WP4
Automated Precision Assembly Procedures

Lutz Feld
RWTH Aachen
Susanne Kühn
Uni Freiburg

1st Project Meeting '*Enabling Technologies for Silicon Microstrip Tracking Detectors at the HL-LHC*'
Mainz, 28. Feb 2013

From the proposal

- many modules needed (order 20’000 per exp.)
- double sided modules for L1 triggering need precise front-to-back alignment
- automated precision placement of sensors is needed everywhere
- explore assembly and QA procedures for single sided and back-to-back modules which allow high throughput and yield at the required accuracy
- deliverable will be a documentation of the developed procedures and possibly results from actual assembly exercises

	Aachen	Berlin	DESY	Freiburg	Hamburg	Karlsruhe
assembly procedures	X	X	X	X	X	

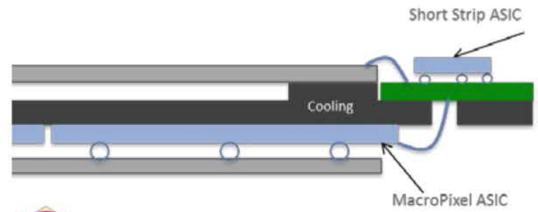
Questions for today

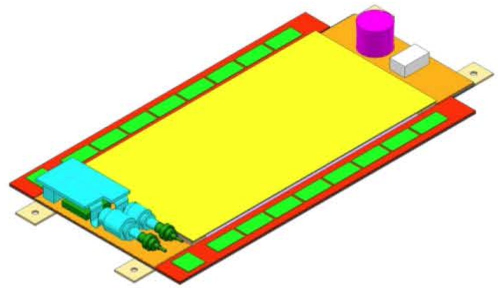
- who is interested to work on this subject?
- what do ATLAS and CMS need?
- what are the subjects of common interest?
- which questions do we want to answer within this Alliance project?
- how do we organize the work?

THE CMS SIDE

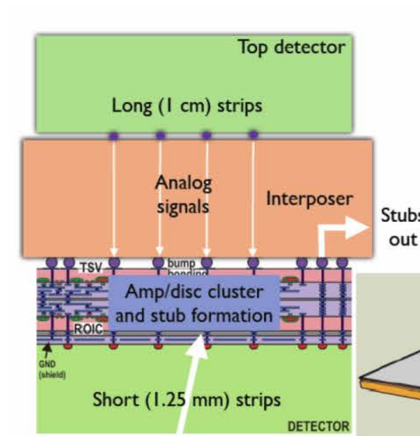
Three Front-End Module Types

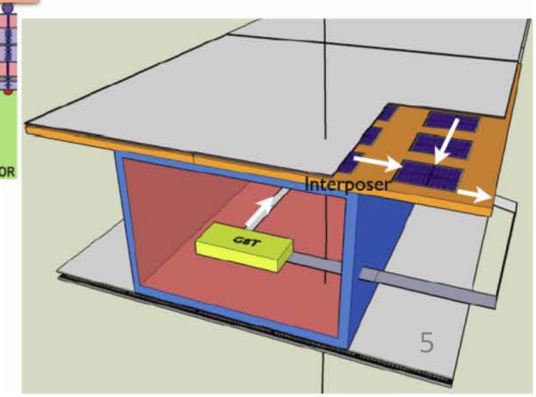
2: PS Modules



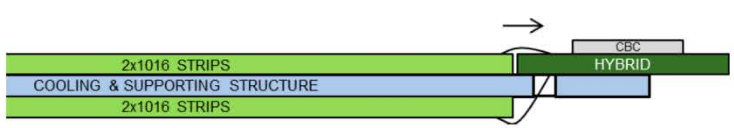


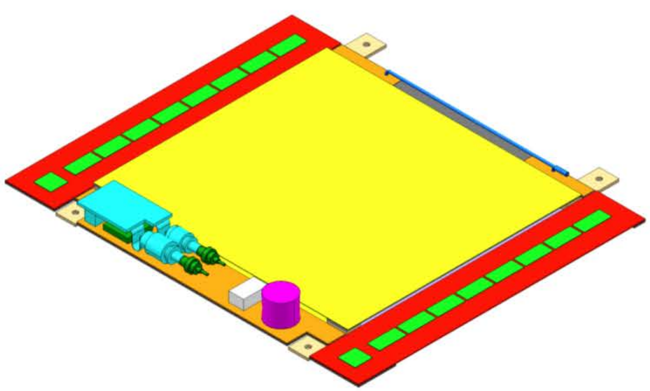
3: VPS Modules



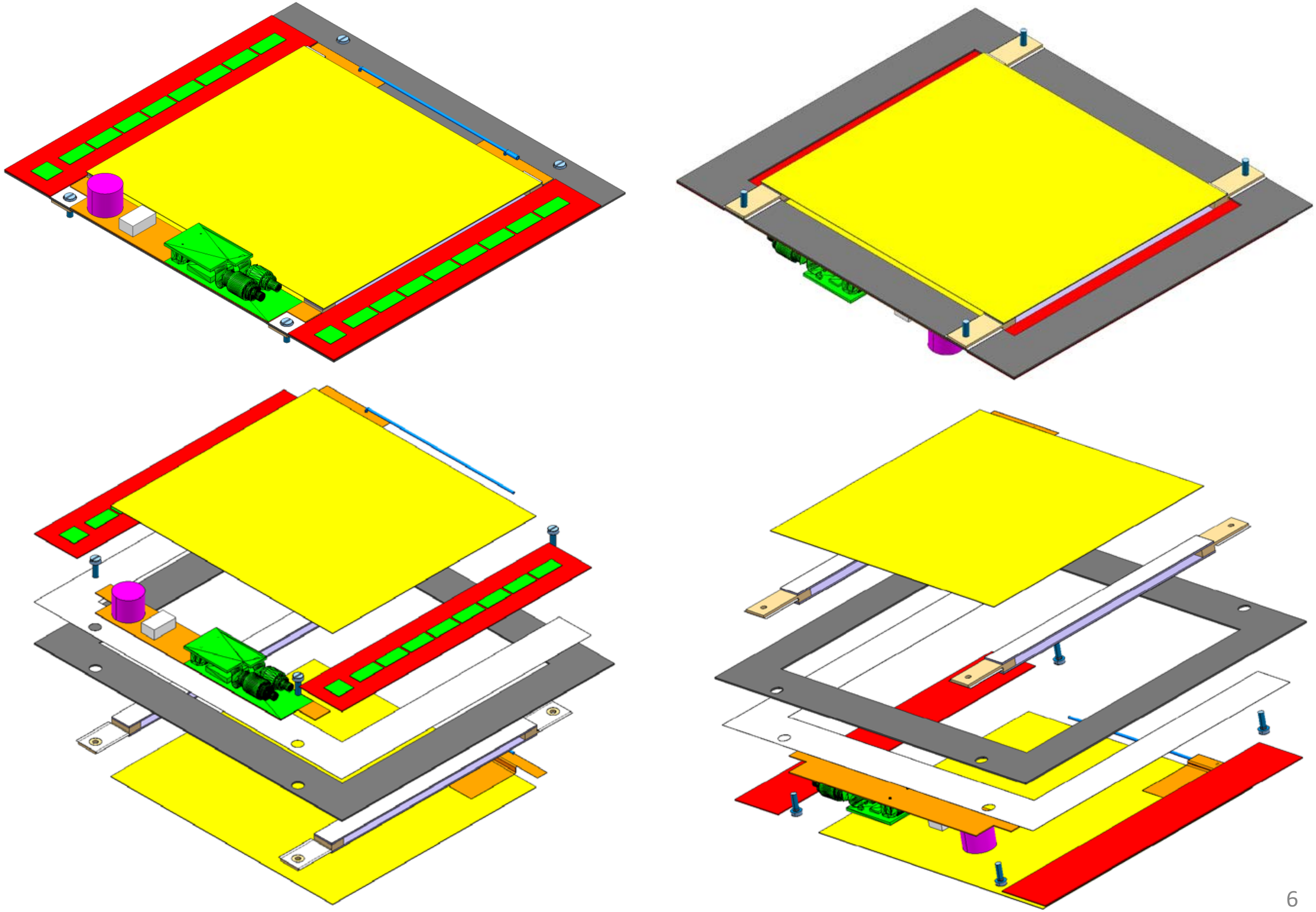


1: 2S Modules



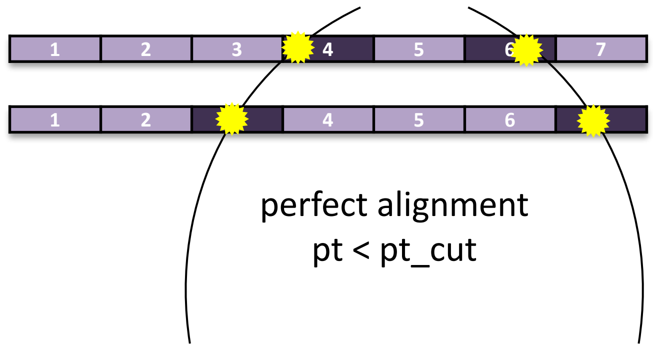


Focus on ‘2S’ modules

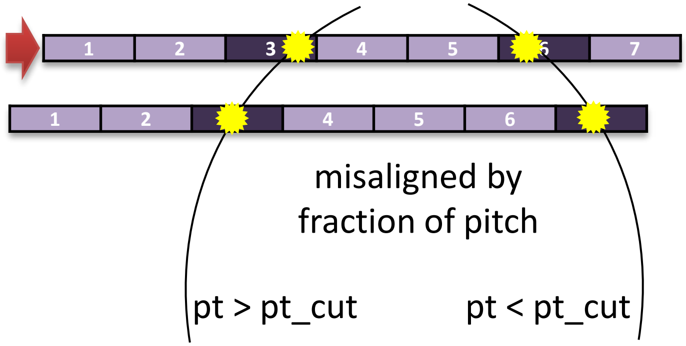


Why internal alignment matters

- pt is measured through offset of hits in two layers
  - → misalignment will cause systematic error on pt measurement
  - → sign of error depends on charge sign of particle
  - → trigger turn-on off-set from nominal, charge asymmetry



- internal misalignment cannot be corrected through track based alignment since hit correlation can only be shifted by multiples of pitch and it is unclear if re-programming of ASIC is possible / feasible



- systematic misalignment (e.g. due to assembly) will lead to global trigger charge asymmetry
  - → offline cuts need to be hard enough (i.e. trigger is less selective)
- random misaligment will still lead to trigger inefficiency and trigger rate increase

→ requirements on internal module alignment should be well understood

pt measurement error

From the drawing:

$$\frac{r_2/2}{R} = \cos\alpha$$

$$\frac{r_1/2}{R} = \cos\left(\alpha + \Delta\varphi\right)$$

$$\rightarrow \quad \frac{r_1/2}{R} = \cos\alpha\cos\Delta\varphi - \sin\alpha\sin\Delta\varphi$$

$$= \frac{r_2}{2R}\cos\Delta\varphi - \sqrt{1-\left(\frac{r_2}{2R}\right)^2}\,\sin\Delta\varphi$$

$$\rightarrow \quad r_2\cos\Delta\varphi - r_1 = \sqrt{\left(2R\right)^2 - r_2^2}\,\sin\Delta\varphi$$

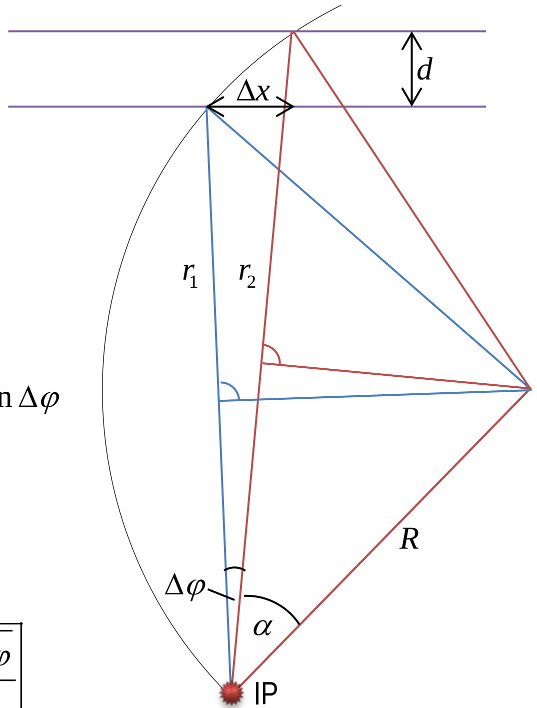
$$\rightarrow \quad R^2 = \frac{r_1^2 + r_2^2 - 2r_1r_2\cos\Delta\varphi}{4\sin^2\Delta\varphi}$$

$$\rightarrow \quad \boxed{p_t = qBR = qB\frac{\sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos\Delta\varphi}}{2\sin\Delta\varphi}}$$

In natural units with $B = 3.8\mathrm{T}$:

$$\rightarrow \quad p_t\left[\mathrm{GeV}\right] = \frac{cB}{10^9}\frac{\sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos\Delta\varphi}}{2\sin\Delta\varphi}$$

$$\rightarrow \quad \boxed{p_t\left[\mathrm{GeV}\right] \approx 0.57\frac{\sqrt{r_1^2 + r_2^2 - 2r_1r_2\cos\Delta\varphi}}{\sin\Delta\varphi}}$$



Typical values:

$$r_1 \approx r_2 \approx r \approx 0.5\mathrm{m}$$

$$d = r_2 - r_1 \approx 1\mathrm{mm}$$

$$\Delta x \approx \mathrm{pitch} \approx 100\,\mu\mathrm{m}$$

$$\rightarrow \quad \Delta\varphi \approx \frac{\Delta x}{r} \approx 2\cdot 10^{-4}$$

Approximations:

$$\sin\Delta\varphi \approx \Delta\varphi \qquad \cos\Delta\varphi \approx 1$$

$$\Delta\varphi \approx \frac{\Delta x}{r}$$

$$\rightarrow \quad p_t\left[\mathrm{GeV}\right] \approx 0{,}57\frac{\sqrt{r_1^2 + r_2^2 - 2r_1r_2}}{\Delta\varphi} = 0.57\frac{d}{\Delta\varphi}$$

$$\rightarrow \quad \boxed{p_t\left[\mathrm{GeV}\right] \approx 0.57\frac{r\,d}{\Delta x}}$$

Error on p_t measurement:

$$\delta p_t \approx 0.57\frac{r\,d}{\left(\Delta x\right)^2}\cdot\delta\left(\Delta x\right)$$

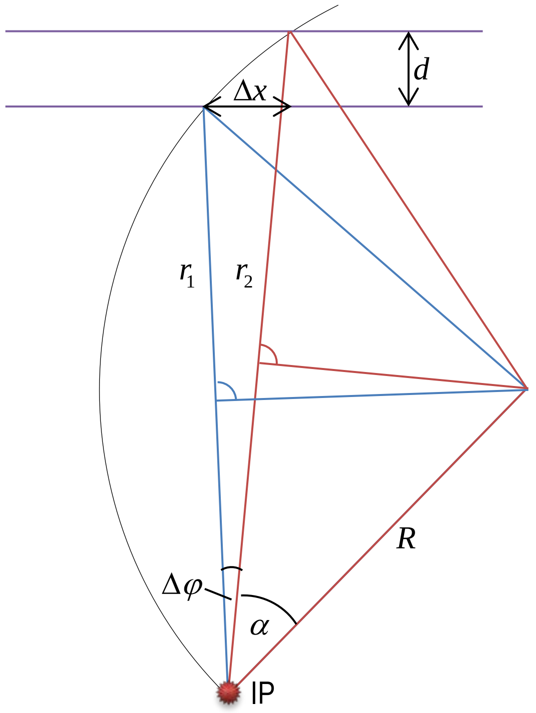
$$\rightarrow \quad \delta p_t \approx \frac{p_t^2}{0.57\,r\,d}\cdot\delta\left(\Delta x\right)$$

$$\rightarrow \quad \boxed{\frac{\delta p_t}{p_t} \approx \frac{p_t\left[\mathrm{GeV}\right]}{0.57\,r\,d}\cdot\delta\left(\Delta x\right)}$$

Required internal alignment accuracy

Error on p_t measurement:

$$\boxed{\frac{\delta p_t}{p_t} \approx \frac{p_t\,[\mathrm{GeV}]}{0.57\,r\,d} \cdot \delta(\Delta x)}$$



Using $r = 0.5$ m and $d = 1$ mm:

$$\rightarrow \quad \frac{\delta p_t}{p_t} \approx \frac{p_t\,[\mathrm{GeV}]}{285\ \mu\mathrm{m}} \cdot \delta(\Delta x)$$

Assuming pitch of 90 μm and binary read-out: $\delta(\Delta x) = \sqrt{2}\,\frac{90\ \mu\mathrm{m}}{\sqrt{12}} = 37\ \mu\mathrm{m}$

$$\rightarrow \quad \frac{\delta p_t}{p_t} \approx 0.13\,p_t\,[\mathrm{GeV}]$$

At $p_t = 2$ GeV we obtain 26% error of the p_t measurement - for perfect internal alignment.

At $p_t = 2$ GeV the displacement of the hits in the two layers is $\Delta x \approx 0.57\,\frac{r\,d}{p_t} = 142.5\ \mu\mathrm{m} \approx 1.6 \times \mathrm{pitch}$

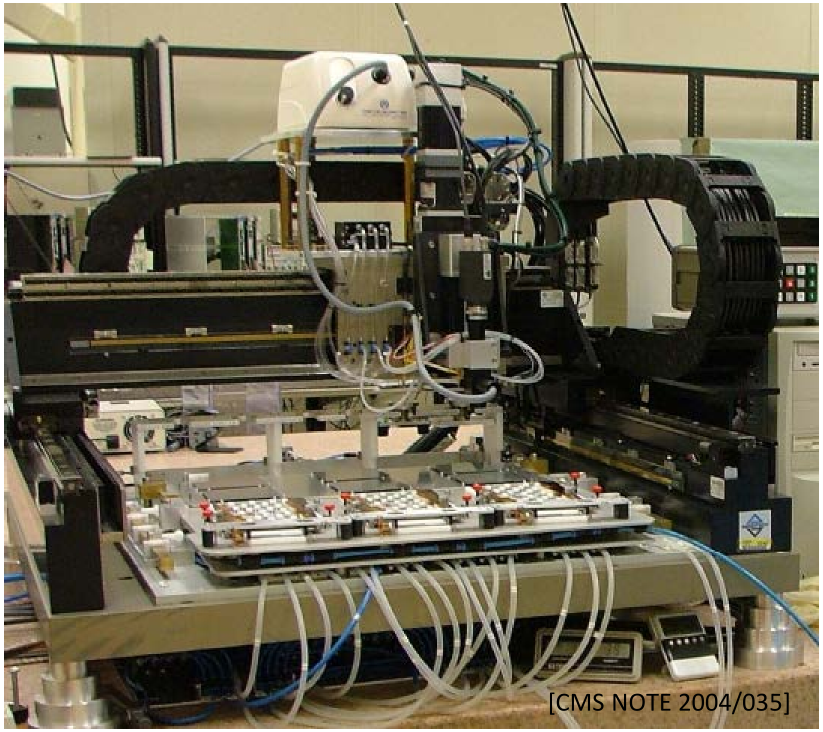
An internal alignment off-set will cause a systematic shift of the p_t measurement.
In order to limit the systematic shift to 10% we need an internal alignment accuracy of

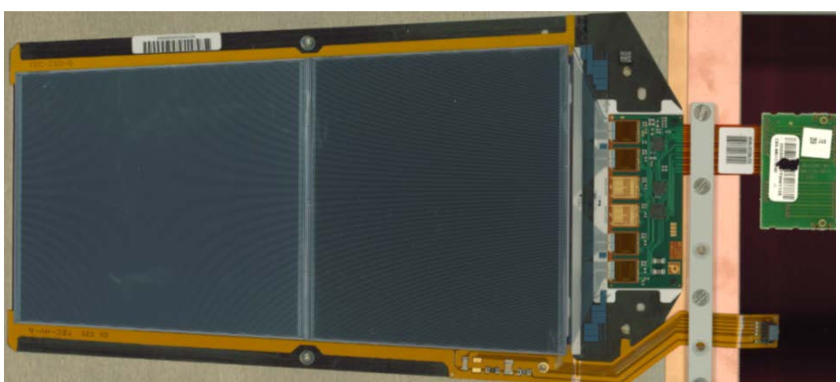
$$\delta(\Delta x) \approx \frac{\delta p_t}{p_t}\,\frac{0.57\,r\,d}{p_t\,[\mathrm{GeV}]} = 14\ \mu\mathrm{m}$$

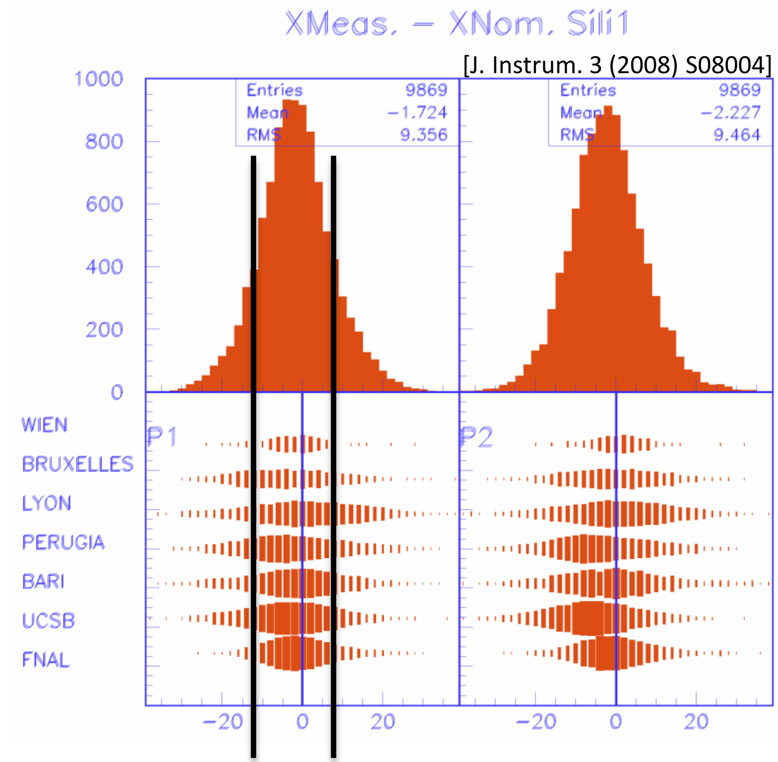
N.B.: this is not a gaussian sigma but a limit (may be taken to be 3σ)

limit error on pt measurement to 10%
→ need an internal alignment accuracy about 14 μm (not a CMS spec!)

CMS Gantry Module Assembly







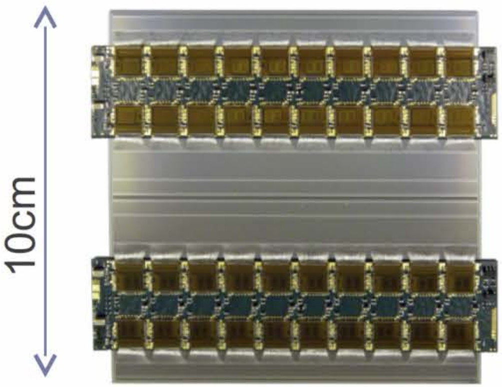
$\sigma \approx 10\ \mu\text{m}$

accuracy $\approx 20 \ldots 30\ \mu\text{m}$

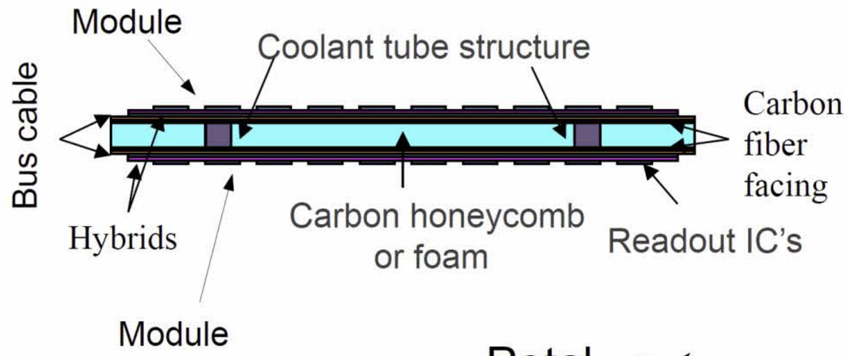
THE ATLAS SIDE

ATLAS Stave and Petal Concept

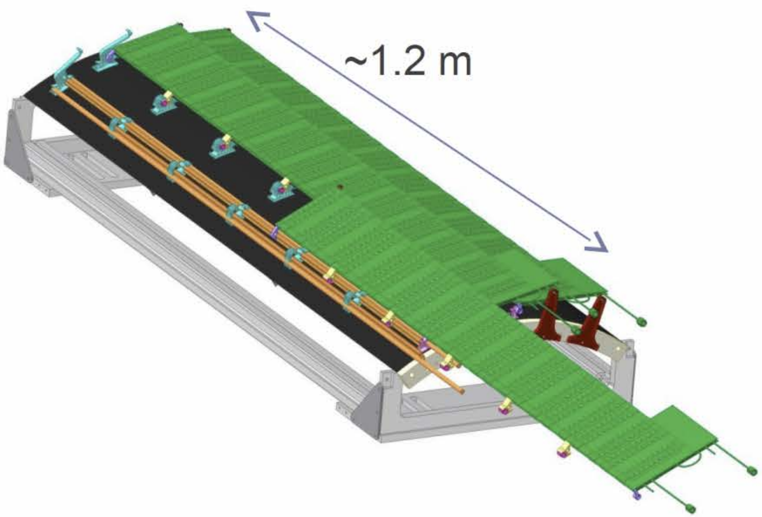
Barrel module



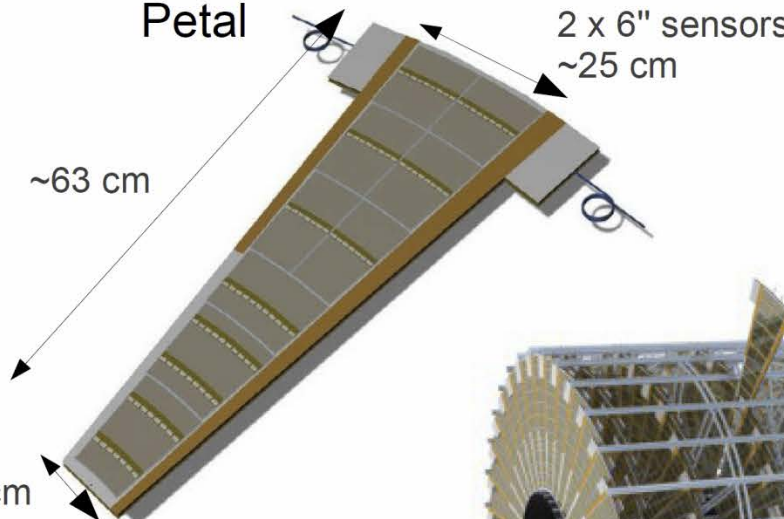
Double sided Stave



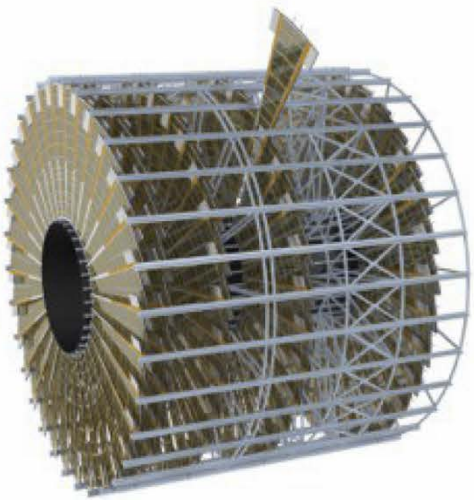
Staves mounted on global support structure



Petal



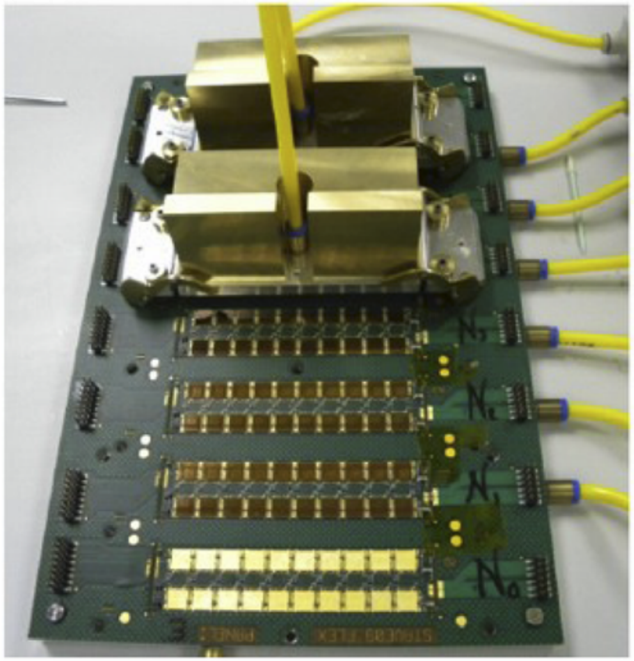
Endcap structure



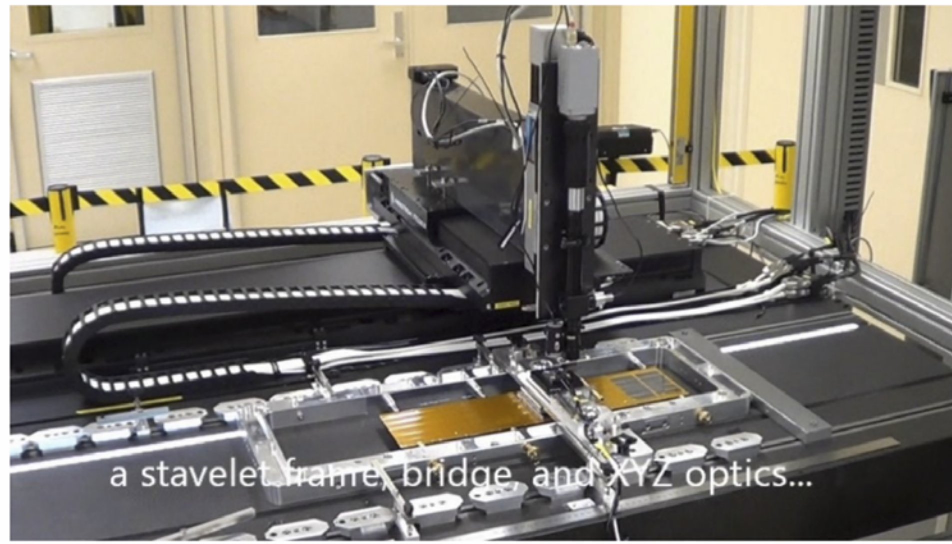
Prototyping and Alignment

Prototyping with focus on mass production:

Panel of hybrids



Test of stave assembly manually and with gantry



Alignment:
– Modules on Staves/Petals, two-sided and with up to 1 m length
– Staves/Petals on support structure
– Support structure itself

ATLAS SCT Endcap Modules

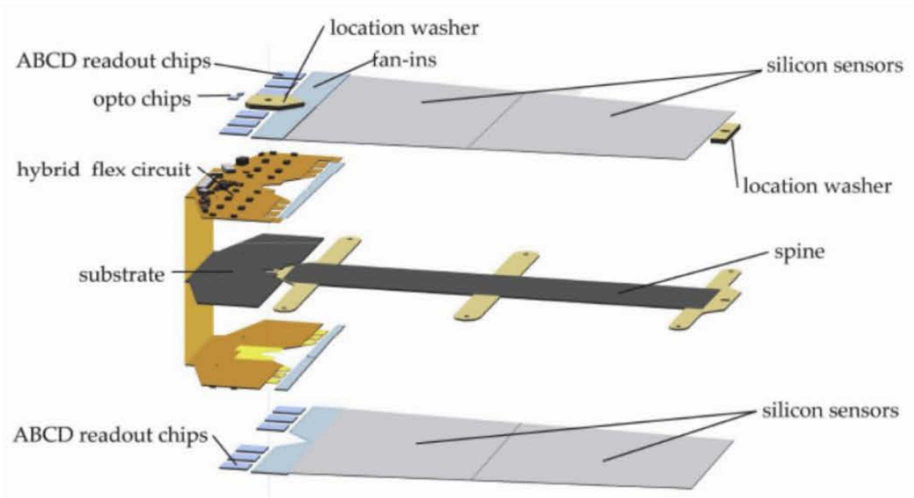
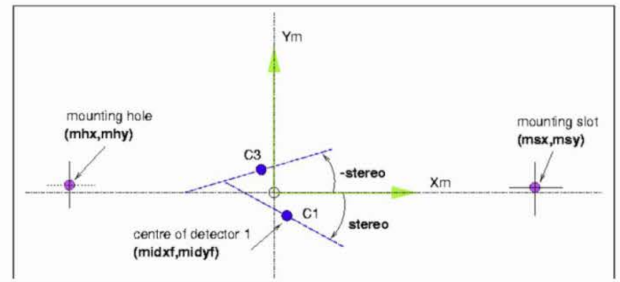


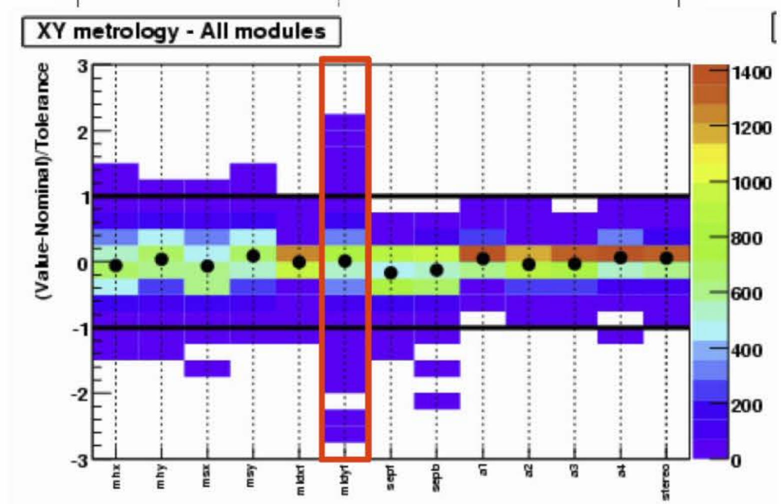
Figure 1.1. Exploded view of an SCT end-cap module showing the different components.

Manual production allows precision with tolerance of 5 µm (out of 2380 modules)

SCT Barrel detectors were also assembled with module mounting robot for module-to-disk assembly

Total yield in 2-years production (including 15 % spares) about 93 %





Parameter (unit)	Tolerance	Nominal values			
		Outer	Middle	Short-mid	Inner
mhx (mm)	0.020	-78.136	71.708	41.764	45.060
mhy (mm)	0.020	0.000	0.000	0.000	0.000
msx (mm)	0.100	62.244	-66.672	-96.616	-34.320
msy (mm)	0.020	0.000	0.000	0.000	0.000
midxf (mm)	0.010	0.000	0.000	0.000	0.000
midyf (mm)	0.005	-0.040	-0.053	-0.652	0.000
sepf, sepb (mm)	0.010	61.668	59.900	*	*
a1 - *a4* (mrad)	0.130	0.000	0.000	*	*
stereo (mrad)	0.130	-20.000	-20.000	-20.000	-20.000

[ATL-INDET-PUB-2006-007]

Conclusion on assembly accuracy

- 5 µm back-to-back accuracy is feasible with
  - elaborate and complex jigs
  - optical survey
  - transparent alignment marks
  - fixation of both sensors while glue cures
  - temperature control (aluminium: 23 µm/(m.K))

- gantry type assembly procedure
  - achieved accuracy on one side: 20-30 µm
  - back-to-back accuray will at best be slightly worse

Subjects of common interest

- precise automated placement of sensors
  - lessons from the past
    - which procedures have been followed?
    - what precision has been reached?
    - what where the dominant error sources?
    - what assembly speed has been achieved?
  - current plans for ATLAS and CMS
  - open issues
- gluing procedures, choice of glue, co-curing
- metrology (module alignment, front-to-back?)
- rework procedures
- options for mass/automated production
- …