Forward tracking

LC2013,

DESY, May 28th 2013

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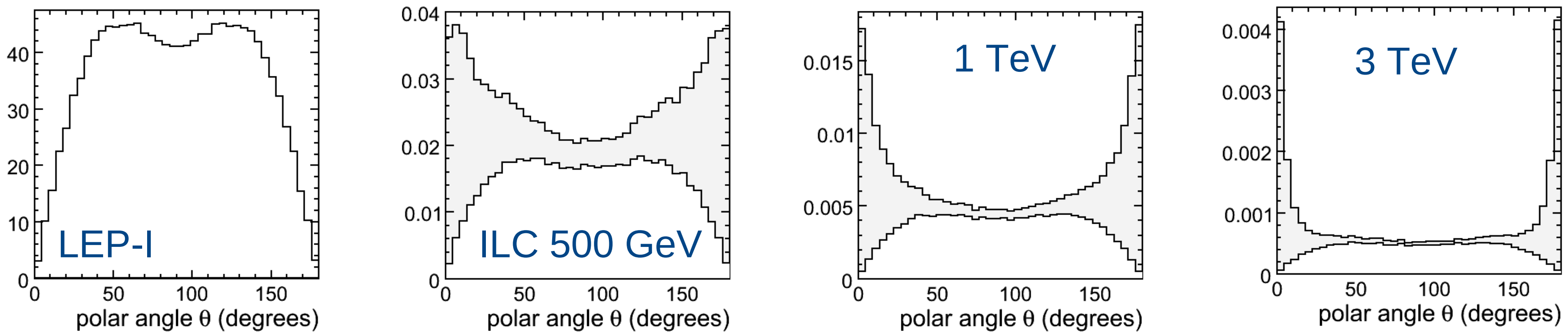
IFIC

Outline

Brief 'physics case & requirements'
Brief summary of the 'challenge'
Some first thoughts about pixelated disks

From LEP-I to the ILC to CLIC: Standard Model

The impact of ISR on $e^+e^- \rightarrow Z/\gamma^* \rightarrow \mu^+\mu^-$



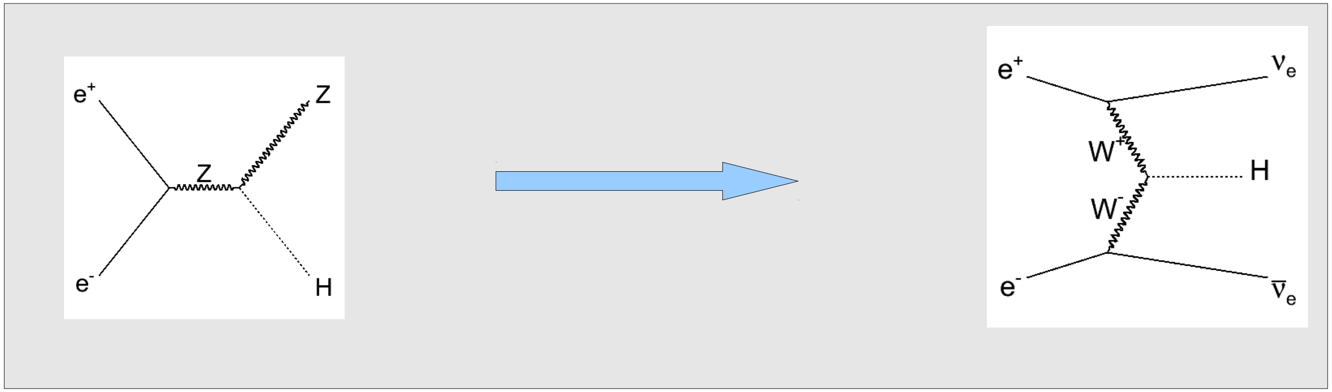
Many-fermion final states

√s	91 GeV	500 GeV	3 TeV
machine	LEP-I	ILC	CLIC
$\langle N_{jets} \rangle$	<3	5	6.4
P (forward fermion $t\bar{t}$)		60%	40%

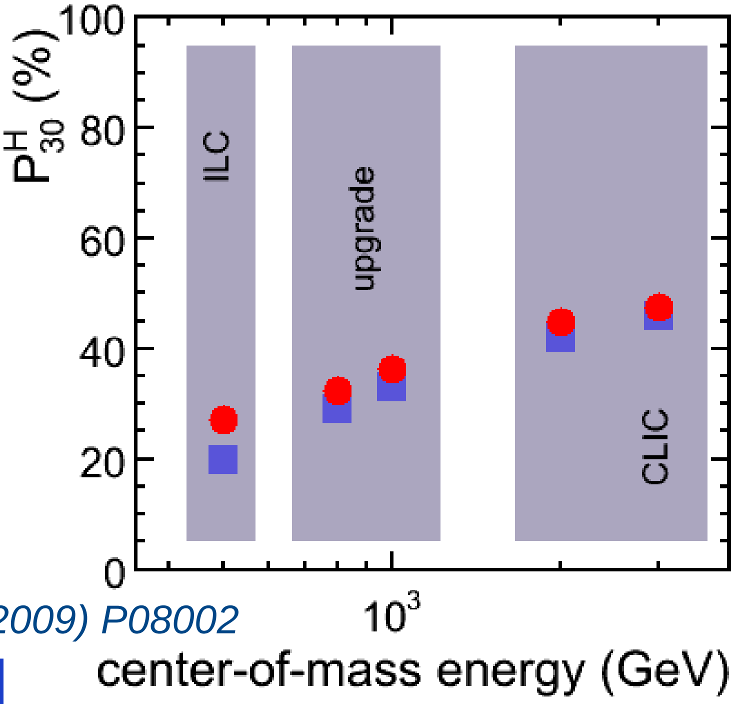
For a more elaborate formulation of this point: JINST4 (2009) P08002

From LEP-I to the ILC to CLIC

Higgs production



- Higgs-strahlung is the dominant Higgs production process at small √s. Recoil-mass reconstruction is the tracking benchmark analysis par excellence.
- Beyond 500 GeV vector boson fusion takes over. Final state neutrinos (WW fusion) and electrons (ZZ fusion) have a markedly forward profile. 20-50% of Higgs bosons produced with polar angle < 30 degrees.



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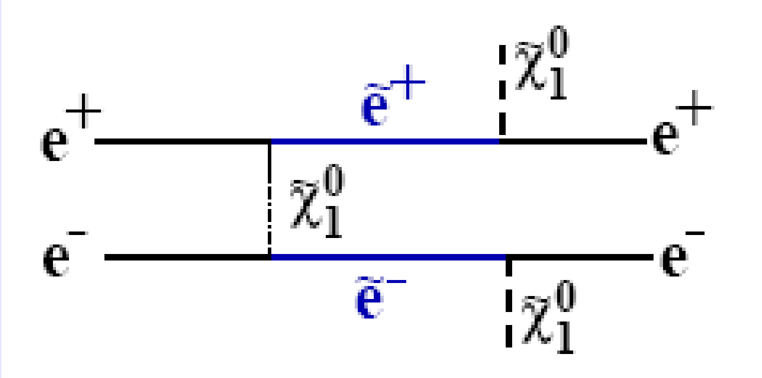
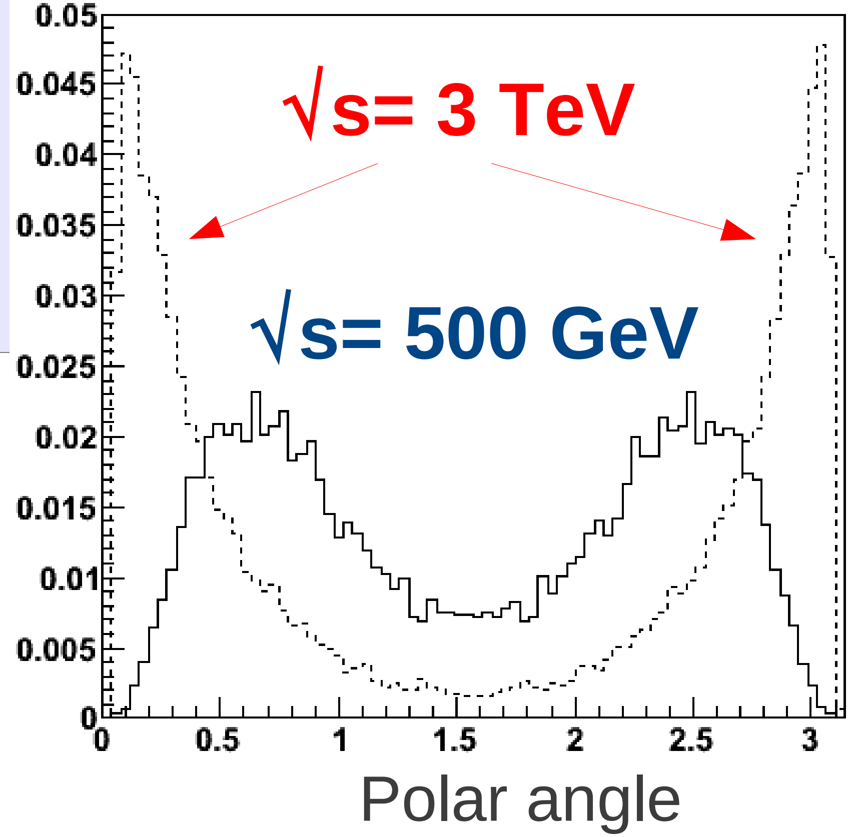
From LEP-I to the ILC to CLIC

t-channel processes





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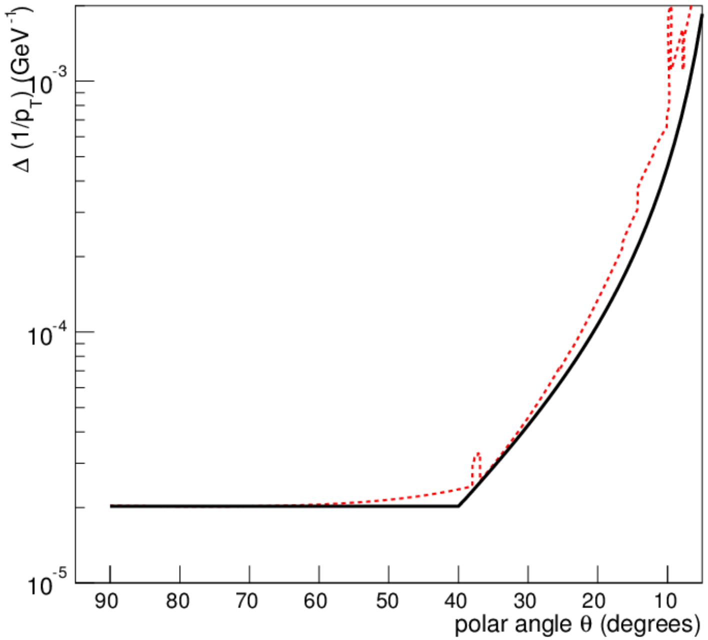
Momentum resolution

LC tracking specification: momentum resolution $\Delta(1/p_T) < 2 \times 10^{-5}$ (GeV^{-1})

Precision required to reconstruct the Higgs boson using the recoil method, for the H → μμ measurement and to reconstruct SUSY end-points

Gluckstern formula – with fixed resolution and number of points - predicts a considerable degradation (——)

ILD performance (------) indeed follows the general behaviour



Momentum resolution

LC tracking specification: momentum resolution $\Delta(1/p_T) < 2 \times 10^{-5}$ (GeV^{-1})

ILD00 momentum resolution

- ✔ Performance ~ stable down to 36°
- ✔ Steep loss between 6-36°

What about low momentum tracks?

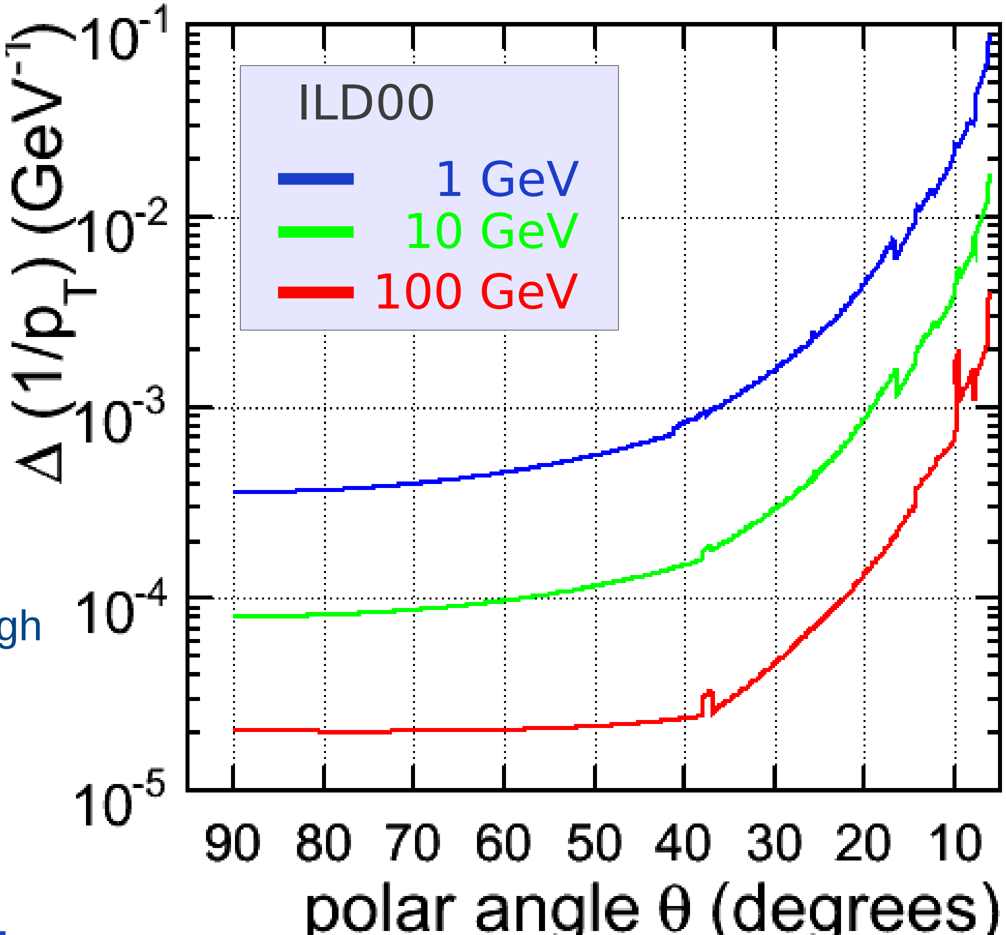
(= material budget)

Higgs-strahlung recoil analysis:

$\Delta(1/p_T) < 10^{-3}/p \sin\theta$

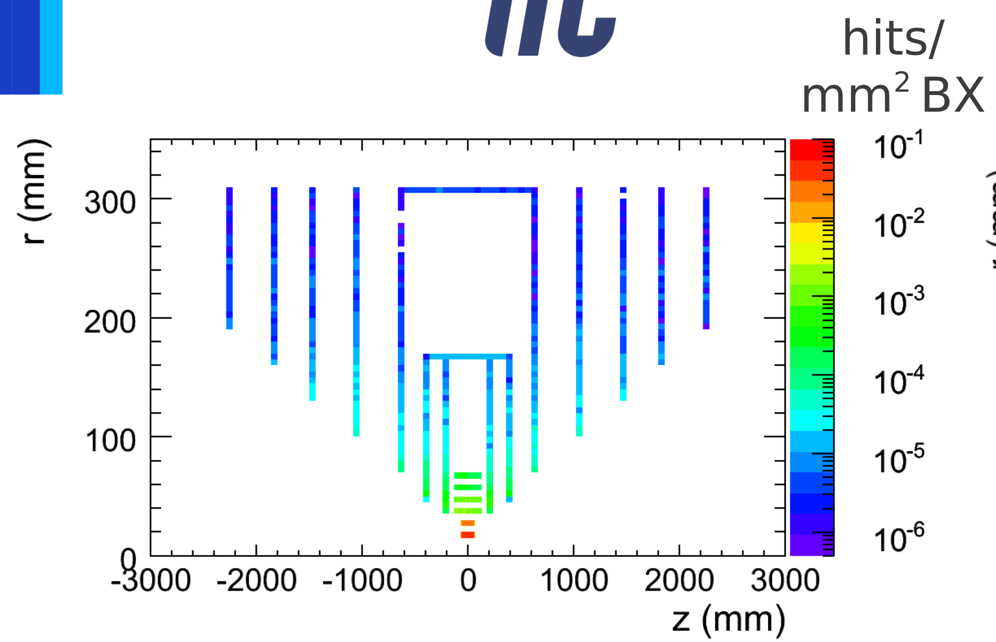
For PFA moderate resolution is enough

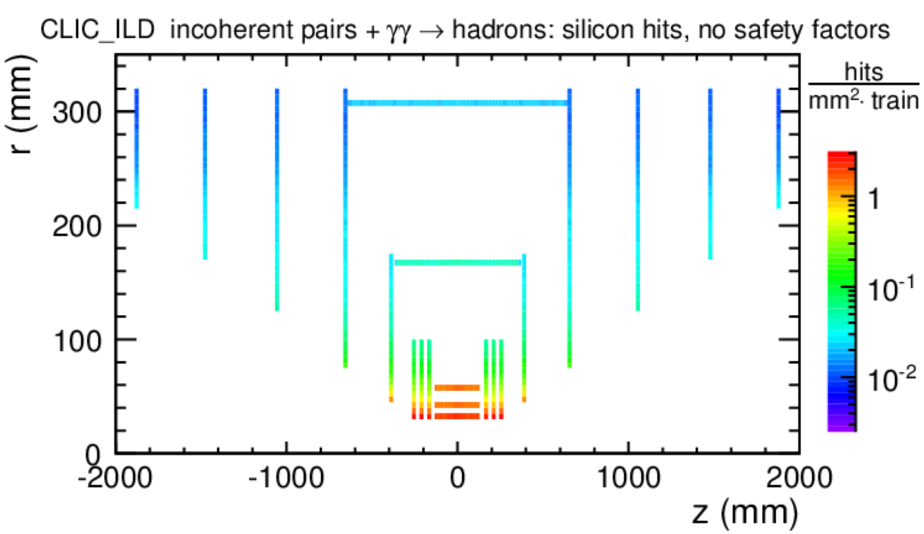
$\Delta p_T/p_T << \sigma_E/E = 3.5\text{-}5\%$



Environment

A multi-TeV produces more background





- **Innermost VXD layer**
  R = 1.5 cm
- **Specify BKG/BX**

- **Innermost VXD layer**
  R = 3 cm
- **Specify BKG/train**

Environment

ILC

$N_{BX} = 1356$

BX spacing = 550 ns

$t_{train} \sim 1$ ms

$t_{inter} = 200$ ms

CLIC

$N_{BX} = 300$

BX spacing = 0.5 ns

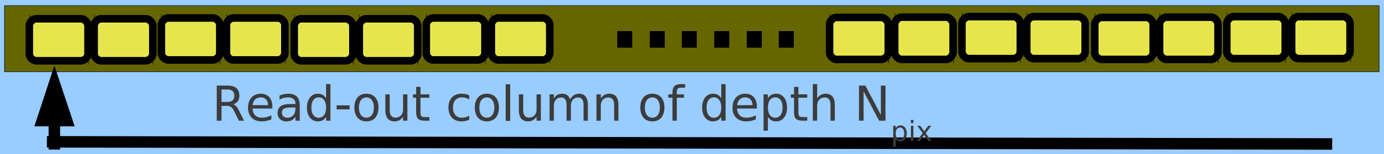
$t_{train} \sim 150$ ns

$t_{inter} = 1$ ms

Rolling shutter...

Row-by-row read-out instead of high-speed, massive, parallel extraction of the data

Integrating/Time slicing detector: rolling shutter

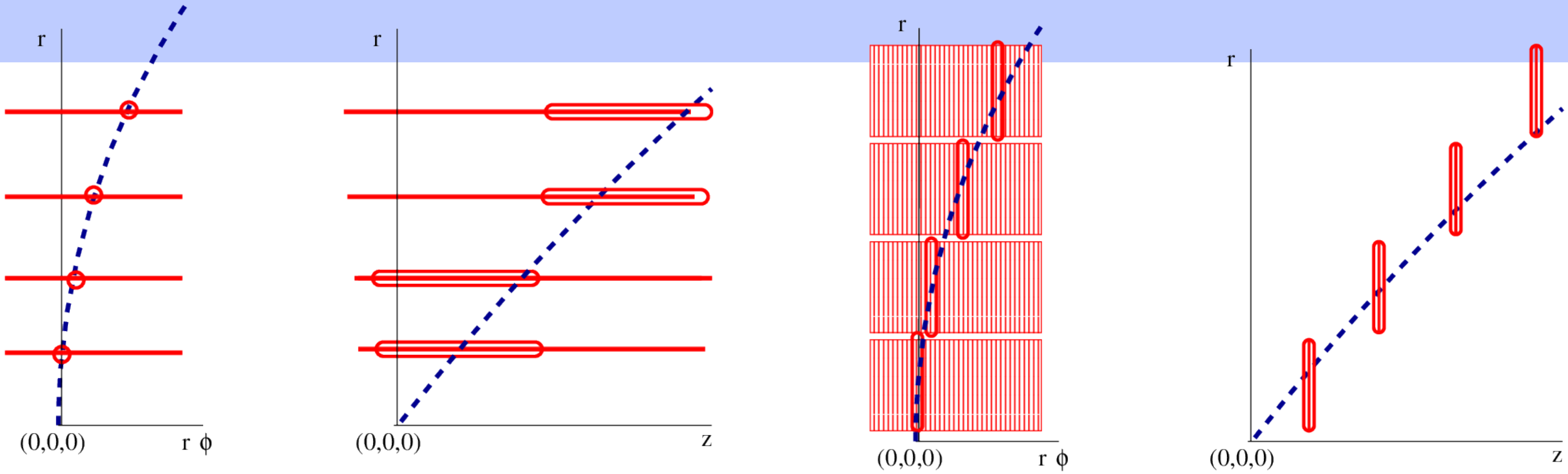


Allows for great spatial segmentation at low power, but is not fast Great if you get a dense event every few hundred BX...

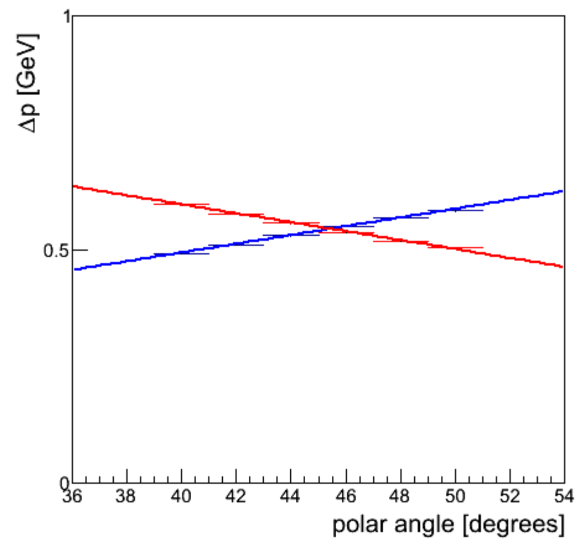
Technology	Cell area (µm x µm)	Integration time	Peak occupancy
VXD	25 x 25	50 µs	6×10^{-6} + 1×10^{-6}/BX
Hybrid pixel	50 x 500	10 - 100 ns	2×10^{-4} + 4×10^{-5}/BX
µ–strip	50×10^{5}	10 – 100 ns	5 % + 1 %/BX

Occupancy due to signal and background/BX for different choices of segmentation (cell area) and integration times

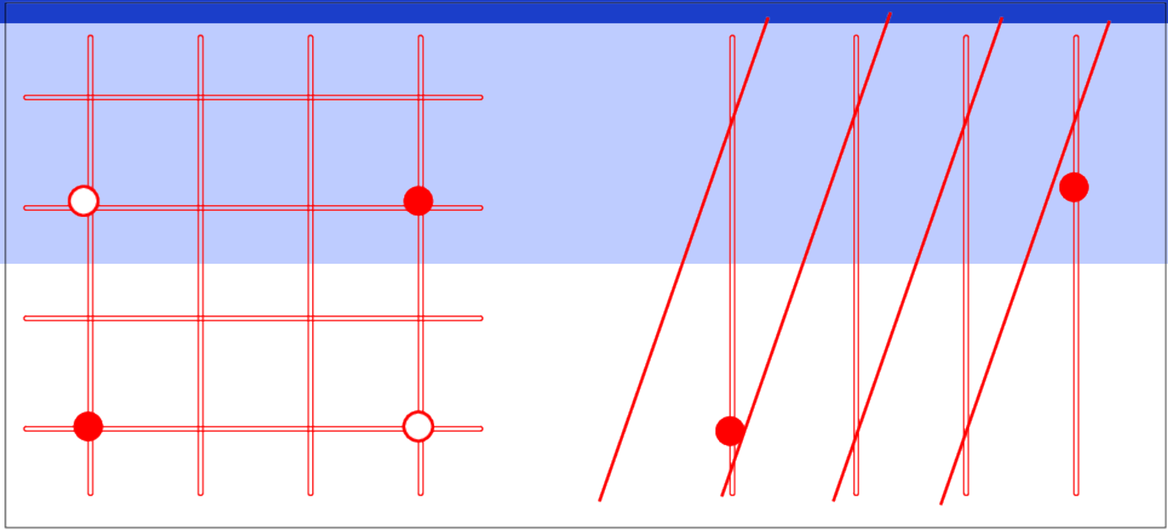
Track reconstruction



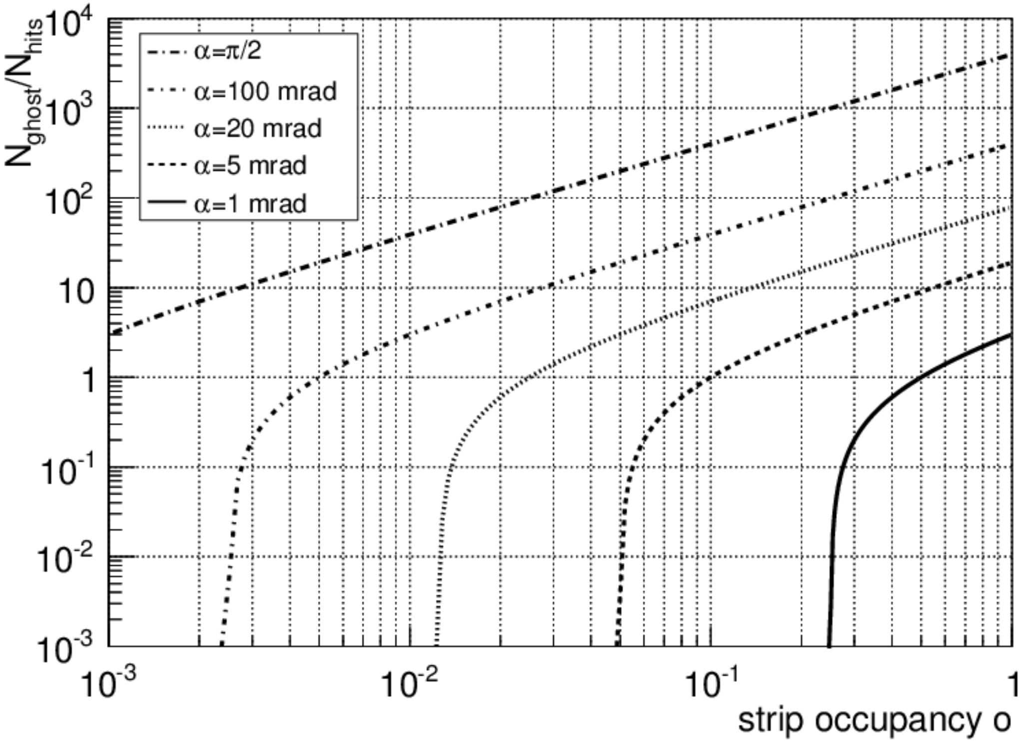
Compare barrel and end-cap geometries at $\theta = 45^{o}$ to verify tracks are equally constrained.



Ghost hits



In forward region the angle between stereo micro-strips must be quite small...



Impact parameter resolution

VXD: impact parameter resolution 5 – 10 μm.

This precision is required to achieve excellent heavy flavour tagging, particularly for couplings of the Higgs boson to charm ($c\tau$ ~150 μm) and bottom ($c\tau$ ~ 450 μm)

	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 μm Si)

This functional form is inspired by the typical performance of a barrel geometry detector, not about what is required by physics

Impact parameter resolution

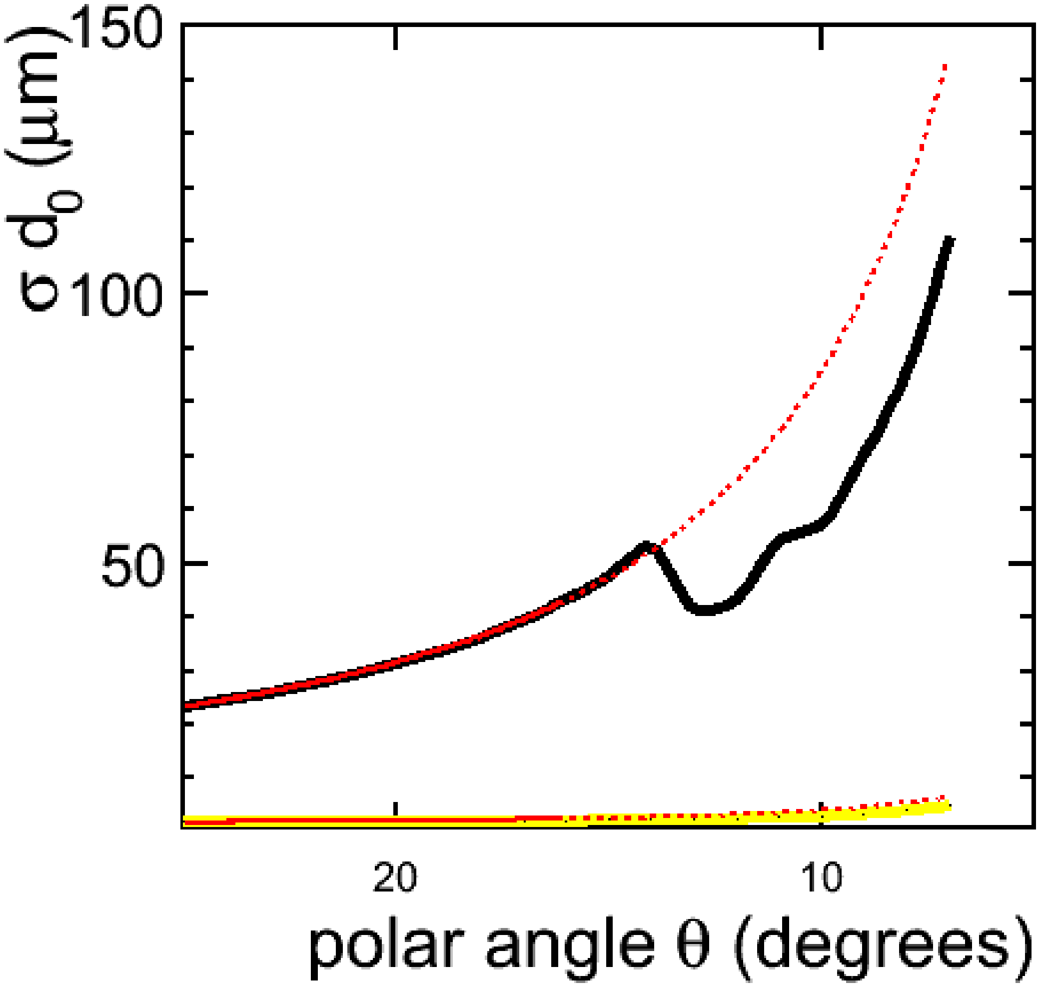
Assuming constant resoltuion, the simple $\sin^{3/2}\theta$ is formula adequate to describe barrel performance → implies rather strong degradation with polar angle

Beyond the barrel coverage the material term changes:

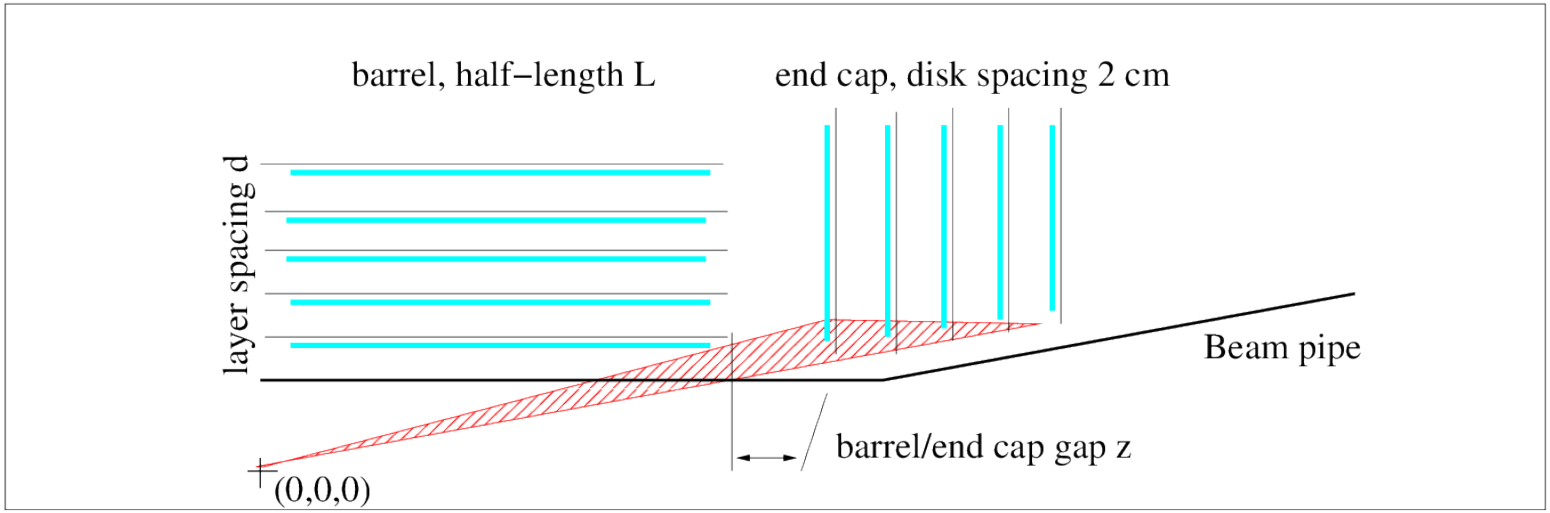
$b \rightarrow b \times z_0/R$

Where z_0 is the location along the beam line of the disk and R the inner radius of the barrel layer

$\sin^{3/2}\theta \rightarrow \cos^{3/2}\theta$



Impact parameter resolution



Result on previous slide is for an ideal detector:

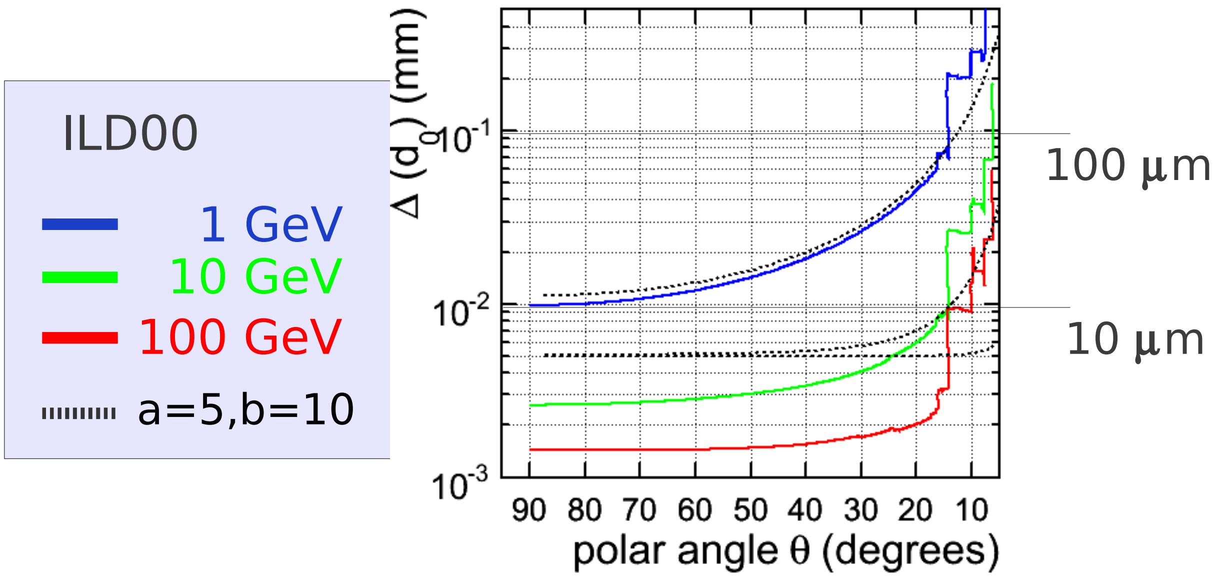
- L=6.25 cm
- very narrow barrel-end-cap gap
- no additional material in red cone

Need more realism... Miguel Angel Villarejo (CERN/IFIC) is producing a CAD model for CLIC_ILD and feeding it back into GEANT4

Impact parameter resolution

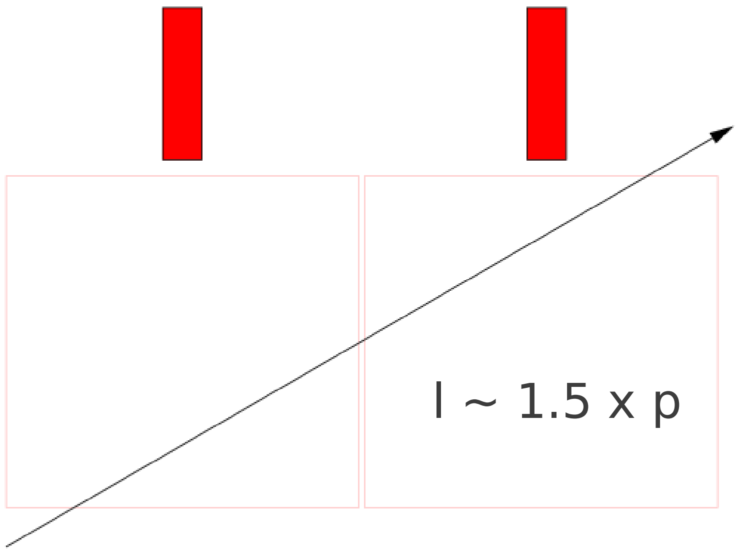
VXD: impact parameter resolution 5 – 10 μm.

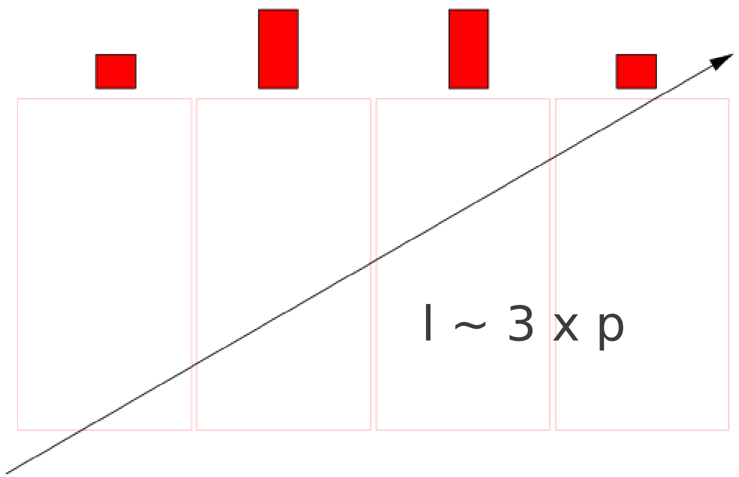
In ILD the z_0/R ratio is rather large...



(Finally) written up in part II of 'forward tracking at the next e^+e^- collider'
http://arxiv.org/pdf/1303.3187.pdf

Beyond constant resolution...



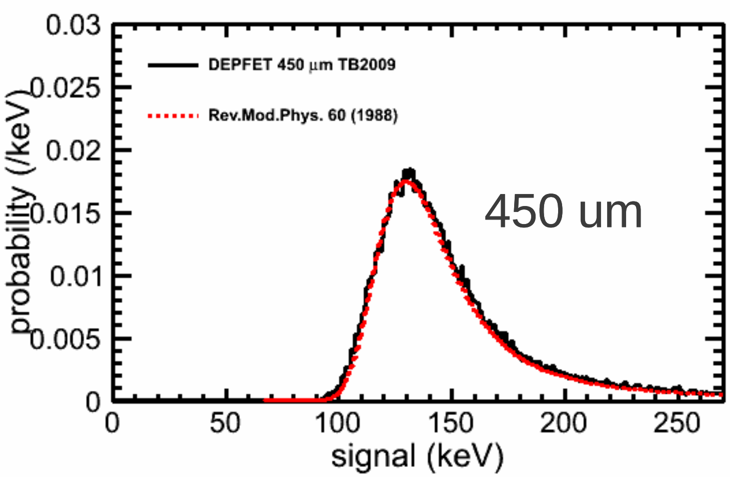


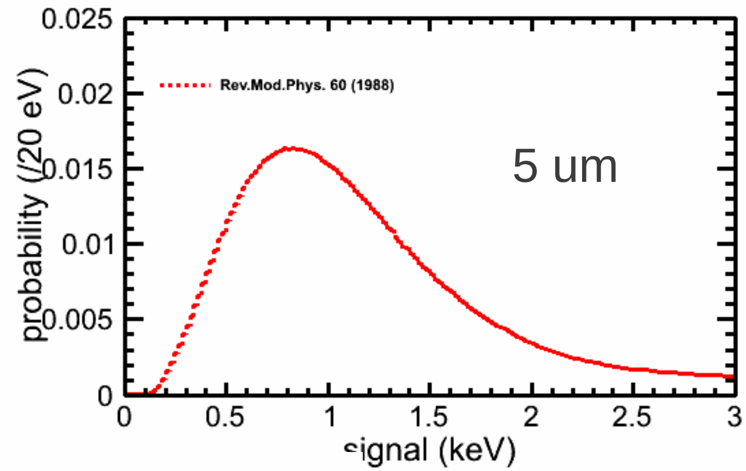
Linear charge sharing leads to optimal resolution for p<l<2p

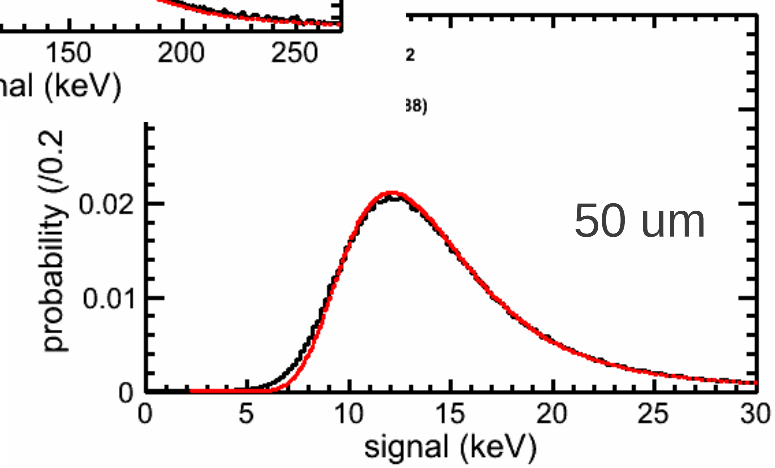
Spatial resolution normally degrades when projected arc l >> p

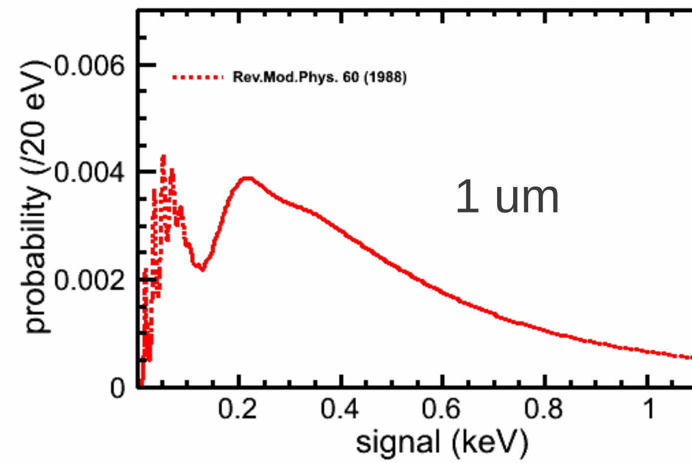
Forward tracks cross the barrel VXD at a shallow angle.
Several options:
- make sensors very thin (CMOS, FPCCD)
- for 50 um thick sensors increase pixel size along z to keep l~p...

Shallow tracks









Fluctuations in signal deposition per unit length of the particle trajectory in the silicon (Landau fluctuations) limit the resolution.

Fluctuations become more pronounced for thin sensors
Compare to GEANT4...

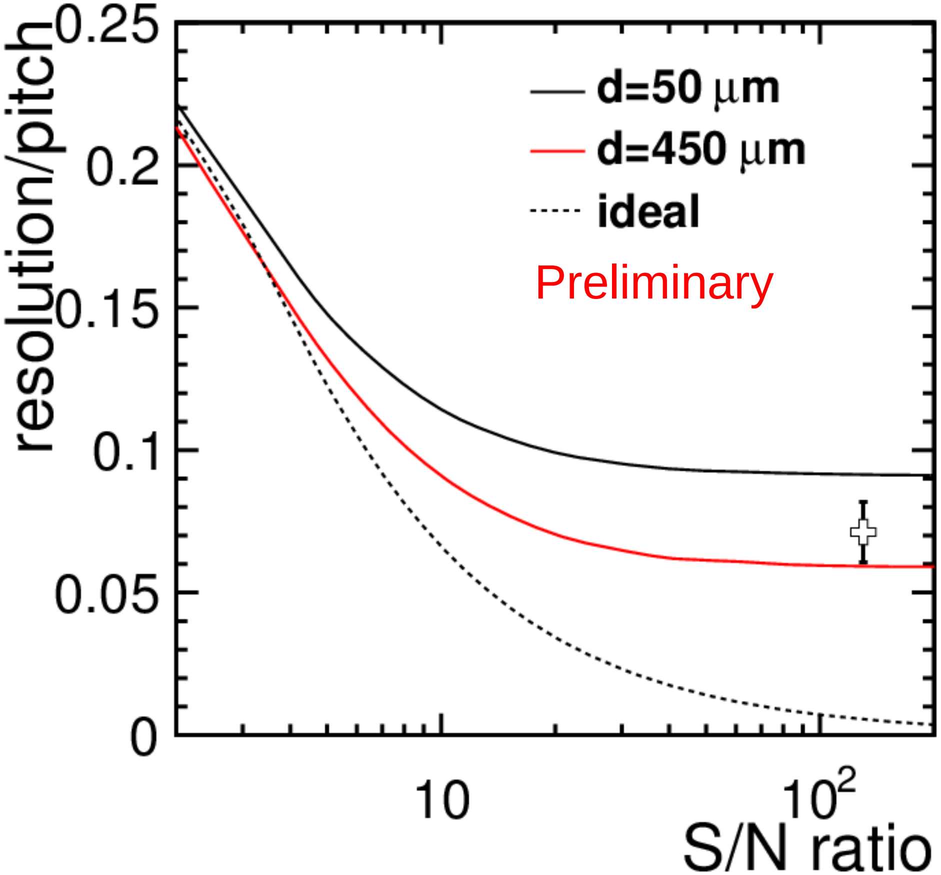
Resolution for l=p

Resolution limited by 'Landau' fluctuations:

σ/p ~ 7% for thick sensors
(d=300-500 um)

σ/p ~ 10% for thin sensors
(d=50 um)

Comparison with TB data from other groups in progress (TimePix,...)



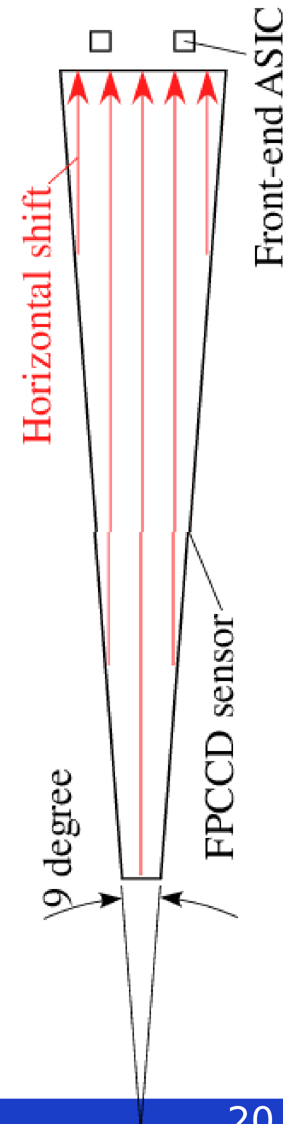
For digitizer studies, see Benjamin Schwenker's talk in this session

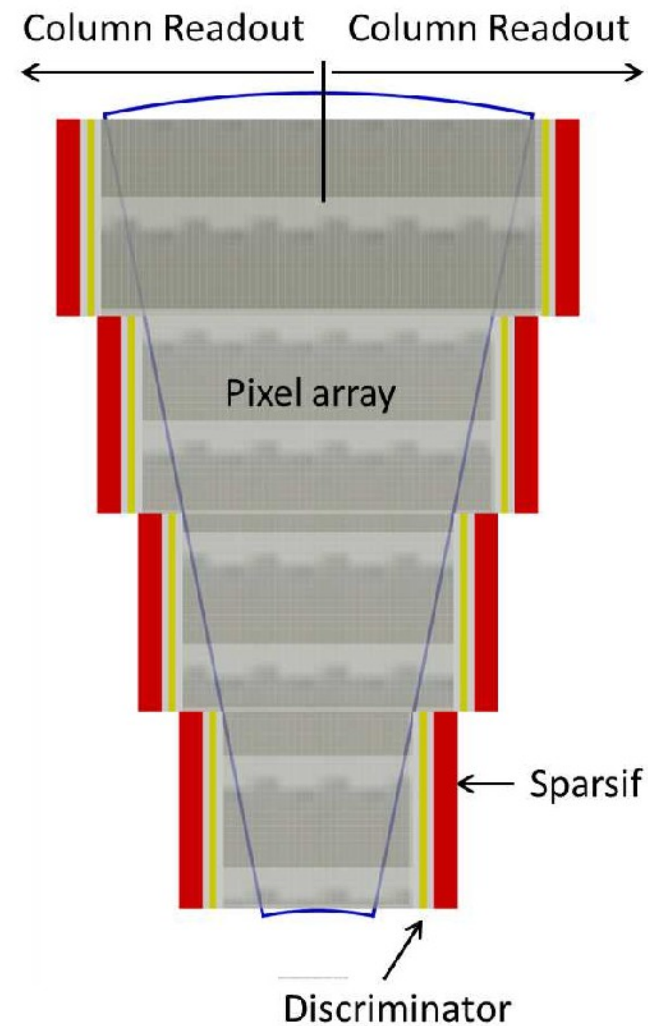
Towards a design for the FTD/end-cap disks

ILD DBD has a first description of pixel solutions for a petal geometry

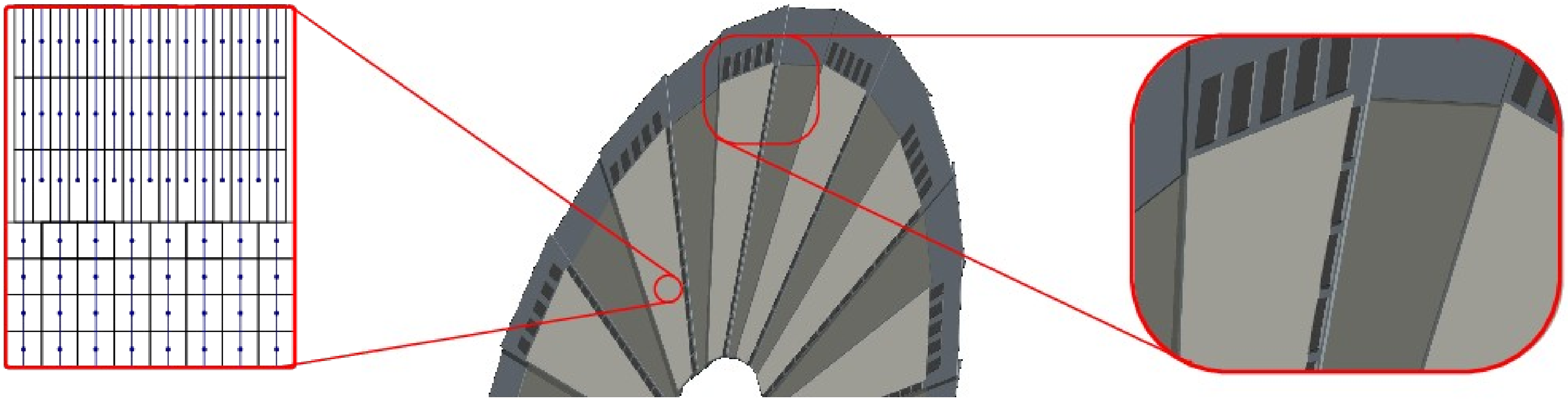
Requirements: excellent resolution & fast read-out, especially in the innermost ring

Mechanical constraints:
Keep openings for air flow?
Spiral geometry?
See Fernando Ramos' talk





Towards a design for the FTD/end-cap disks



If columns are oriented radially, pitch increases by a factor 4 between inner and outer ring. Define two regions.

Conclusions

Forward region gains in relevance with Ös

Quantified in JINST 4 (2009)

Forward tracking performance represents a challenge

Second edition of "forward tracking at the next e^+e^- collider" accepted by JINST

Spatial resolution vs. polar angle of barrel vertex detector must cope with shallow angle tracks (large clusters, Landau fluctuations)

Adaptation of technologies to petal geometry just starting