Detector R&D towards the International Linear Collider

ILC Tracking

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CLIC Workshop

17. October 2007

ILC Detector Concepts

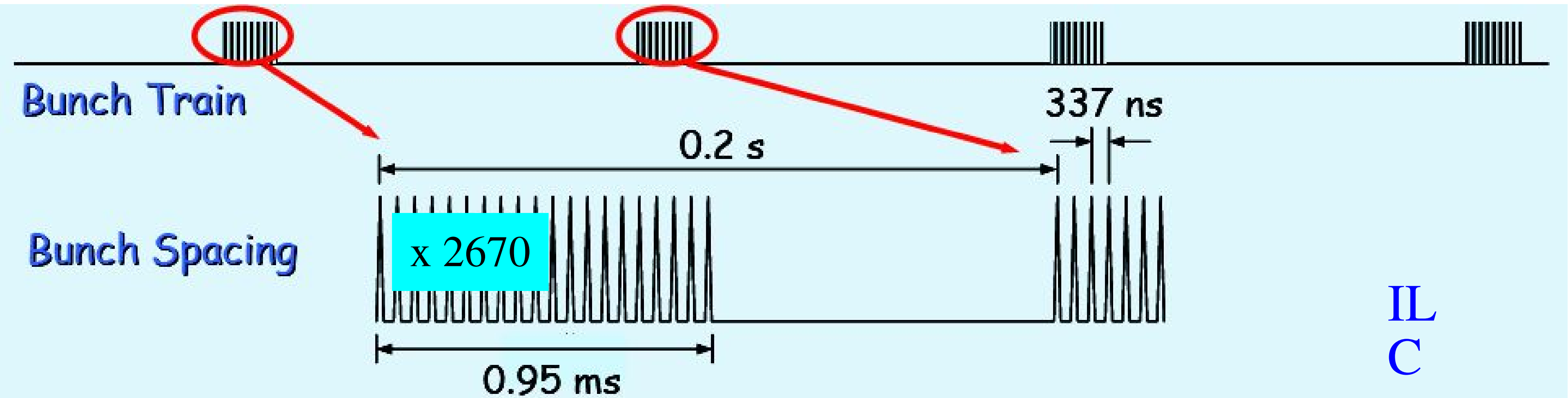
- Three out of Four ILC Detector concepts (4th Concept, GLD, LDC) have gaseous tracker as central tracking device: TimeProjectionChamber TPC

- TPC with GEM / MicroMegas Readout

- SiD concept has a full Si tracker

Parameter comparison

	CLIC(3000)	CLIC(1000)	CLIC(500)	ILC	Unit
E_{cms}	3	1	0.5	0.5	TeV
Luminosity	7	2.7	2.1	2	10^{34} /cm^2/s
Linac repetition rate	50	75	100	5	Hz
# of particles/bunch	4	4	4	20	10^9
# of bunches/pulse	311	311	311	2670	
overall two linac length	41.7	14.4	8	22	km
proposed site length	48.25	20.55	14.15	31	km



ILC Physics Requirements

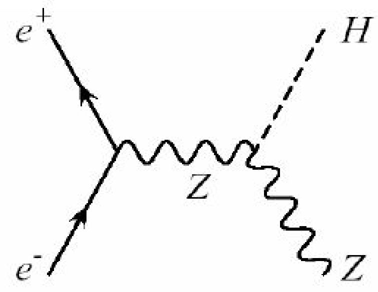
Many ILC physics measurements rely on the precise knowledge of the initial state:

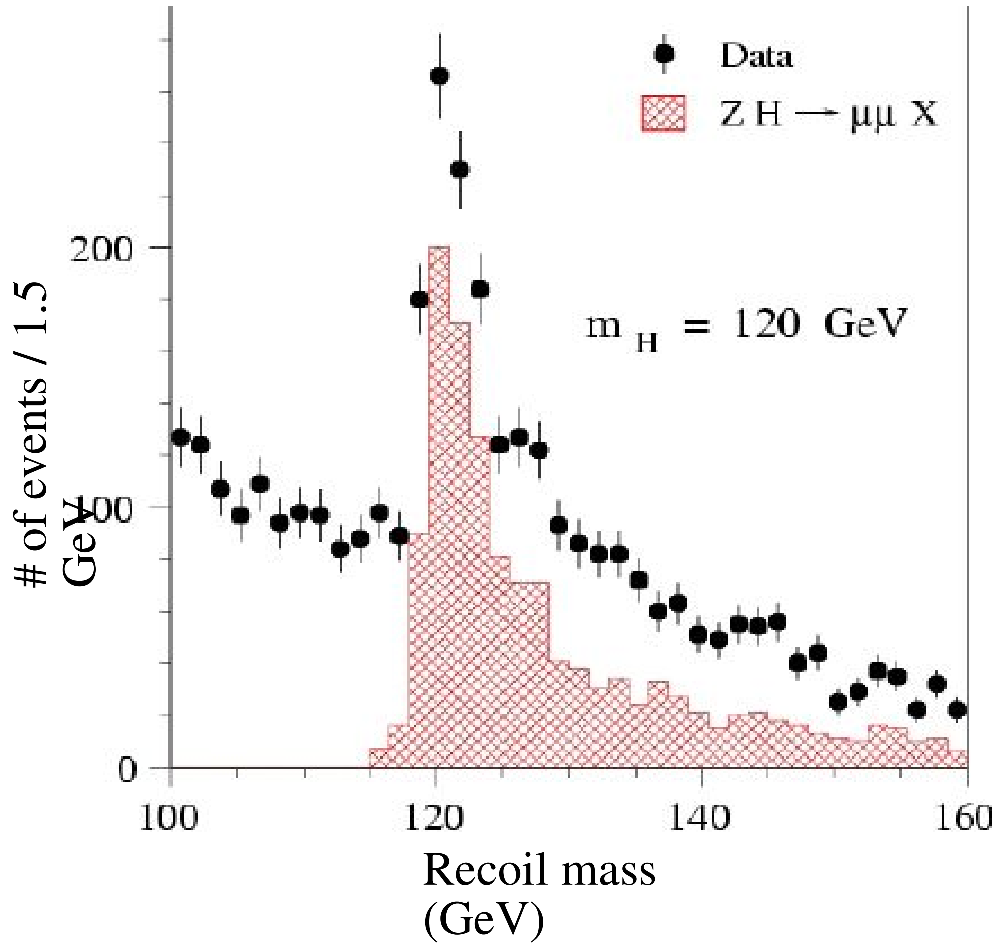
- Luminosity
- Polarization
- E_{cms}
  - WW threshold: 5 MeV (50 ppm)
  - tt threshold and Higgs mass: ~ 50 MeV (100-200 ppm)

ILC Physics Requirements

- High prescision in momentum determination driven by mass resolution of recoil to leptonic Z^0
- Goal for full tracking:

$\sigma(1/pt) \sim 5 \times 10^{-5}$ GeV^{-1} (or better)





SiD concept (former US small detector concept)

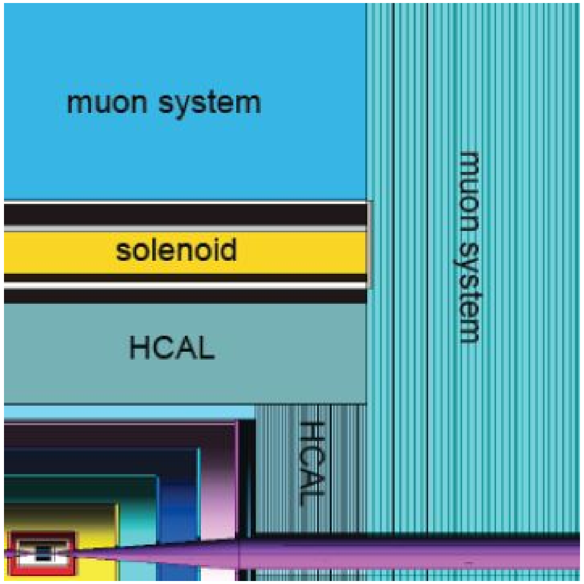
ECAL → Si – W

HCAL → RPC - W

full Si tracker →

outer tracker radius: 1.3 m

magnetic field : 5 T



4th Concept concept (new detector concept)

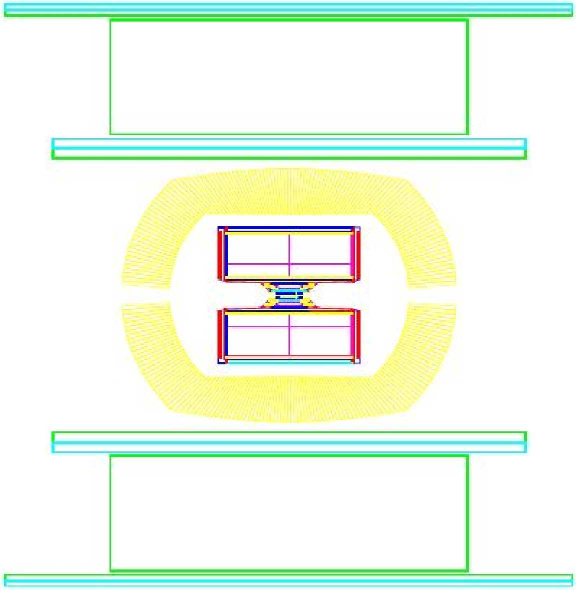
ECAL → Crystals

HCAL → Fibers (Scintillator/Quartz) - W

TPC tracker →

outer tracker radius: 1.4 m

magnetic field : 3.5 T



GLD concept (former Asian detector concept)

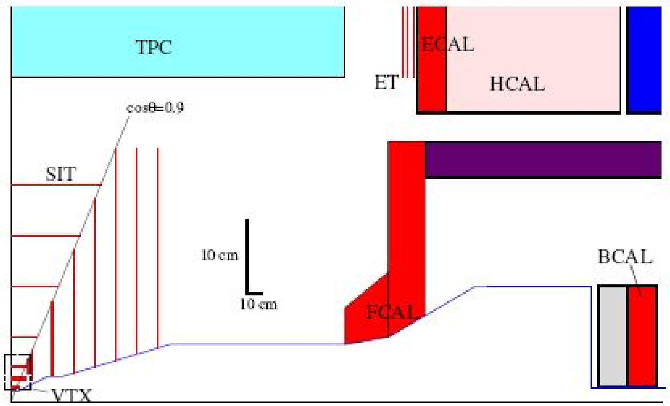
ECAL → Scintillator – W

HCAL → Scintillator - Pb

TPC tracker →

outer tracker radius: 2.1 m

magnetic field : 3 T



LDC concept (former European TESLA detector concept)

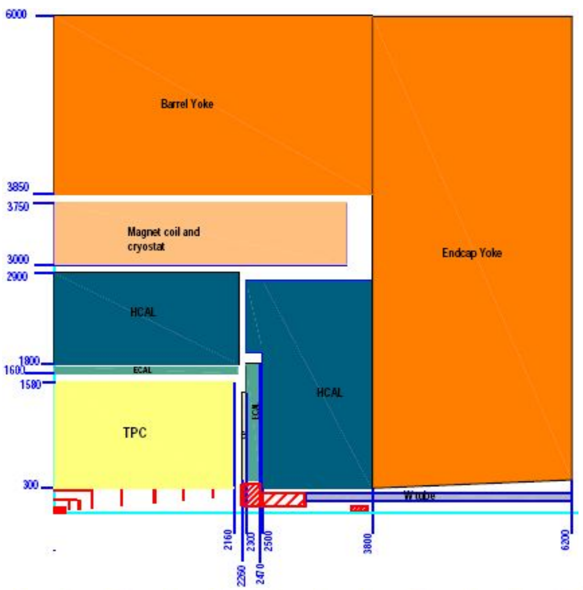
ECAL → Si – W

HCAL → Scintillator - Fe

TPC tracker →

outer tracker radius: 1.3 m

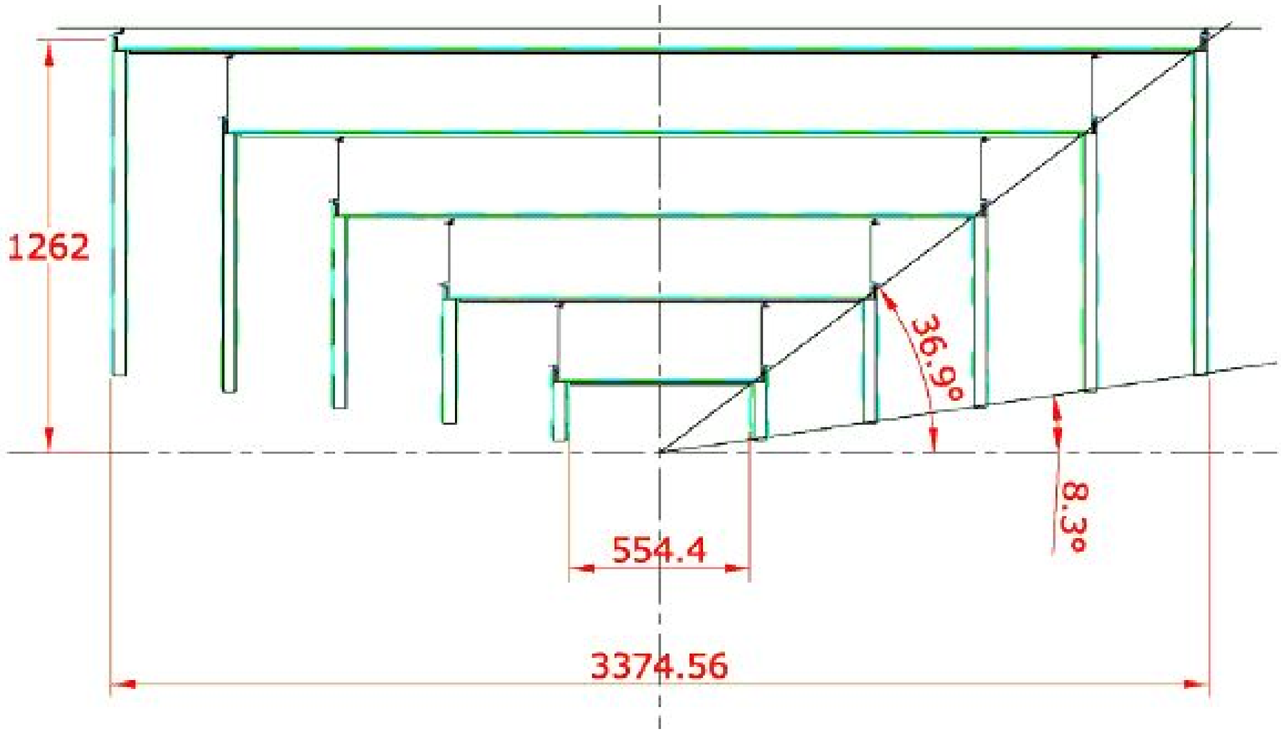
magnetic field : 5 T



SiD Concept

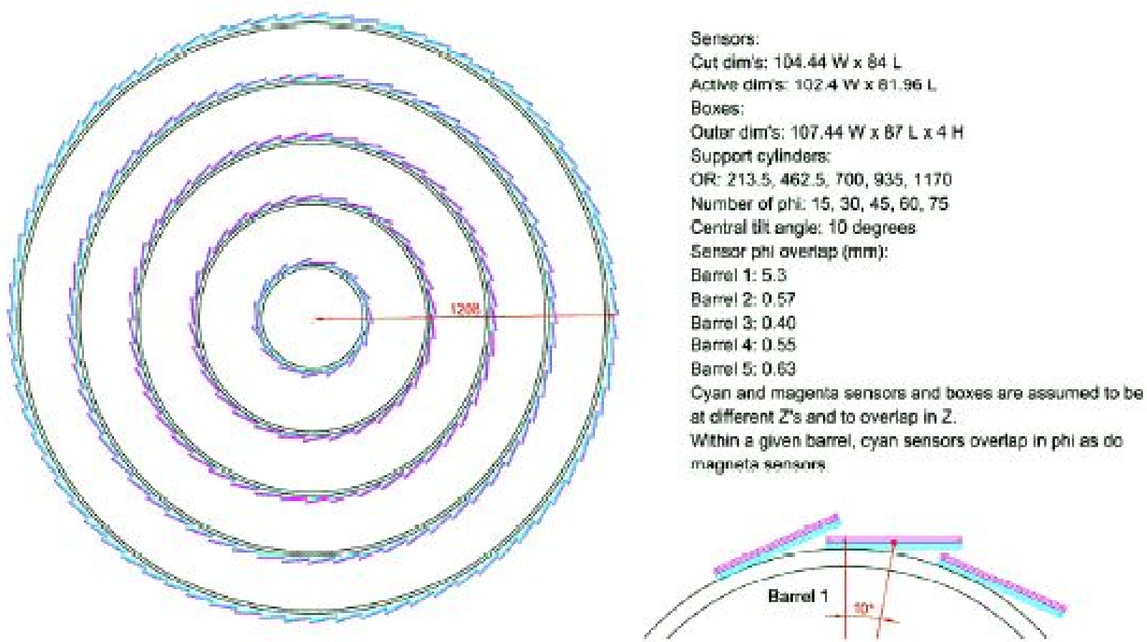
	Barrel R (cm)	Z (cm)	End Cap Z (cm)	R (cm)
Layer / Disk 1	20.0	26.7	28.7	4.0 – 24.5
Layer / Disk 2	46.3	61.7	63.7	7.9 – 50.8
Layer / Disk 3	72.5	96.7	98.7	11.8 – 77.0
Layer / Disk 4	98.8	131.7	133.7	15.6 – 103.3
Layer / Disk 5	125.0	166.7	168.7	19.5 – 129.5

5 nested barrels in the central region:
layer of Si modules;
4 disks in each of the end regions:
both sides equipped with Si modules;

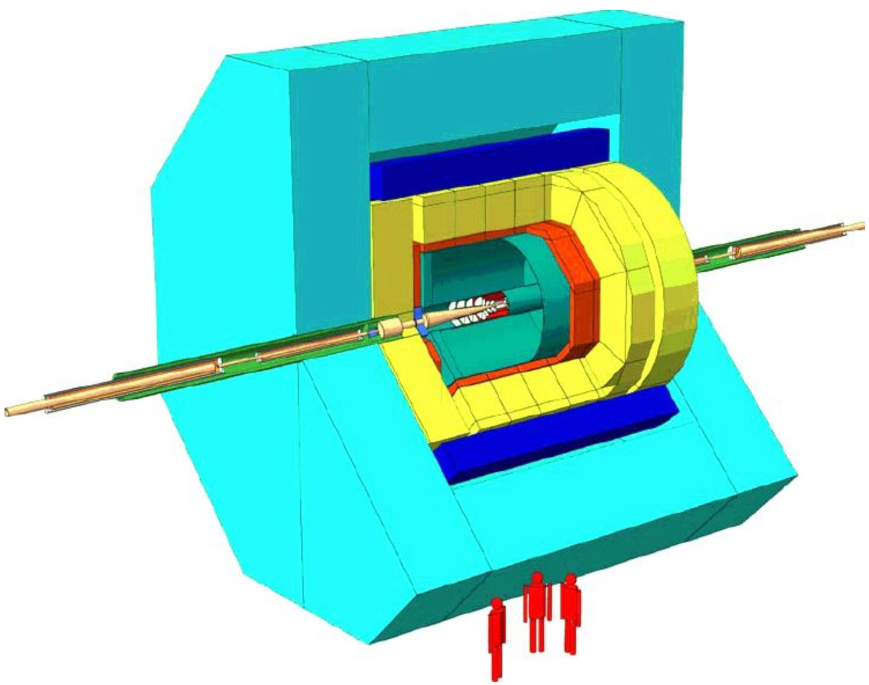


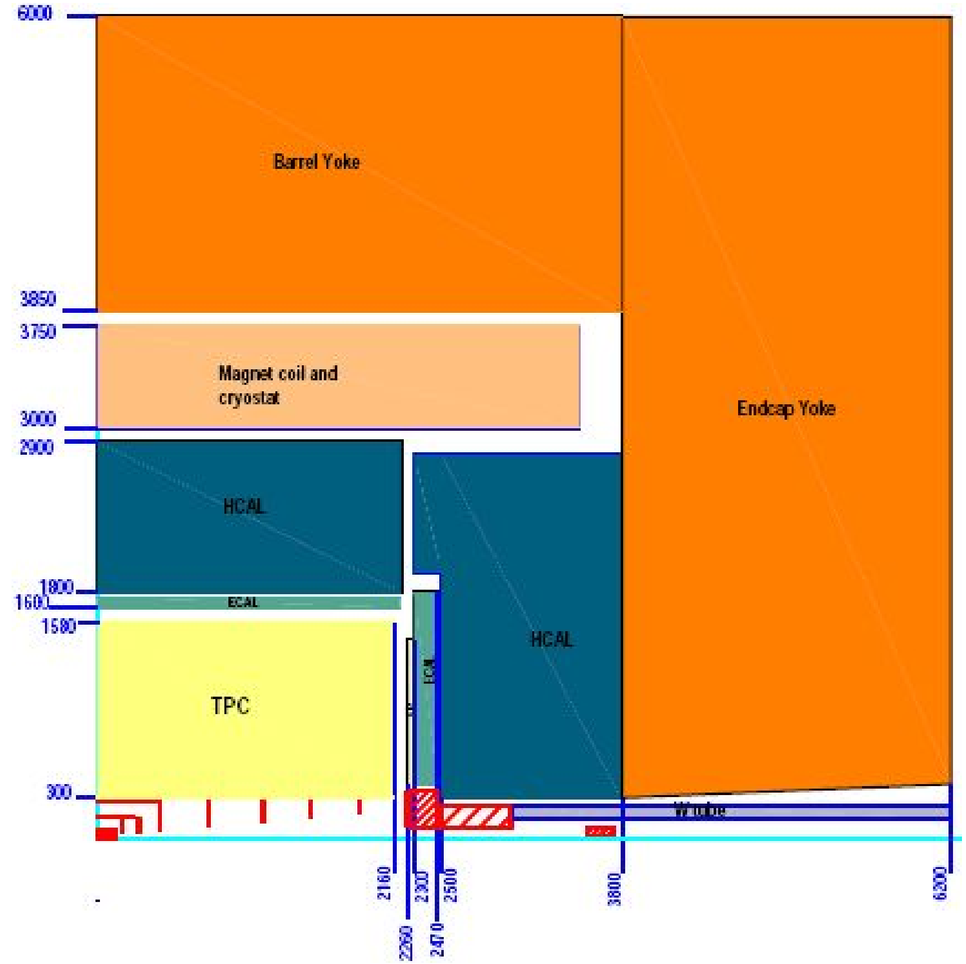
SiD Concept

- Integrated Si-strip tracker with uniform technology and fully integrated forward tracking system
- Minimal material in the tracking volume to reduce multiple scattering and secondary particle production
- High precision in a compact tracking volume with B = 5 T



LDC Concept





$\text{Ø}_{\text{TPC}} \approx 3 - 4\ \text{m}$

TPC Properties

- Tracks are measured with a large number of true 3-D points (~ 200)
- Minimum of material to crossing particles
- Fine granularity coverage
- Timing precise to 2 ns (50 μm/ns in conjunction w/ silicon inner detector w/ 100 μm pitch)
- Usable in strong magnetic field: electrons drift ∥ to B-field lines → improves two-hit resolution
- Good particle identification via specific energy loss *dE/dx* (electron-identification, particle flow)
- Robust and easy to maintain

LDC TPC

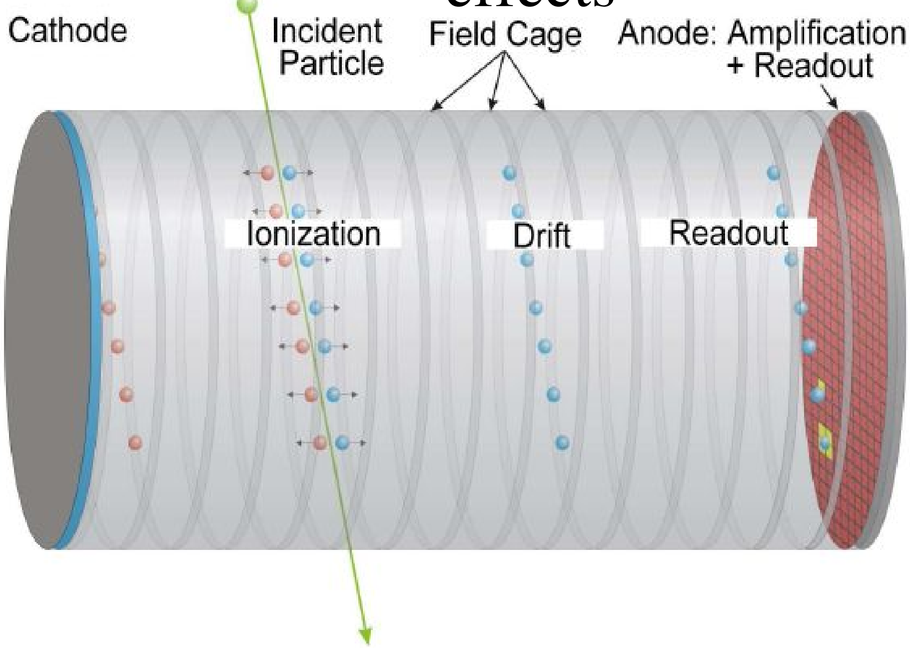
➤ Performance goals and design parameters for a TPC with standard electronics at the ILC detector

Size (LDC–GLD average)	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 10 \times 10^{-5}$/GeV/c TPC only; $\times$ 0.4 incl. IP
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 3 \times 10^{-5}$/GeV/c (TPC+IT+VTX+IP).
Solid angle coverage	Up to at least $\cos\theta \sim 0.98$
TPC material budget	$< 0.03X_0$ to outer fieldcage in r $< 0.30X_0$ for readout endcaps in z
Number of pads	$> 1\times10^6$ per endcap
Pad size/no.padrows	$\sim$ 1mm×4–6mm/$\sim$200 (standard readout)
$\sigma_{\text{singlepoint}}$ in $r\phi$	$\sim 100\mu$m (for radial tracks, averaged over driftlength)
$\sigma_{\text{singlepoint}}$ in rz	~ 0.5 mm
2-hit resolution in $r\phi$	< 2 mm
2-hit resolution in rz	< 5 mm
dE/dx resolution	< 5 %
Performance robustness (for comparison)	$>$ 95% tracking efficiency for all tracks–TPC only) ($>$ 95% tracking efficiency for all tracks–VTX only) $>$ 99% all tracking[13]
Background robustness	Full precision/efficiency in backgrounds of 1% occupancy (simulations estimate $<$ 0.5% for nominal backgrounds)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds at the ILC start-up.

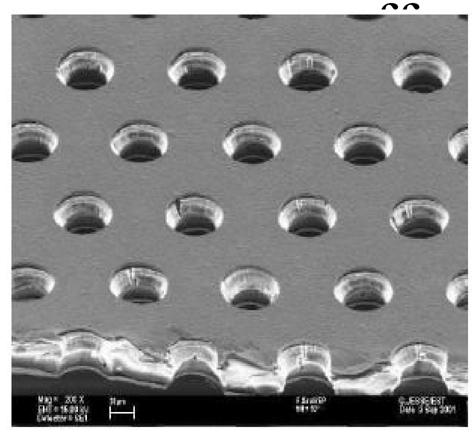
with MPGD

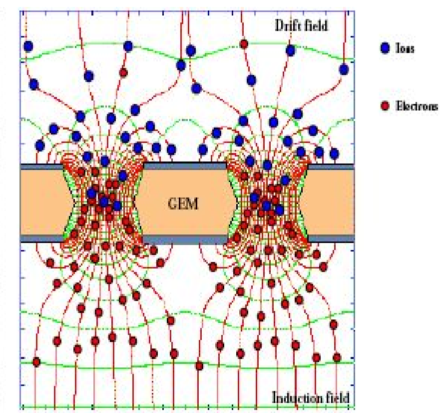
TPC with MPGD

TPC with
MultiWireProportionalChamber MWPC
has been ruled out: limited by **E** x **B**
effects

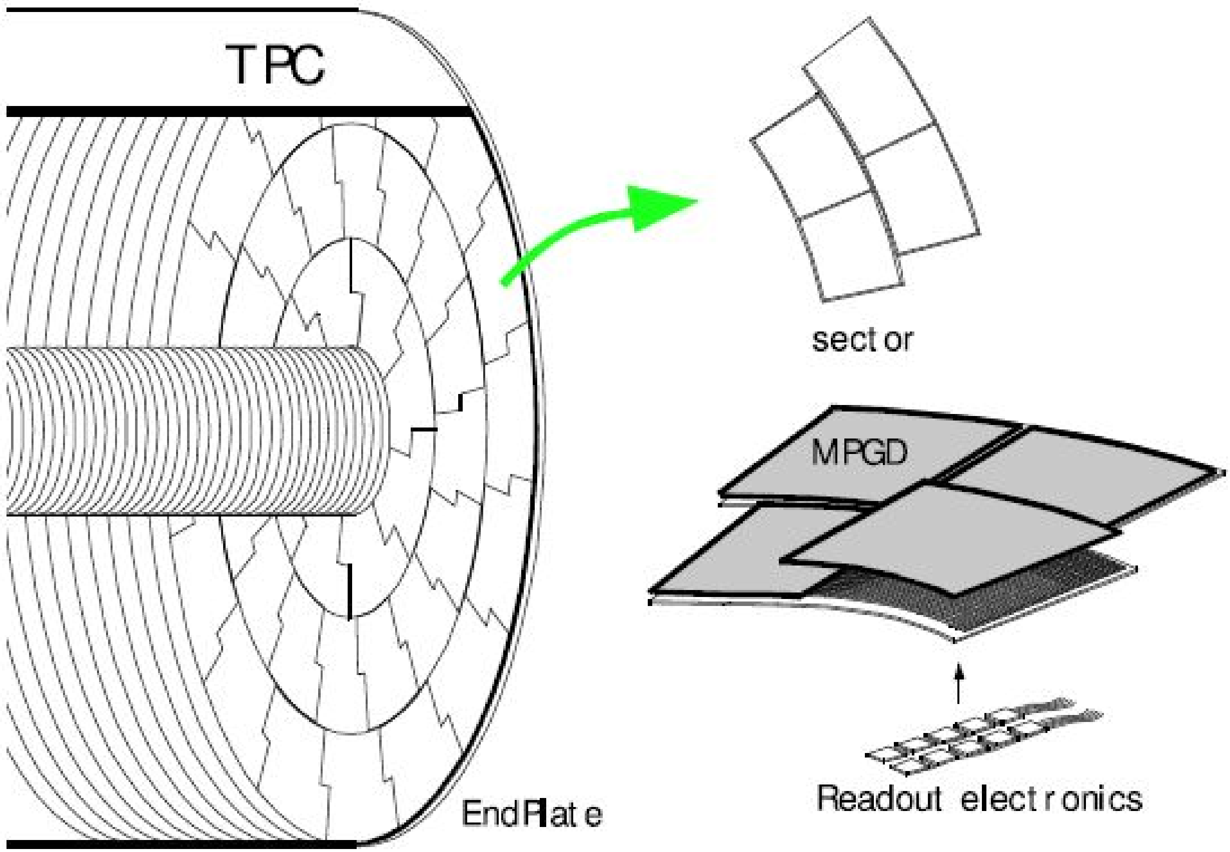


MicroPatternGasDetector
MPGD
not limited by **E** x **B**

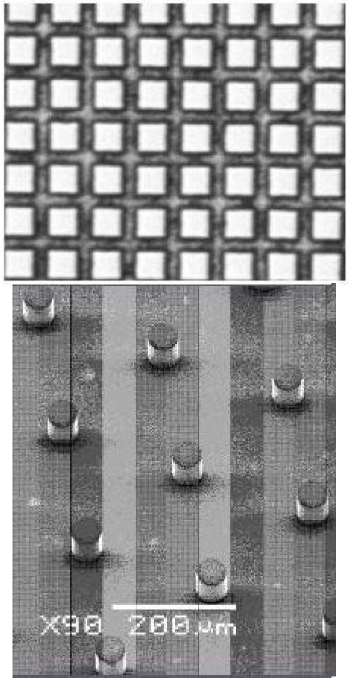




TPC with MPGD

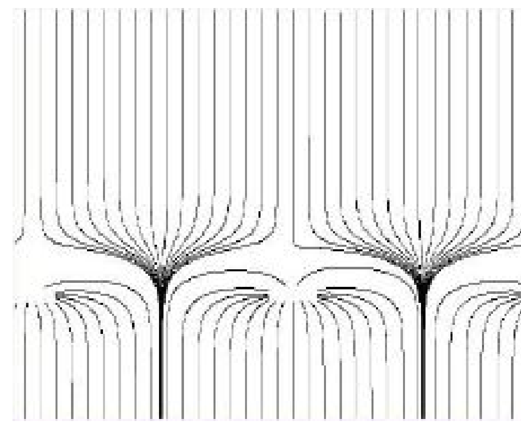


MPGD MicroMegas

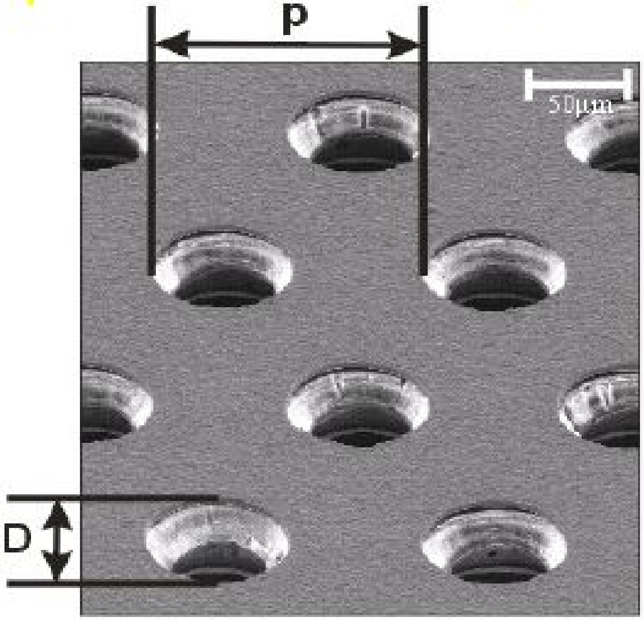


MicroMeshGaseousStructure
(Micromegas):
micromesh sustained by 50 µm pillars, multiplication between anode and mesh;
one stage

Multiplication

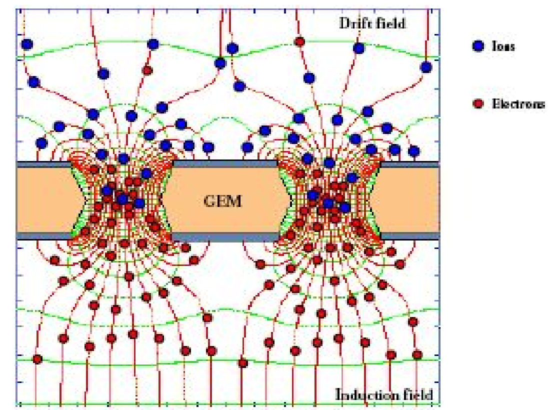


MPGD GEM



p=140 μm
D=70 μm

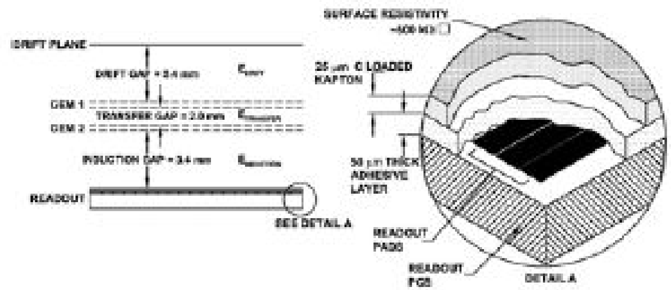
Multiplication

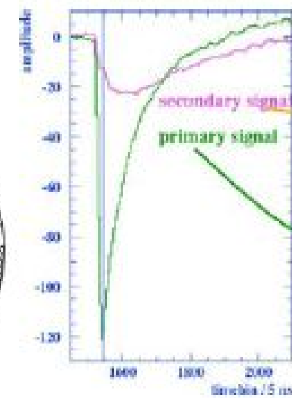


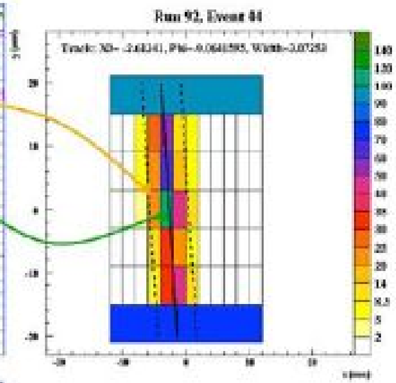
GasElectronMultiplier (GEM):
50 μm Kapton foil, each side covered with 5 μm Cu clad; multiple stage

TPC Prototype

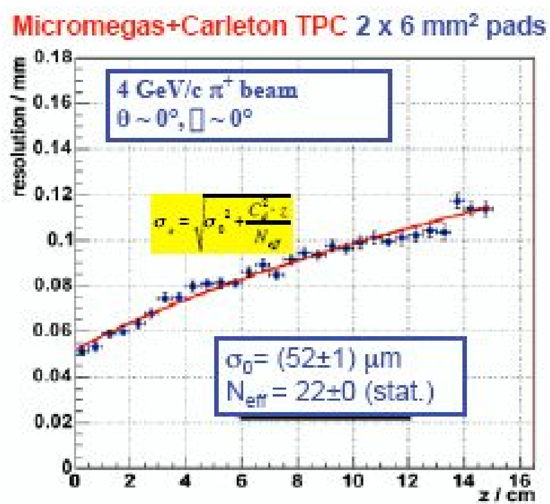
- Track Point Resolution measurements with MicroMegas

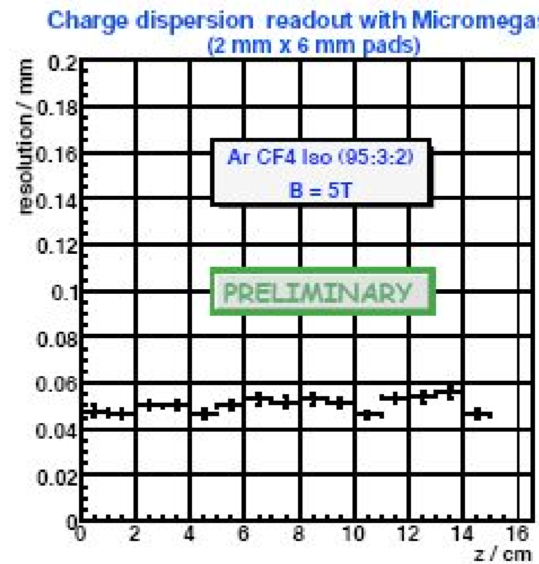






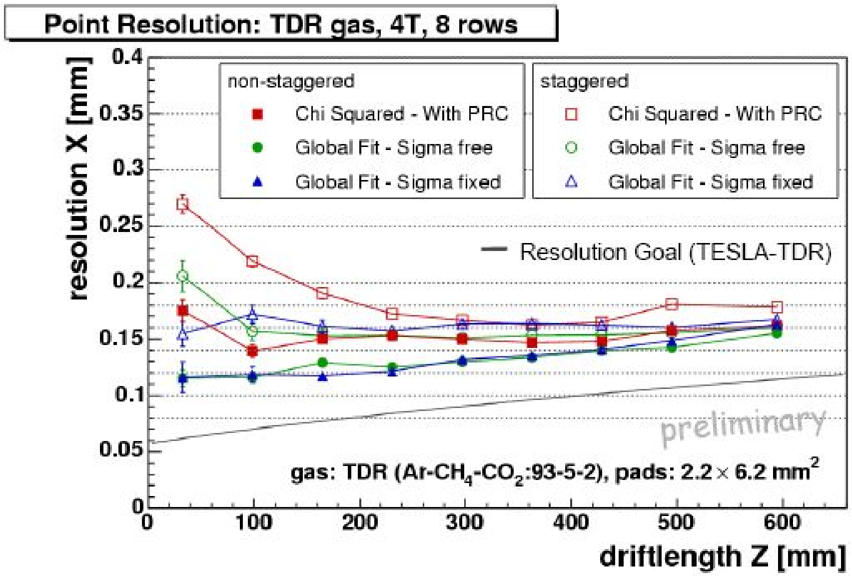
without and with resistive anode





TPC Prototype

- Track Point Resolution measurements with GEMs

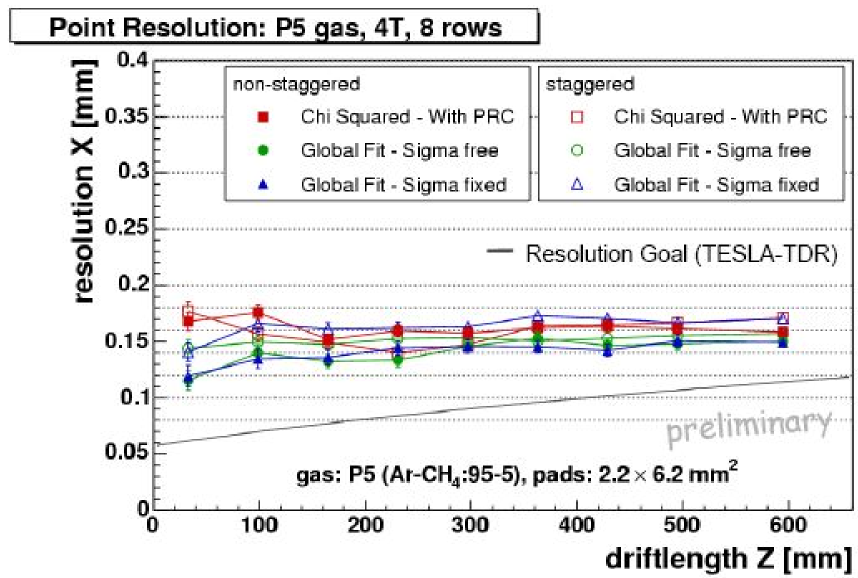


Cosmic Muon tracks

Pad layout:

24 columns, 8 rows

pitch 2.2 mm x 6.2 mm



Resolution between

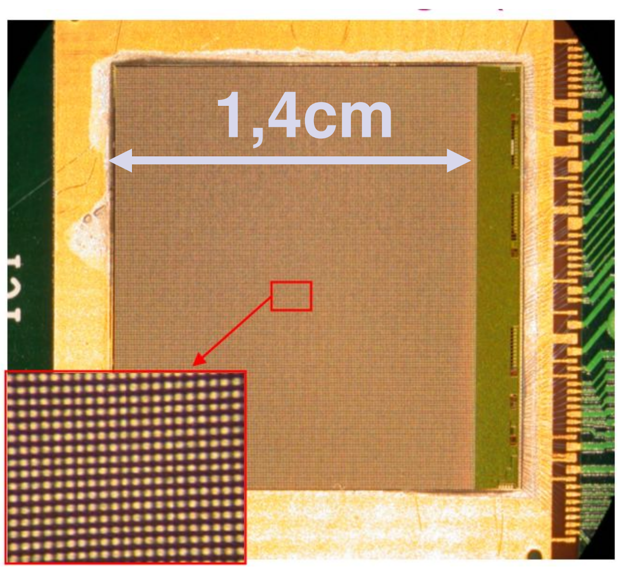
120 µm and 180 µm

for drift distances

≤ 600 mm

TPC with CMOS Pixel Readout

- TPC with ASIC readout
- MediPix2/TimePix state of the art readout systems
- Initial “proof-of-principle” tests



Medipix2/TimePix similarities

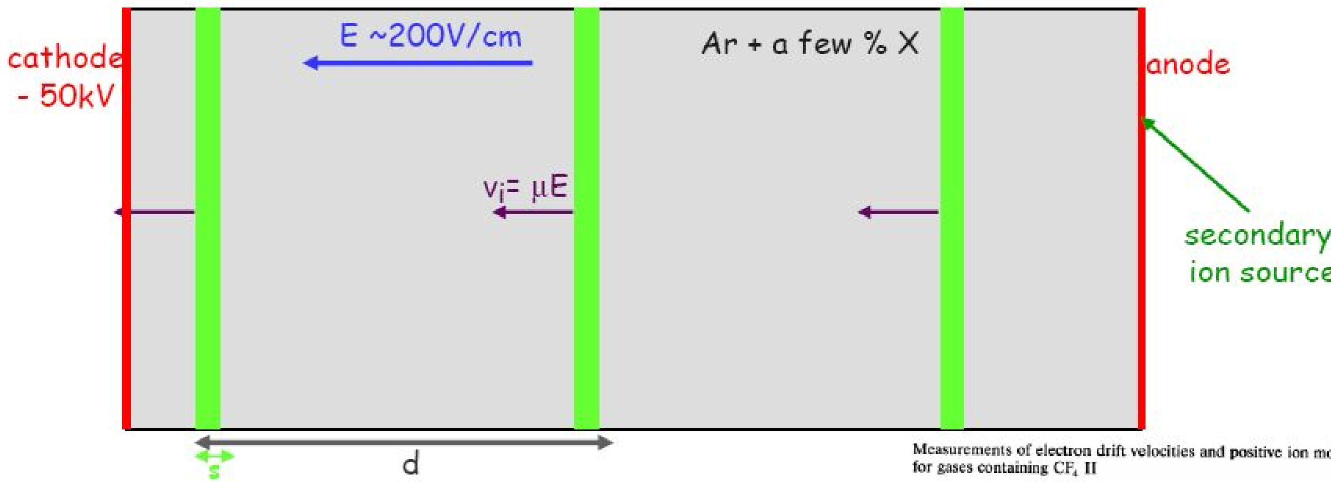
- **Pixel size 55µm, arranged in a 256x256 Matrix**
- **dimensions of the *sensitive area*: *1,4x1,4cm²***
- **Used equalized and calibrated chip with lower threshold of**
  - **Medipix2 990 e⁻**
  - **TimePix ≈ 700 e⁻**

TPC Space Charge

- Three sources of space charge
  I. **Ion build-up at the readout plane**
  II. **Ion build-up in the drift volume**
  III. **Ion backdrift**
- ILC operational conditions
  - **long bunch trains**
  - **high physics rate**

  require open-gate operation
- Few mm thick charge sheets through sensitive region during subsequent bunch trains
  - **few fC/cm^3**
- Gating plane foreseen: open throughout one full train, else closed

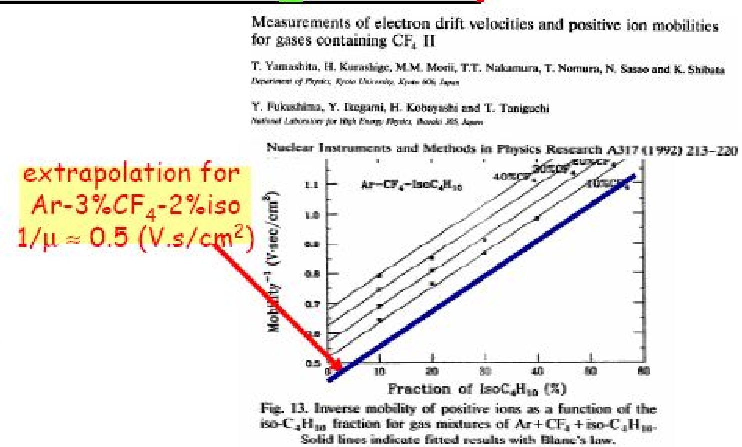
TPC Space Charge



gas mixture: Ar dominant
ions X^+
transport properties of ions
dominated by **Ar**

typical values

- **$\mu \approx 2cm^2/(Vxs)$ in Argon** (Kr:1, Ne:4, He:5-10)
- slice s = $\mu x E x \delta t$ = **4mm** for δt=1ms
- distance between 2 slices separated by Δt=200ms:
  d = μ xExΔt = **80cm**



so with Ar+a few % X:
n~3 slices of ions together in the TPC with $L_{TPC} \approx$240cm

dream: to have d $\approx L_{TPC}$ -> n=0 slice

also measurements by D. Schutz, G. Charpak, F. Sauli, J. Phys. Appliquée, 12(67)1977
«mobilities of pos. ions in some gas mixtures…»: $\mu_{Ar} \approx 2cm^2/(Vxs)$

Vincent Lepeltier

Summary & Outlook

- TPC very promising as main tracker in an ILC experiment
- Three out of four ILC-Detector concepts foresee TPC as main tracker
- Is a gaseous tracker viable for E_{cms} = 3 TeV ?
  - **background will be higher as E_{cms} increases**
  - **CLIC: large coherent-pair background**

    → at small polar angle θ, at large angles essentially unchanged from ILC
  - **time stamping: 0.667 ns vs 337 ns ?**
  - **dense jet environment ?**

Summary & Outlook

Some properties related to beam-beam backgrounds.

	TESLA 0.5 TeV	CLIC 3.0 TeV
$N_{e^\pm}$ per bunch ($\times 10^{-10}$)	2.	.4
BX per train	2820	154
Trains per second	5	100
Time between BX (ns)	337	.67
$N_{beamstr.e^\pm}$/BX (θ >150mrad, p_T >20MeV/c)	44	60
Hadr.ev./BX ($E_{\gamma\gamma-c.m.s.} \geq$5GeV)	.2	4.
Minijet ev./BX (p_T^{min}=3.2GeV/c)	.006	3.4
BX/2ns (e.g. 2-track-timing accuracy of a TPC)	1	3
BX/50μs (e.g. TPC integrating over 2.5m drift)	148	154
Hadr.ev./2ns	.2	12
Hadr.ev./50μs	30	620
Minijet ev./2ns	.006	10
Minijet ev./50μs	.9	520
TPC→Total tracks	40	3300
TPC→Background-track occupancy	.0001	.008
TPC→Converted-γ occupancy	.004	.004
TPC→Total occupancy	.004	.012

R. Settles