

WORKSHOP-Micro-pattern Gas Detectors: status & perspectives
CERN, January 20 2006

LHC and ILC: Future Detector Challenges

(Why, what and how to confront them)

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Origin of detector challenges

- **The Physics Challenges**
- **The Machine parameters:**
 - Colliding particles**
 - E_{cm}**
 - Luminosity**
 - Bunch Train Timing**
 - Radiation levels**
 - Machine Schedule**

**Different machines will have different conditions of work and thus different detector challenges to confront;
However there are common issues and thus there is a synergy between LHC & ILC**

The achievement of the detector challenges will strongly depend on the state-of-the-art of the technologies

Learning from past

CDF is one of the HEP experiments with the highest longevity. It turned 20 and will last about 25 years.

The secret:

The contributions of several generations of talented physicists and engineers who didn't hesitate to make continuous upgrades based on the forefront high-tech in order to achieve the Physics challenges.

Pioneering the use of microvertex in an hadronic environment,
Triggering on gaseous tracking detectors (@level2 first & then @ level 1 when high tech allows to do it),

Triggering on microvertex detector to tag b-quarks in realtime (level2)

Challenges that people thought were impossible missions but were successfully achieved.

With tremendous assets/benefits for the Physics!

Ecm: LHC & ILC entering the TeV range

The importance of the forward & very forward regions:

1) The Physics is produced at larger angles.

2) The colliding objects are different, but:

❖ beamstrahlung in e^+e^- at LC

❖ underlying event + pile up events in pp collisions

Make that the forward region is a very difficult region in both machines; It requires highly performing detectors down to a very small angle wrt beam axis.

➤ The need for higher granularity

When energy increases the produced jets are more focused and Physics produces events with higher jet multiplicity (ex: W or Z+Njets, Wpaires etc...)

➤ The need for larger dimensions & higher B-field

Heavier objects are produced that must be contained in the detection volume. The tracking part requires a larger radius even if higher B field. The calorimetry must have enough absorption length.

Ecm: LHC & ILC entering the TeV range (cont'd)

➤ The importance of flavour tagging

Light quarks, heavy quarks, and increasing importance of the tau lepton tagging

➤ The increased dynamic range

Heavy objects with cascade decays thus production of low momentum decay products.

➤ The need for realtime sophisticated selection & processing

Heavier objects are produced with much lower cross sections than SM mechanisms: huge Physics backgrounds make harder digging out the signals.

➤ Higher flux of information per event

High number of tracks and large variety of elementary objects (jets, leptons of all kinds and possibly unknown objects) per event.

All have to be correctly identified and very precisely measured.

Luminosity

In order to confront the challenges due to luminosity the detector must be able to cope with:

- The dramatic change in luminosity (ex:occurring in the first years.)
- The increasing nb of pile-up events
- The higher radiation levels

The main impact will be on:

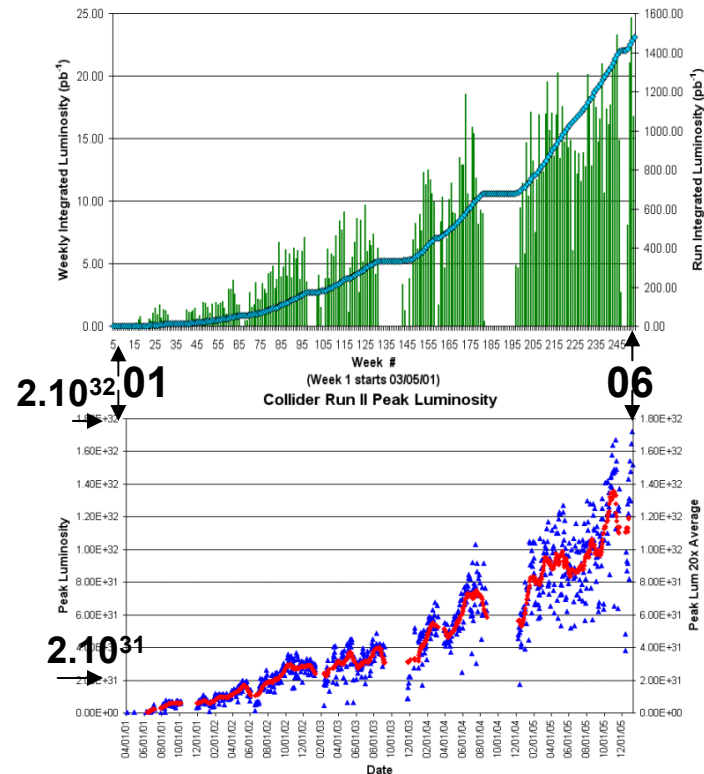
- The tracking devices
 - The whole Front-End & readout electronics
 - The data processing & triggering.
- Leading to the need of upgrades.

LHC:

Nb of pile up events @ $2.10^{33} = 4.6$

Nb of pile up events @ $10^{34} = 23$

Collider Run II Integrated Luminosity



Tevatron Run II Luminosity

2007 1 month $2 \cdot 10^{30}$
 2 months 10^{31} 0.02 fb⁻¹??

2008 2 months 10^{32}
 75ns, $\beta^*=2$, 41010
 3 months $4 \cdot 10^{32}$ ~1 fb⁻¹
 25ns, $\beta^*=1$, 31010

2009 4 months 1-2 10^{33} 4-8 fb⁻¹
 with 1 month ~ Nsec \times lum / π

D. Treille guesswork, following crudely the commissioning plans(Corfu05)

2010 running @ 10^{34} (my personal guess)

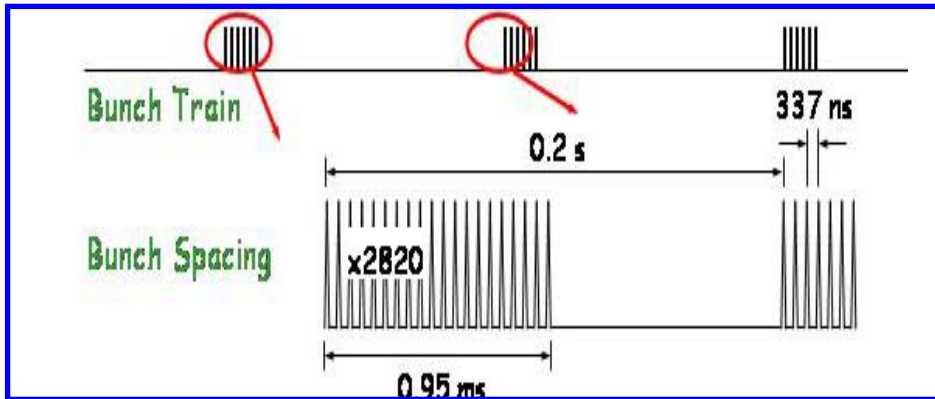
LHC Luminosity

Bunch Train Timing

It drives the electronics design from the Front-End to the DAQ

ILC low frequency machine

CLIC case:

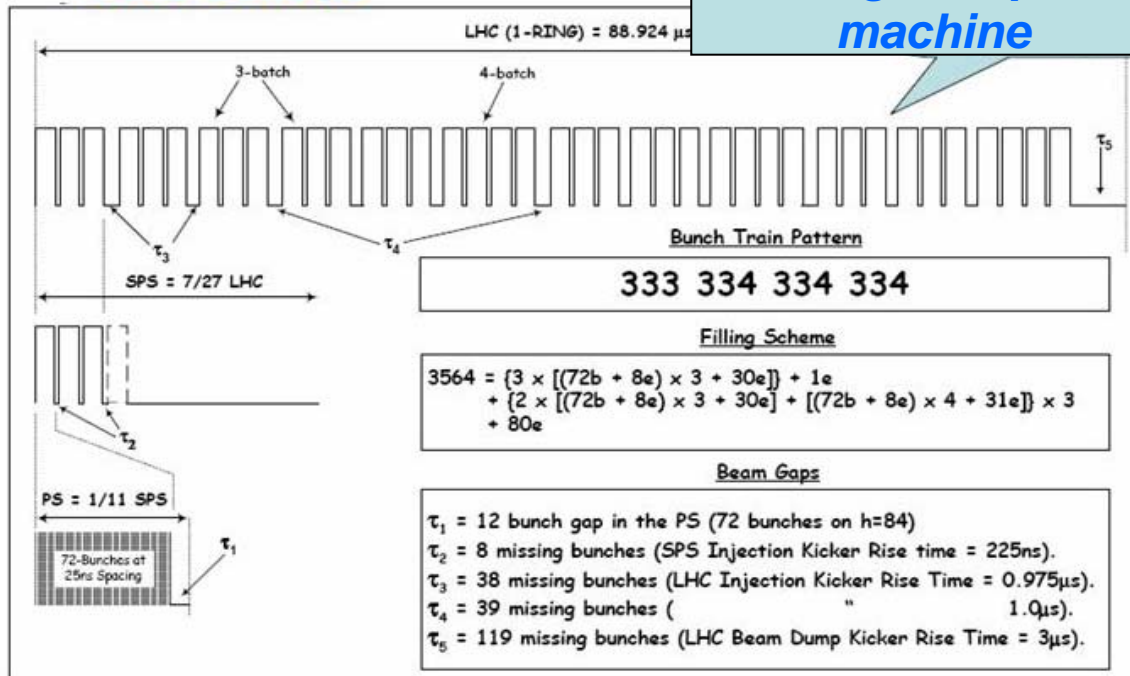


Rep. Rate (Hz)	150
Bunches / pulse	220
Bunch spacing (cm)	8

240 ps/bunch, train duration = 53 ns
6 ms in between pulse

25ns Scheme

LHC high frequency machine



Common feature at ILC & LHC:
bunch tagged FE electronics
(more difficult with CLIC!)
Possibility of *power cycling*
at ILC

Radiation levels

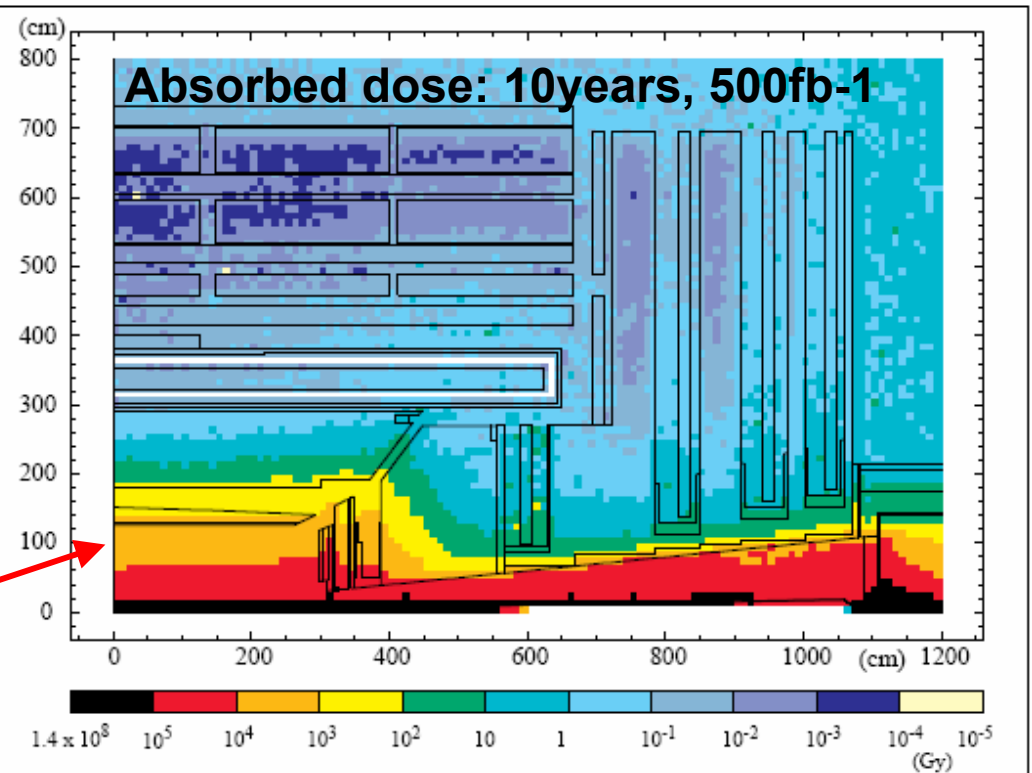
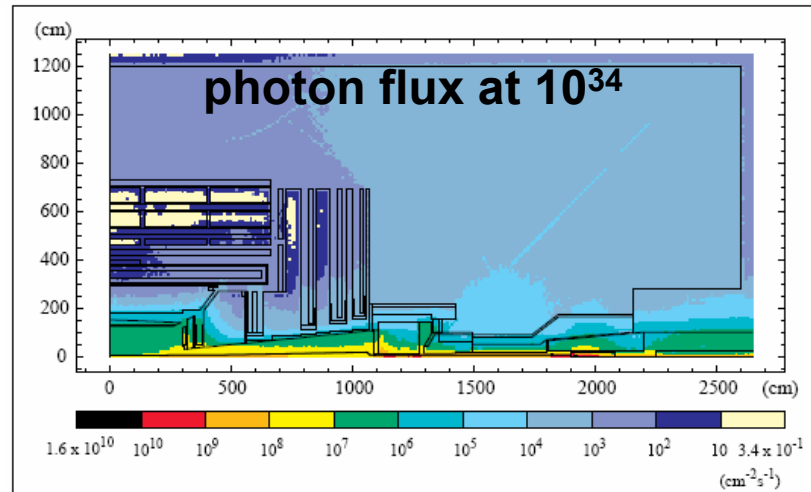
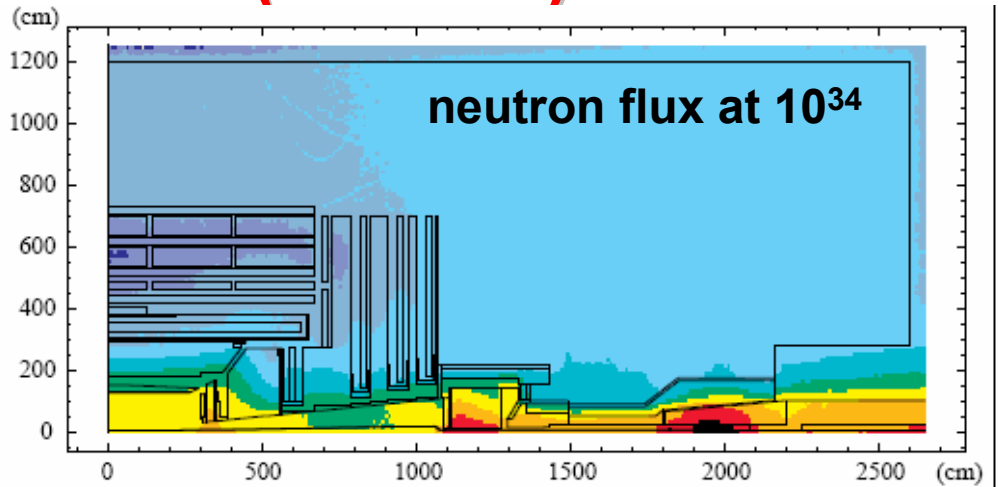
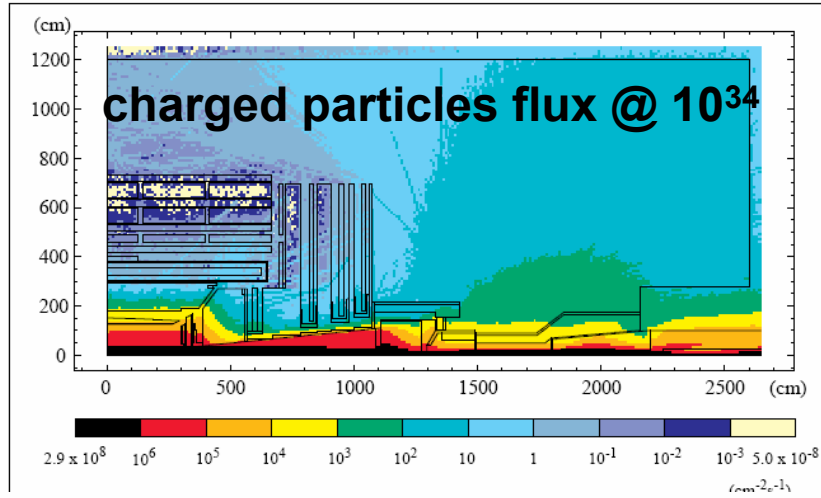
Impact on the detectors & the electronics, leading to:

- Stringent requirements on the cooling
- Detector, Electronics and all associated services must be radiation tolerant or radiation hard.

This affects primarily the innermost parts (microvertex and the overall tracking) with an increase in material budget for these crucial parts.

Two different cases but at the end also some common issues and way to solve problems.

LHC radiation doses (ex CMS)



CMS Barrel tracker		CMS ECAL	
R=4cm	840KGy	$\eta = 0-1.5$	3KGy
R=11cm	190KGy	$\eta = 2$	20 KGy
R=75cm	7KGy	$\eta = 2.9$	200KGy

Radiations & the very forward issue at ILC

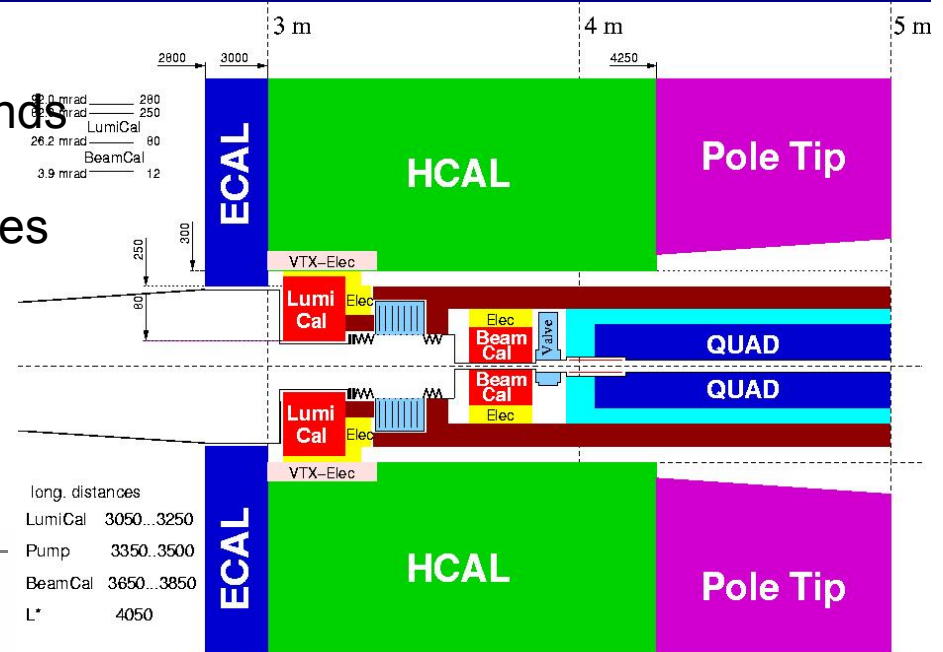
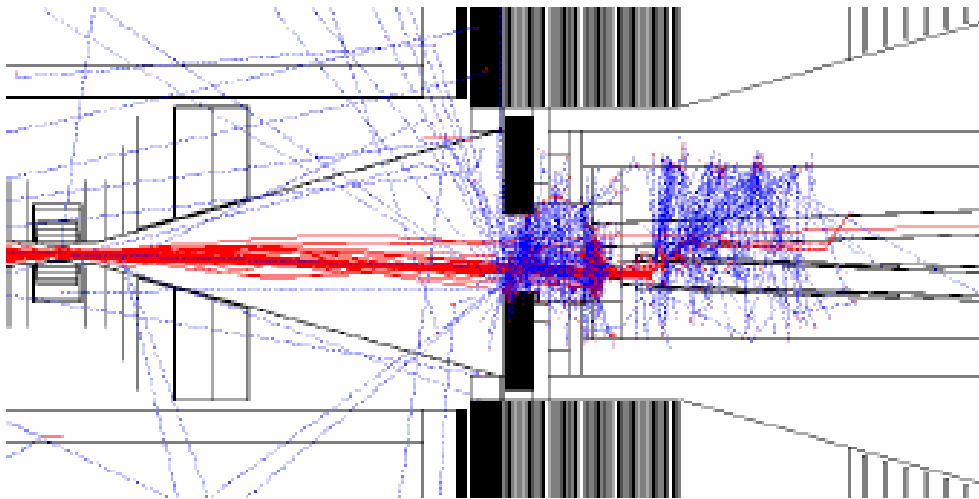
The **VERY FORWARD DETECTION ZONE** serves for:

- Measurement of Luminosity with precision $O(<10^{-3})$ using Bhabha scattering
- Detection of e^- and γ at small polar angles (important for searches)
- Beam survey and monitoring

Beamstrahlung or more correctly its collateral effects are the main cause of beam backgrounds affecting the detectors.

It depends on the beam parameters and causes an increase in number of hits in the detectors rather than radiation doses

NOTE that this is under study and no definite numbers are yet available!

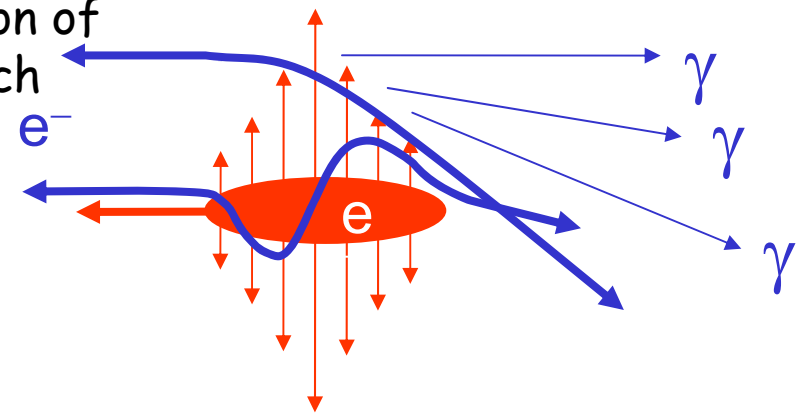


Simulated event in the LDC concept with the effect of local solenoid compensation included

Beamstrahlung & background sources @ILC

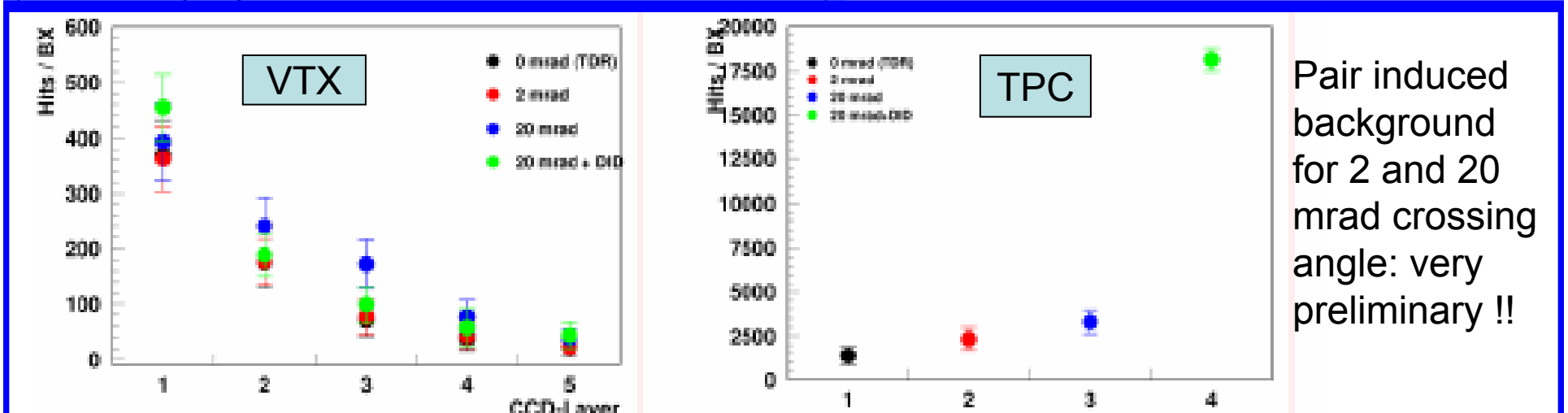
Beamstrahlung is a new phenomena @ILC: radiation of photons in the field created by the oncoming bunch
 e^+e^- pairs are the main source of background

- beams have to be focused very strongly ($\sigma_y = 5$ nm)
- beam-beam interaction creates beamstrahlung
- beamstrahlung photons scatter to e^+e^- ($10^5 / BX$)
- e^+e^- crash into forward calorimeters and magnets
- lots of photons, neutrons, and charged particles are created close to the tracking detectors



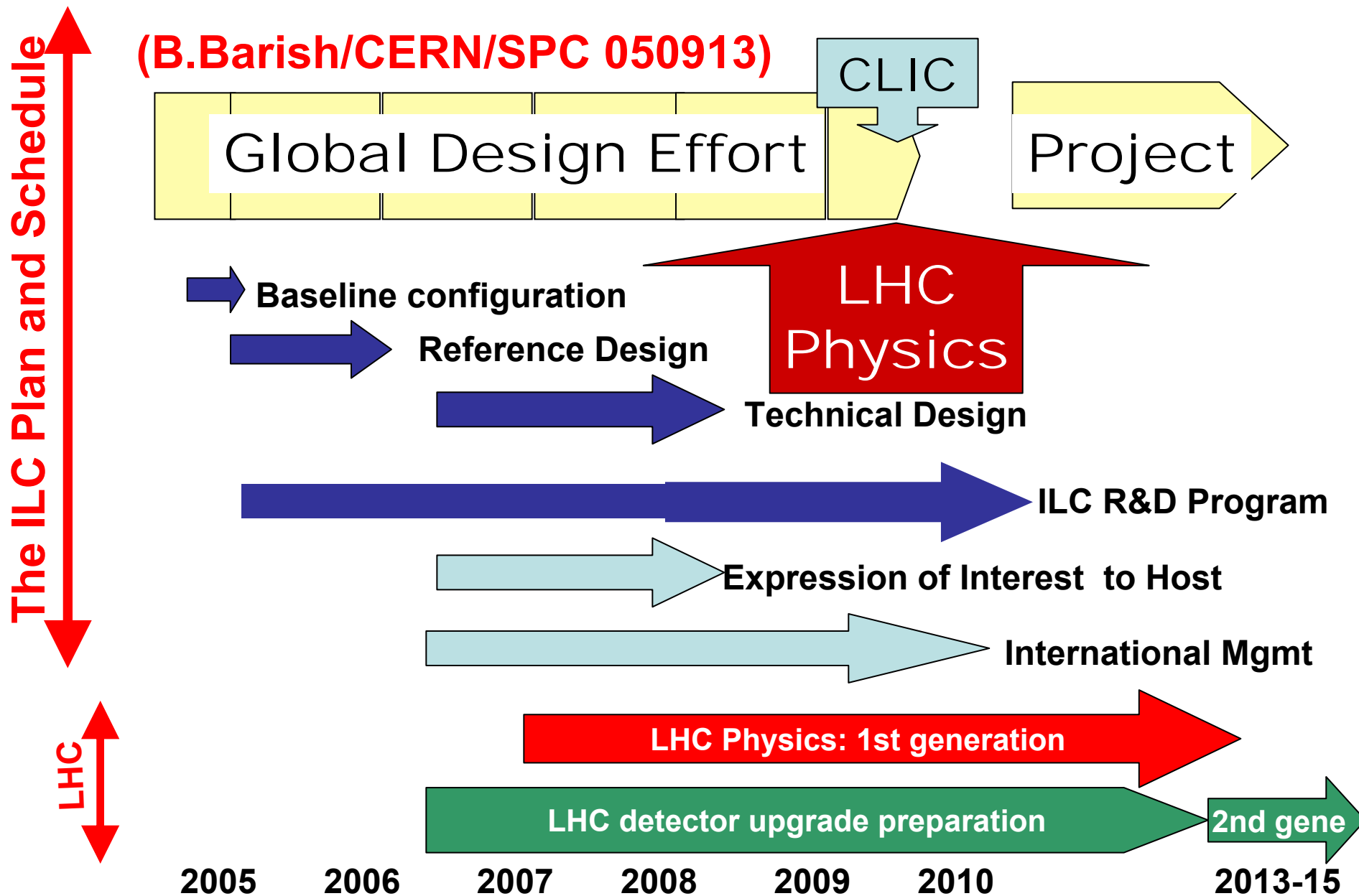
- energy loss of the beams (few %)
- production of large number of photons in the IP
- blowup of the beam spot

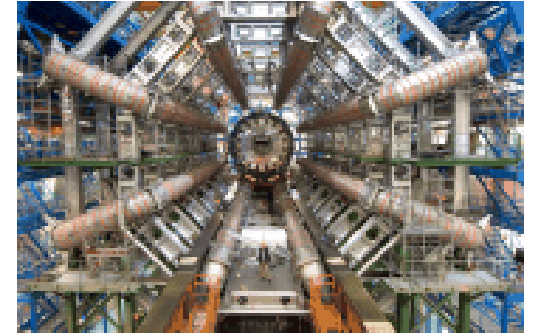
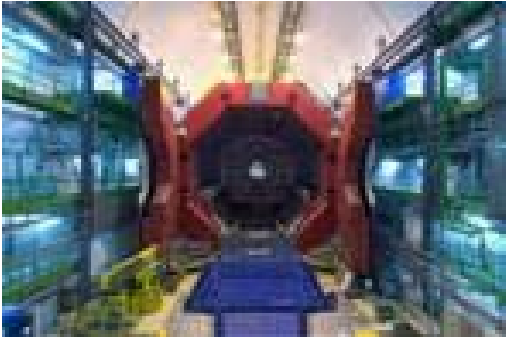
Other sources are supposed to be negligible
 (beam dump, synchrotron radiation, radiative Bhabhas)



Pair induced background for 2 and 20 mrad crossing angle: very preliminary !!

The Machines Schedule





LHC future detector challenges

- Commissioning of the biggest and largest instruments ever built in HEP (it includes the machine itself!)
- Getting the first LHC generation experiments to run at full speed and routinely, in order to get the Physics.
- In parallel starting to work on the upgrades for the second generation phase of these detectors



Future detector challenges for both LHC and ILC

- Unprecedented detector performances requested
- In the overall detector volume
- Enormous number of channels to read out
- Need for realtime & sophisticated data processing
- Difficult environments
- Make an EASY access to data from data taking to full data processing to everyone and everywhere!
- Robustness and reliability
 within the new more stringent conditions

Advanced High Tech Helps!

- HEP Field triggers high tech progress in various ways, as it requires highly performing and sophisticated devices.
- But the use of high tech also imposes constraints... (need of expert people, of the follow up of sometime short-lifetime technologies etc...)

➤ **The semi-conductor revolution!**

Electronics: μ electronics \rightarrow nanoelectronics

Detectors are more and more based on semi-conductor technology: from the microvertex to the calorimetry.

➤ **The revolution in computing technologies:** hardware & software

➤ **The revolution in technics of telecommunication & data transfer**

This will help tackling many of the future detector challenges



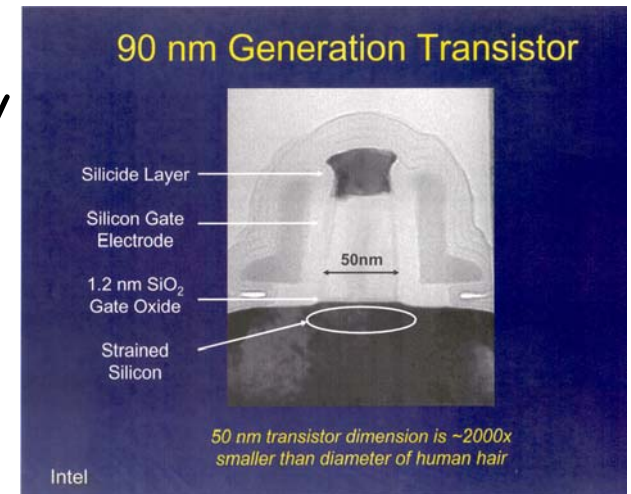
The semi-conductor REVOLUTION!

- **Electronics**
from MICRO to NANO
technologies
- **Detectors**
Microvertex
Trackers
Calorimeters



On-detector System-On-Chip electronics using (Very) Deep Sub-Micron CMOS technologies

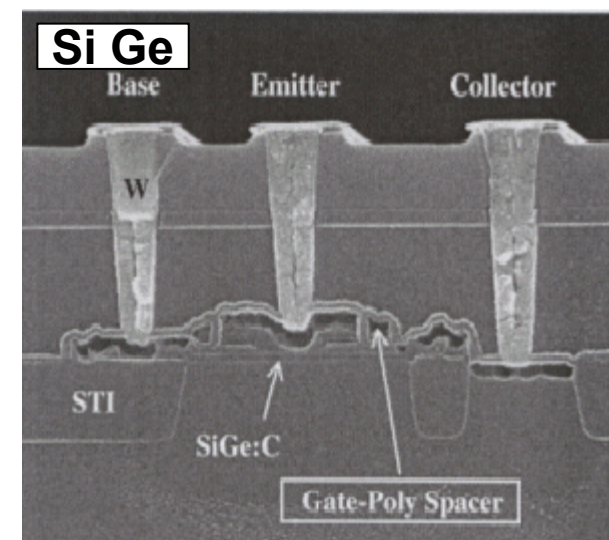
- On detector low-noise amplifiers mandatory
- Radiation tolerance & hardness
- Less on-detector material: Silicon, wiring, packaging, cables, kaptons, connectors ...



90 nm Intel transistor

- Processing: A/D conversion, zero suppression, calibration, realtime data processing & filtering; thus reduced output dataflow
- Less power dissipation
- Speed: Si Ge faster than CMOS for same power dissipation and CMOS compatible
- Excellent reliability

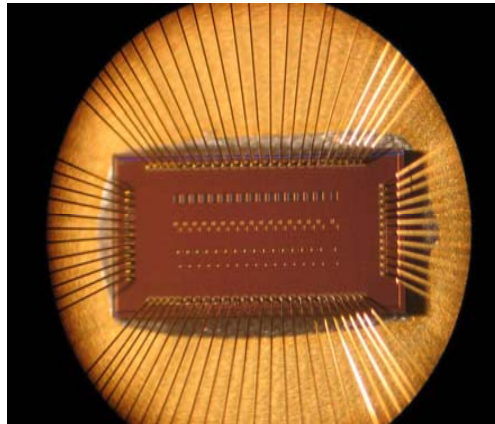
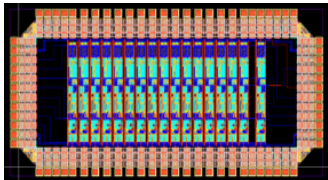
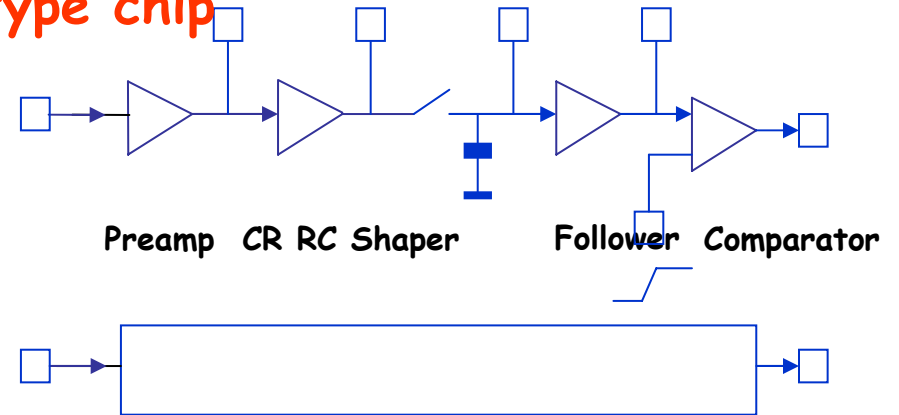
There is no other way !



Paris Front-end Prototype Chip

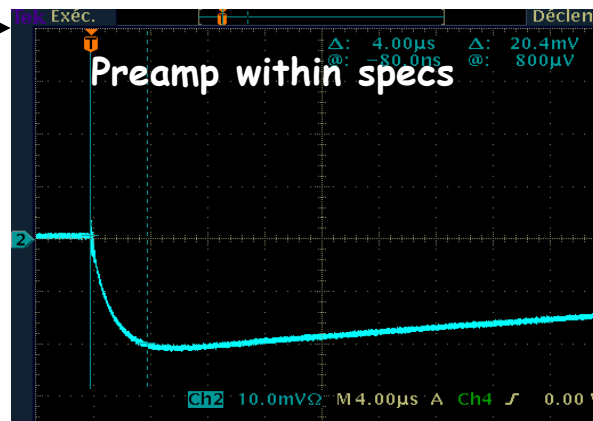
CMOS 180 nm Si strips readout prototype chip

- Low noise amplification + pulse shaping
- Pulse sampling
- Threshold detection
- Power dissipation less than 500 μ W/channel

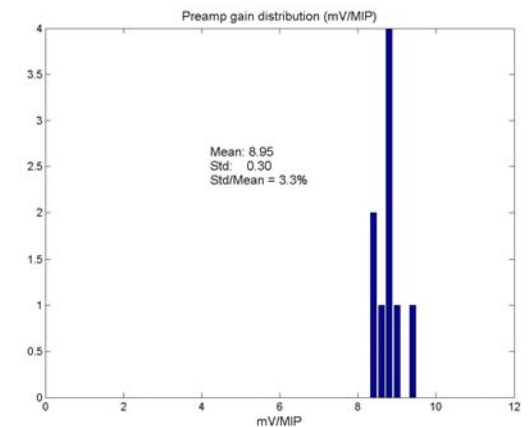


3mm

New version 128 ch
including sampling & A/D
in CMOS 130nm under design



16 identical
channels



**Measured process
spreads:
3.3 % quite good**

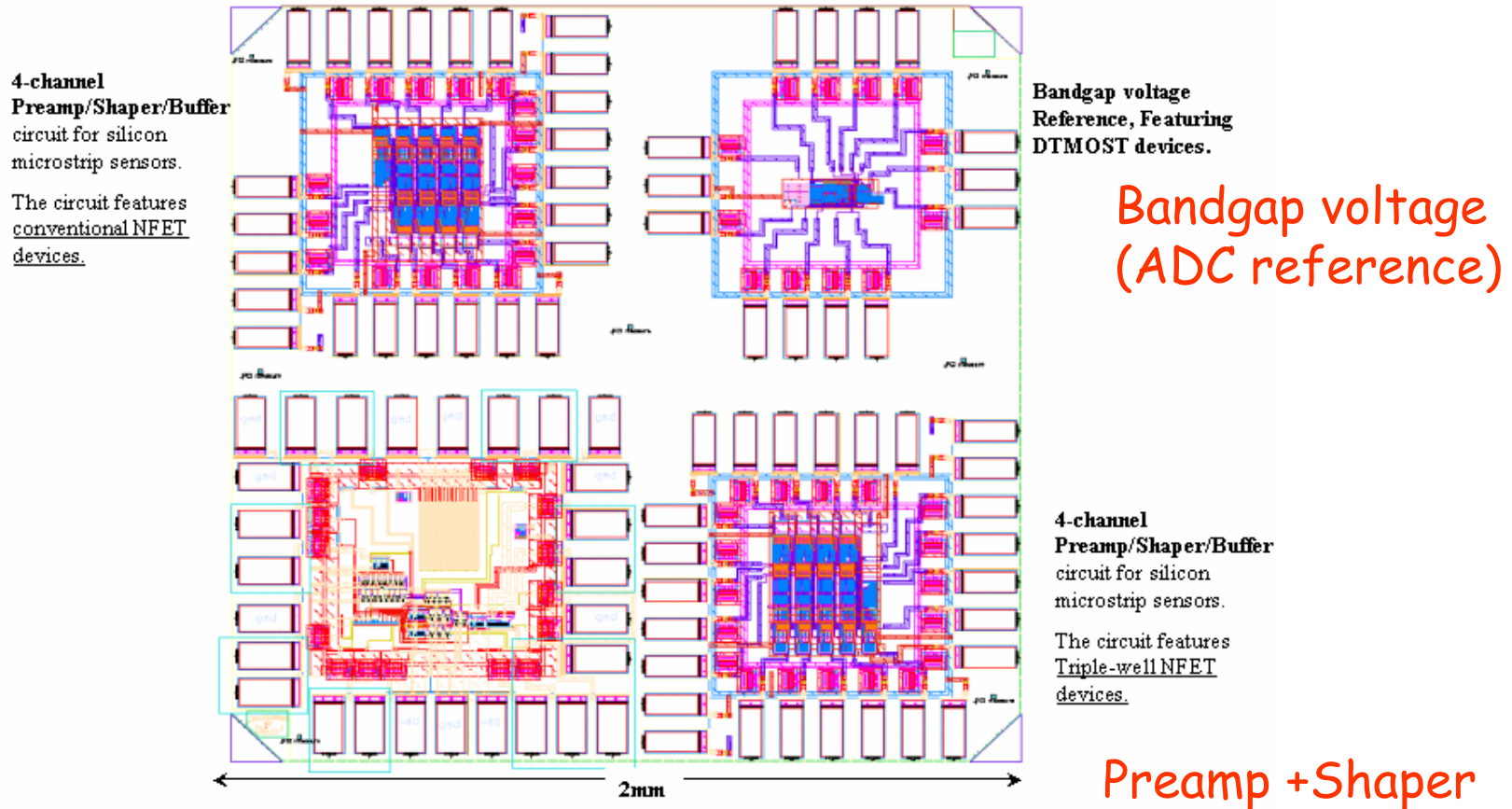
Courtesy J. F. Genat

Experimental chip (NIKHEF) based on 130 nm CMOS techno

The experimental chip (NIKHEF part).

Preamp + Shaper

(the chip was submitted in CuTe2 MPW run on May 10, 2004.)



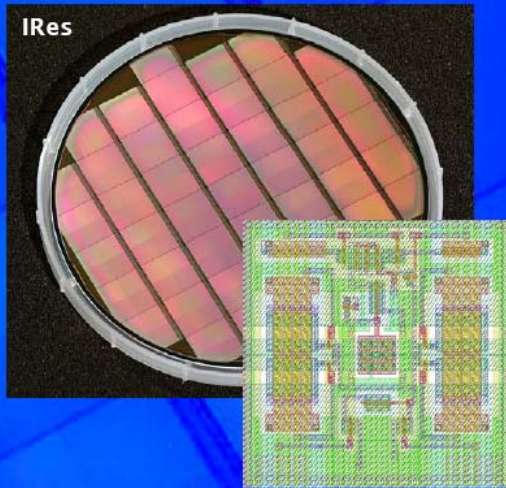
Courtesy: Wladimir Gromov

Integrate sensitive cell and electronics in same substrate

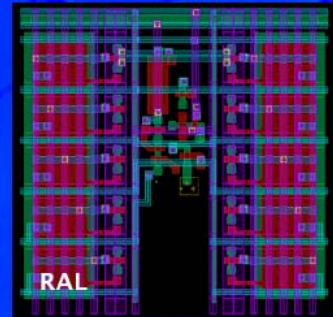
Various architectures developed:

CMOS

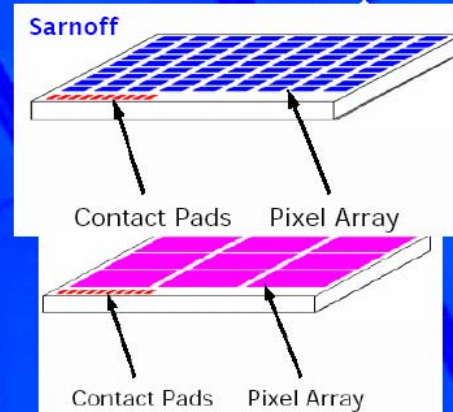
Continuous Read-out:
Fast Column Parallel Architecture



Delayed Read-out
Multi-memory Cell Pixels
(FAPS)



Micro-Pixels
Macro-pixels



New pixel Technologies for Microvertex

SOI

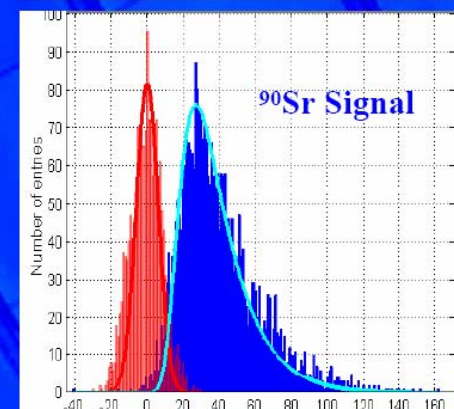
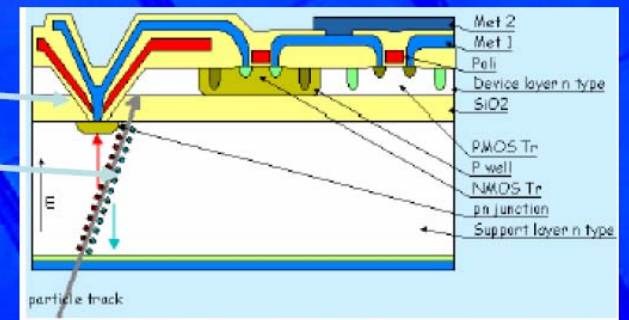
CMOS electronics
High resistivity fully depleted sensitive volume
Not standard process
Development started 3 years ago
Proof of principle accomplished
ILC dedicated development being defined with partner company

Beamstrahlung constraints:
(very preliminary thus be cautious with these nbs!)

<5hits/cm²/BX at 90°
(R0=15mm, 4T)

Impact on readout speed:
<25μs in L0
~50μs in L1 (R1~25mm)

Ionising damage
<50 kRad/yr



DEPFET Sensors

Europe, Bonn U., Mannheim U., MPI Munich, HLL (Germany)

DEPFET sensor-amplifier structure:

FET transistor on fully depleted and sensitive bulk;

Small size, thick prototypes produced in MPI laboratory with complete silicon technology, **in house capability** to build all ILC VTX sensors;

Prototype Module electronics with nearly full functionality developed and tested with prototype sensors;

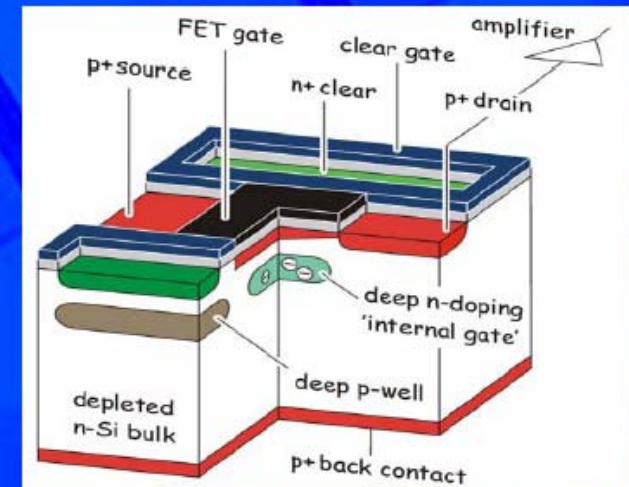
Readout and data sparsification with 20 frames/train;

Radiation hardness to 1 Mrad ^{60}Co tested, expect good neutron tolerance;

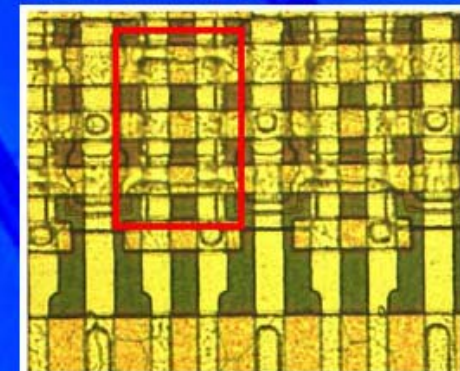
Low power consumption (4W for full detector) operate at **room temperature** with air flow cooling;

Operation of small size prototypes demonstrated;

Current R&D to obtain fully engineered and tested system.



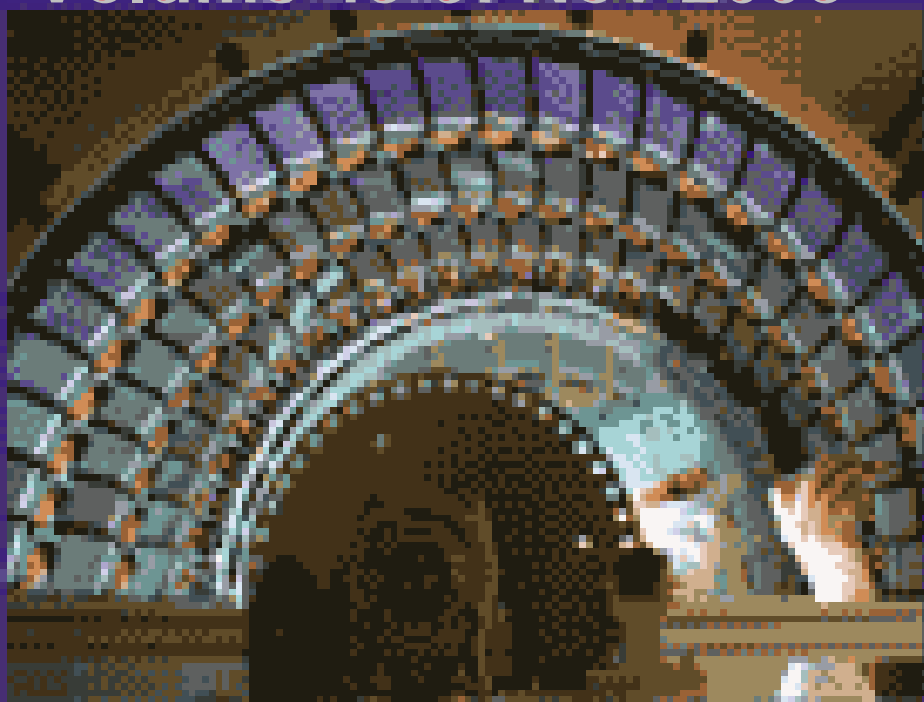
Micrograph of prototype sensor
(128x64 pixel, double pixel cell 33 x 47 μm^2)



Publications, Technology and Education Division

CERN COURIER

Volume 45-9: Nov 2005



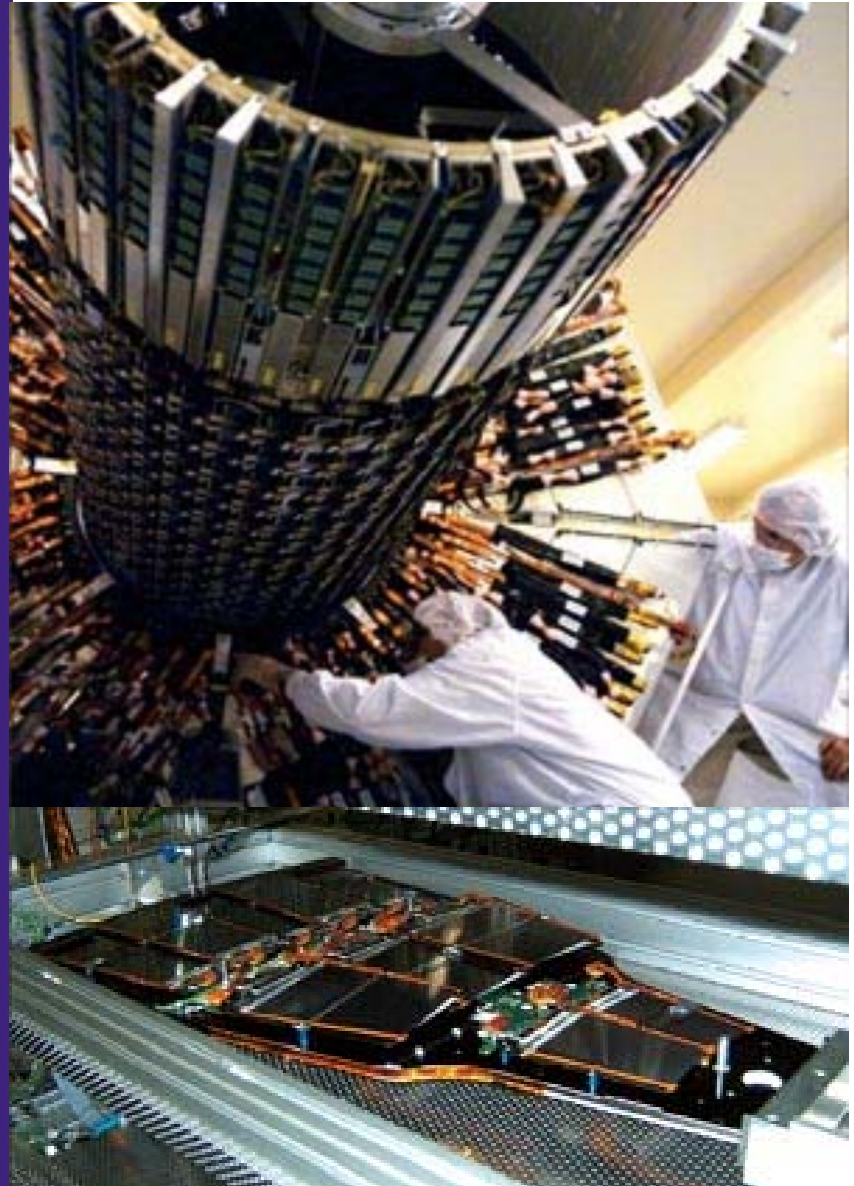
A formidable LHC challenge!

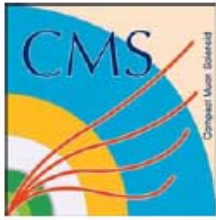
But what's next...?

HEP
HEP connects the
physics and technology

HEP
HEP connects the
physics and technology

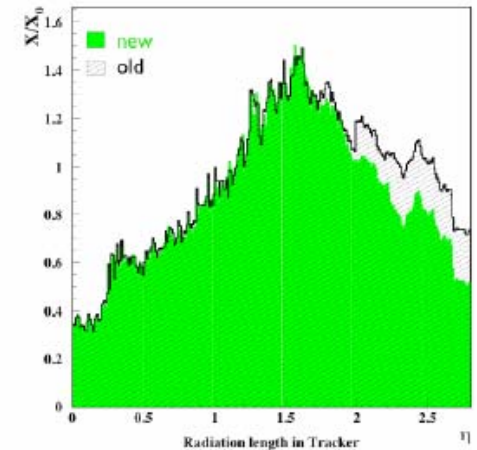
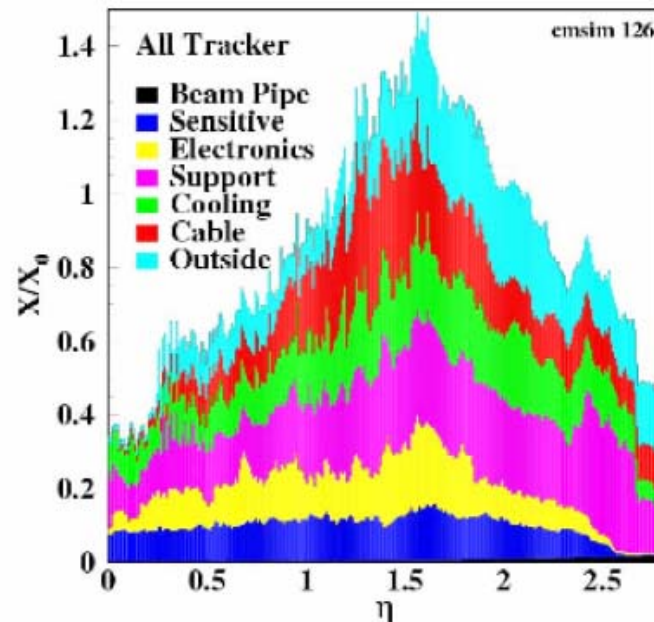
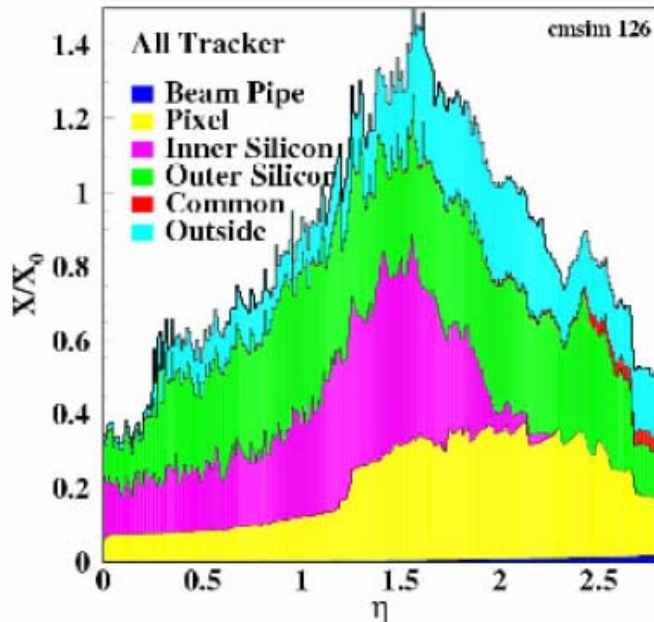
Large area Silicon Tracker





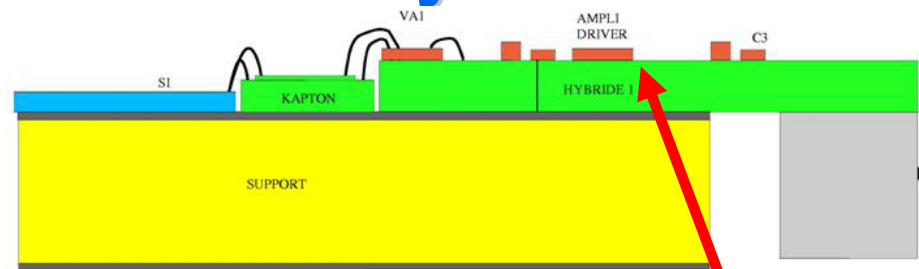
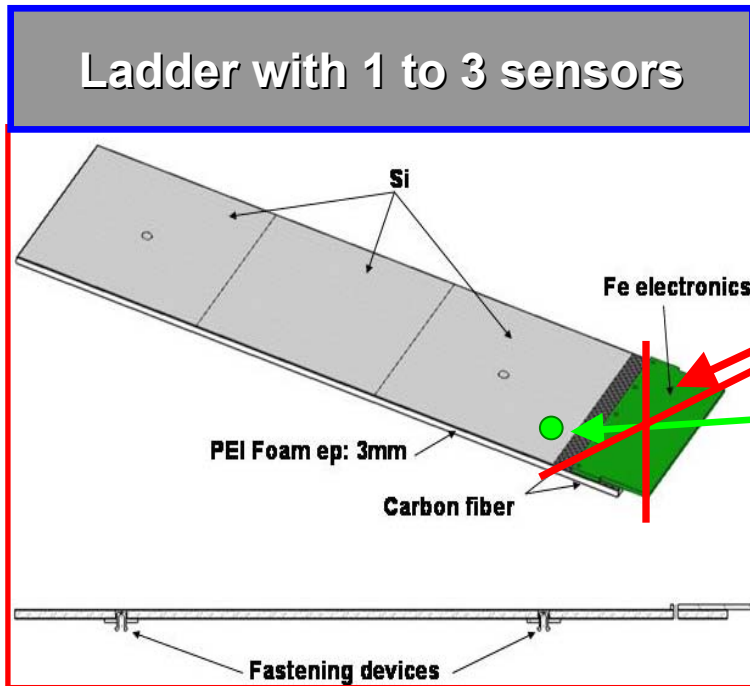
Material budget

- Design goal in 1999: $X/X_0 < 1$
- Most of the material is electronics related (electronics, cooling, cable, ...)
- New description (with most importantly a better description of the bulkheads collecting the services behind the endcaps) predicts less material in the forward region



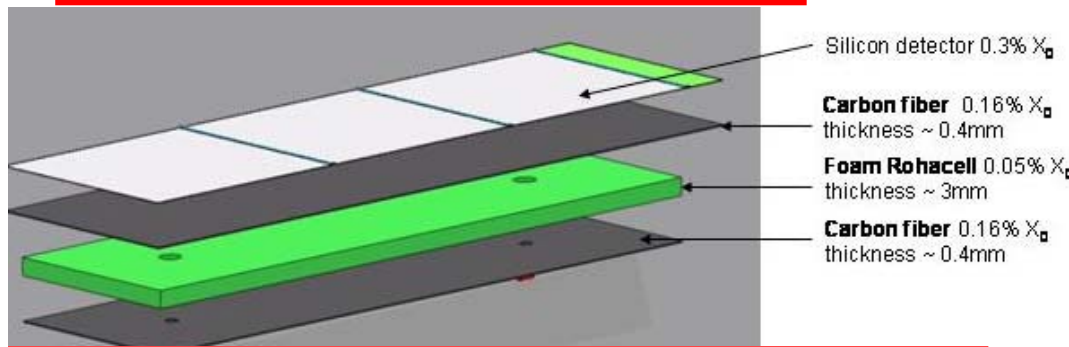
And this is not the only issue thus still a lot to do for the next generation of Si trackers!

Elementary modules: to be totally revisited!



Old fashioned FE electronics!!

**Next step = chip inserted onto the detector:
connectics/VDSM/cabling issues**



0.7% X0

**Modules: light, precise,
robust, easy to build & assemble**

- ✓ **New sensors (next generation)
larger wafers, thinning**
 - ✓ **Support: materials & design**
 - ✓ **FE electronics wiring,
packaging and cabling**
 - ✓ **Module positioning on
large size support structure**
 - ✓ **Easy to build (robotisation ?)**
 - ✓ **Industry Transfer (large #)**
 - ✓ **Universal sensor vs diff. types**
- Be innovative!**

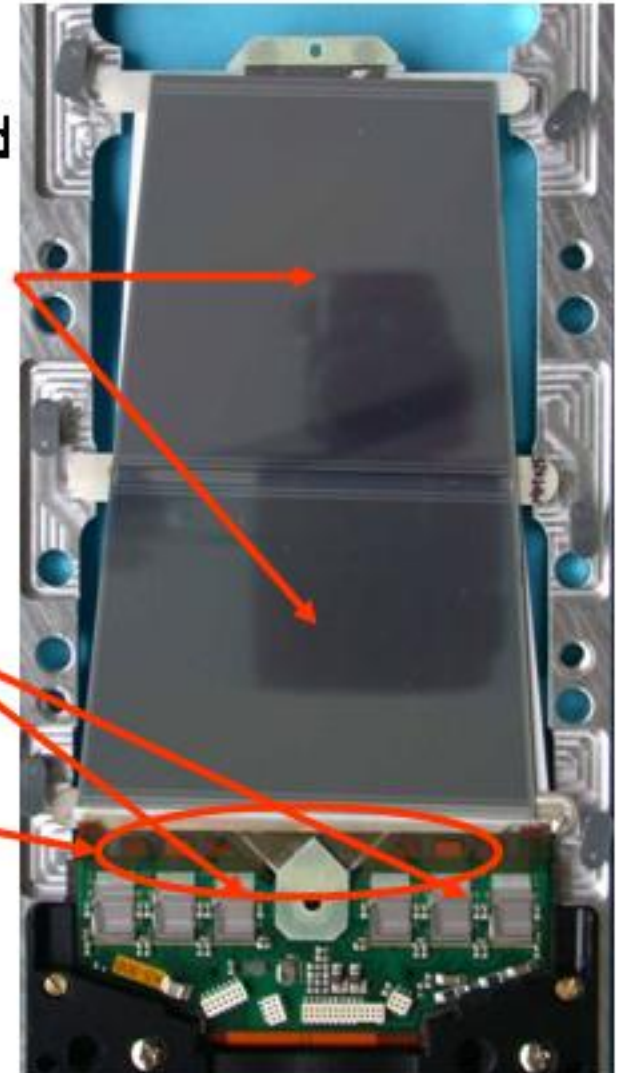
**N.B. This is just a very first ladder prototype:
just a very preliminary exercise...
By no means what will be the final one!!**

Enlightening talk by Manolo Lozano IMB-CNM/CSIC @SiLC meeting

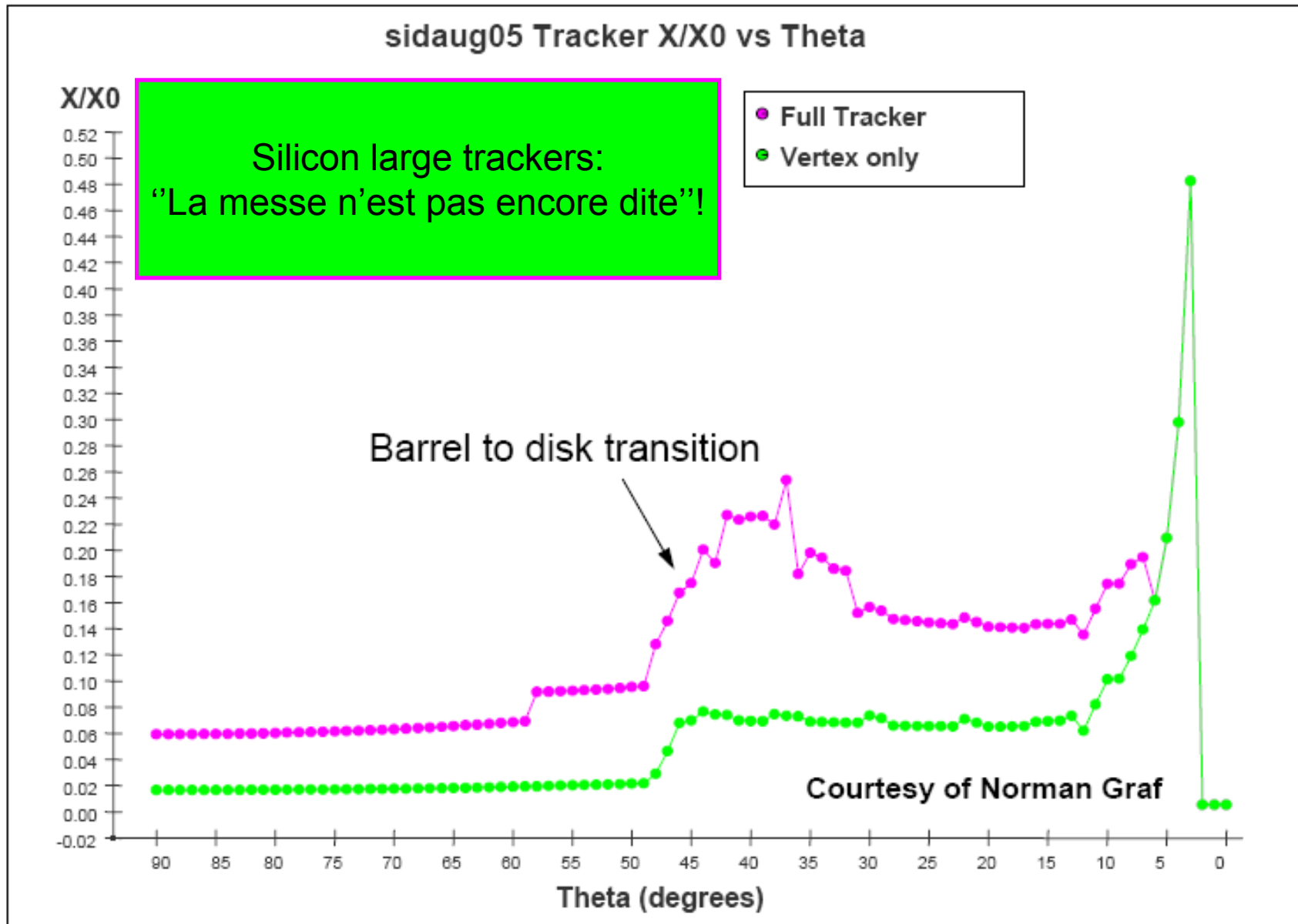
Detector modules

- High Energy Physics Experiments need very accurate spatial information
- Particle detectors have high integration level (strips or pixels)
- High number of channels per detector
- Readout electronics also high integration level
- Electronics has to be very close to detector
- Problems with pitch adaptation between detectors and electronics

DIFFICULT INTERCONNECTION
Detectors → Electronics

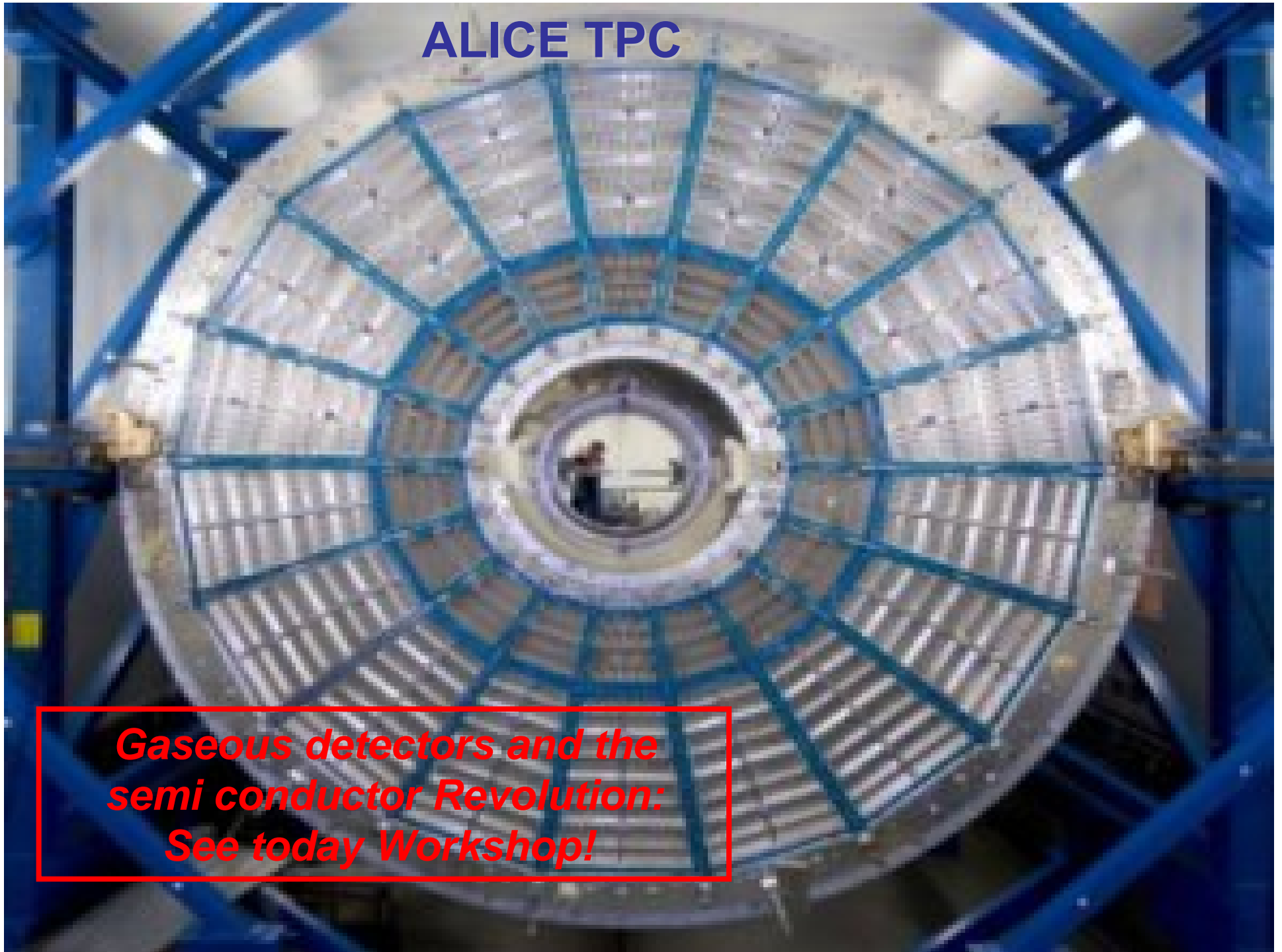


August 2005 SiD Simulation



ALICE TPC

*Gaseous detectors and the
semi conductor Revolution:
See today Workshop!*



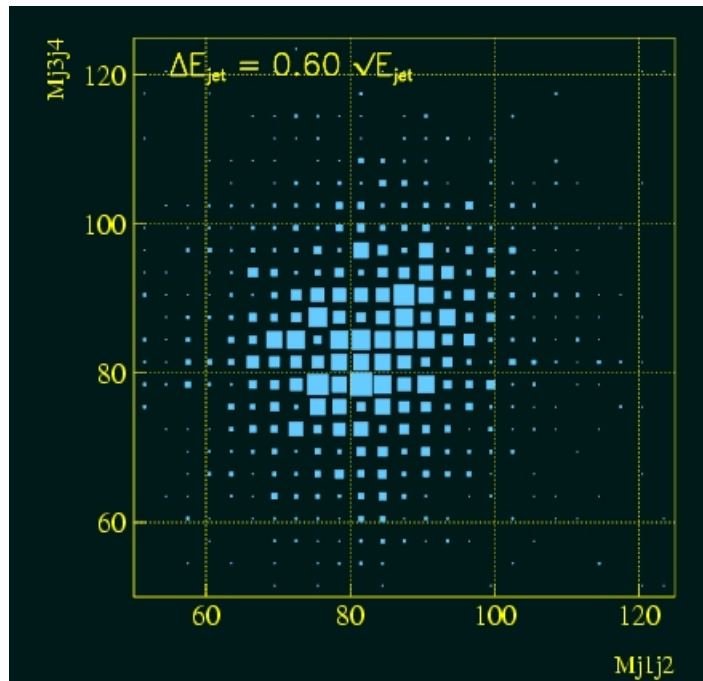
Silicon technology also in Calorimetry!

Physics motivation:

Need excellent capability to separate different final states

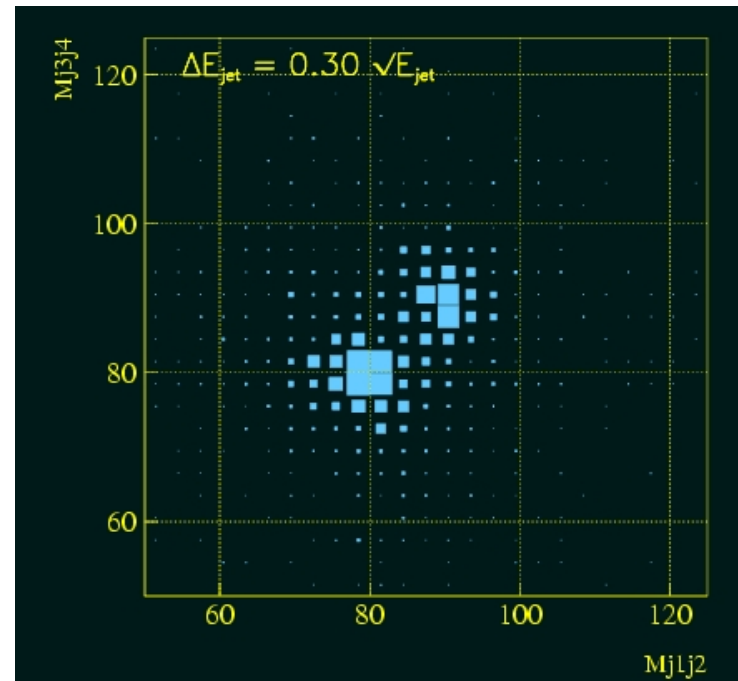
Example: W-Z separation (hadronic channel)

60%/√E



“traditional” methods

30%/√E



The Goal

→ Worse resolution for $\alpha=60\%$ is equivalent to a loss of ~40% luminosity

Requirements

Particle Flow stresses:

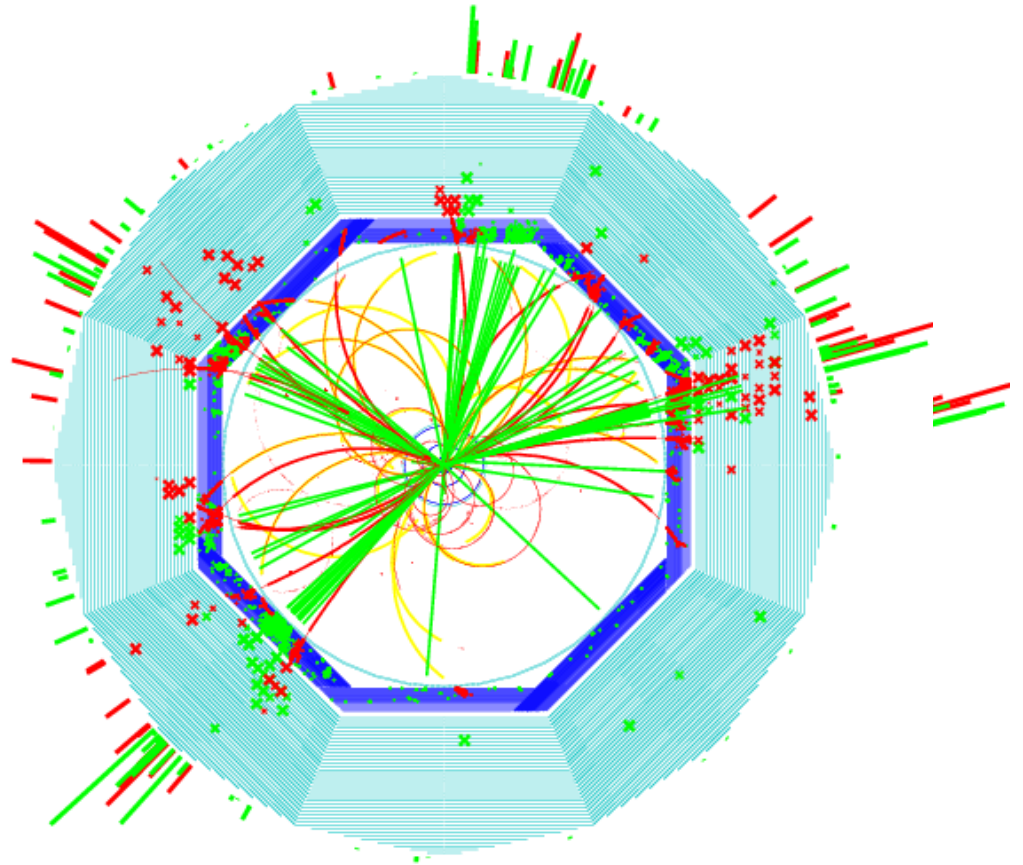
- reconstruction of individual particles
- separation of particles

Less important:

- single particle energy resolution of ECAL

Detector requirements:

- excellent tracking, in particular in dense jets
- excellent granularity in the ECAL
- good granularity in the HCAL
- excellent linkage between tracker – ECAL – HCAL



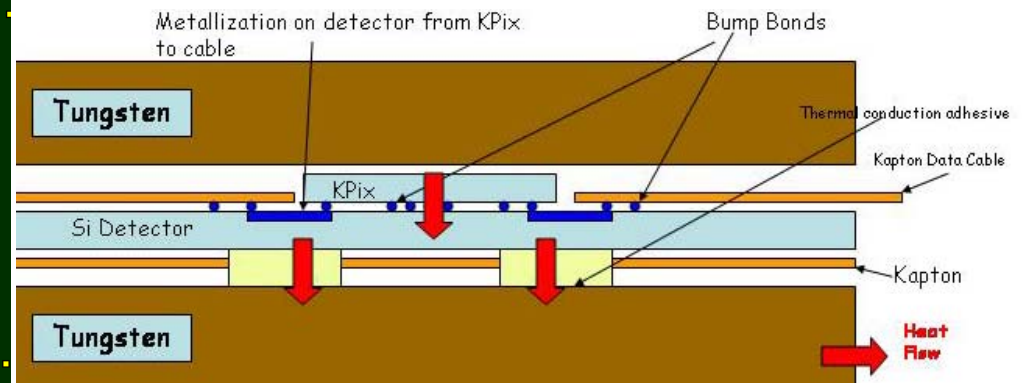
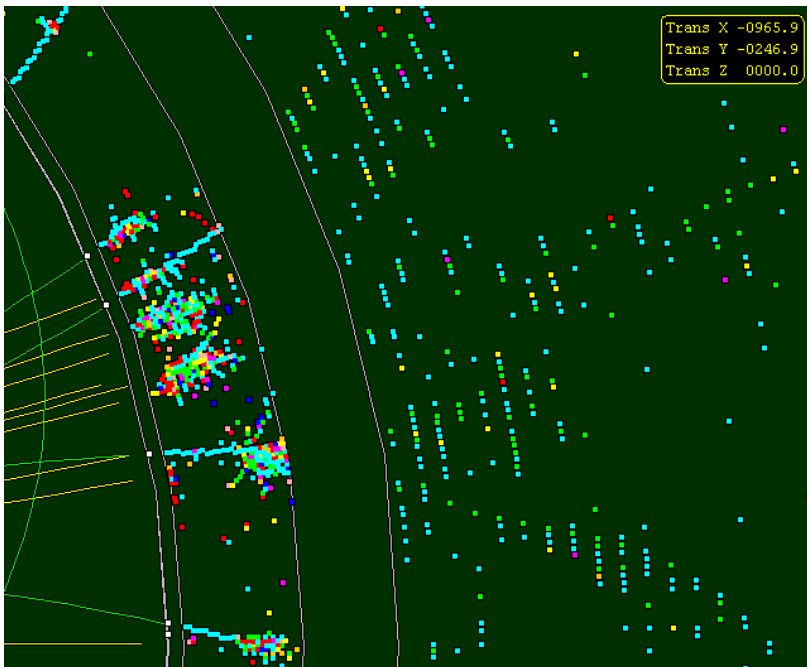
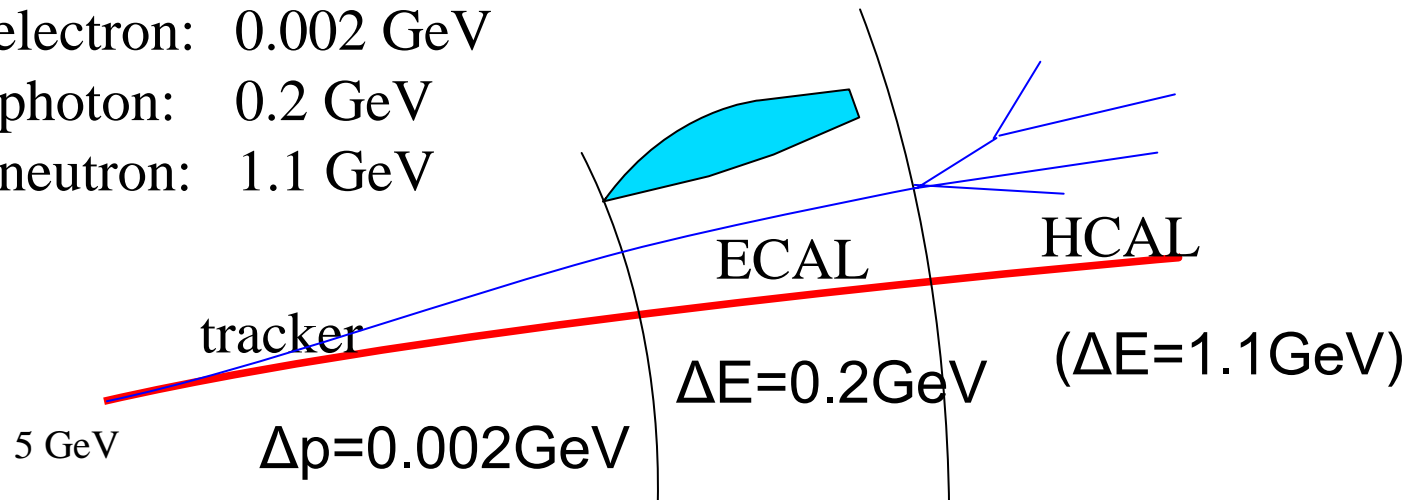
An integrated detector or matching at best tracking/calorimetry

For LC energies: tracker is most precise **Utilize the precise tracker as much as possible**

5 GeV electron: 0.002 GeV

photon: 0.2 GeV

neutron: 1.1 GeV

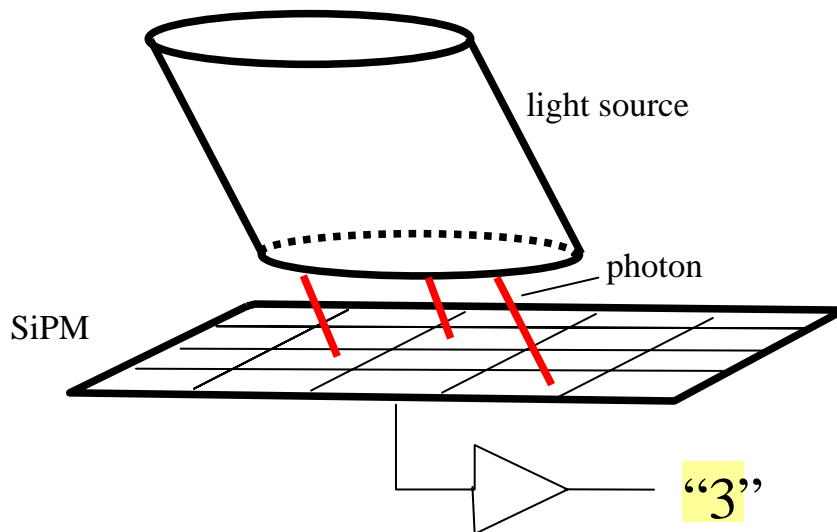


Structure of SiW em calorimeter

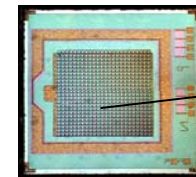
Silicon Photo-Multipliers

Silicon photo-multiplier (SiPM):

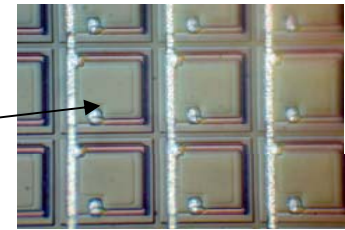
- new detector concept, first test with beam
- sizes: $1 \times 1 \text{ mm}^2$, 1024 pixels/ mm^2
- gain $\sim 1 \times 10^6$ → No preamplifier needed
- quantum eff. $\sim 15\text{-}20\%$
- single tile read out / mounted directly on tile



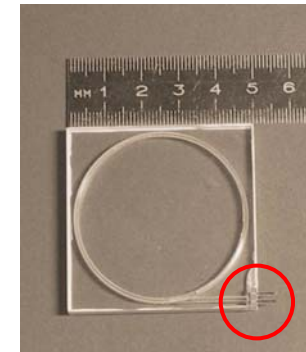
Silicon PhotoMultiplier (SiPM)
MEPhi&PULSAR



SiPM



Pixels of
the SiPM



Robotization & Collaboration with Industry

- The increase in the number of basic elements to be mass produced
- The sophistication of some detector components or its associated electronics will need to further develop the technics of **robotization**, and the **technology transfer**, this last point indeed implying to further develop *real collaboration between the research and the industrial worlds*, both at the R&D stage and at the mass production stage. This already exists for instance in Japan and Finland.

Safety, Robustness, Reliability

High precision detecting devices require:

- More & more reliable and highly performing calibrations and monitoring systems
- Better handling of distortions/disfunctions in the detector
- More and more precise alignment and positioning system(s)
- Remote access for the follow up.
- Slow controls revisited...
- Realtime access to the collected data (both raw data and fully processed data) for data quality control & monitoring.

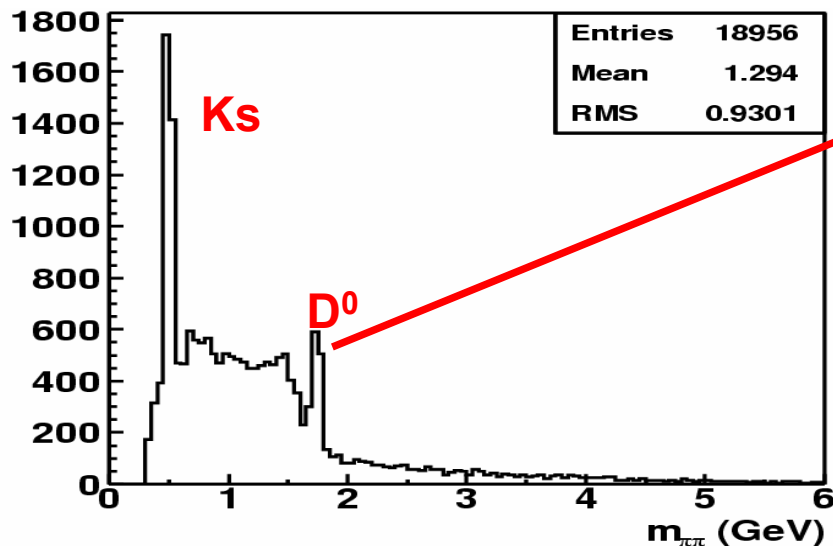
Very difficult access to the detector and on detector electronics implies:

- Redundancy in the detector and electronics design
- Preference for more robust solutions
- Remote access for surveying the functioning of detectors & readout chain
- Anticipate as much as (im)possible all possible failures and incidents by extensive simulations studies, modelling all possible cases; but also continue to rely on real prototyping giving useful and necessary inputs to the simulations!

All this is already undergoing in running experiments or in the forthcoming LHC experiments but there also there will be at least an order of magnitude to be gained!

A triggered or realtime processed world

- High granularity + high detector performances + reliability require a constant monitoring on the running of the detector and a data quality control including Physics performances.
- Triggering and/or processing the data at the earliest stage of the data taking with a reduction of the data information flow: sparsification filtering & preprocessing.
Also requested by the search for rare and tricky Physics process.

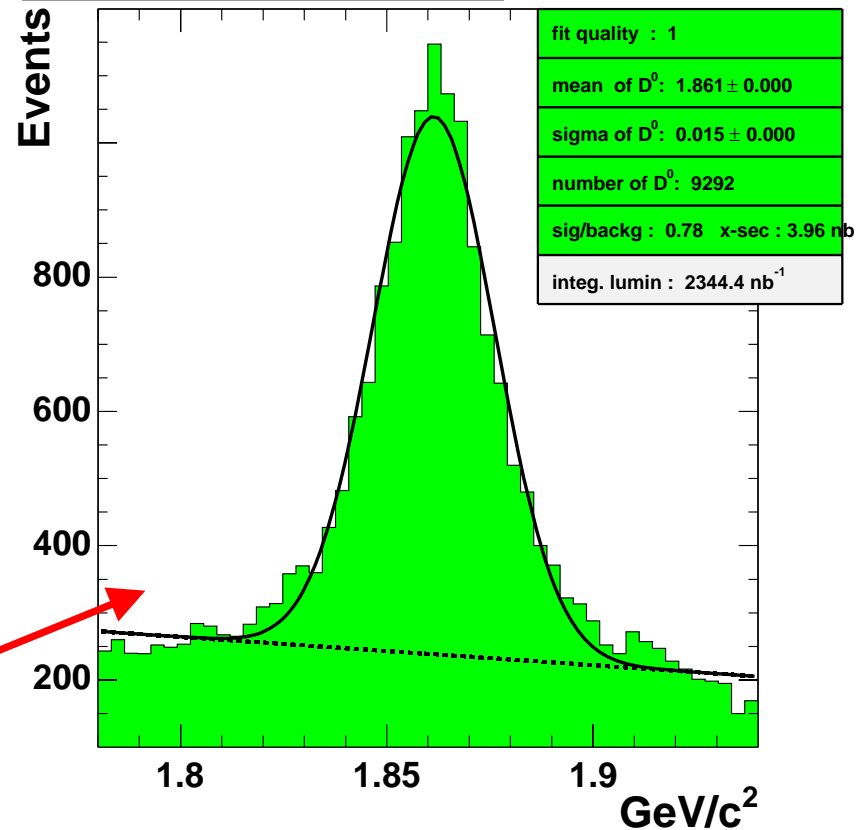


ObjectMon #100 SVTMonitor Slide Show

Run:192424 Event: 11231427 # of Events:229465 Time: Wed Jan 19 13:50:56 2005 Ref.Run:-1

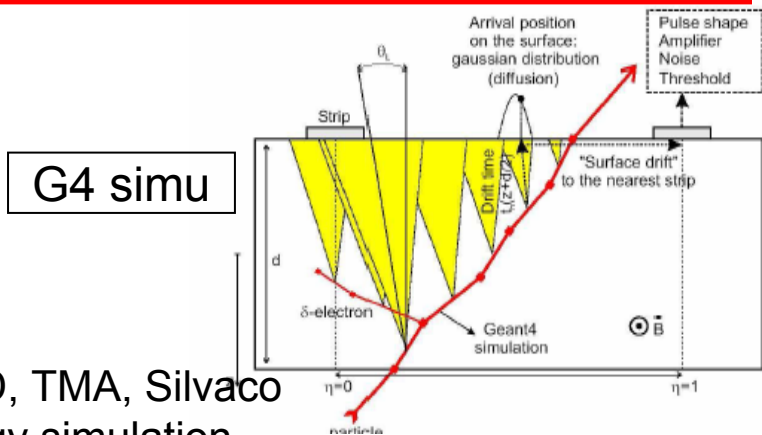
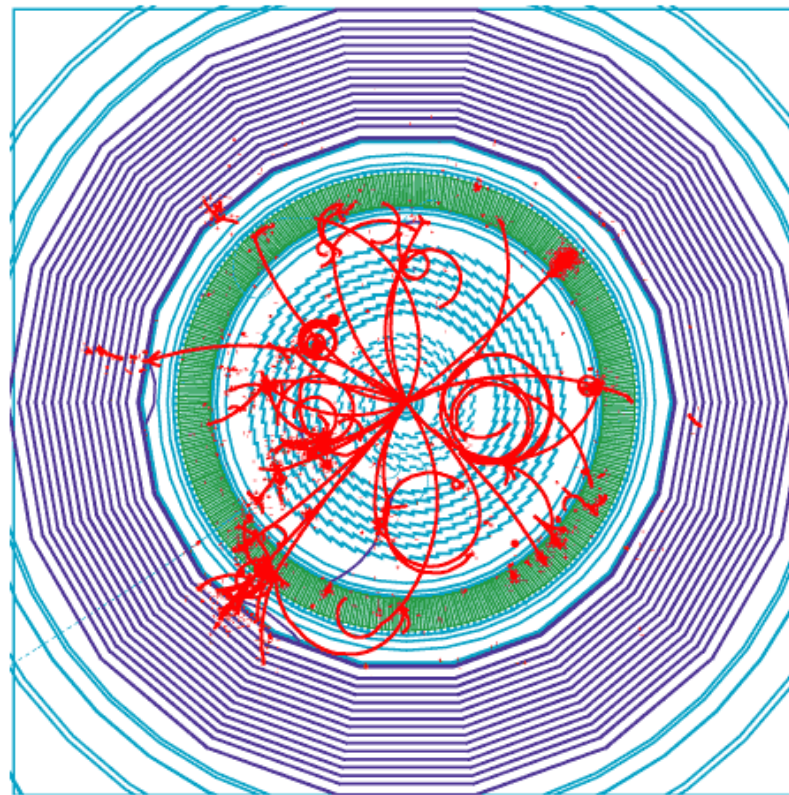
D⁰ invariant mass

SVT @CDF



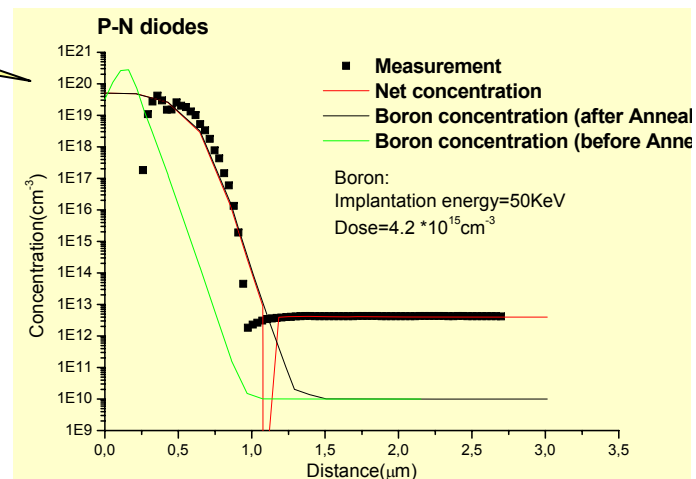
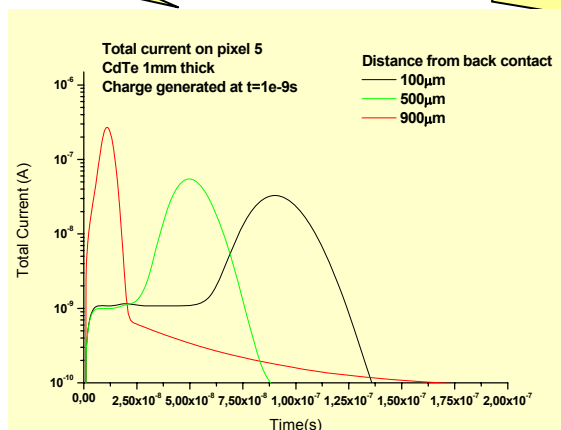
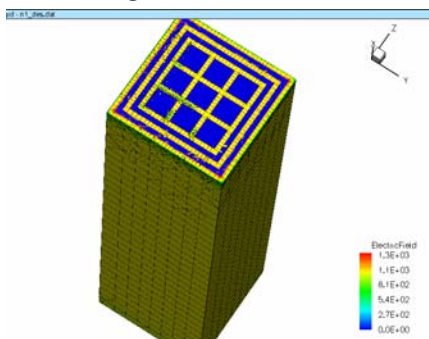
A virtual world

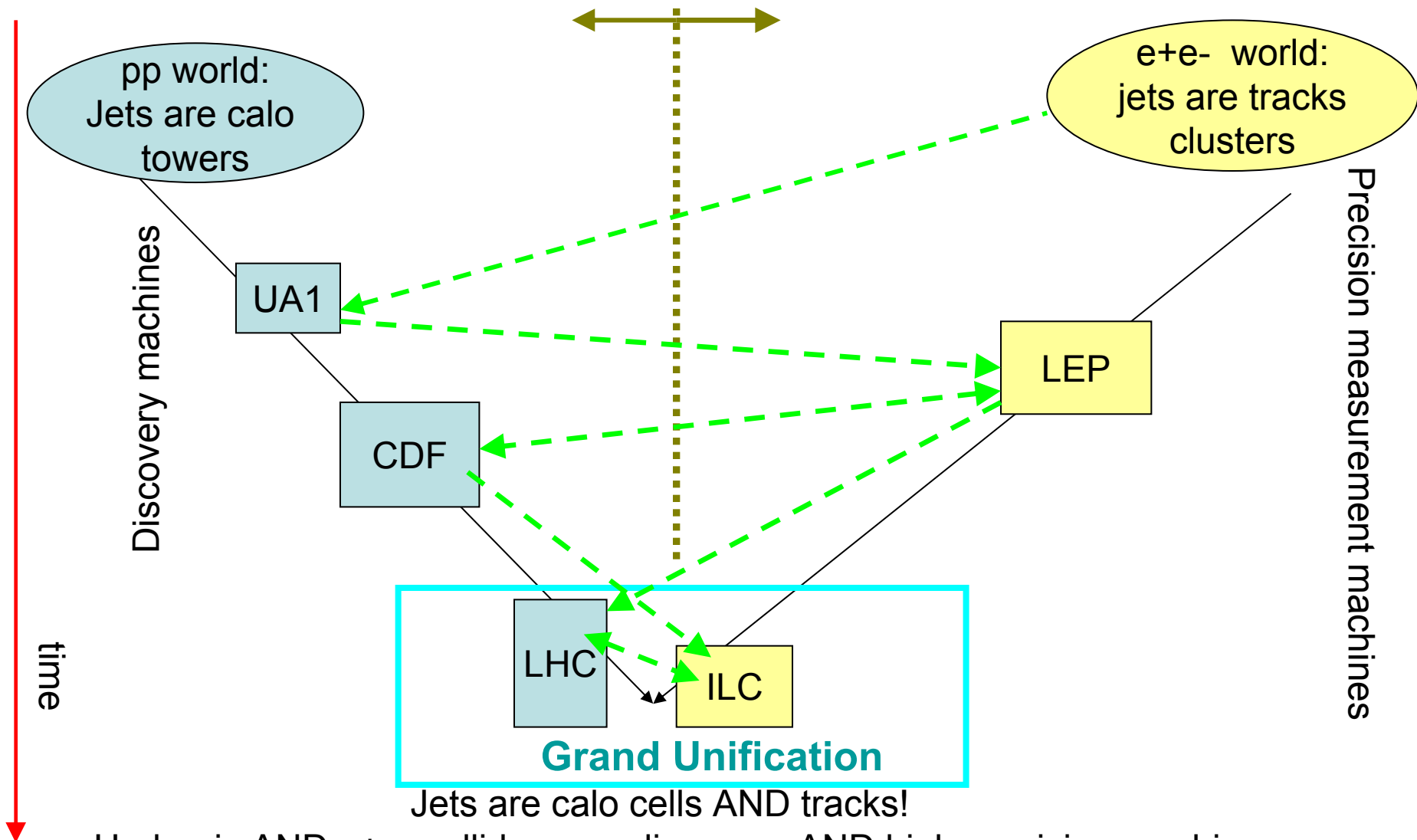
The use of simulations at all stages must be further exploited on: Mechanics, Electronics, detector prototyping and design, Physics studies from ME generator to full MC simulations with detector).



ISE-TCAD, TMA, Silvaco
Technology simulation
Electrical simulation

Charge collection
charge sharing in
3D





Hadronic AND e+e- colliders are discovery AND high precision machines
 Need of innovative spirit & high tech advances plus mixture of different cultures, and of course a little bit of adventurous mind,
TO SUCCESSFULLY CONFRONT FUTURE DETECTOR CHALLENGES

Many thanks to

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