Tracking Options at a Muon Collider

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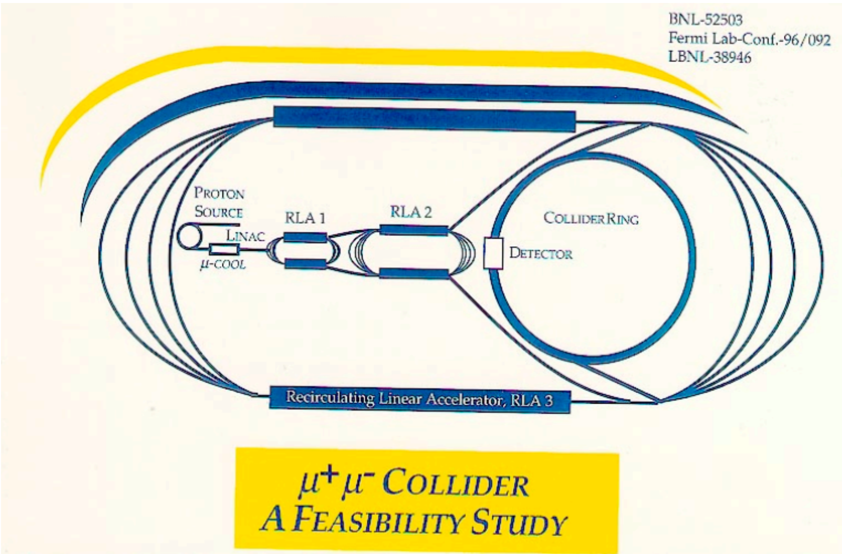
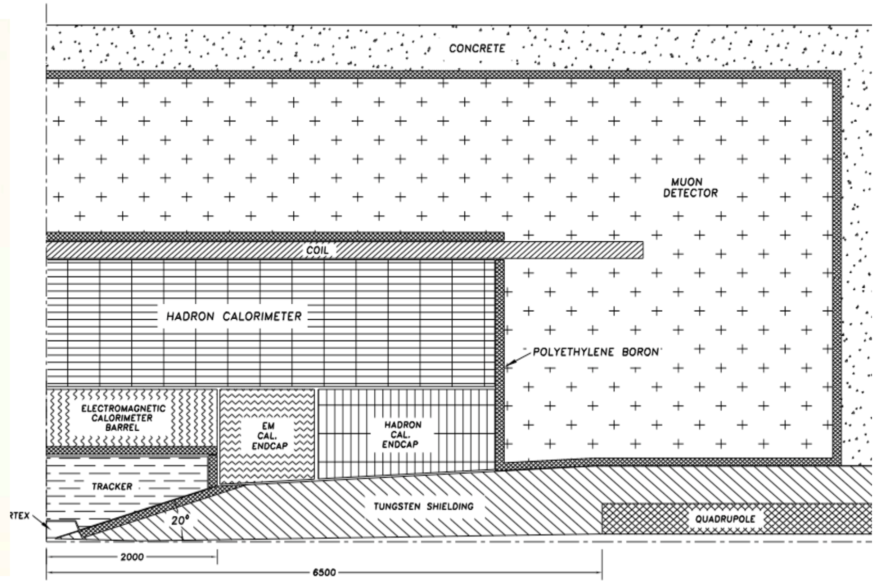
Outline

- Machine and Detector Framework
- Background Considerations
- Tracking Performance Requirements
- Possible Options
- ***CluTim***: a "*zero-mass*" Tracker

Machine and Detector Framework





Major sources of reference

J. Gallardo, R. Palmer, A. Tollestrup, A. Sessler, A. Skrinsky et al., ***$\mu^+\mu^-$ Collider: A Feasibility Study***
DPF/DPB Summer Study on New Directions for High Energy Physics, Snowmass, Colorado, 25 Jun – 12 Jul 1996,
BNL - 52503, Fermilab - Conf - 96 - 092, LBNL - 38946, http://www.cap.bnl.gov/mumu/pubs/snowmass96.html

G. William Foster and Nikolai V. Mokhov, ***Backgrounds and detector performance at a 2 x 2 TeV $\mu^+\mu^-$ collider***
AIP Conf. Proc. 352 (1996) 178, http://lss.fnal.gov/archive/test-preprint/fermilab-conf-95-037.shtml

Stumer et al., ***Study of detector backgrounds in a $\mu^+\mu^-$ collider***
Snowmass 96, http://www.slac.stanford.edu/pubs/snowmass96/PDF/DET081.PDF

Background Considerations

Machine induced backgrounds

No attempt to take into account bunch length and beam time structure

All backgrounds considered instantaneous and synchronous (except neutrons)

- muon halo

  muons lost from the beam bunch and unshielded

  rate depends on beam profile, halo, losses and shield

- beam-beam interactions

  coherent and incoherent, maybe negligible

- muon decay

  $2x10^{12}$ 2 TeV muons generate $6x10^{9}$ electrons m^{-1} s^{-1}
  consider only those in the final 130 m straight section.

Background Considerations

Electron induced background

- electromagnetic showers

  photons mean energy 1 MeV. Uncorrelated noise hits in a tracker with 2 Tesla field.

  (700 Gev) ***electrons*** synchrotron radiate,in the quadrupoles, 300 photons in average with 500 MeV mean energy (≤ 20%)

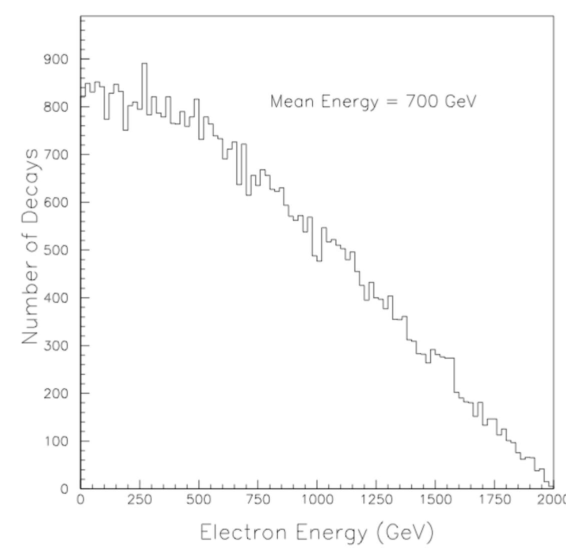
- Bethe-Heitler muon pairs

  probability of $6x10^{-4}$ and

  mean muon momentum of 27 GeV.

- hadron background

  from photon interaction in the shielding

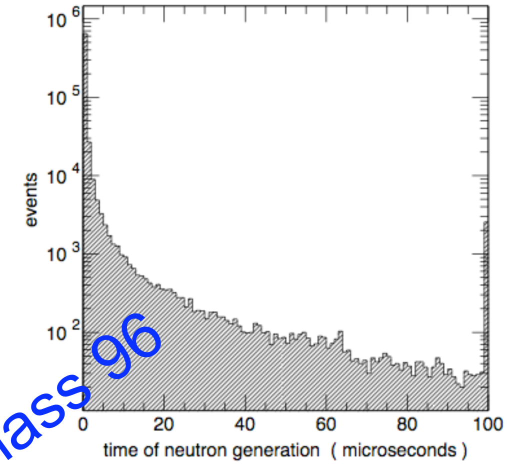


Background Considerations

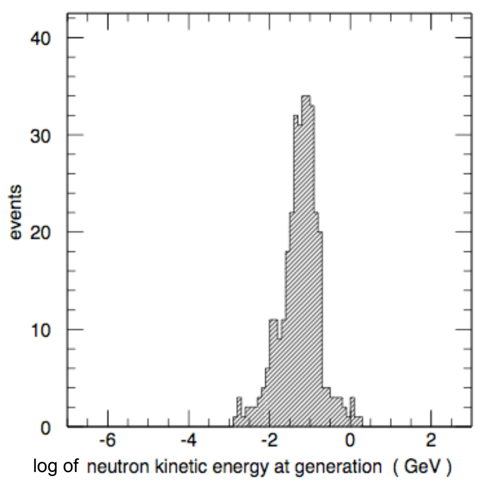
Photon induced background

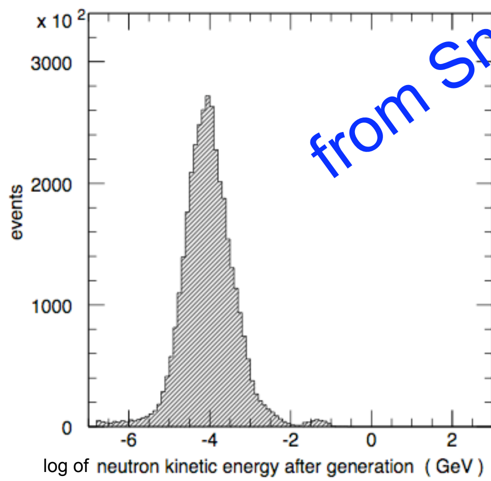
- hadron background

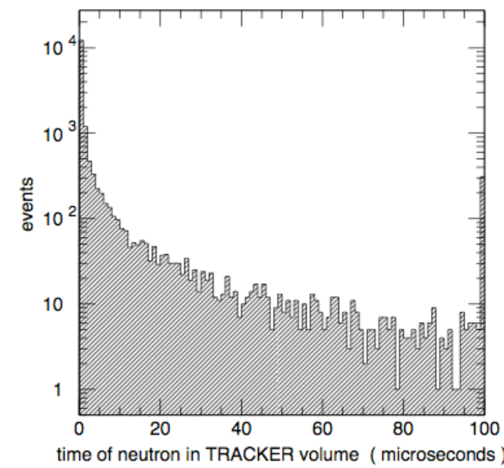
  more than one neutron and one proton from each photon interaction in the shielding. Rate model dependent. Including the proposed shielding



from Snowmass 96





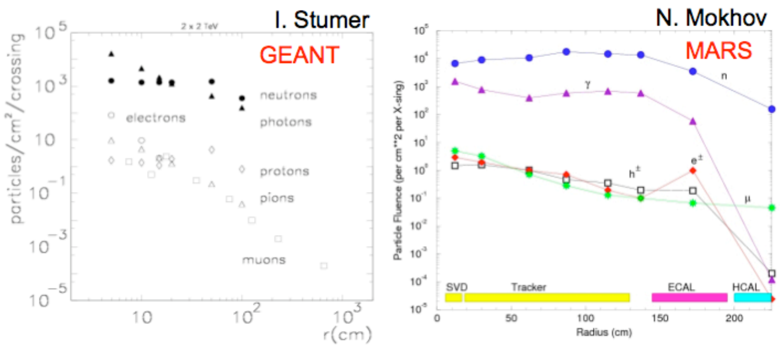


Background Fluences

General agreement on predicted fluences despite many different details.
Shielding (Cu, polyboron, W) cones are included.

4 TeV Collider Backgrounds

Results from Summer 1996



Background calculations & shielding optimization was performed using (independently) MARS & GEANT codes … the two calculations were in broad agreement with each other (although the designs were different in detail).

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from S. Geer 07

Particles/cm² from one bunch with 2×10^{12} muons (2 TeV)

GEANT (I. Stumer) Results from LBL Workshop, Spring 1997

r (cm)	γ	n	p	π	e	μ
5	2700	120	0.05	0.9	2.3	1.7
10	750	110	0.20	0.4		0.7
15	350	100	0.13	0.4		0.4
20	210	100	0.13	0.3		0.1
50	70	120	0.08	0.05		0.02
100	31	50	0.04	0.003		0.008
calo						0.003
muon						0.0003

Thresholds: E_γ>25KeV, E_n>40KeV, E_p>10MeV, E_π>10MeV

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Fight the high flux of particles in the detector either with the **highest granularity** or with the **least interacting** detector

Detector Occupancy

for vertex detector fight with the highest granularity

VERTEX DETECTOR HIT DENSITY

- Consider a layer of Silicon at a radius of 10 cm.
- GEANT Results (I. Stumer) for radial particle fuxes per crossing:

750 photons/cm^2	$\rightarrow$ 2.3 hits/cm^2
110 neutrons/cm^2	$\rightarrow$ 0.1 hits/cm^2
1.3 charged tracks/cm^2	$\rightarrow$ 1.3 hits/cm^2
TOTAL	**3.7 hits/cm^2**

from S. Geer 07

- $\rightarrow$ 0.4% occupancy in 300x300 μm^2 pixels
- MARS predictions for radiation dose at 10 cm for a 2x2 TeV Collider comparable to at LHC with $L=10^{34}$ $cm^{-2}s^{-1}$
- At 5cm radius: 13.2 hits/cm^2 $\rightarrow$ 1.3% occupancy

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Detector Occupancy

for tracking detector fight with the least interacting media

Example: drift chamber gas (1 MeV photon absorption in Ar/He =10)
inner wall of drift chamber made of 0.125 mm of C-fibre

	photons		neutrons		charged		tot	Tot*
cm	*#/cm²*	Hits/cm²	*#/cm²*	Hits/cm²	*#/cm²*	Hits/cm²	Hits/cm²	**Hits/cm²**
20	*210*	0.35	*100*	0.08	*0.53*	0.53	**0.96**	**0.77**
50	*70*	0.06	*120*	0.09	*0.15*	0.15	**0.30**	**0.15**
100	*31*	0.03	*50*	0.04	*0.05*	0.05	**0.12**	**0.05**

Major contribution to charged particles comes from pions

Tot* when neutrons and protons iare integrated over first 1 μs)

For a high granularity drift chamber (50 mm^2 drift cells), occupancy would be marginal only at the inner layers.

Tracking Requirements

Detector Performance Requirements.

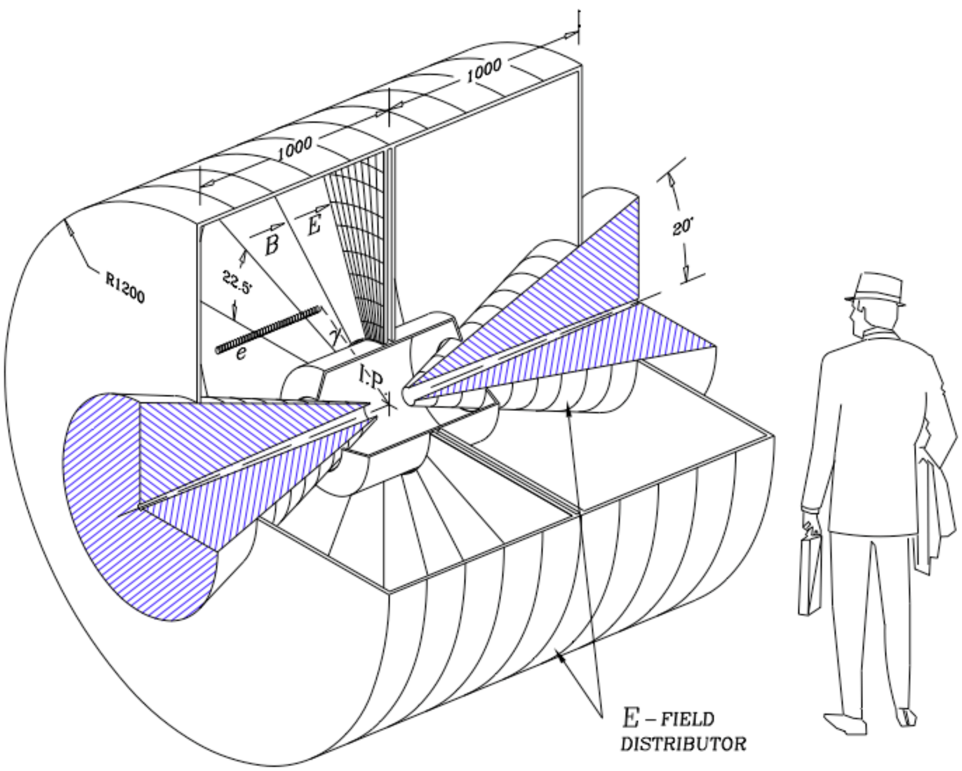
Detector Component	Minimum Resolution/Characteristics
Magnetic Field	Solenoid; $B \geq 2$ T
Vertex Detector	b-tagging, small pixels
Tracking	$\Delta p/p^2 \sim 1 \times 10^{-3} (\mathrm{GeV})^{-1}$ at large p High granularity
EM Calorimeter	$\Delta E/E \sim 10\%/\sqrt{E} \oplus 0.7\%$ Granularity: longitudinal and transverse Active depth: 24 X_0
Hadron Calorimeter	$\Delta E/E \sim 50\%/\sqrt{E} \oplus 2\%$ Granularity: longitudinal and transverse Total depth (EM + HAD)$\sim 7\lambda$
Muon Spectrometer	$\Delta p/p \sim 20\%$ 1 TeV

From Snowmass 96

Proposed Alternatives (1)

Low field large gas tracking volume

R_{in}=35cm, R_{out}=120cm, σ_φ=80μm, σ_z=300μm, B=2Tesla, readout=3x4mm^2



TIME PROJECTION CHAMBER

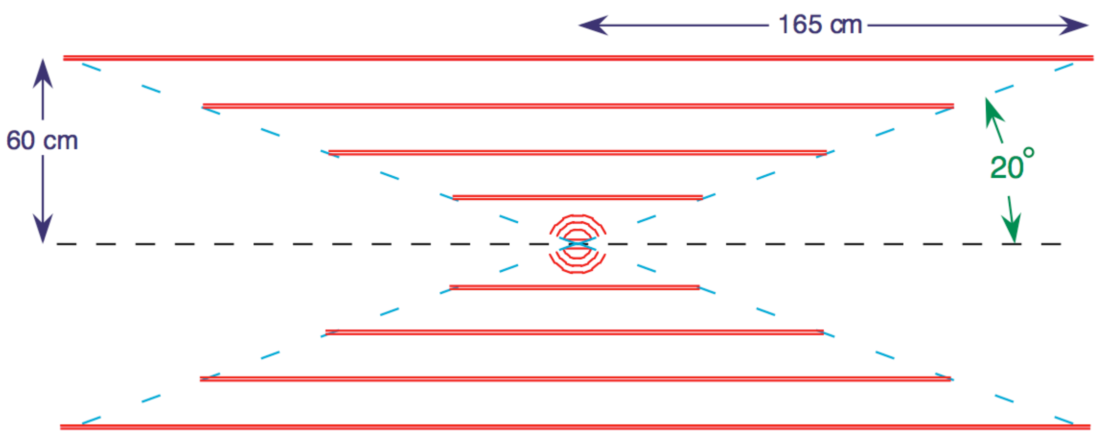
Criticisms:

- can't operate in He (too slow, too small n_p)
- Ar (10x) and Ne (5x) larger photon interact.
- positive ion backflow at amplification region
- E-field distortions in the drifting volume due to build up of the primary ionization of the large background
- large channel count (1M)
- thick end-plates

Proposed Alternatives (2)

High field compact Si tracker

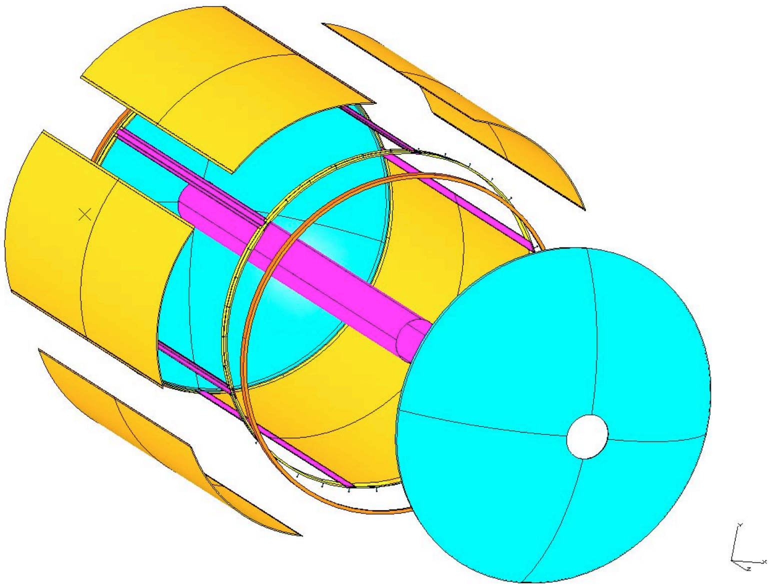
4 inner pixel layers 50x50μm + 4 outer μstrip layers 50x300μm
B = 4 Tesla, $0.15X_0$ at 90º



Criticisms:

- radiation hardness
- lack of redundancy
- difficult track finding (bkgnd)
- no Kinks, no Vees
- underestimated excessive thickness (15% X_0)
- very large channel count (10^8-10^9 channels)
- power dissipation

Central Tracker of 4th @ ILC



Central Tracker:

CluCou

- all stereo, cluster timing drift chamber
- light He based gas mixture
- mechanical structure entirely C-fibre
- max drift time contained in one BX
- total tracking volume (inner wall, gas and wires) < 0.5% X_0
- endplates (2.9% X_0), services (~5% X_0)

$$\frac{\Delta p_\perp}{p_\perp} = \frac{\sqrt{320}\cdot\sigma_{xy}}{0.3\cdot B\cdot\ell^2\cdot\sqrt{n}}\cdot p_\perp \oplus \frac{5.4\times10^{-2}}{B\cdot\ell}\sqrt{\frac{\ell}{X_0}}$$

(transverse length ℓ, σ_{xy} and X_0 in [m], B field in [T], momentum in [GeV/c]).

Required performance at ILC: $3.\times10^{-5} \oplus 1.\times10^{-3}$

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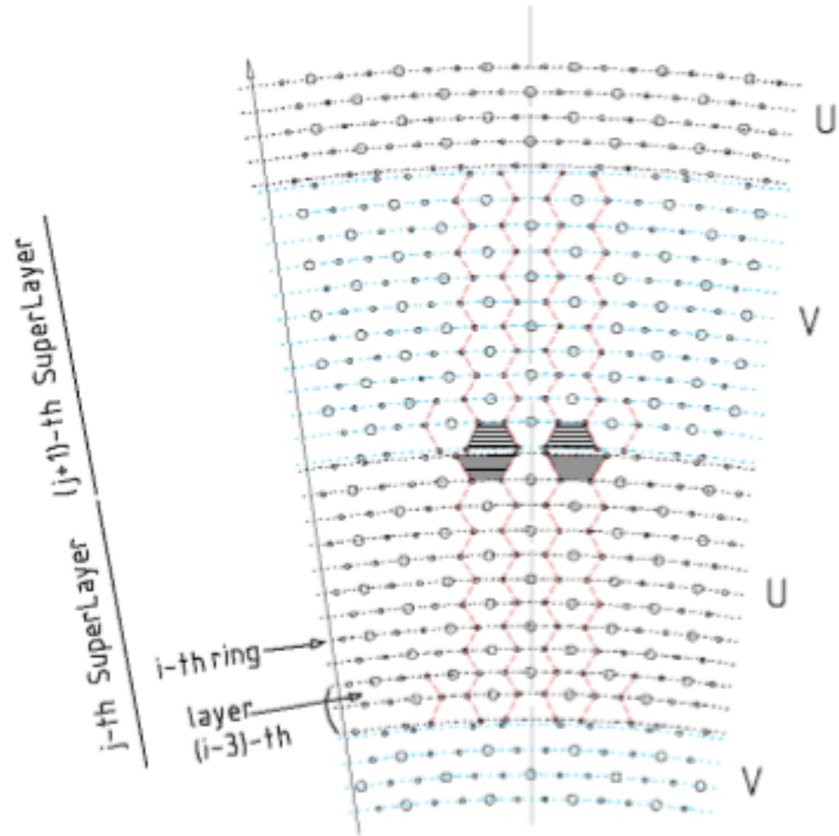
F. Grancagnolo - 4th LOI : detector
April 17, 2009 - Tsukuba

TILC09 - Joint ACFA Physics and Detector Workshop and GDE Meeting on International Linear Collider
April 17 - 21, 2009, Tsukuba, Japan

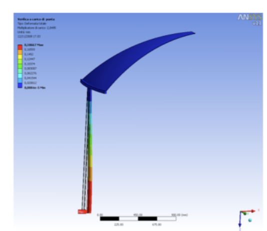
Central Tracker of 4th @ ILC



General layout based on successful operation of KLOE drift chamber

R_{in} = 19 cm
R_{out} = 150 cm
R_{dome} = 242 cm

Cell size from 0.4 cm to 0.7 cm side
160 axial measurements (on average)
Stereo angles from 55 mrad to 220 mrad
sense wires = 66000 (5X KLOE)
field wires = 150000 (4X KLOE)



Design, structural stability, types of carbon fiber and other component materials are given in a mechanical engineering thesis, together with a strategy for the wiring procedure, taking into account the deformation of the structure while the wires are tensioned.

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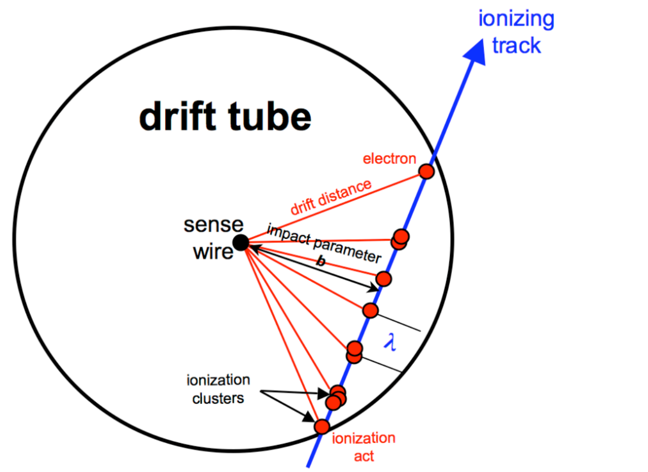
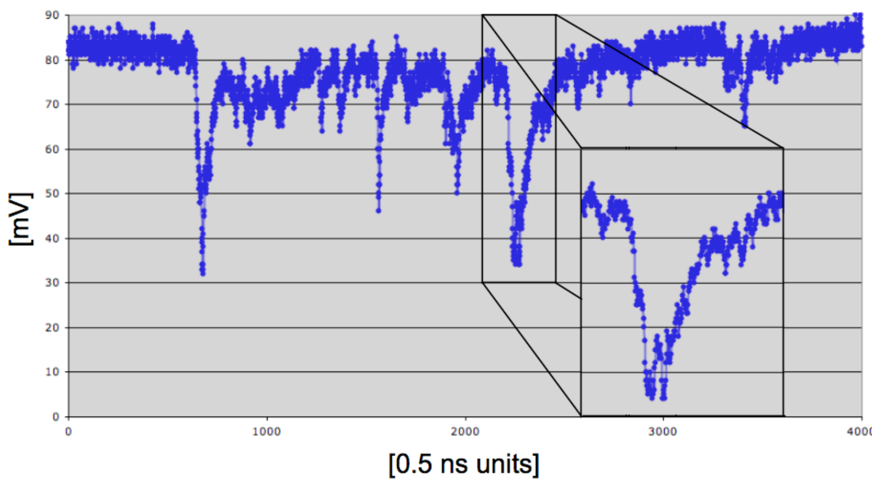
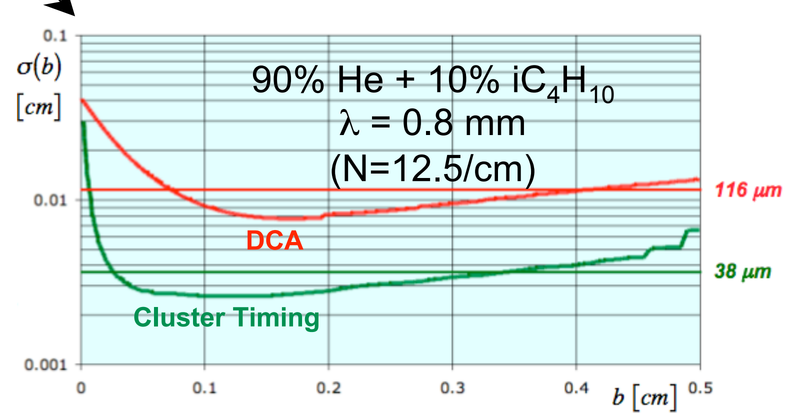
Central Tracker of 4th @ ILC

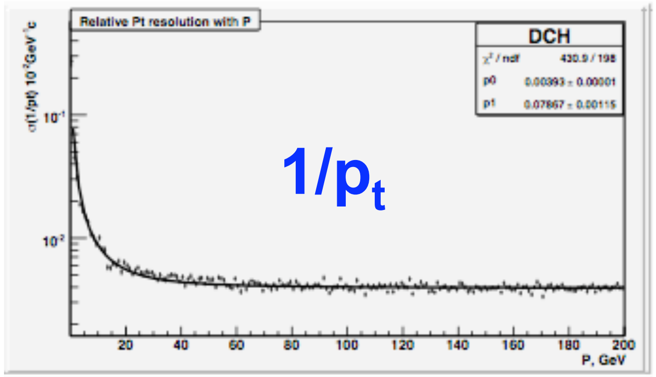
Cluster timing in drift chambers consists in recording the drift times of all individual ionization electrons collected on a sense wire and due to the passage of an ionizing track in the active gaseous medium.
This leads to spatial resolutions like

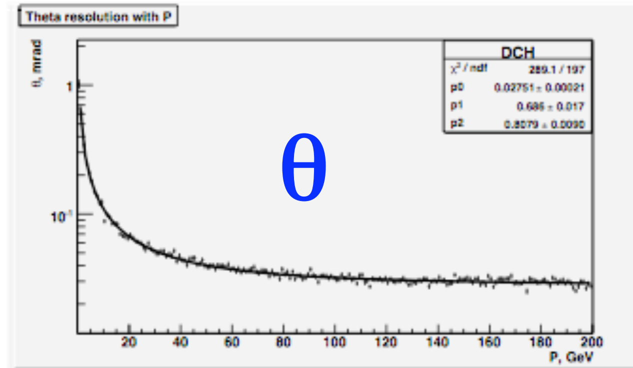






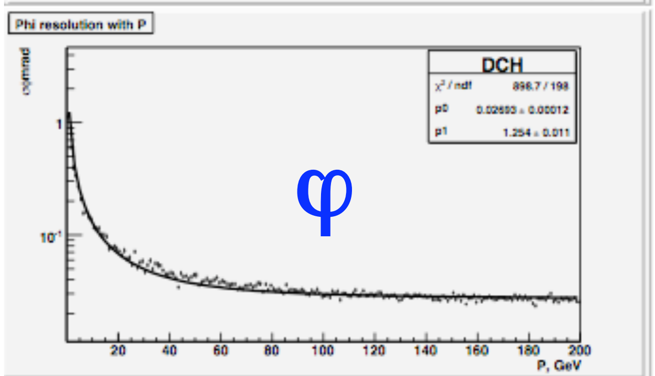
Central Tracker of 4th @ ILC

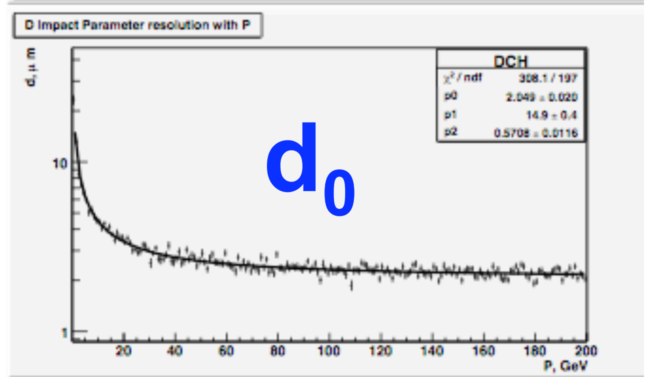


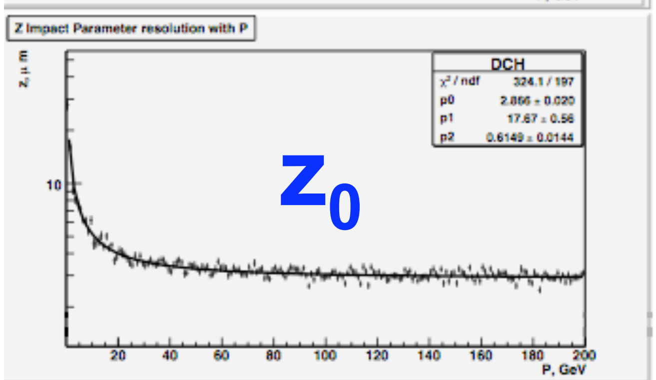


CluCou

Track parameters resolutions



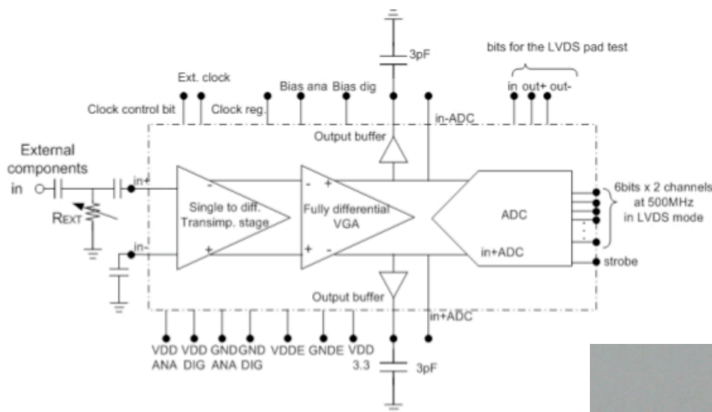




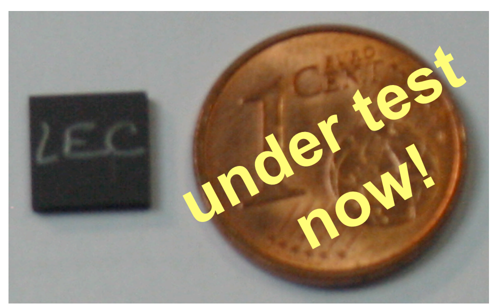
track parameter	fit results stochastic term	multiple scattering term
$\sigma(1/p_T)$	3.9×10^{-5} (GeV/c)$^{-1}$	$\oplus$ $7.9 \times 10^{-4}/p_T$
σ_θ	0.69 mrad$/p_T^{0.80}$	$\oplus$ 0.027 mrad
σ_ϕ	1.25 mrad$/p_T$	$\oplus$ 0.027 mrad
σ_d	14.9 μm$/p_T^{0.57}$	$\oplus$ 2.0μm
σ_z	17.7 μm$/p_T^{0.58}$	$\oplus$ 2.9μm

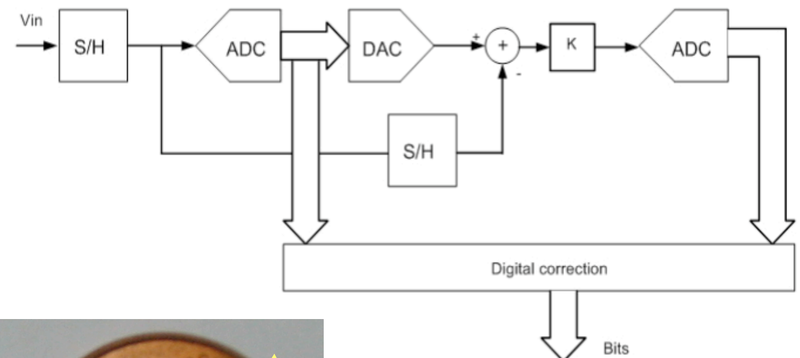
Central Tracker of 4th @ ILC

The implementation of the cluster timing technique requires a **low cost**, **high-speed**, **low-power** electronic interface able to process the drift signals. We have designed a **CMOS 0.13μm** integrated readout circuit, including a **fast preamplifier** (with a -3dB bandwidth of **700 MHz**) and **1 GSa/s-6bit ADC** to fulfill all the requirements for cluster timing. (2nd version by June 2009)



preamplifier

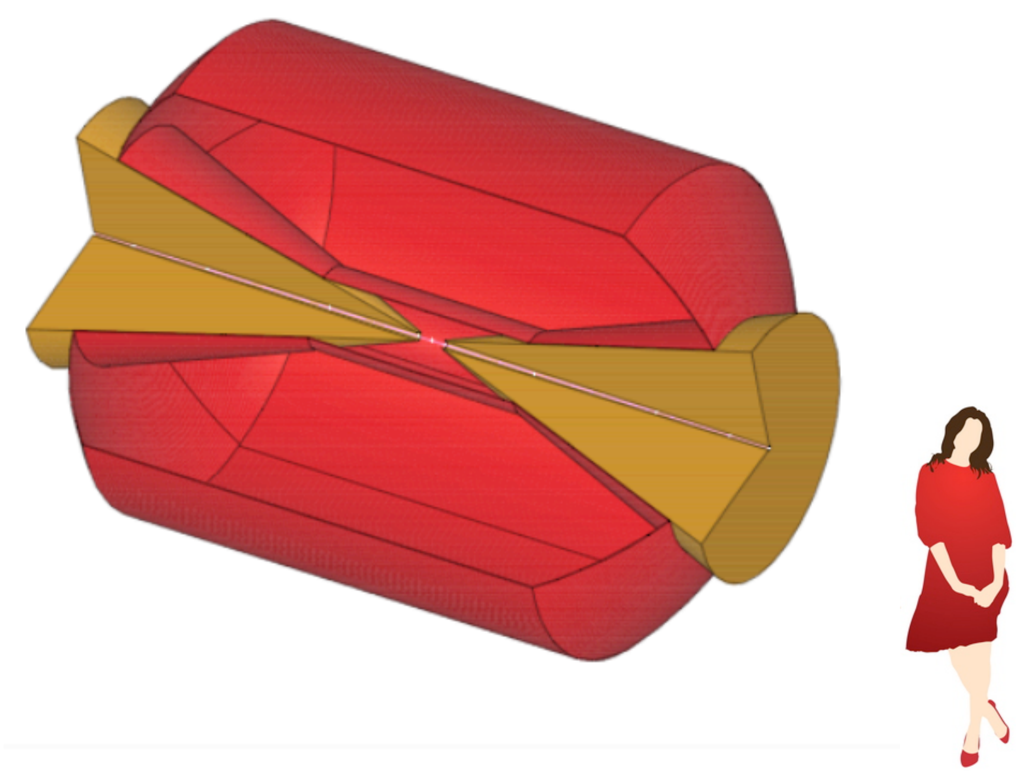




Flash ADC

New Tracker Option @ MC

"CluTim"



20 degrees W cones
B = 4 Tesla
R_{in} = 20 cm, R_{out} = 120 cm
σ_{xy} = 60 μm
σ_z = 300 μm
cell size = 4-6 mm hex.
# of layers = 133
# of s.w. = 50,000
(20 μm W)
# of f.w. = 115,000
(80 μm Al)
X_0 (gas+w.) = 2.44×10^{-3}
δ (gas+w.) = 6.94×10^{-4} g/cm^3

Expected Momentum Resolution

$$\sigma_{p_\perp} \big/ p_\perp^2 = 0.76 \times 10^{-4} \oplus 5.60 \times 10^{-4} \big/ p_\perp \sin\vartheta \left[GeV/c\right]^{-1}$$

Just for comparison, the expected momentum resolution for the considered alternative detectors

TPC

$$1.44 \times 10^{-4} \oplus 6.62 \times 10^{-4} \big/ p_\perp \sin\vartheta$$

gas 90%Ne-10%CF_4 - X_0 = 345 m

$\sigma_{r\varphi}$ = 100 μm

200 measurements along the track

L = 120 - 35 cm

B = 4 Tesla

Si

$$1.20 \times 10^{-4} \oplus 42.2 \times 10^{-4} \big/ p_\perp \sin\vartheta$$

0.05 X_0 (instead of 0.15 indicated)

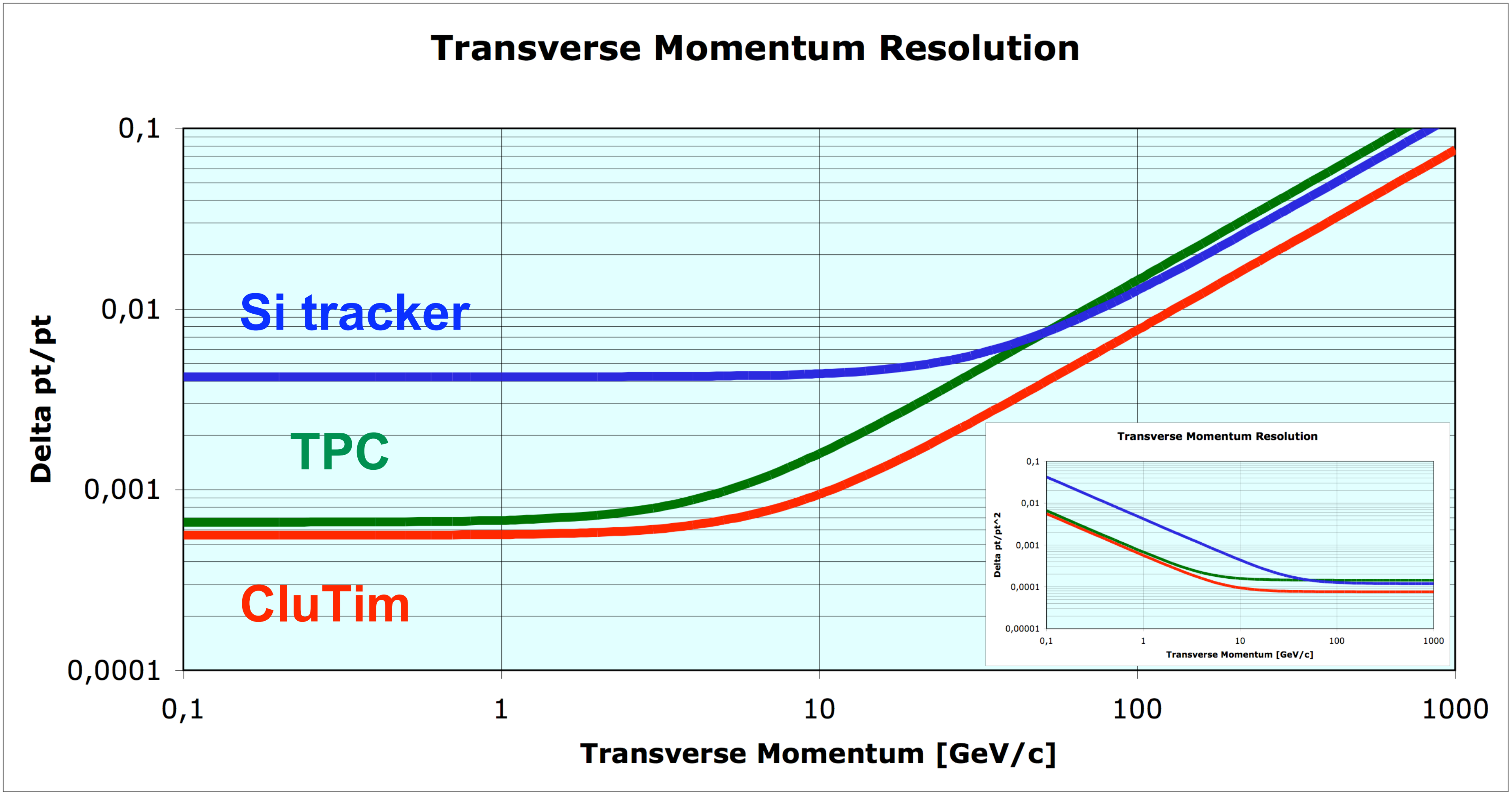
$\sigma_{r\varphi}$ = 10 μm

8 measurement planes

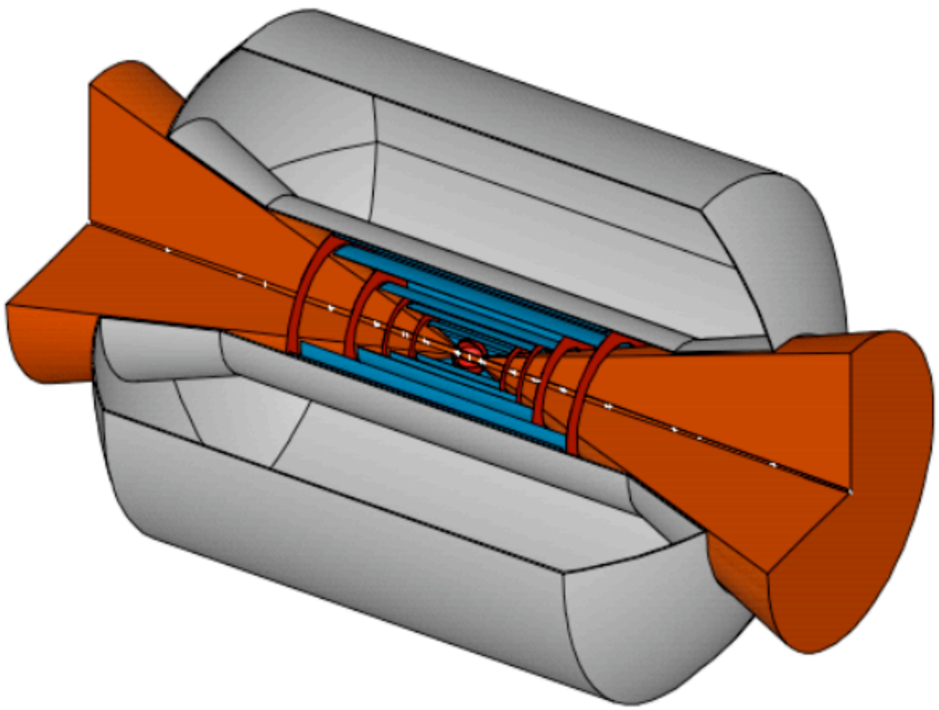
L = 60 cm

B = 4 Tesla

Expected Momentum Resolution



...a better option: Hybrid CluTim



20 degrees W cones
5 inner Si μstrip cylinders
(total X_0 < a few %)
5 inner Si pixel disks
B = 4 Tesla
R_{in} = 50 cm, R_{out} = 150 cm
σ_{xy} = 60 μm
σ_z = 300 μm
cell size = 5-7 mm hex.
# of layers = 107
# of s.w. = 52,000
(20 μm W)
# of f.w. = 120,000
(80 μm Al)
X_0 (gas+w.) = 2.54×10^{-3}
δ (gas+w.) = 7.10×10^{-4} g/cm^3

Conclusions

- Tracking at a Muon Collider is very challenging …
- Two different strategies may be applied to cope with the huge bkgnds:
  - increase **detector granularity**
  - increase **transparency** to neutrals and use low **density** for electrons
- Of the proposed tracking options
  - **TPC** suffers from longer integration of bkgnd, heavier and more interacting gas, more material overall, problem of ion build-up
  - **Si tracker** suffers from lack of redundancy (cannot afford too many planes) and complicated track finding, besides radiation
  - **CluTim** alone may not be able to cope with bkgnd at small radii and increasing its granularity impairs the transparency.
- **Hybrid CluTim (SiCT)** could suggest a promising solution to the problem.

Integrate the Si tracker with the vertex (as close as possible to the interaction) and let the outer chamber solve the track finding, leaving a Si plane as close as possible to the chamber to increase lever arm and to join track segments.