UT TDR Summary

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Participants

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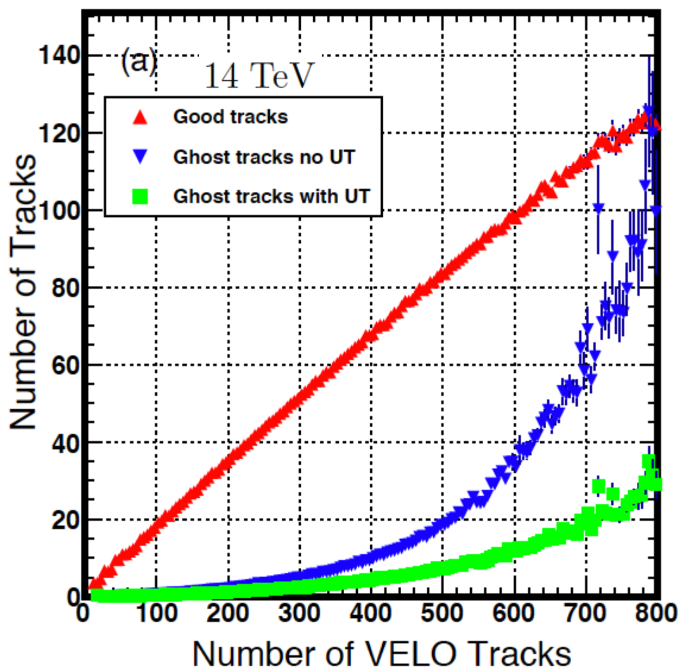
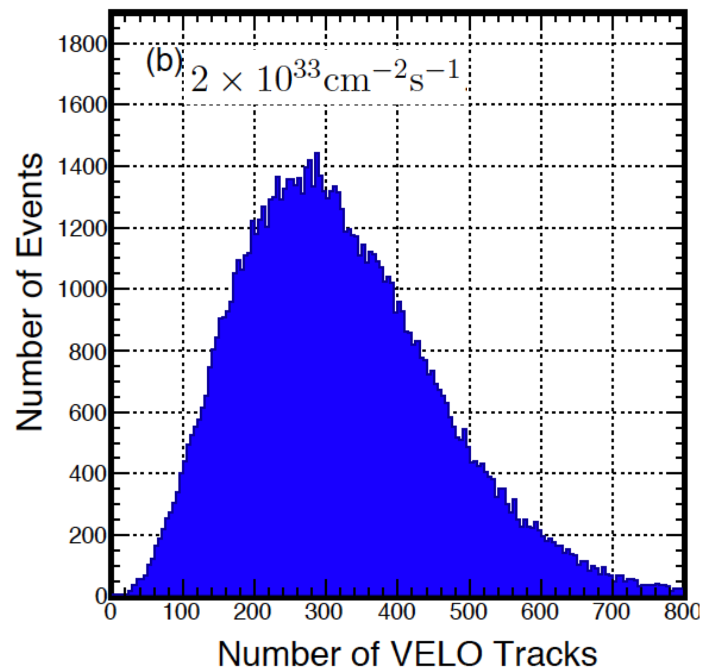
Current TT uses

- Finds K_s & Λ about 2x those in VELO
- If used, improves S/B: in $B_s \rightarrow D_s^+ \pi^+ \pi^- \pi^-$, with $D_s \rightarrow K^+ K^- \pi^+$, B/S 12.2%→8.4% requiring that all 6 tracks have at least 3 TT hits
- If tracks have TT hits mass resolutions are improved, e.g. on Υ, by 25%
- Ghost are also reduced if TT is used, e.g. measurements of $W^\pm$ require TT hits
- For upgrade: 40 MHz read out requires fully replacing TT; also occupancies & rad damage would be excessive

UT Requirements

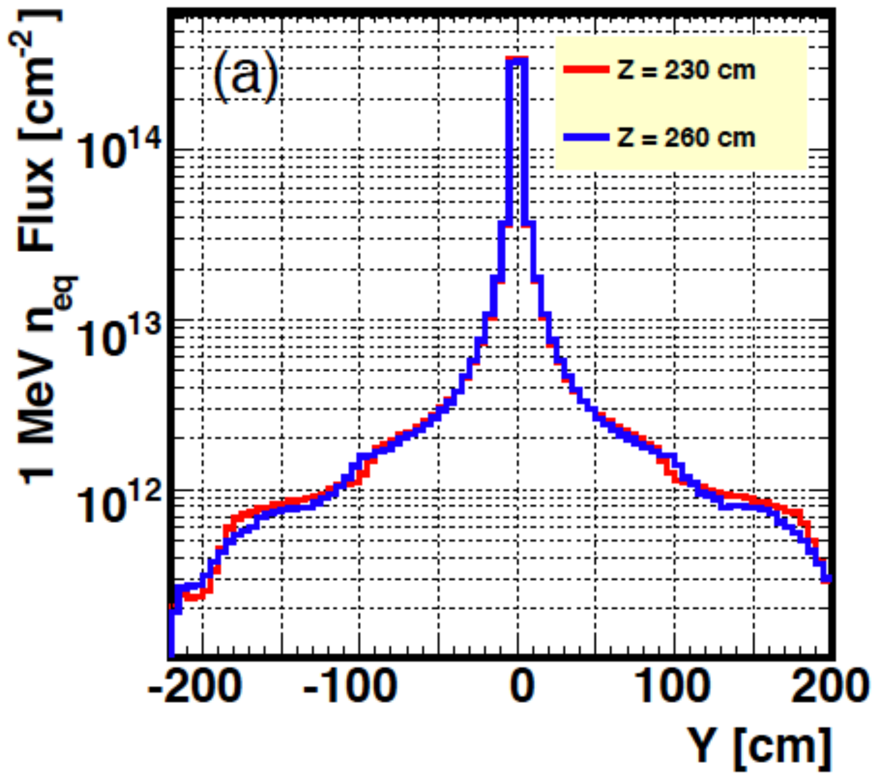
- Must be efficient, >99.0% everywhere within the detector acceptance. Then having 3/4 hits gives a per track efficiency of >99.9%
- With this efficiency Can use in trig to speed up forward tracking, & allows for efficient ghost track rejection



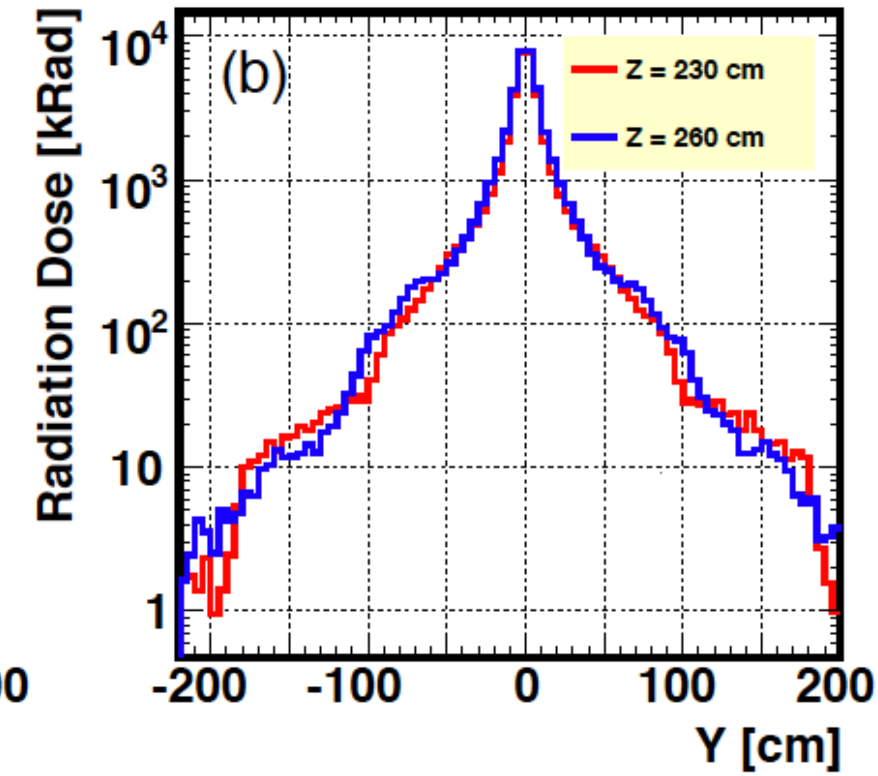


Radiation

Fluence



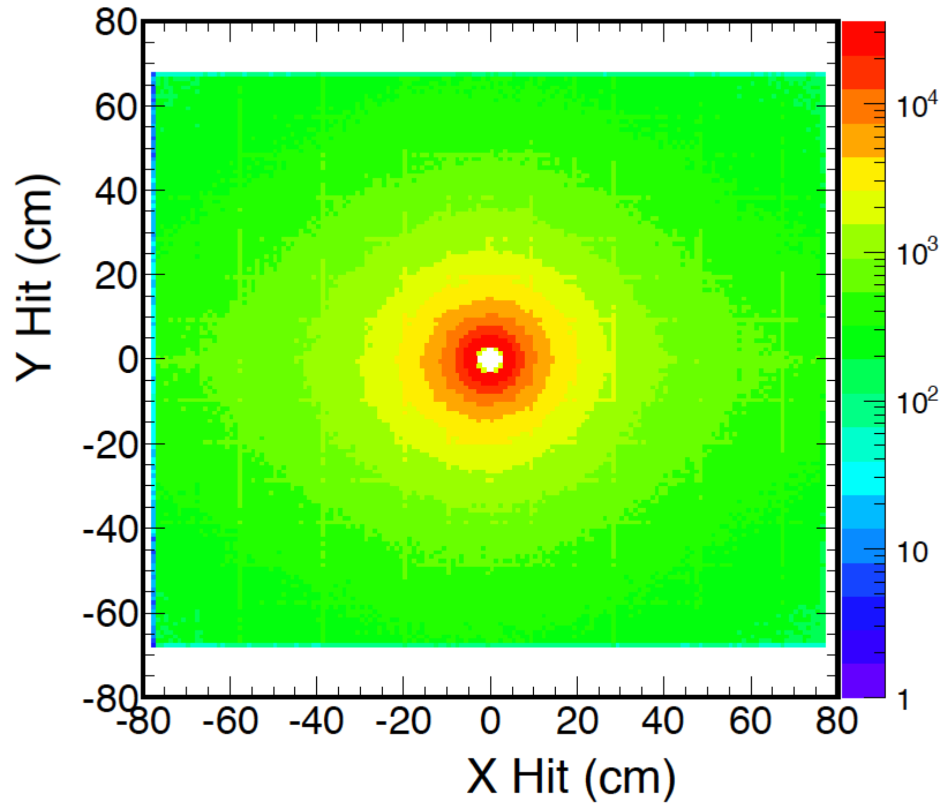
Dose



- X=0, shows the highest radiation slice

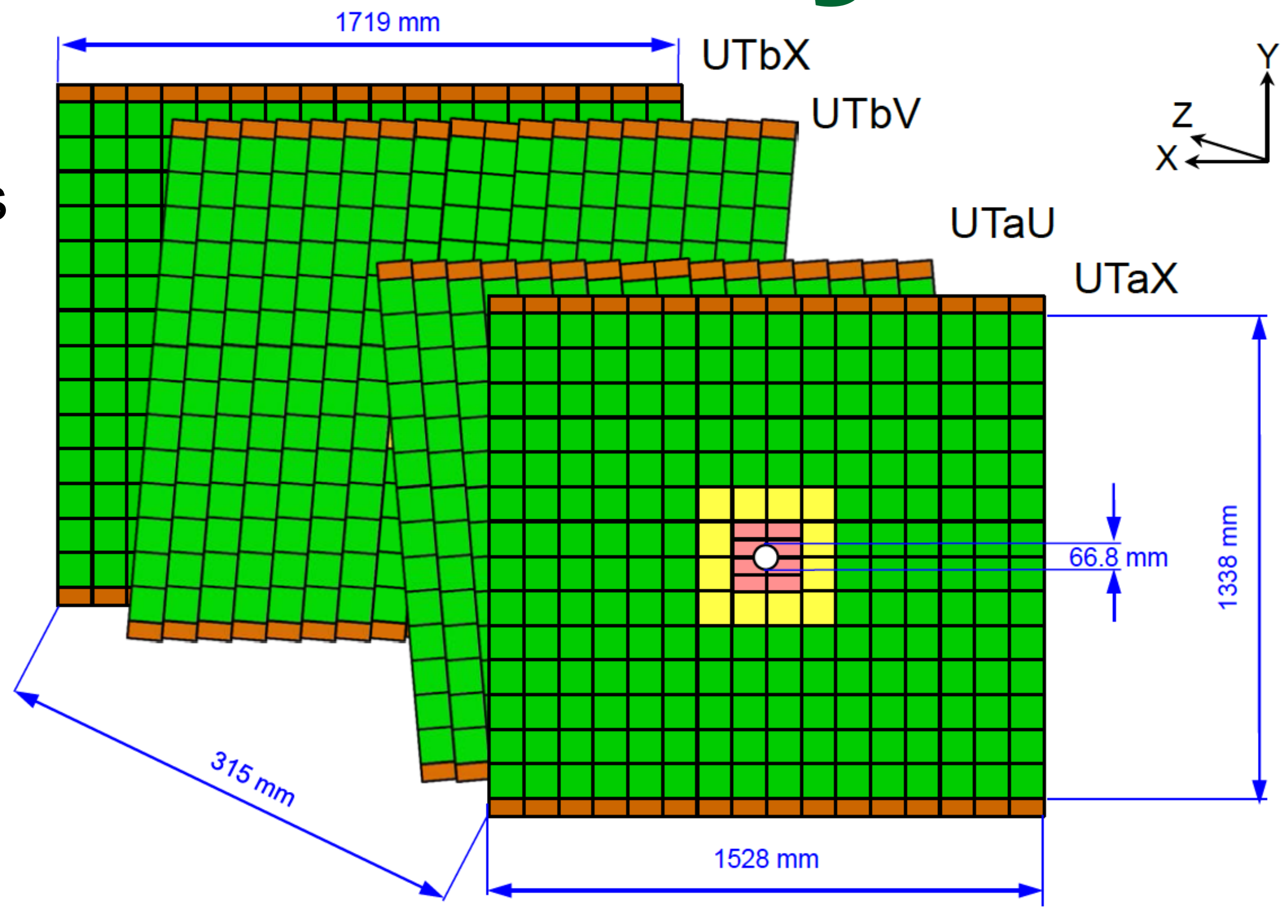
Occupancy

- Highest dose region corresponds to highest occupancy
- Must handle read out rate
- Many specific requirements in each TDR section



Geometry

- Z locations same as TT
- Each green box is a 190 μm pitch, 250 μm thick, 10x10 cm^2 silicon sensor individually read out
- Yellow are 95 μm pitch
- Pink are 85 μm pitch 10x5 cm^2

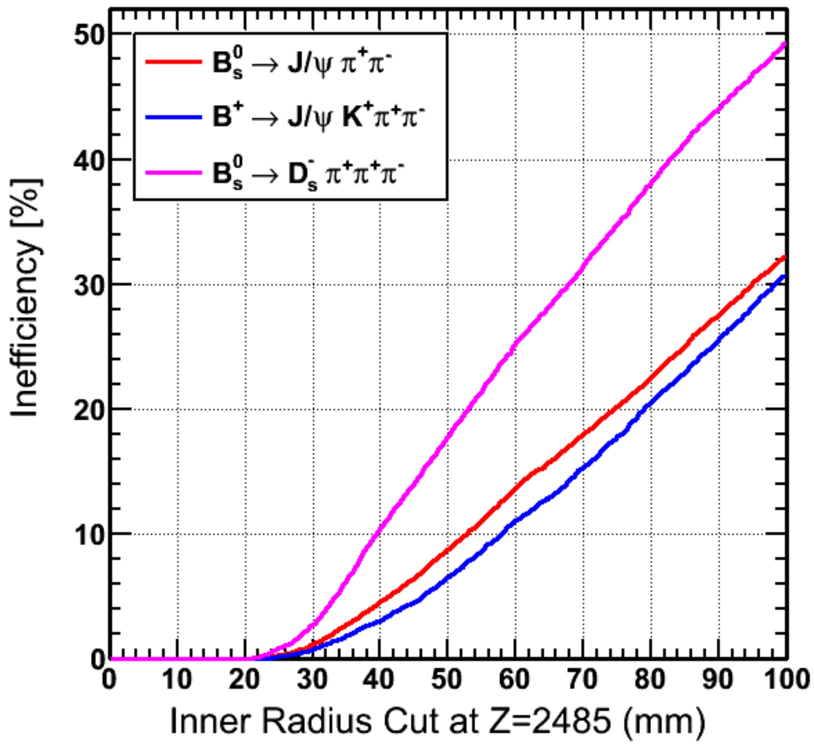


UTaU and UTbV are 5° stereo

Beam pipe hole

- Physical hole diameter is 2 x 33.4 mm for physical hole in sensors. Includes space for beam pipe wrapping with kapton & pyrogel as designed by Kaan Vatansever
- Arises from beam pipe radius at most downstream plane, 27.4 mm, thermal insulation is 5.0 mm but compresses to 3.5 mm, giving a 2.5 mm radial clearance
- Sensor active area goes down to R=34.2 mm due to 0.8 mm guard ring

Effects of hole size



Hole Radius	B inefficiency (%)		
	$B_s \to J/\psi\ \pi^+\pi^-$	$B^+ \to J/\psi\ K^+\pi^+\pi^-$	$B_s \to D_s^-\pi^+\pi^+\pi^-$
28.1 mm	0.8	0.5	1.9
30 mm	1.2	0.8	2.9
35 mm	2.8	1.9	6.6
40 mm	4.7	3.2	10.7
~TT Hole	6.2	4.8	13.9

- Conclude: extra B inefficiency is small below 35 mm inner sensor radius

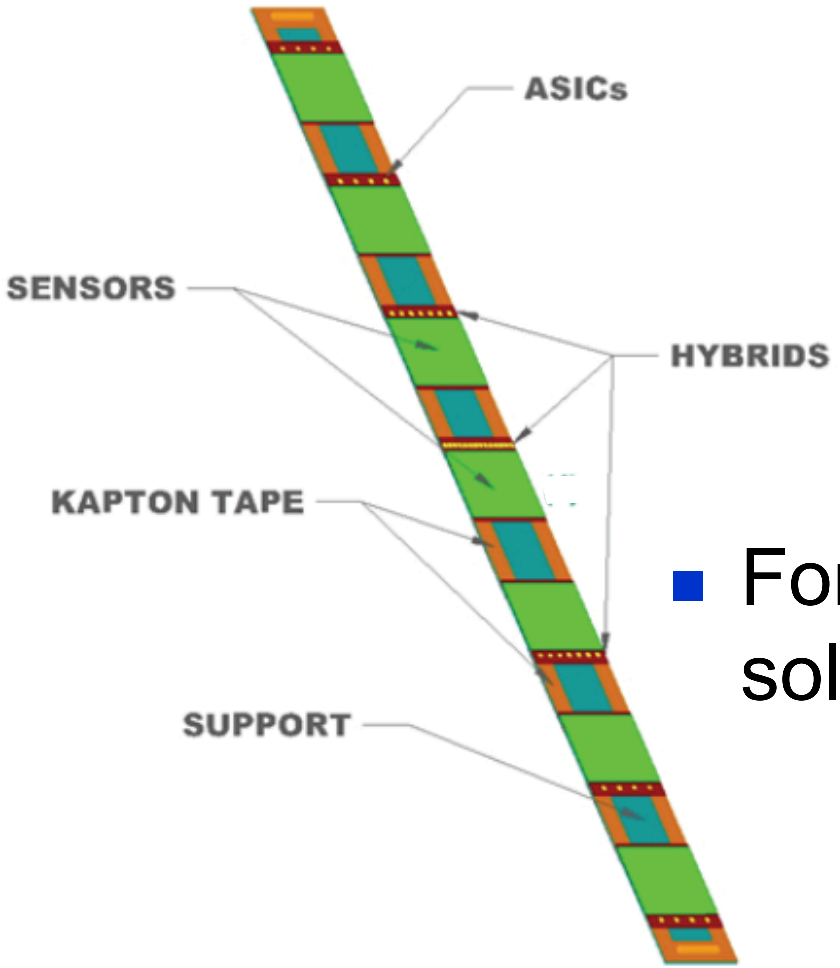
Mechanical requirements

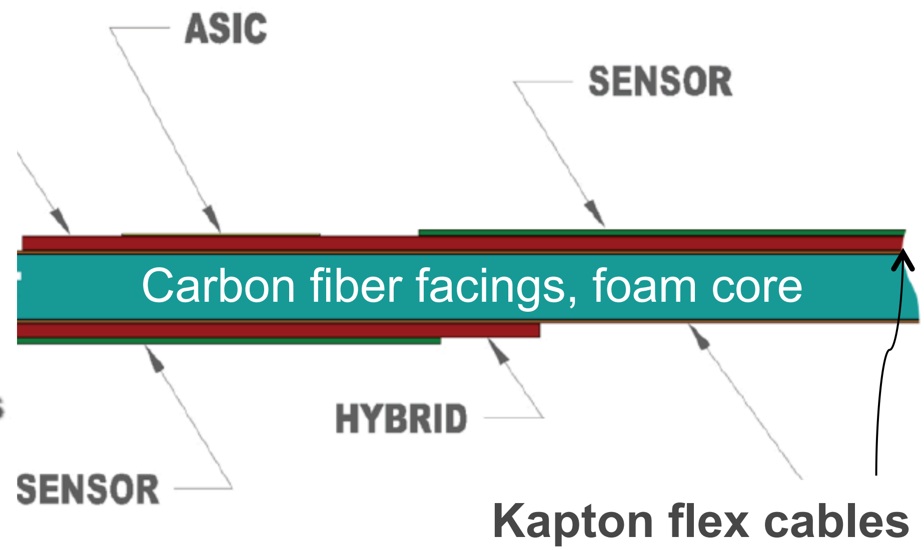
- Structure must support Si (~10 cm x 10 cm) including overlaps of sensors (~2 mm)
- Structure must be stable enough to prevent wire-bonds from breaking due to flexing or other motions
- Structure must not move during data taking, with position stability < 20 μm
- Minimal thickness in radiation lengths, no thicker than TT
- Provide cooling to Si & electronics (Si temp < -5^{o} C)
- Ability to move out of the way when beam pipe is baked
- Provide Cable support
- Outer box for optical, thermal and gas isolation

Strategy

- Use local readout to reduce noise due to capacitance
- Allows use of thin 250 μm thick Si
- "Borrow" many ideas from ATLAS upgrade silicon. However ATLAS must support the Si horizontally ———, while we require vertical |
- ATLAS concept is based on "staves"

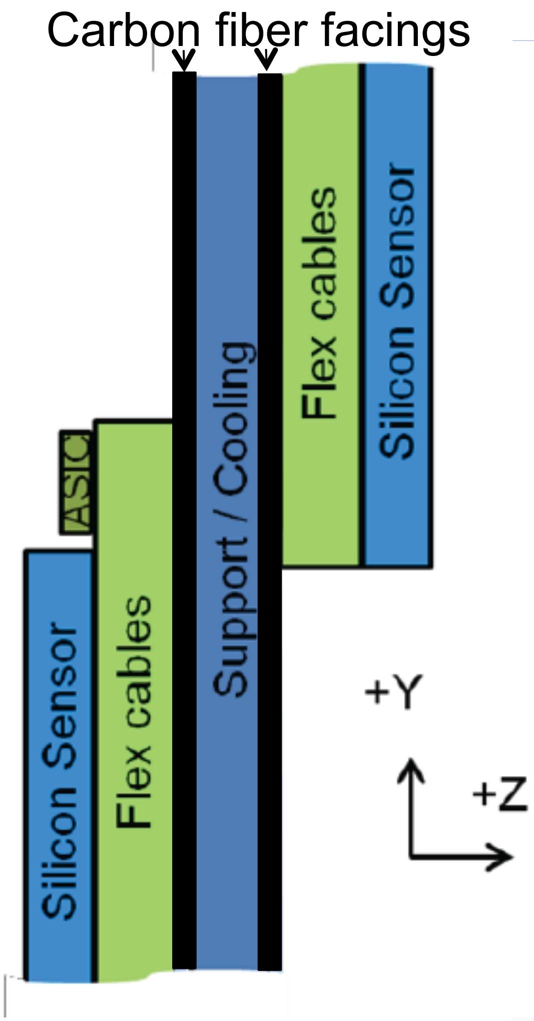
Stave sketch

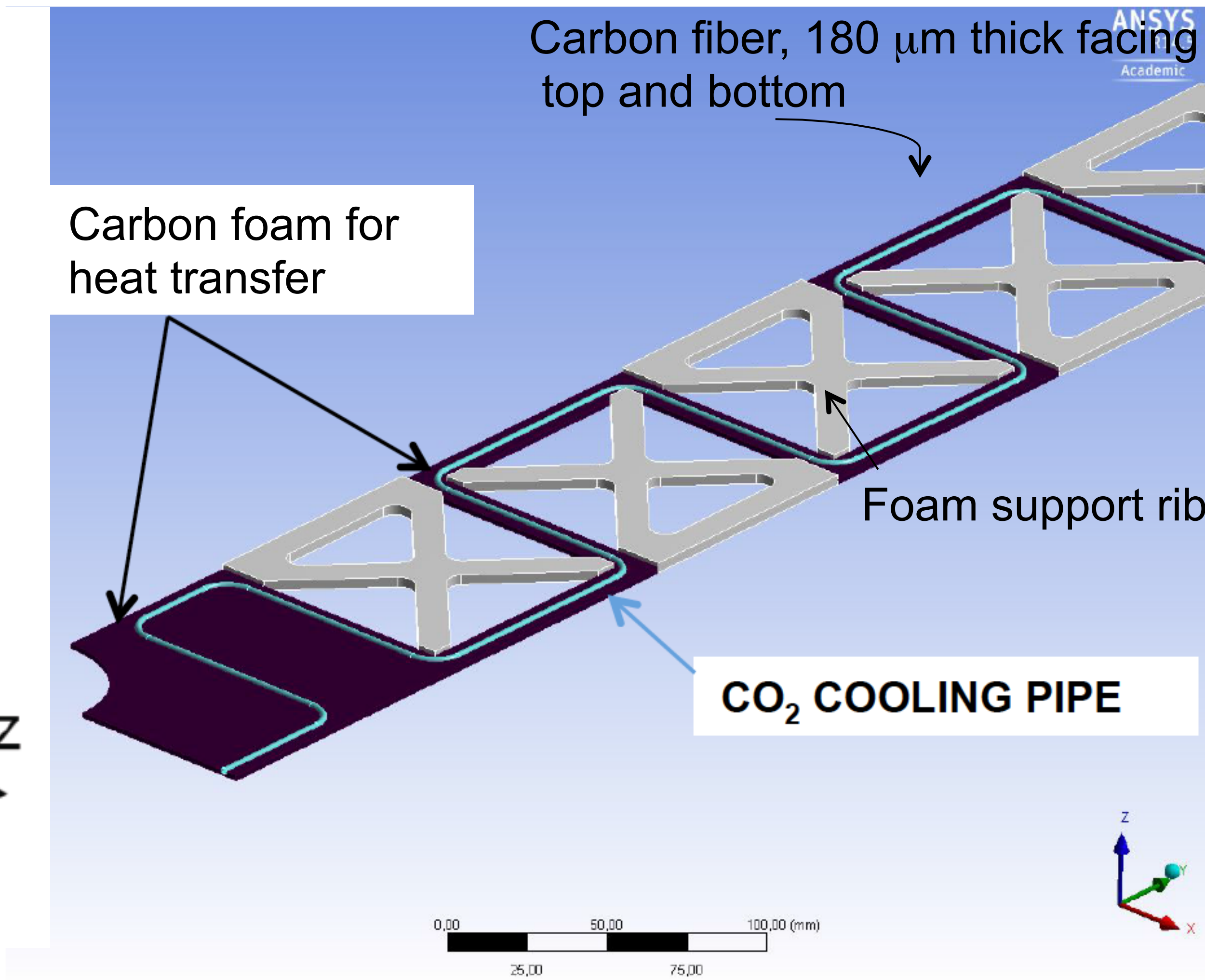




- For support ATLAS uses a solid foam core

UT Staves


Carbon fiber facings
Silicon Sensor
Flex cables
Support / Cooling
Flex cables
Silicon Sensor
ASIC
+Y
+Z


Carbon fiber, 180 μm thick facing
top and bottom
Carbon foam for
heat transfer
Foam support ribs
CO_2 COOLING PIPE
ANSYS
Academic
0,00
50,00
100,00 (mm)
25,00
75,00

Overlaps

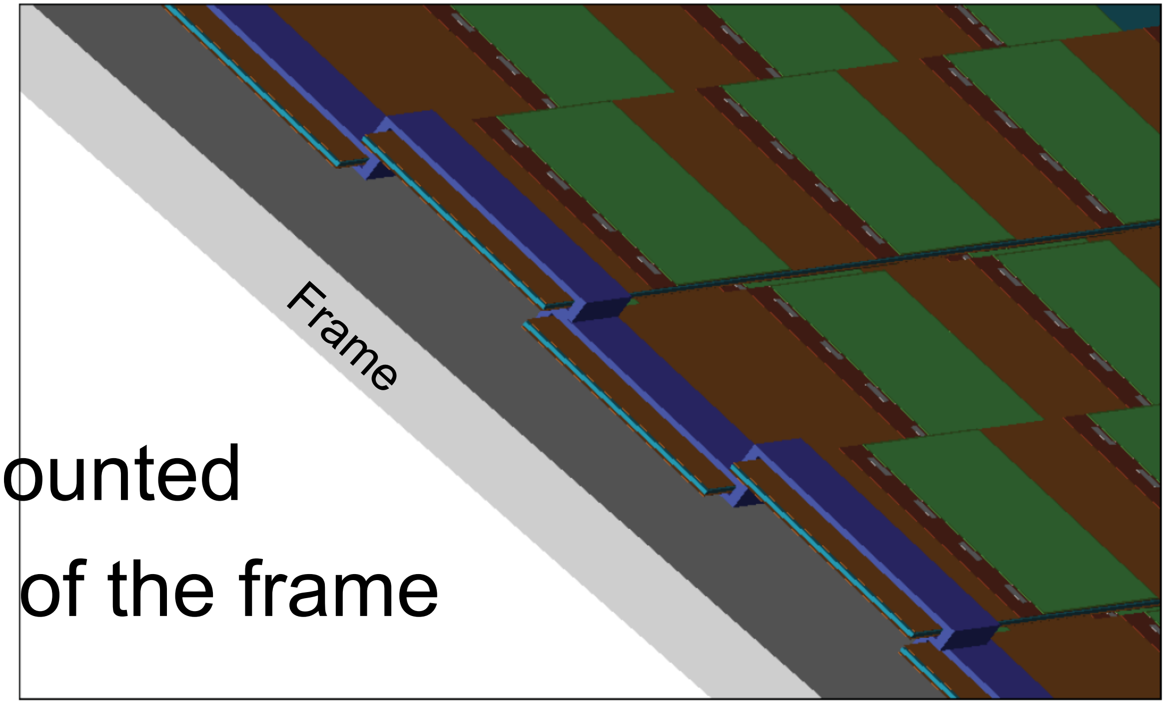
- Easy to get overlaps vertically (Y), just overlap Si on both sides of staves
- Horizontally (X) need to stagger stave mounting
- Not a design,

but shown so

you get the idea

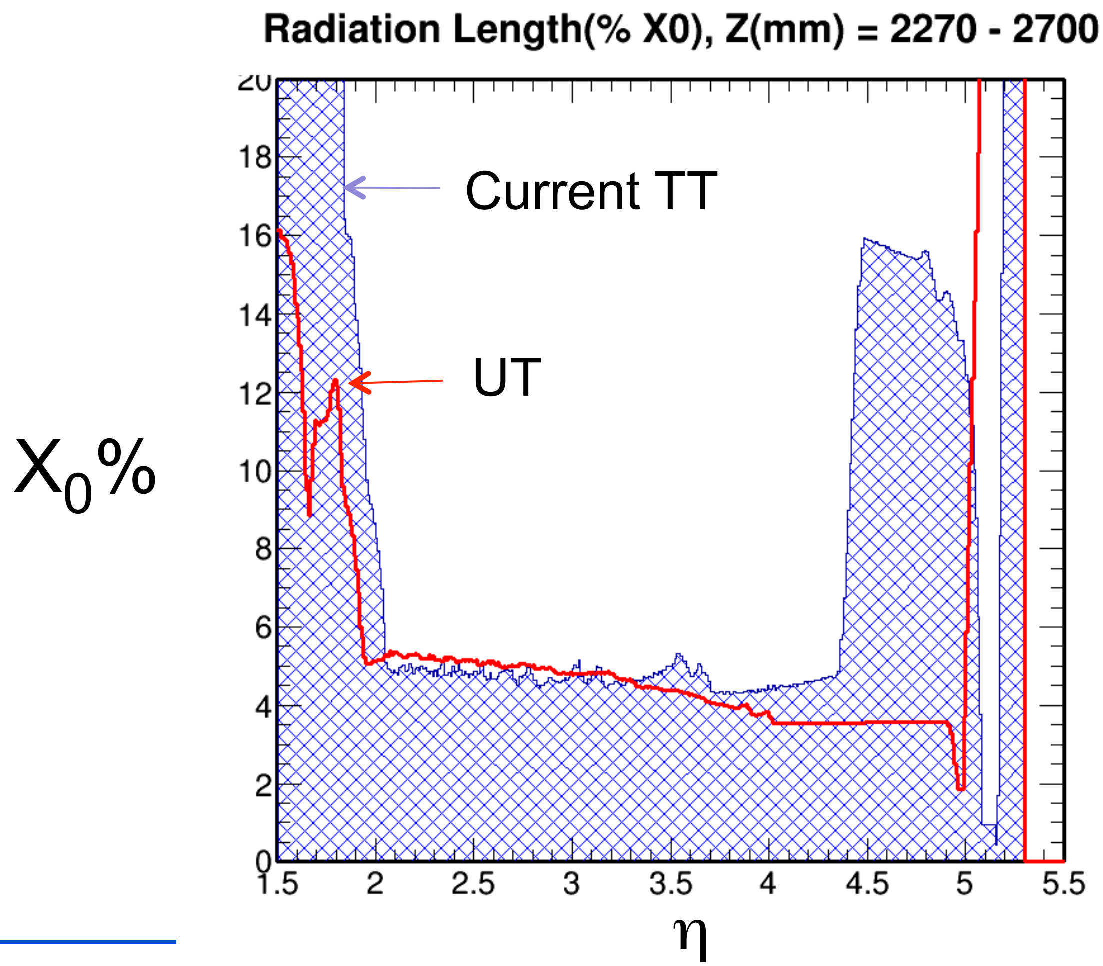
- Next layer is mounted

on the other side of the frame



Radiation lengths

- Preliminary: details reflect current design

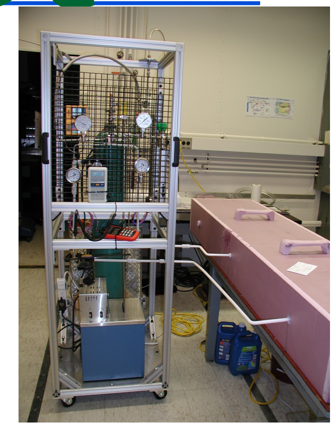


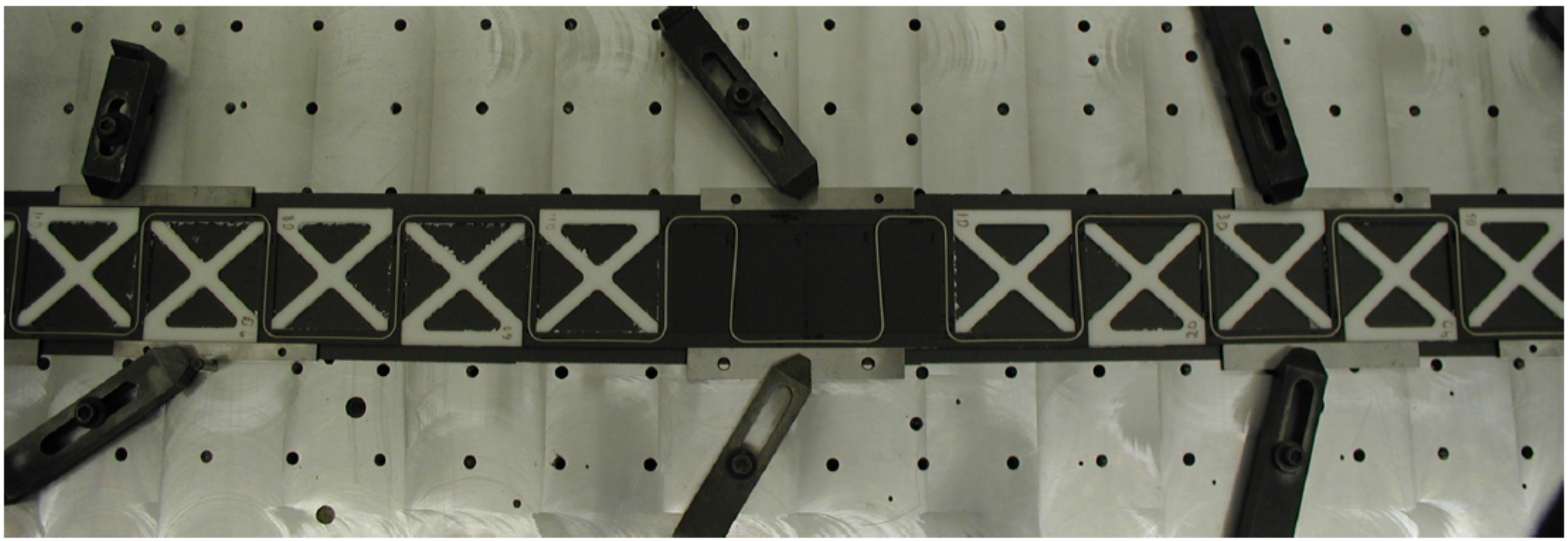
Cooling: evaporative CO_2

- Need to keep sensors < -5°C that are heated by the front-end chips, the SALT ASICs: currently we assume it to be 0.77 W/chip [6mW/ch]. Final system may achieve less power consumption! Also heat from Si
- Cooling simulation studies (INFN Mi) & measurements with mechanical mock-up and CO_2 cooling system (Syracuse) have been done

Cooling test

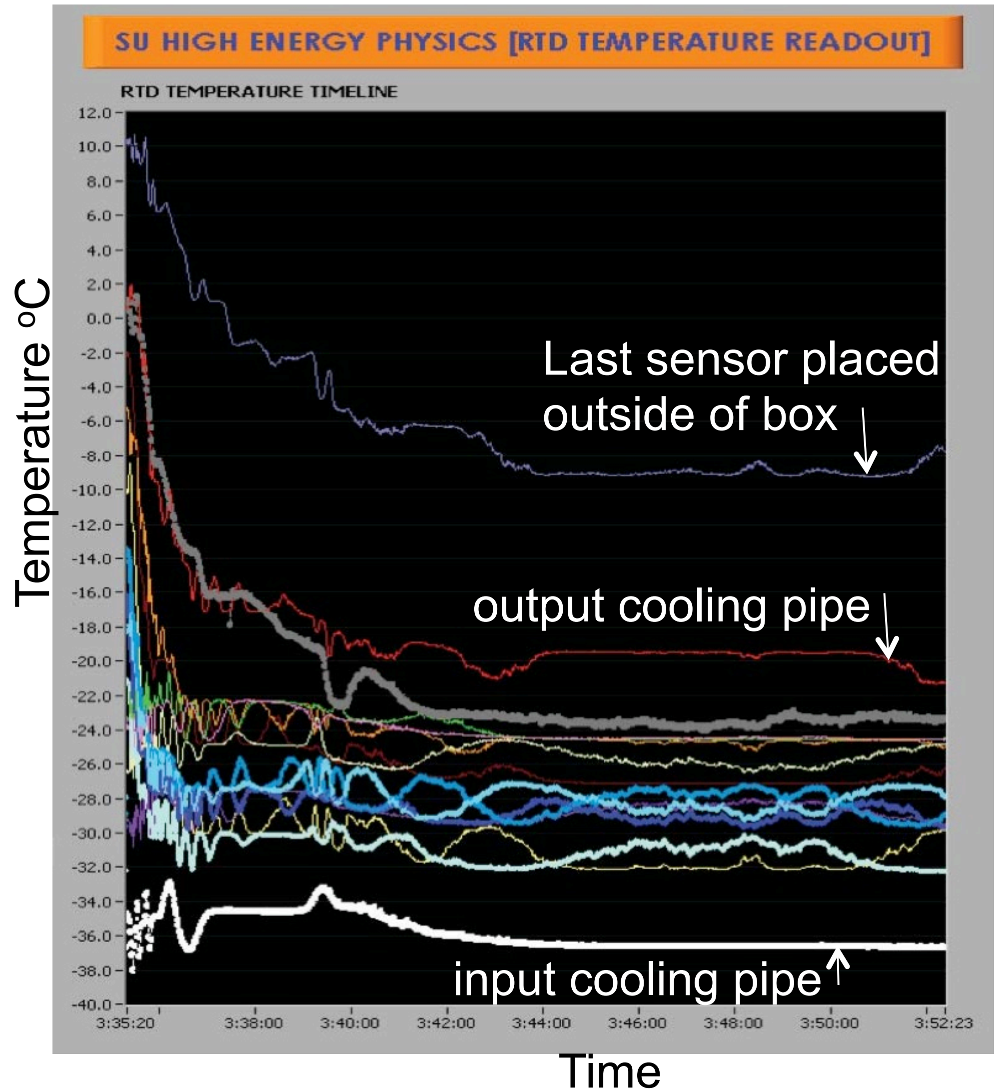
- CO_2 “blow through” system constructed at Syracuse
- First test stave also made



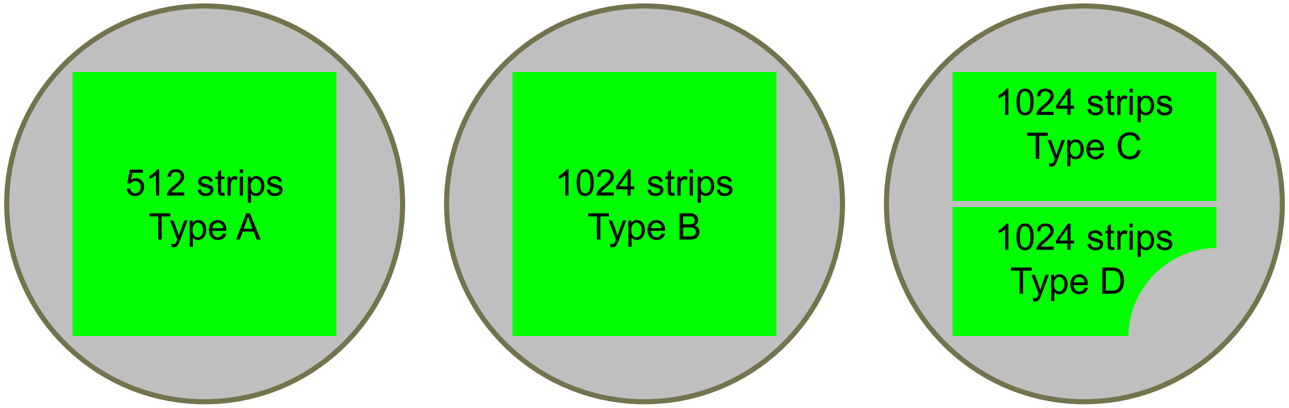


Test results

- Stave was completed with Si sensors (some brass), kapton cables, heaters for ASIC's
- Actual carbon-fiber sheets, & foams
- After 1st run all sensor temps < -5°C
- Stave maintains its mechanical integrity, now after 9 cycles



Sensors and hybrids



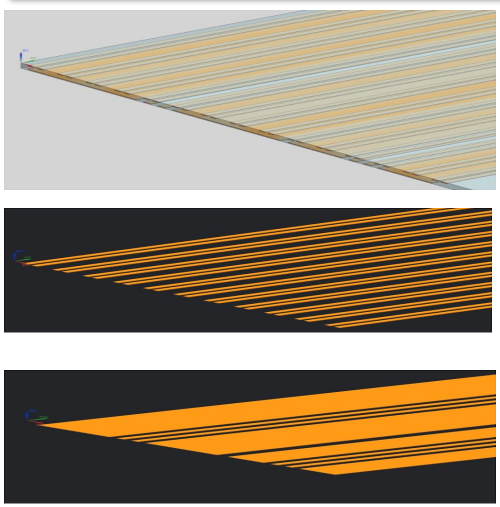
Property	Sensors B,(C,D)	Sensors A
Technology	n^+-in-p	p^+-in-n
Thickness	250 μm	250 μm
Physical dimensions	98 mm X 98 (49) mm	98 mm X 98 mm
Length of read-out strip	98 (49) mm	98 mm
Number of read-out strips	1024	512
Read-Out strip pitch	95 μm	190 μm
Sensor number (needed)	48 (16,16)	888

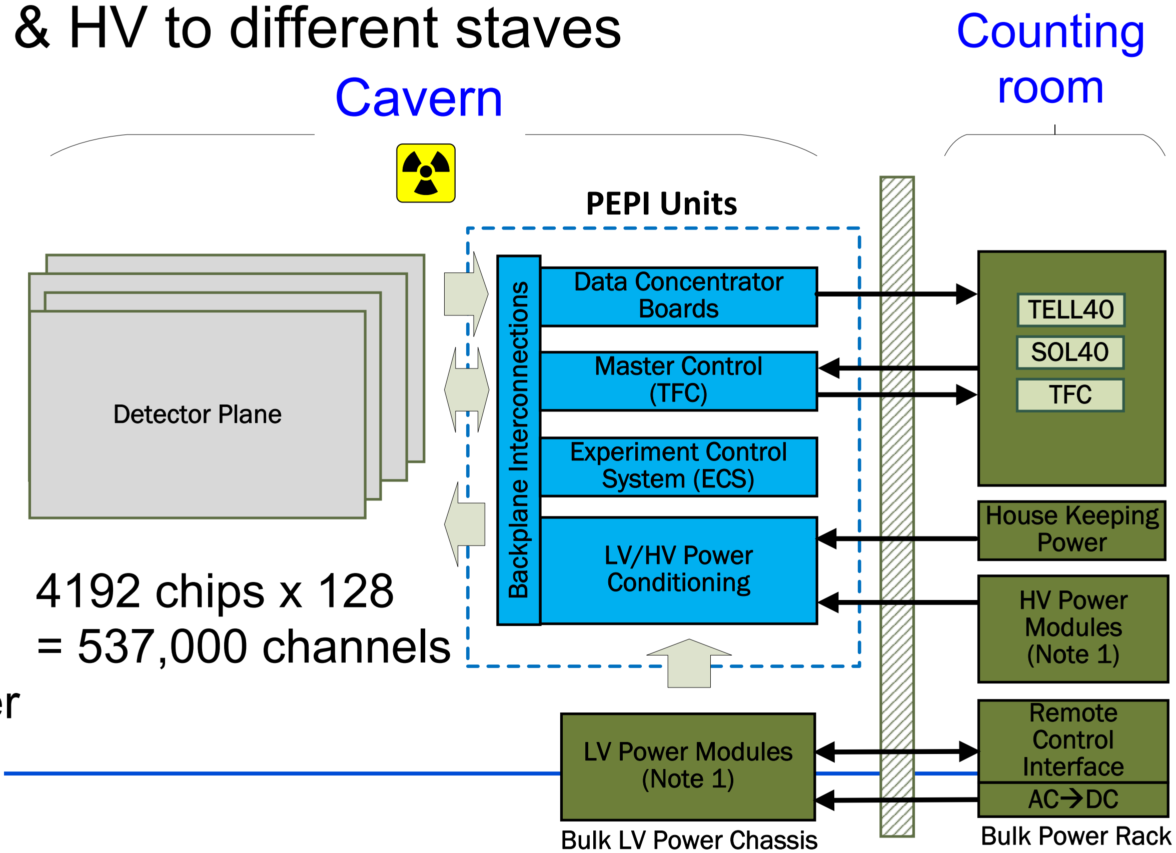
Sensors: Standard technology except for fan-in & circular hole. Hybrids: low mass flex circuits mounted on an FR4 carrier, host SALT chips & some filtering.

Electronics

- The main components:
  - Flex cables bringing power and data from hybrids to balcony electronics that:
    - aggregates data and implements the electro-optical transition
    - distributes LV & HV to different staves

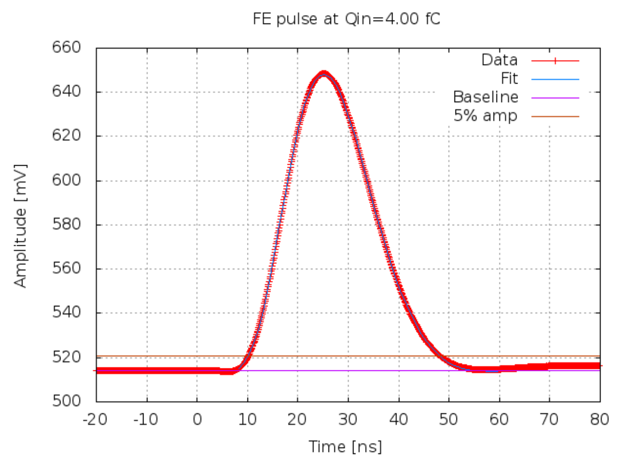
Conceptual design of UT cables (micro-strip [data] and power layers)

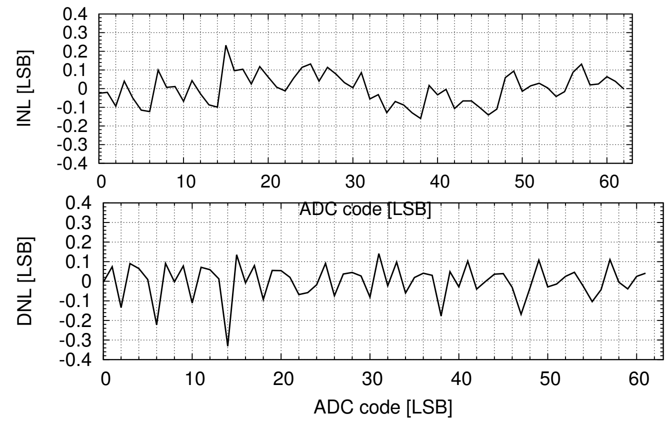




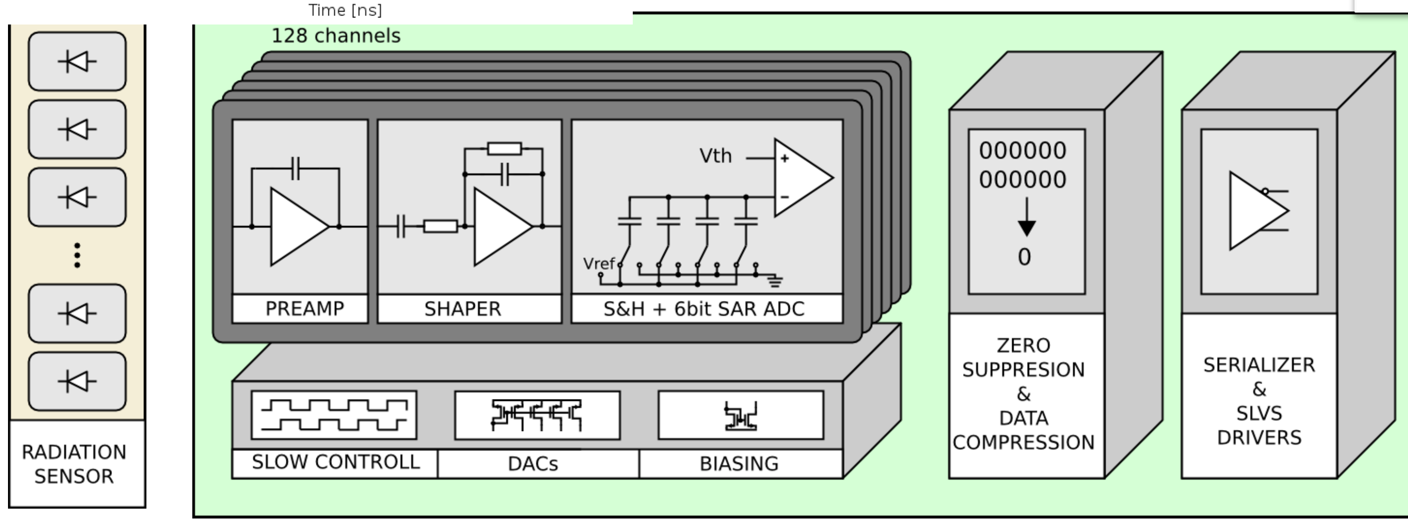
4192 chips x 128 = 537,000 channels

The SALT ASIC – AGH Krakow





Differential and integral non linearity of the ADC <0.35 (DNL) & 0.25 (INL) LSB



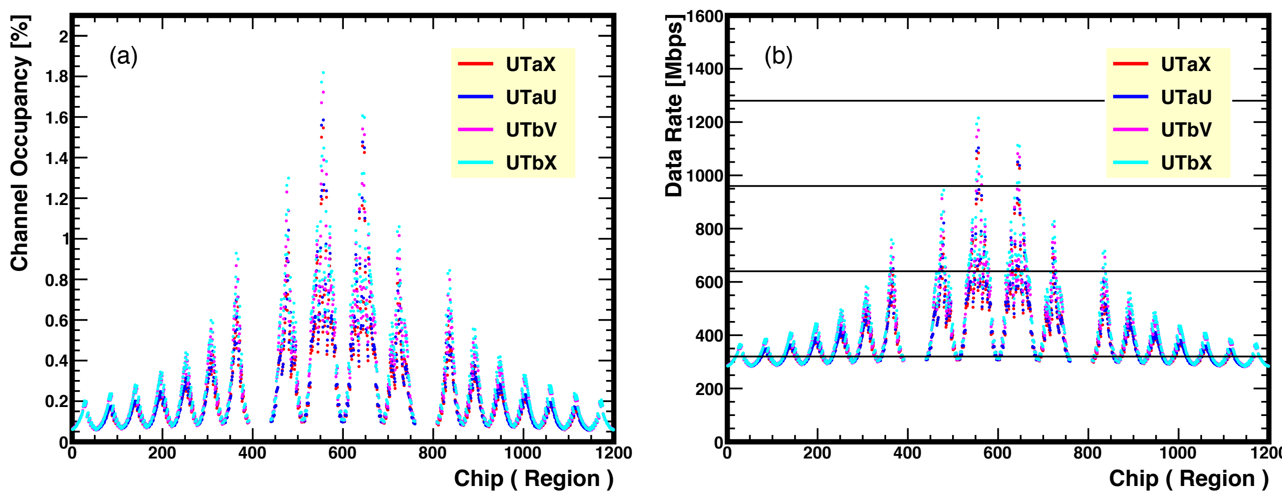
DAQ Integration

- 1 SALT has 1-5 e-links synchronously sending data at 320 Mbits/s on the flex cable to the GBTx ASIC on the DCB board
- 1 GBTx processes up to 10 e-links & send signals to AMC40 board

Event packet format (LHCb specifications)

Header Field (6 or 12 bits)				Data Field	Comment
BXID	NoData	IsTrunc	Length		
4-bit	1	0	-	-	BXVeto, HeaderOnly, or NumHits = 0
0000	1	1	-	-	Idle packet
4-bit	0	0	6-bit	Hits	Normal event, 0 <NumHits ≤63
4-bit	0	1	6-bit	-	Truncated event, NumHits>63 or bufferFull
4-bit	0	1	11 1111	Data	NZS packet, fixed length of data
12-bit	-	-	-	Pattern	Synch packet, with preset pattern

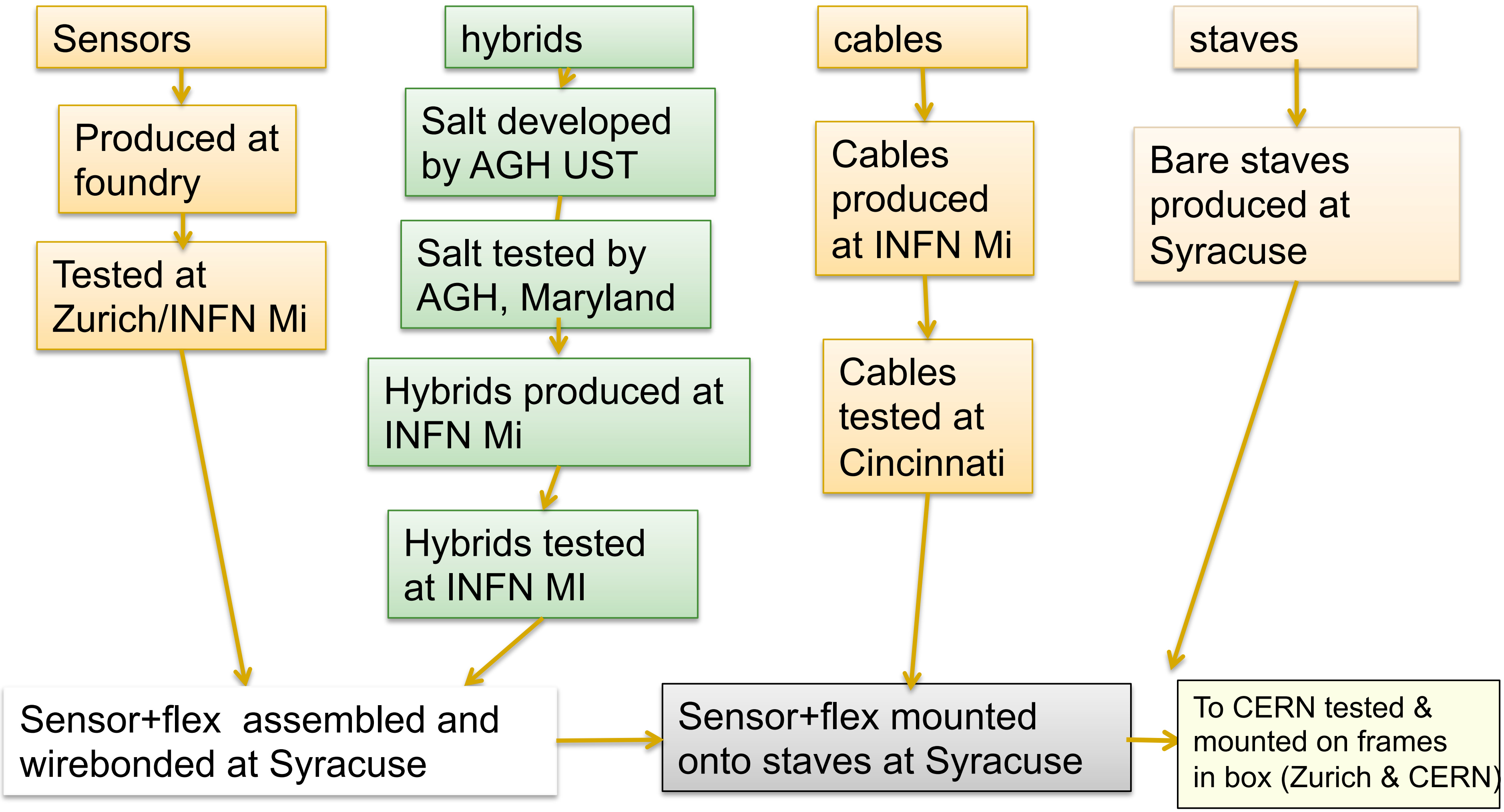
Data rate/ASIC



Responsibilities

Work-package	Institution(s)
Sensor and hybrid module	INFN Mi, Syracuse
SALT	AGH-UST
Electronic	INFN Mi, Maryland, Syracuse
Data acquisition and Experiment control	Maryland, Syracuse, Zurich
Mechanics and cooling	Syracuse, INFN Mi, CERN, Cincinnati
Integration and testing	All
Integration with LHCb	INFN Milano, Syracuse, Zurich, CERN

UT construction



Project cost

Detector component	Cost(kCHF)
Si Sensors & Hybrids	2700
SALT	1300
Cables	160
PEPI Electronics	620
DAQ HV/LV	780
Staves & Hybridization	510
Infrastructure	130
Cooling	300
Subtotal	6500
US personnel (project)	430
Total	6930

Trigger tracking

- Idea here is to use the magnetic field

Between the VELO and UT to get a rough measurement, Δp/p~15%, that Allows a drastic reduction in the # of candidates passed to Forward (match with T track), as well as a tighter search window

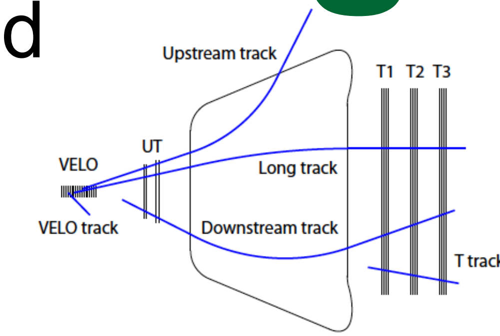


Table 4.19: Timing numbers for the VELO-Forward and the VELO-Upstream-Forward reconstruction sequence. These numbers were obtained using samples of simulated minimum bias events.

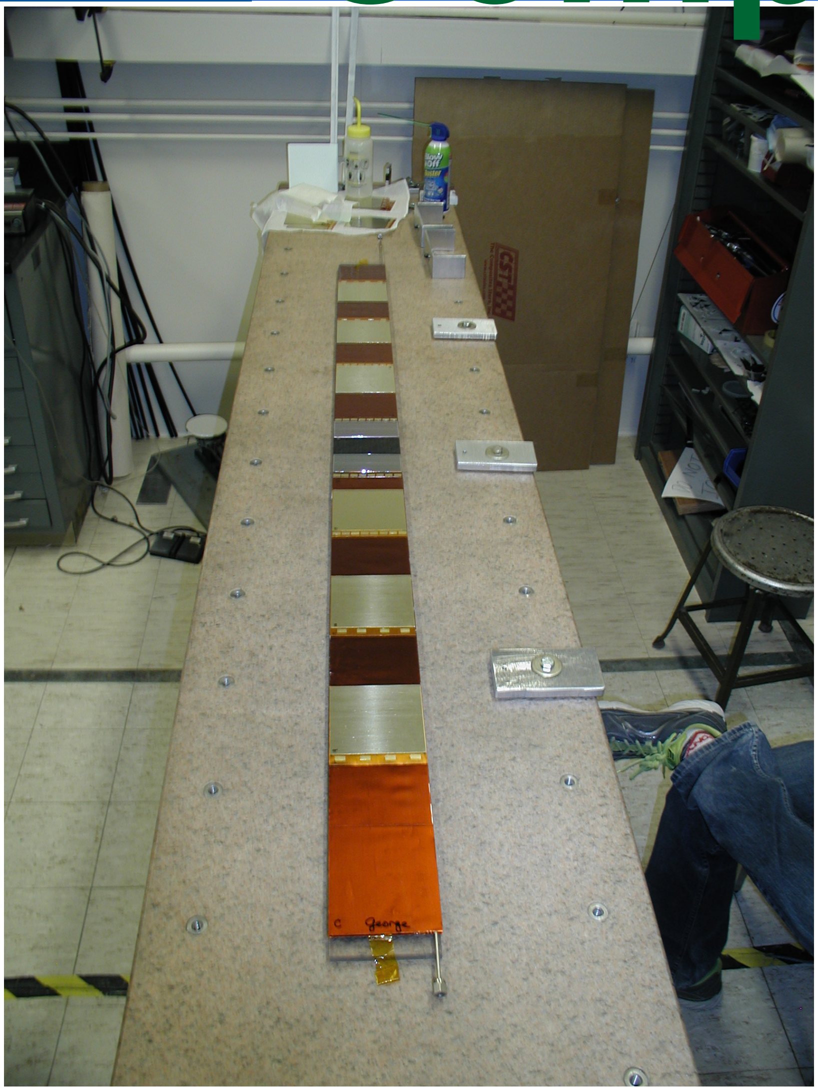
	VELO-Forward		VELO-Upstream-Forward	
time [ms/events]	$\nu = 3.8$	$\nu = 7.6$	$\nu = 3.8$	$\nu = 7.6$
VELO	0.7	1.8	0.7	1.8
Upstream	-	-	0.9	2.2
Forward	4.0	22.5	1.2	4.1
Total	4.7	24.3	2.8	8.1

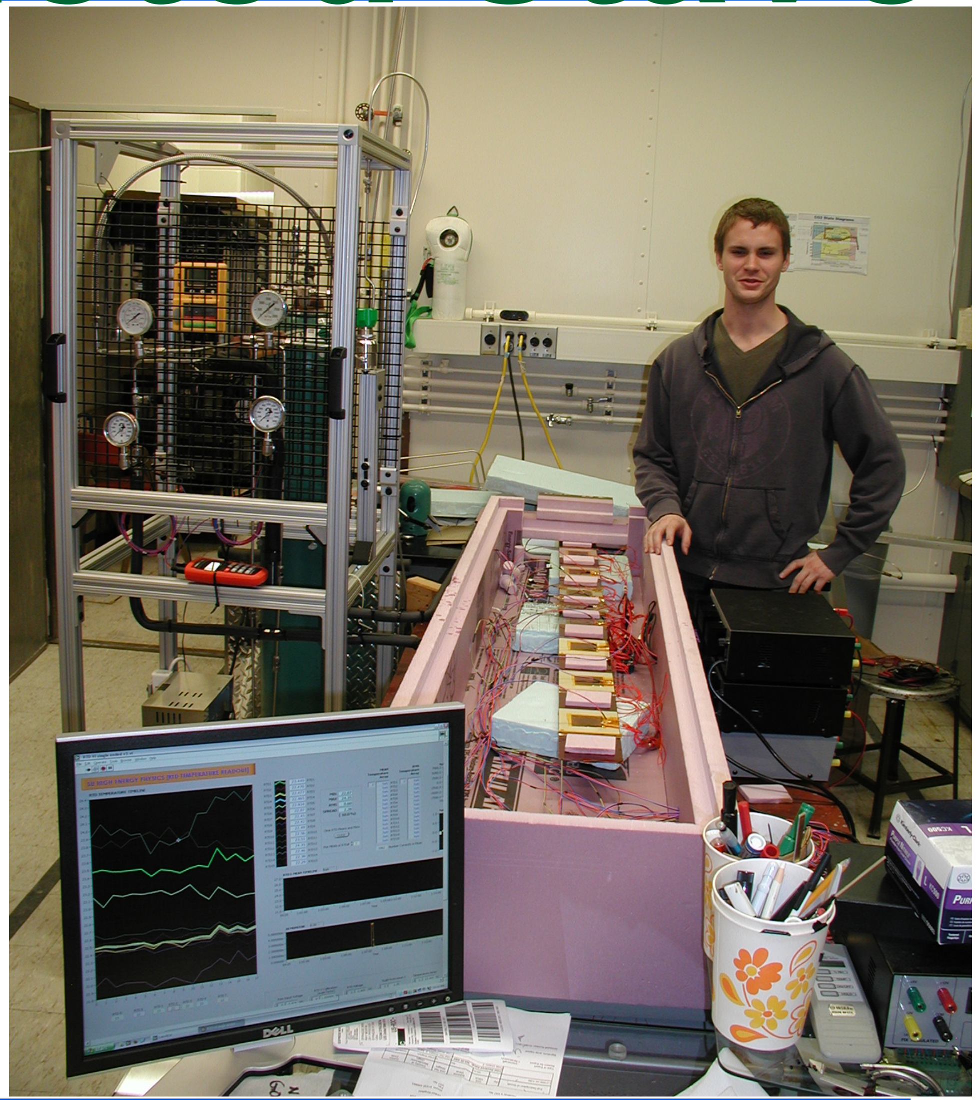
Conclusions

- UT R&D is well underway
- We believe that we have a high performance, lightweight, & constructible design
- Funding is being actively sought, some has been granted, and we are optimistic
- The UT should be a very useful device in LHCb
  - Large reduction in ghost rates
  - Essential for Vee finding
  - Improves momentum resolution
  - Speeds up trigger timing by ~factor of 3

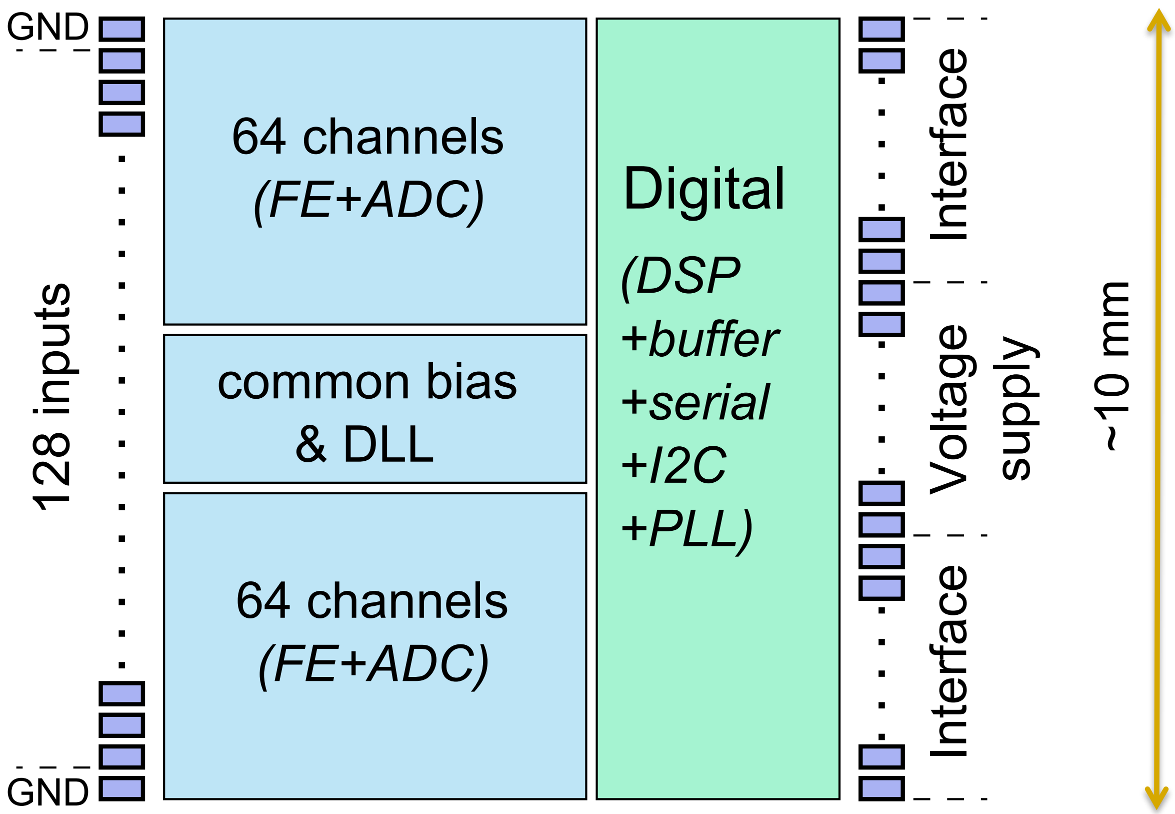
The End

Completed stave





SALT chip blocks



- No side pads (allow to mount ASIC close to each other in 8 CHIP hybrids)
- Ancillary blocks (PLL, DLL, SLVS, DACs) needed, some of them already designed

Si planes

- Four planes, z locations & related inner hole dimensions

Table 1. Nominal Z-location of each UT plane and beampipe radius at that location. The UT inner radius for all planes is 33.4 mm.

UT Plane	Z Plane (center) [mm]	Outer Radius (beampipe) [mm]	Outer Radius (exclusion) [mm]	Inner Radius (UT active) [mm]
UTAX	2327.5	26.0	32.0	32.8
UTAU	2372.5	26.0	32.0	32.8
UTBV	2597.5	27.0	33.0	33.8
UTBX	2642.5	27.4	**33.4**	34.2
MAX (ref.)	2750.0	28.5	34.5	35.3

Note: "excluded" refers to the outer radius of the beampipe plus an insulating jacket (5 mm) and mechanical clearance (1 mm). For the minimum inner radius for the active area of a sensor, a guard ring (0.8 mm) is added. "Max" refers to the largest local radius in the current beampipe.

- Same stereo angles $\pm 5^o$ as current TT

Effects of hole size

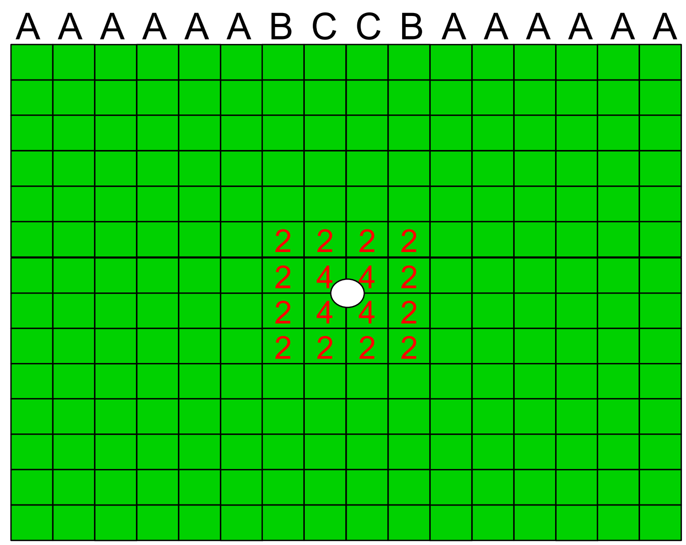
- Three different channels are selected, which represent different multiplicities in the final states.
  - $B_s \to J/\psi\, \pi^+\pi^-$, $J/\psi \to \mu^+\mu^-$ 4 tracks
  - $B^+ \to J/\psi\, K^+\pi^+\pi^-$, $J/\psi \to \mu^+\mu^-$ 5 tracks
  - $B_s \to D_s^-\pi^+\pi^+\pi^-$, $D_s^- \to \phi\pi^-$ 6 tracks

- The signals are simulated at E_{CM} = 14 TeV, L=2x10^{33} cm^{-2}s^{-1}

- The detector configuration include three upgrade sub-detectors: VP-compact with micro-channel, UT & FT.
- For K/π: P_t > 0.3 GeV, P > 3 GeV, for μ: P_t > 0.55 GeV, P > 6 GeV
- Tracks required to be in Velo pix & FT acceptance

Si design

- 250 μm thick
- Three different sensor types to take into account different track densities
  - nominal: 190 μm wide strips, 10 cm long
  - intermediate: 95 μm wide strips, 10 cm long (2)
  - high density: 95 μm wide strips, 5 cm long, on a single piece of silicon (4)



Outer box

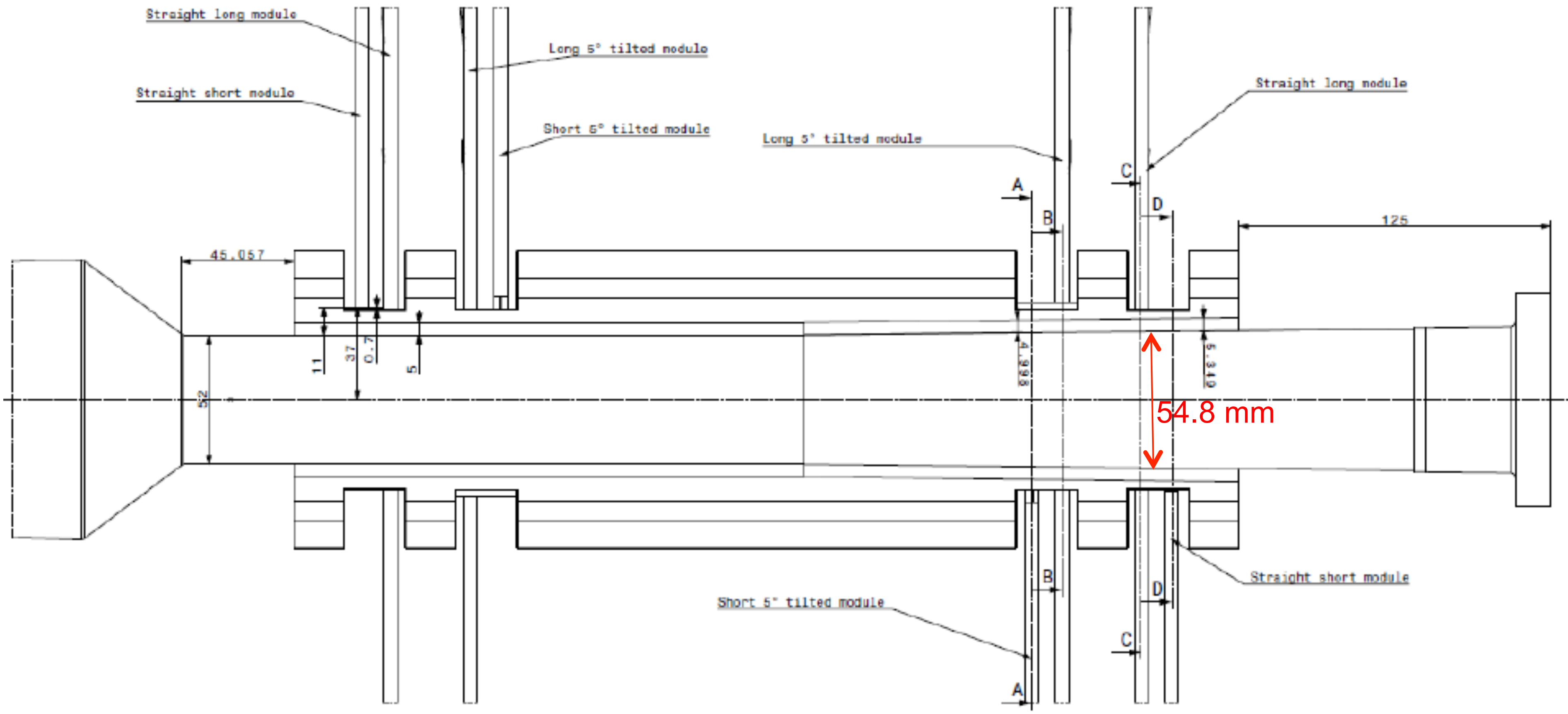
- Need to put detector in box to exclude light, electrical noise and provide an inert environment (N_2)
- Must have thin entrance and exit windows
- Must seal to beam pipe

X_0 Table

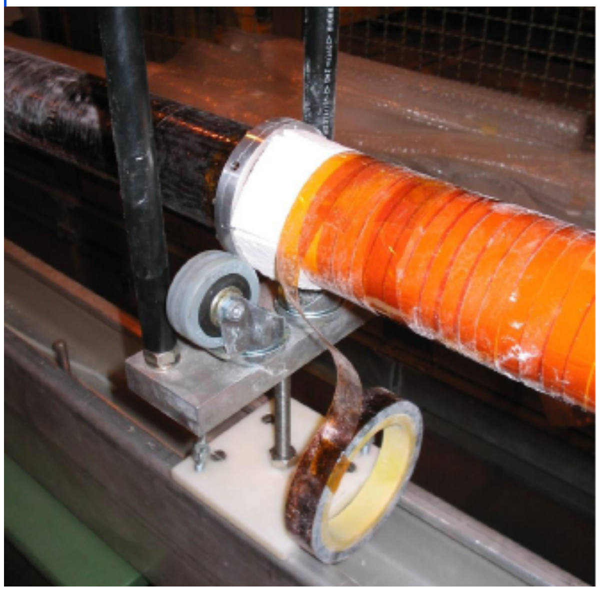
Parts		Material	Thickness (μm)		RL (%X_0) ($2<\eta<4.9$)
Hybrid	Sensor	Si	250	260	0.29
		Al	10		
	ASIC	Si+ Al	120	120	0.002
	Hybrid Flex	Kapton	100	217	0.17
		Ground Al	11		
		Traces, wirebonds	6		
		Thermal epoxy	100		
Kapton Cable		Kapton	100	133	0.16
		Ground, traces, epoxy	11 + 2 x 11/2 + 11		
Module Stave		POCO foam	3000 (½)	3460 (1757)	0.34
		CFRP face	2x130 (½)		
		Epoxy	4 x 50 (½)		
		Titanium	2x ϕ=2.2, t=0.12 mm		
		Cooling fluid	-		
UTaX					0.96
Box		Graphite, glue, Kevlar	2 x 400		0.34
Air			430 mm		0.14
Avg. $2<\eta<4.9$					4.36

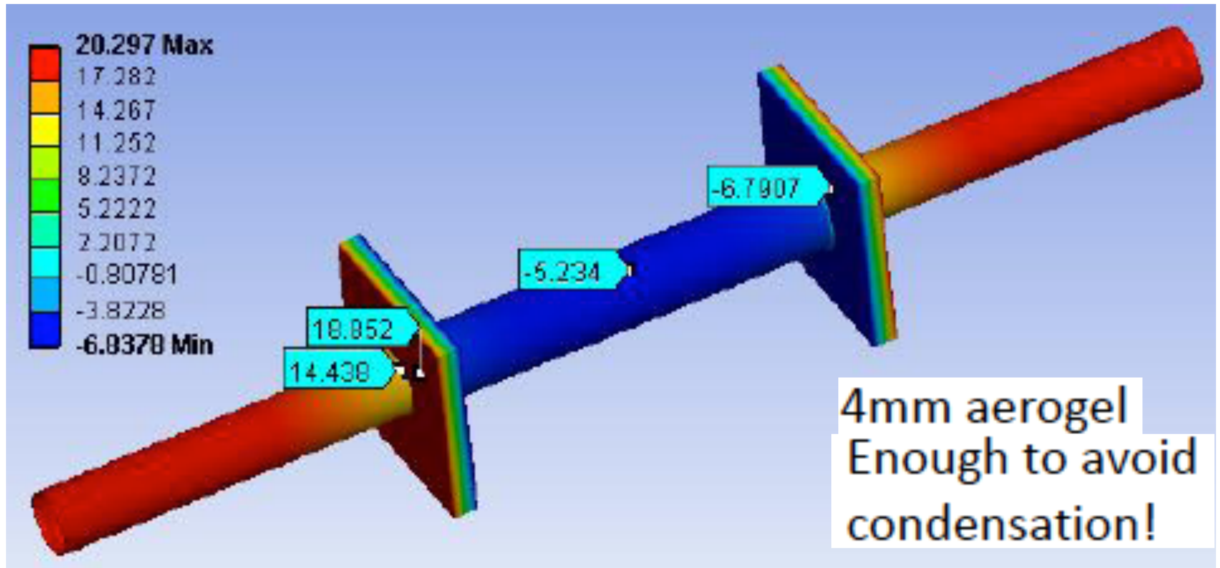
Beam pipe

- Keep current metal



Thermal simulations & measurements from Kaan





Aerogel shows a sufficient insulation for 5mm thickness (compressed 3,5mm including Kapton)

No condensation was present at any point

Higher relative humidity inside the box must be avoided to keep the heat transfer coefficient low

For -10° C one should extend the insulation to the outside of the box

Bake out kapton heaters (0.2mm thickness) can be implemented with this configuration, the aerogel gives a dT of more than 100°C to the outer surface.

Downstream tracking

- Efficiency increased by requiring that T-station track is not near center of the detector

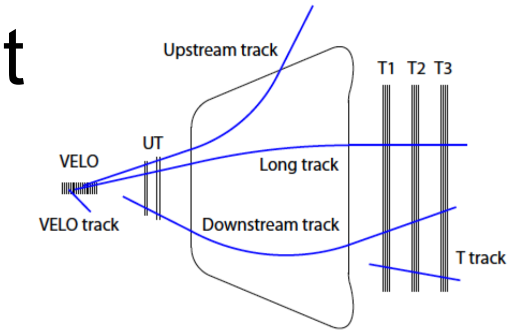


Table 4.14: Performance of the Downstream tracking algorithm on samples of simulated $D^* \to D^0(\to K^0_S\pi\pi)\pi$ events. Any inefficiency from the Seeding algorithm is not included in these numbers.

	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	39.3	41.5	54.6
Reconstruction efficiency			
strange daughters	79.6	71.0	62.7
strange daughters, $p > 5\,\mathrm{GeV}/c$	84.1	75.3	67.5
strange daughters, $p > 5\,\mathrm{GeV}/c$, $p_\mathrm{T} > 400\,\mathrm{MeV}/c$	-	81.7	76.3
strange daughters from D or B	84.3	79.1	73.2
strange daughters from D or B, $p > 5\,\mathrm{GeV}/c$	87.5	81.5	76.1
strange daughters from D or B, $p > 5\,\mathrm{GeV}/c$ $p_\mathrm{T} > 400\,\mathrm{MeV}/c$	-	85.5	81.4