Possible Advances in Detectors

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On behalf of
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Snowmass Instrumentation Frontier Conveners

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“New directions in science are launched by new tools much more often than by new concepts.

The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained”

Freeman Dyson

Discoveries in Particle Physics

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN (1960)	π N interactions	Neutral Currents -> Z,W
AGS BNL (1960)	π N interactions	Two kinds of neutrinos Time reversal non-symmetry charm quark
FNAL Batavia (1970)	Neutrino Physics	bottom quark top quark
SLAC Spear (1970)	ep, QED	Partons, charm quark tau lepton
ISR CERN (1980)	pp	Increasing pp cross section
PETRA DESY (1980)	top quark	Gluon
Super Kamiokande (2000)	Proton Decay	Neutrino oscillations
Telescopes (2000)	SN Cosmology	Curvature of the universe Dark energy

Precision instruments are key to discovery when exploring new territory.

S. Ting

Chamber Type	Accuracy (rms)	Resolution Time	Dead Time
Bubble	± 75μ	≈ 1 ms	≈1/20 s[a]
Streamer	±300μ	≈ 2 μs	≈100 ms
Optical spark	±200μ[b]	≈ 2 μs	≈ 10 ms
Magnetostrictive Spark	±500μ	≈ 2 μs	≈ 10 ms
Proportional	⩾±300μ[c,d]	≈50 ns	≈200 ns
Drift	±50 to 300μ	≈ 2 ns[e]	≈100 ns

Review of Particle Properties (1978)

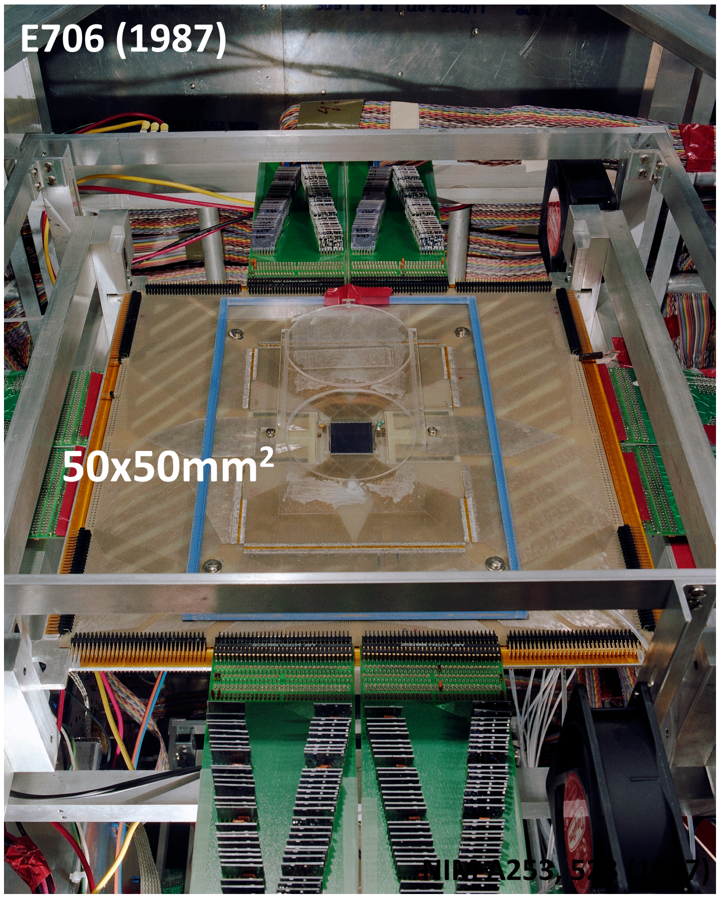
Detector Type	Intrinsinc Spatial Resolution (rms)	Time Resolution	Dead Time
Resistive plate chamber	$\lesssim 10$ mm	1–2 ns	—
Streamer chamber	300 μm[a]	2 μs	100 ms
Liquid argon drift [7]	∼175–450 μm	∼ 200 ns	∼ 2 μs
Scintillation tracker	∼100 μm	100 ps/n[b]	10 ns
Bubble chamber	10–150 μm	1 ms	50 ms[c]
Proportional chamber	50–100 μm[d]	2 ns	20-200 ns
Drift chamber	50–100 μm	2 ns[e]	20-100 ns
Micro-pattern gas detectors	30–40 μm	< 10 ns	10-100 ns
Silicon strip	pitch/(3 to 7)[f]	few ns[g]	$\lesssim 50$ ns[g]
Silicon pixel	$\lesssim 10$ μm	few ns[g]	$\lesssim 50$ ns[g]
Emulsion	1 μm	—	—

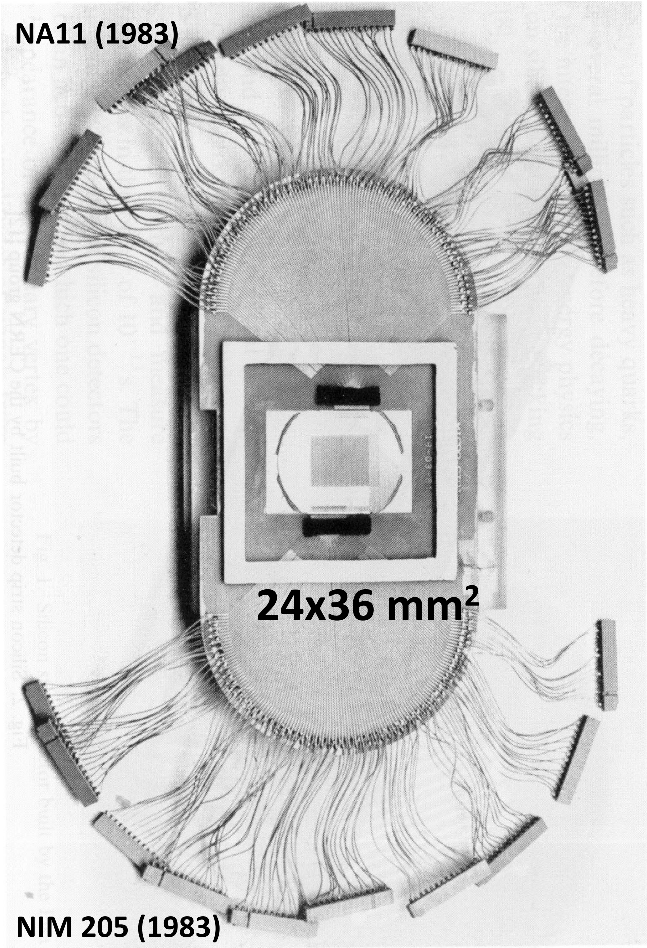
Review of Particle Properties (2011)

New technologies have enabled a rich physics program

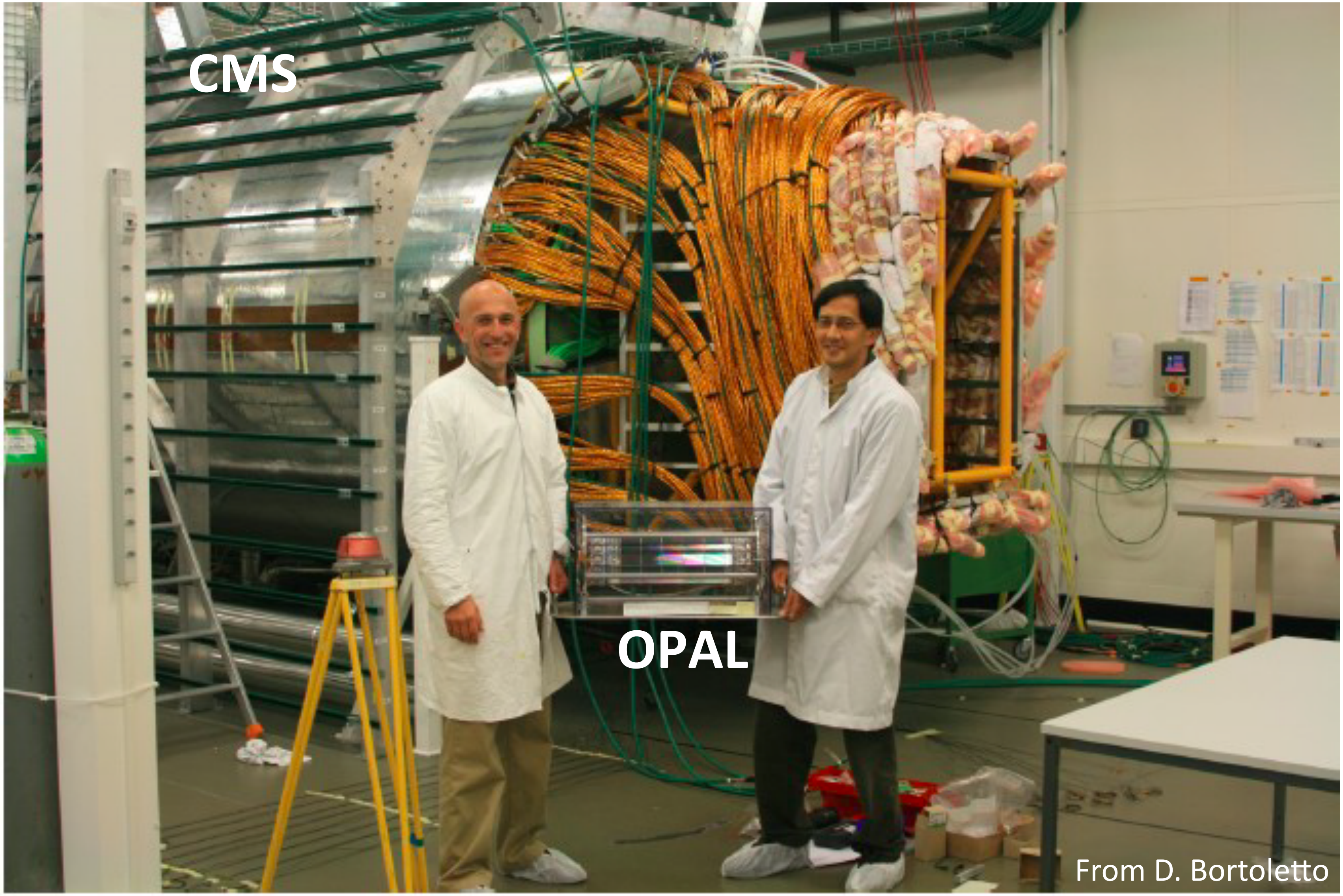
Silicon Detectors

- A breakthrough: development of planar silicon strip detectors in combination with readout ASICs, leveraging the semiconductor industry developments
  - Fast, good resolution, low dead time, radiation hard

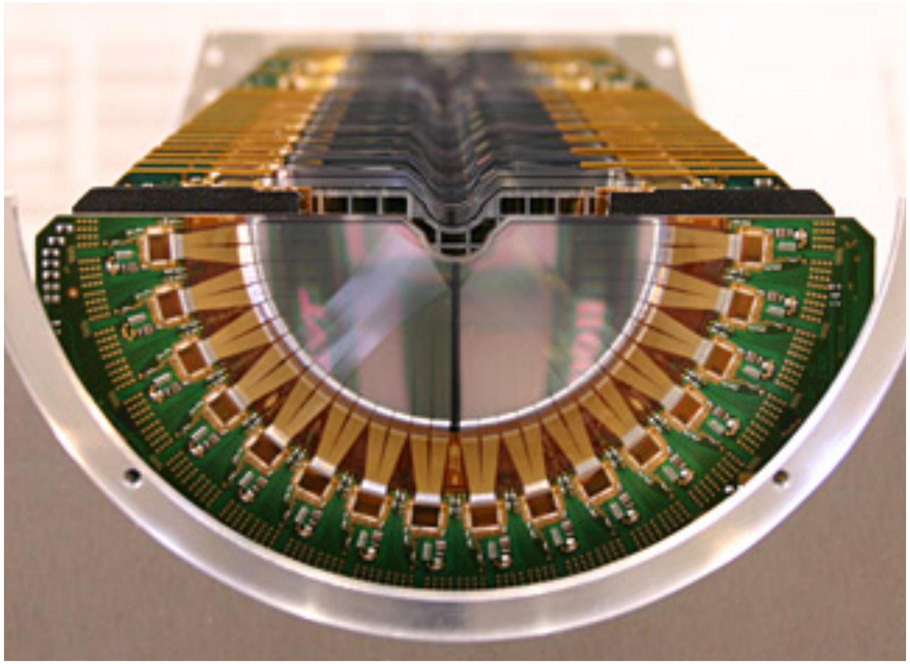




From LEP to the LHC

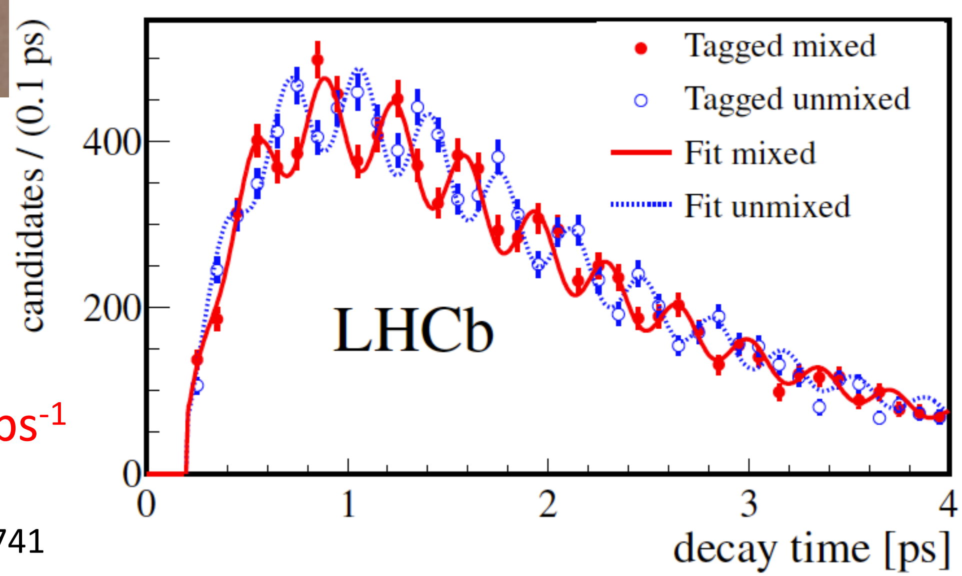


Wealth of Physics



LHCb Vertex Locator Silicon detector

$B_s - \overline{B}_s$ oscillation frequency in the decay $B_s \rightarrow D^-_s \pi^+$



$\Delta m_s = 17.768 \pm 0.023\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1}$

arXiv: 1304.4741

Two Cornerstones …

- In 1974 Bill Willis and Veljko Radeka studied noble liquids for the first time at Columbia and BNL for calorimetry
- LAr used in fixed target (E706, E515, E653) and collider experiments (D0, ATLAS)

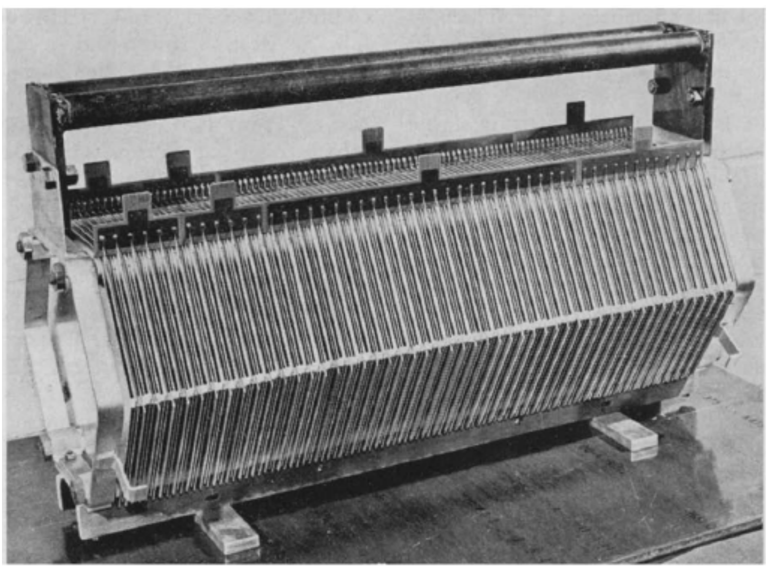
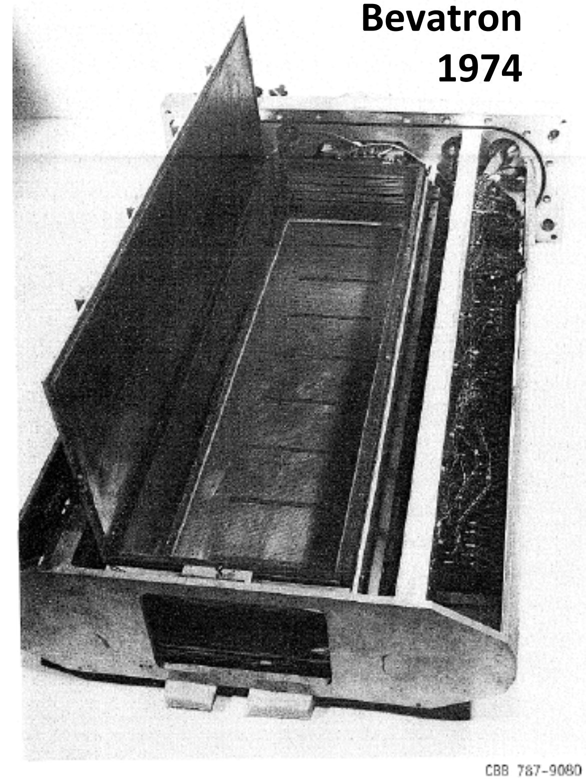
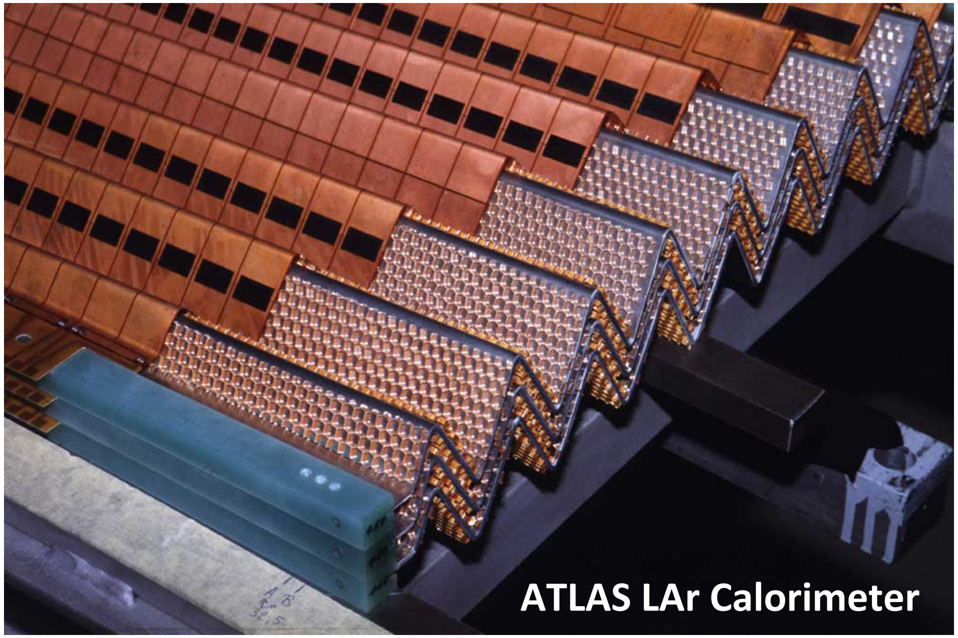


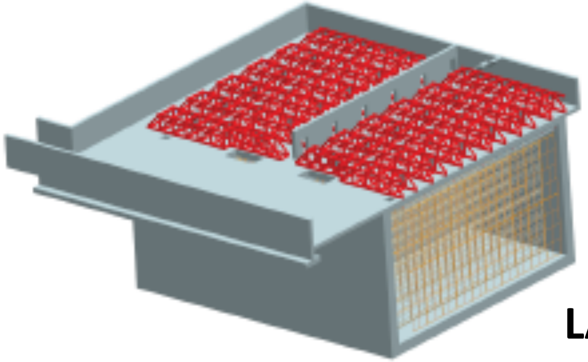
Fig. 10. Large test chamber with 200 steel plates, 1.5 mm thick, with 2.0 mm gaps.



- In 1976 Dave Nygren invented the Time Projection Chamber at Berkeley
- Used in Aleph, Delphi, STAR, ALICE experiments

The Engines of Current and Planned Experiments

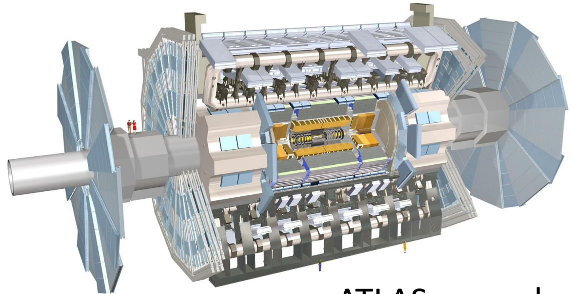




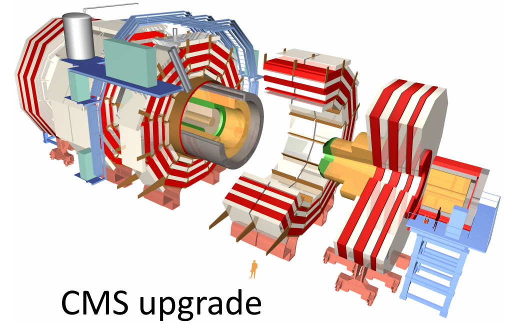
LAr TPC LBNE

The seeds sown long ago in the US

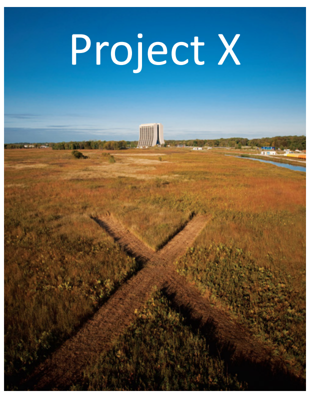
Big Ambitions …

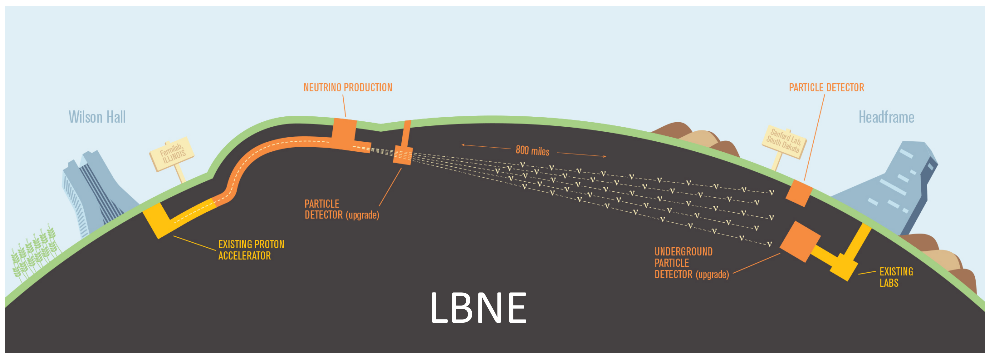


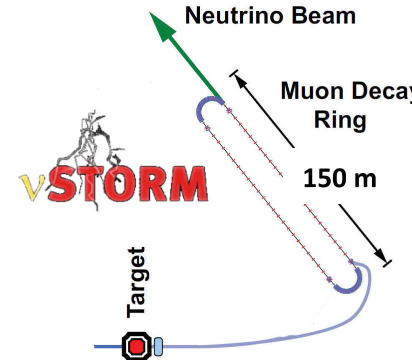
ATLAS upgrade

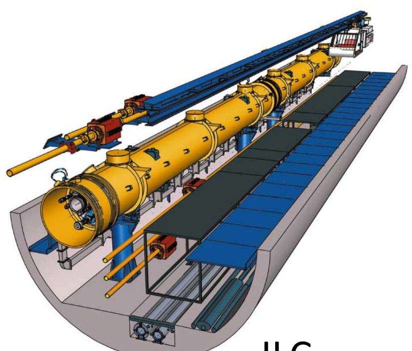


CMS upgrade

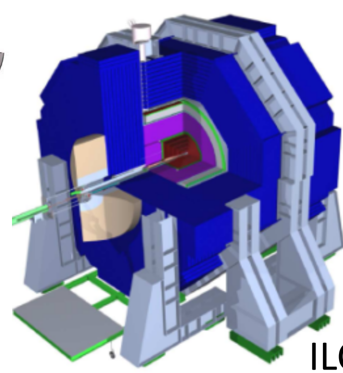




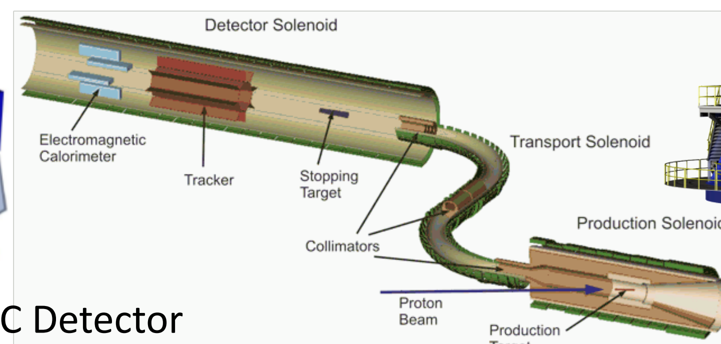




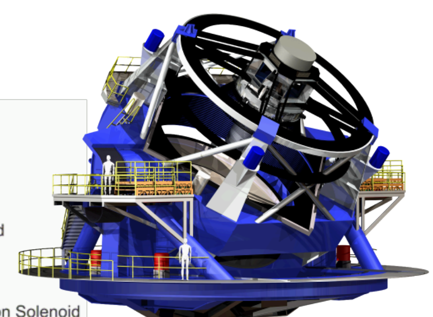
ILC



ILC Detector

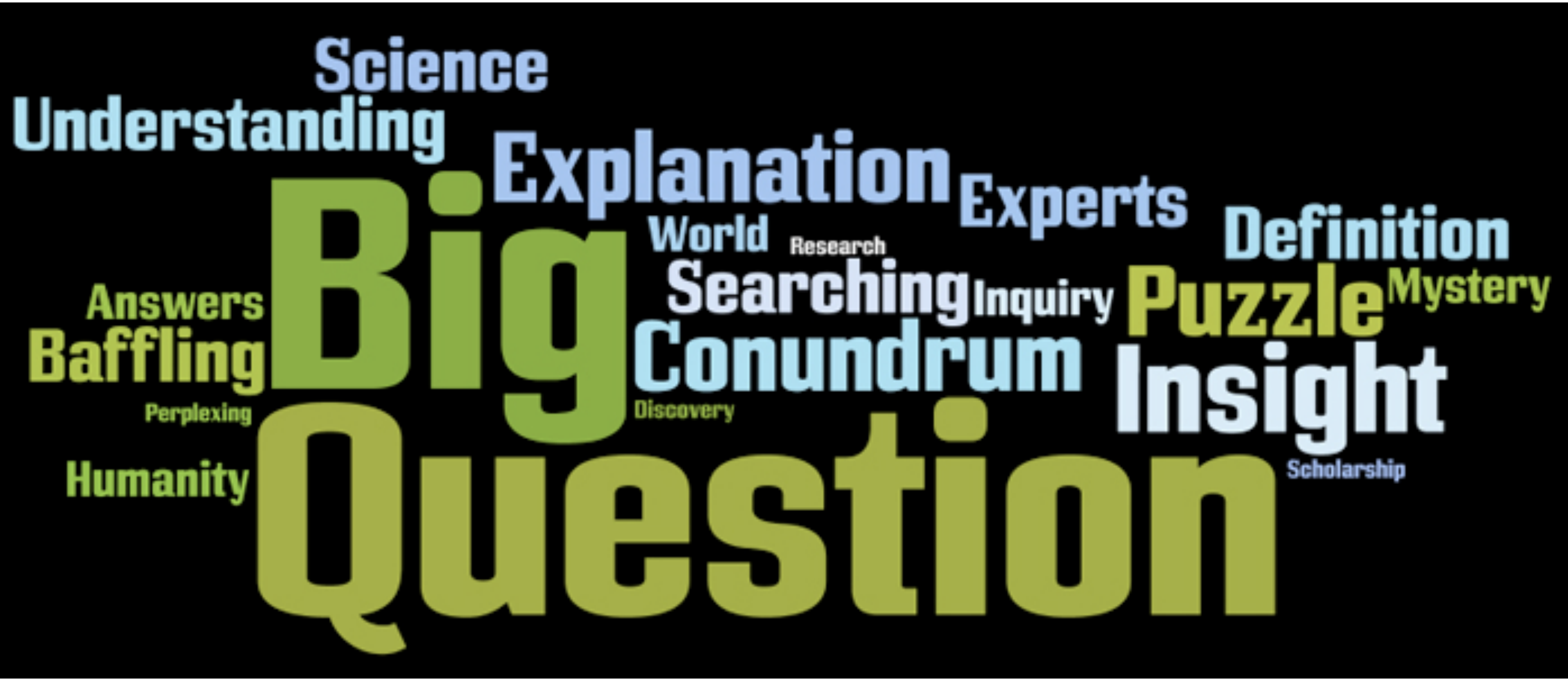


Mu2e



LSST

Big Questions …



But the Real Big Question …

The Real Big Question

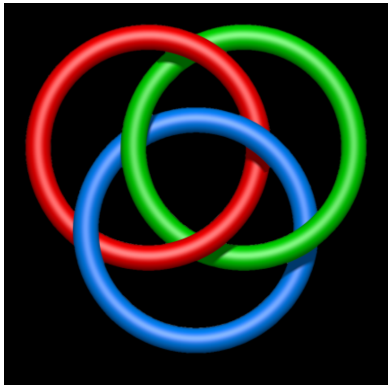
- **How can we fit our ambitions within our budget ?**
  - Carry out a flagship domestic program, and have a leadership role in off-shore projects
  - Invest in the future such that the US is again recognized as a leader in high energy physics

- Before, during (and after) Snowmass addressed the question of the Role of instrumentation:
  - What opportunities are there for instrumentation?
  - What role does instrumentation play in addressing the science questions?
  - What role does instrumentation play in enabling the experiments?
- **Since instrumentation is the enabler of science, role is significant.**

Levels of Instrumentation Development

- At the lowest level is the instrumentation development that takes place within the individual experiments; R&D is very much project driven and project funded; not considered "generic" detector R&D

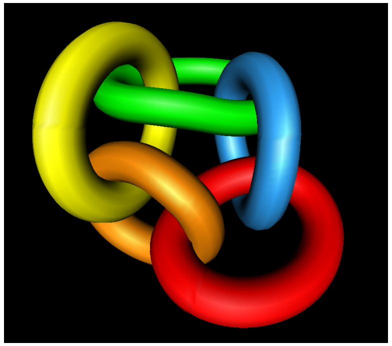
Levels of Instrumentation Development



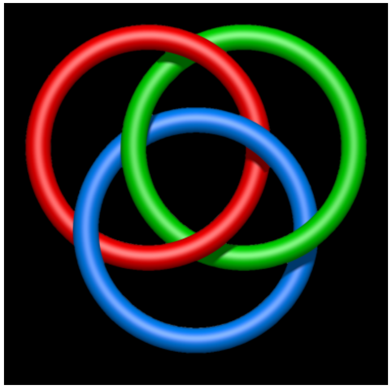
- At the intermediate level is the generic R&D, motivated by common needs in instrumentation among several experiments. R&D is more long term and adds value to all projects

- At the lowest level is the instrumentation development that takes place within the individual experiments; R&D is very much project driven and project funded; not considered "generic" detector R&D

Levels of Instrumentation Development



- At the highest level is the instrumentation development that adds value to the field as a whole; R&D is long term and is aimed at being truly transformational



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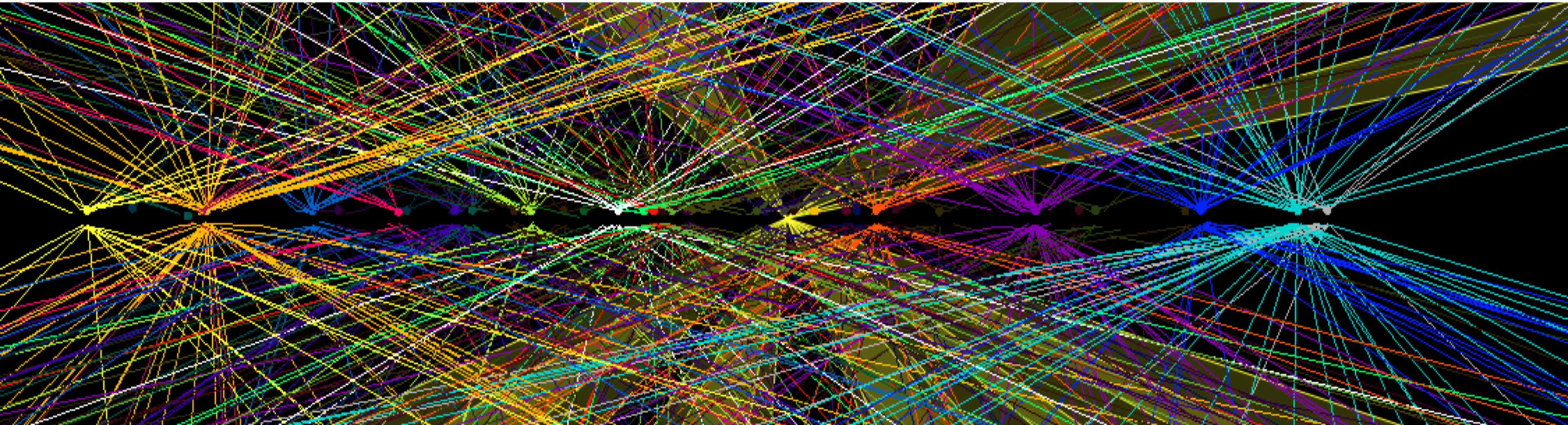
Organization for Snowmass

Technologies	Energy	Intensity	Cosmic
	Ulrich Heintz	David Lissauer	Juan Estrada
Sensors	Semiconductor sensors,Bolometers,Light sensors,Crystals,Radiation hard sensors		
Marina Artuso	Daniela Bortoletto (Purdue)	Matt Wetstein (Chicago)	Andrei Nomerotksi (BNL)
Abe Seiden	Sally Seidel (New Mexico)	Henry Frisch(Chicago)	Clarence Chang (Chicago)
	Ren-yuan Zhu(Caltech)	J. Va'vra(SLAC)	Jim Fast (PNNL)
Gaseous Detectors	Micropattern detectors, RPCs, Gas TPCs		
Gil Gilchriese	Andy White (UTA)	James White (Texas A&M)	
Bob Wagner	Marcus Hohlmann (FIT)	Brendan Casey (FNAL)	
	Vinnie Polychronakos (BNL)		
Detector Systems	Calorimetry, Neutrino Detectors, Noble liquid TPCs and detectors, Low background materials, Mechanics		
Ed Blucher	Roger Rusack (Minnesota)	Bonnie Fleming (Yale)	Karen Byrum (ANL)
David Lissauer	Adam Para (FNAL)	Bob Svoboda (UC Davis)	Peter Gorham (Hawaii)
			David Nygren (LBL)
			Dan Akerib (Case Western)
			Greg Tarle (Michigan)
Electronics/DAQ/Trigger	ASICs, Trigger systems, Power delivery, Data communication, Data processing systems (TCA…)		
Ulrich Heintz	Dong Su (SLAC)	Gary Varner (Hawaii)	Günther Haller (SLAC)
Ron Lipton	Wesley Smith (Wisconsin)	Yau Wah (Chicago)	Frank Krennrich (Iowa State)
	Maurice Garcia-Sciveres (LBNL)		
Novel/Emerging Technologies	Graphene, ALD, Flexible electronics ...		
Jim Alexander	Ted Liu (FNAL)	Steve Ahlen (BU)	Juan Estrada (FNAL)
David MacFarlane	Julia Thom (Cornell)		
Software	Frameworks, Machine Backgrounds, Simulation		
Norman Graf	Erich Varnes (Arizona)	Robert Kutschke (FNAL)	Salman Habib (ANL)
Facilities	Test Beams, Low Background Facilities, Assembly and test facilities, Engineering		
	Carsten Hast (SLAC)	Jae Yu (UTA)	Erik Ramberg (FNAL)

CHALLENGES AND OPPORTUNITIES IN INSTRUMENTATION



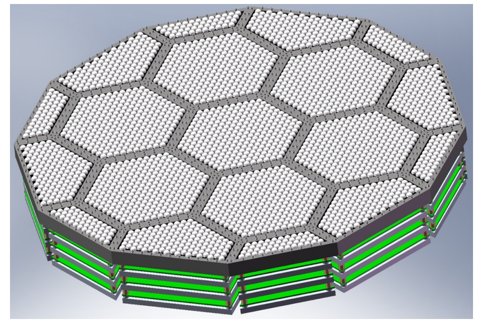
Cryogenic Detectors

Transition Edge Sensors

Multi-Chroic Transmission

Signal Multiplexing

Kinetic Inductance Sensors

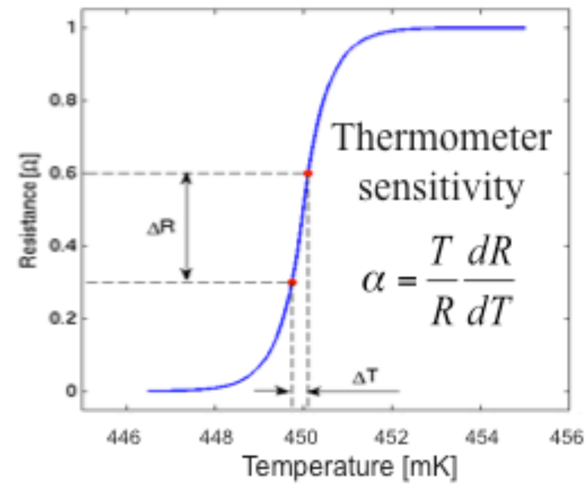


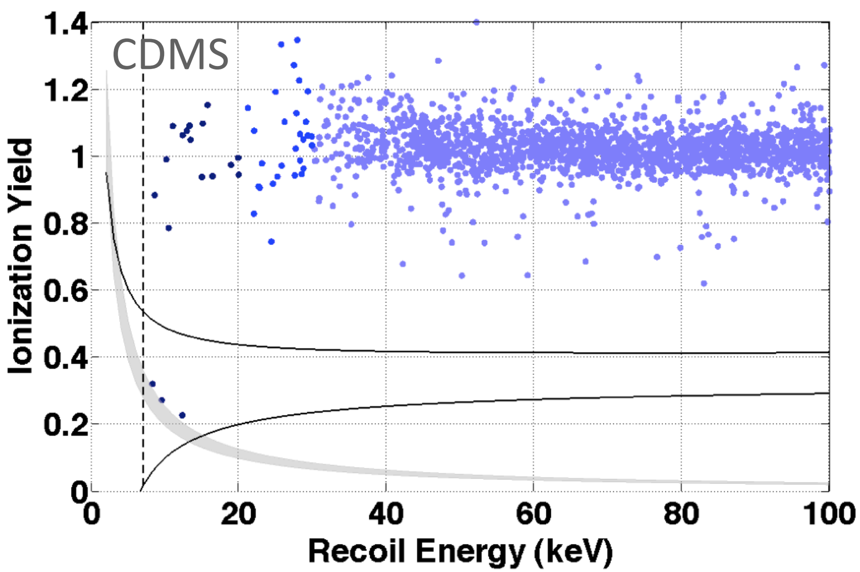
Science Reach:

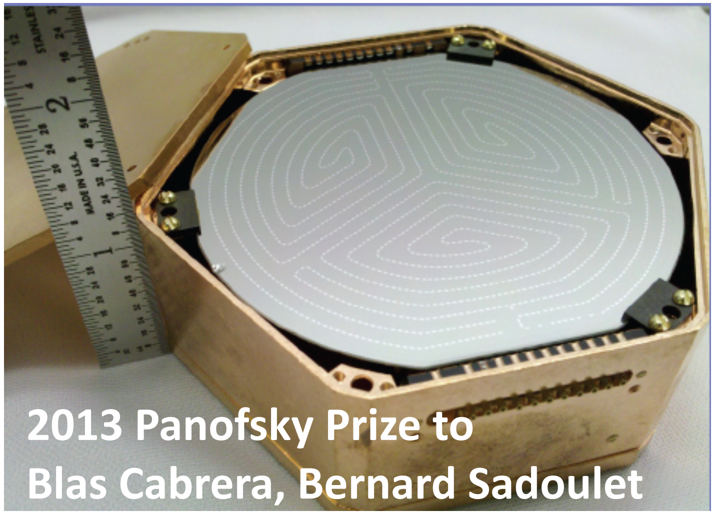
- Dark Matter
- CMB
- Effective number of neutrinos
- Σm_ν
- Dark Energy, w
- Inflation & GUT scale physics
- $0\nu\beta\beta$-decay
- Relic neutrinos
- Absolute neutrino mass
- Spectroscopic galaxy information

Superconducting Detectors and Dark Matter

- Transition Edge Sensor (TES) invented by HEP for Dark Matter studies
- Advances require enhanced sensitivity
  - Increasing target mass (bigger and more detectors)
  - Lowering energy threshold
- If a signal were observed, how to proof beyond doubt that it is dark matter?

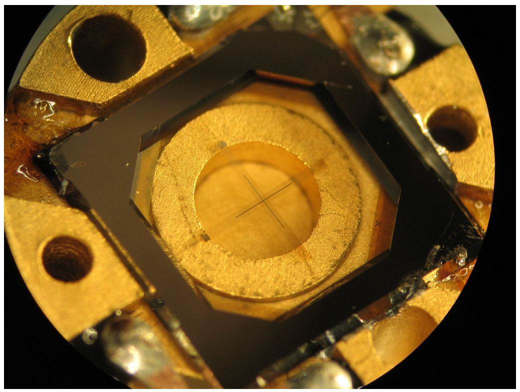




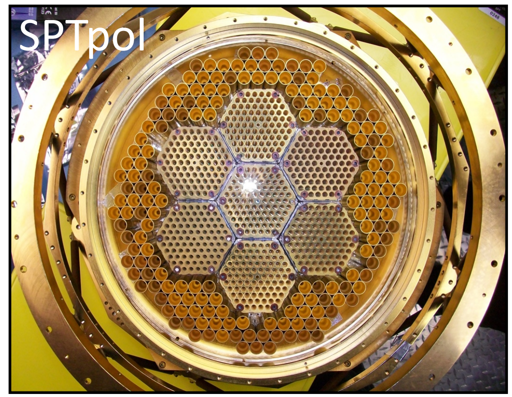


Superconducting Detectors and CMB

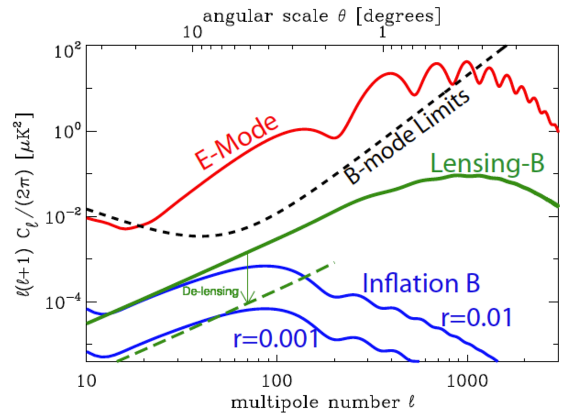
- Measuring the cosmic microwave background radiation (mm wave photons) with TES detectors. Recently measured B-mode polarization ! (arxiv:1307.5830)



Superconducting TES

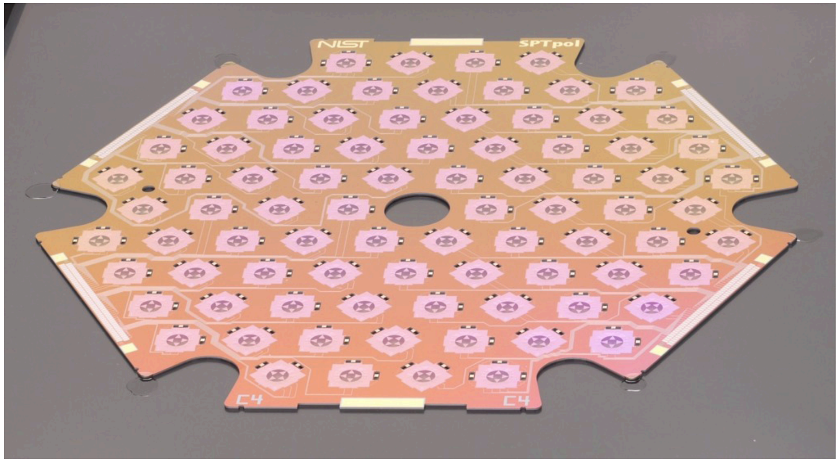


Focal Plane



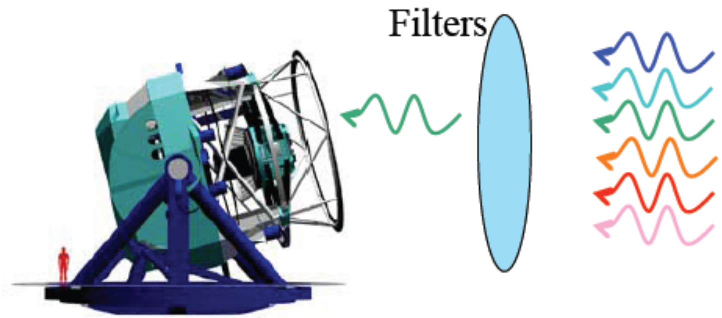
Multipole Power Spectrum

- Can’t change flux of energy from the cosmos! Can only change instrument.
  - Increase spatial instrumentation (large arrays)
  - Increasing energy bandwidth
  - Increasing readout throughput



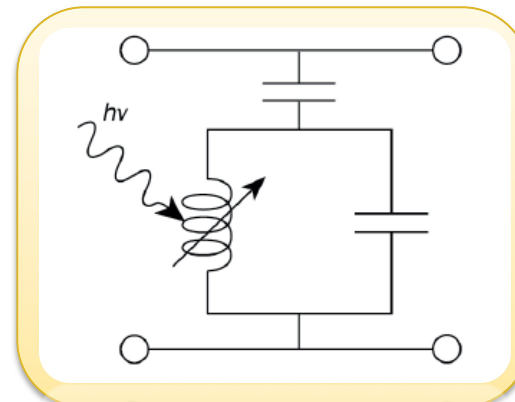
Superconducting Detectors and Dark Energy

- Wide-area optical surveys for cosmology use filters, which is an untenable proposition for the future

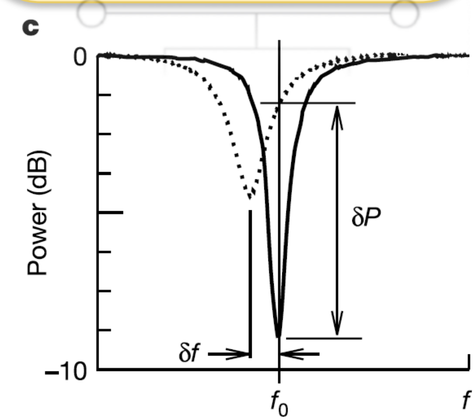


- Determination of Photo-Z is critical for addressing many questions in cosmology

- A new technology, Kinetic Inductance Detectors, could address this issue
  - The kinetic inductance of the superconducting strip is inversely proportional to the density of Cooper pairs and thus the color of the photon

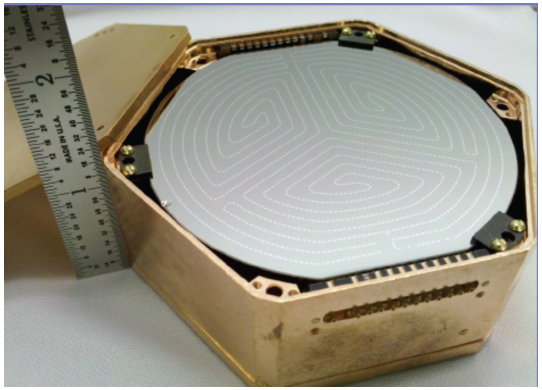


- Development of this technology, or spectral sensitive CCDs, would be truly transformational: simultaneous imaging and spectroscopy



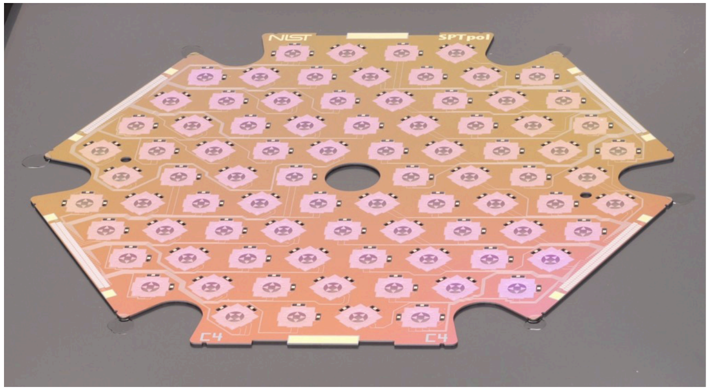
Cross Cutting Development

Dark Matter



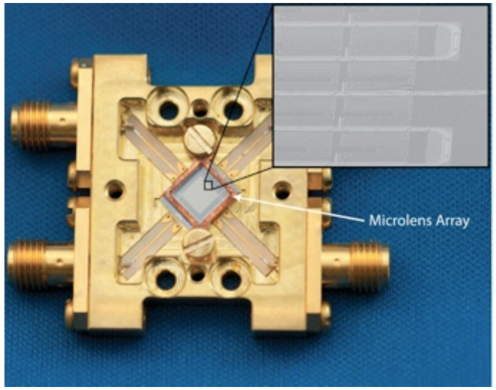
- Reduce threshold
- Increase mass

CMB



- Larger Focal Plane
- Increase optical bandwidth

Dark Energy

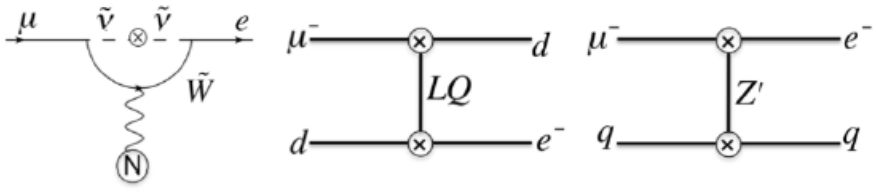


- Imaging and Spectral sensitivity
- Extend IR sensitivity

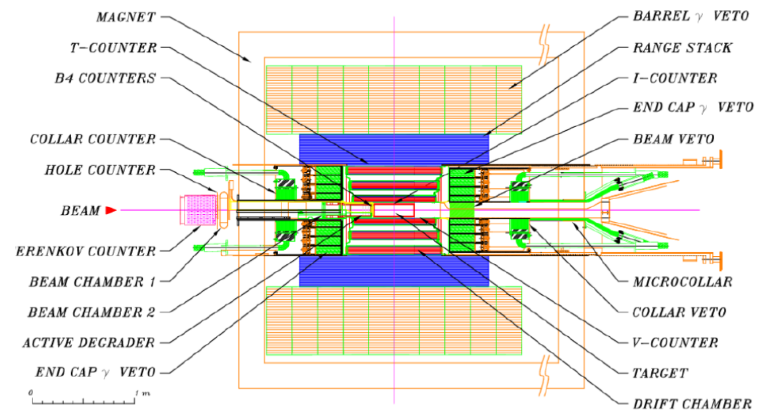
Cryogenic systems that use multi-disciplinary skills and resources:

Thin film deposition
Micromachining
Microwave electronics

Calorimetry and Rare Decays



Mu2e experiment uses stopped muon beam to resolve $\mu^- N \rightarrow e^- N$ decay



ORKA experiment uses stopped Kaon beam to resolve $K^0 \rightarrow \pi^0 \nu\nu$ from background

- Requires cost-effective calorimeters with good e/γ pointing and time of flight: <20mrad, 10ps and good energy resolution for low momenta

Crystal (doping)	NaI (Tl)	CsI (Tl)	CsI	BaF_2	BGO	LYSO (Ce)	PWO	PbF_2
Decay Time (ns)	245	1220	30 6	650 0.9	300	40	30 10	?

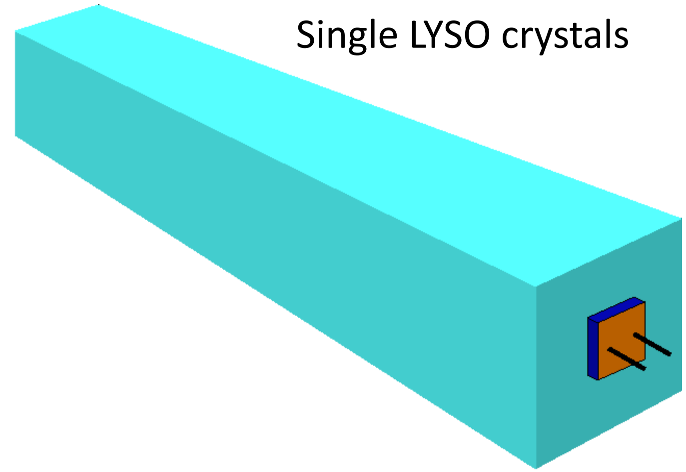
Calorimetry and Forward Physics

- Forward EM calorimeter of CMS will not survive HL-LHC

- Development of cost-effective radiation hard alternative: LYSO crystals with effective doping

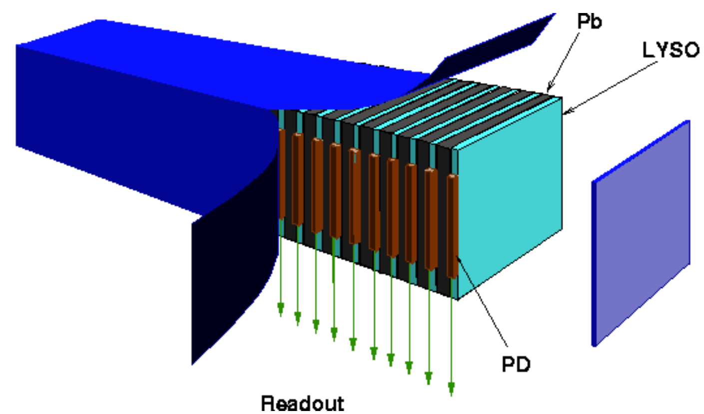
- Two options being considered:
  - Single Crystals with photodetector readout
  - Sampling calorimeter with photodetector readout or WLS fibers

Single LYSO crystals



Expected Crystal Cost: ~$90M@$30/cc

LYSO sampling calorimeter



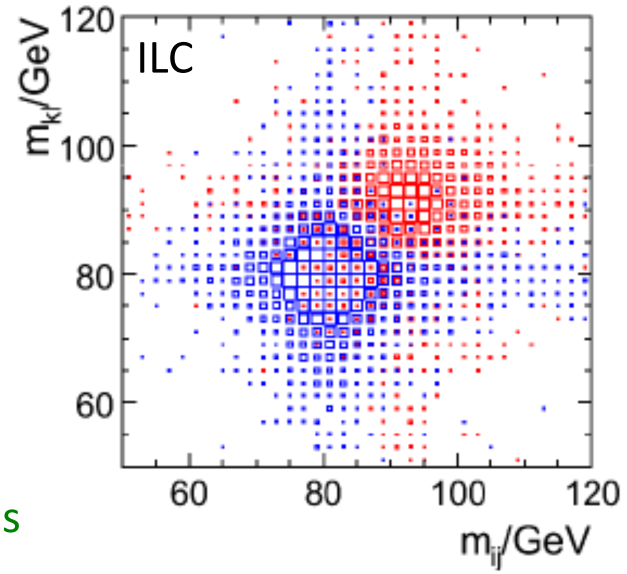
Expected Crystal Cost: ~$18M@$30/cc

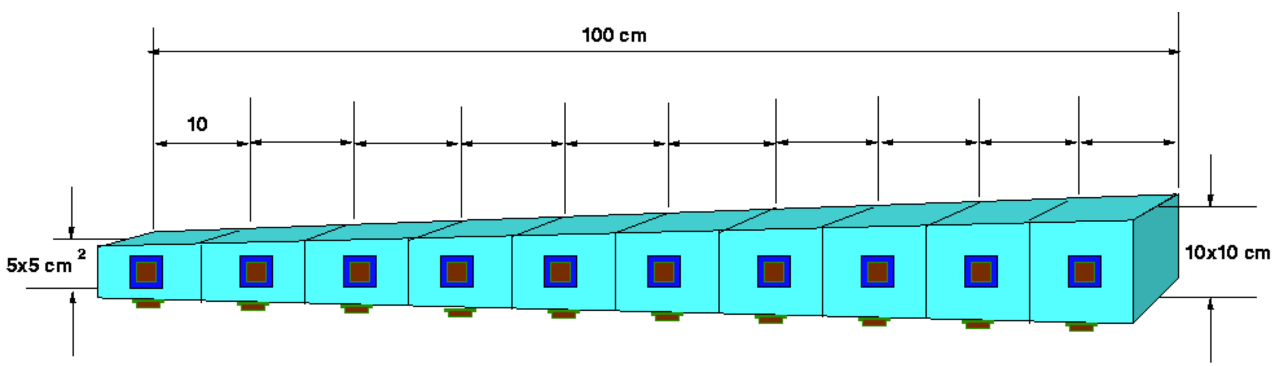
Calorimetry and Lepton Colliders

- Lepton Collider goal of 3% jet energy resolution to resolve hadronic decays of W and Z
- Obtained through Particle Flow

- Can hadron calorimetry be developed with resolution similar to electromagnetic calorimetry?

- Concept of total absorption calorimetry that distinguishes between Cherenkov and scintillation light

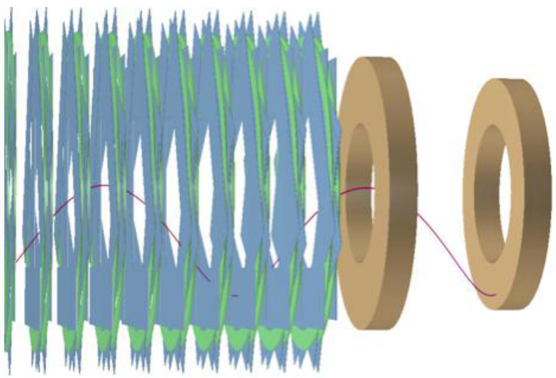




BSO candidate crystal for having scintillation and Cherenkov light

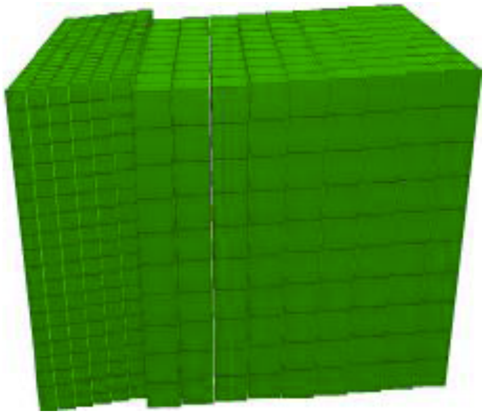
Cross Cutting Development

Rare Decays



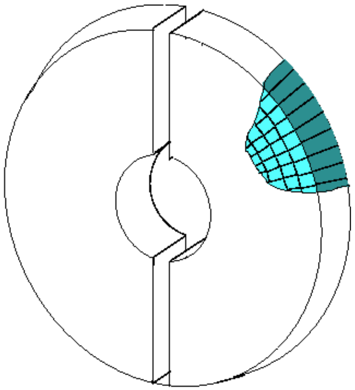
- Excellent timing
- Excellent pointing

Lepton Collider



- Scintillation and Ckov discrimination
- Cost-effective

LHC

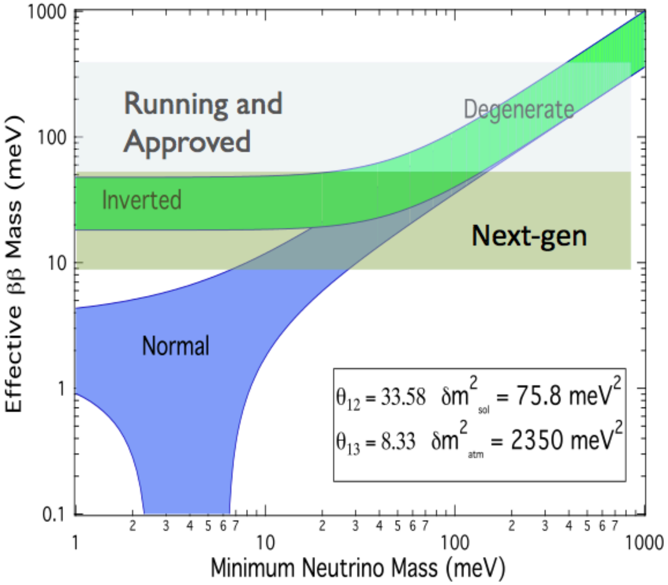


- Radiation hardness
- Cost-effective

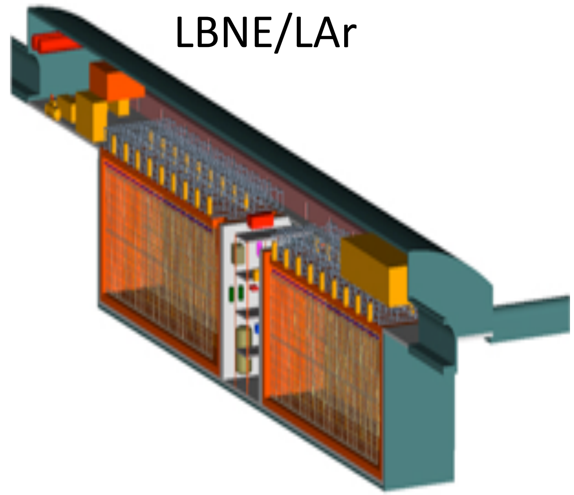
Crystal development

Scintillation centers at right wavelength
Photo-Readout
Radiation Hard
Cost-effective

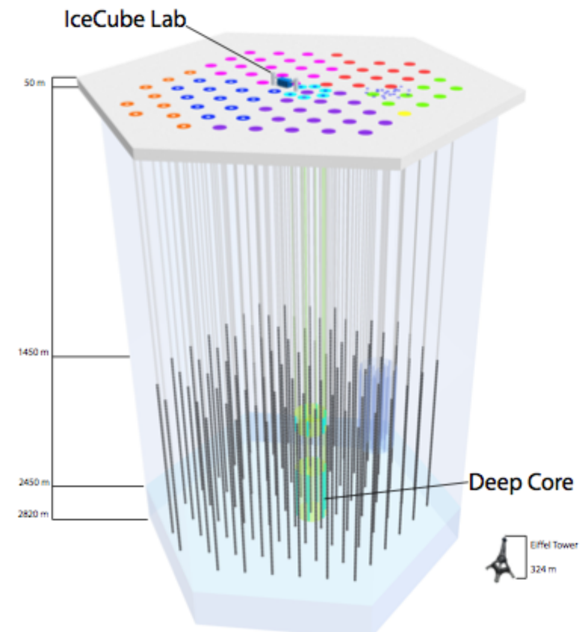
Cross Cutting Detector …

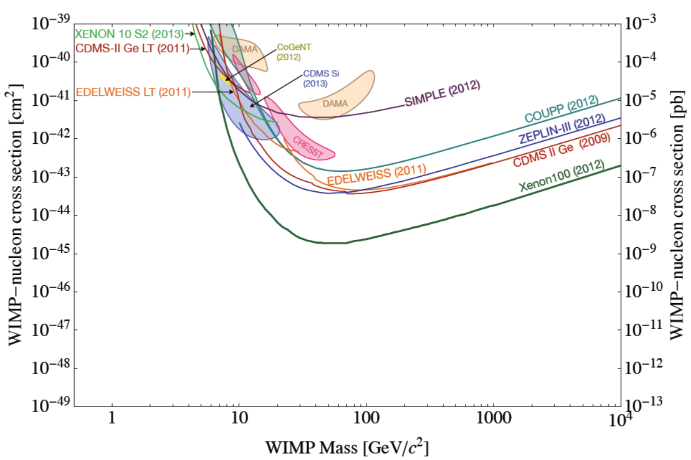


LBNE/LAr



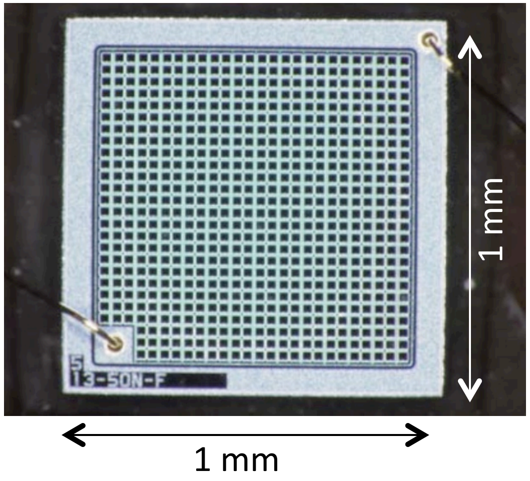
IceCube/Pingu





Photodetectors

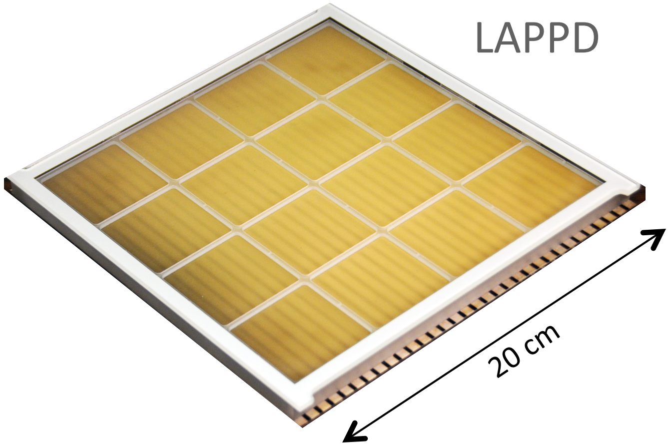
- Compact Silicon Photo-Multiplier (SiPM)
  - single-photon sensitivity
  - Experiments want large arrays with fast sophisticated front-end for signal discrimination, timing and background rejection
  - ILC imaging calorimeters already deploy 10k SiPMs
- Replacement for expensive PMTs
  - Large area coverage, high QE
  - Radiopure detectors
  - Different wavelength sensitivity (LAr: 128 nm)
  - Fast timing (ps or less)



Exp.	# tubes	size
JUNO	15,000	20”
HyperK	99,000	20”
LENA	30,000	12”
SNO	9.500	8”

... + many more

LAPPD



High Luminosity LHC

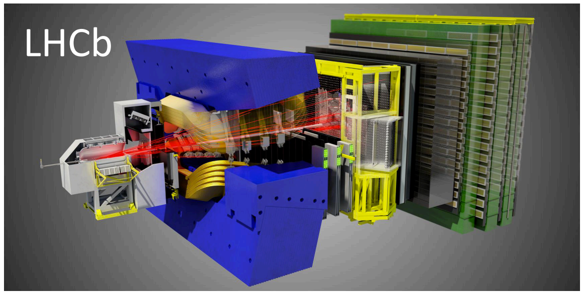
- Maintain the LHC detector performance goals at the higher luminosities
  - Trigger challenge
  - Vertex identification, fast timing
  - Tracking challenge in forward region and forward calorimetry to η=4 for WW scattering and HH studies
  - Radiation hardness
  - Computing challenge: reconstruction of more complex events

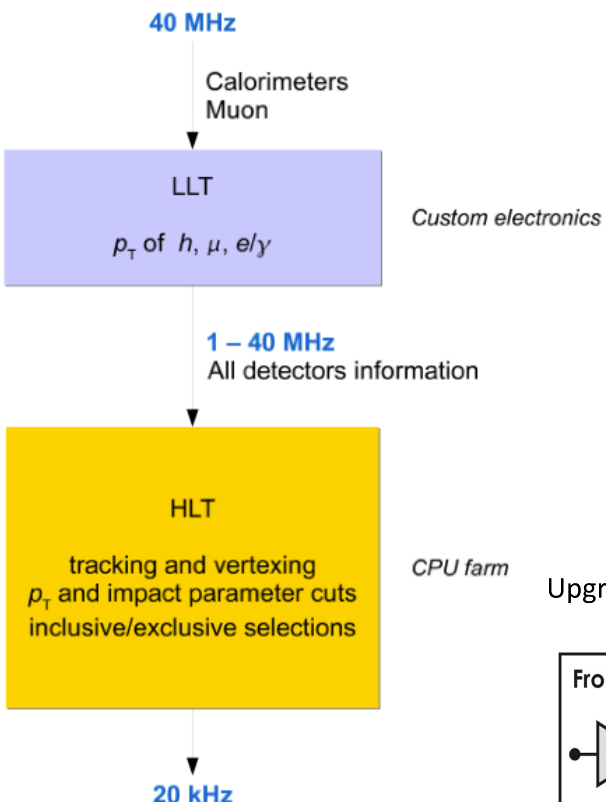
	LHC (Run 1)	LHC (Run 3)
Beam Energy	4 TeV	~ 7 TeV
Luminosity	$7.7 \times 10^{33}/cm^2/s$	$5 \times 10^{34}/cm^2/s$
Integrated Lumi	24/fb	3000/fb
# interactions / X	≈20	≈140
Bunch spacing	50 ns	25 ns
Radiation dose (5cm)	3×10^4 Gy	5×10^6 Gy

Trigger and DAQ

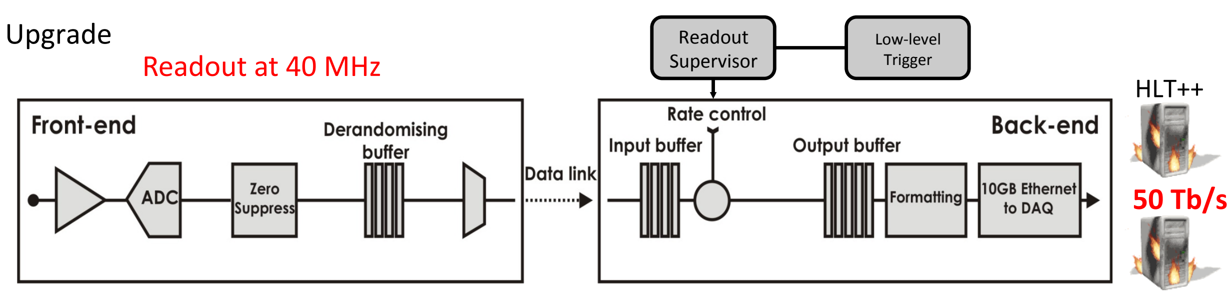
- **HL-LHC Experiments Triggered**
  - Network:
    - 1 MHz with 10 MB: aggregate network load 80 Tbps
    - Links for Event Builder ~10,000 links of 10 Gbps
  - HLT computing:
    - 10 times current rate, factor two in pile-up
    - Factor 20 compared to today
- **HL-LHC Experiments Triggerless**
  - Network
    - 40 MHz with 10 MB: aggregate network load ~3,000 Tbps
    - Links for Event Builder ~10,000 links of 100 Gbps
    - Readout Cables: Mass budget !
  - HLT computing:
    - 400 times current rate, factor two in pile-up
    - Factor 800 compared to today. Impossible?
- **LBNE: Triggerless up to 0.8 Tbytes/s**
- **LSST: 3 Gbytes/s**

LHCb: Triggerless



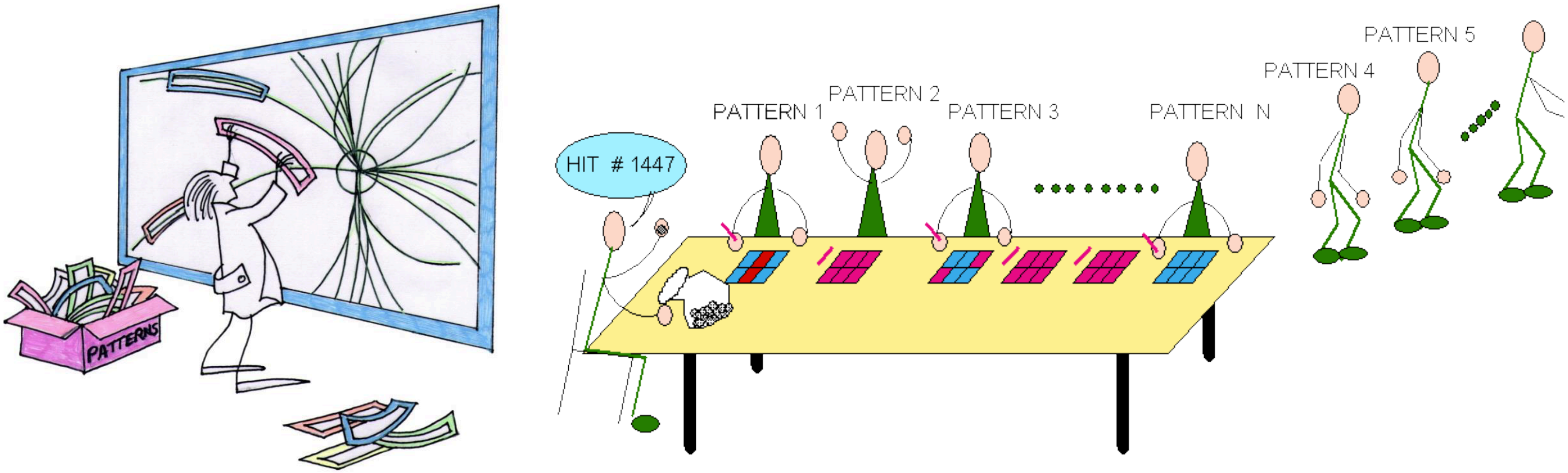


- LHCb operation at 2 x $10^{33}/cm^2s$, 25 ns bunch crossing
  - Currently at 4 x $10^{32}/cm^2s$, pile up 4 max!
  - Integrate 50 fb^{-1}
- Provide 40 MHz readout: digest data rate ~ 3000 Tbps
  - ~10,000 links of 100 Gbps
- Execute the whole trigger on the (HLT) CPU farm
  - ~800 times current processing power
- Integrate
  - VELO + Silicon Tracker
  - Scintillating Fiber Tracker
  - RICH, Calorimeter, Muon



ATLAS: Fast Track Trigger

- To maintain physics reach, need track information at Level 1
- Possible approach: associated memories



- Simulate all possible track patterns with full ATLAS simulation
  - A pattern consists of a Super-Strip in each layer (10s of pixels/strips wide)
- Store patterns in HEP-specific content addressable memory (CAM) custom chip
- About one billion patterns need to be stored (LS2)
- CAM: one hit presented to all patterns simultaneously!
- When hits have all been sent off detector, pattern recognition is done.

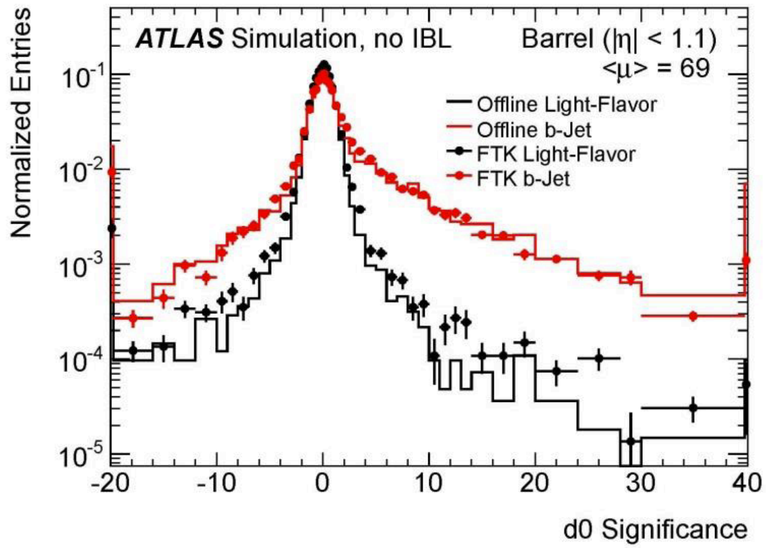
Massive Parallelism

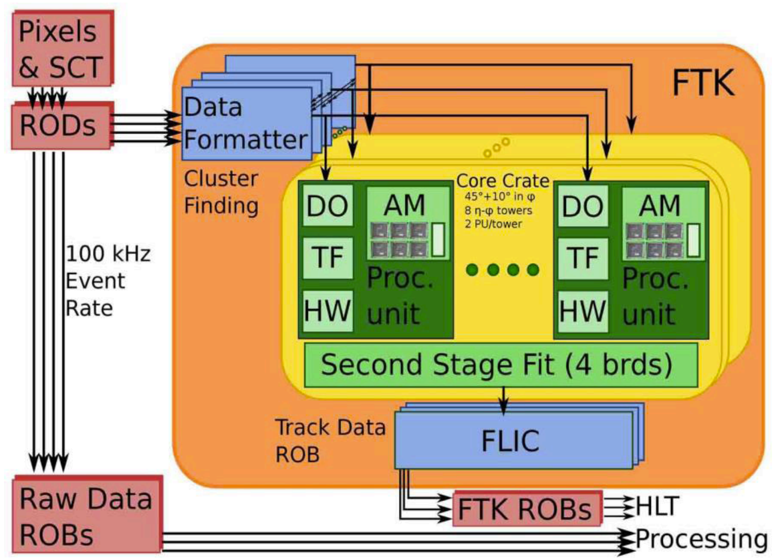
- System requires 16,000 custom made AM chips, each holding 128,000 patterns
- All silicon hits transferred to Track Trigger each bunch crossing; 40 Gb/s per board

- System highly adaptable
- Extrapolation to HL-LHC: > 10G patterns needed?

- Challenges and new Ideas needed:
  - L1 complexity vs. HLT input rates (GPUs)
  - L1 Trigger Latency
  - L1 Track Triggers
  - High bandwidth & dense optical interconnects
  - New packaging & interconnect technologies: ATCA, µTCA, RCE
  - Interdetector communication

ttbar events, Ecms = 14 TeV

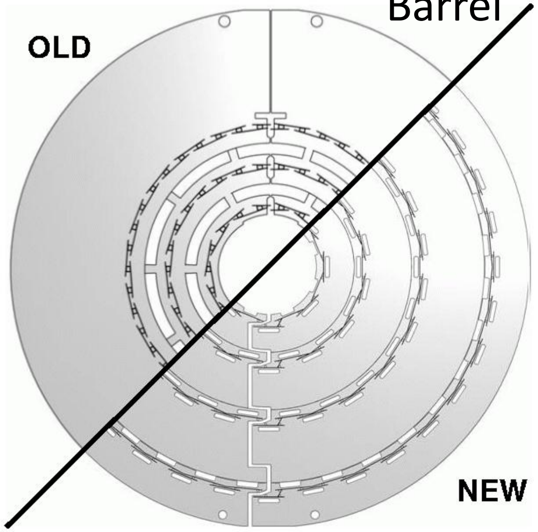




Vertexing and Tracking

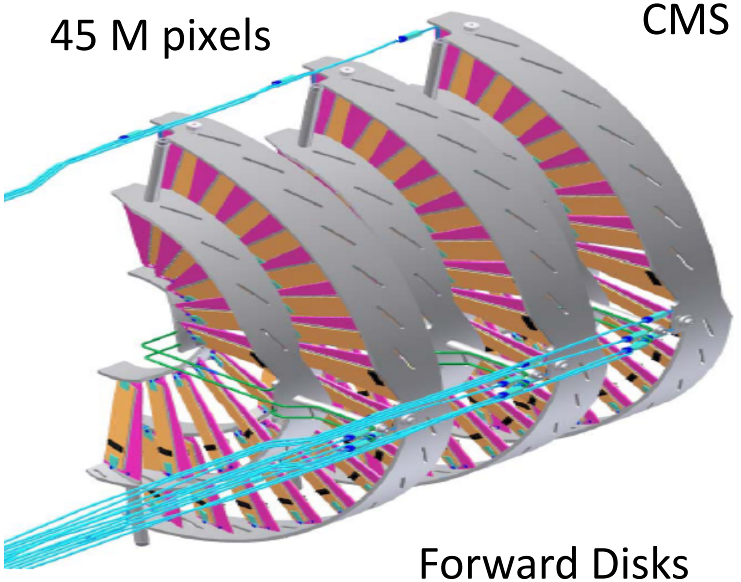
- Low mass, pixelated radiation hard detector are needed for the LHC experiments, ILC, CLIC, muon collider, B and tau factories and Rare Decay experiments to arrive at the physics
- Often requires sophisticated in-pixel processing such as time stamping, cluster finding or inter-cell hit correlation
- Often have conflicting demands
- Technologies
  – Silicon with electronics integration
  – Commercial wafer-scale processes
  – Straw Trackers
  – Micro-pattern gas detectors

Barrel



45 M pixels

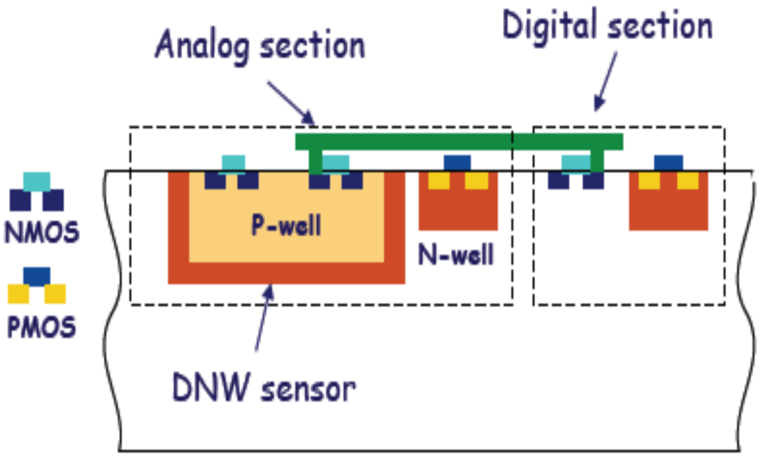
CMS



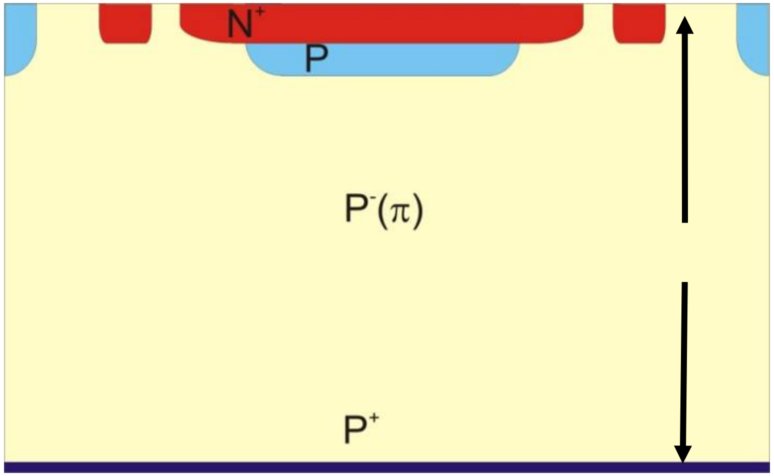
Forward Disks

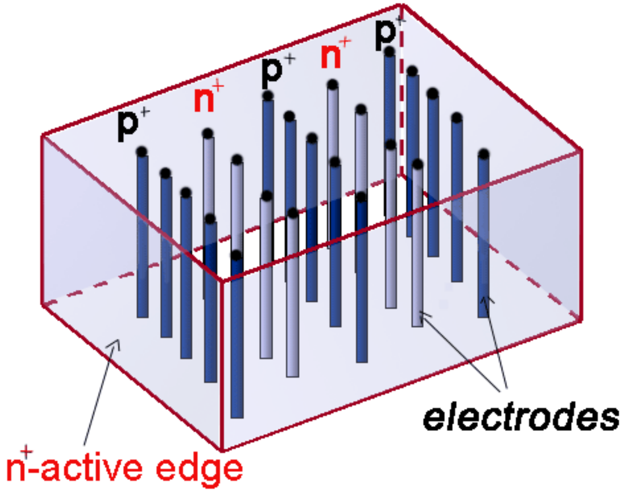
Vertex Detector Developments

- In quest for low-mass, low-power, ... actively pursuing Monolithic Active Pixel Sensors
  - Charge sensing and first level front-end electronics integrated in sensor



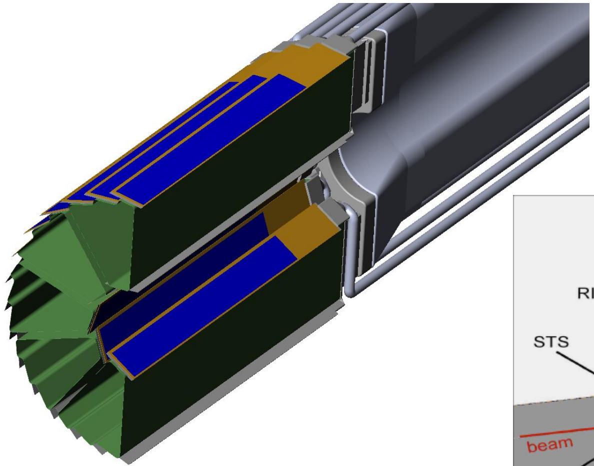
- Development of "4D Si Sensors": very fast (10ps) timing information through thin planar or columnar sensors with intrinsic gain



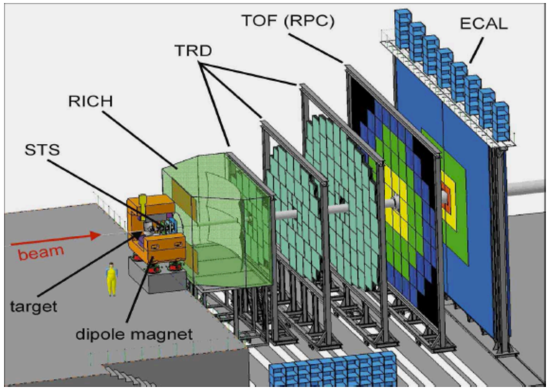


Vertex Detector Developments

- CMOS Pixel Sensors (CPS)

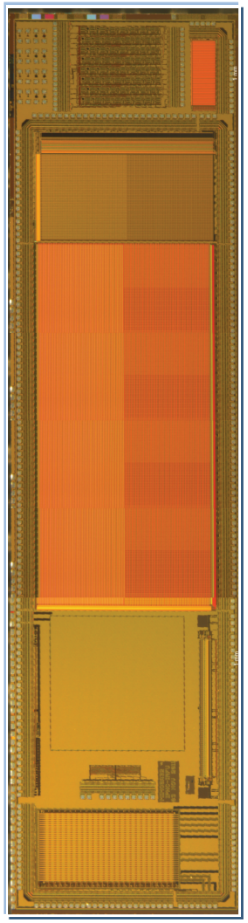


Heavy flavor tracker for STAR experiment at RHIC (BNL)



PoS (BORMIO2010) 041

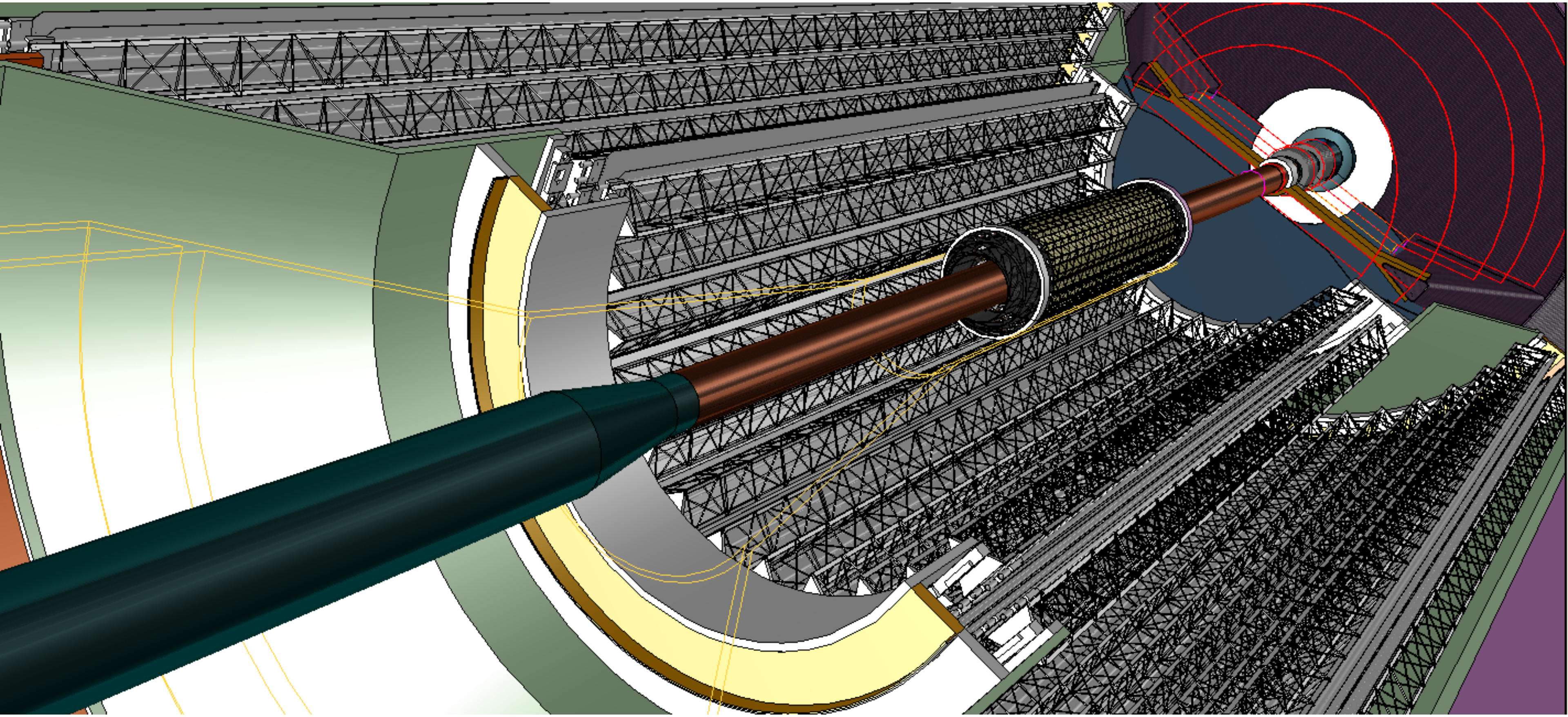
Micro Vertex Detector for CBM experiment at FAIR (GSI)



MISTRAL = Mimosa for Inner Silicon Tracker of Alice

Dosimetry for space applications

ALICE Vertex Detector (LS2)

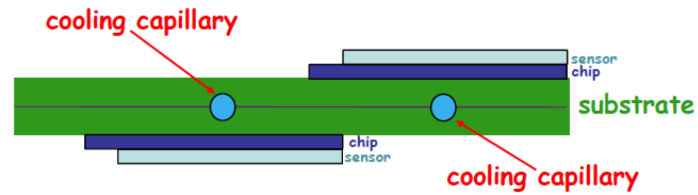


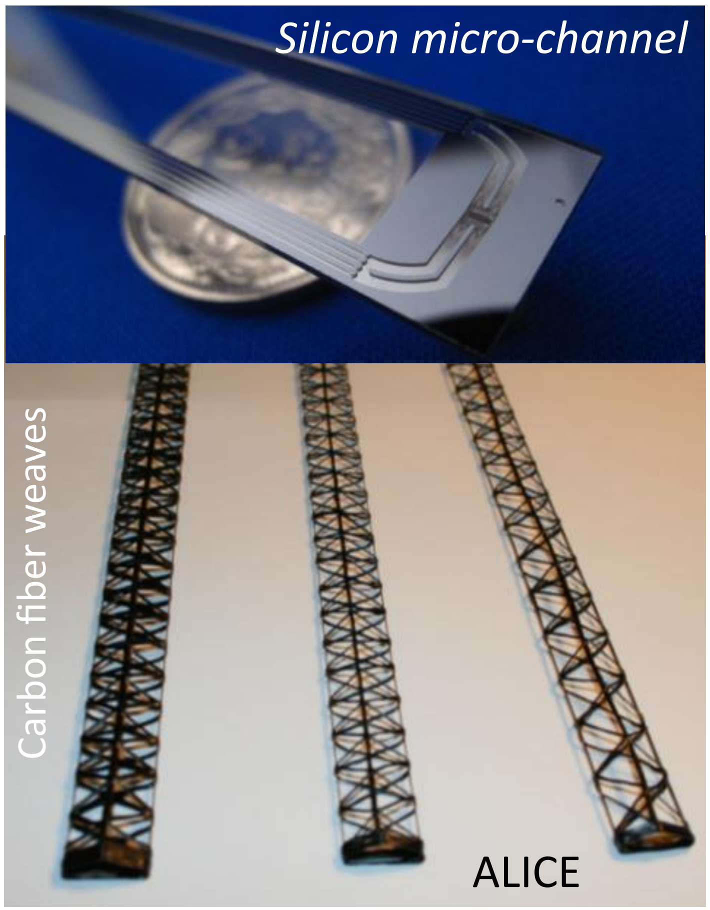
- Seven Pixel Layers (3 + 4)
- R from 22mm – 430 mm
- Mass budget 0.3% Xo inner layers
- Data volume ~ 1 Tb/s

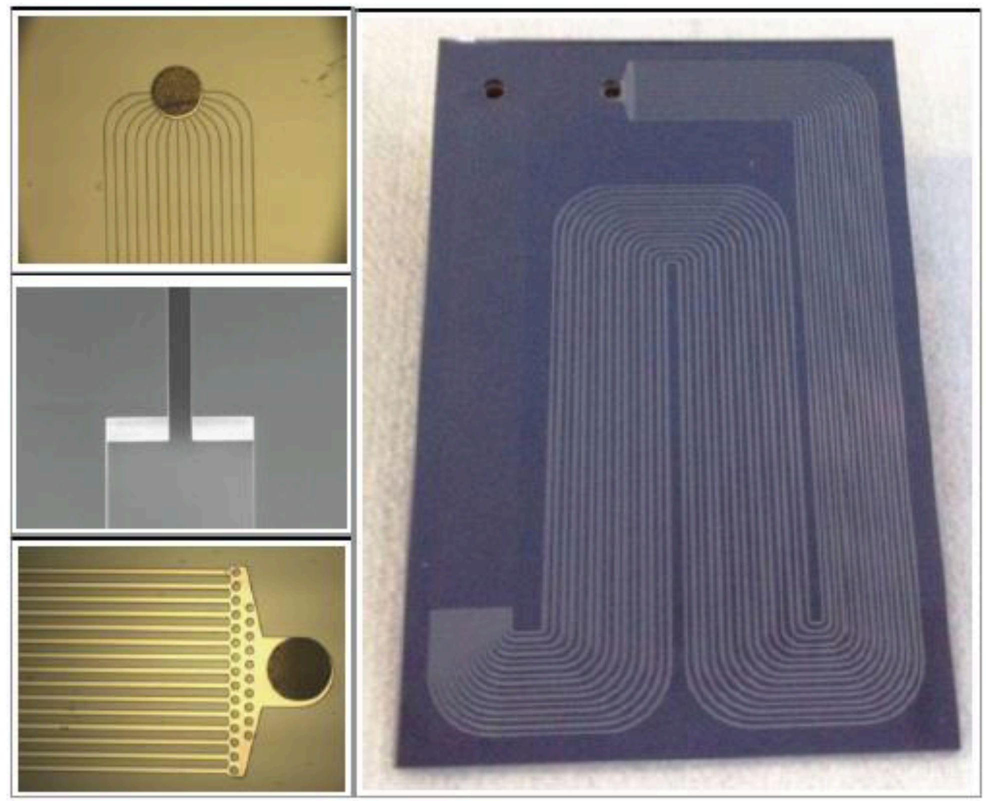
One billion pixels

Power and Low Mass Structures

- Integrated CO_2 cooling at 50 psi



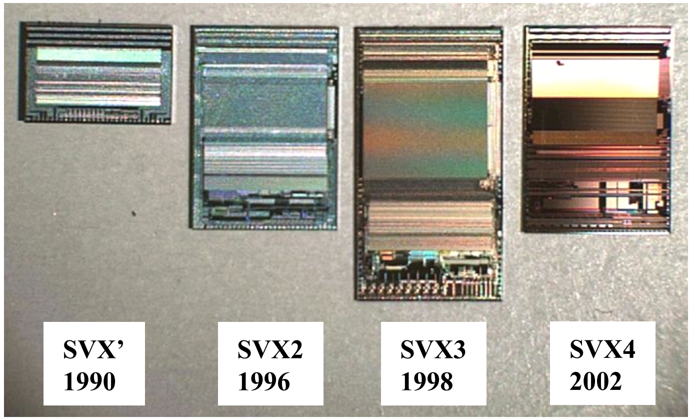




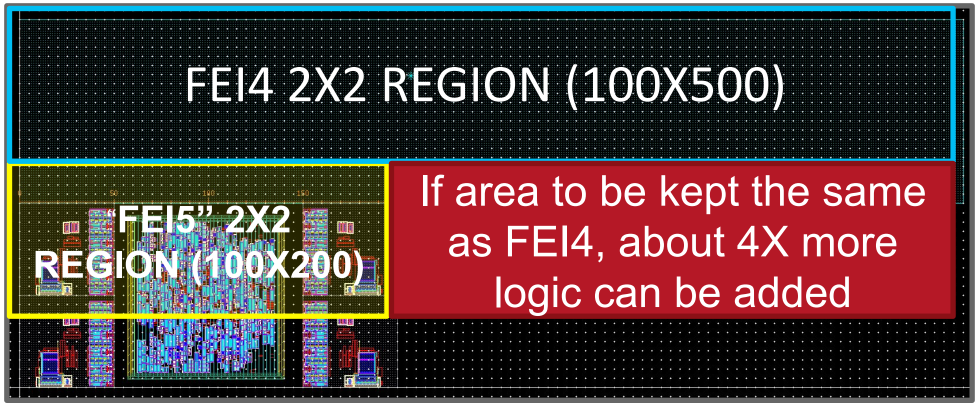
LHCb

Application Specific IC

- Particle Physics has led the way in adopting ASICs into their experiments
- Essential tool to get at the science
- New effort to move to 65nm process (CERN RD53 collaboration)
- Provides for new opportunities in powerful designs!



- ASIC-related R&D required in a number of areas to improve science output or simply make possible future experiments at the various frontiers:
  - High-speed waveform sampling
  - Pico-second timing
  - Digitization and digital data processing
  - High rate data transmission
- Challenges:
  - Radiation hardness, low radioactivity
  - Low power, power distribution
  - Low temperature operation
  - Complexity, Cost

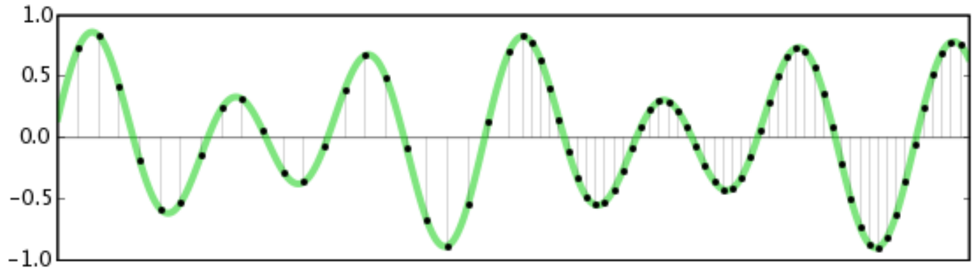


LHC Pixel Chip Generations

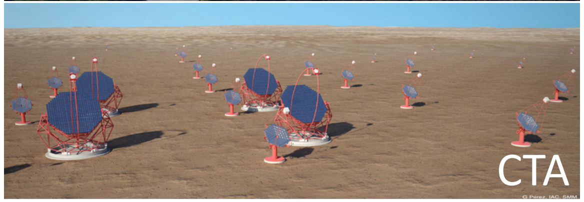
Generation	Current FEI3, PSI46	Phase 1 FEI4, PSI46DIG	Phase 2
Pixel size	100x150um^2 (CMS) 50x400um^2 (ATLAS)	100x150um^2 (CMS) 50x250um^2 (ATLAS)	25x100um^2 ?
Sensor	2D, ~300um	2D+3D (ATLAS) 2D (CMS)	2D, 3D, Diamond, MAPS ?
Chip size	7.5x10.5mm^2 (ATLAS) 8x10mm^2 (CMS)	20x20mm^2 (ATLAS) 8x10mm^2 (CMS)	**> 20 x 20mm^2**
Transistors	1.3M (CMS) 3.5M (ATLAS)	87M (ATLAS)	**~1G**
Hit rate	**100MHz/cm^2**	**400MHz/cm^2**	**1-2 GHz/cm^2**
Hit memory per chip	0.1Mb	1Mb	~16Mb
Trigger rate	100kHz	100KHz	200kHz - **1MHz**
Trigger latency	2.5us (ATLAS) 3.2us (CMS)	2.5us (ATLAS) 3.2us (CMS)	6 - **20us**
Readout rate	40Mb/s	320Mb/s	**1-3Gb/s**
Radiation	1MGy (100Mrad)	3.5MGy (350Mrad)	**10MGy (1Grad)**
Technology	250nm	130nm (ATLAS) 250 nm (CMS)	**65nm**
Architecture	Digital (ATLAS) Analog (CMS)	Digital (ATLAS) Analog (CMS)	Digital
Buffer location	EOC	Pixel (ATLAS) EOC (CMS)	Pixel
Power	~1/4 W/cm^2	~1/4 W/cm^2	**~1/4 W/cm^2**

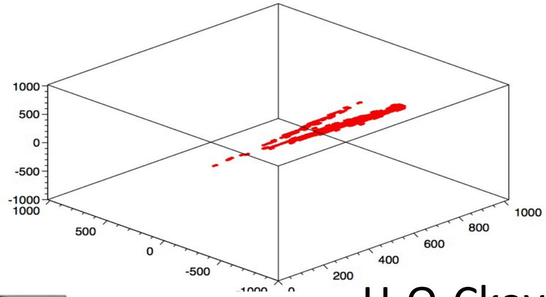
Timing through Waveform Sampling

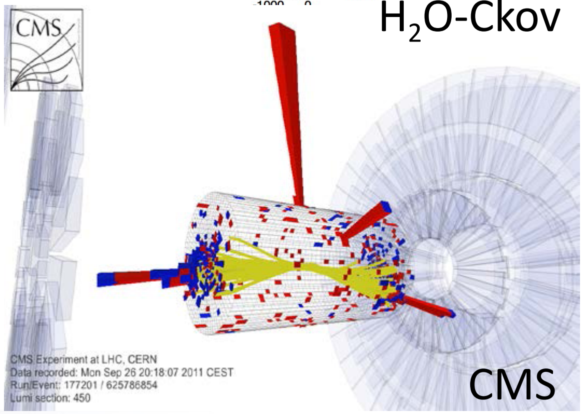
- Precision timing very powerful discriminant for broad spectrum of experiments:
  - Directionality and background rejection for UHE γ-rays
  - Background rejection for noble liquid detectors
  - Background rejection for water Cherenkov detectors
  - Vertex association for collider experiments
  - Extinction for study of rare decay processes



- Array of waveform sampling ASICs designed: IRS3b, TARGET, BLAB, PSEC4, ...
- Precision timing available at Level 1 trigger, with integrated electronics?
- What limits timing? 100fs possible?

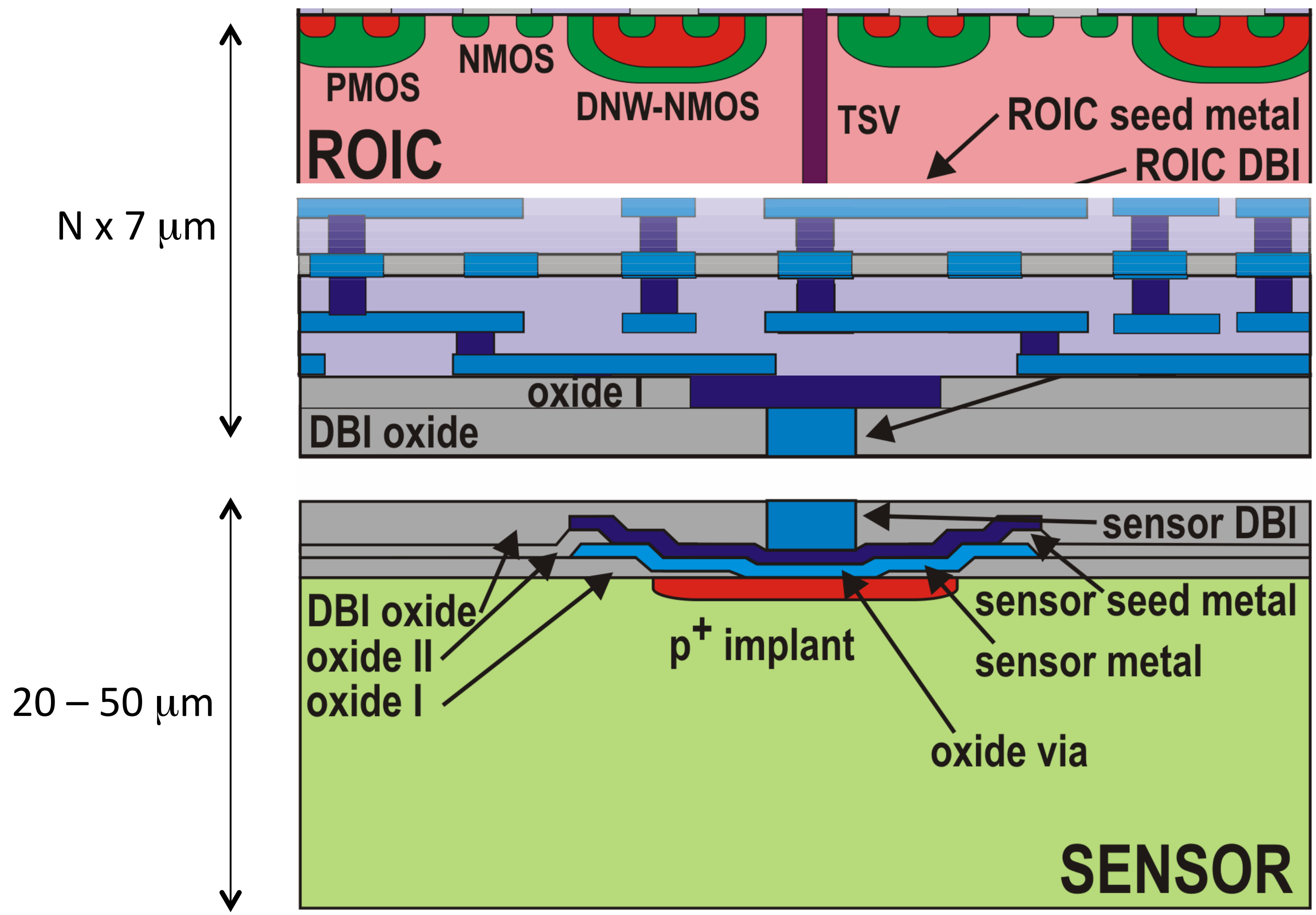






The Third Dimension

Combine Sensing Medium and multiple (N) ASICs into one unit: 3D silicon

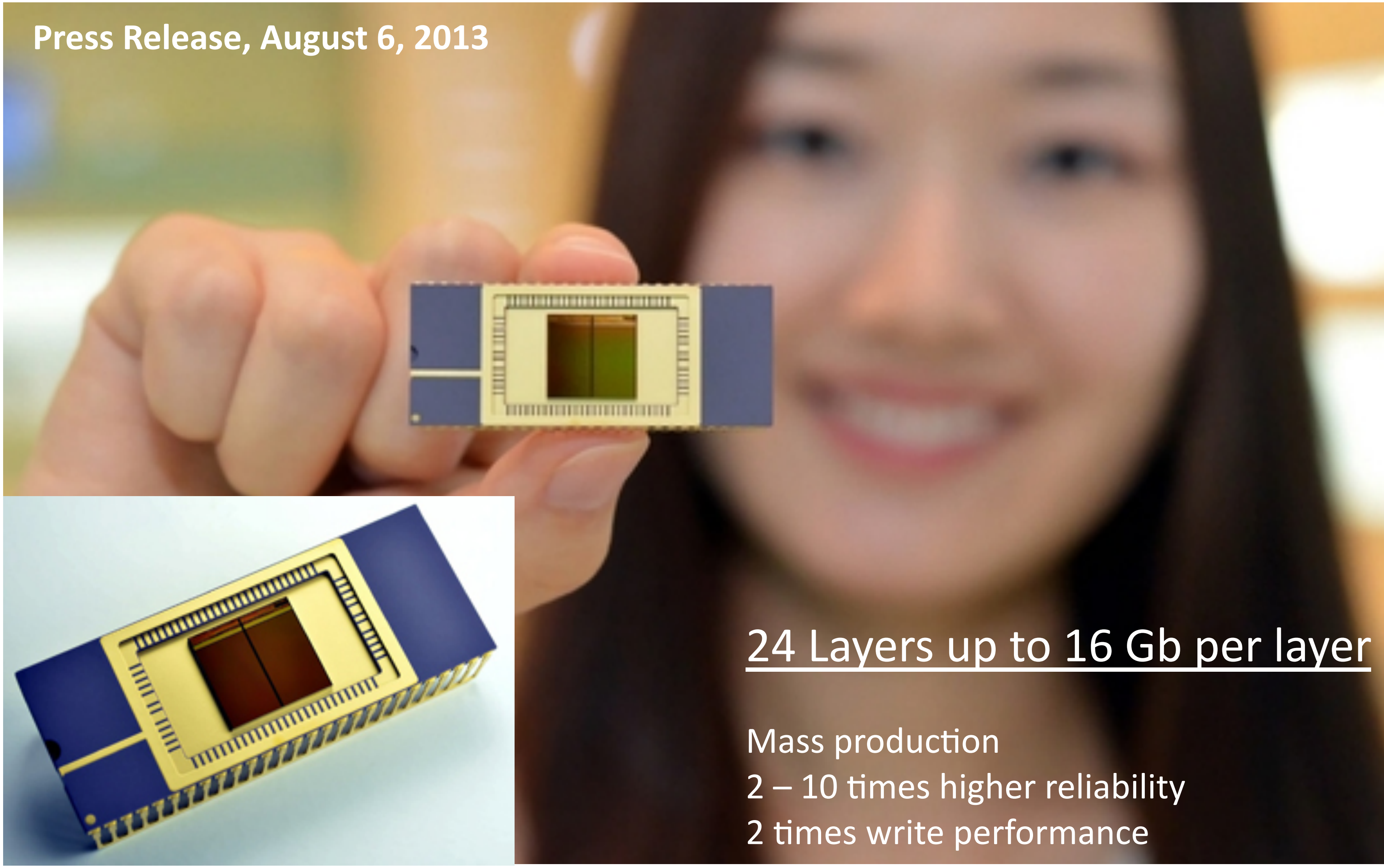


Dope ....

Proposition 19 ?

SAMSUNG: Vertical NAND Flash Memory

Press Release, August 6, 2013



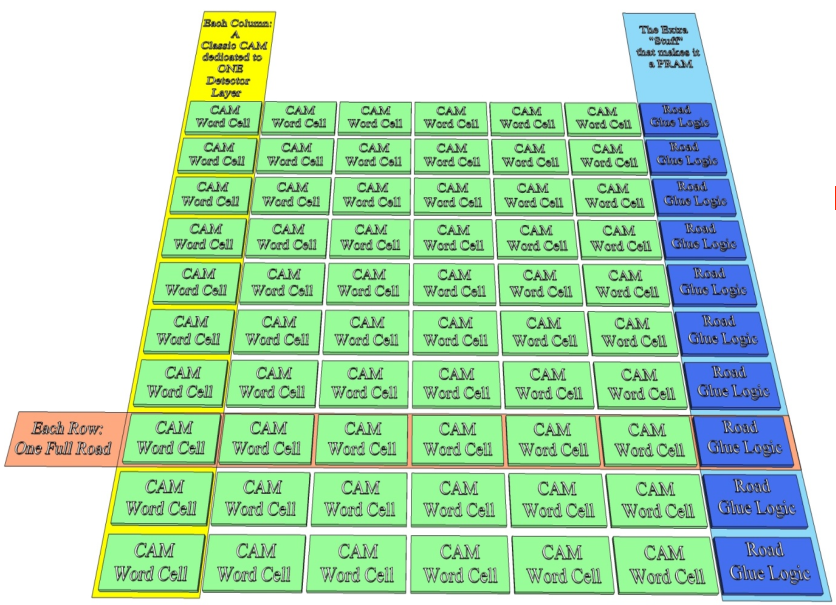
<u>24 Layers up to 16 Gb per layer</u>

Mass production
2 – 10 times higher reliability
2 times write performance

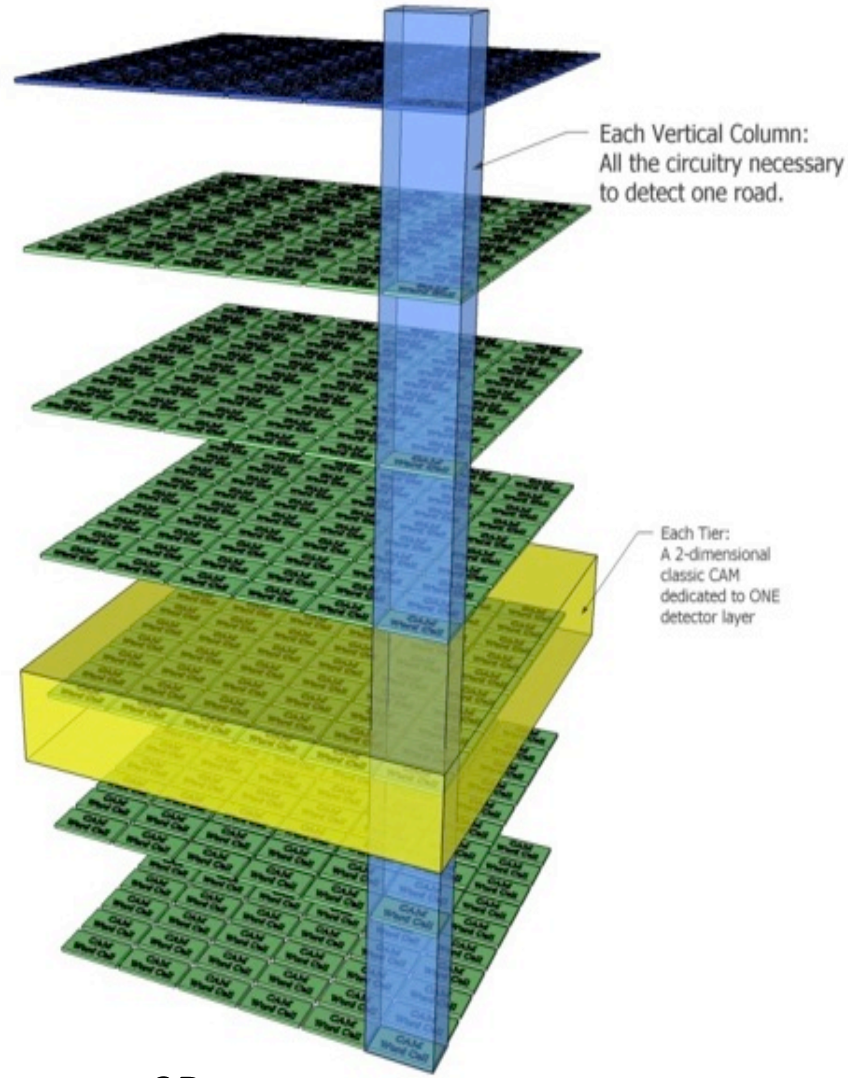
http://www.samsung.com/global/business/semiconductor/news-events/press-releases/detail?newsId=12990

LHC Trigger

- Silicon Track Trigger based on Content Addressable Memories ideally suited for adoption to 3D silicon structures: Each tracker layer corresponds to a layer in the silicon IC



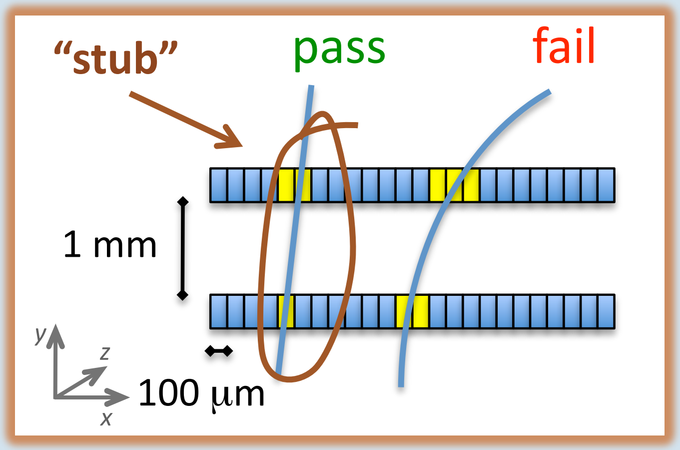
2D



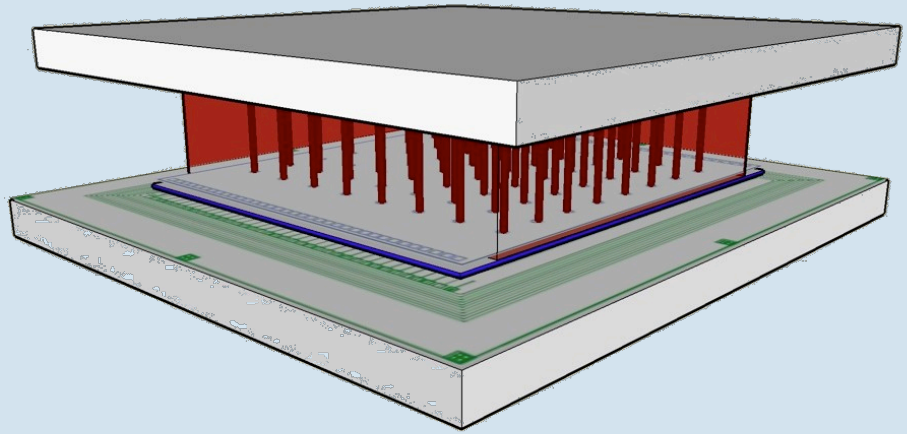
3D

Track Trigger

- HL-LHC: pile-up O(140) @ 5×10^{34} cm^{-2} s^{-1} leveled with 25 ns bunch crossing
- True trigger challenge to make tracking information available at Level 1



Mitigation through new trigger primitives



CMS Tracker Upgrade

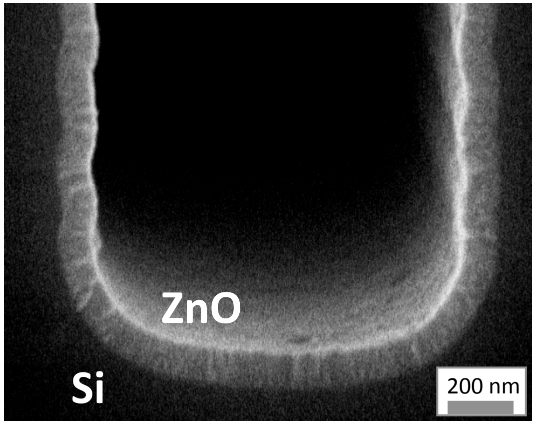
- Combine information from two closely spaced layers to form track stubs as trigger primitive
- Key technology is Through Silicon Via (TSV)

Cross Cutting Developments

- Taking advantage of developments in other areas of science and industry

Flexible circuit boards

Wavelength shifting through Quantum Dots



Materials by design through Atomic Layer Deposition

- **Possible Advances in Detectors ...**

- Possible Advances in Detectors ...

- Countless advances in detectors are possible, only limited by your imagination.
- And, they are urgently needed for the field to reach the science goals and to stay competitive.

- Conclusion of Snowmass for Instrumentation ...

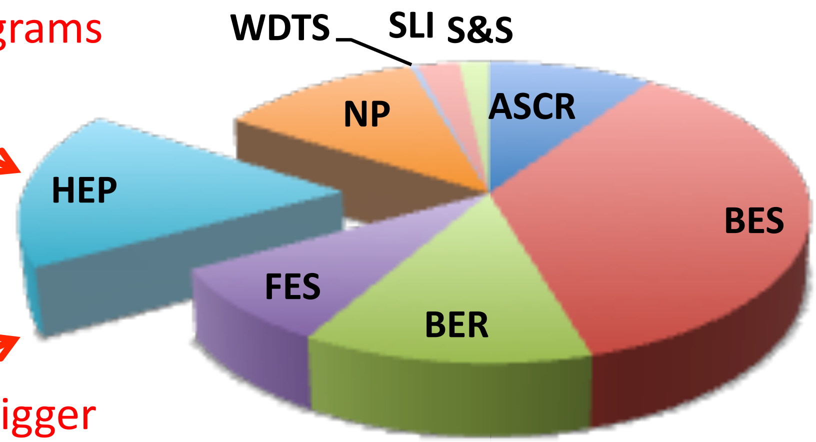
Instrumentation Frontier

- Our vision is for the US to have an instrumentation program for particle physics that:
  - Enables the US to maintain a scientific leadership position in a broad, global, experimental program
  - Develops new detection capabilities that provides for cutting edge contributions to a world program

Strategic Goals

- Develop more cost-effective technologies with increased reach

Fit more programs into this slice



Office of Science 2013 Budget

Make slice bigger

1. Develop balanced Instrumentation, based on our strengths, aligned with research priorities
2. Balanced funding level between projects and R&D and a program with appropriate "portfolio of risk"
3. Develop process for integrating universities, national laboratories, other branches of science and industry
4. Create opportunities for careers in HEP instrumentation
5. Identify opportunities for technology transfer and collaboration with other sciences

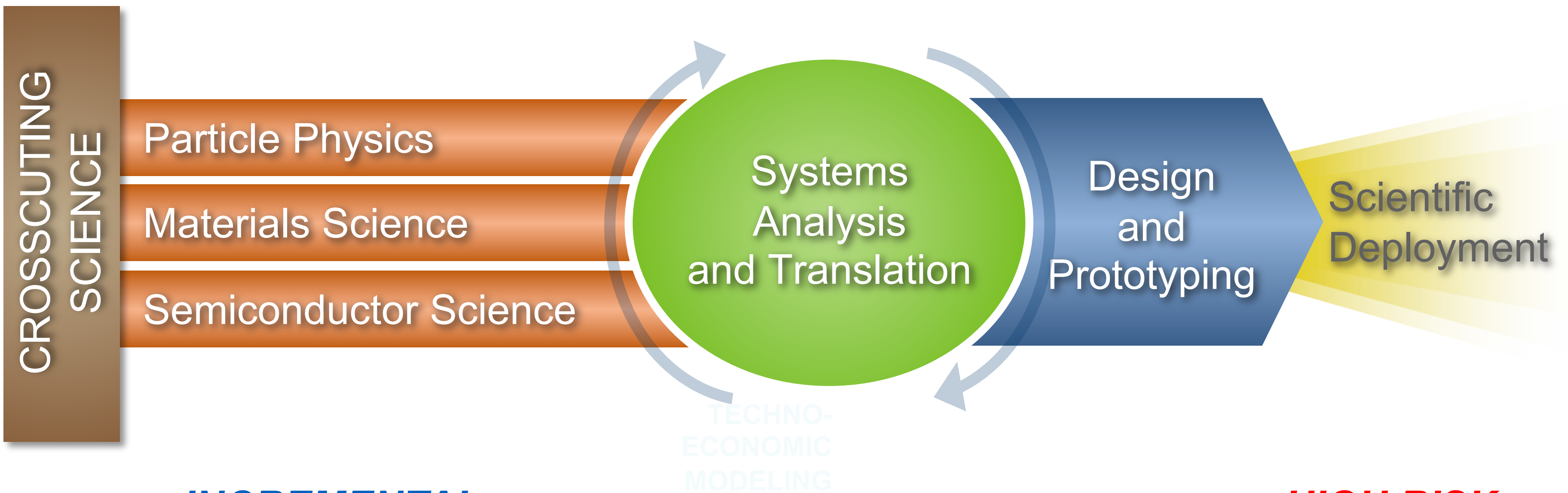
Why an Instrumentation Program ?

- The old paradigm for detector development no longer works
- During economic hard times there is enormous pressure on “discretionary” funding
- Support for new instrumentation development is an investment in the future
- Paradigm altering advances are happening in other branches of science, which hold the potential to lead to transformational new technologies for HEP
- This arguably could not be a more critical time to strategically invest in detector R&D.
- It is imperative that the field takes advantage of these opportunities,
- Supported by the administration (PCAST report)

The opportunity for innovation is tremendous !

Voice of Instrumentation

- Advocate of instrumentation to articulate, promote, coordinate and implement the strategic goals for instrumentation: CPAD



INCREMENTAL CHANGE ← *RISK* → ***HIGH RISK HIGH GAIN***

SHORT TERM ← *TIMESCALE* → ***LONG TERM***

CPAD

CPAD appointed in 2012
http://www.hep.anl.gov/cpad/

Coordinating Panel for Advanced Detectors

Balanced Portfolio of Risk

- R&D is more and more driven by present or incoming experiments with their limiting constraints: schedule and risk
- 2012 European survey shows that 85% of detectors R&D is done within existing experiments
- **Program needed with a balance between evolutionary and revolutionary detector R&D and and appropriate level of 'generic' project related detector R&D**
- **Program to be structured to allow for excellent mistakes**
- **Innovation distinguishes between a leader and a follower**

Innovation Through Partnerships

Materials Science

Nano Technology

Photonics

Electrical Engineering

National Laboratories

The Ames Laboratory — U.S. Department of Energy
Argonne National Laboratory
Brookhaven National Laboratory
Fermilab
INL Idaho National Laboratory — Operated by Battelle Energy Alliance
Berkeley Lab — Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory — Est. 1943
NETL
NREL
Oak Ridge National Laboratory — Managed by UT-Battelle for the Department of Energy
Pacific Northwest National Laboratory — Proudly Operated by Battelle Since 1965
PPPL Princeton Plasma Physics Laboratory
Sandia National Laboratories
SRNL Savannah River National Laboratory — We Put Science To Work
SLAC National Accelerator Laboratory
Jefferson Lab

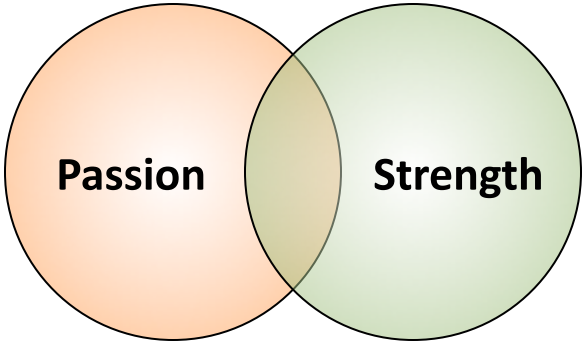
Academia

Industry

RMD A Dynasil Company
ziptronix
INCOM
VOXTEL OPTO

Community

- Key enabler is the (young) physicists
  - Need to provide the challenges
  - Need to provide a career path



Community

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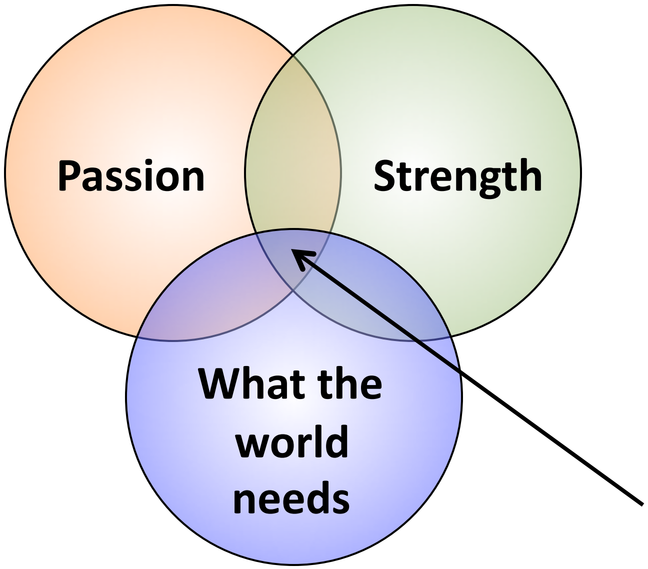


Has to be part of our mission !

- Use our strengths to do what we love ...
- **And** do work worth paying for that solves a problem or helps others
- Instrumentation is the obvious path to address this and provides a means to increase the overall HEP budget

Funding Balance

- What is the right balance between project funding and support for generic detector development ?

- **Would you be willing to invest, say, a penny on the dollar in the development of a potentially transformative technology even if it does not directly benefit your project ?**

You !

- Should be viewed as the "1% Investment" (pay yourself first)

Strategic Themes from Snowmass

- From the plethora of technologies and needs of all the frontiers, identified key candidate areas for strategic investment that could form pillars of a future HEP program

- Criteria applied:
  - Hold promise of substantial cost saving
  - Hold promise of being breakthrough technology
  - If successful, should have enormous impact on the science reach
  - Based on the existing strengths and capabilities in the country
  - Preferably have impact in fields other than HEP

Summary Strategic Themes

Instrumentation Area	Possible Technology	Energy F.	Intensity F.	Cosmic F.	Nucl. Phys.	BES	Applied
Photodetectors	LAPPD or SiPM	✓	✓	✓	✓	✓	✓
Spectral Sensitive Pixels	MKID or Tiered Silicon			✓		✓	✓
Calorimetry	Crystal EM calorimetry, compensating	✓	✓		✓	✓	
Low Background Techniques	Neutron veto detectors Photodetectors, materials			✓	✓		✓
Intelligent Tracking	3D Silicon	✓	✓		✓		
Custom Electronics	Waveform sampling ASIC Cold electronics	✓	✓	✓	✓	✓	✓
Low-mass tracking	Carbon, G-pixel Si, power delivery	✓	✓		✓		
DAQ	ATCA, high-speed optical links	✓	✓	✓	✓		

Grand Challenges

- Suggest to enhance the detector development program with periodic competitive call for “Grand Challenges”:
  - To address key technological issues that currently limit science reach
  - Adopt innovative approach that could prove transformational if successful
  - Has emphasis on multi-disciplinary approach
  - Builds on close collaboration with universities and national laboratories given the cross-disciplinary aspect of the research
  - Be a periodically reviewed longer term program at adequate funding level

- Make instrumentation a most attractive setting which provides a challenging environment, to develop, recruit, and retain the best and brightest throughout the world

Take a Chance !

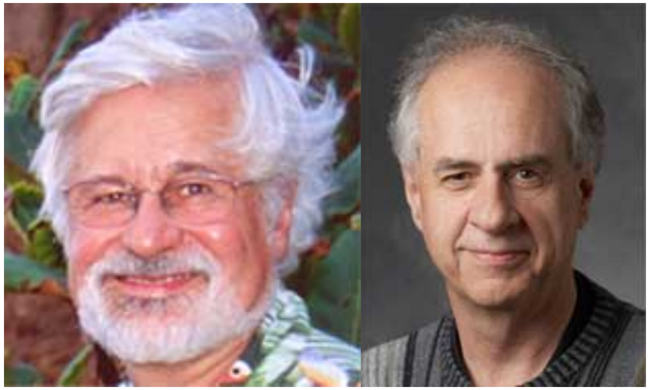
It's what HEP is founded on

It's an investment in the future !

Backup Slides

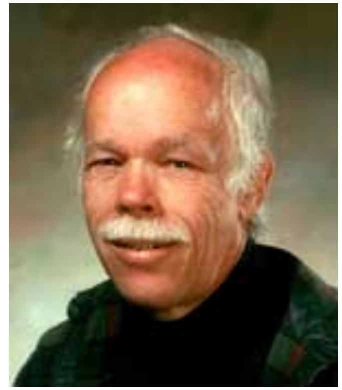
DPF Panofsky Prize

2013



Development of phonon detection technique

2012



Design and construction of Fermi-GLAST LAT

2009

Silicon vertex detectors and trigger

2008

Development of atmospheric fluorescence technique

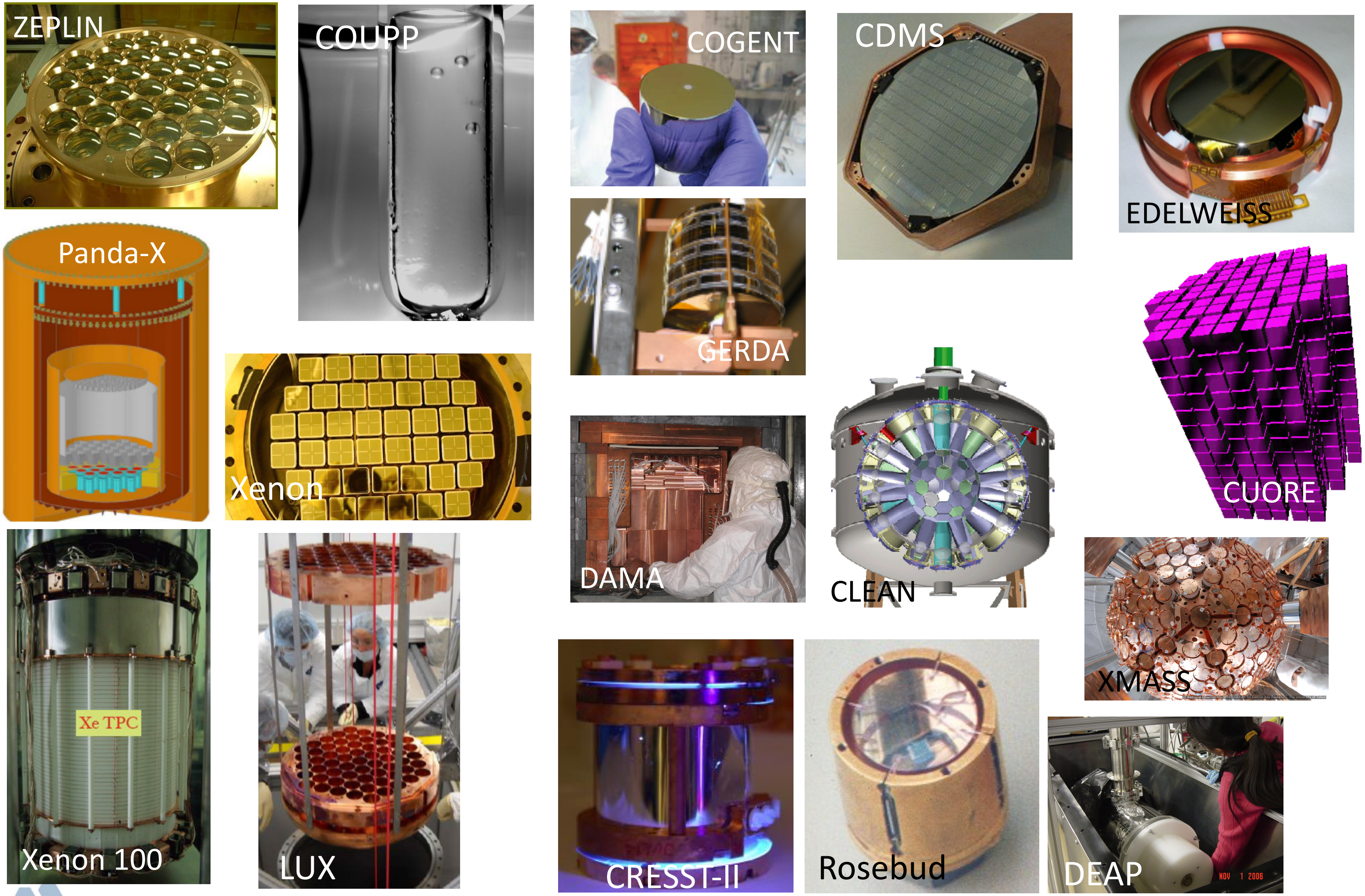
2003

Development of LAr and transition radiation

1998

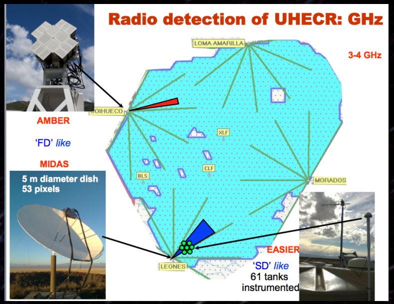
Invention of TPC

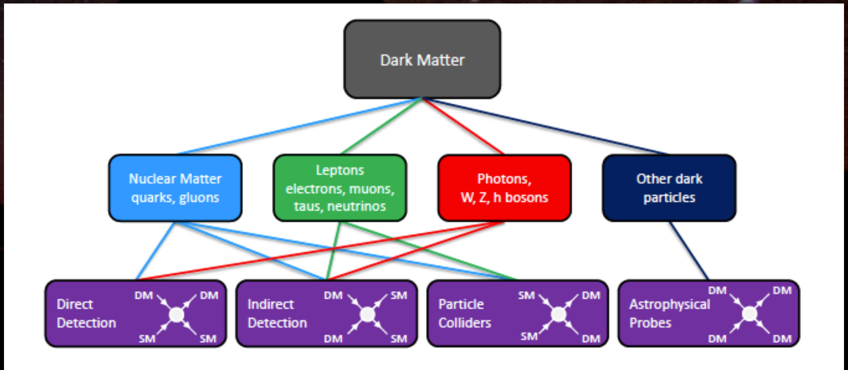
Dark Matter Experiments



Cosmic Frontier Challenges

- UHE-CR
  - Low rates at high energy
  - R&D: Radio Detection, detection of air shower from space
- UHE-neutrinos
  - R&D: Need development of new antennas, low noise amplifiers for detection of Cherenkov radio emission
- Gamma rays
  - R&D: Cherenkov and water tank arrays, Low-cost photosensors/low-power digitizers
  - Distributed timing across large arrays
- Dark Energy
  - R&D path: Low-resolution spectroscopy and spectroscopic capability to wide field optical surveys
- Dark Matter
  - Large program looking for larger mass, lower thresholds and directionality
- CMB
  - R&D path towards readout of large cryogenic multi-chroic arrays





CPAD

Coordinating Panel for Advanced Detectors

- CPAD: to promote, coordinate and assist in the research and development of instrumentation for High Energy Physics nationally, and to develop a detector R&D program to support the mission of High Energy Physics for the next decades.

- CPAD Membership
- From Universities
  - Jim Alexander (Cornell)
  - Marina Artuso (Syracuse)
  - Ed Blucher (Chicago)
  - Ulrich Heintz (Brown)
  - Howard Nicholson (Mt. Holyoke)
  - Abe Seiden (UCSC)
  - Ian Shipsey* (Purdue)
- From Laboratories
  - Marcel Demarteau* (Argonne)
  - David Lissauer (Brookhaven)
  - David MacFarlane (SLAC)
  - Ron Lipton (Fermilab)
  - Gil Gilchriese (LBNL)
  - Bob Wagner (Argonne)
- International
  - Ariella Cattai (CERN)
  - Junji Haba (KEK)

CPAD appointed spring 2012

http://www.hep.anl.gov/cpad/

(*) = co-chair