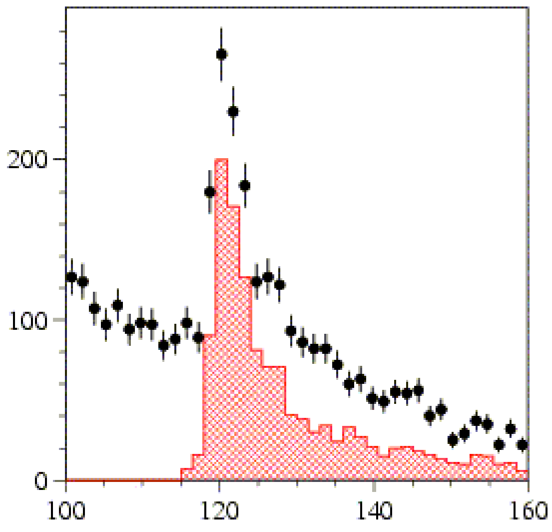
Review Tracking and Vertexing

Jan Timmermans - NIKHEF

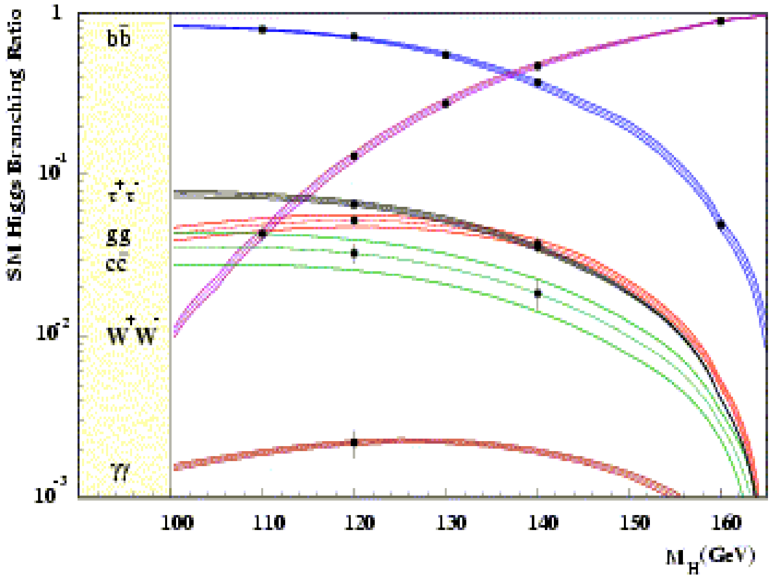
32 presentations in total:

- 12 vertex detector related
- 10 on SI tracking
- 10 on TPC R&D

Physics

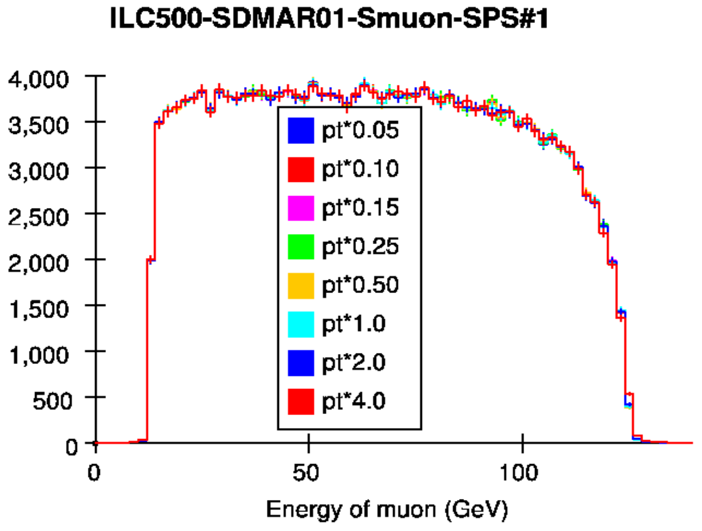


Inclusive Higgs:
Z Recoil mass



H Branching Ratios

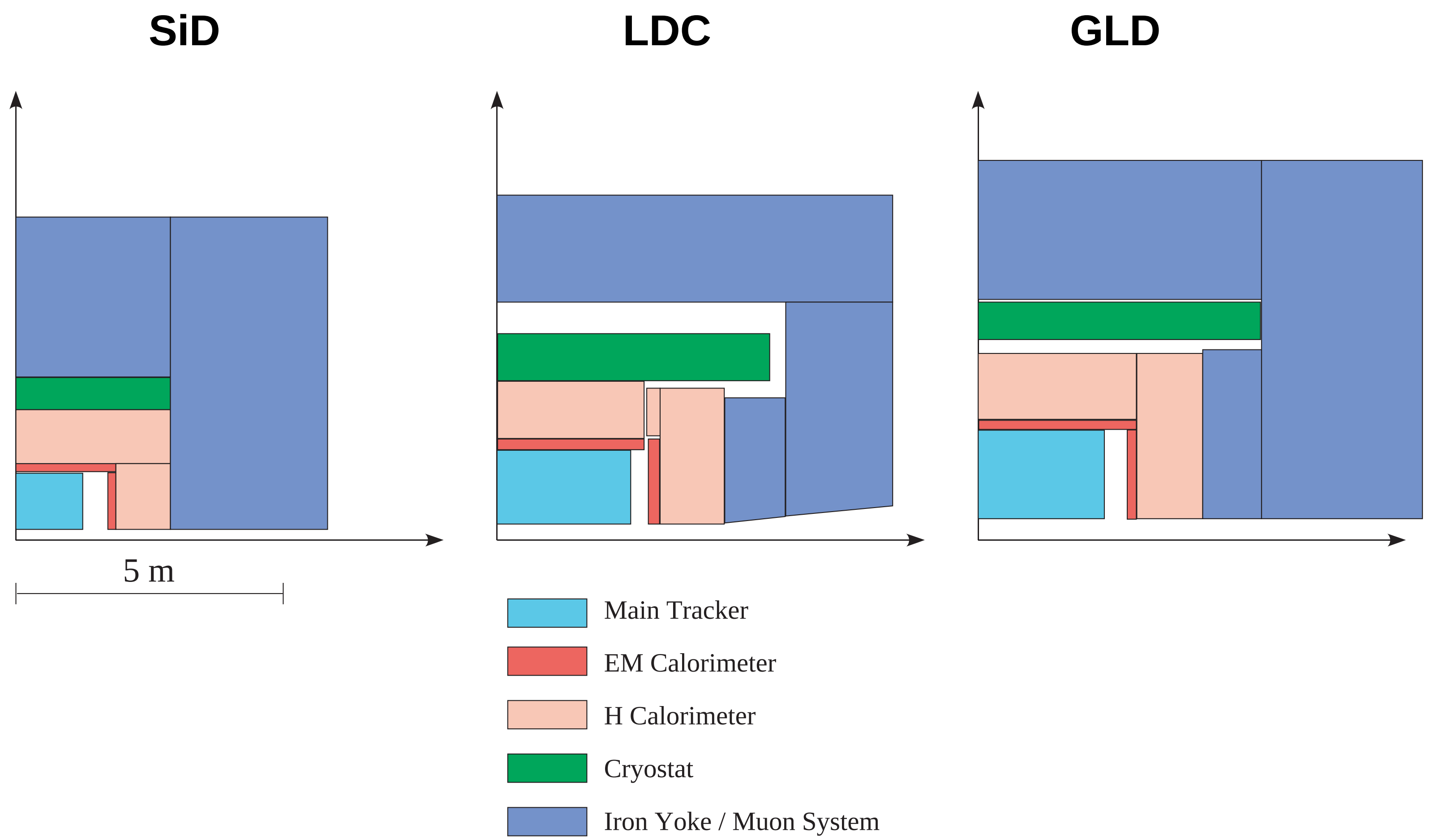
Smuon pair-production



Basic design concept

- Performance goal (common to all det. concepts)
  - Vertex Detector: $\delta(IP) \leq 5 \oplus 10 / p \sin^{3/2} \theta$
  - Tracking: $\delta p_t / p_t^{\,2} \leq 5 \times 10^{-5}$
  - Jet energy res.: $\delta E / E \leq 0.3 / \sqrt{E}$

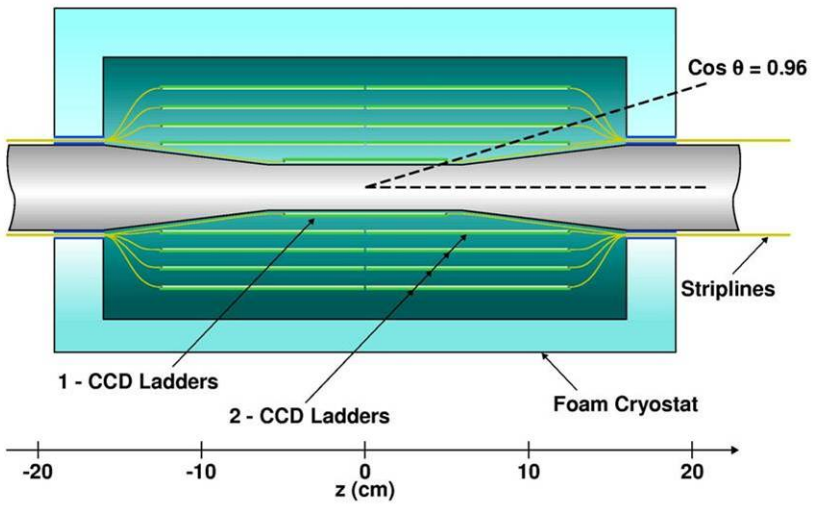
➔ Detector optimized for Particle Flow Algorithm (PFA)


SiD
LDC
GLD
5 m
Main Tracker
EM Calorimeter
H Calorimeter
Cryostat
Iron Yoke / Muon System

Comparison of parameters:

		SiD	LDC	GLD
Solenoid	B(T)	5	4	3
	R(m)	2.48	3.0	3.75
	L(m)	5.8	9.2	9.86
	E_{st}(GJ)	1.4	2.3	1.8
Main Tracker	R_{min} (m)	0.2	0.36	0.4
	R_{max}(m)	1.25	1.62	2.0
	$\sigma(\mu m)$	7	150	150
	N_{sample}	5	200	220
	$\sigma(1/pt)$	3.6e-5	1.5e-4	1.2 e-4

Vertex Detector



- pixels ~ 20 x 20 μm^2
- point resolution ~3 μm
- material <0.1% X_0
- 1st layer at ~1.5 cm

To keep occupancy below 1%:

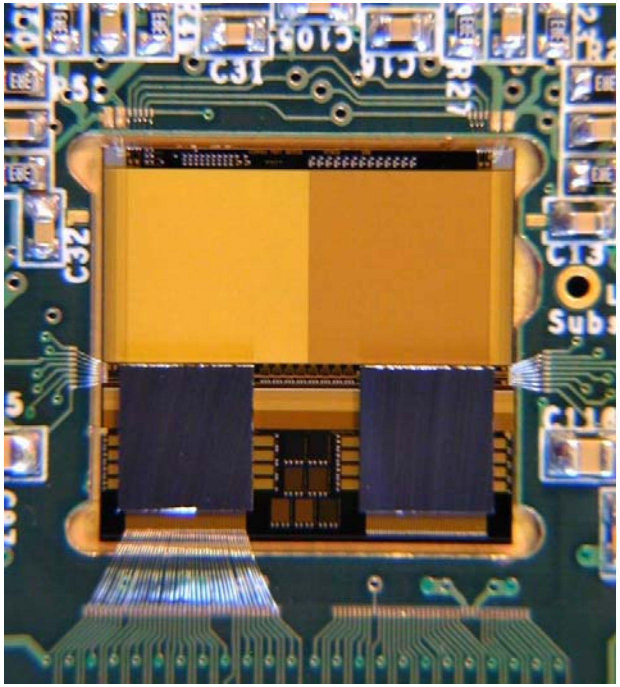
- readout ~20 times during bunch train or store signals
- OR make pixels smaller (FPCCD 5 x 5 μm^2)

Many variants: CPCCD, FPCCD, DEPFET, MAPS, FAPS, SoI, ISIS

New at LCWS05:

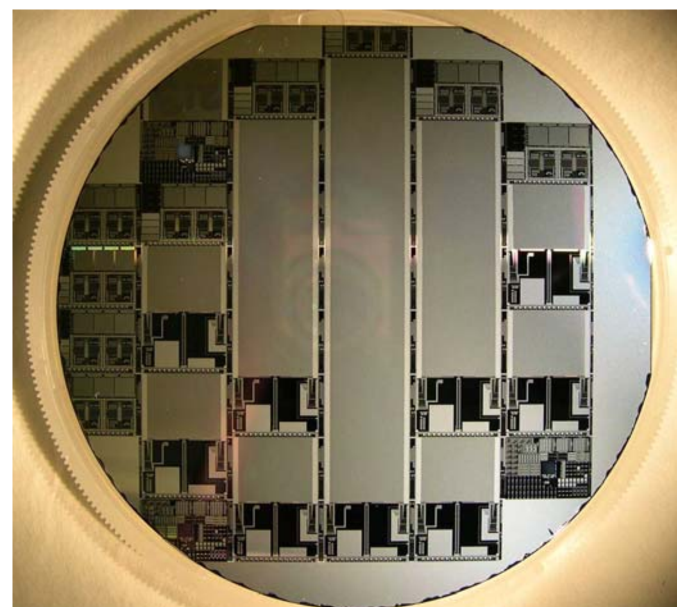
- (revolver)ISIS
- Add time stamping (Baltay, Bashindzhagyan)

CPCCD, (revolver)ISIS (K. Stefanov - LCFI)

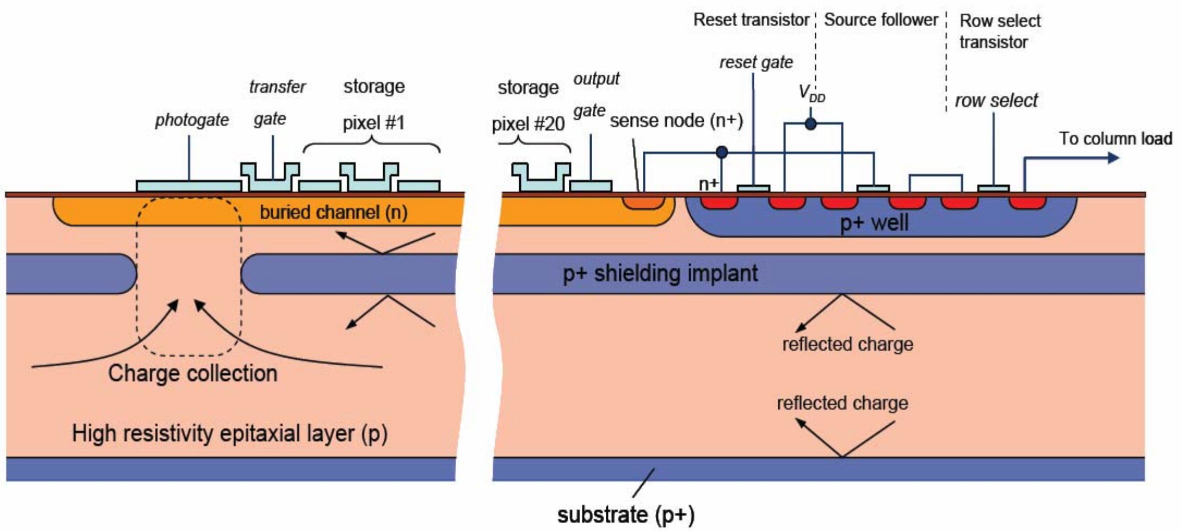


- CPC1: 750x400 pixels, 20x20 μm^2
- Bump bonded by VTT to readout CPR1
- Clocked at 25 MHz
- Various sized (up to 92mmx15mm) CPC2 detector chips

+ISIS chips in production

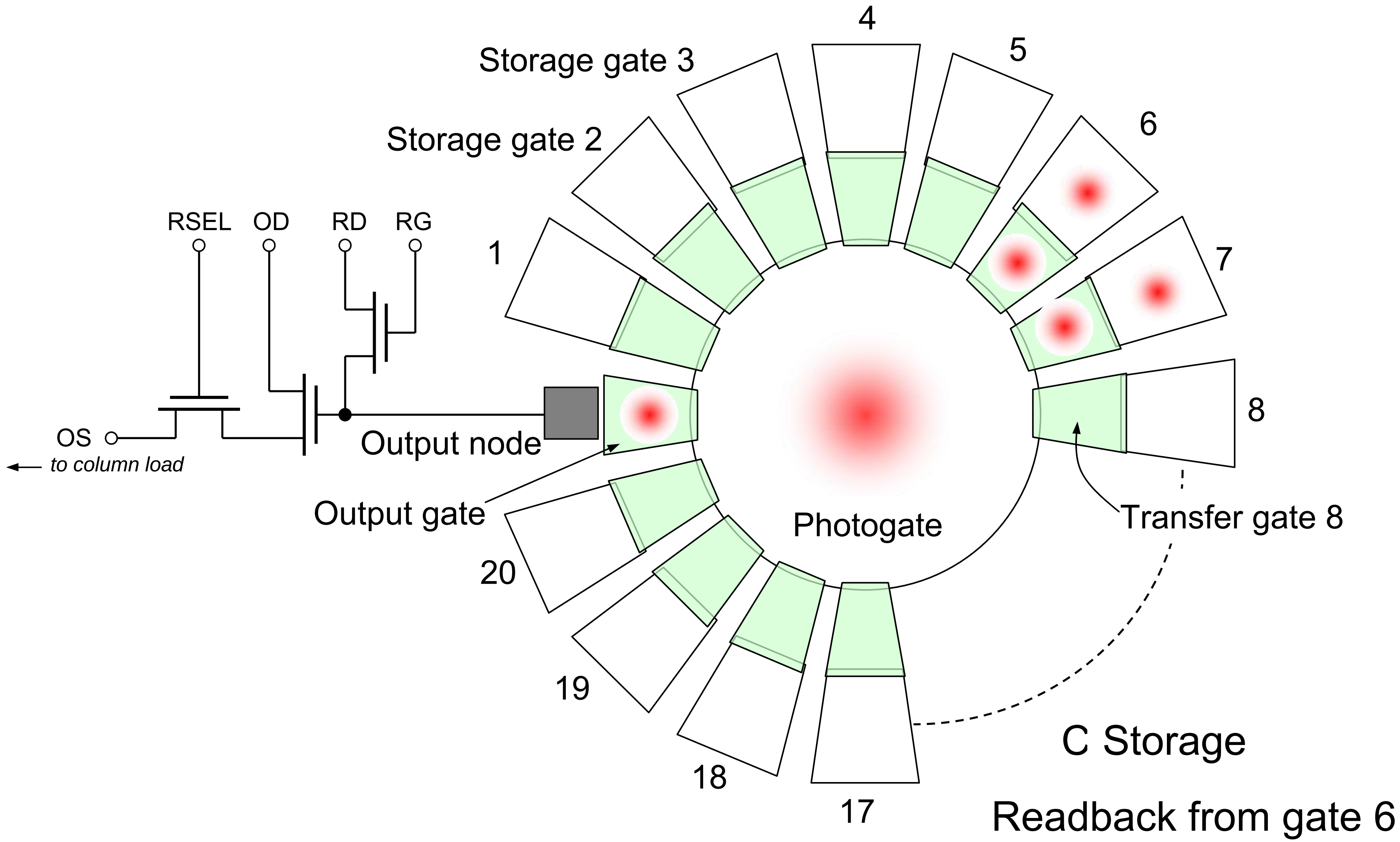


ISIS R&D



- RF pickup is a concern for all sensors converting charge into voltage during the bunch train;
- The In-situ Storage Image Sensor (ISIS) eliminates this source of EMI:
    - ❖ Charge collected under a photogate;
    - ❖ Charge is transferred to 20-pixel storage CCD in situ, 20 times during the 1 ms-long train;
    - ❖ Conversion to voltage and readout in the 200 ms-long quiet period after the train, RF pickup is avoided;
    - ❖ 1 MHz column-parallel readout is sufficient;

Revolver ISIS



Idea by D. Burt and R. Bell (E2V)

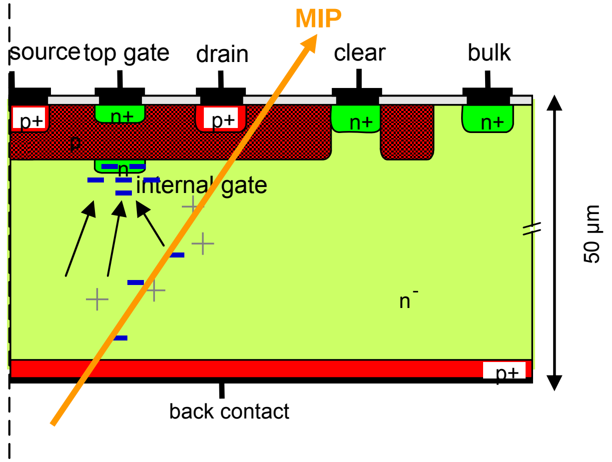
Vertex Detector Options

Y.Sugimoto - KEK

- FPCCD
  - Accumulate hit signals for one train and read out between trains
  - Keep low pixel occupancy by increasing number of pixels by x20 with respect to "standard" pixel detector
  - As a result, pixel size should be as small as ~$5 \times 5 \mu m^2$
  - Epitaxial layer has to be fully depleted to minimize charge spread by diffusion
  - Operation at low temperature to keep dark current negligible (r.o. cycle=200ms)

Tracking efficiency under beam background is critical issue; simulation needed.

DEPFET (M. Trimpl) – Bonn, Mannheim, MPI



charge collection in fully depleted substrate

- small pixels 20-30µm
- radiation tolerance (>200krad)
- low noise
- thin devices (50µm) → S/N = 40
- low power (row-wise operation)
- fast readout (cold machine), 50MHz line rate
- zero suppressed data

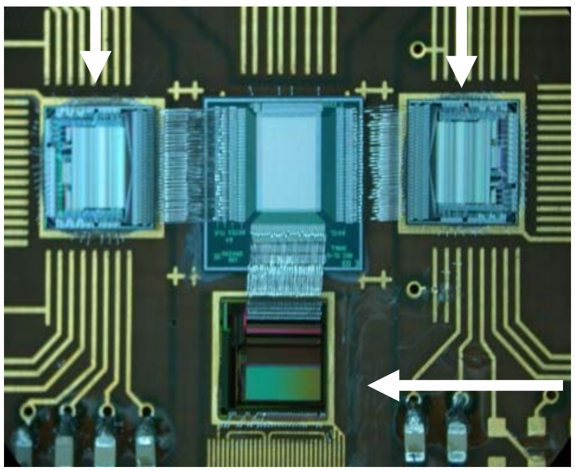
•FET transistor in every pixel (first amplification)

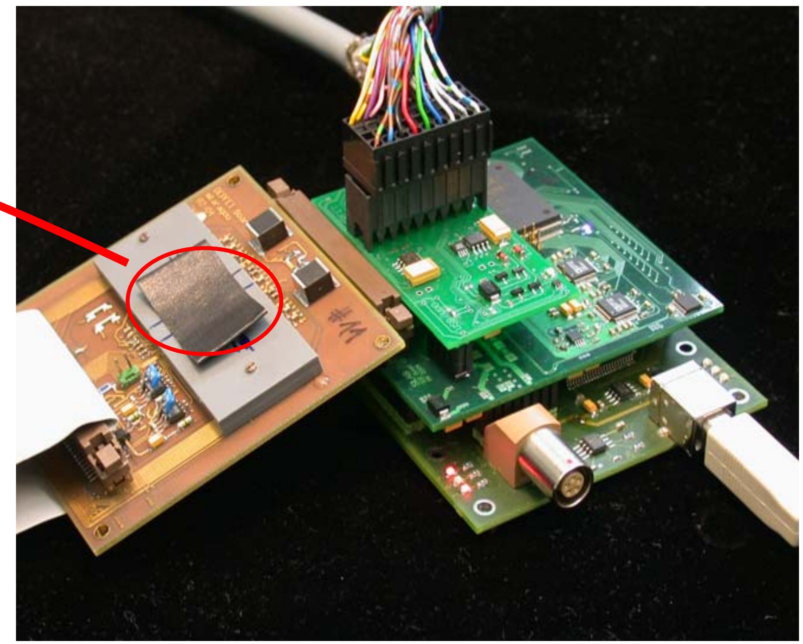
•Electrons collected at internal gate modulate the transistor current. Signal charge removed via CLEAR

•No charge transfer

•Low power consumption: ~5W for full VXD

ILC-DEPFET system

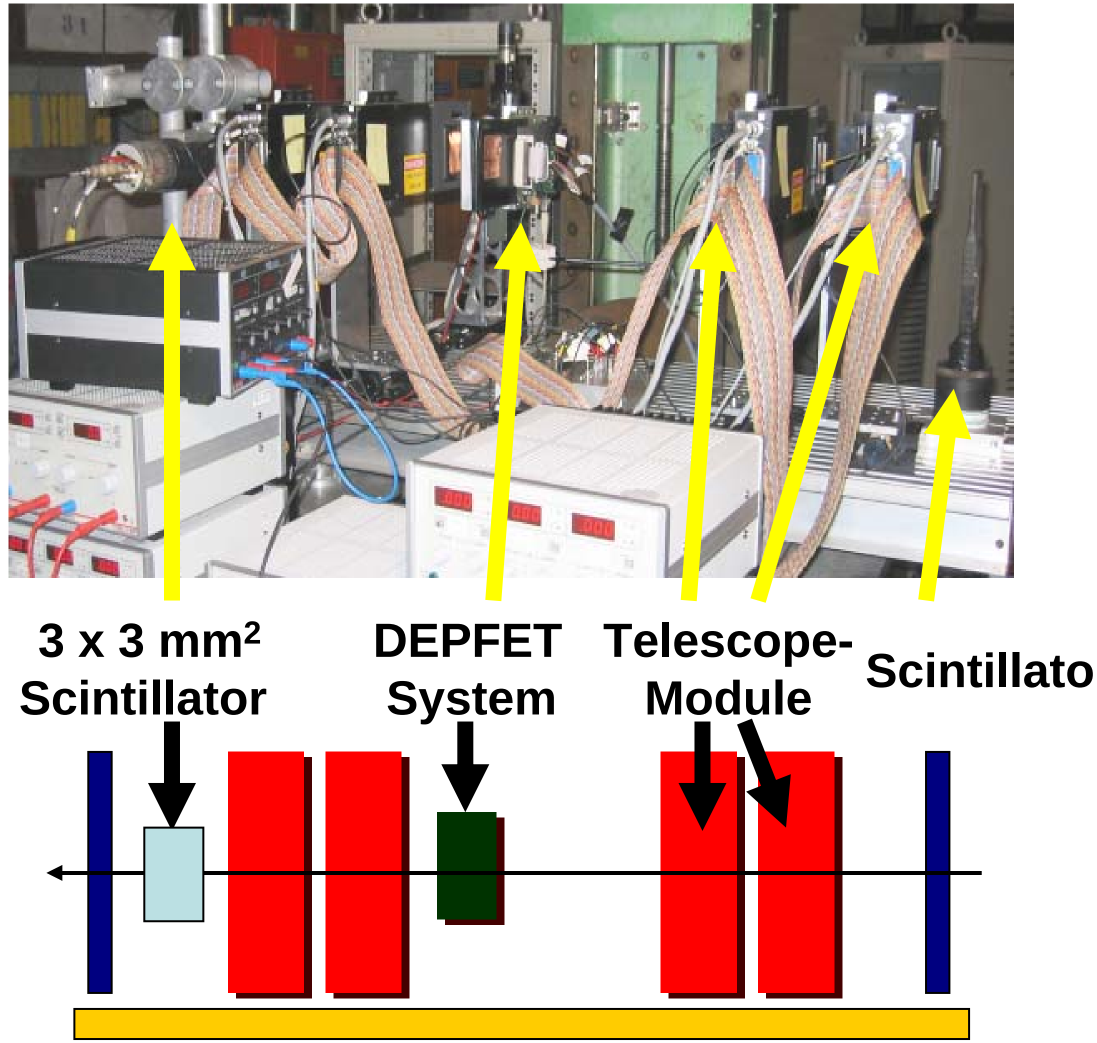




Testbeam: Setup

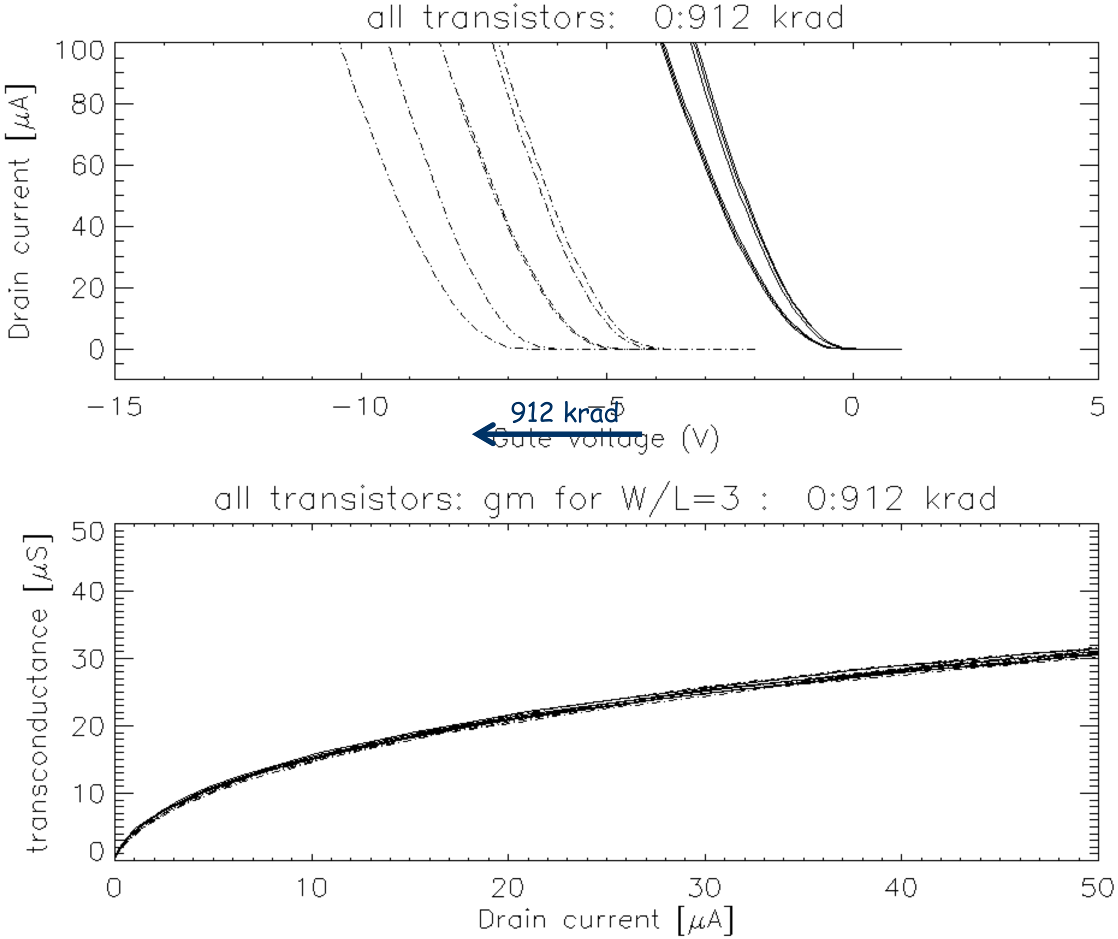
Testbeam 24 @ DESY

Jan + Feb 2005



The Active DEPFET Pixel Sensor: Irradiation Effects due to Ionizing Radiation

L. Andricek

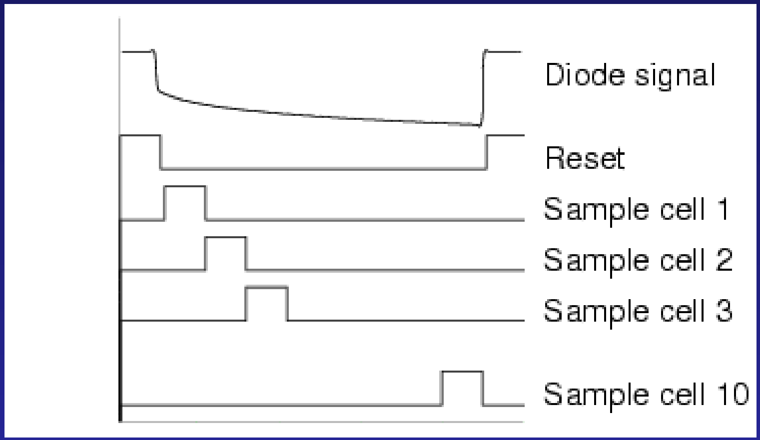


Irradiated with ^{60}Co gammas up to 912 krad

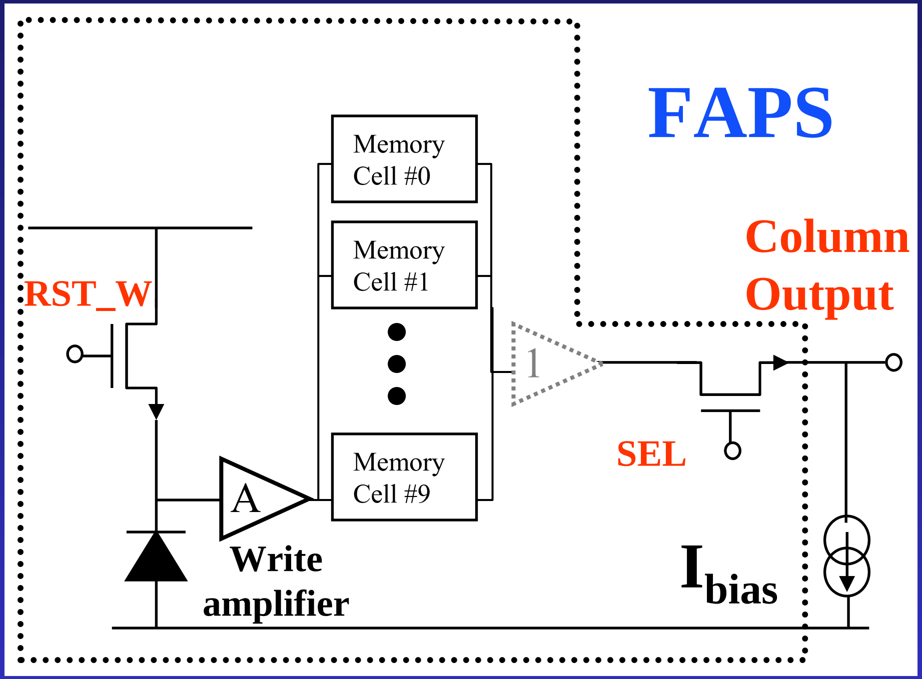
Acceptable small shift in threshold voltages (for 6 DEPFETs)

Flexible APS

J. Velthuis –
UK MAPS



- FAPS=Flexible APS
  - Every pixel has 10 deep pipeline
- Designed for TESLA proposal.
  - Quick sampling during bunch train and readout in long period between bunch trains

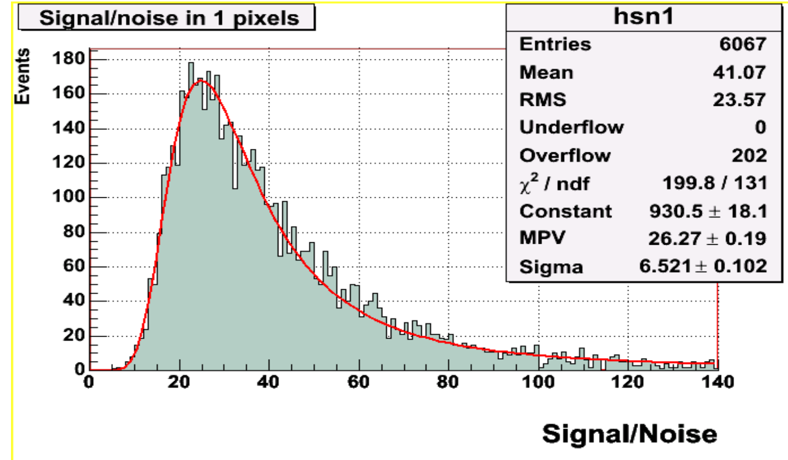


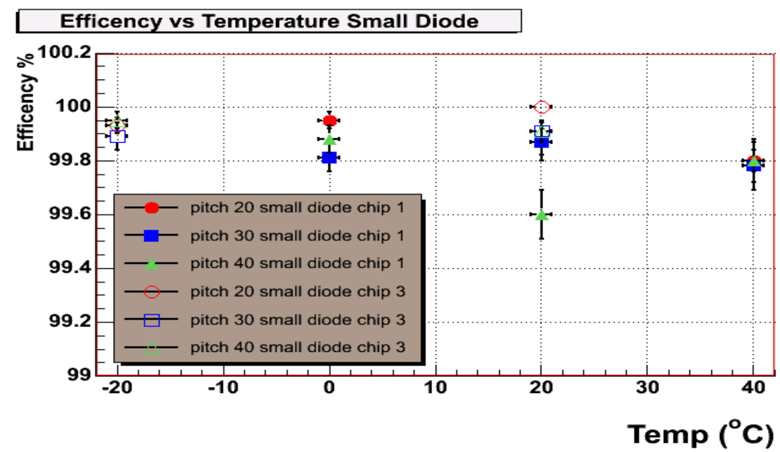
•S/N between 14.7 and 17.0

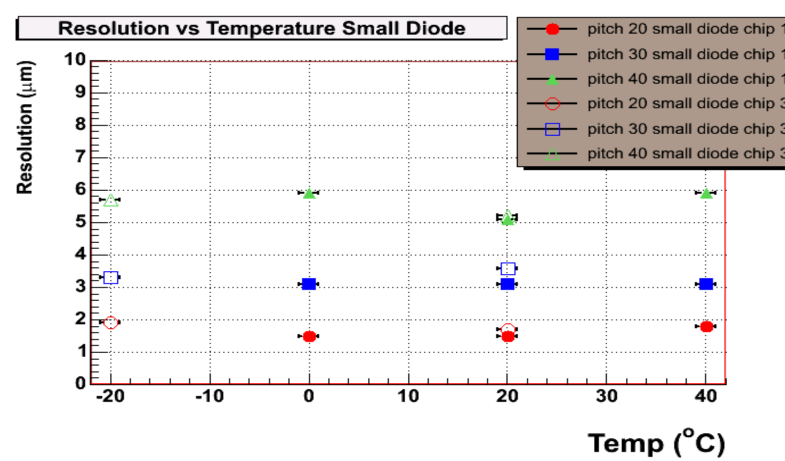
Performances Achieved with MIMOSA chips

- 11 MIMOSA prototypes designed and fabricated since 1999
- 6 fabrication processes explored:
  AMS-0.6μm, AMI-0.35μm, AMS-0.35μm (opto and ordinary), IBM-0.25μm, TSMC-0.25μm
- Most chips tested with ~10^2 GeV/c π^- **(CERN-SPS)**
  - S/N ~ 20-30 (MPV) ⇨ ε_{det} ~ 99-99.9 %
  - σ_{sp} = 1.5-2.5 μm (20 μm pitch) ;
    σ_{2hits} ≥~ 30 μm
  - Rad. Tol. For ILC conditions checked with neutrons and X-Rays
  - Reticle size chip fabricated and working well (e.g. imager)
  - Assessment of 50 μm thinning under way
- Application to STAR, CBM, etc.

M. Winter - Strasbourg







Summary and Outlook

- Concept of vertex detector using features of CMOS sensors progressing, based on requirements accounting for uncertainties (e_{BS} !)
- Well established performances:
  - **S/N, ε_{det}, σ_{sp}**
  - **Rad. Tolerance to neutrons and X-Rays**
  - **120 μm thinning of Megapixel sensors**
- Most recent achievements
  - **Fast col. // pixel architecture (integrated CDS) found, with low noise (< 20 e^- ENC) and small pixel-to-pixel dispersion**
  - **Assessment of a well performing R&D fabrication process: AMS-035 μm (opto and epi-free) ⇨ very good perfo. even with 40 μm pitch (L4)**
  - **Checks of tolerance to 10-20 MeV electrons under way**
  - **Outcome of thinning to 50 μm under study (≥~ 15 μm not yet OK)**
- Next important steps:
  1) **Fast column // sensor with digital output, adapted to L0-1 (integrated low power, fast and compact 4-bit ADC)**
  2) **New multi-memory cell sensor adapted to L2-4**
  - **Complete study of MIMOSA-5 thinning to ~ 50 μm with LBL**
  - **Investigate characteristics of new fab. processes (e.g. IBM-0.13 μm, UMC-0.18 μm)**
  - **Thinning no-epi sensors is very appealing: any possibility ?**
  - **Privileged contact with a foundry would be very valuable…**
- ➢ Aim for a fast col. // megapixel proto providing digital output in 2007

Conclusions & Outlook

Beam-test of CMOS sensors with 6 GeV electrons at DESY

- Results for signal, S/N and noise consistent with known values (from Strasbourg tests)
- No significant temperature effect observed between -15°C and +5°C
- Efficiency still under study

Irradiation with 10 MeV electrons

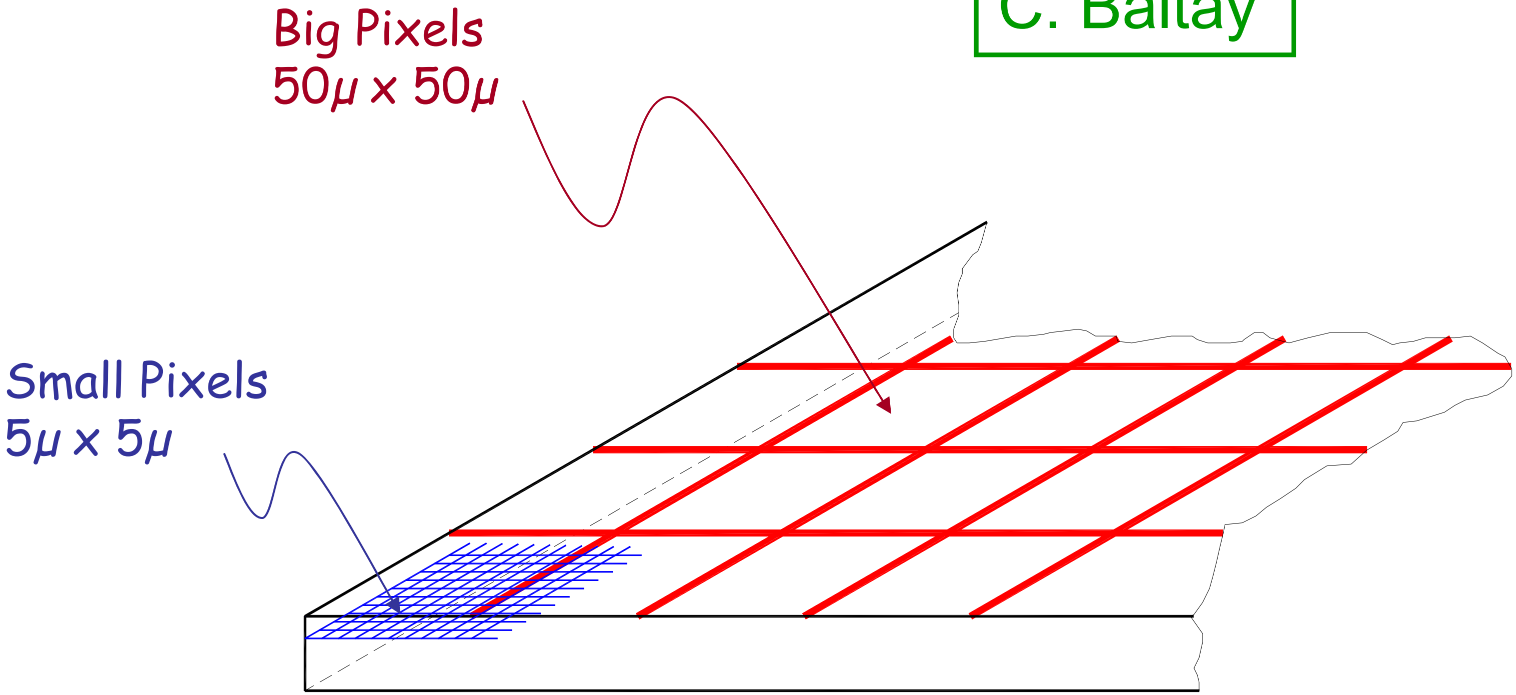
- Irradiation at doses comparable with expectations for first VXD layer background
- Preliminary results from ^{55}Fe calibration show loss in performance after 3×10^{12} e/cm^2: further investigations under way

Next steps

- Efficiency check: priority!
- Improve telescope performance/alignment: eventual position resolution studies from energy scans
- Beam-test of irradiated chip

Monolithic CMOS Pixel Detectors

C. Baltay



After selecting hits in same bunch: occupancy ~10^{-6}

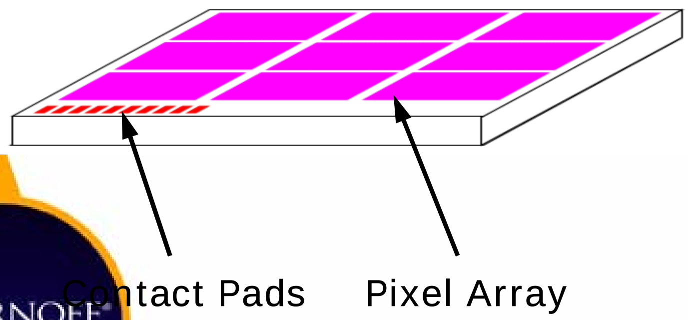
Two active particle sensitive layers:

Big Pixels – High Speed Array – Hit trigger, time of hit
Small Pixels – High Resolution Array – Precise x,y position, intensity

Array Designs

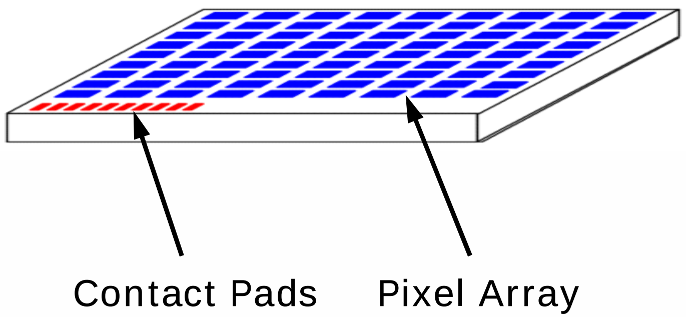
High-speed arrays

- Designed for quick response.
  - Threshold detection only.
  - Large pixels (~50 x 50 μm).
- Transmits X,Y location and time stamp of impact.



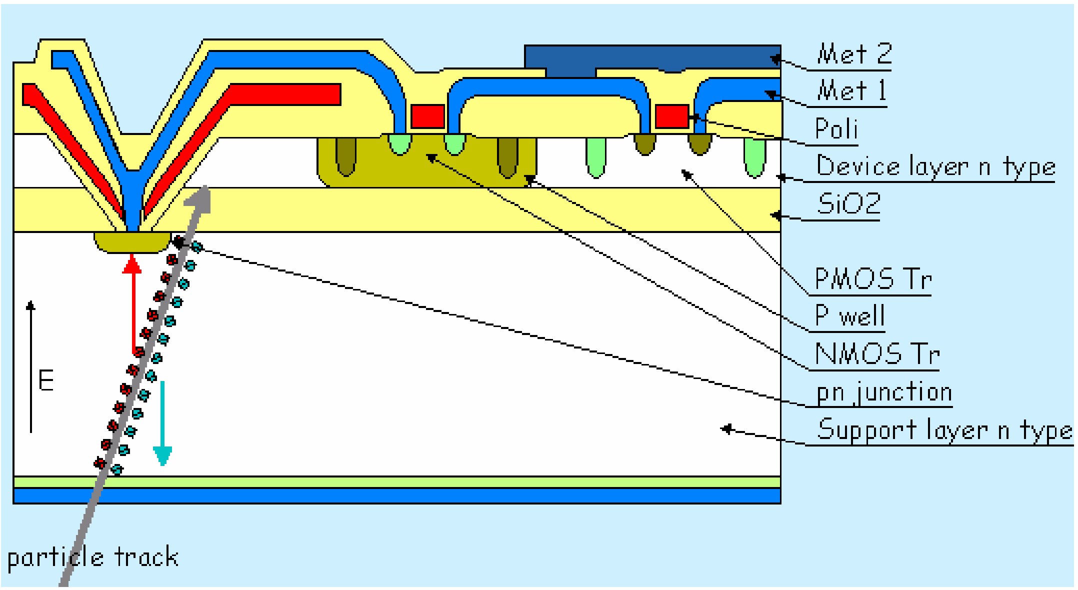
High-resolution arrays

- Designed for resolution and querying.
  - Smaller pixel size (~5 x 5 μm).
  - Random access addressability.
  - Records intensity.
- Provides intensity information only for pixel region queried.



A. Bulgheroni - Como

Principle of SOI monolithic detector



Integration of the pixel detector and readout electronics in a wafer-bonded SOI substrate

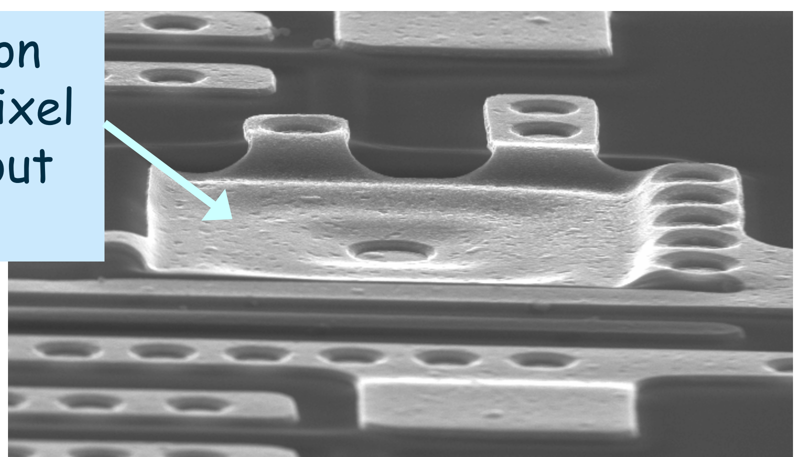
Detector → handle wafer

- High resistive (> 4 kΩcm,FZ)
- 400 μm thick
- Conventional p^+-n

Electronics → active layer

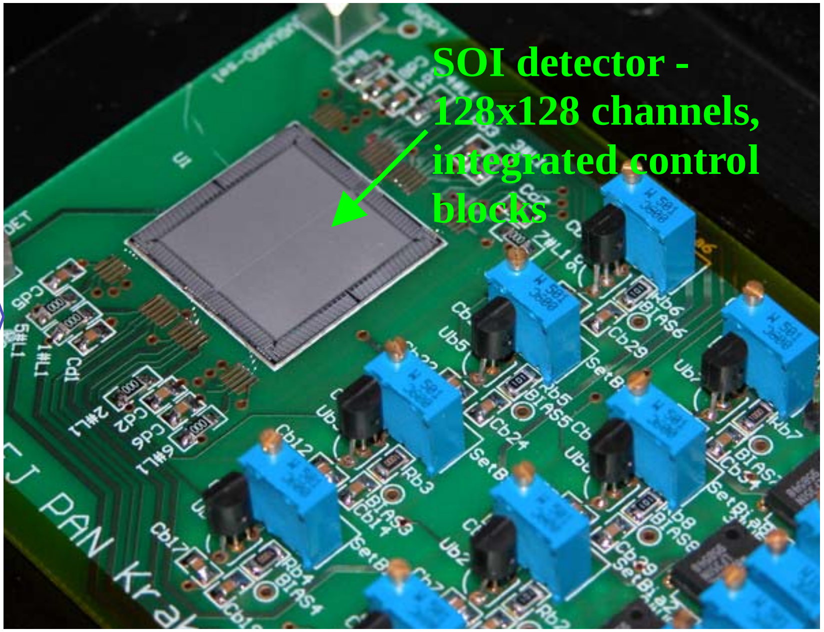
- Low resistive (9-13 Ωcm, CZ)
- 1.5 μm thick
- Standard CMOS technology

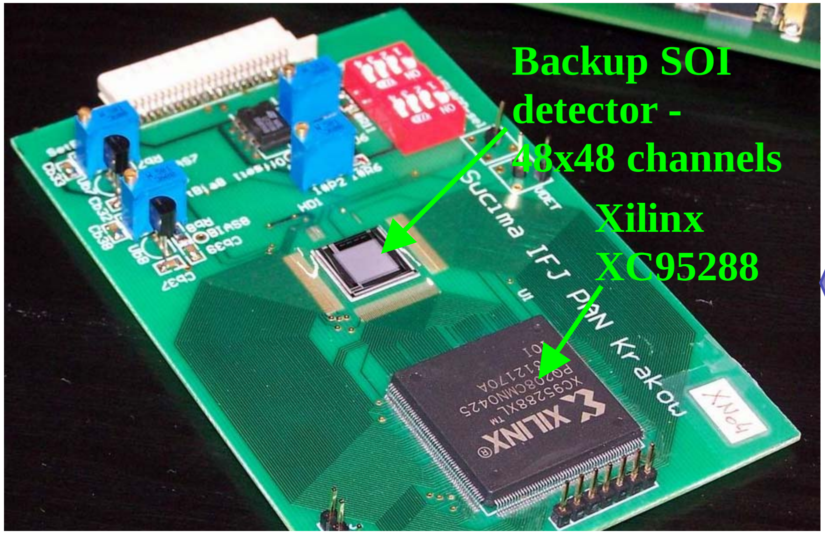
Connection between pixel and readout channel



First large-scale SOI Detectors

- Fully functional detectors with implemented readout blocks on chip
  - 128 x 128 readout channels
  - area 2.4 cm x 2.4 cm
  - 4 independent sub-matrices
  - Operation in charge integration mode
  - Dead time below 1% with respect to integration time
- Optimised for medical applications





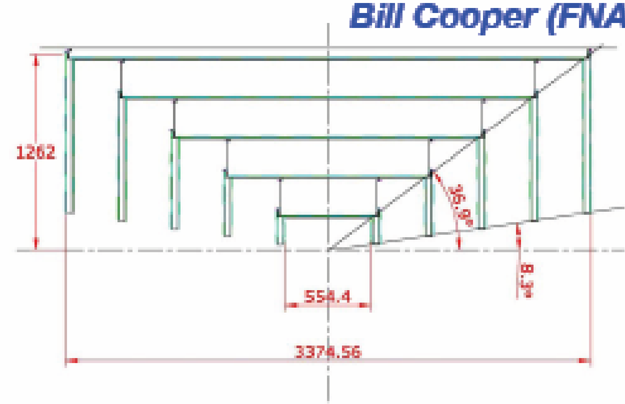
- „Baby Detector" – 48 x 48 readout channels, area 1.2 cm x 1.2 cm, no digital control blocks
- Column, row and reset signals generated by Xilinx CPLD (XC95288XL)

Si Tracking

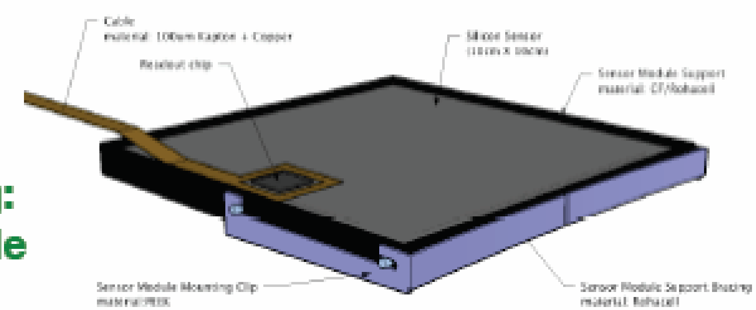
8

Alternative: Small Modules

Bill Cooper (FNAL)

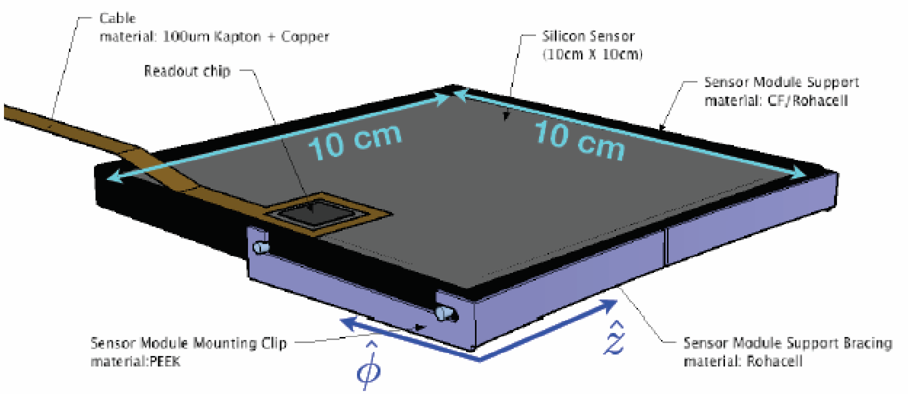


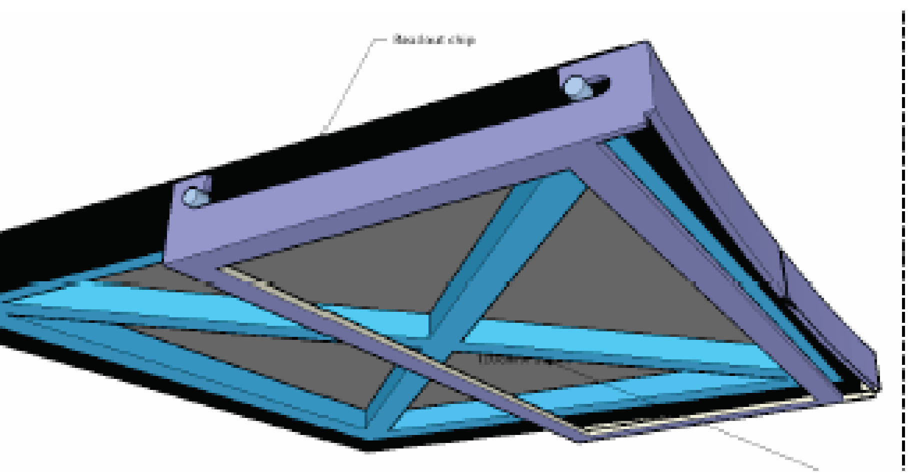
- *Shift responsibility for rigid/robust support onto underlying structure:* Nested, closed carbon-fiber / Rohacell cylinders (a la D0 CFT, Atlas SCT)
- *Tile cylinders with small, simple modules, each with own readout*
  - Very high S/N (~20)
  - Simple, low-risk assembly
  - "One hand" installation/handling: even in-situ replacement possible



T.Nelson

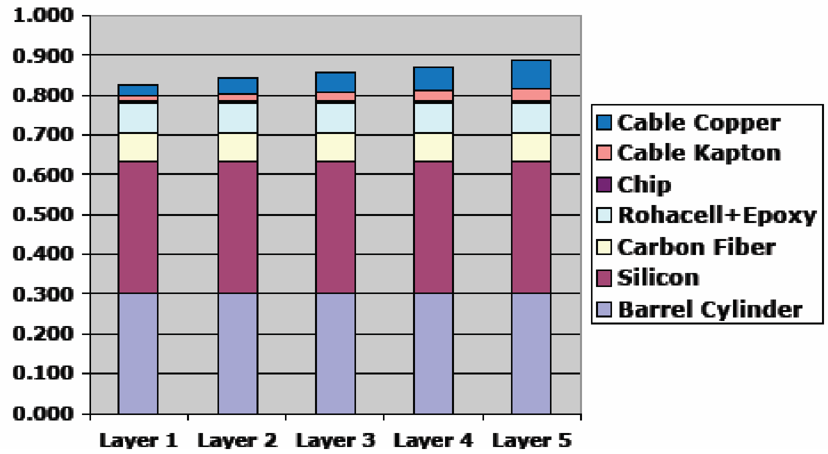
Short Module Design





Barrel Material

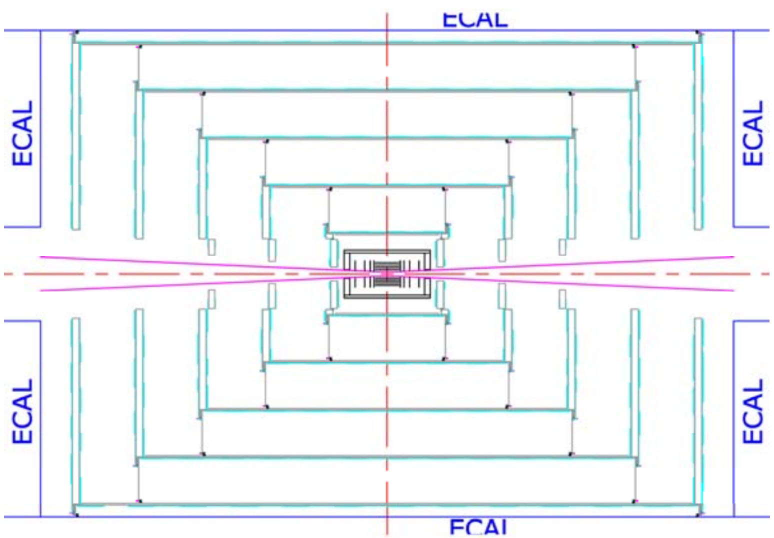
X0/Unit Coverage (%) for Barrels with Short Silicon Modules



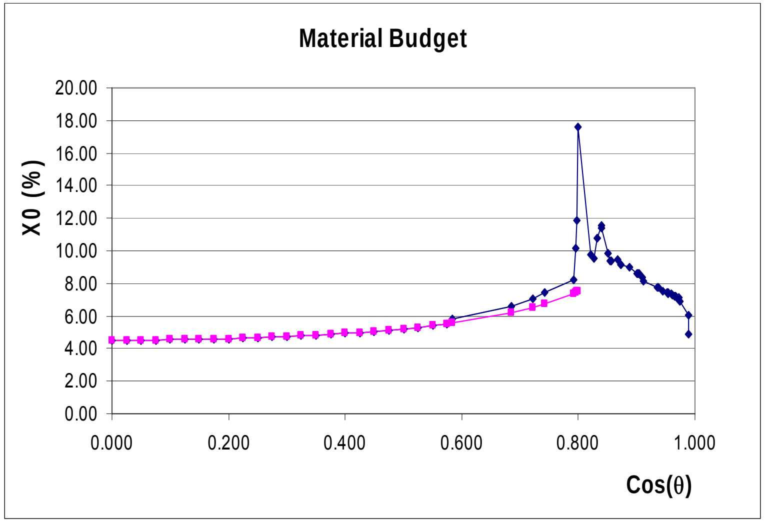
Design of the SiD Silicon Tracker

- Support of barrels and disks is based upon sandwiches of carbon fiber (epoxy) – Rohacell – carbon fiber (epoxy).
- Barrel lengths vary with radius to allow disks to be inset.
  - Barrels of uniform lengths with disks at ends are also under consideration.
- The Victoria design assumed:
  - Single-sided sensors
  - No stereo in the barrels and approximately 90° stereo in the disks
  - Forced air cooling, which implies that readout chip power must be cycled.
- Simulation studies are in progress to understand the number of barrels and disks, and the number of stereo layers, needed.

Outer silicon tracker and VXD



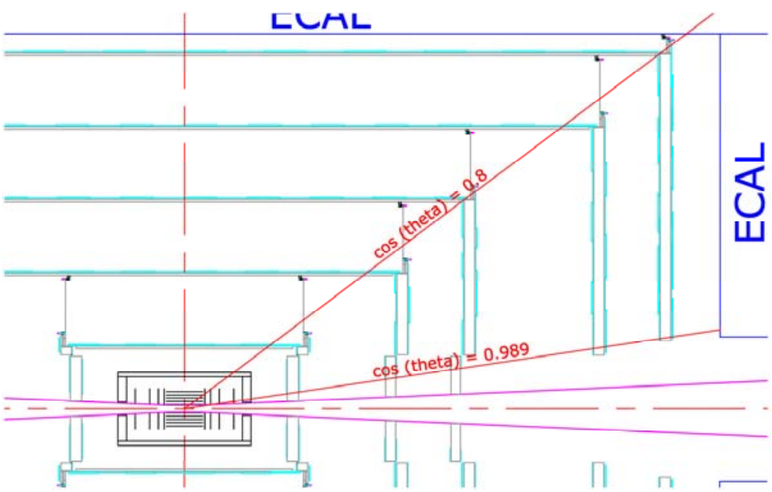
X0 (%) versus cos(θ)
(VXD and beam pipe are not included)



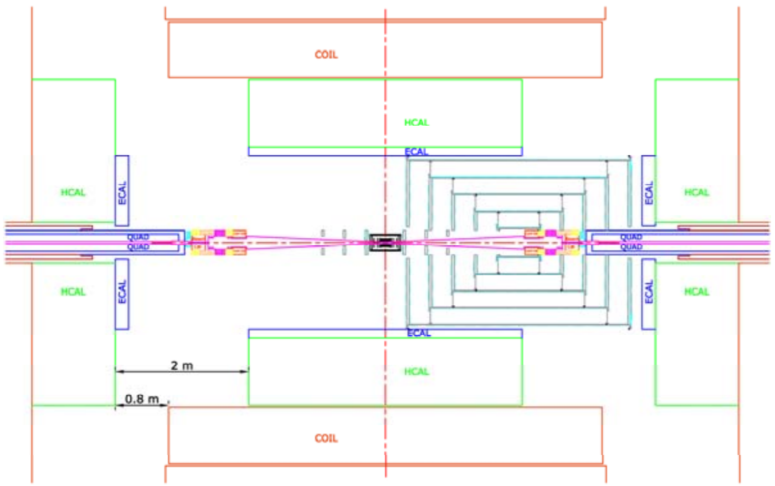
Modifications to the Design

- Barrel lengths can be varied to redistribute material in the X0 peak at $\cos(\theta) \approx 0.82$.
- Possible designs of barrel sensor module support structures have been proposed.
- Work to integrate the outer silicon tracker and the VXD geometries has begun.
  - Provisions to service the VXD assume that the outer tracker is moved longitudinally while the VXD and beam line elements remain fixed.
  - Disks of the outer tracker have been separated into inner and outer portions to achieve that. Inner portions would be supported from the beam pipe.

Layout with barrel lengths adjusted to distribute X0 peak. Separated disk portions are shown, also.



Tracker opened for VXD servicing



Frequency Scanned Interferometer for ILC Tracker Alignment

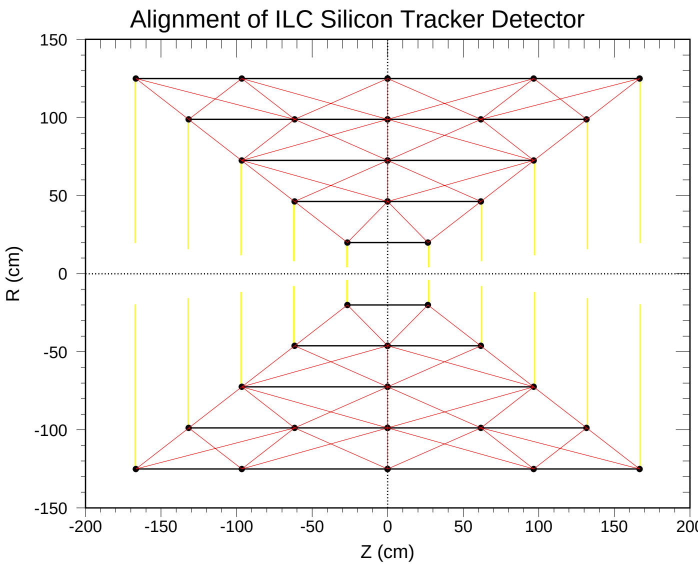
Hai-Jun Yang, Sven Nyberg, Keith Riles

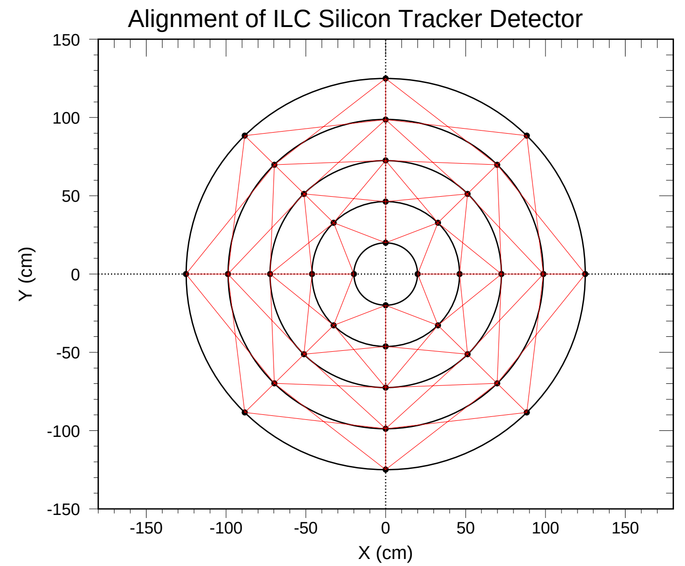
University of Michigan, Ann Arbor

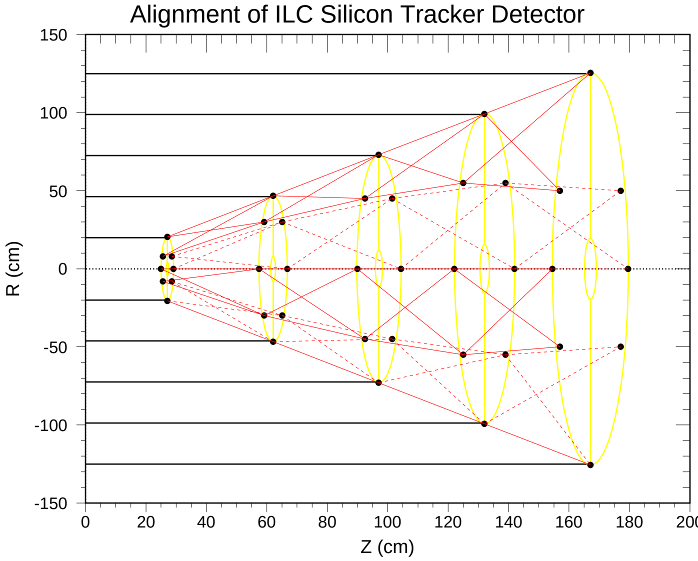
8th International Linear Collider Workshop

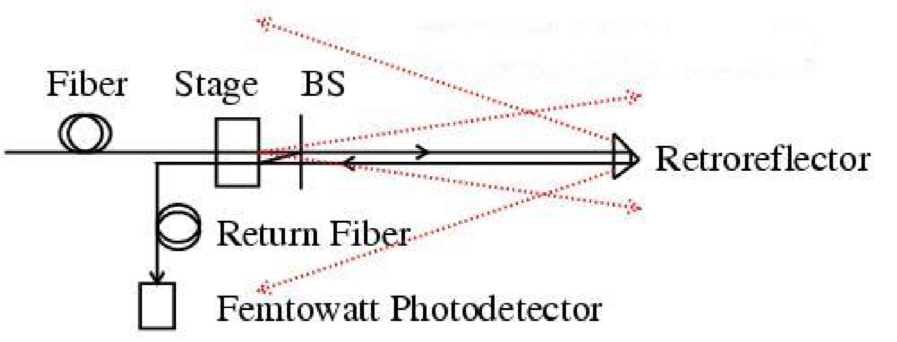
SLAC, March 18-22, 2005

A Possible SiD Tracker Alignment









752 point-to-point distance measurements

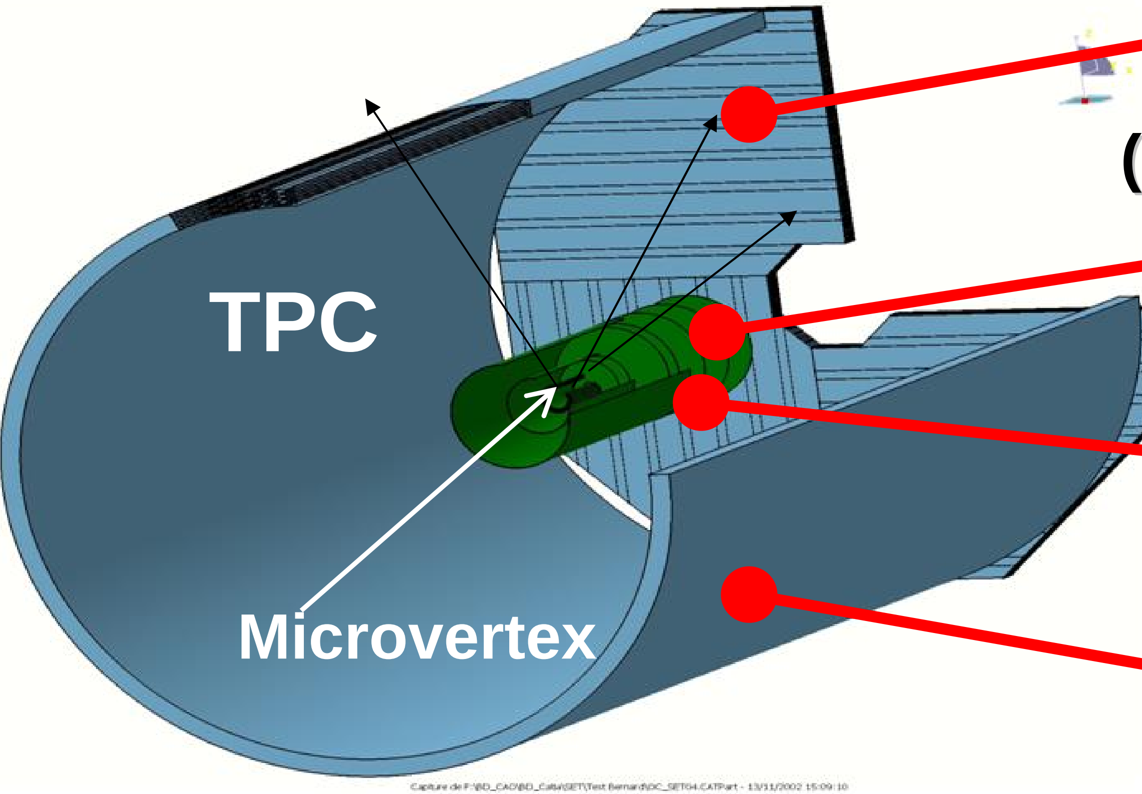
Worldwide Study of the Physics and Detectors for Future Linear e+ e- Colliders

Summary and Outlook

- ➔ Two FSI demonstration systems, with or without optical fibers, were constructed to make high-precision absolute distance measurements.
- ➔ Two new multi-distance-measurement analysis techniques were presented to improve absolute distance measurement and to extract the amplitude and frequency of vibration.
- ➔ A high precision of ~50 nm for distances up to 60 cm under laboratory conditions was achieved.
- ➔ Major error sources were estimated, and the expected error was in good agreement with spread in data.
- ➔ We are investigating dual-laser scanning technique used by Oxford ATLAS group currently.
- ➔ Michigan group has extended the frontier of FSI technology, but much work lies ahead.

Silicon Tracking System with a central gaseous detector

The Silicon Envelope concept =
ensemble of Si-trackers surrounding the TPC (LC-DET-2003-013)



The Si-FCH:
TPC to calorimetry
(SVX,FTD,(TPC),SiFCH)

The FTD:
Microvertex to SiFCH

The SIT:
Microvertex to TPC

The SET:
TPC to calorimetry
(SVX, SIT, (TPC), SET)

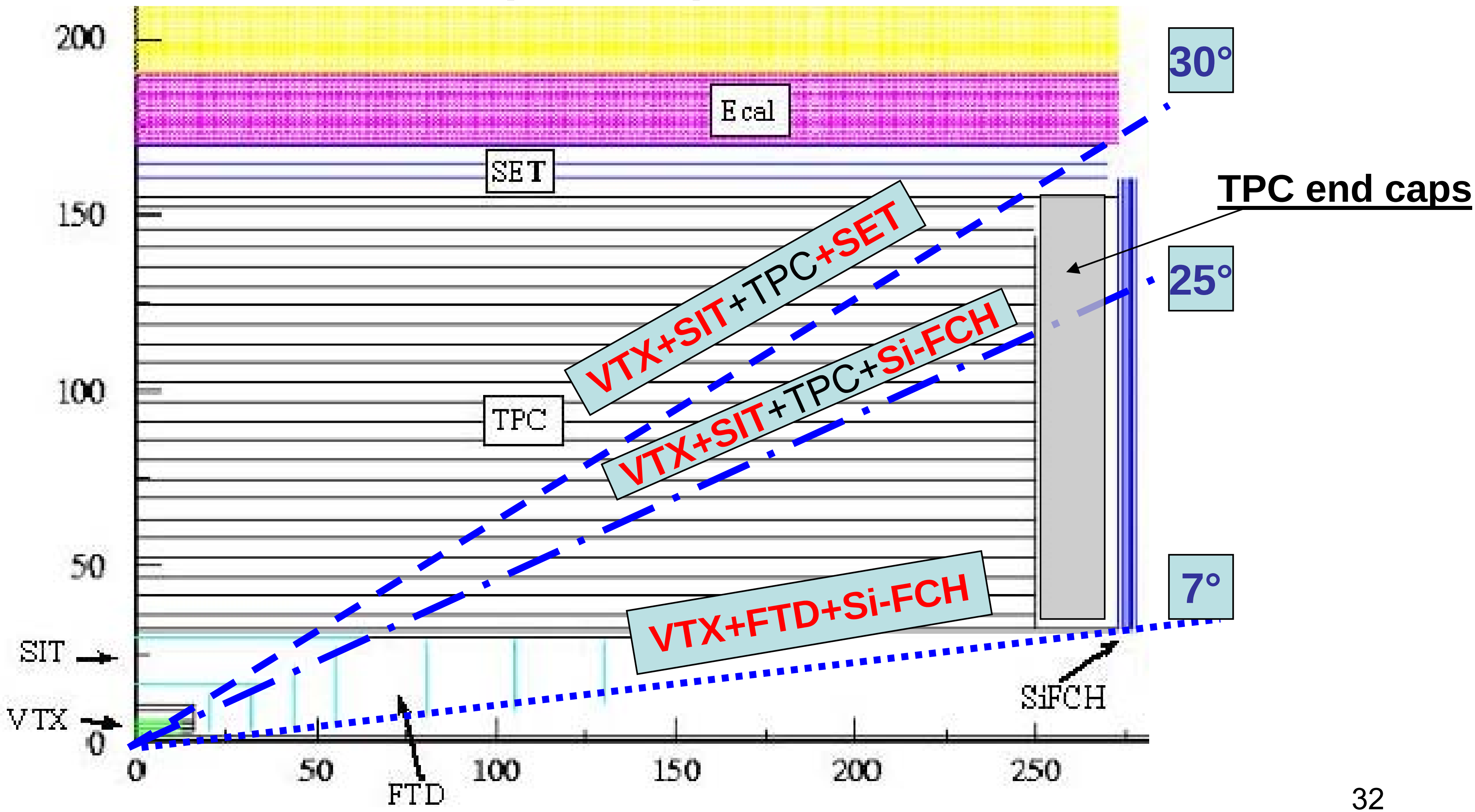
A. Savoy-Navarro

Crucial Keywords:

✓Robustness

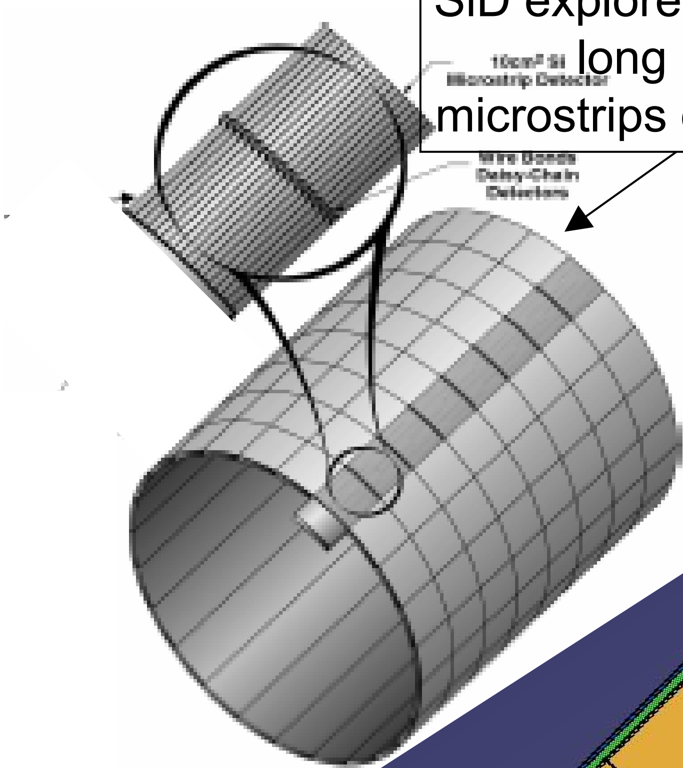
✓Full coverage

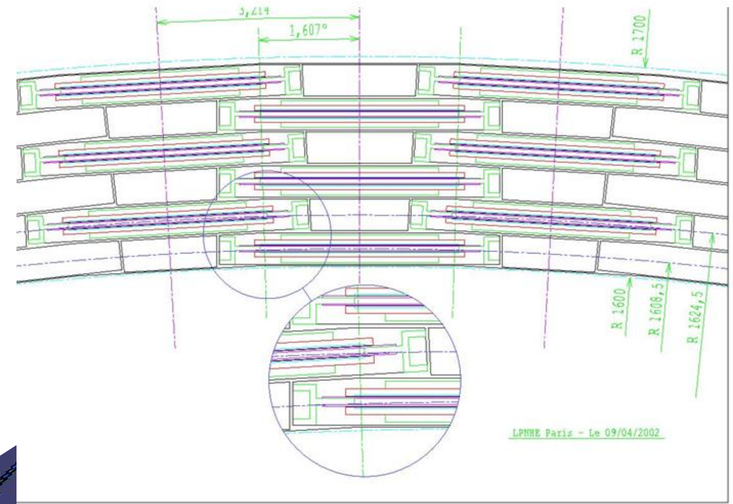
✓Improved performances

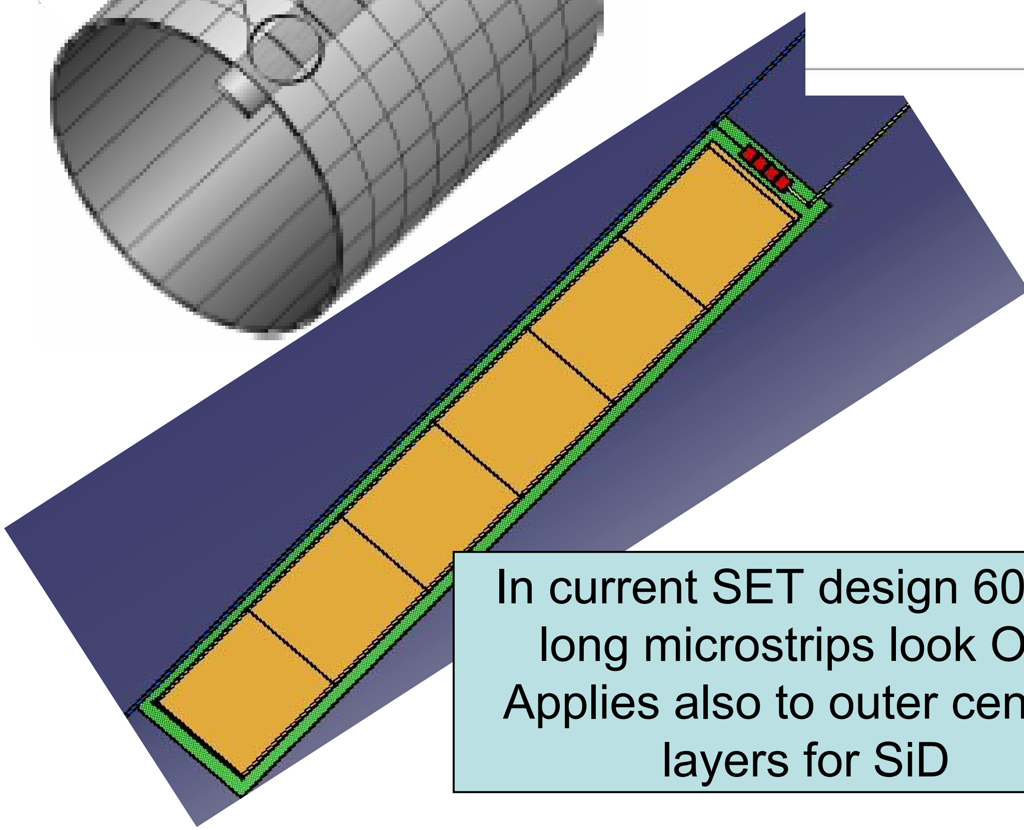


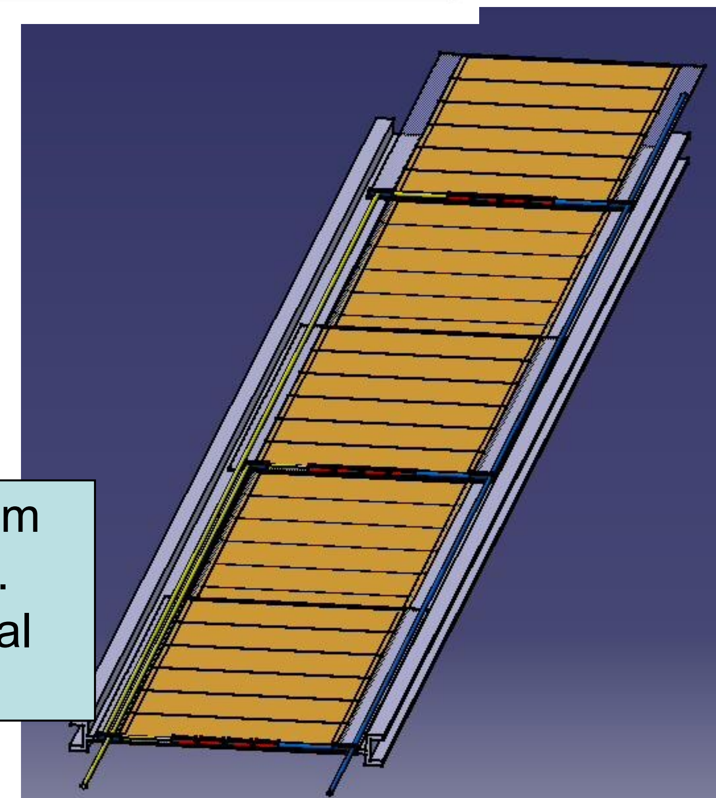
Central Outer Si layers: current design

SiD explores very long microstrips or tiles



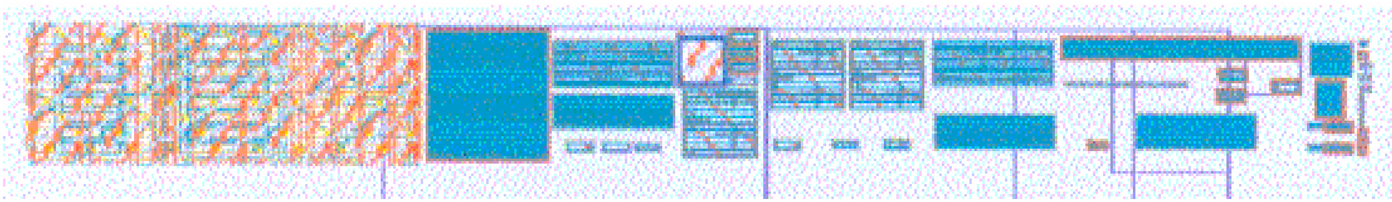






In current SET design 60 cm long microstrips look OK. Applies also to outer central layers for SiD

Prototype chip received February 28th



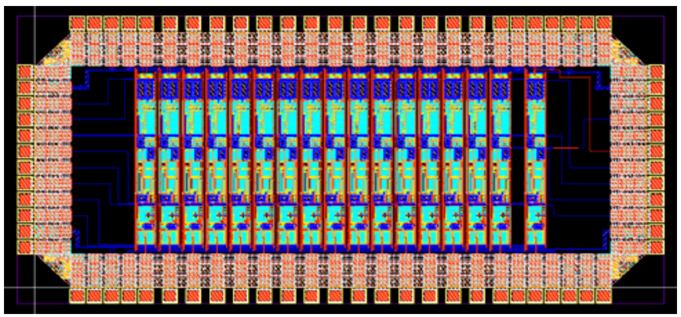
One analog channel

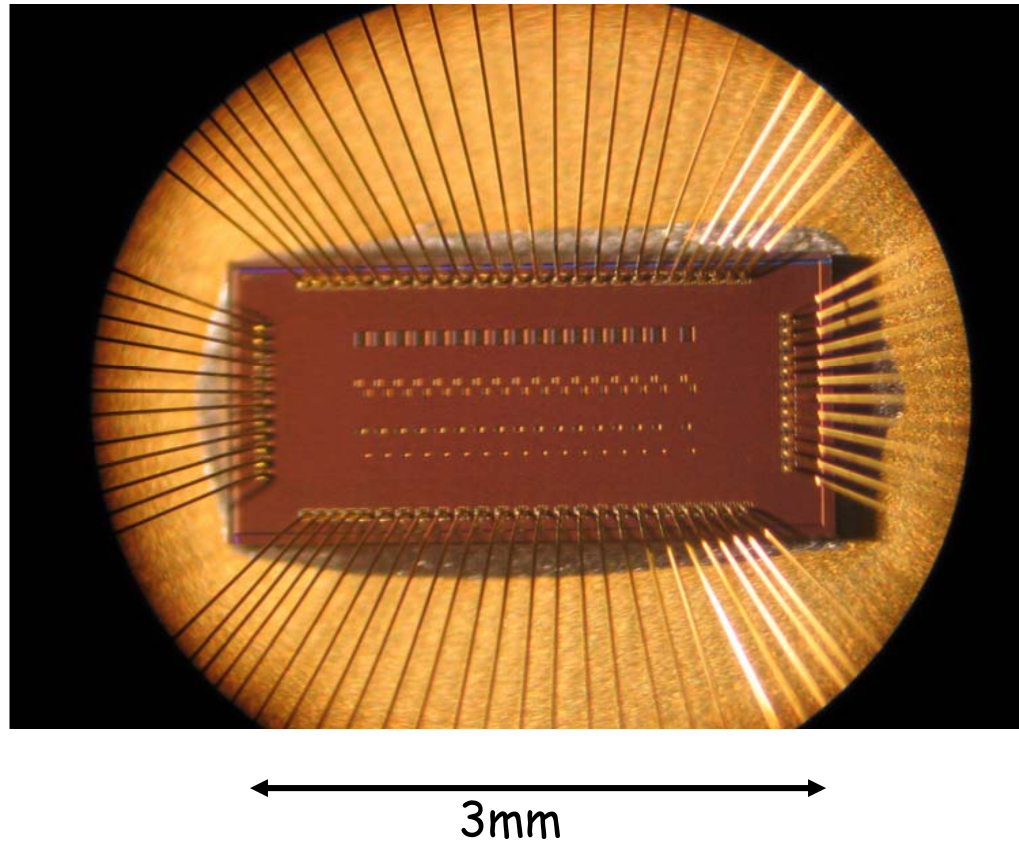
UMC 0.18 μm CMOS *Europractice (Leuven, Belgium)*

- **16 ch + 1 Preamp, Shaper, Sample & Hold, ADC Comparator**
- **Two blocks of 1.6 x 1.6 mm^2 each**

J.-F. Genat

Silicon





16 + 1 channel UMC 0.18 um chip (layout and picture)

Just received !
Very first preliminary results

Two tested chips fully functional

Preamp + Shaper Under

Preamp: Gain 8mV/MIP OK

Linearity +/-1.5%

Dynamic range: 75 MIP OK

Noise @ 3.3pF input cap, 3 μs shaping time:

205 e- 140 e- expected

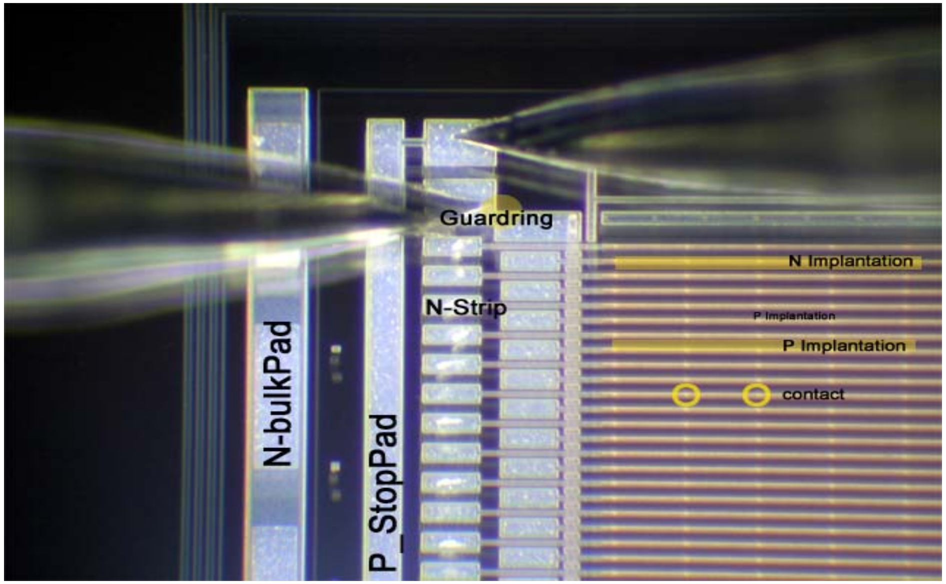
Shaper: 2 - 10 μs tunable peaking time OK

Power: Preamp 90 μW 70 μW expected

Shaper 110 μW OK

30 W full detector

Development of Double-sided Silicon Strip Detector



- **Introduction**
- **Electrical Test**
- **Source Test**
- **Radiation Damage Test**
- **Summary and Future Plan**

•Fabrication “in house”

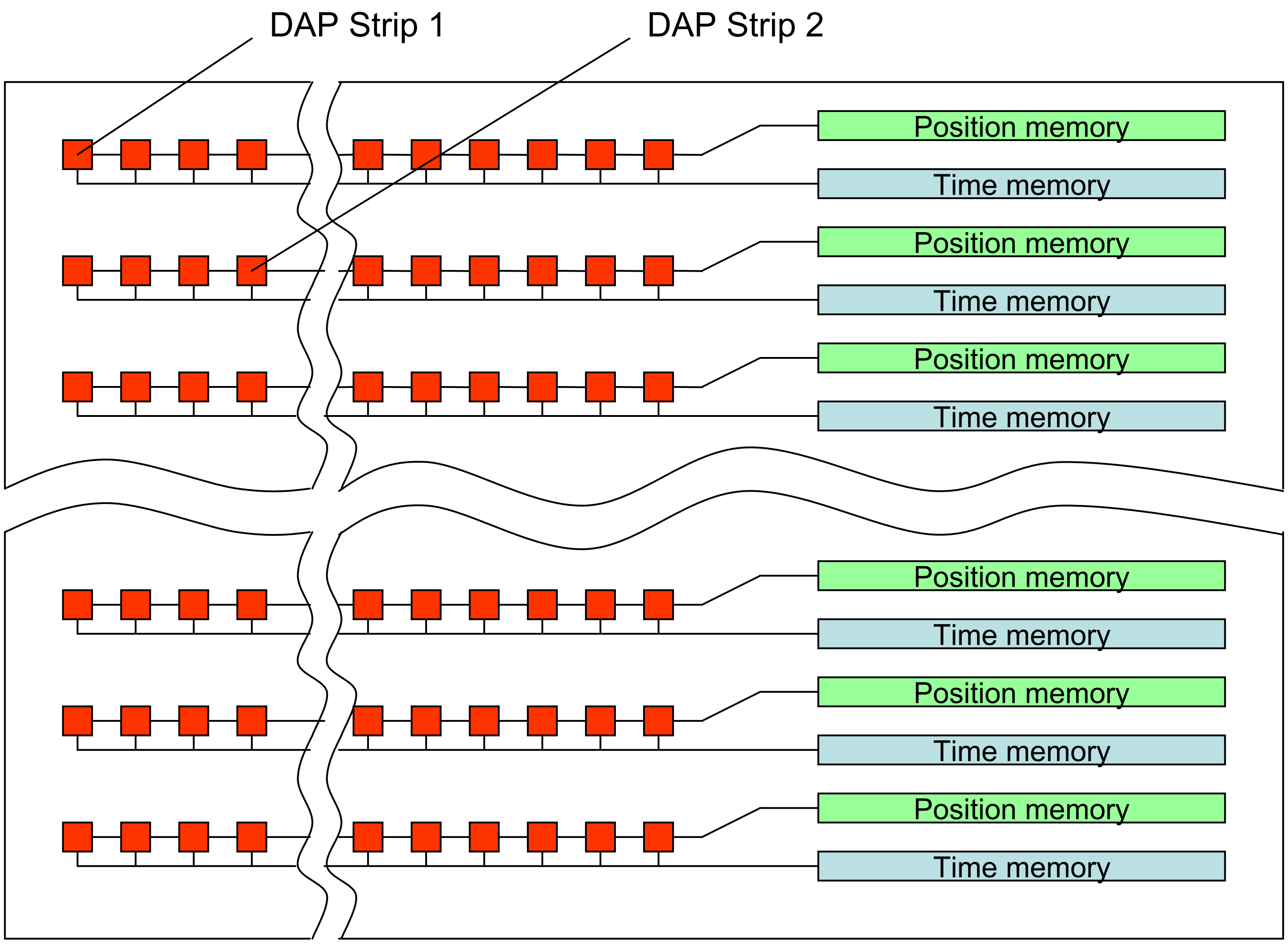
•5” wafers

H. Park (BAERI, KNU)
On behalf of Korean Silicon Group

Digital Active Pixel Array

G.Bashindzhagyan

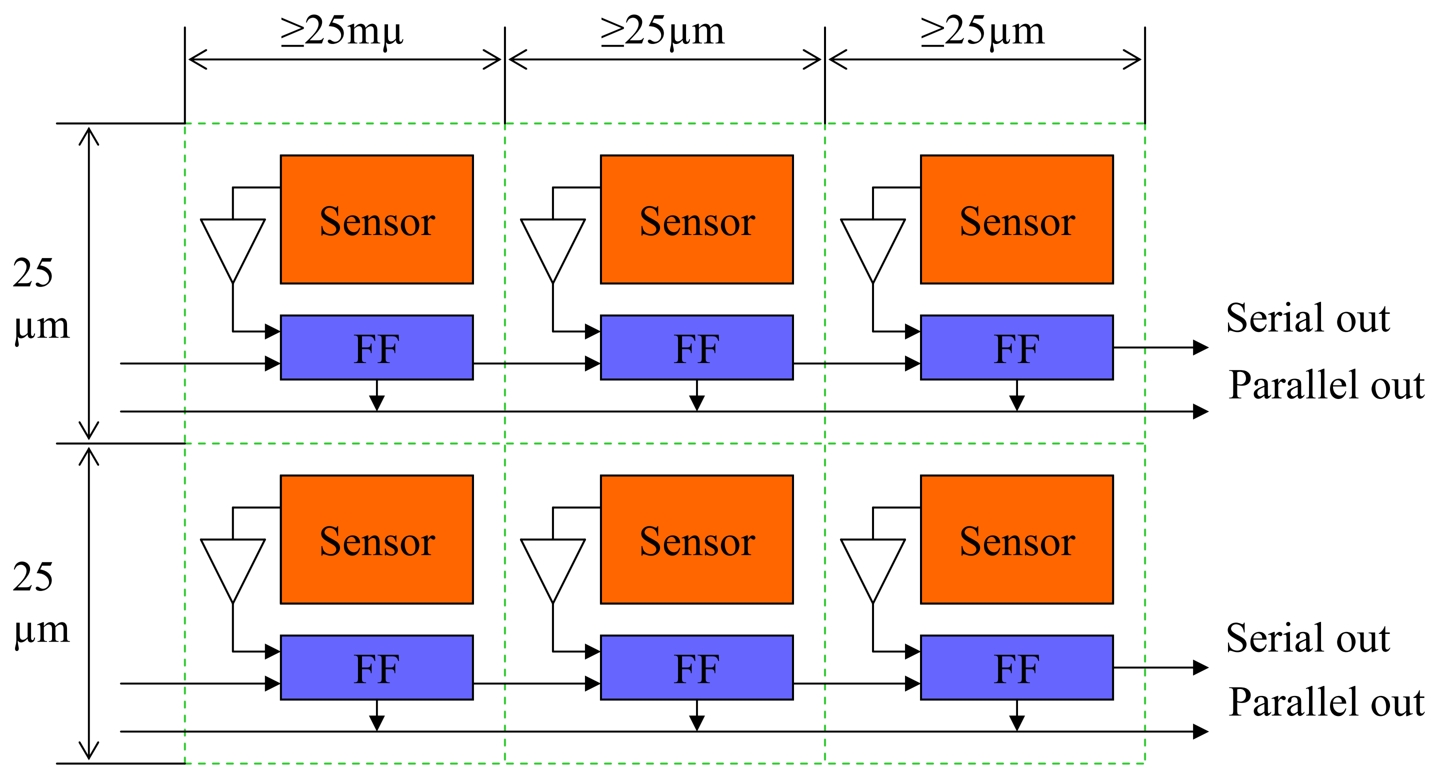
25x25 μm^2 pixels



G.Bashindzhagyan
N.Sinev   LCWS 2005

Digital Active Pixel Array

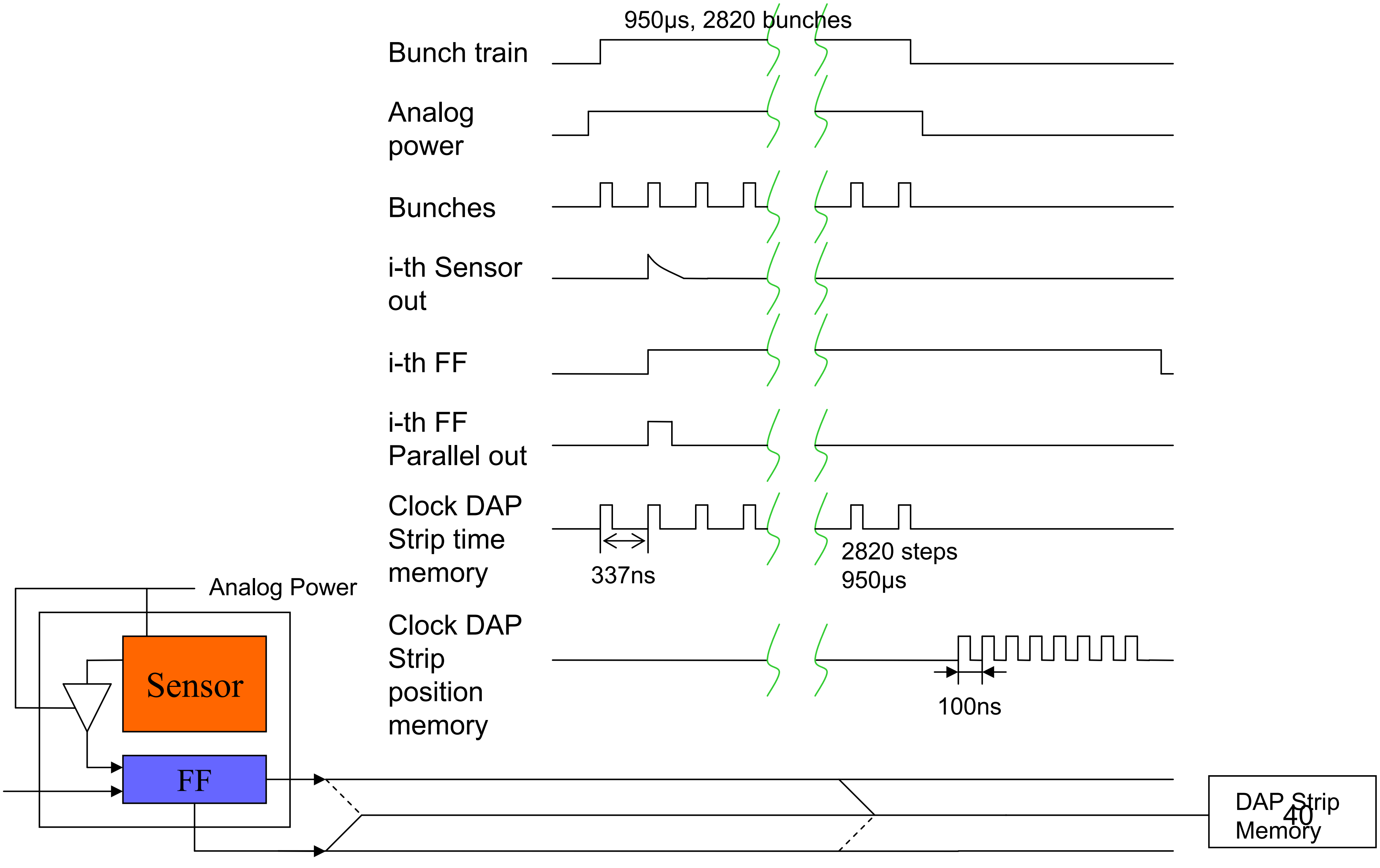
Pixel Structure



G.Bashindzhagyan
N.Sinev LCWS 2005

Digital Active Pixel Array

Timing Diagram



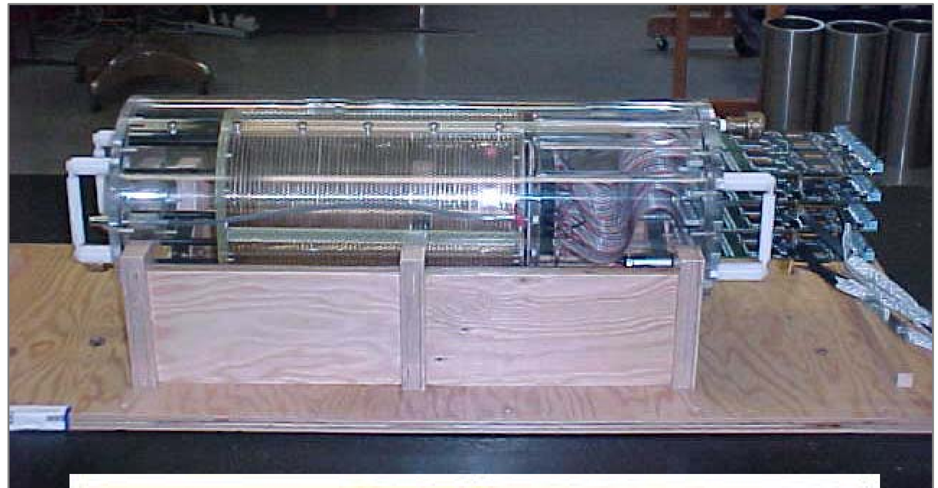
TPC R&D

- Gas amplification: GEM, Micromegas; compare with wires
- Different gases:

Ar-CH4(5%)-CO2(2%)	'TDR'
Ar-CH4(5%,10%)	P5, P10
Ar-iC4H10(5%)	Isobutane
Ar-CF4(2-10%)	CF4
He-iC4H10(20%)	Helium

- Laser studies
- Field cage optimisation
- Mapping a large parameter space

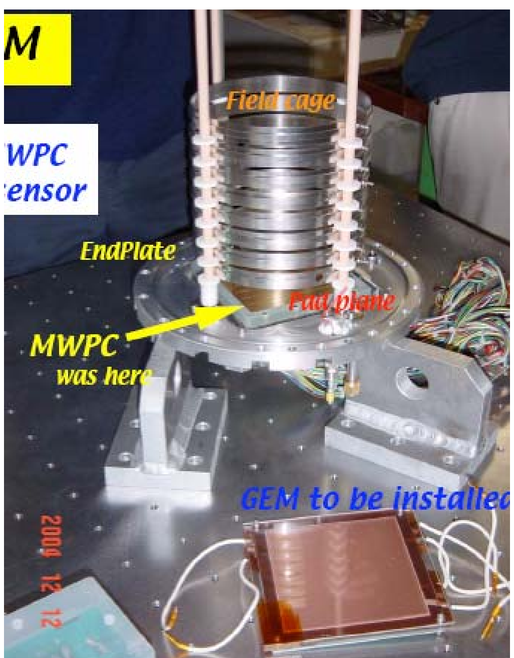
Aachen



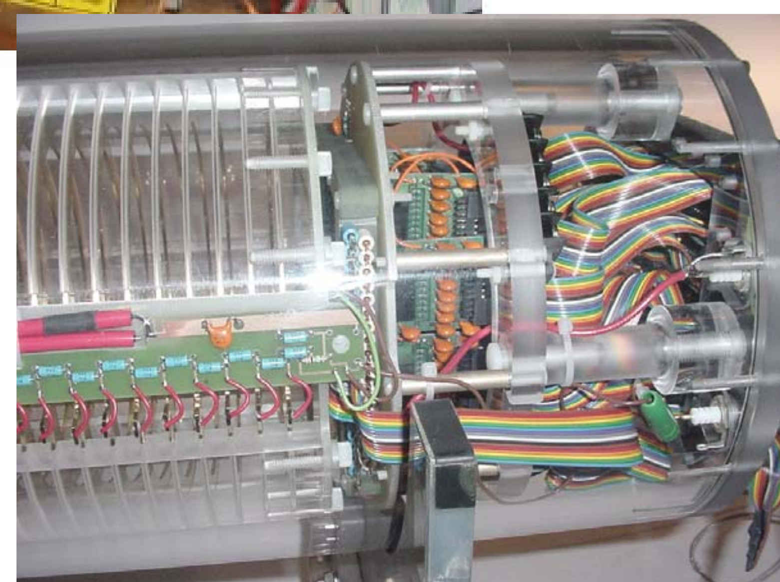
Victoria

DESY

MPI/Asia



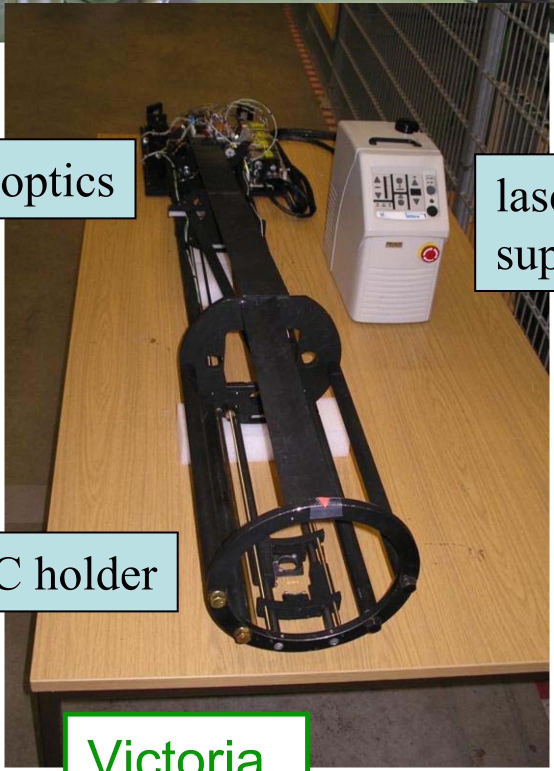
Cornell/
Purdue




Desy 5T magnet,
cosmics, laser
ANSALDO


Saclay 2T magnet,
cosmics


Kek 1.2T, 4GeV
hadr. test-beam


laser + optics
laser power supply
TPC holder
Victoria

Many groups involved:

•Aachen, DESY, Hamburg U., Karlsruhe, Krakow, MPI-Munich, NIKHEF, BINP Novosibirsk, Orsay, Rostock U., Saclay, PNPI StPetersburg

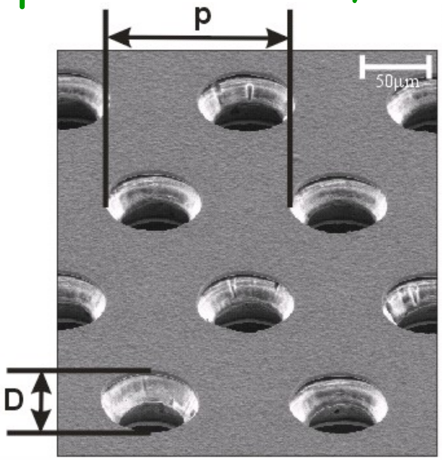
•Carleton, Berkeley, Montreal, Victoria

•Chicago/Purdue, Cornell, MIT, Temple/Wayne State, Yale

•Chiba U., Hiroshima, Minadamo, Kinki U., Osaka, Tokyo (4 groups), Tsukuba (2 groups)

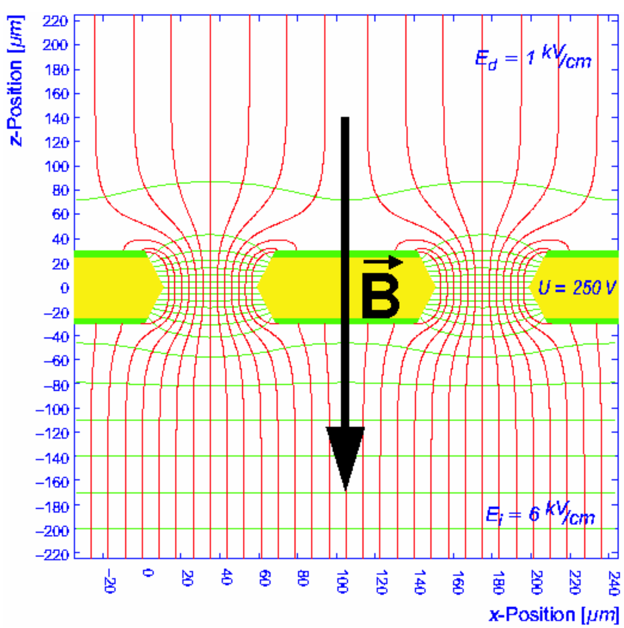
Gas-Amplification Systems: Wires & MPGDs→

GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

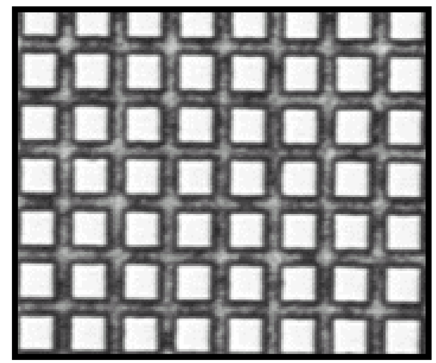


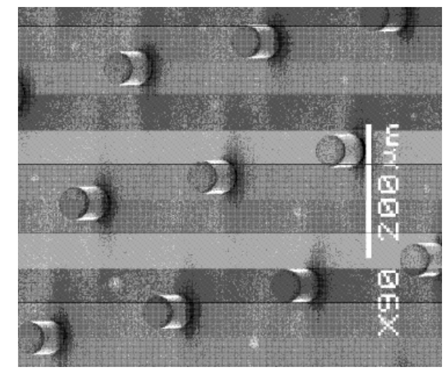
P~140 µm

D~60 µm

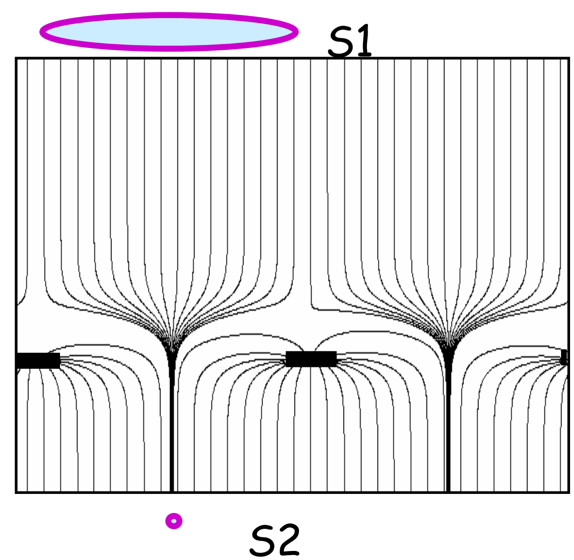


Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage





S1/S2 ~ Eamplif / Edrift

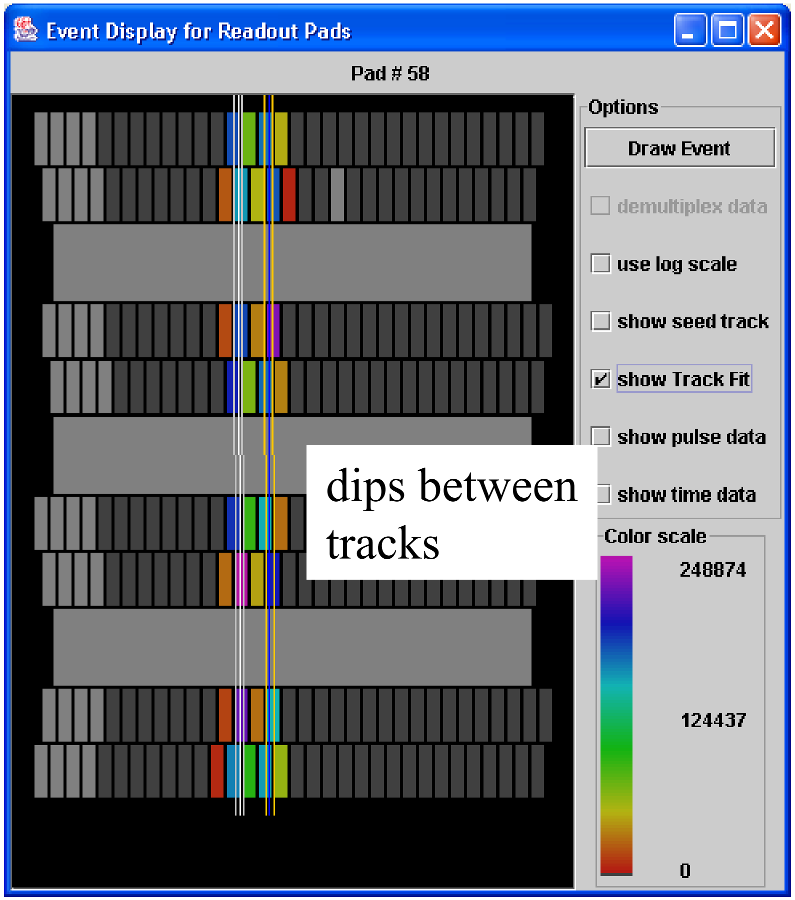


Double track fits: 2mm wide pads

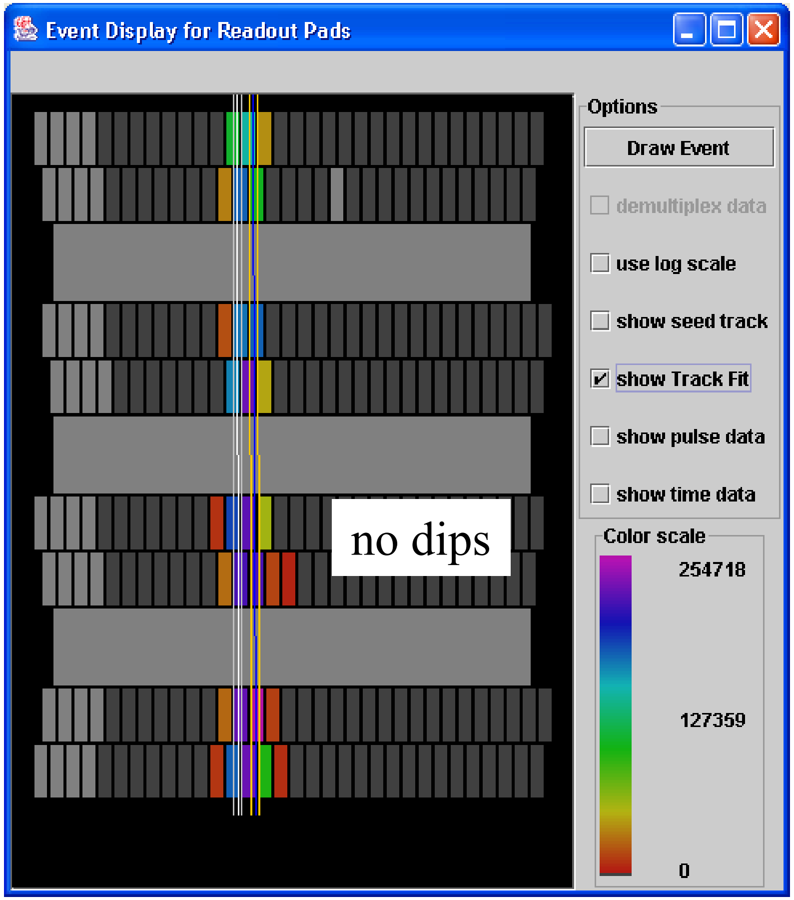
D. Karlen

σ = 0.5 mm

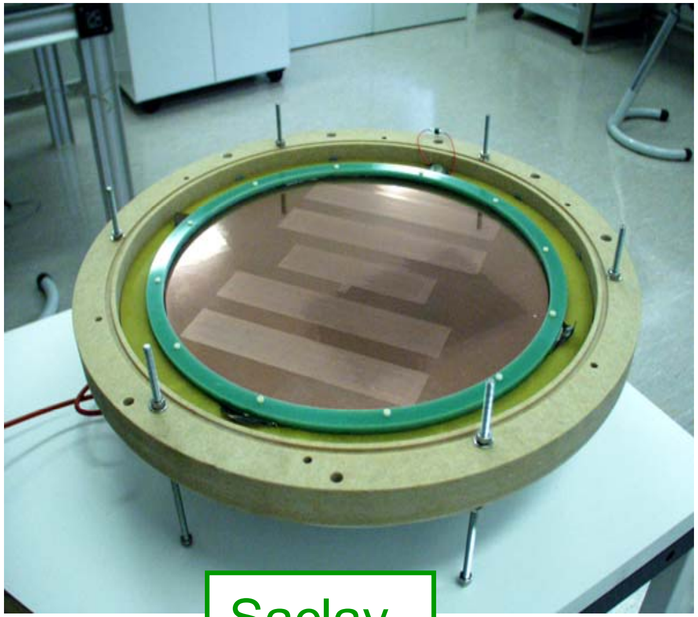
Δx = 3.8 mm



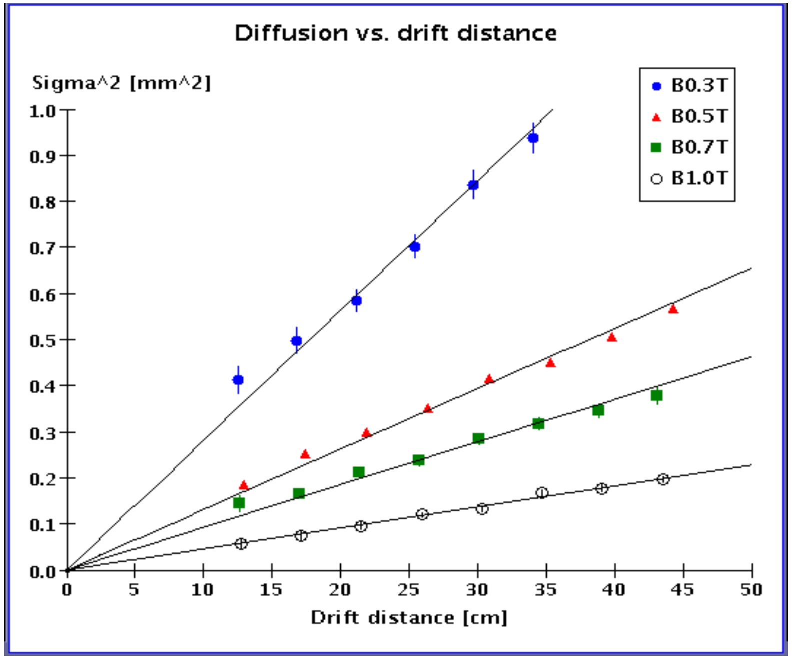
Δx = 2.0 mm



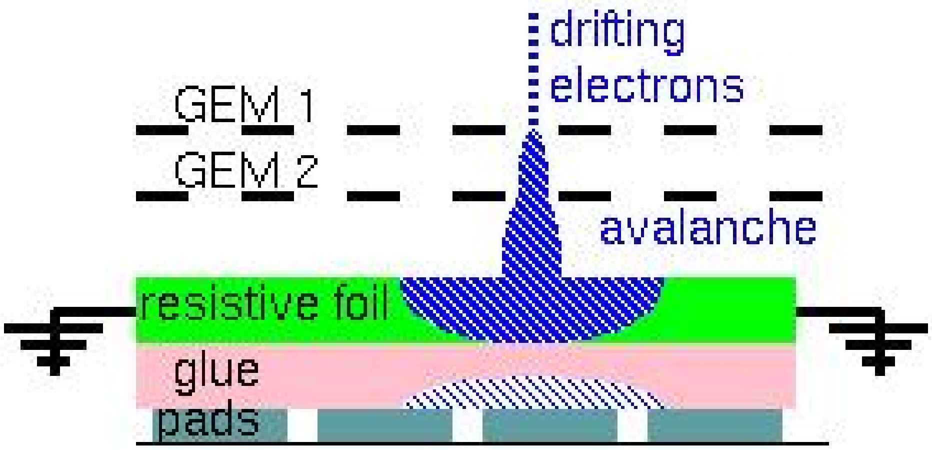
Micromegas:Diameter 50 cm



Saclay



Charge spreading through resistive foil; can still use 'wider' pads – Carleton + Orsay + Saclay

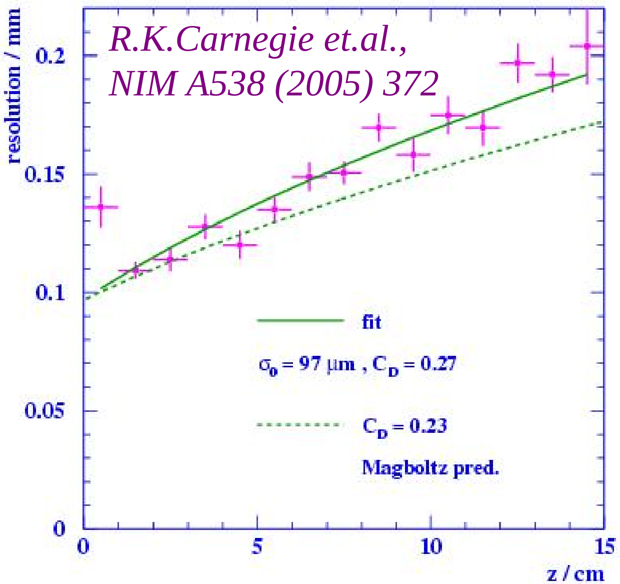


M. Dixit

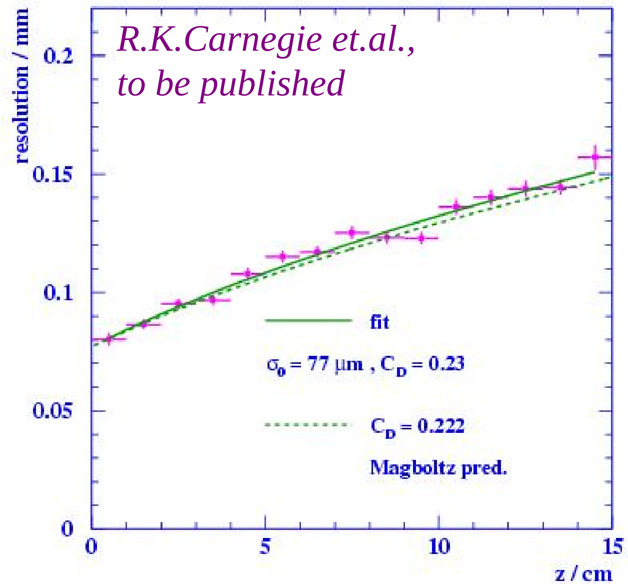
2 x 6 mm^2 pads

TPC transverse resolution for Ar:CO_2 (90:10)

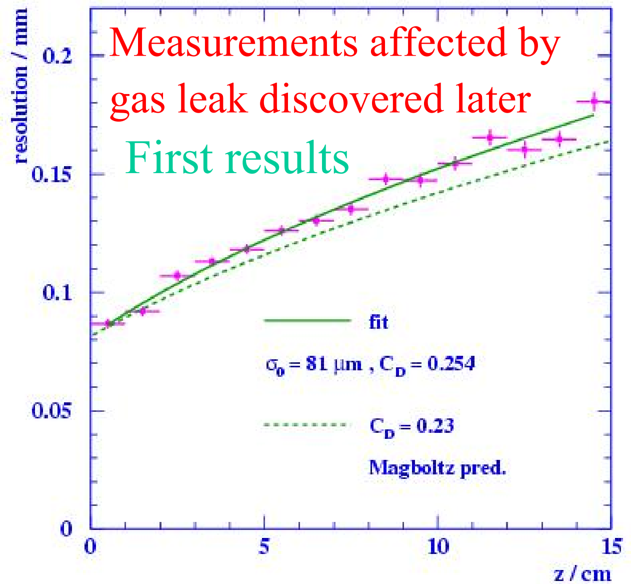
GEM with direct charge readout



GEM with charge dispersion readout



Micromegas with charge dispersion readout



$$\sqrt{\sigma_0^2 + \frac{C_D^2}{N_e} z}$$

(Diffusion limit of resolution)

Compared to direct charge readout, charge dispersion gives better resolution for GEM with Z dependence close to the diffusion limit. For Micromegas, the resolution, even with electron loss, is better than for direct charge GEM readout.

Resolution measurements (best results obtained):

- 90-110 μm for 2x7 mm^2 pads,   P5 gas at 4T

•70-80 μm for 1.2x7 mm^2 pads, P5 gas, 4T

•~100 μm for 2x6 mm^2 pads, P10 gas, 1T

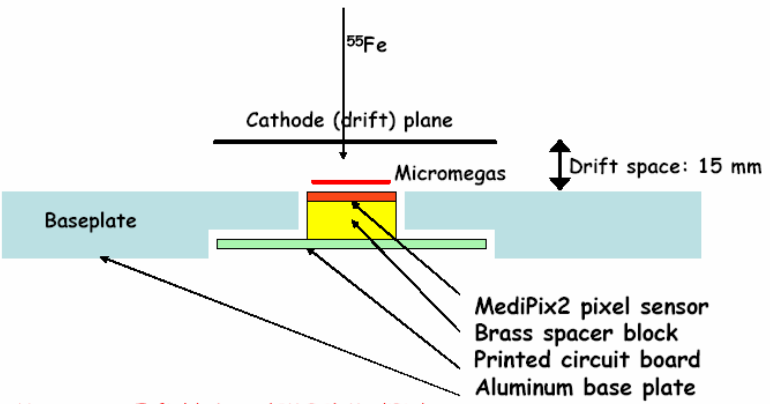
•77 μm at short drift distance for 2x6 mm^2 pads, B=0, Ar-CO2 (90%-10%); at 4T ~100 μm up to 2.5 m drift appears within reach.

•Transverse diffusion seems smaller than with Magboltz calculation

•Laser study: 2-track separation (transv.) of ~2mm; (longit.) <1 cm

Results pixel readout gas detectors

With Paul Colas & Ioannis Giomataris:
MediPix2 & Micromegas



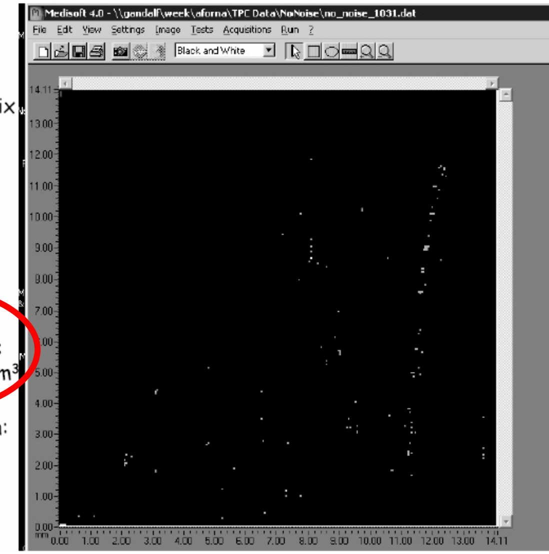
Very strong E-field above (CMOS) MediPix!

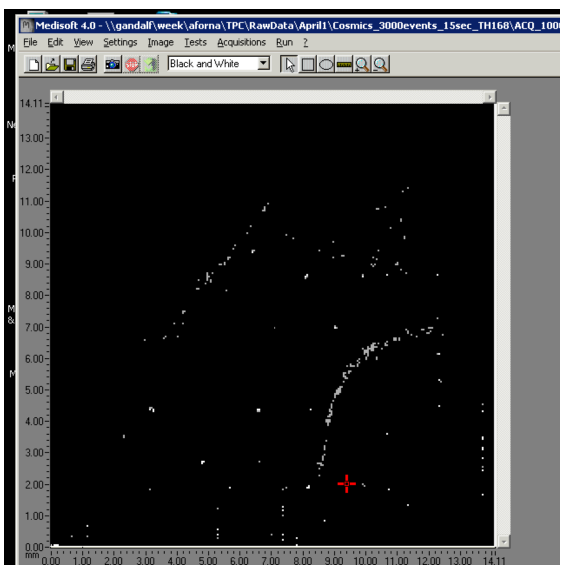
He/Isobutane
80/20
Modified MediPix

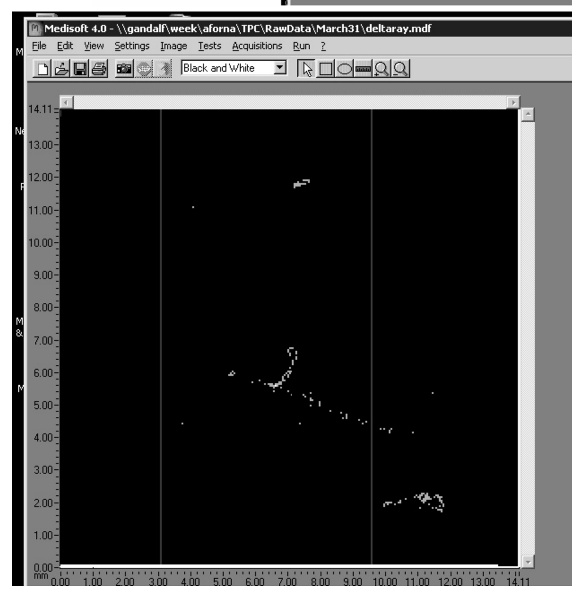
31 March 2004

Sensitive area:
14 x 14 x 15 mm^3

Drift direction:
Vertical
max = 15 mm







δ ray

Observation of min. ionising cosmic muons: high spatial resolution + individual cluster counting !

A. Muennich - Aachen

TPC Simulation

Independent from simulation packages

Simulation in three steps:

- Primary ionisation (blue)
- Drifting (red)
- Amplification with GEMs

Studies of:

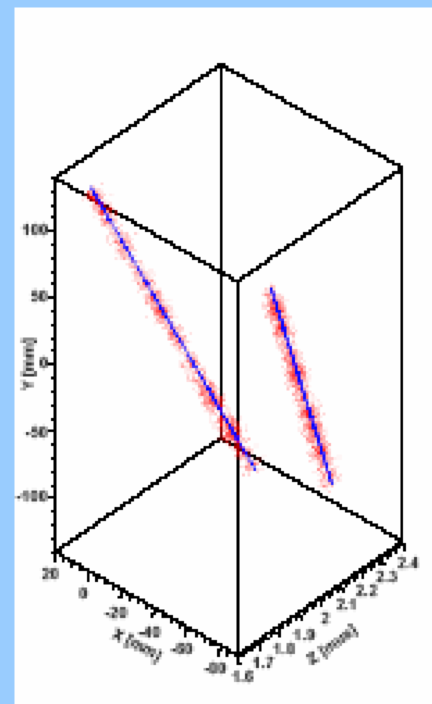
E & B fields, ion backdrift, pad geometry etc.

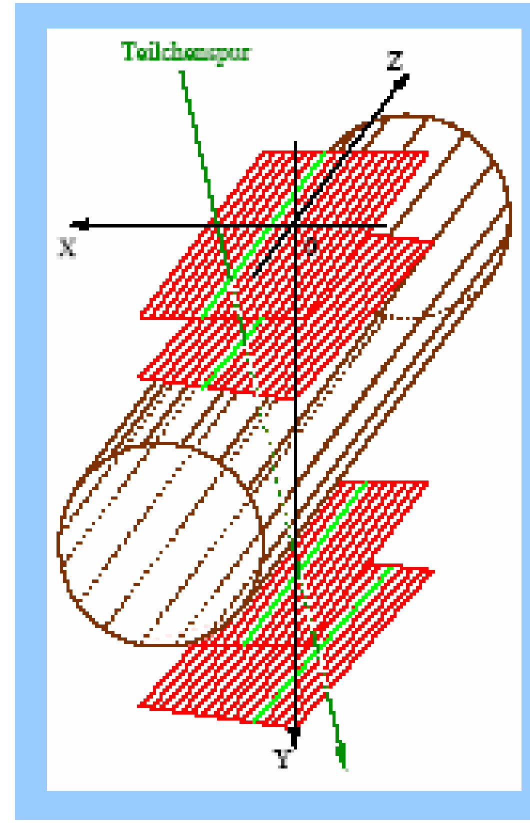
First results:

Agreement with TPC prototype

Next:

Systematic studies





Hodoscope Si modules, 122 µm pitch

Also detailed simulation in Victoria (D. Karlen)

Some physics resolution studies:

- S. Hillert (Oxford) – heavy flavour ID and quark charge measurement
- H. Yang (Michigan) – Higgs and slepton properties
- B. Schumm (Santa Cruz) – SUSY constraints on fw tracking

Many activities, new devices, new results.

For sure a lot more at next meeting.

Apologies for omissions, my mis-understandings, wrong presentations, etc.…