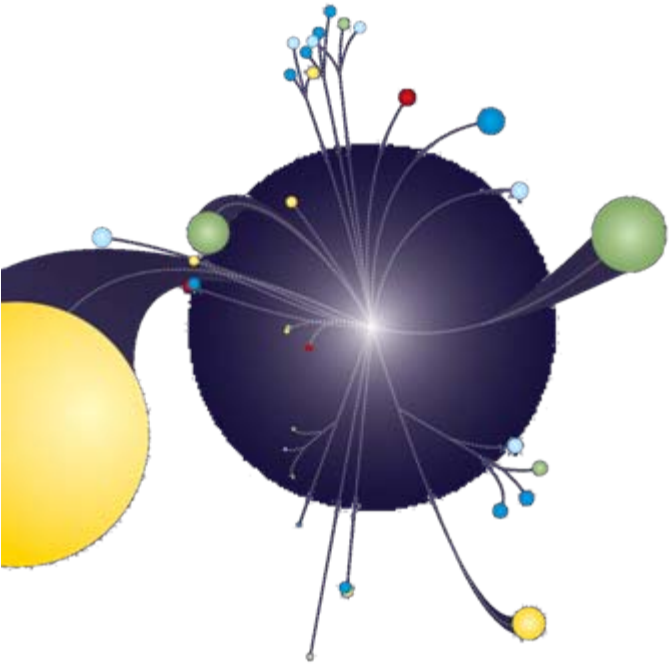
Plans for Detector R&D

for 2009



Marcel Demarteau

November 3, 2008
Fermilab

Areas of Detector R&D

- **Vertical Integrated Silicon Technology and its application**
  - **3D Vertical Integrated Silicon Technology**
  - **Pixel Detectors**
  - **Low mass detectors and support structures**
  - **Power Issues**

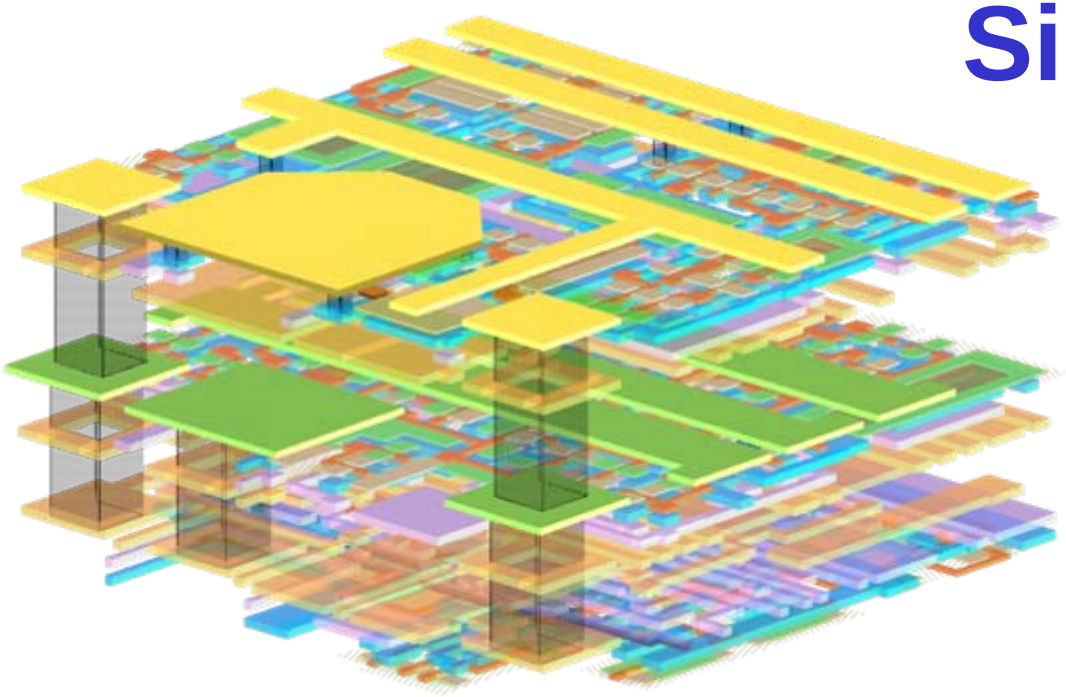
- **Total Absorption Calorimetry with Dual Readout**
  - **Crystals**
  - **Pixelated Photo-Detectors (PPD)**

- **Not covered today:**
  - **Liquid Argon Detectors**
  - **Bubble Chamber Detectors**
  - **Small Initiatives**

Mini-Reviews Being Planned

- **R&D for HEP experiments in the US will have high priority for the next 5-10 years as we work to define the next generations of experiments that will push the boundaries of our knowledge in the energy, intensity, and cosmic frontiers. To that end, Fermilab needs to have a well focused program of detector R&D, so that the directions taken are appropriate, understood, and supported. PPD is going to have a series of mini-workshops to go over the status, progress, and prospects for all known R&D efforts in the division.**
  - **GammeV (tentatively scheduled for December 1)**
  - **COUPP**
  - **Liquid Argon**
  - **Collider Detector**
  - **CMB**
  - **...**

Silicon Detectors



Fermilab and Silicon Detectors

- **The topic most frequently mentioned at the IEEE conference two weeks ago was 3D Integrated Silicon Detectors!**

- **Fermilab has many "firsts" in the silicon area:**
  - **Working 3-tier device for pixel detector readout**
  - **Established low-mass bonding technologies at 20 micron pitch with 100 micron thick sensors**
  - **Organizing a world-wide 3D Multi-Project Wafer run with 12 participating international institutions**
  - **Designed dedicated Serial Powering Interface ASIC**
  - **Demonstrated all silicon support structure**

- **Fermilab has extensive and unique expertise and infrastructure in silicon**

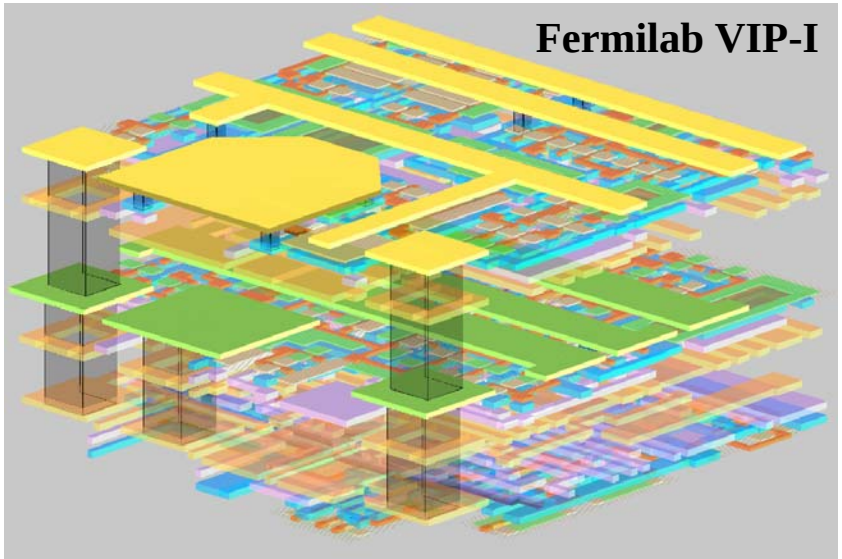
- **Fermilab HAS TO capitalize on its unique, premier position in this area !**

VIP-1 and VIP-2a

- Three-tiered ILC readout chip developed: VIP-1 chip
- Submitted Oct. 2006; ~20 devices delivered late 2007
- Chip works !
- Major breakthrough in the development of advanced ASICs and integrated detector systems

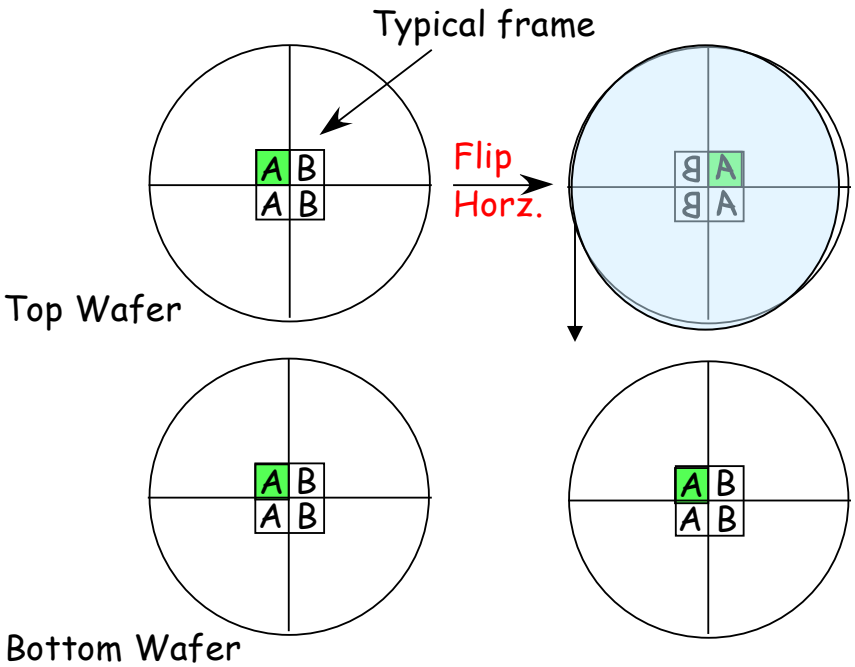
- Submitted an improved version of VIP1 on October 13, 2008 (150nm, SOI, 3 tiers): VIP-2a

- VIP I needs more testing
- VIP II, when it arrives, needs a lot of testing



Fermilab 3D Multi-Project Run

- **Fermilab will be hosting a 3D multi project run with Tezzaron**
- **There will be only 2 layers of electronics fabricated in the Chartered 130 nm process, using only one set of masks. (Useful reticle size is 16 x 24 mm)**
- **The wafers will be bonded face to face**



Note: top and bottom wafers are identical.

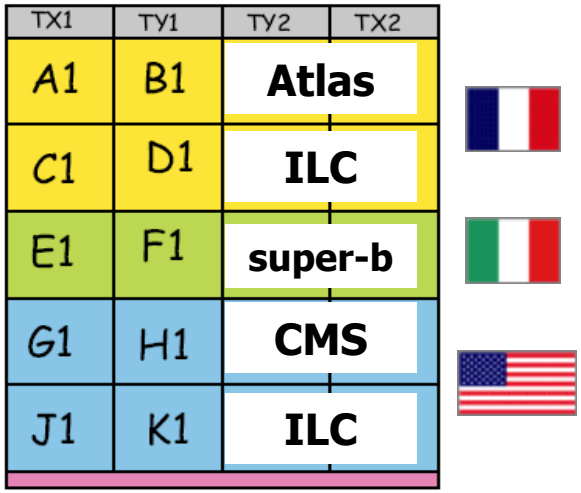
- **Participants in MPW run:**
  - **Fermilab, Batavia**
  - **University at Bergamo**
  - **University at Pavia**
  - **University at Perugia**
  - **INFN Bologna**
  - **INFN at Pisa**
  - **INFN at Rome**
  - **CPPM, Marseilles**
  - **IPHC, Strasbourg**
  - **IRFU Saclay**
  - **LAL, Orsay**
  - **LPNHE, Paris**
  - **CMP, Grenoble**
- **Discussions with:**
  - **BNL (NSLS)**
  - **SLAC (LCLS)**

Fermilab 3D Multi-Project Run

- **Expected submission some time in March '09**
- **Possible four-way split of the reticle**
  - **Fermilab responsibility**
    - Redesign of the VIP chip, adopted to 2 tiers VIP-2b
    - New 3D chip to explore the advantages of 3D for the sCMS pixel detector (LHC)

- **Will take at least 3 ASIC engineers full time to work on the VIP design, plus 0.5 FTE of support for design kits (Shenai)**
- **Will needs additional effort for a CMS chip (not decided)**

- **Chip expected back 6-8 weeks after submission**
- **Extensive array of tests to follow**
  - **Asic engineers**
  - **Design of data acquisition system**
  - **Beam tests**

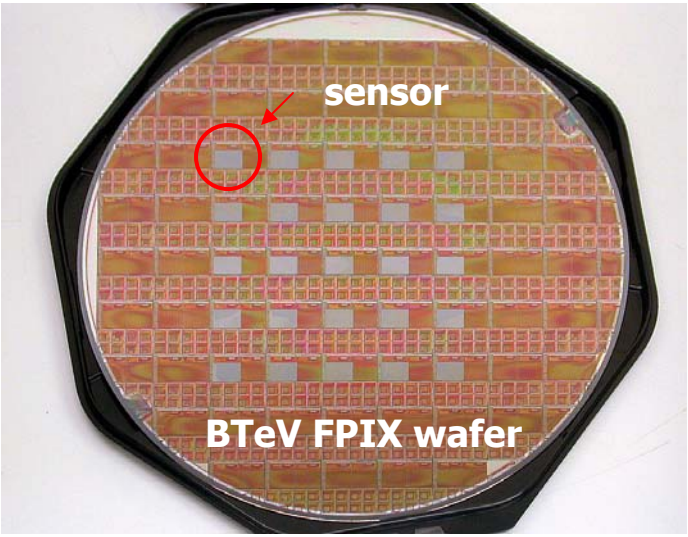


Frame layout

Yellow = France
Green = Italy
Blue = USA
Magenta = alignment
Grey = test chips

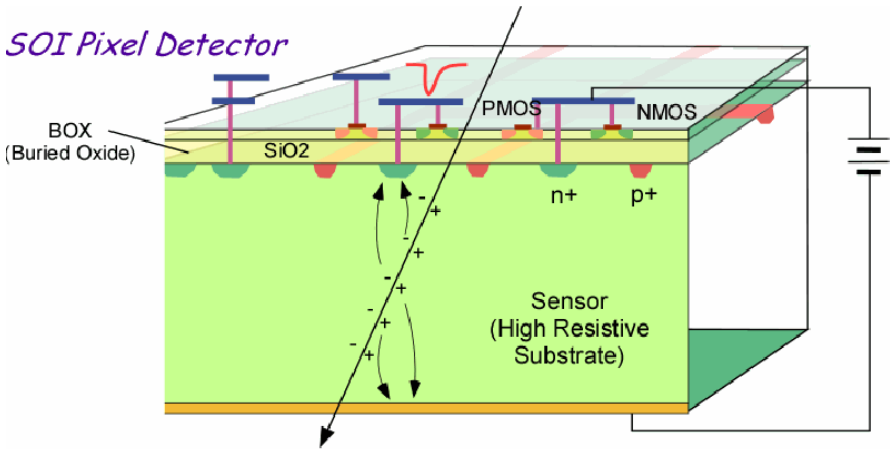
Integrated Detectors

- Bonded MIT-LL sensors to BTeV FPIX chip on 8" wafer (20 μm pitch)
- Ziptronix Direct Bond Interconnect (DBI)
  - Significantly reduces material budget
  - Allows aggressive post bond thinning due to the strength of the oxide bond
  - Understood bond yields for 10 μm pitch with 1Mbonds/cm^2
- Sensors (after bonding) thinned to 100 μm
- 25 functional devices in hand



- Bench testing performed by post-doc
- Would like to put it in a beam
- Post-doc involvement is critical !

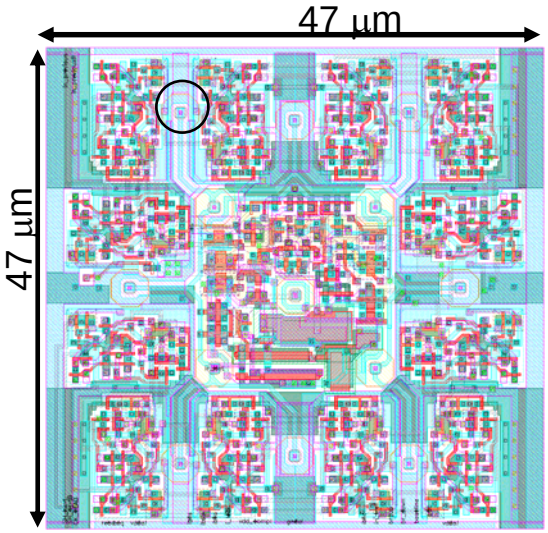
SOI Detector Development



- **Bonded Silicon on Insulator Wafer**
  - low resistive top layer; standard CMOS Electronics (NMOS, PMOS)
  - separated through a Buried OXide (BOX) layer to
  - Bottom substrate layer which forms detector volume; diode implants are formed beneath the BOX and connected by vias

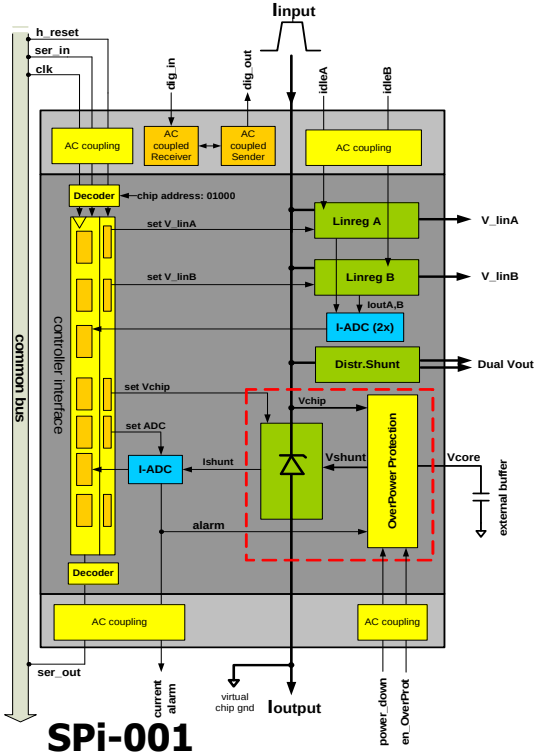
- **Designed two SOI devices in the OKI process MAMBO-1 and Mambo-2**

- **OKI has another MPW run in mid-January**
- **Not clear we have the resources to participate !**
  - **(Also not clear if we want to participate)**



Power Issues

- LHC experiments suffer (dramatically) from ‘ cable pollution’
- Designed serial powering chip: SPI-001
  - Enables studies on various (to date all) SP approaches
  - Will be able to power a whole module (large I)
  - Very versatile in offered voltage range
- Design in collaboration with Penn/RAL
  - Chip submitted September 23, 2008
- Chip manufactured; is at TSMC. Expected back in two weeks or so
- Will need serious testing
- Group could use another ASIC designer !
  - Argonne MoU ?!

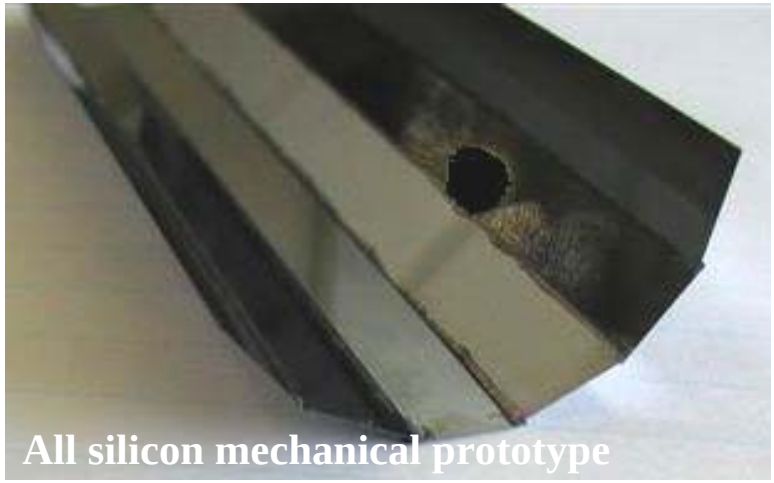


Summary

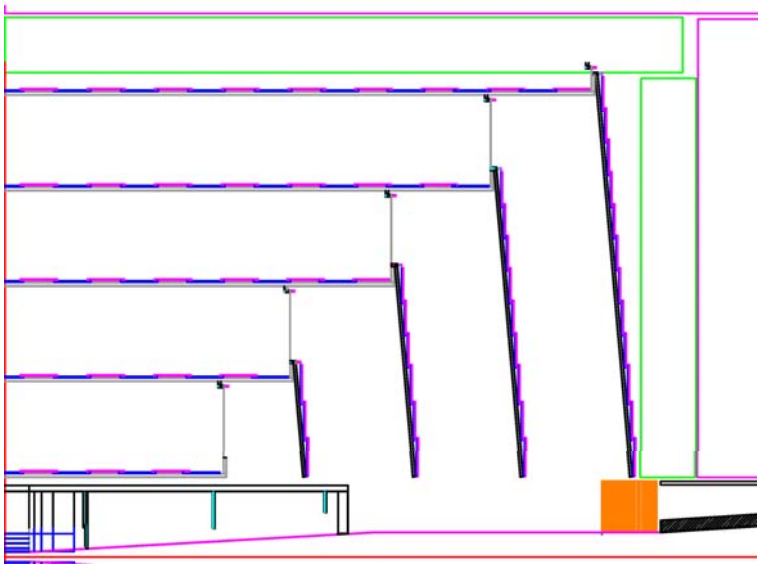
- **Chip Design**
  - **3.5 full time ASIC designers (could certainly use one more!!)**
  - **1.0 FTE of EE support**
  - **1.0 Physicist**
- **Chip Testing**
  - **3.0 FTE of EE**
  - **2.0 FTE of ET**
  - **0.5 FTE design**
- **System Testing**
  - **1.0 post-docs**
  - **1.0 Physicist**
  - **0.5 EE**
  - **0.5 MT**
  - **1.0 ET**

Low Mass Support Structures

- All silicon vertex detector
  - Design
  - Tooling
  - Fabrication
  - Measurement
- 1.0 ME
- 0.5 MT
- 1.0 Designer

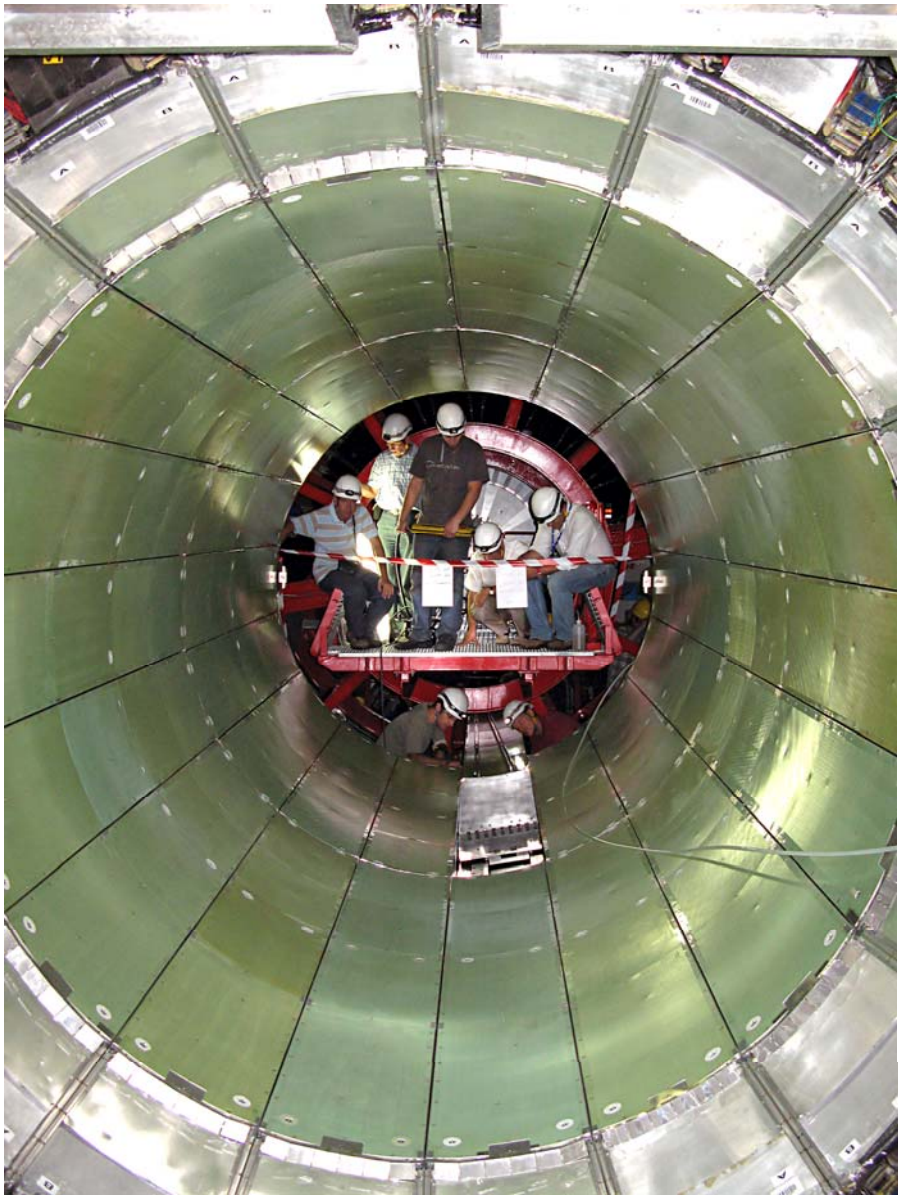


- Carbon fiber support
  - Vertex Detector
    - Build Exoskeleton
  - Outer tracker
    - Build “lamp shade” support structures
- 0.25 ME
- 0.5 MT
- 0.5 Designer



Summary Silicon

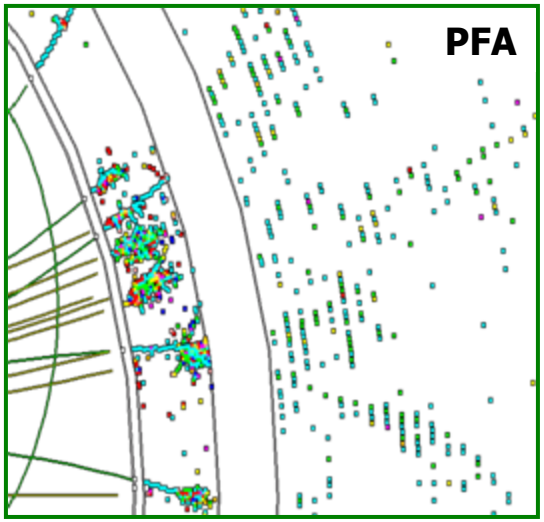
- **Our silicon work is first class in all areas**
- **The range of applicability of our work is very broad**
- **We owe it to ourselves to retain our position of world leadership**



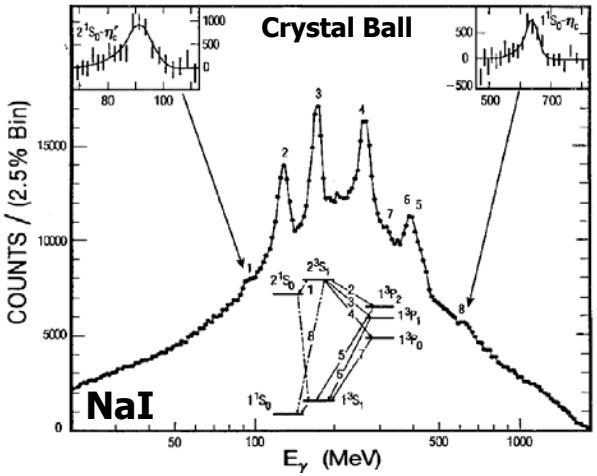
Calorimetry

Hadron Calorimetry

- Hadron calorimeters have traditionally had poor energy resolution
- Possible approach for improvement is Particle Flow
- Being questioned is its performance and how it scales with cms energy



- Total absorption crystal EM calorimeters obtain best energy resolution (CsI, BGO, $PbWO_4$)
- Question: can this technology be extended to hadron calorimetry? Dual Readout Calorimetry
- Dual-readout calorimetry: measure every shower twice
  - Scintillation light: from all charged particles
  - Čerenkov light: β=1 particles, mainly EM
- Correct on a shower-by-shower basis using the correlation of the total observed ionization (S) and Cherenkov (Č) light



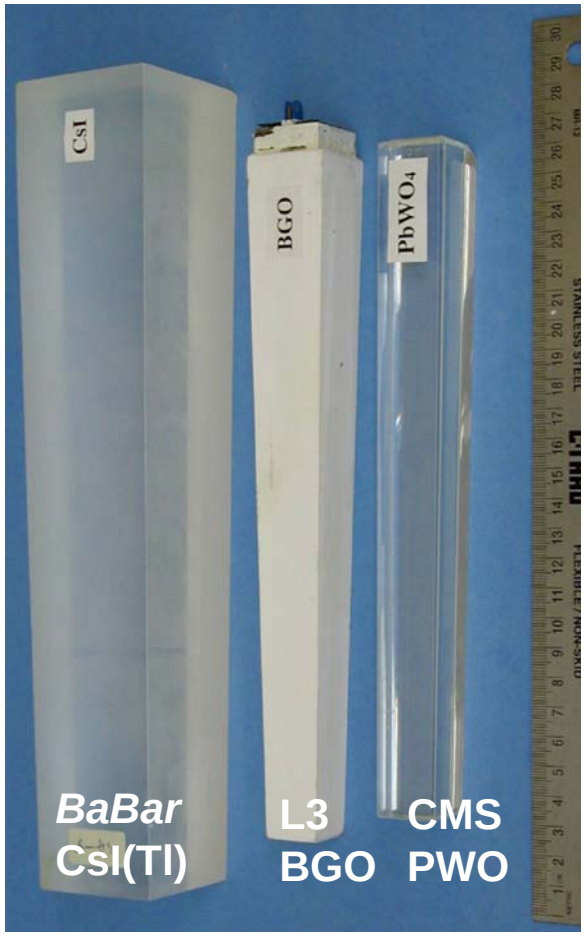
Total Absorption Dual Readout Calorimetry

- **Need to establish on scale of prototypes**
  - **Heavy scintillating crystals**
  - **Silicon photo-detectors**

- **Crystals**
  - **Develop crystals suitable for scintillation – Čerenkov light separation**

- **Light collection**
  - **Separation Č-light and scintillation light**
  - **Yield, wavelength,**
  - **uniformity, # SiPM**
  - **Simulation of scintillation and Č-light**

- **Readout: the enabling technology is pixelized photon detectors**



Status

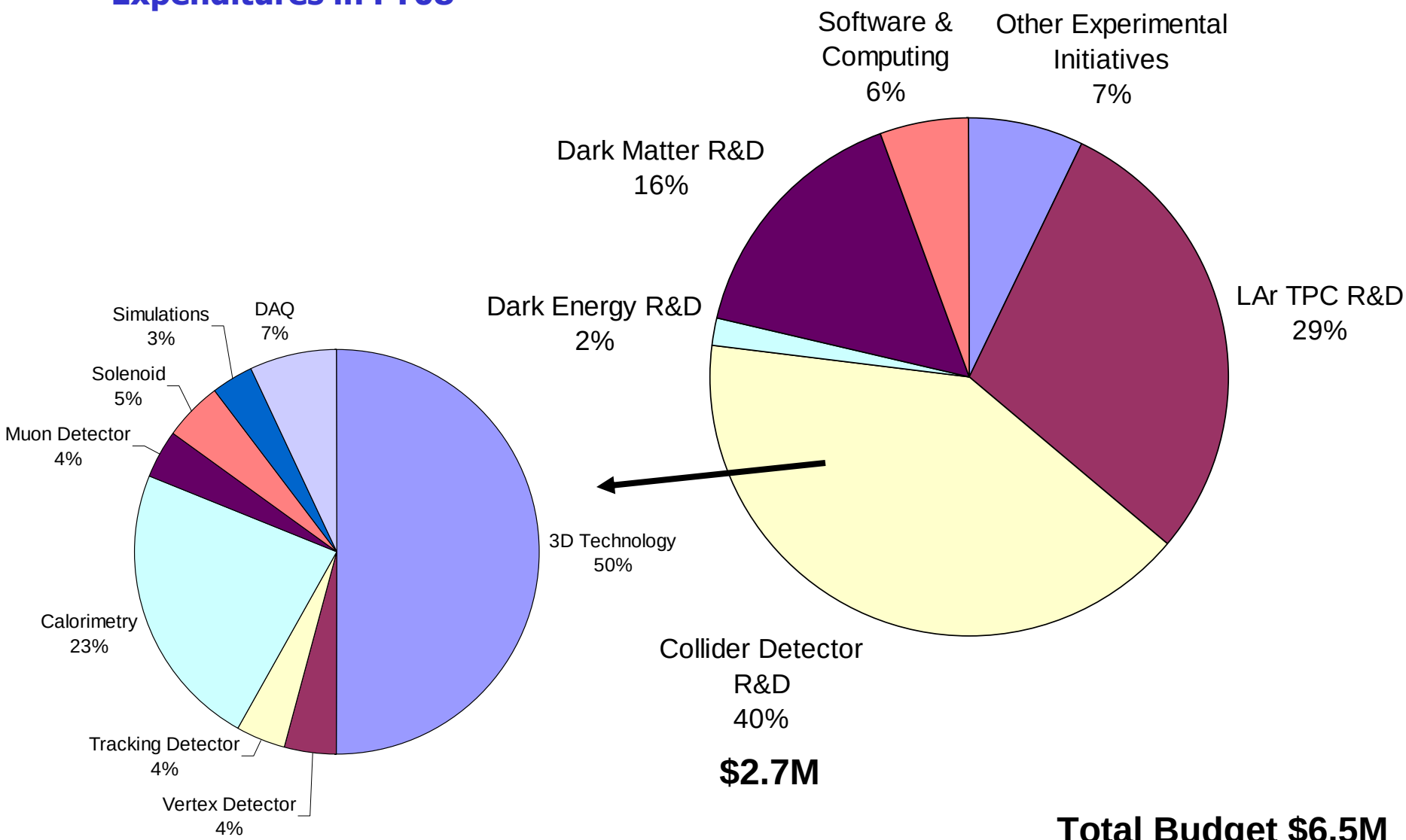
- To date we have invested in the setup of a facility for the characterization of PPDs
  - SiDet facility and readout for muon detector with silicon strips
- Level of effort
  - 1.0 physicist, 0.7 EP, 0.5 EE, 0.5 ET, 0.25 MT

- Dual Readout Calorimetry is gaining more and more traction and the community is looking for Fermilab to take a leadership role.

- I would like to double our effort in this area this year working towards a complete system test of a stack (3x3 -> nxn) in the test beam

FY08

- **Expenditures in FY08**



Total Budget $6.5M

Labor Estimate

- **FY08 are actuals**

		M&S ($M)	FTE's	Total ($M)
Collider Detector R&D	FY08	0.5	22	2.7
Collider Detector R&D	FY09	1.1	24.9	3.6

Concluding Remarks

- **We need to open detector R&D to post-docs**
- **Additional ASIC engineering is very welcome**
- **We need to maintain our infrastructure**
- **Suggest to call a "facilities task force" to participate in the mini-reviews who will address the need for facilities at Fermilab for the next generation of projects**