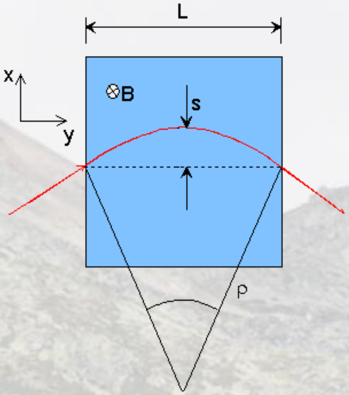
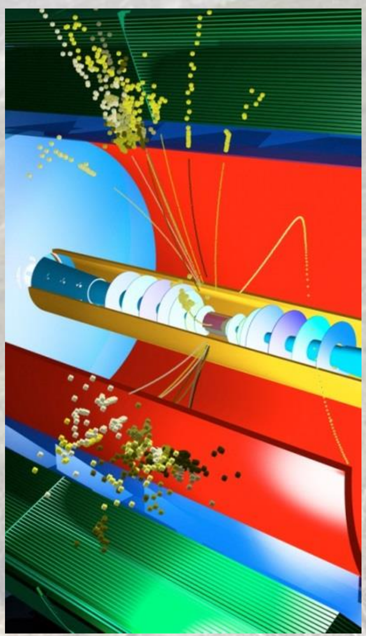
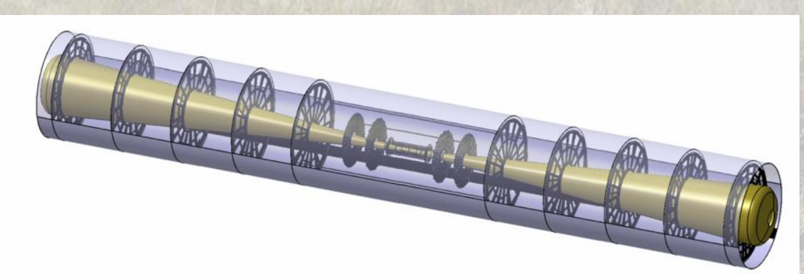
Status of the Forward Tracker Detector







A.Ruiz-Jimeno, on behalf of FTD team

Outline

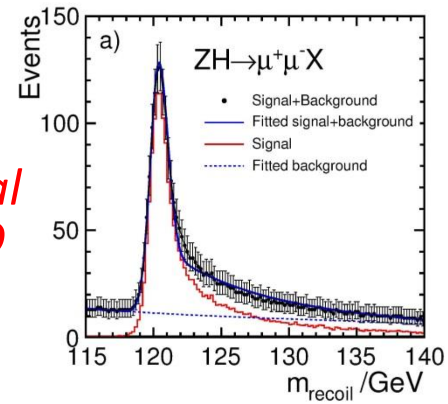
- Motivation
- Critical and beyond-the-baseline R&D.
- Brief status report and long term R&D plans.
  - Module design: sensors and hybrids.
  - Mechanics, integration & services
  - Front-end electronics.
  - Power distribution & EMC.
  - Alignment and monitoring.
- Summary & conclusions

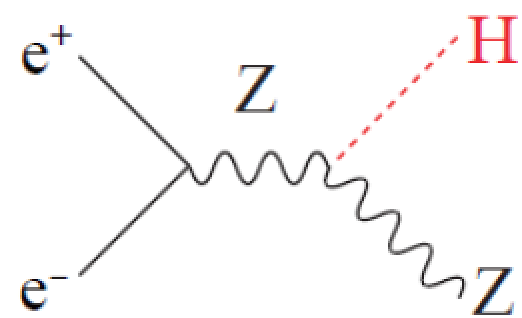
Motivation

Good momentum resolution

$$\sigma_{1/p_T} \approx \sqrt{\left(\frac{2\times10^{-5}}{\mathrm{GeV}^{-1}}\right)^2 + \left(\frac{10^{-3}}{p_T[\mathrm{GeV}]\sin\theta}\right)^2}$$

→ Goal ILD





Good impact parameter precision

b,c, τ tagging

$$\sigma_{r\phi} = 5 \oplus 10/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$

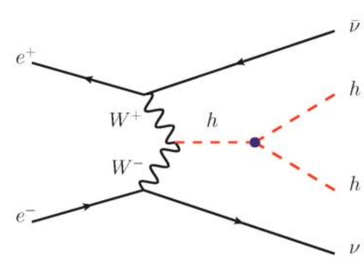
→ **barrel**

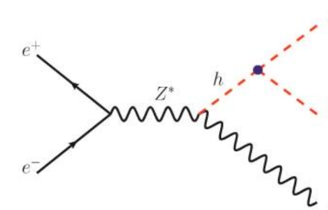
Forward- backward

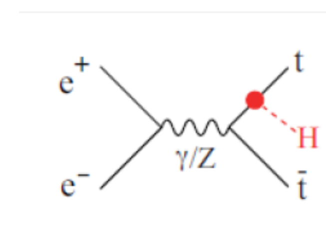
$$\Delta d_0 = a[\mu\mathrm{m}] \oplus \frac{b\times\frac{L}{R}[\mu\mathrm{m}]}{p[GeV]\cos^{3/2}\theta}.$$

Good pattern recognition

Full angular acceptance

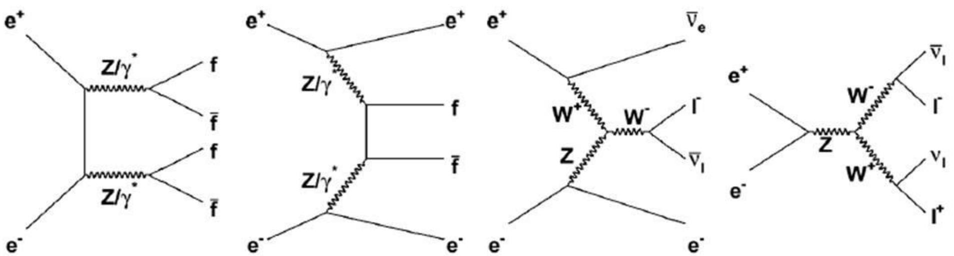




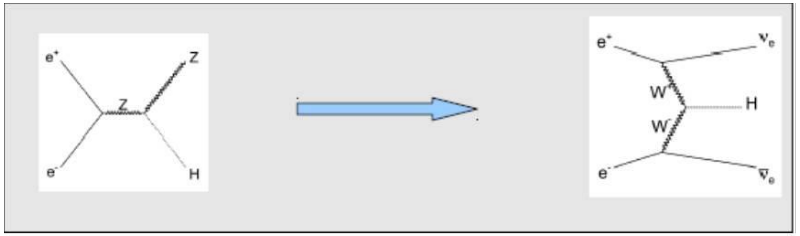


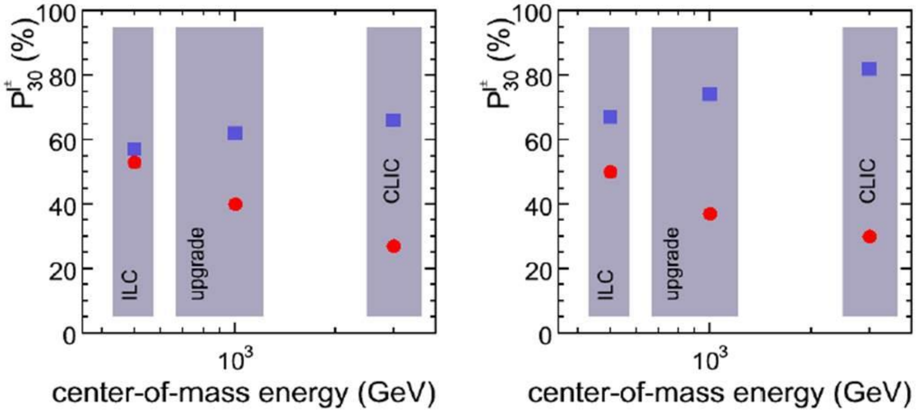
High jet multiplicity

Full angular acceptance



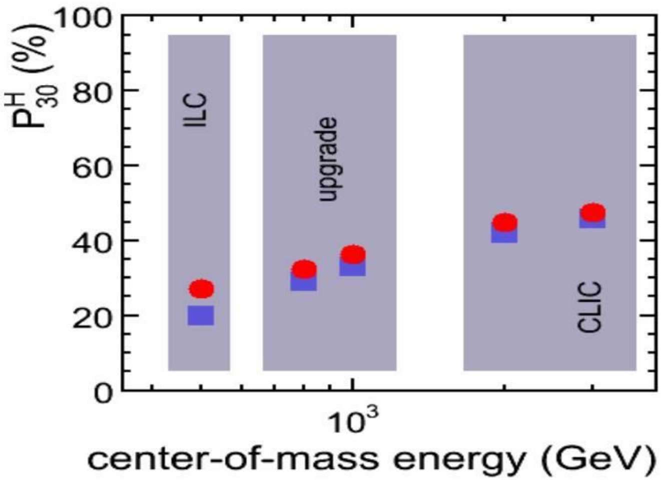
Forward tracking increasingly important with higher c.m.s. energy





(a) $l^+l^-\nu\bar{\nu}$ (b) $l^+l^-l^+l^-$

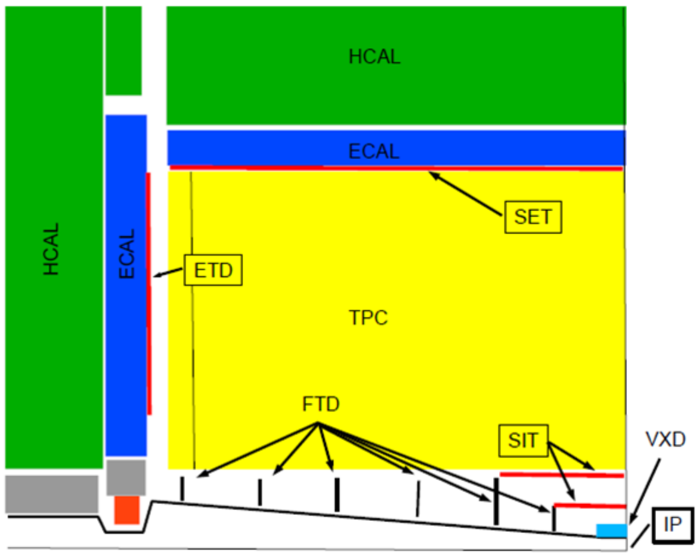
Figure 11. MadGraph [13] prediction for the fraction of charged leptons emitted in the forward direction $l^+l^-\nu\bar{\nu}$ and $l^+l^-l^+l^-$ events. The round markers represent $P_{30}^{l\pm}$, while the squared markers correspond the total fraction of forward charged leptons ($\theta < 30°$).



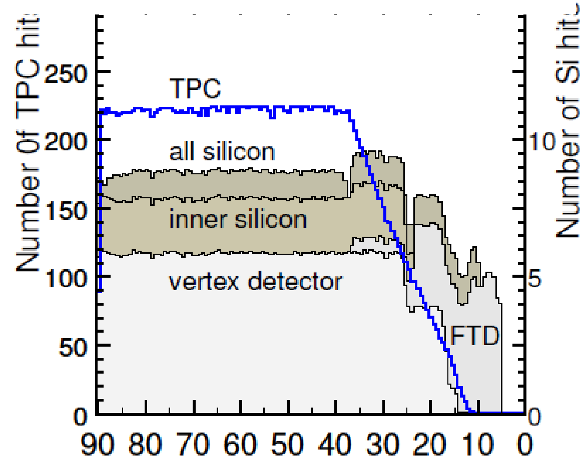
2009 JINST4 P08002

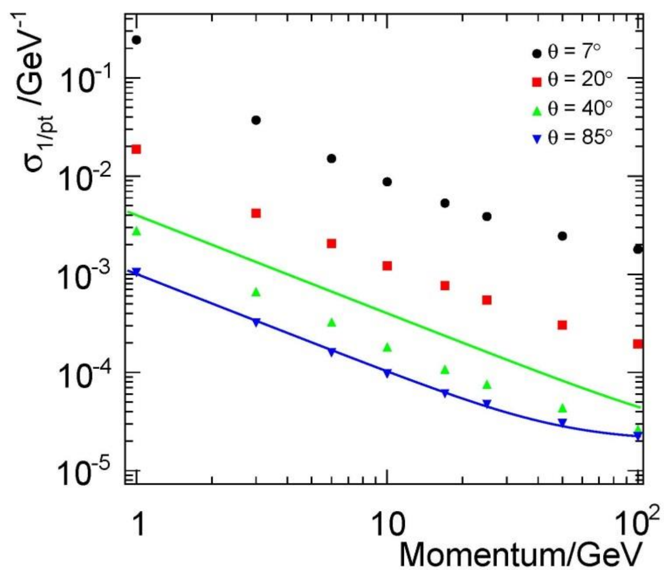
Good momentum resolution

Real layout ILD inner part



$$\frac{\sigma(p_T)}{p_T} = \sqrt{\frac{720}{N+4}}\sigma_{r\phi}\frac{p_T}{0.3BL^2},$$ *(ideal)*





Complex tracking system:

– $\sigma_{r\phi}$ not uniform

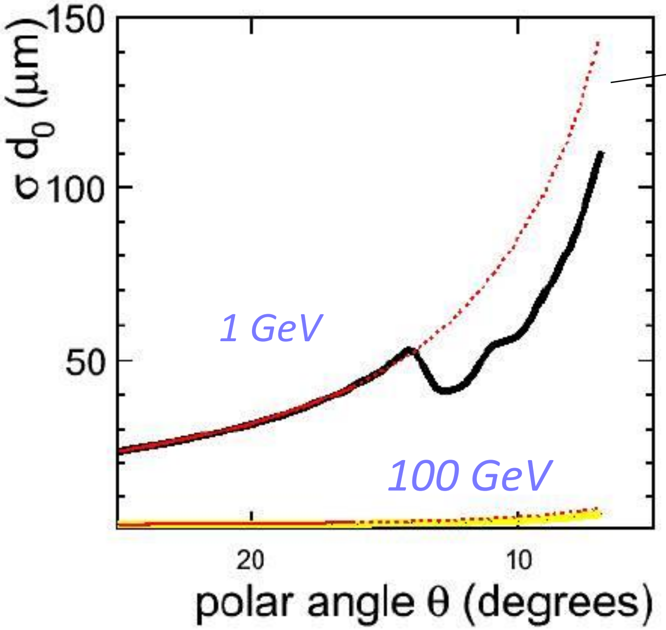
- at angles<40º, N decreases, added to shorter L

- forward tracking, N<10, $\sigma_{r\phi}$ ~7μm

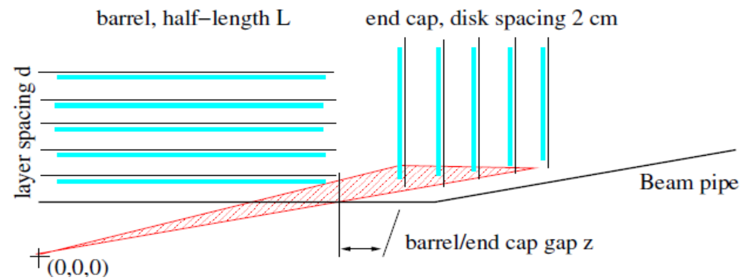
Multiple scattering contribution depends on the material budget. Equals the other term at p~50GeV, at large angle

A. Ruiz-Jimeno,LCWS13-Tokyo

Good impact parameter precision

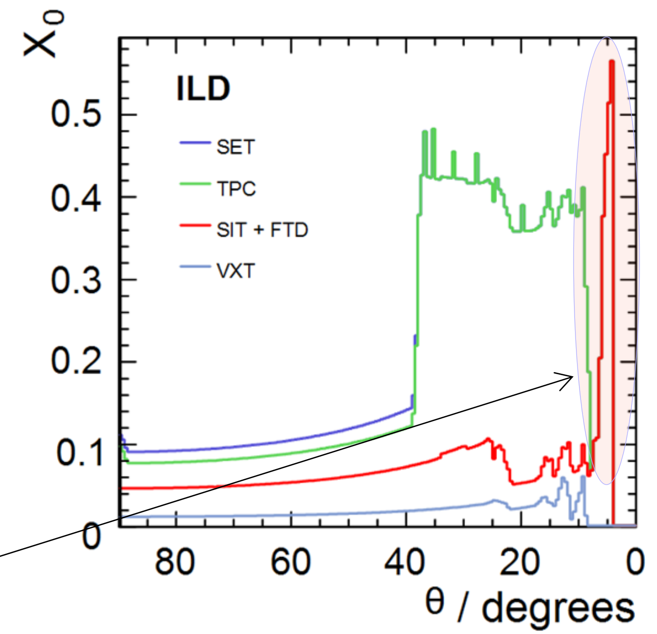


Functional form, toy detector with 0,12% X_0 per layer, 3 μ spatial resolution in rϕ and z



*JINST **8** T06001 2013*

Realistic material budget can degrade notoriously the impact parameter resolution



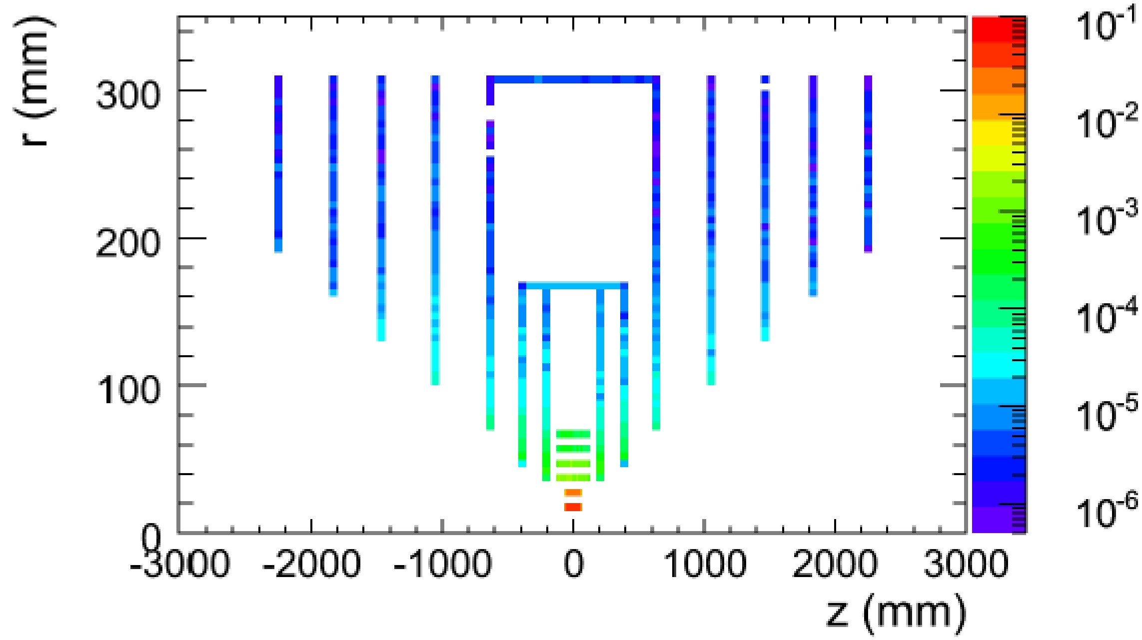
Mainly cables, services… (not FTD)

A. Ruiz-Jimeno,LCWS13-Tokyo

Good pattern recognition

OCCUPANCY AT ILD/ILC

Detector element	Hit density (hits/mm^2/BX)
VXD1	3.2×10^{-2}
VXD6	2.4×10^{-4}
SIT2	4.0×10^{-5}
FTD1	10^{-3} - 10^{-5}
FTD7	1.0×10^{-5}



FTD1 (ee→tt) average

$$1 \times 10^{-4} \frac{\text{hits}}{\text{mm}^2} + 1.6 \times 10^{-4} \frac{\text{hits}}{\text{mm}^2\text{BX}}.$$

FTD1 (ee→tt) peak

$$1 \times 10^{-2} \frac{\text{hits}}{\text{mm}^2} + 1.6 \times 10^{-3} \frac{\text{hits}}{\text{mm}^2\text{BX}}.$$

JINST **8** T06001 2013

OCCUPANCY AT ILD-ILC (500 GeV operation, LoI results)

Technology	Cell area (μm x μm)	Integration time	Peak occupancy
VXD	25 x 25	50 μs	$6 \times 10^{-6} + 1 \times 10^{-6}$/BX
Hybrid pixel	50 x 500	10 - 100 ns	$2 \times 10^{-4} + 4 \times 10^{-5}$/BX
μ–strip	50×10^{5}	10 – 100 ns	5 % + 1 %/BX

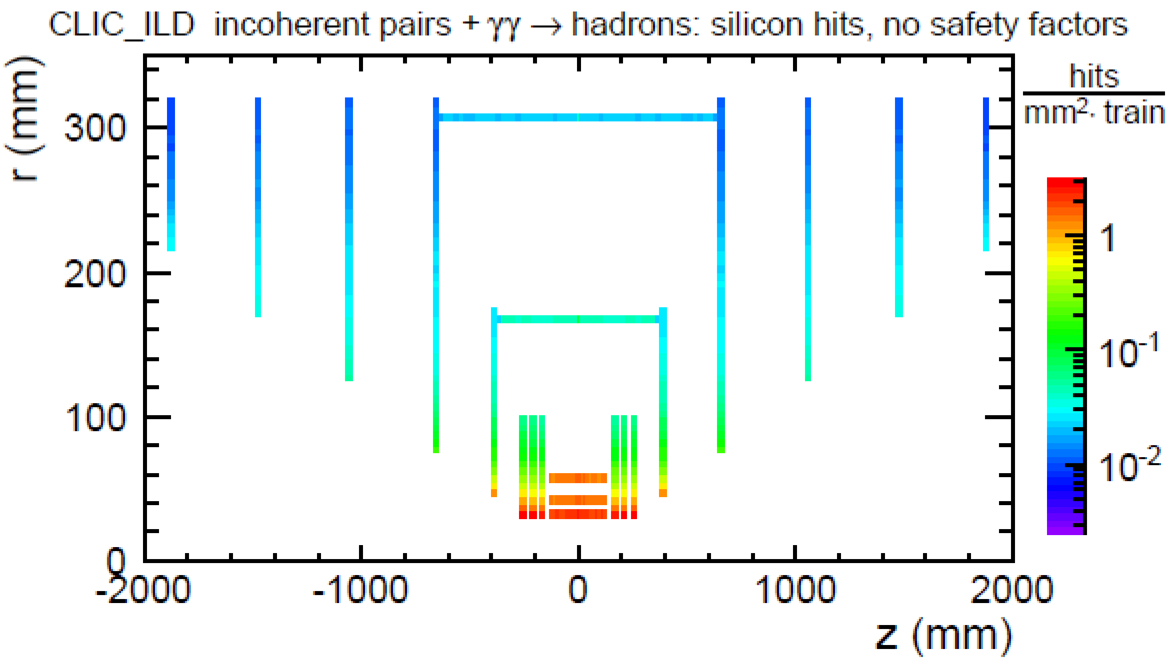
10 cm long, 50 μm wide strips → peak occupancy of 6%/BX, too high

Pixels of 25*25 μm^2 in the most inner region allows robust pattern recognition for a readout time of 50 μsec (about 100 BX) →occupancy at peak about 10^{-4}, comfortable

Also acceptable pixel CCD detectors 10*10 μm^2 integrating 1312 BX

OCCUPANCY AT CLIC

Detector element	Hit density (hits/mm^2/BX)
VXD1	7×10^{-3}
VXD6	8×10^{-4}
SIT2	7×10^{-5}
VXEC1	7×10^{-3}
	- 5×10^{-5}
FTD1	7×10^{-3}
	- 1×10^{-4}
FTD5	9×10^{-4}



BX separated 0.5 nsec, tracking and vertex detector integrating over the train duration of 156 nsec.

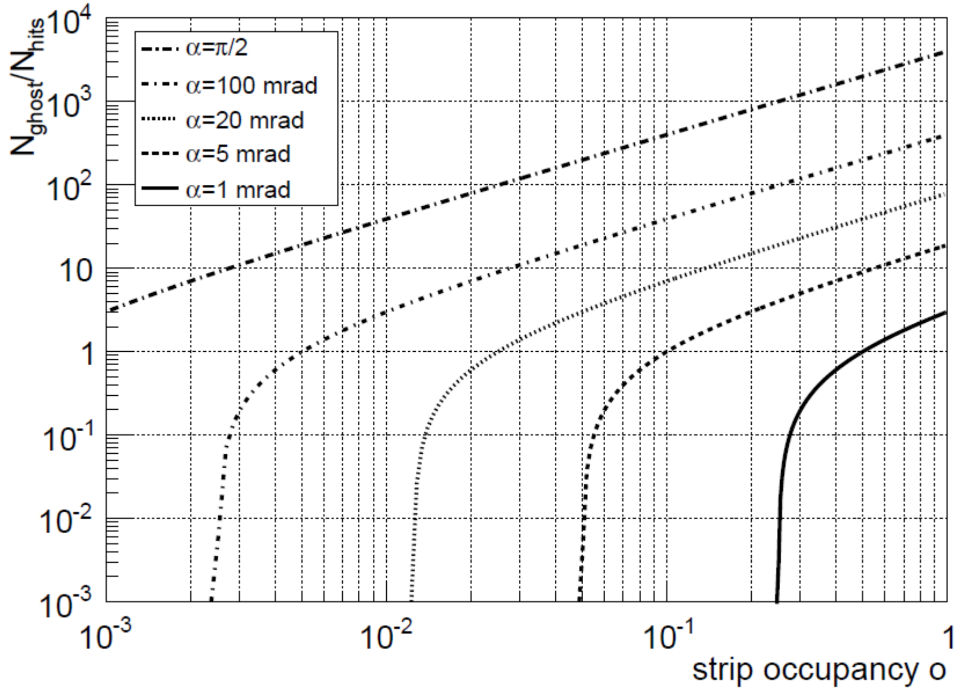
To maintain comfortable level of occupancy, time stamping with 10 nsec. precision is sufficient

Low-mass and low-power hybrid pixel detectors with a pitch of aprox.25*25 μm^2 and readout architecture based on TimePix are foreseen

Ultra-fast detectors with Time stamping at the level of 1 BX in study

Good pattern recognition

Microstrip detectors in the forward tracker have radially oriented strips. To constraint the second coordinate with a low proportion of ghost hits, an stereo angle α of about 100 mrad will be used



$$\sigma(r\phi) = \frac{\sigma}{\sqrt{2}\cos(\alpha/2)},$$

$$\sigma(r) = \frac{\sigma}{\sqrt{2}\sin(\alpha/2)}$$

*100*100 mm^2 sensors with 25 μm pitch*

α= 100 mrad → $\sigma(r) = 20\ \sigma(r\phi)$

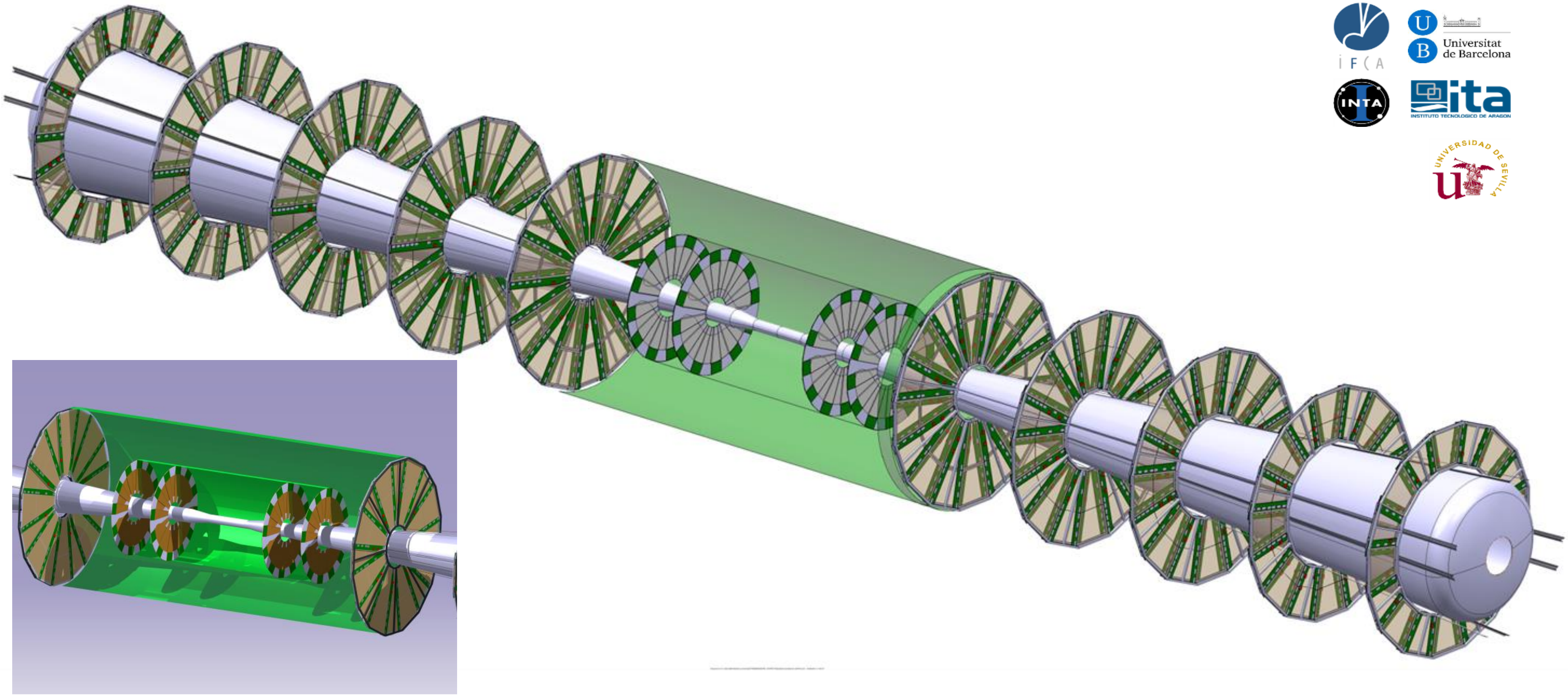
Moderately precise r-measurements should be needed in all the forward tracking layers to have a robust pattern recognition

*JINST **8** T06001 2013*

FORWARD TRACKER STATUS

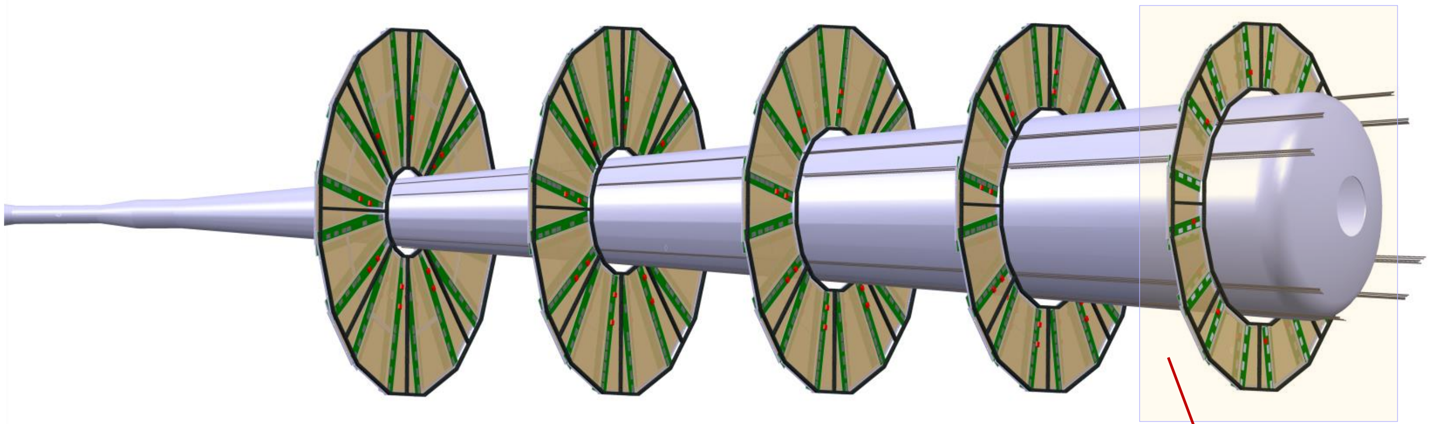
Baseline sensor: *conventional microstrip sensor with integrated signal routing in a second metal layer.*

Baseline operational unit: *petal (sensor+standard hybrid board(s) with readout, powering and data link circuitry.*

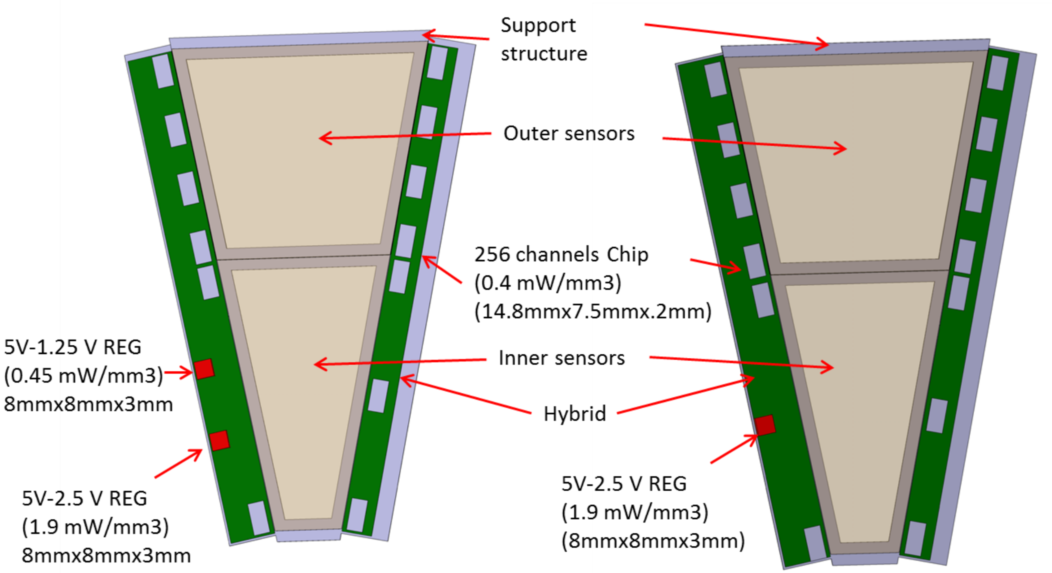


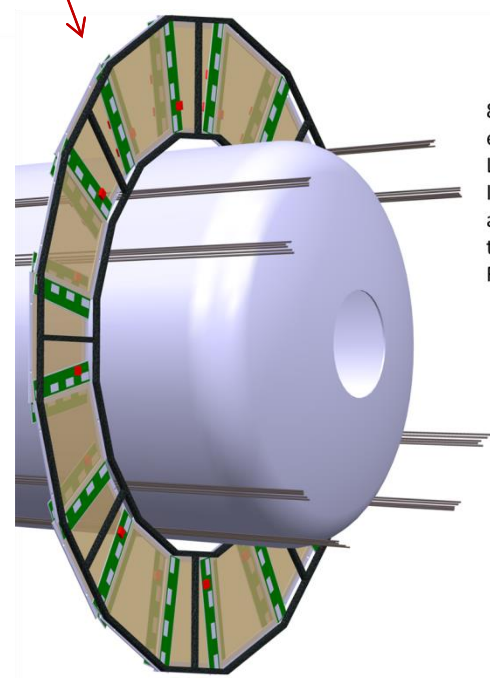
FORWARD TRACKER STATUS

MECHANIC,CABLES



FRONT SIDE



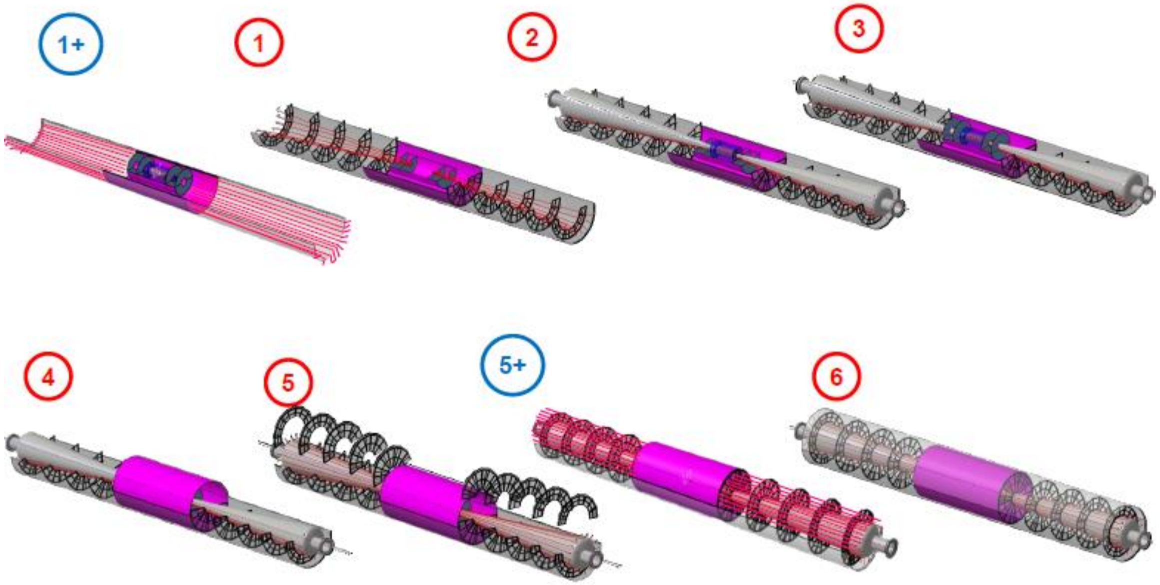


8 cables bunches each composed of 5 LV and 5 HV cables. In total 40 LV cables and 40 HV cables at the outer part (only FTD3-7.

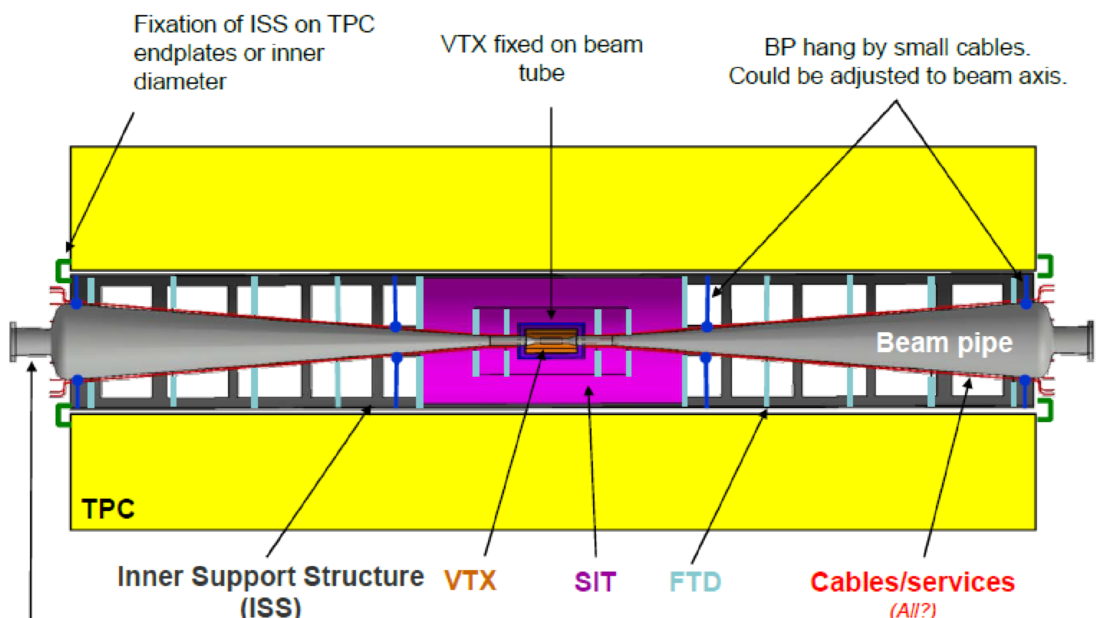
STUDY, PROGRESSING

FORWARD TRACKER STATUS

ASSEMBLING



STUDY, PROGRESSING



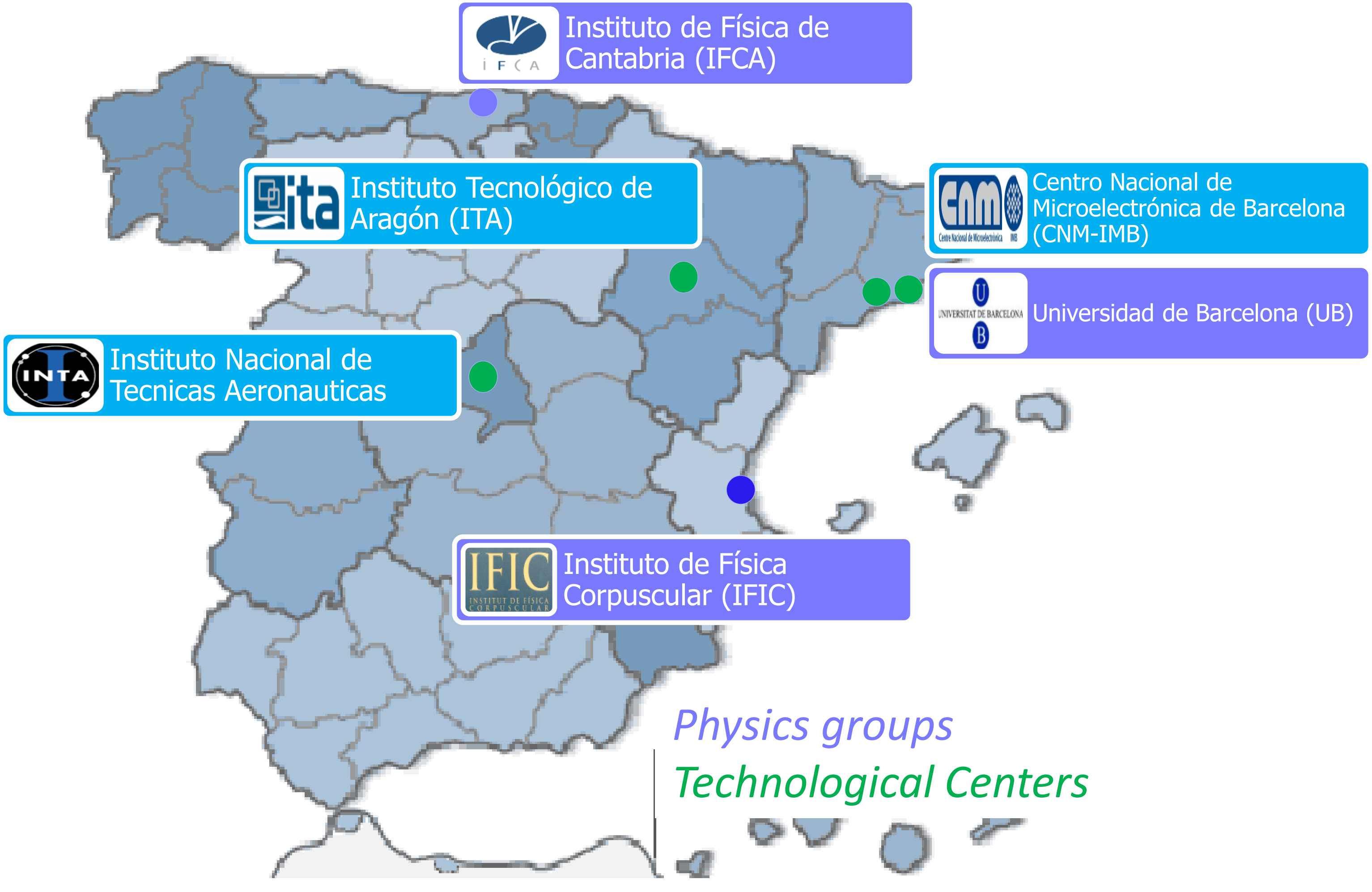
A. Ruiz-Jimeno,LCWS13-Tokyo

Critical & Beyond the baseline R&D

- What are the Critical R&D activities mandatory to fulfill the base line design ?
- What are the R&D beyond-the-baseline RD lines that will enhance the detector performance ?

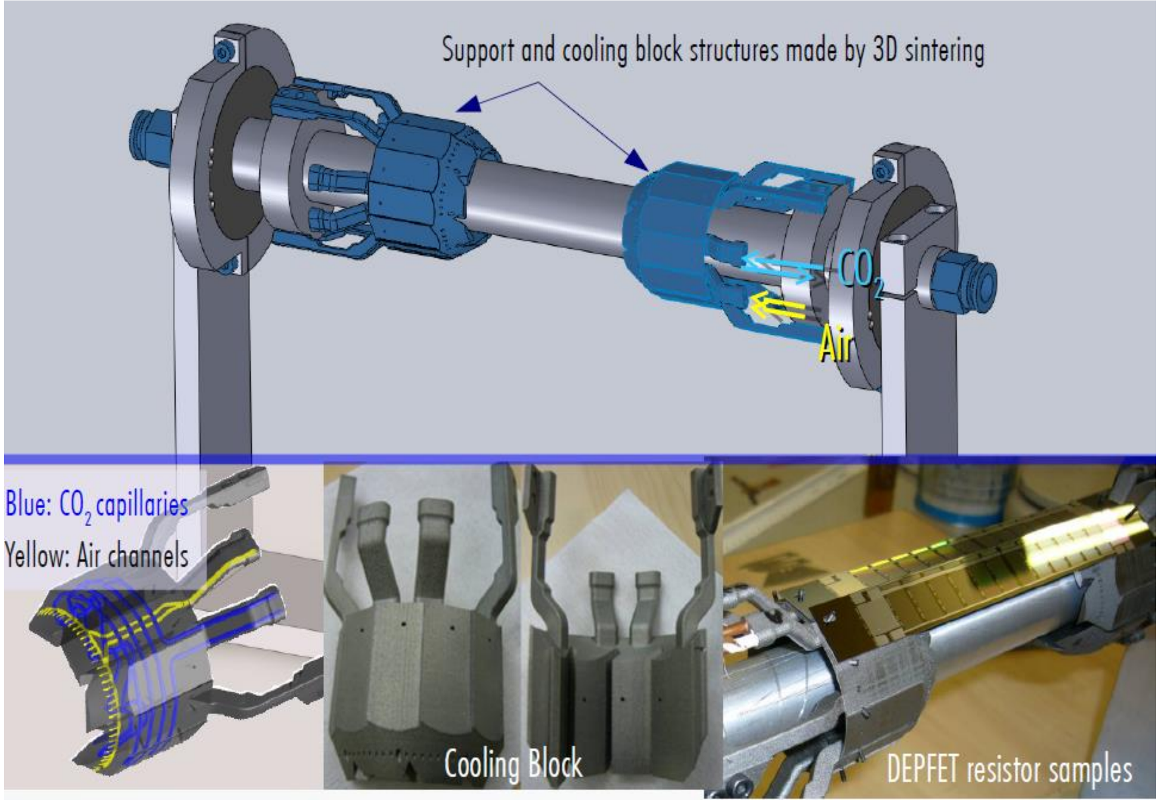
R&D	Critical	Beyond Baseline
Granularity: Short strips / Resistive electrodes		X
Thermal management: air(gas) cooling, thermal disipation	X	
Front-end: R/O chip, data link.	X	
Powering: Power pulsing, Long term Reliability	X	
Mechanics and integration: Structural Self-monitoring, alignment		X

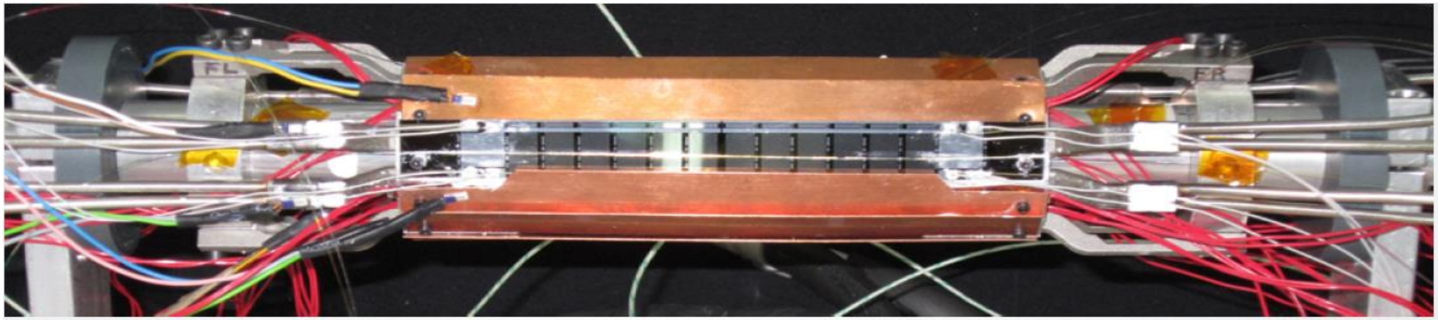
Coordinate (three year scale) R&D project in preparation + Ciemat (Calorimetry)



Critical R&D: Thermal Management

- Goal: gas(air) cooling (avoid active cooling burden)
- Challenging task for inner tracking system.
- Partial synergy with Belle-II PXD cooling system.
  - Air cooling system
  - Small footprint fast optical FBGs sensors for thermal mockup diagnostic.





Valencia PXD Mockup

Thermal Management

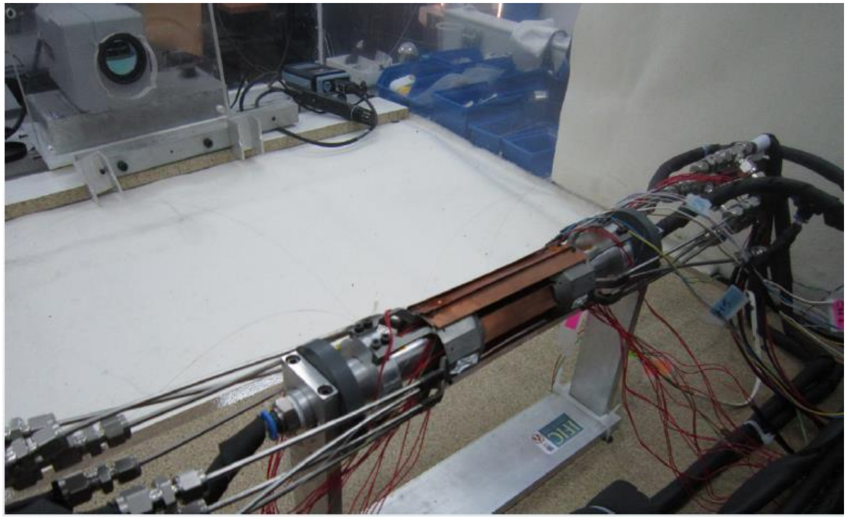
Stainless Steel Cooling Blocks, enclosed with copper foil ladders equipped with resistive heaters in the end flanges for both layers.

A single Si thinned detector with printed Al resistors

Liquid CO_2 circulating in the cooling blocks at -35 º C. Injection of N_2 gas cooled at 0ºC towards the sensor region at 3 bar and 15L/min flow rate. The beam pipe is kept at 15ºC with a composite liquid coolant

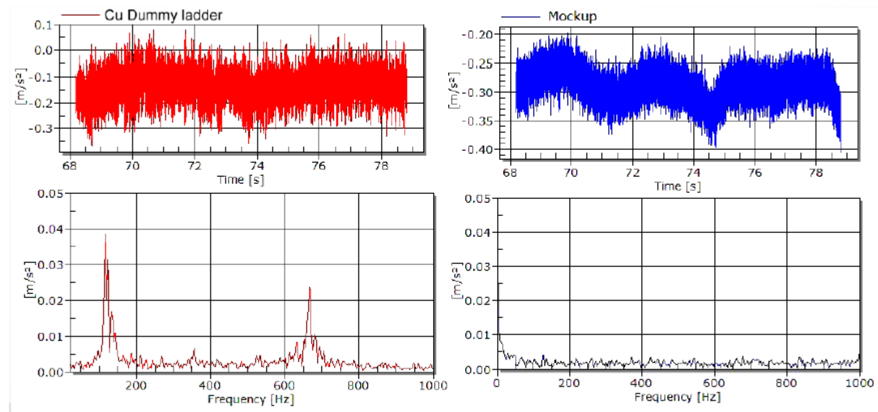
The measurement equipment inside a sealed methacrylate box consist of

- Infrared thermal imaging camera
- Fibber Bragg Grating (FBG) temperature and humidity sensors
- Pt110 probes



Sensor T	Ambient T = 25ºC	
Without convective cooling	T_{MAX}=~40ºC	ΔT=~15ºC
With convective cooling	T_{MAX}=~25ºC	ΔT=~5ºC

No vibrations were observed below 2kHz (sensor cutoff) with the cooling requirements (3 bar in the entrance pipes).



THERMAL MANAGEMENT:

- Needed more effort to characterize innermost disks
- Fabrication mock-ups, measurements and simulation
- We have instalations

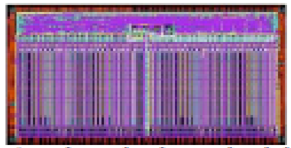
FRONT END ELECTRONICS

FPA2008-04122-E | FPA2008-05979-C04-02 | AIDA

2007 · 2008 · 2009 · 2010 · 2011

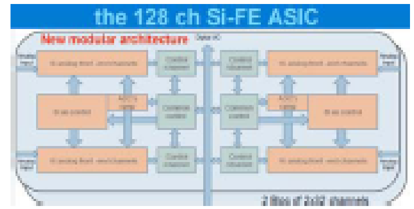
Start of collaboration with IN2P3
Design of the digital part

SiTR-88-130UMC

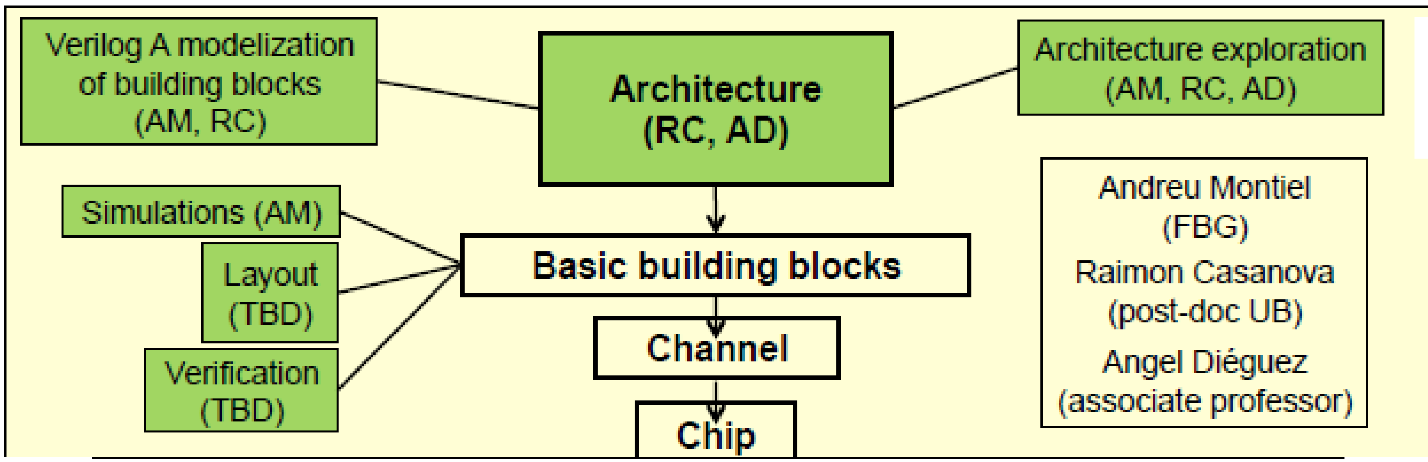


(1st mixed signal chip)

Definition of new architecture



Complete new design (responsability of UB)



Dr. Ángel Diéguez adieguez@el.ub.edu
Electronics Departament, University of Barcelona

VLSI Design Group

Department of Electronics Universitat de Barcelona

Universitat de Barcelona

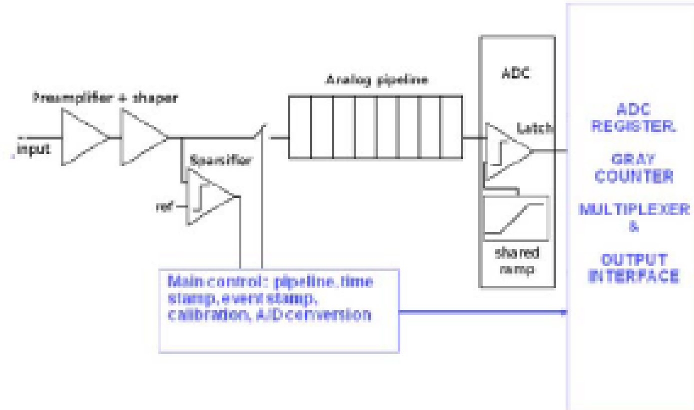
In an initial phase. Much work to be done

There are possible fall-back solutions

Critical R&D: R/O ASIC

Universitat de Barcelona

- In AIDA-WP9 a readout chip for Si-microstrips for ILD is being developed by UB with 65nm process
  - ✓ Designed:
    - *T indep current source*
    - Amplifier in the preamplifier
    - Preamplifier, shaper
  - ➢ *To be designed*
    - Analog pipeline, Ramp or SAR ADC,
    - Discriminator, sparsifier, digital logic, I2C/SPI, LVDS, …



Concurrent designs with 65nm process:

- 65nm process is used in the development of the DHP together with Bonn Univ. in the framework of DEPFET collaboration for Belle II
  - ✓ Designed, fabricated and tested:
    - *T indep current sources, current-mode DAC*
  - ➢ *Designed*
    - T sensor

AIDA

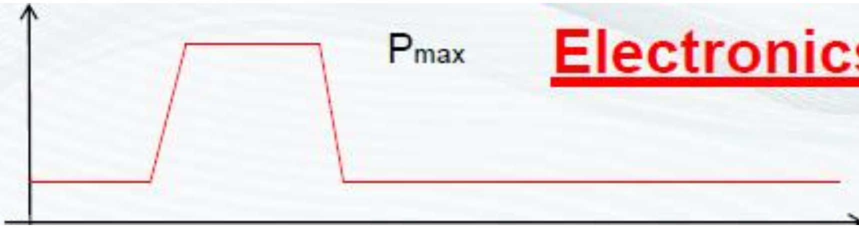
Critical R&D: R/O ASIC (2)

Universitat de Barcelona

– Medium term plans

TASKS	Responsible Centre	Responsible Person	First Year				Second Year				Third Year			
			1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT
5.1 Module design	UB	Coord: AD UB: AD, RC, OA, JC, EV, LUB	■	■	■	■	■	■	■	■	■	■		
- Front-end, biasing circuits, config. DACs			■	■	■	■	■	■	■	■	■	■		
- ADC							■	■	■	■	■	■		
- Digital modules							■	■	■	■	■	■		
2.2 Channel integration	UB	Coord: AD UB: AD, RC, OA, JC, EV, LUB					■	■	■	■	■	■		
- Single channel							■	■	■	■				
- 16/32 channels									■	■	■	■		
2.3 Customized DAQ and Test '	UB, USE	Coord: RP, ML UB: AD, ML, OA, JC USE: RP, RF			■	■	■	■	■	■	■	■	■	■
- Software and configware development					■	■	■	■	■	■	■	■	■	■
- ASIC validation tests						■		■		■	■		■	■
- Hybrid prototype development					■	■	■	■						
- DAQ for channel/multi-channel ASICs							■	■	■	■	■	■	■	■

Critical R&D: Pulsed powering . Medium term plans



Electronics duty cycle /power ?

$P_{standby}$ = 20% P_{max}

5ms/200ms
20%P_{max}

- The total Strip-FTD current / power demanded is:
  - Bunch crossing state 458 A (**≈ 860 W**)
  - Stand-by state 91.6A (**≈ 171W**)

	MIDDLE PITCH									
FTD	*FTD3*		*FTD4*		*FTD5*		*FTD6*		*FTD7*	
	INN	*OUT*	*INN*	*OUT*	*INN*	*OUT*	*INN*	*OUT*	*INN*	*OUT*
Nº Readout	***33920***	***61504***	***41600***	***64224***	***45472***	***65504***	***51232***	***67424***	***63424***	
Chips per petal (256 ch)	*24*		*26*		*28*		*29*		*16*	
Optical links per petal	*1/2*		*1/2*		*1/2*		*1/2*		*1/2*	
I1.5 (A) per Petal	*1.75 / 0.35*		*1.9 / 0.38*		*2.05 / 0.41*		*2.12 / 0.42*		*1.16 / 0.23*	
I2.5 (A) per Petal	*1.05 / 0.21*		*1.13 / 0.23*		*1.22 / 0.24*		*1.27 / 0.25*		*0.7 / 0.14*	
I per petal	*2.79 / 0.56*		*3.03 / 0.61*		*3.26 / 0.65*		*3.39 / 0.68*		*1.86 / 0.37*	
I per disk	*44.6 / 8.9*		*48.5 / 9.71*		*52.08 / 10.42*		*54.19 /10 .84*		*29.76 /5.95*	
TOTAL Mstrip- FTD Current (both sides)		*458 A / 91.6 A*								

(CMS upgrade TK el

ita

Critical R&D: Pulsed powering .

	DC-DC	Super-caps
Power dissipation	228 W	395 W
EMI phenomena	Yes	No*
RAD tolerant	Yes	? (First test OK)
Material budget	(240 DC-DC) ?	(80 SC) ?
Reliability	?	?
Power pulse applications	Not frequent	Yes
Installed power	1.4 kW	0.48 kW
Primary PS	≈ 36 W	≈ 15 W
Mains protection (UPS effect)	No	Yes

WORK ONGOING SATISFACTORILY

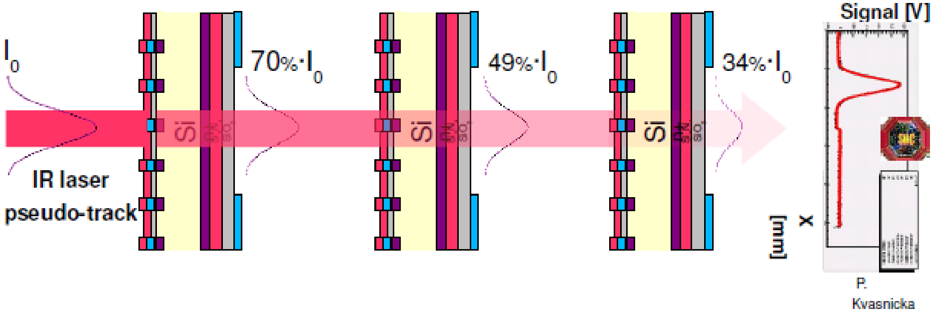
Critical R&D: Pulsed powering (2)
Medium term plans

TASKS	Responsible Centre	Responsible Person	First Year				Second Year				Third Year			
			1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT
Super-capacitor Hardness Assessment.	ITA	A.Pradas	■	■	■	■	■	■	■	■				
EMC issues in power pulsing systems for HEP.	ITA	M.Iglesias						■	■	■	■	■	■	■
Reliability studies of Super-capacitors and DC-DC co for power pulsing applications in HEP .	ITA	FJ. Piedrafita				■	■	■	■	■	■	■		

DELIVERABLES	Type	First Year				Second Year				Third Year			
		1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT	1st QT	2nd QT	3th QT	4th QT
D4.1 Supercapacitor characterization unit for Radiation Environments (Prototype)				■									
D4.2 Specification of radiation hardness of super capacitor for physics experiments. (Paper)									■				
D4.3 EMC (conducted and radiated emissions) mapping of a power pulsing system (Paper)													■
D4.4 Design criteria to be followed for a FEE –hybrid – sensor design to operate in power pulsing system.												■	
D4.5 Overall reliability of a power pulsing system (Paper)											■		

ALIGNMENT

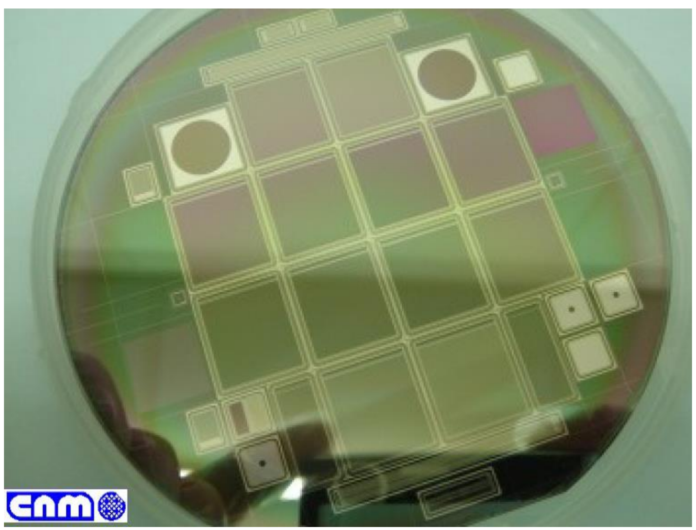
• Laser tracks can be used by a hardware system to align the tracker

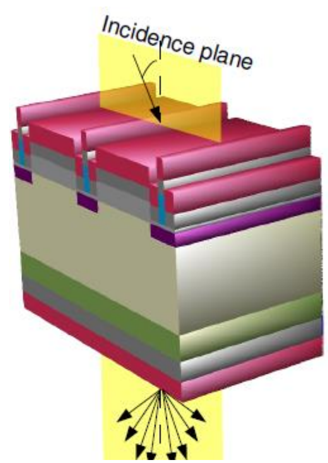


Improved InfraRed transparent microstrips detectors for tracker alignment

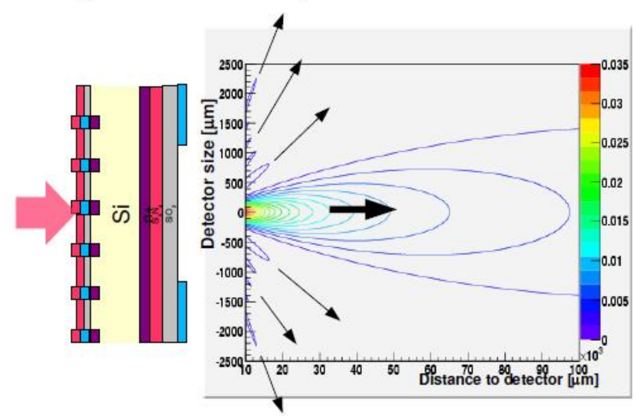
• First implemented by AMS I, then AMS II and CMS

WELL ADVANCED





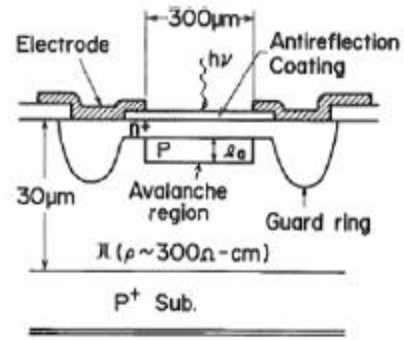
Including diffractional effects



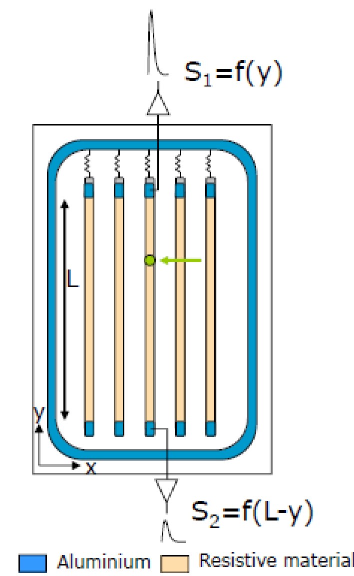
Beyond-the-base line R&D:

Sensors: Two R&D lines

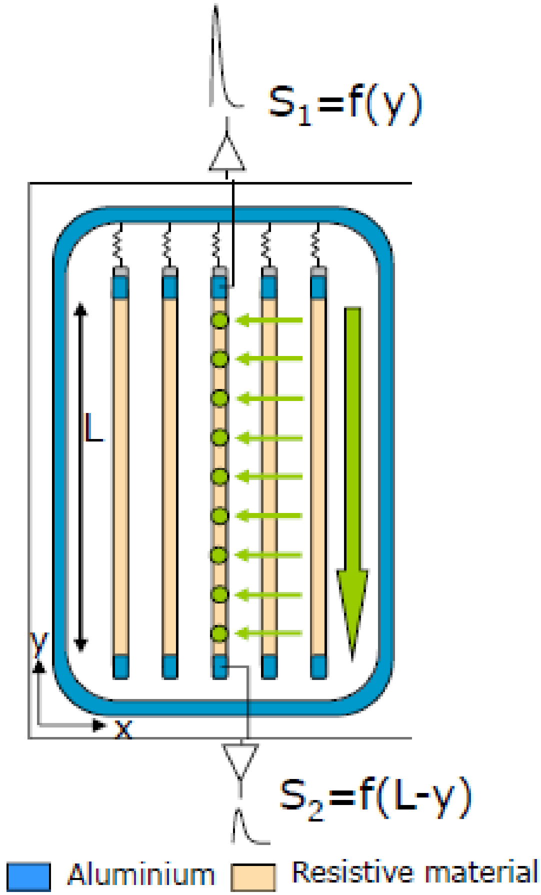
- Low gain p-type segmented pixels or strips →thinner sensor with same S/N



- Charge division in microstrips to reduce the complexity of double-sided sensors



Polysilicon resistive detectors

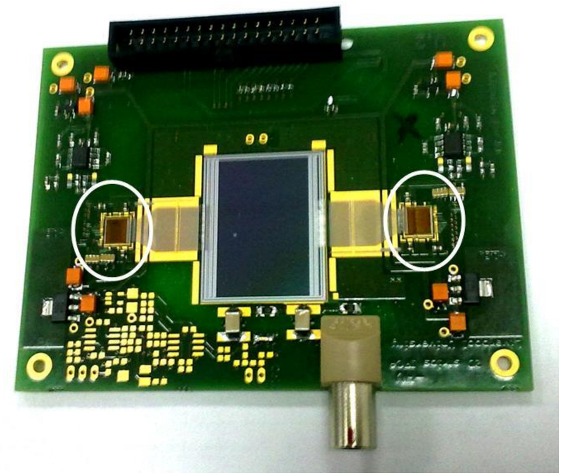


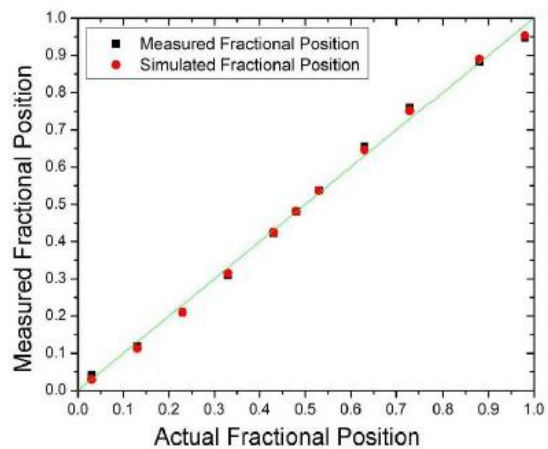
*** V. Radeka, IEEE Transaction on Nuclear Science NS-21 (1974) 51*

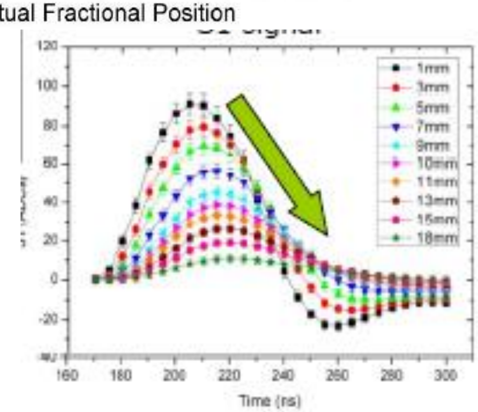
X-coordinate: cluster-finding algorithms for strip detectors

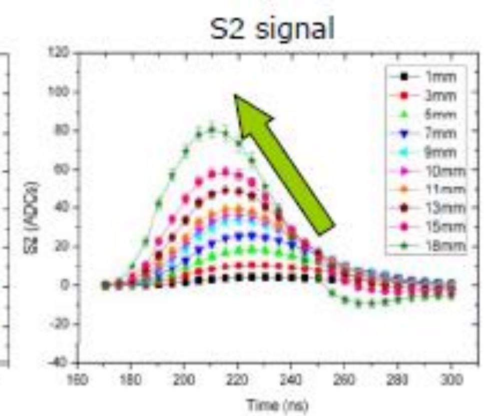
Y-coordinate: resistive charge division method

$$\frac{y}{L} = \frac{A_2}{A_1 + A_2}$$

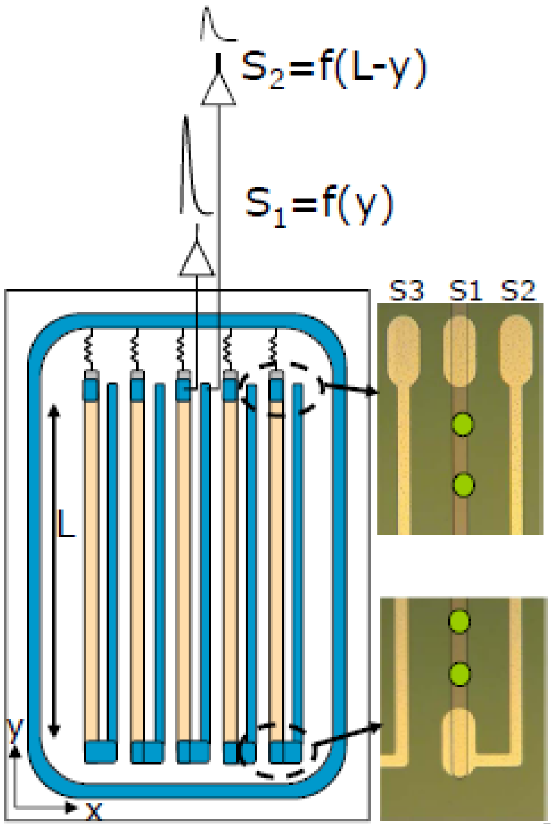




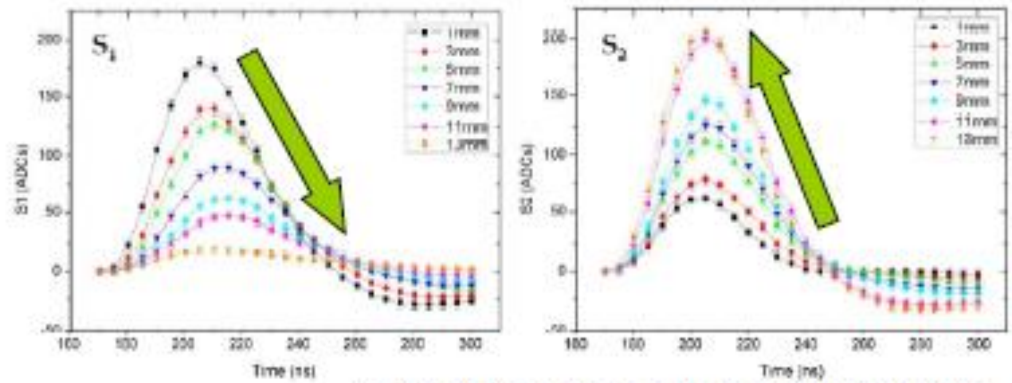




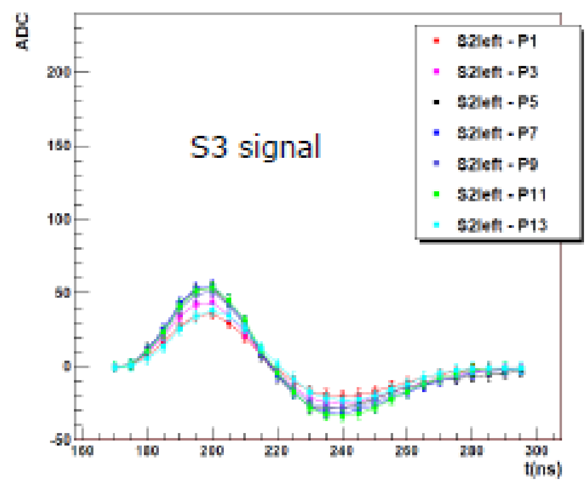
Polysilicon resistive detectors, integrate routing



Microstrips:
Length: 14mm
Width: 20um
Pitch: 160um
R/um=20Ω/um



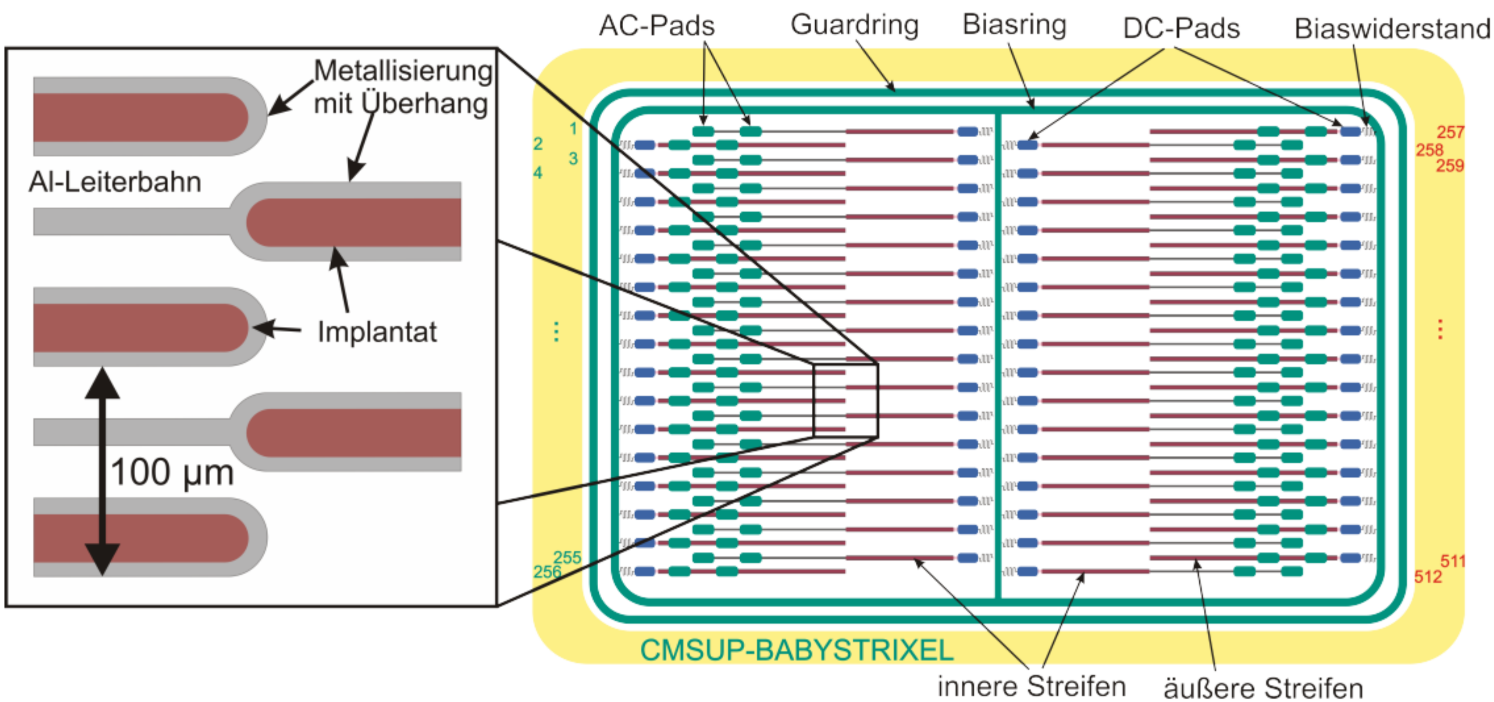
D. Bassignana et al., J. Inst. 7 (2012) C04008



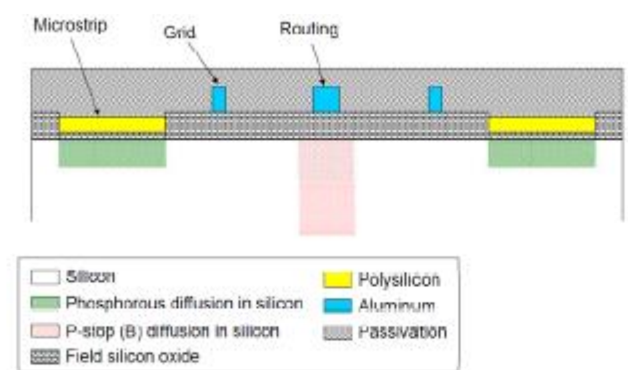
Signal not connected with iluminated strip

Similar to Foster issues

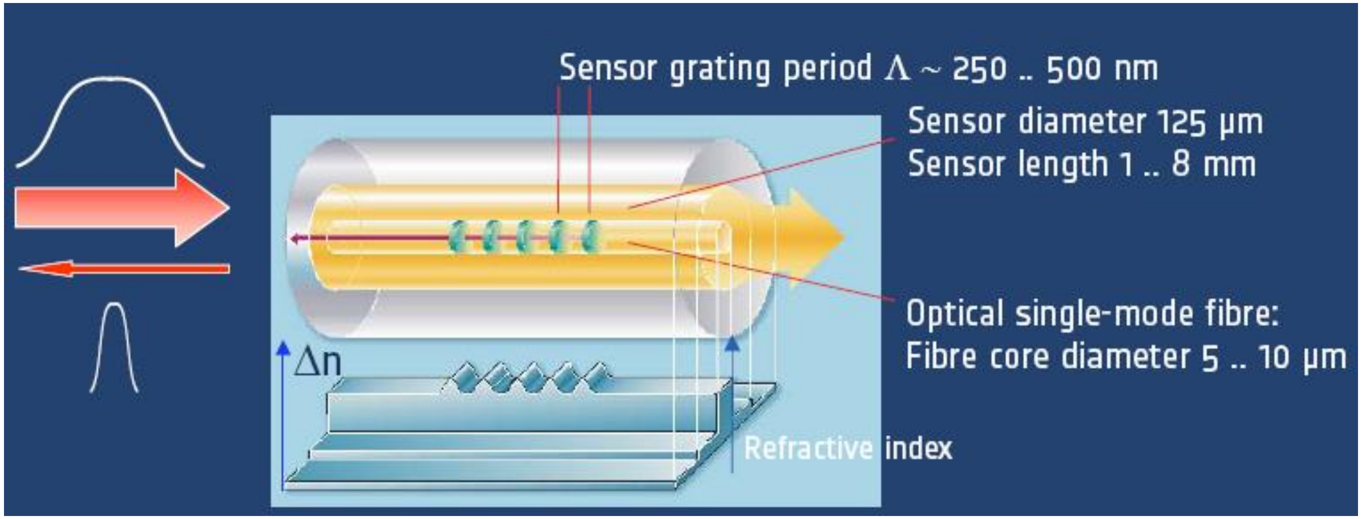
FOSTER sensors – A. Dierlamm, M. Strelzyk, M. Printz

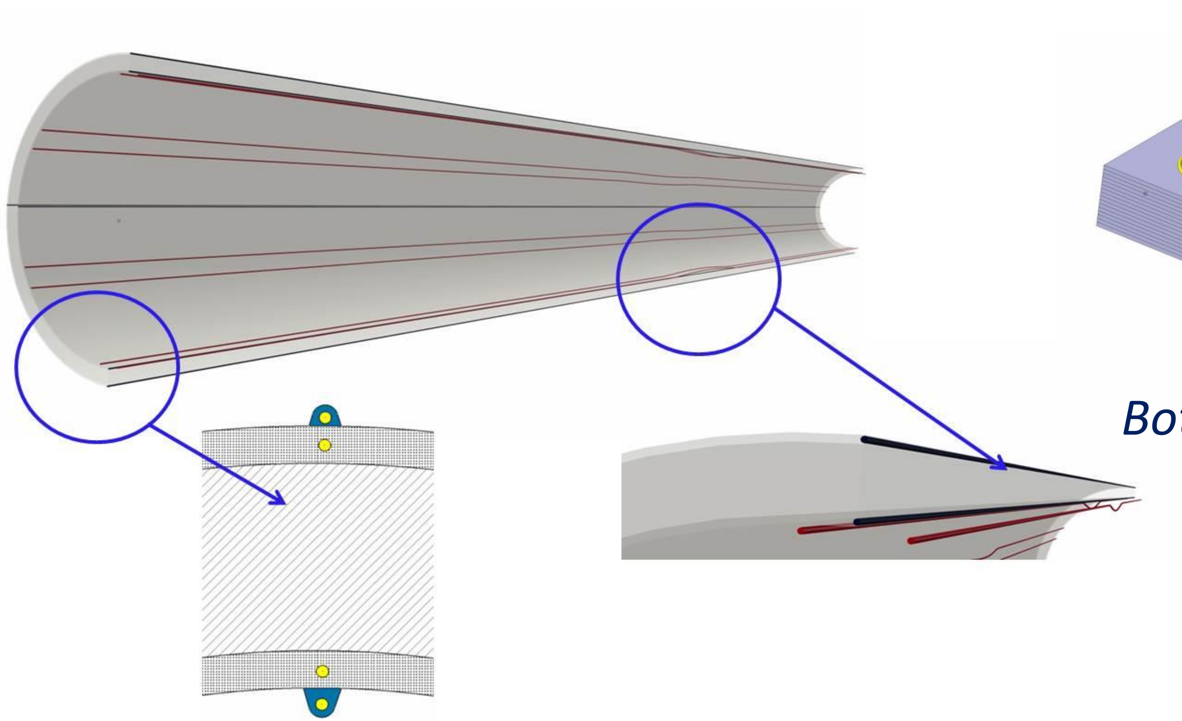


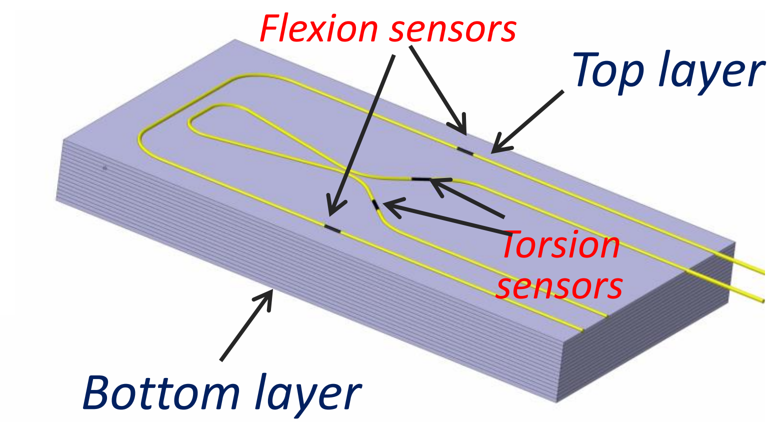
Idea: to implement a metal grid line to close the electric field lines and limit the crosstalk between polysilicon contact and routing line



Beyond the baseline: Smart Mechanics

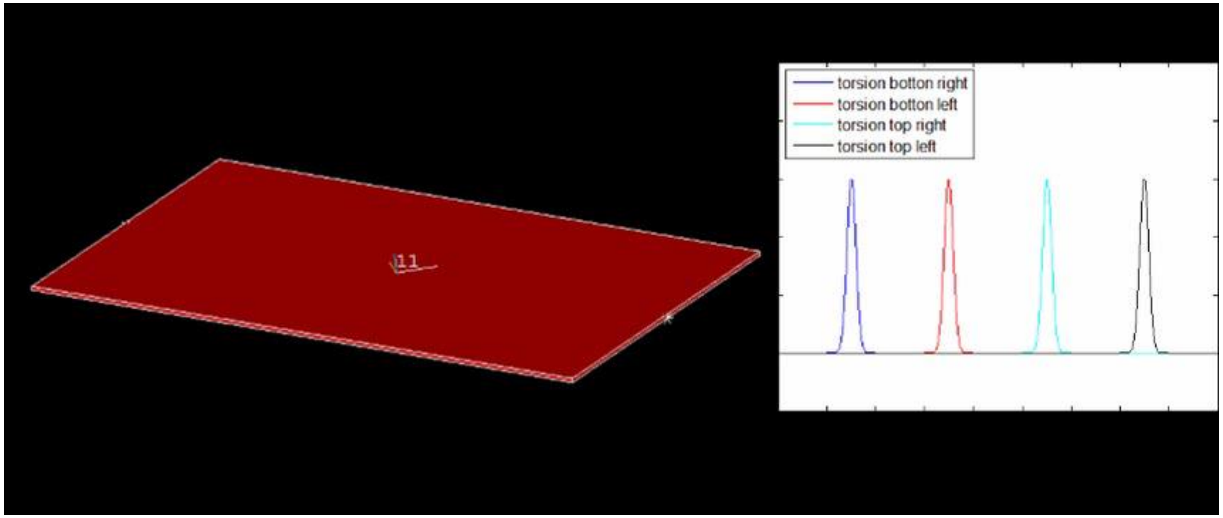


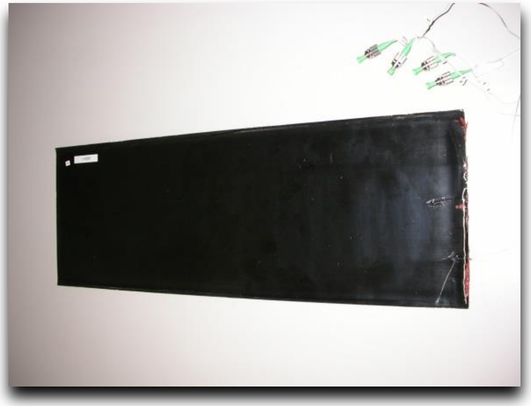


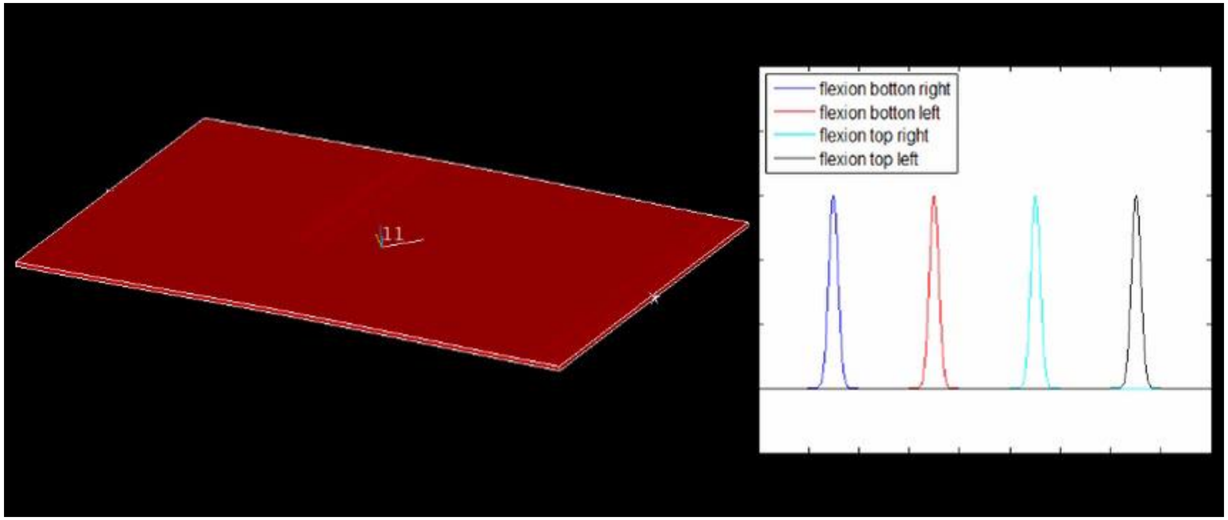


Beyond the baseline: Smart Mechanics (2)

Smart plate able to self monitor its own temperature, torsion and flexion deformations & vibrations

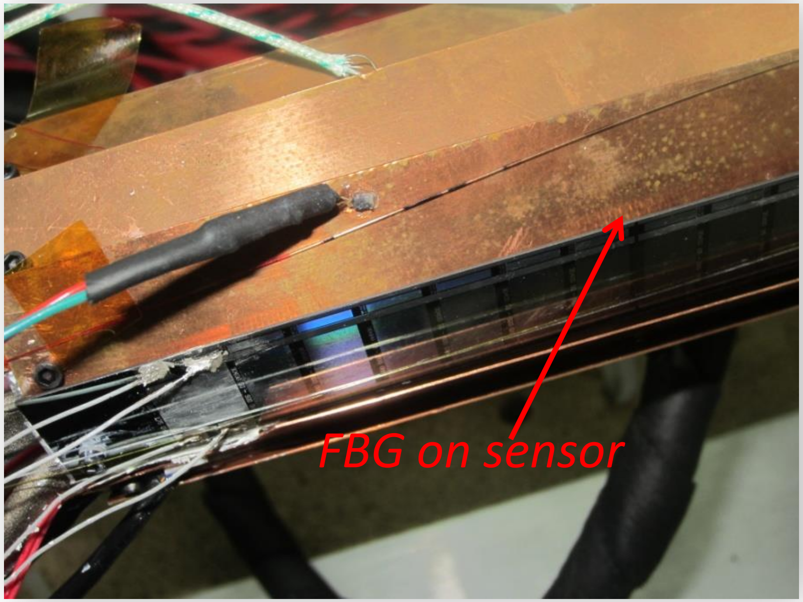


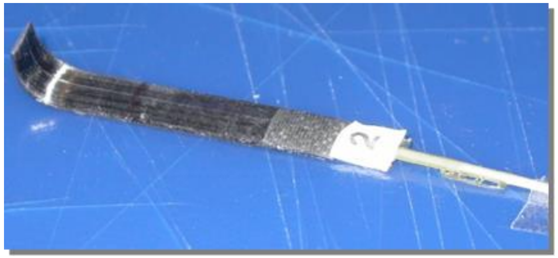


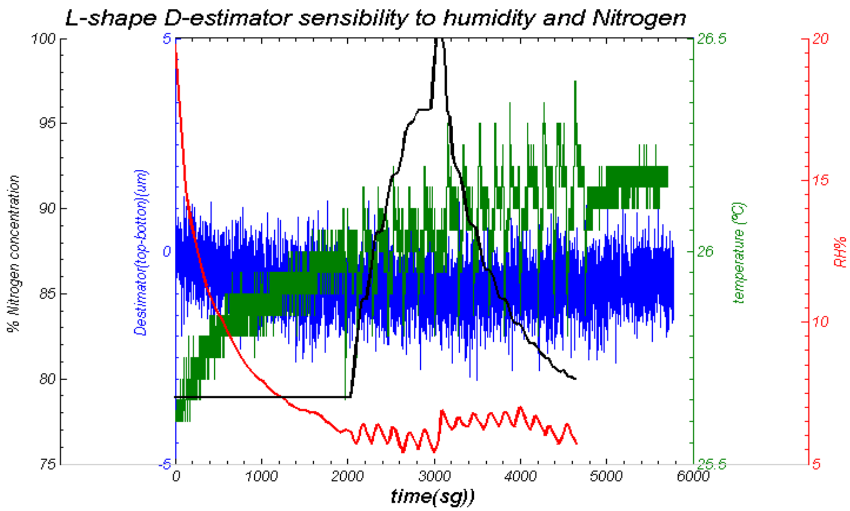


Beyond the baseline: Smart mechanics (3)

– Component-wise characterizations: FBGs calibrations and sensibility to nitrogen, humidity atmosphere.







Summary

- Critical R&D lines with different degree of coverage:
  - Thermal management & cooling
  - Pulse powering.
  - Readout ASIC
- Enhanced performance via additional R&D: Sensor granularity, smart mechanics:
- Moving from generic or Belle-II oriented R&D towards a coordinated and ILD oriented R&D project.

BACKUP

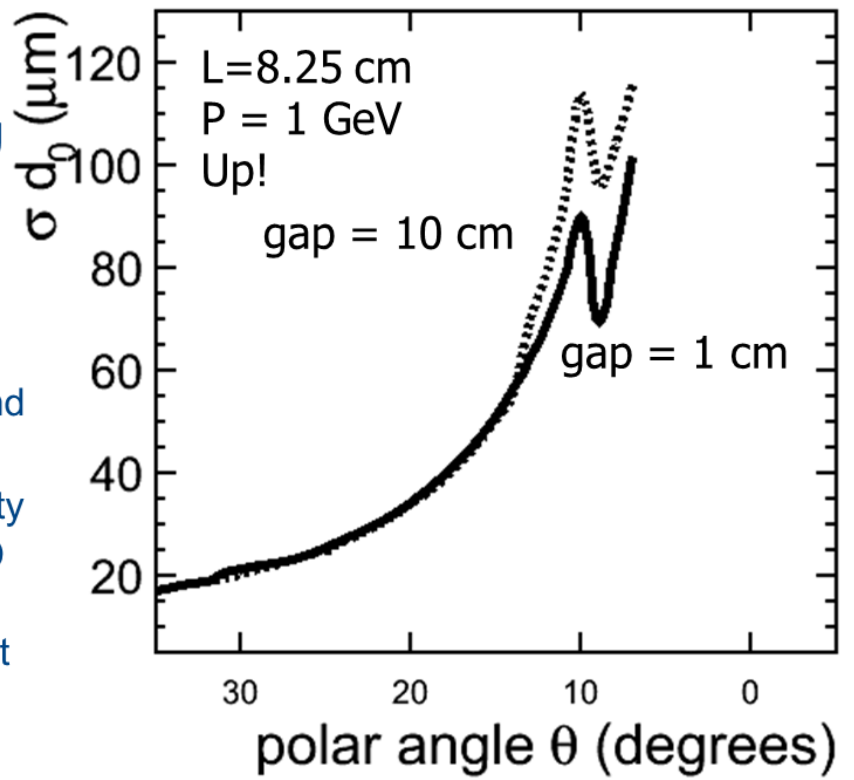
Zgap between the FTD1 and VTX

Comparison z_{gap}

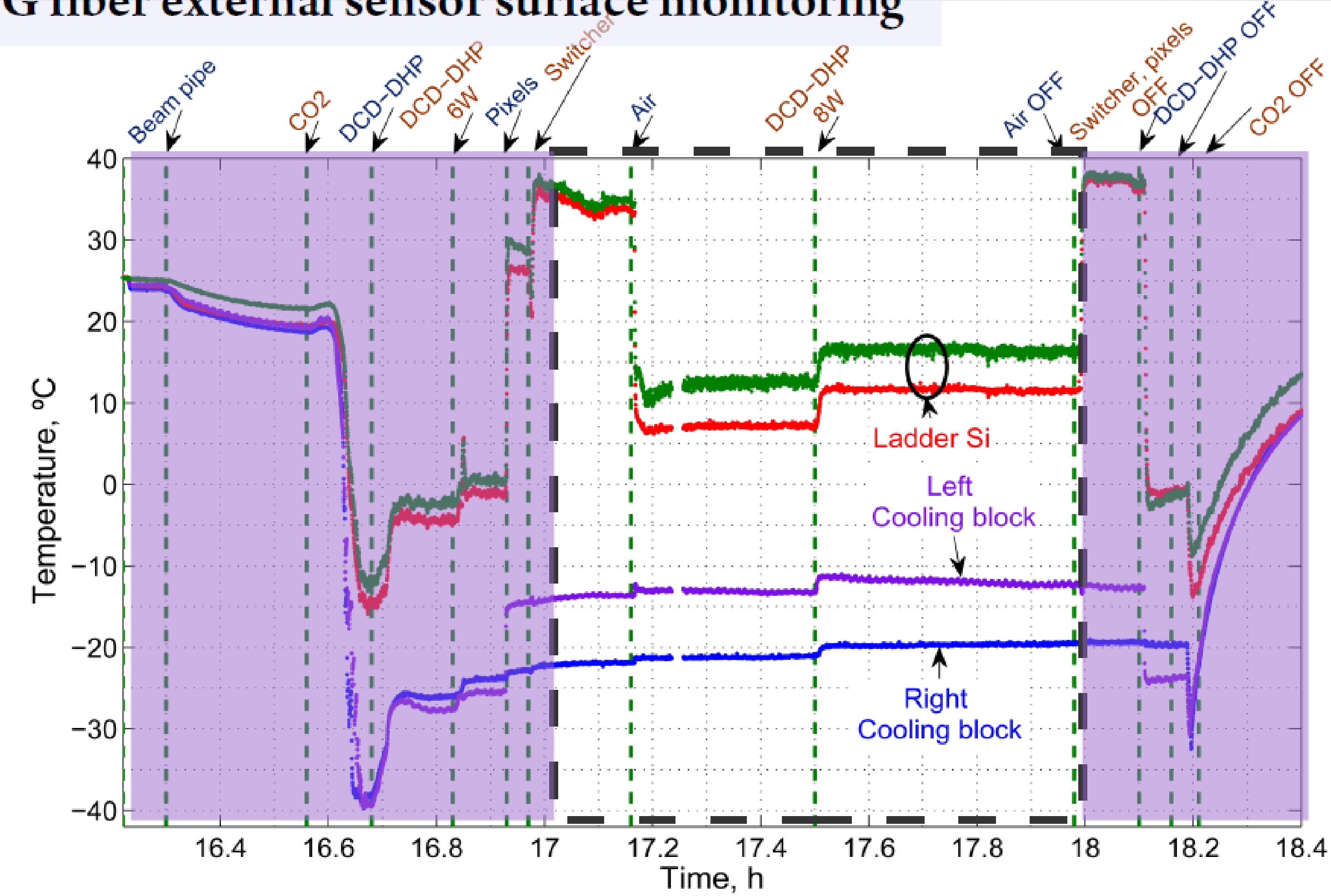
Minimize the gap! *

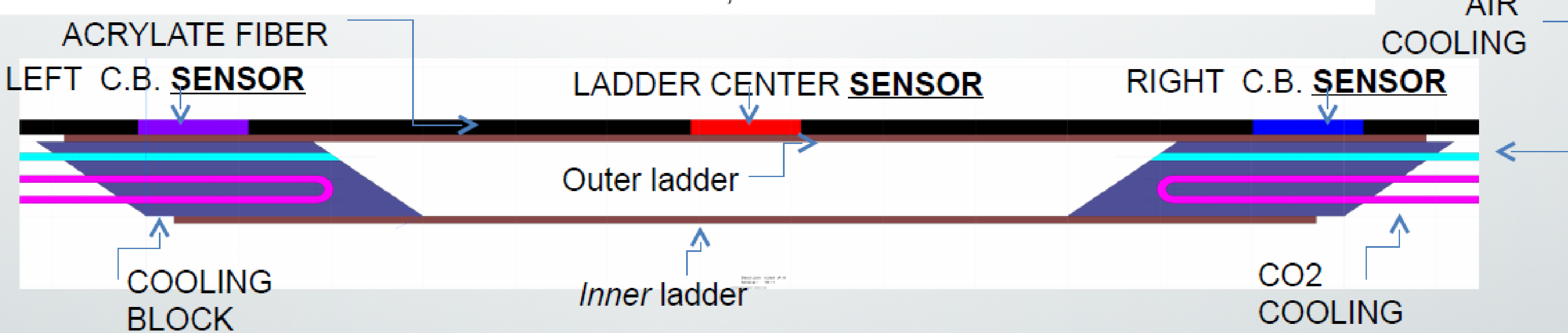
But: if we route the services along the beam pipe, the forward vertexing performance is terrible and essentially insensitive to z_{gap}

* In ILD the distance between VXD and innermost FTD is close to 10 cm. This clearance is motivated by the possibility to fit in a VXD cryostat. If a "cold" VXD technology is chosen, a short gap implies one has to install the innermost disks inside the cryostat.

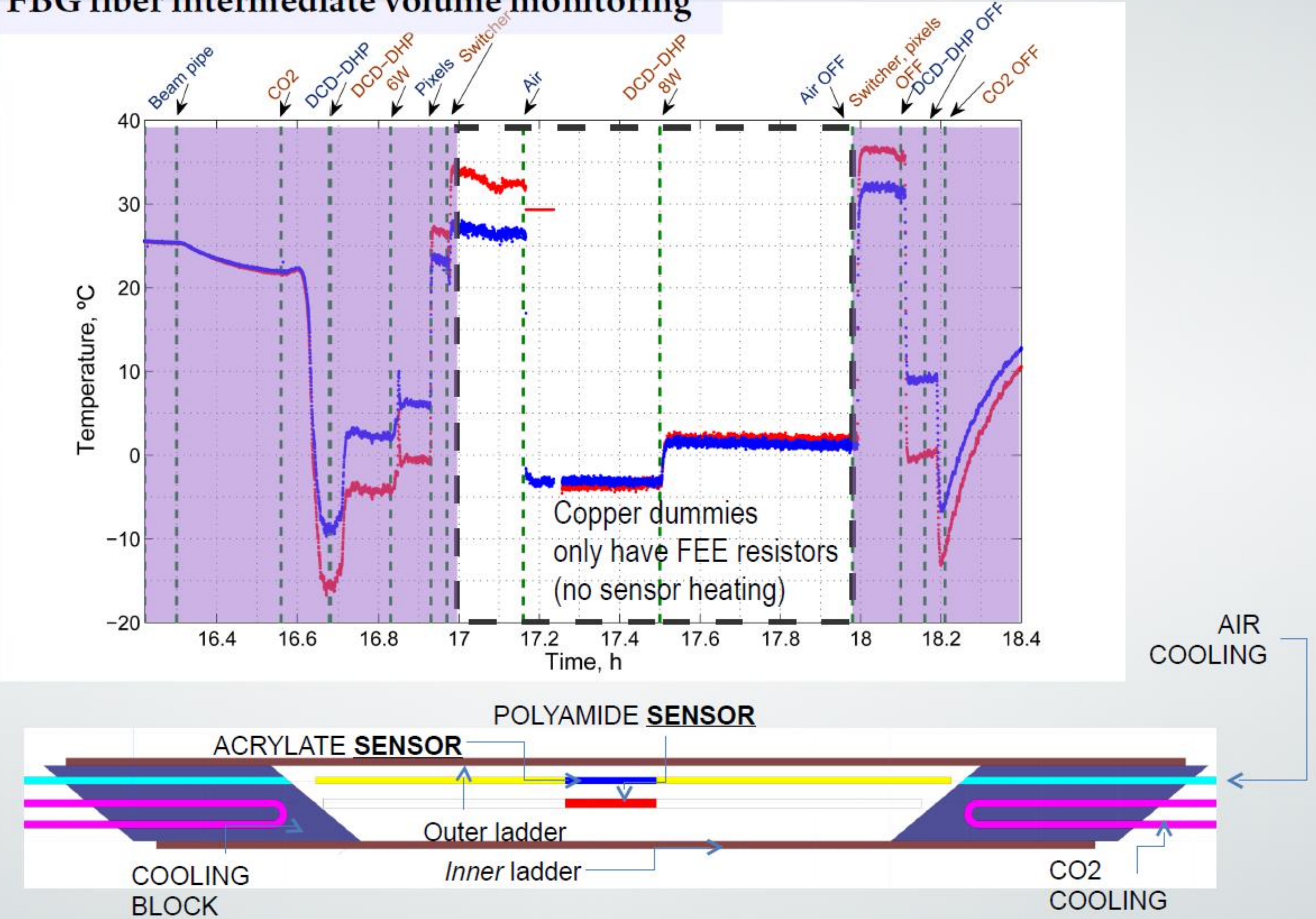


FBG fiber external sensor surface monitoring



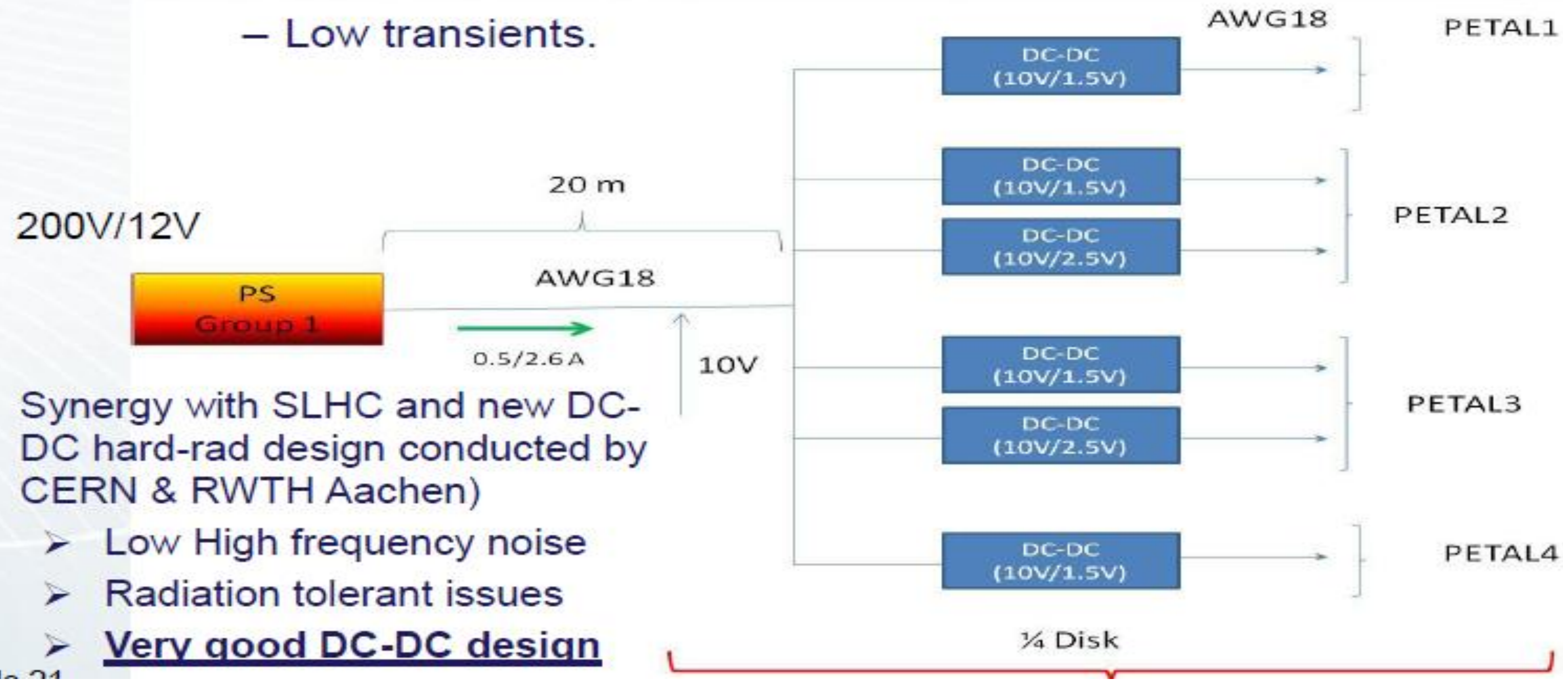


FBG fiber intermediate volume monitoring



DC-DC-based Power System

– It absorb transients related to power pulsing system.
  - Low currents before DC-DC due to converter ratio.
    – Low transients.



Synergy with SLHC and new DC-DC hard-rad design conducted by CERN & RWTH Aachen)

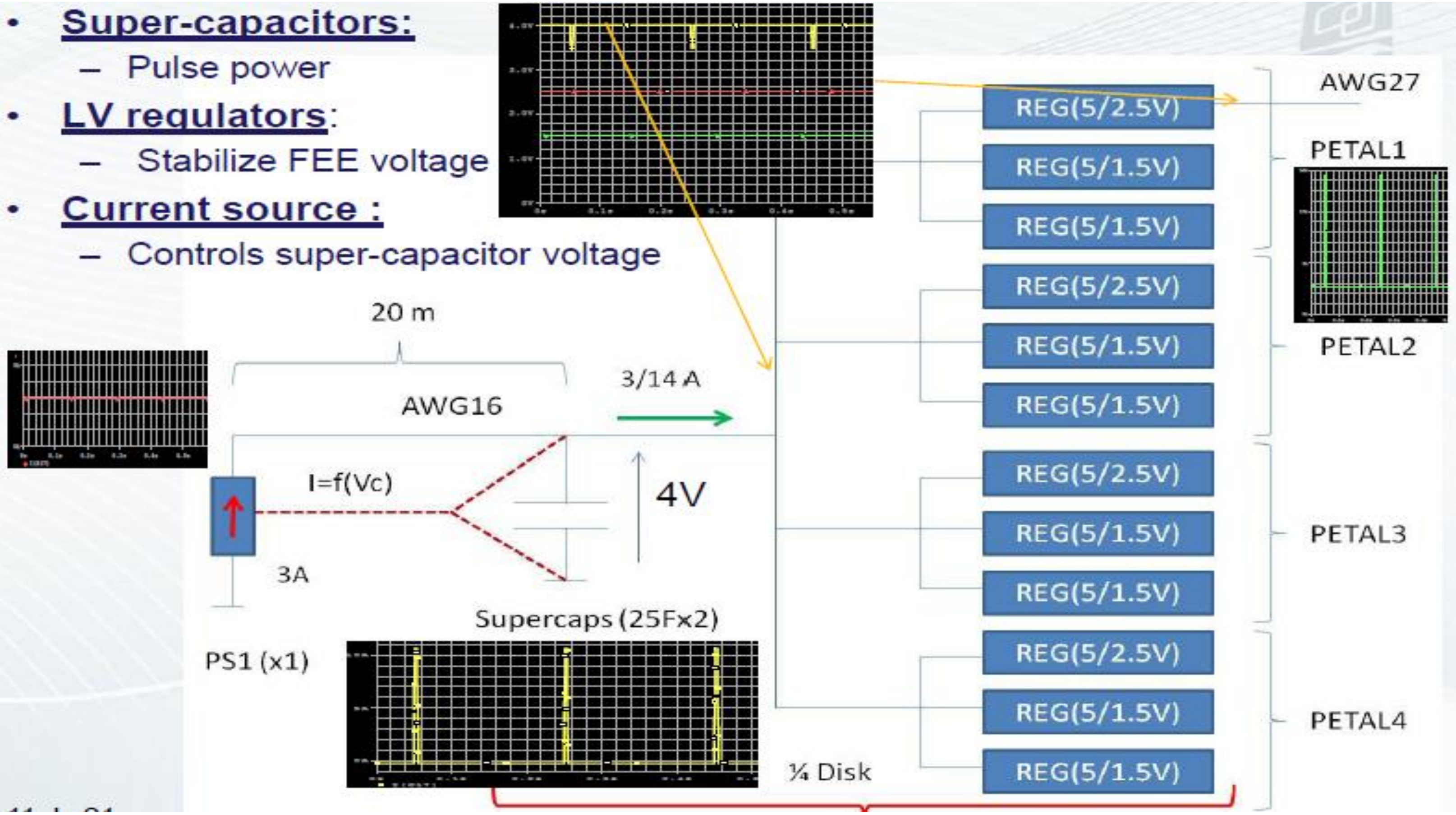
- Low High frequency noise
- Radiation tolerant issues
- **Very good DC-DC design**

	POWER (W)
HALF SIDE	114 W
TOTAL FTD	228 W

Group	FTD 3+	FTD4+	FTD5+	FTD6+	FTD7+
FEE	4.6	5	5.4	5.6	3
CABLE	0.02	0.033	0.039	0.041	0.012
DCDC*	0.92	1	1.07	1.11	0.61
TOTAL (1/4)	5.55	6.04	6.48	6.74	3.69
TOTAL DISK	22	24.1	26	27	14.7
External cable (20m)	0.23	0.27	0.31	0.34	0.1

Super-capacitor based PS

- **Super-capacitors:**
  - Pulse power
- **LV regulators**:
  - Stabilize FEE voltage
- **Current source :**
  - Controls super-capacitor voltage



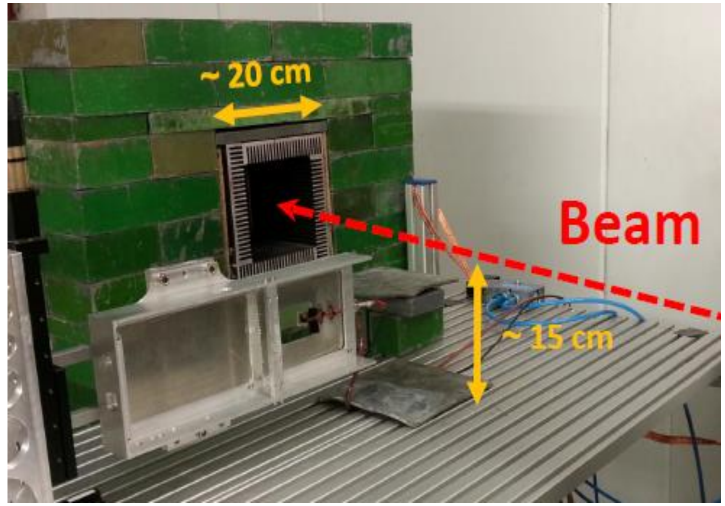
Group	FTD 3+	FTD4+	FTD5+	FTD6+	FTD7+
FEE	4.6	5	5.4	5.6	3
CABLE AWG 27	0.04	0.04	0.05	0.06	0.02
LV REG	4.9	5.41	5.74	5.96	3.24
SUPERCAPS	0.06	0.072	0.083	0.089	0.027
TOTAL (1/4)	9.63	10.6	11.3	11.7	6.4
TOTAL DISK	38.5	42.1	45	46.5	25.5
External cable (20m) – AWG 16	2.92	3.515	4	4.4	1.26

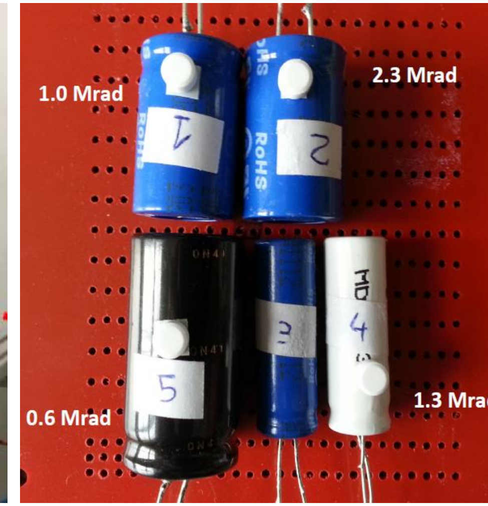
	POWER (W)
HALF SIDE	197 W
TOTAL FTD	**395 W**

Radiation test for Super-capacitors

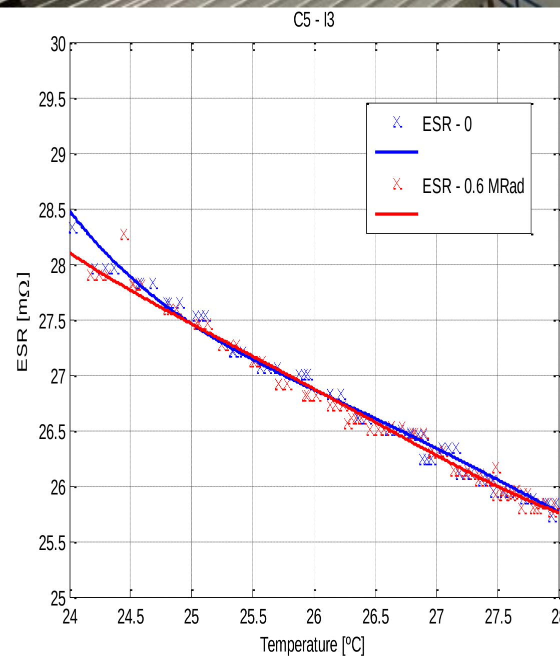
Radiation test has been performed at Electron Stretcher Accelerator

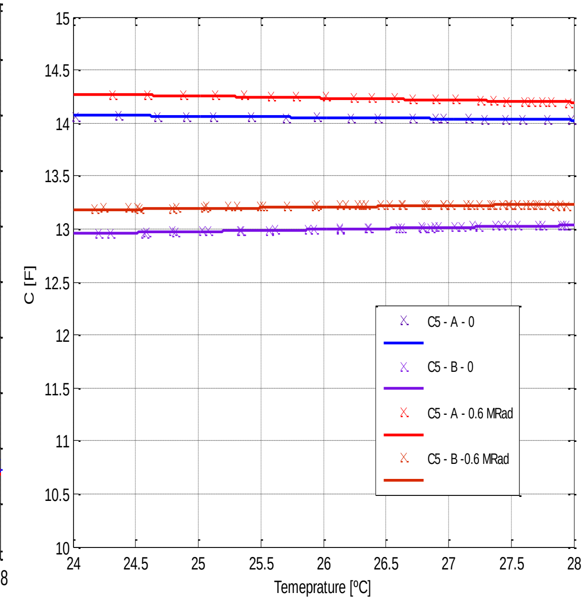
(ELSA, Bonn)





- Electrons at 20 MEV
- Beam spot – 3x3 cm2
- 4 hours of irradiation.
- Total dose :
  - 0.6 Mrad -2.3 Mrad (3%)
- C and ESR were measured
  - 5 capacitors





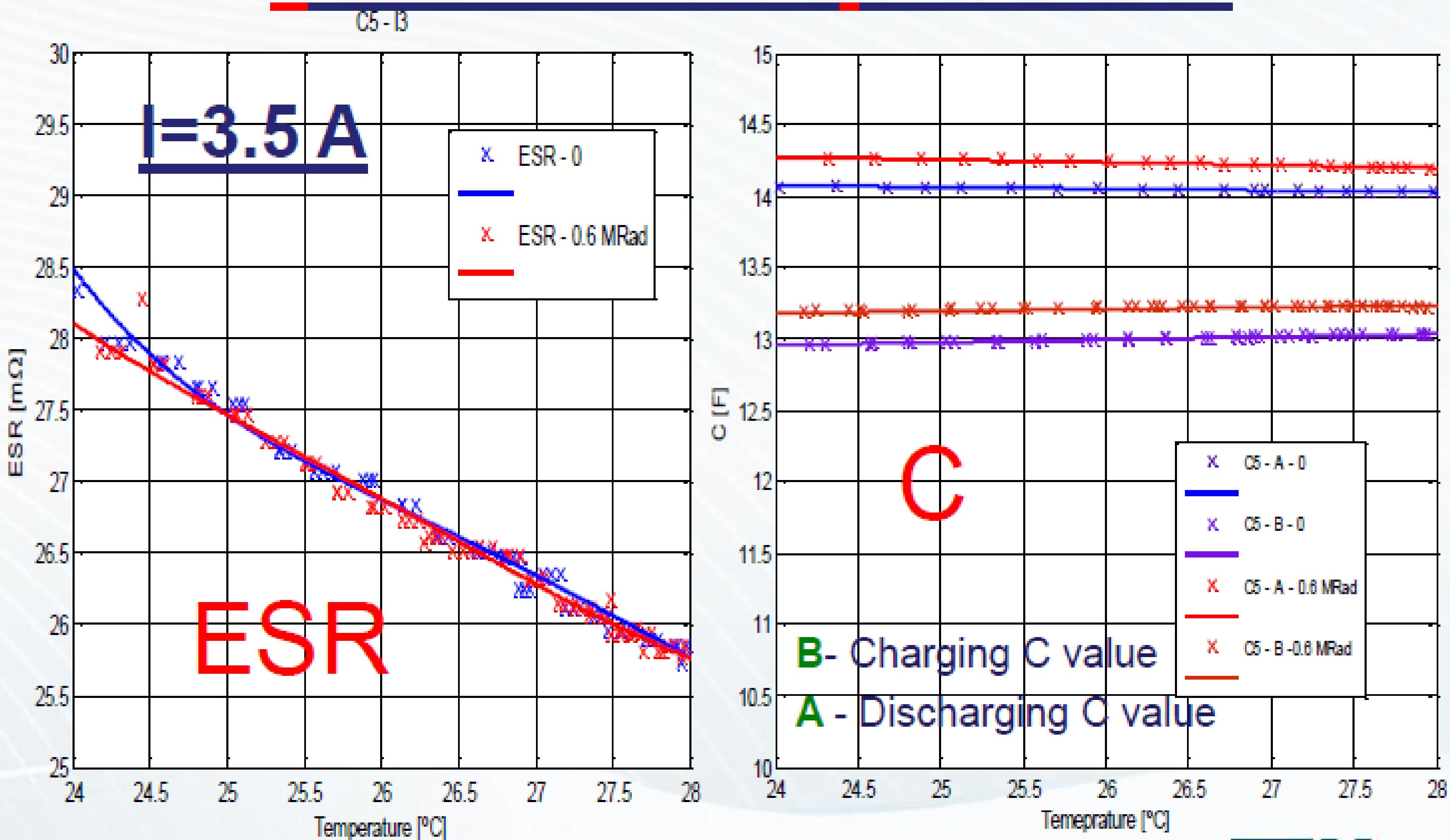
A. Ruiz-Jimeno,LCWS13-Tokyo

4.1 Radiation test for Super-capacitors

C = 10 F – Panasonic - 0.6 Mrad

Blue – Before radiation / Red – After radiation

X Measured values / - Fitted values



ILD meeting
Cracow, September 2013

4. Conclusions

- A first radiation test campaign has been carried out to validate super-capacitors for HEP applications.
- 5 Super-capacitors
  - Maxwell, Nesscap and Panasonic (10F & 25F)
- Tests have been performed based on constant current
  - Normal operation (2.7A, 5A)
  - Stress operation (10 A and 16 A)
  - ERS,C and T have been measured
- There was not found big difference on the main characteristics and SC performance
  - No stoppers have been found
- More tests and analysis are planned
  - Temperature & Higher dose.
  - Annealing effects

_Bragg grating Multiplexing