Overview of the ATLAS Upgrade Programme

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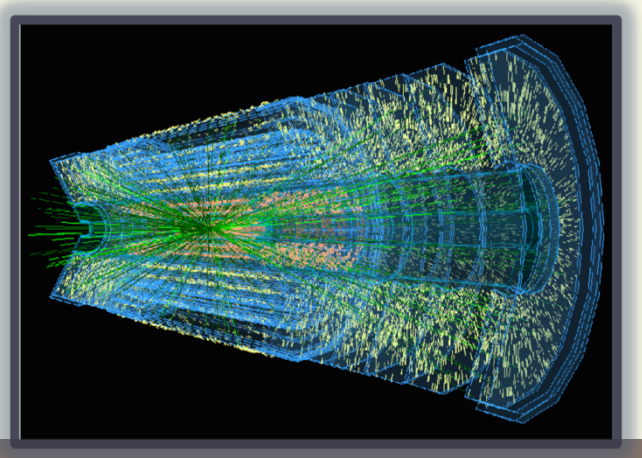


Outline

- Introduction
  - Run I: State of the Art
  - LHC Upgrade Schedule
- ATLAS Upgrades Towards HL-LHC
  - Physics Potential
  - Detector Upgrades
- Conclusions

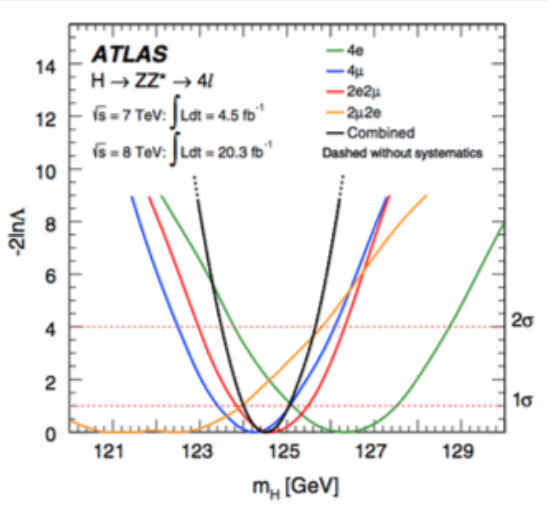
CAVEAT EMPTORS:

- PLENTY OF GUESSWORK
- NOT A THOROUGH REVIEW OF ATLAS UPGRADES
- MISTAKES ARE ALL MINE!
- SORRY IF THIS WILL SOUND MORE LIKE AN OVERVIEW OF TOOLS: NO FIRM STRATEGY YET!

The state of the (ATLAS) art

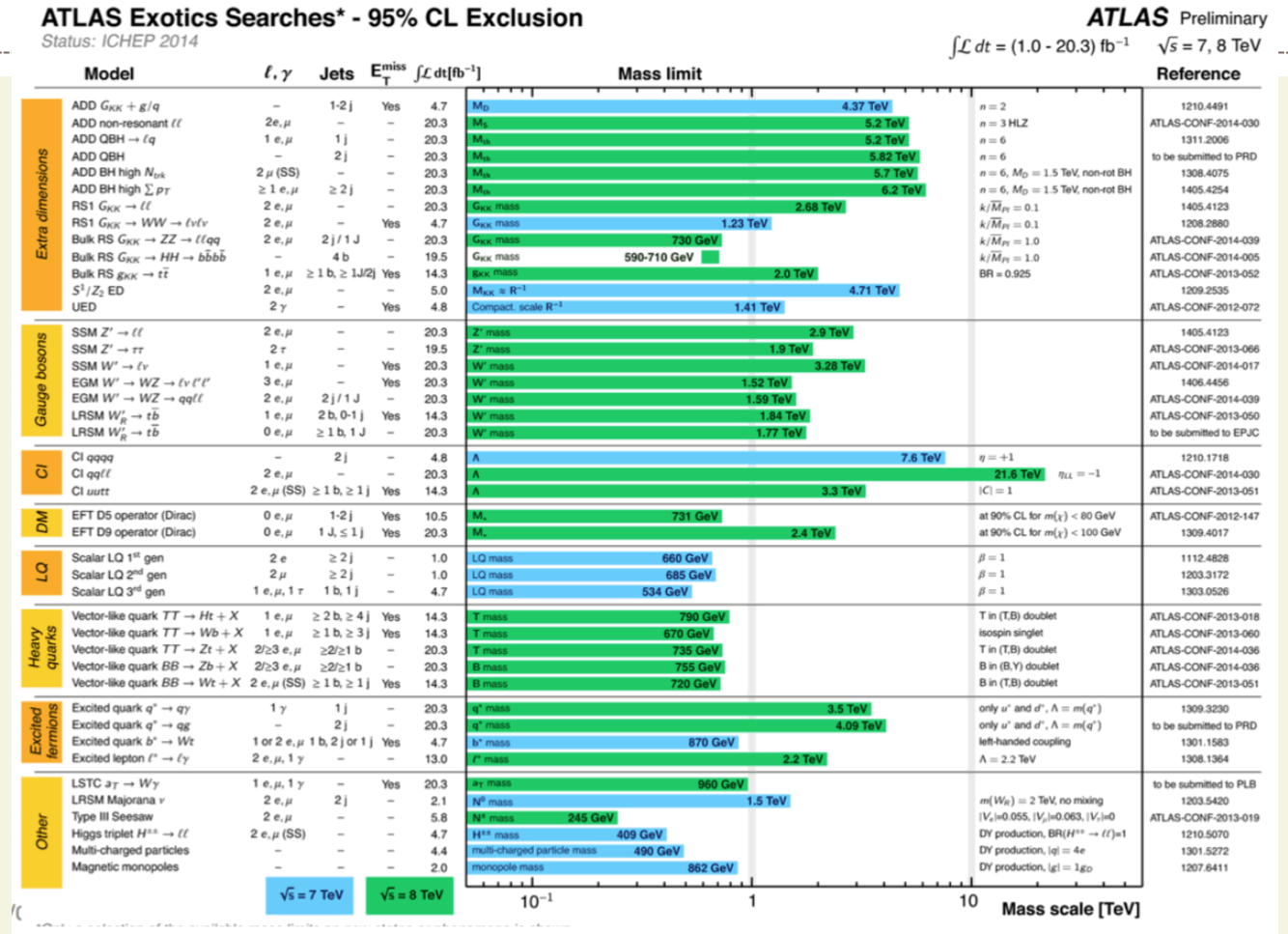
- We found a pretty SM-like Higgs Boson! PRD 90 052004 (2014)
  - Mass…
    - as predicted!
    - Precise: 125.4±0.4±0.2 GeV
  - Spin-parity consistent with 0^+
  - Run I: 40 candidates → Run II: ~500/mode
  - H couplings are falling into place too

ATL-CONF_2014-009



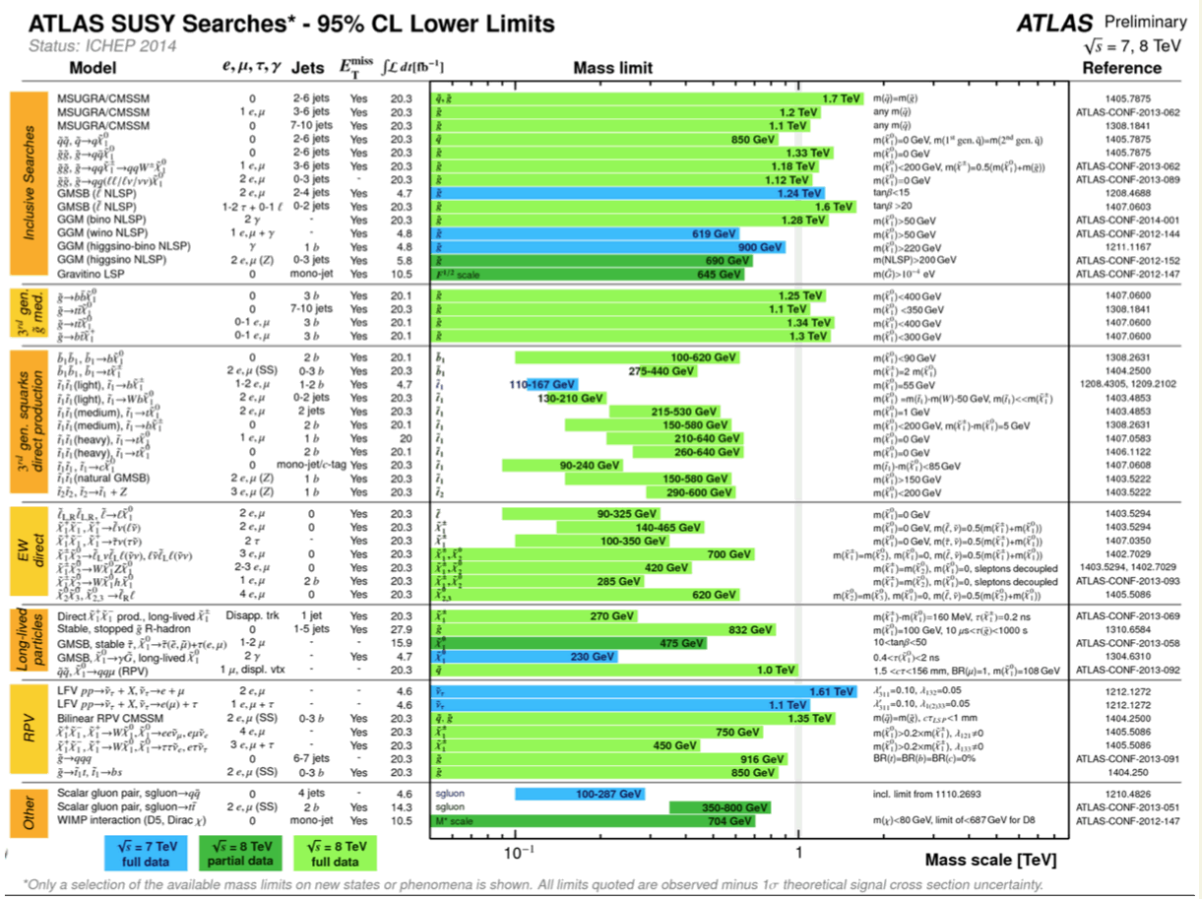
- LHC is a top factory! ATL-CONF_2014-008 ATL-CONF_2014-055
  - Production σ ↔ proton structure
  - t mass is still an important SM constraint

Exotic Searches



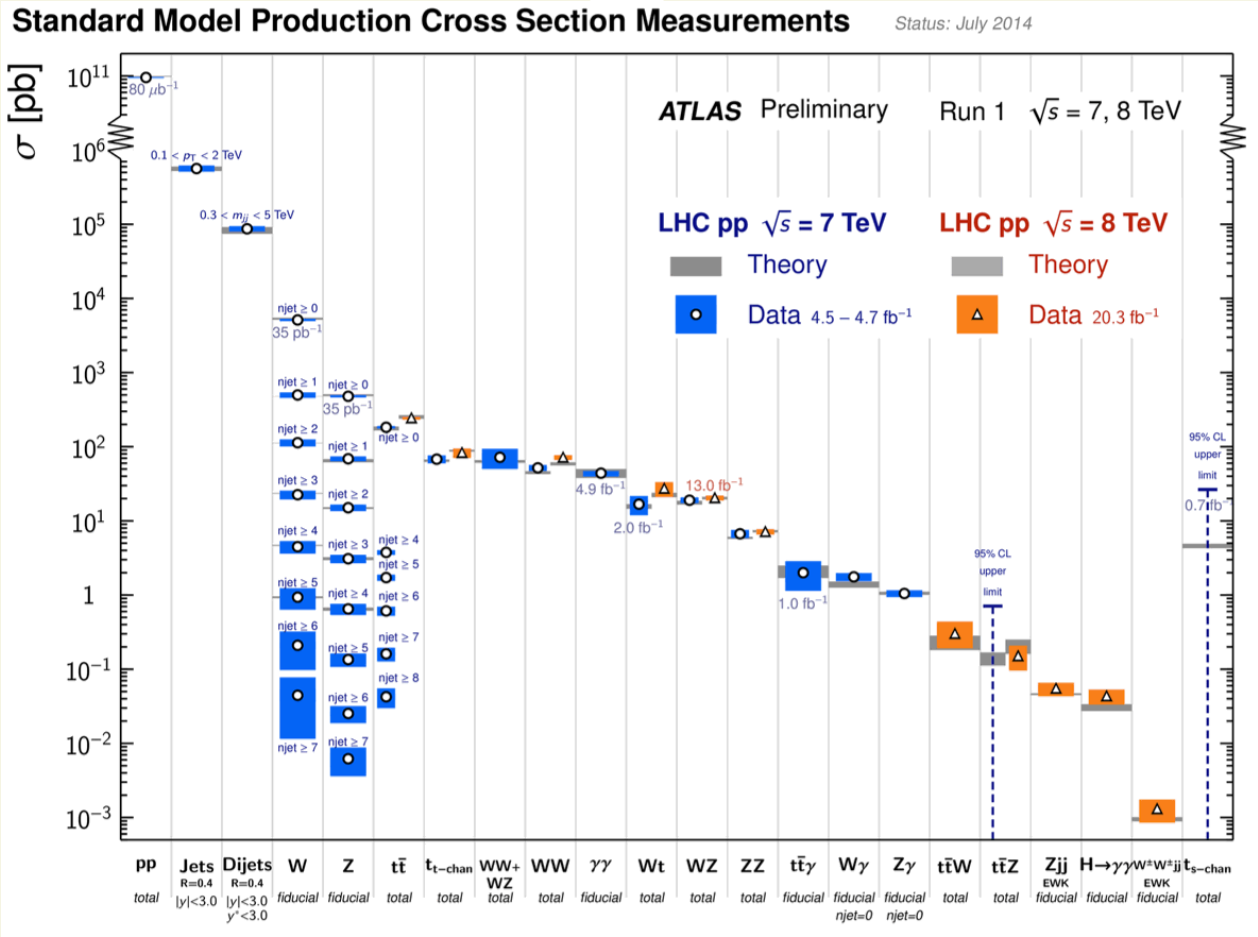
- Limits at ~TeV scale, obviously model dependent…

SUSY



- TeV Scale… “less obviously” model dependent!

Last but not least: SM!



- Impressive agreement across 9 orders of magnitude!

And Now What?

What's our best bet?

- The CERN council adopted ECFA's recommendation, including prioritisation:
  - Higgs Boson properties
    - SM test
    - New Physics search
  - LHC is in a strategic position, including the high-luminosity upgrade
- HEPAP in US (May 2014) supports and recommends HL-LHC as "the first high-priority large-category project"

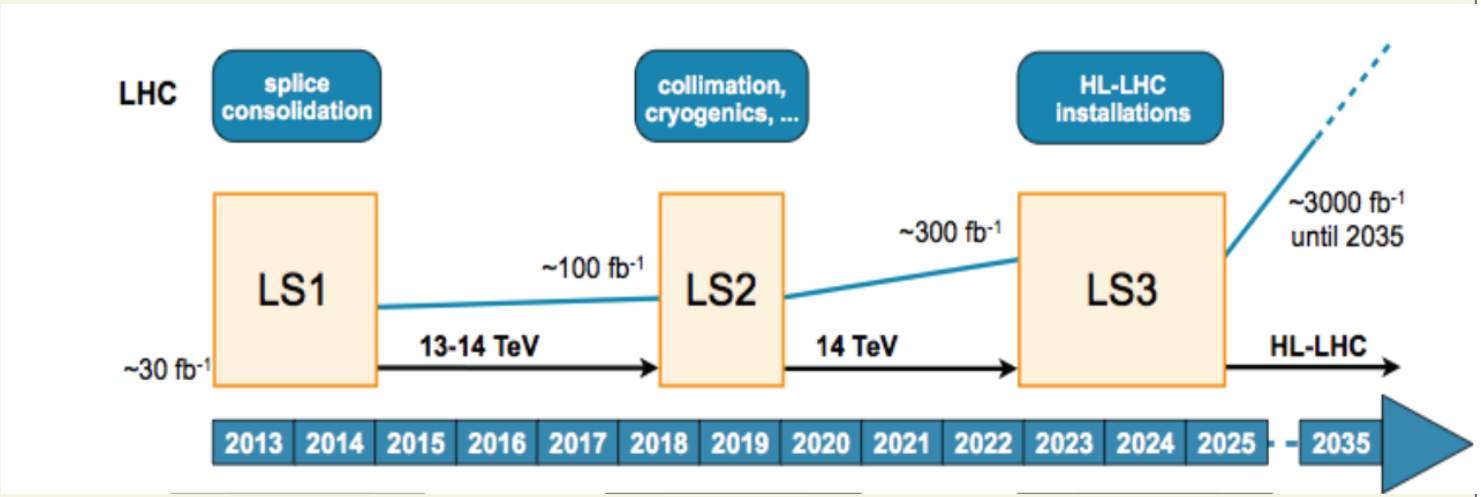
ATLAS Upgrade: Physics Goals

- Understand the Higgs Boson
  - Mass, CP, Standard Model couplings,…
- Measure t, W and Z properties
  - Strongest coupling to H
- Search for new TeV-scale particles
  - What is the importance of this scale to SM?
- Find/understand any Standard Model anomalies
- …flavour?

The LHC Upgrade Roadmap

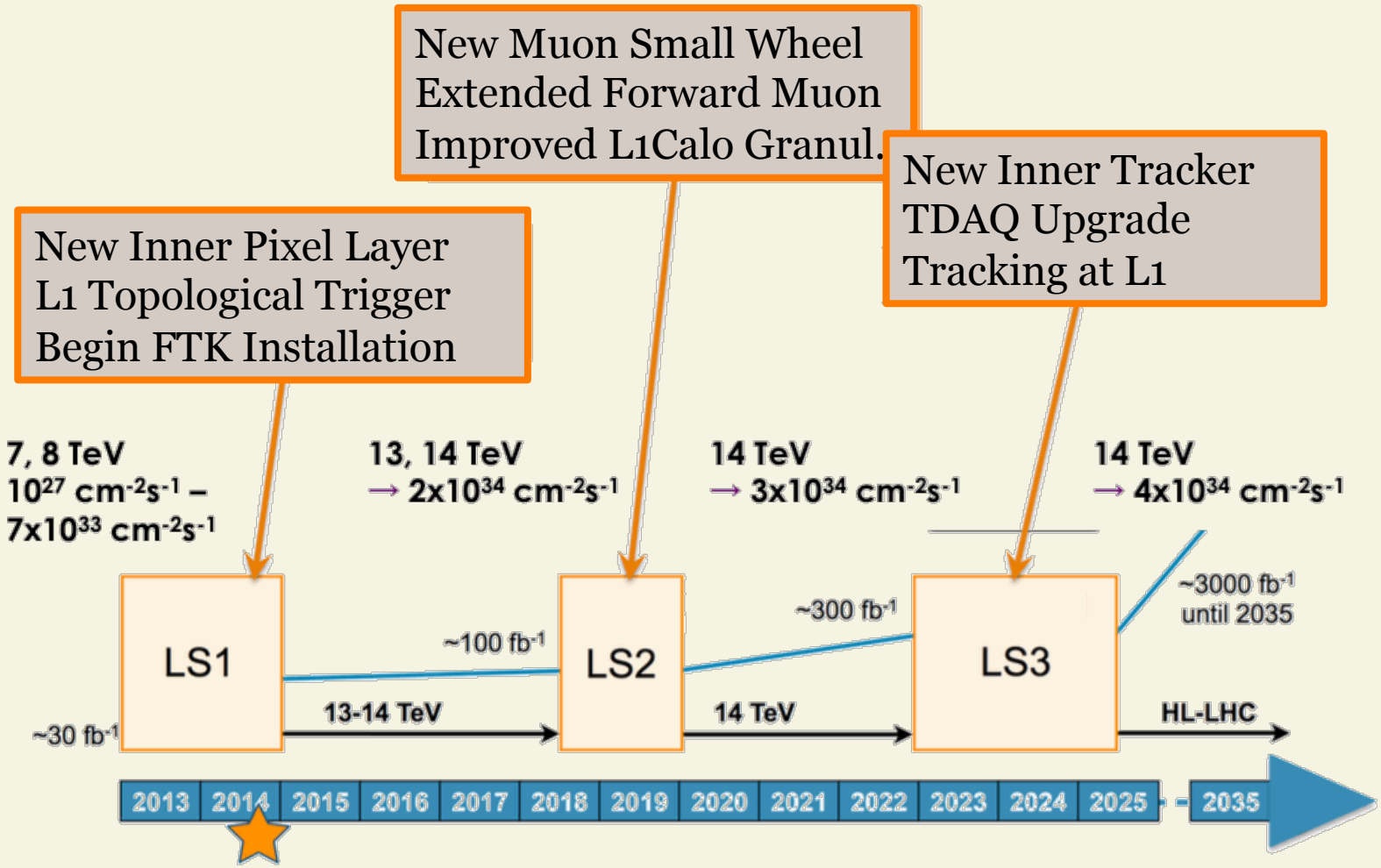
LS2:
- Start: 2018
- 18+3 Months

LS3:
- Start 2023
- 30+3 Months



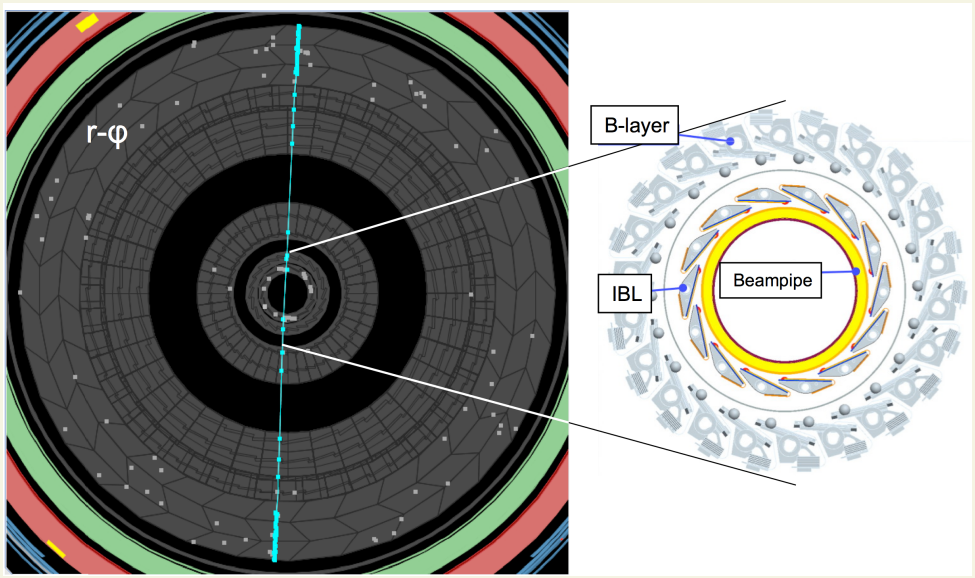
HL-LHC: Major upgrades for LHC+detectors
New project ⇒ significant R&D ongoing

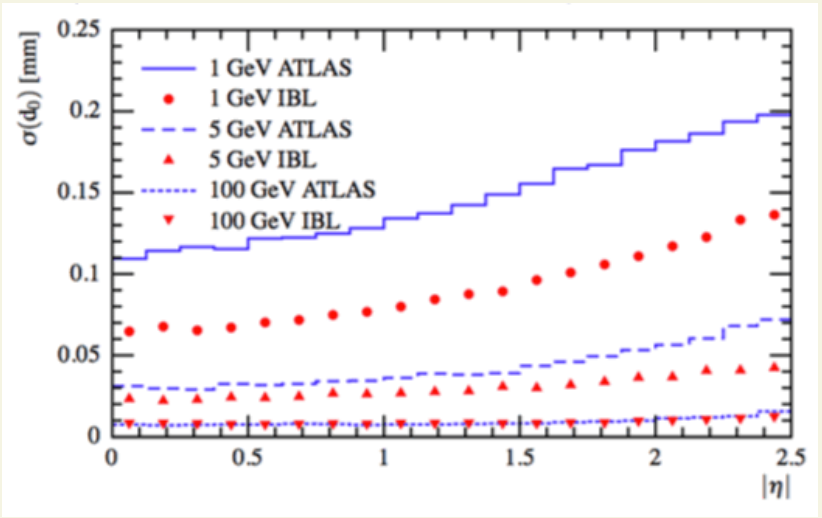
ATLAS Roadmap



ATLAS Tracker: Run II

- Additional Insertable B layer (IBL)
  - 32-38 mm (vs 50.5 mm innermost layer in Run I)
  - Fourth pixel layer improves
    - σ_{do} and σ_{zo}
    - θ and φ @ low p_T (~1 GeV)





First cosmic rays just observed in fully installed IBL!

ATLAS Tracker: HL-LHC

- Facing x5 fluence
- Higher η coverage
- Lighter
- Up to 14 hits/track

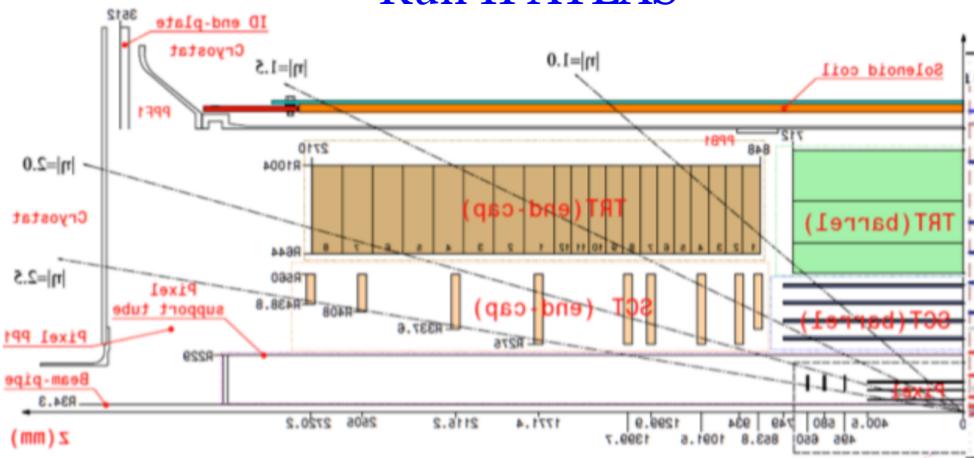
Pixels

- 80 → 638 Mchan.
- 50×400→ 25×150/50×250 μm²
- 1MHz Readout

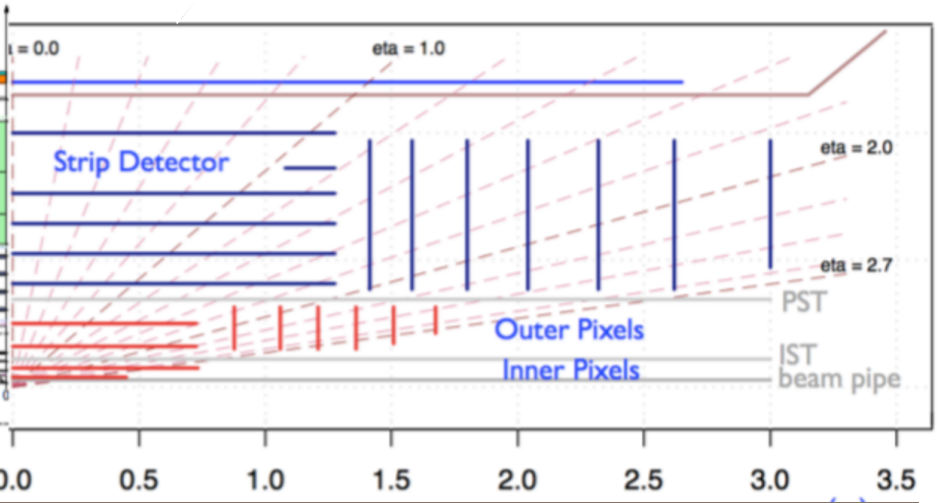
Double-sided strips

- 6 → 74 Mchan.
- 2.45-4.9 cm
- 74.5 μm pitch
- 40 mrad st. angle
- Slower read-out (chip size & placement)

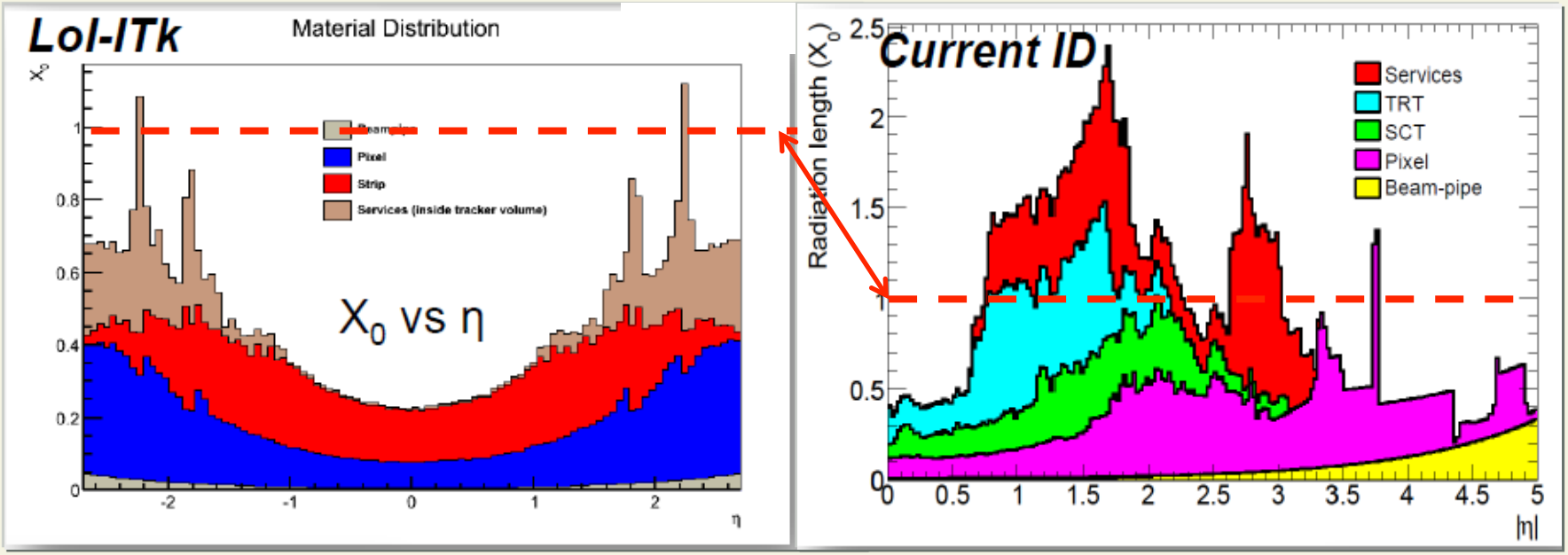
Run II ATLAS



HL-ATLAS



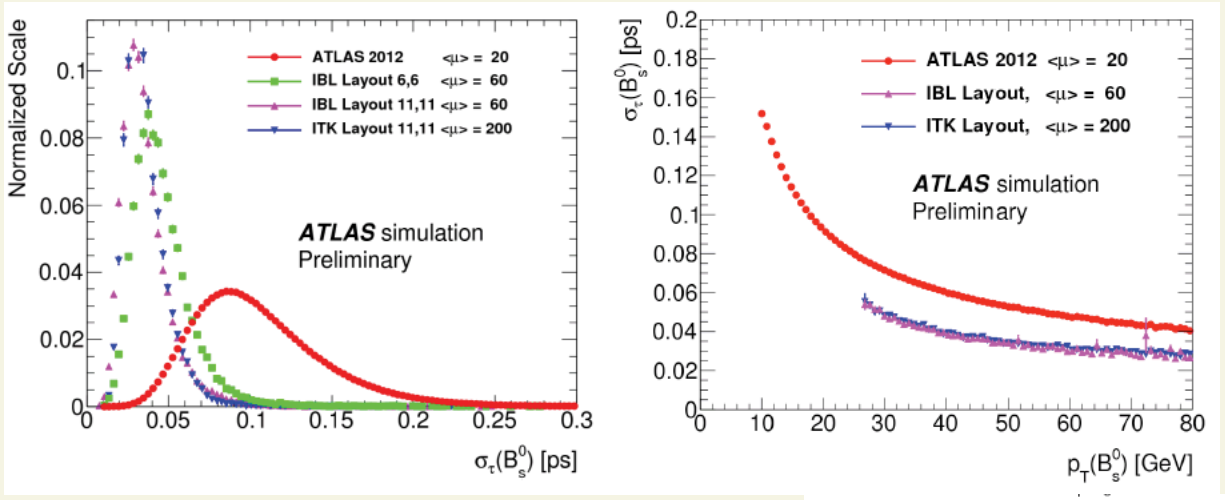
Detector Mass Distribution



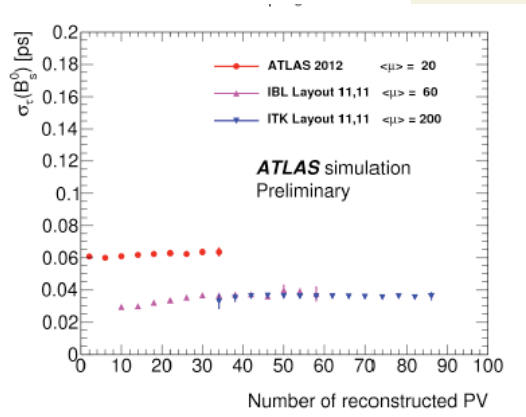
- ITK has significantly less detector mass in tracking volume

Performance with IBL and ITK

- Lifetime resolution improved by ~30% wrt Run I
- Higher p_T reach further enhances resolution



- σ~35 fs
- Soft dependence on #PV!



φ_s Predictions

- Improvement mitigated by the (potential) increase in trigger thresholds!
- Extrapolating this to proper HL-LHC conditions… your (back of envelope) guess as good as mine!

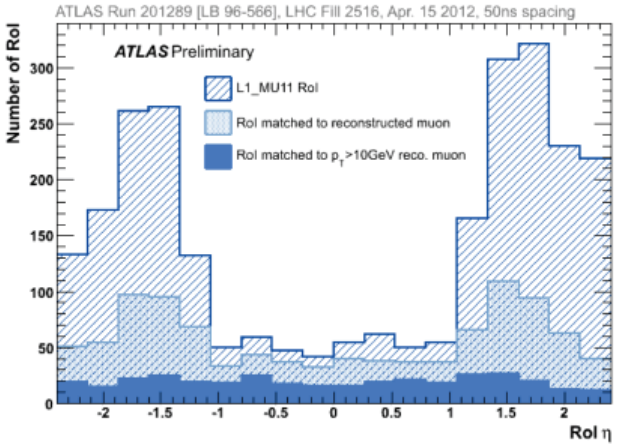
	2011	2012	2015-17		2019-21	2023-30+
Detector	current	current	IBL		IBL	ITK
Average interactions per BX $<\mu>$	6-12	21	60		60	200
Luminosity, fb^{-1}	4.9	20	100		250	3 000
Di-μ trigger p_T thresholds, GeV	4 - 4(6)	4 - 6	6 - 6	11 - 11	11 - 11	11 - 11
Signal events per fb^{-1}	4 400	4 320	3 280	460	460	330
Signal events	22 000	86 400	327 900	45 500	114 000	810 000
Total events in analysis	130 000	550 000	1 874 000	284 000	758 000	6 461 000
MC $\sigma(\phi_s)$ (stat.), rad	0.25	0.12	0.054	0.10	0.064	0.022

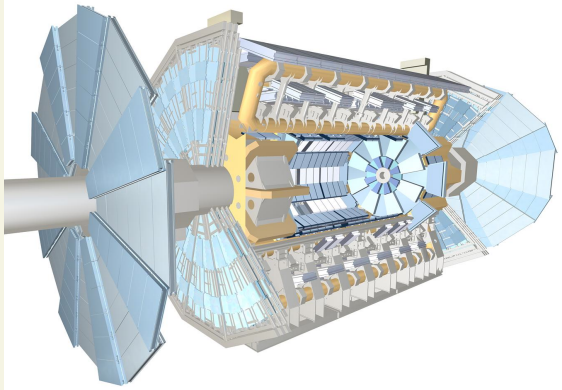
NB: topological trigger and FTK not considered!

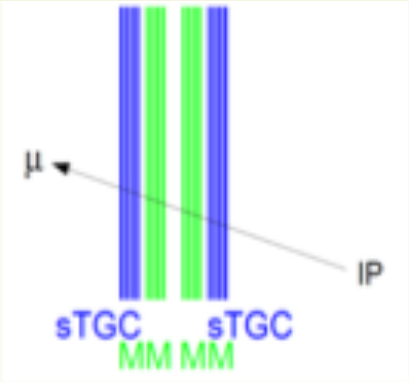
CERN-LHCC-2011-012
CERN-LHCC-2013-018

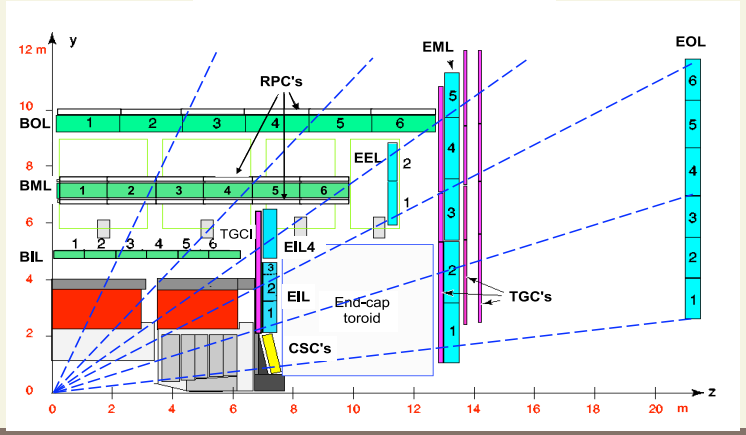
New Muon Small Wheel

- Forward triggers have higher fake rates
  - @3E34 ⇒ forward triggers exceed max. storage!
- New Muon Small Wheel (LS2)
  - Additional trigger segment matched
  - Kill fake muon triggers with high quality (σ~1mrad) pointing to IP
  - Coupled to μ detector extension to large η (2.5-4)









ATLAS TDAQ Upgrade

Run I:

L1 →Dedicated Hardware 75KHz accept rate

L2, L3 ("EF")→ Commercial CPU 3KHz/200 Hz accept rate

L1→HLT via regions of interest

Run II (phase 0 upgrades, LS1):

- L2+EF→HLT (100 KHz @ L1, 300-500 Hz @HLT)
- FTK: global hardware-based tracking for HLT
- Topological capabilities in L1
- Improved pile-up suppression in L1 calorimeter trigger (L1Calo)

Run III (phase 1 upgrades, LS2):

- Refine L1Calo granularity
- New Muon Small Wheel

HL-LHC (phase 2 upgrades, LS3):

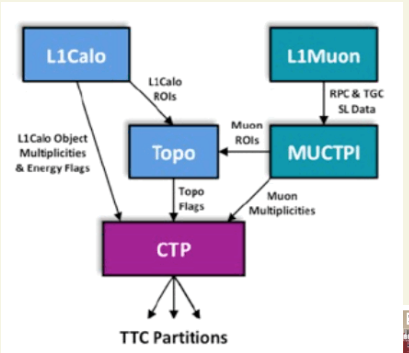
- Tracking at L1 (L1TT)
- μ Barrel and Big-wheel electronics replacement

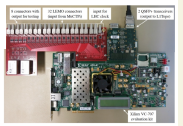
Event Selection for HF

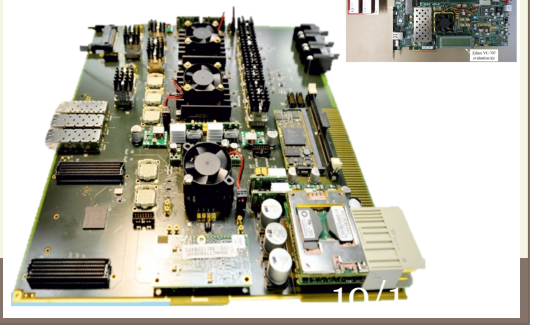
- Current HF programme based on di-muon triggers
- As $\mathcal{L}$ increases, so will μ pT thresholds
  - Could maintain (4,4) in the first fb of Run II
  - Will move to (4,6)→(6,6)→(11,11) by 2016(7)
  - High-p_T single-muon triggers can become attractive

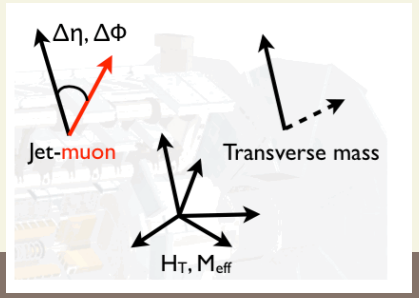
High pT (~> 60 GeV) di-muons will appear as single-μ

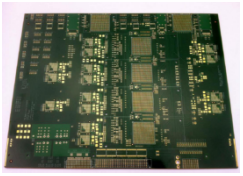
  - L1 topological trigger
    - Simple di-object combinatorial
    - Δφ, Δη,...
    - Can significantly improve low-p_T μμ acceptance for specific modes...



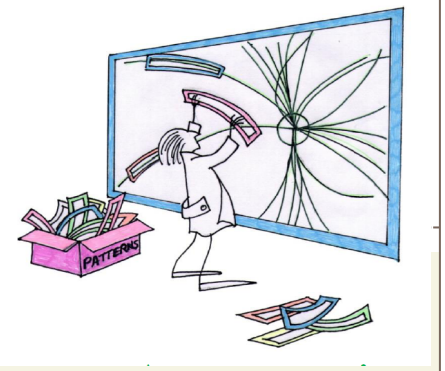




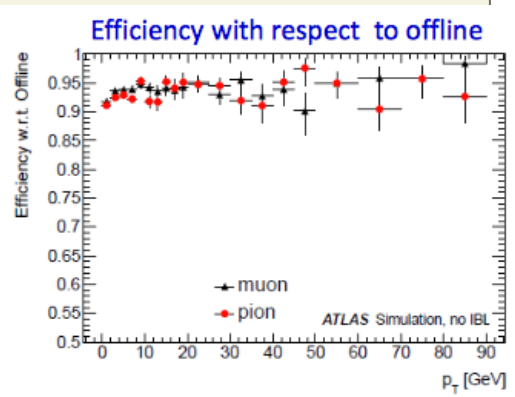


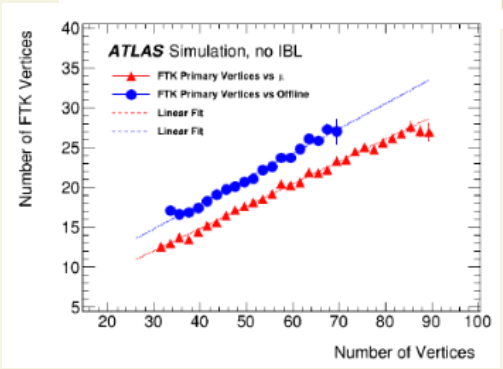


FTK Upgrade



- Hardware based track finding and fitting
  - Fully parallel pattern recognition (→AMChip)
  - 10^9 Pre-loaded patterns (from simulation)
    - Coarser detector resolution
    - Simultaneously compared to oncoming detector hits
  - Pattern recognition ~done once detector is read-out
  - FPGA-based track fitting (1 fit/ns):
    - Track parameter determination
    - Solve combinatorial problem within one "pattern"
- Full IT volume tracking
  - down to 1 GeV
  - Within 40 μs
- Being deployed along Run II!

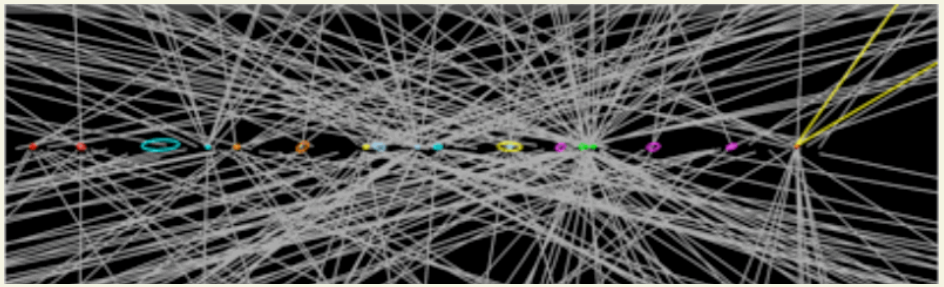




FTK will provide additional flexibility in the selection of HF events with the ATLAS HLT

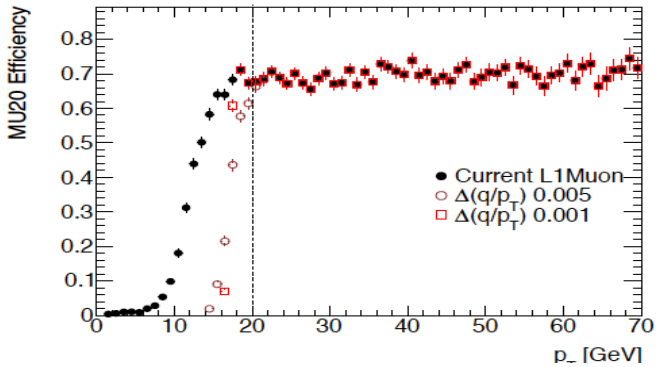
FTK Use

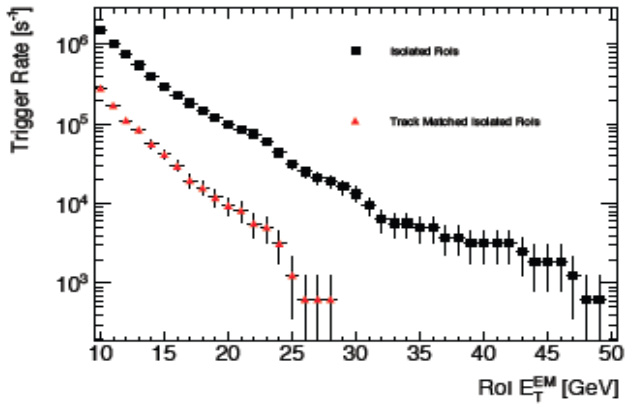
- Improve rejection at HLT level:
  - Exploit complex topologies (J/ψφ, K*ll…)
  - Lifetime cut
  - Much more selective mass selection than what possible @L1
- ATLAS as a "parallel" LHC-B physics experiment at "levelled" luminosity
  - 1 GeV tracking
  - 4ish GeV muon ID
  - Offline-like resolutions



Tracking at L1 for HL-ATLAS: L1TT

- Complement muon and EM triggers:
  - Improve muon p_T resolution
  - Improve EM ID
- Implemented as 2-level scheme
  - Accommodate legacy electronics
  - Reduce links from strip tracker
  - → Reuses phase-1 L1 trigger improvements for new L0
- FTK technology effective on RoI-based approach





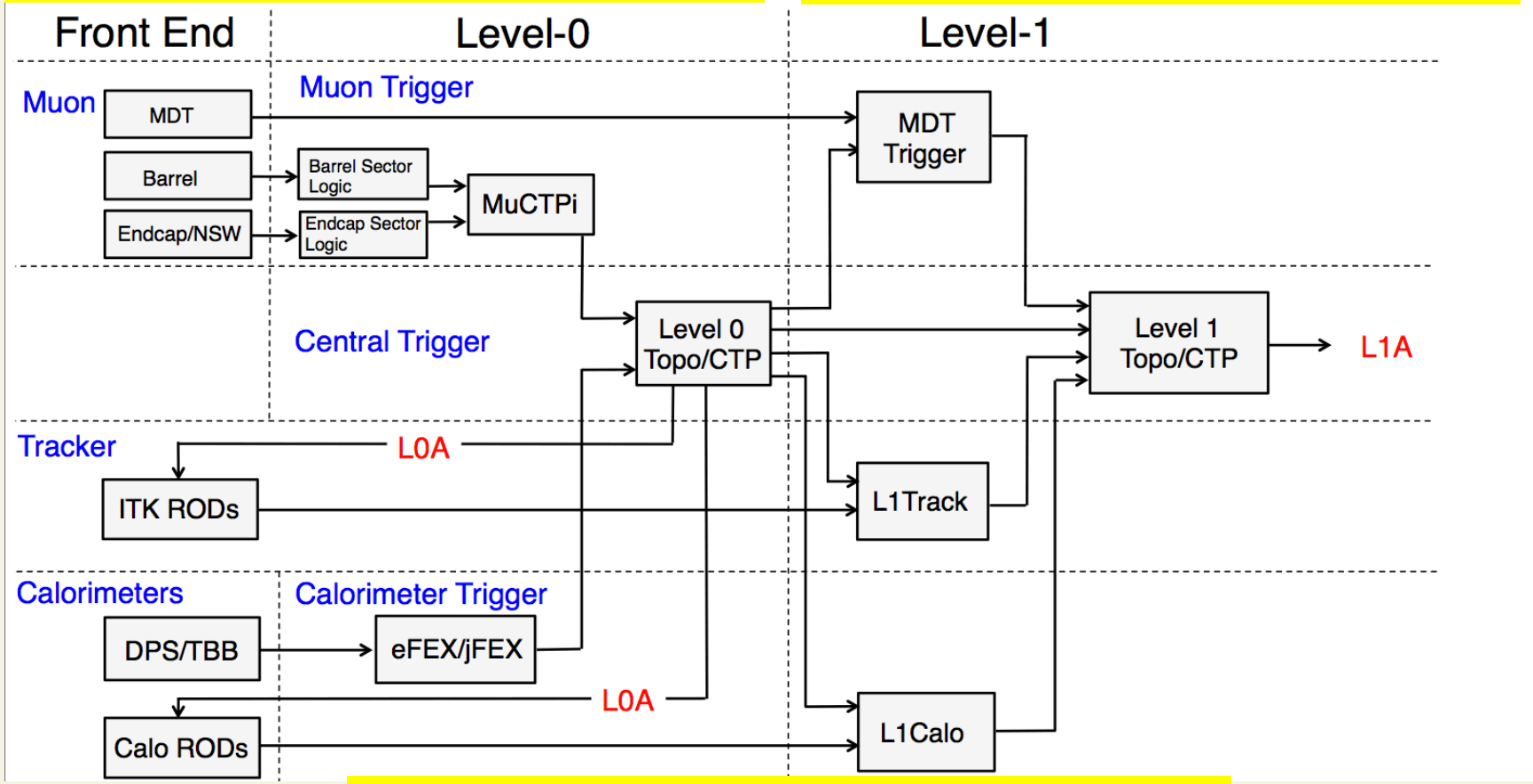
What potential for HF selections @L1?

- Better mass/angular resolution @ L1
- Further potential in non-topological approach

A New Trigger Level in HL-ATLAS

Most of "2019" L1: 500 KHz, 6μs latency

New L1: 200 KHz, ~30μs latency



Under investigation: L0A/L1A at 1 MHz/400 KHz

Conclusions

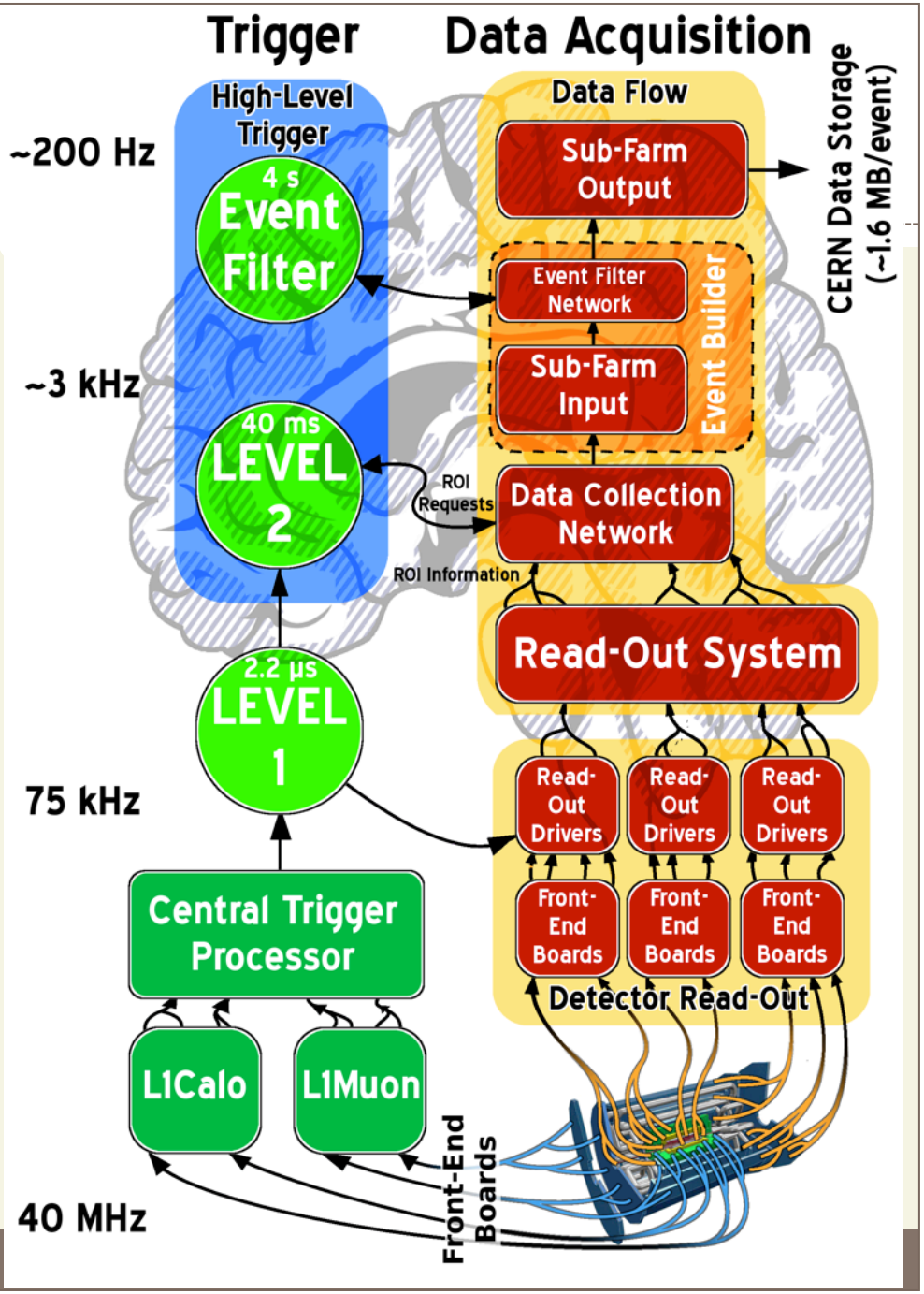
- Onia/HF program in ATLAS will remain healthy
  - If a little boosted
- Preparations for first Run II quarkonium/B physics measurements show us the way as $\mathcal{L}$ grows:
  - Must maximally and cleverly exploit improvements:
    - Tracking
    - Trigger HW and strategies
    - Muon coverage
  - Low p_T reach will become increasingly harder
    - There may be exceptions for specific modes/topologies
  - Study of high-p_T and/or complex topologies favoured as $\mathcal{L}$ increases
- The tools are there: we need to get creative!

Backup

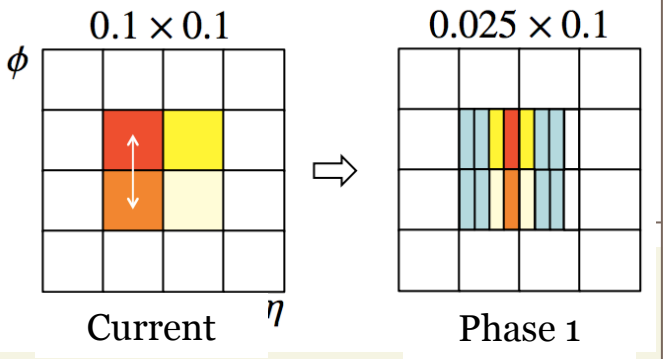
The ATLAS Run I trigger

3-tier system

- Level-1 → HW implementation
- L2+L3 commercial CPU
- L1→HLT via Regions of Interest



Phase I trigger upgrades (2019)

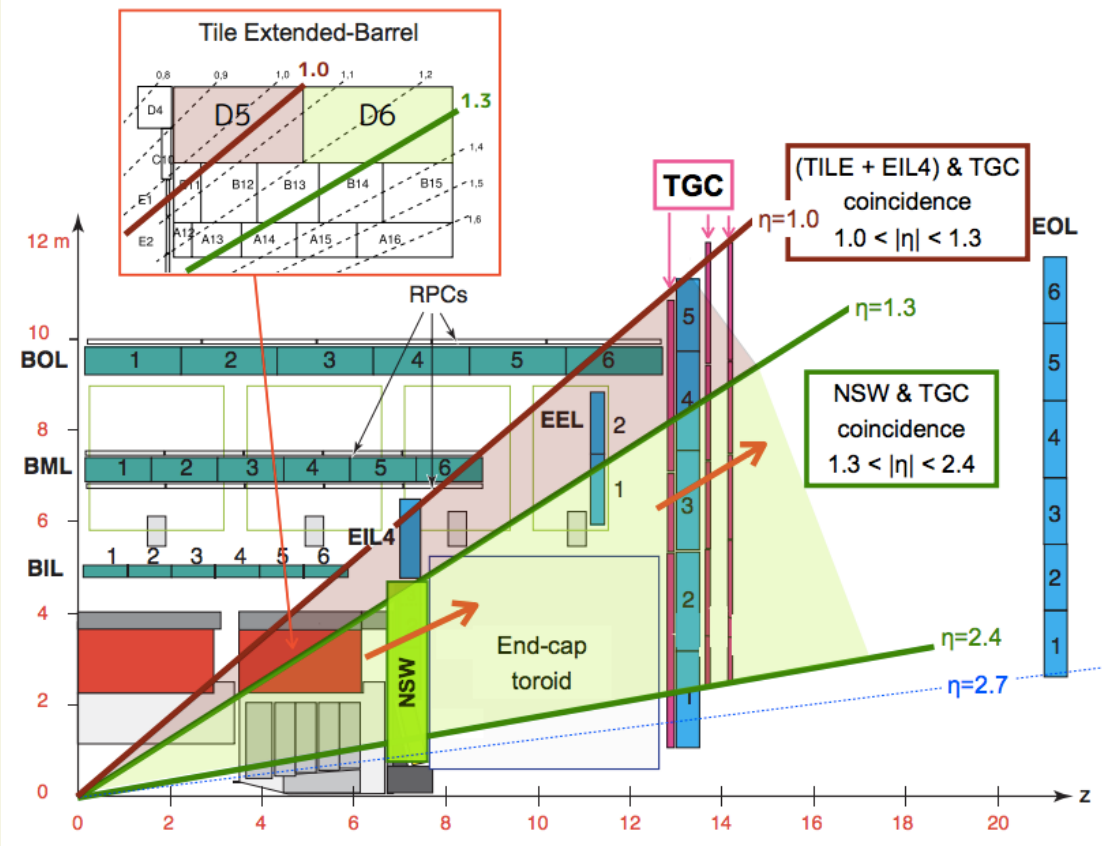


Phase 0:

- L2+EF → HLT
- FTK: global tracking for HLT (installation completed with phase I)
- Topological capabilities at L1
- Improved pile-up suppression In L1Calo

Phase I:

- Refine L1Calo granularity
- New muon small wheel (NSW)

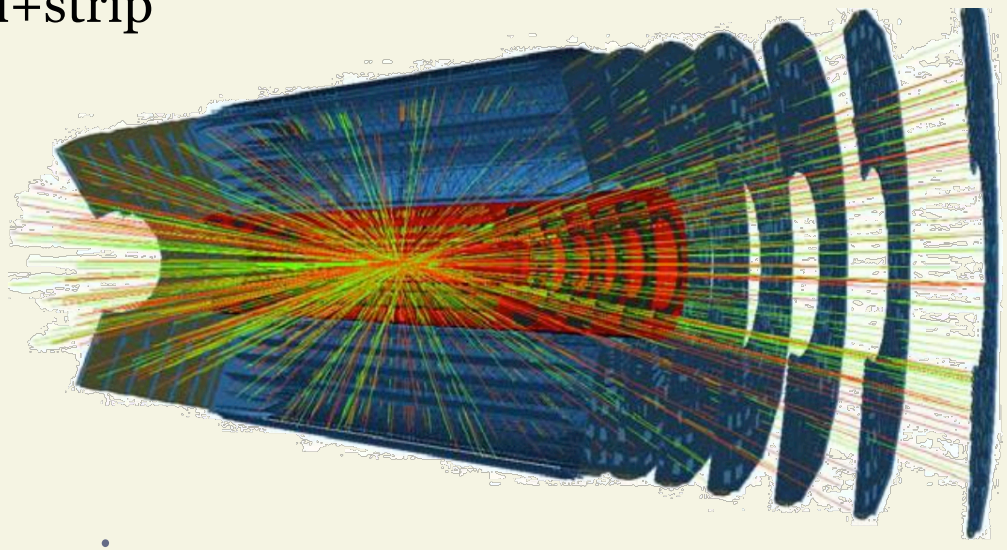


Reduced fakes, improved resolution

ATLAS for HL-LHC (2023)

- Software and Computing
- Detector:
  - Brand-new Si detector
    - Inner tracker (ITK): pixel+strip
  - LAr calo electronics
  - Muon drift chamber
  - Forward detector
  - Shielding
- Trigger:
  - L1 Track Trigger (L1TT)
  - μ barrel & big wheel electronics

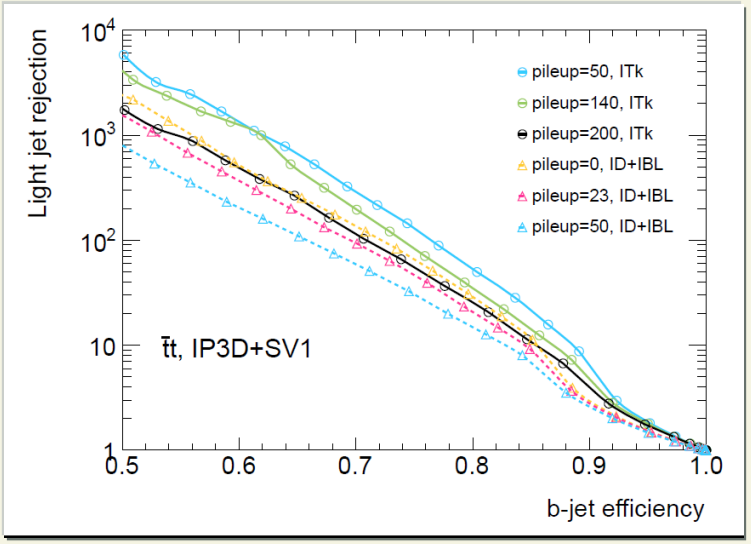
<μ>~140 @ 25ns x-rate
⇒ 2-3×10^{16} 1 MeV $neutron_{eq}/cm^2$

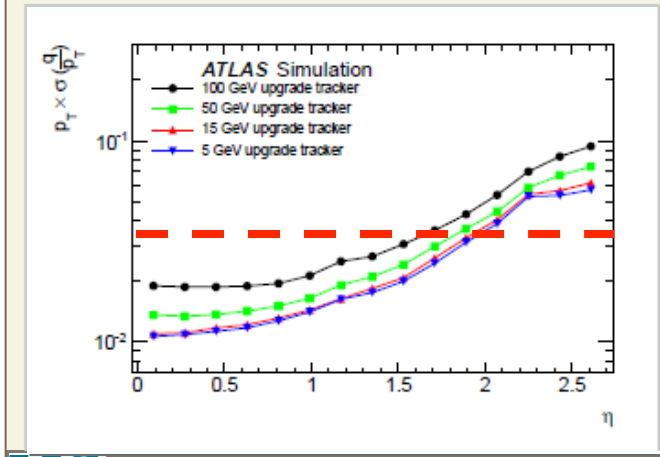


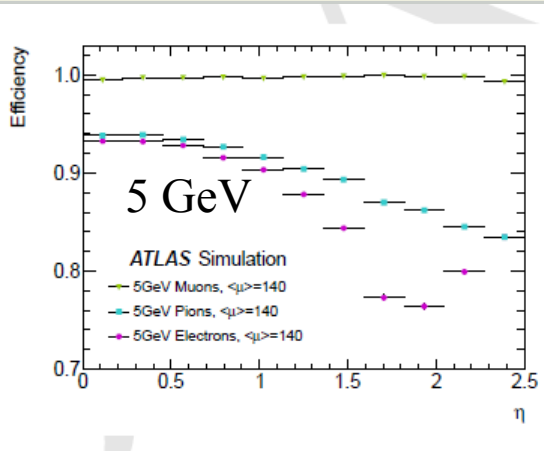
Detailed ITK Performance

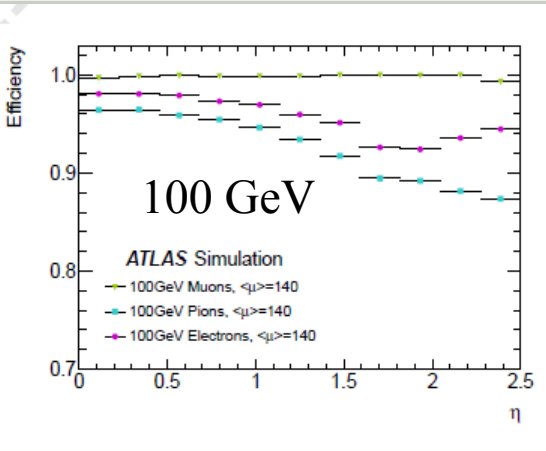
Integration and Performance

- Cooling, services, integration, removal, installation etc all being studied and key is understanding activation issues
- Optoelectronics (GBT) being working on in common with other experiments
- DAQ/DCS exists for prototype operation but not yet designs for final system
- Detailed layout optimisation underway to understand cost/performance trade-offs

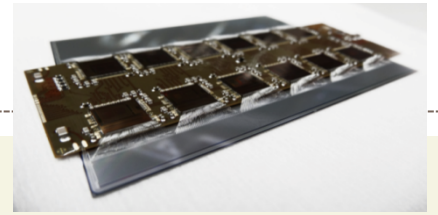






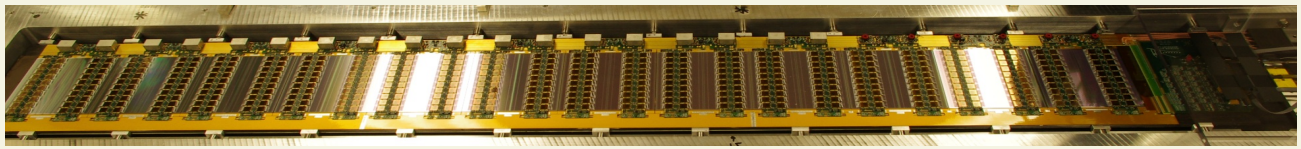


ITK Status



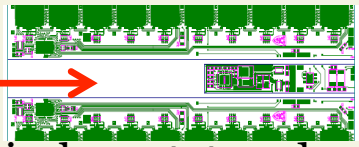
Strip Detector

- New prototype n-in-p sensors delivered with 4 rows of 2.4cm long strips at 74.5µm pitch
- New (256 channel) 130nm CMOS ASIC now received after mask corrections
- Many strip modules (single and double sided) prototyped with 250nm ASICs
- Large area stave DC-DC prototype (120cm×10cm) produced and under study

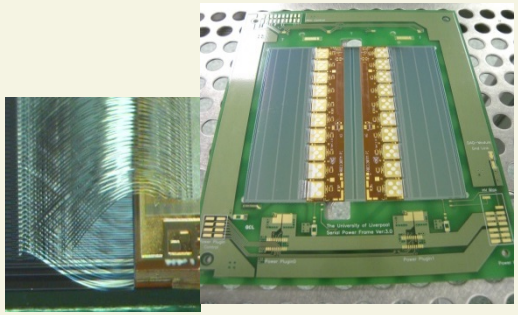


- Serial and DC-DC powering studied in detail on short versions of 250nm stave
- Several other new chips (HCC, HV multiplex, SP, DC-DC,..)
- Hybrid/module designs for these completed

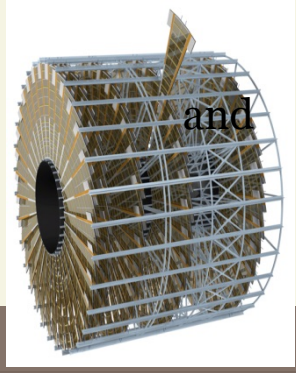
Module with on-board DC-DC converter



- Local supports extensively prototyped further material reduction achieved
- Progress in Petal and Stave support designs
- End-of-stave card for 130nm developed

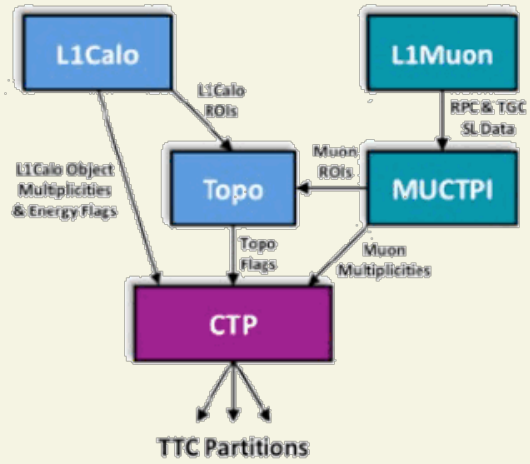


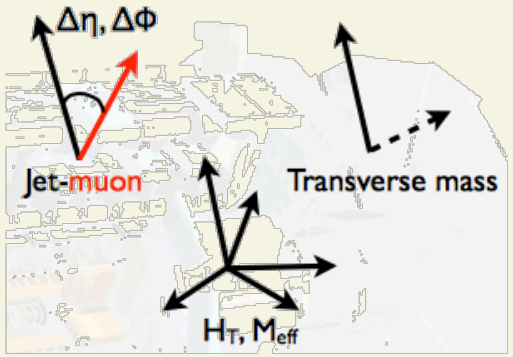
Wedge for Forward Tracker and Global Mechanics



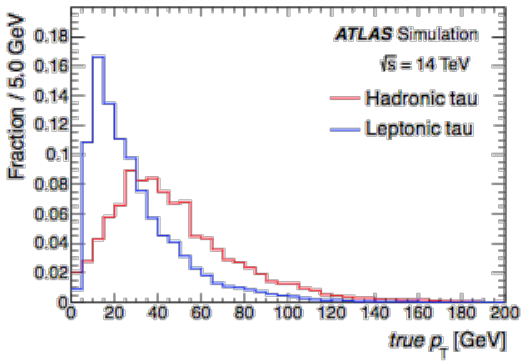
More on L1 Topo

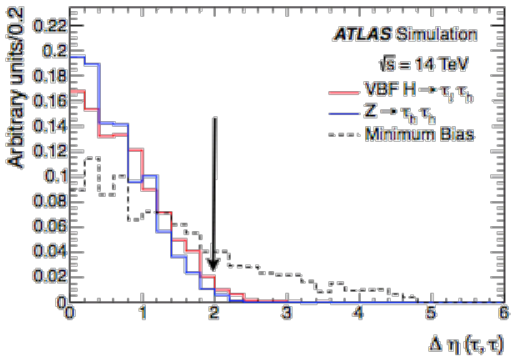
New L1 hardware for topological cuts



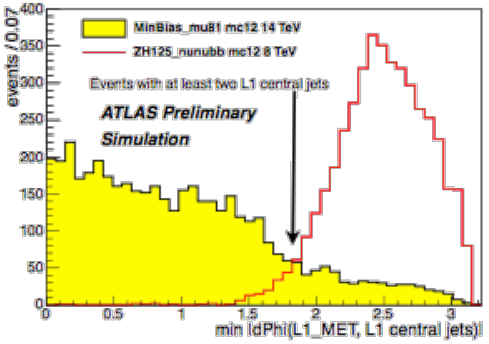


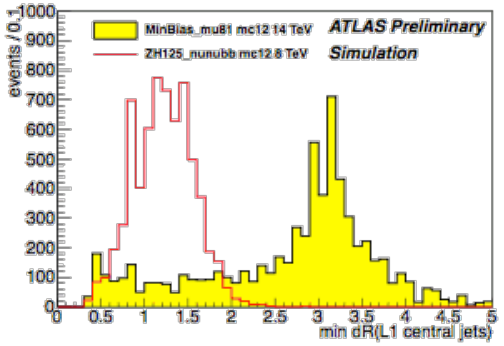
Example : using Δη cut for H→ττ



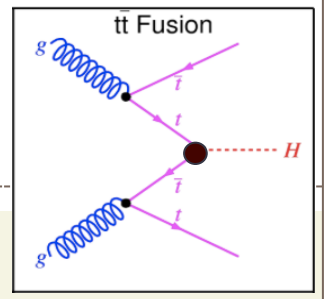


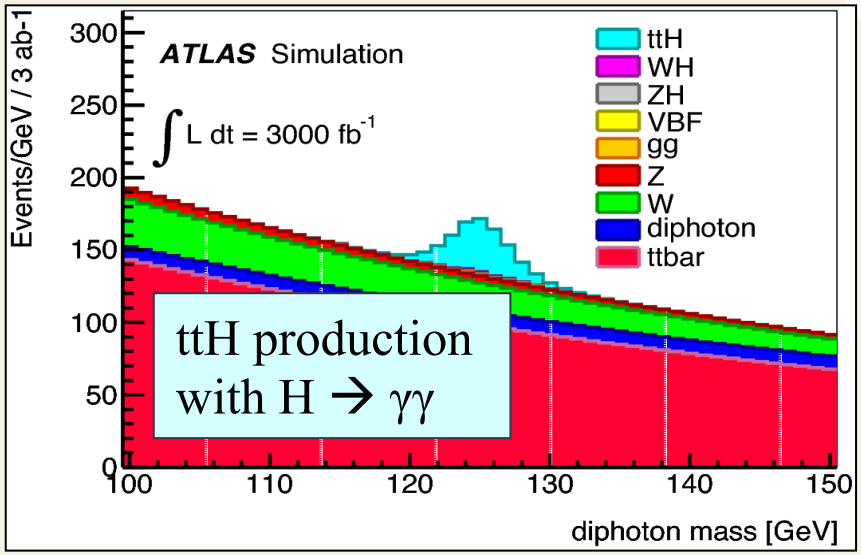
Example : using Δφ cut for Higgs from Vector Boson Fusion





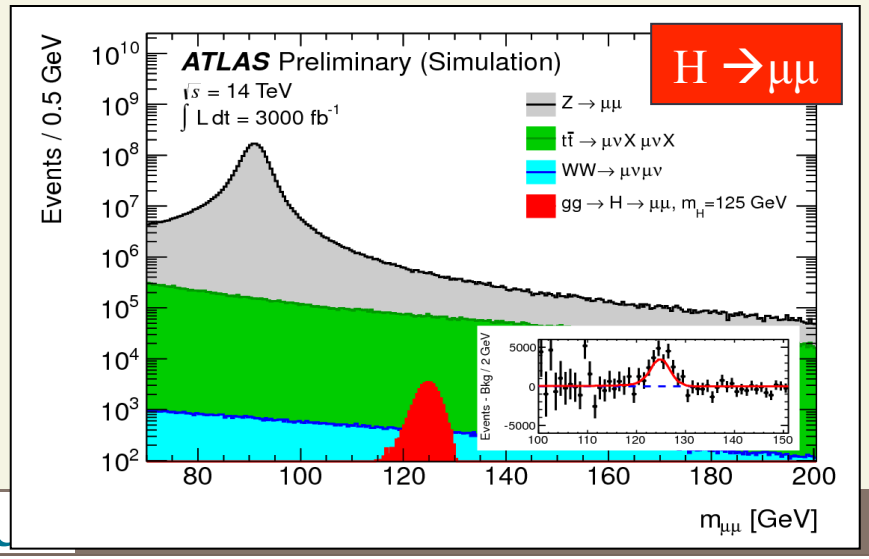
Future Physics Reach





ATL-PHYS-PUB-2014-012

- Gives direct access to Higgs-top coupling (intriguing as top is heavy)
- Today's sensitivity: 6xSM cross-section
- With 3000 fb^{-1} expect ~200 signal events (S/B ~ 0.5) and significance **8.2σ**
- Higgs-top coupling can be measured to better than 10%



- Gives direct access to Higgs couplings to fermions of the second generation.
- Today's sensitivity: 8xSM cross-section
- With 3000 fb^{-1} expect 17000 signal even (but: S/B ~ 0.3%) and ~ 7σ significance
- Higgs-muon coupling can be measured to about 10%

ECFA-13-284

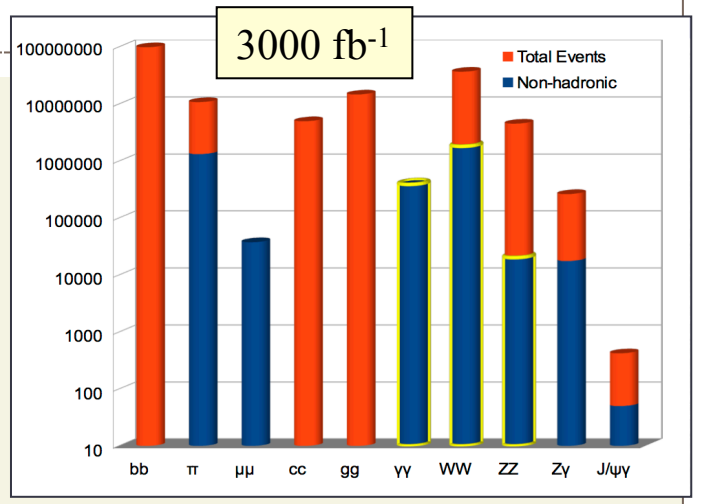
Future Physics Reach (Cont'd)

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

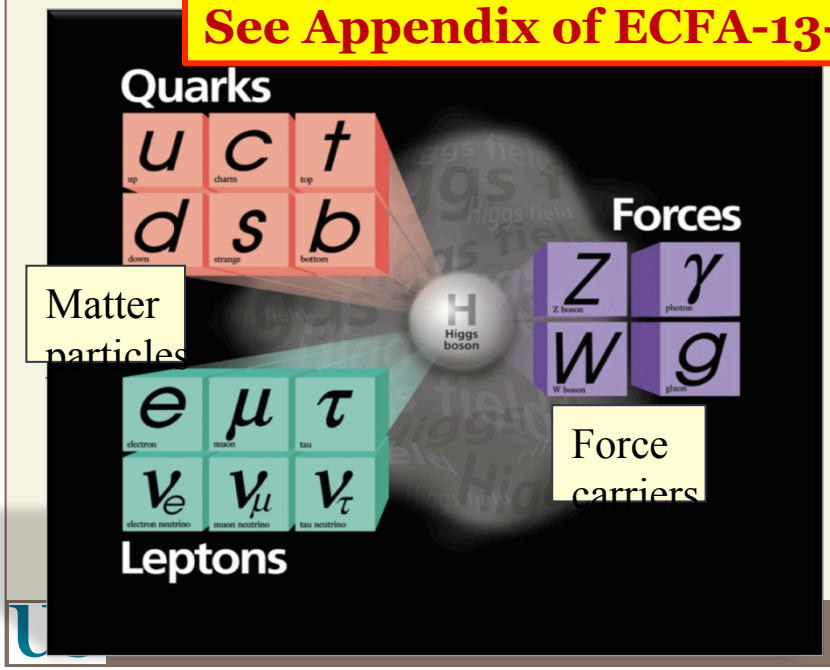
HL-LHC (3000 fb^{-1}): a true Higgs factory:
- ❑ > 170M Higgs events produced
- ❑ > 3M useful for precise measurements

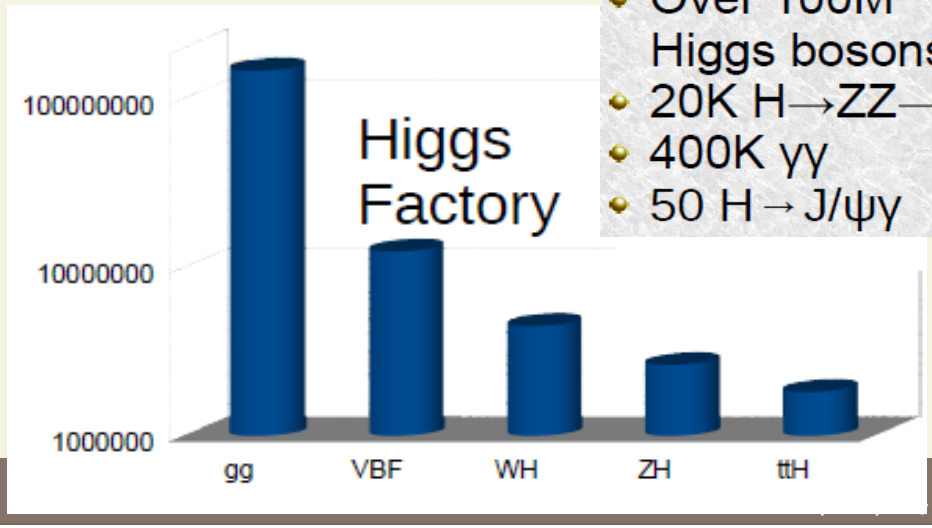
(more than or similar to ILC/CLIC/TLEP)

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



See Appendix of ECFA-13-284 for many more details

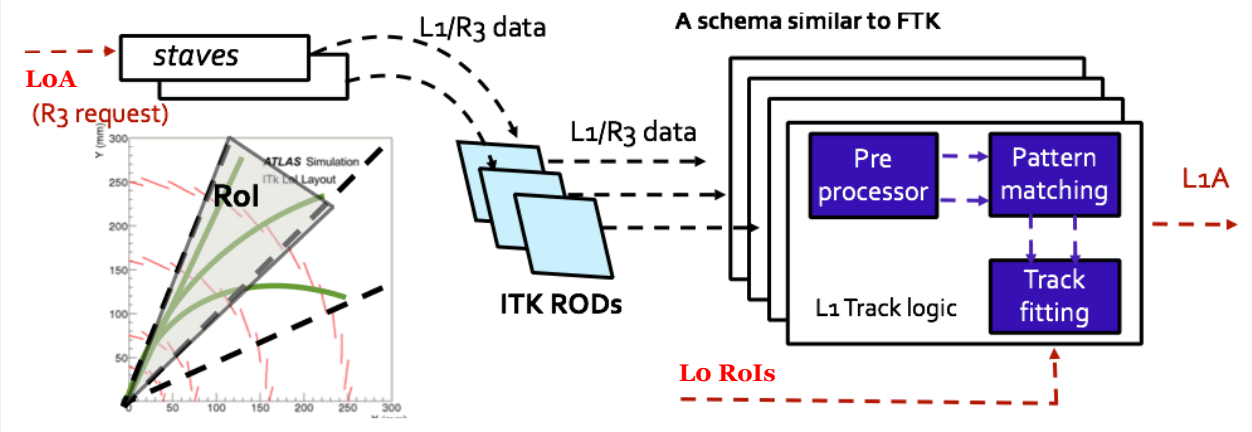




- Over 100M Higgs bosons
- 20K H→ZZ→llll
- 400K γγ
- 50 H→J/ψγ

L1TT Finding tracks: FTK style

- L1TT input B/W:
  - Limit with fine η×φ segmentation:
    p_T>4 GeV
    ↕
    0.05×0.05
    (12600 towers)



- How many patterns?

$$N_{\text{Pattern}} \propto N_{\text{Pileup}} \cdot \frac{1}{p_T} \cdot N_{\text{Layer}}$$

  - Current FTK design based on 8000 AMChip6 ⇒ 10^9 patterns
    (higher capacity AMChip evolutions possible →Gentsos presentation)
  - FTK → L1TT:
    - Same detector
    - x2-3 pile-up increase
    - 8/12 → 12/14 layers

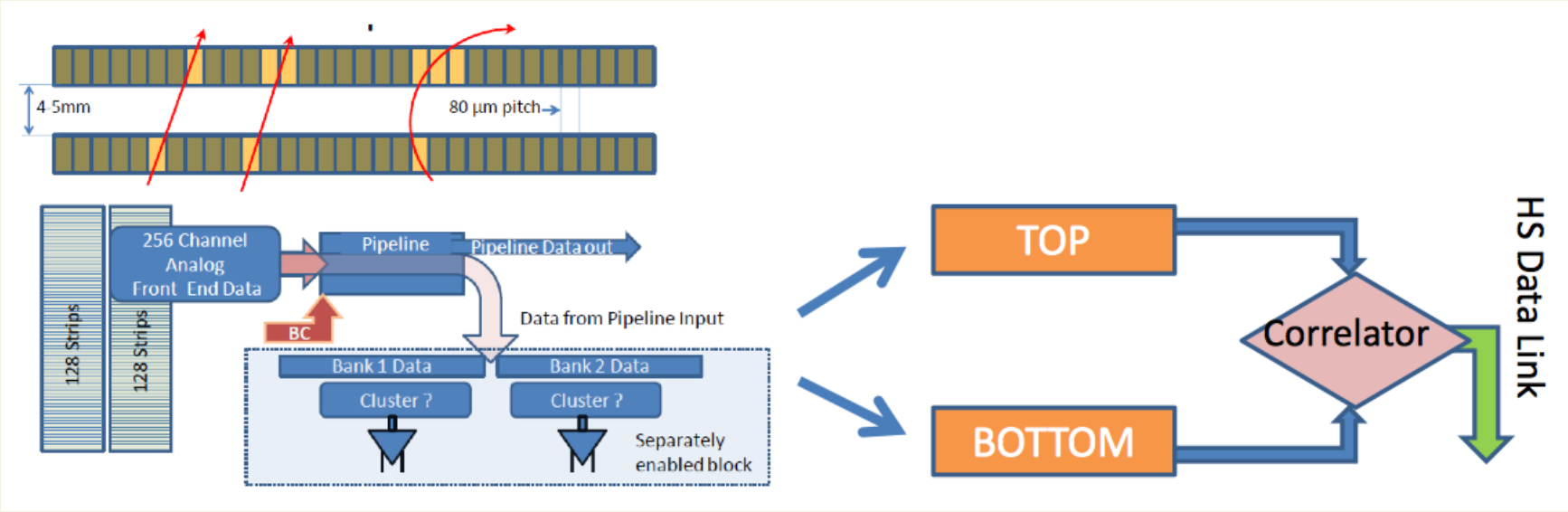
Possible with mitigation from RoI-based concept? Increase pT threshold?

L1TT Alternative approach

RoI-less hierarchical approach:

- Limit off-detector data flow:
  - On-detector "stub" finding based on double-sided detectors
  - Match 2-3 "stubs" for further pT discrimination
  - Fast cluster-finding in pixel detector
- Compatible 4 Gb/s readout rate per detector stave

- Variation (sketch below): detector layer doublets at 4-5 mm distance



L1TT Outlook

- Tracking at L1
  - x3-x10 rejection improvement
- 6/30 μs L0/L1 latency splitting possible with proposed double buffering scheme
  - 1-10% of detector R3
  - 500 kHz L0 and 200 kHz L1 rates
- Additional flexibility in the ATLAS TDAQ pipeline

Next steps:

2015: full specifications for L1TT

2016: Inner TracKer TDR