An ultra-light Drift Chamber with Particle Identification capabilities for future e^+e^- Colliders

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Future Collider Monthly Meeting (kick-off)
Korea Future Collider Consortium
February 25, 2021

Outline of the talk

- **Performance evolution of central trackers at e^+e^- colliders – where do we stand?**
  - Momentum Resolution
  - Particle Identification with dE/dx
  - End-Plates Mechanical Structure (X_0)
- **Tracker requirements and choices for next generation e^+e^- colliders**
  - Requirements
  - Si trackers drawbacks
  - TPC drawbacks (my personal biased point of view)
- **Genesis, evolution and innovations of the IDEA drift chamber for FCCee and CEPC**
  - Mechanical structure (wire tension recovery, new wire types, ...)
  - Cluster counting for particle identification
  - Cluster timing for resolution improvement (and more)
- **IDEA drift chamber description and expected performance**
  - General layout
  - Material budget
  - Momentum and Angular resolutions
  - Particle Identification

Trackers at e^+e^- Colliders

past

SPEAR	**MARK2**	Drift Chamber
	MARK3	Drift Chamber
DORIS	**PLUTO**	MWPC
	ARGUS	Drift Chamber
CESR	**CLEO1,2,3**	Drift Chamber
VEPP2/4M	**CMD-2**	Drift Chamber
	KEDR	Drift Chamber
	NSD	Drift Chamber
PETRA	**CELLO**	MWPC + Drift Ch.
	JADE	Drift Chamber
	PLUTO	MWPC
	MARK-J	TEC + Drift Ch.
	TASSO	MWPC + Drift Ch.
TRISTAN	**AMY**	Drift Chamber
	VENUS	Drift Chamber
	TOPAZ	TPC

PEP	**MARK2**	Drift Chamber
	PEP-4	TPC
	MAC	Drift Chamber
	HRS	Drift Chamber
	DELCO	MWPC
BEPC	**BES1,2**	Drift Chamber
LEP	**ALEPH**	TPC
	DELPHI	TPC + DC + MWPC
	L3	Si + TEC
	OPAL	Drift Chamber
SLC	**MARK2**	Drift Chamber
	SLD	Drift Chamber

DAPHNE	**KLOE**	**Drift Chamber**
PEP2	**BaBar**	**Drift Chamber**
KEKB	**Belle**	**Drift Chamber**

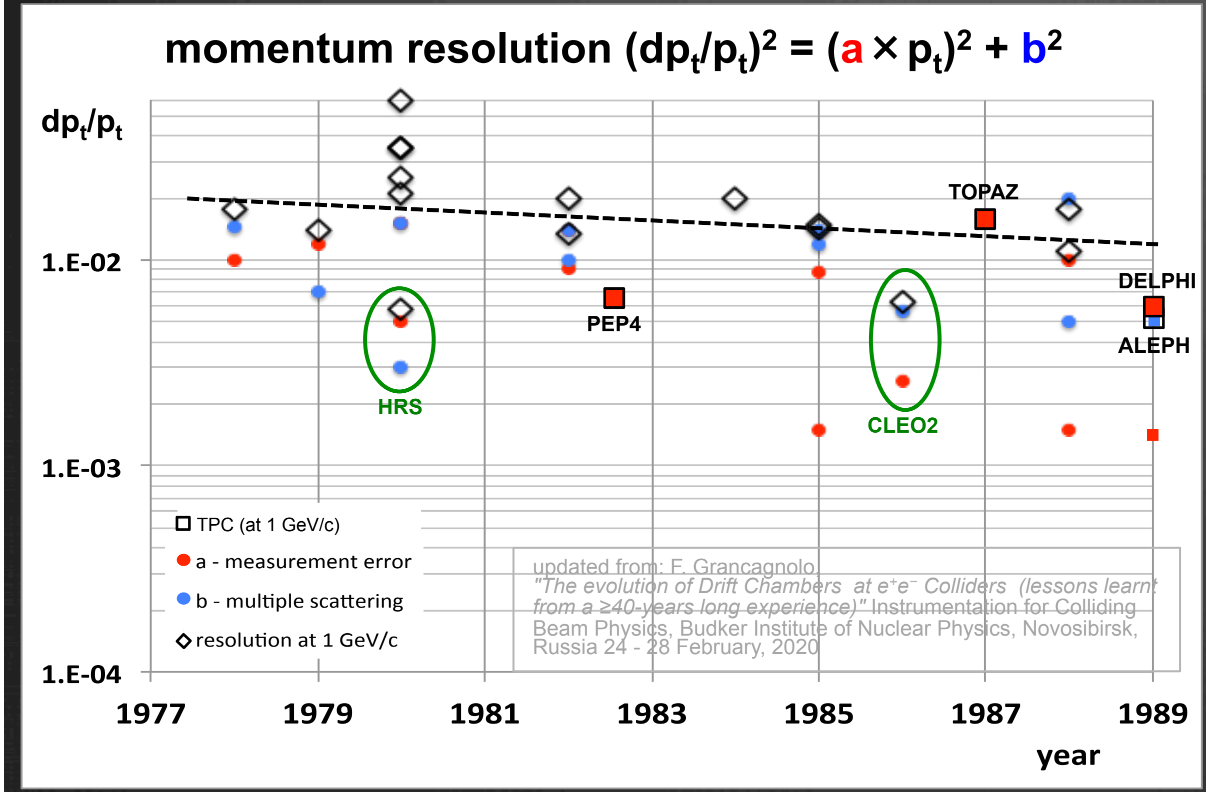
present

VEPP2000	**CMD-3**	**Drift Chamber**
VEPP4	**KEDR**	**Drift Chamber**
BEPC2	**BES3**	**Drift Chamber**
S.KEKB	**Belle2**	**Drift Chamber**

future

ILC	**ILD**	TPC	
	SiD	Si	
CLIC	**CLIC**	Si	
FCC-ee	**CLD**	Si	
	IDEA	**Drift Chamber**	
CEPC	**Baseline**	TPC	Si
	IDEA	**Drift Chamber**	
SCTF	**BINP**	**Drift Chamber**	
STCF	**HIEPA**	**Drift Chamber**	

p_t resolution in early DC and TPC



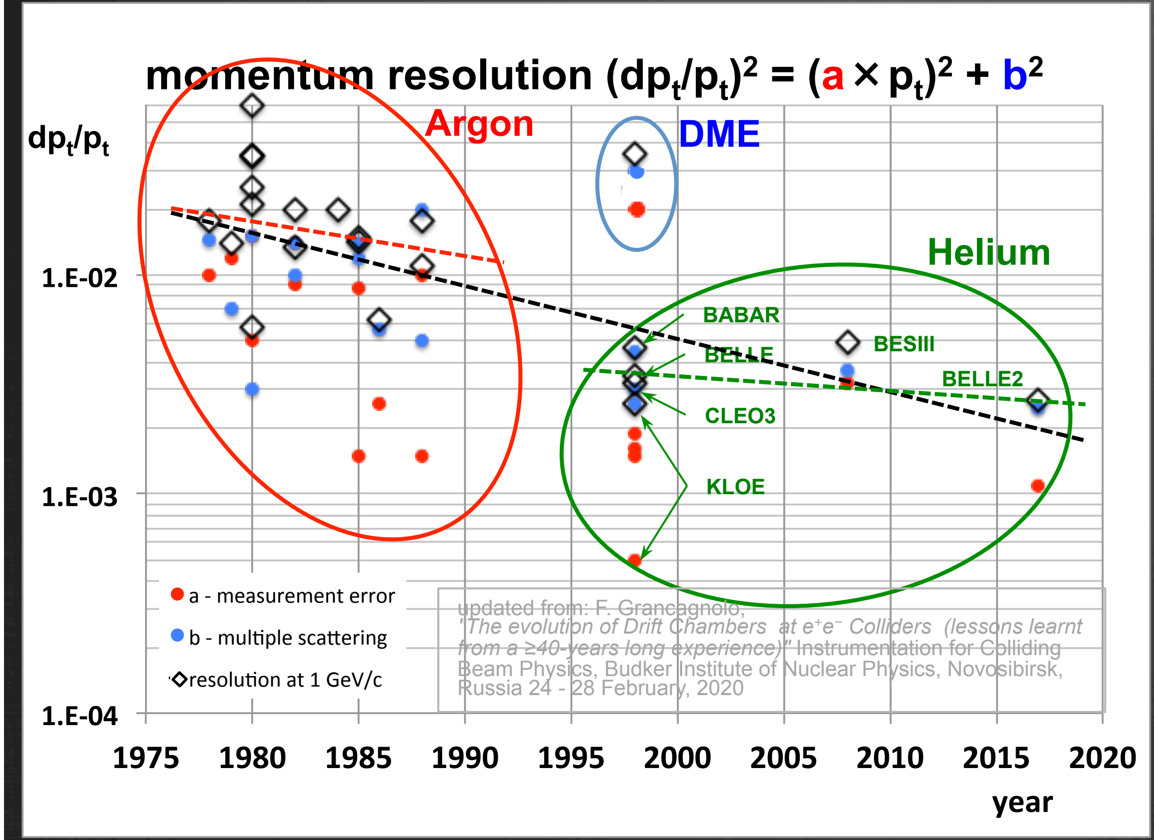
momentum resolution $(dp_t/p_t)^2 = (a \times p_t)^2 + b^2$

updated from: F. Grancagnolo, *"The evolution of Drift Chambers at e⁺e⁻ Colliders (lessons learnt from a ≥40-years long experience)"* Instrumentation for Colliding Beam Physics, Budker Institute of Nuclear Physics, Novosibirsk, Russia 24 - 28 February, 2020

$$(dp_t/p_t)^2 = [8\sqrt{5}\sigma_{r\varphi}/(0.3BL^2\sqrt{N})]^2 p_t^2 + \\ + [5.4\times10^{-2}/BL\sqrt{(L/X_0)}]^2$$

- Despite the large variety of different parameters involved, **momentum resolution** (at p=1GeV/c) clusters around **1-2%** for all chambers.
- Initially, resolution dominated by the sagitta measurement error.
- With improved cell configurations, the dominant error became multiple scattering,
- claiming for a **breakthrough** in the **gas mixture** and in the **wires**.
- **TPC** momentum resolutions not too different from **DC**

p_t resolution in DC after He



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W. Zimmermann et al., *Helium-propane as drift chamber gas*, Nucl. Instrum. Meth. A243 (1986) 86

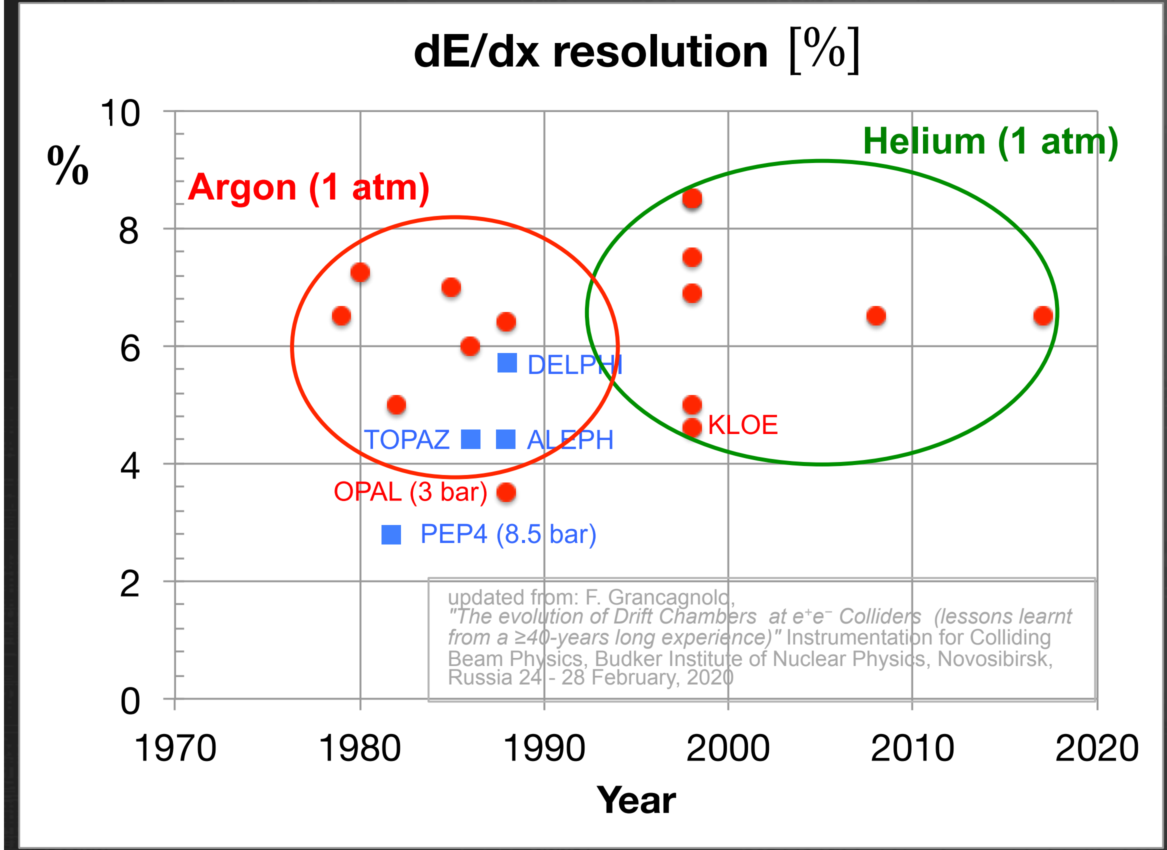
F. Grancagnolo, *A Helium Drift Chamber as the Central Tracker of a B-Factory*, Proc. Workshop on Heavy Quarks Factory and Nuclear Physics Facility with Superconducting Linacs, Courmayeur, 1987, eds. E. De Sanctis, M. Greco, M. Piccolo and S. Tazzari (Atti di Coferenze, Società Italiana di Fisica, Bologna 1987) p. 599

F. Grancagnolo, *A Central Tracking Detector for a B-Factory*, Nucl. Instrum. Meth. A277 (1989) 110

Momentum resolution
from 1-2% (in Ar) to
a few $\times10^{-3}$ (in He)

However,
too large fractions of quencher mitigate
the advantages of the
long radiation length of Helium

DC & TPC dE/dx resolution



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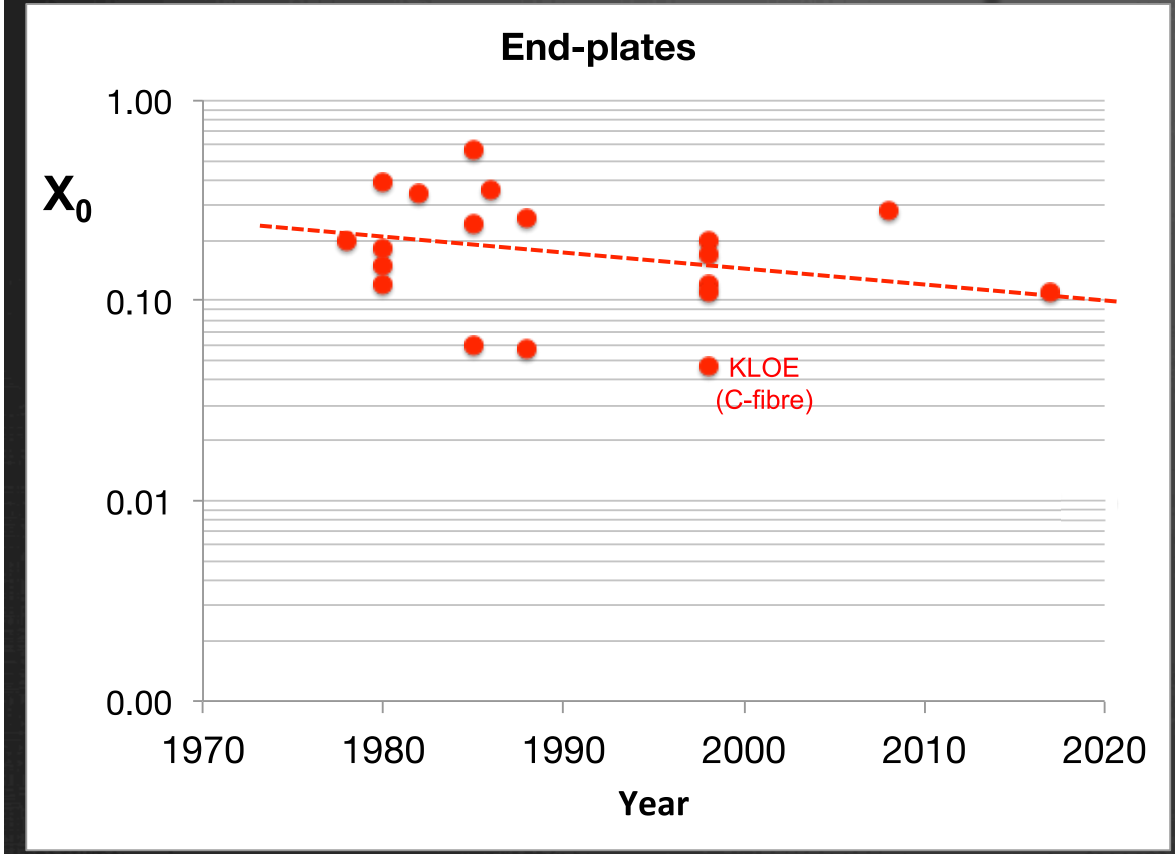
- **Methodology dating back to '80s. Very little progress in performance since then.**
- **Helium** based gas mixtures, a priori disfavored because of the lower ionization statistics, compensate with fewer fluctuations and equal the **Argon** performance.
- Using the Allison-Cobb parameterization, **dE/dx resolutions around 4.5%** are granted
- An increase in pressure might improve the separation power (by 20% at 2 bar) without jeopardizing too much the momentum resolution.
- A further 25% improvement may come at the expensive cost of a finer drift cell granularity.
- Furthermore, new SW techniques (**ML**?) might make the difference with respect to maximum likelihood and/or truncated mean methods.
- However, only a completely different approach, like **cluster counting**, may provide the necessary breakthrough.

DC **end-plate X_0**



Before 1998, end-plates made of **solid Aluminum**
$X_0 \geq 10\%$

KLOE drift chamber structure made entirely in **C-fibre**
$X_0 \leq 5\%$

To further reduce the end-plates **X_0**,
one needs a
new approach to the design

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Tracker requirements

- Large **angular coverage**

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- High **granularity** (to cope with occupancy at inner radii)

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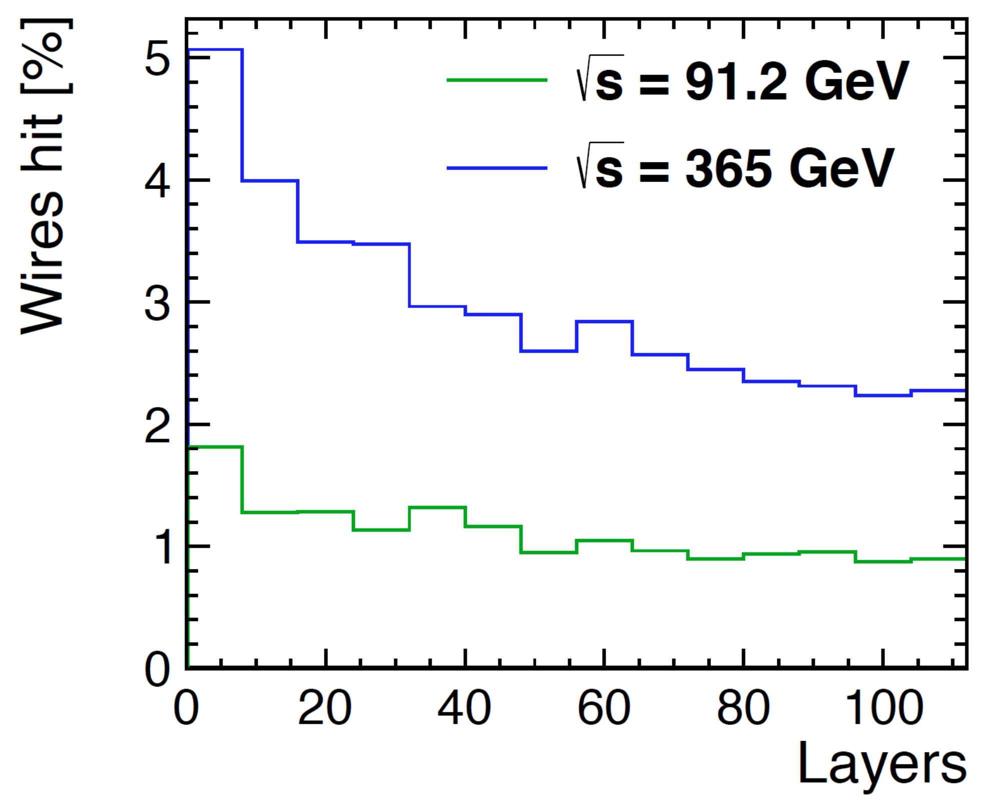

her radii)

Simulation of the main background contribution due to incoherent pair conversion
in IDEA drift chamber
at FCC-ee MDI

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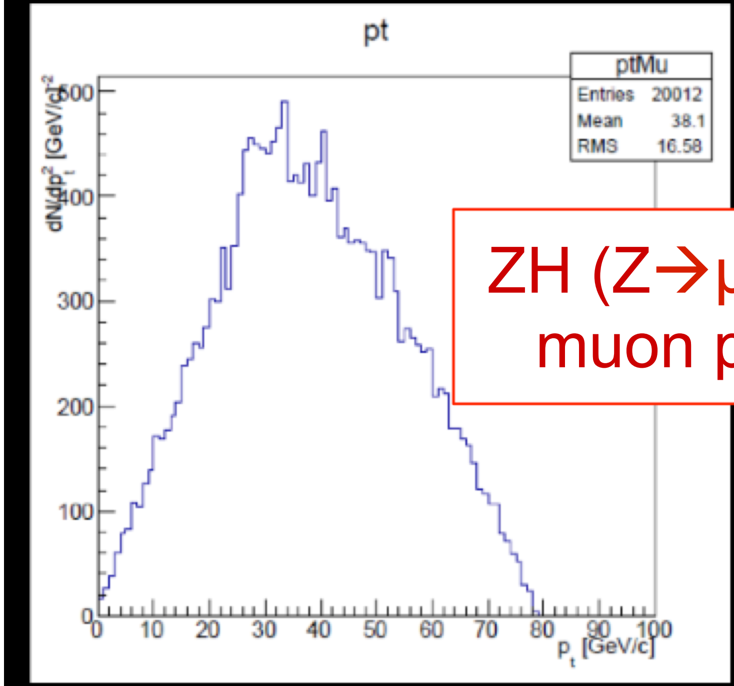
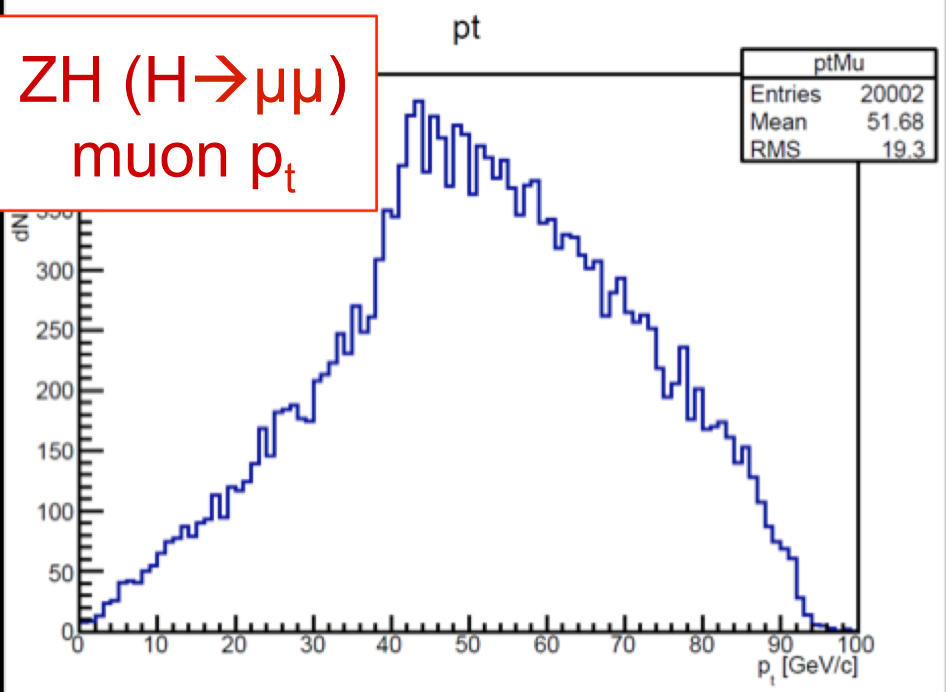


ZH (Z→μμ) muon p_t



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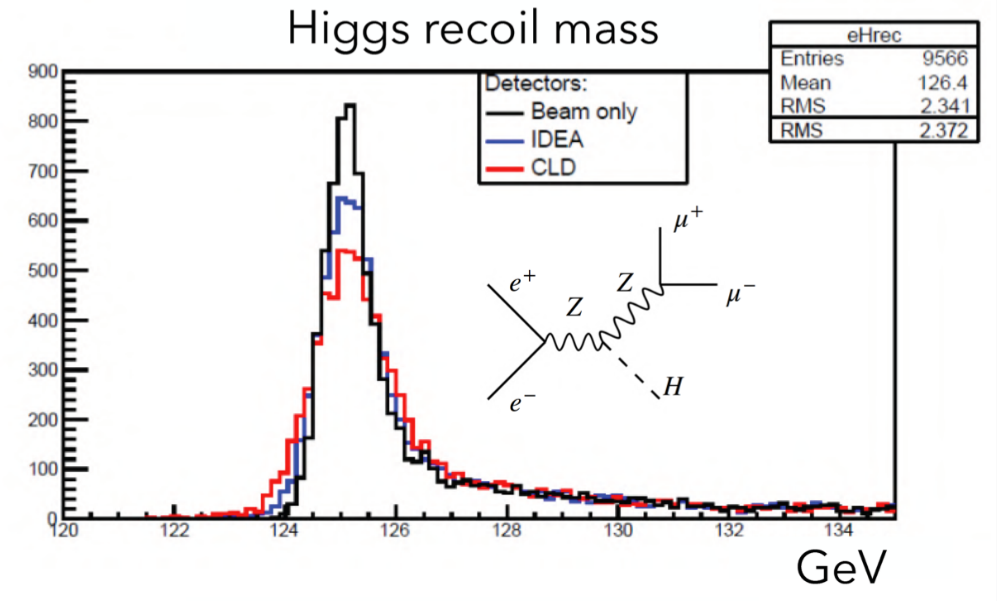

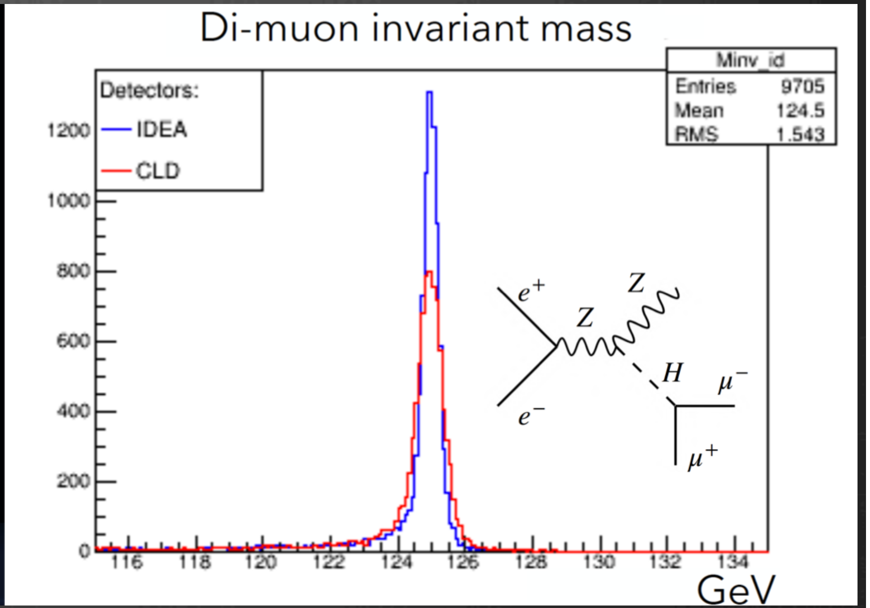

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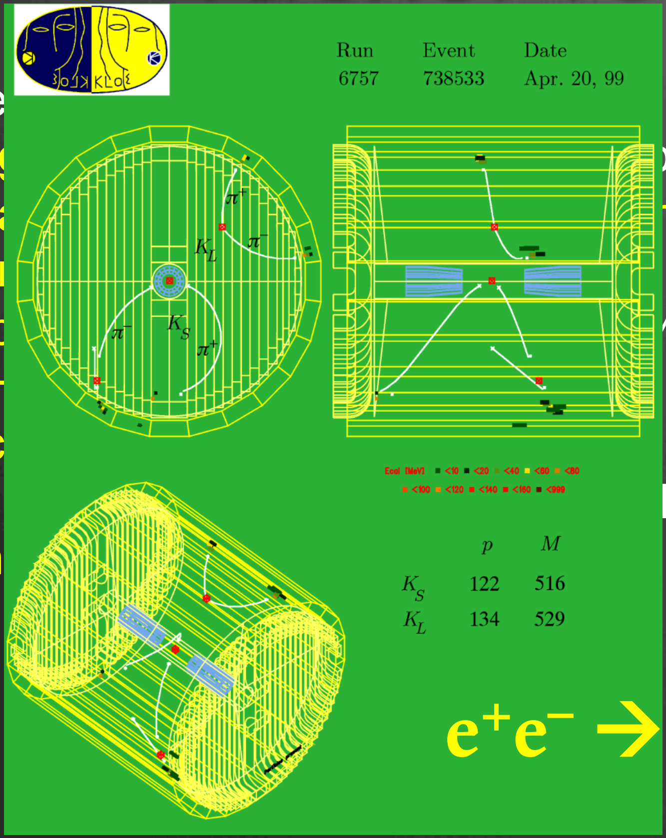

$$e^+e^- \rightarrow \Phi \rightarrow K_SK_L \rightarrow \pi^+\pi^-\pi^+\pi^-$$

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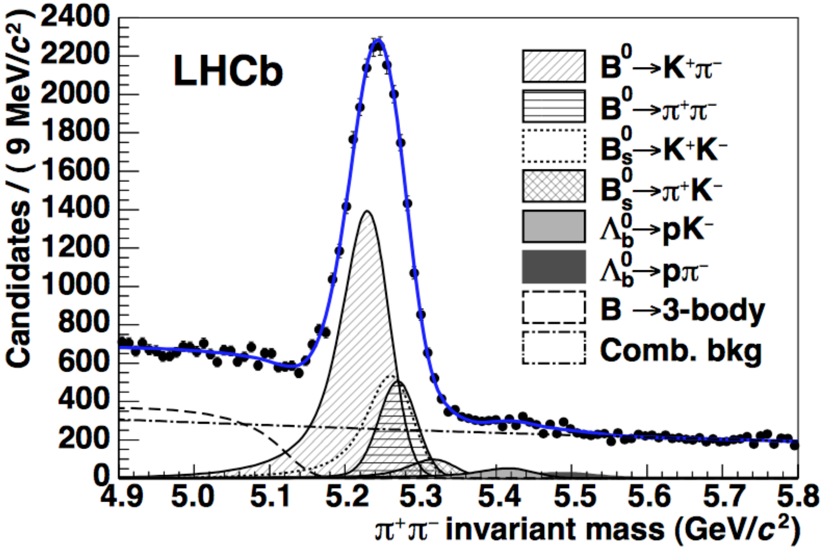
Example: 2-prongs B-decays

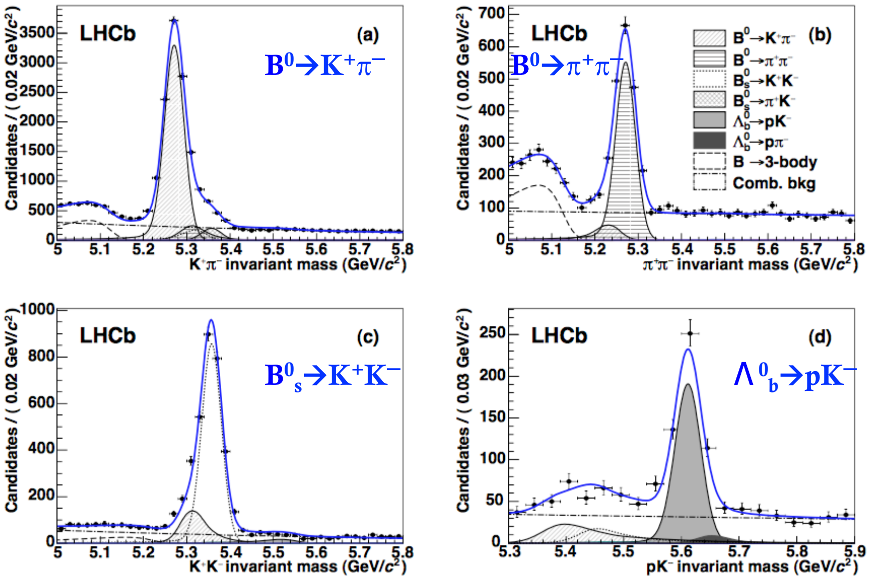
LHCb - JHEP 10 (2012) 037

Particle identification mandatory to disentangle different final states

before PId



after PId

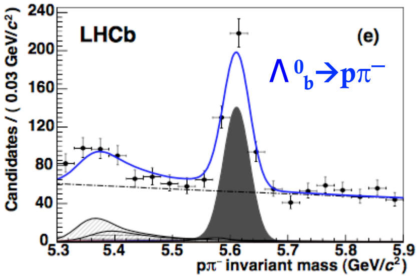


$B^0\to K^+\pi^-$

$B^0\to\pi^+\pi^-$

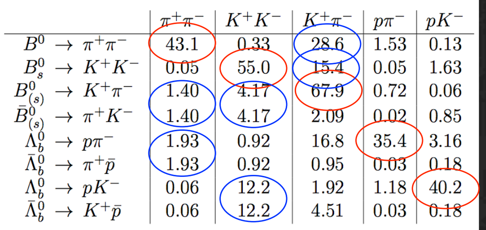
$B^0_s\to K^+K^-$

$\Lambda^0_b\to pK^-$



$\Lambda^0_b\to p\pi^-$

PId cut efficiencies and misidentifications



	$\pi^+\pi^-$	K^+K^-	$K^+\pi^-$	$p\pi^-$	pK^-
$B^0\to\pi^+\pi^-$	43.1	0.33	28.6	1.53	0.13
$B_s^0\to K^+K^-$	0.05	55.0	15.4	0.05	1.63
$B_{(s)}^0\to K^+\pi^-$	1.40	4.17	67.9	0.72	0.06
$\bar{B}_{(s)}^0\to\pi^+K^-$	1.40	4.17	2.09	0.02	0.85
$\Lambda_b^0\to p\pi^-$	1.93	0.92	16.8	35.4	3.16
$\bar{\Lambda}_b^0\to\pi^+\bar{p}$	1.93	0.92	0.95	0.03	0.18
$\Lambda_b^0\to pK^-$	0.06	12.2	1.92	1.18	40.2
$\bar{\Lambda}_b^0\to K^+\bar{p}$	0.06	12.2	4.51	0.03	0.18

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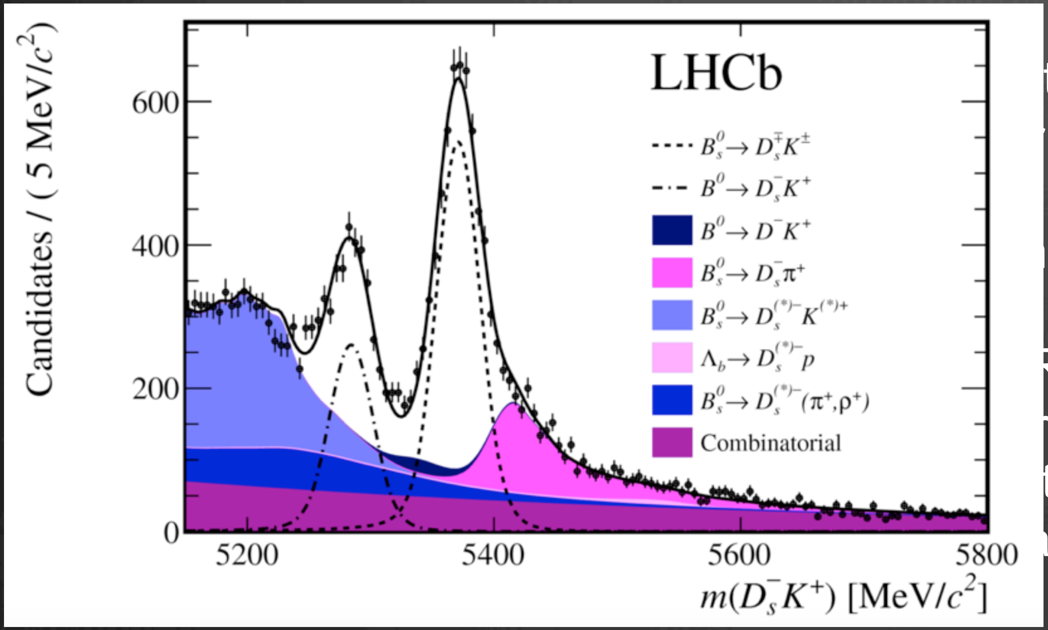

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monitoring beam spread (Z→μμ))

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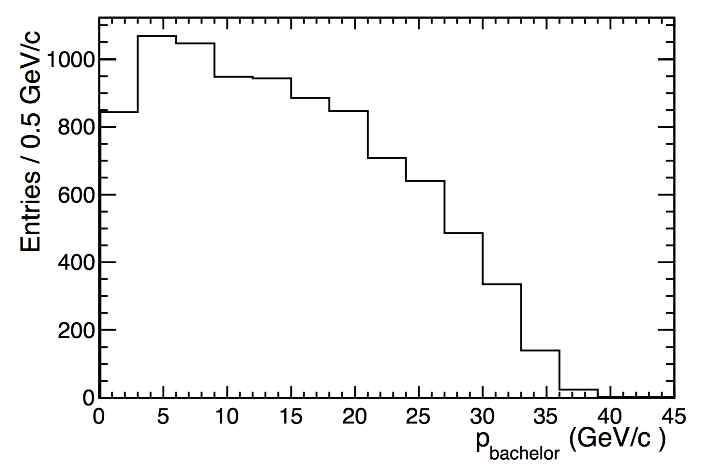

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  - $A_{FB}(b)$, exclusive b-hadron decays reconstruction

Si tracker drawbacks

❖ **Multiple scattering**

- Contribution to momentum resolution due to multiple scattering dominant for the full momentum range

❖ **Redundancy**

- Only a limited number N of layers can be implemented, hindering the momentum resolution, proportional to σ/√N, despite the excellent spatial resolution σ (**25 μm/√6 ≈ 100 μm/√100**)
- Very low efficiencies for "kinks" and "vees" (LLP)
- Low redundancy against hit inefficiencies and background hits

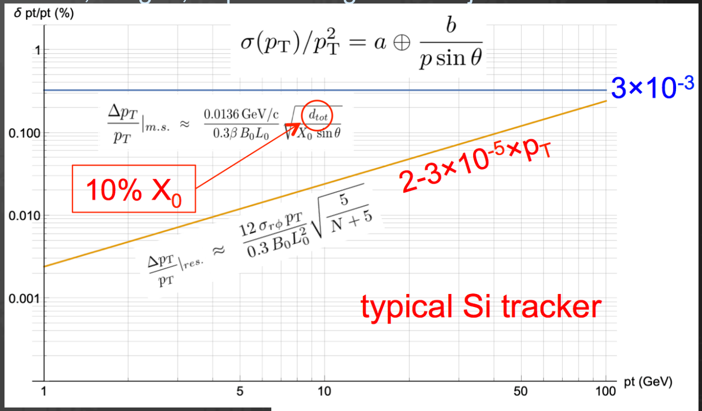
❖ **particle identification**

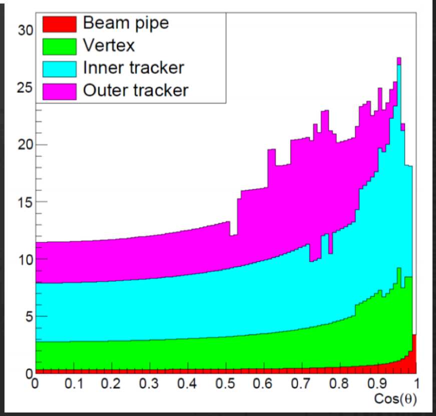
- Limited PId possible (maybe TOF, for small range of p, if 10 ps resolution can be granted over many m^2)

❖ **system complexity**

- Order of 10^9 channels for a limited number of space points on a track with a lever arm compatible with the momenta to be measured
- Stability of relative and absolute alignment

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





TPC drawbacks* 1

* my personal biased point of view

❖ Multiple scattering

- Need of using heavier gas mixture
- Field cage alone (> 14 Ton) 3% X_0 (ALICE TPC). 15% X_0 expected in end-plates

❖ Operation

- B-field limited to 2Tesla to contain beam emittance ⇨ transverse diffusion
- No gating option for continuous beams (at FCCee and CEPC), unlike at ILC (ILD TPC)
- MPGD readout (CEPC TPC) 1×6 mm^2 ⇨ 3×10^6 RO channels
- Need 10^{-3} IBF suppression to limit distortions at level of 40μm at inner radius for $L = 1.6\times10^{35}\ cm^{-2}s^{-1}$ (300μm at 10 × L at FCCee)
- Need control of power consumption < 5mW/ch (total 15KW) ⇨ massive cooling system

❖ Parameters control

- Drift field (400 V/cm) distortions at 10^{-4} level contribute with >200μm to spatial resolution (2m drift)
- Temperature stability < 0.1°K, corresponding to ≈1mm for vdrift = 2.5 cm/μs, needs a complex cooling systems (HV distribution and FEE)

TPC drawbacks* 2

* my personal biased point of view

Parameters control

- $\Delta v_{drift}/v_{drift} = -6.4\times\Delta(CO_2)/(CO_2) = -1.0\times\Delta(N_2)/(N_2) < 10^{-4}$ ⇨ Δ(CO2)/(CO2) < 0.01%! ⇨ gas chromatograph + thermal conductivity detector + high precision drift velocity monitoring necessary
- 5 ppm of O_2 attach 25% of electrons after 2m drift. Gas tightness and fresh gas flow rate (high cost of Ne) are critical

Calibration systems

- Pad by pad calibration stability (aggravated by the large number of channels), necessary for particle identification, accomplished with radioactive Kr gas.
- Complex and sophisticated laser system for monitoring distortions and alignments (ALICE makes use of 336 synchronous laser beams, split by remotely controlled beam splitters and prisms and monitored by a calibrated energy meter and imaged with CCD's.

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Genesis and evolution

I. **KLOE** ancestor chamber at INFN LNF Daϕne φ factory (commissioned in 1998 and operated for the over 20 years)

II. **CluCou** chamber proposed for the **4th-Concept** at ILC (2009)

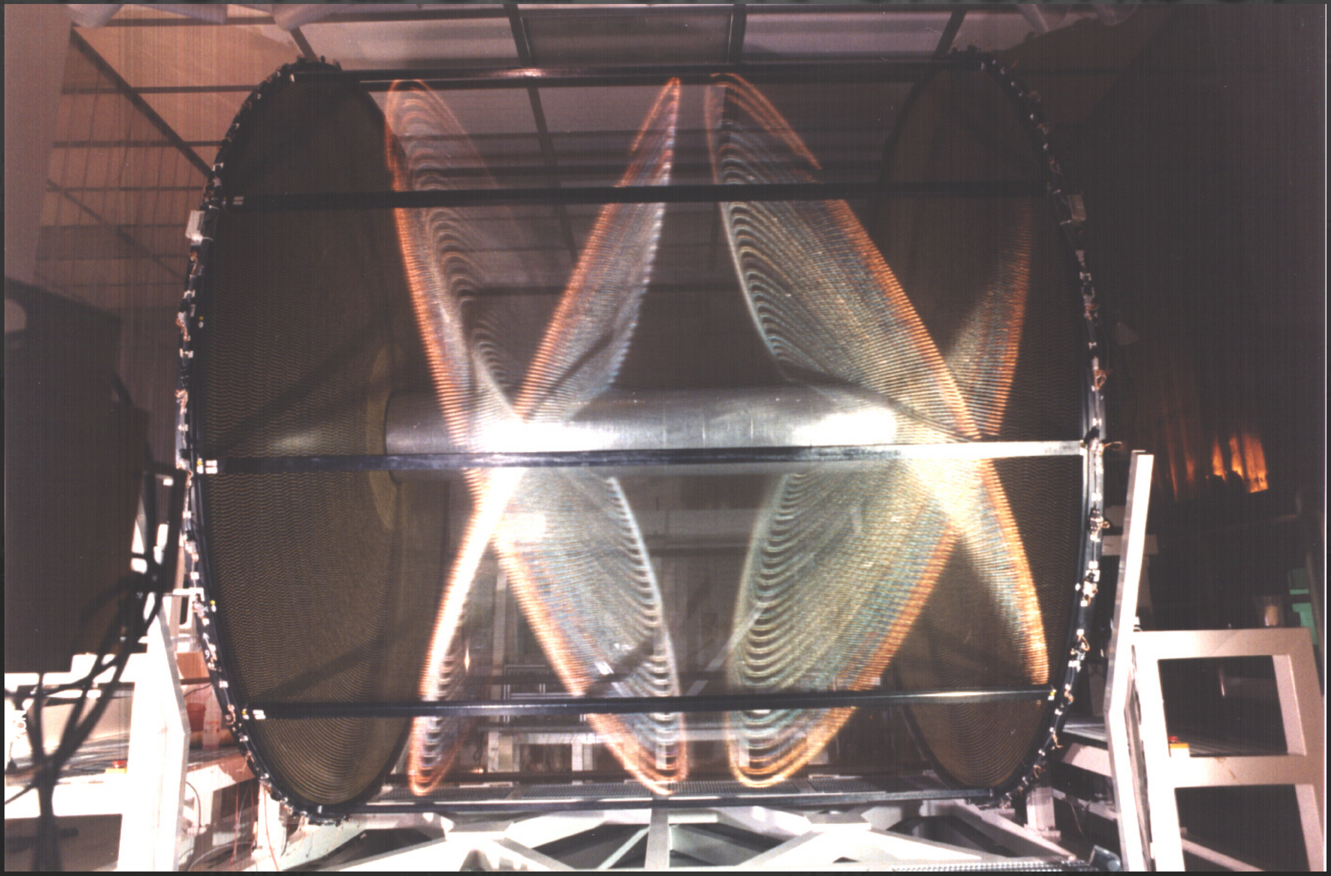
III. **I-tracker** chamber proposed for the **Mu2e experiment** at Fermilab (2012)

IV. **DCH** for **MEG2** at PSI (designed in 2014, now and under commissioning)

V. **IDEA** drift chamber proposal for **FCC-ee** and **CEPC** (2016)

VI. **TraPId** drift chamber proposal for the Russian **SCTF** (2018)

The KLOE drift chamber



Innovations introduced

from KLOE ...

I. Wire configuration **fully stereo** (no axial layers)

II. new **light Aluminum** wires

III. Very light gas mixture (X_0 = 2300 m) **90% He – 10% iC_4H_{10}**

IV. Mechanical structure entirely in **Carbon Fiber** (0.047 X_0)

V. Largest volume **drift chamber** ever built (45 m^3)

... to IDEA

I. Separating **gas containment** from **wire support** functions

II. New concepts for **wire tension compensation**

III. Using **a larger number** of **thinner** (and **lighter** wires)

IV. New wire type (**C monofilament**)

V. No **feed-through** wiring

VI. Using **cluster counting** for particle identification

VII. Using **cluster timing** for improved spatial resolution

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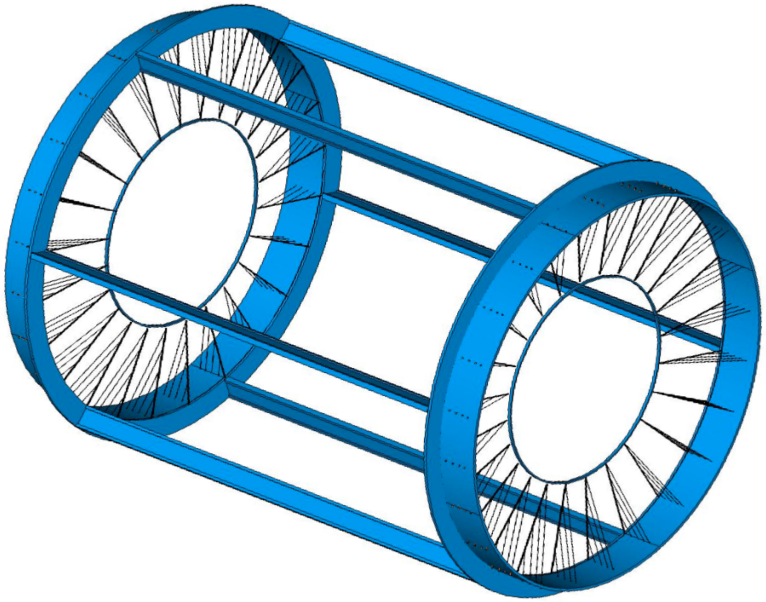
"Traditional" drift chamber

A cylindrically symmetric gas volume with (para-)axial wires defining a strong electric field, strung under mechanical tension for electrostatic stability and fixed at their extremities to the end walls by means of feed-through.

CONSTRAINTS:

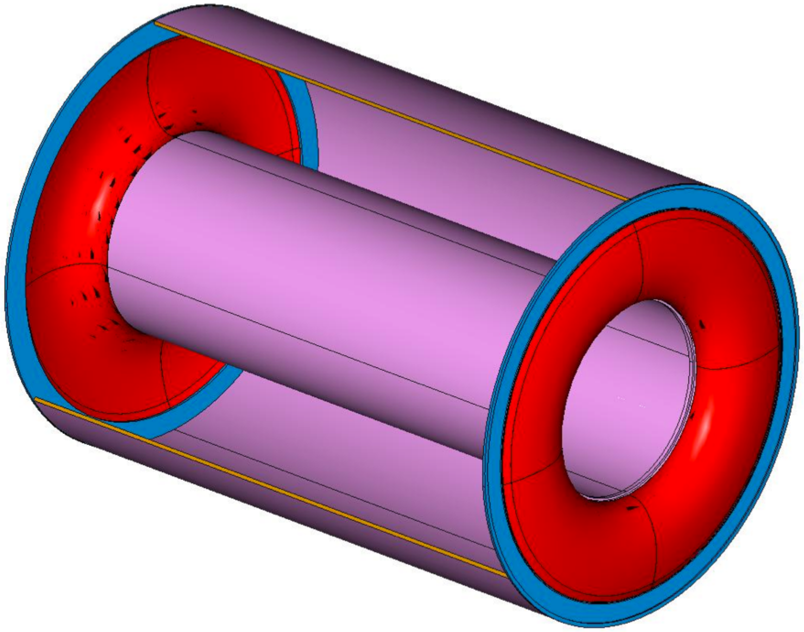
- The **end walls**, holding the feed-through (which limit the chamber granularity), the FE electronics and the relative cabling, must be rigid enough to transfer the load due to the wire tension (of the order of several Tons) to the **outer cylindrical wall**, without deforming.
- The **inner cylindrical wall**, usually, does not bear any load, to minimize the multiple scattering of incoming particles.
- The **gas tightness** relies on the hermetic properties of all surfaces and of all their relative joints.

Separate functions of mechanical structure



Wire support:

Wire cage structure not subject to differential pressure can be light and feed-through-less.



Gas containment:

Gas envelope can freely deform without affecting the internal wire position and tension.

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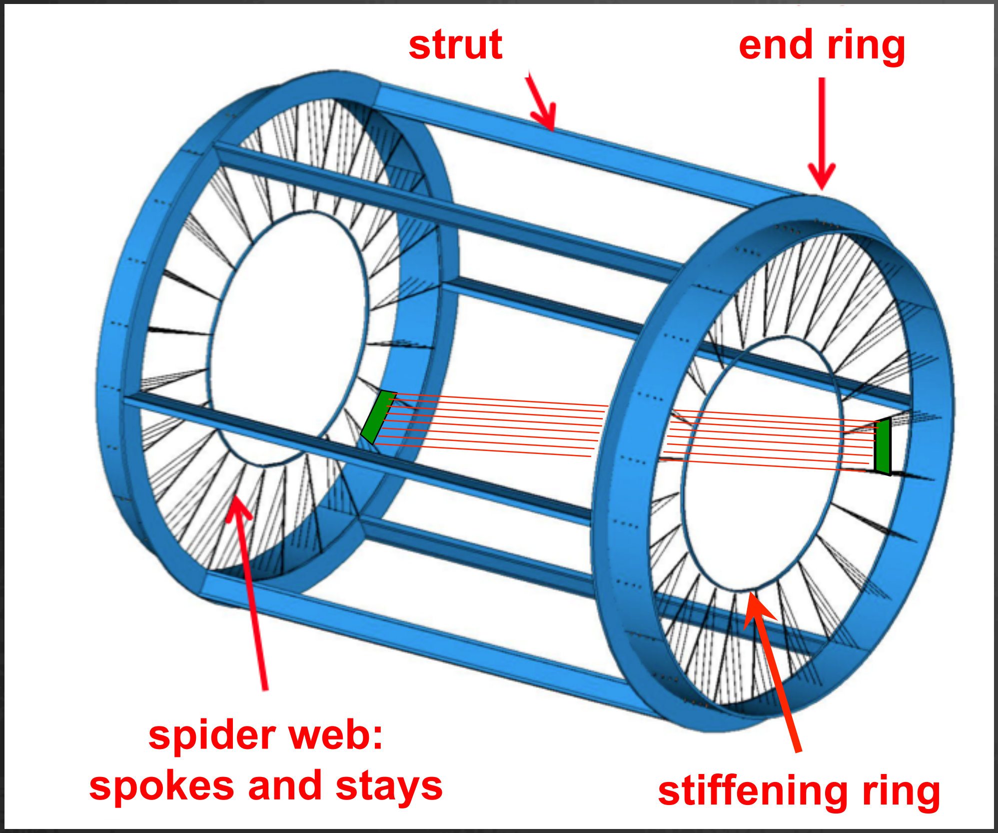
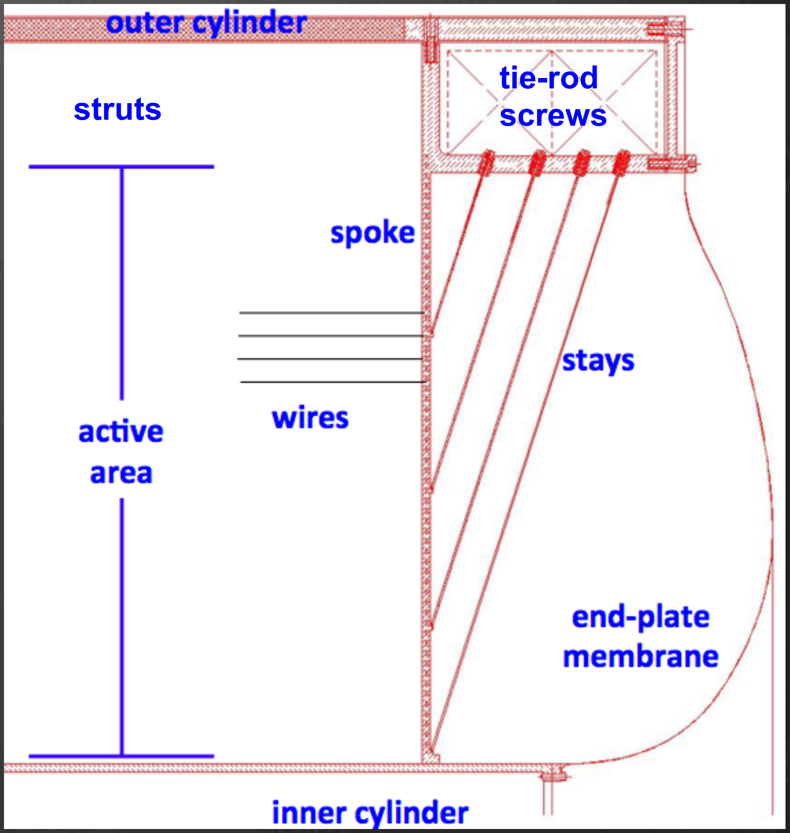
Wire tension compensation





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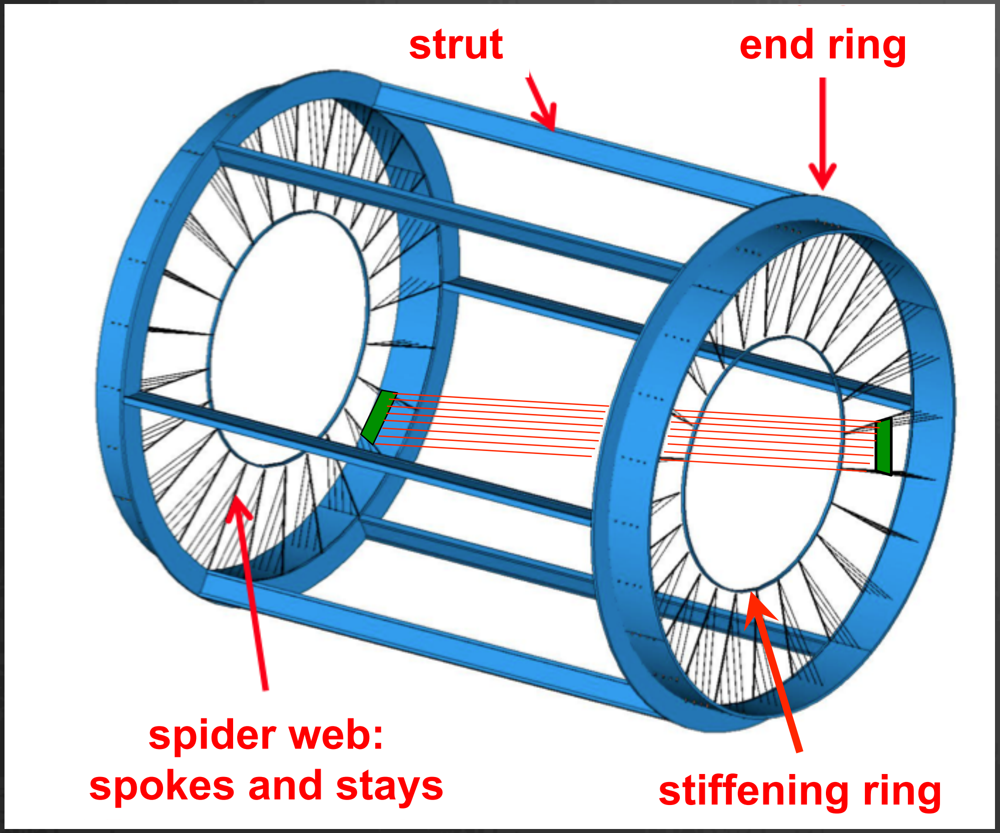
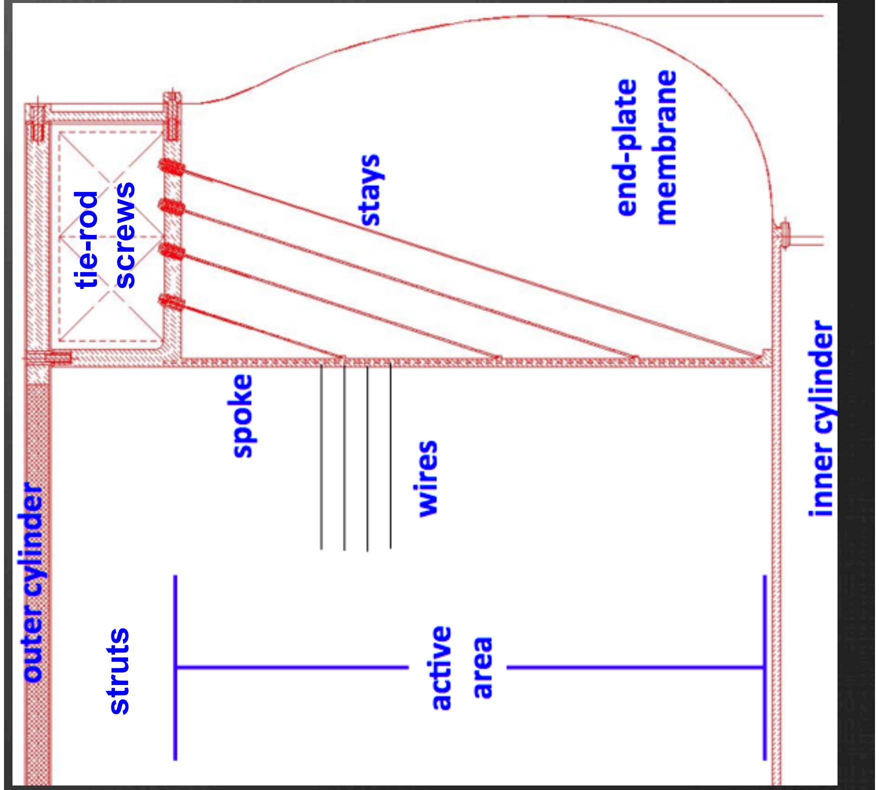
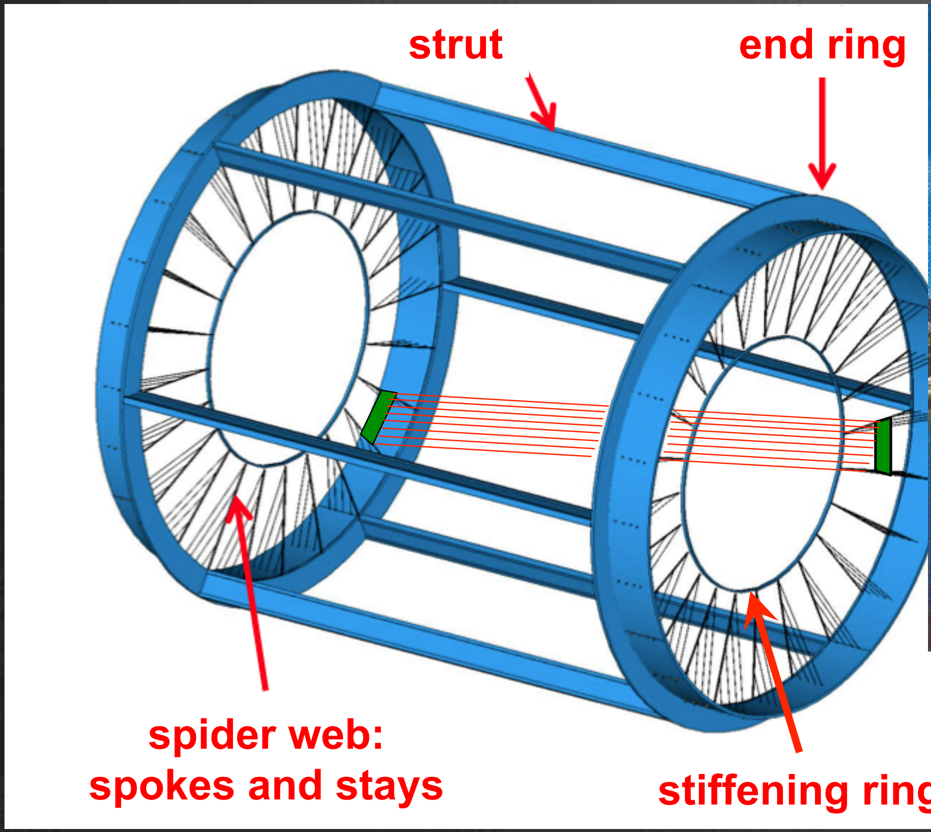
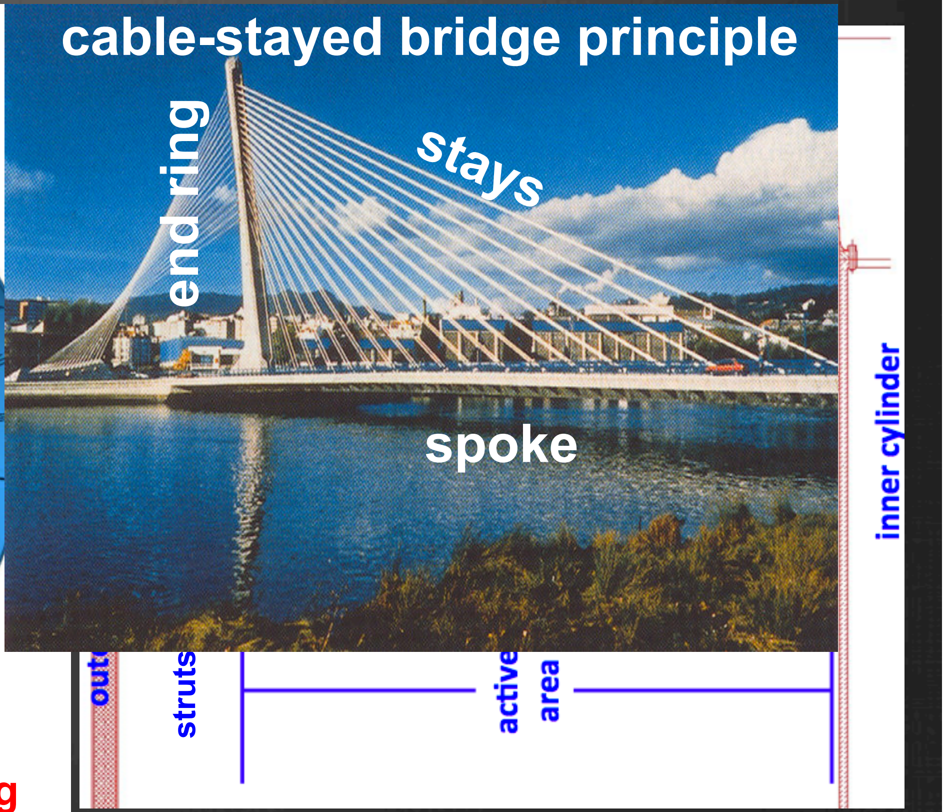


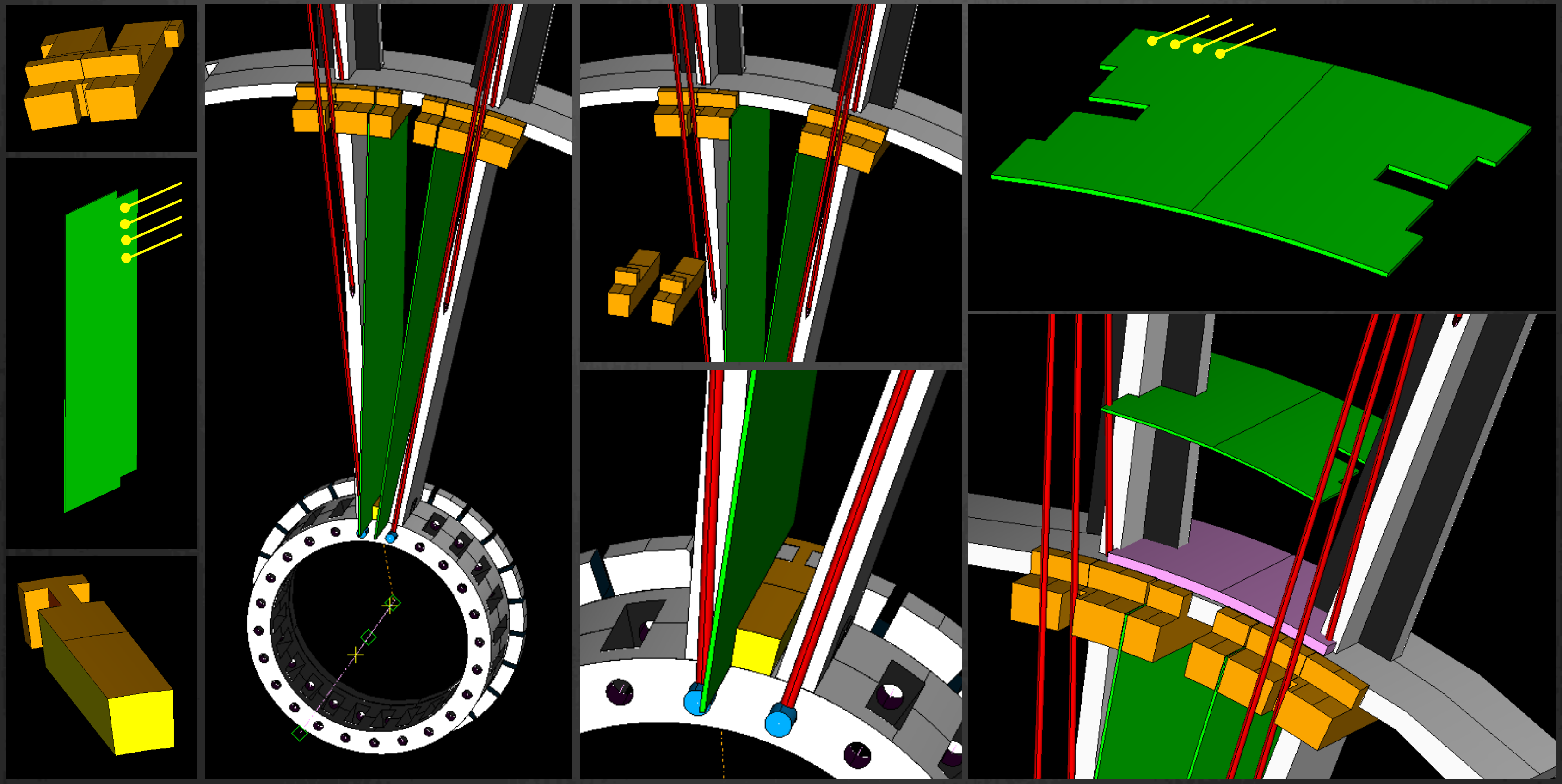


Wire tension compensation





The (de-materialized) end-plate



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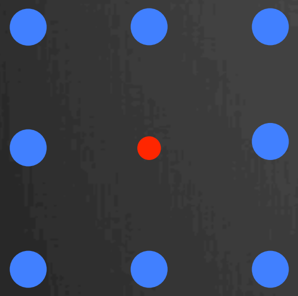
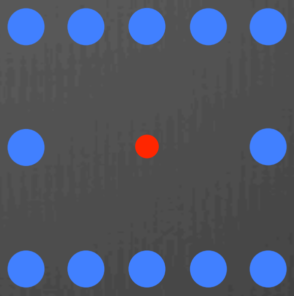
More wires doesn't mean more mass!



$R_{fs} = \frac{\text{field wires}}{\text{sense wire}} = 3{:}1$



$R_{fs} = \frac{\text{field wires}}{\text{sense wire}} = 5{:}1$

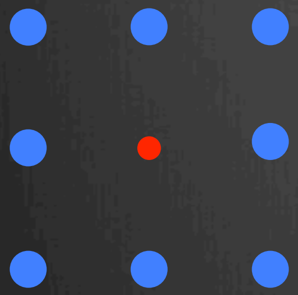
- For a reasonable gain on the sense wire $E_{sense} \approx 200$ KV/cm
- Aging requirements impose $E_{field} < 20$ KV/cm, i.e. $E_{sense} / E_{field} > 10$ or

  $r_{field} > 10 \times r_{sense} / R_{fs}$

- $r_{sense} = 20$ μm → $r_{field} > 67$ μm (for $R_{fs} = 3{:}1$); $r_{field} > 40$ μm (for $R_{fs} = 5{:}1$)

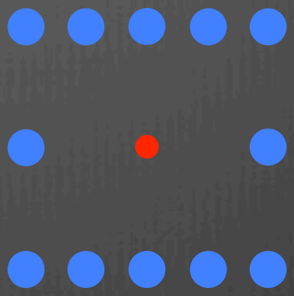
However, multiple scattering contribution is proportional to the wires mass, i.e. to the square of the radius and, for each drift cell, the contribution of the field wires is proportional to $r^2_{sense} \times (100/ R_{fs} \times \delta_{field})$: the larger R_{fs}, the **smaller** the **multiple scattering contribution** and the **total tension on the end-caps**.

More wires means thinner wires!



● 20 μm W(Au)

● 70 μm Al(Ag)



● 20 μm W(Au)

● 40 μm Al(Ag)

single cell (1 cm^2): **2.2×10^{-5} X_0** **1.7×10^{-5} X_0**

1 cm gas (90% He – 10% iC_4H_{10}) = **4.4×10^{-6} X_0**

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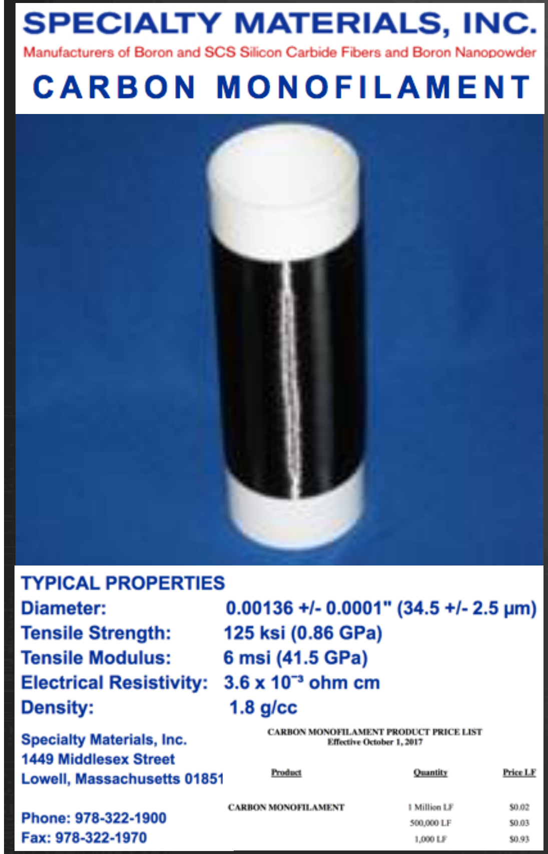


SPECIALTY MATERIALS, INC.

Manufacturers of Boron and SCS Silicon Carbide Fibers and Boron Nanopowder

CARBON MONOFILAMENT

TYPICAL PROPERTIES

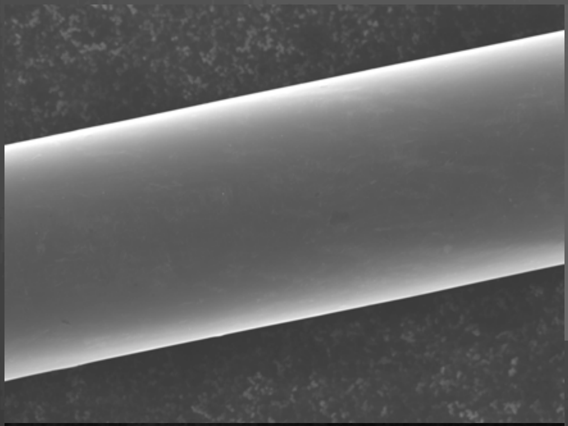
Diameter:	**0.00136 +/- 0.0001" (34.5 +/- 2.5 µm)**
Tensile Strength:	**125 ksi (0.86 GPa)**
Tensile Modulus:	**6 msi (41.5 GPa)**
Electrical Resistivity:	**3.6 x 10^{-3} ohm cm**
Density:	**1.8 g/cc**

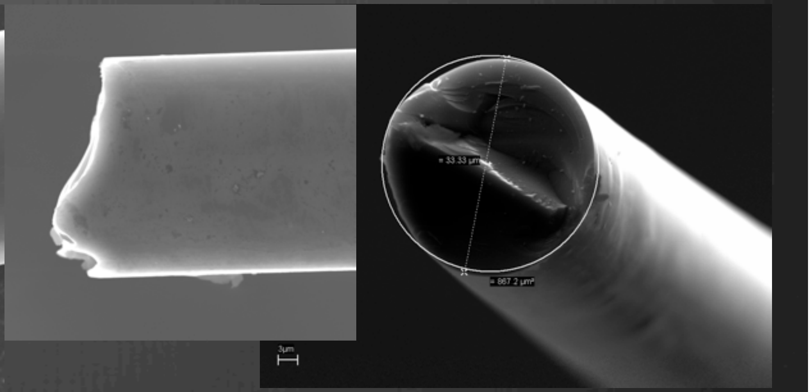
Specialty Materials, Inc.
1449 Middlesex Street
Lowell, Massachusetts 01851

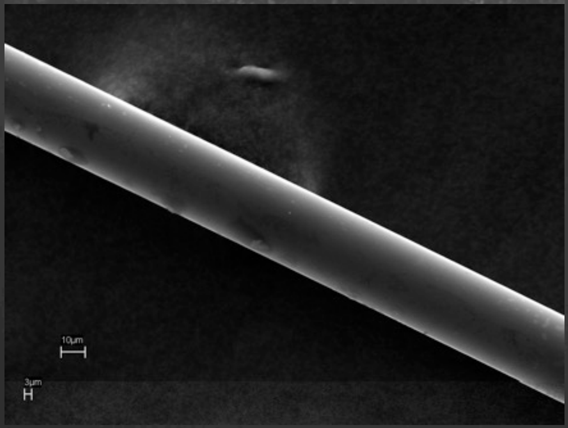
Phone: 978-322-1900
Fax: 978-322-1970

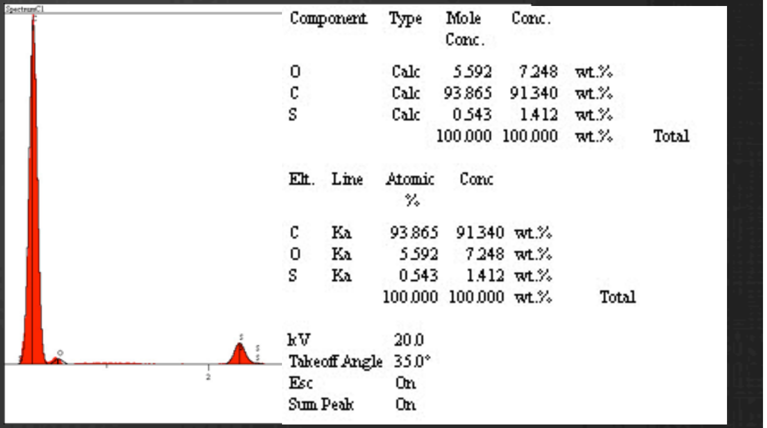
CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

Product	Quantity	Price LF
CARBON MONOFILAMENT	1 Million LF	$0.02
	500,000 LF	$0.03
	1,000 LF	$0.93









Component	Type	Mole Conc.	Conc.		
O	Calc	5.592	7.248	wt.%	
C	Calc	93.865	91.340	wt.%	
S	Calc	0.543	1.412	wt.%	
		100.000	100.000	wt.%	Total

Elt.	Line	Atomic %	Conc		
C	Ka	93.865	91.340	wt.%	
O	Ka	5.592	7.248	wt.%	
S	Ka	0.543	1.412	wt.%	
		100.000	100.000	wt.%	Total

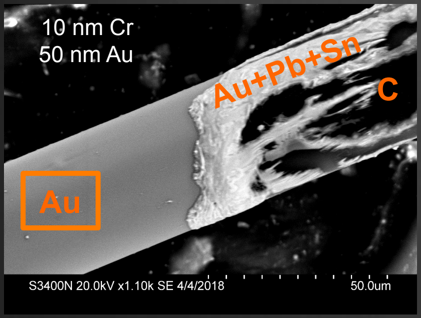
kV	20.0
Takeoff Angle	35.0°
Esc	On
Sum Peak	On

New wire type: C monofilament

C wire metal coating

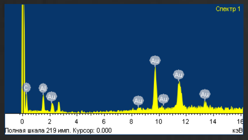
HiPIMS: High-power impulse magnetron sputtering

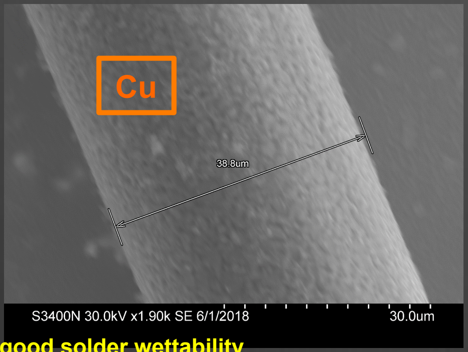
physical vapor deposition (PVD) of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm^2 in short pulses of tens of microseconds at low duty cycle <10%)



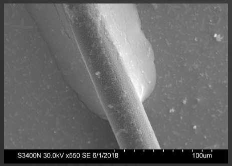
soldering attempt

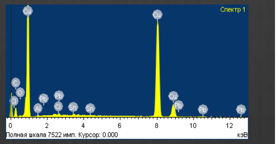
Lead forms intermetallic compound with gold and completely dissolves the 50 nm Au layer.

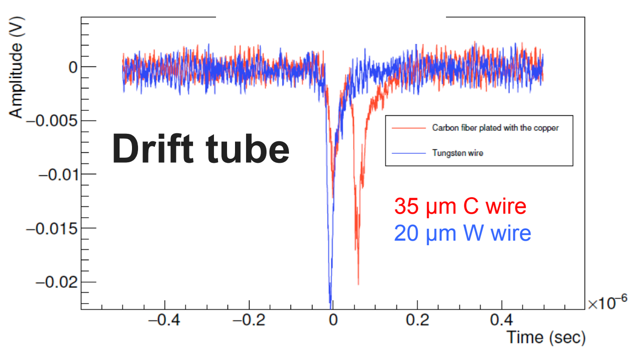


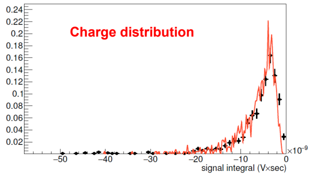


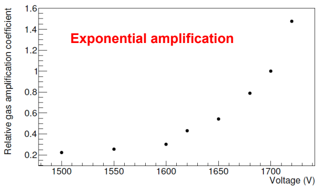
good solder wettability on Cu



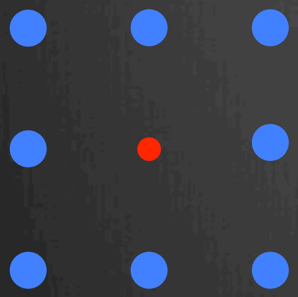






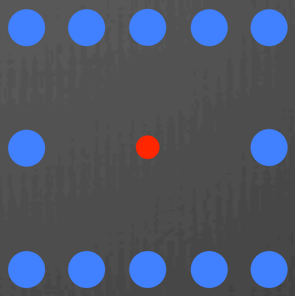


New wires : Mo + C



● 20 µm W(Au)

● 70 µm Al(Ag)



● 20 µm W(Au)

● 40 µm Al(Ag)

single cell (1 cm^2): **$2.2\times10^{-5}\ X_0$** **$1.7\times10^{-5}\ X_0$**

● 15 µm Mo(Ag)
● 35 µm C
→ $3.9\times10^{-6}\ X_0$

1 cm gas (90% He – 10% iC_4H_{10}) = **$4.4\times10^{-6}\ X_0$**

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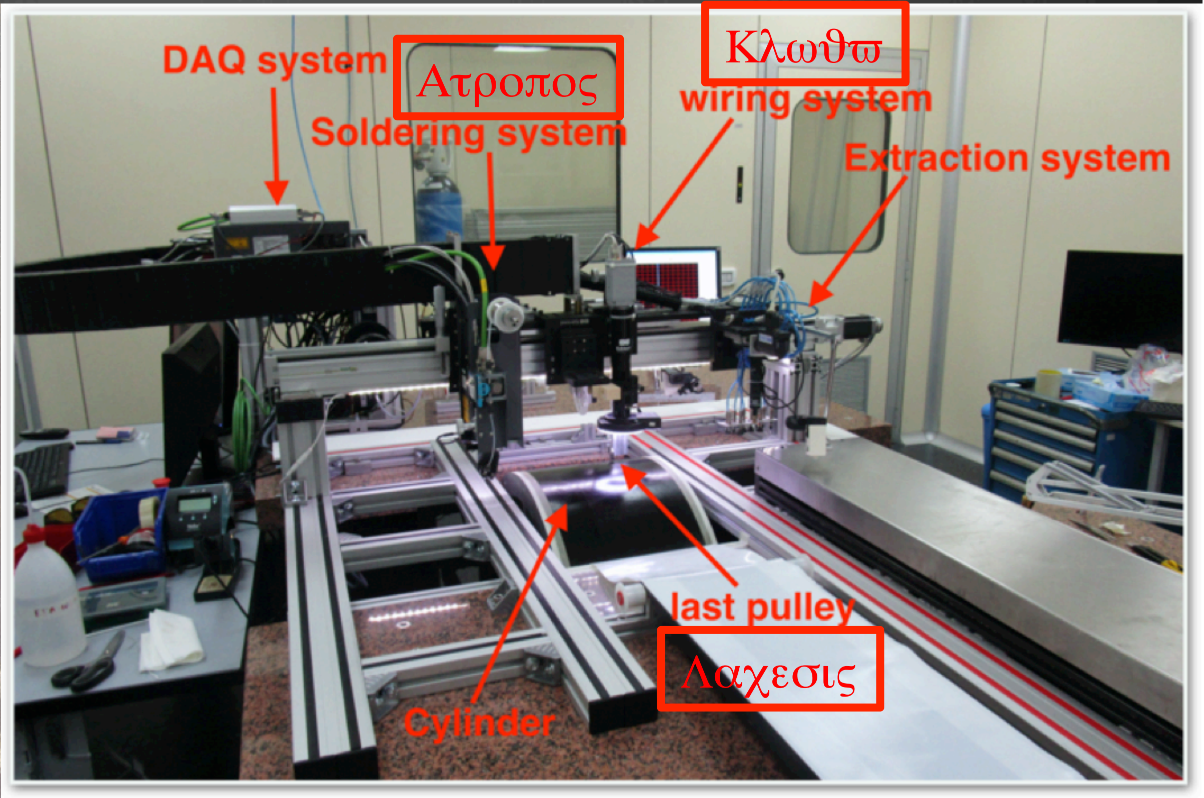
Feed-through-less wiring system

The Old Way

Bernardo Strozzi – Le tre Parche – Venezia, circa 1620

The New Way



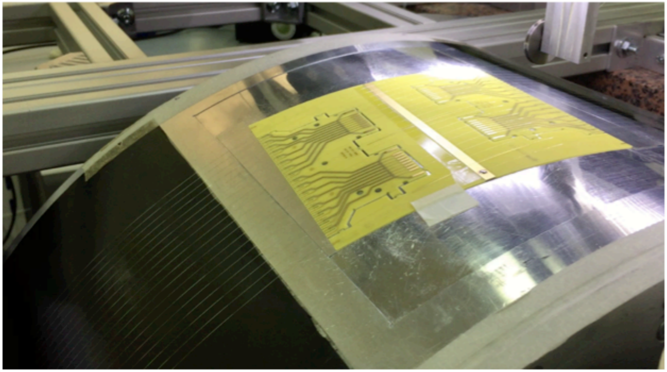
Feed-through-less wiring system

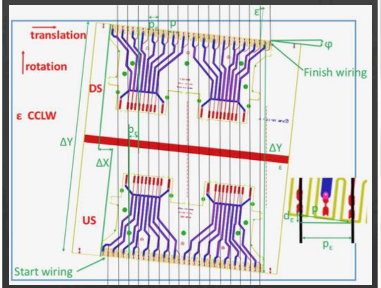
Small drift cells (high chamber granularities), using thinner and lighter field wires, requires high precision assembly procedures, necessarily **feed-through-less**, which call for a novel approach to the wiring problem.

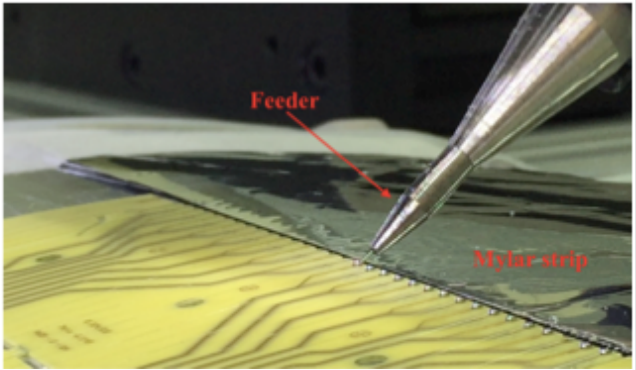
To this purpose, a wiring robot has been designed and built:

- to wind variable pitches, variable lengths and variable stereo angle configurations with continuity;
- to position the wires (accuracy <20 μm) for a simultaneous wiring of multi-wire frames and to apply and to maintain constant and uniform (±0.05g) a pre-defined mechanical tension to the wires throughout the whole procedure;
- to monitor the wires location and their alignments and to solder both wire ends with a contactless infrared laser soldering tool to the wire supporting PCB's.

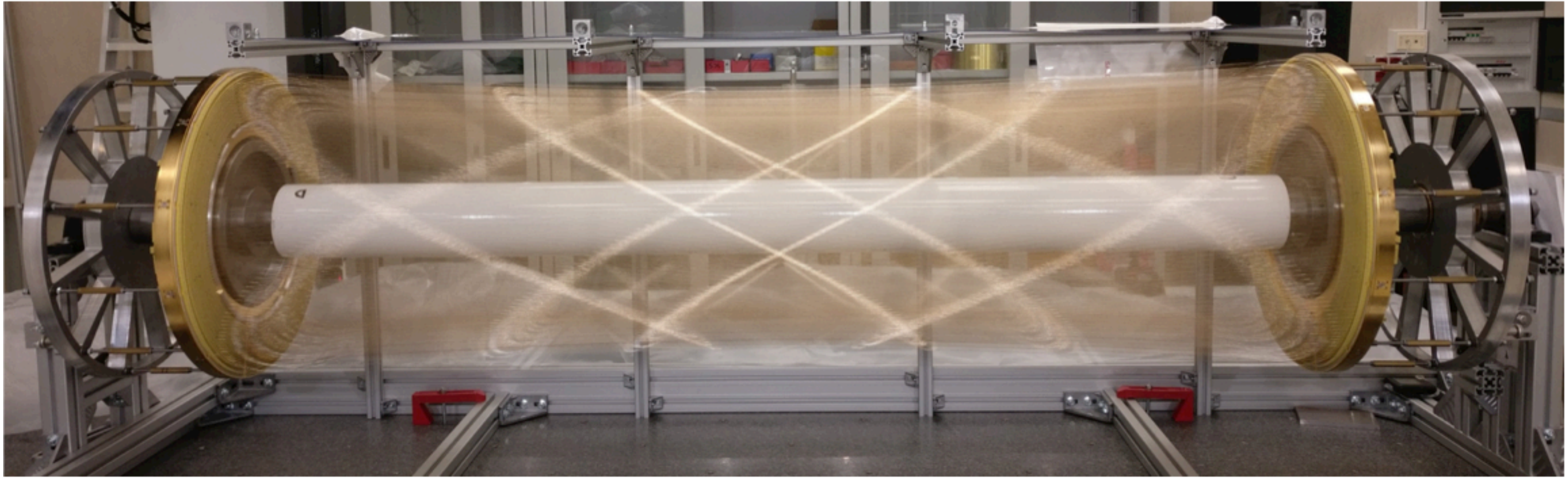
Such a technique has been used for the construction of the **MEG2 drift chamber**.







Feed-through-less wiring system MEG2 drift chamber



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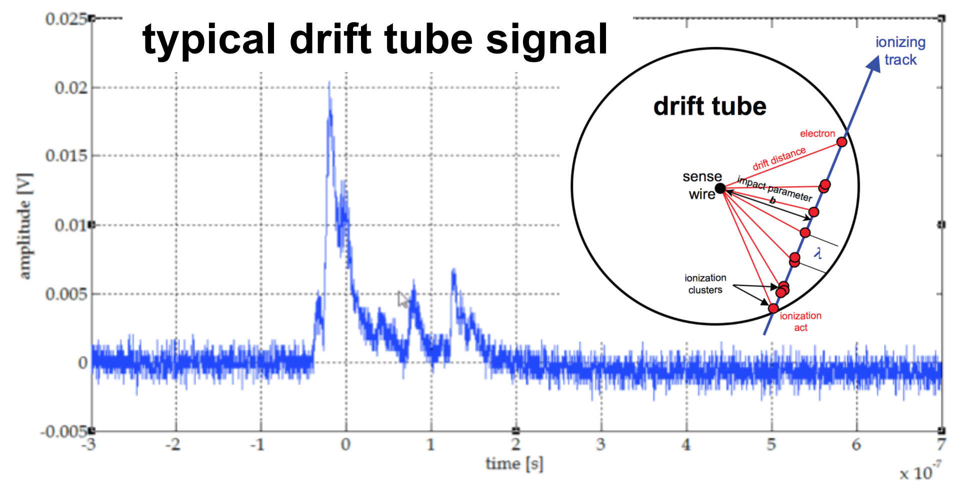
Cluster counting

- **Cluster counting** consists in identifying, in every recorded detector signal, **the isolated structures related to the arrival at the anode wire of the electrons belonging to a single ionization act**.
- In order to achieve this goal, special experimental conditions must be met: **pulses from electrons belonging to different clusters must have a little chance of overlapping in time** and, at the same time, **the time distance between pulses generated by electrons coming from the same cluster must be small enough to prevent over-counting**.
- The fulfillment of both these requirements involves **incompatible time resolutions**: it appears that **the optimal counting condition can be reached only as a result of the equilibrium** between the fluctuations of those processes which forbid a **full cluster detection efficiency** and of the ones enhancing the **time separation among different ionization events**.

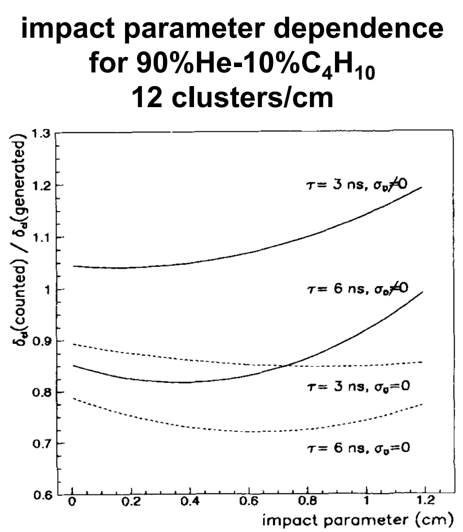


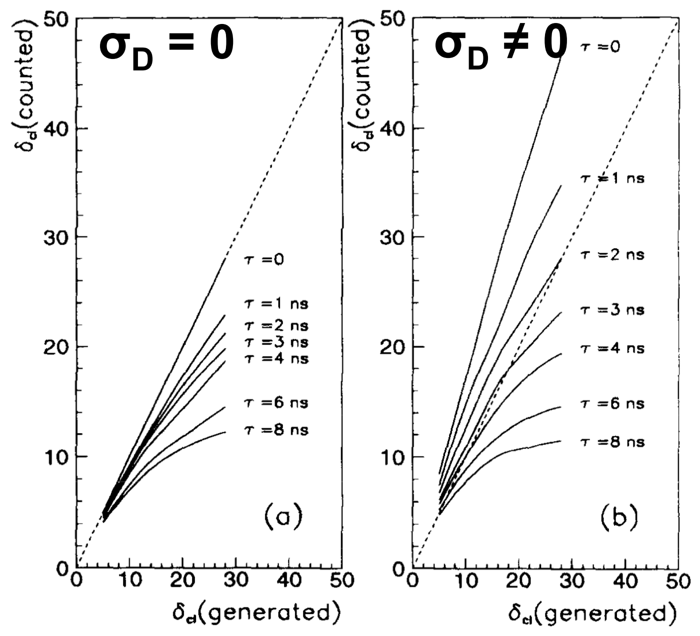
Cluster counting/timing recipe

- High front end bandwidth (≈ 1 GHz)
- S/N ratio > 6
- High sampling rate (2 GSa/s)
- ≥ 12 bit

Cluster counting: first approach

- The relevant parameters for a cluster counting measurement are **the resolving time τ** and **the single electron diffusion σ_D**.
- The ideal conditions, which guarantee a real Poisson distribution of the cluster counting, are met with a resolving time **τ = 0**, in absence of diffusion, **$\sigma_D = 0$**.
- For the $90\%He\text{-}10\%C_4H_{10}$ gas mixture and a 2.5 cm drift cell, the real optimal conditions are met with **τ = 4 ns**
- It should be stressed that the obtained result is strictly related to the **detector geometry** as it depends on the impact parameter and on the dimension of the drift cell for the given gas.
- Corrections due to the track angle, impact parameter, saturation effects, attachment (for long drift) are necessary

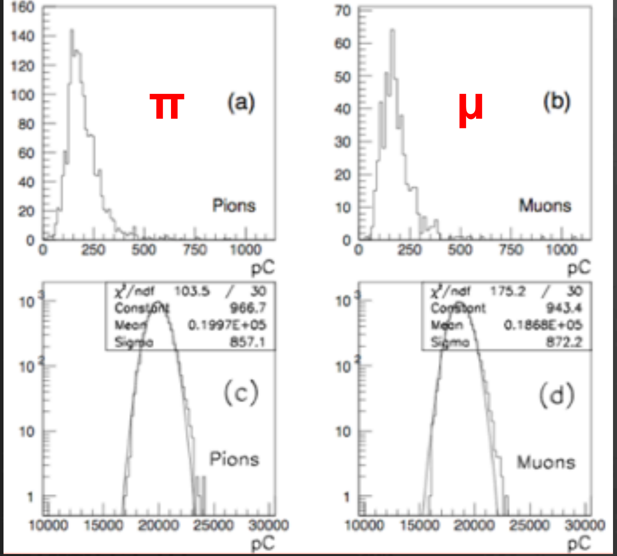

impact parameter dependence for $90\%He\text{-}10\%C_4H_{10}$ 12 clusters/cm



G. Cataldi, F. Grancagnolo, S. Spagnolo *Cluster counting in helium based gas mixtures* NIM A386 (1997) 458

Cluster counting: exp. results

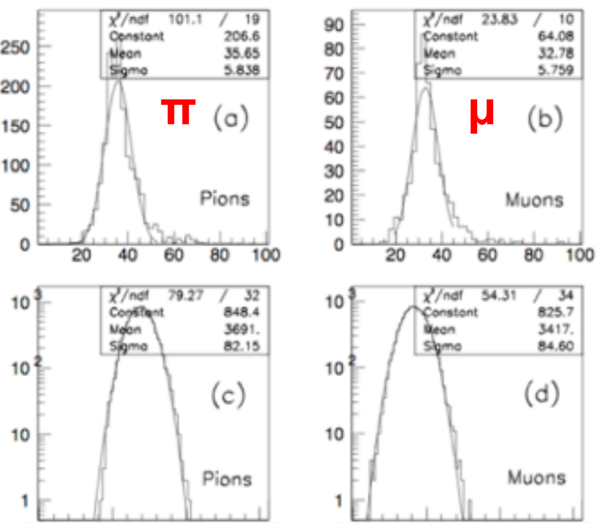
μ/π separation at 200 MeV/c in He/iC$_4$H$_{10}$ – 95/5 100 samples 3.7 cm
gas gain 2×10^5, 1.7 GHz – gain 10 amplifier, 2GSa/s – 1.1 GHz – 8 bit digitizer



single sample
20% truncated
mean

test beam data

sum over
100 samples



single sample

π: $\sigma/\sqrt{N_{cl}}$=0.978
μ: $\sigma/\sqrt{N_{cl}}$=1.006

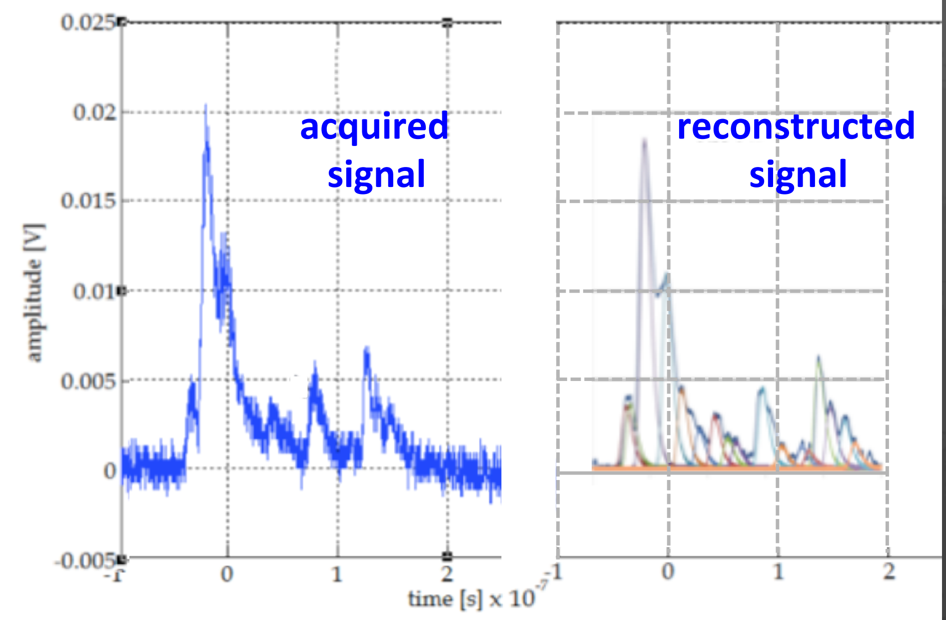
sum over
100 samples

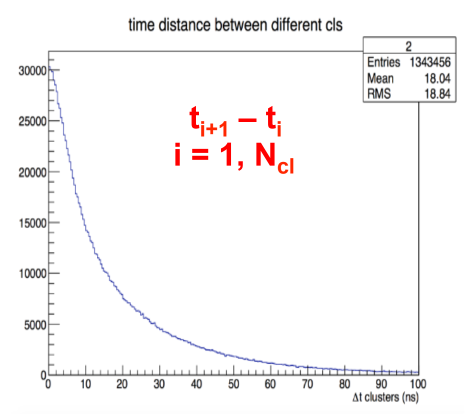
π: $\sigma/\sqrt{N_{cl}}$=1.35
μ: $\sigma/\sqrt{N_{cl}}$=1.45

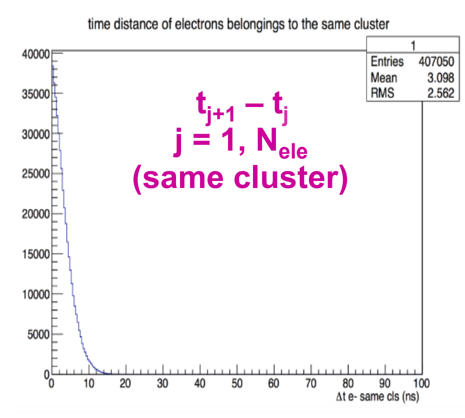
integrated charge
expected 2.0 σ separation
measured 1.4 σ separation

cluster counting
expected 5.0 σ separation
measured 3.2 σ separation

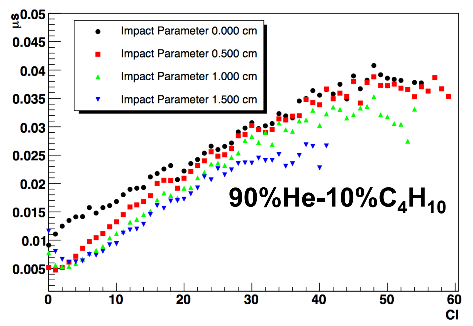
Cluster counting: second approach

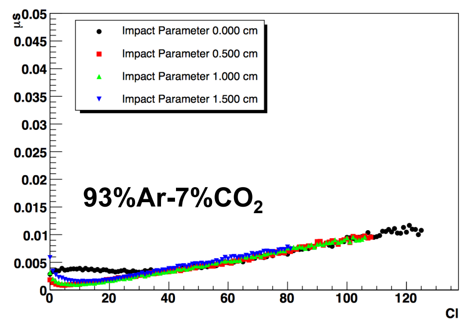






$t_i - t_{i+1}$





From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, one can reconstruct **the most probable sequence of clusters drift times** $\{t_i^{cl}\}, \ i=1,N_{cl}$ and **N_{cl}**:

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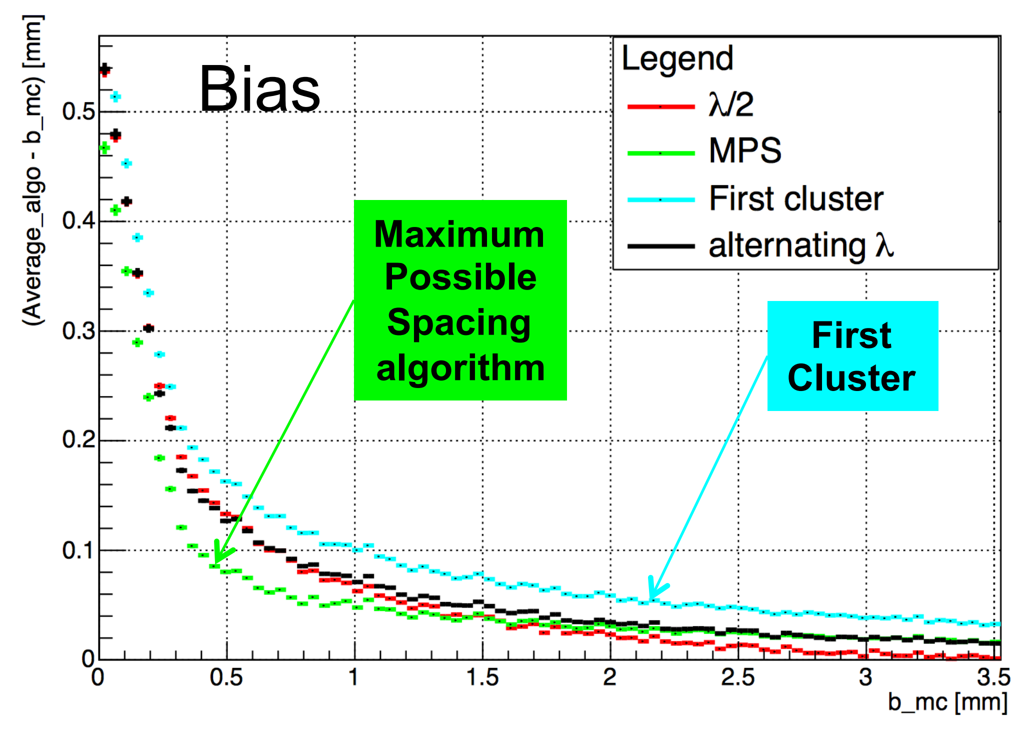
Cluster timing: spatial resolution

$$\left\{t_i^{cl}\right\}, \; i = 1, N_{cl}$$

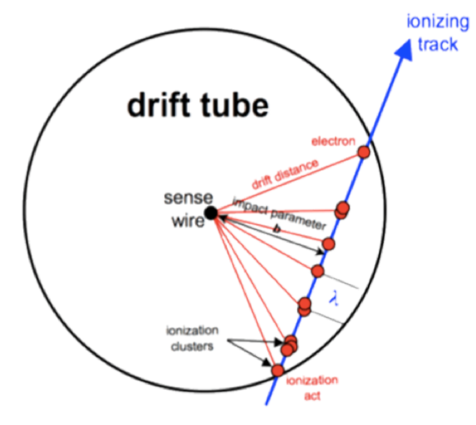
For any given first cluster (**FC**) drift time $\mathbf{t_1}$, the **cluster timing technique** exploits the drift time distribution of all successive clusters to statistically determine, hit by hit, the most probable **impact parameter**, thus reducing the **bias** and improving the average **spatial resolution** with respect to that obtained from with the FC method alone.

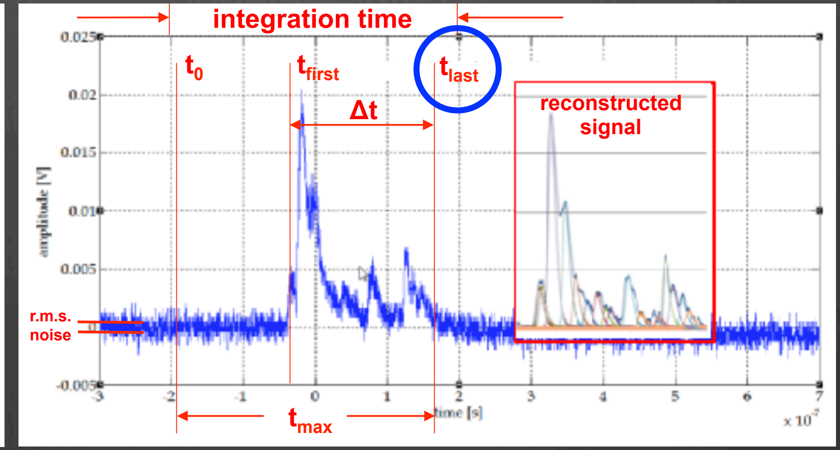


Maximum Possible Spacing algorithm

First Cluster

Cluster timing: noise filtering

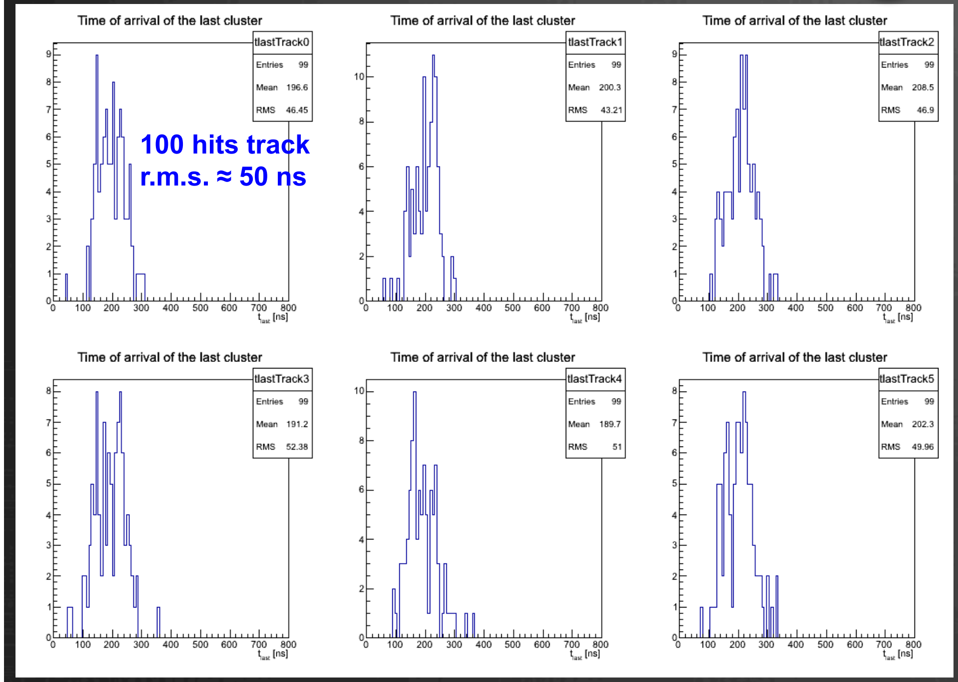




Digitized signal
(1 GHz, 2 GSa/s)

- **$t_{i+1} – t_i$ ≈ a few ns** at small **t_i**, **$t_{i+1} – t_i$ ≈ a few × 10 ns** at large **t_i**
- **t_{max} constant** in ideal case (slightly depending on track angle in drift cell case)
- **$\Delta t \leq t_{max}$**, length of digitized signal, depends on impact parameter **b (t_{first})**
- **N_{cl}** depends only on **Δt** (or **b**, or **t_{first}**) and on the track angle
- **t_{last} constant** in the ideal case => defines the **trigger time $t_0 = t_{last} − t_{max}$**

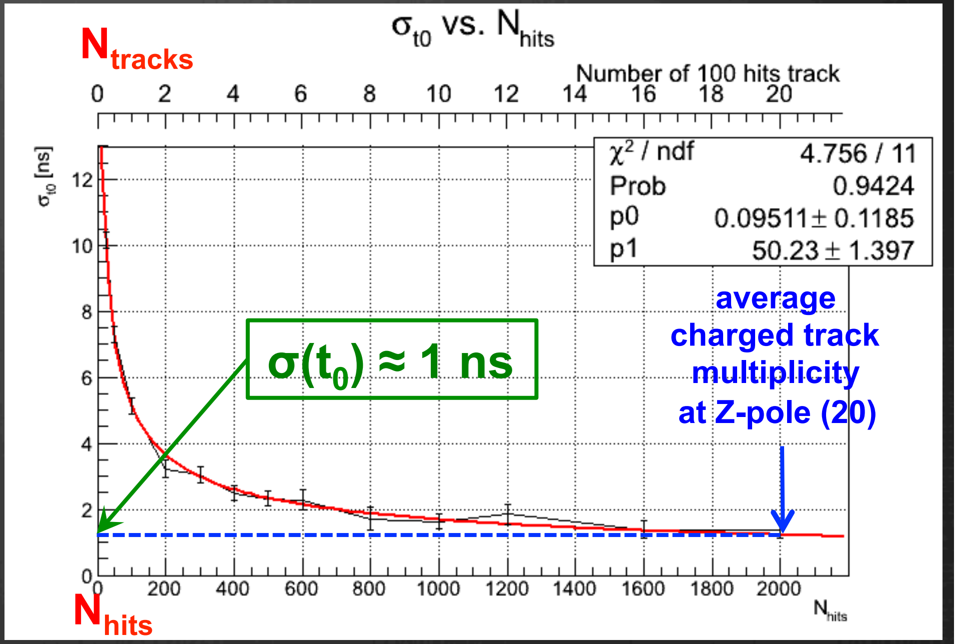
Cluster timing: time stamping



100 hits track
r.m.s. ≈ 50 ns

t_{last} for a single 100 hits track
$\sigma(t_{last}) \approx 5$ ns (r.m.s./√100)

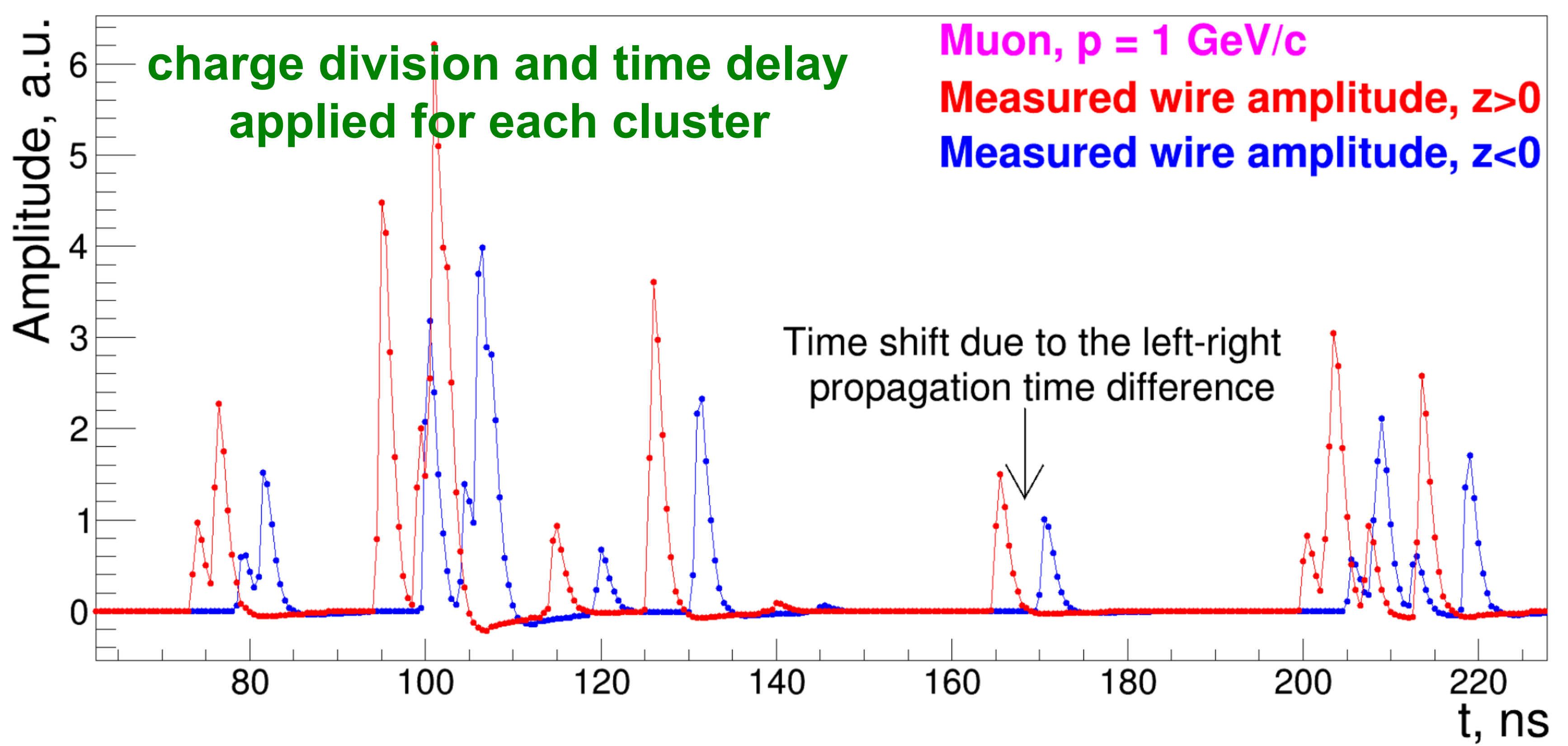
$\sigma(t_0)$ as a function of N_{tracks}
($t_0 = t_{last} - t_{max}$)



$\sigma(t_0) \approx 1$ ns

average
charged track
multiplicity
at Z-pole (20)

Cluster timing: longitudinal coord.



charge division and time delay applied for each cluster

Muon, p = 1 GeV/c

Measured wire amplitude, z>0

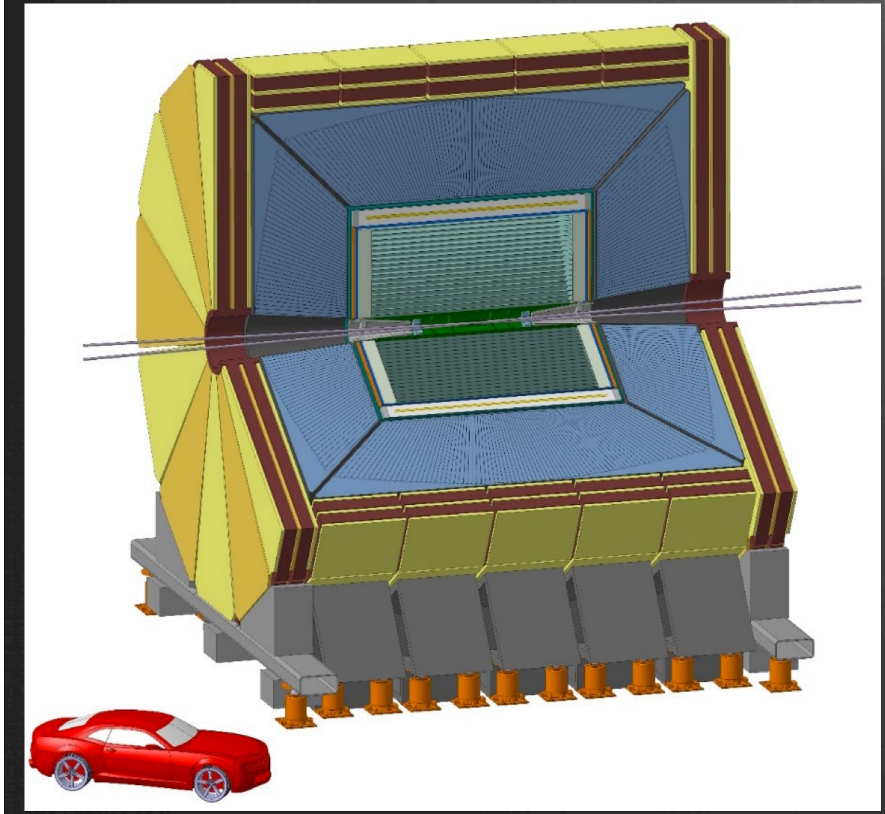
Measured wire amplitude, z<0

Time shift due to the left-right propagation time difference

Outline of the talk

- **Performance evolution of central trackers at e^+e^- colliders – where do we stand?**
    - Momentum Resolution
    - Particle Identification with dE/dx
    - End-Plates Mechanical Structure (X_0)
- **Tracker requirements and choices for next generation e^+e^- colliders**
    - Requirements
    - Si trackers drawbacks
    - TPC drawbacks (my personal biased point of view)
- **Genesis, evolution and innovations of the IDEA drift chamber for FCCee and CEPC**
    - Mechanical structure (wire tension recovery, new wire types, ...)
    - Cluster counting for particle identification
    - Cluster timing for resolution improvement (and more)
- **IDEA drift chamber description and expected performance**
    - General layout
    - Material budget
    - Momentum and Angular resolutions
    - Particle Identification

The IDEA detector

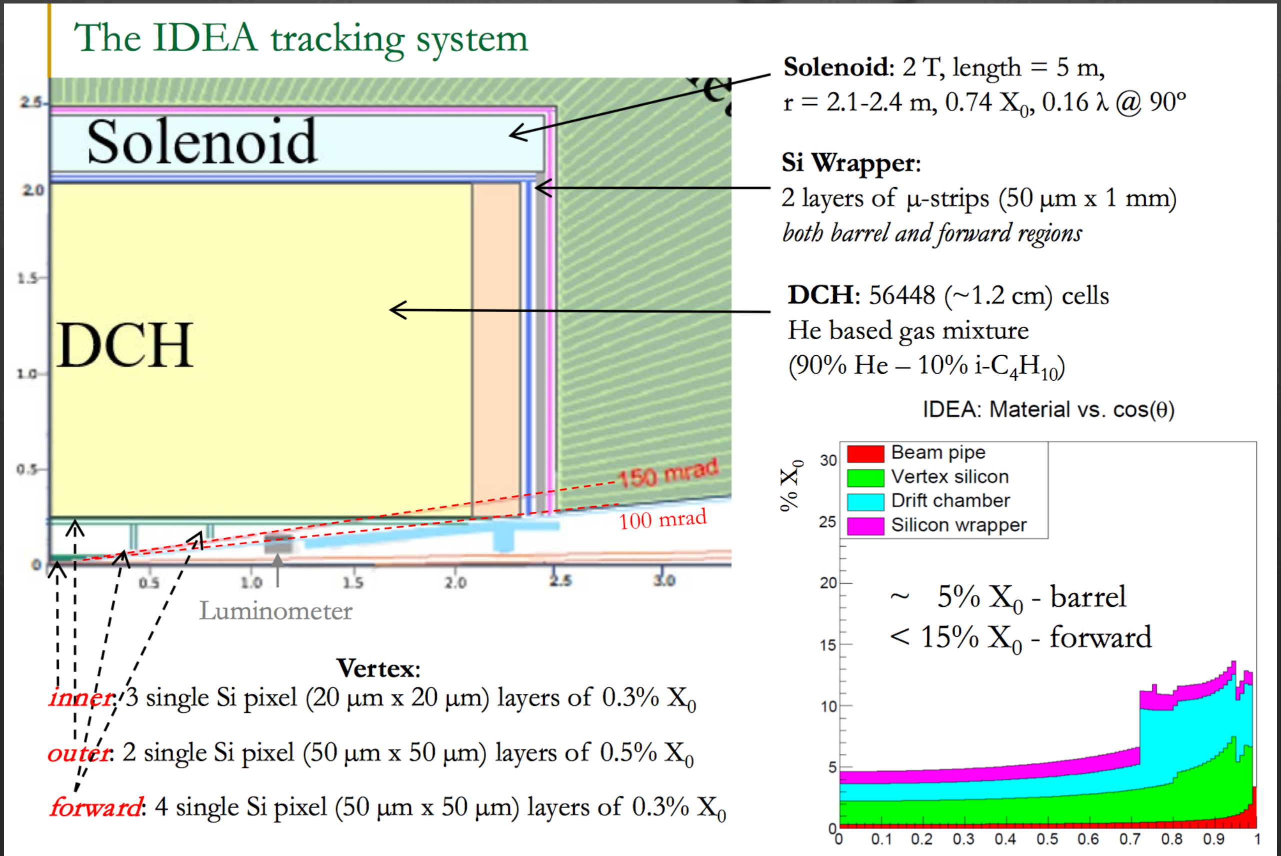


Innovative Detector for E^+e^- Accelerators

vertex detector	tracker	calorimeter	magnet and muon detector
ALICE MAPS	**cluster c. drift chamber**	**Dual Readout**	**μ-RWELL**
3 double layers 20μm×20μm double μ-strips 50μm×1mm 4 forward disks 50μm×50μm	112 layers 1.4 cm square cells 100μm×750μm point resolution Si wrapper 50μm×1mm	fully projective towers Δϑ = 1.125° Δϕ = 10.0° 2880 in barrel 2×1260 end-cap	30cm total envelope 2T field cold mass + cryostat 0.28 + 0.46 X_0 0.6m steel yoke
0.6-1% X_0 per double layer	1.5% X_0 radially 5% X_0 forward	2m D.R. (Cu) 8.2λ	3 layers μ-RWELL 1.5mm×500mm granularity

Si wrapper
pre-shower (μ-RWELL)
solenoid magnet inside calorimeter

IDEA tracking system



The IDEA tracking system

Solenoid: 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X_0, 0.16 λ @ 90°

Si Wrapper:
2 layers of μ-strips (50 μm x 1 mm)
both barrel and forward regions

DCH: 56448 (~1.2 cm) cells
He based gas mixture
(90% He – 10% i-C_4H_{10})

~ 5% X_0 - barrel
< 15% X_0 - forward

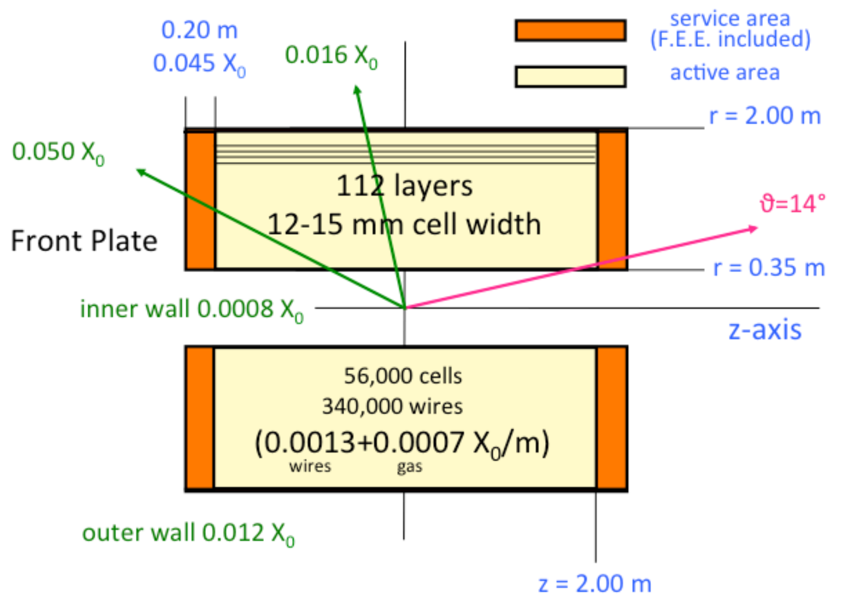
Vertex:

inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0

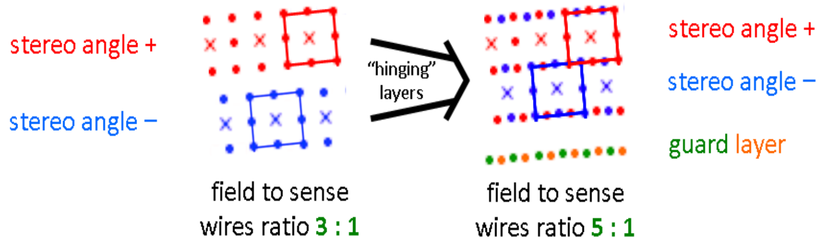
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0

Drift chamber layout



0.20 m
0.045 X_0
0.016 X_0
service area (F.E.E. included)
active area
r = 2.00 m
0.050 X_0
112 layers
12-15 mm cell width
Front Plate
ϑ=14°
r = 0.35 m
inner wall 0.0008 X_0
z-axis
56,000 cells
340,000 wires
$(0.0013+0.0007\ X_0/\mathrm{m})$
wires gas
outer wall 0.012 X_0
z = 2.00 m

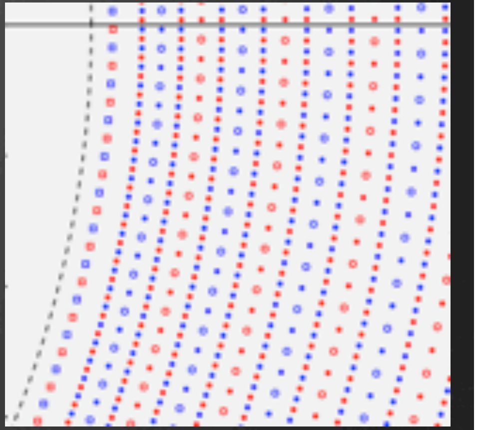


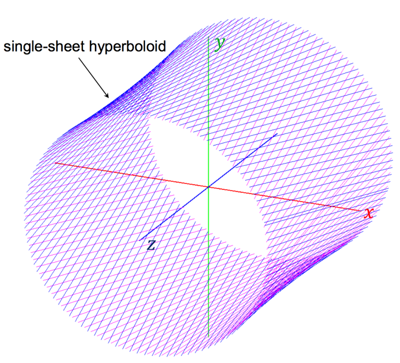
stereo angle +
stereo angle −
“hinging” layers
field to sense wires ratio **3 : 1**
field to sense wires ratio **5 : 1**
stereo angle +
stereo angle −
guard layer

14 co-axial super-layers, 8 layers each (**112 layers**) with alternating sign stereo angles ranging from 50 to 250 mrad, in 24 equal azimuthal (15°) sectors

12 to 15 mm wide square cells, 5:1 field to sense wires ratio, **56,448 cells**

20 µm W(Au) => 56448 sense wires
40 µm Al(Ag) => 229056 field wires
50 µm Al(Ag) => 58464 guard wires
343,968 wires in total





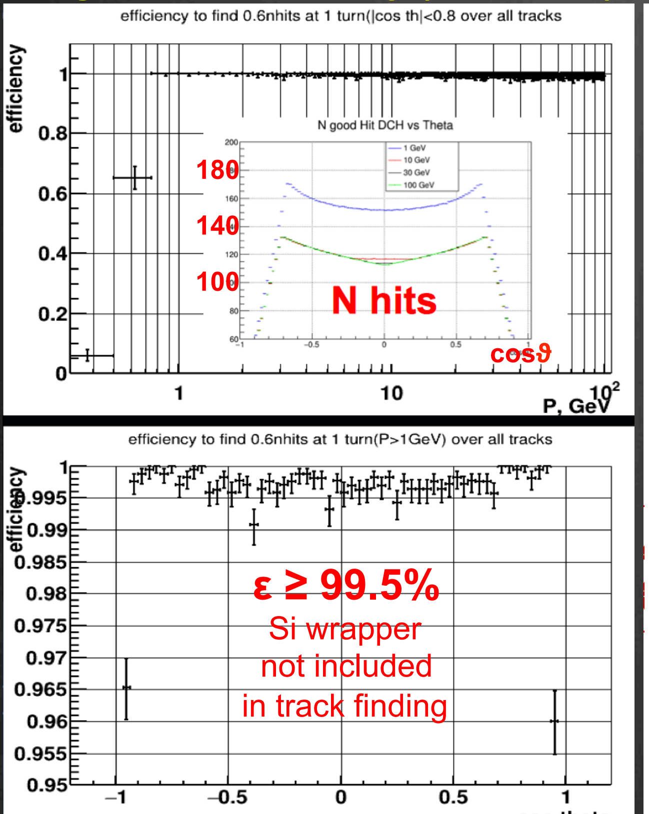
material budget

Conservative estimates:

Inner wall (from CMD3 drift chamber) 200 µm Carbon fiber	**$8.4\times10^{-4}\ X_0$**
Gas (from KLOE drift chamber) 90% He – 10% iC_4H_{10}	**$7.1\times10^{-4}\ X_0/\mathrm{m}$**
Wires (from MEG2 drift chamber) 20 µm W sense wires $4.2\times10^{-4}\ X_0/\mathrm{m}$ 40 µm Al field wires $6.1\times10^{-4}\ X_0/\mathrm{m}$ 50 µm Al guard wires $2.4\times10^{-4}\ X_0/\mathrm{m}$	**$1.3\times10^{-3}\ X_0/\mathrm{m}$**
Outer wall (from Mu2e I-tracker studies) 2 cm composite sandwich (7.7 Tons)	**$1.2\times10^{-2}\ X_0$**
End-plates (from Mu2e I-tracker studies) wire cage + gas envelope incl. services (electronics, cables, ...)	**$4.5\times10^{-2}\ X_0$**

Drift chamber full MC performance

single track efficiency (>60% hits)

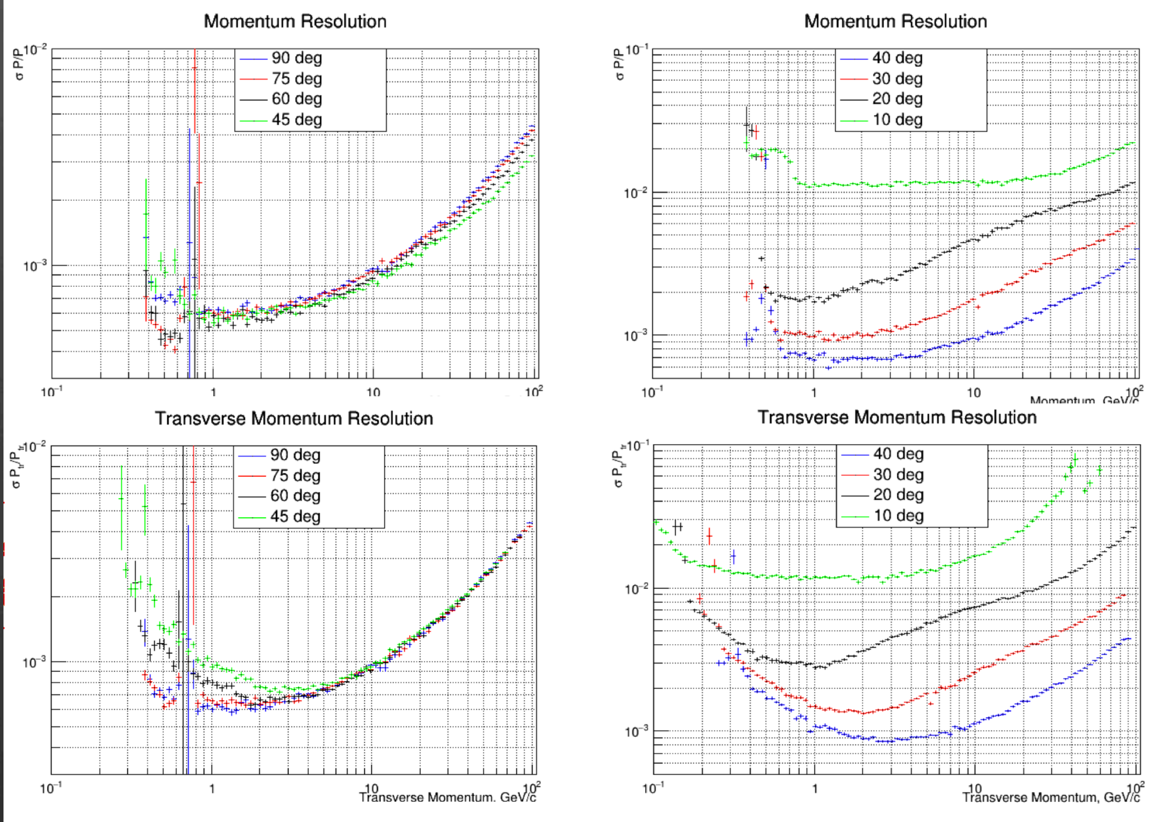


N hits

ε ≥ 99.5%

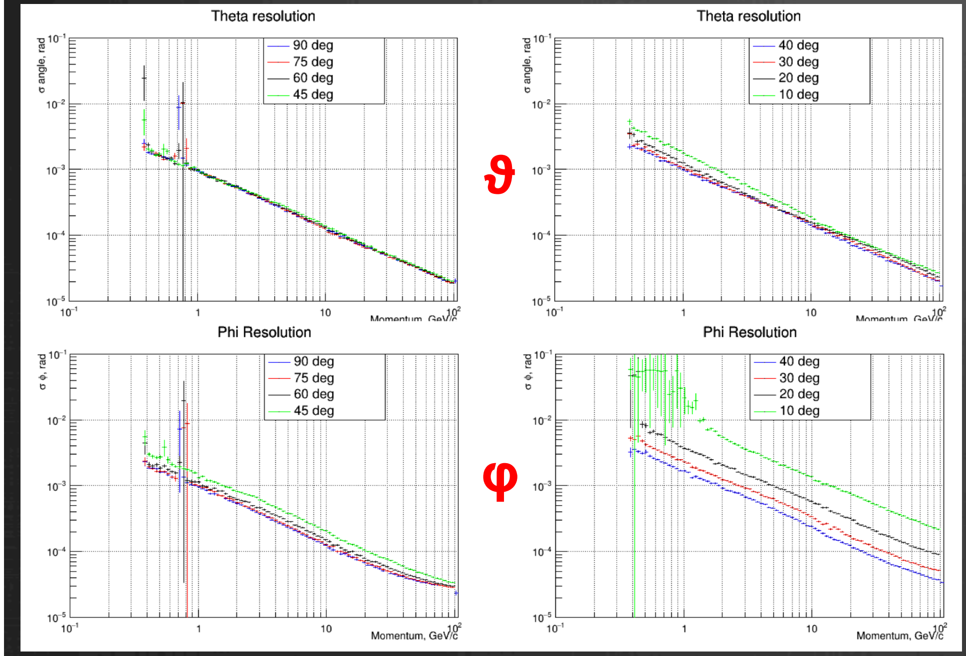
Si wrapper
not included
in track finding

momentum and transverse momentum resolution vs p_t

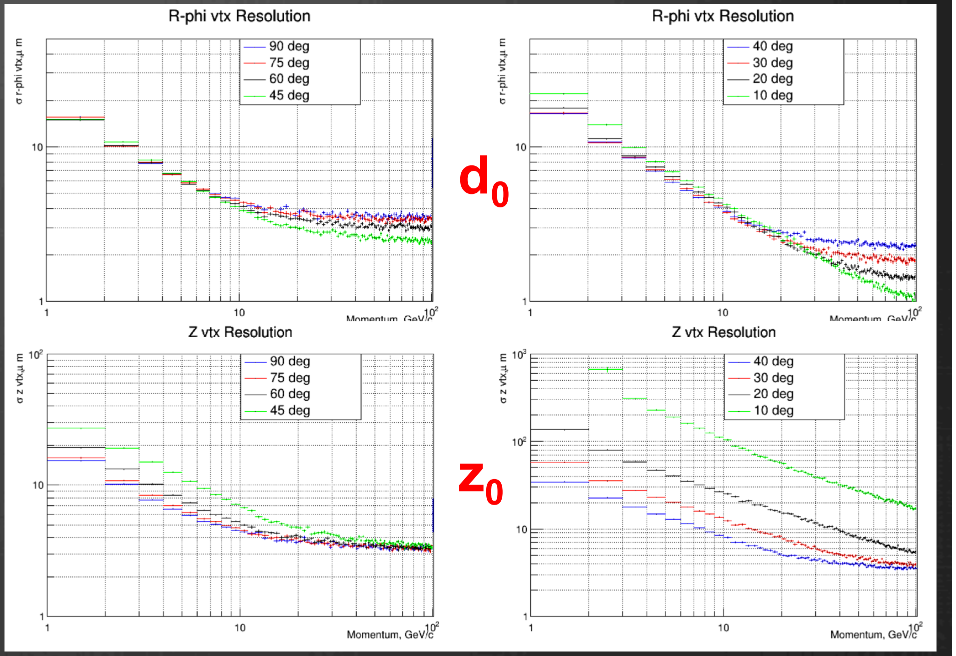


Drift chamber full MC performance

angular resolution vs p_t

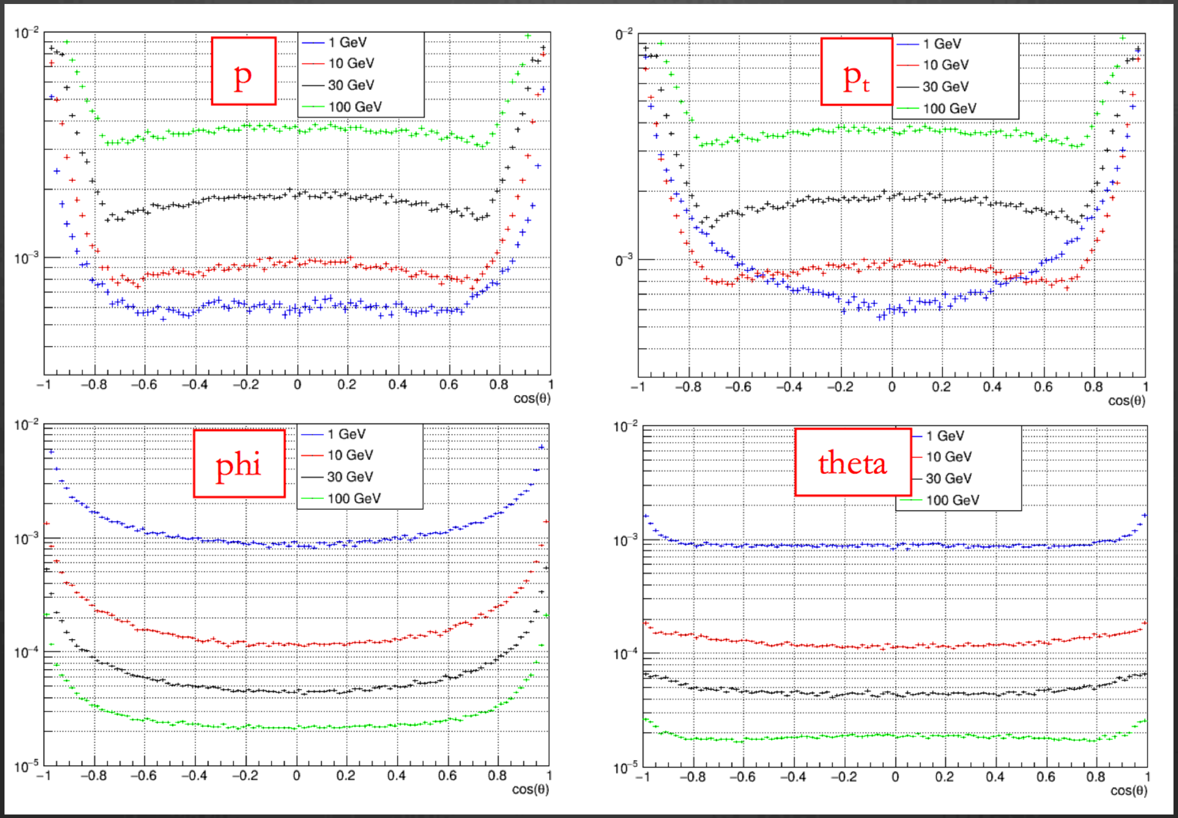


impact parameter resolution vs p_t



Drift chamber full MC performance

momentum, transverse momentum and angular resolutions vs $\cos\vartheta$



Drift chamber Particle Identification

$$\frac{\sigma_{dE/dx}}{\left(dE/dx\right)} = 0.41 \cdot n^{-0.46} \cdot \left(L_{track}\left[m\right] \cdot P\left[atm\right]\right)^{-0.32}$$

W. Allison and J. Cobb *Relativistic charged particles identification by energy loss*
Ann. Rev. Nucl. Part. Sci. 1980. 30: 253-98

- 5-80% truncated mean method
- statistical fluctuations of gas gain (< 1%)
  - drift distance dependence
  - z-dependence along the wire
  - wire sagging ($\Delta w/w < 3 \times 10^{-3}$)
- statistical fluctuation of energy loss (Landau)
- attachment (gas quality)
- avalanche saturation (angle dependence)
- rate effects
- double track separation
- wire to wire calibration

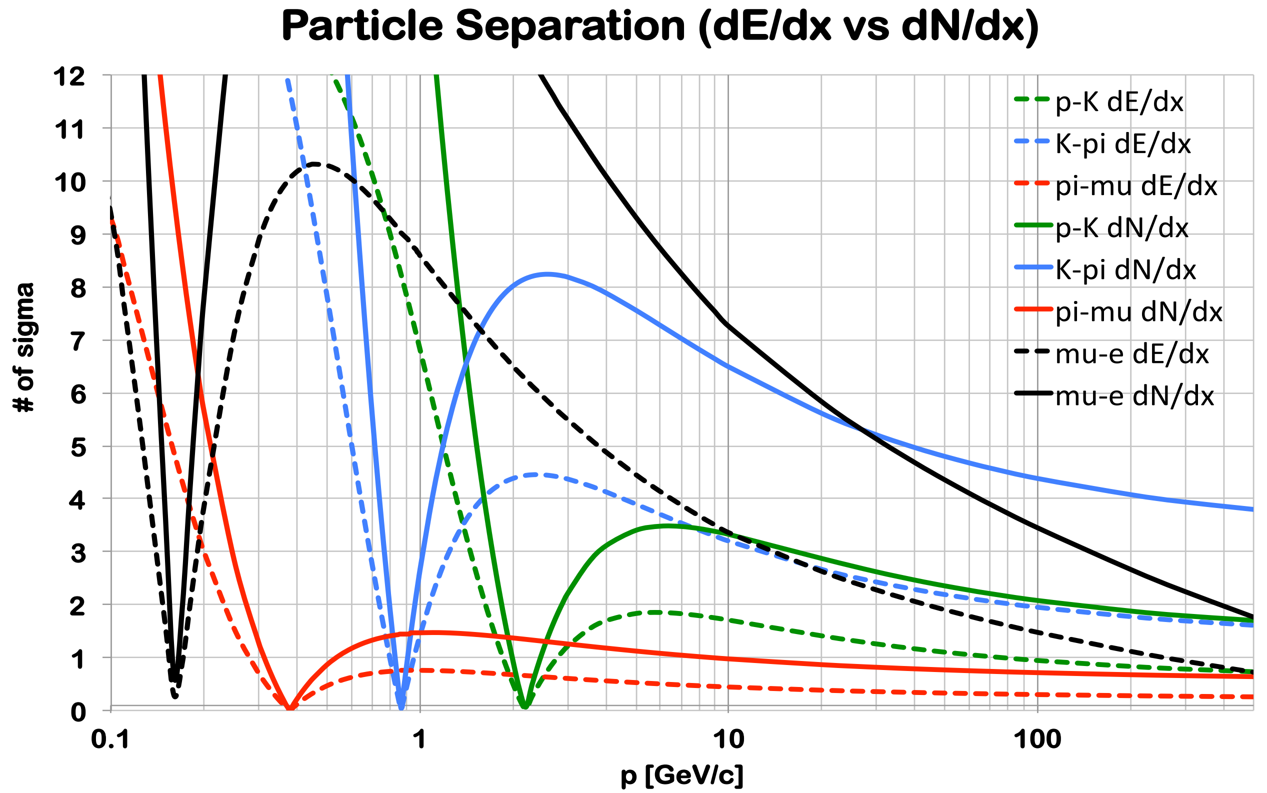
$$\frac{\sigma_{dN_{cl}/dx}}{\left(dN_{cl}/dx\right)} = \left(\varepsilon_{counting} \cdot \delta_{cluster} \cdot L_{track}\right)^{-0.5}$$

G. Cataldi, F. Grancagnolo and S. Spagnolo, *Cluster counting in helium based gas mixtures*, Nucl. Instr. and Meth. A386 (1997) 458-469.

- Poisson statistics
- $\delta_{cluster}$ = 12.5 cluster/cm in
  ($90\%He\text{-}10\%iC_4H_{10}$)
- outperforms dE/dx by a factor ×2
- even at very low counting efficiency ($\varepsilon_{counting} \approx 20\%$) better than dE/dx
- insensitive to
  - gas gain variations
  - lower dependence on gas composition
  - slighter dependence on avalanche saturation
- no wire to wire calibration needed

Drift chamber Particle Identification

Expected from analytical calculation for IDEA Drift Chamber

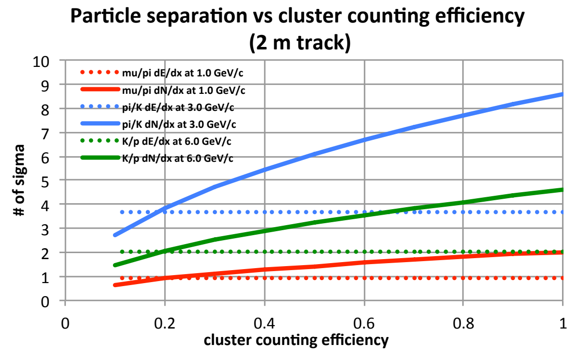


He/iC_4H_{10} 90/10
$\delta_{cl}=12\ cm^{-1}$

$\sigma(dE/dx)/(dE/dx)$
=4.3%

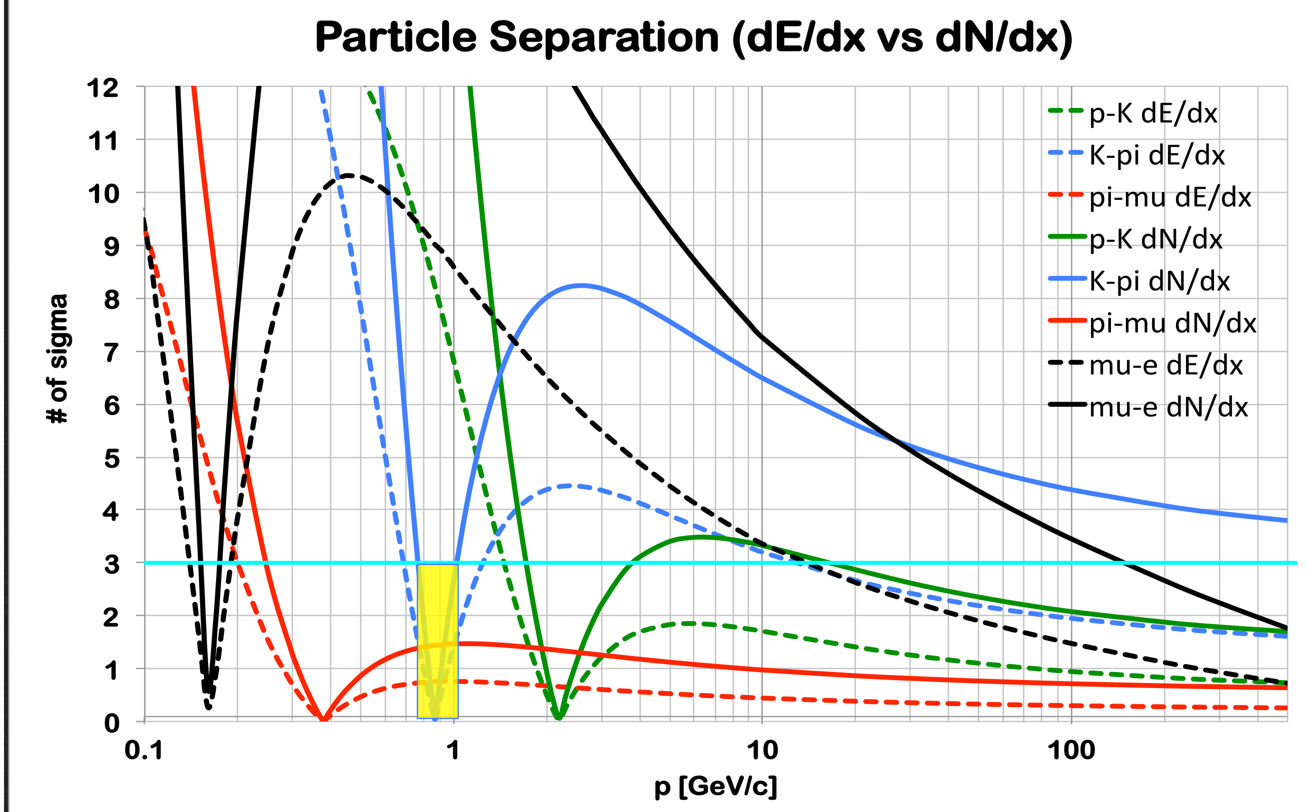
80% cluster counting efficiency

$\sigma(dN_{cl}/dx)/(dN_{cl}/dx)$
=2.3%



Drift chamber Particle Identification

Expected from analytical calculation for IDEA Drift Chamber


Particle Separation (dE/dx vs dN/dx)

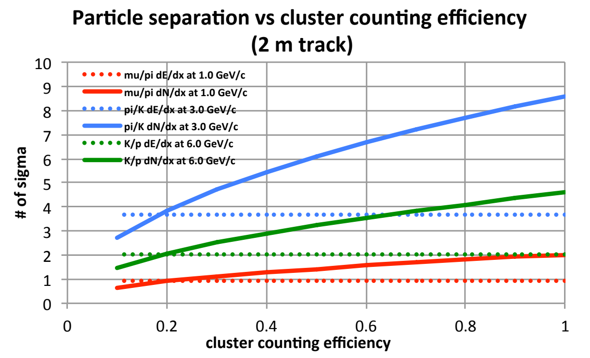
He/iC$_4$H$_{10}$ 90/10

δ_{cl}=12 cm^{-1}

σ(dE/dx)/(dE/dx) =4.3%

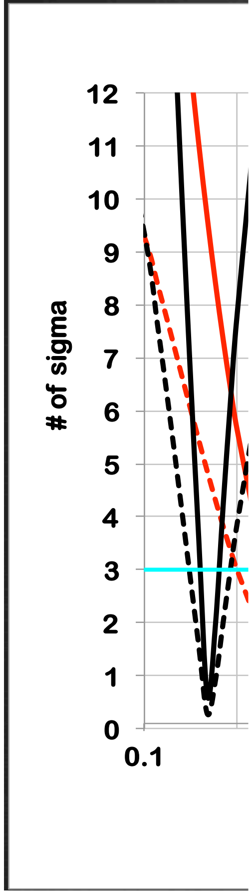
80% cluster counting efficiency

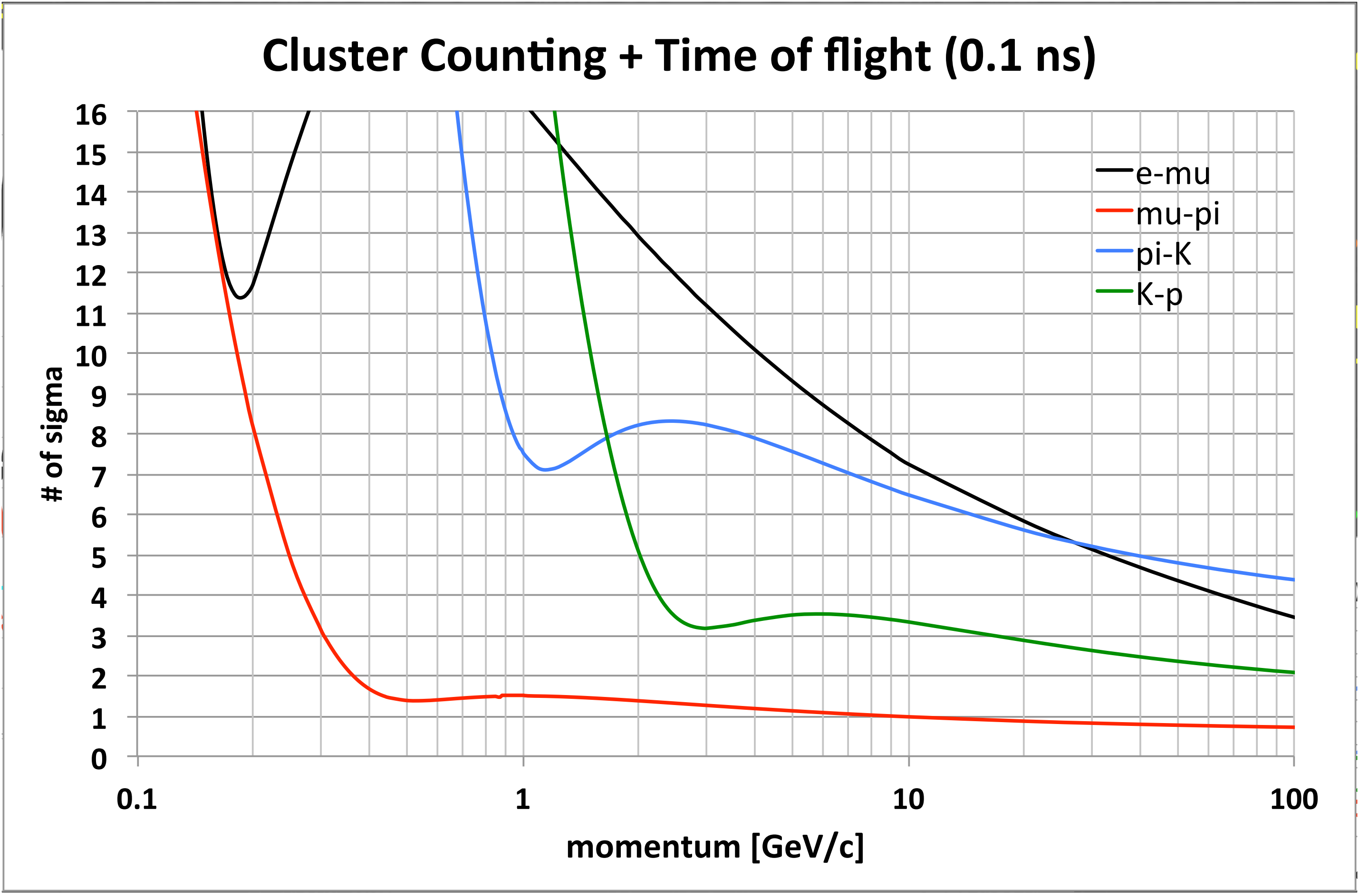
σ(dN$_{cl}$/dx)/(dN$_{cl}$/dx) =2.3%


Particle separation vs cluster counting efficiency (2 m track)

Drift chamber Particle Identification

Expected f





0 90/10

cm^{-1}

(dE/dx)

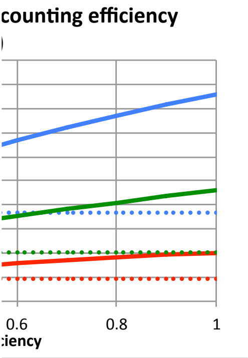
%

uster

fficiency

(dN_{cl}/dx)

%



Drift chamber Particle Identification

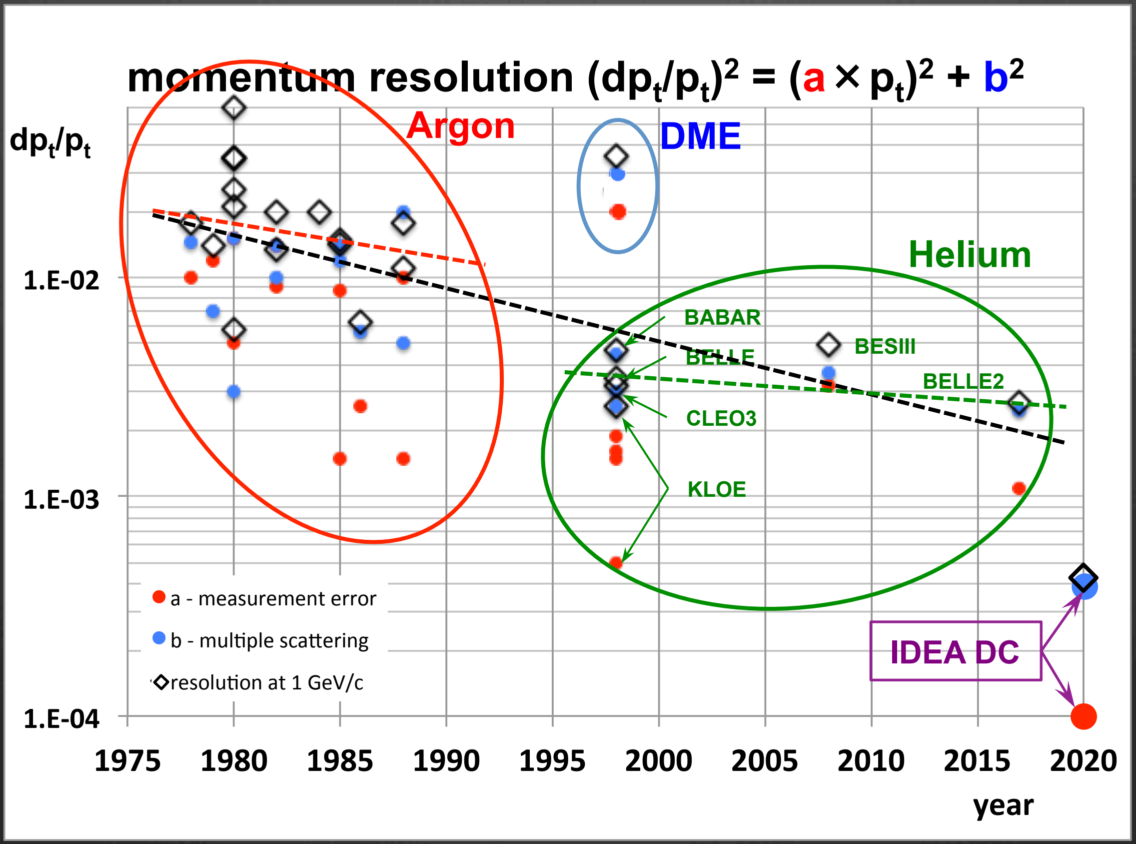
Comments:

- **PID** comes (almost) for free in drift chambers.
- It suffers from blindness at the "crossing points", where additional help is needed
- **dE/dx** resolutions of around **5%** are granted, provided high stability is reached on HV and gas parameters and on continuous electronics calibration. Alternatives to the maximum likelihood / truncated mean techniques are highly desirable.
- **dN_{cl}/dx** resolutions are potentially a **factor 2 better** with respect to dE/dx. Cluster counting requires fast electronics and sophisticated counting algorithms to be fully efficient. However, given its digital nature, it is less dependent on gain stability issues.

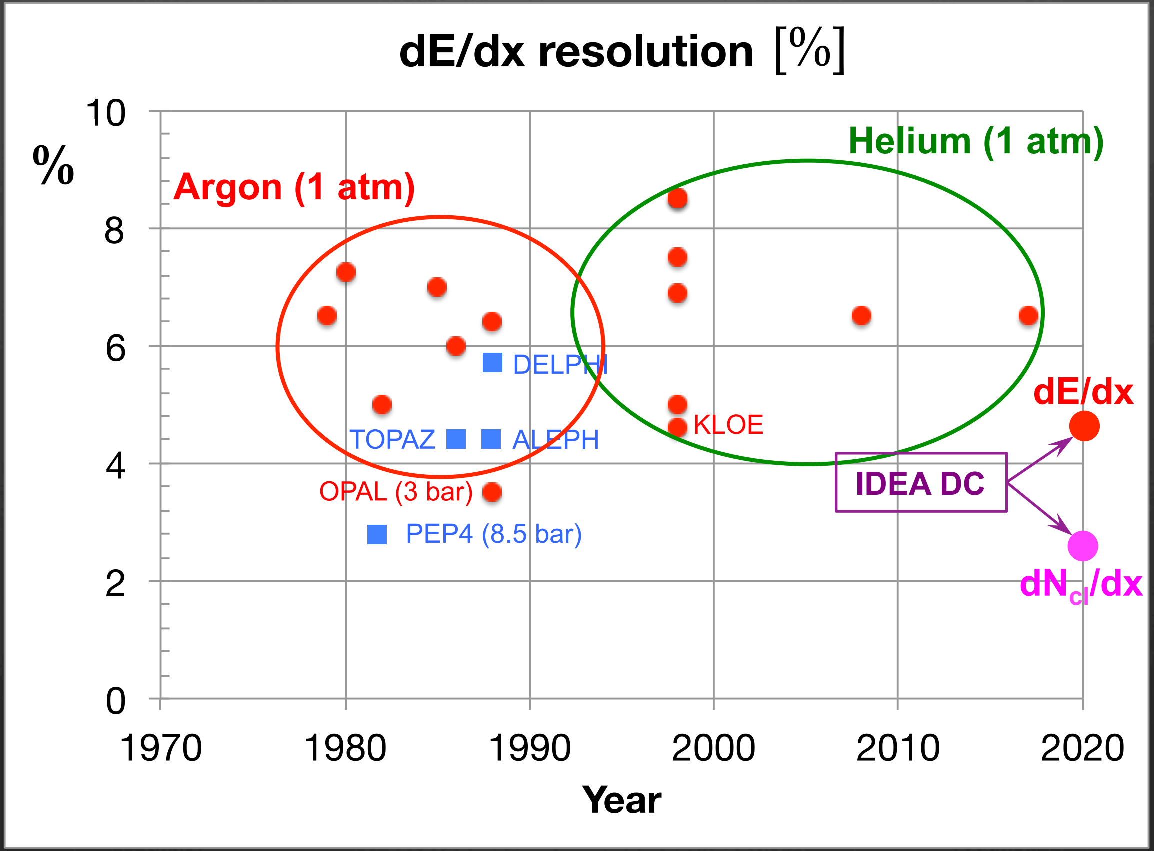
Remarks:

- these techniques require **no added complexity (and material!)** to the whole detector!
- this is particularly relevant for a high precision EM calorimeter at a few %/sqrt(E)
- **no compromise on performance and hermeticity of the detector** (control of acceptance required at Z-pole at the level of 10^{-5}!)

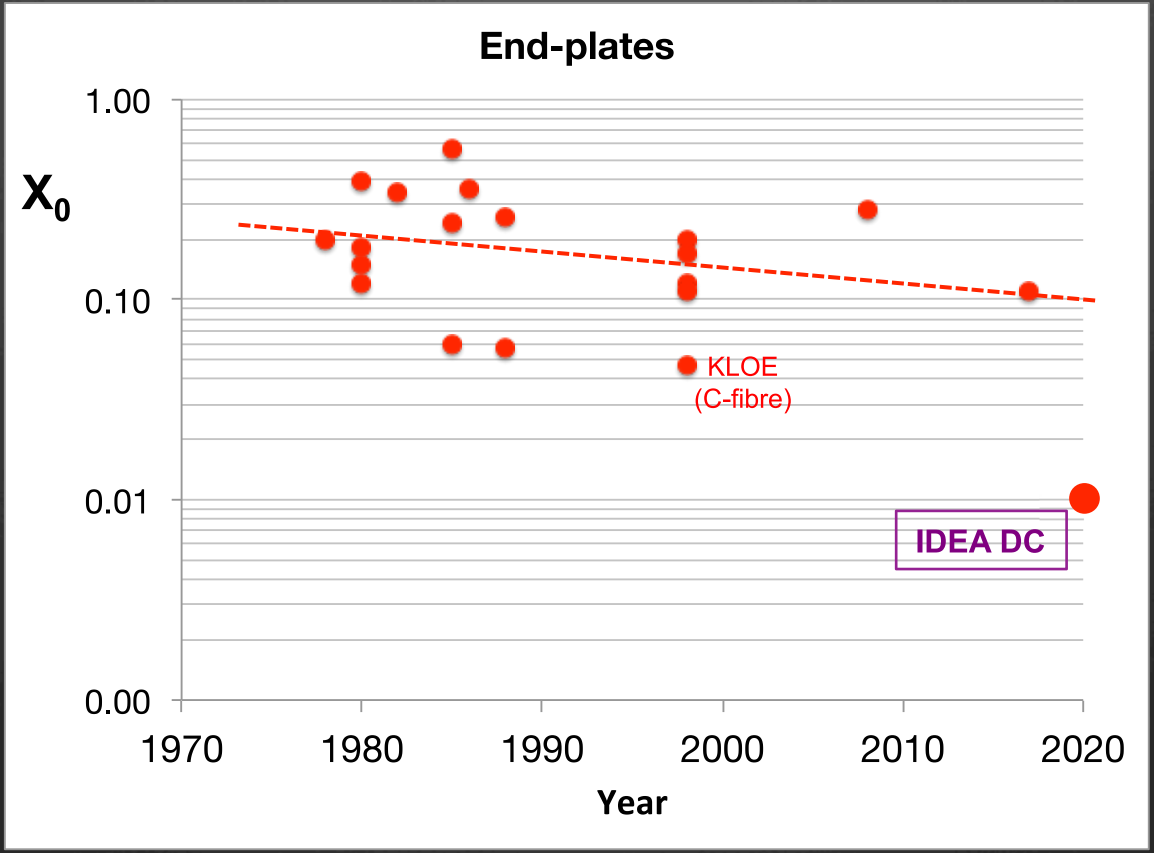
Where does IDEA DC stand?



Where does IDEA DC stand?



Where does IDEA DC stand?



Conclusions

- we have presented the **evolution of drift chambers** at e^+e^- colliders over the past 40 years
- we have described the **innovations** introduced with the design of the **IDEA drift chamber** at FCCee and CEPC, the most relevant ones regarding the **mechanical structure** (including new types of wires) and the **cluster counting** and **cluster timing**
- we have presented the expected performance in terms of **momentum and angular resolutions** and **particle identification** capabilities with **dE/dx** and with **dN/dx**
- we have **not** discussed about the **front-end electronics** and the **data acquisition** and **processing** of the wire signals.