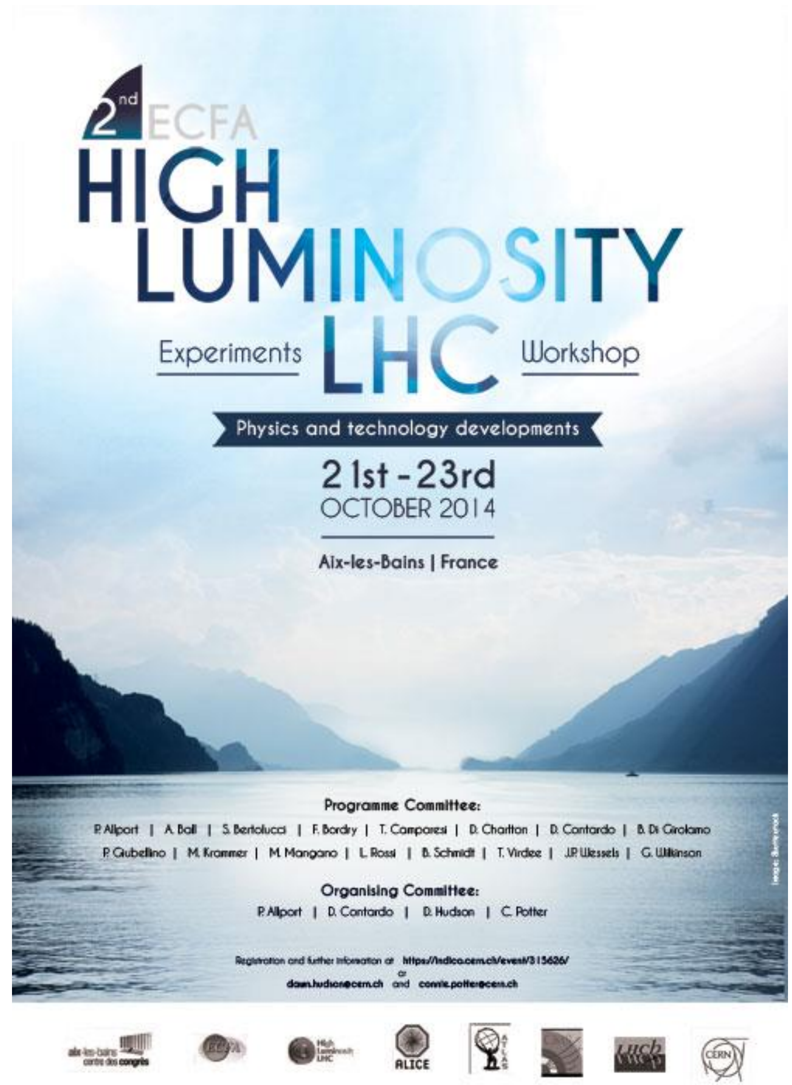
2^{nd} ECFA HL-LHC Workshop

presented by Fido Dittus (CERN)

Summary mostly prepared by Phil Allport and Didier Contardo

- Introduction
- Overview of Physics Updates
- Accelerator & experiment interface
- Some Detector Highlights
- Outlook



Context of the Workshop

(D. Contardo HL-LHC Coordination Working Group, Nov. 3rd 2014)

- May 2013 - CERN Council approves the European Strategy report recommending the HL-LHC as the top HEP priority
- May 2014 - US Particle Physics Project Prioritization Panel (P5) makes similar recommendation
- June 2014 - CERN Council discusses the planning up to 2025 & approves the 2015-2019 plan, including first HL-LHC expenses

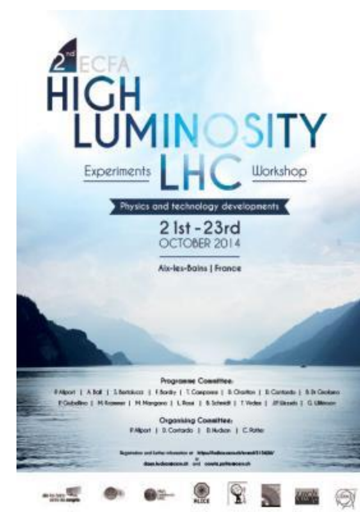
➢ The HL-LHC project is acknowledged as the next crucial step in any future for collider HEP

- Funding is yet to be agreed - 2015 will be crucial for discussion with Funding Agencies, particularly for ATLAS & CMS

➢ ECFA workshops contribute to demonstrate HL-LHC physics goals, that upgrades are well motivated and that the community is organized to minimizes the resource needs through sharing of experience and common R&D programs

Workshop Links and Organization

- ECFA 2013 - agenda
  https://indico.cern.ch/conferenceDisplay.py?confId=252045
- ECFA 2014 - agenda http://indico.cern.ch/event/315626/other-view?view=standard
  - Opening session: accelerator and experiments perspective
  - 8 sessions organized across communities by Preparatory Groups to address including accelerator & experiment interface - physics goals & performance reach - R&D progress in all areas



    - PG1: Physics theory, physics experiment, performance
    - PG2: Solid state tracking detectors
    - PG3: Scintillating devices
    - PG4: Gaseous detector systems
    - PG5: Electronics systems
    - PG6: Mechanics and cooling
    - PG7: Trigger, online and offline computing
    - PG8: Accelerator & experiment interface, activation & mitigation

Physics Studies - Higgs

(PG1)

Aim to measure as many Higgs couplings to fermions and bosons as possible to really test if this is the SM Higgs or a pointer to the BSM physics we know has to exist

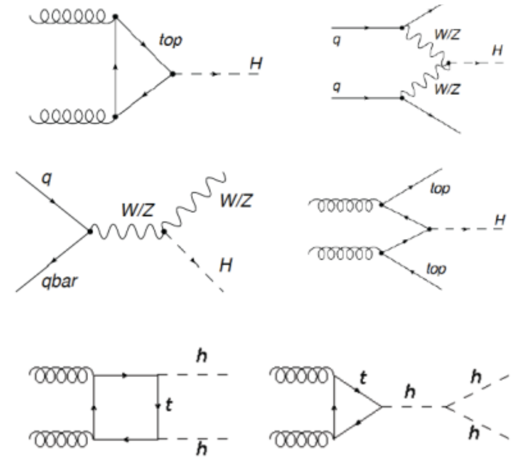
HL-LHC (3000 fb^{-1}): a true Higgs factory:

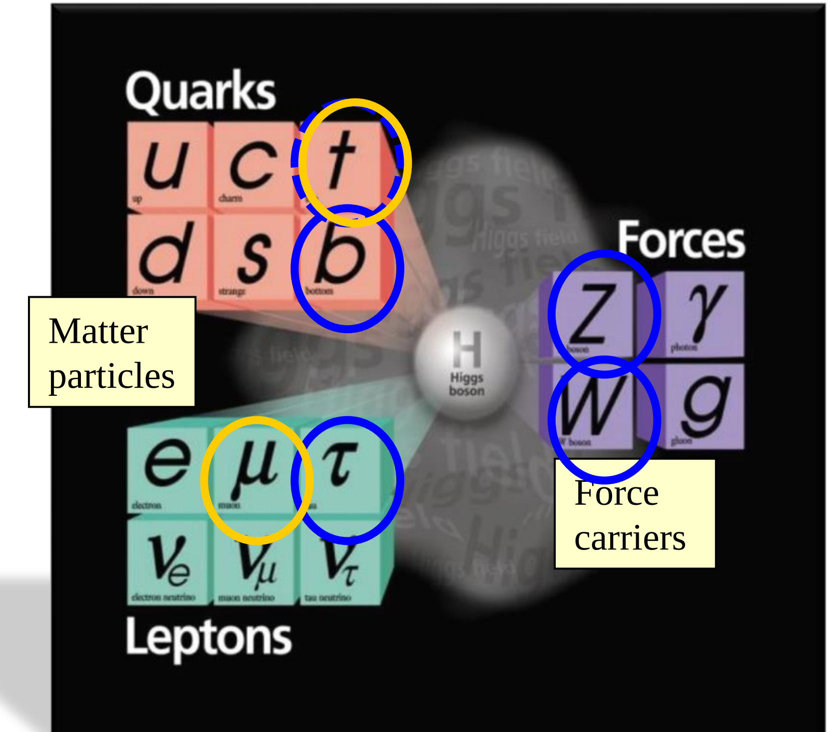
- ❑ 170M Higgs events produced
- ❑ > 3M useful for precise measurements (more than or similar to ILC/CLIC/TLEP)

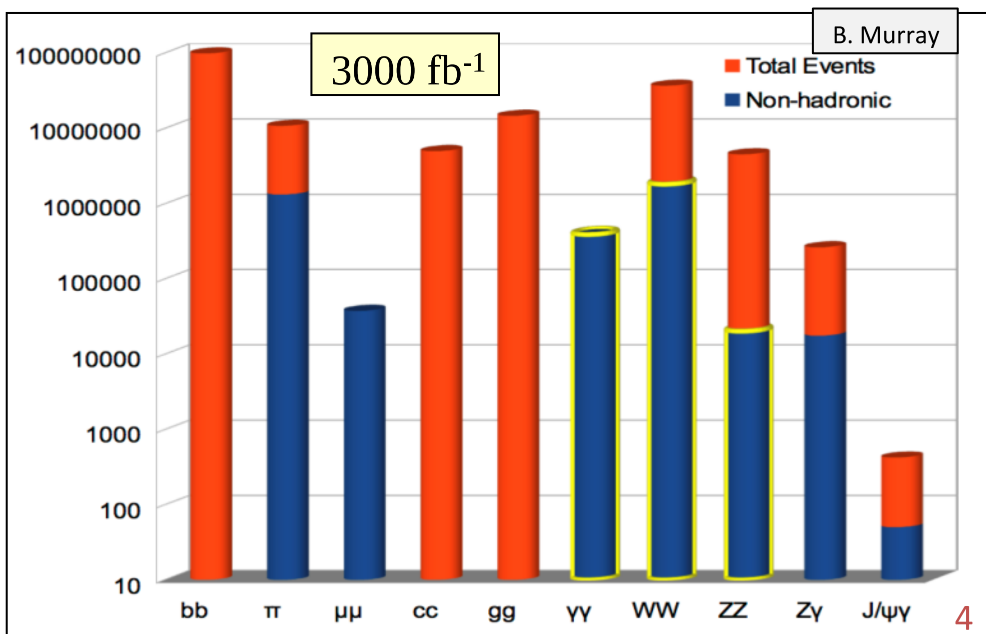
LHC gg→ H (50pb); e^+e^-→ ZH (0.2-0.3pb)

	Higgs bosons at √s=14TeV
HL-LHC, 3000fb^{-1}	170M
VBF (all decays)	13M
ttH (all decays)	1.8M
H->Zγ	230k
H->μμ	37k
HH (all)	121k

Aram Apyan



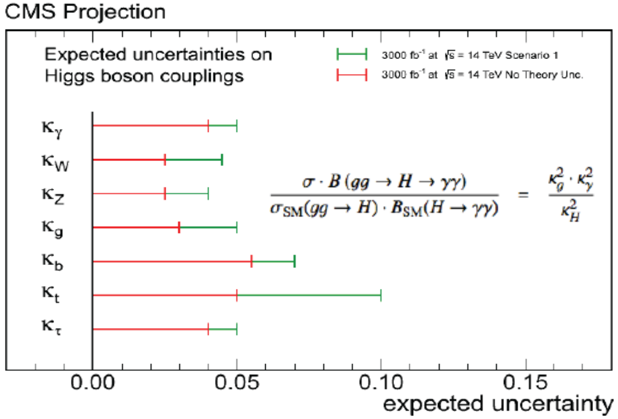


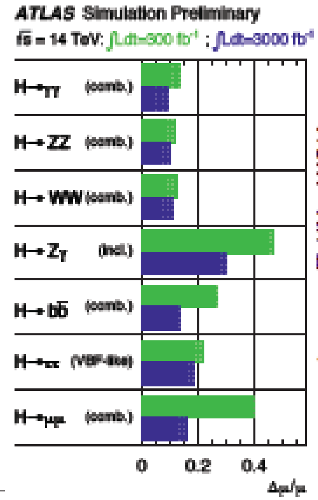


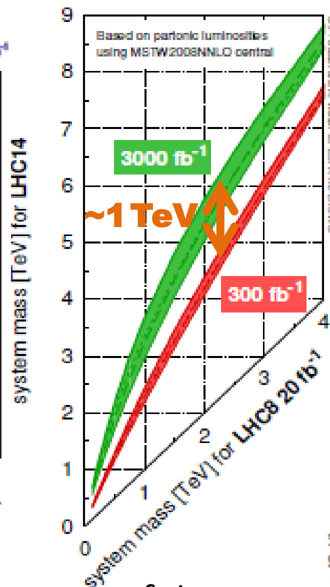
Physics Studies - Higgs – BSM

(PG1)

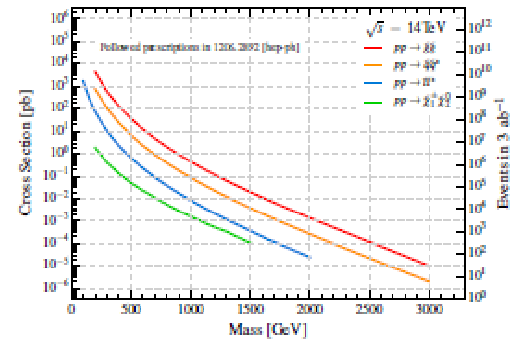
Stéphane Willocq



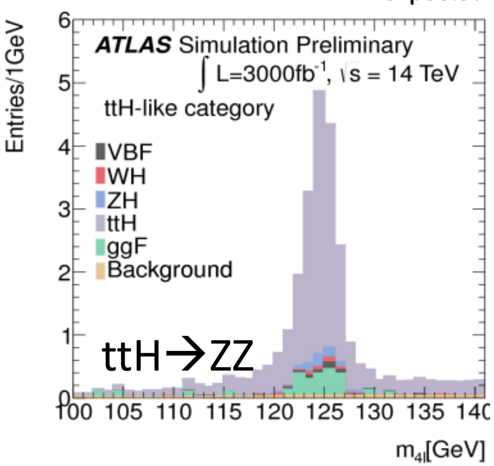


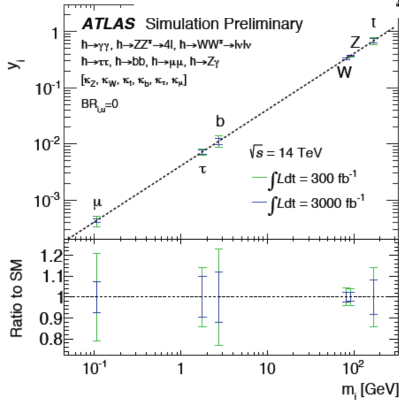


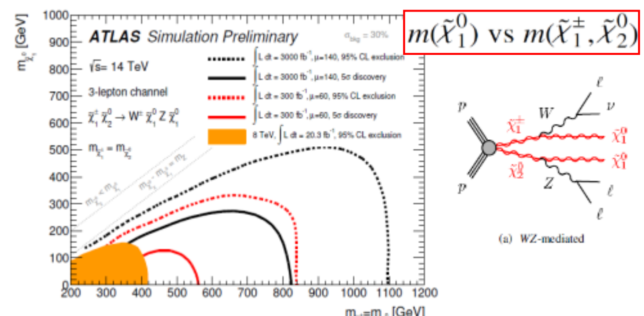
System mass probed so far



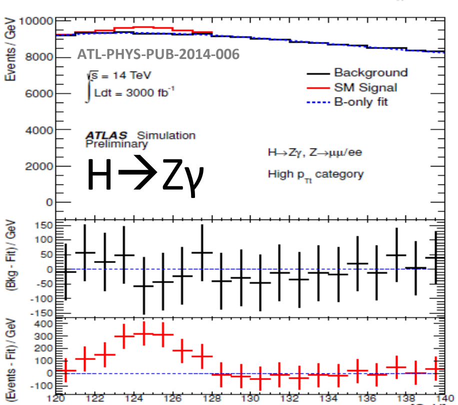
NLO SUSY Cross-section calculations







SUSY Limits at 300fb⁻¹ and 3000fb⁻¹

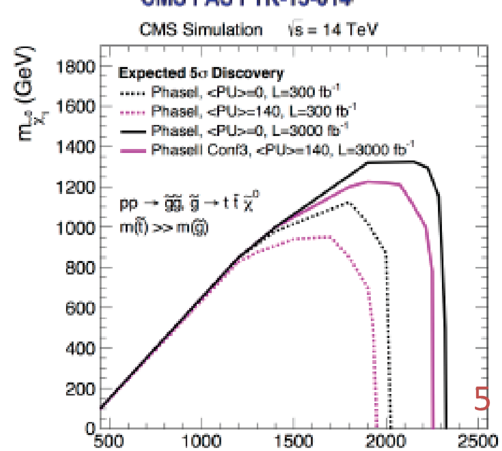


Improvements in coupling ratios with HL-LHC. (Depends on systematics and theory uncertainties)

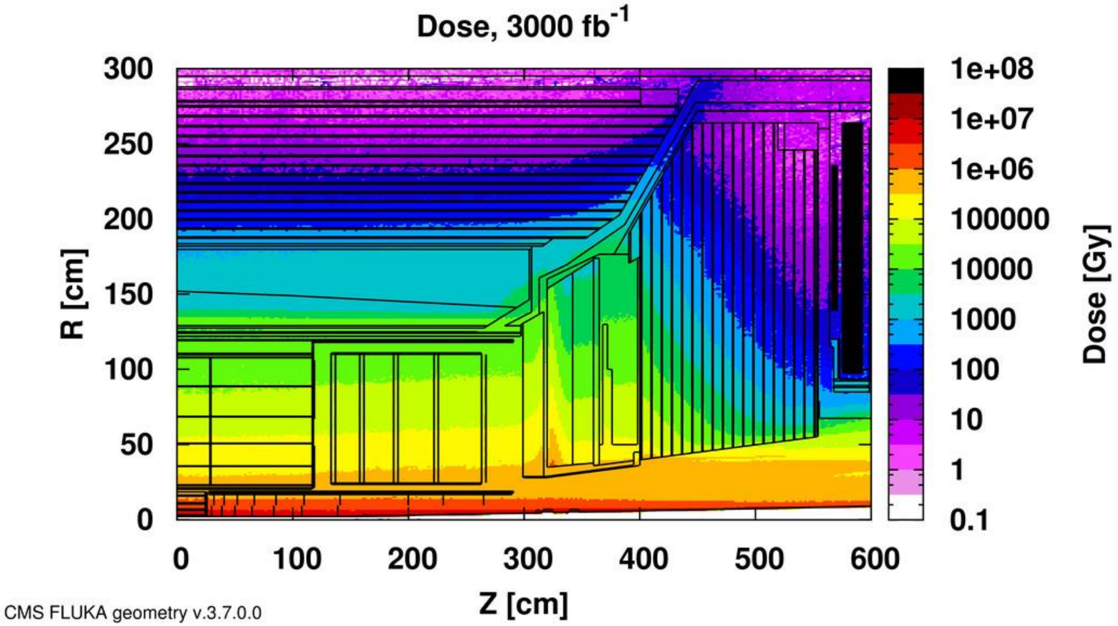
Process / Selection Stage	HH	ZH	$t\bar{t}H$	$b\bar{b}H$	$\gamma\gamma$+jets	γ+jets	jets	$t\bar{t}$
Object Selection & Fit Mass Window	22.8	29.6	178	6.3	2891	1616	292	113
Kinematic Selection	14.6	14.6	3.3	2.0	128	96.9	20	20
Mass Windows	9.9	3.3	1.5	0.8	8.5	6.3	1.1	1.1

CMS HH studies. Both experiments close to reaching required sensitivity but very difficult channel.

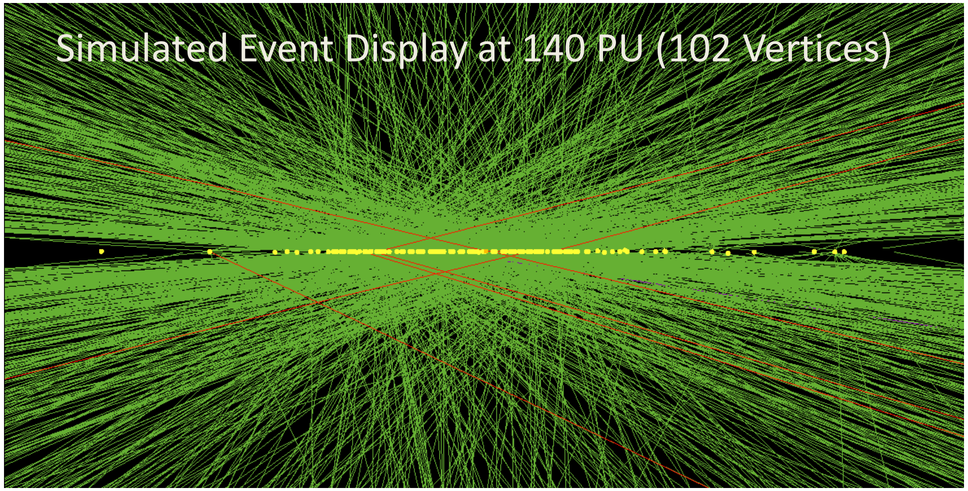
CMS PAS FTR-13-014



The HL-LHC is a very bright lamp to see physics details, which makes it a challenging environment for detectors and reconstruction



- Radiation
  - Ionizing dose
  - Neutron fluences up to 2 x 10^{16} n/cm^2 in pixels

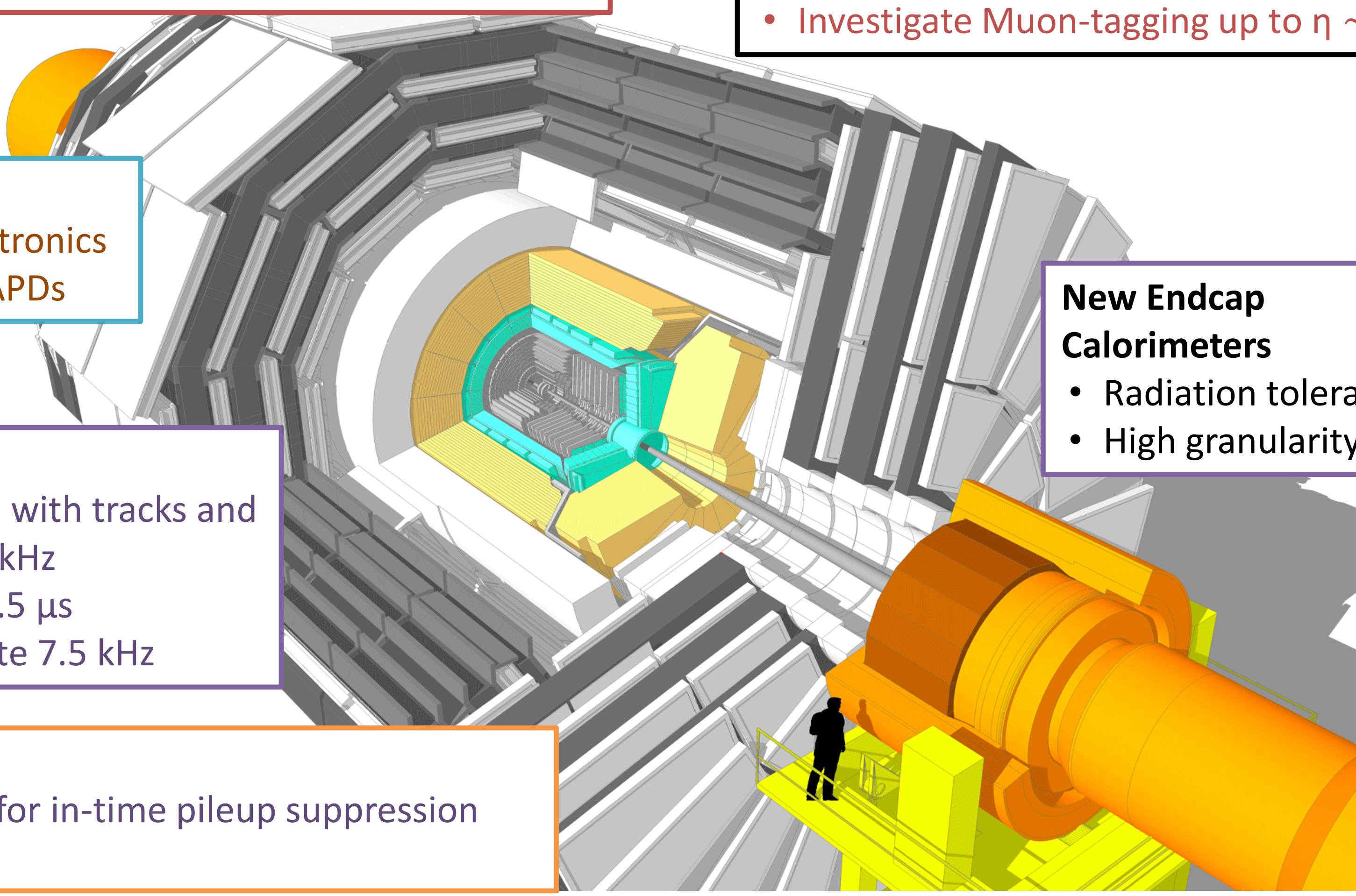


- Pileup
  - 140 average simultaneous interactions (many events with > 180)

CMS has a comprehensive plan for adjusting detector, where necessary, to cope with these challenges.

New Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

Muons
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 3



Barrel ECAL
- Replace FE electronics
- Cool detector/APDs

New Endcap Calorimeters
- Radiation tolerant
- High granularity

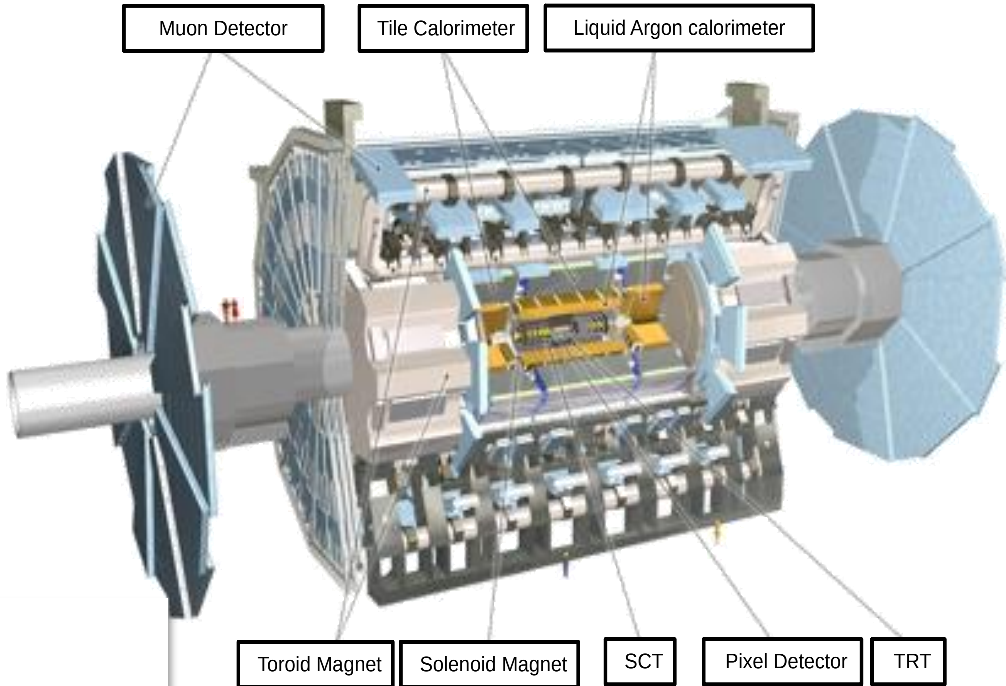
Trigger/DAQ
- L1 (hardware) with tracks and rate up ~ 750 kHz
- L1 Latency 12.5 μs
- HLT output rate 7.5 kHz

Other R&D
- Fast-timing for in-time pileup suppression
- Pixel trigger

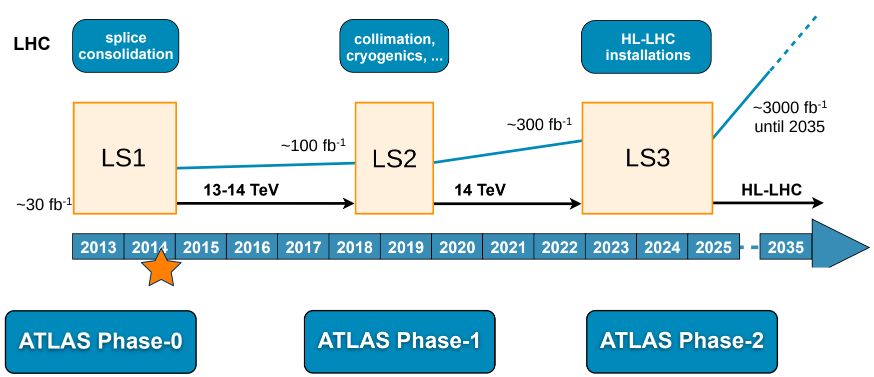
Jeremy Mans

Introduction

- ATLAS detector being re-commissioned for Run 2.
- Biggest challenge during LS1: additional pixel layer added (IBL).
- Detailed upgrade plans for Phase-1 and Phase-2 taking shape.



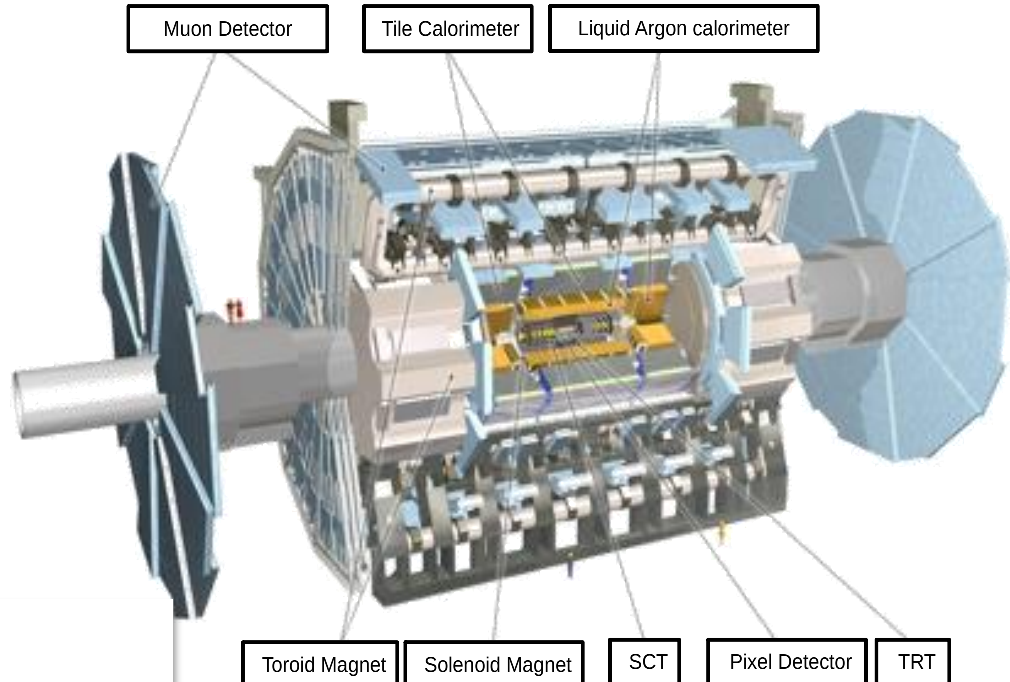
The ATLAS Roadmap



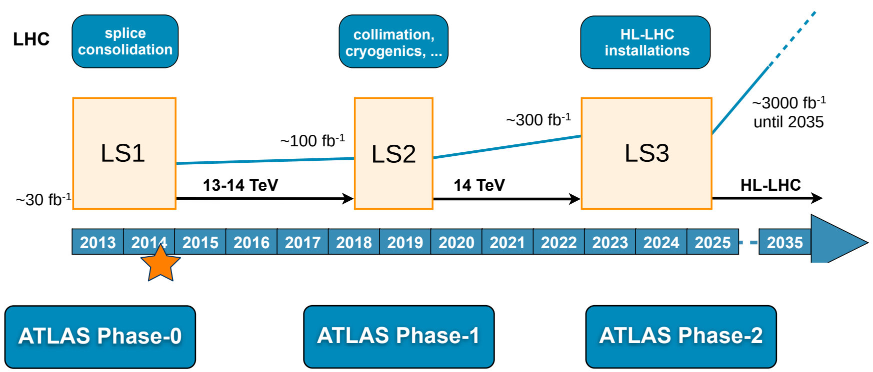
Introduction

Selection of upgrades: **Phase-I**

- Fast TracKing (FTK) input to HLT (already started)
- New Small Wheel (NSW) for the forward Muon Spectrometer
- Finer granularity LAr data to Level-1
- TDAQ Upgrades to Level-1/HLT
- Additional forward proton system (AFP)



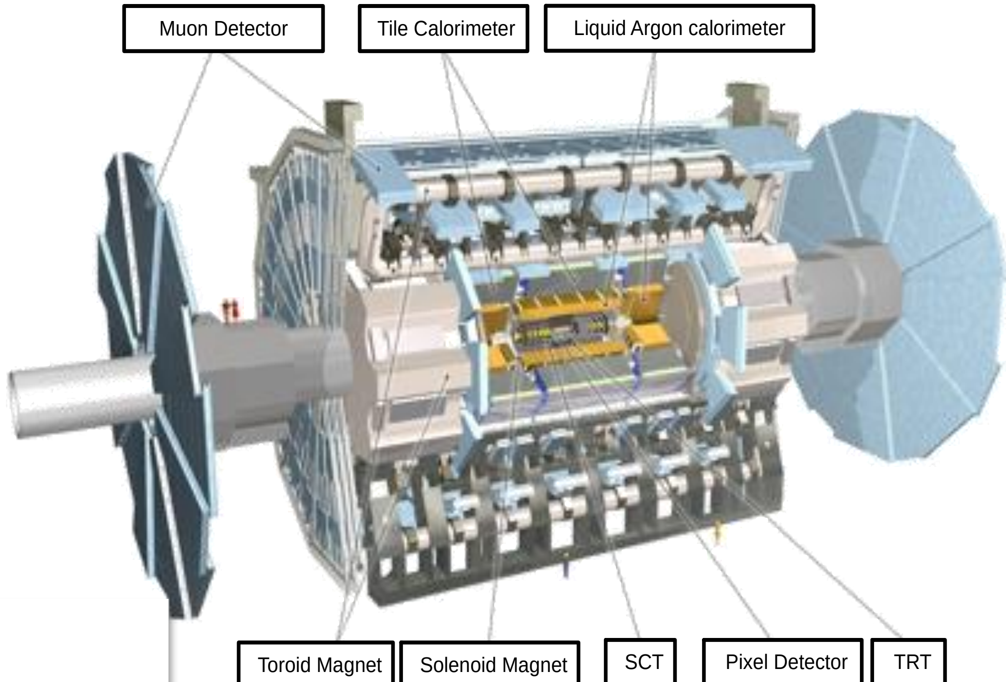
The ATLAS Roadmap



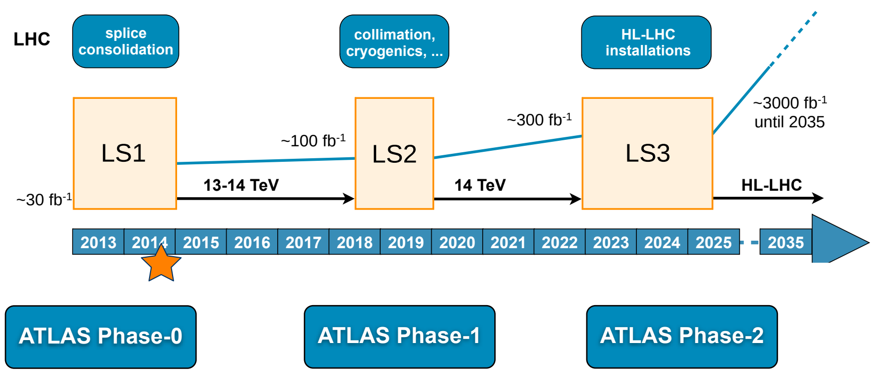
Introduction

Selection of upgrades: Phase-II

- All new Inner Tracking Detector
- Introduction Level 0/1 trigger
- Level-1 track trigger
- Calorimeter electronics upgrades
- Upgrade muon trigger system and electronics
- DAQ upgrade
- Enhancements to high-eta region



The ATLAS Roadmap



10

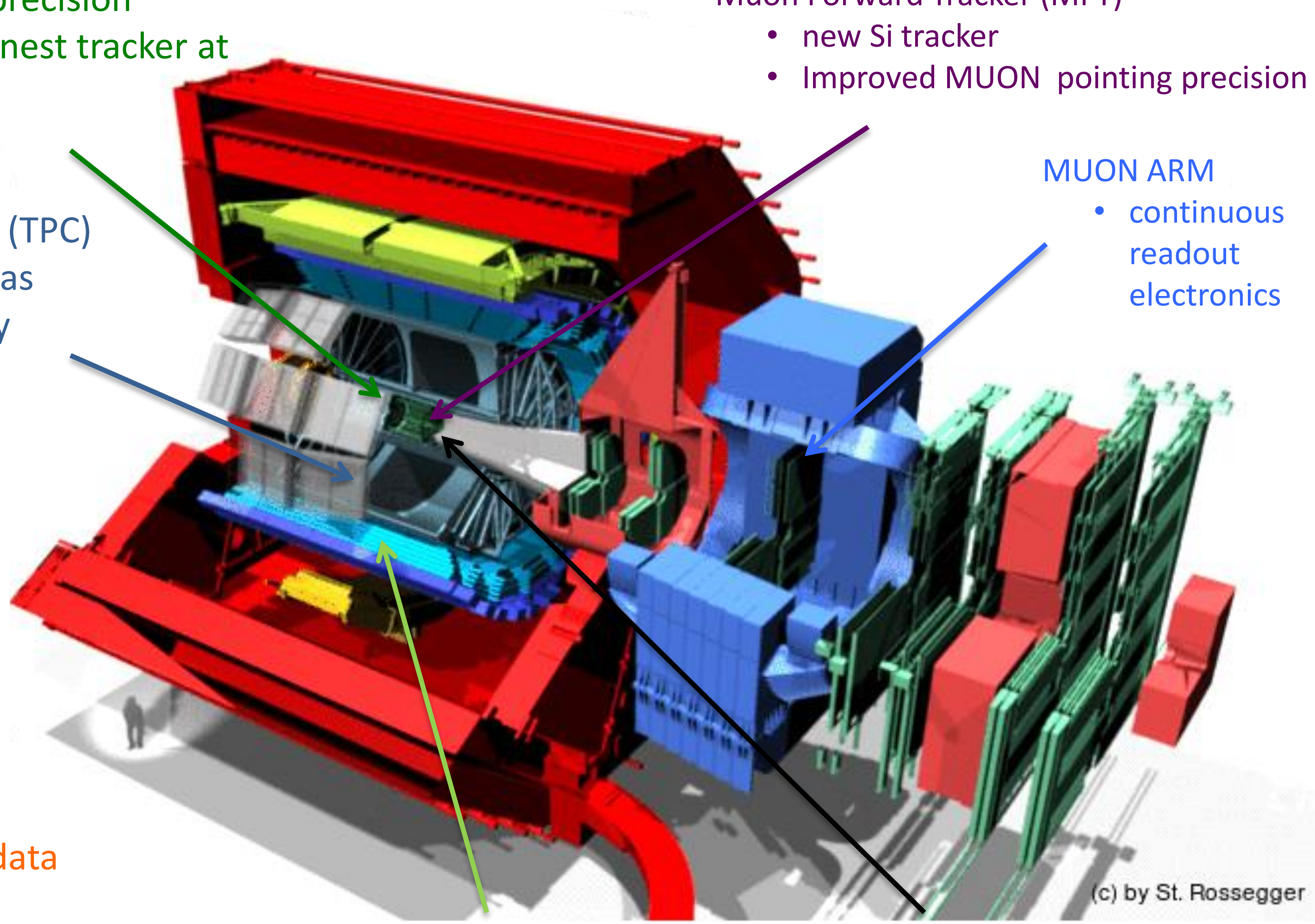
ALICE Upgrade

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

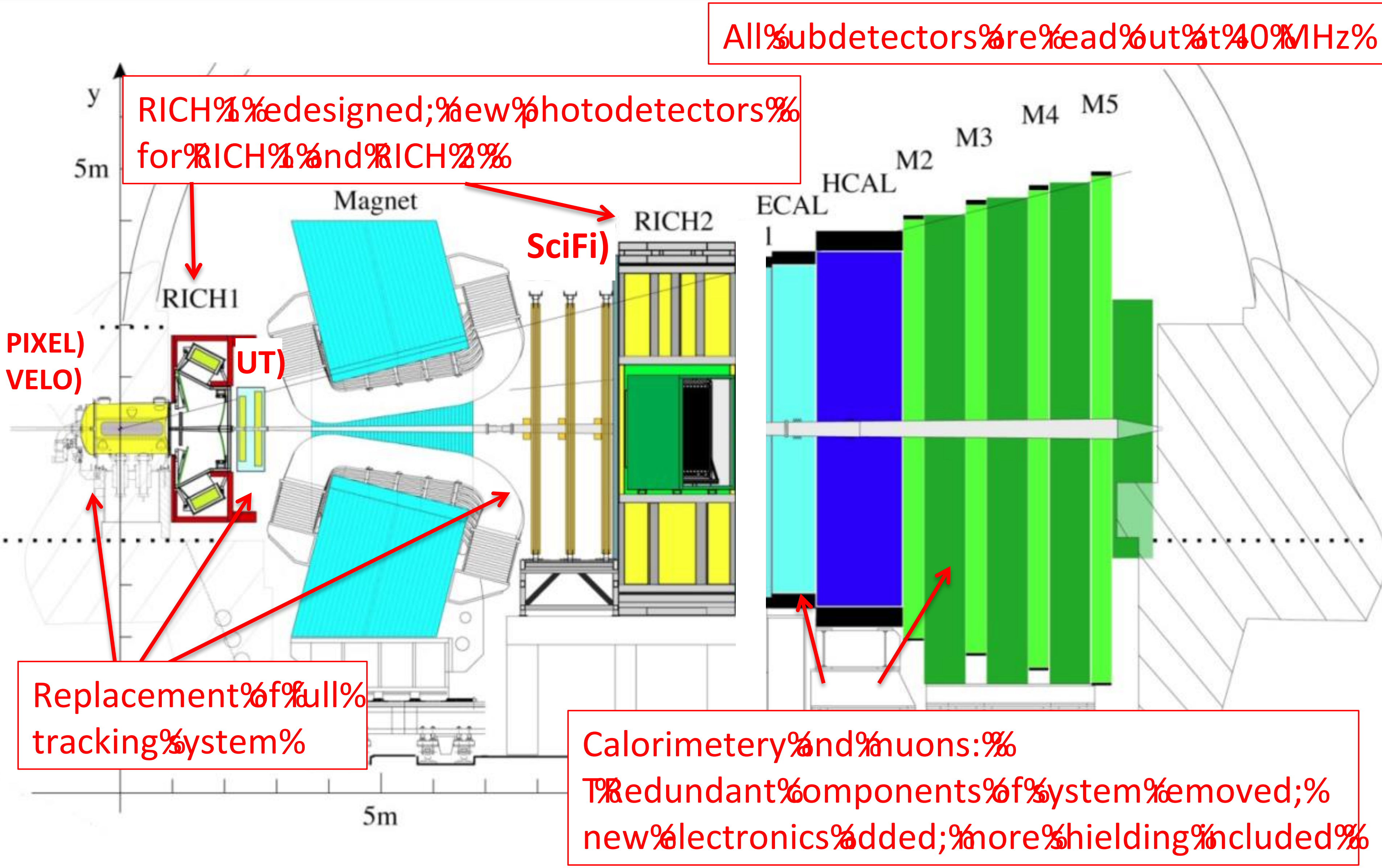


New Central Trigger Processor (CTP)

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

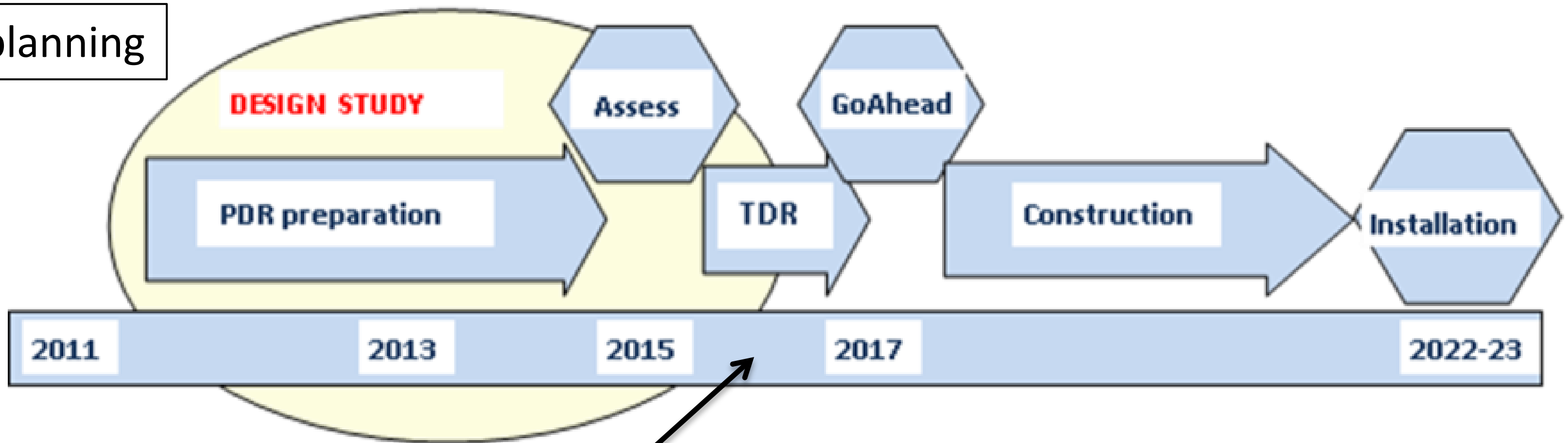
TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

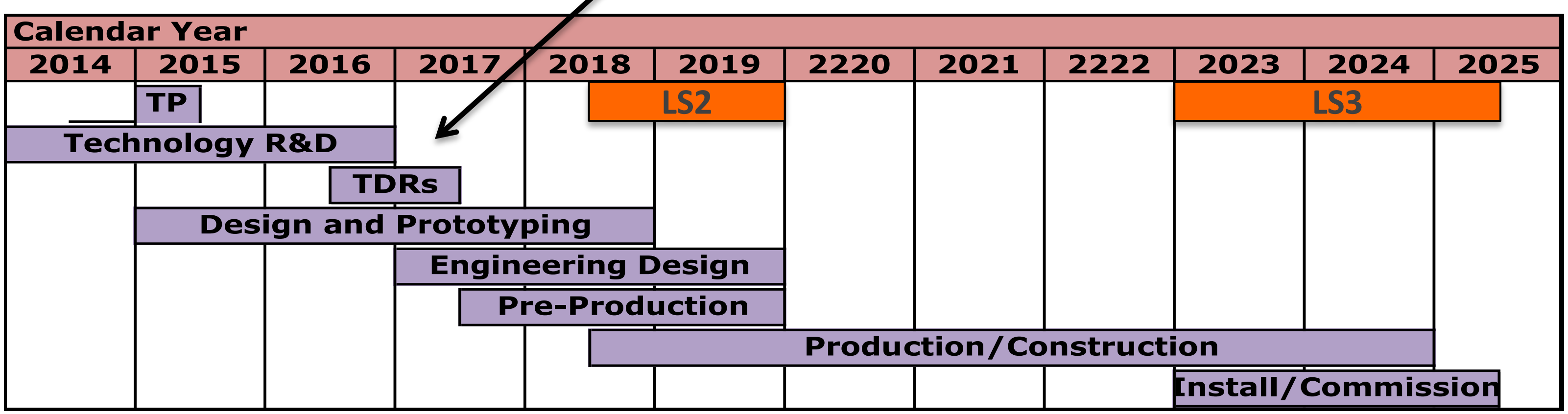

All%subdetectors%are%read%out%at%40%MHz%
RICH%1%redesigned;%new%photodetectors%%
for%RICH%1%and%RICH%2%%
y
5m
Magnet
RICH2
ECAL
HCAL
M2
M3
M4
M5
SciFi)
RICH1
PIXEL)
VELO)
UT)
Replacement%of%full%
tracking%system%
5m
Calorimetery%and%muons:%%
T%Redundant%components%of%system%removed;%
new%electronics%added;%more%shielding%included%%

Similar tight timelines for different steps for Accelerator, ATLAS & CMS - ≤ 3 years to complete designs & R&D

HL-LHC planning



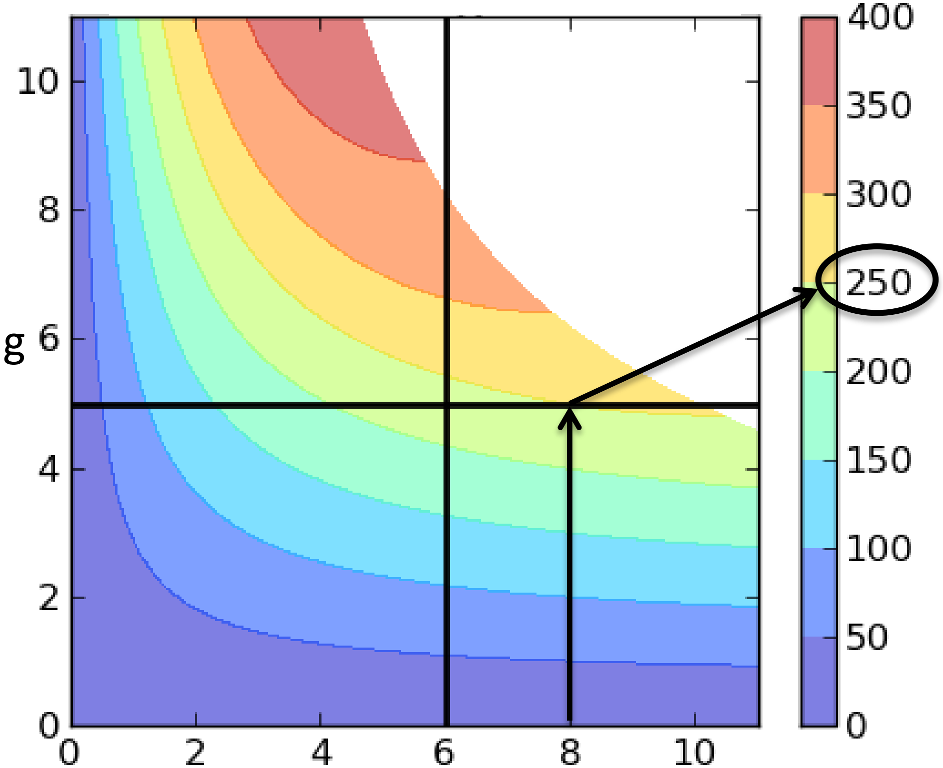
Example of the CMS planning for major upgrade work - it is similar for ATLAS



Based on O. Bruning's & J. Mans's presentations

Targeted beam conditions & integrated luminosity

“Nominal” Leveling
5 x 10^{34} (Hz/cm^2)



Integrated Lumi. (fb^{-1})
160 days/year operation

Fill duration current → 8 h

“Nominal” conditions → ≃ 2000 fb^{-1} in Phase 2 by end 2035 (+ 300 fb^{-1} in Phase 1)
Mean number of collisions (PU) upper value of 140 (https://cds.cern.ch/record/1606109?ln=fr)
Including cross section uncertainty - average of Poisson distrib. with σ ≃ 12 events
And additional Out Of Time (OOT) PU for detectors with time response ≥ 25ns

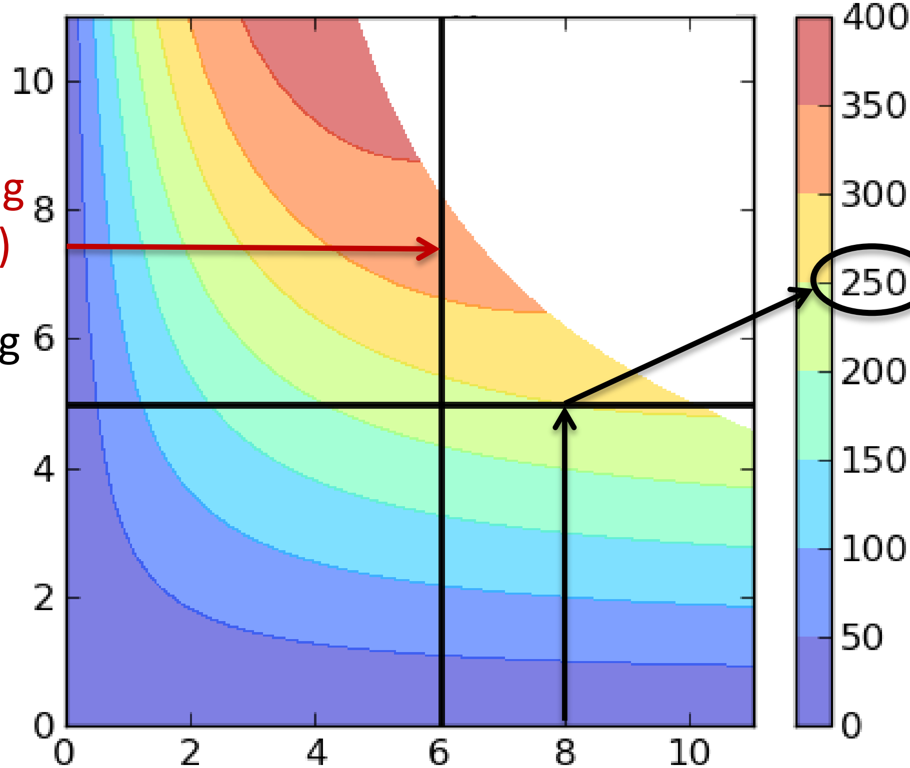
Based on O. Bruning’s presentation

Targeted beam conditions & integrated luminosity

(PG8)

“Ultimate” Leveling
7.5 x 10^{34} (Hz/cm^2)

“Nominal” Leveling
5 x 10^{34} (Hz/cm^2)



Integrated Lumi. (fb^{-1})
160 days/year operation

Fill duration current → 8 h

“Nominal” conditions → ≃ 2000 fb^{-1} in Phase 2 by end 2035 (+ 300 fb^{-1} in Phase 1)

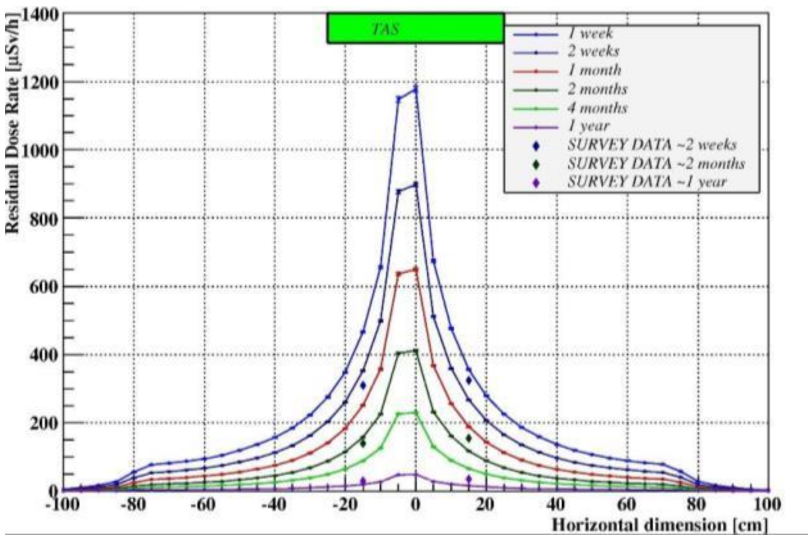
“Ultimate” conditions → ≃ 2600 fb^{-1} in Phase 2 by end 2035 (+ 300 fb^{-1} in Phase 1)

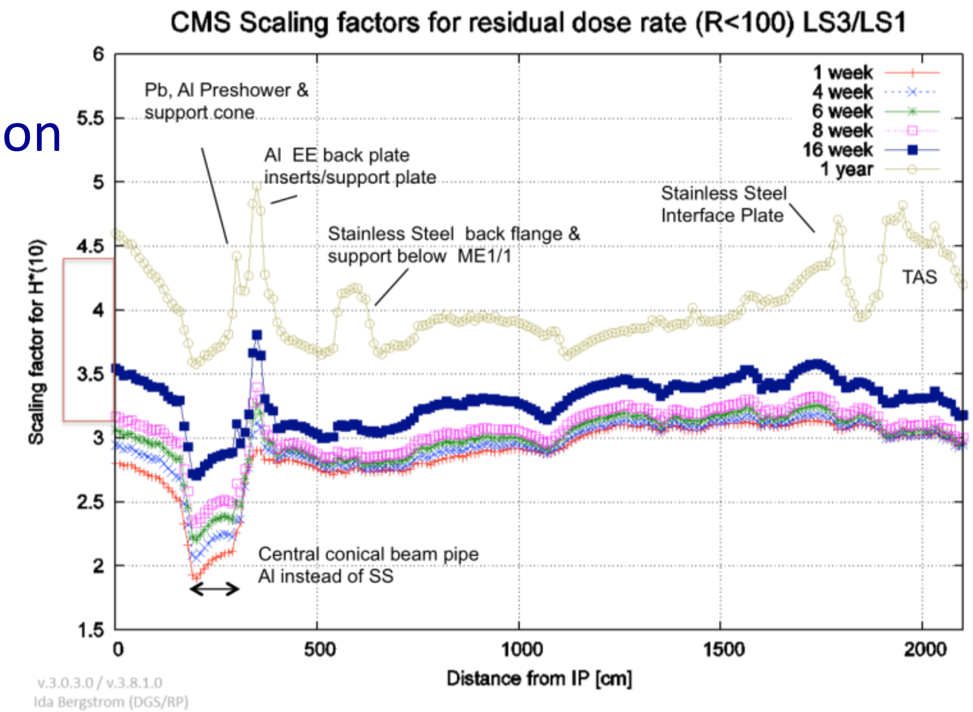
- set severe constraints on experiments to perform at PU ≃ 200
- gain in number of physics operation days would also benefit integrated luminosity

Based on O. Bruning’s presentation

Good agreement of activation estimates from Accelerator, ATLAS and CMS - similar scaling factors

Model validated with data - some discrepancies due to material description





ATLAS "design" - R < 100 cm

Dose LS#/LS1	1 wk	4 wks	6 wks	8 wks	16 wks	1 year
LS2	1.9	1.9	1.9	2.0	2.3	2.7
LS3	2.9	2.9	3.0	3.1	3.3	4.0
LS4	15	16	16	17	18	21
3000 fb^{-1}	15	16	16	17	21	27

CMS "design" - R < 100 cm

Dose LS#/LS1	1 wk	4 wks	6 wks	8 wks	16 wks	1 year
LS2	2.0	2.0	2.1	2.2	2.5	3.4
LS3	3.1	3.2	3.3	3.4	3.8	5.0
LS4	17	18	18	19	20	26
3000 fb^{-1}	17	18	18	19	23	34

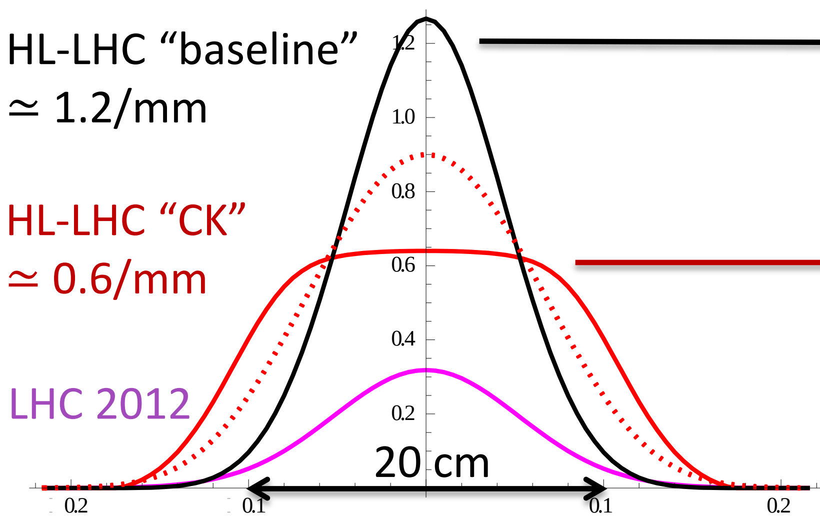
Based on O. Beltramello's, S. Bally's & I. Bejar Alonso's presentations

2nd ECFA HL-LHC… Physics goals and performance reach

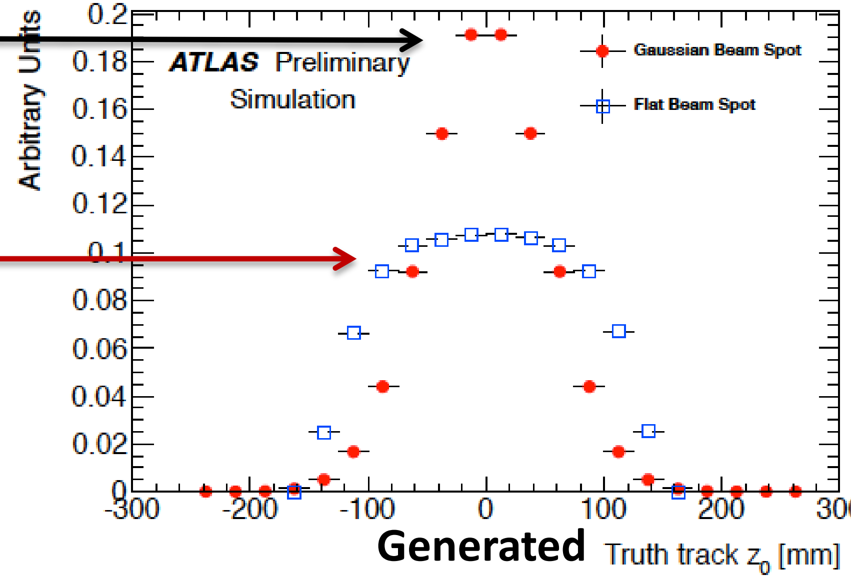
Several areas of progress shown at the workshop - a unique opportunity for common theory and experiments community discussions - general feeling that this should continue

- Experiments continue substantial efforts in full simulation to optimize upgrades
  - ATLAS and CMS to assess PU mitigation capabilities and develop motivation for new scope (high eta tracking - muon tagging - timing measurement…)
- Improvements of performance reach projection studies with detector parameterization
- Progress of work to reduce theory errors, long endeavour but prospect to halve the errors - following the increase in statistics
- Proposals to investigate new physics channels
- Implementation of theoretical models in performance reach studies and studies of model interpretation if discoveries

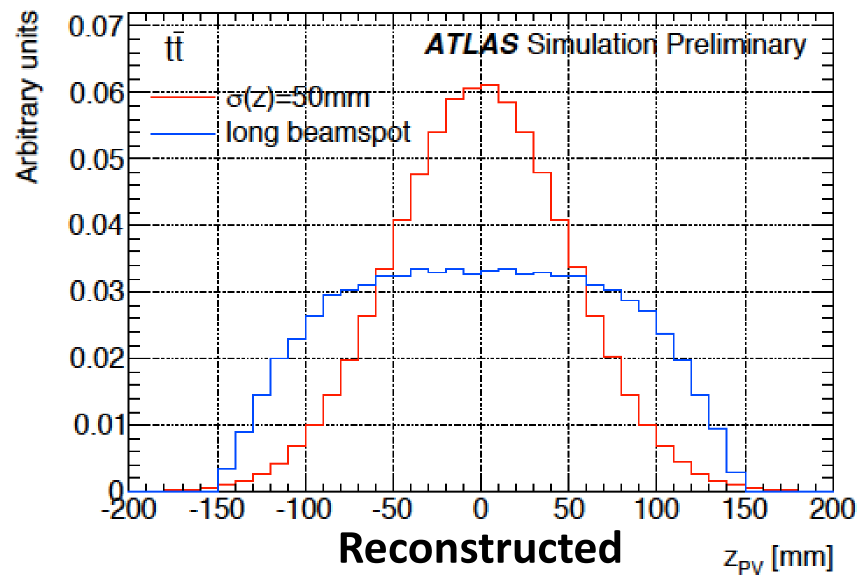
Beam luminous region different lengths in baseline & Crab Kissing (CK) do not affect track reconstruction efficiency



Vertex density vs z at 5 x 10^{34} Hz/cm^2



Similar results for ATLAS & CMS

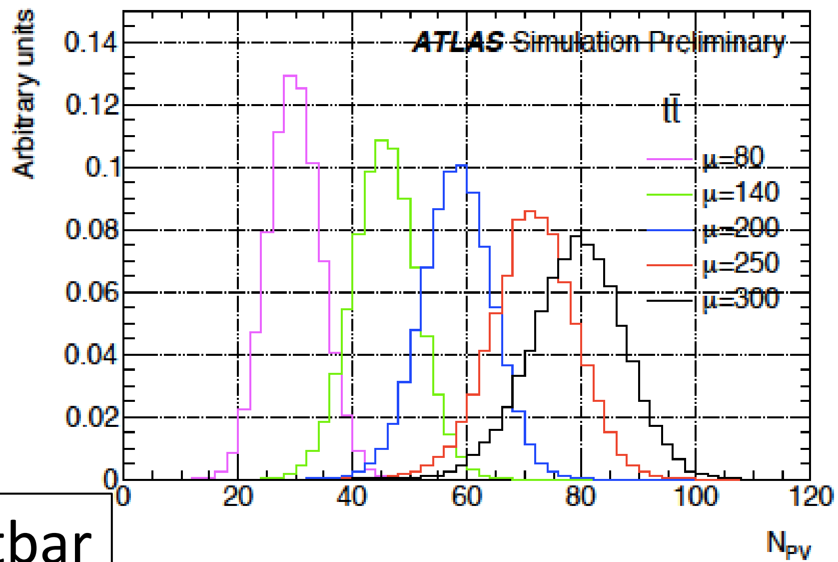


P. Wells & T. Tabarelli de Fatis presentation’s

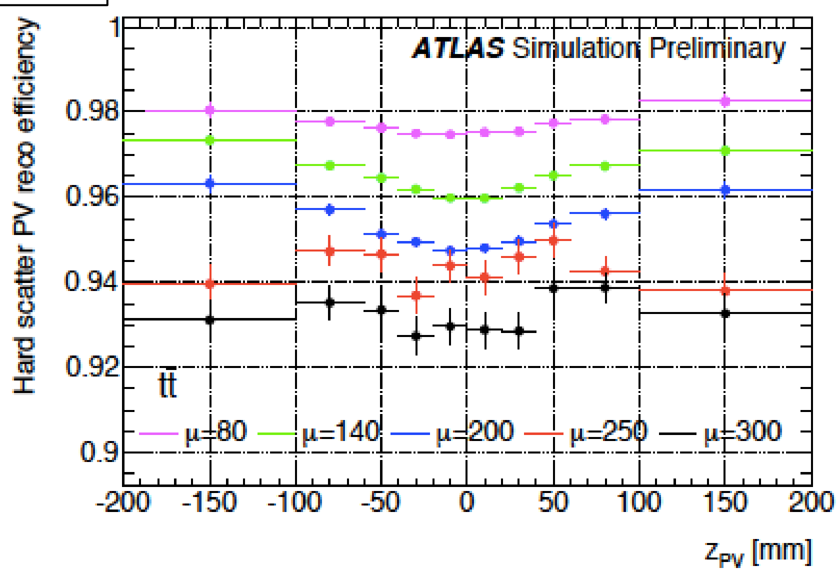
Primary Vertex reconstruction efficiency degrades with PU

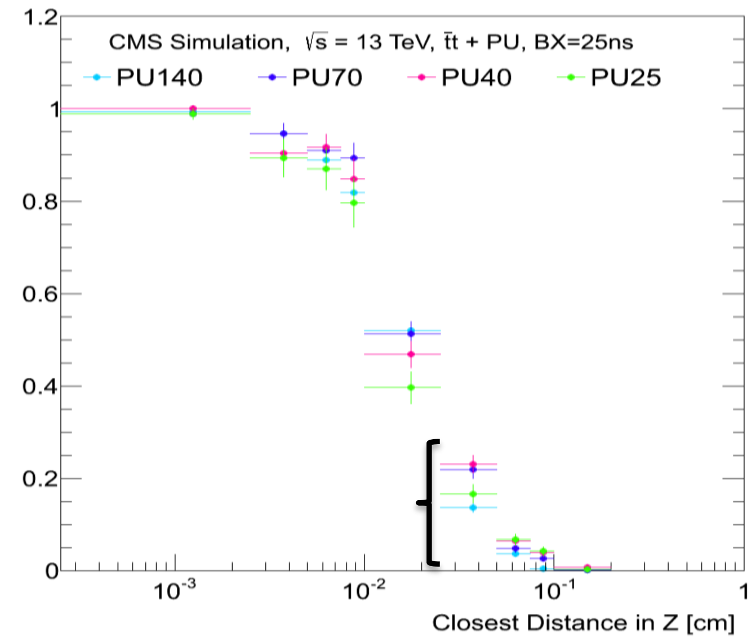
All PVs

Gaussian, μ [80,300]



ttbar



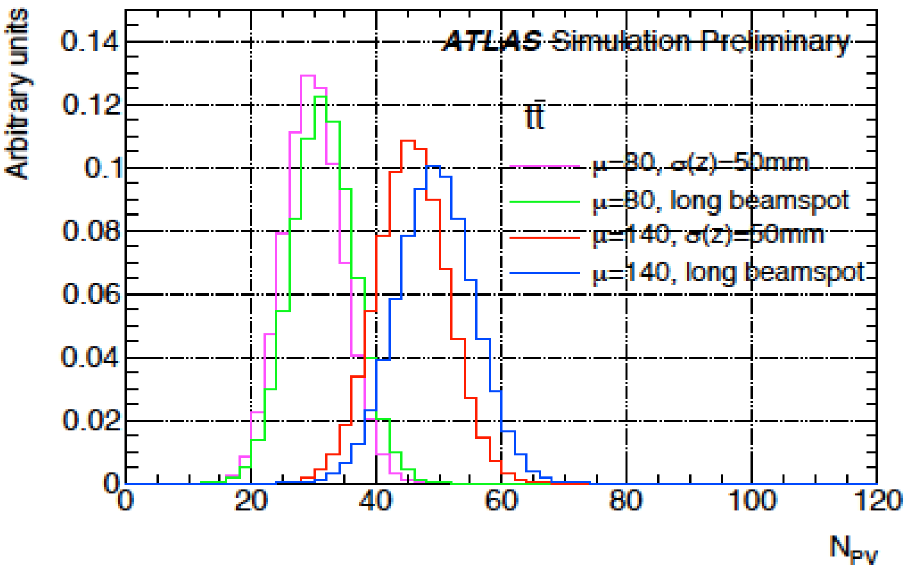


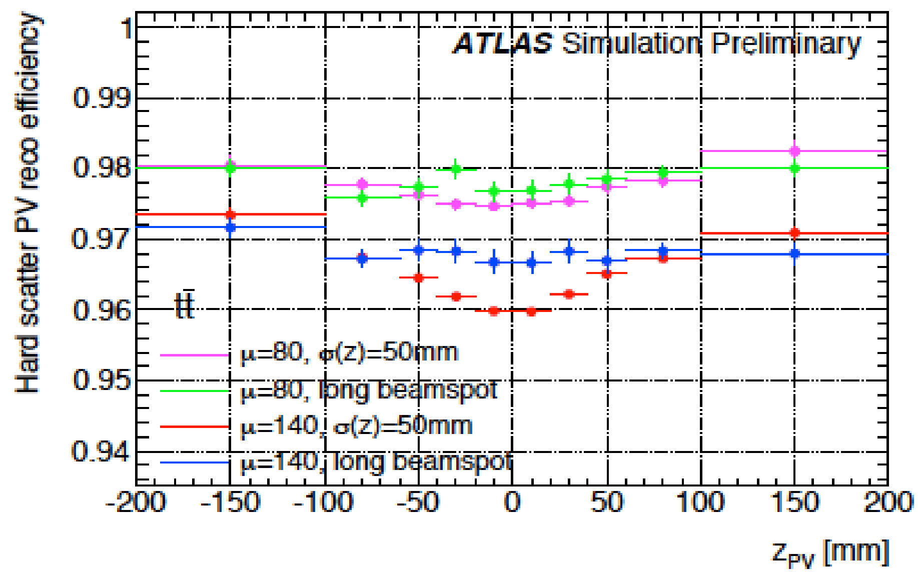
And rate of merged PVs increases with PU density

P. Wells & T. Tabarelli de Fatis presentation's

Primary Vertex reconstruction efficiency improves for lower vertex density (CK scenario)

(PG1)





10% increase in effic. for all PVs

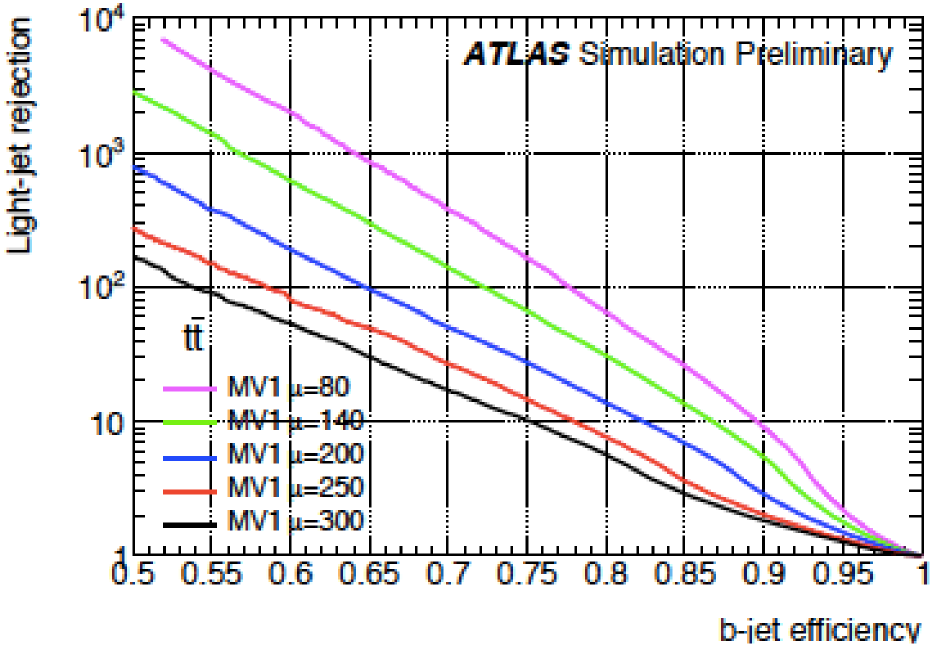
Improvement becoming more pronounced at μ=140 for tt PVs

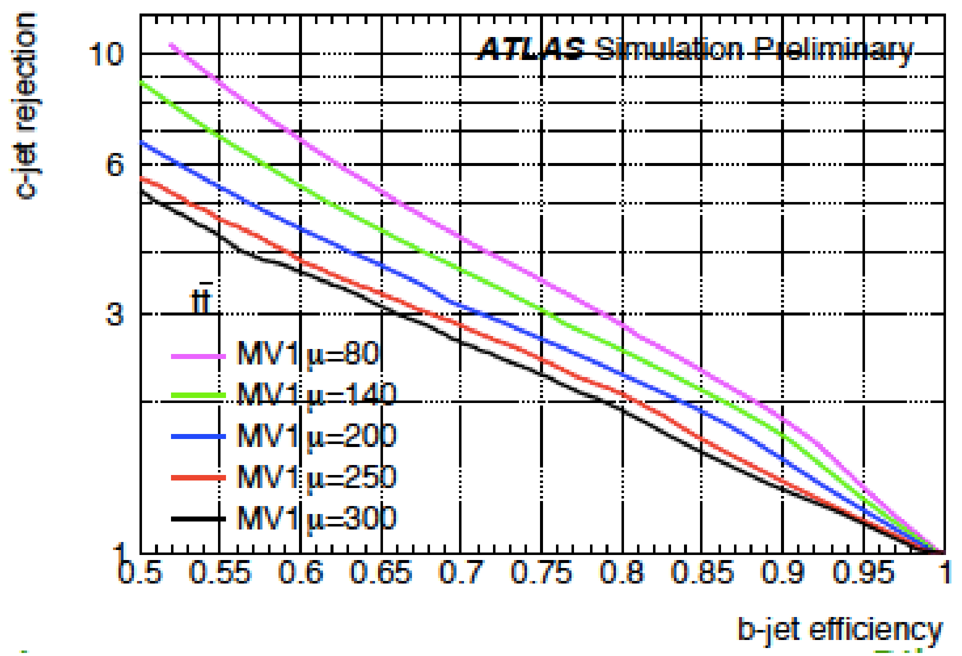
Improvement should become more substantial at higher PU

P. Wells presentation's

B-tagging reconstruction efficiency degrades with PU

(PG1)





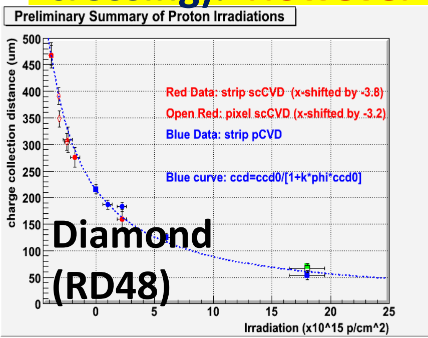
Substantial degradation is observed with increasing PU but this strongly depends on pixel detector design & resolution – not yet fully defined

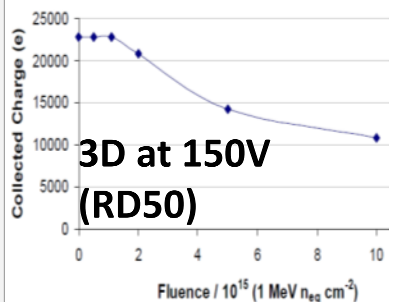
P. Wells presentation's

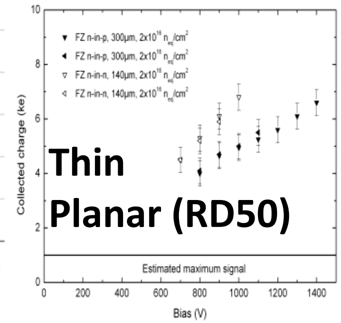
Hybrid Pixel Detector R&D for LHC Upgrades

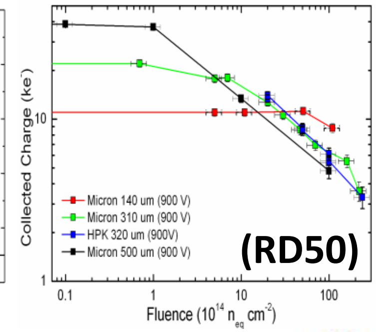
(PG2)

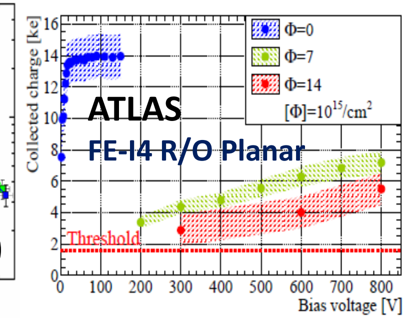
HL-LHC ($3000fb^{-1}$) implies doses up to $2\times10^{16} n_{eq}/cm^2$ and 1Grad (also up to 200 collisions per beam crossing). However n-in-n, n-in-p planar, 3D and diamond sensors are useable after such doses



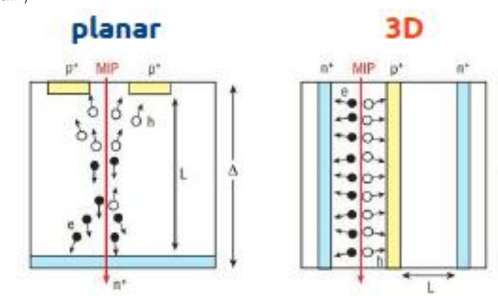








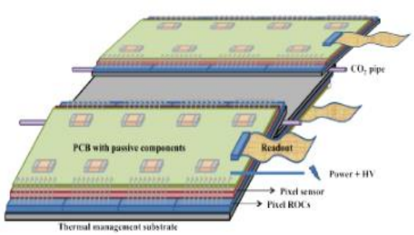
→ **The mechanisms leading to larger than expected signals (also seen in 3D sensors) is mostly understood and is even now being exploited (doping profile, trenches) to enhance the signals after radiation**



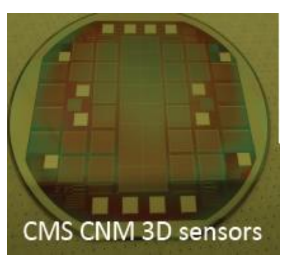
(3D sensors installed in ATLAS IBL)

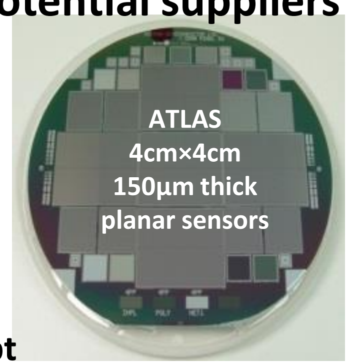
Propose to use 65nm CMOS ASIC technology to allow pixel sizes of 55µm×55µm (LHCb VeLoPIX 130nm) or ~50µm×50µm (RD53)

Large format sensors needed to tile larger areas and examples have been prototyped with a number of potential suppliers



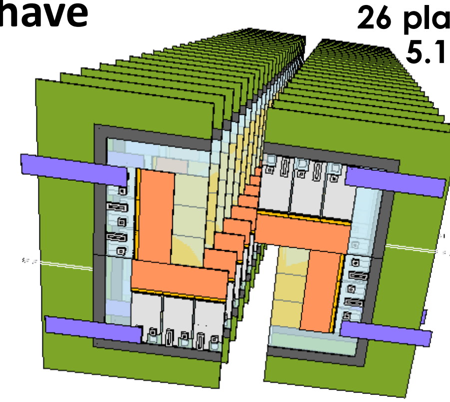
CMS Phase-II Pixel Module Concept





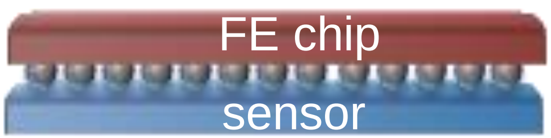
LHCb VeLoPix Module Design

26 planes of sensor 5.1mm to beam

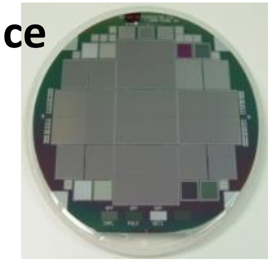


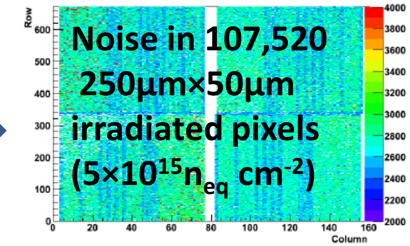
Hybrid Pixel Detector R&D for LHC Upgrades

- **Irradiated single and quad n-in-p pixel modules (for higher radii) studied in test-beam with excellent performance**



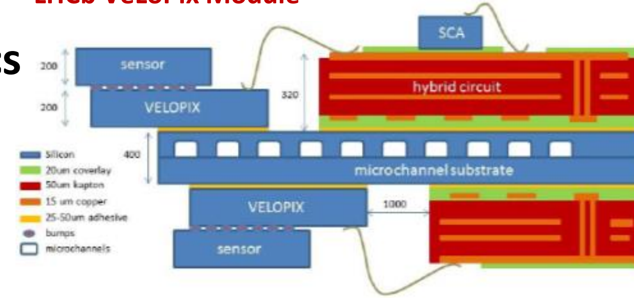
Conventional bump-bonding

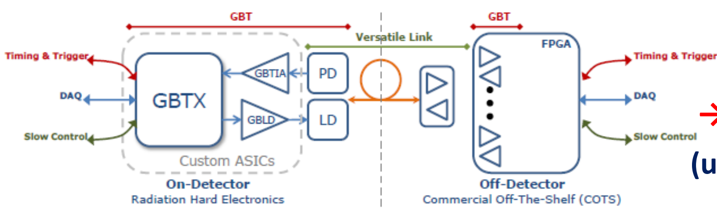




- **Micro-channel in-silicon cooling (NA62, ALICE, LHCb)**
- **Need custom rad-hard, low power, fast opto-electronics**

LHCb VeLoPix Module

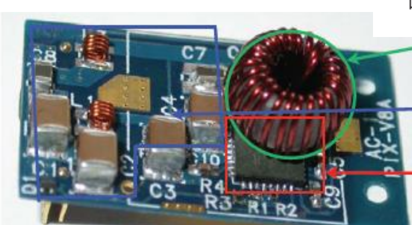


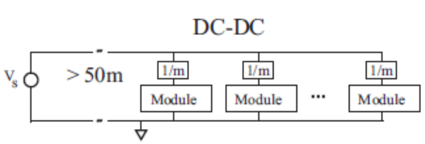


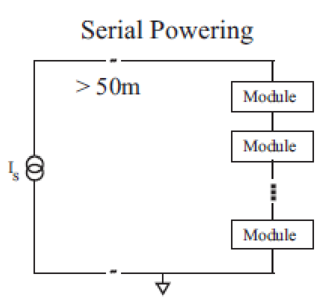
→ **lpGBTx, + VTTx**
(up to 10 Gbit/s and versatile link)

- **Low mass structures, services (electrical link to optical for innermost layers), LV (serial powering for innermost layers, DC/DC elsewhere), CO_2 cooling…**

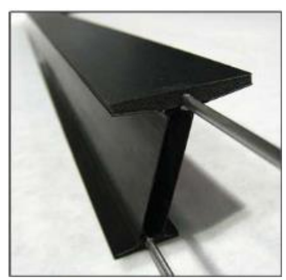
DC to DC converter to step down 10V→2.5V

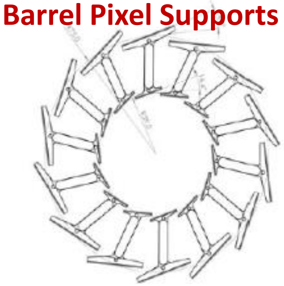

AC_PIX_V8 A: 2.8cm x 1.6cm; ~ 2.0g



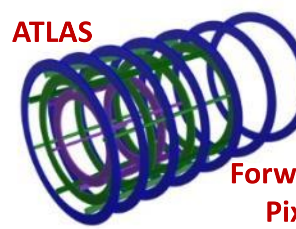


ATLAS Phase-II Prototype Barrel Pixel Supports



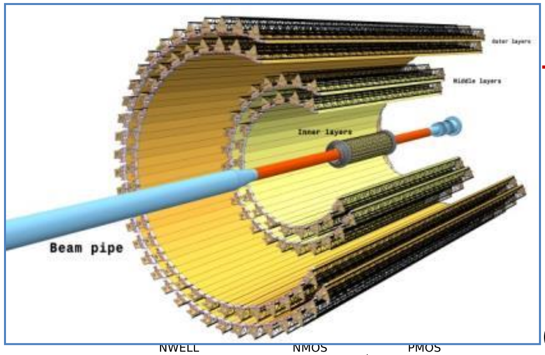


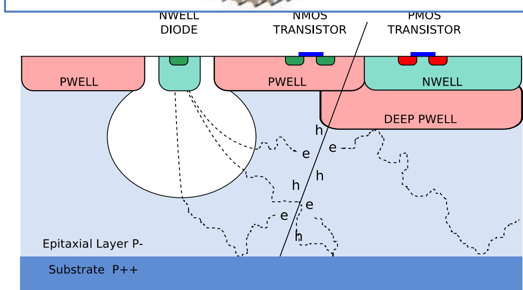
ATLAS

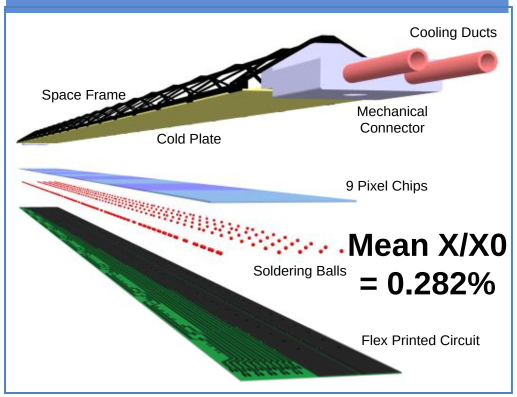


Forward Pixels

MAPS/CMOS Detector R&D for LHC Upgrades







Mean X/X0 = 0.282%

MAPS installed at STAR (RHIC)

MAPS for ALICE

Priority is ultra-low radiation length due to the low p_T of the decay products of interest.

Target:

Pb-Pb up to 13 nb^{-1}

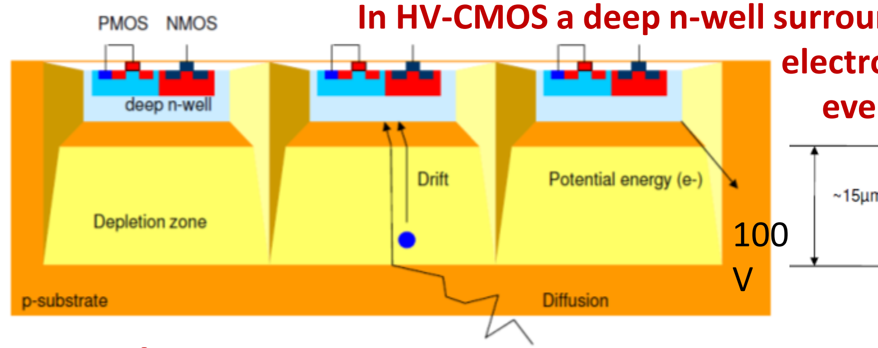
→ 8 x 10^{10} events

pp ≥ 6 pb^{-1}

→14 x 10^{10} events

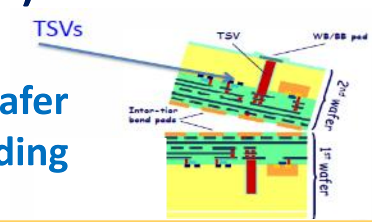
Read-out all Pb-Pb (50 kHz)

(L = 6 x 10^{27} $cm^{-1}s^{-1}$)

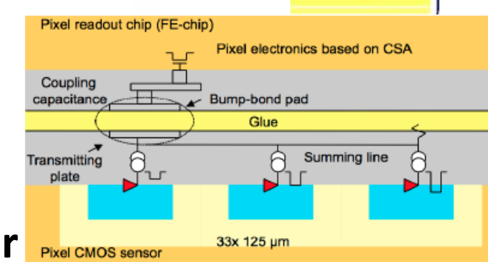


In HV-CMOS a deep n-well surrounds the electronics of every pixel

In HR/HV-CMOS charge collection through drift greatly improves radiation hardness and speed - use at pp collision rates → HL-LHC Upgrades? Can consider pixels with CMOS-based pixel electronics either monolithic or capacitively coupled pixel detectors (CCPDs) based on sensor implemented as a smart diode array with wafer bonding or glued to ASICs (no bumps)



Wafer Bonding



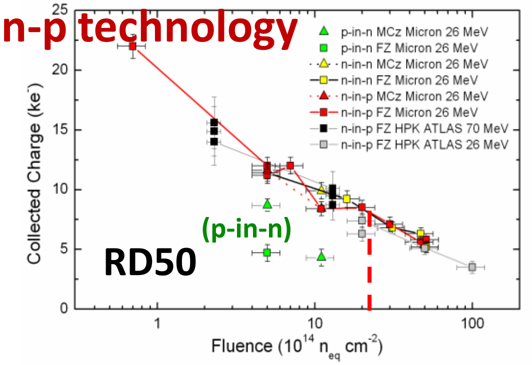
Some key fundamental issues around HV/HR-CMOS sensors are not yet fully understood, in particular the charge collection and efficiencies (especially after irradiation) which all need further R&D. Also a reasonable sized detector still needs to be demonstrated in particle beams

Silicon Strip Detectors for Large Area Tracking

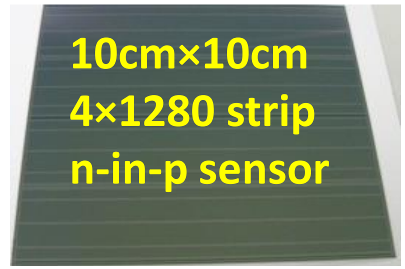
(PG2,5,7)

HL-LHC Need radiation hardness of current n-in-n pixel sensors at fraction of the cost

→ n-in-p technology

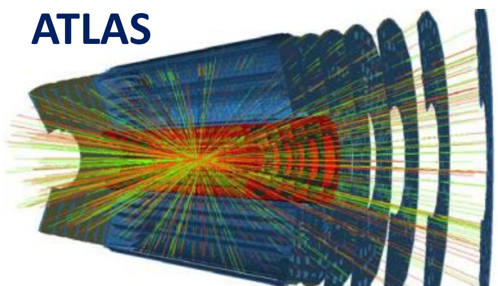


Many large area prototypes produced



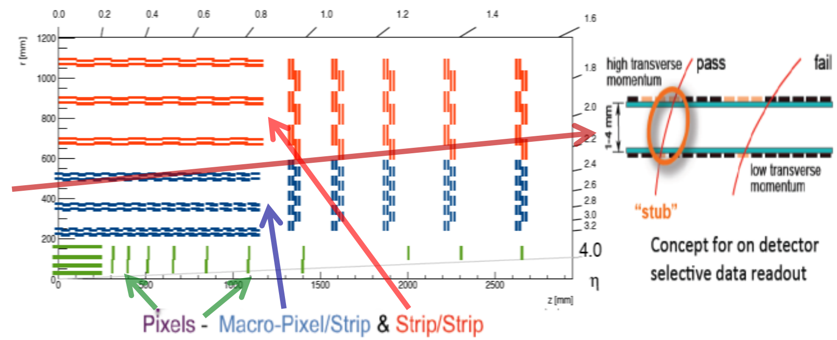
Interest in larger (8”) wafers particularly for forward regions

ATLAS

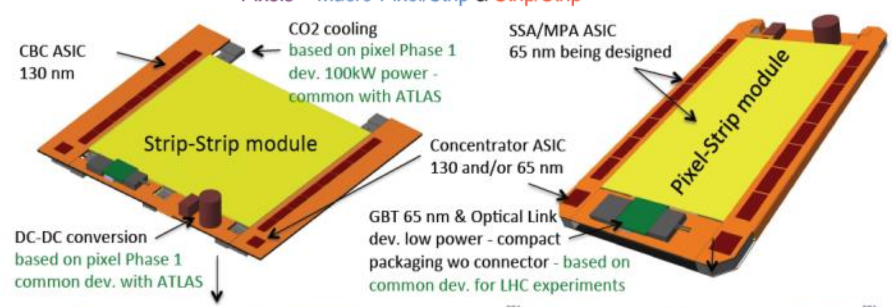


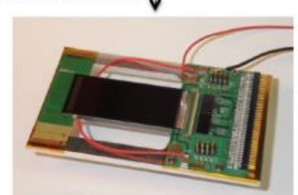
~200m² strip ~10m² pixel

CMS proposes paired layers for fast track p_T selection for input to level-1 trigger

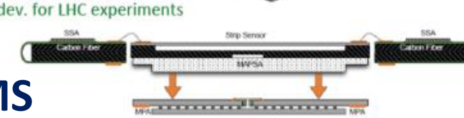


ATLAS uses paired strip modules with small angle stereo (for z determination) around a central structure with embedded cooling (Trigger: Level-0 trigger objects from calorimeter and muon systems plus tracker information available to level-1 trigger)





CMS



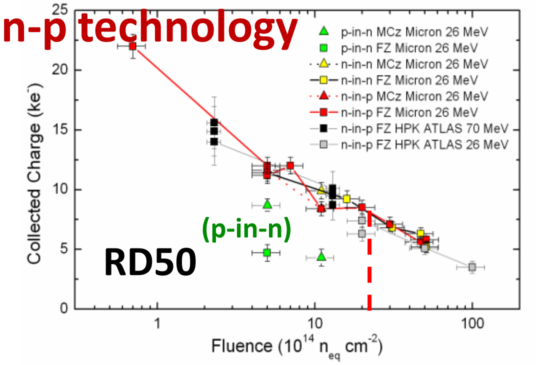
Flex hybrid - Flip-Chip assembly - possibly TSV for inter-chip connection

Strip-Strip Module Prototype

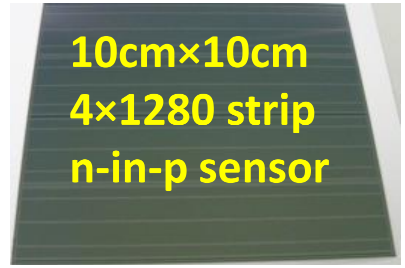
Silicon Strip Detectors for Large Area Tracking

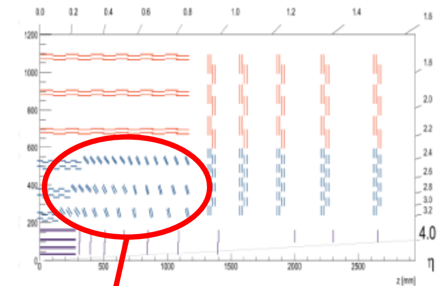
HL-LHC Need radiation hardness of current n-in-n pixel sensors at fraction of the cost

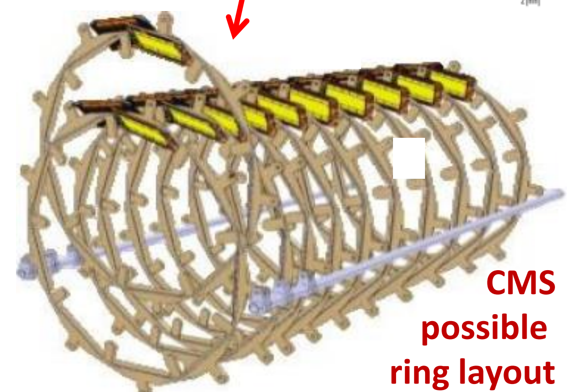
→ n-in-p technology



Many large area prototypes produced

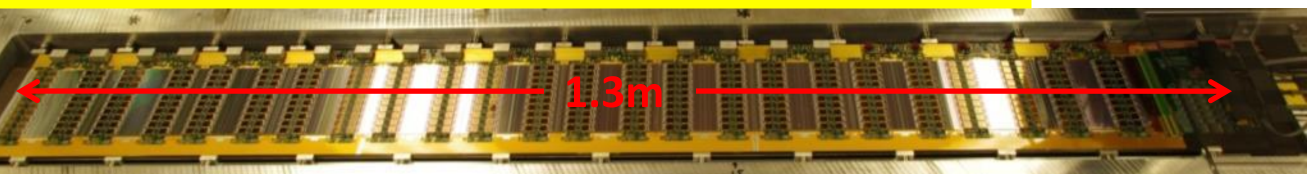






CMS possible ring layout

12 module ATLAS prototype stave: 61440 channels ~600e noise

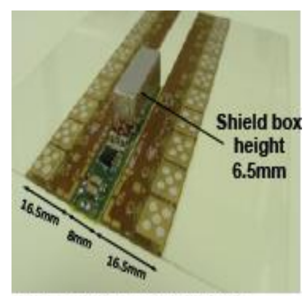


4 row wire bonds

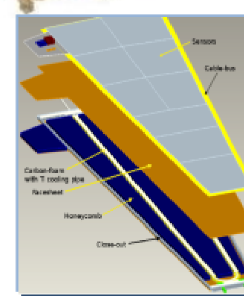
Powering (DC/DC or Serial), HV multiplexing, CO_2 embedded cooling, low mass modular supports & services

STV10 DC-DC on module

Module with on-board DC-DC converter



Thermo-Mechanical Module with compact DCDC converter

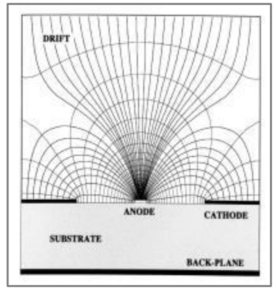


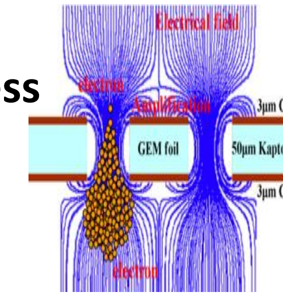
ATLAS Wedges and Discs

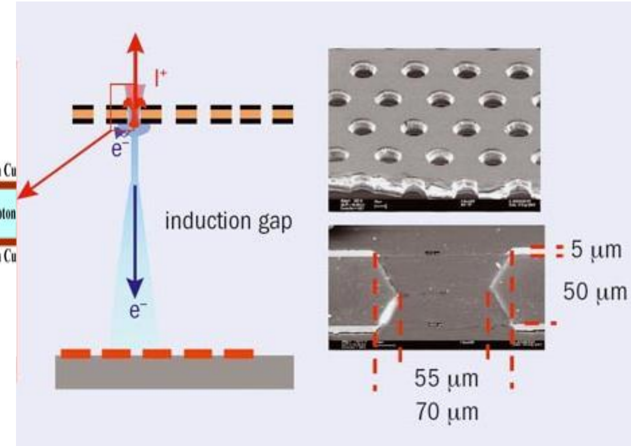
Gaseous Detector R&D (including micro-pattern)

Main R&D activities for ATLAS and CMS are for new muon chambers in the forward directions.

- **Increase rate capabilities and radiation hardness**
- **Improved resolution (online trigger and offline analyses)**
- **Improved timing precision (background rejection)**



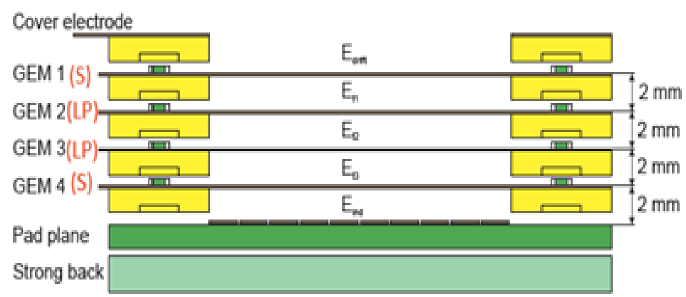


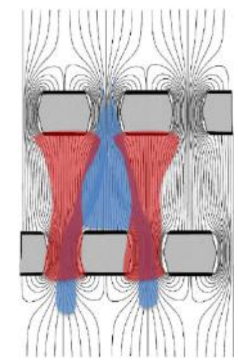


Technologies

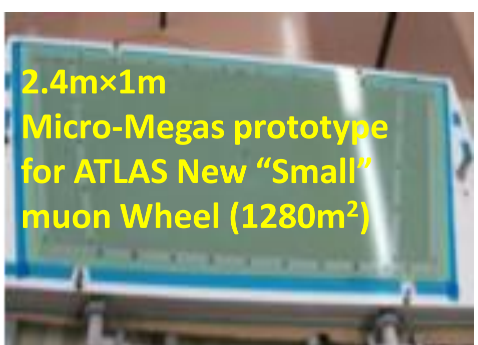
- **Gas Electron Multiplier detectors (LHCb now, ALICE TPC - CMS forward chambers)**
- **Micro-Megas and Thin Gap Chambers (TGCs) (ATLAS forward chambers)**
- **Resistive Plate Chambers (RPCs) - low resistivity glass for rate capability - multi-gap precision timing (CMS forward chambers)**

GEM stack for ALICE TPC R/O



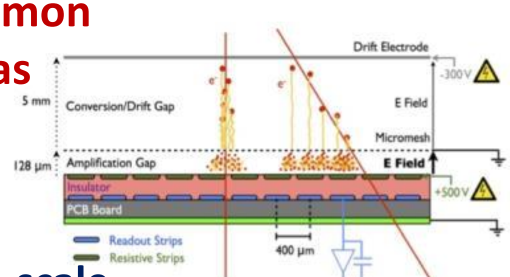


4 layer stack to target Ion backflow < 1% given continuous readout at 50kHz

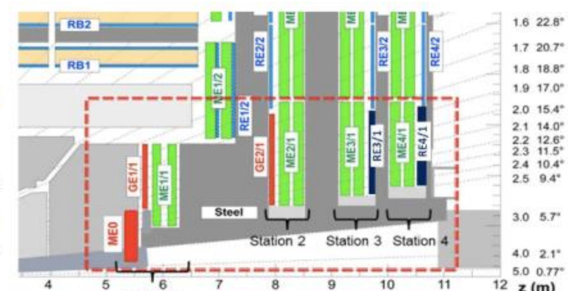


CERN RD51 common micro-pattern gas detector R&D

Need to develop commercial large-scale production capabilities



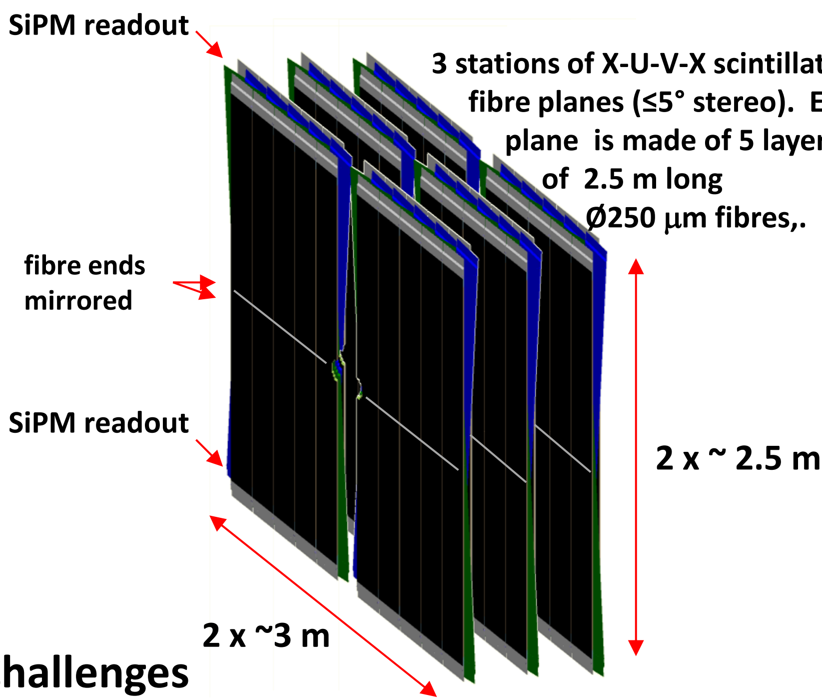
Micro-Megas Principle



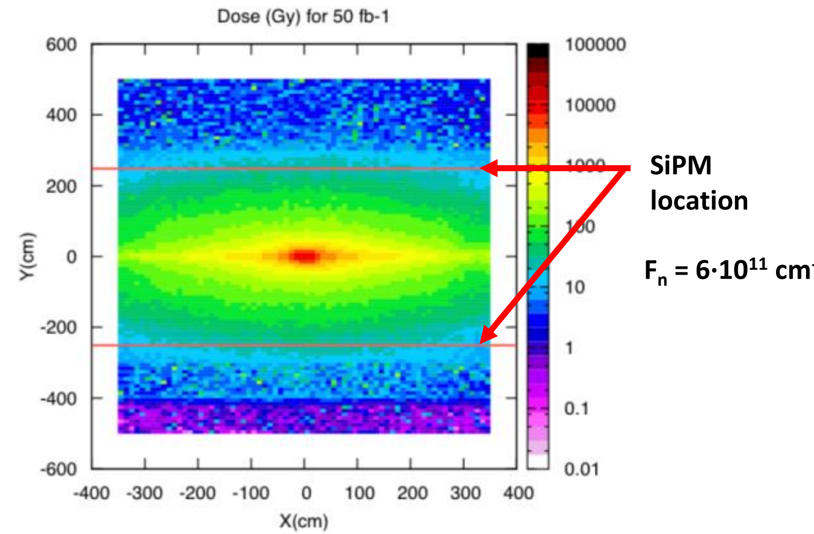
CMS triple-GEM detectors (double stations) in $1.5<|\eta|<2.2$ endcap region

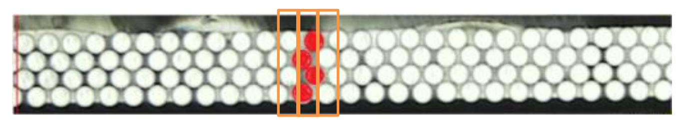
Scintillating Fibre Detector R&D

Large scale SciFi tracker for LHCb

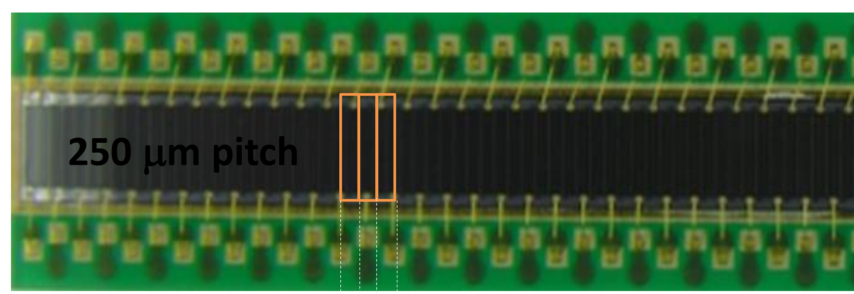


3 stations of X-U-V-X scintillating fibre planes (≤5° stereo). Every plane is made of 5 layers of 2.5 m long Ø250 μm fibres,.





4 layer proto mat

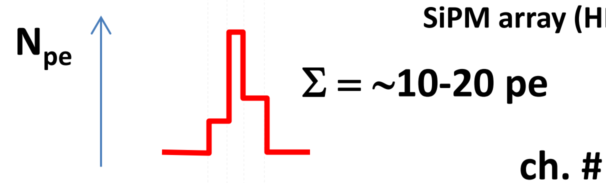


SiPM array (HPK)

Challenges

- Large size – high precision
- O(10,000 km) of fibres
- Operation of SiPM at -40°C

3 million (SCSF-78 MJ baseline) scintillating fibres with up to 30kGy non-uniform exposure



R&D for Sampling Calorimeters at HL-LHC

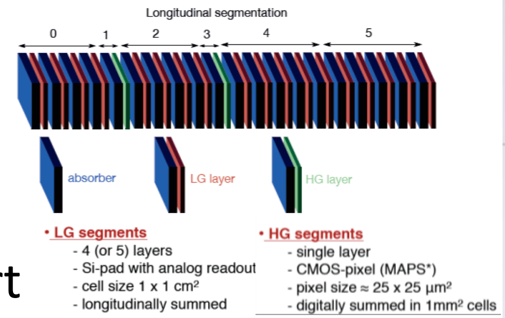
LHC Upgrades:

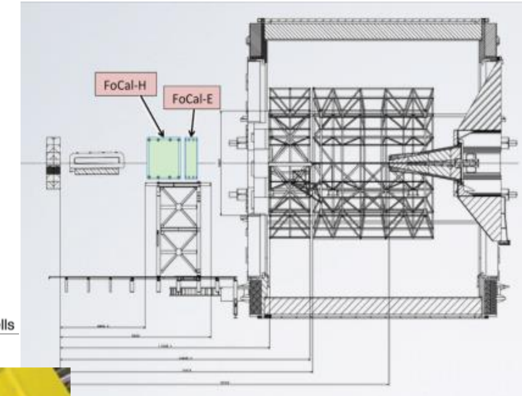
ALICE new forward calorimeter (FoCal)

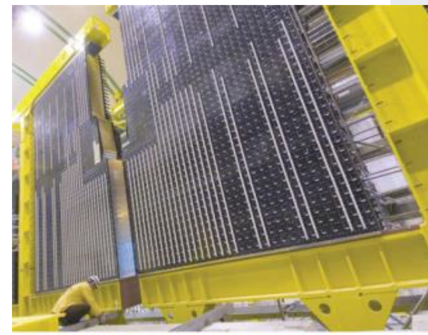
R&D on Tungsten-Silicon sampling Electromagnetic Calorimeter

LHCb minor replacement in central part of ECAL due to radiation damage

ATLAS investigating replacement of forward calorimeter (LAr) with greater granularity







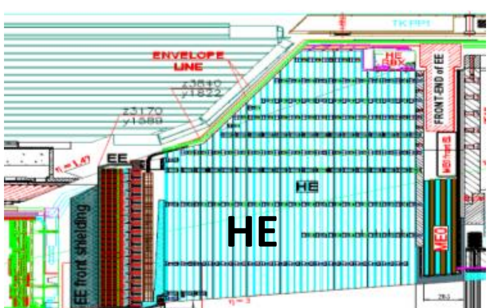
LHCb ECAL Tiles

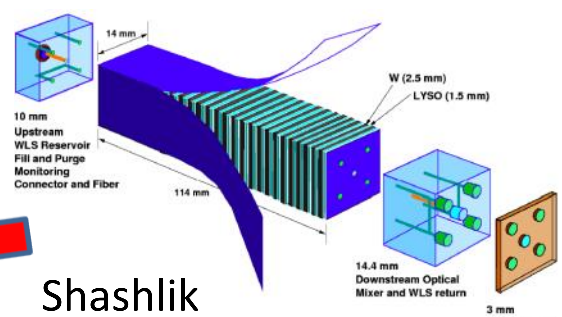
CMS need to replace ECAL and HCAL end-cap calorimeters due to radiation damage

Limitation mostly from loss of transparency with radiation

LYSO or CeF_3 offer very high light yield. One CMS proposal for ECAL is a compact W+LYSO/ CeF_3 Shashlik using quartz capillary with WLS core and readout using GaInP

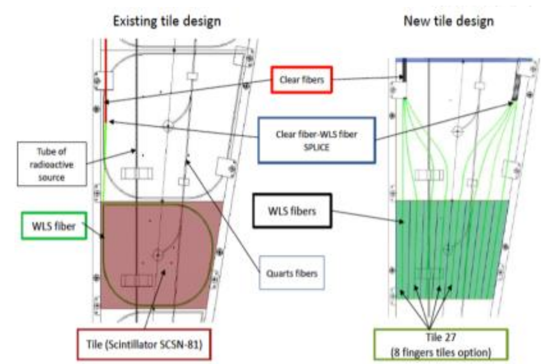
CMS scintillator-based HCAL with 30% of volume replaced by finger tiles to reduce optical path and attenuation



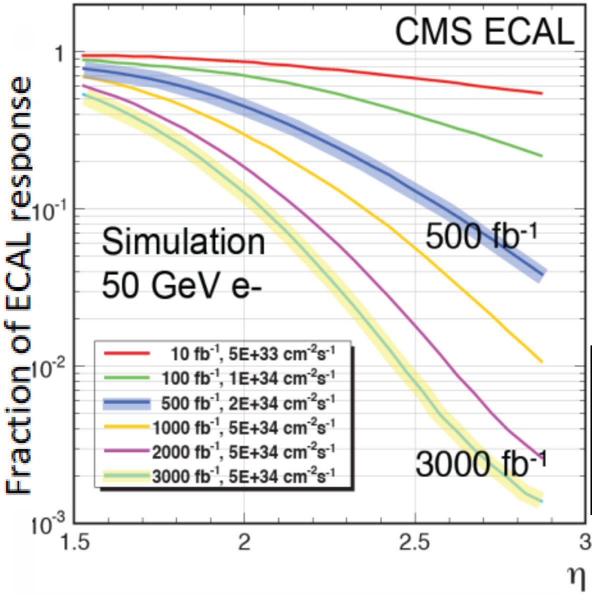


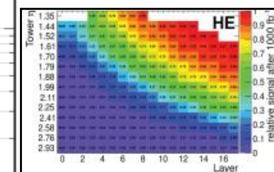
Shashlik

$\Delta E/E \sim 10\%/\sqrt{E} + 1\%$



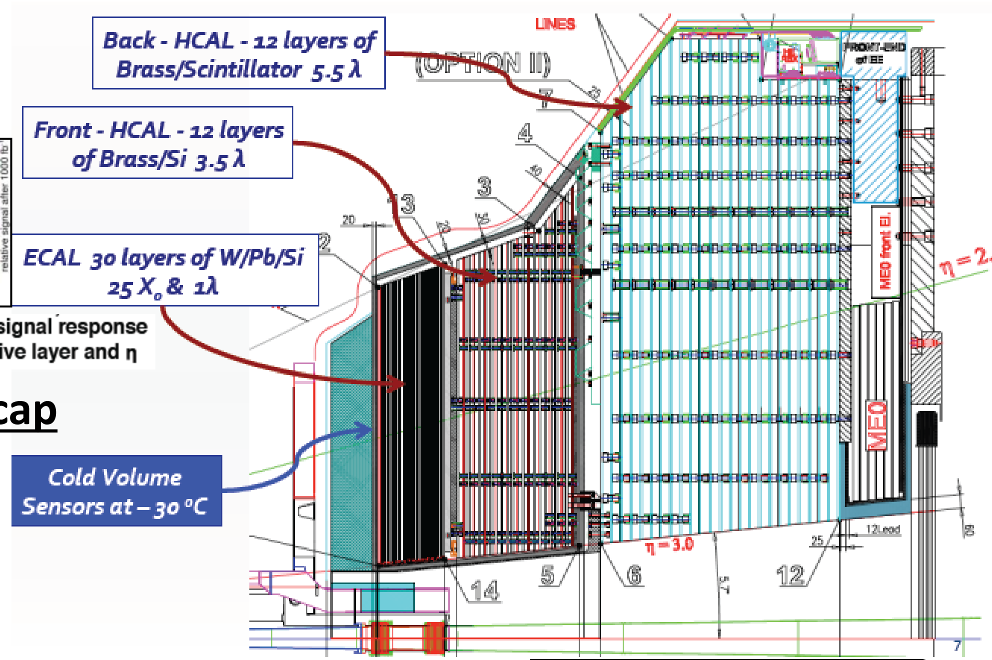
R&D for Sampling Calorimeters at HL-LHC





Predicted HCAL Endcap signal response after 1000fb-1 versus active layer and η

CMS PFA Upgrade Option high granularity calorimeter

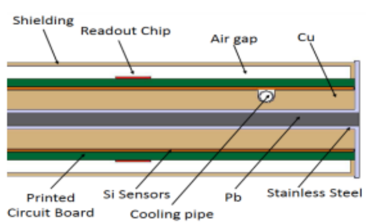


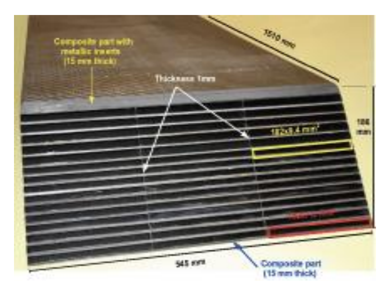
CMS need to replace ECAL and HCAL end-cap calorimeters due to radiation damage

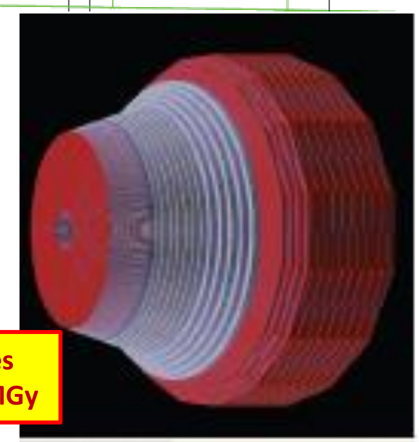
Silicon-W/Pb/Cu **ECAL** (25 X_0, 1λ)
and silicon-brass **front HCAL** (3.5 λ) 8.7 M channels, pad sizes 0.9 cm² or 0.45 cm² depending on η
Scintillator-brass **backing HCAL** (5.5 λ, lower radiation zone)

420 + 250 m² Silicon :

e/γ resolution ~20%/$\sqrt{E}$ + ≤ 1%

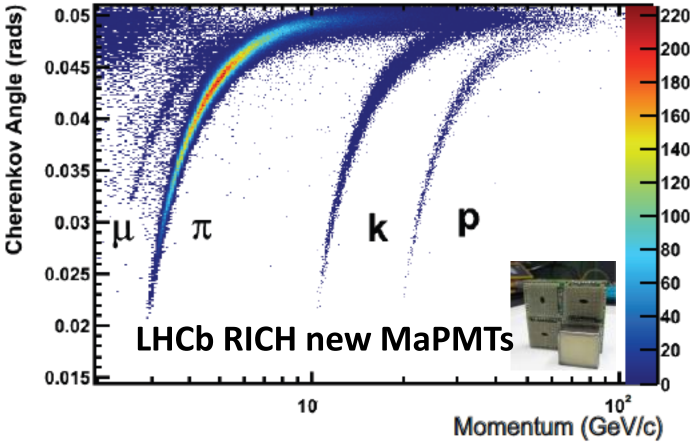




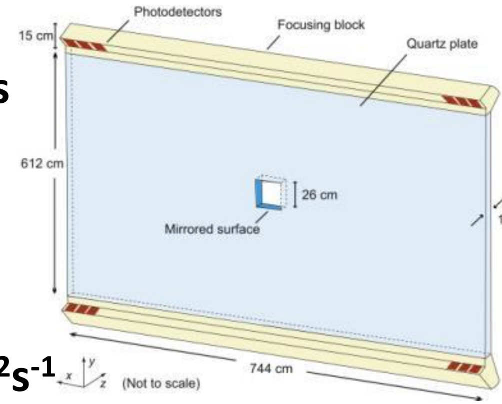


Silicon pads to withstand doses up to 10^{16}n/cm² and several MGy

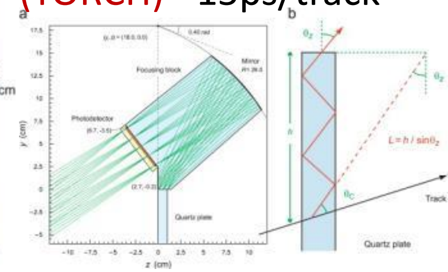
Particle ID and Timing Detectors

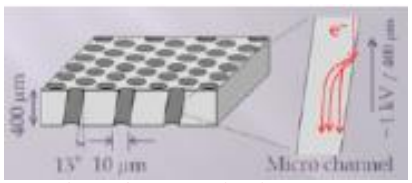


LHCb RICH system needs upgrades for triggerless operation at higher rates: $\mathcal{L}=2\times10^{33}cm^{-2}s^{-1}$

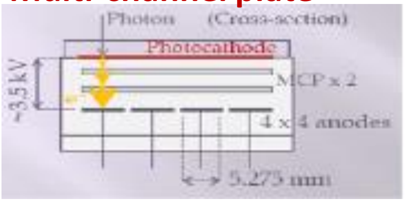


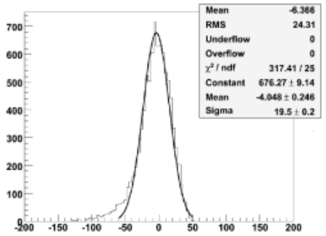
Also Time Of internally Reflected CHerenkov (TORCH) ~15ps/track

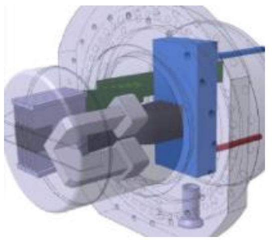




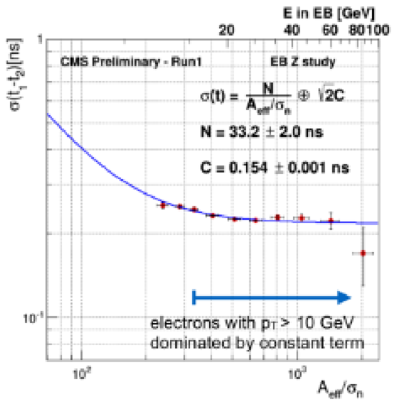
Multi-channel plate







ATLAS AFP (MCP-PMT) Timing Detector for far-forward proton tagging 6 independent quartz bars combined→14ps



CMS crystal calorimeter shows 150ps in operation (test beam down to 20ps)

Other technologies: high doped silicon (RD50), diamond (RD42), Multi-gap RPC,..

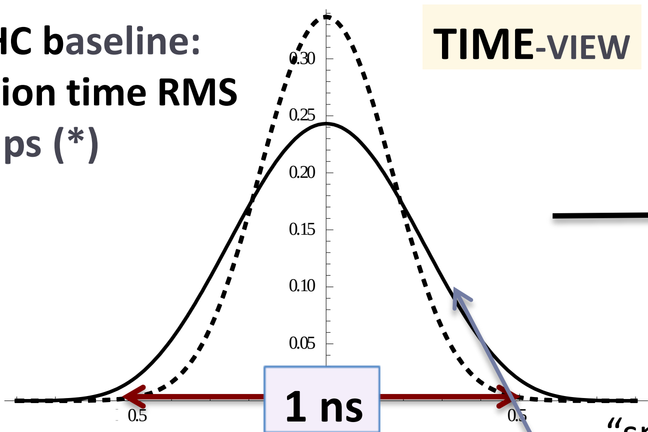
For 140 PU and "crab kissing", HL-LHC can deliver collision spread up to ~1ns

→ Use 20-30ps timing to better associate high p_T objects to vertices

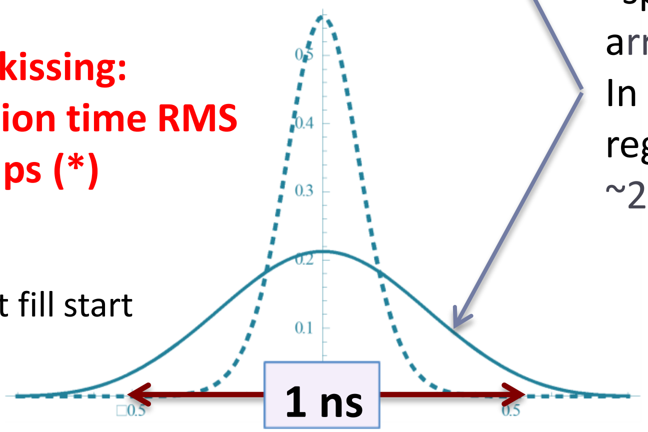
(PG1,8)

Mitigation of neutral PU with fast timing devices is being investigated - may depend on collision time distribution

HL-LHC baseline:
Collision time RMS
~160 ps (*)

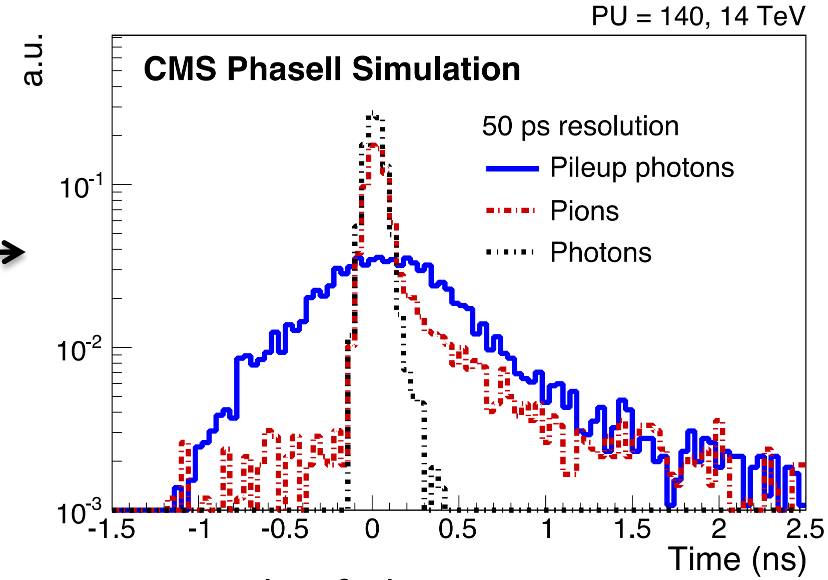


Crab kissing:
Collision time RMS
~100 ps (*)

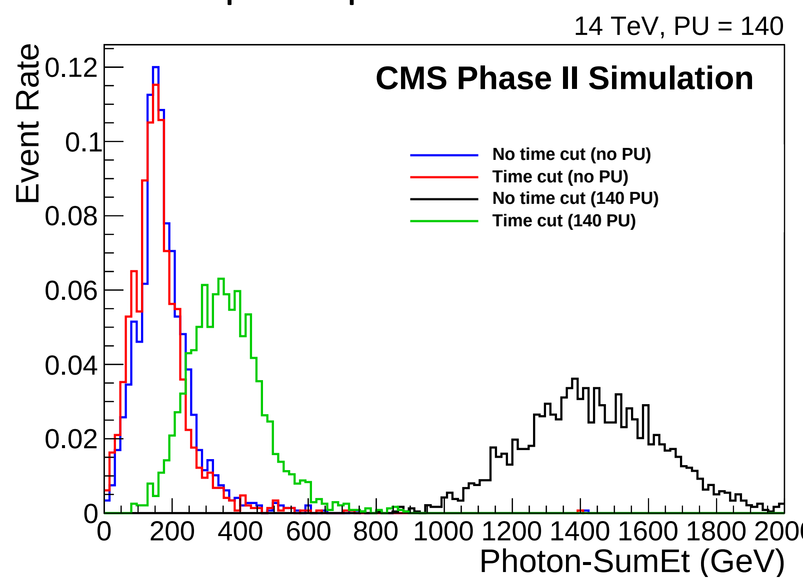


(*) At fill start

"spread of arrival time In forward regions" ~250 ps



Example of photons



Also need more studies in PFlow reconstruction framework

T. Tabarelli de Fatis presentation's

2nd ECFA HL-LHC… R&D for Mechanics and cooling

For HL-LHC detectors, particularly for Trackers or HGC, high power dissipation makes the thermo-mechanical design a challenge - although designs are different, material & techniques are mostly similar in all experiments

- Mechanical & thermal design are strongly coupled and shall proceed in parallel - new material or techniques (3D printing) being investigated in all aspects including radiation tolerance - need updated DB
- With the trend to lower temperature, to lighten cooling structures and to achieve a "greener" system, CO_2 evaporative cooling is becoming a standard technology. Work ongoing to standardize all system aspects and develop common prototype for future $\sim$ 50 kW $\sim$ -35° plants
- Micro-channel cooling presents further advantages in material reduction & thermal expansion mismatch - ALICE (ITS) and LHCb (VELO) are leading the developments
- QA, integration and environmental aspects need to be addressed at an early stage to keep system simple and reliable

2nd ECFA HL-LHC… R&D for Electronics systems

Several FE ASIC chips already available as prototypes - this is more advanced than it was for construction of current detectors - R&D focus on 65 nm technology supported by TSMC contract (IBM 130 nm situation to be monitored)

- ALICE: ITS (ALPIDE & MISTRAL) & TPC (SAMPA, FEERIC) prototypes available
- ATLAS: Strips ABC130 prototype available, HCC submitted - Calorimeters (ADC) & Muon (VMM, ART and TDS) prototypes available
- CMS: Strips (CBC) prototype available - Pixel-strips (MPA & SSA) under design (65nm), Muons (GEM, VFAT3) under design
- LHCb: Velo (VELOPIX) prototype (= Timepix3), Fibres (PACIFIC) & Tracker (SALT) prototypes available
- RD53: 65 nm - common ATLAS & CMS architecture defined - extensive radiation tests - developing IP blocks

2nd ECFA HL-LHC… R&D for Electronics systems

Optical data transfer - GBT & Versatile Link is a crucial (common) development to all experiments and all detectors

- GBT chipset and VTTX/VTRX ready for production
- Low power GBT (65 nm) and Versatile Link + started development
- Also testing of some photonics devices

Powering scheme development, especially for pixel detectors, would benefit from new contributions

- Radiation-hard point of load DC-DC first version in production (>200 Mrad & 8 10^{14} 1 MeV.n.cm^{-2})
- Serial power and DC-DC successfully tested
- Some progress on HV switches (silicon sensors bias)

Interconnection

- First positive results for TSV last techniques

Modular electronics

- Progress made (µTCA in CMS), xTCA in the others
- First "CERN specification" for procurement

2nd ECFA HL-LHC… R&D for Trigger, DAQ and computing

ALICE & LHCb proceeding with computing trigger architectures while ATLAS & CMS still need a hardware trigger selection to allow full data readout

- Need to implement track trigger and increase L0/L1 rates in ATLAS & CMS is well motivated by trigger object rates and physics menu studies
  - Current BW for data transfer becomes limiting factor for acceptable power consumption and material weight, particularly for inner OT and pixel layers
- Track trigger involves modification of calorimeter & muon readouts (longer latency, higher rates) - trend is to readout at 40 MHz - also allowing full granularity & resolution usage at L1
- Higher rates require fast online software processing - fully exploiting new many-core architectures, and based on new algorithms
- Progress in network switches & high speed links should be sufficient for future DAQ system requirements

The experience of ALICE and LHCb on these two last aspects will greatly benefit ATLAS and CMS

2nd ECFA HL-LHC… R&D for Trigger, DAQ and computing

Natural CPU and disk growth resources will fall short by x 3-5 (at least) for HL-LHC requirements - this must be gained from proper usage of new technologies

- Costs of disk and speed of I/O are a concern
  - New network technologies and on-demand data distribution
- Diversification of resources (Era of Xeon x86 mono-culture is over)
  - Kernels of reconstruction and simulation code must be portable
- Efficient memory access is the key to optimal use of clock cycles
  - Data Oriented Design
- Multi-threaded code is a requirement
  - Framework evolution is advancing well, algorithmic code to follow
- Simulation must get faster, ex. track triggers simulation is difficult
  - Mix fast and full simulation for best physics results within budget

This work needs to establish dedicated expertise

2^{nd} ECFA HL-LHC… Outlook

- HL-LHC is now acknowledged as the next crucial step in any future for collider particle physics
- Funding is yet to be agreed - 2015 will be critical for discussion with Funding Agencies
- ECFA workshops are good opportunities to discuss upgrade goals and key techniques to fully exploit the HL-LHC physics potential. A lot of material was covered in this intense, 3-day workshop.
- In 2015, experiments will be busy with RUN 2 data taking & analysis, in addition to Phase-I upgrade construction and on-going Phase-II upgrade optimisation
- A new ECFA workshop is envisaged in 2016, when ATLAS & CMS will approach TDRs, and ALICE & LHCb will be experiencing upgrades construction