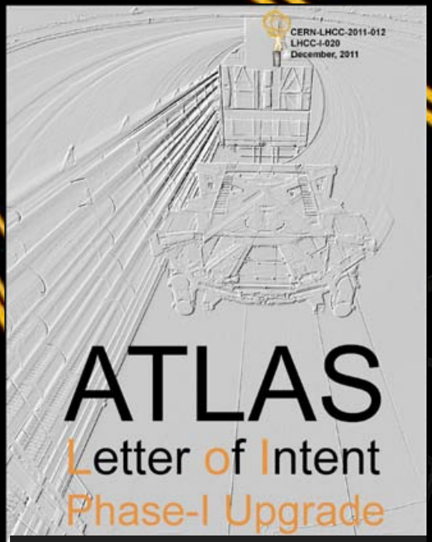
Markus Elsing

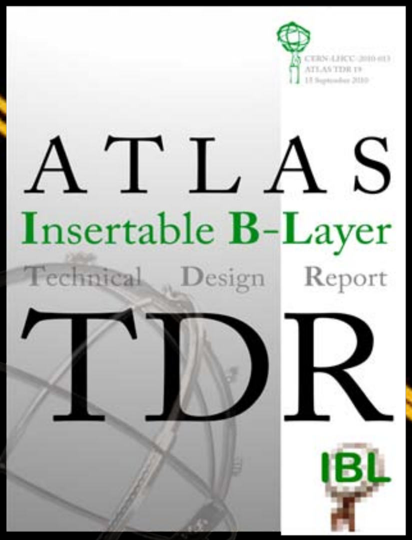
ATLAS Upgrades Towards the High Luminosity LHC

extending the discovery potential

on behalf of the ATLAS Collaboration

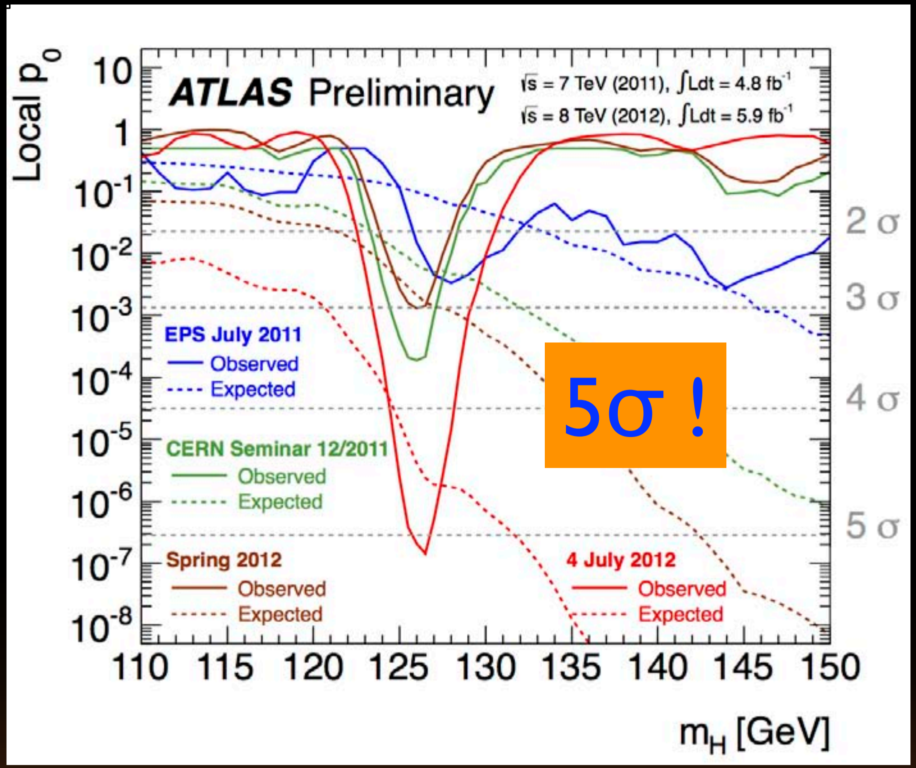


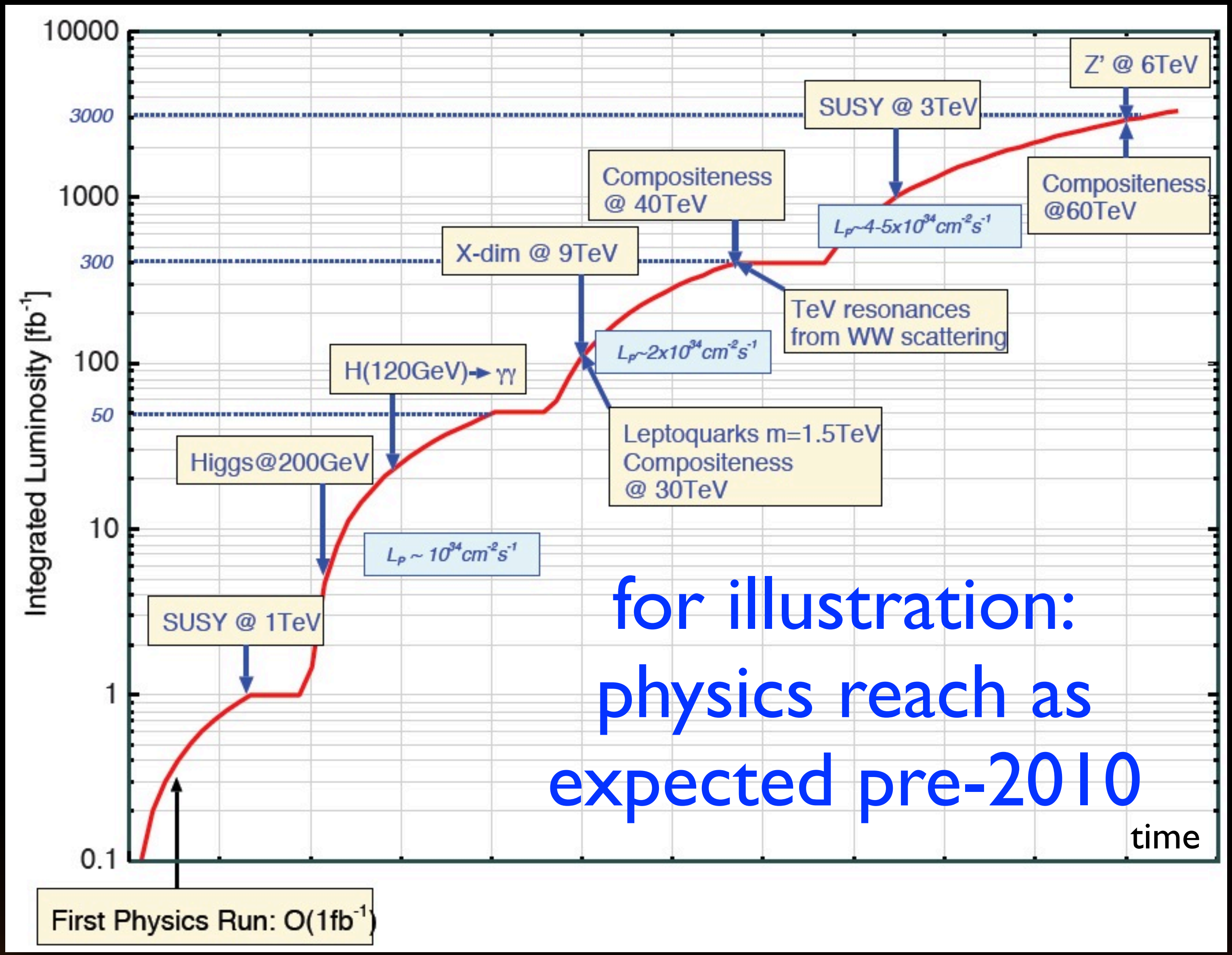
https://cdsweb.cern.ch/record/1402470/
(CERN-LHCC-2011-012)



Motivation

- expectations and present status

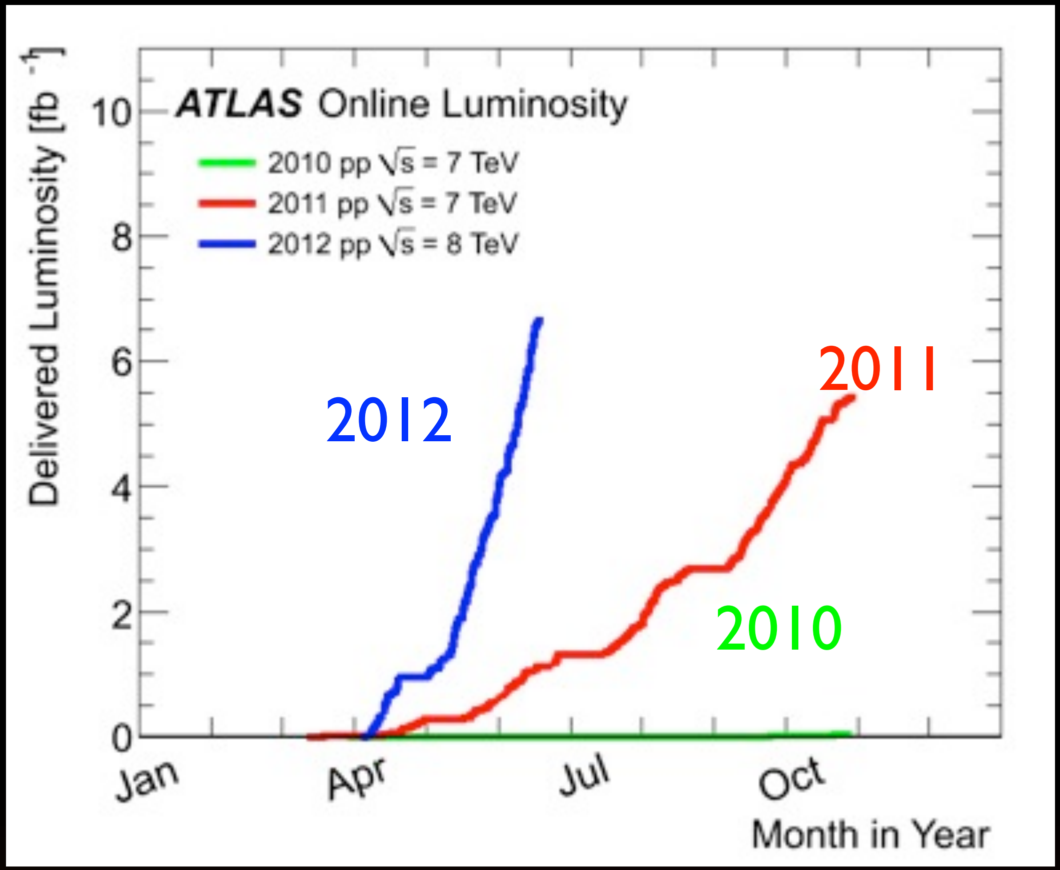


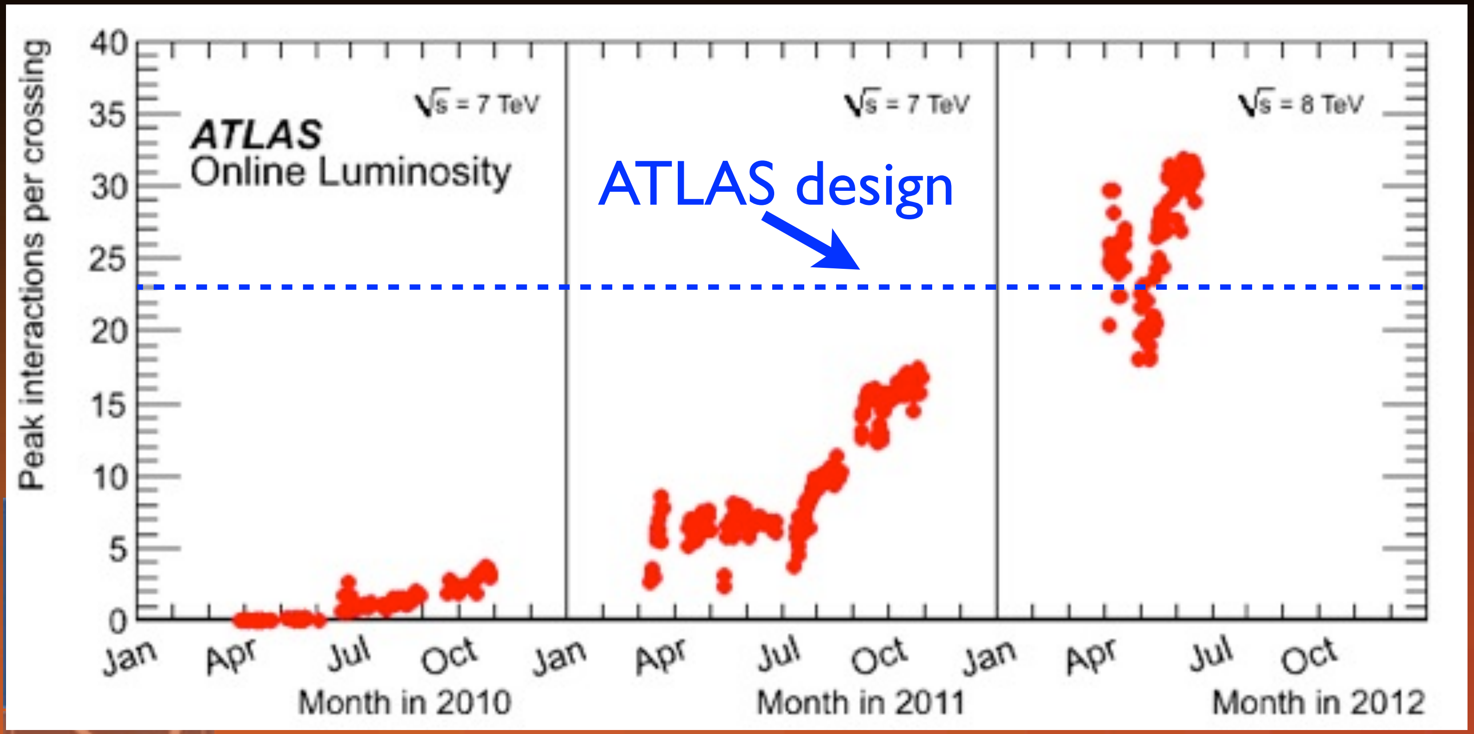


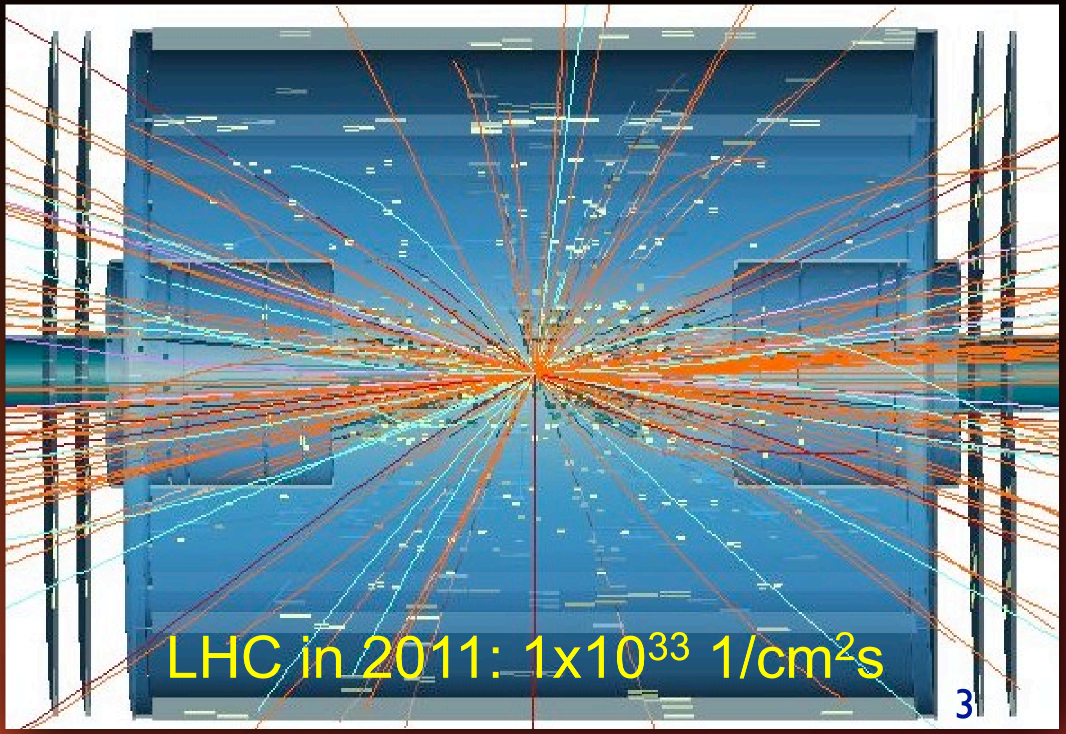
- motivations for higher luminosity
  - ➡ perform measurements of Higgs properties
  - ➡ observe/measure rare (SM and BSM) processes that occur at rates below the current sensitivity
  - ➡ extend exploration of the energy frontier to increase the discovery reach

LHC is doing fantastically well

- 2012 operation
  - ➡ peak event pileup routinely exceeding design values
- event pileup and other induced effects (e.g. radiation damage)
  - ➡ challenge for the detector, T/DAQ and offline
    - so far ATLAS is doing very well
  - ➡ aim of the ATLAS upgrade program:
    - preserve and improve physics performance to fully benefit from increasing luminosity







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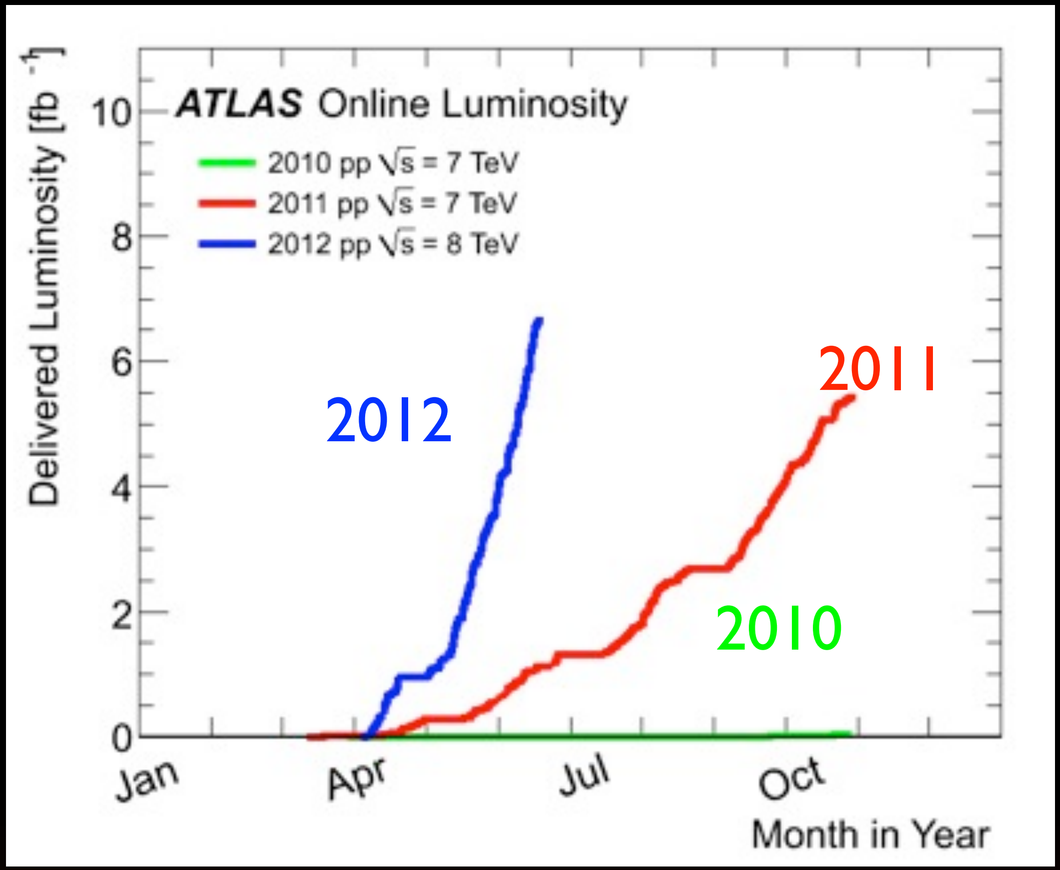
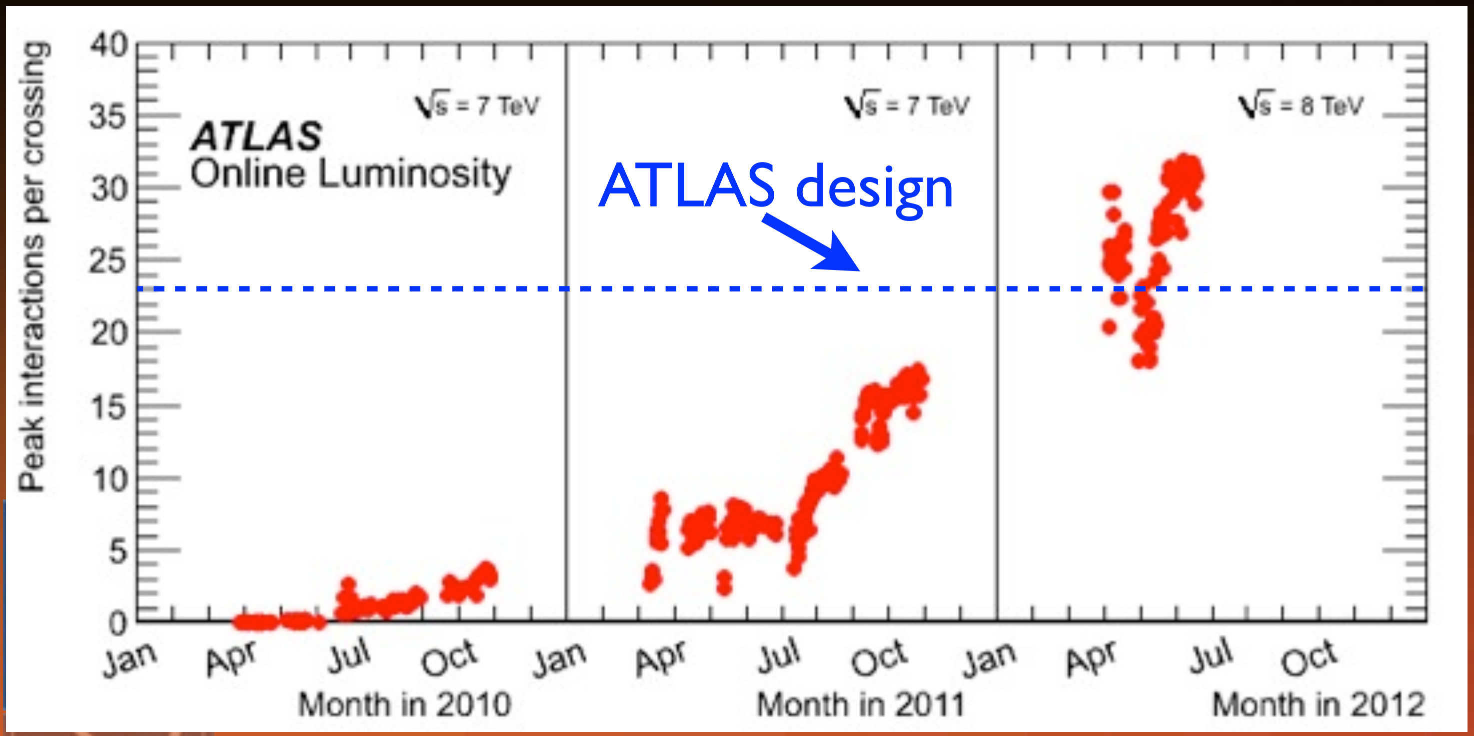
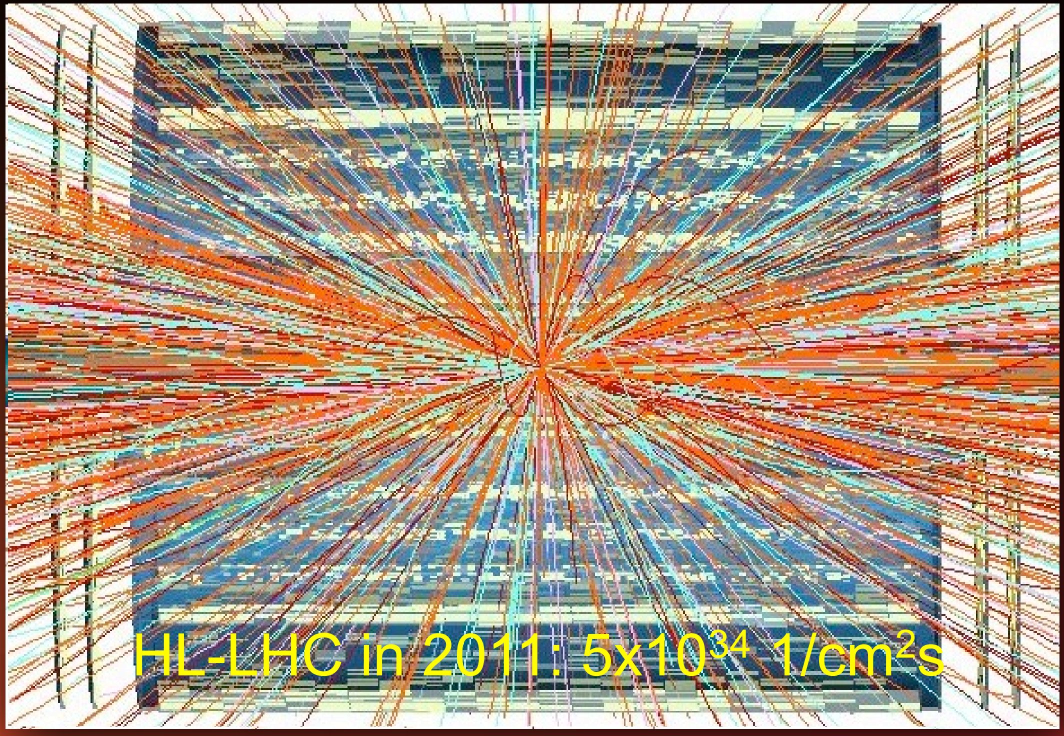
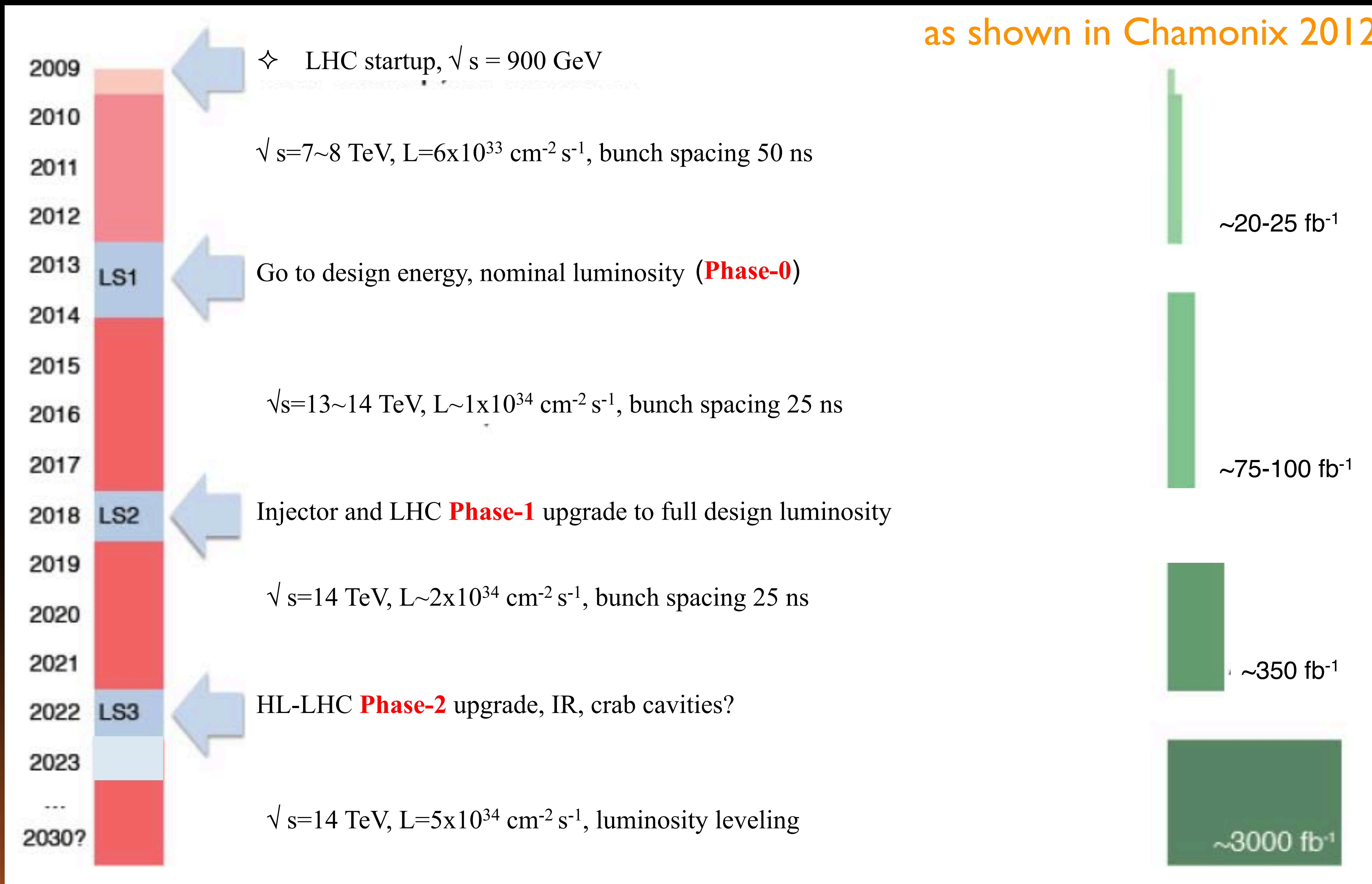


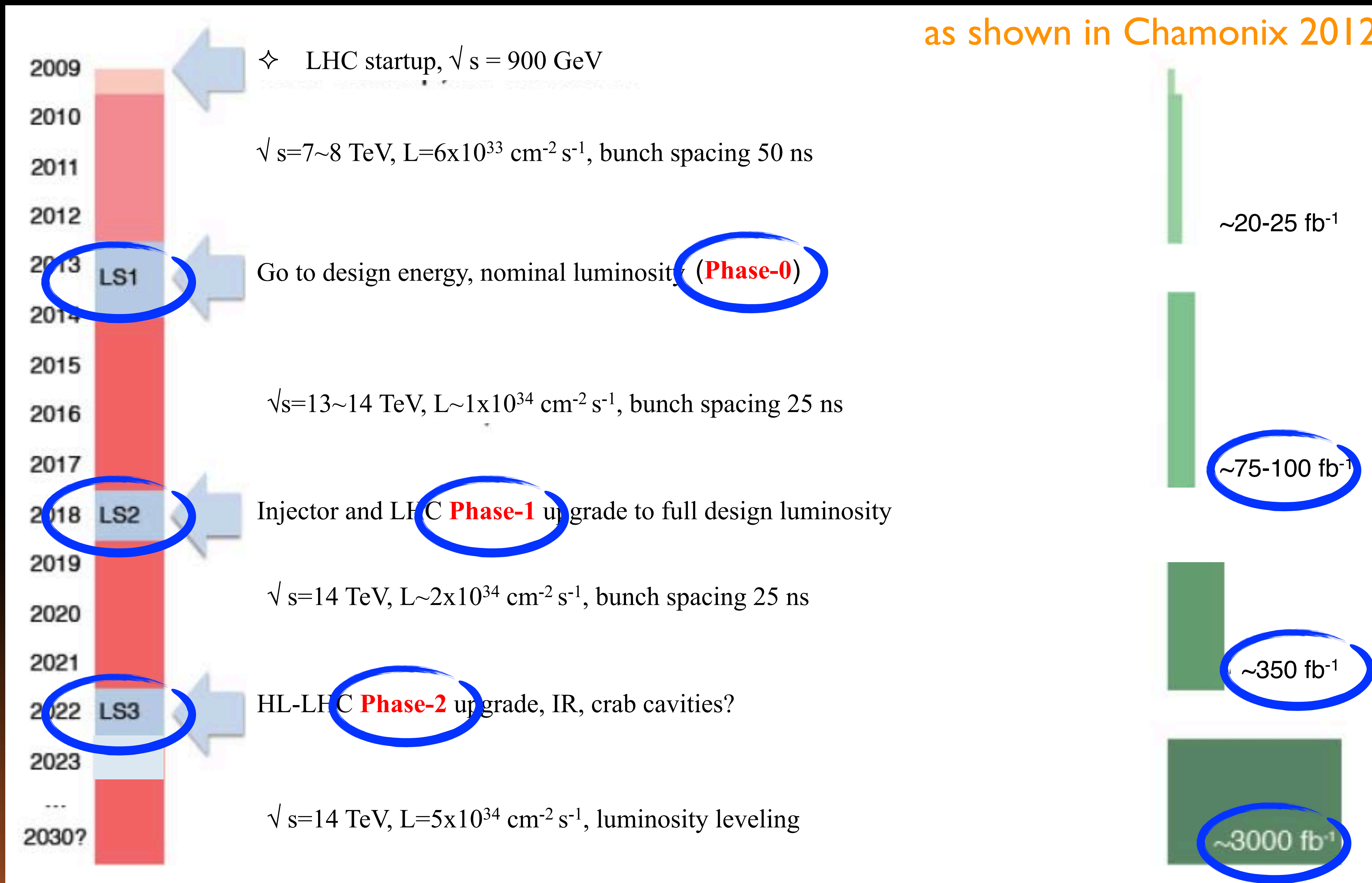




Upgrade Schedule Assumptions



Upgrade Schedule Assumptions

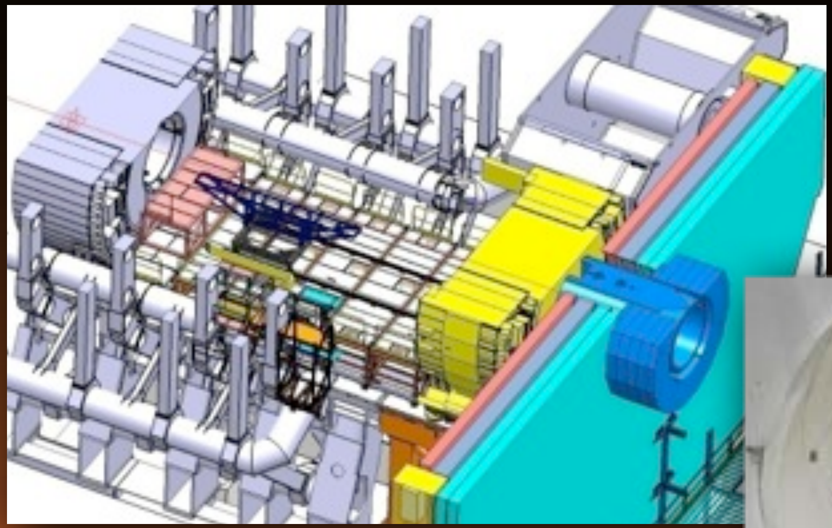


➡ ... outline for the following

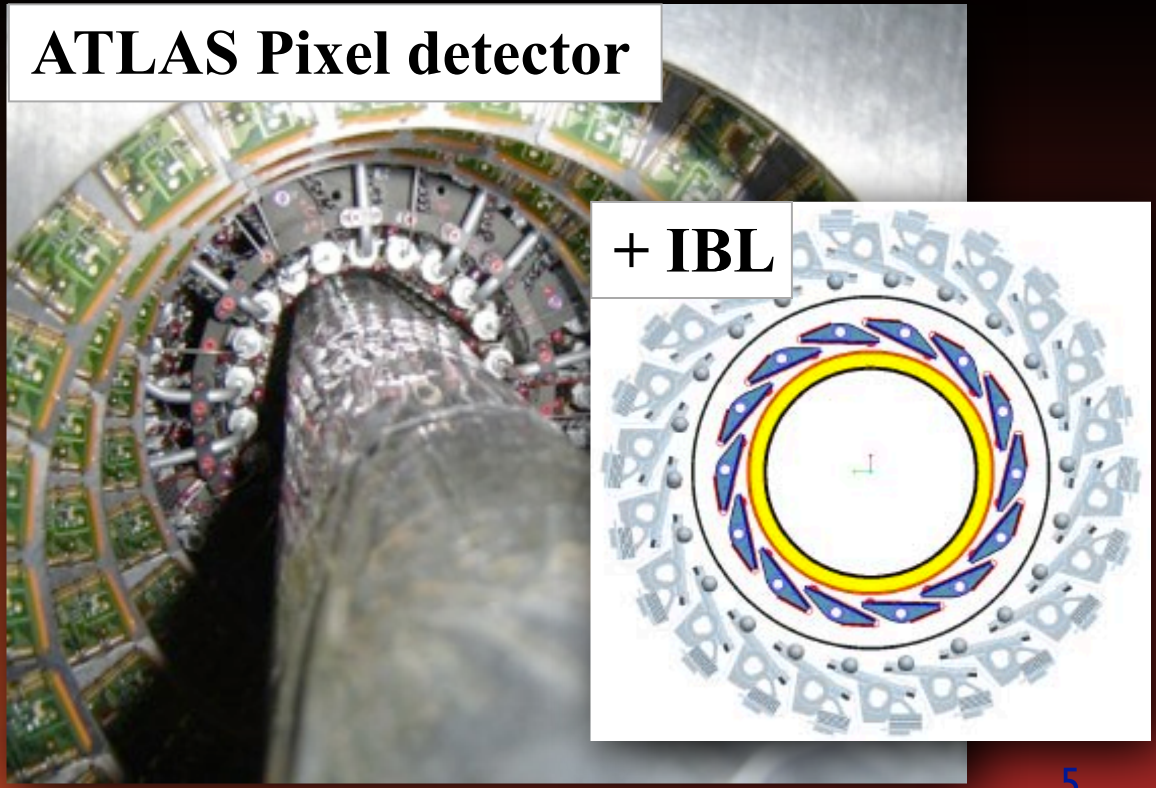
Phase-0: 2013/14 Shutdown (LS1)

- detector **consolidation**:
  - ➡ new tracker evaporative cooling plant
  - ➡ new Calorimeters LV power
  - ➡ magnets cryogenics consolidation
  - ➡ muon spectrometer consolidation
  - ➡ infrastructure consolidation (electronics, ventilation, radiation protection,…)
  - ➡ maintenance and repairs everywhere

- detector **upgrade**:
  - ➡ Insertable B Layer (IBL): 4th pixel layer
    - install (?) new pixel services (nSQP), incl. new Diamond Beam Monitor
  - ➡ new small radius central Be pipe
    - new forward aluminum beam pipes
  - ➡ new chambers in the muon spectrometer to improve geometrical coverage



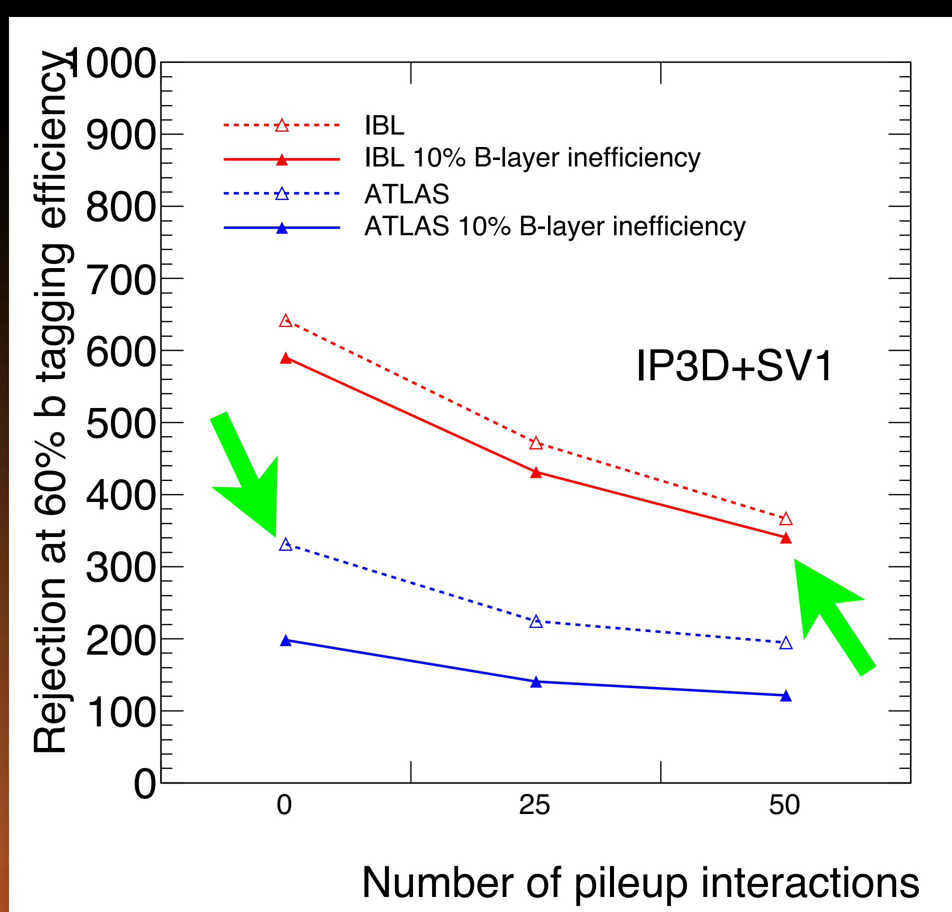
complex access with only ~20 months available

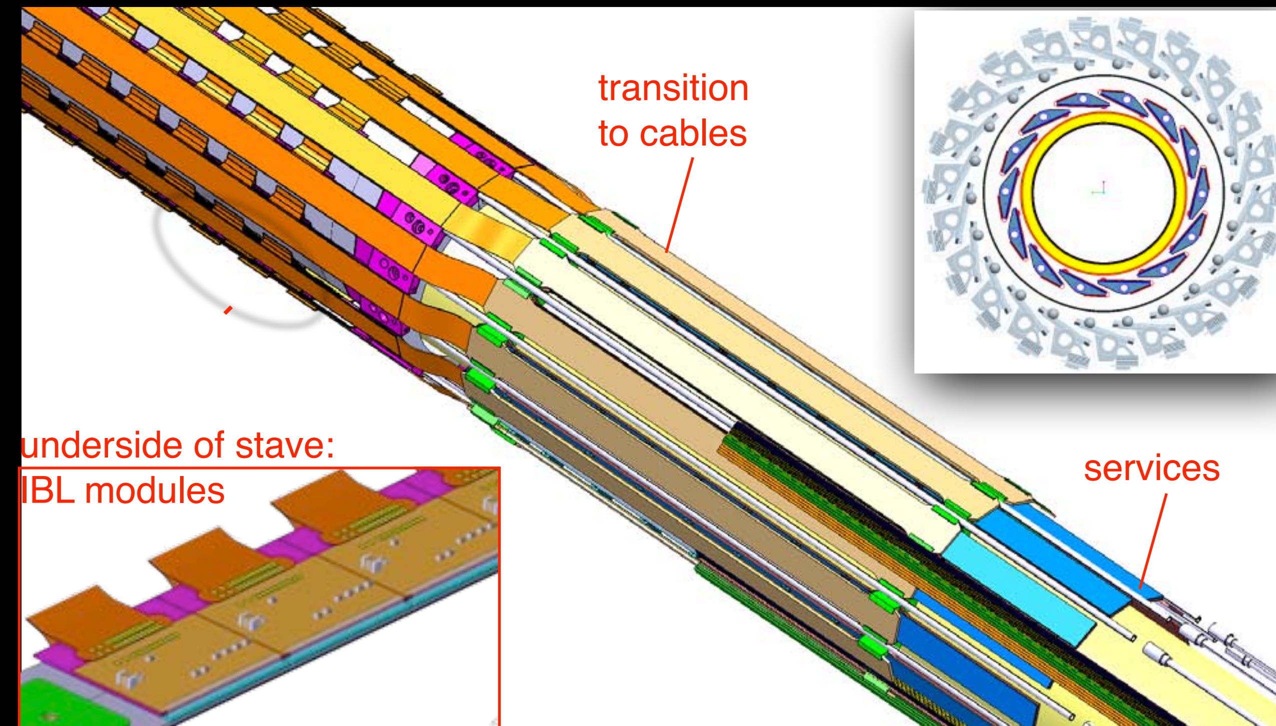


Insertable B Layer (IBL)

see talk by M.Giordani

- 4th pixel layer
  - ➡ add low mass layer closer to beam, with smaller pixel size
    - improve tracking, vertexing, b-tagging and τ-reconstruction
  - ➡ recovers from defects, especially in present b-layer
  - ➡ FE-I4b overcomes bandwidth limitations of present FE-I3

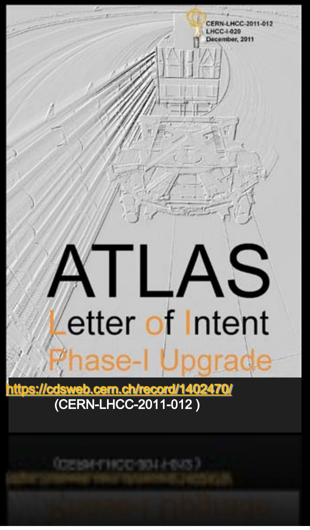




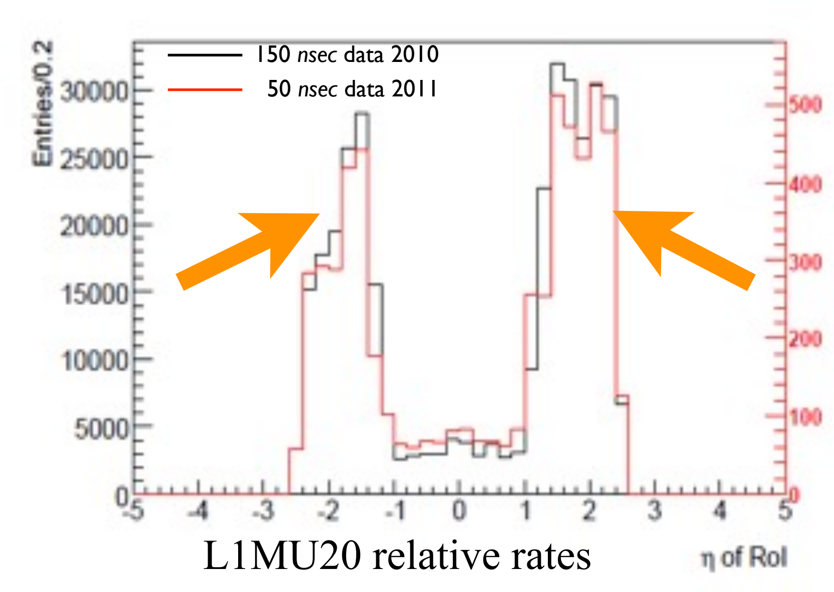
- IBL key specifications:
  - ➡ 14 staves, <R> = 33.25 *mm*
  - ➡ CO2 cooling, T < -15°C @ 0.2 *W/cm²*
  - ➡ X/X0 < 1.5 % (B-layer is 2.7 %)
  - ➡ 50 *μm* x 250 *μm* pixels (**planar** and **3D** sensors)
  - ➡ 1.8° overlap in ϕ, < 2% gaps in Z
  - ➡ 32/16 single/double FE-I4 modules per stave
  - ➡ radiation tolerance $5 \cdot 10^{15}$ *neq/cm²*
- mounted on new beam pipe
  - ➡ installation options still to be decided
  - ➡ may extract present Pixel Detector to replace nSQPs (decision this year)

stave -1 after loading

Phase-1: Installation in or before LS2

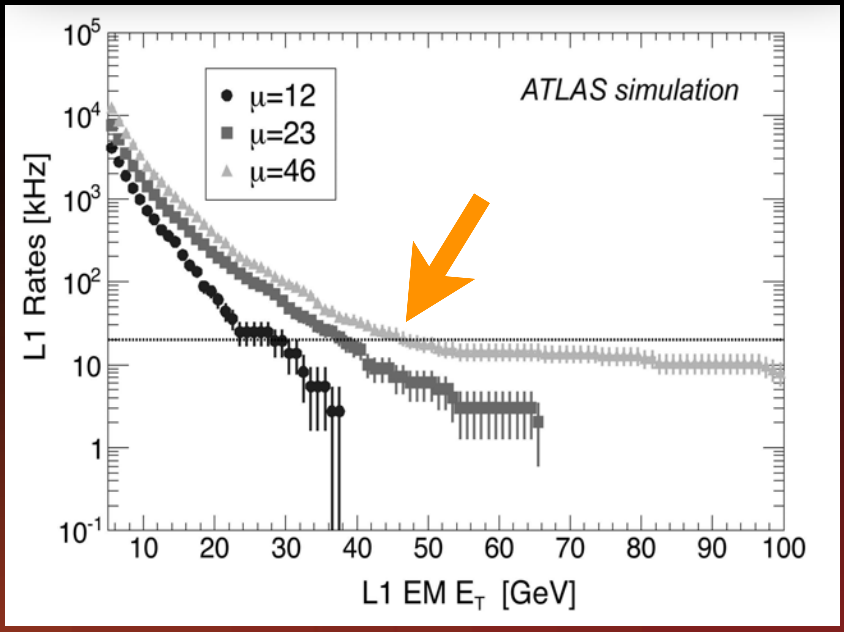


- pileup up to 80 at luminosities up to $3 \cdot 10^{34} cm^{-2} s^{-1}$
  - ➡ challenge: keep trigger threshold around 20-25 *GeV*
  - ➡ raising muon p_T thresholds not effective in the forward
  - ➡ higher EM E_T thresholds eat into physics acceptance



- trigger and related upgrades
  - ➡ new muon small wheels for forward trigger and tracking
  - ➡ high granularity calorimeter Level-1 trigger electronics
  - ➡ fast tracker trigger (FTK) using Pixel and SCT information
  - ➡ topological trigger processor for Level-1 (starts before LS2)
  - ➡ High Level Trigger farm upgrade, especially network
  - ➡ new Tiles crack-gap scintillators and trigger electronics

see talk by M. della Volpe

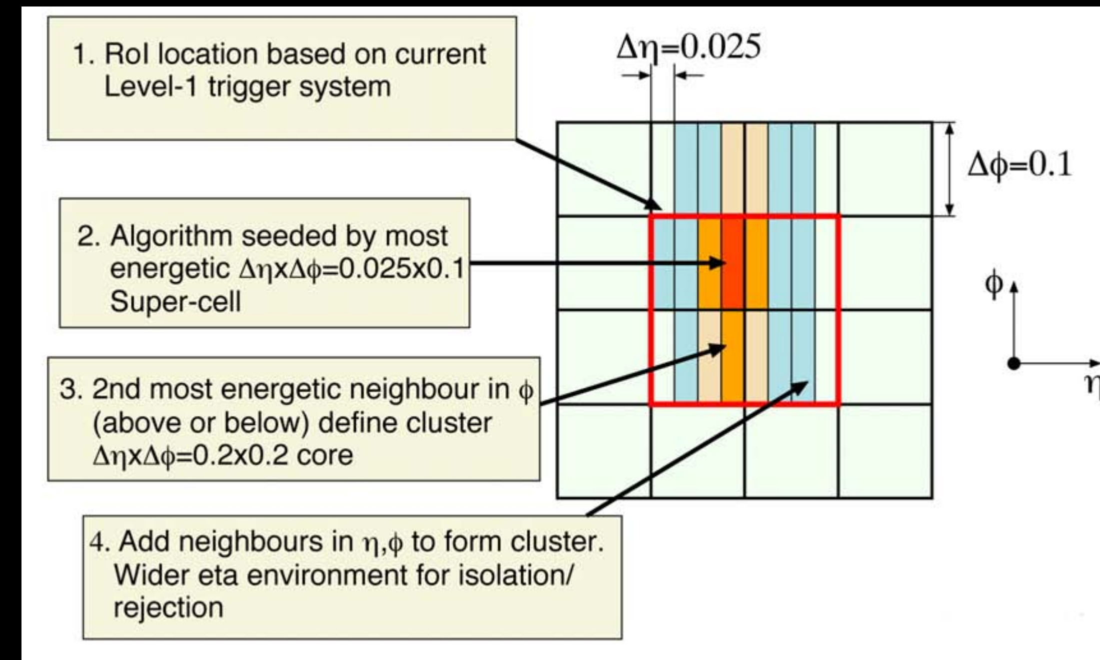


- ATLAS Forward Physics (AFP)
  - ➡ new forward detectors installed at 210 *m*, start before LS2

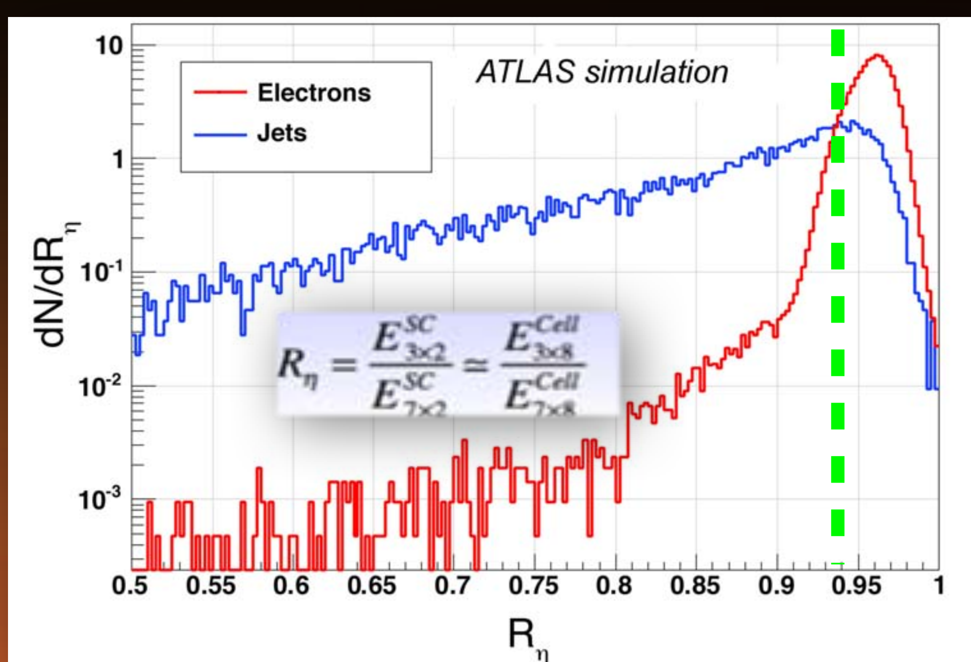
Granularity LVL1 Calorimeter Trigger

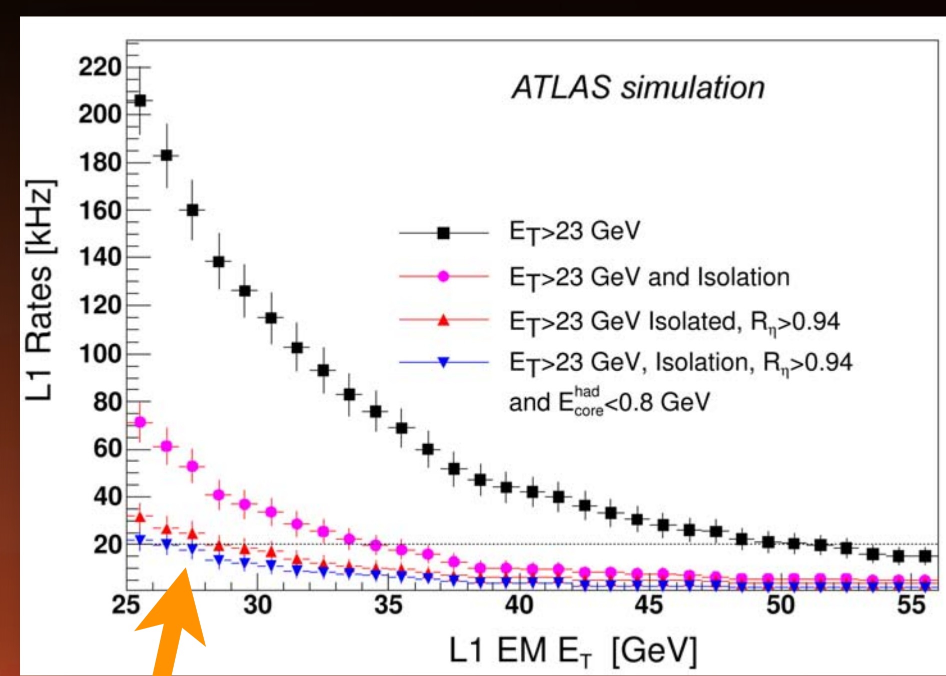
see talk by M. della Volpe

- explore LAr lateral show shapes to improve trigger rejection
  - ➡ super-cells formed in 2nd layer of EM calorimeter
  - ➡ goal: reduced Level-1 trigger rate and preserve un-prescaled threshold at ~25 *GeV*



- requires new front end digital chain
  - ➡ super-cells with higher granularity are formed in the front end shaper sum ASIC and individually digitized
  - ➡ Level-1 uses ratio of energies of different size clusters

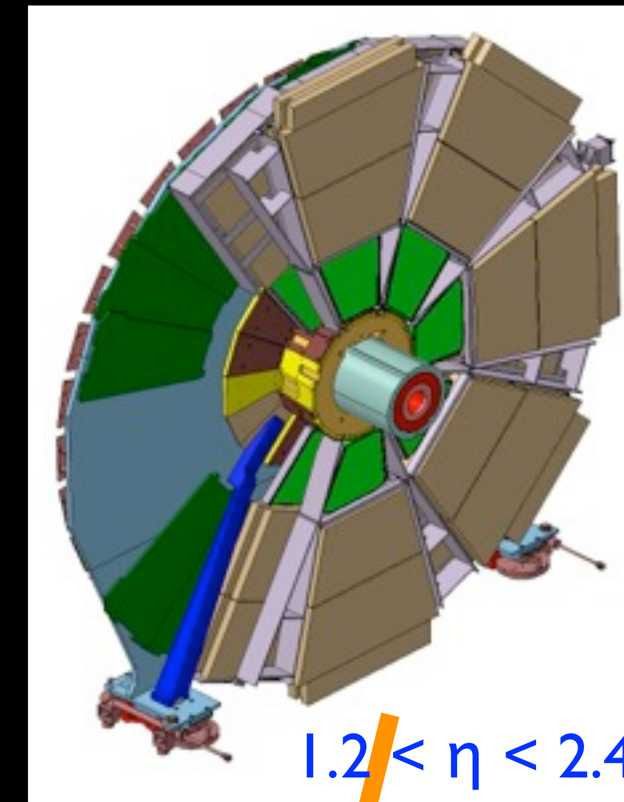


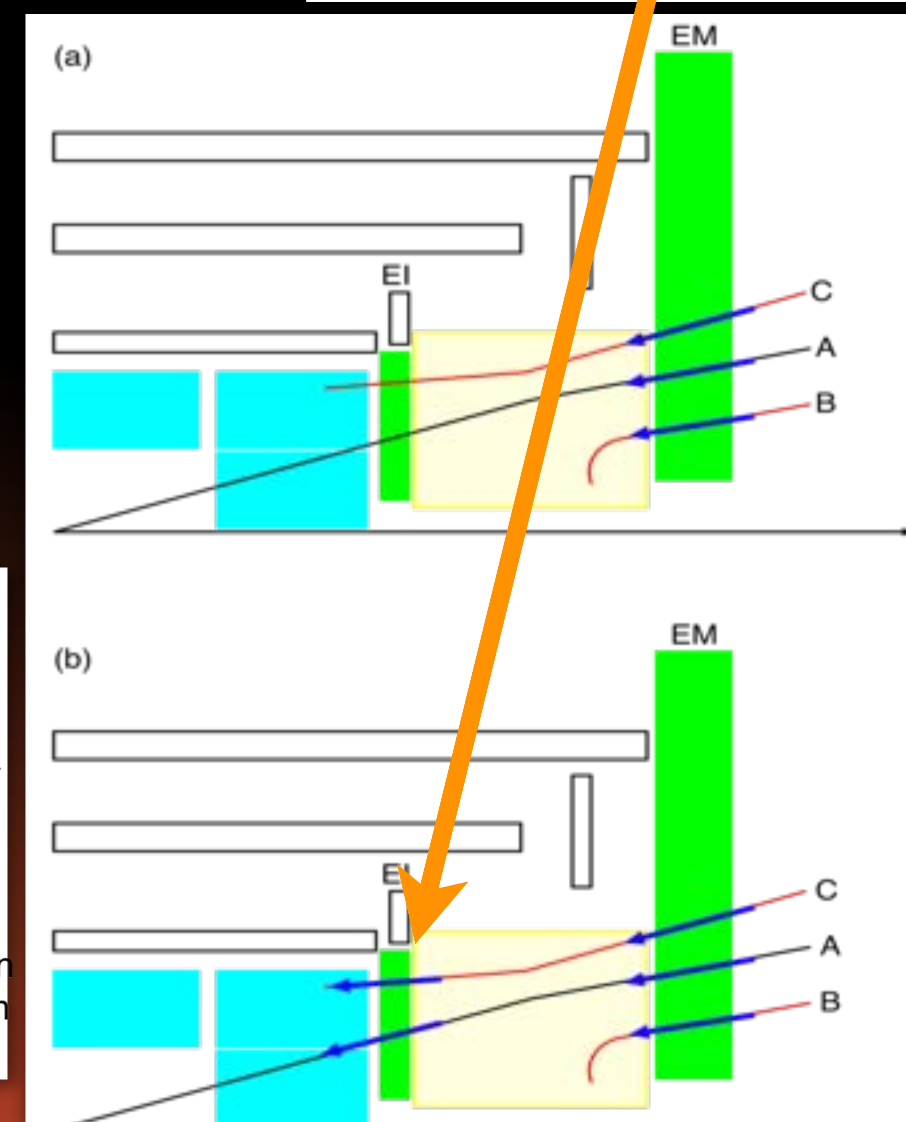


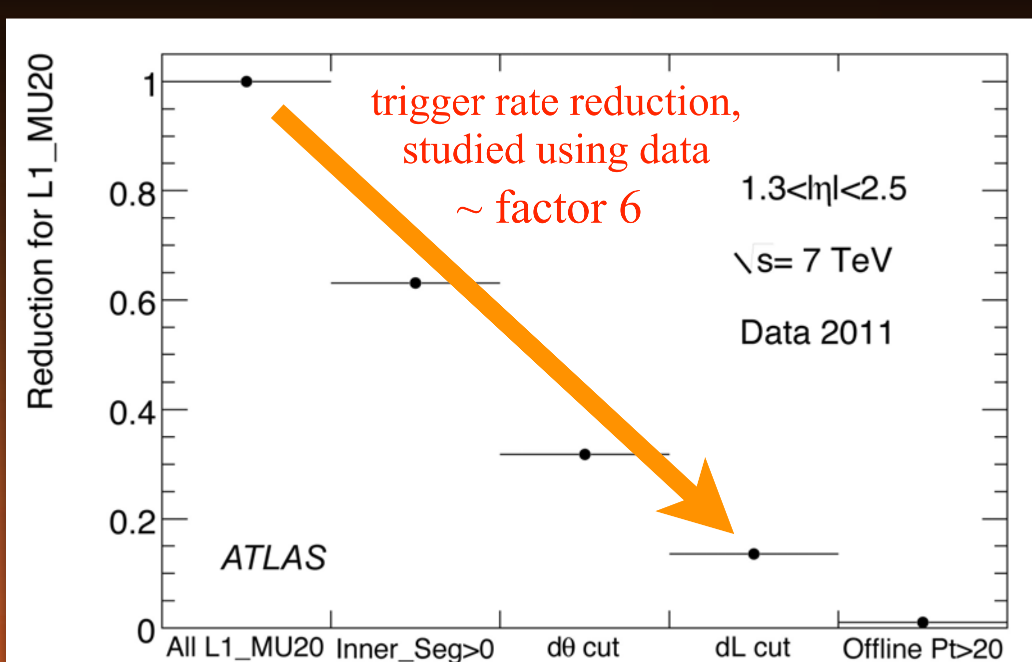
see talk by R.Hertenberger

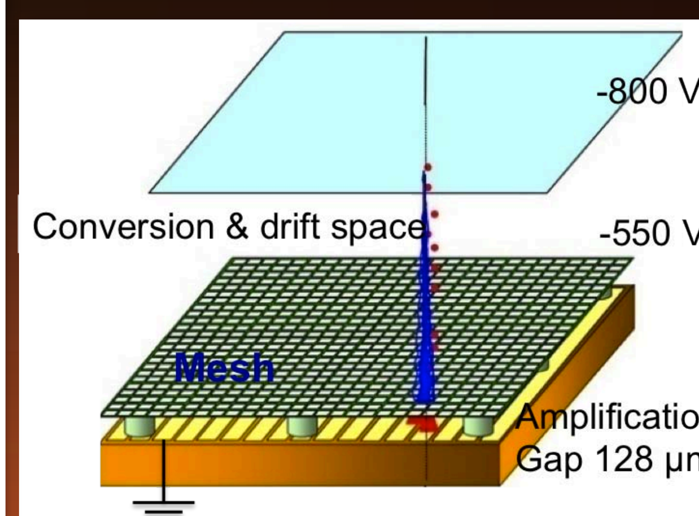
New Muon Small Wheel

- improve forward muon trigger
  - ➡ < 1 *mrad* angular resolution on track segments at Level-1
  - ➡ trigger studies demonstrate Level-1 rate reductions
- 2 multilayers per sector, each with
  - ➡ 4 layers sTGC (Thin Gap Chambers) for trigger
    - reduced cathode resistivity, rates > 30 kHz/cm^2
  - ➡ 4 layers of MicroMegas for a total of 2 *M* channels
    - both coordinates, direction information, ~ 70 *um*
- TDR planned for 2013



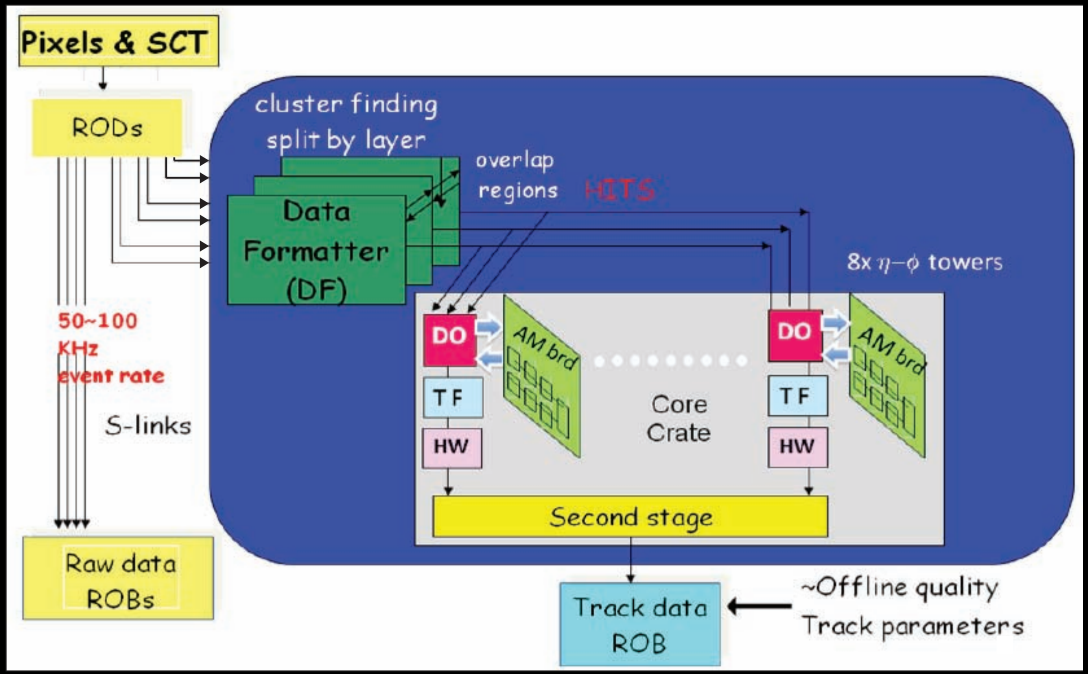


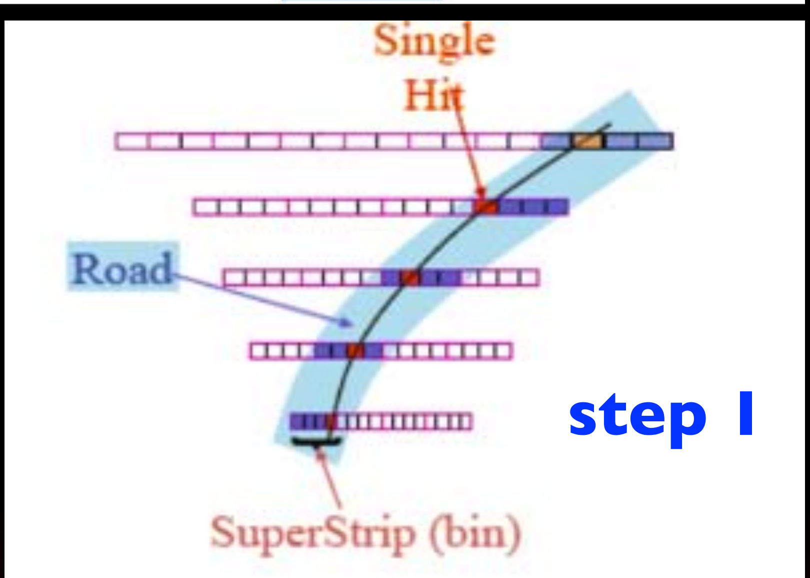




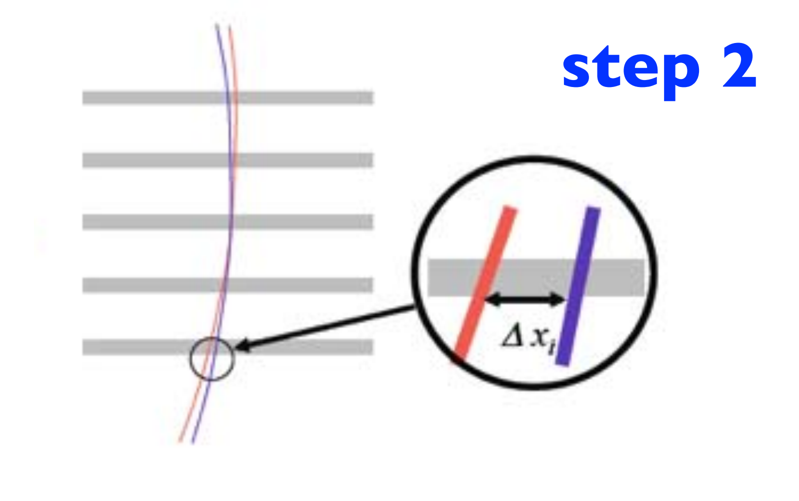
The Fast Tracker (FTK)

- current ATLAS trigger chain
  - ➡ Level-1: hardware based (~50 *kHz*)
  - ➡ Level-2: software based with RoI access to full granularity data (~5 *kHz*) ← tracking enters here
  - ➡ Event Filter: software trigger (~500 *Hz*)
- FTK: hardware based tracking
  - ➡ descendent of the CDF Silicon Vertex Trigger (SVT)
  - ➡ inputs from Pixel and SCT
    - data in parallel to normal read-out
  - ➡ two step reconstruction
    - associative memories for parallel pattern finding
    - linearized track fit implemented in FPGAs
  - ➡ provides track information to Level-2 in ~ 25 μs
- major Level-2 improvement for
  - ➡ b-tagging, τ-reconstruction
  - ➡ lepton isolation
  - ➡ primary and pileup vertex reconstruction





Pattern recognition in coarse resolution (superstrip➔road)

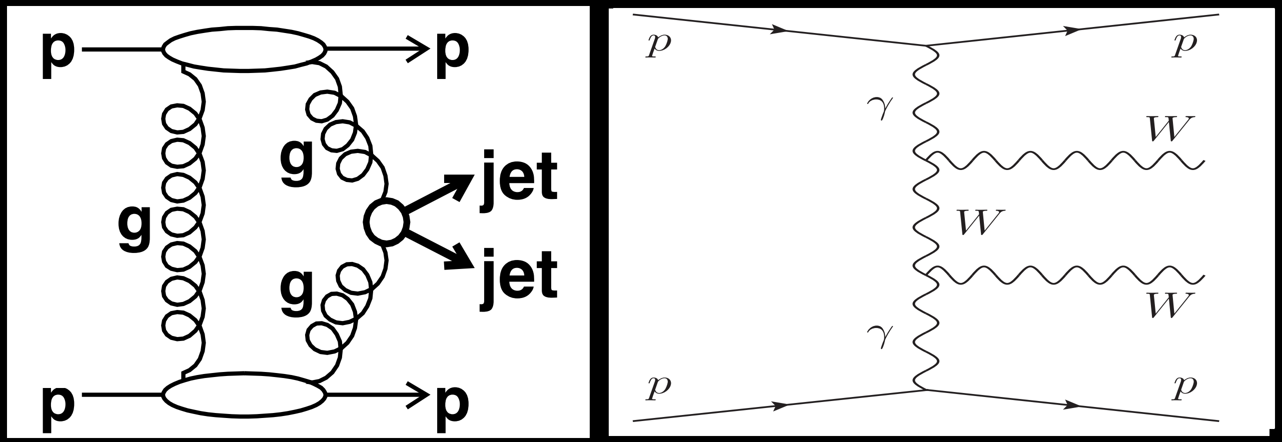


Track fit in full resolution (hits in a road)

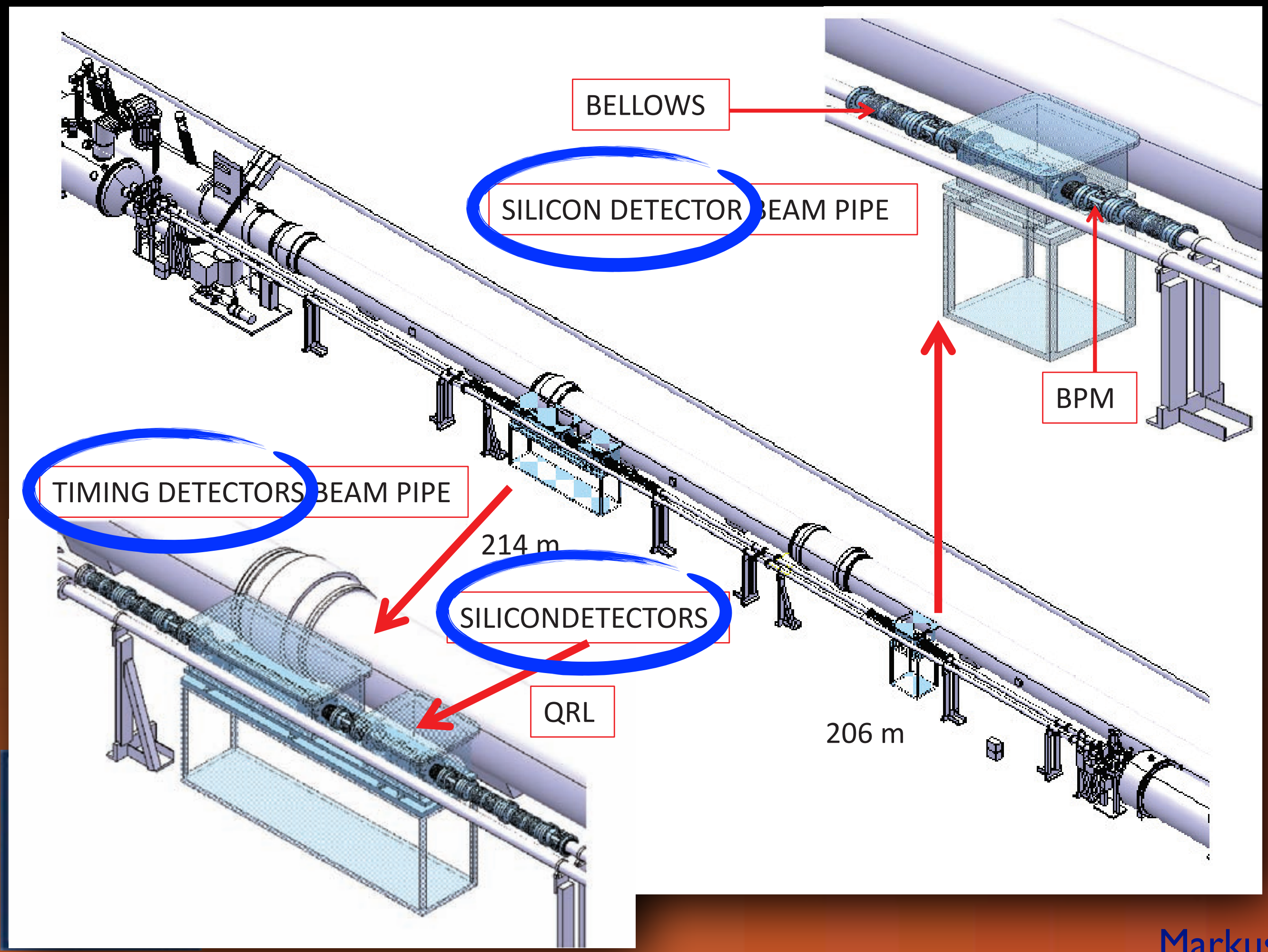
$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$

ATLAS Forward Physics (AFP)

- study tagged color singlet or photon exchange processes
  - ➡ p-p tagged high mass central system
  - ➡ anomalous WW couplings, diffractive jet production, new physics ?

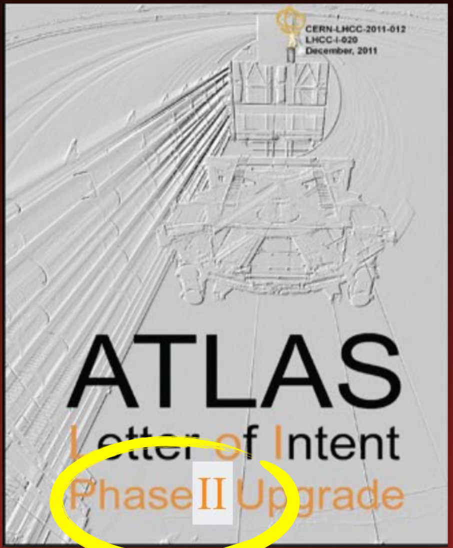


- system of timing and silicon detectors
  - ➡ installed in movable beam pipe to move detectors in while stable beams
  - ➡ at 210 *m* away from P1
  - ➡ 2x6 layer 3D pixel detector (IBL) to measure proton position ~15 *µm*
    - radiation few *mm* from beam
  - ➡ array of 4x8 quartz bars to measure proton timing ~10 *psec* to separate signal and pileup interactions

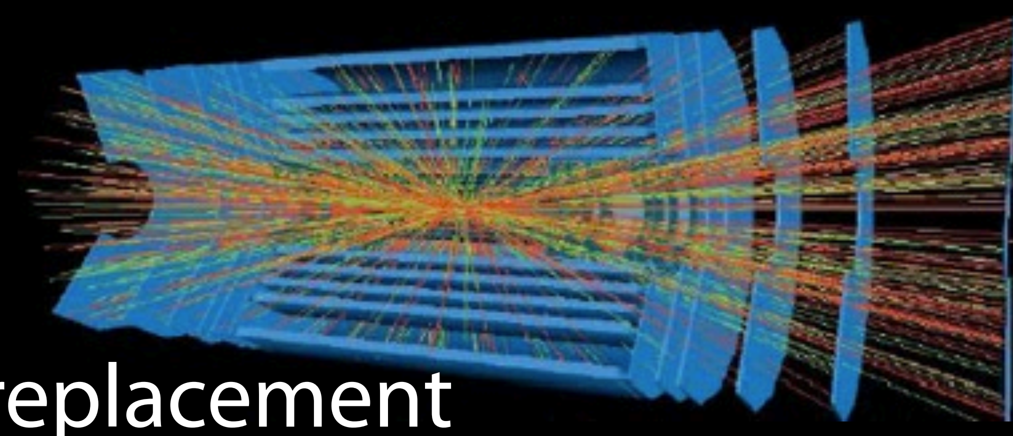


Phase-2: Installation 2022/23

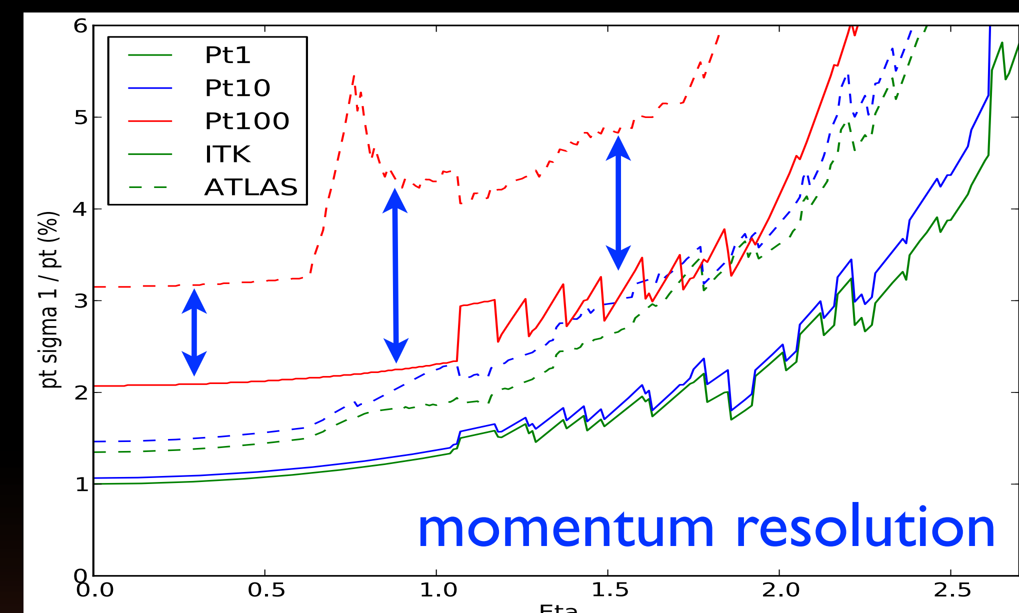
- by end of Phase-1 LHC will have delivered 300-500 fb^{-1}
  - ➡ LHC will be made ready for $5 \cdot 10^{34} cm^{-2} s^{-1}$ with luminosity leveling
- ATLAS Phase-2 upgrade program is taking shape
  - ➡ main activity is construction of a new Inner Detector
    - already ongoing major R&D, prototyping and engineering effort
    - including feasibility studies for a Level-1 hardware track trigger (Level-0 seeded)
  - ➡ Phase-2 conditions mays require to replace FCAL (Forward Calorimeter) and change HEC (Hadronic EndCap) electronics
  - ➡ muon spectrometer will be upgraded, in particular in the big wheel region
  - ➡ existing electronics/computing/TDAQ will need to be upgraded and modernized to face additional 8-10 years of running in extreme conditions
- plan is to be ready for installation in 2021
  - ➡ will need a 2 year shutdown to prepare ATLAS for its new phase
- Letter of Intent to be presented in December

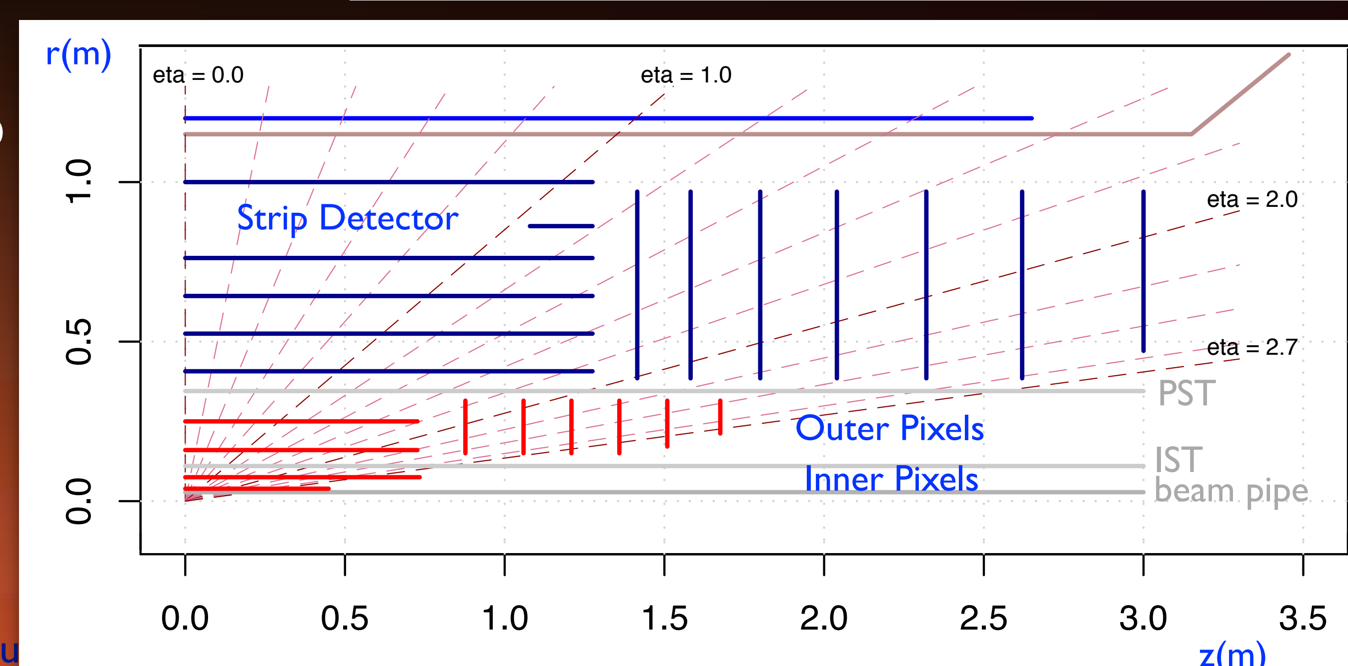


Inner Tracker Upgrade

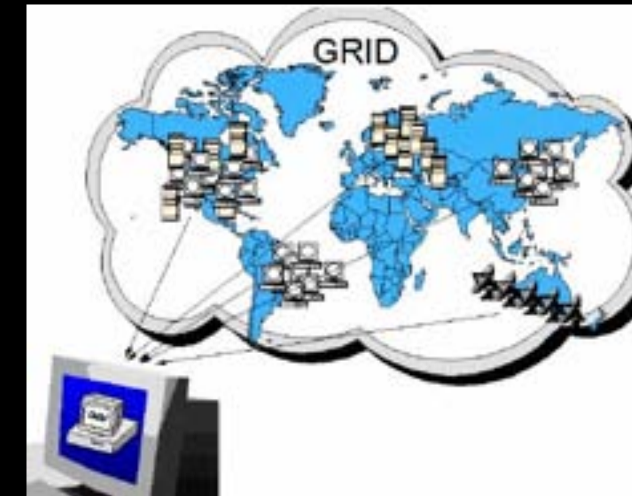


- to keep ATLAS running requires tracker replacement
  - ➡ current tracker designed to survive up to 10 *MRad* in strip detectors (≤ 700 fb^{-1})
  - ➡ replace with an all silicon tracker to match the challenge of 140-200 pileup events
- main ITK design parameters
  - ➡ **Inner Pixels:**
    - 2 replaceable layers close to enlarged Phase-2 beam pipe
    - smaller pixel pitch to improve b-tagging (FE-I5)
  - ➡ **Outer Pixels:**
    - 2 barrel layers at increased radii to improve tracking in jets
    - pixel endcaps ensure full tracking coverage to η=2.5
    - some standalone tracking capability to η=2.7 (muons)
  - ➡ **Strip Detector:**
    - maximize momentum resolution (*B·dl*)
    - double sided strips in 5 layer, 7 disk, plus stub
    - shorter strips close to PST to limit occupancy
  - ➡ overall a 14 hit system down to η=2.5
    - robustness, avoid fakes at high pileup
    - overall much reduced material budget





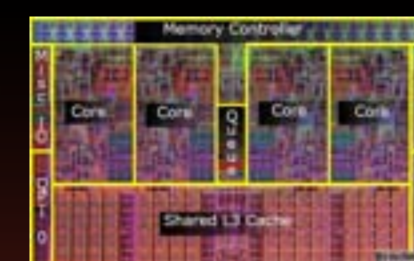
Computing and Offline



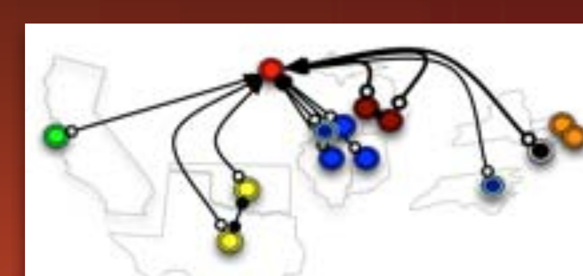
- vital part of the upgrade program
  - ➡ support upgrade with detector simulation
  - ➡ upgrade of the computing and offline software infrastructure

- many challenges ahead
  - ➡ computing infrastructure is constantly evolving
    - GRID middleware, cloud computing, storage systems, networking...
  - ➡ increasing integrated luminosity, trigger rates and event sizes
    - ATLAS Production System and Data Management needs to scale
    - GRID luminosity for simulation is becoming rapidly a factor
  - ➡ reconstruction needs to cope with even higher levels of event pileup

Not Only SQL



- upgrade on the fly, while experiment is operating
- industry may move to new technologies
  - ➡ many-core architectures may replace present X86 boxes (*a la* Intel MIC)
  - ➡ need to be prepared to adapt or re-implement large parts of framework as well as offline (and high level trigger) software chain
- part of Phase-2 Letter of Intent


global access/data federation

Summary of ALTAS Upgrade Program

- preserve excellent detector performance to take full benefit of increasing luminosity to fully explore the ATLAS physics potential
  - ➡ adapt and upgrade detector, electronics, TDAQ and offline computing to match challenges ahead
- Phase-0: preparation advancing well
  - ➡ IBL approaches construction phase
- Phase-1: Letter of Intent
  - ➡ various upgrades to cope with luminosities up to $3{\cdot}10^{34}\ cm^{-2}s^{-1}$
  - ➡ next year(s) to prepare TDRs
- Phase-2: ensure ATLAS operation until the end of the next decade for a total of 3000 fb^{-1}
  - ➡ LoI in preparation

BACKUPS…

10 year plan (not yet approved)

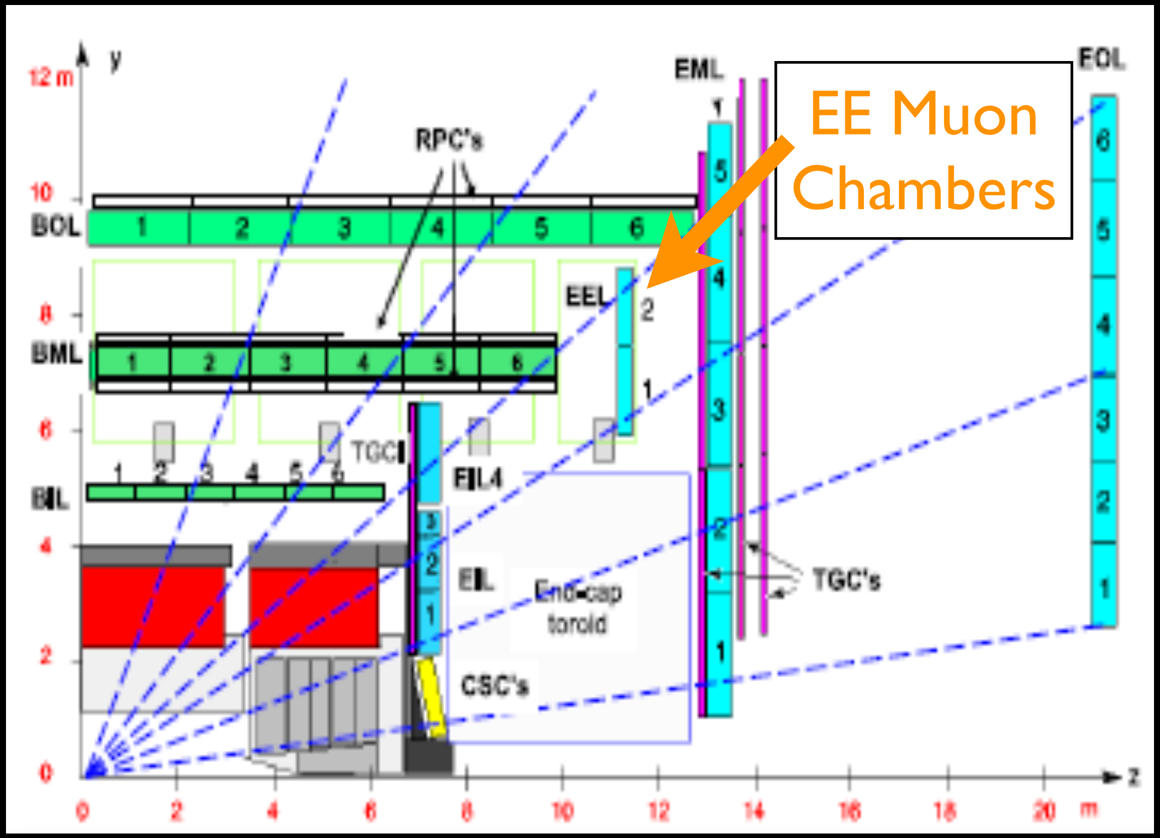
	J	F	M	A	M	J	J	A	S	O	N	D
2011	7 TeV	1	2	3	4	5	6	7	8	9	IONS	
2012	8 TeV		1	2	3	4	5	6	7	8	IONS	
2013	LS1 - SPLICE CONSOLIDATION											
2014									RECOM	RECOM	1	2
2015	13 TeV 1	2	3	4	5	6	7	8	9	10	IONS	
2016	14 TeV	1	2	3	4	5	6	7	8	9	IONS	
2017		1	2	3	4	5	6	7	8	9	IONS	
2018	LS2											
2019		1	2	3	4	5	6	7	8	9	IONS	
2020		1	2	3	4	5	6	7	8	9	IONS	
2021		1	2	3	4	5	6	7	8	9	IONS	
2022	HL-LHC upgrade											

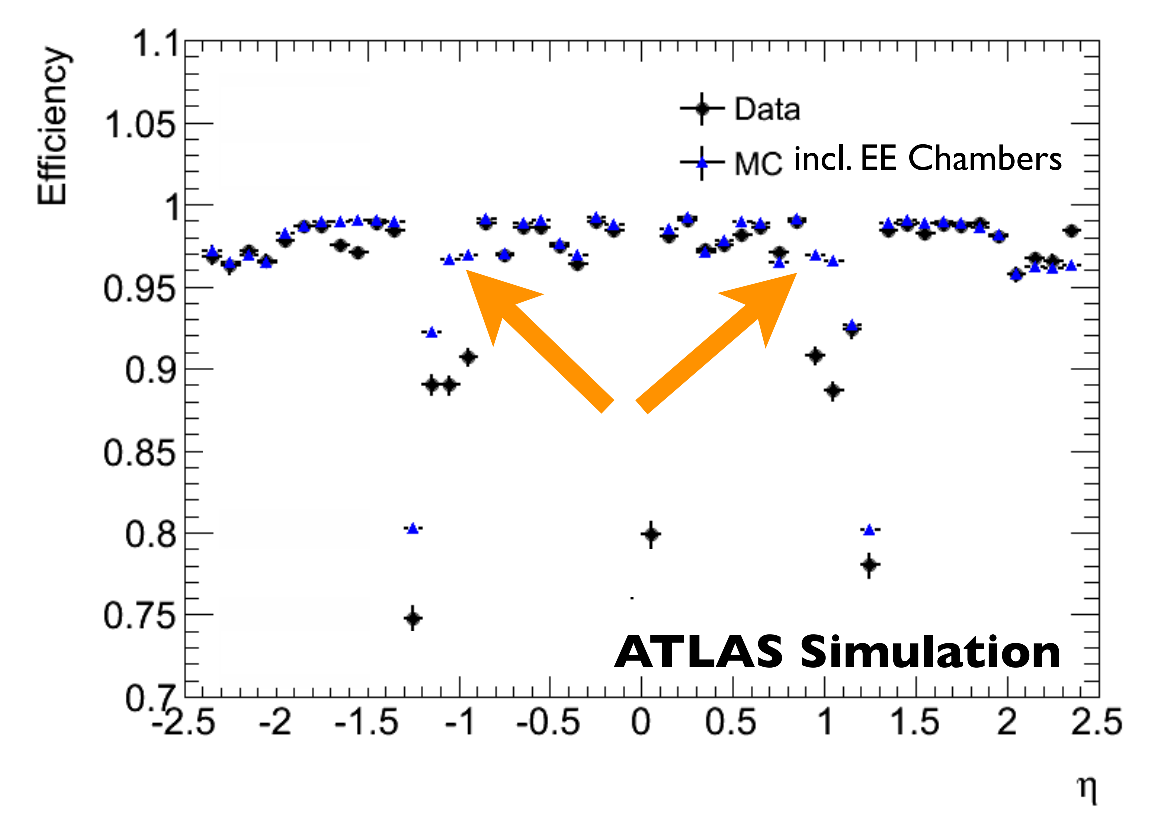
Technical stop or shutdown
Proton physics
Ion Physics
Recommissioning

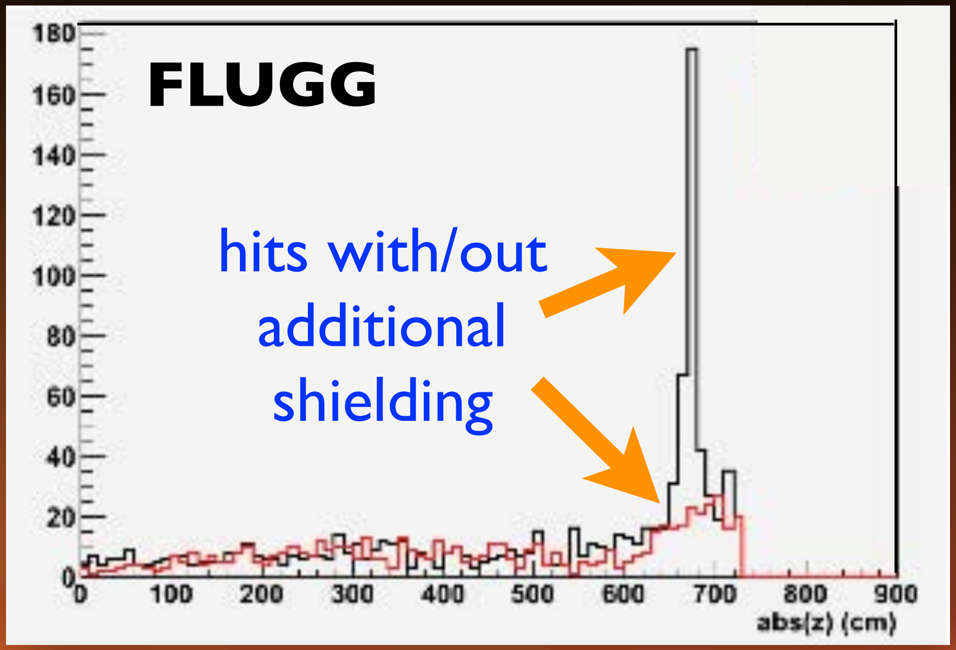
Mike Lamont (CERN BE-OP) 21.5.2012 at CMS Upgrade week

Improve Muon Spectrometer Coverage

- Endcap Extension (EE) Chambers
  - ➡ improve coverage in 1.0<|η|<1.3
  - ➡ will install missing 52 chambers (out of 62)
  - ➡ address low tracking efficiency in the region
- new shielding at 7 *m*
  - ➡ cover gap between forward calorimeter and shielding disk
  - ➡ reduce forward hit occupancy in Muon Small Wheel region







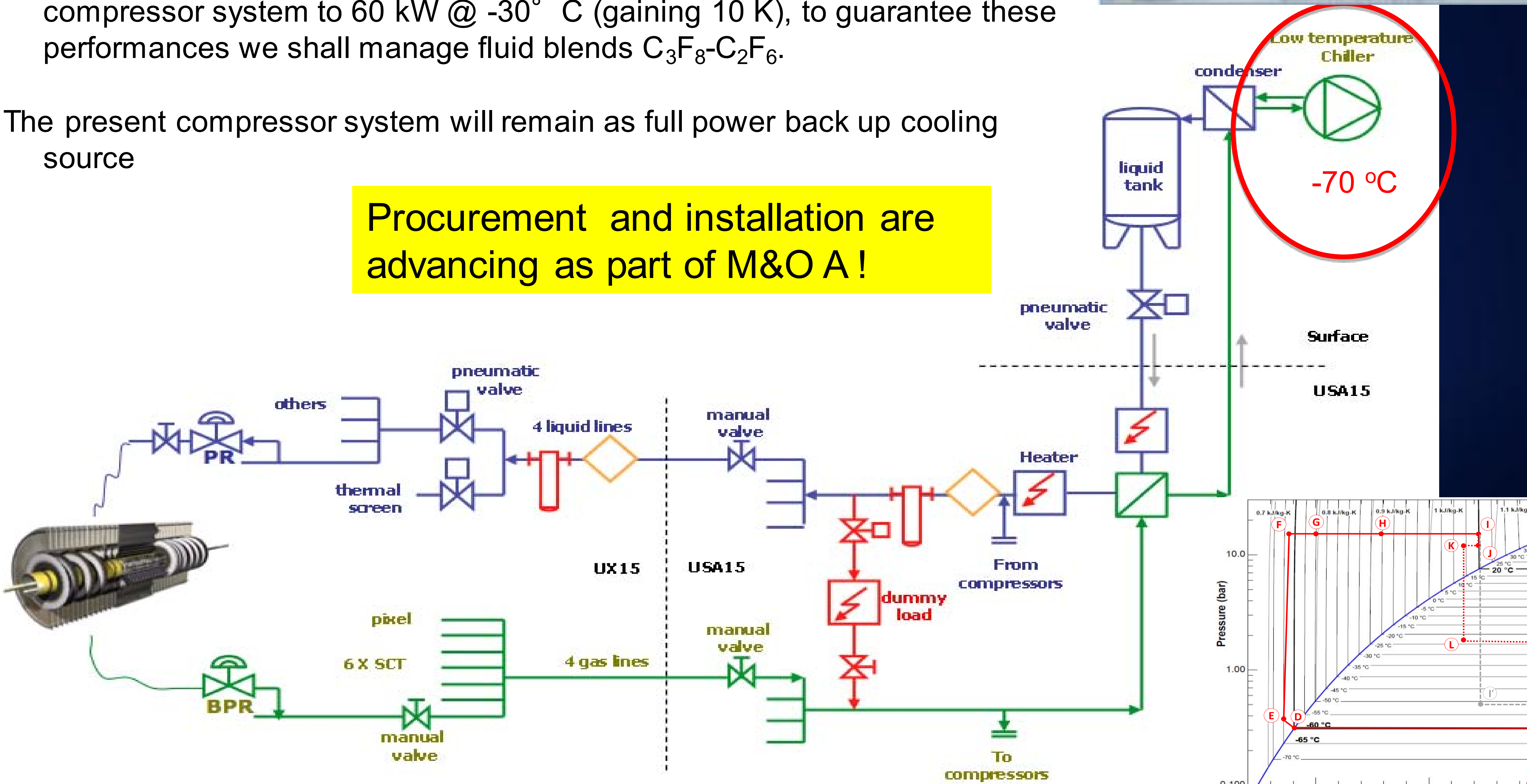
New Evaporative Cooling Plant

The thermosiphon is the **baseline solution** for the consolidation of the ATLAS ID evaporative cooling system.

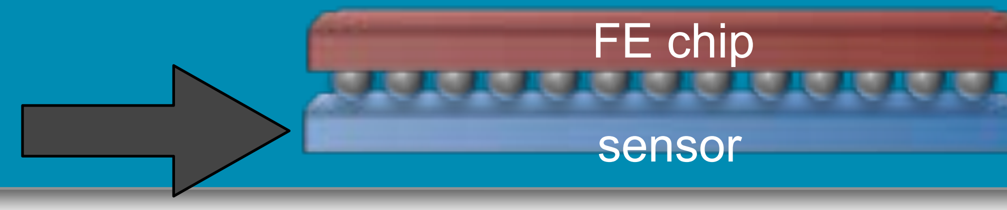
The new cooling system will increase the present performances of the existing compressor system to 60 kW @ -30° C (gaining 10 K), to guarantee these performances we shall manage fluid blends C_3F_8-C_2F_6.

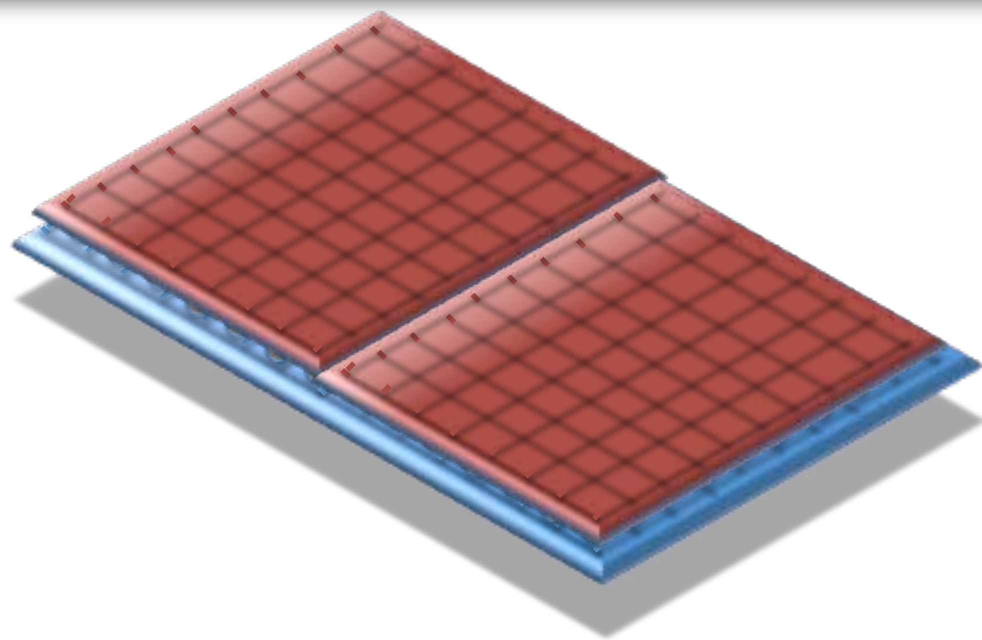
The present compressor system will remain as full power back up cooling source

Procurement and installation are advancing as part of M&O A !

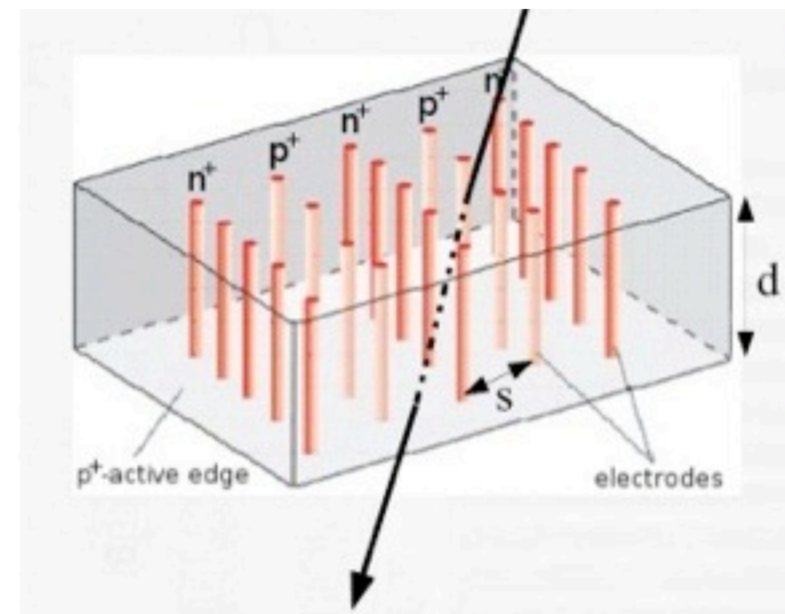


Active Sensor





Hybrid Pixel Chip Assembly:
- sensor and FE chip are produced separately
- connected via bump bonding



Planar Sensor

- "classic" sensor design
- oxygenated n-in-n
- 200µm thick
- Minimize inactive edge by shifting guard-ring underneath pixels (215 µm)
- Radiation hardness proven up to $2.4 \cdot 10^{16}$ p/cm^2
- Problem: HV might need to exceed 1000V

3D Silicon

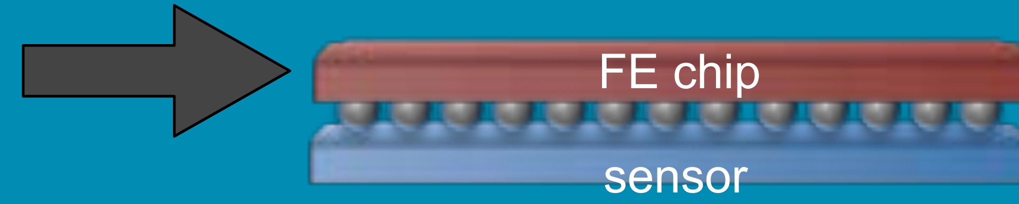
- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage
- Low charge sharing

IBL baseline:

– 75 planar sensors

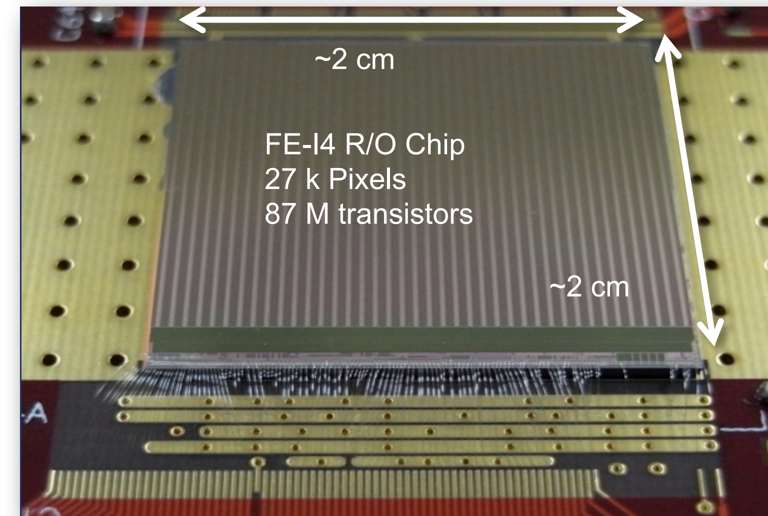
– 25 (3D sensors@large eta)

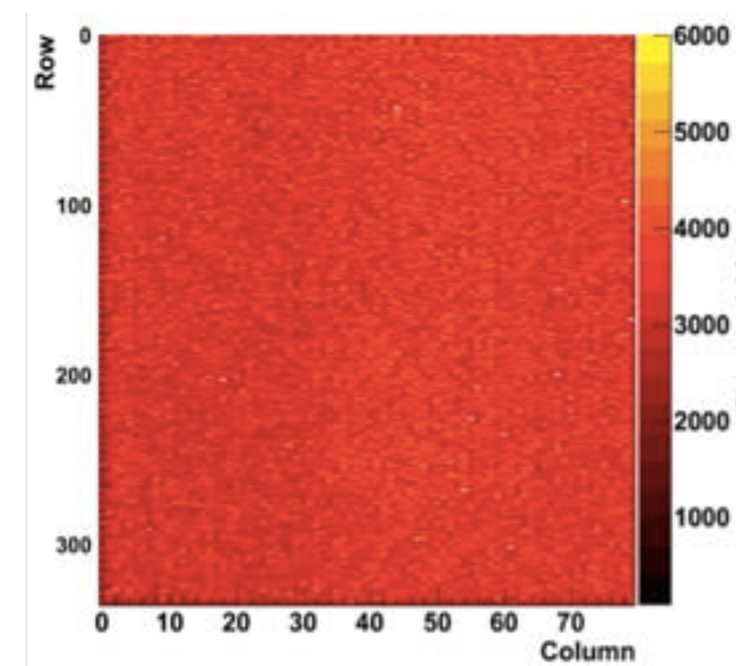
New Front End Chip FE-I4



- Reasons for a new front-end chip
  - Increased radiation hardness (> 250 MRad)
  - Greater fraction of the footprint devoted to pixel array
    - Move the memory inside the array
  - Lower power
    - Don't move the hits around unless triggered
  - Able to take higher hit rate
    - Store the hits locally and distribute the trigger
  - Still able to resolve the hits at higher rate
    - Smaller pixels and faster recovery time
  - No need for extra control chip
    - Significant digital logic blocks on array periphery

=> 19 x 20 mm^2 130 nm CMOS process, based on an array of 80 by 336 pixels (each 50 x 250 μm^2)





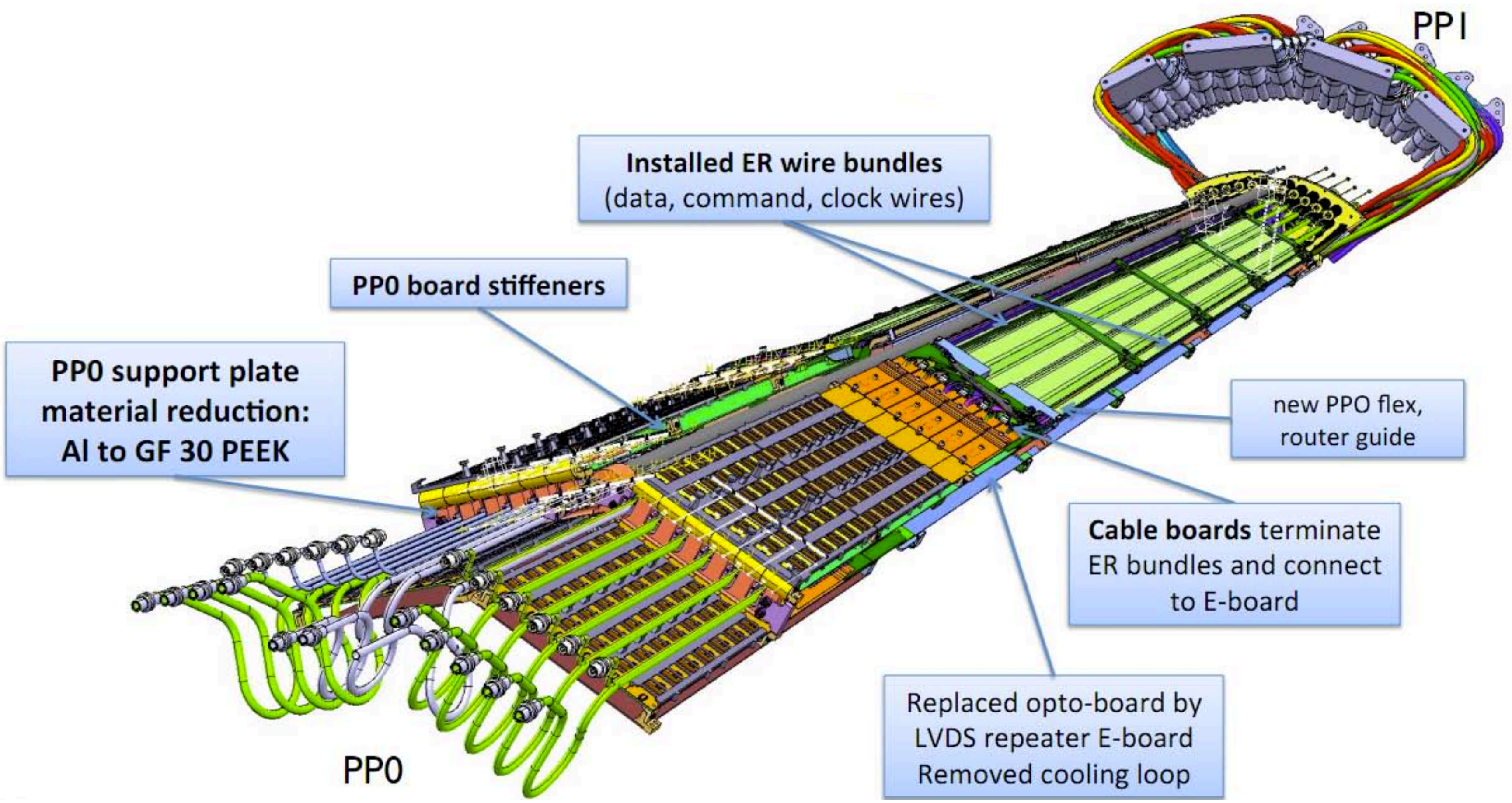
FE-I4B Threshold scan

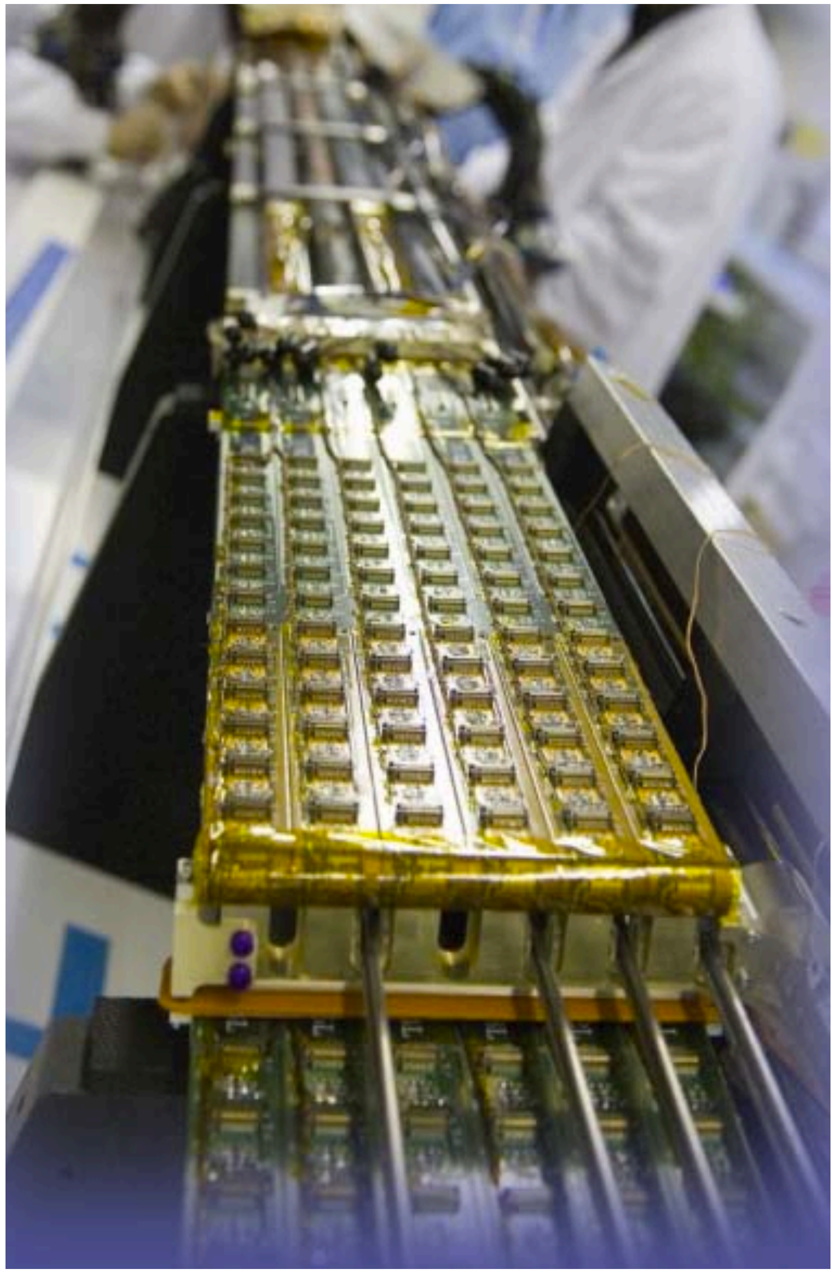
Improved version B was received and used for various tests

New Service Quater Panel

Be ready to take the final decision if to extract and repair or not the pixel detector on the surface during 2012 (first half)

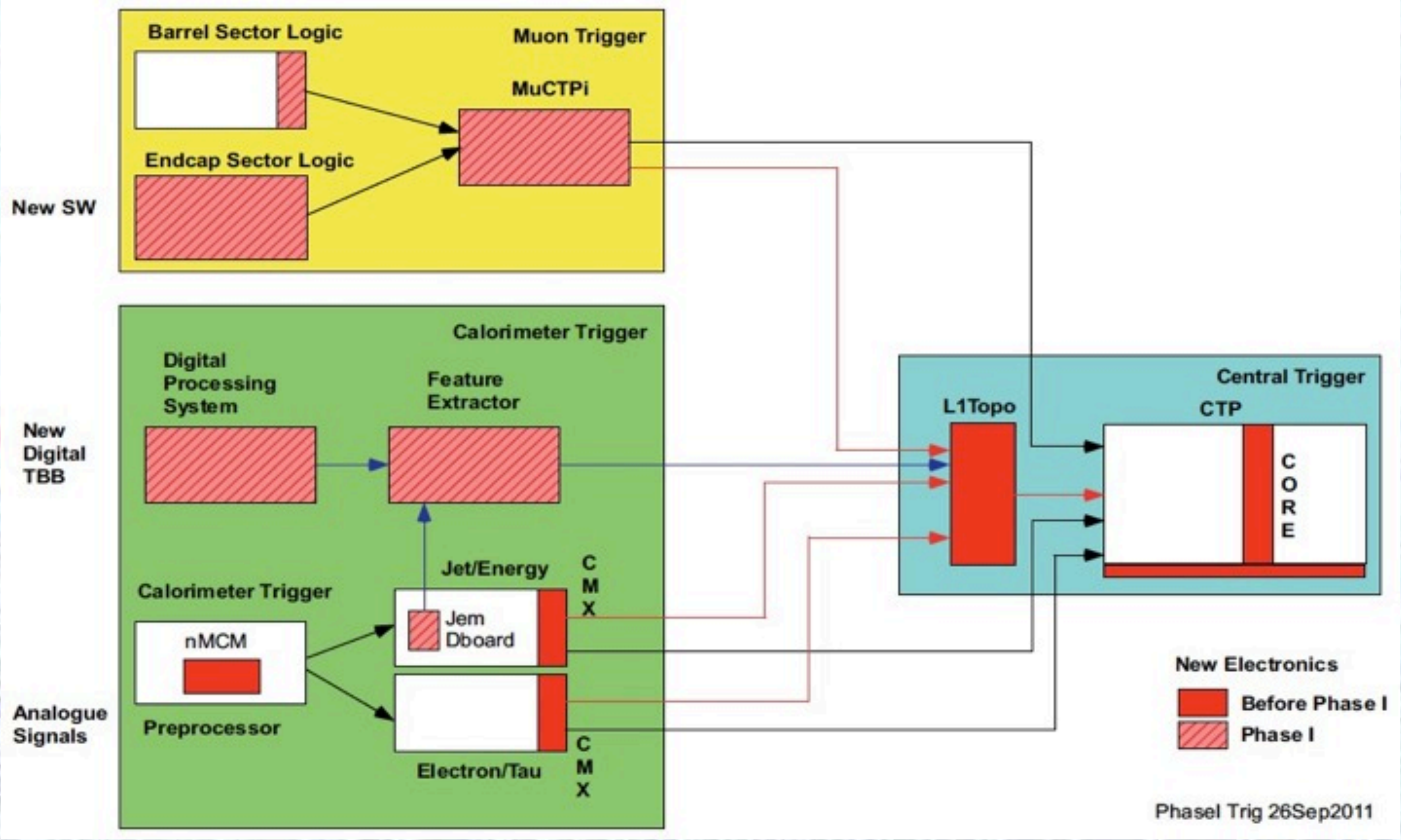
- New service layout for all pixel service (nSQP)
- Redundant and safer location for fibers transmitters
- Doubling of the readout bandwidth in view of Phase 1 upgrade
- **Diamond Beam Monitor attached to nSQP**
  - Uses Diamond Si detectors produced for IBL trials
  - Will provide very fast monitoring of beam in high rate environment



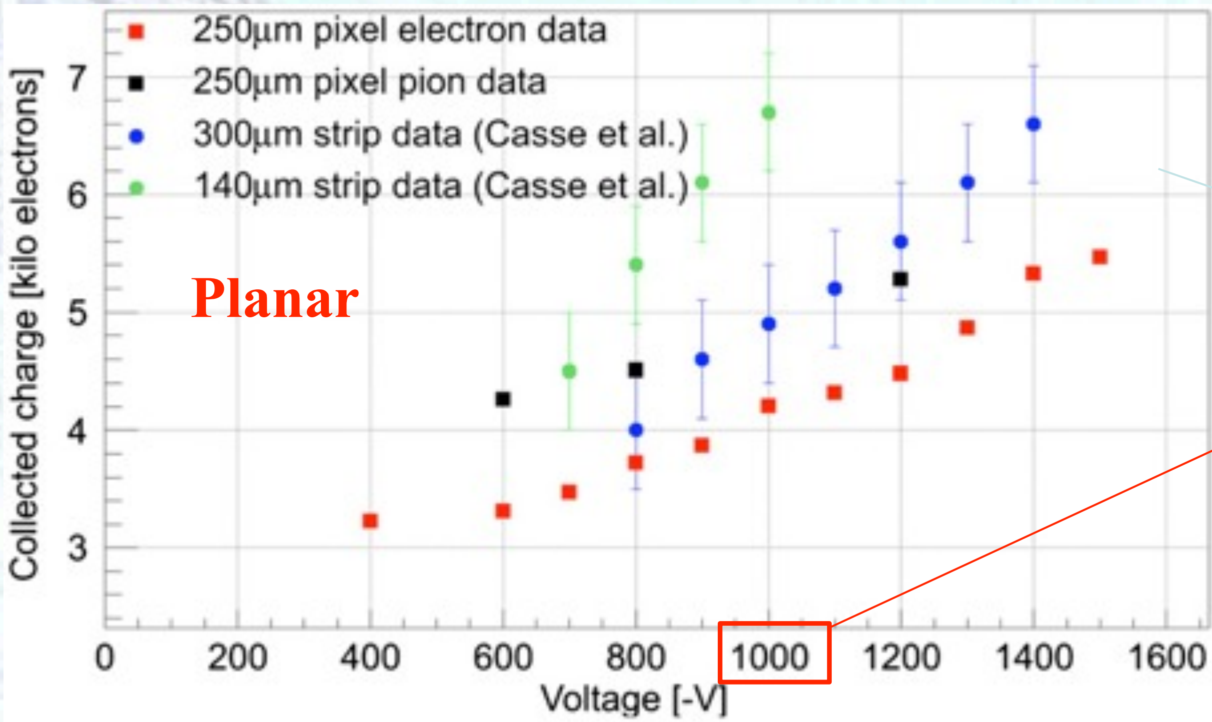


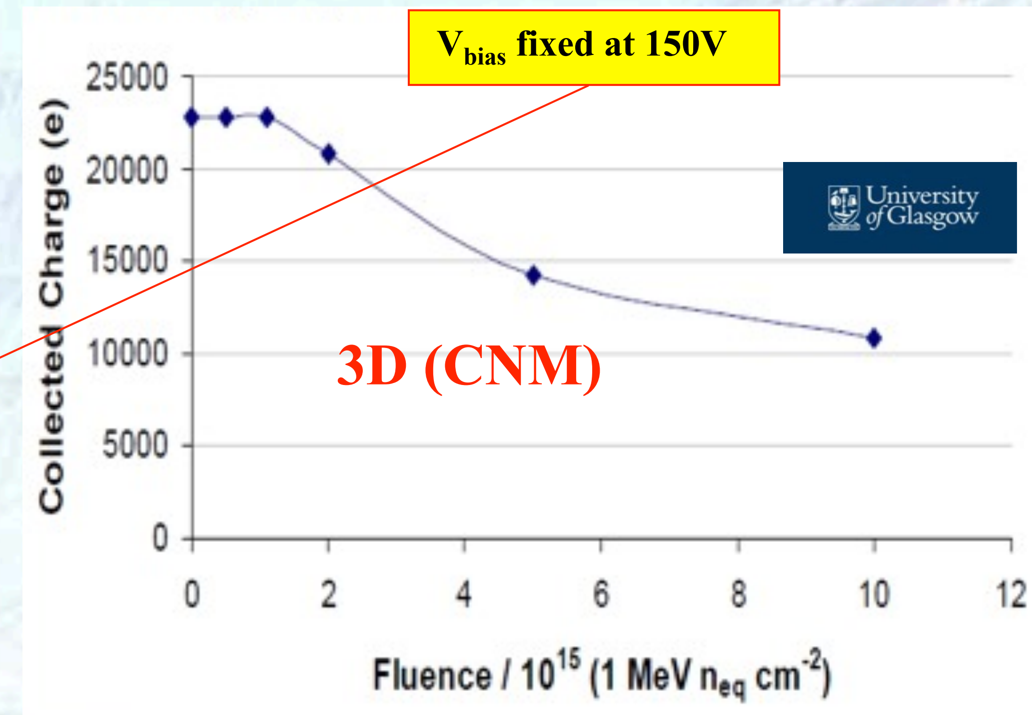
Phase 1: Trigger & DAQ Upgrades

- Incorporate Muon Small Wheels, L1Calo higher granularity, FTK
- L1 (including topological trigger) -> FTK -> L2 & EF
  - Greater integration of Level-2 and Event Filter selections + Event Builder



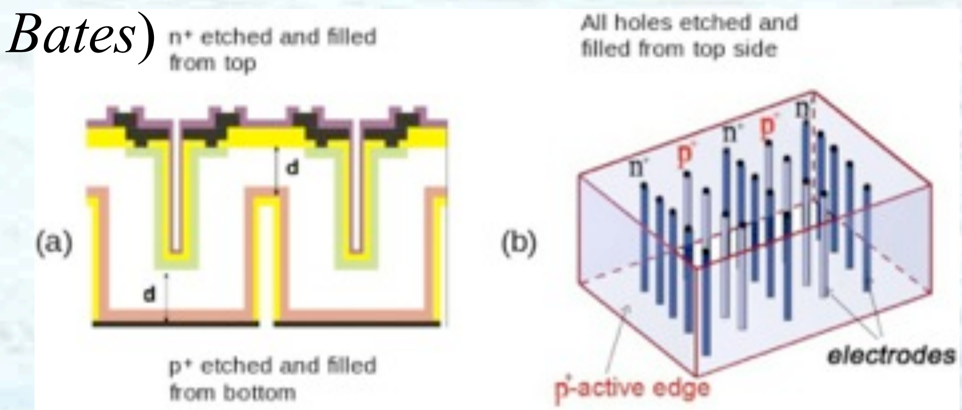
$3000 fb^{-1}$: Inner Pixel Charge Collection



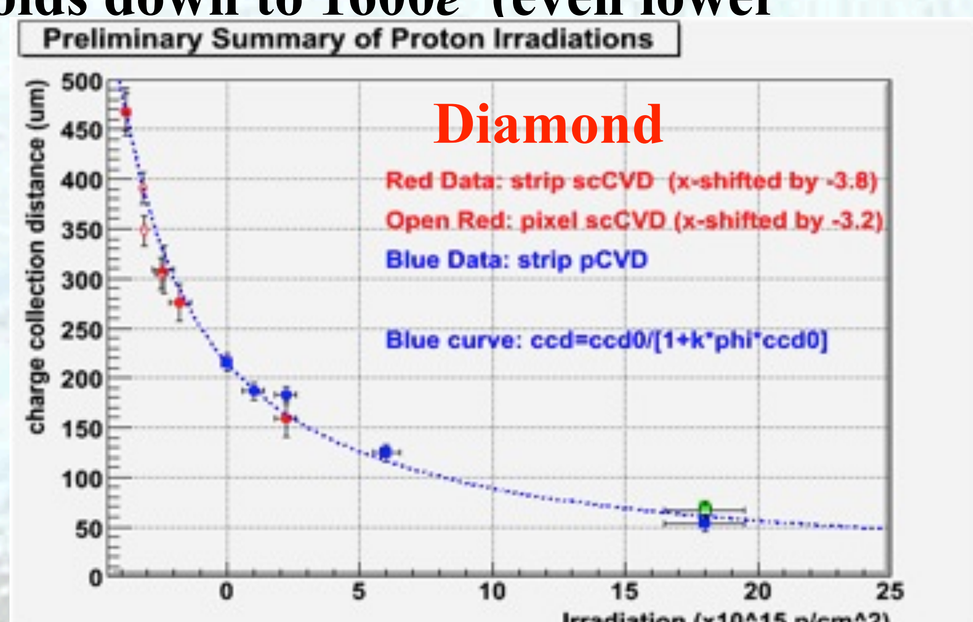


p-type (n-in-p) and n-in-n pixel and miniature strip planar silicon detectors irradiated to HL-LHC inner layer doses of $2\times10^{16} n_{eq} cm^{-2}$ (*D. Muenstermann*)

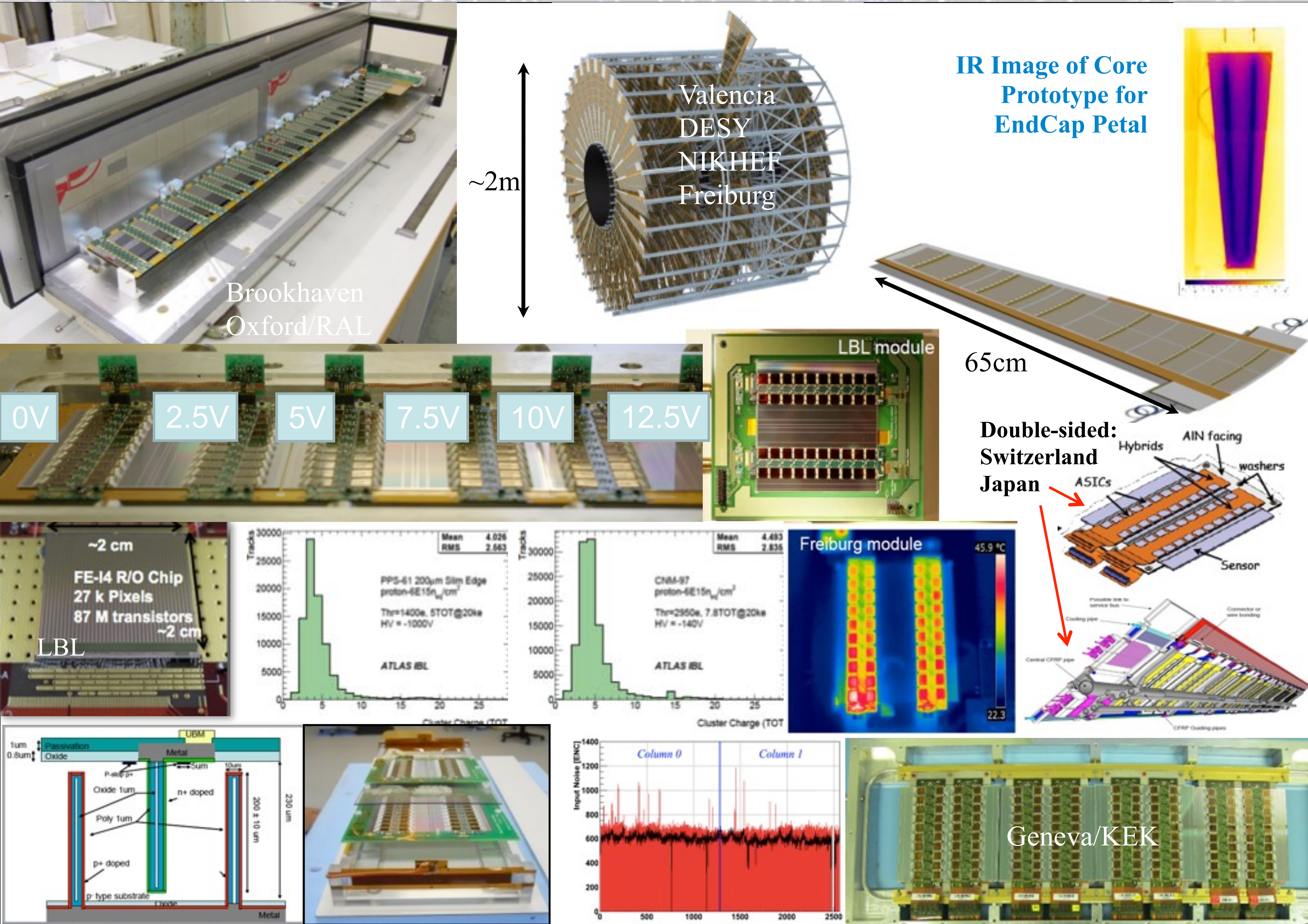
3D strip read-out detector signal vs dose (*R. Bates*)



FE-I4 thresholds down to 1600*e* (even lower for diamond)



Diamond detector charge collection distance vs dose (*H. Kagan*)

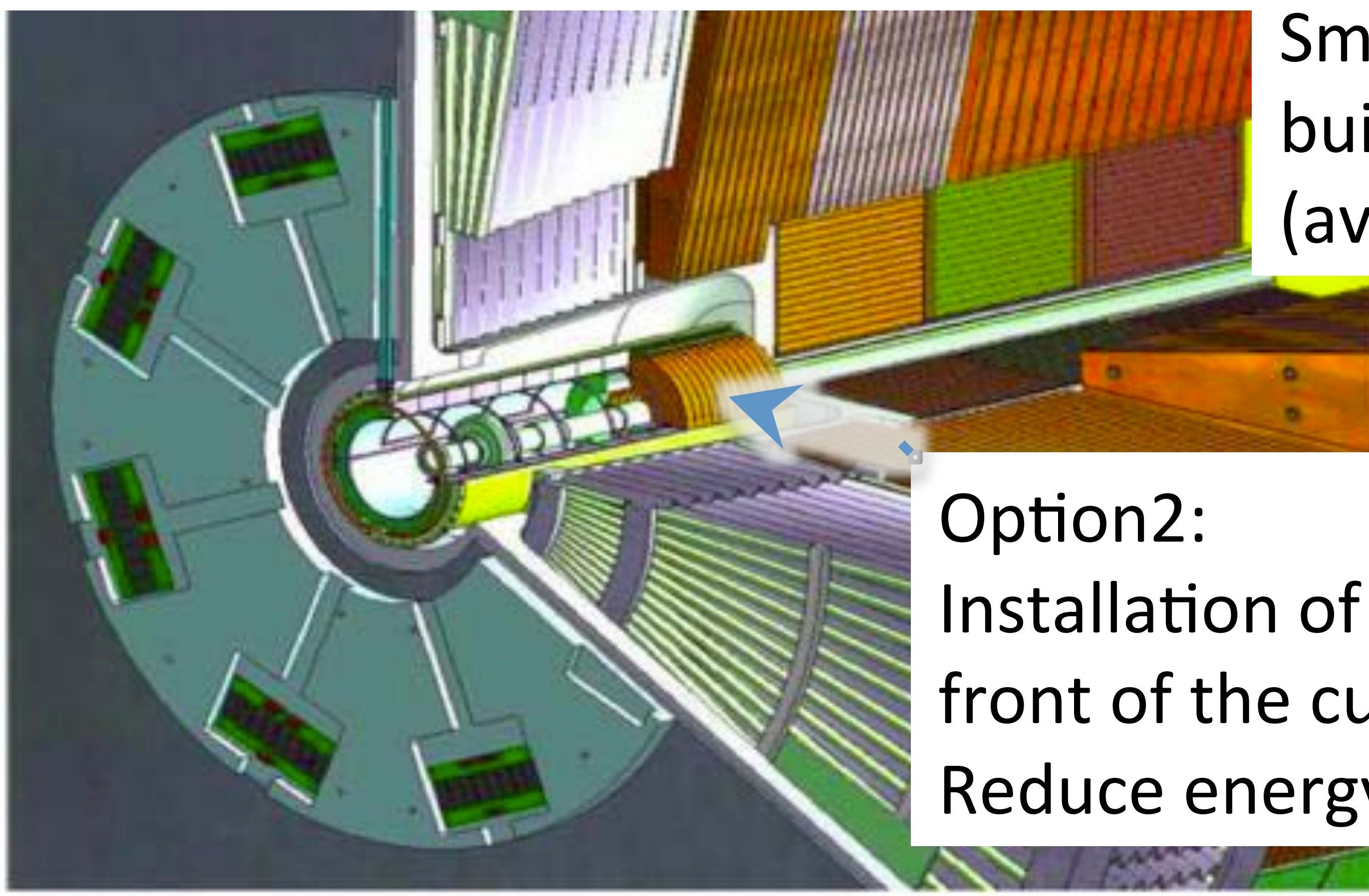

Brookhaven
Oxford/RAL
~2m
Valencia
DESY
NIKHEF
Freiburg
IR Image of Core
Prototype for
EndCap Petal
65cm
0V
2.5V
5V
7.5V
10V
12.5V
LBL module
Double-sided:
Switzerland
Japan
Hybrids
AlN facing
washers
ASICs
Sensor
~2 cm
FE-I4 R/O Chip
27 k Pixels
87 M transistors
~2 cm
LBL
PPS-61 200µm Slim Edge
ATLAS IBL
CNM-97
ATLAS IBL
Cluster Charge (TOT)
Freiburg module
45.9 °C
22.3
Passivation
Oxide
Metal
UBM
Oxide 1um
n+ doped
Poly 1um
p+ doped
p- type substrate
Column 0
Column 1
Input Noise [ENC]
Strip
Geneva/KEK
CNM Barcelona
Liverpool

Phase 2 Upgrade 2022-23 Run 2023-3x => 3000fb^{-1} @ 14 TeV

Phase 2: Calorimeters

- EM LAr Barrel & Tile Calorimeter will work fine: no upgrade.
- Full upgrade of FE and BE electronics (radiation, lifetime, performance …)
  - Both LAr and Tiles
- Hadronic EndCap electronics designed for 1000 fb^{-1} – possible replacement
- Forward Calorimeter @ HL-LHC instantaneous luminosity: overheating / ion build-up / HV drop / signal loss...

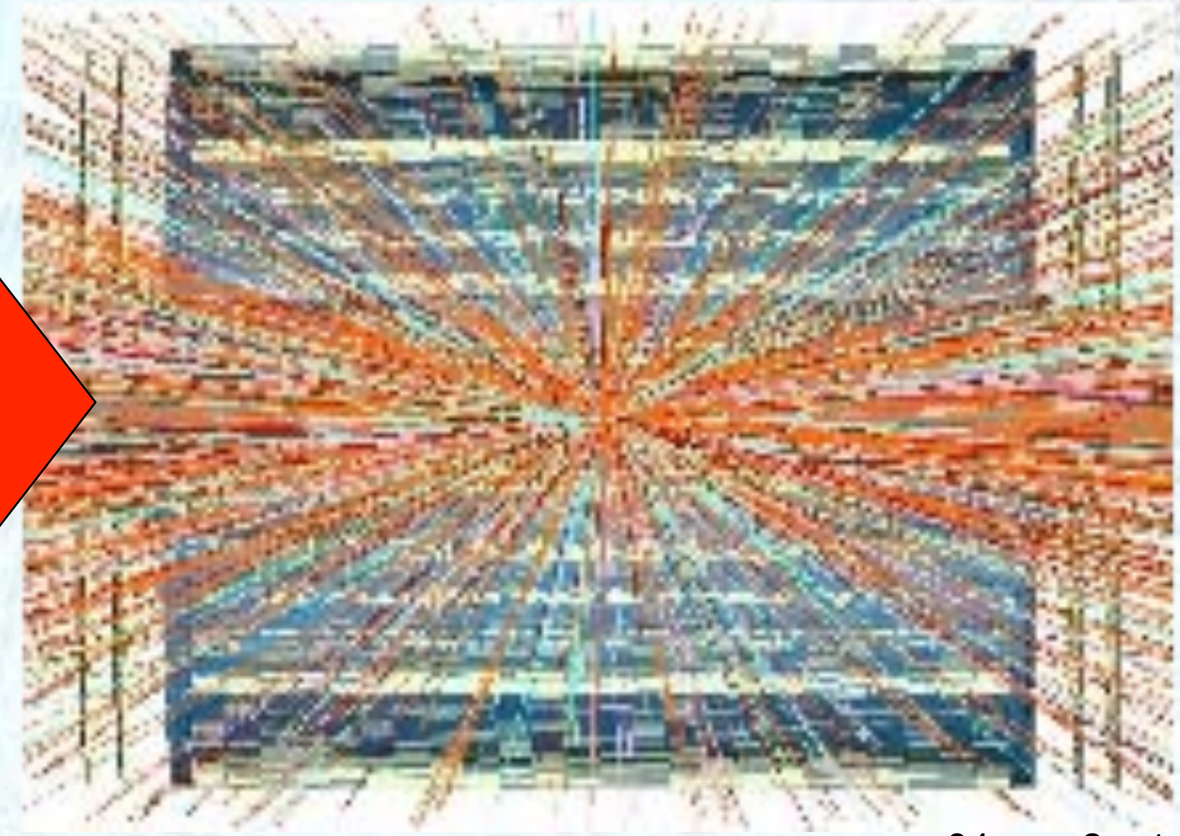
Option1:
Complete replacement of the FCal
Smaller LAr gaps (to reduce ion build-up/HV drop) + better cooling (avoid overheating)



Option2:
Installation of a small calorimeter in front of the current FCal: Mini-FCal => Reduce energy and ionization @ FCal

Radiation Background Simulation

LHC in 2011: $1\times10^{33}cm^{-2}s^{-1}$



HL-LHC: $5\times10^{34}cm^{-2}s^{-1}$

At inner pixel radii - target survival to 2-3×10^{16} n_{eq}/cm^2

Numbers obtained 9/10/09 (corresponding to new layout) assuming 3000fb-1 and 84.5mb

Strip barrel 1 (SS)	(r=38cm; z=0cm)	4.4x10^14
	(r=38cm; z=117cm)	4.9x10^14
Strip barrel 4 (LS)	(r=74.3cm; z=0.0cm)	1.6x10^14
	(r=74.3cm; z=117cm)	1.8x10^14
Strip Disc 1 (z=137.1, Rinner=33.6)		6.0x10^14
Strip Disc 2 (z=147.6, Rinner=33.6)		6.2x10^14
Strip Disc 3 (z=174.4, Rinner=33.6)		5.8x10^14
Strip Disc 4 (z=214.1, Rinner=33.6)		6.1x10^14
Strip Disc 5 (z=279.1, Rinner=44.4)		5.8x10^14
Strip Disc 5 (z=279.1, Rinner=54.1)		4.4x10^14
Strip Disc 5 (z=279.1, Rinner=61.7)		3.9x10^14
new		
Strip Disc 5 (z=279.1, Rinner=73.6)		3.0x10^14
Strip Disc 5 (z=279.1, Rinner=84.9)		2.7x10^14

For strips 3000fb^{-1} ×2 implies survival required up to ~1.3×10^{15} n_{eq}/cm^2

1 MeV neutron eq fluence