Silicon Tracking

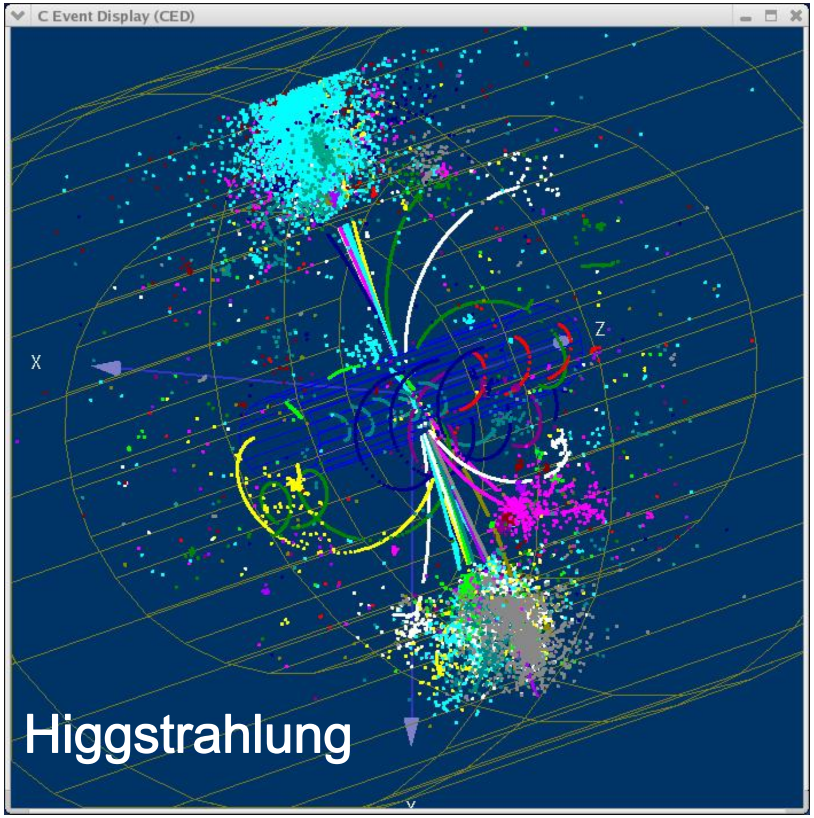
Valeri Saveliev (OSU)
Aurore Savoy-Navarro (LPNHE)
Marcel Vos (IFIC)
on behalf SiLC Collaboration

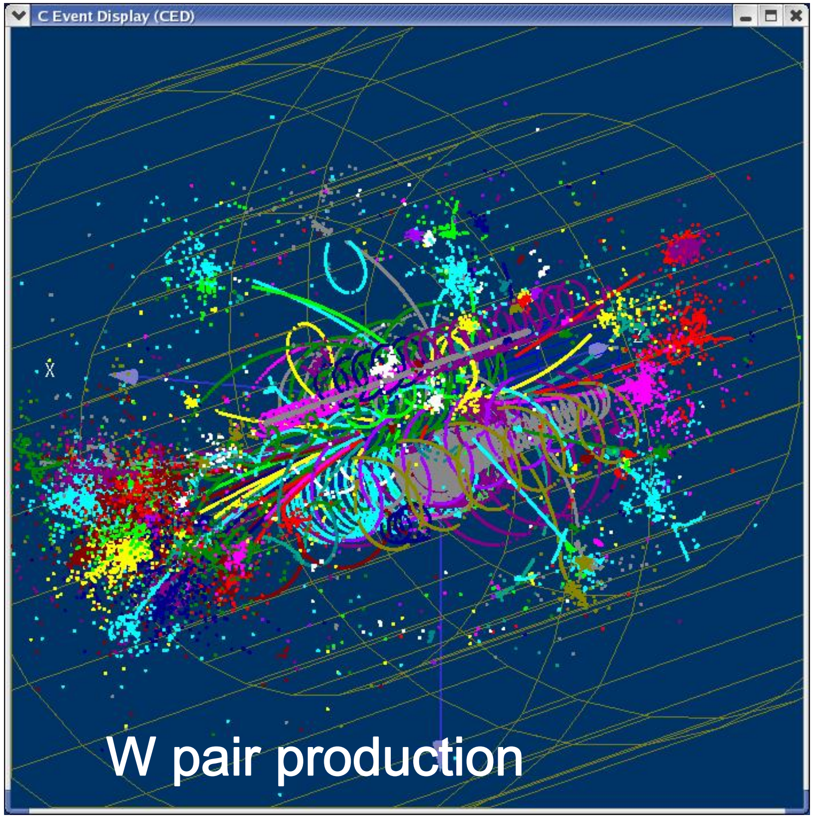
Main Topics

- Physics Motivation and Detector requirements
- Comparison of Silicon tracking LDC and GLD concepts: differences & similarities
- Main Silicon tracking components: their role & Technological choices and issues
- Optimization: Tools, present results and issues
- Integration: issues, present proposed solutions

Physics Requirements & Tracking requirements

Challenge: to build highly performing tracking system for precise measurements (space/momentum), full coverage (including endcap and forward/MDI connection), with minimal %X0, in complicated environment, examples:





General Detector Requirements from Physics

- Vertexing: 1/5 $r_{beampipe}$, 1/30 pixel size (wrt LHC) : b,c tags ...

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p \sin^{3/2}\theta$$

- Tracking: 1/6 material, 1/10 resolution (wrt LEP) : tagged Higgs ...

$$\sigma(1/p) = 5 \times 10^{-5} /\mathrm{GeV}$$

- Jet energy (quark reconstruction): 1/2 resolution (wrt LEP) : W,Z separation...

$$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

- Hermicity down to:

$$\theta = 5 mrad$$

- Sufficient timing resolution to separate events from different bunch-crossings

General Tracking Requirements

- Main momentum resolution requirements for central region driven by precision Higgs study, in particular reconstruction of Z mass in Zh channel, threshold scan Goal : $\Delta M(\mu\mu) < 0.1 \times \Gamma(Z°)$, $\sigma(1/p) < 10^{-4} Gev/c^{-1}$

- But many processes are peaked in the forward region: Bhabha scattering, W-pair production, fermion pair production has highest sensitivity to forward-backward asymmetry, Z' effects of extra dimensions and many others…

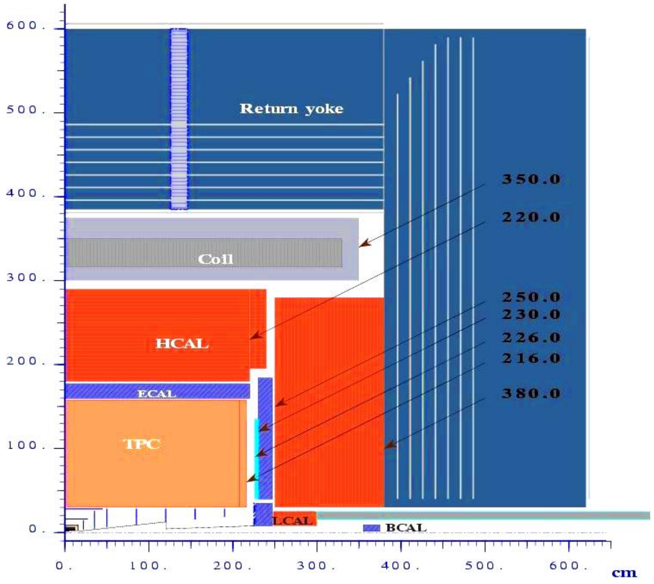
- Full angular coverage and contribution to the PFA where excellent tracking is also part of the game

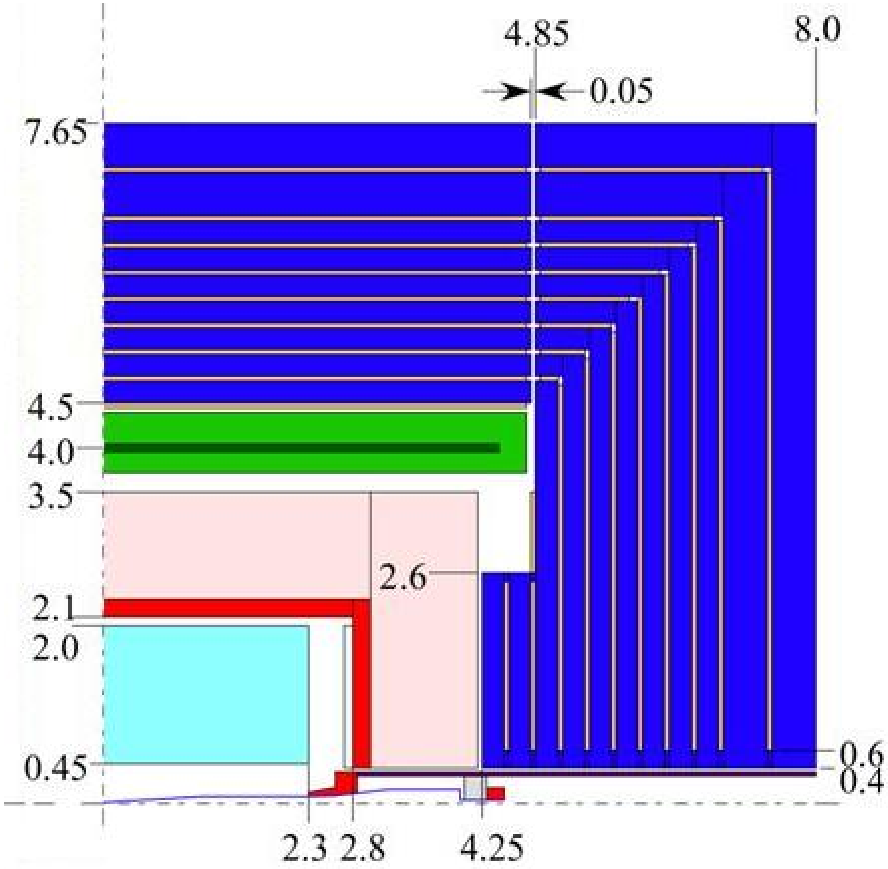
Tracking requirements are very demanding (e.g.10 x higher in momentum wrt LEP as well as in spatial and full coverage)

Excellent and robust solution is by combining a powerful vertex detector, with a central large TPC together with a Silicon tracking system, each with excellent tracking efficiency 98%

Comparison Si tracking systems LDC/GLD

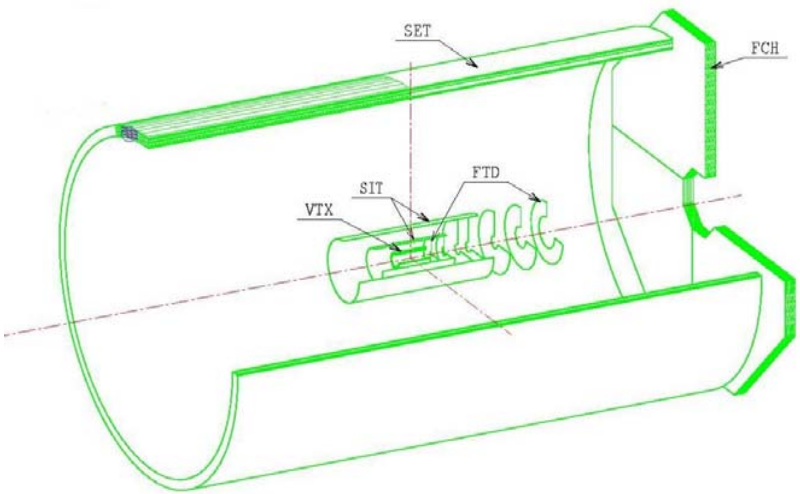
LDC, GLD Concepts





Si Tracking in LDC/GLD

LDC Silicon system:



Silicon teams from LDC and GLD are participating in the SiLC R&D Collaboration.
As a result, the Silicon tracking systems in both concepts have evolved jointly; the only main difference is SIT vs IT

July 18, 2007,Yasuhiro Sugimoto,KEK

Sub-detector	**GLD**	**LDC**
Vertex det.	FP CCD	CPCCD/CMOS/DEPFET/ISIS/SOI/…
Si inner tracker	Si strip (4-layers)	Si strip (2-layers)
Si forward trk.	Si strip/pixel (?)	Si strip/pixel (?)
Main trk.	TPC	TPC
Additional trk.	Si endcap/ outer trk. (option)	Si endcap/ external trk.

GLD/LDC Si Tracking

LDC/LDC main Si trackers parameters:

	R (cm)	Z(cm)	cosθ	t (μm)	Resolution
SIT	16.0	38.0	0.9216	tbd	R-φ: 25-50μm strip σ=4μm Z: 50μm strip σ=25μm
	27.0	66.0	0.9255		
FTD	2.9-14.0	22.0	0.8437-0.9914	tbd	σ=7μm
	3.2-14.0	35.0	0.9285-0.9958		
	3.5-21.0	50.0	0.9220-0.9976		
	5.1-27.0	85.0	0.9531-0.9982		
	7.2-29.0	120.0	0.9720-0.9982		
	9.3-29.0	155.0	0.9829-0.9982		
	11.3-29.0	190.0	0.9886-0.9982		
ETD	30.5-149.0	236.8	0.8464-0.9918	tbd	σ=7μm
SET	160.0	250.0	0.8423		

	R (cm)	Z(cm)	cosθ	t (μm)	Resolution
BIT	9.0	18.5	0.8992	560	R-φ: 50μm strip σ=10μm Z: 100μm strip σ=50μm
	16.0	33.0	0.8998		
	23.0	47.5	0.9000		
	30.0	62.0	0.9002		
FIT	2.4-7.6	15.5	0.8979-0.9882	560	σ=25μm
	3.2-14.0	29.0	0.9006-0.9940		
	3.7-21.0	43.5	0.9006-0.9964		
	4.7-28.0	58.0	0.9006-0.9967		
	5.7-38.0	72.5	0.8857-0.9969		
	6.6-38.0	87.0	0.9164-0.9971		
	7.6-38.0	101.5	0.9365-0.9972		
ET	45.0-205.0	270.0	0.7964-0.9864	560	σ=25μm
		274.0	0.8007-0.9868		
		278.0	0.8048-0.9872		

Main Si Tracking components: Their role & technological choices and issues

LDC: Silicon Tracking Matrix

Flavor

SIT	SET
FTD	ETD

Magnitude

Main Si Tracking components: Their role

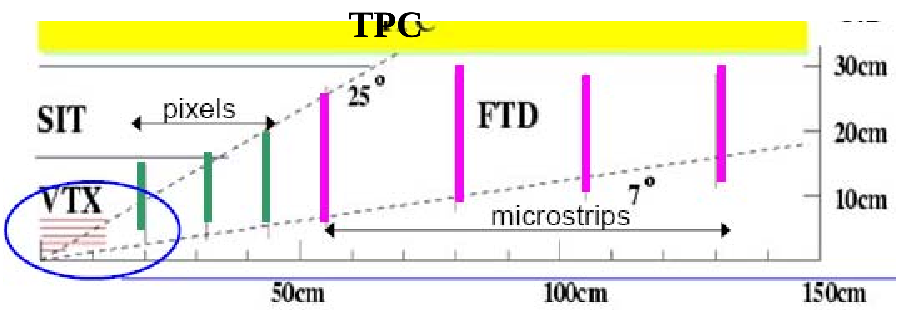
- Inner components:
  - SIT/IT: link VTX & TPC
    - improve the momentum resolution
  - FTD/FIT: extend/replace VTX & TPC at low angles (FWD)

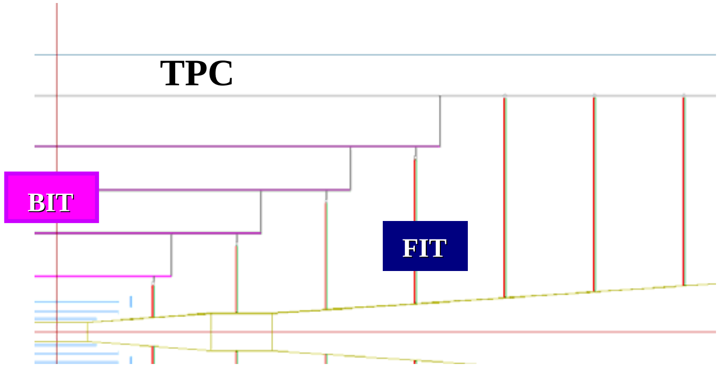
- Outer components:
  - SET: link TPC to em calo and helps in PFA
  - ETD/ET: same in the endcap region

- Moreover these 4 components provide an almost full angular coverage (also standalone tracking => redundancy)

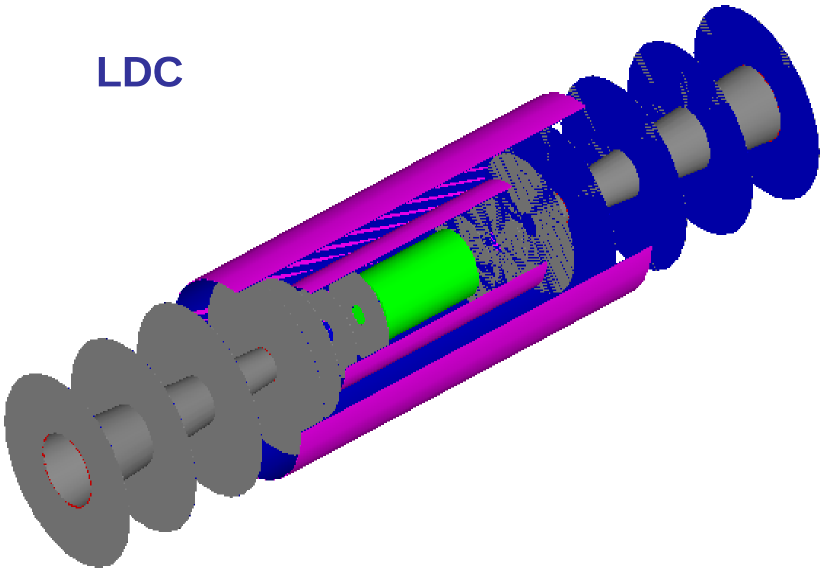
Lot of work and studies devoted to emphasize these roles.

Ex: Si Tracking in LDC/GLD (Inner Part)

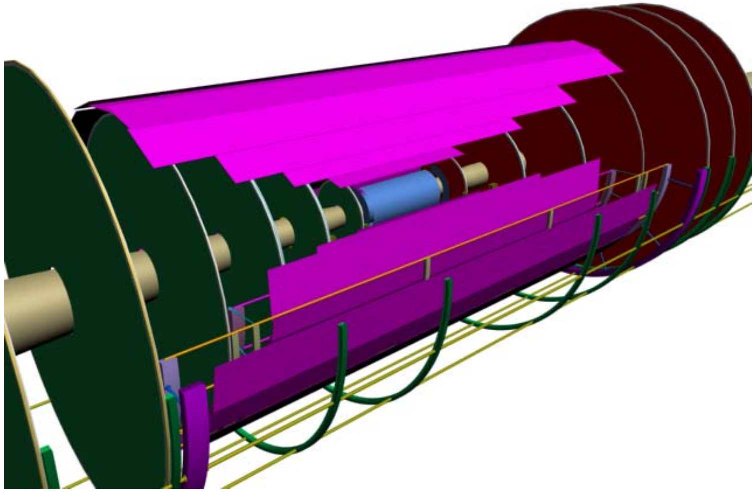




LDC

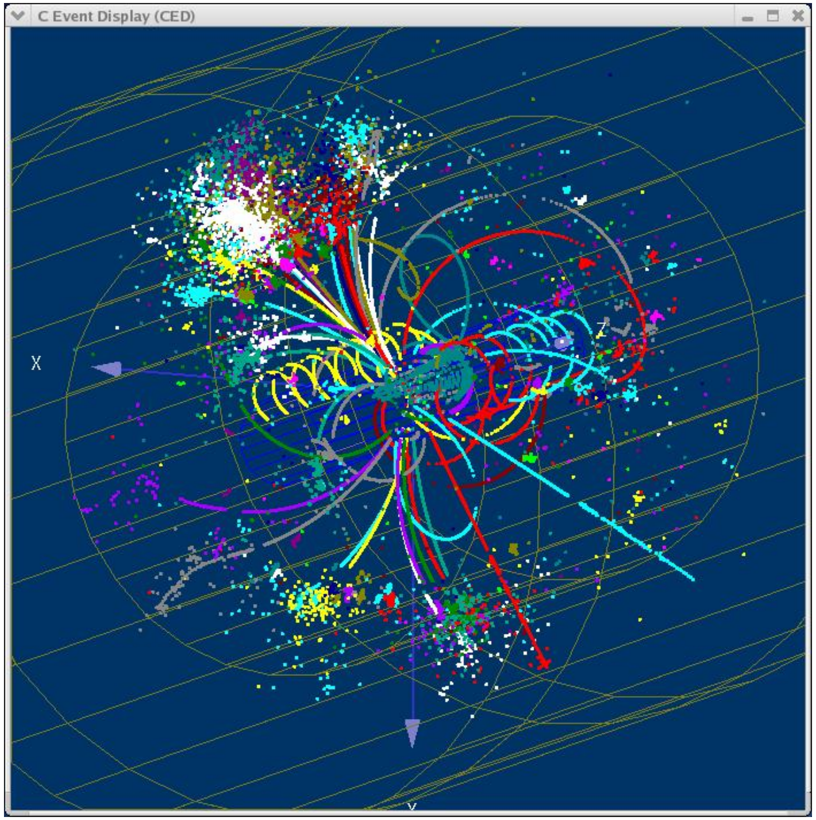


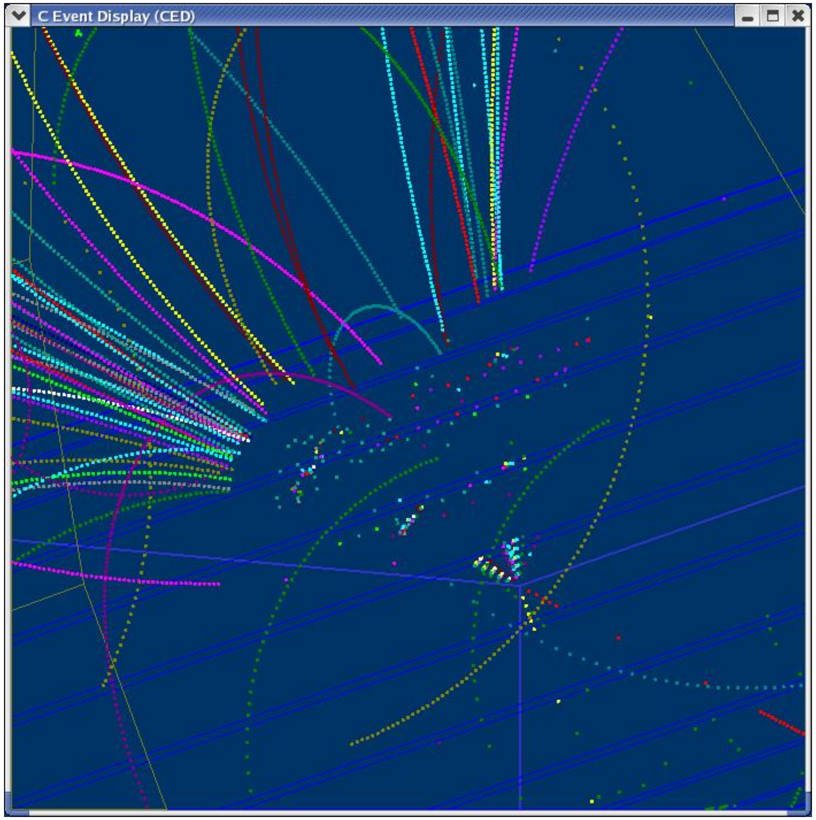
GLD



Importance of the Inner central tracking (SIT/IT)

Challenge: to build high efficient detector system for precise measurements in complicated environment: Example of importance of SIT





Main Si Tracking components: technological choices and issues

Among the main goals: lowering %X0, improving S/N, spatial resolution (granularity) momentum resolution.
It translates into R&D work performed by SiLC R&D Collaboration on:

Sensors:
- Si-strip
- Pixel technologies (SiLC teams involved with MAPs & DEPFET R&D)
- New Sensors technologies (mainly driven by 3D on strips and pixels)

Electronics:
- DSM FEE
- direct connection to the Silicon sensor (strip or pixel)
- integration to the overall readout and DAQ

Integration Technologies: mechanical support and construction of elementary module (tile), cooling, connection of electronics to detector, cabling, alignement, mechanical integration of these components within the overall detector

BaselineTechnologies of Si Sensors (SiLC)

Future Linear Collider Experiment will have a large number of silicon sensors

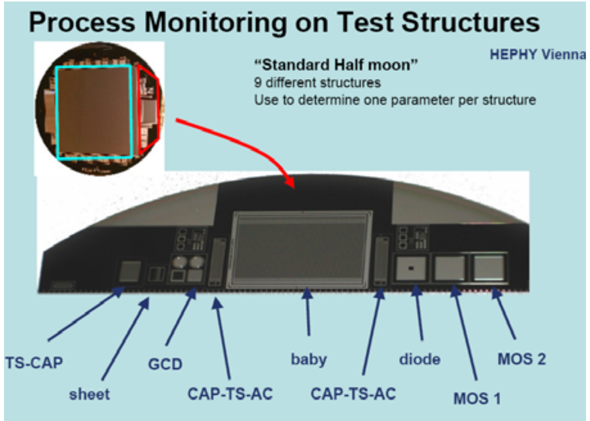
- Order of 100-200 m2 (CMS has 200 m2)
- Tradeoff between large scale, precision, material budget and power consumption are main direction

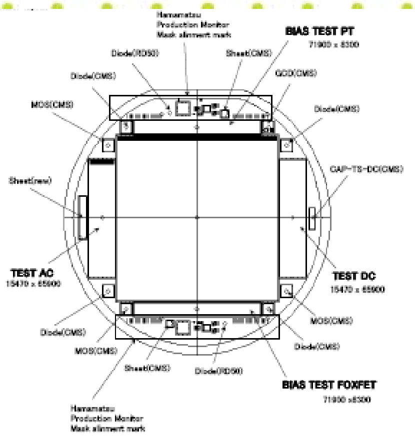
- SiLC baseline for outer layers
  - 8”, high resistivity FZ sensors
  - Thickness: 200 μm
  - AC coupled strips
  - 50μm pitch
  - Strip length between 10 and very maximum 60 cm

- SiIC baseline for inner layers
  - double sided 6” high resistivity FZ sensors
  - AC coupled strips
  - 25-50μm pitch

- SiLC baseline for inner forward layers:
  - Pixels

Technologies developments on sensors: ex

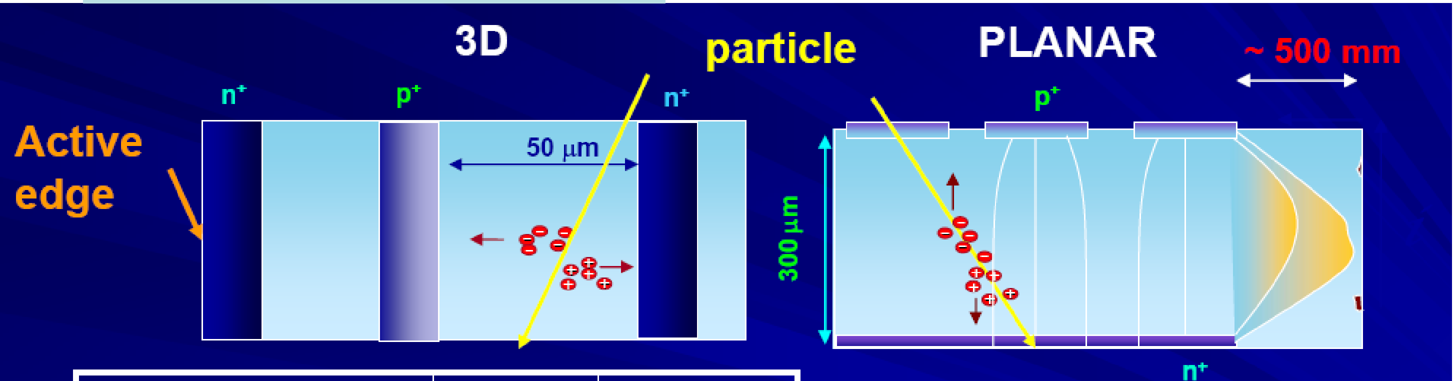




New and presently: HPK μstrips
Pitch=50μm, thick: 320μm;
Length: 9.15cm, 6'' wafer

New technological approach:
3D Planar μstrips:

Edgeless (hermetic)
Low V
Lower Thickness
Faster
Rad hard

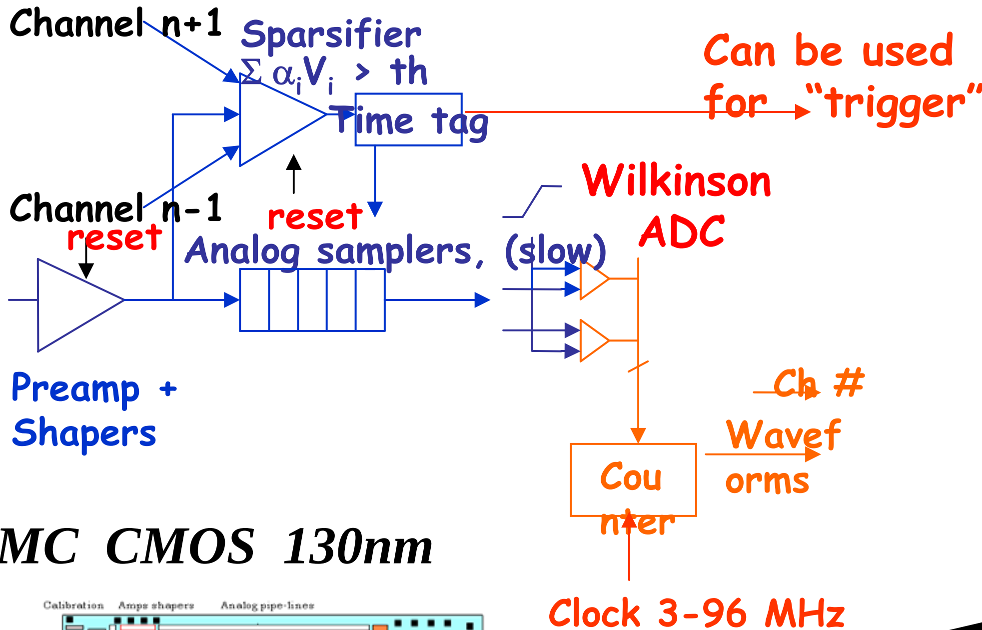


	3D	Planar
Q collection path	50μm	300 μm
$V_{depletion}$	<10V	70 V
Edge sensitivity	10μm	500 μm
Q Collection time	1-2 ns	10-20 ns

Proposed by Parker, Kenney1995

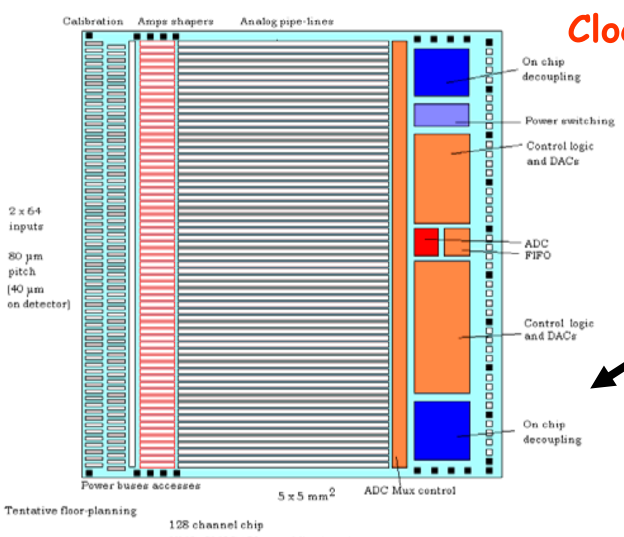
- NIMA 395 (1997) 328
- IEEE TNS 46 4 (1999) 1224
- IEEE TNS 48 2 (2001) 189
- IEEE TNS 48 6 (2001) 2405
- IEEE TNS 48 5 (2001) 1629
- CERN Courier, Vol 43, Number 1, Jan 2003

Technologies developments: DSM FE electronics

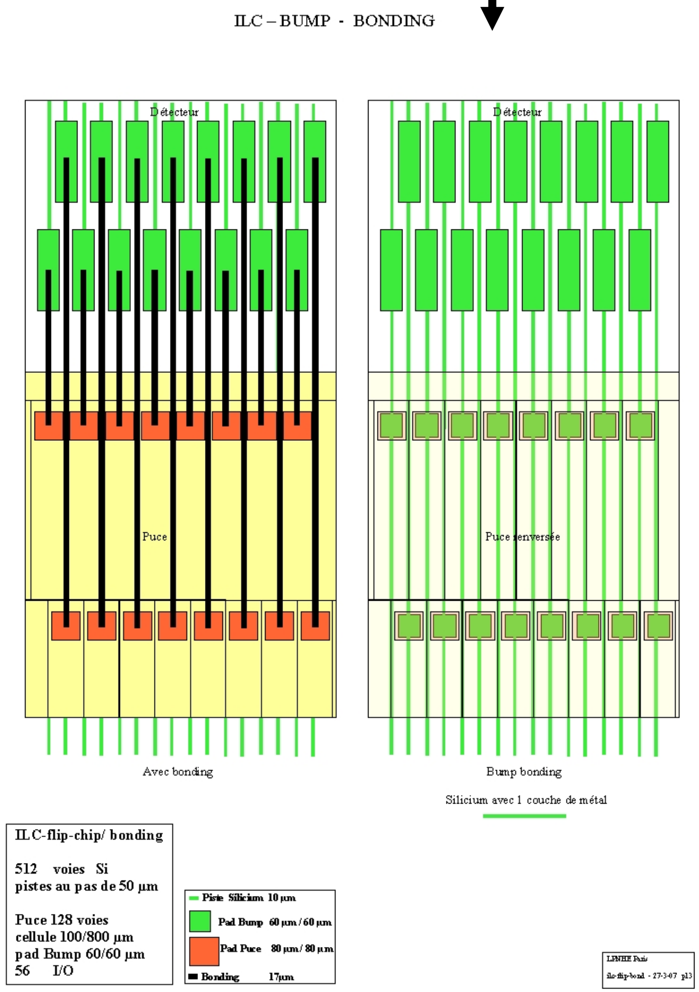


Inline routing of FEE
underway with HPK/LPNHE

UMC CMOS 130nm



Digitized DSM FEE-128 ch

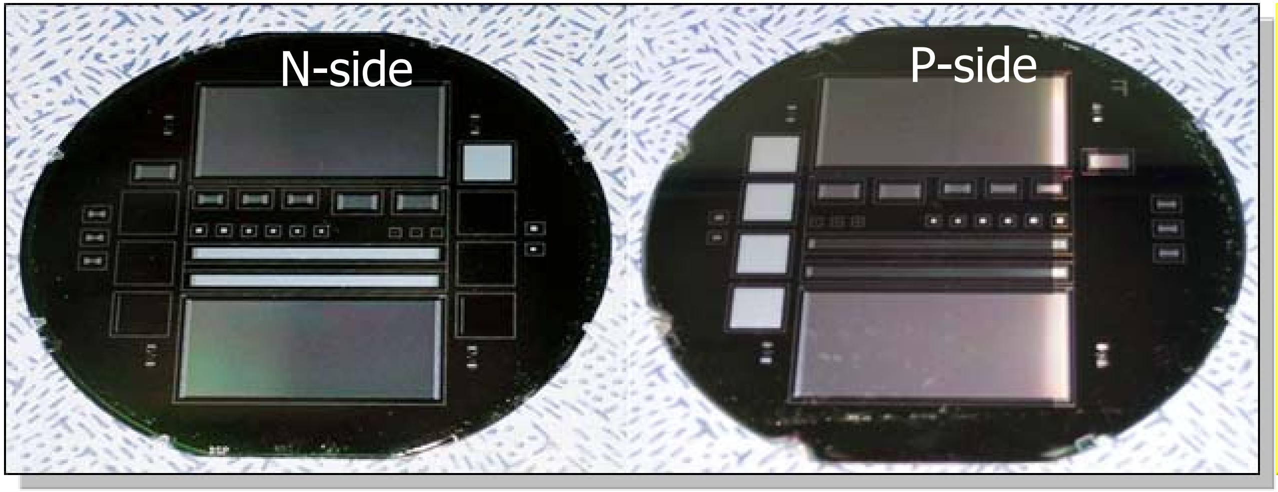


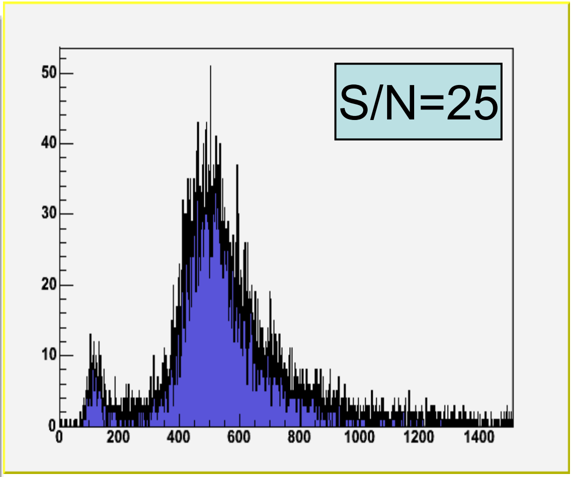
Si strip Sensors R&D at GLD (Korean team)

GLD Korean Team
Part of SiLC

DSSD Designed, Fabricated and Tested:
- IV/CV shows good quality sensor
- S/N shows that the sensors are in good shape
- more tests are in progress
- will fabricate AC-SSD on 6-inch(400 mm) and 8-inch(500 mm) wafers

Prototype





wafer	**TOPSIL** (5inch, high resistivity, (100), FZ, DSP)	strip width	9µm
		strip pitch	50(100) µm
thickness	380 µm	readout pitch	50µm
size	51 x 26 mm^2	readout channel	512(512)

Optimization: Tools, present results & issues

Fast simulations: LiCToy and SGV

- Full simulations GEANT4 based: MOKKA + Marlin Reco

  Jupiter (Korean team in GLD)

  ILCROOT (for comparison)

- Test beams

Main goals:

=> Optimization of each component design in collaboration with each concerned subdetector(s)

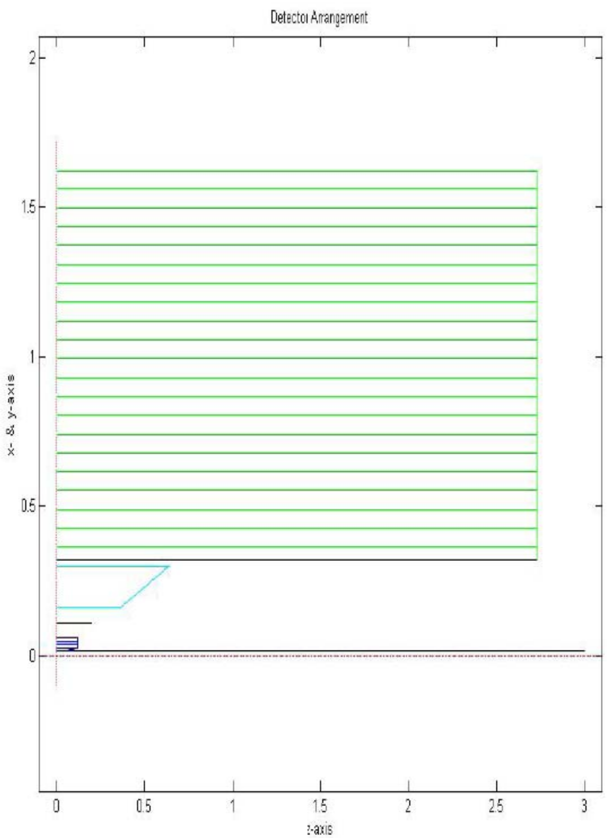
=> Study of the large angle and FWD region (connection with MDI and VFWD)

=> Comparison with an all-Si-tracking design

SiLC has started a task force on full simulation/optimization since 07. It took responsablity in defining and maintaining the geometry DB (people in charge: V. Saveliev & M. Vos)

Optimization Tools: Ex1 = LiC Toy

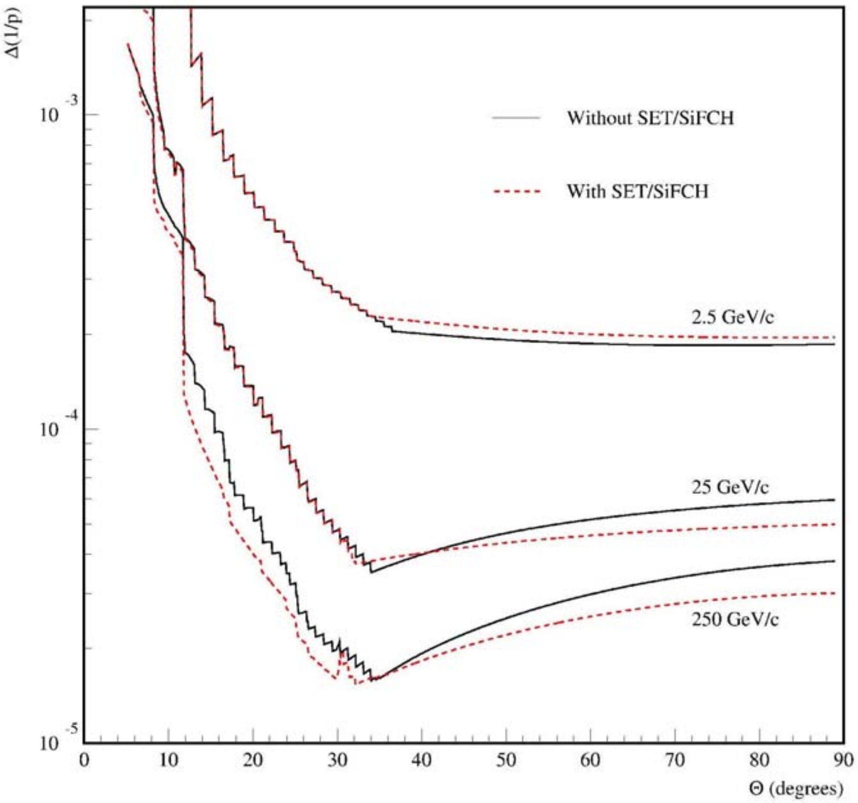
LiC Detector Toy, M. Regler, M. Valentan, R. Frühwirth, Vienna University: A mini simulation and track fit programme, written in MATLAB, for fast and flexible detector optimization study (see W. Mitaroff's presentation at TOOL session)



RMS		$0 \le \lambda \le \pi/12$	$\pi/12 \le \lambda \le \pi/6$	$\pi/6 \le \lambda \le \pi/4$
$R\Phi$	without IT	3.95 10^{-6}	3.99 10^{-6}	3.98 10^{-6}
	with IT	3.90 10^{-6}	3.98 10^{-6}	4.33 10^{-6}
	modified IT	3.81 10^{-6}	3.87 10^{-6}	4.26 10^{-6}
z	without IT	4.35 10^{-6}	4.65 10^{-6}	4.88 10^{-6}
	with IT	4.32 10^{-6}	4.02 10^{-6}	4.26 10^{-6}
	modified IT	4.27 10^{-6}	3.97 10^{-6}	4.12 10^{-6}
ϑ	without IT	1.50 10^{-4}	1.46 10^{-4}	1.17 10^{-4}
	with IT	1.19 10^{-4}	1.17 10^{-4}	1.00 10^{-4}
	modified IT	1.14 10^{-4}	1.15 10^{-4}	0.967 10^{-4}
ϕ	without IT	1.14 10^{-4}	1.19 10^{-4}	1.27 10^{-4}
	with IT	1.16 10^{-4}	1.21 10^{-4}	1.27 10^{-4}
	modified IT	1.10 10^{-4}	1.16 10^{-4}	1.22 10^{-4}
$\Delta p_t/p_t$	without IT	1.06 10^{-3}	1.08 10^{-3}	1.16 10^{-3}
	with IT	1.05 10^{-3}	1.02 10^{-3}	1.05 10^{-3}
	modified IT	1.05 10^{-3}	1.03 10^{-3}	1.05 10^{-3}
$\Delta p_t/p_t^2$	without IT	1.02 10^{-4}	1.01 10^{-4}	1.14 10^{-4}
	with IT	0.927 10^{-4}	0.921 10^{-4}	0.977 10^{-4}
	modified IT	0.942 10^{-4}	0.931 10^{-4}	0.998 10^{-4}

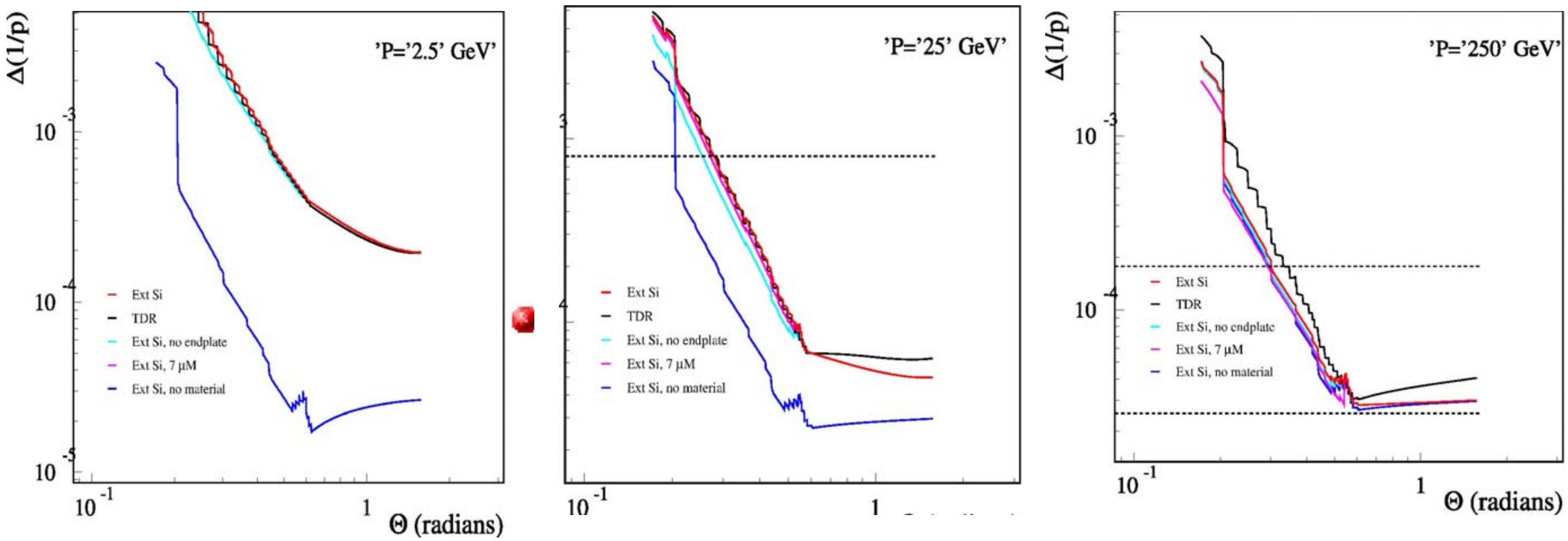
Optimization (SGV) M. Berggren

SGV studies have helped to define the optimal geometry of the the SET, and to show how the Silicon Envelope can ameliorate the momentum resolution for the LDC detector:



Optimization (SGV)

Given the effect performance curves wrt. Angle and momentum, it is interesting to try to see what the ultimate performance for a given geometry would be.
With SGV, it is easy to change the material, and even to completely remove it (but keeping the measurement...)



OptimizationTools: Track Fitting

Track Fitting (Marcel Vos) : CMS Kalman filter tool-kit .

The result of years of work by a lot of people. Validated in large-scale MC productions.

Extracted all relevant code in a series of libraries with limited external dependencies (CLHEP, ROOT).

Interfaced to toy geometries in standalone programme. Tested results for internal consistency and against existing fast-simulation packages.

Interfaced to MarlinReco (GEAR geometry, LCIO hits)

CSIC

IFIC

Momentum resolution

$\Delta(1/p_T)$ @ 10 degrees :

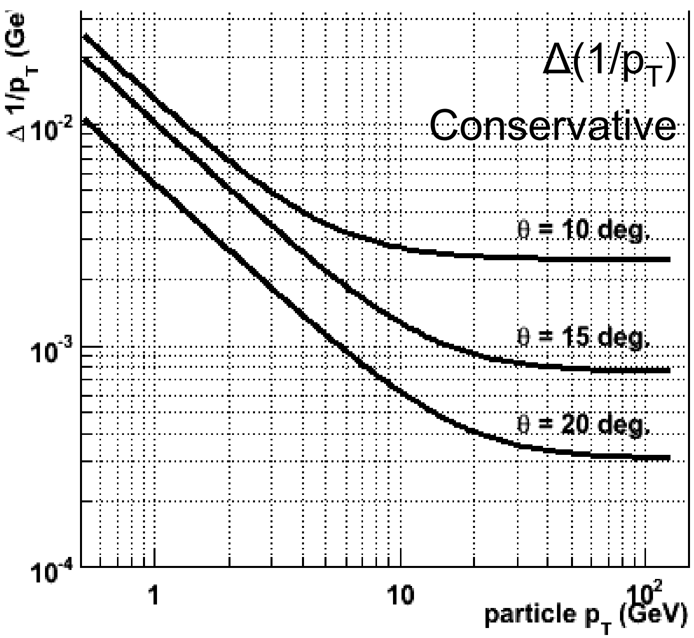
Reference (TESLA) set-up

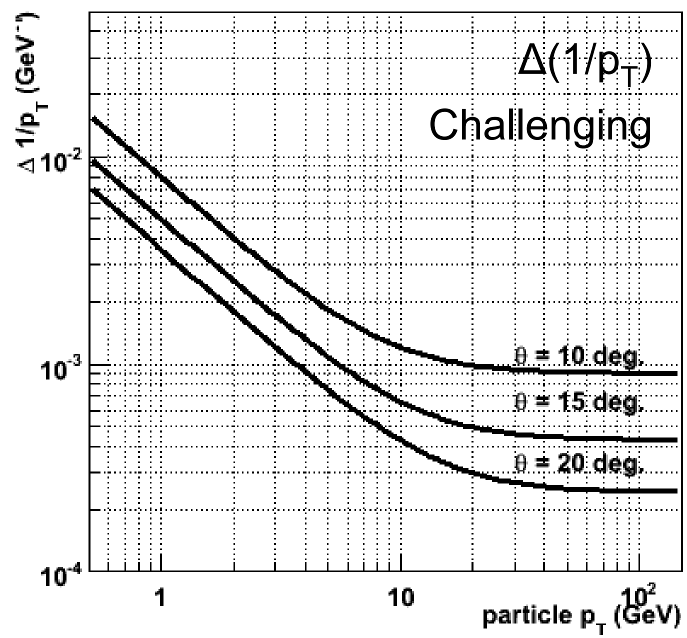
1.8×10^{-3}□$1.3\times10^{-2}/\ p_T$

Challenging setup

(5 μ m Rφ resolution, 1.2 ‰ X0/disk for FTD1-3, 4 ‰ X0/disk for FTD4-7)

$\Delta(1/p_T)=0.9\times10^{-3}$□$0.8\times10^{-2}/\ p_T$





Tools: Pattern Recognition

Combinatorial algorithm based on KF kit

The baseline algorithm of the ATLAS (arXiv:0707:3071) and CMS (NIM A 559 143) experiments

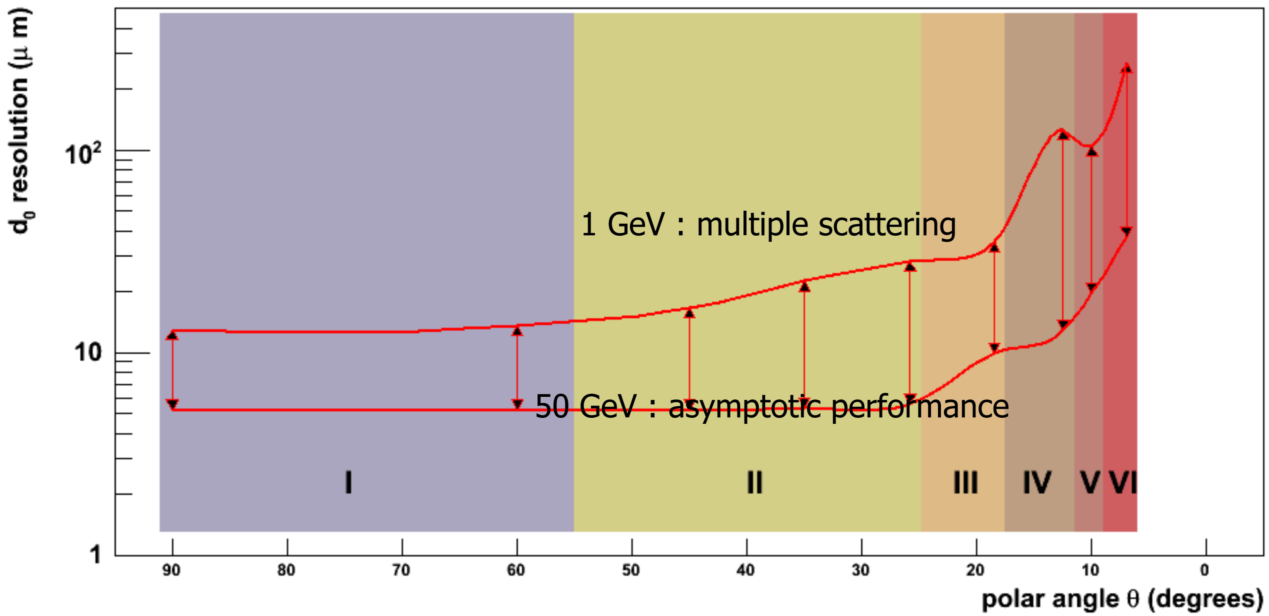
Standalone FTD reconstruction implemented in MarlinReco processor

Run on tt events with superposed pair background.

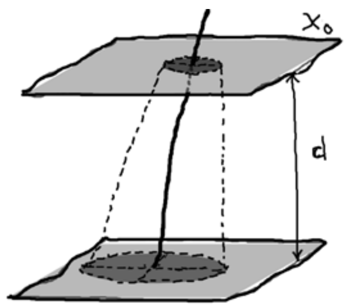
- Reference FTD (TESLA layout)
- 10 mm R-f resolution
- 1.2 % X_0/disk (1-3) and 0.8 % X_0/disk (4-7).
- Several scenarios for R-resolution, from pixel to single-sided strip.

Vertexing with Forward Tracking

* I	35	<	θ <	90	5 VXD + SIT
* II	25.8	<	θ <	35	5 VXD + FTD1
* III	18.5	<	θ <	25.8	3 VXD + FTD1+2
* IV	12.5	<	θ <	18.5	VXD2 + FTD
* V	10	<	θ <	12.5	FTD1,...
* VI	6.5	<	θ <	10.0	FTD2,...

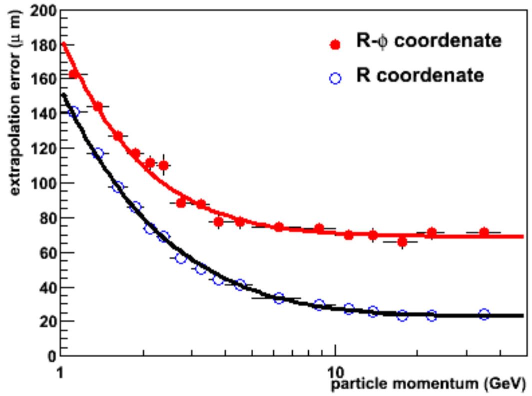


Tools: Pattern Recognition

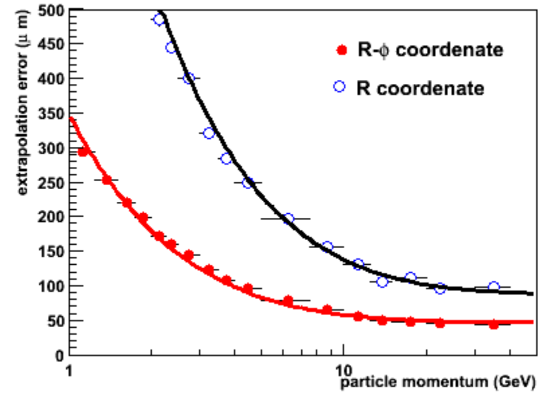


Extrapolation precision

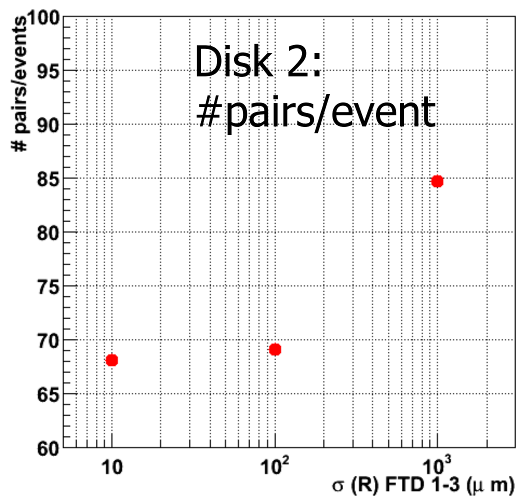
Innermost disks
R very precise (pixel detectors)
R f -> weakly constrained p_T

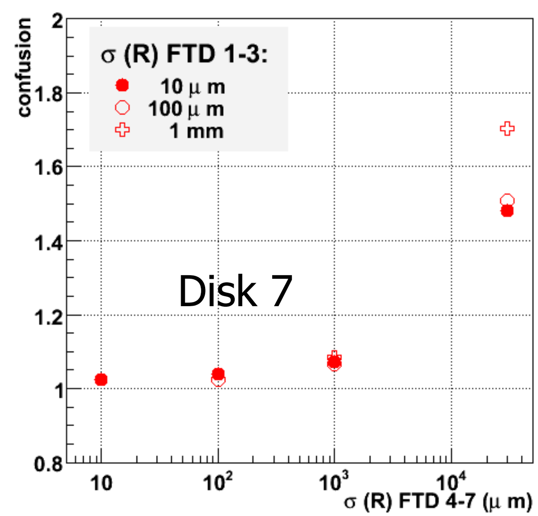


Outermost disks
R degraded (single sided strips)
R f -> OK



Confusion



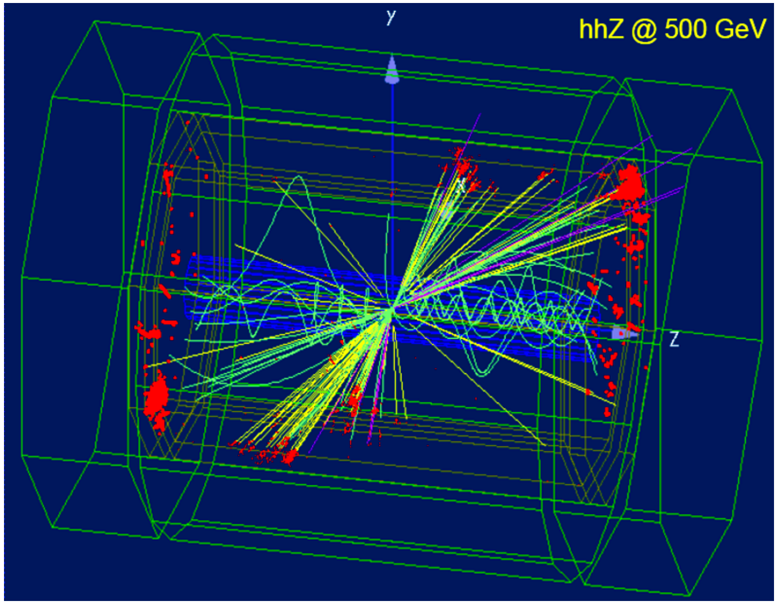


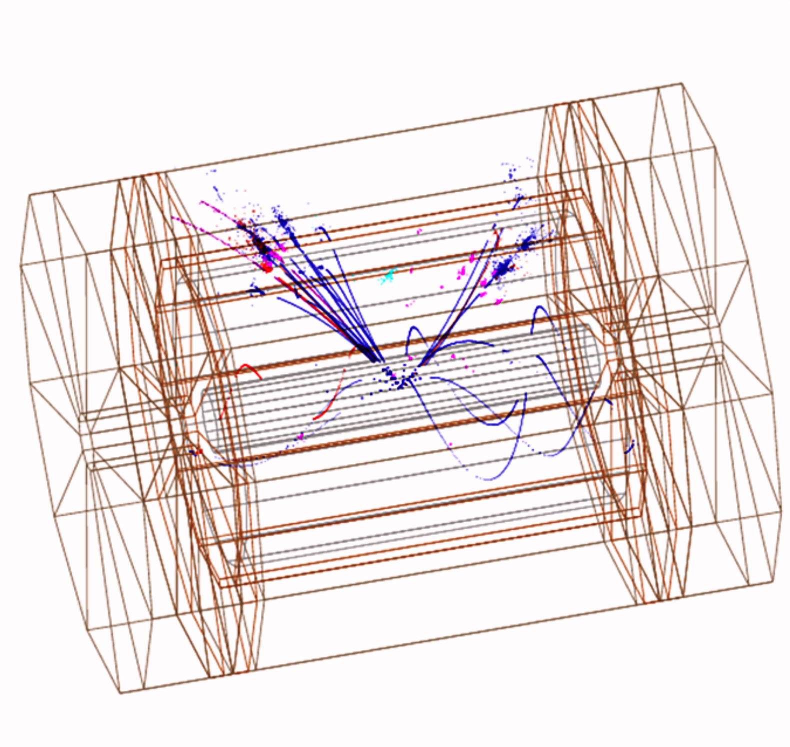
Optimization

Full Detector Simulation and Reconstruction

- LDC: Mokka and Marlin Reconstruction OO Frame work
- GLD: Jupiter and jsf – Root based Framework

PFA – Particle Flow Algorithm





Necessary Joint Effort

Tools: Pattern Recognition

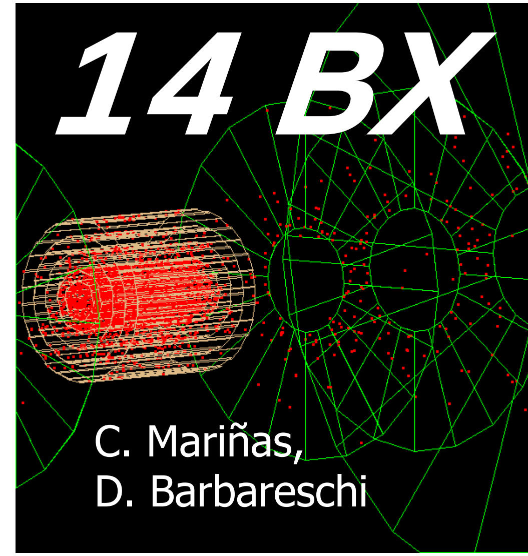
Low momentum tracks are a real challenge!

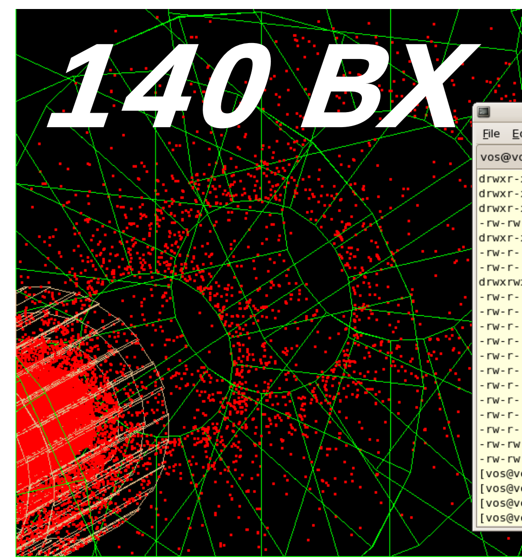
The stand-alone FTD is able to resolve patterns down to a p_T of 100 MeV, provided:

R-segmentation: in innermost disks < 500 mm, in outermost disks O(1cm)

Read-out speed: beyond O(10) bunch crossings the density of low momentum tracks prevents algorithm convergence

Material: an increase of the material beyond 1%/disk has dramatic consequences on pattern recognition

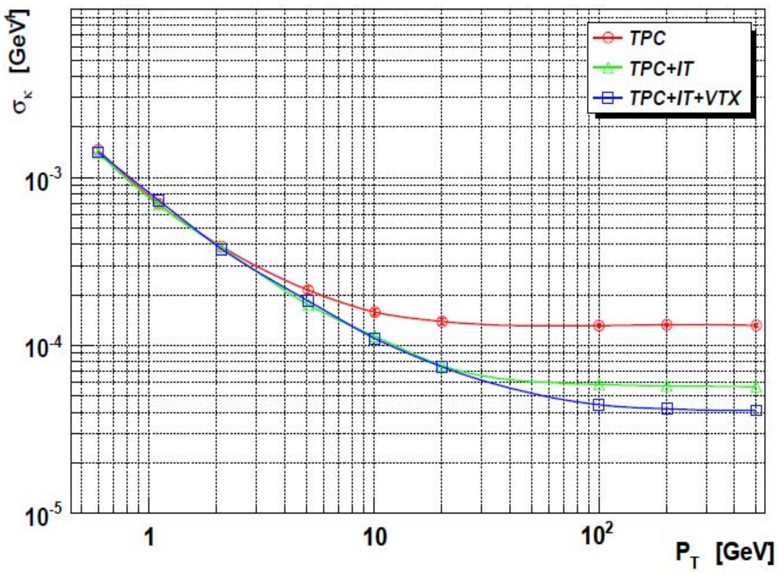


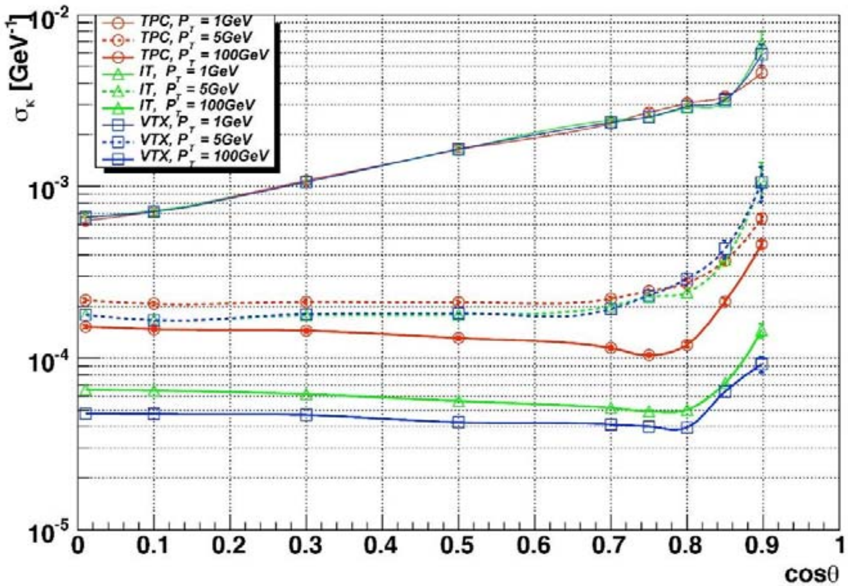


Optimization (Jupiter, Satellites,Uranus)

GLD Tracking Study:
- Jupiter, Satellites and Uranus – Geant4 and ROOT based full detector simulation

Track reconstruction:
- Track Finder is a cheating version using MC truth
- Track Fitter is based on Kalman Filter



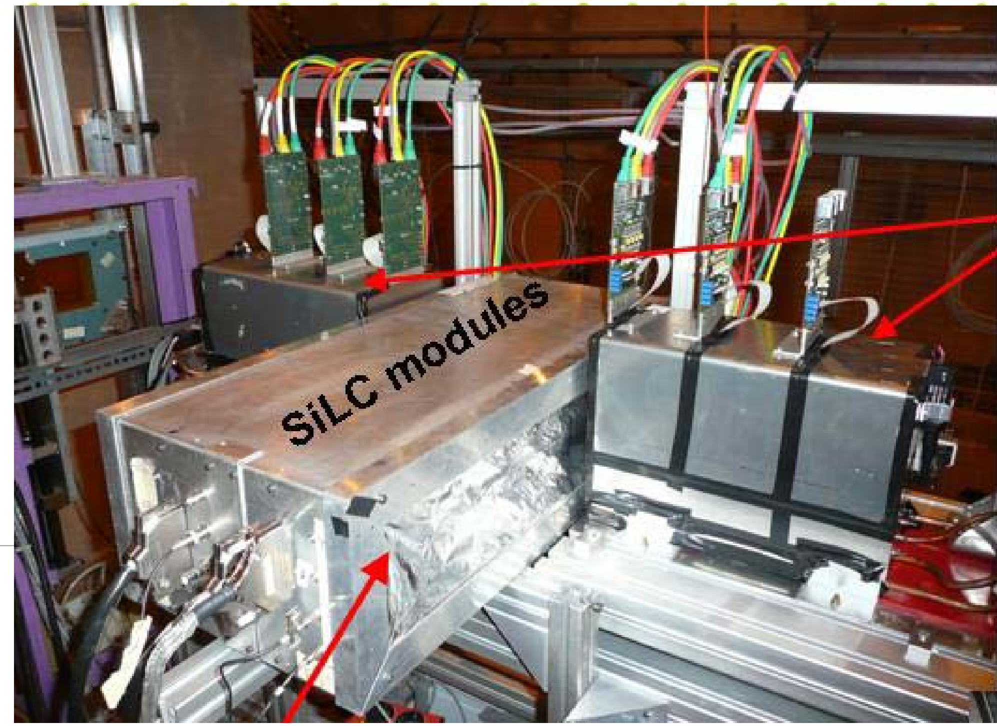


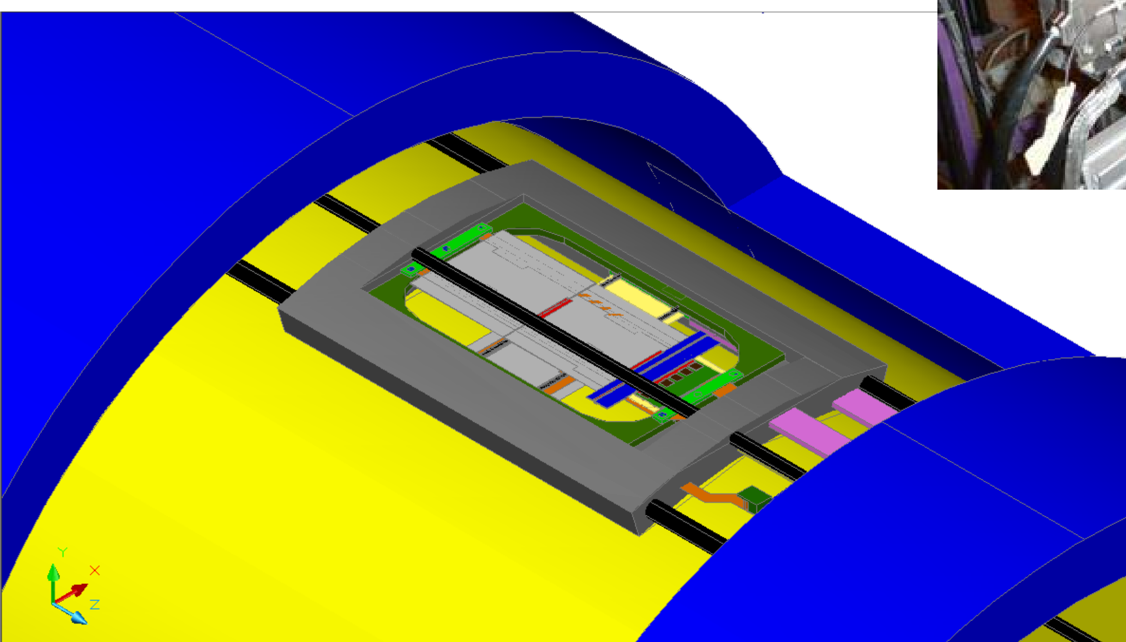
Can perform hybrid track fitting with TPC, IT,VTX, taking into account
- Energy loss,
- Multiple Scattering

A Study of Tracker Performance with Jupiter, A.Yamaguchi

Optimization tools: testbeams, ex:

Test beam at CERN Oct 07:
Combined Si strips with EUDET Telescope will be pursued in 08





LCTPC in 2008:
test SIT/SET system around the TPC

SiLC R&D Collaboration

U.S.A

Michigan U.
SCIPP-UCSC

Close connections:

- FNAL (DOE prop 05 funded)UCSC, FNAL, LPNHE
- SLAC (DOE prop 03: funded): UCSC, SLAC Michigan U, LPNHE and meetings SiD
- CERN (developed interest)

Europe

IMB-CNM/CSIC, Barcelona (SP) *(eudet ass.)*
Uni of Barcelona (SP)
Helsinki U. and VTT (Fi) *(eudet)*
IEKP, Karlsruhe U. (D)
Uni of Liverpool, (UK)
Moscow St. U. , Moscou(Ru) *(eudet ass.)*
Obninsk St. U., Obninsk (Ru) *(eudet ass.)*
LPNHE, Paris (Fr) *(eudet)*
Charles U. , Prague (CZ) *(eudet)*
IFCA, Santander(Sp) *(eudet)*
Torino U., Torino -INFN(IT)
IFIC-CSIC Valencia (Sp) *(eudet ass.)*
HEPHY, Academy Sci., Vienna (Au)

Asia

Kyungpook U. Taegu, Ko
Yonsei U., Seoul, Ko
Korea U. Seoul, Ko
Seoul Nat. U., Seoul, Ko
SungKyunKwan U. Seoul
Tokyo U. (Japan)
HAMAMATSU (Japan)

SITRA= sub sample of SiLC but many SiLC partners Are joining tests beam and related isues (EUDET}

Launched January 2002, Proposal to the PRC May 2003, Report Status May 2005, ILC tracking R&D Panel at BILCW07 February 2007, next PRC Status report April 08

The optimization of the Silicon tracking for ILD will be pursued within our ongoing Collaboration with Silicon tracking team als part of SiLC

Summary: Integration Issues