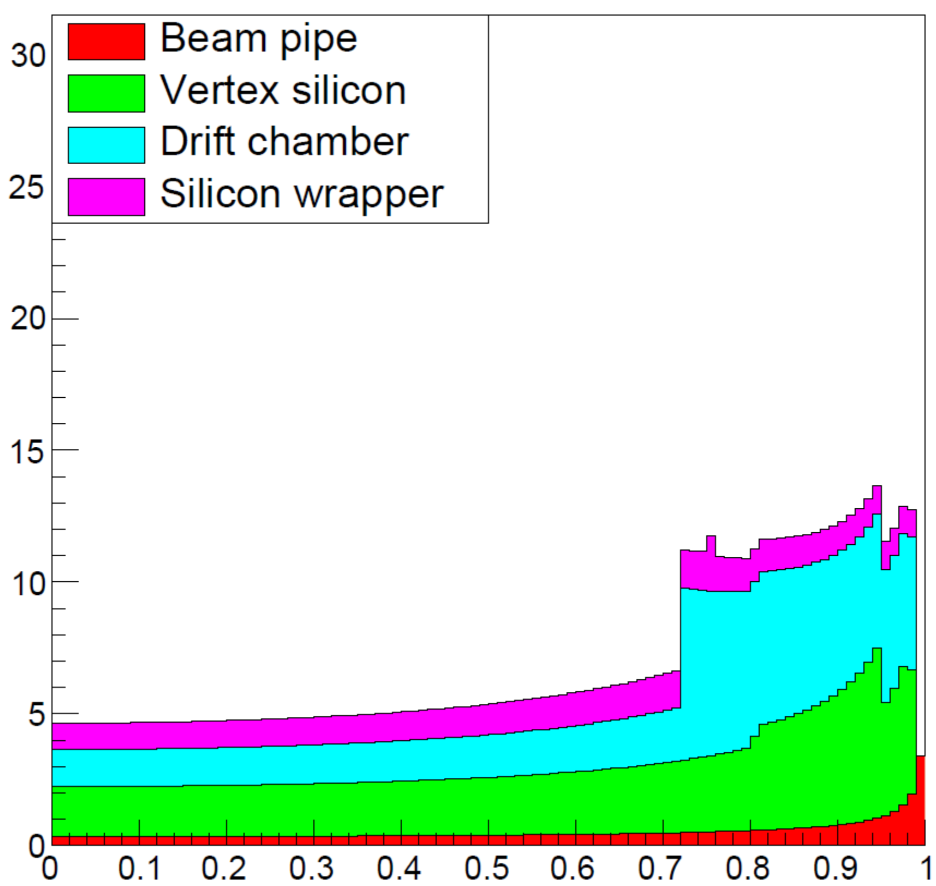


Material budget

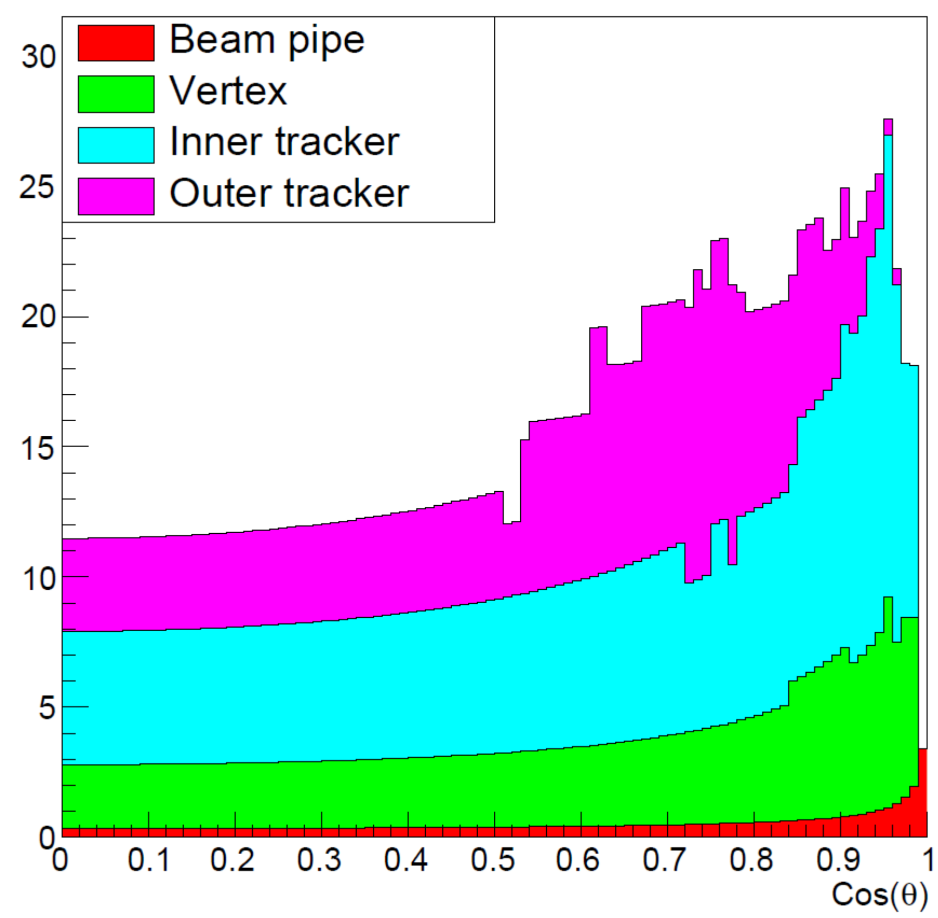
% X_0 vs. cos θ

F. Bedeschi's talk

IDEA



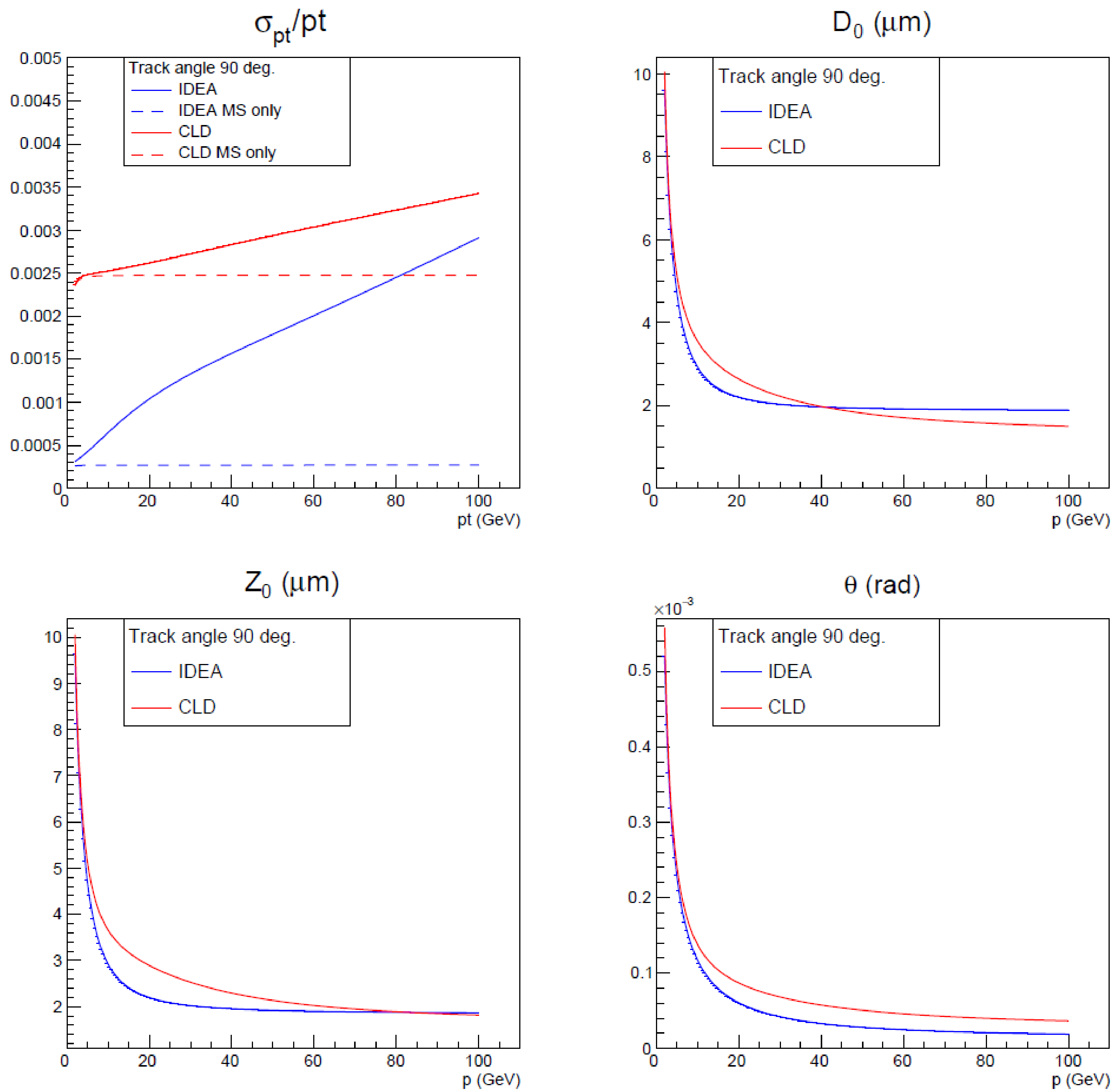
CLD



Vertex Detector

Build on ALICE ITS technology

- ~ 20 × 20 μm MAPS
  - ~ 3 μm spatial resolution
- X_0 : 0.15-1.0 % (in-out)
- ~ 20 mW/cm^2 (in-out)
- > 100 kHz readout
  - (or even faster)



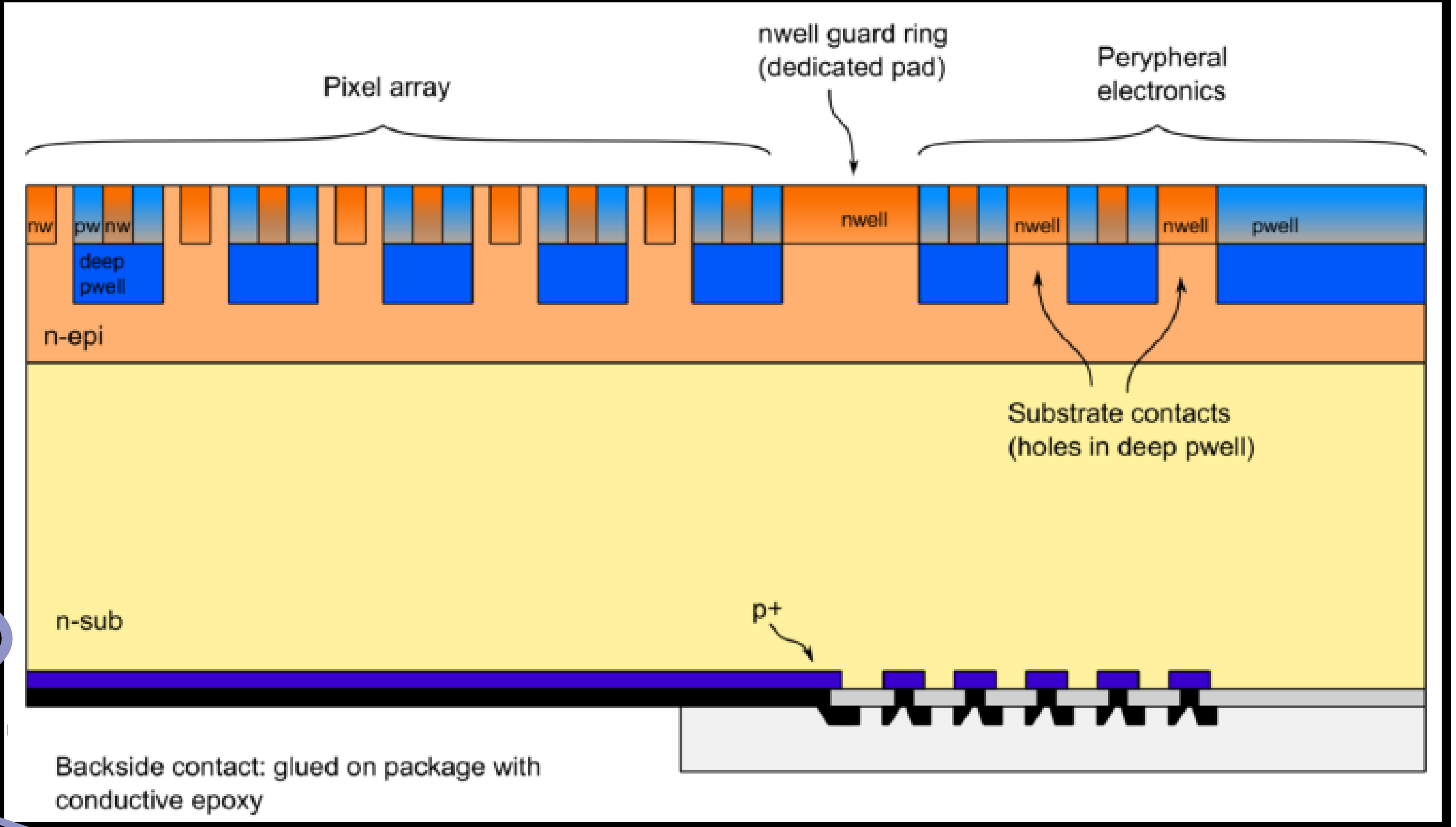
F. Bedeschi's talk

Pixel Detector R&D

ARCADIA: System-grade Demonstrator

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

- INFN CSNV Call Project: budget 1MEur
- Active sensor thickness in the range 50 μm to 500 μm or more
- Operation in full depletion with fast charge collection by drift
- Small charge collecting electrode for optimal signal-to-noise ratio
- Scalable readout architecture with ultra-low power capability (O(10mW/cm^2)
- Easy compatibility with standard CMOS processes.
- Deliverable: full-size system-ready demonstrator of a low-power High-density pixel matrix CMOS monolithic sensor



Critical to avoid liquid cooling

Drift Chamber

Ultra-light Drift Chamber (< 1% X_0)

- gas: He 90% - iC_4H_{10} 10%
- 4 m long, ~ 1 cm drift length

  - fast (drift time ~400 ns)
  - good spatial resolution (σ_{xy} < 100 μm)

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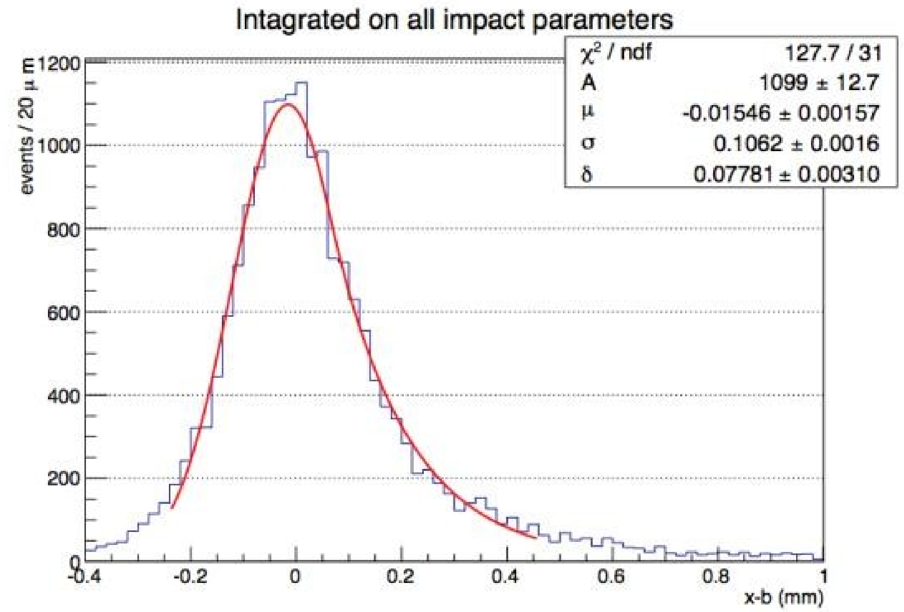

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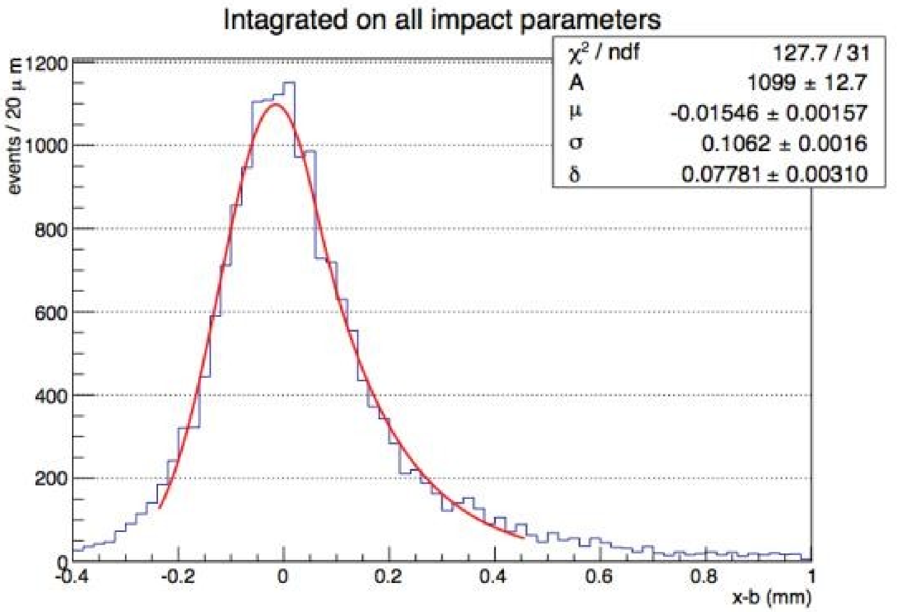

$L = 1.7$ m , $N_{meas} = 112$ → $\Delta(1/P_T) \approx 7 \times 10^{-5}$ / GeV (standalone)

See F. Grancagnolo's talk

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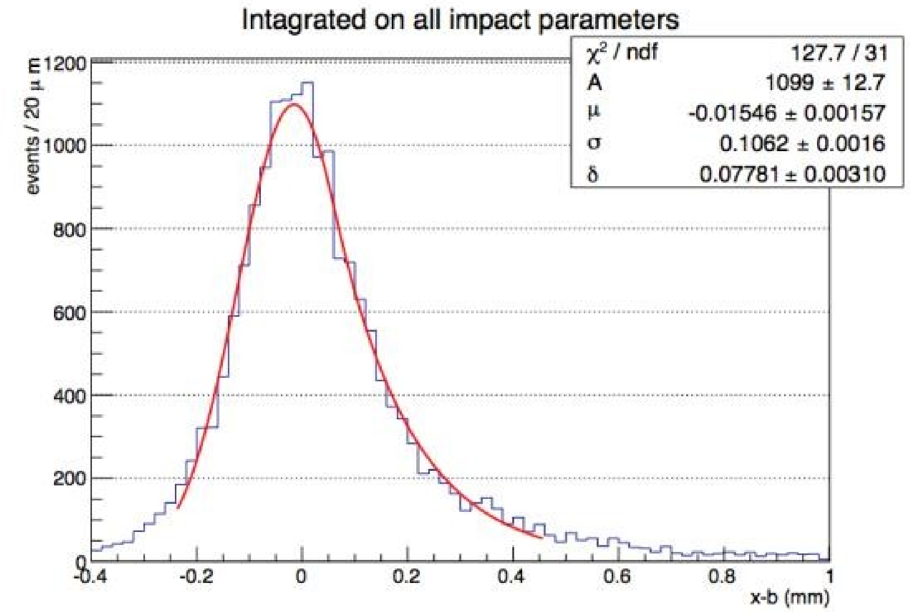
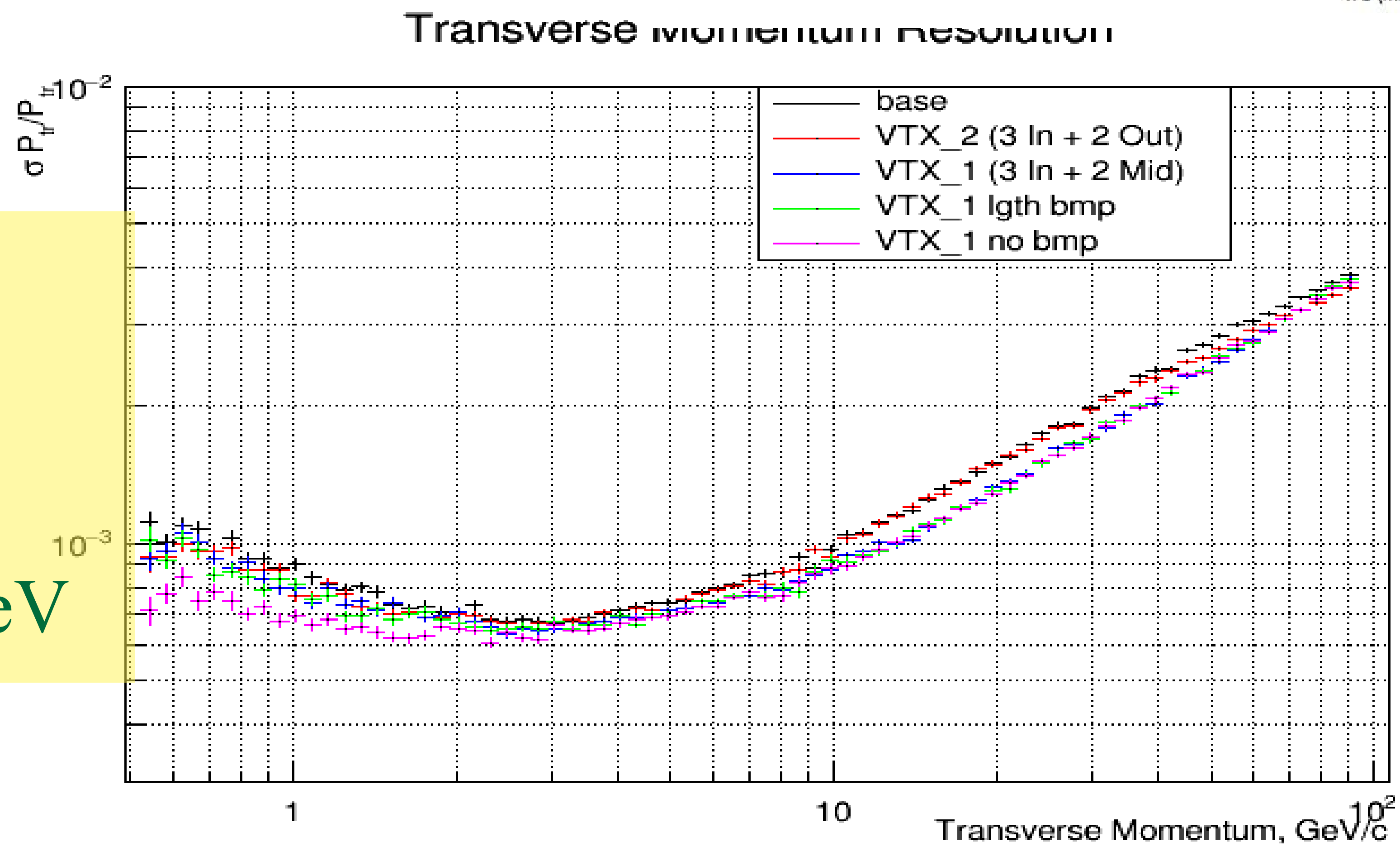




θ = 65°

DCH + VTX + Silicon

$\Delta P_T/P_T$ ~ 0.4% @ 100 GeV

Drift Chamber

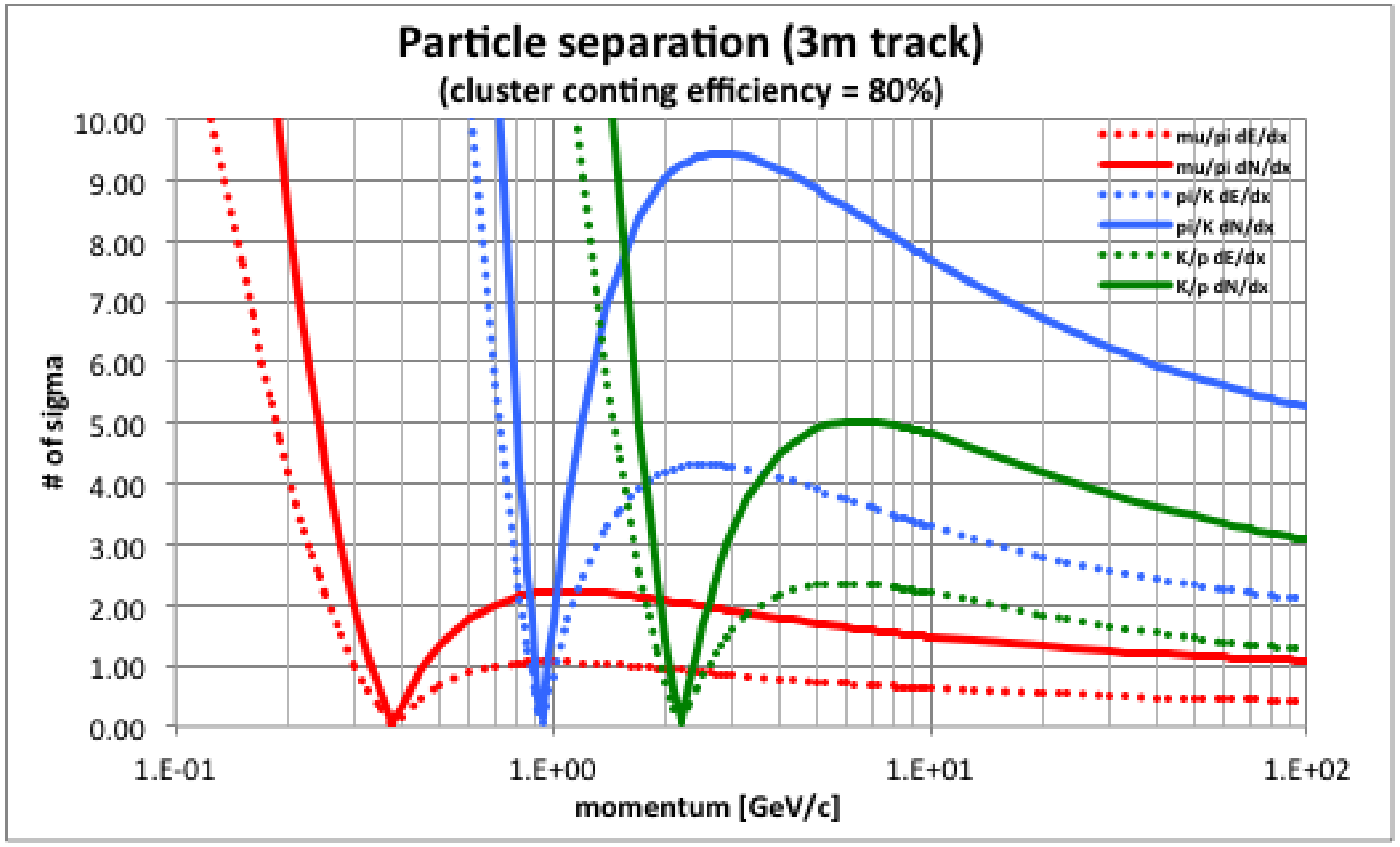
Ultra-light Drift Chamber (< 1% X_0)

gas: He 90% - iC_4H_{10} 10%

4 m long, ~ 1 cm drift length

excellent PId w/ cluster counting

dE/dx ~ 4%
dN/dx ~ 2%



Tested w/ beam in September 2018

Solenoid

1) Ultra-thin & transparent

→ ~ 30 cm (0.74 X_0 at $\eta = 0$)

2) Around tracker R_{in} ~ 2 m

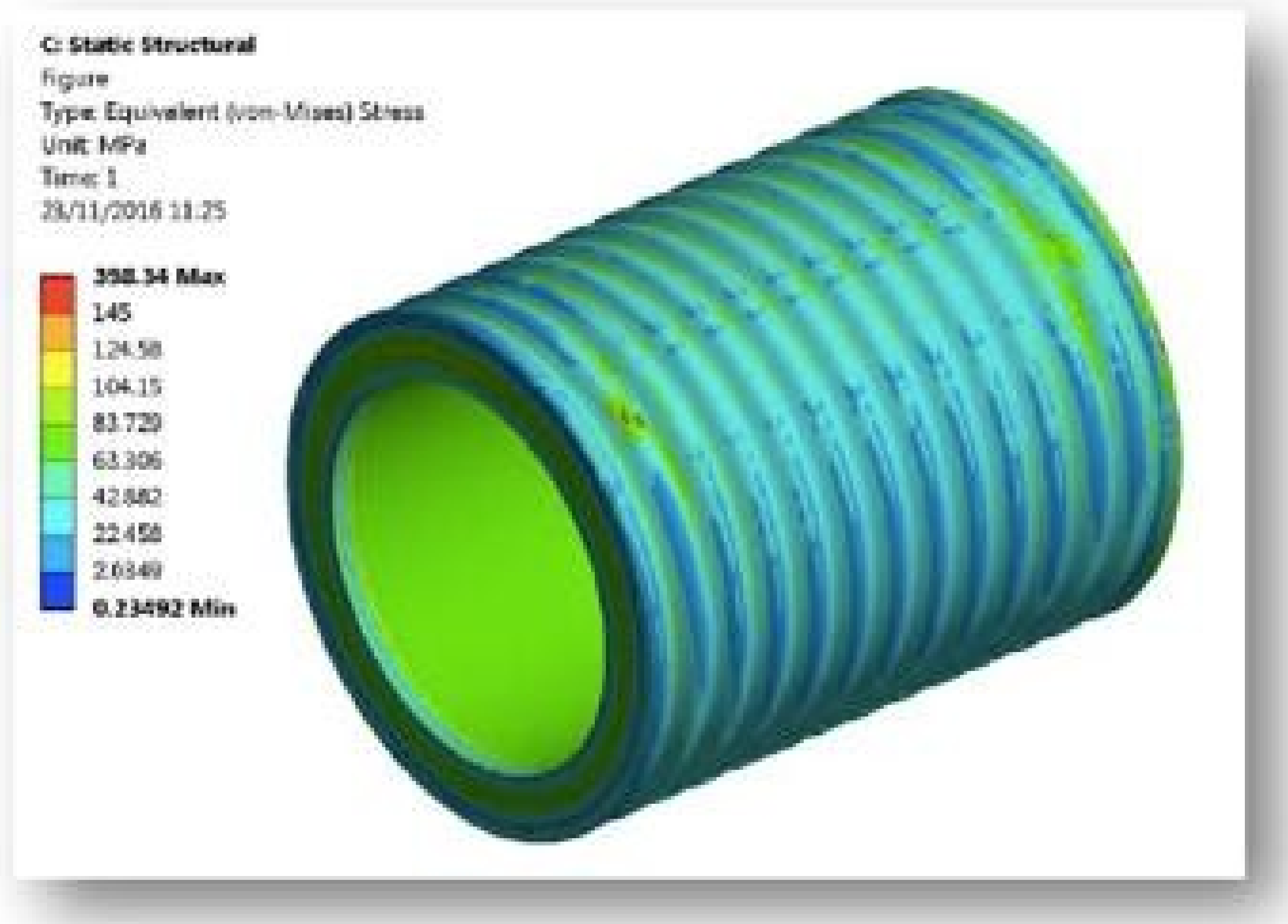
→ saving (with respect to R_{cal} ~ 4 m) :

factor ~ 4.2 in stored energy

factor ~ 2.1 in cost

See H. Ten Kate's talk at FCCee workshop

Property	Value
Magnetic field in center [T]	2
Free bore diameter [m]	4
Stored energy [MJ]	170
Cold mass [t]	8
Cold mass inner radius [m]	2.2
Cold mass thickness [m]	0.03
Cold mass length [m]	6

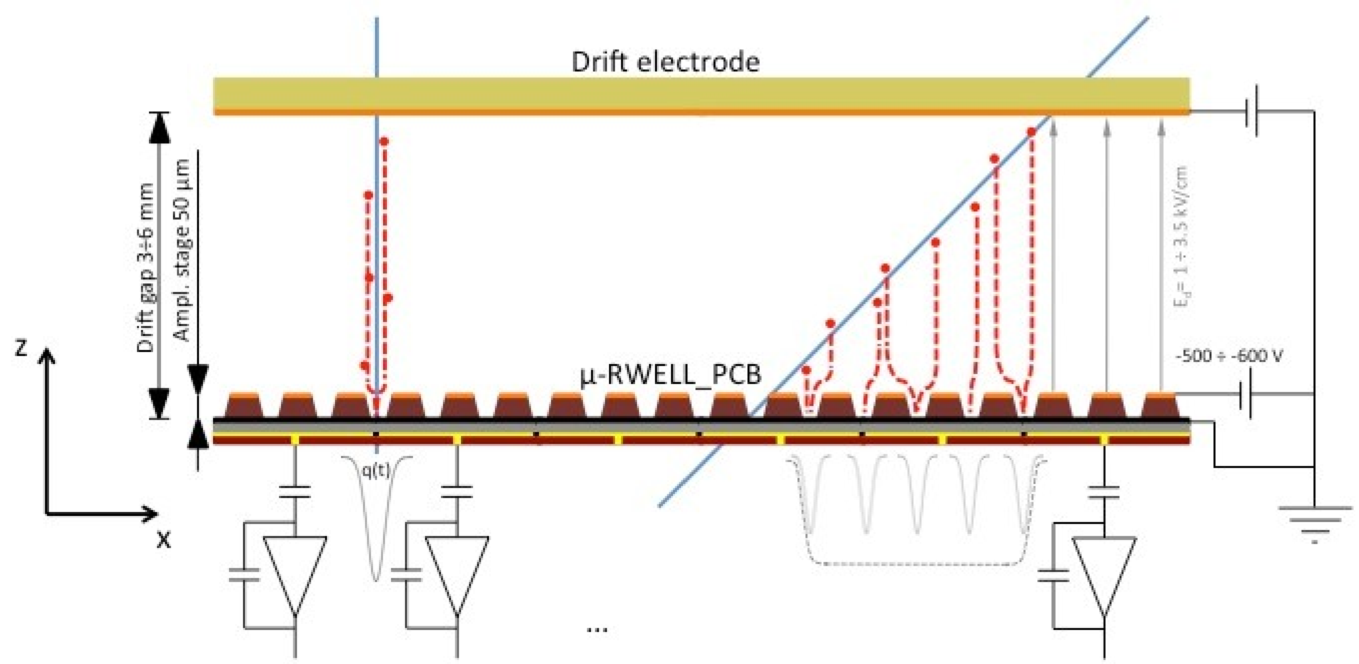


Preshower & Muon Detectors

Preshower : ~ 120 (240) m^2 of 2D (1D) readout planes
Muon spectrometer : ~ 900 (1800) m^2 of 2D (1D) readout planes

→ new generation (fusion) MPDG
→ micro-resistive Well (μ-RWELL)
→ resolution < ~ 40 μm

Tested w/ beam in September 2018

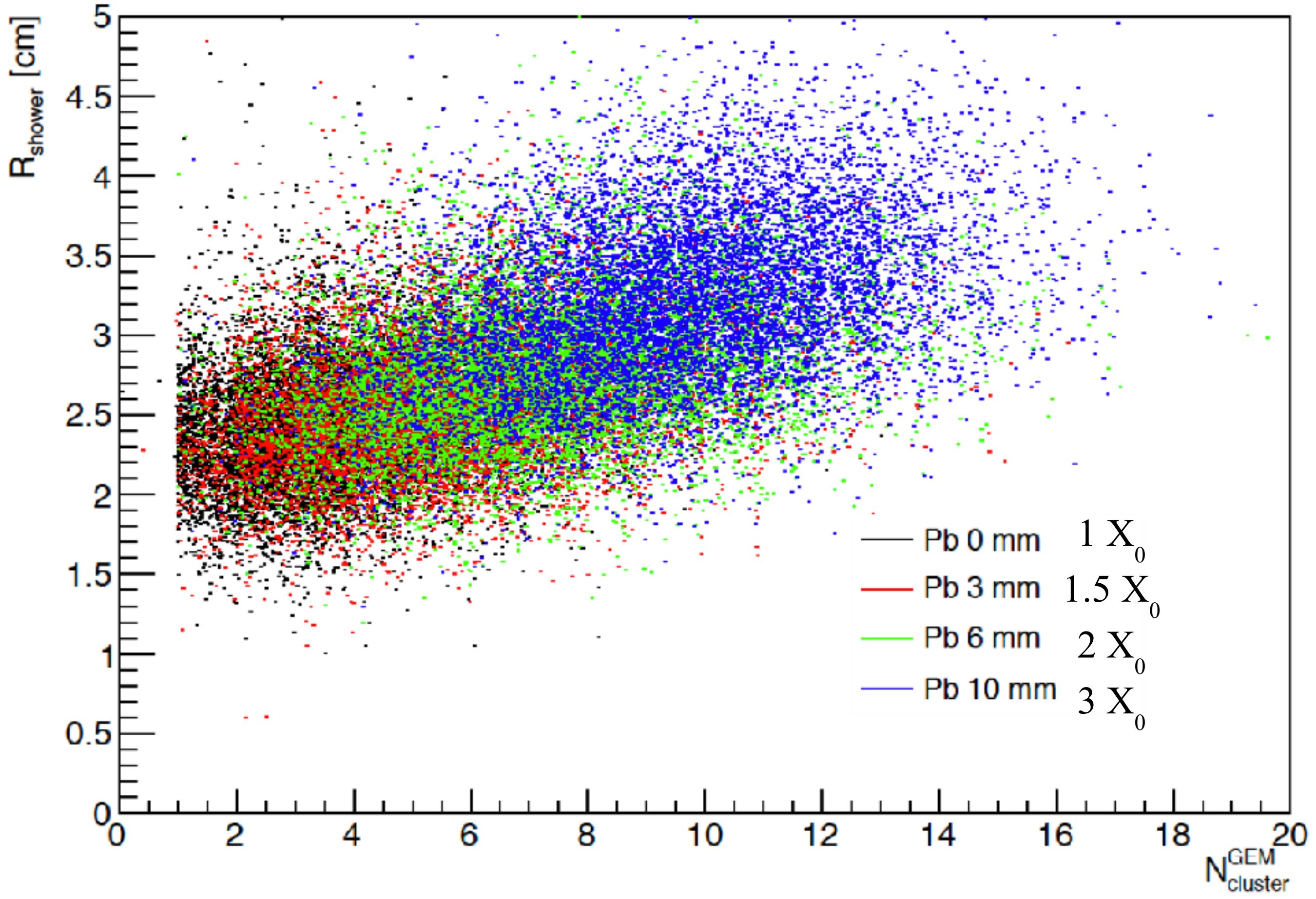


See G. Morello's talk

Preshower

2 triple-GEM detector
Study of material budget impact → no effect on calorimeter resolution

calorimeter cluster radius
vs.
# of preshower clusters



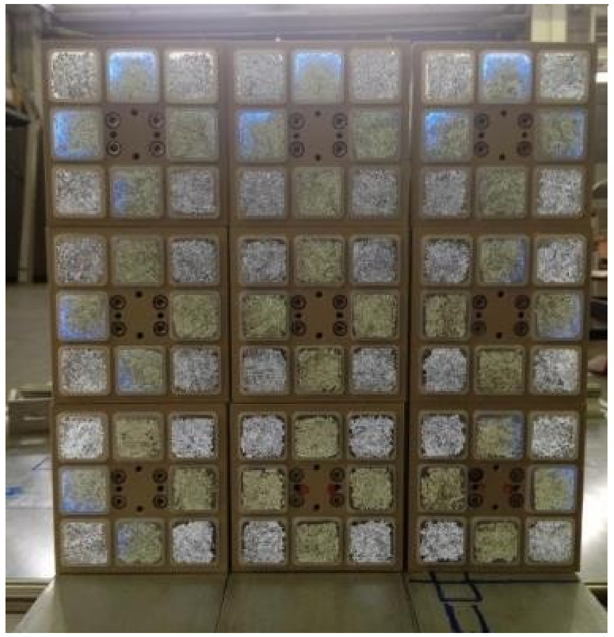
Tested w/ beam in September 2018

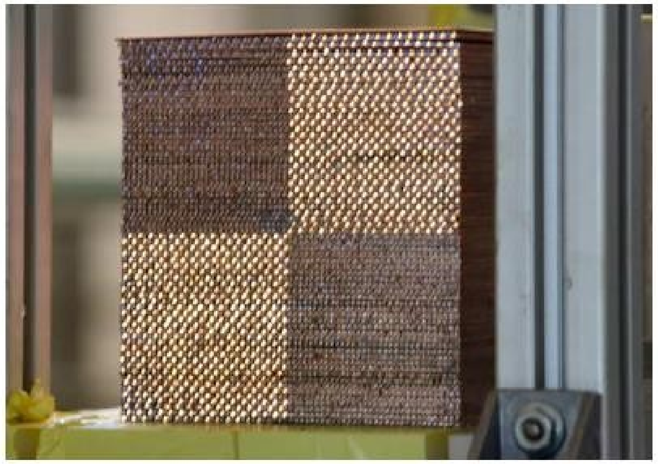
See I. Vivarelli's talk

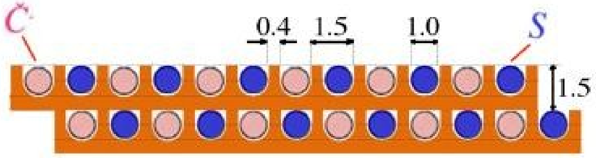
Dual-readout Calorimeter

Build on DREAM/RD52 experience

→ fibre sampling solution
→ high transverse granularity





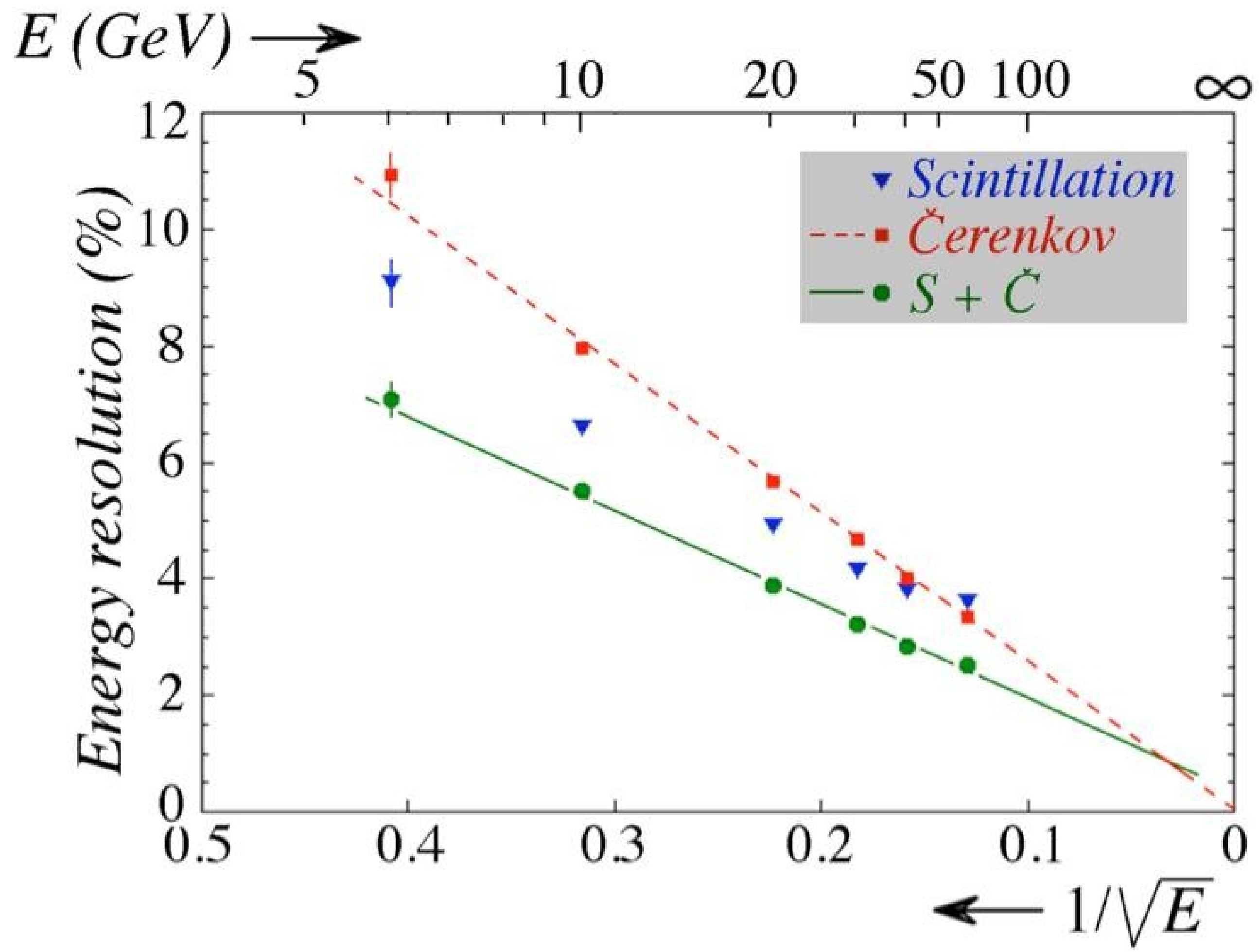


Dual-readout Calorimeter

Build on DREAM/RD52 experience

→ fibre sampling solution
→ high transverse granularity

em resolution close to 10%/√E



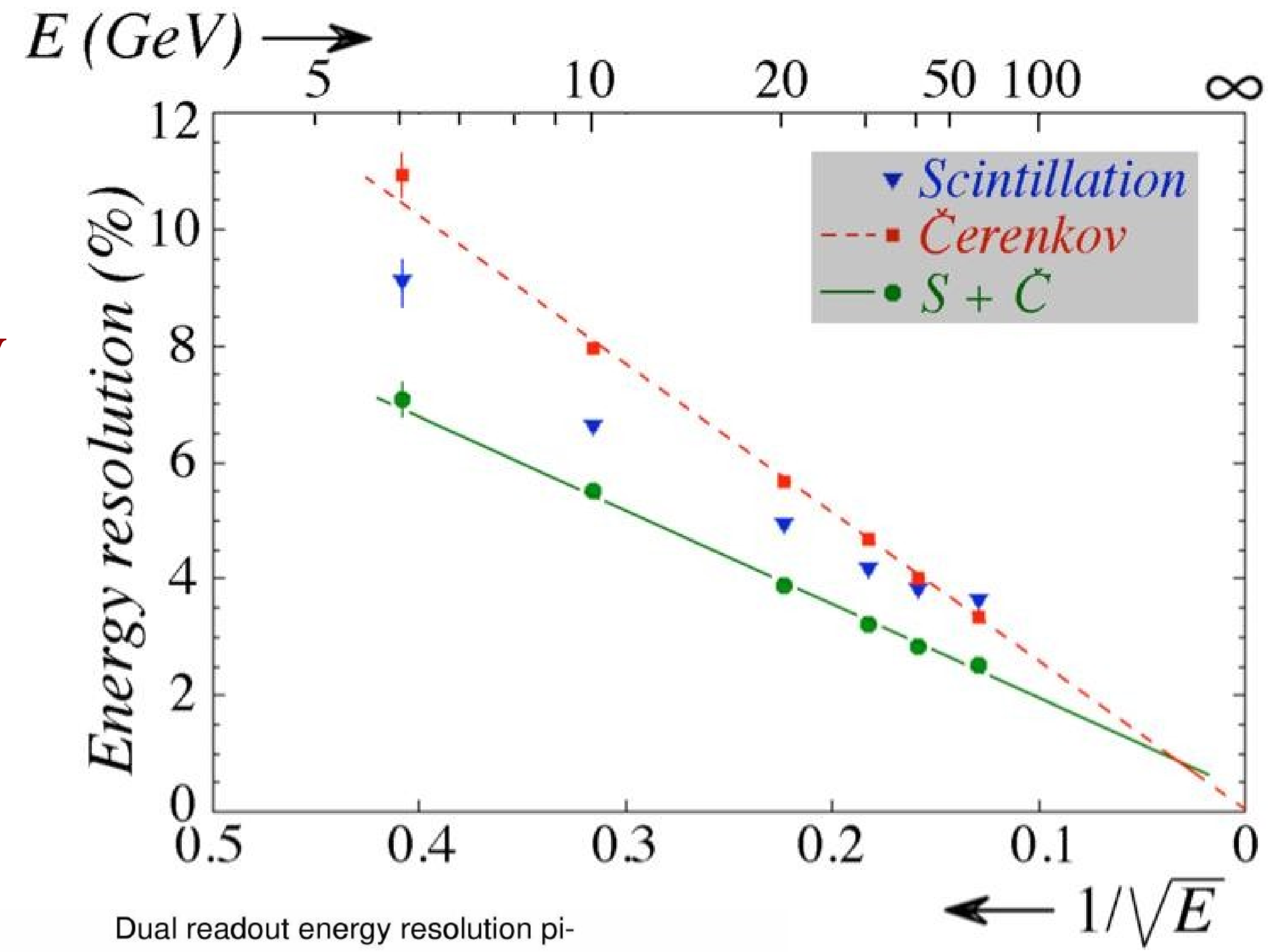
Dual-readout Calorimeter

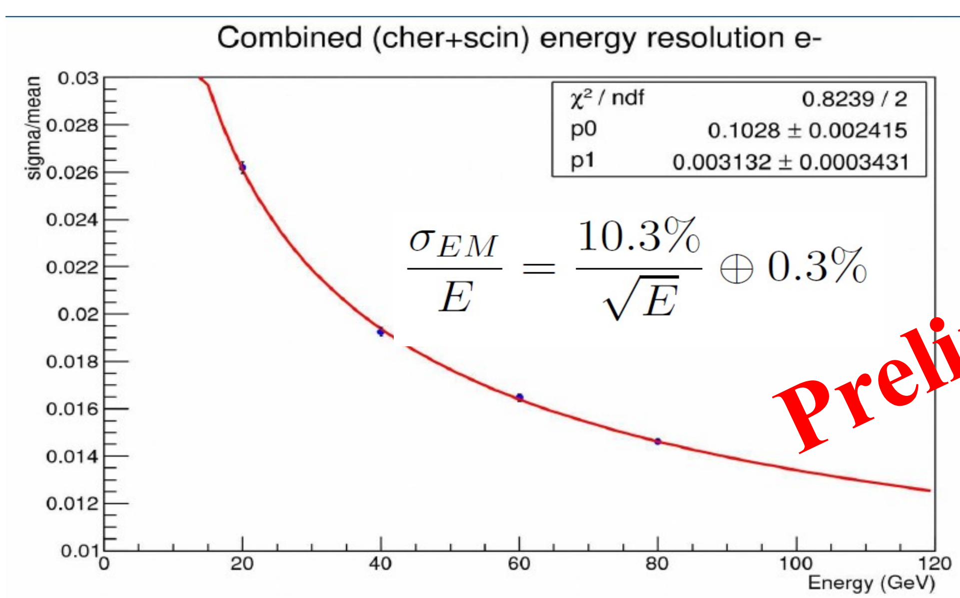
Build on DREAM/RD52 experience

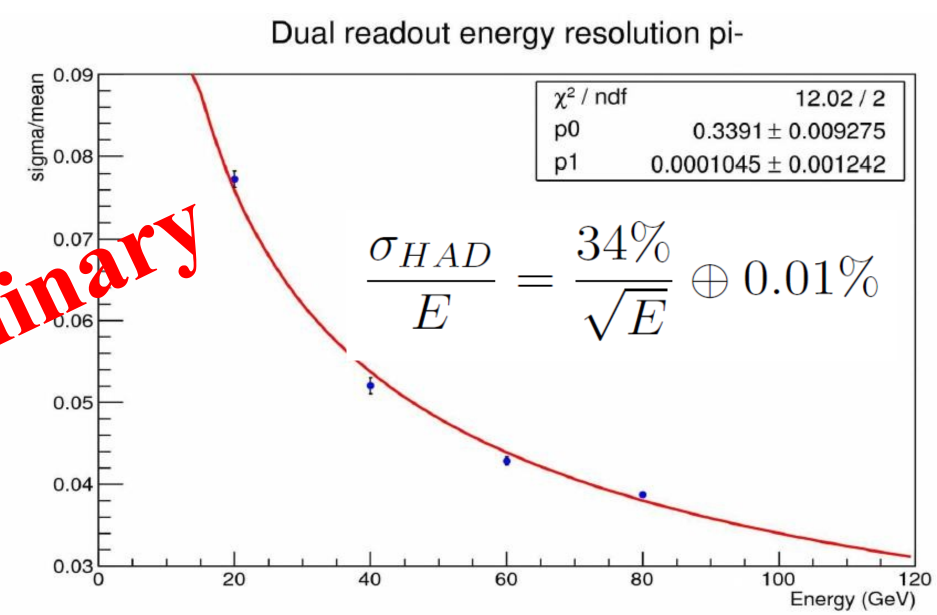
→ fibre sampling solution
→ high transverse granularity

em resolution close to 10%/√E

had resolution ~30-40%/√E



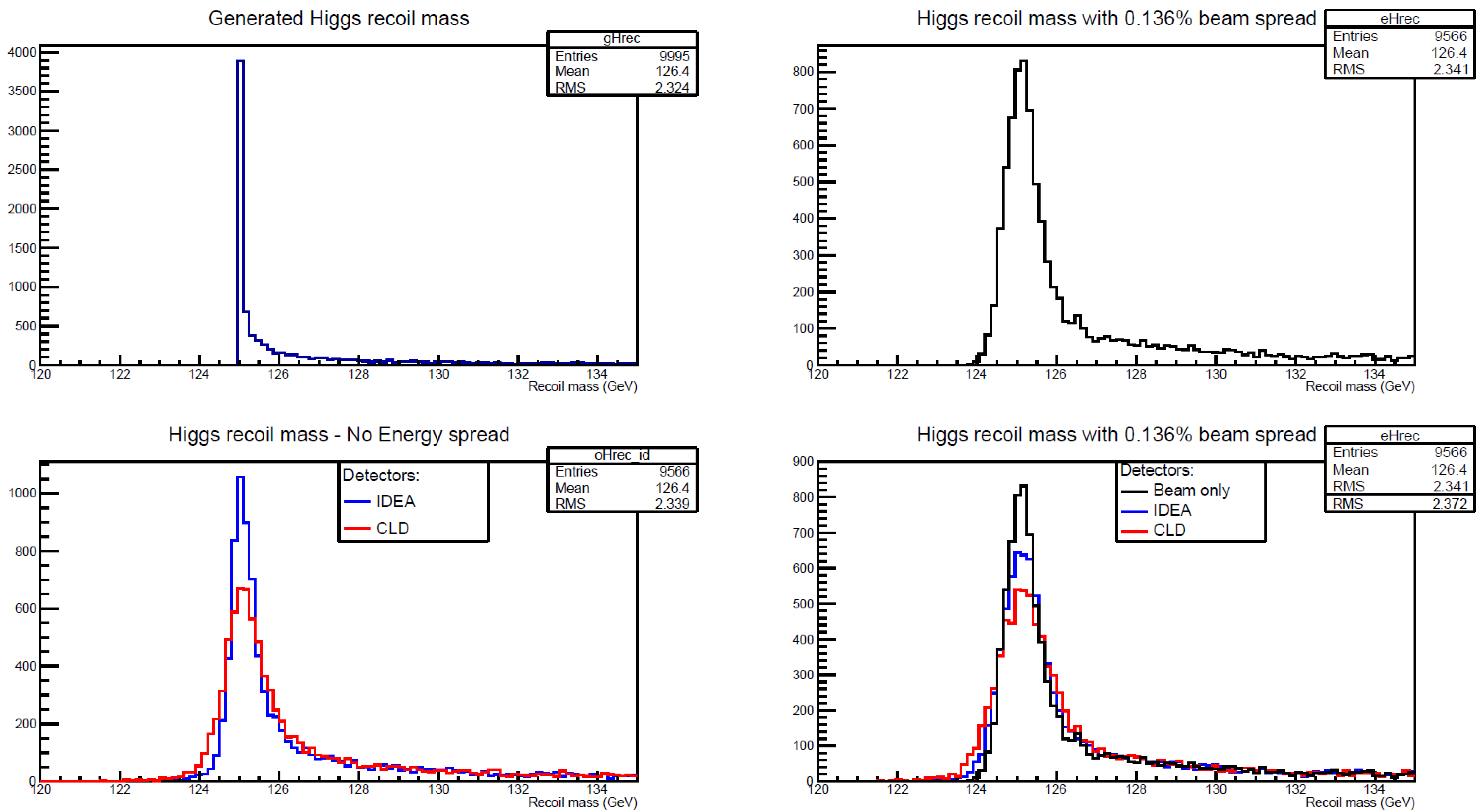




Recoil mass (Delphes)

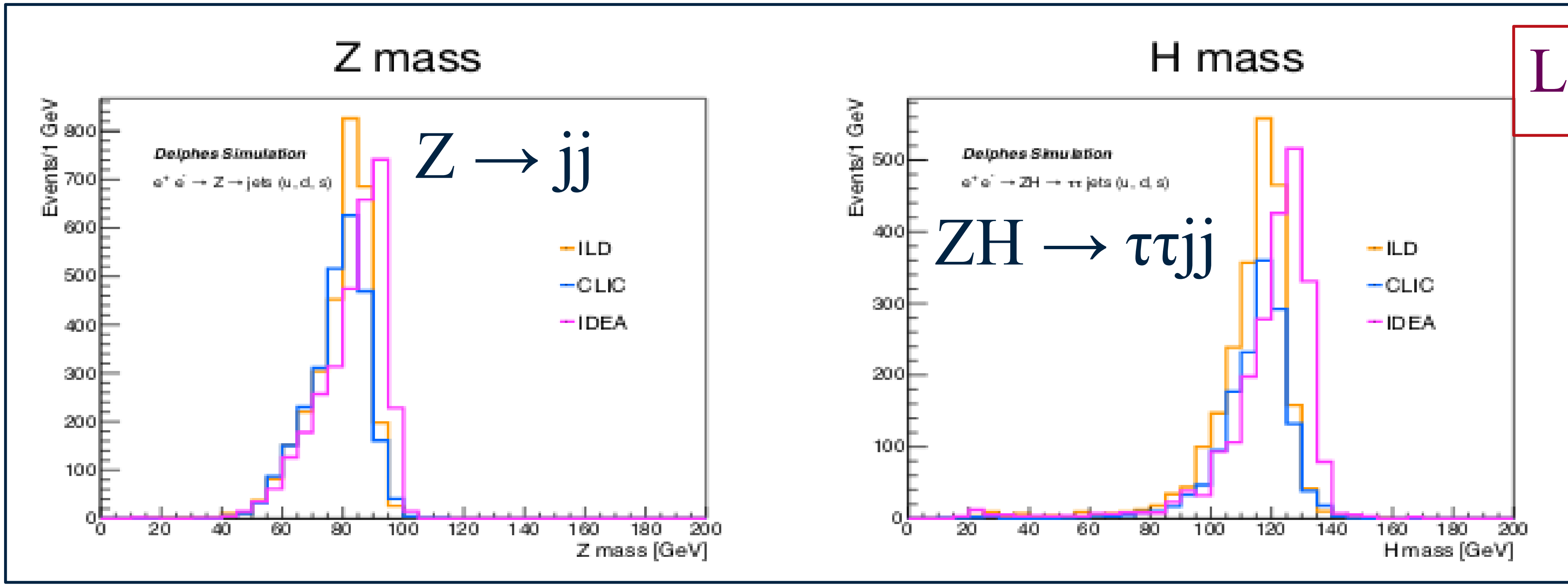
ZH (Z → $\mu^+\mu^-$)

F. Bedeschi's talk

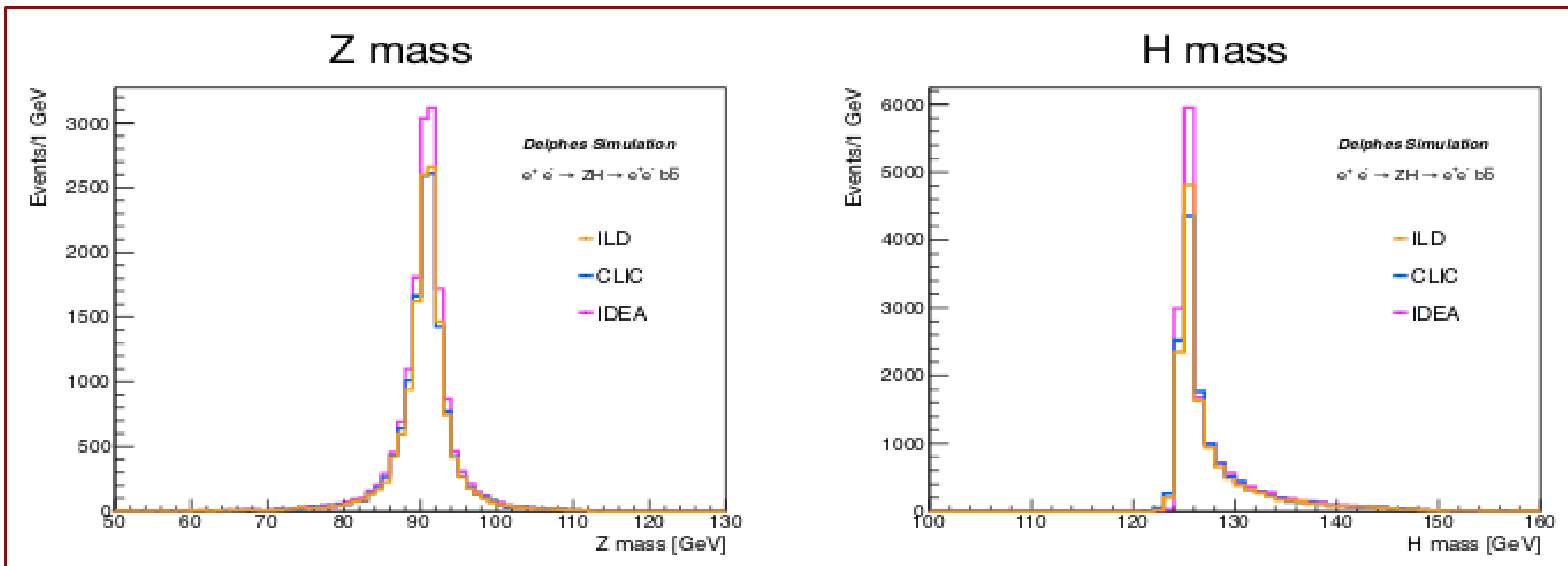


Invariant mass (Delphes)

L. Pezzotti's talk



$ZH \to e^+e^-b\bar{b}$

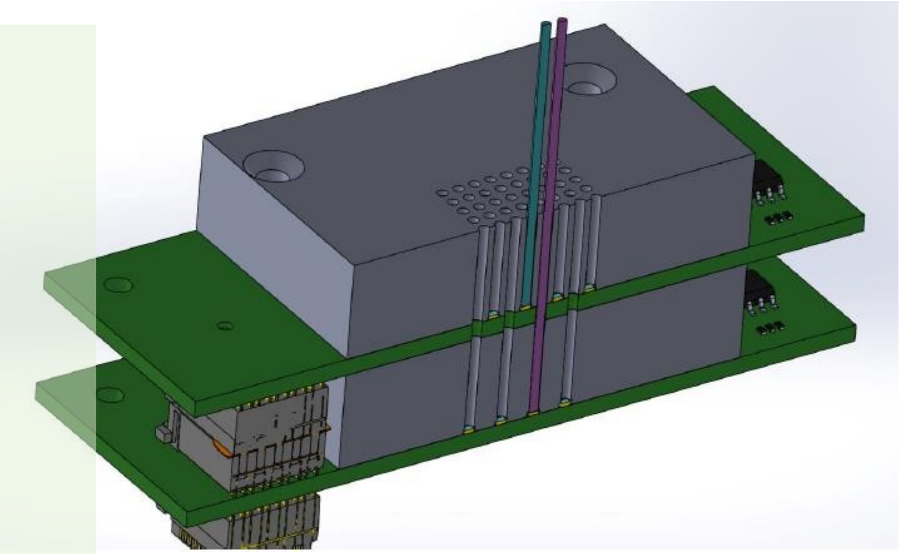


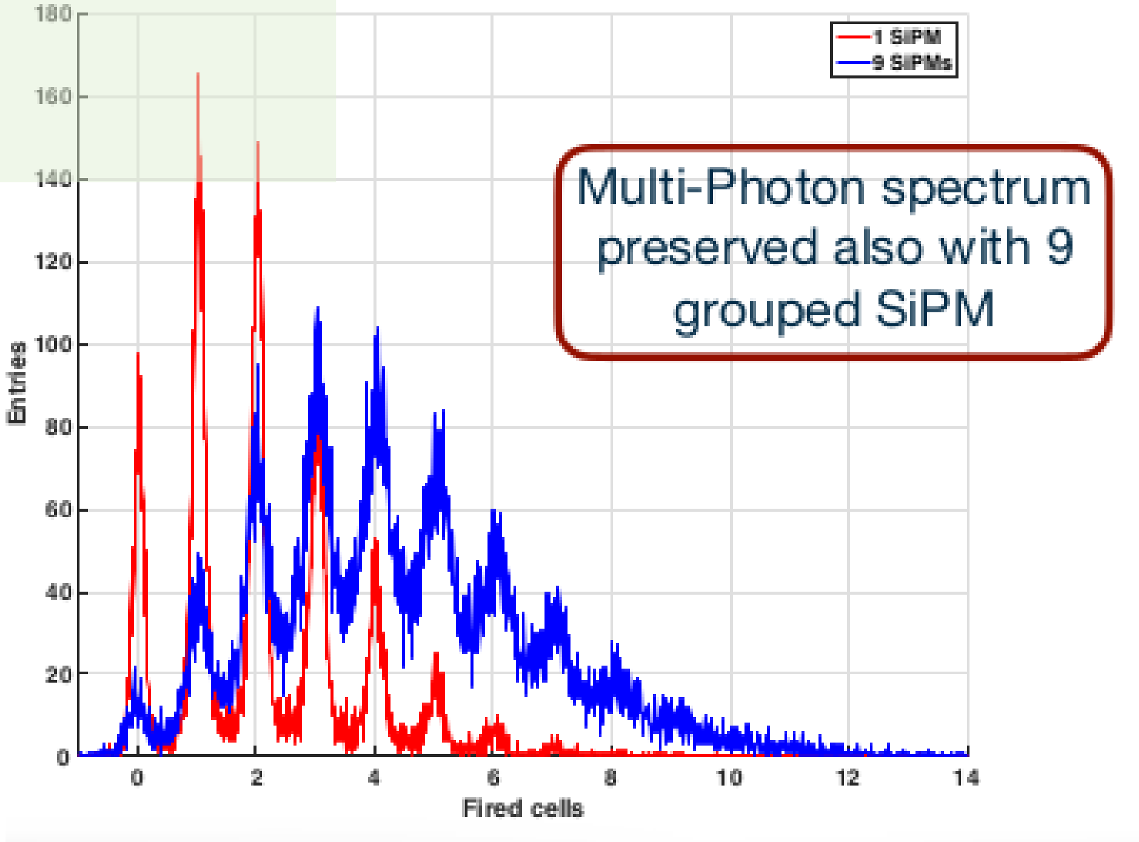
Calorimetry open issues

SiPM readout:

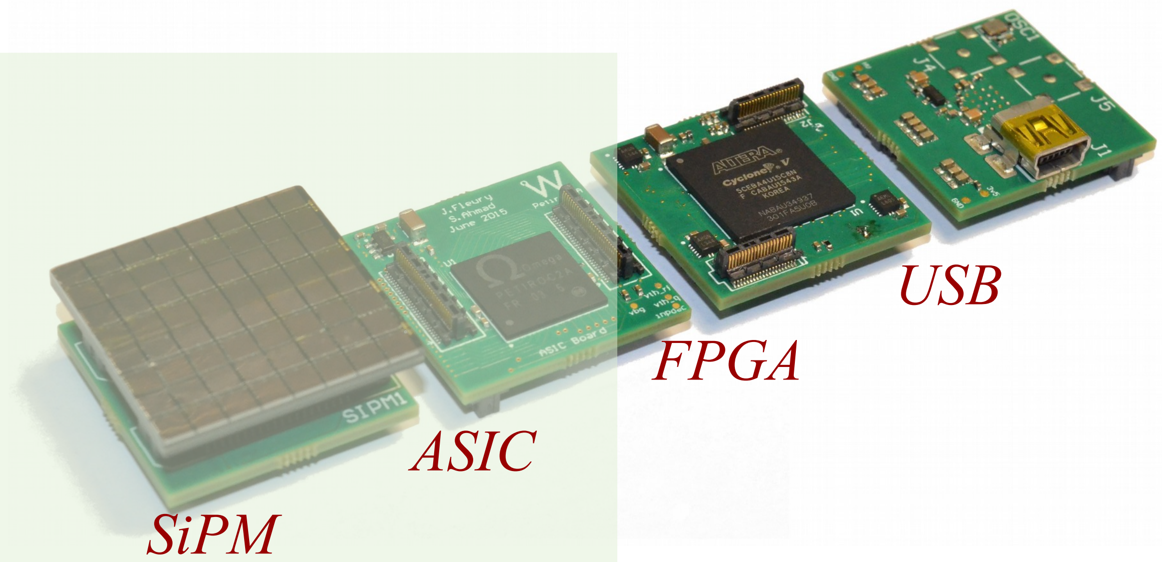
linearity and cross-talk
→ solution seems very close
→ unprecedented spatial (lateral) resolution

same likely true for dynamic range and channel grouping





Calorimetry open issues



SiPM readout (2):

digitiser (ASIC) & feature extraction (FPGA)

→ started investigating

→ time stamps w/ O(100 ps res)
→ get shower longitudinal development

$[\ \Delta x \sim 5\ cm \Rightarrow \Delta t \sim 100\ ps\ ]$

→ started looking at neural network implementation

More controversial issues

A non exhaustive list:

1) absorber

2) calibration and energy reconstruction for single hadrons and jets

3) longitudinal segmentation & particle id

4) alternative approaches (i.e. tiles vs. fibres)

5) Geant4 simulation validations !

(few more details in backup slides)

Particle id

Problem for closeby particles (e.g. photons and charged pions)

Started looking at

$$\tau^{\pm} \rightarrow \rho^{\pm}\nu \rightarrow \pi^{\pm}\pi^{0}\nu$$

with deep learning (convolutional neural network) algorithms

a) produced events with "time-stamped" photo-electrons
b) added scintillation decay-time
c) propagated through SiPM
d) output to be crunched by neural network for training
$\rightarrow$ e) then study performance

Fibres vs. tiles

→ + tiles : fully tunable longitudinal segmentation
→ + tiles : no attenuation length issues
→ + tiles : no fibre-to-fibre fluctuation issues
→ + tiles : simpler and cheaper

→ + fibres : lateral segmentation
→ + fibres : highly homogeneous and compact
→ + fibres : higher sampling frequency
→ lower sampling fraction - f_{samp}
→ lower volume

$\sigma_{samp} \sim 2.7\% \times \sqrt{(d/f_{samp})}$:

$\sigma_{samp} \sim 10\% \Leftrightarrow f_{samp} \sim 7\% \times d(mm)$

Fibres vs. tiles

Tiles : Cherenkov light yield ?

needs study and prototyping

Summary

IDEA detector concept optimised for CepC with

a) ultra-light tracker
b) ultra-light solenoid coil
c) dual-readout calorimeter outside

Detector elements based on proven techniques

but G4 simulations need nevertheless validation

Still R&D ongoing to optimise design, sort and validate options with

testbeams
simulations and sw developments
mechanical engineering and electronics

Performance seems to properly match requirements for CepC/FCCee

Backup

Calorimeter absorber choice

absorber : active volume = 62 : 38

	Iron	Brass (Cu260)	Lead
ρ (gr/cm^3)	5.31	5.71	7.46
λ_N (cm)	23.7	23.3	24.7
χ_0 (cm)	2.75	2.35	0.9
R_M (cm)	2.48	2.38	2.32
$\rho \times \lambda_N^3$ (kg)	71	72	113
$\lambda_N : \chi_0$	8.6	9.9	27.6

Lead:

(-) ~ 60% more mass

(+) a factor of ~ 3 in longitudinal separation of em and hadronic showers

Absorber choice

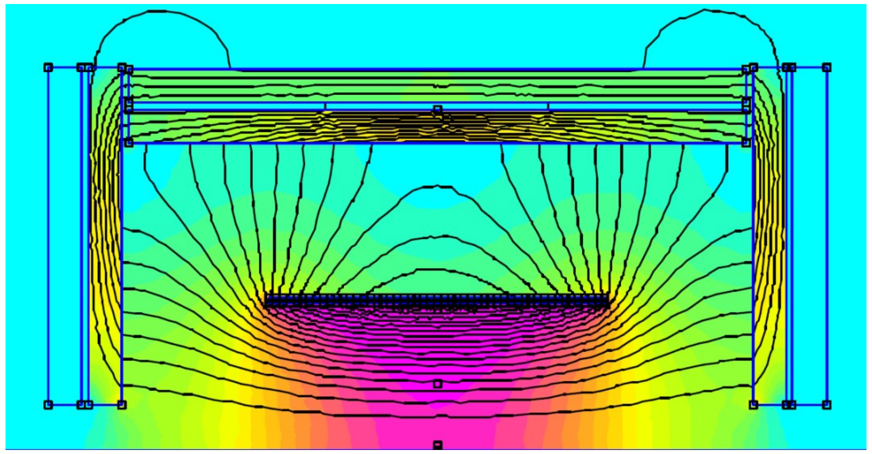
Investigating:

performance (resolution, PId)

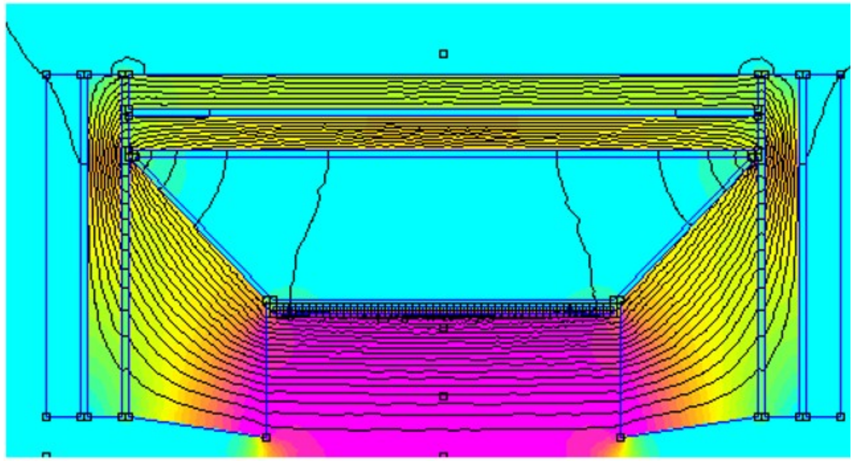
construction (and cost) mechanical issues

got few small pieces both 3D printed and electrical discharge machined → analysing results

impact on magnetic field



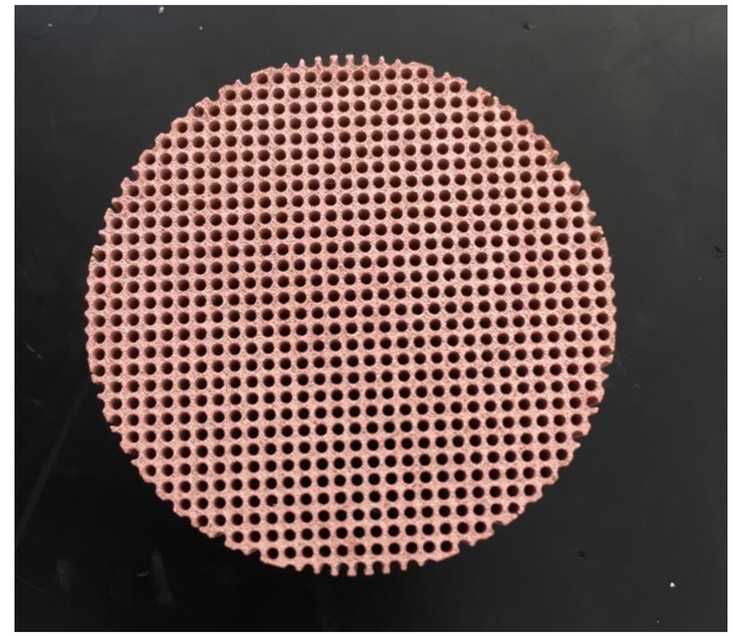
Lead absorber

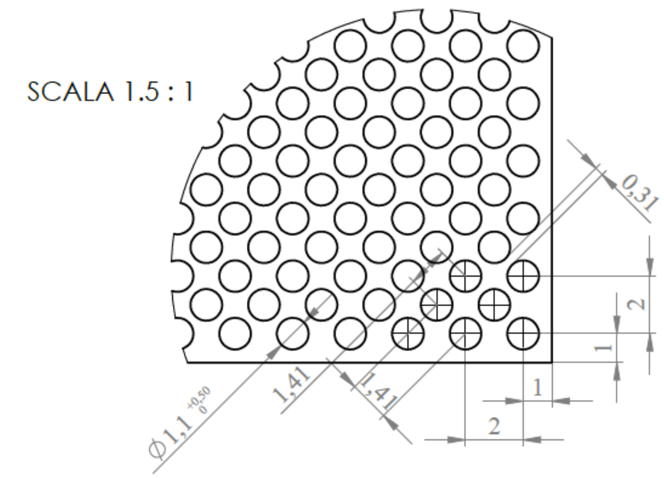


→ forward with Iron

3D printing @ LNGS

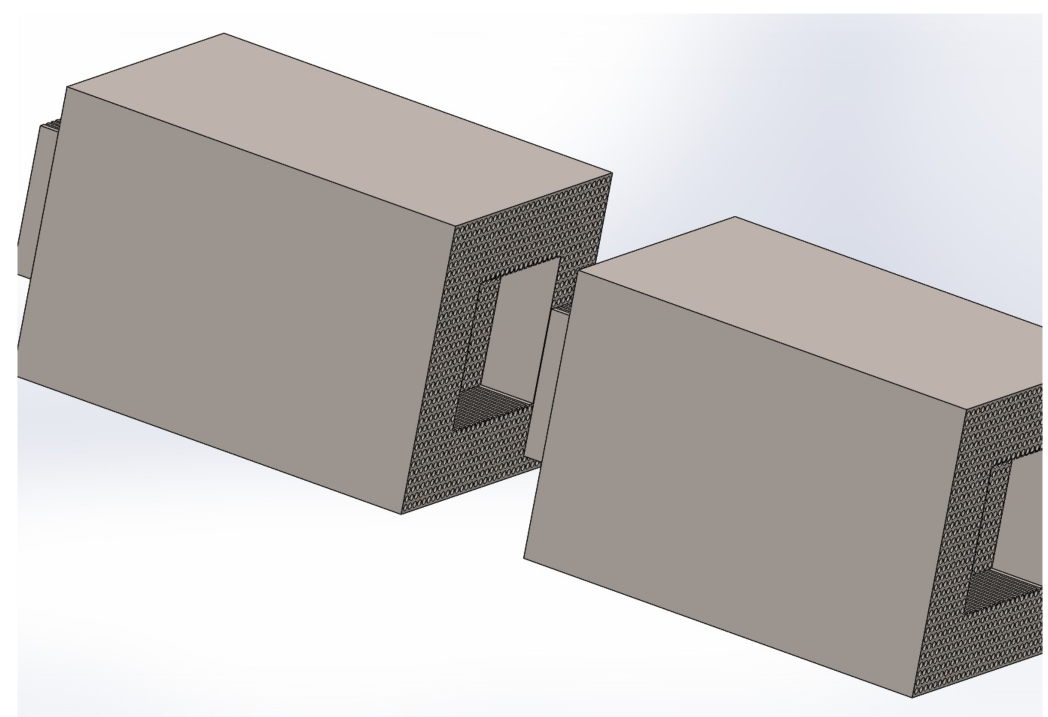
First test : cylinder w/ 45 mm radius and 15 mm thick





Next:

produce two, 75 mm long, 50x50 mm^2 square modules with alignment nose



- Test w/ copper
- Test w/ iron
- QC of modules, alignment and fibre shoving

Hadronic energy performance

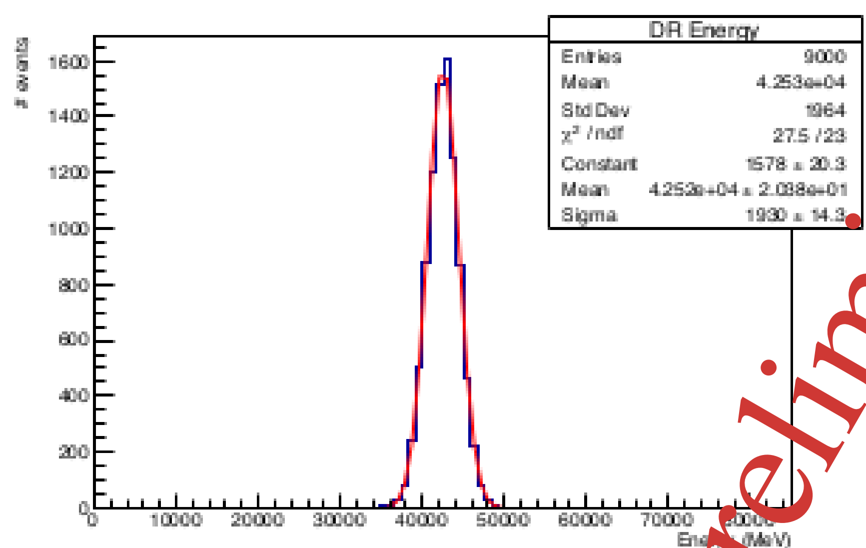
Working on both

a) standard “dual-readout” approach

b) machine-learning technique

”Jets” →

DR method

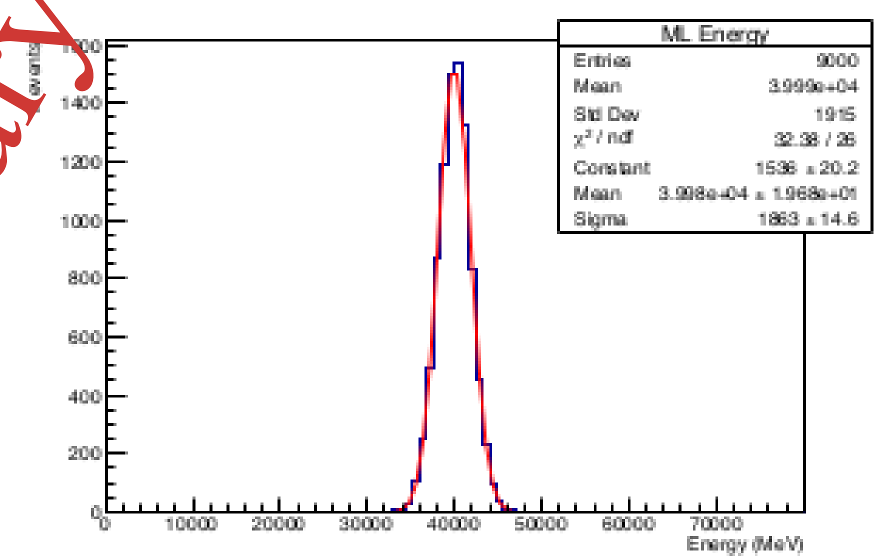


With the classical approach the average reconstructed energy is slightly overestimated:

$$\frac{e}{mip} < 1$$

preliminary

Machine Learning



With machine learning The energy is on average correctly reproduced:

Soft hadrons are present also in the trained database

Hadronic energy performance

Simulations need to be validated
w/ realistic containment prototypes!

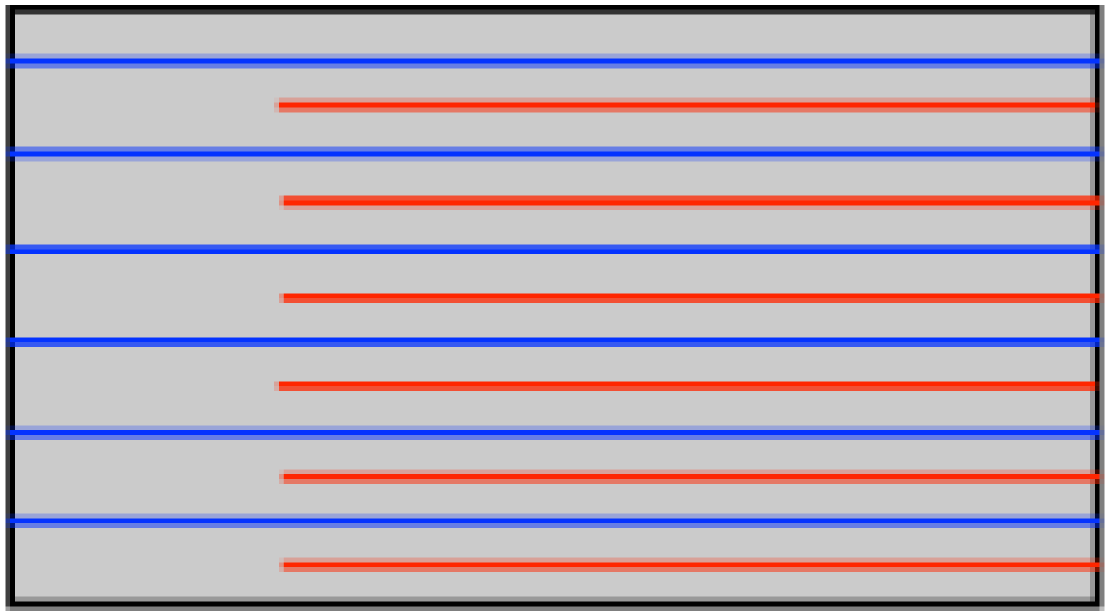
Longitudinal segmentation

Prototype w/ staggered fibres

a) "HAD" section → E (short fibres)

b) "EM" section → E (long fibres) – E (short fibres)

view from above



Calibration ?

See I. Vivarelli's talk

Longitudinal segmentation

a) calibrate long fibres w/ electrons
b) cross-calibrate short fibres w/ pions