SiD ECal overview

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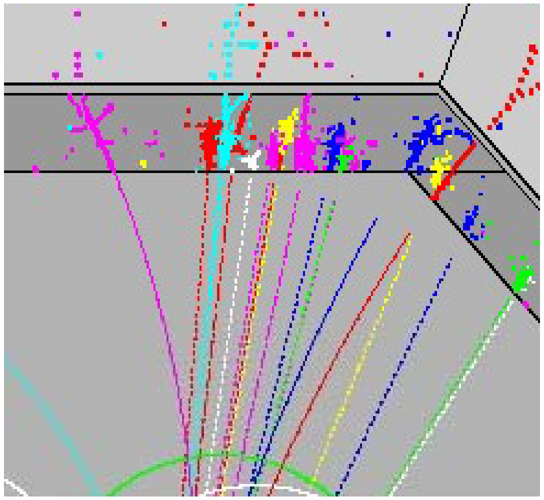
- Physics (brief)
- Proposed technical solutions: silicon/tungsten
  - "traditional" Si sensors
  - MAPS
- Progress and Status

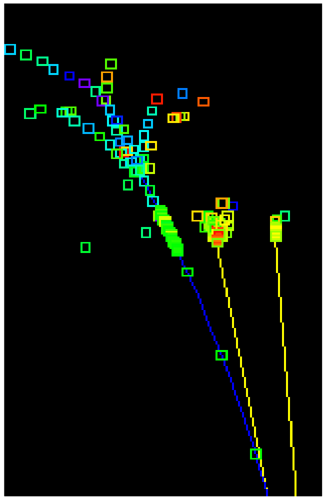
- Fallout from December …   Prospects

Physics and ECal

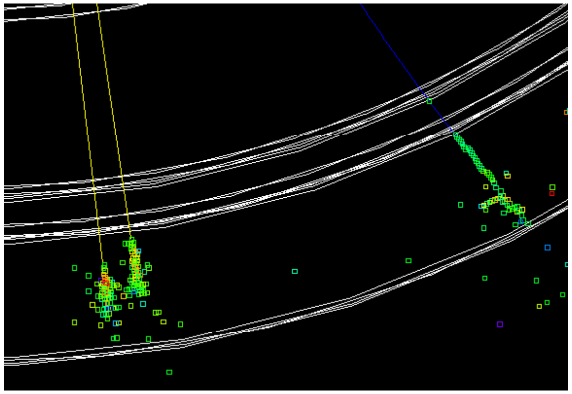
Guiding principles: Measure all final states and measure with precision

- Multi-jet final states
  - π° measurement should not limit jet resolution
  - id and measure h° and h± showers
  - track charged particles
- Tau id and analysis





- Photons
  - Energy resolution, e.g. $h \rightarrow \gamma\gamma$
  - Vertexing of photons ($\sigma_b \sim 1$ cm), e.g. for GMSB
- Electron id
- Bhabhas and Bhabha acollinearity
- Hermiticity



$\Rightarrow$ Imaging Ecalorimetry can do all this

tau id and polarization

- Analysis of tau final states can provide crucial information on new physics
- Important & broad example: $e^+e^- \rightarrow \tilde{\tau}_1^+\tilde{\tau}_1^- \;,\; \tilde{\tau}_1^\pm \rightarrow \tilde{\chi}_1^0\tau^\pm$
- The SUSY model leaves fingerprint on tau polarization:

$$\tilde{\chi}_1 = N_{11}\widetilde{\mathrm{B}} + N_{12}\widetilde{\mathrm{W}} + N_{13}\widetilde{\mathrm{H}}_1 + N_{14}\widetilde{\mathrm{H}}_2$$

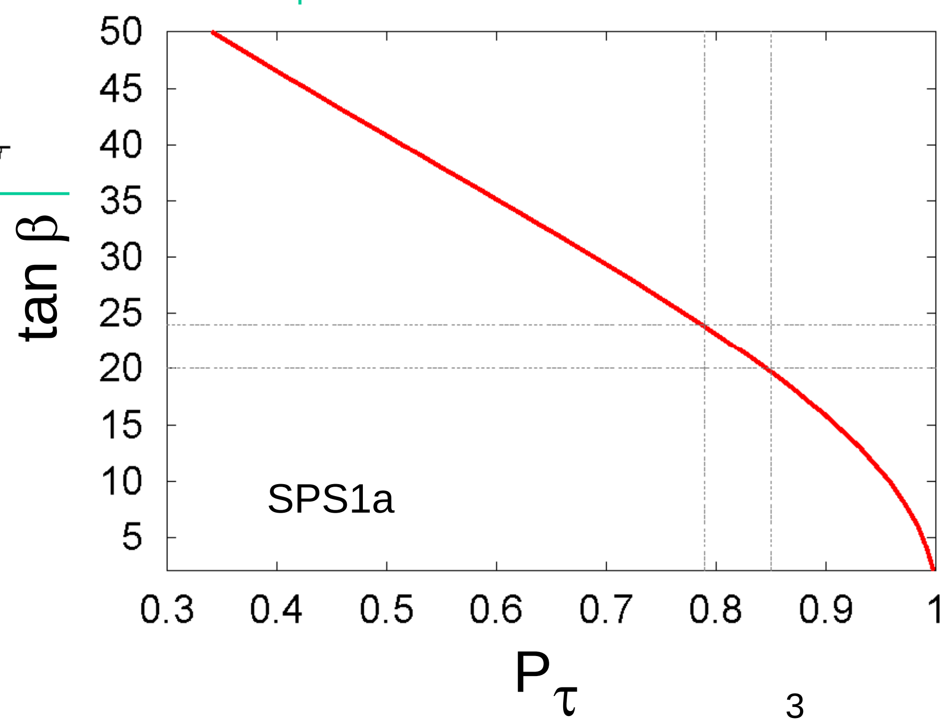
- mSUGRA: $\tilde{\chi}_1 \sim \widetilde{\mathrm{B}} \Rightarrow P_\tau \approx +1$
- non-universal SUGRA: $\tilde{\chi}_1 \sim \tilde{\mathrm{H}} \Rightarrow P_\tau \approx \cos^2\theta_\tau - \sin^2\theta_\tau$
- AMSB: $\tilde{\chi}_1 \sim \widetilde{\mathrm{W}} \Rightarrow P_\tau \approx -1$
- GMSB: $\tilde{\tau}_1^\pm \rightarrow \widetilde{\mathrm{G}}\tau^\pm \Rightarrow P_\tau \approx \sin^2\theta_\tau - \cos^2\theta_\tau$

References:

M. Nojiri, PRD 51 (1995)

E. Boos, et al, EPJC 30 (1993)

Godbole, Guchait, Roy, Phys Lett B (2005)



lessons from LEP

Precision electroweak measurements on the Z resonance. Phys.Rept.427:257,2006.

	$\tau \to \rho\nu$	$\tau \to \pi\nu$	$\tau \to e\nu\overline{\nu}$	$\tau \to \mu\nu\overline{\nu}$	$\tau \to a_1\nu$ $a_1 \to \pi^\pm\pi^+\pi^-$
Branching fraction	0.25	0.12	0.18	0.17	0.09
Maximum sensitivity:					
no 3D τ direction	0.49	0.58	0.22	0.22	0.45
with 3D τ direction	0.58	0.58	0.27	0.27	0.58
Normalised ideal weight:					
no 3D τ direction	0.44	0.30	0.06	0.06	0.13
with 3D τ direction	0.47	0.22	0.07	0.07	0.17

$\tau \to \rho\nu$ is most powerful

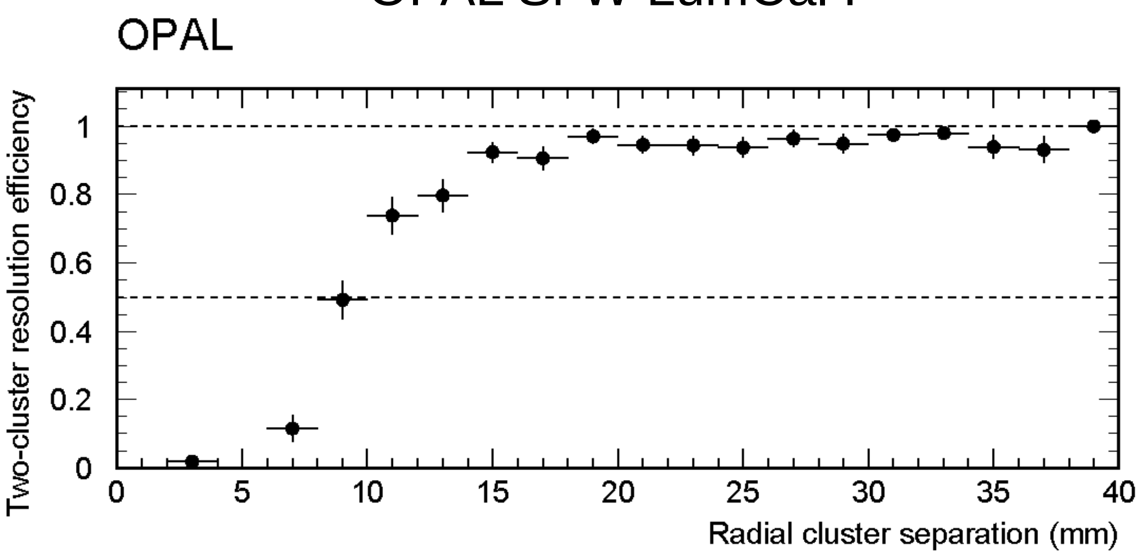
Need to separate:

- $\tau^+ \to \rho^+\nu \quad (\pi^+\pi^o\nu)$
- $\tau^+ \to \pi^+\nu \quad (\pi^+\nu)$
- $\tau^+ \to a_1{}^+\nu \quad (\pi^+\pi^+\pi^-\nu,\ \ \pi^+\pi^o\pi^o\nu)$

Segmentation requirement

- The above benefit from a highly segmented (in 3d) ECal
- In general, we wish to resolve photons in jets, tau decays, etc.
- The resolving power depends on Moliere radius and segmentation.
- We want segmentation significantly smaller than R_m – how *much* smaller is an open question

Two EM-shower separability in LEP data with the OPAL Si-W LumCal :



$$f_E \simeq \frac{R_{cal}}{\sqrt{R_M^2 + (4d_{pad})^2}}$$

$$d = 2.5\text{mm} \ , \ R_M \sim 17\text{mm}$$

Proposed technical solutions in SiD

A.) silicon/tungsten B.) silicon/tungsten

A) “traditional” silicon diodes with integrated readout

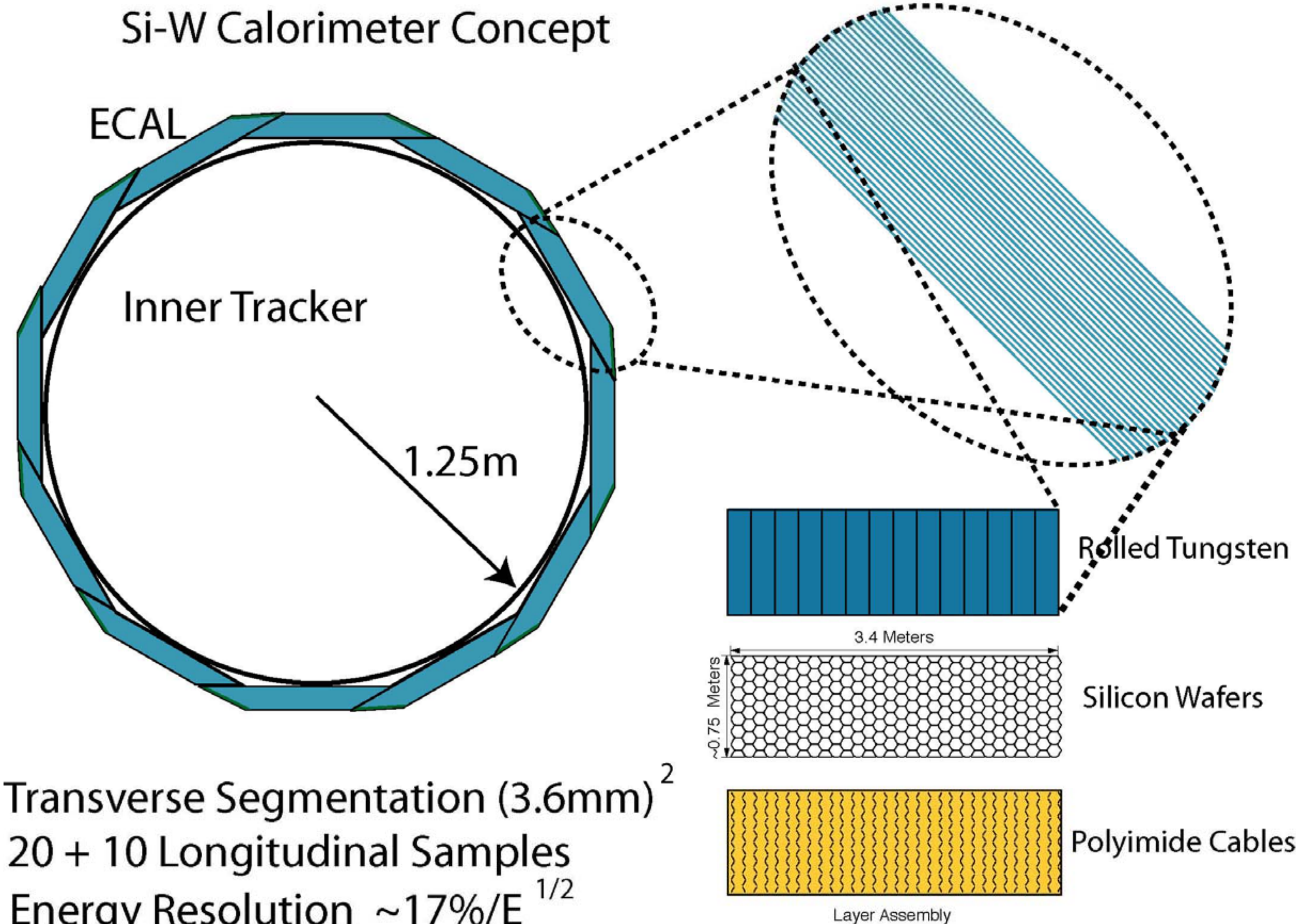
Transverse segmentation 3.5 mm (Moliere radius ≈13 mm)

B) MAPS active CMOS pixels (Terapixel option)

Transverse segmentation 0.05 mm (Moliere radius ≈13 mm)

Goal: The same mechanical design should accommodate either option

SiD Silicon-Tungsten ECal



Transverse Segmentation $(3.6\text{mm})^2$
20 + 10 Longitudinal Samples
Energy Resolution ~17%/$E^{1/2}$

<u>Baseline configuration:</u>

- longitudinal: (20 x 5/7 X_0) + (10 x 10/7 X_0) $\Rightarrow$ 17%/sqrt(E)
- 1 mm readout gaps $\Rightarrow$ 13 mm effective Moliere radius

Generic technical considerations

- Small readout gap
  - Maintains small Moliere radius, hence performance
  - Big impact on cost
  - ≈1 mm still looks feasible

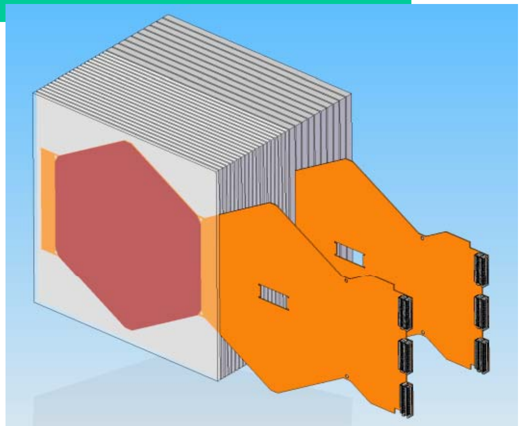
Config.	Radiation length	Molière Radius
100% W	3.5mm	9mm
92.5% W	3.9mm	10mm
+1mm gap	5.5mm	14mm

- Power cycling
  - Turn off power between beam trains

  ⇒ Passive cooling (highly desirable!)

  - for (A), passive conduction of 20 mW to module end (≈75 cm) via the tungsten radiator results in a few °C temperature increase ⇒ OK !
  - for (B), this is an open question

Si/W (A) R&D status overview



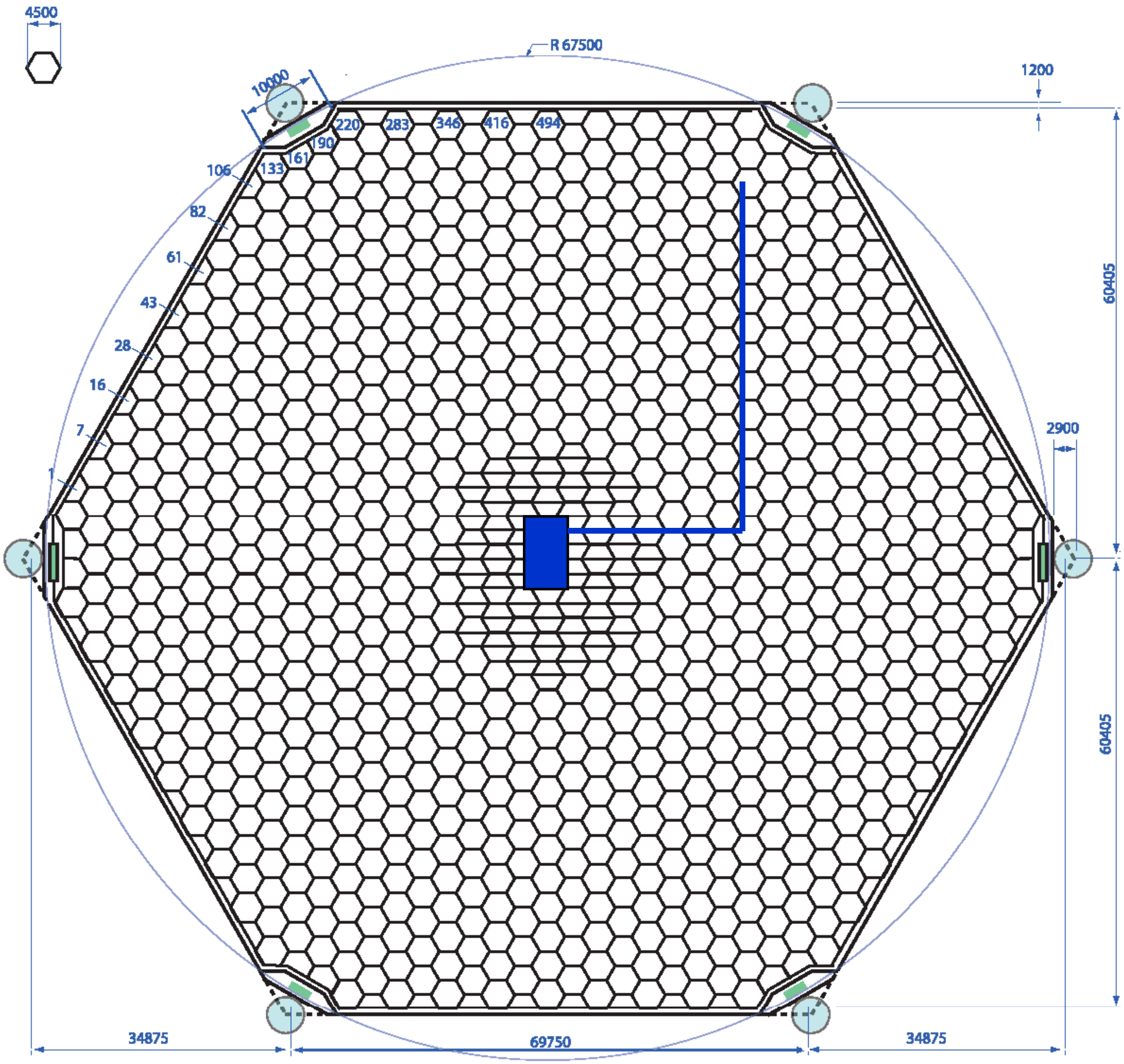
Goal: Produce full-depth (30 layers = 30 sensors) module for evaluation in a test beam using technology which would be viable in a real ILC detector.

- Require 1024-channel KPiX ASIC chips (Strom talk)
  - Evaluating 64-chan prototypes (KPiX-6 is latest)
    - Noise is OK for Ecal, but not understood to our satisfaction
  - Has been the critical-path item
- Silicon sensors
  - v1 evaluated successfully
  - v2 on order – expect to have 40 ~ Mar 08
- Bonding of KPiX to Si sensors
  - First trials completed (gold bump-bonds)
- Tungsten – in hand
- Readout cables – short kapton cables OK
- Module mechanics and electromechanical - serious work starting
- DAQ

Si/W (A) R&D Collaboration

Collaborators	Responsibilities
M. Breidenbach, D. Freytag, N. Graf, R. Herbst, G. Haller, J. Jaros *Stanford Linear Accelerator Center*	• KPiX readout chip • downstream readout • mechanical design and integration
J. Brau, R. Frey, D. Strom, Barrett Hafner (ug), Andreas Reinsch (g) *U. Oregon*	• detector development • readout electronics
V. Radeka *Brookhaven National Lab*	• readout electronics
B. Holbrook, R. Lander, M. Tripathi *UC Davis*	• cable development • bump bonding
S. Adloff, F. Cadoux, J. Jacquemier, Y. Karyotakis *LAPP Annecy*	• mechanical design and integration

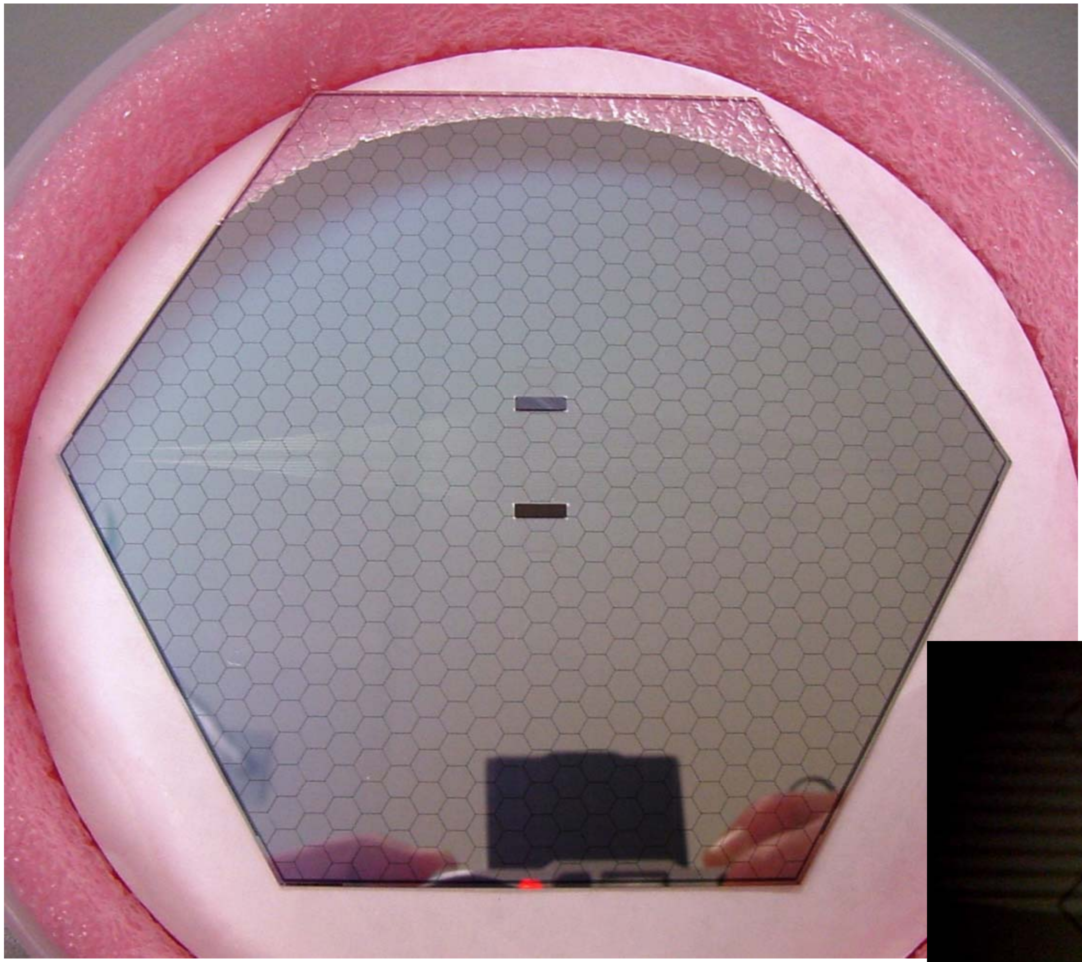
v2 Si sensor – for test beam module



- 6 inch wafer
- 1024 13 mm^2 pixels
- improved trace layout near KPiX to reduce capacitance
- procurement in progress, 40 sensors, Hamamatsu

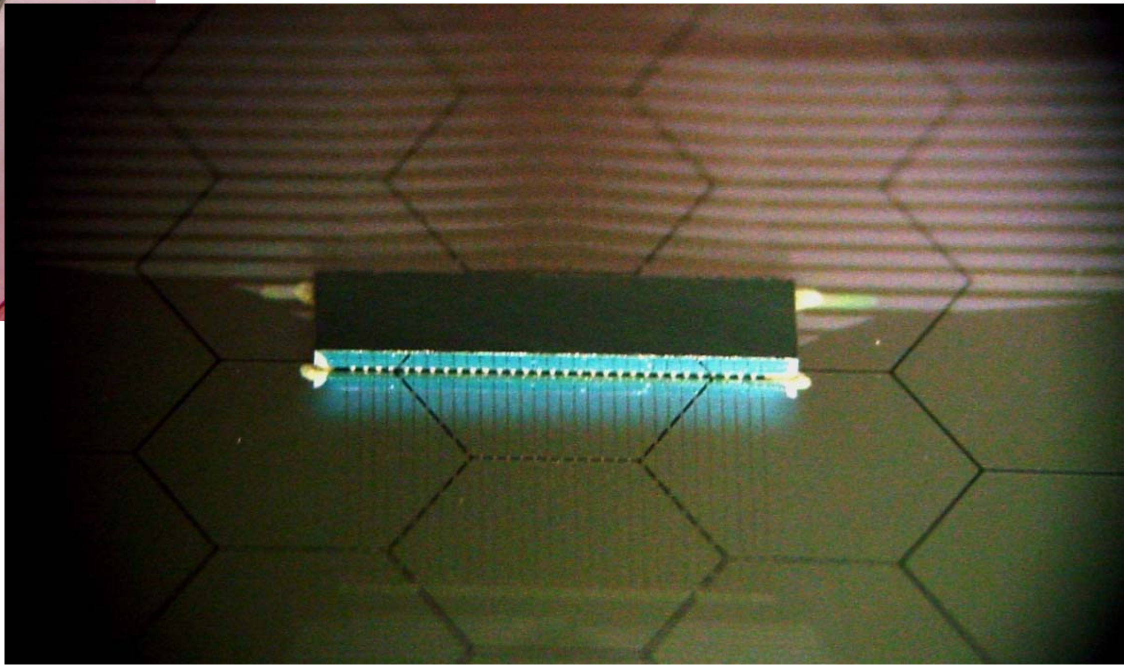
KPiX ASIC and sample trace

KPiX-v6 gold-stud bonded to v1 sensors
UC Davis group, Jan 08



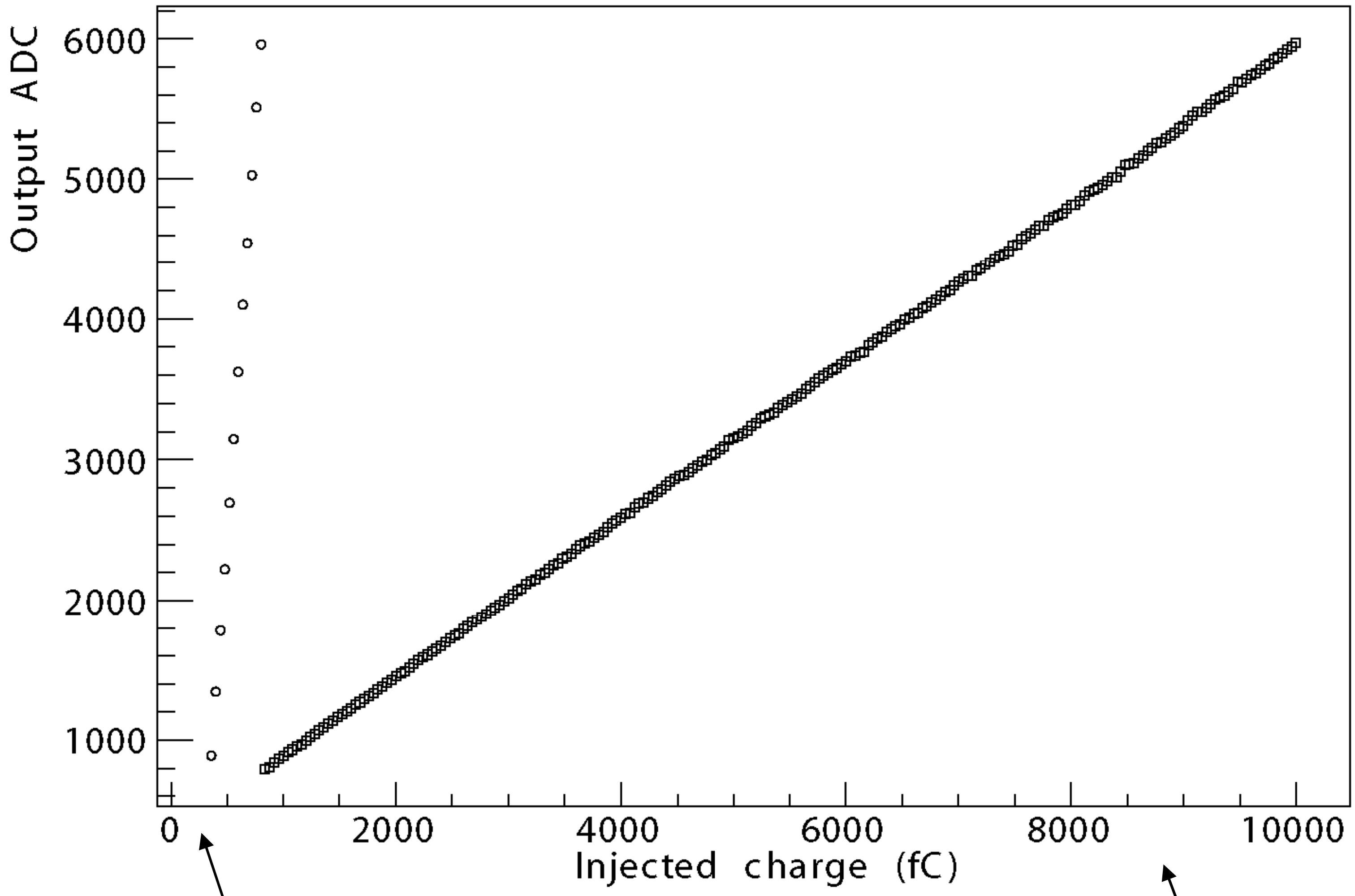
Initial test results (1/25/08, UO) of first attempt (Palomar Tech.):

one open / 24 connections tested



KPiX dynamic range

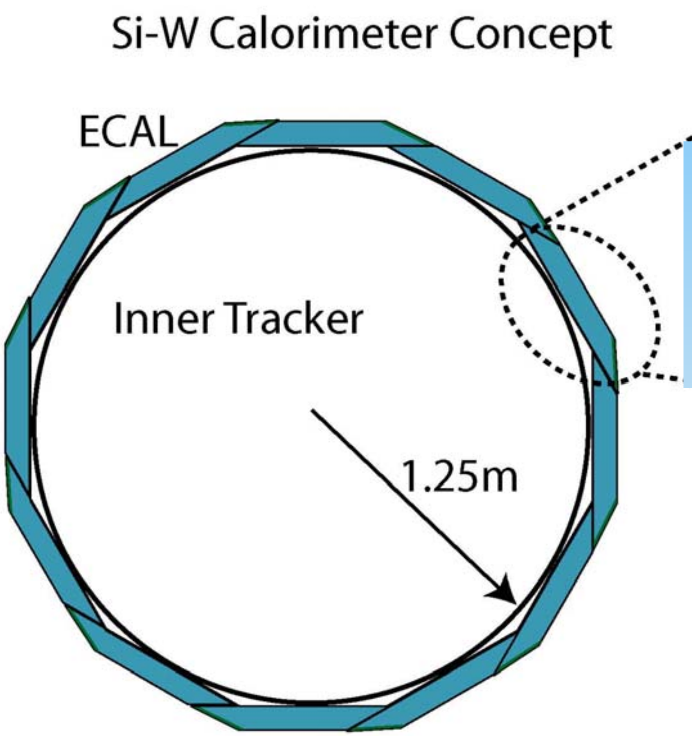
KPiX prototype on the test bench

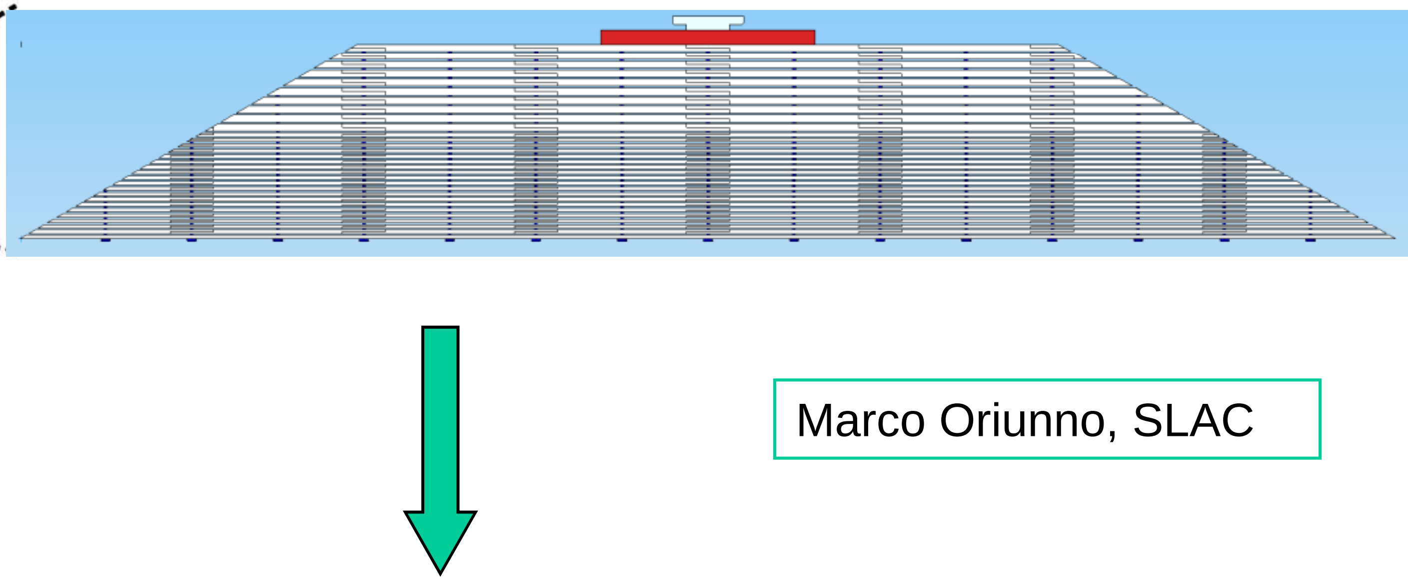


1 MIP (4 fC)

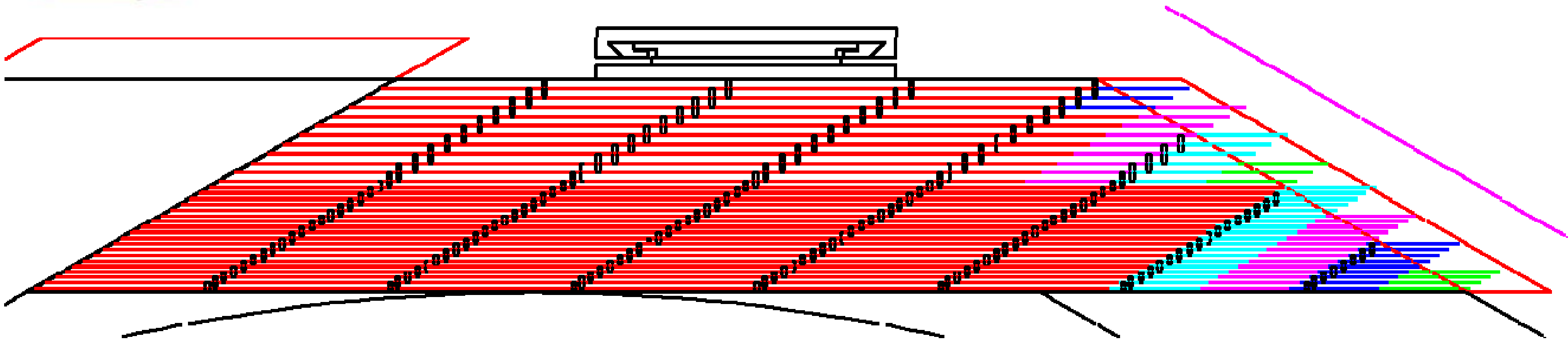
Max signal: 500 GeV electron

Towards a mechanical design…





Marco Oriunno, SLAC



Only 2 Si sensor mask-sets required

DoE review (A) – 6/07

The US effort is focused on silicon-tungsten calorimetry with KPiX (1k pixels per si sensor) readout of 1024 channels of few millimeter-sized hexagonal pixels. This program is well conceived with strong groups participating. There are many challenges to overcome, and there is a need to demonstrate solutions with beam and bench tests. The bump bonding techniques must be proven to be sufficiently robust. The layout and test of the signal traces to the KPiX must be shown to give adequate signal to noise. The KPiX design has not yet converged and demonstrated scalability to a fully operational 1024 channel chip. A calibration strategy using 241Am sources is defined, but as yet untested at the 1% channel-to-channel level using realistic readout electronics; exploration of alternate schemes would be useful. The planned tests of a module are crucial. The group is aware of all these issues, and the proof of concept for the Si-W calorimetry remains a high priority of the R&D program.

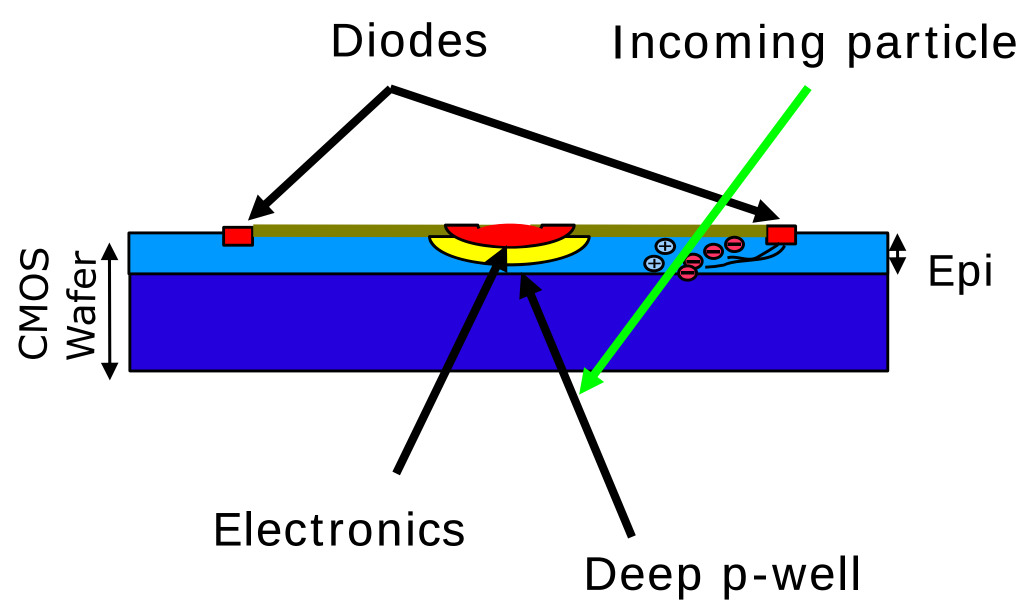
B.) MAPS (Terapixel) Si/W

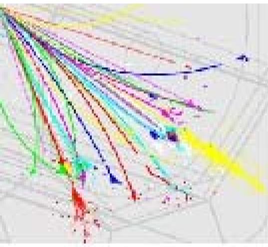
The MAPS ECAL

Y. Mikami, O. Miller, V. Rajovic, N.K. Watson, J.A. Wilson
University of Birmingham
J.A. Ballin, P.D. Dauncey, A.-M. Magnan, M. Noy
Imperial College London
J.P. Crooks, M. Stanitzki, K.D. Stefanov, R. Turchetta, M. Tyndel, E.G. Villani
Rutherford Appleton Laboratory

What are MAPS ?

- **M**onolithic **A**ctive **P**ixel **S**ensor
- Integration of Sensor and Readout Electronics
- Manufactured in Standard CMOS process
- Collects charge mainly by diffusion
- Development started in the mid-nineties, now a mature technology

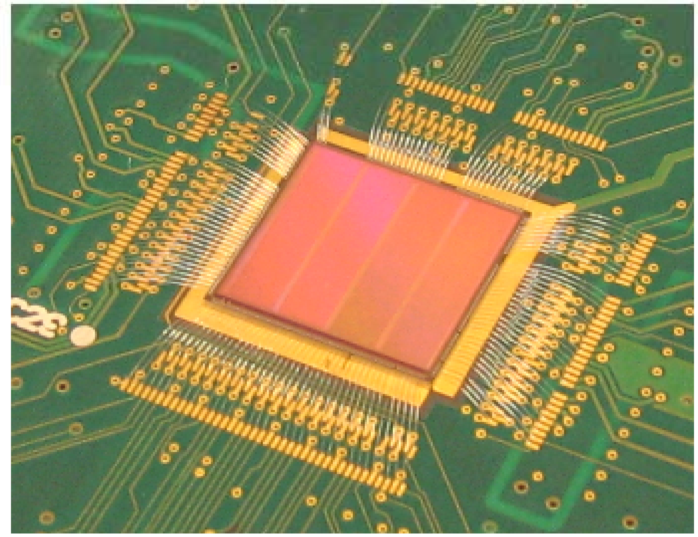




The Chip - Specifications

- 50x50 micron cell size
- Binary Readout (1 bit ADC)
- 4 Diodes for Charge Collection
- Time Stamping with 13 bits (8192 bunches)
- Hit buffering for entire bunch train
- Capability to mask individual pixels
- Threshold adjustment for each pixel

⇒ Usage of INMAPS (deep-p well) process

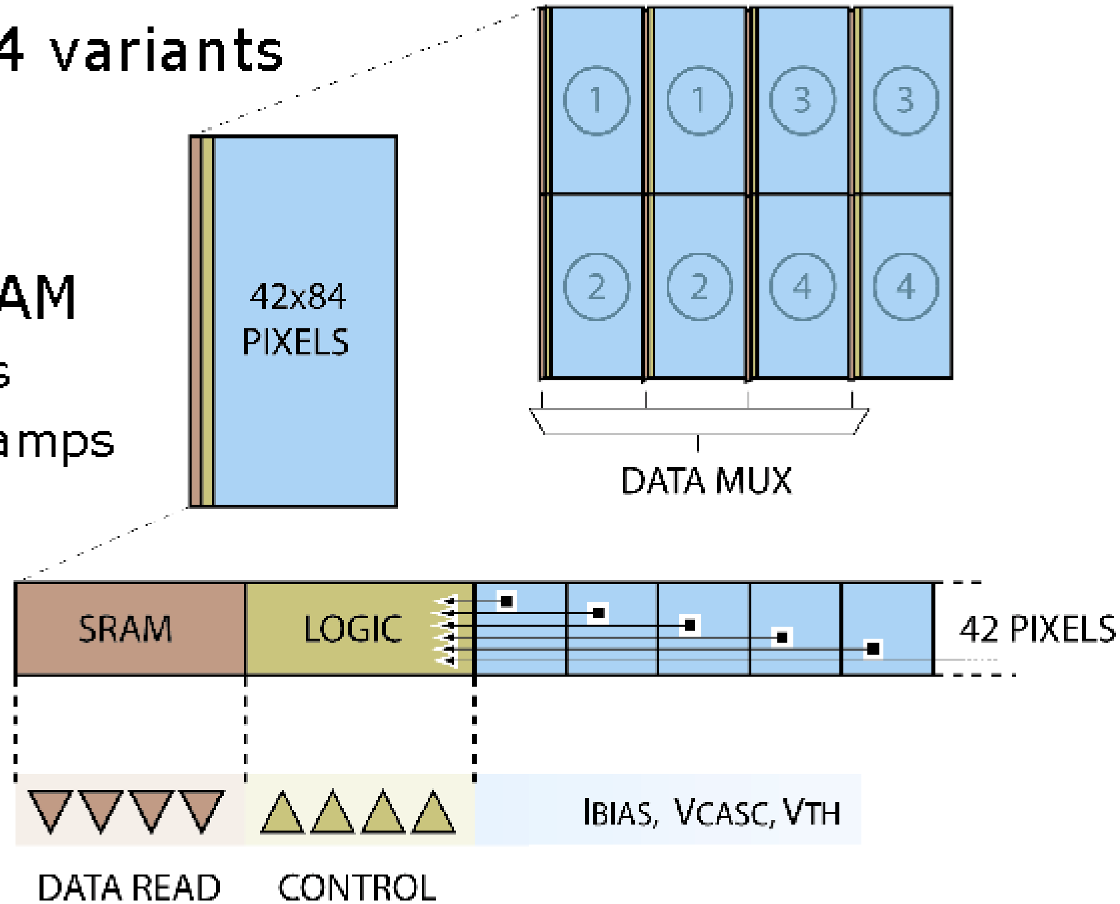


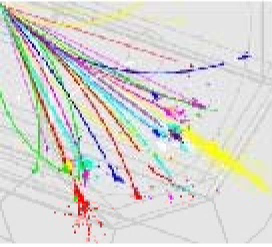
The Chip : TPAC1 (ASIC1)

- 8.2 million transistors
- 28224 pixels; 50 microns; 4 variants
- Sensitive area 79.4mm²

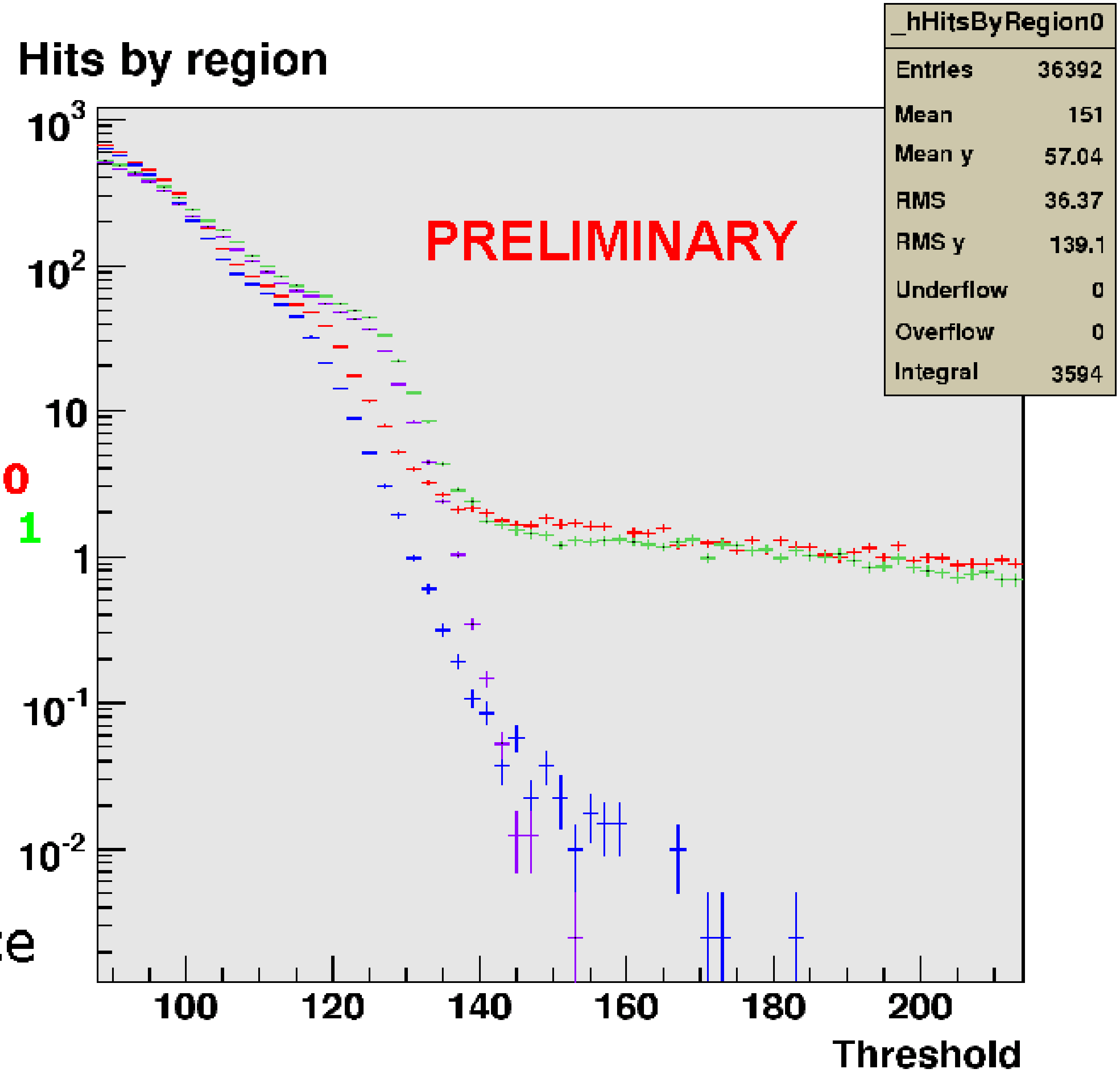
- Four columns of logic + SRAM
  - Logic columns serve 42 pixels
  - Record hit locations & timestamps
  - Local SRAM

- Data readout
  - Slow (<5 MHz)
  - Current sense amplifiers
  - Column multiplex
  - 30 bit parallel data output



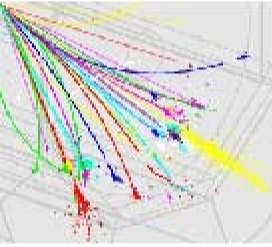


Threshold scan



red - with source, region 0
green - with source, region 1
blue - no source, region 0
purple - no source, region 1

Made using a β source



Plans

(from Nov 07)

- Calibrations / Gain measurements
- Test beam at DESY (10 days)
  - All effort focusing on this right now
- Power measurements
  - Also try power pulsing
  - The chip is up for it
- Detailed charge collection studies
  - Deep p-well
  - Epi-thickness
- Design a second chip !

This happened !
No results yet.

??!!

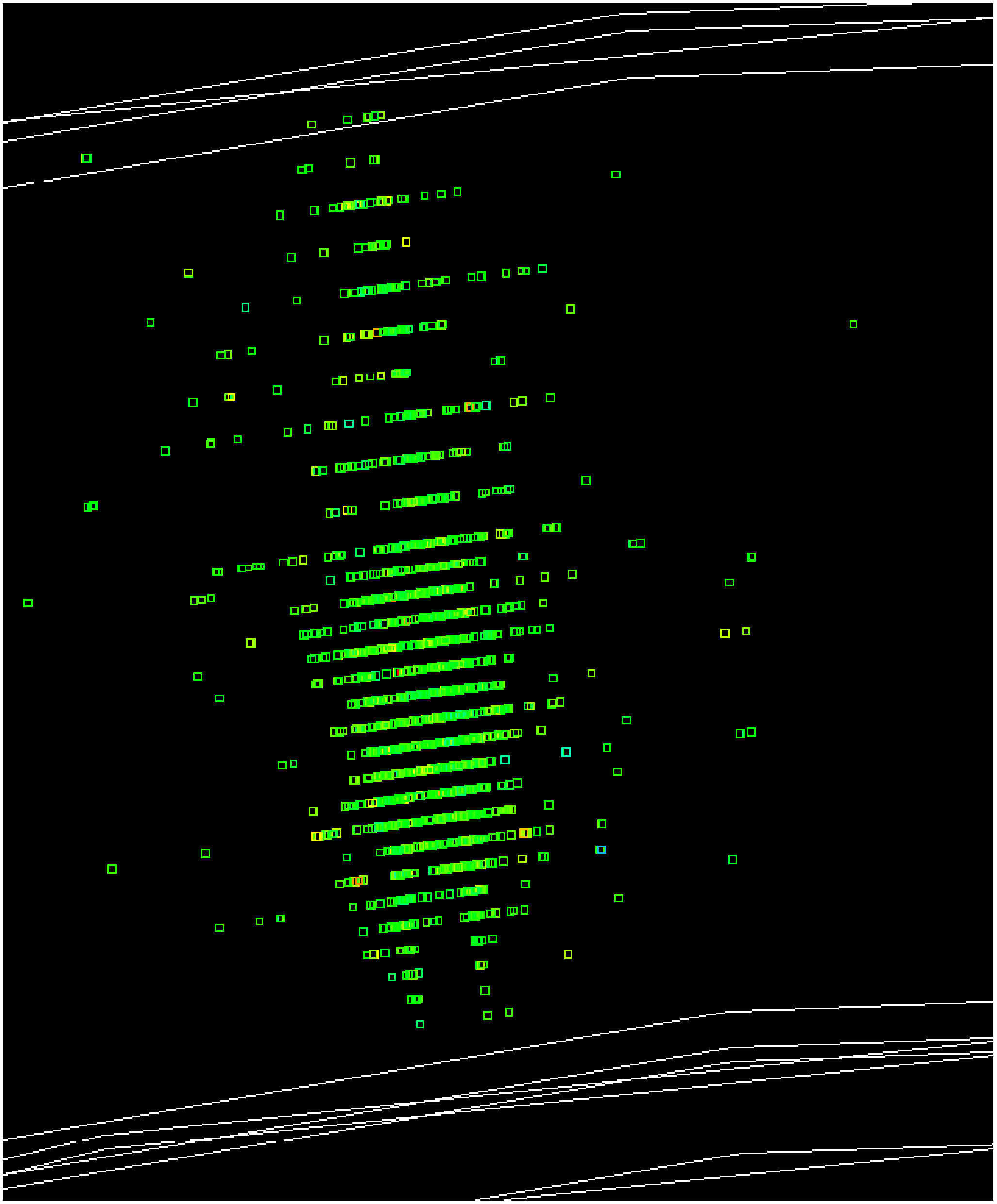
Circa Nov 2007: The path to the LOI

- Technology choice
  - MAPS terapixel still needs to be proven as a viable ECal technology
  - Si diode/W ECal technology is well established for relatively small calorimeters. But the integrated electronics needs to come together.
  - What does the physics say? Is there a physics case for segmentation<< R_m ? Perhaps. The case needs to be made and weighed against the risks.

  - Suggestion: Make Si diodes the default, but continue the R&D and studies for terapixel. Attempt to make an ECal mechanical structure which can accommodate either without important compromise.

- We need to do a lot of work to solidify and amplify the physics case for the LOI -- simulation studies at all levels.

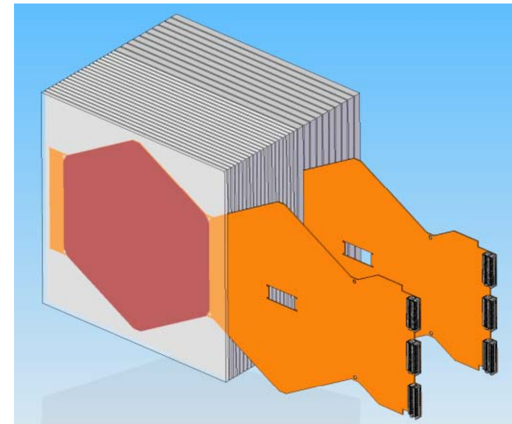
Do we need < few mm segmentation?



- EM showers are narrower than R_m for the first few radiation lengths.
- π° id and reconstruction are important, perhaps crucial:
  - Jet resolution
  - Tau id and analysis
  - Flavor tagging ??
- A few layers of MAPS ??
  - This avoids saturating the MAPS pixels at shower max.

- MAPS for the inner endcap? Forward tracking? ??

Post December 07: the path forward…



December 07 disasters… now what??

The short answer: Continue as best possible

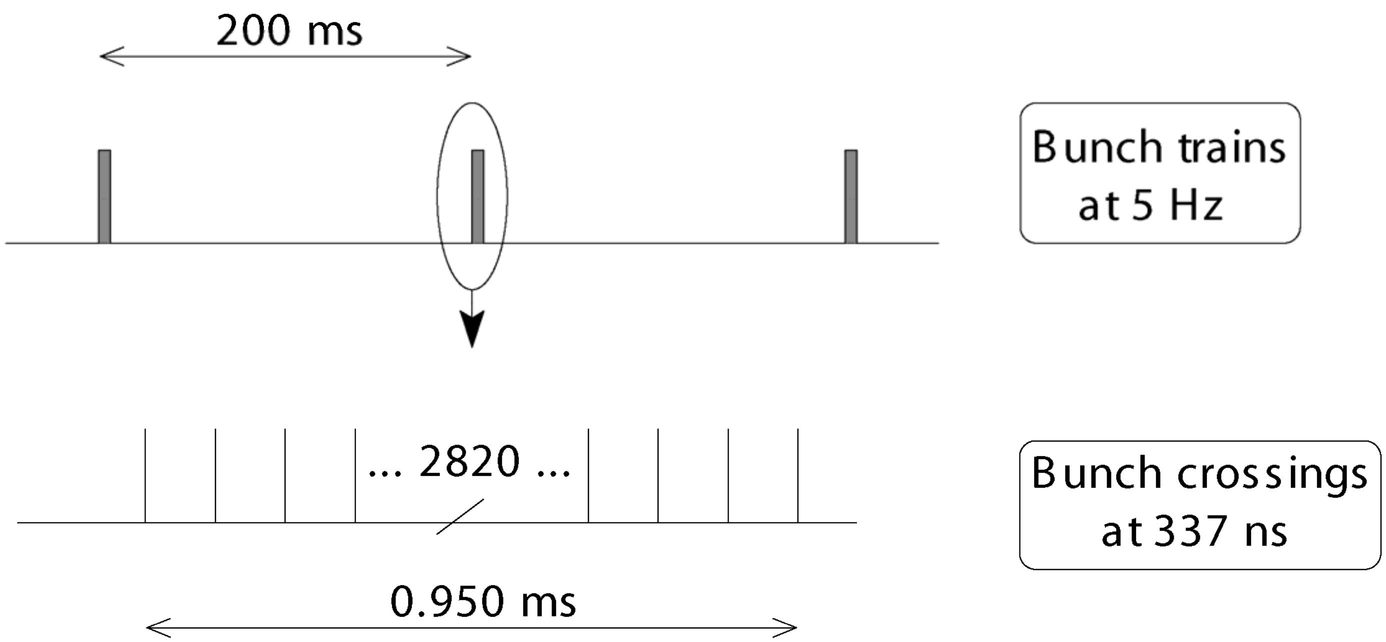
- For option (A): Try to complete the R&D – to make a test beam module with ILC-ready technology
  - UO/Davis apparently out of funding summer 08
  - Not yet clear what form the KPiX chip will take
  - Message from DoE: go "generic" ? warm/cold compatible?

ilc $\longrightarrow$ $\boxed{\sqrt{-1}\,LC}$??

- For option (B): Taking stock. No new chip prototypes??

Beam crossing time structure

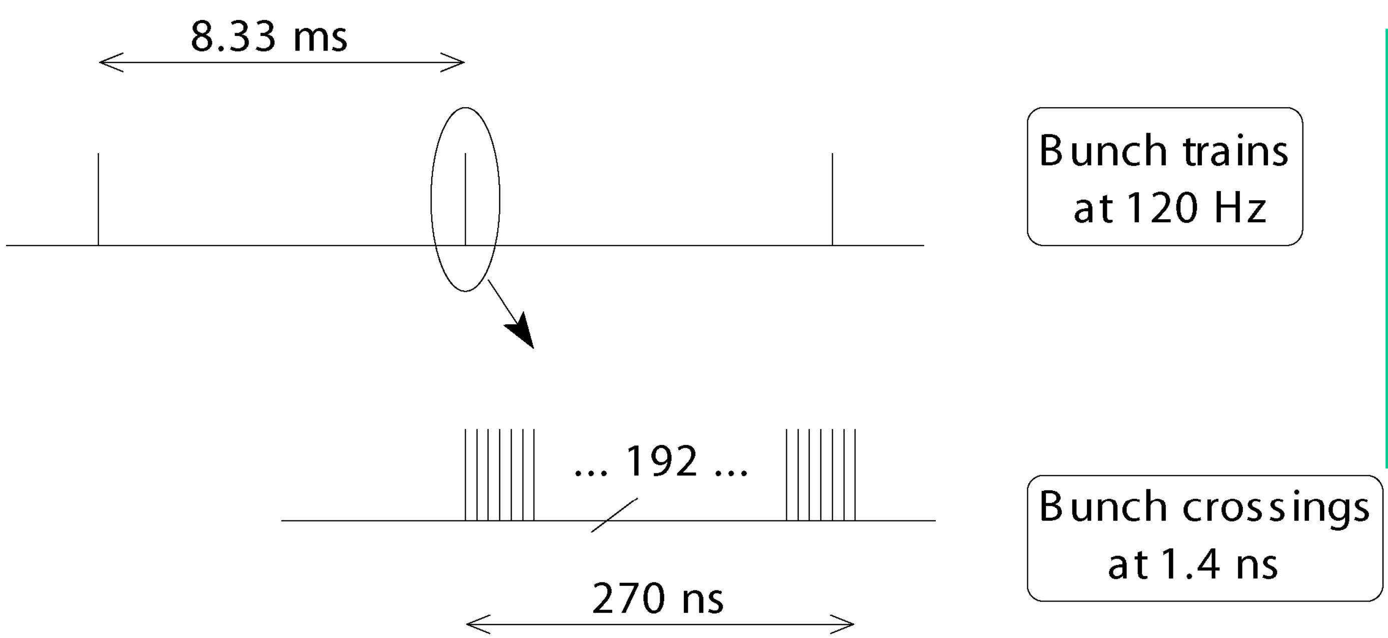
Cold



- Fast readouts: OK, no pileup
- pipeline
- bx live: 5×10^{-3}

$\Rightarrow$ power pulse

Warm



- Pileup over bunch train
- Or fast timing
- bx live: 3×10^{-5}

$\Rightarrow$ power pulse

Summary

- The silicon/tungsten approach for the SiD ECal still looks good.
- We think it can meet the LC physics and technical challenges.
- Two technical approaches:
  - Baseline: Si diode sensors with integrated (KPiX) electronics
  - MAPS (terapixel) – completely integrated
- There has been good, steady progress.

- The recent political choices in the U.S. and U.K. have thrown a monkey wrench in the works.
- We are “taking stock” of the situation, but vow to press on to the extent possible.