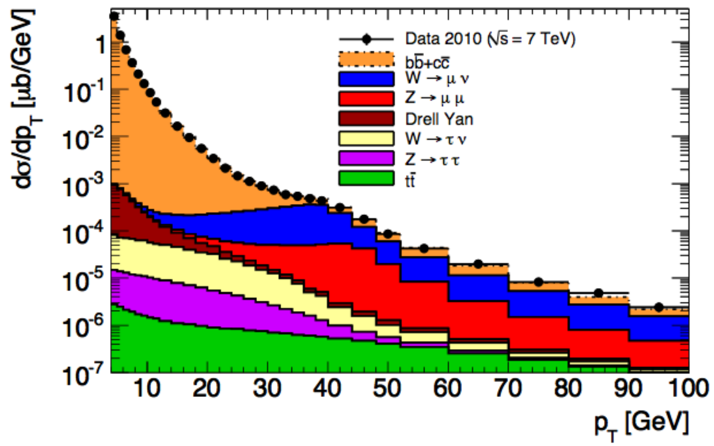
LPNHE Seminar
Paris, 15/03/2012

Understanding ATLAS plans for future luminosities

F.Pastore (RHUL)

F.Pastore Curriculum Vitae

- Ph. Diploma, Un. Rome "La Sapienza" (1998)
- PhD, Un. Of Genova (2001)
- Research Assistant in Rome (2001-2008)
- CERN Fellow (2008-2011)
- Research Assistant in RHUL (2011)



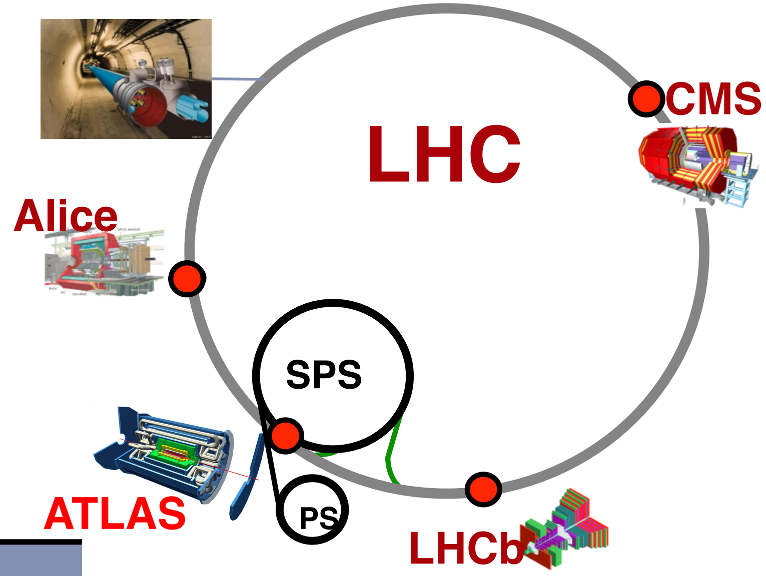
- Experience in BaBar (1996-2001)
  - Drift Chamber: Performance studies for gas choice
  - Muon Spectrometer (RPC): detector optimization and maintenance, online system development, reconstruction
  - Study of a decay channel of the B meson into CP eigenstate for angle beta measurement
- Work in ATLAS (2002-2012)
  - From prototypes to final project, installation and commissioning of the First-level trigger for muons in the Barrel (RPC technology) – Rome
    - 2002-2007: from the prototypes towards the in-situ commissioning
      - Boards (on and off detector): development of device communication, configuration, functional tests
      - Development of: online system, data quality monitor, calibration tools for timing alignment
      - Data analysis for certifications (cosmic runs)
    - 2008: Coordination of the activities for in-situ commissioning with cosmic-rays
      - Installation, connections, calibrations with cosmic rays
      - Ensure dataflow and rate stability
    - 2009-2011: Coordination of the commissioning with collisions and performance validation
  - Upgrade studies for the ATLAS trigger upgrade (2011)
    - First-level trigger with tracking: a possible upgrade for Phase-2
    - Feasibility studies of High level-trigger running on single node (for Phase-0)

Outline of the seminar

- Why LHC upgrade? Physics potentials
- Machine upgrade into steps
- Expected detector performance and experimental challenges: ATLAS upgrade
- Main accent on the trigger upgrade, driving the changes

The Large Hadron Collider and Super LHC

- A discovery machine with possibility of steady increase of luminosity → large discovery range
- Spectacular numbers in 2011:
  - Bunches of O(10^{11}) particles each
  - Superconducting magnets cooled to 1.9 K with 140 tons of liquid He (magnetic field ~ 8.4 T)
  - Energy of one beam = 362 MJ (300 x Tevatron)

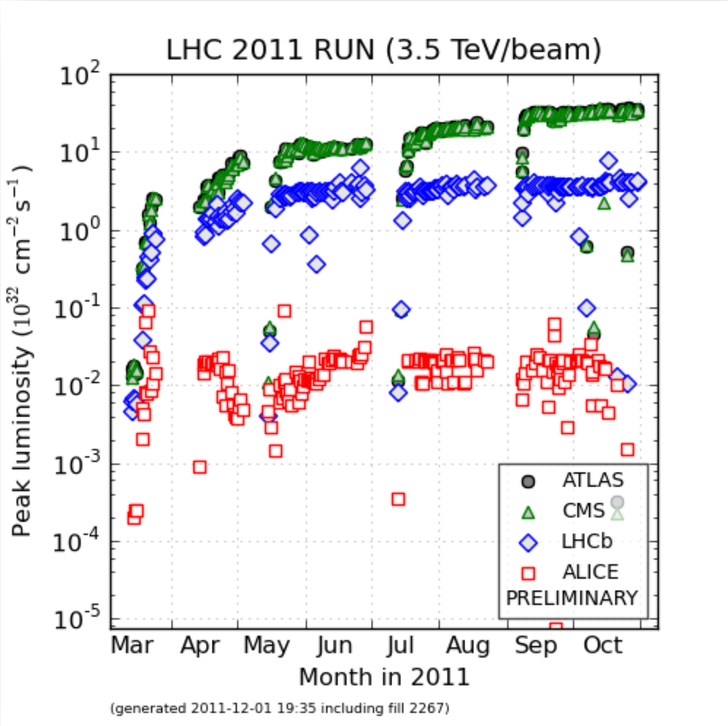


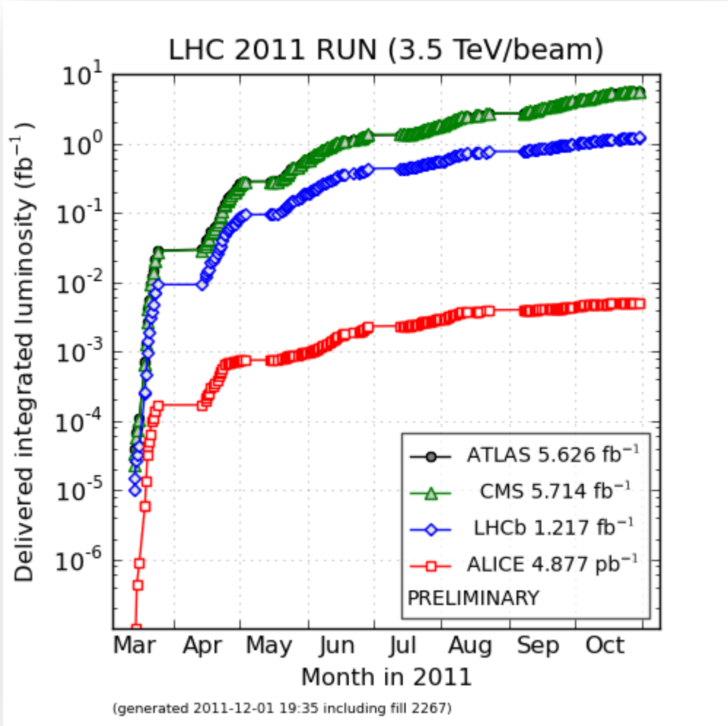
colliders		Energy (GeV)	BC time	collision rate	Design luminosity (cm^{-2} s^{-1})
LEP	e+e-	200	22 ms	45 kHz	7×10^{31}
Tevatron	ppbar	2000	396/132 ns	2.5/7.6 MHz	4×10^{32}
Nominal LHC	pp	14000	25 ns	40 MHz	10^{34}
2011 LHC	pp	7000	50 ns	40 MHz	3×10^{33}
HL-LHC	pp	14000	25 ns	40 MHz	10^{35}

Every 3 years a 1 year long (at least) shutdown needed for major component upgrades

LHC 2011 luminosity

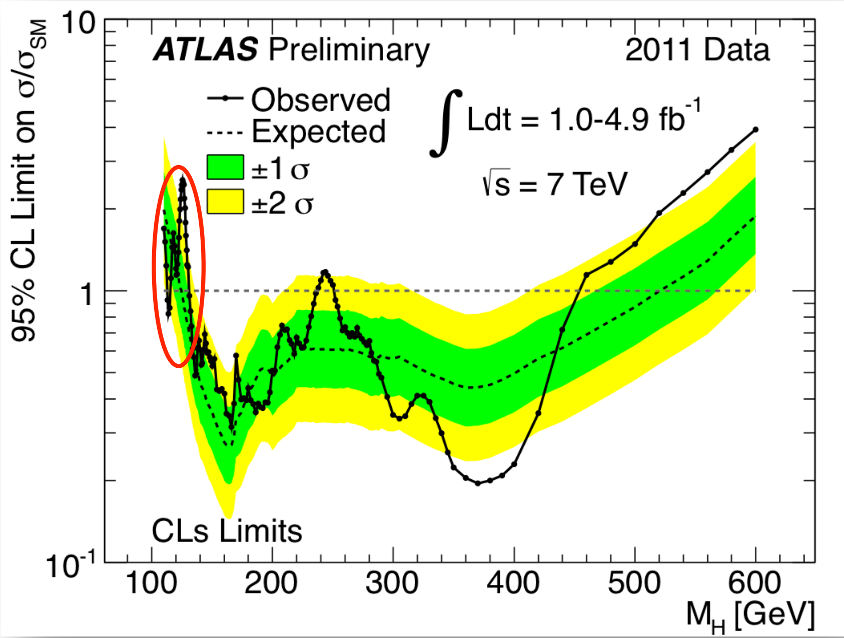
- Peak luminosity increased almost linearly over the year – now near the limit
  - Improving bunch intensity and squeeze beams beyond design limits
  - Doubling the expectations up to 3.3/nb/s
- Pile-up reaches average peak 16 interaction/collision, much more than the experiments expected
- LHC and the experiments had already been pushed very close to their limits and will require some major work

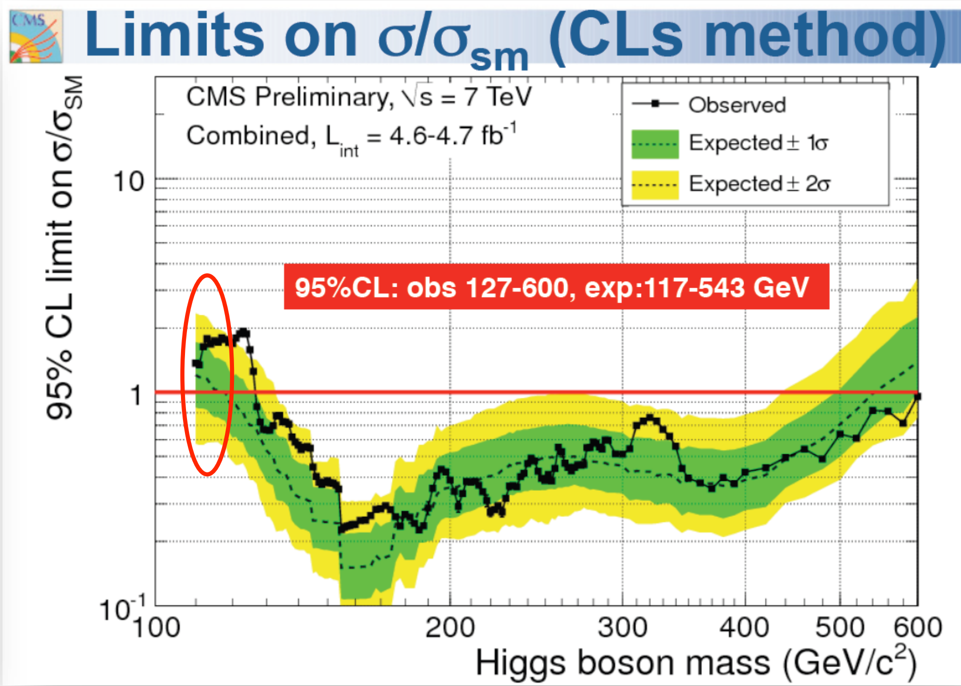




Physics highlights

Latest results from Moriond 2012



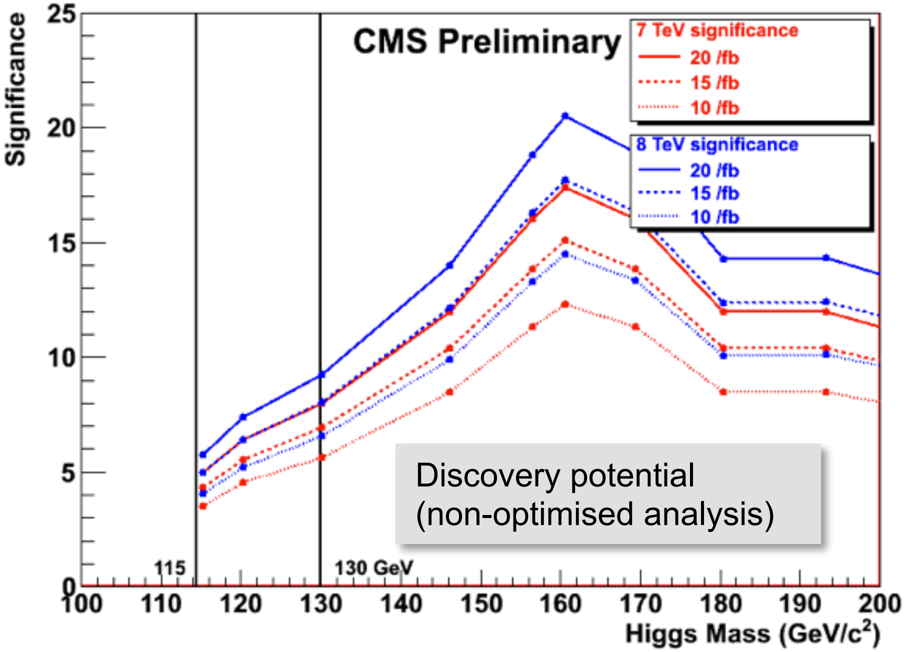


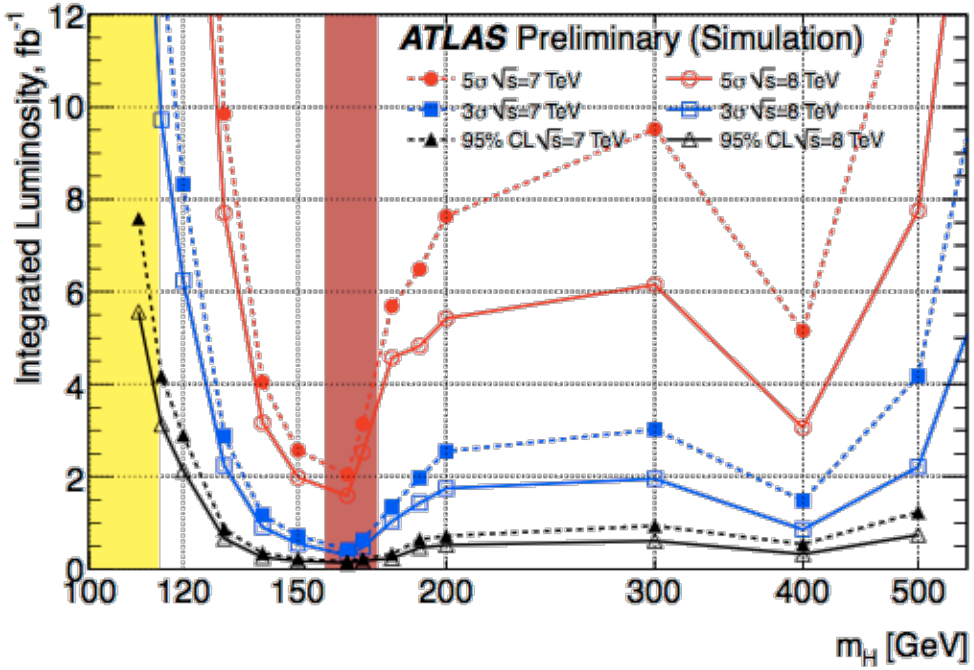
- Due to high pile-up, the performance of missing ET measurements (resolution) is worsened, mainly affecting the Higgs decay mode to WW*: crucial for mass range 120-140 GeV

2012 target luminosity for p-p runs

Minimal result for 2012:

- Either discovery of Higgs or exclusion at 95% CL down to 115 GeV
- 5 σ discovery per experiment requires > 15 fb^{-1}
  - Difficult to tell precisely as we are at the edge of experimental sensitivity





- Ideal target is ~20 fb^{-1} before long shutdown in 2013
  - To accommodate possible inefficiencies due to high pileup

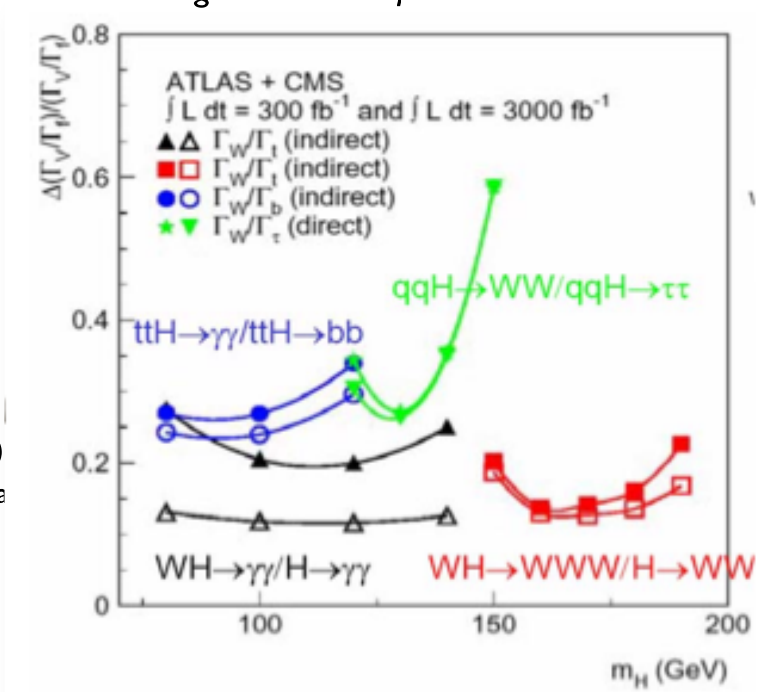
SM Higgs search with increasing Luminosity

- Increased statistics allows discover/exclude SM Higgs
  - Isolated **leptons** with 20 GeV pT for the W W* decay

- If Higgs exists:
  - 300 fb^{-1} : observe all H decay modes
  - 3000 fb^{-1} : precision measurements of H properties
    - Mass 0.1%, width and rates (sigma x BR) < 10%
    - Couplings (WWH, ZZH, ttH) 10-20% →5-10%
      - WH→ $\tau\tau$ /bb/WW*/ZZ*, with lepton tagging
        - Lepton trigger and τ / b **reconstruction are crucial**

- If Higgs is excluded:
  - Boson-boson strong interactions in the EWSB?
    - VB scattering enhanced by high-mass resonances at TeV scale (~fb)
      - But in the non-resonant case, lots of data needed to have convincing signa
    - Most likely need another collider to full explore strong dynamics
    - Identified by two high-pt tag jets in the forward region
      - Full coverage in the forward direction
      - Leptons, **forward jet tag** and central jet veto to suppress background

*Expected **uncertainties** on the measured ratios of the Higgs widths to final states involving bosons and fermions*



hep-ph/0204087 from 2002

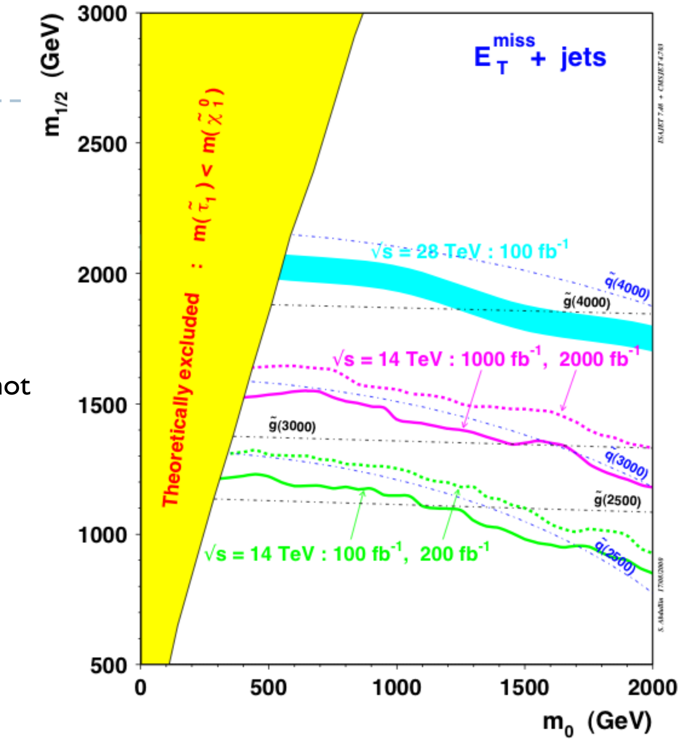
Higgs search through tagging of leptons, b/tau, forward jets

HL-LHC physics potential

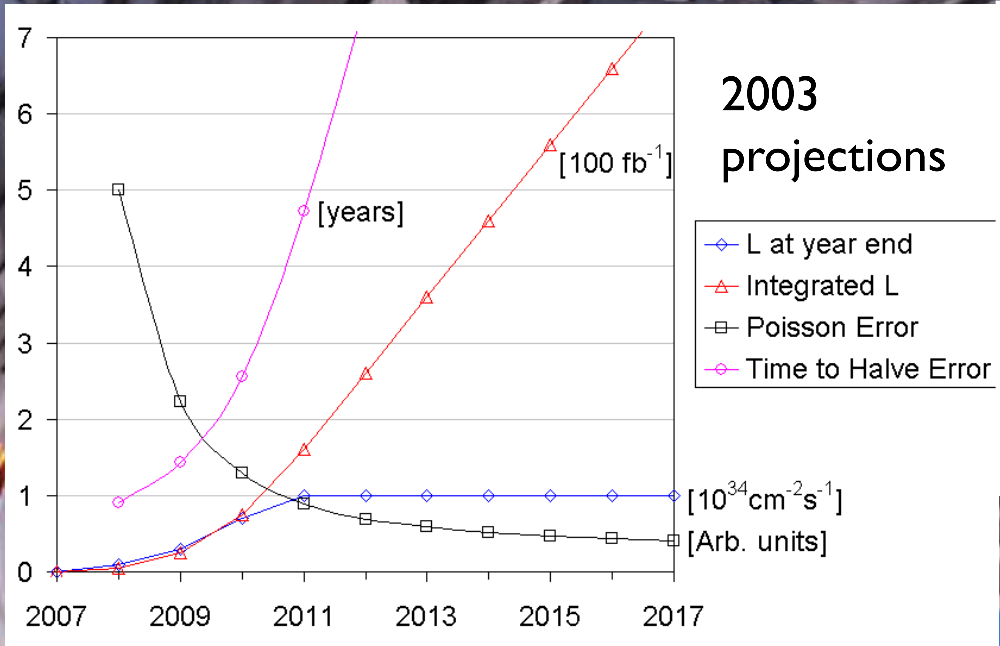
- The Higgs discovery is just the tip of the iceberg
- With 3000 fb^{-1}, we can enlarge the scenario, known with large uncertainties (in some cases extrapolation)
- SM physics:
  - Not primary motivation
    - Ultimate precision ($\Delta M_W \sim 15$MeV, $\Delta M_{top} \sim 1.5$GeV) dominated by systematics, not easily reducible at hadron colliders
  - QCD studies: increase $\{x, Q^2\}$ reach from higher $\sqrt{S}$, L
  - Triple Gauge Couplings:
    - Anomalous contributions to WWγ and WWZ vertices
- SUSY (exclude or extend the kinematic range)
  - Mass reach up to 2.5 TeV for SUSY q, g (model independent) or other sparticles (model dependent)
  - Precise measurements (masses) to constrain theory parameters <10%
- New gauge bosons: Z', W'
  - Mass reach linear in $\sqrt{S}$ and L: up to 20 TeV with precision 2%
- Compositeness
  - Conclusive evidence of some models (excited quarks), gain ~10%
- Extra-dimensions
  - Mass reach gains 30%

For SUSY and NP models, sensitivity to low pt leptons (~20GeV) and Missing Et is crucial

Expected 5 σ discovery contours in the mSUGRA plane m0 versus m1/2



Channel / particle	LHC 14 TeV, 10^{34}	SLHC 14 TeV, 10^{35}
Jet E_T (TeV)	≈ 2.5	≈ 3
$\tilde{q}, \tilde{g}$ (TeV)	≈ 2.5	≈ 3
W' (TeV)	≈ 6	≈ 7
Z' (TeV)	≈ 4.5	≈ 5.5
q* (TeV)	≈ 6.5	≈ 7.5
Λ comp. (TeV)	≈ 40	≈ 60
Extra-dim. (TeV)	≈ 9	≈ 12
Strong $W_L W_L$ ($\int$Ldt for 5σ)	~ 300 fb^{-1}	> 300 fb^{-1}
TGC (λ_γ)	0.0014	0.0006



① Extending physics potential!

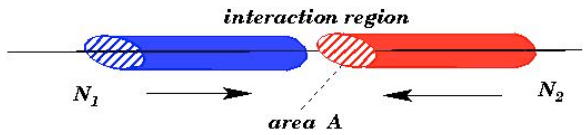
② After few years, statistical error hardly decreases

③ Radiation damage limits IR quadrupoles (~700 fb^{-1}), reached by ~2016

LHC upgrade

How to increase LHC luminosity

$$N = L\sigma$$



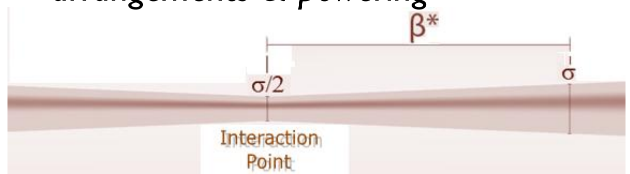
$$L = \frac{kN^2 f}{4\pi\sigma^*_x\sigma^*_y} = \frac{kN^2 f\gamma}{4\pi\,\beta^*\varepsilon}$$

k = number of bunches
N = no. protons per bunch
f = revolution frequency = 11.25 kHz
σ^*_x, σ^*_y = beam sizes at collision point

Depends on injection

- Increase number of bunches (bunch spacing: 50→25 ns)
  - Limited by total current limit (vacuum, RF)
  - With 25 ns emittance is larger
- Increase bunch intensity (quadratical!)
  - Up to beam-beam limit
  - Pile-up increases
- Reduce beam size: small emittances, small β^*
  - Depends on beam optics: need to change quadrupole triplets at IP
- Reduce beam-beam effects: long-range separation

β^* = beam envelope at Interaction Point (IP), determined by magnets arrangements & powering



- Any change of: train length, gap, spacing, emittances, β^*, requires adjustment of the crossing angle

Most parameters are relevant for luminosity as well as beam-beam effects

LHC: Today, Design, Beyond Design

Energy limit at 18 TeV: present magnets technology up to B =10.5 T

	2011 Status	Design	Beyond Design
Beam energy (*TeV*)	3.5 (½ design)	7 (7x Tevatron)	-
Bunch spacing (*ns*)	50 (½ design)	25	-
N of colliding bunches	1331 (~½ design)	2808	-
peak luminosity ($cm^{-2}s^{-1}$)	**3.3 10^{33} (~30% design)**	**10^{34} (30x Tevatron)**	**5 10^{34} (leveled)**
protons/bunch (10^{11})	1.25 (>design)	1.1	1.7- 3.4 (with 50 *ns*)
β^* (*m*)	1 (~½ design)	0.5	0.15

Interventions needed to reach design conditions

LHC can go further → Higher Luminosity

2012: LHC limits

- Not possible to reach design performance today: limits on
  - Beam Energy: joints between s/c magnets limits to E = 3.5 TeV/beam
  - Beam Intensity: collimation limits luminosity to ~5×10^{33} $cm^{-2}s^{-1}$
- The important quantity this year is not the luminosity per se, but the integrated useful luminosity
- While pushing to the limits
  - Single Event Effects due to radiation
  - Unidentified Falling Objects (UFO), fast beam losses

- What LHC can do as it is today at 3.5 TeV:

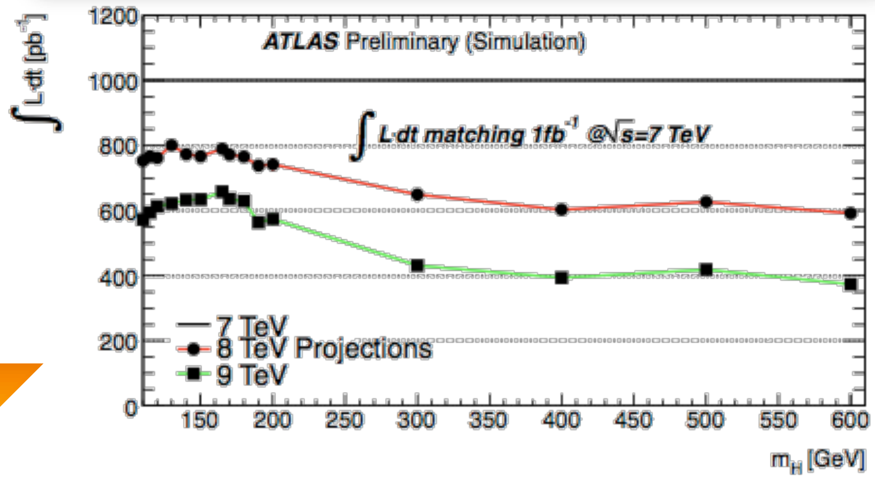
Spacing (ns)	#bunch	Bunch Intensity	Beta* (m)	L (/cm²s)
50	1380	$1.7\ 10^{11}$	1.0	5×10^{33}
25	2808	$1.2\ 10^{11}$	1.0	4×10^{33}

2012 LHC running

From Chamonix 2012

2012

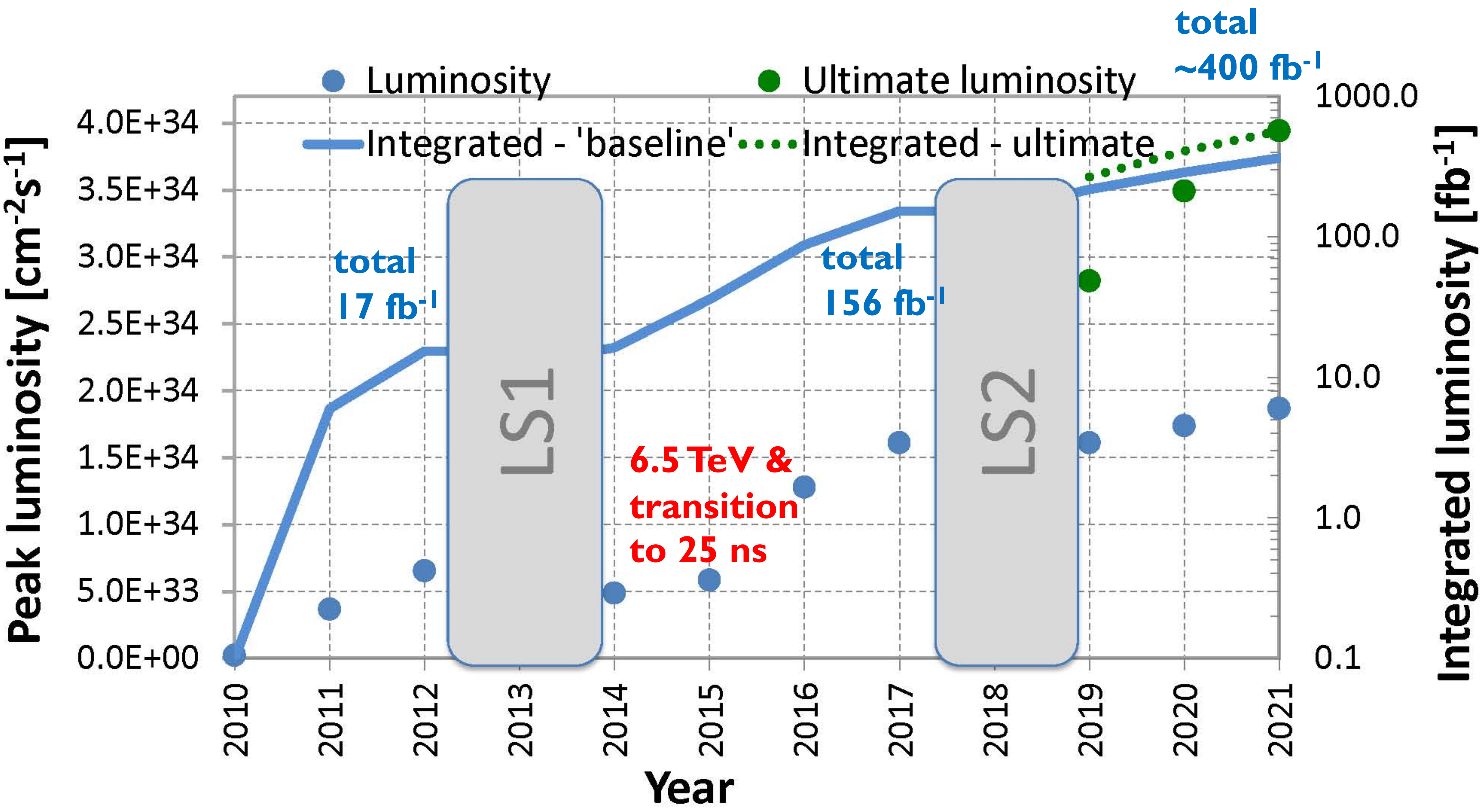
- Top priority: allow ATLAS and CMS independent Higgs discovery/exclusion before the first long shutdown in 2013
  - Required luminosity $>15fb^{-1}$, $5fb^{-1}$ for ICHEP
  - With current upgrade on LHC, this limit can be easily reached
  - If needed for Higgs discovery, the shutdown can be delayed



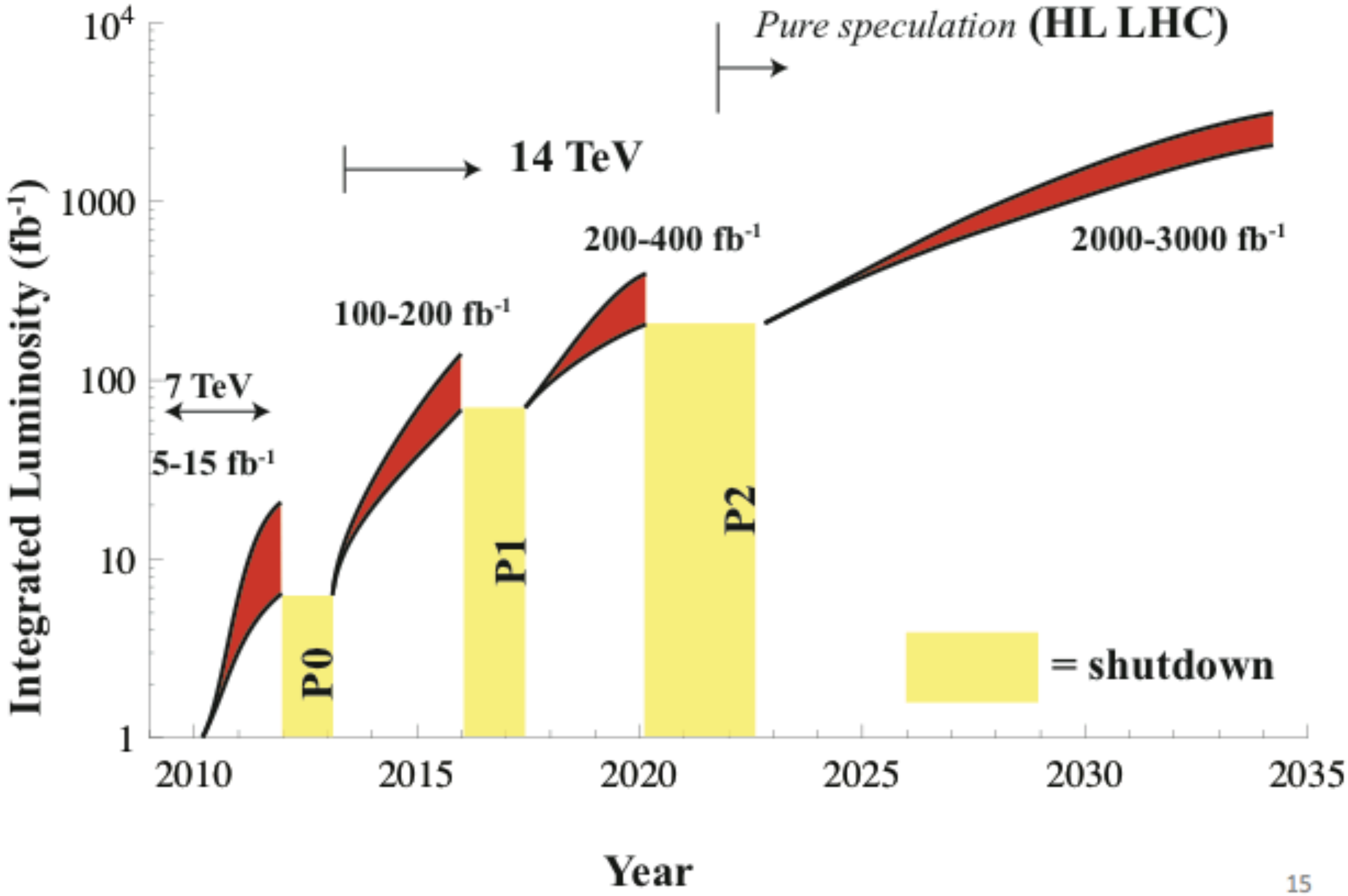
8 TeV, Max expected peak L: $7x10^{33}$

- Maintain 50 ns bunch spacing
  - Larger integrated L with current injection
  - 25 ns will be reached at nominal LHC
- Squeeze the beams: β^* down to 0.6 m and tight collimators
  - N. interactions/collision to 30 → pile-up
    - Detectors limited to 42 (twice nominal)
- Increase center-of-mass energy: 8 TeV
  - Small increase of LHC risks
    - 5x risk of safe beam (interconnection burning), same probability of accident
  - ~15% more events due to the increased cross-section
    - ~30% Higgs σ, ~10% higher mass reach for exotics, 2-4 times greater sensitivity on SUSY reach
    - Increase QCD background (faster than EW with $\sqrt{S}$): 20% S/N
  - Less demanding request on peak L

10-year luminosity forecast



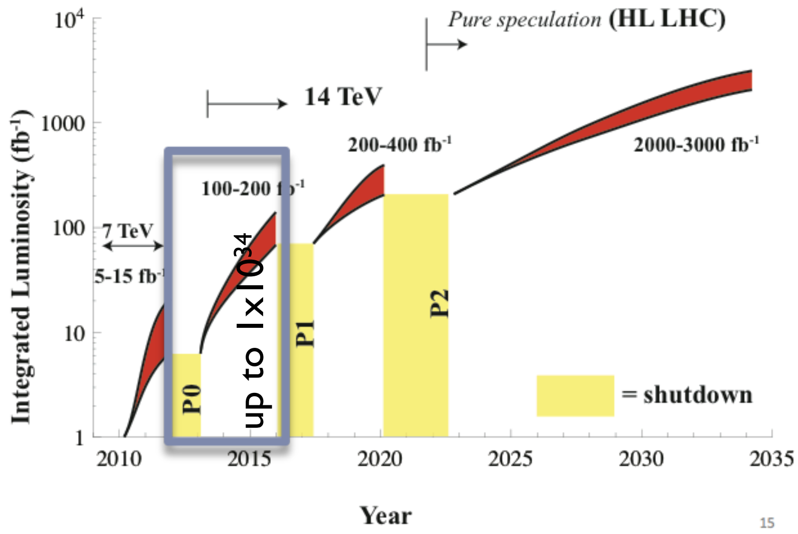
10-year luminosity forecast



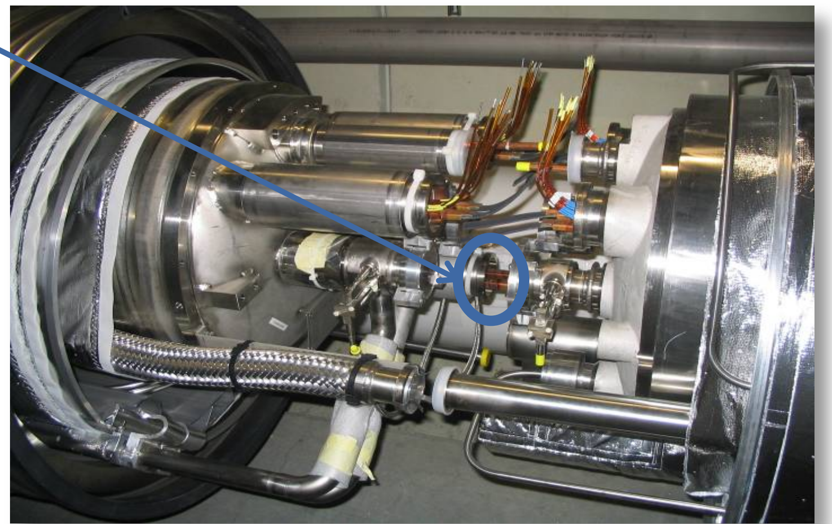
LHC upgrade plans: Phase-0, consolidation

2013

The integrated luminosity is determined not only by the peak luminosity, but also by the luminosity decay and the efficiency of operation (**availability**)



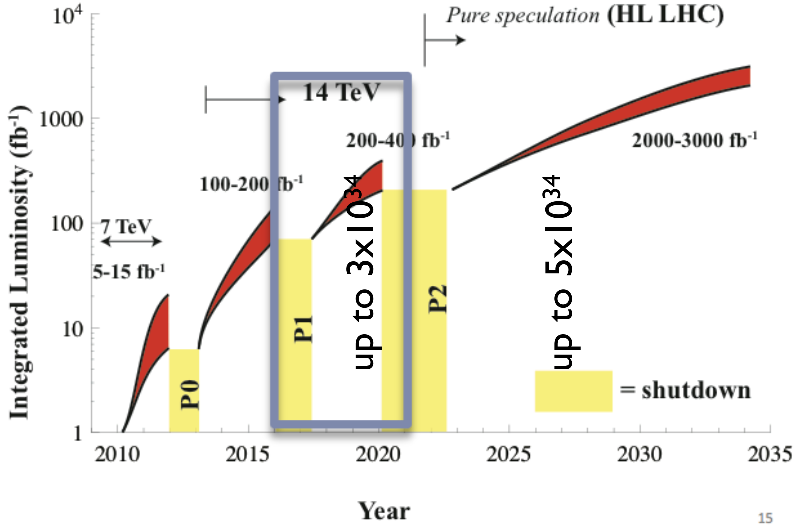
- Phase-0 (December 2012-2014)
  - Consolidate the superconducting circuits
    - Solve the problem at the origin of 2008 incident: the main circuits will run at the design current value without protection issues
  - Full maintenance and consolidation to ensure reliable operation at nominal performance (also on the injectors)
    - Change of electronics for high radiation
    - Vacuum upgrade: reduce the sensitivity to beam losses
    - Improvement of the cryogenic system
    - RF consolidation and upgrade



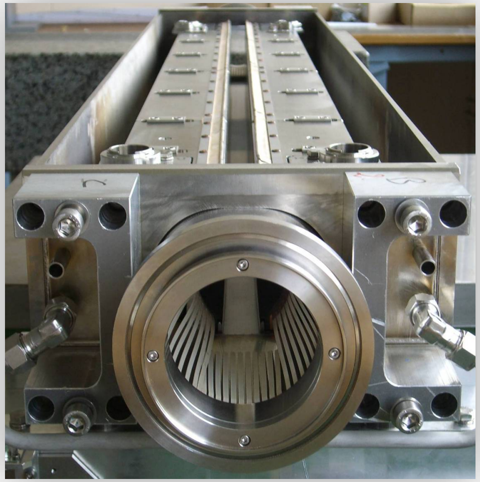
Nominal LHC: E_{beam}=7 TeV, Max expected peak L: 1x10^{34}

LHC upgrade plans: Phase-1 and Phase-2

- Phase-1 (2017): nominal LHC
  - L up to $3\text{x}10^{34}$ to reach 300 fb^{-1}
  - Upgrade works
    - Main upgrades of the injector chain (Linac4)
    - Collimation upgrade



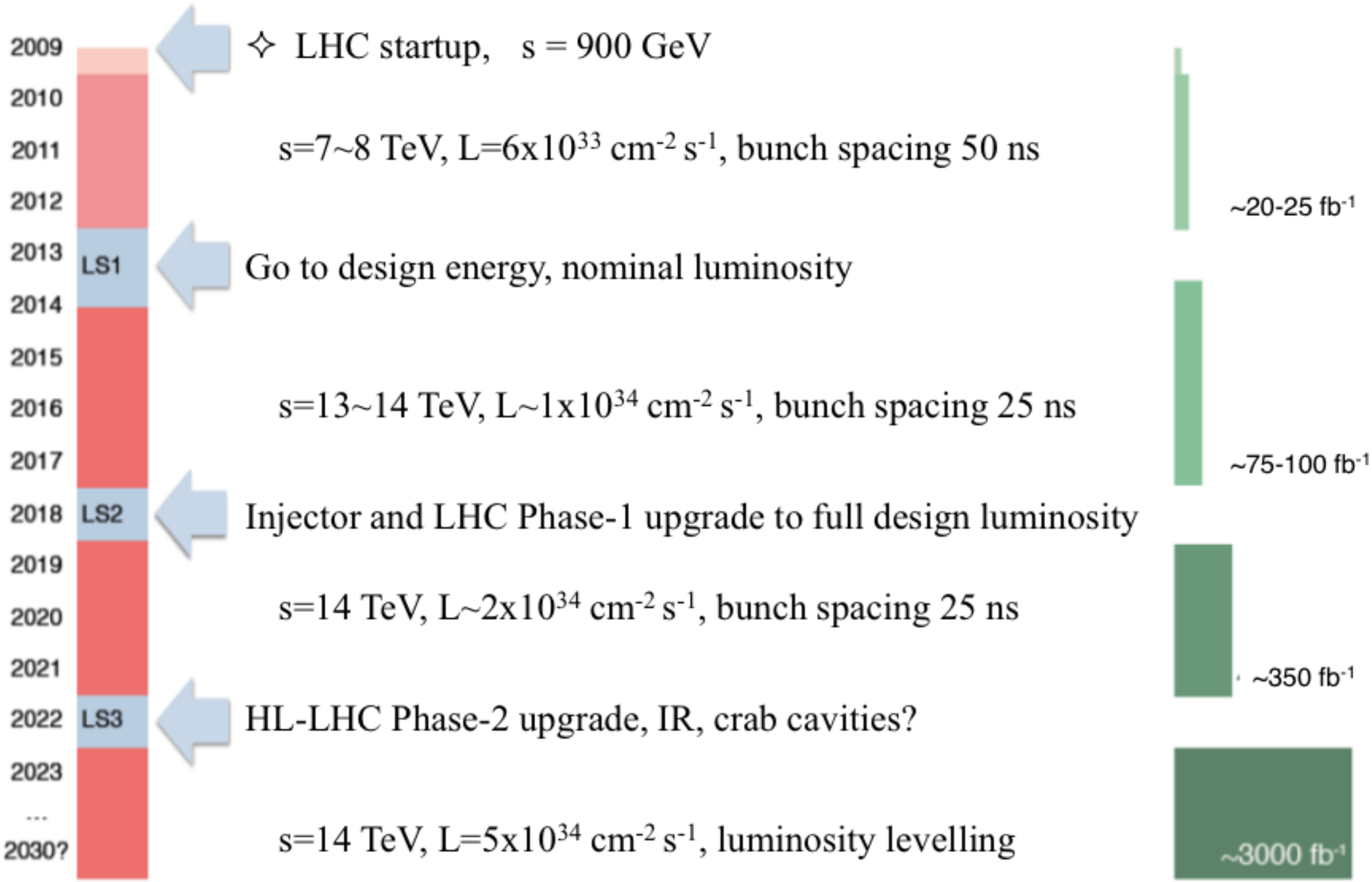
- Phase-2 (2022): the HL-LHC, over design performance
  - L up to $5\text{x}10^{34}$ (to reach 3000 fb^{-1})
  - Upgrade works
    - New magnet technology for the IR (now dipole at 8.3T)
    - New bigger quadrupoles → smaller $\beta*$
    - New RF Crab cavities (?)



New collimation system necessary to be protected from high losses at higher luminosity

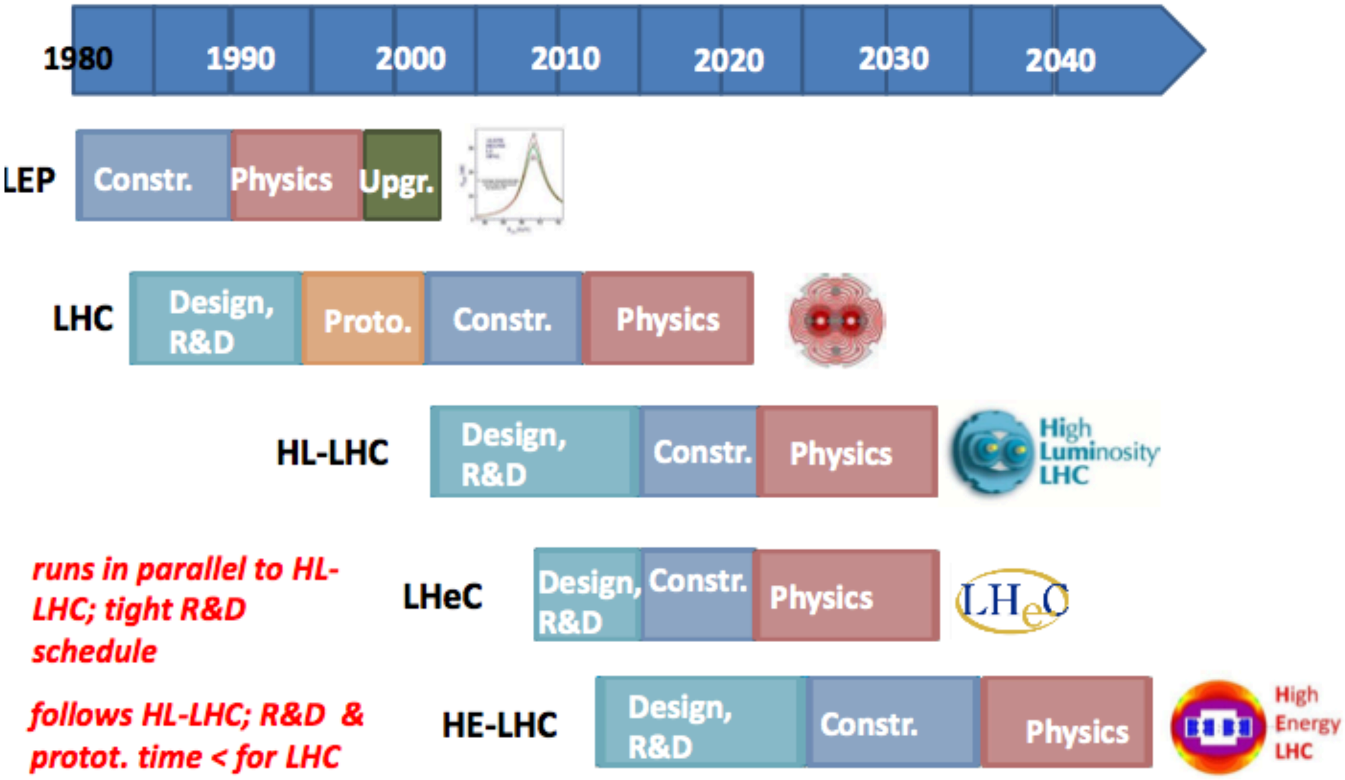
HL-LHC: E_{beam}=7 TeV, Max expected peak L<$1\text{x}10^{35}$

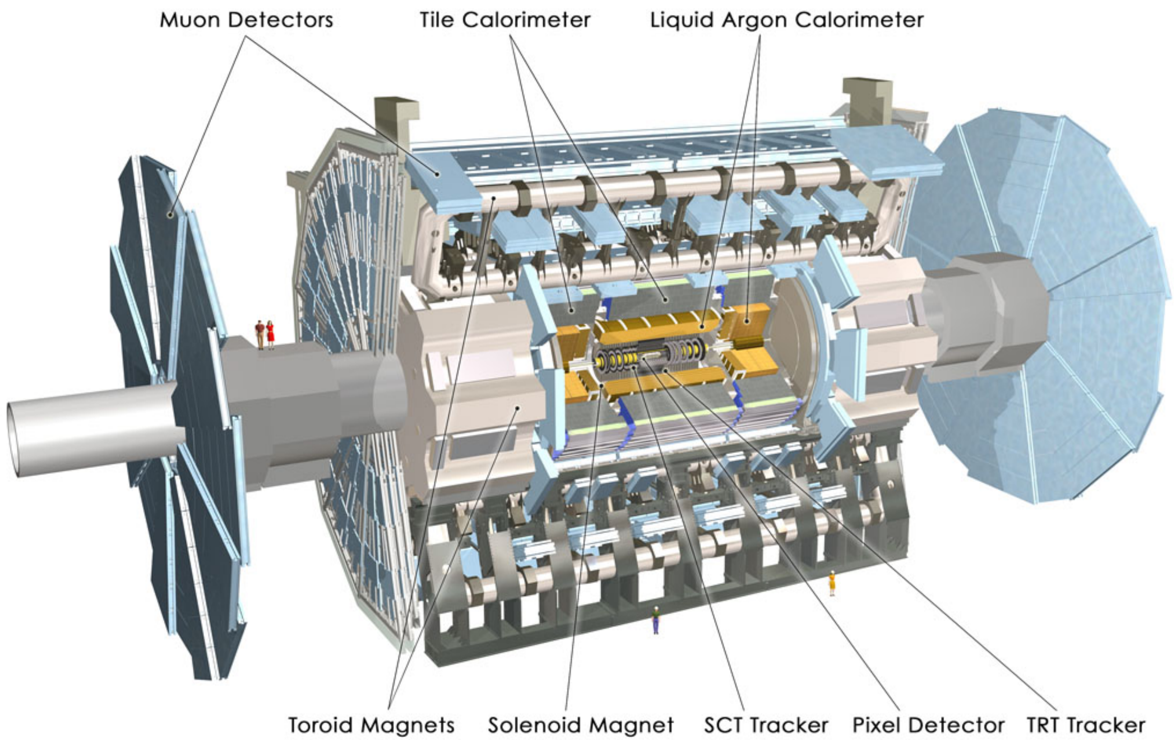
LHC upgrade summary

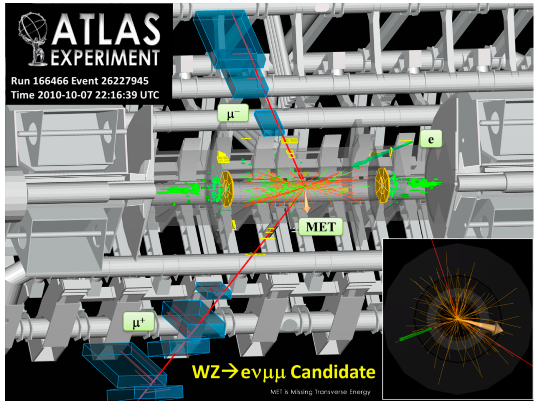


Timeline for CERN-HEP projects

- LHeC: e^- @ 60 GeV, ee and ep @ $L\sim10^{33}$
- High Energy LHC: p @16.5TeV in LHC tunnel, $L\sim2 \times 10^{34}$
  - Key component: 20 T magnets







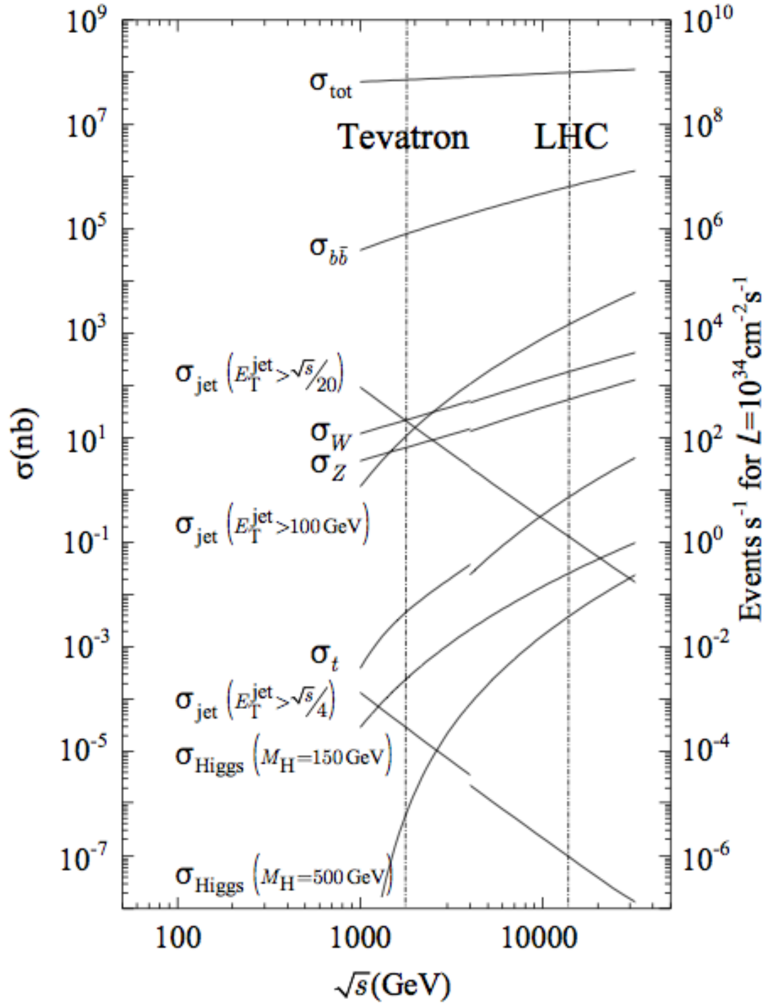
The challenge of the LHC experiments - ATLAS

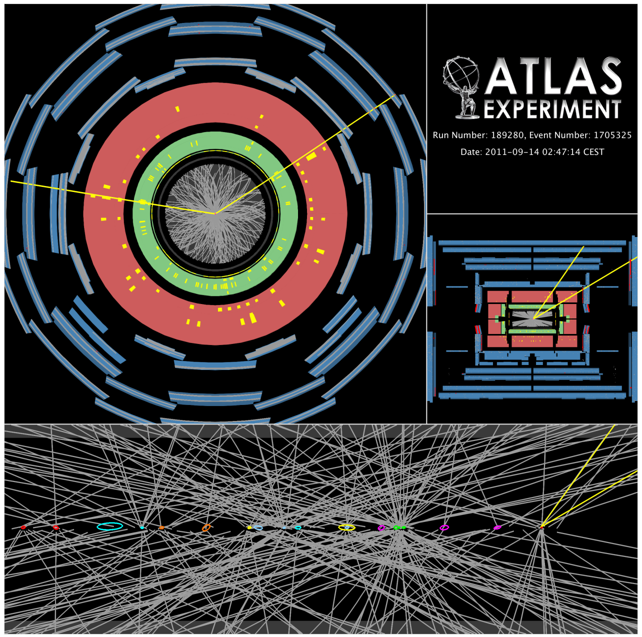
Successful results of the experiments is crucially dependent on the Upgrade performance of the detectors

LHC Experiments Design (ATLAS/CMS)

- LHC environment (by design)
  - σ_{pp} inelastic ~ 70 mb - Event Rate = 7 10^8 Hz
  - Bunch Cross (BC) every 25 ns (40 MHz)
  - ~ 22 interactions / BC
- Stringent requirements for detectors
  - Fast electronics to resolve individual bunch crossings
  - High granularity (many channels) to resolve pile-up
  - Radiation resistant

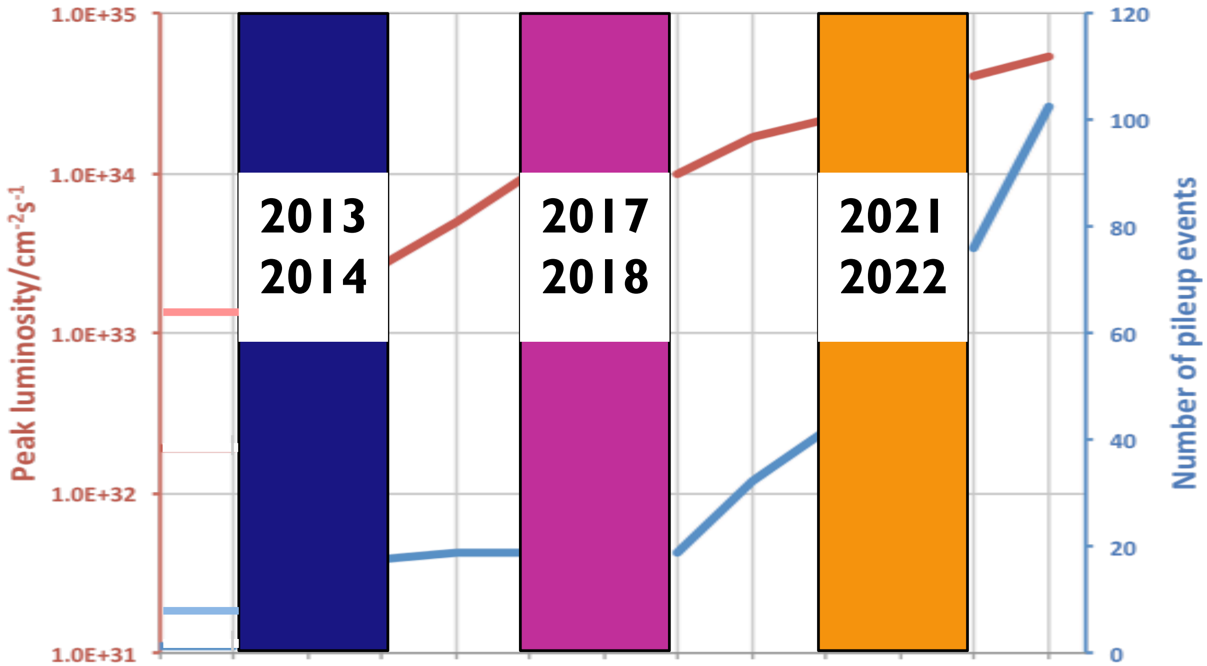
$$\frac{\sigma_{tot}}{\sigma_{H(500\,\mathrm{GeV})}} \approx \frac{100\,mb}{1\,pb} \approx 10^{11}$$





Z→ μ μ candidate with
20 reconstructed vertices

HL-LHC impact on the experiment



- HL-LHC upgrade could push mass reach for Physics Beyond SM by typically 20% with no major detector changes
- However, with upgraded detectors could fully benefit from luminosity increase: more convincing conclusions for signals at the limit of the sensitivity

- Major impact on LHC experiments
  - Higher peak luminosity → higher pile-up (noise in calorimeters x 3)
    - More complex trigger selection
    - Higher detector granularity
    - Radiation hard electronics
  - Higher integrated Luminosity → higher occupancy and radiation (x 10):
    - Trackers damage: worst b-tag, electron identification, etc…
    - Increase shielding of Muon Spectrometer: at the price of reduced forward acceptance

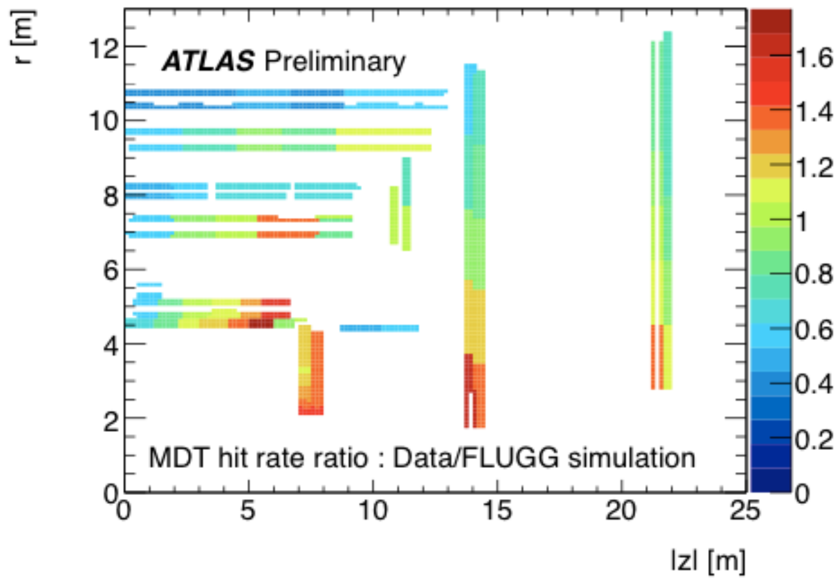
μ = n. of interactions per collision seen by the detector

$$\mathscr{L} = \frac{\mu n_b f_r}{\sigma_{inel}}$$

What we have learnt so far

- Work has been done during the first years of data taking to
  - Gain experience as important guidance for upgrade decisions
  - Quantify expected performance for HL-LHC
    - Simulations
    - Limitations
    - Cross-check with data (2011 high L and heavy ions runs)
  - Assess feasibility of increasing rejection power
    - With/without modest changes in the current TDAQ

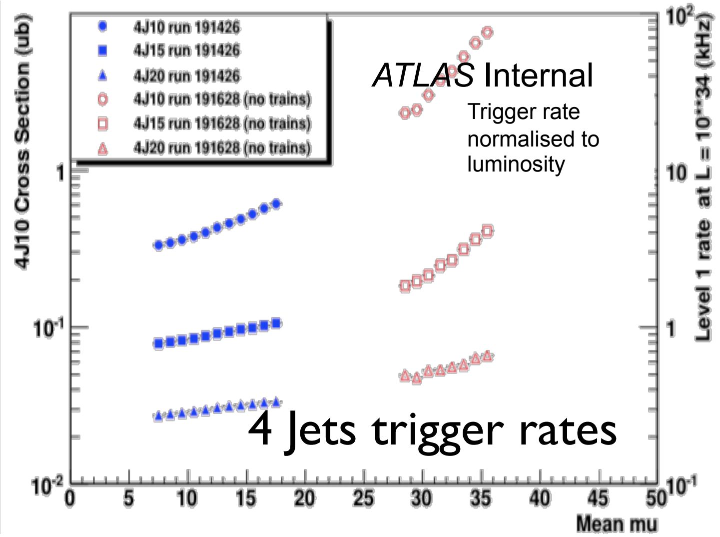
Ratio of measured to simulated MDT hit rate during 2011 – 7 TeV

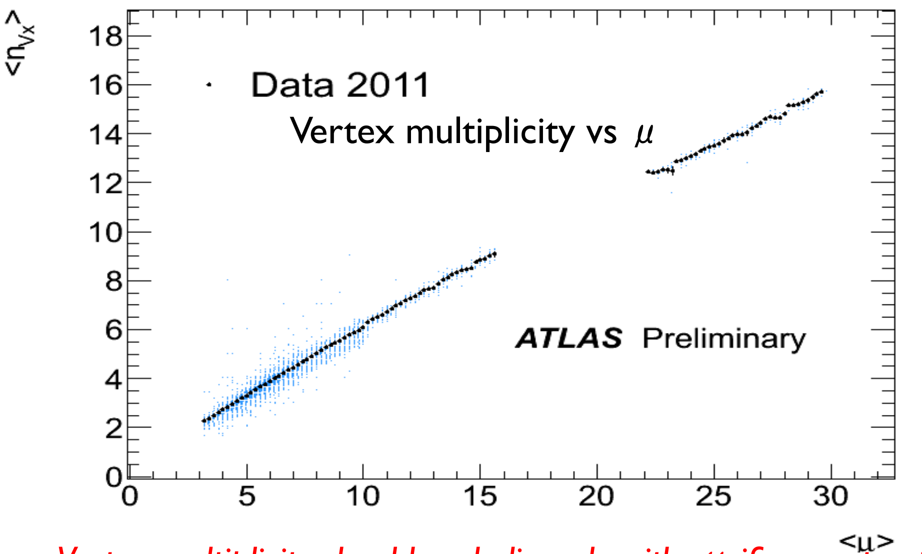


- Take into account
  - Changes in the detectors
  - Phase-1 safety factors
    - 30% for extrapolations to $L \sim 3\times10^{34}$, $\mu \sim 80$, 400 fb^{-1}
    - Additional factor 2 for irradiation tolerance
  - Quantitative assessment of parameters for Phase-2
    - Any component installed in Phase-I fully operational also through Phase-II (μ ~200)

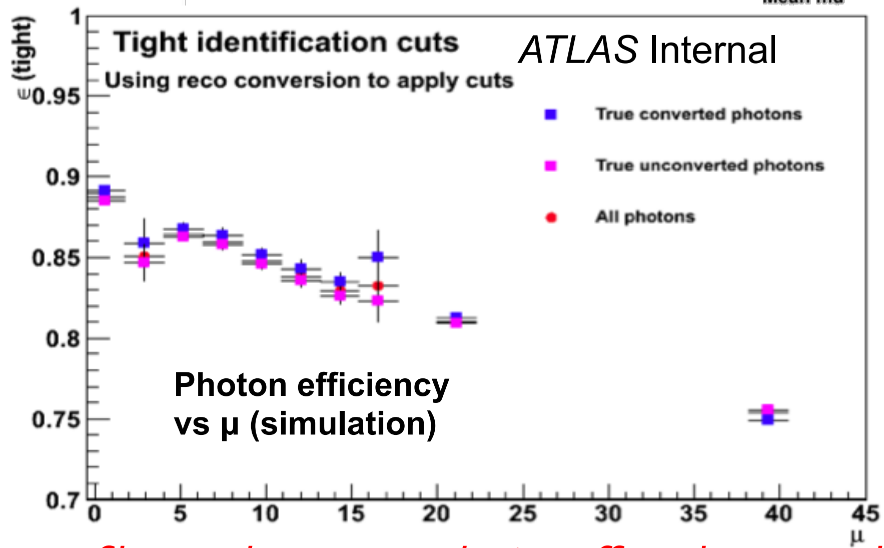
Effects of pileup on the performance

- Some that probably can be mitigated
  - Worse vertex reconstruction efficiency, offset in energy, higher rates of low-pt jets
  - Improvements are expected: algorithms can be optimized (pile-up subtraction)
- … and some that cannot
  - Degradation of energy resolution (missing ET)
  - Need for more disk/CPU resources





Vertex multiplicity should scale linearly with μ if reconstruction efficiency is constant: observe deviation after μ~20



Shower shapes perturbation affect electron and photon identification efficiencies

Major detector requirements at 10^{35}

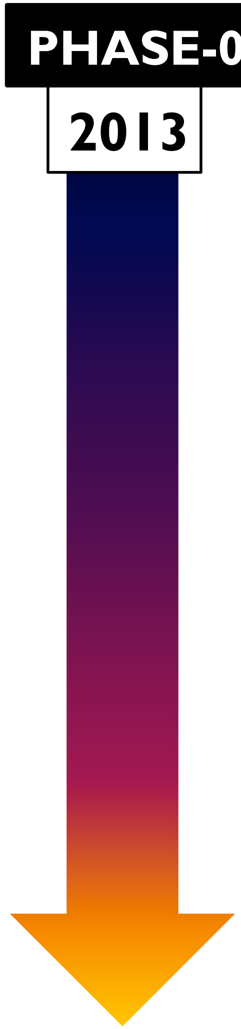
- Maintain electron/muon identification and measurement (E, p, charge) up to 1 TeV with resolution < 10%
  - Maximum E_T up to 3 TeV: can maintain calorimeters (for jets and E_T^{miss}), but trackers need more precision

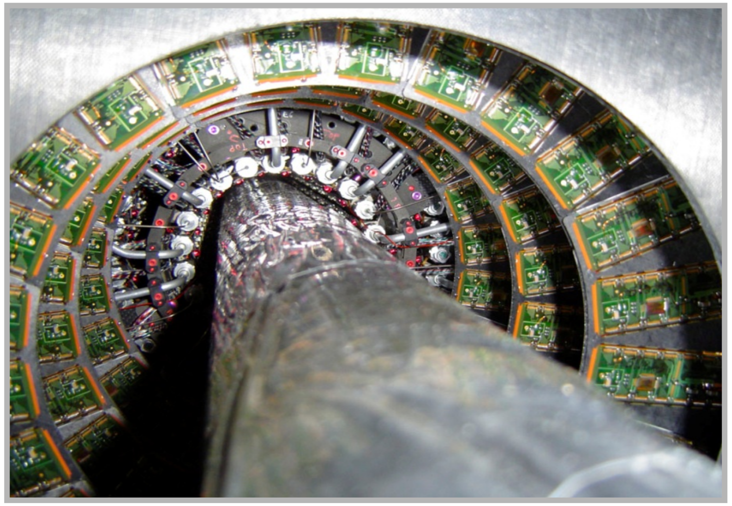
- Tracker:
  - Good momentum resolution up to 1TeV
  - Maintain B-tagging and τ identification performance

- Calorimeters:
  - Very good constant term, granularity, fast response
    - Current technology can ensure up to 10^{34}
  - Acceptable for e/γ/jet measurements, but degradation of forward jet tag and low-p_T jet veto (needed for strong WW scattering)
    - Challenge for forward jets

- Muon spectrometer
  - Maintain good momentum resolution up to 1TeV
    - Challenge <10%
  - Cavern background increase leads to very high occupancy

ATLAS plans for Phase-0

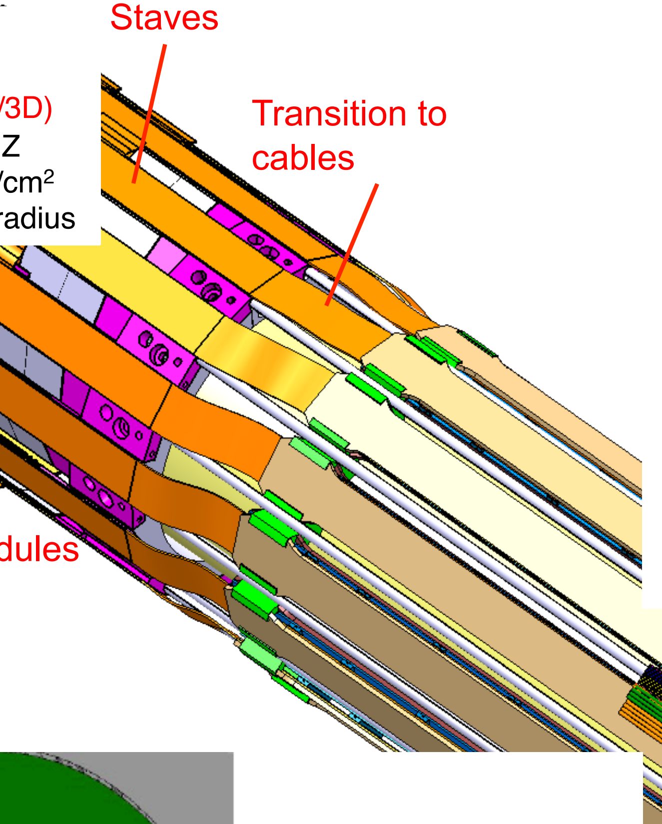


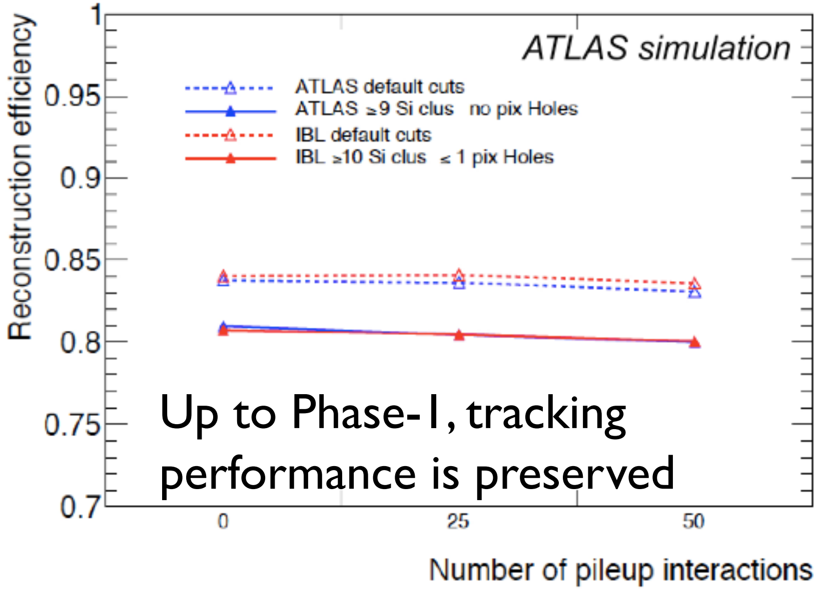


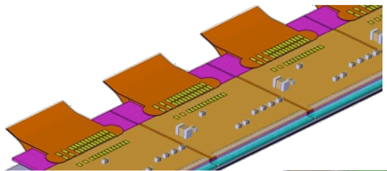
- Muon Spectrometer
  - Add specific neutron shielding where necessary (behind endcap toroid, USA15)
- Calorimeters
  - Replace all calorimeter Low Voltage Power Supplies
- Change in the IP region
  - New Aluminum beam pipes to prevent activation problem
    - And reduce muon background, forward region by 30%
  - New insertable pixel b-layer (IBL) + new pixel services
    - Current innermost pixel layer will have significant radiation damage, largely reduced detector efficiency
  - New evaporative cooling plant for Pixel and SCT + IBL
- Maintenance/consolidation
  - TDAQ farms & networks consolidation
  - Revisit the entire electricity supply network and upgrade the magnets cryogenics

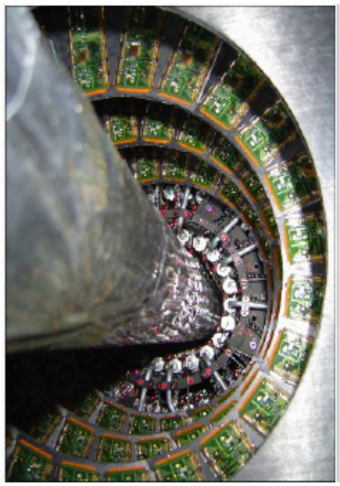
IBL Detector (4th pixel layer)

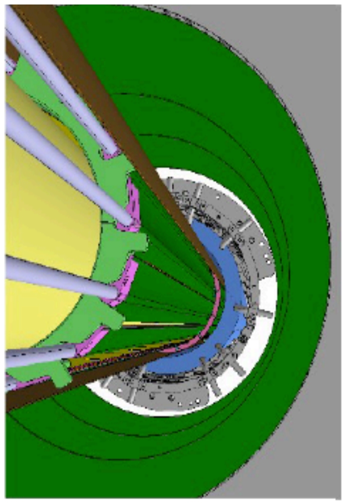
- 14 staves, <R> = 33.25 mm
- X/X_0 < 1.5 % (B-layer is 2.7 %)
- 50 μm x 250 μm pixels (planar/3D)
- 1.8° overlap in φ, <2% gaps in Z
- Radiation tolerance 5×10^{15} n_{eq}/cm^2
- New Be beam pipe of smaller radius

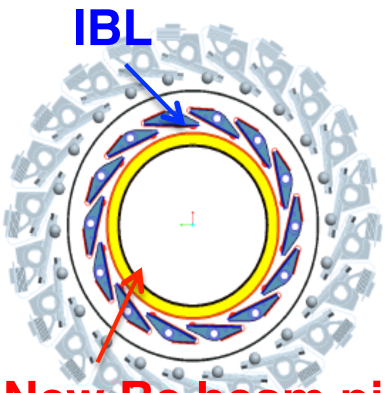










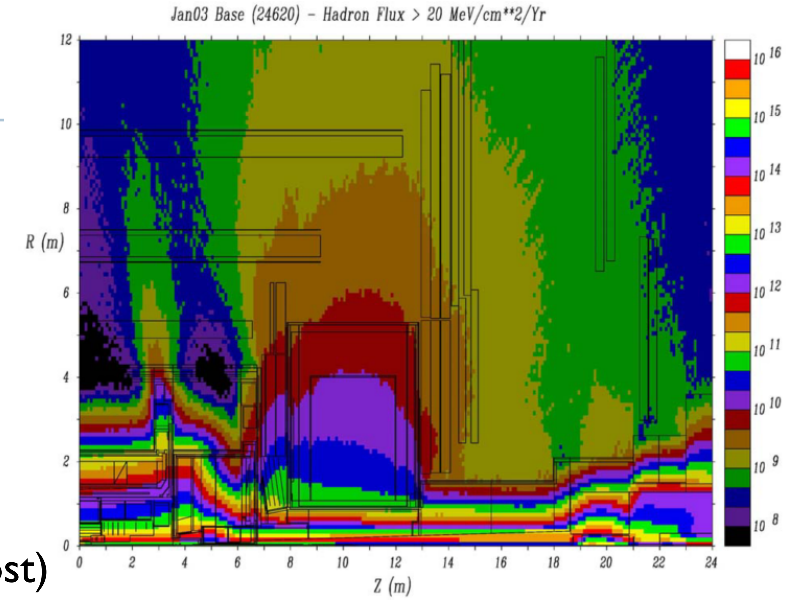


ATLAS plans for Phase-1

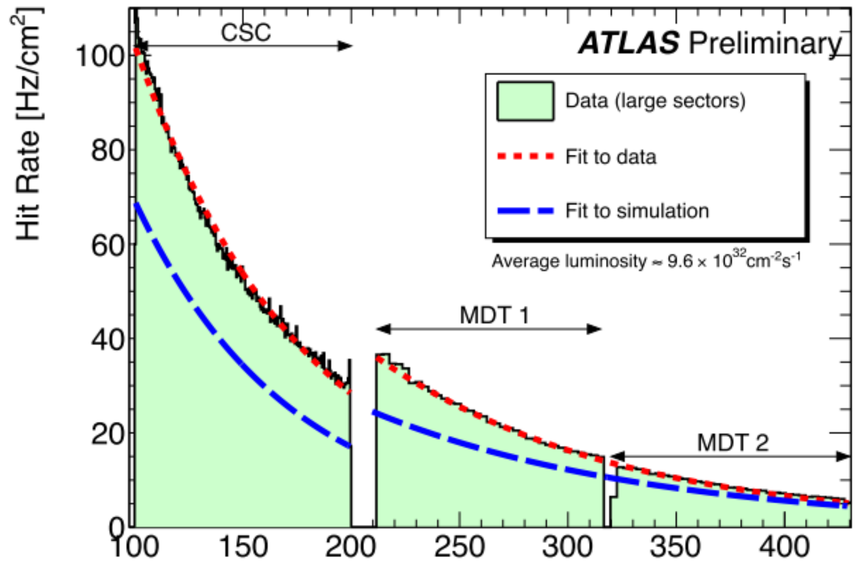
- Muon Upgrade in the Forward region
  - Replacement of the muon chambers in the inner forward region
    - To maintain tracking performance under expected large cavern background
    - To reinforce L1 trigger rejection power of large fake rates
- Calorimeter readout intermediate upgrade
  - Partial upgrade on the Front-End read-out architecture to increase L1 rejection
- Fast Tracker for L2 selection
- Forward Physics system (AFP)
  - Physics motivation: exploration of NP via anomalous VB couplings or QCD measurements ("pomerons")
  - Diffractive protons detection at very small scattering angle on both sides with retractable silicon trackers (vertex resolution within few mm using timing coincidence)
- Approved already by the collaboration with a LoI

Muon background

- Cavern background at L = 10^{33} cm^{-2} s^{-1}
  - In the hottest forward regions (inner):
    - 40 kHz/cm^2 N
    - 18 kHz/cm^2 photons
    - 400 Hz/cm^2 charged (dominant, due to sensitivity)
- Hit rate (currents) linearly depends on luminosity (over 4 decades)



- Very high occupancy for nominal LHC (add SF=2 for E boost)
  - R>2m: close to limit of current MDT technologies (<800Hz/cm^2)
  - At smallest R=1m → kHz/cm^2
- Phase-0: expected reduced background
  - New beam pipe (~30% reduction of fakes)
  - Improved shielding
- Phase-1: major change in the inner forward
  - Maintain tracking performance
  - Provide better angular resolution to the L1 trigger
- Small margin to operate at higher L: Phase-2 (7x10^{34})
  - About factor 70 increase: at small R=1m
    - Hit rate ~ 14kHz/cm^2, accumulated charge ~ 1 C/cm^2 (MDT a

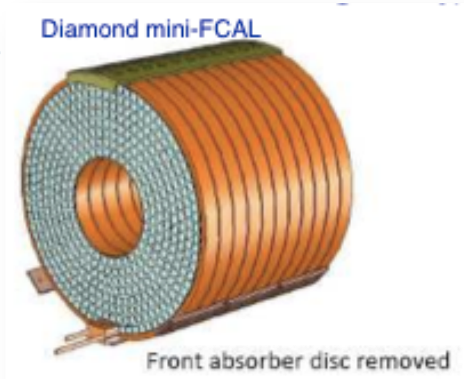


Hit rate measurement at 10^{33}

- Choice of technologies still under discussion

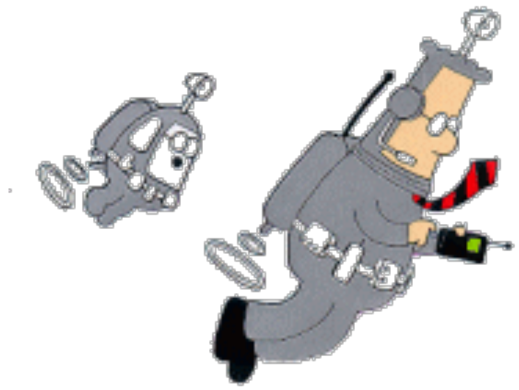
ATLAS (draft) plans for Phase-2

- Over ATLAS detectors specifics
- Muon Spectrometer Upgrade
  - Related to trigger requirements



- Calorimeter: impossible to change all detectors (budget, time, manpower), upgrade related to
  - Radiation damage of electronics
    - Go to fully digital readout electronics on both technologies
    - Add redundancy to power supplies, readout fibers from PMTs in the Tiles
  - L1 trigger requirements
  - Loss of efficiency due to space charge effects in the Forward
    - New Forward EM calorimeter – different technologies under discussion
- Inner trackers replacement
  - Current silicons damaged by radiation dose
  - TRT limit due to occupancy
  - Needs for more granularity
    - Sensor technologies and layout still under discussion (trigger capabilities?)

Most of the changes in the detectors are driven by the trigger requirements

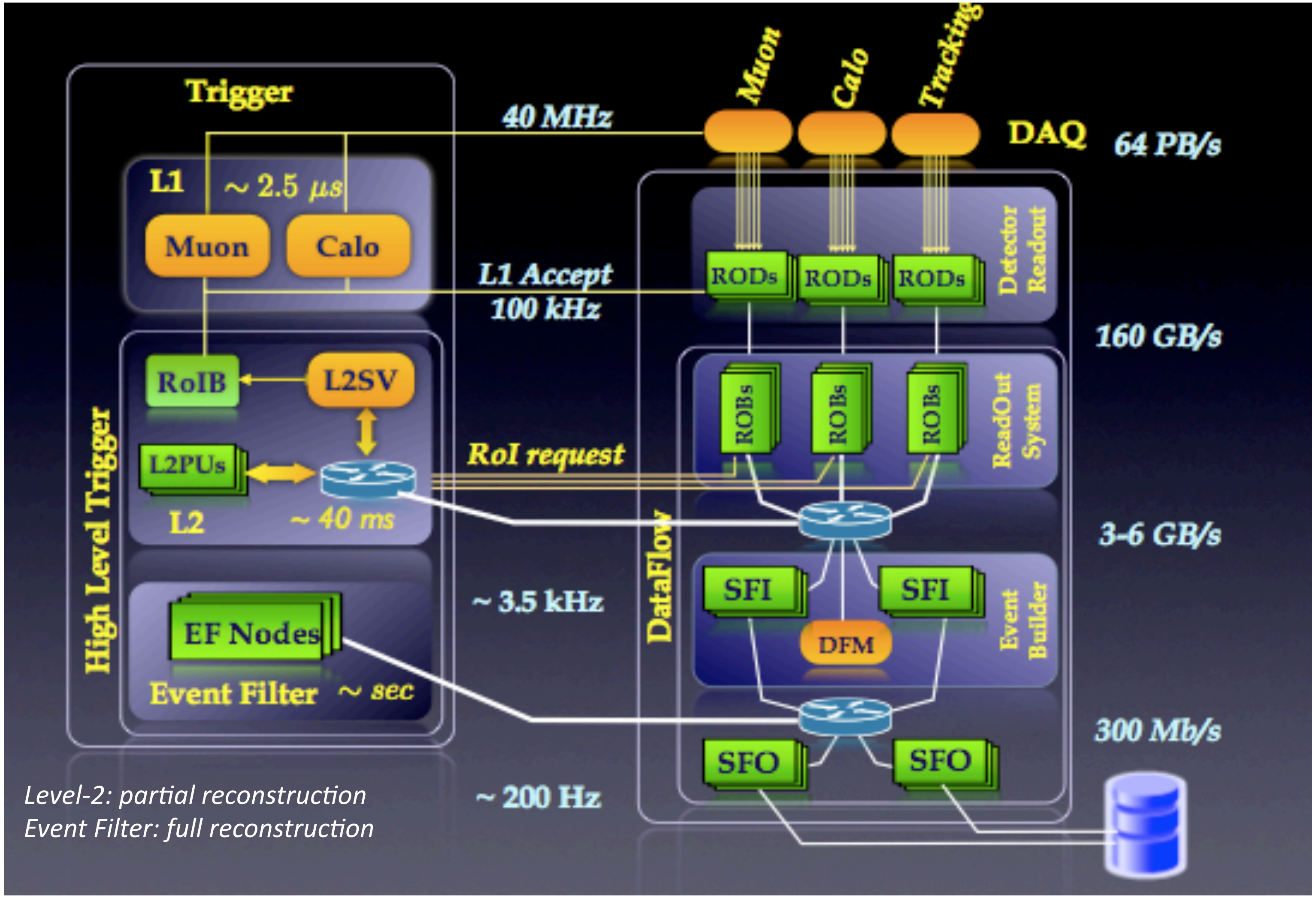


The future of the ATLAS trigger and DAQ

Here is the beast!

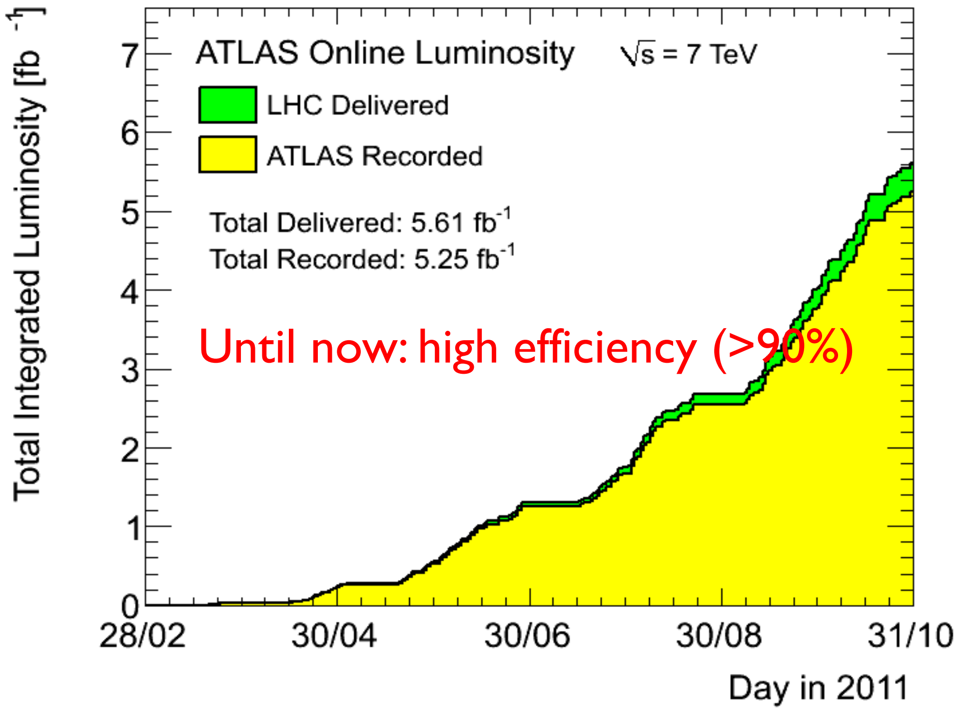
The ATLAS trigger/DAQ system

L1: Reduced-granularity information from Muon detectors and calorimeters



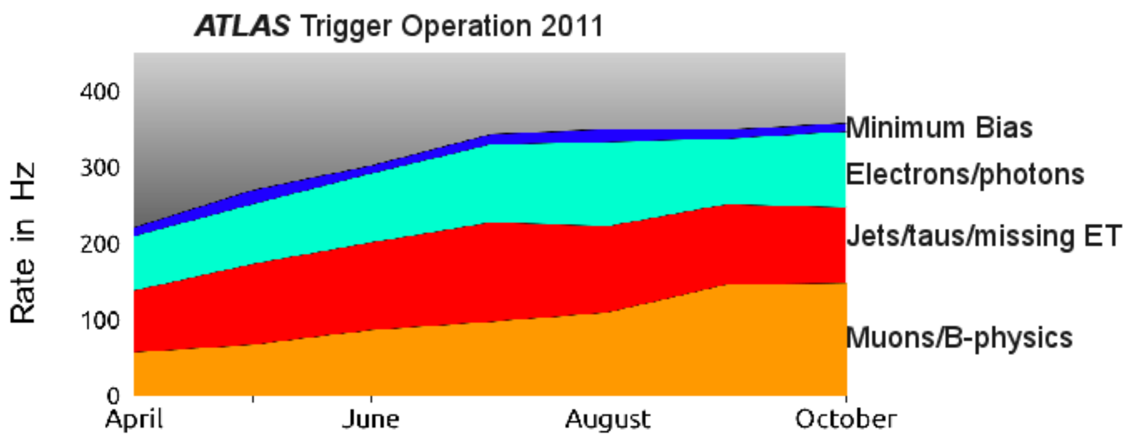
Trigger design Goal:
Reduce decision latency and network traffic

Trigger/DAQ performance (today)

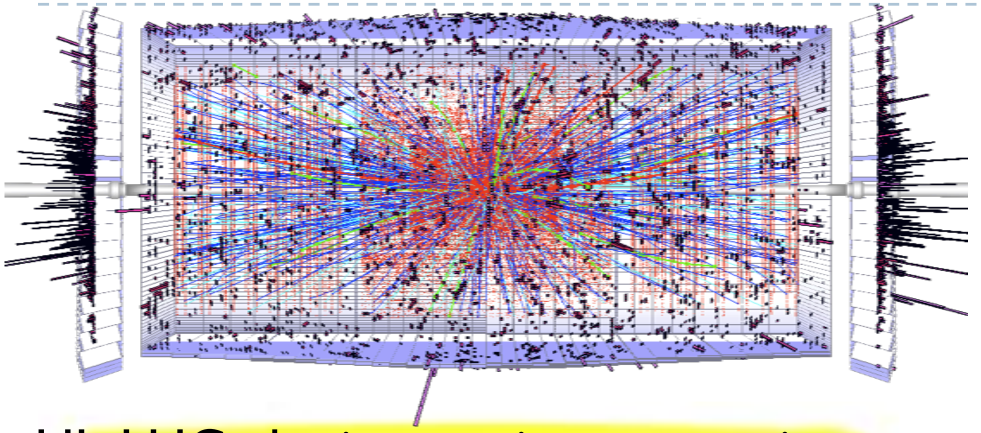


	2010 (2E32/cm²s)	2011 (2E33/cm²s)	Limited by
L1 output rate	50 kHz	75 kHz	Front-End (TGC, Tile)
ROS data request rate	20 kHz	27 kHz	Event size on calo
Event building rate (=L2 out)	5 kHz	7 kHz (1.3Mb/ev)	# of EB nodes
Recording rate avg (=EF out)	300 Hz (peak up to 600Hz)	400 Hz, change computing model	Disk-buffer, CPU and replication

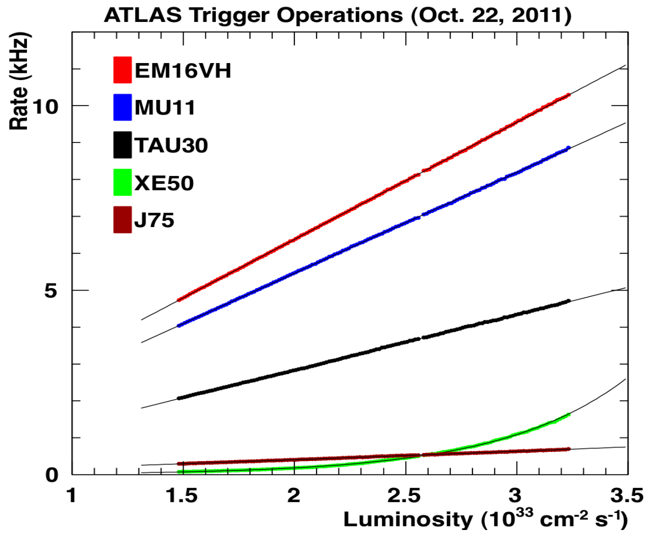
- The significant part of the bandwidth is taken by the high p_T lepton triggers
  - 20 kHz at L1 for muons/electrons



Requirements for a trigger at HL-LHC



- HL-LHC physics requires open triggers



- Triggers to increase discovery reach: higher mass, rare processes
  - Inclusive isolated lepton triggers, not biased
  - (very) high-pt objects: increased thresholds
  - Di-lepton triggers
- Triggers to increase precision: for statistically limited processed
  - Use W/Z
  - Similar thresholds to LHC
  - Exclusive / multi-object selections

Conditions at 10^{35} will impact trigger rates

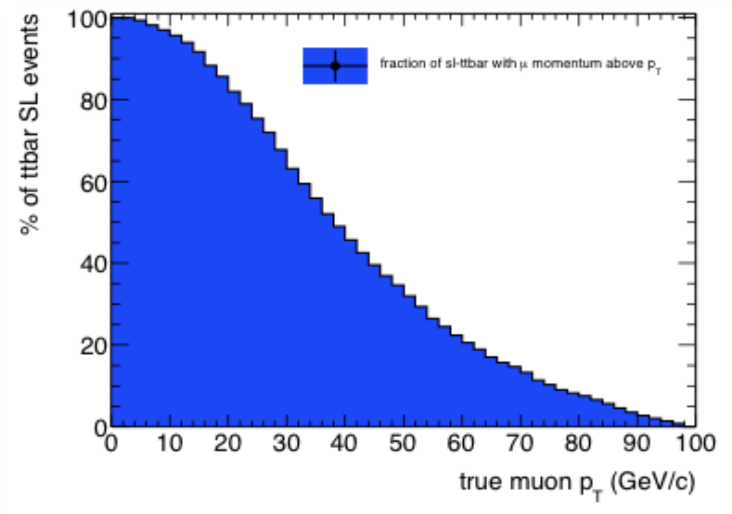
from hep-ph/0204087

Selection	LHC Threshold (GeV)	LHC Rate (kHz)	SLHC Threshold (GeV)	SLHC Rate (kHz)
inclusive single muon	20	4	30	25
inclusive, isolated e/gamma	30	22	55	20†
muon pair	6	1	20	few
isolated e/gamma pair	20	5	30	5
inclusive jet	290	0.2	350	1
jet + missing ET	100+100	0.5	150+80	1-2
inclusive ET			150	<1
multi-jet triggers	various	0.4	various	low

Note that inclusive e/γ trigger dominates rate. (†Added degradation from pile-up not included above)

Impact of HL-LHC on the trigger

- Main source of background
  - From jets mimicking electrons and high radiation in the forward directions
- Higher rates for fixed thresholds due to
  - Trivial increase by corresponding increase in luminosity
  - Reduced rejection power due to
    - Worse resolution in calorimeters
    - Less effective isolation/ pattern recognition
  - Increase in fake rate due to higher occupancies
    - Increase in double object trigger rates
- Simple increase of thresholds can reduce signal efficiency drastically
  - By factor 2 for WH associated production and some SUSY scenarios



Drop in acceptance as a function of the lepton's pT, in events with leptonically decaying W or top

Need for more sophisticated trigger criteria

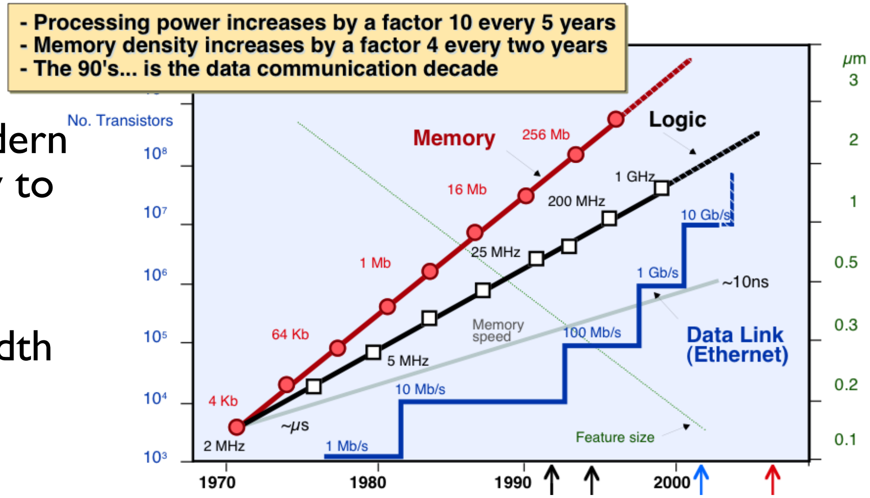
- **Level-1**
  - **Move software algorithms into electronics**
  - **Require better resolution**
  - **Add inner tracker information**
- **High level trigger:**
  - **More complex reconstruction**

BUT:

- Reconstruction complexity/timing naively scale with the number of tracks
  - Adapt trigger algorithms
    - Possibility to have longer latencies
    - At L1 means changing the FEE readout
  - Increase trigger/offline CPU needs

Readout/trigger electronics at HL-LHC

- Help from technology to reach increased bandwidth, maintenance, flexibility
  - Parallelism (processing, multi-core)
  - Dramatic increase in computing power & I/O
  - Chips with increasing densities and reduced size
- Trends on the market
  - Fast FPGAs
    - Moving from custom ASICs to powerful modern FPGAs with huge processing & I/O capability to implement more sophisticated algorithms
  - Fast connections
    - Optical links up to 10GBit for larger bandwidth
    - Network switches technologies
  - New high precision clock @CERN (TTC)
  - Larger buffers
    - Track finding with CAM/LUT
    - Possibility to extend L1 Latency on detector FEE
  - Bus infrastructure based on μTCA – under study



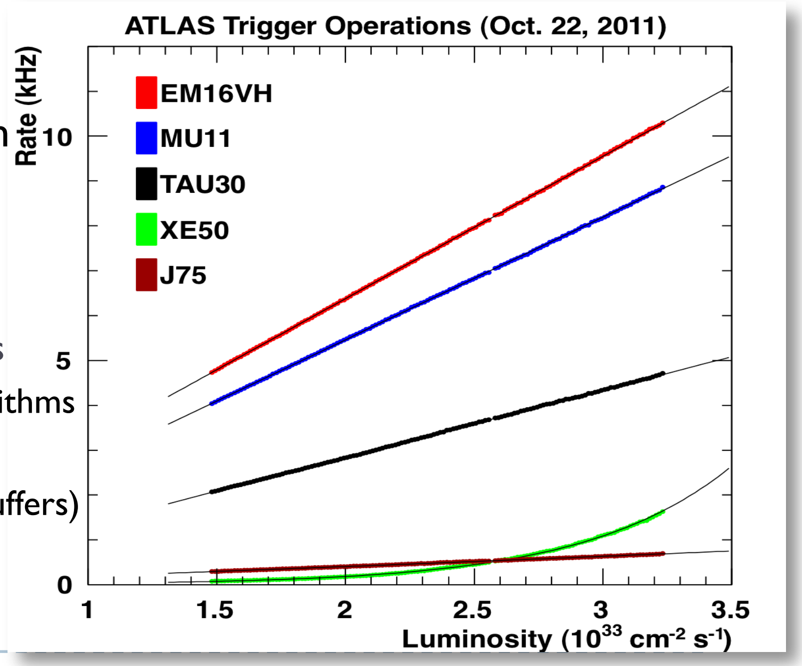
Level-1 trigger evolution

2013

2017

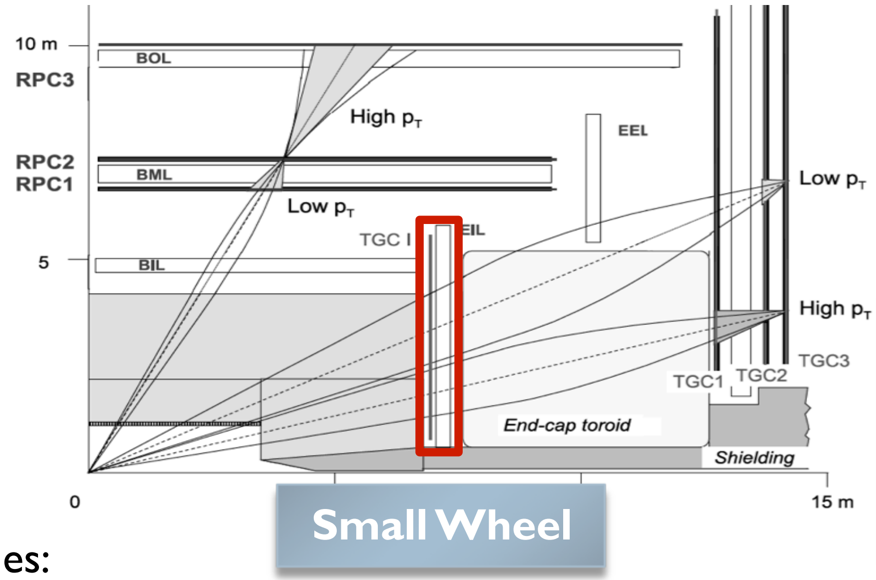
2022

- Not planned major architectural changes to the detector read-out and DAQ up to Phase-I
  - Trigger detector pipeline latency limits of ~2.5 μ s, using spare ~0.5 μ s (20 bunch crossings)
  - Maximum average Level-1 Accept rate not exceeds 75 kHz (upgradeable to 100 kHz)
- Phase 0: design limit
- Phase 1: add more flexibility in L1 selections to reduce fake rates
  - Muon: add one coincidence layer in the Endcap (New Small Wheel)
  - Calorimeter: provide increased calorimeter granularity
  - Allow topological criteria / more exclusive selections
- Phase 2: refine algorithms, with higher resolution
  - Rate over limit allowed by detector FEE
  - Move part of the rejection done at L2 into L1
    - For calorimeters, muons, trackers (if needed)
  - Extend latency to allow for more complex algorithms
    - An additional μ s implies doubling the time for algorithms
    - Split level into two stages
    - Or just profit from advanced technologies (longer buffers)

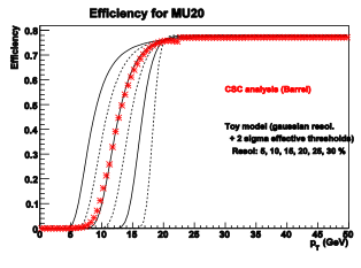


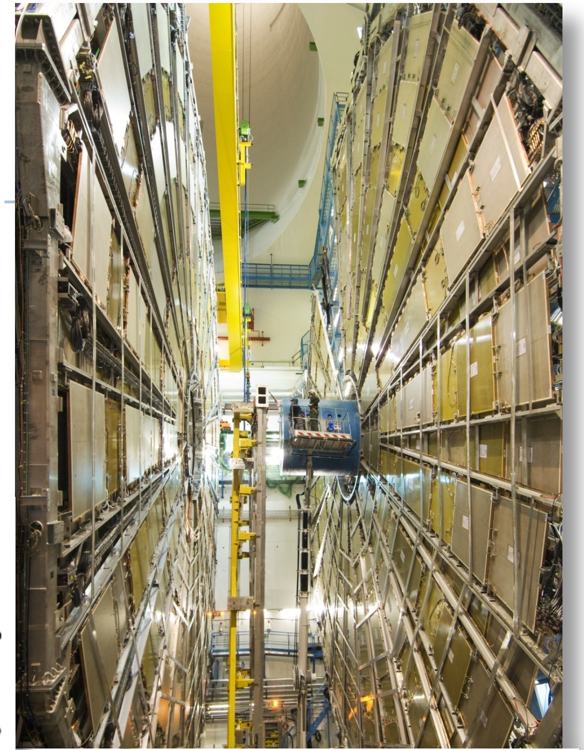
Probable major upgrade for Phase-2

L1 muon trigger issues



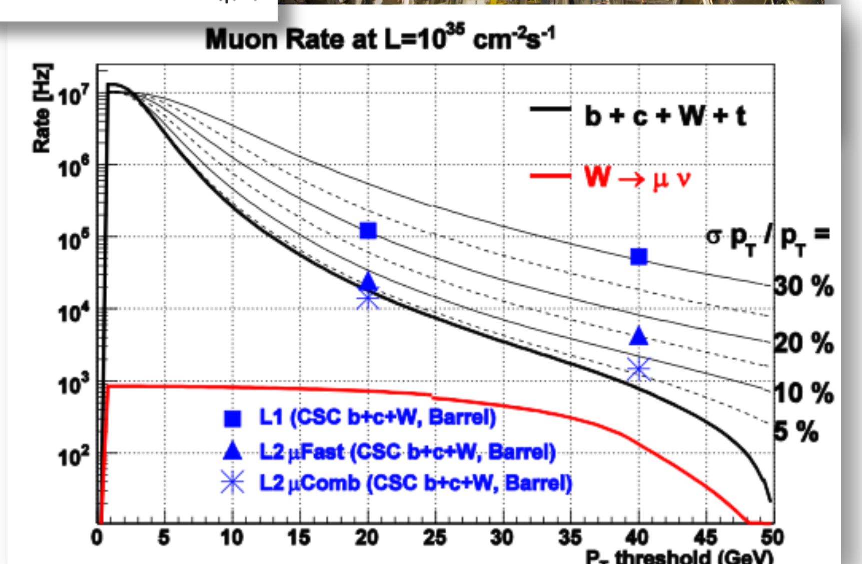
Faster turn-on curves





- Issues:
  - Unexpected increased rate in the forward region due to fakes
  - Impact of cavern background and survival of muon chambers
  - Radiation tolerance of electronics

- Phase-1: New Small Wheel (NSW)
  - Additional coincidence layer in the Forward to improve angular (and pt) resolution: rate reduction up to factor 10
  - Technology choice under study (combine TGC, small MDTs, MicroMega)
    - Segment position resolution < 60 μ m
    - Segment angular resolution < 0.3 mRad



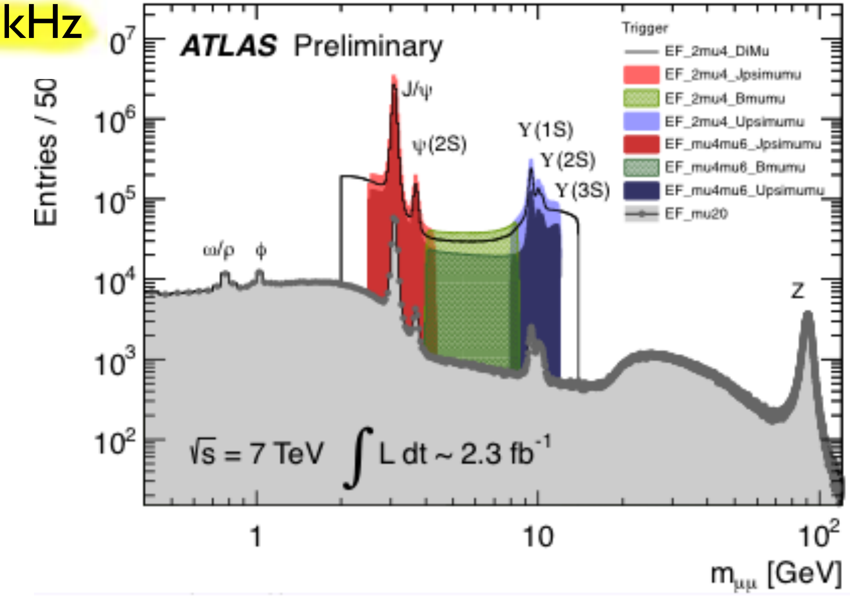
Expected rate reduction as a function of pt with increasing pt resolution

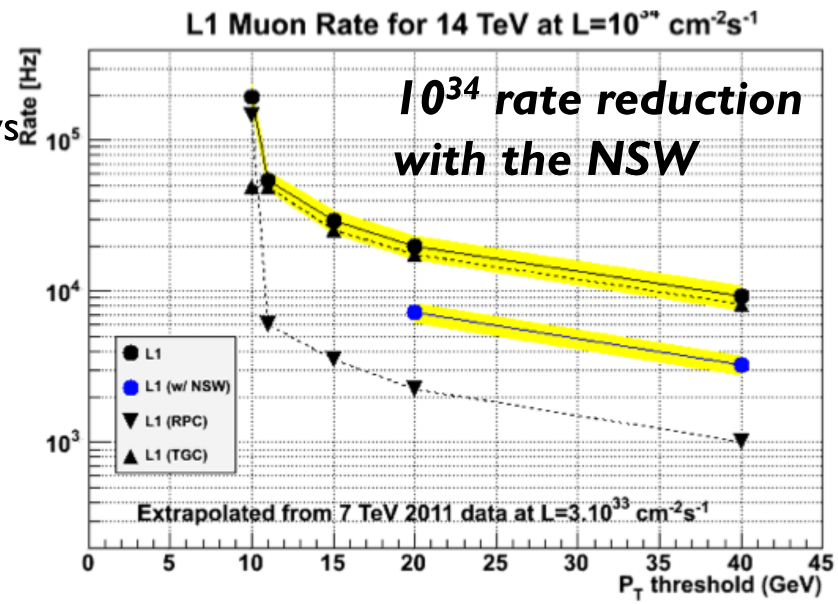
L1 muon upgrade prospects

L1 MU rate limit: 20 kHz

- 2011 (max L=3x1033)
  - Single muon : L1_MU11: 15 kHz → seed all HLT chains
  - Di-muon: L1_2MU0 : 3 kHz → primary for B-physics
- 2012 (and up to L=1034)
  - Small increase in thresholds
  - L1_MU15, 2MU6, 3MU4 ~kHz for exotics, etc….
- Phase-1 extrapolation (w/ uncert. 7 TeV→14 TeV)
  - Current system MU20: 60 kHz
  - With NSW MU20: 20 kHz
- Phase-2: as from the physics requirements MU20 allows to maintain the performance, but rate is over the allowed bandwidth
  - Magnet system allows for different detector layout:
    - Finer granularity detectors
    - Refined algorithms
  - Possible options (with extended latency):
    - Precision MDT chambers added in the trigger
      - Dismount as less as possible
    - Track trigger can help

Bphys Main triggers in 2011
L1_2MU0, 2MU4 seeded

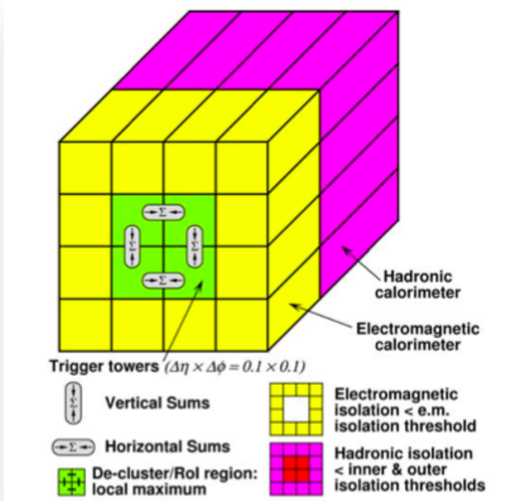


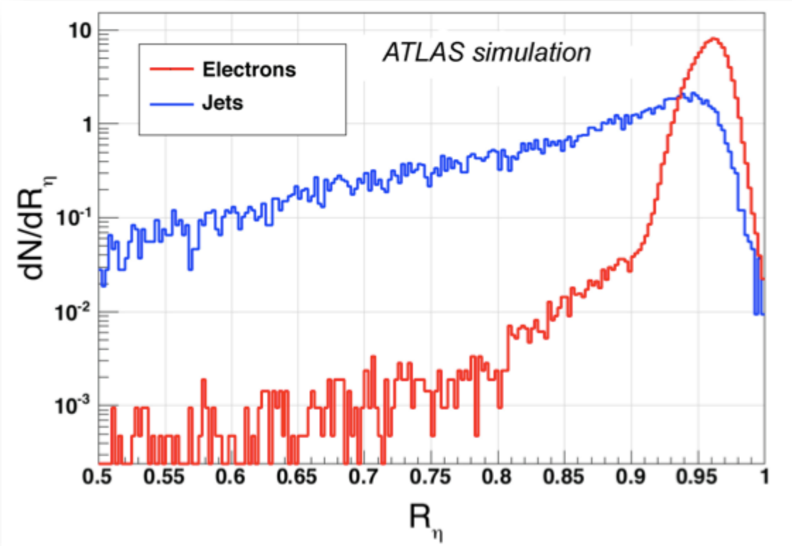


ATLAS calorimeter trigger (today)

- e, γ, τ, jets, ETmiss, Σ ET
  - Various combinations of cluster sums and isolation criteria
    - Isolation criteria can be imposed to control the rate (reducing jet background at low energy thresholds)
    - Efficiency degraded with the pile-up level
- Level-1 (limited granularity)
  - Summed Energy over <60 cells
  - Dedicated processors apply simple cluster algorithms and programmable ET thresholds
    - e/ γ : narrow shower shapes, no longitudinal leakage, transverse isolation
  - Peak finder for BC identification
- High-Level trigger (full calorimeters granularity)
  - Topological variables and tracking information
    - Cluster shape at L2
    - Jet algorithms at Event Filter

Level-1 clustering algorithm

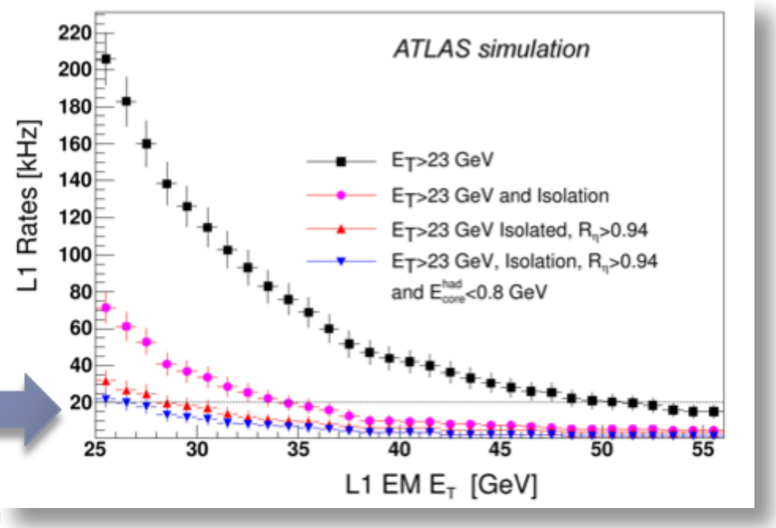




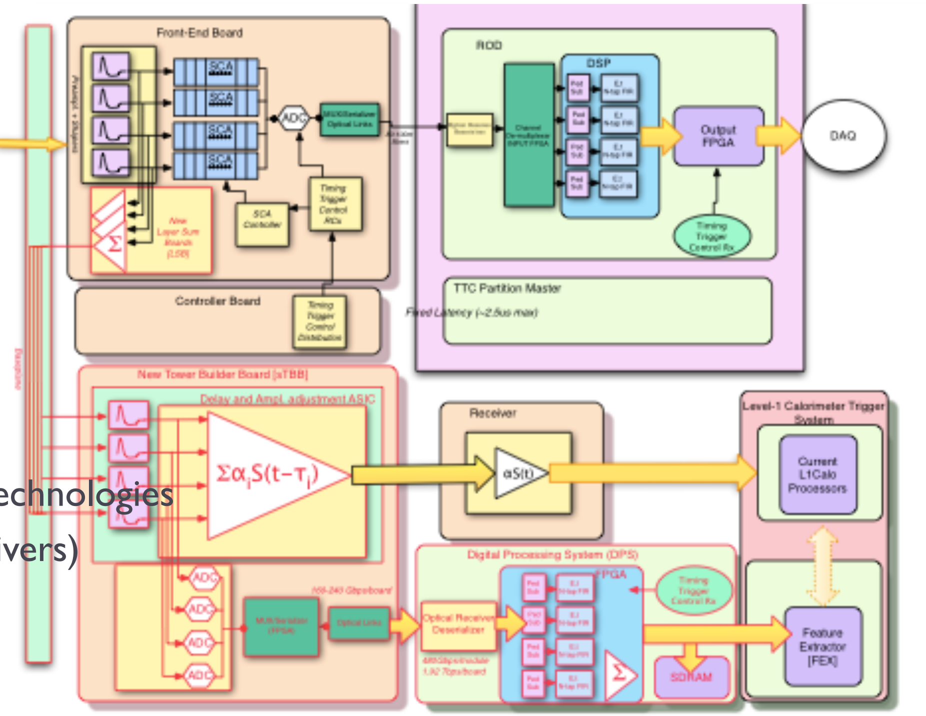
Cluster shape variable used in HLT for e/γ selection

L1 calorimeter upgrades

L1 EM rate limit: 20 kHz



- Increased rejection power with high transverse granularity
  - EM shower shape: factor 3-5 rejection on low pt jets
  - EM+H depth information to improve resolution on τ, jets and MET
- Phase-I: Trigger access to full calorimeter resolution
  - Change the read-out for trigger information
  - Mixed analog-digital design: adiabatic change from the current system
- Phase-2: at 10^{35} L1_EM30 rate is still over limit!
  - With current system ≈ 500 KHz → reduced by factor 5 (x2 for isolation)
  - Full digital read-out (data & trigger) with finer granularity?
    - Fast data transmission or latency concerns
  - Track trigger will help

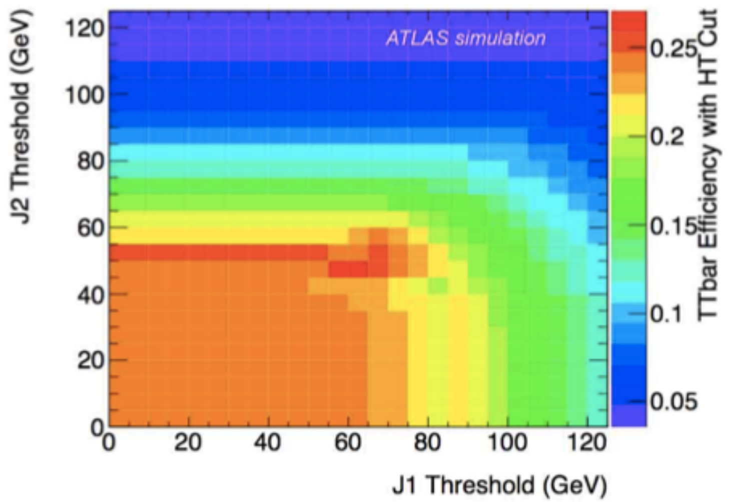


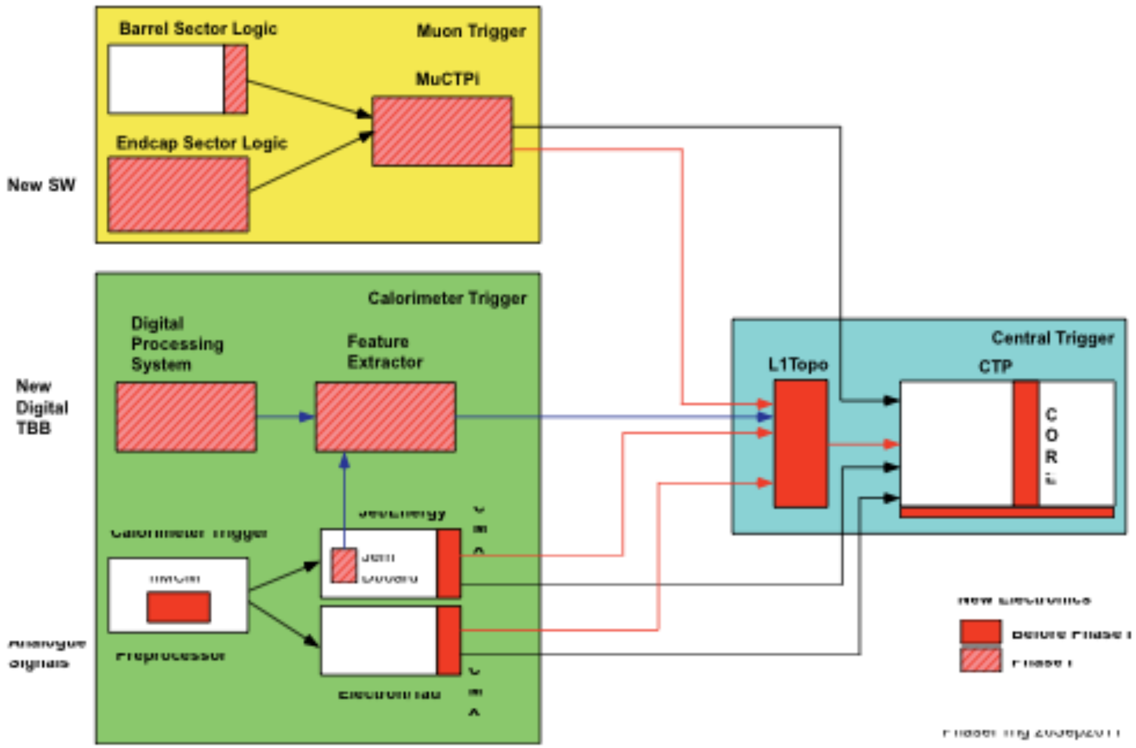
- R&D topics
  - Algorithms/architecture: need for simulation studies
  - High-speed backplanes: explore present limitations, new technologies
  - Fast rad-tolerant 10 Gb/s links (or parallel optical transceivers)
  - PCB technologies: study new standards: μ/A-TCA
  - Low-jitter clocking

L1 Topological Trigger

- Add flexibility to the L1 trigger
  - Angular distances, vetos, transverse mass…
    - Single lepton: electron/jet, muon isolation
    - Multi-objects: di-lepton M_T selects W/Z, multi-leptons SUSY modes
    - Used in L2: rate reduction by factor of 2–5

Efficiency of the L1 ttbar trigger as a function of the two leading jet ET thresholds, requiring HT>180GeV and 5kHz output rate

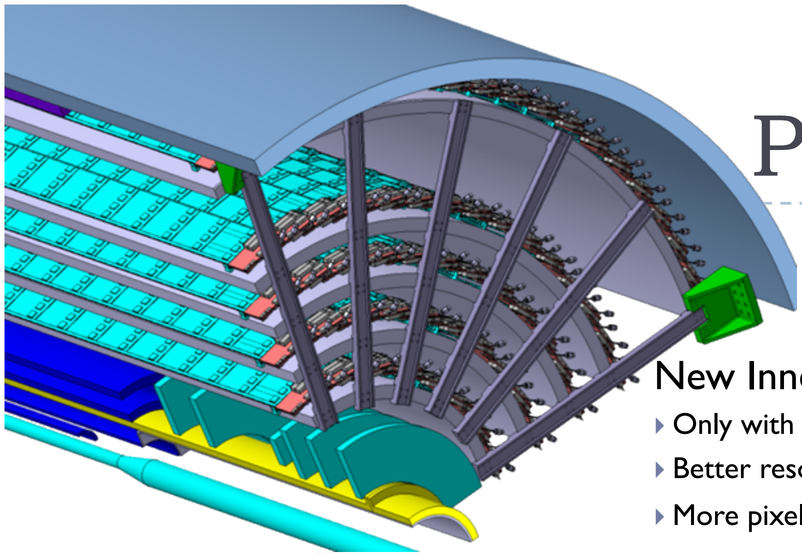




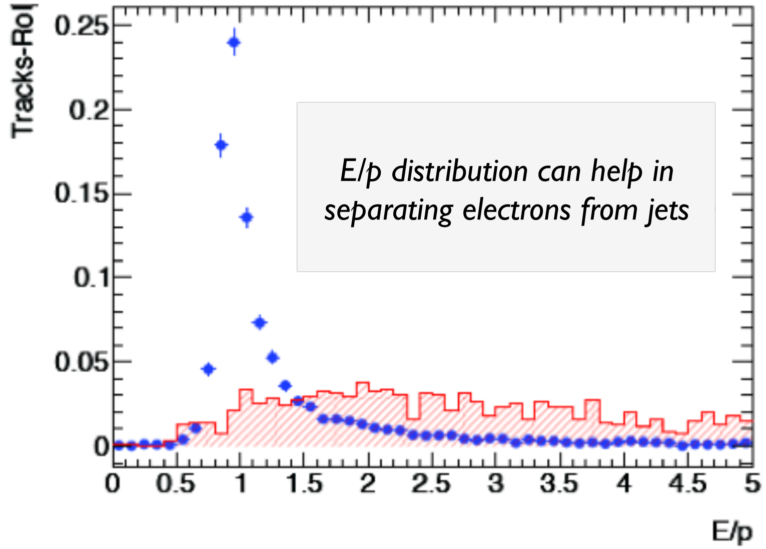
- New L1 processor with input from calorimeter and muon detectors, connected to new CTP
  - Increase number of thresholds, add functionalities
- Consequence:
  - Longer latency
  - Common tools for reconstructing topology both in muon and calorimeter

> - Demonstrator under construction
> - Phase-0: consolidate physics case
> - Phase-1: final prototype installed

Phase 2 – L1 Track Trigger



New Inner Detector
- Only with silicon sensors
- Better resolution, reduced occupancy
- More pixel layers for b-tagging



Tracking is a key ingredient in the current Level-2 trigger.
Use at Level-1 to:

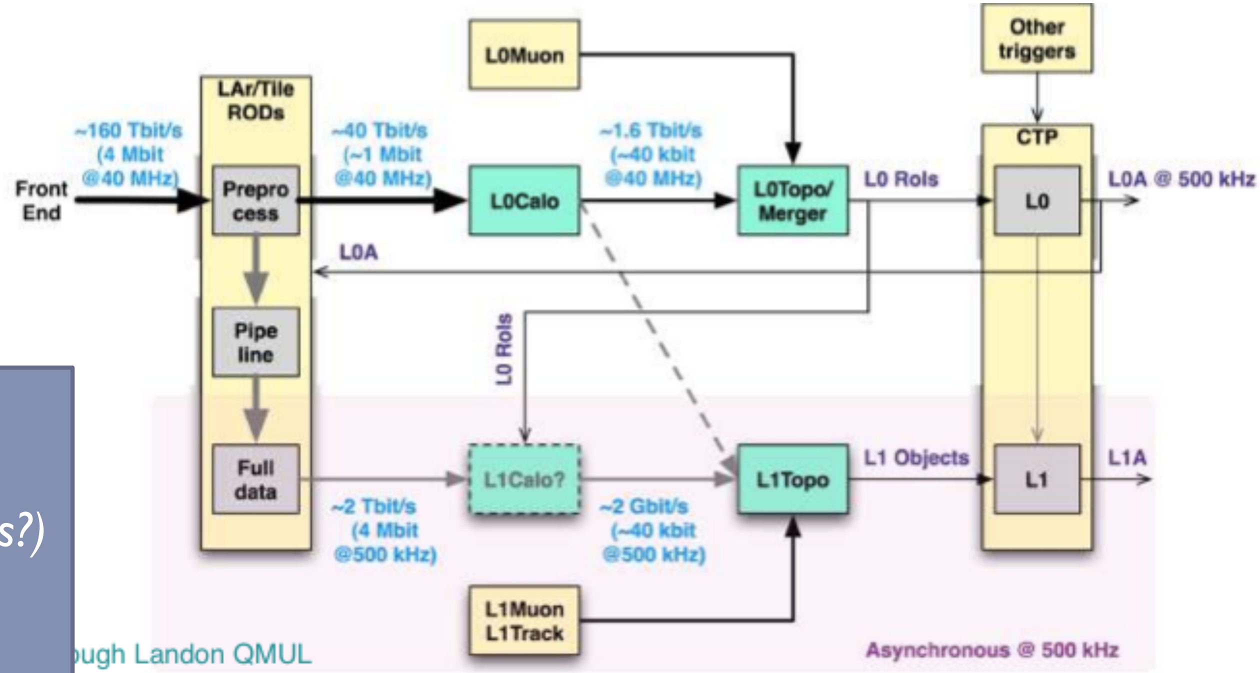
- Keep L1 rate within 100 kHz
  - Combine with calorimeter to improve electron selection (factor 10)
  - Correlate muon with tracks and reduce fake tracks (factor 5)
- Help many signatures
  - Provide track isolation and multiplicity for τ identification, impact parameter for L1 b-tagging
- Provide flexibility
  - Gives handles in unexpected conditions
- With a challenge
  - Reduce latency and bandwidth due to tracker data

- Two approaches:
  - Self Seeded
    - High p_T tracks as seed
    - Fast communication to form coincidences between layers
    - Redesign of tracker – material budget
    - Latency ~3 μs
  - ROI Seeded
    - Need to introduce a L0 trigger to provide RoIs
    - Long ~10 μs L1 latency

Under discussion

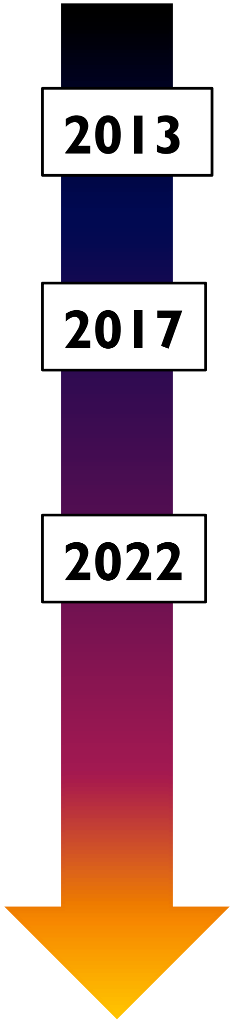
Two stages trigger in Phase-2: L0 + L1?

- L1 trigger driven by RoIs provided by a L0 trigger at 500 kHz
  - Extended latency (10-30 μs), add buffers, add complexity
- This schema allows/needs
  - Use full L2 resolution at L1, with increasing rejection
    - Track trigger at L1
    - MDTs in the trigger and more refined calorimeter data
  - Major changes in the electronic FE due to extended latency (and use the new precision TTC)
    - But some MDT electronics not accessible: MDTs resist up to L1=100kHz, max latency=6.4 μs



Still to understand:
- *L0 rate (500kHz? 1MHz?)*
- *Max L0 latency (6.4, 10, 30 μs?)*
- *TTC replacement*
- *Consequences to the readout*

Higher levels trigger evolution



- Harder life for HLT due to
  - Increased L1 rejection power
  - Performance degradation of algorithms
- Technology improvements should allow to handle increased demands
  - Hardware preprocessors (like FTK) integrated in the TDAQ system
  - More resources needed (CPU, memory)
  - Number of TDAQ applications running will increase as well
    - Issues for configuration, control and monitoring
- Phase-1:
  - Fast Tracking Trigger
- Phase-2:
  - Change of number of physical trigger levels?
    - Intermediate trigger levels / reduction in number, …

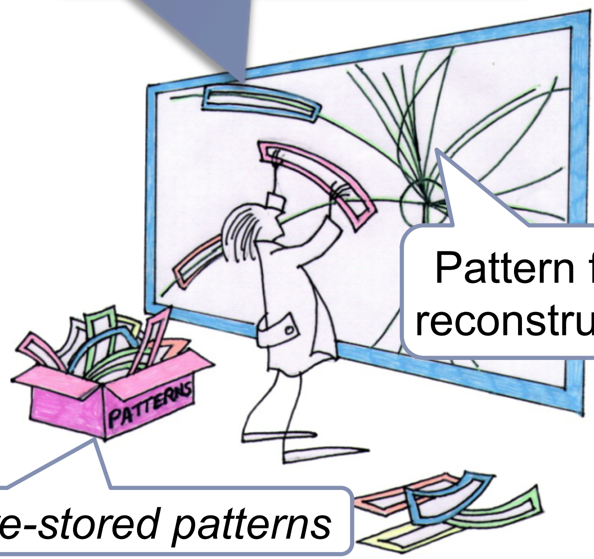
Fast Track Processor (FTK)

- Extension of the successful SVT project adopted in CDF
  - Reconstruct tracks >1 GeV at the Phase-1 Luminosity
  - Enhancing the capability for b / τ tagging and lepton isolation

- Introduce highly parallel processor for full Si-Tracker
  - Provide tracking parameters at full L1 rate (100kHz) within O (100 μ s) L2 latency
    - Optimize L2 selection (tracks available earlier)
  - Scalable to higher luminosities?

- Tracks reconstruction with 2 stages
  - Low resolution: pattern recognition with AM chips (with variable size resolution)
  - High resolution: track fitting with DSP (FPGAs)
  - 90% efficiency compared to offline (with 50M patterns) up to μ ~100

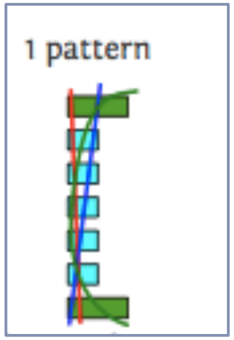
Good match between *Pre-stored* & **Recorded** patterns



Pattern from reconstruction

Pre-stored patterns

Discarded patterns



Variable size pattern

2010: Technical Proposal
2012: slice with prototype boards
2013: full prototype and TDR
Phase-1: full installation

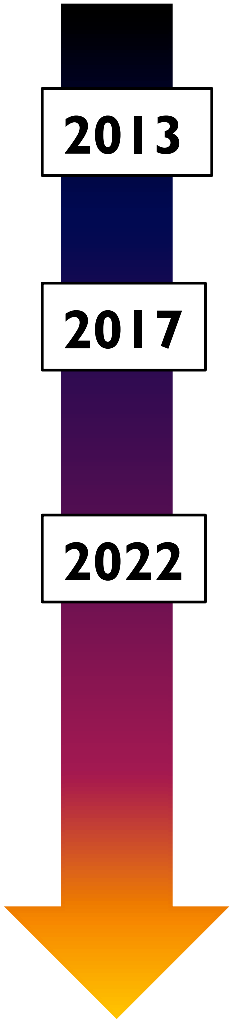
A lot of work on-going/to be done
- hw, sw and physics cases
- Performance validation during 2012 run
- Choice of trigger strategy

HL-LHC effects on the DAQ

Beyond design → new working point to be established

- Changes in sub-detectors to be taken into account
  - Higher detector occupancies
  - Higher detector granularity → higher number of read-out channels → increased event size
- Higher data throughput, hence load on DAQ
  - Higher data rate → **network** upgrade to accommodate higher bandwidth
  - Need for increased local data **storage**
- Possibility to profit from changes in sub-detectors
  - And/or front-end electronics
  - To provide improved trigger algorithms
- As of today, planning is difficult: driven by
  - Maintain trigger and DAQ excellent efficiency
  - Choice of new technologies
  - Coherence with all the upgrade phases

Evolution of the TDAQ Farm



- Mostly based on commodity components
  - Profit from technology advance
    - Higher bandwidth networks
    - More powerful CPUs
  - Exception
    - ROS system as custom developed components
- Today: architecture with many farms & network domains
  - CPU/network resources balancing on 3 different farms (L2, EB, EF) requires expertise
  - Huge configuration
- Phase-0 proposal: merge L2, EB, EF within a single homogeneous system
  - Each node can perform the whole HLT selection steps
  - Automatic system balance
  - A single HLT instance
  - Merge of networks
- Broad changes under discussion for next phases
  - Phase-1: retain interface to readout elements, partially switched ROSes
  - Phase-2: new sub-detector FEE?

TDAQ upgrade parameter space

- Still many decisions to be made. Lots of parameters we can play with
  - L1 accept rate
    - Increase to > 100 kHz has severe implications
      - Rebuild L1 processors, FEE electronics of all subdetectors
      - Now excluded yet: could be essential
  - L1 latency
    - Increase from 2.5 to 5 μs seems feasible in all cases
    - Could not be enough (if tracking included)
  - Number of physical trigger levels
    - L0 with short latency, L1 with longer
    - Closer L2/EF ?
  - Further parameters determining expected DAQ values
    - Total event size
    - Segmentation of events
    - Maximum fragment size

What if L0/L1 scheme?
What if L1 several 100's kHz?
What's the effect of L1 latency?

Timelines and references

- ATLAS Phase-0 and Phase-1 already approved with a LoI:
  - https://cdsweb.cern.ch/record/1402470/files/LHCC-I-020.pdf
    - To be approved soon by LHCC
  - TDR within the end of 2013 will start engineering design

- ATLAS Phase-2: many decisions to be taken in 2012, before the P-1 TDR
  - ATLAS Upgrade week in SLAC (starting next week)
  - ATLAS L1-trigger LoI by 2012
  - ATLAS P-2 LoI by 2013

Time is ready to start making decisions

…before it's too late!

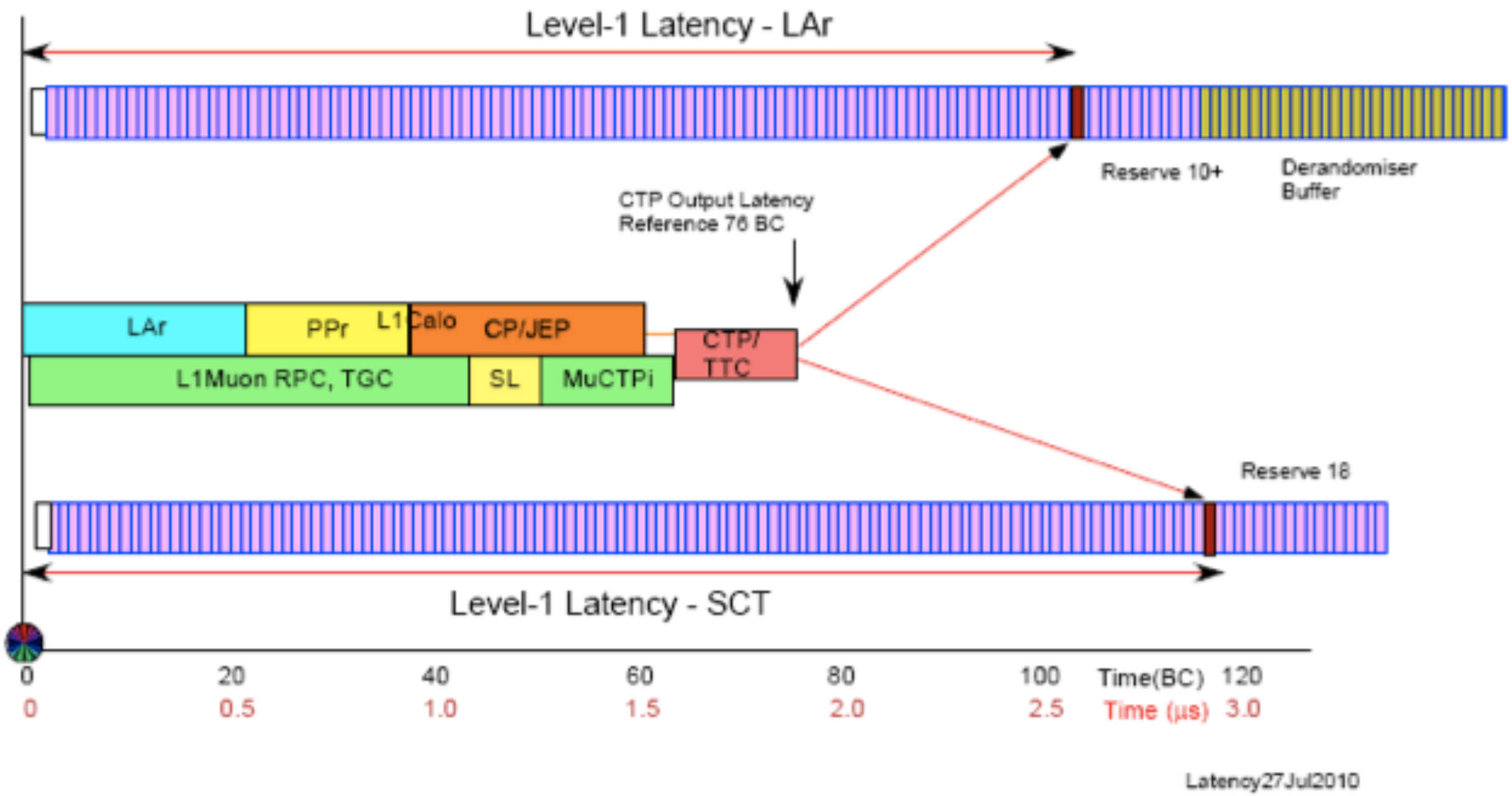
Back-up slides

CNRS project: FTK interfaced in the HLT

- Three different approaches
  - May include the FTK tracks only in the electron/muon selection
  - May include the FTK track parameters as seed of a subsequent refit which improves selection using more precise error handling and material corrections
  - May re-do pattern recognition in the RoIs as currently done at the third level trigger
- Different scenarios to be studied over a wide energy range
  - Different pile-up conditions
  - Different silicons acceptance (dead channels, noise)
  - With beam spot movements
- Test from data, with a HL menu (tighter cuts)
  - How helps isolation?
    - E/p measurement for electrons
    - Performance at very low pt for taus (<1.5GeV)
  - B-tagging, vertexing
- Online performance: timing, resolution

L1 latency budget

- Add new functionalities → Longer latencies – must fit in available latency budget



ATLAS planned upgrades

Element	Phase 0&1 (now through LS2)	Phase2 (after LS2)
Tracking	4^{th} barrel pixel layer (IBL), new pixels services (nSQP), New evaporative cooling plant, CO2 cooling plant for IBL, FTK level 1+ tracking. New tracking detector at 220 m (AFP)	Major revision, new Inner Detector, including possible LVL1 trigger capability + all new services
Calorimetry	Change all power suppliers, New LVL1 trigger electronics LAr. Additional better trigger capability for muons in the Hadron Tiles calorimeter.	New Front and back-end electronics, including trigger. New Forward calorimeter if proven necessary. Fix LAr hadronic cold electronics if neces.
Muon System	Install EE-chambers staged. Add additional chambers in key positions inside the barrel. Sharpen LVL1 muon trigger. New muon small wheels.	Increase trigger capability in the big wheels, add additional trigger inner layers in the barrel. New front-end electronics
Trigger/DAQ	New LVL1 trigger processors which make use of better detector granularity. Add a trigger level (FTK) between LVL1 and LVL2.	Major revision
Common systems	New forward pipes in Aluminum, new small radius Be beam pipe. More neutron shielding in the forward region and in between caverns. UPS extension. Consolidate cryogenics.	New TAS and forward shielding. Major infrastructure consolidation, including safety systems

CMS planned upgrades

Element	Phase 0&1 (now through LS2)	Phase2 (after LS2)
Tracking	Pixel--> 4 (barrel)+3(endcap) layers, low mass, CO_2 cooled, improved ROC Pixel and strip trackers cold operation.	Major revision, new pixel & strip trackers including trigger capability
Calorimetry	HCAL Phototransducer change HB/HE Depth segmentation Front and back-end electronics	New technology in endcap & forward regions.
Muon System	4'th endcap muon station (CSC+RPC) 1'st endcap μ station high η granularity DT MB1 TRB repl, DT Sector Collector move.	DT minicrate revision. Rate and background mitigation,
Trigger/DAQ	New L1 trig in μTCA(improved ganularity & algoritms). Revised optical links (Opto SLB's. HCAL & ECAL Trigger fibres and crates). Event builder & HLT renewal.	Major revision
Common systems	YE4 shielding wall, 45mm o/d beampipe, Magnet cryo redundancy. Lower risk moving system,(YE's + HF) UPS extension. Beam monitors PLT and BSC 2, N2 system upgrade.	Rebuild of forward pipes, TAS, shielding. BCM system replacement

LHC beam parameters

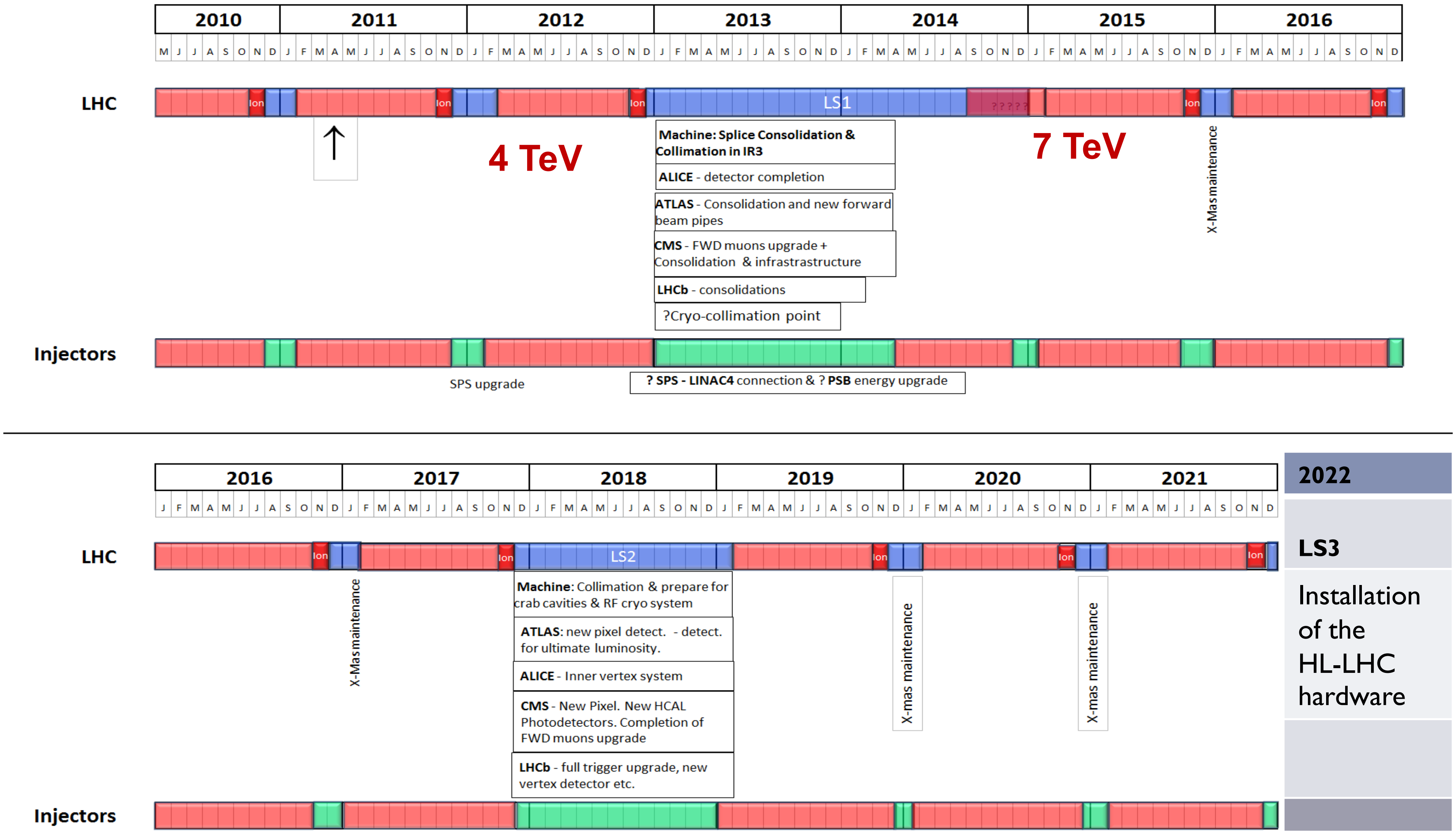
	design	October 2011	end 2012 ?	2016 ??
Beam energy	7 TeV	**3.5 TeV**	**4 TeV**	**6.5 TeV**
transv. norm. emittance	3.75 μm	**2.5 μm**	**2.5 μm**	**3.5 μm**
beta*	0.55 m	1.0 m	0.7 m	0.5 m
IP beam size	16.7 μm	24 μm	19 μm	17 μm
bunch intensity	1.15×10^{11}	**1.5×10^{11}**	**1.6×10^{11}**	**1.2×10^{11}**
# colliding bunches	2808	1331	1350	2800
bunch spacing	25 ns	**50 ns**	**50 ns**	25 ns
beam current	0.582 A	0.335 A	0.388 A	0.604 A
rms bunch length	7.55 cm	9 cm	9 cm	7.6 cm
full crossing angle	285 μrad	240 μrad	240 μrad	260 μrad
"Piwinski angle"	0.64	0.37	0.51	0.61
peak luminosity	10^{34} cm^{-2}s^{-1}	**3.6×10^{33} cm^{-2}s^{-1}**	**7.4×10^{33} cm^{-2}s^{-1}**	**1.3×10^{34} cm^{-2}s^{-1}**
average peak pile up*	25	**18**	**36**	**30**

*with σ~80 mbarn

10 year plan 2011-2021

from early 2011

New rough draft 10 year plan



Overall LHC Injector Upgrade Planning

	Linac4	PS injector, PS and SPS	Beam characteristics at LHC injection
2011 - 2012	Continuation of construction…	• Beam studies § simulations • Investigation of RCS option • Hardware prototyping • Design § construction of some equipment • TDR	25 ns, 1.2 10^{11}p/b, **~2.5 mm.mrad** 50 ns, 1.7 10^{11}p/b, **~2.2 mm.mrad** 75 ns, 1.2 10^{11} p/b, ≤ 2 mm.mrad
2013 – 2014 (Long Shutdown 1)	• **Linac4 beam commissioning** • **Connection to PSB ?**	• PSB modification (H^- injection) ? • PSB beam commissioning ? • Modifications and installation of prototypes in PS and SPS	
2015 - 2017	• Progressive increase of Linac4 beam current	• If Linac4 connected: progressive increase of PSB brightness • Some improvement of PS beam (Injection still at 1.4 GeV) • Equipment design § construction for PS injector, PS and SPS • Beam studies	• Limited gain at LHC injection (pending PSB (or RCS), PS and SPS hardware upgrades)
2018 (Long Shutdown 2)		• **Extensive installations in PS injector, PS and SPS** • **Beam commissioning**	
2019 –2021			**After ~1 year of operation: beam characteristics for HL-LHC…**

TDAQ readout-slice