ATLAS High Granular Timing Detector
Conceptual design and R&D

L. Serin on behalf of the ATLAS collaboration

- Detector location & requirements
- Sensor R&D
- Electronics R&D
- Conceptual design and on going optimisation
- Conclusion

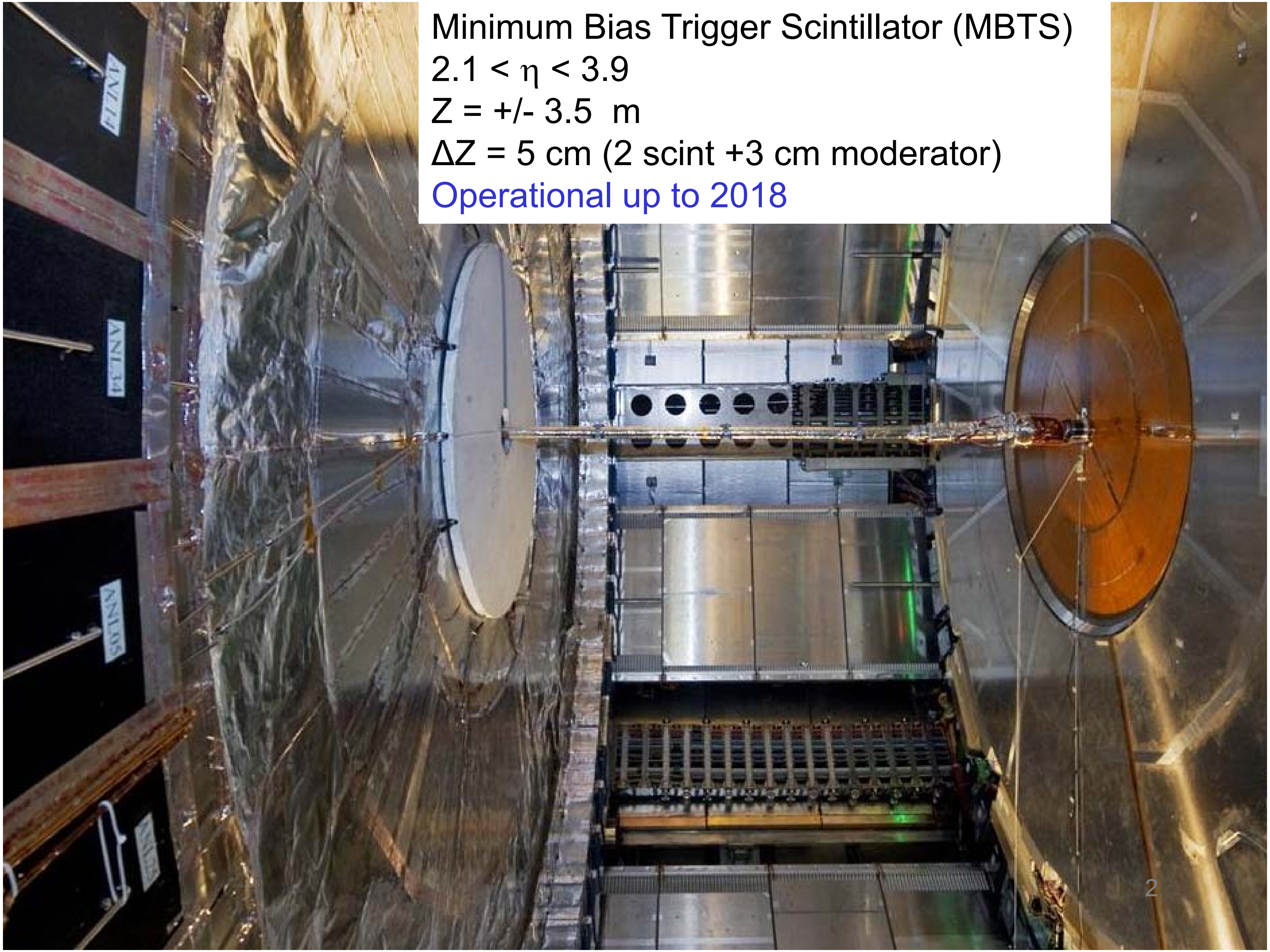
Minimum Bias Trigger Scintillator (MBTS)

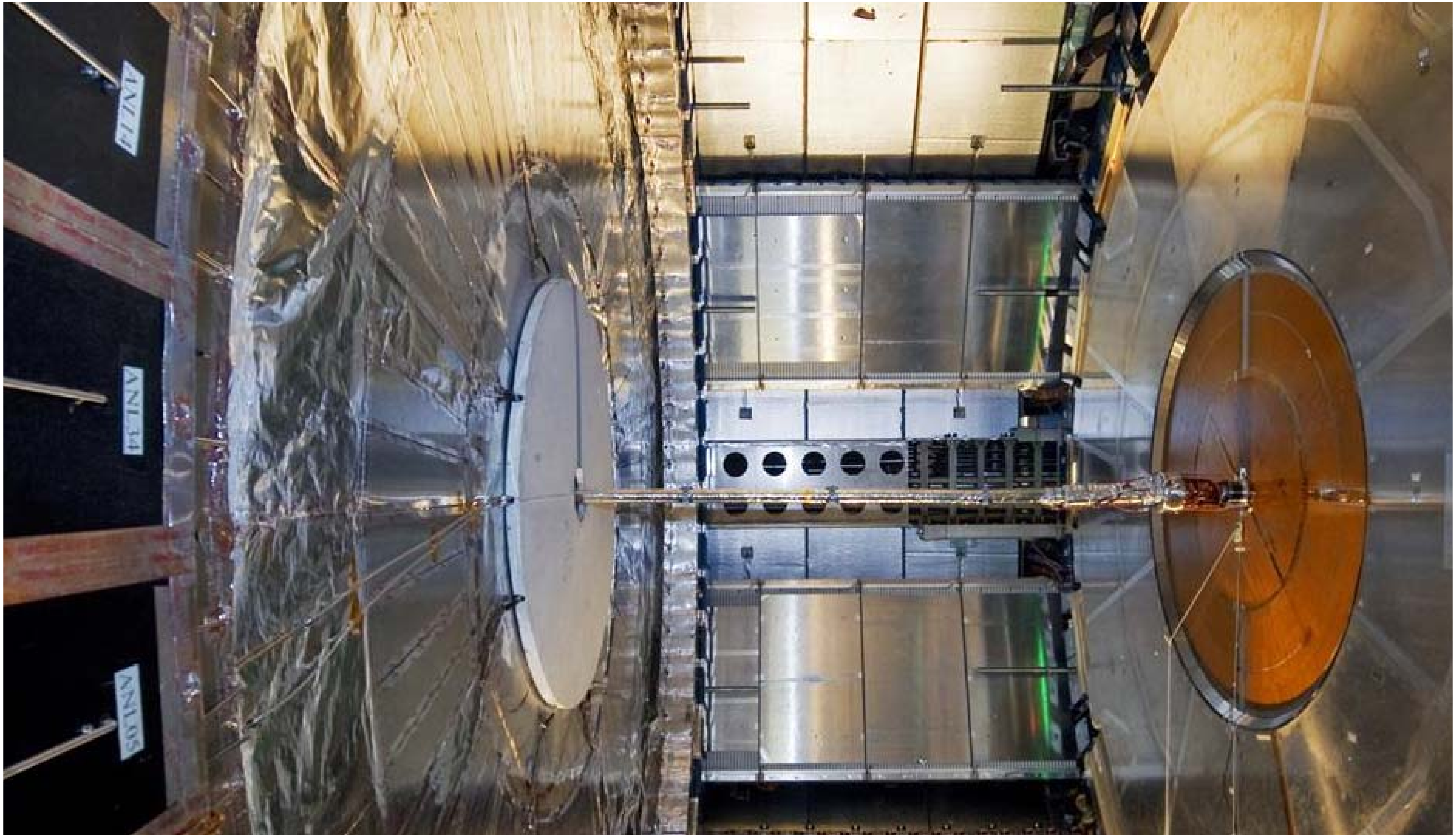
$2.1 < \eta < 3.9$

Z = +/- 3.5 m

ΔZ = 5 cm (2 scint +3 cm moderator)

Operational up to 2018





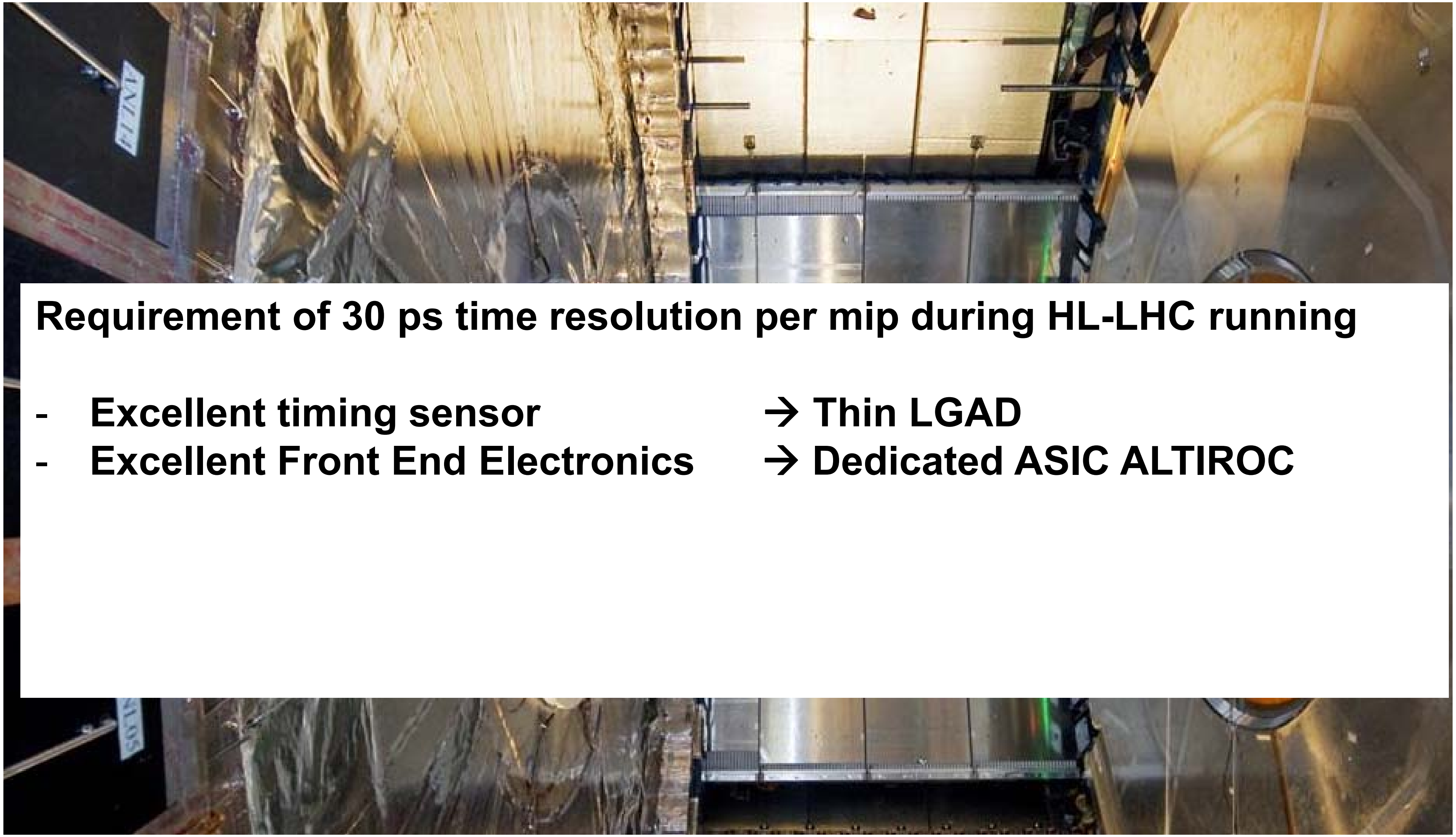
Proposed HGTD :

Radially constrained by ITk/HGTD services (64cm) and pump (12cm)

$2.4 < \eta < 4.0$

Thickness constrained to $\Delta Z = 7.5$ cm (+ 5 cm moderator)

Detector with individual planar layers (modularity/installation)



Requirement of 30 ps time resolution per mip during HL-LHC running

- **Excellent timing sensor** → **Thin LGAD**
- **Excellent Front End Electronics** → **Dedicated ASIC ALTIROC**

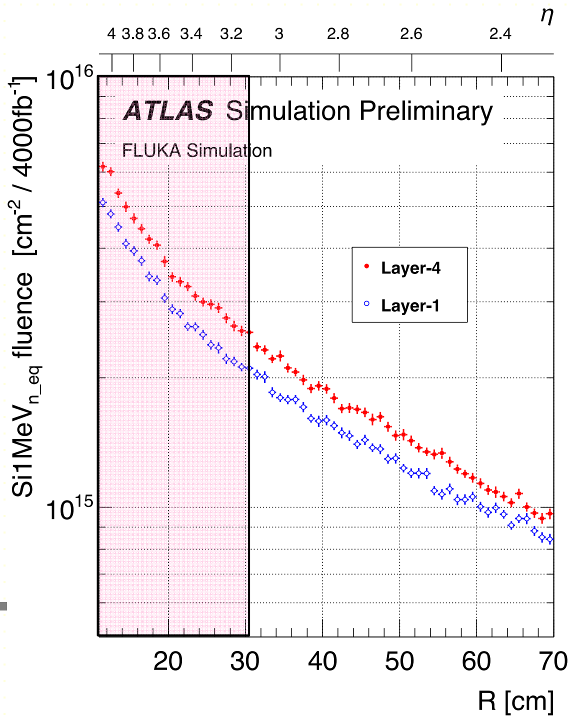
Proposed HGTD :
Radially constrained by ITk/HGTD services (640mm) and pump (120mm)
$2.4 < \eta < 4.0$
Thickness constrained to ΔZ = 75 mm (+ 50 mm moderator)
Detector with individual planar layers (modularity/installation)

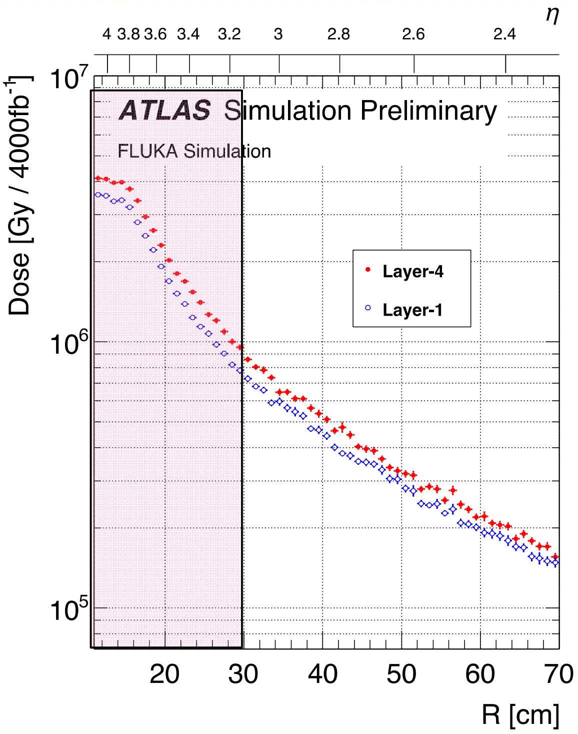
Expected radiation levels

- Max neutron fluence / dose after 4 ab^{-1}, including safety factors:
  - At r=12 cm 9 x 10^{15} n_{eq}/cm^2 and 9 MGy
  - ~20% of sensors + ASICs (r<30 cm) need replacement at 1/2 life time of HL-LHC

→max. doses : 4.5 × 10^{15} n_{eq}/cm^2 and 4.5 MGy (r < 30 cm)

4.0 × 10^{15} n_{eq}/cm^2 and 2.1 MGy (r> 30 cm)





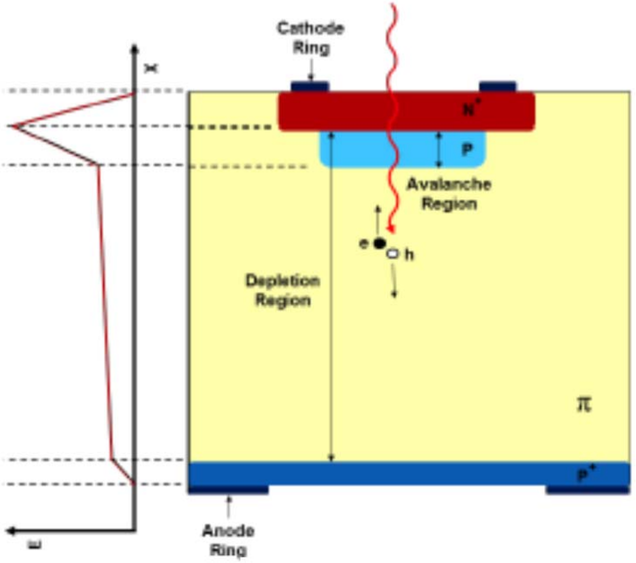
No safety factor applied in these plots

1.5 for simulation

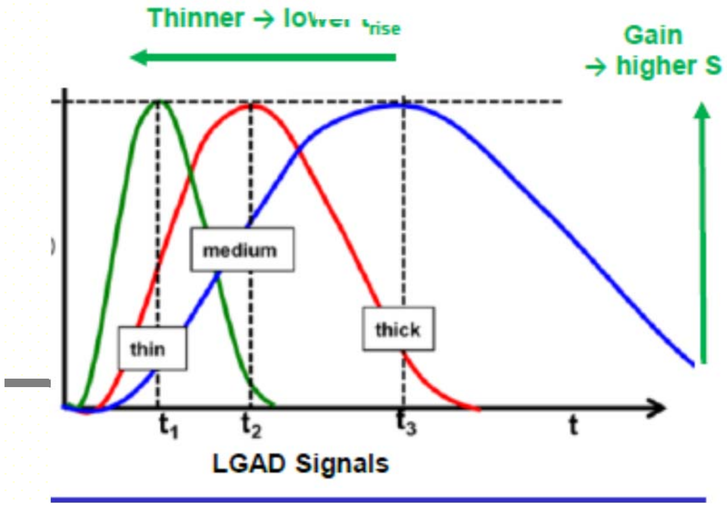
x 1.5 for ASIC

Radiation
→ Operation at -30°c
→ C02 cooling

Thin LGAD



$$\sigma_{\text{Jitter}} = \frac{N}{(dV/dt)} \simeq \frac{t_{\text{rise}}}{(S/N)}$$



Standard n-p silicon diode with an extra highly doped p layer

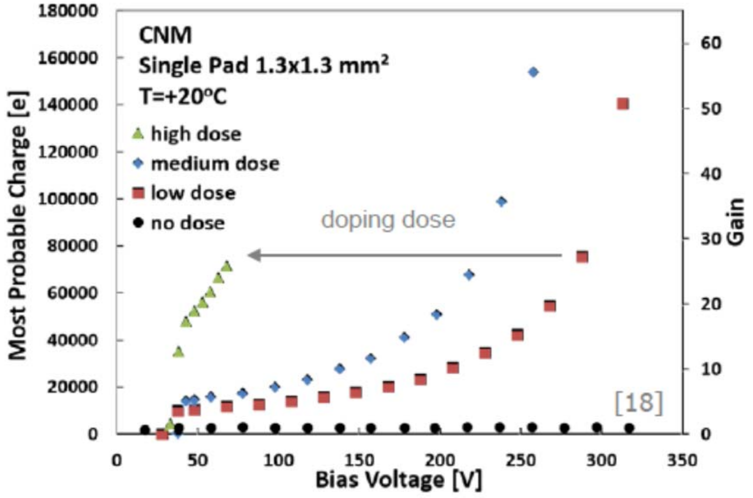
- Moderate gain ~20 with respect to pin diode
  → increase signal and keep sensor noise limited

- Thin detector :
  → better radiation hardness and short rise time (smaller jitter and Landau fluctuation)

A lot of work done with the RD50 collaboration and with 3 possible vendors : CNM, HPK and FBK

Tests with different fabrication technologies, different structure, doping level, pad size before and after irradiation ……

Unirradiated sensors performance (50 µm LGAD)



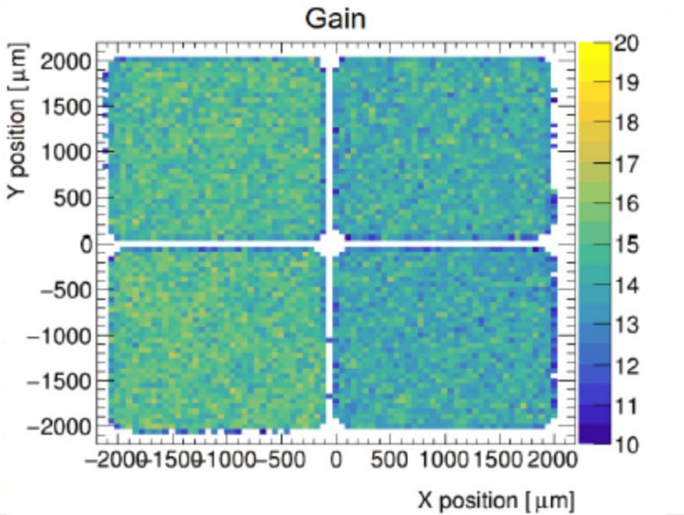
Breakdown and gain depends on multiplication layer doping

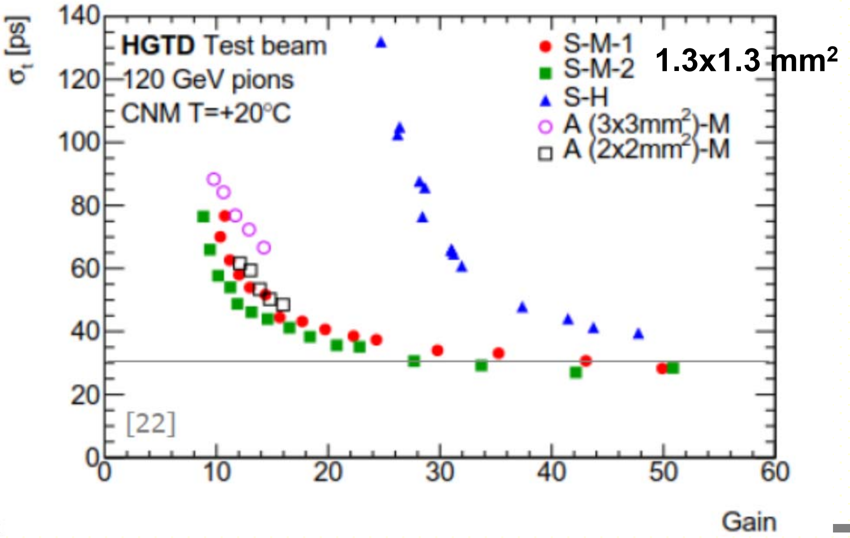
Gain up to 50 achieved but target is 20

Uniform over pads

Time resolution :

- 25 ps at large gain (Landau term dominated).
- 35-40 ps at G=20
- Similar performance HPK/CNM



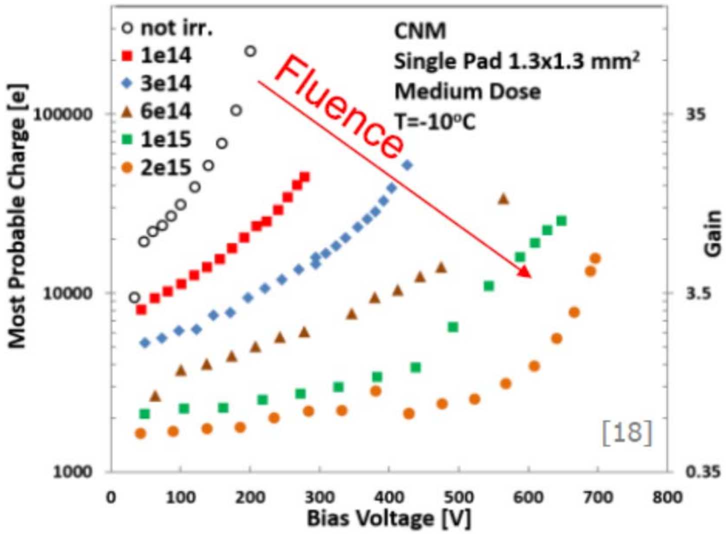


1.3x1.3 mm²

HGTD publication to be submitted to JINST in December

Irradiated sensors performance (50 µm LGAD)

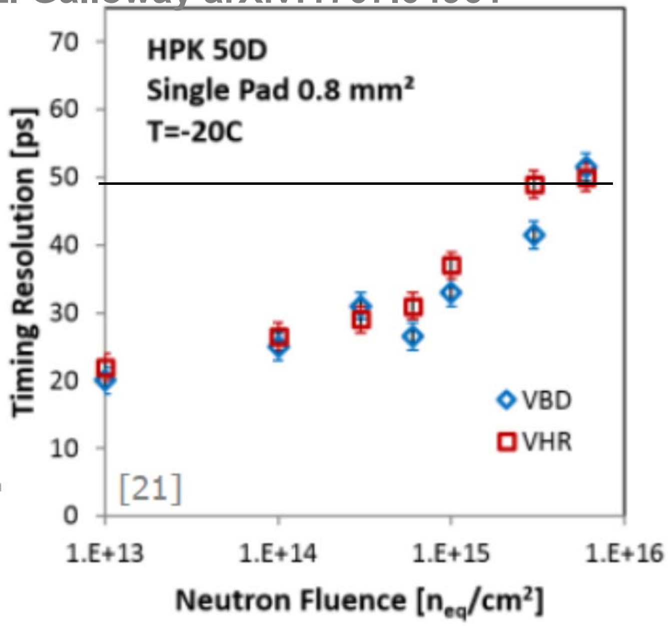
G. Kramberger et al, to be sumitted



Radiation damage :

- Trapped of charge carriers (→thin sensor)
- Increase of leakage current (→ -30 °c)
- Modification of effective doping concentration
  → modification of multiplication layer
  → Reduction of gain thus increase of time resolution. Partially mitigated by larger bias voltage

Z. Galloway arXiv:1707.04961



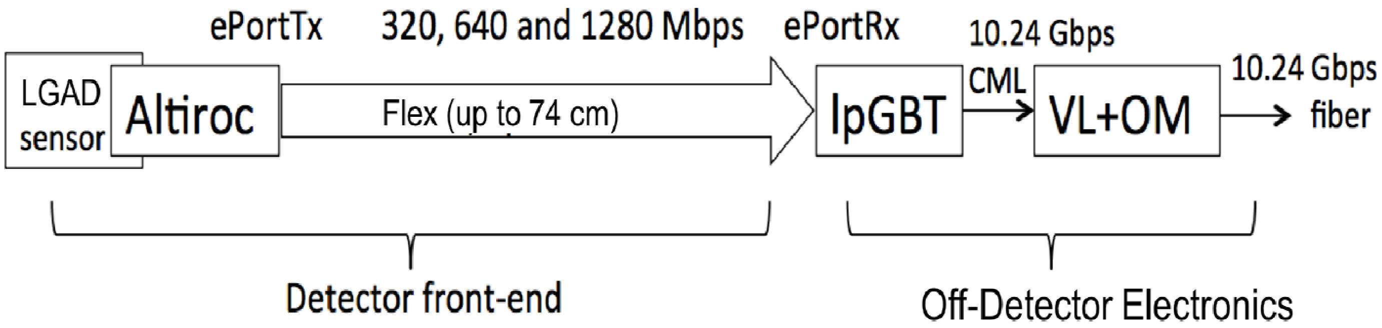
Time resolution :

- Operate at safe bias voltage / breakdown
- Achieved 50 ps up to 6.10^{15} n_{eq} /cm^2 at -20 °c

On going R&D

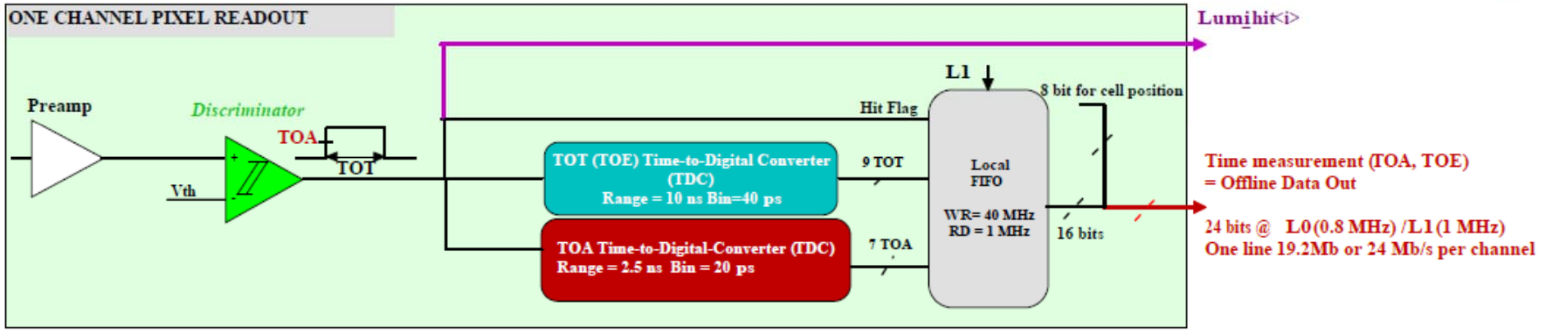
- Improving radiation hardness (Ga/B, C spray)
- Thinner LGAD 35 µm (excellent first measurements)
- Improving fill factor

Electronics



Single pixel readout

$$\sigma^2_{\mathrm{elec}} = \sigma^2_{\mathrm{jitter}} + \sigma^2_{\mathrm{TW}} + \sigma^2_{\mathrm{TDC}}$$



Broadband preamplifier common source configuration followed by fast discri and TDC (vernier lines)

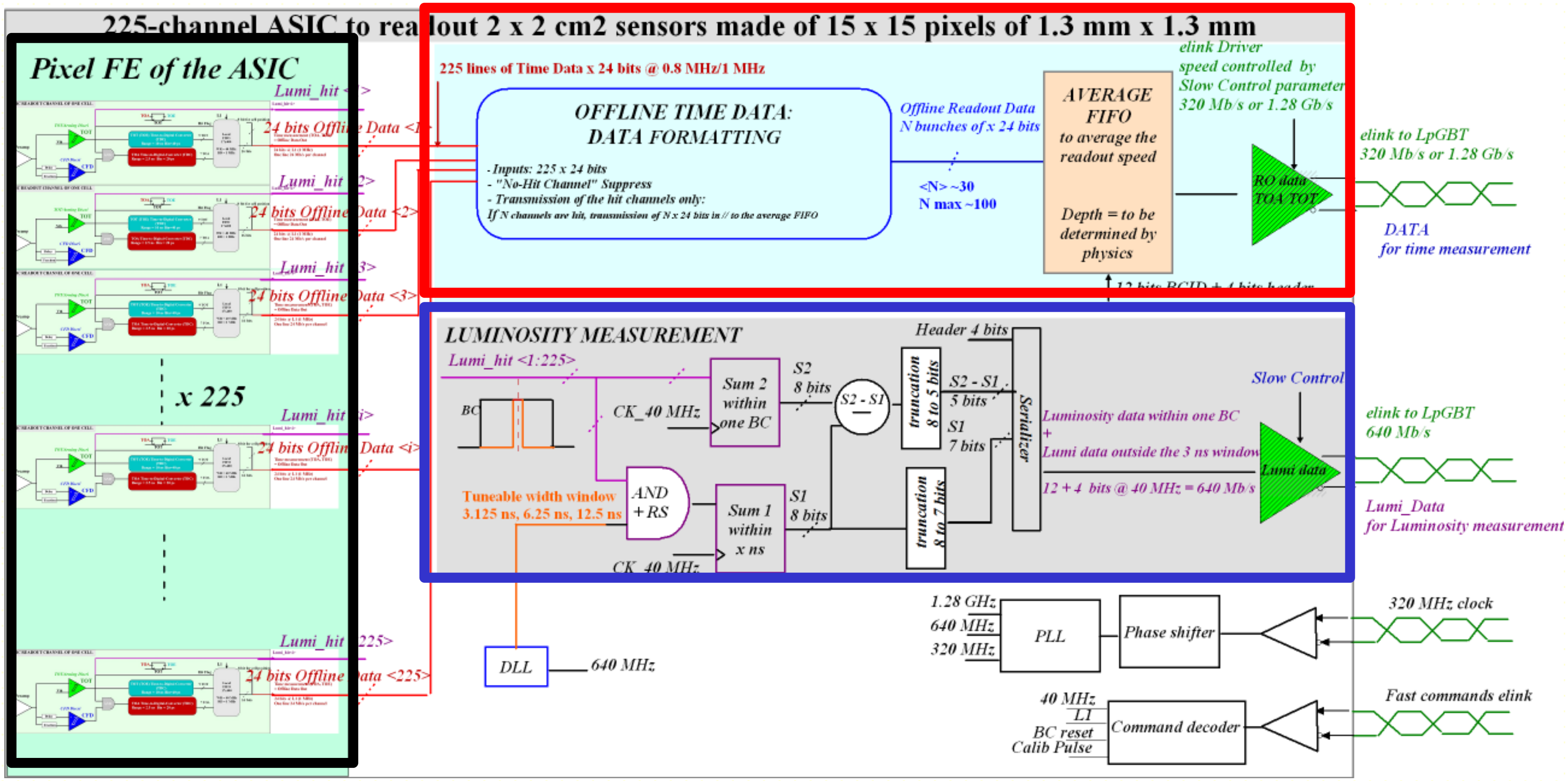
- TOA measurement (20 ps) + TOT measurement (40 ps) + local FIFO until L0/L1

TSMC CMOS 130 nm

Electronics

Single pixel

Data formatting/ suppression + rate average



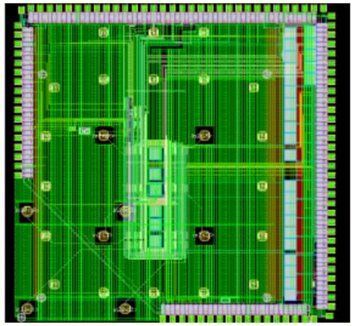
Luminosity block : provides hits in 3 ns window centered on bunch crossing and outside the window at 40 MHz

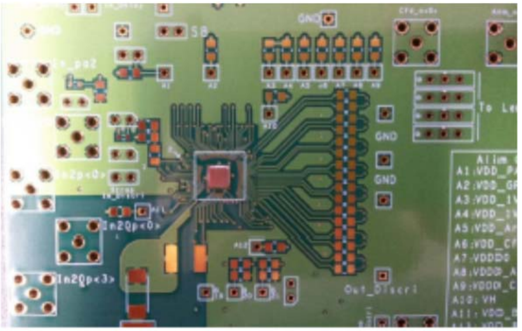
Dedicated back end

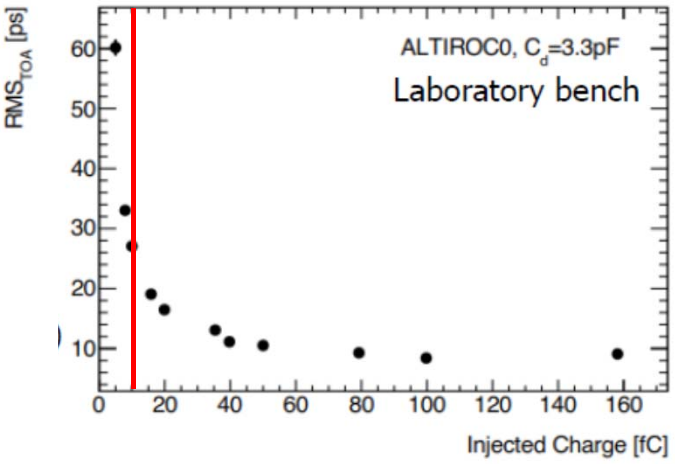
ALTIROC Front End ASIC

TSMC 130 nm

ALTIROC0 : 4 channels only analog part

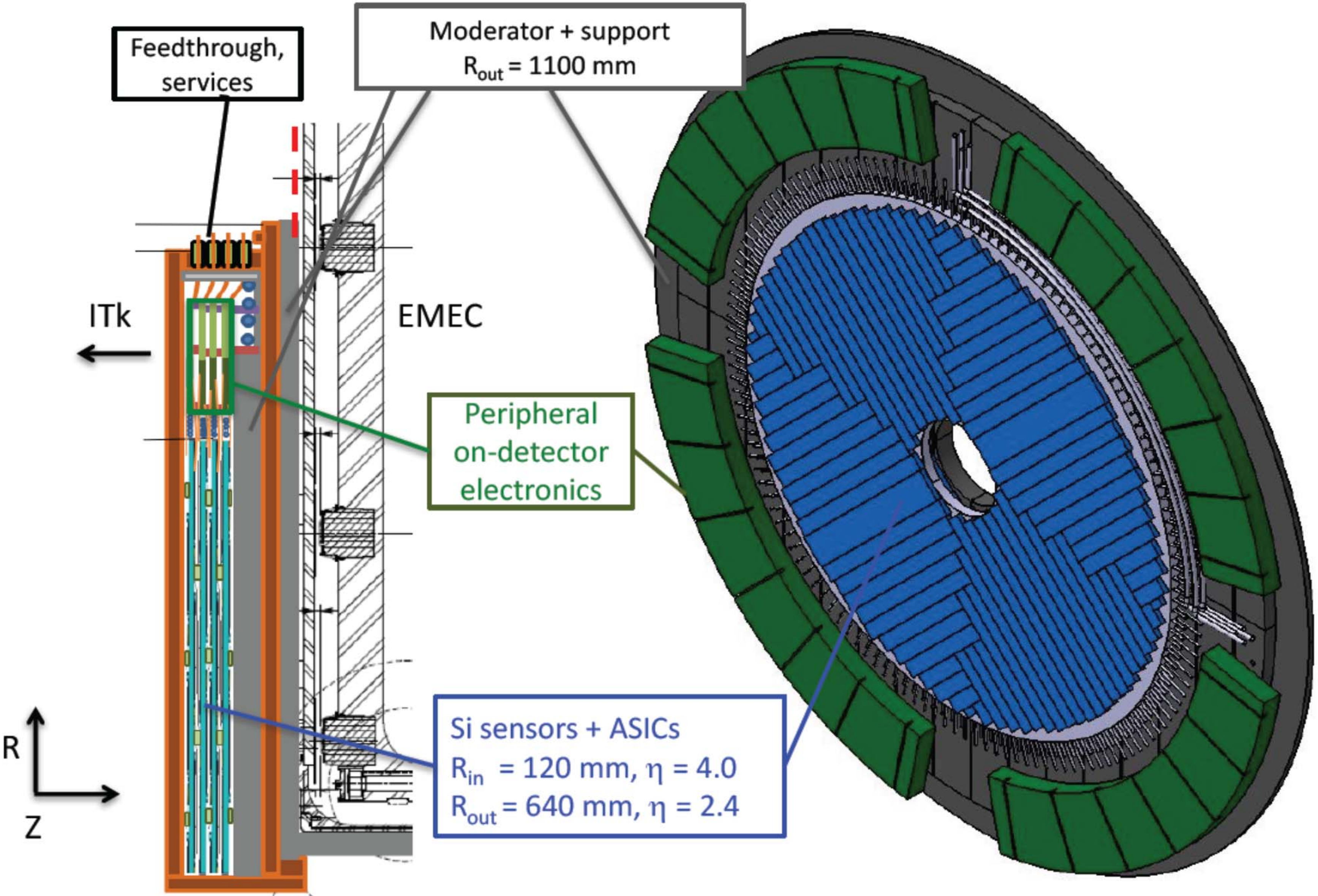






25 ps for one mip (10 fC at G=20)
→ Noise to be improved and bandwidth too small
→ New version in building block submitted in December
Has been bump bonded to LGAD and exposed to beam

ALTIROC 1 : 25 channels with full single pixel readout (analog+TDC+FIFO)
to be submitted in Feb 2018, and bump bonded to sensor Q3/1018



Feedthrough, services

Moderator + support
R_{out} = 1100 mm

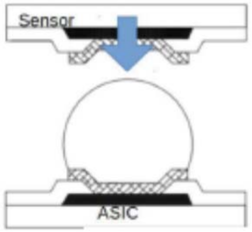
Peripheral on-detector electronics

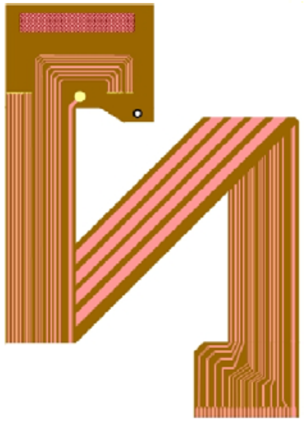
Si sensors + ASICs
R_{in} = 120 mm, $\eta = 4.0$
R_{out} = 640 mm, $\eta = 2.4$

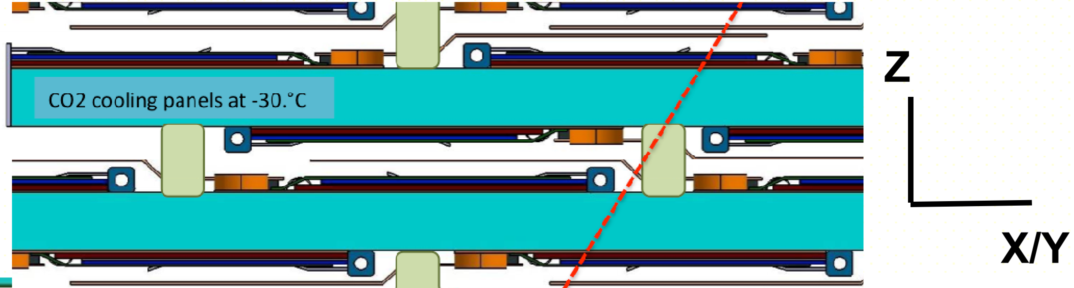
Total HGTD CO2 cooling for 4 layers/side : 20 kW
1.4 m^2 LGAD sensor area per layer

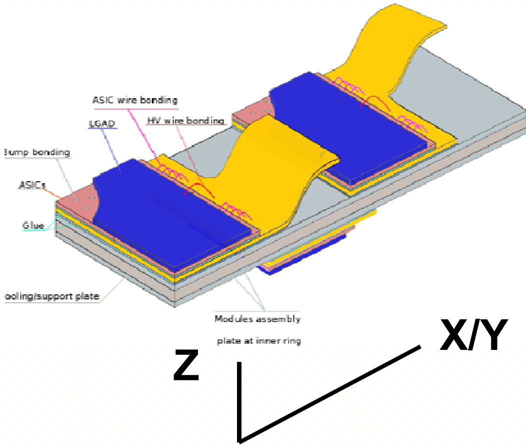
Modules + Layer R-phi view

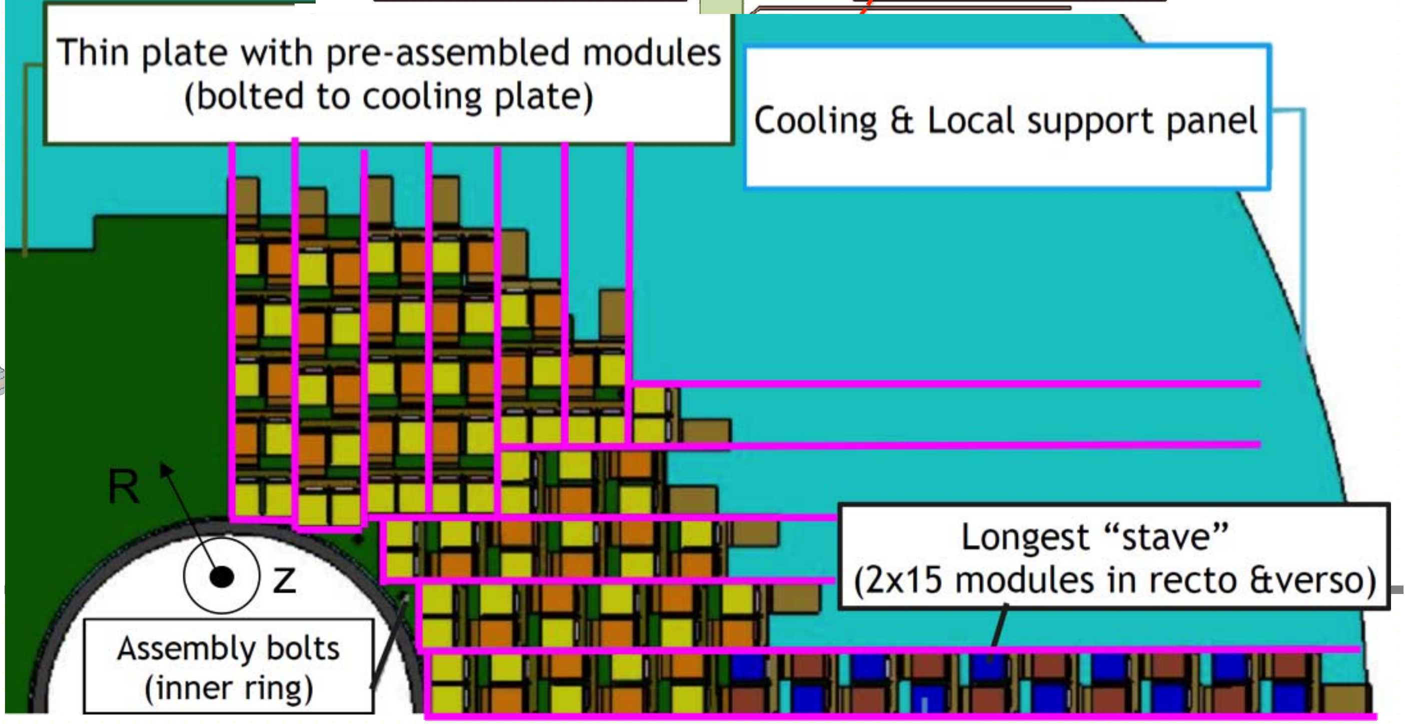
Module / stave definition still to be optimized
Thermal conductivity/ overlap /modularity
→ Technical prototypes in Q18







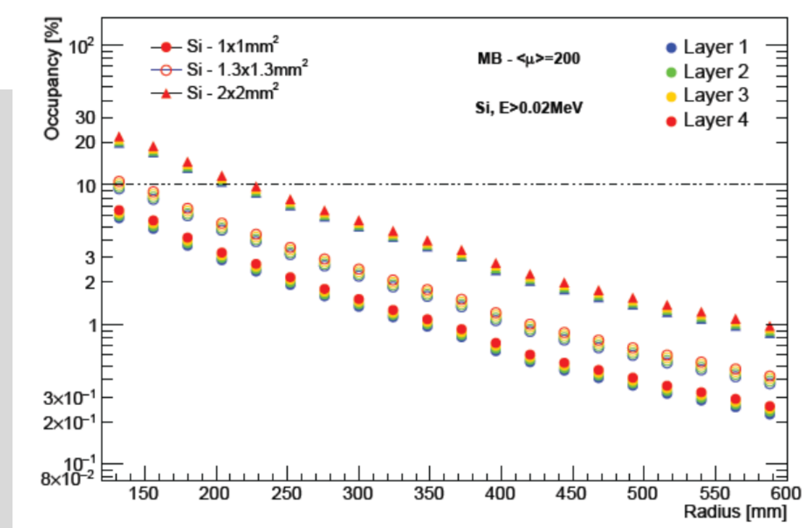




Optimisation towards final baseline design

Sensor size (4x2 cm^2) :
- fitting the inner radius
- sensor yield and flip-chip yield
- unique sensor size

Granularity (1.3x1.3 mm^2) :
- occupancy < 10 %
- Time resolution (detector capacitance)



Number of layer :
- Dead area / efficiency
- Time resolution after irradiation

	Two layers	Three layers	Four layers
$N_{\text{hits}} \geq N_{\text{layers}}$	86%	82%	78%
$N_{\text{hits}} = 0$	0.5%	0.11%	0.07%
$< N_{\text{hits}} >$	2.04	3.08	4.1
$< \sigma_t >$	43 ps	37 ps	32 ps

< 1 % geometrical inefficiency for 2 layers
From 32 ps to 43 ps at worse radiation level radius assuming 60 ps/hit

Integration :
- Half disk/vessel for easier installation
- Inner module wheel

→ 2 (3) hits at large (small) radius might be a good compromise

Conclusion

Intensive R&D since organised activity started mid 2015

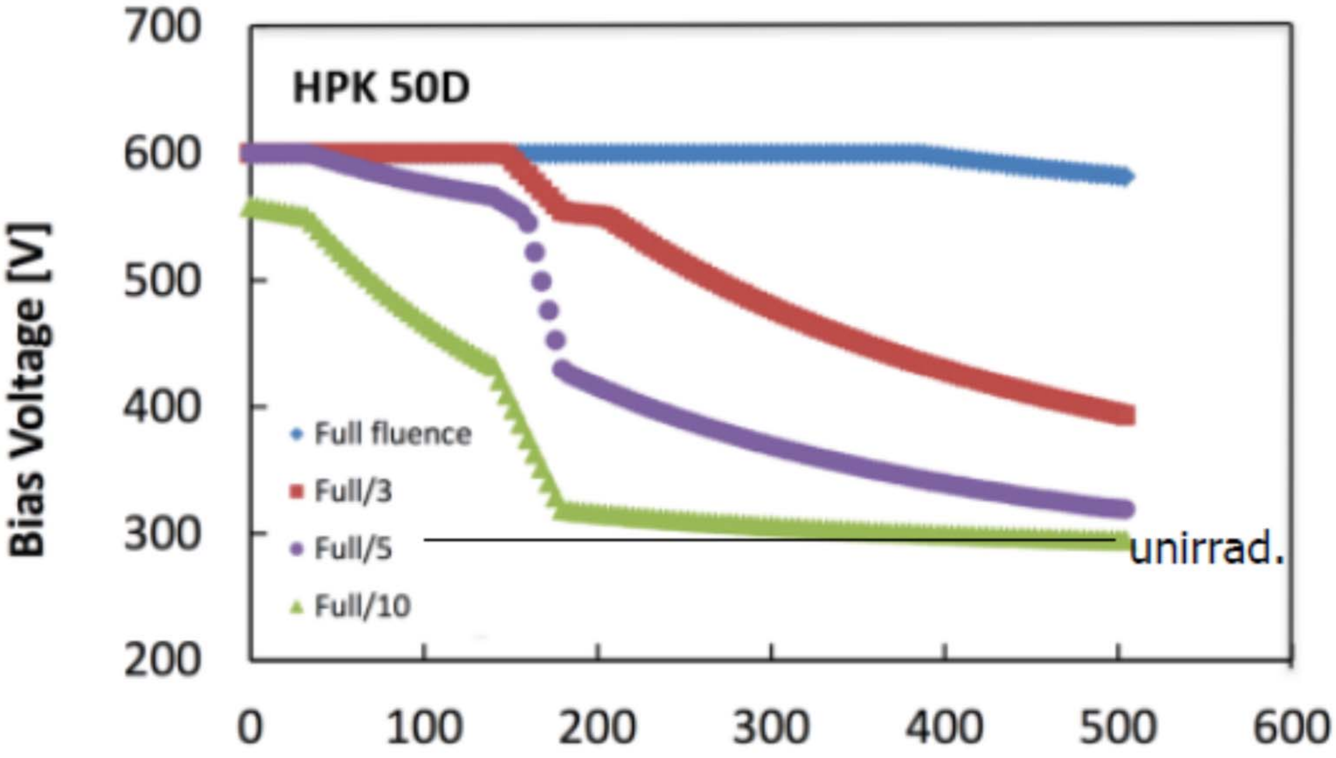
→ 30 ps time resolution for mip over HL-LHC period looks feasible
but still R&D on sensors and electronics to validate it

Overall detector design under optimisation to find the best trade-off between performance, construction/installation complexity/schedule and cost (to be provided In Technical Proposal in April 2018)

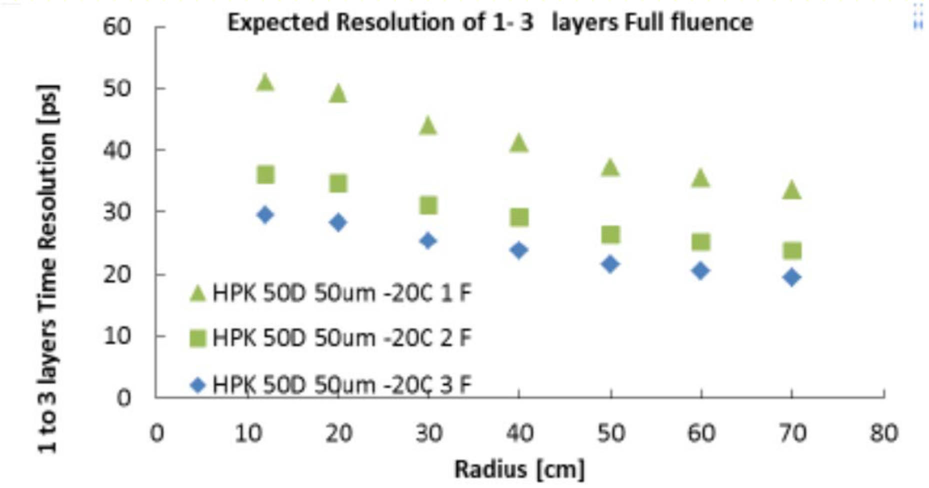
A highly motivated community (~20 institutes from 7 countries) is willing to build it for Phase II and improve the ATLAS detector performance under the harsh HL-LHC environment.

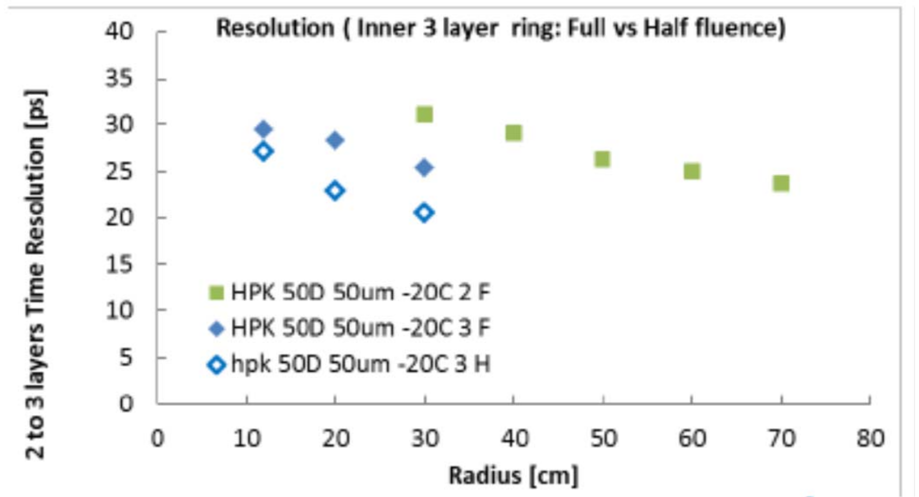
Back up

HV along radius

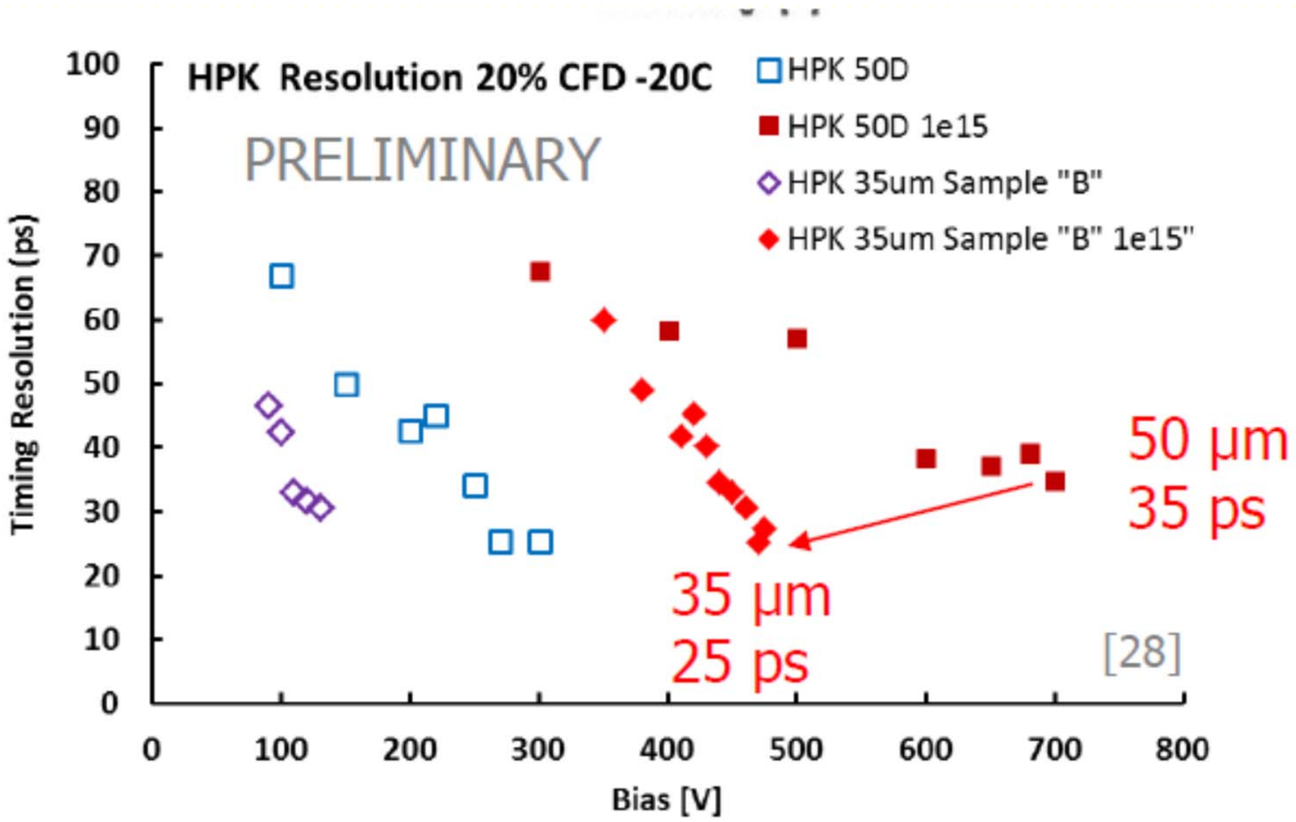


Expected sensor alone time resolution at HL-LHC





Preliminary performance with 35 µm LGAD

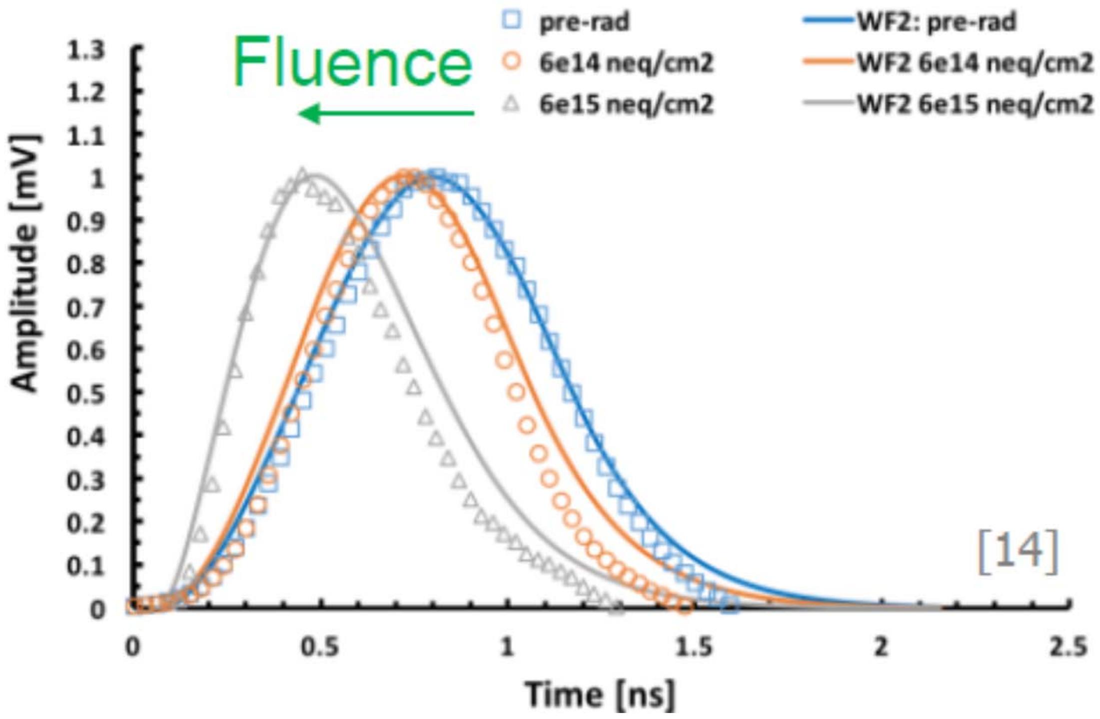


50 µm
35 ps

35 µm
25 ps

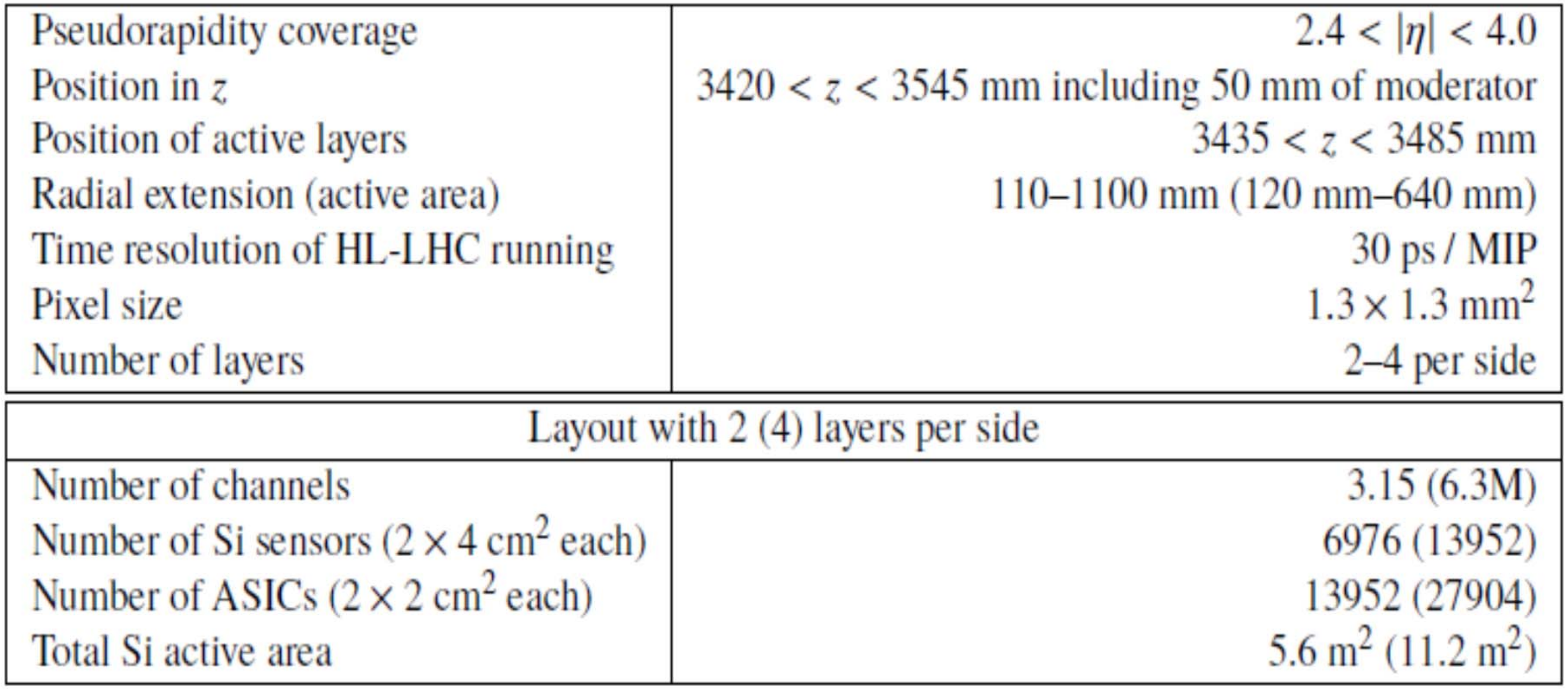
[28]

Pulse shape with irradiation



[14]

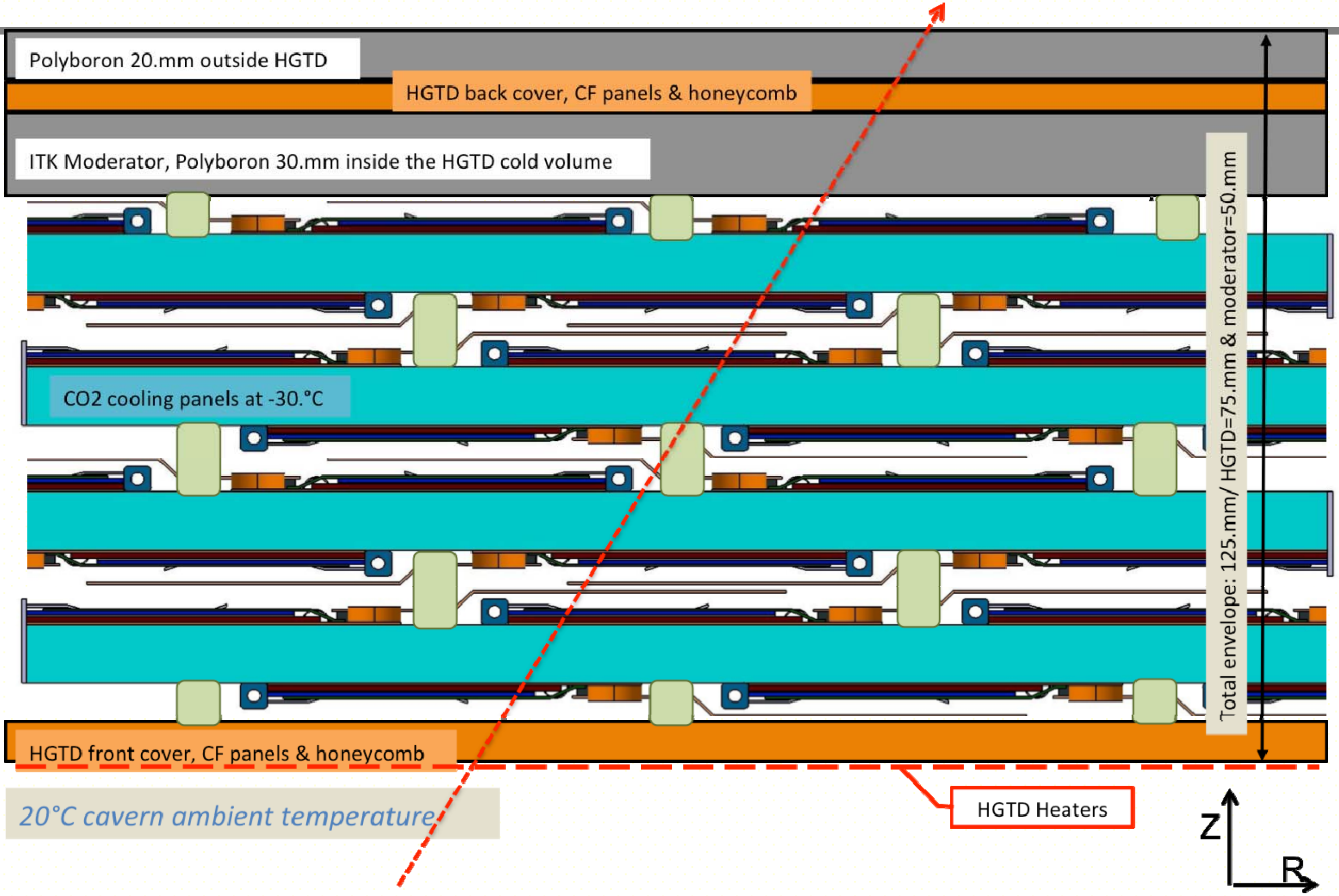
Main HGTD parameters



Pseudorapidity coverage	$2.4 < \lvert\eta\rvert < 4.0$
Position in z	$3420 < z < 3545$ mm including 50 mm of moderator
Position of active layers	$3435 < z < 3485$ mm
Radial extension (active area)	110–1100 mm (120 mm–640 mm)
Time resolution of HL-LHC running	30 ps / MIP
Pixel size	1.3×1.3 mm^2
Number of layers	2–4 per side

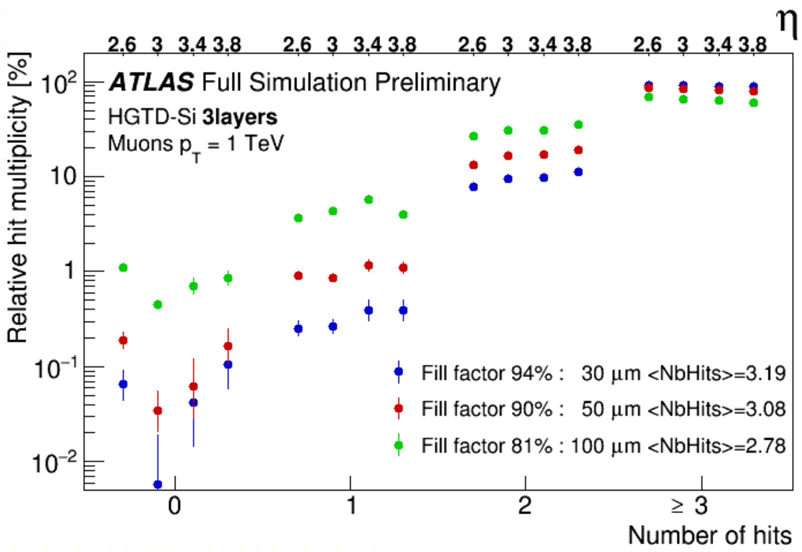
Layout with 2 (4) layers per side	
Number of channels	3.15 (6.3M)
Number of Si sensors (2×4 cm^2 each)	6976 (13952)
Number of ASICs (2×2 cm^2 each)	13952 (27904)
Total Si active area	5.6 m^2 (11.2 m^2)

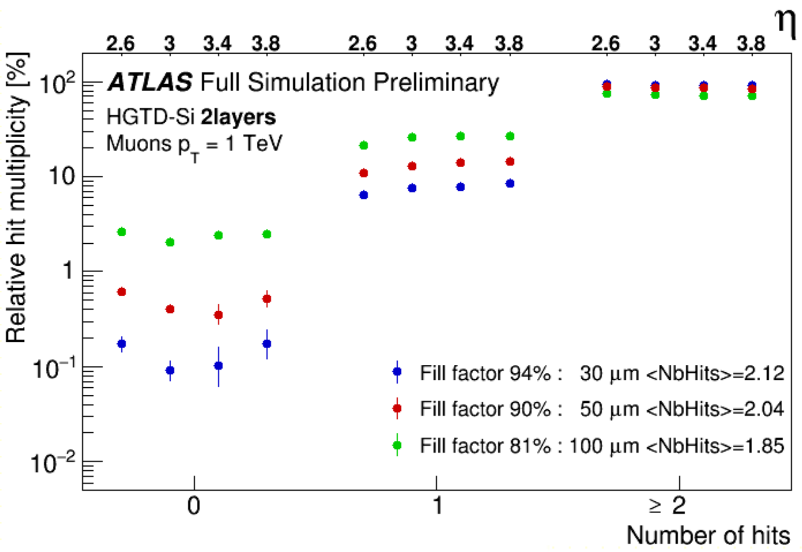
R-Z view



A 4-layer design would fit in the allocated thickness but strict tolerance required

Number of layers/performance/cost on going optimisation





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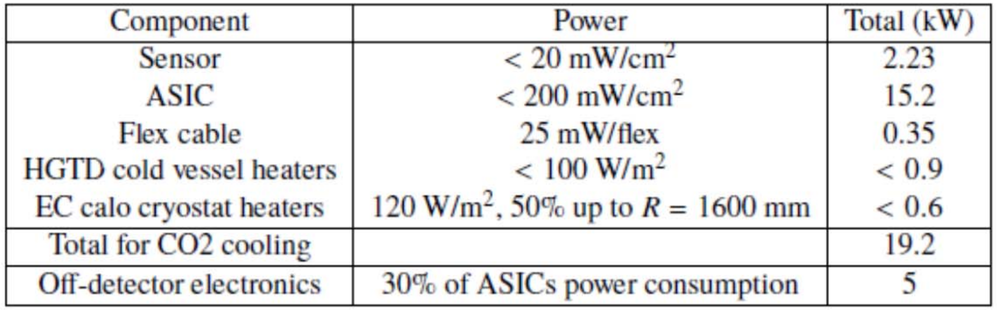
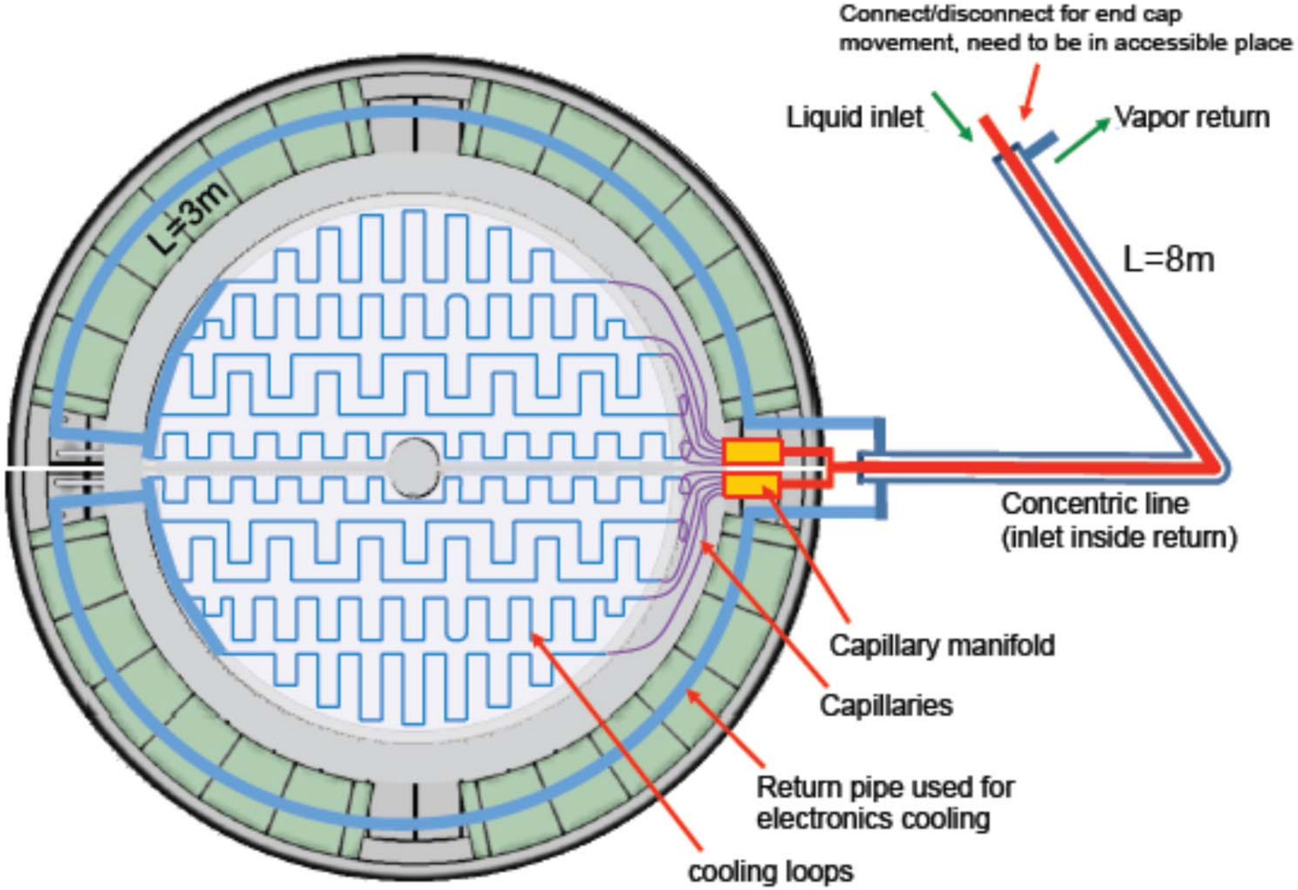
$< N_{\text{hits}} >$	2.04	3.08	4.1
After 4000 fb-1 $< \sigma_t >$	43 ps	37 ps	32 ps

0.5 % geometrical inefficiency for 2 layers
From 32 ps to 43 ps at worse radiation level radius assuming 60 ps/hit

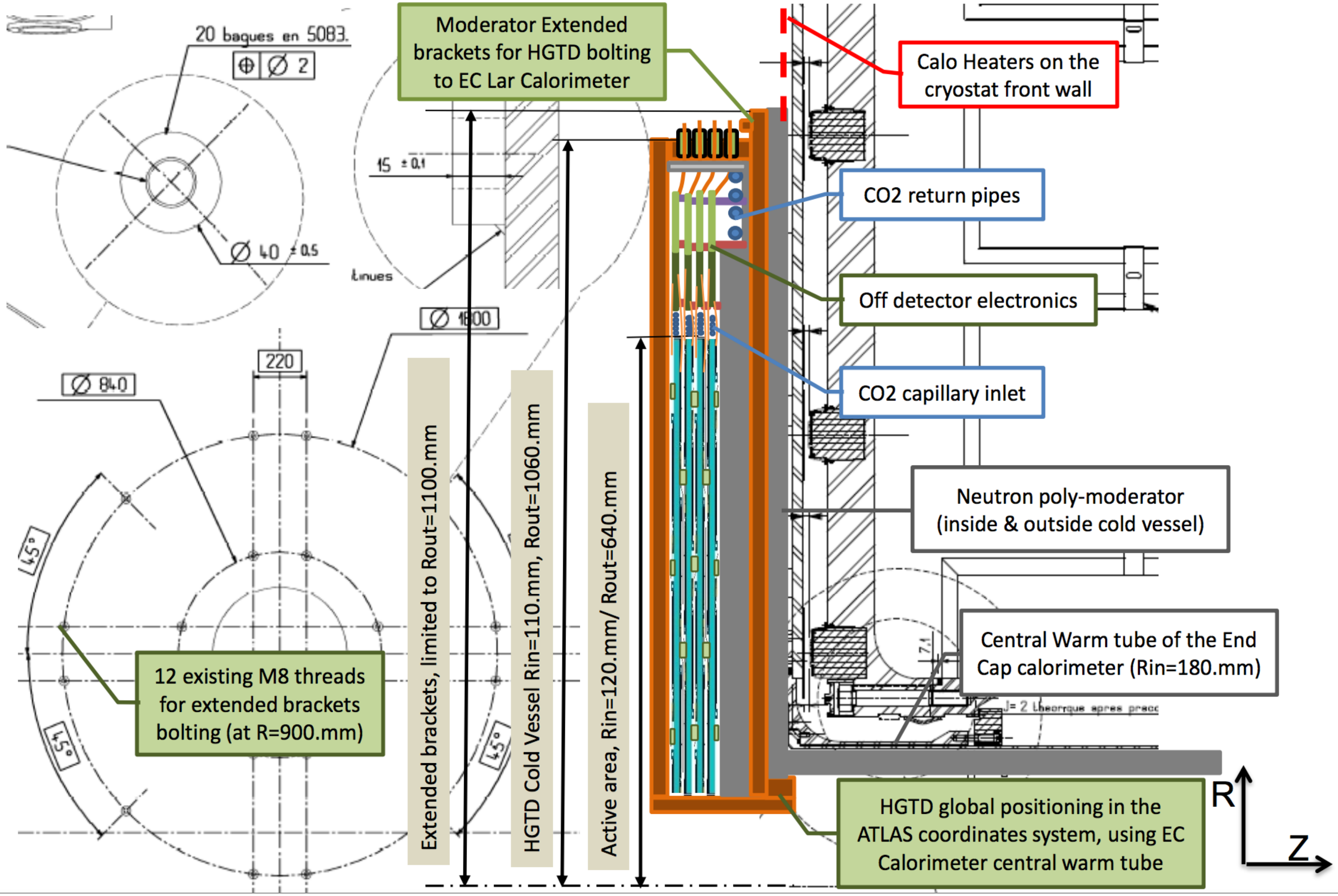
CO2 cooling



Component	Power	Total (kW)
Sensor	< 20 mW/cm^2	2.23
ASIC	< 200 mW/cm^2	15.2
Flex cable	25 mW/flex	0.35
HGTD cold vessel heaters	< 100 W/m^2	< 0.9
EC calo cryostat heaters	120 W/m^2, 50% up to R = 1600 mm	< 0.6
Total for CO2 cooling		19.2
Off-detector electronics	30% of ASICs power consumption	5



HGTD integration



Moderator Extended brackets for HGTD bolting to EC Lar Calorimeter

Calo Heaters on the cryostat front wall

CO2 return pipes

Off detector electronics

CO2 capillary inlet

Neutron poly-moderator (inside & outside cold vessel)

Central Warm tube of the End Cap calorimeter (Rin=180.mm)

12 existing M8 threads for extended brackets bolting (at R=900.mm)

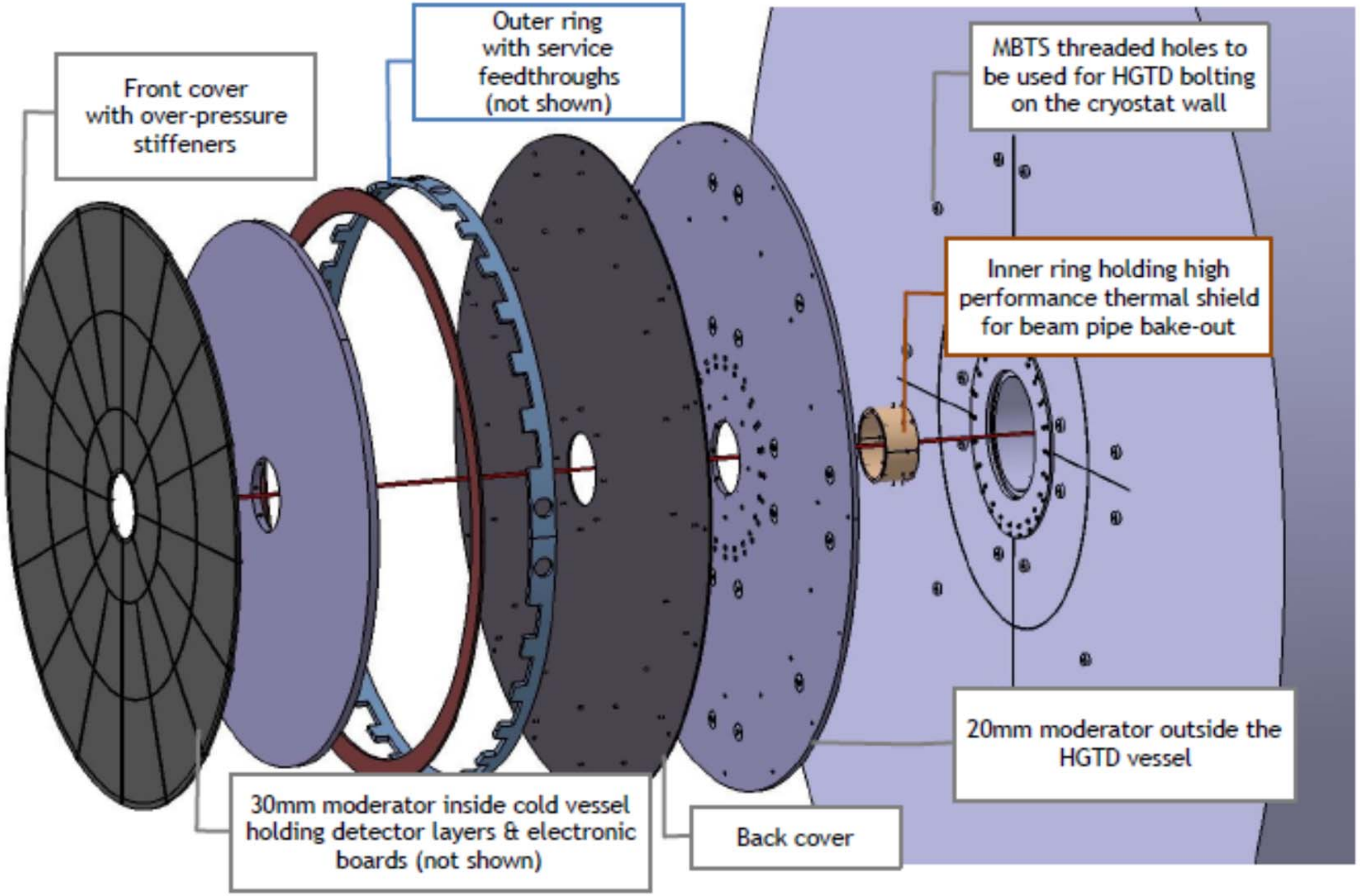
HGTD global positioning in the ATLAS coordinates system, using EC Calorimeter central warm tube

Extended brackets, limited to Rout=1100.mm

HGTD Cold Vessel Rin=110.mm, Rout=1060.mm

Active area, Rin=120.mm/ Rout=640.mm

HGTD integration



Front cover with over-pressure stiffeners

Outer ring with service feedthroughs (not shown)

MBTS threaded holes to be used for HGTD bolting on the cryostat wall

Inner ring holding high performance thermal shield for beam pipe bake-out

20mm moderator outside the HGTD vessel

30mm moderator inside cold vessel holding detector layers & electronic boards (not shown)

Back cover