Potential U.S. Detector scope as it relates to a Higgs Factory

US Higgs Factory Planning Meeting
SLAC
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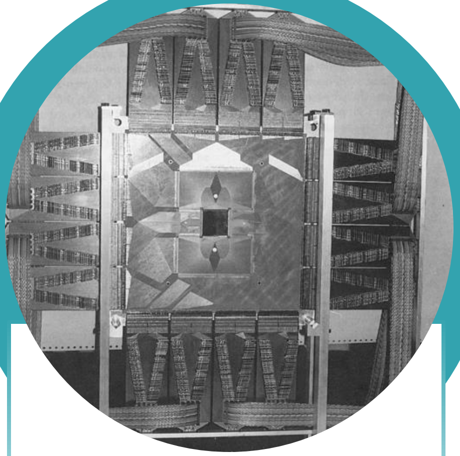
Marcel Demarteau
demarteau@ornl.gov

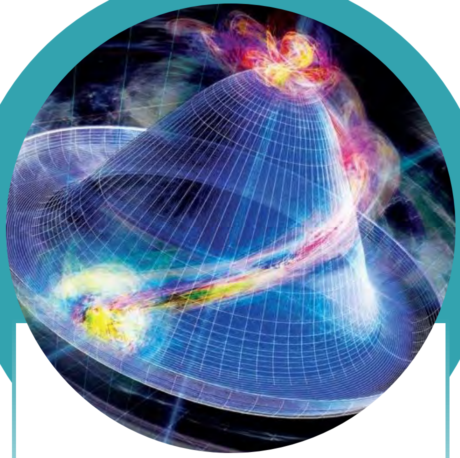
With many thanks to Jon Kotcher, Mike Tuts, Steve Nahn, Anders Rydt, all L2 and L3 coordinators and many more ….

Outline: US Contributions



Historical Perspective

Innovation by the US HEP program

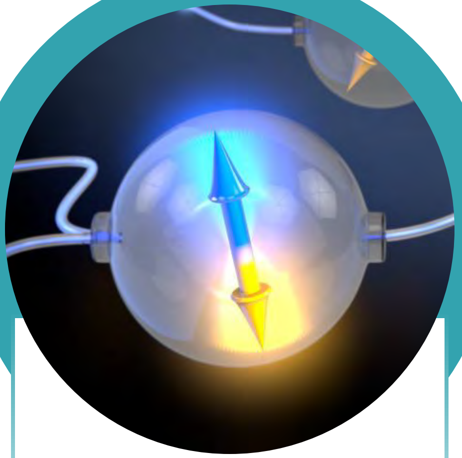


LHC +

US contributions to current collider experiments

Interests

Current interests of the community



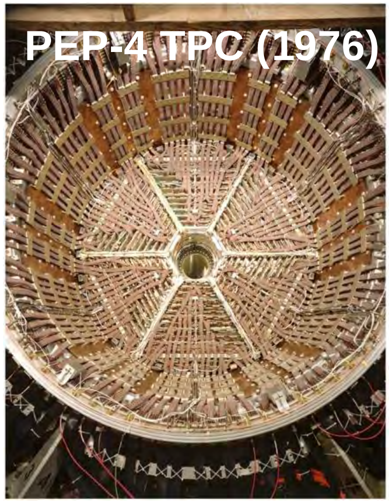
Perspective

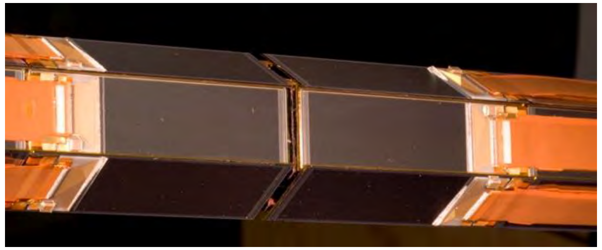
Keep perspective

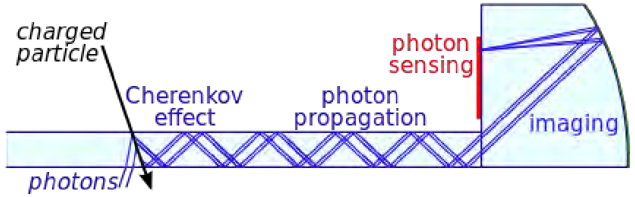
- *Apologies for incompleteness given limited time.*

A Bit of History

- The US has a remarkable legacy in the development and advancement of detector technologies for high energy physics.
  - Invention of the Time Projection Chamber
  - Advancing and scaling liquid argon calorimetry
  - Low-noise electronics
  - Silicon strip detectors
  - Detection Internal Reflected Cherenkov light
  - Low-mass silicon structures
  - Track trigger
  - Fiber Tracker
  - Deployment of Visible Light Photon Counters
  - LGAD detectors
  - Digital Calorimetry
  - …. …. ….

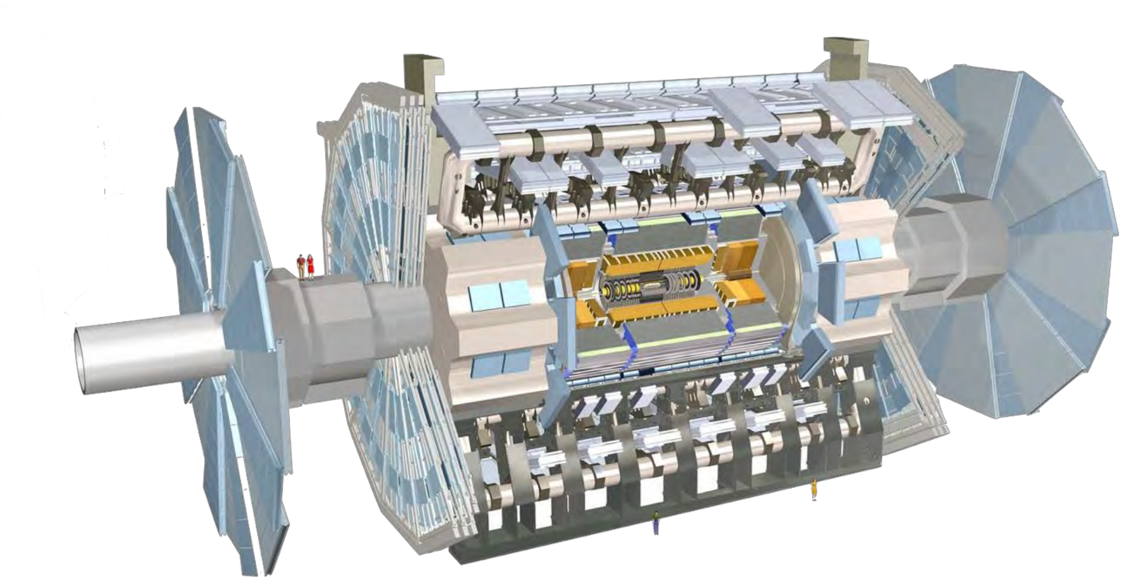


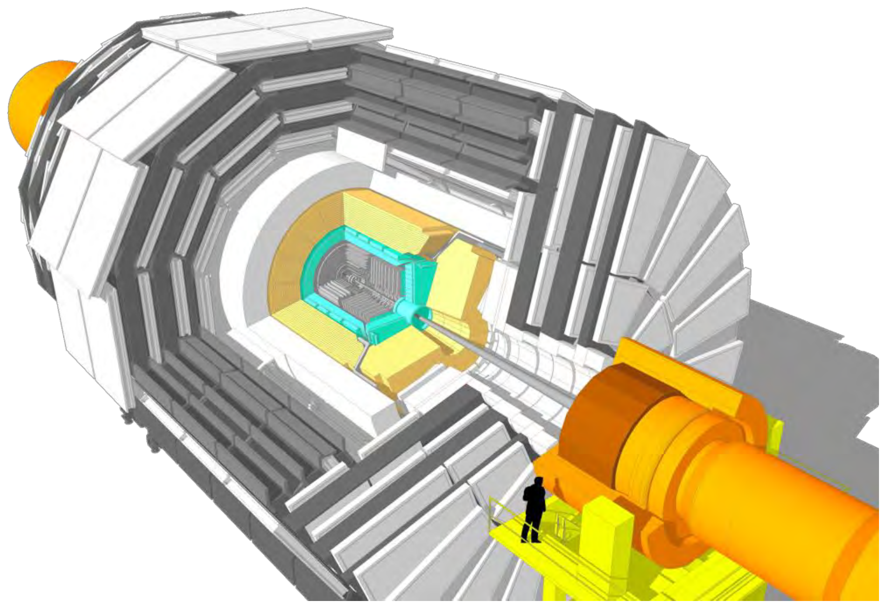




The LHC Experiments

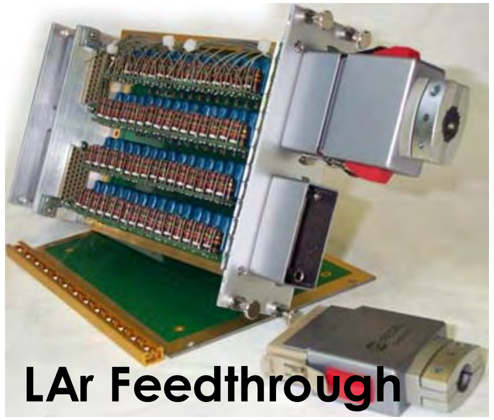
- The US had very significant scope for the construction of the two multi-purpose LHC experiments, ATLAS and CMS.

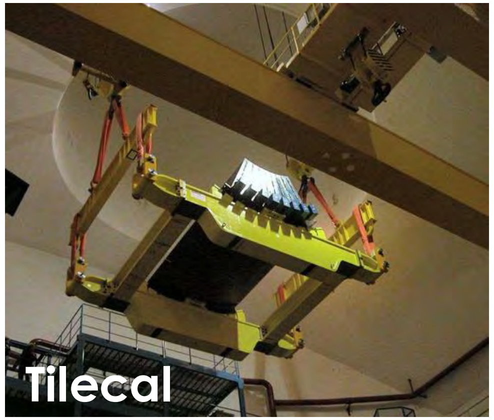


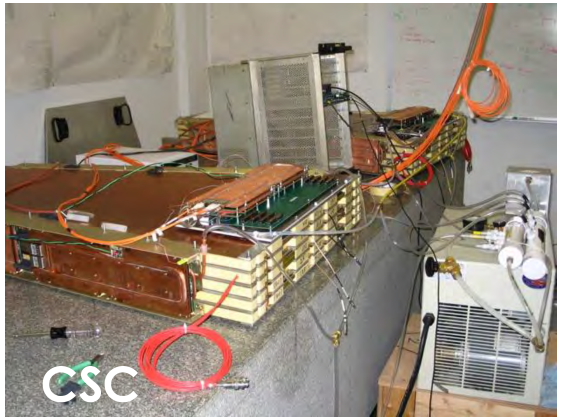


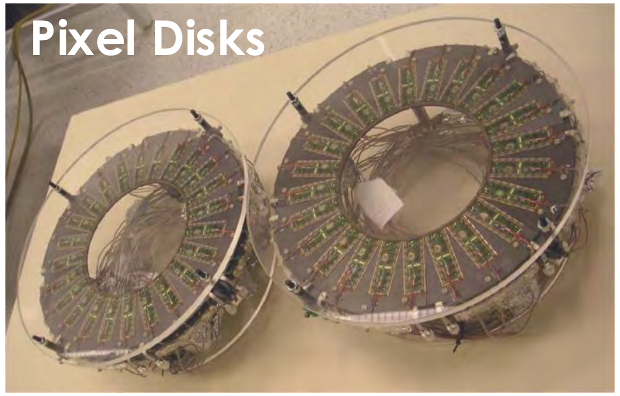
ATLAS Phase-0

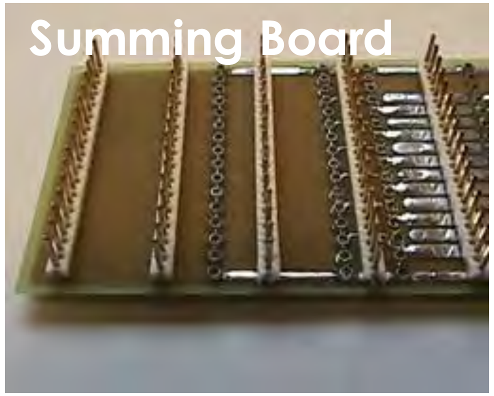
- Pixel tracker, Transition Radiation Tracker, LAr calorimeter, Tile calorimeter, Cathode Strip Chambers, ….

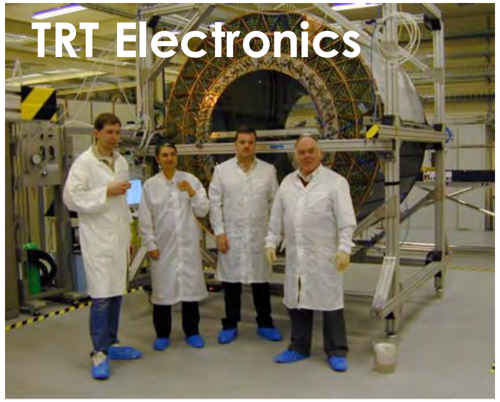


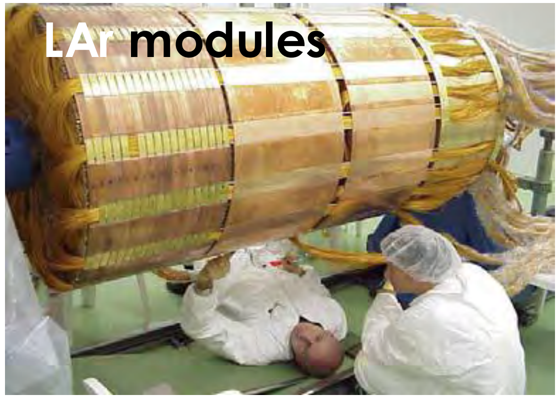












ATLAS Phase-0: Cost

DOE contributions and cost towards original ATLAS experiment

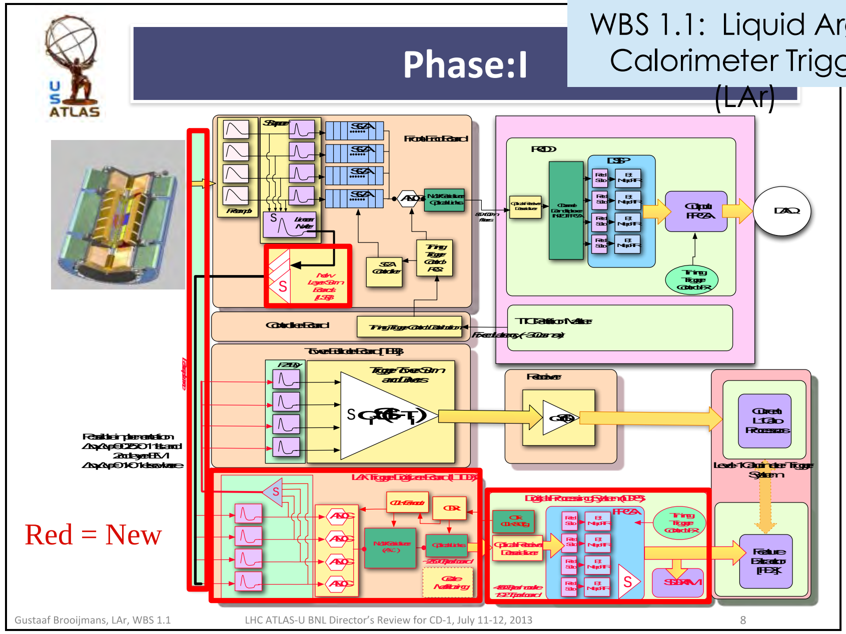
Project WBS Item	Budgeted Cost of Work Performed (through CD-4A)
1.1 Silicon Subsystem	$23,937.9k
1.2 TRT Subsystem	$11,878.3k
1.3 LAr Calorimeter Subsystem	$47,522.3k
1.4 Tile Calorimeter Subsystem	$11,552.3k
1.5 Muon Spectrometer Subsystem	$30,185.7k
1.6 Trigger/DAQ Subsystem	$5,170.6k
1.7 Common Projects	$15,313.5k
1.8 Education Outreach	$135.2k
1.9 Project Management	$8,380.2k
1.10 Technical Coordination	$3,095.3k
TOTAL U.S. ATLAS Project	$157,171.3k

Date: 30 Sept. 2005
CD-4a Closeout Report

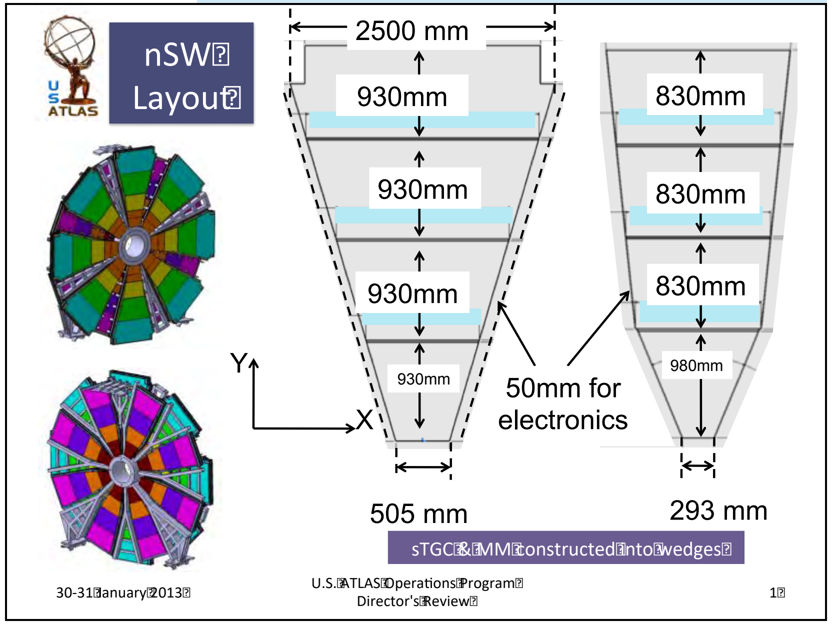
DOE Total contribution was $250M (ATLAS + CMS)
NSF additional contribution of $81M (ATLAS + CMS)

ATLAS Phase-1: Scope

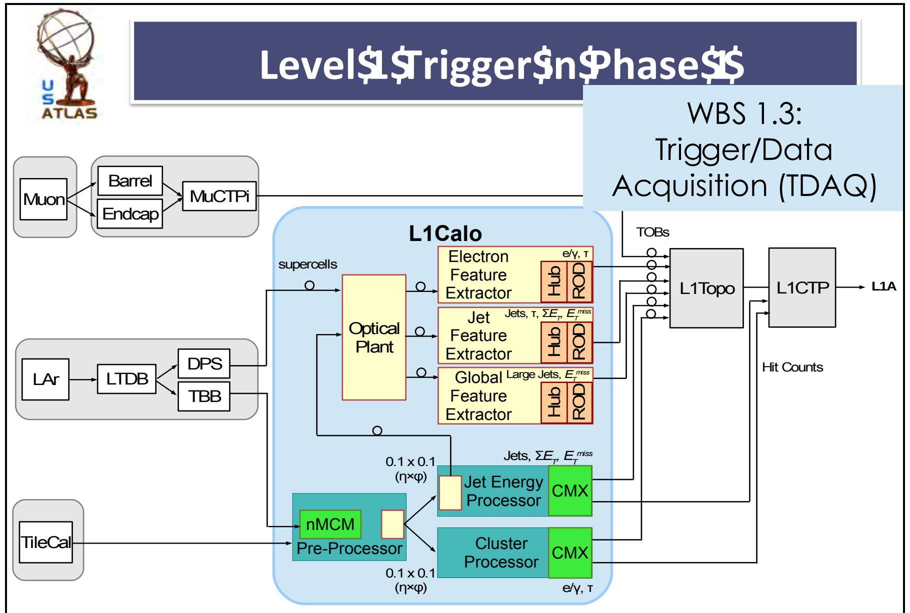
WBS 1.1: Liquid Argon Calorimeter Trigger (LAr)



WBS 1.2: Muon New Small Wheel (nSW)



WBS 1.3: Trigger/Data Acquisition (TDAQ)



- US Focus:
  - Increased granularity and functionality in the Liquid Argon Calorimeter Level 1 trigger.
  - Forward Muon (New Small Wheel) front-end readout, trigger, and alignment systems.
  - Use of fine-granularity LAr data in the Level 1 Calorimeter trigger, and overall readout system enhancement (TDAQ).

ATLAS Phase-1: Scope

- 1.1 Liquid Argon Calorimeter Trigger Readout (LAr)
  - 1.1.1 Baseplanes
  - 1.1.2 Layer Sum Boards
  - 1.1.3 Liquid Argon Trigger Digitizer Boards
  - 1.1.4 Back-End Electronics
- 1.2 Muon New Small Wheel (nSW)
  - 1.2.1 VMM Chip
  - 1.2.2 Front End Card
  - 1.2.3 ART Data Driver Card
  - 1.2.4 MM Trigger Processor
  - 1.2.6 nSW Alignment
  - 1.2.7 Trigger Data Serializer
- 1.3 Trigger/Data Acquisition (TDAQ)
  - 1.3.1 Algorithm Firmware
  - 1.3.2 FEX ATCA Hub
  - 1.3.3 FEX Fiber Plant
  - 1.3.4 gFEX System
  - 1.3.5 FELIX Firmware
- 1.4 Project Management

nSW is funded by DOE only.
Funding for LAr and TDAQ is split between DOE & NSF.

Deliverables are at Level 3 or below, and are uniquely assigned to NSF or DOE. Control accounts, and reporting, are at Level 3.

Green = DOE only, Red = NSF only, Purple = DOE & NSF

ATLAS Phase-1: Cost

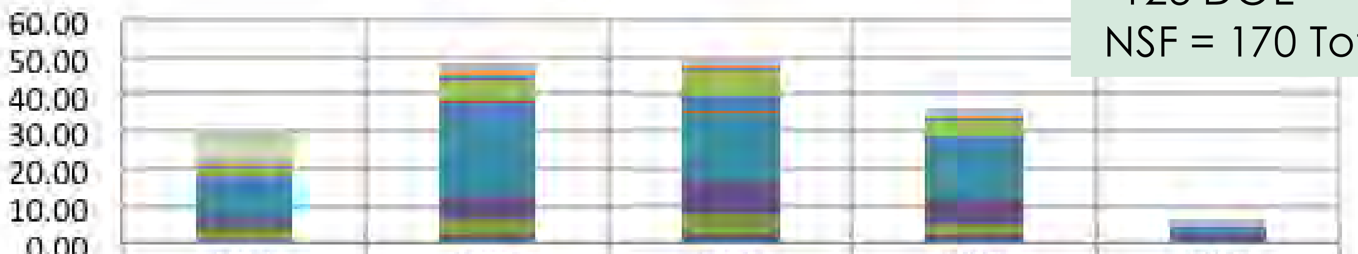
US ATLAS Phase I Upgrade, AYk$	DOE						NSF					
DOE	Total FY14	FY15	FY16	FY17	FY18	TOT	Total FY14	FY15	FY16	FY17	FY18	TOT
LAr	1,802	1,536	1,603	1,503	134	6,873	586	1,435	2,178	1,694	67	5,960
nSW	1,191	2,421	3,684	3,511	13	10,949	-	-	-	-	-	-
TDAQ	378	1,174	1,444	1,089	63	4,149	55	605	362	639	50	1,711
PM	799	699	619	592	521	3,732	119	213	219	226	233	1,009
Base Estimate Subtotal	4,170	5,830	7,349	6,695	731	25,703	760	2,253	2,759	2,558	349	8,680
Level 2 Project Contingency	-	2,229	1,941	1,540	129	5,839	-	750	641	617	56	2,065
Global Risk-Based Contingency	-	325	735	564	85	1,708	-	125	282	216	33	655
LHC ATLAS-U Total	4,170	8,383	10,025	8,799	945	33,250	760	3,128	3,682	3,392	437	11,400
Fractional Contingency	-	0.44	0.36	0.31	0.29	0.29	-	0.39	0.33	0.33	0.25	0.31
DOE Guidance	6,250	7,500	9,500	8,500	-	33,250	2,400	2,850	3,200	2,750	200	11,400
Guidance + Carryover	6,822	10,152	11,269	9,744	945	33,250	2,400	4,490	4,562	3,630	438	11,400
Balance/Carryover	2,652	1,769	1,244	945	-	-	1,640	1,362	880	238	-	-

- Total DOE+NSF: $44.65M

ATLAS Phase-1: Labor

Total FTES:
123 DOE + 47
NSF = 170 Total

Total FTE

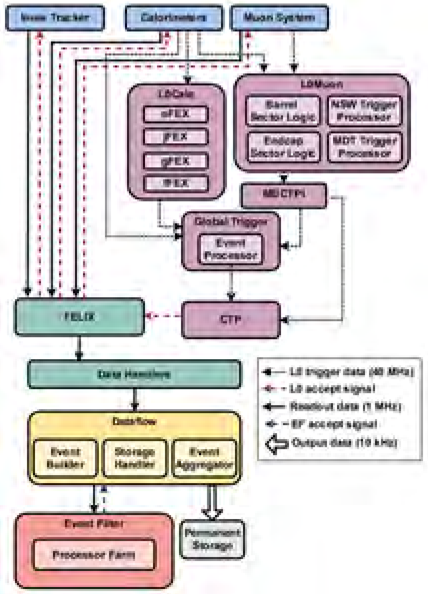


	FY14	FY15	FY16	FY17	FY18
MGMT (Act. through 4/2014)	1.07				
ENGR (Act. through 4/2014)	7.01				
U-Admin		0.50	0.50	0.50	0.25
Proj. Mgmt	0.75	1.40	1.40	1.40	1.18
U-Stu	0.56	1.40	0.61	0.40	0.04
U-Postdoc	0.35	0.58	0.36		
Inst-Phy	0.47	0.73	0.80	0.47	0.03
Postdoc	1.70	5.25	6.45	4.05	0.12
U-Eng	0.35	0.72	0.38	0.34	0.01
U-Phy	3.83	5.23	4.04	3.43	1.30
Physicist	0.14	0.25	0.23	0.21	
Engineer	6.82	19.23	18.59	13.09	1.01
Technician	2.52	6.26	9.05	6.74	0.73
Student	3.43	4.21	4.98	2.84	0.01
Designer	0.48	1.03	1.19	1.10	0.16
Admin	0.65	1.30	1.30	1.30	1.10

ATLAS Phase-II: Scope

Liquid Argon Calorimeter (LAr)
- electronics only - 40 MHz r'dout

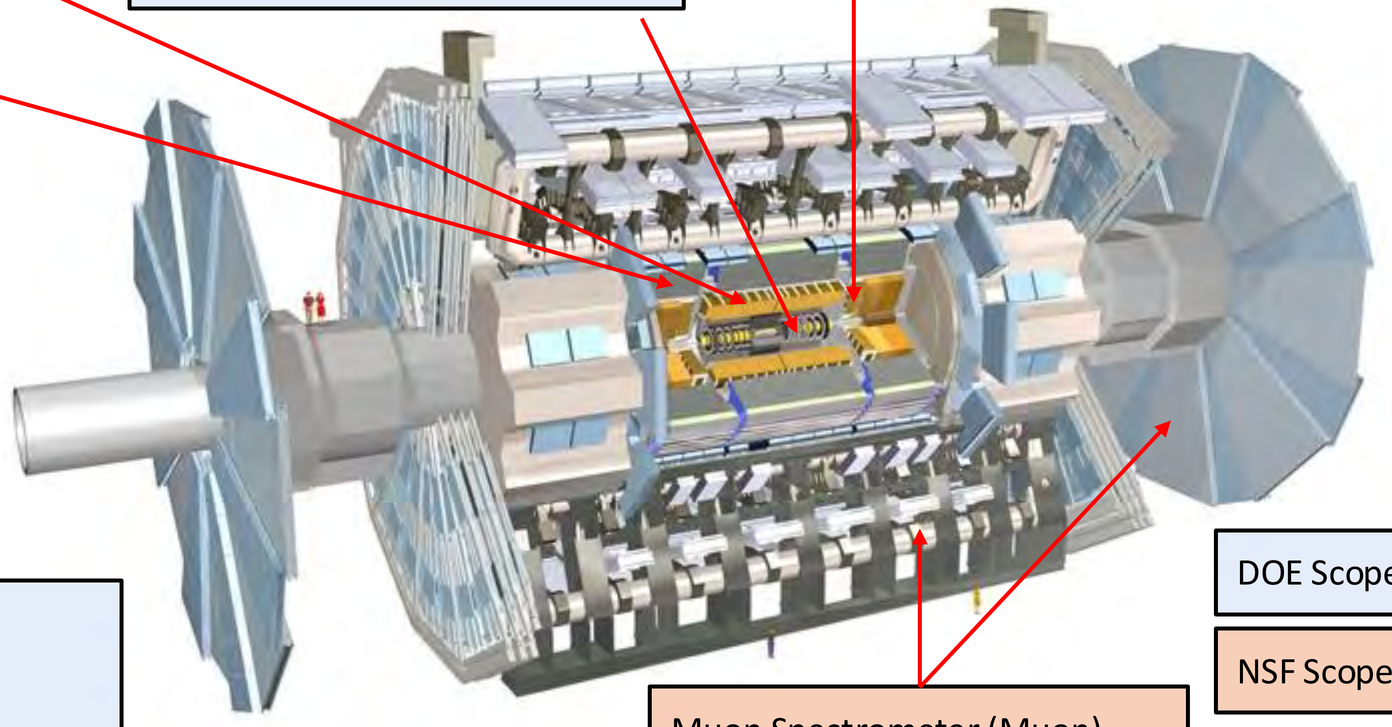
Tile Calorimeter (Tile)
- electronics only - 40 MHz r'dout



Trigger & DAQ (TDAQ)
- 1 MHz L0 Trigger
- tracking trigger
- new DAQ & dataflow

Inner Tracker (ITk)
- Pixel & Strips Detectors
- Mechanics & Electronics

HIgh Granularity Timing Detector (HGTD)
- improve pileup rejection at high eta



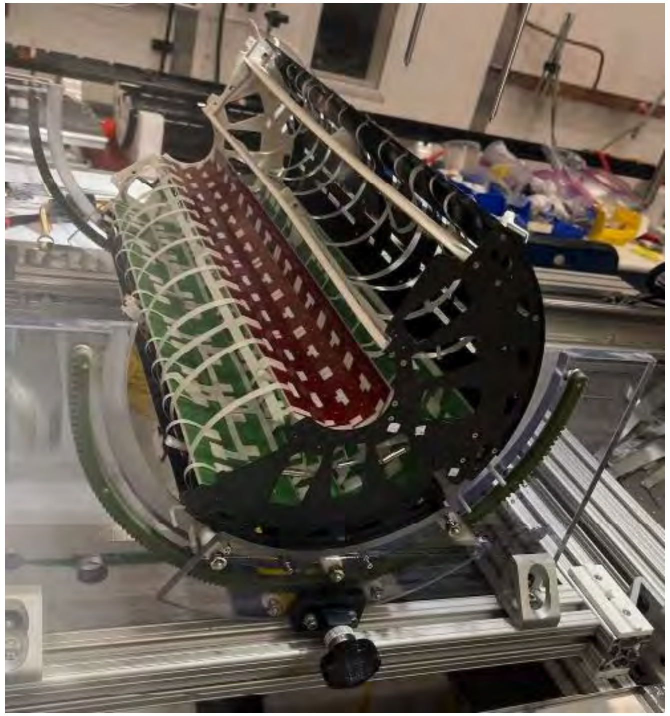
Muon Spectrometer (Muon)
- add chamber coverage
- replace electronics

DOE Scope

NSF Scope

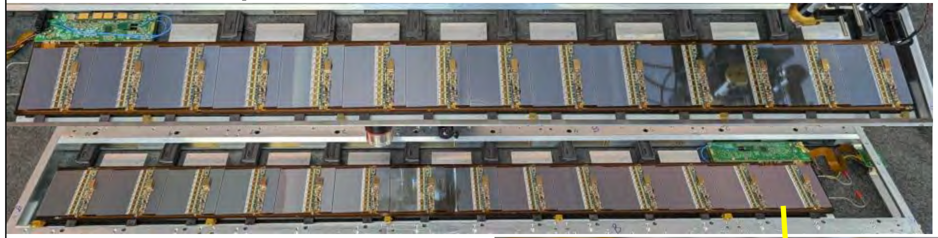
ATLAS Phase-II: DOE Cost

WBS	Total
Deliverables	
6.01 Pixel	34,921
6.02 Strips	48,055
6.03 Global Mechanics	17,459
6.04 LAr	6,804
6.07 Data Handling/DAQ	14,188
6.09 Common Costs	3,370
6.10 PMO	15,883
Total Deliverable Base Cost	140,680
Total Deliverable CTG	***74,838***
Contingency on Deliverables	
MC Contingency (89% CL)	31,677
Top-Down (PM) Contingency	31,677
Fractional Contingency	0.423
Total Deliverable Cost	***172,357***
Install. & Integ. (I&I)	
6.11 Inst. & Integ. (I&I)	17,418
Contingency on I&I (30%)	5,225
Total I&I Cost	**22,643**
Total Project Cost (Deliv. + I&I)	***195,000***
Funding/Carryover	**Total**
DOE Funding (Deliv. + I&I)	200,00
Guidance + Carryover	-
Balance/Carryover	-



TPC (DOE): $200M

1st US interposer stave loaded

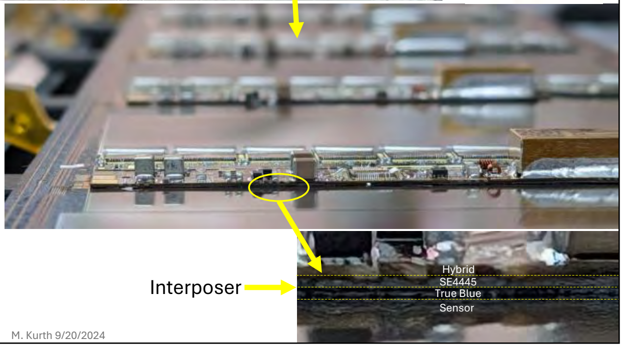


Brookhaven National Laboratory

BERKELEY LAB

SCIPP SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS UC SANTA CRUZ

- 28 interposed modules
- Bonding and testing next week
- TC down to -45C before sending to RAL for climate chamber TC



M. Kurth 9/20/2024

ATLAS Phase-II: NSF Cost and Institutions

Task (WBS)	Institution
LAr front end electronics, ADC ASIC, optical chips	Columbia, SMU, UT Austin
LAr front end-board	Columbia, Pittsburgh
LAr Back-End Electronics	Columbia, NYU, SMU, Stony Brook, Arizona
TileCal Main Board	Chicago
TileCal ELMB2 Motherboard	MSU
TileCal LVPS	NIU, UT Arlington
Muon Monitored Drift Tubes, sMDT	MSU, Michigan
Muon TDC ASIC	Michigan
Muon Chamber Service Module	Michigan
Muon L0MDT trigger	BU, UC Irvine, UMass Amherst
Trigger Level 0 Calorimeter Trigger System Optical Plant	MSU
Trigger Global Event processor Firmware and Algorithms	Indiana, MSU, Chicago, Oregon, Pittsburgh, SMU, Stanford
Trigger Event Filter Tracking	NIU, Arizona, UC Irvine, Chicago, UIUC, Penn

Effort: On-project (technical) 210 FTE-Years; Uncosted scientific labor (off project) 77 FTE-Years
Cost (AYk$) TPC: $82,850 (includes contingency)

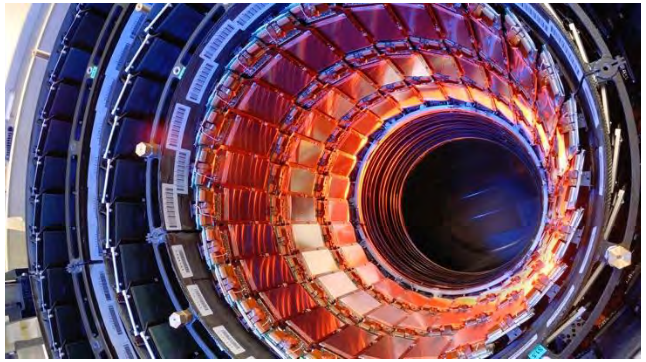
ATLAS To Date

- The U.S. has made, and continues to make, substantial and unique contributions to the ATLAS detector.
- Approximately ~ 20% of the Ph.D. physicists are from the U.S – 14% on the DOE HEP side.
- The U.S. holds ~ 30% of the Level 1, 2 & 3 leadership positions on the International ATLAS HL-LHC upgrade.
- Total contributions: $151.2M + $33.3M + $200M (DOE)
$(share of $81M) + $11.4M + $82.9M (NSF)

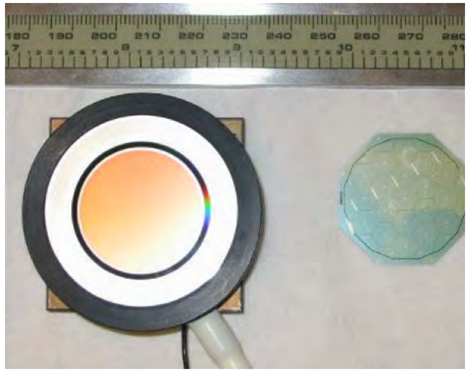
CMS Phase-0

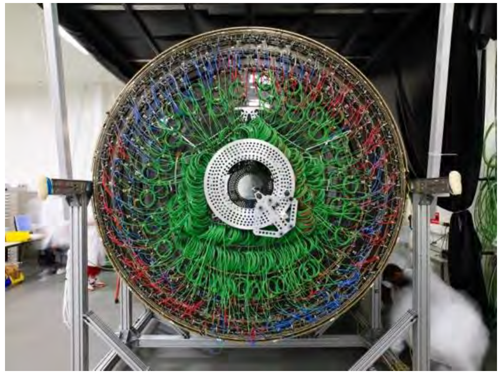
- Pixel and strip tracker, calorimeter (HB, HO, HE and HF), muons, trigger, electronics, readout, ….





First time full silicon tracker

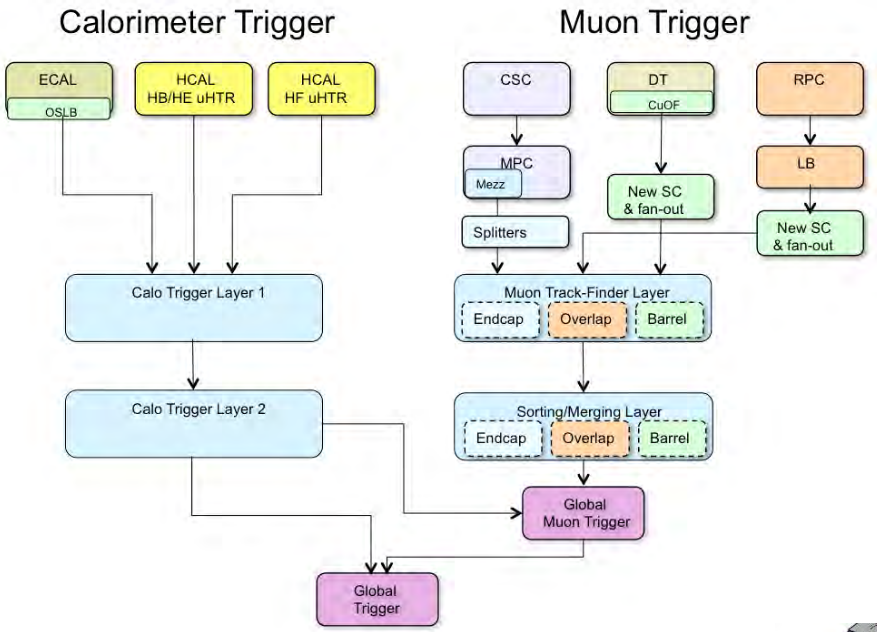



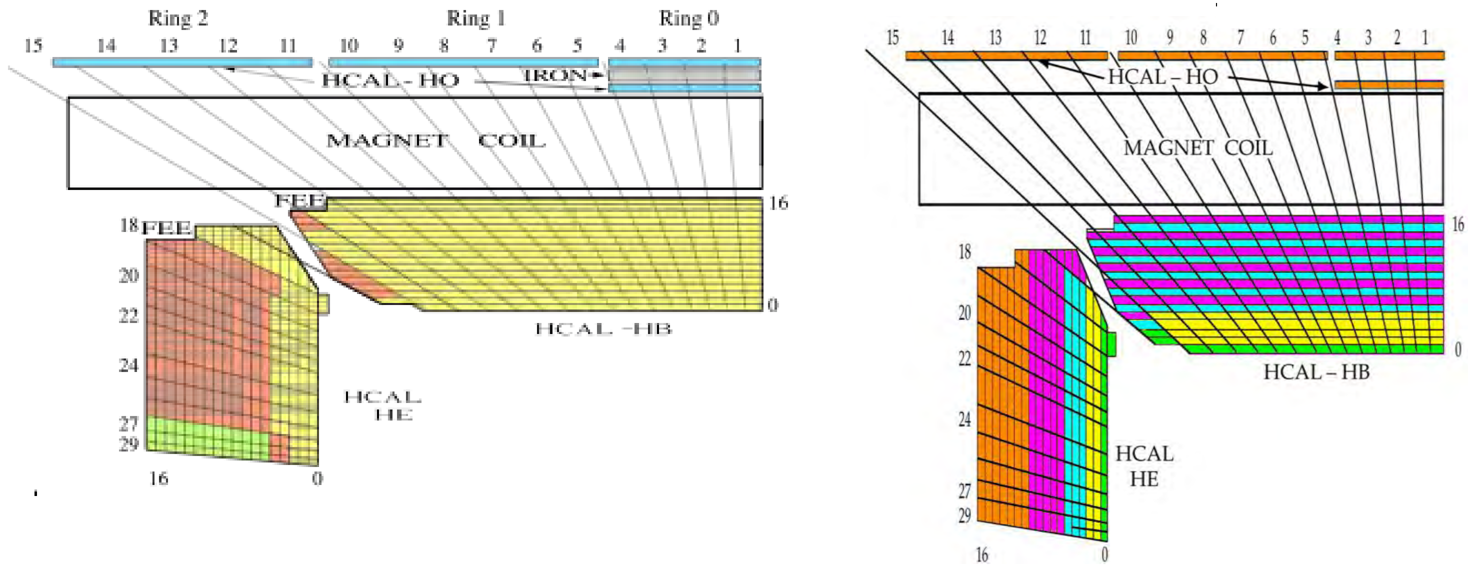


DOE contribution to the construction of the original detector construction the same as for ATLAS

CMS Phase-I: Scope

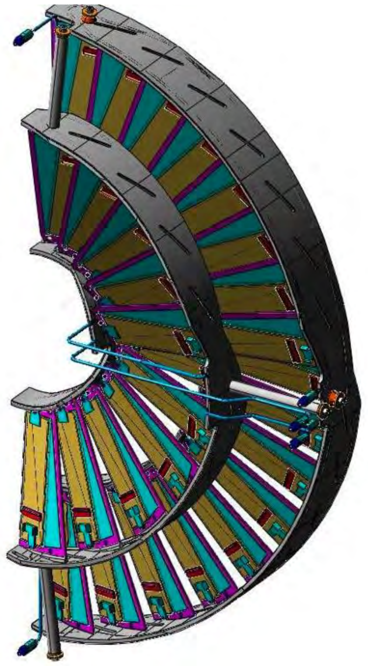
- CMS Phase 1 Upgrade:
  - Pixel detector replacement
  - HCAL electronics upgrade
  - L1-Trigger upgrade





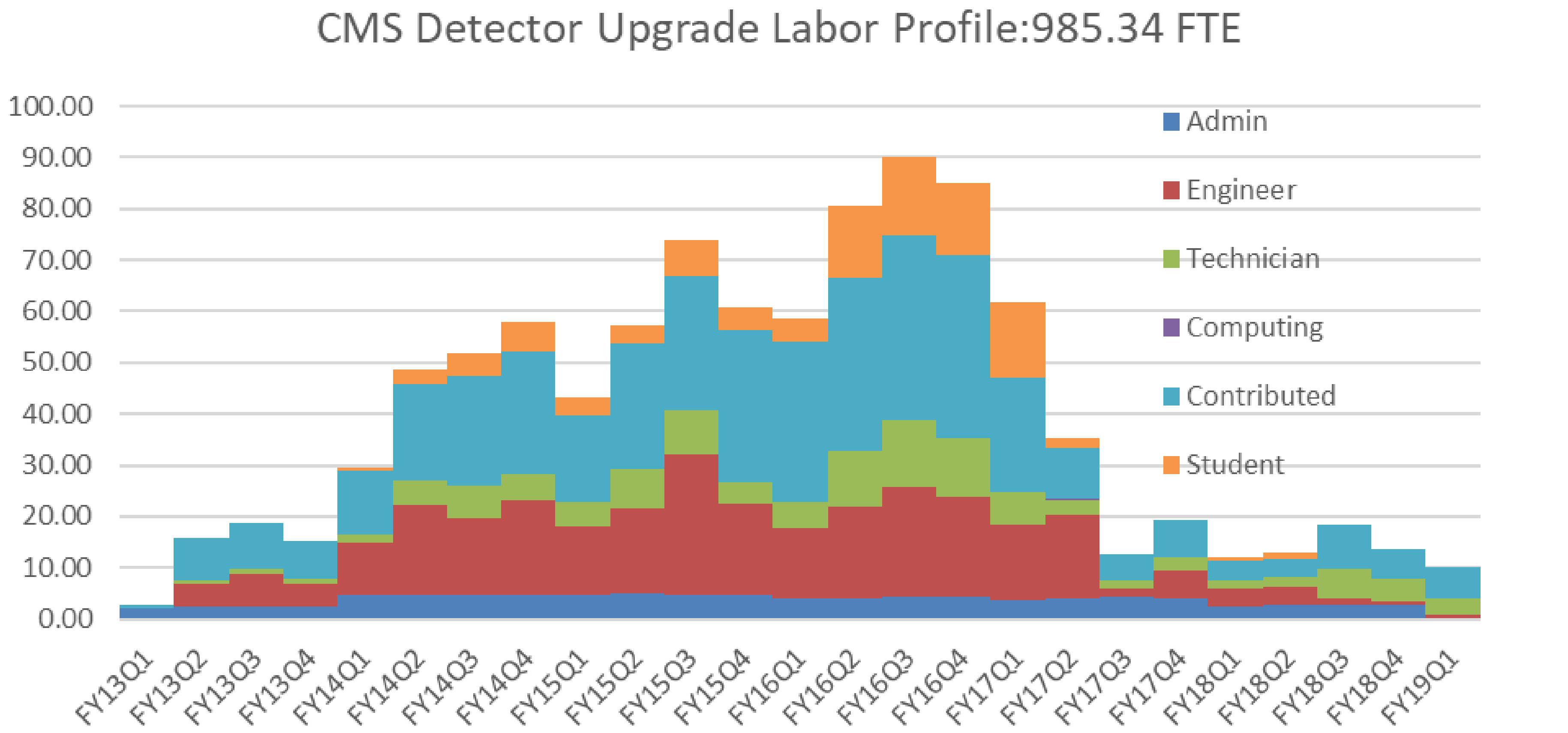
Longitudinal segmentation HB/HE and photodetectors

Pixel Detector Replacement added layer + disks



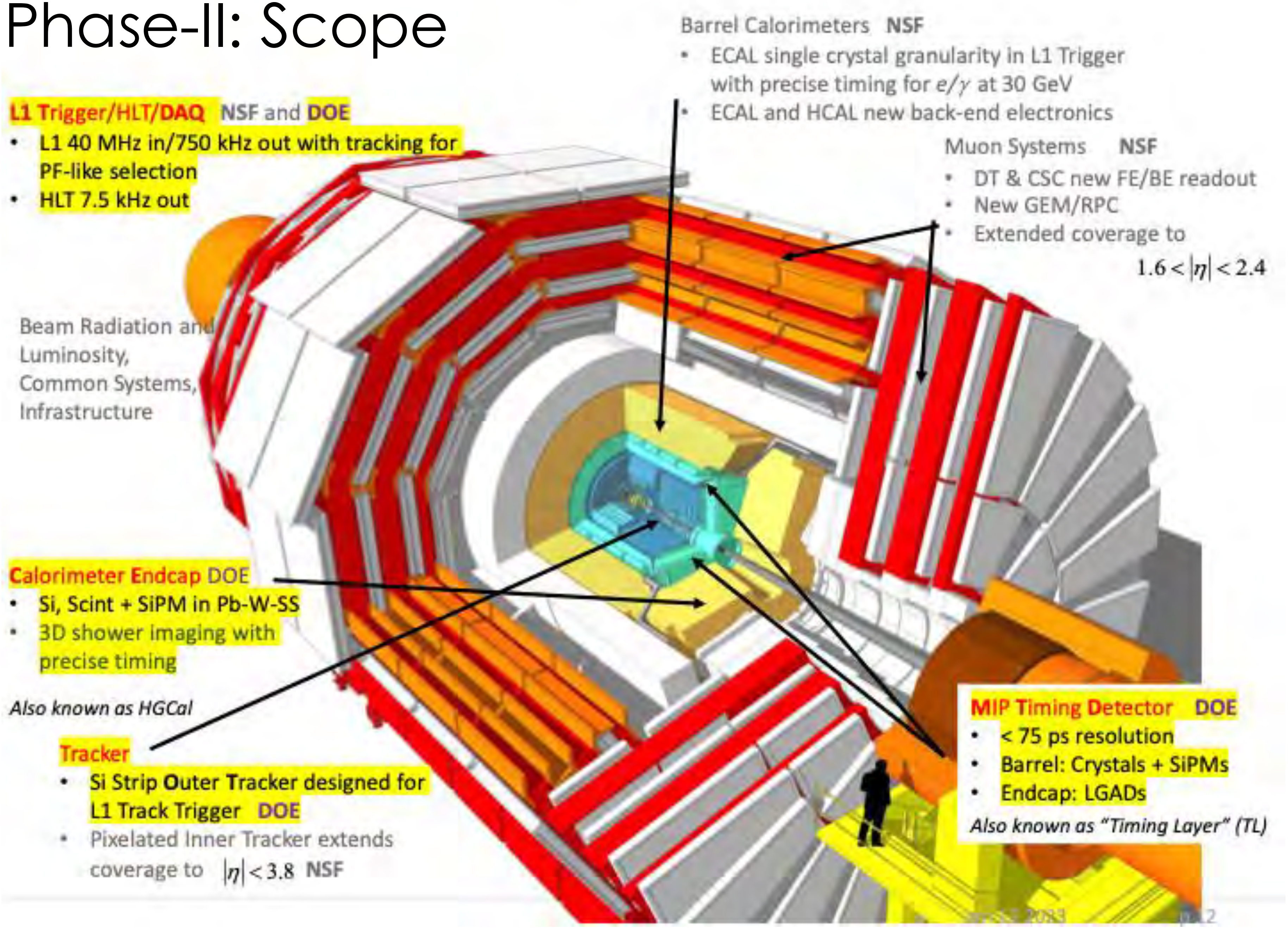
CMS Phase-I: Labor (DOE)

Phase 1: Actual Cost 40.8M (includes NSF and DOE) for about 21 Institutes,



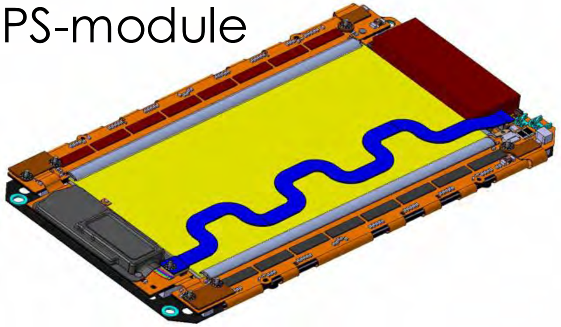
985 FTE over 6 years. 408 of them Contributed labor, 97 Student, 91 Admin, Rest Technical

CMS Phase-II: Scope

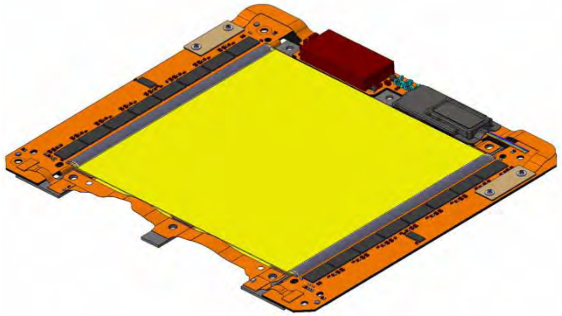


CMS Phase-II: Scope

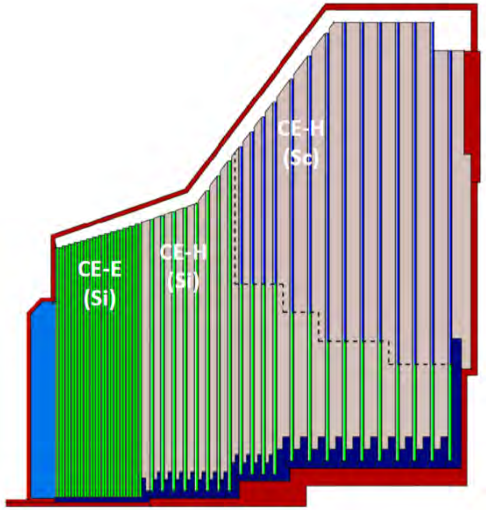
PS-module

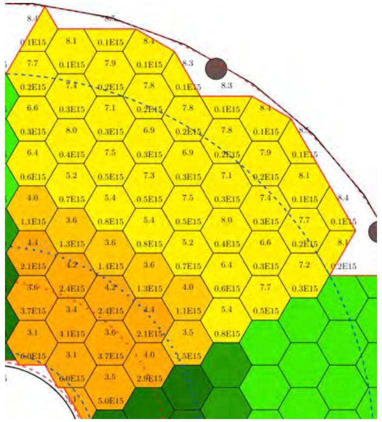


2S-module

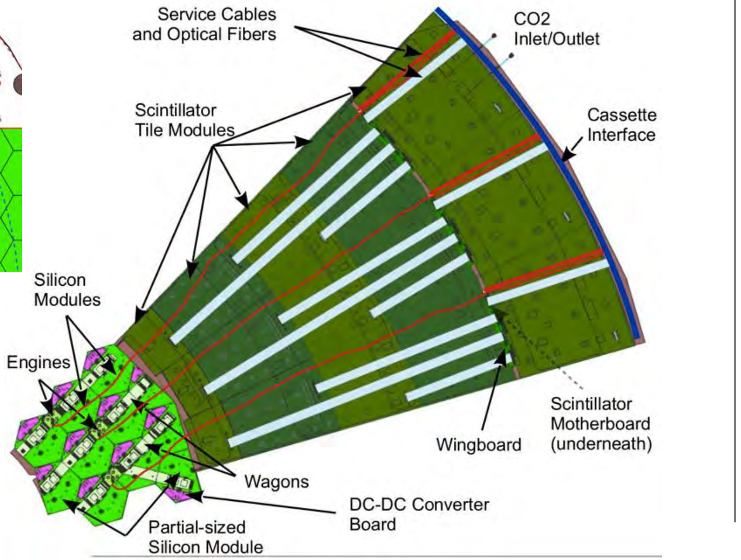


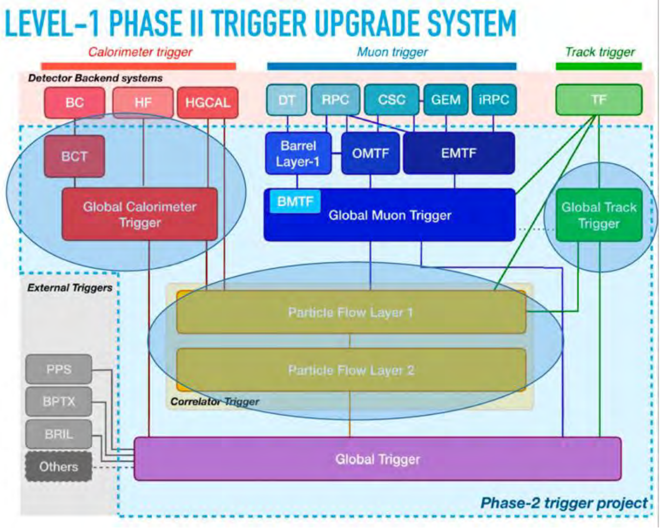
Silicon Outer Tracker



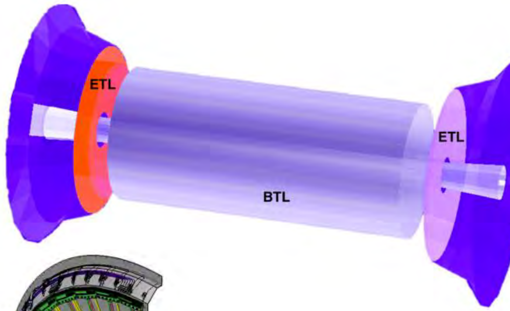


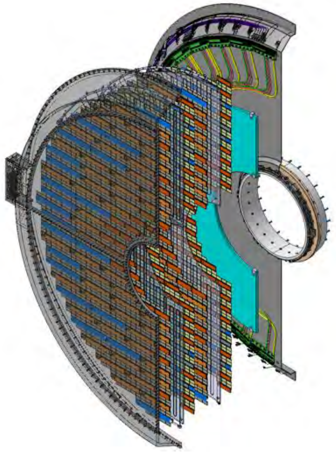
Endcap HGCAL (silicon/ scintillator)





Trigger





Timing Layer LYSO and LGAD

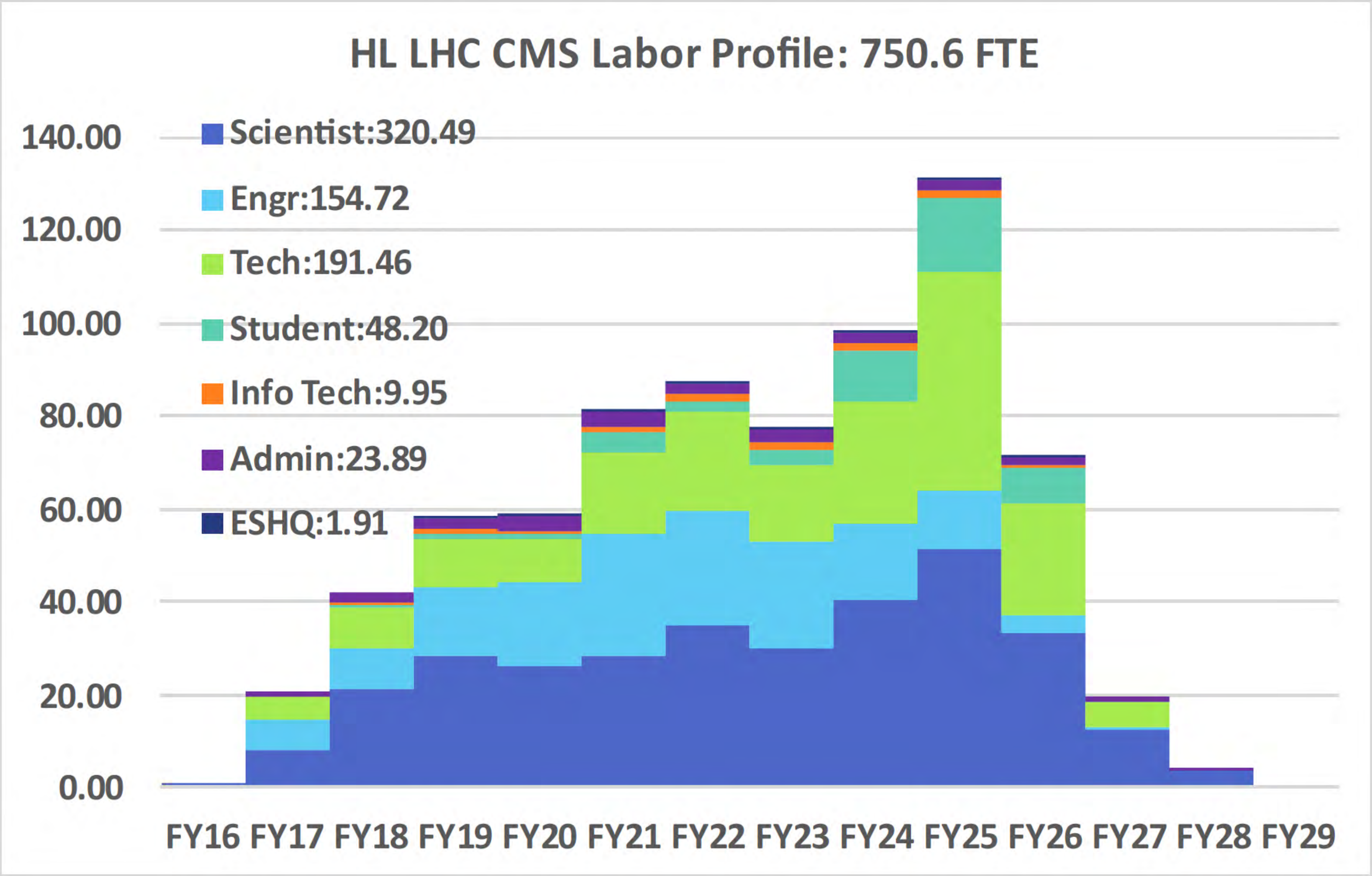
CMS Phase-II: Cost

Total cost ($M)	Labor BAC	Labor EU	Material BAC	Material EU	Total BAC	Total EU	Total = AC + ETC + EU + RC
402.1 Project Management	13,218	556	8,573	1,206	21,791	1,762	
402.2 Outer Tracker	23,680	2,821	26,827	2,945	50,507	5,766	
402.4 Calorimeter Endcap	28,996	4,782	27,805	5,705	56,801	10,487	200.00
402.6 Trigger and DAQ	6,310	912	5,225	756	11,535	1,669	
402.8 Timing Layer	10,850	2,230	10,111	1,510	20,961	3,739	
TOTAL	**83,054**	**11,301**	**78,540**	**12,123**	**161,594**	**23,424**	**200.00**

	Total
Non-I&I	186.00
I&I (Integration and Installation)	14.00
Total	**200.00**

Total funding available (Jan. 2023): $200M

CMS Phase-II: Effort (DOE)



CMS Phase-II: NSF Cost and Institutions

Task (WBS)	Institution (32)
Barrel Calorimeter - ECAL	Notre Dame, Northeastern, Minnesota, Virginia, and Wisconsin
Barrel Calorimeter – HCAL	Maryland and Notre Dame
Forward Muons - CSC	Northeastern, Rice, Texas A&M, The Ohio State U., and UCSB
Forward Muons – GEM	Boston, Florida Inst. of Tech., Rice, Texas A&M, UCLA, Wisconsin, and Wayne State
Forward Pixels - ROC & Sensors	Cornell, Kansas State, Purdue Northwest, U. of Colorado, UIC, UTK, Siena College, UC Riverside
Forward Pixels – Modules	Catholic U. of A. Nebraska, Boston, Florida Inst. of Tech., Purdue U., Purdue Northwest, The Ohio State U., UIC
Forward Pixels – Electronics	Boston, Cornell, Kansas State, Rice, Ohio State U., UIC, U. of Kansas, Vanderbilt
Forward Pixels - Mechanics and Integration	Cornell, Purdue U., UC Davis, Johns Hopkins, SUNY Buffalo,, U. of Puerto Rico
Trigger - Muon Trigger	Rice, Texas A&M, UCLA, U. of Florida
Trigger - Track Trigger	Boston, Cornell, Northeastern, Northwestern, Notre Dame, The Ohio State U., Rutgers, U. of Colorado, UTK

Effort: On-project (technical) ~200 FTE-Years; Uncosted scientific labor (off project) 170 FTE-Years
Cost (AYk$) TPC: $88.00M (includes contingency)

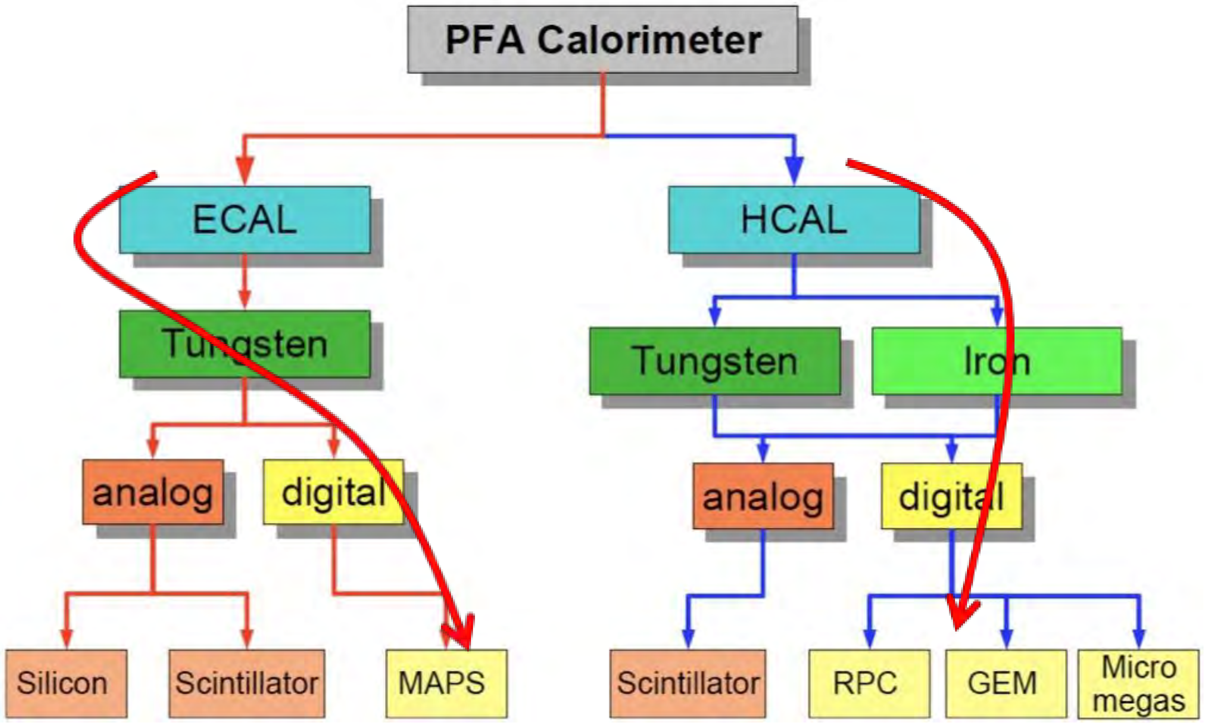
Summary US Contributions to ATLAS and CMS Experiments

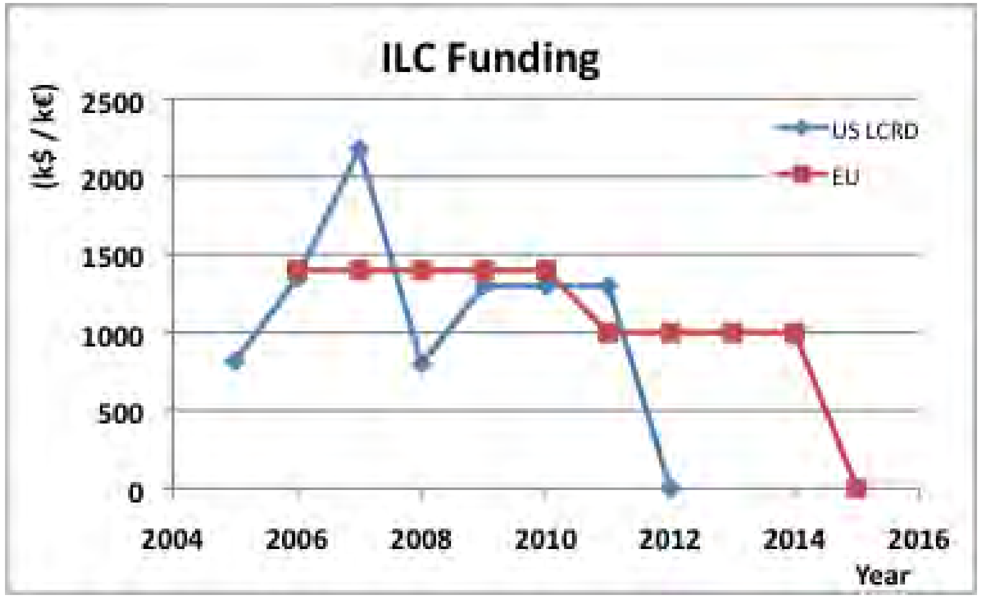
ATLAS + CMS	DOE (M$)	NSF (M$)	Total (M$)	Institutions (DOE+NSF)
Original Construction	250	81	331	
Phase-I Upgrade	33.3 + ~30.8	11.4 + ~10	86	23 + 21
Phase-II Upgrade	200 + 200	82.9 + 88	571	37 + 51
Construction Total			**988**	
Operations per year	**25 -- 27**	**10 –11**	**35 – 38**	

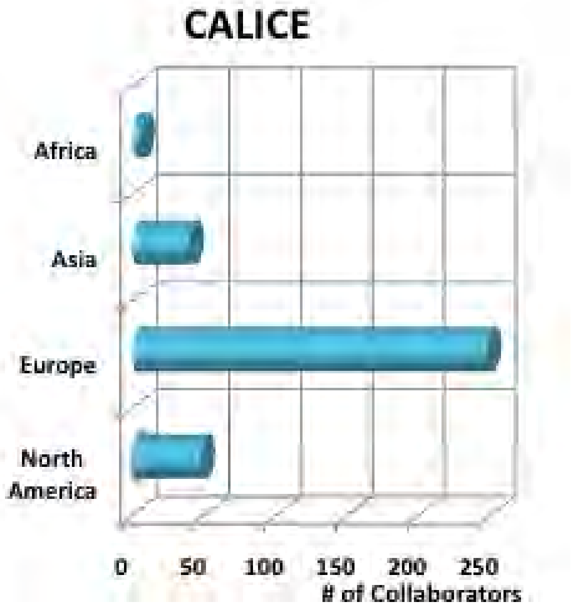
- Since the initial collaboration to today, the US contribution to PED is about $1.7B (excluding contributions to LHCb and to the accelerator)

ILC Detector Contributions

- During 2004 – 2010 the US was also a major player in detector development for ILC detectors:
  - Luminosity, Energy, Polarization measurement
  - Vertex Detector and Tracking
  - Calorimetry and Particle ID

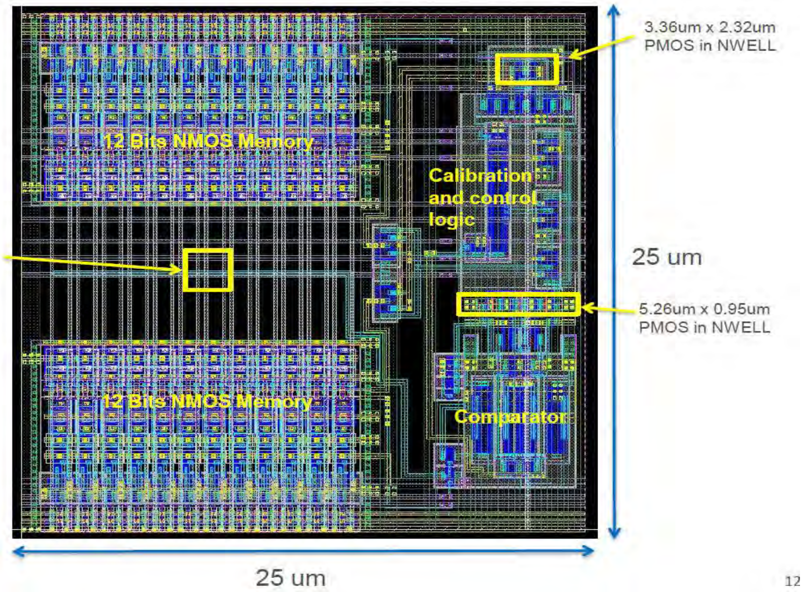


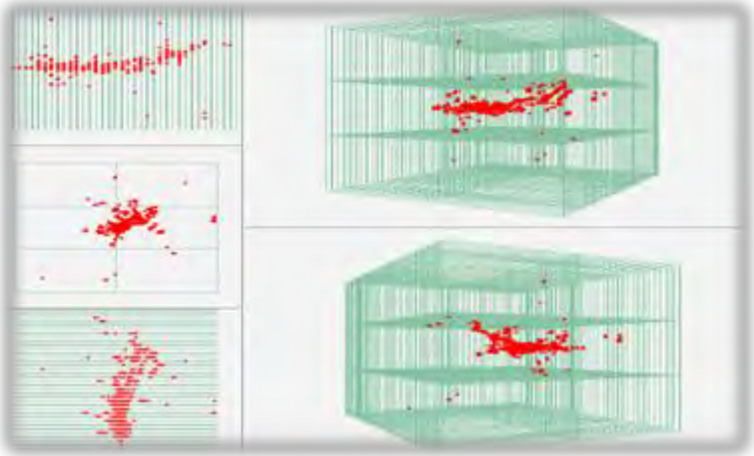




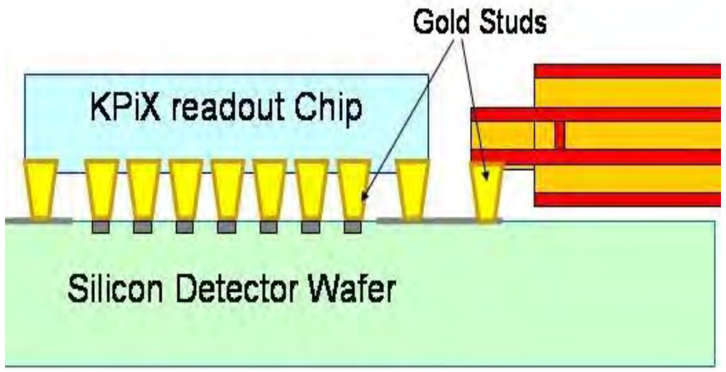
Scope Elements

Pixel chip with individual bunch crossing time stamping (chronopix)





Designed, build and operated the first most fine-grained RPC-based Imaging calorimeter of 500,000 channels with embedded integrated readout electronics

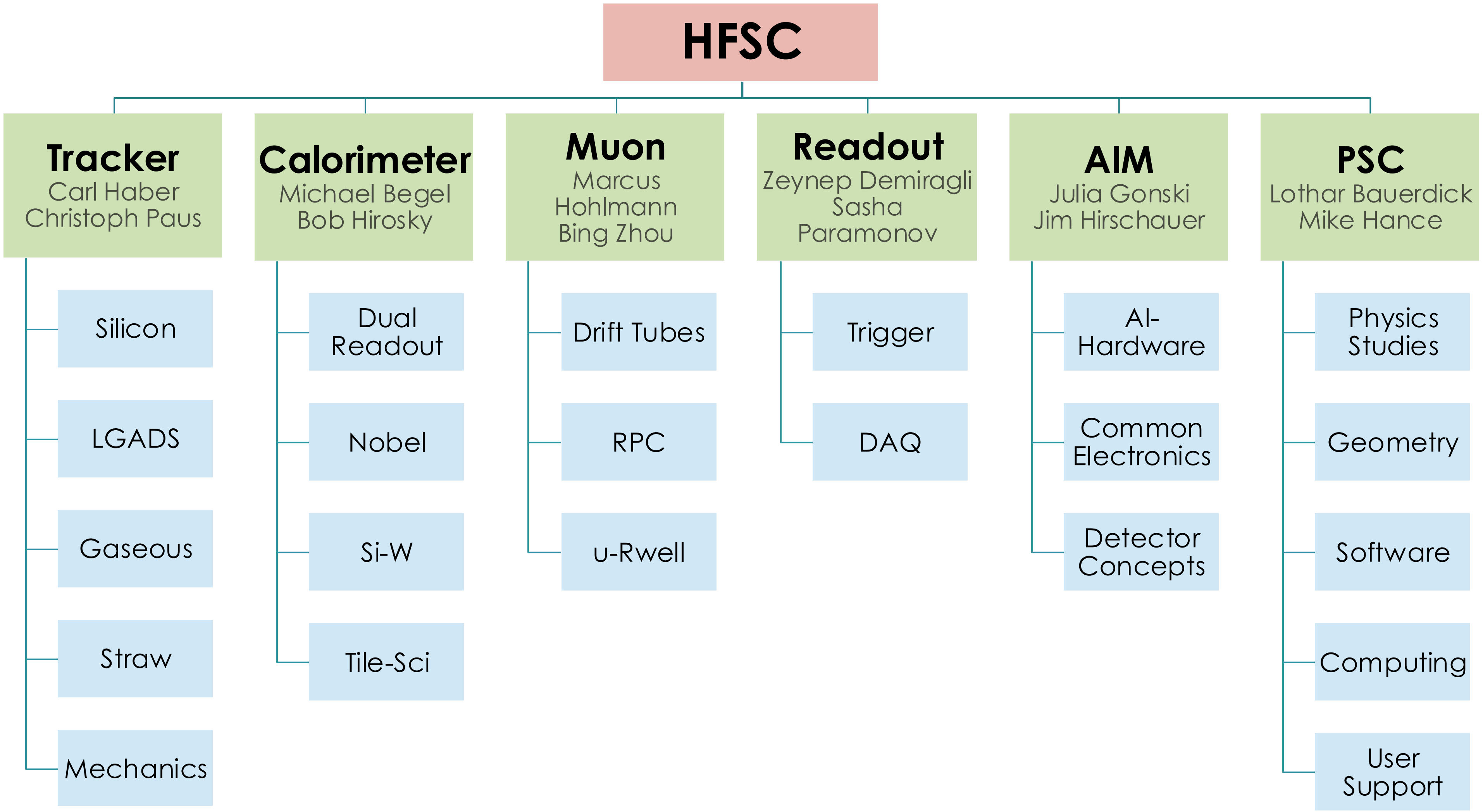


Silicon Strip Readout with 1k channels

Summary

- The U.S. has had **major roles** in the construction of the two multi-purpose LHC and ILC detectors spanning a large range of technologies.
- The U.S. holds **~ 30%** of the Level 1, 2 & 3 leadership positions on the International LHC HL-LHC upgrade projects, commensurate with the US participation in the experiment.
- This reflects the **broad and well-recognized expertise** in the U.S., and its strong historical engagement in the experiment.
- The U.S. has in general **many leadership positions** in the LHC experiments, including spokespersons for CMS and upcoming ATLAS spokesperson.
- The anticipated level of commitment towards future detectors will be **on a par with the LHC commitments**.
- The L2/L3 groups are **identifying priority research areas** and forming research collaborations.

L2/L3 Structure



AIM: AI, Integration and Microelectronics
PSC: Physics, Software & Computing

Some Observations

- The U.S. particle physics community has a history of developing novel detector concepts and has broad expertise.
- The U.S. experimental HEP workforce is formidable, and has been a trusted partner with CERN on the LHC. The investment to-date in the construction + upgrades of the two multi-purpose detectors are significant and help realize the physics program of the LHC.
- The community will continue to collaborate with the next proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise.
- The aim for a high precision and discovery machine will require **leadership, novel technologies and new ideas**.

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2021- 25: Feasibility Study → **2027/2028:** project approval by CERN Council → **2032:** construction starts → **2041:** HL-LHC ends → **2045:** Operation of FCC-ee → **2070:** Operation of FCC-hh

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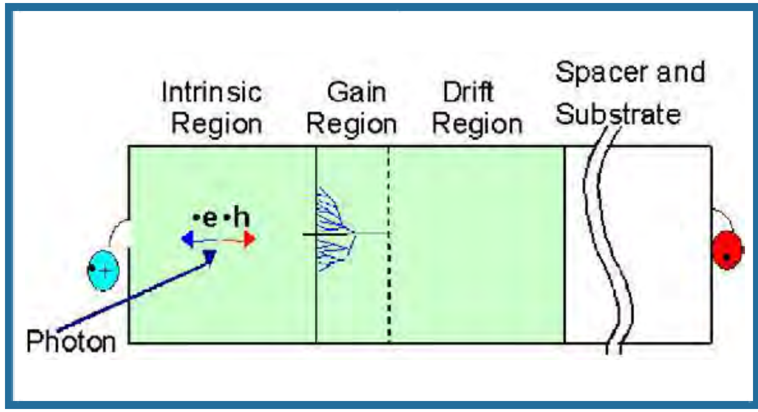
- There is plenty of time to explore new ideas; think out of the box and **rethink current paradigms**.

Keep an Open Mind

- Let's continue to "bounce ideas" for **new detector technologies** to strengthen the case for **a** Higgs Factory; we will all benefit.

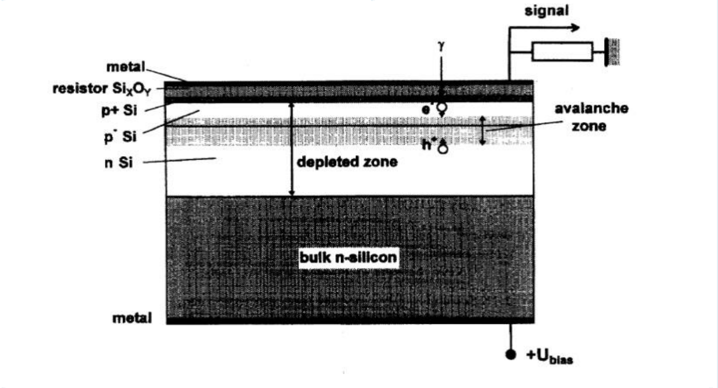
The Underpinning Of Scientific Progress

VLPC (Rockwell, 1987)



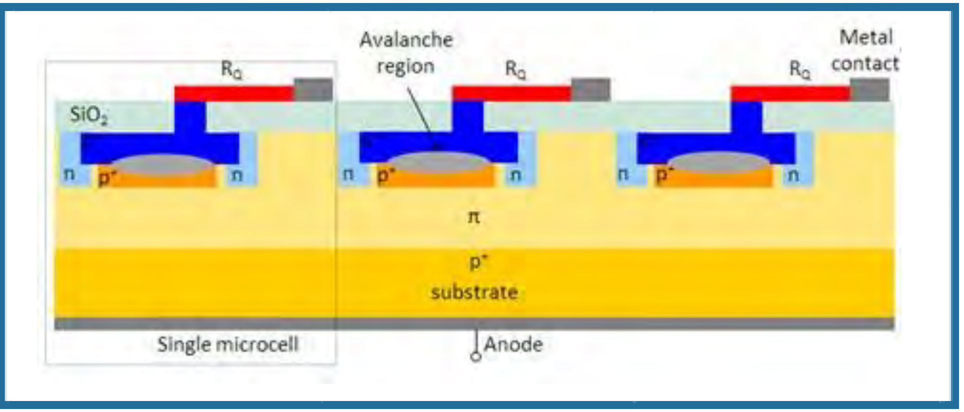
Bross et al., NIM A477, 172 (2002)

MRS APD (Russia, ~1995)



Antich et al., NIM A 389 (1997) 491

MPPC (Russia, ~2003)

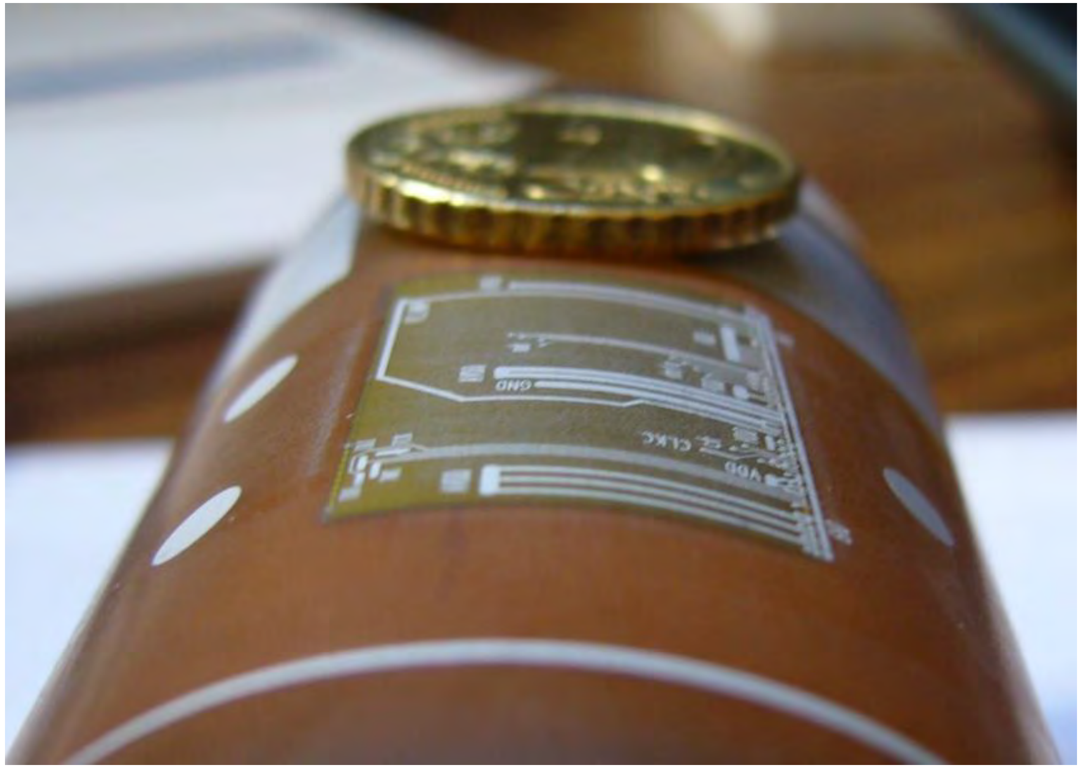


Dolgoshein et al., NIM A 504 (2003) 48
Sadygov patent (1998)

- From difficult beginnings (VLPC operated at 7K for Dzero scintillating fiber tracker) to being a workhorse for the field in a mere twenty years.

VLPC: Visible Light Photon Counter
MRS: Metal- Resistor-Semiconductor
MPPC: Multi-Pixel Photon Counter (SiPM)

Flex embedded sensors



Already more than a decade ago, PLUME, SERVIETTE and PLUMETTE collaboration investigated and succeeded at **embedding thin MAPS sensors in Kapton flex**

New fabrication and packaging technologies for CMOS pixel sensors are **closing the gap between hybrid and monolithic**

https://indico.cern.ch/event/276611/contributions/622863/attachments/502969/694527/dulinski_FEE-2014.pdf

Conclusion

- The U.S. has the breadth, depth and intent for strong participation in the development of the experimental program of a future Higgs factory, resources permitting. That is the message to be conveyed to the ESG
- Currently, the priority is completing the HL-LHC detector upgrades and resources are currently dedicated to its completion.
- The community will continue to collaborate with the next proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise.

With many thanks to Jon Kotcher, Mike Tuts, Steve Nahn, Anders Rydt, Jim Brau, Andy White, all L2 and L3 coordinators and many more ….