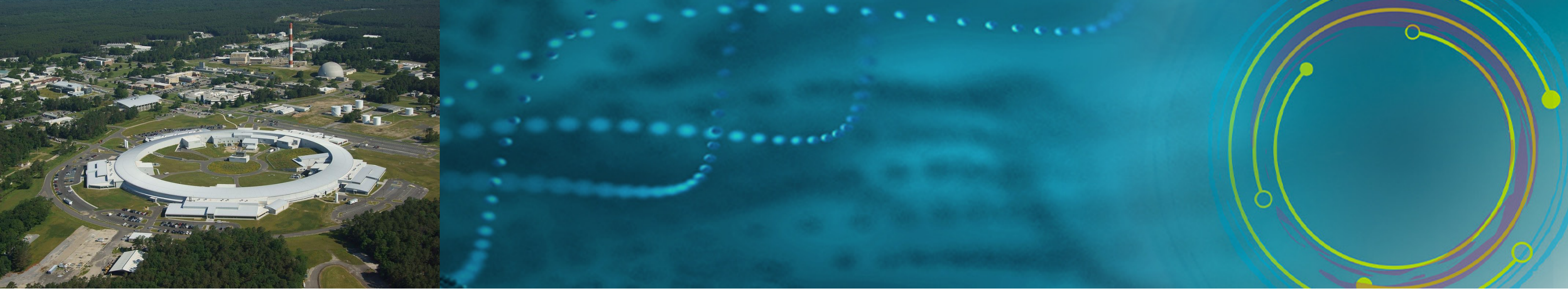


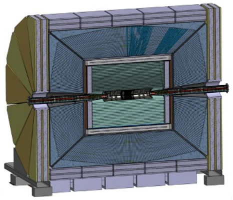
The IDEA tracking detectors

Nicola De Filippis
Politecnico and INFN Bari
on behalf of the IDEA community

First Annual U.S. Future Circular Collider (FCC) Workshop 2023

Brookhaven National Laboratory, April 24-26, 2023

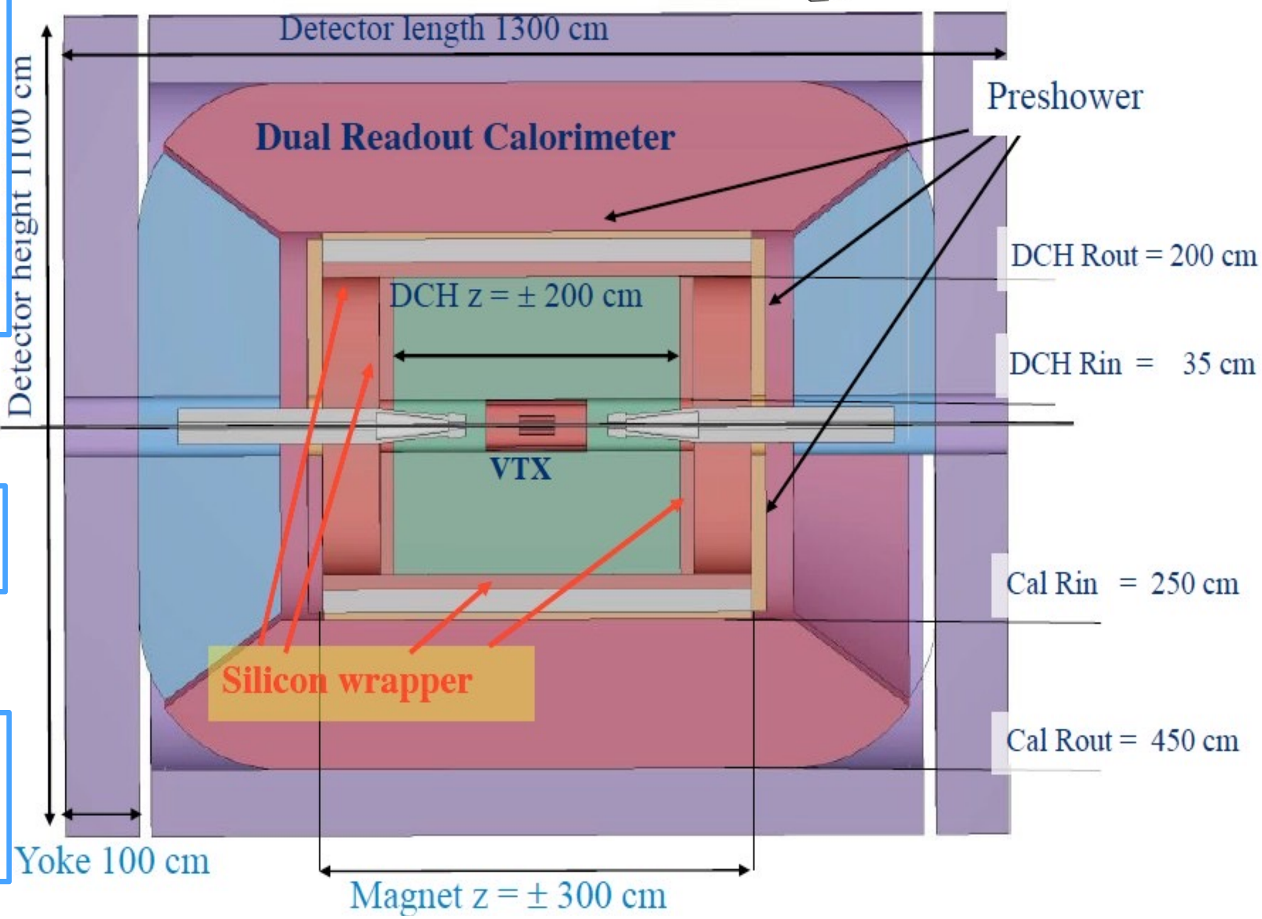
The IDEA detector at e^+e^- colliders



Innovative Detector for E+e- Accelerator

IDEA consists of:

- a silicon pixel vertex detector
- a large-volume extremely-light **drift chamber**
- surrounded by a layer of silicon micro-strip detectors
- a thin low-mass superconducting solenoid coil
- a preshower detector based on **μ-WELL technology**
- a dual read-out calorimeter
- muon chambers inside the magnet return yoke, based on **μ-WELL technology**



Low field detector solenoid to maximize luminosity (to contain the vertical emittance at Z pole).

→ optimized at 2 T

→ large tracking radius needed to recover momentum resolution

Silicon detectors for precision measurements:

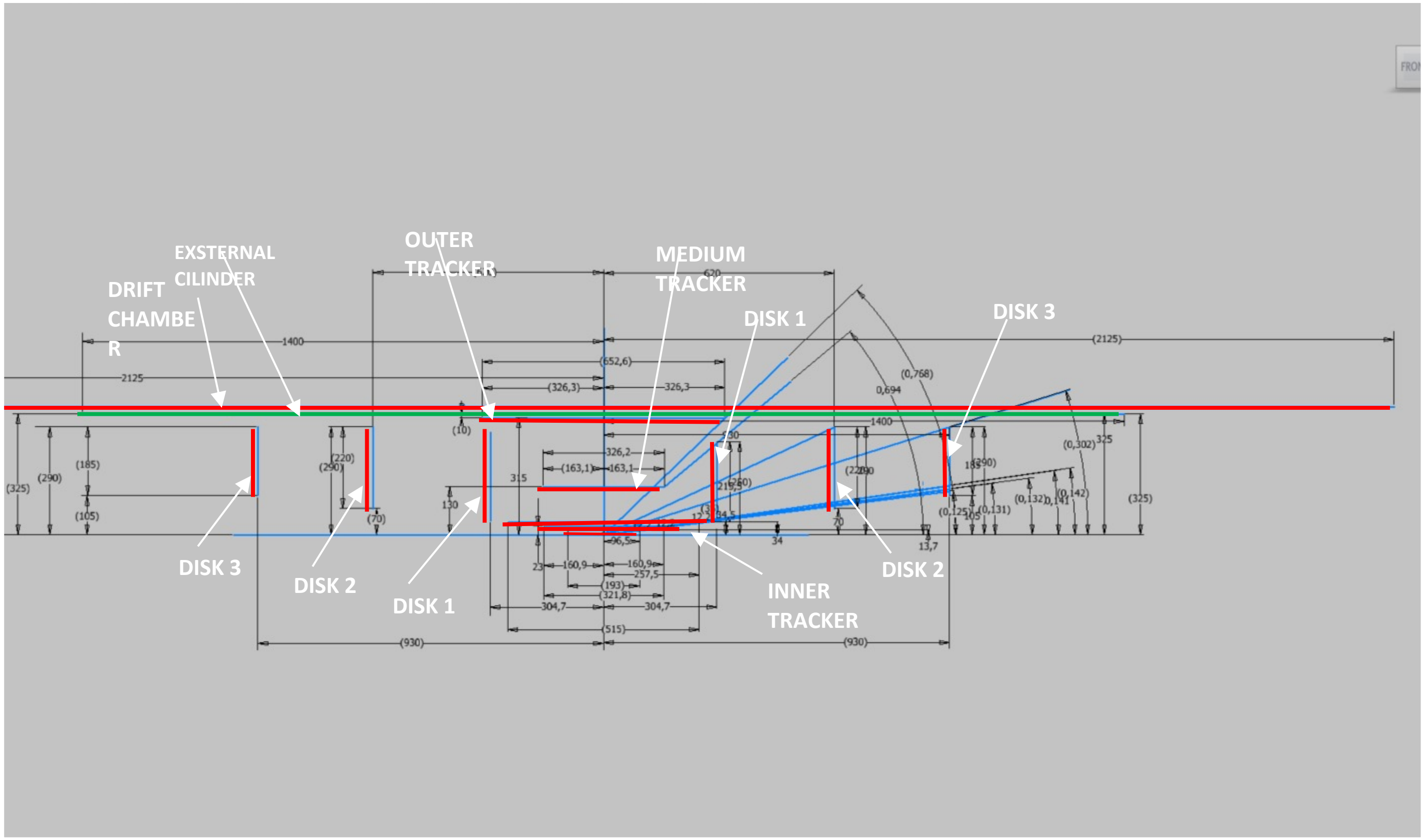
- vertex detector/inner tracker (VTX)
- silicon outer tracker
- silicon wrapper (SET)

+ design of the mechanical structure (light-weight staves)

See F. Palla talk for details

+ activity with the MDI group for the integration of the vertex detector

See F. Palla and M.Boscolo talks for details

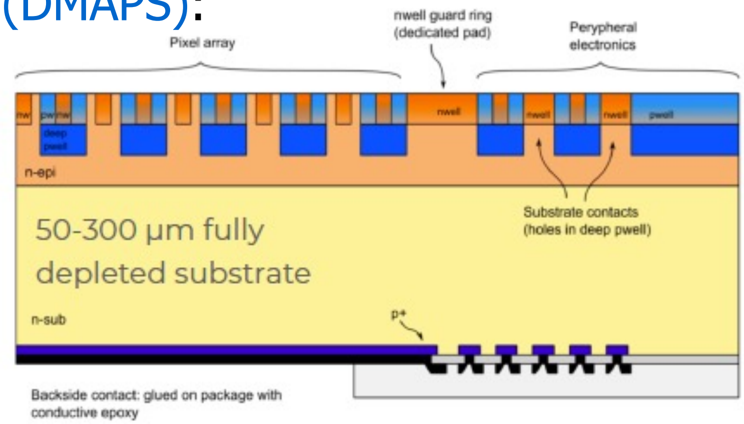


Vertex detector Insubria U.+ Milano U.

ARCADIA INFN prototype

Technology: Depleted Monolithic Active Pixel Sensors (DMAPS):

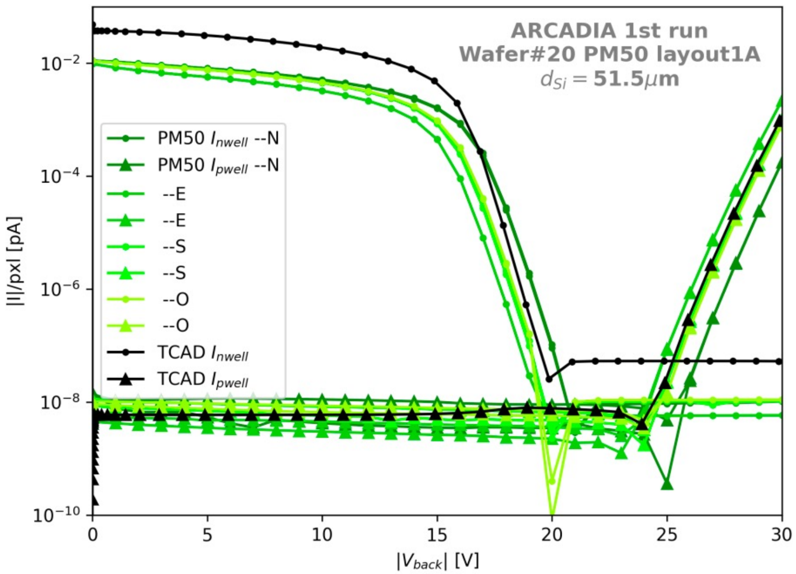
- 25 x 25μm^2 pixel size for hit resolution ~ 3 μm
- 5 μm shown by ALICE ITS (30 μm pixels)
- prototype with thickness ~ 200 μm down to 50μm
- low power consumption (< 20 mW/cm^2)



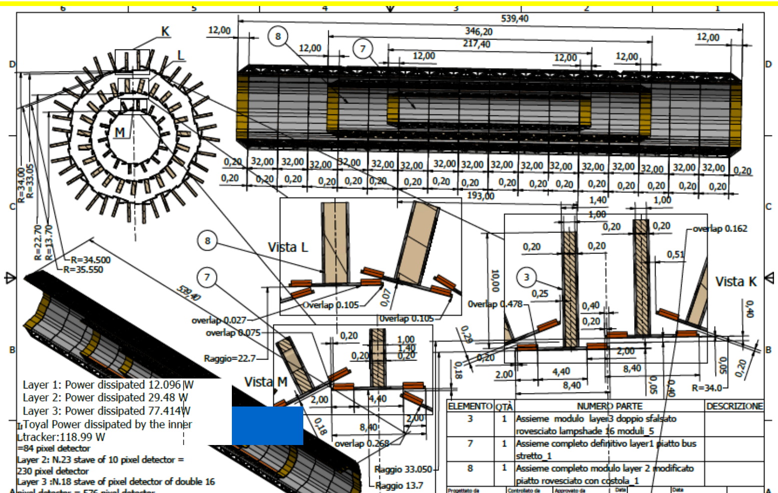
Tests of different design options:

- IV and CV measurements of test-structures from the first and second production run: proven functionality, stable operation at full depletion, and good agreement with TCAD simulations

A 2nd iteration prototype is working and will be tested soon at a test beam area



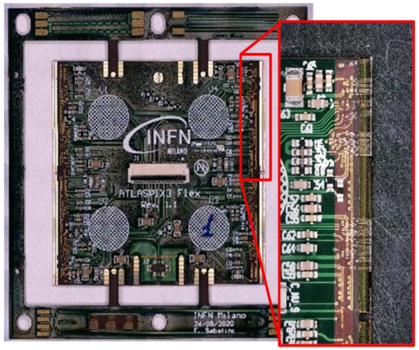
VTX mechanical strcture



3 barrel layers at
- 13.7, 23.7 and 34-35.4 mm radius

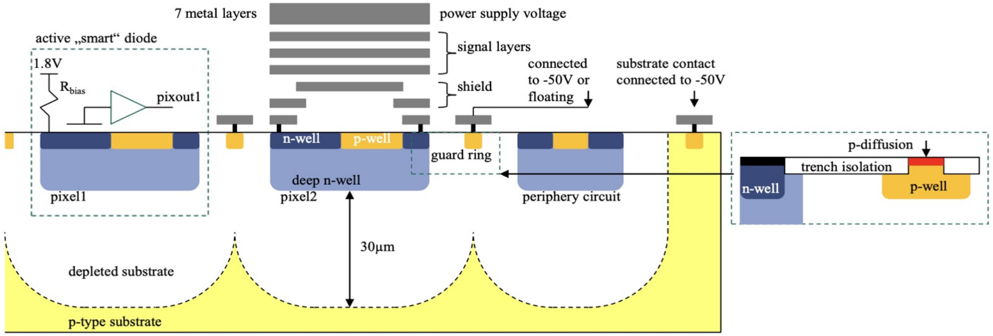
Silicon medium and outer tracker KIT+UK+IHEP+INFN

ATLASPIX3 modules: a full-size system on chip, targeting the outer tracker



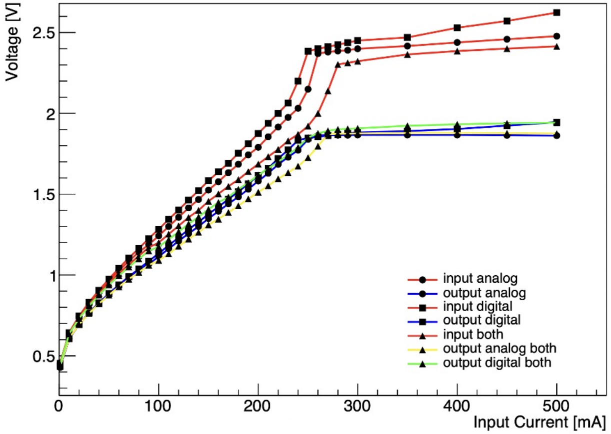
- Intermediate barrel at 15 cm radius
- Outer barrel at 31.5 cm radius

- quad module, inspired by ATLAS ITk pixels
- pixel size 50×150 μm^2
- TSI 180 nm process on 200 Ωcm substrate
- 132 columns of 372 pixels



Power consumption:

- ATLASPIX3 power consumption 100-150 mW/cm^2



Complete system consists of 900'000 cm^2 area / 4 cm^2 chip = 225k chips (56k quad-modules)

Data rate constrained by the inner tracker:

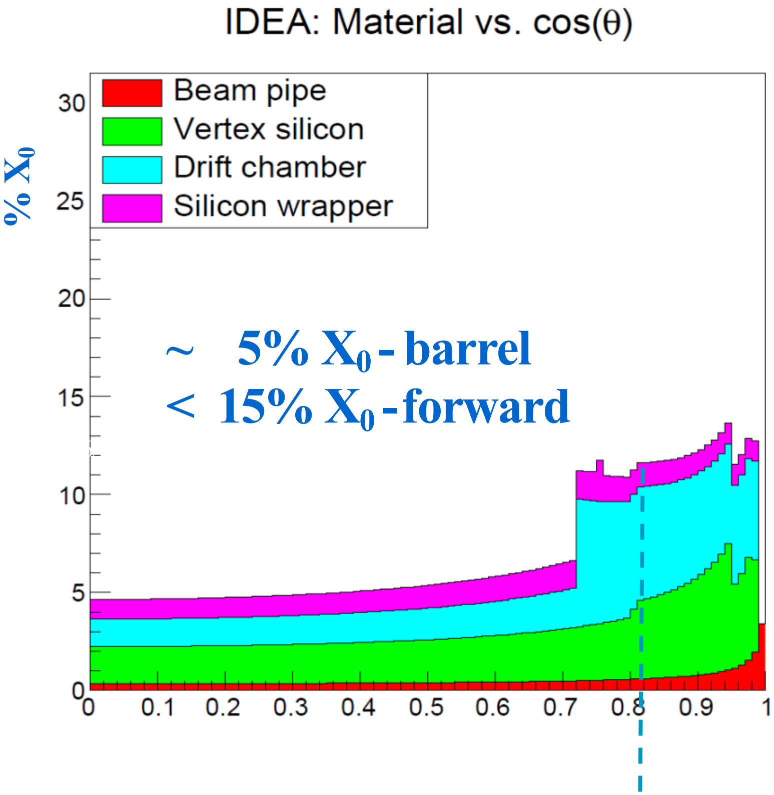
- average rate 10^{-4} - 10^{-3} particles cm^{-2} event^{-1} at Z peak
- assuming 2 hits/particle, 96 bits/hit for ATLASPIX3
- 640 Mbps link/quad-module provides ample operational margin
- 16 modules can be arranged into 10 Gbps fast links: 3.5k links
- can also assume 100 Gbps links will be available: 350 links

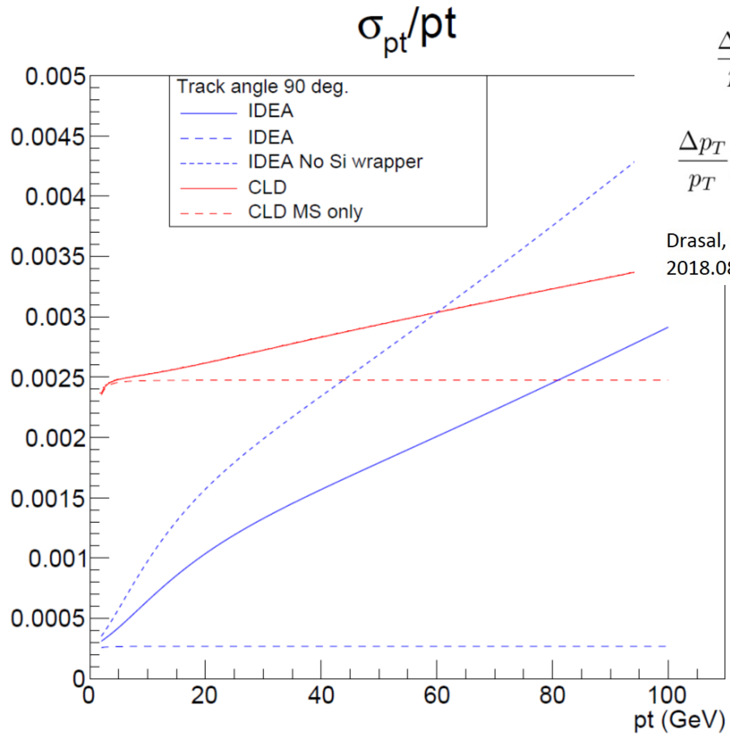
Design features of the IDEA Drift Chamber

INFN Bari and Lecce, IHEP + contributions from UCL, NWU and FSU

For the purpose of tracking and ID at low and medium momenta mostly for heavy flavour and Higgs decays, the IDEA drift chamber is designed to cope with:

- transparency against multiple scattering, more relevant than asymptotic resolution
- a high precision momentum measurement
- an excellent particle identification and separation





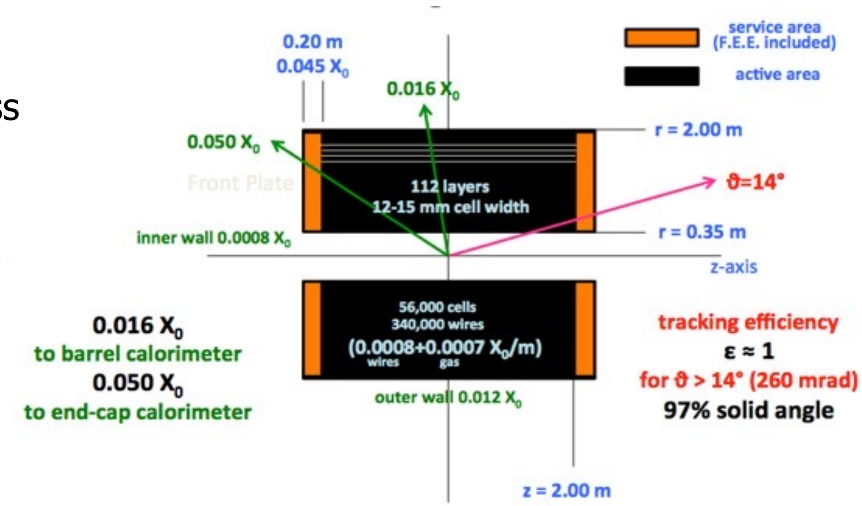
Particle momentum range far from the asymptotic limit where MS is negligible

$$\frac{\Delta p_T}{p_T}\Big|_{res.} \approx \frac{12\,\sigma_{r\phi}\,p_T}{0.3\,B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} \approx \frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\,B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}$$

Drasal, Riegler, https://doi.org/10.1016/j.nima.2018.08.078

The Drift Chamber



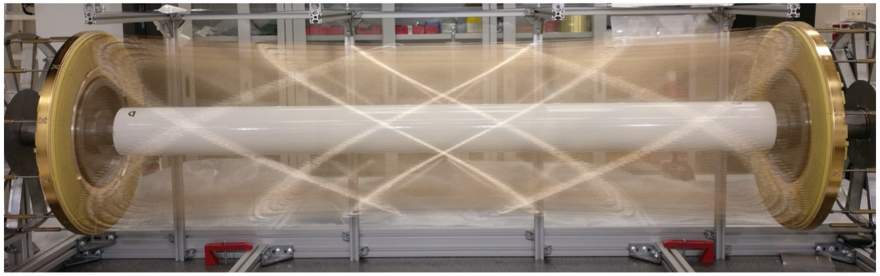
The DCH is:

- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius R_{in} = 0.35m, outer radius R_{out} = 2m
- length L = 4m
- drift length ~1 cm
- drift time ~150ns
- $\sigma_{xy} < 100\ \mu m$, $\sigma_z < 1$ mm
- 12÷14.5 mm wide square cells, 5 : 1 field to sense wires ratio
- 112 co-axial layers, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors, with frontend electronics
- 343968 wires in total:

  sense vires: 20 μm diameter W(Au) => 56448 wires

  field wires: 40 μm diameter Al(Ag) => 229056 wires

  f. and g. wires: 50 μm diameter Al(Ag) => 58464 wires



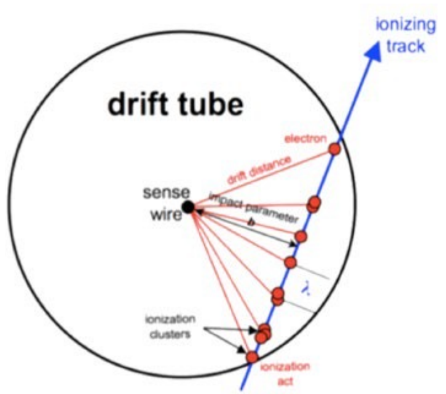
- the wire net created by the combination of + and – orientation generates a more uniform equipotential surface → better E-field isotropy and smaller ExB asymmetries)

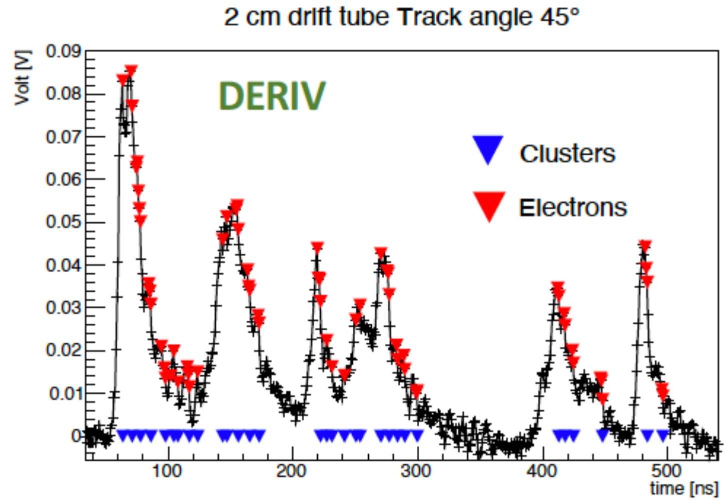
- a large number of wires requires a non standard wiring procedure and needs a feed-through-less wiring system → a novel wiring procedure developed for the construction of the ultra-light MEG-II drift chamber

The Drift Chamber: Cluster Counting/Timing and PID

Principle: In He based gas mixtures the signals from each ionization act can be spread in time to few ns. With the help of a fast read-out electronics they can be identified efficiently.

- By counting the number of ionization acts per unit length (dN/dx), it is possible to identify the particles (P.Id.) with a better resolution w.r.t the dE/dx method.





- collect signal and identify peaks
- record the time of arrival of electrons generated in every ionisation cluster
- reconstruct the trajectory at the most likely position

- Landau distribution of dE/dx originated by the mixing of primary and secondary ionizations, has large fluctuations and limits separation power of PID → primary ionization is a Poisson process, has small fluctuations

- The cluster counting is based on replacing the measurement of an ANALOG information (the [truncated] mean dE/dX) with a DIGITAL one, the number of ionisation clusters per unit length:

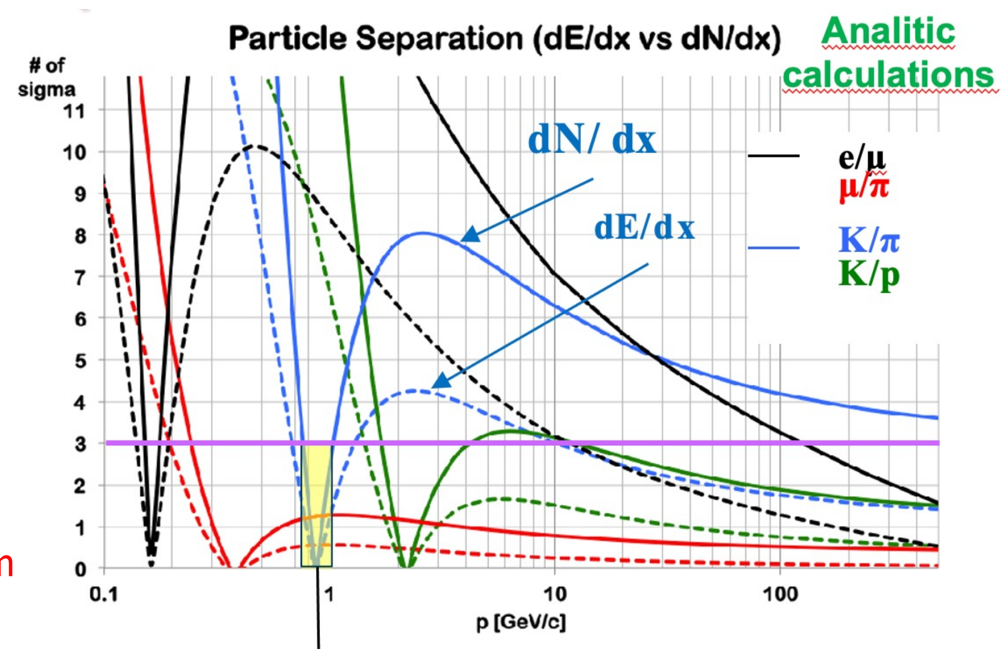
dE/dx: truncated mean cut (70-80%), with a 2m track at 1 atm give $\sigma \approx$ 4.3%

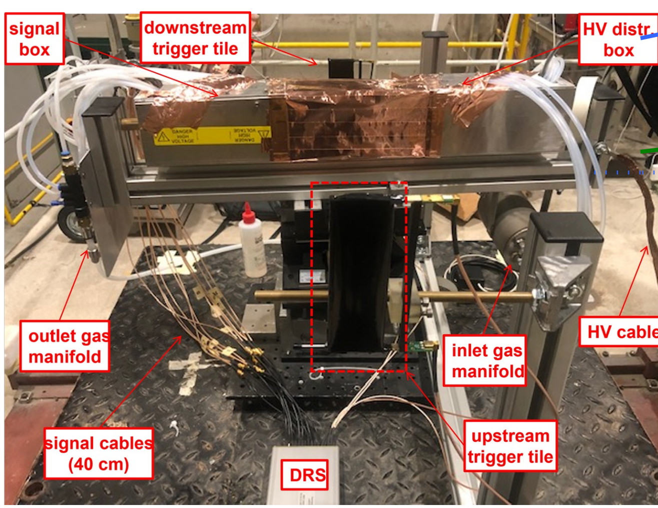
dN_{cl}/dx: for He/iC_4H_{10}=90/10 and a 2m track gives $\sigma_{dNcl/dx}$ **$/(dN_{cl}/dx)$** < 2.0%

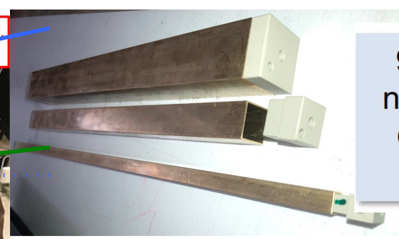
The Drift Chamber: Cluster Counting/Timing and PID

- Analitic calculations: Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)

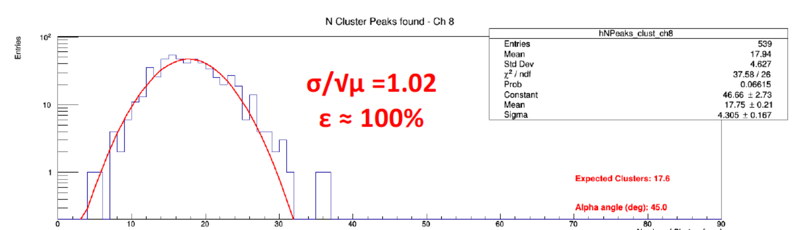
- Simulation with Garfield++ and with the Garfield model ported in GEANT4:
  - the particle separation, both with dE/dx and with dN_{cl}/dx, in GEANT4 found considerably worse than in Garfield
  - the dN_{cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of βγ with a steeper slope
  - finding answers by using real data from beam tests at CERN in 2021 and 2022







$90\%He-10\%iC_4H_{10}$
nominal HV+20, 45°,
Gas gain ~ $2 \cdot 10^5$,
165 GeV/c



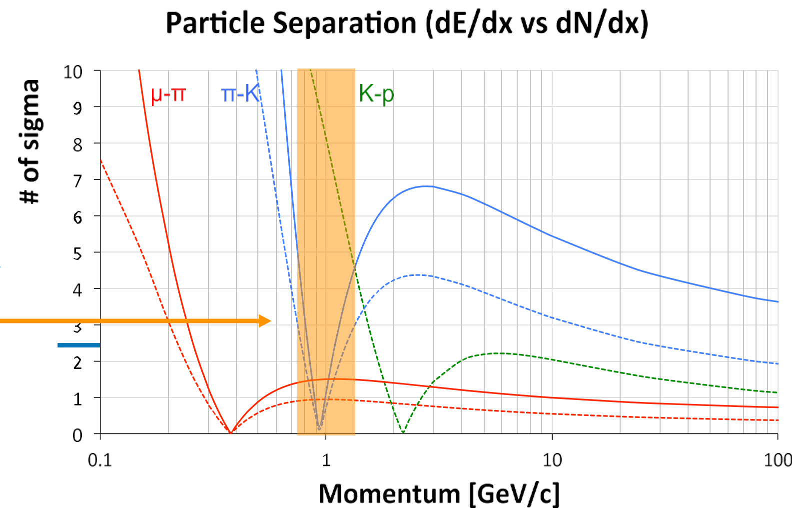
- Poissonian behaviour of the number of clusrers
- Meaurements vs predictions about the number of clusters are in very good agreement
- Same results in independent drift tubes

Silicon wrapper

INFN Genova

In IDEA concept, tracking and PID provided by the DCH (+ VTX + outer Tracker)

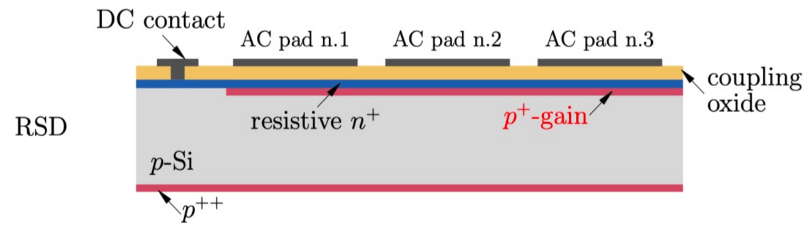
- Silicon wrapper for precise polar angle measurement
- Good K-π separation from dE/dx except for p ~ 1 GeV

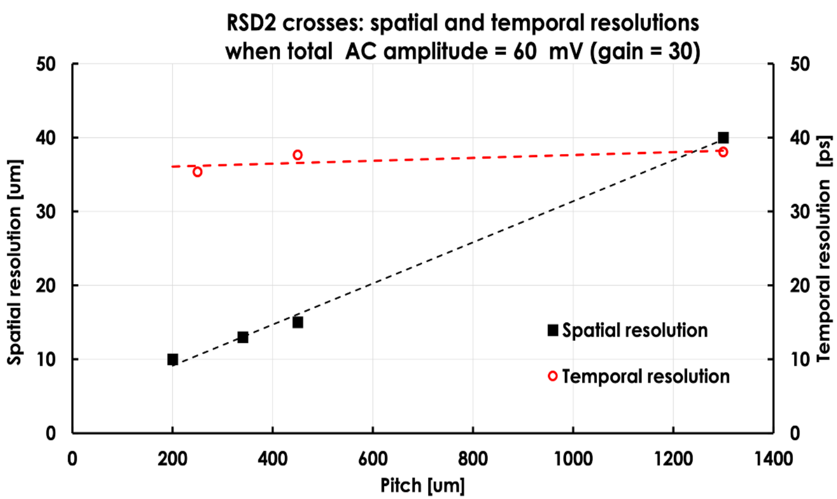


Baseline: ATLASPIX3 modules **BUT**

LGAD (Low-Gain Avalanche Diodes) with RSD (Resistive Silicon Detectors) technology are a possible option:

- TOF with excellent time resolution
- in resistive readout the signal is naturally shared among pads without the need of B field or floating pads





Reconstruction of the position from the signal distribution between contiguous electrodes

Need to show that LGAD could be produced with acceptable cost

- Technology developed by INFN Turin group, production by FBK
- External funding also (ERC, PRIN)

Muon detectors for IDEA: guiding principles

INFN Frascati, Ferrara, CERN

Future colliders experiments require extremely large muon detectors :

- ~10000 m^2 in the barrel
- 3-5000 m^2 in the endcap
- 300 m^2 in the very forward region

PRESHOWER requirements:

- high-spatial-resolution layer between magnet and calorimeter
- charge measurement to help discriminating the electromagnetic nature of the clusters
- barrel + two endcaps

- ✓ Efficiency > 98%
- ✓ Space Resolution < 100 μm
- ✓ Pitch = ~400 μm
- ✓ Strip capacitance ~70 pF
- ✓ 1.5 million channels
- ✓ FEE cost reduction —> custom ASIC
- ✓ Arranged in tiles 50x50 cm^2
- ✓ Mass production —> T.T.

MUON CHAMBERS requirements:

- low particle rate
- rough resolution to detect muons behind the calorimeter
- with higher resolution could help detecting secondary vertices from Long-Lived Particles decaying into muons

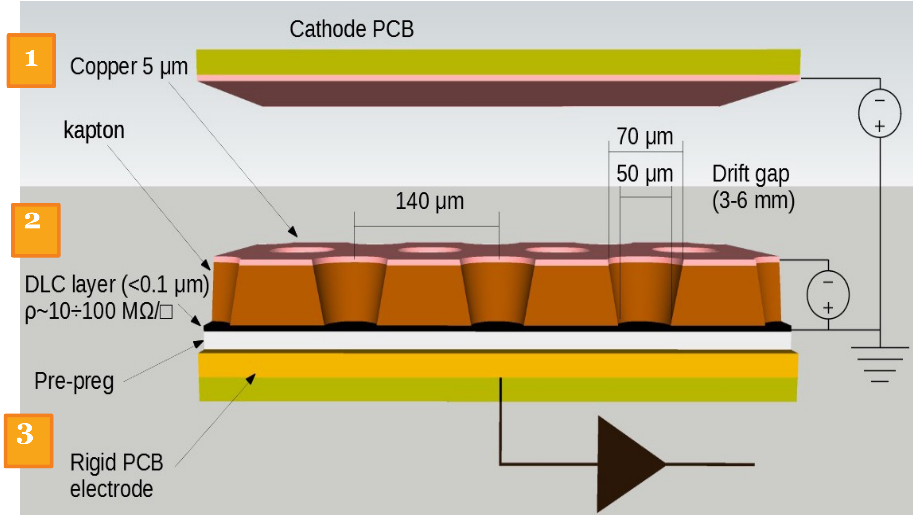
- ✓ Efficiency > 98%
- ✓ Space Resolution < 400 μm
- ✓ Pitch = ~1.5 mm
- ✓ Strip capacitance ~270 pF
- ✓ ~5 million channels
- ✓ FEE cost reduction —> custom ASIC
- ✓ Arranged in tiles 50x50 cm^2
- ✓ Mass production —> T.T.

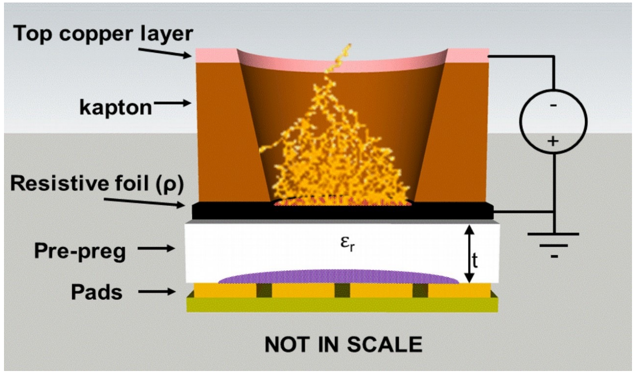
The μ-RWELL detector schema

R&D on μ-RWELL technology mainly motivated by the wish of improving:

- ✓ the stability under heavy irradiation (discharge suppression)
- ✓ the construction technology (simplifying the assembly)
- ✓ the technology transfer to industry (mass production)

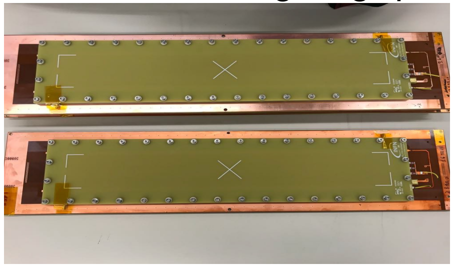
The μ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the μ-RWELL_PCB and the cathode.





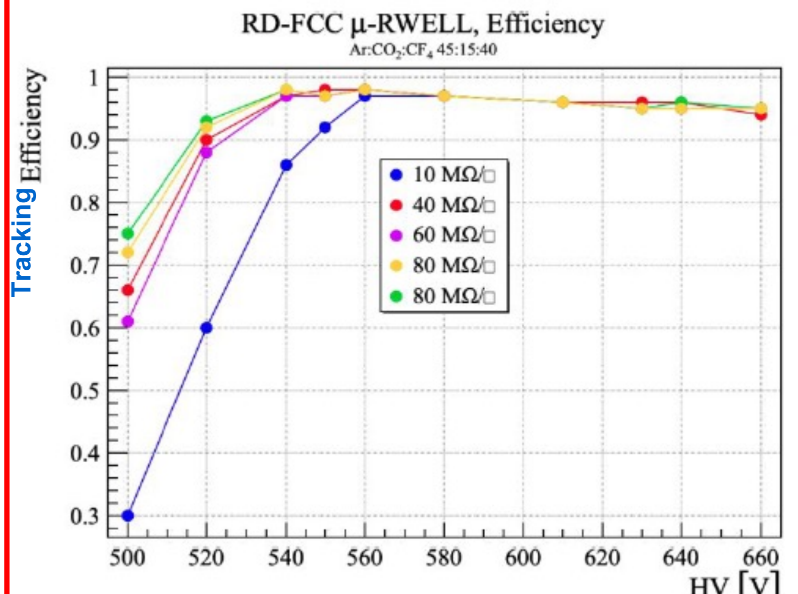
Applying a suitable voltage between the top Cu-layer and the DLC the WELL acts as a multiplication channell for the ionization produced in the conversion/drift gas gap.

1. A WELL patterned kapton foil acting as amplification stage (GEM-like)
2. a resisitive DLC layer (Diamond Like Carbon) for discharge suppression w/surface resistivity ~ 50÷100 MΩ/sq
3. a standard readout PCB

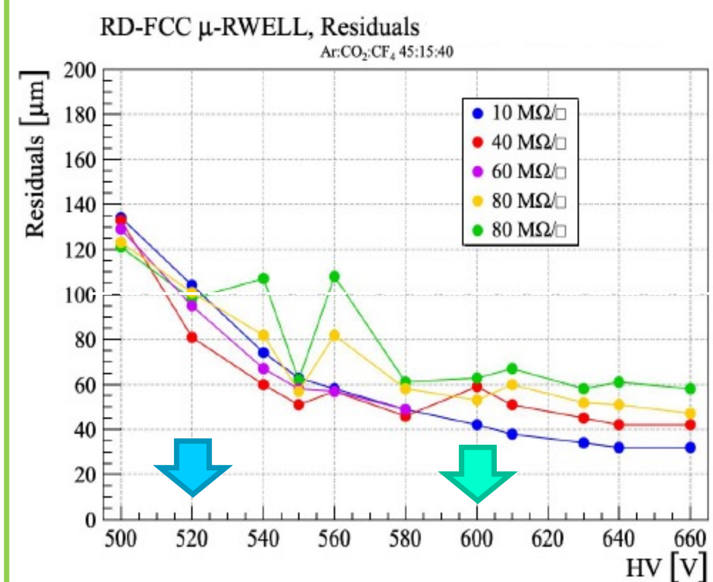


Test beam at CERN with μ-RWELL prototypes with
- 40cm long strips
- 0.4 mm strip pitch
- 1D readout

μ-RWELL test beam results and technology transfer



A large eff. pleateau (> 100 V) measured



With a pitch 0.4 mm at HV=520 V and with CL=1.5 → σ < 100 um

Technology transfer with ELTOS/CERN: flow chart

INFN LNF - DDG (Istituto Nazionale di Fisica Nucleare)

Responsibility:
- Detector design (GERBER);
- Link with ELTOS
- Link with CERN-Rui
- Quality Control detector
- DLC Machine managment (>2023)

ELTOS

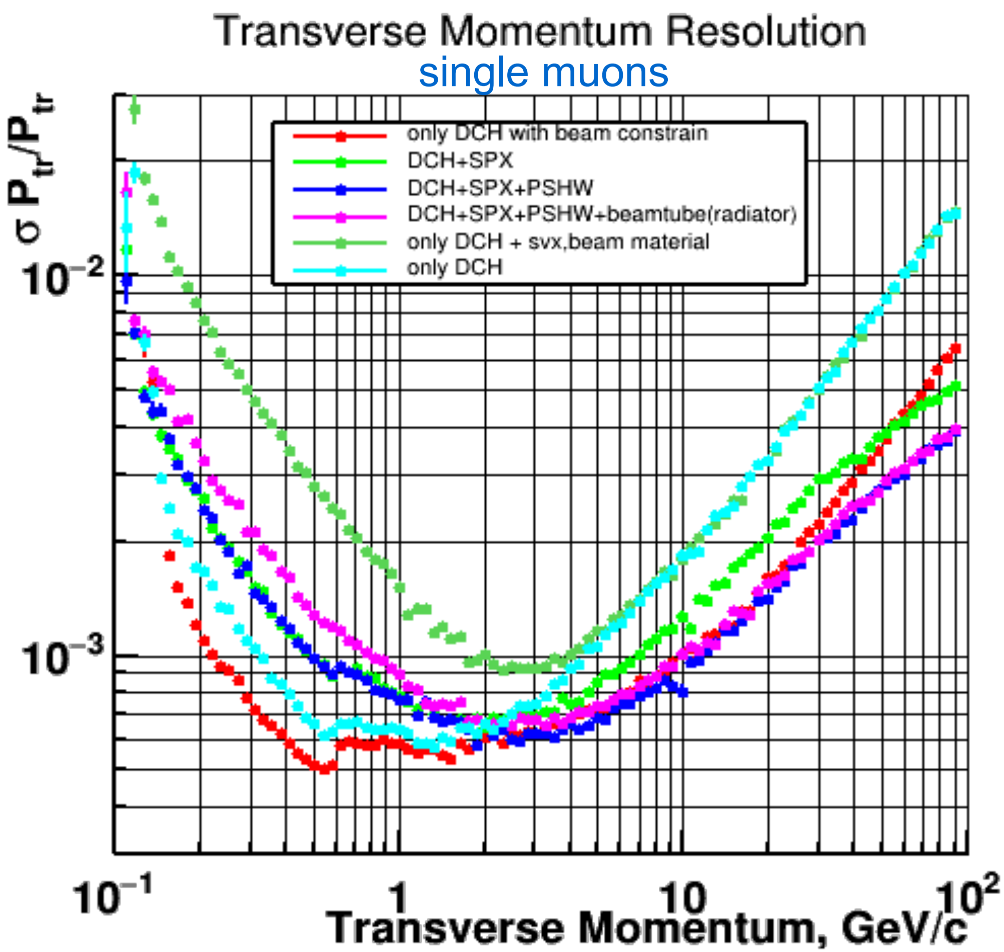
Responsibility:
- PCB RWELL production
- Cathode production
- DLC+PCB RWELL coupling

CERN

Responsibility:
- PCB RWELL finalization
- Hot Electrical Cleaning
- Detector closure

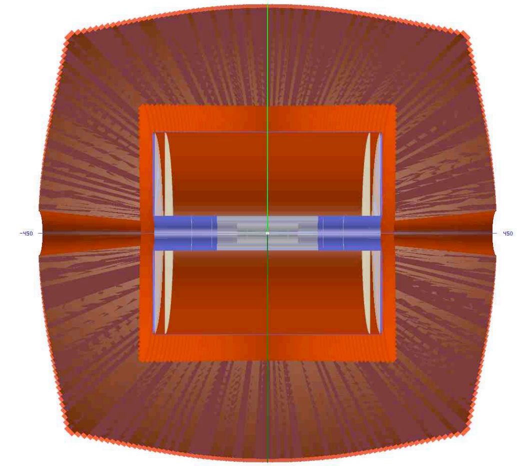
Simulation and performance of the IDEA tracking system

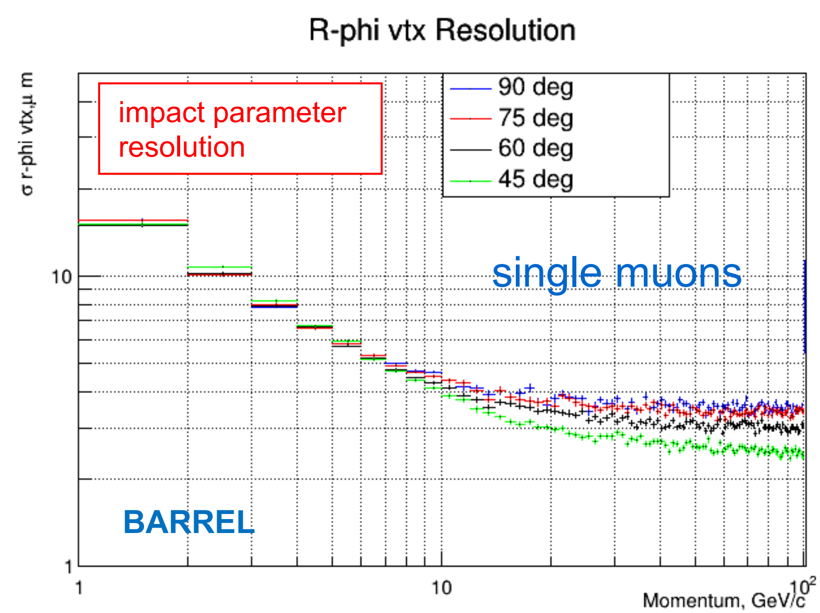
A full standalone Geant4 (and partially DD4HEP) simulation of the Silicon Vertex (and Si wrapper), DriftChamber, DR Calorimeter and Muon Preshower



$\sigma(p_t)/p_t$ (100 GeV) $= 3\text{x}10^{-3}$

but new studies ongoing





Summary/Conclusions

Advanced R&D effort on tracking detectors:

- vertex pixel detector, based on ARCADIA
- silicon medium and outer tracker, based on ATLASPIX3
- silicon wrapper, based on ATLASPIX3 (LGAD under evaluation)
- drift chamber design and cluster counting study, sinergy with MEG2
- muon chambers, synergy with LHCb upgrades

Plenty of areas for collaboration:

- detector design, construction, beam test, performance
- local and global reconstruction, full simulation
- physics performance and impact
- etc.

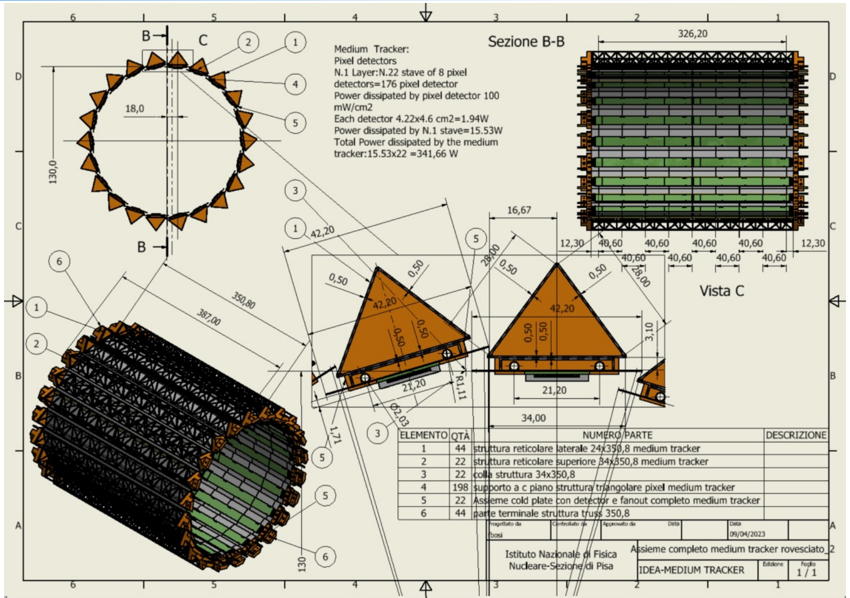
Effort to build international collaboration on going (in some areas well advanced) and to be enforced

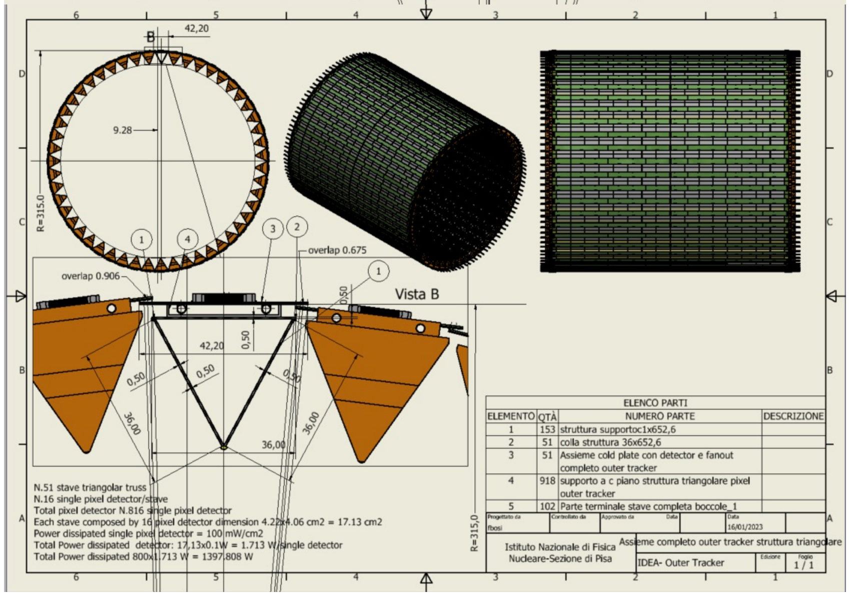
Manpower, funding under continuous discussion

Backup

Silicon medium and outer tracker

See F. Palla talk for details





Intermediate Tracker Barrel
At 13 cm radius

22 staves of 8 modules each.

Lightweight reticular support structure (ALICE/Belle-II like)

Outer Tracker Barrel
At 31.5 cm radius

51 staves of 16 modules each

Lightweight reticular support structure (ALICE/Belle-II like)