

Global concepts for an **FCC-ee** detector: **IDEA** and **CLD**

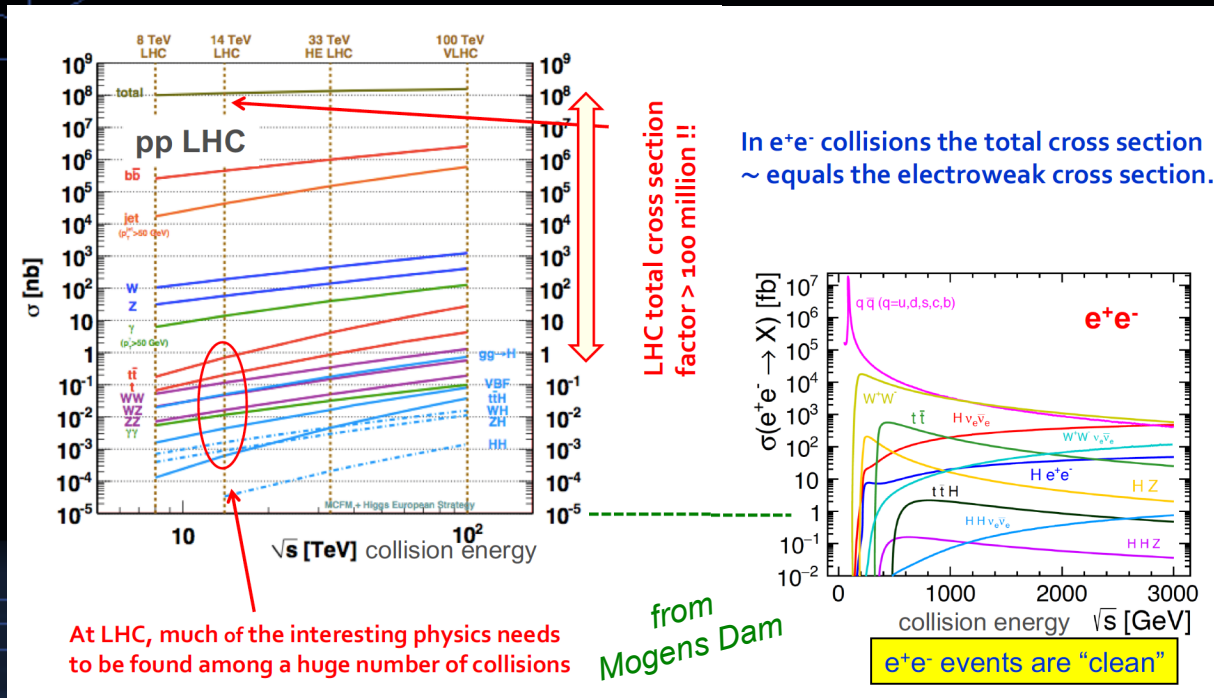


F. Grancagnolo
INFN – Lecce



Workshop FCC-France
LPNHE-Paris, May 14-15, 2020

advantages of e^+e^-



partial vs total cross section

clean experimental environment

no pile-up, no underlying events

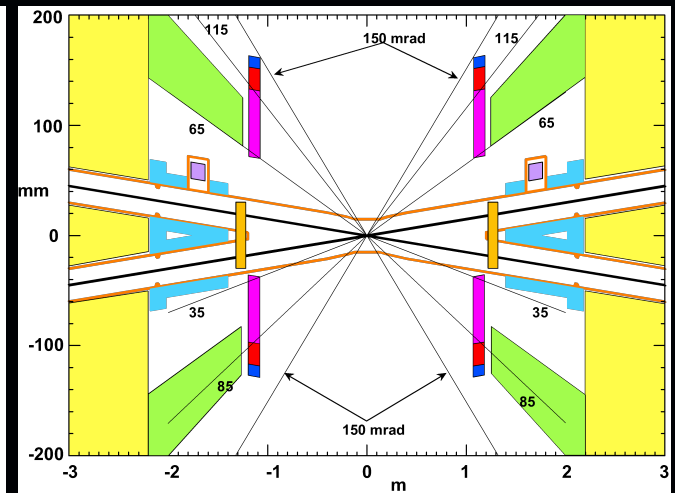
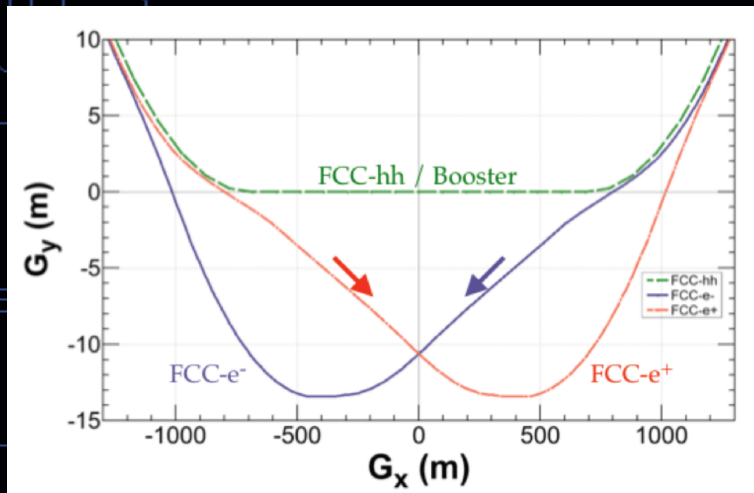
kinematical constraints (initial E, p)

low radiation levels

challenges

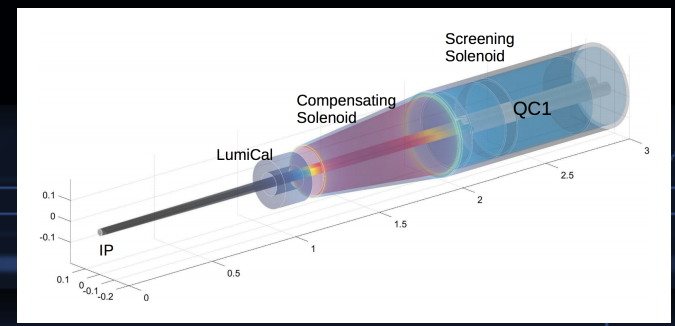
- **Extremely high luminosities:**
large statistics (high statistical precision) – control of systematics (@ 10^{-5} level)
- **Physics event rates up to 100 kHz (at Z pole)**
strong requirements on sub-detectors DAQ systems
- **Bunch spacing down to 20 ns (at Z pole)**
"continuous" beams (no power pulsing),
- **Large beam crossing angle – very complex MDI**
- **Large beam crossing angle – emittance blow-up with detector solenoid field (< 2T)**

MDI



- HOM absorbers
- shielding
- compensating solenoid
- luminometer
- QC1

- beam crossing angle = 30 mrad
- small bend before IP to limit synchrotron radiation in detector
- larger bend after IP (all bends in the horizontal plane)

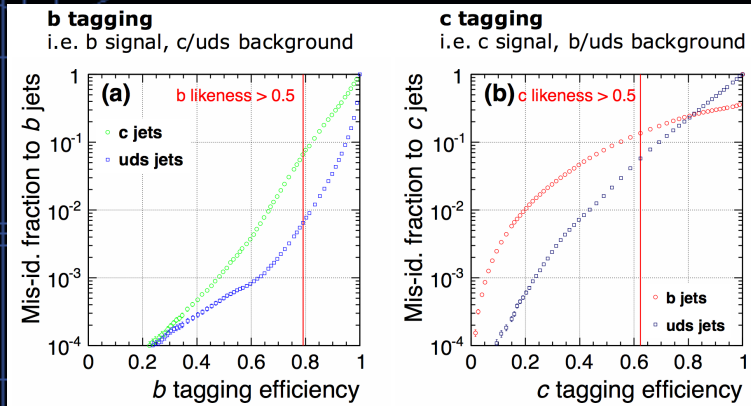


challenges

- **Extremely high luminosities:**
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"continuous" beams (no power pulsing),
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- **More physics challenges at Z pole:**
 - luminosity measurement at 10^{-5} – luminometer acceptance $\approx 1-2 \mu\text{m}$
 - detector acceptance definition at $< 10^{-5}$ – detector hermeticity (no cracks!)
 - stability of momentum measurement – stability of magnetic field wrt E_{cm} (10^{-6})
 - b/c/g jets separation – flavor and τ physics – vertex detector precision
 - particle identification (preserving hermeticity) – flavor physics (and rare processes)

Detector requirements: impact parameter resolution

from ILC studies



Tanabe
at IAS-HEP 2017

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2} \theta}$$

$a \simeq 5 \mu\text{m}; \quad b \simeq 15 \mu\text{m GeV}$

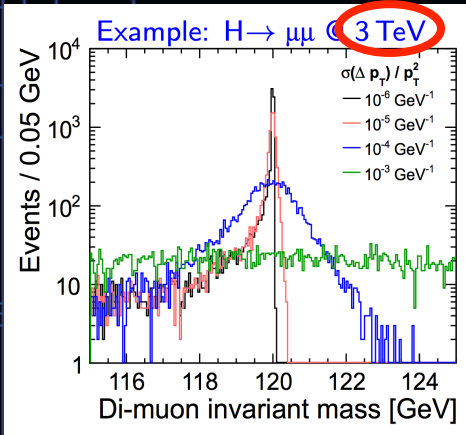
very challenging!

- a single point accuracy of $3 \mu\text{m}$;
- a vertex detector geometry providing a first measured point of tracks at $\sim 15 \text{ mm}$ from the IP.
- a material budget between the IP and the first measured point restricted to a few per mill of radiation length.

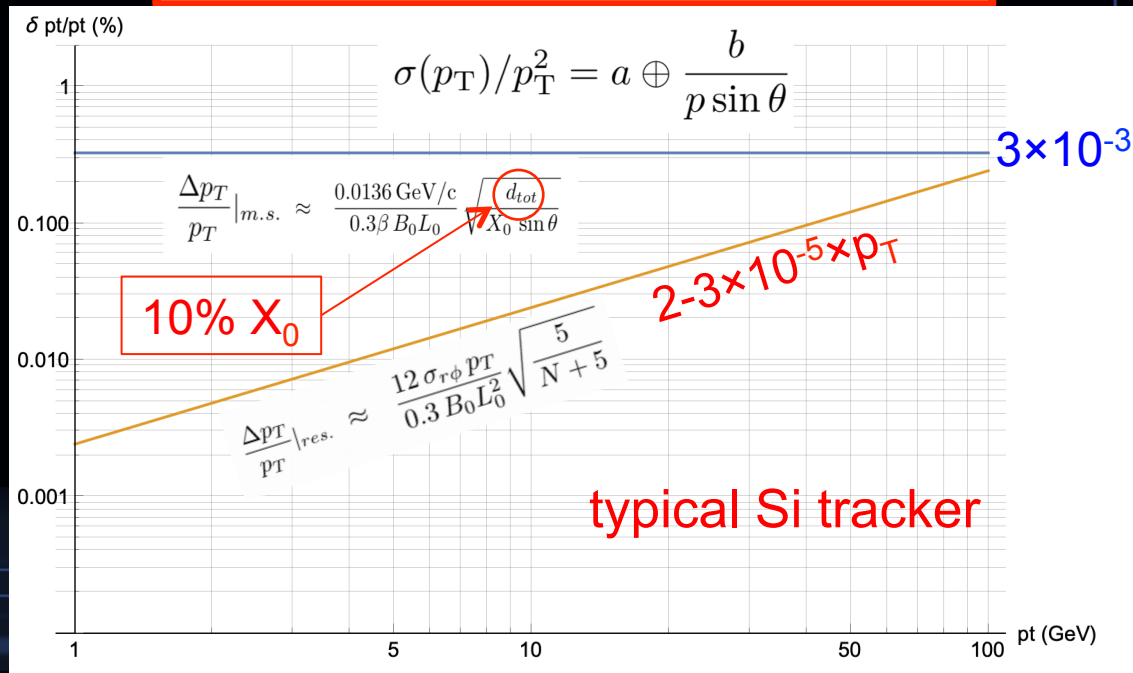
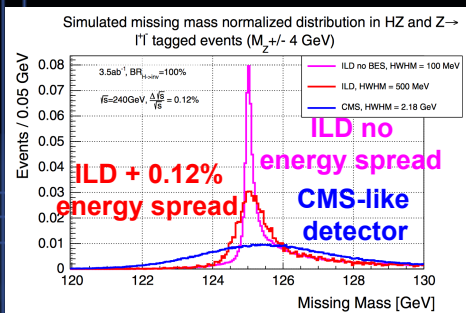
Accelerator	a (μm)	b ($\mu\text{m} \cdot \text{GeV}/c$)
LEP	25	70
SLC	8	33
LHC	12	70
RHIC-II	13	19
ILD	< 5	< 10

Detector requirements: momentum resolution

$$\sigma_{p_T} / p_T^2 \approx 2 \times 10^{-5} \text{ GeV}^{-1}$$



Sicking at TIPP2017



Detector requirements: energy resolution

Energy coverage < 200 GeV ($22 X_0$, 7λ)

Jet energy $\delta E/E \leq 30\%/\sqrt{E}$ [GeV]

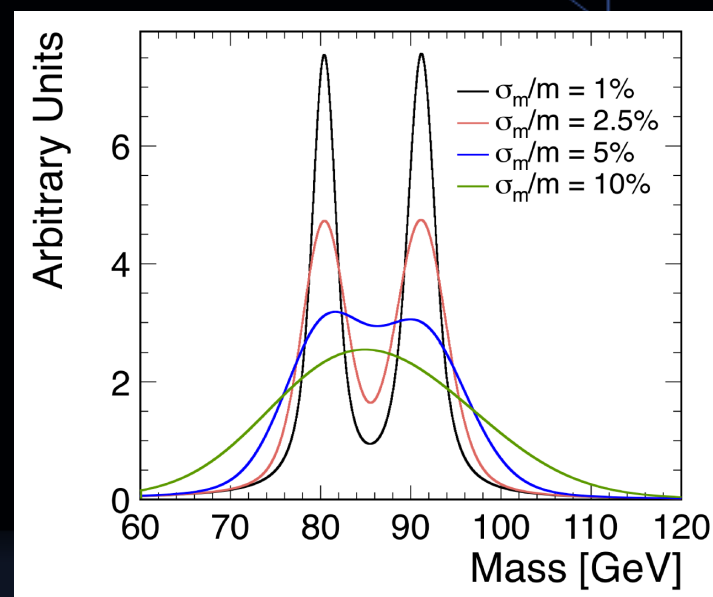
e/ γ energy $\delta E/E \leq 15\%/\sqrt{E}$ [GeV]
(down to 300 MeV)

Particle identification Excellent e/ γ ID

Time stability and acceptance knowledge
(Normalization to 10^{-5} level)

π^0 identification for τ physics

W/Z/H separation



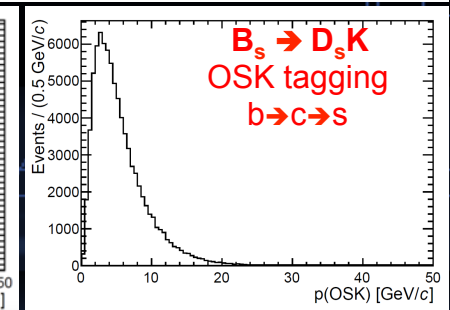
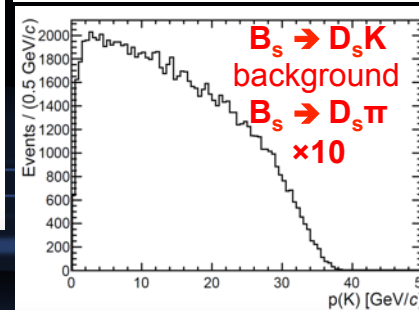
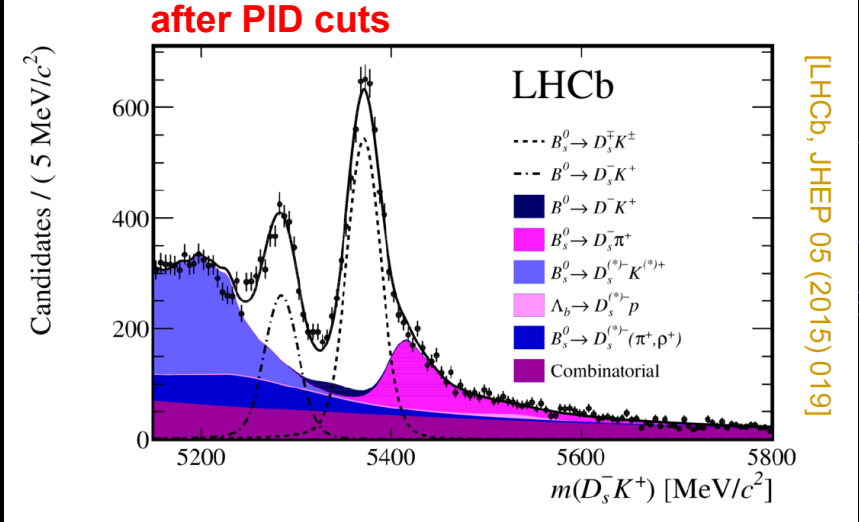
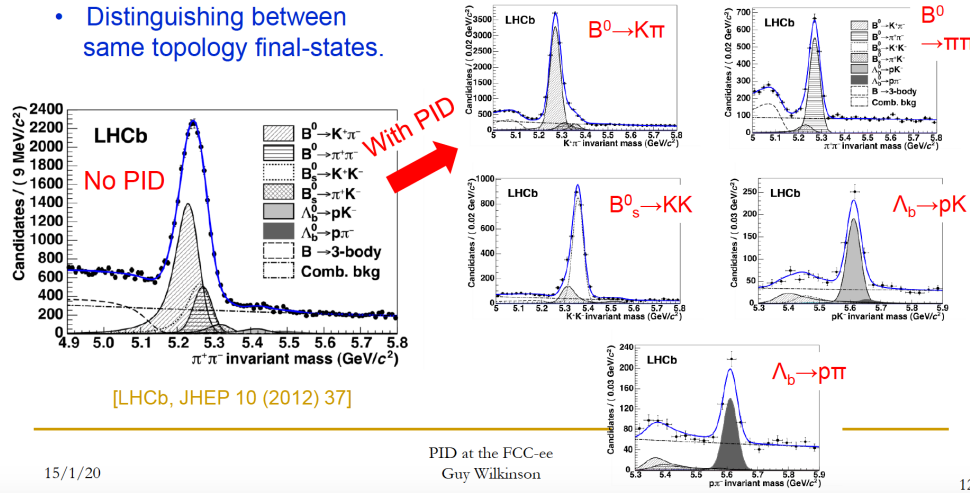
$\sigma(E)/E \sim 3-5\%$ for $E \geq 50$ GeV

Detector requirements: particle identification

PID requirements in b-physics & hadron spectroscopy

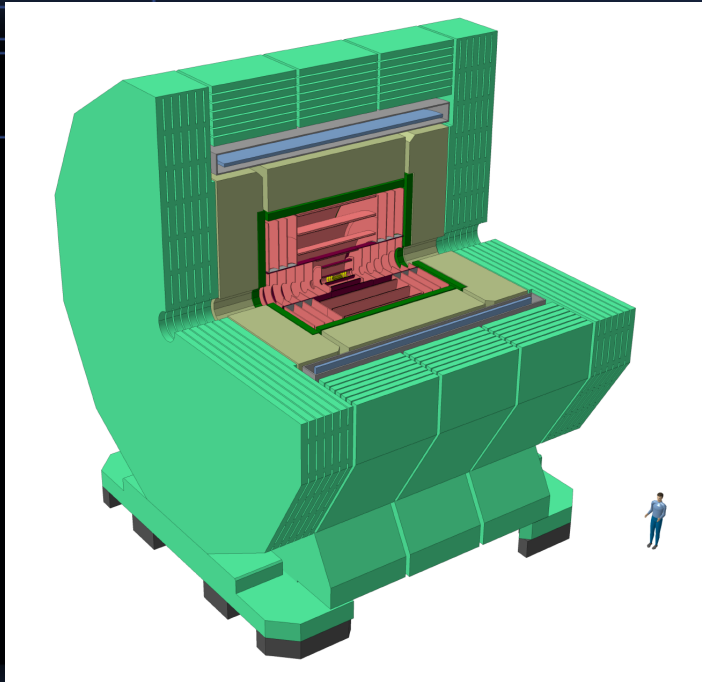
Hadron identification essential for a large set of flavour physics measurements.

- Distinguishing between same topology final-states.



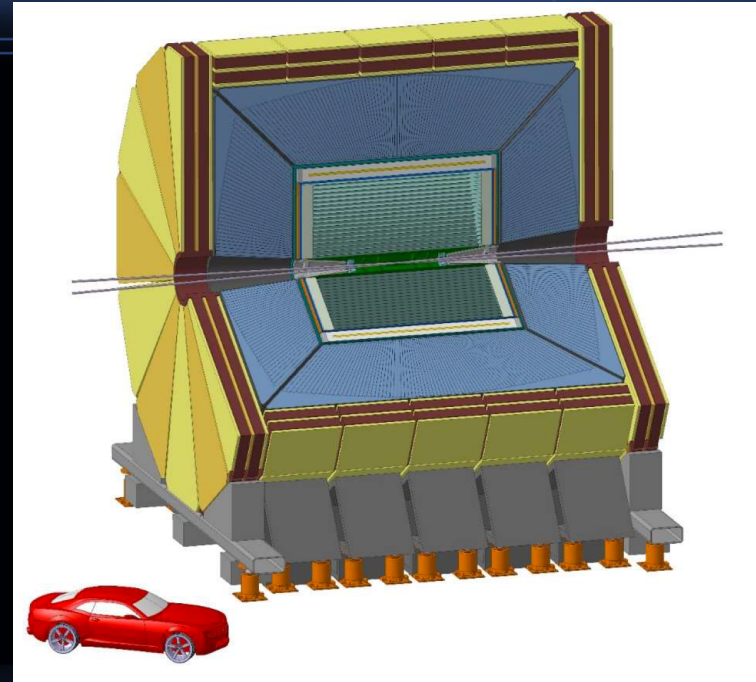
from: Wilkinson at 3rd FCC Physics and Experiments Wkshp

CLD



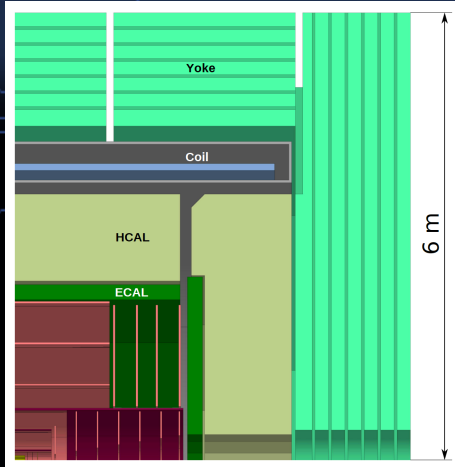
Adaptation from CLIC detector
Full silicon tracker
High granularity PFA calorimeter
Solenoid outside calorimeter

IDEA



New, innovative (cheaper?) detector
Ultra-light drift chamber
Dual Readout calorimeter
Solenoid inside calorimeter

CLD



3 double layers +
3 double disks

25 μm ×25 μm
pixel

50 μm sensor

0.6-0.7% X_0
per double layer

pixel and μ -strips
7 μm ×90 μm
(5 μm ×5 μm 1st layer)

point resolution

3 layers + 7 disks
inner tracker

3 layers + 4 disks
outer tracker

1-1.5% X_0 per layer

ECAL 20cm
5m×5m Si-W
1.9mm W

40 layers 22 X_0 , 1 λ

HCAL 117cm
30mm×30mm Sci-steel
19mm steel

44 layers 5.5 λ

90 mm Al coil
2T field

1.5m steel yoke

6 layers RPC
30mm×30mm
granularity

vertex detector

3 double layers
20 μm ×20 μm
double μ -strips
50 μm ×1mm
4 forward disks
50 μm ×50 μm

0.6-1% X_0
per double layer

tracker

112 layers
1.4 cm square cells
100 μm ×750 μm
point resolution

Si wrapper
50 μm ×1mm

1.5% X_0 radially
5% X_0 forward

calorimeter

fully
projective towers

$\Delta\theta = 1.125^\circ$

$\Delta\phi = 10.0^\circ$

2880 in barrel
2×1260 end-cap

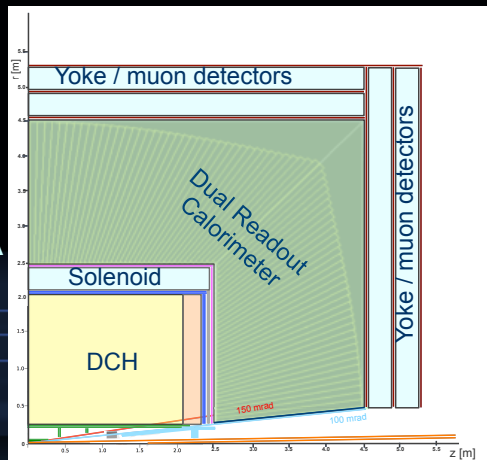
2m Cu
8.2 λ

magnet and muon detector

30cm total envelope
2T field
cold mass + cryostat
0.28 + 0.46 X_0
0.6m steel yoke

3 layers μ -RWELL
1.5mm×500mm
granularity

IDEA



14/05/2020

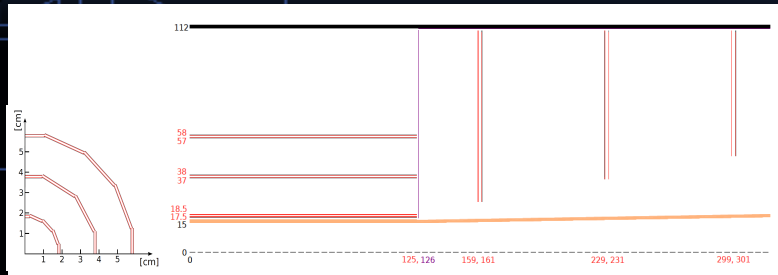
F. Grancagnolo - IDEA and CLD at FCC-ee

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CLD

Vertex detector

IDEA

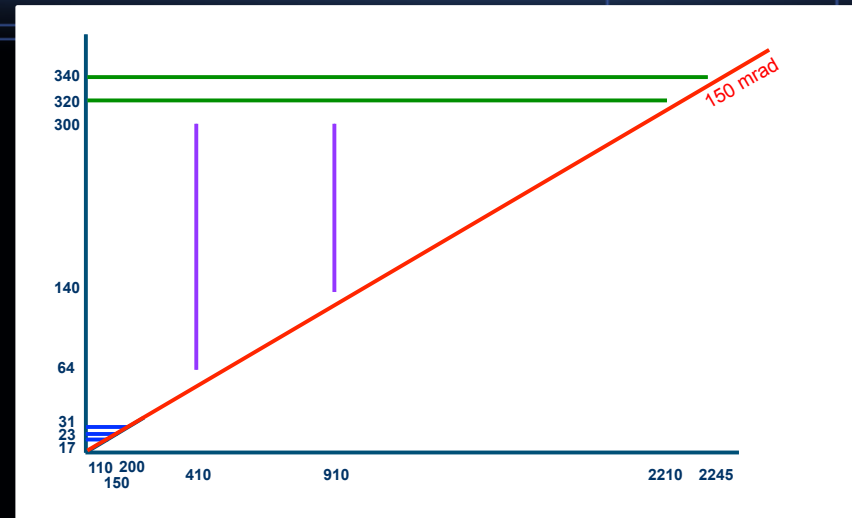
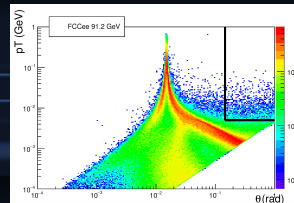
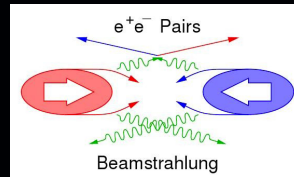
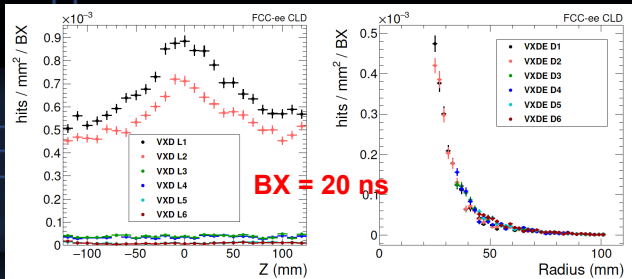


0.5 m²
≈ 10⁹ ch.

- Silicon pixels (25 x 25 μm²), 3 μm single point resolution
- 3 double layers in barred R = 17, 27, 57 mm
- 3 double layers in end-cap disks Z = 160, 230, 300 mm
- Material budget: 0.6%/0.7% X₀ per double layer in barrel/e-c

Full MC simulation

Occupancy at Z pole < 1-2 × 10⁻³ hits/pixel



Inspired by ALICE ITS based on MAPS technology

- inner layers 20×20 μm² pixel 0.3% X₀ per layer expected point resolution 3 μm
- outer layers 0.05×1 mm² strips 1% X₀ per layer
- disks 50×50 μm² pixel 0.3% X₀ per layer

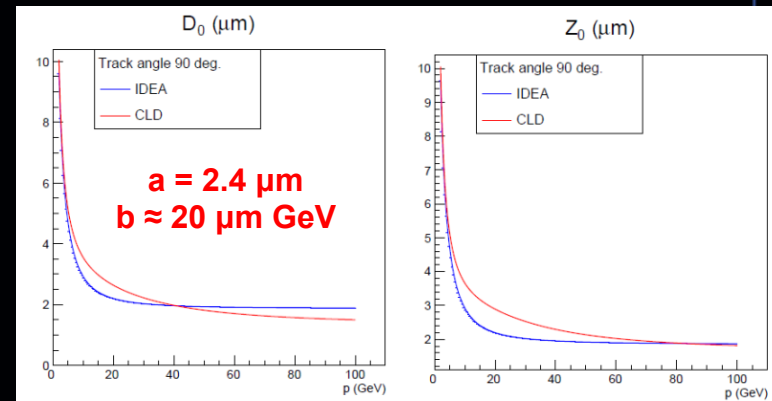
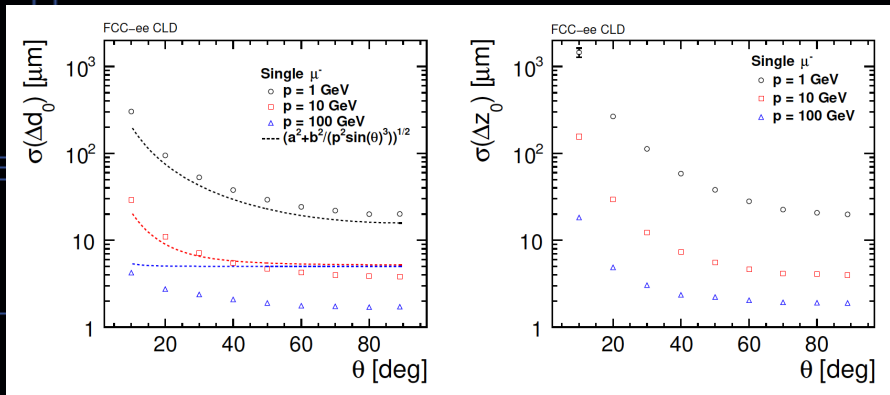
to be optimized ...

2 m², ≈ 1.2 × 10⁹ ch. (+ 20 m², ≈ 0.4 × 10⁹ ch.)

CLD

Vertex detector

IDEA



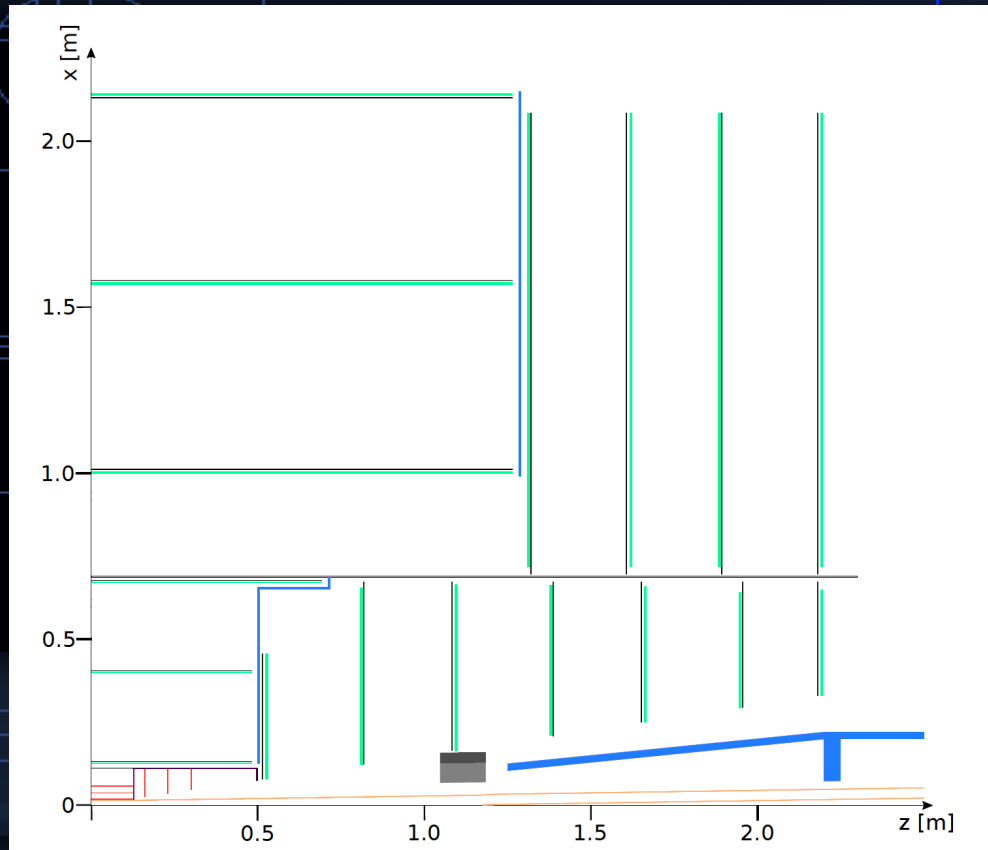
CLD

Vertex detector

IDEA

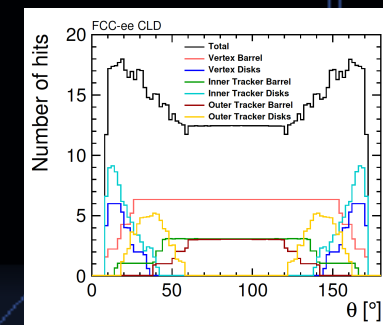
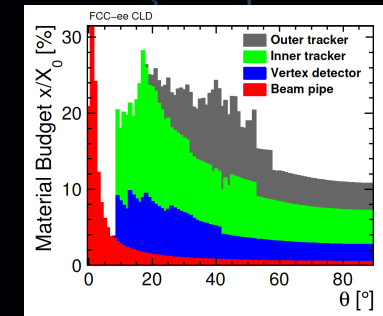


CLD Tracker



200 m²
3×10⁹ ch.

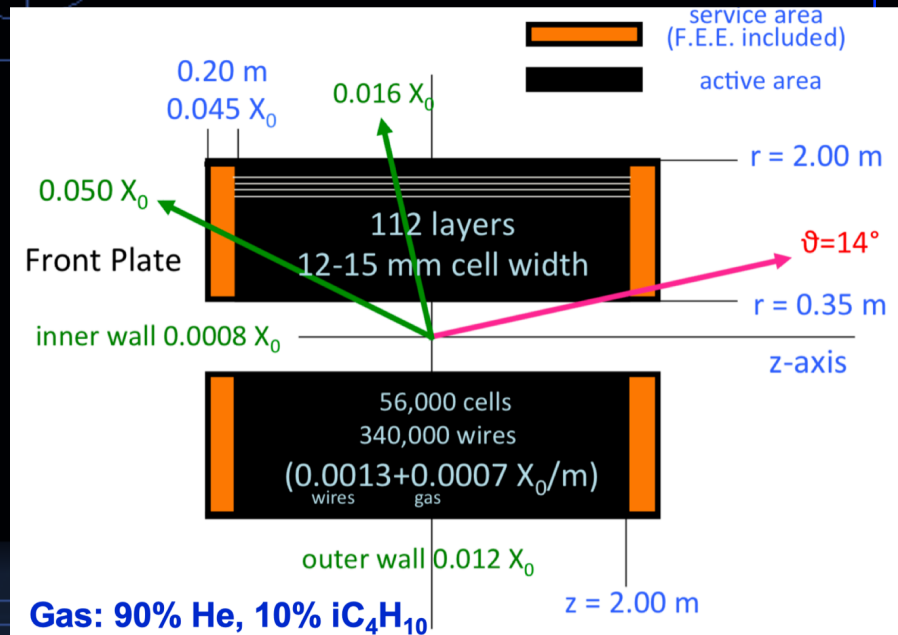
- **Inner Tracker:**
3 barrel layers
0.05×1 mm²
+ 7 disks
25×25 μm², 0.05×1 mm²
- **Outer Tracker:**
3 barrel layers + 4 disks
0.05×10 mm²
- **Single point resolution:**
1st IT disks: 5×5 μm²
rest: 7×90 μm²
- **Material budget:**
1.1 - 1.6% X₀ per layer
+ C-fiber + support tube + ...



from 12 to 18 space points
per track, angle dependent

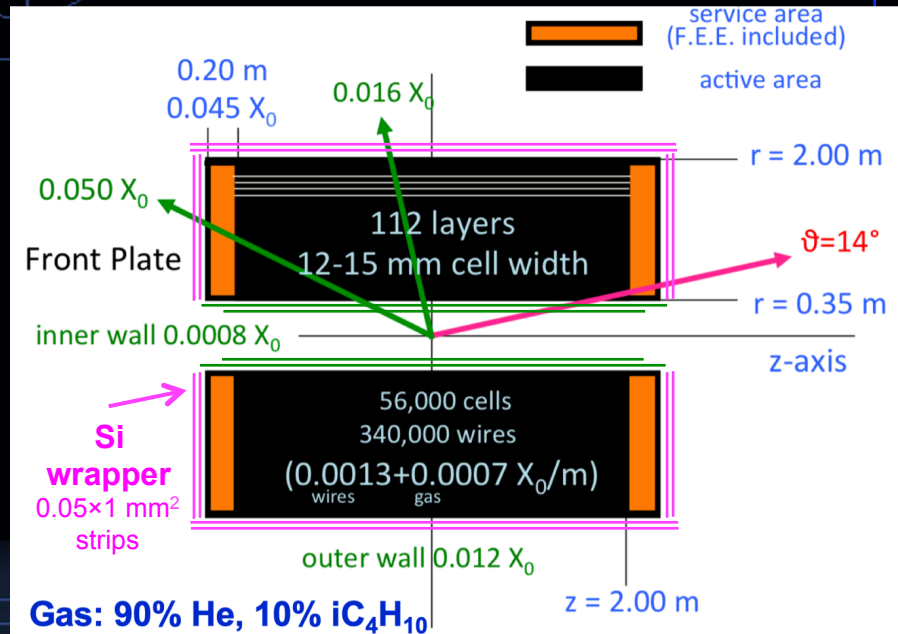
IDEA Tracker

Drift Chamber with cluster timing/counting



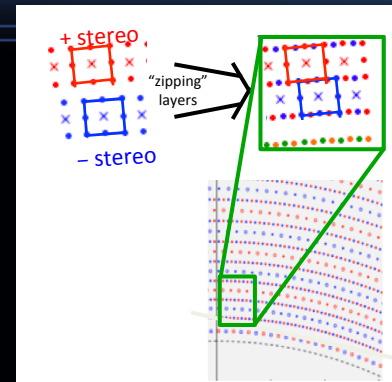
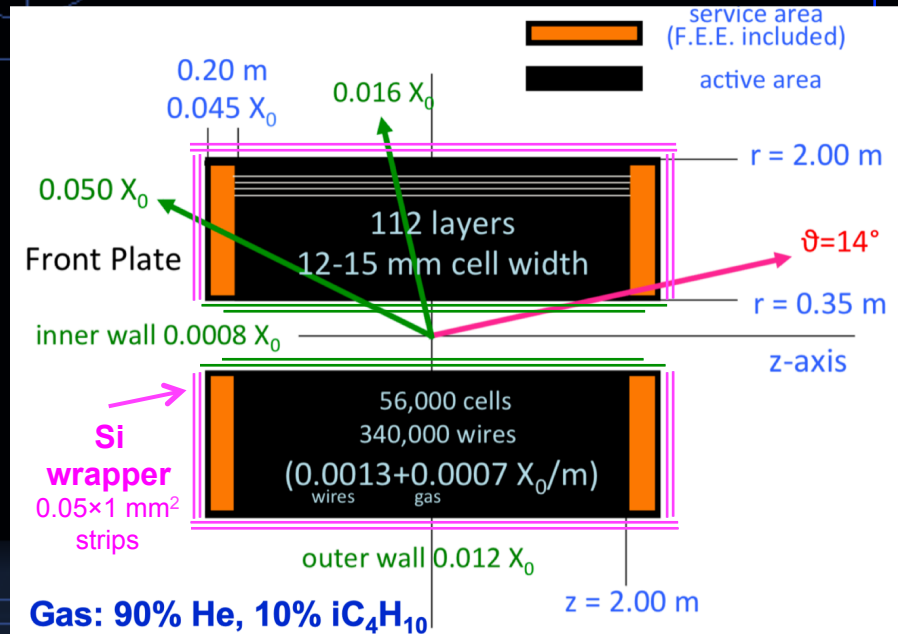
IDEA Tracker

Drift Chamber with cluster timing/counting
+ Silicon wrapper



IDEA Tracker

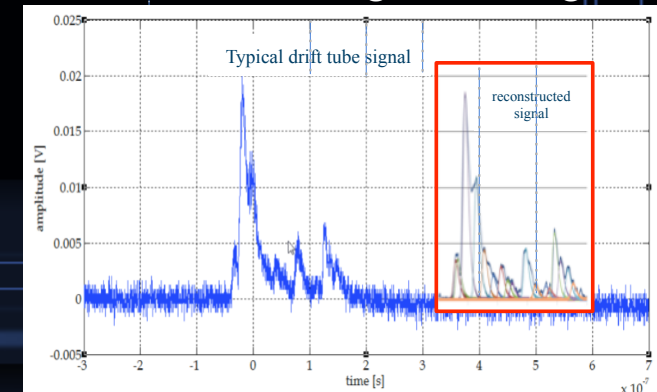
Drift Chamber with cluster timing/counting
+ Silicon wrapper



Drift chamber
 ≈ 50 m³
112000 ch.

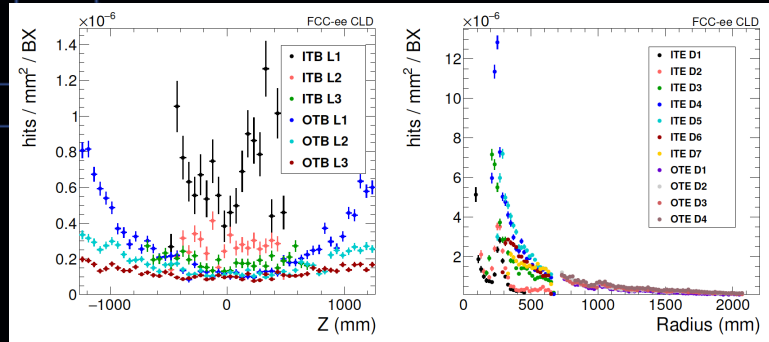
S wrapper
175 m²
 3.5×10^8 ch.

Cluster timing/counting

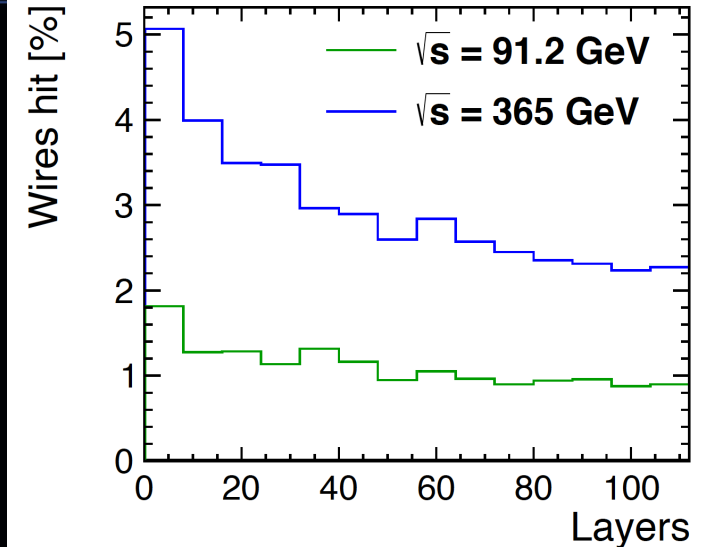
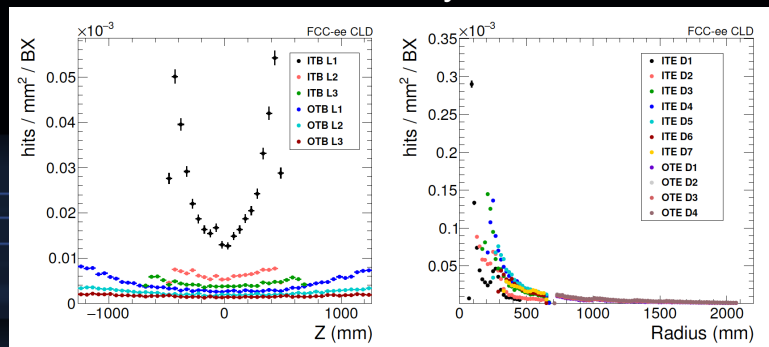


CLD Tracker Occupancy IDEA

IPC background at Z pole: < 1% occupancy



IPC background at $t\bar{t}$: < 0.2% occupancy
similar contribution from synchrotron radiation

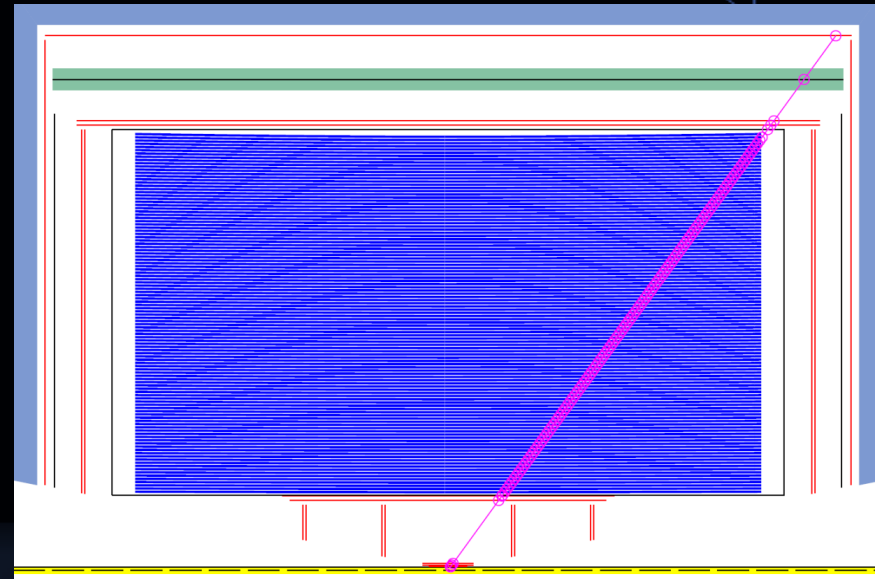
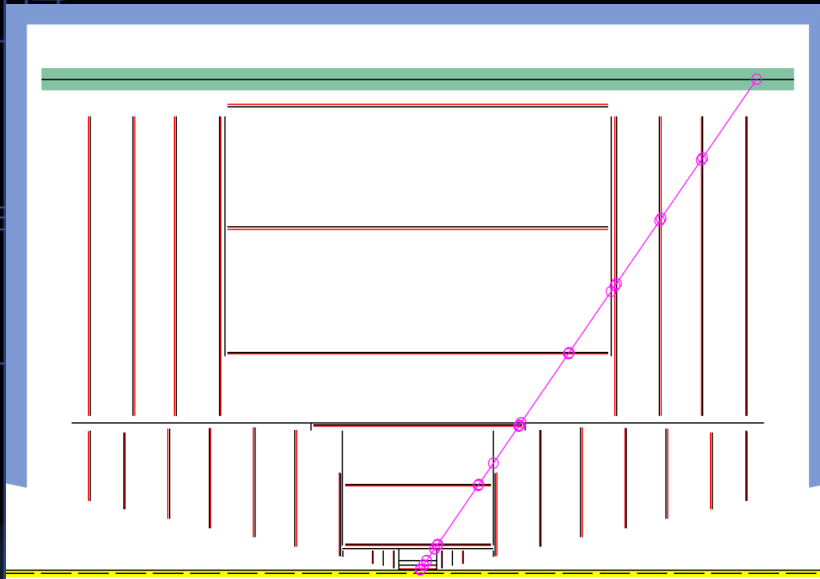


Background	Average occupancy	
	$\sqrt{s} = 91.2 \text{ GeV}$	$\sqrt{s} = 365 \text{ GeV}$
e^+e^- pair background	1.1%	2.9%
$\gamma\gamma \rightarrow$ hadrons	0.001%	0.035%
Synchrotron radiation	negligible	0.2%

CLD

Tracking

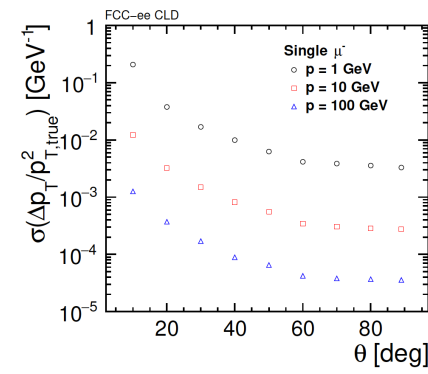
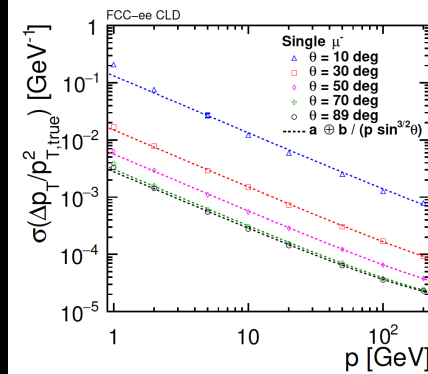
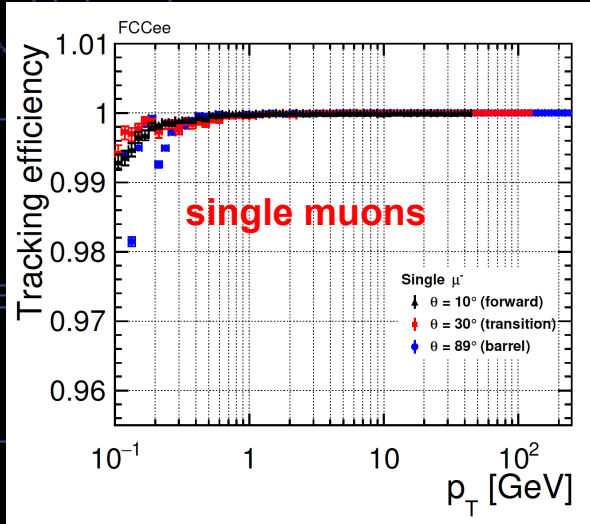
IDEA



CLD Tracker Resolution

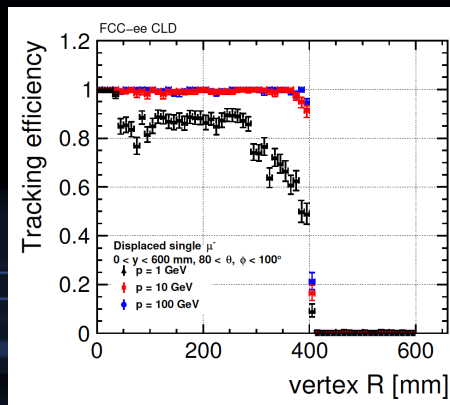
efficiency

resolutions (full simulation)

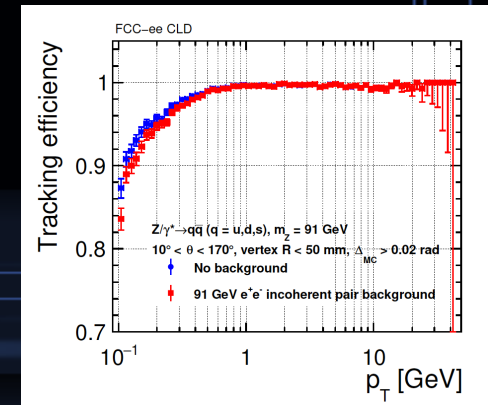


$$\sigma(\Delta p_T / p_T^2) = a \oplus \frac{b}{p \sin^{3/2} \theta}$$

θ	a	b
10°	$7.4 \cdot 10^{-5}$	0.010
30°	$1.8 \cdot 10^{-5}$	0.005
50°	$9.2 \cdot 10^{-6}$	0.004
70°	$8.3 \cdot 10^{-6}$	0.003
89°	$8.6 \cdot 10^{-6}$	0.003



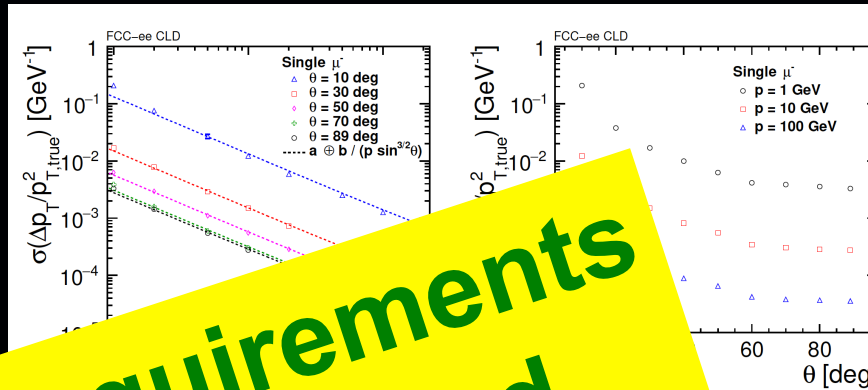
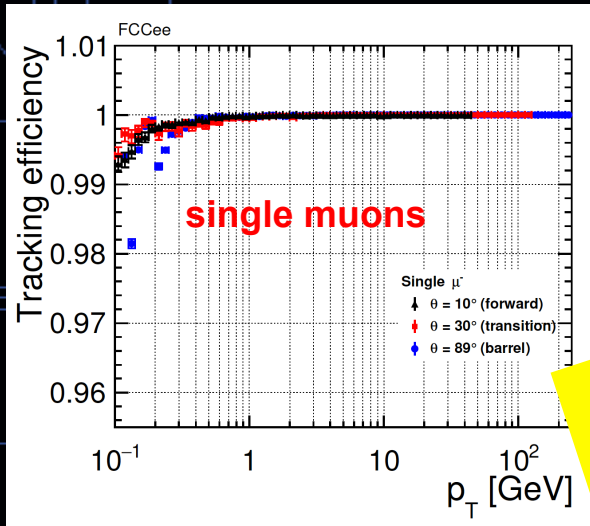
efficiency for muons at displaced vertices



CLD Tracker Resolution

efficiency

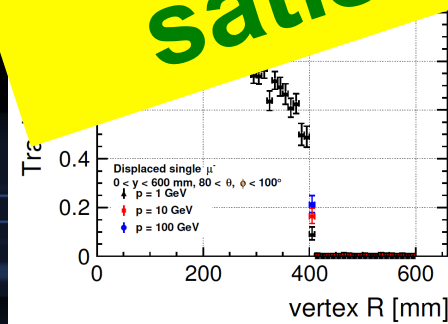
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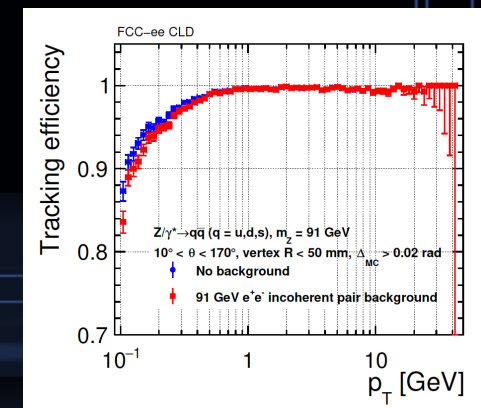
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requirements satisfied

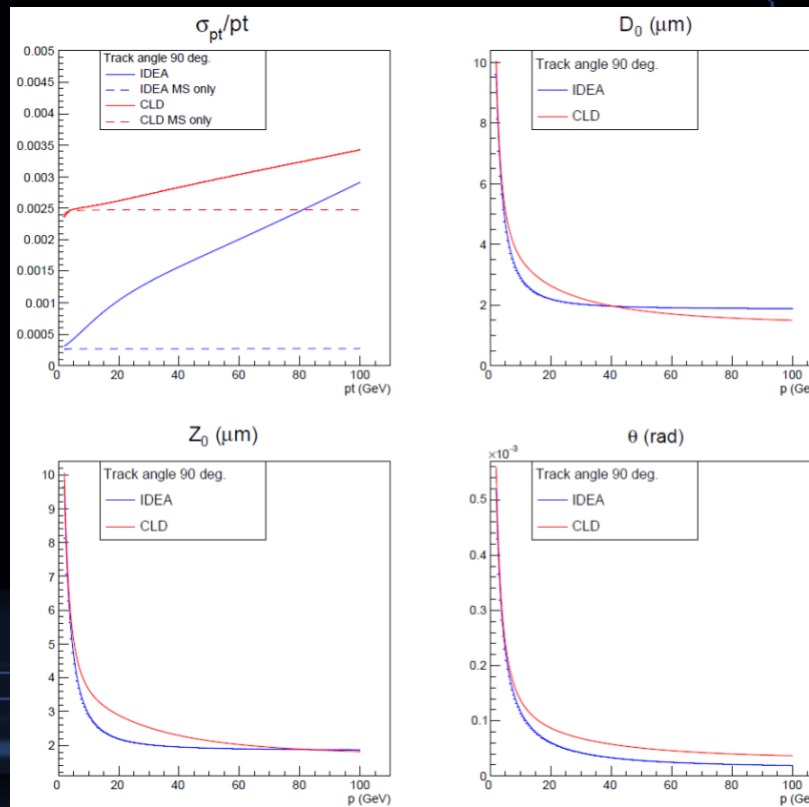
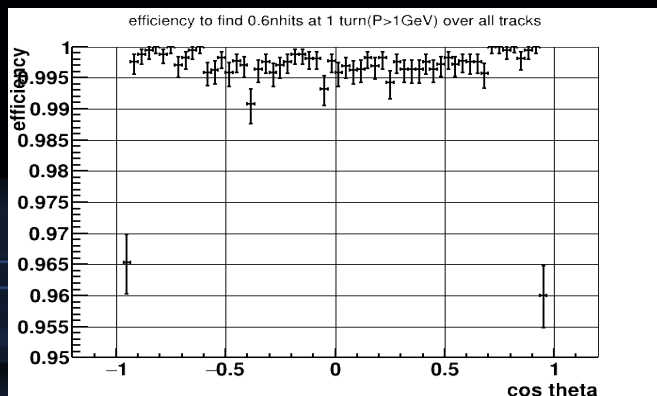
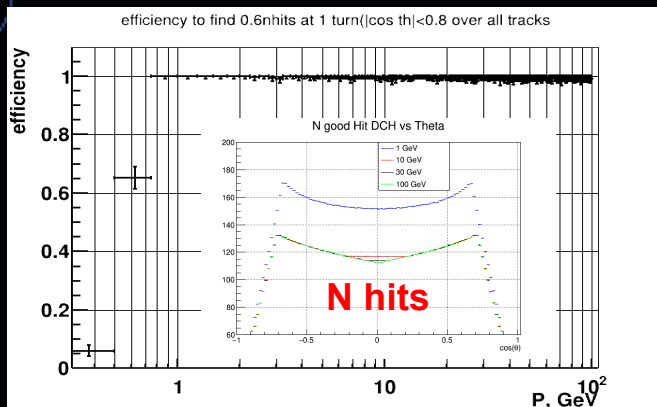


efficiency for muons at displaced vertices



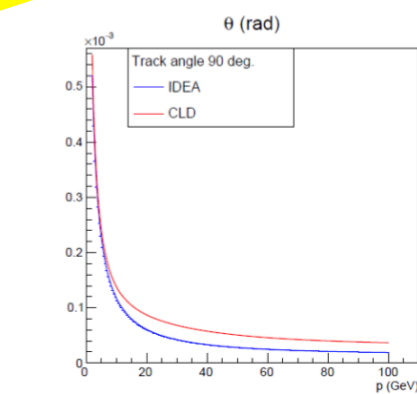
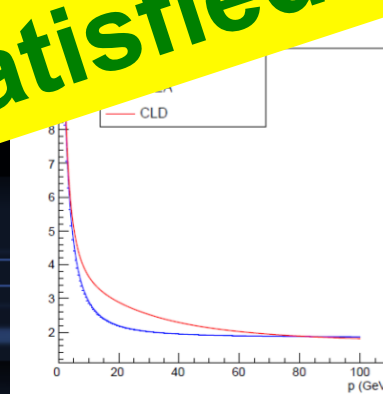
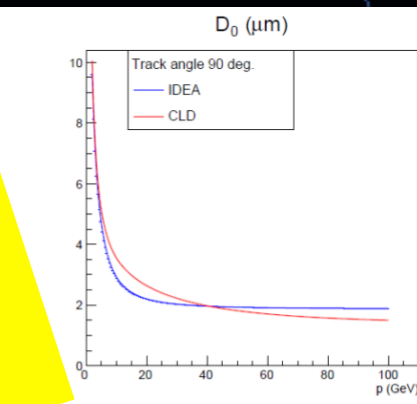
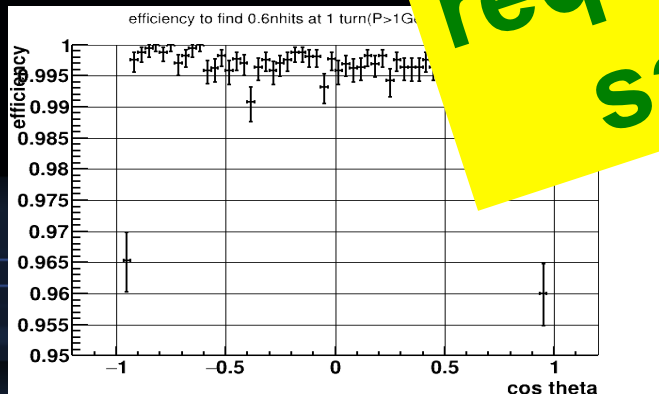
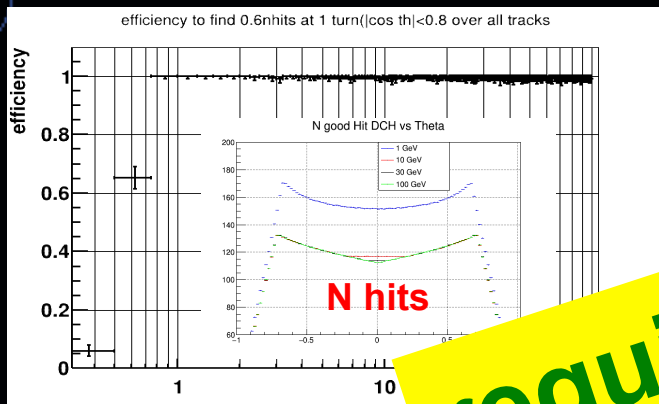
IDEA Tracker Resolution

efficiency



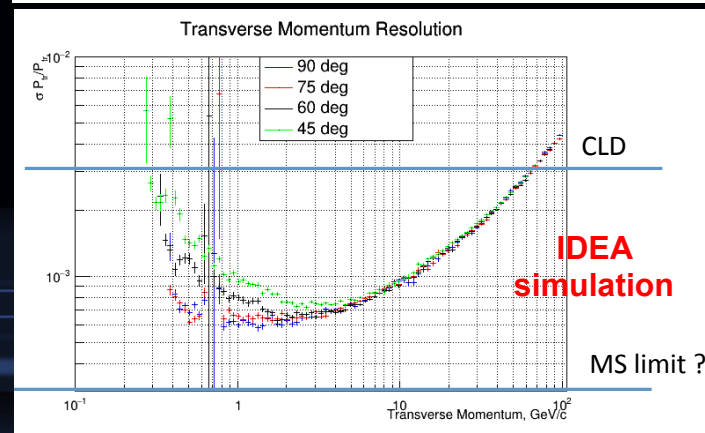
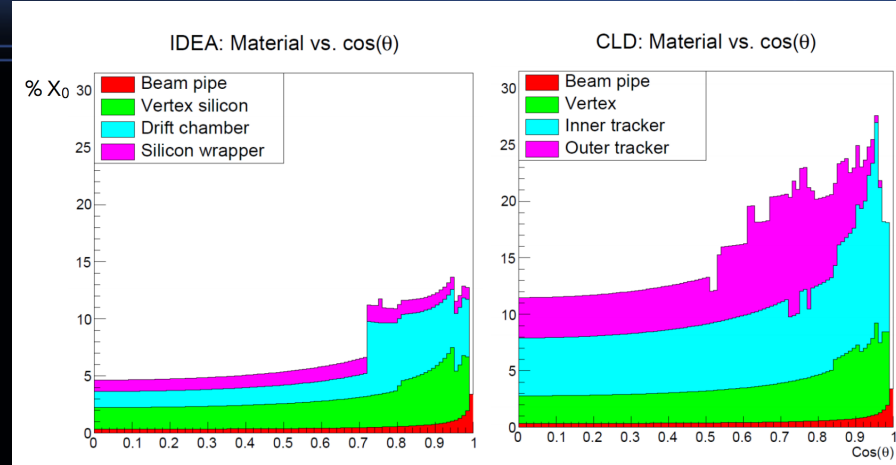
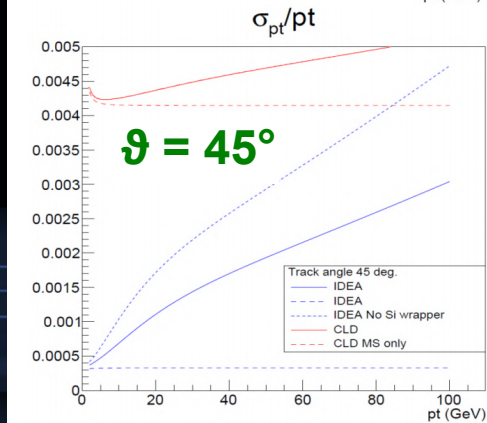
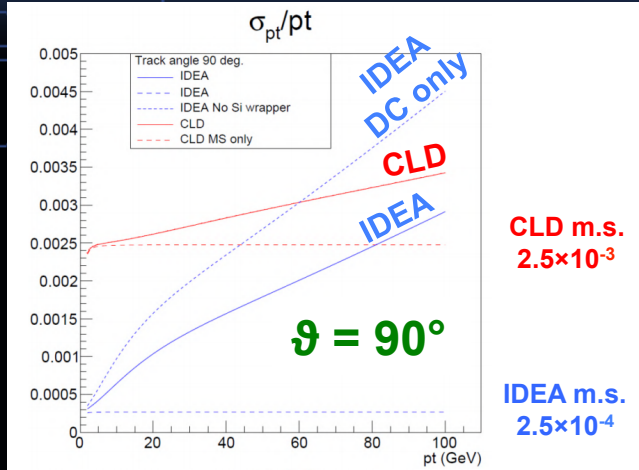
IDEA Tracker Resolution

efficiency



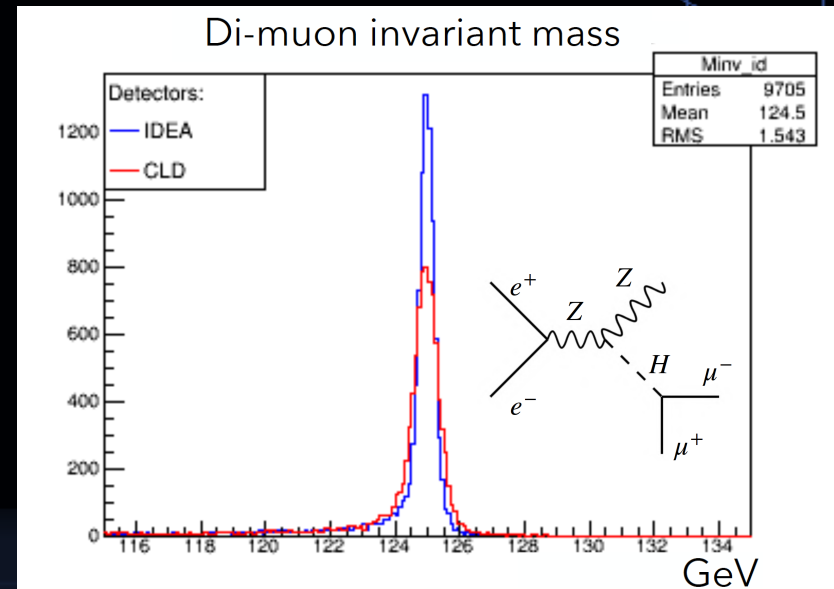
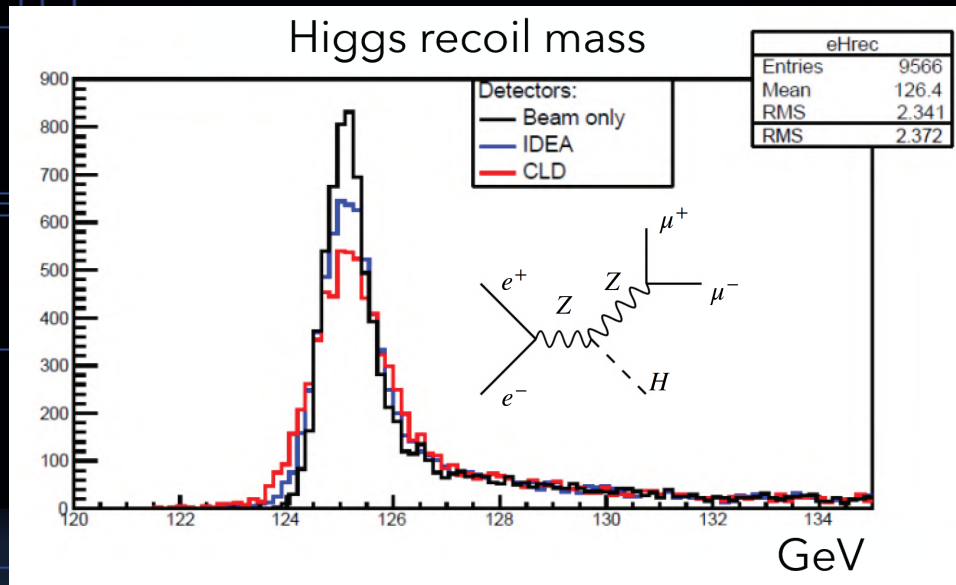
requirements satisfied

Momentum resolution



from
Riegler at
11th FCC-ee Wrkshp

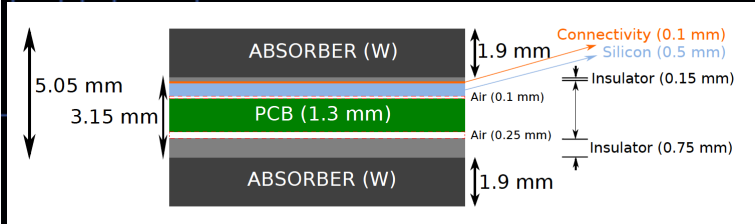
Momentum resolution



CLD Calorimeter

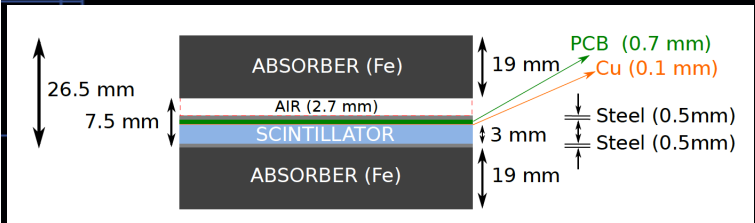
High granularity for PFA

ECAL



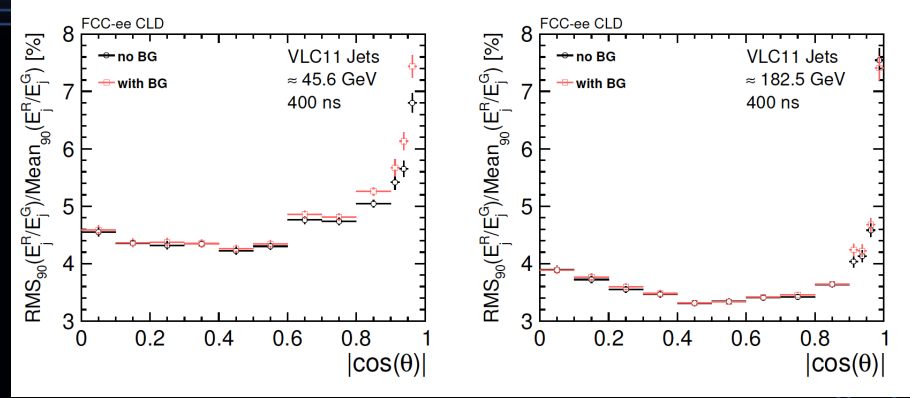
4000 m²
5×5 mm²
1.6×10⁸ ch.
40 layers
22-23 X₀
200 cm deep
4.4 m long
2.5 m radius

HCAL

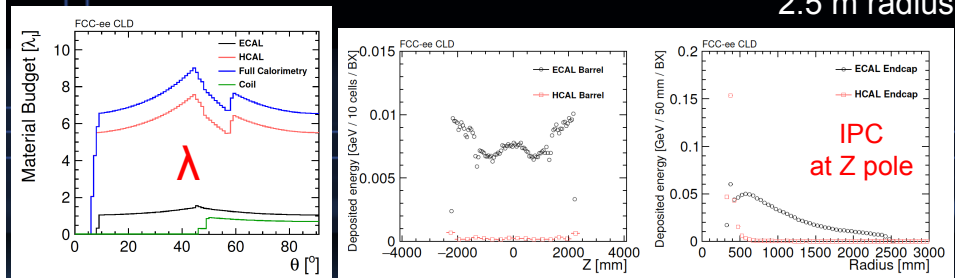
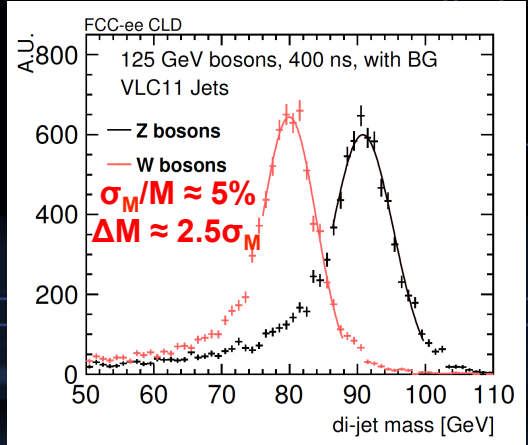
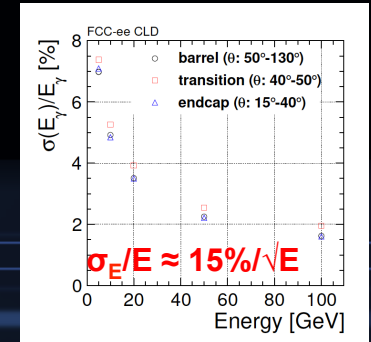


8400 m²
30×30 mm²
9.2×10⁶ ch.
44 layers
5.5 (+1) λ
1.2 m deep
4.4 m long
2.5 m radius

q \bar{q} jet energy resolution



photons



14/05/2020

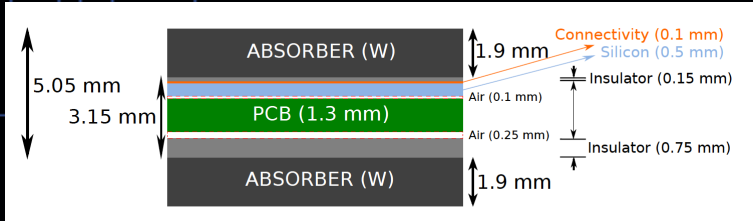
F. Grancagnolo - IDEA and CLD at FCC-ee

27

CLD Calorimeter

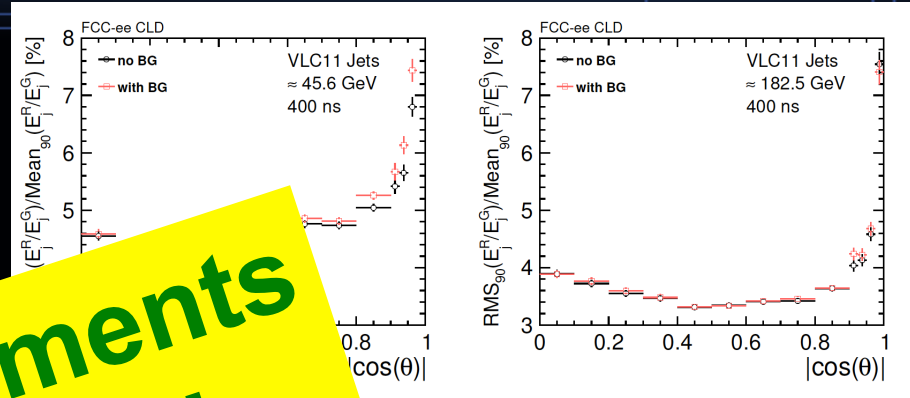
High granularity for PFA

ECAL

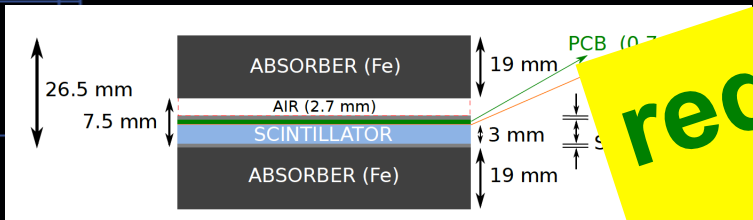


4000 m²
5×5 mm²
1.6×10⁸ ch.
40 layers
22-23 X₀
200 cm deep
4.4 m long
2.5 m radius

q \bar{q} jet energy resolution

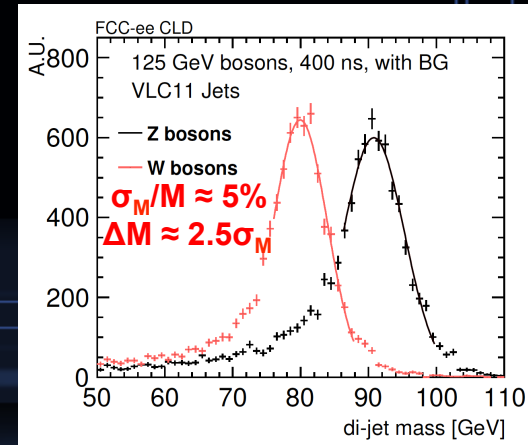
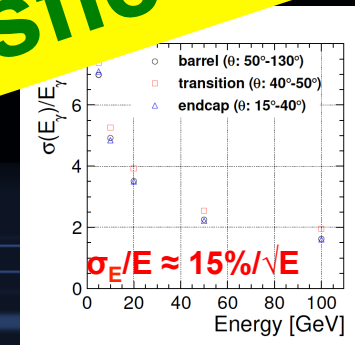
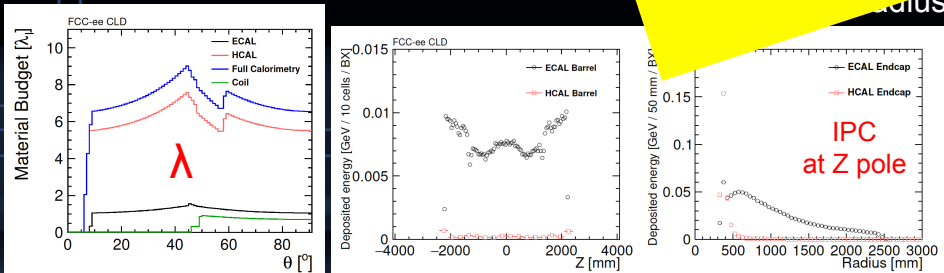


HCAL

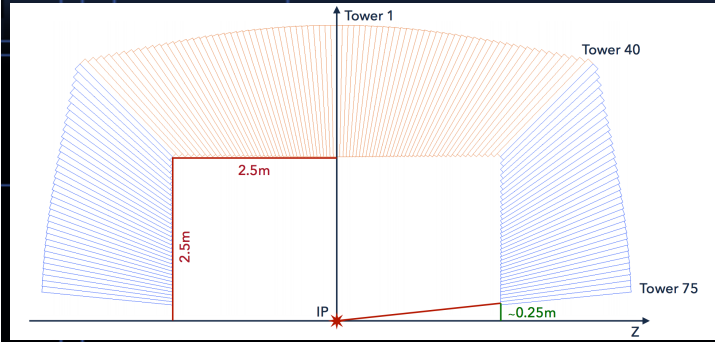


8400

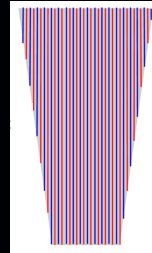
requirements satisfied



IDEA Calorimeter

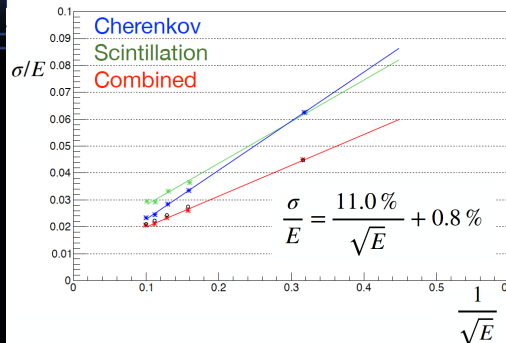
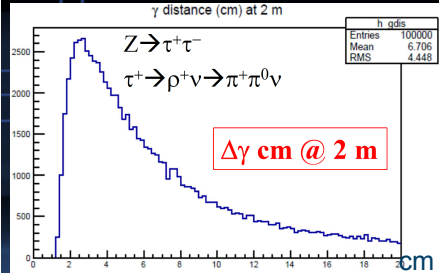


5400 towers
 $\Delta\theta = 1.125^\circ$, $\Delta\phi = 10.0^\circ$
 2 m Cu based towers: $\sim 8.2 \lambda$
 both C/S fibers: 1 mm diameter
 0.5 mm absorber in between
 Total number of fibers: $\sim 131 \text{ M}$



constant sampling fraction

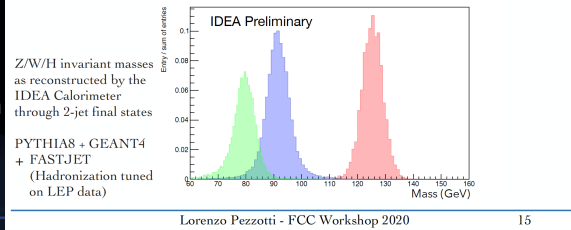
$< 1 \times 1 \text{ cm}^2$ adequate granularity



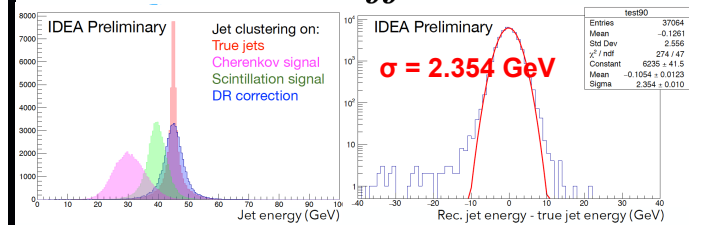
Z/W/H jets

Same procedure applied to several 2-jet final states:

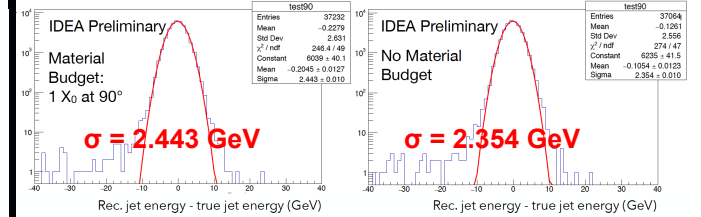
- $e^+e^- \rightarrow HZ \rightarrow \tilde{\chi}^0 \tilde{\chi}^0 jj$ → Only decays to u,d,s,c - c semileptonic decays excluded
- $e^+e^- \rightarrow WW \rightarrow \nu_\mu \mu jj$ → Contribution of tagged muon from Monte Carlo truth subtracted from the calorimeter signal - c semileptonic decays excluded
- $e^+e^- \rightarrow HZ \rightarrow bb\nu$ → b semi-leptonic decays excluded



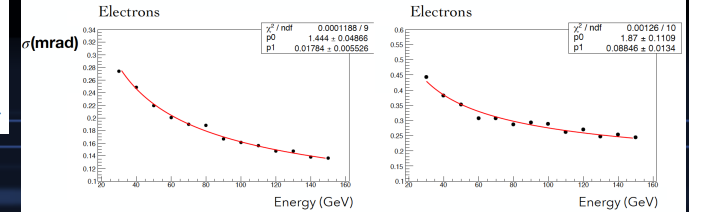
$e^+e^- \rightarrow Z \rightarrow jj @ 90 \text{ GeV}$



effect of pre-shower (magnet)



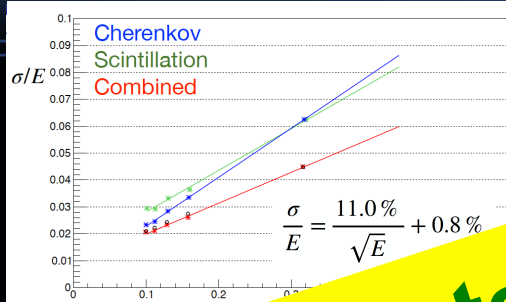
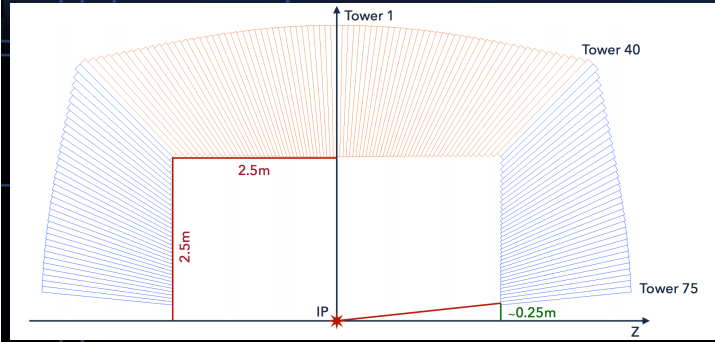
electron angular resolutions



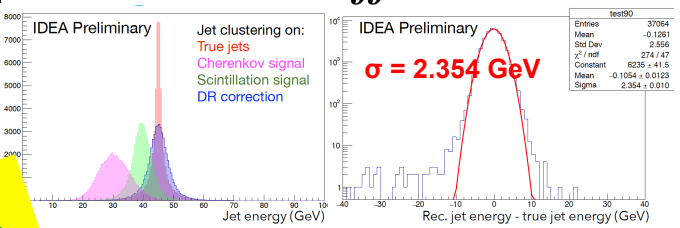
$$\sigma_\theta = \frac{1.4}{\sqrt{E}} + 0.018$$

$$\sigma_\phi = \frac{1.8}{\sqrt{E}} + 0.088$$

IDEA Calorimeter



$e^+e^- \rightarrow Z \rightarrow jj @ 90 \text{ GeV}$

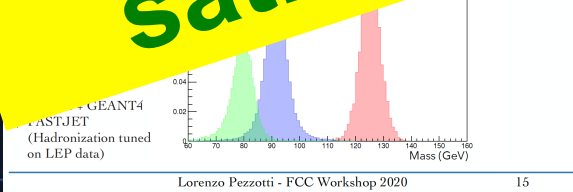
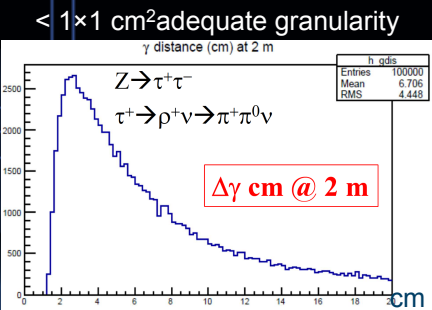
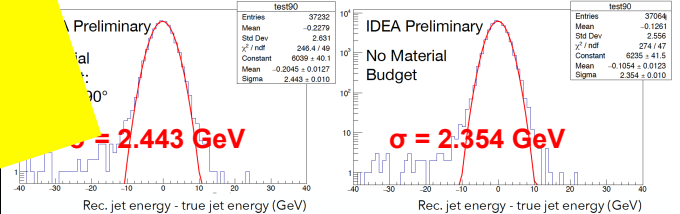


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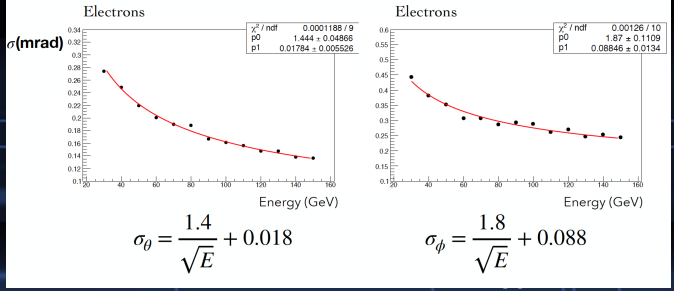


requirements satisfied

effect of pre-shower (magnet)



electron angular resolutions



Particle Identification

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot (L_{track} [m] \cdot P [atm])^{-0.32}$$

from Walenta parameterization (1980)

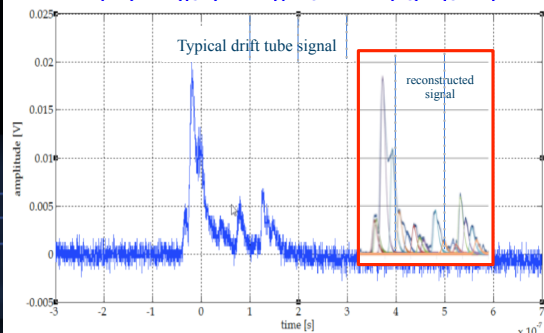
dE/dx

truncated mean cut (70-80%) reduces the amount of collected information

$n = 112$ and a **2m track** at **1 atm** give

$\sigma \approx 4.3\%$

Increasing **P** to 2 atm improves resolution by 20% ($\sigma \approx 3.4\%$) but at a **considerable**



versus

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = (\delta_{cl} \cdot L_{track})^{-1/2}$$

from Poisson distribution

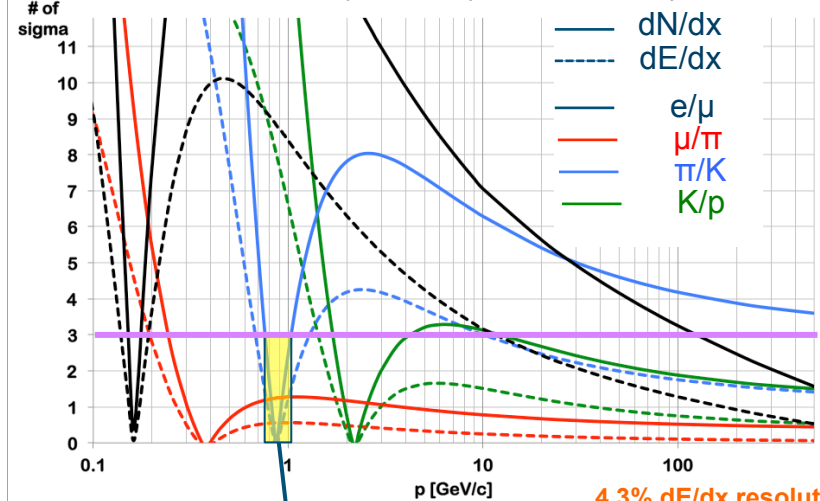
dN_{cl}/dx

$\delta_{cl} = 12.5/cm$ for He/iC₄H₁₀=90/10 and a **2m track** give

$\sigma \approx 2.0\%$

A small increment of iC₄H₁₀ from 10% to 20% ($\delta_{cl} = 20/cm$) improves resolution by 20% ($\sigma \approx 1.6\%$) at only a **reasonable** cost of multiple scattering contribution to momentum and angular resolutions.

Particle Separation (dE/dx vs dN/dx)



4.3% dE/dx resolution
80% cluster counting efficiency



Particle Identification

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot (L_{track} [m] \cdot P[atm])^{-0.32}$$

from Walenta parameterization (1980)

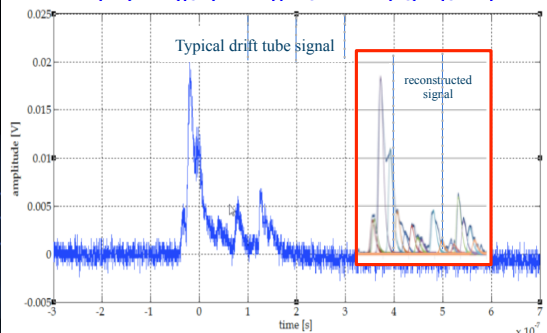
dE/dx

truncated mean cut (70-80%) reduces the amount of collected information

$n = 112$ and a 2m track at 1 atm give

$\sigma \approx 4.3\%$

Increasing P to 2 atm improves resolution by 20% ($\sigma \approx 3.4\%$) but at a considerable



versus

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = (\delta_{cl} \cdot L_{track})^{-1/2}$$

from Poisson distribution

dN_{cl}/dx

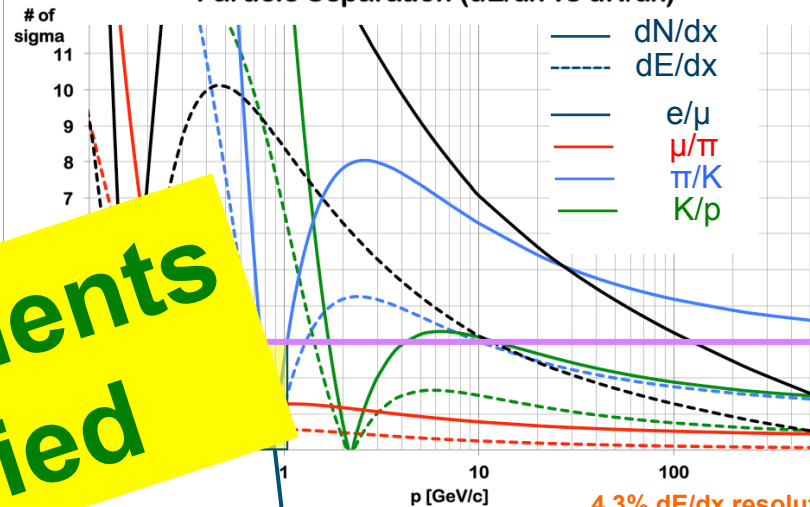
$\delta_{cl} = 12.5/cm$ for He/iC₄H₁₀=90/10 and a 2m track give

$\sigma \approx 2.0\%$

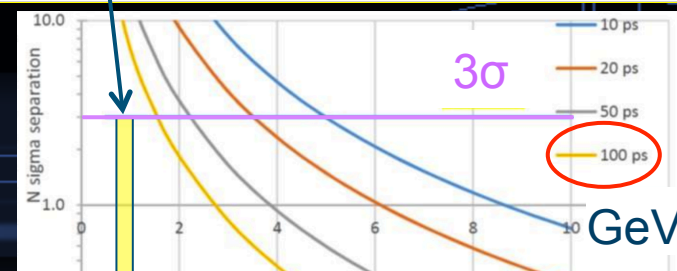
A sm

requirements satisfied

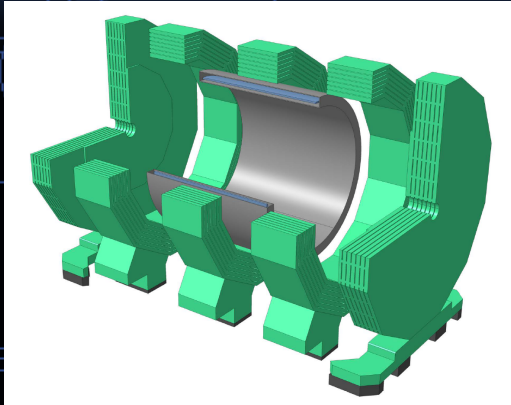
Particle Separation (dE/dx vs dN/dx)



4.3% dE/dx resolution
80% cluster counting efficiency



CLD

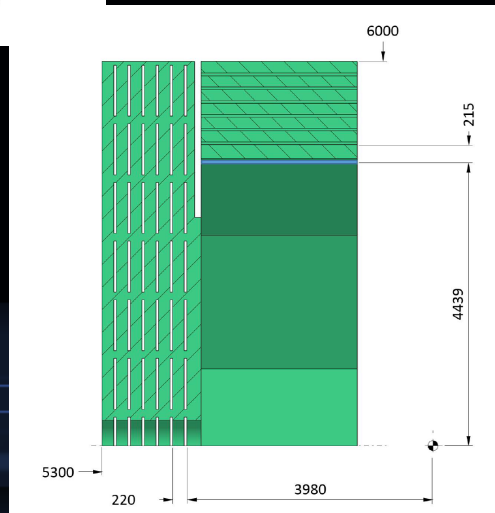


return yoke

1.5 m steel

muon detector

6 (+1) layers
30×30 mm² RPC
(crossed sci. bars
as option)
in 40 mm gap



Magnet and muons

IDEA

self-supporting single layer coil

inside DR calorimeter

0.75% X_0

30 cm thick

return yoke

1.0 m steel

16,000 m²
1.5×500 mm²
2×10⁶ ch.

μRwell

