Data challenges at FCC-hh

W. Riegler

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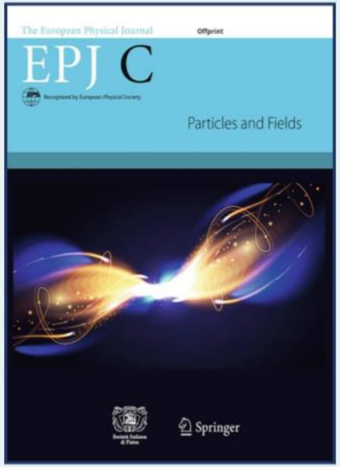
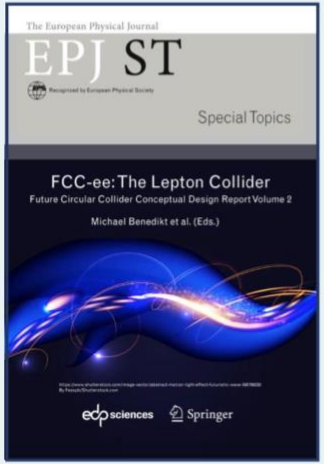
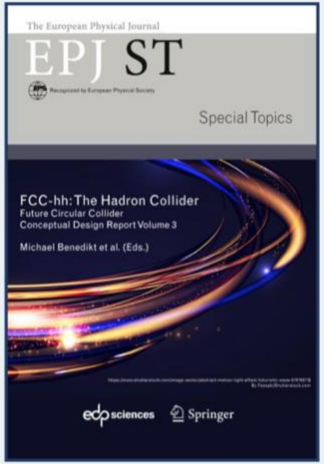
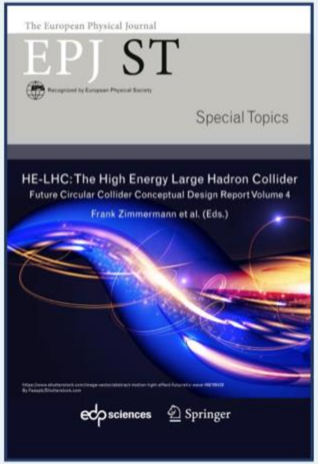
SPRINGER NATURE

and Future Circular Collider





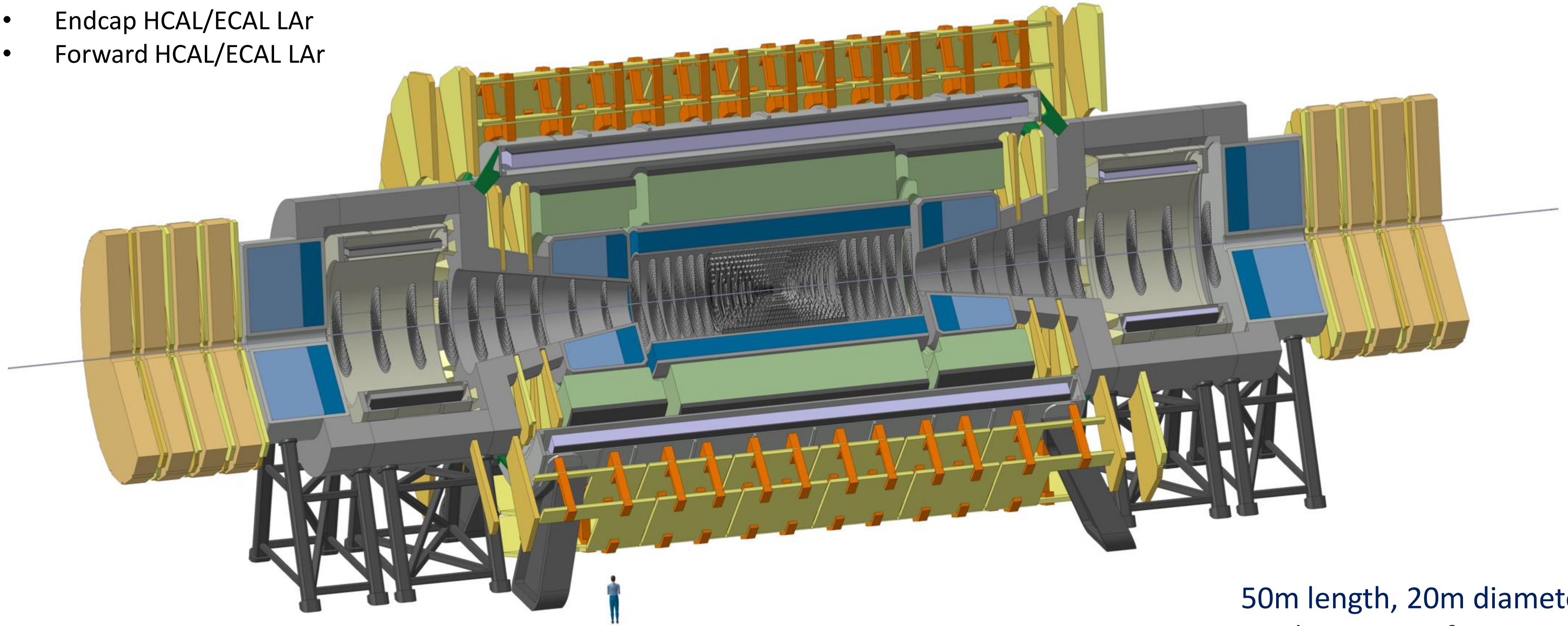




ADVANCING DISCOVERY

FCC-hh Reference Detector

- 4T, 10m solenoid, unshielded
- Forward solenoids, unshielded
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr



50m length, 20m diameter
similar to size of ATLAS

Table 7.1: Key numbers relating the detector challenges at the different accelerators.

Parameter	Unit	LHC	HL-LHC	HE-LHC	FCC-hh
E_{cm}	TeV	14	14	27	100
Circumference	km	26.7	26.7	26.7	97.8
Peak $\mathcal{L}$, nominal (ultimate)	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1 (2)	5 (7.5)	16	30
Bunch spacing	ns	25	25	25	25
Number of bunches		2808	2760	2808	10600
Goal $\int \mathcal{L}$	ab^{-1}	0.3	3	10	30
σ_{inel} [331]	mb	80	80	86	103
σ_{tot} [331]	mb	108	108	120	150
BC rate	MHz	31.6	31.0	31.6	32.5
Peak pp collision rate	GHz	0.8	4	14	31
Peak av. PU events/BC, nominal (ultimate)		25 (50)	130 (200)	435	950
Rms luminous region σ_z	mm	45	57	57	49
Line PU density	mm^{-1}	0.2	1.0	3.2	8.1
Time PU density	ps^{-1}	0.1	0.29	0.97	2.43
$dN_{ch}/d\eta\|_{\eta=0}$ [331]		6.0	6.0	7.2	10.2
Charged tracks per collision N_{ch} [331]		70	70	85	122
Rate of charged tracks	GHz	59	297	1234	3942
$<p_T>$ [331]	GeV/c	0.56	0.56	0.6	0.7
Bending radius for $<p_T>$ at B=4 T	cm	47	47	49	59
Total number of pp collisions	10^{16}	2.6	26	91	324
Charged part. flux at 2.5 cm, est.(FLUKA)	$\mathrm{GHz\,cm}^{-2}$	0.1	0.7	2.7	8.4 (10)
1 MeV-neq fluence at 2.5 cm, est.(FLUKA)	$10^{16}\,\mathrm{cm}^{-2}$	0.4	3.9	16.8	84.3 (60)
Total ionising dose at 2.5 cm, est.(FLUKA)	MGy	1.3	13	54	270 (300)
$dE/d\eta\|_{\eta=5}$ [331]	GeV	316	316	427	765
$dP/d\eta\|_{\eta=5}$	kW	0.04	0.2	1.0	4.0
90% $\mathrm{b\bar{b}}$ $p_T^b > 30$ GeV/c [332]	$\|\eta\|<$	3	3	3.3	4.5
VBF jet peak [332]	$\|\eta\|$	3.4	3.4	3.7	4.4
90% VBF jets [332]	$\|\eta\|<$	4.5	4.5	5.0	6.0
90% $\mathrm{H} \to 4l$ [332]	$\|\eta\|<$	3.8	3.8	4.1	4.8
$\mathrm{b\bar{b}}$ cross-section	mb	0.5	0.5	1	2.5
$\mathrm{b\bar{b}}$ rate	MHz	5	25	250	750
$\mathrm{b\bar{b}}$ $p_T^b > 30$ GeV/c cross-section	µb	1.6	1.6	4.3	28
$\mathrm{b\bar{b}}$ $p_T^b > 30$ GeV/c rate	MHz	0.02	0.08	1	8
Jets $p_T^{jet} > 50$ GeV/c cross-section [331]	µb	21	21	56	300
Jets $p_T^{jet} > 50$ GeV/c rate	MHz	0.2	1.1	14	90
$\mathrm{W^+ + W^-}$ cross-section [333]	µb	0.2	0.2	0.4	1.3
$\mathrm{W^+ + W^-}$ rate	kHz	2	10	100	390
$\mathrm{W^+} \to l + \nu$ cross-section [333]	nb	12	12	23	77
$\mathrm{W^+} \to l + \nu$ rate	kHz	0.12	0.6	5.8	23
$\mathrm{W^-} \to l + \nu$ cross-section [333]	nb	9	9	18	63
$\mathrm{W^-} \to l + \nu$ rate	kHz	0.1	0.5	4.5	19
Z cross-section [333]	nb	60	60	100	400
Z rate	kHz	0.6	3	25	120
$\mathrm{Z} \to ll$ cross-section [333]	nb	2	2	4	14
$\mathrm{Z} \to ll$ rate	kHz	0.02	0.1	1	4.2
$\mathrm{t\bar{t}}$ cross-section [333]	nb	1	1	4	35
$\mathrm{t\bar{t}}$ rate	kHz	0.01	0.05	1	11

Parameter Table

… to define the specifications and requirement for such a detector.

… to relate the challenges for detectors at the between LHC/HL-LHC/HE-LHC and FCC-hh.

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31 GHz of pp collisions

Pile-up 1000

4 THz of tracks

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First tracking layer:

10GHz/cm^2 charged particles

10^{18} hadrons/cm^2 for 30ab^{-1}

Increased Boost at 100TeV 'spreads out' light SM physics by 1-1.5 units of rapidity.

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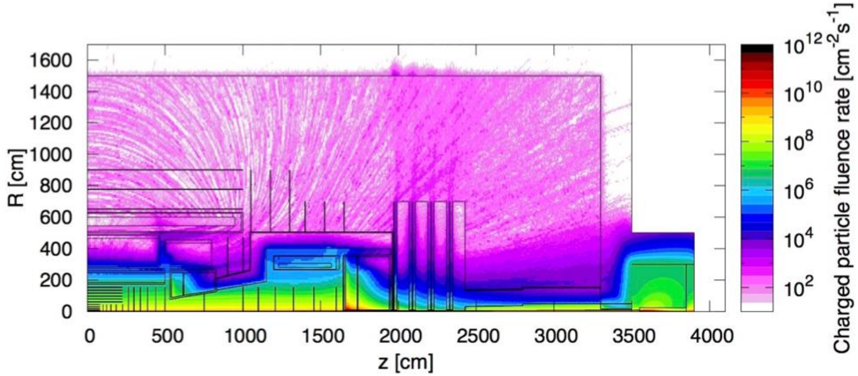
100MHz of jets p_T>50GeV

400kHz of Ws

120kHz of Zs

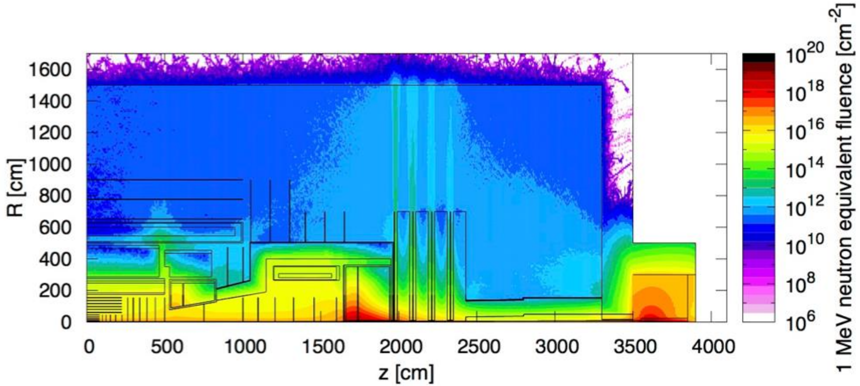
11kHz of Top

Radiation Studies for L=$3x10^{36}$ $cm^{-2}s^{-1}$ and $30ab^{-1}$



Maximum of 10kHz/cm^2 of charged particle rate in the Barrel and Forward Muon System, similar to HL-LHC Muon Systems.

In the tracker volume the charged particle rate is just a function of distance from the beampipe with rather small dependence on z.

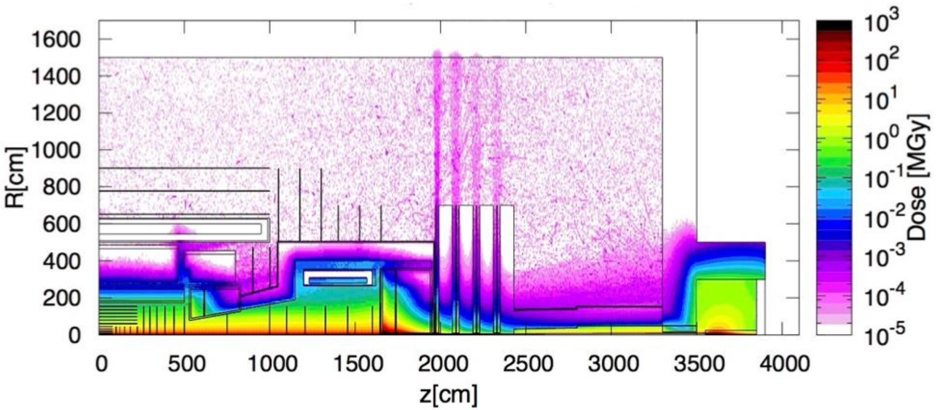


Hadron fluence in the order of 10^{18} /cm^2 close to the beampipe and 10^{15} -10^{16} /cm^2 (HL-LHC levels) for r>40cm.

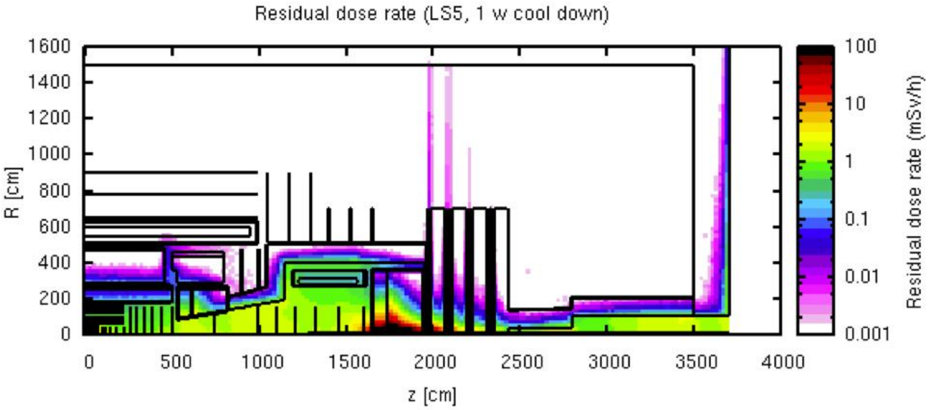
Extreme fluences in the forward calorimeter …

Triplet (z=40m), Triplet shielding TAS (z=35m) and related radiation are nicely ‘burried’ inside the tunnel.

Radiation Studies for L=$3x10^{36}$ $cm^{-2}s^{-1}$ and $30ab^{-1}$



Dose of 300MGy in the first tracker layers.
<10kGy in HCAL barrel and extended barrel.



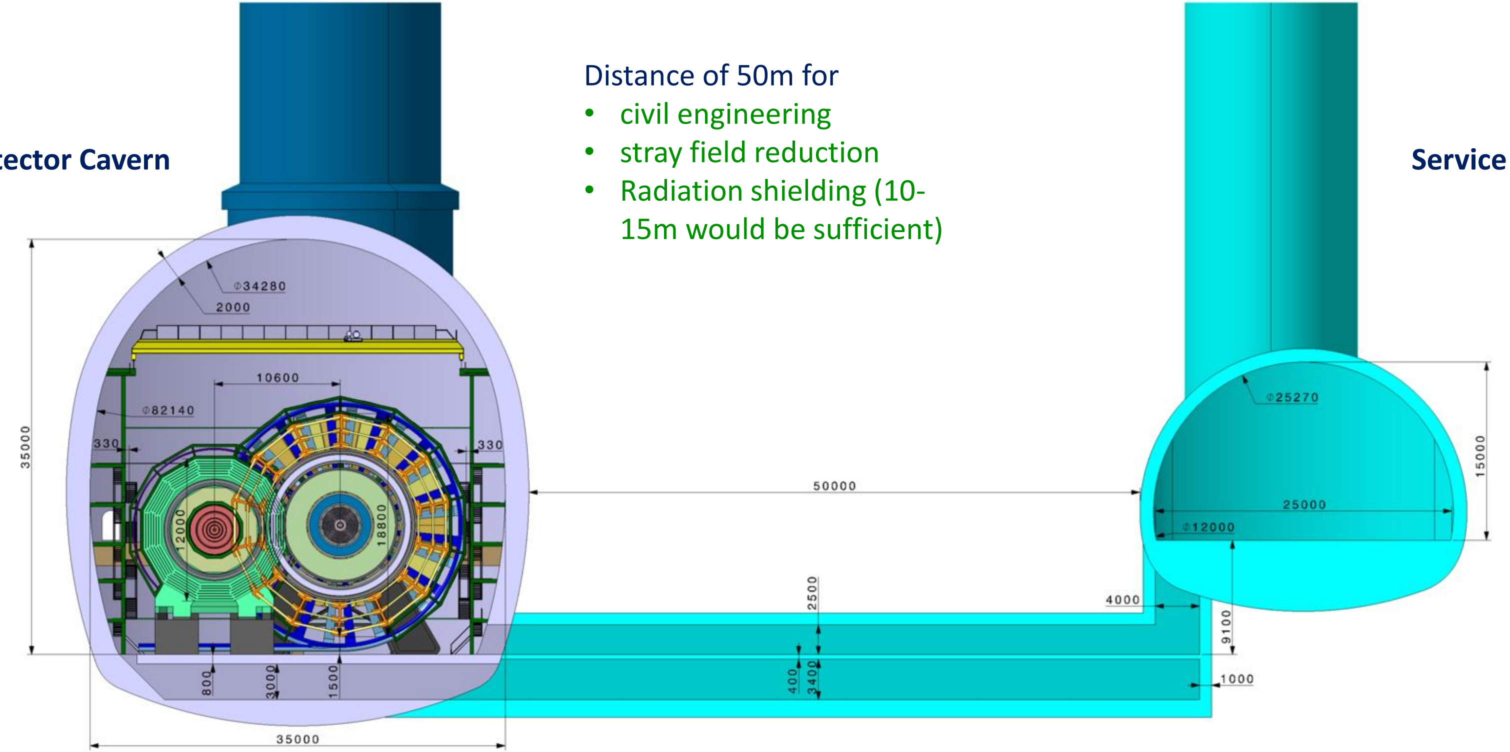
Dose from activation towards the end of FCC operation, 1 week of cooldown, so significant decrease for 1month, 1 year.

FCC-hh Reference Detector Cavern

Distance of 50m for
- civil engineering
- stray field reduction
- Radiation shielding (10-15m would be sufficient)

Detector Cavern

Service Cavern



Tracker Layout

Silicon tracker, two options studied, ‘tilted’ and ‘’flat’ layout’.

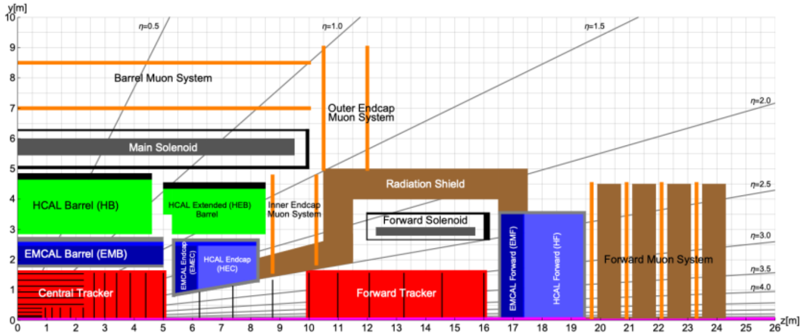
390m² of silicon for tilted layout and 430m² for flat layout.

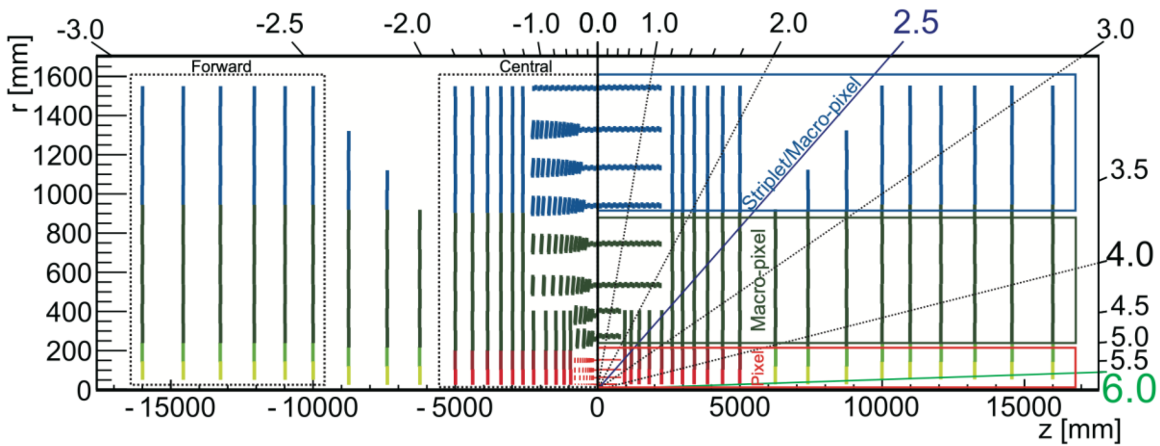
ATLAS CMS Phase-II silicon trackers have around 250m².

25-33.3µm x 50-400µm pixels for r < 200 mm
33µm x 400µm pixels for 200 mm < r < 900 mm
33µm x 2-50mm strips for 900 mm < r < 1600 mm

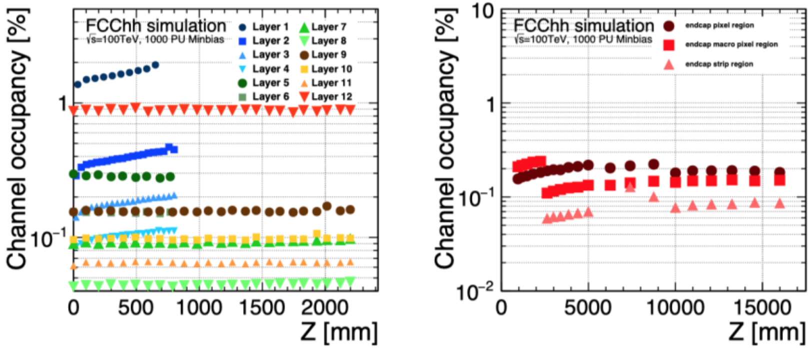
This represents and r-phi resolution of 7.5-9.5µm per detector layer

16 x 10^9 channels vs. 6 x 10^9 and 2.2 x 10^9 for ATLAS/CMS Phase-II trackers





Data Rates and Occupancies



(a) (b)

Fig. 6.36: The channel occupancy for each ring of the barrel layers along z-direction (left) and of the end-cap regions (right): pixel (circles), macro-pixels (squares) and striplets (triangles). All curves are simulated for granularity of tilted tracker, arranged in non-inclined layout.

Granularity was optimized for reasonable occupancy

Data rates [TB/s]	Flat layout (no threshold)	with threshold	with tilted granularities
Pixels (inner)	1054.3 + 379.6	944.5 + 337.9	1056.3 + 380.2
Macro-pixels (middle)	559.2 + 423.1	515.4 + 391.4	560.3 + 423.8
Striplets/Macro-pixels (outer)	127.8 + 192.8	118.8 + 179.1	165.4 + 242.4
	2737 TB/s	**2487 TB/s**	**2828 TB/s**

3 PB/s of data from the tracker

Table 6.4: Summary of total data rates as estimated for the three tracker regions: pixels (inner tracker), macro-pixels (middle tracker) and striplets/macro-pixels (outer tracker), as well as for different scenarios: Flat layout with/without energy threshold (3.6 keV to activate a pixel/striplet) and assuming tilted granularities (i.e. smaller striplet size). Each number is shown as a sum of respective numbers of the central and forward tracker.

Calorimetry

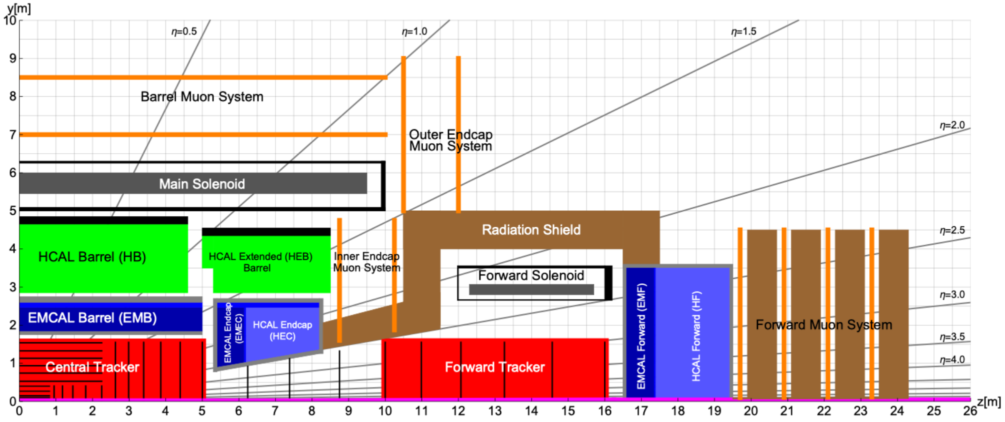
$$\frac{\sigma_E}{E} \approx \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

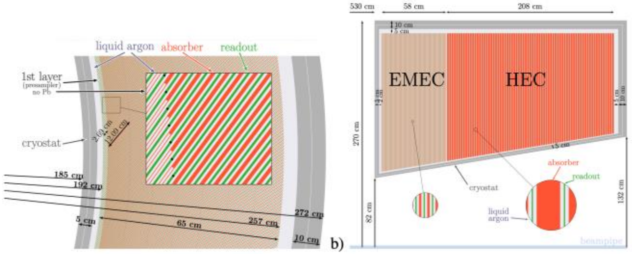
LAr and Fe/Pb/Sci are used as reference technologies. Silicon calorimetry will be extensively 'evaluated' in the CMS Phase-II upgrade.

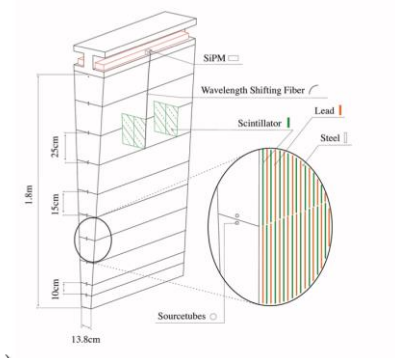
The calorimeter system is 'inspired' by ATLAS (LAr, TileCal), with increased granularity and with the forward for (η > 2.5) moved to z=16.5m to make space for the forward tracker und to achieve coverage up to η = 6.

For the EMCAL Barrel, the demand for increased granularity motivated a deviation from the ATLAS 'accordion' structure to a geometry with inclined plates.

	η_{min}	η_{max}	a	c	$\Delta\eta$	$\Delta\phi$	Fluence	Dose	Material	Mix	Seg.
Unit			$\%\sqrt{\text{GeV}}$	%			cm^{-2}	MGy			
EMB	0	1.5	10	0.7	0.01	0.009	5×10^{15}	0.1	LAr/Pb/PCB	1/0.47/0.28	8
EMEC	1.5	2.5	10	0.7	0.01	0.009	3×10^{16}	1	LAr/Pb/PCB	1/0.75/0.6	6
EMF	2.5	4	10	0.7	0.025	0.025			LAr/Cu/PCB	1/50/6	6
	4	6	30	1	0.025	0.025	5×10^{18}	5000	LAr/Cu/PCB	1/50/6	6
HB	0	1.26	50	3	0.025	0.025	3×10^{14}	0.006	Sci/Pb/Fe	1/1.3/3.3	10
HEB	0.94	1.81	50	3	0.025	0.025	3×10^{14}	0.008	Sci/Pb/Fe	1/1.3/3.3	8
HEC	1.5	2.5	60	3	0.025	0.025	2×10^{16}	1	LAr/Cu/PCB	1/5/0.3	6
HF	2.5	4	60	3	0.05	0.05	5×10^{18}	5000	LAr/Cu/PCB	1/200/6	6
	4	6	100	10	0.05	0.05	5×10^{18}	5000	LAr/Cu/PCB	1/200/6	6

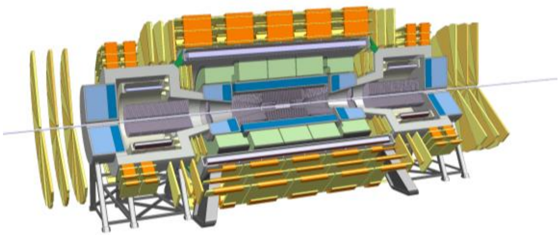






HCAL Barrel

Trigger/DAQ



Calorimetry:

ATLAS Phase2 calorimetry will be digitized at 40MHz and sent via optical fibers to L1 electronics outside the cavern at 25TByte/s to create the L1 Trigger at about 10us latency.

ATLAS Muon system will also be read out at 40MHz to produce a L1 Trigger.

Reading out the FCC detector calorimetry and muon system at 40MHz will result in **200-300 TByte/s**, which seems feasible.

Tracking:

Reading the tracker at 40MHz would produce about **3000 TByte/s.**

Questions to be studied:

Can the L1 Calo+Muon Trigger have enough selectivity to allow readout of the tracker at a reduced rate of e.g. 1MHz ?

Is an un-triggered readout of the tracker at 40MHz feasible ?

How to deal with the radiation requirements for the electronics and the links ?

Moore‘s Law

http://www.livescience.com/23074-future-computers.html

“If the doubling of computing power every two years continues to hold, then by 2030 whatever technology we're using will be sufficiently small that we can fit all the computing power that's in a human brain into a physical volume the size of a brain”,

explained Peter Denning, distinguished professor of computer science at the Naval Postgraduate School and an expert on innovation in computing.

"Futurists believe that's what you need for artificial intelligence. At that point, the computer starts thinking for itself.“

→ Computers will anyway by themselves figure out what to do with the data by 2060.