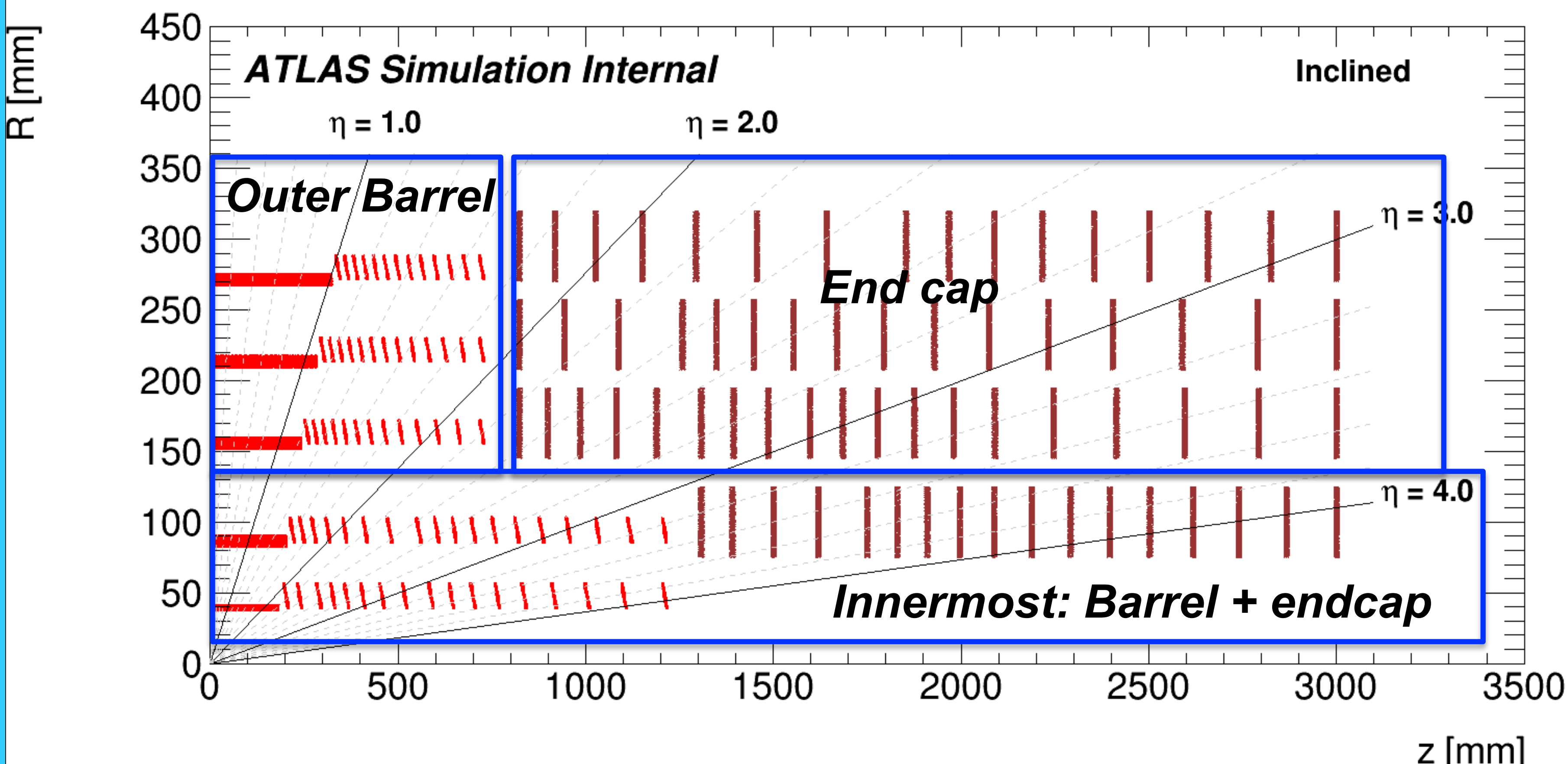
UK feedback

Claudia & Paolo (INFN Genova)

09.02.2017

ITK Pixel detector



Same Endcap in both layouts, optimized for the Extended

E cosa costruiamo in Italia?

- We are discussing if to take responsibility of building one End-cap, so far uncovered.
  - The other one is built by UK colleagues.
  - Building the innermost barrel layers - as originally proposed to better match our sensor interests - seems to be difficult as there is a strong US interest and our design and engineering capabilities are limited.
  - This is not expected to damage our interest and leadership in the 3D sensors as the pixel production model decouples the module production&test from their installation on detector.

- This is an ambitious project (2.5 m length, 60 cm diameter, 2.5 m^2 surface) but may be a big opportunity to boost the Italian contribution:
  - New groups have shown interests in this opportunity (Lecce, Frascati).
  - As an opposite example, IBL was so small that the participation of the Italian groups to the project was very limited.

Discussions in UK

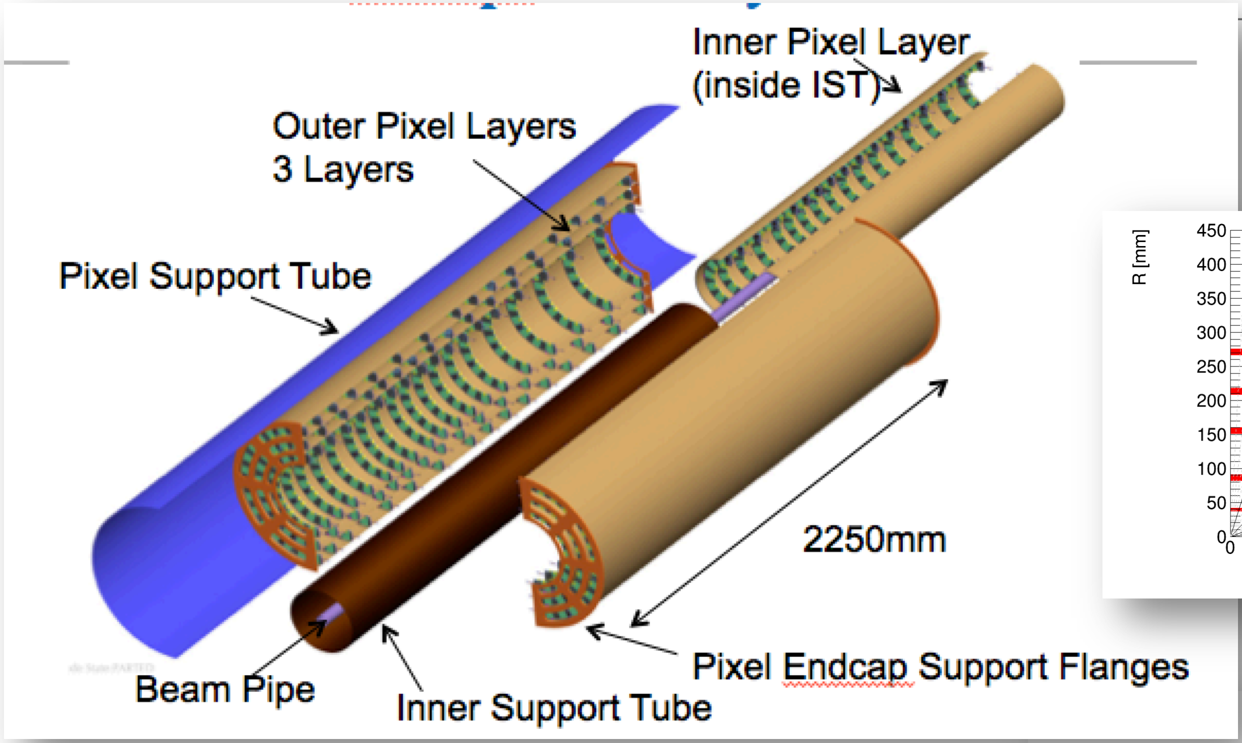
✓ In Fall Craig Butter (UK ATLAS Upgrade coordinator) has invited us to visit them and show us what they are doing (now I understand why…)

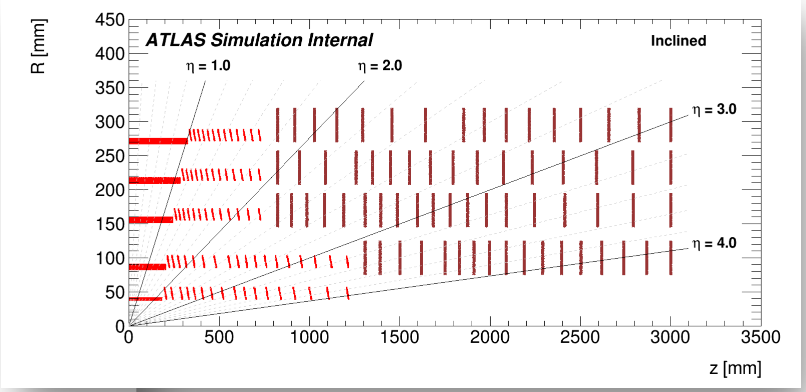
- Meeting in RAL on Thursday 2/2, See *https://indico.cern.ch/event/610289/*

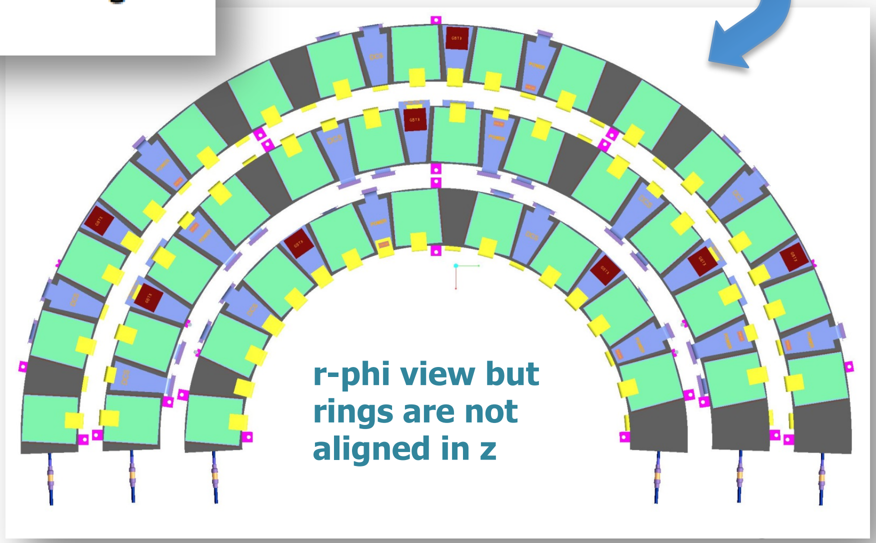
- Very nice review of all the aspects – considered very useful also by the UK colleagues for themselves.
- Focus on how is their organization, manpower, aspects that need development or are critical.

- We present an extract from their presentations.

Endcap overview







19 Inner Rings
16 Middle Rings
16 Outer Rings

UK pixel programme: Introduction

Craig Buttar

Proposed UK pixel contribution

Now 19/16/16 rings and 2500 is the baseline in the simulation

- UK proposes to build one endcap
  - Originally this was based on the current 5,8,12 layout to eta=2.5
  - Following scoping document move to 12,16,16 layout to eta=4
    - Component QA: testing of sensors, *FE-chips,* hybrid flexes, Flex tape QA, testing of ring→pp1 cables, EoS cards
    - Module assembly & QA*: **~2500 modules*** (inc 20% spares/yield), QA of bare modules from bump-bonding, mounting of flex hybrid and testing of assembled modules
    - Ring manufacture & QA: ***~60 half-rings***, manufacture of rings including integration of cooling pipes and flex tapes
    - Module mounting on rings & QA: mounting of modules on rings, mounting of EoS (power and data) on rings, connection to ring flex tapes, survey, system tests
    - Construction/procurement of superstructure: manufacture of structure in which the rings are supported.
    - Installation of disks in superstructure: install fully assembled rings in superstructure and run services to service connection at end of superstructure, survey of rings and modules in superstructure
    - Delivery of assembled endcap to CERN and installation into global support mechanics, together with the collaborators responsible for global supports.
    - NOT cables to from PP1

Organization in 4 workpackages

Current UK pixels institutes

- Glasgow: module building, data tapes
- Edinburgh: services, module building/testing
- Lancaster: Sensor QA
- Liverpool: module building, endcap assembly
- Manchester: ring construction, module building
- Sheffield: thin flexible pipes
- Oxford: module assembly
- RAL: module -> ring mounting, DAQ
- QMUL: Mechanics
- UCL: DAQ
- Total effort: 124SY over 6 years for construction not including

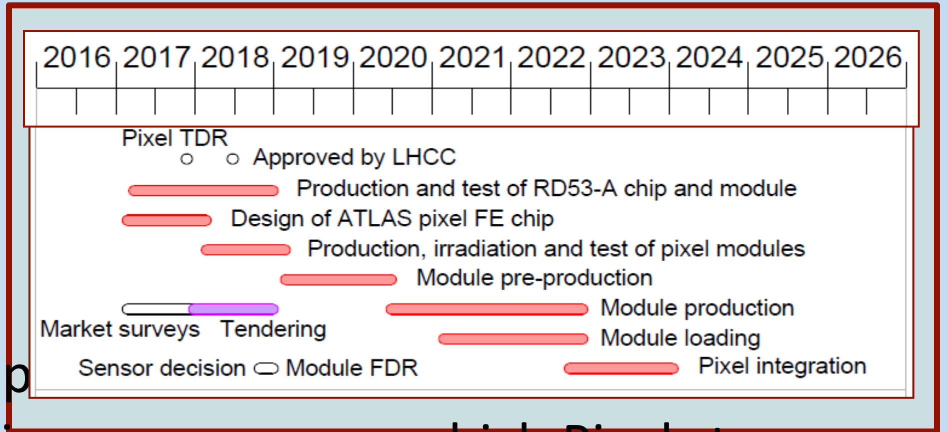
UK Pixel effort going forward

Figures compiled by Ian Wilmut Feb 2017

Stuff to know before you look at these numbers

- This is not guaranteed effort, it is **BID FOR** effort
  - i.e. what we expect to need to build the endcap
- This is all the effort regardless of where it comes from
  - i.e. does not line up with bid documents as some of this comes through other routes
- The only thing that is excluded is students
- I have drawn out the types of people – as everyone seems to have different role definitions I suggest you consider these:
  - Ac = academic, university teaching post, mostly providing oversight and management
  - AP = Applied Physicist – full time project staff
  - E = Engineer
  - T and SRF = Technician

Total pixel project effort



- This is all the effort dedicated to p
- We do have UK DAQ and Irradiation programmes which Pixels tap into
  - i.e. DAQ development and Irradiation studies effort is not included in these figures
- 23/24 and 24/25 sees huge drop off in effort this is when we are completing assembly, and then integrating at CERN
- UK will have a commissioning project that follows our production project (and probably slightly overlaps) which will contain our CERN integration effort.

Row Labels	18/19	19/20	20/21	21/22	22/23	23/24	24/25
Ac	0.7	0.6	0.6	0.6	0.3	0.1	0.1
AP	8.9	9.0	8.7	8.1	5.6	2.4	1.4
E	5.4	5.4	4.8	2.8	2.6	0.5	0.6
SRF	0.6	0.6	0.6	0.6	0.3	0.0	0.0
T	10.1	10.8	10.2	6.6	3.2	1.0	0.0
T	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Grand Total	**25.8**	**26.4**	**25.0**	**18.7**	**11.9**	**4.0**	**2.6**

Under review:
Total: 124.4SY

Effort by WP

Module building

Row Labels	18/19	19/20	20/21	21/22	22/23	23/24	24/25
Ac	0.3	0.2	0.2	0.2	0.2	0.0	0.0
AP	5.0	4.9	4.9	4.9	3.1	0.5	0.0
E	2.0	1.7	1.6	1.2	0.8	0.0	0.0
SRF	0.6	0.6	0.6	0.6	0.3	0.0	0.0
T	4.9	5.1	5.1	4.7	2.7	0.0	0.0
Grand Total	**12.8**	**12.5**	**12.4**	**11.6**	**7.1**	**0.5**	**0.0**

Total: 56.9SY

Ring building

Row Labels	18/19	19/20	20/21	21/22	22/23	23/24	24/25
AP	0.4	0.4	0.4	0.2	0.0	0.0	0.0
E	1.5	1.3	1.2	0.2	0.0	0.0	0.0
T	1.7	1.9	1.9	0.6	0.0	0.0	0.0
Grand Total	**3.6**	**3.6**	**3.5**	**0.9**	**0.0**	**0.0**	**0.0**

Total: 11.5SY

Module mounting

Row Labels	18/19	19/20	20/21	21/22	22/23	23/24	24/25
Ac	0.3	0.3	0.3	0.3	0.0	0.0	0.0
AP	1.7	1.7	1.7	1.0	0.0	0.0	0.0
E	0.1	0.1	0.1	0.1	0.0	0.0	0.0
T	2.3	2.3	2.3	0.9	0.0	0.0	0.0
Grand Total	**4.4**	**4.4**	**4.4**	**2.3**	**0.0**	**0.0**	**0.0**

Total: 15.5SY

Endcap building

Row Labels	18/19	19/20	20/21	21/22	22/23	23/24	24/25
Ac	0.1	0.1	0.1	0.1	0.1	0.1	0.1
AP	1.8	2.0	1.7	2.0	2.5	1.9	1.4
E	1.9	2.3	1.9	1.4	1.8	0.5	0.6
SRF	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T	1.2	1.6	1.0	0.5	0.5	1.0	0.0
T	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Grand Total	**4.9**	**5.9**	**4.7**	**3.9**	**4.8**	**3.5**	**2.6**

Total: 40.3SY (additional tech effort)

Agenda

- 1. General introduction (Craig, Claudia, Paolo) 11-11:30
- 2. Module assembly and QA (Richard B) 11:30-12:00

- Lunch 12:00-13:00

- 3. Ring construction, manufacture and QA of the rings (Jo) 13:00-13:30
- 4. Module -> ring mounting and QA (John) 13:30 -14:00
- 5. Support structures (Peter) 14:00-14:30
- 6. Endcap assembly, ring installation and service mounting (from ring to PP1) (Tim) 14:30-15:00
- 7. Discussion 15:00-16:00
-
- Tour of strip stave and pixel ring loading: 16:00-17:00

Status of UK project

- R&D funding to end March 18th
- Preparing bid for construction funding, start April 18th for 6 years

Modules (Richard)

- ✓ We have a lot of experience on this item (Genova, Milano, Udine).
  - Moreover we plan for 3D assembly and QA as a delivery item, independently on the EC construction.
  - We could assemble quad-modules for the EC, but maybe this is not needed at all
    - Japan could produce and QA the modules instead?

- ✓ However problematics are similar to the ones listed by Richard.

- ✓ In house flip-chip mentioned but not discussed as the person in charge was not available.

Richard's Summary

Summary of R&D required

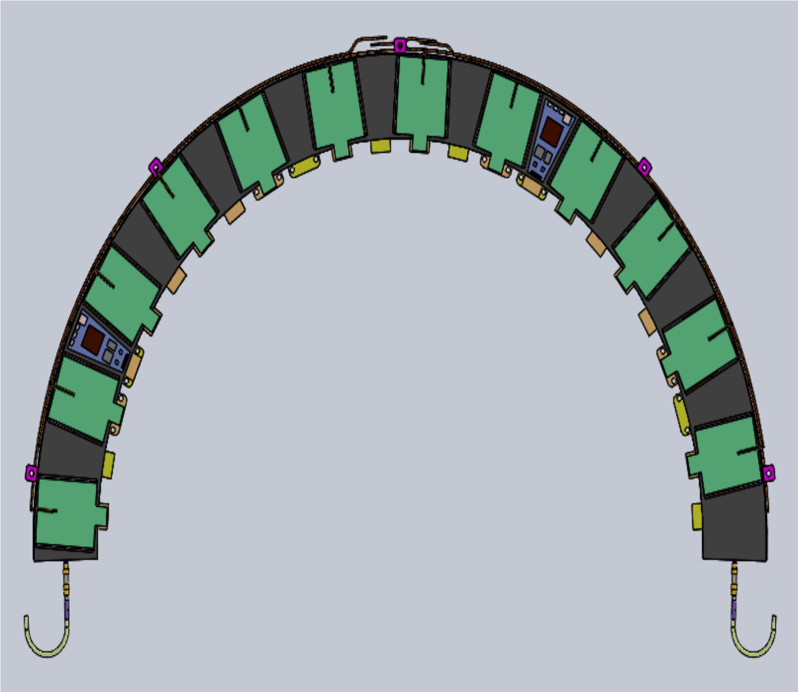
- RAL Indium flip-chip
  - Demonstrate 50x50 ATLAS pixel design
- Flex design (specific to endcap)
  - High speed data and PSPP chip
- Flex-to-assembly attach
  - Process development
- Wirebond protection
  - Production methods
- QA testing
  - Thermal shock
  - Burn-in/long term testing
- HV protection

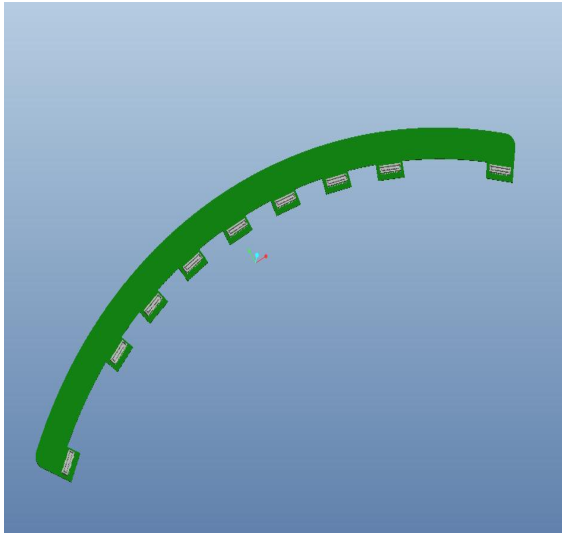
Interesting for Leonardo

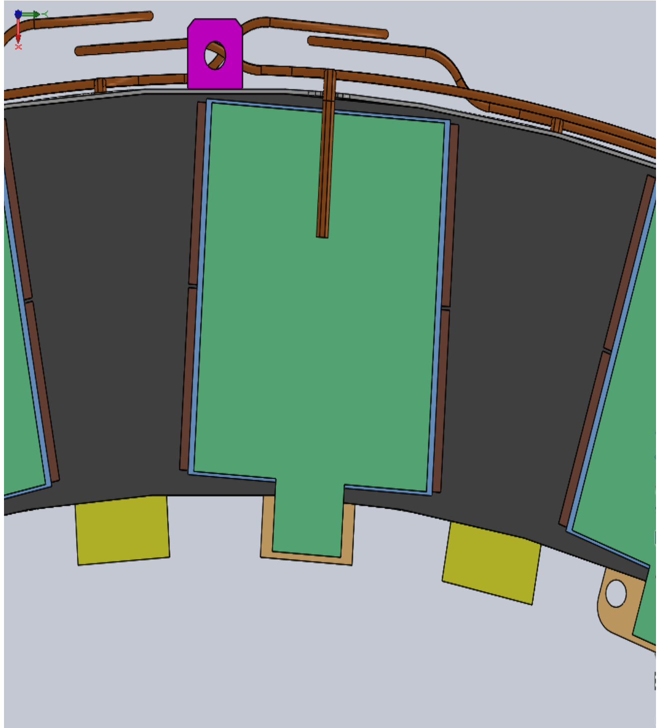
Interesting! 3D or quad or CMOS?

Independent on our role

Ring with module







Module design

- All quad modules for Endcap
- EC specific Flex design
  - Unions with ring power tape: LV, HV, CLK/CMD, DCS
  - Tx Data straight off hybrid
- First Flex designed for old ring tape

R&D areas

- PSPP DCS chip will be on ring tape
  - Not the module
- MUX chip on the module
  - Still to be designed
- High speed signals

Flex Development required

- Short hybrid flex-to-ring tape tab
  - Further development to allow a module tab to bend to aid cooling of PSPP chip
- Prototyping flex data tab
  - Route data from FE to inner radius of cylinder without on-module connector
  - Connection to Twin-axial cable on inner cylinder radius
  - 5Gbps data line

Sensors & Flip-chip

- Sensor development with Micron
  - Progressing well
- UBM at Advacam and Micron
  - Progressing well
  - QA techniques under development
- Bump deposition
  - LETI for bump deposition with SnAg
    - Will be expensive for 300mm trials
    - Thin chip solution still under development
  - RAL Indium bumps
    - Will not be able to deposit bumps on 300mm wafers
- Flip-chip
  - Advacam for SnAg working well

- RAL flip-chip
  - Ambition to be flip-chip site with Indium bumps
  - In-house solution demonstrated with Medipix and FEI4
  - Desire to work in collaboration with Genoa and Selex
    - Supply of 300mm bumped wafers
    - Exchange of daisy chain test structures to happen soon

Apparatus for flex to assembly attach

- 3 options under investigation in the UK
  - Simple, cheap – rice paper and dowel pins
    - Few £100
    - Takes 10-20 minutes to make
    - Relatively easy to master
  - Low cost – manual glue stamper
    - ~£5k
    - Time for assembly still to be determined
    - Should be fast
  - Higher cost equipment - glue robot
    - £expensive
    - Maybe faster than manual assembly
    - Less personnel

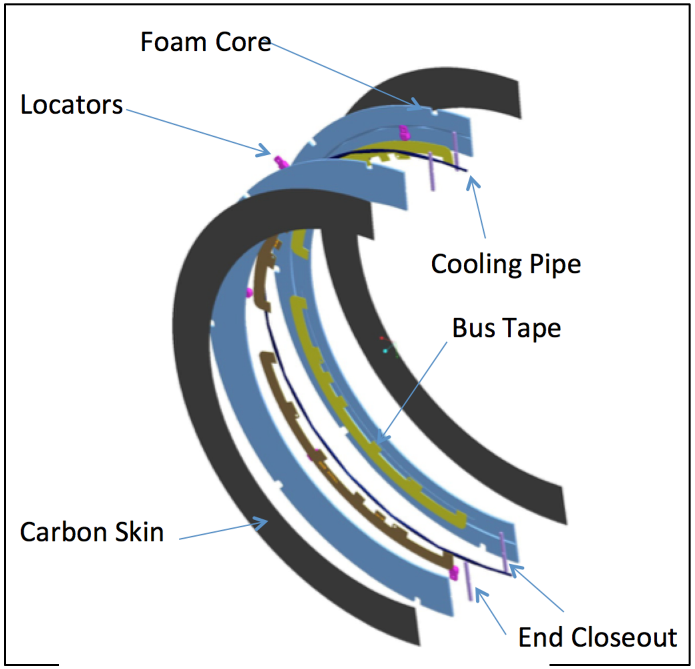
Scale of UK module ambition

- Number of modules
  - 1 endcap's worth of modules
  - Assume 2200 good modules
  - 2500-2700 sensor starts
- Time scale ~ 2 years
- 4 sites in total
  - Glasgow, Oxford, Liverpool, Manchester/Edinburgh
- 275 average module flex attach and QC /year / site
- 6 per week
  - 46 weeks / year
- Remember there is a ramp up phase during pre-production
  - Not included here

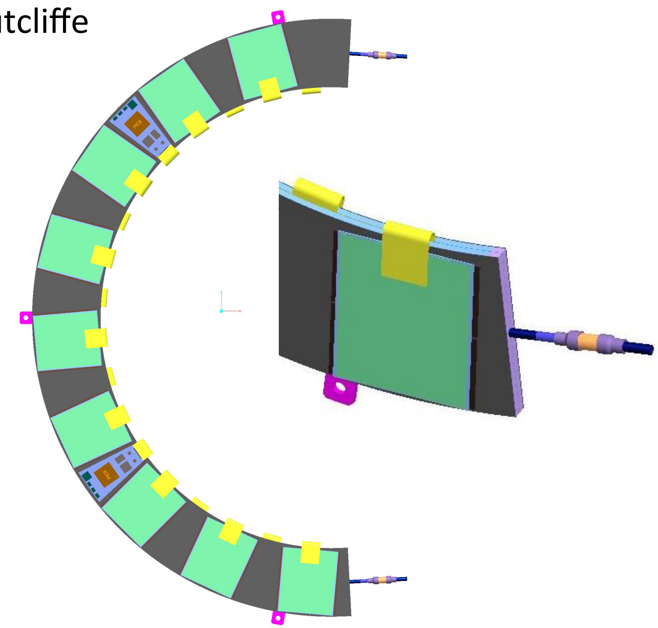
Supports (Jo)

- ✓ This is one of the skills we have in our labs as an experience done for the Pixel detector (supports in Genova, Milano) and IBL (Services - Genova, FEA - Milano).

- ✓ Building the rings is still very preliminary and has a lot of possible interesting items to be studied together and better
  - Parts and assembly the half ring
  - Pipe bending and gluing
  - Flex of the ring (type0)
  - Connection flex module – flex half ring
  - Data cables
  - End of stave (half ring) card



P.Sutcliffe



Half-Ring Design

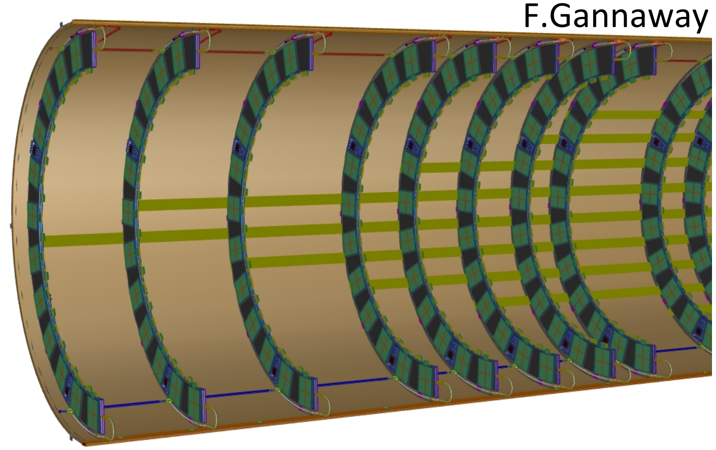
The half-rings are Carbon-fibre/ carbon-foam sandwiches

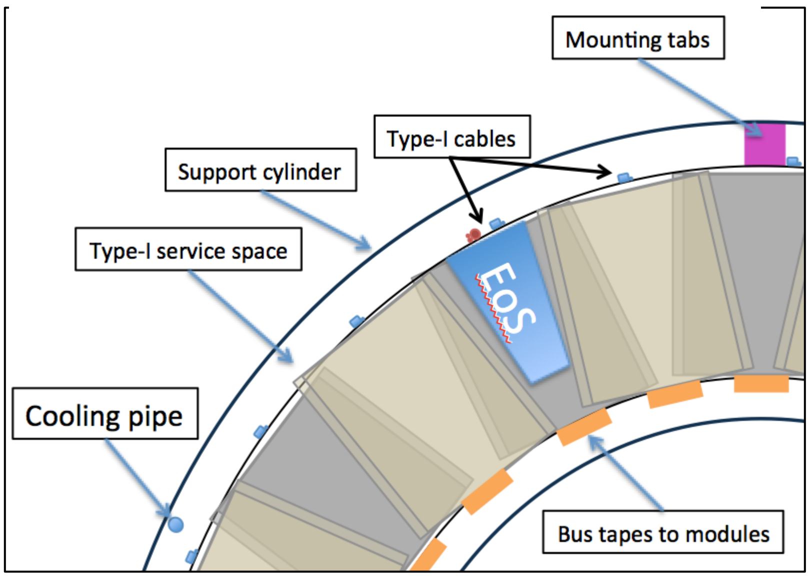
- One row of modules per ring
  - Phi overlap achieved by alternating modules front/back
- Embedded bus tape and cooling pipe; electrical isolators on pipe
  - Pipes are Titanium OD 2.275mm
- Electrical patch cards ("EoS cards") on surface to transfer power, slow controls and clock/commands to modules via bus tape
  - Shown conceptually at left in blue
    - more information on next slide
  - No data on bus tape, data cables will connect directly to modules

Rings' connection to cables

- Half-rings are mounted inside half-cylinder
- Type-I services exit between the rings and the cylinder
  - cables build up with increasing z
  - cables should be routed carefully to avoid ground loops, potential cross-talk
- Connection to embedded bus tapes happens at inner rim of ring

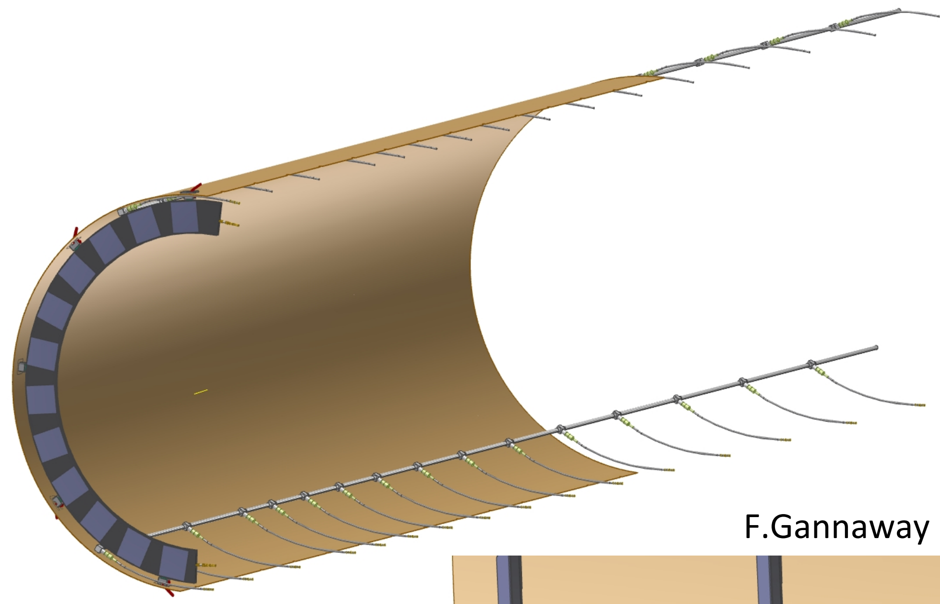
F.Gannaway



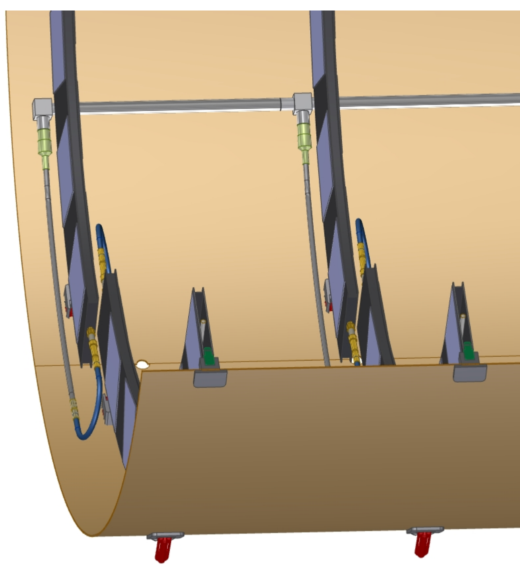


Cooling Connections

- rings in a half-layer are manifolded in parallel
  - inner and middle layers as shown: one inlet and one outlet per half-layer
  - outer layer may require two circuits:
    - lower-z rings
    - higher-z rings
- Lower drawing shows overlap at half-layer join



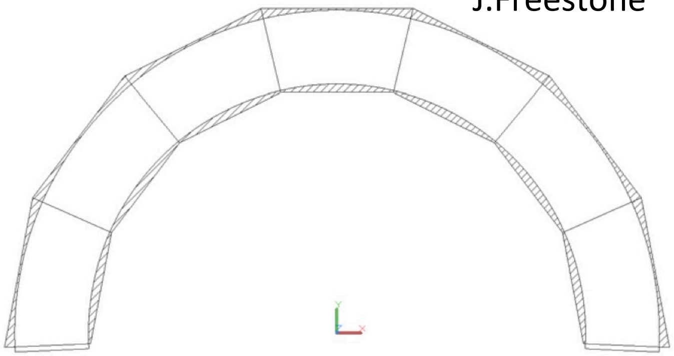
F.Gannaway



Steps in making a half-ring

- produce cooling pipe (no photo)
  - cut, bend to shape, attach electrical breaks and pressure fittings
  - bending the long smooth curve is more art than science!
- machine carbon foam "wafers"
  - 3mm thick slices, trapezoid shape
  - tricky part is holding the foam still
- machine one side of wafers flat
- affix foam to Cfibre
  - using vacuum jig (top photo)
  - in past have cured Cfibre as facesheets, then glued foam
    - uses a lot of glue
    - suspect not a good bond –delamination seen
  - now experimenting with co-curing (bottom photo)

ring gluing jig

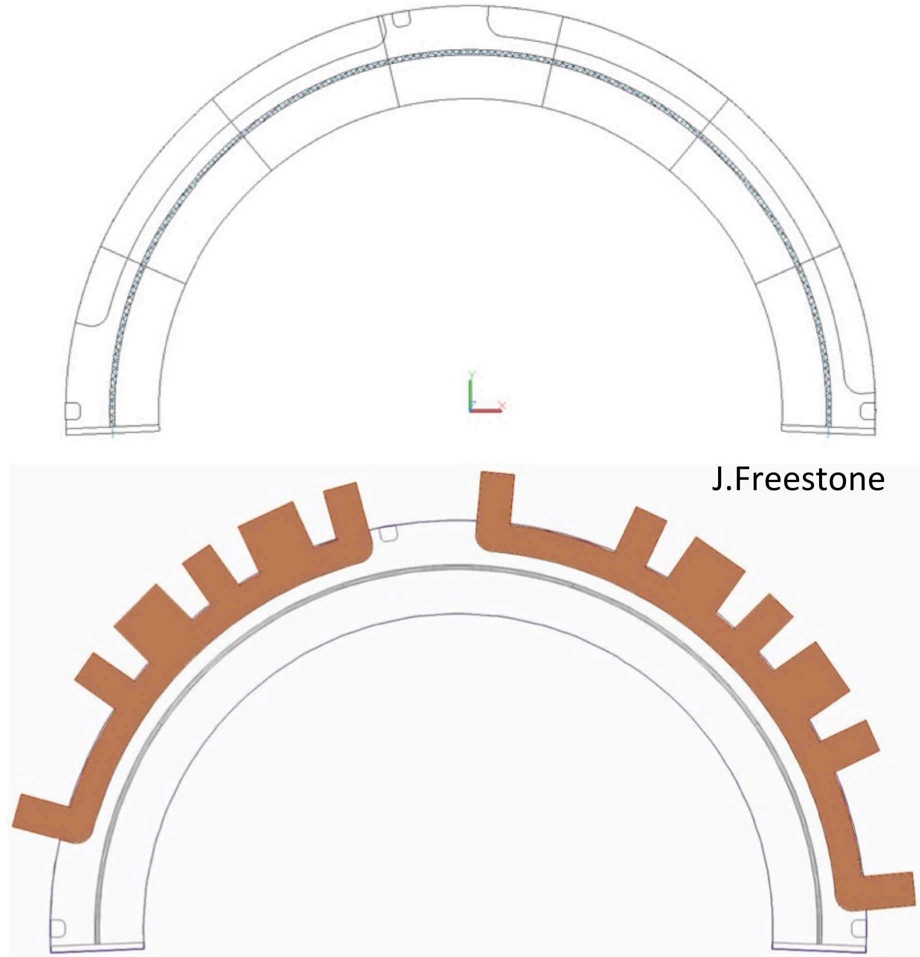


J.Freestone

P.Cooke, T.Jones

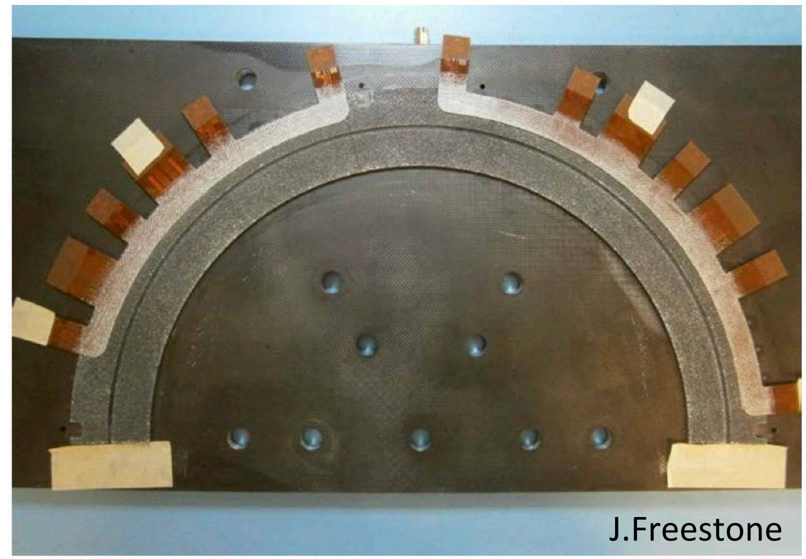
Steps in making a half-ring, p2

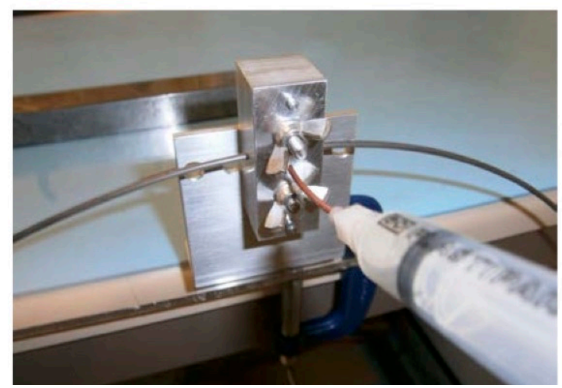
- machine foam faces of half-sandwiches flat and to desired thickness (2.4mm)
- machine grooves for cooling pipe, bus tapes, locators, closeouts
- glue tapes in place
  - glue applied to tapes with roller
  - approx 50u thick

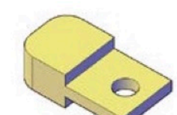


Steps in making a half-ring, p.3

- apply glue over foam and tapes
  - roller application – controlled thickness
- apply glue to pipe using custom applicator (bottom picture)
- brush glue onto mounting lugs
- assemble halves, cure in vacuum press







Steps in making a half-ring, p.4

Glue in pipe-support closeouts and carbon-fibre edging strips

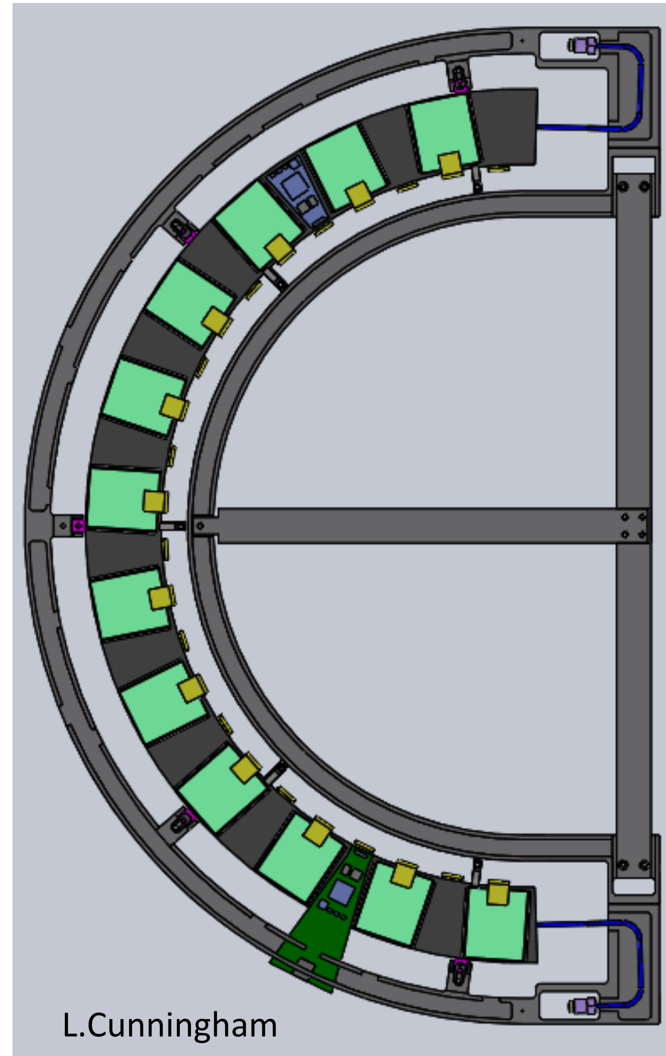
A finished ring →

Four middle rings in production

- now through summer:
- TFM
- QC development
- electrical tests

Ring Handling Frame / Transport Box

- The ring handling frame fulfils a number of functions:
  - Allows safe handling of the pixel rings in the lab
  - Secures the rings during module mounting
  - Allow testing of modules after mounting on the ring
    - via patch panels at outer rim
  - secure transport to get pixel rings to assembly sites
    - ring shown fits in a bespoke box
  - Forms part of the pixel ring insertion tooling
- Make ~ half as many frames as rings and re-use



Quality Control during Production

- Cooling loops pressure tested to ~200 bar before embedding in rings
- Bus tapes produced in industry, we do thorough reception testing
  - automatic test system (sw controlled) prototype exists; has been used to test current tapes
- Half-rings:
  - Recently started working on ring QC ideas
  - TFM measurements
    - one inner ring measured at CERN and Manchester
      - much higher TFM than expected, but delamination of Cfibre from foam observed
      - will measure TFM of the four new middle ring prototypes this summer
        - » compare to FEA
        - » first idea of spread during production
  - want to develop a way to measure TFM without modules
    - strips (QMUL) developing a technique using heat exchange of stave with ambient + an IR camera
  - Fault finding
    - IR camera (fast video mode) + rapid cooling may show up construction faults (bad adhesions)
    - first tests ongoing now with test pieces with deliberate flaws

Half-Rings Construction Time, Manpower

- Right now it takes about 2 days' work to make a half-ring → should be no problem to make and test 1-2 half-rings per week
  - need to make ~ 100 half-rings to make + spares
  - one year pre-production: make 10-20%
  - two years' production
- Effort required:
  - ~12 FTE over 4 years 2019-2023
    - concentrated in first 3 years, then tailing off
    - foam machining done by university workshops
    - gluing and co-curing done by group technicians
    - QC done by physicists/students

Module Loading (John Matheson, RAL)

- ✓ This is one item we did for the Pixel detector (Genova). So reasonable experience is still in our groups.

- ✓ 1 or 2 loading site with possibility to test and reworking (wirebonding).
  - It could be that more sites do the QA of the half-ring.

Overall Summary

John's Summary

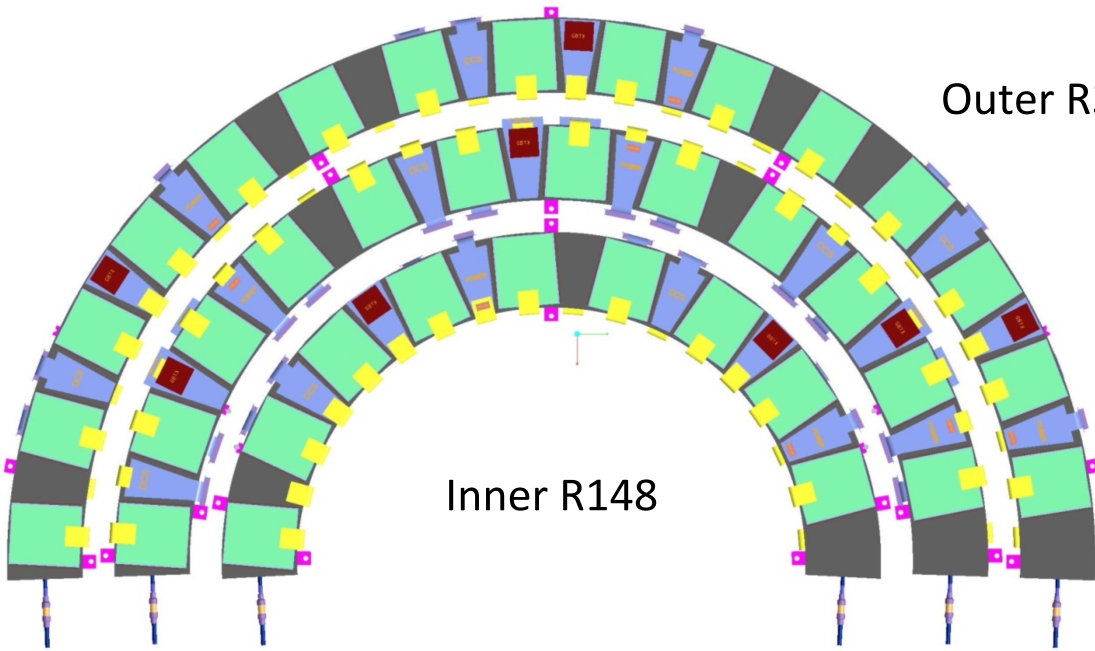
- So far STFC/RAL is sole Endcap module mounting site. For two endcaps, we must have two mounting sites.

- We have defined a method of module mounting and demonstrated its feasibility. Details of hardware, software and procedures are evolving, particularly to ensure we can cope with the challenging schedule.

- We are ready to share the design we have developed with other mounting sites.

- So far we have concentrated on the precision mounting and gluing operation. Development of test hardware, software, etc. for assembled half-rings also needs to be looked at.

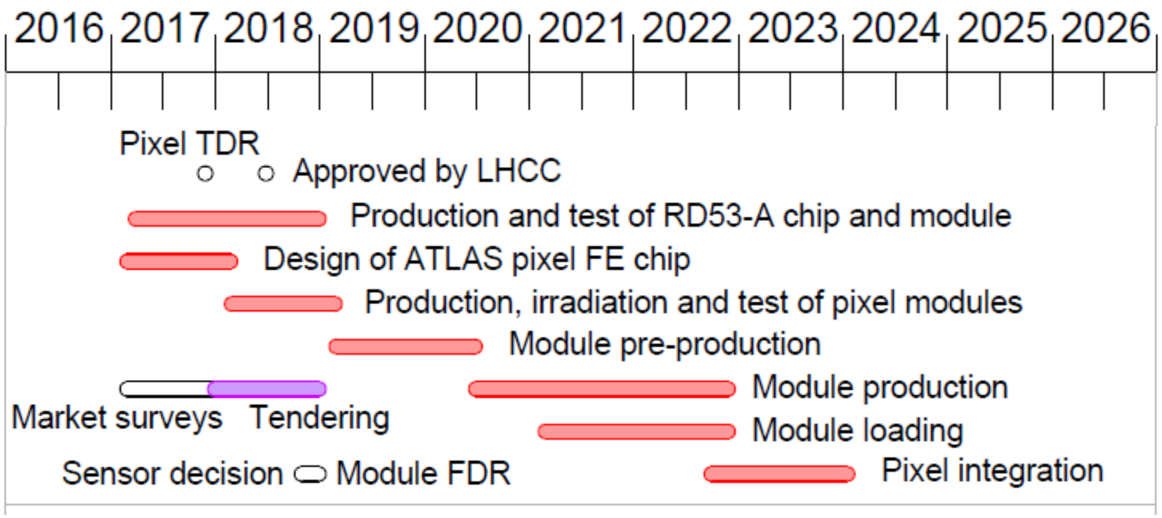
Pixel endcap half-rings



Inner: 18 modules/half-ring
Middle: 24 modules/half-ring
Outer: 30 modules/half-ring
36 x 19 = 684
48 x 16 = 768
60 x 16 = 960

- The half-rings will be assembled into a complete end-cap.
- Total number of modules to mount = **2412** (plus spares => 2538)
- Plus EOS cards: propose to put these down first using jigs
- Position accuracy must:
  - Preserve HV clearances
  - Guarantee sufficient overlap between modules
  - Give a starting point for track-based alignment
- Currently aiming for +/-25 micron (knowledge of position)
- Trade-off between accuracy and speed ?

Proposed schedule

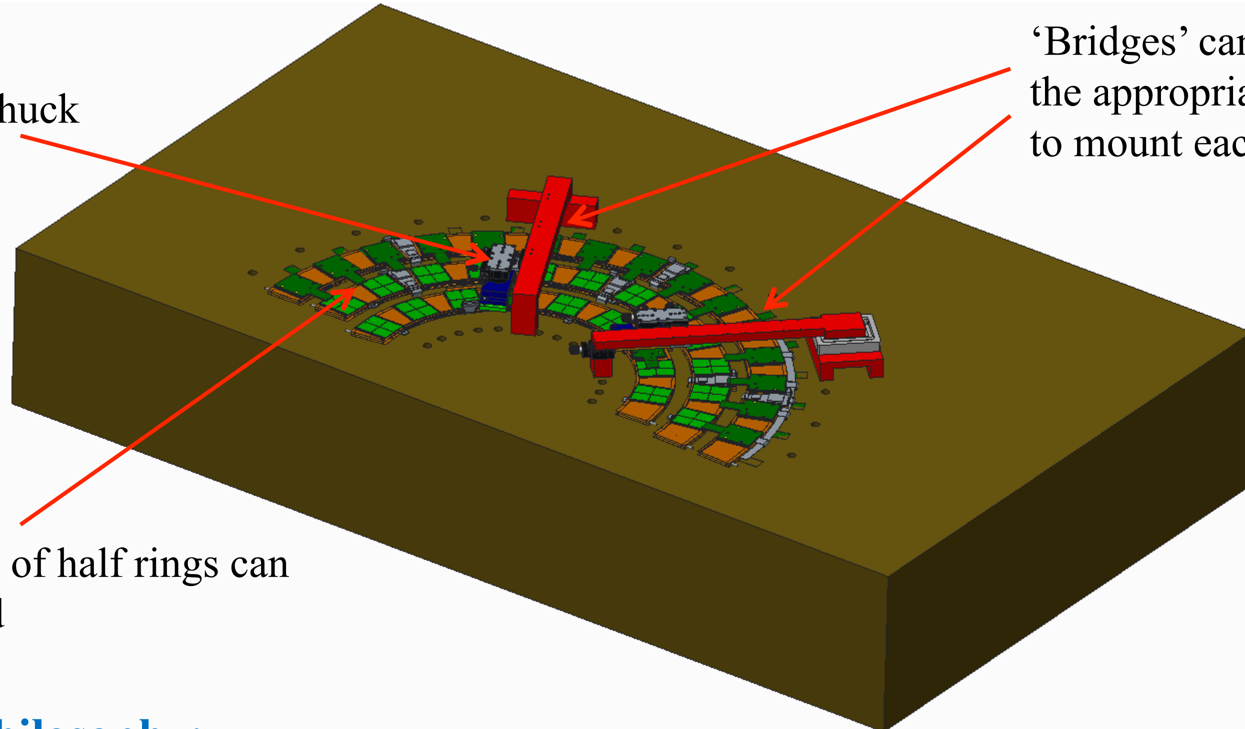


- Module to local supports loading in 2021 and 2022
- 24 months for module loading onto half-rings during production phase

- Early 2019 – mid-2020 is module pre-production
- Module production begins mid-2020
- We must aim for pre-production loading to start ramping asap (mid 2019)
- By Jan 2021 we have must have amassed significant experience

- Suggest each mounting site has 2 FT technicians + 1 physicist (minimum)

Pixel Module Mounting – as prototyped



Philosophy:

As STFC/RAL approach for strip tracker staves

We manipulate the modules "by hand" in X,Y,Z and theta on small stages

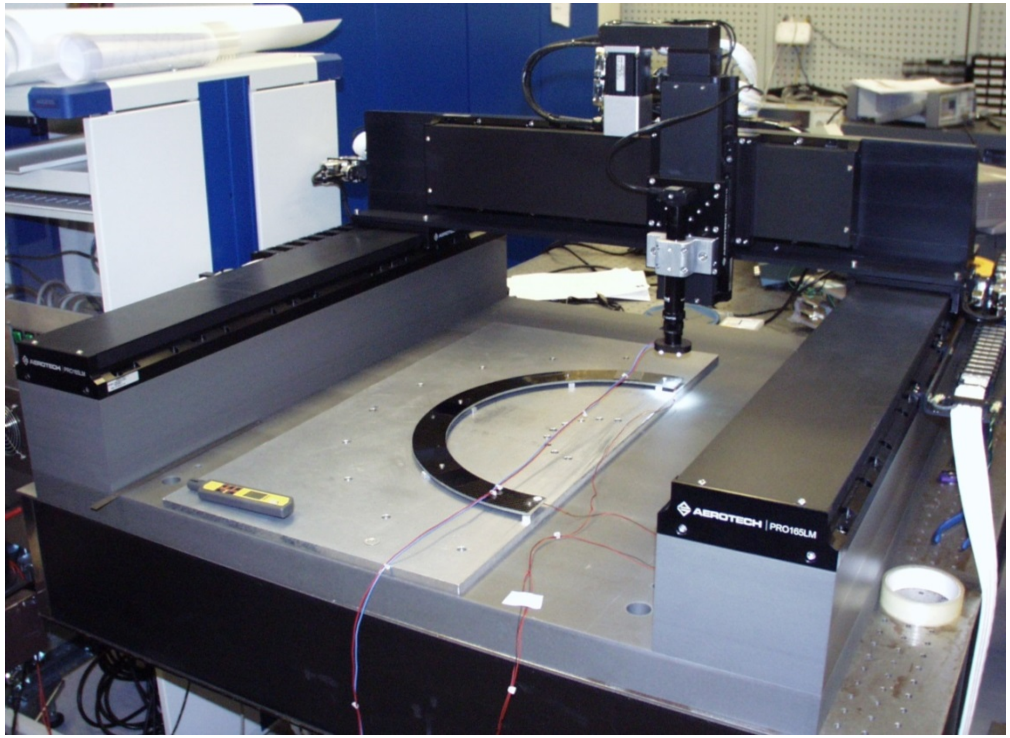
The work area is covered by optics moving on motorised XY stages

We use the optics to:

1) define a coordinate system relative to fiducials
2) provide a reference for the alignment of the modules
3) survey the result of the gluing operation

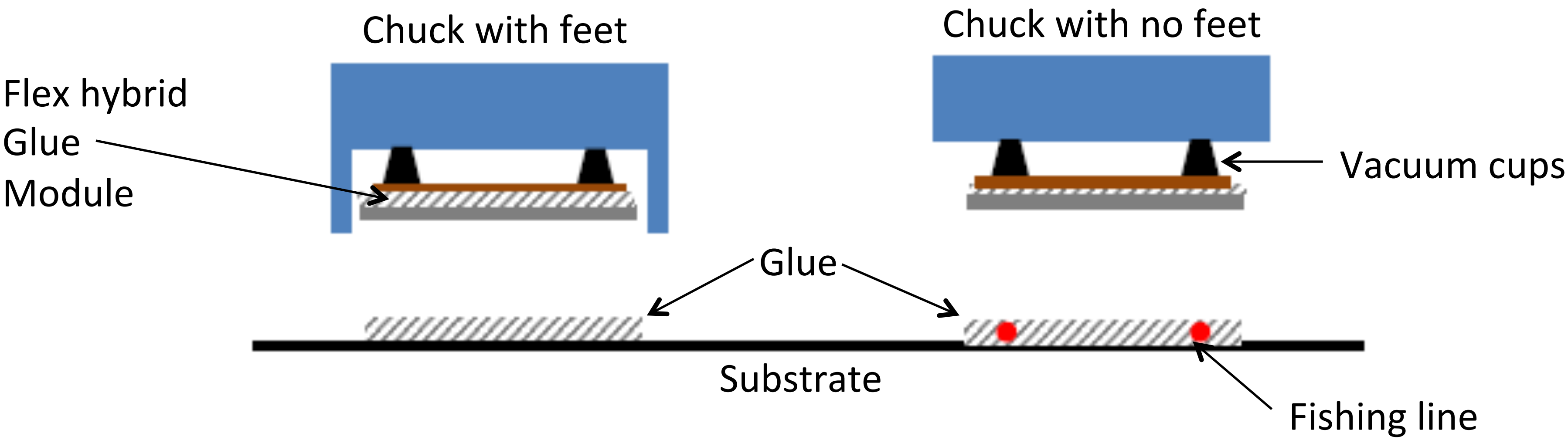
As prototyped so far, there is room to mount every second position

Pixel Module Mounting – stages and optics



- Custom gantry made from Aerotech stages, motion 500 x 800mm
  - If one can afford it, Aerotech standard gantries 1000mm x 1000mm
- Camera and optics can be positioned over workpiece – Labview software
- Accuracy to position optics: specification is 10 micron
- We now have a half-ring handling frame (Glasgow design)
- Use several interchangeable tooling plates to be quicker – add means of location

Setting the glue thickness



Chuck with feet –

Distance between feet and vacuum cups sets glue thickness

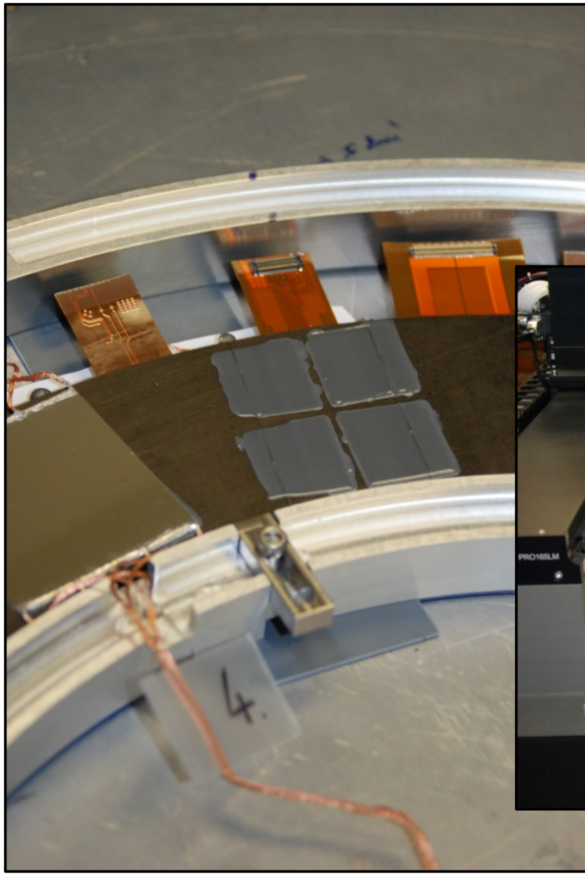
Works well with glass dummies but, with real module, upper glue layer nonuniformities will affect lower glue layer. How much ?

Without feet –

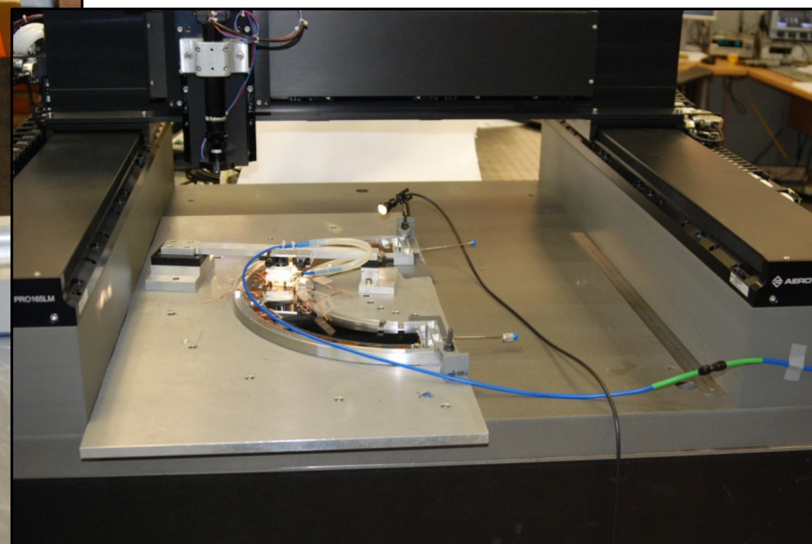
Used this method here, with 300 micron Si thermal dummies. Glue thickness is set using fishing line. If the lines are not perfectly below the cups, the module starts to take on a banana shape when pushed. Less good than the chuck with feet so far, but could be optimised.

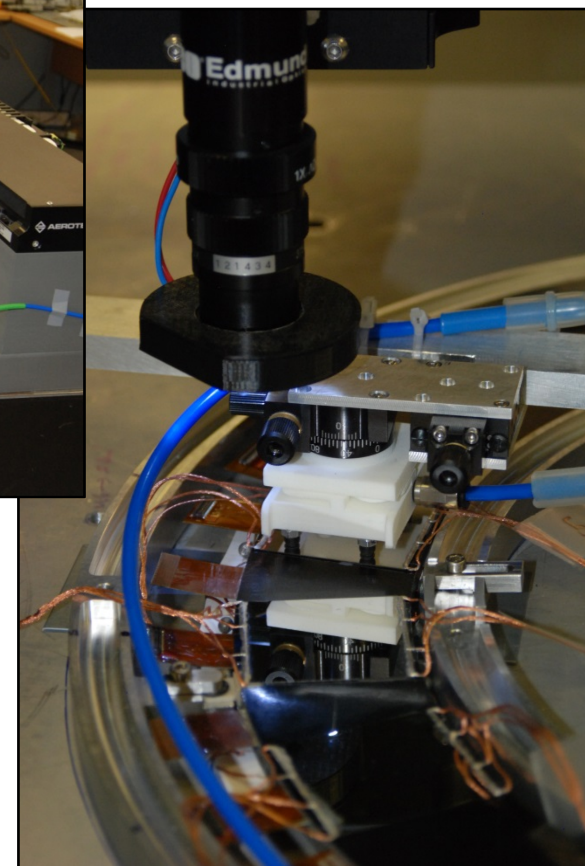
Could 3D print the chuck to conform to the module topography so can push over more surface

Building the first thermal half-ring



- SE4445 glue applied using stencil (difficult).
- Narrow half-rings, small clearances to handling frame make glue application difficult
- Fishing line was used to define glue thickness in this case





- Last module (of 5) aligned using gantry.
- Very useful exercise to refine procedures.
- Will re-visit handling frame design.
- A mechanical half-ring coming soon.
- More thermal half-rings in 2017.

Method and time to mount a single module

Current Method:

- Pick up fiducials in handling frame and define coordinate system. *Not every time, say once per day, 15 min total => 1 min/module*
- Calculate coordinates for module corners. *Automated.*
- Pick up module with chuck. *Optimised jigging and procedure, 5 min*
- Put bridge in place and position module. *Slightly fiddly, 10 min*
- Remove bridge and set aside. *5 min*
- Apply glue*. *Have to mix it first. Currently applying by hand (we estimate machine deposition will take 3 min for a 16 sq cm module). Allow 20 min currently.*
- Replace bridge and push module onto glue** *5 min*
- Minor adjustments *Slightly fiddly, 5 min*
- Wait till glue sets***. *Overnight, possibility to gain time here.*
- Remove bridge. *Well….*
- Survey. *One side at a time, depends on number of modules. Mostly automated, allow 15 min per module, 0.5 day total. Can't be done in parallel !*

Say 1 hr per module…… how to speed up comes later !

* Currently Dow Corning SE4445, applied by stencil printing
** Chuck feet or fishing line set how far to push
*** Also could use UV-cure adhesive to hold

Numbers of modules to mount and timescales

- **Most naïve assumption for 2538 modules:**
- 1 hr to mount a module, say 35 hr/week
- 73 weeks, close to **1 year 8 months** (44 working weeks/year)

- **Refinement: How well does the modularity fit with a working week ?**
- I assume we can populate every second position and leave overnight to cure the glue. One side at a time.

- 18-module half-rings:
- 9 modules takes 2 days => 4 days/half-ring => 39 x 4 = 156 days

- 24-module half-rings:
- 12 modules takes 2 days => 4 days/half-ring => 34 x 4 = 136 days

- 30 module half-rings:
- 15 modules takes 3 days => 6 days/half-ring => 34 x 6 = 204 days

- 496 working days at 22 working days/month => **23 months**

Without spares: 117 +128 + 192 = **20 months**. Middle rings fit this working day best !

How much time needed to test the half-rings ?

We discuss a bit if this test should be down at the operational temperature or not (of course it adds some complications) → most probably yes, in order to demonstrate that the thermal performance is appropriate.

Functionality testing:

- Per HSIO setup, we probably need about 1 hour to test basic functionality of 4 quads. DAQ is easily expandable so below is worst case.

- 3 hours/side inner half-ring => 6 hours/half-ring => 234 hours total
- 3 hours/side middle half-ring => 6 hours/half-ring => 204 hours total
- 4 hours/side outer half-ring => 8 hours/half-ring => 272 hours total

- Naively looks near 20 weeks **not including** time for cabling, cooldown, warmup, flushing with dry N2…. Quicker if more quads are tested in parallel.

- Testing time << assembly time, to be done in parallel to mounting (needs enough hands !)

Source testing:

- Check for disconnected bumps. IBL used 30 MBq Sr-90, exposure time 7 min per FEIC
- Pixel size not the same as IBL, may be some leeway in source rate or possibility to use >1 source
- Say 0.5 - 1hr per quad exposure time ?

- Something like 50+ weeks, also in parallel (one source). **Could be significant, needs thought**

- If we make a measurement of noise vs sensor bias, maybe don't need to do this

Numbers include spares

How will Rework impact the schedule ?

It has been suggested that significant rework will be necessary….

IBL experience:

20 module placements per stave
6 out of 20 staves made did not require replacement of a module
at least 14/400 chance of replacement of a module = 3.5%

For 2400 modules this suggests 84 replacements
How long to replace ? 2.5 hours each ? Implies additional 30 working days.

This is something of an oversimplification ! Allow 2 months initially

I would argue to look into the IBL experience in more detail and aim to find pre-mounting QA and mounting procedures which minimise rework.

Next Steps

- Build a trial half-ring with Glasgow dummy modules, to be measured on RAL gantry and Oxford Smartscope. Will investigate mechanical details and accuracy.
- 4 middle half-ring thermal prototypes proposed starting now and extending into 2017. Each likely 5 modules as before. Maybe 1 to be fully loaded later.
- Inner and outer rings - thermal prototypes mid 2017

Supporting structures (Peter)

- ✓ At this stage of the assembly, it may make sense to uniform the tools as much as possible
  - Each end-cap has "only" 3 x 2 half-shells. → same production for the two endcaps?

- ✓ (electrical) services to PP1 are basically uncovered.

Summary and future work

Peter's Summary

- Prototyping of half cylinders is encouraging with both Autoclave and oven cured lamina
- Future prototyping work will concentrate on the joining of half cylinders and end flanges.
- Move this on to a 1.4m long half cylinder
- Test discrete component assembly and survey.
- Detailed FE shows good results for deflection and modal frequency
- Cooling structure prototyping underway
- Detailed services routing underway

The UK Deliverable is the 3 Outer layers

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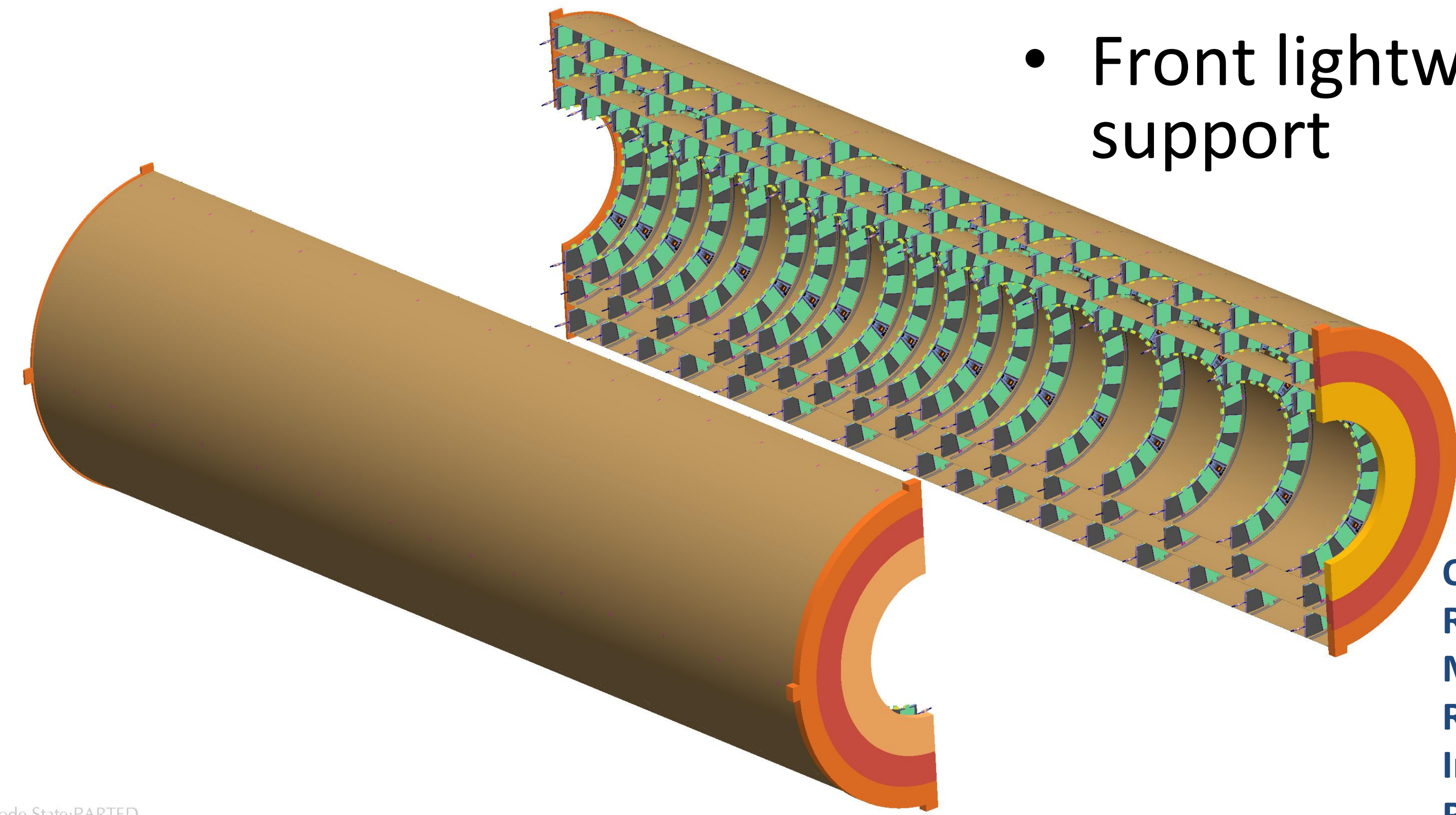
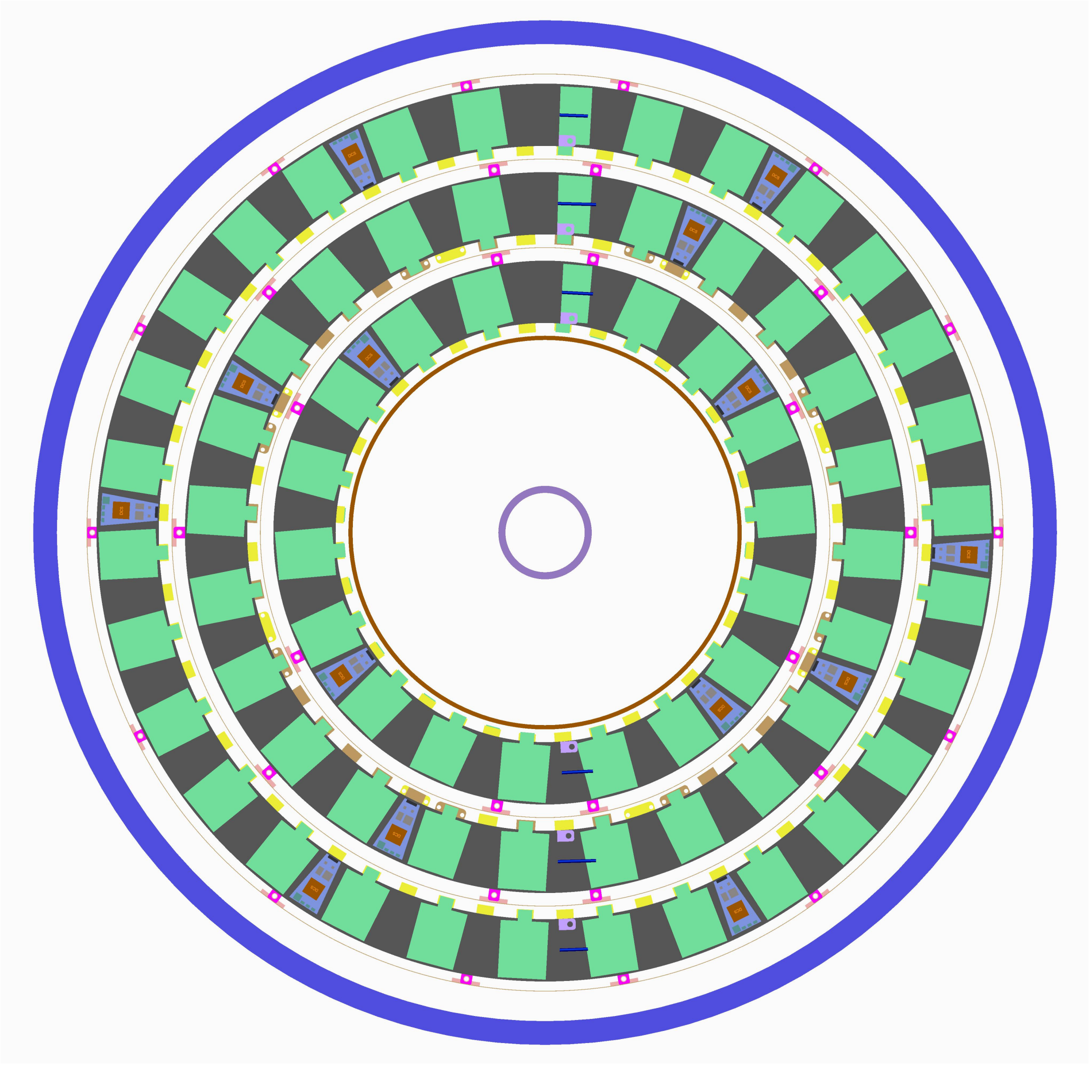
- Outer 3 layers
- Services bulkhead
- Front lightweight support



Outer cylinder R326.65
Middle Cylinder R263.95
Inner Cylinder R201.45

Endcap End view

- Dimensions
  - CAD Model
  - Envelope
    - Outer Radius 326.65mm
    - R330
    - Inner Radius (Tapes) 141.75
    - R139



FE Analysis - static deflections
Oxford University K.Arndt, S.Yang

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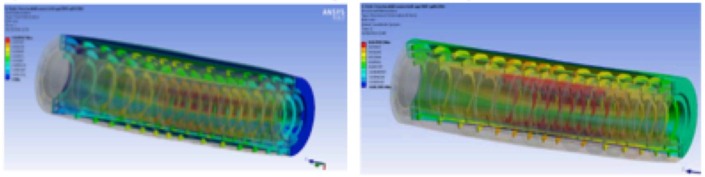
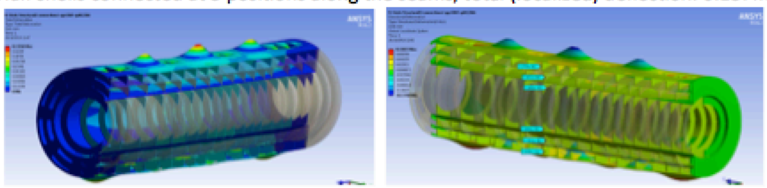
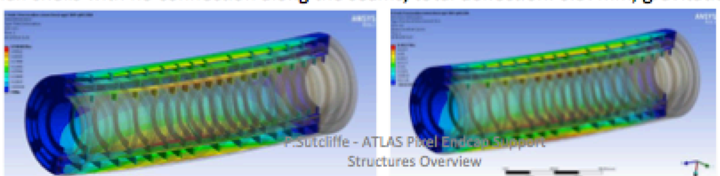
1. Full cylinders, total deflection: 0.029mm, gravitational sag: 0.025mm



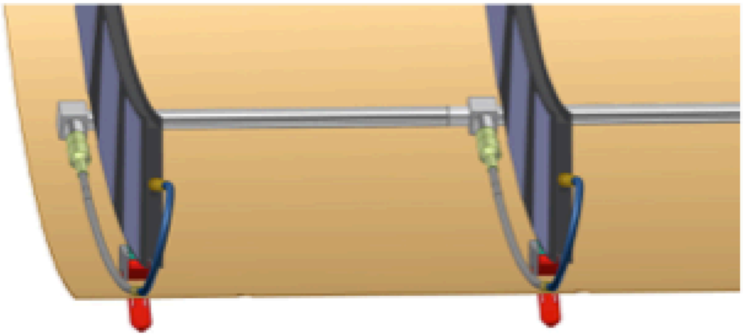
2. Half shells connected at 3 positions along the seams, total (localized) deflection: 0.137mm

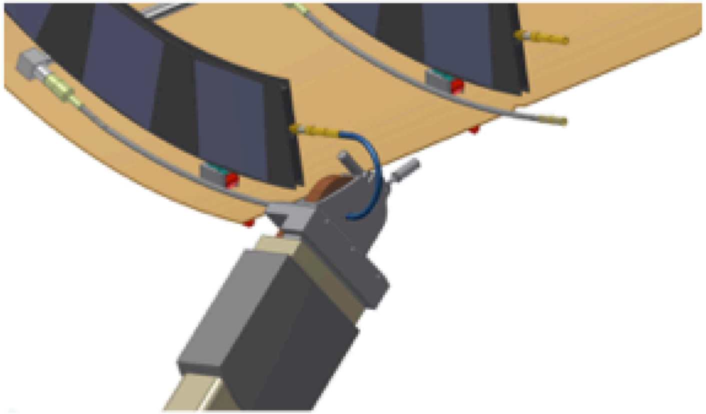


3. Half shells with no connection along the seams, total deflection: 0.57mm; gravitation sag is 0.47mm.



Manifolding of cooling tubes and orbital welding
Fred Gannaway QMUL





Welding of Ring and Manifold

Orbital Welding
Richard French, Sam Edwards Sheffield University

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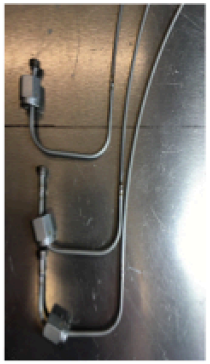
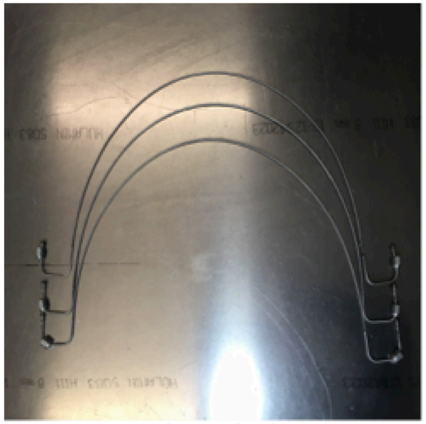
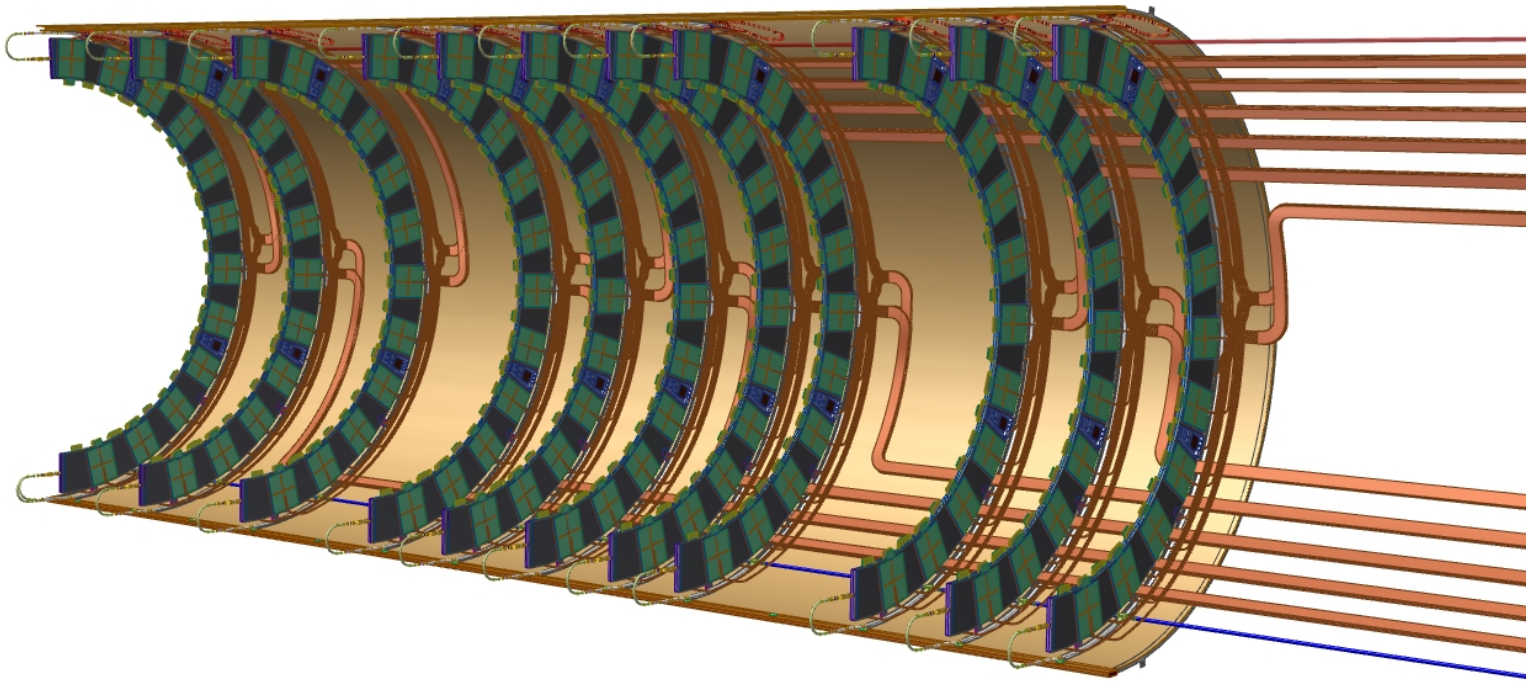
3 Complete ½ loops with no electrical break. Managed final welds of U with VCR to ½ loops with no failures, however would have been more comfortable with extra test pieces.





Services Routing
Fred Gannaway QMUL



11 Ring model showing cable routing
This is out of date but does show the volume of cables for each ring

Current Prototyping Program- Middle layer prototype

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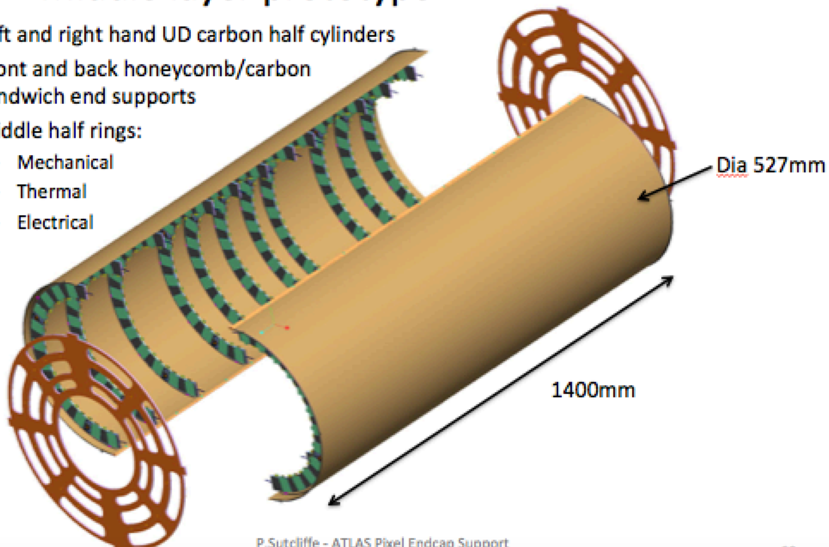
- Left and right hand UD carbon half cylinders
- Front and back honeycomb/carbon sandwich end supports
- Middle half rings:
  - Mechanical
  - Thermal
  - Electrical



Top and bottom joint details

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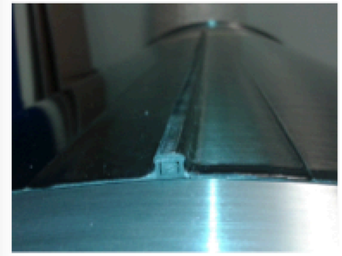
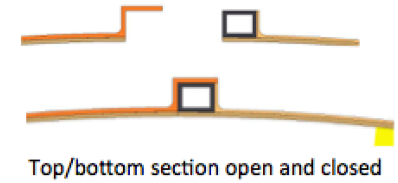
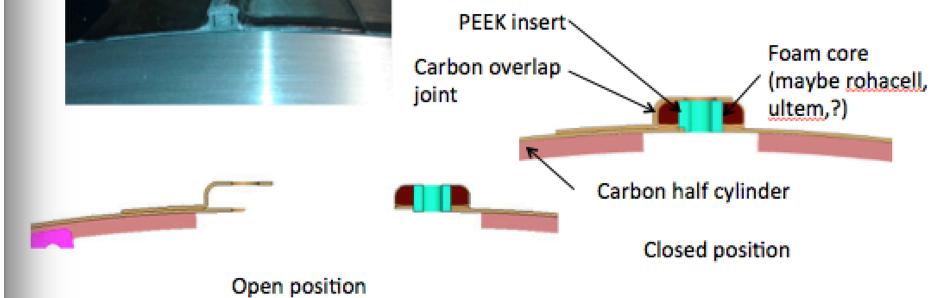
- Current prototype uses a square section carbon rod







Proposed joint system

New idea – similar to existing pixel stave

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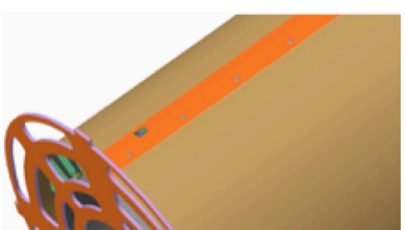
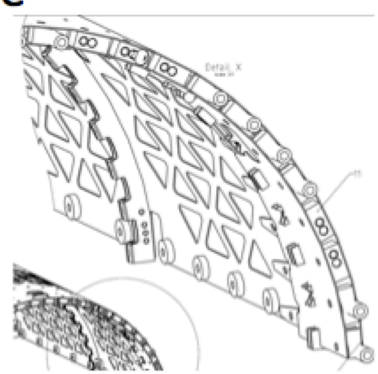
- Existing pixel idea using bonded inserts





Location ribs

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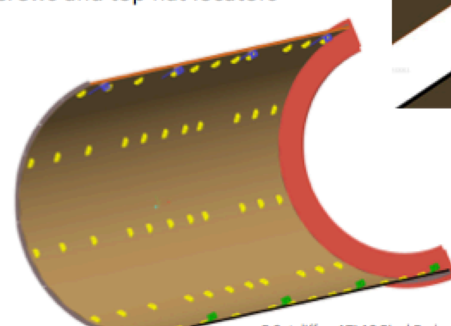
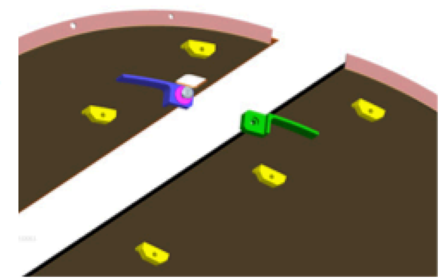
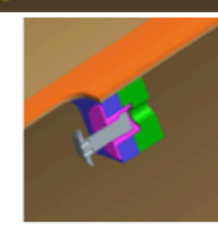
- Several location ribs will be placed along each cylinder
- These are to give a repeatable location for joining the half cylinders together.
- These will be fixed with captive screws and top hat locators

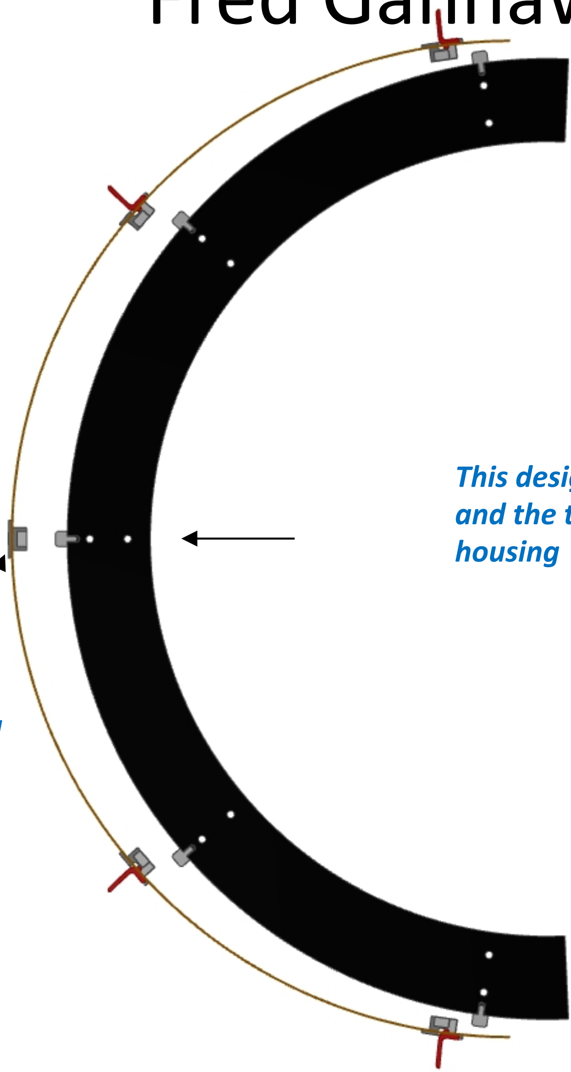


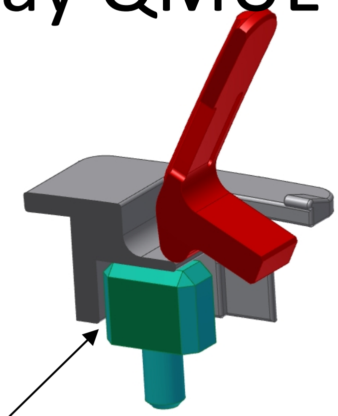




Half ring fixings
Fred Gannaway QMUL

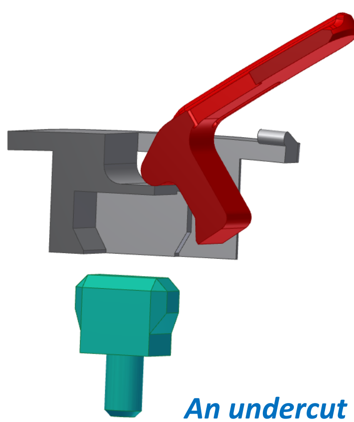
- The diagrams show different half ring location schemes
- These will be tested on the middle layer prototype





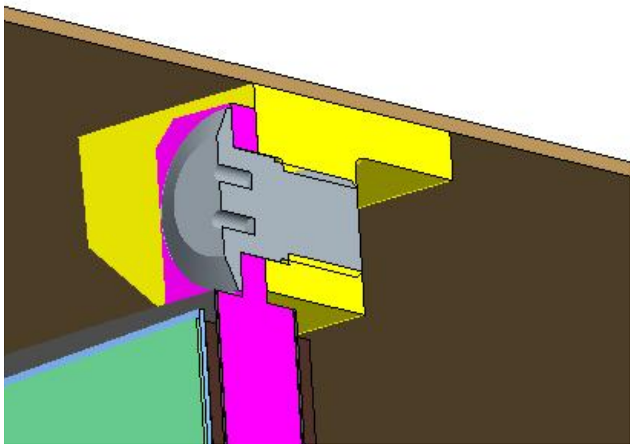
This design allowed the shell to flex and the tab coming free of the housing

Datum Housing



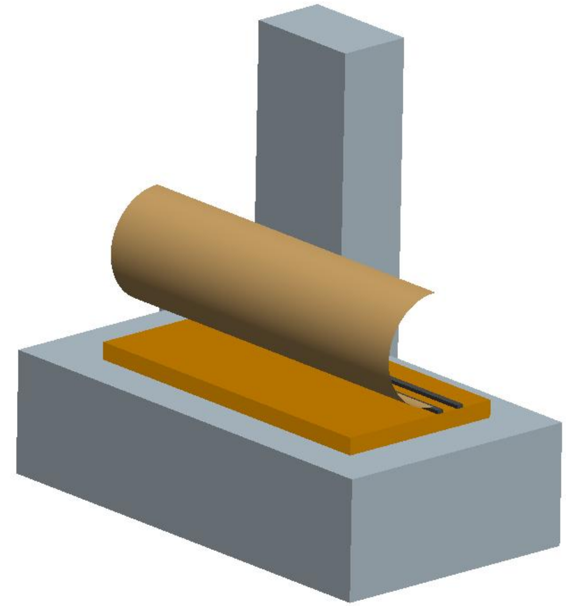
An undercut has been added to the tab, lever and housing to prevent the shell flexing

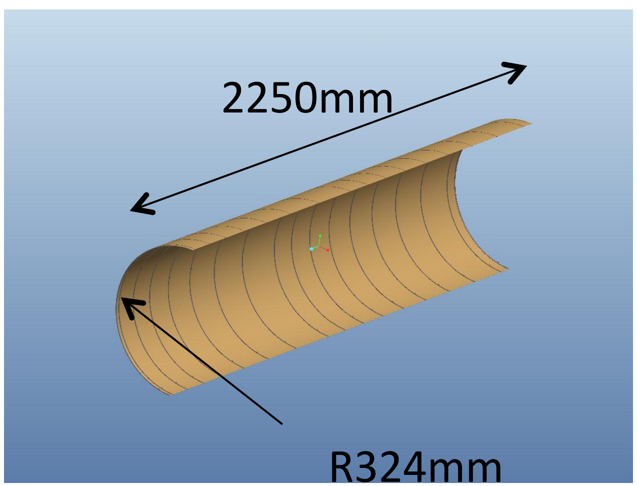
Needs design review



Half cylinder component bonding

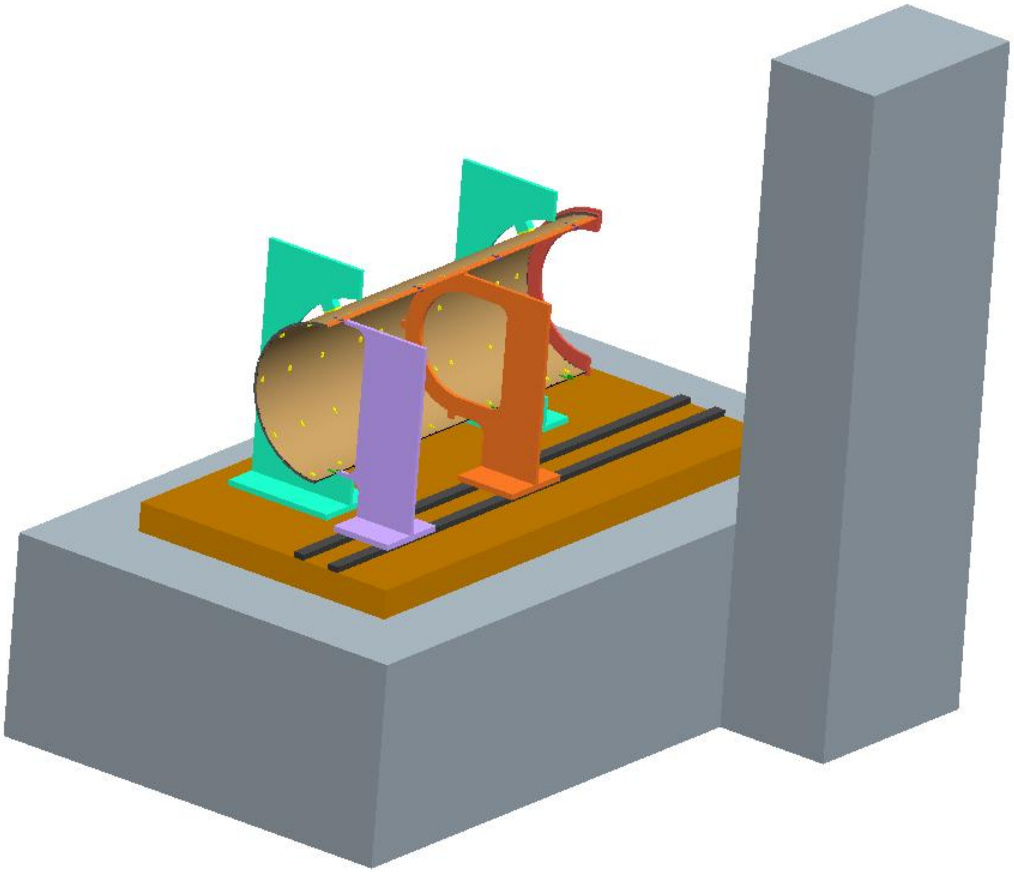
- Proposed that the components should be bonded to the half cylinder on a CMM
- CMM length 2.7m
  - Working length around 2m
- Picture shows the largest outer cylinder on the CMM
- 3 sets of carbon steel tooling cylinders have been quoted for and are within budget





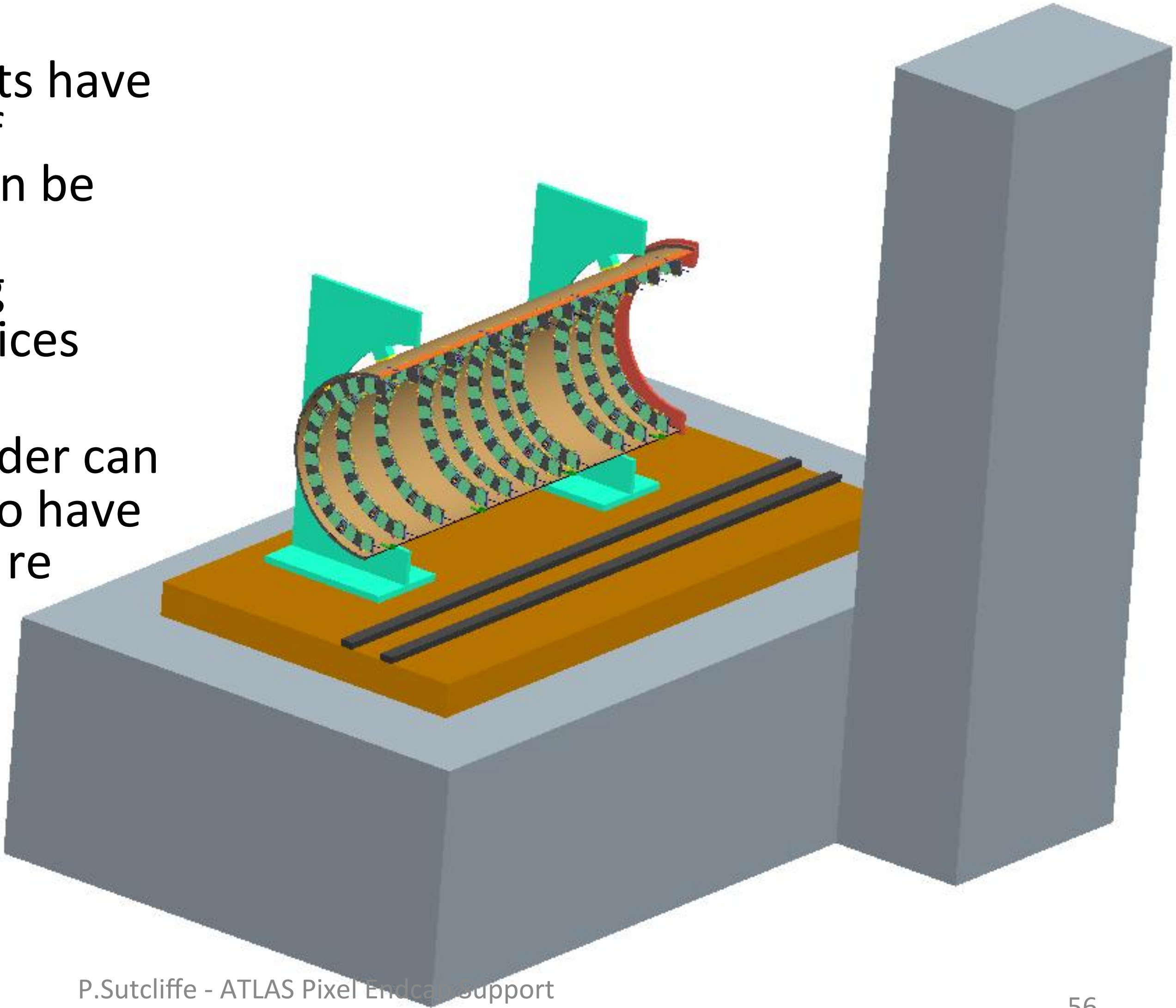
Prototype half cylinder

- Mount the half cylinder on the bed using temporary fittings on the outside
- Using various tooling fixtures the joining brackets, half ring mounting brackets and other components can be placed in position and bonded.
- This is done using a linear rail system with the tooling mounted on top.
- Throughout the assembly procedure the components can be checked and re-checked with the CMM from pre defined datum's.
- This gives a real time assessment of the components as they are assembled to check for any problems that may occur over time.



Half ring mounting

- Once the components have been added, the half cylinder assembly can be removed, with the temporary mounting system, to have services added.
- Finally, the half cylinder can return to the CMM to have half rings added and re surveyed.



Pre-prototype half cylinders

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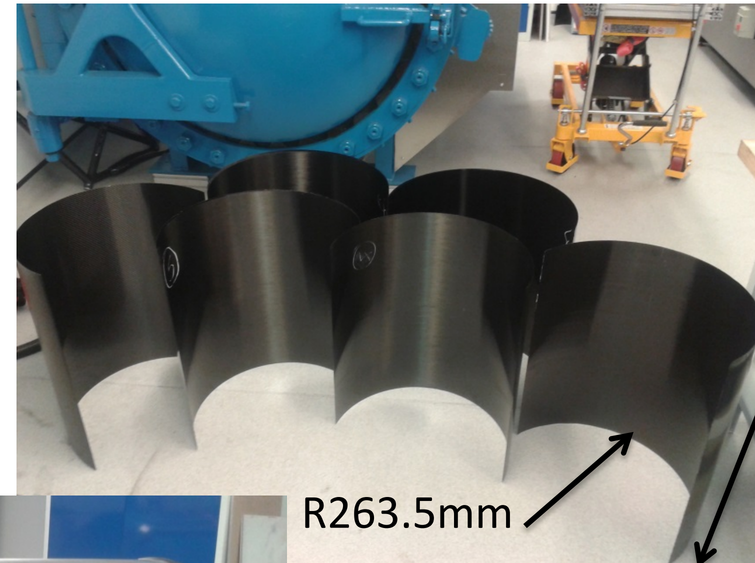
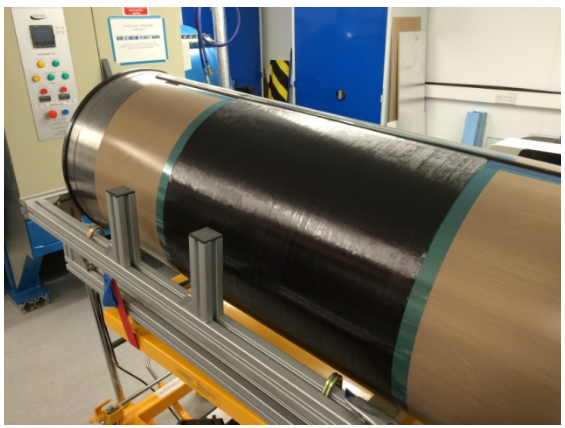
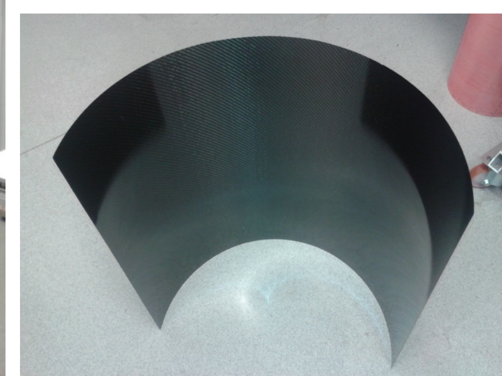
- Manufactured 5 different layups of half cylinders. Length of cylinders are around 60cm with a radius of 263.5mm
- Manufactured on a carbon steel cylinder and cured in the Autoclave (Peter Cooke) using a carbon pressure plate for uniformity.



L 600mm





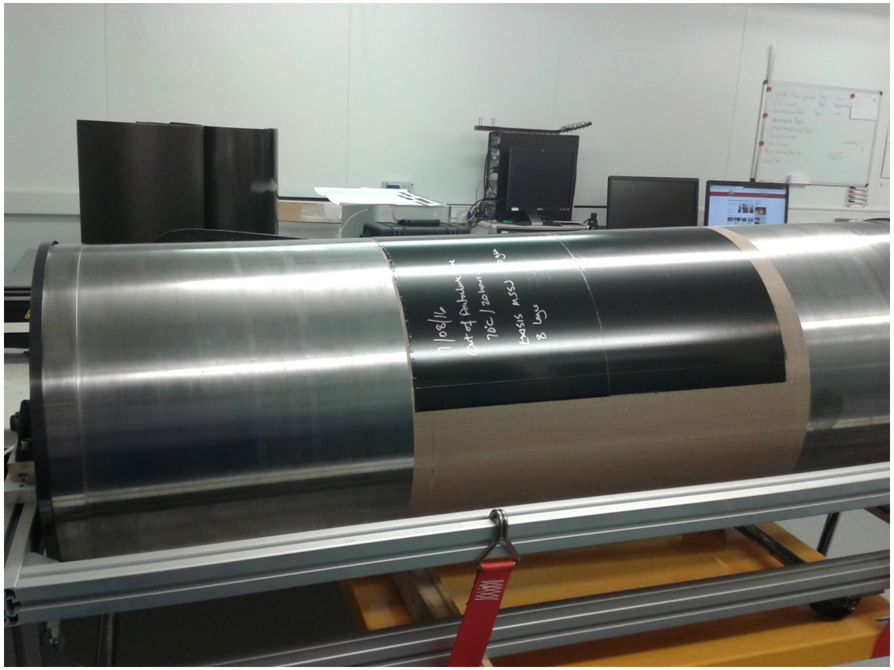
Pressure Plate

Oven curing of half cylinders

- LTM110/M55J
- Oven cure at 70C for 20 hours
- Trial to see if full size cylinders can be oven cured
  - Oven size 3m long x 2m x 2m
- Carbon has an out of freezer life of 3 days, so this does not give much time for layup.
- Peter Cooke looking for a longer out of freezer life resin.

Successful manufacture of oven cured half cylinder

- The half cylinder shows similar stiffness and dimensional accuracy to autoclave cured composite.



Integration and Assembly (Tim)

- ✓ We have past experience in survey (Genova/Milano), integration tools (Milano)
  - Part of our community (Danilo, Paolo, Claudia,.. .) has done a similar integration/test at Cern in 2006/2007 for the pixel
  - Never done a similar effort in Italy.

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Summary

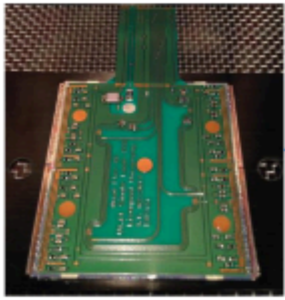
Tim's Summary

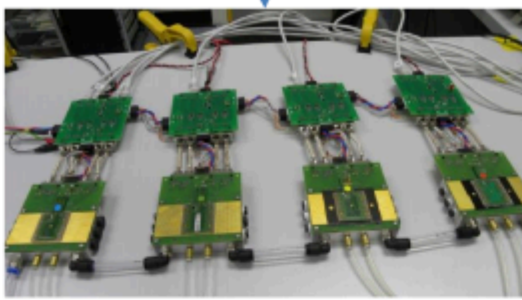
- System test sometime in 2019 ?
- Global support structures begin to arrive mid-2020
  - Should aim to have all support frames & integration **tooling** on-site by end 2019
  - Dry-assembly of global support structure
- Production on-cylinder services delivery starts Jan 2021
- Target mid-2021 as start of half-ring installation
  - Test infrastructure fully working
    - Cooling, DAQ, LV/HV, slow-control, dummy patch panels, etc
- The on-cylinder services suggests testing full module performance for phi-specific groupings of up to 19 rings(10% of final system, 3.1kW)
- During integration, limited DAQ & LV/HV will require multiple test configurations.

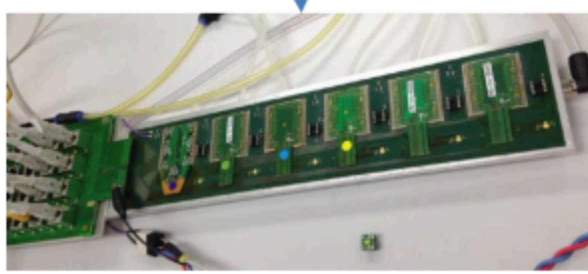
UK Deliverable

- The UK will supply one **complete** & **fully-tested** endcap pixel sub-detector to the ITk Integration team
  - Complete = An assembly of ….
    - 2 conjoined halves of …
    - 3 half-cylinders of …
    - 19 / 16 / 16 half-rings
    - together with all cabling, cooling, support structures, alignment features, interface cards, PP1's, temperature sensors, humidity, radiation, pressure, vibration, sensors, etc…etc
  - Fully-tested = Documented results for …
    - All part QC (module, half-ring, power tape, readout interconnect, cooling structure, global supports)
    - Full characterisation of the performance of every "system-level" unit
    - Results of CERN reception tests

System Test



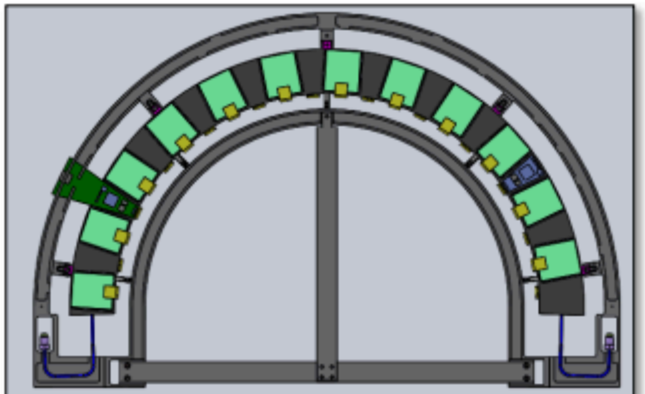


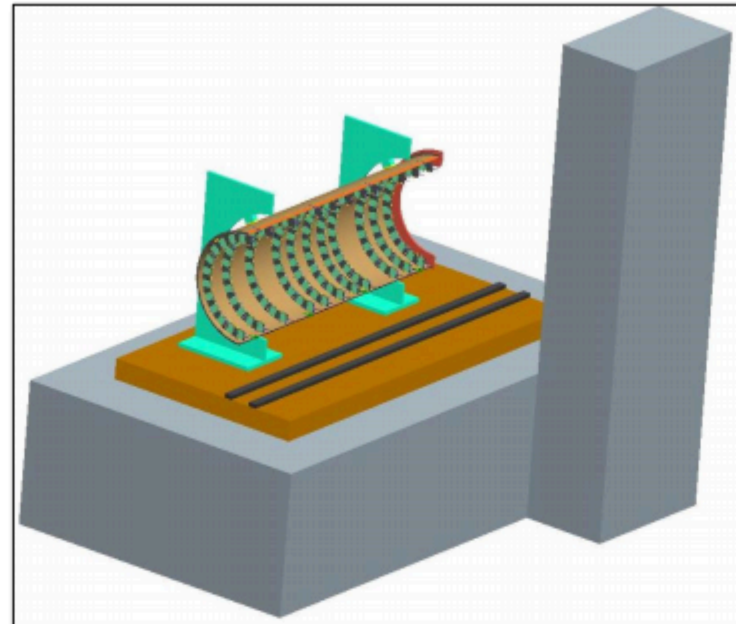


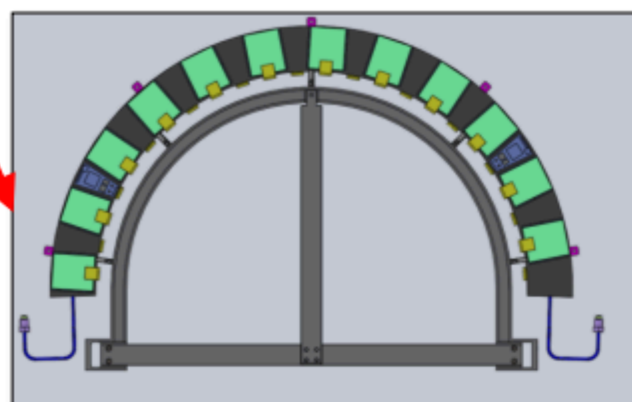
- Important to prove overall system architecture
  - Increasing 'reality'
- Building CFRP 'straight-ring'
- Target is prototype half-ring + prototype ½ cylinder, services, G&S, etc

Assembly

- Half-ring Mounting







Testing after Half-ring Insertion

- Fully assembled and characterized half rings will arrive from RAL in transport frames.
  - Confirm that no damage had been sustained in transit.
  - Visual inspection
  - Perform a sub-set of the characterization tests

- CFRP half-cylinder shells, complete with all fixations, access holes, clips, etc, will arrive from their assembly site.
  - Geometric survey
  - Mount into a support frame and populate with cooling and electrical service interconnections. The 'PP1 ends' of the services will be connected to local dummy interface panels to minimise the number of connect/dis-connect cycles during integration.

  - The functionality of all services sub-systems will be tested to ensure everything is OK.

- Half-ring Testing
  - Following half-ring insertion, the cooling tubes will be welded to the cooling services manifolds
  - Connect the interface boards on the rings to the power tapes
  - Connect the data links to each module.
  - Perform functional test in power tape groupings
    - For the cooling manifolds, we envisage having 'O' ring sealed compression fittings to close off the ends of all un-used branches. Provided these seals will successfully take > 60 bar then we would perform a quick electrical test on each half-ring as it is installed with CO_2 evaporating at 15°C.
    - The power load required to test a complete half-ring is 288 to 480 W.

Half-cylinder Integration

- Once each half-cylinder has been completed and qualified it will be integrated with its partner to form a complete cylinder and with the end supports, starting from the inner-most cylinder and working out.

- Other than the mechanical interfaces between half-cylinders, no other systems (cooling, electrical services, etc) mix two half-cylinders together at this point.
  - This system-level autonomy should result in minimal interference between half-cylinders as they are integrated together and testing should be limited to that which picks up any interconnection faults.

- As half-cylinders are integrated together, the electrical services harnesses may need to be disconnected from their half-cylinder services supports and routed through apertures in the large-Z end-flanges. As each pair of half-cylinders is integrated it will be important to check that none of these services have been damaged during their manipulation.
  - Half-cylinder support frame should allow a simple services transfer

- Test at room temperature
  - One module per tape (depending on the ring type there are 4, 5 or 6 (9, 10 or 12) modules per tape), on every tape to check for connectivity.

- Once a pair of half-cylinders are integrated together and fastened to the end-flanges the system is ready to receive the next pair of half-cylinders. The middle pair will then be integrated and tested as above and finally the outer pair.

Final System Test

- Power:
  - 236 (118) channel power supply system
- Cooling
  - If only one (two) module(s) per tape is (are) turned on then the total power of a fully populated inner half-cylinder is 1.2kW, the middle is 1kW and the outer is 1.5kW giving a combined total of 3.7kW.
- Data Transfer
  - Reading out every module of a complete half-endcap would require 342 + 384 + 480 links = 1,206
  - If we were to limit the number of modules to one per tape then there would have to be 236 DAQ channels.
- Testing
  - If time permitted, we could step through each (pair) of the modules on a tape (i.e. up to 6 configurations) to test the performance of every single module.
- This might be the kind of final test done just before shipping and again on reception at CERN.

Space & Facilities

- 82 sq.m Class 7
- 4.2 x 3.2m cold room

Spares by Craig

AWP3: Pixel Module assembly and QA (Richard)

- ***Sensor QA***
  - Sensors on wafers will be tested prior to shipping for bump-bonding: visual inspection, I-V and C V curves to confirm low current, HV breakdown and depletion voltage.
- ***Sensor production management***
- ***ASIC QA***
  - FE-IX wafers will be probed to classify chips as green, yellow, red and produce chip maps for module assembly
- ***Hybrid QA***
  - Flex hybrids will arrive fully populated and undergo visual and electrical testing.
- ***Module Assembly & QA***
  - Modules arrive at sites after bump-bonding and undergo visual inspection and readout tests on a probe station.
  - Hybrids will be glued to the modules and wire bonded to the FE-IX chips.
  - The modules will then undergo a full readout test including tuning to determine noise & threshold maps and bump-bond yields. Some fraction of modules will undergo extended testing such as long-term testing or irradiation tests.
- ***Module production management***
- ***3-D Sensor & Module QA ← under discussion***
  - 3-D sensors for the innermost layer of the barrel pixel detector will be qualified. Modules will be inspected and electrically tested. Modules may be assembled. The infrastructure required is in common with the planar endcap modules.

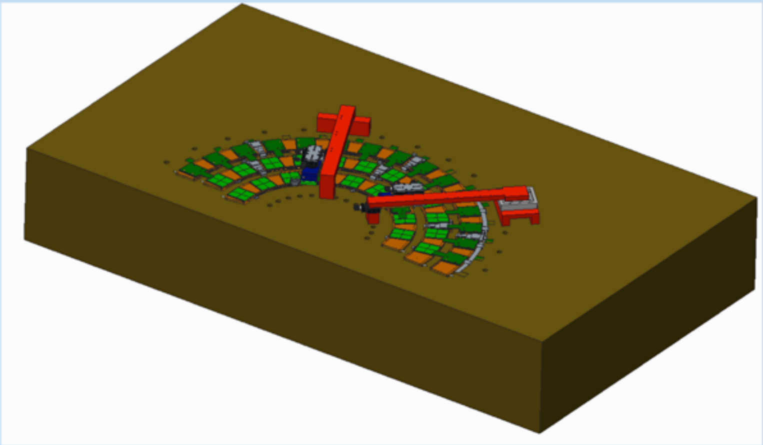
AWP6: Pixel Endcap Ring Manufacture and Assembly (Jo)

- Assembly-frame and transport-box fabrication
  - Each half-ring will be constructed and tested on an assembly and handling frame which will fit securely into a test- and transport-box
- Cooling-loop fabrication and QA
  - Pipes will be cut to length and bent to shape using bespoke jigs
  - Temporary high-pressure fittings will be attached and tested
- Bus-tape and EoS-card sourcing and QA
  - Manufactured in industry; electrically tested in institutes
- Carbon-fibe shell fabrication
  - Infrastructure exists; jigs must be designed and made before production
- Foam cutting and half-ring assembly
  - Foam-machining infrastructure exists; specialised jigs must be designed and manufactured
- Half-ring QA
  - Thermal and mechanical validation

AWP9: Pixel-Ring Module Mounting and Electrical QA (John)

Tasks:

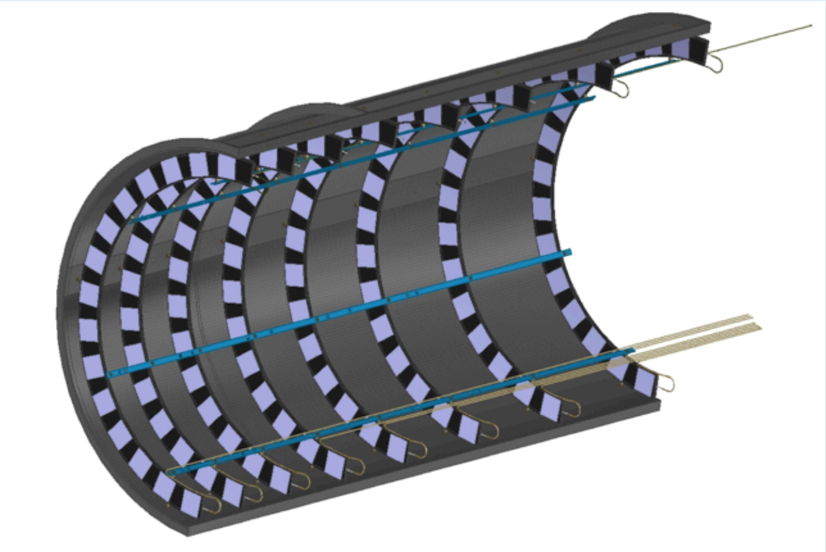
- Module and EoS-card Reception Testing
  - Will require a readout system at each site (2 foreseen)
- Half-Ring Reception Testing
  - Will require CO2 blowoff and/or low-temperature monophase cooling systems
- Module and EoS Mounting
  - Using specially-designed mounting system currently under development (will need to be duplicated)
- Electrical connections
  - Flex-tape tabs will be bent around to mate with on-disk components
  - Electrical connections will be made (eg wire bonds, tab soldering)
- Electrical QA of finished half-rings
  - System-test style readout tests
  - Rework if necessary
  - Rings passing QA will be surveyed



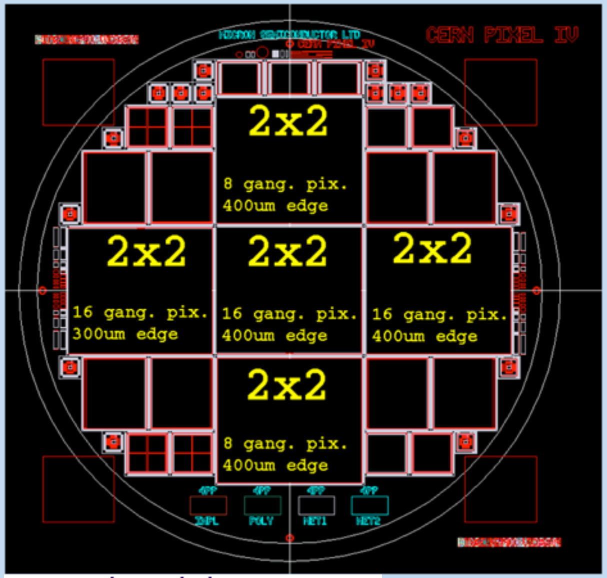
AWP10: Endcap macro-assembly (Tim & Peter)

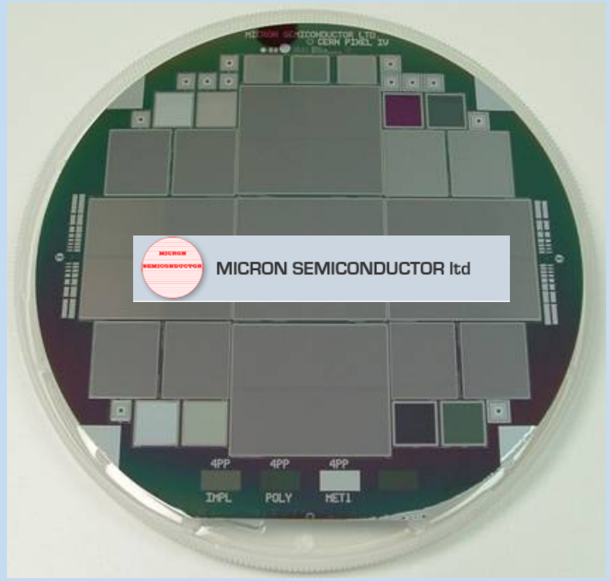
Tasks:

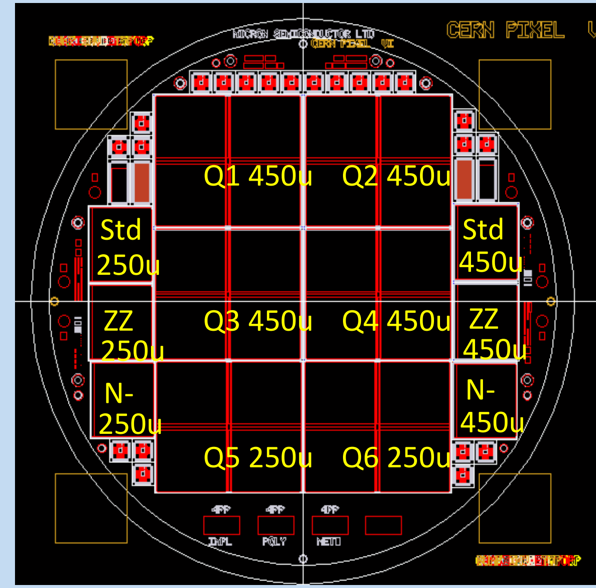
- Superstructure procurement and QA
  - Cylinders may be produced in collaboration with industry
  - Auxilliary support frames must be designed and manufactured
  - Cooling and survey equipment will be required
- Type-I service assemblies
  - Cooling tubes will be cut to length, bent to shape and connected to internal manifolds
  - Cables (supplied by industry) will be reception tested and attached to rings and superstructures
- Half-ring reception testing
- Endcap assembly and QA
  - Assembled rings will be installed into the superstructures
  - Jigs and tooling will need to be designed and manufactured
- Delivery of completed endcap to CERN
  - Including unpacking and reception testing upon arrival



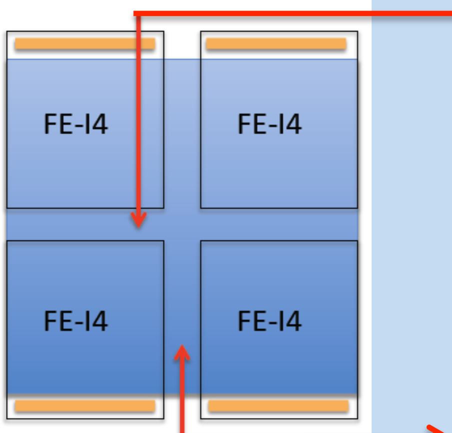
R&D WP1: Planar sensor design



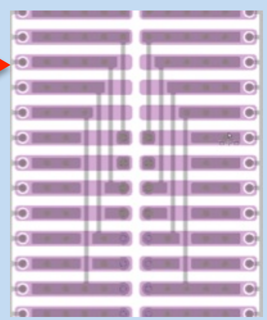




Ganged pixels keep horizontal area active

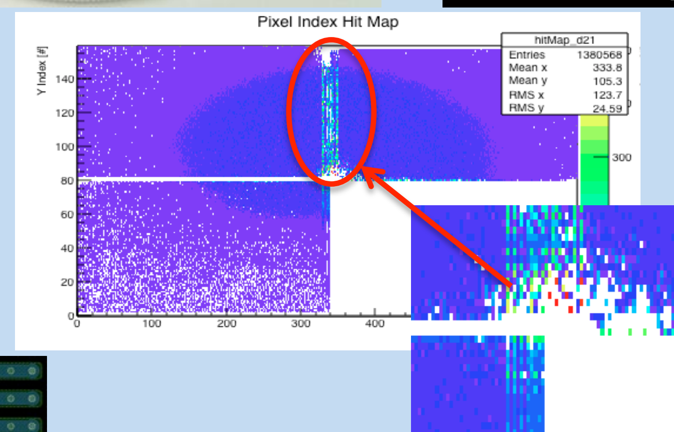


Long pixels keep vertical area active

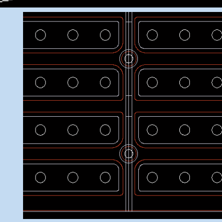


500µm 250µm

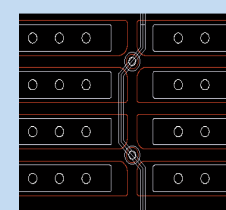
Filling the gaps



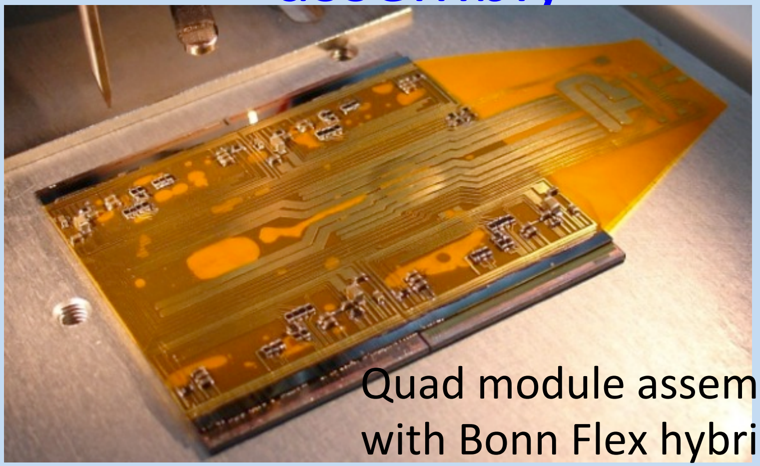
Testbeam studies



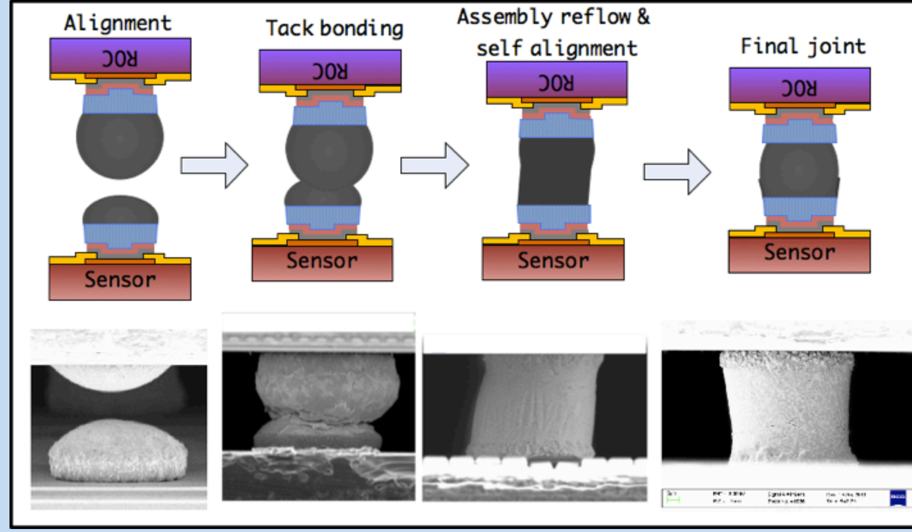
Biasing structures



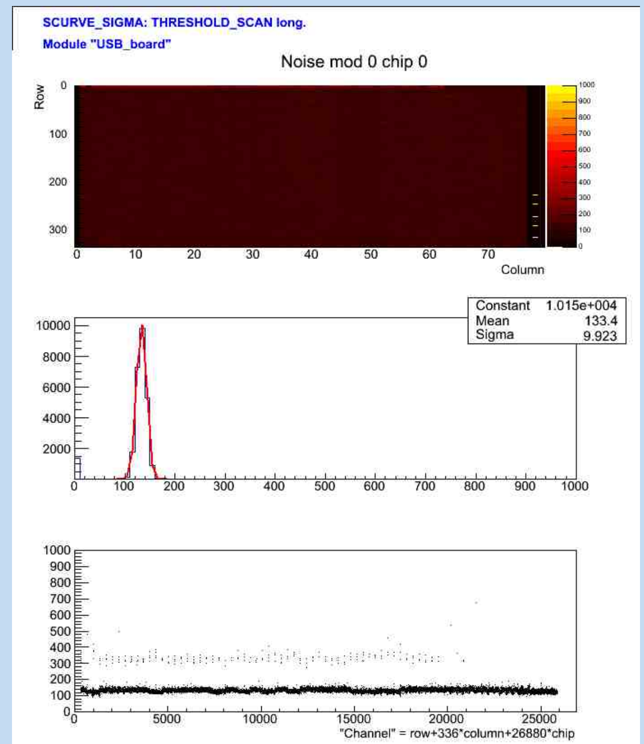
R&D WP1: Quad module assembly



Quad module assembly with Bonn Flex hybrid



FEI4: Ni/SnPb – Sensor: Ni/SnPb



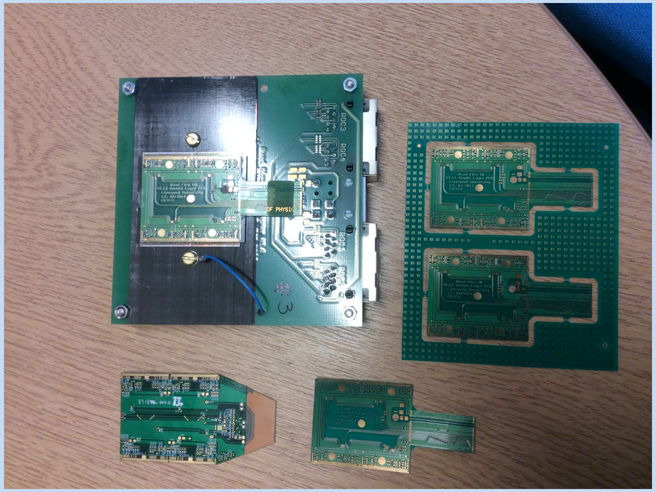
- Sensor and FEI4: UBM and flip-chip at VTT
- Full thickness modules: 700μm FE-I4 & 300μm Sensor:
- Develop solder based bump-bonding with VTT/Advacam & Cea-Leti and In based bump bonding with RAl
- Aiming for thinned modules: 100-150μm FE-I4 & 150μm sensor

- Testing with USBpix and RCE systems
- Tuning of FE-I4 chip to 1600e @100V
- Mean noise = 133e
- Noise is comparable to single chip assemblies

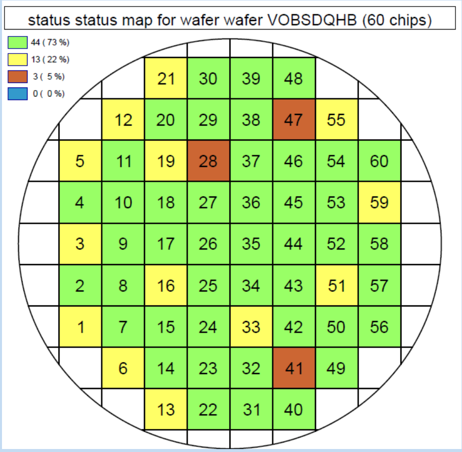
- Characterisation in testbeam

R&D WP1: Quad module assembly & FE-I4 wafer testing

- Quad module assembly
  - Hybrid designed, improvements on Bonn prototype
  - Prototype in production
  - Assembly jig designed and in production

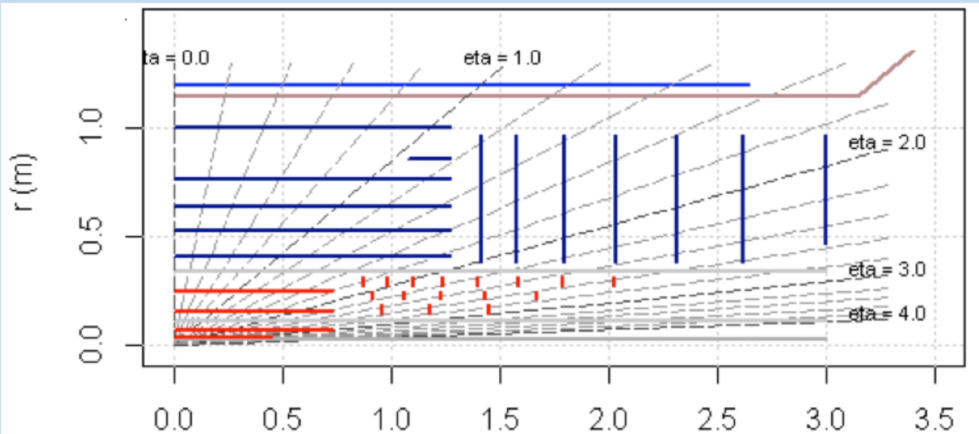


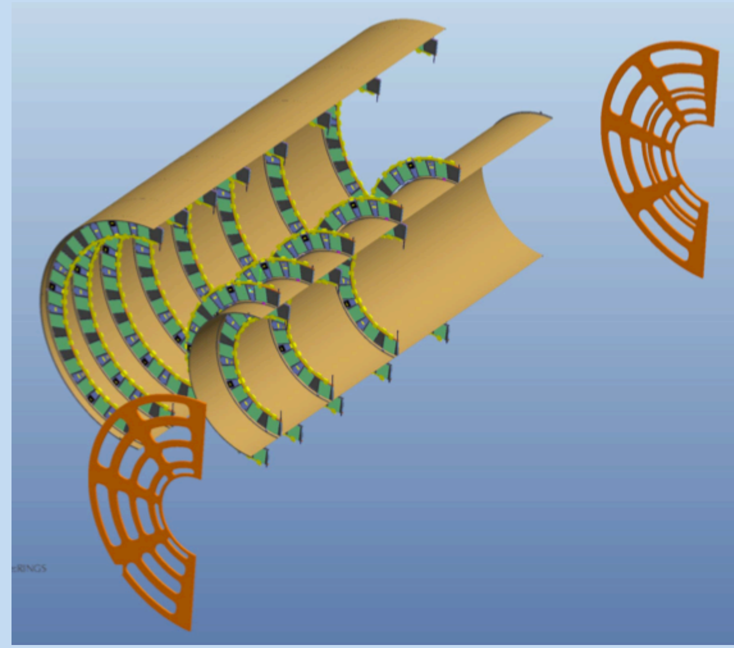
- FE-I4 wafer testing
  - Testing for FE-I4 wafers prior to distribution for UBM and dicing

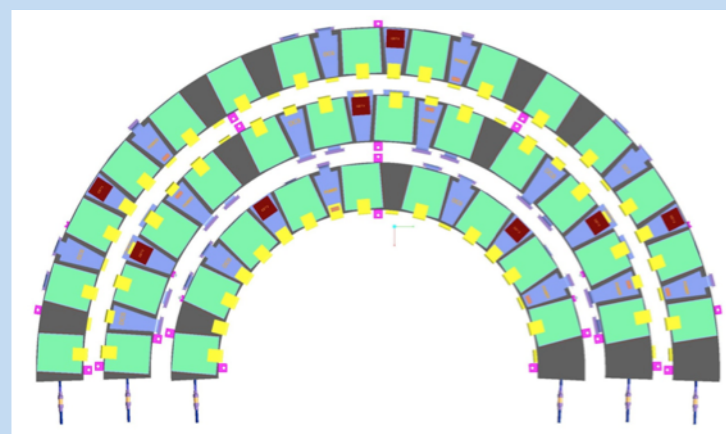


Final wafer map after regrading the blue chips
green 73% yellow 22% red 5%
Bonn: green 61% yellow 31% red 9%

R&D WP2 – Pixel Endcap Mechanics
Layout and Engineering Design: "Open Rings"







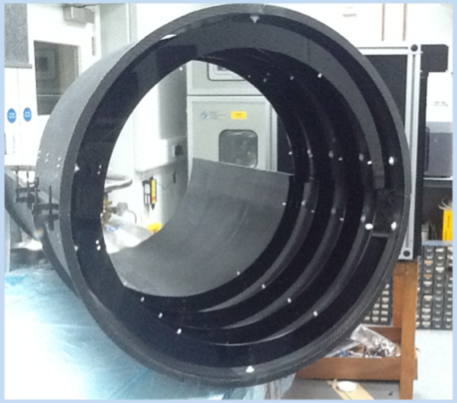
Quad modules are mounted on rings which are strategically placed in z to provide hermeticity

- More hermetic and easier to construct than Letter-of-Intent layout (LoI)
- Uses less silicon
- Performance is similar to LoI
- Flexible e.g. to high eta
- Attractive between-rings service-routing option

R&D WP2 – Pixel Endcap Mechanics

Prototyping

- First thermal-deformation measurements of prototype ring
  - Show a few tens of microns out-of-plane distortion.
    - May be due to ad-hoc supports
    - Needs repetition with increasingly realistic disk(s) and supports
- Next ring prototype manufactured
  - With bus tapes and CO2 cooling
  - Will be used with modules for system test
- Full-scale mechanical mockup started



Services, Module Mounting

- Bus tape prototypes manufactured
  - 5 quads per tape; innermost disk
- EoS card design:
  - Split functionality being developed to accommodate ring design
- Module mounting concept being developed – see figure
  - In coordination with disk engineering design