4th-Concept Tracking

CluCou Drift Chamber Update

by
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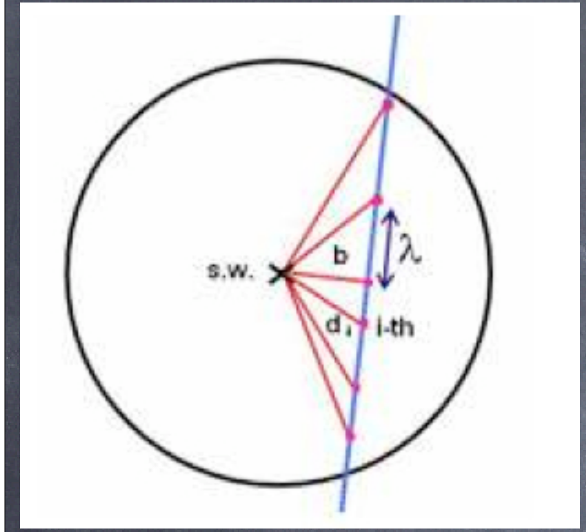
INFN - Lecce

ECFA 2008
International Linear Collider ECFA Workshop
9-12 June 2008, Warsaw Poland

Outline

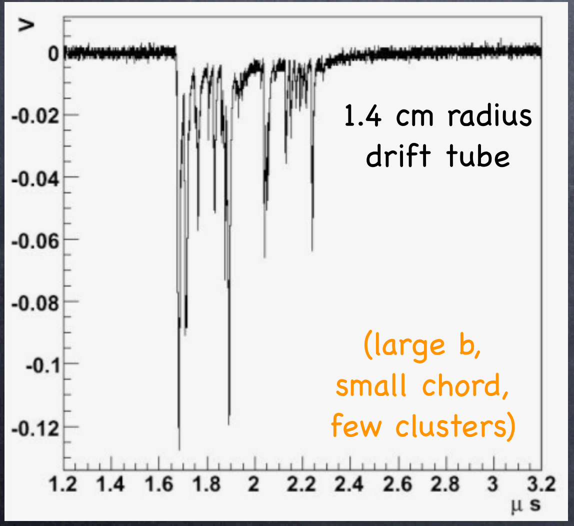
- Cluster Counting Technique: a reminder
- 4^{th}-Concept Tracking Chamber update
- Results from simulation (see talks by C.Gatto)
- R&D in Progress

CLUster COUnting Technique (1)

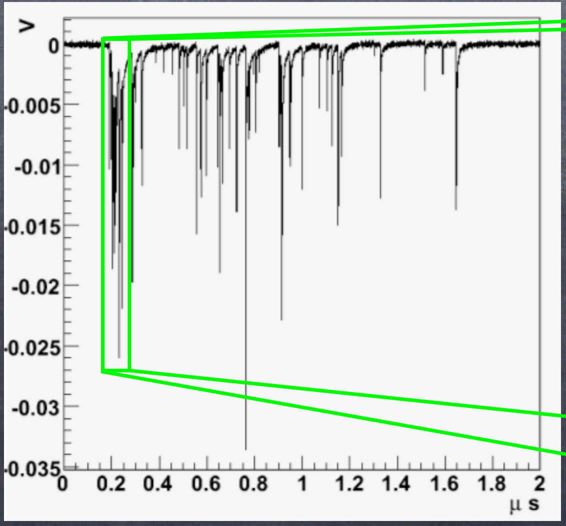


- Use a low primary ion, low drift velocity gas (Helium based mixture) and small cells (6 mm ≡ max drift time ≈ 350 ns)
- Digitize electron drift signal at high sampling rate (1-2 Gsa/s) and large bandwidth (1 GHz)
- Develop an efficient electron counting algorithm

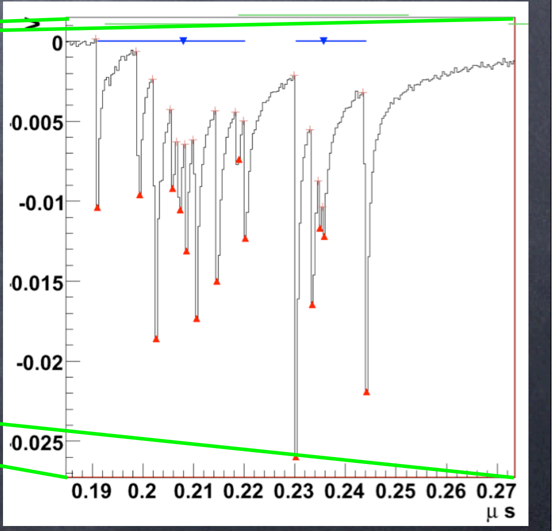
Real ampl. (x5) signal



MC simulated signal



Counting Algorithm



CLUster COUnting Technique (2)

Advantages:

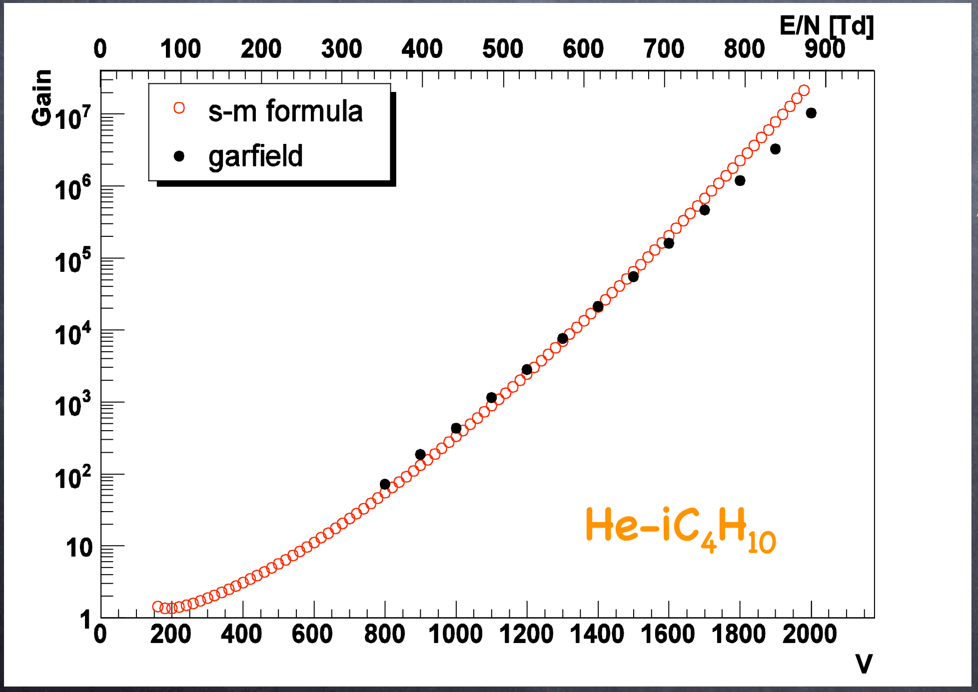
- each cluster gives an (almost) independent estimate of the impact parameter b (can reach $\sigma_b \sim 50\ \mu m$)
- clusters are Poisson distributed: $\sigma[\int(dN_{cl}/dx)dx] \sim 1/\sqrt{N_{cl}}$: for $N_{cl} = 11.3$/cm and 2m track, $\sigma[\int(dN_{cl}/dx)dx] \sim 2.1\%$ expected
- $N_{cl}(\beta,\theta)$, for a m.i.p., gives indication of the track dip angle θ within a single cell
- the latest cluster of all hit cells in one event identify the beam crossing time to better than 1 ns (triggering)
- the small cell radius allows for max drift time to be contained within one bunch Xing (no event pile up)
- the use of He based gas allows for:
  - ✳ low primary ionization and slow drift velocity which enhance cluster separation
  - ✳ low contribution to multiple Coulomb scattering (dominant for low p_t)
  - ✳ low cross section for low energy photons (insensitivity to most backgrounds)

CLUCOU Simulation: Gas parameters

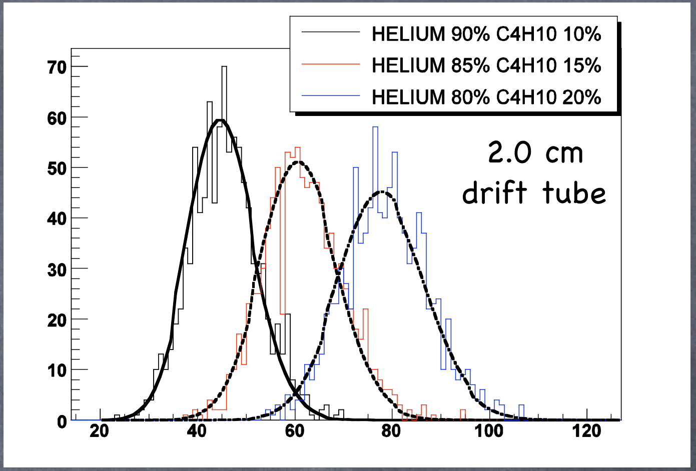
Based on packages: HEED, MAGBOLTZ, GARFIELD9 and ROOT

Number of clusters/cm and e-/cluster

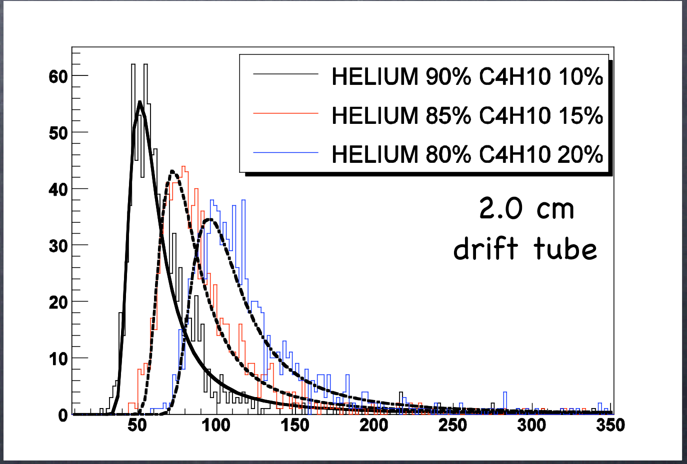
He-iC_4H_{10}	90%-10%	85%-15%	80%-20%
n_{cl}/cm	11.3	15.3	19.6
n_{el}/n_{cl}	1.60	1.62	1.62



Clusters Poisson ionization statistics

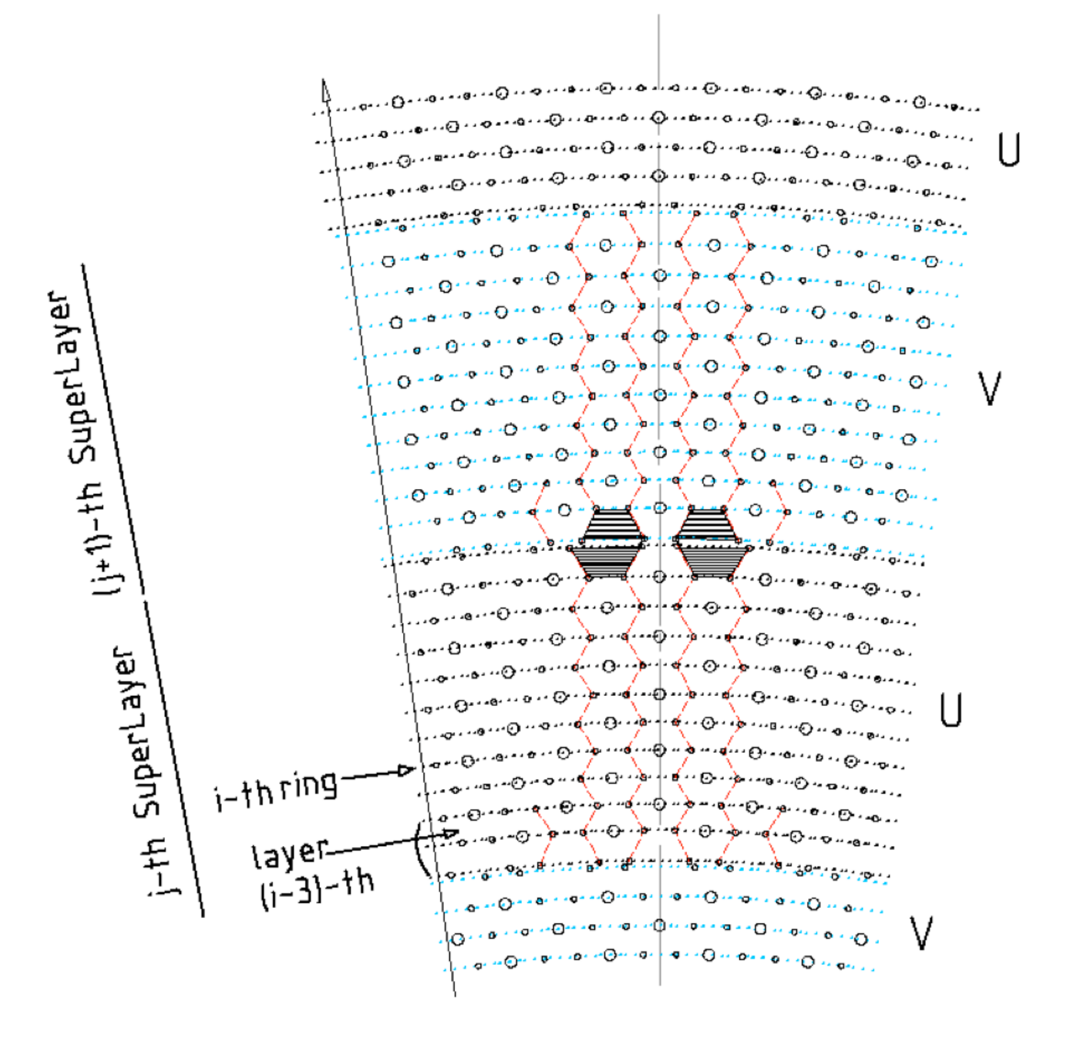


Electron Landau ionization statistics



4th-Concept Drift Chamber (1)

Cell and Layer Structure



Hexagonal cells f.w./s.w.=2:1

cell width: 6.0 / 8.0 mm

(max. drift time ~ 350 ns !)

20 superlayers, in 200 rings
10 cells each (133 hits radially)
at alternating stereo angles
±50 ±180 mrad (drop = 2.5 cm)

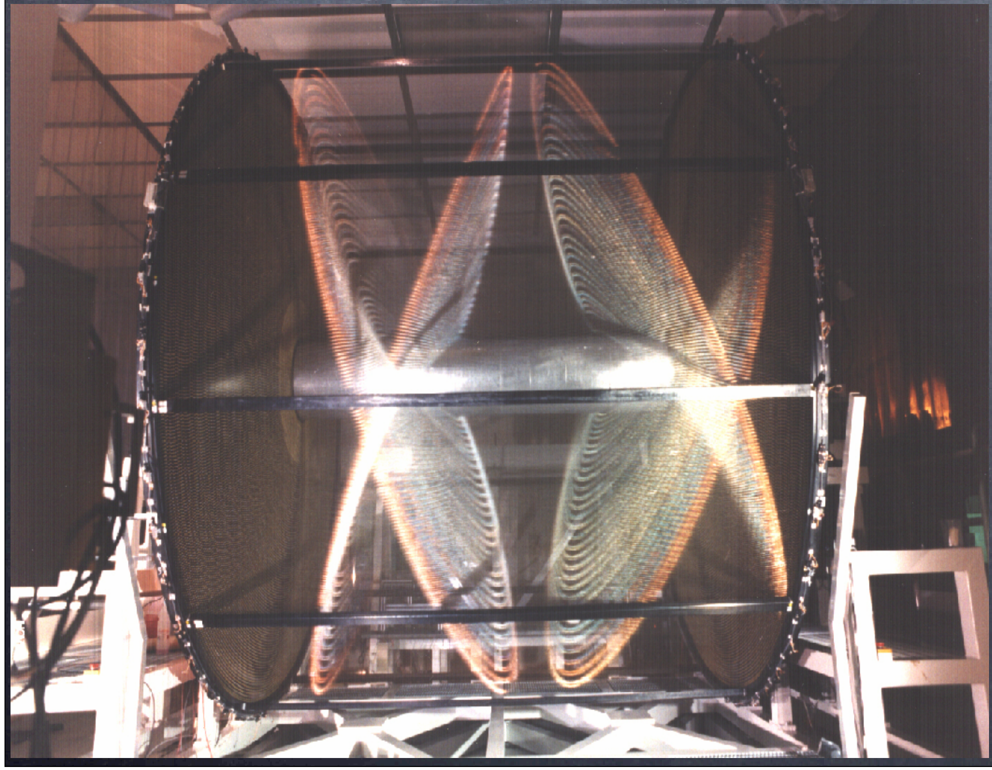
54000 sense w. 20 mm W
124000 field w. 80 mm Al

"easy" (few param.) t-to-d r(t)

~91% sampled volume

4^{th}-Concept Drift Chamber (2)

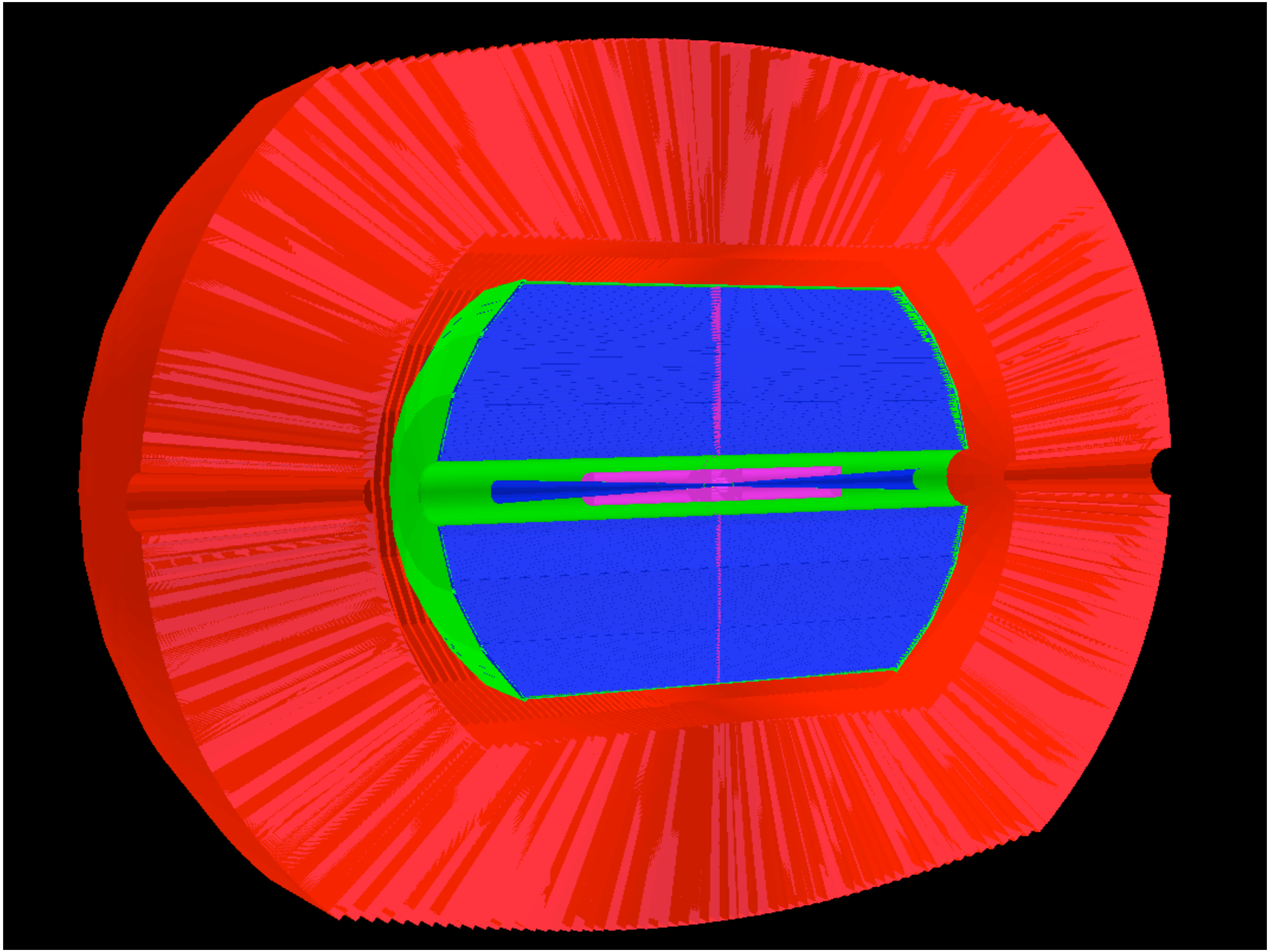
Extrapolating from the
KLOE chamber @ DAPHNE:



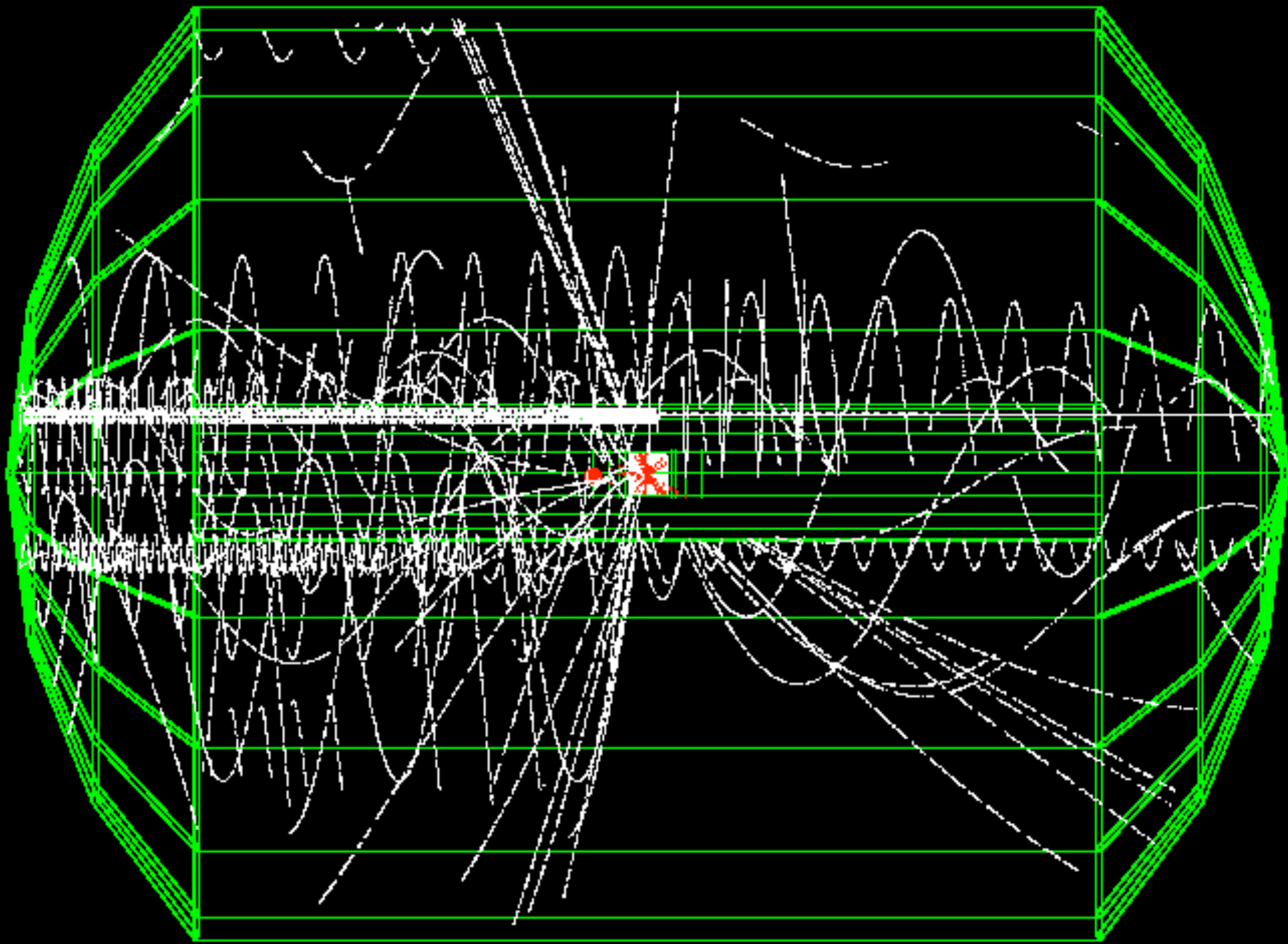
	KLOE		CLUCOU	
end plates diameter	2.00 m		1.50 m	
radius of curv.	10.00 m		– 2.12 m	
length	3.30 m		4.24 m @ r=0 3.00 m @ r= 1.5 m	
eff. N. of layers	54		133	
cell size	square 3:1	2 × 2 and 3 × 3	hexagonal 2:1	0.6 ÷ 0.8
n. of sense w.	12600	25 μm W	54000	25 μm W
n. of field w.	40000	80 μm Al	124000	80 μm Al
stereo ε / drop	±60 ÷ ±150 mrad	1.5 cm	±50 ÷ ±180 mrad	2.5 cm
thickness	material	X_0	material	X_0
end plates	8 mm C-fiber + 30 μm Cu	0,032	16 mm C-fiber + 30 μm Cu	0,062
inner cylinder	0.7 mm C-fiber + 30 μm Al	0,003	0.2 mm C-fiber + 30 μm Al	0,002
outer cylinder	C-fiber/hexcell sandwich	0,02	C-fiber/hexcell sandwich	0,024
gas	90% He + 10% iC_4H_{10}	0,0013	90% He + 10% iC_4H_{10}	0,0011
wires		$(2.8 \oplus 3.6)\times10^{-4}$		$(9.0 \oplus 8.4)\times10^{-4}$
gas + wires		1.33×10^{-3}		1.65×10^{-3}
expected $p_\perp$ resolution ($\Delta p_\perp/p_\perp^2$)	$(0.74 \oplus 2.2/(p_\perp \sin\theta)) \times 10^{-3}$		**$(0.32 \oplus 4.1/(p_\perp \sin\theta)) \times 10^{-4}$**	

from Gluckstern:

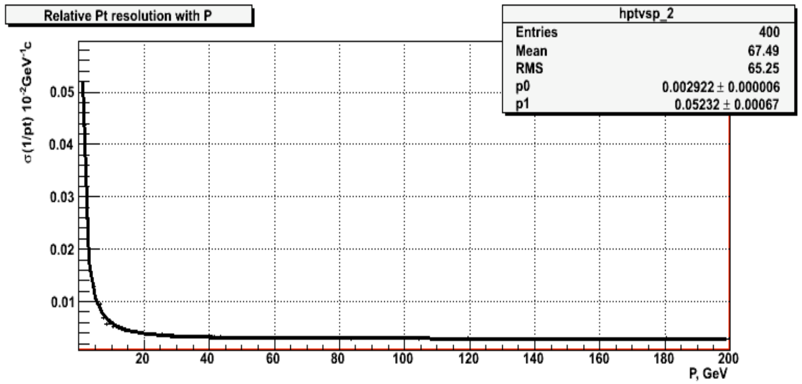
$$\kappa = 1/\rho \quad \rho = p_\perp/0.3B \quad (\delta\kappa)^2 = \left(\frac{\varepsilon_\perp}{L_\perp^{\ 2}}\sqrt{\frac{320}{N+4}}\right)^2 + \left(\frac{0.016\,(GeV/c)}{L\beta p_\perp \sin\theta}\sqrt{\frac{L}{X_0}}\right)^2$$

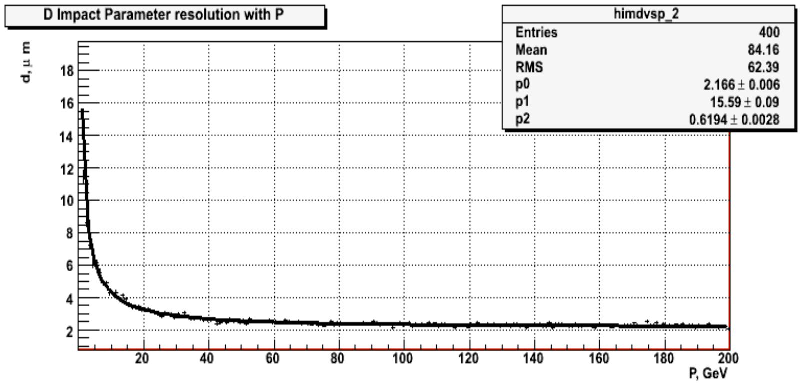


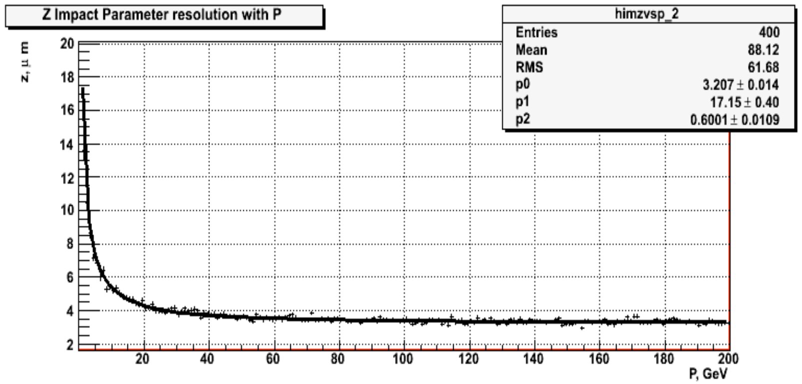
ttbar->6 jets event in 5 T field

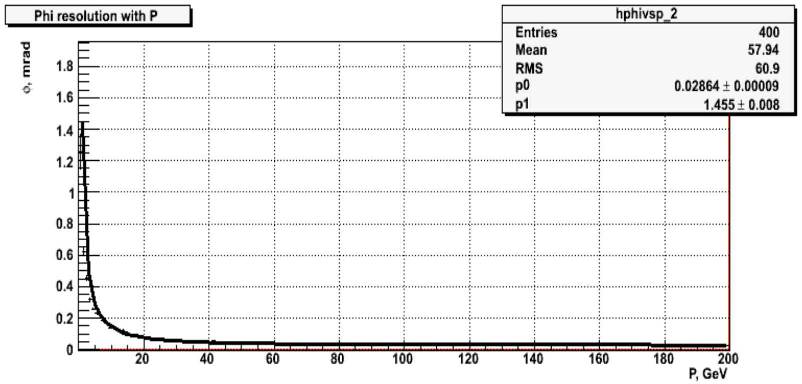


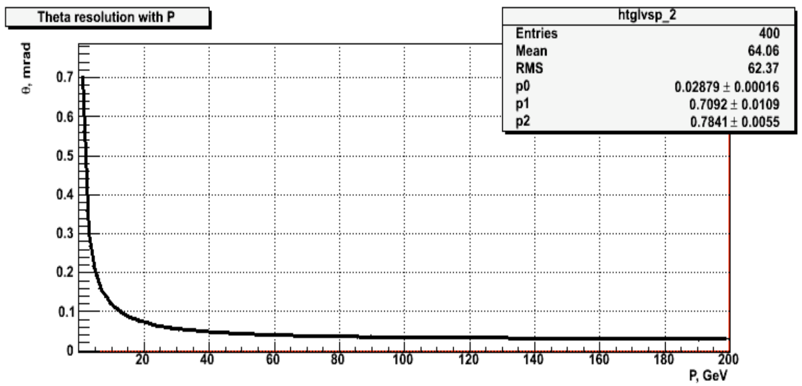
CluCou Drift Chamber resolutions











$$\sigma(P_t^{-1}) = 2.9/P \oplus 0.52\times10^{-4}\, GeV^{-1}c$$

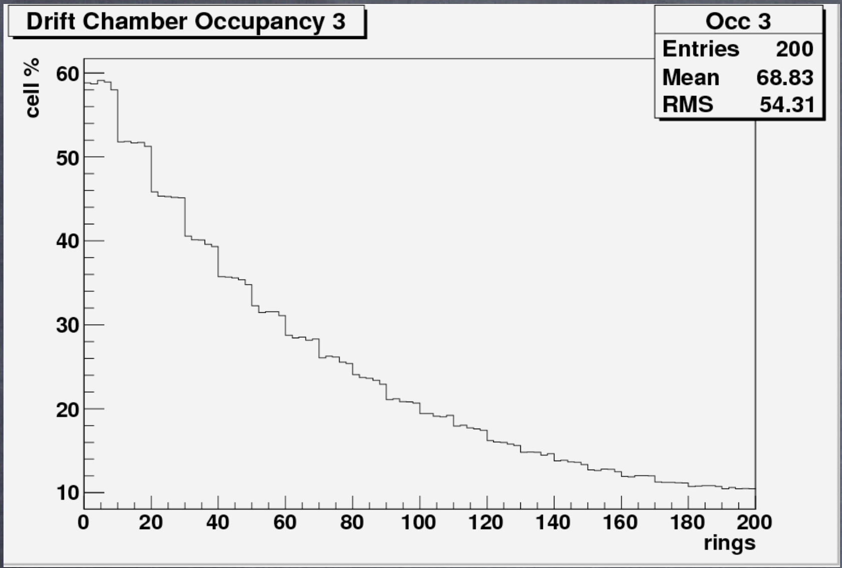
$$\sigma(\vartheta) = 0.71/P^{0.78} \oplus 0.029\ mrad$$

$$\sigma(\varphi) = 1.46/P \oplus 0.029\ mrad$$

$$\sigma(D_o) = 15.6/P^{0.62} \oplus 2.2\ \mu m$$

$$\sigma(Z_o) = 17.2/P^{0.60} \oplus 3.2\ \mu m$$

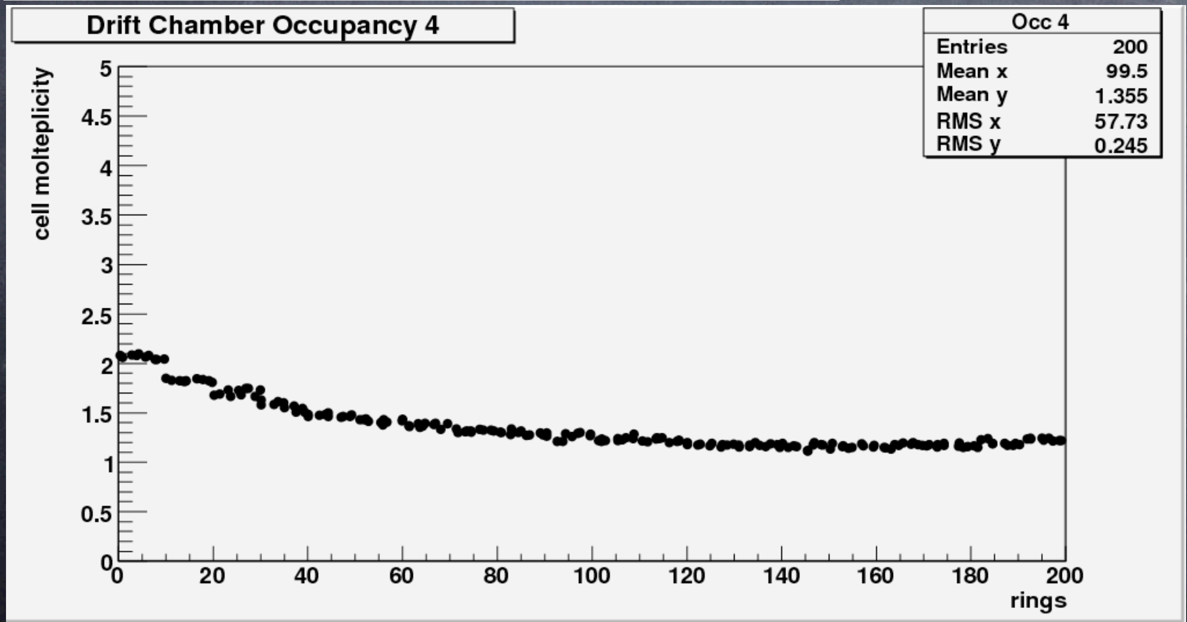
Chamber Occupancy



ttbar → 6 jets

(worst case!)

Average number of hit cells per sublayer



Average number of tracks per hit cell in each sublayer

R&D in progress

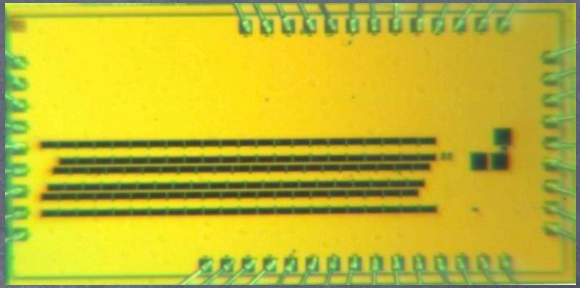
- Front end chip (first version)
- DAQ scheme
- New materials:
  - metal coated plastic and C wires
  - composite Boron fiber
- Test drift tubes
- Tracking telescope

Front end VLSI chip

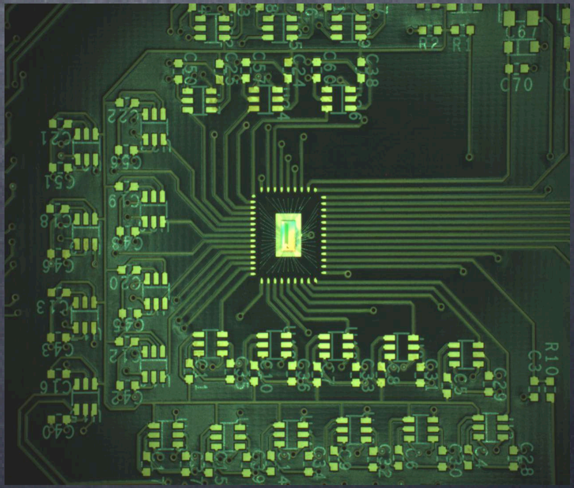
- Integrated 0.13μm CMOS technology provided by UMC though Europractice;
- 3 costitutive blocks:
  - 500MHz bandwidth amplifier with programmable DC-gain;
  - 6-bit@1Gsa/s ADC;
  - 6-bit@1Gsa/s to 30bits@200Msa/s buffer;
- Very low power consumption (~40 mW)
- Fully differential architecture

72 chips delivered as of today

chip microphotography

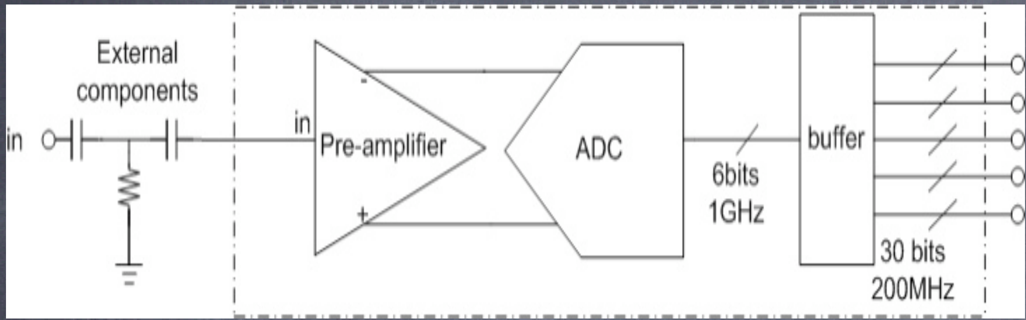


test board

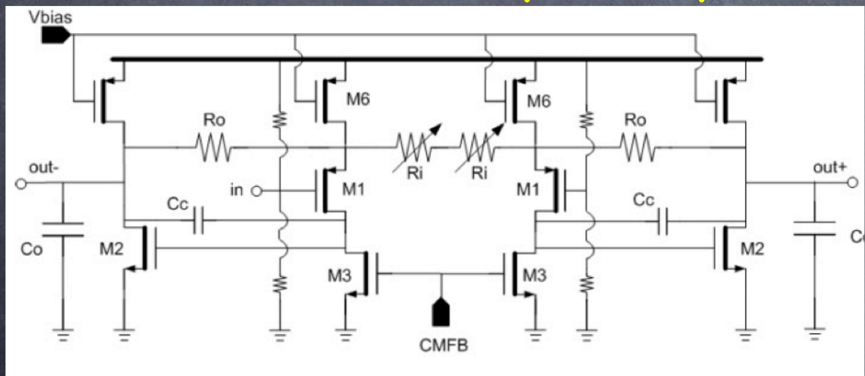


Front end VLSI chip

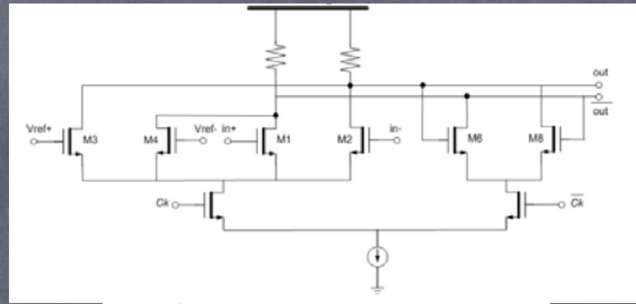
Read out architecture



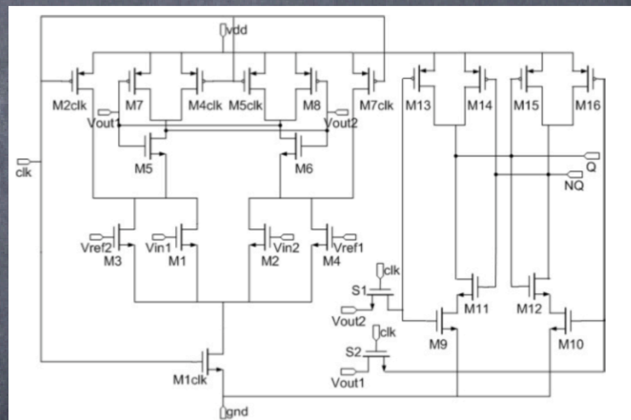
schematic of the preamplifier



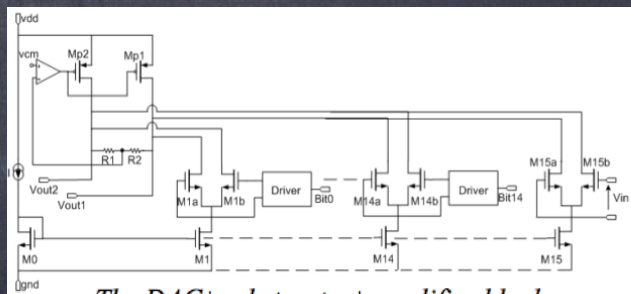
schematic of the ADC



The 1st sub-ADC comparator schematic



The 2nd sub-ADC dynamic comparator schematic



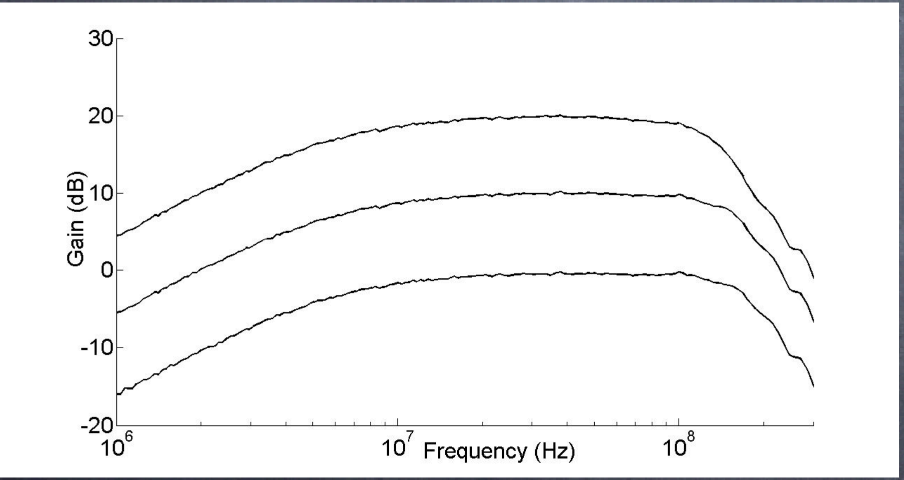
The DAC+substractor+amplifier block

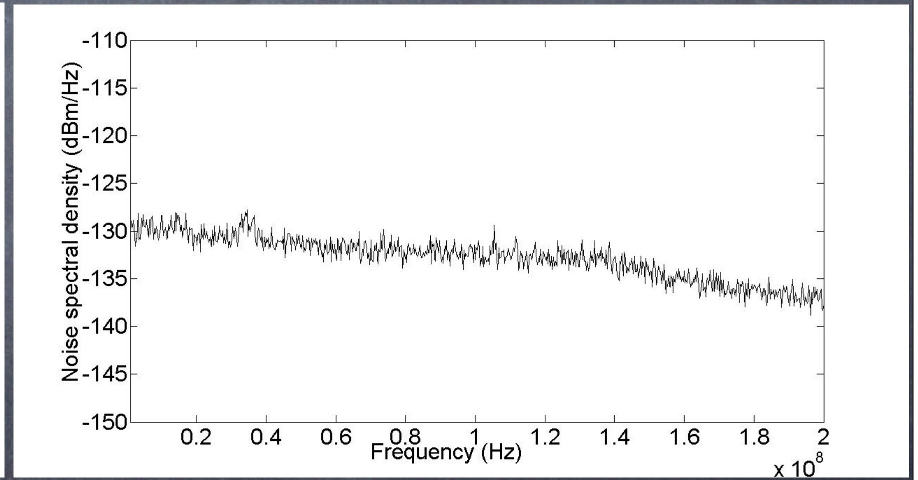
A CMOS high-speed front-end for cluster counting techniques in ionization detectors
Proceeding of 2-nd IEEE International Workshop on Advances in Sensors and Interfaces, Bari, 26-27 Giugno 2007

test of the preamplifier section

bias
linearity
gain vs frequency
spectral response
noise spectrum

successful (almost) according to simulations





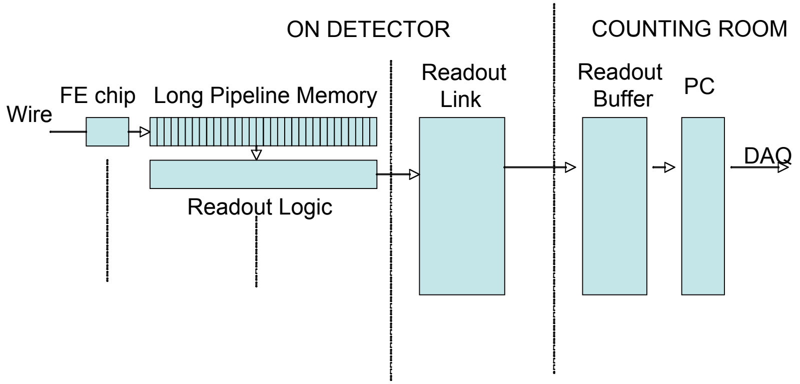
next, test of the ADC section

DAQ scheme

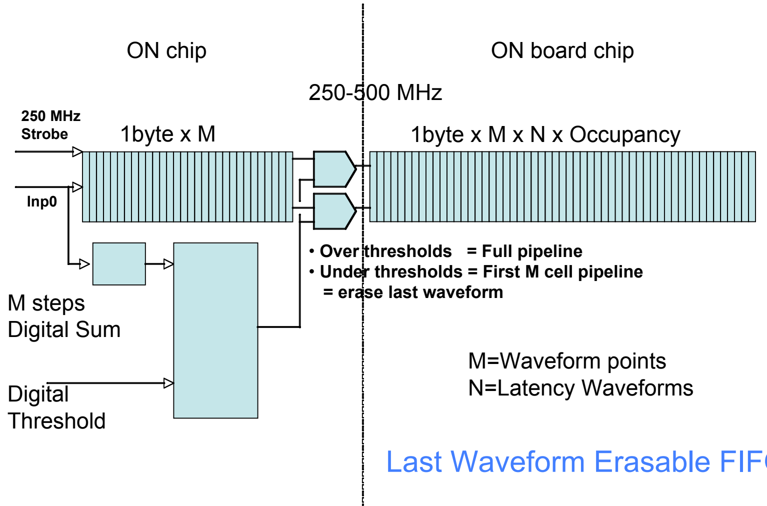
Thanks to
G. Chiodini (INFN Lecce)

DAQ development: Conceptual design (1)

1. Pipeline the data in Local Memory Buffer
2. Move data out by Readout Link
3. CLUCOU algorithm implemented in FPGA

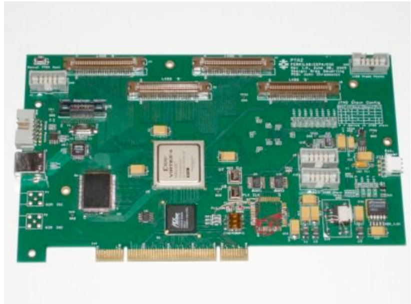


Zero Suppression Algorithm



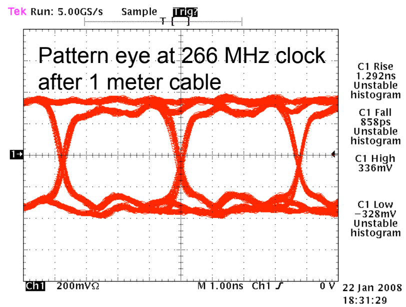
Last Waveform Erasable FIFO

DAQ development: Fermilab PCI board



New PTA Fermilab from ESE department
- **PCI bus**
  - **80 LVDS I/O**
  - **VirtexIV FPGA**
  - **We have one in Lecce**

Many thanks to Fermilab ESE department (M. Turqueti, L. Uplegger and S.Kwan)



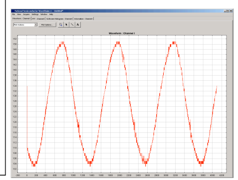
Short term plans:

- *Readout 1 to 5 CLUCOU V1 chips*
- *Implement Last WF Erasable FIFO*
- *Implement Peak Finder*
- *Implement Data-Serializer*
- *…*

DAQ development: NS Development Board

ADC08D500DEV:
- **2 Channels**
- **8 bit @ 1.5Gs/sec**
- **dynamic range +/-280 mV**
- **VIRTEX-IV FPGA**
- **In/Ext clock**
- **Vision Software**

GOALS
- **Both end drift-tube readout**
- **FPGA firmware development**
- **Banch-mark for real DAQ based on:**
  - **FE-ADC Lecce-ASIC**
  - **GHz Multi clock distribution**
  - **CLUCOU Data Combiner Board**



Example of 1.5 GHz sampling waveform data capture in Lecce.

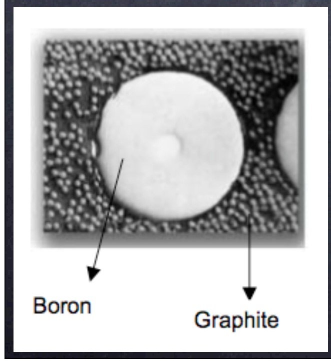
new materials: wires

- start test and characterization of metal (Ni, Ag, Au) coated wires
  - carbon (7 µm, 33 µm diameter, maybe other sizes) δ = 2.2 g/cm^3, X_0 = 18.8 cm
  - polyimide (kapton) (20 µm, 40 µm) δ = 1.42 g/cm^3, X_0 = 28.6 cm
  - PET (mylar) (19 µm, 28 µm) δ = 1.39 g/cm^3, X_0 = 28.7 cm
  - SiC (silicon carbide) (79 µm, 142 µm) δ = 2.8 (3.0) g/cm^3, X_0 ~12 cm

Advantages of light wires

	density [g/cm³]	X_0 [cm]
W	19,3	0,35
Al	2,70	8,9
Ag	10,5	0,88
Kapton	1,42	28,6
Mylar	1,39	28,7
Carbon	2,20	18,8

	mechanical tension [g]	total tension [Ton]	tension on end plates [Ton]	equivalent X_0 [rad. l.]
25 μm sense wires W	60	3,2	13,7	9.0×10^{-4}
80 μm field wires Al	85	10,5		8.4×10^{-4}
20 μm sense wires Kapton (Ag)	5	0,24	6,8	0.5×10^{-4}
80 μm field wires Kapton (Ag)	53	6,6		4.7×10^{-4}



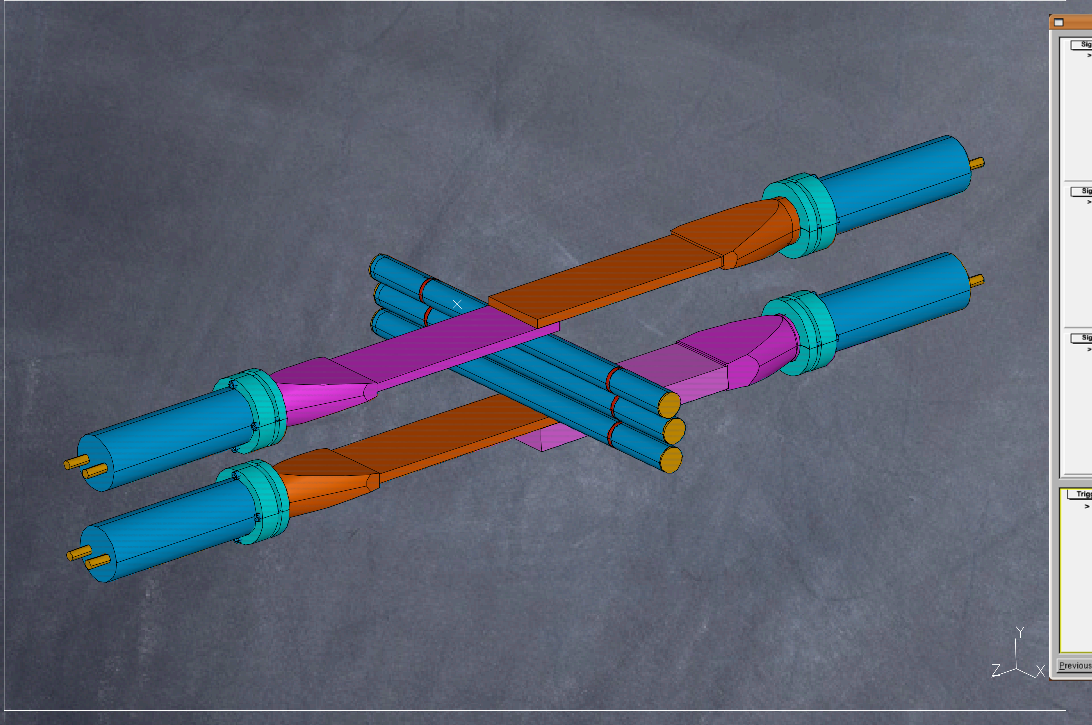
end plate thickness reduced by a factor 2

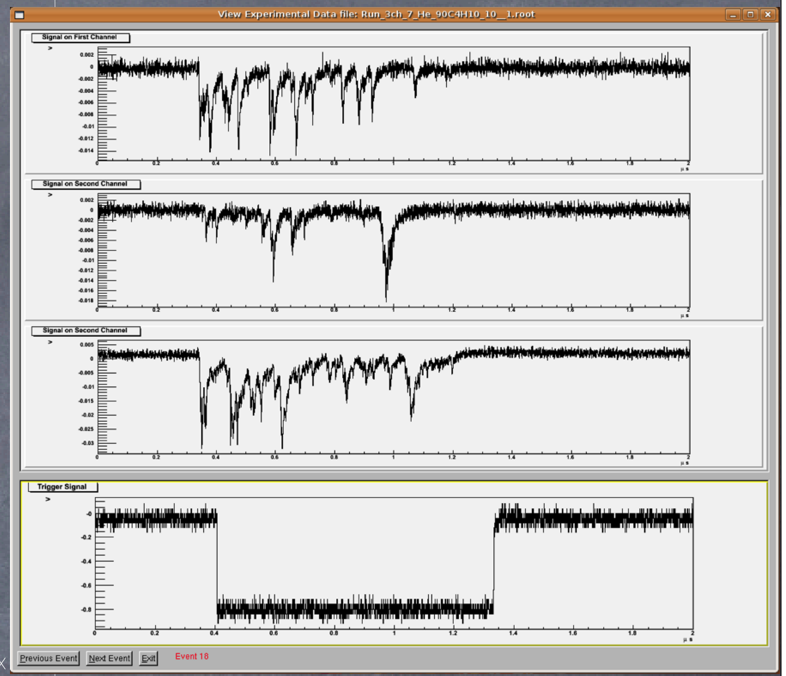
$0.062\ X_0 \Rightarrow 0.032\ X_0$

further reduction (30%÷50%) with use of Boron loaded Carbon fibers

negligible contribution to multiple scattering from wires

Test drift tubes



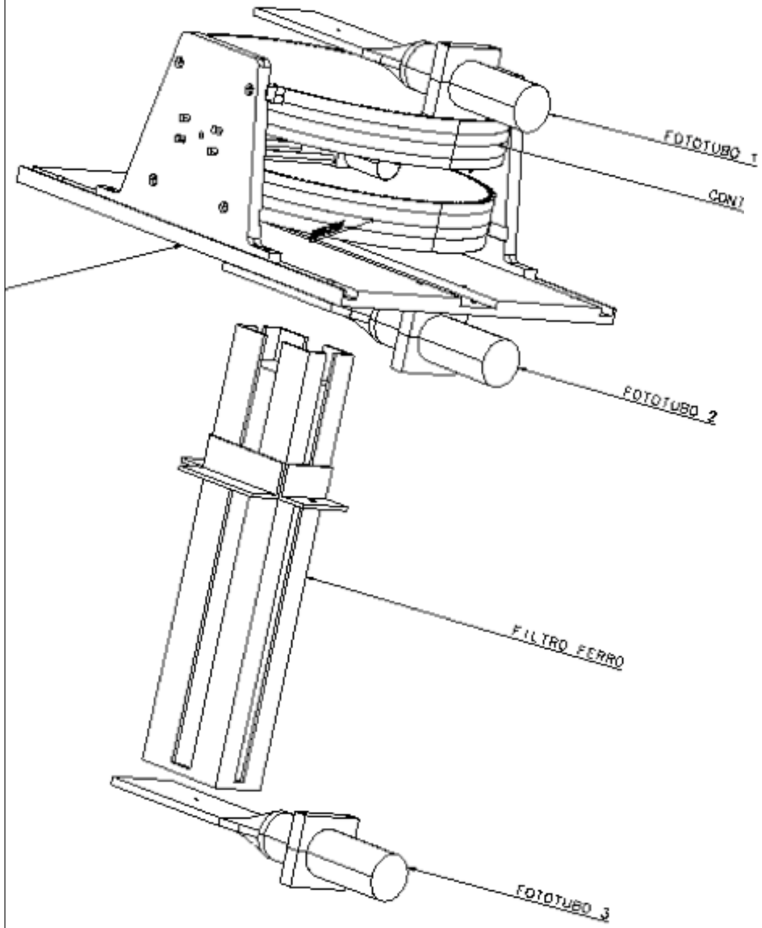


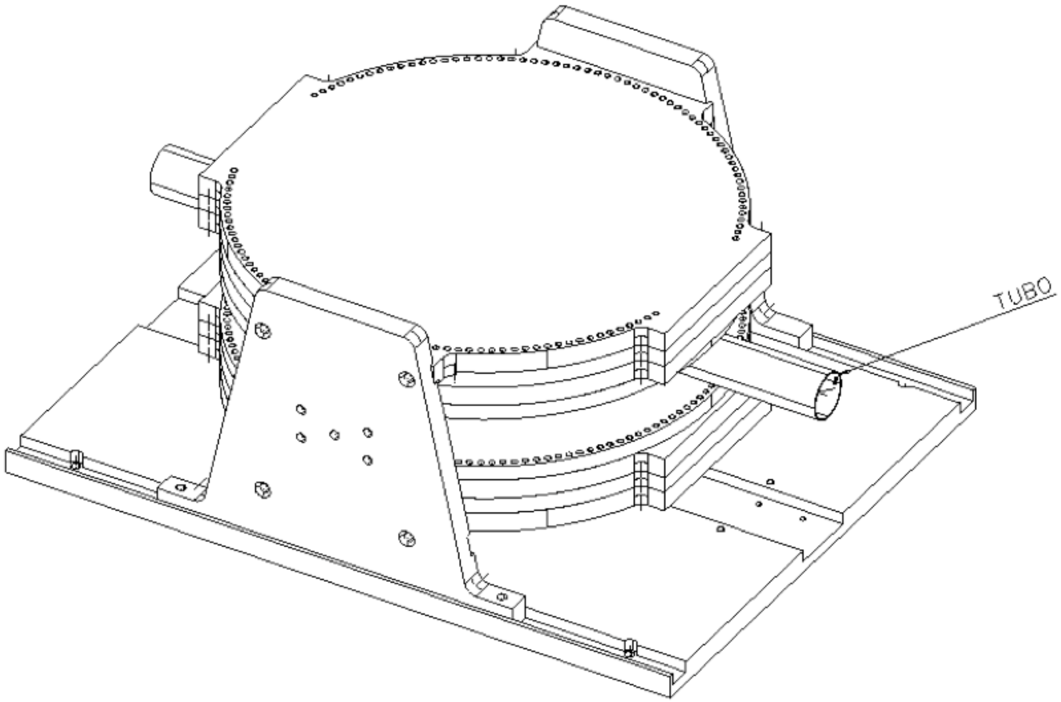
Cosmic ray trigger (3 cm × 8 cm), rate = 0.04 s^{-1}
Drift tubes (3 cm diameter) staggered by 0.5 mm

Tuning of parameters for efficient cluster counting
Check of time-to-distance relation
Measurement of intrinsic time resolution
Possibility of selecting β and θ of cosmic ray
Very slow! Requires a lot of patience!

Acquisition on a fast scope
4 GHz bandwidth at
2.5 GSa/s (0.4 ns)
on 50 Ω (SMA)
full scale is 20 mV × 2 μs
amplification ×5 (1.7 GHz)

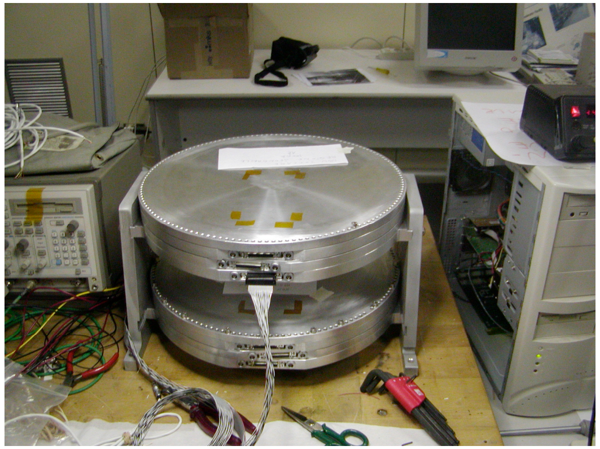
Si telescope update

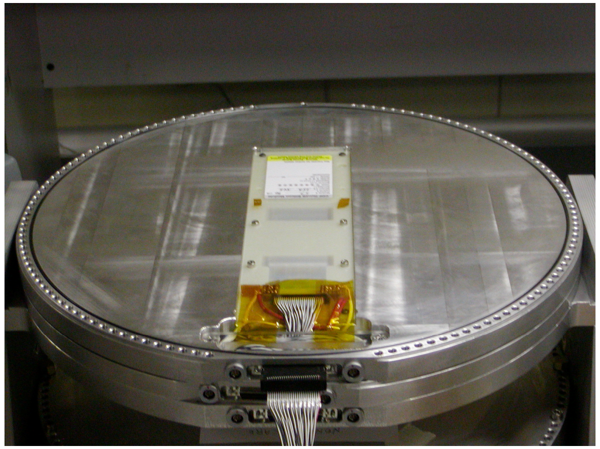




Si telescope update

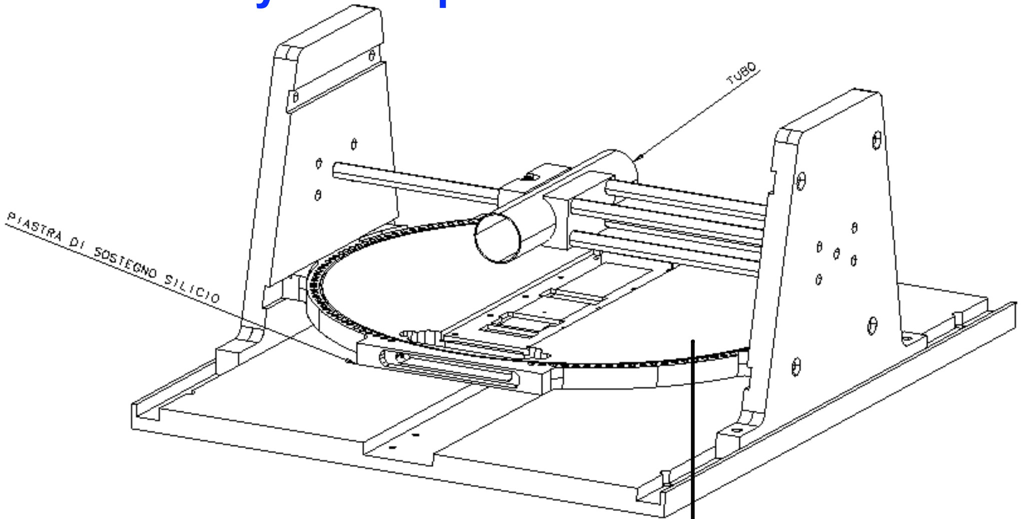
6 plane microStrip-Si telescope



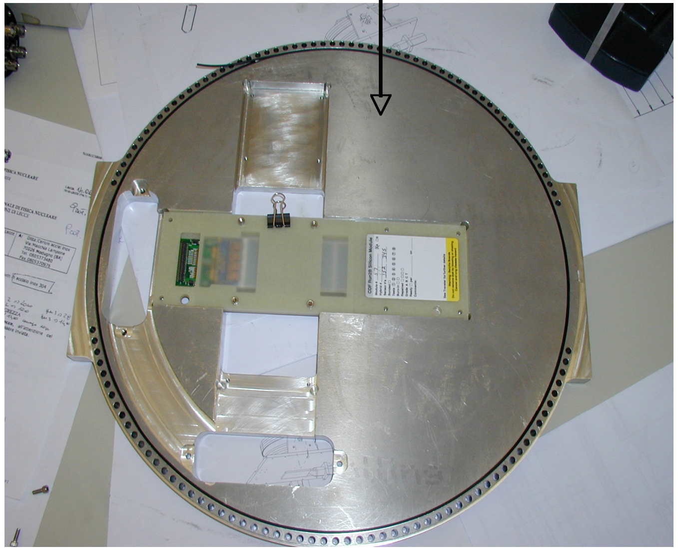


Next: Tracking on cosmics
- X_0 Material not optimized yet

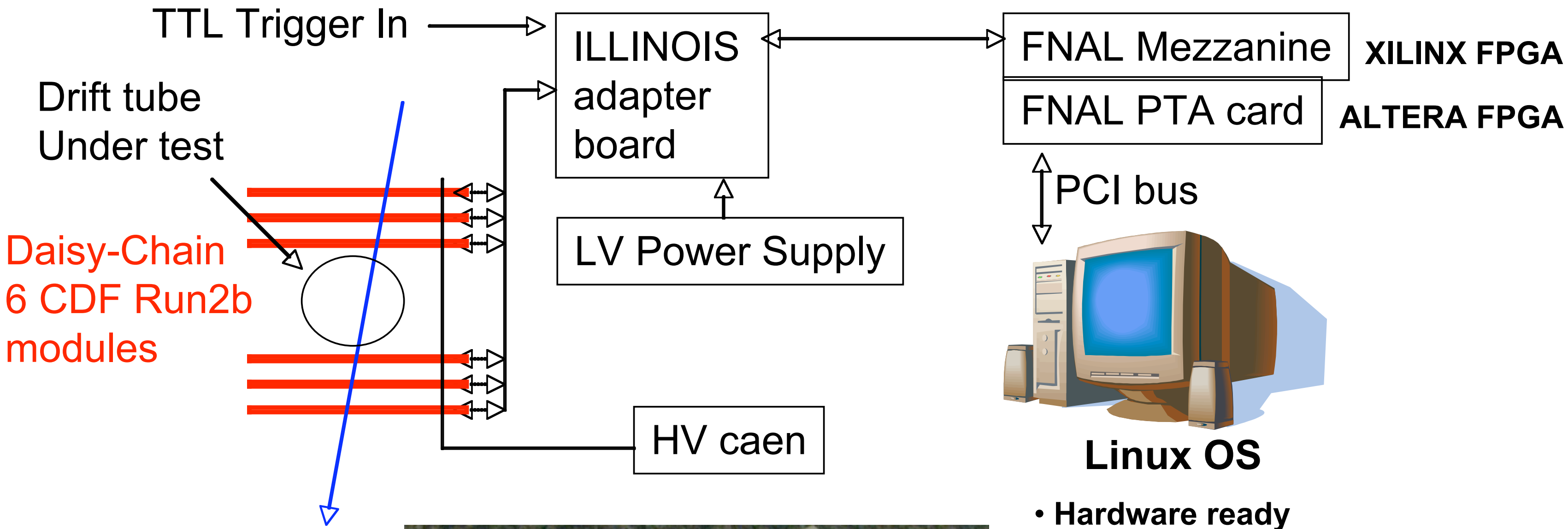
Si - telescope and Device Under Test.
Only one Si plane show out of 6.



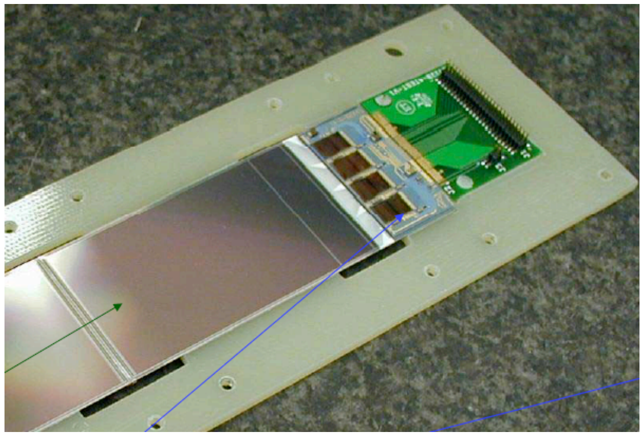
- Full adjustable angles 1.2^0 step
- Easy to upgrade to more planes



Si telescope update



Module~4x18 cm^2 =
1 hybrid+ 2 Si sensor:
- **8 bit ADC**
- **p+/n sensors**
- **75um readout pitch with intermediate floating strips**



- **Hardware ready**
- **Firmware ready**
- **Software to finalize for:**
  - **tracking**
  - **analysis**
- **Two Si-modules already readout in daisy chain**
- **External trigger readout**
- **6 modules + 4 spare available**
- **Mechanical assembly and HV ready.**

Many thanks Fermilab ESE department and Thomas Junk (IL Urbana University) !!!

Conclusions

- Progress slow (we suffer from lack of resources) but steady
- Performance of CLUCOU drift chamber in line with physics requirements of ILC (see C. Gatto's talks in the Detector Performance and Optimization sessions)
- Design optimization include:
  - reduction of inner radius from 22.5 cm to 19.0 cm to increase θ acceptance
  - use of Ag coated PET wires to lower weight load on end plates and multiple scattering contribution, but also to allow for smaller cells in the inner layers to reduce occupancy
  - mechanical Engineering design of chamber structure (boron loaded C-fiber) and shape and characterization of physical properties of plastic wires
- concrete possibility of $\leq 0.08\ X_0/\sin\theta$ in the forward region by further reducing the front end contribution (plastic feedthroughs for field wires and front-end chip ($4\ mm^2$) directly on wire)
- expected results on impact parameter resolution and on dN_{cl}/dx with drift tubes set up and Si telescope in the next few months
- front end chip tests to be completed in order to design a second improved version
- design a small prototype chamber with 24×4 cells (a few hundred wires) to be tested in a beam