Instrumentation Frontier at Snowmass 2013

Marcel Demarteau

on behalf of
Instrumentation Frontier Conveners
(Ron Lipton, Howard Nicholson, MD)

CPAD chairs
(Ian Shipsey, MD)

SiD Workshop
SLAC, Jan. 16 – 18, 2013

Outline

- Organization pre-Snowmass
- Snowmass:
  - What is it?
  - What is the goal of Instrumentation?
  - How are we organized?
- Brief Report on, and Impressions of, the Community Instrumentation Frontier Workshop held last week at Argonne, Jan 9 – 11, 2013
- Personal observations
- Suggestions for discussion on ILC strategy

Instrumentation Pre-Snowmass

- Triggered by the 2009 DOE review of the Detector R&D program at the five national HEP laboratories, a workshop was organized on Detector R&D in the US, sponsored by the DPF, October 7– 9, 2010 at Fermilab

- The main outcome of the meeting was the creation of a taskforce on Instrumentation in Particle Physics, to evaluate its current status and future role

The DPF Instrumentation Task Force

From Universities

- Marina Artuso, Syracuse
- Ed Blucher, Chicago
- Bill Molzen, Irvine
- Gabriella Sciolla, Brandeis
- Ian Shipsey*, Purdue
- Andy White, UT Arlington

From laboratories

- Marcel Demarteau*, Argonne
- David Lissauer, Brookhaven
- David MacFarlane, SLAC
- Greg Bock, Fermilab
- Gil Gilchriese, LBNL
- Harry Weerts, Argonne

Ex-officio

- Chip Brock, DPF MSU
- Patty McBride, DPF Fermilab
- Howard Nicholson, DOE Emeritus

Instrumentation in Particle Physics

Commissioned by the Executive Committee of the Division of Particles and Fields, American Physical Society

October 2011

Prepared by the Task Force Members:

Authors: Marina Artuso (Syracuse), Ed Blucher (Chicago), Ariella Cattai (CERN), Marcel Demarteau (co-chair, ANL), Murdock Gilchriese (LBNL), Ron Lipton (FNAL), David Lissauer (BNL), David MacFarlane (SLAC), Bill Molzon (UCI), Adam Para (FNAL), Bruce Schumm (UCSC), Gabriella Sciolla (Brandeis), Ian Shipsey (co-chair, Purdue), Harry Weerts (ANL). Ex-officio: Chip Brock (Michigan State), Patricia McBride (FNAL), Howard Nicholson (Mount Holyoke).

http://www.hep.anl.gov/cpad/docs/dpf_report_v11.pdf

Taskforce created Spring 2011

Report submitted October 2011

- Key recommendation formation of a panel on instrumentation

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)

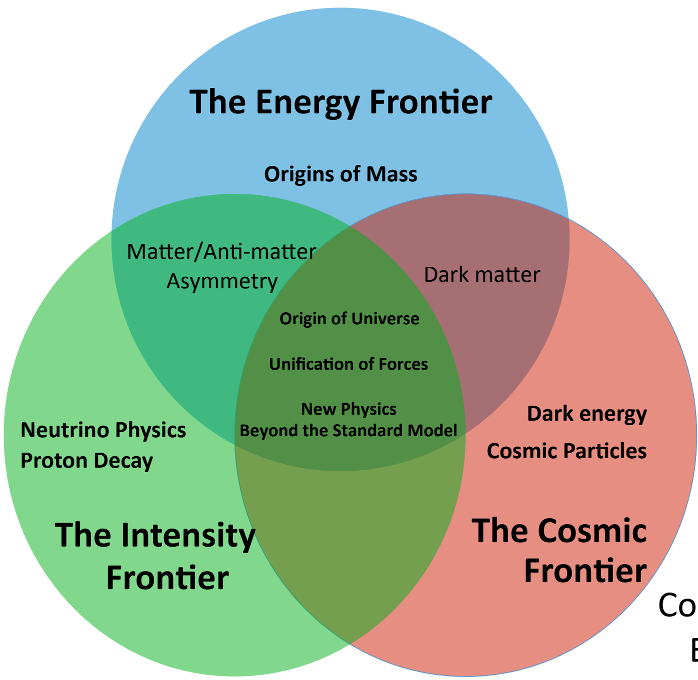
CPAD appointed spring 2012

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

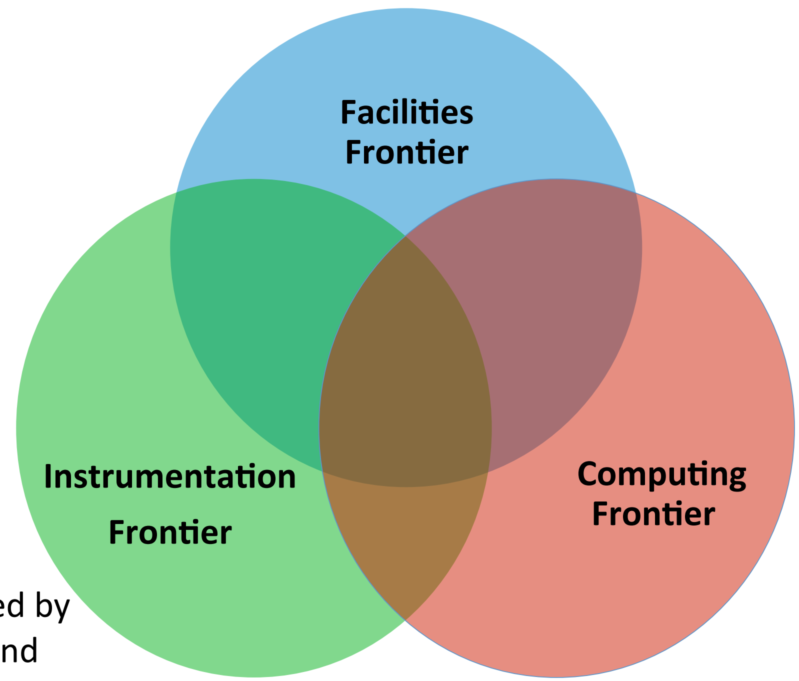
(*) = co-chair

Snowmass and the DPF Charge

- Snowmass is a long-term planning exercise for the high-energy physics community.
- Its goal is to develop the community's long-term physics aspirations. Its narrative will communicate the opportunities for discovery in high-energy physics to the broader scientific community and to the government."



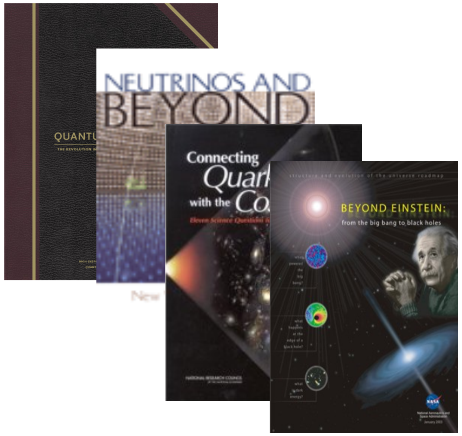
Complemented by Education and Outreach



Physics Frontiers

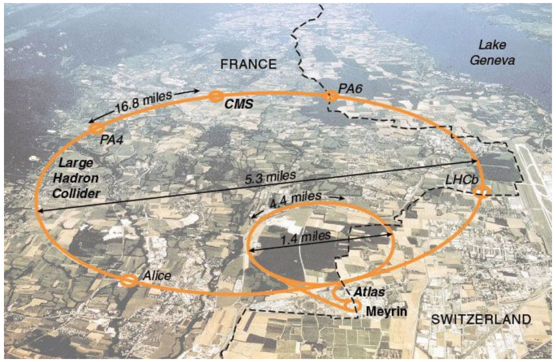
Enabled by Advanced Technologies

Instrumentation



Science

- The Physics Questions and Challenges are being well formulated by the three physics frontiers;
- Each frontier is now a "precision frontier"



Facilities

- Existing facilities will have an extended life
- New facilities are costly; environment is very competitive

Instrumentation

- New instrumentation to get the most out of existing, upgraded facilities
- Cost-effective innovative techniques and technologies for new experiments

Instrumentation will have a tremendous impact on the future program

'Decadal' Survey

- The Snowmass process is effectively to embark on a decadal survey for instrumentation: **to identify leading-edge scientific questions, and identify the observations and instruments required to answer them**

- **Because of the nature and timescale of high-energy physics projects provide the information for instrumentation in three categories:**
  - **Measurements in the Current Decade**
  - **Measurements for the Next Decade**
  - **Observations on Instrumentation itself**

- Snowmass is the voice of the community. There is no prioritization and no process to develop an instrumentation program for HEP.
- Eventually it needs to be sorted out 'what we need' from 'what we want' to realistically address the important science questions (P5, HEPAP, CPAD)
- CPAD is fully integrated in the Snowmass Instrumentation process; CPAD and the Snowmass Instrumentation Frontier work as one unit until the Minnesota meeting

https://indico.fnal.gov/conferenceDisplay.py?confId=6050

The Next Decade

- Instrumentation needs for the next decade will be closely tied to currently proposed experiments and upgrades of existing experiments
- Instrumentation needs will be based on clear physics objectives
- Development will be mostly lower risk and incremental, commensurate with project time scale

- We agreed upon preparing an overview of current experiments, key physics measurements and signatures, their main technologies, physics reach and key requirements/limitations

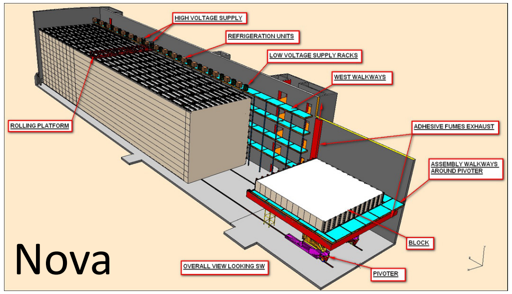
Experiment	Measurement	Reach	Technology	Characteristic	Requirement	Limitation
CMS	g(Hγγ)	~10% (300/fb)	PWO Crystal Calorimetry	80,000 crystals	$\sigma(E) \sim 4\%/\sqrt{E}$	Radiation hardness
ILC	...					
Same for all	experiments ...					

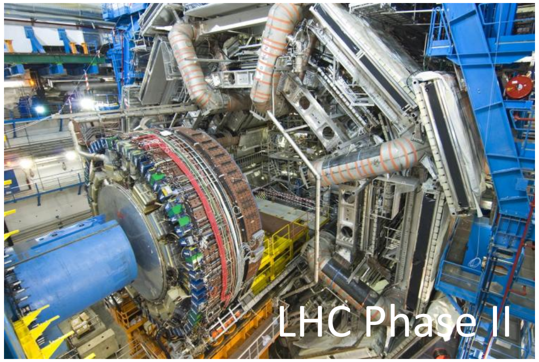
- Needs close coupling with physics frontiers

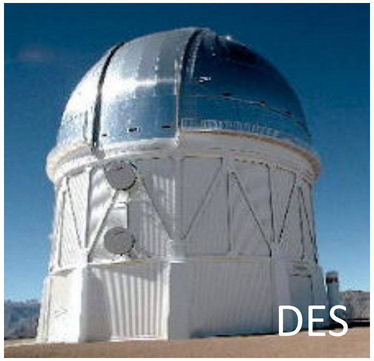
Beyond The Next Decade

- For projects beyond the next decade – that is beyond Phase II for the LHC – the community needs a *technology development and innovation program* guided by the science questions
- Determine what's really needed to take the next steps in improving the experiments: cost drivers and performance requirements
- Allows for balanced portfolio of high vs. low risk and long-term development

- Question is really beyond ....





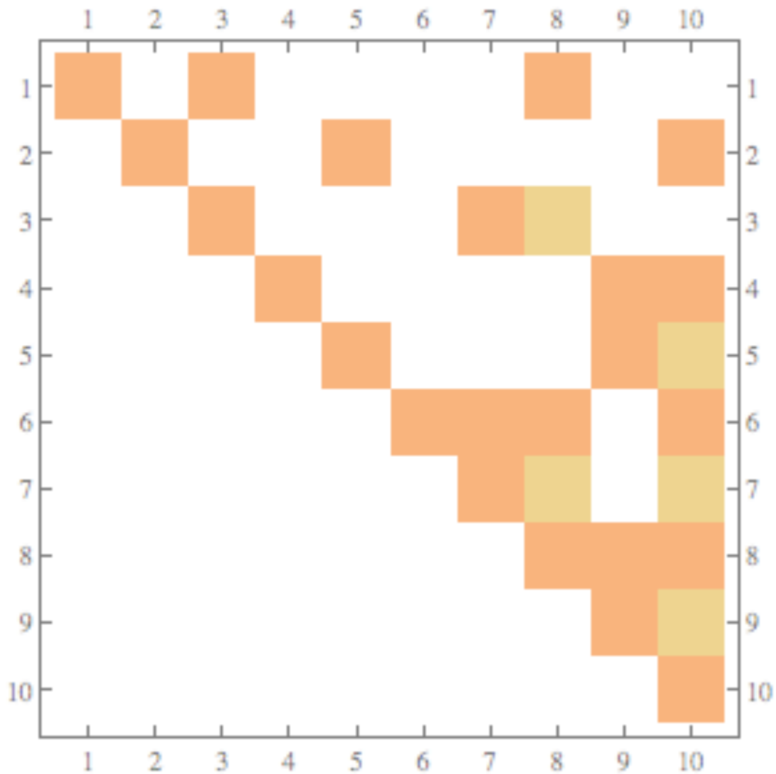


Diagonalization and Liaison Matrix

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)

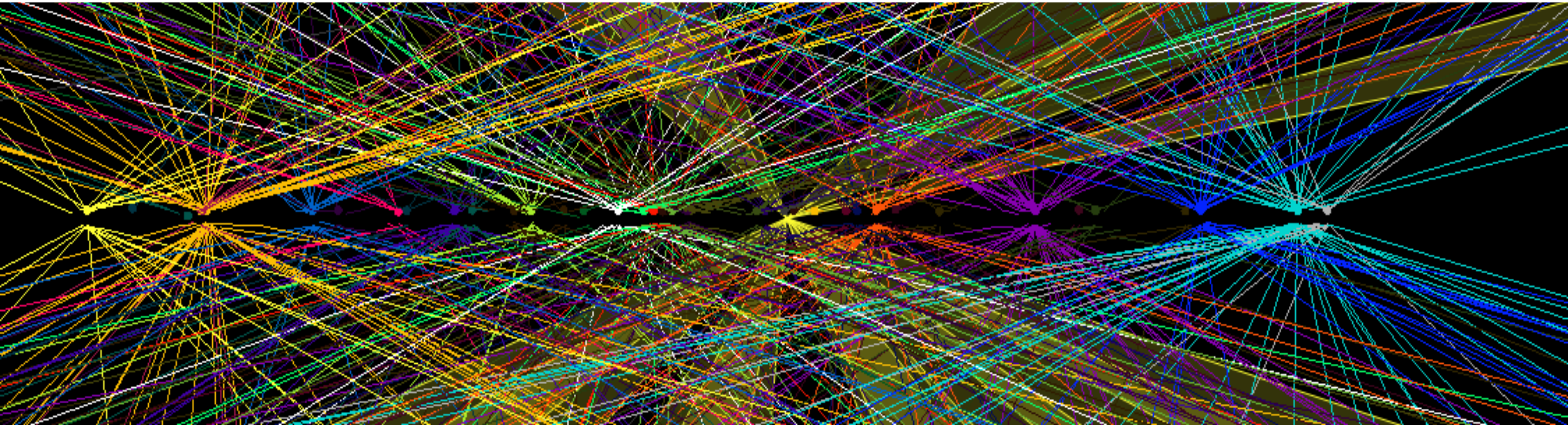
Defining The Metric

- The proposed Diagonalization along Physics Frontiers and Technologies is an initial step to develop a coherent overview
- Ultimately, what an experiment needs is not a technology but an instrument that is able to adequately address the science questions
  - An experiment is not interested in a tracker per se, but is interested in:
  - Momentum resolution
  - dE/dx, PID, single bunch crossing resolution



- Synergies between instrumentation efforts should be considered
- Developing the correct metric will be a process to which we seek input from all frontiers.

ENERGY FRONTIER

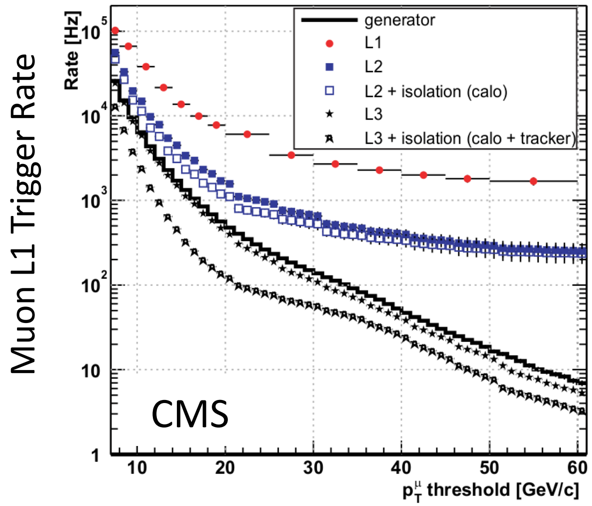


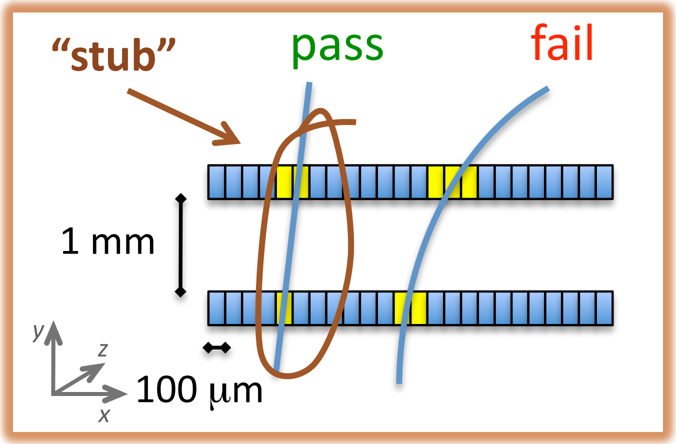
Future Goals of the Energy Frontier

- Precision measurements of the new state. Is it the SM Higgs?
  - Measurement of Higgs branching ratios and related couplings
  - Measurement of the Higgs Coupling to the top quark
  - Higgs quantum numbers determination
  - Higgs mass precision measurement
  - Higgs boson self couplings
  - Total Higgs decay width
- Determination of the structure of the theory
  - Invisible Higgs Decay through higher-order operators
- Sensitivity to new physics through loop-induced effects
  - Interpretation of the $H \to \gamma\gamma$ and $H \to gg$ branching fractions
- Precision electroweak measurements
  - Precision mass measurements (W, Z, top, …)
  - Anomalous couplings
- Direct discovery of new physics
  - Dark matter, dark energy, SUSY
  - What is the mass scale of the new physics?

HL-LHC Challenges

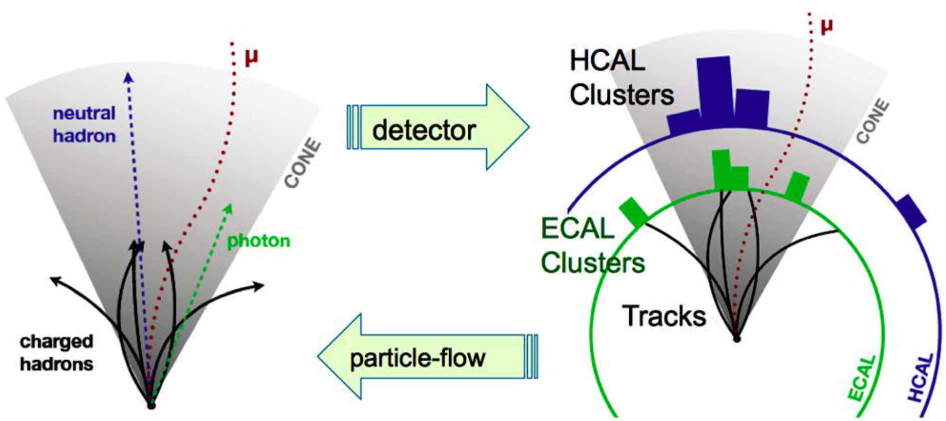
- HL-LHC: pile-up O(140) @ 5×10^{34} cm^{-2} s^{-1} leveled with 25 ns bunch crossing
- Trigger challenge





Mitigation through new trigger primitives

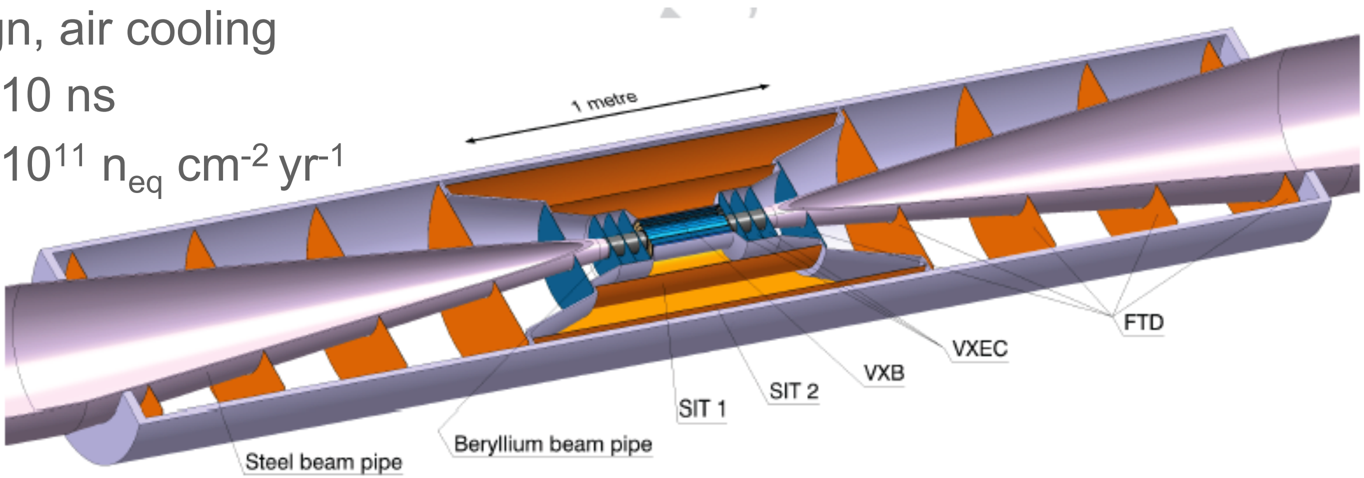
- Analysis challenge
  - maintain high and stable efficiency for e, mu, tau, jets, met, b-jets …
  - Mitigation through timing, vertexing, particle flow, ...



Vertex Detector Challenge at e^+e^-

- Small pixel size: ~20 μm^2
- 0.1% X_0 material per layer
- Low-power design, air cooling
- Time stamping <10 ns
- Radiation level $<10^{11}\ n_{eq}\ cm^{-2}\ yr^{-1}$

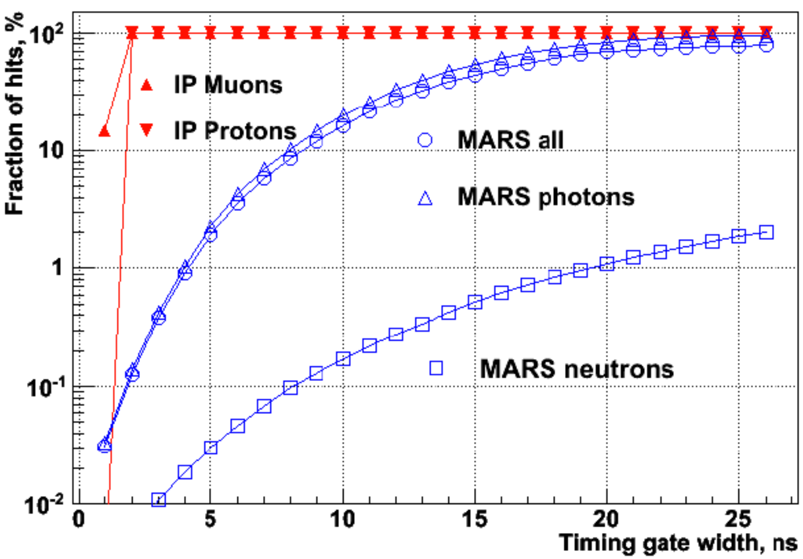
CLIC vertex detector

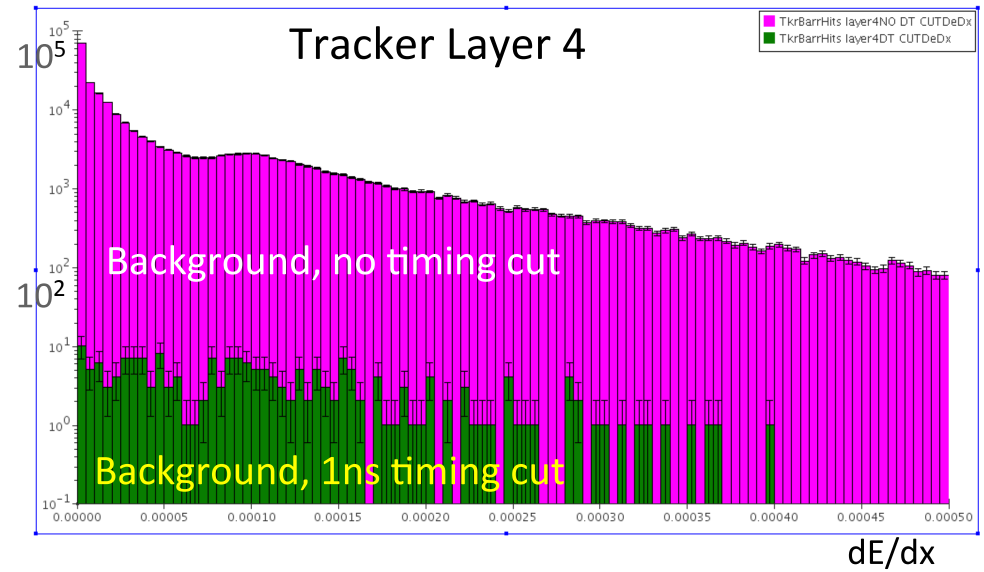


	CLIC_ILD	CLIC_SiD	CMS
Material X/X0 (90º)	~0.9% (3x2 layer)	~1.1% (5 layer)	~10% (3 layer)
Pixel size	20 x 20 μm^2	20 x 20 μm^2	100 x 150 μm^2
# pixels	2.04 G	2.76 G	66 M
Time resolution	~10 ns	~10 ns	<~25 ns
Avg. power/pixel	<~0.2 µW	<~0.2 µW	28 µW

Muon Collider Background Challenge

- Muon decays from the beams are the dominant background at a muon collider
  - For a 62.5 GeV muon beam of 2×10^{12}, 5×10^{6} decays/m per bunch crossing
  - For a 0.75 TeV muon beam of 2×10^{12}, 4.28×10^{5} decays/m per bunch crossing; 0.5 kW/m.

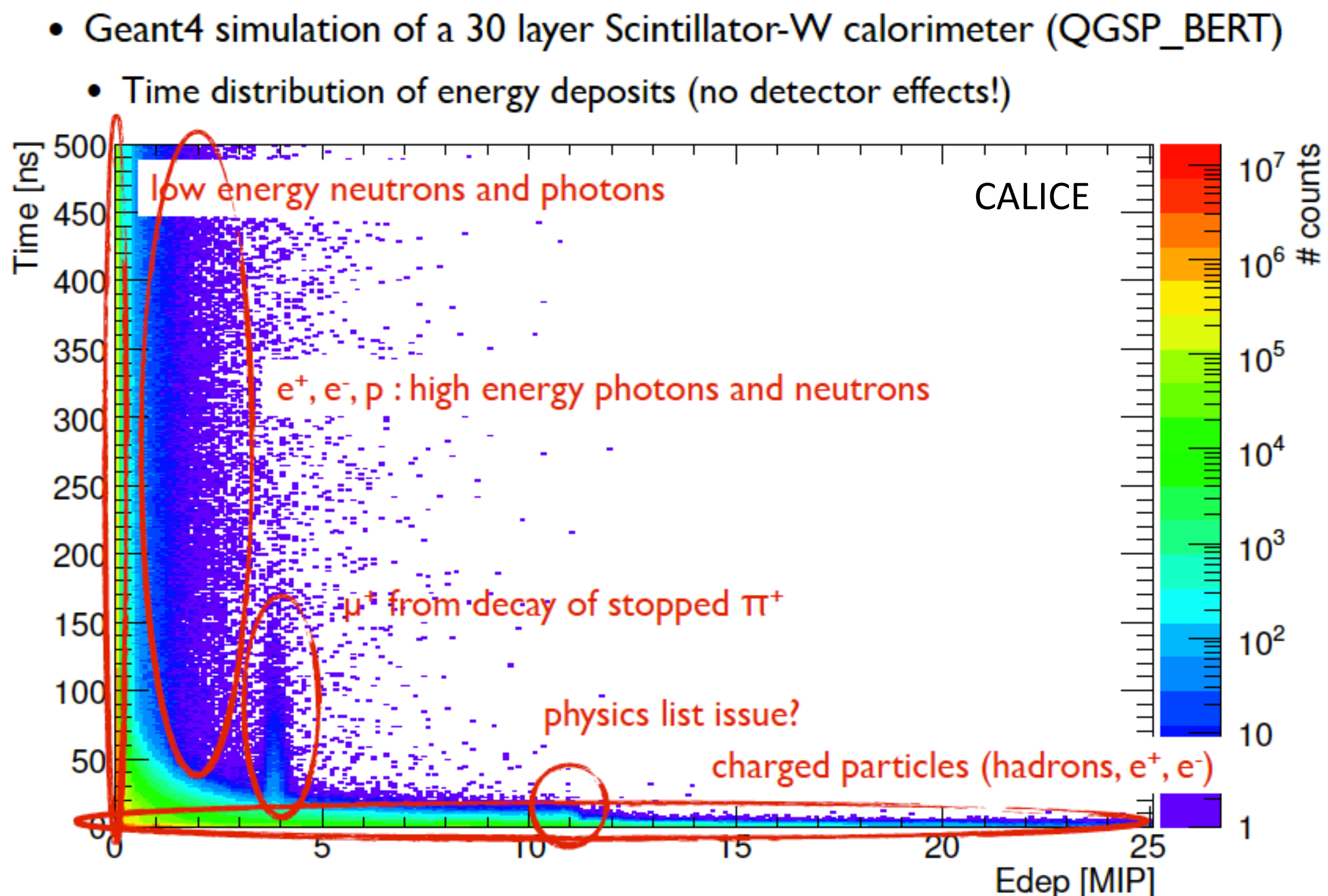




- Timing is the most important handle to reduce the background at a Muon Collider
  - Reduces backgrounds by 3 orders of magnitude
  - dE/dx also is also needed for S/N and time walk corrections
- Also critical for ILC/CLIC

Particle Flow Challenge

- Timing is a key control of the backgrounds
- Tension between signal formation and calorimeter integration and background control

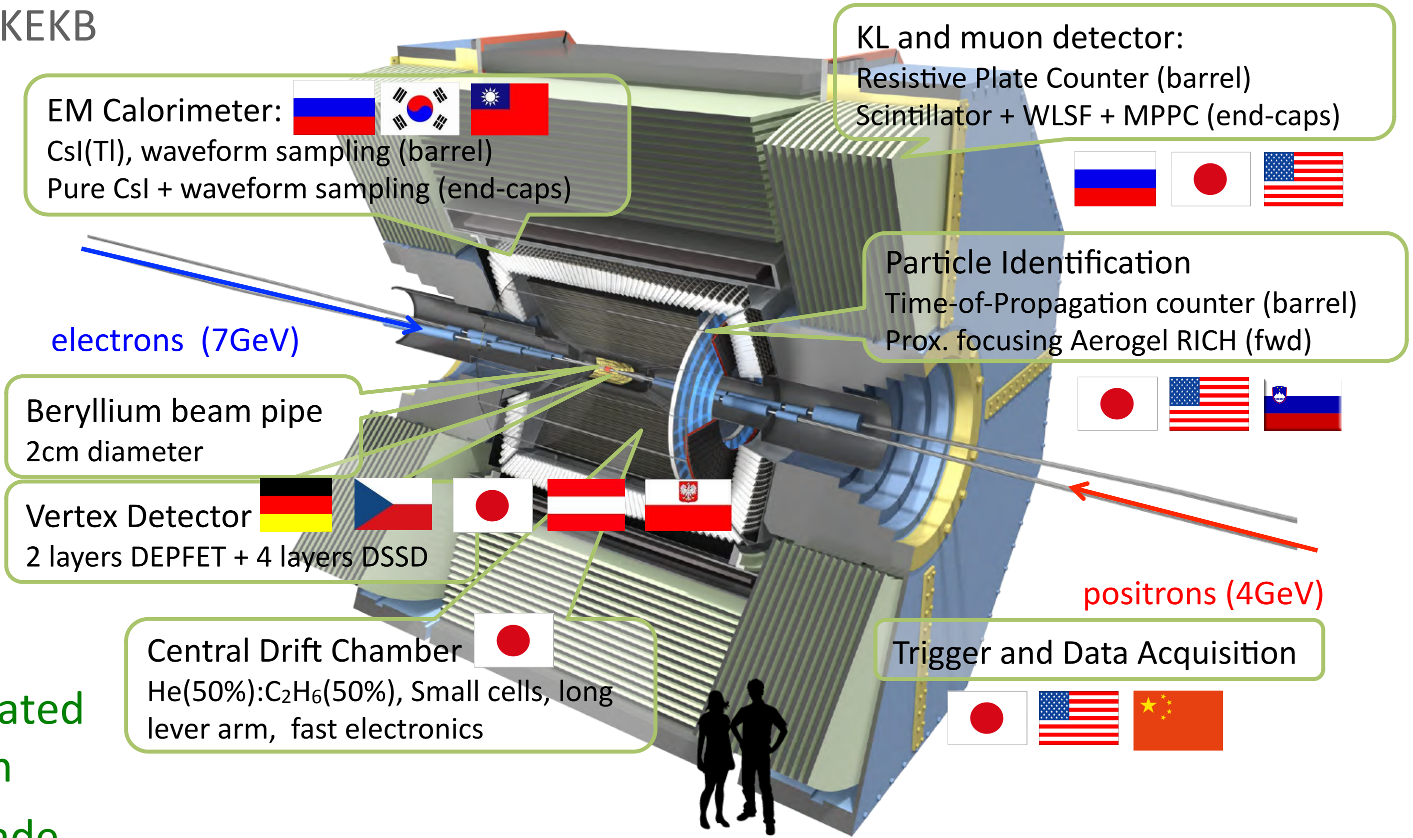


R. Lipton

INTENSITY FRONTIER

B-Factories

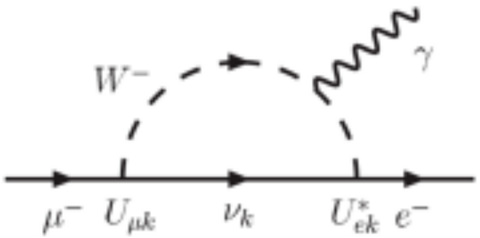
- Belle II at SuperKEKB



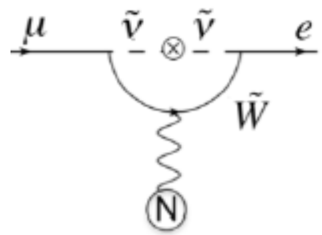
- Very well motivated physics program
- BELLE II.V Upgrade
  - Endcap crystal calorimeter
  - Replacement of Belle II pixels with radiation hard pixel detector
  - Cluster counting (dN/dx) in drift chamber for PID
  - Trigger/DAQ/electronics

Charged Lepton Flavor Violation

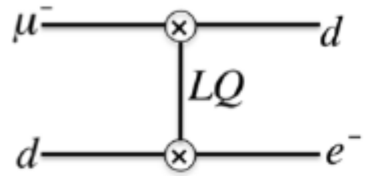
- MEG and Mu2e experiments aimed at CLFV



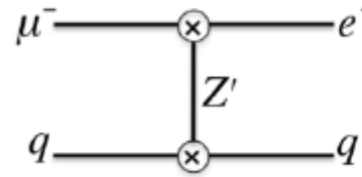
Br(μ-> eγ) < 10^{-54}



SUSY

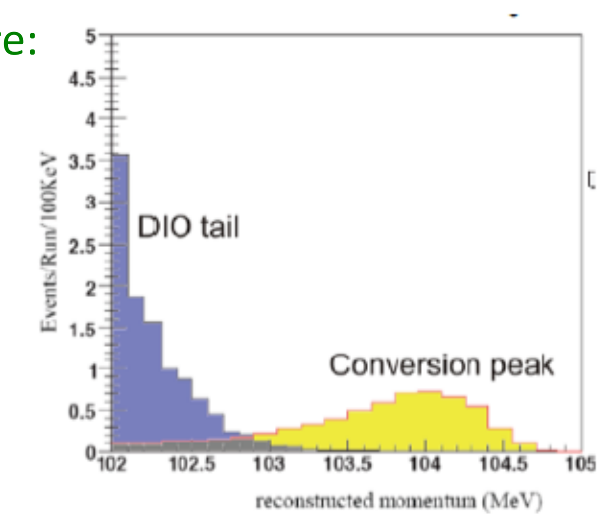


Leptoquarks



FCNC with Z'

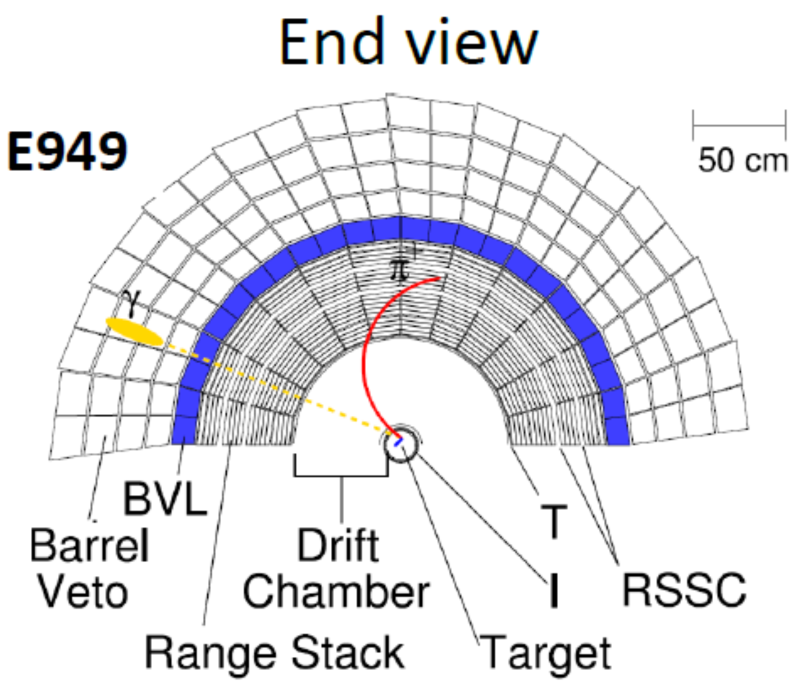
- Limiting factors for the Mu2e conversion experiment are:
  - Precision tracking with very low (<0.1% X_0) mass to reject decays in orbit from conversions: δp/p of 0.1% on 100 MeV electrons.
  - Intensity: high rates imply need for low latency and resistance to radiation damage
  - Proposed Straw tracker: 21600 straws, 12.5 μm wall straws in vacuum 100 kHz per straw

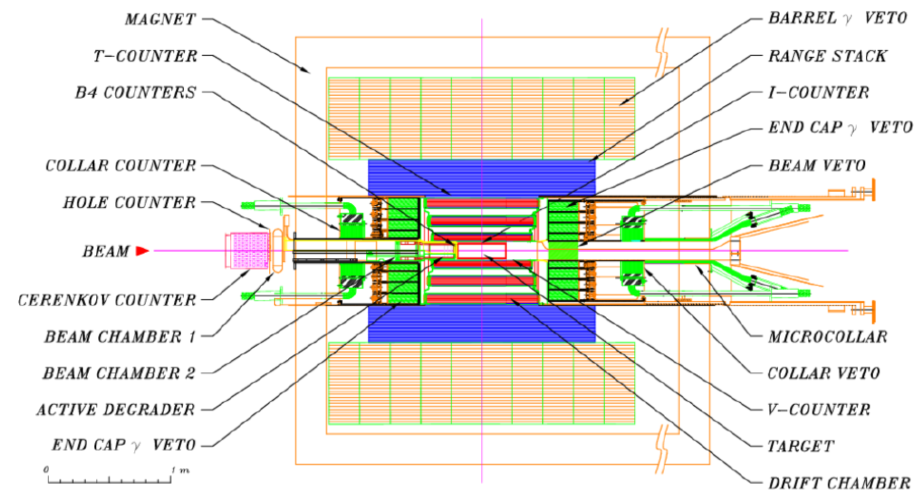


B. Svobodo

Rare K-Decays

- ORKA experiment uses stopped Kaon beam
- Resolve K^0 -> π^0 $\nu\nu$ from background





- Very low-mass tracking needed
  - $0.2\%\ X_0$ in tracking volume
  - $\sigma(p)/p$ <1% at 150-250 MeV
  - B = 1.3 Tesla
  - 150 kHz rate per wire for drift chamber configuration

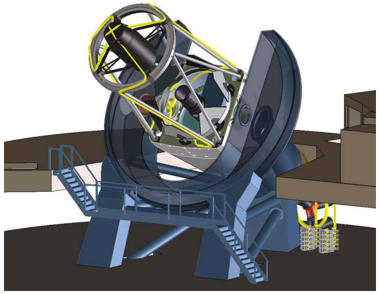
B. Tschirhart

COSMIC FRONTIER

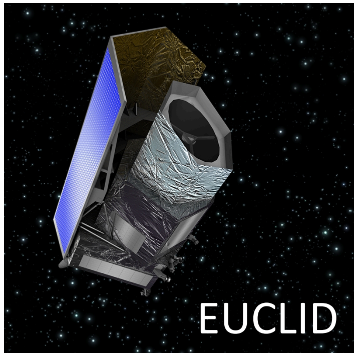
Study of Dark Energy

- For Dark Energy studies measure the following objects over as large a volume as possible (many Gpc^3):
  - Galaxy shapes, types, angular position and red-shifts
  - Supernovae (Sne Ia)
  - Angular position and spectrum of quasars. Mapping of hydrogen clouds.

- Future projects that will do that on a large scale are:
  - DES: imager with 5 filters; running
  - MS---DESI (BigBOSS/DESpec): Spectrograph (2017?)
  - EUCLID: launch ~2019.
  - LSST: imager with 6 filters; 2021



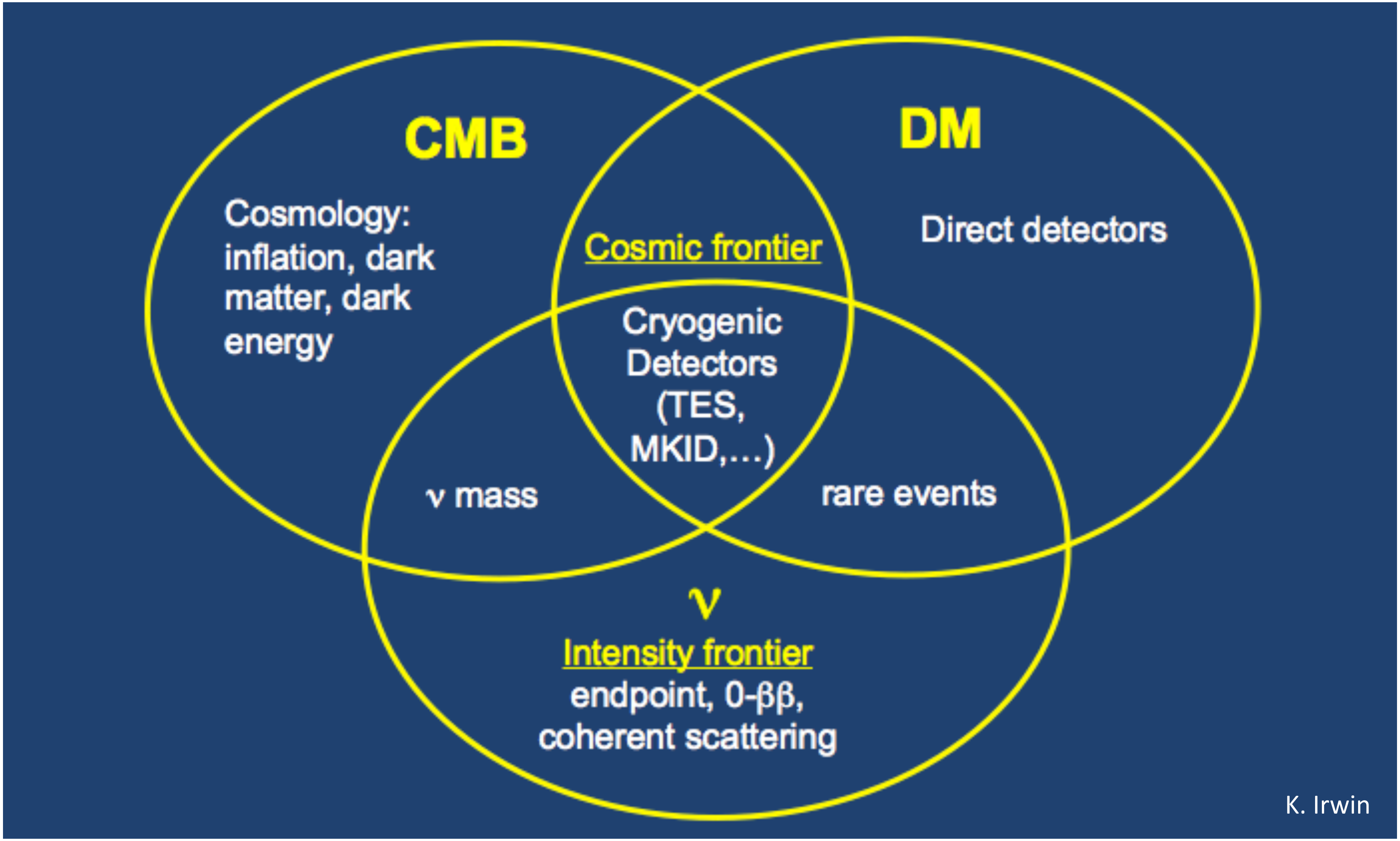
BigBOSS



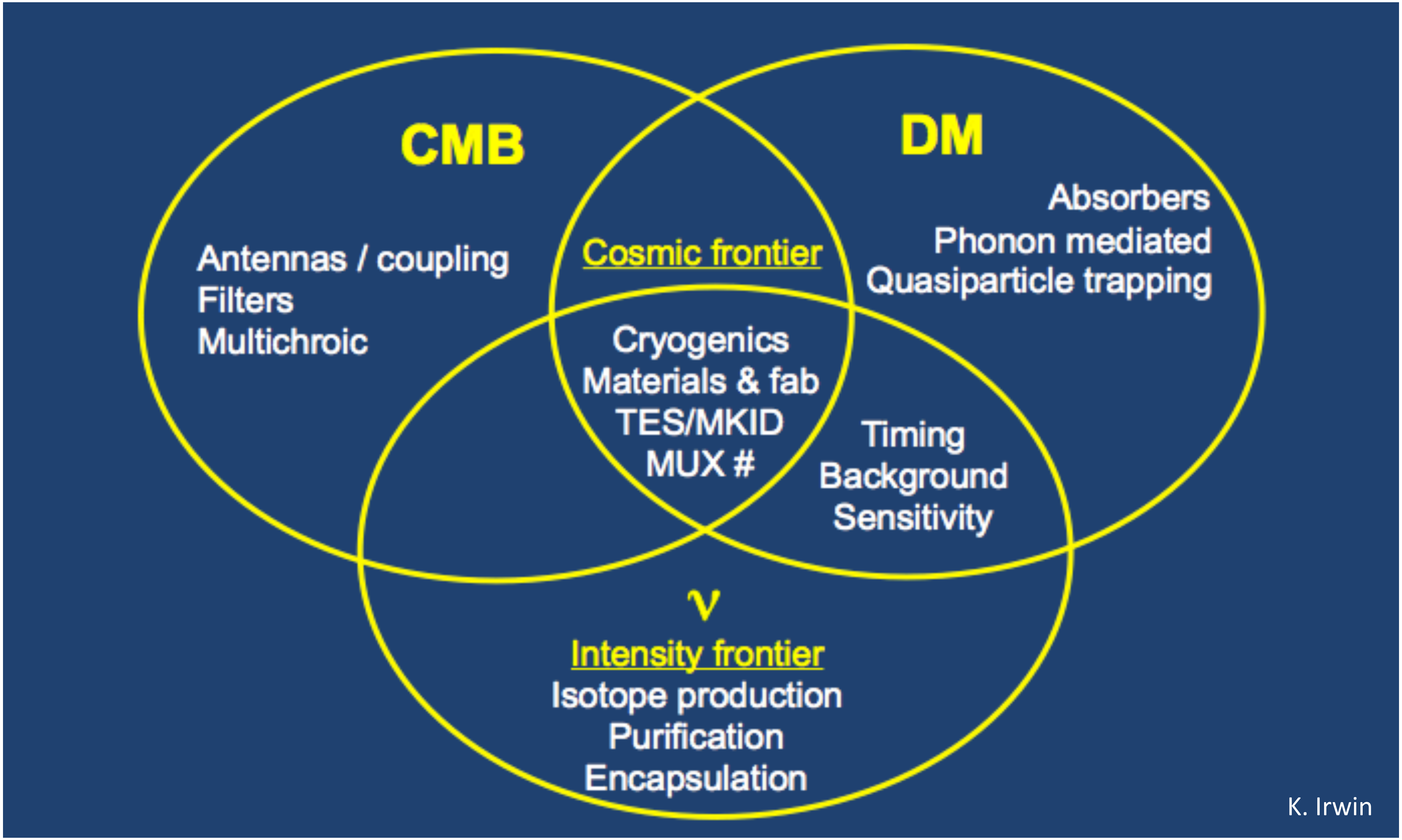
- What is needed to go beyond LSST, that is 2030 ?

LSST

Cryogenic Detectors



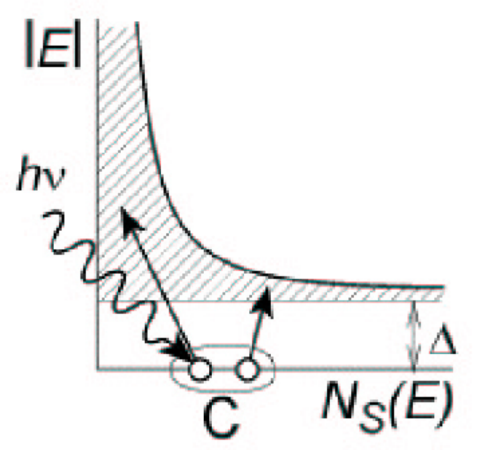
Cryogenic Detectors Technology Needs

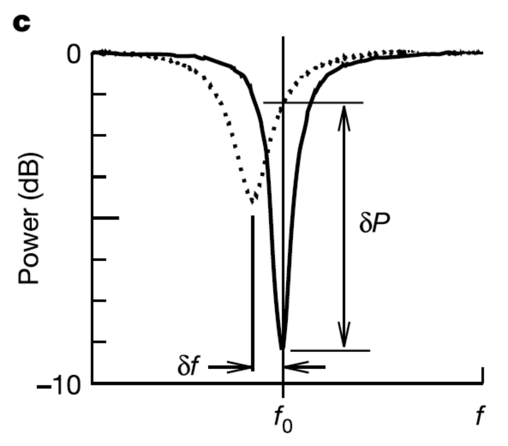


Cryogenic Detectors Technology Needs

- Physics signal starved; need larger arrays
- Standard technique: Time Division or Frequency Division Multiplexing
- New technique: GHz multiplexing

Microwave kinetic inductance detectors (MKIDs)





Naturally multiplexed

Not yet successfully used as x-ray calorimeters

P. Day, Nature (2003)

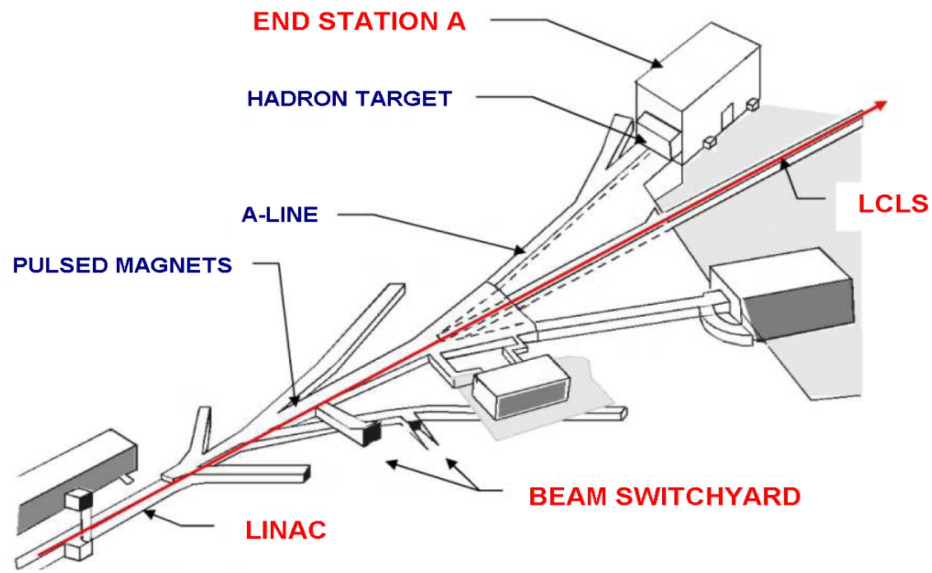
- Enables the construction of 1 -10 kpixel arrays at the intersection of three fundamental physics areas

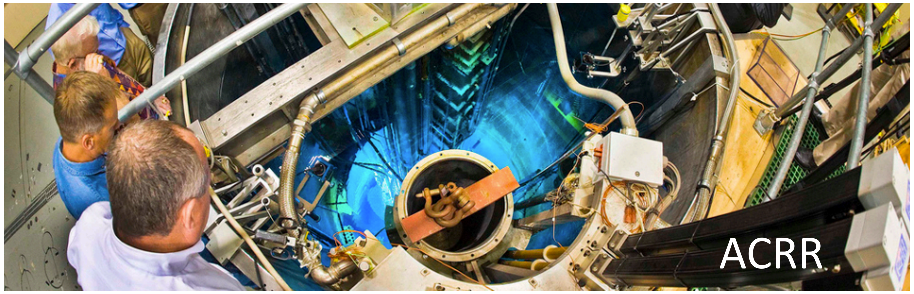
B. Cabrera

Facilities

- Past of the Snowmass process for instrumentation is to document the need for facilities: test beams and underground
- A whitepaper on on both kind of facilities is being written
- Request whitepaper from the ILC community on articulating the ILC needs

- Test beam facilities
  - End Station Test Beam (SLAC)
  - Fermilab Test Beam Facility
- Irradiation facilities
  - LANSCE at Los Alamos
  - Annular Core Research Reactor (ACRR) at Sandia
  - Gamma Irradiation Facility at Sandia
  - NASA Space Radiation Lab at BNL
  - BNL LINAC Isotope Producer (BLIP)
  - ...
- Underground facilities

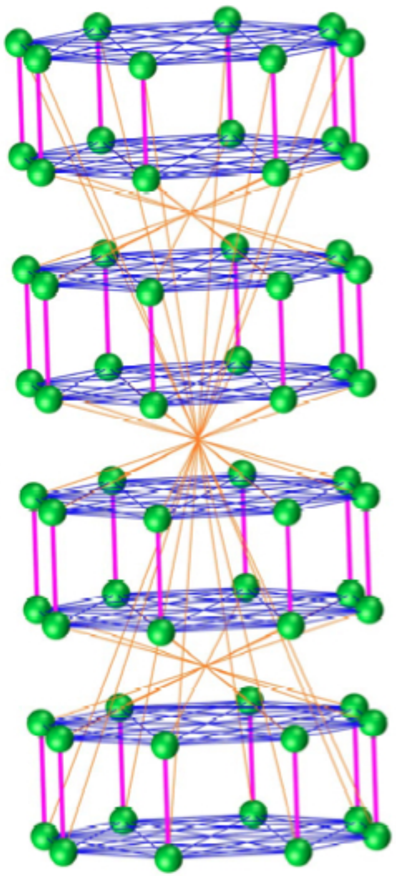


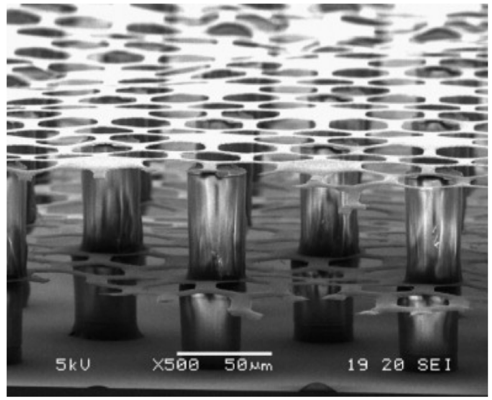


Technologies

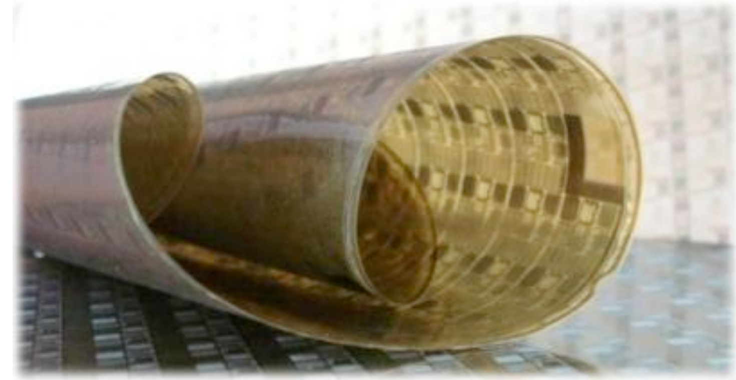
- Considered technologies have broad range ...

Data sharing in ATCA



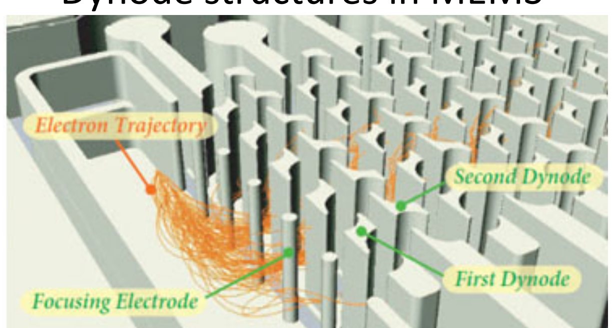


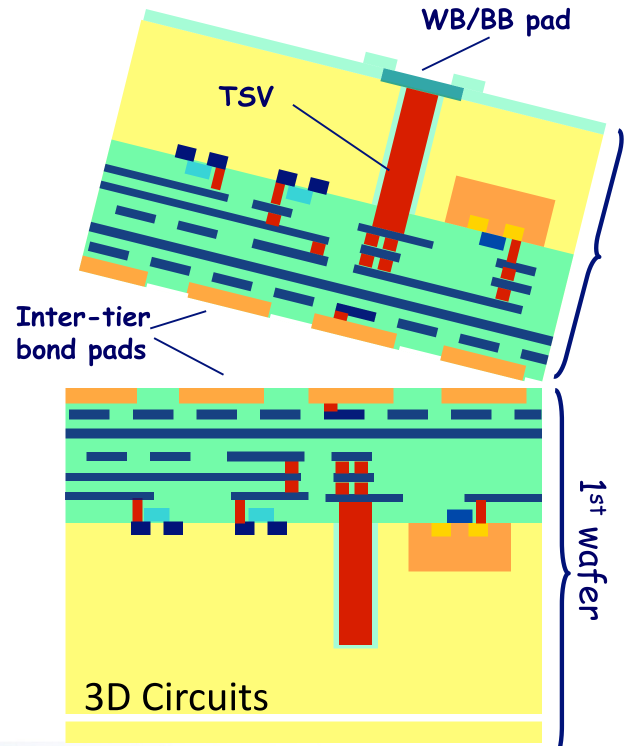
CMOS Integrated Grid



Circuits on flexible support

Dynode structures in MEMS

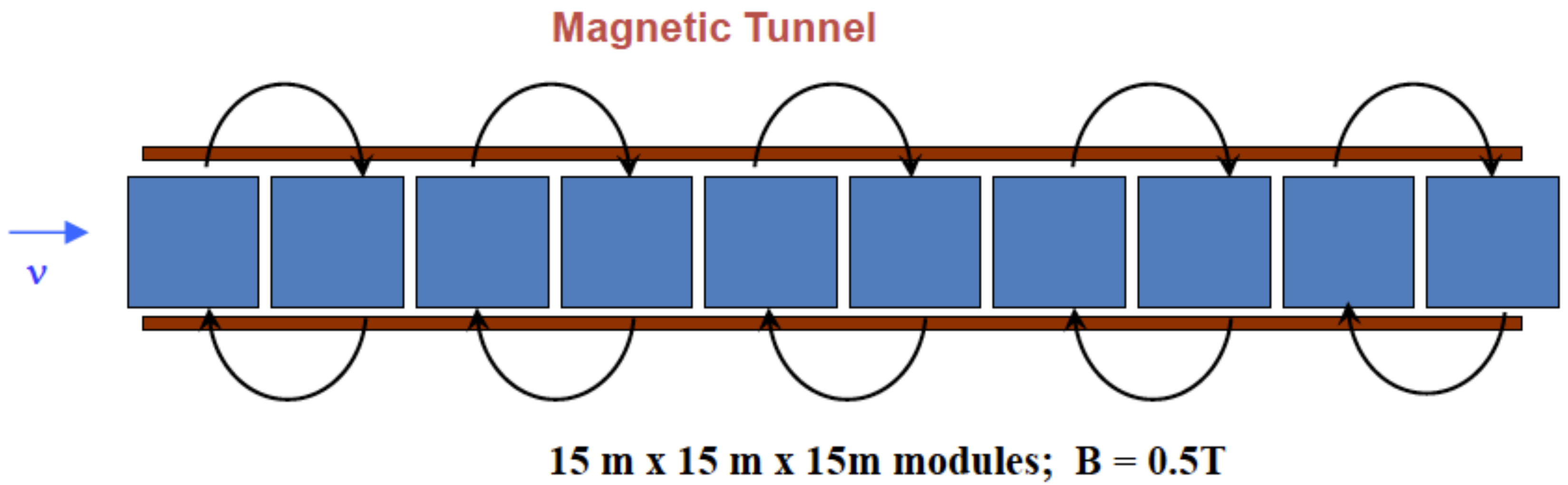




3D Circuits

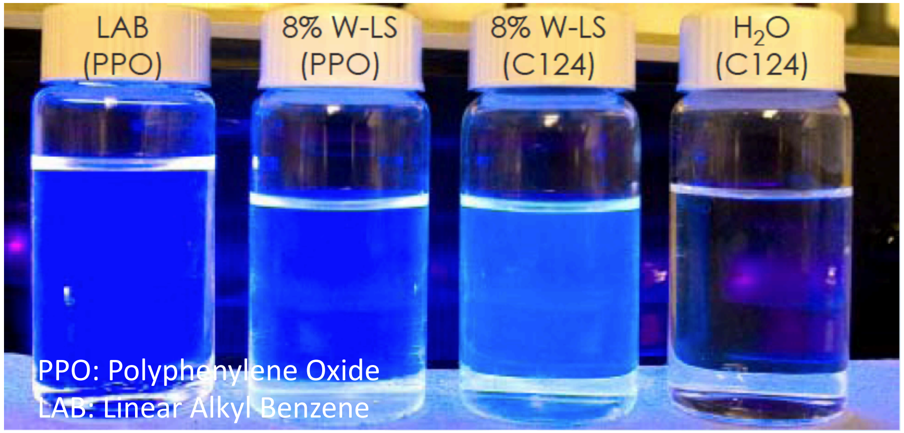
Technologies

- Cost-effective large volume magnets



- Water-based liquid scintillator

A. Bross



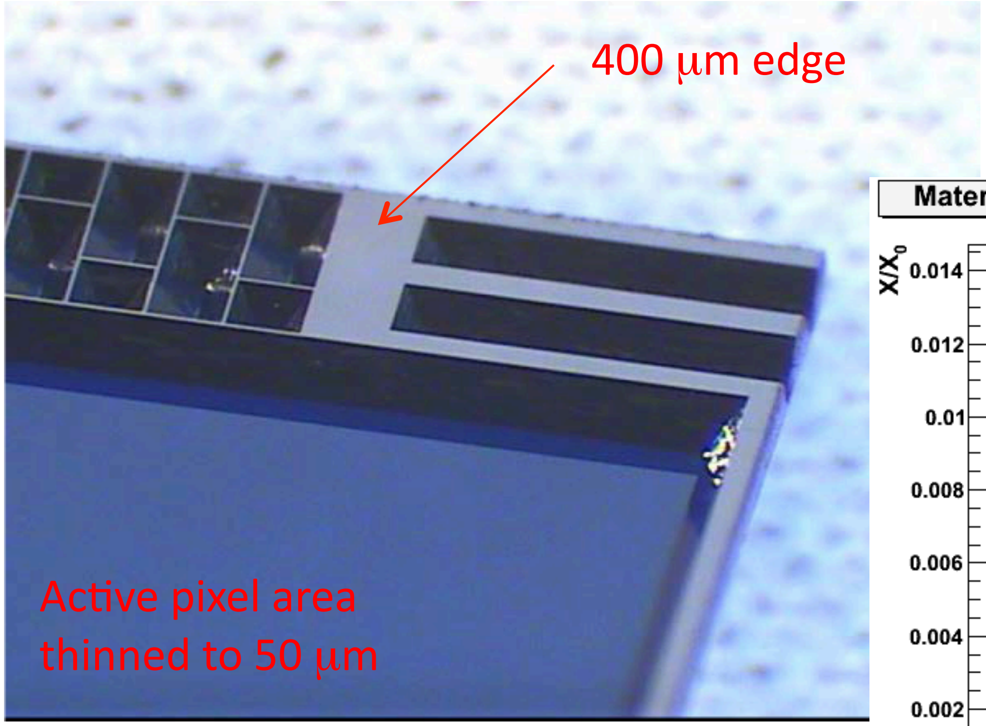
Minfang Yeh

Global Picture

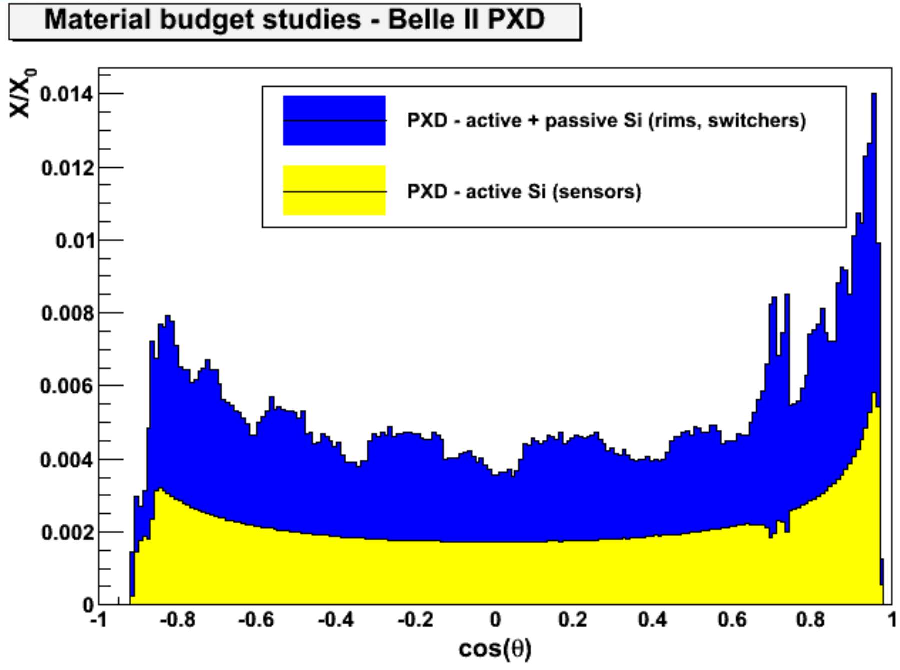
- Efforts elsewhere ...
- Leadership .... ?

Bold Ideas

- We should not be risk averse tackling instrumentation issues.
- Other areas of the world are putting forward rather bold ideas

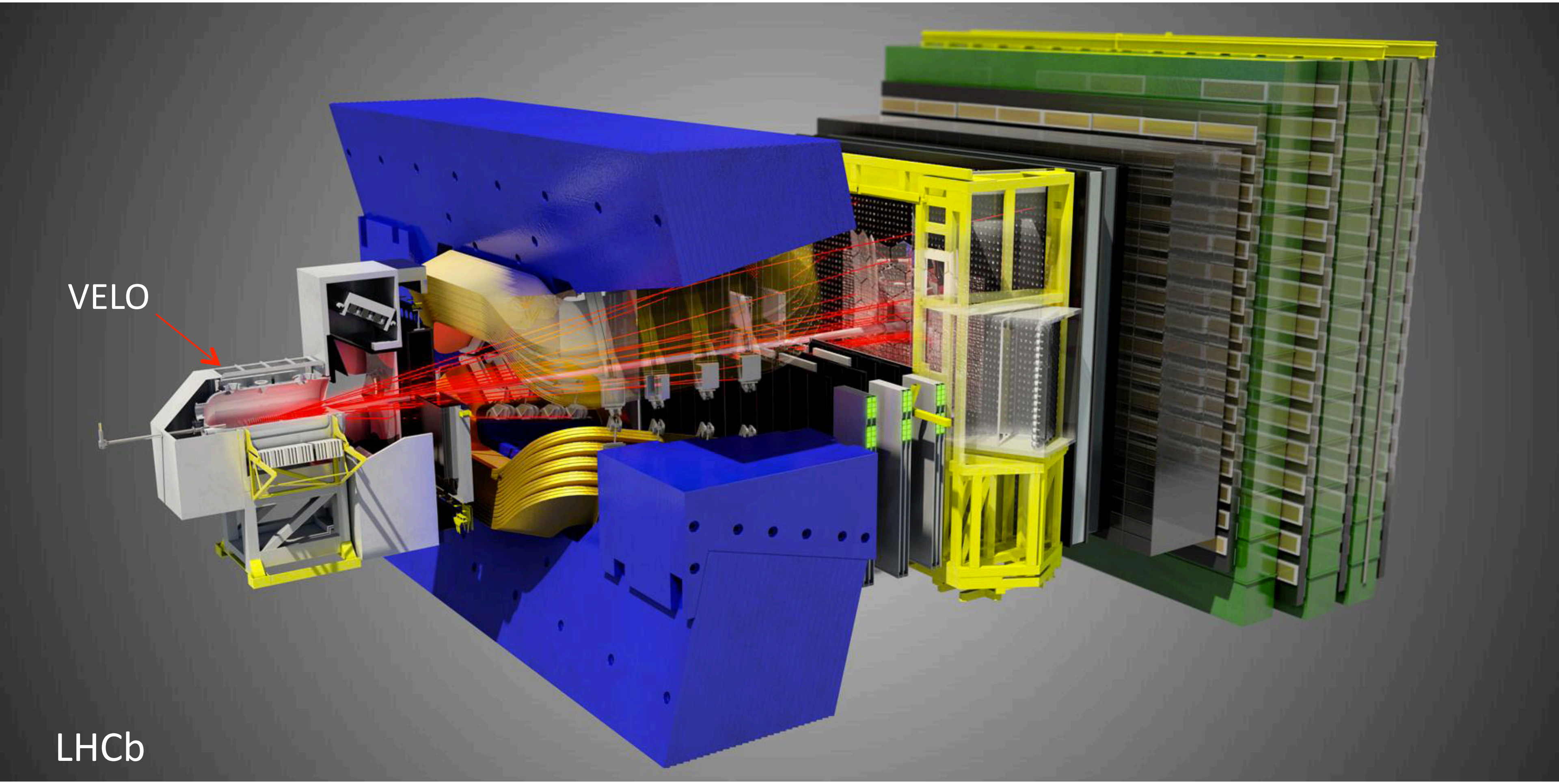


Overall material budget of 0.05% X_0 per layer of active area achievable



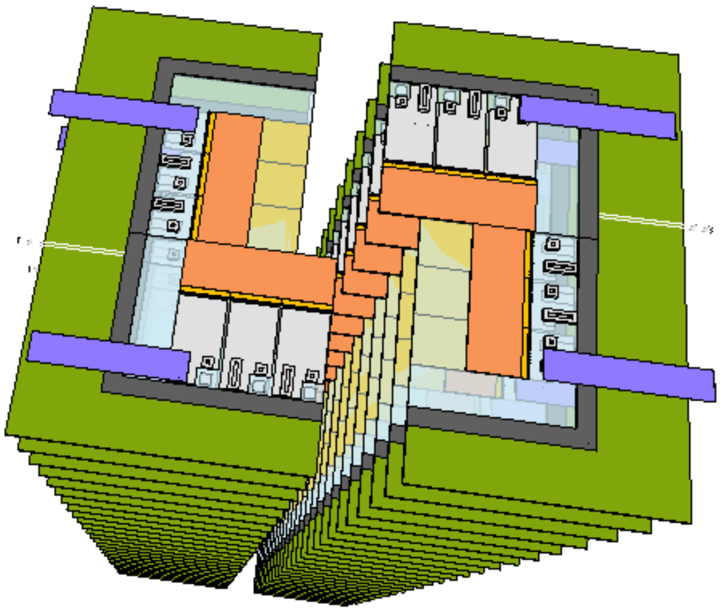
Bold Ideas …

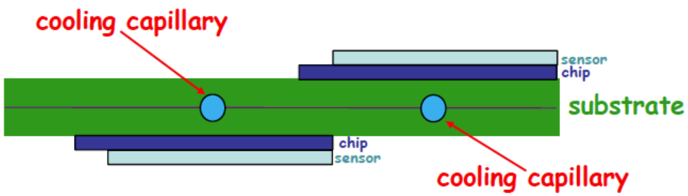
- LHCb Vertex Locator (VELO) detector to be installed in 2018 !

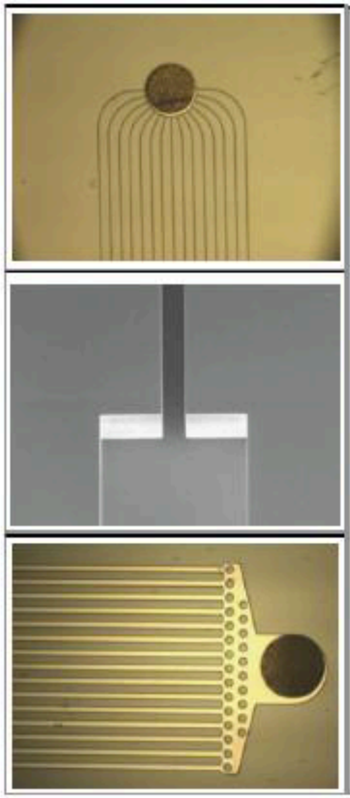


Bold Ideas …

- LHCb Vertex Locator (VELO) detector to be installed in 2018 !



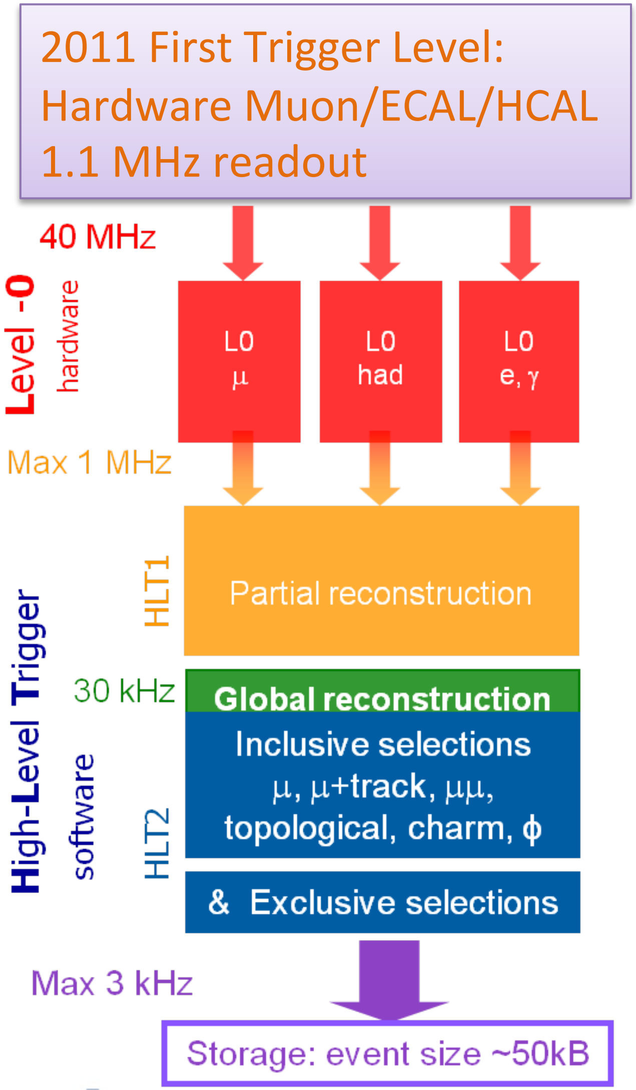




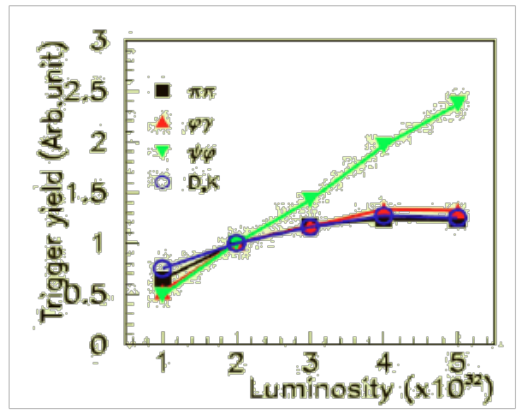
- Cooling tube for CO_2 cooling is integrated in the substrate
- All material is silicon: no CTE mismatch due to mechanical stress
- Coolant pressure is 150 bar !

LHCb Trigger

Current

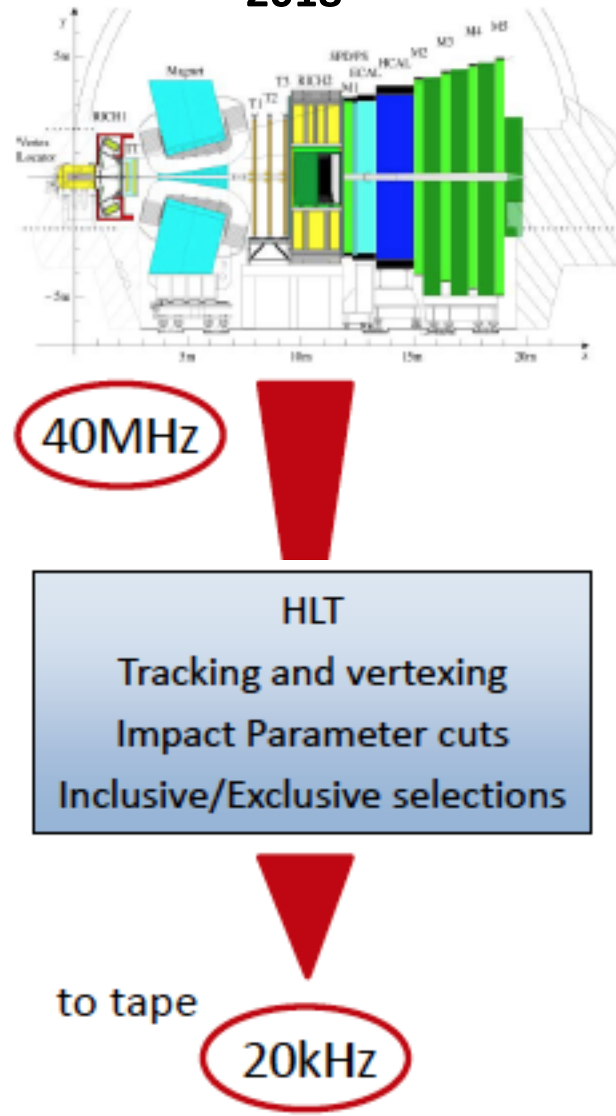


Motivation



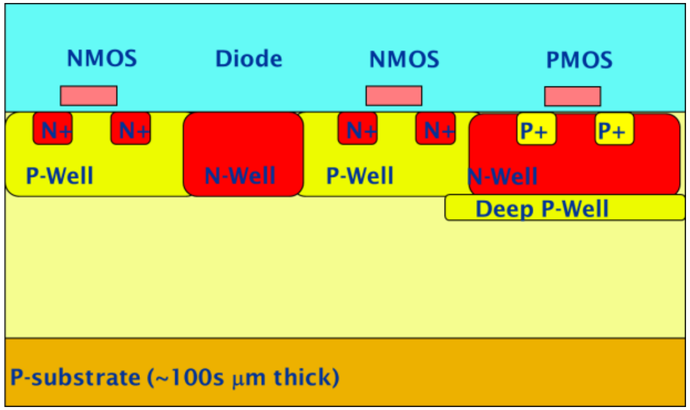
The hadronic channel yields saturate at high luminosity

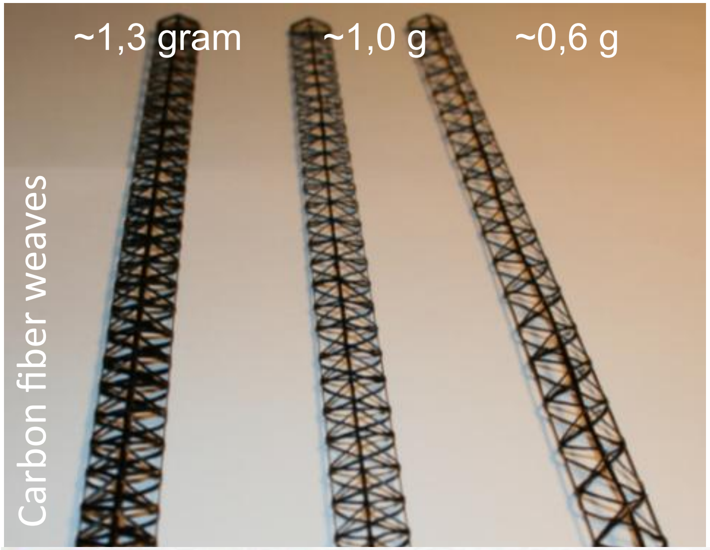
2018

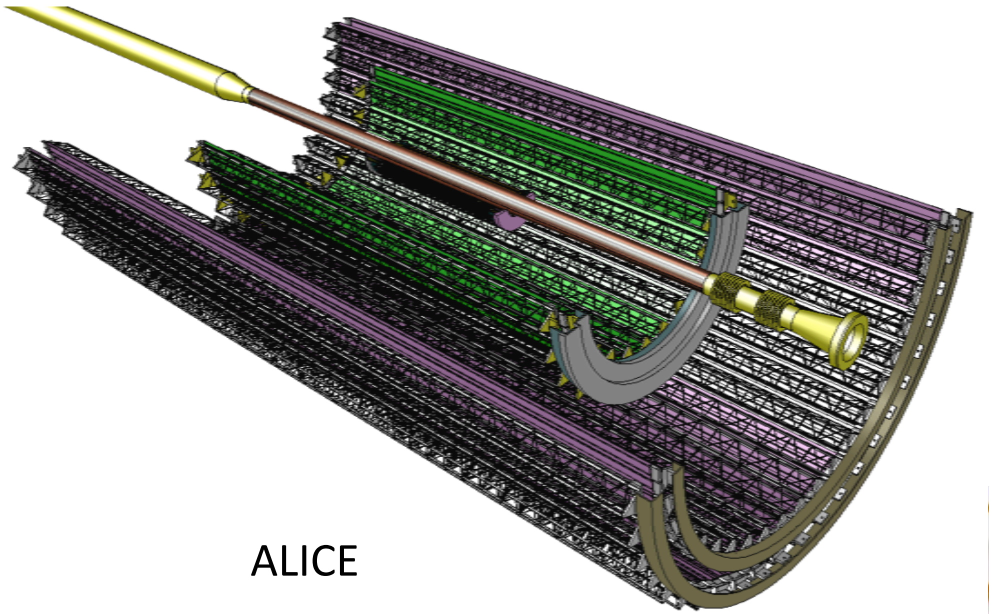


ALICE Upgrade

- 7-layer pixel detector, 20x20μm^2
- Monolithic pixels, 18 micron epitaxial layer
- Detector parameters
  - ~1 Gpixels
  - Number of modules: 346
  - Total data throughput: 824 GB/s
  - Number of links: 130







ALICE

SiD AND SNOWMASS

Central Themes

- Central, common themes are emerging for instrumentation
  - Data acquisition and triggering (energy, intensity)
  - Low mass, precise tracking (energy, intensity)
  - Fast sensors with precise timing (energy, intensity)
  - Radiation hard sensors (intensity, energy)
  - Large volumes (cosmic, intensity)
    - double beta
    - Neutrino
    - atmosphere ...
  - Very low noise, low background sensors (cosmic)
  - Waveform sampling ASICS
  - New and emerging technologies (all)
- Basic tools
  - Electronics and asics
  - test beams
  - support facilities

Observations

- There is a tension between designing for experiments now and therefore using existing technology, and developing technology for the future
- The ILC took a daring approach 10 years ago in proving certain technology concepts; for example, particle flow calorimetry was conceived and proved in about five to six years
- Currently, there seem to be more bold ideas and transformational technologies being contemplated overseas.
- For SiD I see two timescales: Snowmass and after Snowmass
- Instrumentation for the ILC after Snowmass: Is there an opportunity to address a detector limitation through proposing an aggressive new technology path?

Snowmass

- SiD (and ILD) should submit a whitepaper to the Instrumentation Group for Snowmass describing the current status of the ILC instrumentation, its physics reach, areas where further R&D is needed and indicate the limitations of existing technology.

- I propose that SiD (and ILD) should submit another whitepaper to the Instrumentation Frontier that proposes new, longer-term, more aggressive, high impact R&D for the ILC with a narrative on the science impact of the proposed development, transformative potential and estimate of the time scale for development. The narrative could address the 3% versus 1% measurement

- The proposed new R&D should have broader community impact

Take-Away Big Picture Message

- The U.S. HEP program is unlikely to be able to outspend our international competition
- The U.S. political system is averse to long-term investments and not strong in planning
- Our only hope to maintain leadership in the long-term is to out-innovate the competition, and/or exploit unique capabilities
  - Focus on areas where US can have leadership
  - "High-risk, high-impact" as opposed to incremental advances
- We need your help

G. Crawford
ANL Instrumentation workshop

Summary

- **Innovation in accelerator and particle detector technology has been a historic strength of HEP**
  - We need to preserve and reinvigorate this core competency for the future

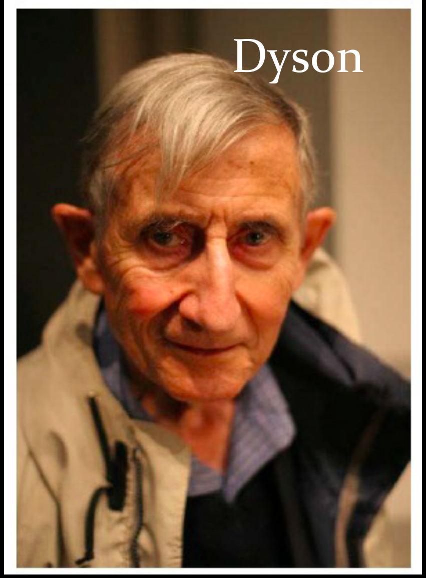
The DOE recognizes the issues and wants to help

- **In the past the stewardship of these efforts has rested largely with the HEP labs and some university groups as part of their institutional heritage**
  - Today the institutional model has largely eroded
  - We must forge new collaborative models that cross-cut labs, universities, disciplines

It's our job !

- **The community has a key role in identifying the science opportunities and technology challenges (and executing!)**
- **The agencies have a key role in providing national stewardship and enabling success for good new ideas and people**

That new physics will be uncovered by the tools we develop!



“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

Joint CPAD and Instrumentation Frontier Community (2nd pre-Snowmass) Meeting

April 17-19, 2013 University of Colorado, Boulder

APS April Meeting April 13 - April 16 in Denver

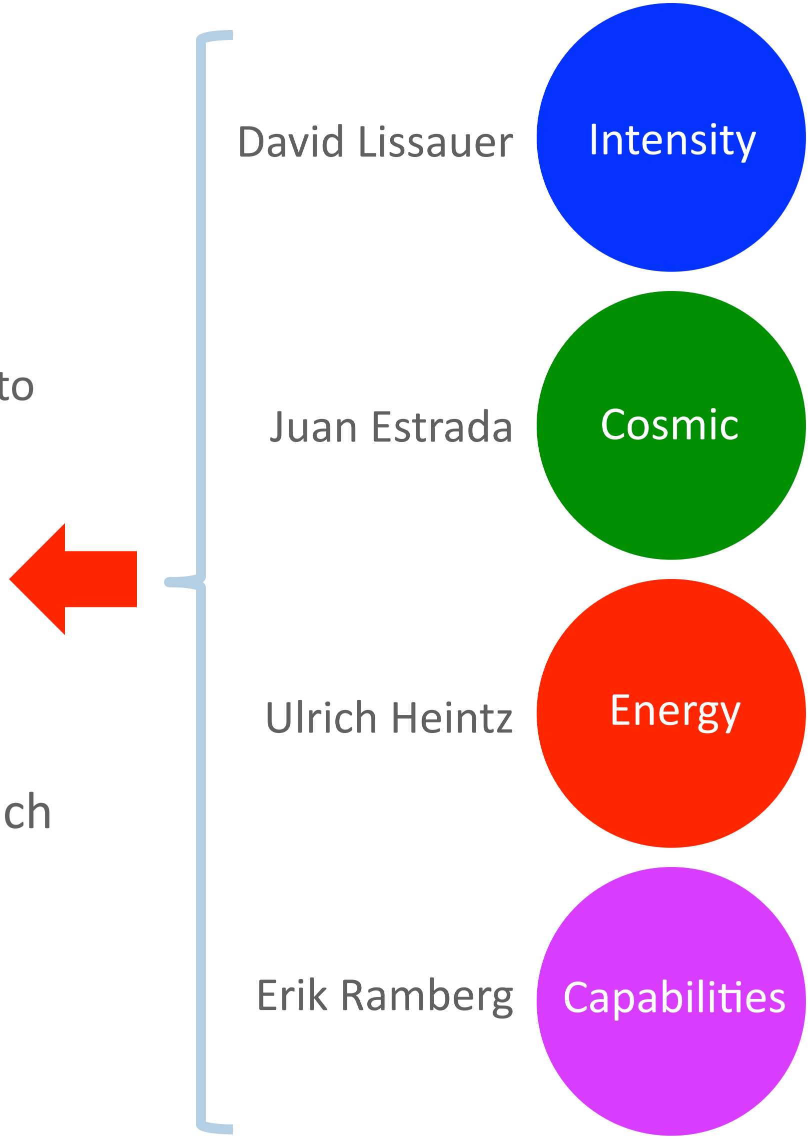
Travel info (hotels, etc) linked from

http://www.snowmass2013.org/tiki-index.php?page=Instrumentation+Frontier

Hope to see some of you there !

Diagonalization

- Parameter space to cover is huge:
  - 4 frontiers
  - Many different existing and future facilities
  - Vast spectrum of technologies
  - Long time horizon which is inherent to R&D
- For the next decade, the natural approach is the physics reach
- Appointed one contact person for each Physics Frontier with Frontier Instrumentation



Diagonalization

	CPAD
Sensors	Artuso Seiden
Gaseous	Gilchriese Wagner
Systems	Blucher Lissauer
Electronics	Heintz Lipton
Software	Graf
Emerging	Alexander MacFarlane

- For the long term, focus on technologies seems appropriate
- Defined six technology categories – any categorization has its limitations
- Two CPAD members assigned to each category, plus additional members in case expertise did not reside within CPAD

Perspective from Two Diagonalizations

	CPAD
Sensors	Artuso Seiden
Gaseous	Gilchriese Wagner
Systems	Blucher Lissauer
Electronics	Heintz Lipton
Software	Graf
Emerging	Alexander MacFarlane

David Lissauer	Intensity
Juan Estrada	Cosmic
Ulrich Heintz	Energy
Erik Ramberg	Capabilities

European Framework Program: EUDET

- EUDET was a Detector R&D program to develop research infrastructure for detector R&D in Europe for the International Linear Collider.
- Supported by the European Union in the 6th Framework Program
- Funding: €21.5M, of which €7M from EU
- Participation: 31 partner institutes from 12 countries
- Funding period: 2006-20010
- Very successful in building infrastructure for detector development

Activities
Management of Infrastructure Initiative
Detector R&D Network
Access to DESY Test Beam Facility
Access to R&D Infrastructure
Test Beam Infrastructure
Infrastructure for Tracking Detectors
Infrastructure for Calorimeters

- The EUDET project was officially closed on 31st December 2010 followed by AIDA

EUDET Detector R&D towards the International Linear Collider

European Framework Program: AIDA

- Advanced Infrastructures for Detectors at Accelerators (AIDA)
- Supported by the European Union in the 7th Framework Program
- Targets infrastructures required for detector development for future particle physics experiments: SLHC, Linear Colliders, neutrino facilities, B-factories in line with European strategy
- Project coordination: CERN
- Funding: €26M, of which €8M from EU
- Participation: 80 partner institutes from 23 countries
- Funding period: 2011-2014

- Broad base of infrastructures covered:
  - Test beams, irradiation facilities, common software tools, common microelectronics tools and engineering coordination offices.
  - AIDA will work closely with industry to develop new technology to lead to new applications for society.

AIDA

Advanced European Infrastructures for Detectors at Accelerators

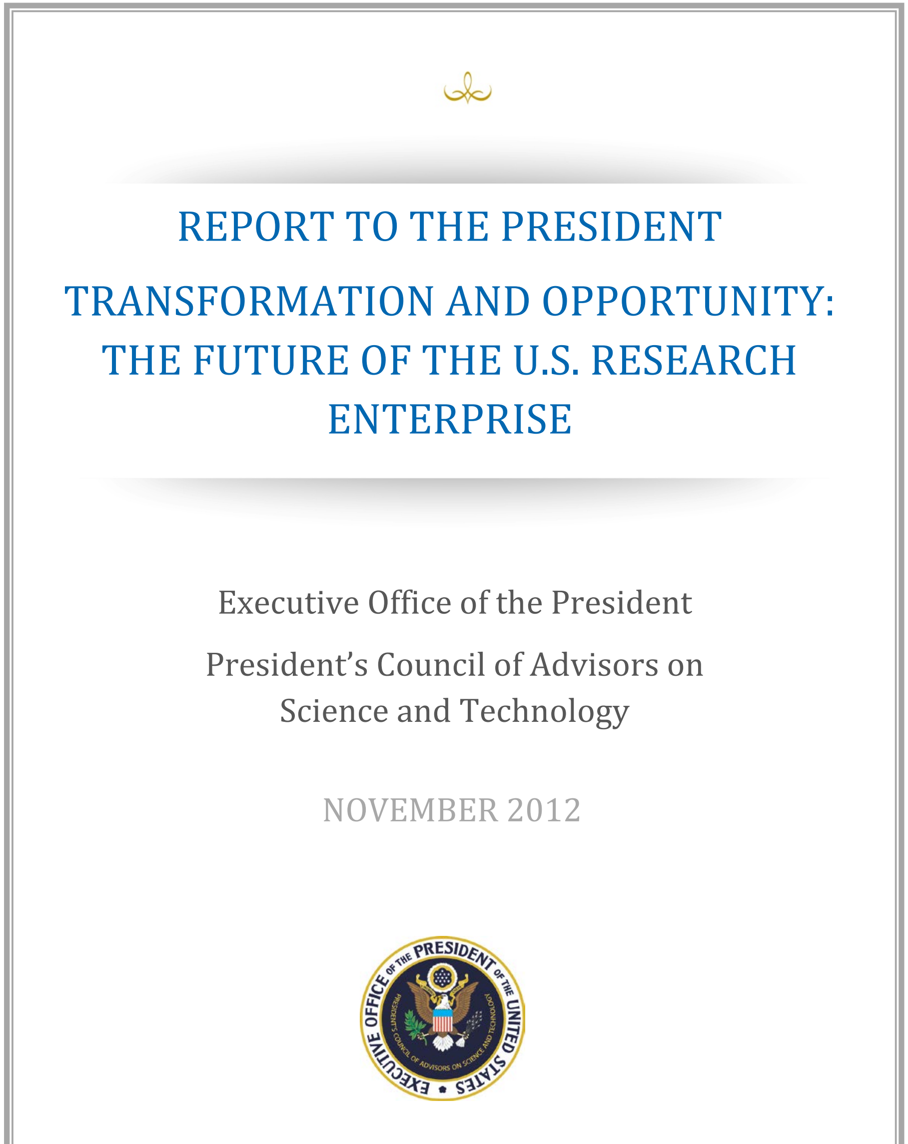
Observations

- Although many key particle physics technologies were invented in the US, in many areas the US has lost its leadership role
- Furthermore, in certain areas the expertise is about to disappear altogether from the US
- Should the US retain a leadership position in areas of traditional strength?

- Industry collaboration in the US has traditionally not been at the same level as in Europe or Japan.
- DOE, with support from government, encouraging utilization of SBIR/STTR program
- How can industry participation be strengthened?

SiPM manufacturers

National Scene


REPORT TO THE PRESIDENT

TRANSFORMATION AND OPPORTUNITY: THE FUTURE OF THE U.S. RESEARCH ENTERPRISE

Executive Office of the President

President's Council of Advisors on Science and Technology

NOVEMBER 2012

http://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports

Table of Contents

Goals:

1) enhancing long-range U.S. investment in basic and early-stage applied research
2) reducing the barriers to the transformation of the results of that research into new products, industries, and jobs.

Fundamental innovative instrumentation development is at the core of HEP

Opportunity aligned with national priorities