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LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Opportunities for low mass mechanics/cooling for FCC-ee

Eric Anderssen

On behalf of many in the Mechanics Forum

FCC Week 2024

11 June 2024

Outline

- Current Detectors in Design/Construction
- Challenges moving to FCC scale detectors
- Mechanics R&D
- Conclusion

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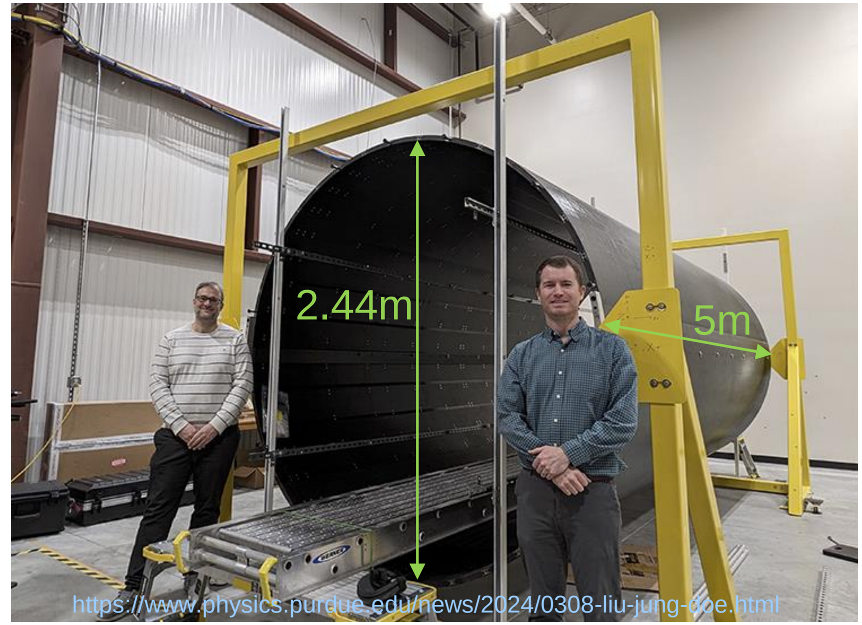
ATLAS and CMS Global Mechanics

ATLAS ITk Outer Cylinder



CMS BTST Outer Cylinder

ATLAS OC just assembled at CERN; CMS BTST expected at CERN in June

Both detectors are a mix of Hybrid Pixels, Strips, and Timing with ~O 200m^2 of Si

Designed for HiLUMI LHC with TID of ~10MGy at low radius requiring -40C cooling and replaceable inner layers

Material and Stability of under 0.5%X_0 per layer and under 2μ RMS stability

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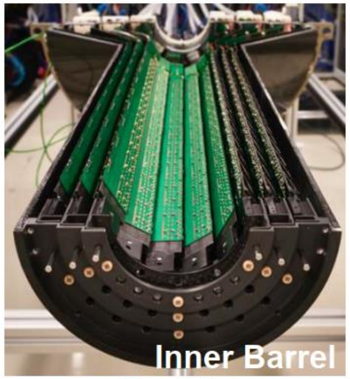
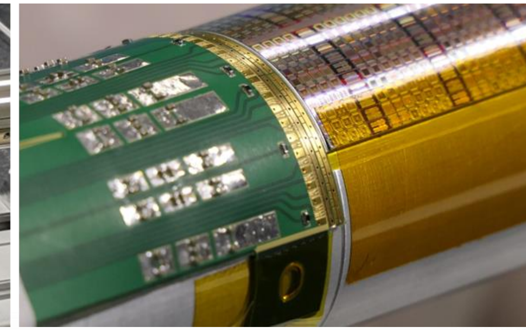
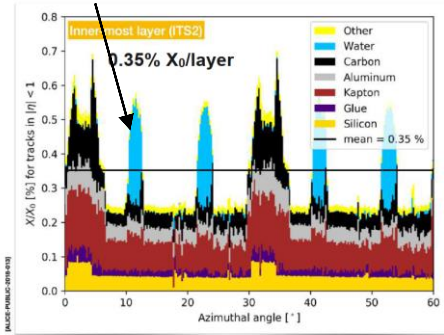
ALICE Detector





Water Cooled

M. Angeletti, FTDM24



C. Pastore, FTDM22

ALICE ITS2 In Operation

ALICE ITS3 for LS3 0.05% X_0/layer

ALICE is pushing the envelope on low mass detectors

Concepts and Electronics used in sPHENIX at RHIC and ITS3 sensors adopted for ePIC at EIC

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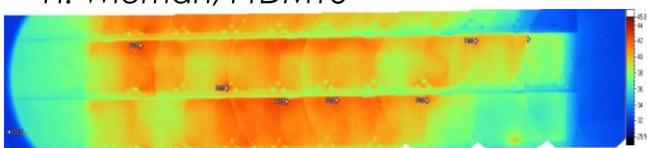
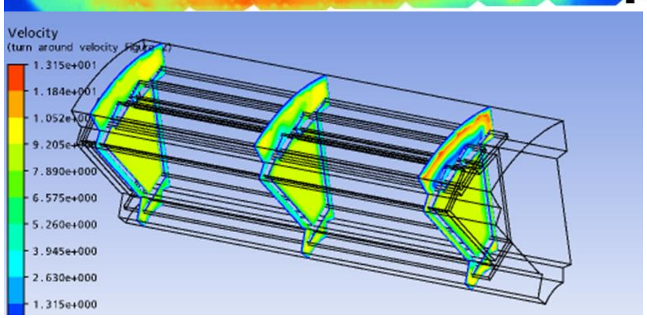
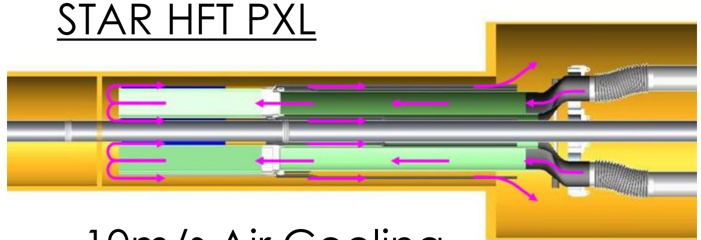
Air Cooling for Low Mass Detectors

H. Wieman, FTDM16

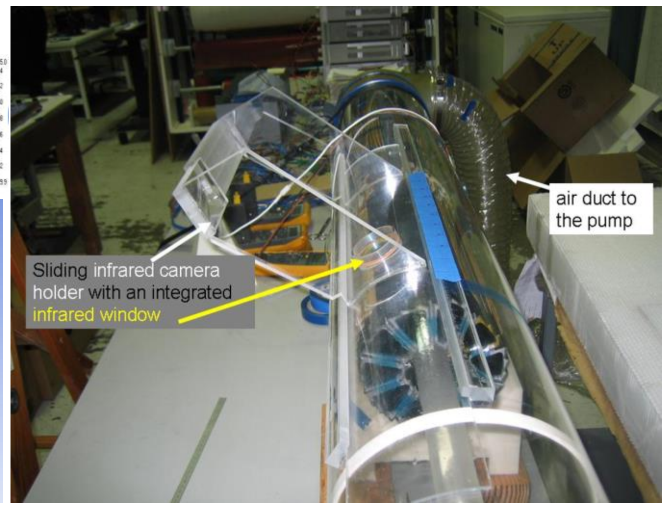


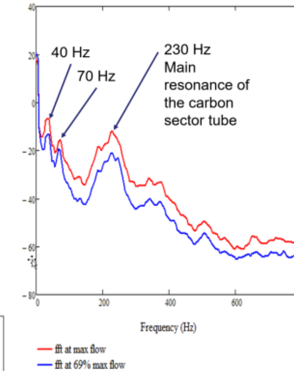


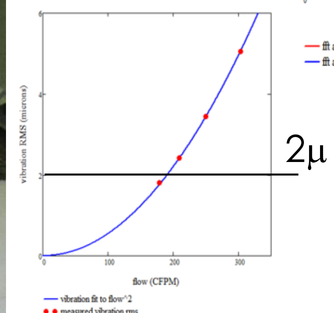
STAR HFT PXL



~10m/s Air Cooling







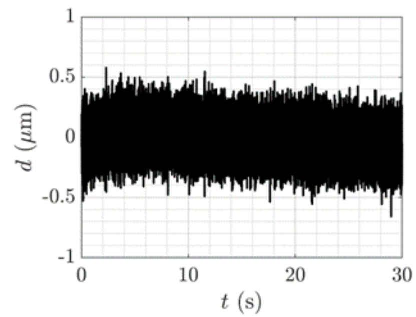
180mW/cm^2 MAPS detector installed in STAR at RHIC, operated from 2012-15
0.35% X_0

Air cooling relies on relatively low power density for direct flow cooling

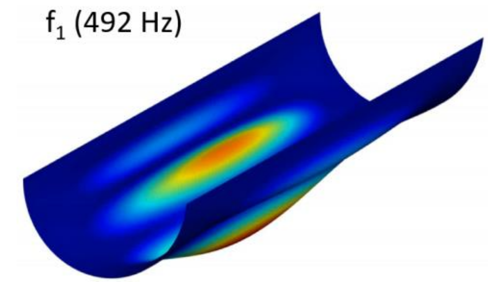
MAPS are approaching under 70mW/cm^2 for Heavy Ion detectors

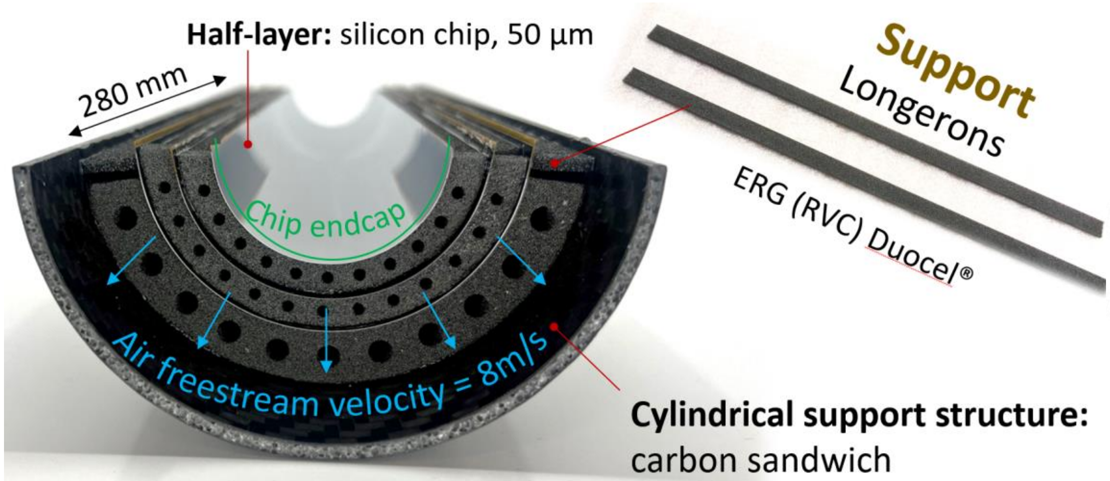
Using Structural elements in flow

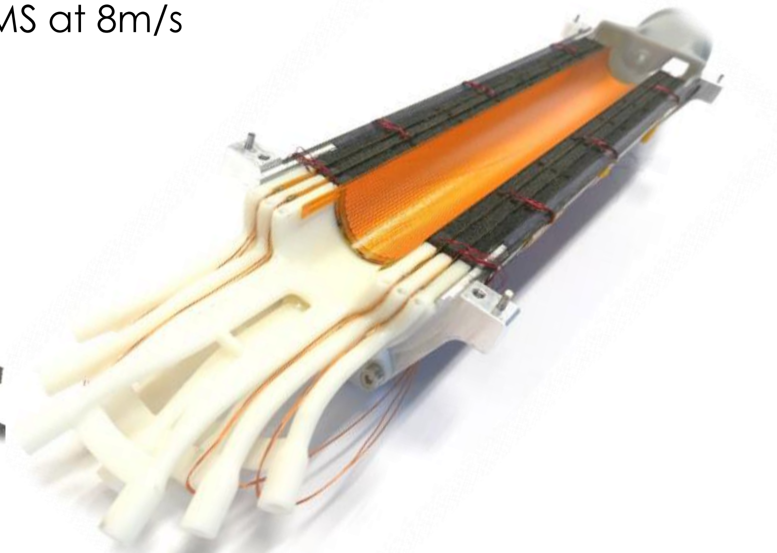
- Structures used to duct flow: reduced net section decrease mass flow requirements at same velocity
- Use of Graphitic foam for enhanced Heat Exchange for end of chip electronics
- External ducting can add material…



RMS at 8m/s







M. Angeletti, FTDM24

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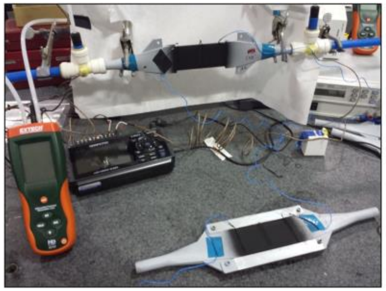
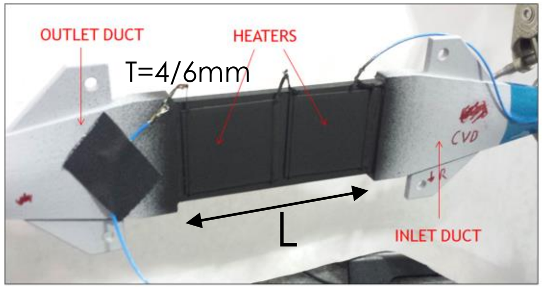
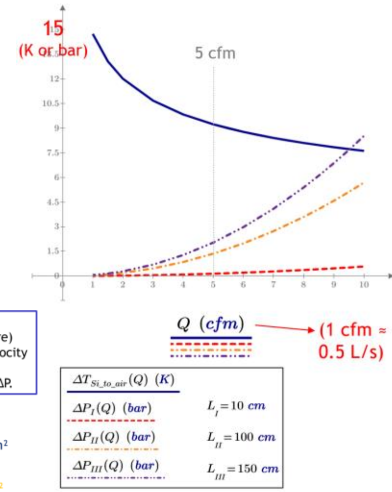
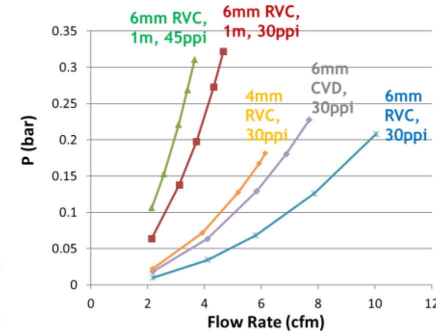
Air Flow at Higher Power Densities

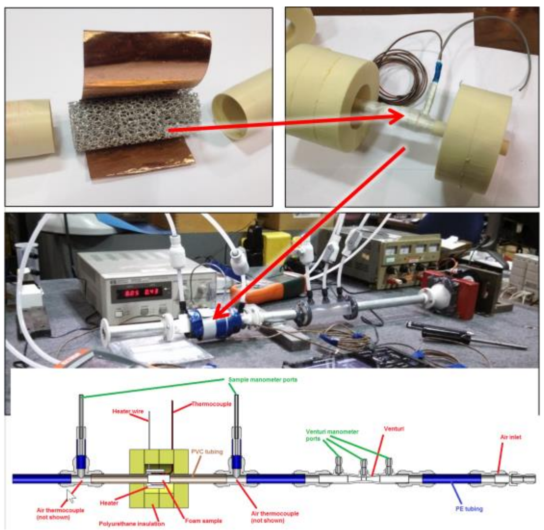


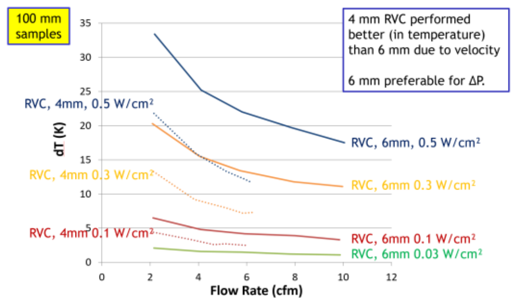






E. Anderssen, FTDM15





Including various foams into HX Channel to enhance Heat Transfer to Gas flow, measured at different density/porosity, Lengths, and Power

Air cooling is attractive for low power densities and low total power—exhaust is to Cavern…

ITS3 and ePIC ~20m², at under average 0.1 W/cm² power density; total power ~4-5 kW (with power/readout asics)

FCC ee MAPS may be 2-4X the power density, and >10X the active area—unsure Air cooling can work for this

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Outline

- Current Detectors in Design/Construction
- Challenges moving to FCC scale detectors
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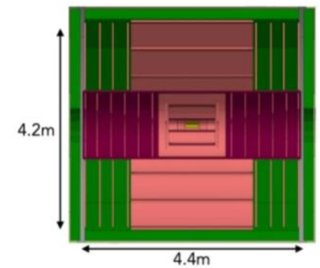
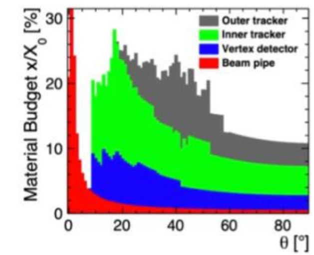
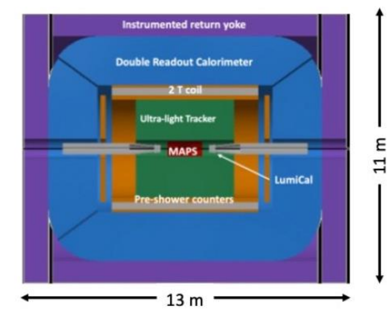
FCC Detector Scales

- To compare to current ATLAS/CMS, structures are 2X Diameter and 2-3X active area (or more)
  - Will likely include Strips, Hybrid Pixels and MAPS
  - Reduction from 0.5 to 0.25%/layer to achieve mass goals (services extra)
- Electronics are not designed yet, but proposed to be 'lower power' than current technologies
  - Mechanical engineers are used to this uncertainty but need to start getting target numbers
  - Cooling technology will be critical to achieving mass goals
  - Services at high η for high data rates will also be a challenge
- Radiation doses will be 2-3X higher than current detectors, up to 10X for FCC hh
  - CERN Yellow reports typically top out at 7MGy, need data for 15-50MGy

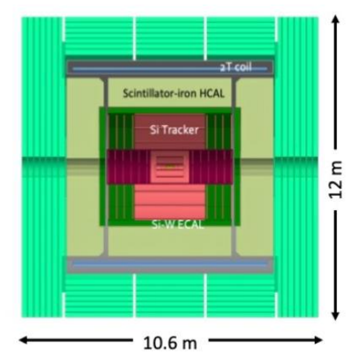




IDEA



CLD



M. Aleksa, GranuLAr WS '22

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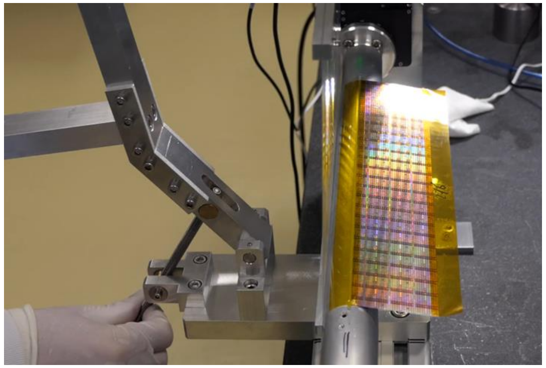
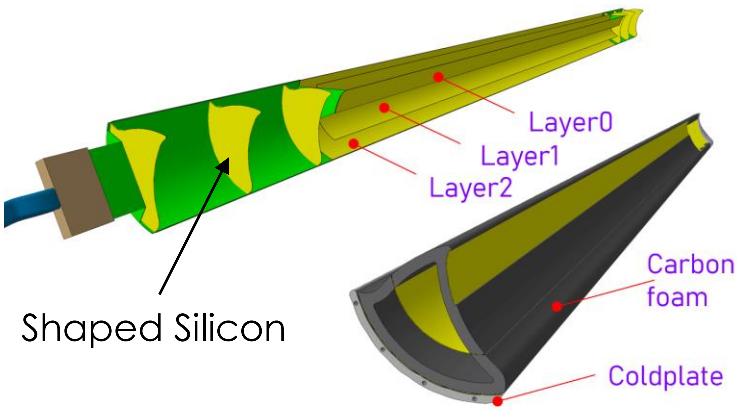
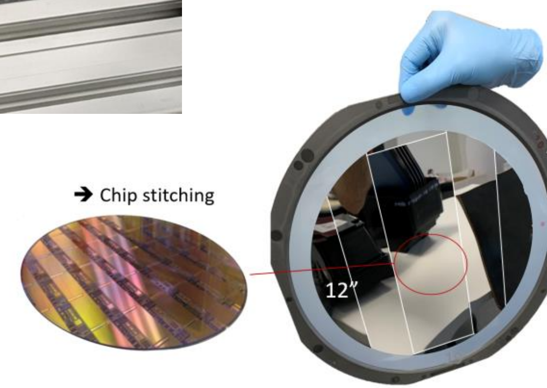
MAPS are Very attractive for Low Mass



Bent Silicon





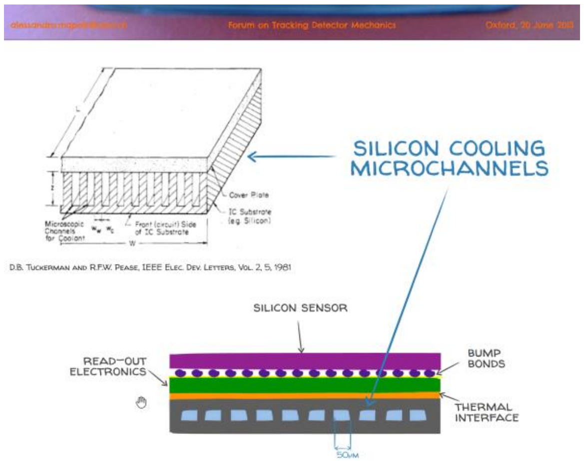
Very thin silicon can be bent into cylinders, but also bent to improve elastic stability (e.g. venetian blind like structures)

Chip Stitching can create large area sensors limited to wafer scale of up to 12" wafers (larger than current Strip Sensors)

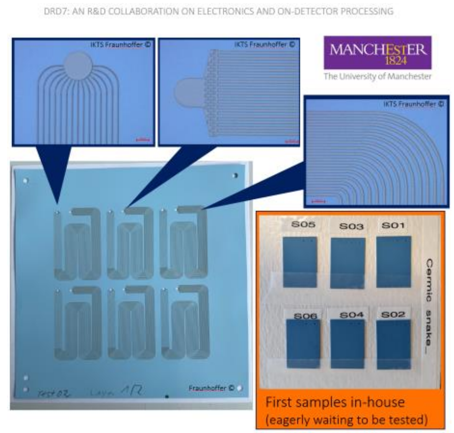
Column Masking (in development) can allow for 'odd' shaped sensor layout—easier to tile for disk/endcap structures

Air cooling may be a limit, other methods exist that may be useful

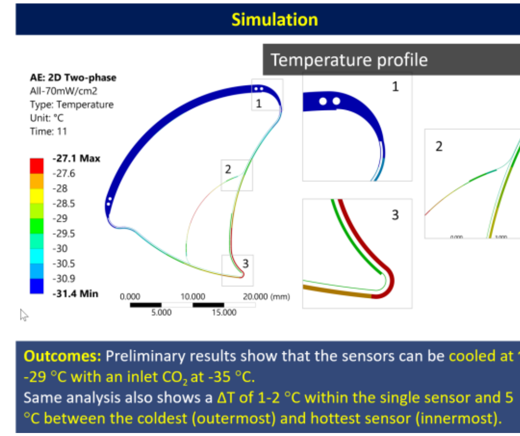
Evaporative Cooling for Low Mass



A. Mapelli, FTDM13



O. Augusto, FTDM24



C. Gargiulo, FTDM24

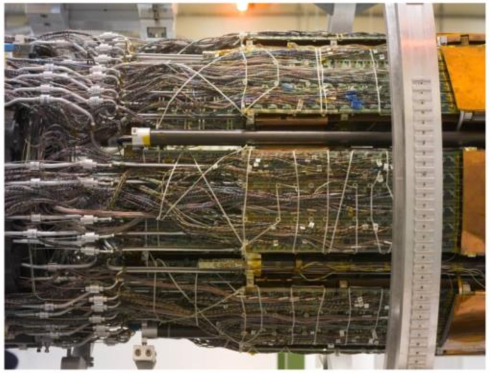
Air cooling may be insufficient for detectors approaching or exceeding 100kW

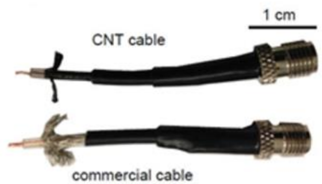
R&D in mechanics have been looking a distributed micro-channel cooling and conductive cooling with different working fluids for well over a decade

Can be integrated with most silicon technologies, may consider how to integrate with ‘Bent’ maps (very challenging).

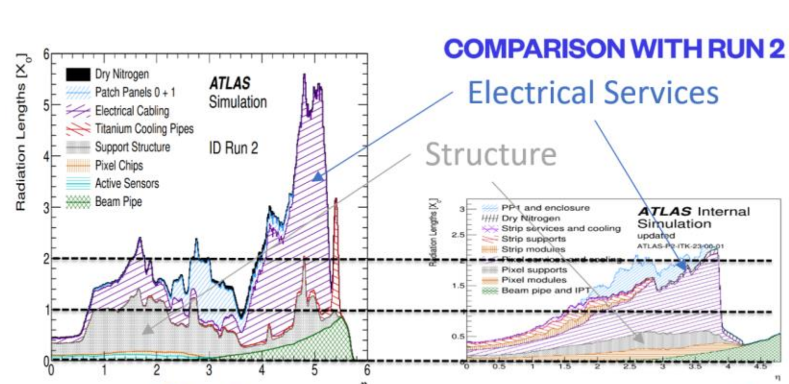
Service connections to thinned silicon remain a challenge, but is being actively addressed

Service Mass Reduction





carbon-nanotube cables. *Common* ***coaxial cables*** *could be made 50 percent lighter with a new nanotube-based outer conductor.*



Structural mass has been optimized—already reduced by factor of 2—maybe another factor 2 is possible but not as impactful

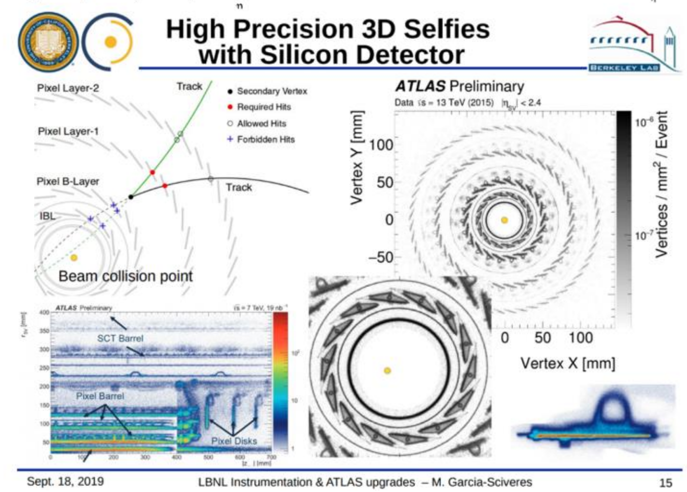
Services run along the length of detectors and increase in cross-section (angle/pseudo-rapidity) along length and also increase as more of the detector is 'serviced'

Power Services used to dominate; now it is dominated by Data services in HiLUMI

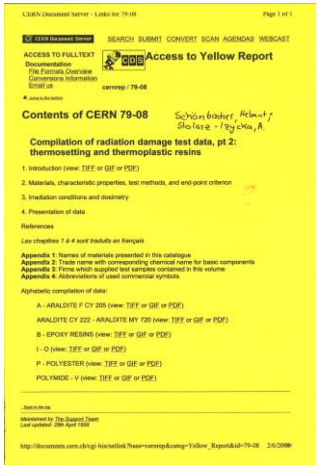
Copper has an X_0 of 1.7cm, Carbon is 22cm (more than 10X better)

Development of Carbon conductors for data transmission could be a key enabling technology for future detectors that will require 5-10X less mass to meet performance requirements

It is a rather high low hanging fruit that may have mechanical solutions—need to demonstrate fabrication of a conductor first and measure electrical properties



Radiation and other Material Data



CERN Document Server - Links for 79-08

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Contents of CERN 79-08

Schönbacher, Helmut; Stolarz - Izycka, A.

Compilation of radiation damage test data, pt 2: thermosetting and thermoplastic resins

1. Introduction (view: TIFF or GIF or PDF)
2. Materials, characteristic properties, test methods, and end-point criterion
3. Irradiation conditions and dosimetry
4. Presentation of data

References

Les chapitres 1 à 4 sont traduits en français

Appendix 1: Names of materials presented in this catalogue
Appendix 2: Trade name with corresponding chemical name for basic components
Appendix 3: Firms which supplied test samples contained in this volume
Appendix 4: Abbreviations of used commercial symbols

Alphabetic compilation of data:

A - ARALDITE F CY 205 (view: TIFF or GIF or PDF)

ARALDITE CY 222 - ARALDITE MY 720 (view: TIFF or GIF or PDF)

B - EPOXY RESINS (view: TIFF or GIF or PDF)

I - O (view: TIFF or GIF or PDF)

P - POLYESTER (view: TIFF or GIF or PDF)

POLYMIDE - V (view: TIFF or GIF or PDF)

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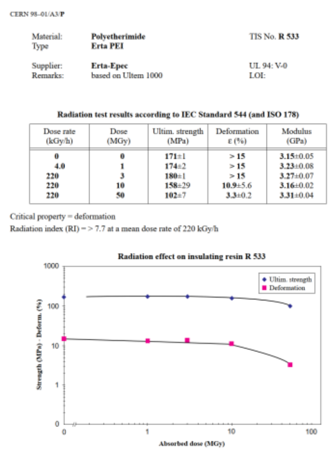
Last updated: 20th April 1999

http://documents.cern.ch/cgi-bin/setlink?base=cernrep&categ=Yellow_Report&id=79-08 2/6/2008



CERN 98–01/A3/**P**

Material:	**Polyetherimide**	TIS No. **R 533**
Type	**Erta PEI**	
Supplier:	**Erta-Epec**	UL 94: V-0
Remarks:	based on Ultem 1000	LOI:

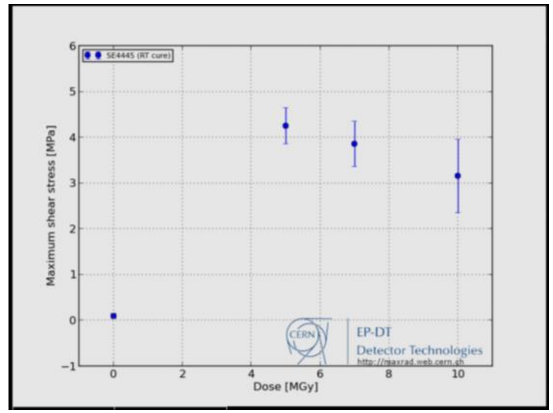
Radiation test results according to IEC Standard 544 (and ISO 178)

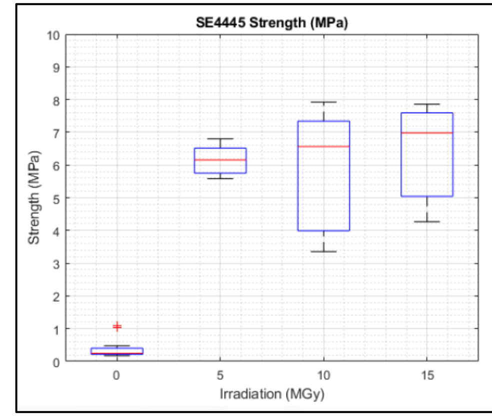
Dose rate (kGy/h)	Dose (MGy)	Ultim. strength (MPa)	Deformation ε (%)	Modulus (GPa)
0	**0**	**171**±1	**> 15**	**3.15**±0.05
4.0	**1**	**174**±2	**> 15**	**3.23**±0.08
220	**3**	**180**±1	**> 15**	**3.27**±0.07
220	**10**	**158**±29	**10.9**±5.6	**3.16**±0.02
220	**50**	**102**±7	**3.3**±0.2	**3.31**±0.04

Critical property = deformation

Radiation index (RI) = > 7.7 at a mean dose rate of 220 kGy/h

Radiation effect on insulating resin R 533





CERN Yellow Reports dating from 1979 thru 2001—some results up to 50MGy, many only to 7MGy and typically only report strength reduction (may need modulus)

Data for Gamma Ionizing radiation most relevant for Plastics and Composites, neutron data relevant when approaching fractional DpA

MaxRAD https://maxrad.web.cern.ch/maxrad/index.php, is a recent DB at CERN intended to collect new radiation data for materials, requires access, developed on AIDA, and nowunder DRD8

Getting to higher doses requires significant exposure time, work being coordinated

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Forum on Tracking Detector Mechanics

https://indico.cern.ch/event/1336746/overview

The first formal FTDM was held at Oxford in 2013 after a kickoff meeting at CERN the previous year

It was noticed during technical reviews that many engineers were solving similar problems, duplicating research and suffering the same pit-falls

Engineers tend to be stove-piped by collaboration artificially as collaboration meetings are designed to not overlap at CERN due to meeting infrastructure

We proposed an annual forum where all detector groups can share results or lessons learned across all Tracking Detector developments

Very informal forum with ample time for discussion and no proceedings with intent to allow open discussion of challenges and solutions

All meetings are publicly available on indico—search for 'Forum on Tracking Detector Mechanics' and include the year for specific meetings

DRD8 and RDC10 Mechanics R&D

CERN has begun to develop R&D collaborations with several focus areas and cross-discipline developments

DRD8 is focused on Mechanics, with sub-groups on Cooling, Mechanical Supports, and several other sub-working groups

RDC10 is a US effort to organize similarly and is an output of CPAD (Coordinating Panel on Advanced Detectors)

Goal is to directly collaborate with DRD8 WG's but to internally organize US Efforts for R&D—it is largely DOE-HEP directed

Both DRD8 and RDC10 are in the early stages of forming collaborations and generating proposals—both benefit largely on the existing framework provided by the FTDM

It is recognized that more regular interactions than annual FTDM is required to develop R&D planning, DRD8 and RDC10 are aimed at this required level of organization

- Colliders are long term projects that need strong investment into R&D now
- Smaller scale experiments provide opportunities for "Mechanics R&D"
- Mechanics R&D is required to achieve future goals

Outline

- Introduction
- Multiscale Coil Models
- Mechanical Limits in Nb_3Sn Coils
- Conclusion

Conclusion

Low Mass Silicon Detector development is continuous and advancing

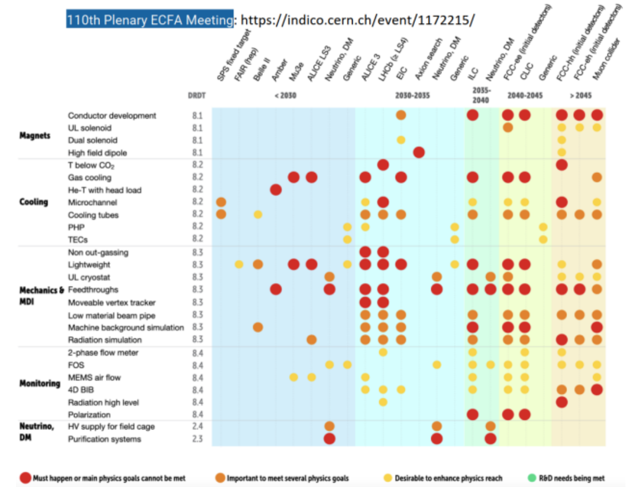
- Several Challenges remain to meet requirements for FCC detectors
- MAPS Detector developments for Heavy Ion experiments are leading the way for Very Low Mass Detectors
- Data Rates and Radiation environments in FCC mean that we cannot directly adopt current solutions
- Services may dominate material cross-sections without significant developments
- Further Work to Extend the Data for new Radiation regimes needs to be planned
- R&D Collaborations for Mechanics are being actively developed in anticipation of future detectors

CPAD & RDC's - What is it & How to engage

- Coordinated Panel for Advanced Detectors / CPAD
  - Structure to form community on "Blue Sky" high risk R&D
  - Funded by DOE, some "bias" to High Energy Physics (Strong desire to enhance)
  - CPAD web page: https://cpad-dpf.org/?page_id=1549
- RDC10 webpage in development
  - https://cpad-dpf.org/?page_id=1727
- How to subscribe to any RDC10:

•To SUBSCRIBE to a mailing list called MYLIST:
•Send an e-mail message to listserv@fnal.gov
•Leave the subject line blank
•Type "SUBSCRIBE MYLIST FIRSTNAME LASTNAME" (without the quotation marks, and using the string before the @ in the mailing list's name as MYLIST- as well as your own name) in the body of the e-mail message

For example "SUBSCRIBE CPAD_RDC1 ALICE SMITH"



RDC#	TOPIC	COORDINATORS	MAILING LIST
1	Noble Element Detectors	Jonathan Asaadi, Carmen Carmona	cpad_rdc1@fnal.gov
2	Photodetectors	Shiva Abbaszadeh, Flavio Cavanna	cpad_rdc2@fnal.gov
3	Solid State Tracking	Anthony Affolder, Sally Seidel	cpad_rdc3@fnal.gov
4	Readout and ASICs	Angelo Dragone, Mitch Newcomer	cpad_rdc4@fnal.gov
5	Trigger and DAQ	Zeynep Demiragli, Jinlong Zhang	cpad_rdc5@fnal.gov
6	Gaseous Detectors	Prakhar Garg, Sven Vahsen	cpad_rdc6@fnal.gov
7	Low-Background Detectors	Daniel Baxter, Guillermo Fernandez-Moroni, Noah Kurinsky	cpad_rdc7@fnal.gov
8	Quantum and Superconducting Sensors	Rakshya Khatiwada, Aritoki Suzuki	cpad_rdc8@fnal.gov
9	Calorimetry	Marina Artuso, Minfang Yeh	cpad_rdc9@fnal.gov
10	Detector Mechanics	Eric Anderssen, Andreas Jung	cpad_rdc10@fnal.gov
11	Fast Timing	Gabriele Giacomini, Matt Wetstein	cpad_rdc11@fnal.gov

https://indico.cern.ch/event/1336746/contributions/5923179/attachments/2868553/5021605/RDC10%20Status%20and%20plans.pdf

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