ATLAS ITk Strip Project Status

Modules in 2022

UNCE Seminar

06. 05. 2022

Martin Sýkora[1]

on behalf of Czech ATLAS ITk Strip Collaboration

[1]Charles University, Prague, Czech Republic

ATLAS Experiment

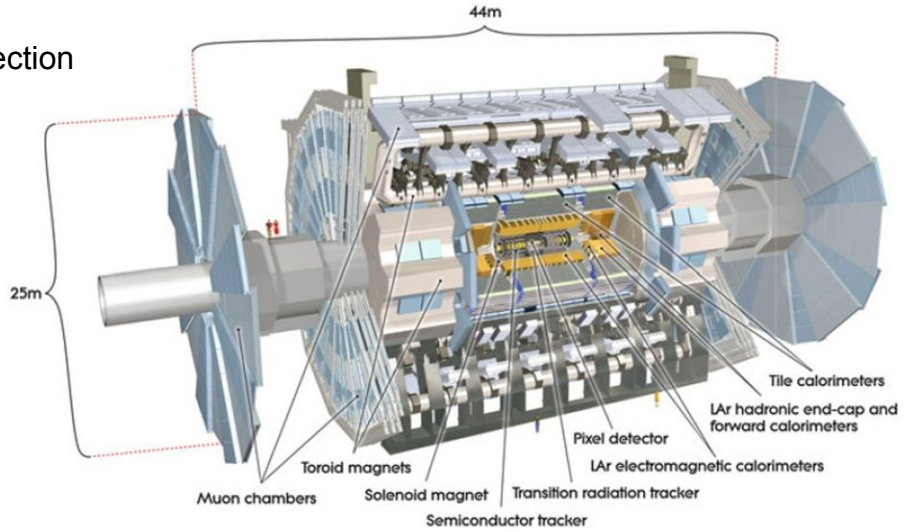
- general-purpose experiment at the LHC, interaction point

- cylindrical symmetry, several detection subsystems

  - inner detector (ID) - track, vertex, momentum and charge reconstruction
  - calorimeter (LAr, TileCal) - energy reconstruction
  - muon spectrometer (CSC, MDT, RPC, TGC) - muon detection

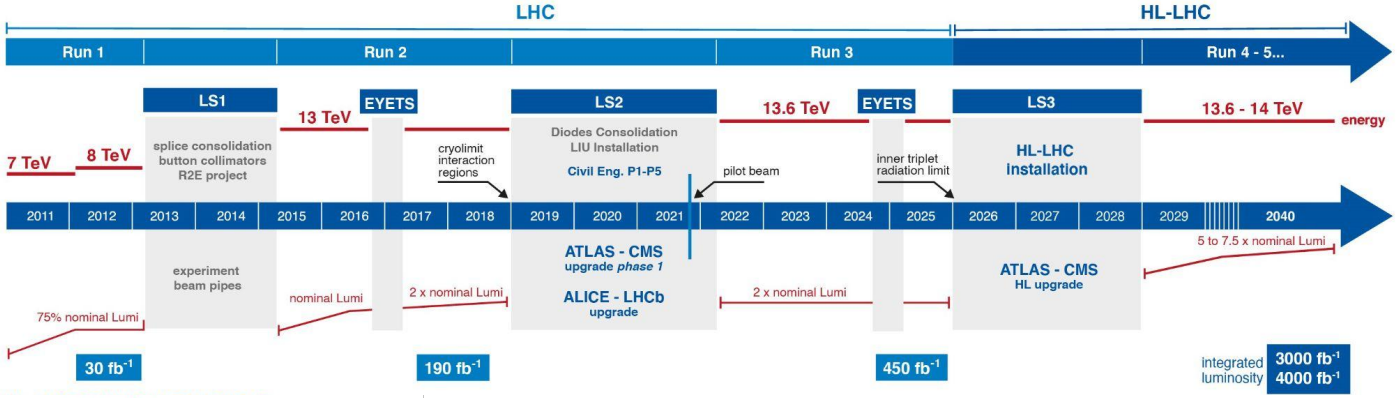
- magnet system

  - central solenoid (2 T)
  - outer toroid (3.5 T)

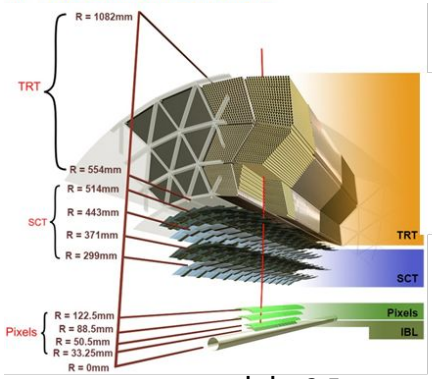


Future Upgrade Plans

LHC



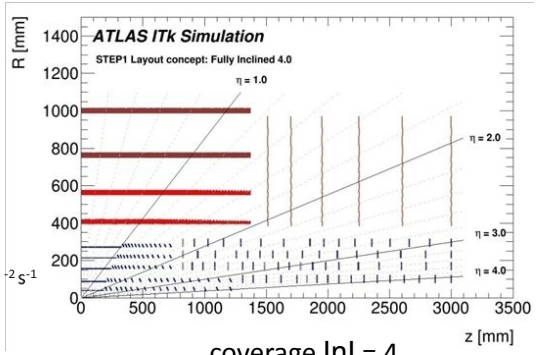
ATLAS ITk



coverage $|\eta| = 2.5$

Inner Detector:
$\sqrt{s}$ = 13.6 TeV
$L_{peak} = 2 \cdot 10^{34}$ cm $^{-2}$ s^{-1}
$\langle\mu\rangle = 37$

Inner Tracker:
$\sqrt{s}$ = 14 TeV
$L_{peak} = 7.5 \cdot 10^{35}$ cm $^{-2}$ s^{-1}
$\langle\mu\rangle = 200$



coverage $|\eta| = 4$

- after extension of Run-3 and LS3 caused by COVID related delays, the schedule for ITk was moved by 17 months (before: strips -7 months, pixels -10 months)

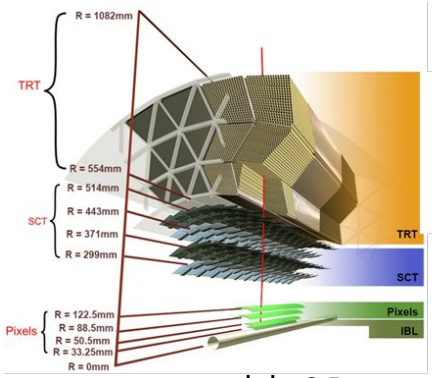
ATLAS Tracker Upgrade Plans

- 4 Central and 3 Forward/Backward Pixel layers
- 4 Central and 9 Forward/Backward Strip layers
- TRT layer with straw tubes

- most resistant IBL pixel layer resistant up to 850 fb^{-1}

- 5 Central and multiple Forward/Backward Pixel layers
- 4 Central and 6 Forward/Backward Strip layers

- all-silicon tracker
- finer granularity, more radiation hardness, material budget reduction (see backups), …



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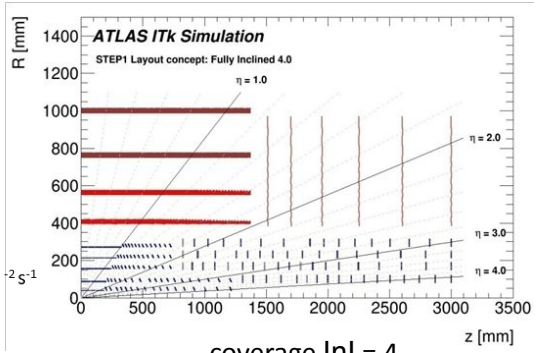
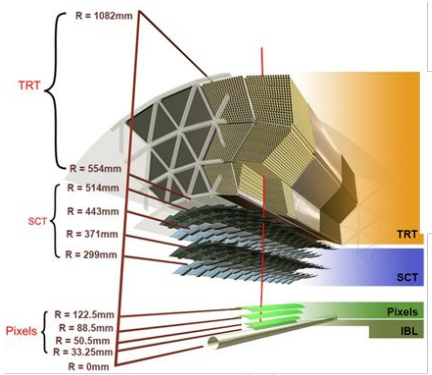


coverage $|\eta|$ = 4

ATLAS Tracker Upgrade Plans

ID	PXD	SCT	TRT
# of channels [x10^6]	92	6	0.35
Surface/Volume	1.9 m^2	60 m^2	12 m^3
Channel Size	50 x 400 um^2 or 50 x 250 um^2	57-94 um pitch	∅ 0.4 x 144 cm^3 or ∅ 0.4 x 39 cm^3

ITk	Pixels	Strips
# of channels [x10^6]	5000	60
Surface	13 m^2	165 m^2
Channel Size	50 x 50 um^2 or 25 x 100 um^2	69-84 um pitch



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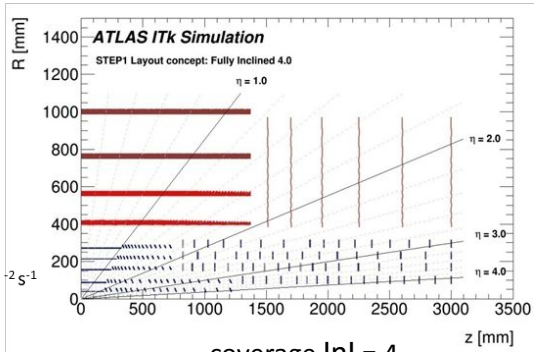
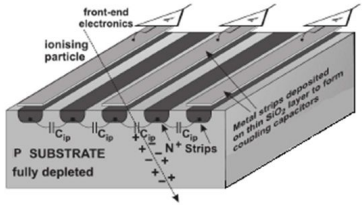
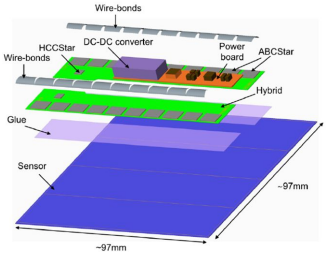
<μ>= 200

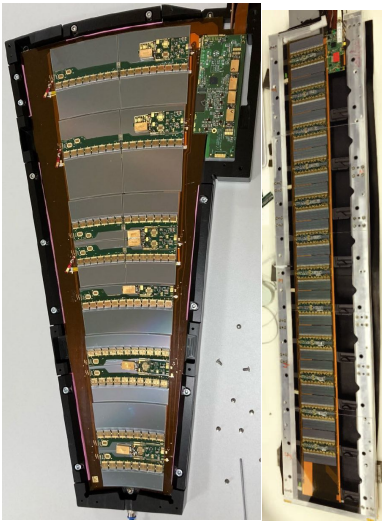


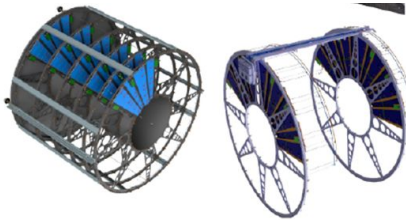
coverage |η| = 4

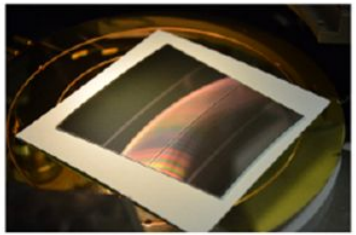
Conceptual Flow of ATLAS ITk Strip Project

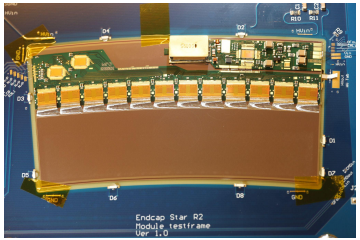


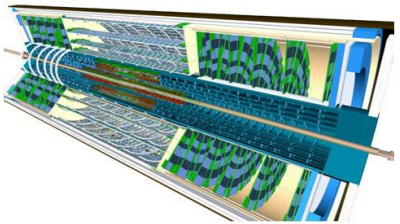








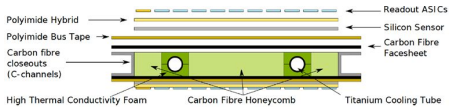




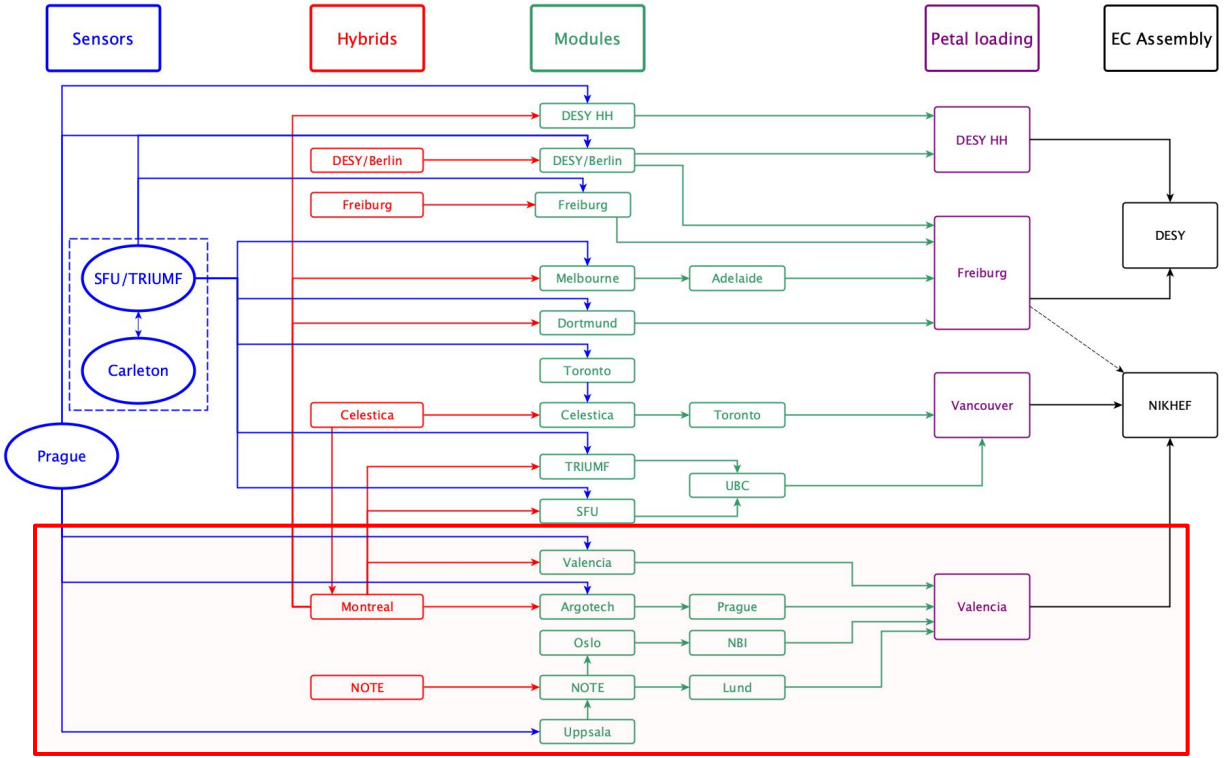
Sensors → **Modules** → **Local Support** (4 EC, 2 B clusters) → **Global Support** (2 EC, 1 B sites)

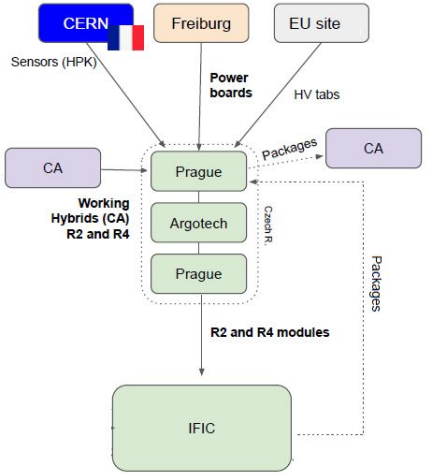
- n+ strips in p silicon bulk (SCT p-in-n)
- sensor width 300 um
- depletion voltage 350 V

- 6 EC and 2 B designs
- control chips glued on PCBs (= hybrids) glued on sensor
- powerboard - LV/HV power + other monitoring (T//U/I)



EC Production Flow





Valencia cluster

General Status of ATLAS ITk Strip Modules

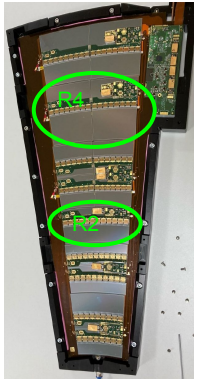
Czech Institutes Involved

ATLAS COLLABORATION DRAFT CERN-MOU-2018-061

ANNEX 1: List of Upgrade Institutes and Contact Persons

Institutes by Funding Agency	Institute Short Name	Institute Representative	P	S
Czech Republic				
Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc	Olomouc	M. Hrabovsky		V
Institute of Physics of the Czech Academy of Sciences, Prague	Prague AS	A. Kupco	V	V
Czech Technical University in Prague, Prague	Prague CTU	Z. Hubacek	V	V
Charles University, Faculty of Mathematics and Physics, Prague	Prague CU	R. Leitner		V

+ external company Argotech a.s.



Czech Commitments

50% of EC sensors (approx. 4500, all designs) -> IoP CAS

9% of EC modules (approx. 700, R2/R4 designs) -> CUNI as a leading institute of Czech cluster

Czech Module Manpower in 2021

6.2 FTE for modules in total

- 4.0 + 0.8 FTE **CU** (Z. Doležal, P. Kodyš, P. Federič, M. Rybář, J. Brož, C. Boldrini, P. Kubík + students: M. Sýkora)
- 0.2 + 0.7 FTE **PU** (J. Kvita + students: R. Přívara)
- 0.5 FTE **CTU** (students: O. Turek)

- ITk qualification tasks - database applications (P. Federič, M. Pešek, Ch. Chauhan, J. Matoušek)

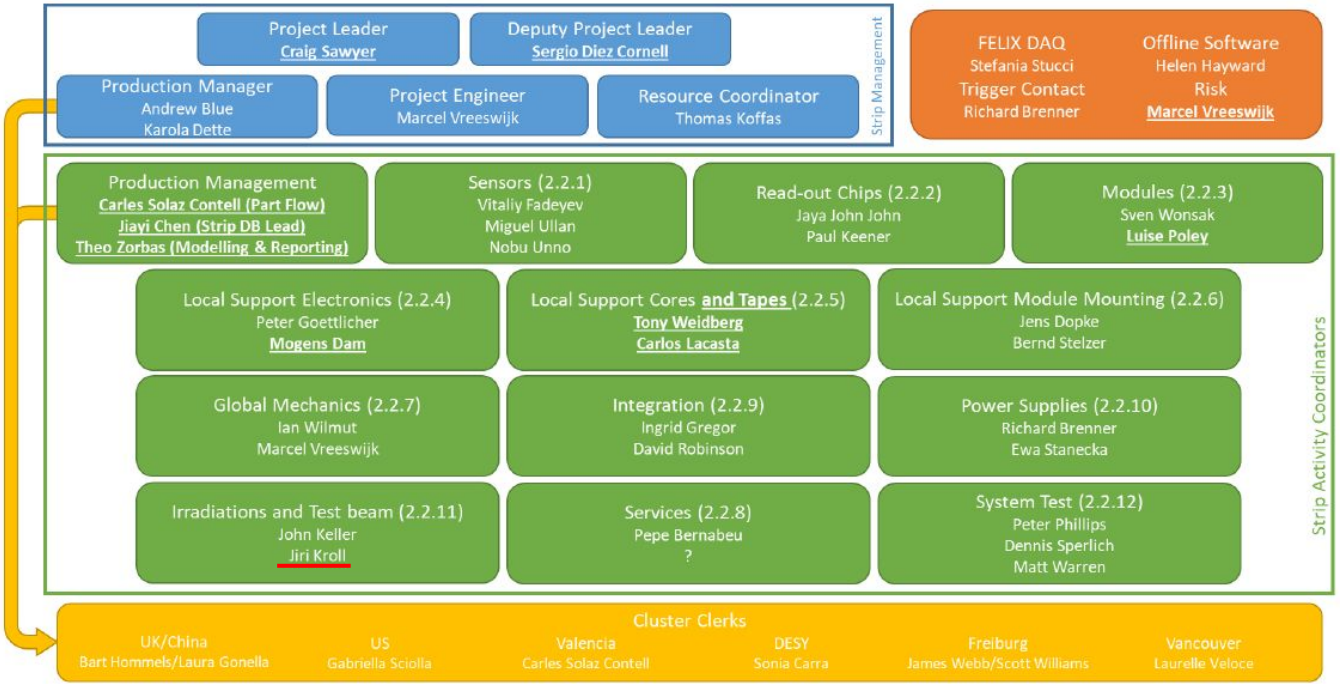
Module Milestones

- 2017 - Technical Design Report (TDR) approved
- 2018 - Preliminary Design Review (PDR) passed
- 2019 - Final Design Review (FDR) passed

- 2021 - start of module Site Qualification
- Apr. 2022 - start of first phase of pre-production (PPA)
- Aug. 2022 - Production Readiness Review (PRR)
- Nov. 2022 - start of full production rate

WBS Structure at the end of 2021

- J. Kroll (CAS) - Strip Activity Coordinator for “Irradiations and Test beam”



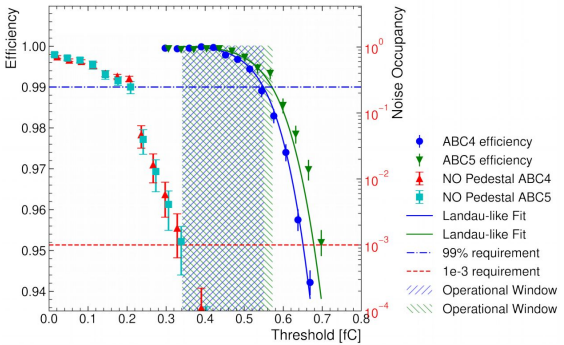
Irradiation and testbeam activity within WBS 2.2.11

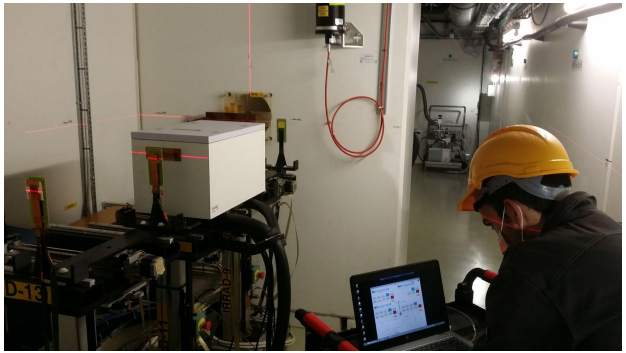
- strong Czech participation (coordinator J. Kroll, members from CAS, CU, PU)

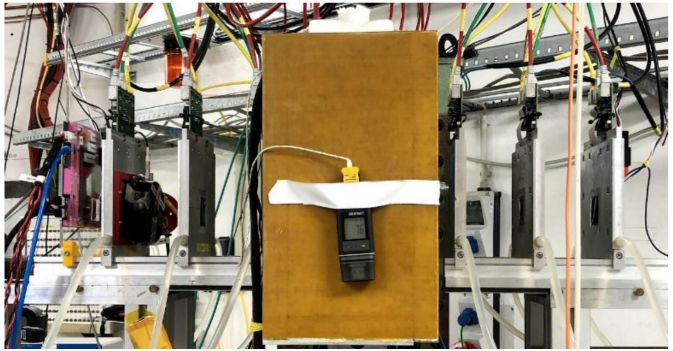
- **DESY testbeam campaigns: Jun. 28 - Jul. 11 and Sep. 13 - Sep. 19**
  - Star SS/R0 modules built from neutron irradiated sensors (1.1E15/1.6E15 n_{eq}/cm^2) and X-ray irradiated readout electronics (58/88 Mrad)
  - Main goal to find out the working operational window with efficiency >99% and noise occup. <0.1% - results were critical for successful ABCStar PRR

- **DESY testbeam campaign: Dec. 13 - Dec. 22**
  - Star R5 module (1st split module) built from neutron irradiated sensors (7.7E14 n_{eq}/cm^2) and unirradiated readout electronics

- **Irradiation campaign at CERN IRRAD facility: Oct. 6 - Oct. 20**
  - Proton irradiation of 8 Testchip&MD8 and 9 Mini&MD8 samples for sensor production QA testing

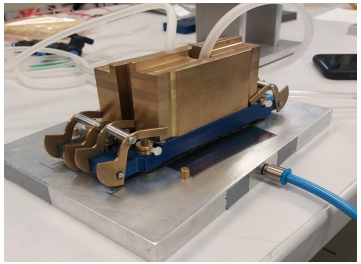


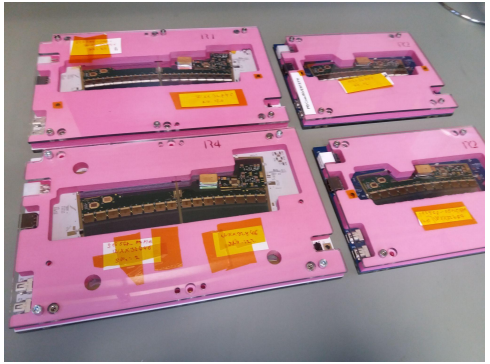


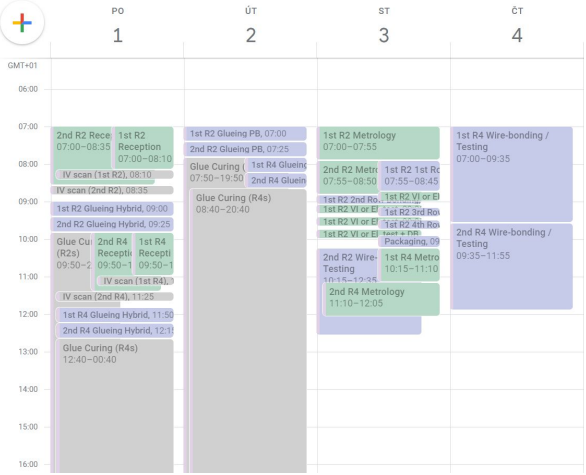


Cooperation with Argotech Company

- 3 R0 modules with pre-final design + 4 R2/R4 prototypes with final design built/bonded
- face-to-face meeting at the end of Nov. 2021
  - estimated duration of individual procedures
  - estimated time schedule of week's production
  - estimated budgetary quotation
- coordinators (CU - M. Sýkora, Argotech - P. Kratochvíl)







Steps / week	Total attended time [min]	
Reception	174	
Assembly	204	
Metrology	80	
Wire-bonding	430	
Electrical Tests	80	
DB + Shipping	40	40
Summary	374	674

Argotech employees

Institute people in Argotech

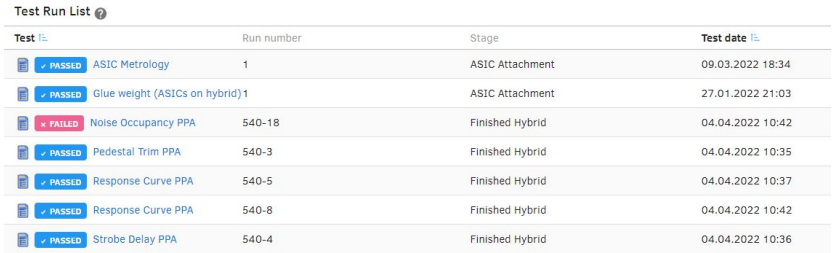
Unattended time in Argotech

Czech Module Procedure Flow

- every single module has to undergo and pass each step:

1. Reception Procedures
2. Assembly Procedures
3. Wire-bonding Procedures
4. Electrical and Metrology Procedures
5. Database Procedures
6. Shipping Procedures

- ITk Production Database is used for tracking all the results



Test Run List

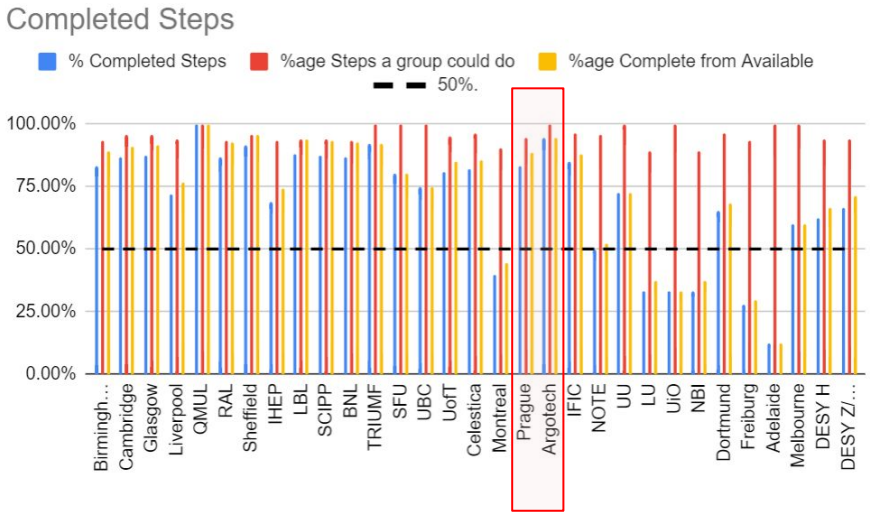
Test	Run number	Stage	Test date
PASSED ASIC Metrology	1	ASIC Attachment	09.03.2022 18:34
PASSED Glue weight (ASICs on hybrid)	1	ASIC Attachment	27.01.2022 21:03
FAILED Noise Occupancy PPA	540-18	Finished Hybrid	04.04.2022 10:42
PASSED Pedestal Trim PPA	540-3	Finished Hybrid	04.04.2022 10:35
PASSED Response Curve PPA	540-5	Finished Hybrid	04.04.2022 10:37
PASSED Response Curve PPA	540-8	Finished Hybrid	04.04.2022 10:42
PASSED Strobe Delay PPA	540-4	Finished Hybrid	04.04.2022 10:36

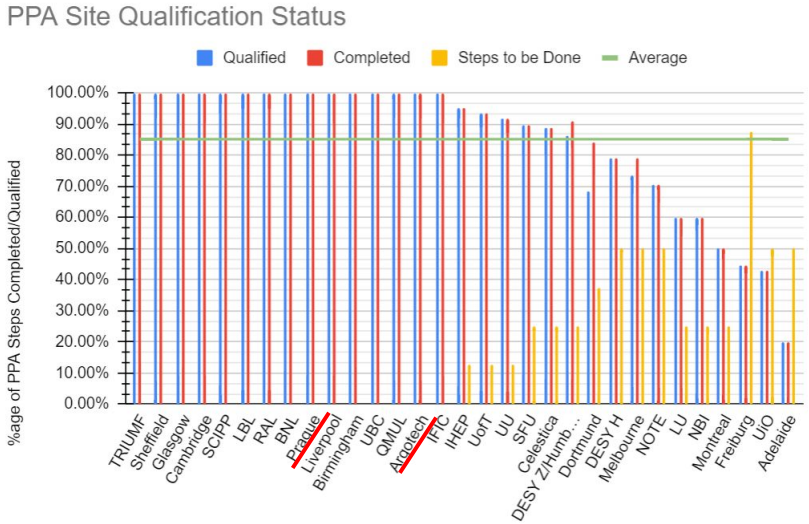
Order	Procedure	Database Interaction
1	Visual Inspection (HP, PBP)	Yes (QC)
2	Electrical Readout (HP, PBP)	Yes (QC)
3	HV-tab Attachment (S + HV-tab = M)	Yes (Reg., Assembly)
4	TF Wire-bonding (M)	No
5	IV Test (M)	Yes (QC)
6	Visual Inspection (M, HP, PBP)	Yes (QC)
7	Vacuum sealing + peli-case packaging (M, HP, PBP)	No
8	Transport to Argotech (M, HP, PBP)	Yes (Shipping)
9	Visual Inspection (M, HP, PBP)	Yes (Receiving, QC)
10	IV Test (M)	Yes (QC)
11	Module Assembly (gluing, weighing)	Yes (Assembly, Stage, QC)
12	Visual Inspection (glued M)	Yes (QC)
13	Metrology (glued M)	Yes (QC)
14	IV Test (glued M)	Yes (QC)
15	TF, H-H, H-PB Wire-bonding	Yes (QC?, R4 Reg.)
16	Electrical Readout (partly bonded M) - optional	Yes (QC)
17	Row-by-row [Wire-bonding + VI/El. Readout]	Yes (QCs, Stage)
18	Electrical Readout (bonded M)	Yes (QC)
19	IV test (bonded M via PB)	Yes (QC)
21	Visual Inspection (bonded M)	Yes (QC, Stage)
22	Vacuum sealing + peli-case packaging (tested M)	No
23	Transport to CAS IoP (tested M)	Yes (Shipping)
24	Visual Inspection (tested M)	Yes (Receiving, QC)
25	IV Test (tested M via PB)	Yes (QC)
26	Thermal Cycling Electrical Readout (tested M)	Yes (QCs, Stage)
27	Visual Inspection (finished M)	Yes (QC)
28	Vacuum sealing + peli-case packaging (finished M)	No
29	Transport to Valencia	Yes (Shipping)

CUNI (CUNI people) Argotech (CUNI/Argotech people) FZU (CUNI people)

Site Qualification - General Status

- idea to certificate each step a site will have to perform during production phase
- qualification for selected steps implies releasing of components for next stage
- idea of site visits of reviewers was abandoned due to COVID restrictions => SQ documentation
- Czech SQ coordination and communication within Valencia cluster (CU, M. Sykora)





Czech Site Qualification and Schedule

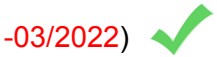
Argotech

Step Number	Qualification Step	Status	Ready for Review?	Review Status
3.1	Sensor Reception	Qualification Rec	Yes	Passed
3.2	Sensor Storage	Qualification Rec	Yes	Passed
6.3	PB Vis Insp	Qualification Rec	Yes	Passed
6.4	PB Storage	Qualification Rec	Yes	Passed
10.2	Storage of hybrids	Qualification Rec	Yes	Passed
11.1	Storage of modules	Qualification Rec	Yes	Passed
11.2	Cleaning module jigs	Qualification Rec	Yes	Passed
11.4	Storage + shipping of glue	Qualification Rec	Yes	Passed
11.5	Removing hybrids from panel	Qualification Rec	Yes	Passed
11.6	Module Assembly	Qualification Rec	Yes	Passed
11.7	Metrology: modules	Needs Developn	No	Not Reviewed
11.8	Bonding procedures: modules	Qualification Rec	Yes	Passed
11.9	Visual inspection: modules	Qualification Rec	Yes	Passed
13.1	Cleanroom standards	Qualification Rec	Yes	Passed
13.2	ASIC Compliance & Handling	Qualification Rec	Yes	Passed
13.3	Bond Pulling Procedures	Qualification Rec	Yes	Passed
14.1	Module Reception	Qualification Rec	Yes	Passed

Prague

Step Number	Qualification Step	Status	Ready for Review	Review Status
1.1	Bonding Procedures	Qualification Rec	Yes	Passed
3.2	Sensor Storage	Qualification Rec	Yes	Passed
6.1	PB Reception	Qualification Rec	Yes	Passed
6.2	PB E tests	Needs Developn	No	Not Reviewed
6.3	PB Vis Insp	Qualification Rec	Yes	Passed
6.4	PB Storage	Qualification Rec	Yes	Passed
10.1	Reception: hybrids	Qualification Rec	Yes	Passed
10.2	Storage of hybrids	Qualification Rec	Yes	Passed
8.7	Visual inspection: hybrids	Qualification Rec	Yes	Passed
8.11	hybrid QC: single panel testing	Qualification Rec	Yes	Passed
11.1	Storage of modules	Qualification Rec	Yes	Passed
11.9	Visual inspection: modules	Qualification Rec	Yes	Passed
11.10	Module Thermal Cycling	Needs Developn	No	Not Reviewed
11.11	Single module Electrical Tests	Requires Parts	No	Not Reviewed
12.1	Shipping modules	Qualification Rec	Yes	Passed
13.1	Cleanroom standards	Qualification Rec	Yes	Passed
13.2	ASIC Compliance & Handling	Qualification Rec	Yes	Passed
14.1	Module Reception	Qualification Rec	Yes	Passed

- red steps - no setup / requirements available in community yet
- green steps - ready for qualification (requirements defined, but parts availability is not fully guaranteed)
- beige steps - required before pre-production A
- white steps - required before pre-production B

1) Prototyping (1 semi-electrical petal, qualification of processes, 01-03/2022) 

2) **Pre-production A** (1 electrical petal, 2xR2 + 2xR4 ; 03/2022 - 06/2022)

- delay of final PBs and SMD populated hybrids, all procedures qualified

3) Pre-production B1 (1 petal, 2xR2 + 2xR4 ; 07/2022)

- petals needed for PRR of system tests

4) Pre-production B2 (1 petal, 2xR2 + 2xR4 ; 08/2022)

- modules for PRR, including thermal cycling (production-like)

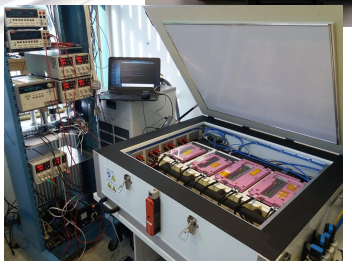
5 Pre-production B3 (1-2 petals, 2-4xR2 + 2-4xR4 ; 09/2022 - 11/2022)

- ramping-up for production, last tuning

6) Production (rest of approx. 650 modules; 11/2022 - 06/2026)

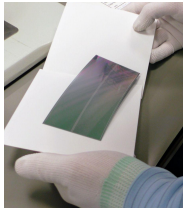
Development of Procedures in 2021

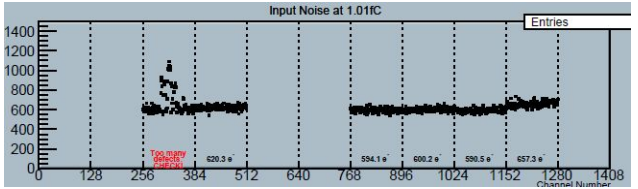
- visual inspection boxes for Argotech/Prague (PU Olomouc; J. Kvita)
- storage capacities increasing (joint lab@CAS, CU)
  - ability to store 5 - 6 months of expected production flow
- shipping procedures (joint lab@CAS, CU; Sykora, Boldrini, Kroll)
  - pelican boxes, Lava vacuum sealer V.400
  - humidity indicators, desiccants, shock sensors
- final design of electrical testing setups (joint lab@CAS, CU, CTU)
  - bonding/testing jigs (built at CTU within CERN-MoU-2019-018; O. Turek)
  - IV (ready) and DAQ (ready) testing setups (CU; Sykora, Kodys)
  - thermal cycling boxes (DESY, C. Boldrini participated, Sykora)
- HV-tab bonding, pull testing procedures (P. Federic)
  - F&S Bondtec pull tester
- metrology (in development at CU for Argotech; M. Rybar, F. Maxin, P. Federic)

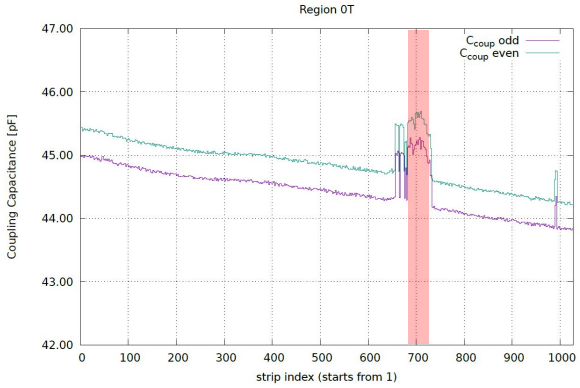


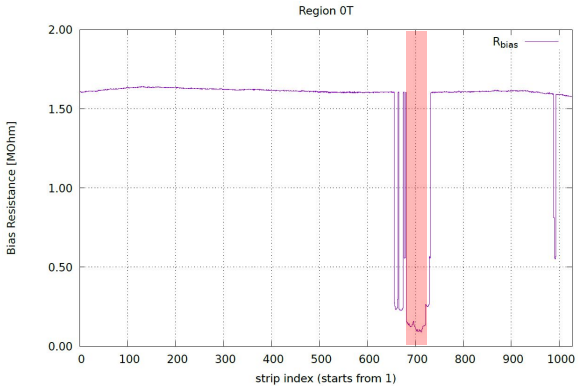
Module Electrical Results

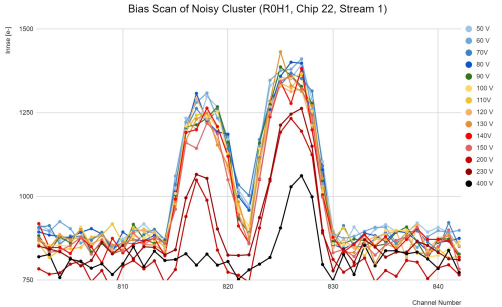
- possibility to reveal noisy clusters, unbonded/dead channels and other module electrical malfunction
- could be caused by handling tools
  - not properly grounded jigs/vacuum pen
  - statically charged shipping plastic sheets
- stuck charge can be removed using UV irradiation





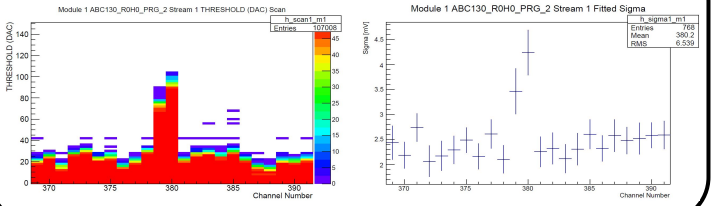






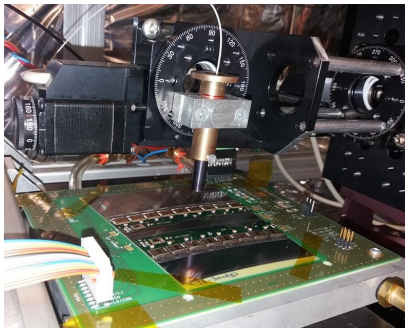
External Charge Injection Results

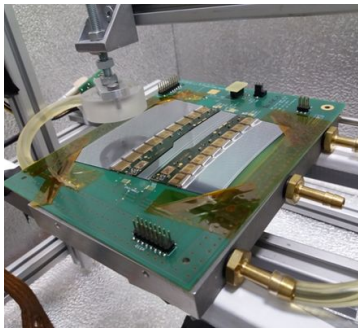
Laser Tests



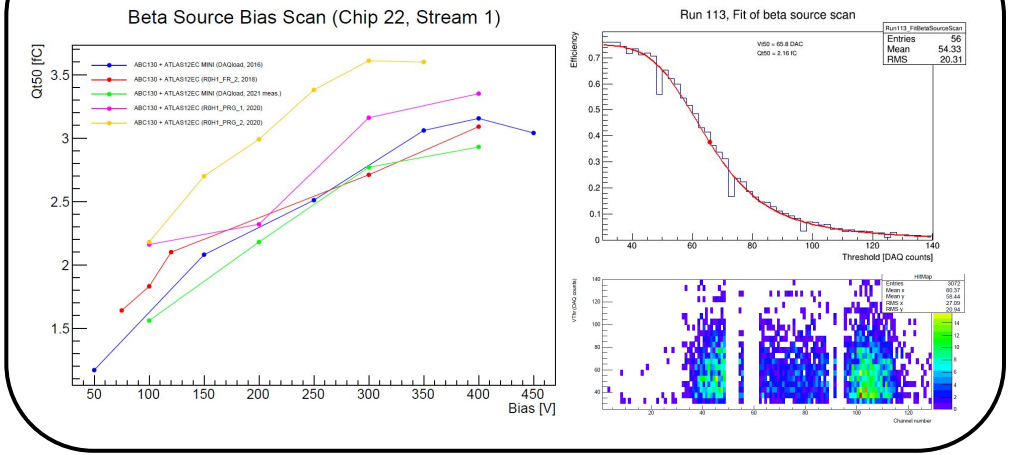
IR Laser

- check of bonding order and charge sharing, good spatial res
- no connected strips observed in the noise bump region





Beta Source Tests

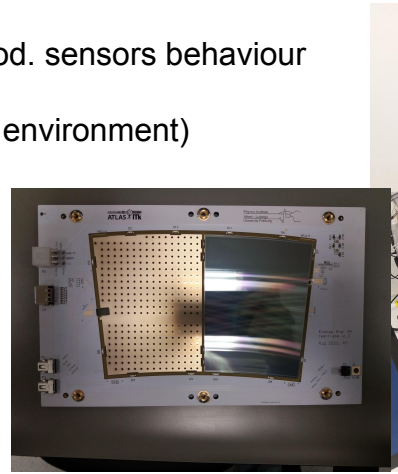


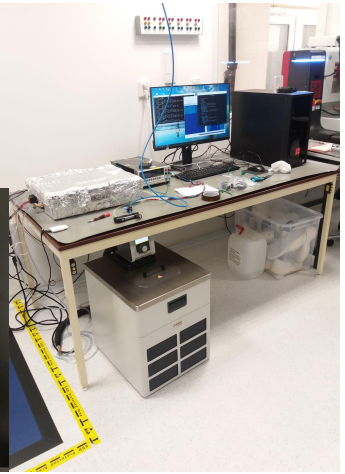
^{90}Sr Beta Source

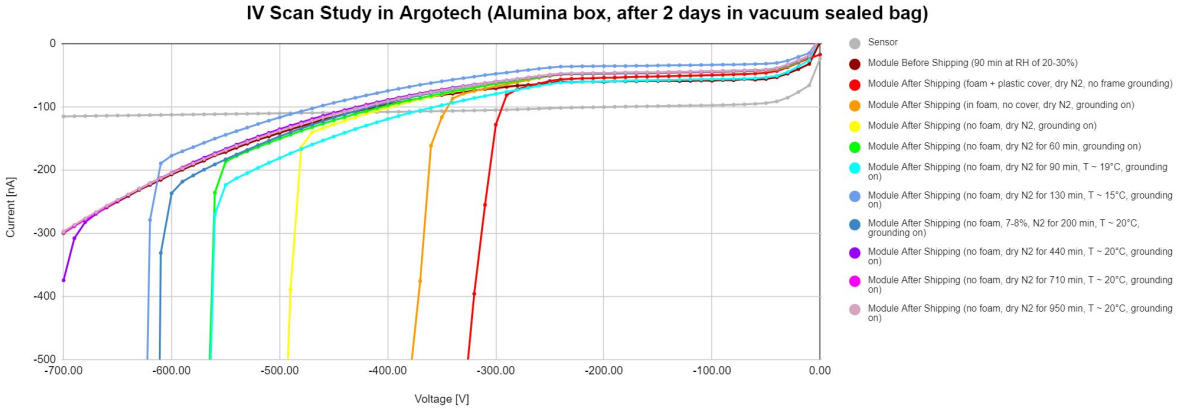
- check hitmaps, Qt50, CS distribution, bias scan,...
- masked noisy channels in hitmap, but no overall chip signal affection

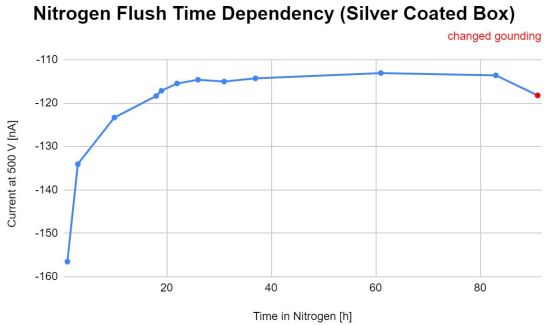
Module IV Results

- IV development and investigation of failed (not electrically) pre-prod. sensors behaviour
- humidity sensitivity of ITk sensors (should be stored in RH < 10% environment)
- breakdown appeared after shipments in vacuum sealed bags
- 24 hours in dry cabinet should be enough for current stabilization



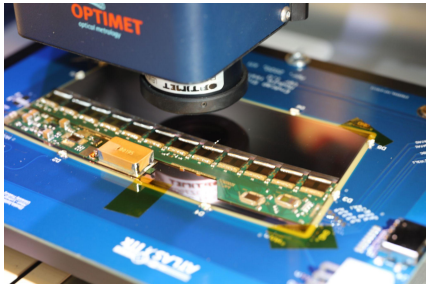


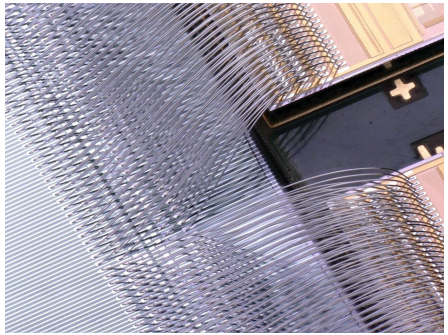


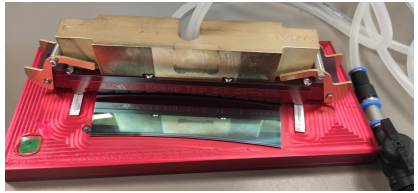


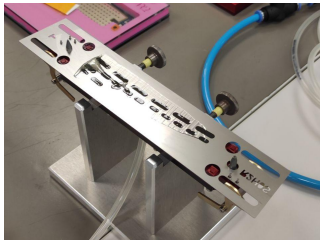
Assembly and Wire-bonding

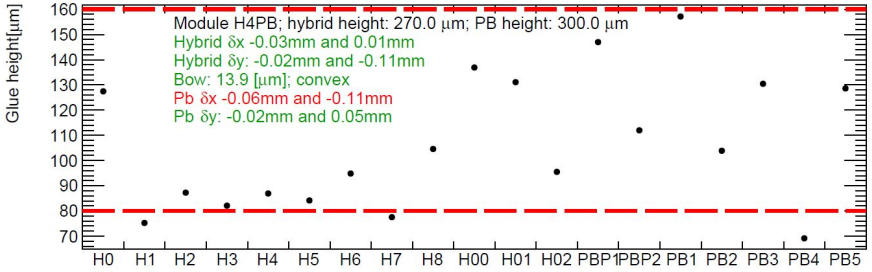
- done in Argotech company, procedures mostly developed in Prague
- quality of module assembly, glue weight and distribution checked by metrology
- technologically challenging 4-row wire-bonding of FE channels

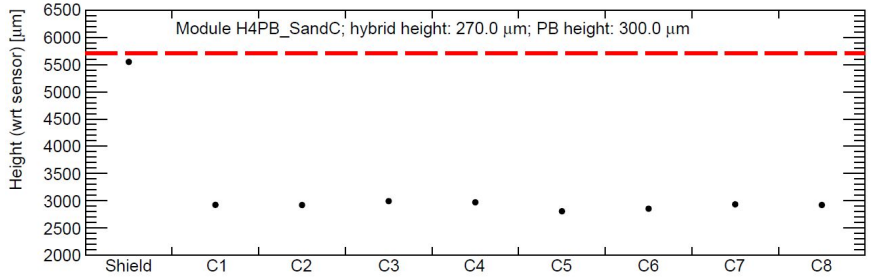












Conclusion

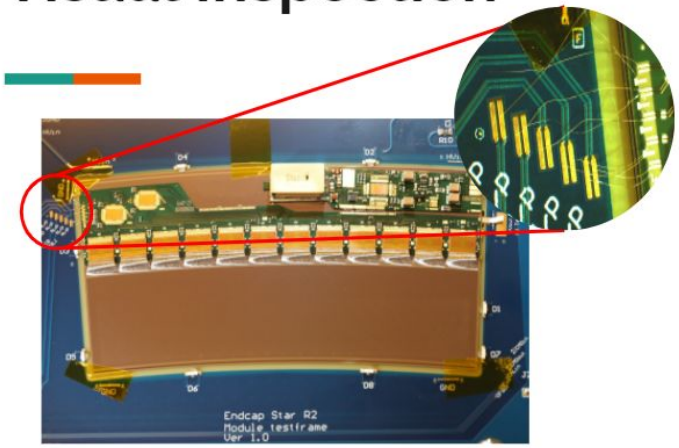
- start of HL-LHC operation moved by 17 months to 2029
- decommissioning of ID and commissioning of ITk will happen during LS3 (2026 - 2028)
- Czech ITk strip commitment ~ 4500 EC sensors and 700 R2/R4 modules
- cooperation with Argotech company
- Prague cluster is on top of EC site qualification

- pre-production A is in process to build first fully electrical modules with final design
- schedule driven by module PRR (Aug. 2022) and production start (Nov. 2022)

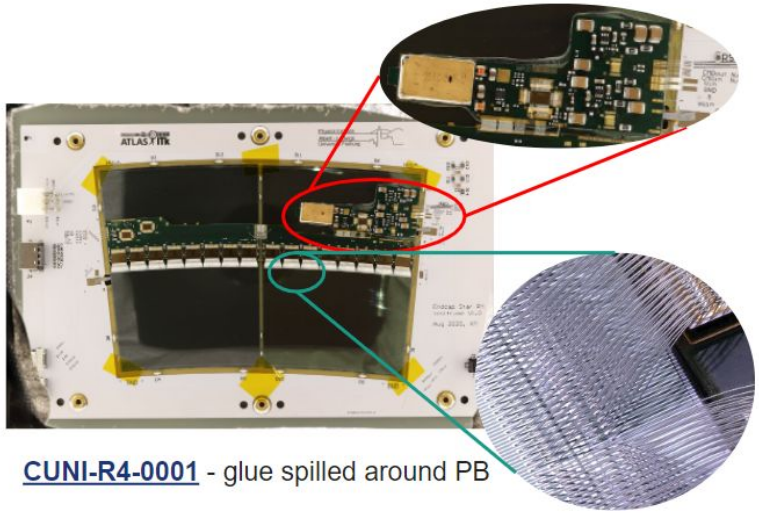
Thanks for attention !

Visual Inspection

Argotech

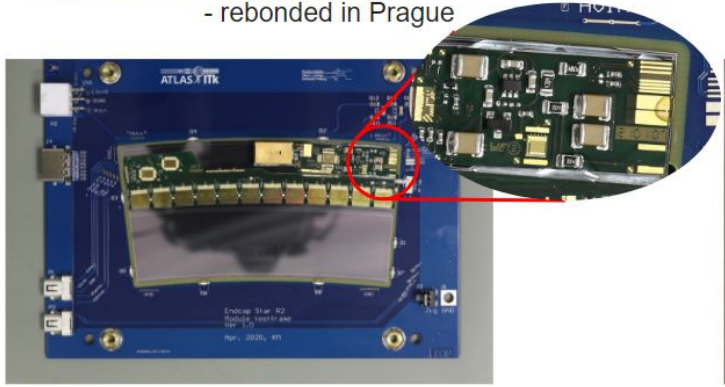


CUNI-R2-0002 - lying data bonds
- rebonded in Prague

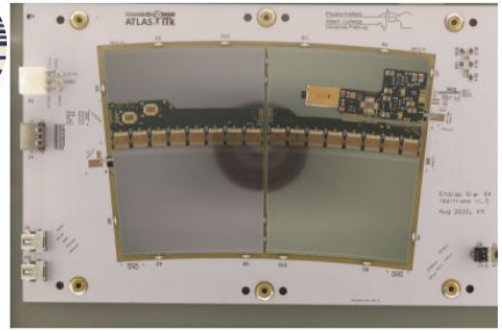


CUNI-R4-0001 - glue spilled around PB

Prague



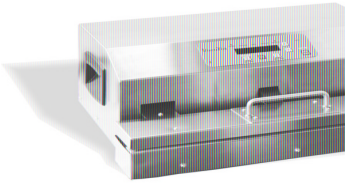
CUNI-R2-0003 - glue spilled around PB
- pad should be cleaned

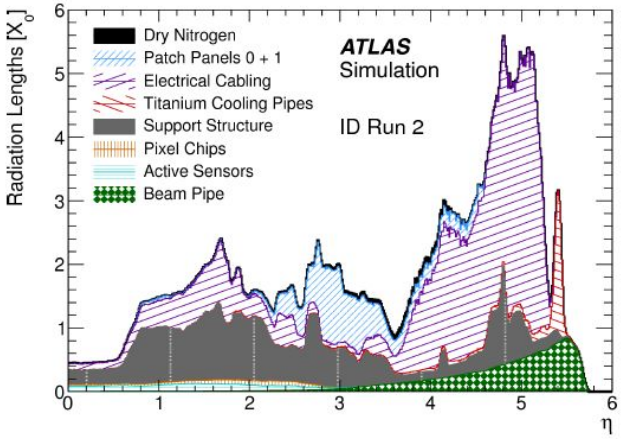


CUNI-R4-0002 - OK

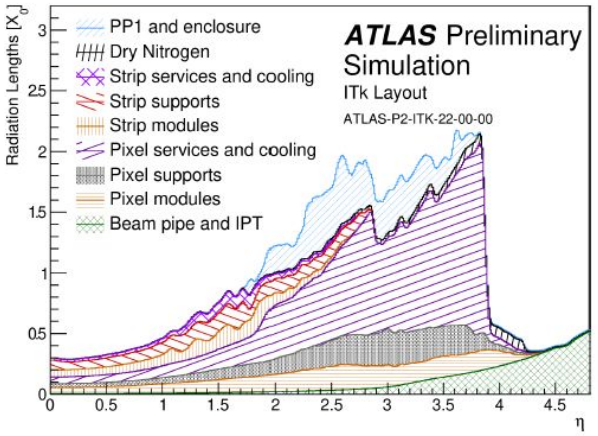
Other Devices Purchased in 2021

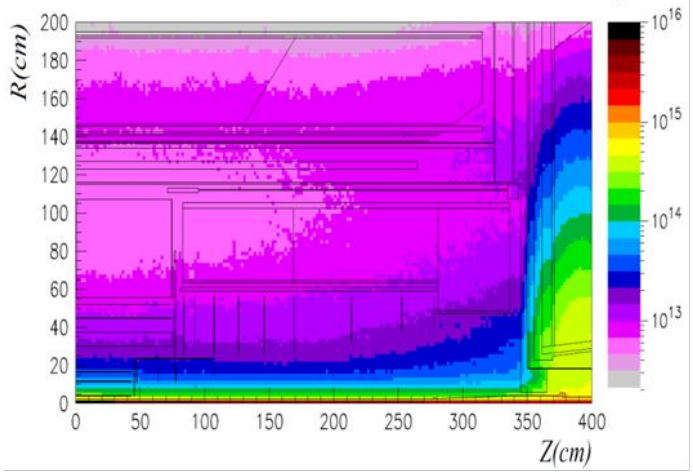
- particle counters for laboratory cleanliness measurement
    - Lasair III 350L (joint lab@CAS), 4x Dylos DC-1700PM (CU, Argotech)
- VACUTEK external suction welding machine (joint lab@CAS)
- digital static field meter and ion gun (joint lab@CAS)
- GAROMA MEZ 0098C 98l dry cabinet (CU)
- RFID reader for reading parts and tooling marked by RFID tags
    - 2x ThingMagic USB Pro Reader (joint lab@CAS, Argotech)
- 3D-printed plastic R0 powerboards for module sites





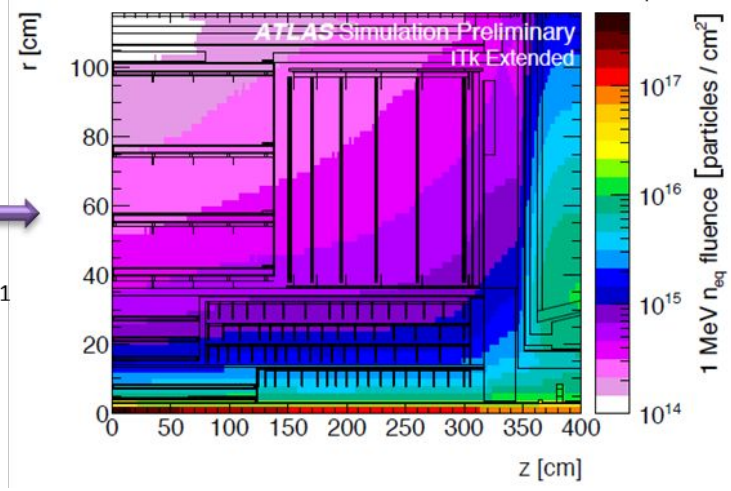
MATERIAL BUDGET





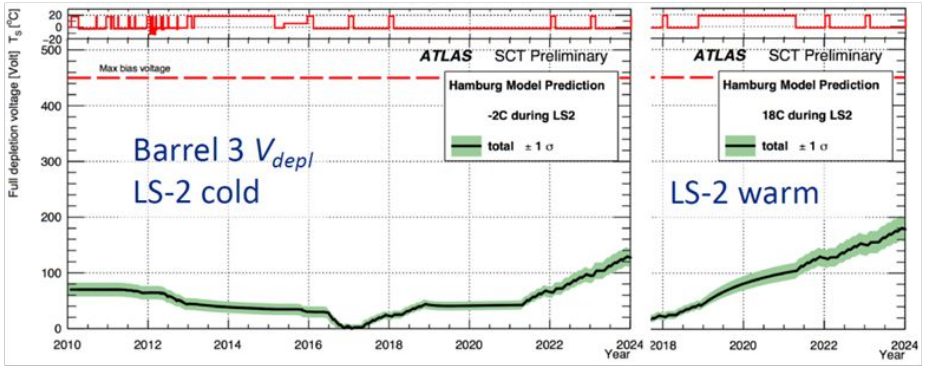
RADIATION HARDNESS

most resistant IBL pixel layer up to 850 fb^{-1}



1) Channel noise occupancy less than 10^{-3} ...

2)...at a threshold resulting in efficiency greater than 99%



- SCT designed to 8:1
- max. V_{depl} = 450 V
- current operation: V_{depl} = 200 V

3) S/N greater than **10:1**, depletion voltage **500 V**

Module Type	Fluence $10^{14}n_{eq}cm^{-2}$	Charge ke^- 500 V	Charge ke^- 700 V	Noise e^-	S/N 500 V	S/N 700 V
SS	8.1	13.7	16.1	630	21.8	25.6
LS	4.1	17.3	19.5	750	23.1	26.0
R0	12.3	11.5	14.0	650	17.7	21.5
R1	10.1	12.5	15.0	640	19.6	23.4
R2	8.7	13.3	15.7	660	20.3	23.9
R3	8.0	13.8	16.2	640	21.4	25.1
R4	6.8	14.6	17.0	800	18.4	21.3
R5	6.0	15.3	17.6	840	18.3	21.1

TDR educated estimate

ABCStar chips

Layer/Ring	Barrel	Disk 0	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5
0	16.4	15.7	15.4	15.0	14.5	13.7	11.8
1		17.9	17.5	17.0	16.4	15.4	13.7
2	15.3	18.1	17.9	17.2	16.6	15.6	14.0
3		19.4	19.2	18.4	17.7	16.6	15.1
4		14.4	14.2	13.6	13.2	12.4	11.5
5		13.9	13.7	13.1	12.7	12.0	11.1

New S/N estimate for 500 V