Electromagnetic calorimeters at Lepton Colliders

R. Frey, U. Oregon

- To understand possible synergies to MuC, should understand what has driven the design of current LC detectors

- The current ECal designs for ILC (and CLIC)
- What about the physics drives the designs ?
- What about the LC environment drives the designs ?

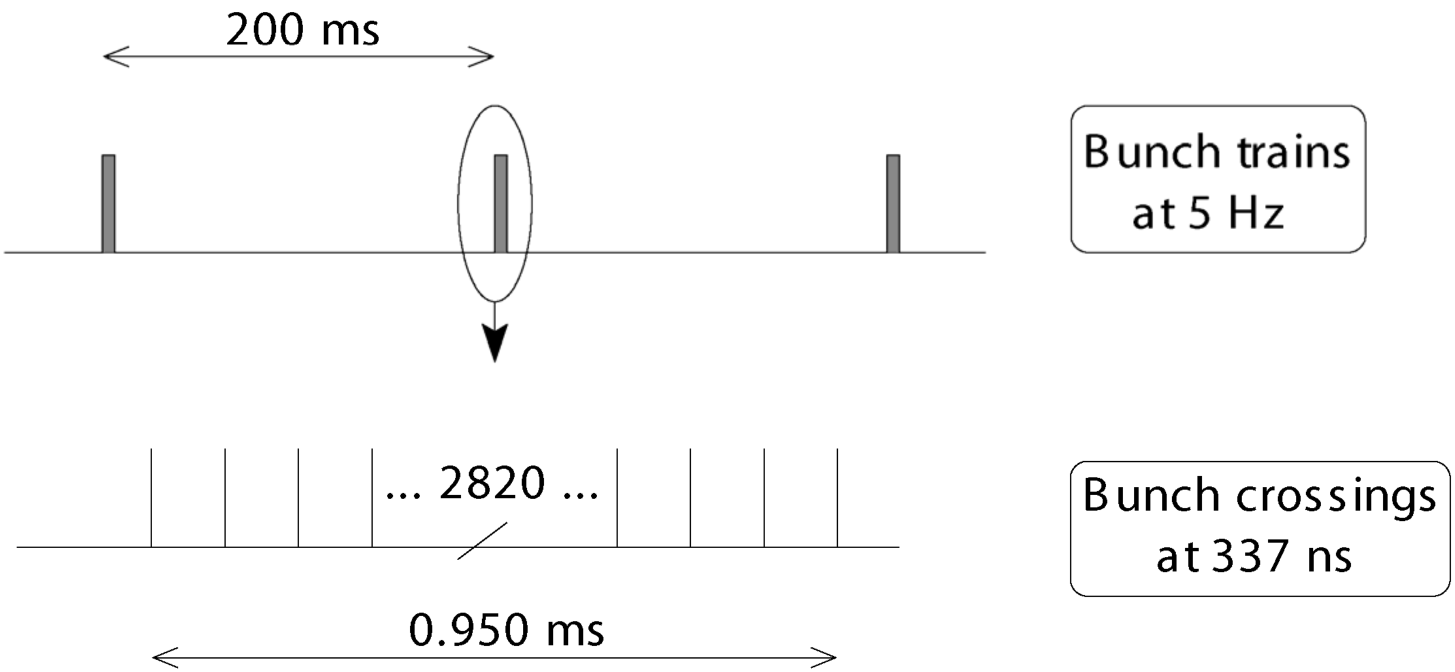
- What aspects of LC designs can be carried over to the MuC ?
- What handles do we have to perhaps take an ECal from ILC → MuC ?
  - Granularity
  - Timing
  - Absorption

The LC ECal efforts

- R&D programs
  - CALICE
  - Misc others, e.g. LCDRD
- ILC detector concepts
  - ILD
    - Silicon/tungsten
    - Scintillator/tungsten
  - SiD
    - Silicon/tungsten
    - MAPS/tungsten
    - [totally absorbing crystals – combined ECAL+HCal - not discussed here]
- CLIC
  - ILD’
  - SiD’

ILC environment

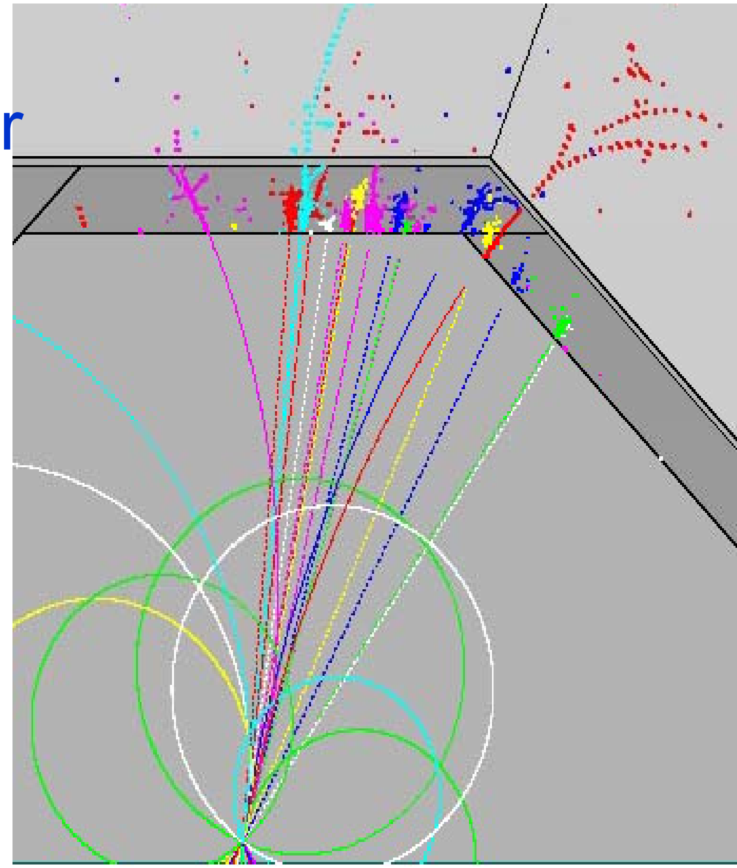
ILC
(SC RF)



- Cross section is small ⇒ 0 or 1 event per bunch crossing
  - Beam backgrounds "large" but rather benign (pairs swept forward)
  - Soft 2-photon events with larger cross section
  - Little or no radiation damage
- All events are interesting ⇒ no trigger (record everything)
- Long time between bunch trains ⇒ turn off (most) power in FE
  - Can use passive cooling ⇒ little dead material

LC ECal design criteria

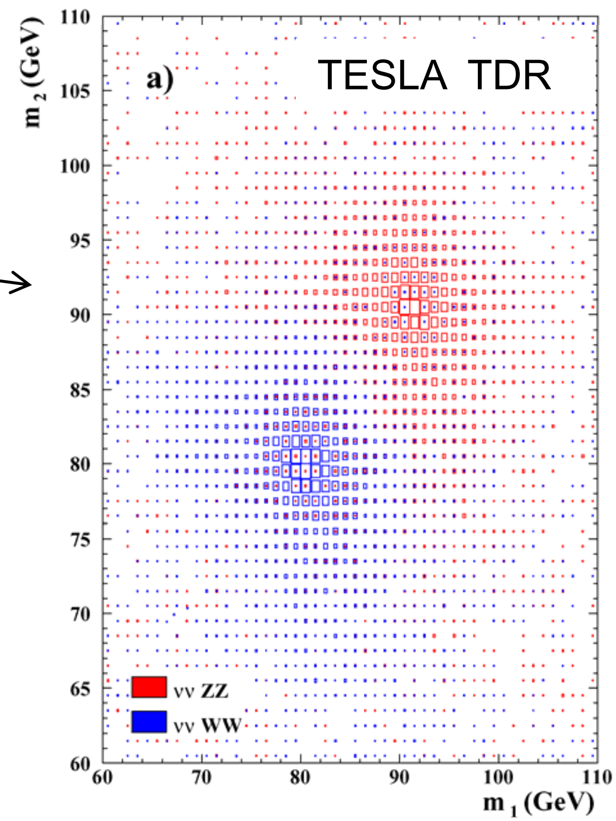
- Many (I)LC measurements are limited more by the detectors, not by the collider environment.
- LC detectors should aim to measure ***all*** final states and measure with precision. For calorimeters:
  - Multi-jet final states
    - With or without beam constraint
  - Leptons (*including* tau)
  - Missing energy/mass



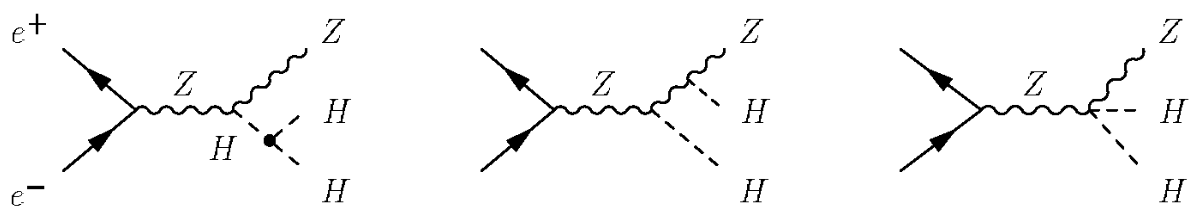
- PFA scheme: use calorimeters to separate particle types ⇒ imaging calorimeters
  - Excellent granularity in 3-d
  - ECal: Modest EM energy resolution $< 0.2/\sqrt{E}$
  - Get ~3% jet energy resolution

(some) implications of excellent jet measurement

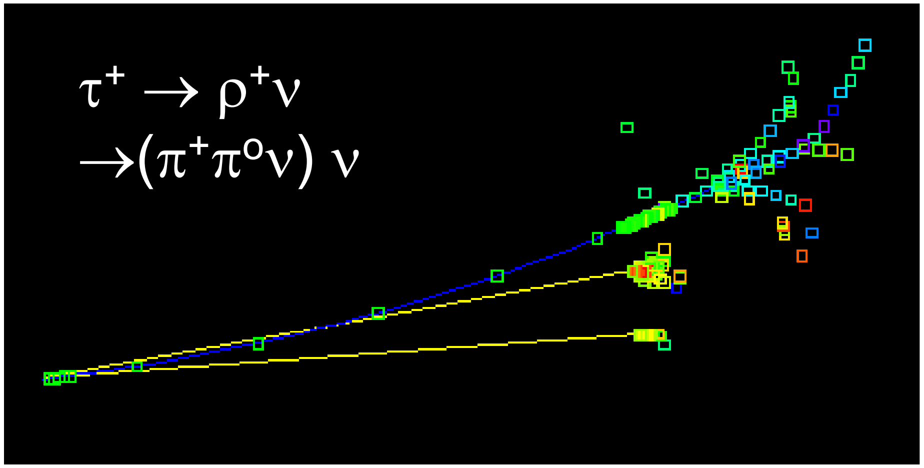
• multi-jet masses in the absence of beam constraints, e.g. $\nu\nu$WW vs $\nu\nu$ZZ, W/Z $\rightarrow$ jets



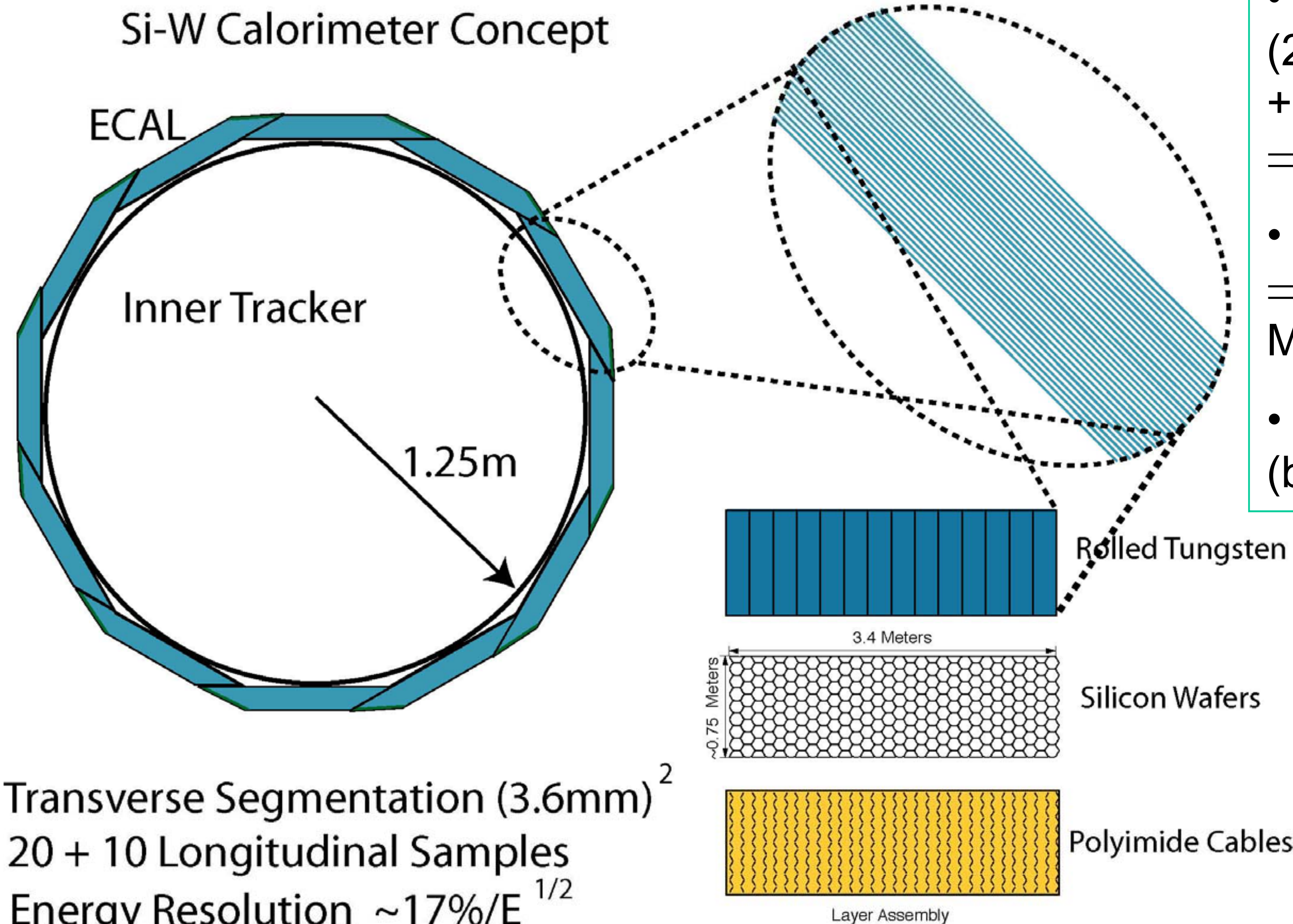
• reducing combinations with intermediate jet masses, e.g. ZHH $\rightarrow$ jets



• segmented, imaging calorimeters open up new measurements, e.g. tau id and polarization; non-pointing photons (GMSB)



e.g. SiD Baseline Silicon-Tungsten ECal



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

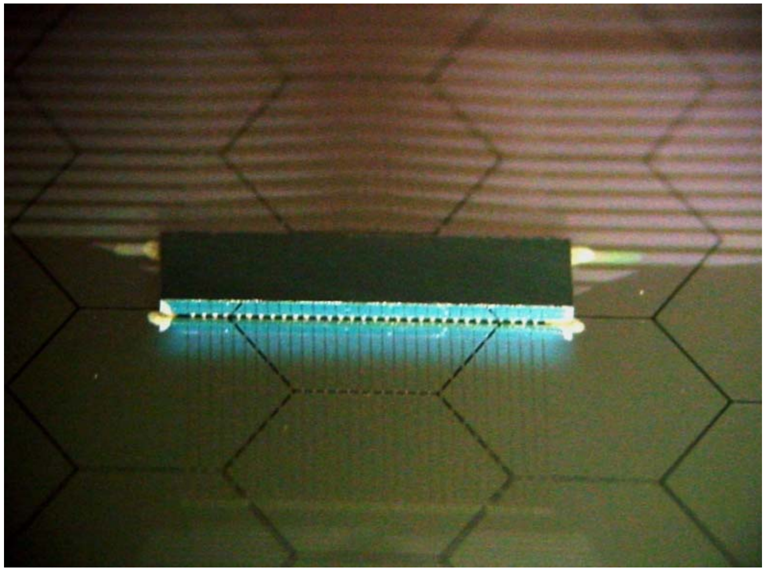
- longitudinal: (20 layers x 5/7 X_0) + (10 layers x 10/7 X_0) $\Rightarrow$ 17%/sqrt(E)
- 1 mm readout gaps $\Rightarrow$ 13 mm effective Moliere radius
- 13 mm^2 pixels (baseline)

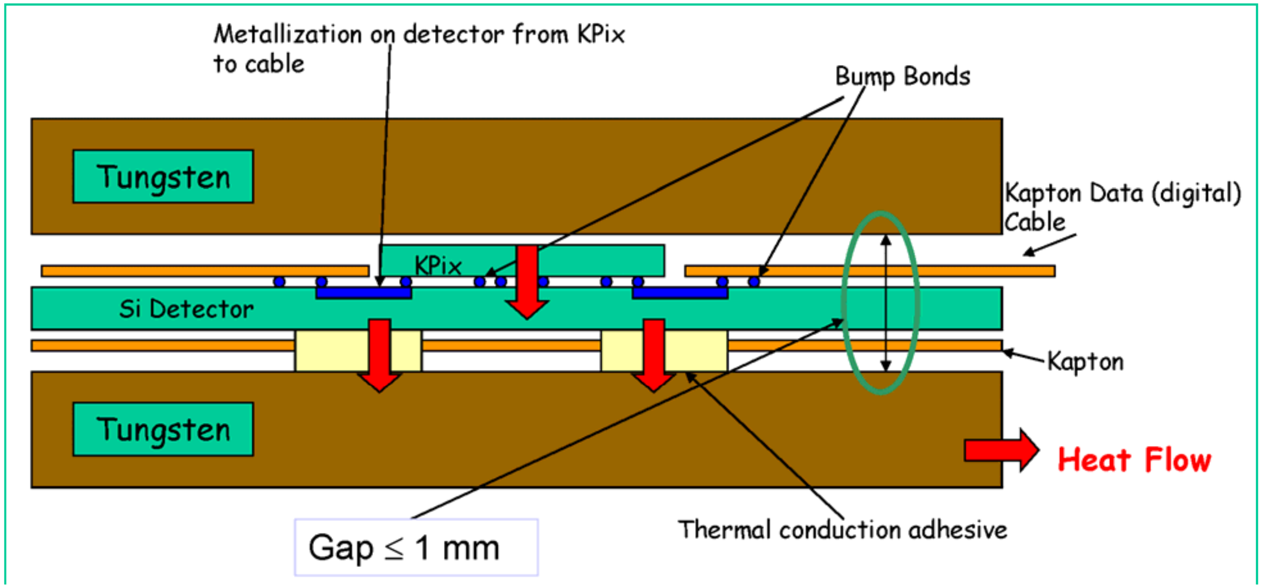
Some design details

- Silicon sensors are thin (300 um) and easily segmented (pixels)
- LC beam timing (allows power pulsing) → passive cooling
- Small Moliere radius → tungsten ⇒ very dense EM showers

⇒

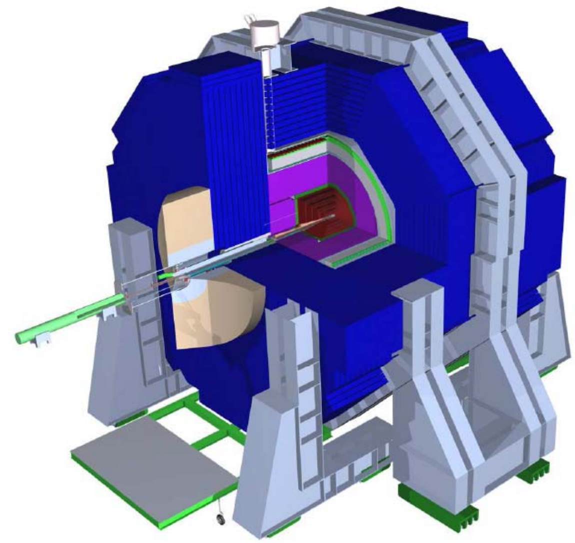
- Small readout gap (1 mm) → preserves tungsten Moliere radius
- Highly integrated readout
  - One chip digitizes all 1024 pixels on a 15 cm sensor
  - MIPs to dense EM showers ⇒ dynamic range of ~2000
  - Requires sensor – readout chip interconnects (e.g. bump bonding)
  - Heat load is ~10 mW per sensor (with power pulsing!)



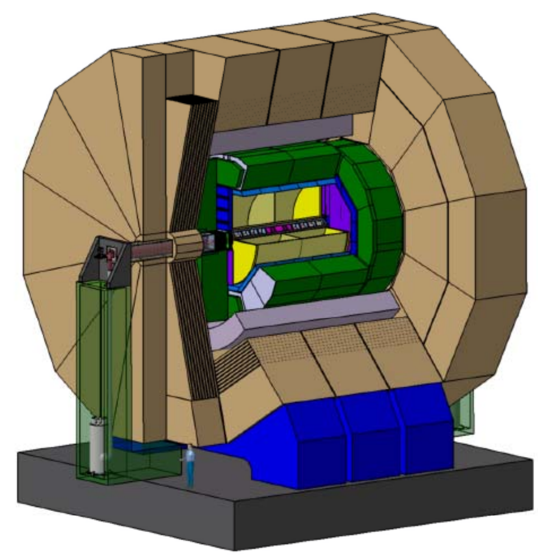


Current ILC ECal status

- The SiD baseline: Si-W (discussed in previous slides)
- The SiD alternative: MAPS → more in a minute

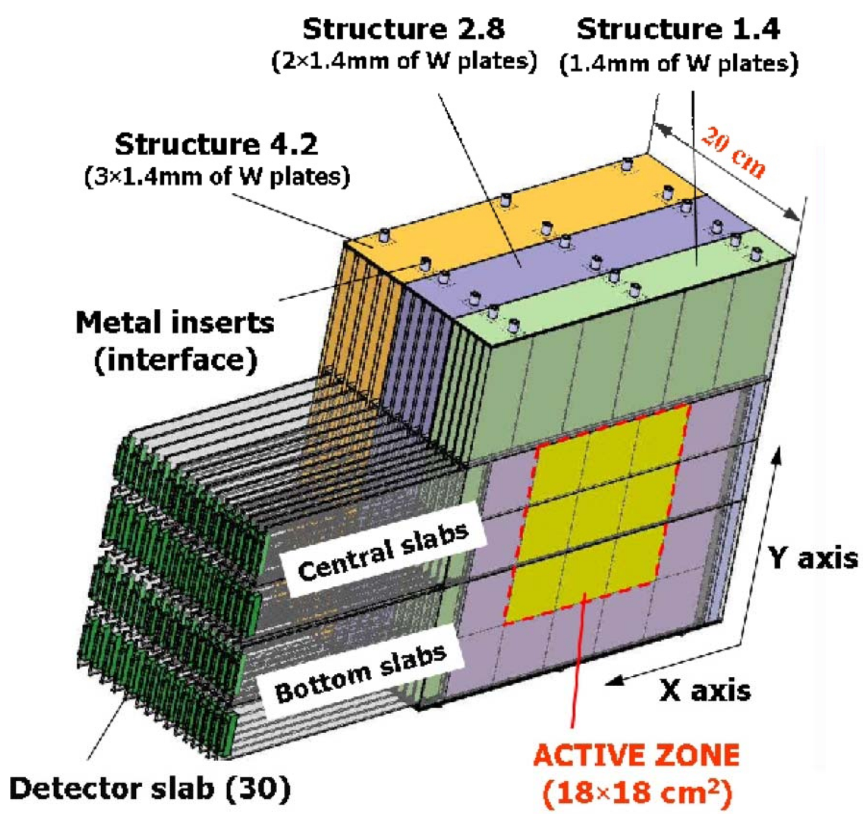


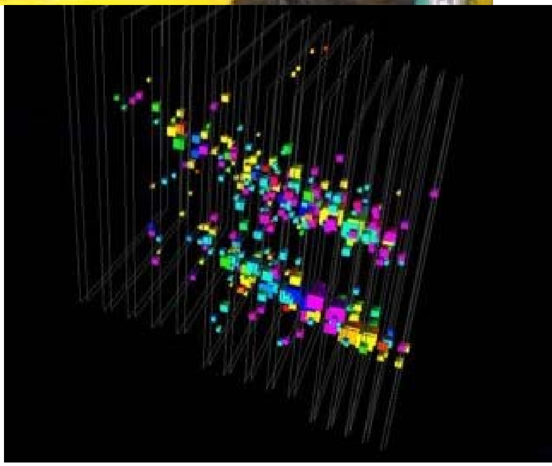
- ILD baseline: Si-W
  - Layout is similar to SiD (at larger radius, coarser granularity)
  - Much experience from CALICE efforts (next slides)
- The ILD alternative: scintillator-W (not discussed here)



CALICE Si-W "physics prototype"

~330 physicists/engineers from 57 institutes and 17 countries from 4 continents



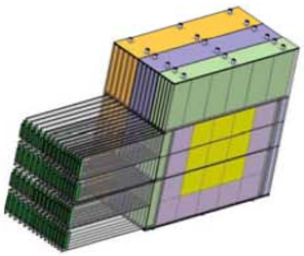


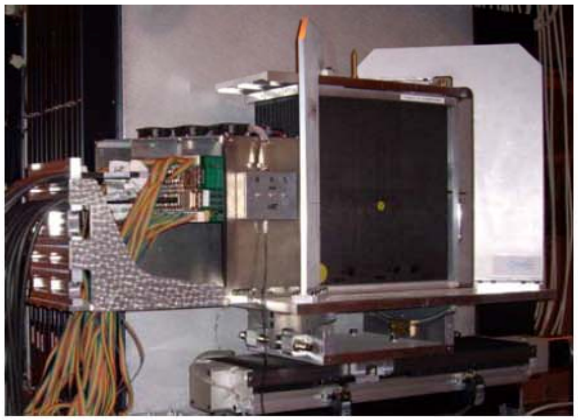
- 1 cm^2 pixels; readout and configuration not intended for a real ILC ECal
- 3 beam campaigns, 2006-8, DESY, CERN, FNAL
- Lots of nice results (and good experience)

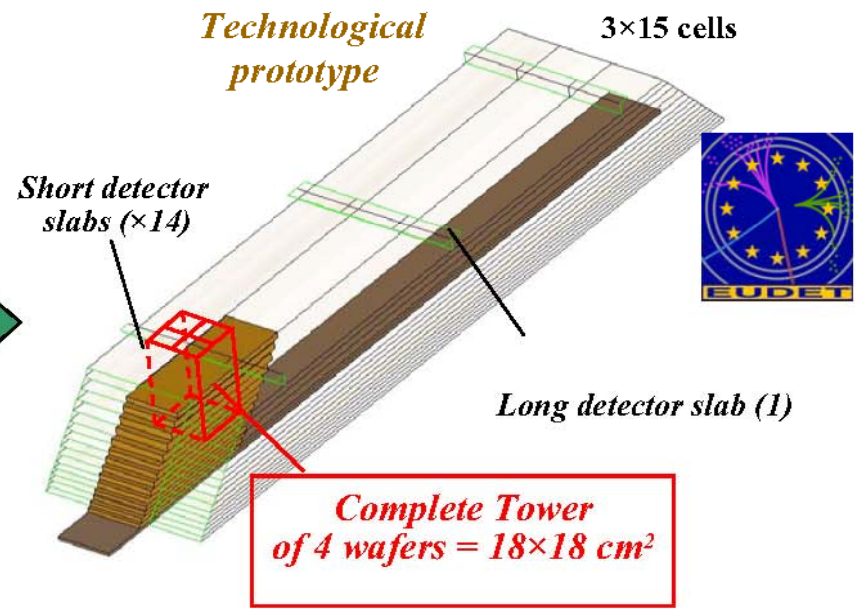
R. Pöschl
ALCPG, Eugene

Technological Prototype

Technical solutions for the/a final detector



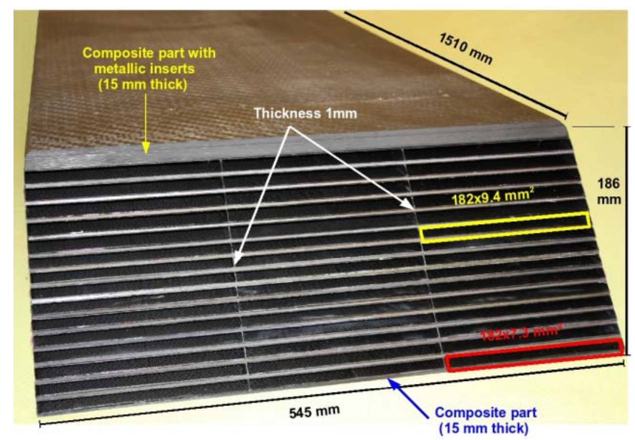




- Realistic dimensions

- Integrated front end electronics

- Small power consumption
  Power pulsed electronics



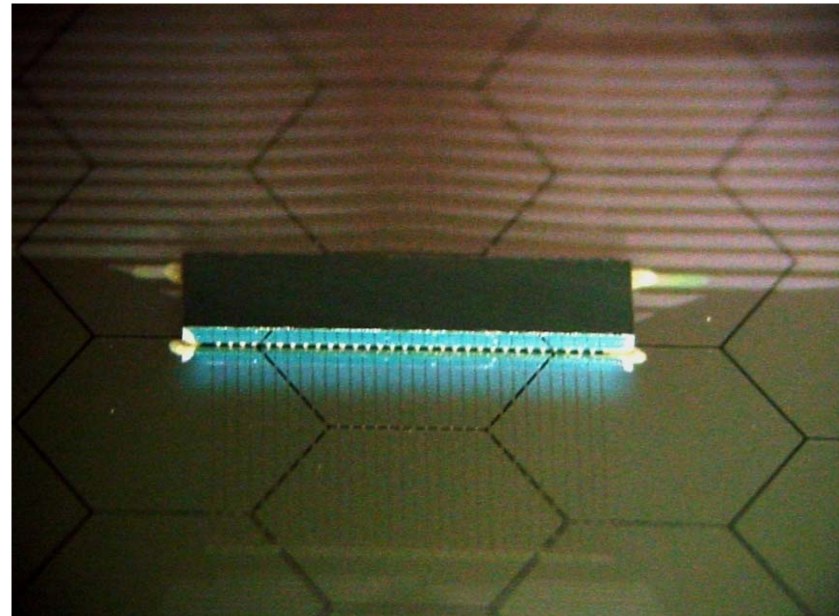
- Construction 2010 – 2012, Testbeams 2012-2013

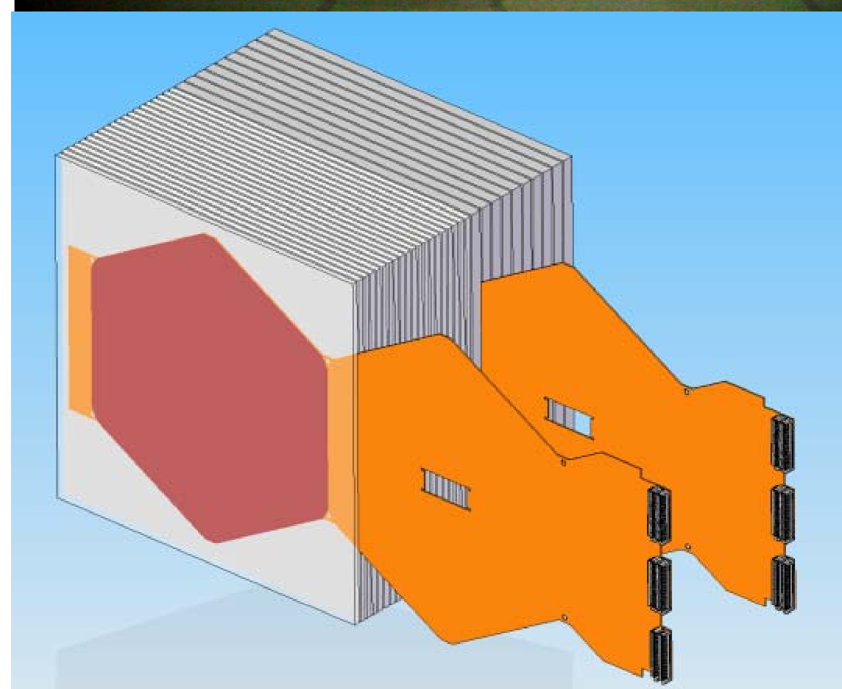
SiD Si-W status

- Our strategy was to skip the "physics prototype" stage, and move directly to technologies which could be inserted into an LC.

- Recently received the 1024-channel readout chip (KPiX)

- Finalizing interconnects
- Hope to have a 30-layer deep, one sensor wide stack fabricated by Fall
- Current plan is to test in the newly re-established SLAC ESTA beamline (late 2011 – early 2012).





LC → MuC ?

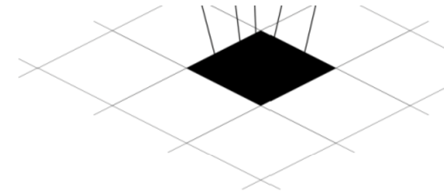
- I understand that, broadly speaking, detector goals of MuC ~ LC
- So let's postulate that one might wish to think about a MuC ECal which is *similar* to an ILC ECal
- However, one must deal with large backgrounds.

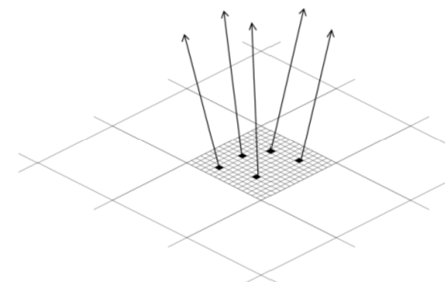
Some possibilities for amelioration…

- (increased) granularity
  - With minor modification, current SiD scheme could go from pixels of 12 mm^2 → few mm^2
  - But perhaps we need to go much smaller (?)…
- Good timing
- Filtering

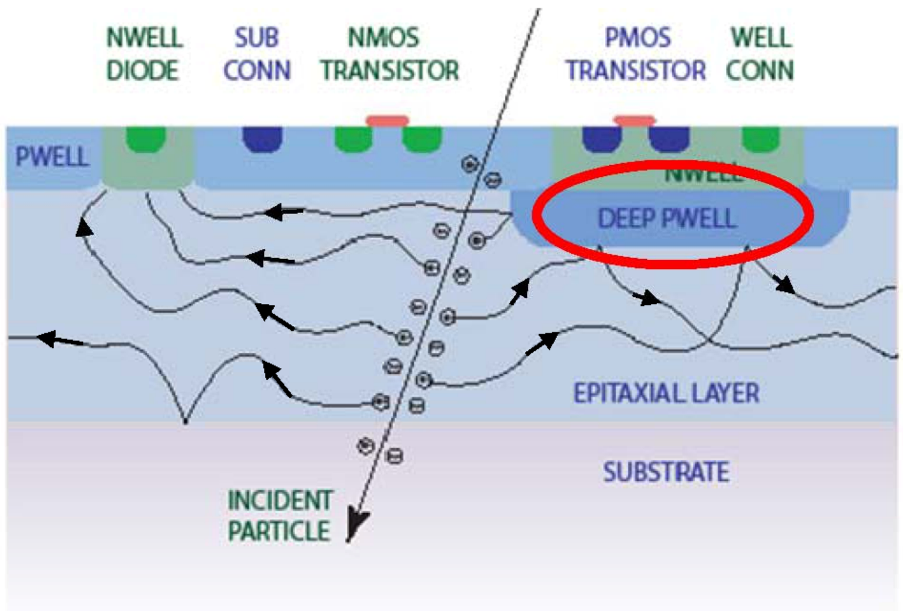
High granularity: the MAPS option for SiD

Led by UK groups: Marcel Stanitski, Paul Dauncey





- Make pixellated detector with small pixels
  - Probability of more than one charged particle per pixel must be small
  - Allows binary readout = hit/no hit
- EM shower density ~100/mm^2 in core so need pixels ~ 50µm
  - Results in huge number of pixels in a real ECAL ~ 10^{12} pixels



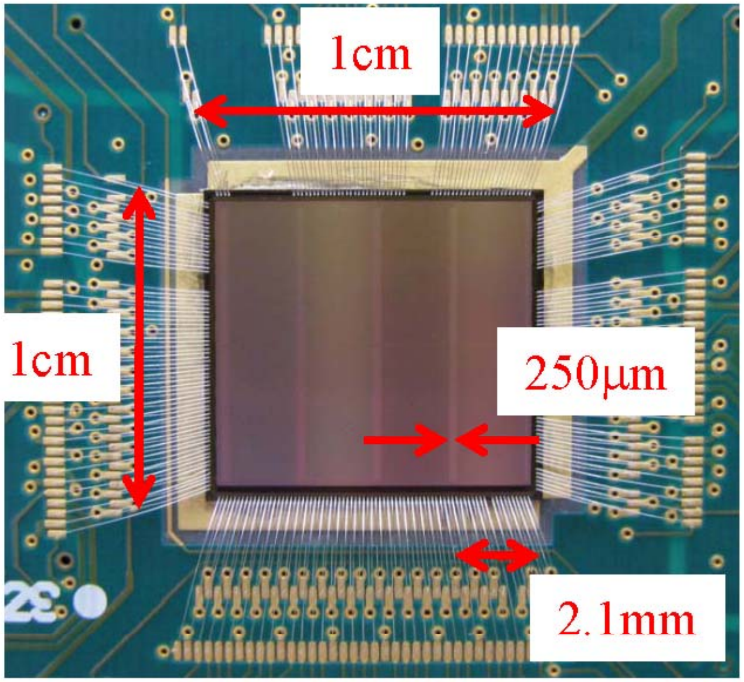
- Cannot afford to have external electronics with individual connections to so many channels
  - Need readout integrated into pixel
  - Implement as CMOS MAPS sensor
  - Includes deep p-well process to shield PMOS circuit transistors

- Very high granularity should help with PFA too
  - Requires major systematic study; here concentrate on EM resolution

MAPS (contd)

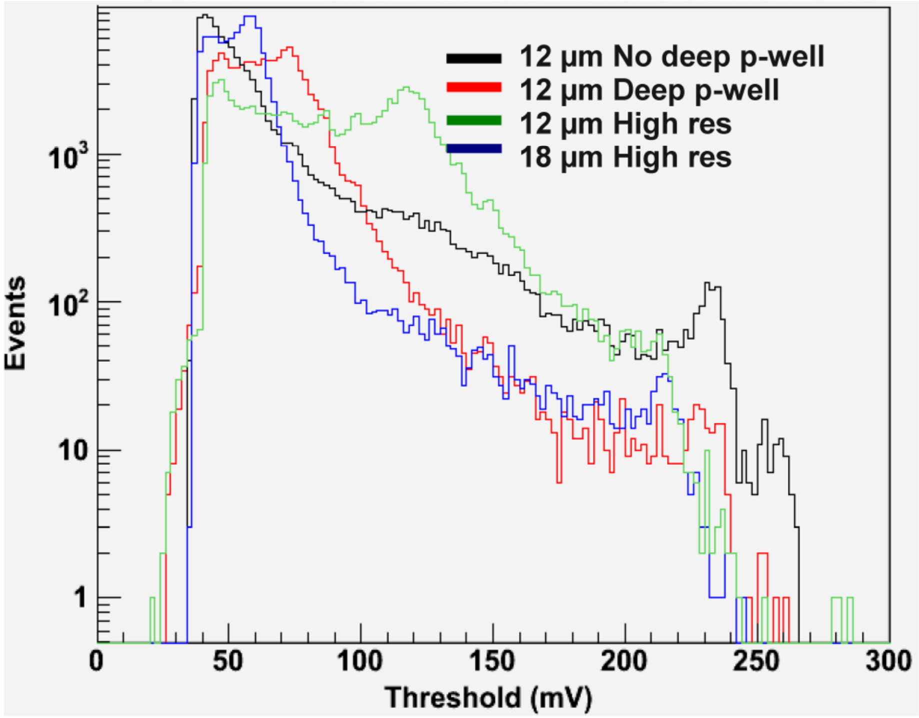
TPAC1.0 Prototype sensor (2008)

- 168×168 pixels = 28k total
- each 50×50μm²
- 0.18μm CMOS process



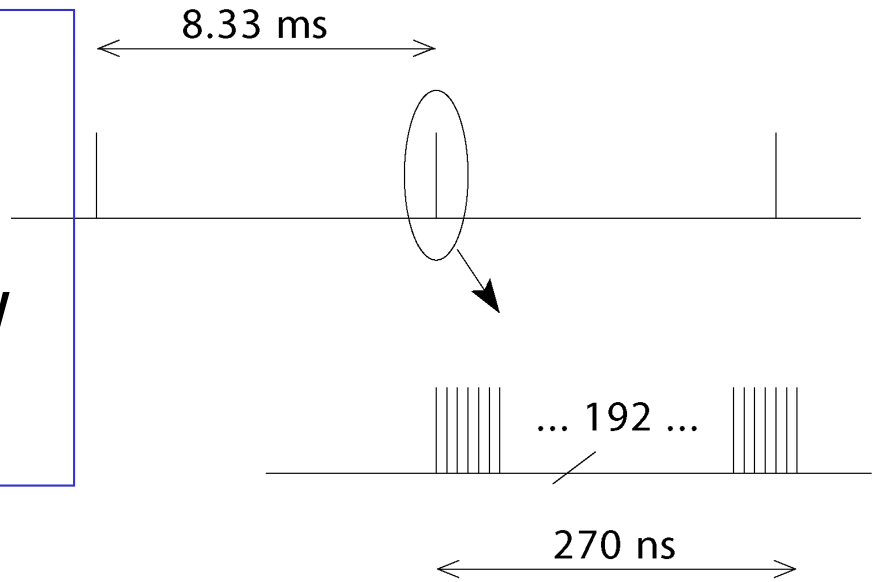
- Results from lab, DESY beam
- Other prototype chips in process
- Would use same mechanical structure as baseline ECal
- Effort limited by UK funding

TPAC1.2
Fe55

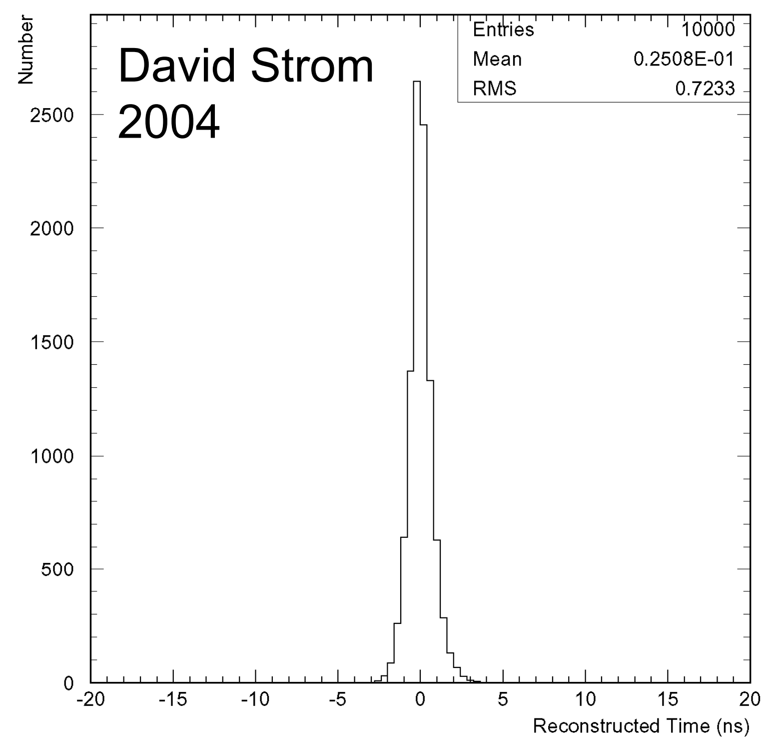


Improved timing with Si/W

For warm LC technology, we considered the ability to do time stamping with the Si/W ECal (ca 2004)



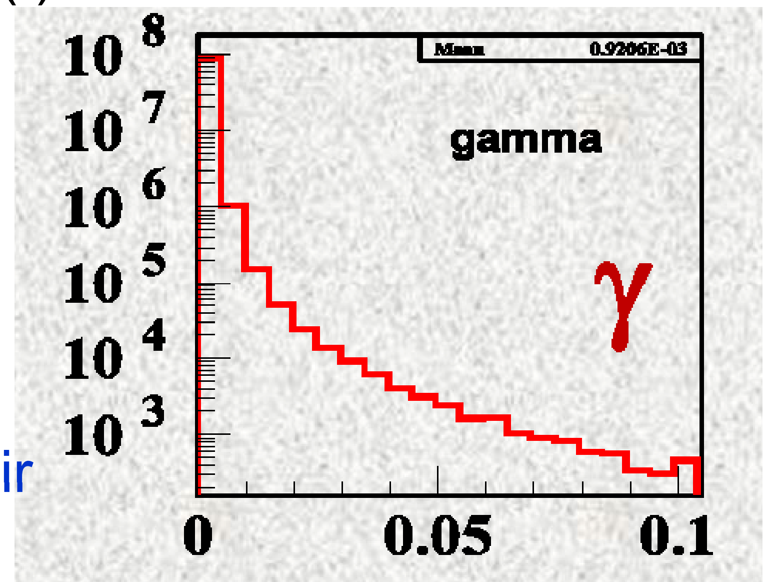
- The ECal was ~ identical to the current baseline Si/W, but with electronics designed for warm.
- A MIP hit would give ~5 ns timing resolution per Si layer
- Result is for simulation of single MIPs (30 layers) with 50 ns time constant in preamp.



filtering?

- Longitudinal structure of SiD baseline Si/W is (20 layers x $5/7\ X_0$) + (10 layers x $10/7\ X_0$)
- Innermost layer is silicon (to aid tracking)
  - At minimum, would need to reconsider this (!)
- Huge flux of low-energy photons
- What is shape of the spectrum < 10 MeV ?
  - Do we care about photons <100 KeV ?
- 1-10 MeV photons are not easily absorbed!
- Do all of the pairs in first few layers destroy their pattern recognition potential?

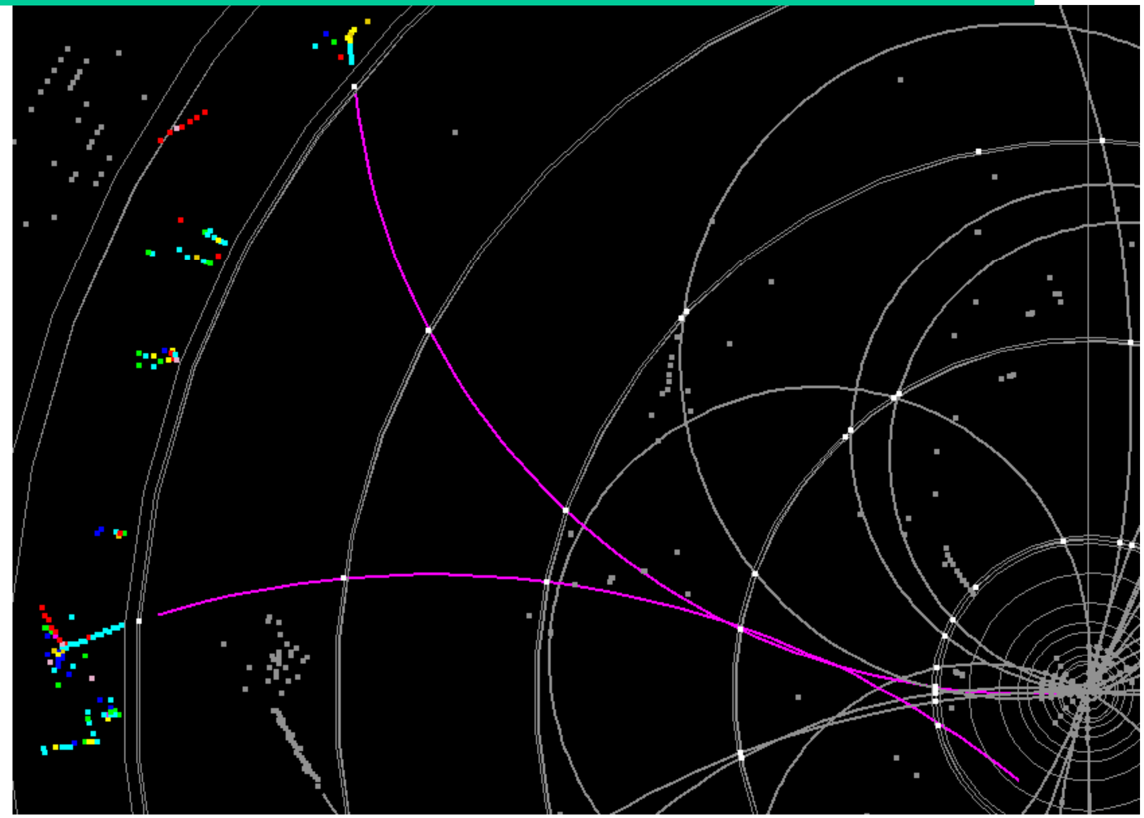
Mokhov



E (GeV)

- Is there a layout which mitigates the photon background but preserves (some of) the important pattern recognition capability?
- Clearly, this deserves study.

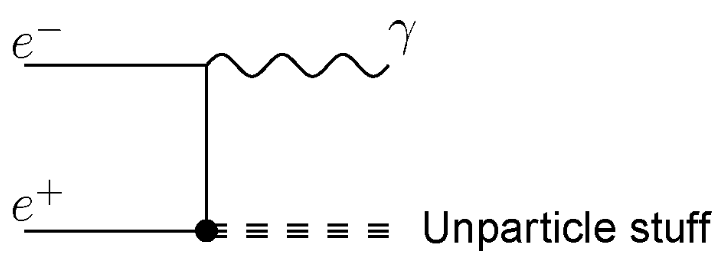
a MIP and photon tracker… oops?

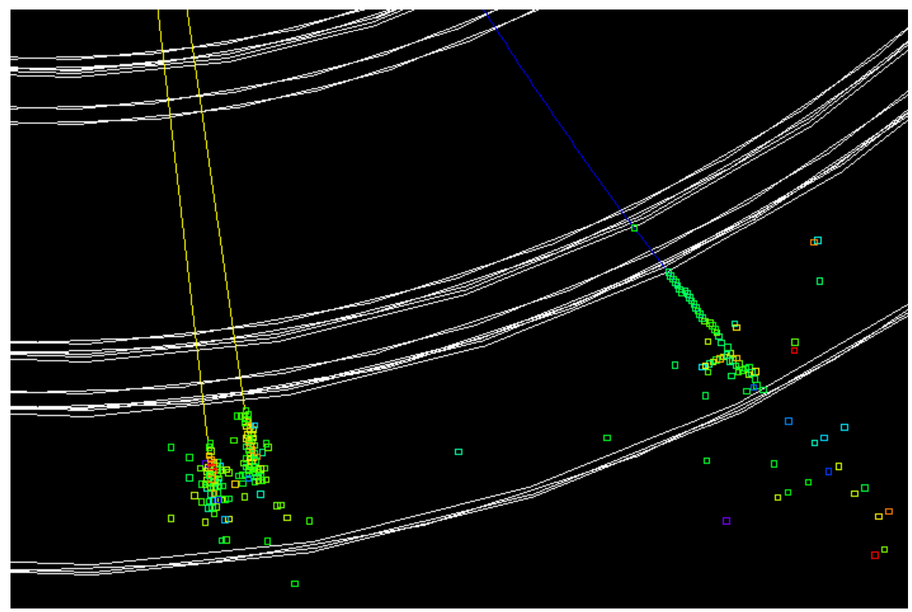


- Charged particle tracking, especially V0 recognition in silicon trackers
- charged hadrons and muons
- Photon vertexing
  - GMSB

$$e^+e^- \rightarrow \tilde{N}_1\tilde{N}_1 \rightarrow \gamma\gamma + \not{E}$$

  - unparticles





- electron id in/near jets

Summary

- We expect the ECal designs for ILC to meet the physics goals and extract the required measurements for all benchmarks
  - Compact, imaging calorimeters
  - Expect these designs to translate reasonably well to CLIC
- Can they be translated to the muon collider?

- Clearly need some good studies
- Some possibilities discussed here:
  - Extreme granularity (e.g. the MAPS option for SiD)
    - But MAPS is slow
    - Are ~1 mm^2 pixels good enough??
  - Improved Si timing (as for warm LC/CLIC)
    - Smaller pixels can help (depends on details of layout/readout)
  - Modification of longitudinal structure (absorber)
- One important change for sure: No power pulsing ☹ So will need active cooling, which will require significant design changes.