Forward Tracking

Marcel Vos – IFIC Valencia

ILC effort in Spain

ILC effort in Spain

Accelerator R&D

final focus, IFIC Valencia

Detector R & D

CALICE – CIEMAT Madrid

SiLC – IFCA Santander, CNM, U. Barcelona, IFIC Valencia

DEPFET – IFIC Valencia, U. Santiago, U.B.

SiLC R&D

The main challenge is to build an excellent AND low-mass tracker; a large fraction of the SiLC effort is directed towards a reduction of micro-strip detector material

Improving micro-strip detector technology

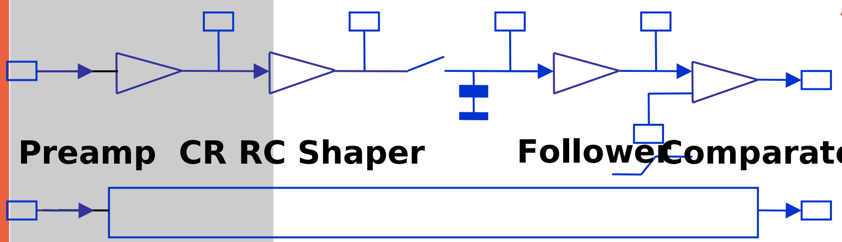
- ✔ SiTRA front-end chip has an instantaneous power consumption of 500 μW/channel (silicon area corresponding to each channel is 50 μm x 10-50 cm)
- ✔ Pulsed power will yield an duty cycle of 1 %
- ✔ Closer integration of sensors and front-end
- ✔ Sparsifying the data

SiTRA FE chip, J.F. Genat et al., LPHNE

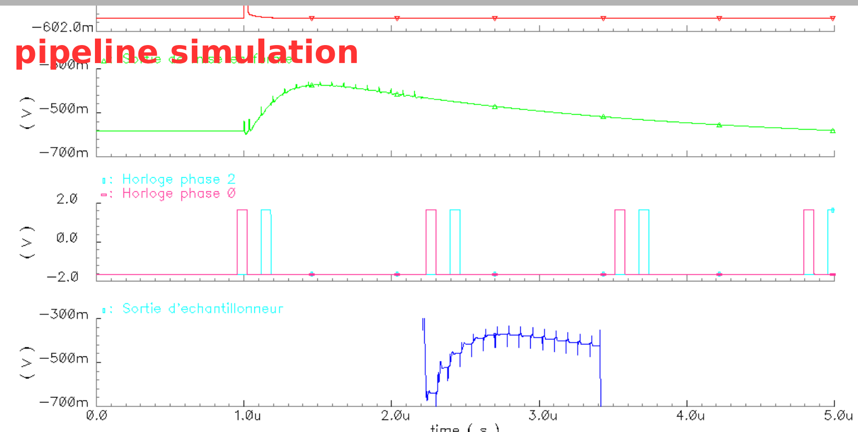
Investigate other detector types

- ✔ In innermost tracker layers

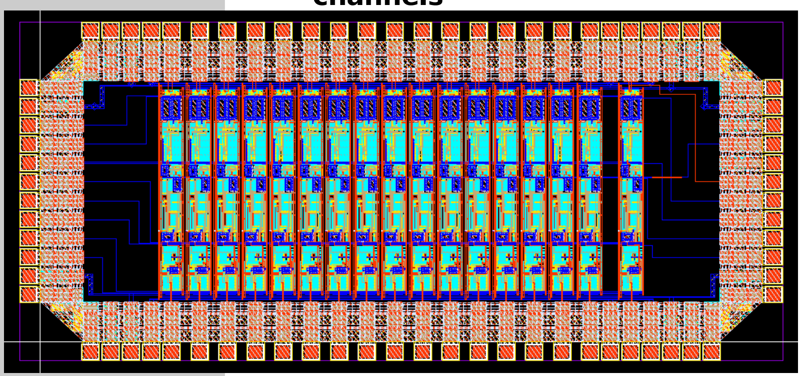
First prototype in CMOS UMC 180nm (2005):SiTR-180 (J.F. Genat, LPHNE)



Analog pipeline simulation



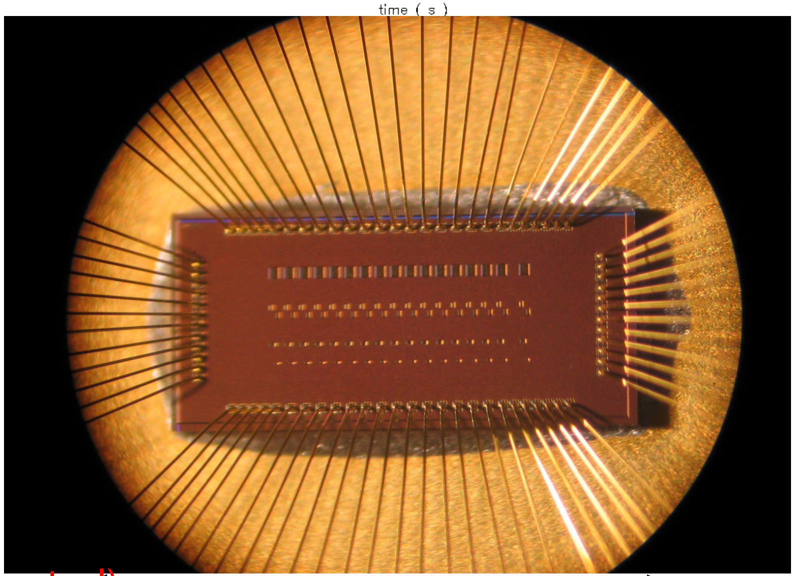
16 identical channels



- Preamp
- Shaper
- Sample & Hold
- Comparator

Power consumption:

575 mW Analog (measured) + 66 mW Digital (expected)

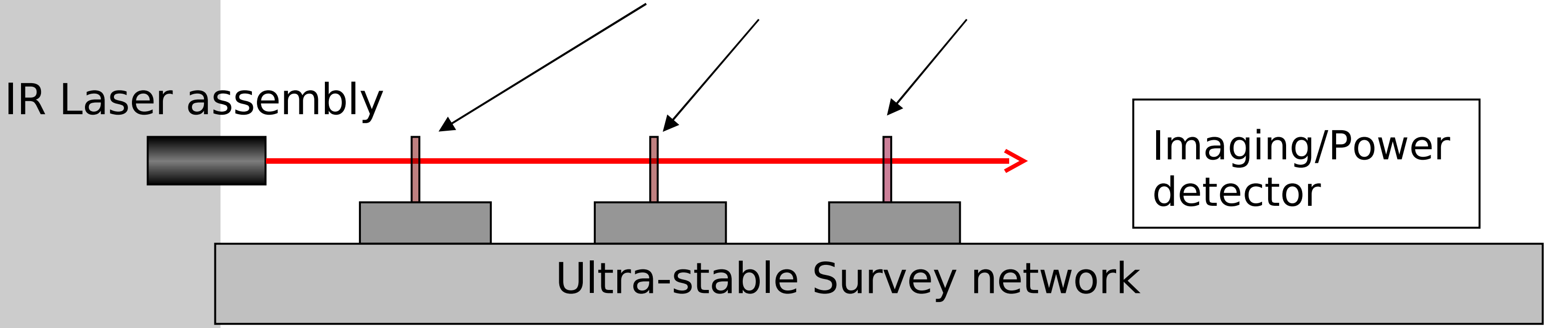


3mm

Based on AMS system, further used in CMS

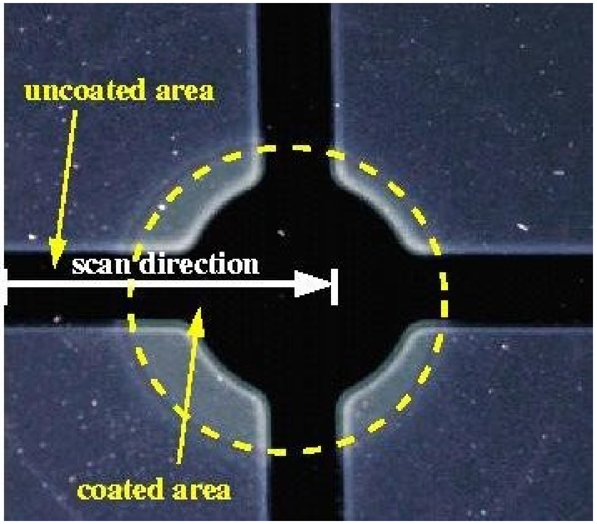
IR laser beams through silicon detectors.

- Particle tracks and laser beam share the same sensors removing the need of any mechanical transfer.
- Minimum interference with Silicon support structures
- No precise positioning of the aiming of the collimators. The number of measurements has to be redundant



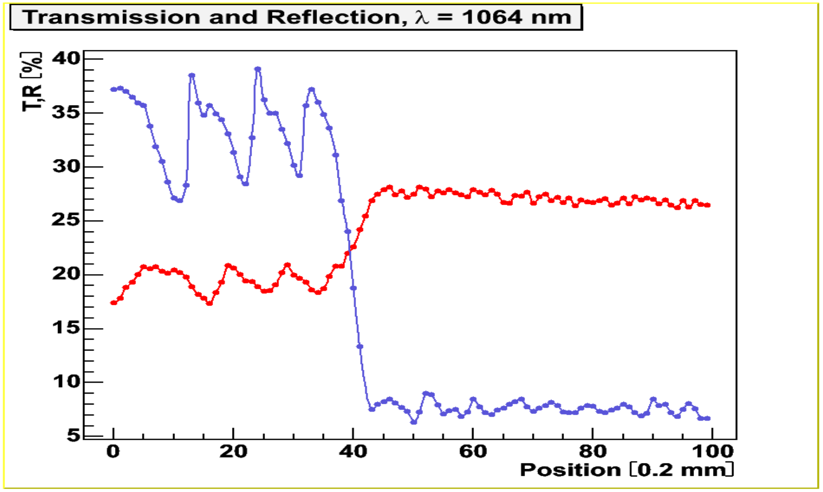
Micro-strip sensor has to operate as a semi-transparent photo-detector.

IFCA Santander and IMB-CNM, within the EUDET are ***performing R&D to optimize the optical properties of silicon sensors*** (transmittance, reflectance, beam deflection, position reconstruction accuracy)



- 10 mm hole in aluminium backside coating
- All sensors with anti-reflective coating

Transmission measured to be 14-20% (at λ=1075 nm)

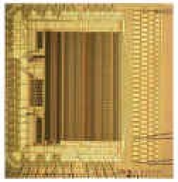


- Reflectivity <= 6%

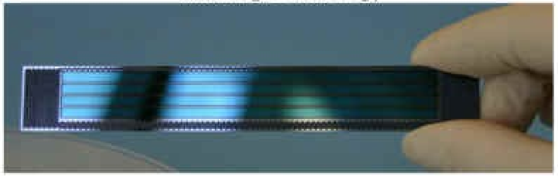
DEPFET

www.depfet.org

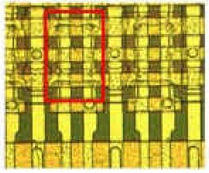
✓ steering chips Switcher



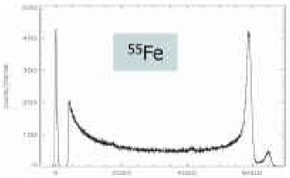
✓ thinning technology

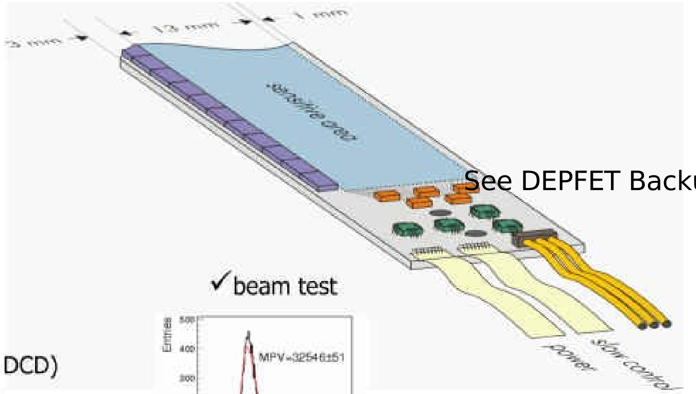


✓ sensor development



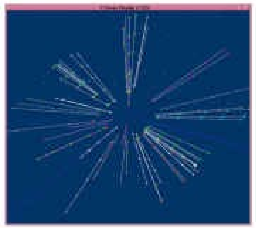
✓ radiation tolerance



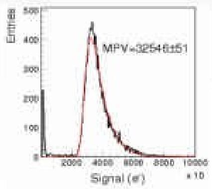


See DEPFET Backup Document at *www.depfet.org*

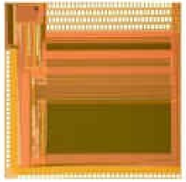
✓ simulation



✓ beam test



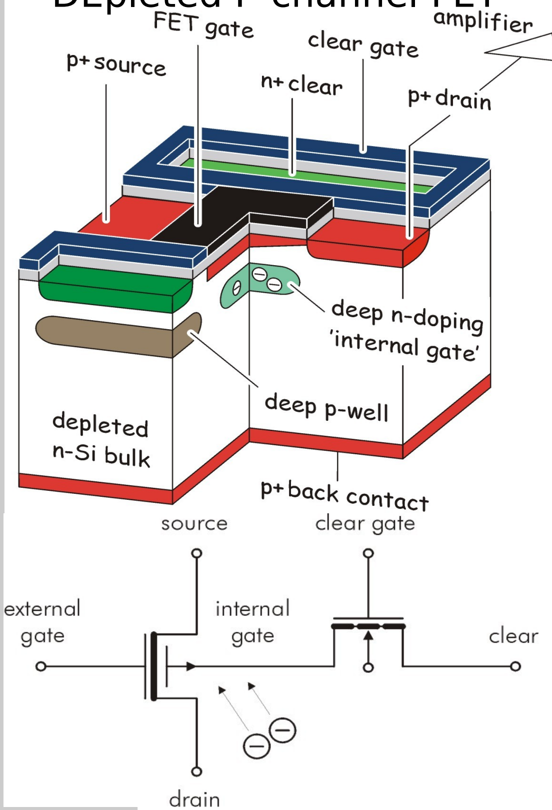
✓ r/o chips (CURO & DCD)

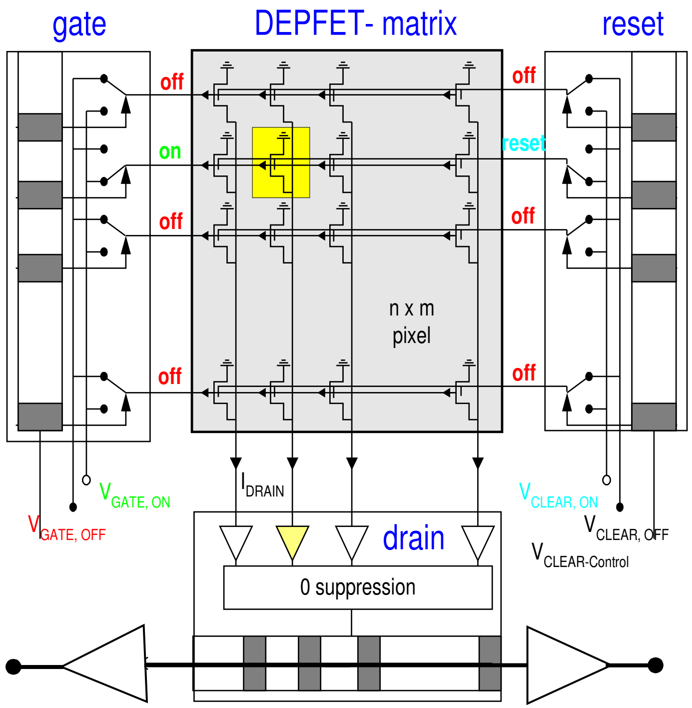


DEPFET Principle

J. Kemmer & G. Lutz, 1987

DEpleted P-channel FET

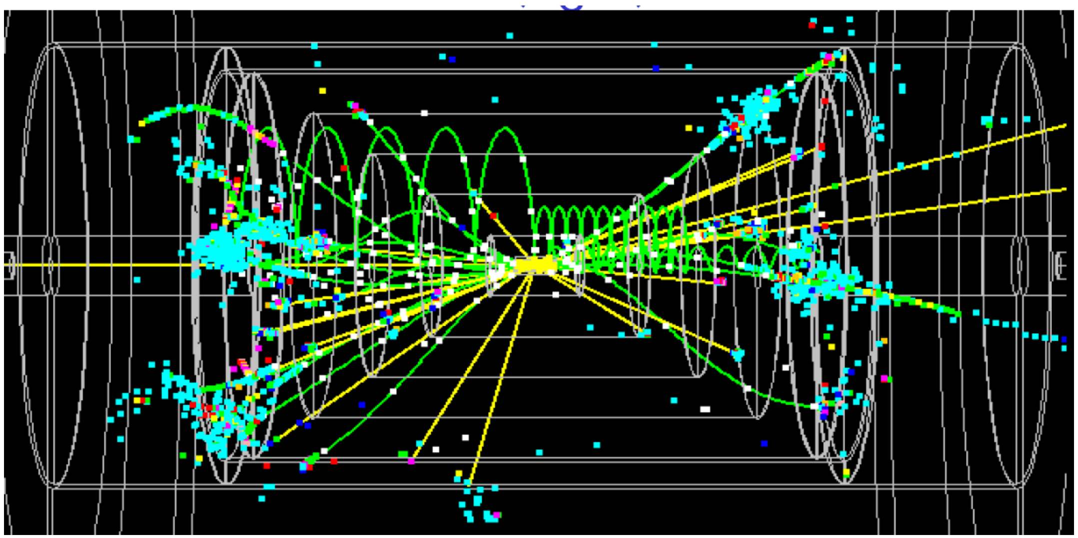




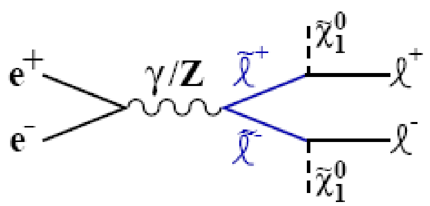
- fully depleted sensitive volume, charge collection by drift
- internal amplification → q-I conversion: 0.5 nA/e, scales with gate length and bias current
- Charge collection in "off" state. Read-Clear-Read sequence.
- Rolling shutter read-out of deep columns using auxiliary chip

Forward Tracking

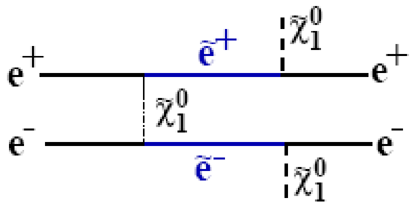
- No longer “just completing the coverage”:
  - Because of increased importance of t-channels and
  - Event topology (many jets almost isotroically distributed)
- PFA algorithms need good tracking to |cosθ|~0.98
- Should be thin enough not to
  - degrade forward calorimetry nor
  - spoil electron ID
- Robust pattern recognition to track low momentum particles
- Never been done (right) !!!



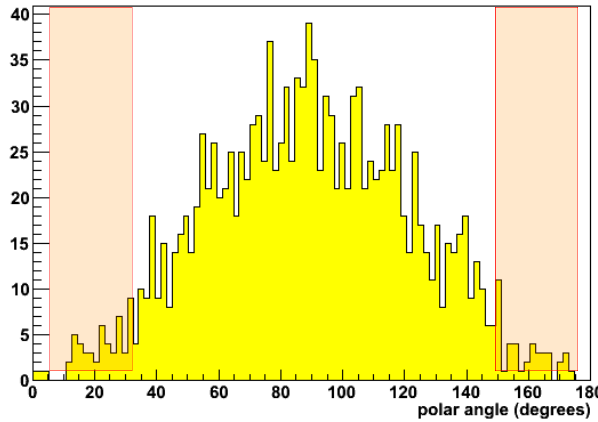
Forward physics

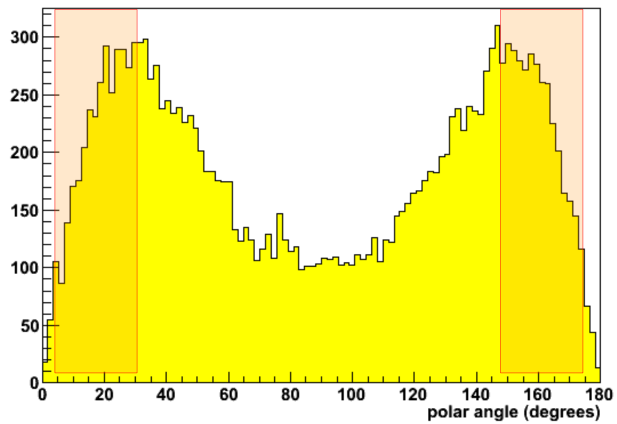


smuon and stau
s-channel
production



selectron:
t-channel



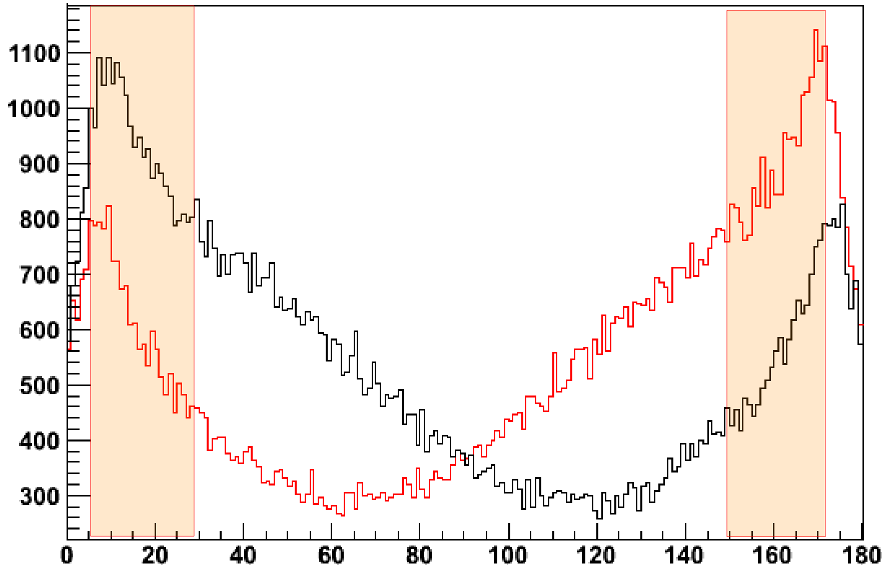


Very forward physics: selectron end-point reconstruction

see S. Gerbode et al., Snowmass 2005, H. Martyn, hep-ph/0408226, T. Barklow,

Polar angle distribution: For SPS1a t-channel selectron pair production @ 500 GeV (1 TeV), 24 % (50 %) of selectrons has $\theta < 30^o$

Very forward physics



Polar angle θ (degrees)

Standard Model charm quark and anti-quark production vs polar angle.

200.000 events.

*** A_{FB} in the cc system**

see M. Battaglia, ILD meeting, Zeuthen.

*** Sensitive probe of forward vertexing performance**

*** Polar angle distribution:** most of the statistics is in the forward tracker (the sensitivity to new physics is not necessarily in this region, though)

ILD: Momentum resolution

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

Detector	*R φ (μm)*	*z/R (μm)*	*Material (% X_0)*
VXD	*5*	*5*	*0.12/layer*
FTD1-3	*10*	*50*	*1.2/layer*
FTD4-7	*10*	*1000*	*0.8/layer*
TPC	*120*	*300*	*1 (field cage)*

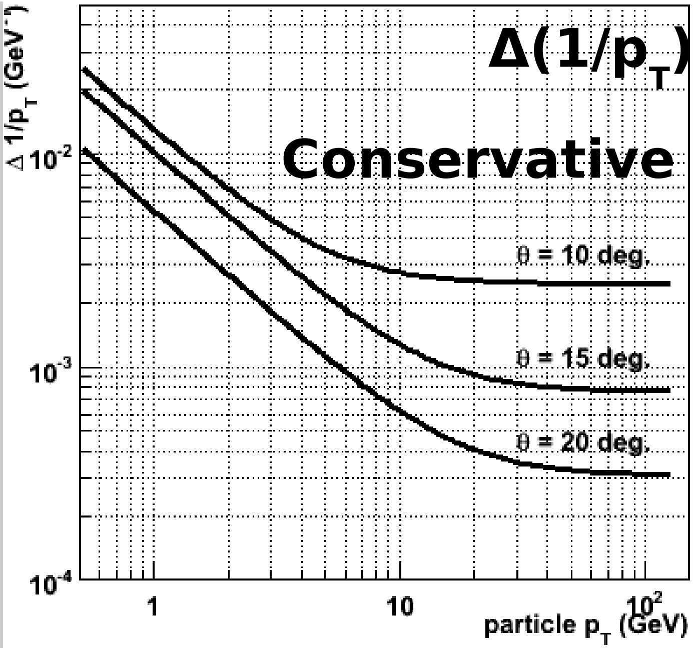
Reference (TESLA) set-up

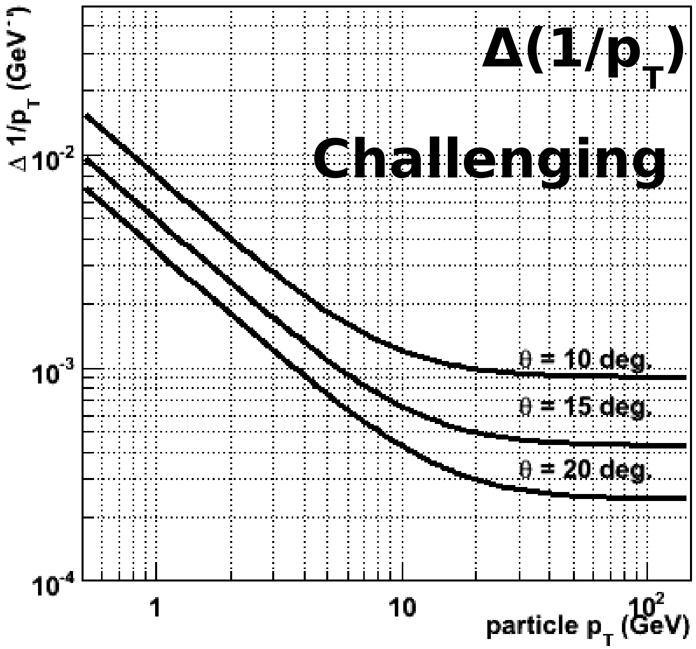
$1.8\times10^{-3}\oplus1.3\times10^{-2}/\,p_T$

Challenging setup

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

$\Delta(1/p_T)=0.9\times10^{-3}\oplus0.8\times10^{-2}/\,p_T$





ILD: Momentum resolution II

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

Reference (TESLA) set-up

$1.8\times10^{-3} \oplus 1.3\times10^{-2}/\ p_T$

Challenging setup

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

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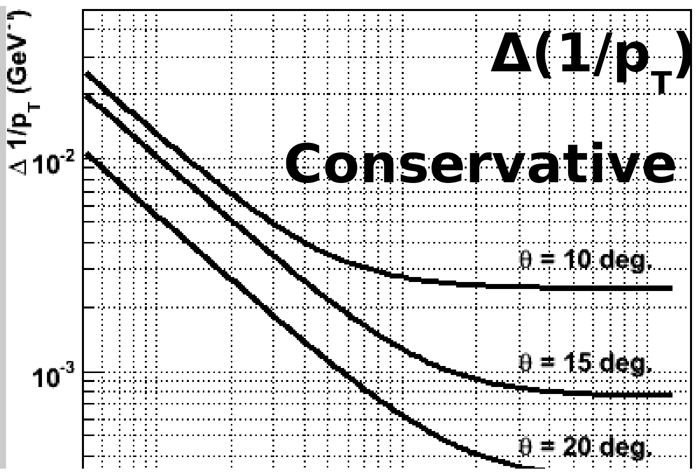
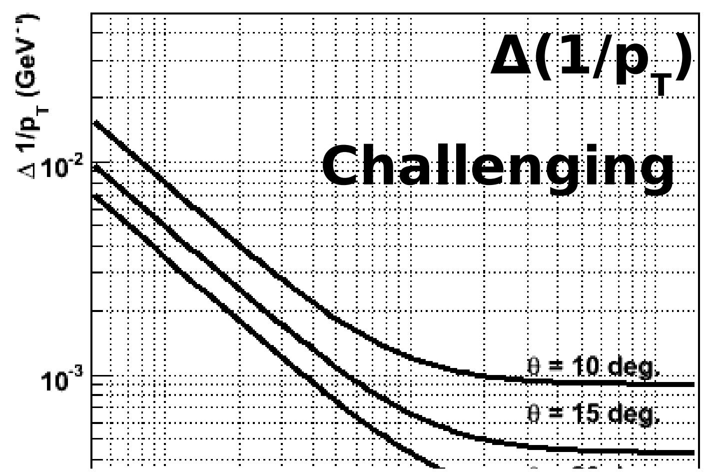




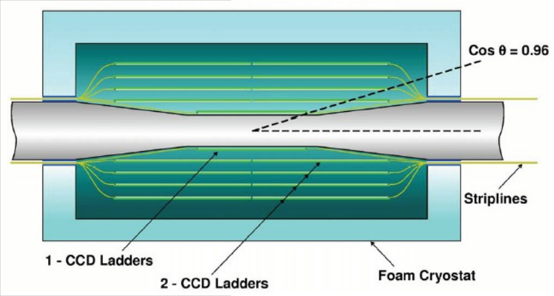
<u>Excellent R-φ space point resolution</u> crucial for asymptotic momentum resolution

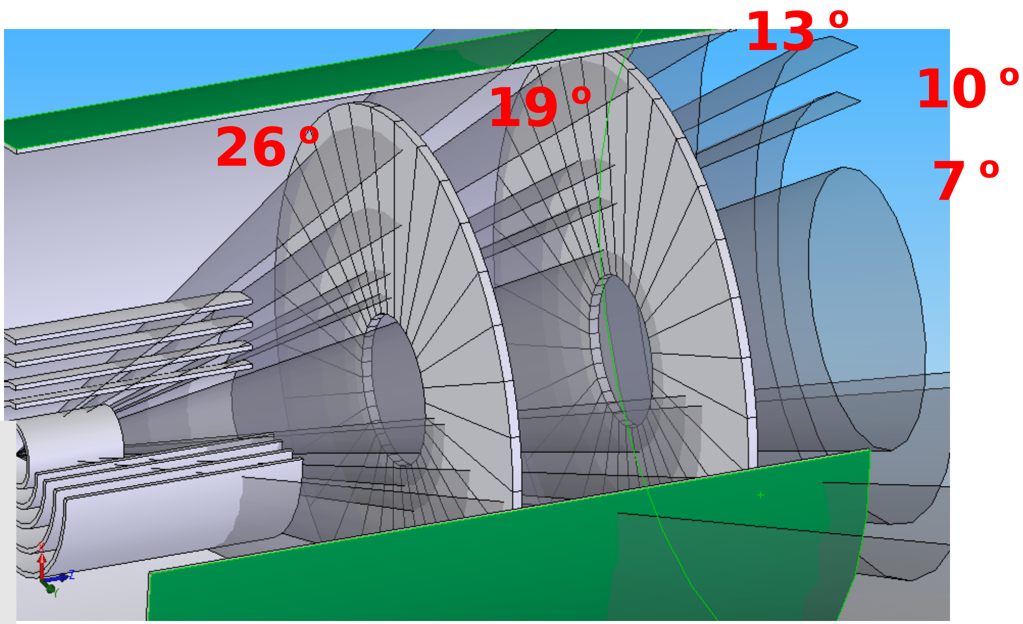
Forward Tracking: interplay with VXD

Concept	Magnetic Field	Angular Coverage 5-point	3-point
SiD	5 T	12.5 (43 barrel)	9
LDC	4 T	26	19
GLD	3T	26 (6 points)	18 (4 barrel + 2 disk)

Long barrel layout (LDC, GLD) has limited coverage for angular region from 7° to 25°

(Very) forward tracking with a “Long barrel” vertex detector





LDC inner tracker layout:

- VXD (cylinders)
- SIT (green)
- FTD disk 1 and 2

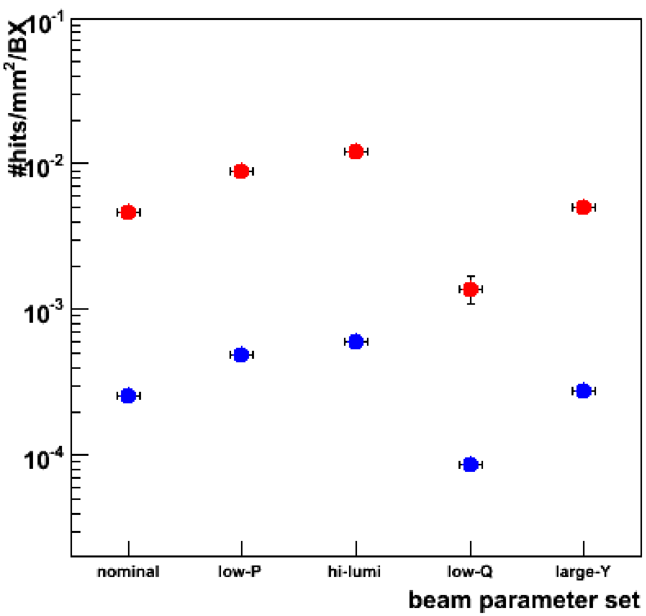
Environment – machine bkg.

Incoherent pair production off beamstrahlung photons yields very signficant hit densities in forward tracker:

$1\text{-}2 \times 10^{-4}$ hits/mm^2/BX

in nominal conditions in the first three disks
- a large fraction (40-45%) of hits is indirect.
- strong dependence on machine parameters (factor 2), and ILC energy (factor 2)
- distance to accumulation zone minimal for disk 2
- magnetic field yields factor ~2 / 0.5 Tesla

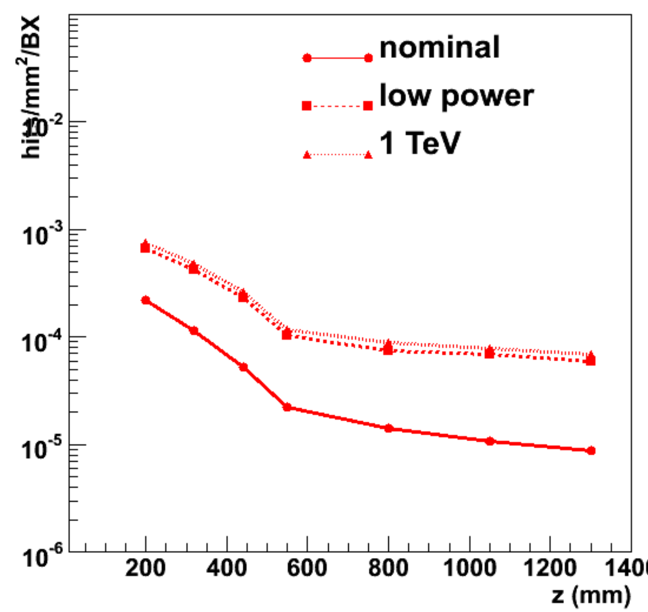
Occupancy in inner ring of the disks is factor 5 larger than disk average.



Hit density in LDC FTD 2 for different FF parametersets.

LDC forward tracker:

Hit density vs distance for three machine parameter sets.



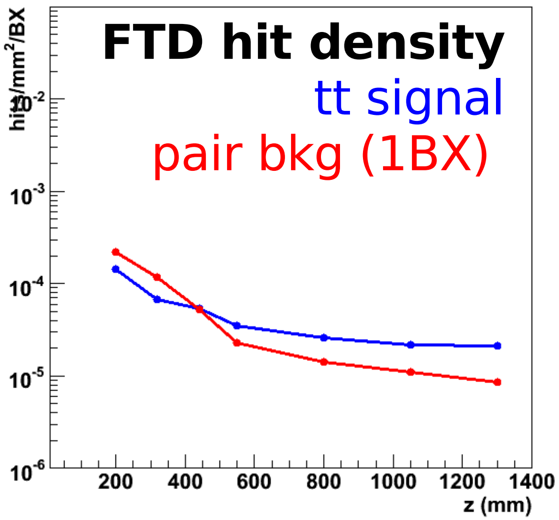
Pattern recognition

Pattern recognition for very forward tracks (θ < 20º):

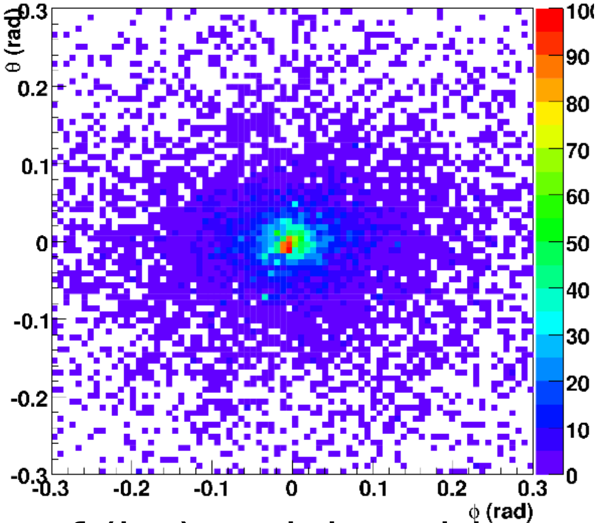
central track in LDC: 5-6 VXD + 2-4 SIT + O(200) TPC

forward track in LDC: 7 Space points

forward region in SiD: 4 VXD + 5 μ-strips.



Continuous trickle of background hits

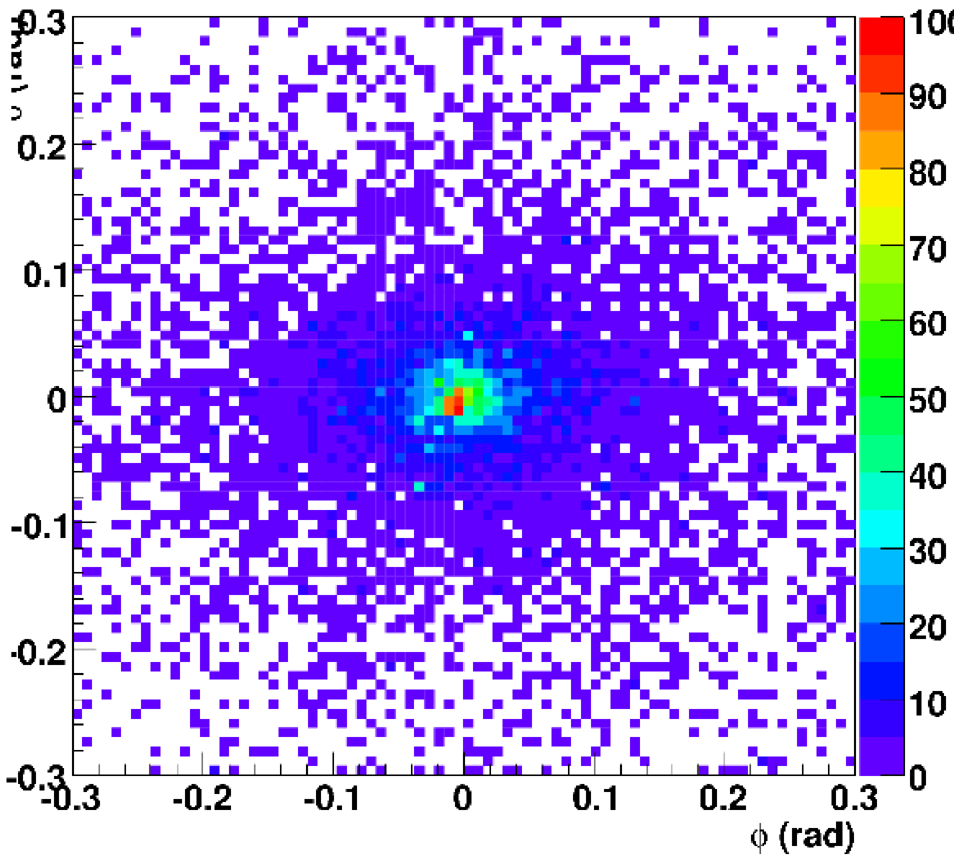


Bursts of (jet) activity with extreme local hit density

Pattern recognition

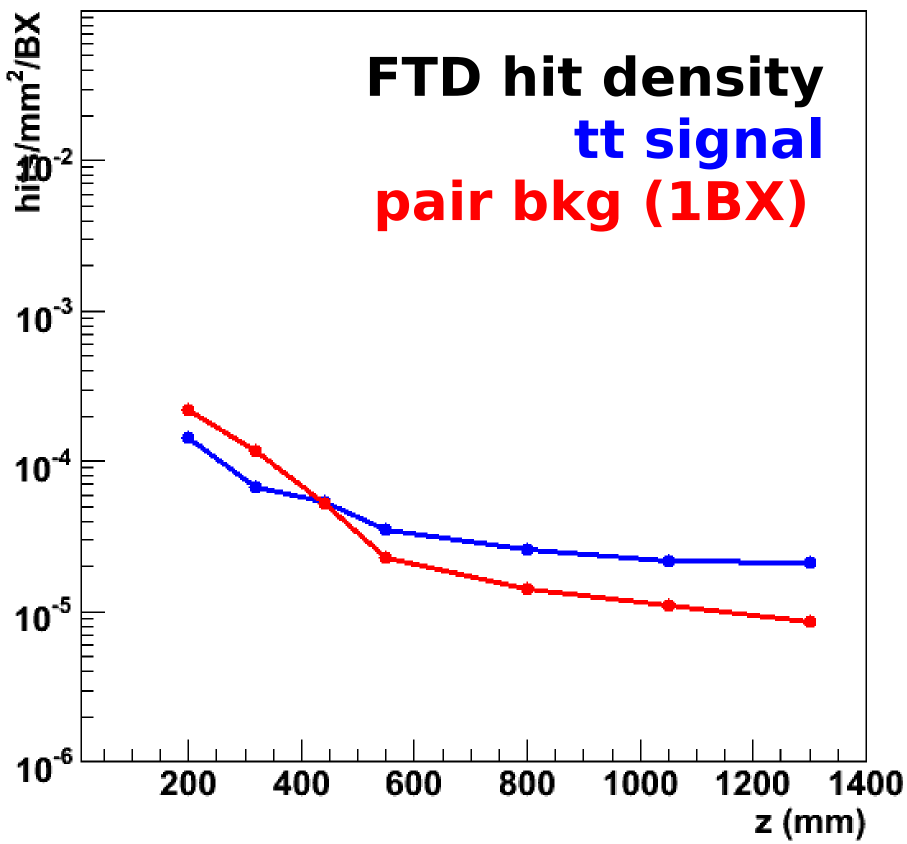
Pattern recognition for very forward tracks (θ < 20°):

Moderate average occupancy, but... peak density much larger:
<u>Signal (jets):</u>.......... x 100



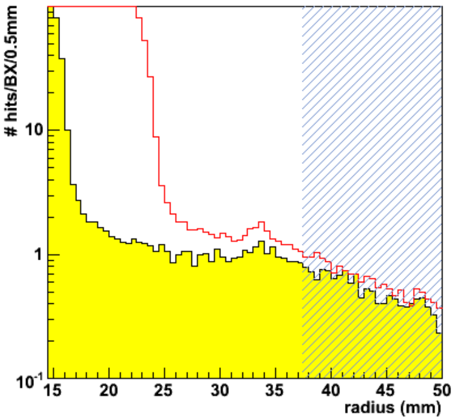
Pattern recognition

Pattern recognition for very forward tracks (θ < 20°):



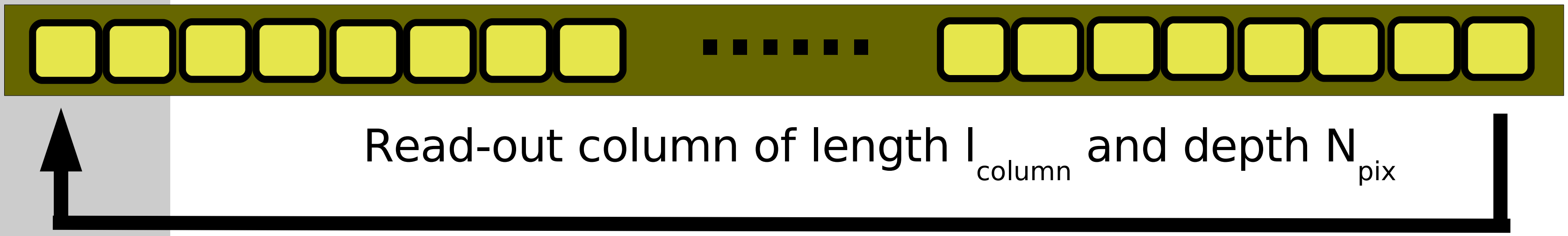
Significant background: hit density due to a single BX comparable to that of a tt-event

Inner ring of the disks has a factor 5 higher hit density.



Pattern recognition

Integrating/Time slicing detector: Rolling Shutter read-out

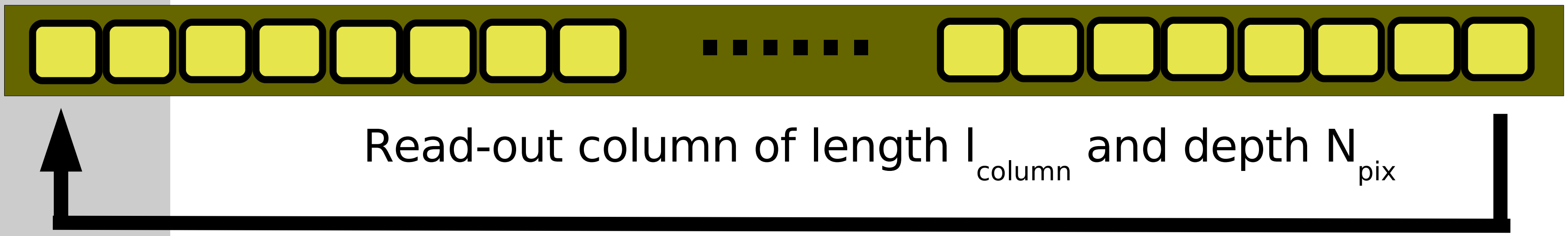


For pixel size (along the column direction) d and a read-out time per pixel t_{pix} the integration time to read a complete frame is given by:

$$\mathbf{t_{frame} = t_{pix} \times N = t_{pix} \times l_{column} / d}$$

Pattern recognition

Integrating/Time slicing detector: Rolling Shutter read-out



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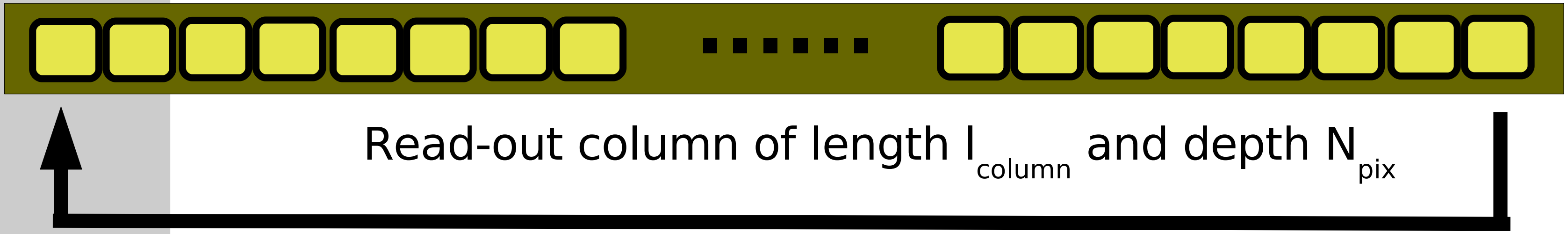
Pixel read-out time constrained by technology

R&D is the only way to bring it down

Pattern recognition

Integrating/Time slicing detector: Rolling Shutter read-out



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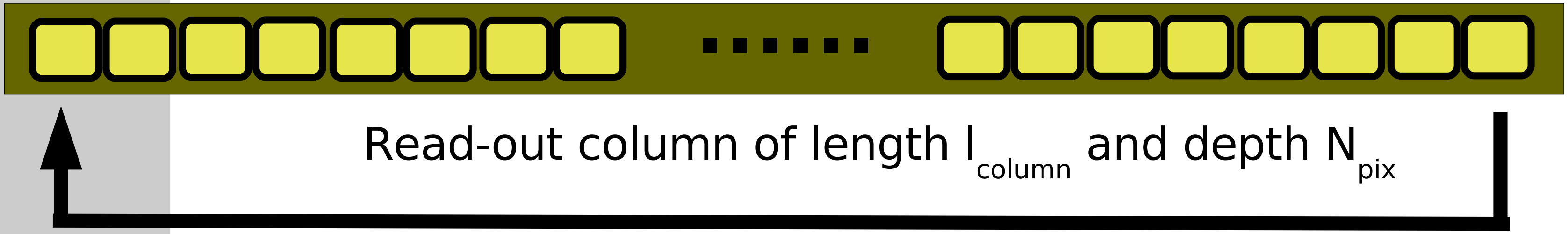
Column length tightly linked to detector layout, keep the material and power consumption minimal

Pattern recognition

Integrating/Time slicing detector: Rolling Shutter read-out



For pixel size (along the column direction) d and a read-out time per pixel t_{pix} the integration time to read a complete frame is given by:

$$t_{frame} = t_{pix} \times N = t_{pix} \times l_{column} / d$$

Pixel size determines spatial resolution

tightly constrained in VXD

z- and R-resolution in tracker

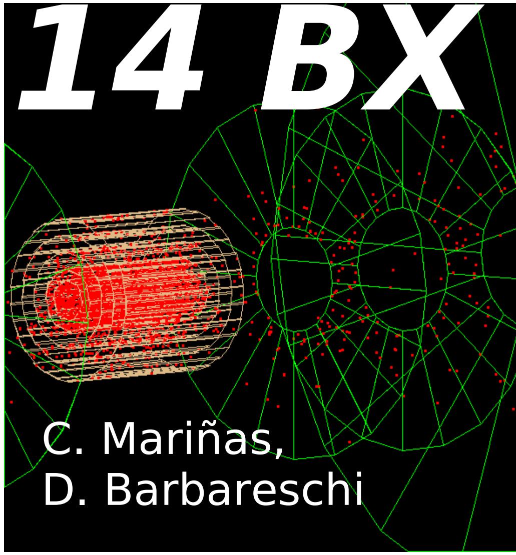
Pattern recognition : connect the dots

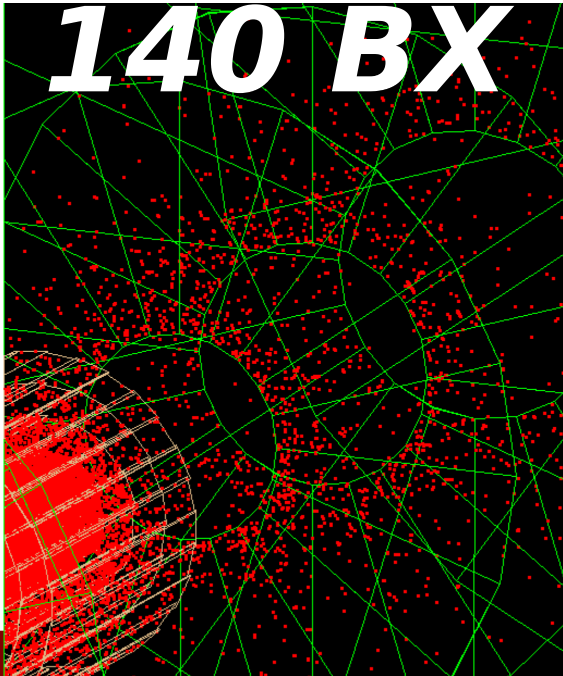
Under variations of the pixel size

(with fixed power budget; column length and pixel read-out time):

- the (dominant) background occupancy is constant

- the number of hits (per area) $\propto t_{frame}$, i.e. 1/d

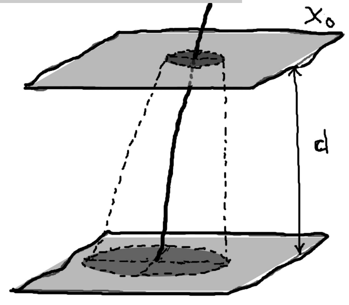




Technology	Cell area (µm x µm)	Integration time	Peak occupancy
VXD	25 x 25	50 µs	$6 \times 10^{-6} + 1 \times 10^{-6}$/BX
Hybrid pixel	50 x 500	300 ns	$2 \times 10^{-4} + 4 \times 10^{-5}$/BX
µ–strip	50×10^{5}	50×10^{5}	5 % + 1 %/BX

Typical occupancies on first FTD disks (signal + bkg/BX)

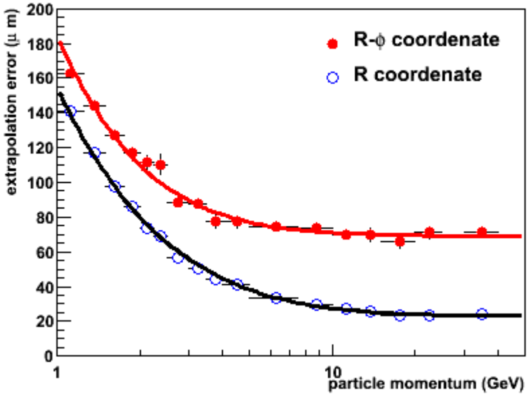
Pattern recognition: quality markers



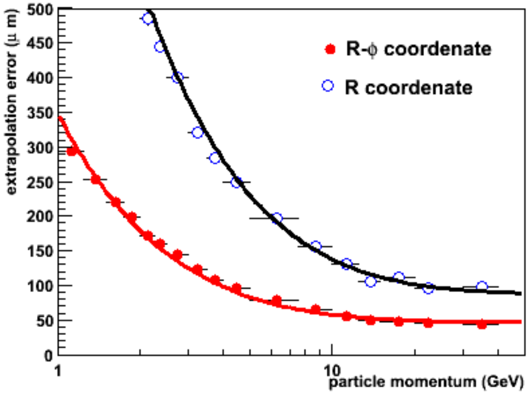
Compatibility of track stub and hit. Extrapolated window is a function of track parameter errors, material (multiple Coulomb scattering) and distance between disks.

Extrapolation precision

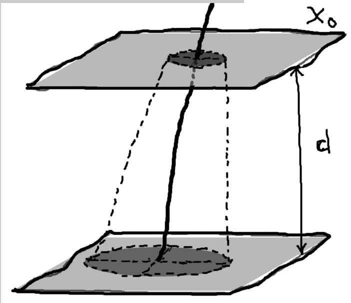
Innermost disks
R very precise (pixel detectors)
R ϕ -> weakly constrained p_T



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

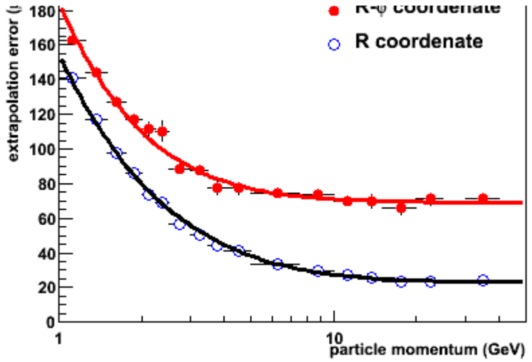


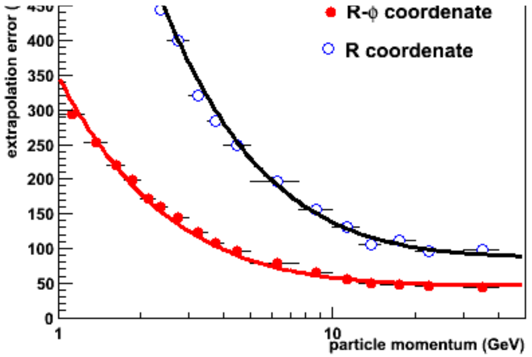
Pattern recognition: quality markers



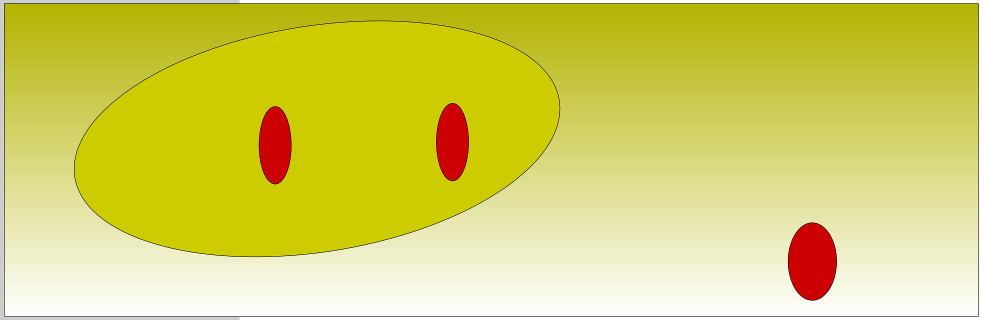
Compatibility of track stub and hit. Extrapolated window is a function of track parameter errors, material (multiple Coulomb scattering) and distance between disks.

Large distance (10-30 cm) between Forward Tracking Disks, in combination with abundant low momentum tracks (loopers), lead to large extrapolation errors



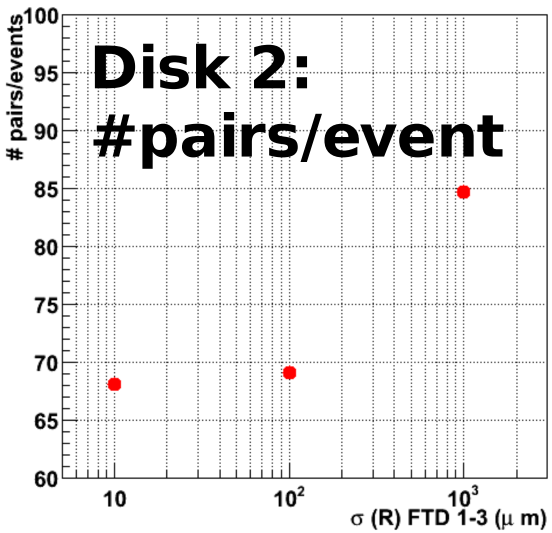


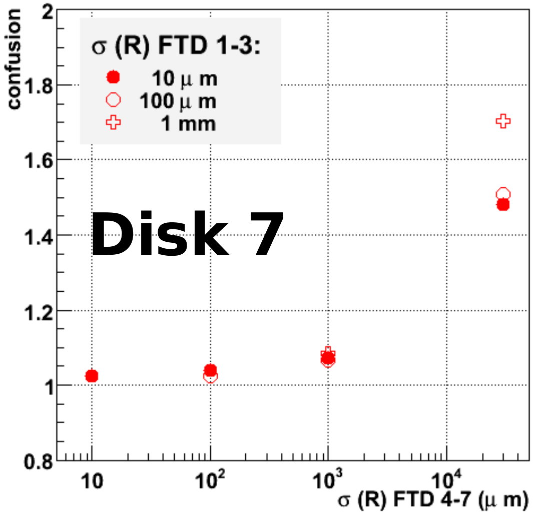
Pattern recognition: quality markers



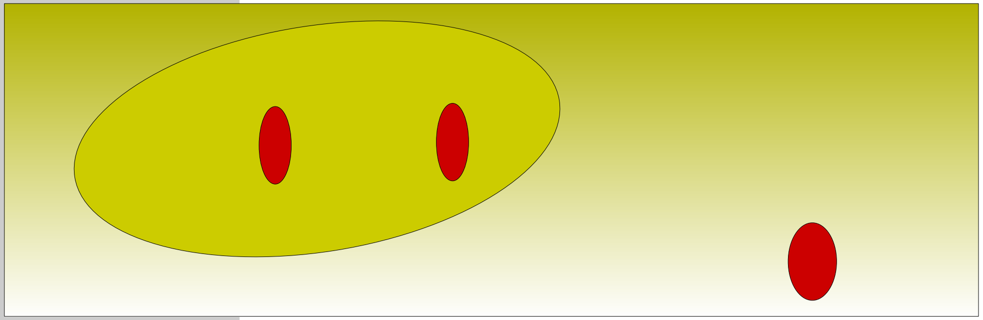
Confusion: the number of hits compatible with the extrapolated position

Confusion



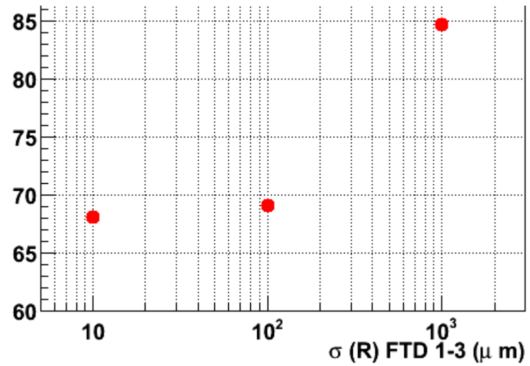


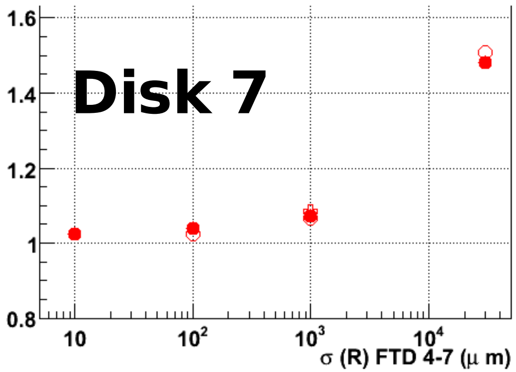
Pattern recognition: quality markers



Confusion: the number of hits compatible with the extrapolated position

Reduce frequent ambiguities in innermost tracking disks by fine segmentation
Moderate (stereo-measurement) segmentation sufficient in outermost disks





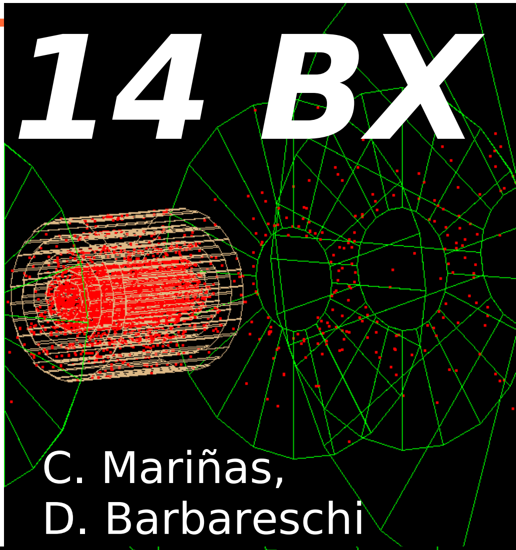
Pattern recognition: detector parameter scan

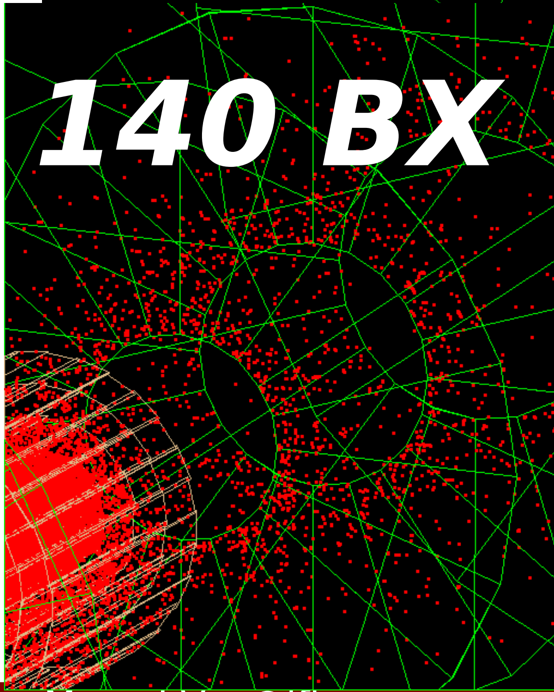
The stand-alone FTD is able to resolve patterns down to a p_T of 100 MeV, provided:

R-segmentation: in innermost disks < 500 μm,
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





Forward tracking requirements

Challenges of ILC very Forward Tracker are being studied in detail . Write-up of results in progress
(see simulation session and http://ific.uv.es/~vos/ilc/ilcFastForward)

As a result of relative small distance to interaction point and non-negligible background level, the very forward region has a specific set of requirements:

- tight control of material budget $\rightarrow$ 0.2-0.5 % X0
- best achievable R ϕ resolution $\rightarrow$ 5 μm
- moderate segmentation in R $\rightarrow$ 500 μm – 1 cm
- moderate background level $\rightarrow$ 1-2 x 10^{-4} hits/mm^2/BX
- fast read-out $\rightarrow$ < 10 BX

ILD study, but with a clear overlap with SiD

Tools – track fitting

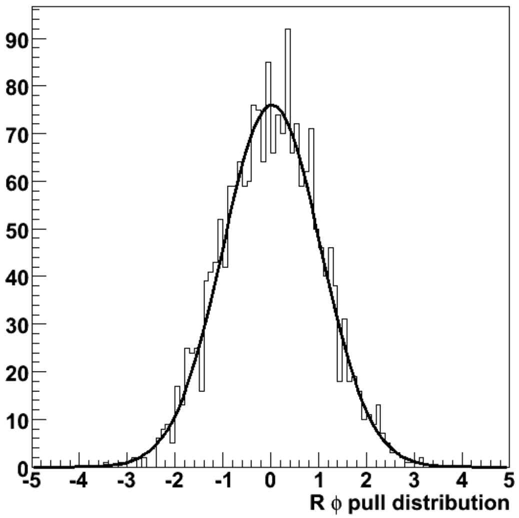
CMS Kalman filter tool-kit.

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

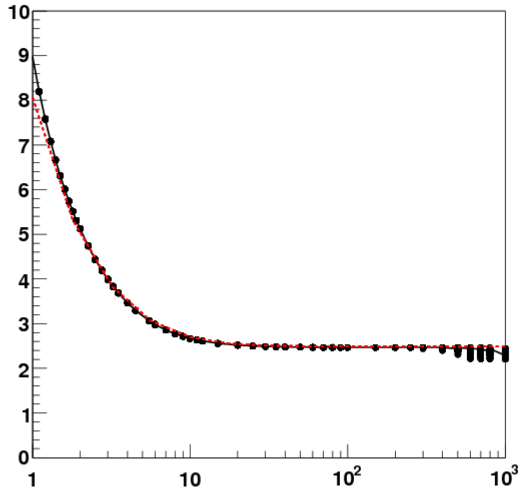
Extracted all relevant code in a series of libraries with limited external dependencies (CLHEP, ROOT).

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)



pull distribution R ϕ coordenate at last measurement plane



LCDTRK vs. KF: Transverse impact parameter resolution vs p_T

Conclusions

“Tracking” and “vertexing” are a somewhat artificial distinction, as are “tracker” and “vertex detector”

Try to distinguish detector regions with specific environment and requirements:

- innermost layers (d < 10 cm): granularity and space point resolution push integration time to the limit

- outermost layers (R > 30 cm): background negligible, spatial granularity therefore possible, but maybe not required

- intermediate central (10 < R < 30 cm): spatial granularity required, and the background level allows for it

- innermost forward (R < 20 cm): compromise between spatial and time granularity

Coordinated ILC effort in Spain

Several of these groups have expressed an interest in finding solutions for very forward tracking...

Pattern recognition: full simulation/reconstrucion

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 μm R-ϕ 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.

Very forward tracking: the forgotten problem?

A few extracts from the tracking review document (Beijing, February 2007)

[...] it will be vital that the tracking system should for the first time perform as well in this [the forward] region as in the central region
executive summary, page 2

It is clear that excellent tracking performance in the forward region is obligatory
introduction, page 5

There is considerable uncertainty regarding the degradation in physics potential resulting from a given material budget, and this is a particularly serious issue in the forward region, where there tends to be an accumulation of material
introduction, page 5

CSIC

IFIC

Momentum resolution

Physics requirement: in the literature one finds: down to

$$\Delta (1/p_T) = 10^{-5}\ \mathrm{GeV}^{-1}$$

the Higgs mass resolution in the recoil analysis is dominated by the tracker resolution.

Caveat I: Higgs-strahlung yields very central distribution

Caveat II: $\Delta (1/p_T)$ is only constant if multiple scattering can be ignored.

But: for Higgs-strahlung at $\sqrt{s}$ = 250 GeV and very forward muons – $\theta < 20$ degrees- the average p_T is reduced to a mere 13 GeV/c.

Caveat III: the very forward region – due to the less favourable orientation of the magnetic field – performs worse than the central tracker, even if it is equally well instrumented.

Must consider other benchmarks: sleptons, luminosity from $e^+e^- \rightarrow \mu^+\mu^-$