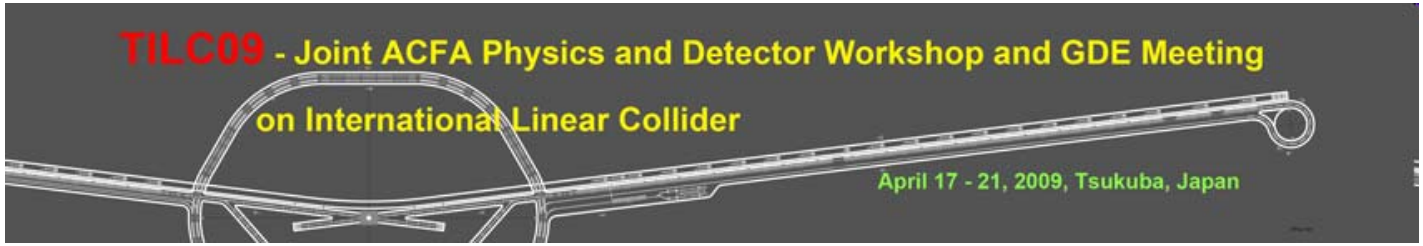
Forward tracking at the next e+e- collider

Alberto Ruiz-Jimeno (IFCA, CSIC-Univ. Cantabria)

(on behalf of the Spanish Network for Future Linear Accelerators)



Outline

- The Spanish Network
- Forward Tracking: the physics case
- Challenges, R&D
- Conclusions

(See also:

Marcel Vos (IFIC, Valencia) talk at Seul, February 2009

Iván Vila (IFCA, Santander) talk at SLAC, March 2009)

Coordinated ILC detector- effort in Spain

Silicon for Large Colliders

IFIC, IFCA (since 2005), UB, CNM, USC
IFCA→EUDET member, several associates

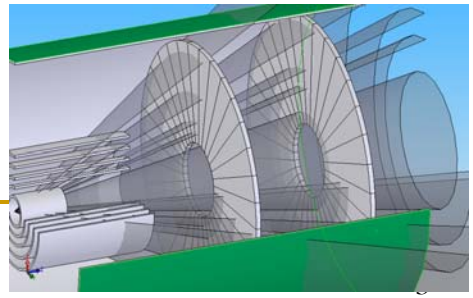
Strong Spanish participation in DEPFET
IFIC (since 2005)
USC, UB, URL, CNM (since 2008)

CALICE

CIEMAT Madrid

and activities in accelerators R&D

Coordinated effort :
- **regular meetings**
- **funding/projects**
- **R&D interests**
- **the forward tracker…**



Forward tracking, physics case

In this talk:
forward region **= 5º < θ < 30º** *(multiple disks layout)*
Range : **0.5-3 TeV**

Forward tracking at the next e^+e^- collider
part I: the physics case

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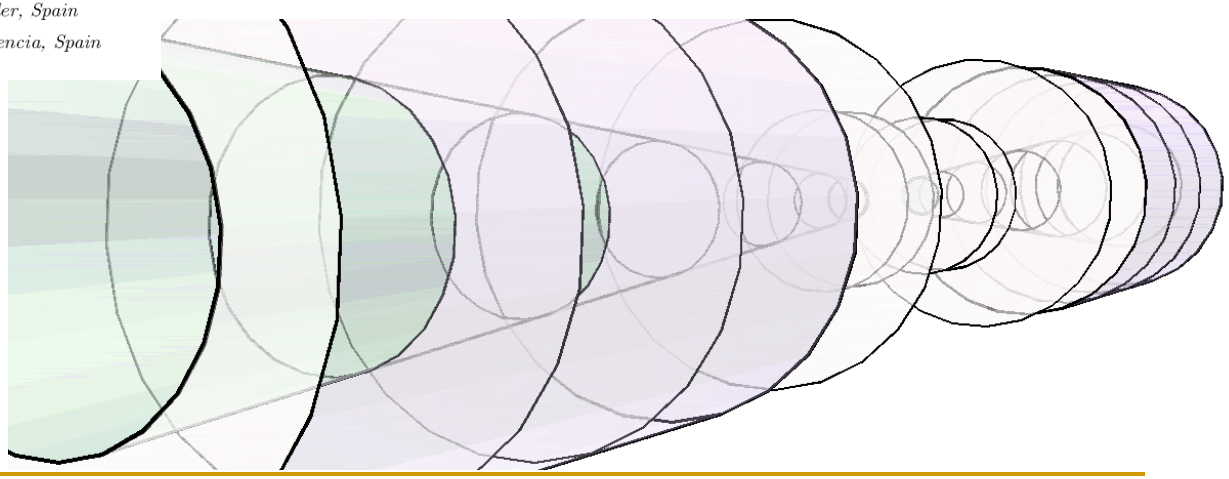
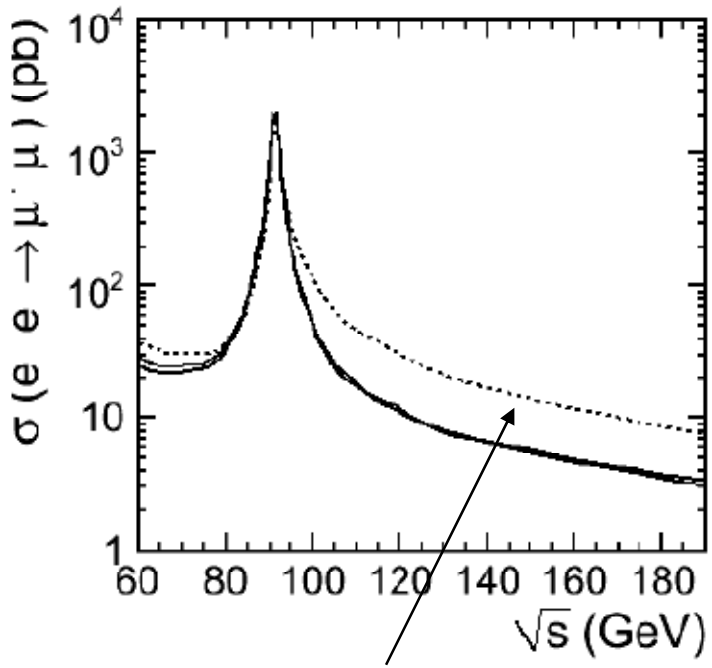
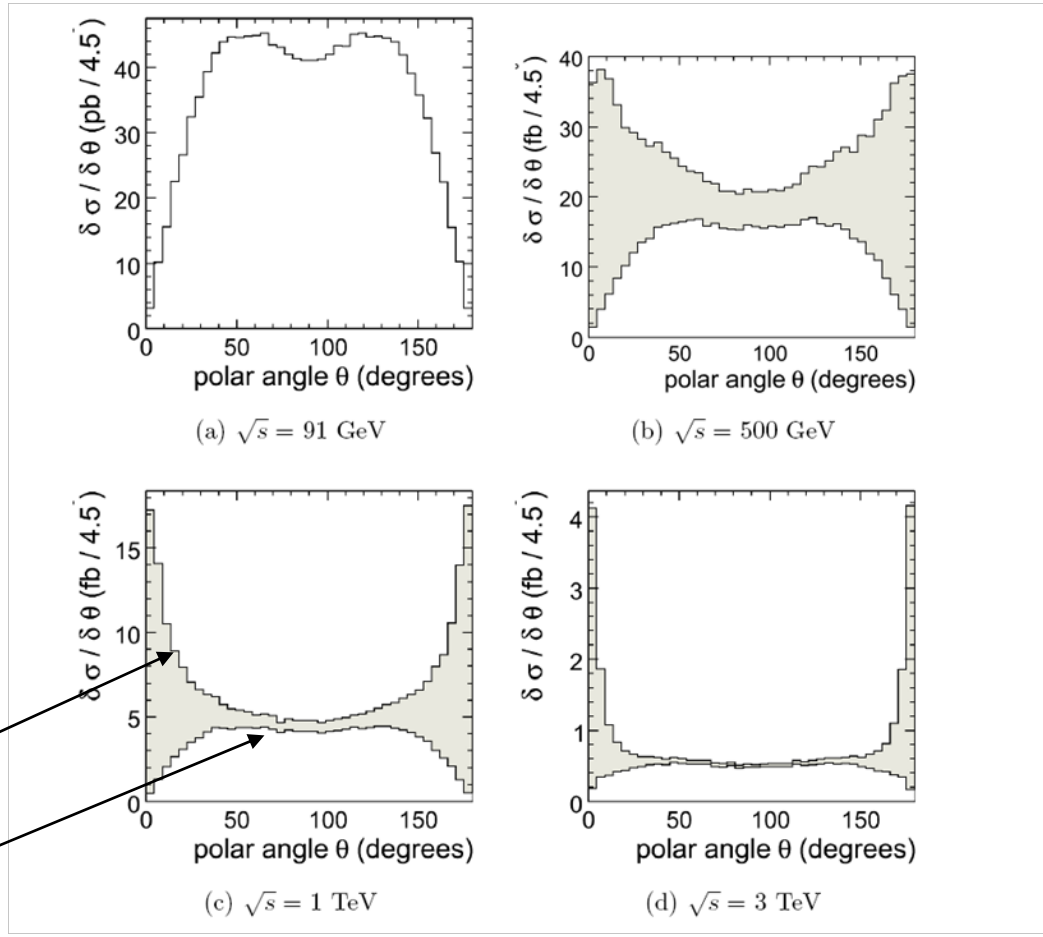


Forward tracking, physics case

$e^+e^- \rightarrow Z/\gamma^* \rightarrow f$ anti-f, from LEP to ILC to CLIC



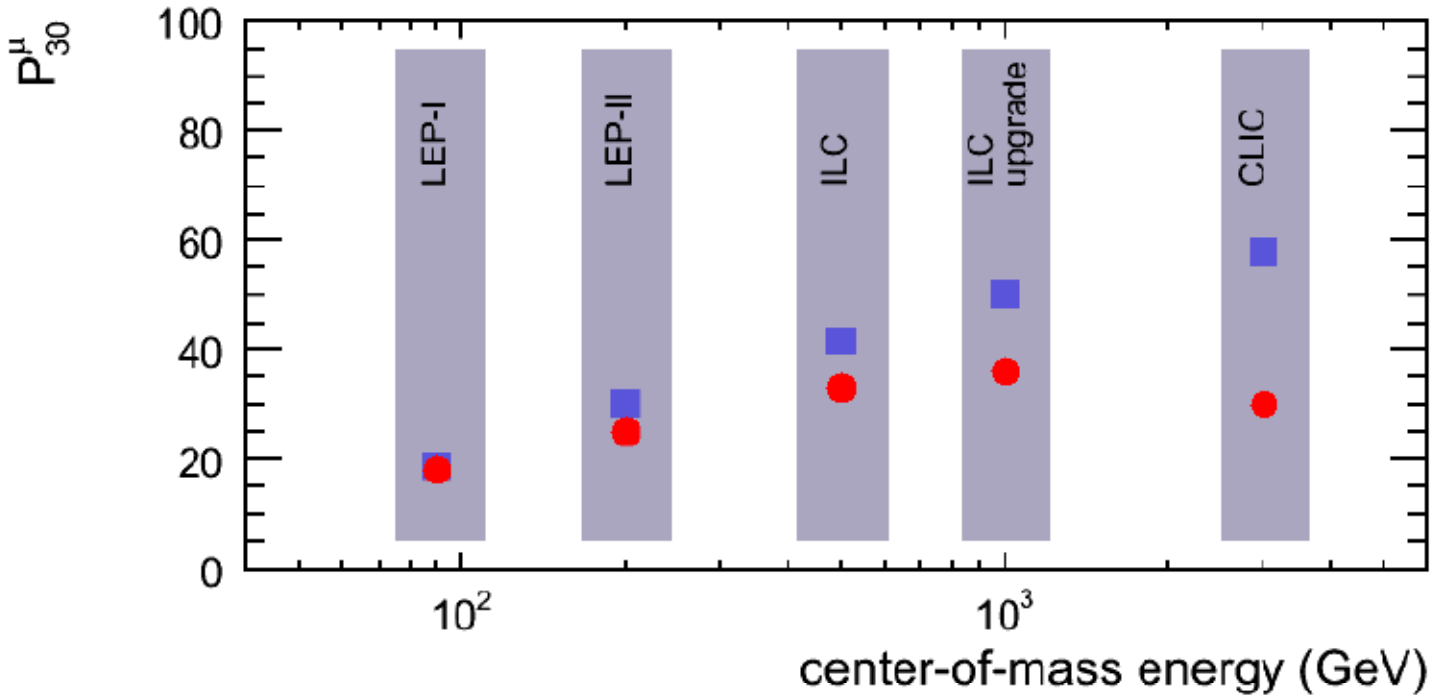


ISR included

$M(\mu^+\mu^-) < 2/5\ E_{beam}$

$M(\mu^+\mu^-)$ about E_{beam}

Forward tracking, physics case



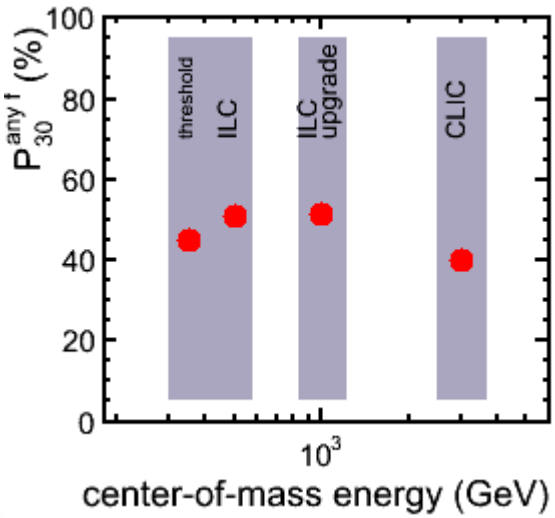
Squares: % fraction of muons with θ <30º or >150º

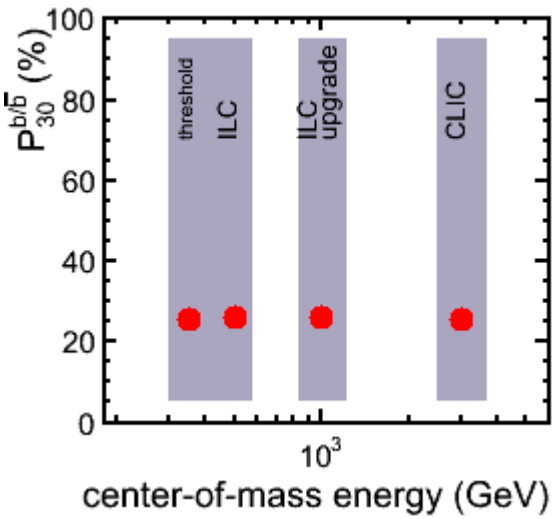
Circles: excluding θ <5º or >175º

Multi-fermion final states

With increasing center of mass energy, higher multiplicity processes increase, so the number of jets

Final states with many fermions
(like ordinary tt-events) are hardly ever contained in the central detector





Left: Fraction of events with at least one of the 6 fermions with θ>30º or >150º

Right: only b or anti-b considered

Multi-fermion final states

P_{30}	$\sqrt{s}$ = 500 GeV	$\sqrt{s}$ = 1 TeV	$\sqrt{s}$ = 3 TeV
One top at least	0.15	0.17	0.23
One b at least	0.22	0.25	0.25
Any fermion	0.51	0.51	0.4

- Thus, precise reconstruction of tt-bar events requires uniform jet energy resolution and lepton reconstruction performance over the full polar angle range
- Identification of very forward b-jet requires the vertex detector coverage to extend to very small angle

Supersymmetry

If LHC reveals the existence of Supersymmetry, an important role of LC is to precisely determine the SUSY parameters

Scalar lepton production can be of special relevance for the determination of the couplings $e - \tilde{e} - \tilde{\chi}^0$, $e^+ - e^- - \gamma$, *Z (predicted to be equal at tree level)*

MSSM has more than 100 free parameters. Simplifying assumptions are needed, as the CMSSM (*soft supersymmetry-breaking scalar and gaugino masses equal at some GUT input scale)*.

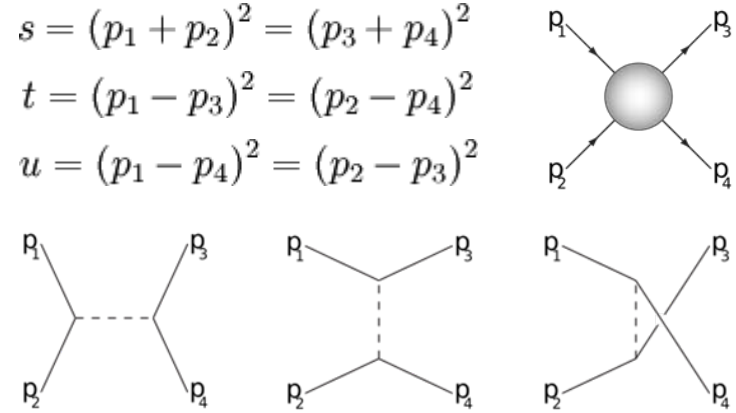
In that case, only 4 free parameters (A_0, $\tan\beta$, $m_{1/2}$, m_0). Benchmark scenarios, as the Snowmass Points and Slopes (hep-ph/0202233) are used here

The t-channel

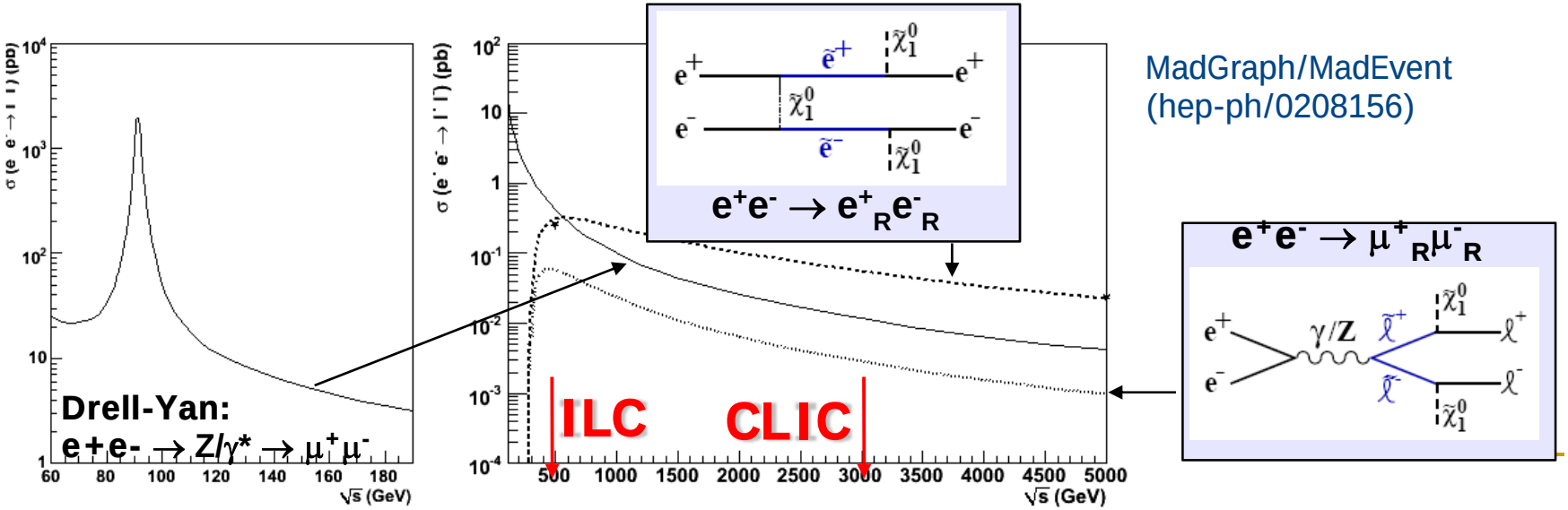
With increasing center-of-mass energy (from LEP-I to to LEP-II to ILC to CLIC)

the importance of the t-channel increases

$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$
$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$
$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$



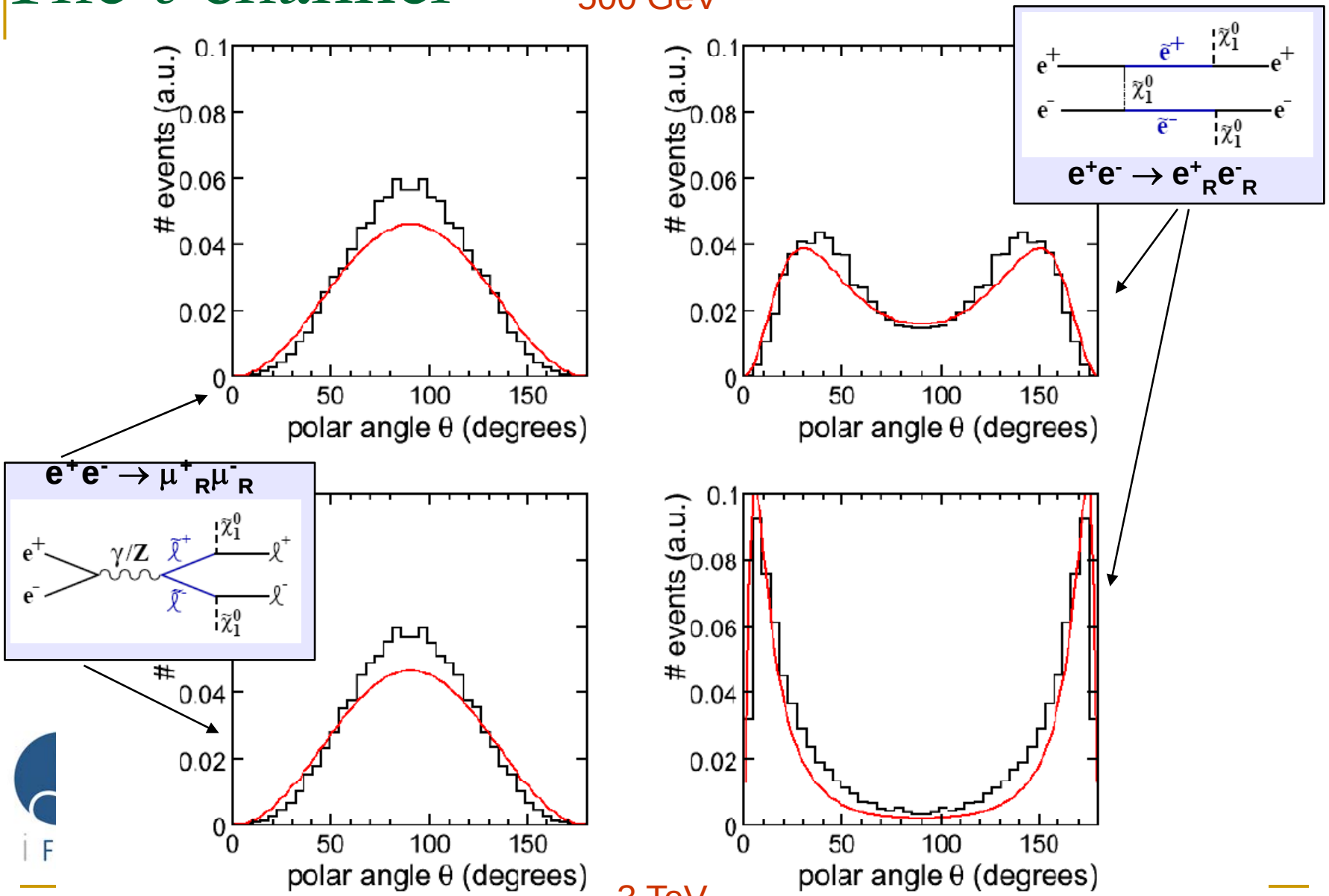
Example: scalar lepton production in SUSY (SPS benchmark point 1a)



MadGraph/MadEvent (hep-ph/0208156)

The t-channel

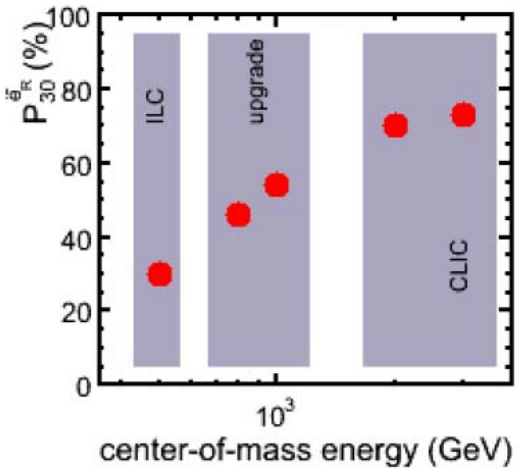
500 GeV



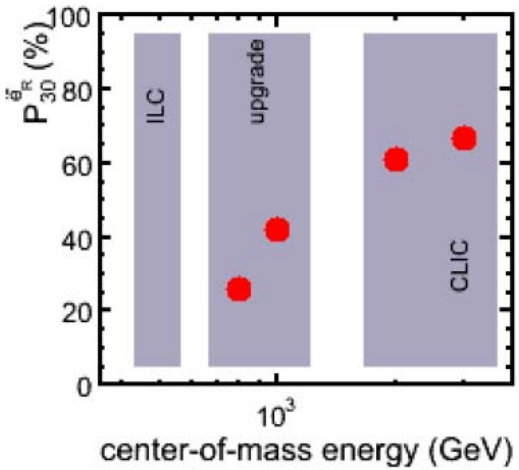
3 TeV

The t-channel

Benchmark point			$P_{30}^{\tilde{e}_R}$ (%) at LC with $\sqrt{s}$ =				
name	$m(\tilde{e}_R)$	$m(\tilde{\chi}_1^0)$	500 GeV	800 GeV	1 TeV	2 TeV	3 TeV
SPS1a	135	99	30	46	54	70	73
SPS2	1451	79	-	-	-	-	10
SPS3	178	160	20	38	48	63	70
SPS4	416	118	-	-	21	65	72
SPS5	192	119	21	47	57	70	71
SPS6	236	189	8	27	38	64	73
SPS7	127	161	25	35	43	65	73
SPS8	176	137	24	44	47	66	72
SPS9	303	175	-	26	42	61	67



(a) SPS1a



(b) SPS9

Two panel:

SPS1a, SPS9

Gauge boson pair production

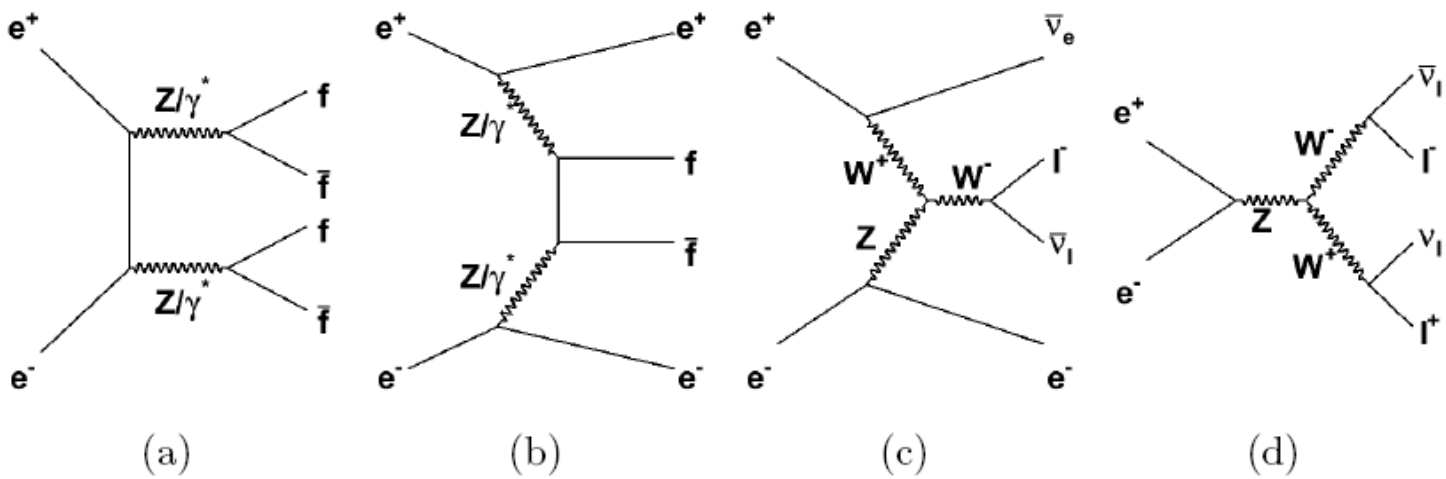
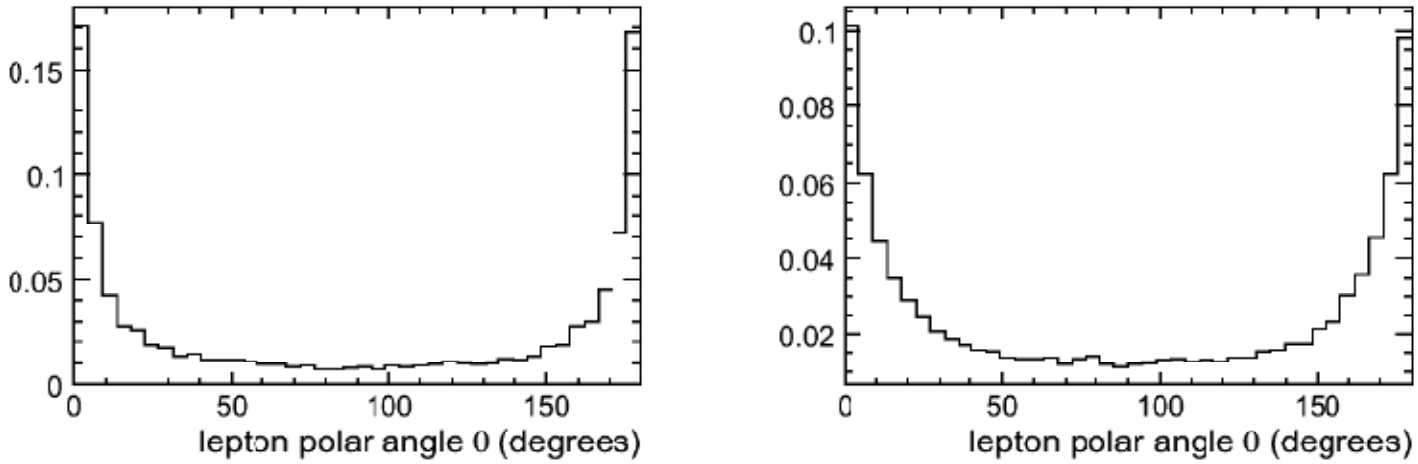


Fig. 9. Some of the Feynman diagrams for the $e^+e^- \to f\bar{f}f\bar{f}$ process (a) and (b) and for the $e^+e^- \to l^+l^-\nu_l\bar{\nu}_l$ process (c) and (d).

Important both:

- as source background for LC
- triple gauge boson vertex sensitive to new physics

Gauge boson pair production



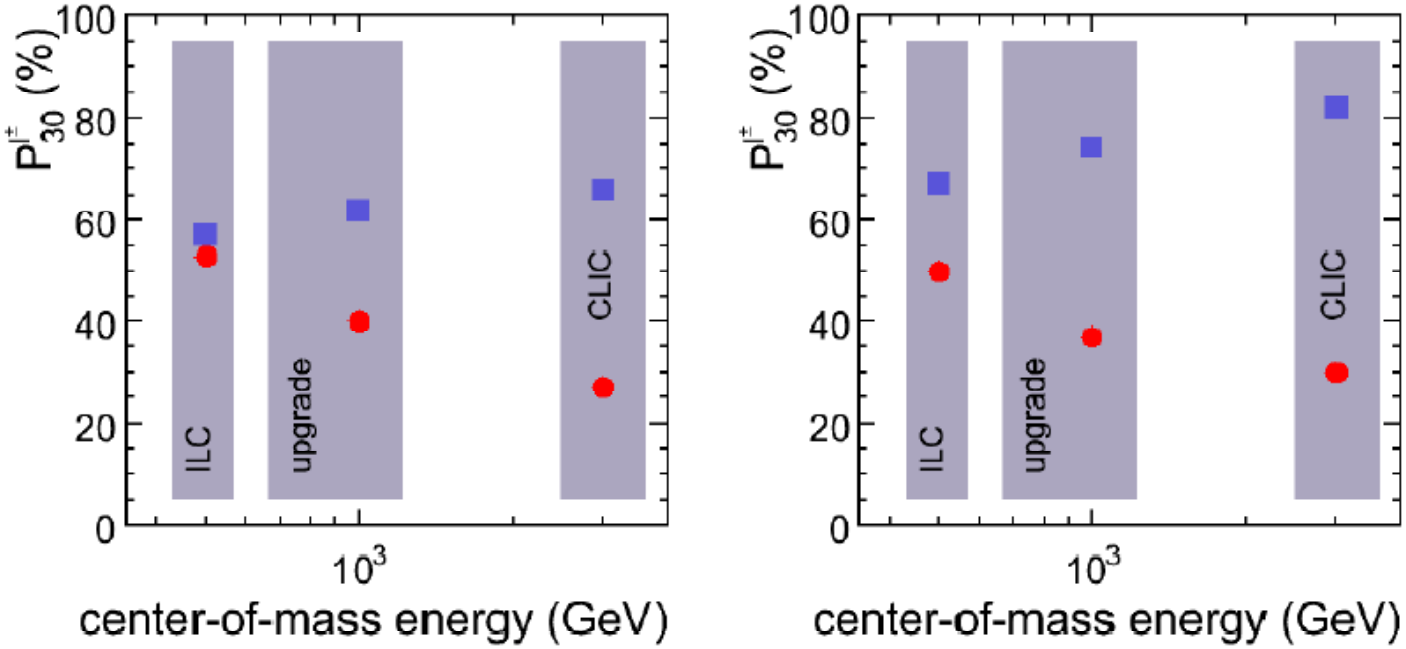
(a) $e^+e^- \to l^+l^-l^+l^-$ **$\sqrt{s}$ = 1 TeV** (b) $e^+e^- \to l^+l^-\nu_l\bar{\nu}_l$

p_T > 10 GeV, θ>1º or <179º

(The forward/backward fraction is more important for electrons/positrons.

Also the fraction of events with electrons and positrons increases from 0.5, at 500 GeV, to 2/3 at 1 TeV)

Gauge boson pair production



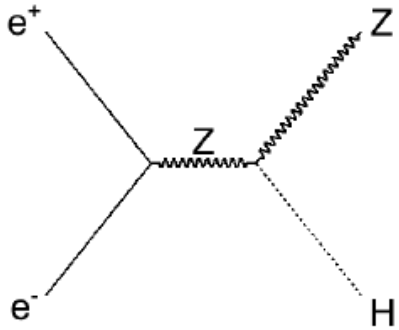
(a) $l^+l^-\nu\bar{\nu}$ (b) $l^+l^-l^+l^-$

Squares: fraction of charged leptons with θ < 30º or > 150º

Circles: excluding θ <5º or >175º

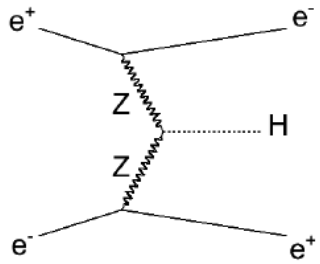
→ The fraction of WW and ZZ fully contained in the central detector is negligible, needed precise lepton reconstruction at low polar angle, mainly for electrons

Higgs boson production

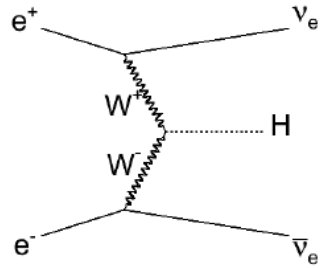


(a) Higgs-strahlung

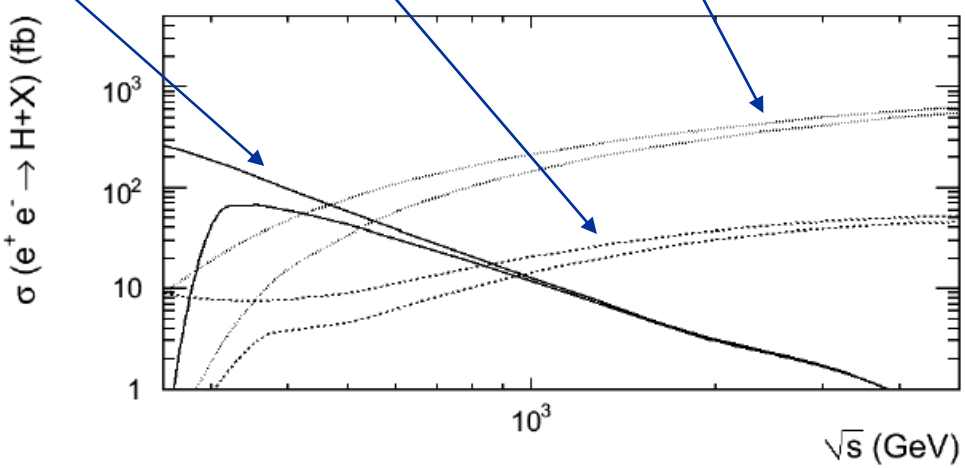
Z → μ+μ-, in the recoil analysis, P_{30}^{μ} =14% at E_{cm}=250 GeV



(b) Z-boson fusion



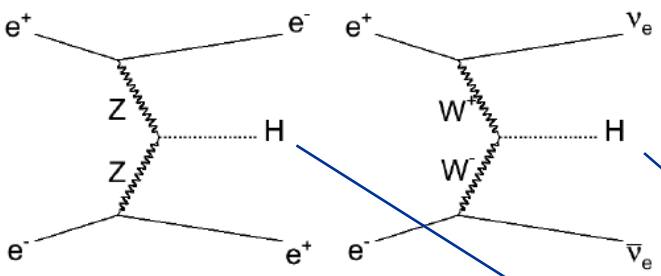
(c) W-boson fusion



M_H= 120 GeV (upper)

200 GeV (lower)

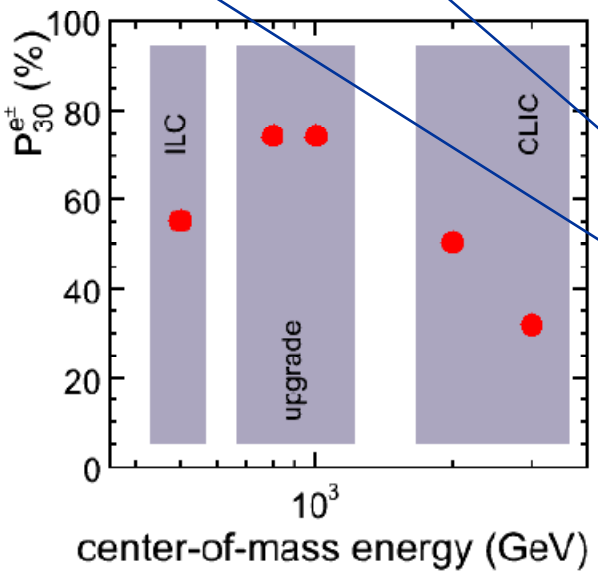
Higgs boson production



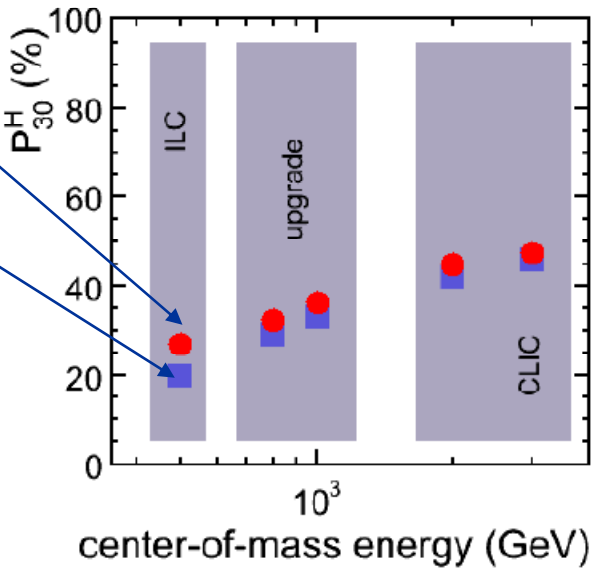
(b) Z-boson fusion (c) W-boson fusion

Vector boson fusion dominant beyond 500 GeV

Z-boson fusion allows use of recoil method



(a) electrons



(b) Higgs boson

Physics case: Conclusions

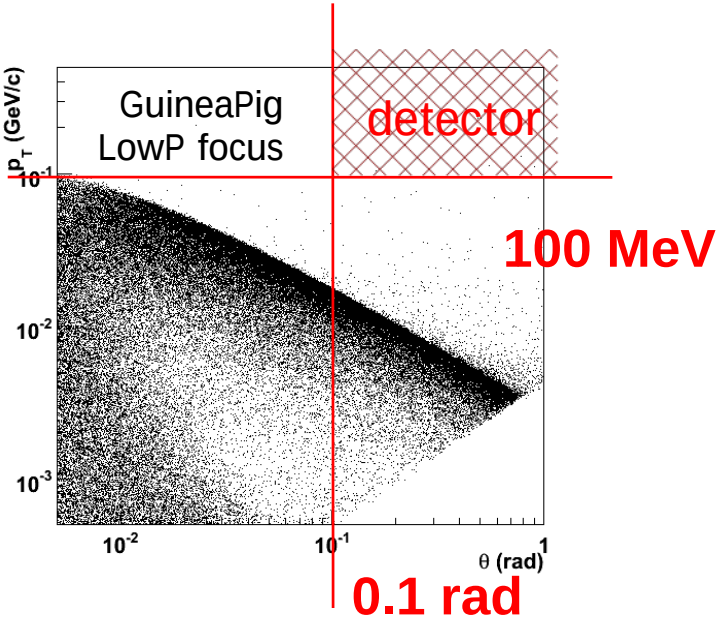
- $e^+e^- \rightarrow Z/\gamma^* \rightarrow l^+l^-$ at the Z-pole has predominantly central final products. But ISR causes increasing fraction of forward-backward at larger center-of-mass energies
- 4, 6,and even 8-fermion abundantly produced with increasing center-of-mass energies. As e.g. *t anti-t → W^+bW^-anti-b,* rarely fully contained in the central detector
- Scalar electron production has a *strong t-channel contribution*, with final state electrons peaking in the forward-backward direction
- Final state fermions in **di-boson production** peaking in the forward-backward direction
- The same for ***Higgs*** boson production through vector-boson fusion
- Forward-backward region specially important for final states with electrons, but not only then
- Other channels not discussed here make a good case for forward tracking

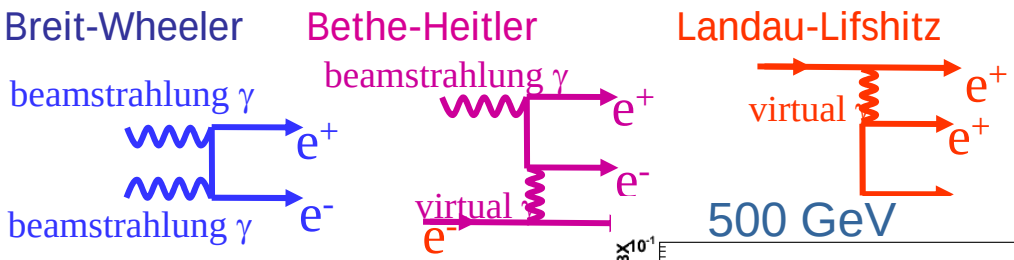
Forward tracking: Challenges

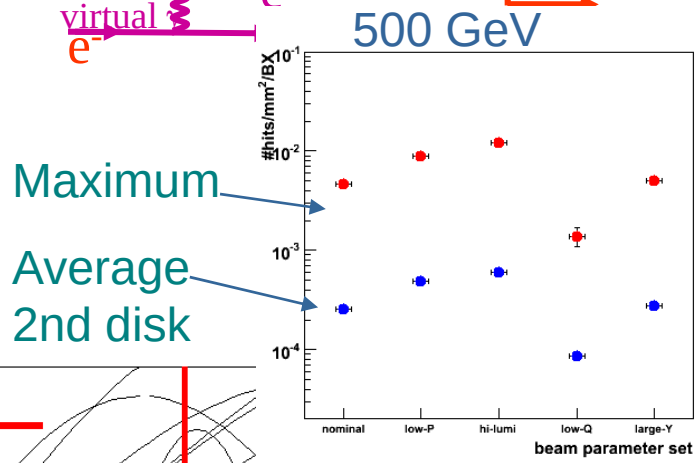
Why is forward tracking challenging?

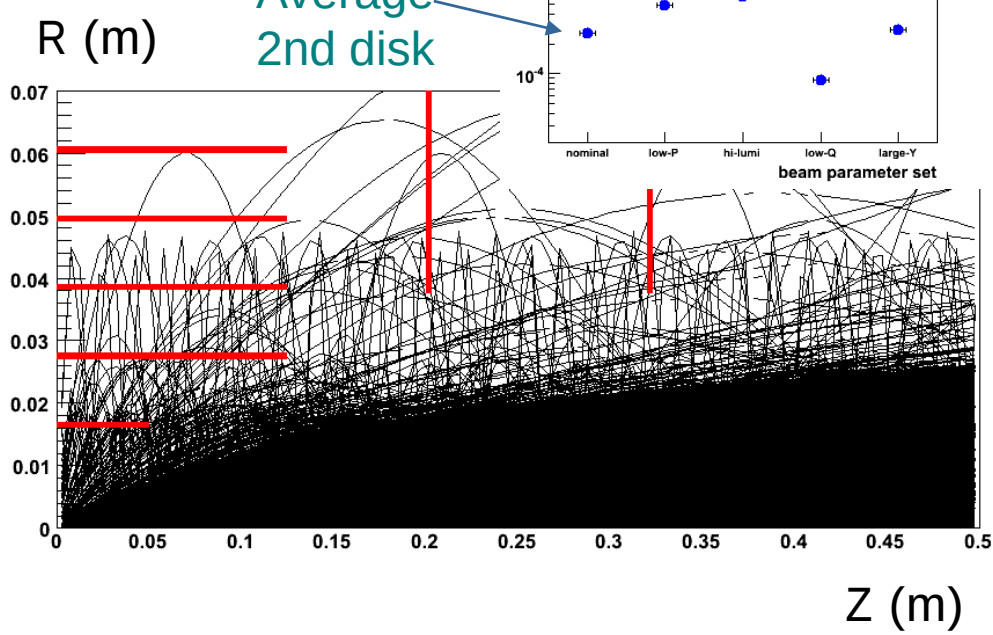
The material!
Hermetic coverage
Significant background at smallest radii
The unfavorable orientation of the magnetic field
Abundant low momentum tracks – pattern recognition

Environment: background level



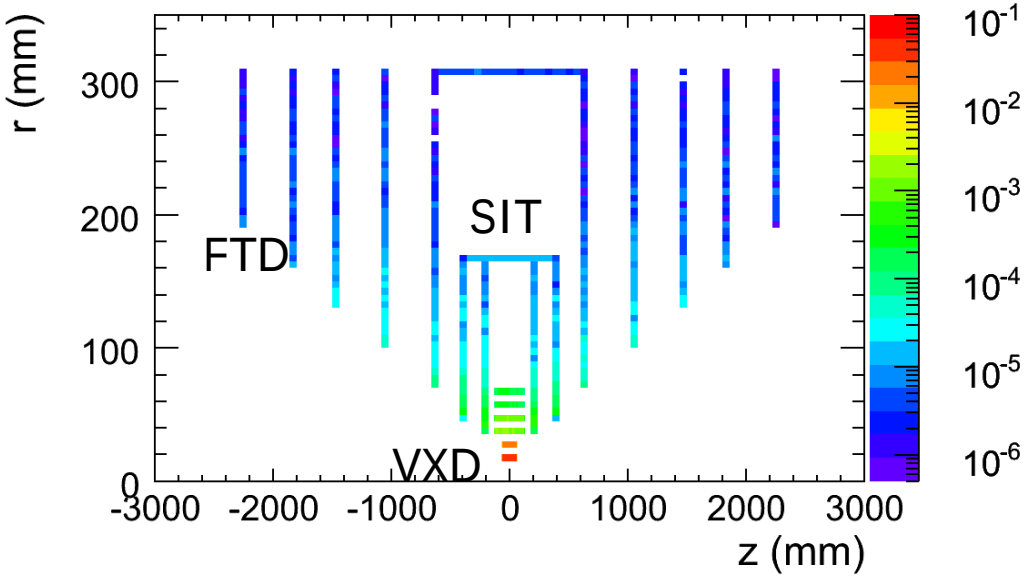






Incoherent e^+e^- pair production off beamstrahlung photons produces a very large number of electrons and positrons each BX. The large majority is soft and/or emitted at low angle and are trapped in the "accumulation zone"

Pair background



GEANT4 simulation of GUINEA-PIG events by Toni Harlin
(thanks also to A. Vogel and Katarzyna Wichman)

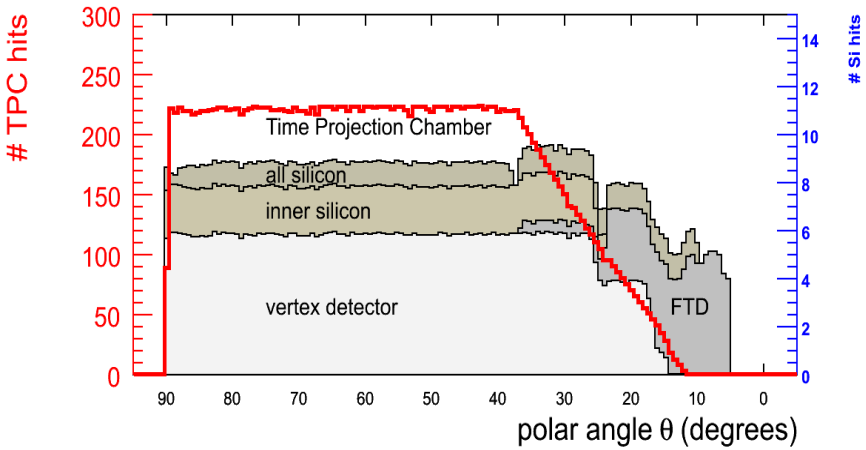
Hit density
(#/mm^2/BX)

detector	min	typical	max
VXD 1		4×10^{-2}	
VXD 6		3×10^{-4}	
FTD1	$<10^{-5}$	1×10^{-4}	2×10^{-3}
FTD7	5×10^{-6}	7×10^{-6}	9×10^{-6}
SIT 1		3×10^{-5}	
SIT 2		3×10^{-6}	

Hit density = number of GEANT4 energy deposits per unit area per ILC bunch crossing
Does not take into account the number of channels fired by a single hit

	Typical area sensitive elements	time resolution:
pixel:	25 x 25 μm^2 = 6.25 x 10^{-4} mm^2	100 BX
strips:	50 μm x 10 cm = 5 mm^2	1 BX

Pattern recognition



Clearly, 6-15 degrees is weakest region in ILD in terms of number of measurements. And remember:

- non-negligible pair background
- First disks close to interaction point (jets!)
- Abundant low-momentum tracks (loopers)

Ongoing study (Carmen Iglesias): evaluate hit densities in tt events per disk and per petal (subdividing disks in 8,20 or 16 single-wafer segments)

- Average #hits/disk falls by a factor 3 due to reduced angular coverage of outermost disks
- Average #hits/petal falls even faster (outermost disks divided in 16 segments)

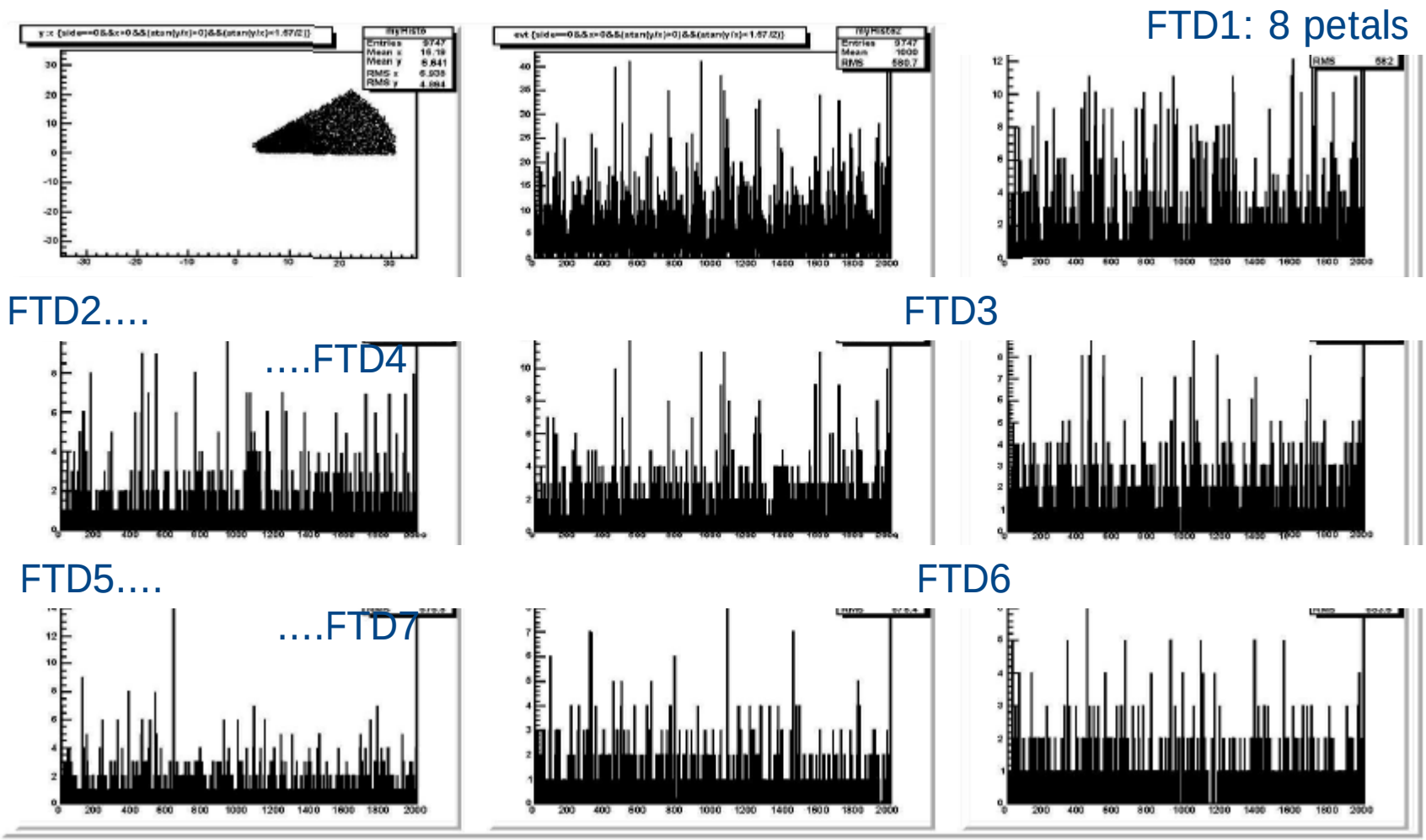
It is important to evaluate the hit density locally (jets)

- A significant probability to receive several hits/petal remains even in the outermost disk

	#hits/disk		#hits/petal	
disk	avg.	peak	avg.	peak
FTD1	9	37	1.1	12
FTD2	5	27	0.6	10
FTD3	8	36	0.4	10
FTD4	6	29	0.3	9
FTD5	5	25	0.3	10
FTD6	4	23	0.2	5
FTD7	3	28	0.2	4

Pattern recognition

Carmen Iglesias (Santiago de Compostela): #hits/petal versus event number (2000 tt events) → stereo meas. clearly needed

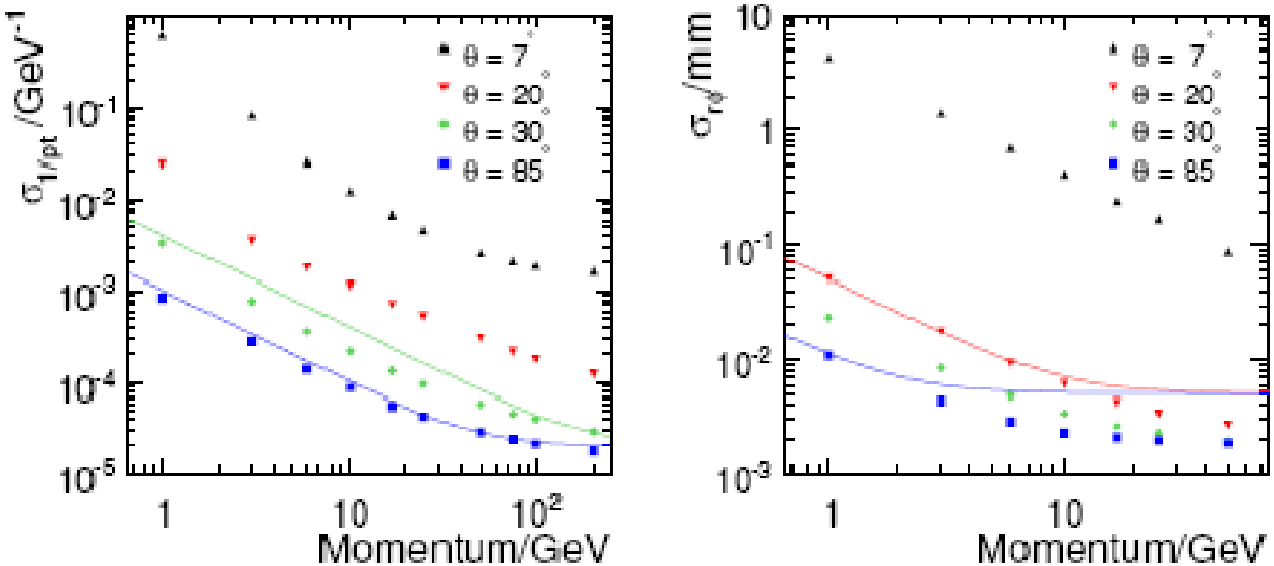


Tracking performance

TESLA ref for low polar angle :
$\sigma(1/p_T) = 1.8\times10^{-3} \oplus 1.3\times10^{-2}/\ p_T$ (GeV^{-1})

ILD: We are nowhere near the goal, and far from the performance of the central tracker (figure lines: $\sigma(1/p_T) = 2.0\times10^{-5} \oplus 1.0\times10^{-3}/\ (p_T \sin\theta)$(GeV^{-1}),
$\sigma_{r\phi}$ = 5 μm ⊕ 10 μm/ ($p_T \sin\theta$))!!

Most of this is plain geometry: unfavorable orientation of the magnetic field ($\sigma(1/p_T)$), and large distance of the FTD1 to the interaction point ($\sigma_{r\phi}$)



Momentum resolution

ILD momentum resolution

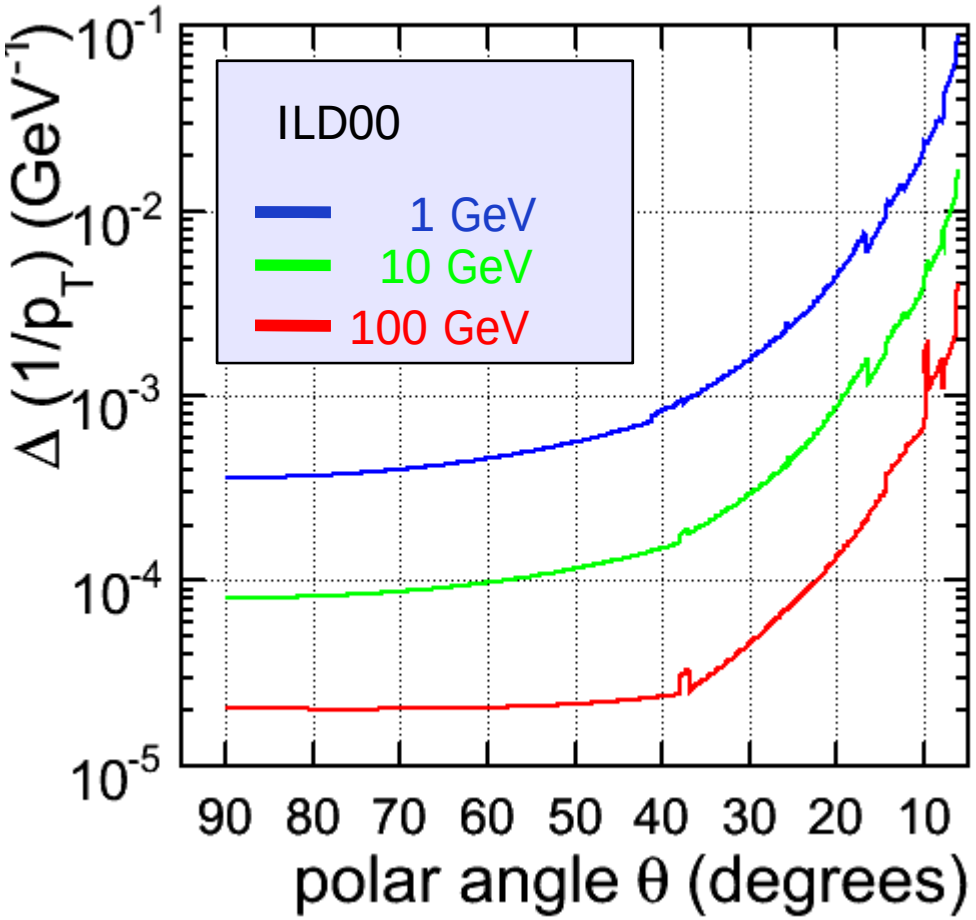
Single muons in ILD00

- Performance ~ stable down to 36º
- Steep loss between 6-36º

worse forward performance is the result of a combination of

(a) magnetic field orientation (inevitable within 4π detector geometry)

(b) loss of # of measurements in TPC



Momentum resolution

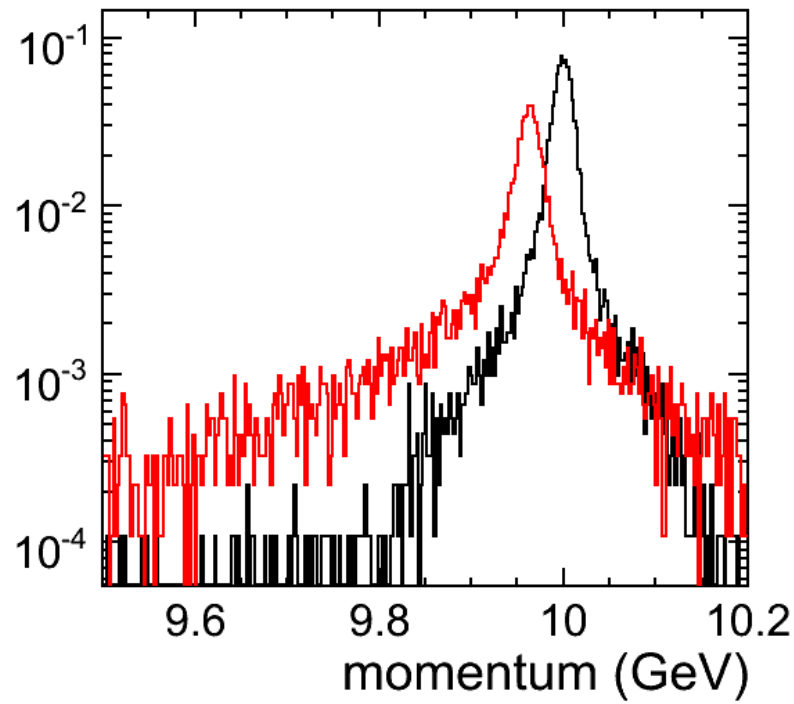
Momentum resolution for electrons (remember t-channel!!)

- Ongoing study (Jordi Duarte, IFCA): generate single-electron samples (private, but available for those interested)
- compare tracker-only momentum resolution of single electrons with the LOI results for muons
- Understand tracker-parameter dependence
  → material!

ILD00 full simulation

10 GeV μ^-

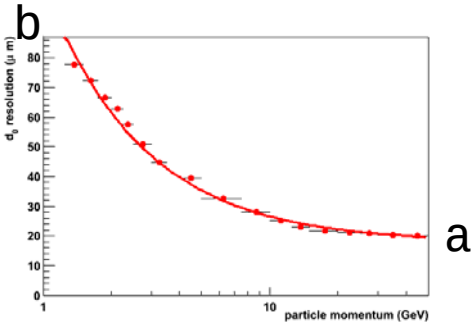
10 GeV e^-



Impact parameter resolution

$$\sigma_{IP} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

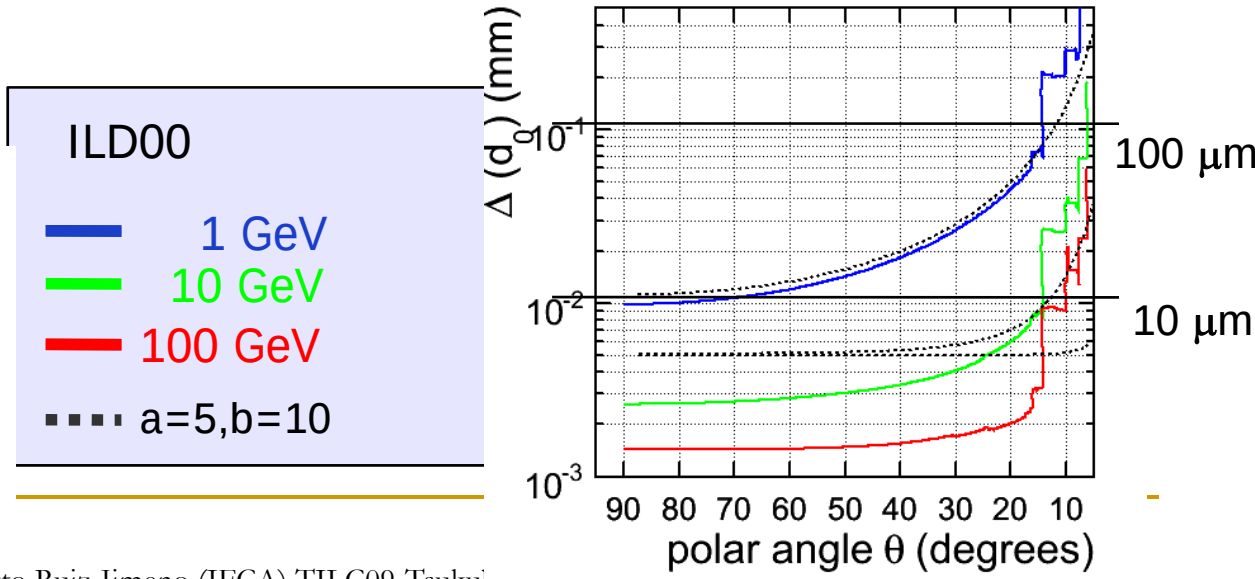
	a (μm)	b (μm . GeV)
LEP	25	70
SLD	8	33
LHC	12	70
ILC	5	10



Unprecedented precision
(small pixels, 20x20 μm^2)

Strongly reduce the multiple Coulomb scattering term
(material: 0.1 % X_0 / layer ~ 100 mm Si)

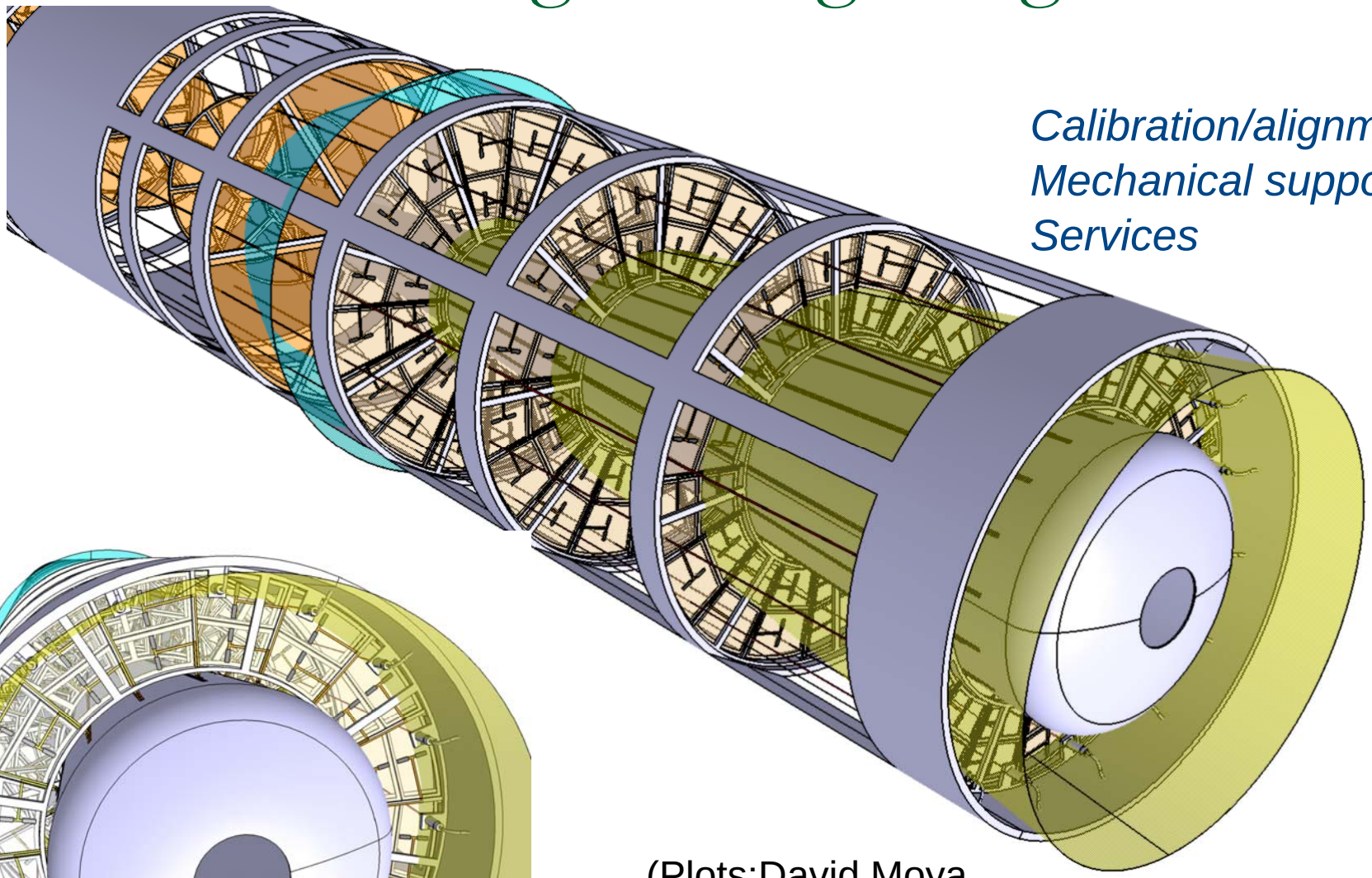
ILD vertexing performance
central: a~1.7 mm
forward:
performance significantly worse than extrapolation of barrel formula with a=5,b=10



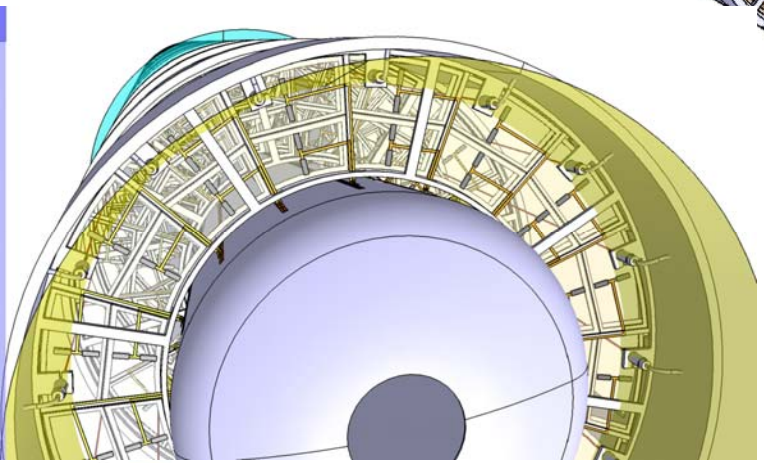
R&D on Detectors

- The bulk of R&D detector activity focused on silicon Traking and vertexing.
- Covering:
  - R&D on sensors: DEPFET pixels, 3D sensors, thinned microstrips, semitransparent microstrips.
  - R&D on FE electronics, development of DSM r/o chip.
  - R&D on mechanics: deformation and thermal analysis.
- So far, “forward physics” oriented.

Towards an engineering design



Calibration/alignment
Mechanical support
Services



(Plots:David Moya (IFCA))

Backup

	$\sigma_{r-\phi}/\mu m$	$\sigma_z/\mu m$		$\sigma_{r-\phi}/\mu m$	$\sigma_z/\mu m$
VTX	2.8	2.8	FTD	5.8	5.8
SIT/SET	7.0	50.0	ETD	7.0	7.0
TPC	$\sigma^2_{r\phi} = 50^2 + 900^2 \sin^2\phi + ((25^2/22) \times (4/B)^2 \sin\theta)\, x\ \mu m^2$ $\sigma^2_z = 40^2 + 8^2 \times x\ \mu m^2$				

TABLE 3.1-1
Effective point resolutions used in the digitisation of the MC samples.

SIT characteristics (current baseline = false double-sided Si microstrips)					
Geometry			Characteristics		Material
R[mm]	Z[mm]	$\cos\theta$	Resolution R-ϕ[μm]	Time [ns]	RL[%]
165	371	0.910	R: σ=7.0,	307.7 (1538)	0.65
309	645	0.902	z: σ=50.0	σ=80.0	0.65
SET characteristics (current baseline = false double-sided Si microstrips)					
Geometry			Characteristics		Material
R[mm]	Z[mm]	$\cos\theta$	Resolution R-ϕ[μm]	Time [ns]	RL[%]
1833	2350	0.789	R: σ=7.0,	307.7 (1538)	0.65
1833	2350	0.789	z: σ=50.0	σ=80.0	0.65
FTD characteristics (current baseline = pixels for first 3 disks, microstrips for the other 4))					
Geometry			Characteristics		Material
R[mm]	Z[mm]	$\cos\theta$	Resolution R-ϕ[μm]		RL[%]
39-104	220	0.985-0.902			0.25
49.6-164	371.3	0.991-0.914			0.25
70.1-308	644.9	0.994-0.902			0.25
100.3-309	1046.1	0.994-0.959	σ=7.0		0.65
130.4-309	1447.3	0.995-0.998			0.65
160.5-309	1848.5	0.996-0.986			0.65
190.5-309	2250	0.996-0.990			0.65
ETD characteristics (current baseline = single-sided Si micro-strips, same as SET ones)					
Geometry			Characteristics		Material
R[mm]	Z[mm]	$\cos\theta$	Resolution R-ϕ[μm]		RL[%]
419.3-1822.7	2426	0.985-0.799	x:σ=7.0		0.65
419.3-1822.7	2428	0.985-0.799	y:σ=7.0		0.65
419.3-1822.7	2430	0.985-0.799	z:σ=7.0		0.65

TABLE 4.2-3
The projected values of basic SIT, SET, FTD, and ETD characteristics.

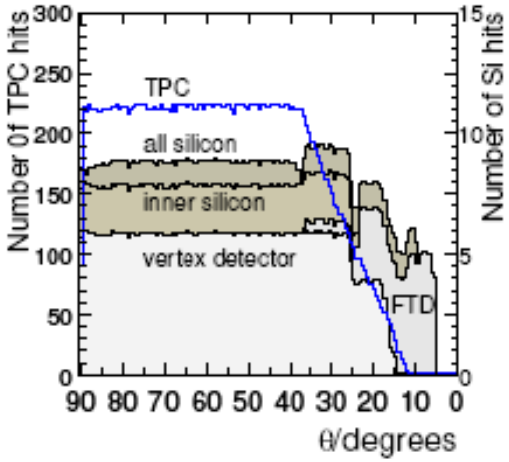
parameter	N	bunch spacing	&beta $_x$	&beta $_y$	&gamma $_x$	&gamma $_y$	&sigma $_z$
unit	(10^{10})	(ns)	(mm)	(mm)	(mm × rad)	(mm × rad)	(&mu m)
nominal	2.05	369.2	20.0	0.4	10.0	0.04	300
high-lumi	2.05	369.2	11.0	0.2	10.0	0.03	150
low-power	2.0	480.0	11.0	0.2	10.0	0.036	200
low-Q	1.0	189.2	11.0	0.2	10.0	0.03	200
large-Y	2.0	369.2	11.0	0.6	10.0	0.08	500

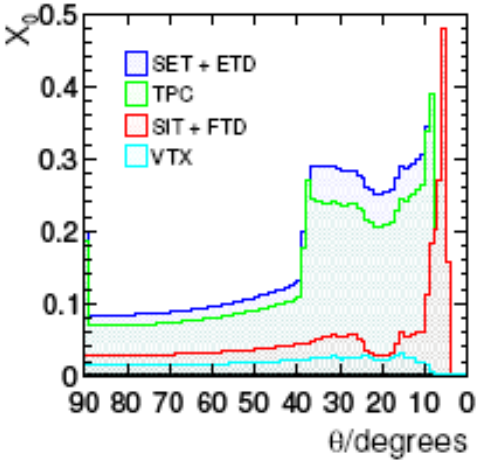
Table: final focus parameters in different scenarios for a center-of-mass energy of 500 GeV. For details, see RDR.

parameter	N	bunch spacing	&beta $_x$	&beta $_y$	&gamma $_x$	&gamma $_y$	&sigma $_z$
unit	(10^{10})	(ns)	(mm)	(mm)	(mm × rad)	(mm × rad)	(&mu m)
nominal	2.0	369.2	30.0	0.3	10.0	0.04	300
high-lumi	2.0	369.2	10.0	0.2	10.0	0.03	150
low-power	2.0	480.0	12.0	0.2	10.0	0.035	200
low-Q	1.0	189.2	15.0	0.2	10.0	0.03	150
large-Y	2.0	369.2	12.0	0.6	12.0	0.08	600

Table: final focus parameters in different scenarios for a center-of-mass energy of 1 TeV.

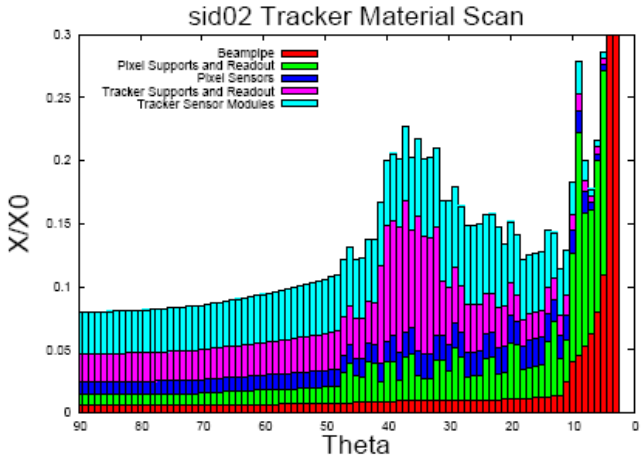
Challenges : Coverage and material budget

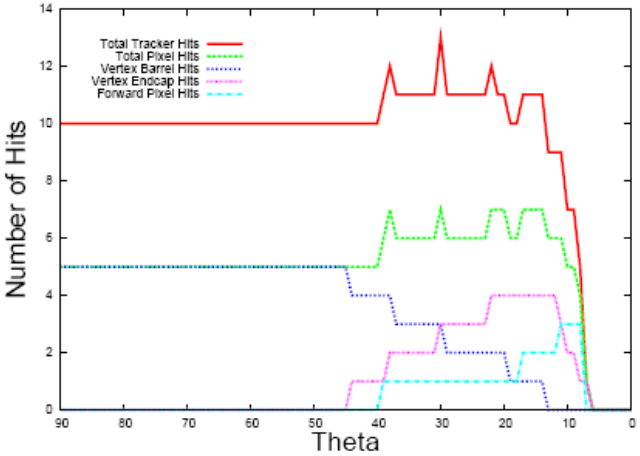




ILD: FTD provides up to a maximum of 5 measurements at small polar angle

SiD: overall more than 5 hits at small polar angle





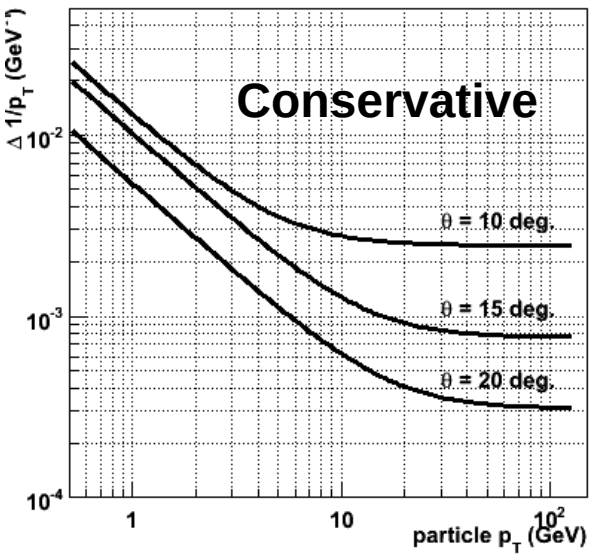
Tracking performance

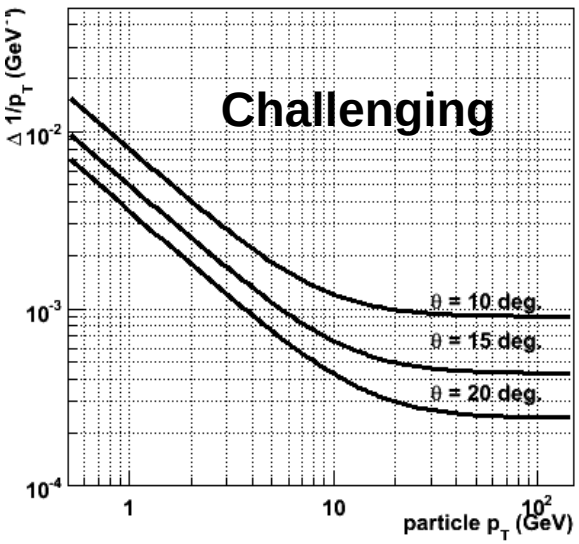
Compare the reference set-up to a more challenging detector:

reduce space point resolution ($R\phi$) from 10 to 5 μm
reduce the material from 1.2 % X_0 to 0.12 % X_0 (innermost disks)
reduce the material from 0.8 % X_0 to 0.4 % X_0 (outermost disks)

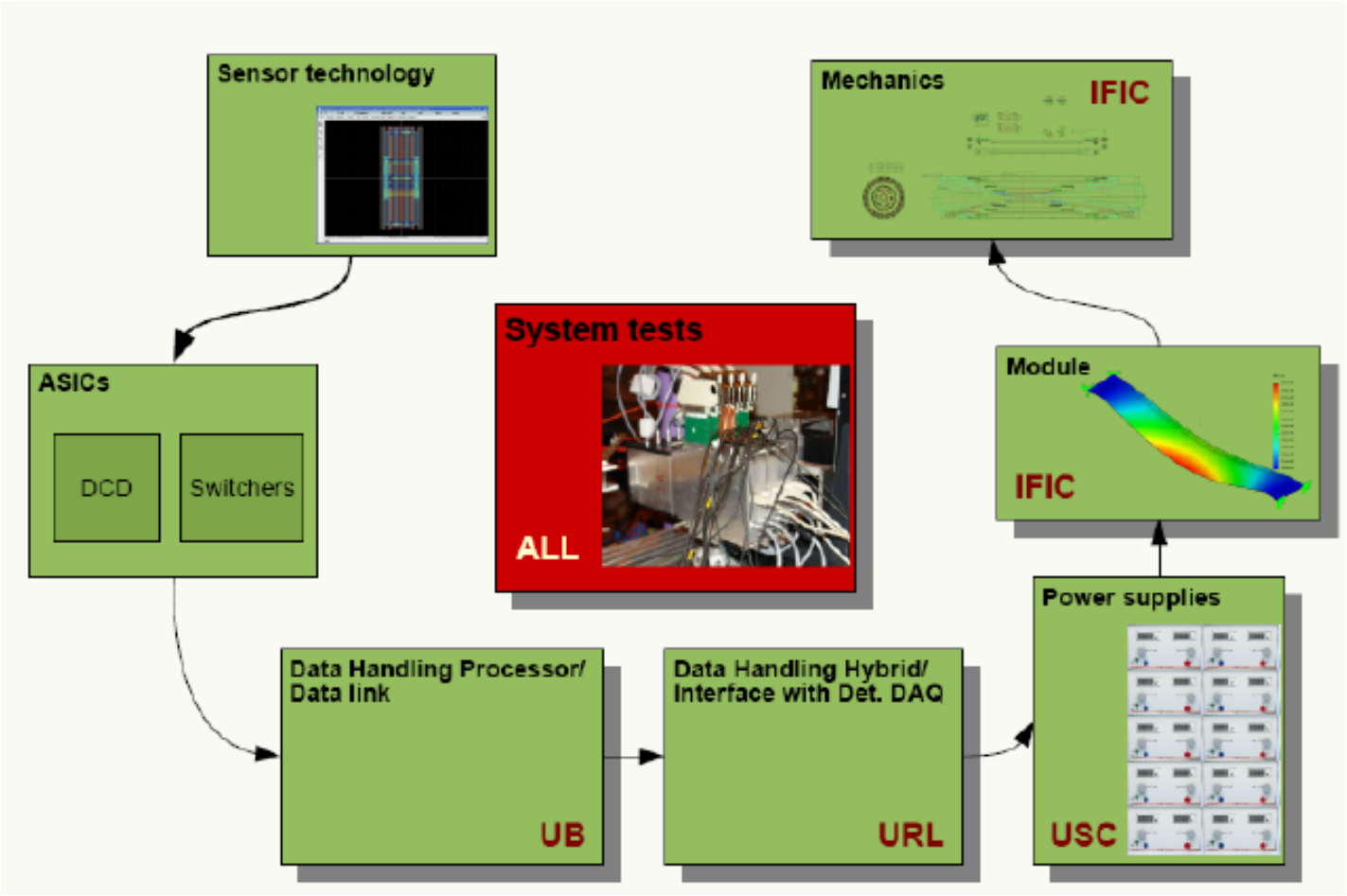
Reference (TESLA) set-up $\sigma(1/p_T) = 1.8\times10^{-3} \oplus 1.3\times10^{-2}/\ p_T$

Challenging $\sigma(1/p_T) = 0.9\times10^{-3} \oplus 0.8\times10^{-2}/\ p_T$

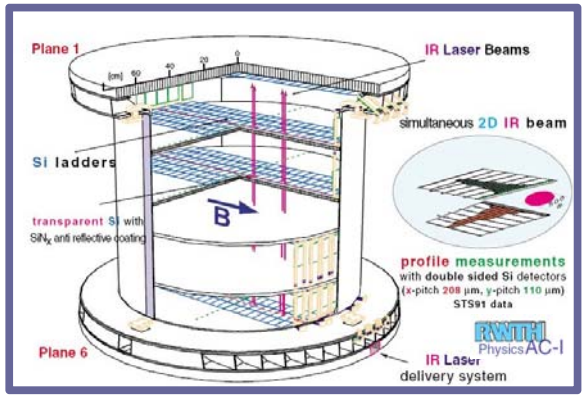




Pixels - DEPFET IFIC, UB, URL, USC



Microstrips - IR Transparent CNM, IFCA



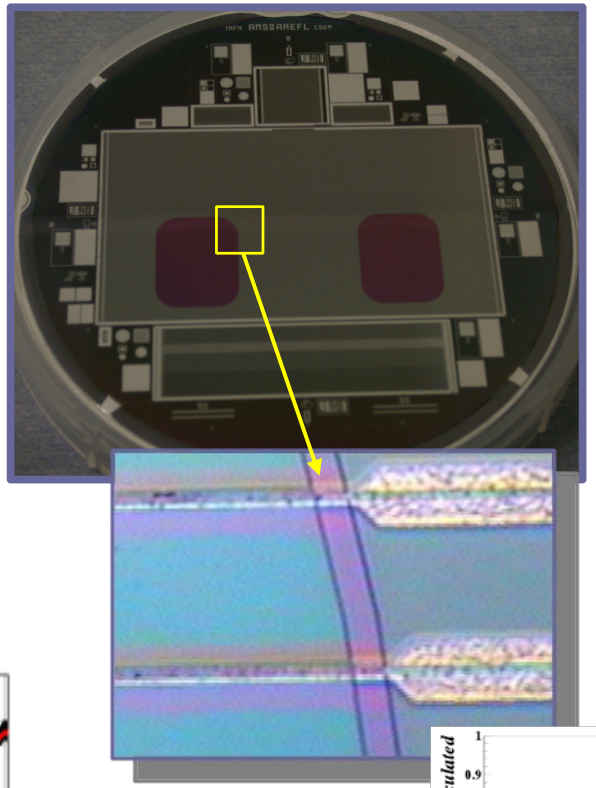
AMS-01 innovation (W. Wallraff)

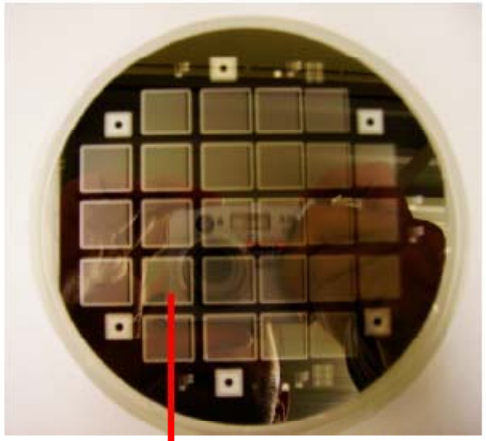
λ = 1082 nm

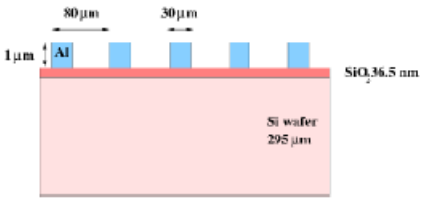
IR "pseudotracks"

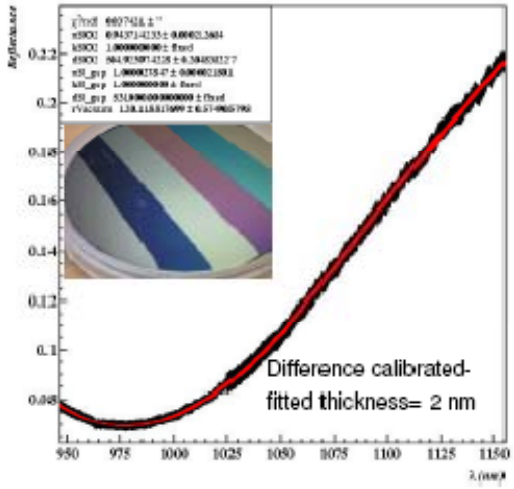
1-2 µm accuracy obtained

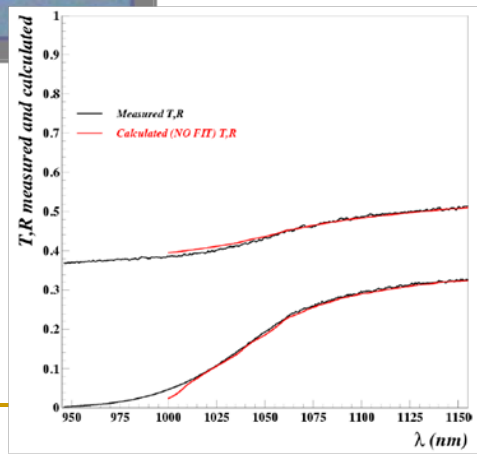
Transmittance~ 50%











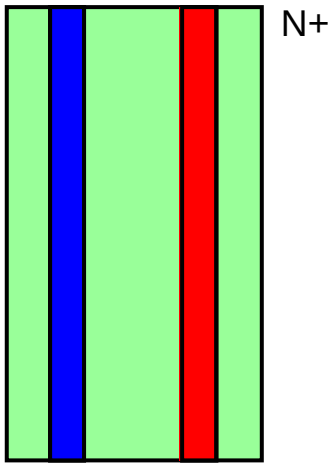
Reflectance and transmittance of wafer 5 matched. No fits involved!!

Compatible with 45 nm roughness of Al surface

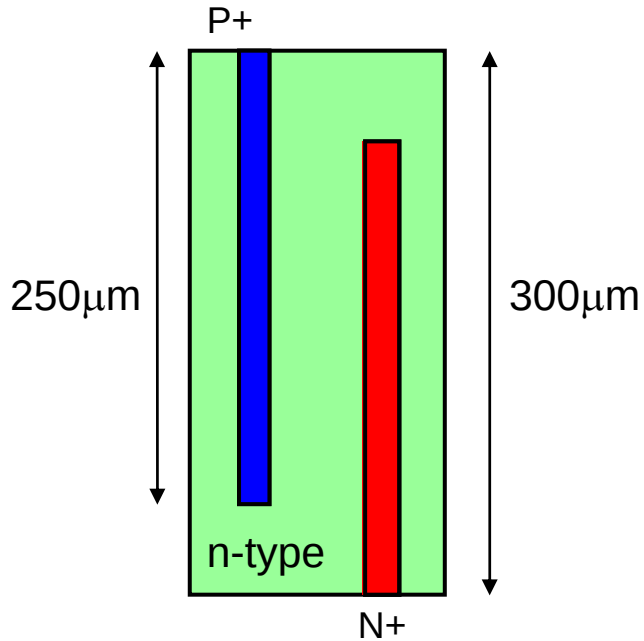
Is this real? We need to measure the wafer roughness. I think it is possible to be done at CERN.

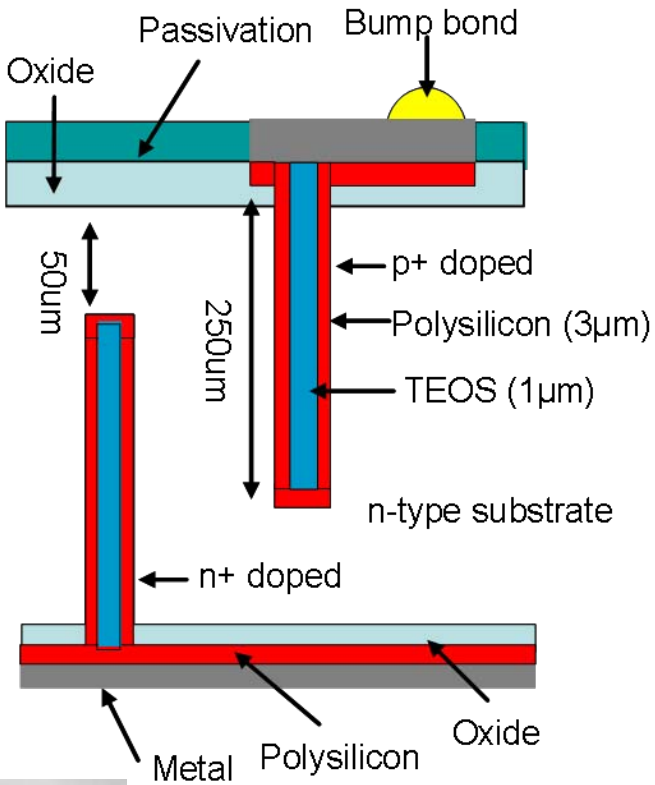
3D sensors – CNM, UB

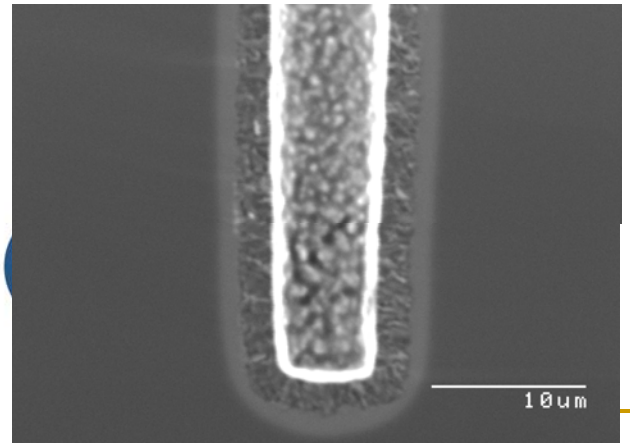
Full 3D

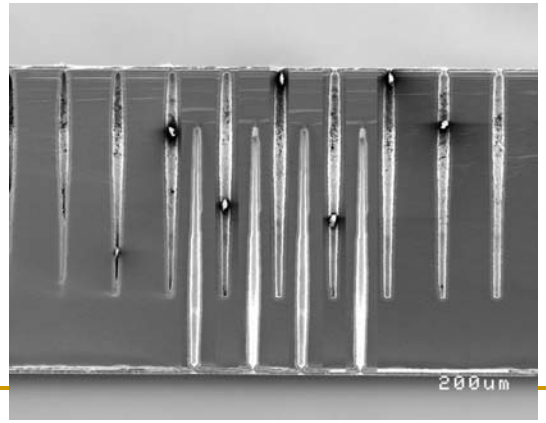


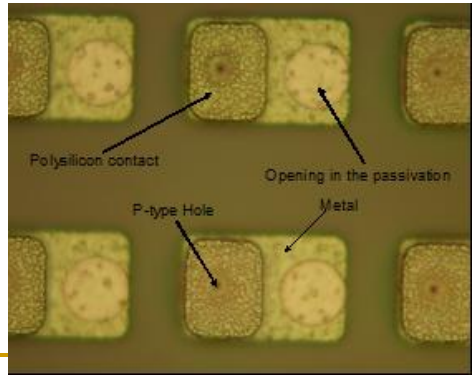
Double–sided 3D









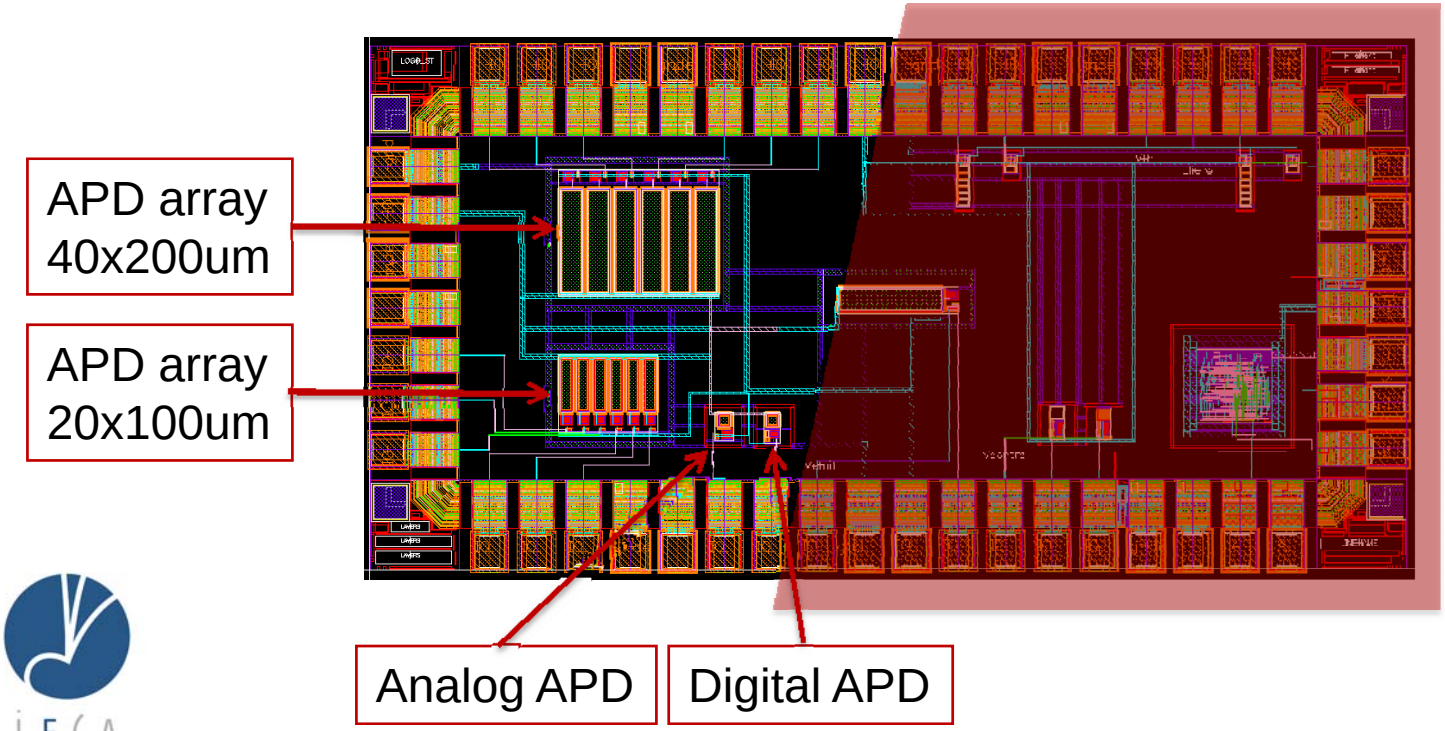


Digital GAPD– CNM, UB, URL

...on design of sensors for future trackers

Integrate electronics and sensors using industrial CMOS processes
Reduce analog readout electronics by using high sensitivity devices

STMicroelectronics CMOS 130nm

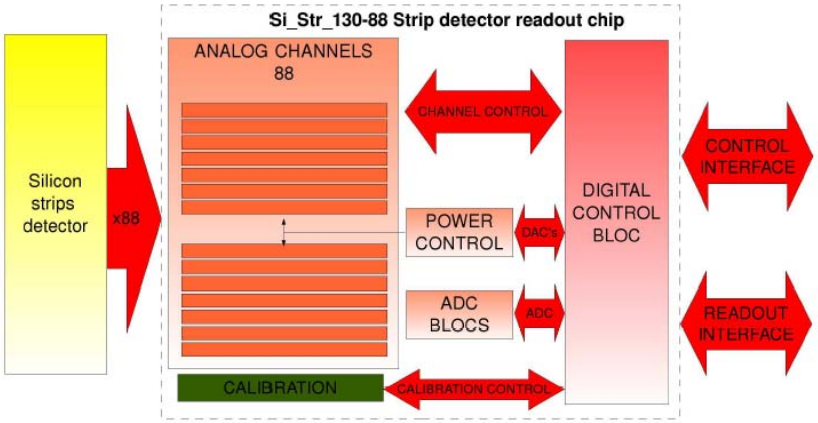


R/O Electronics – CNM, UB, URL

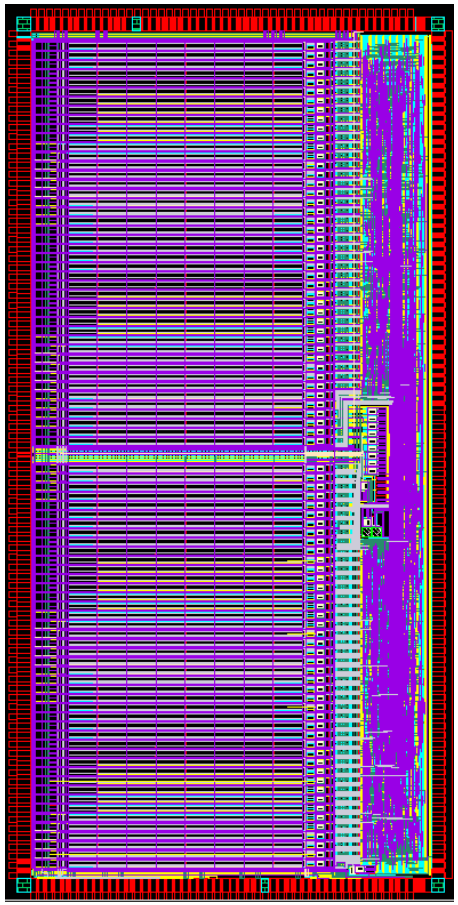
UMC CMOS 130nm
ASIC received first week of October'08

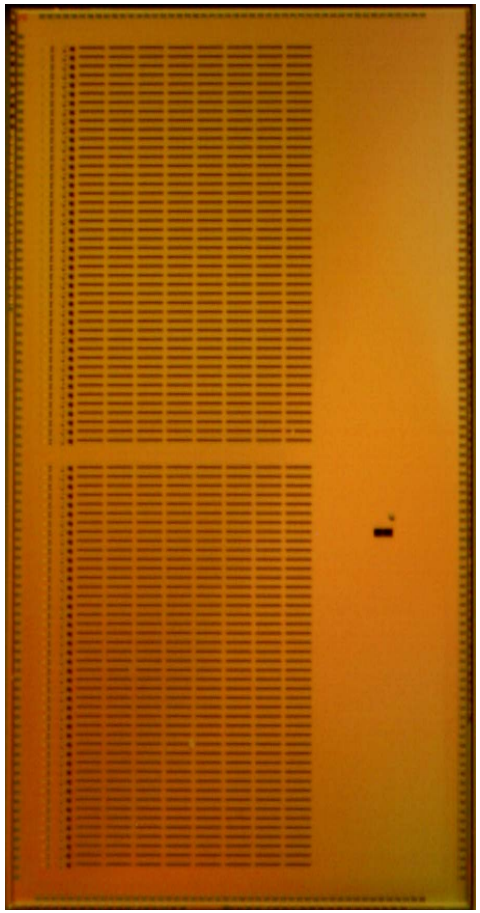
Mixed signal ASIC for readout of Si strip sensors in ILC

Analog part designed by IN2P3
Digital part designed by UB



88 channels

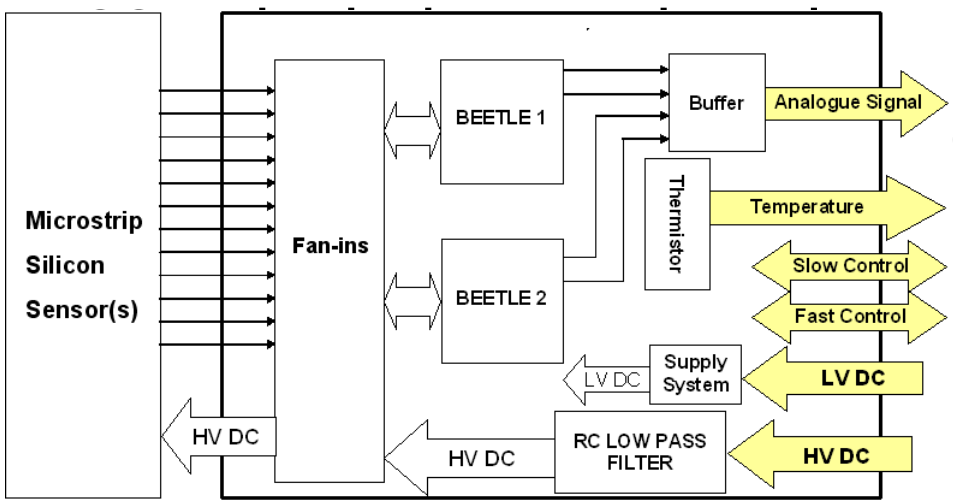




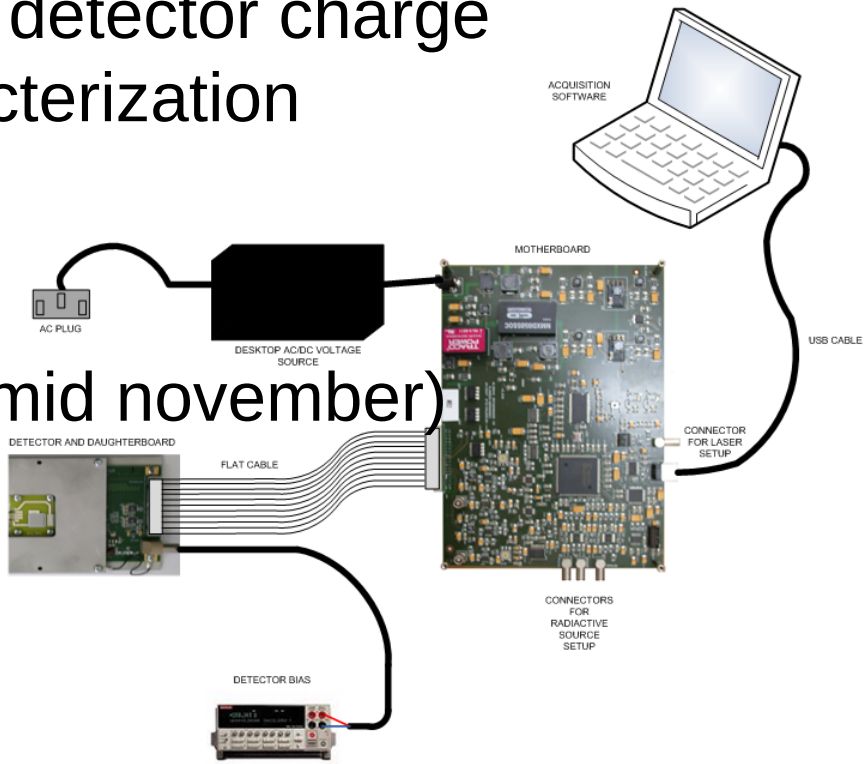
Electronics (2) - CNM, UB, URL

ALIBAVA: A readout system for microstrip silicon sensors

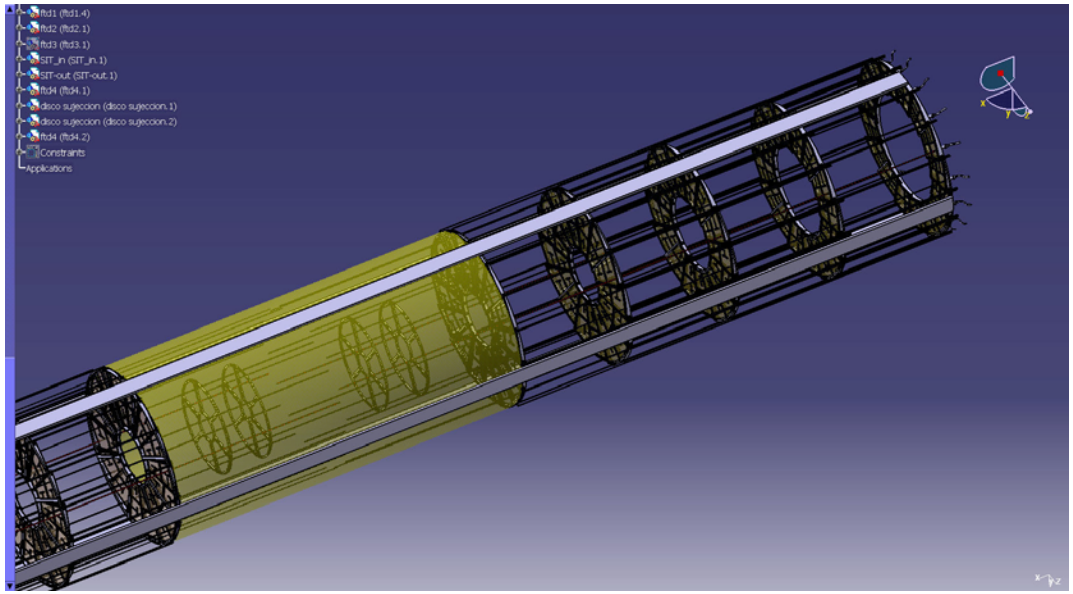
- Joint development of Liverpool Univ., IFIC-Valencia and CNM-Barcelona
- Simple and cheap system for detector charge collection performance characterization

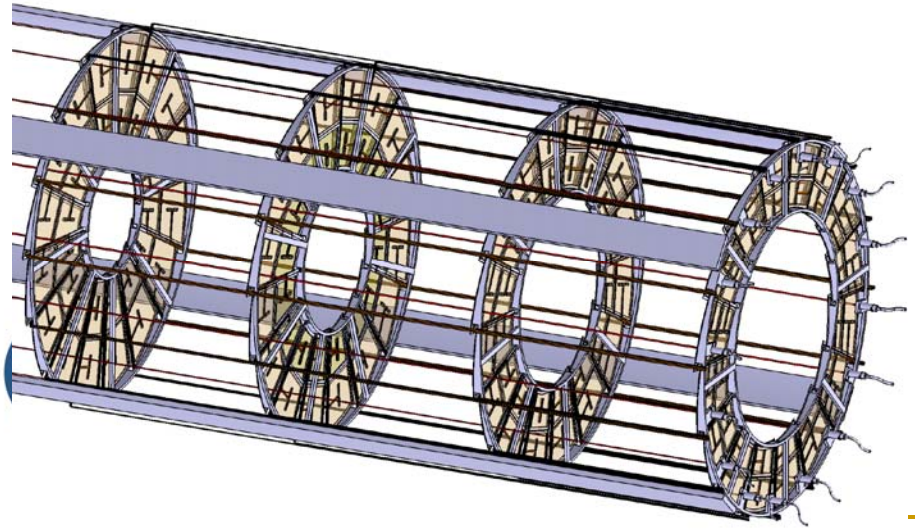


(mid november)



ILD Forward Tracking Disks IFCA, IFIC

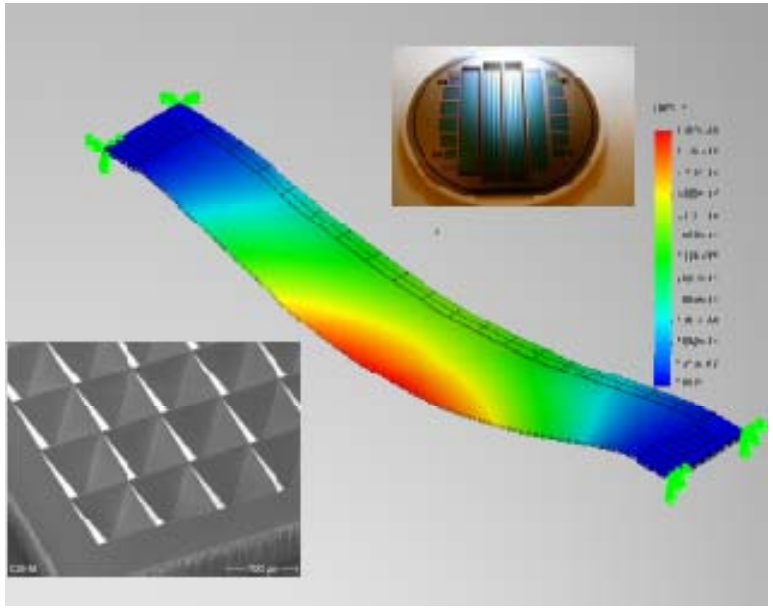


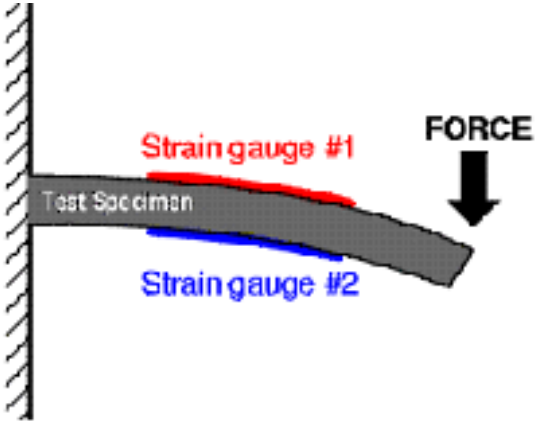


Three inermost disks pixels

Four outermost disks microstrips

Mechanics – IFIC, IFCA





- For the Track structure would be interesting to use a embedded fiber optic sensor.
  - more precise and reliable data
- It could be use 2 side solution
  - Better understanding of the results
  - Useful to quantify the termical strain