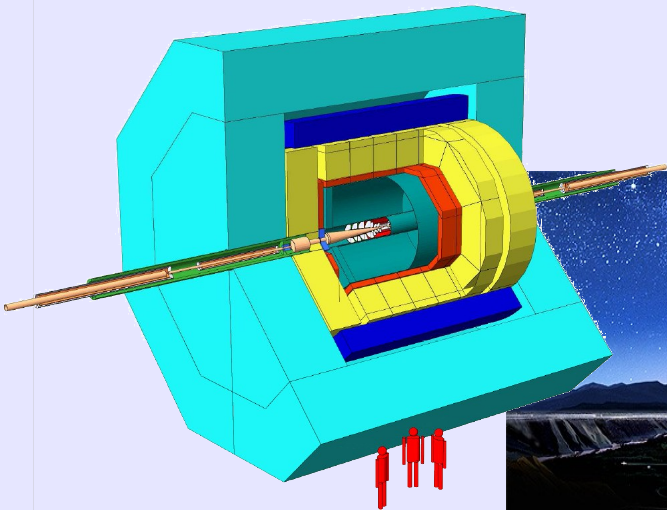
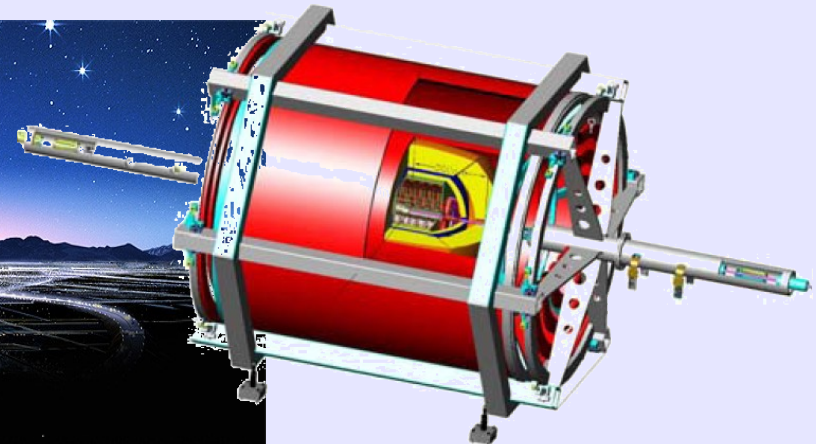
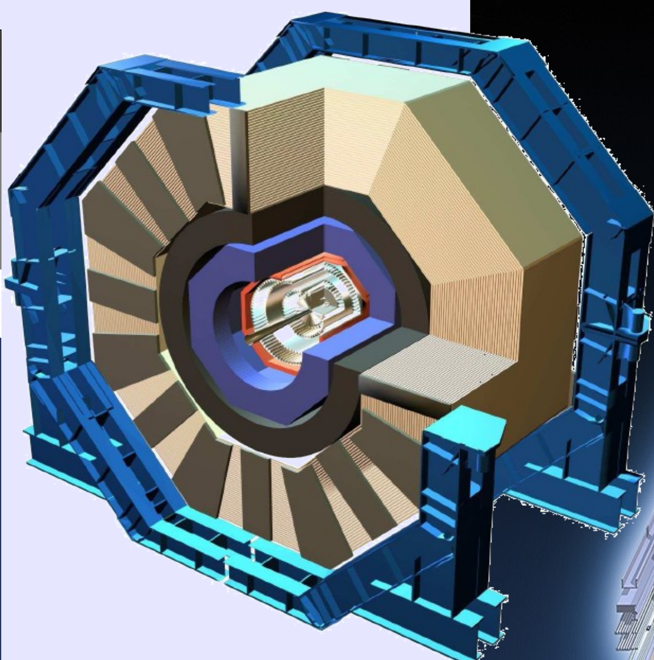
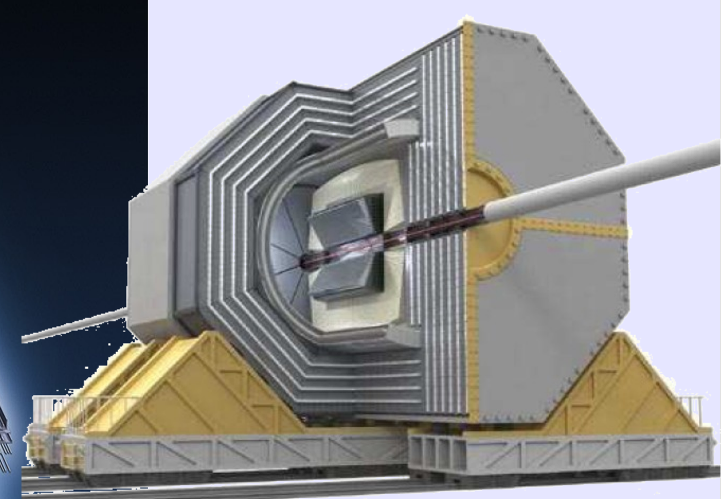
Tracking and alignment at the ILC









Tracking and alignment at the ILC

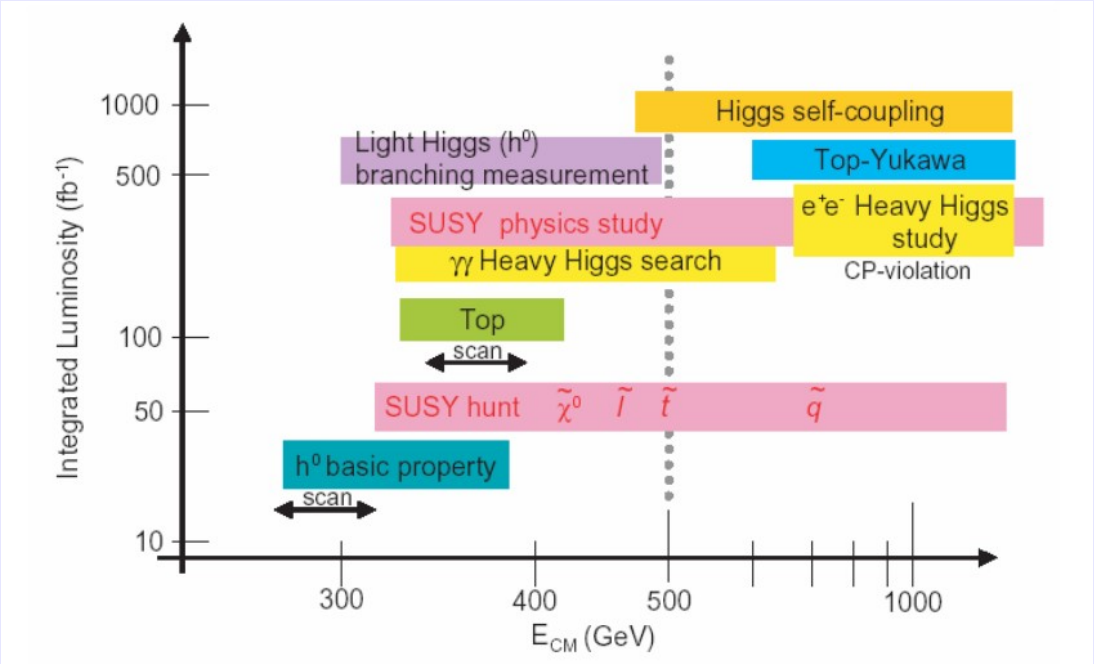
Marcel Vos, IFIC, U. Valencia/CSIC

- Some goals
- Some philosophy
- Important requirements
- The “benign” environment
- The technology – ILC detector R & D
- The detector concepts
- The alignment challenge

The Goals

Much has been said about the complementarity of LHC and ILC hysics interplay of the LHC and the ILC.

- LHC/LC Study Group (G. Weiglein et al.).Phys.Rept.426:47-358,2006
- the Linear collider physics resource book for Snowmass 2001 hep-ex/0106055 (part 1), hep-ex/0106056 (part 2), hep-ex/0106057 (part 3), and hep-ex/0106058 (part 4)
- the GLC report:



Graphical overview of the accessible physics programme as a function of √s, from GLC report

Complete discussion beyond the scope of this talk: pick a few items that have a large impact on detector design

The goal : precision EW physics

Precision EW or signal of strong EWSB?

Unconstrained kinematics needs **high resolution** cal to discriminate WWνν, WZeν, and ZZνν events.

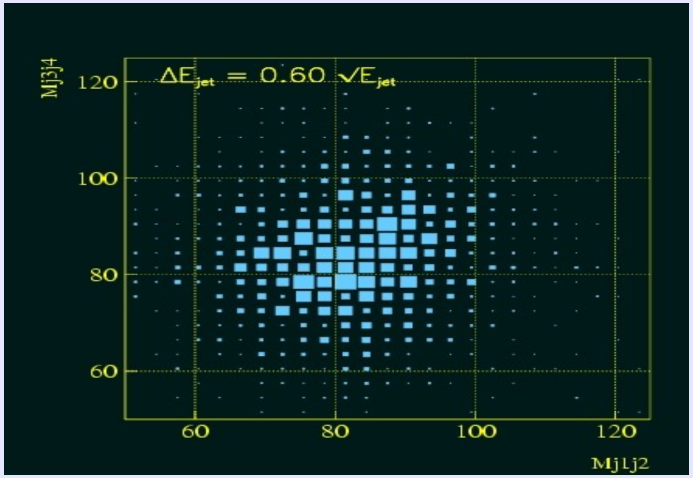
$$e^+e^- \longrightarrow WW\nu\bar{\nu} \quad , \quad e^+e^- \longrightarrow ZZ\nu\bar{\nu}$$

Measure Higgs Self Coupling λ_{hh}

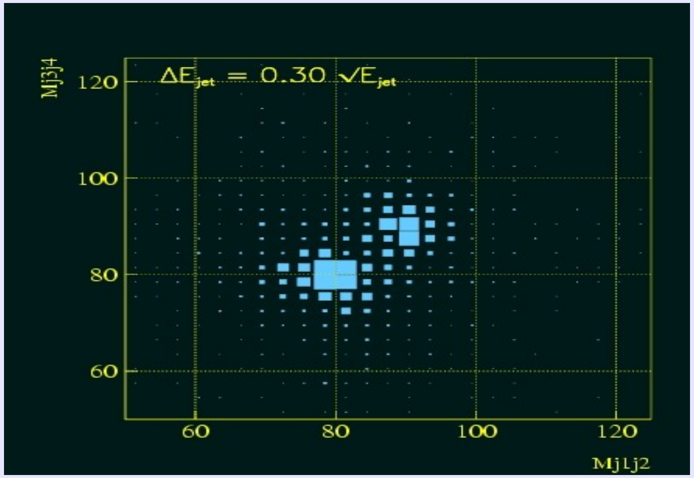
Tiny (0.2 fb @ 500 GeV) signal on large multi-jet backgrounds is only visible with

high resolution

$60\%\sqrt{E}$

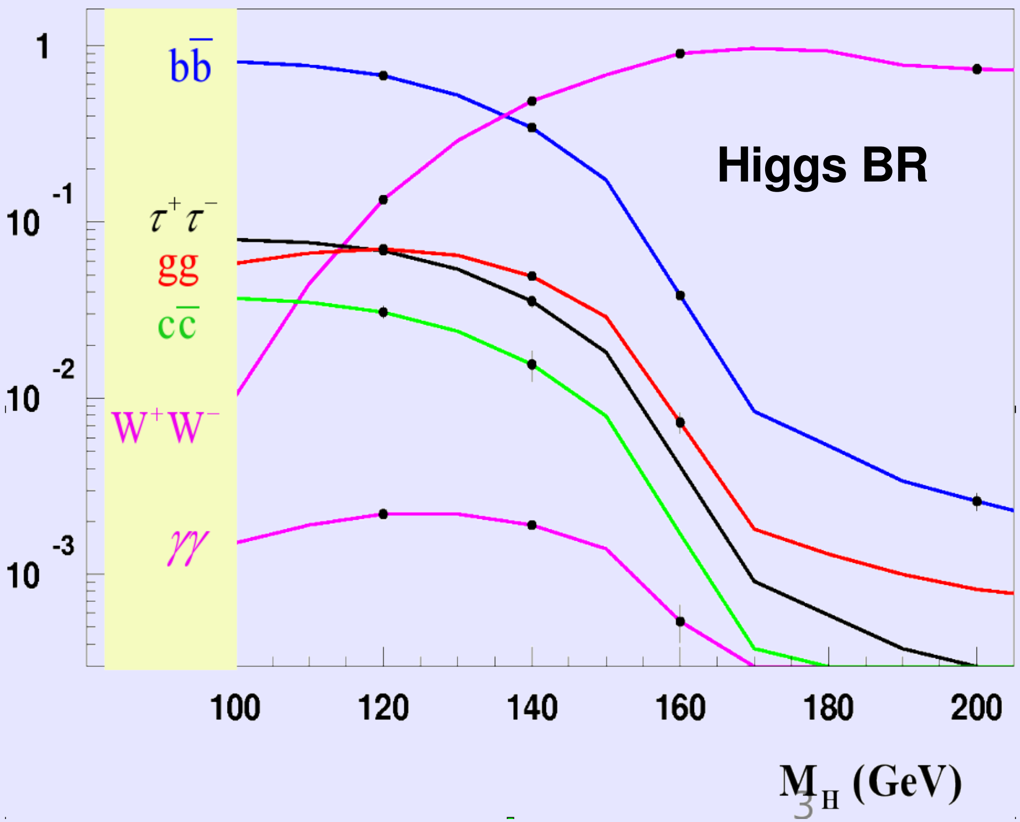


$30\%\sqrt{E}$



The goal: study Higgs properties

- ✔ **Study Higgs couplings.**
  Measurement of higgs branching fractions requires excellent flavour tagging (in particular b/c separation)

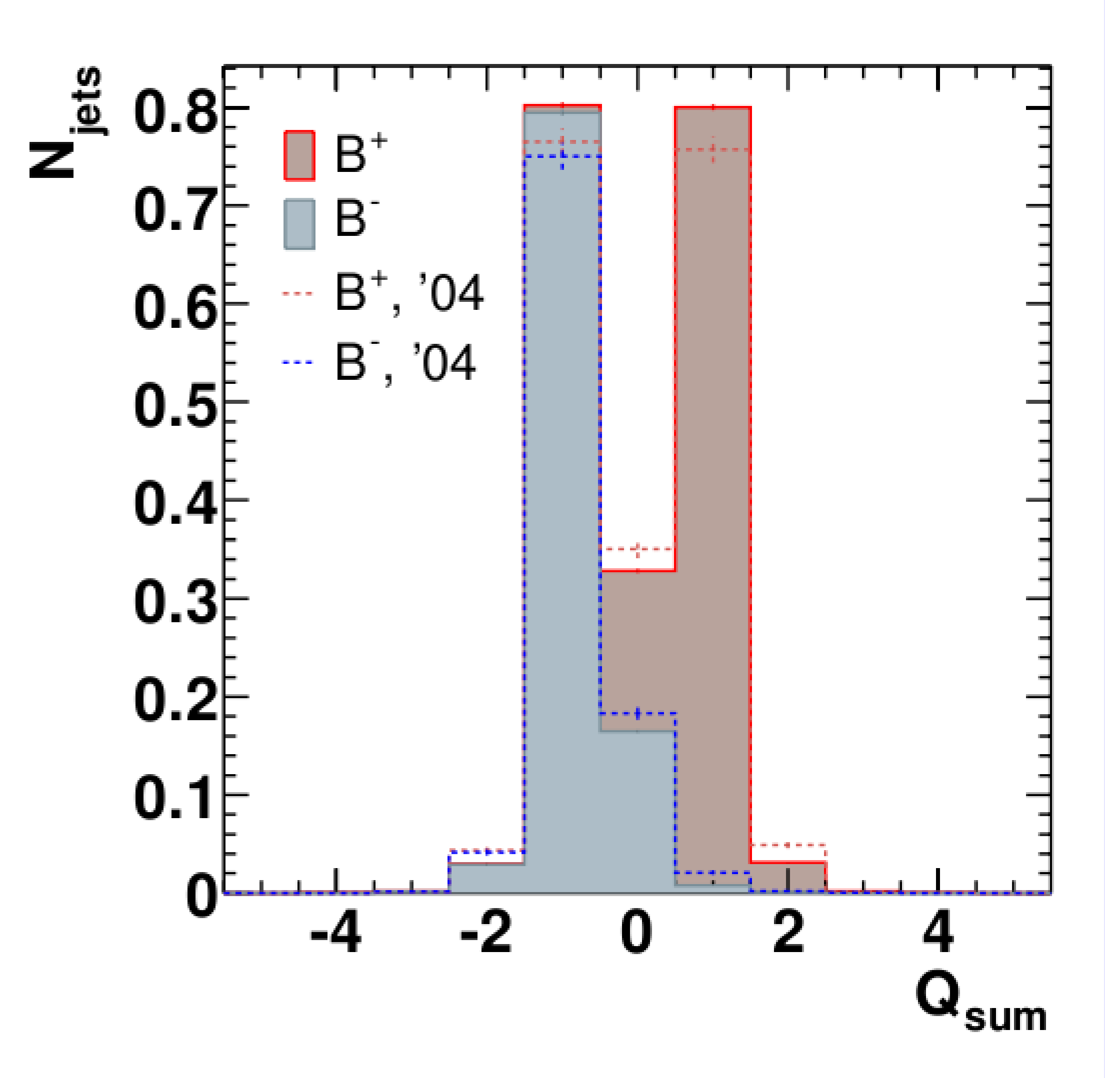


	Higgs Mass (GeV)				
	115	120	140	160	200
$\Delta B_{bb}/B_{bb}$	±0.015	±0.016	±0.018	±0.020	±0.090
$\Delta B_{WW}/B_{WW}$	±0.024	±0.020	±0.018	±0.010	±0.025
$\Delta B_{gg}/B_{gg}$	±0.021	±0.023	±0.035	±0.146	
$\Delta B_{\gamma\gamma}/B_{\gamma\gamma}$	±0.055	±0.054	±0.062	±0.237	
$\Delta\Gamma_{tot}/\Gamma_{tot}$	±0.035	±0.034	±0.036	±0.020	±0.050

Estimated precision for Higgs BR combining results from a 350 GeV and a 1 TeV linear collider, T. Barklow, Les Houches 2003, hep-ph/0406152

The goal: precision measurements

- **Vertex charge** (challenging since it demands correct track association even for very low momentum)
  - Top polarization,
  - W helicity,
  - qqbar asymmetries

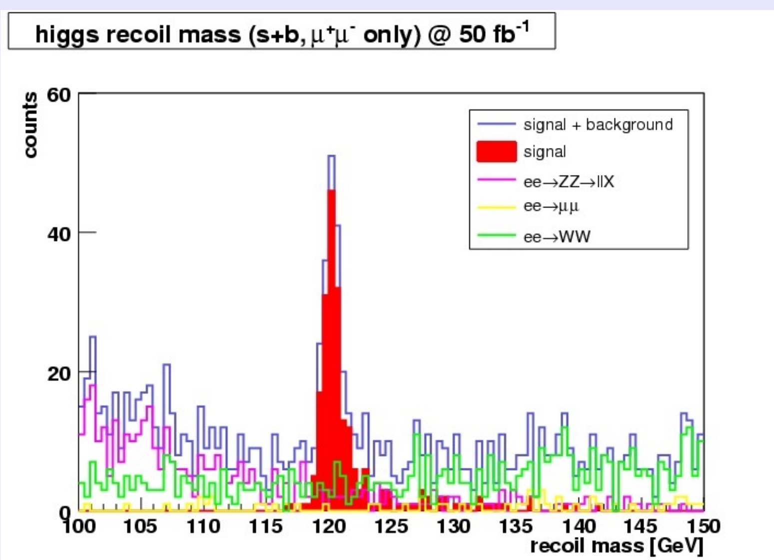


Vertex charge measurement

S. Hillert for the LCFI collaboration, 2005 International Linear Collider Workshop - Stanford, U.S.A.

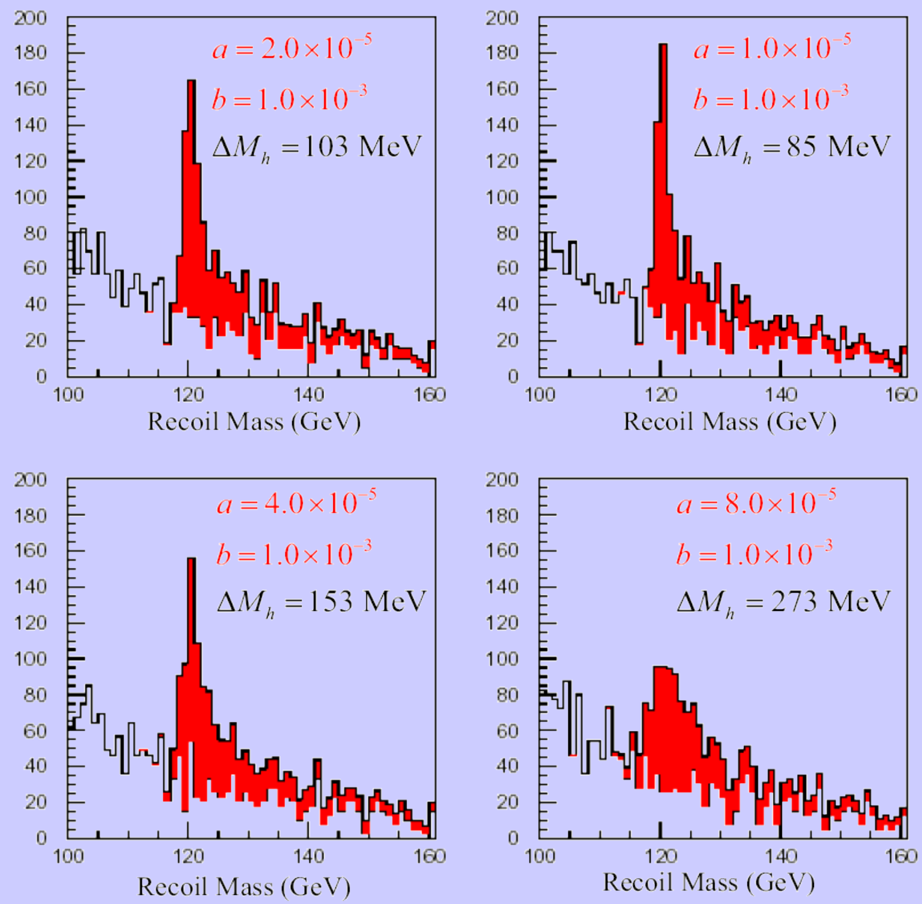
The goal : Higgs mass measurement

- Recoil mass analysis in ZH systems allows to determine the Higgs mass precisely, even for invisible Higgs decay.
- Beam spread has small influence: mass resolution dominated by tracker performance down to
  $\Delta p/p^2 \sim 1 \times 10^{-5}$ (Yang and Riles)
- Expected precision (Tesla): 40 MeV to 70 MeV for m_H between 120 GeV and 180 GeV.



Golden channel e+e- → HZ → μμX

Model independent measurement of Higgs mass



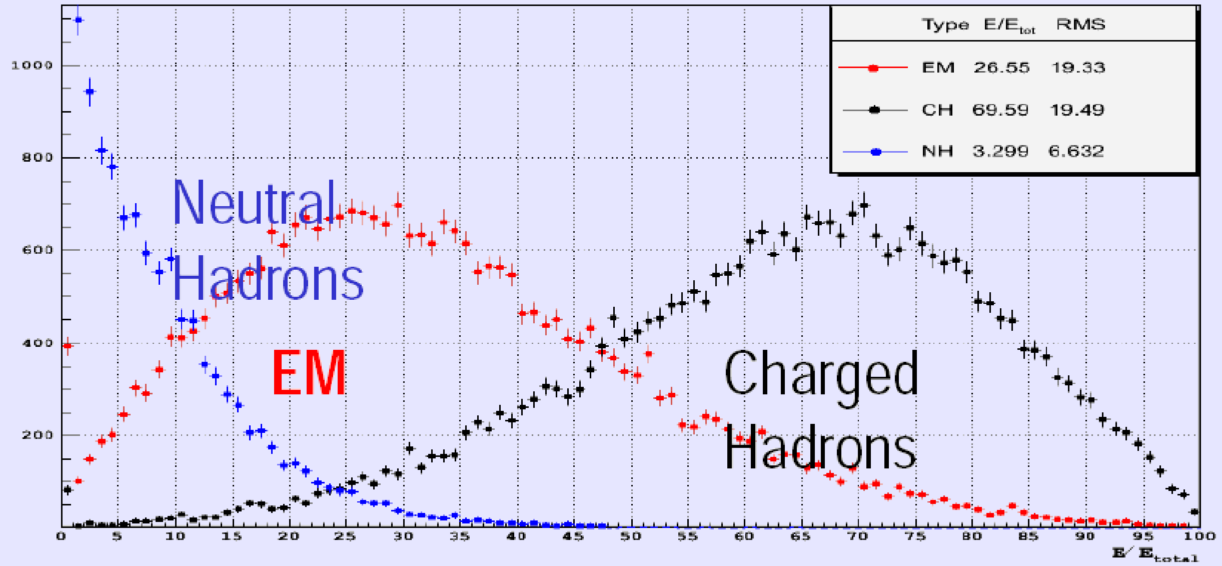
Full simulation study, M. Ohlerich, A. Raspereza, W. Lohmann, ACFA linear collider workshop, Beijing 2007

The philosophy: reconstruction

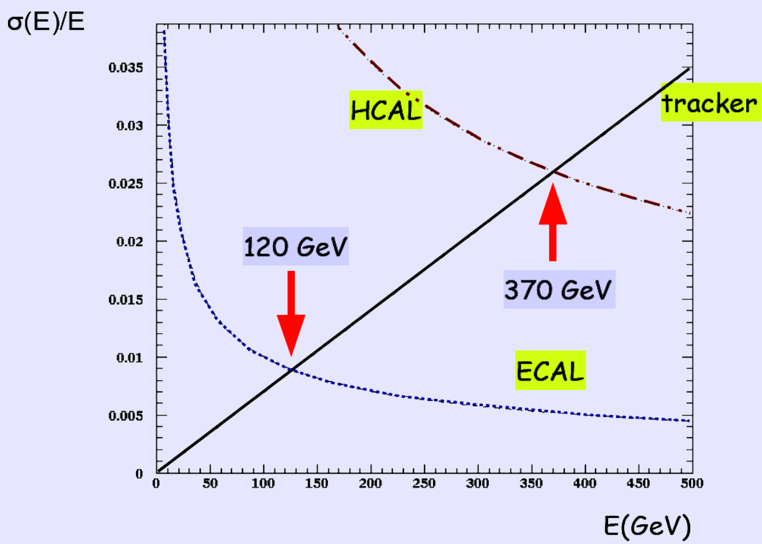
ILC precision is limited by the detector rather than by the environment

- Hadronic final states (jets):
  - precise jet energy measurement is crucial
  - flavour tagging, jet charge
- Leptons up to $\sqrt{s}$ / 2
  - P_T resolution requirement driving tracker design

The philosophy: particle Flow

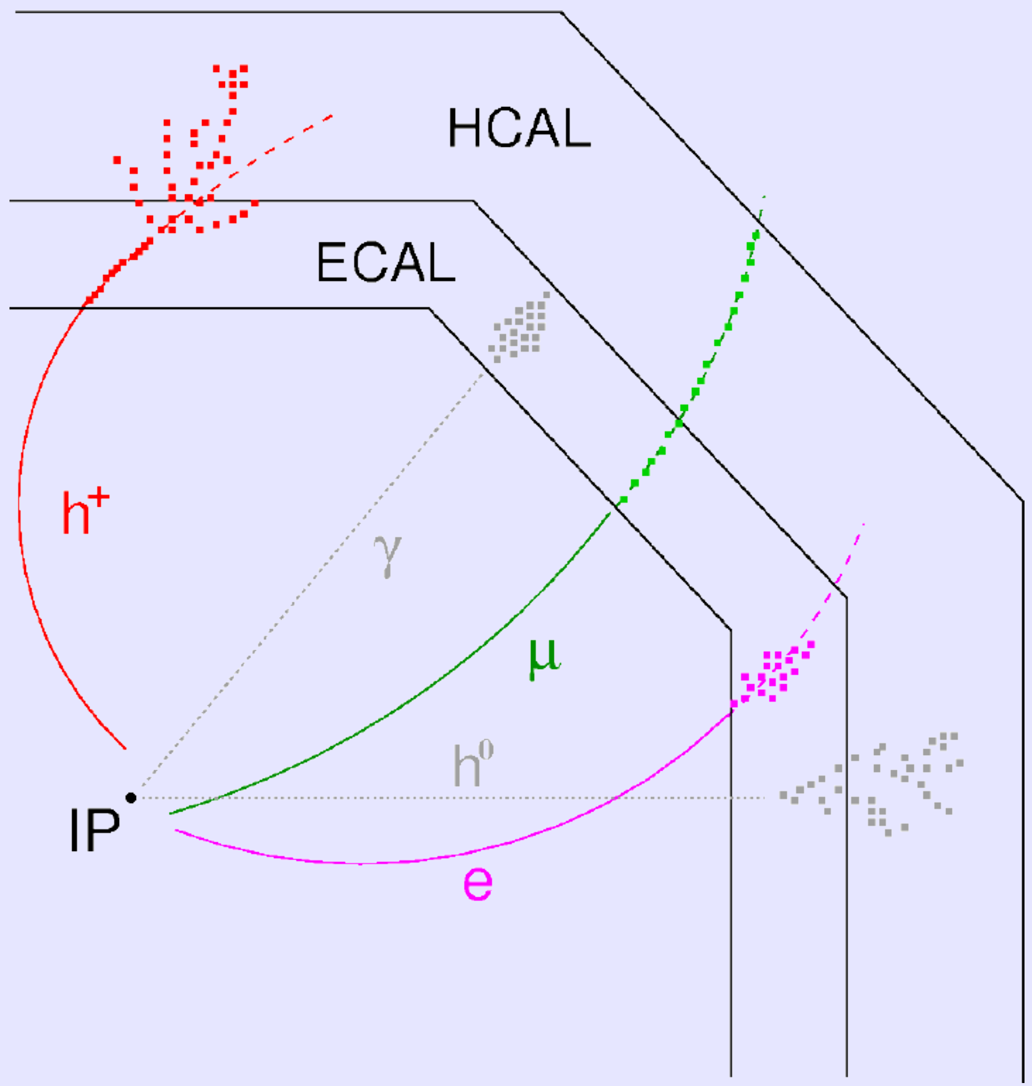


- In the LC the visible jet energy is ~64% due to charged particles
- For the ILC energies the tracker is more precise than the calorimeters: combine p (tracker) and E (calorimeter) measurements
- Novel high-granularity calorimeters are very fit to this concept
- Particle flow emphasizes the role of the tracker in jet physics



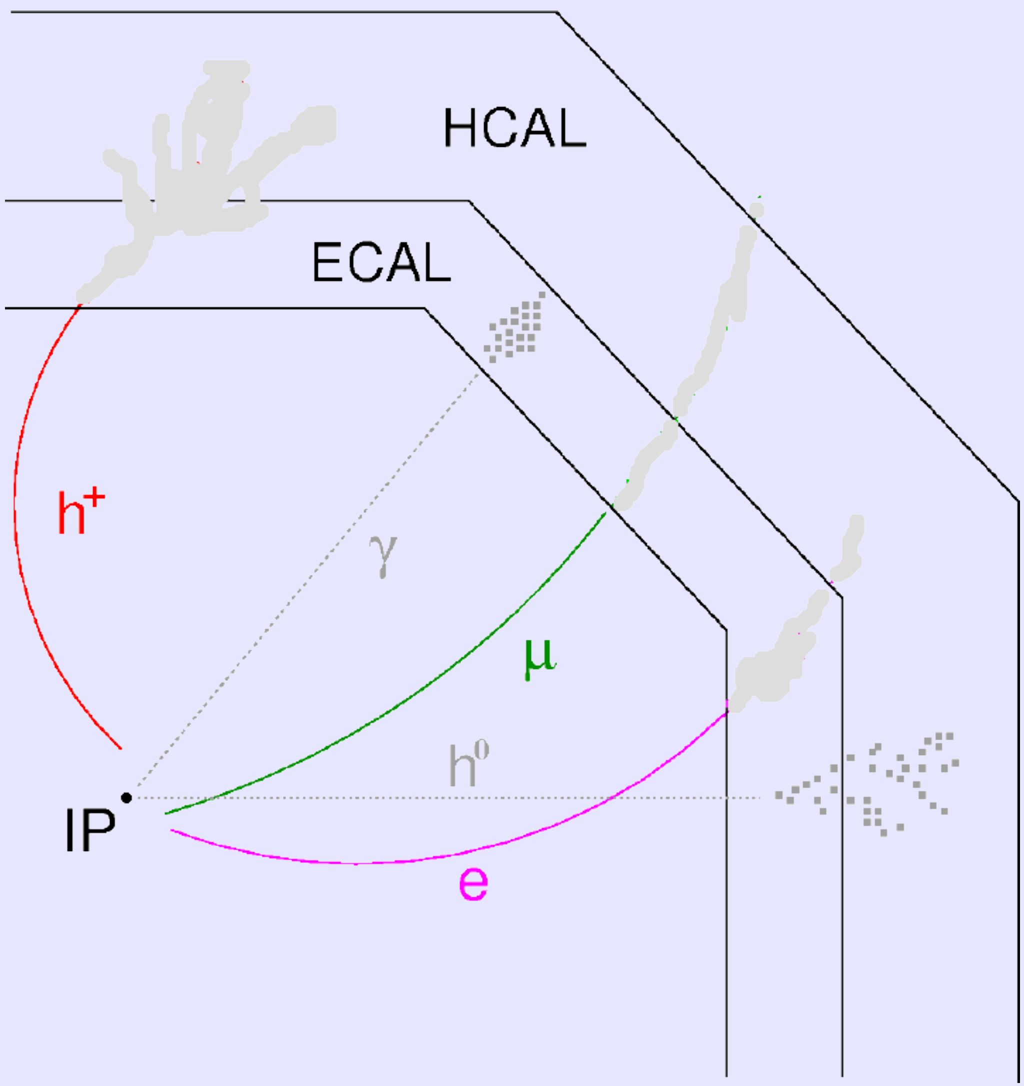
Particle Flow: How does it work ?

- ✔ Track reconstruction
- ✔ Extrapolate tracks to calorimeters
- ✔ Assign MIP stubs to tracks
- ✔ Clustering in calorimeters
- ✔ Particle ID for charged particles



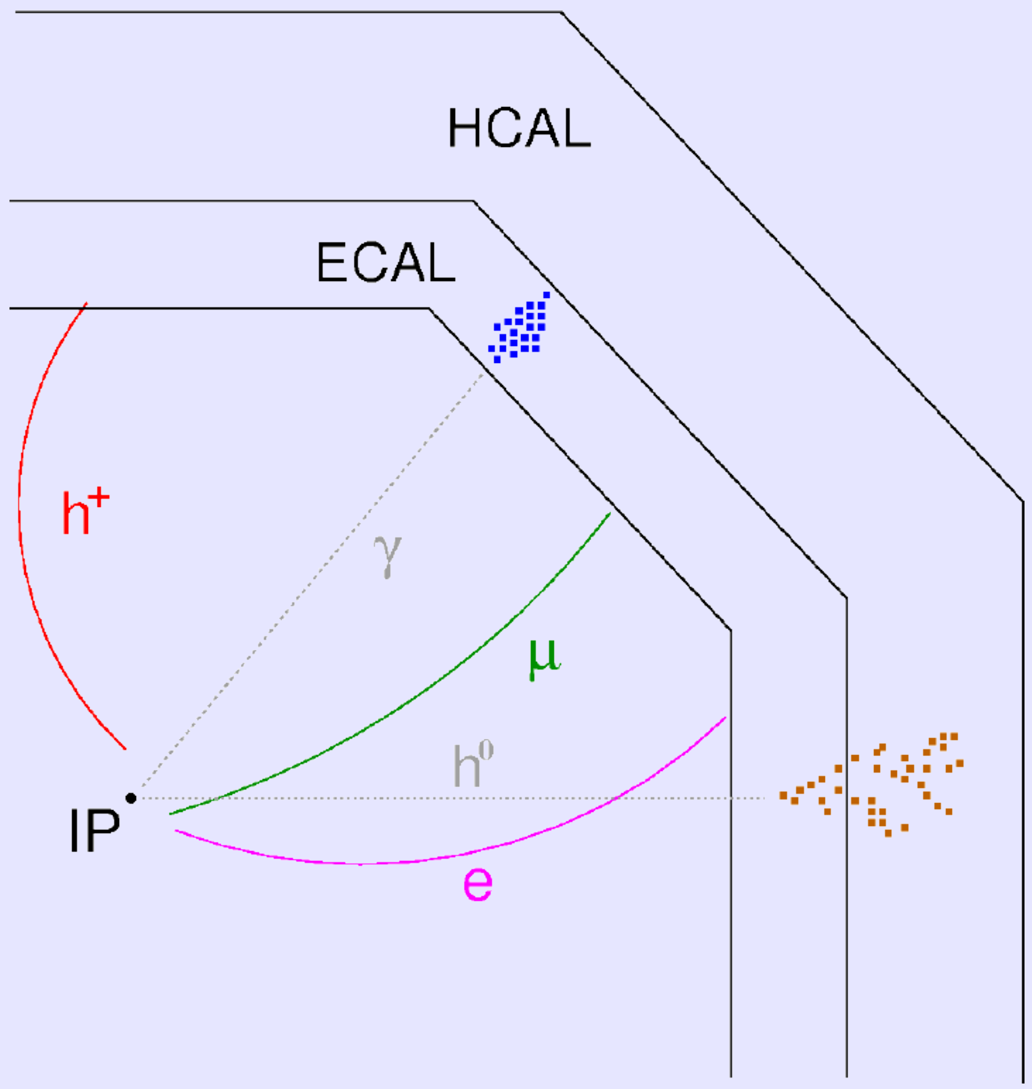
Particle Flow: How does it work ?

- Track reconstruction
- Extrapolate tracks to calorimeters
- Assign MIP stubs to tracks
- Clustering in calorimeters
- Particle ID for charged particles
- Remove charged particle hits in calorimeter



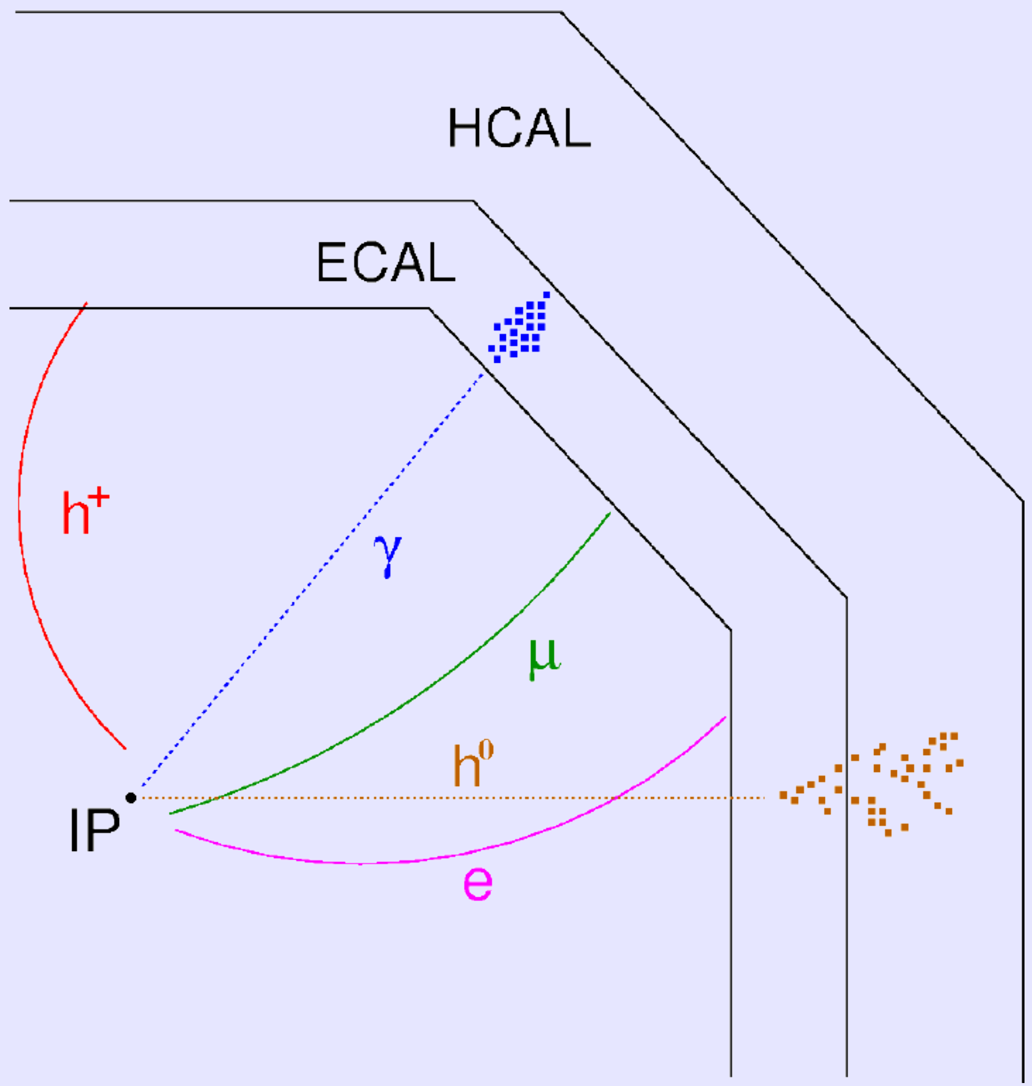
Particle Flow: How does it work ?

- Track reconstruction
- Extrapolate tracks to calorimeters
- Assign MIP stubs to tracks
- Clustering in calorimeters
- Particle ID for charged particles
- Remove charged particle hits in calorimeter
- Clustering of neutral hits



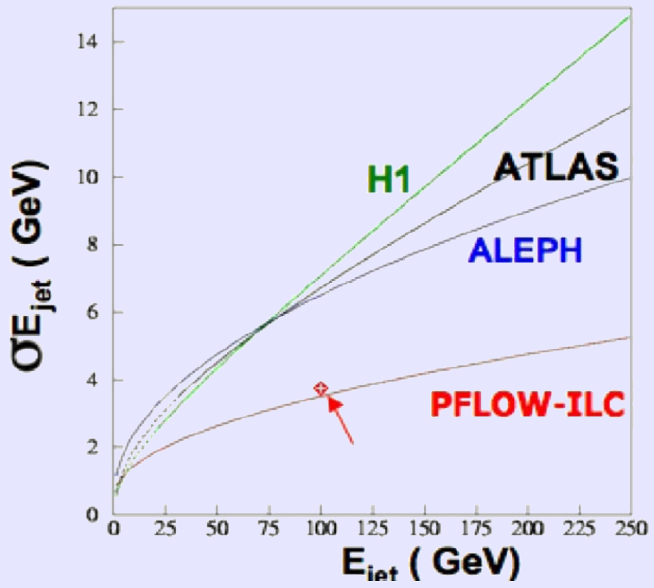
Particle Flow: How does it work ?

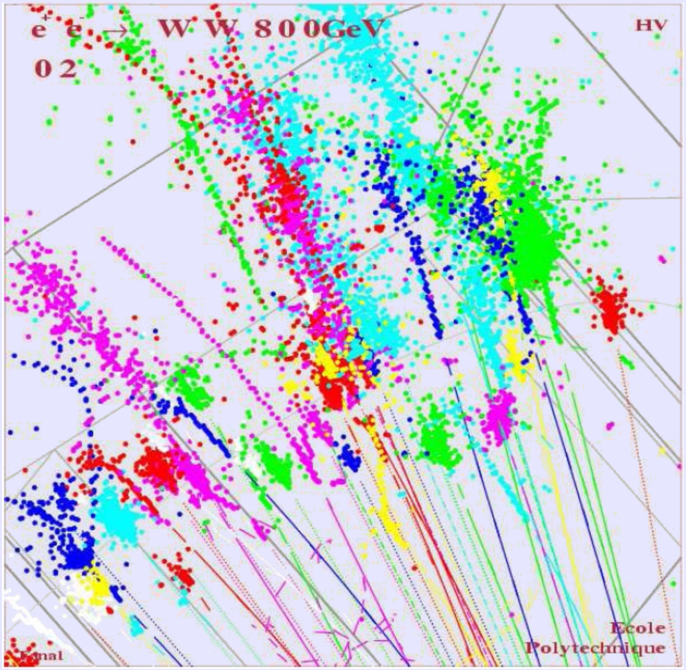
- ✔ Track reconstruction
- ✔ Extrapolate tracks to calorimeters
- ✔ Assign MIP stubs to tracks
- ✔ Clustering in calorimeters
- ✔ Particle ID for charged particles
- ✔ Remove charged particle hits in calorimeter
- ✔ Clustering of neutral hits
- ✔ Particle ID for neutrals



Particle flow

- Particle flow concept studies show that the required performance can be achieved at low energy (E < 150 GeV)
- The ILC detectors are designed having in mind the PFA which in a large extent defines the detectors
- Main problem: confusion
  - At high energies jets are very narrow
    - Difficult to associate hits to tracks
    - Yet more difficult to separate charged and neutral particles.
  - Need high granularity and sophisticated software to separate showers
- The key issue is particle separation rather than intrinsic energy resolution.

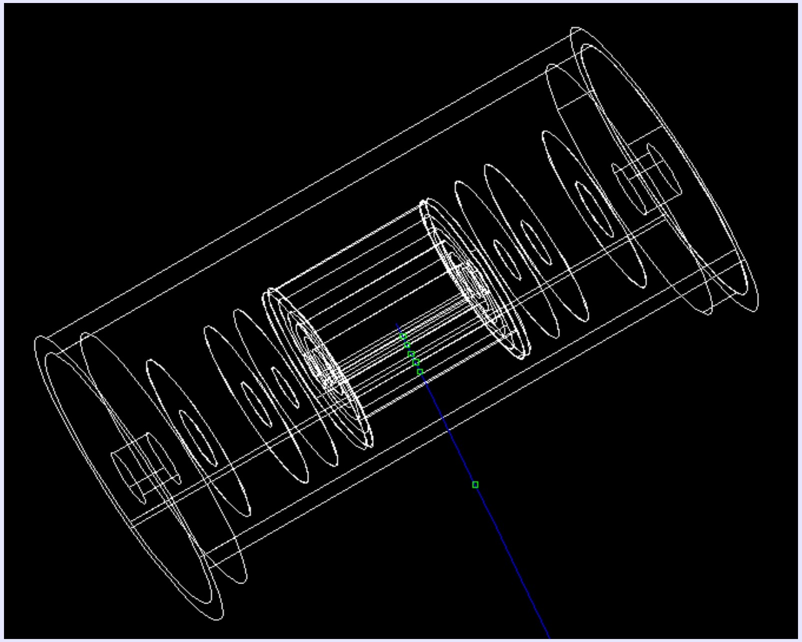




The philosophy: vertexing

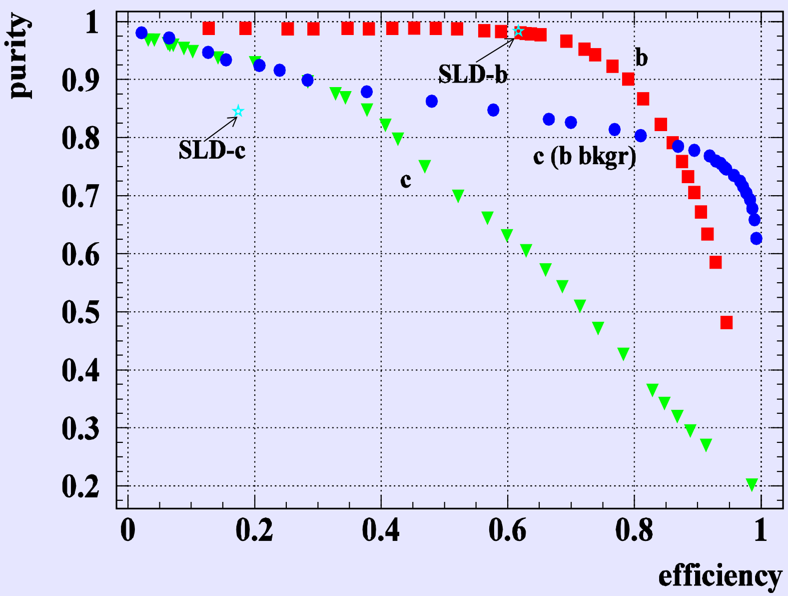
To Achieve ($5\mu m \oplus 10\mu m/(p \sin^{3/2}\theta)$)

- get real close: 12 – 20 mm inner radius!
- Excellent spacepoint precision (< 5 μm)
- Transparency (~0.1% X_0 per layer)
- Occupancy innermost layers -> integration over <150 bunch crossings (45 μsec)

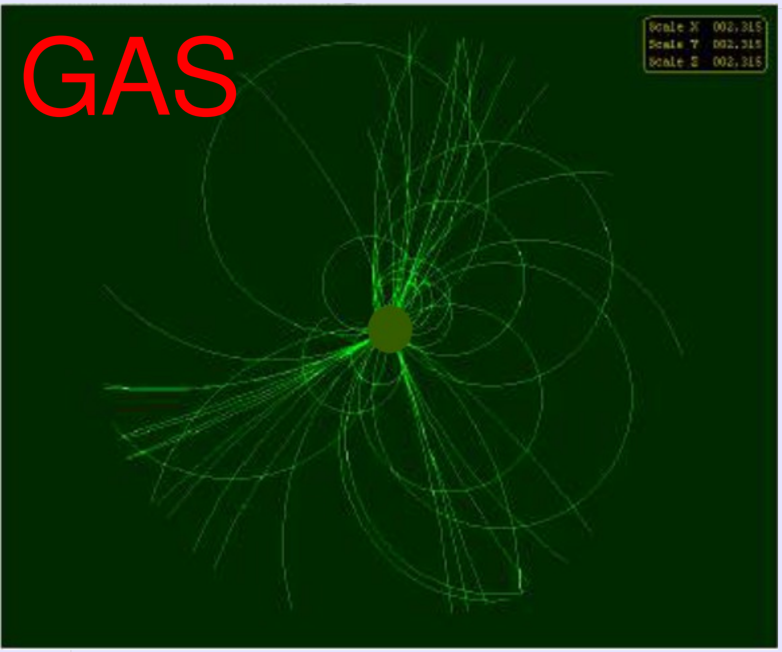


To determine Jet charge

- fully efficient and pure reconstruction down to 100 MeV -> excellent pattern recognition (5-6 high-granularity layers)



Central tracking: two philosophies



TESLA/LDC/GLD gaseous/solid tracker

TPC design/specifications

length: 5.46 m, diameter: 3.4 m, 3-4 T field

single point resolution: ~100 μm

200 space points per track

$\Delta p/p^2 = 1.5 \times 10^{-4}$ GeV^{-1} (TPC stand-alone)

dE/dx accuracy: 5 %

several % X^0 in field cage, 30-50 % X^0 in end-plate

SiD: all silicon solution

similar dimesions and magnetic field 4 T

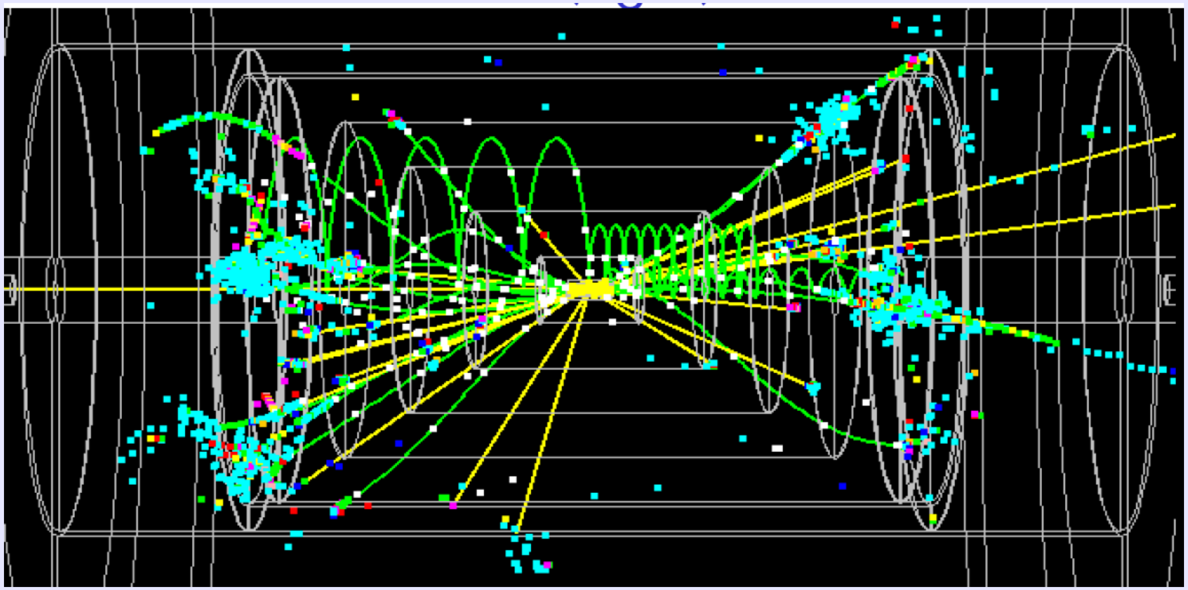
6+5 high precision measurements per track

single point resolution: 20-30 μm

$\Delta p/p^2 = 1 \times 10^{-5}$ GeV^{-1} (including VTX)

Forward Tracking

- Forward region has a very important role in the ILC
  - 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 to track loopers
- Differential luminosity requires extreme angular precision: $\Delta\theta/\theta \sim 10^{-5}$
- Never been done (right) !!!

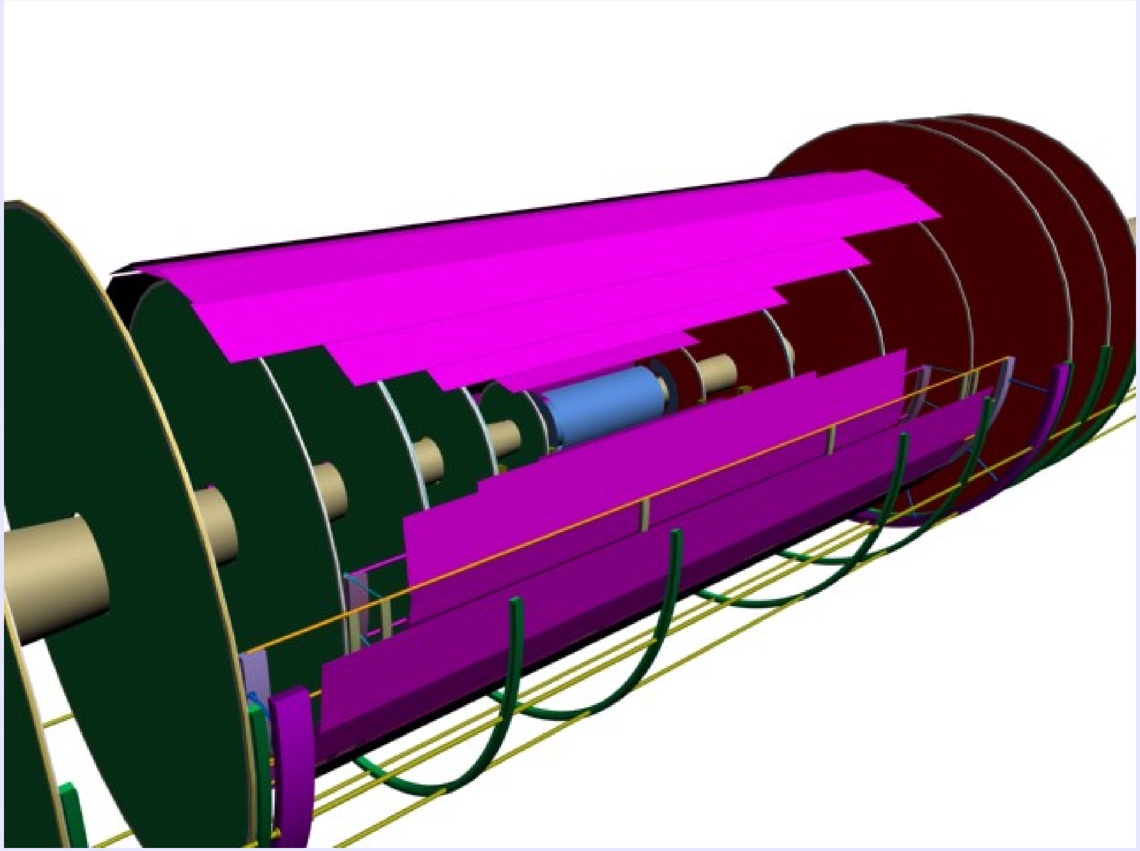


Forward tracking: the philosophy

In all concepts: silicon detector disks covering angles from 6 – 20 degrees.

Technologies: pixel/strip

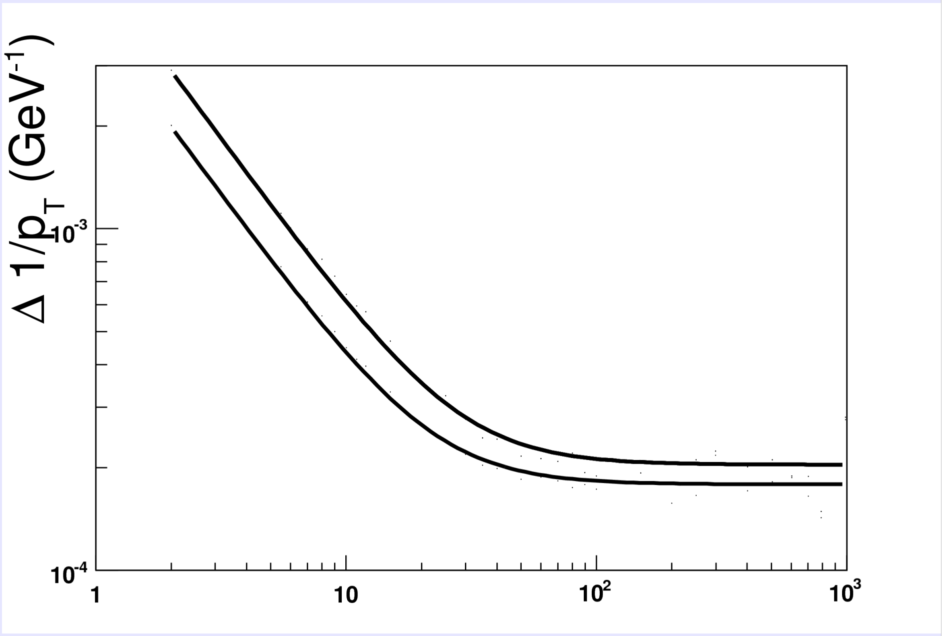
Total area (FTD in LDC) < 3 m^2



Forward tracking: material budget

CMS KF fit on toy geometry for a 20 degrees track in LDC (4 Tesla)

- 3 VXD barrel layers
  - ΔR = 1.1 cm, 1.2 ‰ X_0, σ (Rϕ, z) = 2 μm
- 3 pixel disk
  - Δz = 12 cm, 1.2‰ /1.2 % X_0, σ (Rϕ, R) = 5, 50 μm
- 4 strip disks
  - Δz = 25 cm, 8 ‰ X_0, σ (Rϕ, R) = 10, 1000 μm



P_T (GeV)

CMS KF track fit for θ = 20°

$\sigma(p_T)/p_T^2$ = $1.8 \times 10^{-4} \oplus 4.0 \times 10^{-3}/p_T$ *for 0.12 % X_0 FTD1-3*

= $2.0 \times 10^{-4} \oplus 5.8 \times 10^{-3}/p_T$ *for 1.2 % X_0 FTD1-3*

LiCToy

$\sigma(p_T)/p_T^2$ = $1.8 \times 10^{-4} \oplus 4.3 \times 10^{-3}/p_T$ *for 0.12 % X_0 FTD1-3*

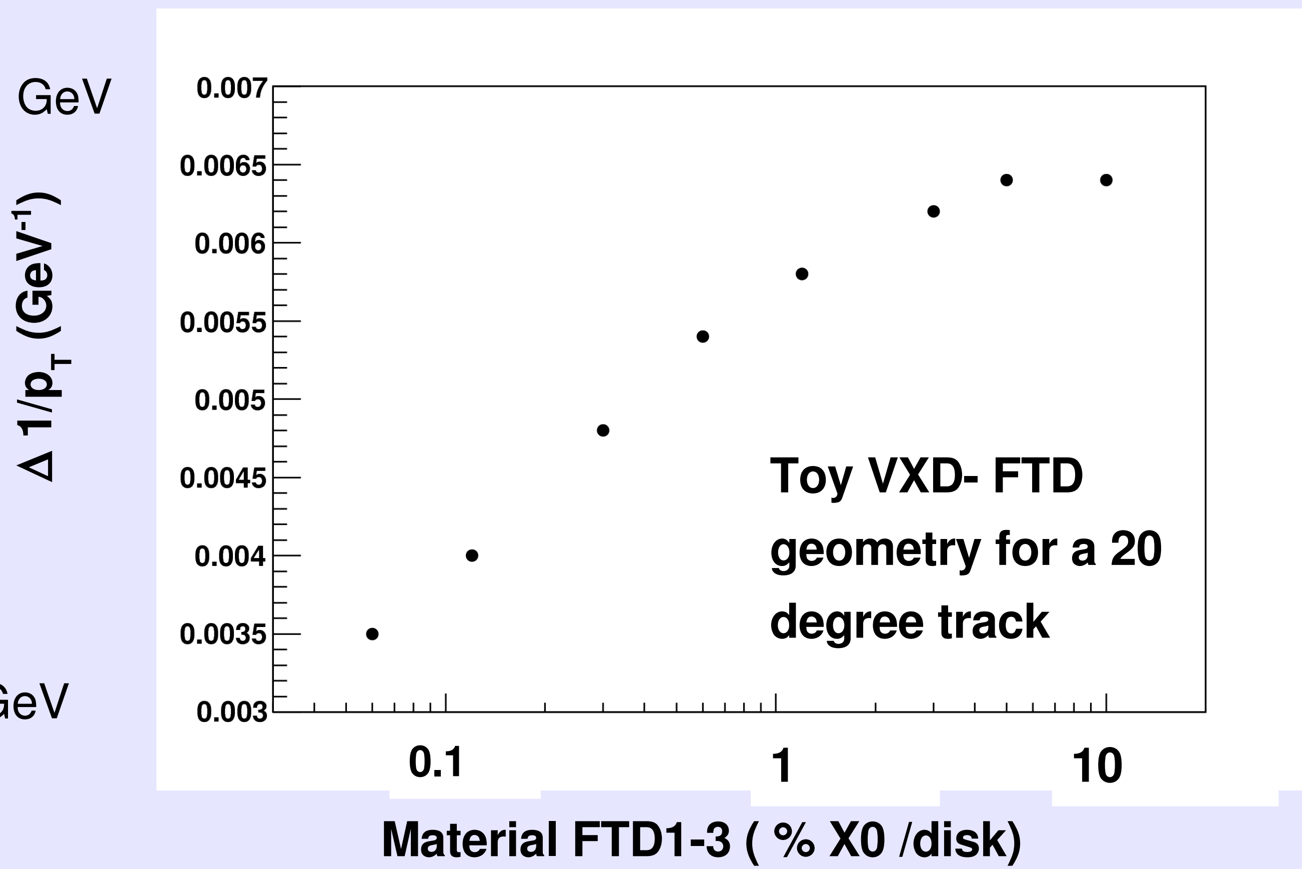
= $1.9 \times 10^{-4} \oplus 6.2 \times 10^{-3}/p_T$ *for 1.2 % X_0 FTD1-3*

Forward tracking: material budget

Impact of the material in the first three FTD disks on the tracking performance of low momentum tracks: vary material per layer from rather optimistic (factor two better than VXD layers) to disastrous (10% X_0).

7×10^{-3} GeV^{-1} @ 1 GeV

3×10^{-3} GeV^{-1} @ 1 GeV



The tracking and vertexing requirements in a nutshell

Momentum resolution spec. beyond current state-of-the-art

Goal: **$\Delta(1/p) \sim 2\text{-}5 \times 10^{-5}$ (GeV^{-1})**

An order of magnitude better than previously achieved

Vertexing performance:

Goal: **$\Delta(d_0) \sim 5\mu m \oplus 10\mu m/(p \sin^{3/2}\theta)$**

Not achieved recently (SLD came close)

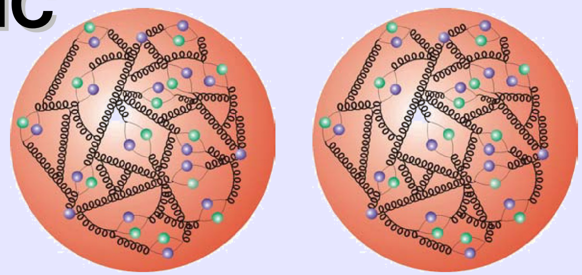
Hermetic coverage: **Full solid angle** for tracks in a **broad momentum range** (from the beam energy to very low momenta required by FPA, flavour tagging and missing energy measurements).

Fully efficient/pure: excellent **pattern recognition** for all tracks

Non-disruptive: only a very ***transparent*** *detector* allows to preserve lepton ID and calorimeter performance, and to achieve the required momentum resolution.

Environment

LHC

p  p

Protons collide at **E_{cm}~14 TeV**

Undefined initial state of proton constituents

Huge QCD backgrounds

Low S/B ratios

10^9 events/s. Trigger sees 1 every 10^7

ILC

e^+ • • e^-

e^+ e^- colliding at **E_{cm}~ 0.5-1 TeV**

Clean environment

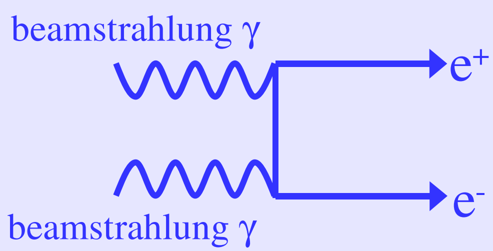
Well defined initial state, beam polarization,...

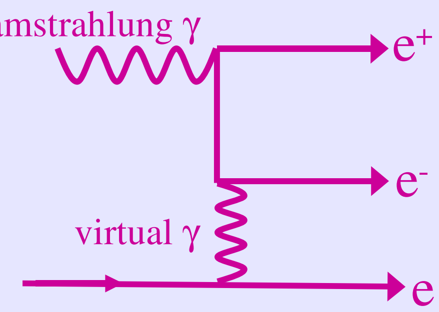
Triggerless operation

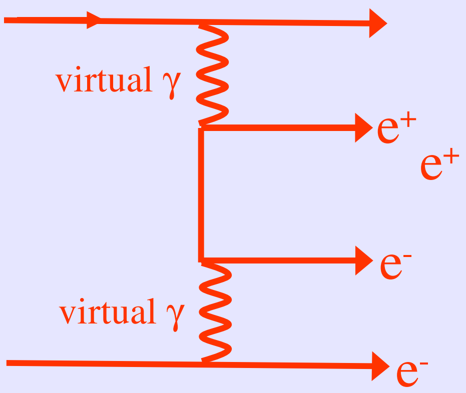
	LHC	ILC
Event rates inclusive	1 GHz (min. bias)	1 kHz (γγ→hadrons)
Bunch crossings	25 ns (40 Mhz) DC	300 ns (15kHz) 0.5% duty factor
Triggering Level 1 & 2 Level 3	40 MHz → 1 kHz ~100 Hz (software)	No hardware trigger ~ 100Hz (software)

Background: incoherent e+ e- pairs

3processes : Breit-Wheeler Bethe-Heitler Landau-Lifshitz

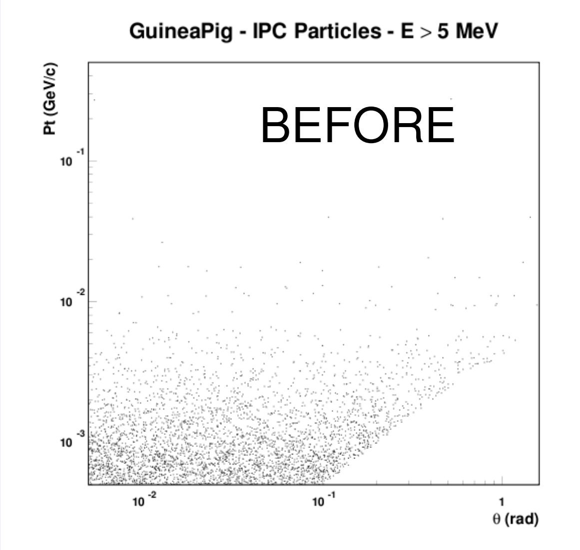


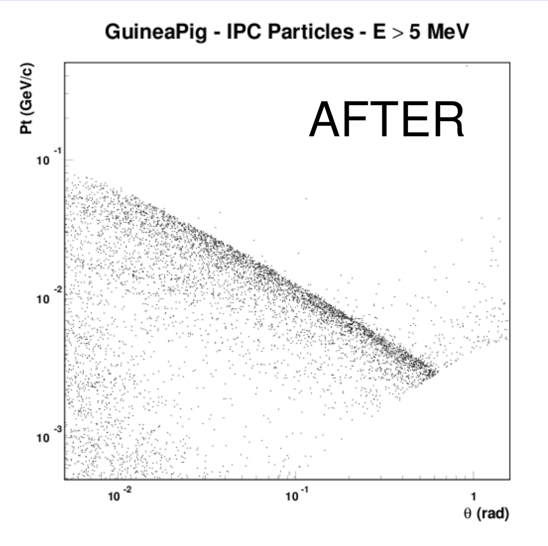




Breit-Wheeler (real-real) calculated explicitly by Guinea-Pig/CAIN

Bethe-Heitler (real-virtual), Landau-Lifshitz (virtual-virtual) use Equivalent Photon Approximation (treat virtual photons as real below virtuality cut-off)





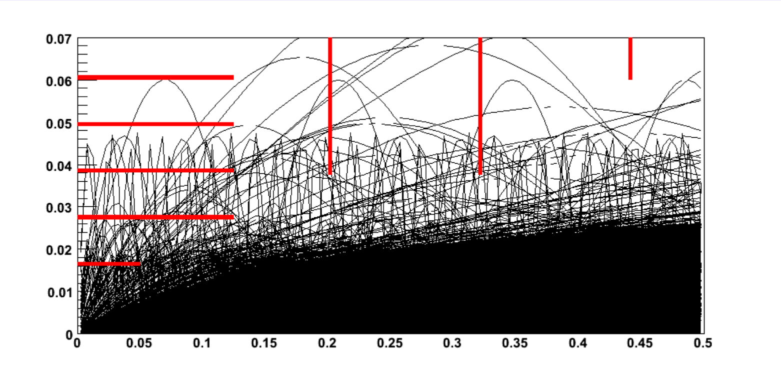
Pairs are deflected by electro-magnetic field of opposite beam. Same-charge particles are focused.

C. Rimbault, P. Bambade, K. Moenig, D. Schulte, Study of incoherent pair generation in Guinea-Pig, EUROTeV report 2005-015-1

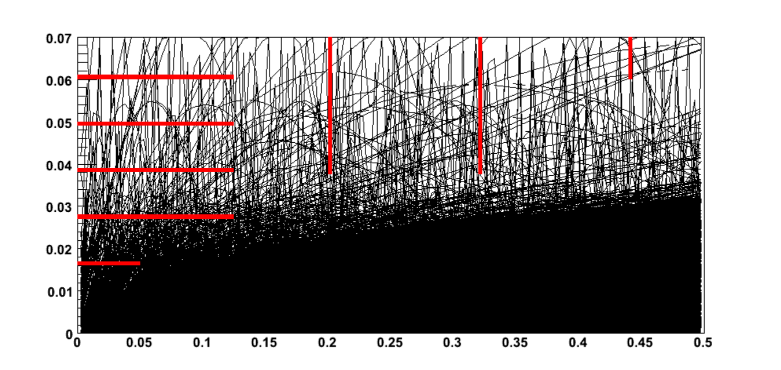
Machine background

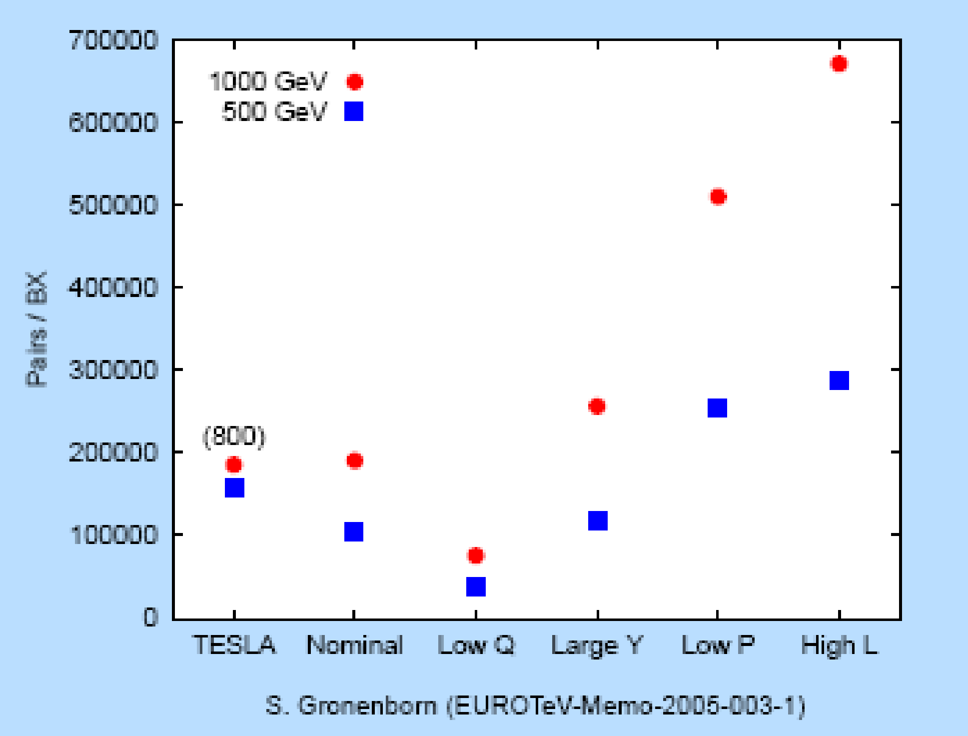
Fast (simple helix) simulation of pair background as it comes out of Guinea Pig (thanks to Cecile Rimbaud) for two parameter sets of the final focus

NOMINAL



LOW-P



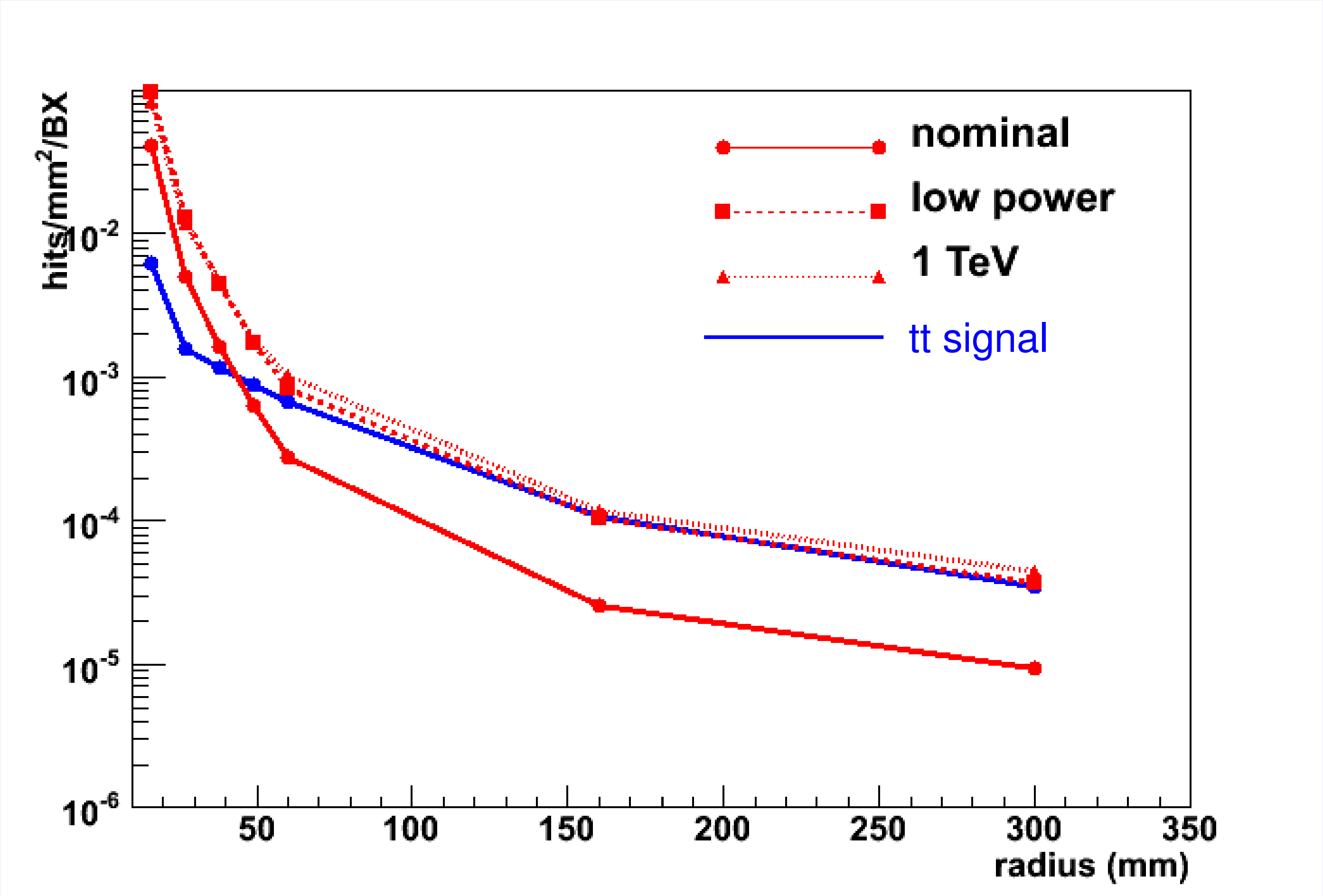


Pair background (# pairs/BX) for a range of machine parameters

Machine background: central tracker

Dense signal topology (tt events)

Pair production background due to beamstrahlung, (GUINEAPIG and Mokka simulation by A. Vogel)



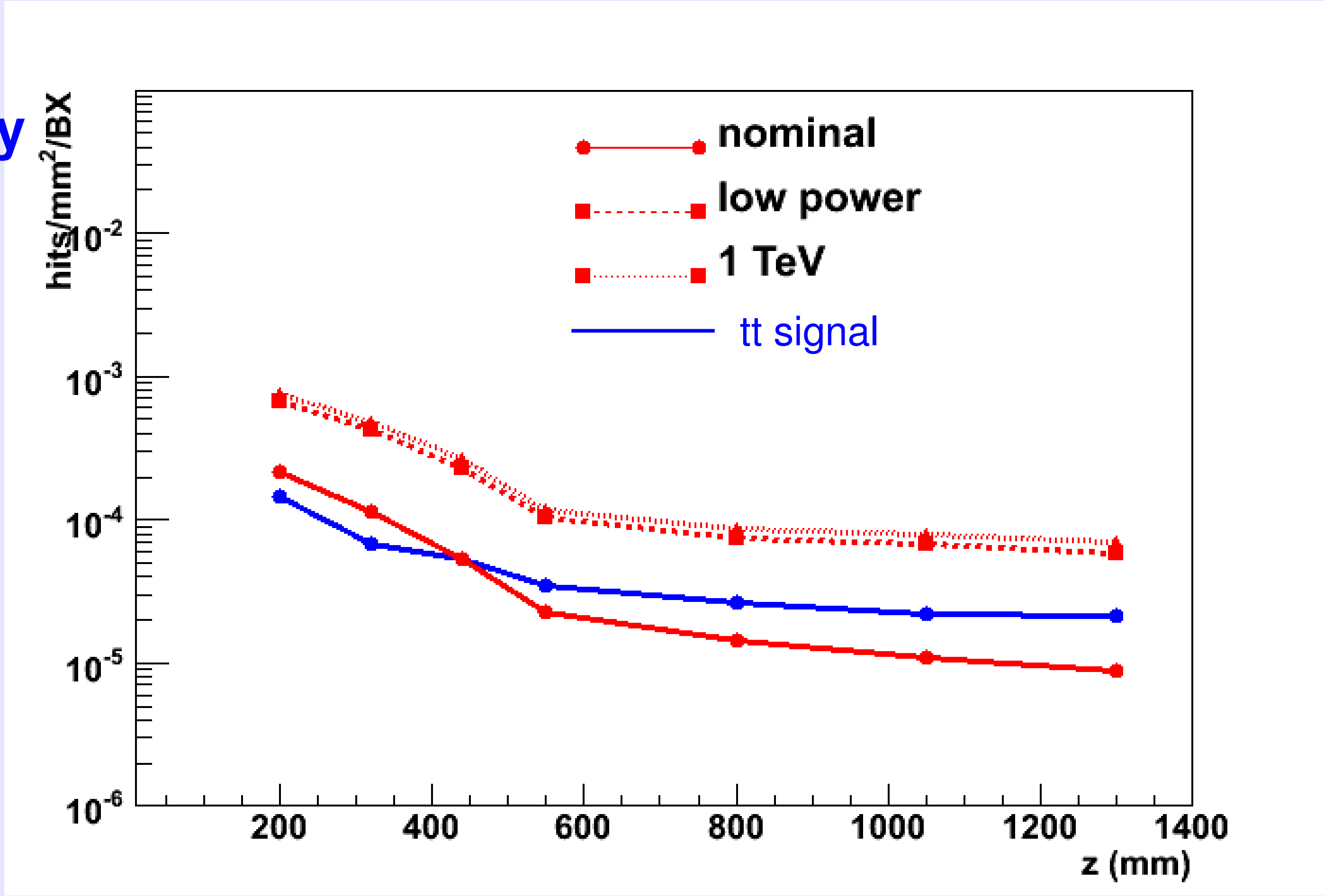
NOTE: low power option has double BX spacing

SIT hit density due to pair bkg an order of magnitude below that of outermost VXD layer (but cell size is of the order of 50 μm x 10 cm, 3 orders of magnitude larger)

Machine background: forward tracker

Dense signal topology (tt events)

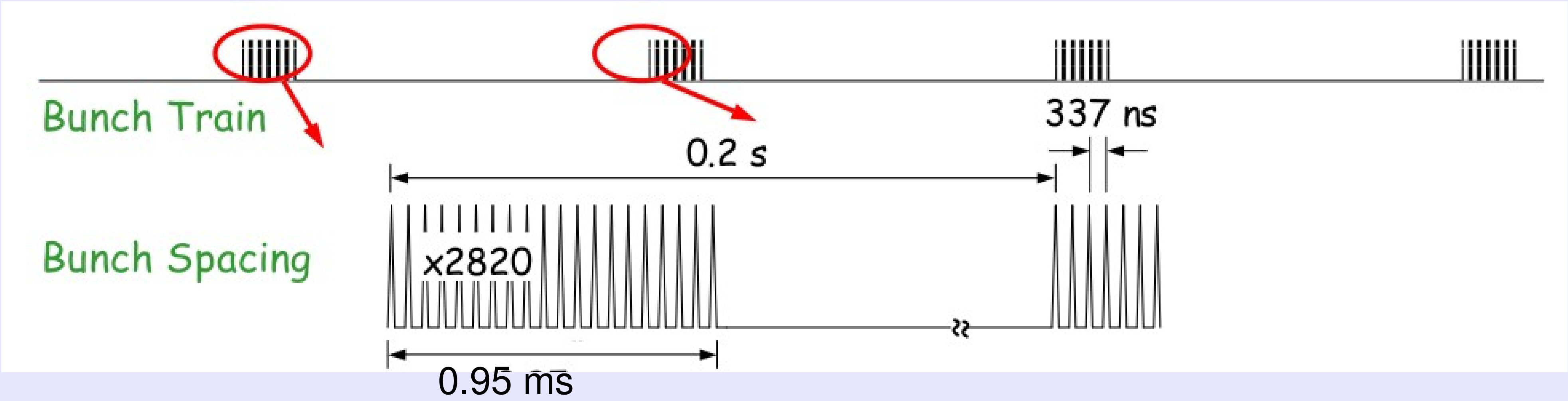
Pair production background due to beamstrahlung,
(GUINEAPIG and Mokka simulation by A. Vogel)



NOTE: low power option has double BX spacing

Inner rings of first 3 FTD disks suffer large hit density from pair bkg.

Occupancy (bunch structure)



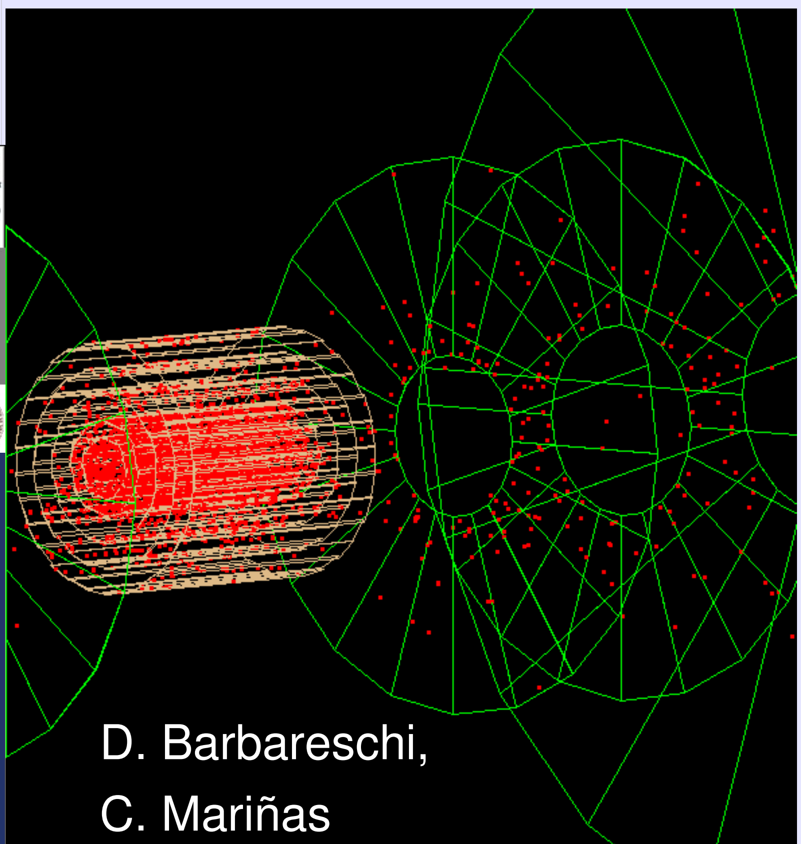
Long (2 ms) empty period between bunch trains

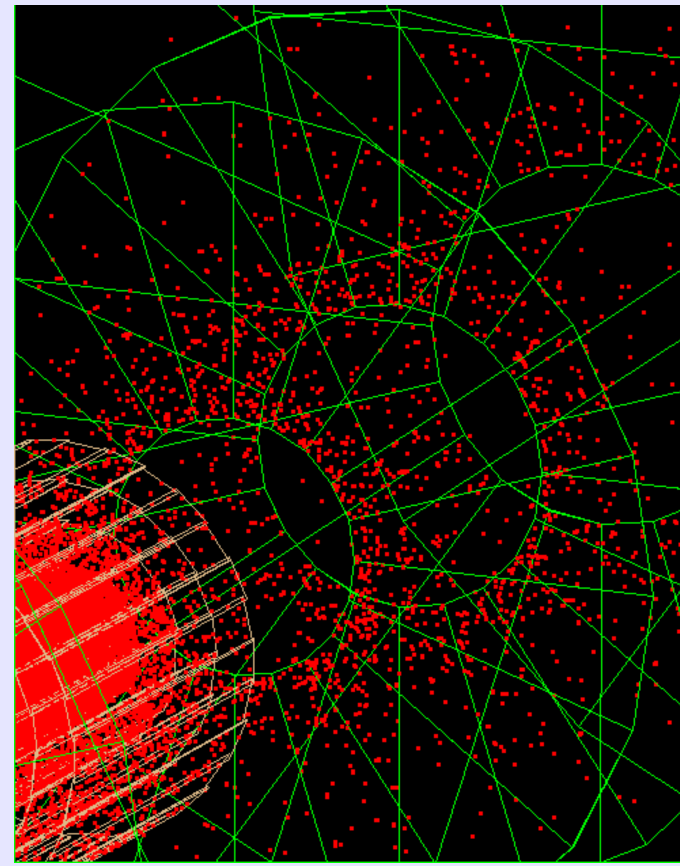
2820 bunches in a 0.95 ms train (337 ns spacing)

Background

Hit densities due to background: an impression

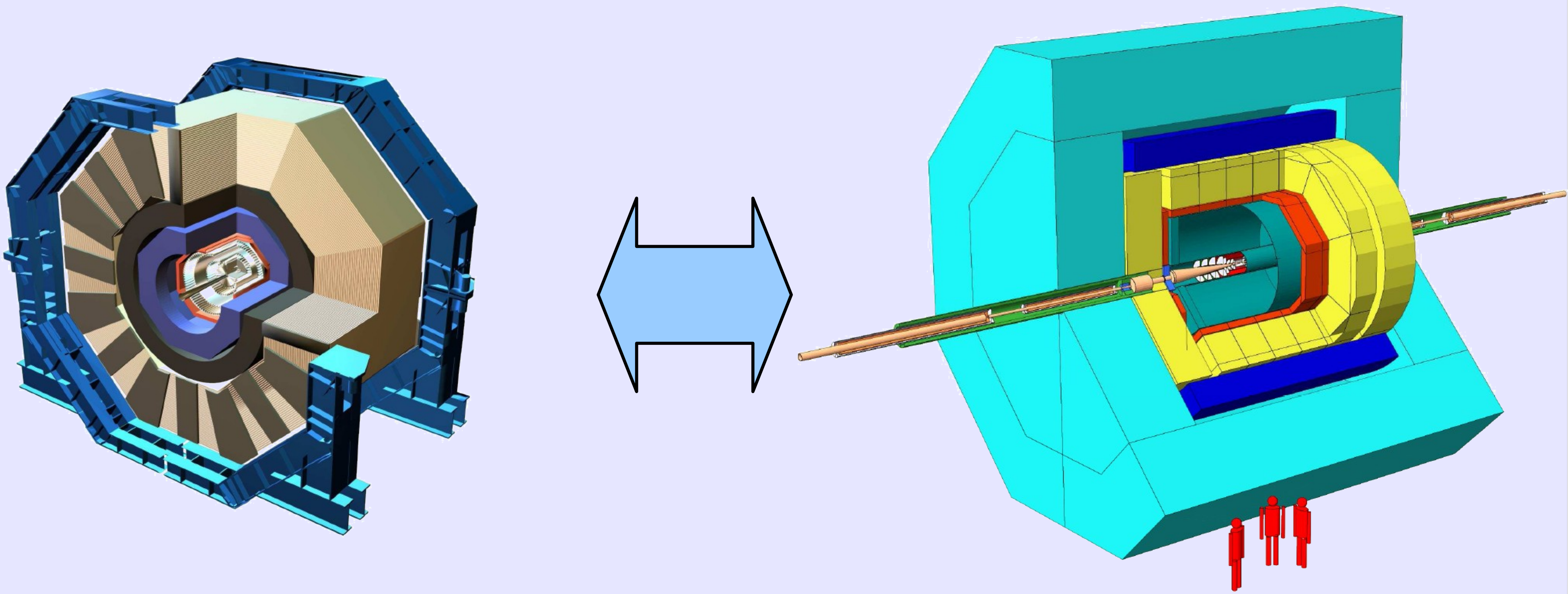
_14 BX_





_140 BX_

Push-Pull



The push-pull scenario saves cost (of a second interaction point, with all its expensive optics)

Every X fb^{-1} (order of several months) swap experiment: move experiment A out of the interaction point, move in experiment B

(Switch-over time 4-5 days.

detector brought to its “old” position within O(mm))

Pulsed power

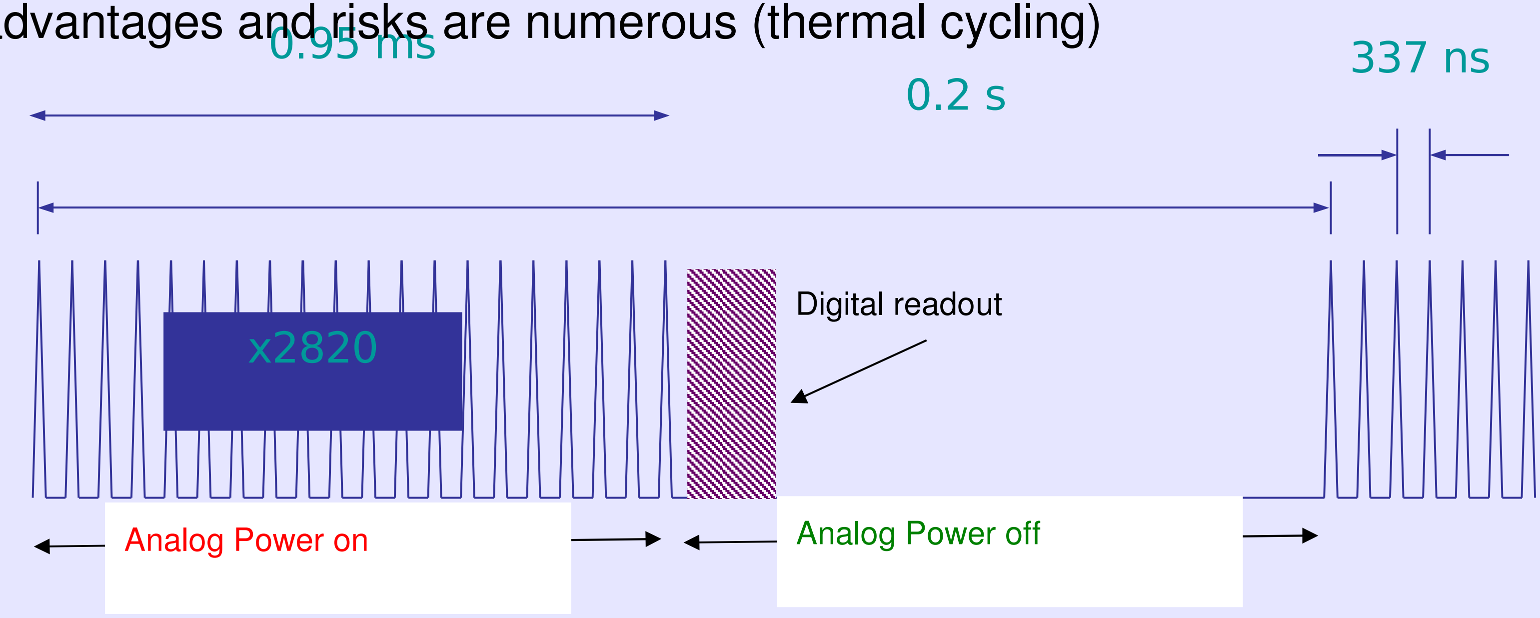
Pulsed power???

In first approximation, it consists of switching off the detector in the long inter-bunch period.

Gains a duty factor of maximally 200 in power consumption (which makes all the difference between being condemned to use liquid cooling and the possibility to rely on gas flow)

Several Front End prototype already incorporate this possibility

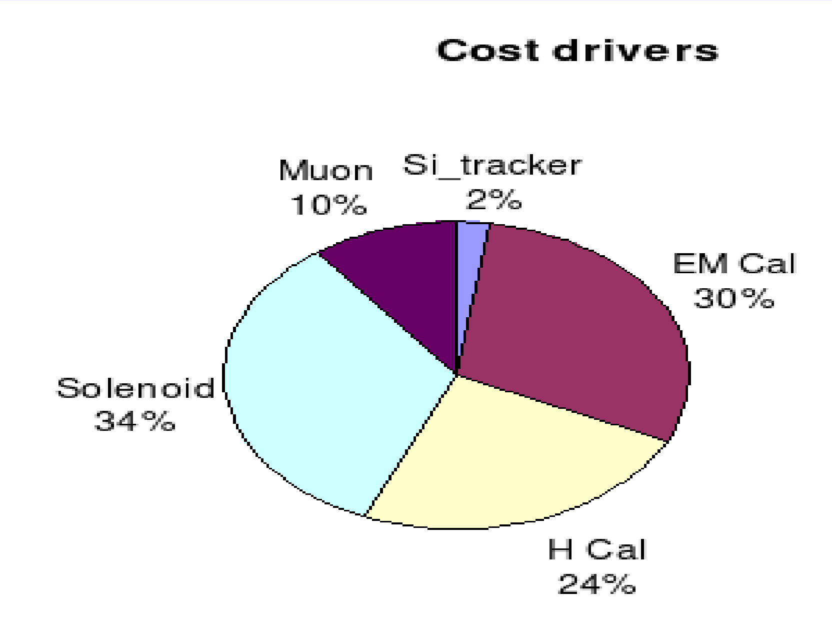
Disadvantages and risks are numerous (thermal cycling)



Cost

Central spectrometer:

Tracking *detectors* are "cheap" the magnetic field is "expensive"



Calibration samples

- Center-of-mass energy variable from 200-500 GeV
- Running at the Z foreseen for calibration (but not too often, large energy change takes “a few weeks”)
- integrate 500 fb^{-1} at $\sqrt{s}$ = 500 GeV in 4 years
- $\sigma(e^+e^- \rightarrow \mu^+ \mu^-)_{pT (\mu) > 10 \text{ GeV/c}} \sim$ 440 fb
-
- Compare rates at the LHC $\sigma (pp \rightarrow \mu^+ \mu^-)_{pT (\mu) > 10 \text{ GeV/c}} \sim$ 1000 pb

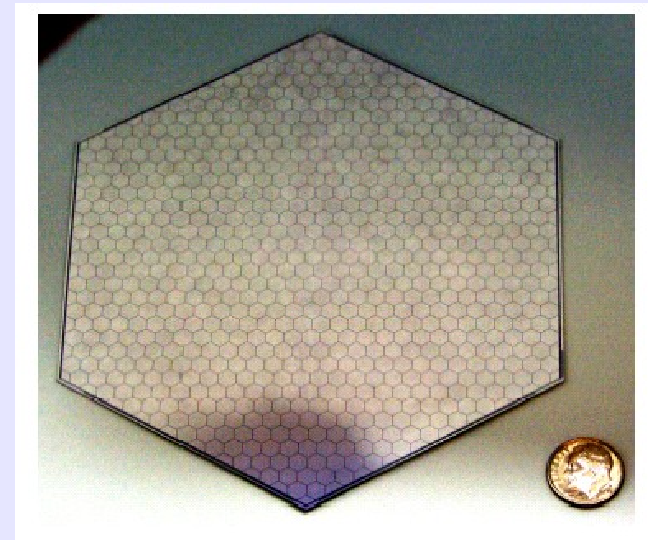
Luminosity	10^{32} $cm^{-2}s^{-1}$		$2 * 10^{33}$ $cm^{-2}s^{-1}$		
Time	few weeks	6 months	1 day	few weeks	one year
Int. Luminosity	100 pb^{-1}	1 fb^{-1}		1 fb^{-1}	10 fb^{-1}
$W^{\pm} \rightarrow \mu^{\pm}\nu$	700K	7M	100K	7M	70M
$Z^0 \rightarrow \mu^+\mu^-$	100K	1M	20K	1M	10M

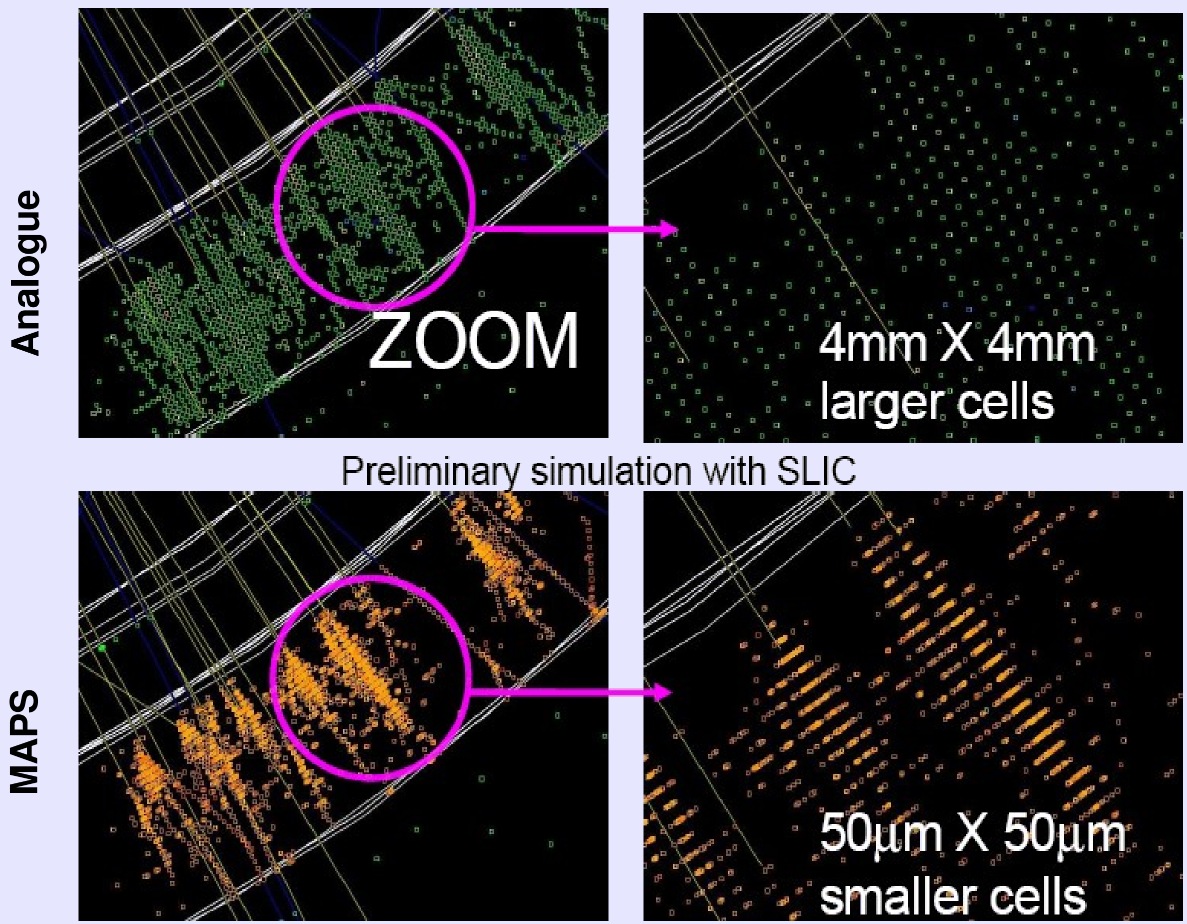
Tracker/vertex environmental constraints

- **Inner vertex detector layers moderately radiation hard**
  - » **<1 Mrad**
- **Occupancy inner vertex detector layers requires:**
  - ✓ very small pixels and/or fast read-out
  - » **400 μm^2 ⊗ 45 μs, alternative: 25 μm^2 ⊗ 2 ms**
- **Radiation hardness/occupancy requirement less stringent by a factor 10 for forward tracking**
- **Time-stamping**
  - » **single BX identification for all tracks**
- **Bunch structure allows for pulsed powering**

EM calorimeters

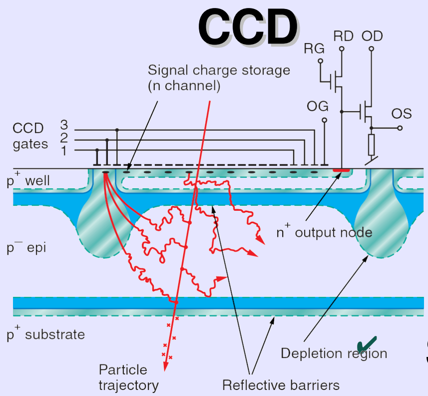
- Si/W calorimeter is one of the options considered for the EM calorimeters in the central detector
  - Baseline proposes silicon pads to reconstruct the showers

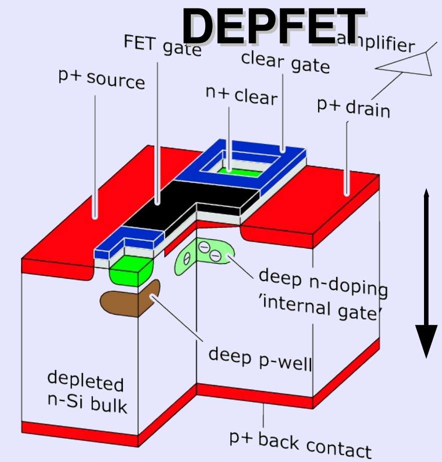




Recently "*binary*" MAPS have been proposed
In the forward region, diamond is considered to cope with radiation

R&D for vertex detectors





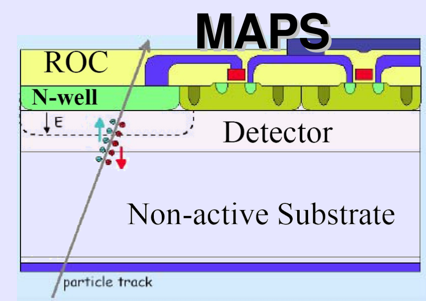
Charge collection from full sensor thickness

✔ Silicon pixel detectors is the way

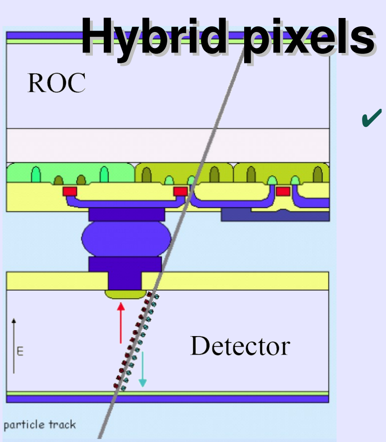
- ➔ Fast and light
- ➔ With ~10^9 channels, consume, on average, less than a light bulb (~10W)
- ➔ The classic hybrid pixels probably discarded because of material bugdet
  - ➘ Look for monolithic detectors with some kind of charge storage to be readout at end of train

✔ We can distinguish

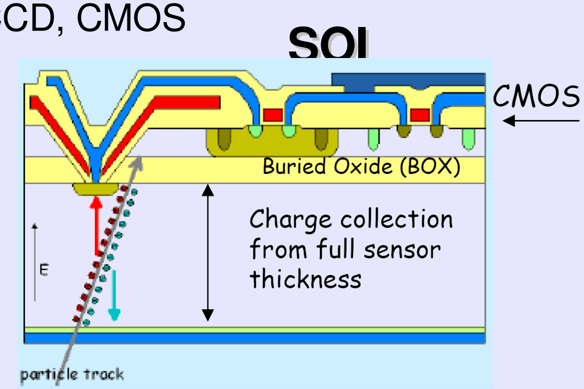
- ➔ Depleted: DEPFET, SOI
- ➔ Undepleted: CCD, CMOS



MAPS Principle

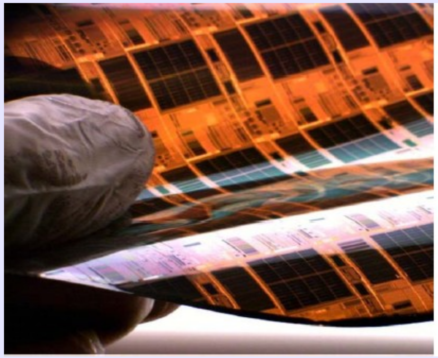


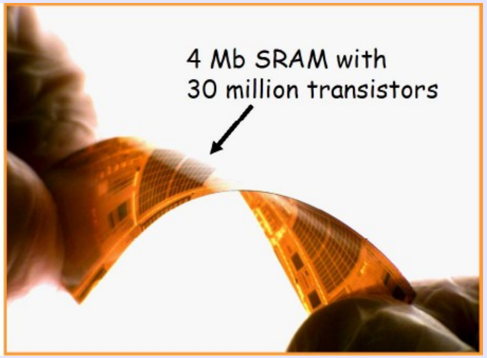
Probably too thick
to be used at the ILC

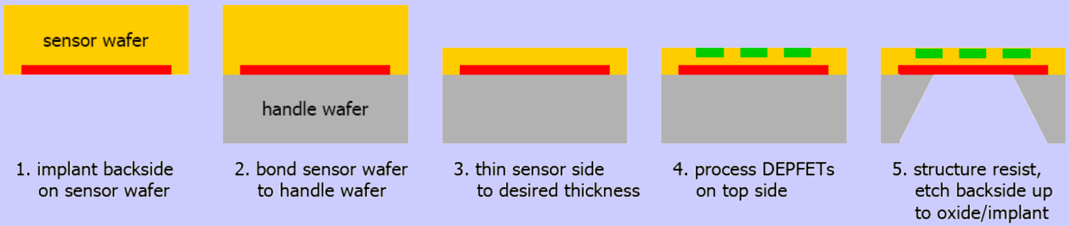


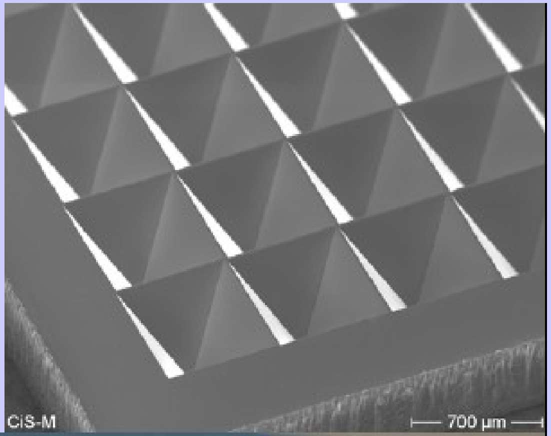
Vertex detectors (thinning)

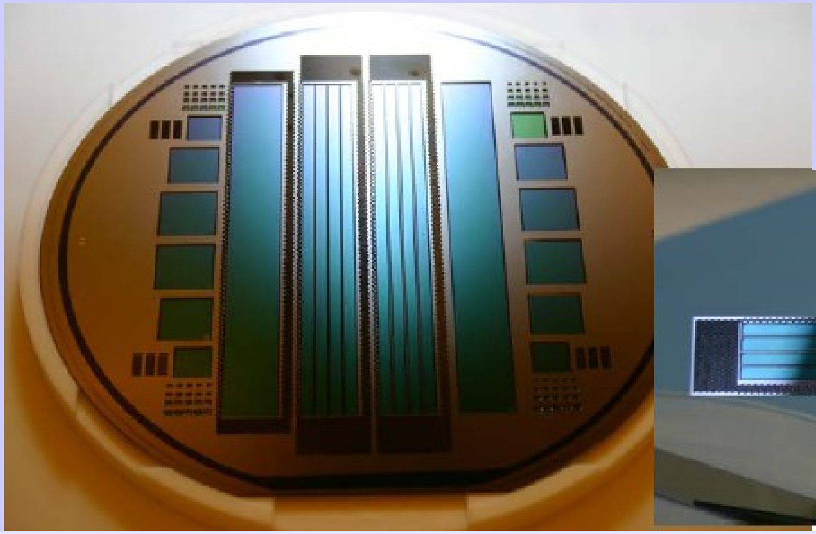
- **Thinning**: max rad. length is 0.1% X_0/layer
  - ➔ 100 µm of Si is 0.1% X_0,
    - ➘ sensors should therefore be **50 µm thick**
- DEPFET coll. has developed an interesting thinning technology (see S. Rummel's talk in this conference)

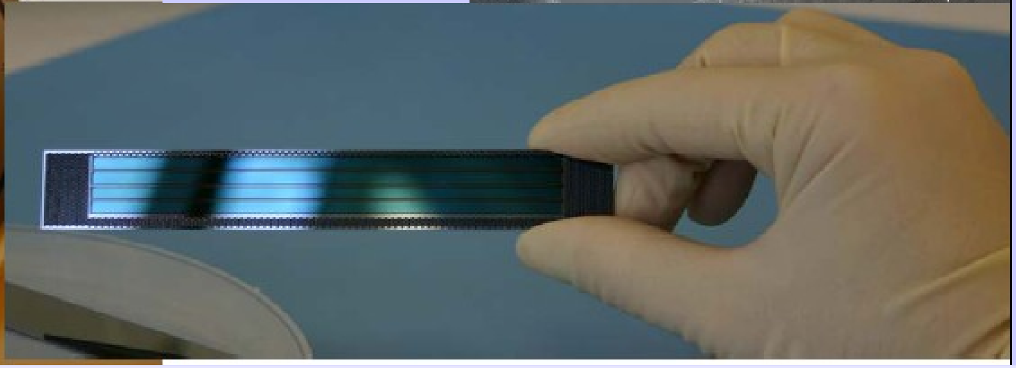




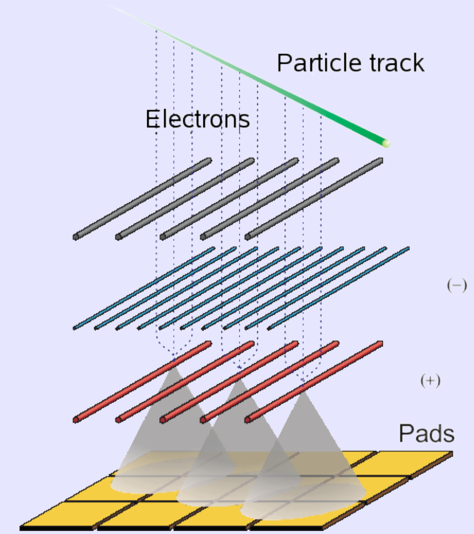




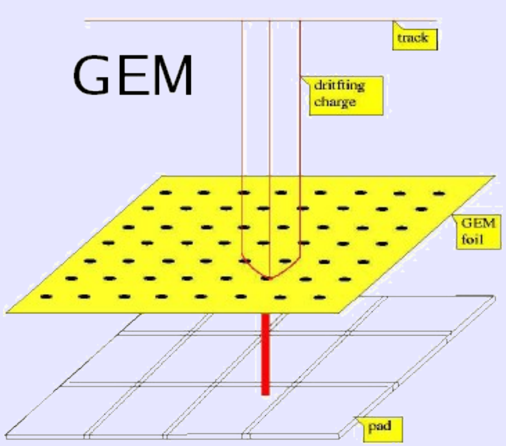




R&D for gaseous tracking (TPC)



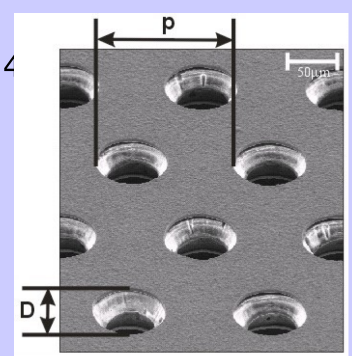
- ✔ Unprecedented requirements for a TPC, in particular on spatial resolution.
  - ➔ Spatial resolution: Rφ: 100μm, Z≤1mm
  - ➔ 2 track separation: Rφ≤2mm, Z≤10mm
  - ➔ $\Delta p_T/p_T \sim 10^{-4}$ (TPC alone)
  - ➔ Identification: dE/dx ~ 4%
  - ➔ High background from photons and neutrons (~600 n/BX)
- ✔ "*Classic*" TPCs cannot achieve this
  - ➔ Replace conventional MWPC system by Micro Pattern Gas Detectors (MPGD)
    - Gas Electron Multiplier (GEM)
    - Micromegas



GEM

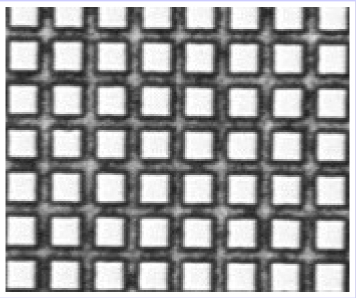
2 copper foils separated by kapton. Multiplication takes places in holes. Uses 2-3 stages

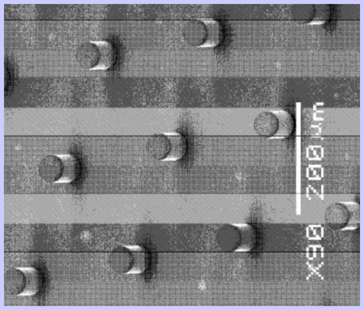
P~14



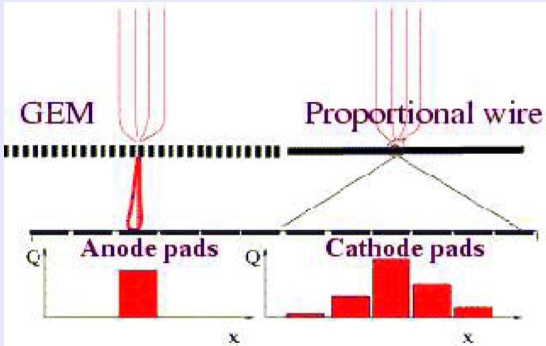
Micromegas

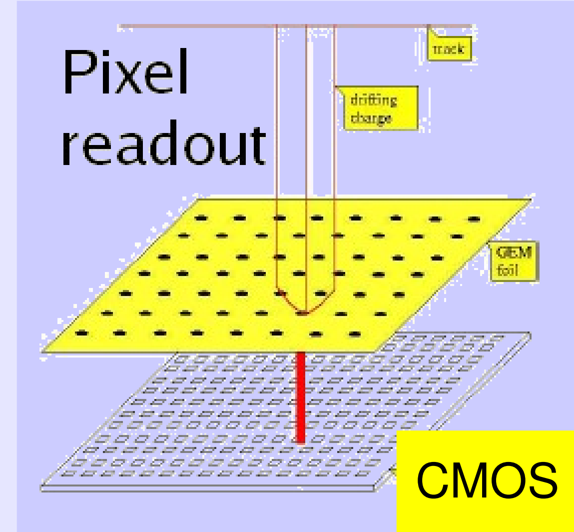
Micromesh sustained by 50 μm pillars. Multiplication between anode and mesh. One stage.





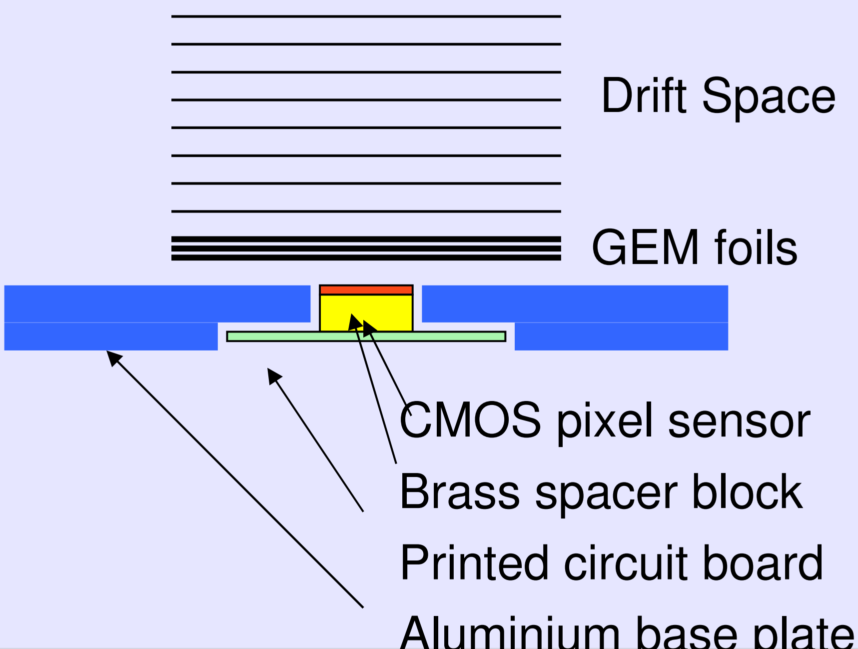
Digital TPC





CMOS pixel readout chip

- ✔ Electron signal “*too*” small to use center of gravity methods...
  - ➔ Resolution is not as good as it could be
- ✔ *Attractive* solution is to use a pixel readout chip with higher granularity instead of the conventional pads.

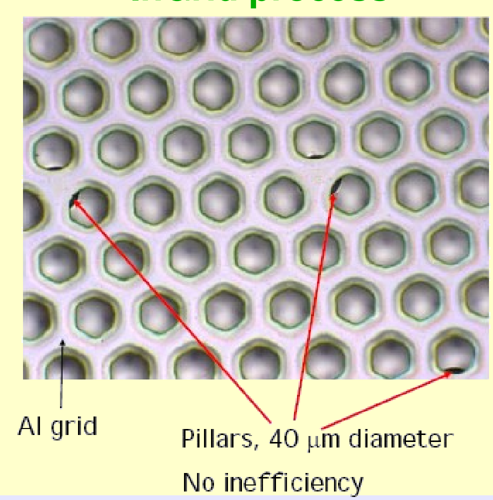


Single electron detection

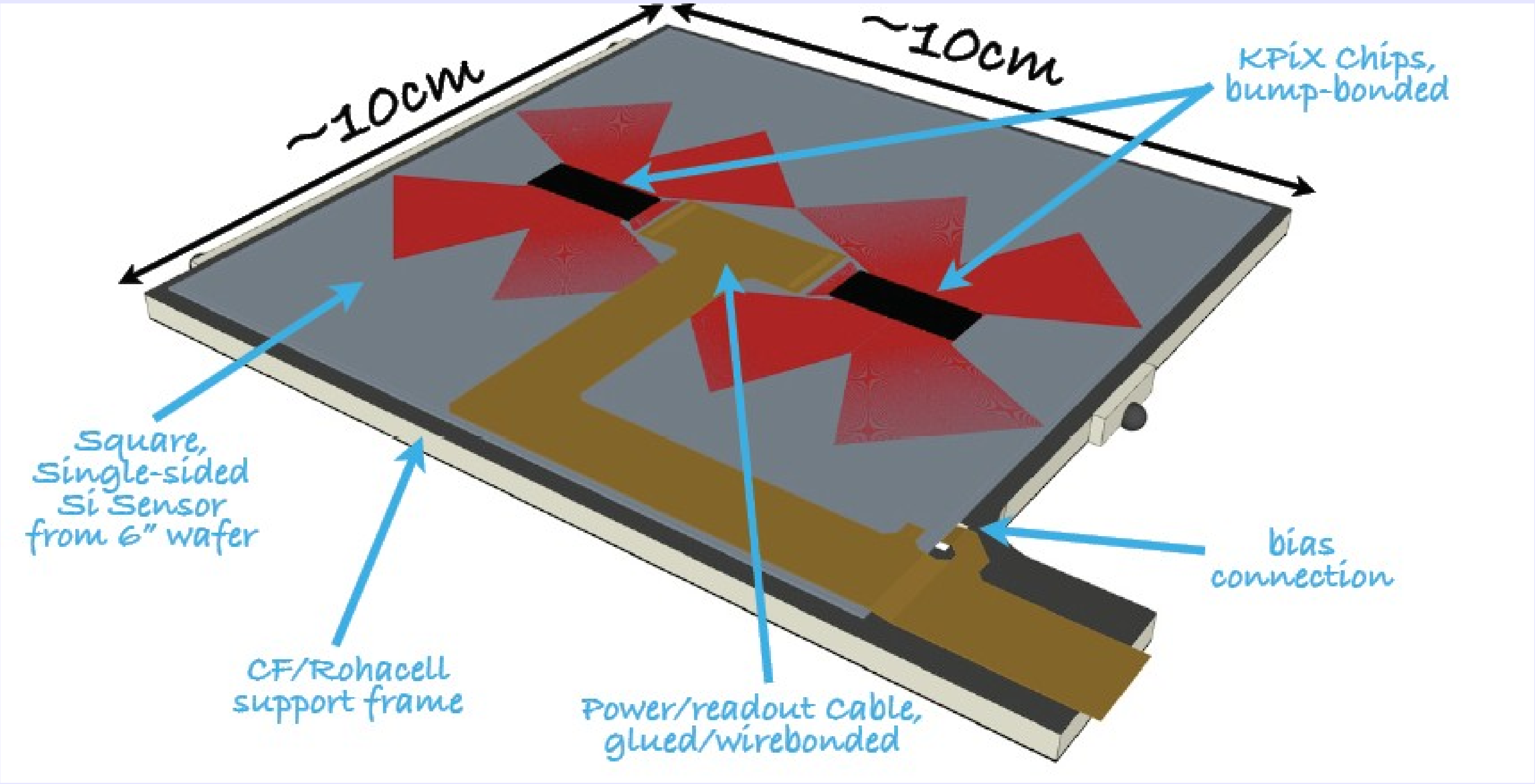
Achievable spatial resolution ~50µm

Integrate GEM/Micromega and pixel chip by wafer post-processing

InGrid process



µ-strip developments: SiD module

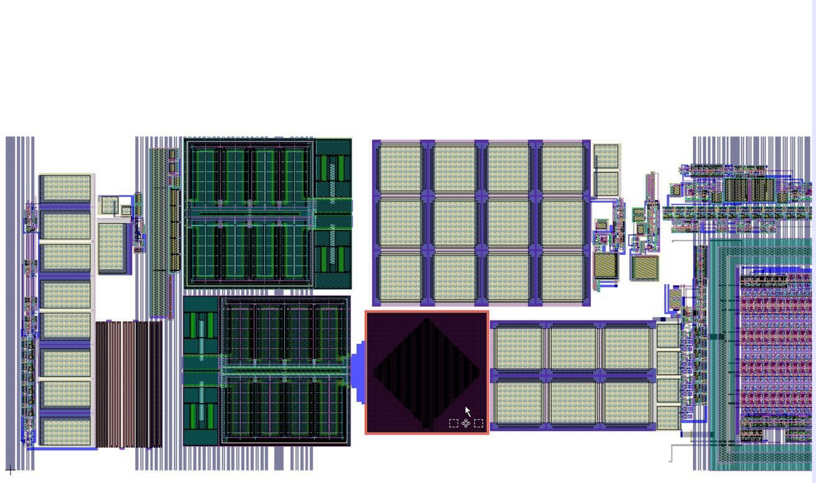


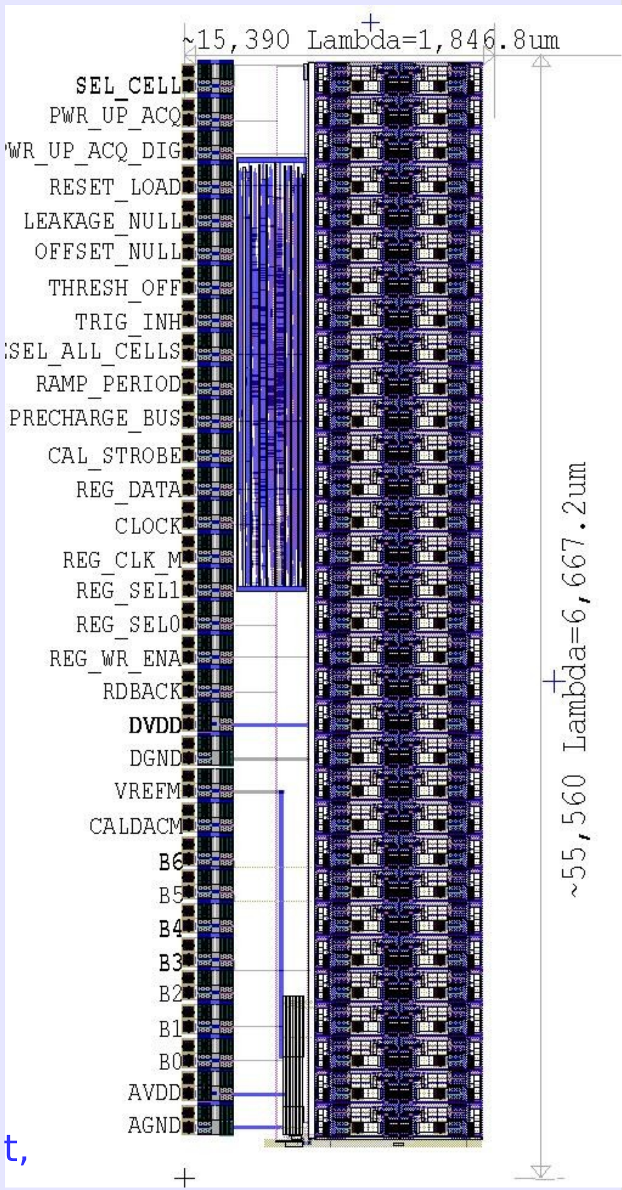
Marcel Demarteau, WWS tracking review, Beijing, 2007

Module design by Tim Nelson

μ-strip developments: SiD "kPiX" Readout Chip

- Was already under development at SLAC for SiD ECAL
- 1024 Channels
- Power-pulsed, average power ~20mW
- 4 time-stamped analog buffers for readout between trains
- Designed for bump-bonding directly to silicon - no hybrid
- Third prototype has been submitted
  - ➔ 2X32 channels

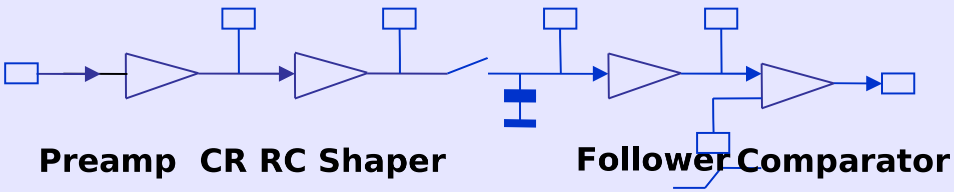




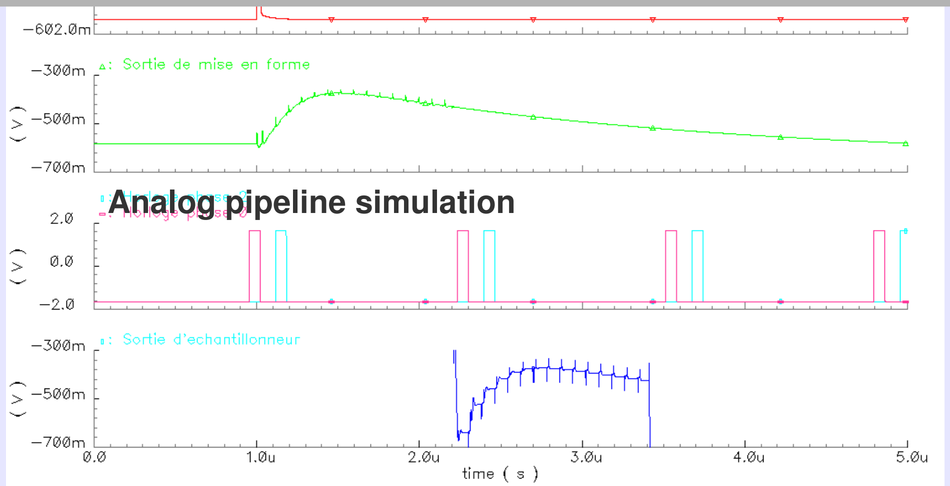
One cell. Dual range, time measuring, 13 bit, quad buffered

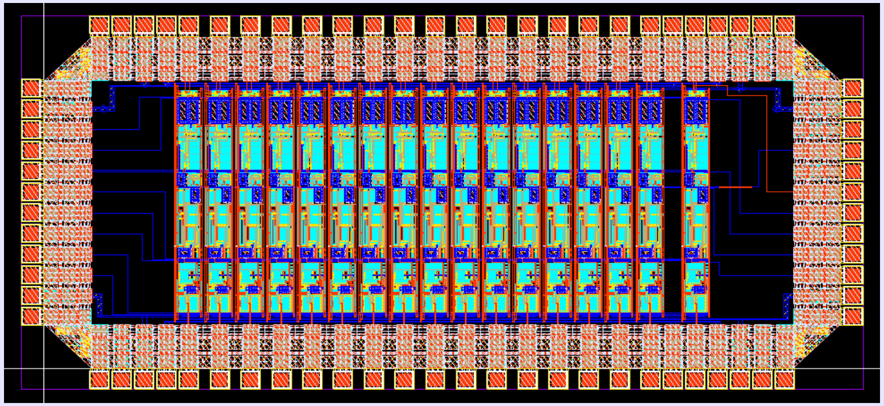
µ-strip developments: SIlicon for the Linear Collider

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

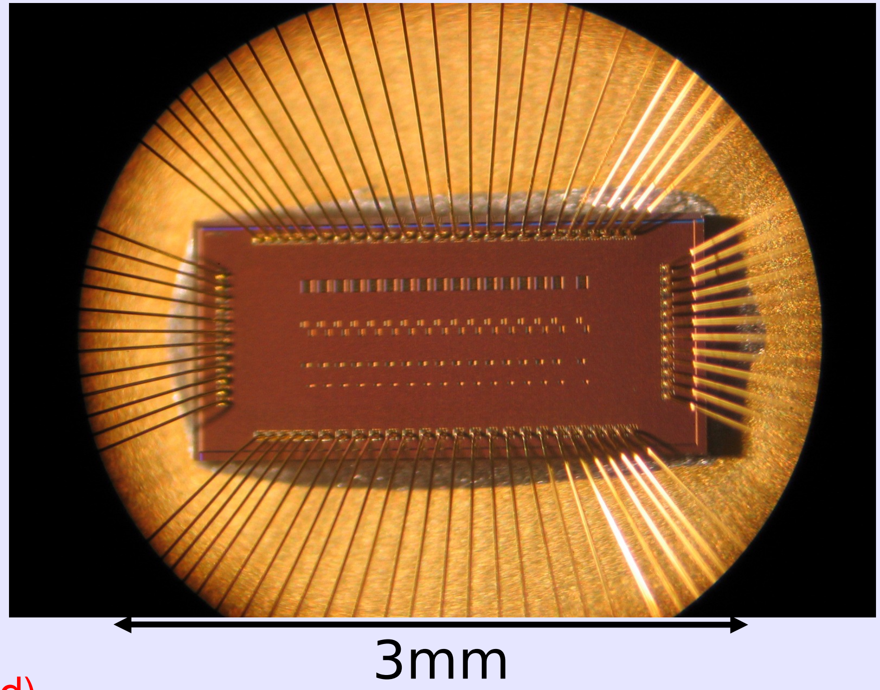


16 identical channels





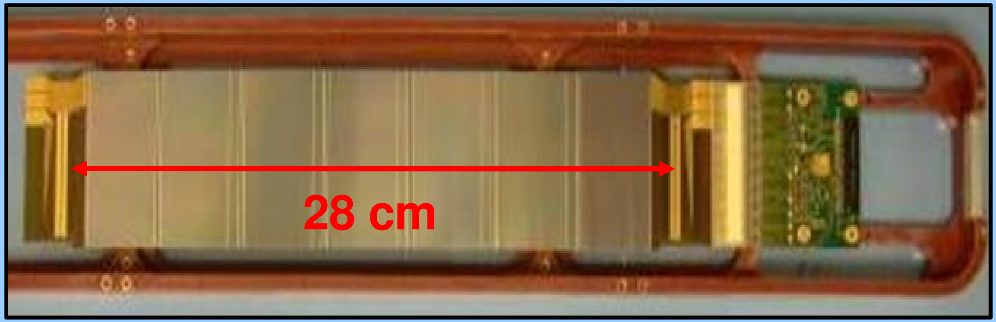
- Preamp
- Shaper
- Sample & Hold
- Comparator



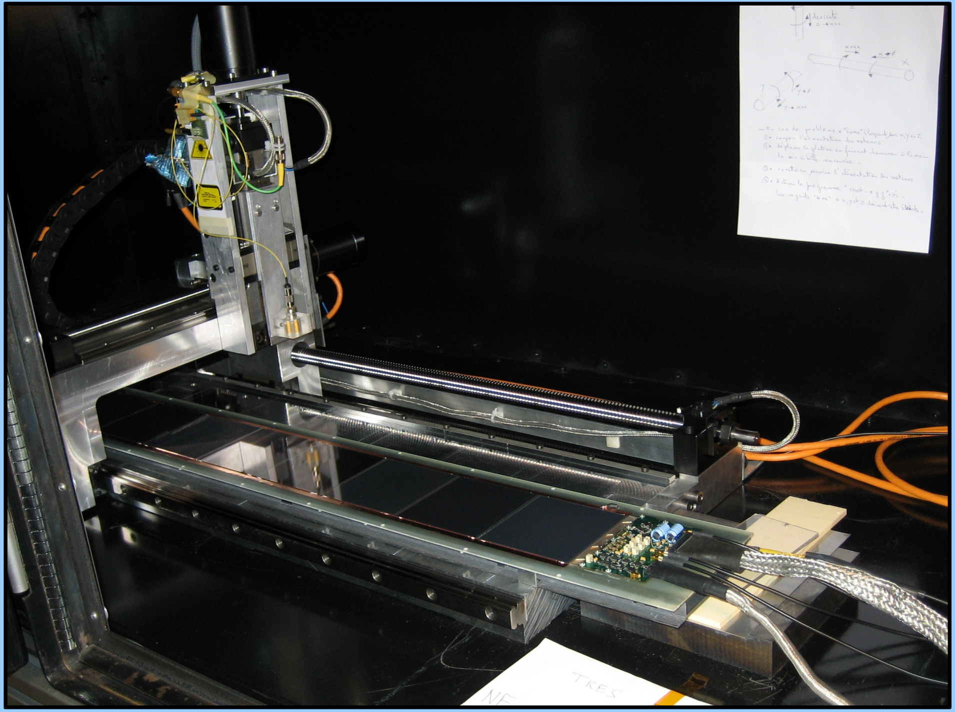
Power consumption:

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

μ-strip developments: Silicon for the Linear Collider



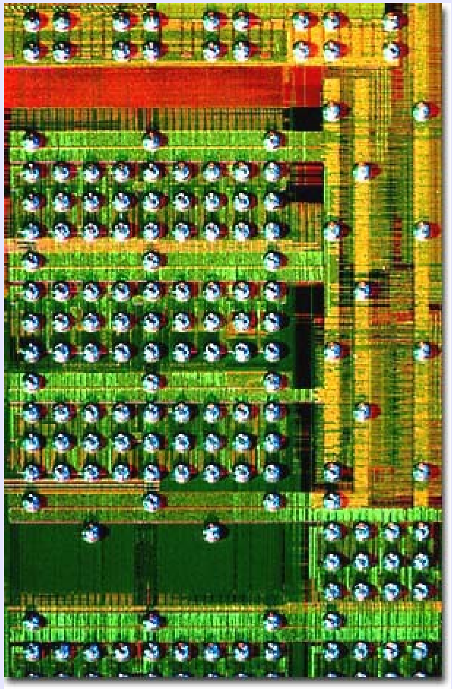
Long ladders for outermost layers to reduce number of FE channels (= power = material)



Chip connection on µ-strips

- Wire bonding
  - Only periphery of chip available for IO connections
  - Mechanical bonding of one pin at a time (sequential)
  - Cooling from back of chip
  - High inductance (~1nH)
  - Mechanical breakage risk

- Flip-chip
  - Whole chip area available for IO connections
  - Automatic alignment
  - One step process (parallel)
  - Cooling via balls (front) and back if required
  - Thermal matching between chip and substrate required
  - Low inductance (~0.1nH)

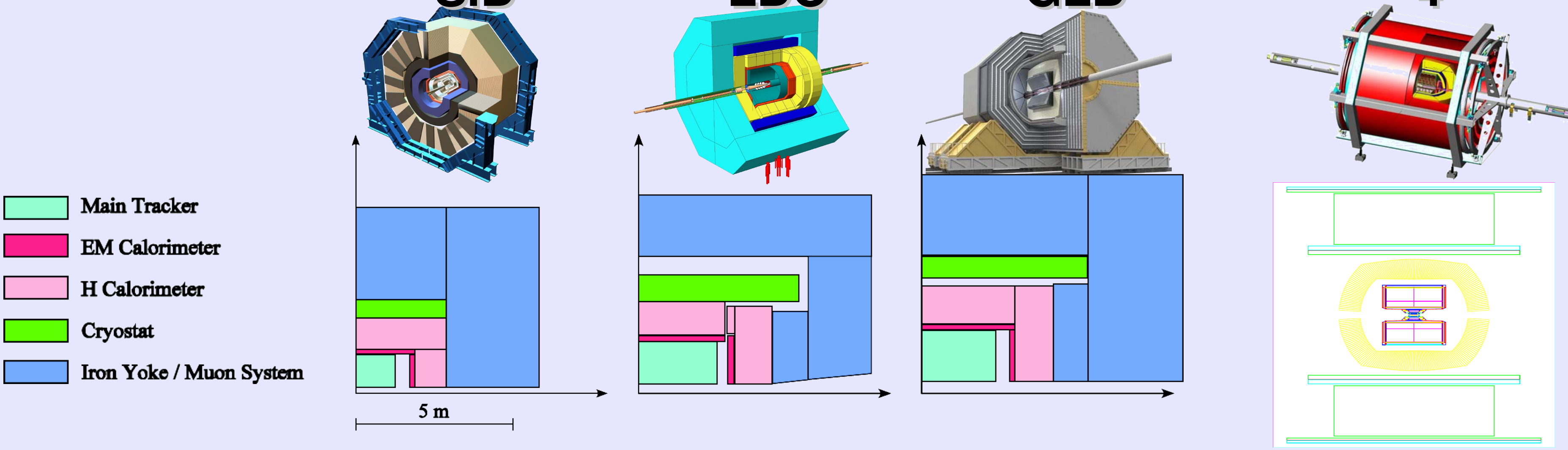


Detector concepts

- There are 4 concepts
  - The different concepts differ mainly in size and aspect ratio
  - The main parameter is the inner radius of the ECAL

Same vertex detector

SiD | **LDC** | **GLD** | **4th**



SiD	LDC	GLD	4th
Small: BR_{in}^2	Large: BR_{in}	Huge: BR_{in}	
Tracking: Silicon	Tracking: TPC+Si	Tracking:TPC+Si	Tracking:TPC+Si
Si-W ECAL	Si-W ECAL	W-scint. ECAL	Dual readout ECAL
High field (5T)	4T field	3T field	4T field

Driven by PFA
Iron return yoke

no PFA
Iron-free dual solenoid

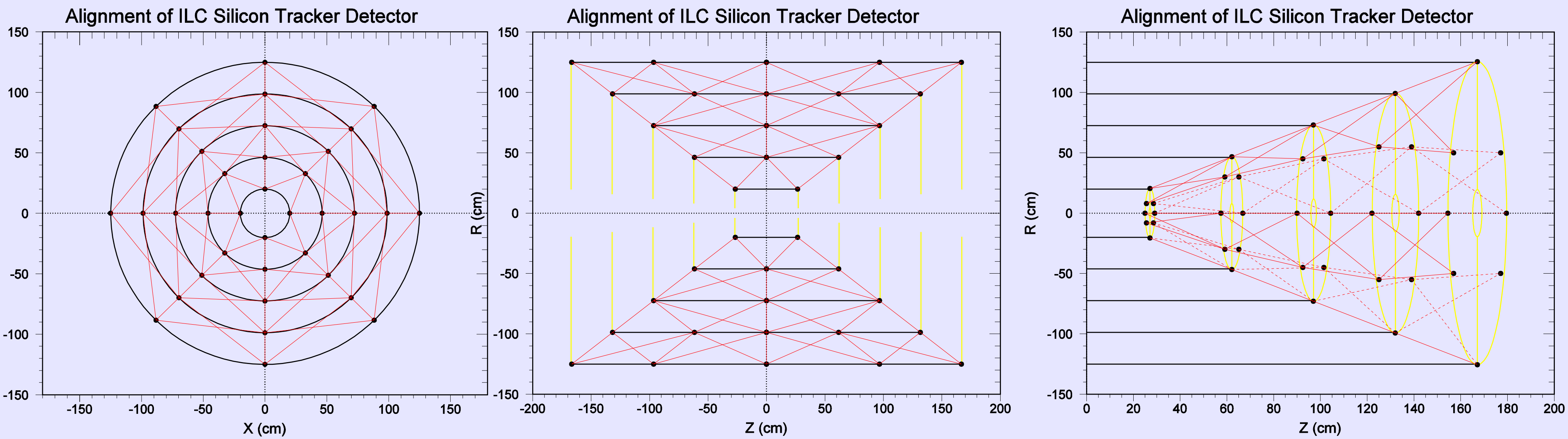
Challenges to the alignment

- Precision physics programme
- Space point resolution (2-5 μm for vertex detector, 5-10 μm for silicon tracker elements, 100 μm in large gaseous detector)
- Alignment sample statistics
- Material budget: extremely thin sensors, large low-mass mechanical support
- Air cooling (vibrations)
- Pulsed powering (vibrations, ΔT @ 5 Hz)
- Push-pull
- Movement of complete detector - cavern floor sinking/rising.
- Monitor position final doublets, nearly inside detector (gallery)

Hardware alignment – FSI

(H.J. Yang & K. Riles University of Michigan)

- Measure hundreds of absolute point-to-point distances of tracker elements in 3 dimensions; based on development in Oxford University for the ATLAS SCT
- Absolute distances determined using a Frequency Scanning Interferometer ("counting fringes") and an array of optical beam splits from a central laser.
- Grid of reference points overdetermined → Infer tracker distortions

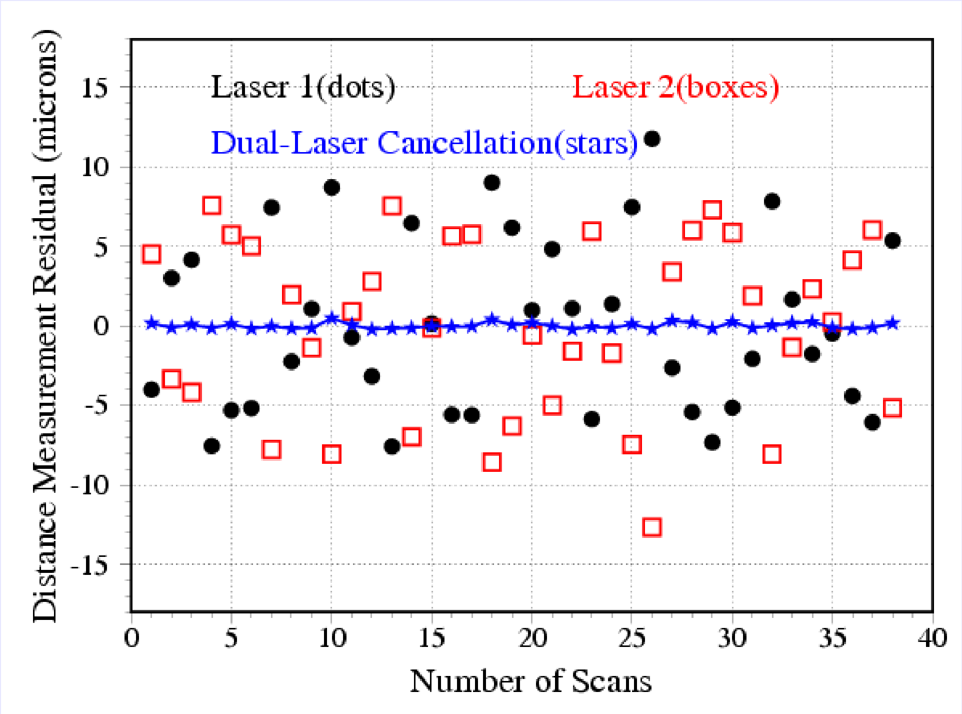


international linear collider

Hardware alignment – FSI (cont'd)

- In well-controlled ambient over distance of 10-60 cm: ~ 50 nm resolution by using multiple-distance measurement technique. Vibration Measurement: 0.1-100 Hz, amplitude as low as few nm. (H.J. Yang, J. Deibel, S. Nyberg, K. Riles, Applied Optics, 44, 3937-44, (2005)
- In real world: temperature fluctuations /drift (refraction index) and vibrations affect distance measurement. Single laser distance resolution degrades to 3-7µm.

Dual-laser technique (Oxford, two independently chopped lasers, scanning over same frequency range in opposite directions) restores precision to 0.2 µm:



Hardware alignment – hybrid

(I. Vila, M. Fernandez, C. Rivero, A. Ruiz, M. Lozano, IFCA-CSIC/Cantabria & IMB)

Hybrid approach is born from the AMS-I and CMS development

Key point is the detection of the laser beams using the position sensitive device itself: the silicon sensors. Thus, mechanical transfer of the alignment system measurement to the active area is avoided.

Furthermore, this approach requires no dedicated DAQ system and reconstruction software.

Precision of the order of 2-3 microns expected.

Hardware alignment – hybrid (cont.d)

Usage of collimated laser beams (IR spectrum) going through silicon detector modules. The laser beams would be detected directly in the Si-modules. This requires:

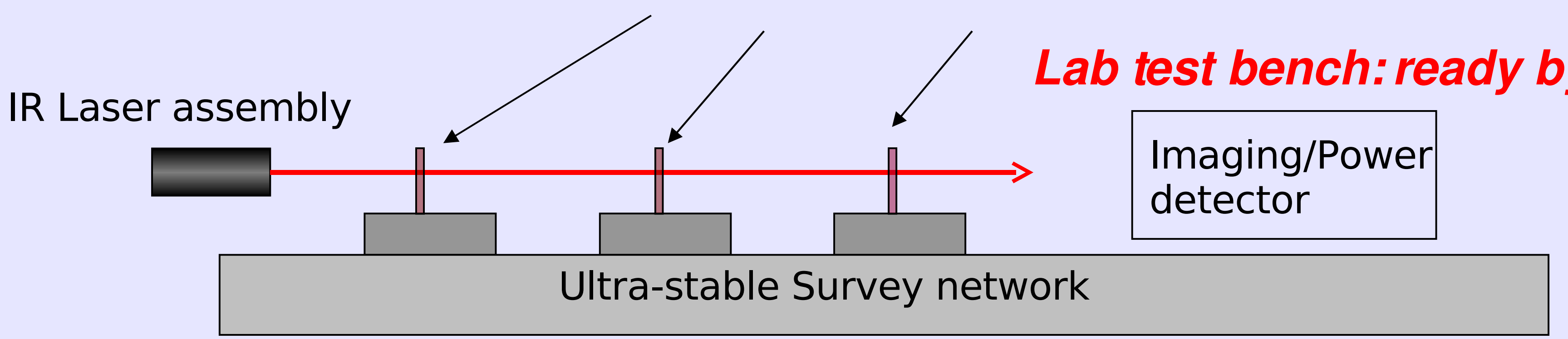
- ➔ Silicon module surface requires special treatement to improved its optical quality/transmitance
  - – Dedicated ultra-stable test stand for "optical" characterization of the modified silicon modules: reflectivity, transmitance, absorption, polarization sensitivity, wedge effect, response uniformity...

Main advantages:

- 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

Optically treated silicon modules

Lab test bench: ready by April 07



Alignment – hybrid approach (cont'd)

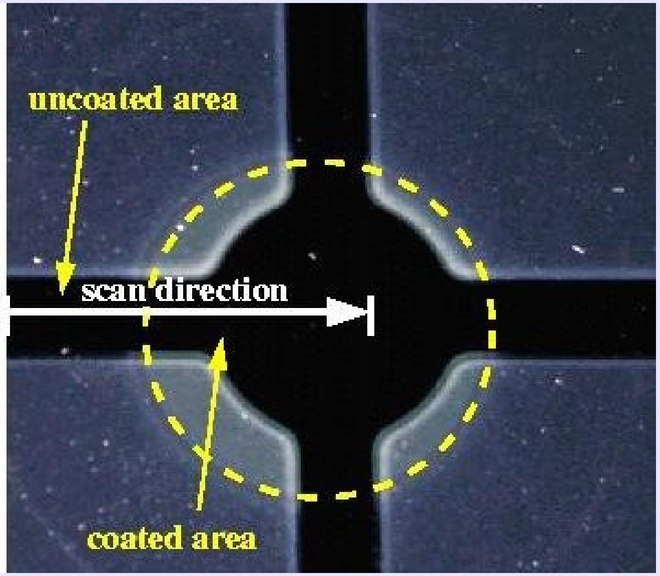
Micro-strip sensor has to operate as a semi-transparent photo-detector.

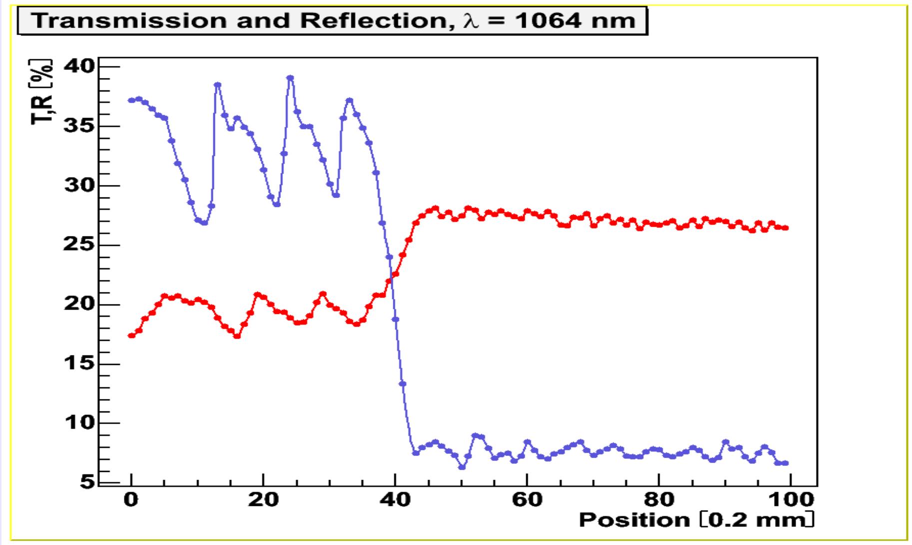
IFCA Santander and IMB-CNM, within the EUDET are ***performing R&D to optimize the optical properties of silicon sensors*** (transmittance, reflectance, beam deflection, position reconstruction accuracy)

- 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%



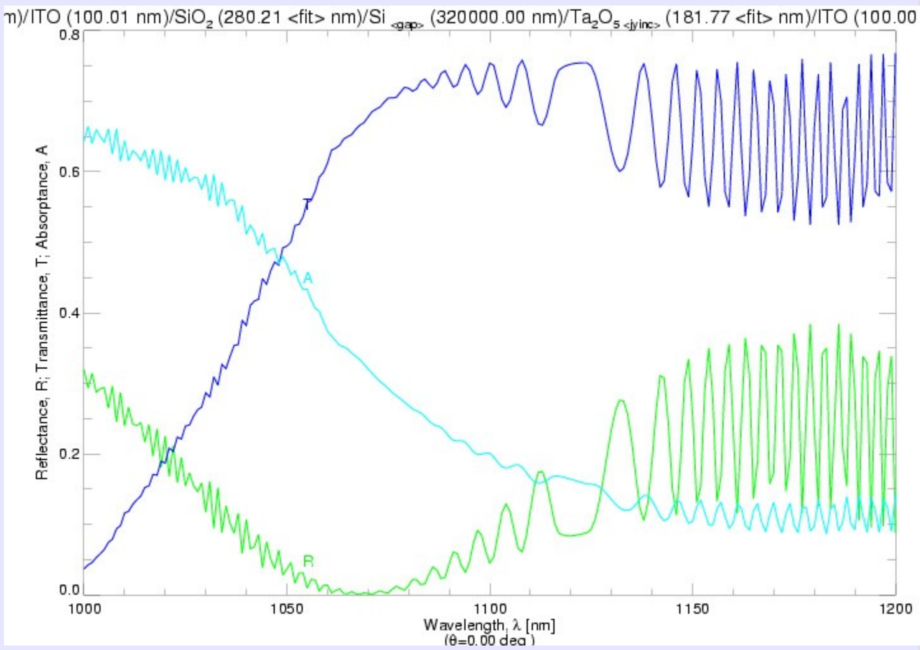


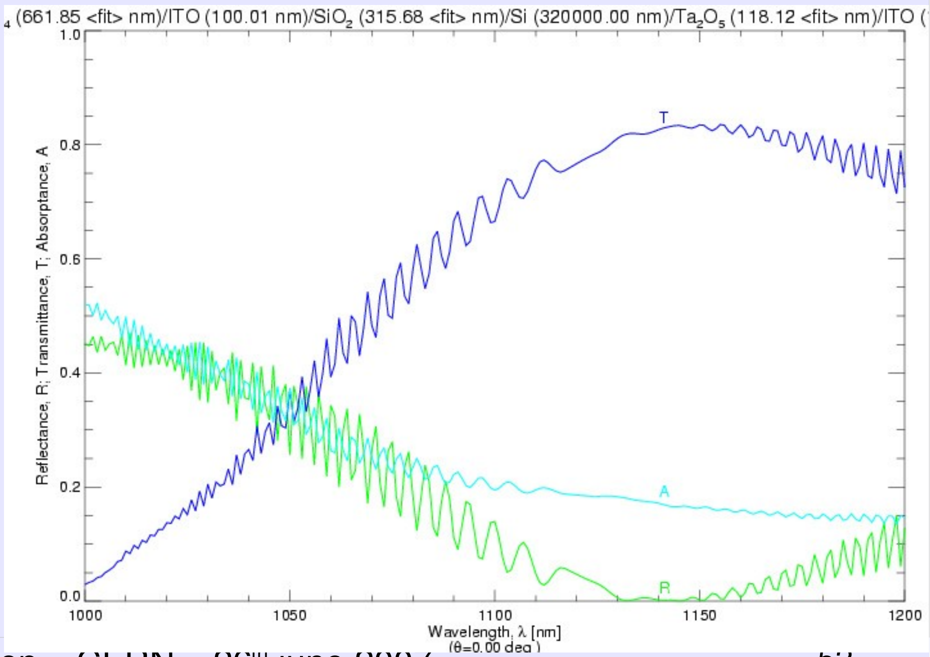
IR transparent detectors

- Alignment strategy with laser beams as straight tracks based on AMS and CMS achievements (as shown previously)
  - ➔ InfraRed Laser beams propagate through several silicon modules
  - ➔ Signal is readout using module electronics
- Both in AMS and CMS standard sensors modified
  - ➔ Transmittance < 50%
- We propose to design from the beginning IR transparent sensors:
  - ➔ Substitute Al electrodes (strips and backplane) by transparent electrodes (TCO) as ITO (In doped SnO_2) or AZO (Al doped ZnO)
  - ➔ Design proper antireflective coating (ARC) using standard microelectronics layers (SiO_2, Si_3N_4)
  - ➔ Take into account all sensor layers
  - ➔ Detailed information from manufacturer needed
  - ➔ Check if with new technological design there is electrical behavior degradation

IR transparent detectors

- Preliminary simulations
  - Transmittances up to 80% can be achieved
  - Zero reflectances
  - Absorbance > 20%; >5% in Si: good signal
  - Important to simulate changes in %T with layer thickness tolerances
- Multilayer design has to be tolerant to allow small changes in %T for moderate changes of layer thickness
- Complex refraction index of materials is wavelength and process dependent:
  - Measure samples to simulate reliable designs
- Strips structure will be modelled as surface roughness





IR transparent detectors

- R&D Proposal by IFCA and CNM
  - Provide by CNM with suitable samples of different layers and thicknesses for optical characterization at the desired wavelength
  - Assess fabrication tolerances of the different layers
  - Study optical coefficient variation in SiO_2 and Si_3N_4 achievable by deposition condition variation
    - To have room for the ARC optimization
  - Optimization of the vertical layout for maximum %T with reasonable %A
    - Different options are acceptable at this stage
  - Account for process variations
  - Fabricate test samples with suitable mask set
  - Bond to readout electronics
  - Optical and electrical test
- Samples have to be designed and tested both, as photosensors and as charged particle detectors
- If success: transfer technology to companies

Alignment - comparison

Both approaches to the hardware alignment system have complementary benefits and challenges (when compared to each other and with respect to the track-based alignment)

CHALLENGES:

- Both: Integration with the system
- The hybrid approach requires the development of sensors with optical properties.
- FSI relies on the mechanical transfer from retro-reflector position to active area.

BENEFITS:

- Both: possiblity to resolve "fast" distortions (1 ms? 200 ms?)
- FSI: measures **arbitrarily chosen coordinates**, constraints on "weak modes" of the track based alignment.
- hybrid: **direct** measurement of parameters that couple strongly to the sensor measurement.

Both systems to be present in SiLC test beams in 2007 (1st HYBRID proto) and 2008 (FSI)

Conclusions

ILC precision physics programme relies on detector performance:

very challenging detector requirements

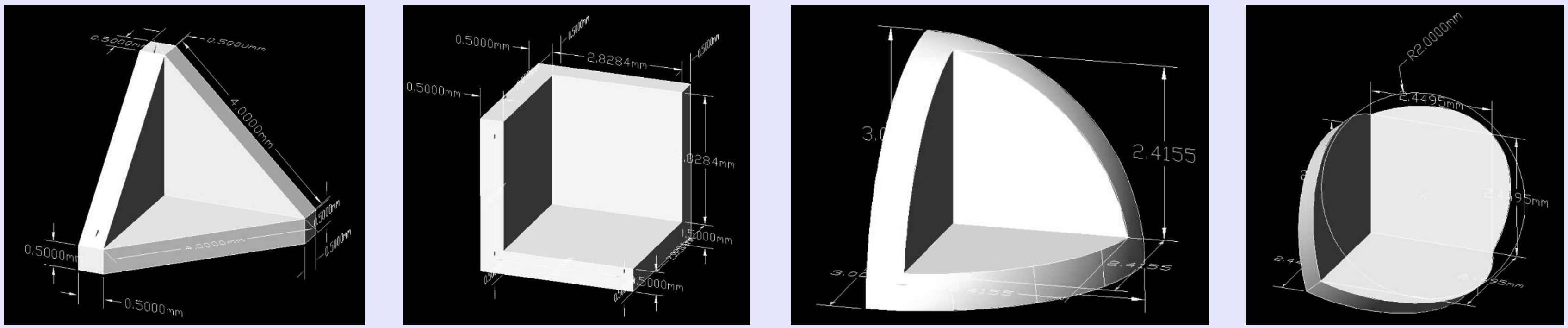
Detector R&D for ILC is a fast-moving field:

can technology meet the challenge?
can we keep up with technology?

And then it all comes down to calibrations:

best achievable performance of our detector ?

Alignment - FSI



Tests so far done using large (1 inch) commercial retroreflectors. First tests o small, low X0 retroreflectors for the ILC very promising.

Cooling

Power that goes in must be taken out. Some educated guessing yields:

The foreseen 130nm Front-End average power with the Paris design (J.F. Genat):

4.5 10^6 channels x (575 x [1/100+1/200] + 66 x 1/8) 10^{-6} =

38.8 W + 37.2 W 76 Watts

(includes gain from power cycling, to be implemented)

Power from the detector:

Assume 50 nA/cm^2 at 100V full depletion,

400 square meters detectors end up with 20 Watts.

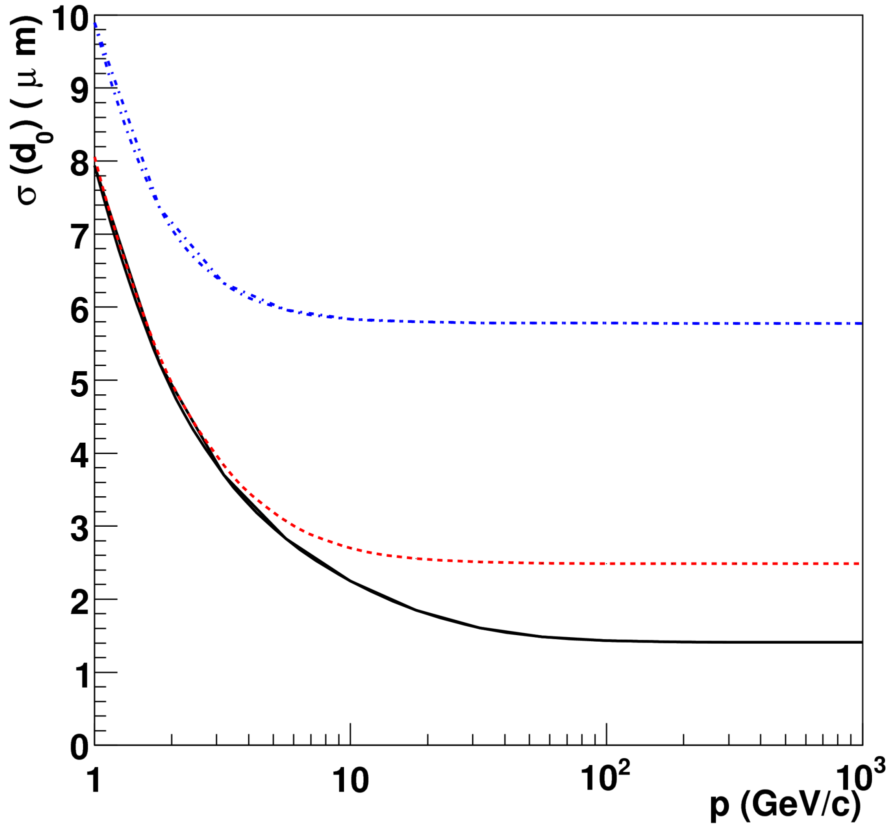
Power from fibers (neglecting micro-coax):

Assume 16 x 2W fibers = 32 Watts

Total: 128 Watts

We assume power in blue (analog) is cycled at 1/200 in time and 1/100 in value. Power in red (ADC + logic) is cycled at 12.5% (1 / [100 microseconds x 16 samples x 16 events])

Impact parameter resolution



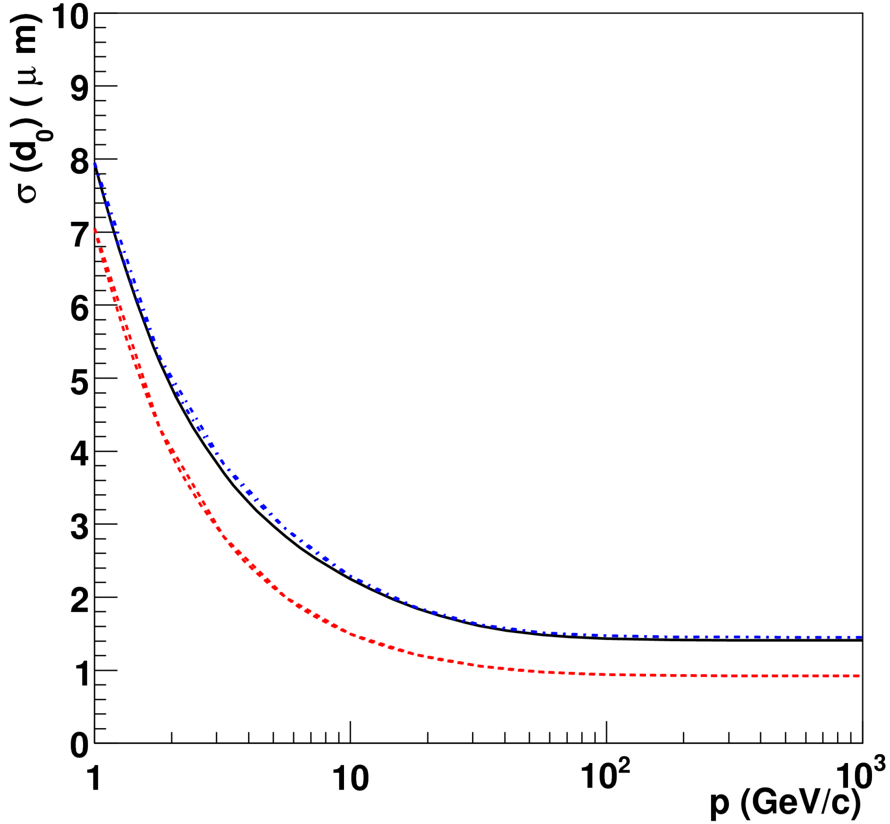
Transverse impact parameter resolution at θ = 90 degrees, calculated with LCDTRK (courtesy of B. Schumm, SCIPP/UCSC) for a VXD with 2 mm space point resolution, together with:

- All (VXD + SIT + TPC)
- VXD + inner tracker (SIT)
- VXD standalone

The VXD standalone has $\sigma(1/p_T) = 10^{-3}$ GeV^{-1}

Adding SIT lever arm yields improvement to $\sigma(1/p_T) = 4\ 10^{-4}$ GeV^{-1}

Impact parameter resolution



Transverse impact parameter resolution at θ = 90 degrees, calculated with LCDTRK (courtesy of B. Schumm, SCIPP/UCSC) for a VXD and SIT:

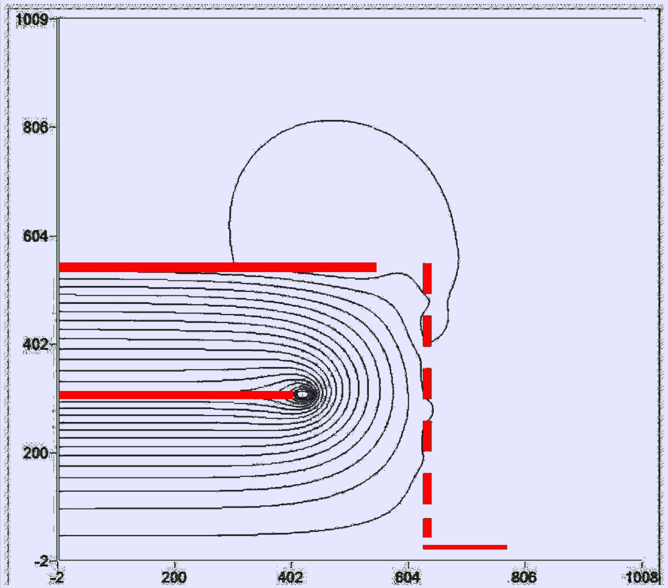
VXD resolution 2 μm

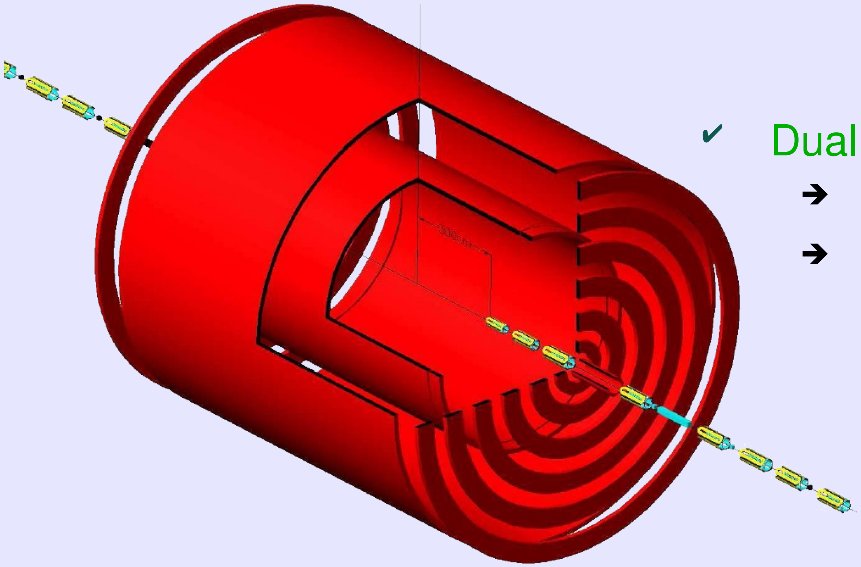
VXD resolution 1 μm

mixed VXD

- resolution 2 um (inner 2 VXD layers)
- Resolution 5 um (outer 3 VXD layers)

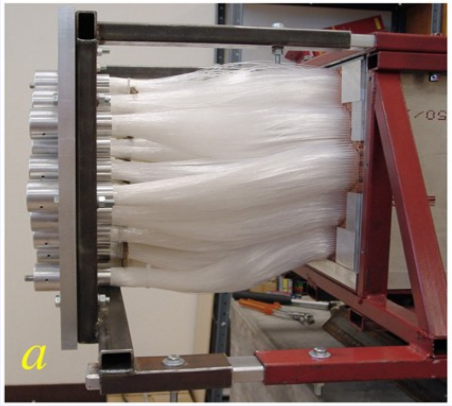
The 4th concept

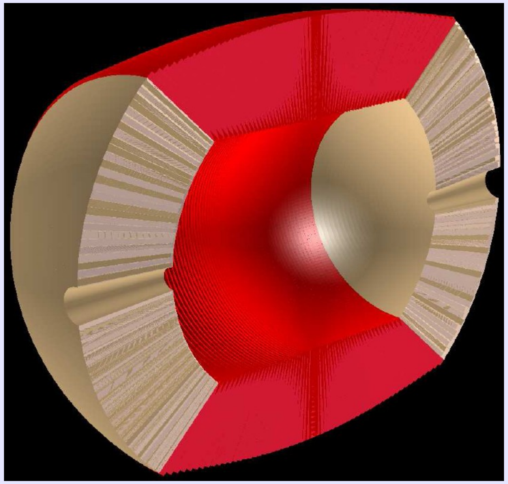




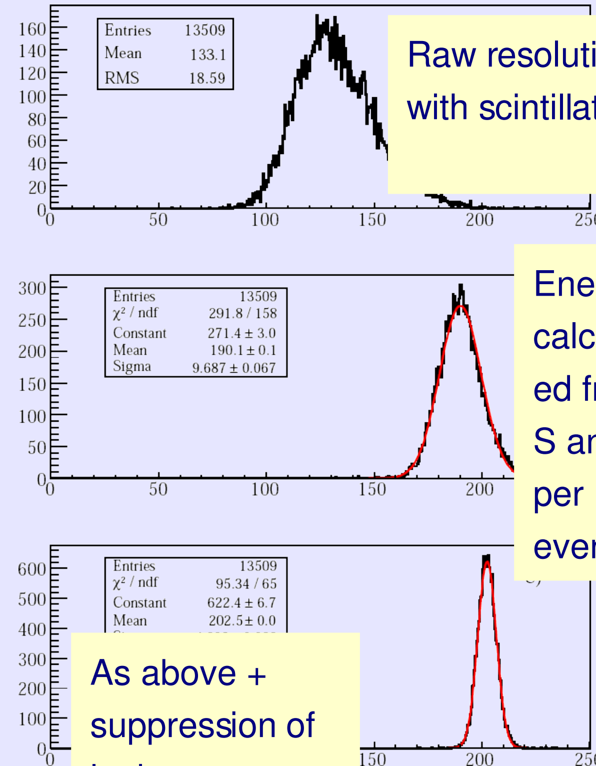
- ✔ Dual solenoid field
  - ➔ Iron free magnetic field
  - ➔ Mouns are bent

- ✔ Dual REAdout Module (DREAM) calorimeter
  - ➔ Dual means:
    - Scintillating fibers (charged energy)
    - Čerenkov fibers (electromagnetic component)





200 GeV pions



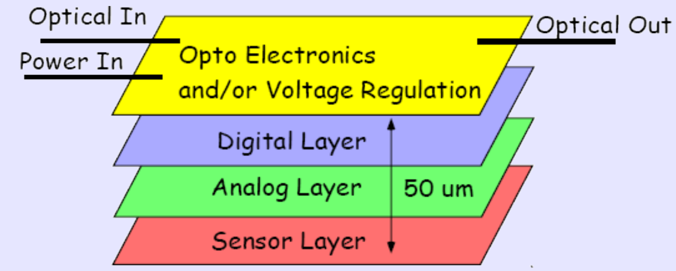
Raw resolution with scintillators

Energy calculated from S and C per event

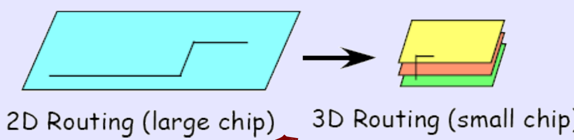
As above + suppression of leakage fluctuations

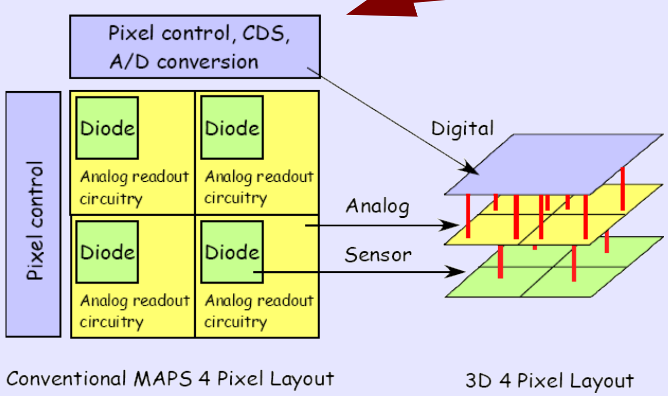
Vertex detectors (connectivity)

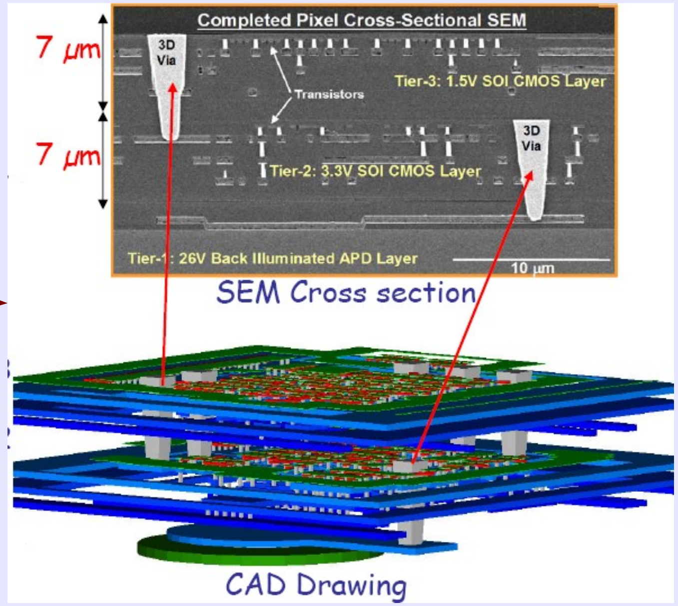
- **Connectivity** is an issue (low mass requirements)
  - ➔ The killer of the very best of the technologies...
- An interesting technology is **3D IC development.**
  - ➔ A chip made by different layers thinned, bonded and interconnected to form a *monolithic* circuit
  - ➔ Often the layers are fabricated in different processes
  - ➔ Industry is moving into this direction...



Physicist's Dream







- More functionality in a given area
- Each layer can be made in different processes
- Each layer can be optimized independently
- Perimeter logic can be largely reduced