Detector concepts for future colliders

SWHEPPS, Lake Aegeri, June 9, 2016

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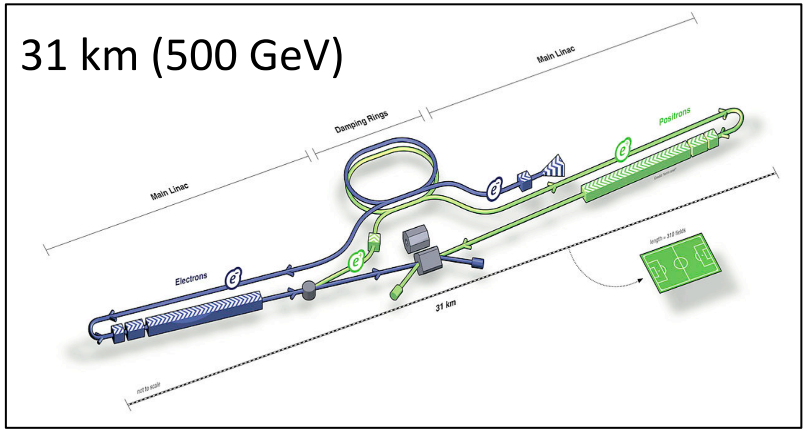
- Plans for future colliders
  - Operation constraints for experiments
- Detector concepts for future colliders
  - Focus on HL-LHC ATLAS and CMS upgrade designs
  - Overview of technical solutions, limitations and trends for future R&D

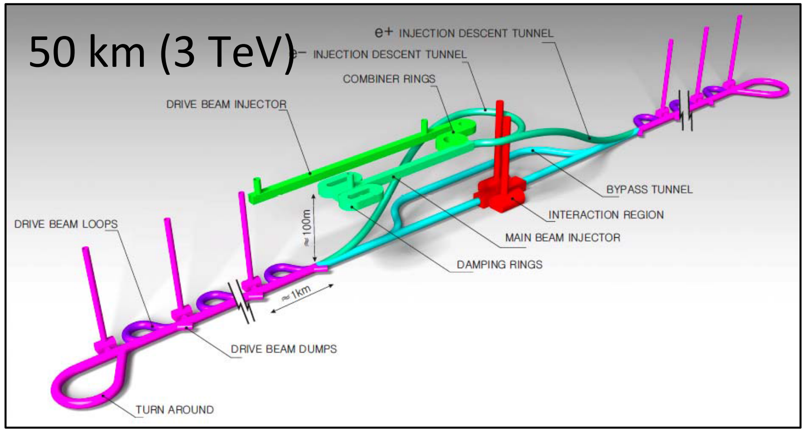
→ Discussion of new techniques in P. Allport's presentation

Plans for future colliders

Future Colliders

- ILC: 2x11 km (Japan), 1.3 GHz SCRF cavities, 30 MV/m ≃ 500 GeV
- CLIC: 2x21 km (Geneva,) drive beams provide RF power, 12 GHz, 100 MV/m ≃ 3 TeV
- 2 push-pull experiments

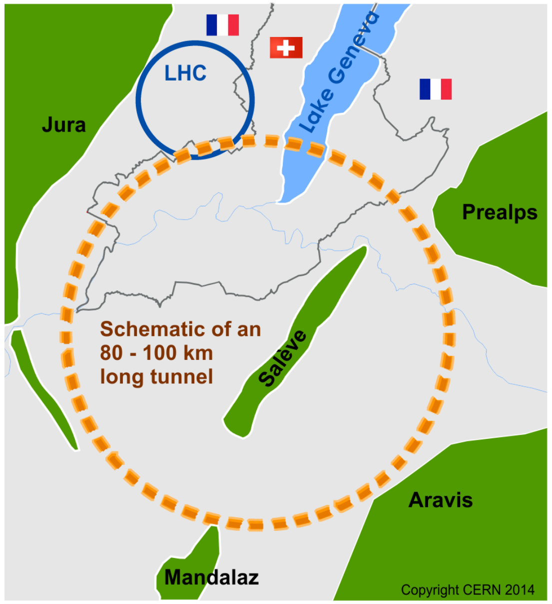




Future Circular Collider (FCC)

- FCC-hh: pp-collider 80-100 km (Geneva) 16 T magnets ≃ 100 TeV (in 100 km)
- FCC-ee: e^+e^- collider potential first step, Z, WW, ZH, tt energies max ≃ 350 GeV
- FCC-he: p-e option ≃ 3.5 TeV
- HE-LHC: with FCC-hh technology ≃ 30 GeV
- 2 Experiments (Interaction Regions)

And similar China project SPPC/CEPC



F. Gianotti's at FCC week in Rome, Apr. 2016

Projected integrated luminosities of proposed future colliders for current operating scenarios

Luminosities x 10^{34} cm^{-2} s^{-1}

Integrated luminosities (ab^{-1})

√s	90 (GeV)	~240 (GeV)	350-380 (GeV)	500 (GeV)	1.4 (TeV)	3 (TeV)	70 (TeV)	100 (TeV)	Total $\int L dt$ at √s>240 GeV	# of years	# H events at production
FCC-ee	90	10	3						13	~ 15	2 M
CepC		5							5	~10	1 M
ILC		2	0.2	4					6.2	~20	1.6 M
CLIC			0.5		1.5	2			4	~20	1.5 M
SppC							30		30	~10	30 B
FCC-hh								40	40	~25	40 B

New particles mass range

≃ 1.5 TeV

≃ 50 TeV

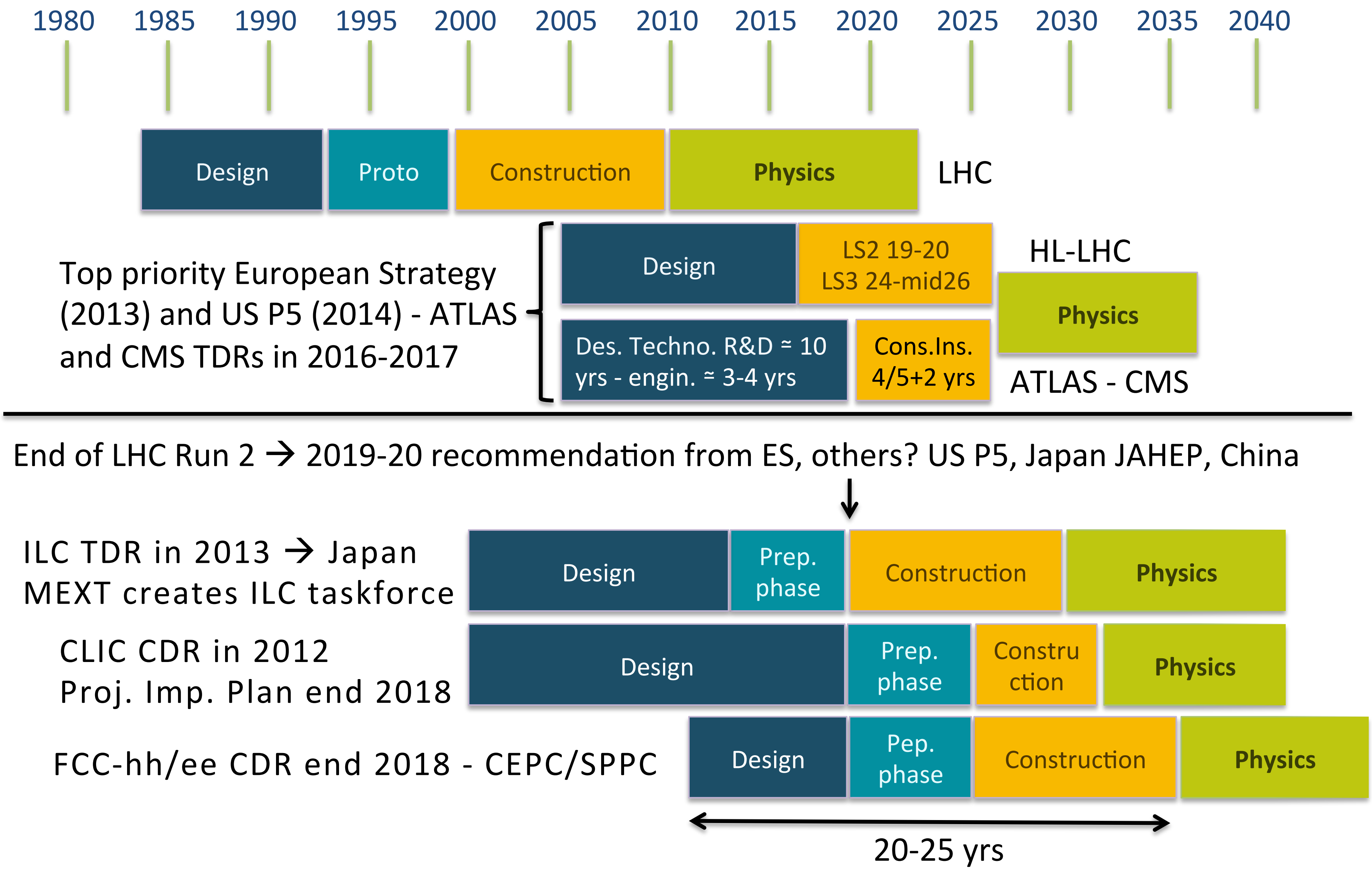
2 experiments assumed for CepC, SppC and FCC-hh, 2 for FCC-ee
L upgrade assumed for ILC and crab waist option for FCC-ee

HL-LHC 3000 ab^{-1}
≃ 200 M Higgs
≃ 8 TeV → 16 TeV at 30 TeV HE-LHC

Note:
- Different definitions of "year" across projects: assumed physics data-taking time varies over 0.5-1.6x10^7 s/year. Note: LHC 2012: 0.6x10^7 s machine operation in physics with stable beams
- pp colliders: usable H events are ~ 10% of total cross-section due to large backgrounds
- H studies are only one of several physics goals

Higgs couplings measurements:
- Couplings to W, Z, g, c, b, τ: best measurements: 0.2-0.8% at FCC-ee (luminosity)
- Couplings to top: best measurements: few % ILC, CLIC, FCC-hh (heavy final state → energy)
- Self-couplings HH: best measurements: ~10 % at CLIC, FCC-hh (heavy final state → energy)

Future Colliders broad-brush planning



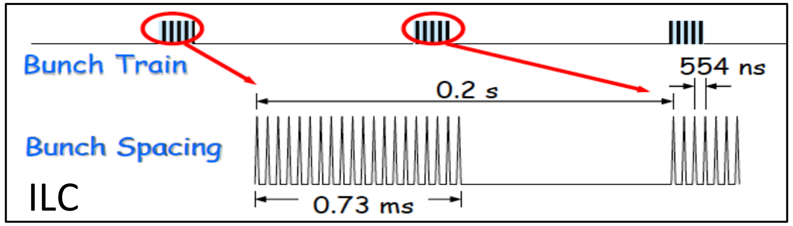
p-p collider beam parameters

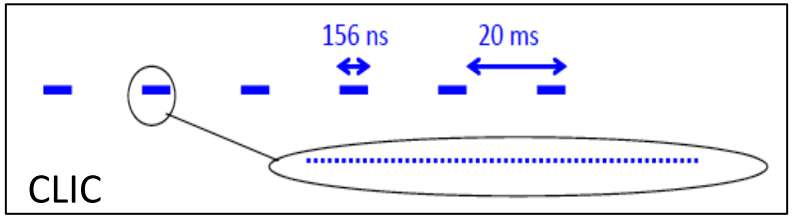
parameter	FCC-hh		SPPC	HE-LHC*	(HL) LHC
collision energy cms [TeV]	100		71.2	>25	14
bunch spacing [ns]	25	25 (5)	25	25	25
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	12	>25	5 (7.5)
Mean collisions/crossing (PU)	170	<1020 (204)	400	850	140 (200)

- 5 x 10^{34} $cm^{-2}s^{-1}$ (170 PU):
  → Similar conditions as for HL-LHC upgrades (can overcome present limitations)
- 30 x 10^{34} $cm^{-2}s^{-1}$ 1020(204) PU:
  → ≳ O(10) x radiation tolerance compared to HL-LHC, a major challenge
  → x 5 pileup will require high granularity (≃ linear increase) and both charged and neutral particles high timing precision measurement for collision (vertex) association
  → 5 ns bunch spacing would still require high granularity (to avoid out of time pileup in same channel), and also good timing precision

e^+e^- colliders beam parameters

	ILC at 500 GeV	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	2×10^{34}	6×10^{34}
BX separation	554 ns	0.5 ns
#BX / train	1312	312
Train duration	727 μs	156 ns
Train repetition rate	5 Hz	50 Hz
Duty cycle	0.36%	0.00078%
σ_x / σ_y (nm)	474 / 6	≈ 45 / 1
σ_z (μm)	300	44





- ILC - CLIC:

→ No pileup but large beam background
→ No radiation tolerance issues
→ Low integrated rates (duty cycle) allows full reconstruction event selection (triggerless) and power pulsing for low mass in tracker and high channel density in calorimeters
→ CLIC requires time stamps and short reconstruction windows

parameter	FCC-ee (400 MHz)				
Physics working point	Z		WW	ZH	tt_{bar}
energy/beam [GeV]	45.6		80	120	175
bunch spacing [ns]	7.5	2.5	50	400	4000
Lumi./IP x $10^{34}cm^{-2}s^{-1}$	210	90	19	5.1	1.3

- FCC-ee:

→ high lumi. at Z mass requires 100kHz to register all Zs
→ power pulsing not possible

HL-LHC beam parameters

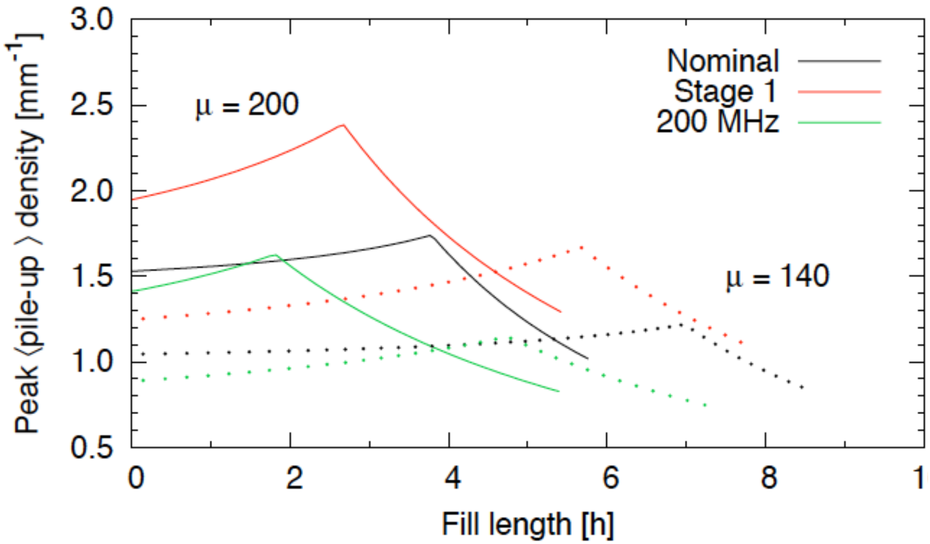
- Max luminosity at beginning of fills is 5 x 10^{35} Hz/cm^2 , operating scenarios are:
  - Nominal luminosity leveling at 5 x 10^{34} Hz/cm^2 , ≃ 140 PU
  - Design for luminosity leveling 7.5 x 10^{34} Hz/cm^2, ≃ 200 PU
  - Integrated luminosity 2.5 ab^{-1} in 10 years

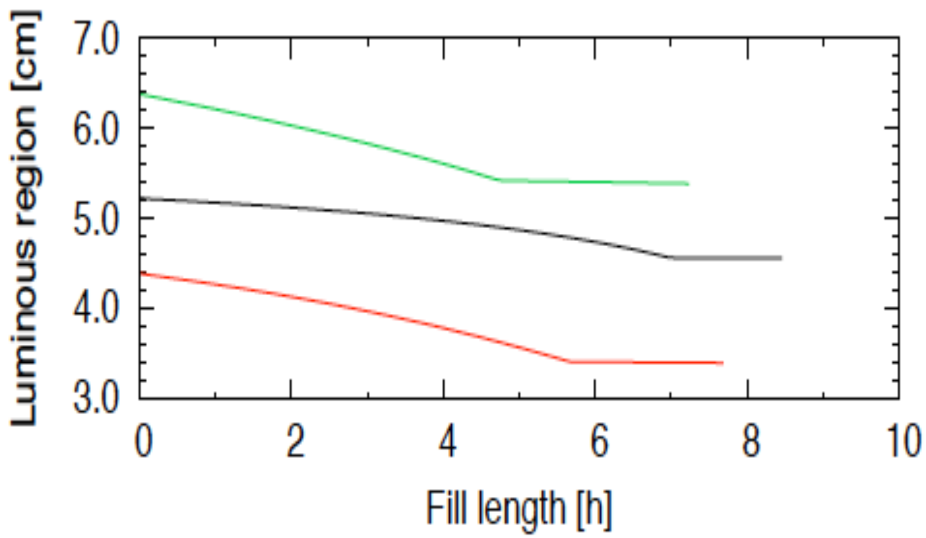
Different scenarios/options considered:

- Full Crab-Crossing (nominal)
- ½ Crab-Cavities installed (stage 1) up to LS4
- 200 MHz RF (option to mitigate e-could)
- Crab-Kissing (option to mitigate pileup effect through smaller z-density

Nominal	Stage 1	200 MHz
255.9 (100 %)	244.7 (95.6 %)	235.7 (92.1 %)
307.0 (100 %)	283.8 (92.5 %)	265.2 (86.4 %)

Integrated luminosity (fb^{-1}/year) 140 PU (top) and 200 PU (bottom)

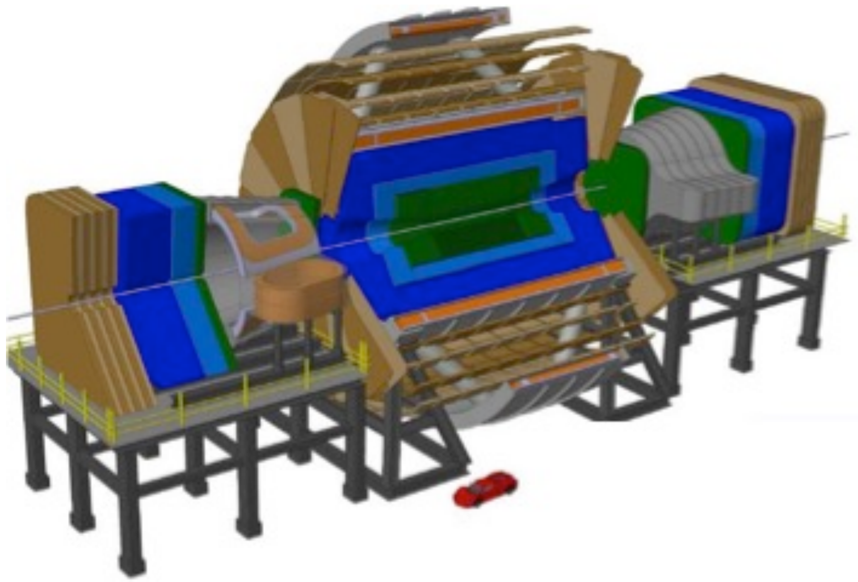


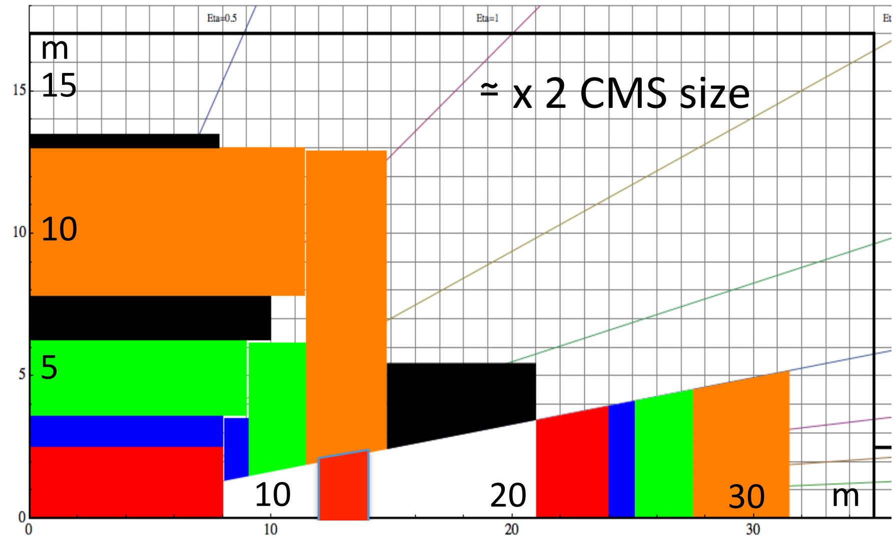


Detector concepts for future colliders

FCC-hh detector Concept

- Min bias event similar to HL-LHC:
  5.4 → 8 charged/η - <Pt> 0.6 → 0.8 GeV/c
- Higgs (highly boosted), HH, VBF/S process, and heavy new resonances:
  - ECAL 30 X_0 and HCAL 12 λ_i
  - Precise tracking ≲ 10% at p_T = 10 TeV
  - Calorimeter resolution EM(Had) 10(50)% (sampling) + ≃ % (constant), up to eta = 4
  - Extend coverage up to η = 6 for jets (eg calorimeters and tracking)
- Baseline design:
  → Twin solenoid ≃ 6T (12 m, no yoke) assuming same tracker resolution as current HL-LHC detectors
  → Dipoles ≃ 6T in forward region
  → Detector concepts at an early stage based on ATLAS & CMS Phase II designs

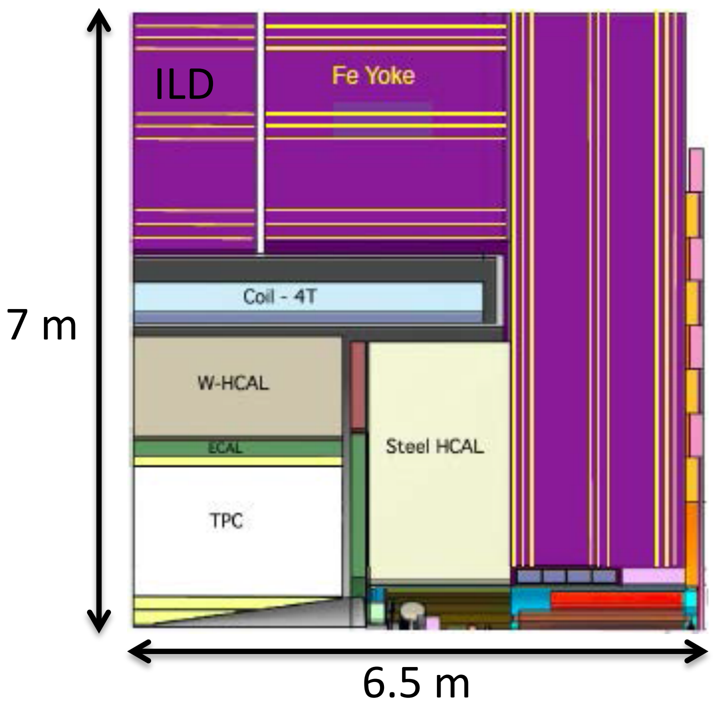


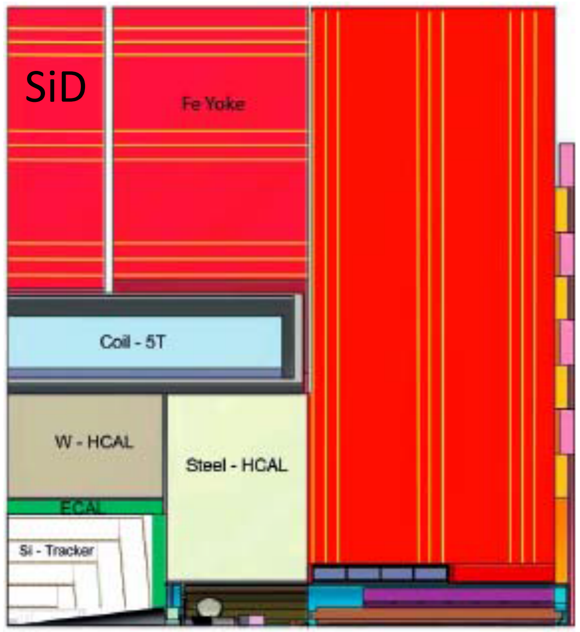


ILC-CLIC detector concepts

- Requirements for Higgs width, precise couplings, Z/W di-jet mass resolution
  - Vertex: resolution at IP of ≃ 5 µm (10 GeV tracks in barrel)
  - Tracking: $\sigma(pt)/pt^2 \simeq 2 \times 10^{-5}\ GeV^{-1}$
  - Jets: $\sigma(E)/E \simeq 3.5\%$ (in the range 50 - 250 GeV)
- LC: 2 detector concepts
  - SiD: 5 T solenoid - full Si-tracker 1.2 m - High Granularity Calorimeter
  - ILD: 3.4 T solenoid, Pixel vtx - Si + TPC/MPGD tracker 1.8 m - Calorimeter as for ILD

Note: FCC-ee detector concept similar to LC but smaller detector with 2T field





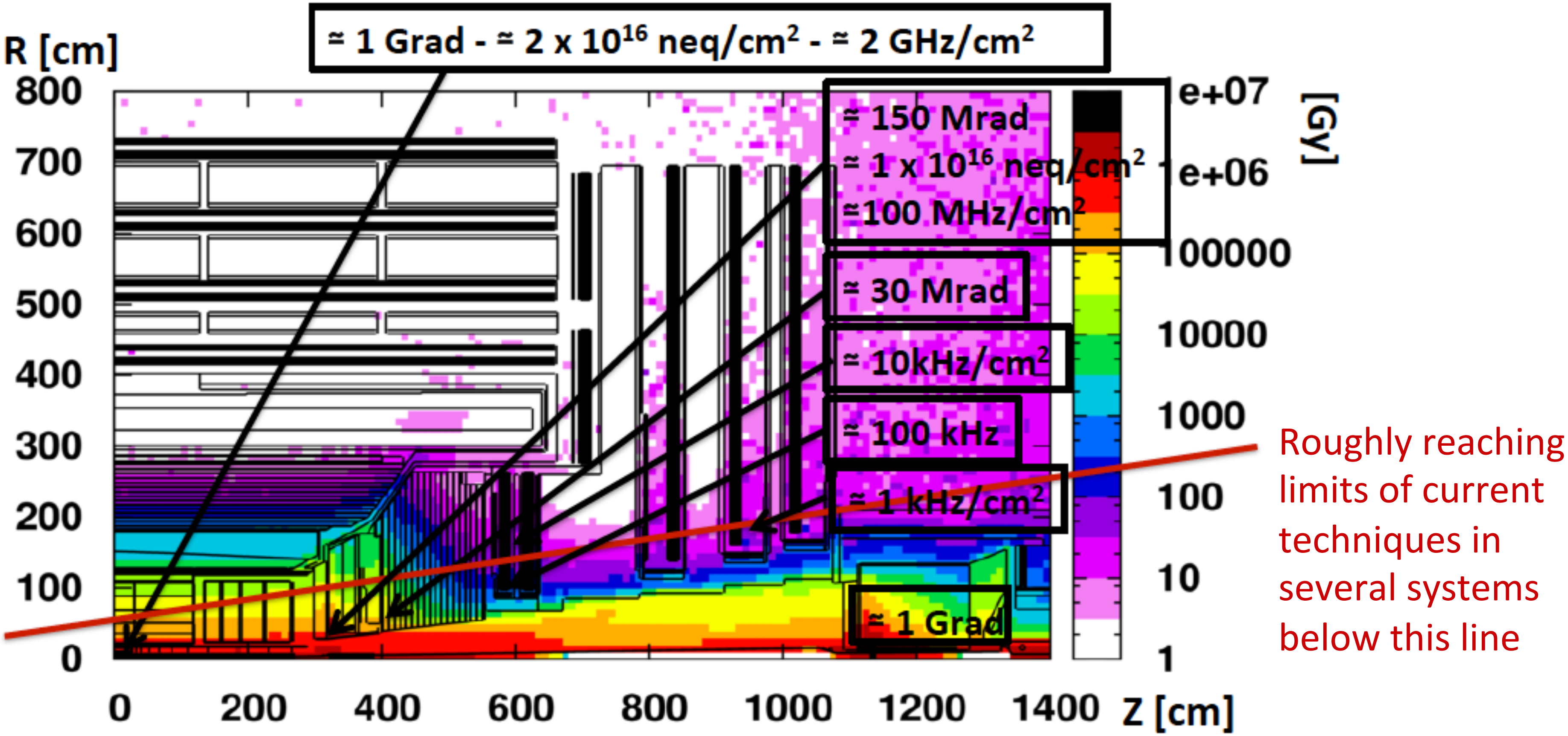
ILC-CLIC detector concepts

- Pixels extremely accurate and light - resolution at IP ≃ /4 current LHC
  - Target ≲ 0.2% X_0 per layer and ≃ 3 µm hit resolution with ≲ 25 µm^2 pixels, thin sensors ≃ 50 µm, airflow cooling with lower power consumption (first layer close to IP ≲ 2 cm)
  - Time window at CLIC ≃ 10 ns
  - Technologies:
    - Hybrid with thin sensors ≃ 50 µm and thinned ASIC ≃ 50 µm (fast for CLIC)
    - MAPs (ILC) - HV-CMOS sensor + amplifier with capacitive coupling to digital ASIC through glue (fast for CLIC?) - also allows smaller pixel size for reduced occupancy although not improving resolution
- Tracking, Pt resolution ≃ /10 HL-LHC
  - Small strip pitch or macro pixels, target 1% X_0 and ≲ 10 µm hit resolution (needs charge sharing)
- Calorimetry resolution ≳ /3 HL-LHC (with PU)
  - High Granularity PFlow concept
    - ECAL ≃ 23 X_0 , ≃ 30 layers, ≃ 0.5 x 0.5 cm^2 W/Si
    - HCAL ≃ 7.5 λ_i, ≳ 50 layers, AnalogHCAL 3 x 3 cm^2 scintillator + SiPM or Semi-DigitalHCAL 1 x 1 cm^2 RPCs pads with multi-thresholds
    - ≃ 80 M channels (x 12 CMS HGC)
    - Time window at CLIC ≃ 10 ns (EM) 100ns (Had.) and precision of ≃ 1 ns
- Muons with scintillator strips + WLS + SiPM or RPCs

ATLAS and CMS Phase II (HL-LHC) upgrades

Radiation and particle rates:

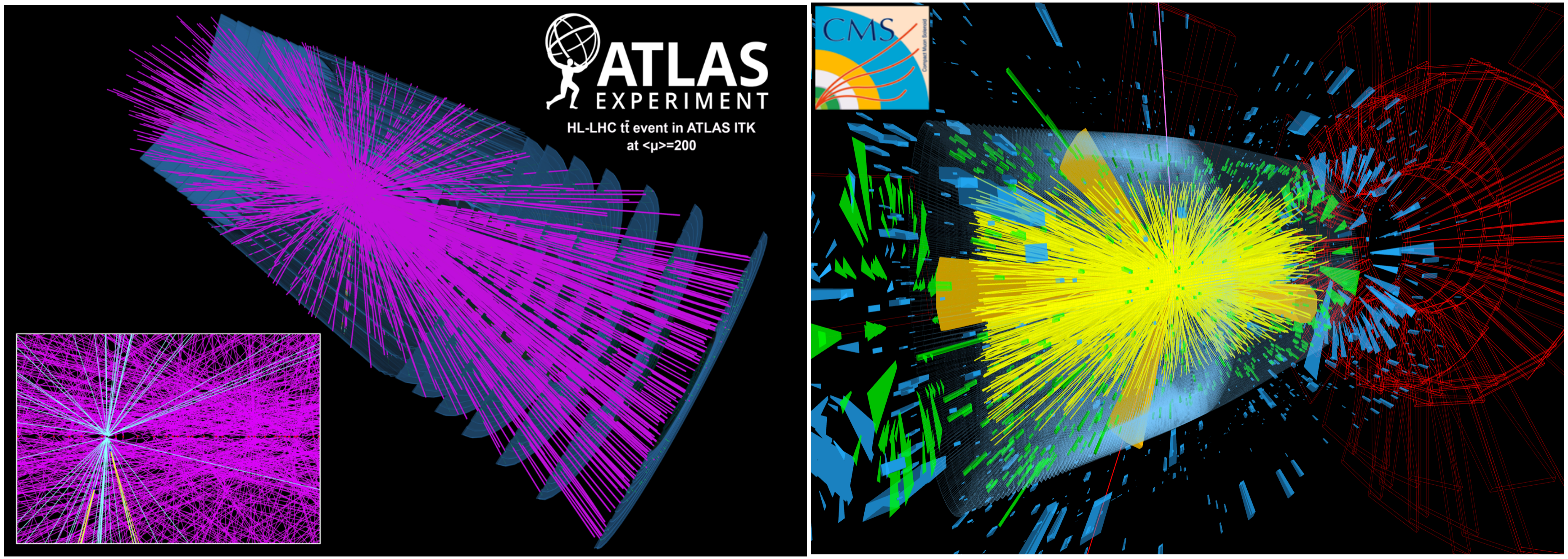
- Require new trackers, and also endcap calorimeters in CMS, new forward muons
- And replacement of most of the readout systems



CMS radiation dose map, neutron equivalent fluence and particle rates for luminosities of 3000 fb^{-1} (integrated) and 5 x 10^{34} Hz/cm^2 (instantaneous)

ATLAS and CMS Phase II upgrades

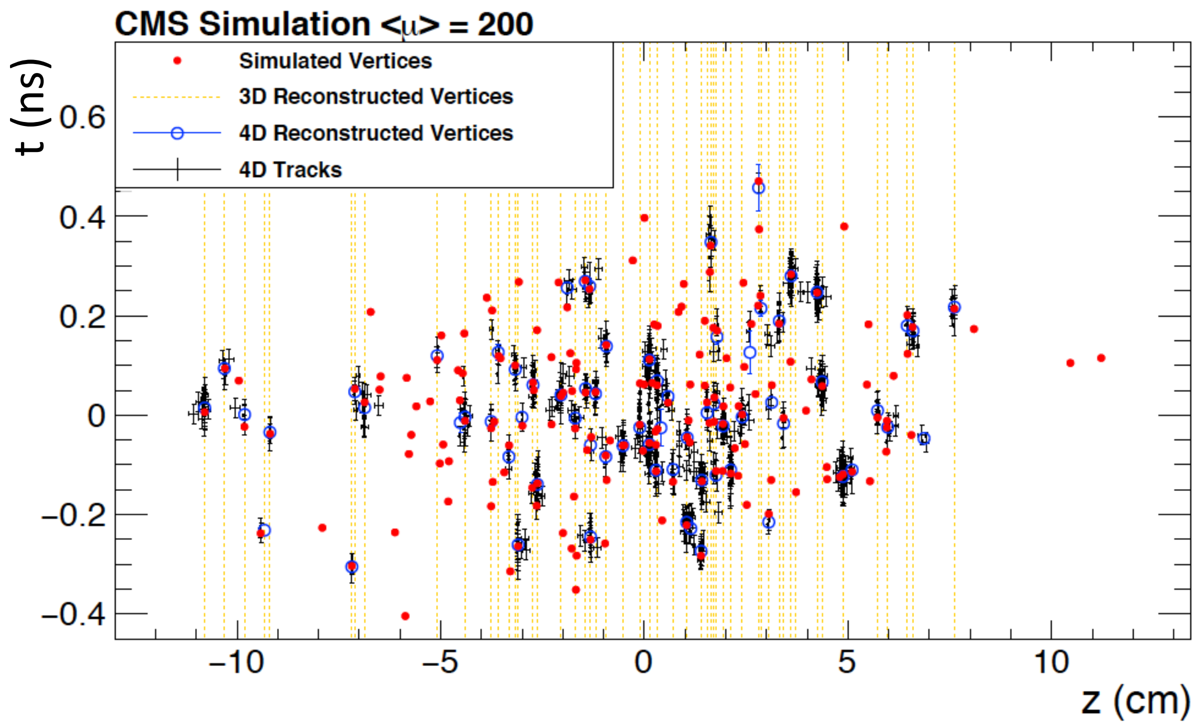
- Upgrades designed to maintain Phase I (50 PU) performance at 140 PU - able to operate at 200 PU with smooth performance degradation



Displays of a $t\bar{t}$ event (left) and of a VBF H → $\tau\tau$ (right) in 200 p-p collisions

ATLAS and CMS pileup mitigation

- High tracking efficiency is crucial for pileup mitigation and tracks are needed at hardware (trigger) event selection, as well as the full calorimeter granularities
- Ultimate PU mitigation would need precise timing measurement (of MIP and neutrals) to unambiguously associate both tracks and neutral energy clusters to each vertex (within precision limits)

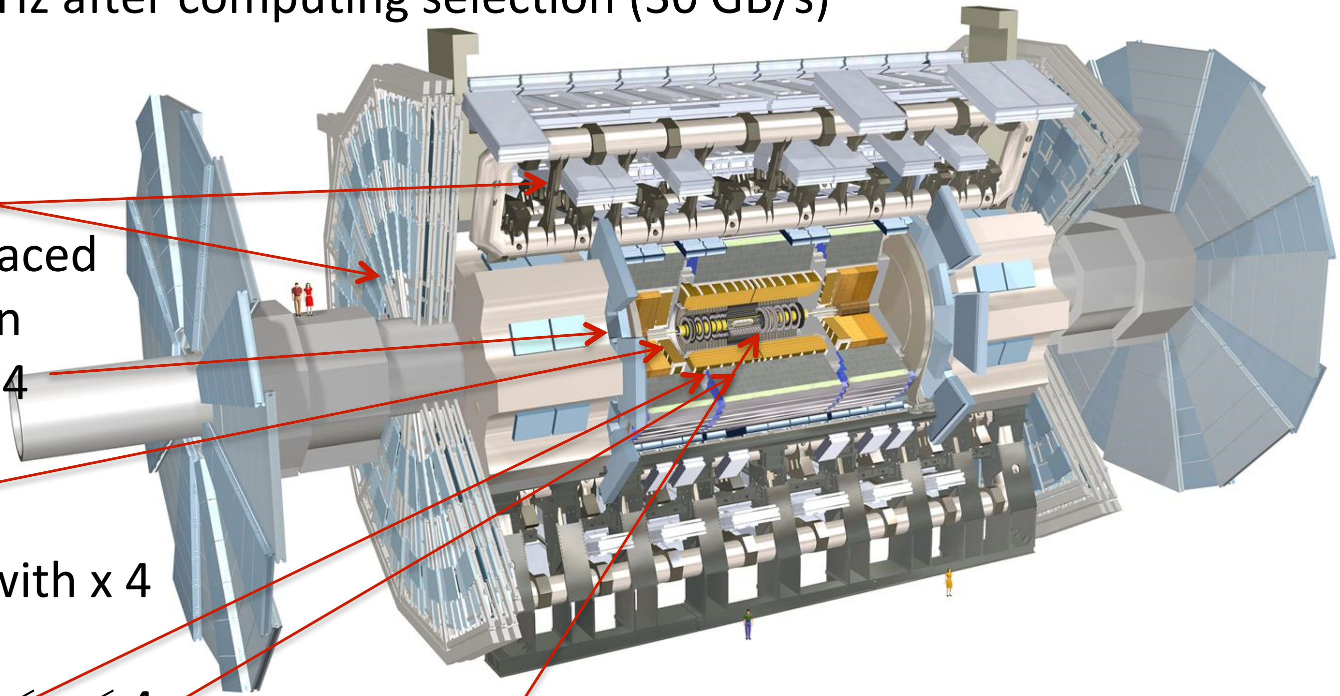


z-t structure of sim. and reco. vertices in a 200 PU event, 3D uses the CMS Phase II tracker (w/o timing) and 4D includes an investigated timing layer with MIP precision of 20 ps

ATLAS upgrades for Phase-II

Trigger/DAQ

- 1 MHz Tracker readout w or w/o Region of Interest after 6 μs latency
- Full read-out at ≃ 400 kHz with track-trigger after ≃ 30 μs latency
- Register up to ≃ 10 kHz after computing selection (30 GB/s)



Muon systems

- New electronics
- Some chambers replaced to improve resolution
- Muon tagging to $\eta \simeq 4$

Forward calorimeter

- Possibly new sFCAL with x 4 granularity
- 5D Si/W to cover $2.4 \lesssim \eta \lesssim 4$

Liquid Argon and Tile calorimeter

- New electronics

New Tracker

- Rad. tolerant, high granularity and light
- Extend coverage to $\eta \simeq 4$

CMS Phase-II upgrades

Trigger/HLT/DAQ

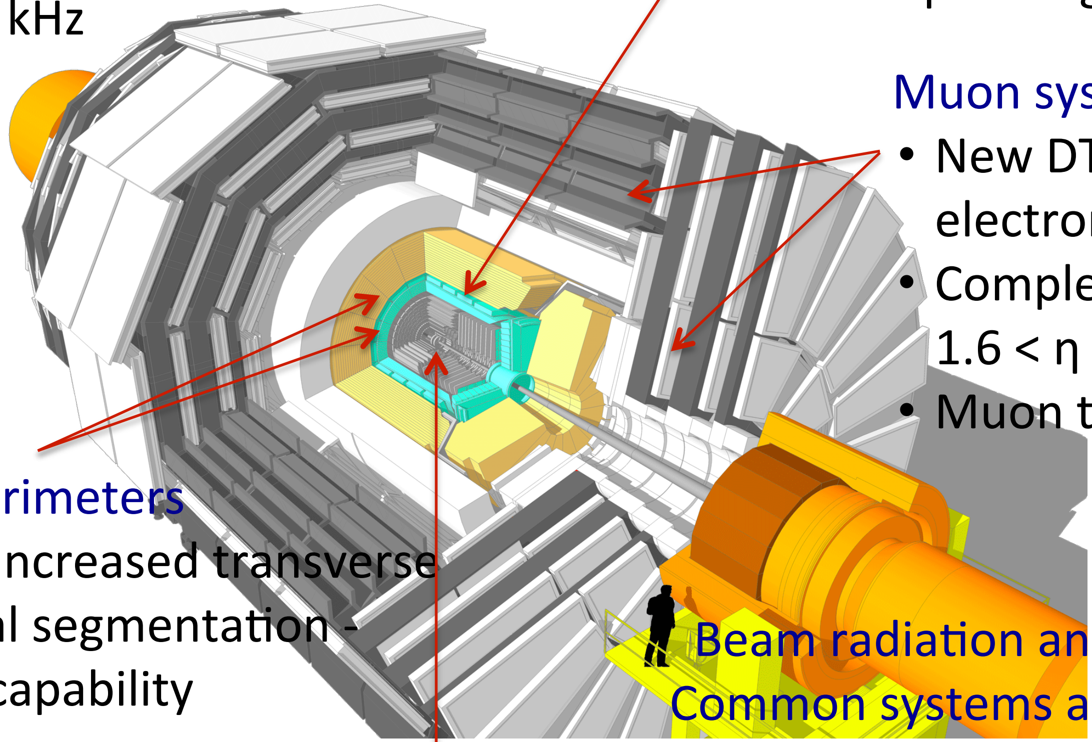
- Track information in L1-Trigger (hardware)
- Trigger latency 12.5 μs - readout rate 750 kHz
- HLT output 7.5 kHz

Barrel EM calorimeter

- New FE/BE electronics with improved time resolution
- Lower operating temperature (8∘)

Muon systems

- New DT & CSC FE/BE electronics
- Complete RPC coverage $1.6 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$



New Endcap Calorimeters

- Rad. tolerant - increased transverse and longitudinal segmentation - precise timing capability

Beam radiation and luminosity

Common systems and infrastructure

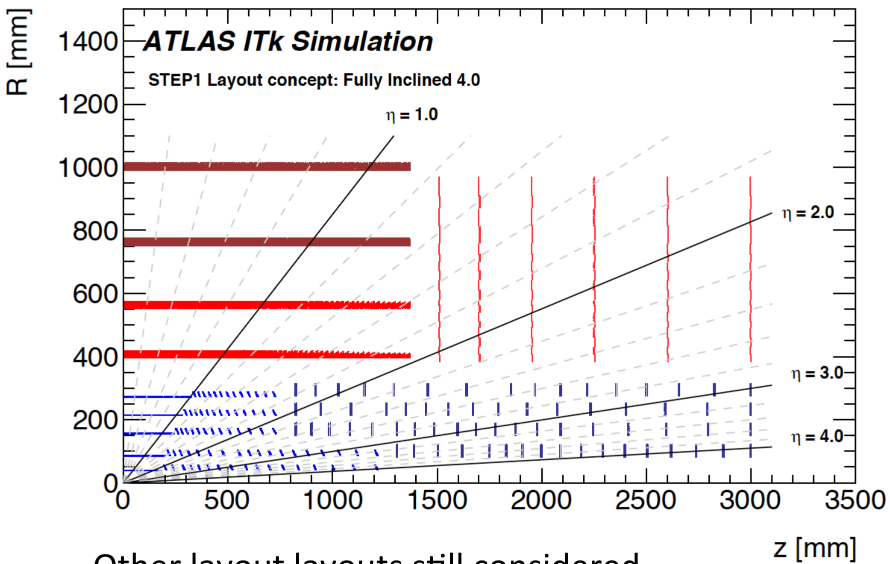
Investigating hermetic MIP timing layer

New Tracker

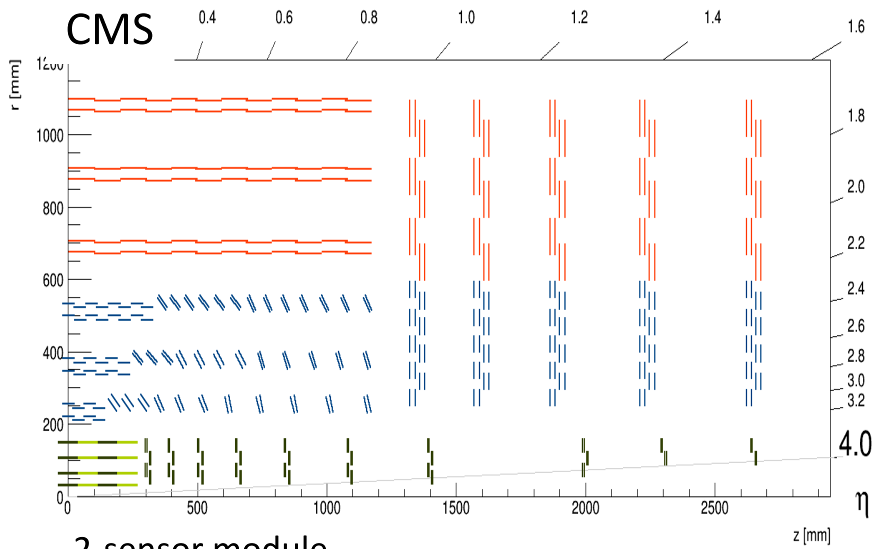
- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout in Outer Tracker for Trigger
- Extended coverage to $\eta \simeq 3.8$

ATLAS and CMS Silicon Trackers

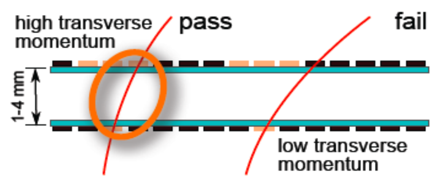
- High granularity (≃ 4 to 6 x present trackers):
  - Pixel sizes in range ≃ 50 x 50 - 25 x 100 μm^2 - first layer(s) replaceable
  - Strip pitch ~ 75 to 90 μm and length ~ 2.5 to 5 cm length
- Light (improve resolution & reduce interactions and γ-conversions):
  - Design, new materials - new cooling (CO_2) - DC/DC, serial powering
- Implementation of tracking information in hardware trigger
- Extension of pixel coverage from η ≃ 2.4 to η ≃ 4



Other layout layouts still considered



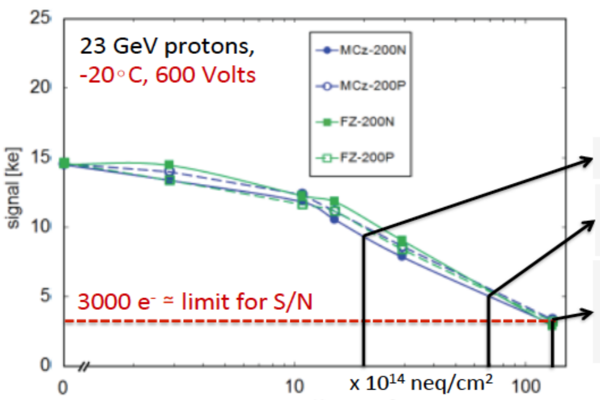
2-sensor module concept for trigger
Pt selective readout
long pixels in inner layers for z

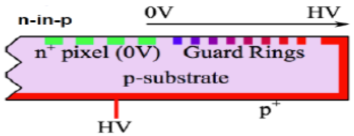


Silicon sensor R&D trends

HL-LHC:

- Thin planar sensors with improved bulk material n-in-p
  - Recent progress in 8” wafers and physically thin (200 μm) sensors
- 3D sensors alternative for higher radiation tolerance - good candidate for 1st pixel layer - (more expensive, 1st layer likely needs replacement due to ASIC rad. tol.)

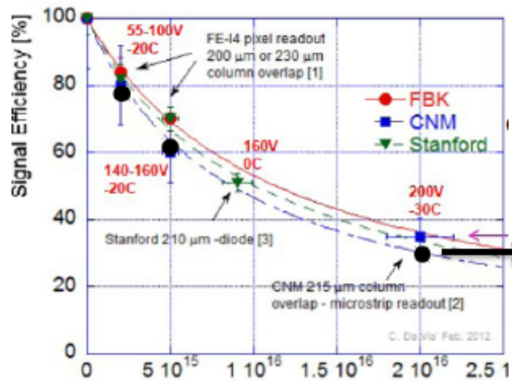


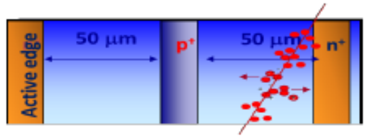


≈ 4000 fb^{-1} at 20 cm 1st strip layer

≈ 4000 fb^{-1} at 7 cm 2nd pixel layer and also ≈ LHCb pixels

≈ 3000 fb^{-1} at 3 cm 1st pixel layer
≈ 5000 fb^{-1} Si/W calorimeter η ≈ 3
confirmed with neutron irradiation





6000 e⁻ after 2 x 10^{16} neq/cm² at -30◦C

pp and ee future colliders:

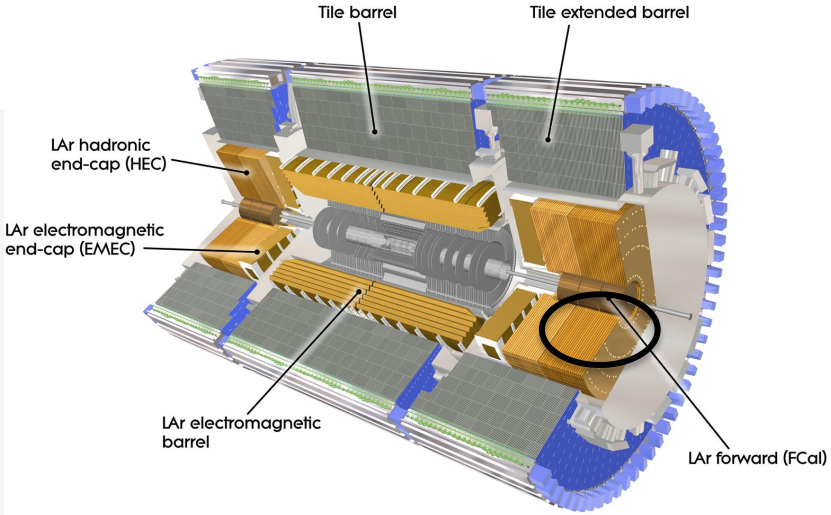
- Higher granularity - lighter, with thinner sensors, smaller pitch, and fast
  - Hybrid technology need to improve bump bonding for size & cost
  - Monolithic (MAPS, HR/HV CMOS) light, not yet enough rad. tol., also relatively slow
  - 3D integration of sensors and electronic functions through SLID to sensors and TSV between ASICs functions analog/digital (good compromise for ee and pp colliders?)

Note this could also apply to Si-HGC (although lightness is not a criteria)

ATLAS Calorimeter upgrades

- ATLAS LAr calorimeters & Scint. Tile
  - need new readout electronics - full granularity at hardware trigger
- Forward CALorimeter ($3 \lesssim \eta \lesssim 5$)
  - Ion space charge effect (due to peak luminosity) is investigated - option to replace with sFCAL - lower gap ≃ 100 µm and x 2 better segmentation in η & Φ, or add mini-FCAL in front of current FCAL
- Thin High Granularity Si/W(Cu) Calo.
  - ($2.5 \lesssim \eta \lesssim 4$) is being investigated to further mitigate PU, including precise timing measurement ($\lesssim$ 50 ps)

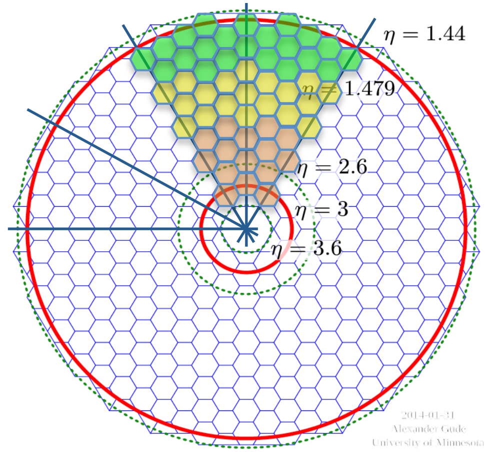
LAr is a good candidate for FCC-hh with higher granularity and rad. tol.

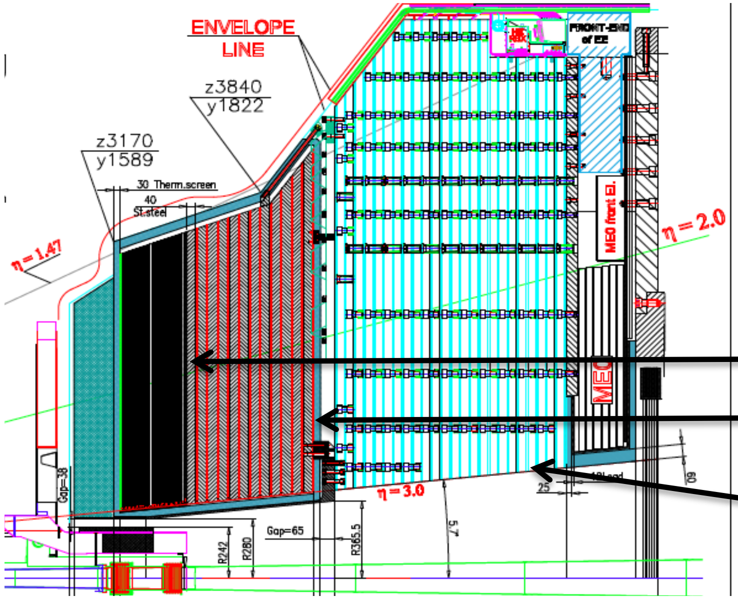


CMS Calorimeter upgrades

- High Granularity Si-Calorimeter inspired from CALICE with 5D shower measurement
  - Electromagnetic 28 layers of Si-W/Cu - 25 $X_{0,}$ 1λ_i
  - Front Hadronic 12 layers of Si/Brass - 3.5 λ_i

Could also be candidate for FCC-hh (yet expensive)

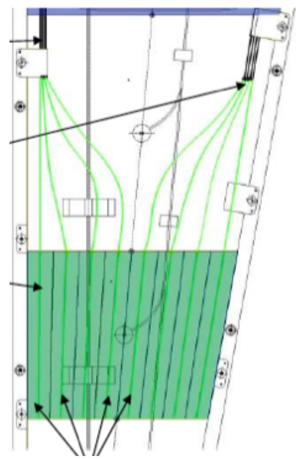




Hexagonal sensors - 3 active thicknesses depending on radius 100/200/300 µm - 0.5 - 1 cm^2 pads for 100 - 200/300 µm

- EE: 380 m^2 - 4.3 Mch - 13.9k modules
- FG: 209 m^2 - 1.8 Mch - 7.6k modules

- Back Hadr. 12 layers scintillator tiles/Brass - 5.5 λ_i
  - Finger concept reduce light path to WLS
  - R&D in plastic scintillators (5-10 Mrad), complex depend on material, environment, rates
  - SiPM - would benefit from higher rad. tol. an quantum efficiency)



Front End electronics ASIC R&D

HL-LHC:

- Chip complexity/design increased - benefit from deep-submicron technologies for lower pixel sizes, lower power consumption limited by radiation tolerance. - eg TSMC 65 nm technology more sensitive than 130 nm, needs specific design rules for analog functions and may only sustain 500 MRads (half HL-LHC innermost pixel layer)

ATLAS/CMS Pixel ASIC TSMC 65 nm

- Smaller Pixel size
- Larger chips ($\gtrsim$ 2 x 2 cm^2)
- Hit rates up ≃ 2-3 GHz/cm^2
- Rad. Tol. up to 1 Grad, 10^{16} n/cm^2
- High trigger rate and latency up to 1 MHz and $\gtrsim$ 10 μs
- Low power budget $\lesssim$ 1 W/cm^2
- Low noise ≃ 1000 e^-

CMS HGCal FE ASIC TSMC 130 nm

- Shaping ≃ 15 ns - noise ≃ 2000 e^- (after 3000 fb^{-1})
- Low power $\lesssim$ 10 mW/ch
- Dynamic range 10 pC - 10 bit ADC ≤ 100 fC and Time over Threshold (ToT) ≥ 80 fC
- Channel calibration better than 1%
- ToT time resolution $\lesssim$ 50 ps

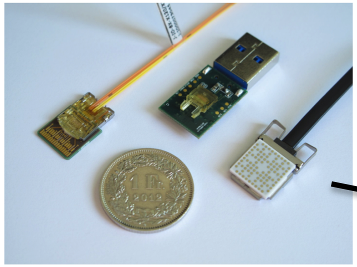
pp future colliders:

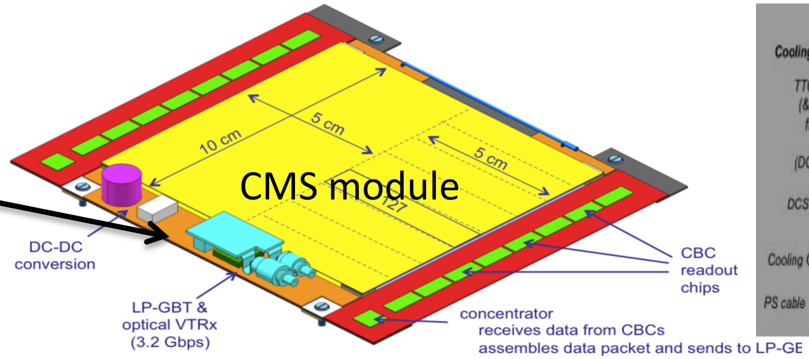
- Radiation tolerance is a complex issue - deeper sub-micron technologies may not work? (and need long lead-time to learn and characterize) - 3D integration to separate analog and digital functions may help?

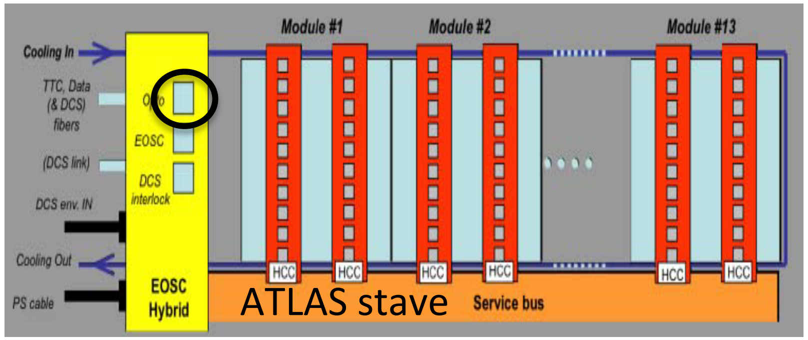
Front End Data transmission R&D trends

HL-LHC:

- GigBitTranciever (GBT) & Versatile Link
  - R&D on low power GBT (≃ 0.5 W) in 65 nm TSMC with 10 Gb/s data transmission
  - Still limiting factor in tracker readout for trigger purpose - size is also important
- Rad. tol. of Versatile Link insufficient for inner radii (1st pixel layer, CMS HGC)
  - Need light high BW electrical link before OL transfer (twinax cables…)







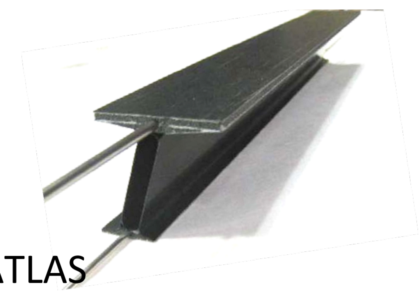
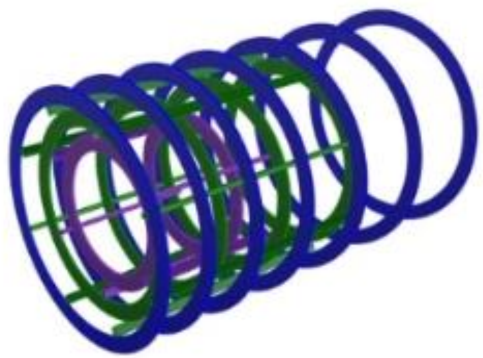
pp future colliders:

- Increased bandwidth is highly desirable for trigger with outer trackers, pixels, HGC (full pixel readout at FCC max lumi. not possible would need 1000 TB/s (40 PB/s evt builder)
  - Silicon photonics (laser, wave guide, modulator, electronics grown on same Silicon)
  - Wireless transmission
  - Needs to be radiation tolerant

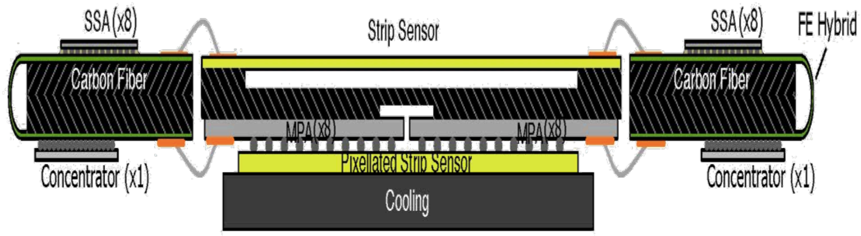
Cooling and Mechanics R&D trends

Present:

- Two-Phase CO_2 cooling ≃ 50 kW and ≃ -35° plants
  - Low-T operation crucial to mitigate radiation damage - low mass material needed
- Light mechanics with high conductive CF polymer skins and thermal foam core…
  - Low-weight crucial for multiple scattering, interactions & photon conversions (ALICE ITS (MAPs) is ≲ 1% X0 per layer) (also needs serial powering to minimize cabling)

ATLAS
pixel CF plate, foam, Ti pipes and barrel CF mechanics



CMS PS-module AlCF frame

pp and ee future colliders:

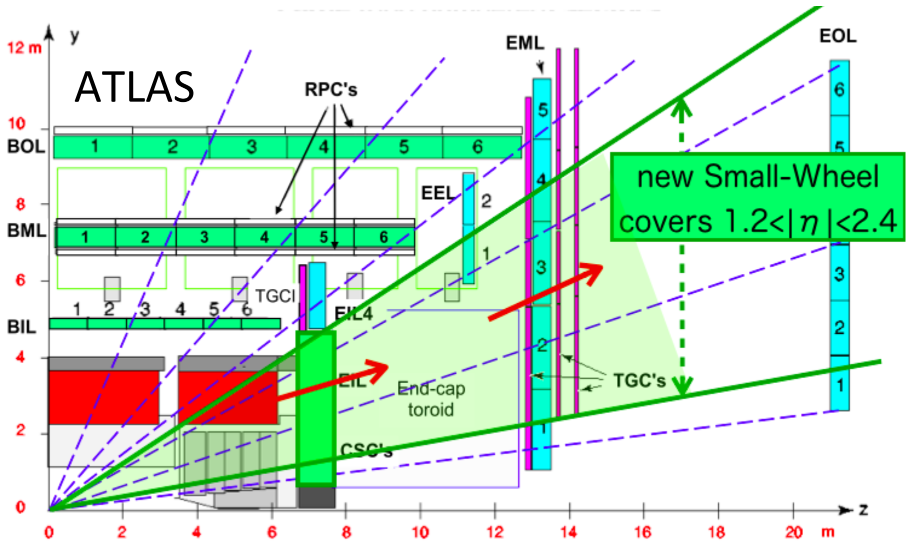
- Cooling
  - Air-cooling (for low power ILC)- Micro-channel embedded in sensors (LHCb VELO) for pp colliders?
- New materials, glues, and assembly technics
  - CFRPs adhesive bonding, new thermal foams, phase change adhesives - 3D printing

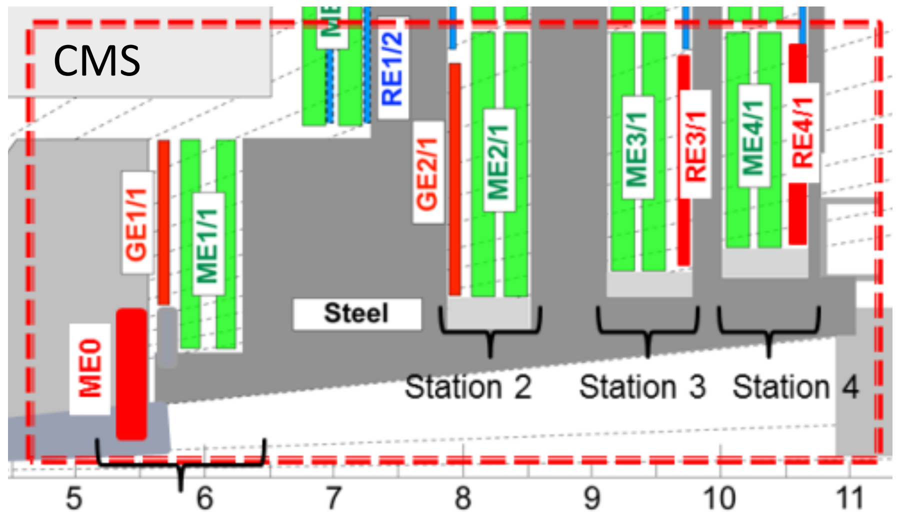
ATLAS and CMS Muon upgrades

- Muon systems are expected to sustain 3000 fb^{-1}
- Increased granularity, higher rate capabilities exploiting MPGDs in endcaps, new readout electronics (for trigger), coverage extended for μ-tagging to η ≲ 4

R&D

- Tests at GIF++ to confirm margins and select eco-friendly gas mixtures x 3 HL-LHC currents
- New multi-gap technics to improve timing precision (both GEMs and RPCs)
- GEM and Micro-Megas for ILD TPC readout 1x6 mm^2 pads (GEMs for ALICE TPC upgrade)



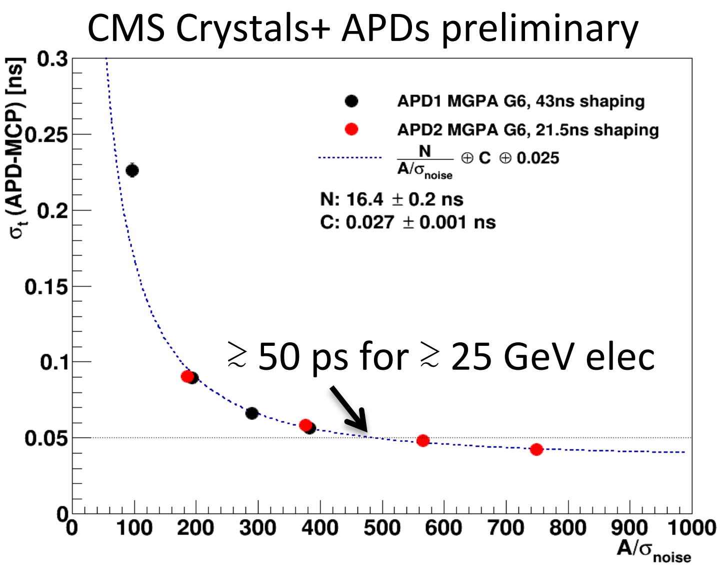


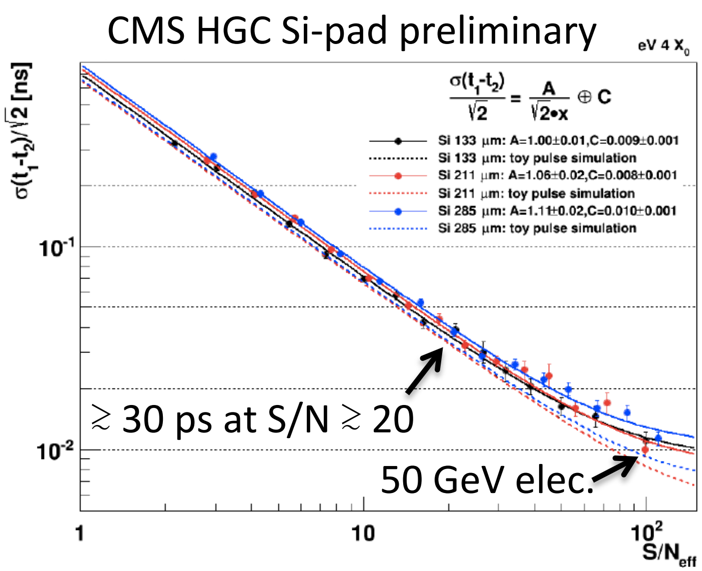
- New Small Wheels - small Thin Gap Chambers strips 2 cm → 3.2 mm (3mm pitch), thinner gap and Micro-Megas (0.5 mm pitch)
- Monitoring Drift Tubes - reduced diameter 30 mm & 200 Hz/cm^2 → 15 mm & 2 kHz/cm^2
- Triple GEM - 140 μm pitch, single mask and new assembly technique
- iRPC's - few kHz/cm^2 low-ρ Bakelite/Glass - multi-gap - thinner electrodes - higher gain FE - time resolution ≲ 100 ps

Precise timing devices R&D trends

HL-LHC:

- ATLAS investigate Si/W calorimeter with Low Gain Avalanche Diodes (LGAD)
- CMS improves barrel ECAL FE, Si-HGC intrinsic precise timing - Investigate MIP timing layer



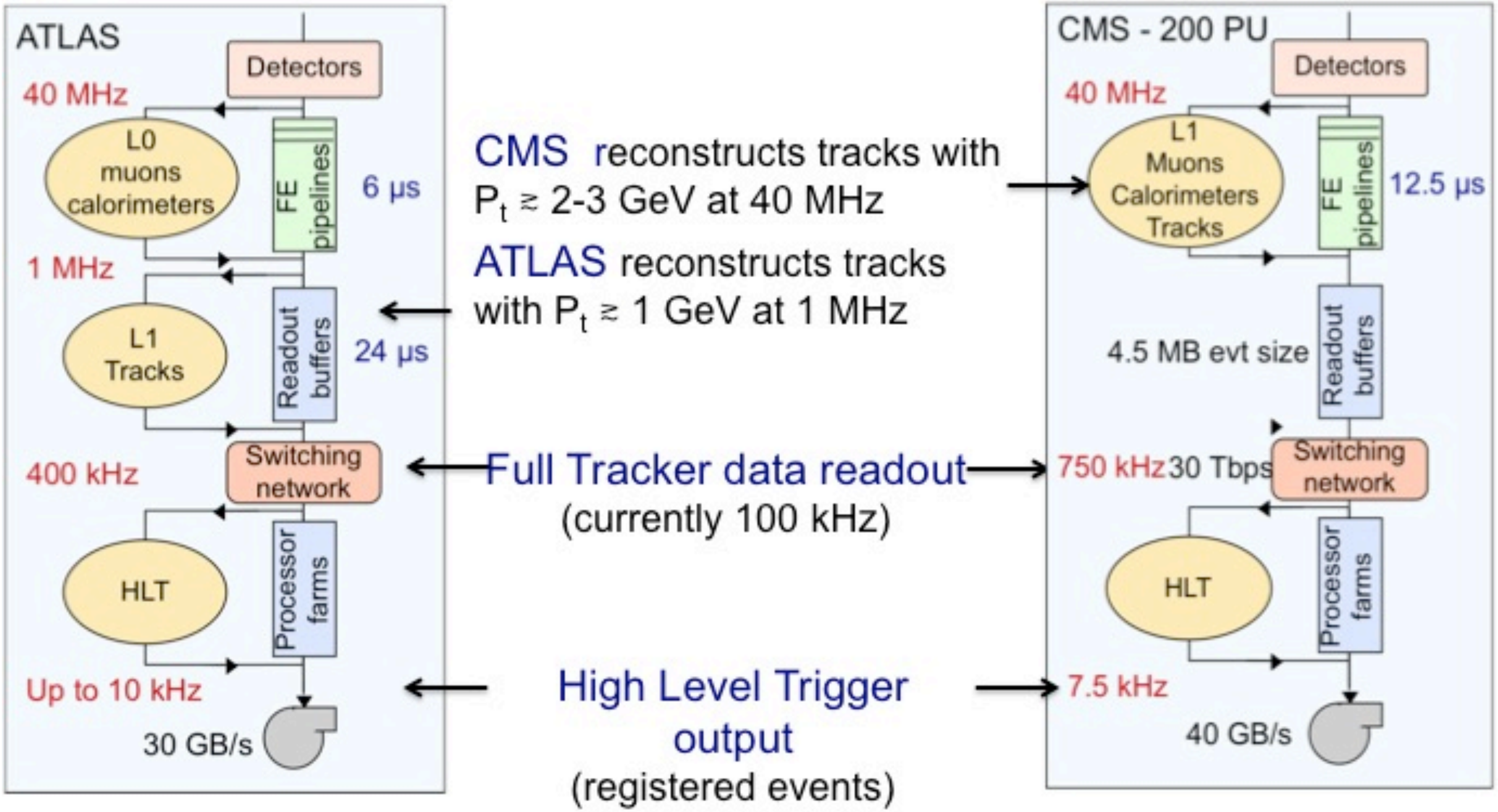


HL-LHC and pp future colliders:

- Radiation tolerant technology with ≃ 10 ps precision
  - Crystals (LYSO…) + SiPMs appears feasible for rad. tol and precision
  - Low Gain Avalanche Diodes (LGAD) - High Gain APDs, Micro-Megas with photo-cathods, MCP-PMT (w-cerenkov radiator or sec. emission) rad. tol. limited, final precision still to be demonstrated

FE/TDC and large clock distribution with precision and stability ≃ 10 ps

ATLAS and CMS Trigger upgrades



- Backend electronics - follow COTs progress in FPGA, high bandwidth links, and ATCA
- Custom ASIC developments - Associative Memories (track trigger pattern recognition) interest in 3D integration with FPGA (event cleaning and parameter fit)
- Computing - follow commercial progress, slower by O(10) compared to increase in CPU needs - R&D see back-up (ideal detectors would select event based on full reco.)

Conclusion

- HL-LHC:
  - Baseline technologies for HL-LHC detectors are identified/demonstrated, several innovations compared to current detectors - large scale and harsh environment operation experience will be useful for future experiments
  - R&D now focused on finalizing specifications and prototyping/engineering - 2 to 4 years effort by start of production - little room for new technologies (but opportunity for test)
- FCC-hh:
  - Large scale detectors - likely need an order of magnitude in granularity and radiation tolerance to fully benefit from accelerator luminosity potential - major R&D effort needed, technology choices could depend on η-r to optimize performance versus radiation tolerance and cost (also needs large effort of simulation studies)
- ILC-CLIC-FCC-ee:
  - Detectors require high granularity and highest possible resolution - several R&D beneficial to HL-LHC and FCC-hh (although rad. tol. is not an issue)

Additional information

HL-LHC ATLAS and CMS Online/Offline/Computing R&D

CPU need for online/offline reconstruction and analyses is expected to be roughly 30/80 times larger than for Run 2 at 140 PU

→ Anticipating x 8 gain at constant resources (25%/year improvement) another factor of ≃ 4/10 gain (online/offline) would be needed at 140 PU

R&D focuses on:

- Low power ARM processors, high performance GPU systems…
  → Develop multi-threaded code - data oriented for memory usage
- More broadly distributed resources to access opportunistic computing
  → Develop portable kernels of reconstruction and simulation code
  → Use cloud provisioning tools
- More efficient use of storage and data distribution
  → Develop dynamic data placement to use remote services through Content Delivery Network techniques

ALICE upgrades in LS2

New Inner Tracking System (ITS)
- improved pointing precision
- less material -> thinnest tracker at the LHC

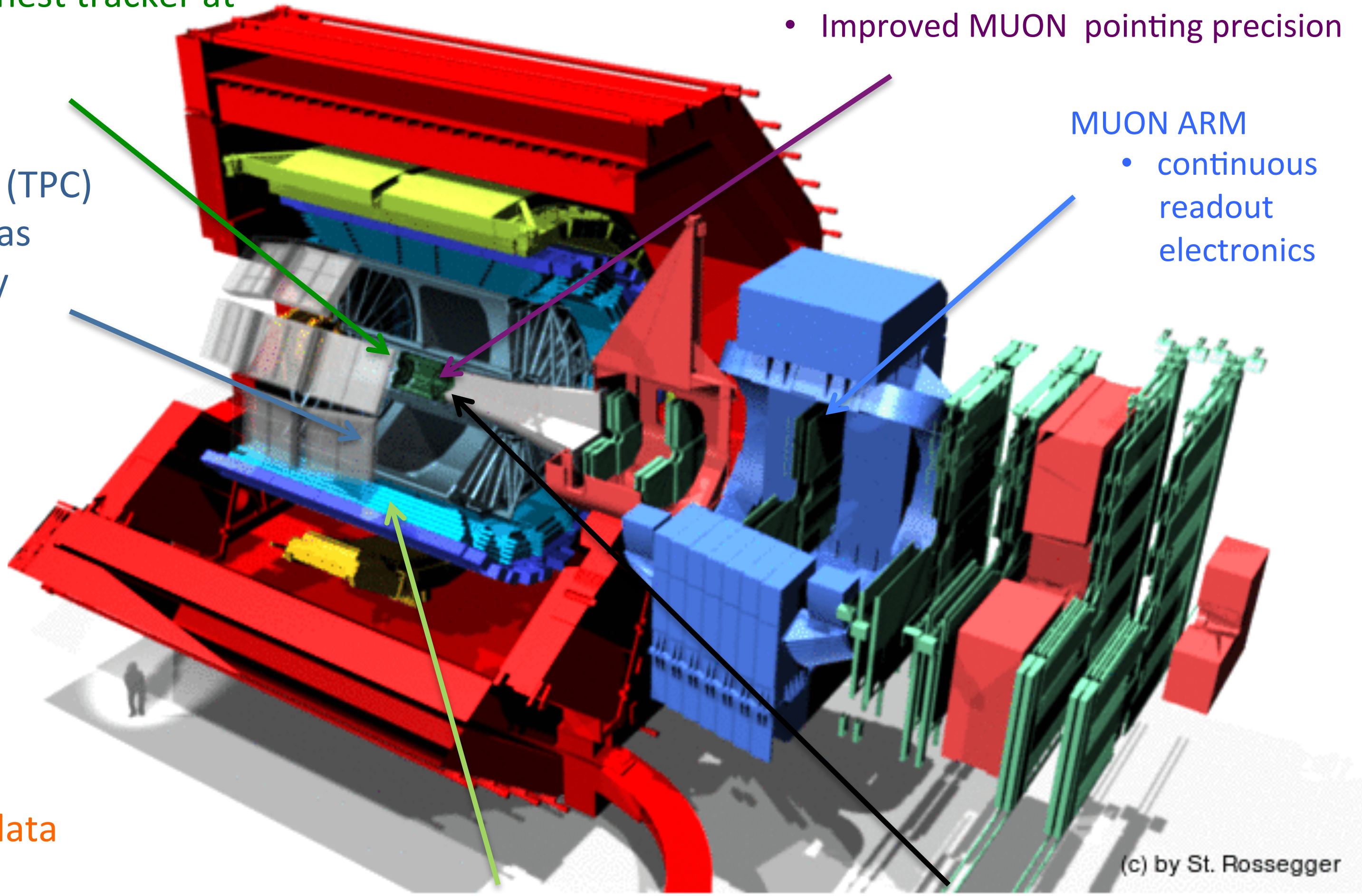
Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- continuous readout electronics

Time Projection Chamber (TPC)
- New Micropattern gas detector technology
- continuous readout

New Central Trigger Processor (CTP)

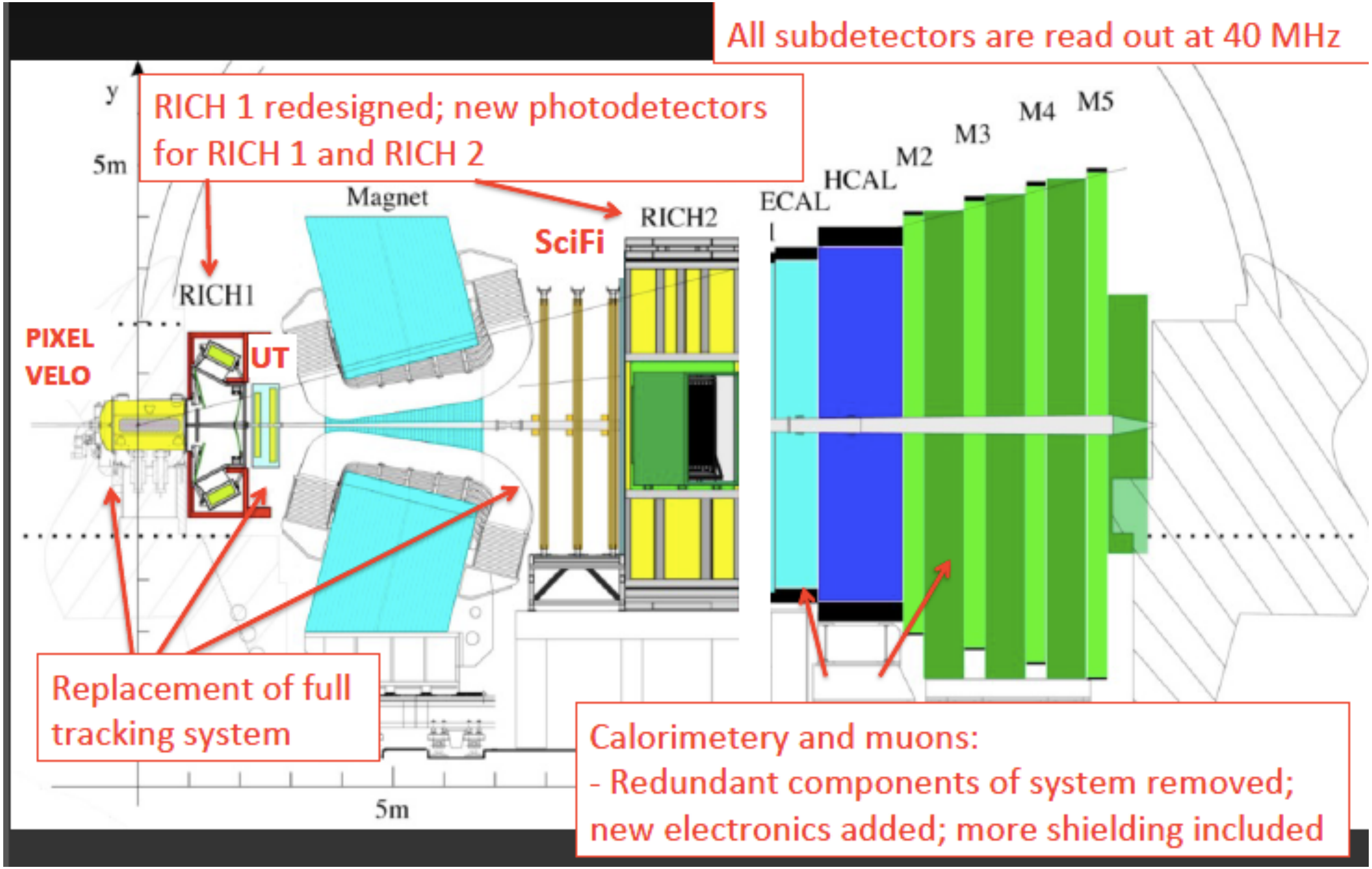
Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate



TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

LHCb upgrades in LS2

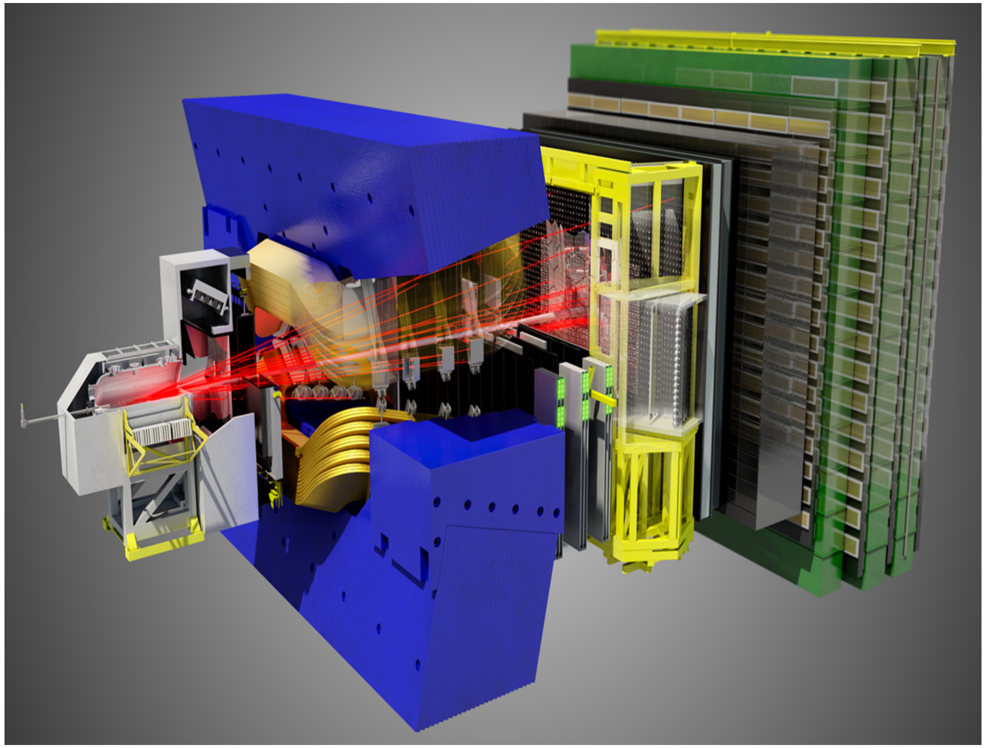


LHCb will upgrade already in LS2 and collect 50 fb-1 at 2×10^{33} cm-^{2} s-^{1} in runs 3 and 4

Software trigger operating at 40 MHz for 20 kHz of p-p events registered
→ Trigger/DAQ throughput at 4 TB/s (≃ ATLAS/CMS at HL-LHC)

New electronics for all detectors and other major innovations:

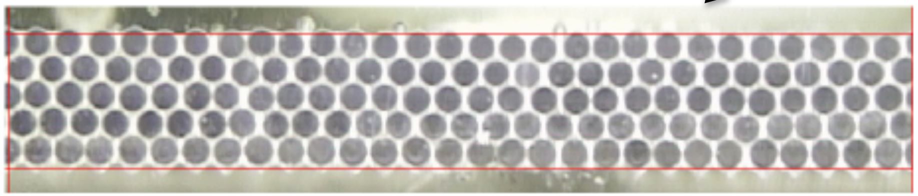
- New Vertex Locator with pixels at 5.1 mm from beam - 55 x 55 μm^2 pixels - fluence of 8×10^{15} n_{eq}/cm^2 - 2 Tbit/s data rate - light mechanics with micro-channels cooling
- Tracking with scintillating fibers (10000 km) and cooled SiPMs (-40◦)



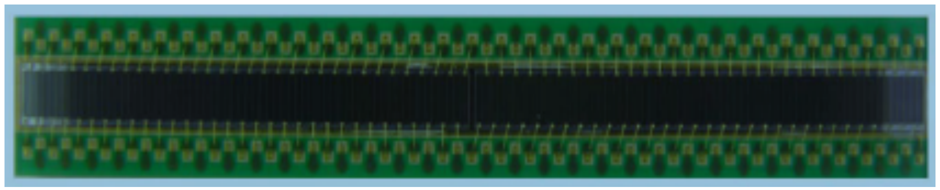
LHCb Scintillating Fiber Tracker R&D

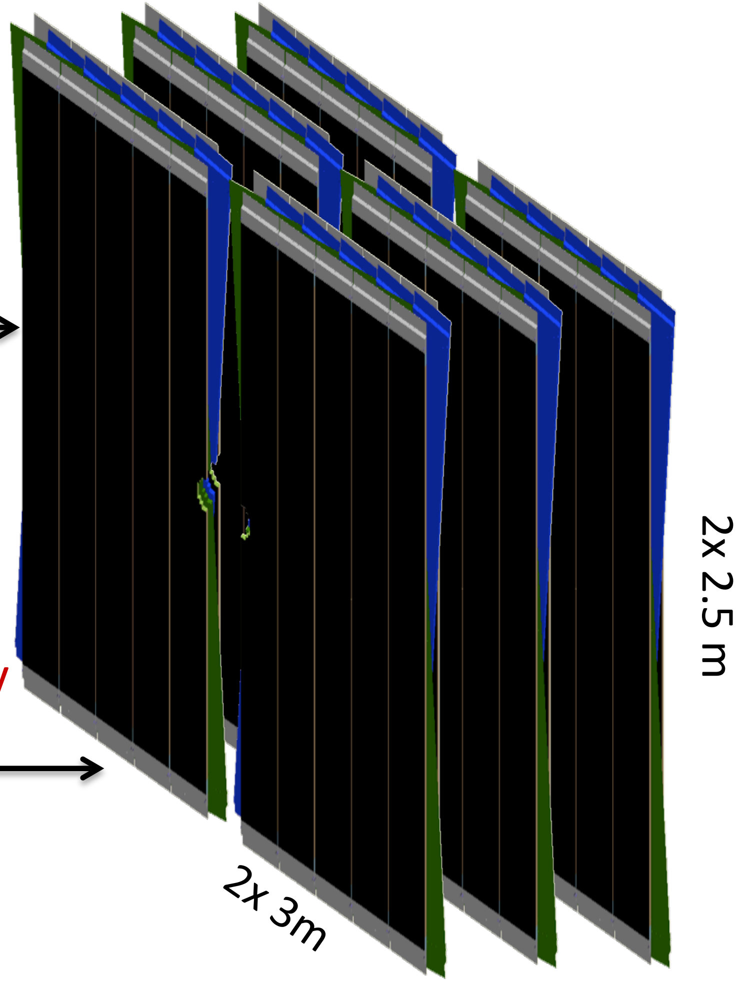
3 stations, each 2.5% X/X0 - 4 plans (X-U-V-X) with ± 5◦ stereo angle - 50-75 µm resolution

- 3 M fibers Φ 250 µm x 2.5 m (10 000 km)
  → Development for 3 Mrad in inner region
  → High precision assembly of fiber mats



- Readout with 128 SiPM array 250 µm pitch
  → -40◦C cooling to sustain $1.2 \cdot 10^{12}$ neq. /cm2
  → Work to improve Photo-Detection Efficiency



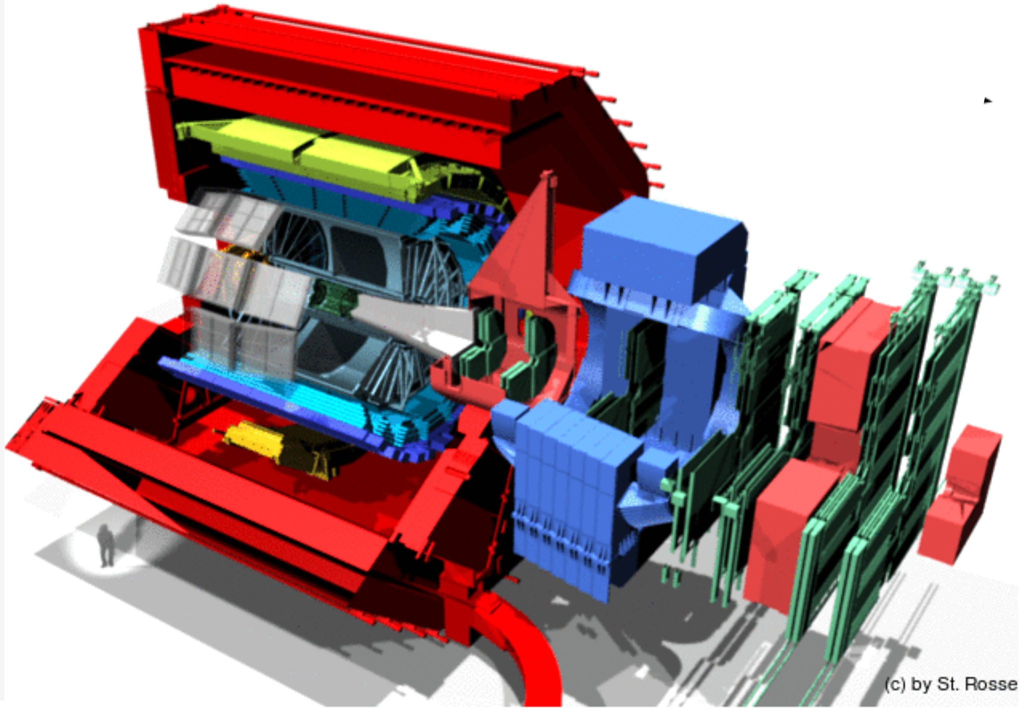


ALICE will upgrade already in LS2 to integrate ~ 10 nb^{-1} at 6 x 10^{27} $cm^{-2}s^{-1}$ in runs 3 and 4

Register all Pb-Pb collisions ≃ 50 kHz → Fast online calibration and reconstruction with FPGAs and GPUs for data compression, from 1 TBps to 50 GBps storage (storage ≃ ATLAS/CMS at HL-LHC)

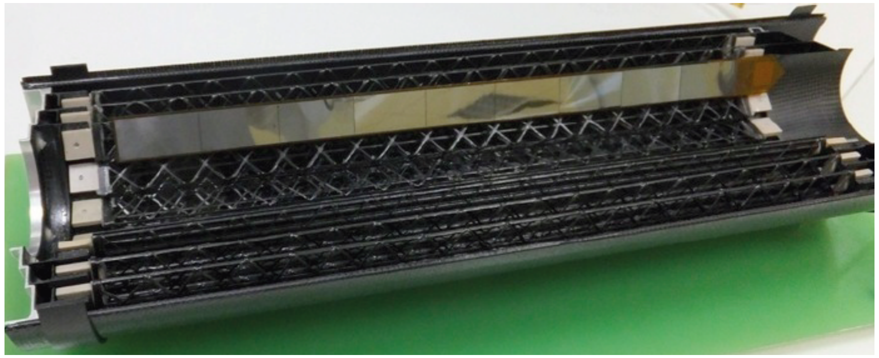
New electronics for all detectors and other major innovations:

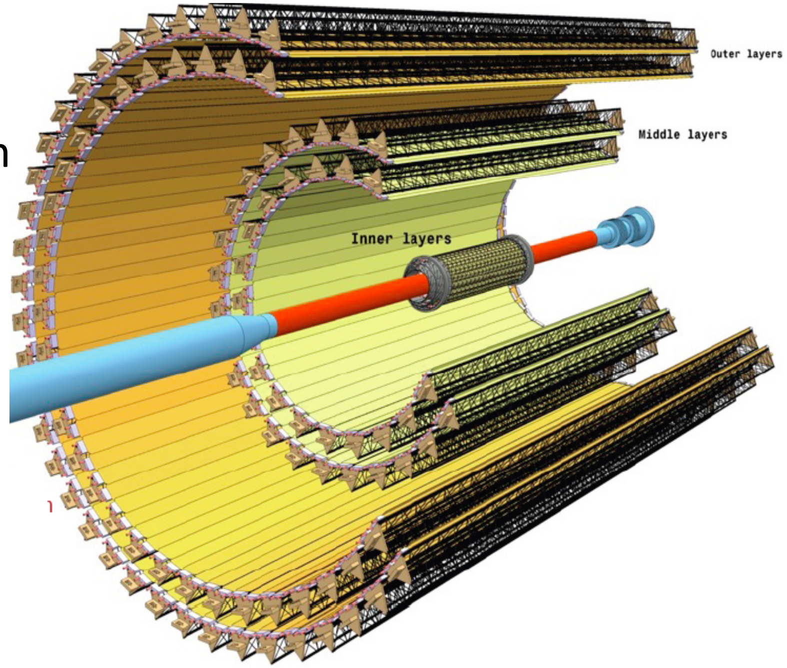
- New Internal Tracker System using Monolithic Active Pixels - 12.5 Gpix. 30 x 30 μm^2 - ultra-light mechanics
- Use Micro-Pattern Gas Detectors for TPC readout (GEM and/or Micro-Megas)
- Trigger timing ≃ 20 ps resolution quartz Cerenkov with MCP-PMT



ALICE Inner Tracker System R&D

- Ultra light system to improve IP resolution by a factor ≃ 3
  - 7 layers of Monolithic Active Pixels ≃ $10m^2$ with 12.5 Gpix
    - 3 inner layer each 0.3% X/X0 from 20 to 40 mm
    - 4 outer layers of 1% X/X0 up to 400 mm





- MAPs Technology
  - Tower Jazz Technology (0.18 μm)
  - Thin sensors ≃ 50 μm
  - Pixels ≃ 30 x 30 μm^2
  - Radiation tolerance 10^{13} neq/cm^2
  - Binary readout