# considerations on muon system for CepC and FCC-ee

G. Cibinetto (INFN Ferrara)

on behalf of RD_FA WP7 group

# the IDEA behind this talk

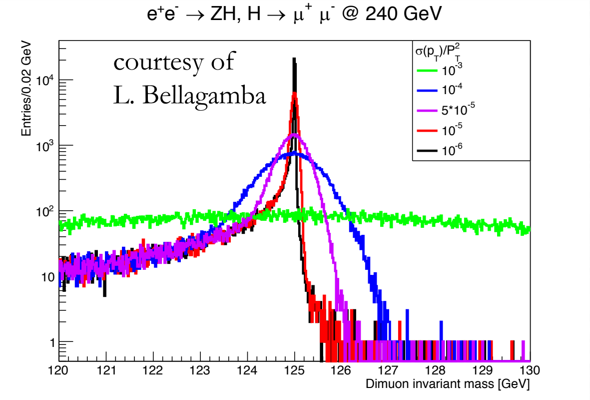
- Explore synergies and common issues for the muon system of different detectors (IDEA, CLIC-inspired, ...) and machines (i.e. FCC-ee and CepC).
- Look for possible improvements of the physics performance with respect to the current designs.
- Start building a team to work on simulation, optimization and R&D.
    - contribution to CepC CDR by 2017
    - contribution to FCC-ee CDR next year

# outline

- detector requirements and designs
- general consideration on muon system
  - iron yoke thickness and segmentation
  - spatial resolution and detection techniques
- some exotic IDEAs
- summary and outlook

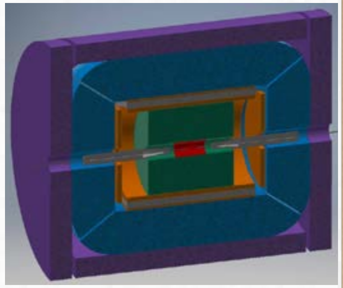
# detector requirements

- **momentum resolution**: matching beam energy spread → $\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5} GeV^{-1}$
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - Endpoint of lepton momentum spectrum v Probe to $10^{-9}$ level lepton flavour violation Z→τe, Z→τμ
  - for high $p_T$ tracks




- **mass reconstruction from jet pairs.** Resolution important for control of (combinatorial) backgrounds in multi-jet final states
  - HZ → 4 jets, $tt_{bar}$ events etc.
  - At δE/E 30% / √E (GeV), detector resolution is comparable to natural widths of W and Z bosons
- **excellent lepton and photon ID** needed q e/π, μ/π, γ/$\pi^0$.
  - lepton ID effciency >95% over full energy range.

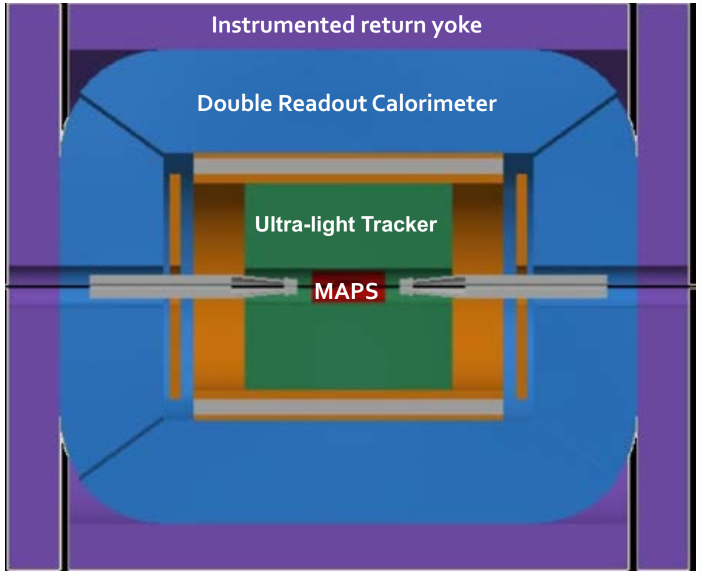
| Physics Process | Measured Quantity | Critical Detector | Required Performance |
|---|---|---|---|
| $ZH \to \ell^+\ell^- X$ | Higgs mass, cross section | Tracker | $\Delta(1/p_T) \sim 2 \times 10^{-5}$ |
| $H \to \mu^+\mu^-$ | $BR(H \to \mu^+\mu^-)$ | | $\oplus 1 \times 10^{-3}/(p_T \sin\theta)$ |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



# the IDEA detector concept

IDEA detector concept based on present state-of-the-art technologies:

- Vertex detector, MAPS (ALICE ITS technology).
- Ultra-light drift chamber with PID
- Pre-shower counter
- Dual read-out calorimetry
- 2 T solenoidal magnetic field
- Possibly instrumented return yoke



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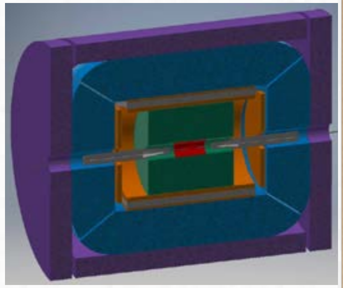

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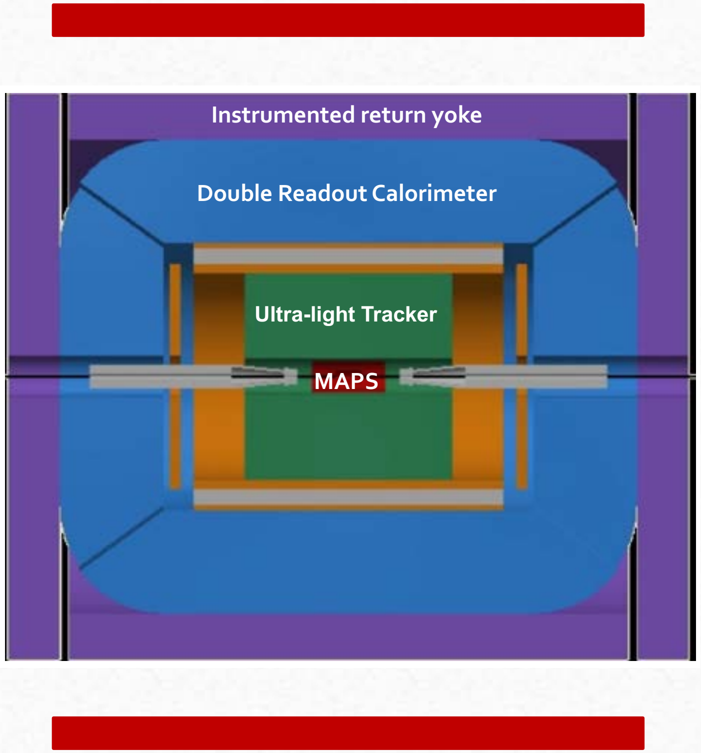
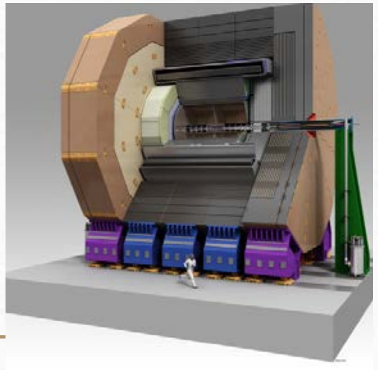
  - **Or possibly surrounded by large tracking volume (R ~8m) for very weakly coupled (long-lived) particles**

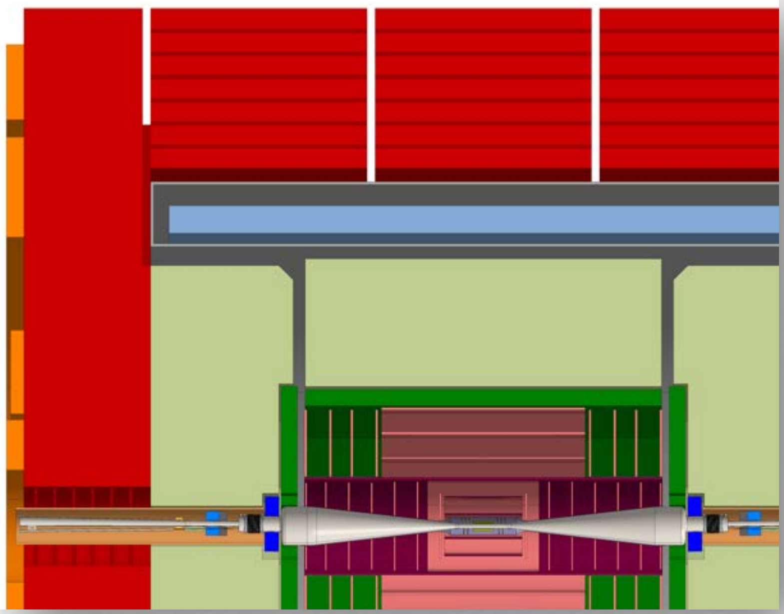


arXiv:1202.5940

# the CLIC/ILD detector concept

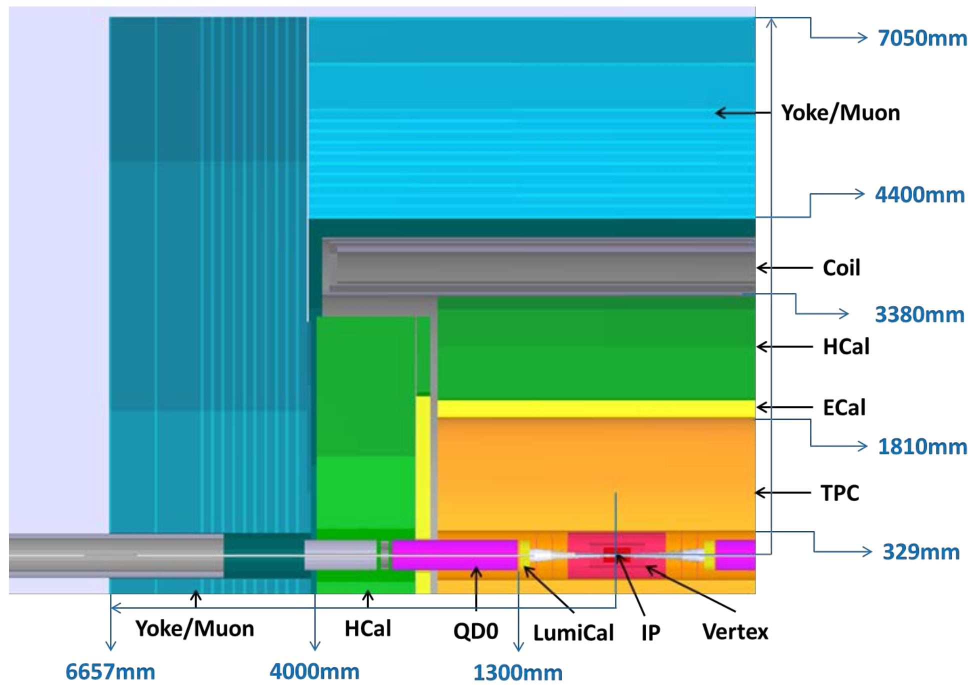


FCC-ee – CLIC inspired detector



it comes in two flavors with very similar layouts

CepC – ILD inspired detector



arXiv:1202.5940

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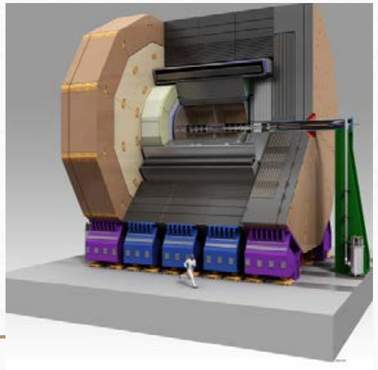
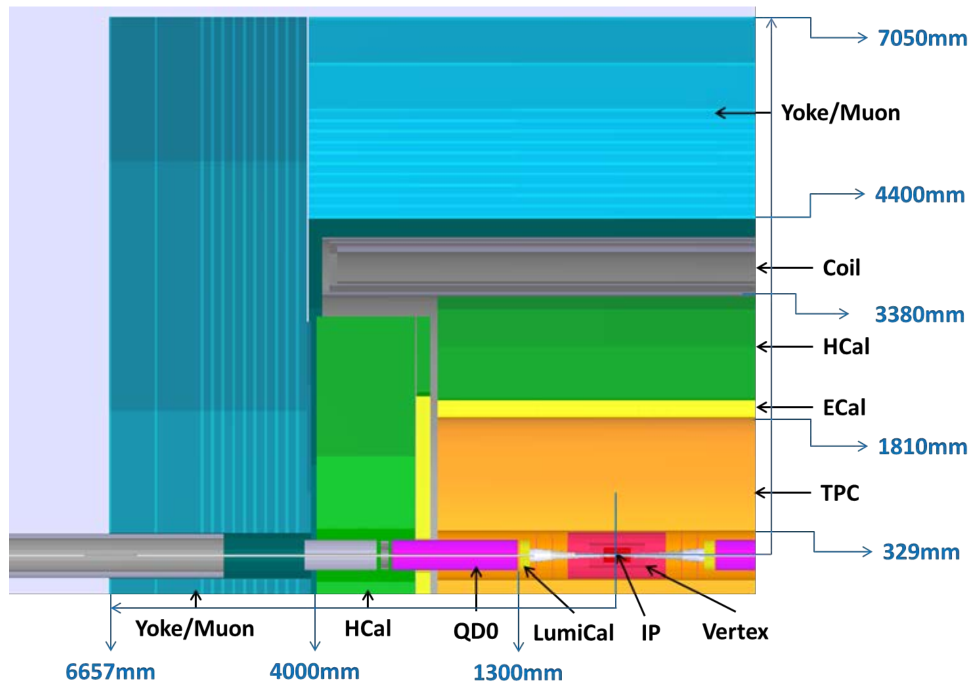


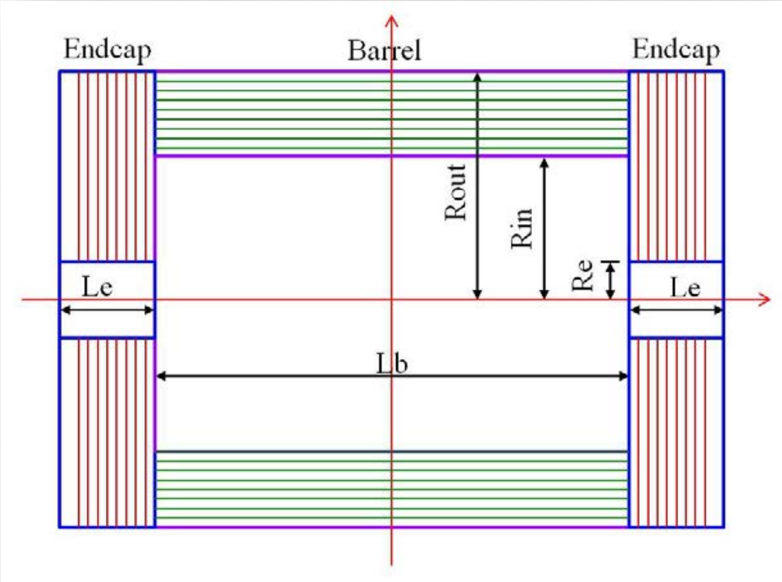
the CLIC-inspired detector is the current baseline for CepC:

- Pixel Vertex Detector
- MPGD based Time Prijection Chamber
- ECAL (SiW sampling calorimeter)
- HCAL (steel + scintillator sampling calorimeter)
- 4 Tesla solenoid
- Fe yoke equipped with muon chambers
  - RPCs or scintillators

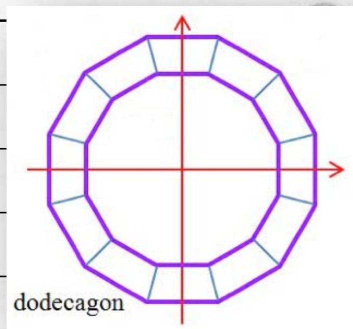
Solenoid B=4T, L~7m, $R_{min}$=3.4m, ΔR=90cm



# CepC muon system current baseline

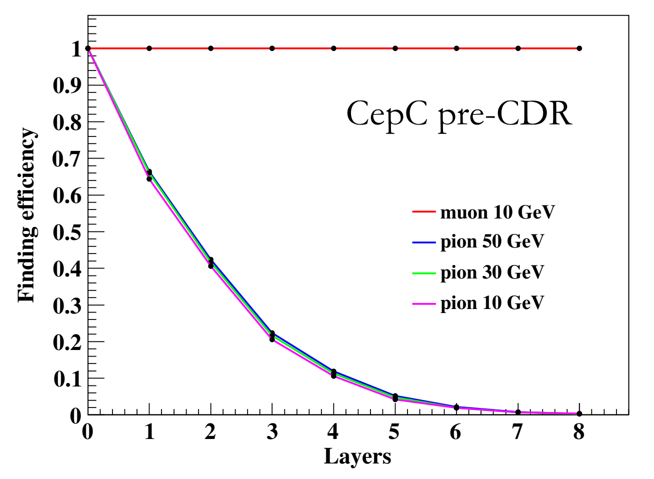



| Parameter | Possible range | Baseline |
|---|---|---|
| Lb/2 [m] | 3.6 – 5.6 | 4.0 |
| Rin [m] | 3.5 – 5.0 | 4.4 |
| Rout [m] | 5.5 – 7.2 | 7.0 |
| Le [m] | 2.0 – 3.0 | 2.6 |
| Re [m] | 0.6 – 1.0 | 0.8 |
| Segmentation | 8/10/12 | 12 |
| Number of layers | 6 – 10 | 8 ($\sim$4 cm per layer) |
| Total thickness of iron | 6 – 10$\lambda$ ($\lambda = 16.77$ cm) | 8 (136 cm) (8/8/12/12/16/16/20/20/24) |
| Solid angle coverage | 0.94 – 0.98$\times 4\pi$ | 0.98 |
| Position resolution [cm] | $\sigma_{r\phi}$: 1.5 – 2.5 | 2 |
| | $\sigma_z$ : 1 – 2 | 1.5 |
| Average strip width [cm] | Wstrip: 2 – 4 | 3 |
| Detection efficiency | 92% – 98% | 95% |
| Reconstruction efficiency ($E_\mu > 6$ GeV) | 92% – 96% | 94% |
| P($\pi \to \mu$)@30GeV | 0.5% – 3% | $< 1\%$ |
| Rate capability [Hz/cm$^2$] | 50 – 100 | $\sim$60 |



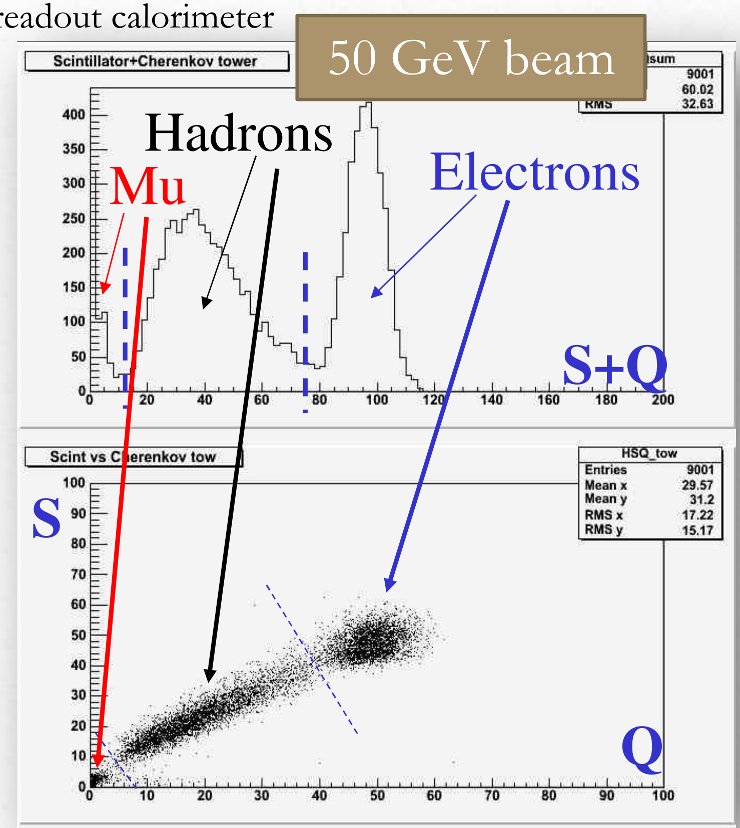
# muon identification: iron yoke thickness

- the CLIC-inspired design exploits about 1.5 m of iron.
- probably redundant (including the HCAL thickness).



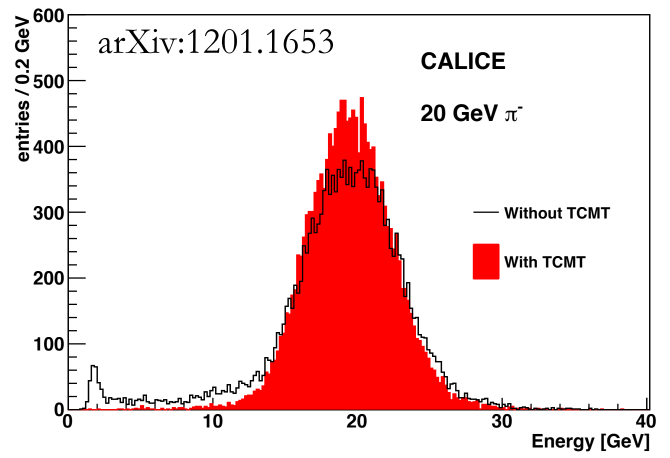

- $\mu/\pi$ separation can be done in conjunction with HCAL and taking into account also the lateral development of the hadronic shower.
- IDEA design more compact.

dual readout calorimeter

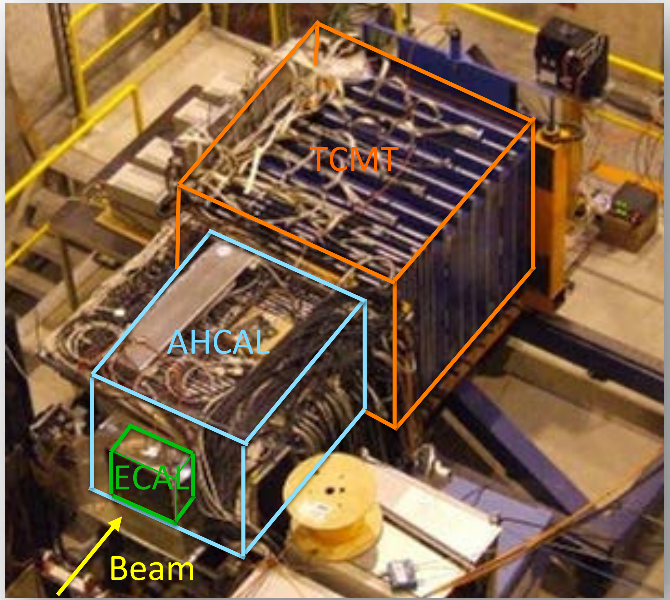


# jet energy measurement: iron segmentation

- Capturing the full physics potential will require jet energy resolution beyond that of currently operating detectors.
- The reconstruction of individual showers in a jet requires fine transverse and longitudinal segmentation of the calorimeters in addition to good intrinsic energy resolution.
- A properly **segmented muon system can act as tail catcher**, therefore help improving the energy resolution.



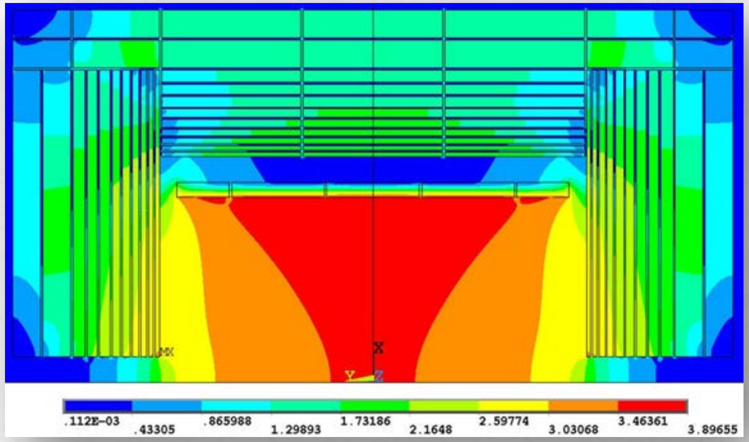

RMS=4.7 GeV
RMS=3.0 GeV



# momentum resolution

- the muon system can help improving the momentum resolution for high $p_T$ muons.

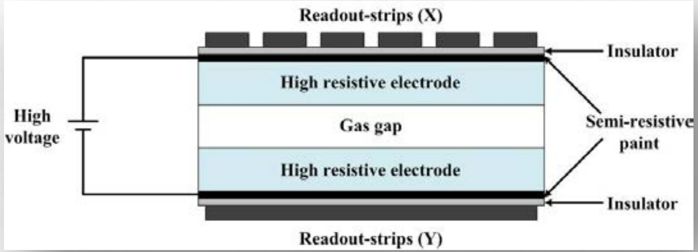
- provided
  - a suitable magnetic field
  - detector with good spatial resolution

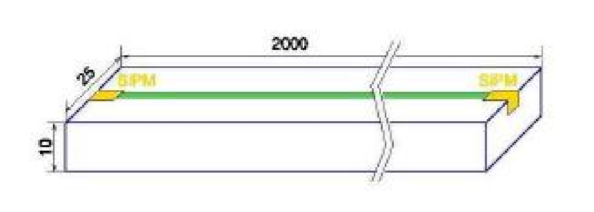



| | | | |
|---|---|---|---|
| Cryostat inner radius [mm] | 3400 | Barrel yoke outer radius [mm] | 7240 |
| Cryostat outer radius [mm] | 4250 | Yoke overall length [mm] | 13966 |
| Cryostat length [mm] | 8050 | Barrel weight [t] | 5775 |
| Cold mass weight [t] | 165 | End-cap weight [t] | 6425 |
| Barrel yoke inner radius [mm] | 4400 | Total yoke weight [t] | 12200 |

# CepC muon system baseline

| | | |
|---|---|---|
| Technology | RPC<br>Scintillating strip<br>Other | RPC (super module, 1 layer readout, 2 layers of RPC ) |
| Total area [m$^2$] | Barrel | ~4450 |
| | Endcap | ~4150 |
| | Total | ~8660 |
| Total channels | Barrel | 26500 |
| | Endcap | 29000 |
| | Total | $\sim 5.55 \times 10^4$ (3 cm strip width, 1-D readout, 2 ends for barrel, 1 end for end-cap) |




spatial resolution not suitable for improving the momentum resolution

# the Micro Pattern Gaseous Detectors

e.g.: Micromegas
GEM detectors [Sauli, 1997]

Micromegas:

Fine cathode mesh collects ions
still fast; no wires …

GEM (Gas Electron Multiplier):

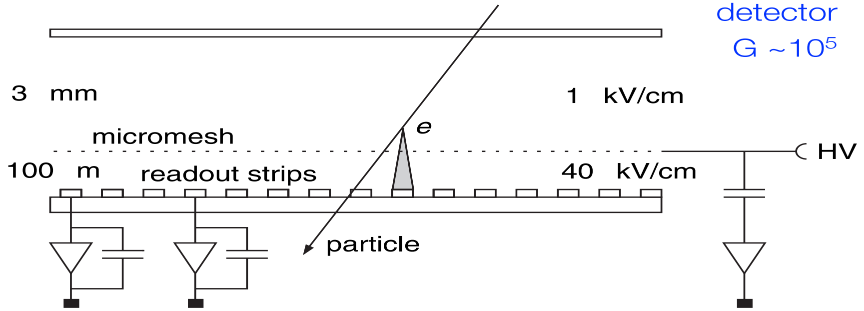
Thin insulating kapton foil
coated with metal film …

Contains chemically produced
holes [100-200 μm]

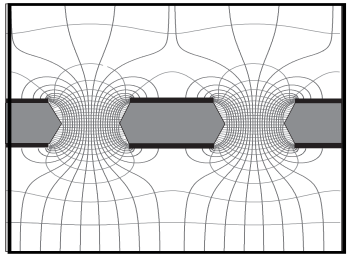
Electrons are guided by high
electric drift field of GEMs …

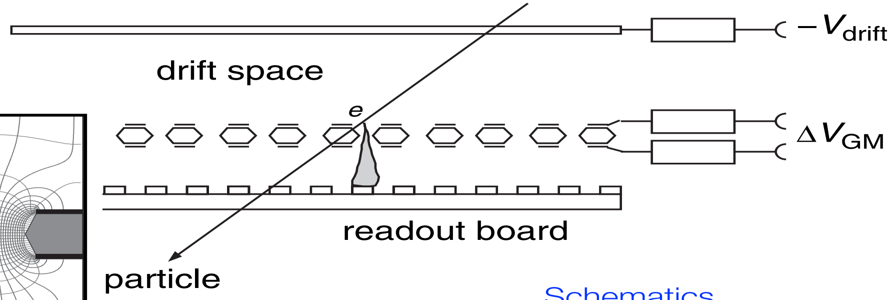
Avalanche production …

Electrons drift to anode
GEM collects ions




Micromegas
detector
G ~$10^5$





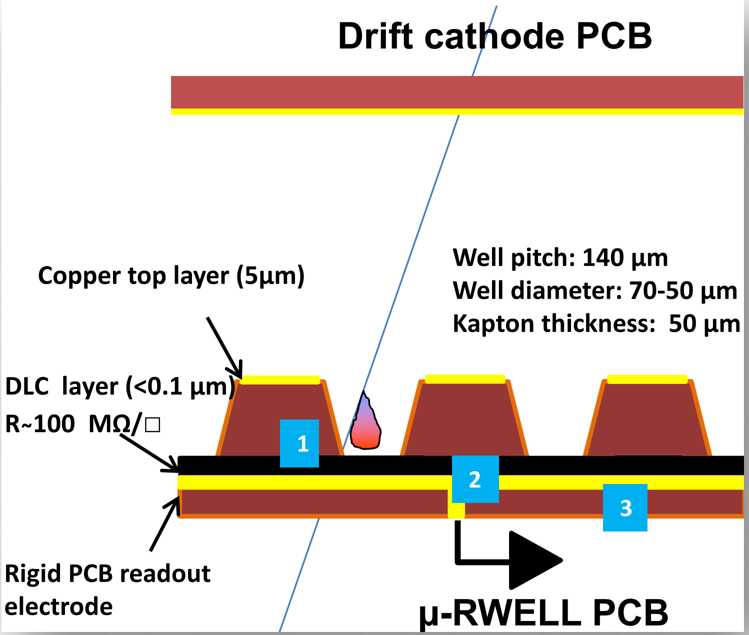

Schematics
of GEM detector

more on next talk

# the μ-RWELL detector

- gas gain > $10^4$
- intrinsically spark protected
- rate capability > 1 MHz/cm2
- space resolution < 60μm
- time resolution ~ 5.7 ns

G. Bencivenni et al., 2015_JINST_10_P02008



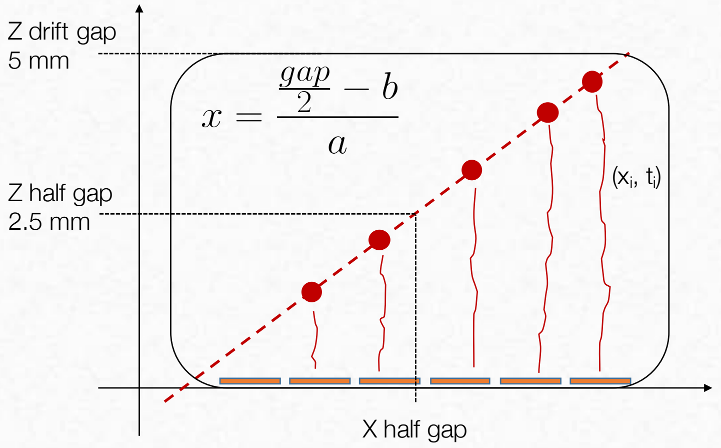

The μ-RWELL is a single-amplification stage, intrinsically spark protected MPGD characterized by:

- simple assembly procedure:
  - only two components: μ-RWELL_PCB + cathode
  - no critical & time consuming assembly steps: no gluing, no stretching, (no stiff & large frames needed), easy handling
- suitable for large area with PCB splicing technique w/small dead zone
- cost effective:
  - 1 PCB r/o, 1 μ-RWELL foil, 1 DLC, 1 cathode and very low man-power
- easy to operate:
  - very simple HV supply → only 2 independent HV channels or a trivial passive divider

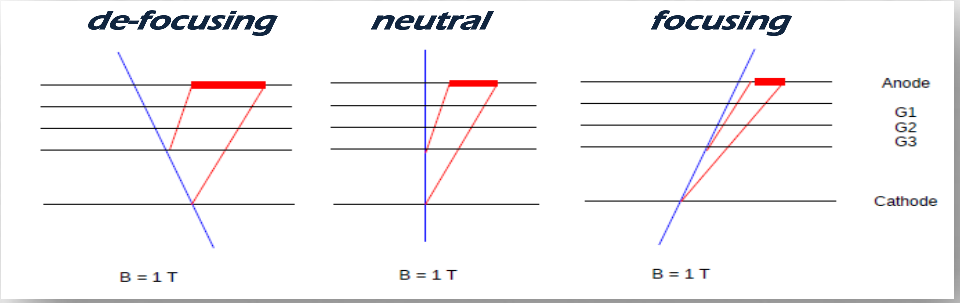
# Tracking performance in magnetic field

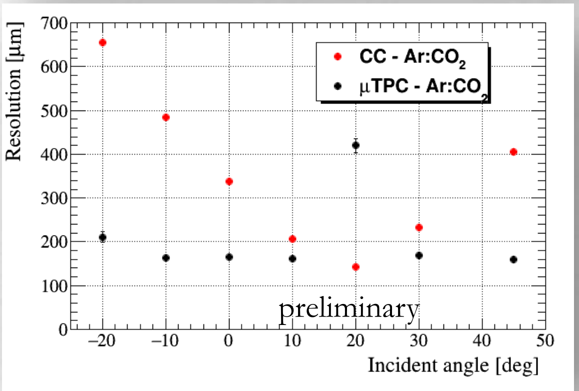
combining

- center of gravity of the cluster charge distribution ➡ $< x >= \frac{\sum_i x_i q_i}{\sum_i q_i}$
- micro-TPC reconstruction of the cluster ➡ $x = \frac{\frac{gap}{2} - b}{a}$




combining incident angle and magnetic field




Test Beam with
GEM prototype
at 1 Tesla
H4 line of SPS

*arXiv:1706.02428*

# Electronics for MPGD

- APV-25 (IBM CMOS 250 nm)
  - COMPASS, CMS, ...
- VMM-2, VMM-3 (IBM CMOS 130 nm)
  - ATLAS small wheel upgrade
- TIGER (UMC(*) CMOS 110 nm)
  - BESIII CGEM-IT

* exportable to PRC

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- TIGER main features


  - 1 – 50 fC Input Charge
  - Signal duration: 30-50 ns
  - Up to 100 pF Sensor Capacitance
  - 60 kHz rate per Channel
  - 4-5ns time resolution (with detector)
  - < 10 mW/channel Power consumption (analog+digital)

# A μ-RWELL based muon system

- Taking as an example the CepC design. →

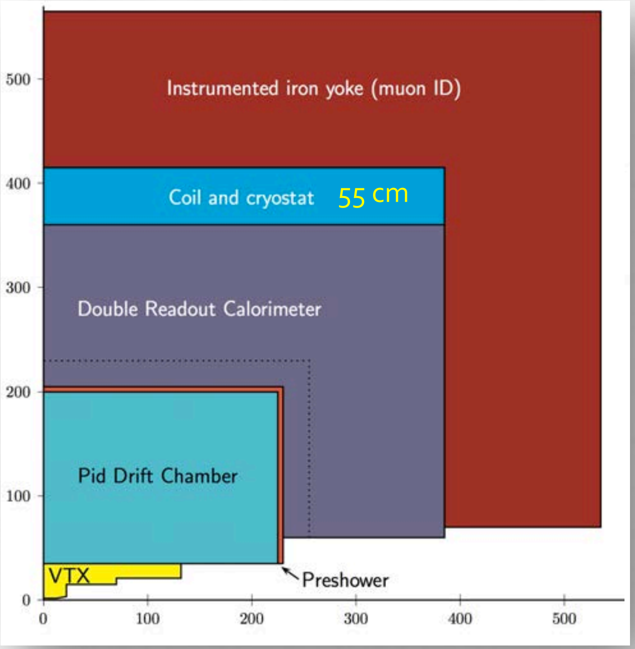
| | | |
|---|---|---|
| R min | 4400 | mm |
| R max | 7240 | mm |
| barrel len | 8286 | mm |
| # of layers | 8 | |

- To instrument the CepC muon system with μ-RWELL detectors →
  - $O(10^6)$ electronics channels (depending on strip pitch and layout optimization)
  - spatial resolution about 100 μm also in magnetic field with μTPC clusterization.
  - Cost of some tens M€ (~50?) very roughly speaking(*), including electronics.
    - but the system would be quite redundant.
- A large system with much better performance.

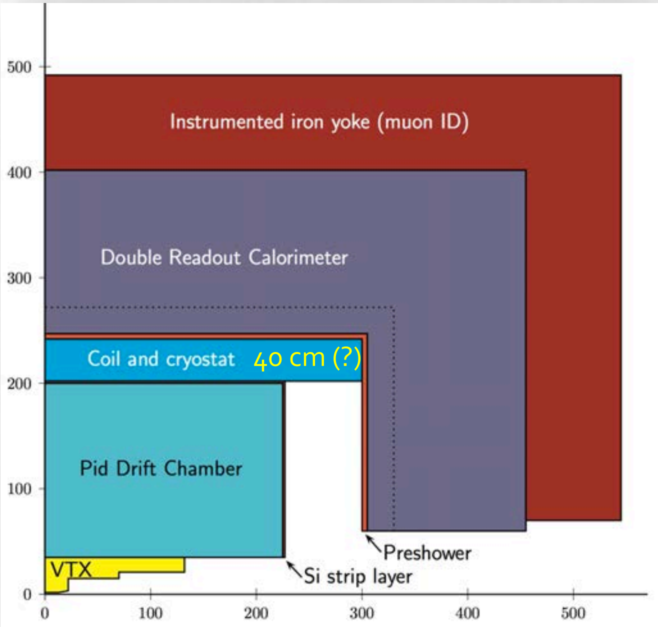
* different system design (iron dimension, segmentation, ...) may lead to different estimate → e.g. the more compact IDEA layout.

# an exotic IDEA

coil outside the calorimeter




coil inside the calorimeter



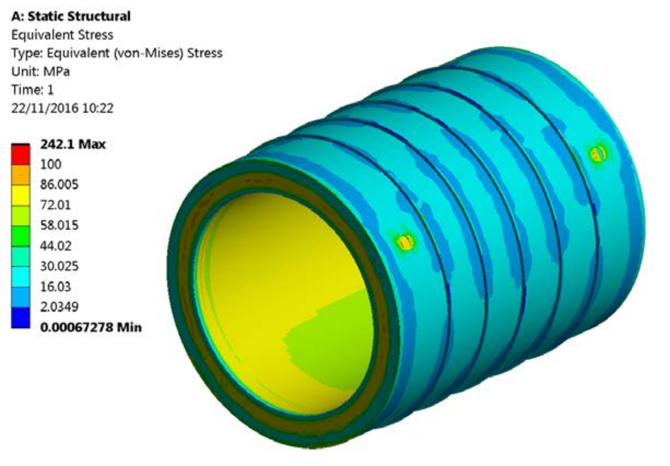
# FCC-ee 2T/4m thin solenoid

- Main features:
  - Material used is Al 5083-O
  - Cold mass: $X_0 = 0.46$, $\lambda = 0.09$
  - Vacuum vessel (25 mm Al): X0 = 0.28, $\lambda = 0.07$
  - Total: $X_0 = 0.74$, $\lambda = 0.16$ (at $\eta = 0$)
  - 300 mm space and 100 mm Al thickness

Two options:

- Large bore (R=3.7 m) – calorimeter inside
- Smaller bore (R=2.2 m) – calorimeter outside
  - ➢ Preferred: simpler/ Extreme EM resolution not needed

A very aggressive design may lead to some 210 mm and 70 mm Al thickness, though this case explicitly requires thickness-reducing engineering driving all dimensions to minimum values.



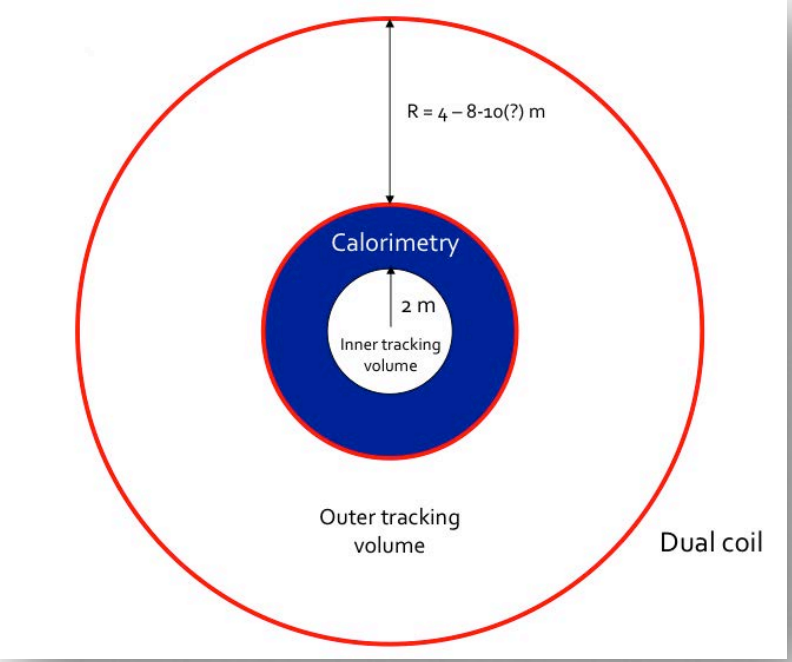

*Herman ten Kate*

*FCC-ee Detector Meeting, CERN, June 19, 2017*

# a more exotic IDEA

Large external tracking volume ?

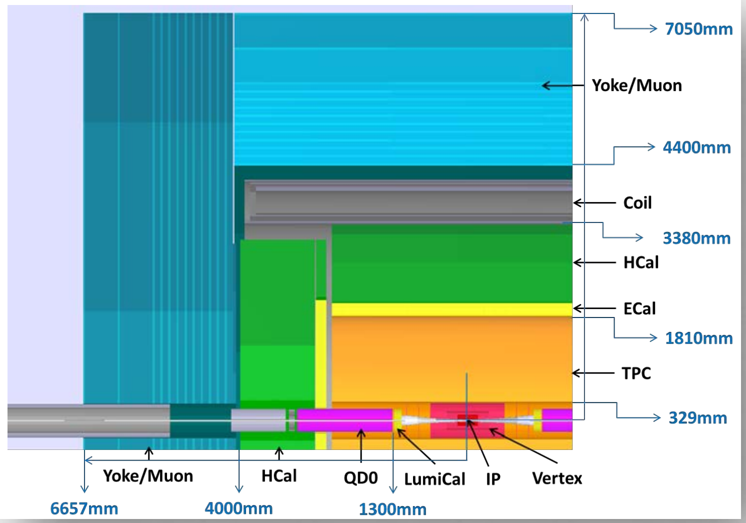
For weakly coupled, very long-lived particles

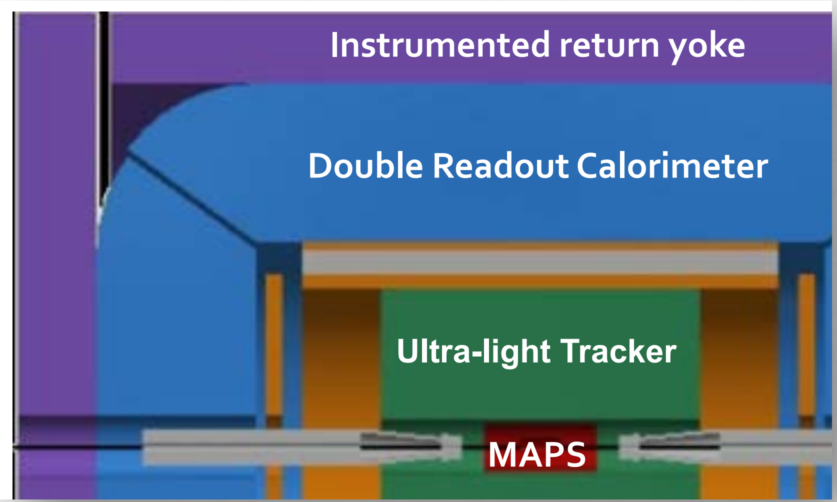



*Mogens Dam*
*WG11 Detector Design Meeting 19 Jun 2017*

# CLIC-inspired vs IDEA

detector concepts too different to be easily compared: need for simulations studies and R&D




interplay with the development of other subdetectors is mandatory.

# Summary and outlook

- A muon system for FCC-ee or CepC detectors can be designed with current state of the art technology.
- Further improvements on muon ID, momentum resolution and jet energy measurement may arise from
  - geometry optimization
  - different choice of detection technique (e.g. MPGD → μ-RWELL)
- Interplay with other subdetectors is will be of paramount importance for final design optimization.
- The time scale for a contribution to the CepC CDR is now.