Lecture 4: Perspectives

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Part IV: a look in the future

New technology needed for

1) Upgrade of the LHC, the SLHC
2) ILC: material budget = 0.1 % of X_0
3) Spatial program
4) Biology

LHC upgrade

Discussion to upgrade the LHC machine:

3 phases:

- Phase 0/1 (limited hardware) 3 - 5 x 10^{34} $cm^{-2}s^{-1}$
- Phase 2 (major hardware) 10 x 10^{34} $cm^{-2}s^{-1}$

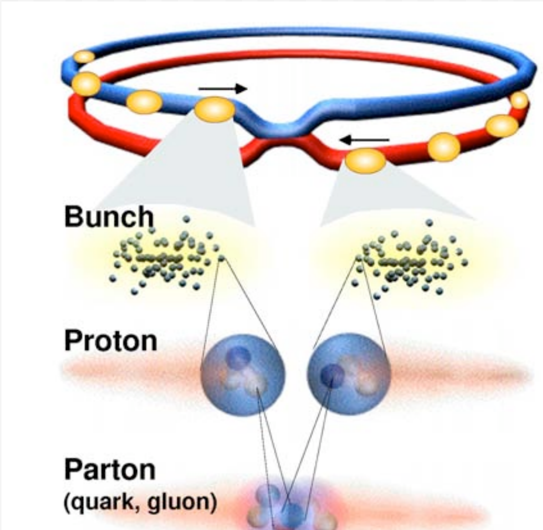
No sharp change in Luminosity

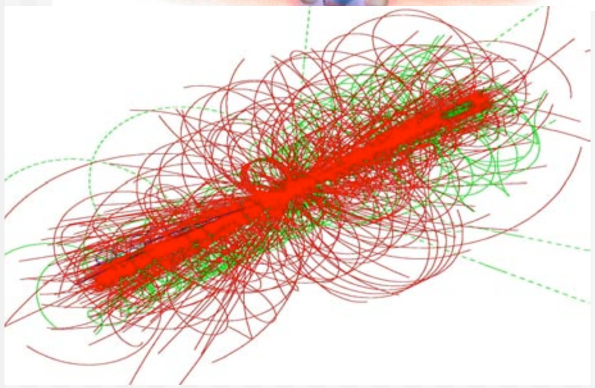
⇒ However, will require change in the tracker:

- Integrated radiation damage of present tracker reaches Design limits
- Rate get too high

=> Need a complete new tracker

Reminder: the LHC





LHC design value:

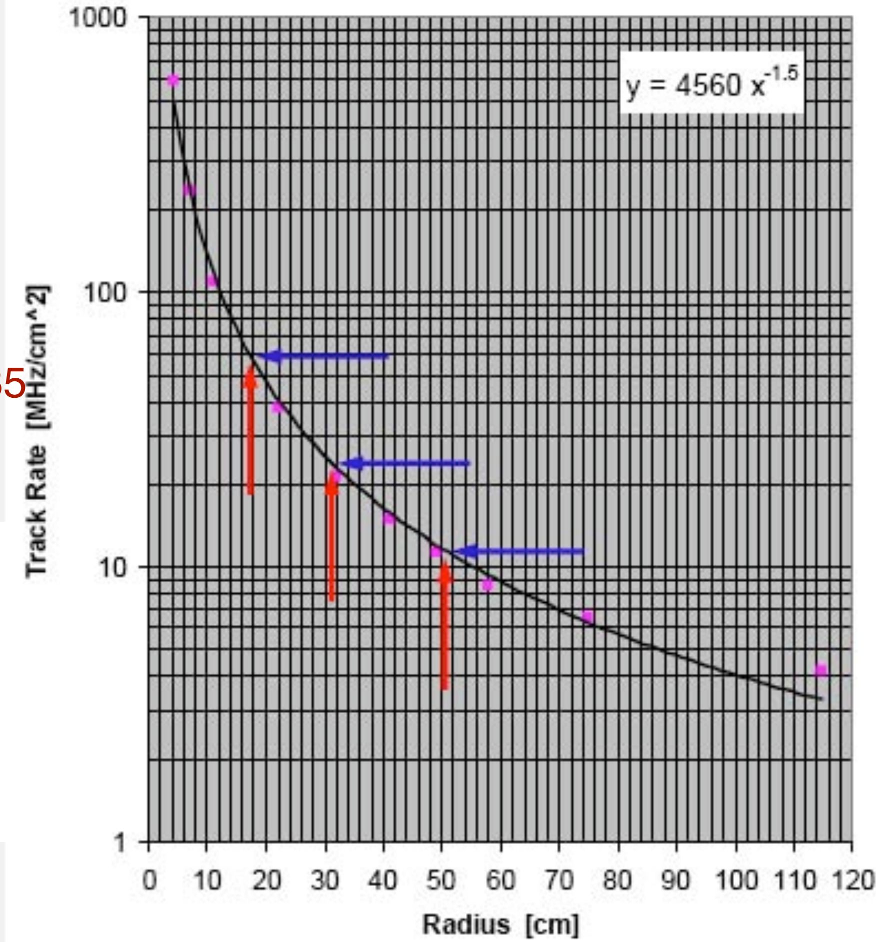
- Proton proton collider, 2 x 7 TeV
- Luminosity: $10^{34}cm^{-2}s^{-1}$
- Bunch crossing: every 25 ns, rate: 40 MHz, event rate: 10^9/s
- Annual operational period: 10^7 s

SLHC situation

Tracks rates at L = 10^{35} $cm^{-2}s^{-1}$

Technology already existing at radii > 20 cm

LHC @ 10^{34}		SLHC @ 10^{35}
r = 4cm	→	r = 18cm
r = 7cm	→	r = 30cm
r = 11cm	→	r = 50cm

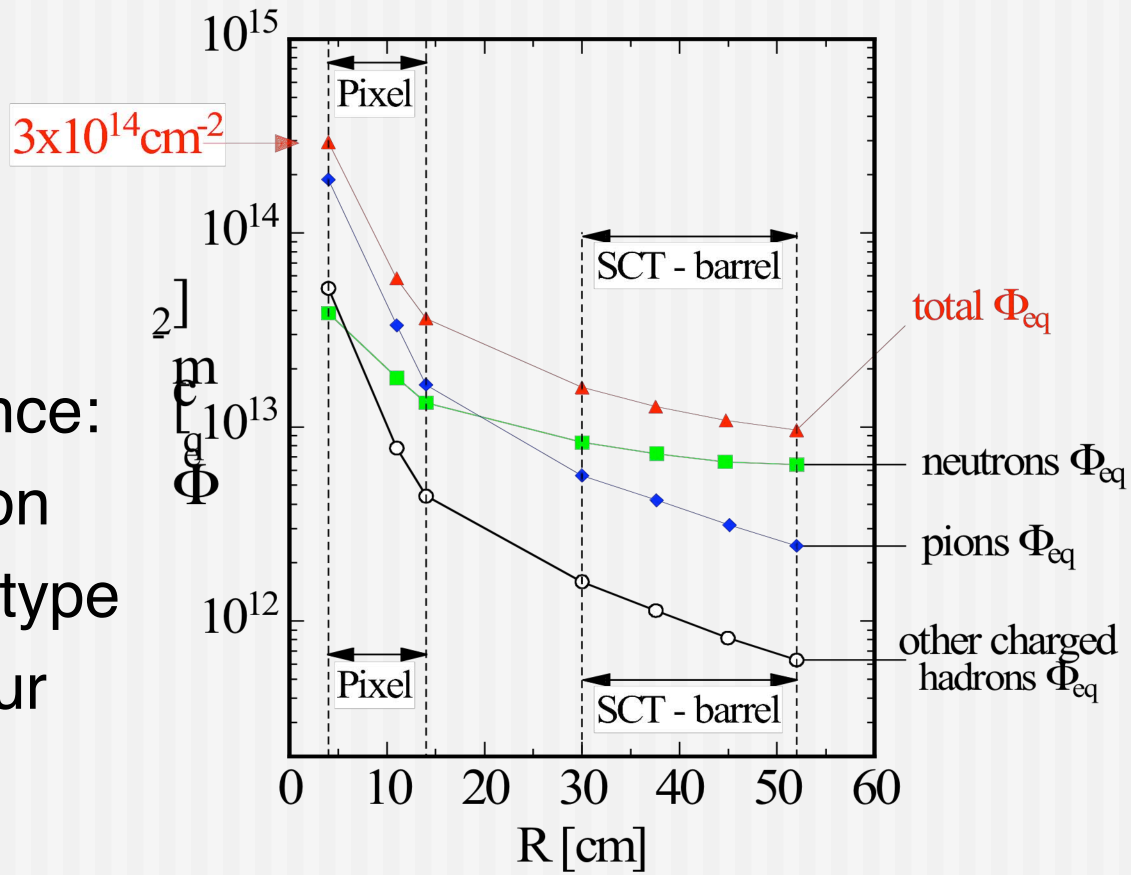


R&D for SLHC

Example: expected radiation damage for ATLAS inner detector:

Annual hadron fluence:

Risk of type inversion after $2*10^{13}$ p/cm^{-2}, type inversion might occur



Preventing type inversion

- ➢ Higher initial doping concentration (more n-type)
- ➢ Reasonable reverse bias during operation
- ⇒ Thinner detector.

How?

Micro-strip, pixel detectors, CCD’s?

Remember, 3 methods to create a silicon detector:

1) Float Zone (FZ)
2) Czochralski (CZ)
3) Epitaxial (EPI) => 25, 50 and 75 μm

Radiation harder detector

Main selection parameter:

- High Charge collected Efficiency
  - =>Negligible trapping effects => Crystal quality
  - =>Higher E field close to readout strip => no type inv
- Low noise
- Low power
  - =>Low leakage current =>Big gap band

New Material…

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	**5.5**	**3.39**	**3.26**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4 \cdot 10^6$	$2.2 \cdot 10^6$	$3 \cdot 10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2 \cdot 10^7$	-	$2 \cdot 10^7$	$0.8 \cdot 10^7$
Z	6	31/7	14/6	14
ε_r	5.7	9.6	9.7	11.9
e-h energy [eV]	**13**	**8.9**	**7.6-8.4**	**3.6**
Density [g/cm3]	3.515	6.15	3.22	2.33
Displacem. [eV]	**43**	20	**25**	**13-20**

Wide band gap
=> Lower I_{leak}

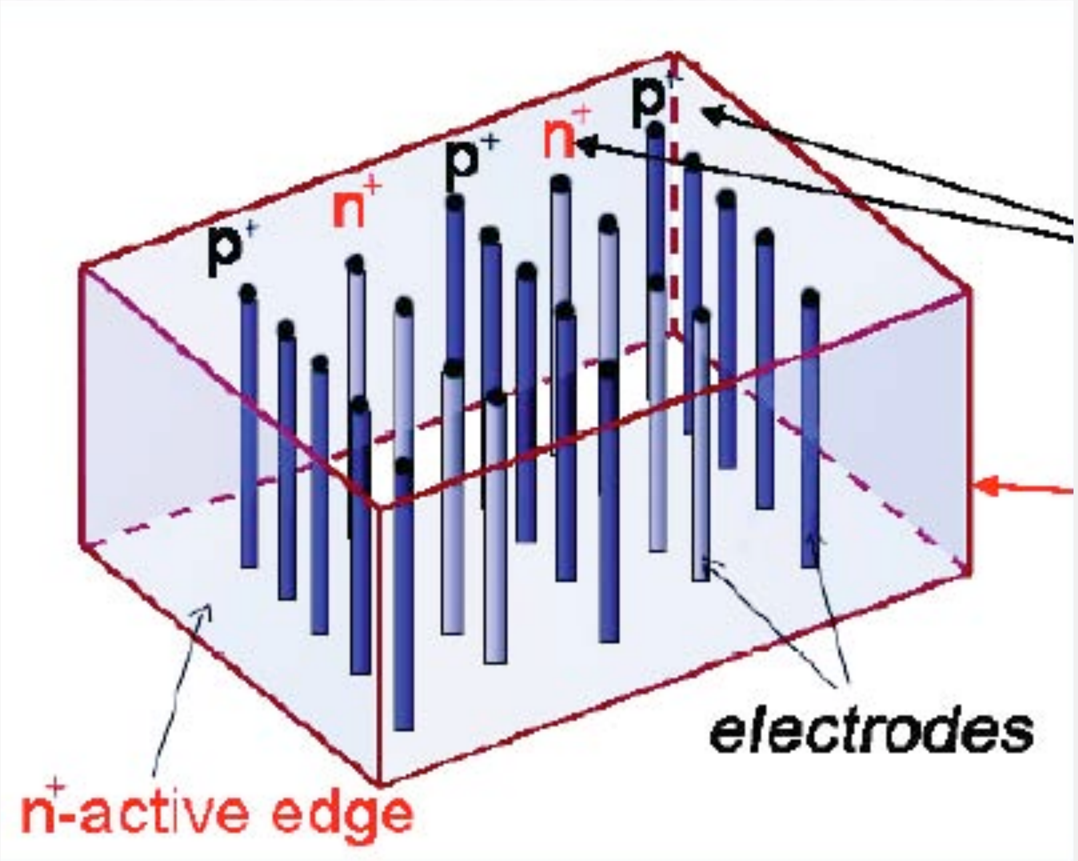
Signal:
Diamond 36 e/μm
SiC 51 e/μm

R&D very active: RD50, 260 members ;-)
http://www.cern.ch/rd50

…Or New Approach?

- Material engineering
- Device engineering
- Change of detector operational conditions

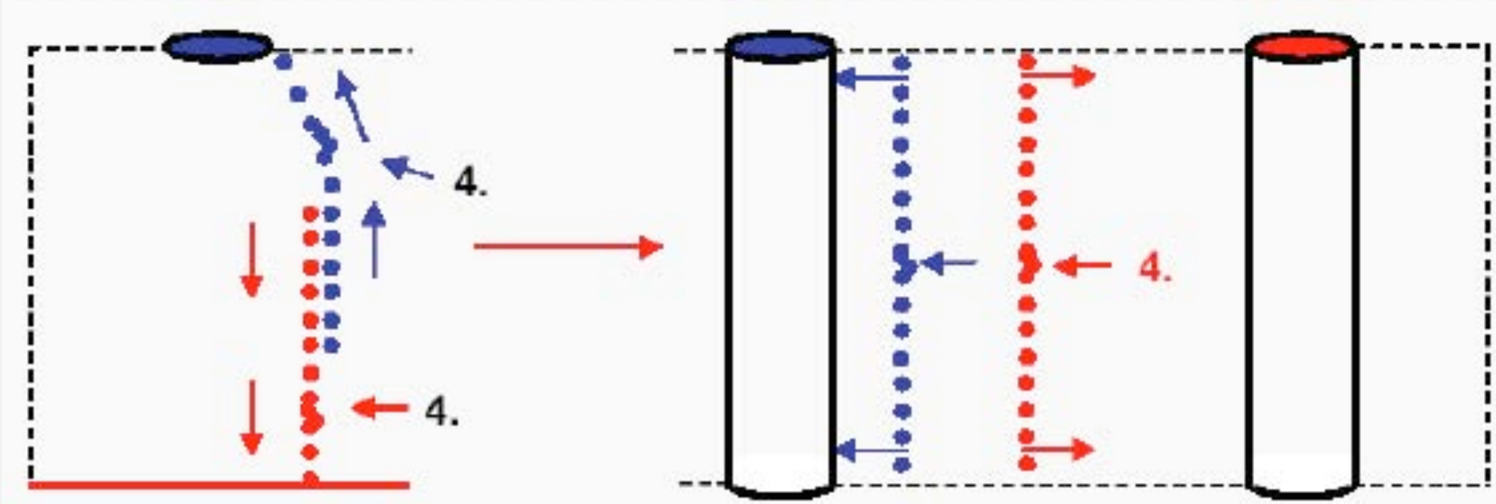
3D silicon detector



Both electrode types are processed inside the detector bulk

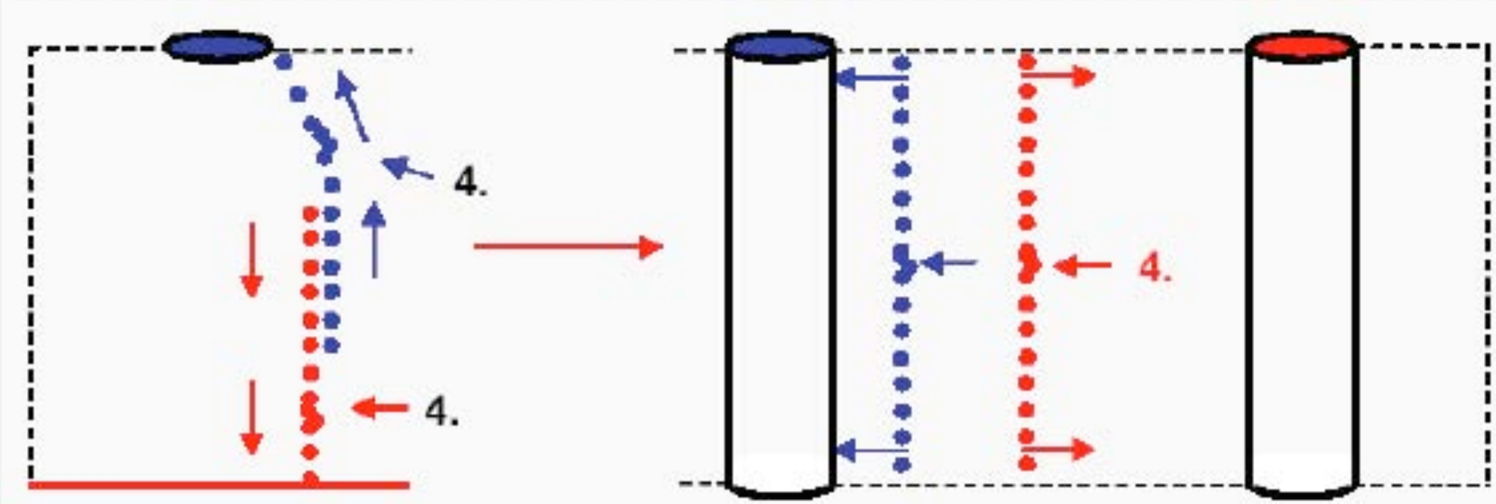
The edge is an electrode. Dead volume at the edge < 5 μm (remember, material budget)

3D: Pro



- Better charge collection efficiency
- Faster charge collection
- Reduced full depletion voltage (also power consumption)
- Larger freedom for electrode configuration

3D: Con

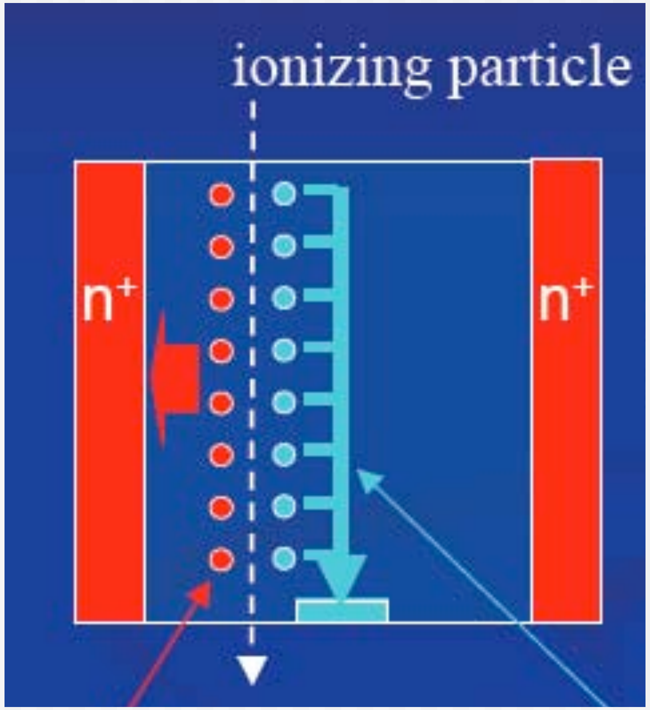


- Columns are dead area (30:1)
- Spatially non-homogenous charge collection efficiency
- Much higher electrode capacitance (noise)
- Availability on large scale
- Time scale and cost

3D: Functioning principle

C. Piemonte et al.

Cross section between two electrodes



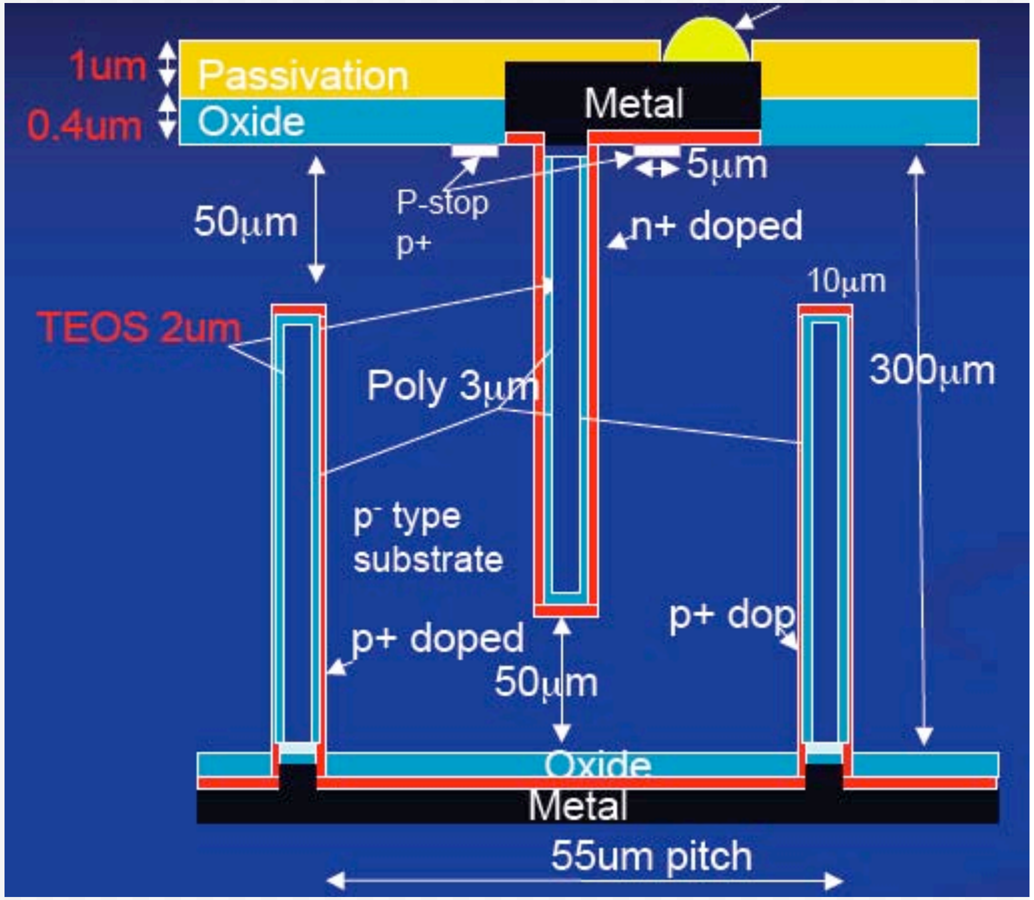
Electrons swept away by the transversal field

Hole drift in the central region and diffuse towards p+ contact

3D, different geometry

Geometry proposed by RD50 collaboration:

- Much simplified process (no support wafer during prod.)
- Single sided processing + extra etching step
- Performance equal to the 3D



A vertex detector at ILC

Constraint:

High precision tracking requires very low material budget:

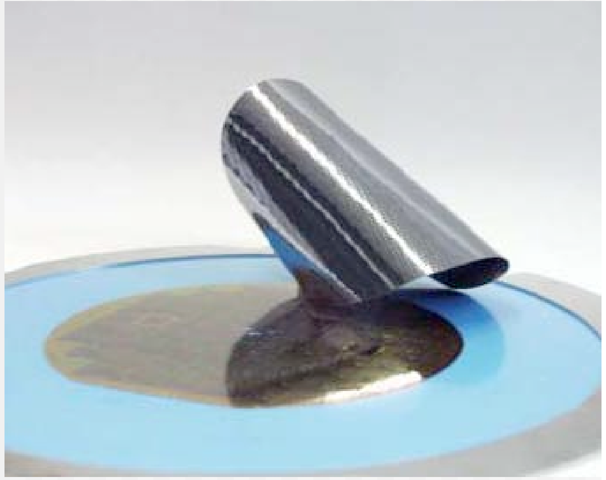
$< 0.1\ \%\ X_0$ is the goal. But X_0 for Silicon is 9.26 cm.

Implies at most 100 μm of Silicon (at all), including readout electronics

⇒ Sensitive area has to be ~ 50 μm

In addition, dE/dx measurement also wanted…

Below 500 μm wafer, non standard processing

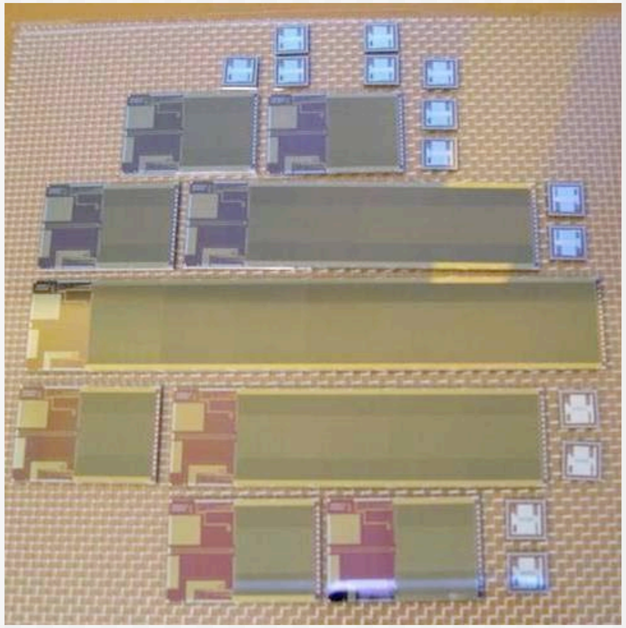


CCD

Successfully used at SLD

Useable only for low rate and low occupancy

=> Vertex detector @ ILC



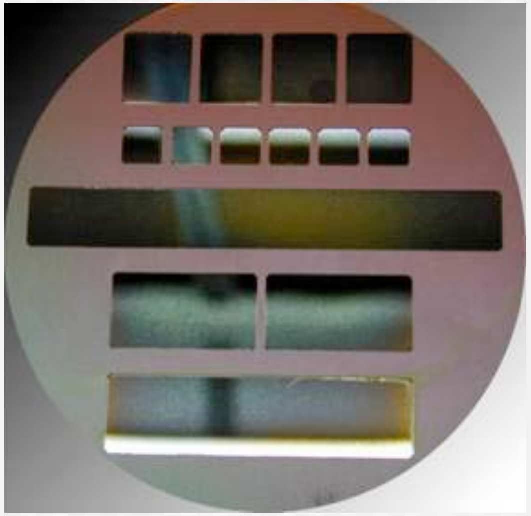
Wafer characteristics:

- 100 Ω.cm/25μm (epitaxi)
- High speed devices, design to operate at 50MHz
- Mechanical support < 0.1% X_0

How thin can we get

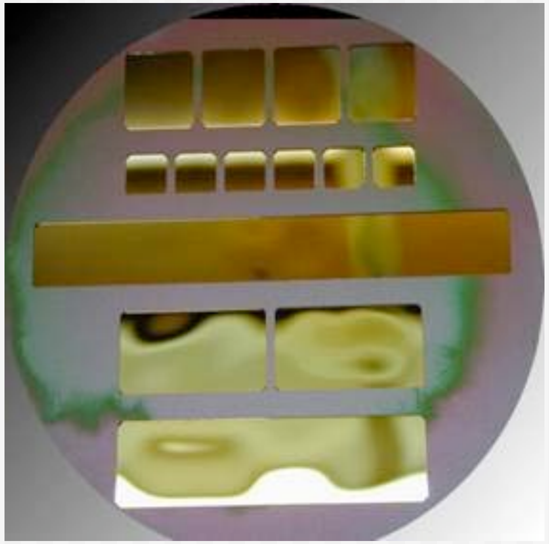
Tests made with 4 inch wafers
Mechanical dummies, no processing:
50 μm: no problems

< 50 μm: Si becomes "flexible" and surface gets distorted



51 μm

More detail:
H-G Moser,
MPI for
physics



26 μm

Spreading out of the field

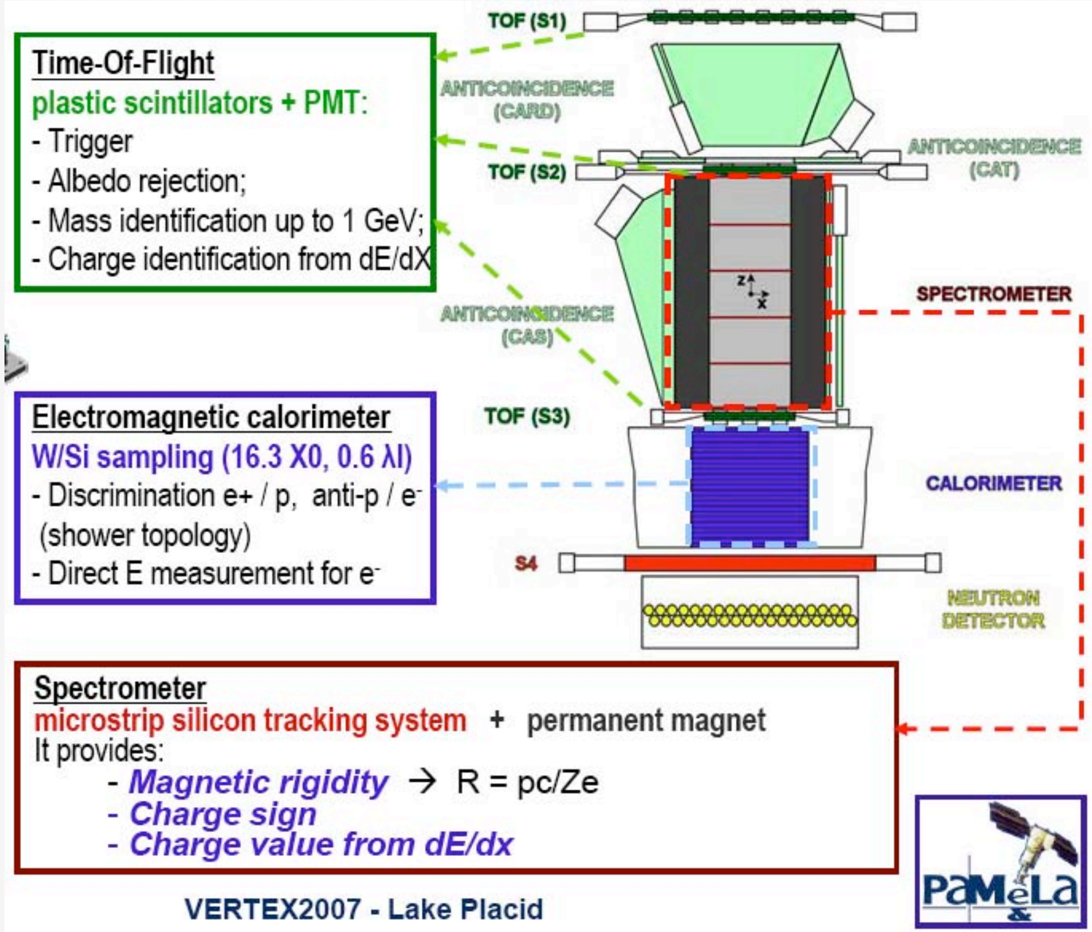
Silicon technology is now mature.

Use pixel or strip for other application:

- Biology
- Space
- Etc …

Astronomy: Pamela

Silicon detector
in space:
Material budget
and physical space,
thermal variation,
small power,
consumption,
redundancy,
limited telemetry.

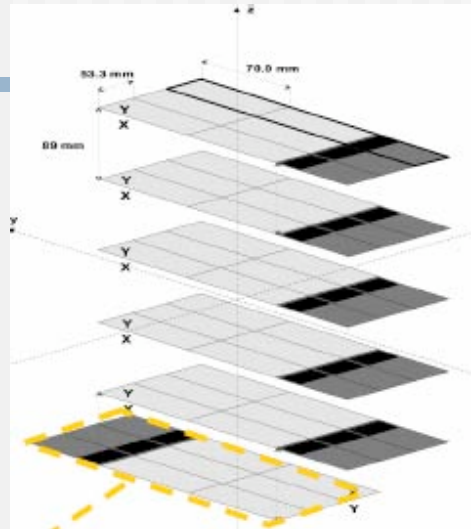


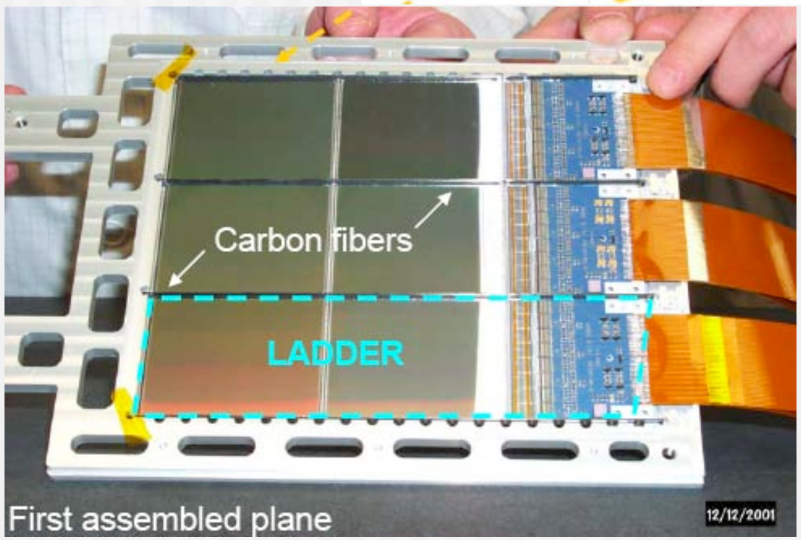
Pamela tracking system

6 detector plans, each composed by 3 ladders

Mechanical assembly:

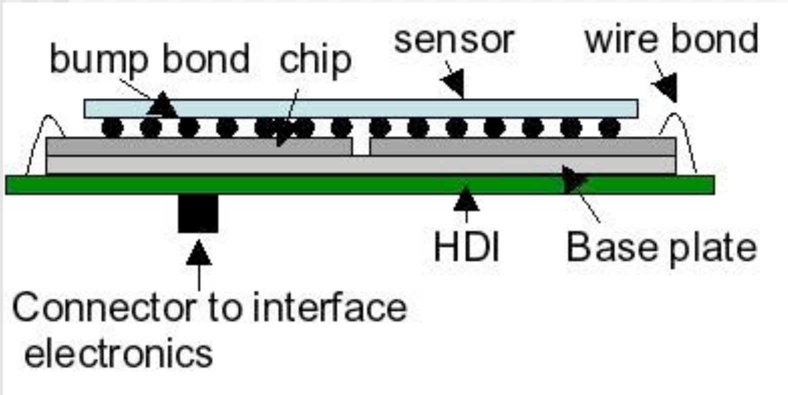
- Aluminum frames
- Carbon fibers stiffeners glued laterally to the ladders
- No material above/below the plane
- 1 plane = 0.3 % X_0

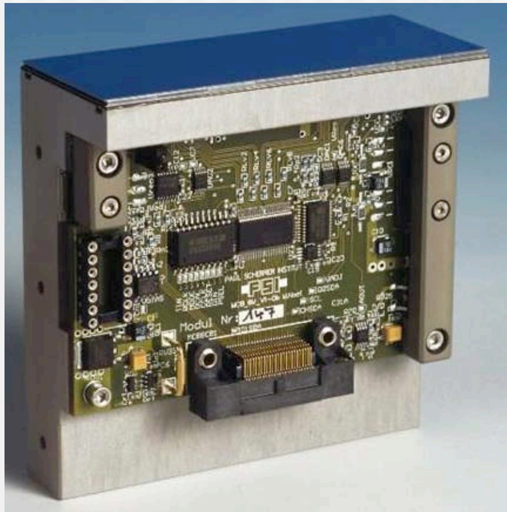


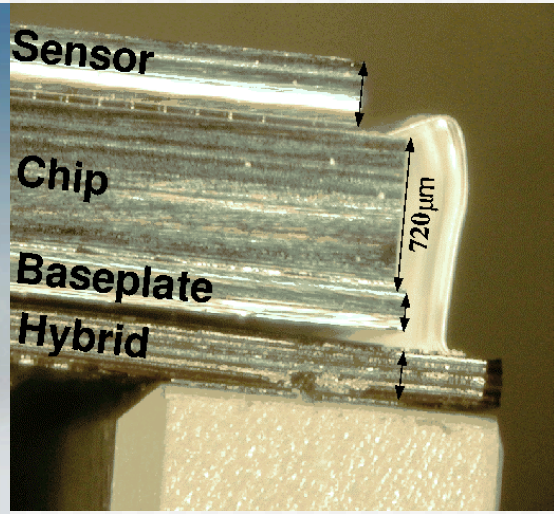


Biology application

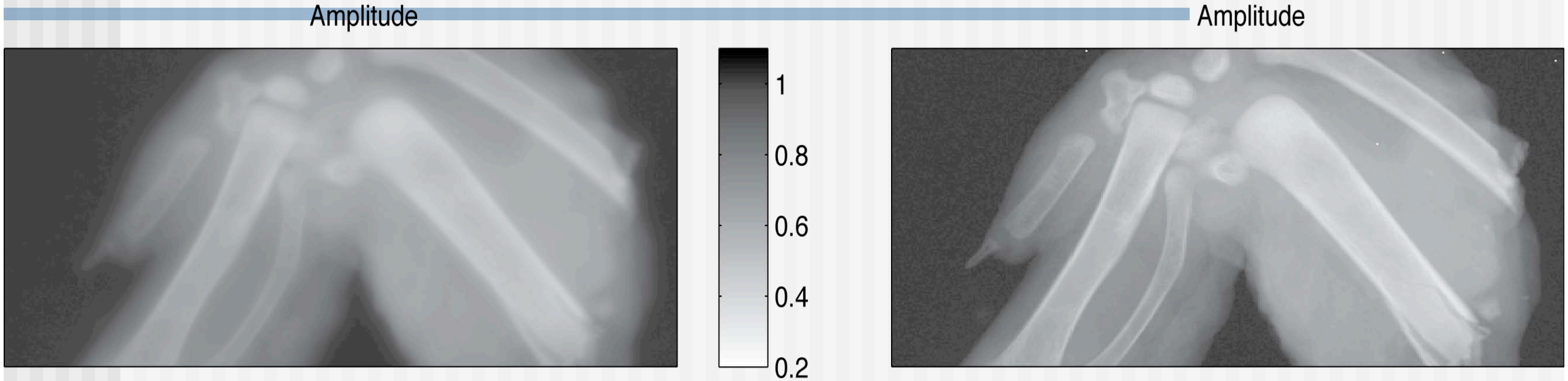
Results from the 6 Megapixel Pilatus System:



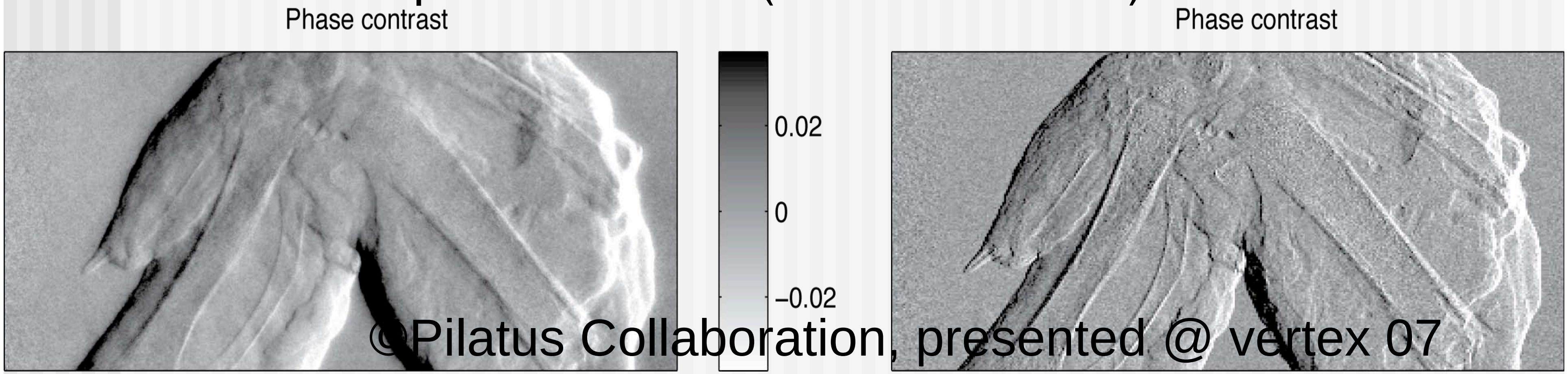




Difference …



- Point spread function (F. Pfeiffer et al.)



Conclusion

A lot of effort to improve semi-conductor devices, in term of:

- Material type
- Geometry
- Material budget
- New component

⇒ Extremely active field

⇒ Stay tuned

Outlook

The perfect detector is the one which suits your need:

- At LHC or (SLHC), the ideal one can be depleted all the time and kept at room temperature
- At the ILC, lowest possible thickness

The most challenging part is however all the services and the engineering work: cooling, cabling, shielding