Detector concepts for FCC-ee

January 16 2017

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Detector concepts for FCC-ee

or
which detector can be built for FCC-ee physics
with today's technology

January 16 2017

The Physics Case includes

- Precise measurement (0.1% to 1%) of the Higgs Couplings
- Improve precision (statistics x 10^5) on the measurements of the Z parameters [M_Z, Γ_Z , R_ℓ, R_b, R_c, Asymmetries & weak mixing angle]. Z rare decays.
- Scan W threshold (aiming at 0.5 MeV precision). W rear decays
- Scan ttbar threshold (aiming at 10 MeV)

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General Detector Requirement

- Be suitable for high precision measurements
- Precise tracking in a low X_0 tracker
- Excellent lepton id and lepton/photon momentum resolution
- Precise angular (and energy) jet measurement
- Particle flow friendly with an adequate calorimeter granularity
- High granularity vertex detector with b and c tagging capabilities
  - …. in a low occupancy environment
  - maximum event rate 20 kHz @ Z peak

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MDI Requirements

- Asymmetric optics with beam crossing angle of 30mrad
- IP displaced by about 9.4 m wrt proton beam line
- Maximum magnetic field 2T (needs compensation)
- Beam pipe radius 22 mm
- Detector has to “stay above” the 100 mrad line
- Simulations show low occupancy induced by beamstrhalung and pair production

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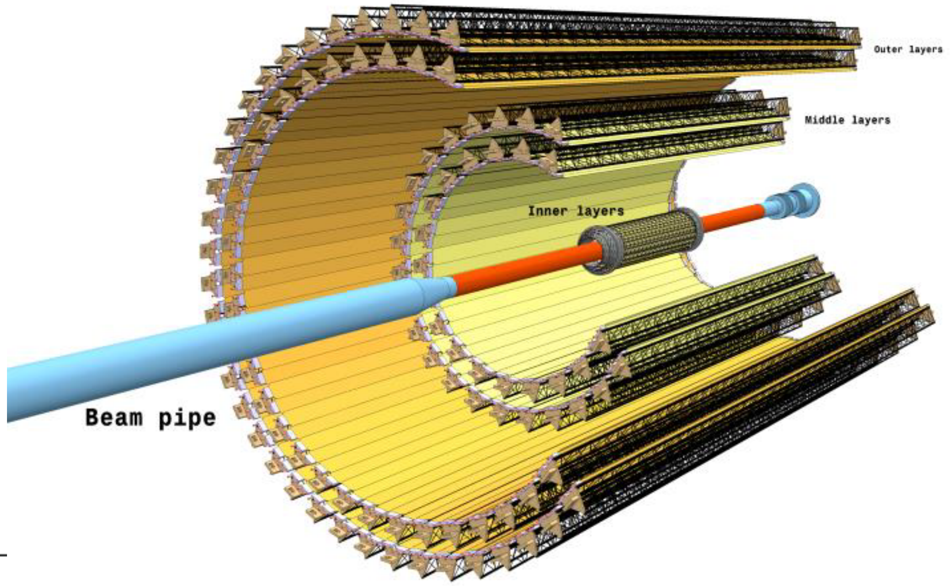
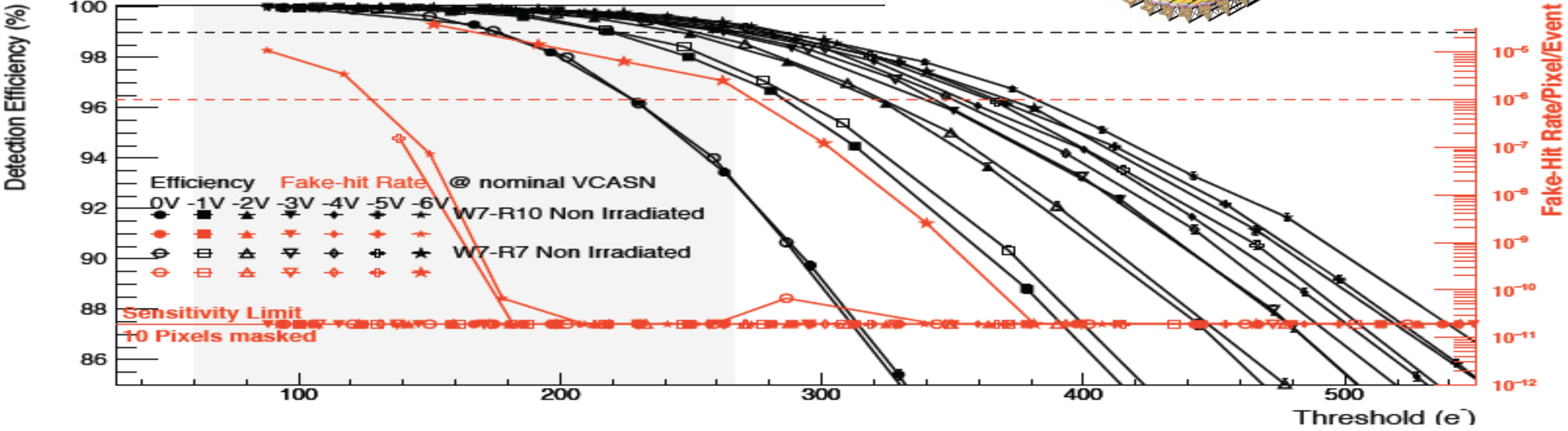
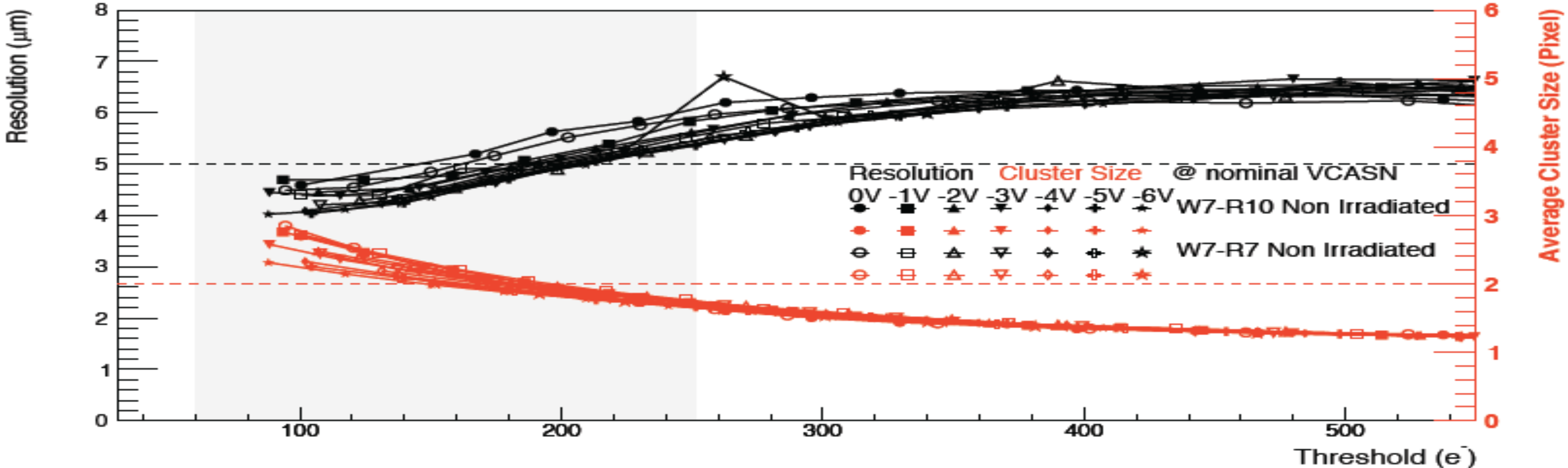
Performing vertex detector for b and charm tagging

ALICE ITS with MAPS :
0.3 -1 % X0/layer
7 layers pixel 30*30 μm





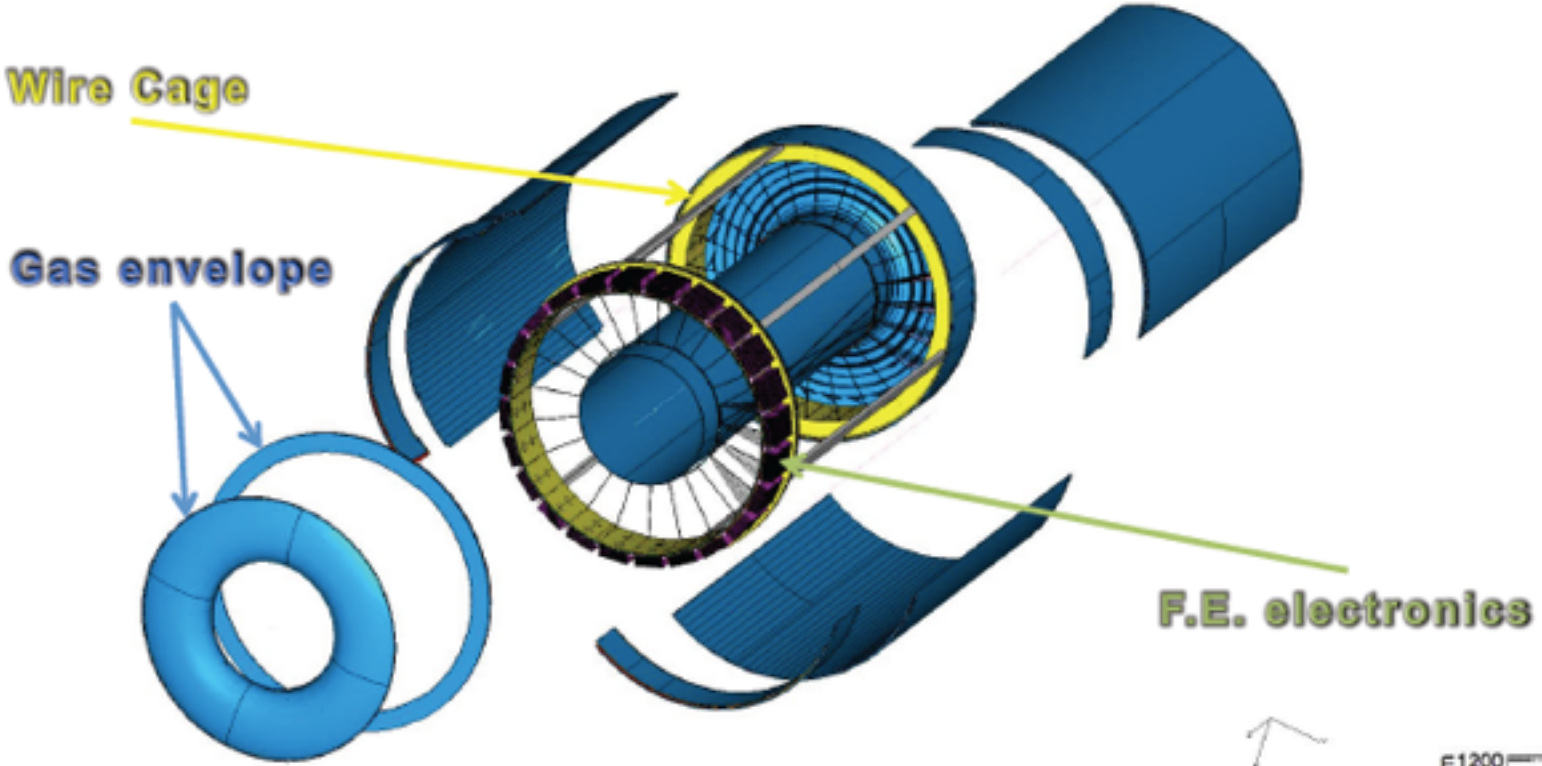


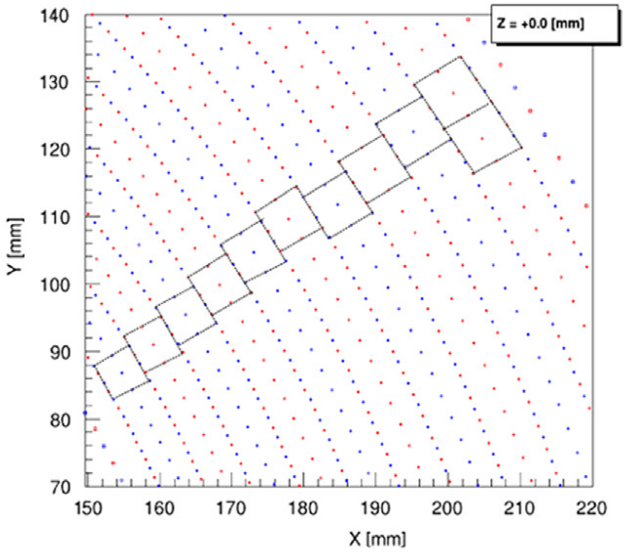
Courtesy of ALICE J.W. van Hoorne

Tracking with redundancy in gas with high precision

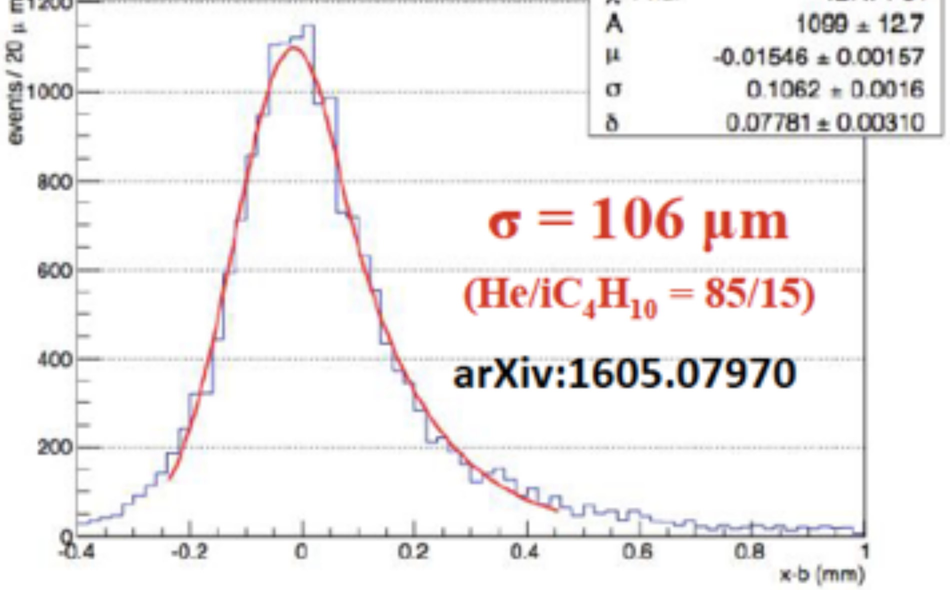
5 m long wires drift chambers, one sense wire every 1.4 cm

σ_{xy}~ 100μm σ_{z}~ 1mm some 100 points per track





Intagrated on all impact parameters



$\sigma = 106\ \mu m$

(He/iC_4H_{10} = 85/15)

arXiv:1605.07970

Less than 1% X_0

Courtesy of Meg2 and Franco Grancagnolo

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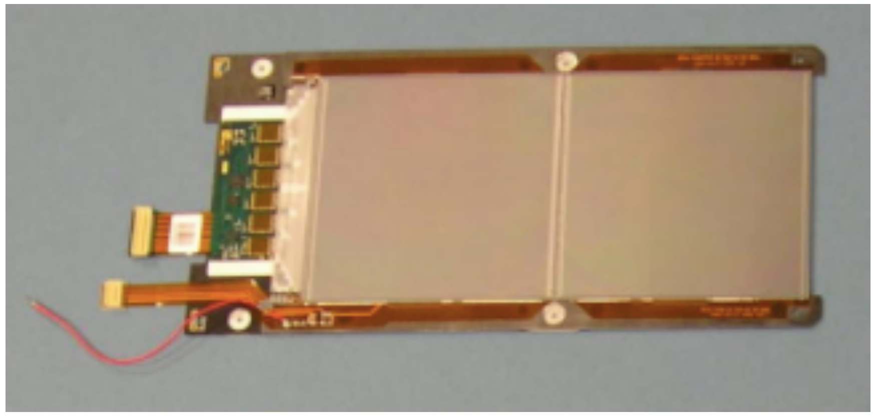
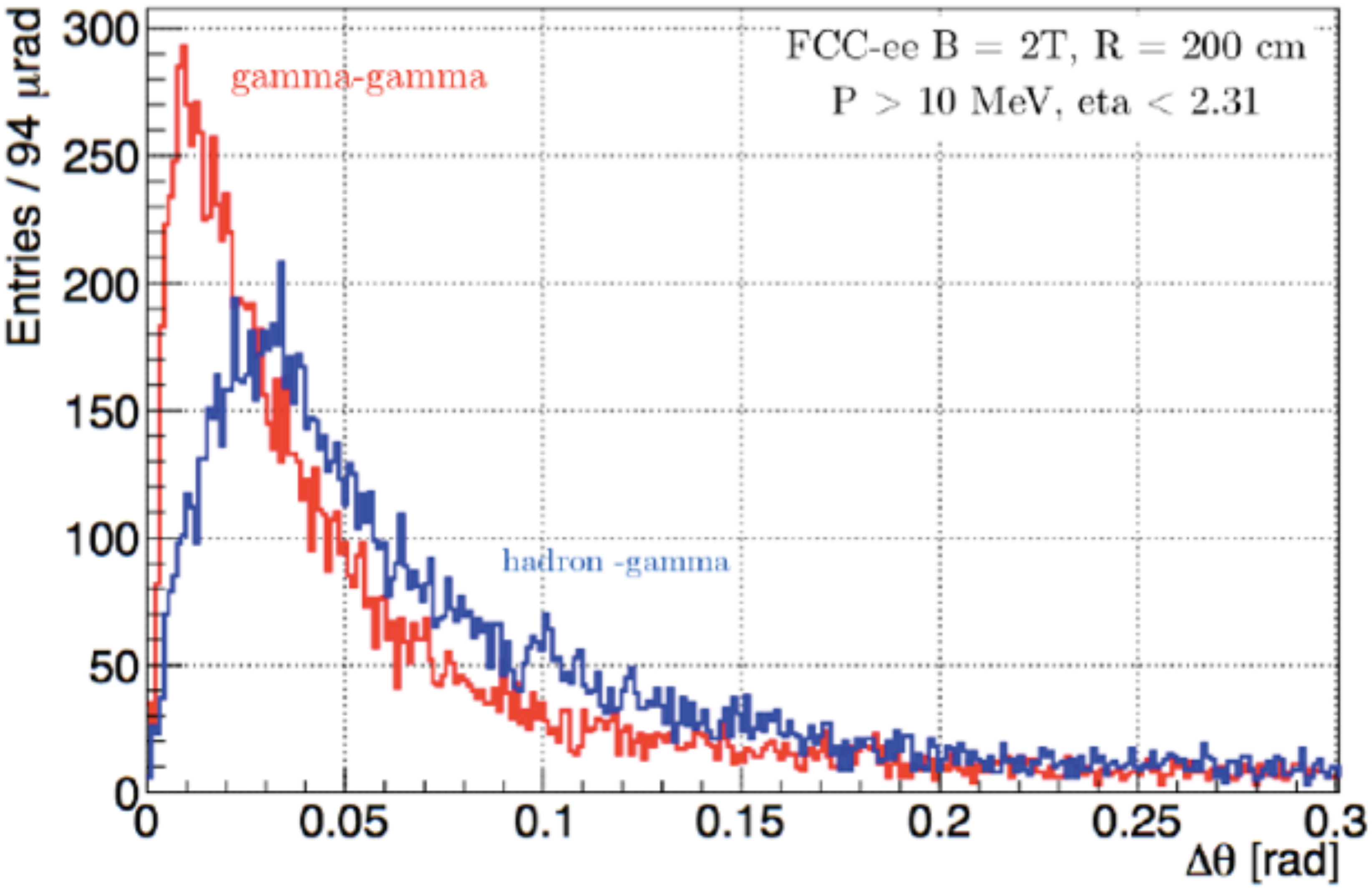
Pre-shower



Silicon strip detectors with overlap
a la CMS + 2-3 mm lead

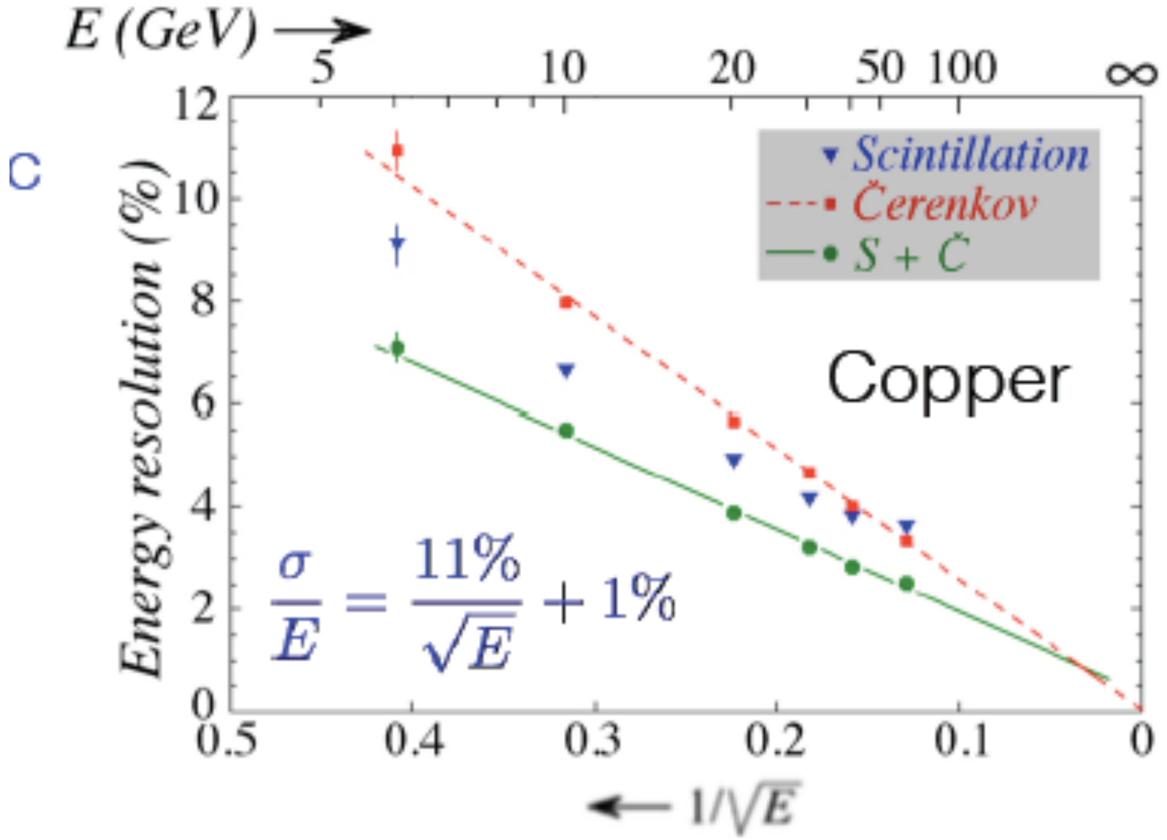
Measures precisely impact points of charged particles and photons. Defines the acceptance .
-60 m^2 /layer

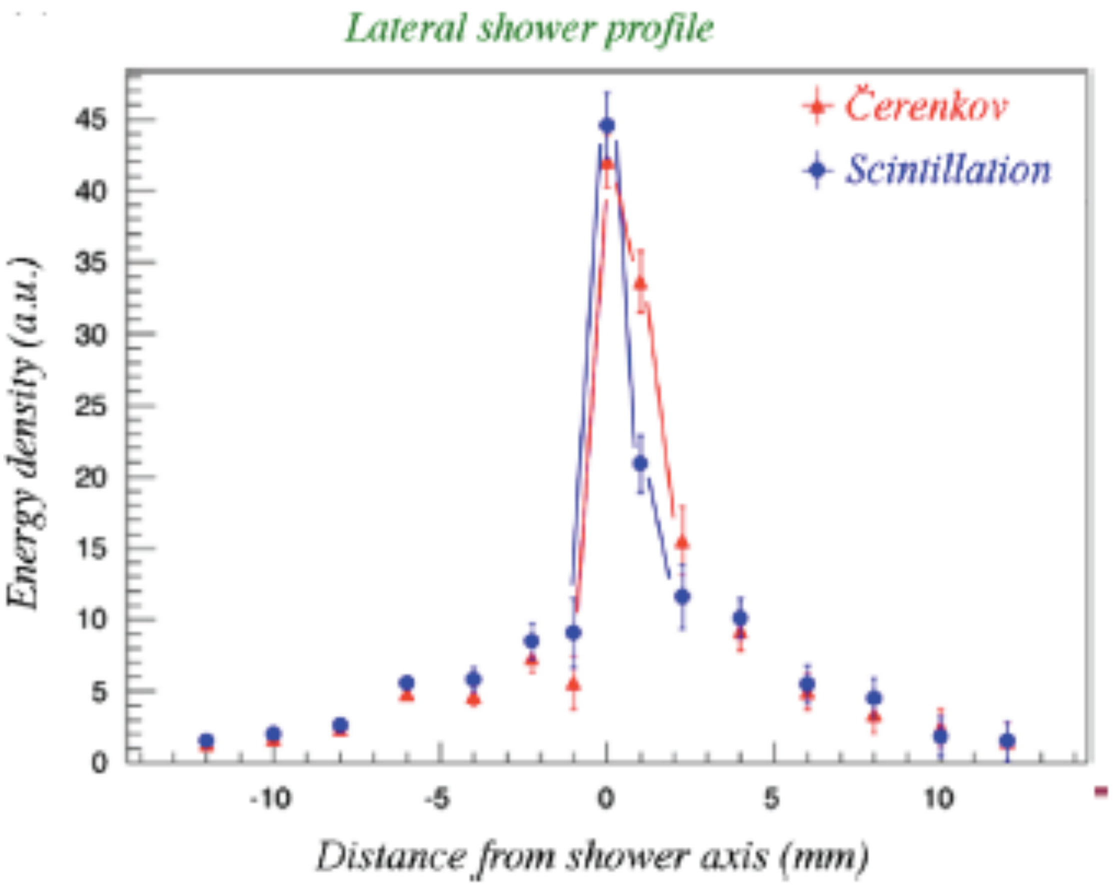
Angular distribution in ee -> ττ events at √s = 240 GeV, 5k events sample



One possibility for calorimetry:

dual readout copper calorimeter 140 cm radial depth





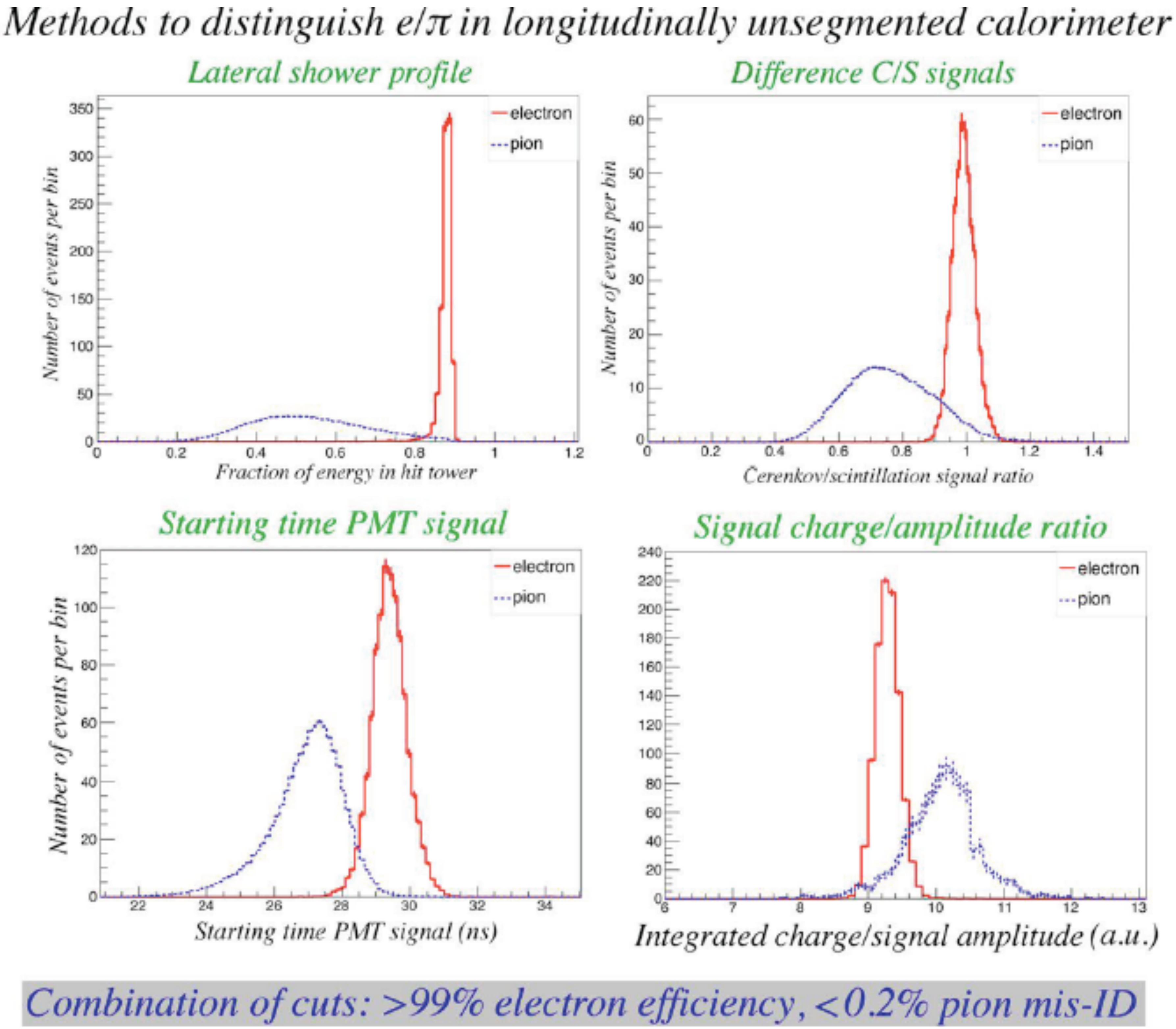
Very good electromagnetic performance

~ 2 GeV resolution on m_h in the γγ channel

Courtesy of RD52 and Gaudio

Dual readout copper calorimeter 140 cm radial depth

Excellent hadron/electron separation



Methods to distinguish e/π in longitudinally unsegmented calorimeter

Lateral shower profile

Difference C/S signals

Starting time PMT signal

Signal charge/amplitude ratio

Combination of cuts: >99% electron efficiency, <0.2% pion mis-ID

Courtesy of RD52 and Gaudio

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Dual readout copper calorimeter 140 cm radial depth

about 7 $\lambda_{\text{interaction}}$

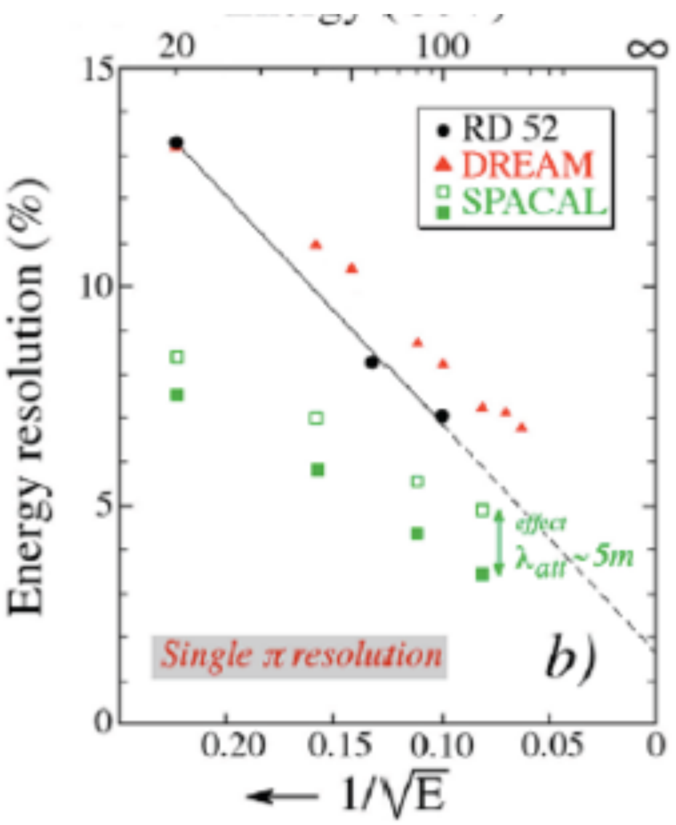
Jet resolution should to be studied with Particle Flow

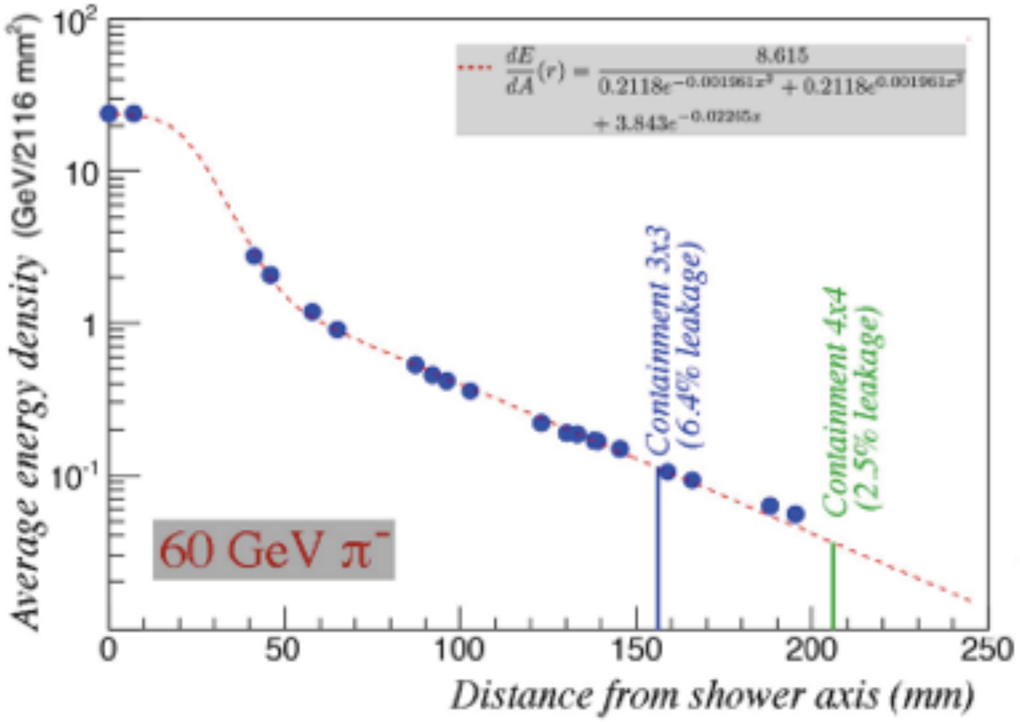
Single particle

Hadronic Resolution
(Pb Module)

$$\frac{\sigma}{E} = \frac{53\%}{\sqrt{E}} + 1.7\%$$

To include corrections on:
- light attenuation
- lateral leakage

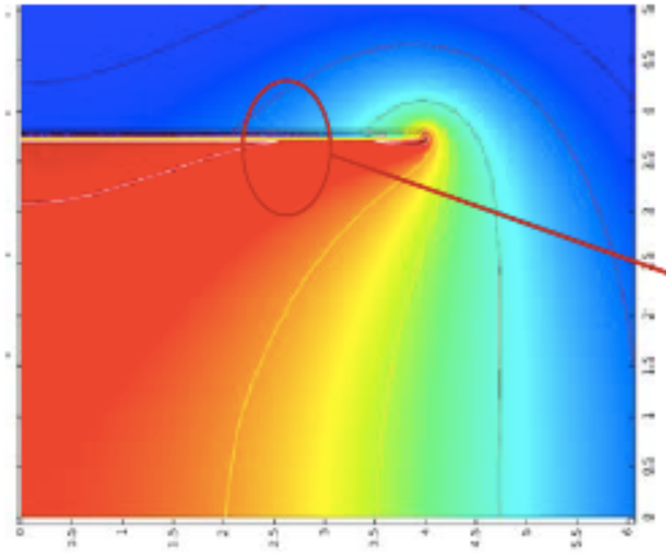


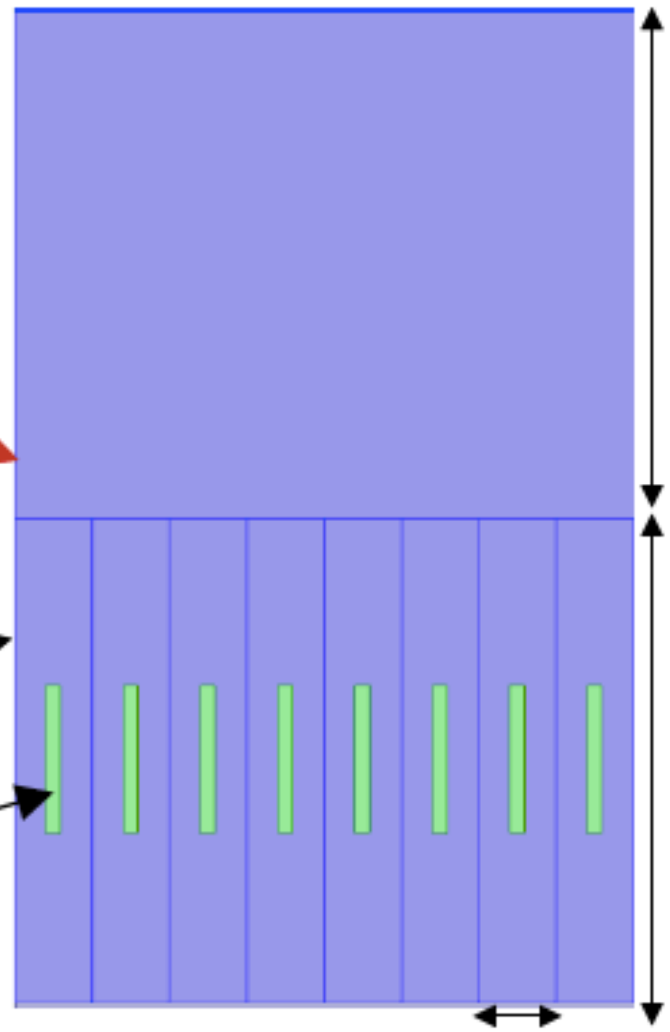


Courtesy of RD52 and Gaudio

4th detector LOI quotes 30%/√E for jets

Magnet concept 1 : 2T solenoid around HCAL





Support cylinder
(Al-alloy)
thickness: 60 mm

Al+0.1 wt% Ni stabilizer

Conductor radial
thickness: 58 mm
(including insulation)

NbTi+Cu Rutherford cable: 32 x
1.1 mm Ø NbTi/Cu strand

Conductor axial thickness: 9 mm (including insulation)

Property	Value
Magnetic field in center [T]	2
Free bore diameter [m]	6.6
Stored energy [MJ]	730
Cold mass [t]	60
Cold mass inner radius [m]	3.7
Cold mass thickness [m]	0.118
Cold mass length [m]	8

Courtesy of H. ten Kate et al

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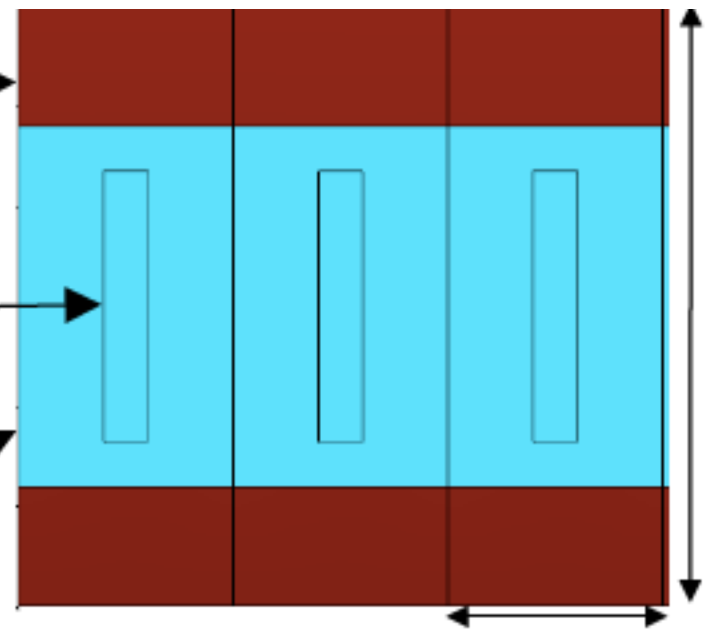
Magnet concept 2 : thin 2T solenoid around tracker



Al-alloy (AW-7020.72)

NbTi+Cu Rutherford cable: 20 x 1.35 mm Ø NbTi/Cu strand

Al+0.1wt% Ni stabilizer

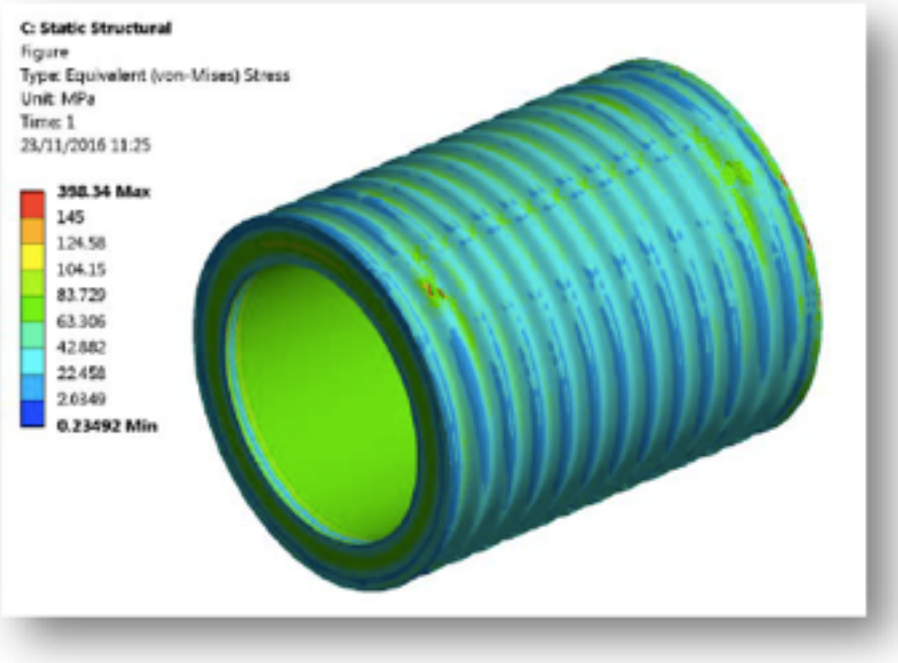
Conductor radial thickness: 30 mm (Including insulation)

Conductor axial thickness: 10 mm (including insulation)

Courtesy of H. ten Kate et al

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

- **Total: $X_0 = 0.74$, $\lambda = 0.16$ (at $\eta = 0$)**



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Muon Momentum resolution

Sagitta of a 100 GeV muon with L=1.8 m and B= 2T is **2.4 mm**

7 Measurement at 5-10 μm from 2.2 to 40 cm

100 Measurements at 100 μm from 40 to 180 cm

2 Measurements at 20 μm @ 185 cm

$\Delta p_t / p_t \sim 0.3\%$ @ $p_t = 100$ GeV

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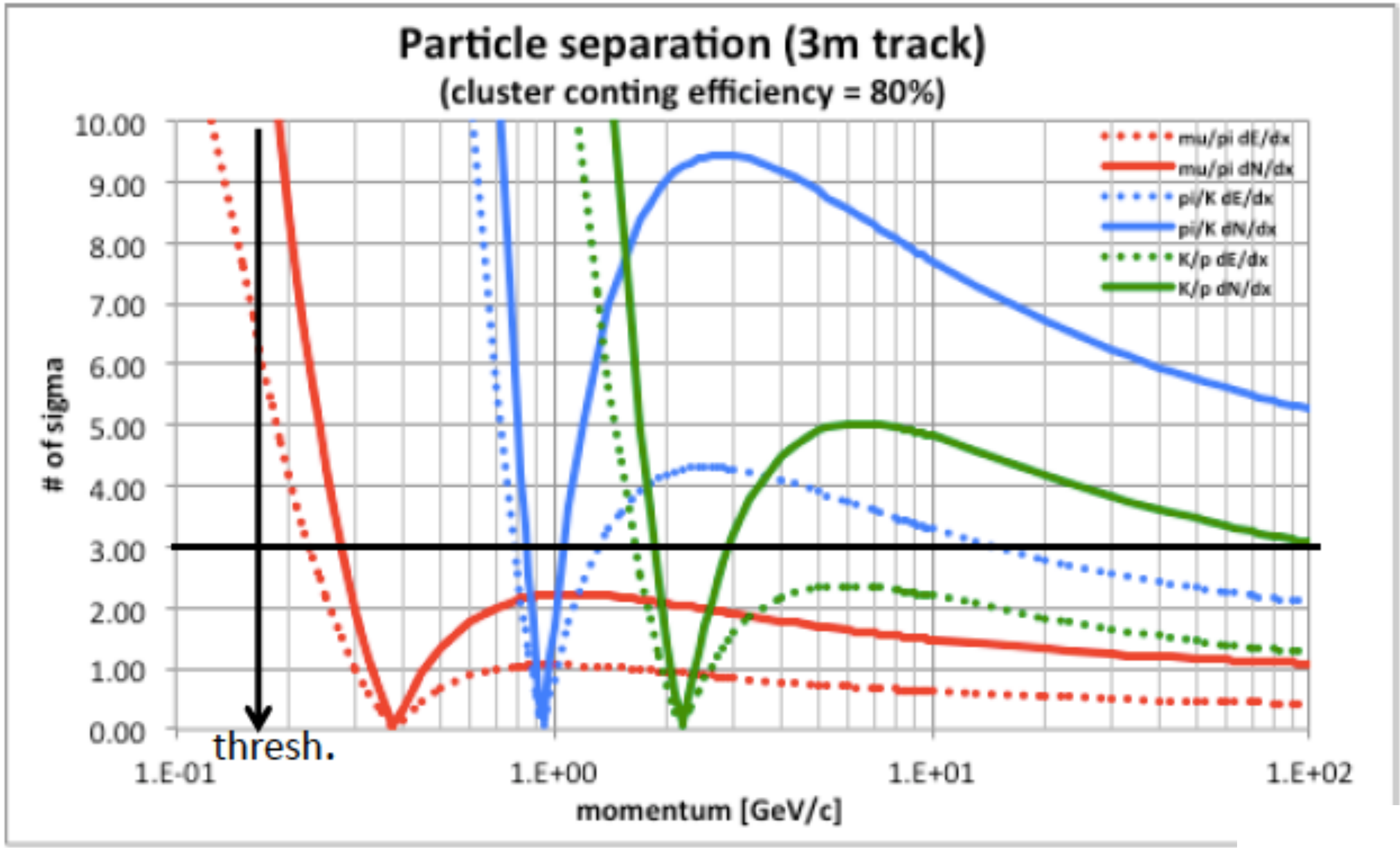
Hadron identification: Cluster counting in the wire chamber

Courtesy of Meg2 and Franco Grancagnolo



$\sigma_{dE/dx}/dE/dx =$

$= 5.4\ L[m]^{-0.37}\ \%$

(Lehraus parametrization)

3.6% for L=3m

cluster counting efficiency

$\varepsilon = 80\%$

$\sigma_{dN_{cl}/dx}/dN_{cl}/dx =$

$= \varepsilon \times L \times 12.5/cm =$

1.8% for L=3m

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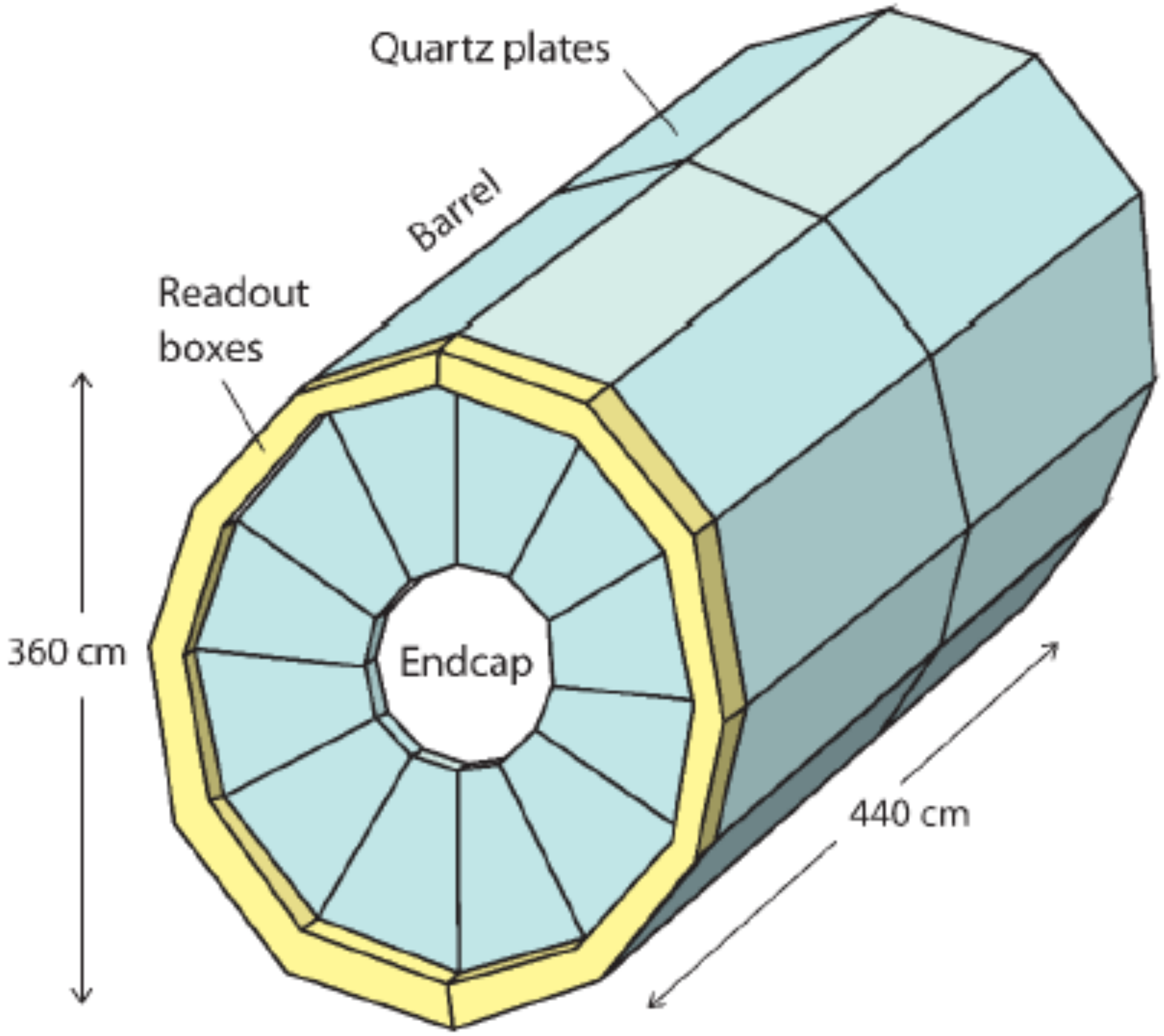
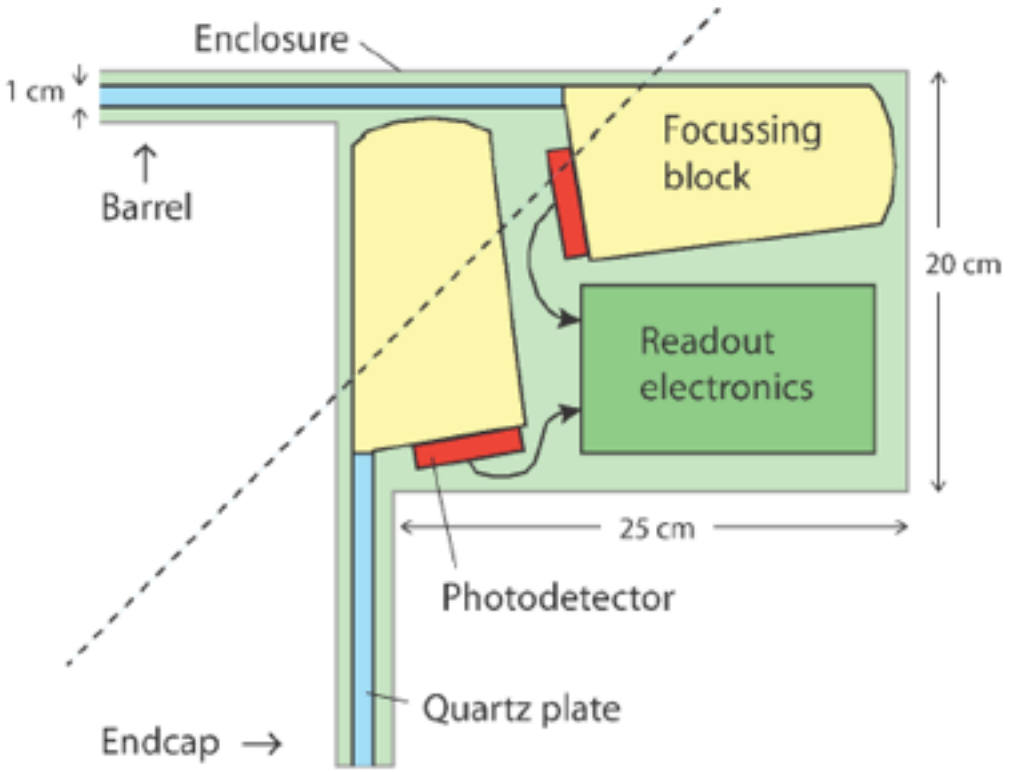
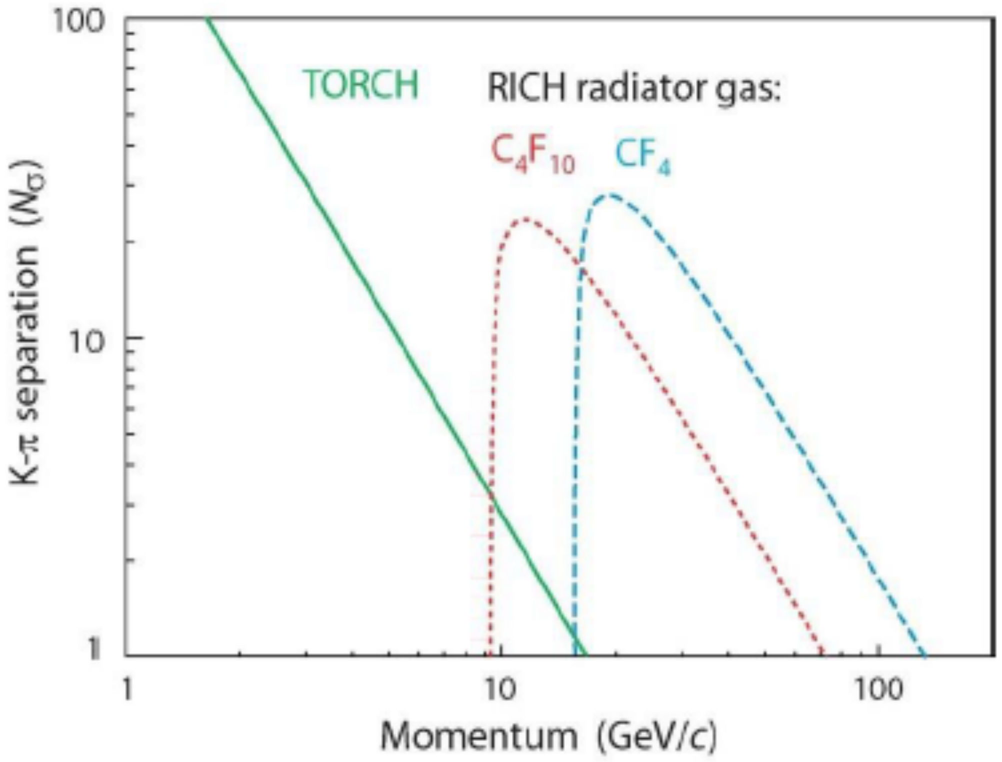
Hadron identification: Torch







Integrated with preshower

0.08% X_0 quartz + support

Courtesy of Roger Forty

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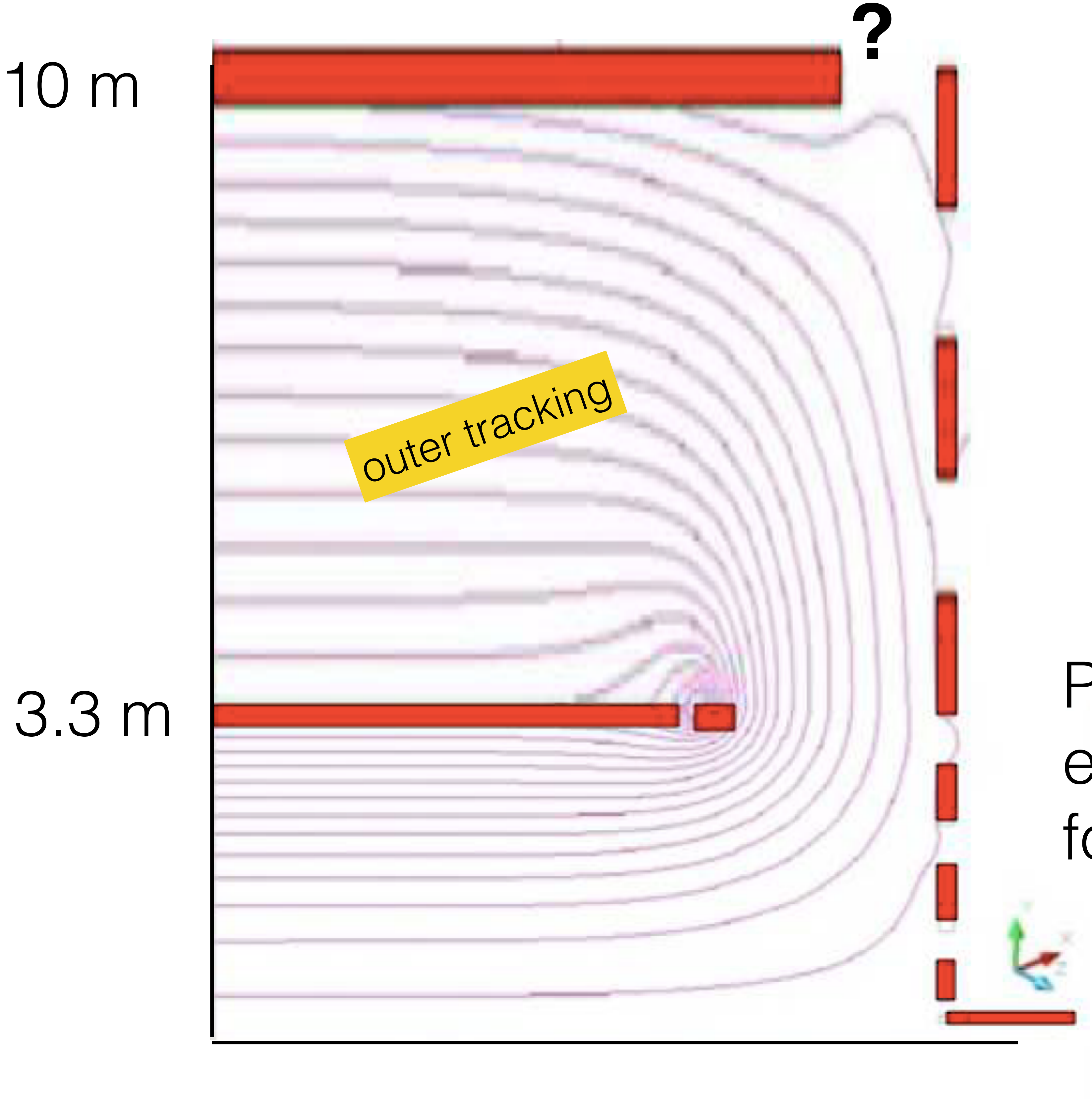
Muon detection and tracking in low magnetic field



Possibility to improve the efficiency for detached vertex configurations (RH neutrinos, dark-sector, etc. etc.)

Possibility to add an external em/h coverage for exotica

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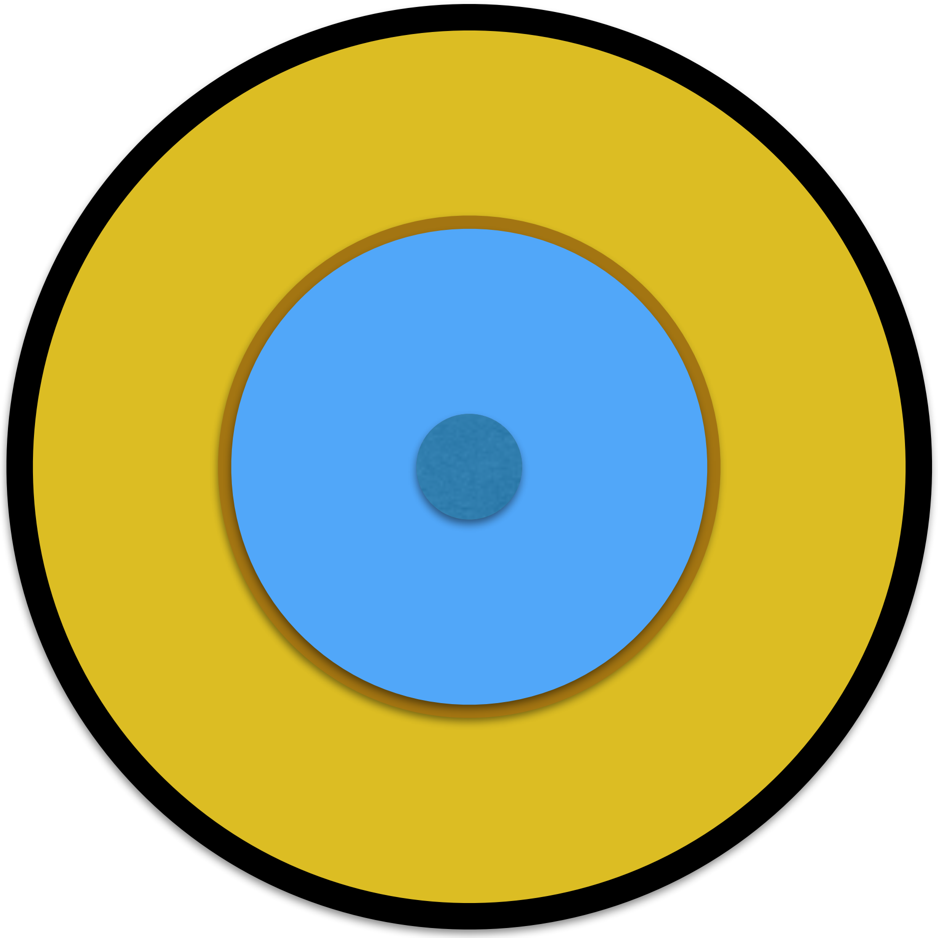
Light silicon vertex r ~ 2.2 to 20-40 cm

Light wire chamber r ~ 20-40 to 180 cm

Pre shower (+ PID ?) r ~ 180 to 190 cm



Copper Dream calorimeter   r ~ 190 to 330 cm

Coil for 2 T field   r ~ 330 to 355 cm

Outer tracking r ~ 355 cm to >1000 cm

Coil for 0.23 T field   r ~ 1000 cm ??

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Material before the calorimeter at normal incidence:

0.01-0.03 X_0 vertex
0.01 X_0 chamber gas+ wires

0.04 X_0 till less than few cm from the calorimeter face

0.01 X_0 outer wall <0.5 cm
1-2 X_0 pre shower ~ 1 cm
[0.1 X_0 torch ~ 2 cm] if torch is installed

[0.75 X_0 coil ~ 5 cm] if coil around the tracker

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Properties of a detector based on these technologies

Very low mass ~ 0.03 X_0 before the pre-shower

Muon momentum resolution of 0.3% at p=100 GeV

E/γ energy resolution ~ 1% at E=100 GeV

Jet energy resolution ~ few % at E=100 GeV

Acceptance defined at ~ 2 μm over few meters

Excellent e-μ-h separation

More than 3 σ π/k separation over a wide momentum range

Very good b and c tagging (to be quantified)

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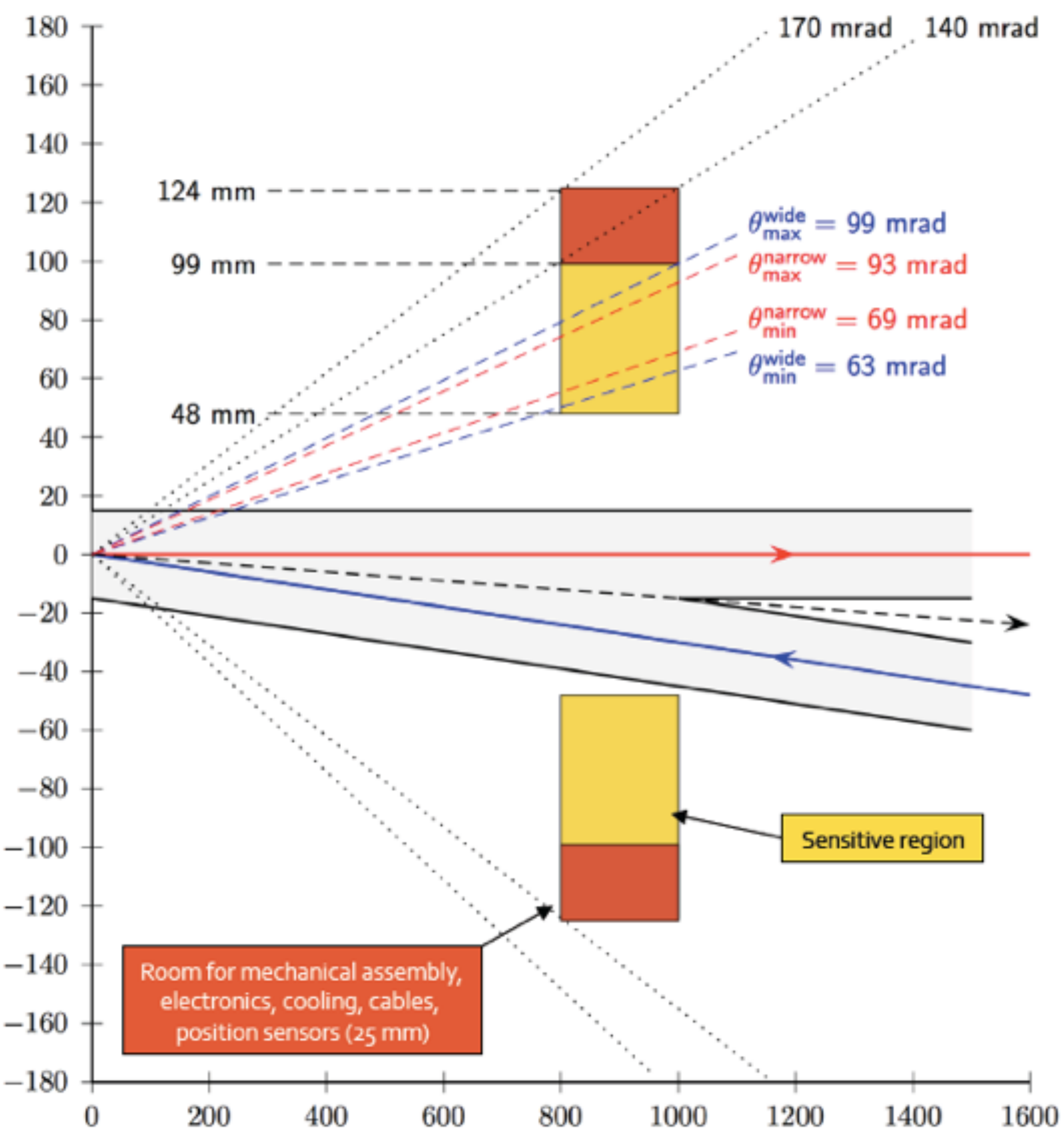
The challenge of the Luminosity measurement



Sensitive region

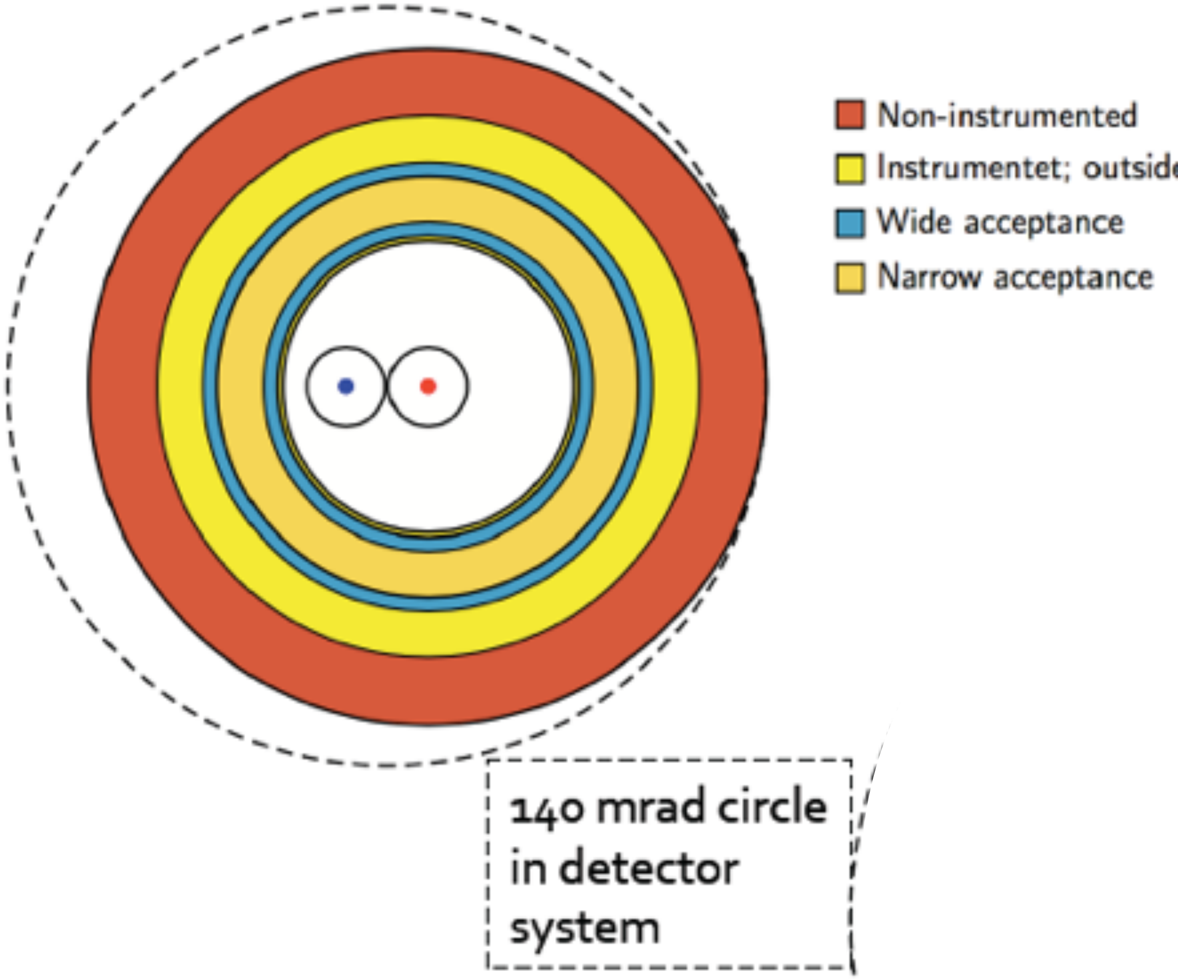
Room for mechanical assembly, electronics, cooling, cables, position sensors (25 mm)

Cross section: $\sigma = 12$ nb

Geometric precision needed for absolute normalization to 10^{-4}

- $\delta z = 43\ \mu m$
- $\delta r_{min} = 1.3\ \mu m$
- $\delta r_{max} = 3.3\ \mu m$

Calorimeter face at $z = 1000$ mm



140 mrad circle in detector system

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Conclusions

It is possible to build with present technologies a detector capable to fulfill the requirements needed for FCC-ee physics program.

Optimization is needed to define the position of the coil vs radius of tracking and calorimeters. And the need of PID beyond what is achievable with the drift chamber.

The final design will profit a lot from improvements beyond the present technology

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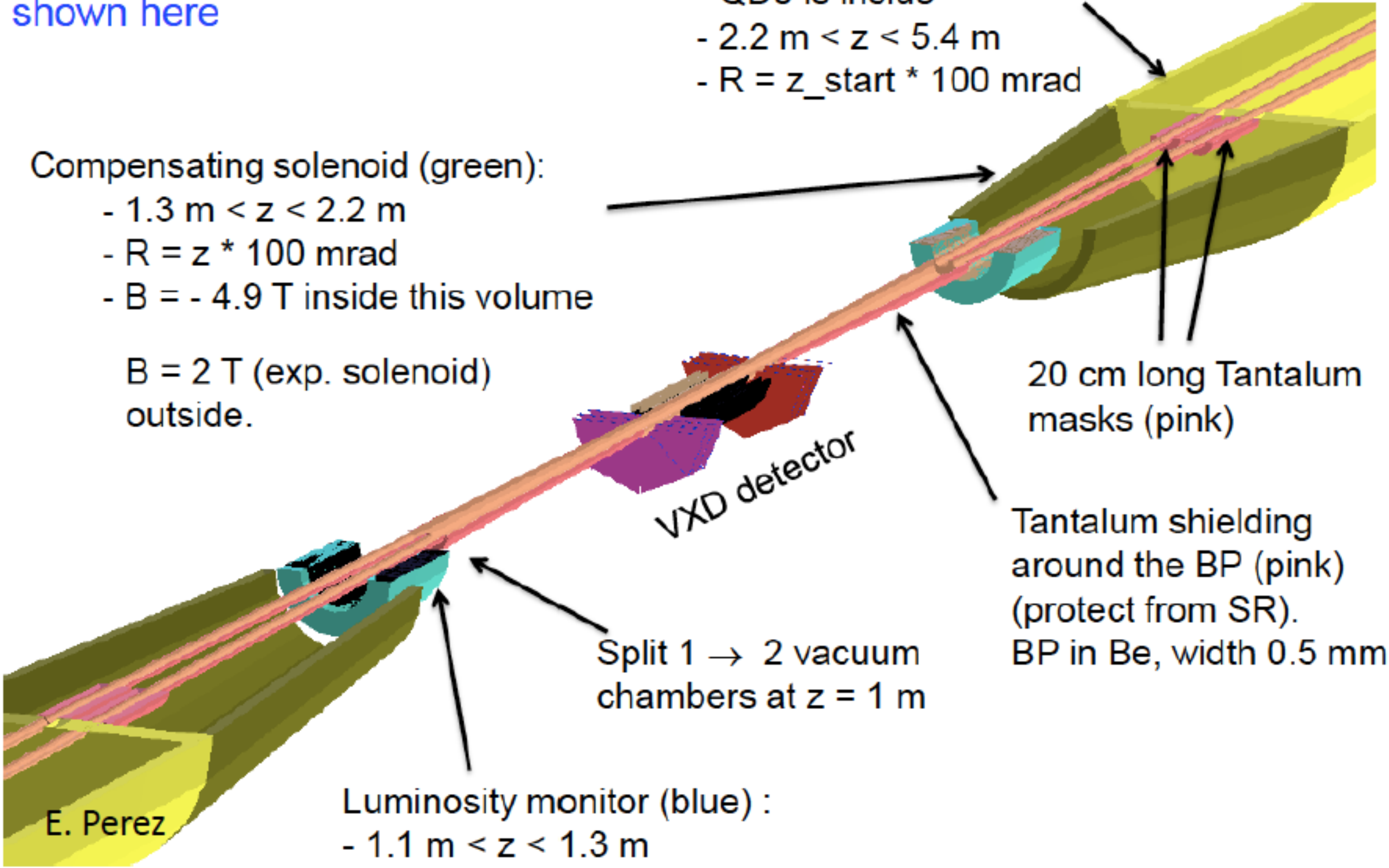
FCC-ee MDI: Geant implementation of the IR

Implemented for the simulations shown here



“envelope” for the shielding solenoid (yellow) :
- QD0 is inside
- 2.2 m < z < 5.4 m
- R = z_start * 100 mrad

Compensating solenoid (green):
- 1.3 m < z < 2.2 m
- R = z * 100 mrad
- B = - 4.9 T inside this volume

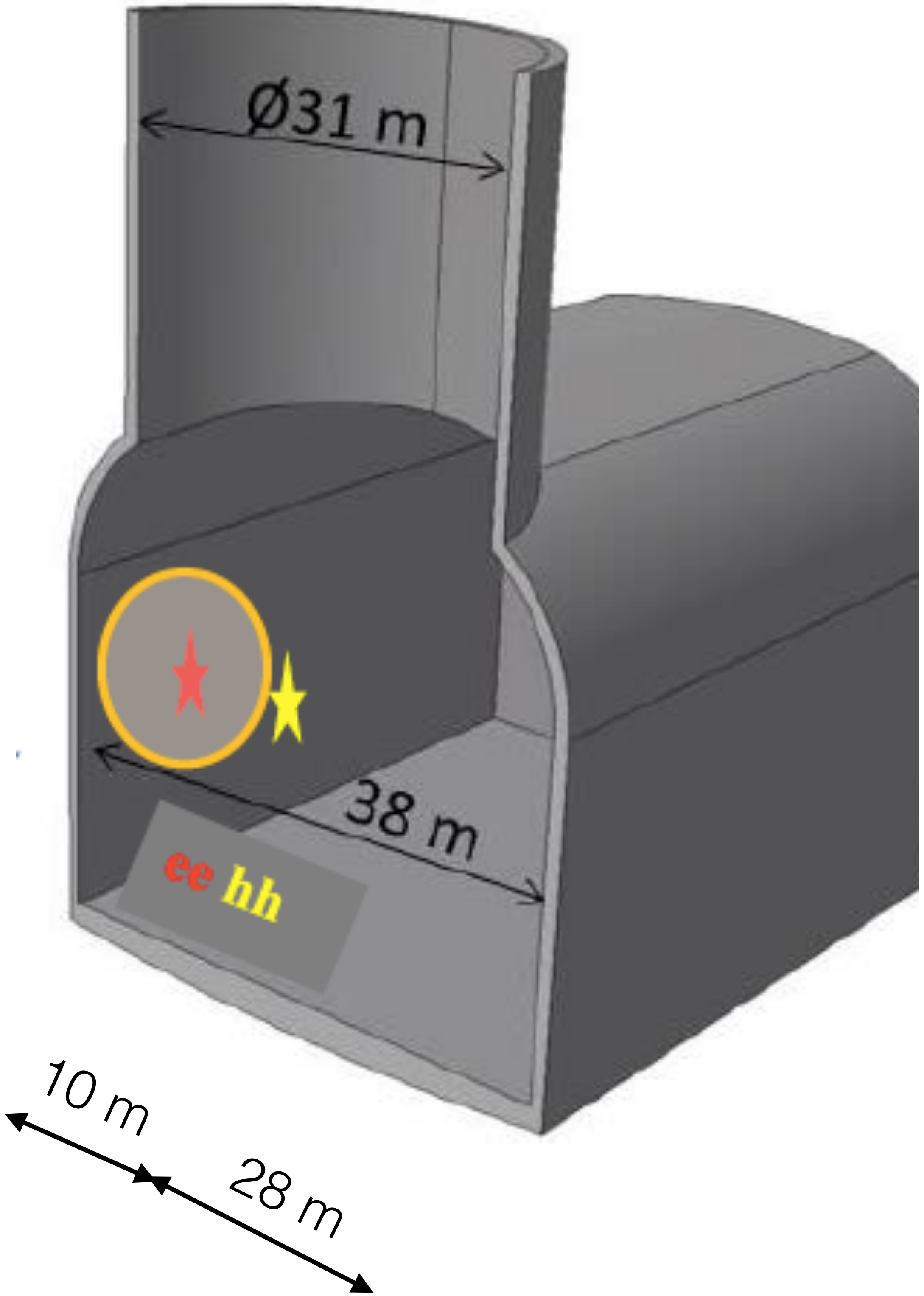
B = 2 T (exp. solenoid) outside.

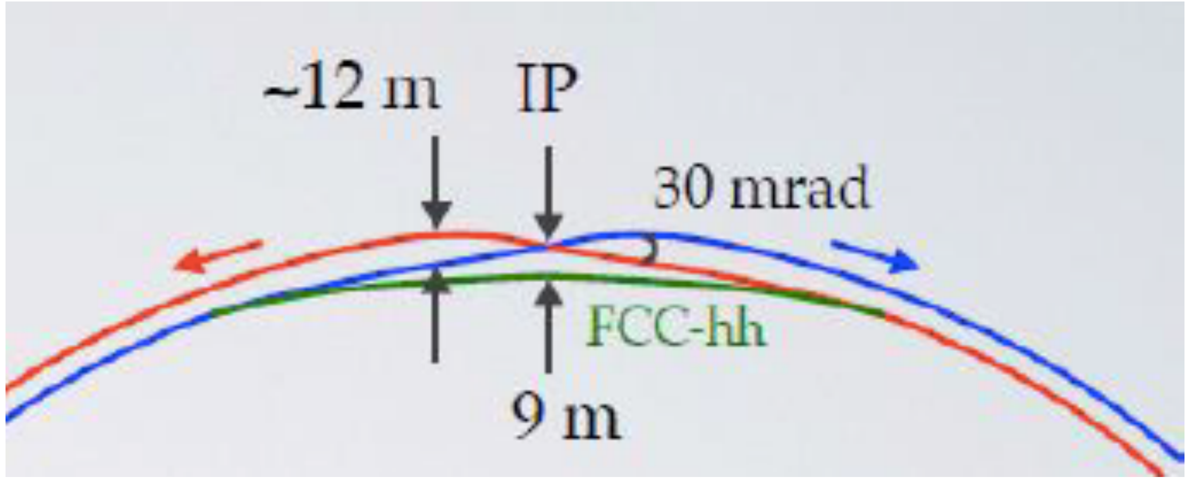
20 cm long Tantalum masks (pink)

Tantalum shielding around the BP (pink) (protect from SR).
BP in Be, width 0.5 mm

Split 1 → 2 vacuum chambers at z = 1 m

Luminosity monitor (blue) :
- 1.1 m < z < 1.3 m





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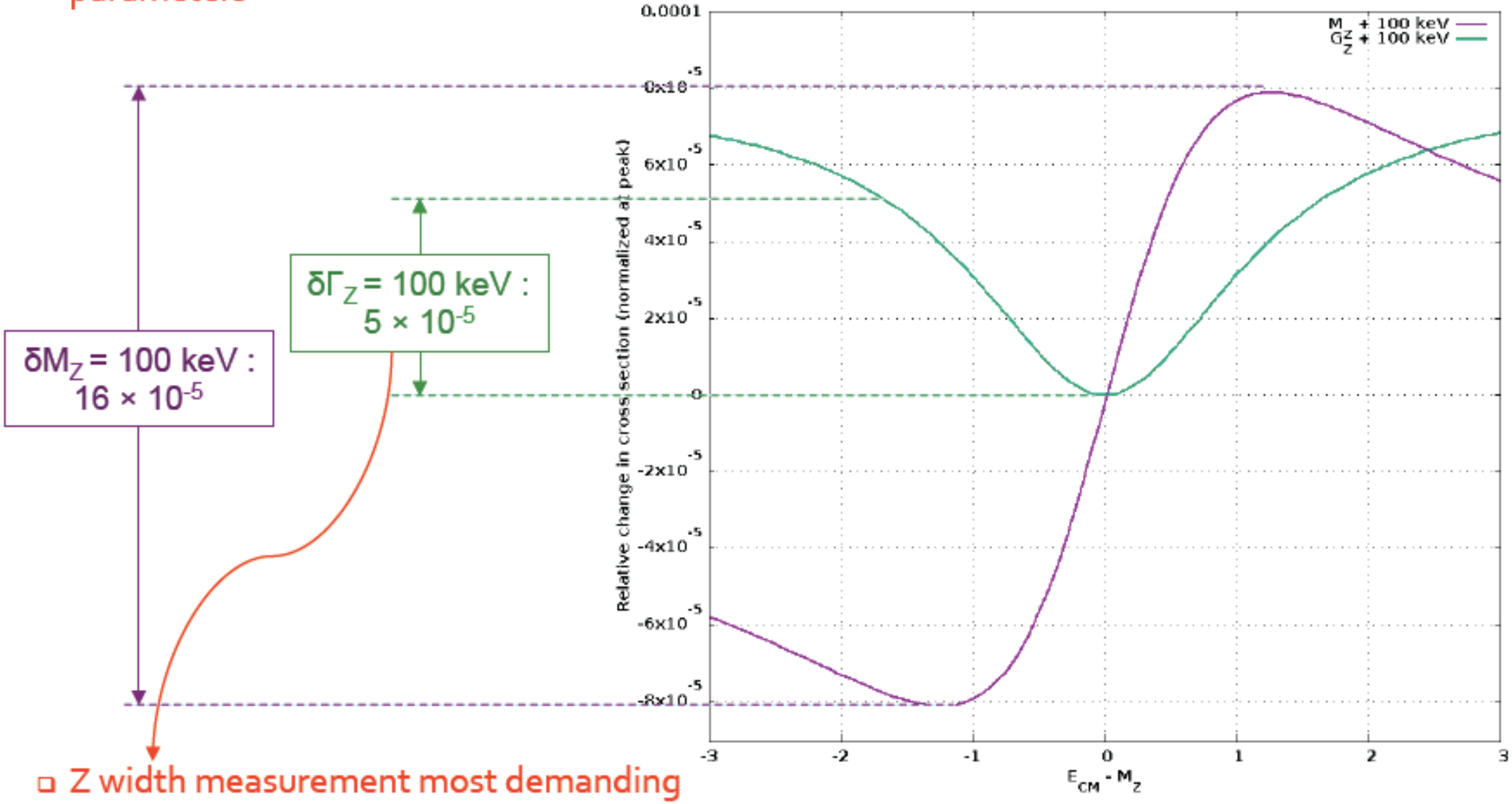
Tera-Z Relative Normalisation (i)

- FCC-ee goal: Determine Z parameters to precisions:

$\delta M_Z = 100$ keV ; $\delta\Gamma_Z = 100$ keV

- Plot shows relative change in cross section across Z resonance for variation of this size in these parameters



$\delta\Gamma_Z = 100$ keV :
5×10^{-5}

$\delta M_Z = 100$ keV :
16×10^{-5}

- Z width measurement most demanding
  - Need **relative** normalisation to about **2×10^{-5}**

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