IFAE
2019

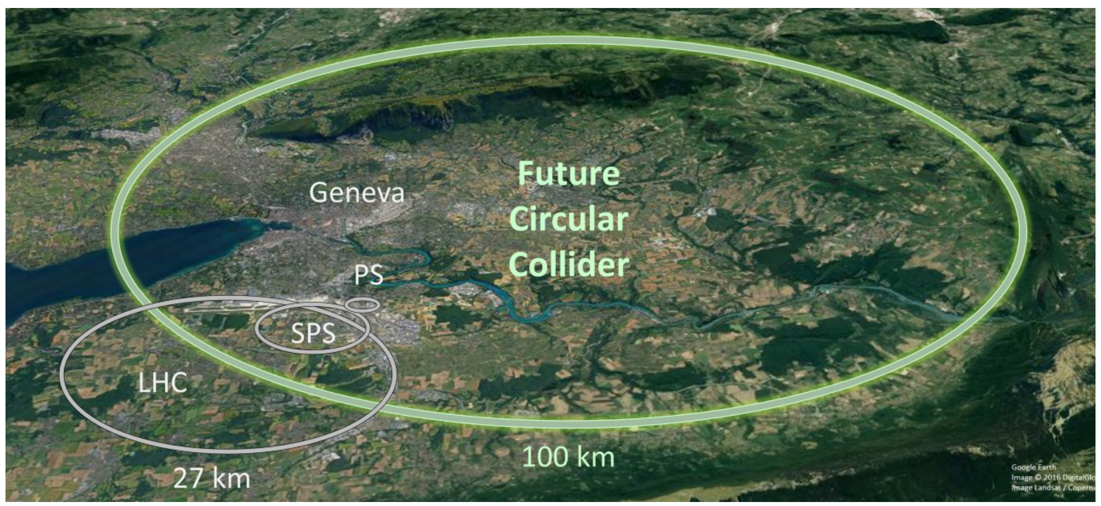
Massimiliano Antonello
on behalf of the:
INFN RD-FA Collaboration

Napoli - 10.04.2019

IDEA:
a detector concept for future e^+e^- colliders

IDEA Detector

Innovative Detector for Electron-positron Accelerator (***IDEA***) is a detector concept specifically designed for operation at the future leptonic colliders.



Future Circular Collider*:

Circumference: 97.76 km. $\sqrt{s}$: 90 - 365 GeV.

Physics Program: Z, W, Higgs, top.

Circular Electron Positron Collider*:

Circumference: 100 km. $\sqrt{s}$: 90 - 240 GeV.

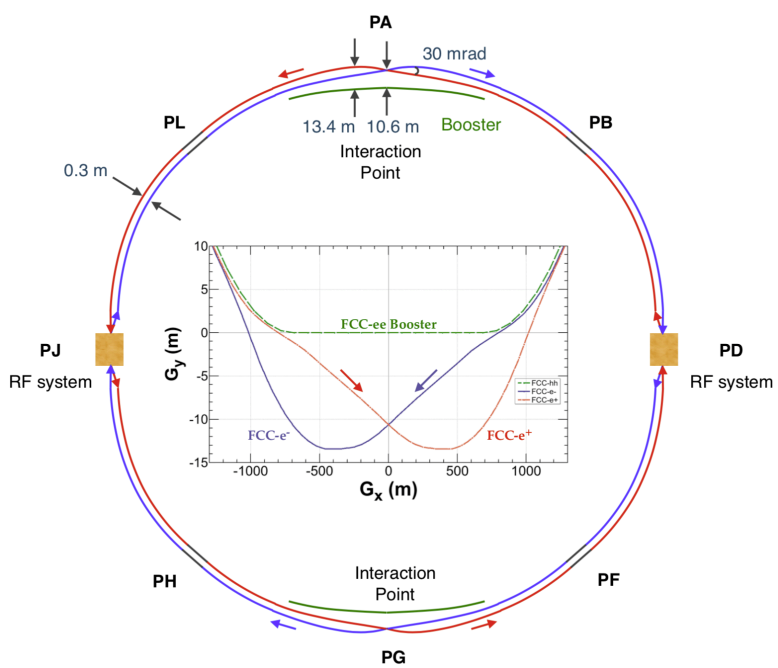
Physics Program: Z, W, Higgs.

*FCC Study: Vol.2 - The Lepton Collider (FCC-ee) **CDR** (2018)
FCC Collaboration, CERN-ACC-2018-0057

*CEPC **CDR**: Vol.2 - Physics & Detectors (2018)
CEPC Study Group, arXiv:1811.10545

Detector requirements

Focus on ***precision measurements***, new rare processes, tiny violations of established symmetries.



Property	FCC				CEPC		
	Z	W	H (ZH)	$t\bar{t}$	Z	W	H (ZH)
Beam Energy (GeV)	45.6	80	120	182.5	45.6	80	120
Luminosity/IP (10^{34} $cm^{-2}s^{-1}$)	**230**	28	8.5	1.55	32	10	3
Bunches/beam	**16640**	2000	393	48	**12000**	1524	242
Bunch separation (ns)	**19.6**	163	994	3396	**25**	210	680

Luminosity up to ~10^{36} $cm^{-2}s^{-1}$ ⇒ Non-negligible **machine background.**

Beam time structure ⇒ Cooling issue: **No power pulsing for vertex.**

Emittance preservation @ IR ⇒ **Solenoid magnetic field limited to 2 Tesla.**

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Detector requirements

Clean experimental environment = high precision measurements:

Tight control of ***acceptance systematic error*** (acceptance boundaries of few µm).

Excellent ***momentum resolution*** and ***flavour tagging.***

Low-mass vertex and ***tracking*** detectors, ***high granularity***.

Excellent ***energy resolution.***

Employ excellent ***calorimeters*** (PFA, dual-readout).

Good ***e-γ-π_0 discrimination*** (to identify τ leptons and measure their polarisation).

Physics Process	*Measured quantity*	*Detector*	*Required Performance*
$ZH \to l^+l^-X$ $H \to \mu^+\mu^-$	H mass, cross section BR $(H \to \mu^+\mu^-)$	Tracker	Momentum resolution (GeV/c) $\Delta(1/p_T) \sim 2 \times 10^{-5} \oplus 1 \times 10^{-3}/(p_T sin\theta)$
$H \to b\bar{b}, c\bar{c}, gg$	c/b tagging, BR $(H \to b\bar{b}, c\bar{c}, gg)$	Vertex	Impact parameter resolution (µm) $\sigma_{r\phi} \sim 5 \oplus 10/(p sin^{3/2}\theta)$
$H \to q\bar{q}, VV$	Separation of W/Z/H in di-jet modes	ECAL/ HCAL	Jet energy resolution (GeV) $\sigma_E^{jet}/E \sim 3-5\,\%$ for jets above 50 GeV
$H \to \gamma\gamma$	BR $(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\,\%/\sqrt{E} \oplus 1\,\%$

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CEPC Study Group, arXiv:1811.10545

IDEA Layout

Beam pipe: R~1.5 cm

Vertex:

5 MAPS layers

R = 1.7-34 cm

Drift Chamber:

4 m long, R = 35-200 cm

Outer Silicon Layers: strips

Superconducting solenoid coil:

2 T, R ~ 2.1-2.4 m

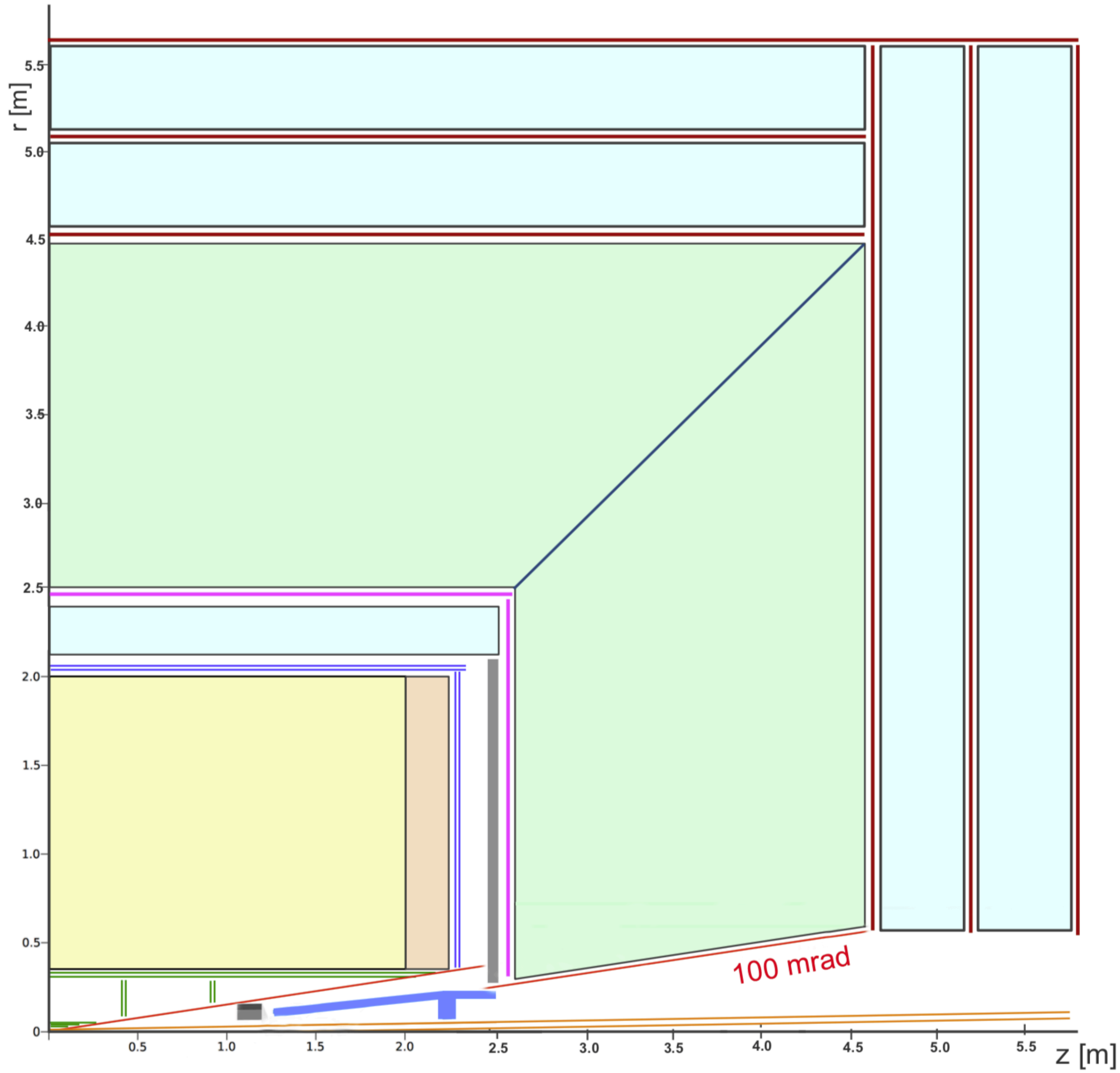
0.74 X_0, 0.16 λ @ 90°

Preshower: ~1 X_0

Dual-Readout Calorimeter:

2m / 7 λ_{int}

Yoke + Muon chamber



Vertex detector

Requirements

Fast readout (***one full frame read-out in less than*** $\Delta t \sim 85\mu s$), low power consumption (***<20 mW/cm²***), low material budget (***0.15%*** X_0), single point resolution of: $\sim 5\mu m$.

Vertex

Today: ***ALICE ITS**** (**5 μ*m*** spatial resolution, >***100 kHz*** readout, ***0.3-1%*** X_0, ***41-27 mW/cm²***).

Tomorrow: Exploit what is being done (e.g. ***ARCADIA*** - INFN project).

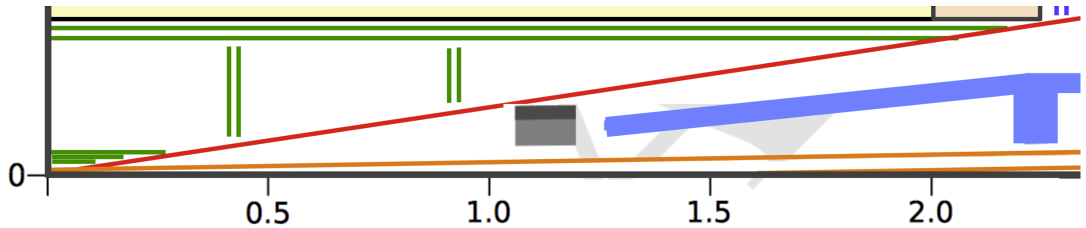
5 MAPS layers:

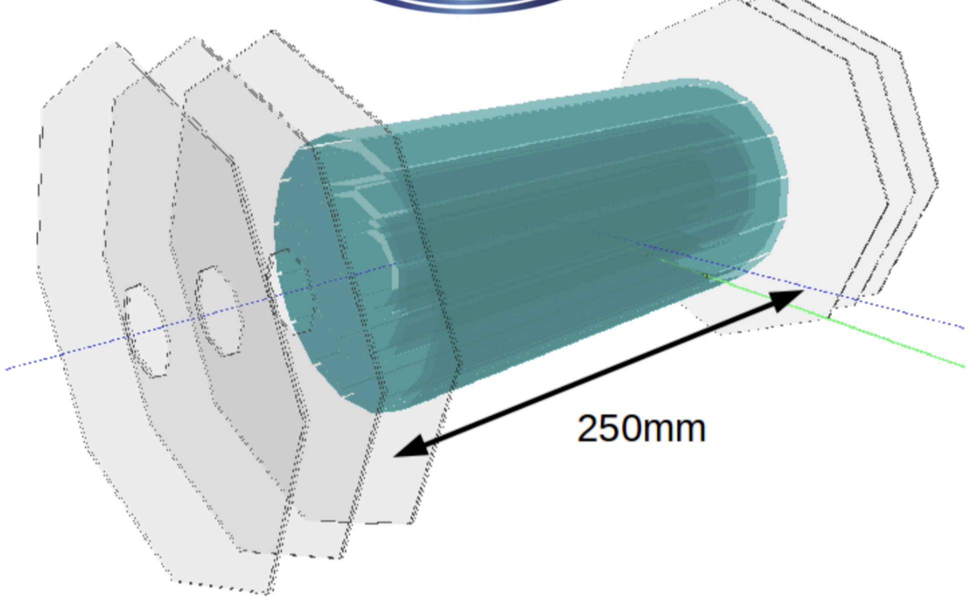
R = 1.7 - 2.3 - 3.1 cm.

Pixel size: 20 x 20 μm²

R = 32 - 34 cm.

Pixel size: 50 x 100 μm²





*MAPS on high resistivity substrates: status and perspective
A.Rivetti, **CEPC International Workshop 2018**

*M.Mager, ALICE Collaboration
NIM A 824 (2016) **434-438**

Tracking system

Requirements

Large solid angle coverage ($|\cos\vartheta| = 0.99$), ***high granularity*** and ***high transparency*** detector.

Good momentum resolution: at level of $\Delta_{p_T}/p_T \sim 10^{-5} p_T$ (a factor 10 better than LEP).

Drift Chamber

Follows design of ***KLOE*** and ***MEG2*** experiments*.

L = 400 cm, R = 35-200 cm.

Gas: **90% He - 10% iC_4H_{10}.**

Material: ***1.6% X_0*** (barrel), ***5% X_0*** (fwd/bkwd).

Drift length: 1 cm, drift time: ***350 ns***.

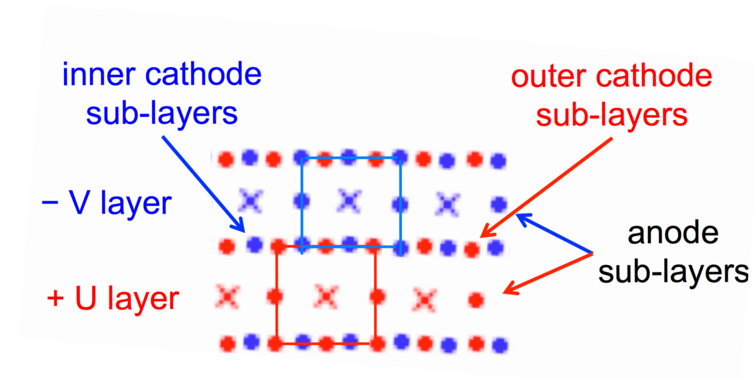
Spatial res: $\boldsymbol{\sigma_{xy} < 100\ \mu m}$, $\boldsymbol{\sigma_z < 1000\ \mu m}$.

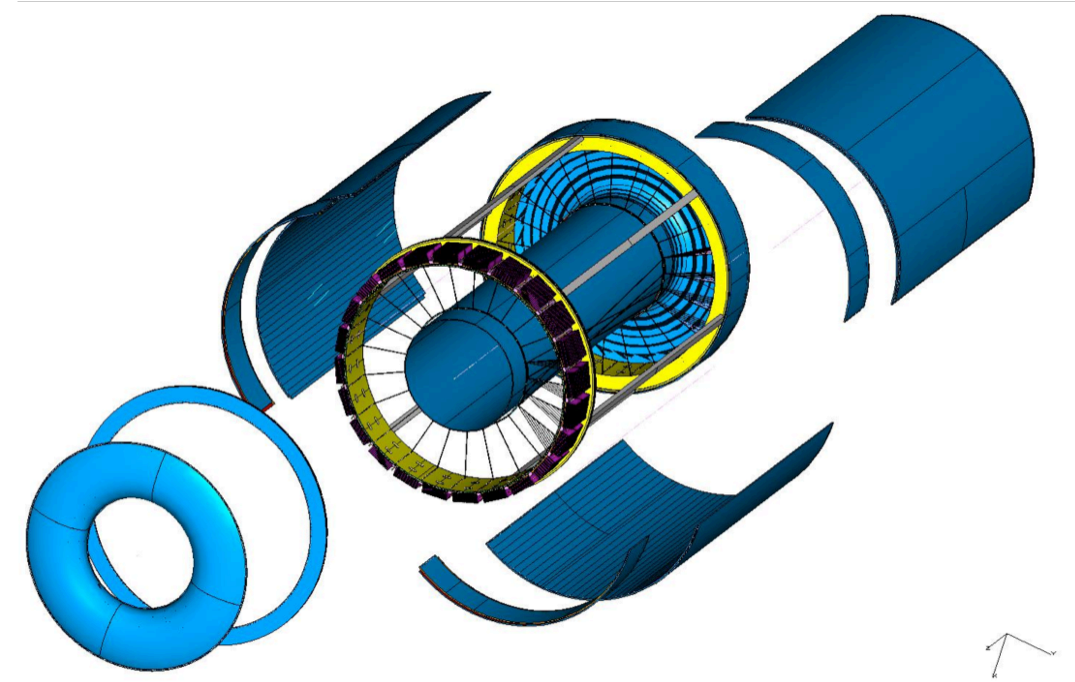
56 448 squared drift ***cells***.

Cell size: 12 - 13.5 mm.

Layers: 14 SL × 8 layers = 112.

Vertex+DCH+Si wrap: ~ 0.27% @ 100 GeV.





*M. Adinolfi et al., NIM A 488 (2002) 51
G. Chiarello, JINST (2017) 12 C03062

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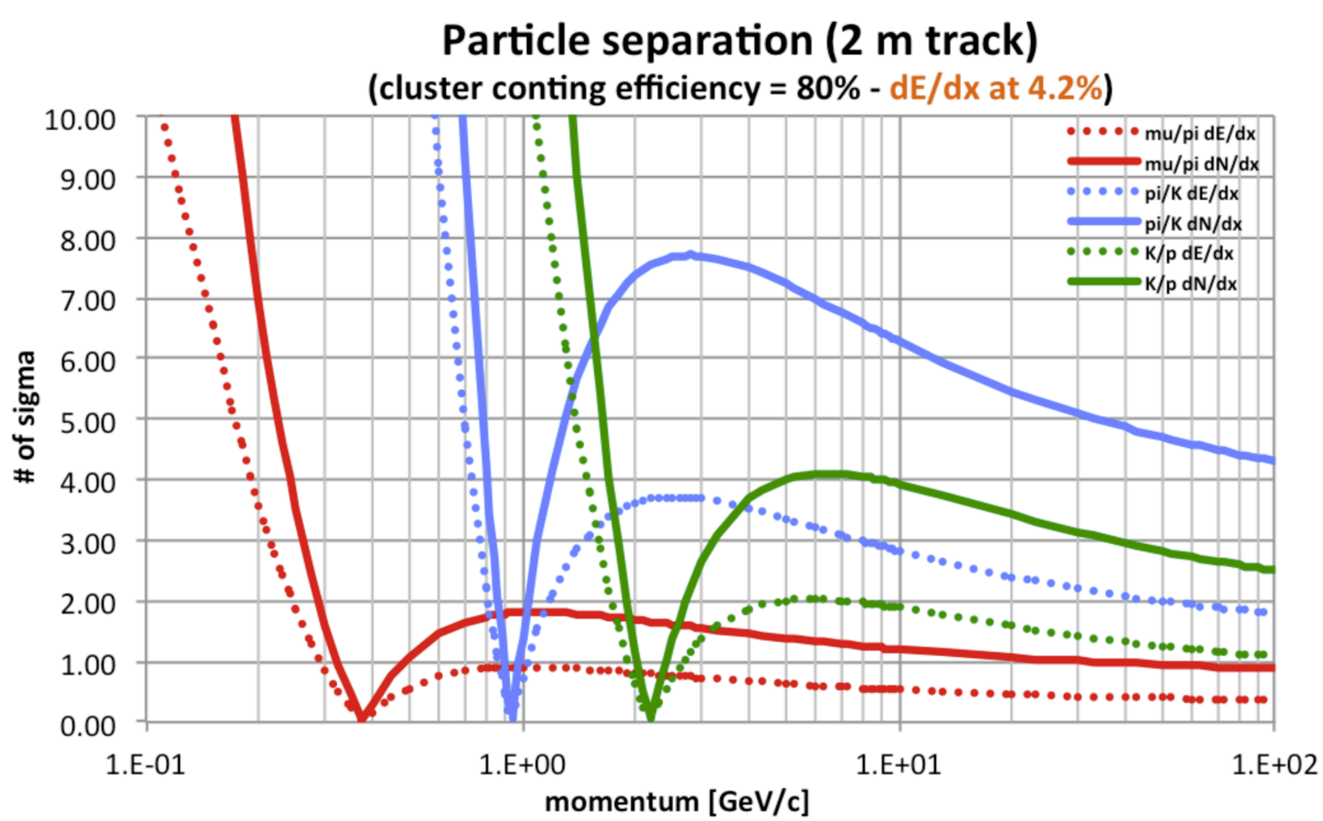
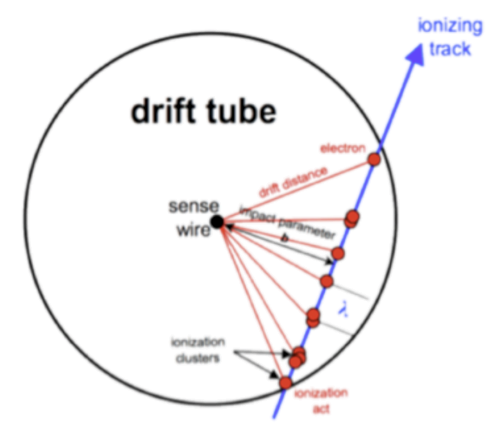
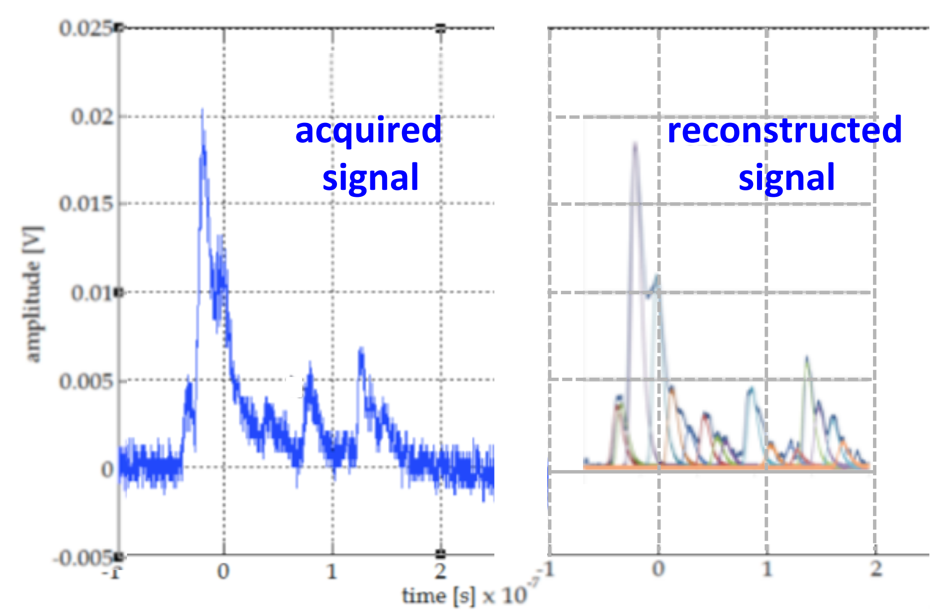
Drift Chamber

Cluster counting for improved particle identification:

$dN_{cl}/dx \sim 2\%$ vs $dE/dx \sim 4\%$







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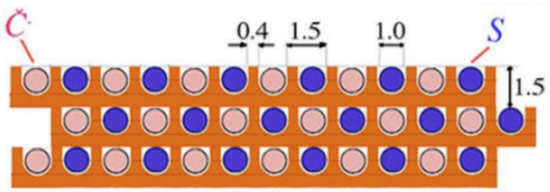
Calorimeter

Requirements

Jet energy resolution: $\sigma_E^{jet}/E \sim 3-5\,\%$ (for jet above 50 GeV), excellent ***particle ID*** capability ($\varepsilon(l)>$ ***99%***, *<2% mis-ID*), em energy resolution: $\sigma_E \sim 16\,\%/\sqrt{E} \oplus 1\,\%$.

Dual-Readout calorimeter

Built on ***DREAM/RD52*** experience*.



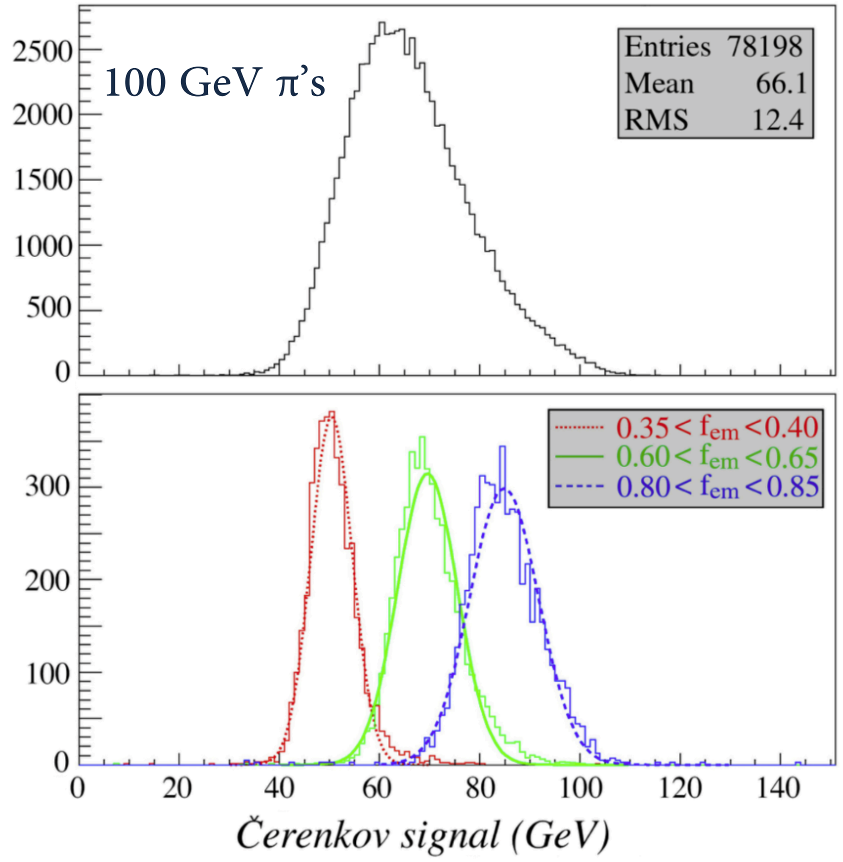
The concept: do not spoil e.m. resolution to get h/e=1 but ***measure f_{em} event-by-event.***

$$S = E\left[f_{em} + (h/e)_S(1-f_{em})\right]$$

$$C = E\left[f_{em} + (h/e)_C(1-f_{em})\right]$$

$$E = \frac{S-\chi C}{1-\chi} \quad \text{with:} \quad \chi = \frac{1-(h/e)_S}{1-(h/e)_C}$$

independent of both ***energy*** and ***type of hadrons***.



*S. Lee et al., NIM. A 882 (2018) **148**

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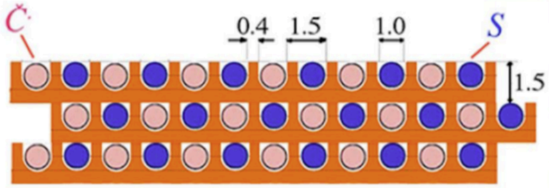


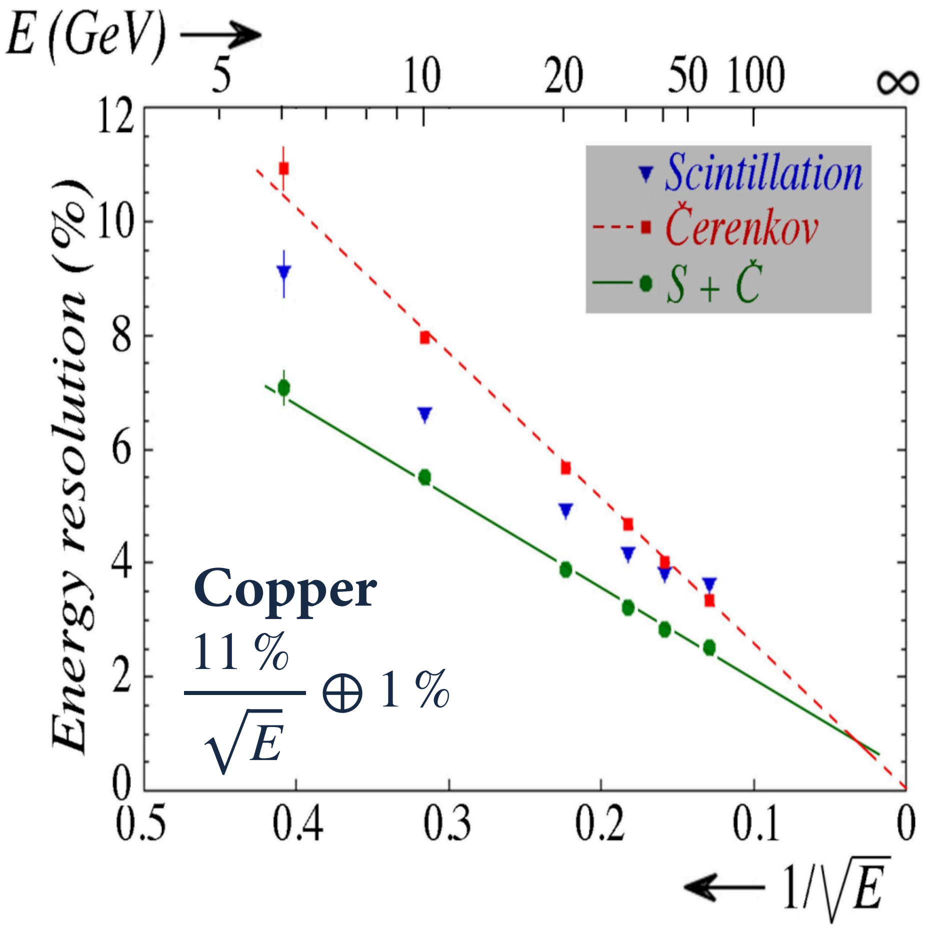
From ***Geant4*** simulation*:

em resolution: $\sim 11\,\%/\sqrt{E} \oplus 1\,\%$.

hadronic (jet) resolution: $\sim 34\,\%/\sqrt{E}$.

A multivariate analysis reached a ***particle ID*** capability of: $\boldsymbol{\varepsilon(e^-) = 99.8\%}$***, <0.2%*** $\boldsymbol{\pi^-}$ ***mis-ID***.

Millimiter transverse granularity reached with SiPM-based readout.



*L. Pezzotti et al, NIM. A (2018) **https://doi.org/10.1016/j.nima.2019.04.017**

* Most of the DREAM/RD52 publications can be found at: **www.phys.ttu.edu/~dream/index.html**

Muon system

Requirements

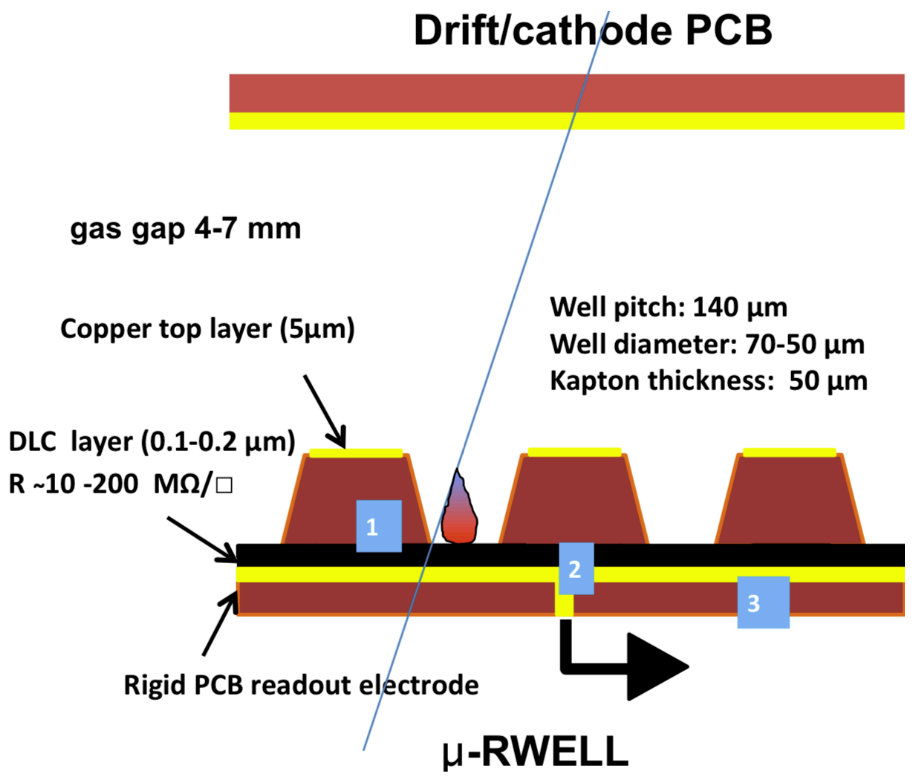
High granularity (for π_0 ID near charged hadrons), ***low cost*** (area of several hundred of m²).
(Pre-Shower: Acceptance definition for γ @ level of **μ*m***, good ***e-γ-π₀ discrimination*** power).

μ-*RWell*

A special, *low cost*, MPGD technology promising for its characteristics and the possibility to be ***industrialised**** (already proven for low rate (<100 kHz/cm²) applications (i.e. SHiP)).

It is essentially consists of:

1. A patterned ***Kapton*** foil (***amplification stage***).
2. A "***resistive stage***" for the discharge suppression & current evacuation.
3. A ***patterned PCB*** for readout.



*Bencivenni et al., JINST (2017) 12 C06027
Bencivenni et al., JINST (2015) 10 P02008

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Momentum measurement:

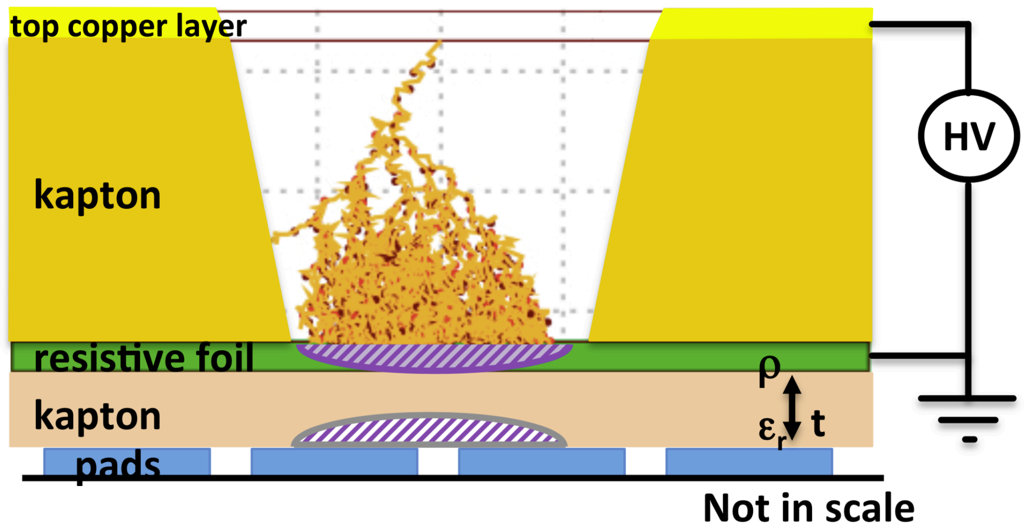
Vertex+DCH+Si wrap: ~ ***0.27% @ 100 GeV***.

ID ok if isolated particles.

Better muon ID in jets:

More filter behind calorimeter (iron yoke >50 cm Fe). 3-4 detector stations, 2 layers (50 x 50 cm²) of **μ-RWell:**

μ track coordinates pos res: < ***60 μm***.



*Bencivenni et al., JINST (2017) 12 C06027
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Conclusions

IDEA is a detector concept, ***based on proven techniques***, capable to fulfill the requirements needed for the future e^+e^- colliders physics program.

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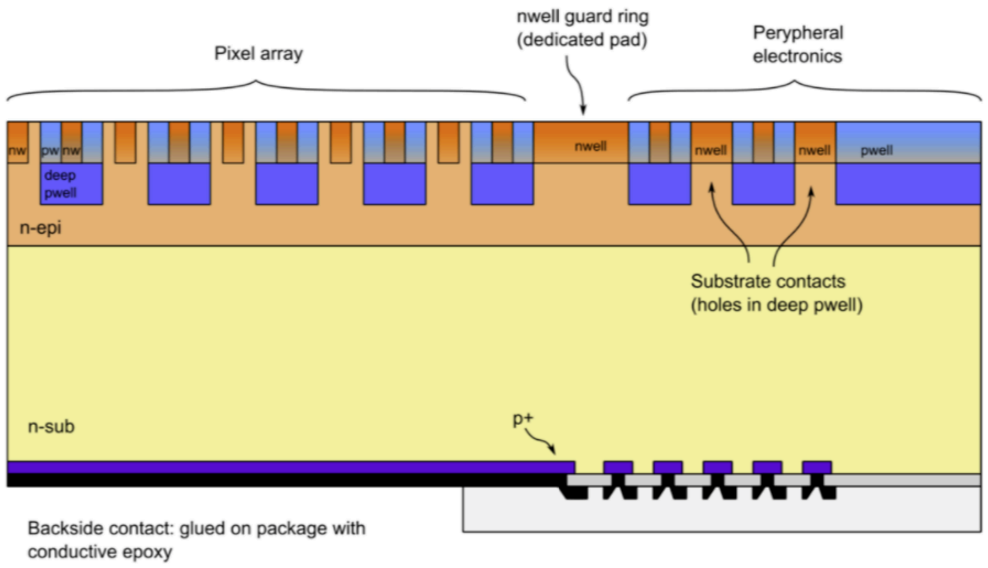
Work in progress to ***optimise*** the design:

Detector **R&D** studies.

ARCADIA* project @ INFN:

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays.



Goal: full depletion in 100-500 µm.

Technology: 110 nm CMOS, high-resistivity bulk.

Both NMOS and PMOS transistors.

Power consumption (<***20 mW/cm²***)

Custom backside process developed (with ***LFoundry***).

Pixel capacitance lower than ***20 fF.***

*MAPS on high resistivity substrates: status and perspective
A.Rivetti, **CEPC International Workshop 2018**

Conclusions

IDEA is a detector concept, ***based on proven techniques***, capable to fulfill the requirements needed for the future e^+e^- colliders physics program.

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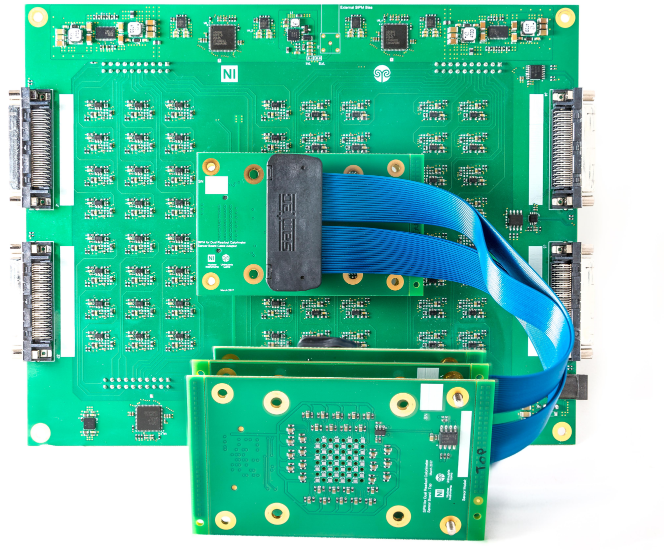
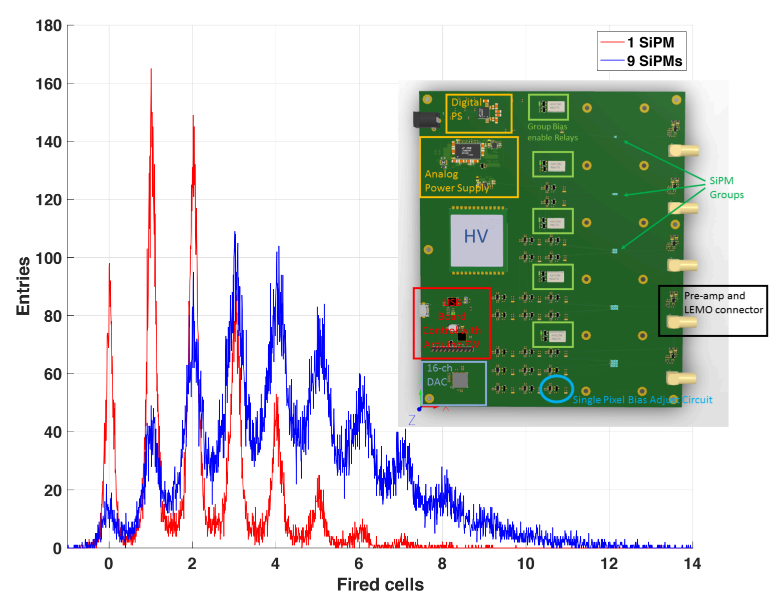
Detector **R&D** studies.

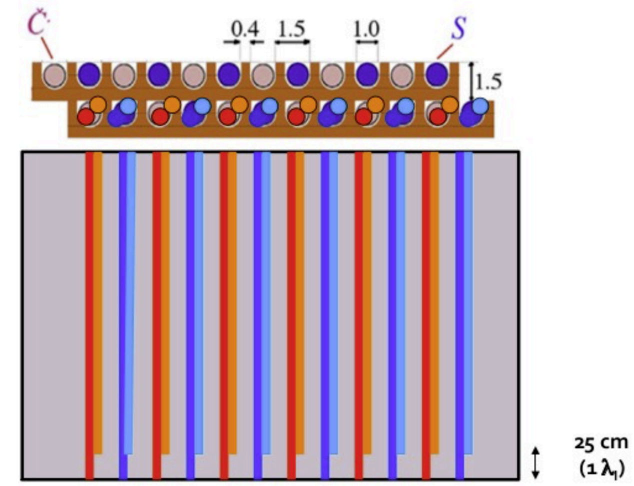
Sipm-based dual-readout beam tests*.



Signal grouping* studies.



Longitudinal segmentation studies (Staggered module*).



*M. Antonello et al, NIM. A 899 (2018) **52**
M. Antonello et al, NIM. A (2018) **https://doi.org/10.1016/j.nima.2018.10.1**

*L. Pezzotti et al, NIM. A (2018) **https://doi.org/10.1016/j.nima.2019.04.017**

Conclusions

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Work in progress to ***optimise*** the design:

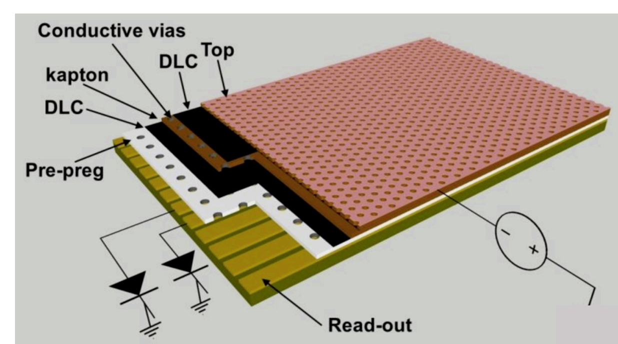
Detector **R&D** studies.

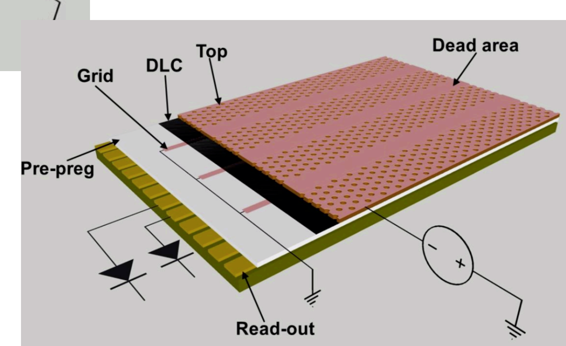
Technology transfer to Industry (ELTOS, TECHTRA).

High rate layouts* (>1 MHz/cm²):

Double Resistive layer.

Single Resistive layout with a grounding grid.





M.Giovanetti talk:
The μ-RWELL detector for high particle rate.

*High space resolution μ-RWELL for high rate applications G.Bencivenni **VCI 2019**

Conclusions

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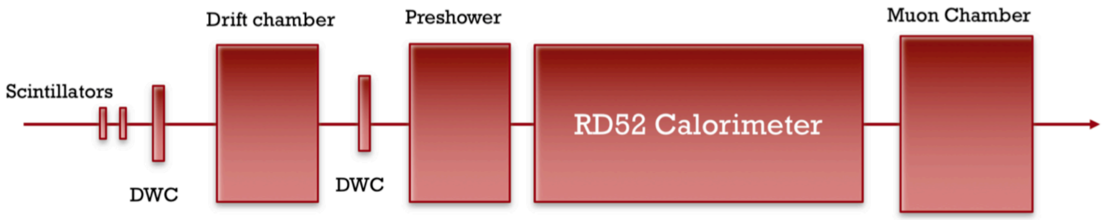
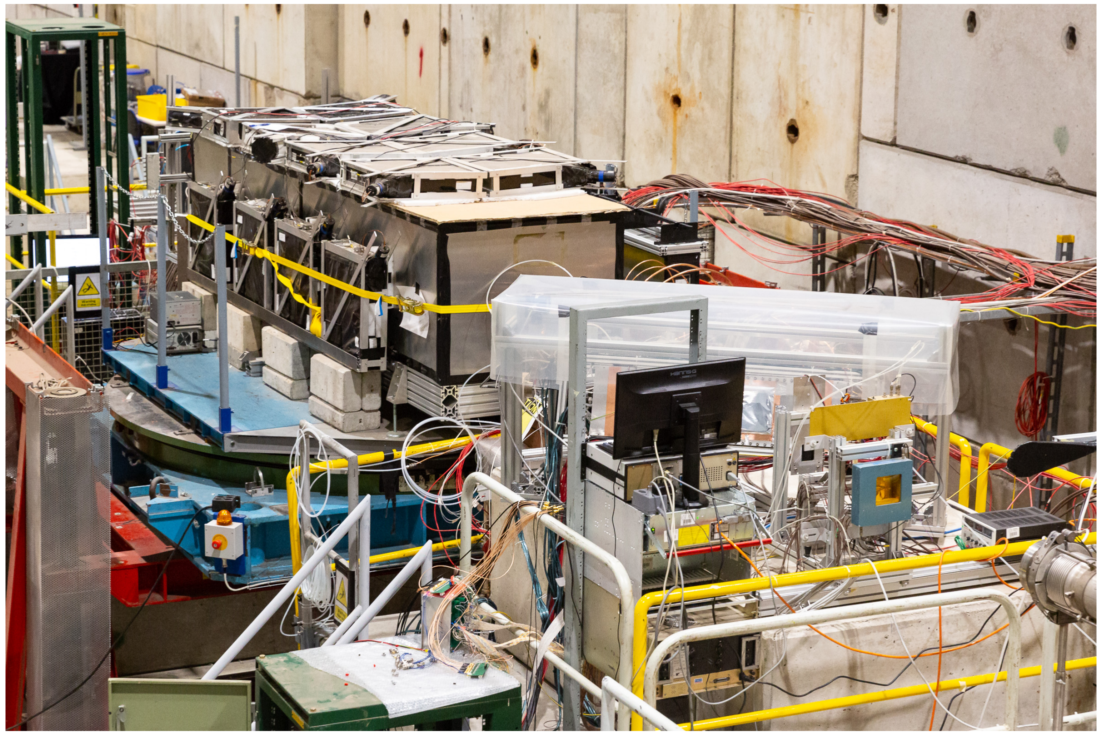
Work in progress to ***optimise*** the design:

Detector **R&D** studies.

In September 2018 @ CERN a first ***combined IDEA beam test**** was performed.





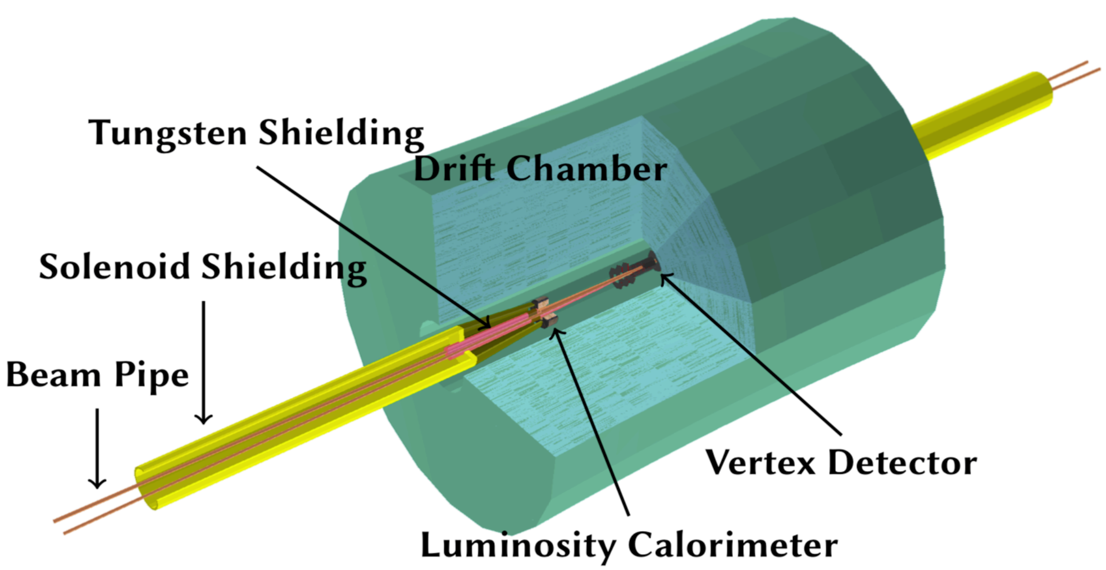
*IDEA test beam results, L.Borgonovi **VCI 2019**

Conclusions

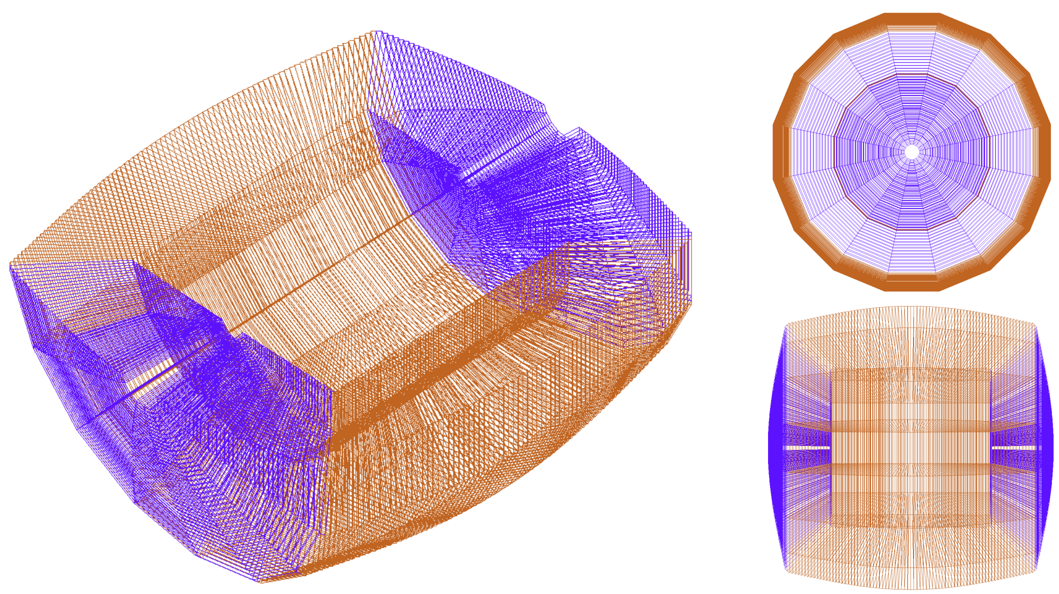
IDEA is a detector concept, ***based on proven techniques***, capable to fulfill the requirements needed for the future e^+e^- colliders physics program.

Work in progress to ***optimise*** the design:

- ***Geometry*** implementation on **FCCSW** and **GEANT4**.
- ***Benchmark studies*** (just started) with both **GEANT4** & **Delphes** simulation.



IDEA detector implemented in FCCSW



Fully projective dual-readout geometry in GEANT4


Thank you

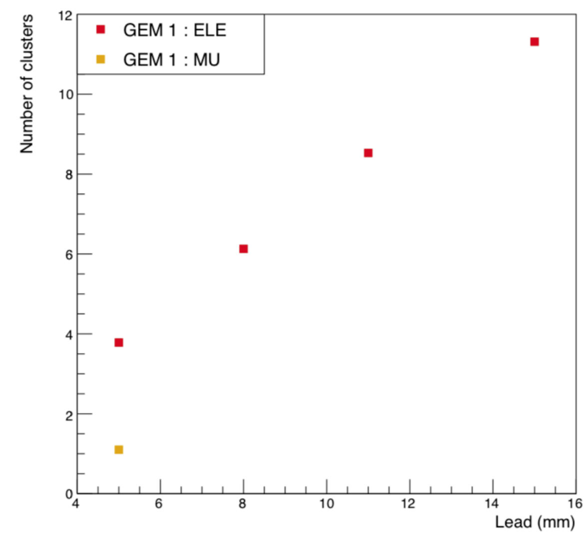
Additional Slides

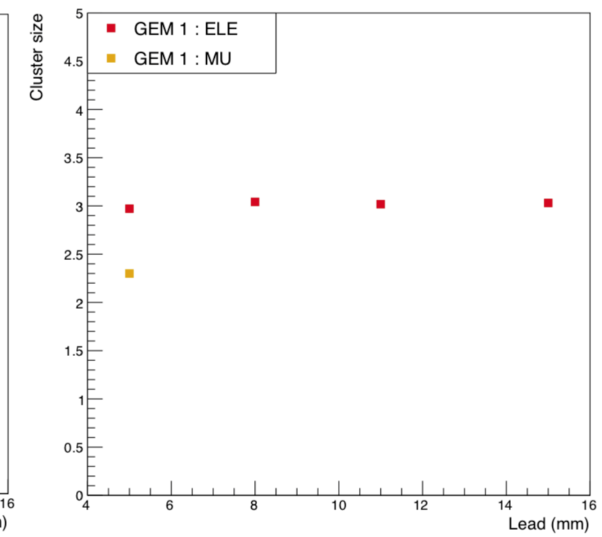
Beam test results

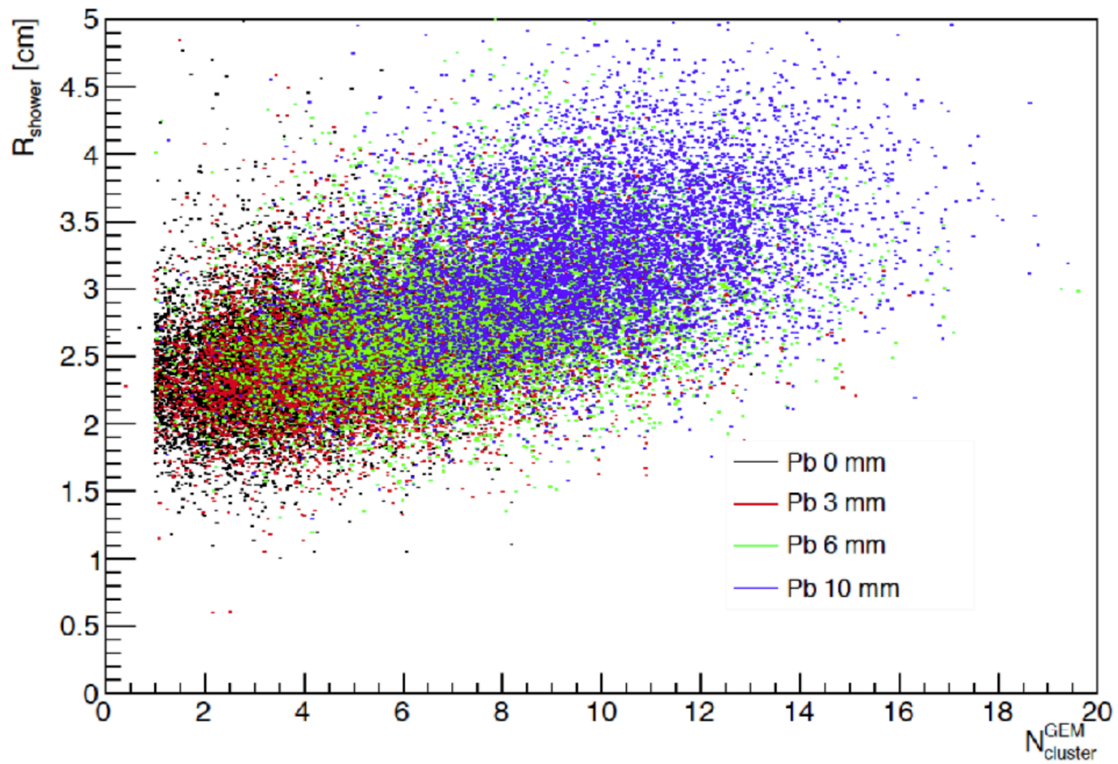
Test beam data (Pre-Shower GEM 2):

Lead thickness: ***5mm (1 X_0), 8, 11, 15mm***.

The ***# of clusters increases*** with lead thicknesses while the ***dimension*** of the clusters remains almost ***constant.***







Calorimeter (20 GeV e-):

No noticeable impact on the mean energy and resolution.

Small impact on the shower shape.

*IDEA test beam results, L.Borgonovi **VCI 2019**

Solenoid

Requirements

Emittance preservation @ IR:

Solenoid magnetic field limited to ***2-3 T***.

Solenoid

2 T field: small yoke thickness (50-100 cm Fe) and cost reduction over large coil.

Thin (~ ***30 cm total***): calorimeter can be located ***outside*** coil.

Low mass: ~ ***0.74 X_0, 0.16 λ*** (@ ϑ = 90°).

Free bore diameter: 4 m.

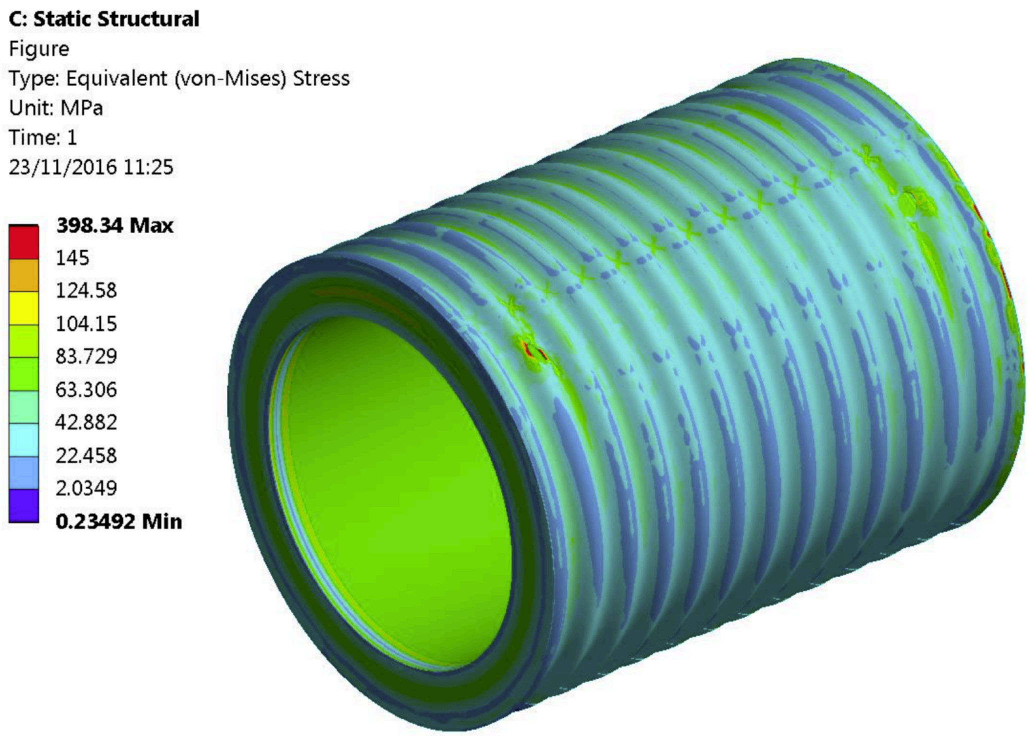
Stored energy: 170 MJ.

Coil mass: 8 t.

Coil mass inner radius: 2.25 m.

Coil mass thickness: 0.03 m.

Coil mass length: 5 m.



*Ultra-light 2T/4m bore Detector Solenoid for FCCee
Herman ten Kate @ ***FCC Week 2018***

Solenoid

<u>Requirements</u>

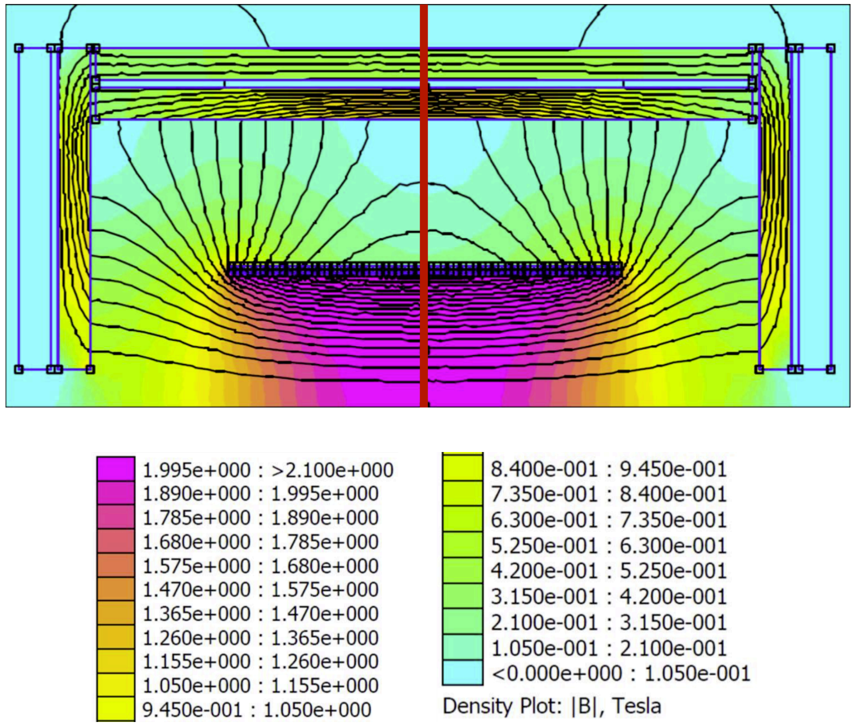
Emittance preservation @ IR:

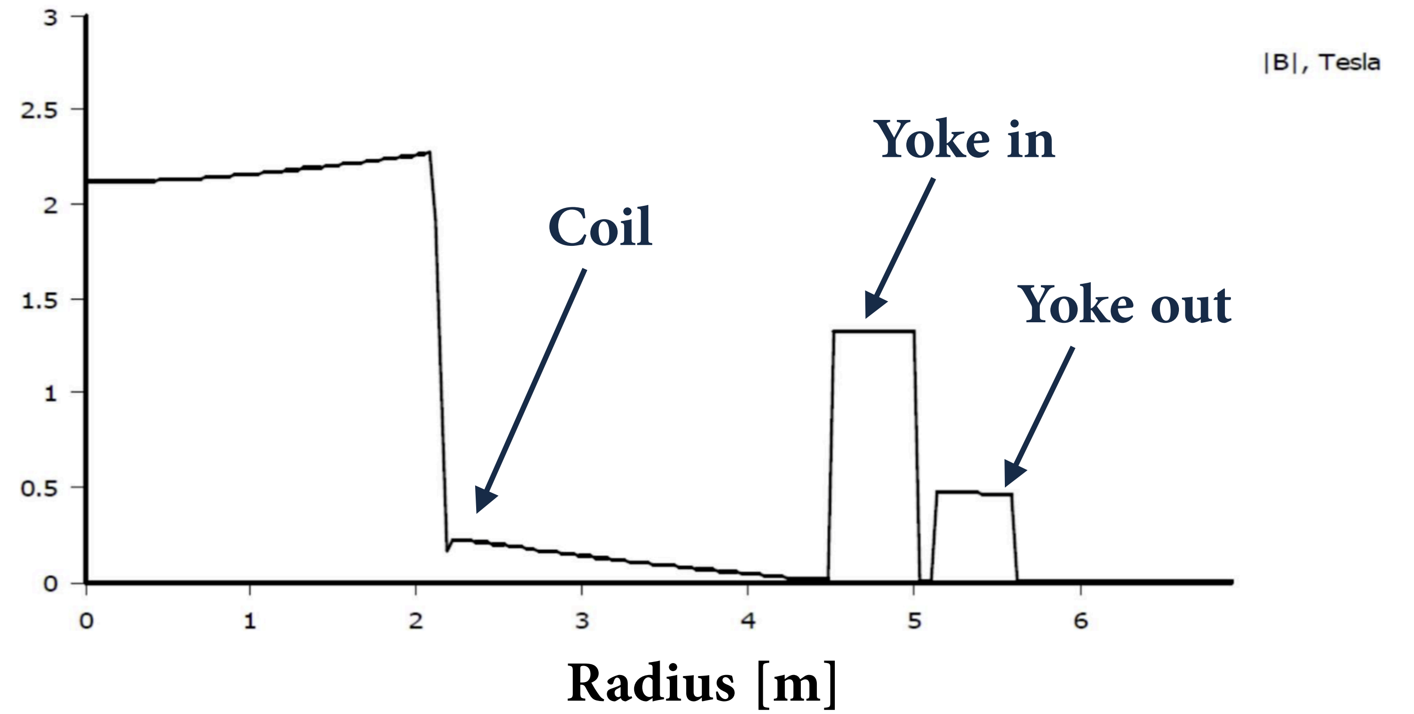
Solenoid magnetic field limited to ***2-3 T***.

Solenoid

Magnetic field needed only in the ***tracker*** and ***muon chambers***.

When coil is positioned ***inside***: factor ***4.2 in stored energy*** and ***2.1 in cost reduction***.





*Ultra-light 2T/4m bore Detector Solenoid for FCCee
Herman ten Kate @ ***FCC Week 2018***

e+e- collider potential

Z pole, WW:

High ***precision measurements @ Z peak*** (> of one order of magnitude better than LEP).

Eliminate ***parametric uncertainty*** from $\alpha_{EM}(Z)$, M_W, $\sin(\vartheta_W)$, etc.

Need N^3LO SM corrections from theory: doable in 5-10 years.

Outstanding ***flavour physics***.

HZ:

One order of magnitude better than LHC.

No model dependence in BR measurements.

New ***physics scale***: $\Lambda \geq (1TeV)/\sqrt{(\delta g_{HXX}/g_{HXX}^{SM})/5\,\%}$.

Higgs couplings can be measured @ the ***% level***.

t:

More than one order of magnitude better than LHC: ***mass, width, Yukawa*** coupling.

Few theory uncertainties in mass interpretation from threshold scan.

Eliminate ***top related parametric uncertainties***.