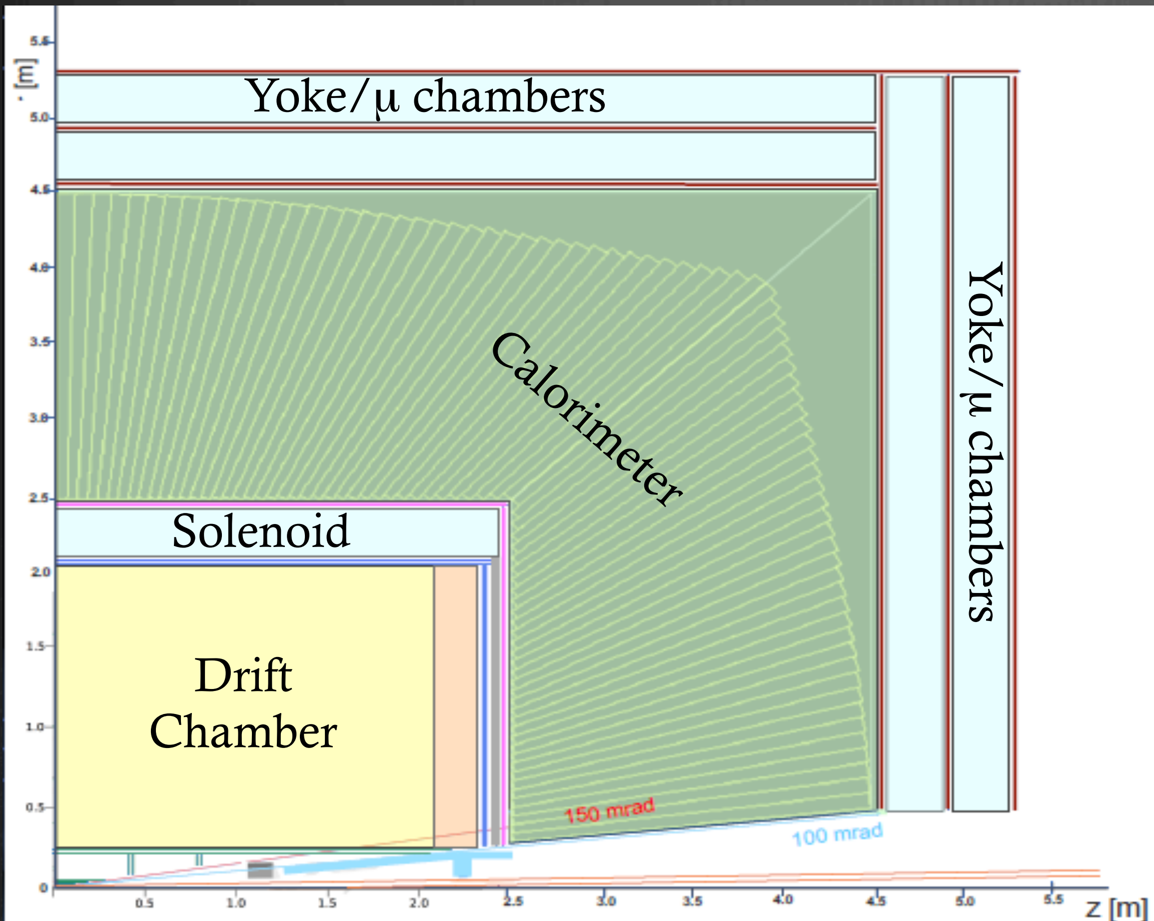
Istituto Nazionale di Fisica Nucleare

The IDEA Drift Chamber

F. Grancagnolo
INFN – Lecce



IDEA concept

- Si pixel vertex detector
  - 5 MAPS layers
    - R = 1.7 – 34 cm
- Drift chamber (112 layers)
  - 4m long, r = 35 – 200 cm
- Si wrapper: strips
- Solenoid: 2 T - 5 m, r = 2.1-2.4
  - 0.74 X_0, 0.16 λ @ 90º
- Pre-shower: μRwell
- Dual Readout calorimetry
  - 2m deep/8 λ
- Muon chambers
  - μRwell

OUTLINE

- Tracker requirements
- Genesis and evolution of the proposal
- Innovations introduced
- Layout and Material Budget
- The IDEA tracking system
- Fast simulation performance
- Full (standalone) Geant4 simulation
- Particle Identification
- Conclusions

Tracker requirements

- Large angular coverage

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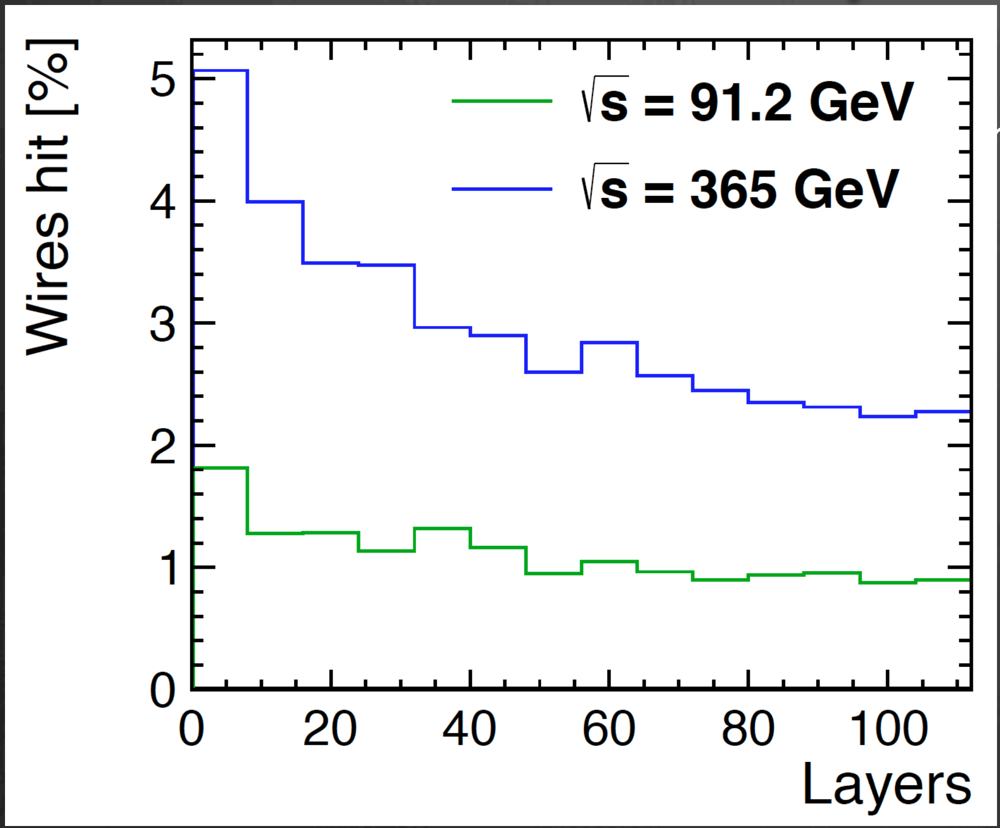

Simulation of the main background contribution due to incoherent pair conversion at FCC-ee MDI

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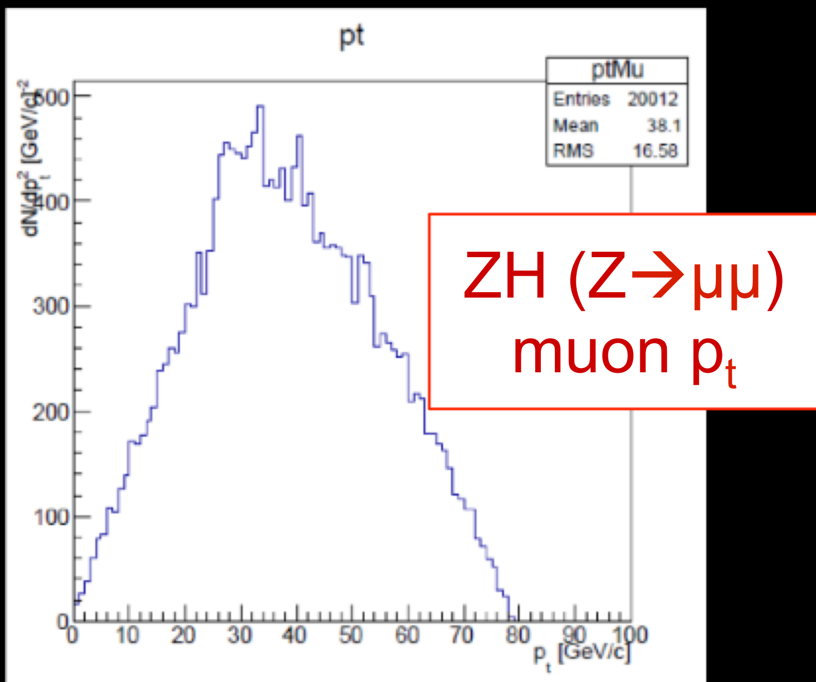

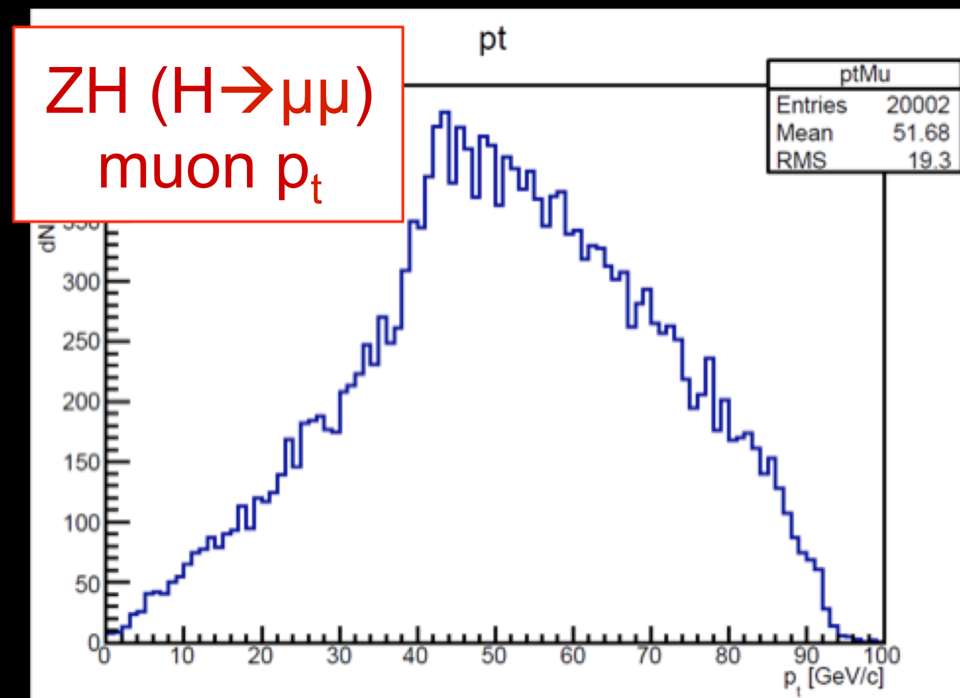

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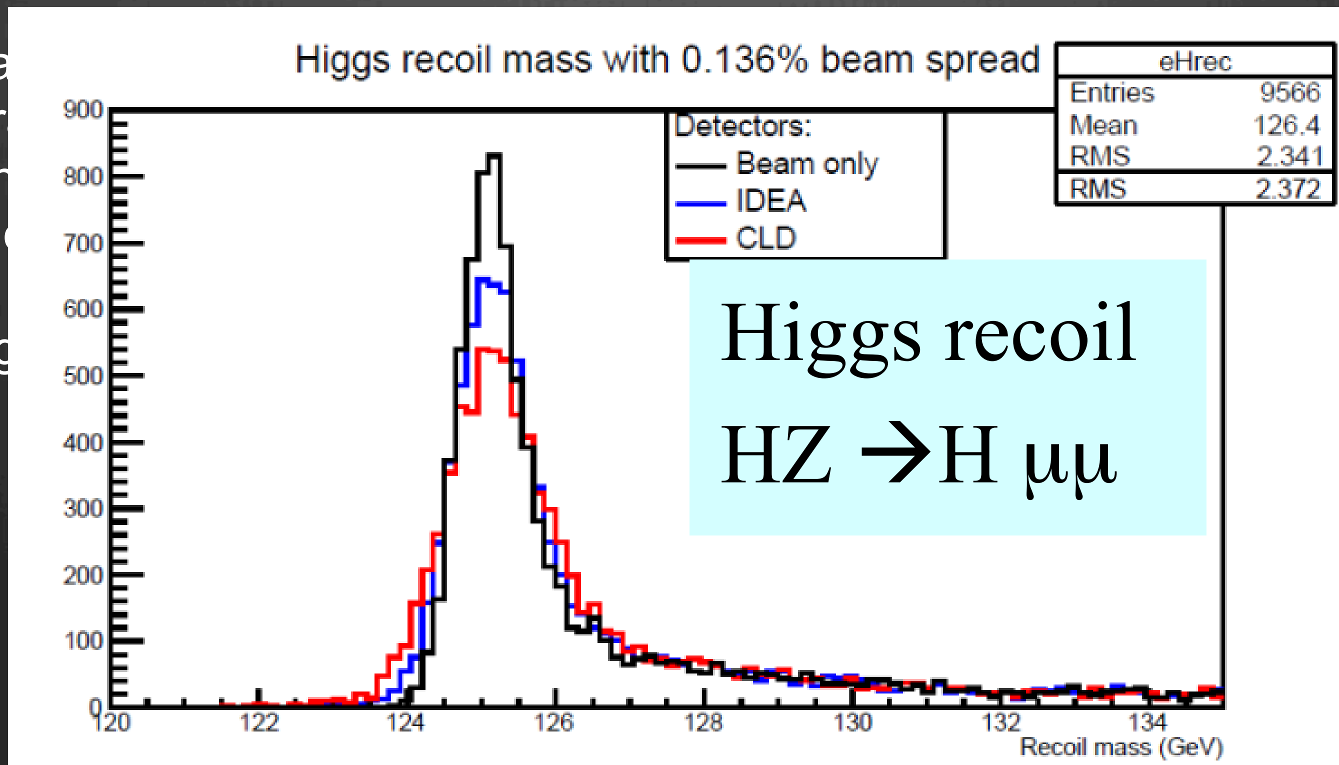

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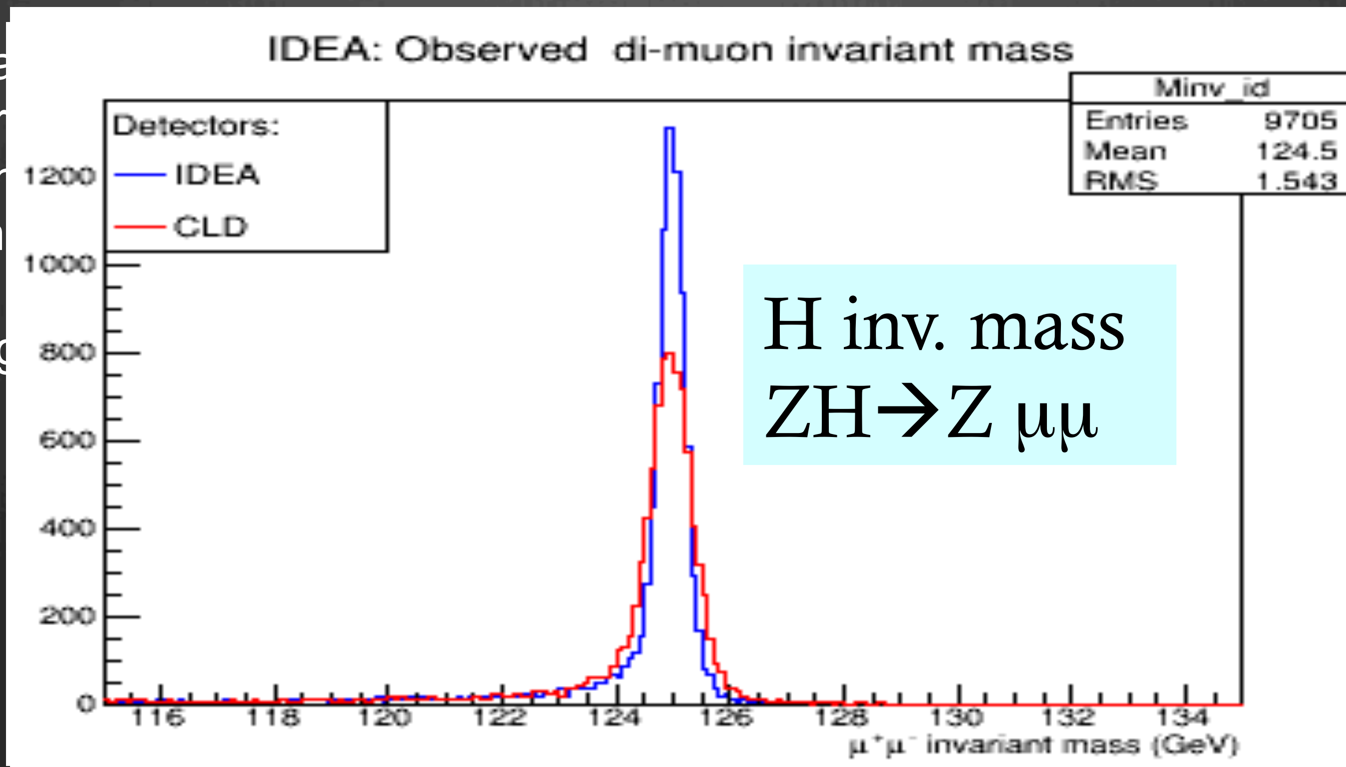

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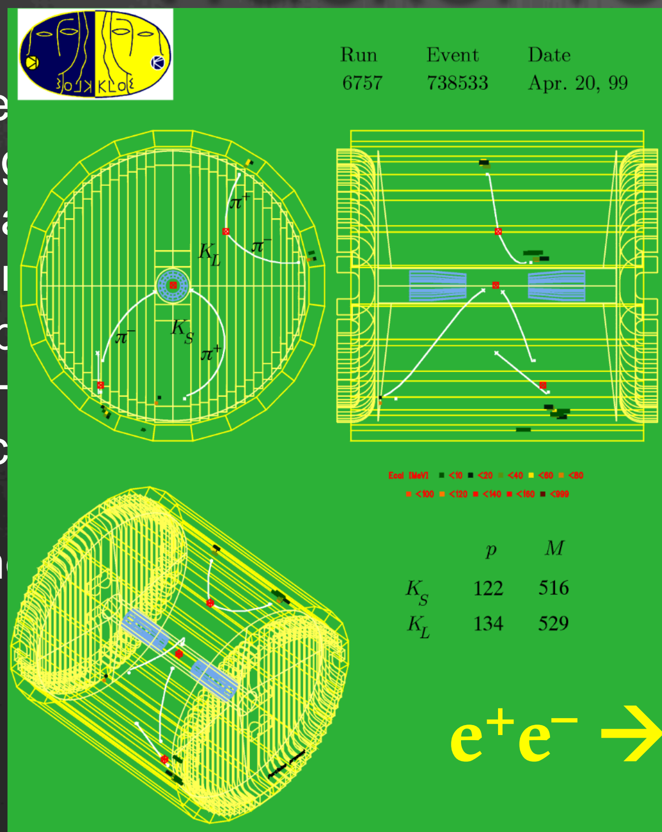

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Tracker requirements

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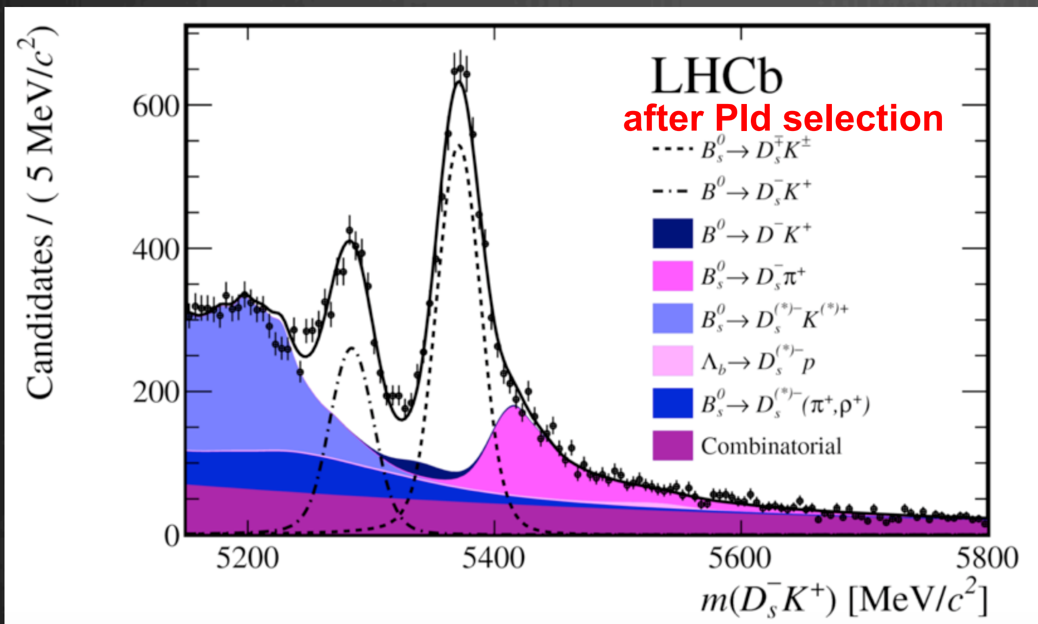

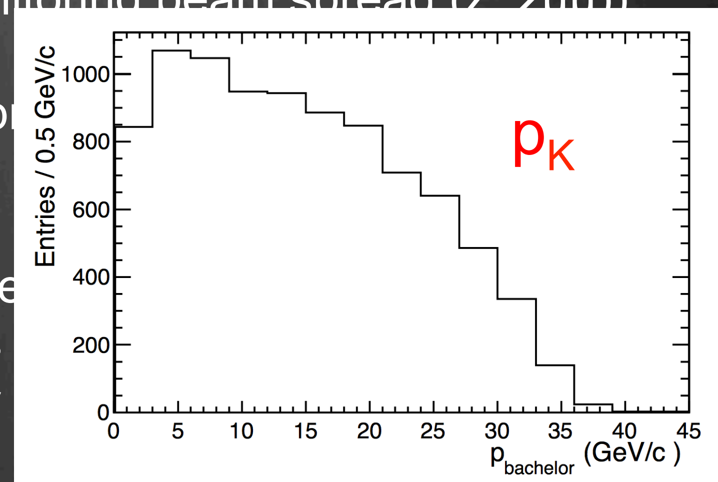

- CPV (e.g. $B_s \to D_sK$)

from S. Monteil

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

Genesis and evolution

I. **KLOE** ancestor chamber at INFN LNF Daϕne φ factory (commissioned in 1998 and operating for the last 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 the **MEG upgrade** at PSI (designed in 2014, now and under commissioning)

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

Innovations introduced

with KLOE

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

II. new **light Aluminum** wires

III. Very light gas mixture **90% He – 10% iC_4H_{10}**

IV. Mechanical structure entirely in **Carbon Fiber**

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

after KLOE

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

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

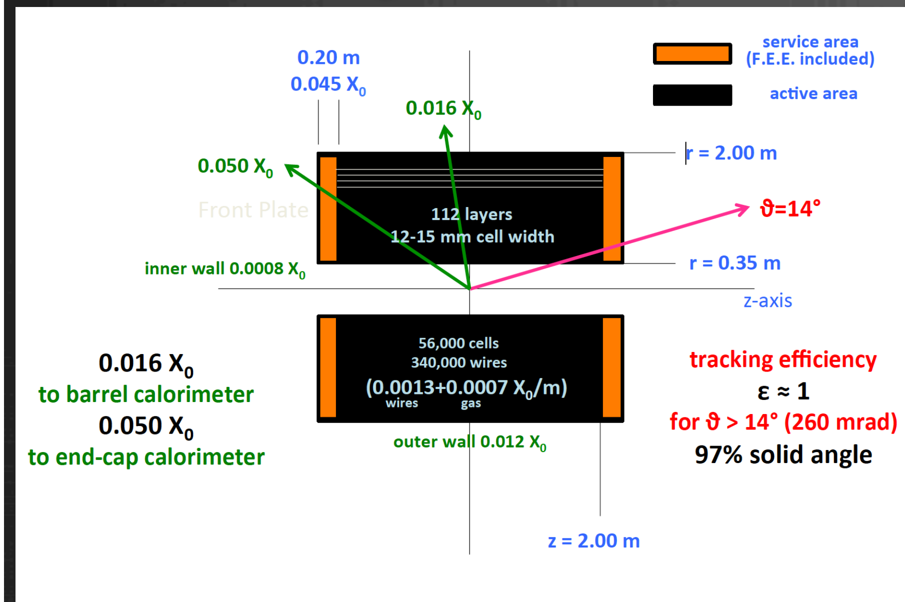
III. Using **a larger number** of **thinner** (and **lighter** wires)

IV. No **feed-through** wiring

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

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

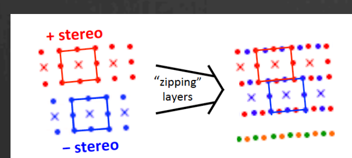
Layout and Material Budget

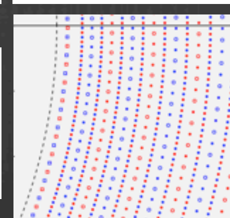


Conservative estimates:

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

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





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

The IDEA Tracking system

Vertex Detector

Layer	R [mm]	L [mm]	Si eq. thick. [µm]	X_0 [%]	pixel size [mm²]	area [cm²]	# of channels
1	17	±110	300	0.3	0.02×0.02	235	60M
2	23	±150	300	0.3	0.02×0.02	434	110M
3	31	±200	300	0.3	0.02×0.02	780	200M
4	320	±2110	450	0.5	0.05×1.0	85K	170M
5	340	±2245	450	0.5	0.05×1.0	96K	190M

Disks	R_{in} [mm]	R_{out} [mm]	z [mm]	Si eq. thick. [µm]	X_0 [%]	pixel size [mm²]	area [cm²]	# of channels
1	62	300	±400	300	0.3	0.05×0.05	5.4K	220M
2	65	300	±420	300	0.3	0.05×0.05	5.4K	220M
3	138	300	±900	300	0.3	0.05×0.05	4.4K	180M
4	141	300	±920	300	0.3	0.05×0.05	4.4K	180M

Drift Chamber

	R_{in} [mm]	R_{out} [mm]	z [mm]
drift chamber	350	2000	±2000
service area	350	2000	±(2000÷2250)

	inner wall	gas	wires	outer wall	service area
thickness [mm]	0.2	1000	1000	20	250
X_0 [%]	0.08	0.07	0.13	1.2	4.5

# of layers	112	min 11.8 mm – max 14.9 mm
# of cells	56448	192 at 1st – 816 at last layer
average cell size	13.9 mm	min 11.8 mm – max 14.9 mm
average stereo angle	134 mrad	min 43 mrad – max 223 mrad
transverse resolution	100 µm	80 µm with cluster timing
longitudinal resolution	750 µm	600 µm with cluster timing

active volume	50 m^3	
readout channels	112,896	r.o. from both ends
max drift time	400 ns	800 × 8 bit at 2 GHz

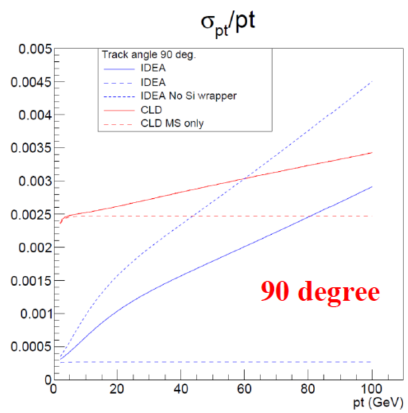
Si wrapper

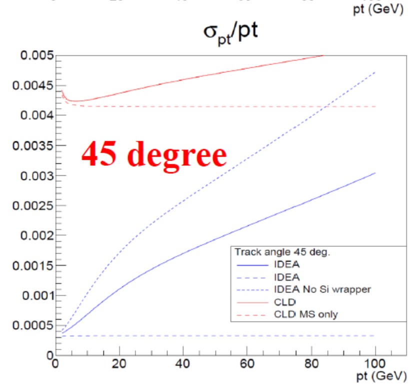
Layer	R [mm]	L [mm]	Si eq. thick. [µm]	X_0 [%]	pixel size [mm²]	area [cm²]	# of channels
1	2040	±2400	450	0.5	0.05×100	616K	12.3M
2	2060	±2400	450	0.5	0.05×100	620K	12.4M

Disks	R_{in} [mm]	R_{out} [mm]	z [mm]	Si eq. thick. [µm]	X_0 [%]	pixel size [mm²]	area [cm²]	# of channels
1	350	2020	±2300	450	0.5	0.05×100	250K	5M
2	354	2020	±2320	450	0.5	0.05×100	250K	5M

Fast Simulation Performance

Tracking performances





@ 90°, p_t > 30 GeV

IDEA

$$\sigma_{p_t}/p_t = 0.7\times10^{-3} + 2.2\times10^{-5}p_t$$

IDEA no Si wrapper

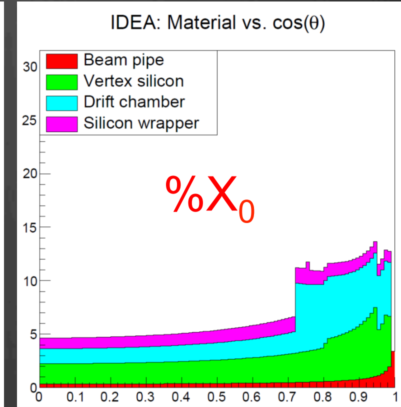
$$\sigma_{p_t}/p_t = 0.5\times10^{-3} + 5.7\times10^{-5}p_t$$

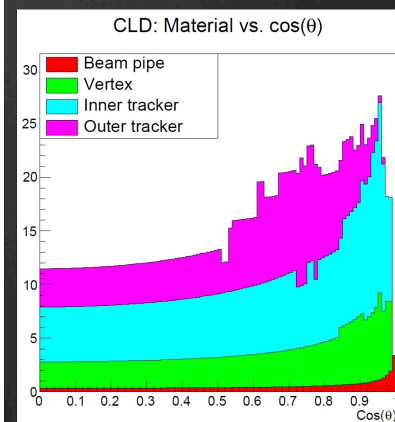
IDEA, Multiple Scattering only

$$\sigma_{p_t}/p_t = 0.25\times10^{-3}$$

CLD, Multiple Scattering only

$$\sigma_{p_t}/p_t = 2.5\times10^{-3}$$





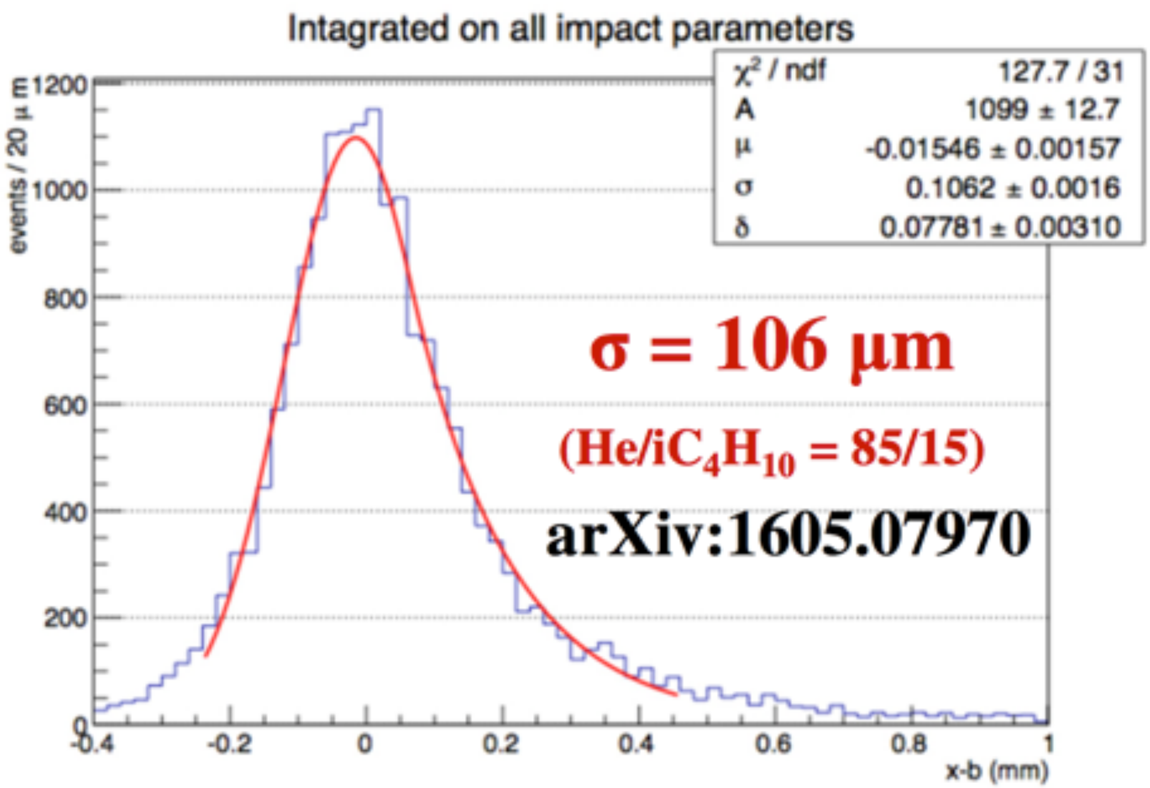
Fast Simulation Performance

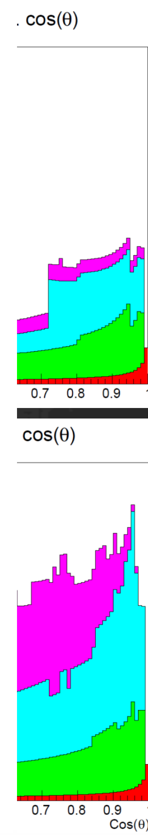
Tracking performance

MEG2 measured spatial resolution

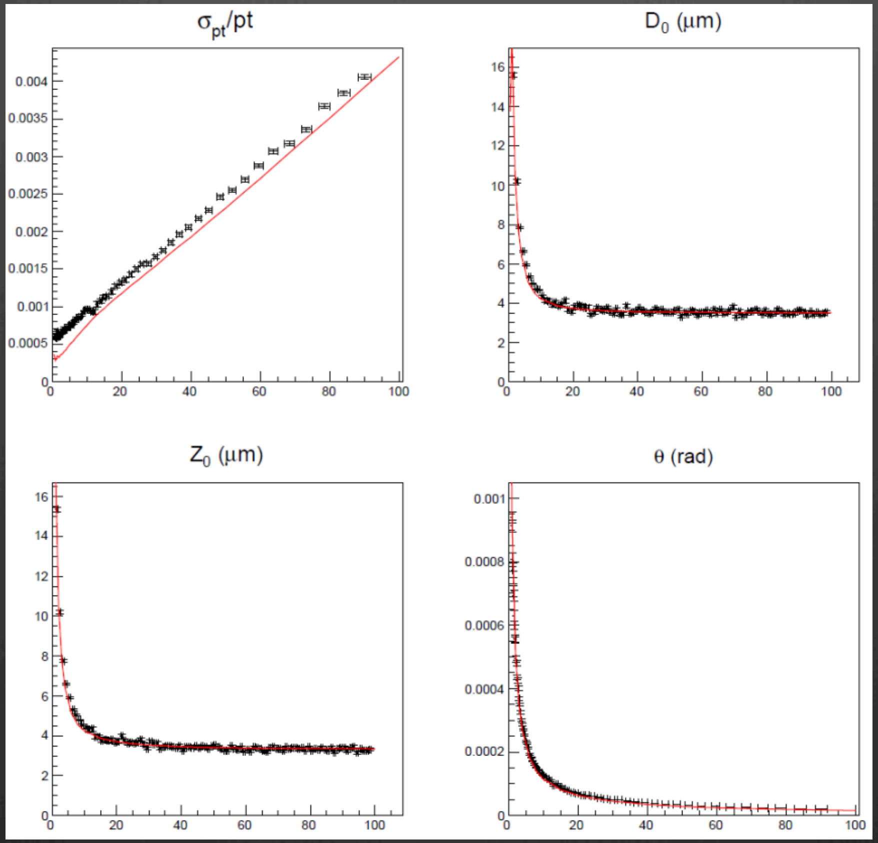
no cluster timing, 7x7 mm^2
expected
12x12 mm^2 ≤ 100 µm

cluster timing → -20%



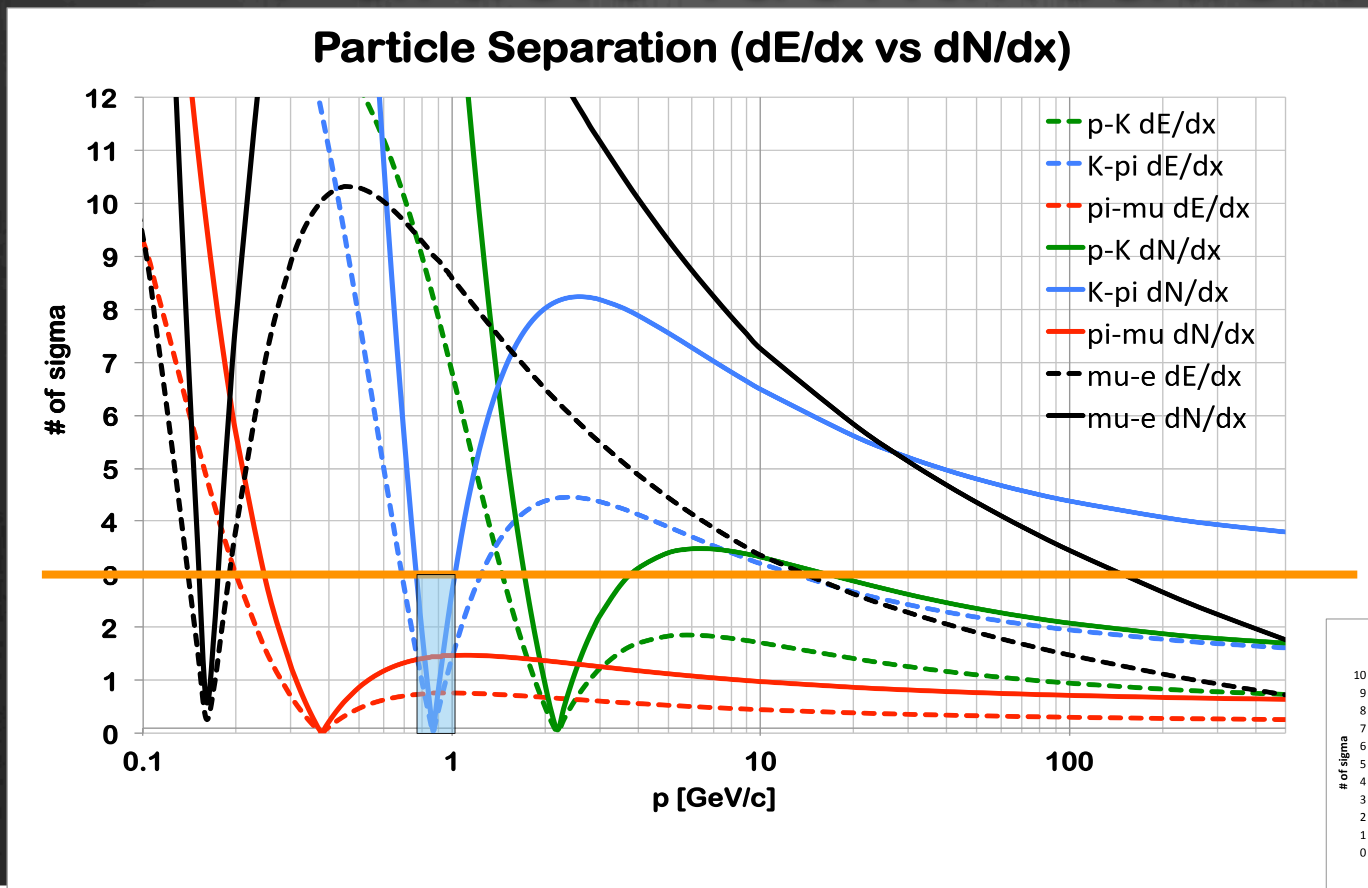


fast/full G4 Simulation comparison



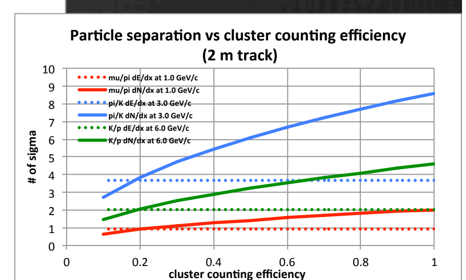
- **Geant4**
- **ROOT based simulation**

Particle Identification



dE/dx resolution
4.3%

Cluster Counting efficiency:
80%



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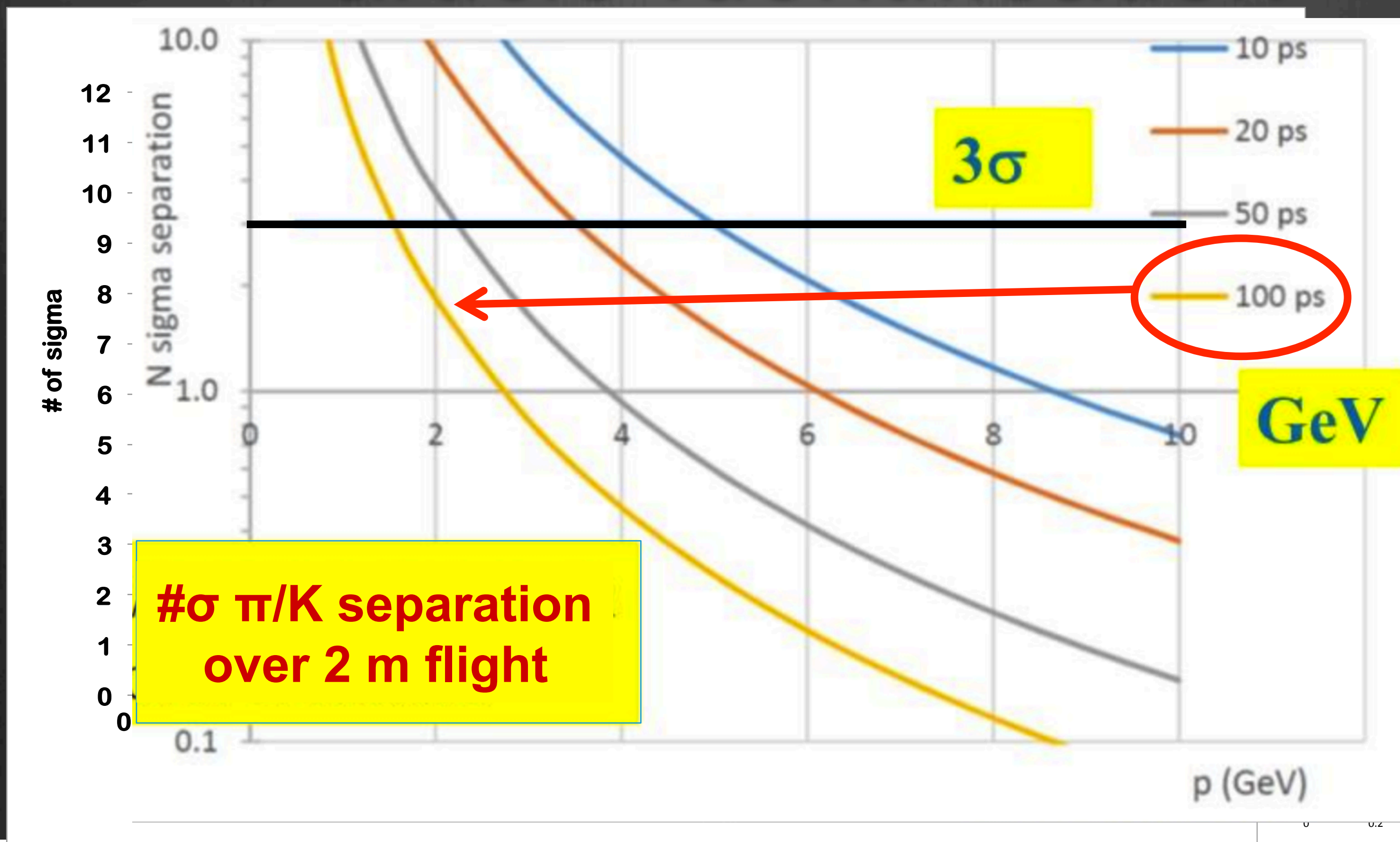

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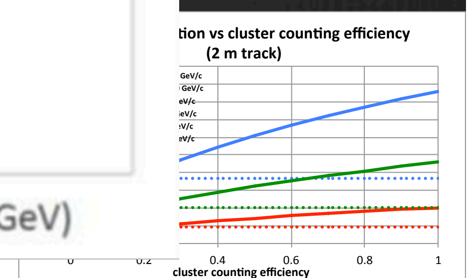

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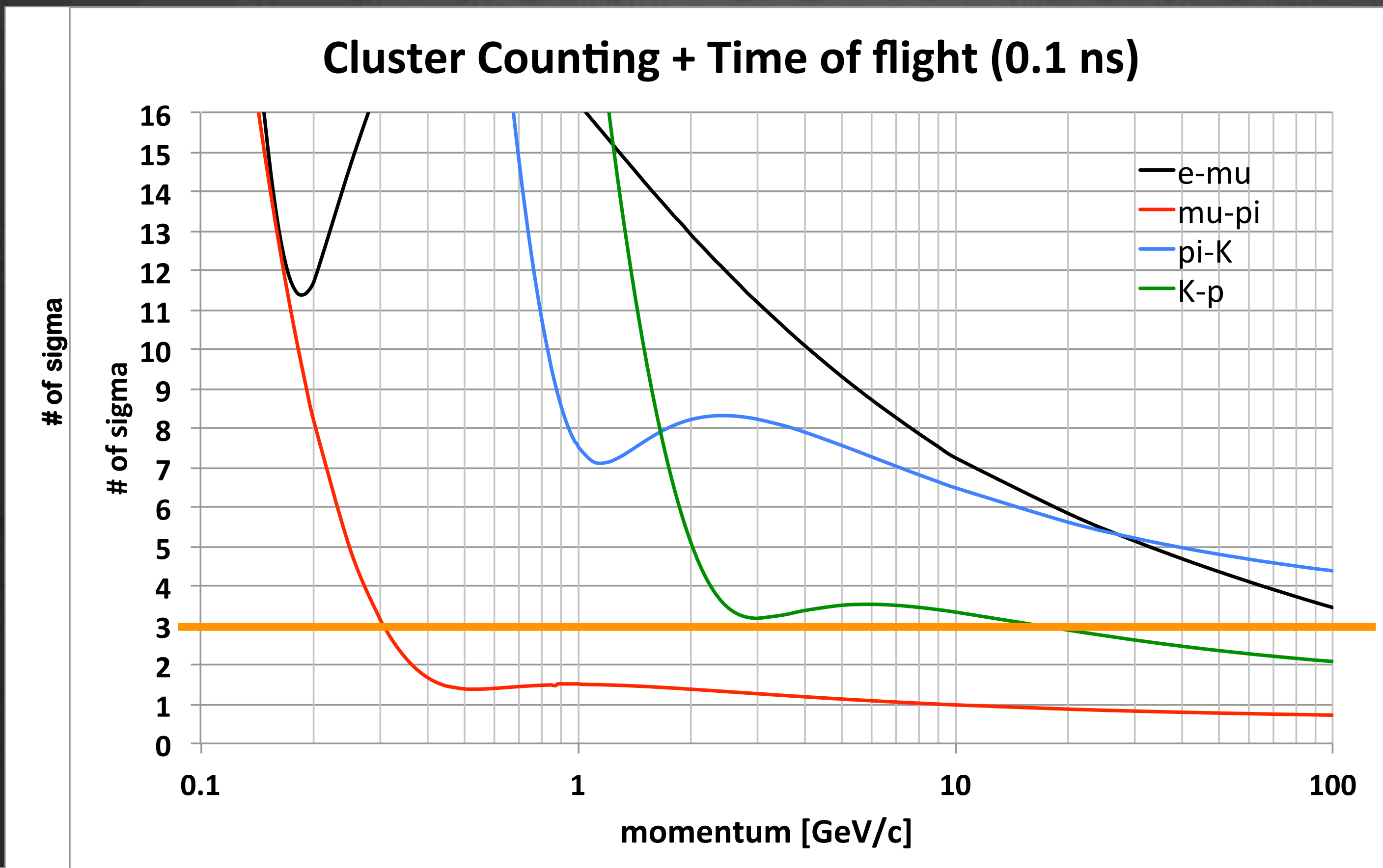

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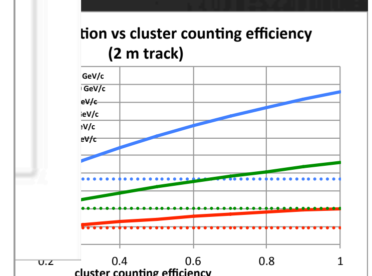
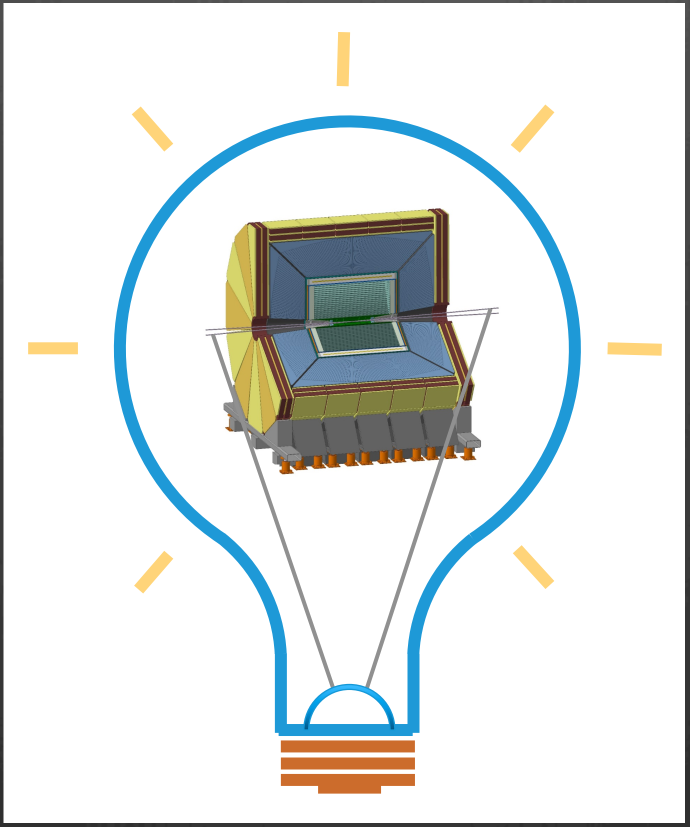


Conclusions

- Conceptual design of tracking system adequate for the physics requirements.
- Ready for transition from CDR to TDR, but still missing ...
  - full software integration within a common framework
  - performance optimization on benchmark physics
  - detector design optimization (cost/performance analysis)
  - construction of full scale prototypes (4 m length!)
    - to test materials and mechanical engineering solutions
    - to develop cost effective electronics (given the number of channels)
- Critical mass far from being reached: ample space for additional international contributions on all the listed items.

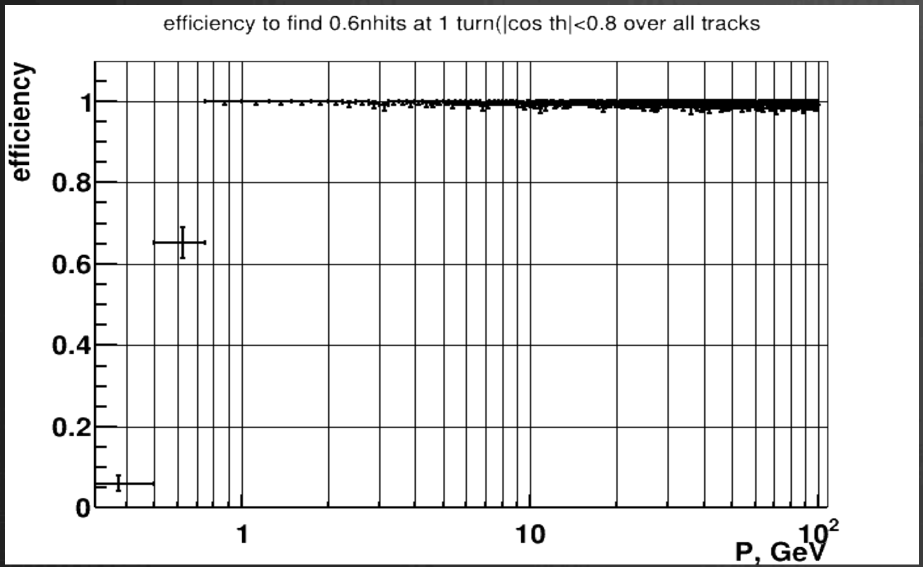
Back up Slides

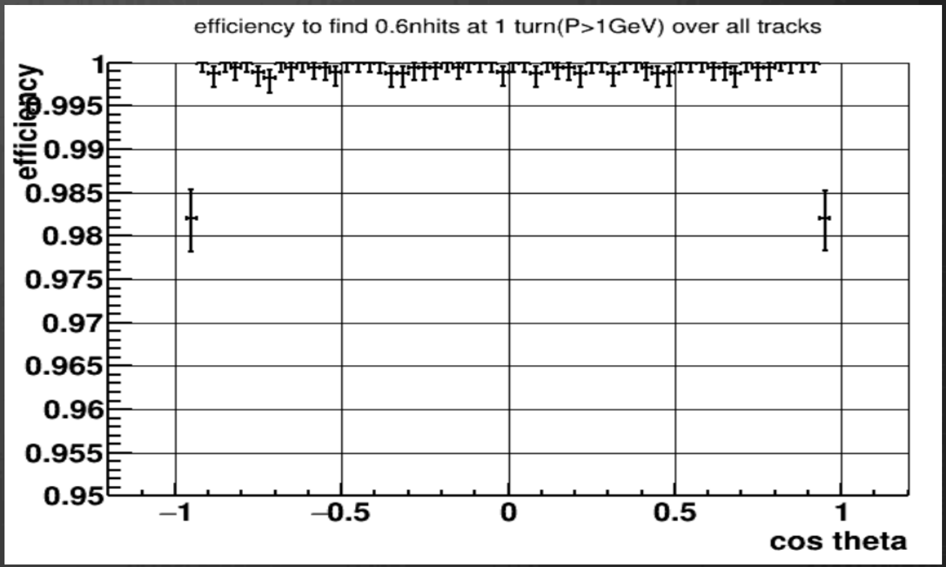
The "brilliant" IDEA Detector



Full G4 Simulation Performance

isolated track reconstruction efficiency





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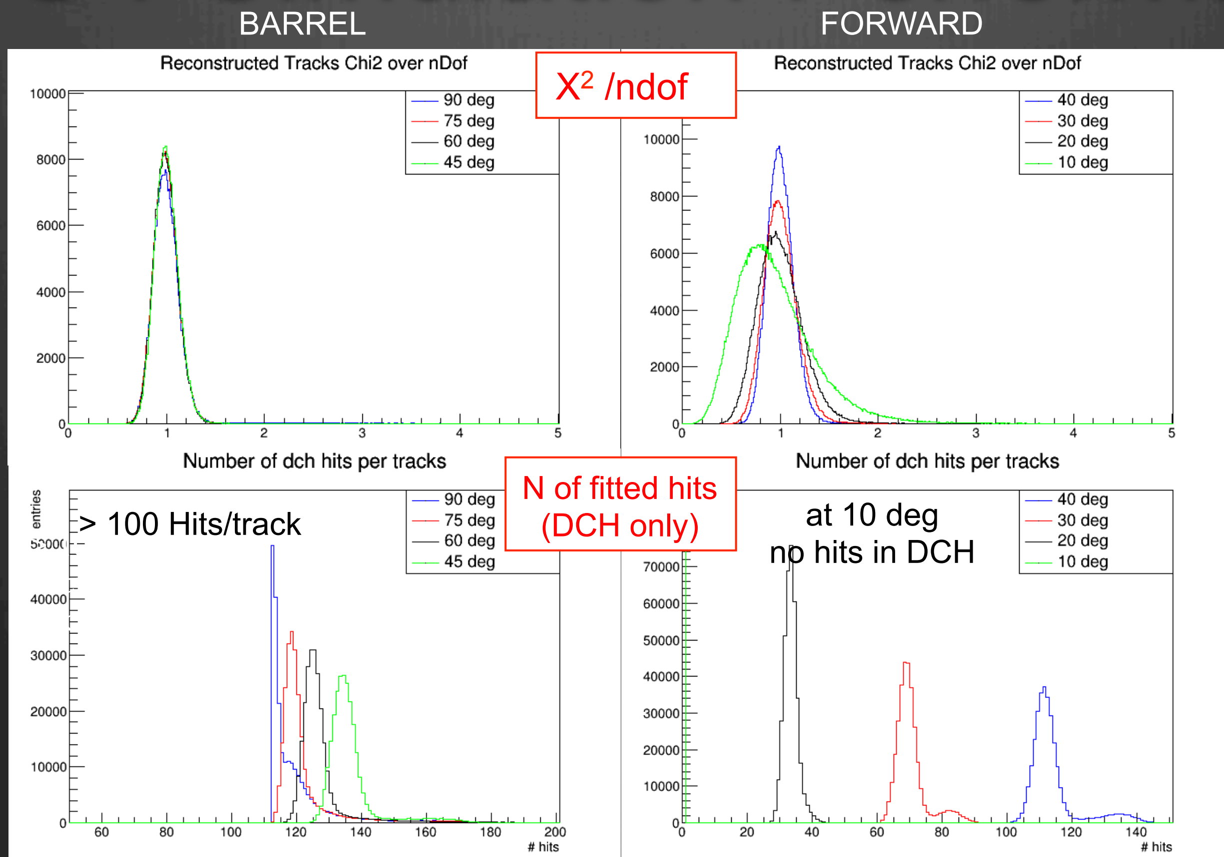
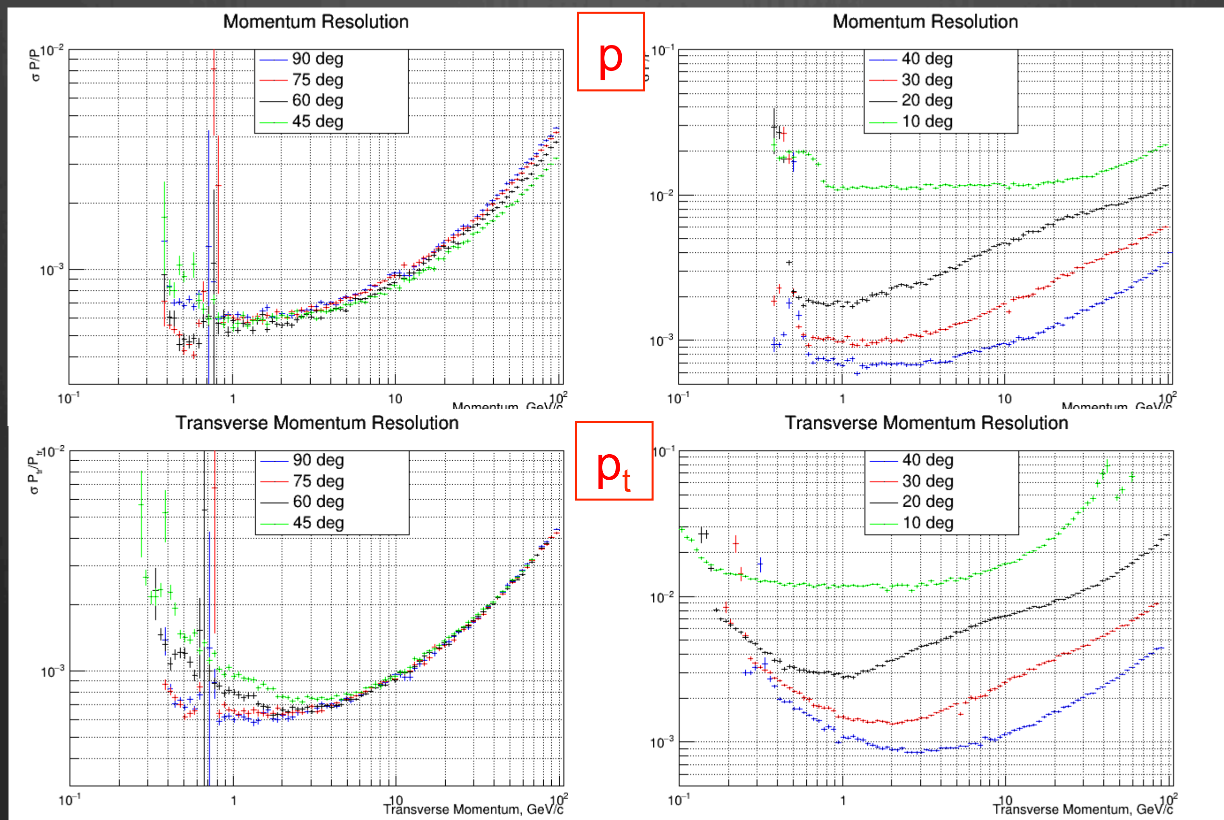


Full G4 Simulation Performance

BARREL FORWARD



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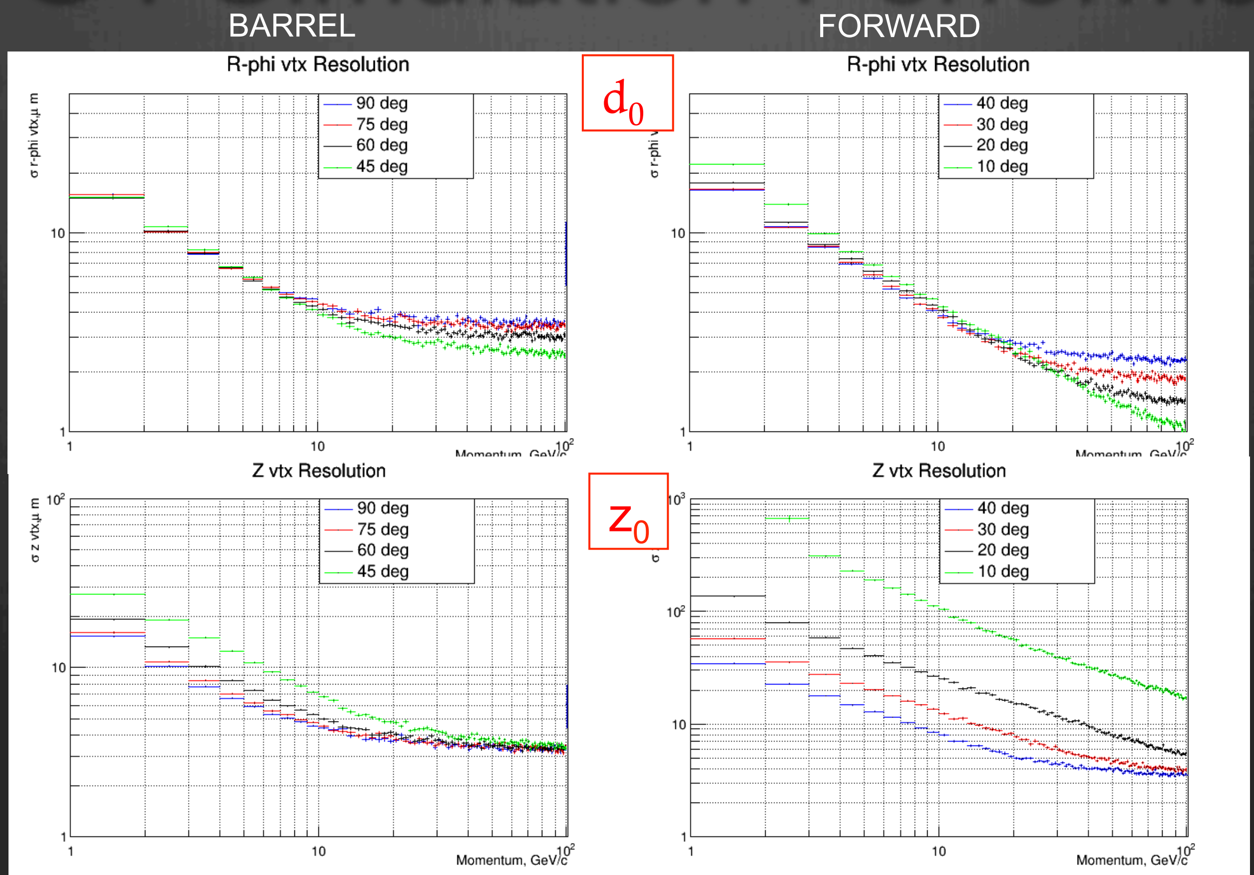

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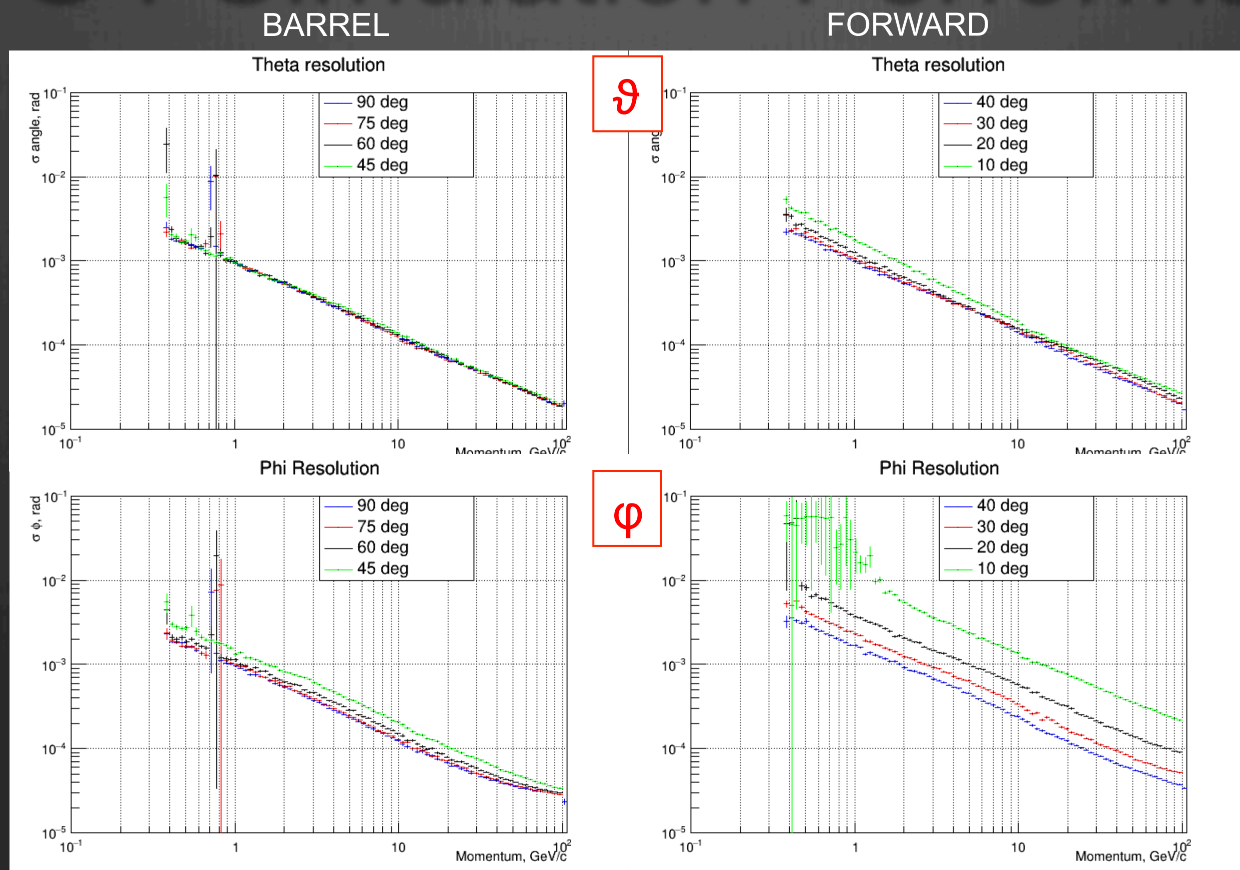
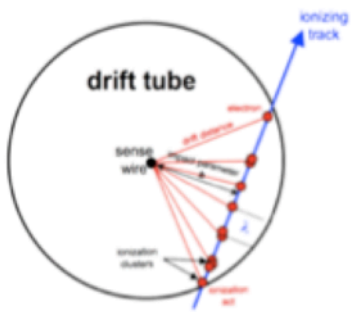
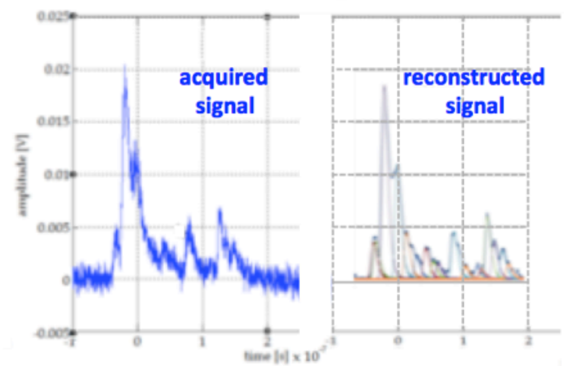
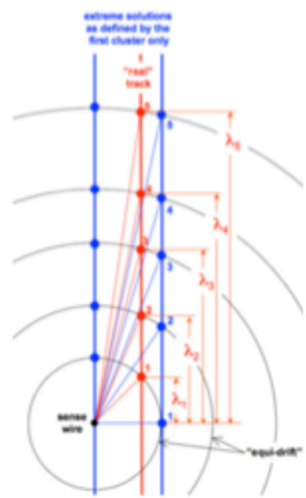


III. Cluster Timing

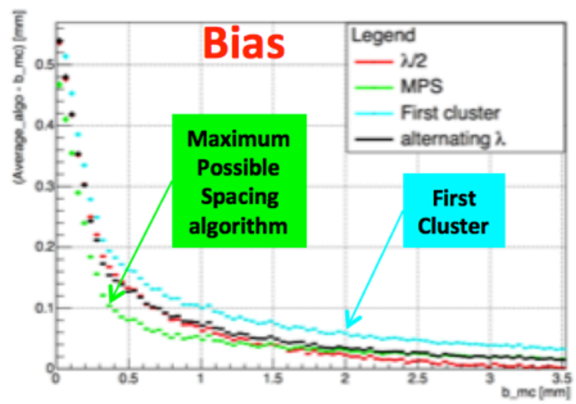


From the **ordered sequence of the electrons arrival times,** considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times:** $\{t_i^{cl}\} \quad i=1,N_{cl}$



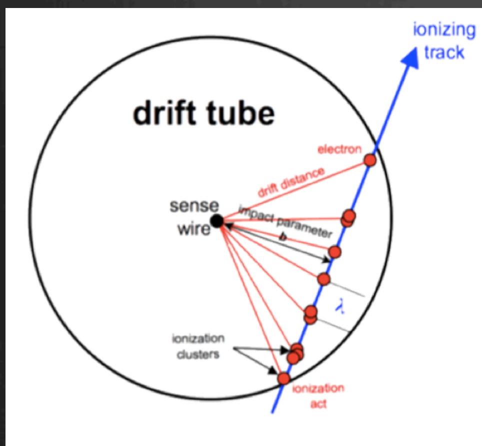


For any given first cluster (**FC**) drift time, the **cluster timing technique** exploits the drift time distribution of all successive clusters $\{t_i^{cl}\}$ to determine the most probable impact parameter, thus reducing the **bias** and the average **drift distance resolution** with respect to those obtained from with the FC method alone.

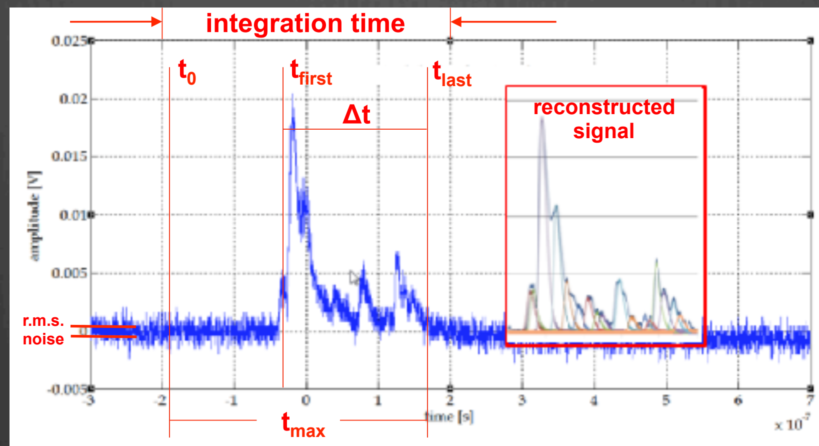


III. Cluster Timing: exploit signal digitization

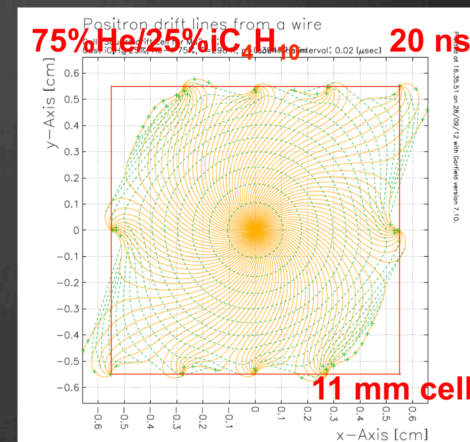
Ideal case: drift tube



Digitized signal (1 GHz, 2 GSa/s)

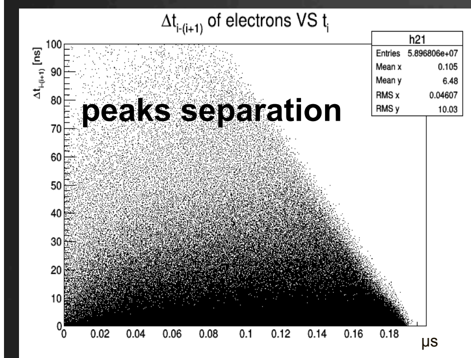


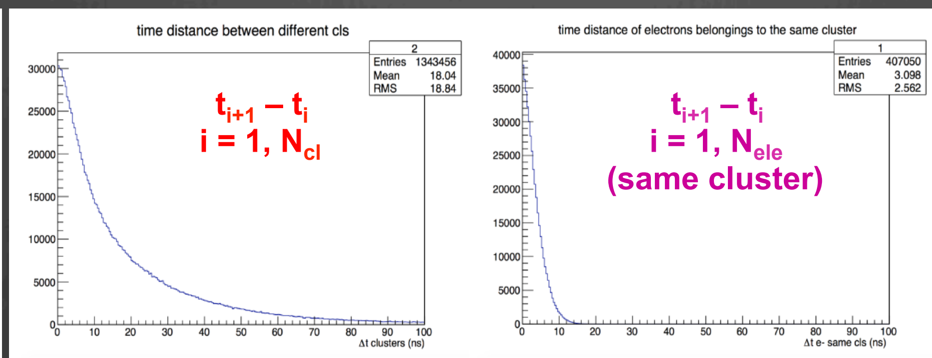
Real case: drift cell

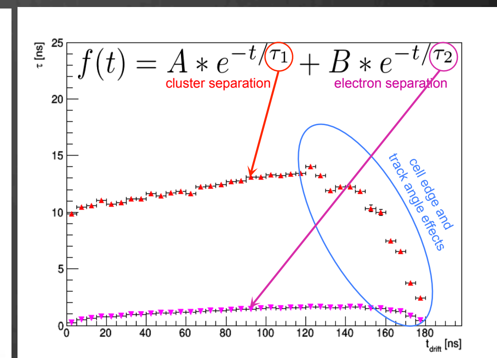


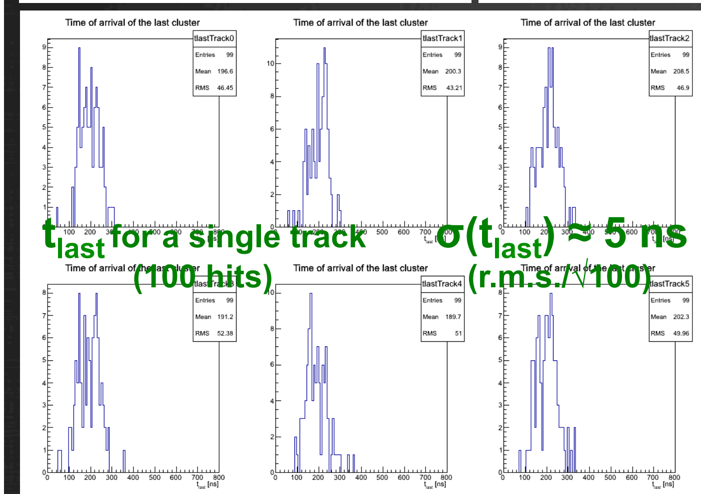
- **$t_{i+1} - t_i \approx$ a few ns** at small **t_i**, **$t_{i+1} - t_i \approx$ a few × 10 ns** at large **t_i**
- **t_{max} constant** in ideal case (slightly depends on track angle in drift cell case)
- **$\Delta t \leq t_{max}$**, duration of digitized signal, depends on impact parameter **b (t_{first})**
- **N_{cl}** depends only on **Δt** (or **b**, or **t_{first}**) in cylindrical drift tube case
- **N_{cl}** doesn't depend on **b** in square drift cell case, but only on the track angle
- **t_{last} constant** in the ideal case => defines the **trigger time $t_0 = t_{last} - t_{max}$**

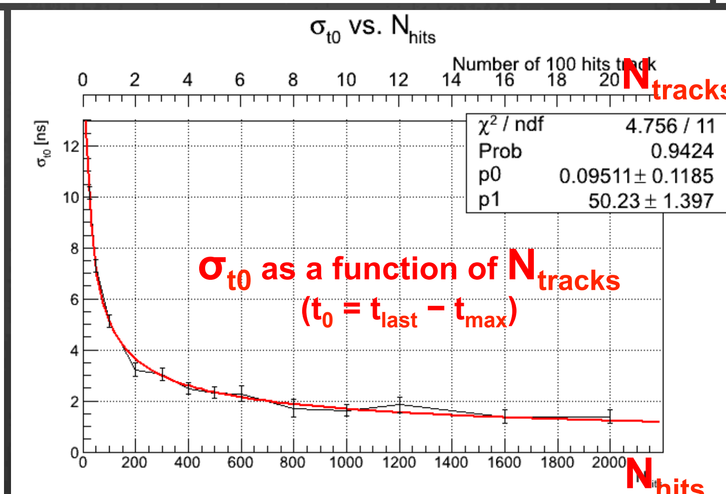
III. Cluster Timing: exploit signal digitization



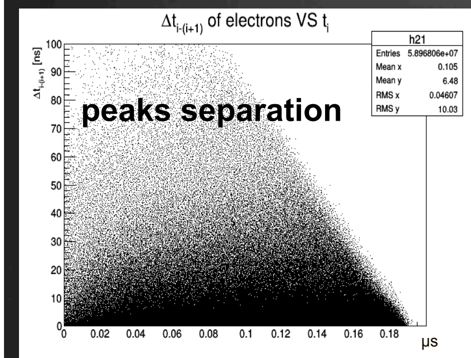


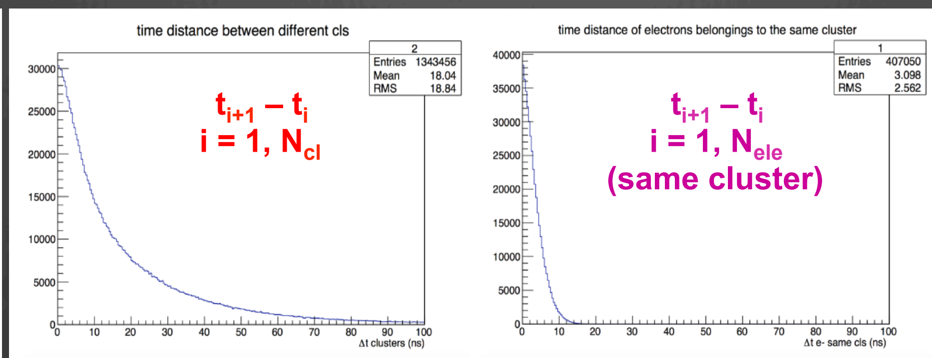


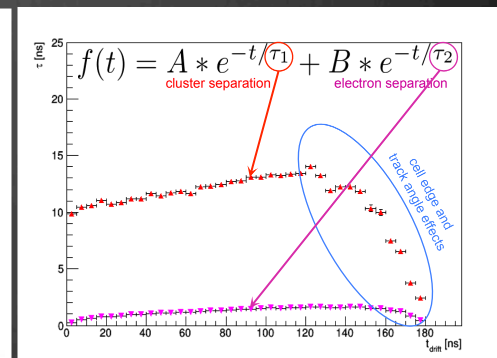


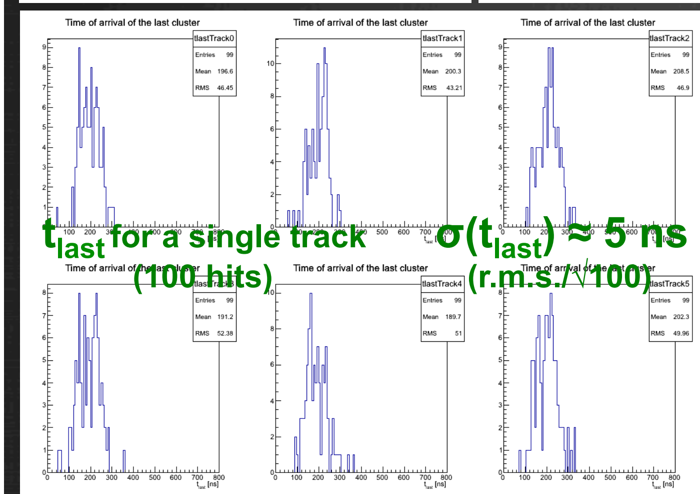


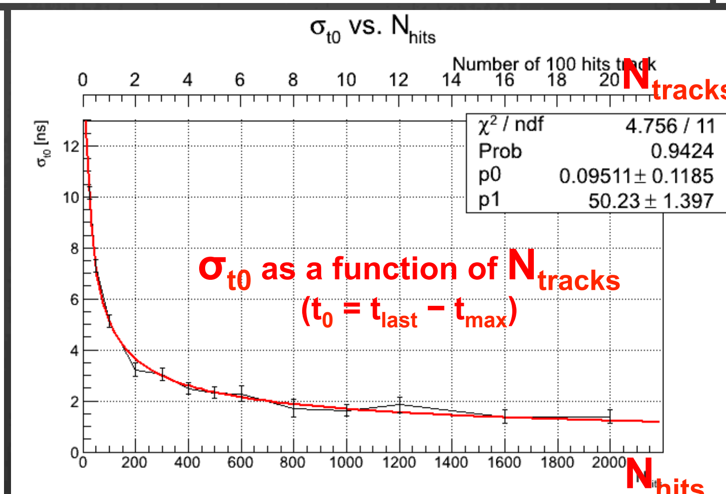
III. Cluster Timing: exploit signal digitization











Bunch Xing identification!

Track filtering!

Trigger capabilities?

IV. Cluster Counting

$$\frac{\sigma_{dE/dx}}{\left(dE/dx\right)} = 0.41 \cdot n^{-0.43} \cdot \left(L_{track}\left[m\right] \cdot P\left[atm\right]\right)^{-0.32}$$

from *Walenta parameterization (1980)*

versus

$$\frac{\sigma_{dN_{cl}/dx}}{\left(dN_{cl}/dx\right)} = \left(\delta_{cl} \cdot L_{track}\right)^{-1/2}$$

from *Poisson distribution*

dE/dx

truncated mean cut (70-80%) reduces the amount of collected information

***n* = 112** and a **2m track** at **1 atm** give

σ ≈ 4.3%

Increasing ***P*** to 2 atm improves resolution by 20% (σ ≈3.4%) but at a **considerable** cost of multiple scattering contribution to momentum and angular resolutions.

dN_{cl}/dx

δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a **2m track** give

σ ≈ 2.0%

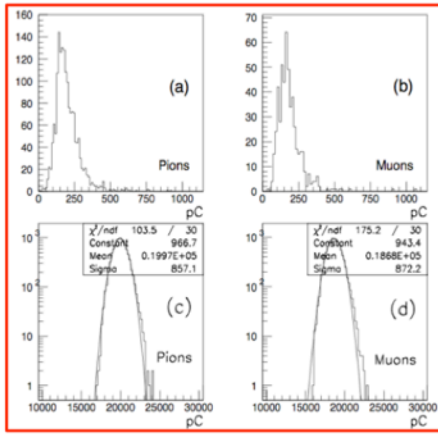
A small increment of iC_4H_{10} from 10% to 20% (δ_{cl} = 20/cm) improves resolution by 20% (σ ≈1.6%) at only a **reasonable** cost of multiple scattering contribution to momentum and angular resolutions.

IV. Cluster Counting

The data shown refer to a beam of **μ and π at 200 MeV/c**, taken with a gas mixture **He/iC_4H_{10}=95/5, δ_{cl} = 9/cm, 100 samples, 2.6 cm** each **at 45°** (for a **total track length of 3.7 m**, corresponding to **N_{cl} = 3340, $1/\sqrt{N_{cl}}$ = 1.7%**).

Setup:
25 μm sense wire
(**gas gain 2x10^5**),
through a high BW preamplifier
(**1.7 GHz, gain 10**),
digitized at
2 GSa/s, 1.1 GHz, 8 bits

(*NIM A386 (1997) 458-469* and references therein)

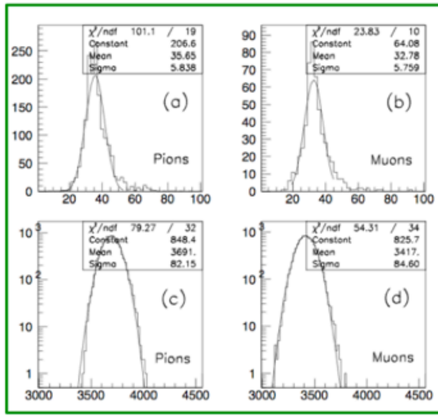


dE/dx

100 samples 3.7 cm

theory:
($\sigma = 0.41\, n^{-0.43}\, (L[m]P[atm])^{-0.32}$)
σ = 3.7%
≈ 2.0σ separation

experiment
20% truncated mean
σ = 4.5%
≈ 1.4σ separation



dN_{cl}/dx

theory
Poisson distribution
σ = 1.7%
≈ 5σ separation

experiment
σ = 2.5%
≈ 3.2σ separation