Software simulation of the IDEA detector

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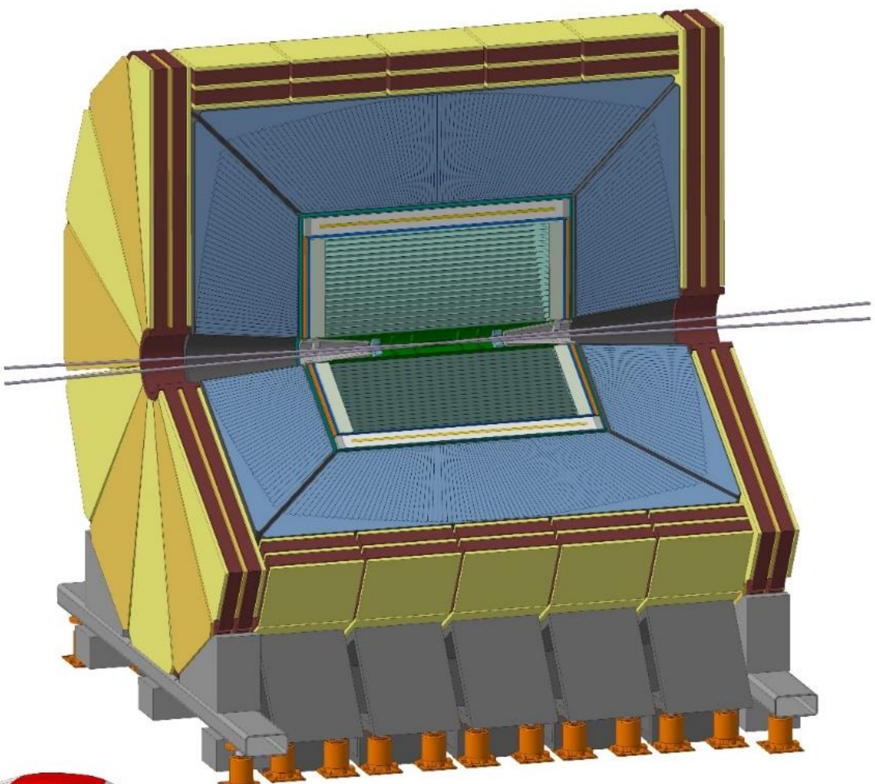
on behalf of the IDEA Proto-Collaboration

Tuesday 21.01.2020 – Hong Kong

IAS Program
High Energy Physics

The IDEA detector concept

Innovative Detector for Electron-positron Accelerators



Specifically intended for e^+e^- high luminosity circular colliders

Adopted by both the FCC-ee and CepC projects

Included in both the CDRs [*]

[*] *Future Circular Collider - Vol. 2 : The Lepton Collider (FCC-ee)*, Eur. Phys. J. ST., CERN-ACC-2018-0057
The CEPC Study Group, *CEPC Conceptual Design Report Volume II - Physics & Detector*, IHEP-CEPC-DR-2018-02

Outline

A standalone full simulation of the IDEA detector in Geant4

Performance and
local reconstruction studies
to optimize the baseline geometry

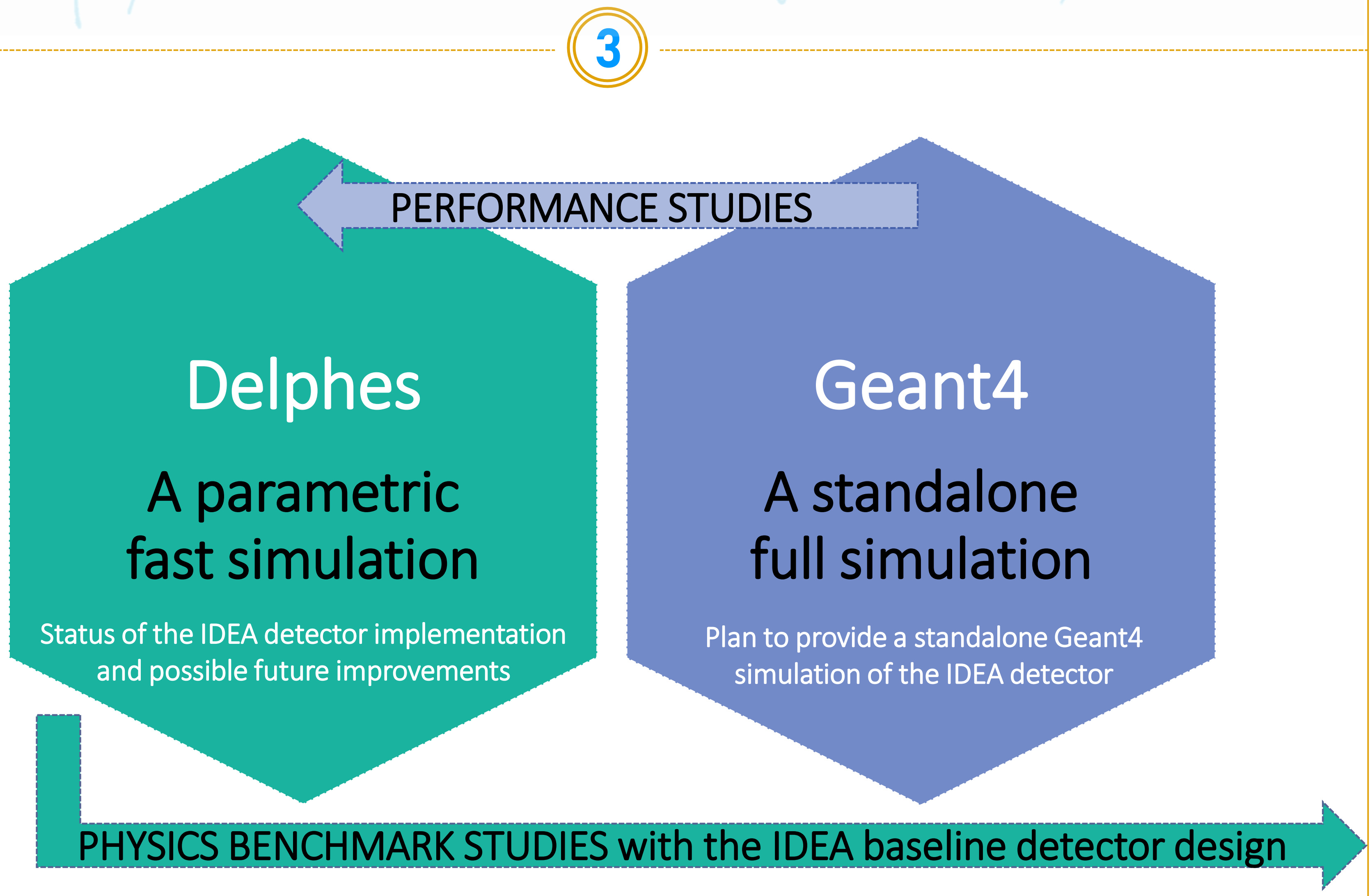
Outline

3

Status of the IDEA
detector implementation
and possible future improvements

A parametric
fast simulation
of the IDEA
detector
in Delphes

Outline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PERFORMANCE STUDIES
Delphes
A parametric fast simulation
Status of the IDEA detector implementation and possible future improvements
Geant4
A standalone full simulation
Plan to provide a standalone Geant4 simulation of the IDEA detector
PHYSICS BENCHMARK STUDIES with the IDEA baseline detector design

Overview of the IDEA detector proposal

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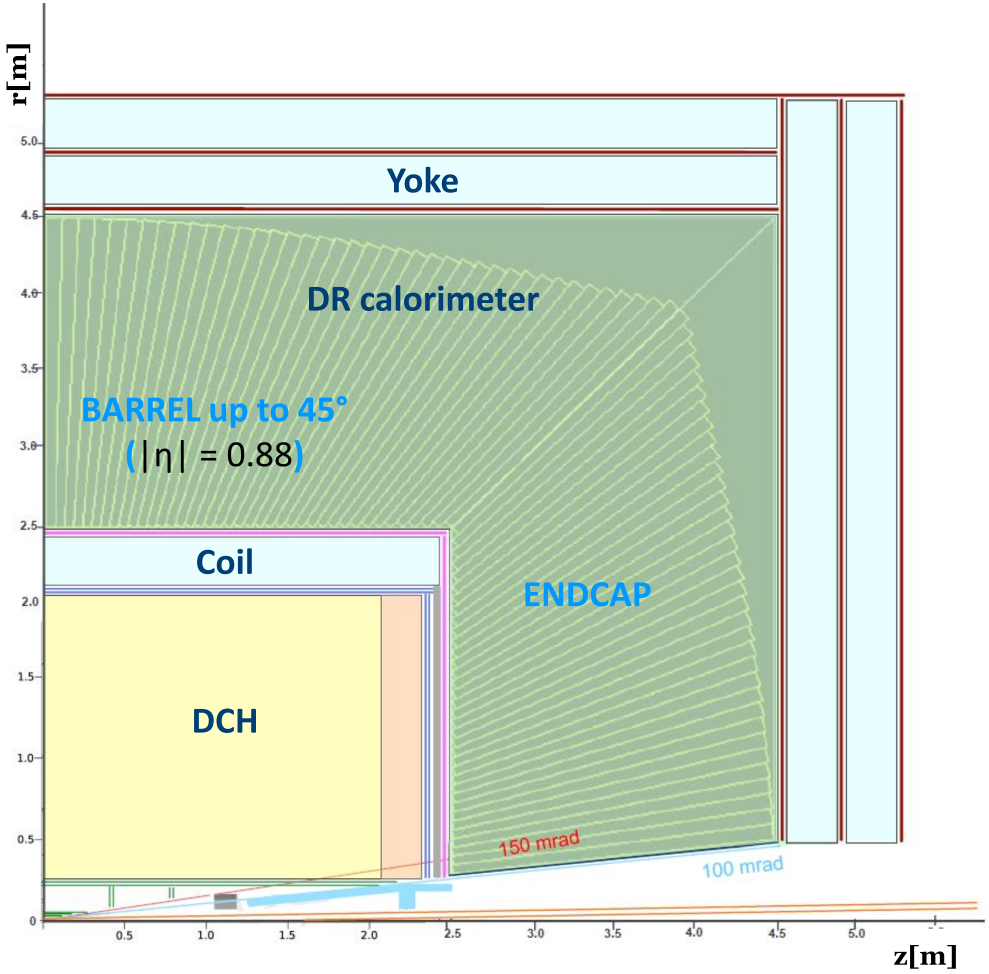
- A **magnetic field** of 2 T
  ($0.74\ X_0$, $0.16\ \lambda$ @ 90°) with:
  - Solenoid length: 5 m
  - Inner radius: 2.1 m; outer radius: 2.4 m
- A **Tracker** composed of
  - a drift chamber (112 layers) and a drift chamber service area (DCH);
  - silicon pixels and a silicon strips double stereo layer;
- A preshower (μ-RWELL double layer)
- A Dual-Readout calorimeter
  2 m deep/8 λ
  Angular coverage up to 100 mrad (η = 3.0)
- A muon system: three μ-RWELL stations (bidimensional view)



The IDEA tracker system

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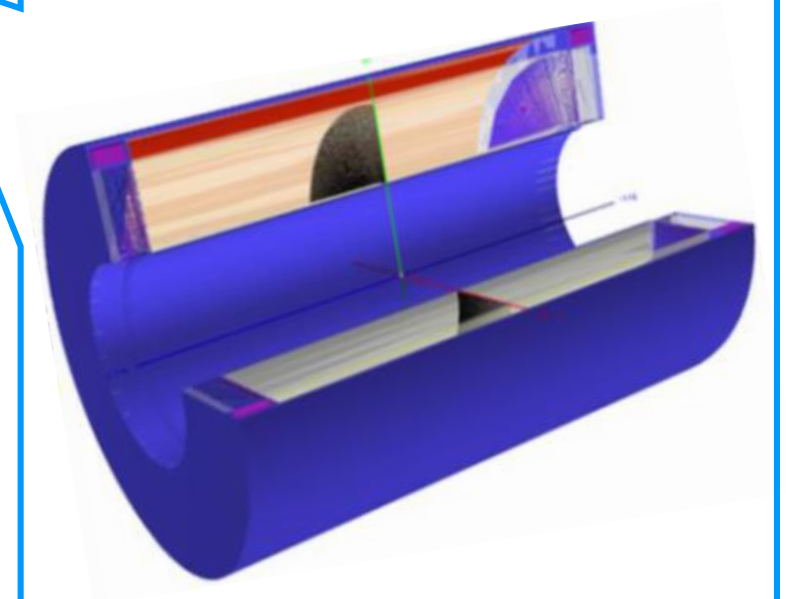
A **standalone Geant4 simulation**

- DCH – Drift chamber simulated at a good level of geometry details;
- SVX – **Vertex detector (silicon pixel layers)**
  - Inner, forward, outer
- SOT – **Silicon wrappers**
- SVX and SOT simulated as a simple layer or overall equivalent material.

N° layers = 112, L = 400 cm, R = 35-200
56448 squared drift cells (12 - 13.5 mm)



Gas: 90% He - 10% iC4H10
Drift length = 1 cm; drift time = 350 ns
Spatial resolution: $\sigma_{xy} < 100\ \mu m$, $\sigma_z < 1000\ \mu m$

Detector signal hits creation:

- DCH: all the hits in a cell coherent in max drift time are grouped together to create a hit with proper DCA smeared with a resolution of 100 μm
- SVX, SOT: the hits are translated in pixel/strip information

Tracker performance

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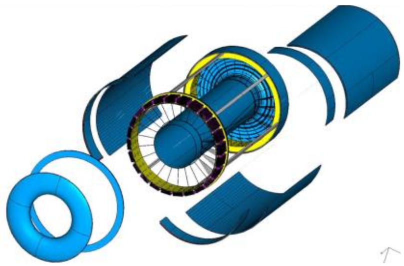
Full tracking performances



(vertex + drift chamber + Si wrapper)

Asymptotic behavior (90°)

IDEA

$$\frac{\sigma_{pT}}{p_T} \simeq 2.2 \times 10^{-5} p_T$$

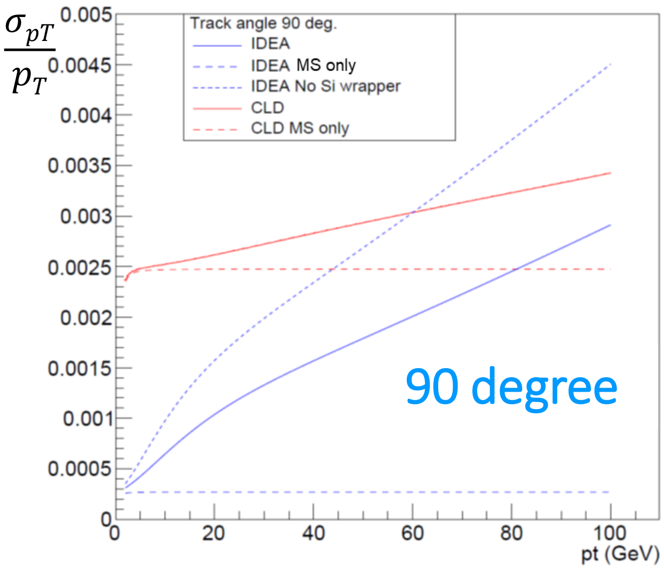
IDEA no Si wrapper

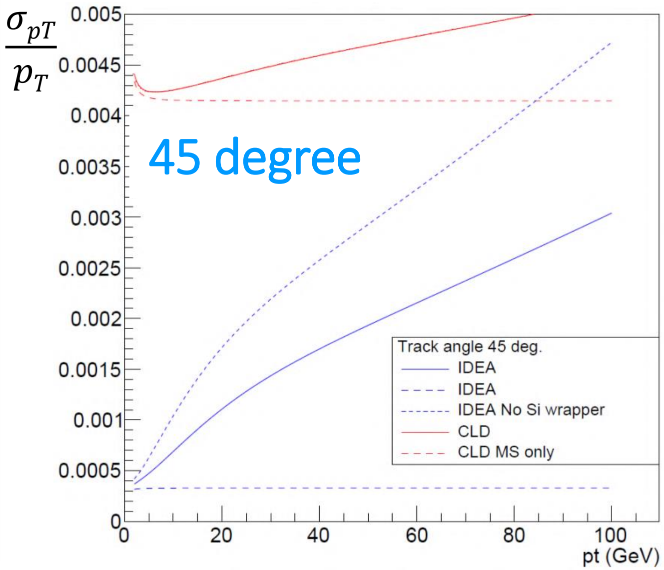
$$\frac{\sigma_{pT}}{p_T} \simeq 5.7 \times 10^{-5} p_T$$

Multiple Scattering only

IDEA: $\frac{\sigma_{pT}}{p_T} = 0.25 \times 10^{-3}$

CLD: $\frac{\sigma_{pT}}{p_T} = 2.5 \times 10^{-3}$





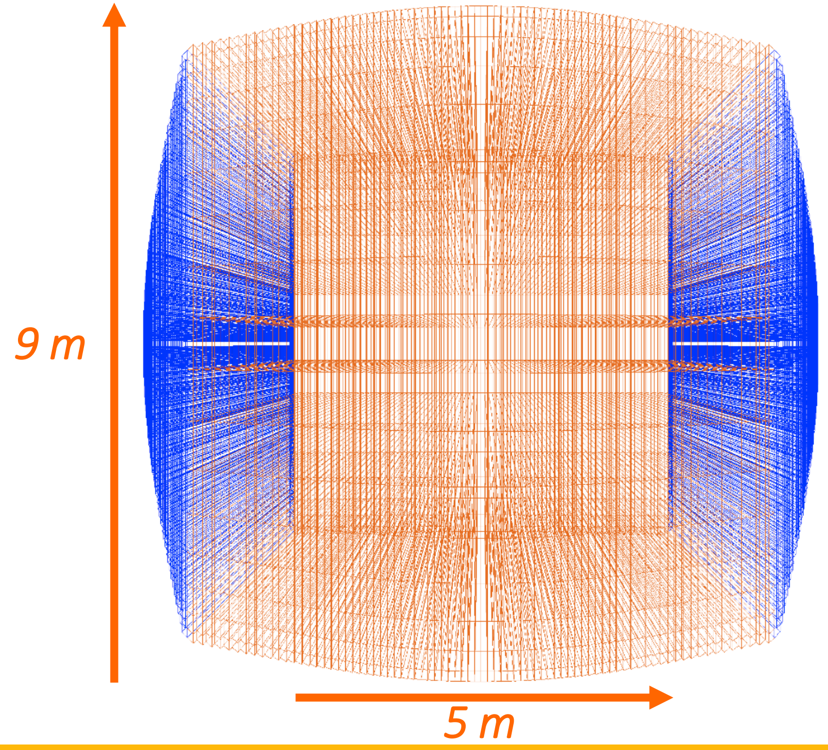
Large solid angle coverage (|cosϑ| = 0.99), high granularity and high transparency detector

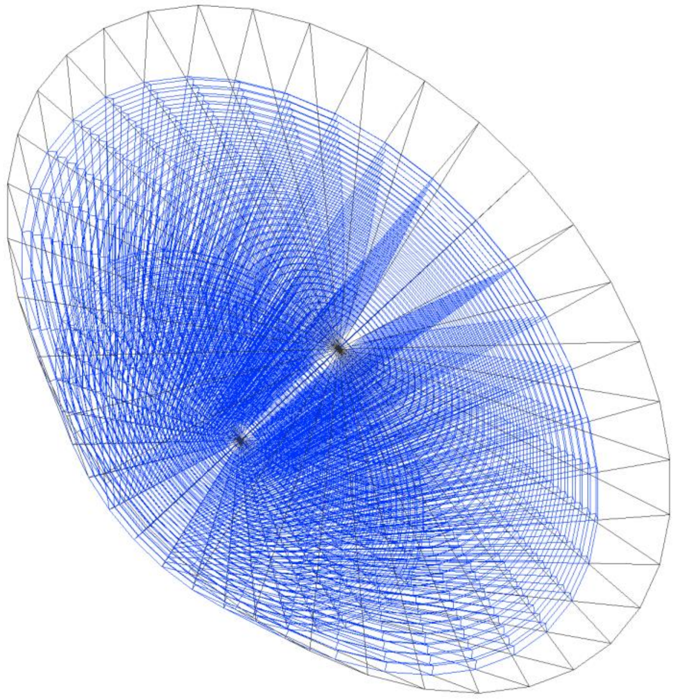
The IDEA dual-readout calorimeter

Geant4 fully projective fiber calorimeter

- *Barrel:* Inner length: *5 m* - Outer diameter: *9 m @ 90°*
- *Endcap:* Range in z: ± (2500 ÷ 4500) mm

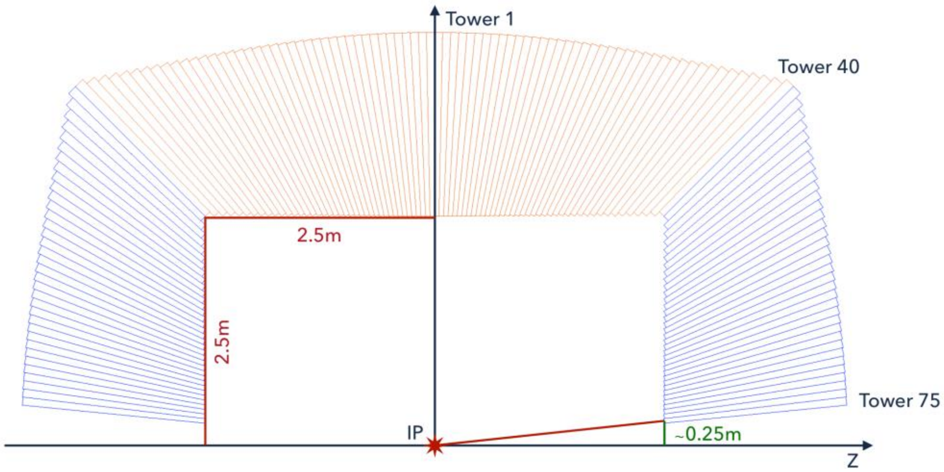
5400 copper-based towers (2 m long; ~8.2 λ)
36 rotations around z axis (slice)





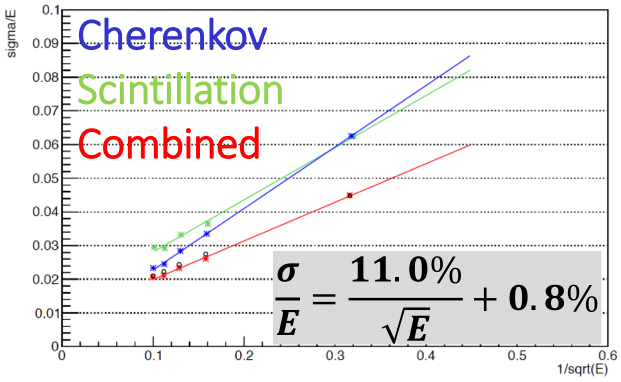
[*] All the details presented in Gabriella's talk yesterday

DR calorimeter - EM performance

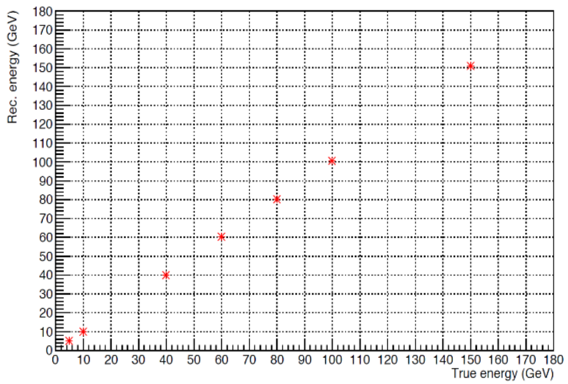


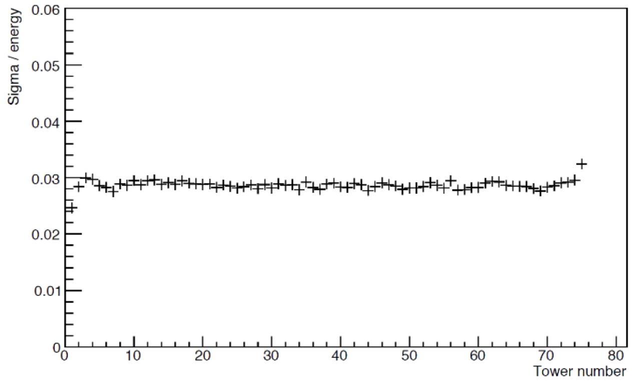
Equalization constants are extracted per each tower by sending electrons of known energy and collecting signals (photo-electrons)

Linearity and uniformity at 40 GeV of the electromagnetic energy resolution



$$\frac{\sigma}{E} = \frac{11.0\%}{\sqrt{E}} + 0.8\%$$





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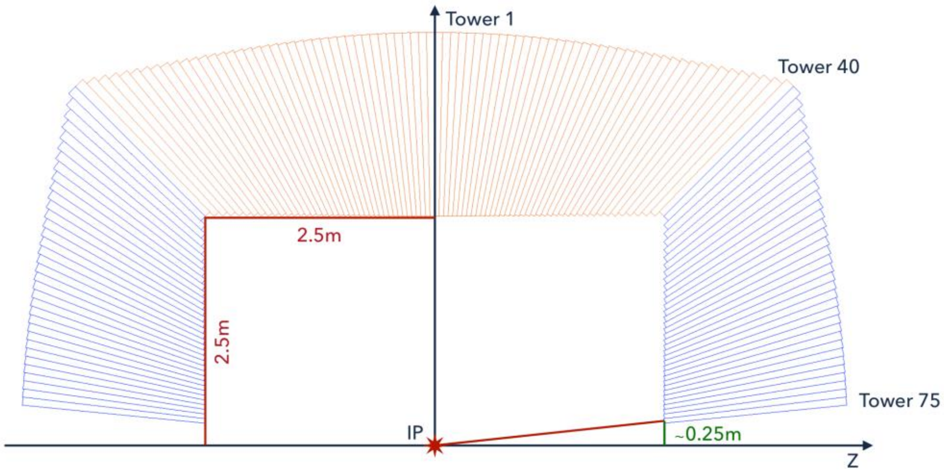
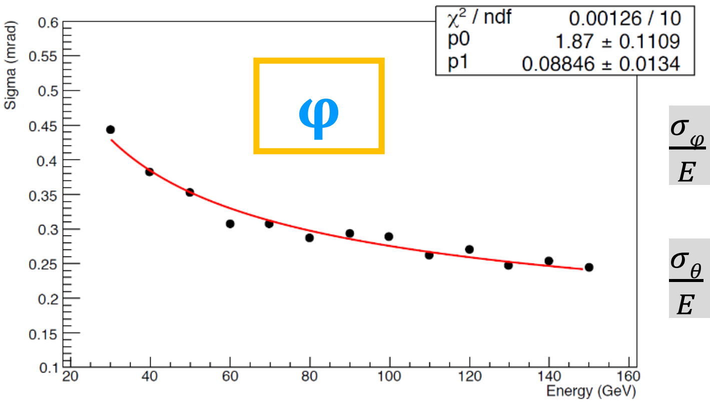
DR calorimeter - EM performance



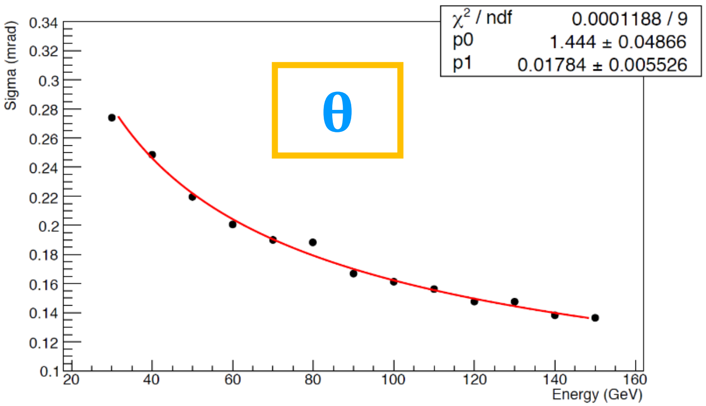
The extremely high granularity allows to very precisely reconstruct the impact point in the calorimeter

Angular resolution for electrons and photons



$$\frac{\sigma_\varphi}{E} = \left(\frac{1.8}{\sqrt{E}} + 0.088\right) \text{mrad}$$

$$\frac{\sigma_\theta}{E} = \left(\frac{1.4}{\sqrt{E}} + 0.018\right) \text{mrad}$$



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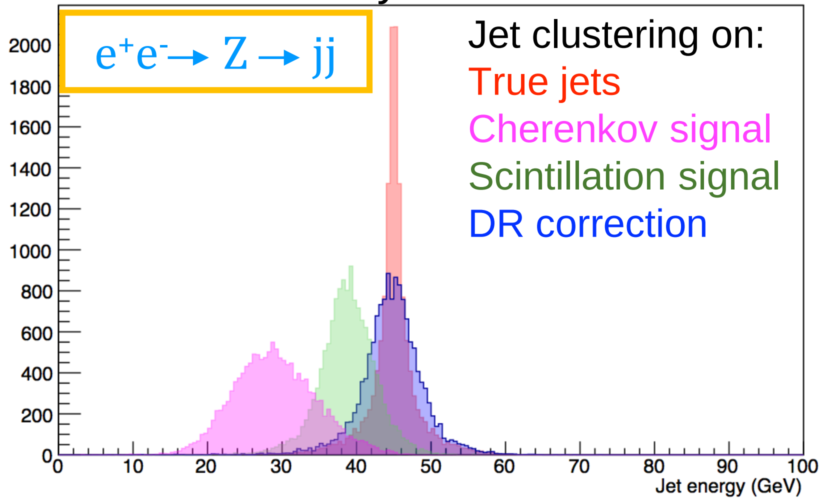
DR calorimeter – HAD performance

IDEA Preliminary



Single had energy resolution: $\frac{\sigma}{E} \simeq \frac{33\%}{\sqrt{E}}$

Jet energy resolution: $\frac{\sigma}{E} \simeq \frac{38\%}{\sqrt{E}}$

A matching of scintillating and Cherenkov jet candidates is performed using the minimum angular separation

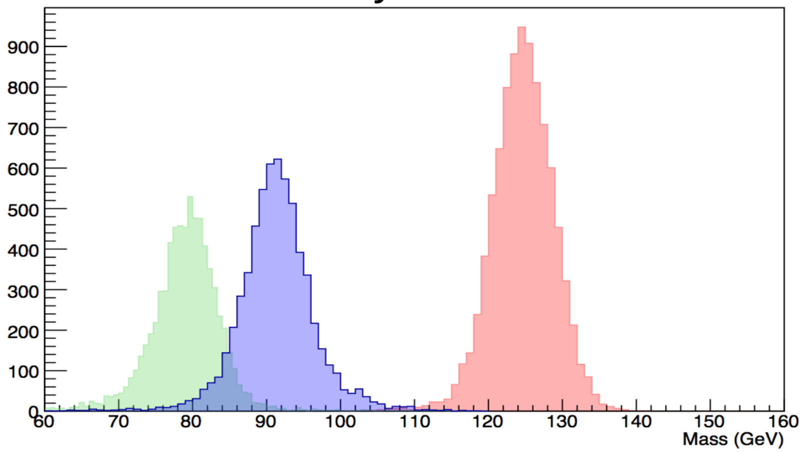
Clearly identify W, Z, H in 2 jet decays

$e^+e^- \rightarrow HZ \rightarrow \tilde{\chi}^0\tilde{\chi}^0 jj$

$e^+e^- \rightarrow WW \rightarrow \nu_\mu \mu jj$

$e^+e^- \rightarrow HZ \rightarrow bb\nu\nu$

IDEA Preliminary



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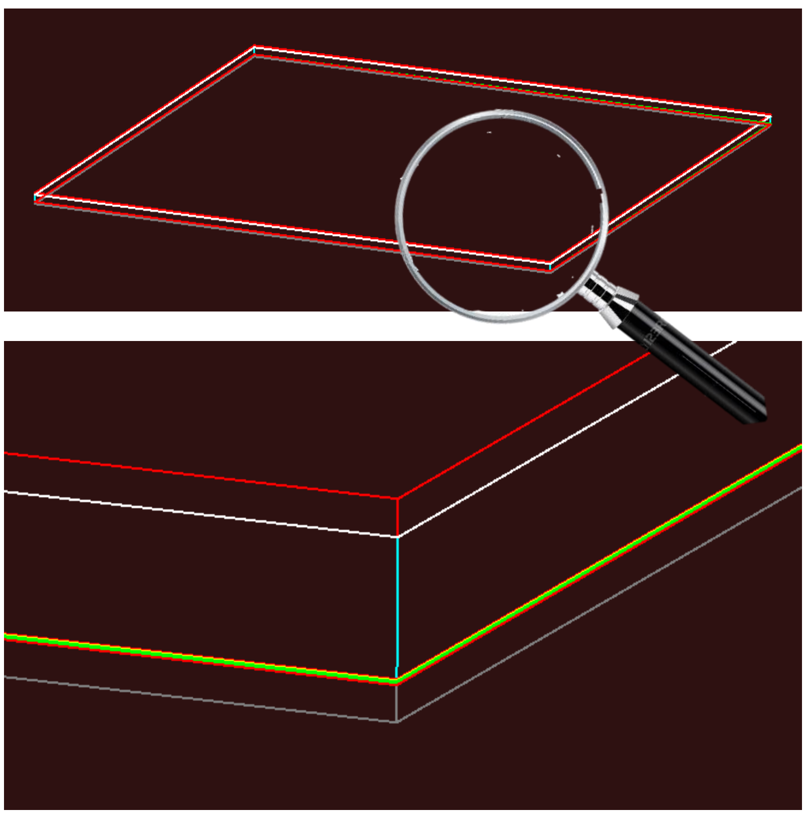
The IDEA preshower: μ-RWELL description

Description of a μ-RWELL
(HR layout [*] - SG2++)
detector implemented in Geant4

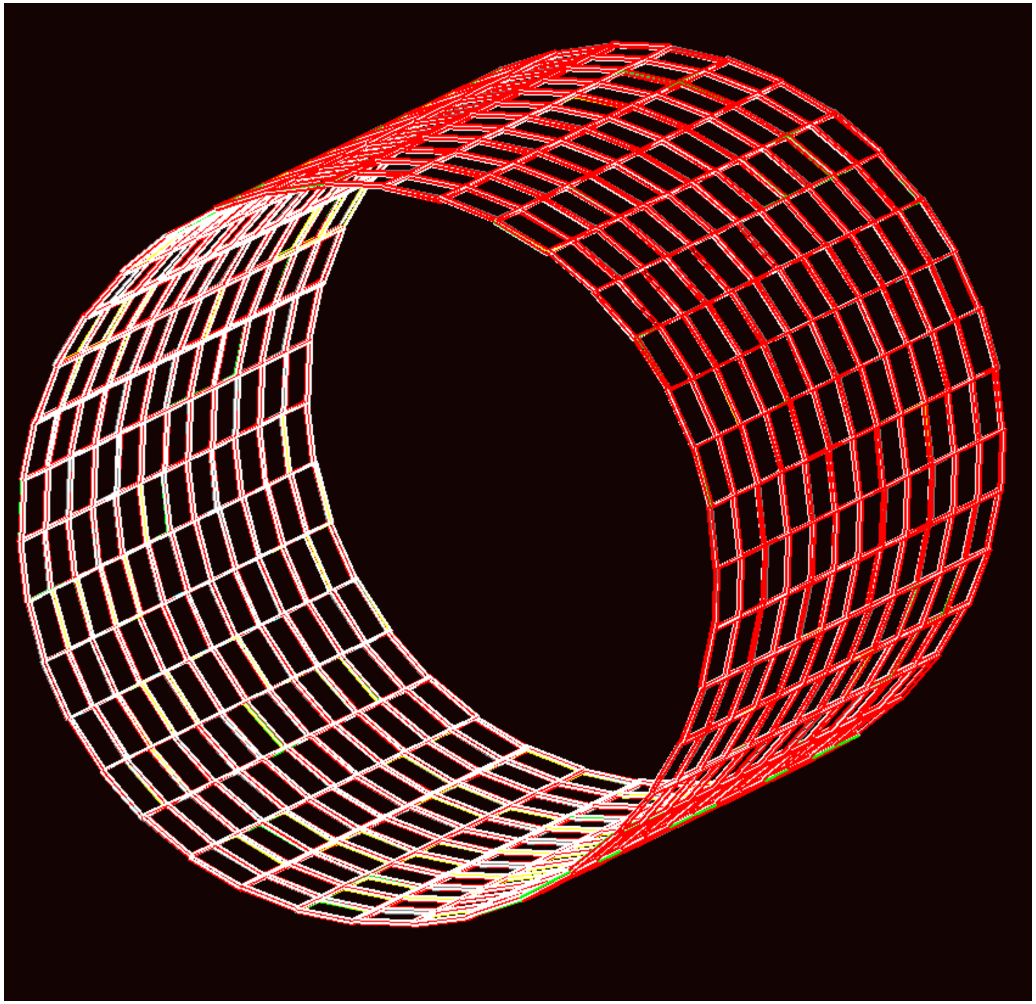


Chamber thickness: 9.4601 mm

- **Cathode thickness**: 1.635 mm
- **Drift gap**: 6 mm
- **μ-RWELL + readout thickness**: 1.8251 mm

CATHODE 1.6 mm 35 μm	 FR4 Copper
GAS GAP 6mm	 $ArCO_2CF_4$ (45/15/40)
μ-RWELL + readout PCB Top copper - 5 μm Kapton - 50 μm DLC resistive layer - 0.1 μm Grid - 35 μm Pre-preg - 100 μm Readout - 35 μm 1.6 μm	In Copper and Kapton holes and dead zones on the amplification stage or strips are taken into account

The IDEA preshower: full barrel geometry



Information provided by preshower detector: particle position

Future μ-RWELL prototypes may provide a bidimensional information per layer

Two μ-RWELL layers

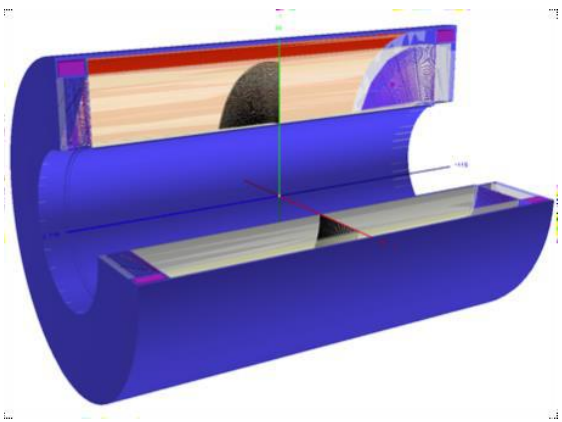
$Z_{preshower} = \pm 2480$ mm = 4960 mm

12 chambers for each sector
38 sectors

BARREL
912 chambers
933888 readout channels

The IDEA full simulation

Plan to provide a standalone Geant4 simulation of the IDEA detector



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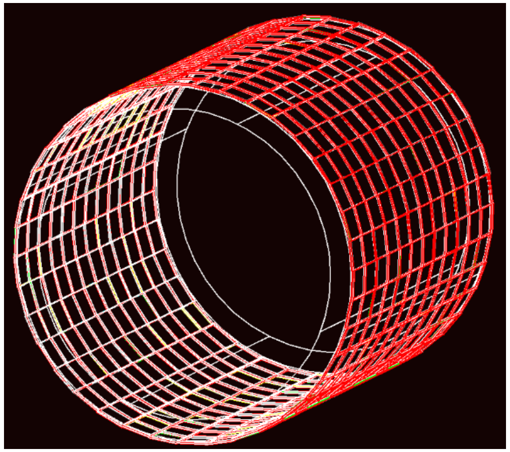

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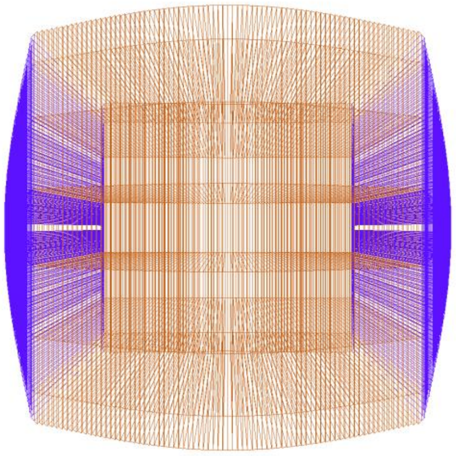


FUTURE

Towards a common software for future experiments [*]

FCC Software & DD4hep

- Beam pipe, beam instrumentation; Lumical, HOM absorber; Vertex detector, Drift chamber
- Dual-Readout calorimeter
- Muon system

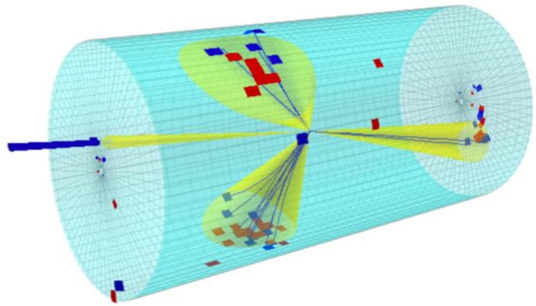
[*] Bologna workshop, June 2019; Gerardo's talk here in HK

Delphes fast simulation

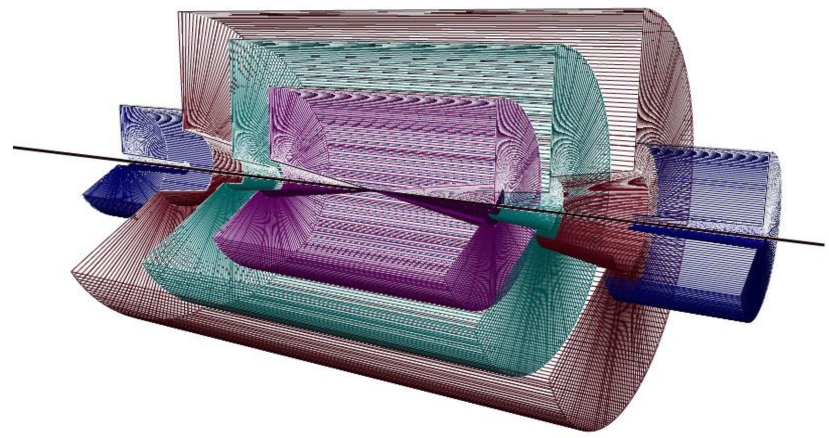
Fast simulation of detector concept

Delphes is a modular framework that simulates the response of a multipurpose detector in a parameterized way:

- Particle **trajectory** is followed in the detector
- It only needs **general volumes** for acceptances, a **resolution driven segmentation**, resolution and response functions taking into account a tracker in a solenoidal magnetic field, a calorimeter with its electromagnetic and hadronic sections, and a muon system



Schematic view of the baseline DELPHES detector



Included:

- pile-up
- particle-flow

Provided:

- leptons, γ, neutral hadrons
- jets, missing energy
- heavy flavour tagging

New official Delphes release (3.4.2pre18) including IDEA card:
https://github.com/delphes/delphes/blob/master/cards/delphes_card_IDEA.tcl

IDEA description in Delphes

B field and tracker

- **B field description**
  (*Particle Propagation* module)

  - Half length of the magnetic field coverage: 2.5 m
  - Radius of the magnetic field coverage: 2.25 m
  - Homogeneous magnetic field: 2 T

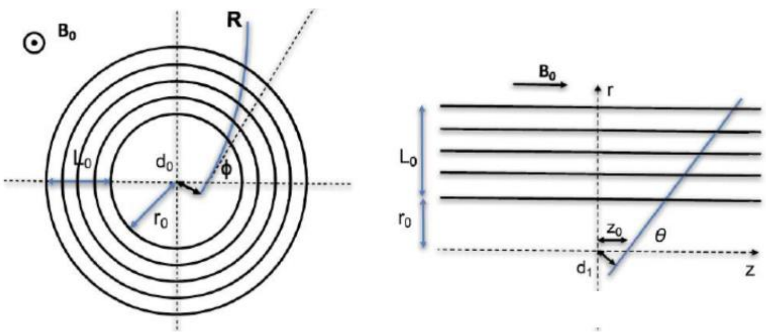
- **Tracker description**
  (*TrackingEfficiency, MomentumSmearing* module)

  The response of tracking detectors has been parametrized in the same way for electrons, muons and charged hadrons:
  => unique efficiency formula (dependent on E and η);

$\lvert\eta\rvert \geq 3.0$	0.00%
$E \geq 500$ MeV in $\lvert\eta\rvert \leq 3.0$	99.7%
$300 \leq E \leq 500$ MeV in $\lvert\eta\rvert \leq 3.0$	65%
$E \leq 300$ MeV in $\lvert\eta\rvert \leq 3.0$	6%

=> p_T resolution formula: $$\frac{\sigma_{pT}}{p_T} = \sqrt{(2.093 \times 10^{-5} * p_T)^2 + 0.00011452 + 0.00020242 * p_T}$$

Idea to include in Delphes the full covariance matrix for tracking parameters smearing provided by a specific fast simulation [*].

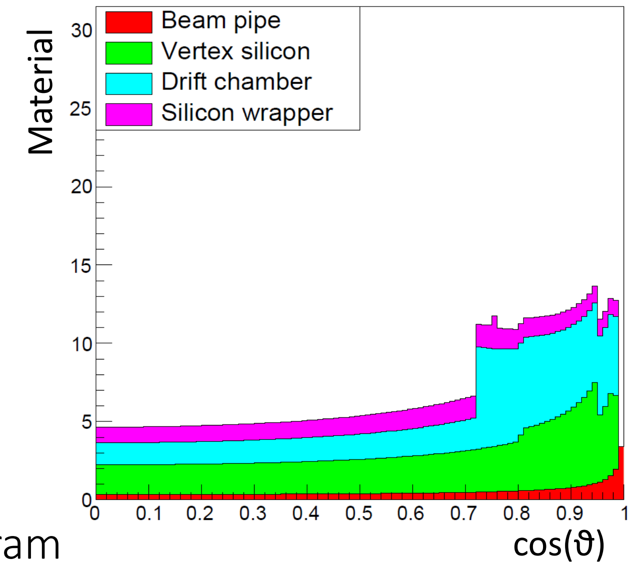


[*] F. Bedeschi @ Oxford: https://indico.cern.ch/event/783429/contributions/3376675/attachments/1829951/2996531/Oxford_April2019_V1.pdf

Fast tracking simulation

ROOT based classes:

- Simple tracking geometry implementation with txt files (including material):
  - ⇒ Easy to implement a modified geometry and change detector performances
- Tracking parameter **covariance matrix** calculation including multiple scattering effects
- Covariance matrix grid stored for fast calculation
  - ⇒ Several parametrizations usable in same program
- Track parameter smearing according to appropriate covariance matrix
  - ⇒ **Validated with full simulation**



Potential implementation in DELPHES

- Provide to Delphes fast simulation a realistic full covariance matrix to parametrize track resolution (currently in Delphes a diagonal smearing in the 5 tracking parameters is applied)
- Study the impact of material and realistic HF tagging simulation

[*] F. Bedeschi @ Oxford: https://indico.cern.ch/event/783429/contributions/3376675/attachments/1829951/2996531/Oxford_April2019_V1.pdf

IDEA description in Delphes

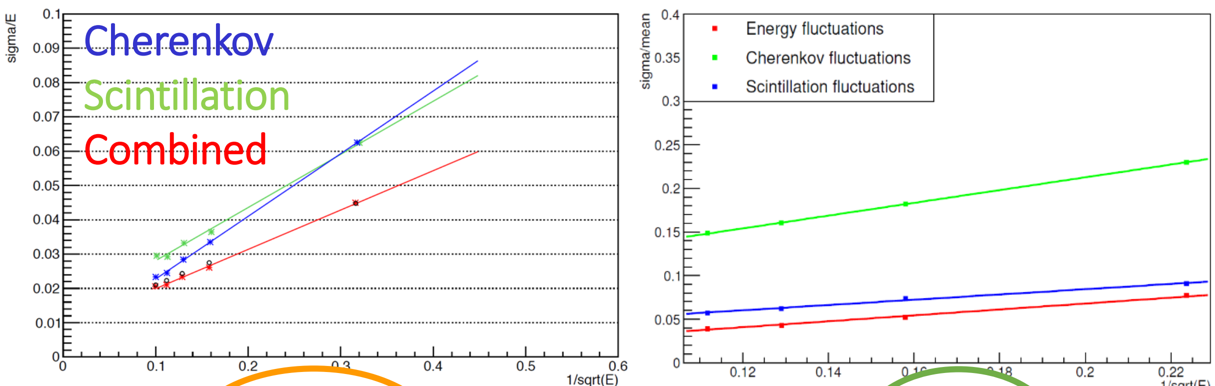
Dual-Readout calorimeter

- **Dual-Readout (DR) calorimeter description** (*DualReadout Calorimeter* module)

Never implemented and never studied in a fast simulation before

Implementation of a monolithic calorimeter in a dedicated IDEA card:

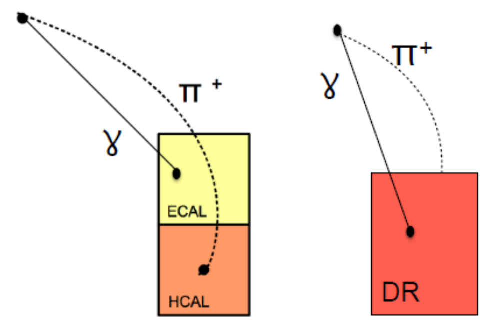
- **single segmentation:** cell size of 6 cm x 6 cm
- **different energy resolution** for electromagnetic and hadronic showers



$$\frac{11\%}{\sqrt{E}}$$

$$\sim \frac{30\%}{\sqrt{E}}$$

- **Dual-Readout particle flow**



If $E_{em} > 0$ and $E_{had} = 0$ => σ(EM) e.g. γ
If $E_{had} > 0$ => σ(had) e.g. π^+ or (γ, π^+)

IDEA description in Delphes

Dual-Readout calorimeter

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  Implementation of a monolithic calorimeter in a dedicated IDEA card:
  - **single segmentation:** 6 cm x 6 cm
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DR calorimeter assumptions

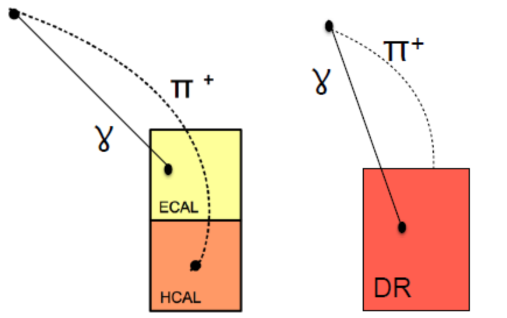
Given a **charged track** hitting **calorimeter cell**:

- Is deposit more compatible with **charged only** or **charged + neutral** hypothesis?
- How to **assign momenta** to resulting components?
- If **charged + neutral**, how to associate particle ID to **charged** and **neutral** components, e.g **(γ, π^+)** or **(e^+, K_L)** ?

DualReadoutCalorimeter module in Delphes assumes that we can always disentangle these two cases:

- Probably ok at FCC-ee => probability of overlap not so large (except for τ?)
- Studied impact of granularity on performance

- **Dual-Readout particle flow**

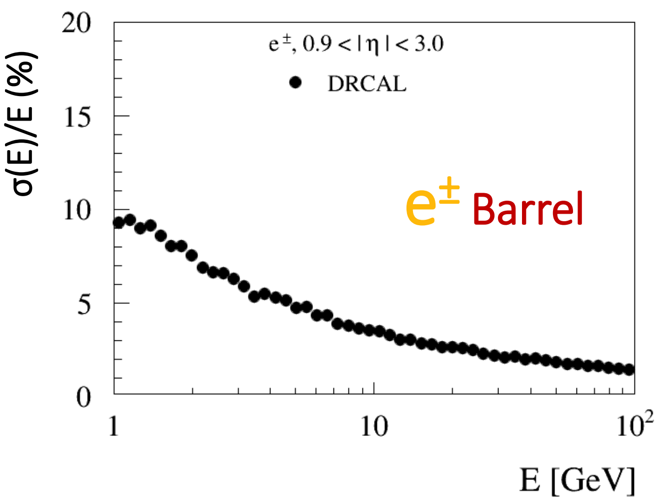


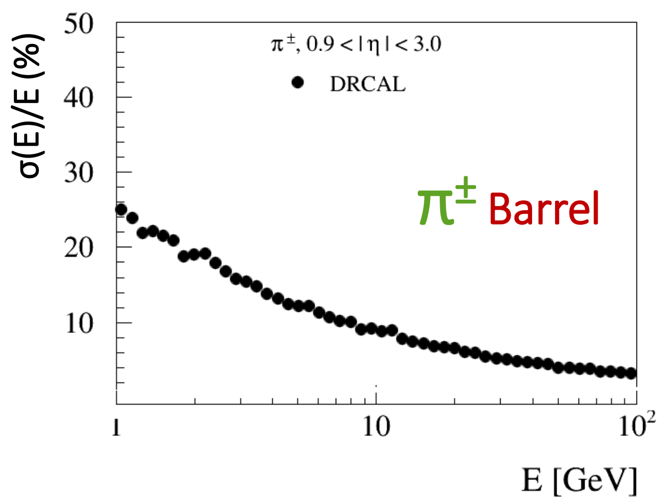
If $E_{em} > 0$ and $E_{had} = 0$
=> σ(EM) e.g. γ

If $E_{had} > 0$
=> σ(had) e.g. π^+ or (γ, π^+)

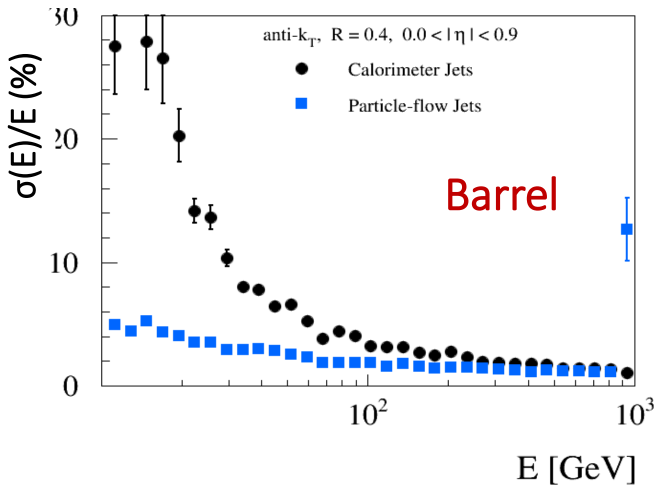
Validation plots for DR calorimeter

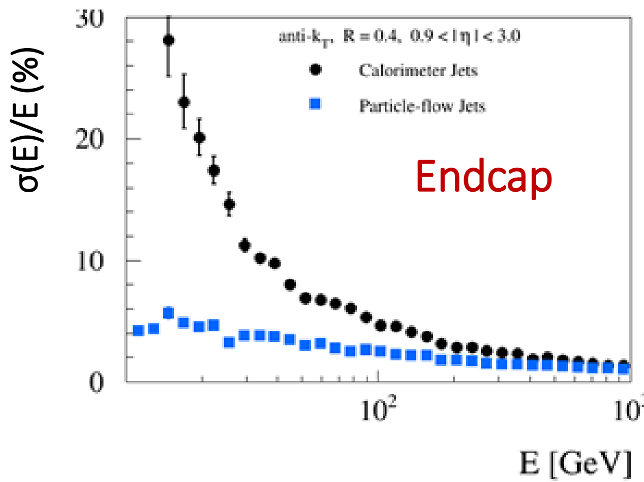
Cell size: 6 cm x 6 cm





Energy resolution for **reconstructed objects** (both had and em particles) considering two different regions of pseudorapidity (η) with particle gun events (electrons and pions)





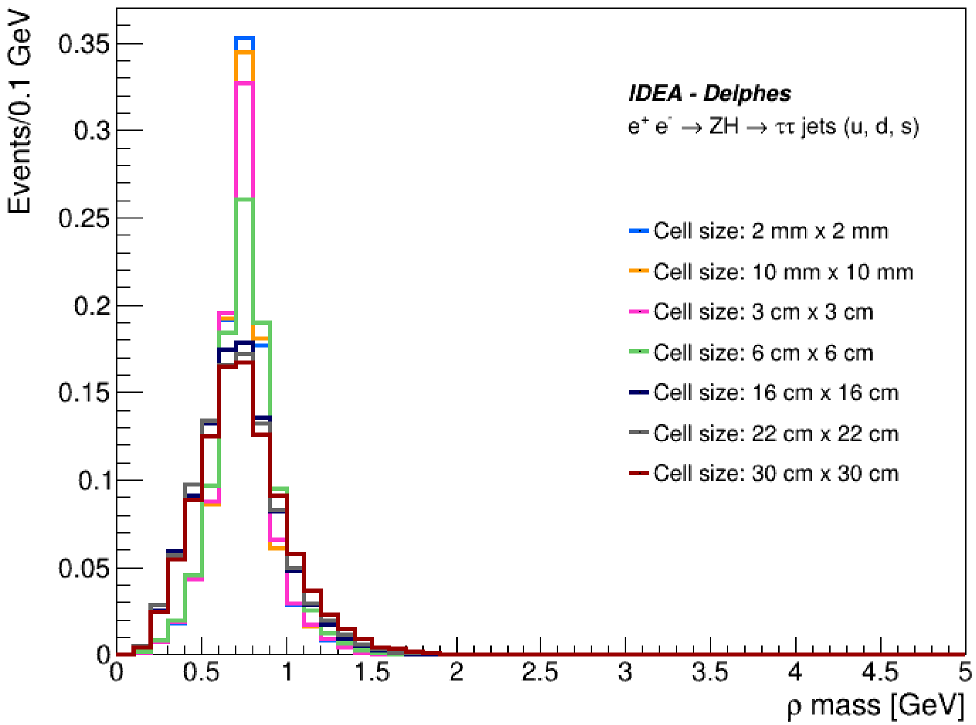
Jet Energy resolution

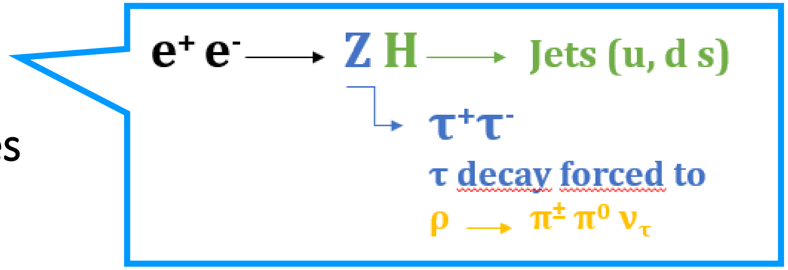
using PF reconstruction and **calo information only**

Performance study with τ jets

ZH(ττ+jets): ρ invariant mass

Combination of both $\pi^{\pm} + 2\gamma$ and $\pi^{\pm} + 1\gamma$ categories





Selected event for each category (%)

	$\pi^{\pm} + 2\gamma$	$\pi^{\pm} + 1\gamma$	$\pi^{\pm} + 0\gamma$
2 mm x 2 mm	51%	35%	14%
10 mm x 10 mm	51%	35%	14%
3 cm x 3 cm	51%	35%	14%
6 cm x 6 cm	43%	43%	14%
16 cm x 16 cm	6%	47%	47%
22 cm x 22 cm	2%	32%	66%
30 cm x 30 cm	0.4%	19.3%	80.3%

For the current version of the IDEA card cell size 6 cm x 6 cm chosen:
investigation will continue in parallel with the development of the full simulation

Detector requirements studies

Need to study physics cases at each energy scale (Z, H, top)
to better define the real detector requirements

Physics at the Z

τ polarization = high granularity and good energy resolution

b- and c-tagging

Light tracker: σ_{p_T}/p_T^2

…

Heavy flavor physics

PID (e.g. Ds π VS Ds K)

Good vertexing → excellent spatial resolution required

Physics at the H

H → 4 jets: had res

H → μμ: mom res

H from Z recoil = Transparency more important than asymptotic mom res

…

Physics at the top

Missing energy resolution: calo hermeticity

VBF study as a function of the calorimeter resolution

[*] See Paolo's talk on Friday

Conclusions and plans

GEANT4 – STANDALONE FULL SIMULATION

⇒ Combined performances of the IDEA sub-detectors have to be investigated with a complete full simulation

⇒ **We are almost ready to try to merge all the IDEA sub-detector in a unique geometry**

⇒ Best solution to have a quick development of the IDEA baseline geometry and then facilitate the import of the detector description in FCC/CEPC framework

DELPHES - FAST SIMULATION

⇒ The implementation is based on the output of dedicated Geant4 simulation of the IDEA tracker and DR calorimeter:

- ⇒ The DR calorimeter implementation will be optimized exploiting new info from full simulation studies

⇒ Delphes is **flexible enough** to provide a fast simulation of the IDEA detector

⇒ Significant improvements can be provided by the inclusion of the full covariance matrix to provide tracks smearing, the development of new algorithms oriented to e^+e^- physics (adeguate clustering for jets), …

THANK YOU!

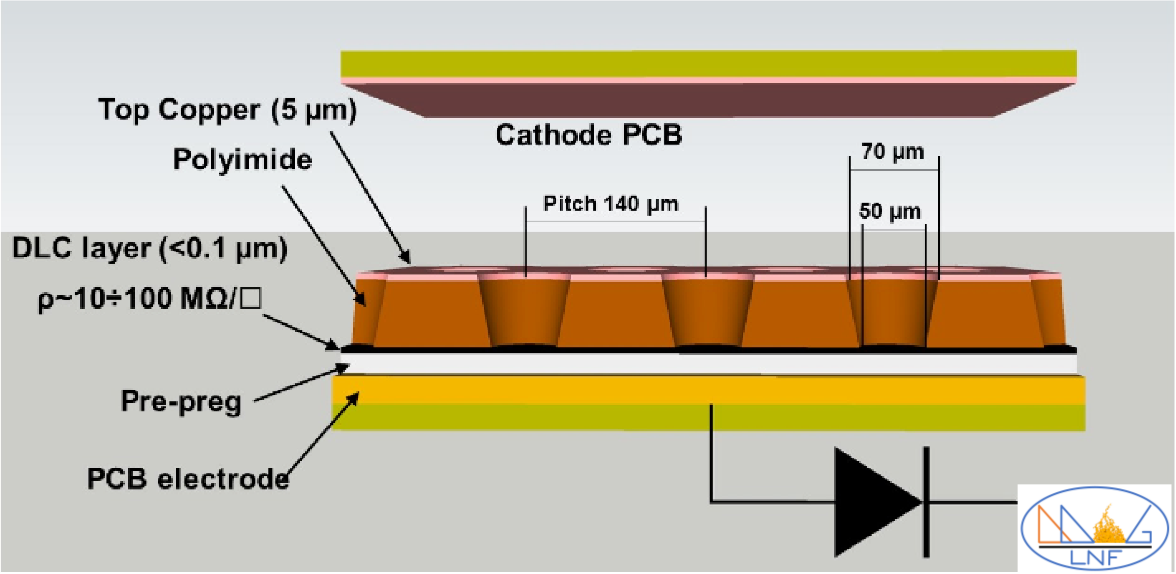
Additional slides

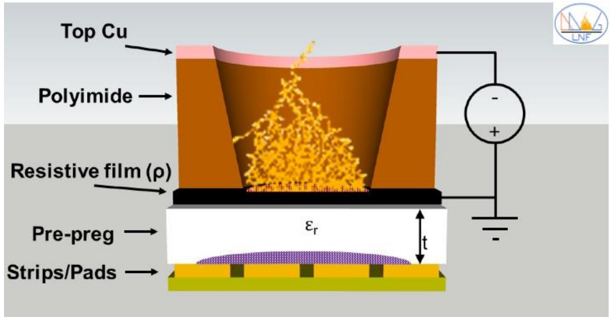
μ-RWELL detector

The μ-RWELL is composed of only two elements: the cathode and the μ-RWELL_PCB

The μ-RWELL_PCB, the core of the detector, is realized by coupling:

1. a **WELL patterned Apical® foil** acting as amplification stage;
2. a **resistive layer** for discharge suppression with surface resistivity ~10÷100 MΩ/☐ (various current evacuation schemes [*next slide]);
3. a standard readout **PCB.**





G. Morello @ Oxford: https://indico.cern.ch/event/783429/contributions/3383656/attachments/1830373/2997438/CepC_2019_morello.pdf

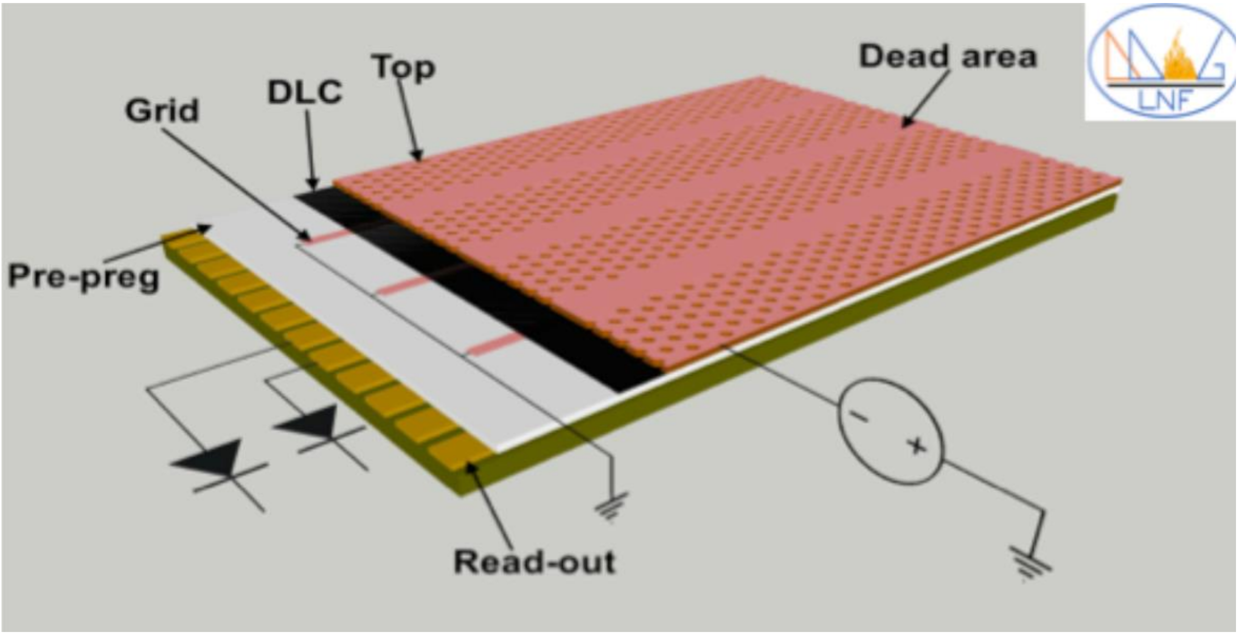
μ-RWELL detector

Two different current evacuation schemes have been studied:

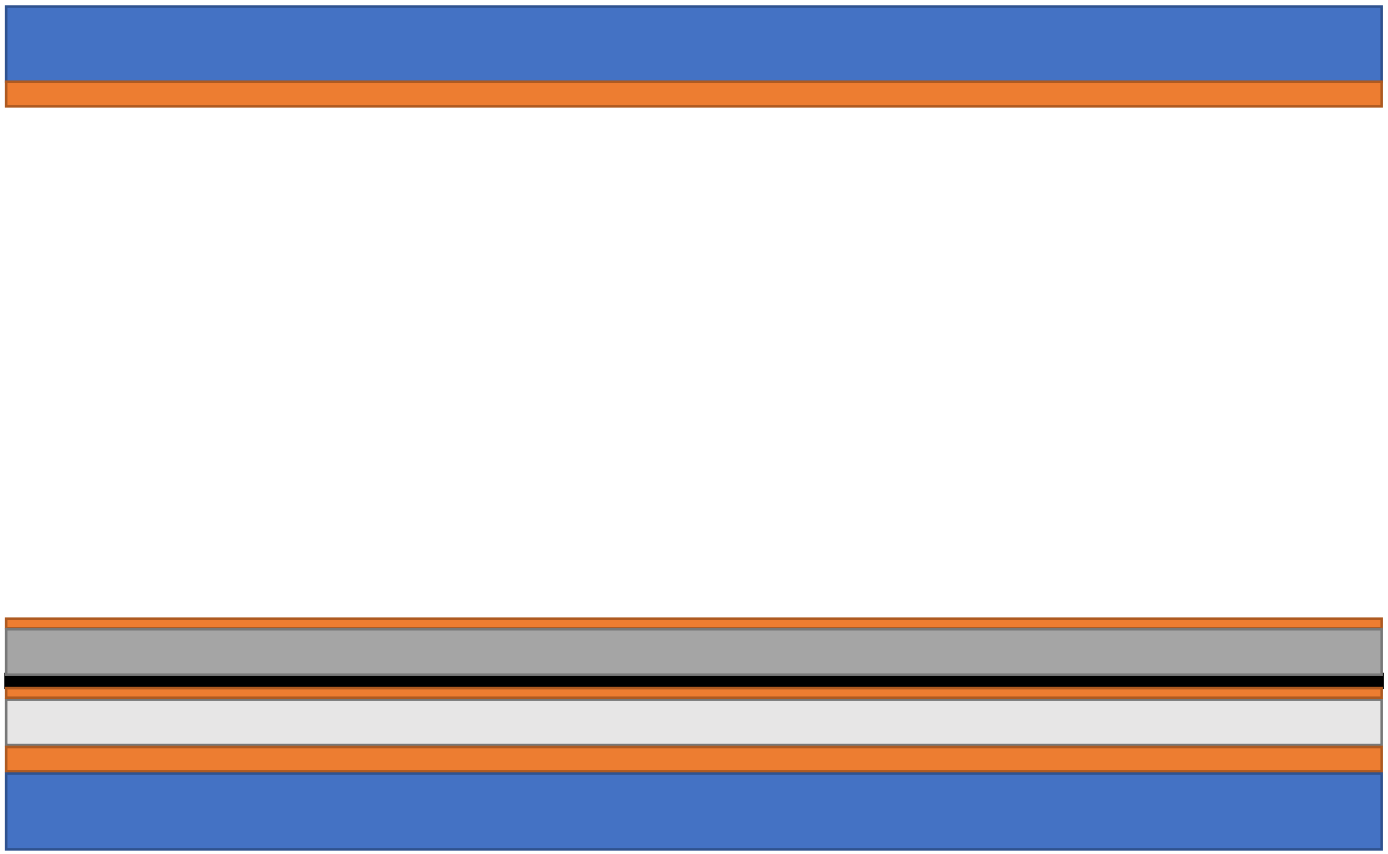
- Low rate layout => LR << 1 MHz/cm^2 - SHiP, CepC, STCF, EIC, HIEPA, FCC-ee
- High rate layout => HR >> 1 MHz/cm^2 - LHCb-Muon upgrade & future colliders (CepC, FCC)
  => Two configurations: the double-resistive layer (DRL) and the silver grid (SG)

IDEA

HR layout => SG2++ (pitch = 12 mm; dead area = 0.6 mm)



µ-RWELL description



Cathode:
FR4 +
copper

Drift gap

µ-RWELL + readout PCB
Top copper (w/ hole) +
kapton (w/ hole) +
DLC +
grid (w/ strips) +
pre-preg +
copper (w/ strips) +
FR4

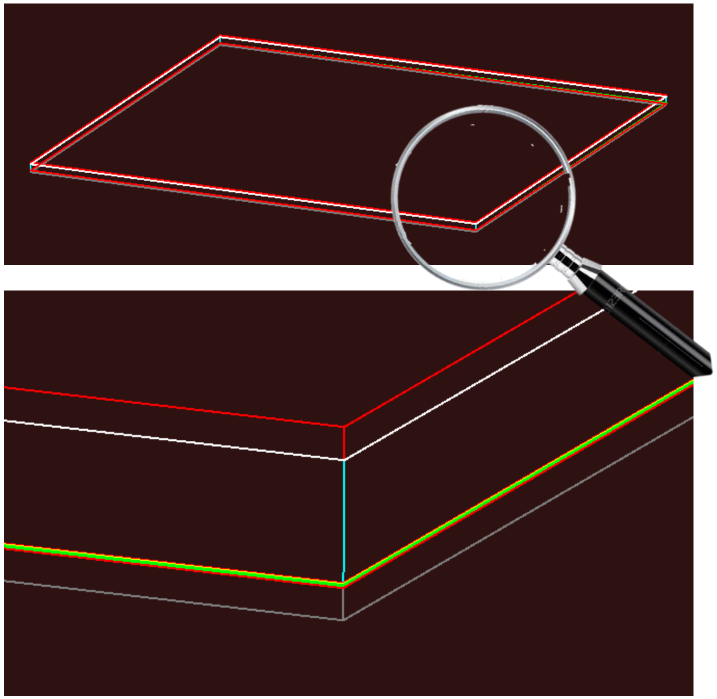
The IDEA preshower: µ-RWELL description

Description of a µ-RWELL (HR layout [*] - SG2++) detector implemented in Geant4

CATHODE 1.6 mm 35 µm	 FR4 Copper
GAS GAP 6mm	 $ArCO_2CF_4$ (45/15/40) Or $ArCO_2$ (70/30)? => Eco-friendly gas mixture
µ-RWELL + readout PCB Top copper + kapton + resistive layer + grid + pre-preg + readout	
5 µm	Copper Taking into account holes and dead zone on the amplification stage [*]
50 µm	Kapton
0.1 µm	DLC (Diamond-like-Carbon)
35 µm	Copper - Taking into account strips [*]
100 µm	Same material of DLC layer (same density)
35 µm	Copper - Taking into account strips [*]
1.6 µm	FR4

Chamber thickness: 9.4601 mm

- Cathode thickness: 1.635 mm
- Drift gap: 6 mm
- µ-RWELL + readout thickness: 1.8251 mm



μ-RWELL materials

- **Copper** and **Kapton** from G4NistManager

- **DLC**: new material with Carbon density (2.00 g/cm^3); the same density is assumed to describe the **film glue** in the pre-preg

- **FR4**: fiber glass (60%, 1.99 g/cm^3) + epoxy (40%, 1.25 g/cm^3)

  ⇒ Simulated as permaglass with FR4 density (1.85 g/cm^3)

  Implemented previously for GEM description

Fiber glass	
SiO_2	60%
B_2O_3	5%
Al_2O_3	13%
CaO	22%

- **$ArCO_2CF_4$**:

  ⇒ Argon and $C0_2$ from G4NistManager (1.661 kg/m^3 and 1.842 kg/m^3)

  ⇒ CF4 implemented as new material with density: 3.78 kg/m^3

  Density of each component weighted accordingly with their volume percentage (45/15/40)

  ⇒ Defined fraction mass values:

  f_Ar = 0.295

  f_CO_2 = 0.109

  f_CF_4 = 0.596

μ-RWELL materials

- In order to take into account holes and dead zone on the amplification stage, copper and kapton density have been redefined:

  - Copper: we consider each hole as a cylinder
    - 5 μm thickness
    - 70 μm diameter
    - 140 μm pitch
  - Kapton: we consider each hole as a trunk of cone
    - 50 μm thickness
    - 50-70 μm diameter
    - 25-35 μm r-R
    - 140 μm pitch

Considering a **pitch** of **12 mm** and a **dead zone** of **0.6 mm**, a weight is introduced to distinguish active (95%) and dead (5%) area on the amplification stage.

  - Grid strip:
    - 100 μm size
    - 12 mm pitch
  - Copper readout:
    - 250 μm size
    - 400 μm pitch

IDEA tracker system geometry

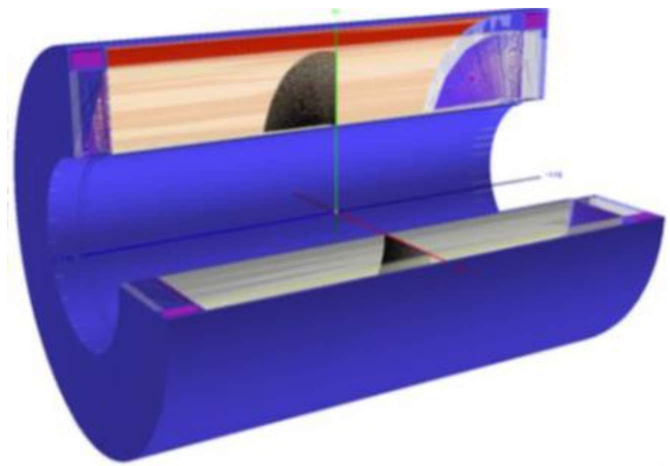
A **standalone Geant4 simulation**

- ❑ DCH – Drift chamber simulated at a good level of geometry details;
- ❑ SVX – **Vertex detector**
  - inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0
  - forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0
  - outer: an inactive Si Layer followed by 1 Si Pixel (50 μm x 50 μm) layer of 0.5% X_0
- ❑ SOT – **Silicon wrappers**

  1 Si Pixel (50 um x 50 um) layer of 0.5% X_0 followed by an inactive Si Layer in barrel and forward regions

- ❑ SVX and SOT simulated as a simple layer or overall equivalent material.

N° layers = 112, L = 400 cm, R = 35-200
56448 squared drift cells (12 - 13.5 mm)

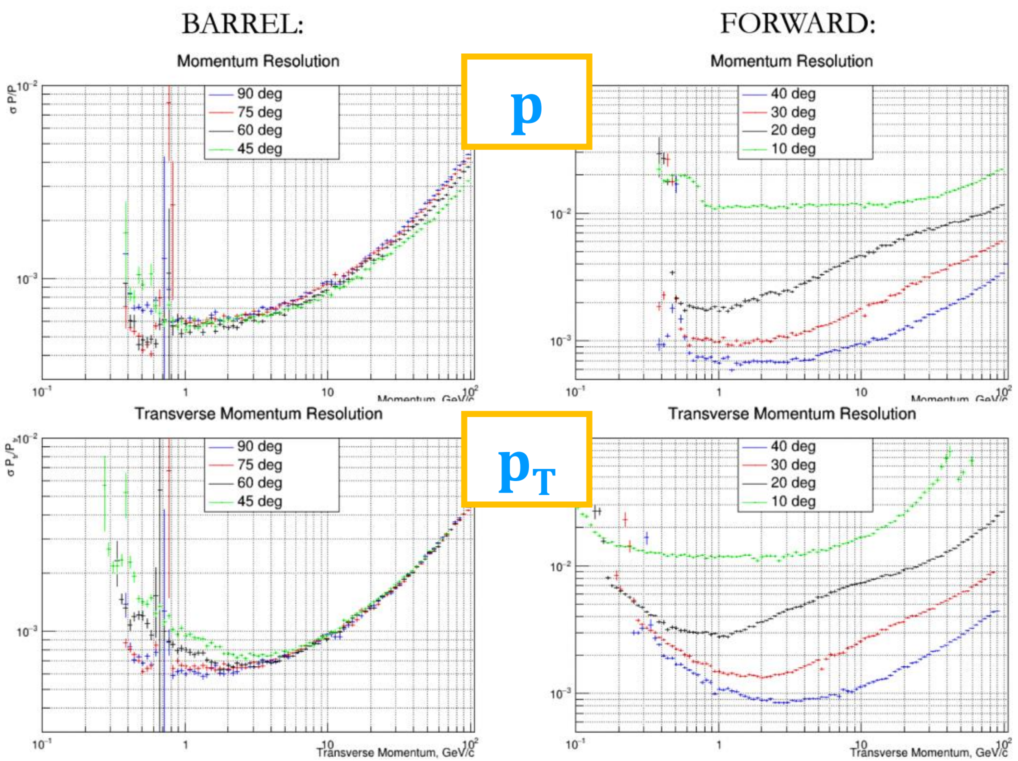


Gas: 90% He - 10% iC4H10
Drift length = 1 cm; drift time = 350 ns
Spatial resolution: σ_{xy} < 100 μm, σ_z < 1000 μm

Detector signal hits creation:

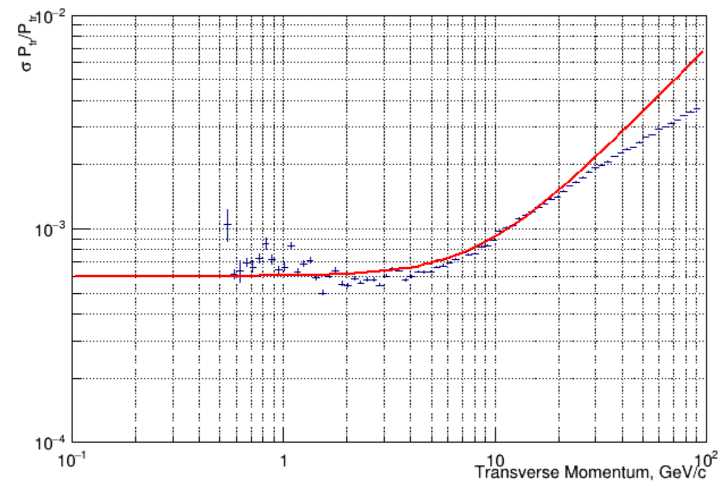
- ❑ DCH: all the hits in a cell coherent in max drift time are grouped together to create a hit with proper DCA smeared with a resolution of 100 μm
- ❑ SVX, SOT, PSHW: the hits are translated in pixel/strip information

IDEA tracker – Geant4



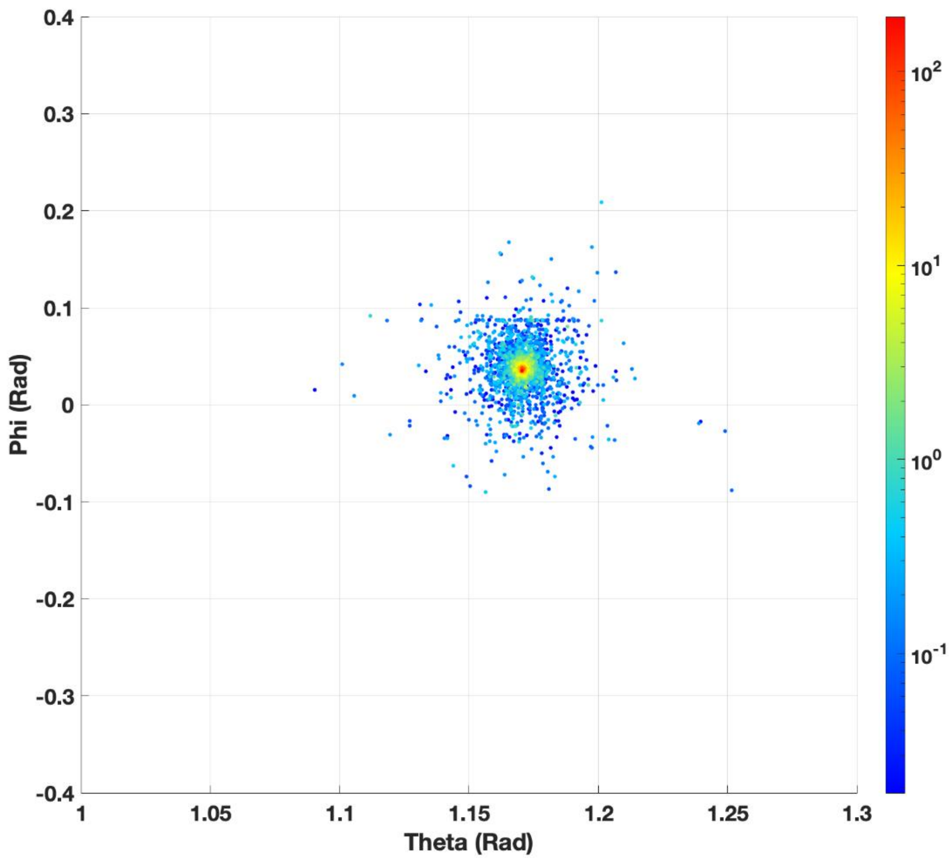
Delphes parametrization from full simulation (without considering silicon wrappers:

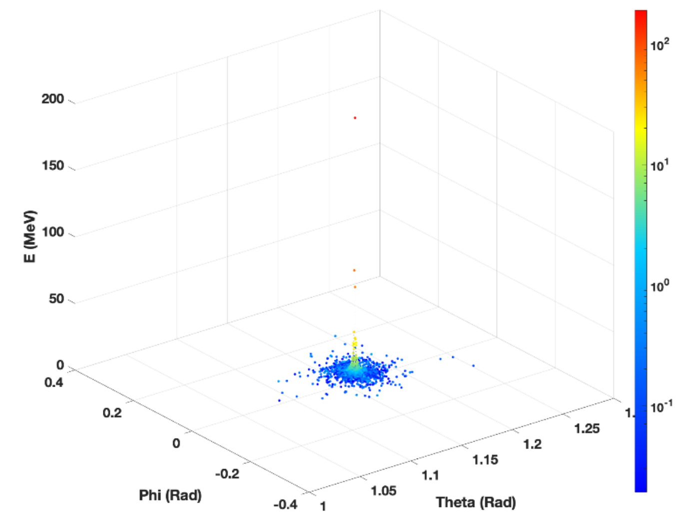
$\sigma_{pT} / p_T = \sqrt{[(7.e^{-5} * p_T)^2 + 0.0002^2]}$



DR full simulation

Electron 40 GeV

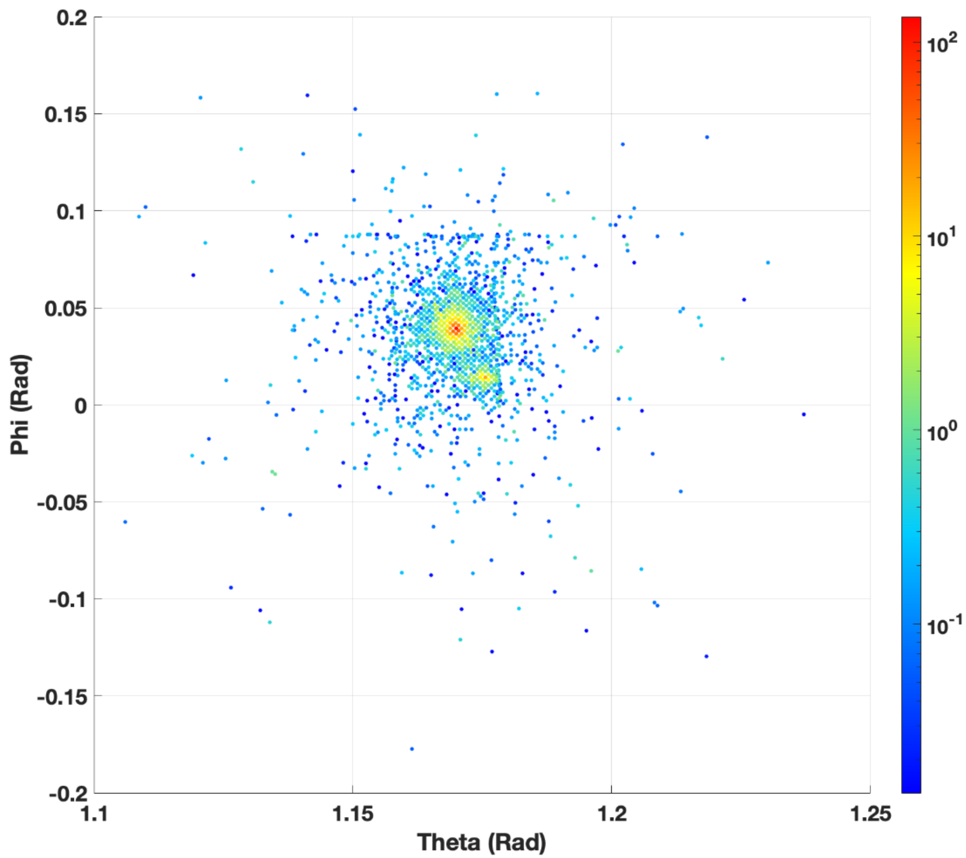


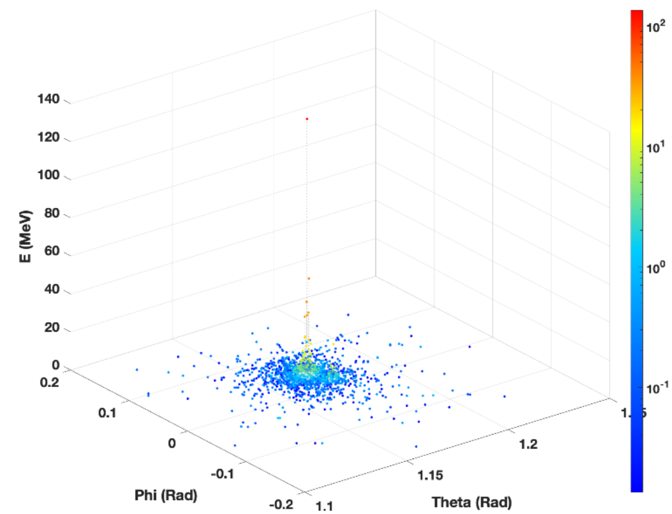


[*] Massimiliano’s talk here in Bologna

DR full simulation

Photons 40 GeV

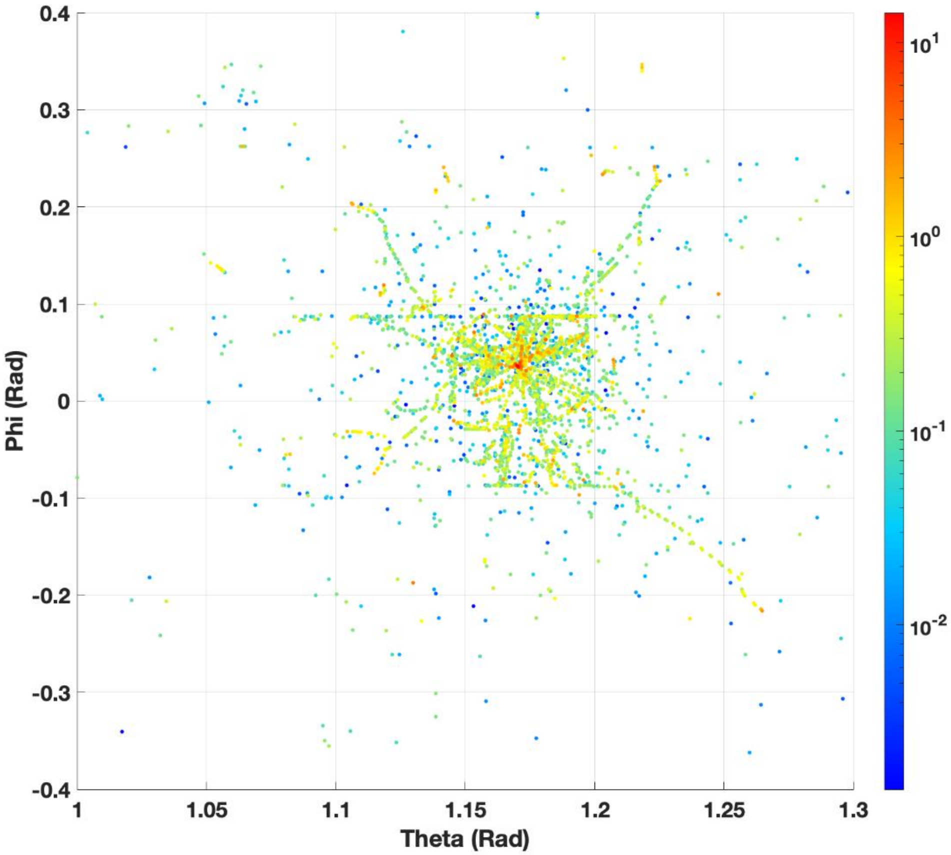


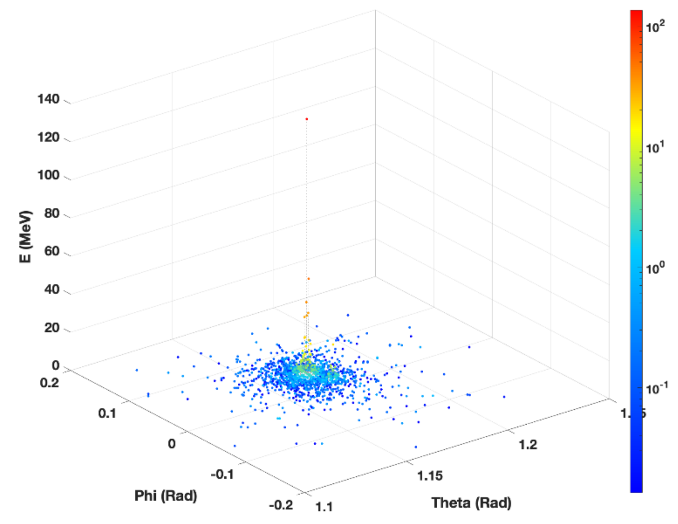


[*] Massimiliano's talk here in Bologna

DR full simulation

Pions 40 GeV



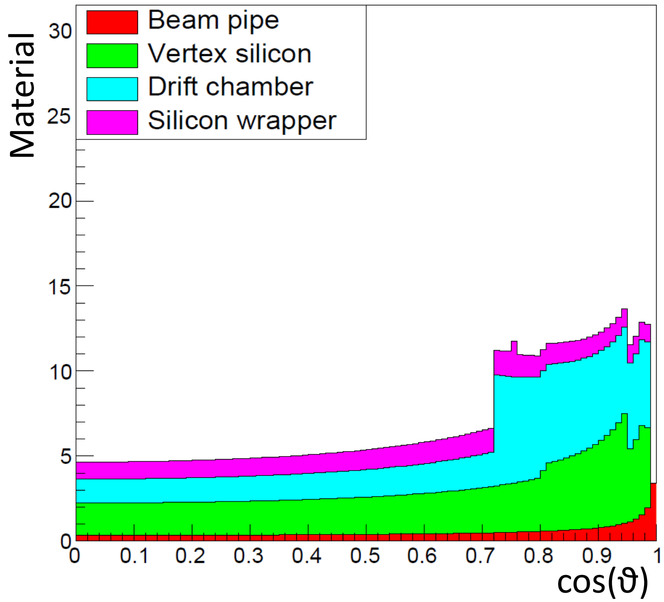


[*] Massimiliano's talk here in Bologna

Fast tracking simulation

- ROOT based classes:
  - Simulation of the tracking system geometry
  - Validation using tracker full simulation in Geant4
  - Easy to implement a modified geometry
  - Easy to change detector performances

d/d* = predicted/measured distance of track from wire or pixel
p = track parameters
S = covariance of all measurements:
resolution & MS
MS → worse resolution and non diagonal correlation terms



Track fit χ^2 linearized in the fit parameters:

$$\chi^2 = \vec{d}^t S^{-1} \vec{d} \simeq (\vec{d}_0 - \vec{d}^* + \frac{\partial \vec{d}}{\partial \vec{p}} \cdot \Delta \vec{p})^t S^{-1} (\vec{d}_0 - \vec{d}^* + \frac{\partial \vec{d}}{\partial \vec{p}} \cdot \Delta \vec{p})$$

Parameter resolution depends only on S and derivatives:

$$C^{-1} = \frac{1}{2} \frac{\partial^2 \chi^2}{\partial \vec{p} \partial \vec{p}} = A^t S^{-1} A, \text{ where } A = \frac{\partial \vec{d}}{\partial \vec{p}}$$

[*] F. Bedeschi @ Oxford: https://indico.cern.ch/event/783429/contributions/3376675/attachments/1829951/2996531/Oxford_April2019_V1.pdf

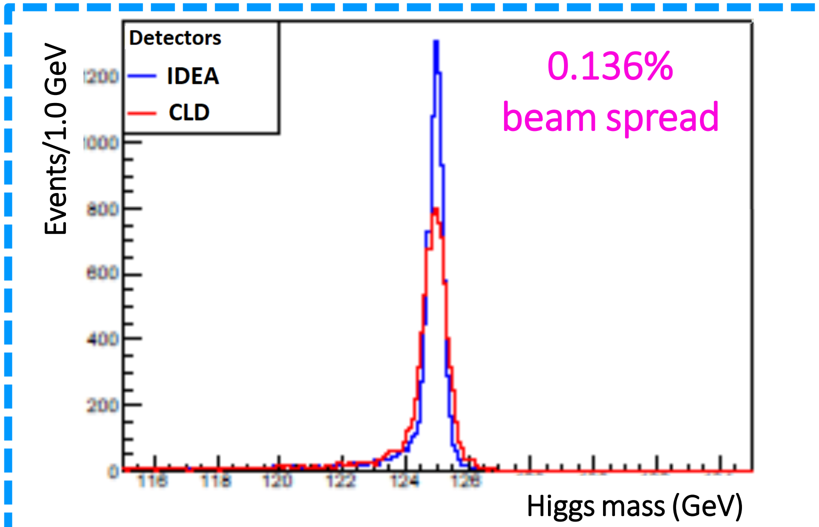
Fast tracking simulation

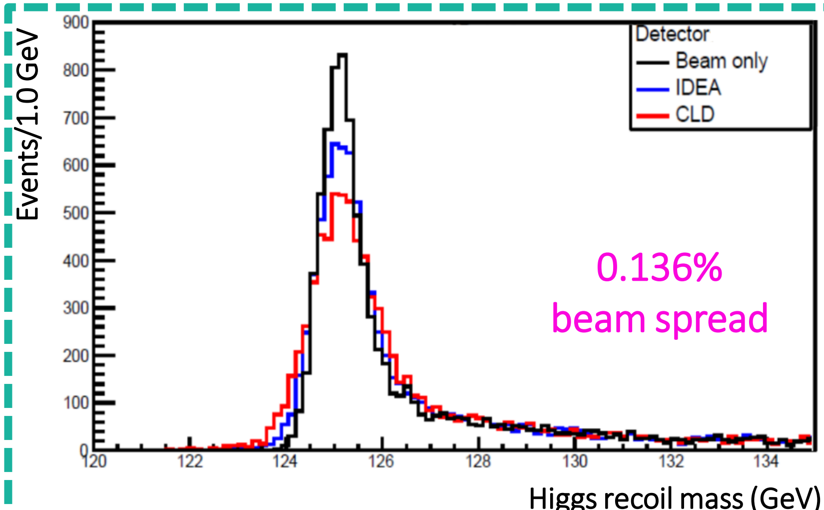
Examples

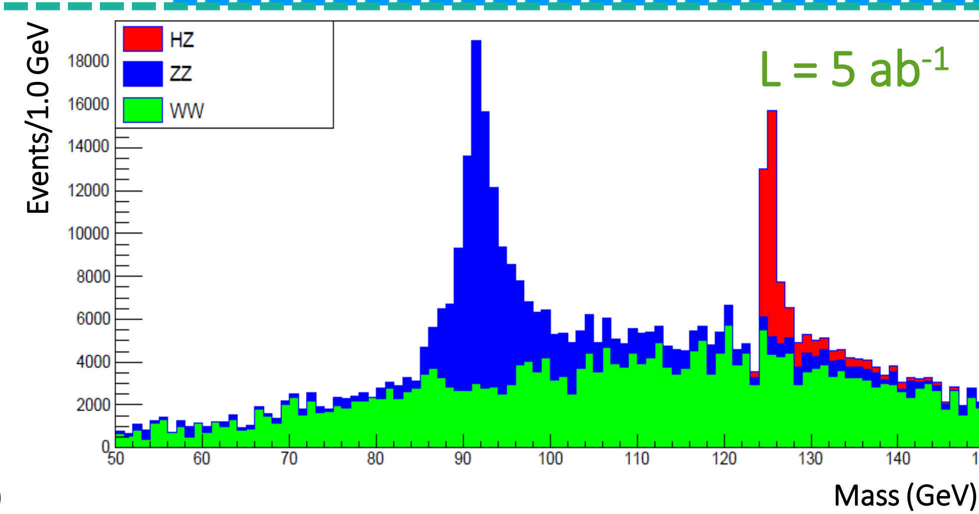
ee → ZH (H → μμ)

ee → ZH (Z → μμ)

- Higgs from Z recoil
- Full recoil study (IDEA)

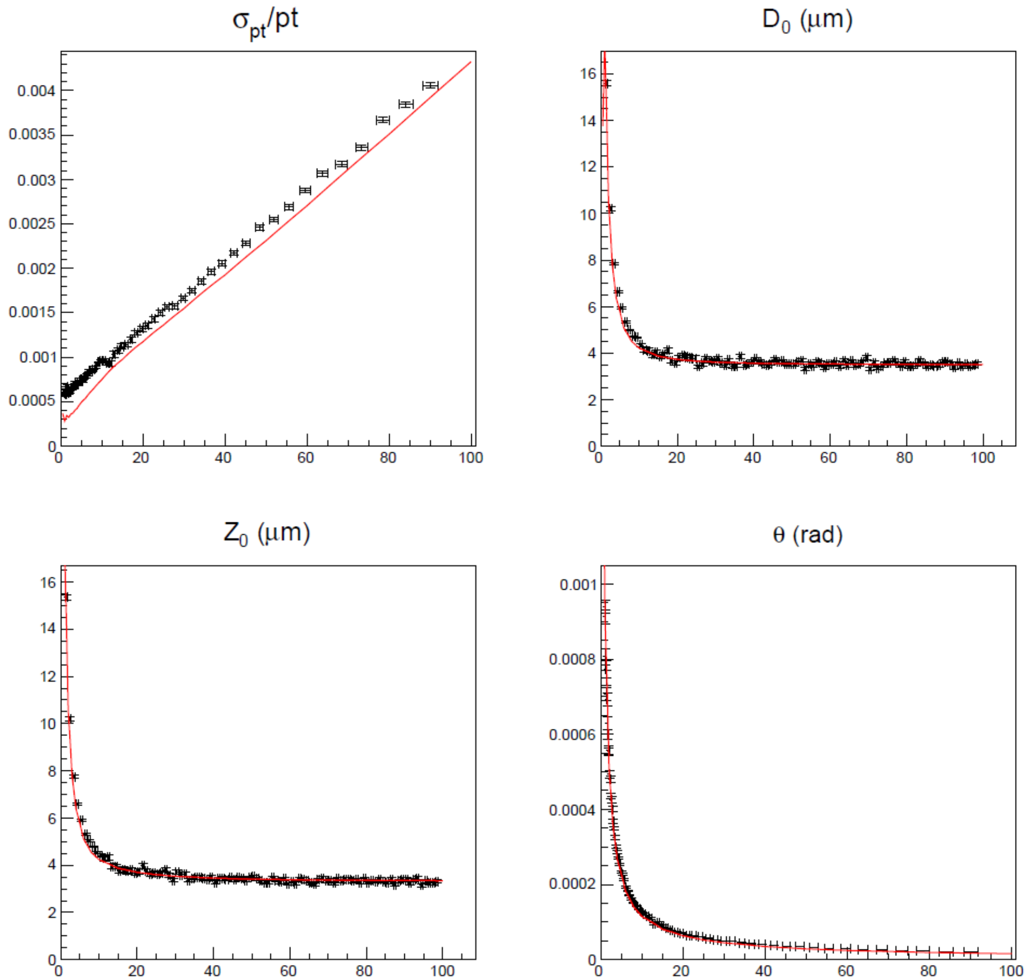






[*] F. Bedeschi @ Oxford: https://indico.cern.ch/event/783429/contributions/3376675/attachments/1829951/2996531/Oxford_April2019_V1.pdf

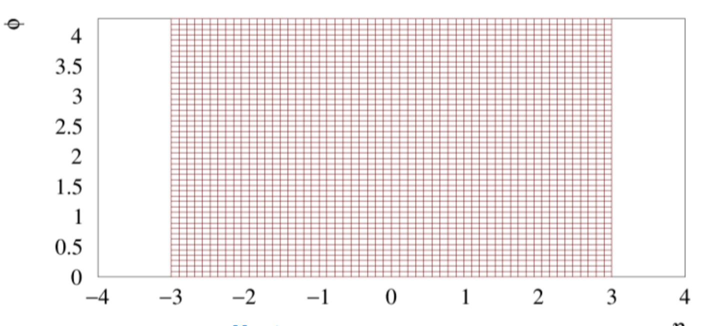
Fast tracking simulation



[*] F. Bedeschi @ Oxford: https://indico.cern.ch/event/783429/contributions/3376675/attachments/1829951/2996531/Oxford_April2019_V1.pdf

IDEA DR calorimeter in Delphes

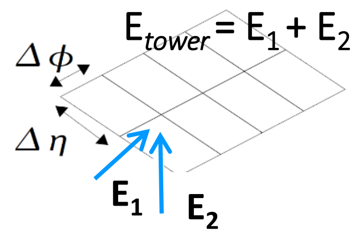
- The geometry is given in Delphes as a segmentation of the calorimeter cylinder in cells (η-ϕ directions).
- Since each tower reconstructed in the calorimeter corresponds to a single cell in Delphes work flow, the **granularity has to be defined accordingly to the physics dimensions of showers.**
    - No clustering
    - No longitudinal segmentation
    - Need to take into account the possible overlap between particles



Cell size: 30 cm x 30 cm

- **Modified Energy Flow in Delphes:** hadronic resolution (pessimistic scenario) in case of an electromagnetic and hadronic deposit in the same cell

    - New branch available in Delphes (by Michele): *branch DualReadout*



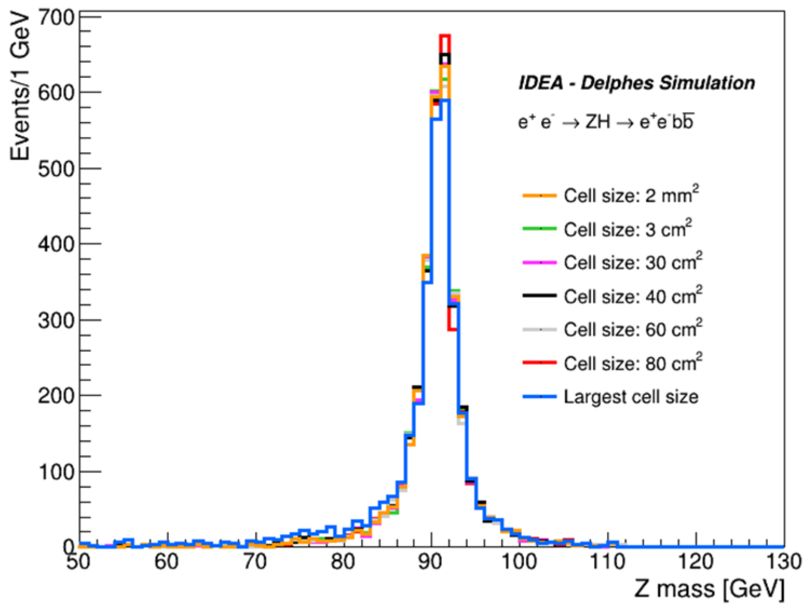
Different cell size Configurations have been implemented and studied for various physics processes

GOAL: Check the effect in Delphes given by changing DR calorimeter granularity

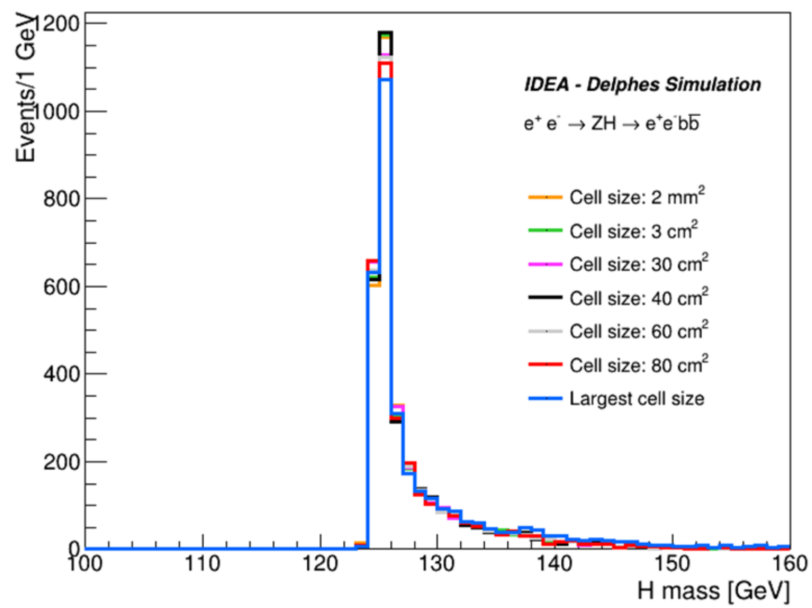
ZH(eebb)

Dilepton invariant mass

Z mass



Higgs recoil mass



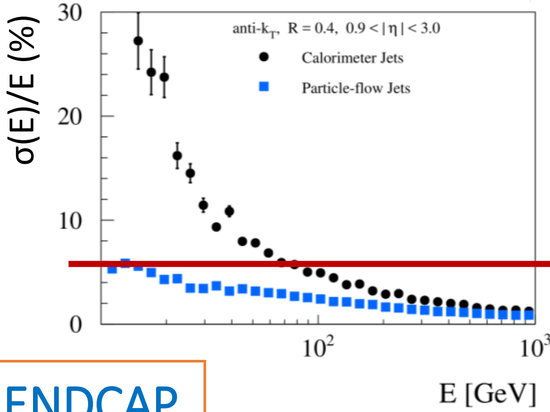
No significant discrepancies on electron/muon resolution mass:
signal leptons are very well isolated,
so changing the granularity does not affect the peak reconstruction

Jet energy resolution

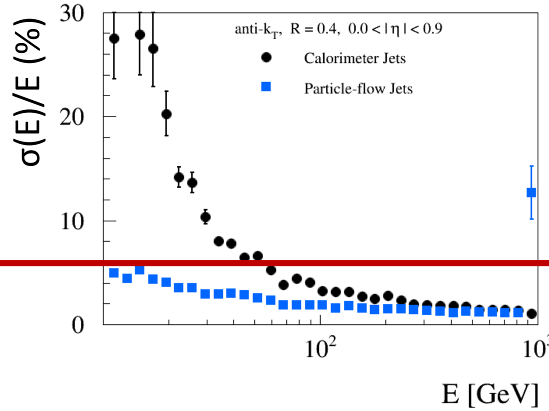
BARREL

The jet energy resolution is **not particularly affected** by the variation of the cell size

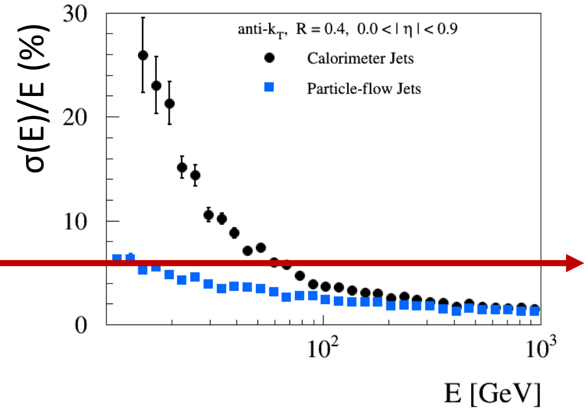
Cell size: 10 mm x 10 mm



Cell size: 6 cm x 6 cm

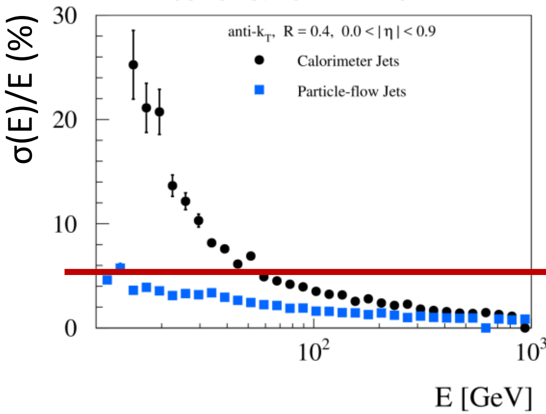


Cell size: 30 cm x 30 cm

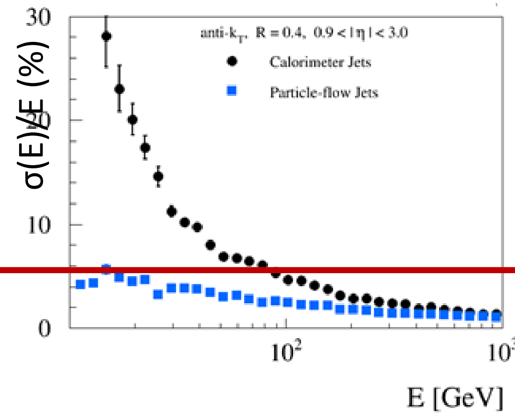


ENDCAP

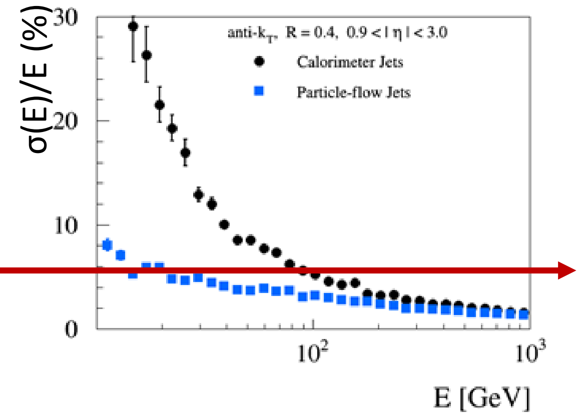
Cell size: 10 mm x 10 mm



Cell size: 6 cm x 6 cm



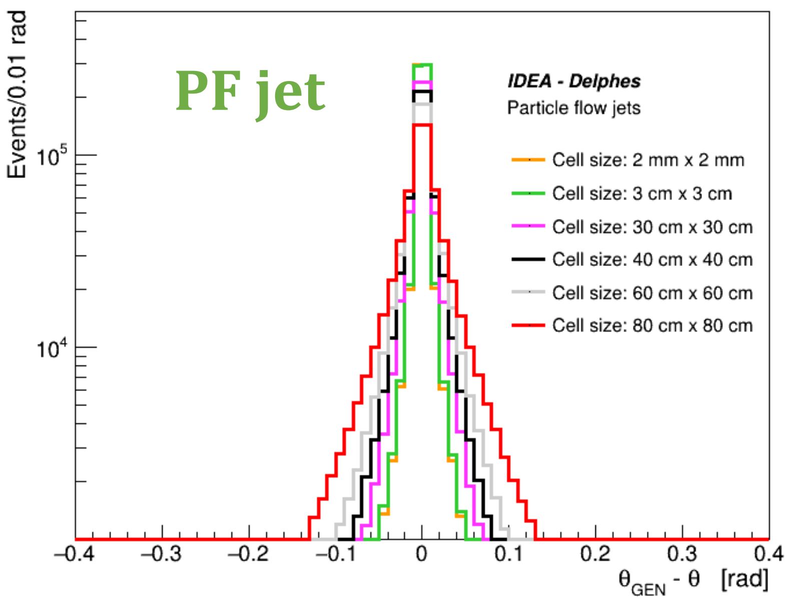
Cell size: 30 cm x 30 cm

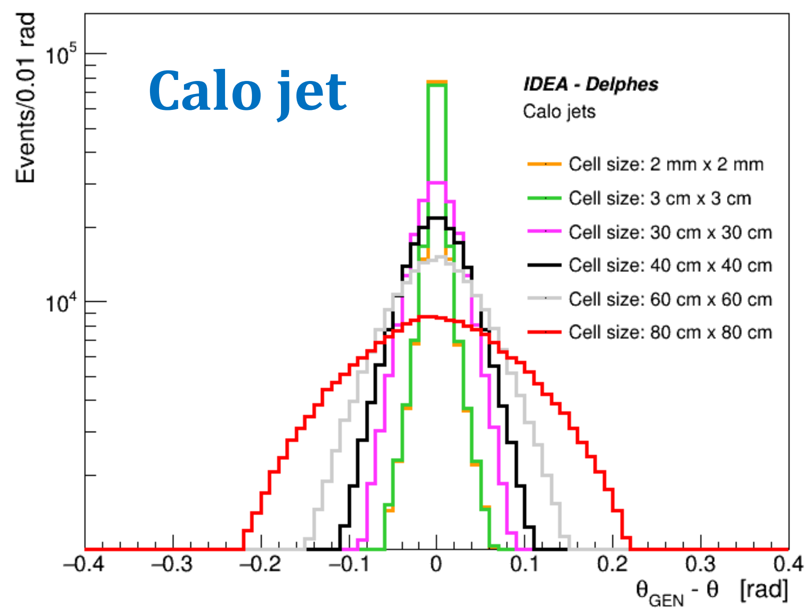


Jet angular resolution

The angular resolution is **not so much dependent on the cell size**. It decreases in the same way with the increase of the cell size for PF and Calo jets.

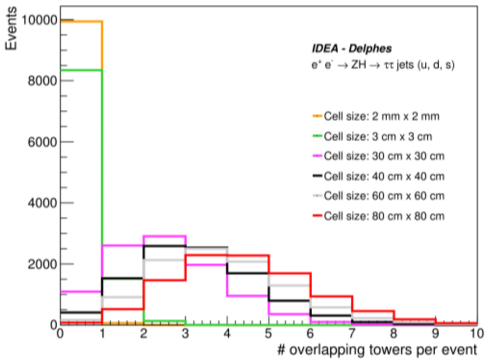
$$\sigma(\theta) = \theta_{GEN} - \theta_{RECO}$$





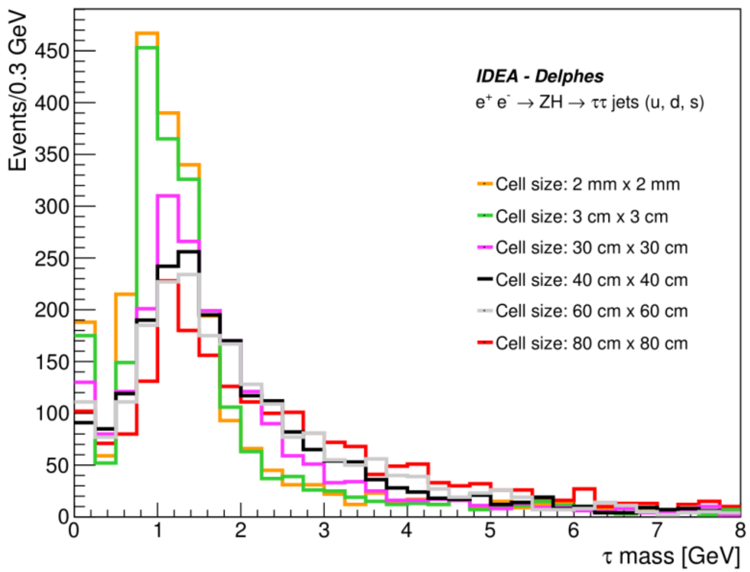
σ(θ) [rad]	2 mm x 2mm	3 cm x 3 cm	30 cm x 30 cm	40 cm x 40 cm	60 cm x 60 cm	80 cm x 80 cm
PF jet	0.01	0.01	0.02	0.02	0.03	0.04
Calo jet	0.03	0.03	0.04	0.05	0.07	0.1

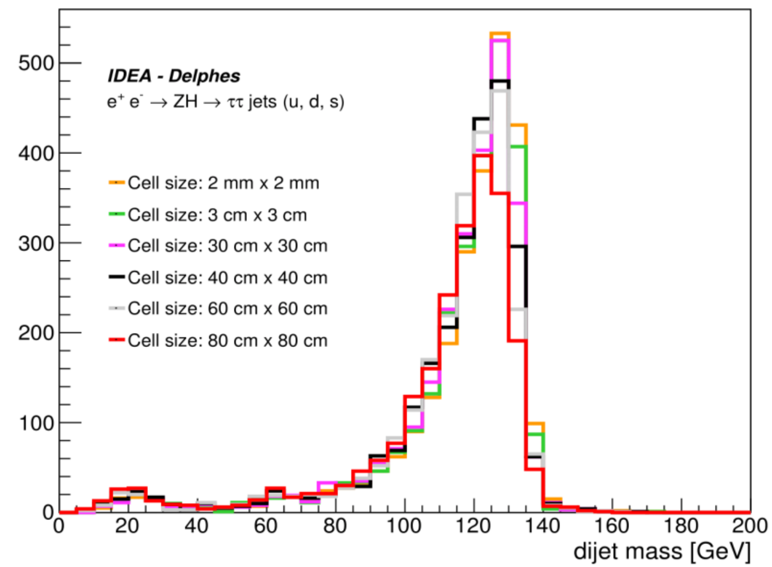
ZH(ττ+jets)



The number of **towers with both an electromagnetic and hadronic deposit** increases when increasing granularity.

Dijet mass resolution is **not significantly affected** by the different cell size, while the τ jet invariant mass **gets worse**.





Need to invastigate this case:

τ studies, considering especially π_0 decay into two photons

ZH(ττ+jets): ρ invariant mass

$e^+e^- \longrightarrow ZH \longrightarrow$ Jets (u, d s)

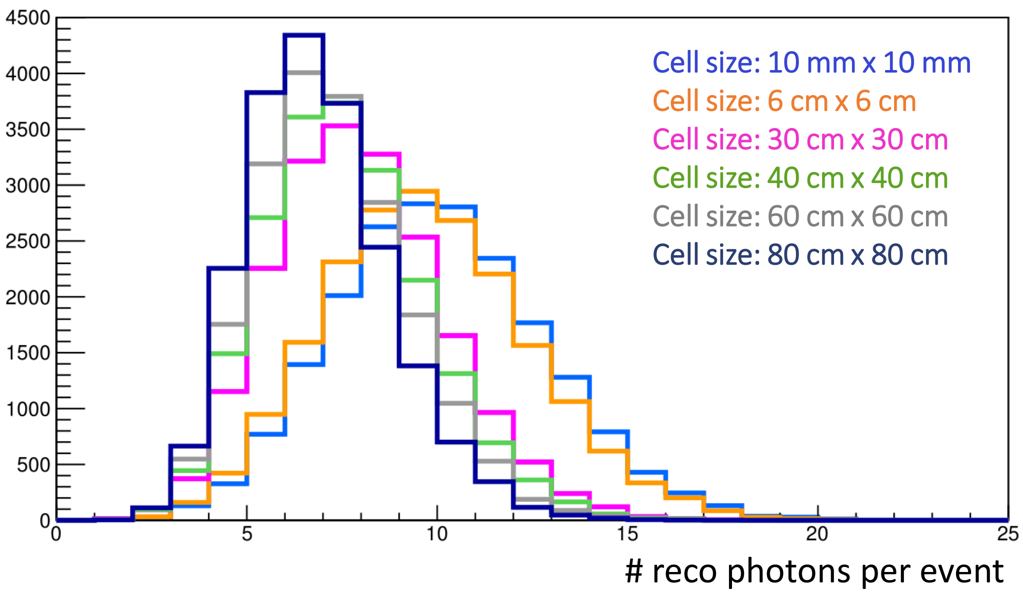
$\hookrightarrow \tau^+\tau^-$

τ decay forced to

$\rho \longrightarrow \pi^{\pm}\pi^0\nu_\tau$

Invariant mass of ρ resonance searching for a charged pion and distinguishing **two categories**:

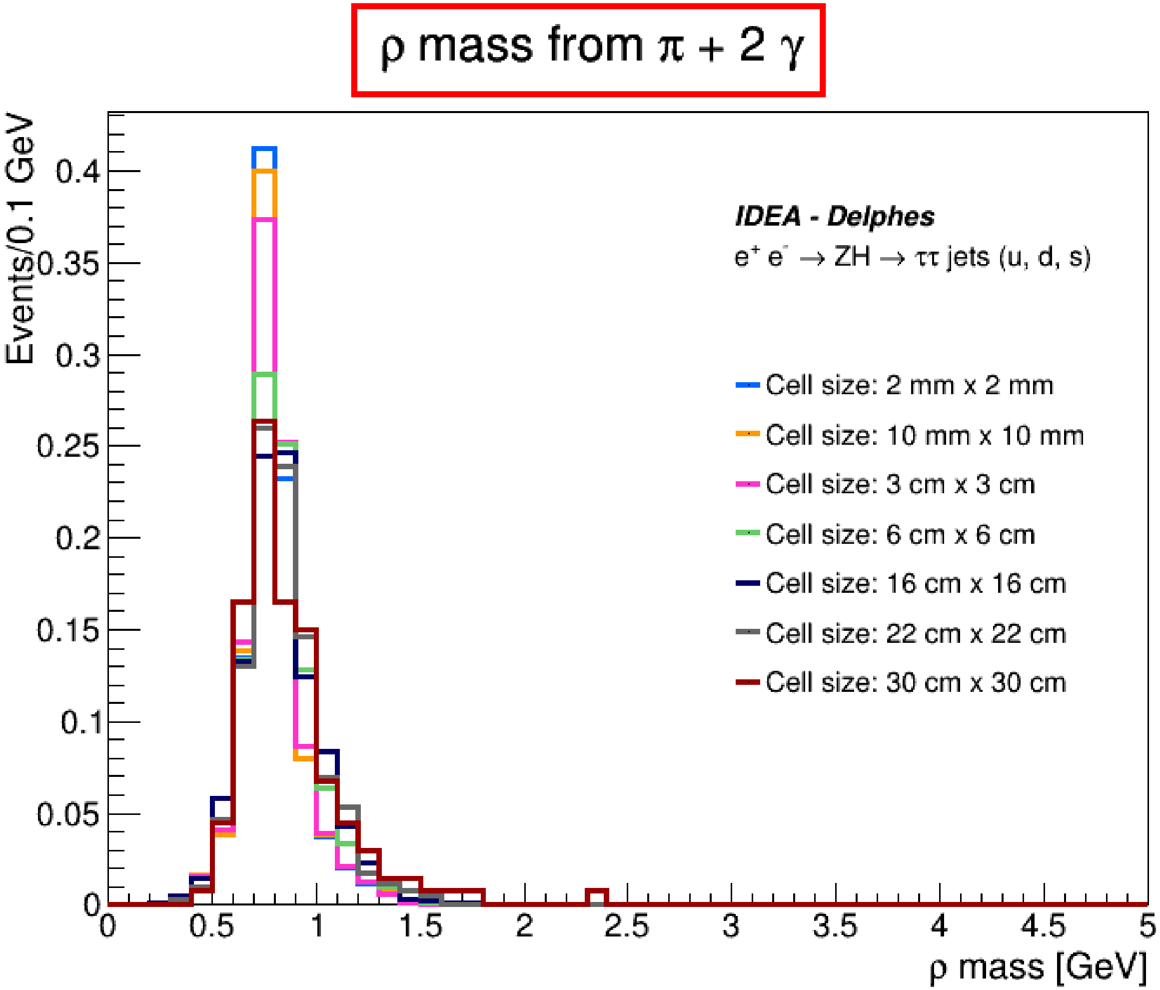
- Presence of two reconstructed pion in the cone around $\pi^{\pm}$
- Presence of one reconstructed pion in the cone around $\pi^{\pm}$



The number of reconstructed photons **per event** decreases with the increasing size of the calorimeter cells.

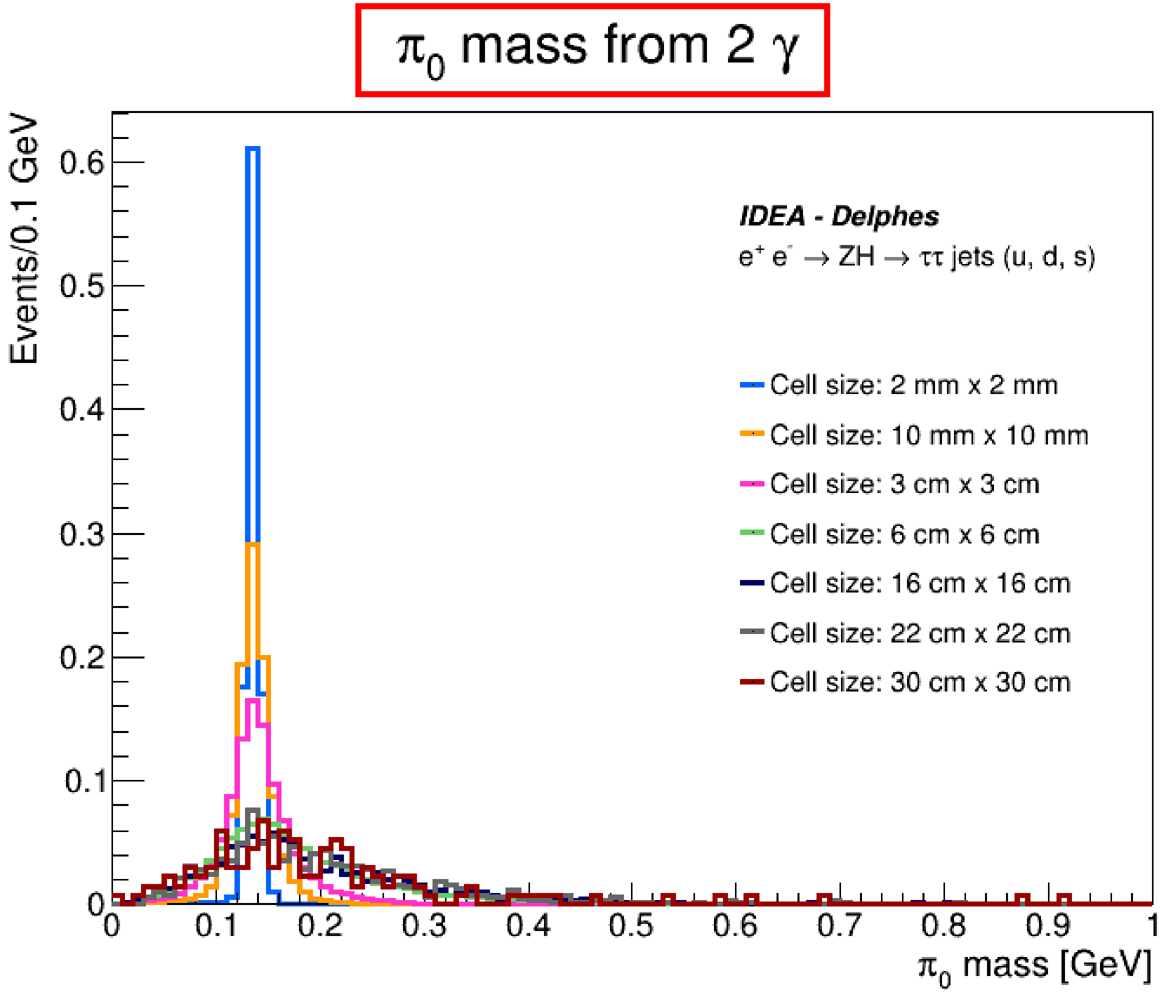
- If more photons arrive in the same cell, we reconstruct only one of them with an energy corresponding to all of them.

ZH(ττ+jets): ρ invariant mass



Considering a cell size of 6 cm x 6 cm or greater, the peak in the $\pi^{\pm} + 2\gamma$ is considerably reduced.

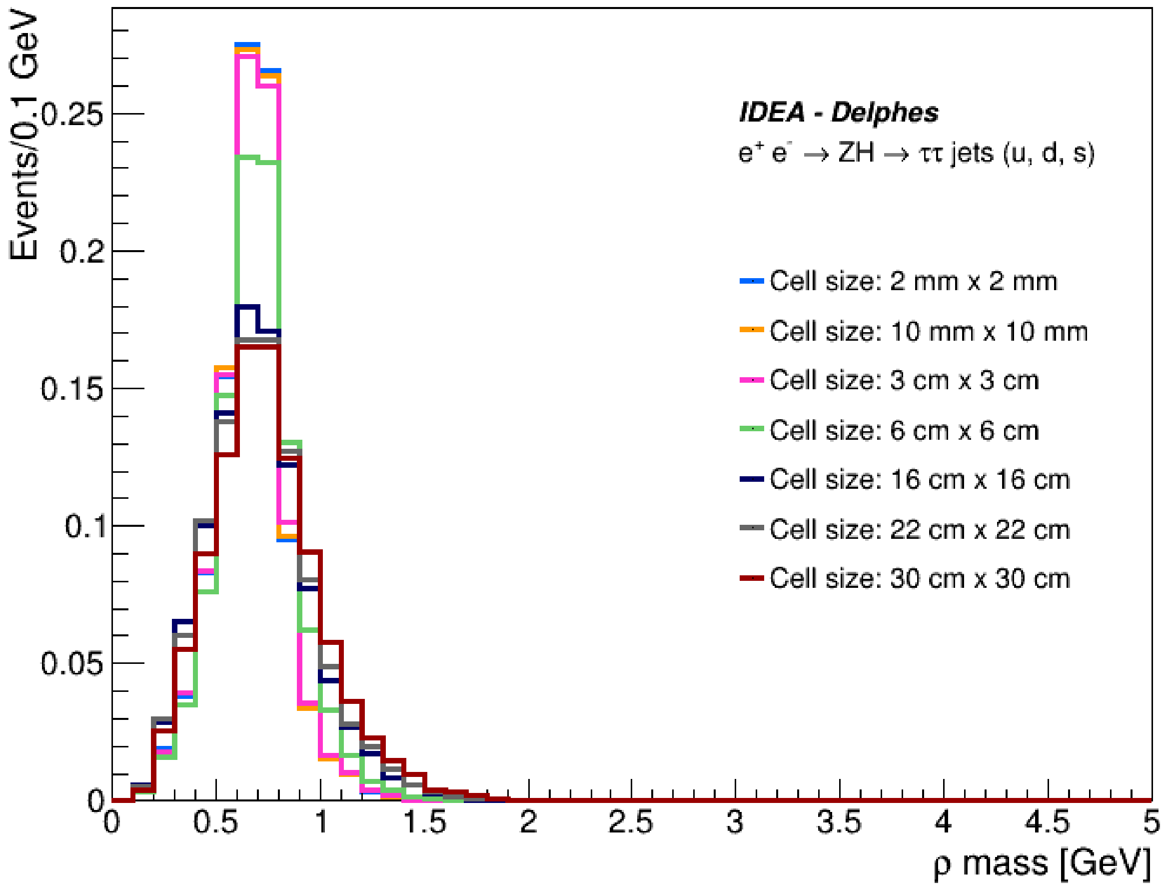
ZH(ττ+jets): ρ invariant mass



The mass resolution on the diphoton invariant mass gets worse changing the cell size from 10 mm x 10 mm to 30 cm x 30 cm ⟶ **effect of the implemented EFlow**

ZH(ττ+jets): ρ invariant mass

ρ mass from π + 1 γ



The category $\pi^{\pm}$ + 1γ show the effect of the worsen energy resolution on the photons increasing the cell size of the DR calorimeter.

ZH(ττ+jets): ρ studies

Summary of selected event for each category

	$\pi^{\pm} + 2\gamma$	$\pi^{\pm} + 1\gamma$	$\pi^{\pm} + 0\gamma$	# $\pi^{\pm}$ matched to τ daughter
2 mm x 2 mm	20309	13757	5508	39574
10 mm x 10 mm	20330	13727	5544	39601
3 cm x 3 cm	20111	13958	5517	39586
6 cm x 6 cm	16889	17131	5575	39595
16 cm x 16 cm	2247	18743	18618	39608
22 cm x 22 cm	616	12745	12745	39594
30 cm x 30 cm	133	7657	31811	39601
40 cm x 40 cm	20	4343	35210	39573
60 cm x 60 cm	5	2547	37017	39569
80 cm x 80 cm	0	1354	38224	39578