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Challenges for the ATLAS detector at the HL-LHC for Higgs physics

Anadi Canepa

CPAD Instrumentation Frontier Meeting

5-7 October 2015

Outline

- **Brief overview of Higgs Physics at the Run1 of the LHC**
- **The HL-LHC**
- **Tracker Upgrade**
- **Forward Calorimeter Upgrade**
- **Timing Detector**
- **Trigger Upgrade**
- **Summary and Conclusions**

Disclaimer! Only selected results and detector upgrades are presented here.
For a complete program,
visit https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

The Discovery

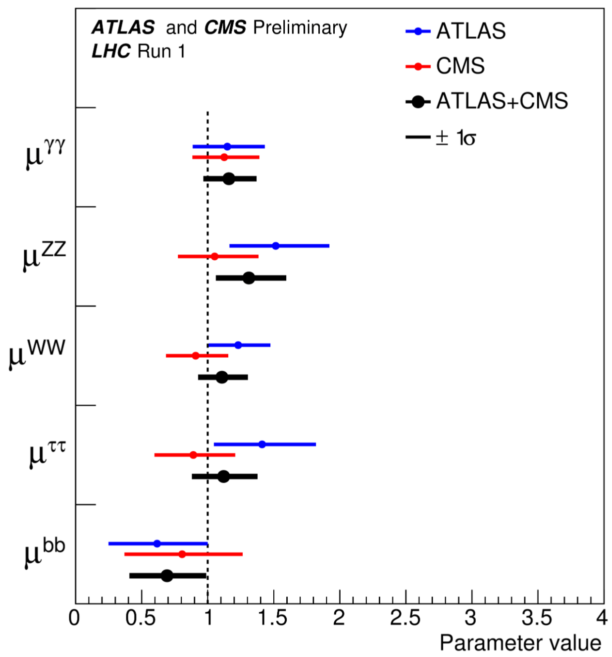
"The Higgs boson has been the object of one of the greatest campaigns in the history of particle physics and a pop-culture icon. On 4 July 2012, the ATLAS and CMS Collaborations announced the discovery of a Higgs-boson candidate with mass near 125 GeV".

(C. Quigg, 1507.02977)

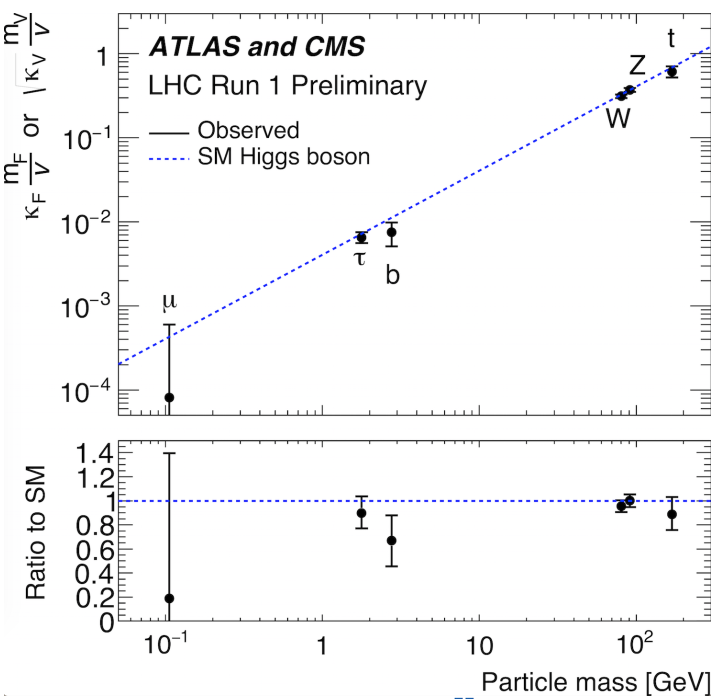
Characterization of the Higgs Boson (I)

ATLAS-CONF-2015-044
CMS-PAS-HIG-15-002

- ATLAS & CMS combined measurement of the Higgs boson's mass
  - unknown parameter in the Standard Model
  - **125.09 ± 0.21 (stat) ± 0.11 (scale) ± 0.02 (other) ± 0.01 (theory) GeV**
  - still statistically limited but scale accuracy at 0.1%!
- Combined measurement of the signal strengths



Interactions specified in terms of known couplings and masses of decay products



Characterization of the Higgs Boson (II)

Results compatible with the SM expectations

$$\mu(\text{ATLAS}) = 1.20\,^{+0.15}_{-0.14}$$
$$\mu(\text{CMS}) = 0.98\,^{+0.14}_{-0.13}$$
$$\mu(\text{Comb.}) = 1.09\,^{+0.11}_{-0.10}$$

- Future milestones:
  - Search for CP mixing in the Higgs sector
  - Search for the pair production of Higgs bosons
    - probing the structure of the Higgs potential
  - Search for rare modes
    - *e.g* Hμμ probing the coupling to 2nd generation
  - **Precision measurements of all accessible production and decay modes**

How Precise?

- Higgs excellent probe for high scale new physics
  - no compelling foundation for EWSB via single complex doublet of scalar fields
  - Higgs may couple to new particles
- **In presence of New Physics, expect deviation from SM ~few %**

Composite Higgs $$\frac{\Delta g_H}{g_H} \cong 6\% \left(\frac{1\ \text{TeV}}{f}\right)^2$$

Top partner $$\frac{\Delta g_{h\_gg}}{g_{h\_gg}} \cong 3\% \left(\frac{1\ \text{TeV}}{M}\right)^2$$

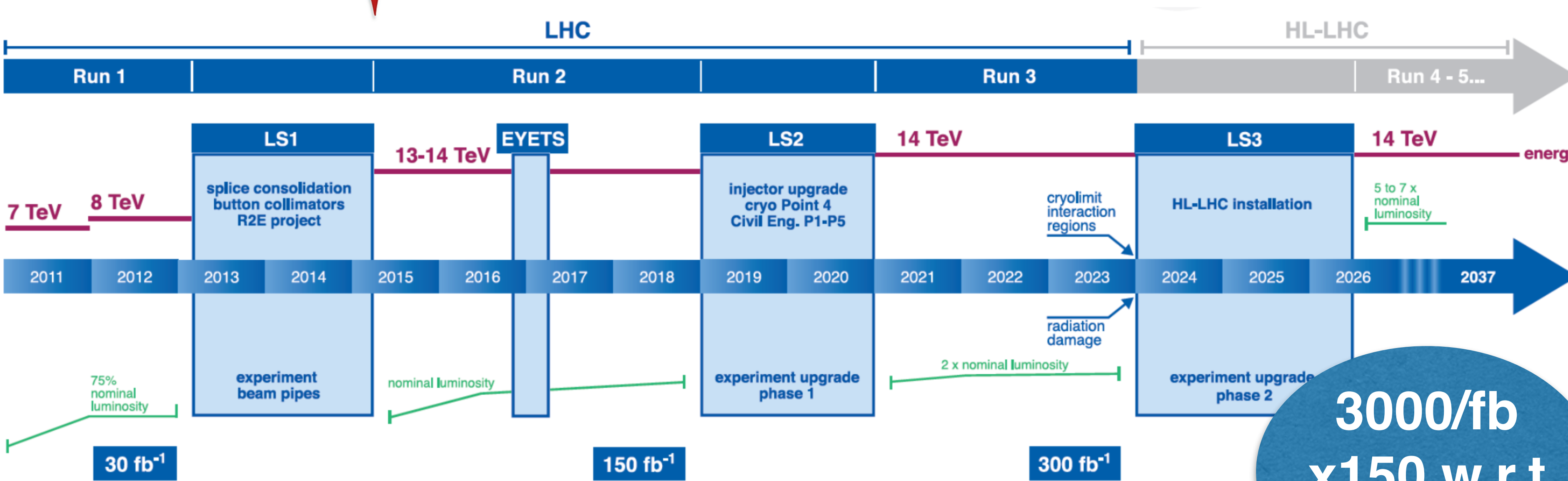
SUSY ($\tan\beta \geq 5$) $$\frac{\Delta g_{h\_bb}}{g_{h\_bb}} \cong 1.6\% \left(\frac{1\ \text{TeV}}{m_A}\right)^2$$

S. Forte, A. Nisati,
G. Passarino, R. Tenchini

"Detailed study of the Higgs sector is a scientific imperative that must be pursue to a much higher level of statistical precision than available today"

http://hilumilhc.web.cern.ch

The High-luminosity LHC



**3000/fb
x150 w.r.t
Run 1**

LHC/ HL-LHC Plan (last update 21.07.2015)

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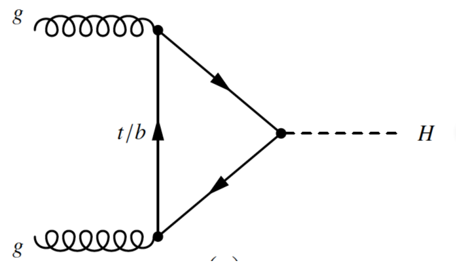
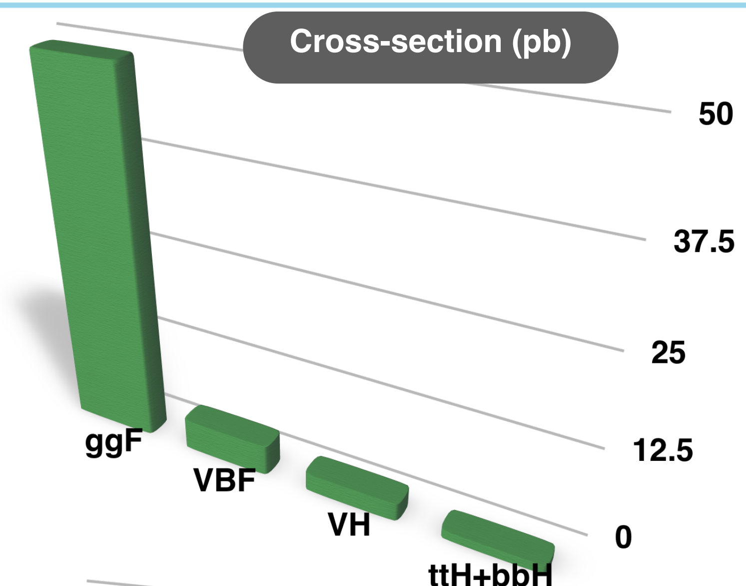
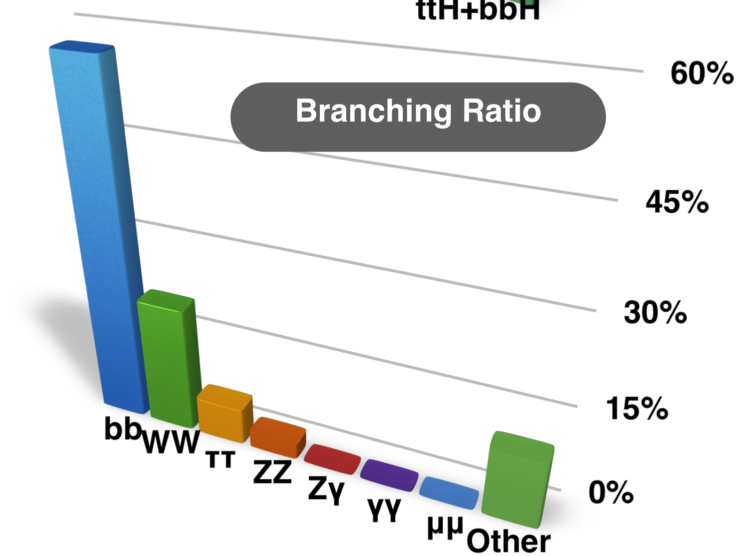
Signature of Higgs boson Production (I)

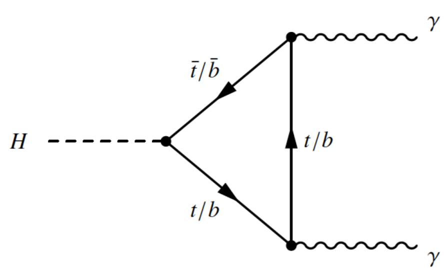
- **Gluon fusion production or "ggF"** has the highest production cross-section

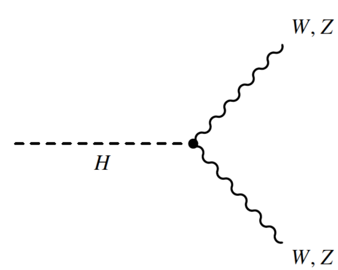




- The ggF mode is only accessible through the cleanest decay modes
  - γγ, WW, ZZ, Zγ, μμ

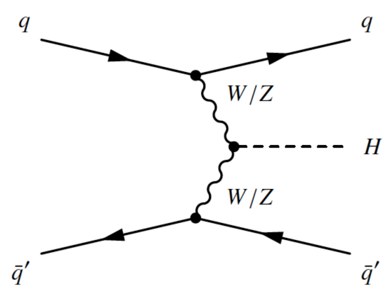


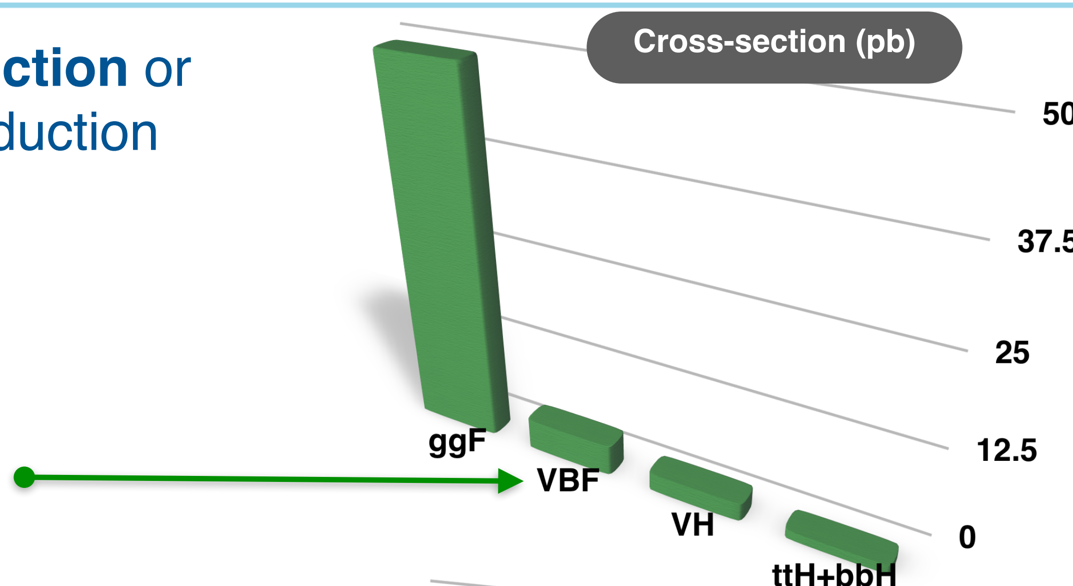




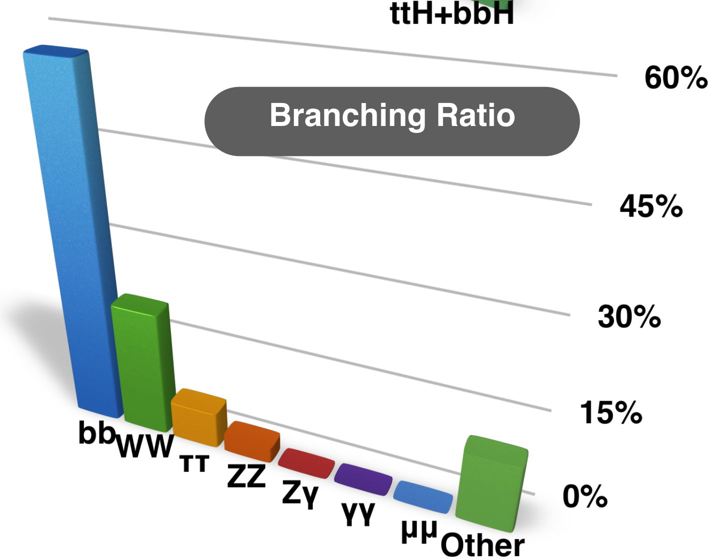
Signature of Higgs boson Production (II)

- **Vector boson fusion production** or "VBF" has a 10x smaller production cross-section w.r.t ggF



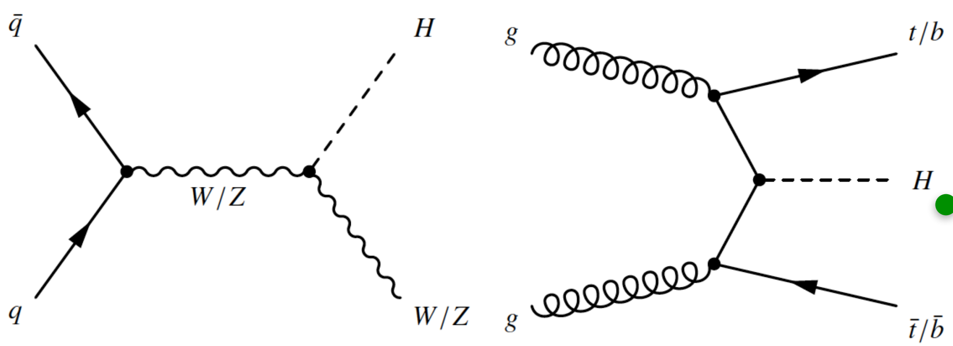


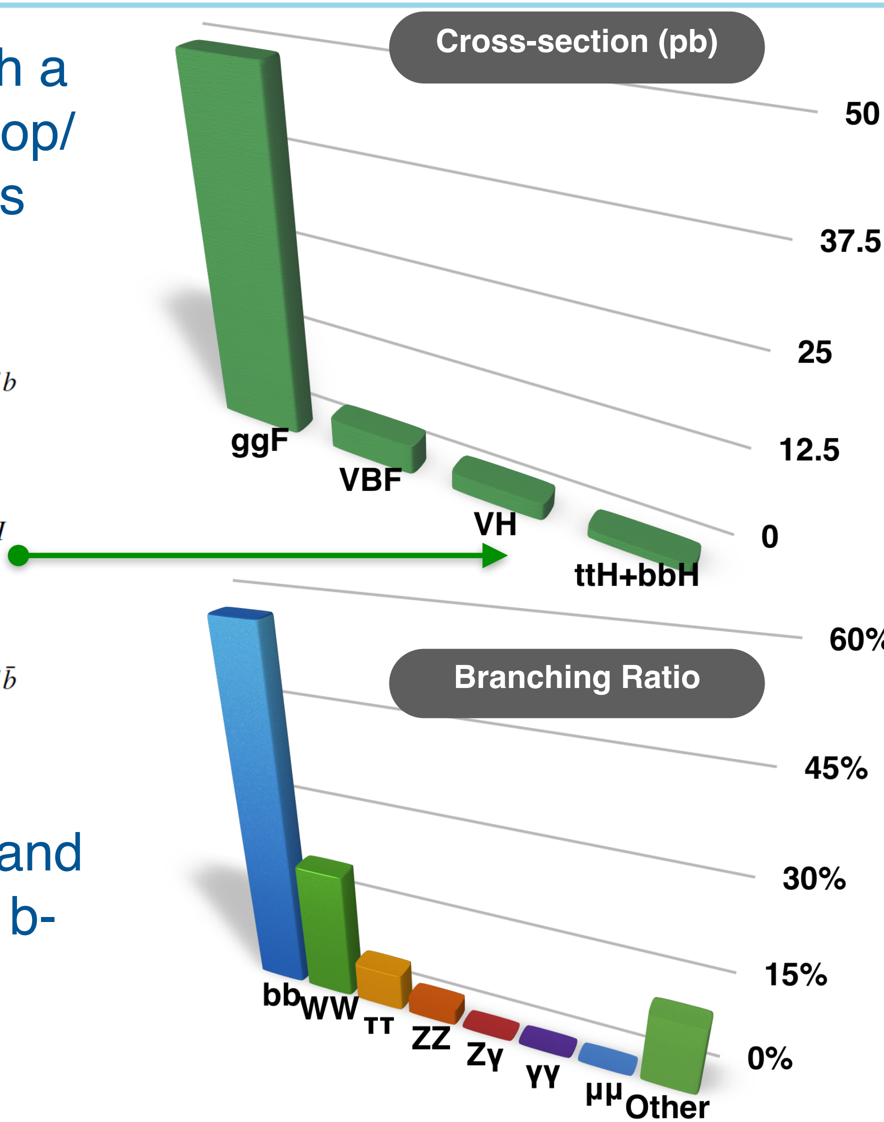
- Yet VBF has a distinct signature of 2 forward jets and can be used to probe challenging decay modes
  - **ττ**
  - **invisible modes** *(Beyond Standard Model searches, e.g. Dark Matter)*



Signature of Higgs boson Production (III)

- **Associated production** of Higgs with a vector boson (W, Z) or with a pair of top/ bottom quarks have ~2x smaller cross sections than VBF

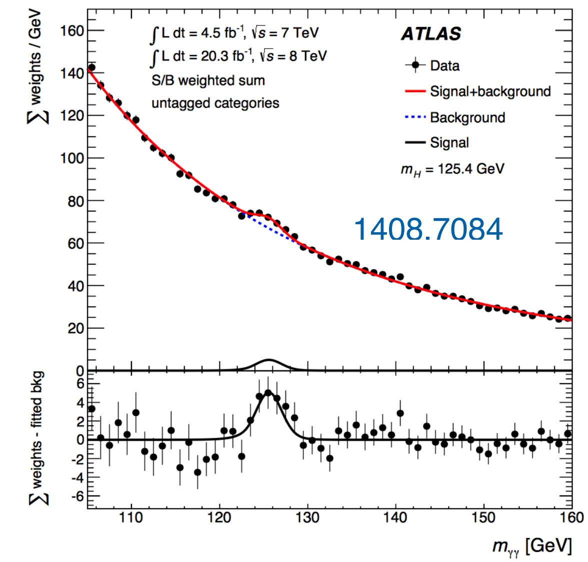


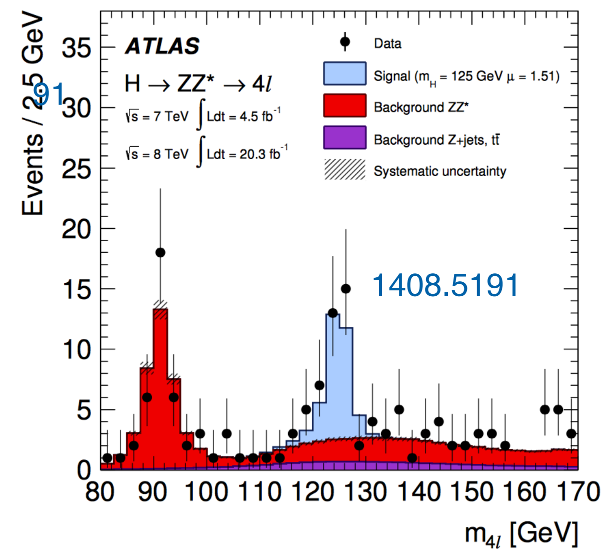


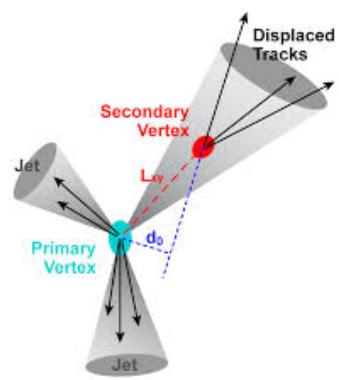
- Large object multiplicity helps discriminate signal from background and measure the coupling of the Higgs to b-quarks and top-quarks
  - bb

Higgs Physics at HL-LHC

- The pillars of a successful program for precision measurements and direct searches are:
  - **high efficiency** of identifying leptons including taus, photons, jets from b-quarks (or ‘b-jets’)
  - **excellent momentum resolution and scale** for leptons, photons and b-jets
    - to achieve invariant mass resolutions of 1% for $m_{\gamma\gamma}$, 1-2% for m_{4L}, better than 10% for m_{bb}
    - good ETmiss resolution
      - to identify neutrinos from W decays
  - **low mis-identification probability** (*e.g.* c-jets mis-reconstructed as a b-jets)
    - to reduce combinatorics

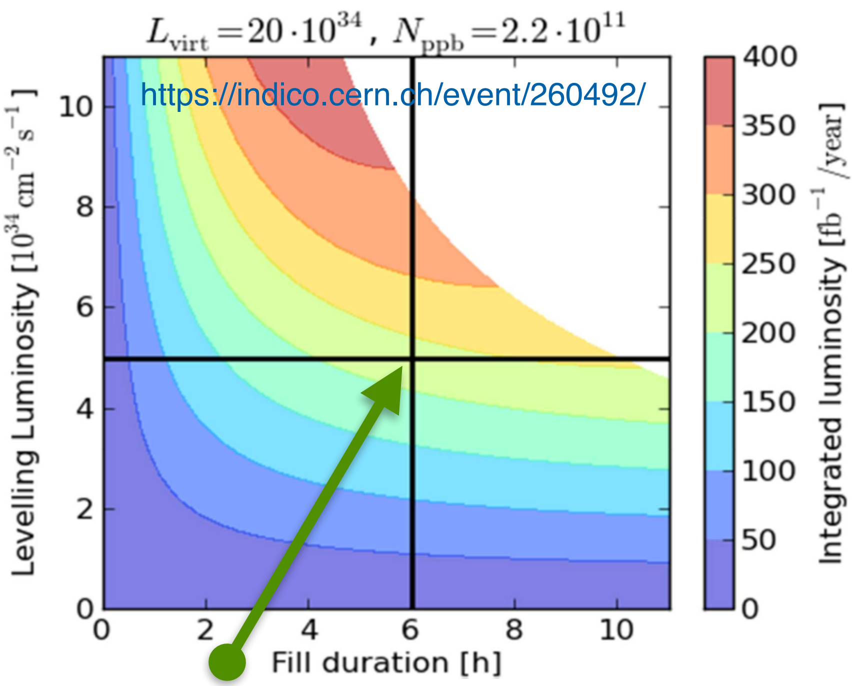






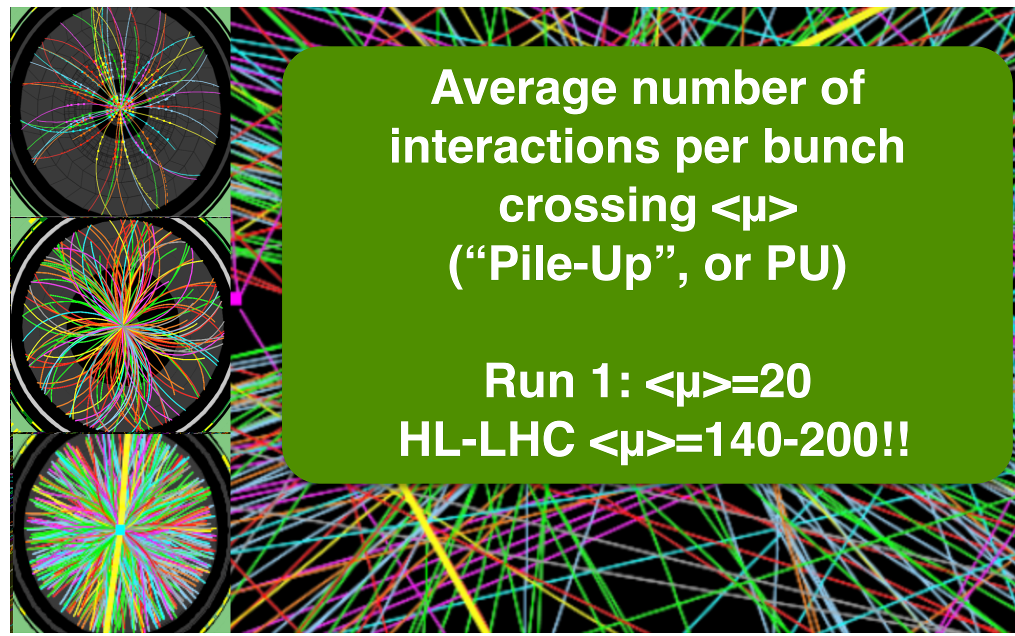
The HL-LHC Environment

- Under the assumption of ~300/fb at Run3, aim for ~270/fb/year for 10 years
  - 160 days per year
  - ultimate luminosity →30% gain in operation time



Nominal
$5x10^{34}$ Hz/cm^2

Ultimate
$7.5x10^{34}$ Hz/cm^2

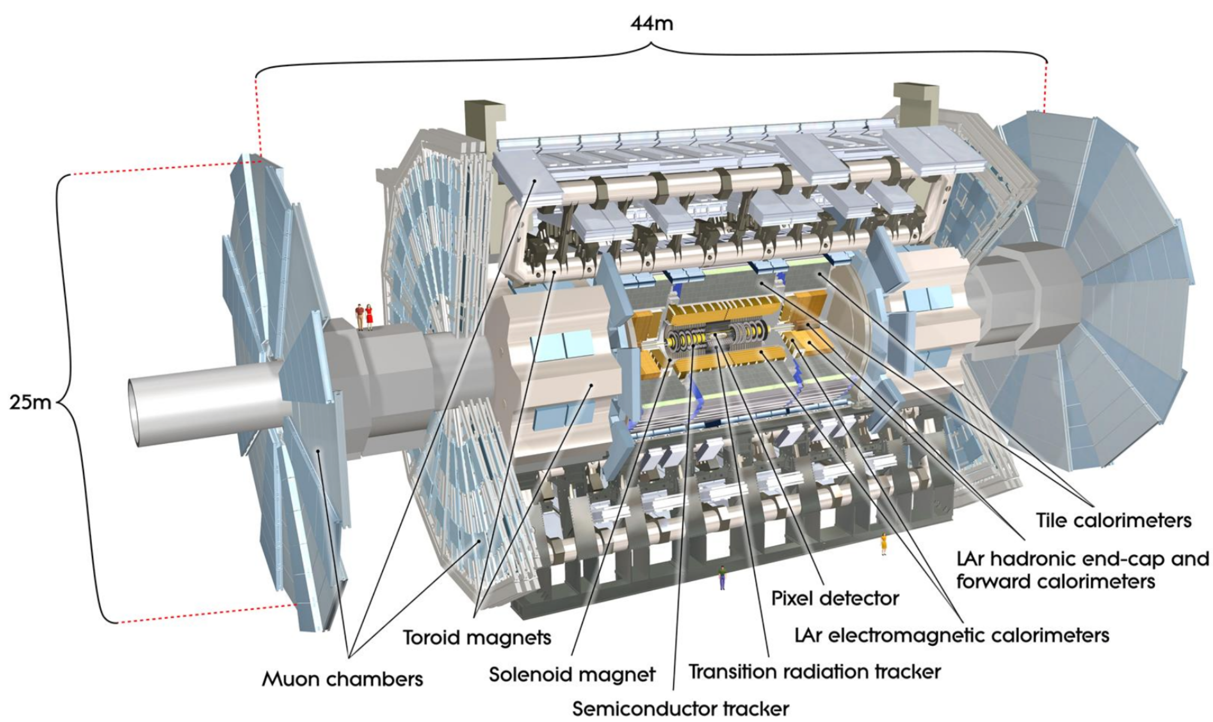


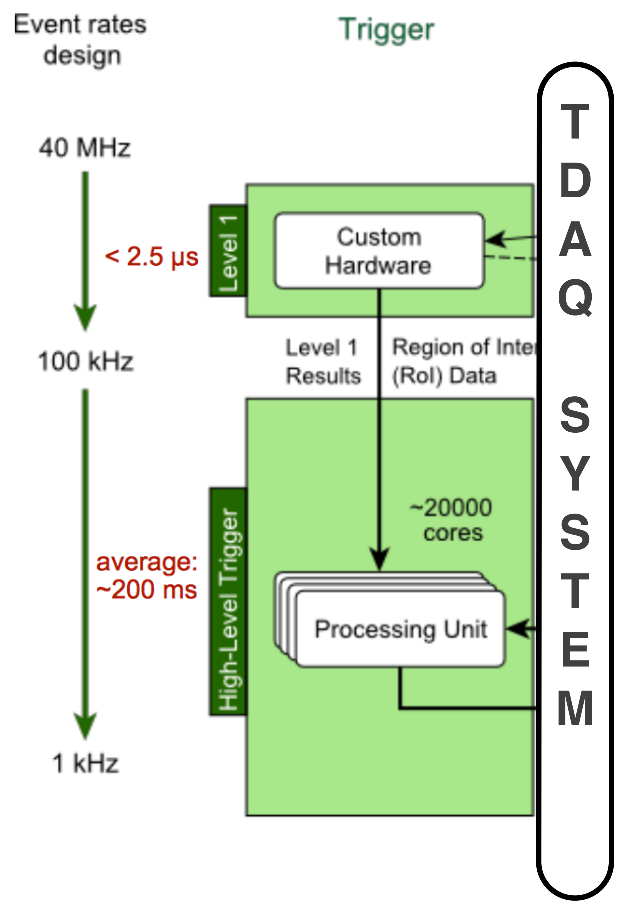
Average number of interactions per bunch crossing <μ> (“Pile-Up”, or PU)

Run 1: <μ>=20
HL-LHC <μ>=140-200!!

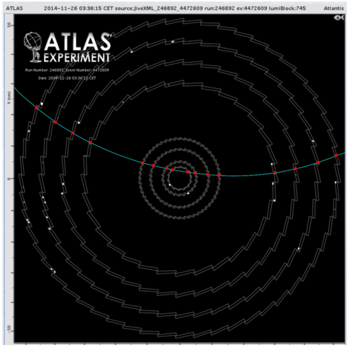
Goal of % precision at a depth of >10 orders of magnitude!

The ATLAS Detector (in Run 2)





- **New insertable B-layer**
  - 3.27 cm
  - planar & 3D silicon sensors
  - 12M pixels, 50×250 μm^2
  - radiation tolerance $5x10^{15}/cm^2$



Upgrade of the Inner Tracker: Motivations

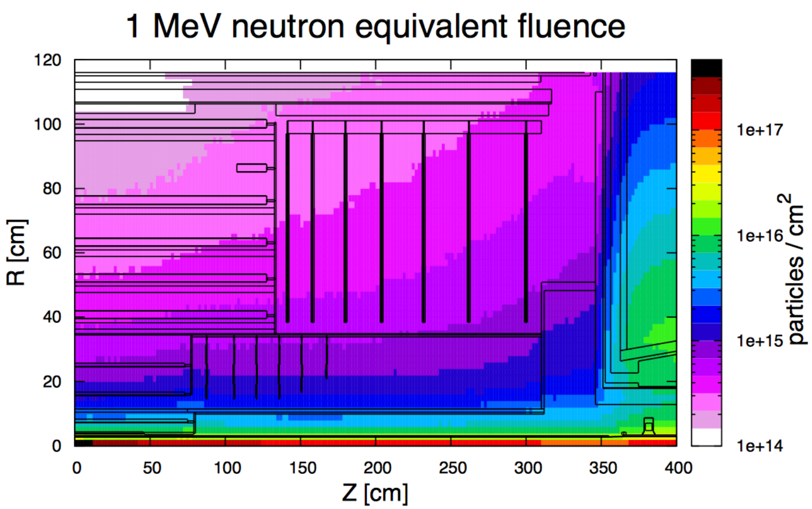
- The ID has outstanding performance but was not designed to operate in very high PU conditions and to withstand the dose expected at the HL-LHC
  - optimized for **peak luminosities of 10^{34}/cm^{2}s** with assumed **23 PU** and events per 25ns bunch crossing
  - withstanding fluences between **2x10^{14}/cm^2 (strips) and 10^{15}/cm^2 (pixel)**
  - with a lifetime of 10 years corresponding to **400/fb (850/fb)** for pixel (IBL) and **700/fb** for strips

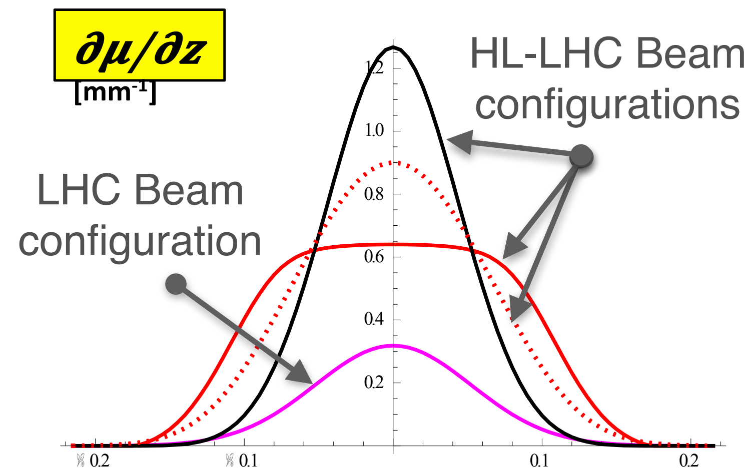
- In ATLAS the tracking information is used for
  - reconstruction of the primary vertex, leptons, taus, photon conversions, Etmiss, b-jets
  - correction of the jet energy scale
  - suppression of jets from PU vertices

Essential and critical to every component of the Higgs program

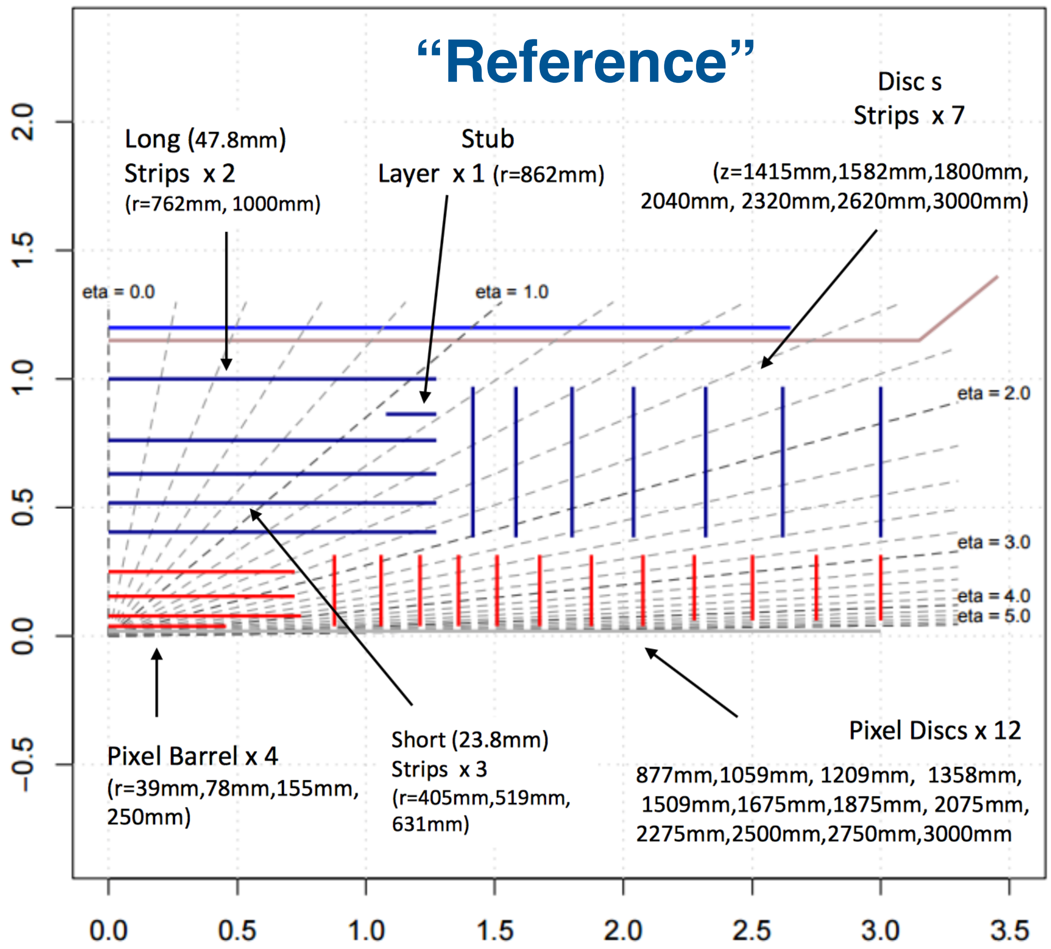
Requirements for a New Tracker at the HL-LHC

- Radiation hardness
  - must withstand fluences up to $1.4 \times 10^{16}/cm^2$
- Small "occupancy"
  - >1000 tracks per unit rapidity expected
  - must resolve close by tracks
- Large bandwidth
  - must solve limitations in buffering and links between on-module and read-out driver cards
    - severe inefficiency in the current pixel for $L_{inst} > 3 \times 10^{34}/cm^2s$
- Larger η coverage
  - to increase the hermetic coverage from primary vertex spread in z





The Upgraded Tracker of ATLAS: ITk



- Designs discussed today:
  - **"Reference"**
    - $|\eta| < 4.0$
  - **"Letter of Intent" or LOI**
    - $|\eta| < 2.7$
- To assess the impact of the layout on the physics program, two modified versions of the Reference design are also considered ("Middle", "Low")

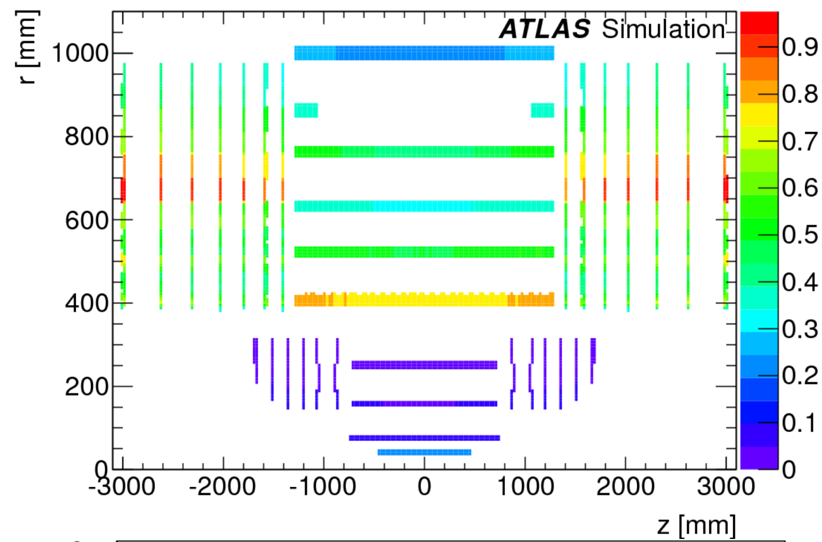
	Reference	Middle	Low
ITk strips - changes w.r.t. LoI layout			
Remove Barrel layer 3			✗
Remove 1 Disc set		✗	✗
Remove 2 stereo layers			✗
Remove stub		✗	✗
ITk η-coverage	4.0	3.2	2.7

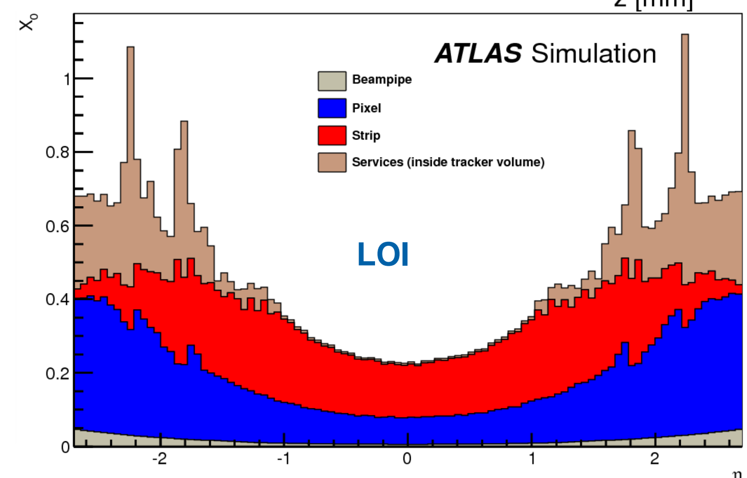
Impact of module mortality is tested by ignoring 10% of randomly distributed modules (referred to as "Scenario-10%")

Does the ITk Meet the Requirements?

- Radiation hardness
  - Planar pixels: 150 μm thick n-in-n & n-in-p
    - **n-in-n can withstand fluences up to $2 \times 10^{16}/cm^2$**
    - other technologies considered (3D, diamond, CMOS)
  - Strips: AC coupled, 320 μm thick, n-in-p
    - can withstand $8 \times 10^{14}/cm^2$
- Small “occupancy”
  - **25x150 and 50x250 μm^2 pixels**
  - **23.8, 47.8 mm strips**
- Reduced material (current ID+IBL ~$1.2X_0$)
  - **modified service routing**
  - efficient multiplexed → fewer HV/LV cables
  - higher performance cooling (CO2 evaporative, smaller diameter tubes)

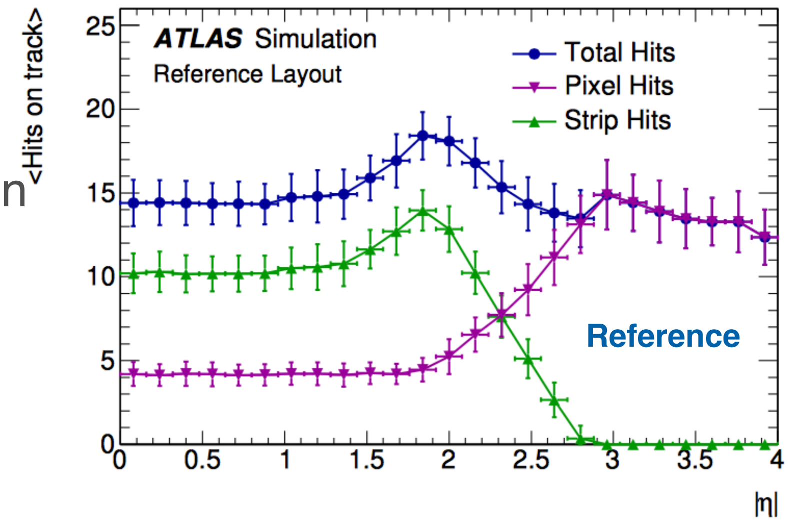
LOI: channel occupancies (in percent) at 200 pile-up events

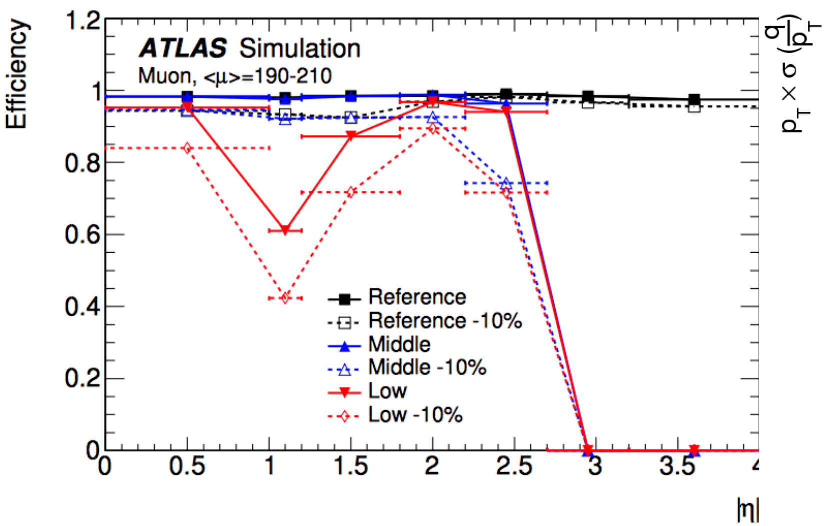


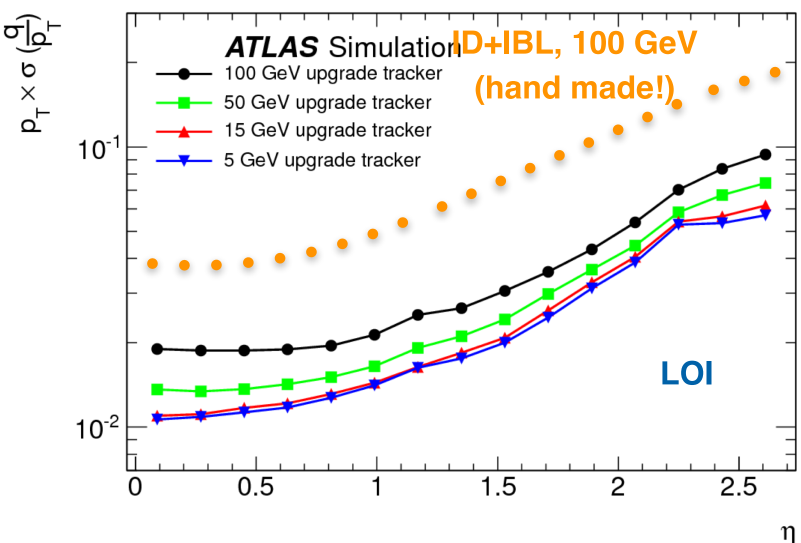


Upgrade of the Inner Tracker: Performance

- Number of hits per track is > 14
  - reduces fake rate (kept < 1%)
  - provides robust pixel seeding in forward region
  - **leads to high efficiency vs η and robust performance against module mortality**
- Good momentum resolution from optimal radial configuration of layers



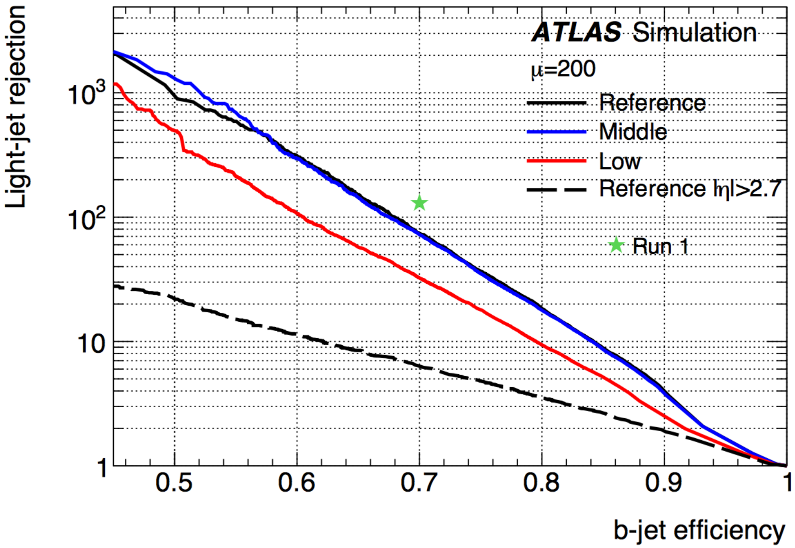


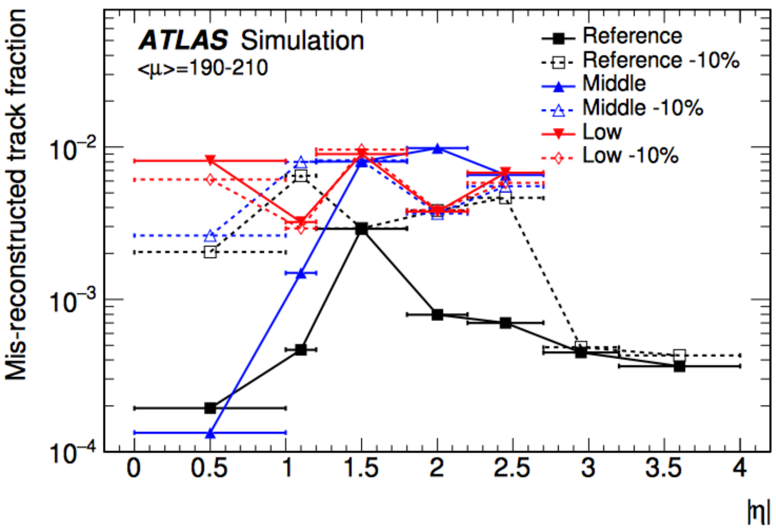


"Low Scenario" *Missing strip layers would lead to up to 40% degradation in p_T resolution for low p_T tracks*

Primary Vertex Finding and b-tagging Capabilities

- Primary vertex PV identification is > 94% for a variety of processes
  - 98% tt, 94* Zμμ, 96% for VBF H (→ **tracks in forward region are critical**)
  - PV vs PU vertex separation ~0.7mm
- The b-tagging performance is similar to that in Run 1 despite the challenging environment
  - thanks to pixel size (two track separation) & vicinity of 1st pixel layer to the beam pipe
  - critically dependent on track fake rate
- A tracker with large η coverage provides b-tagging in the forward region
  - *e.g.* necessary for separating Higgs signals with no bs from tt background





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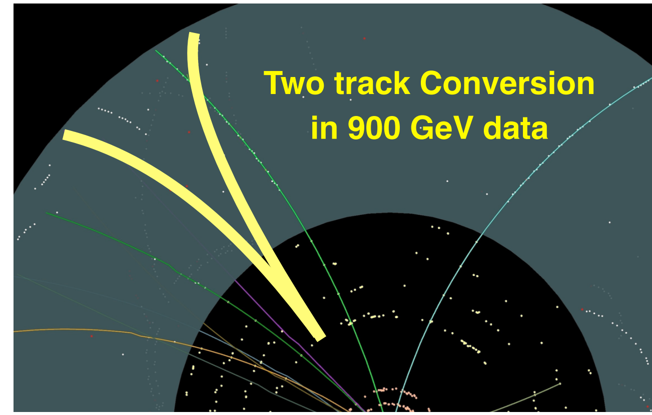
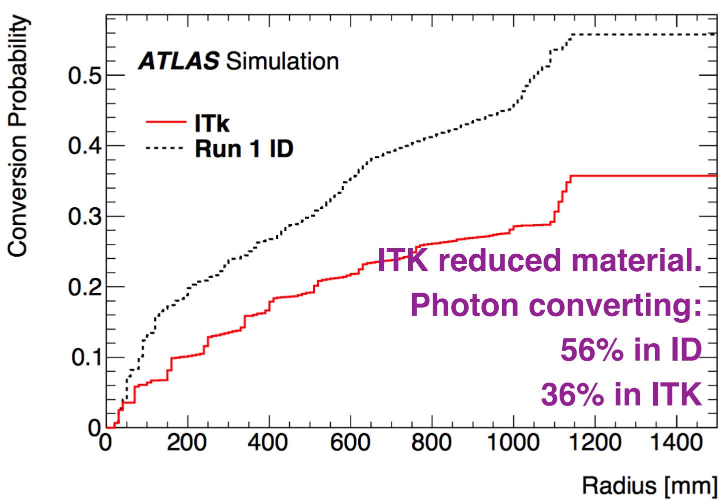
Photon Reconstruction

- Photons from Higgs decay can convert into e^+e^- when hitting the detector material
- Pairs are formed using opposite charge tracks
  - energy resolution of conversions reconstructed from 2 tracks is close to that of electrons
  - it is ~50% worse if only 1 track is reconstructed!
- Performance strongly depends on the material budget upstream from the calorimeter

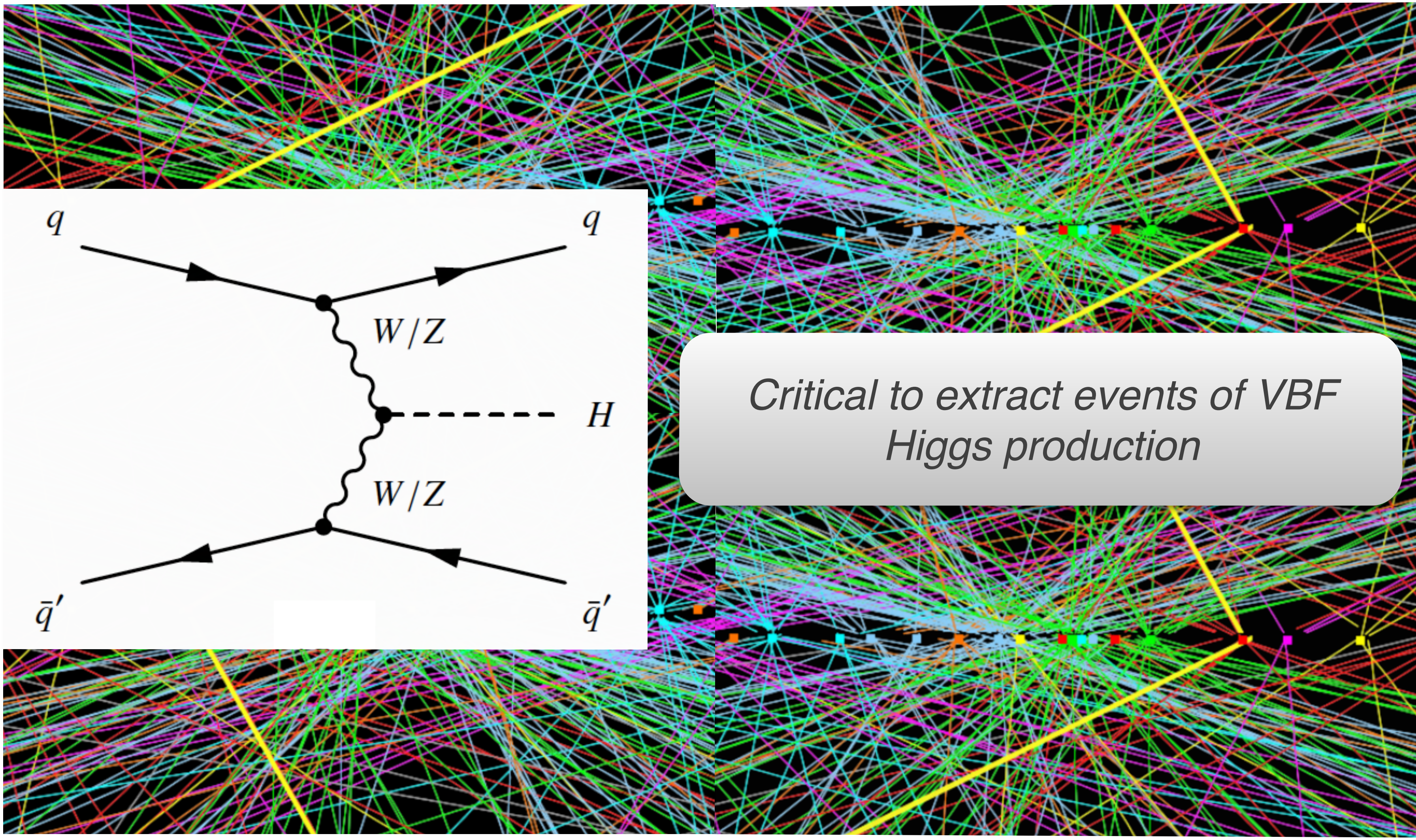




$\mu = 200$	Reference		Middle		Low	
	nominal	-10%	nominal	-10%	nominal	-10%
$\epsilon_\gamma(\%)$	98.3	98.3	98.2	98.3	98.1	98.3
$\epsilon_c(\%)$	46.9	40.5	45.8	39.1	35.2	31.2
$f_1(\%)$	42.3	44.5	42.6	45.1	41.4	44.1
$f_2(\%)$	57.6	55.5	57.3	54.9	58.5	55.9

- **"Low scenario": 25% drop of conversion reconstruction efficiency when removing strip layers**
- Conversion finding is sensitive to module mortality

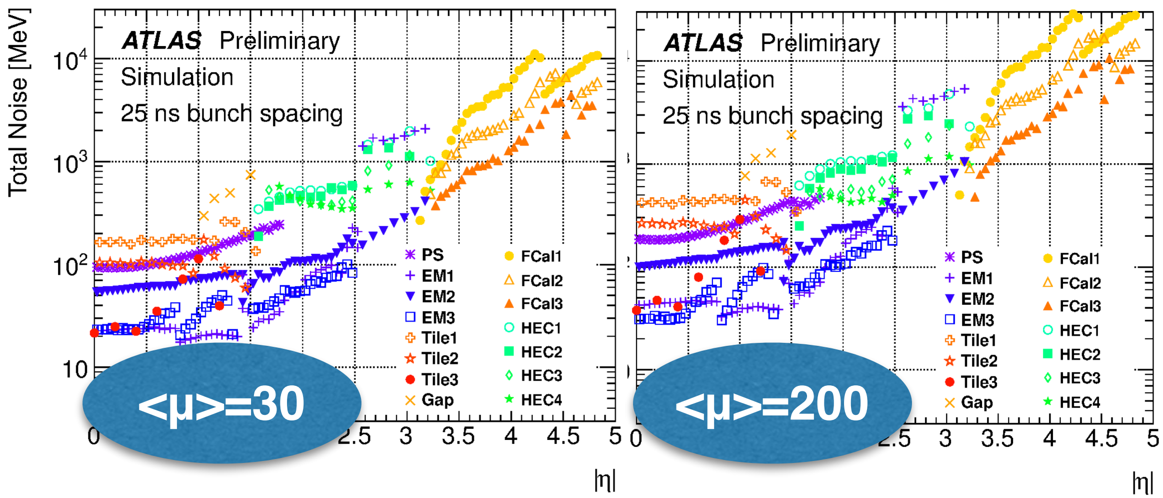
Using Tracking Information to Suppress Pile Up Jets



Critical to extract events of VBF Higgs production

Jet Reconstruction and PU Suppression (I)

- Jets are reconstructed from topo-clusters with the anti-kt algorithm (R=0.4)
  - "topological" clusters built from calorimeter cells with significant signal above noise ← **thresholds adjusted to the PU conditions**



- Simulated noise in the Liquid Argon and Tile calorimeters (quadratic sum of simulated electronics and pile-up noise per calorimeter cell) increasing with PU

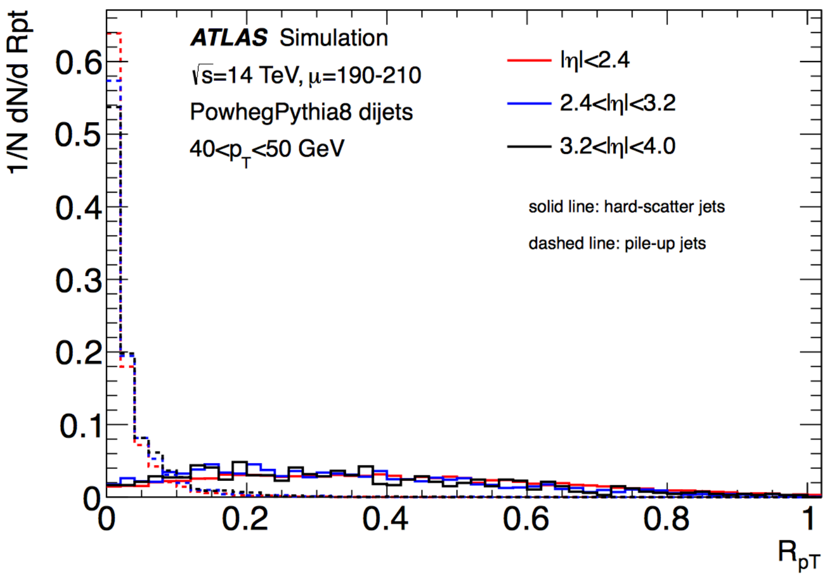
- Jet momentum is corrected for pile-up induced effects using
  - area based correction based on the density of pileup per unit of area (ρ) event-by-event [http://arxiv.org/pdf/0707.1378v2.pdf]
  - residual correction for out-of-time pile up, higher density inside jets, …
  - corrections depending on the number of reconstructed vertices

Jet Reconstruction and PU Suppression (II)

- Jet energy scale corrections are applied to restore the true energy
- Tracking information is then needed to determine whether a jet originates from the hard scatter vertex or not

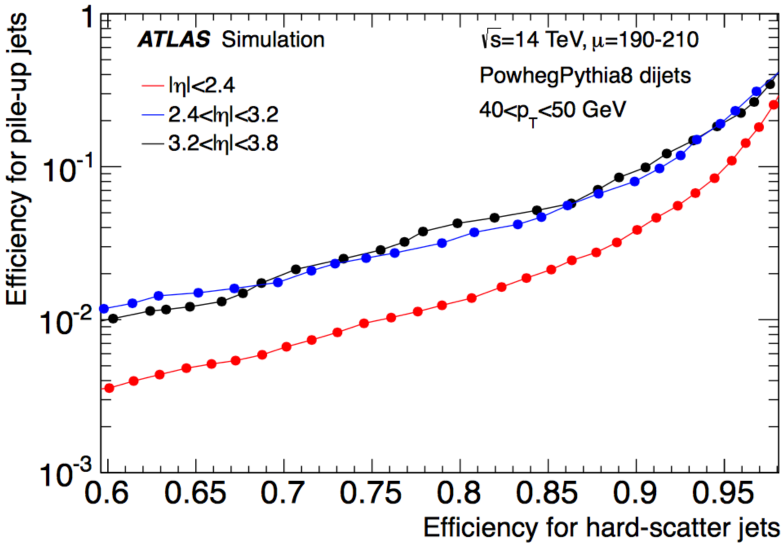
Matched tracks classified as originating from the hard scatter vertex based on longitudinal impact parameter

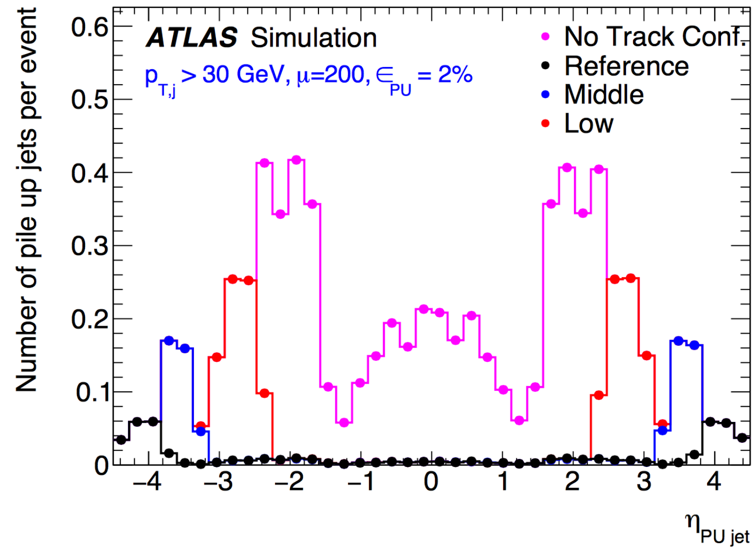
$$R_{pT} = \frac{\Sigma_i (p_T^{\text{track},i})}{p_T^{\text{jet}}}$$

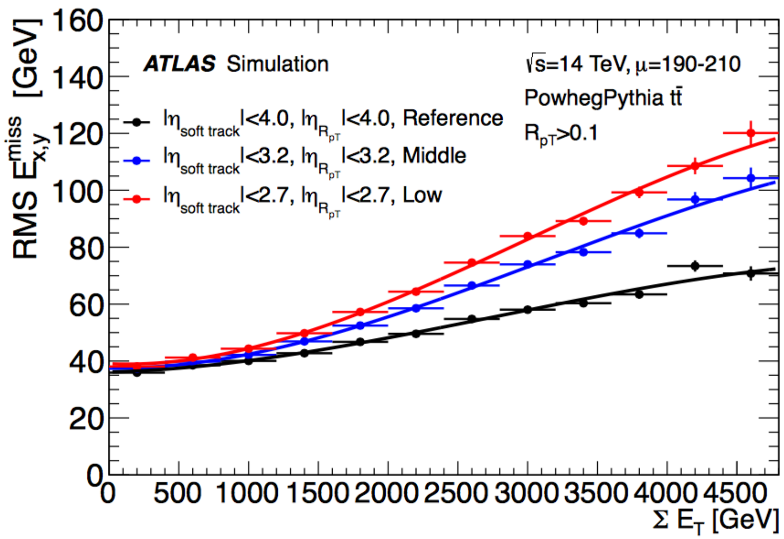


Need high vertex finding efficiency, good PV and HS vertex separation, good track σ_z and pT resolutions

Jet Reconstruction and PU Suppression (III)





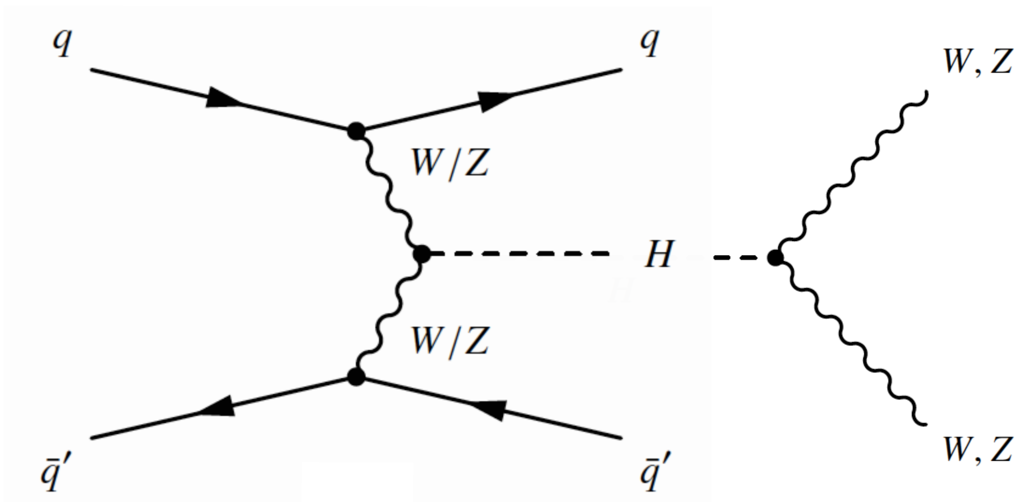


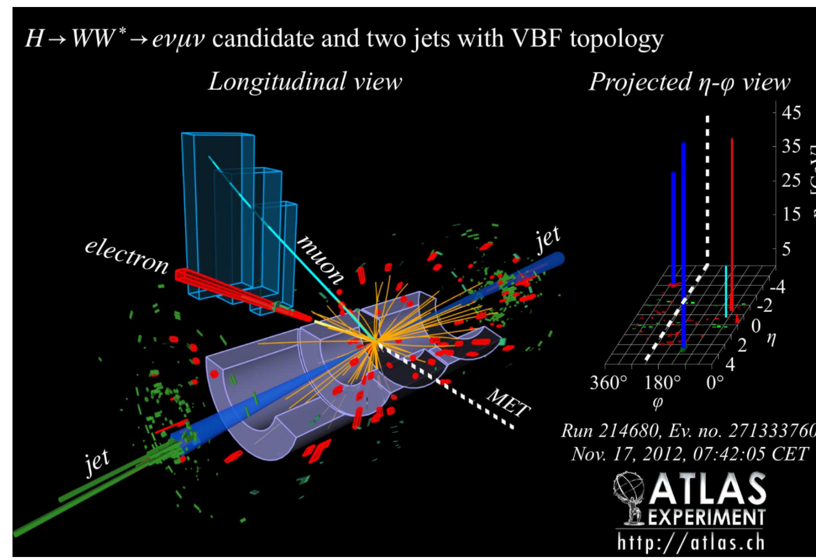
- **Large η coverage of the tracker is essential** to *e.g.* discriminate PU jets and jets from VBF Higgs production and to restore good Etmiss resolution

Impact of the Tracker Upgrade on Higgs Physics

Two selected examples:

- *VBF Higgs decaying into ZZ (4L), not observed at ATLAS yet*
- *VBF Higgs decaying into WW(lnln), signal strength measured at ~40% level*

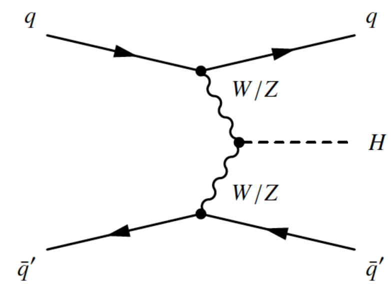




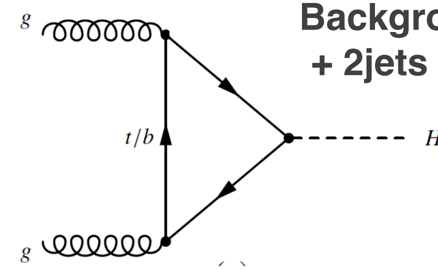
1412.2641, Run 1 event

Separating VBF from ggF Production in the $ZZ^{(*)} \rightarrow 4l$ Modes

- Precision measurements of the couplings require separation of the Higgs productions modes (*e.g.* VBF vs ggF+PU jets)
  - **Suppression of jets from PU is critical**



Signal (VBF), very forward jets



Background (ggF + 2jets from PU)

Tracker Coverage	Scoping Scenario	with theo. unc. $\Delta\mu/\mu$	$\Delta\mathcal{I}$ (fb^{-1})	Z_0-value (σ)
$\|\eta\|<4.0$	Reference scenario	0.167	–	7.64
$\|\eta\|<3.2$	Middle scenario	0.174	350	7.48
$\|\eta\|<2.7$	Low scenario	0.186	1000	6.75

Scoping scenario	Pile-up impurity (%) Bin 1	Bin 2	Bin 3
VBF Sample			
Reference	2.0	4.6	13.1
Middle	3.0	6.4	23.6
Low	5.2	12.0	38.7
ggF Sample			
Reference	23.2	37.9	52.1
Middle	24.0	43.4	65.0
Low	41.2	59.4	76.2

- The large eta coverage of the tracker is critical to achieve an efficient suppression of PU and to increase the S/B discrimination and purity
  - PU contamination increasing x2 when coverage reduced from $|\eta| < 4.0$ to $|\eta| < 2.7$

Fermilab

Extraction of the HWW Coupling in the lvlv Final States

- A high precision measurement of the VBF H →WW enables the extraction of the HWW coupling with a very small theoretical uncertainty
  - Signal to background discrimination relies on:
    - central jet veto
    - b-jet veto
    - ETmiss

Tracker Coverage	Scoping Scenario	without theo. unc. $\Delta\mu/\mu$	without theo. unc. Z_0-value (σ)	with theo. unc. $\Delta\mu/\mu$	with theo. unc. Z_0-value (σ)
IηI<4.0	Reference	0.14	8.0	0.20	5.7
IηI<3.2	Middle	0.20	5.4	0.25	4.4
IηI<2.7	Low	0.30	3.5	0.39	2.7

Run1, 1412.2641:

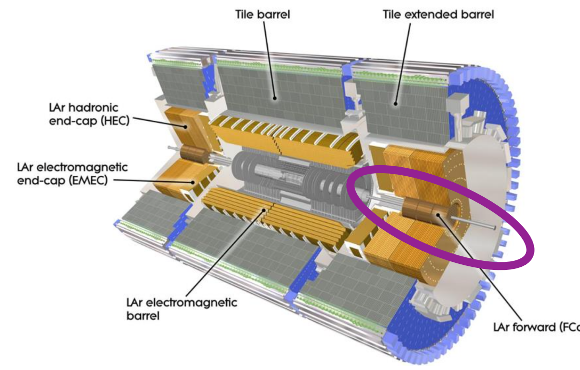
$$1.27^{+0.44}_{-0.40}\ (\text{stat})^{+0.30}_{-0.21}\ (\text{syst})$$

- A large η coverage of the tracker is essential to the measurement of the HWW mode
  - for efficient central jet veto, b-tagging in the forward region, and good Etmiss resolution

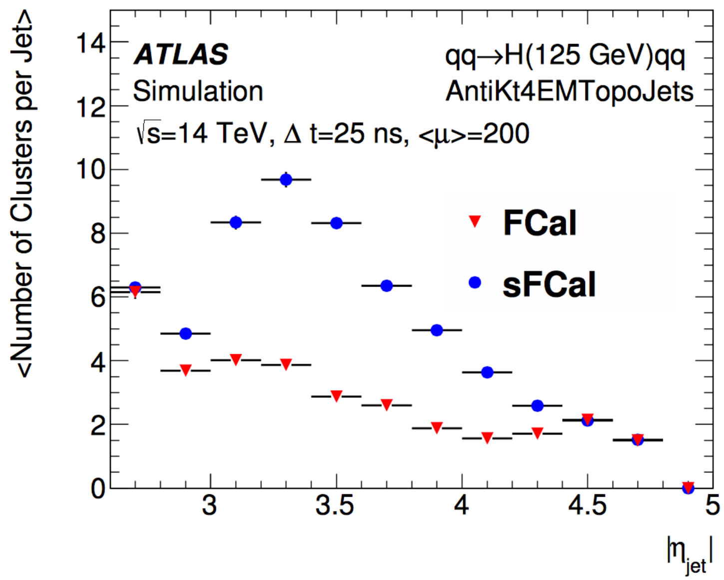
Other Upgrades

Further Improvements of the ATLAS Capabilities (I)

- Current Forward Calorimeter (FCAL) consists of 3 modules with FCAL1 closest to the interaction point
  - 4 electrodes have their signals summed
  - for $L^{inst} > 3x10^{34}$ cm^2s^{-1}, performance degrades due to space charge effects, HV drop and possibly heating up of the liquid argon



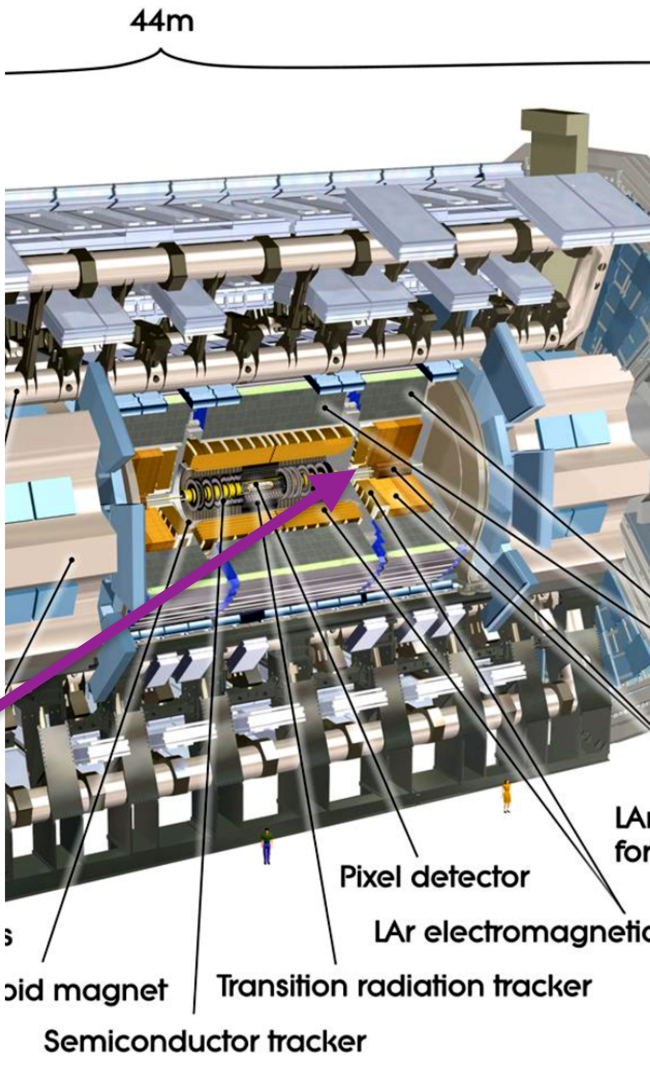
- Two upgrade options are considered
  - **sFCAL**
    - similar to that FCAL but narrower LAr gaps
    - **increase in the readout granularity** (no signal summing & 4x reduction of the cell size of most of the readout cells)
      - **reduction of the pile-up noise RMS by 2.5x**
    - improved cooling system
  - **miniFCAL** in front of the FCAL (diamond or silicon or liquid argon)



Better resolution of the jet substructure in VBF events (gluons vs quarks)

Further Improvements of the ATLAS Capabilities (II)

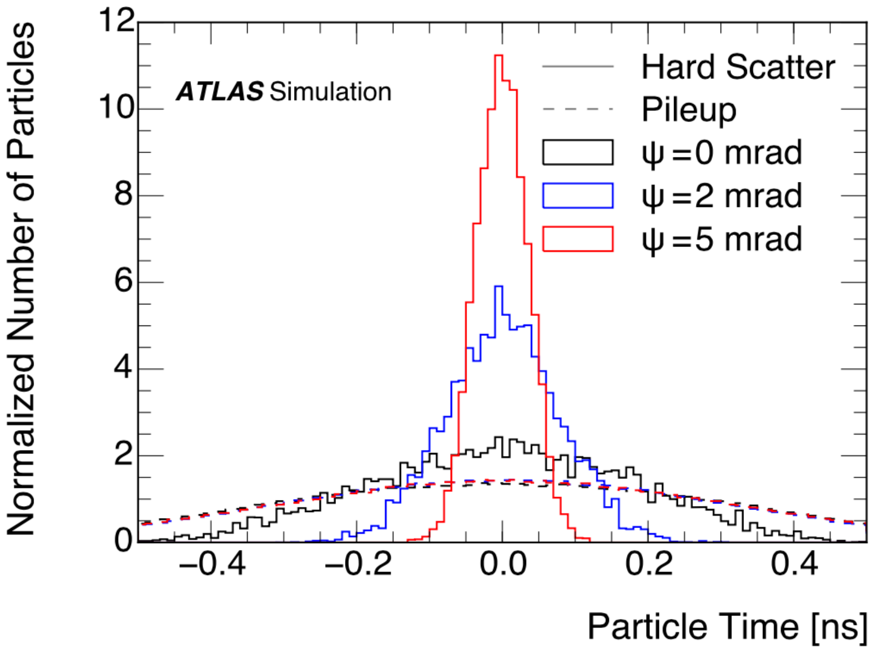
- A precision timing detector can provide the capability of identifying the vertex of origin for forward jets
  - Run 1, time spread of the pile-up interactions ~100 ps which is on the same order as the difference in time of flight of particles originating from vertices spread over a 5 cm beam-spot
- A novel colliding scheme ("crab-kissing") extends the spatial pile-up density profile while reducing the spread of the time density
- **Highly segmented timing detector is under investigation**
  - in front of the EMEC/FCAL in $2.4 < |\eta| < 4.3$
  - high granularity and excellent time resolution
  - several technologies considered (MCP, W/Si,…)

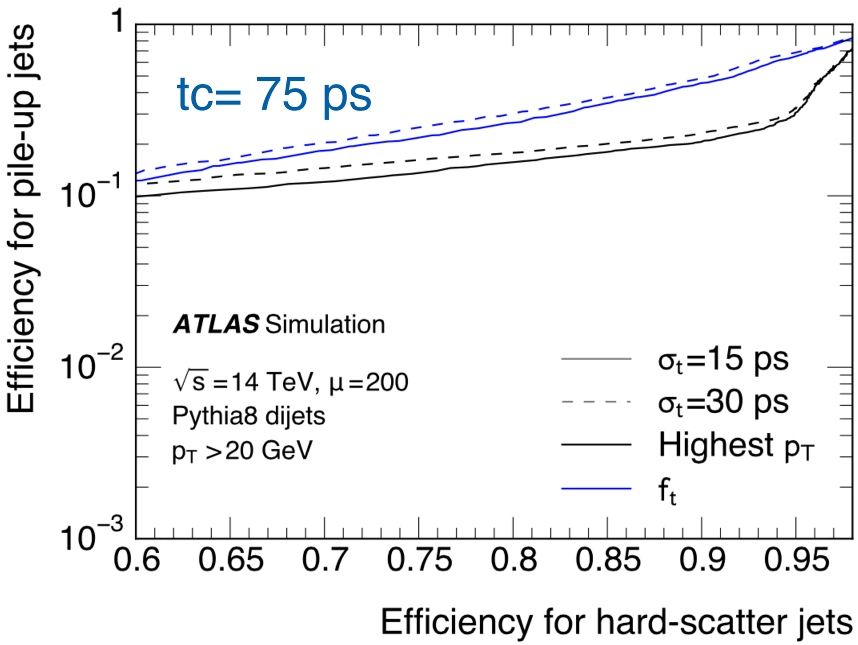


Further Improvements of the ATLAS Capabilities (III)

- To identify and reject pile-up jets, the time measurements need to be associated with the jets
  - time of the highest pT particle in the jet or fraction f_t of time measurements within a certain window $[-t_c, t_c]$ used a discriminant

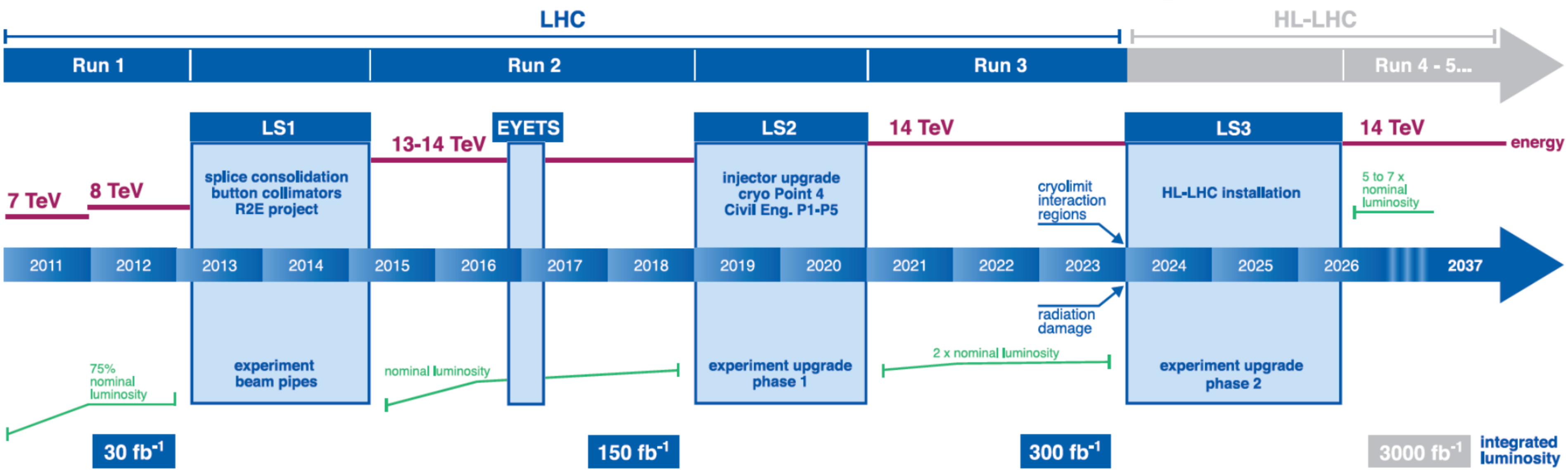
$$f_t = \frac{\int_{-t_c}^{t_c} N_R(t)dt}{\int_{-\infty}^{\infty} N_R(t)dt}$$



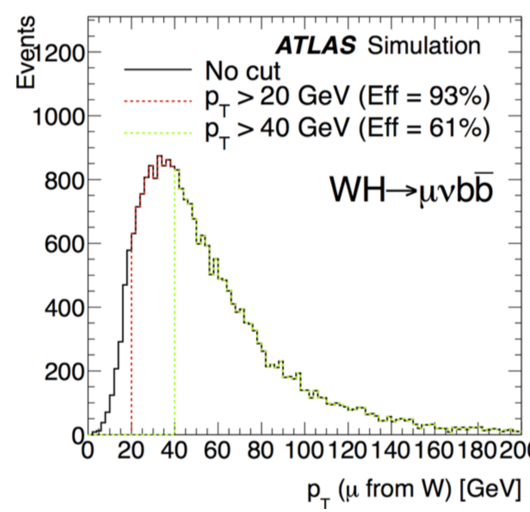


First feasibility study indicating a fake rate of approximately 15% at 80% signal efficiency. More studies on-going including the usage of timing in absence of crab kissing.

Triggering on the Higgs boson



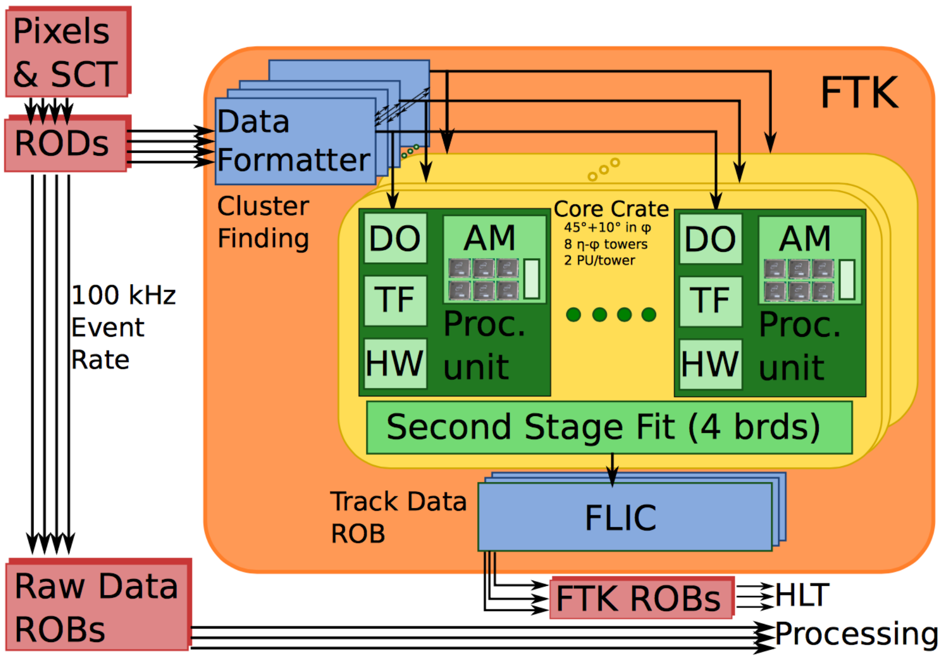
- **Triggering Higgs events with ~20-30GeV objects proved to be a successful approach in Run 1**
- The Run 1 strategy can not be implemented at HL-LHC with current trigger system
  - extrapolated trigger rates ⇒L1A ~500kHz > 100kHz Run2
  - raising the thresholds would jeopardize the program



Fermilab

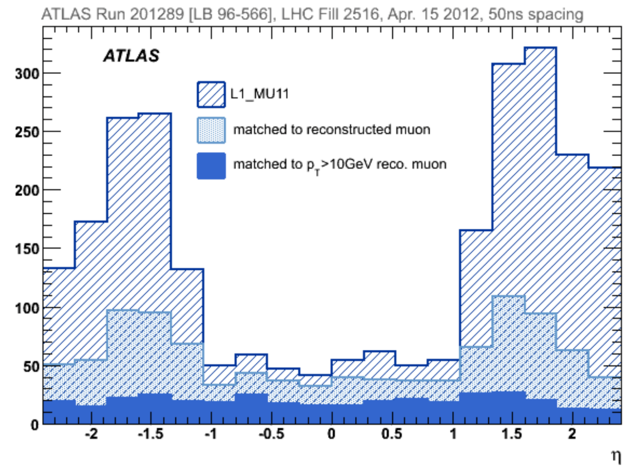
Staggered Upgrades: Fast Track Trigger (2015-2016)

- **A dedicated hardware-based track finder (FTK) is being installed to provide *global* tracking information after L1 as an input to the HLT:**
  - vertexing and pile suppression
    - *e.g.* <Nj(25GeV)> is reduced from 21 to 2.8 in a WH(Lvbb) event at <μ>=69
  - b-tagging
  - tau identification
  - isolation for leptons

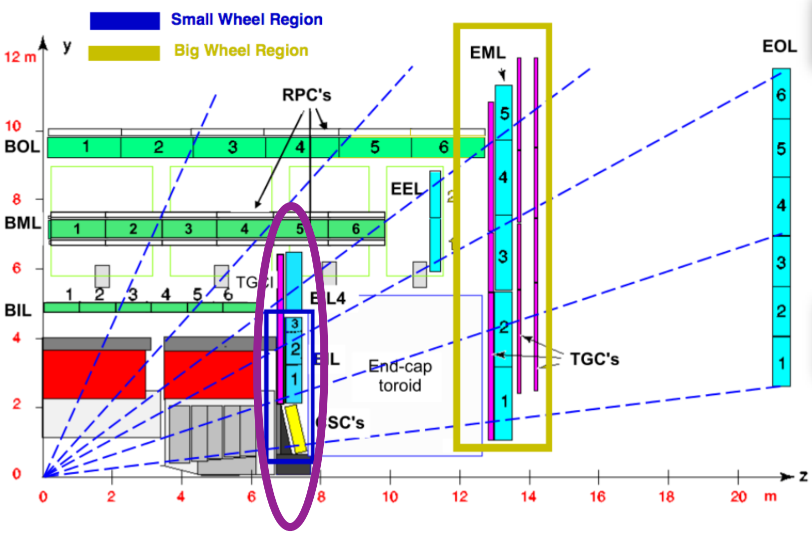


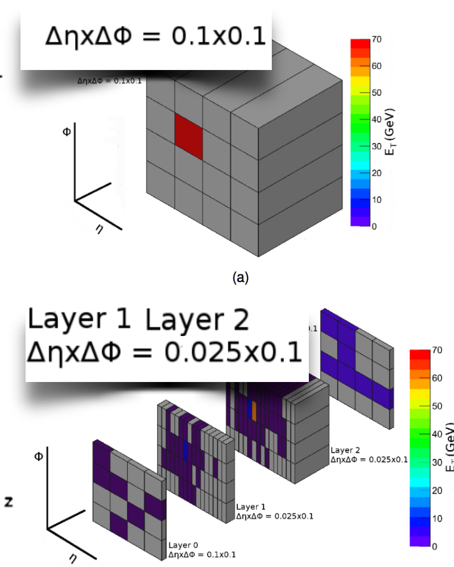
- FTK hardware performs global tracking in two steps:
  - pattern recognition with custom AM pre-loaded with 1B patterns (for $\mathbf{p_T>1GeV}$)
  - all patterns matched in parallel
- FTK operates well for a 100 kHz
  - parallelization to satisfy 1000 16-bit words per link

Staggered Upgrades: New Small Wheel & L1Calo in Phase I



- New Small Wheel
  - **TGC** (sTGC): primary trigger with single bunch crossing identification capability
    - Track vectors with <1 mrad angle resolution
  - **MicroMega** (MM): primary tracker with exceptional precision tracking capabilities
    - position resolution <50 µm or 100 µm per plane



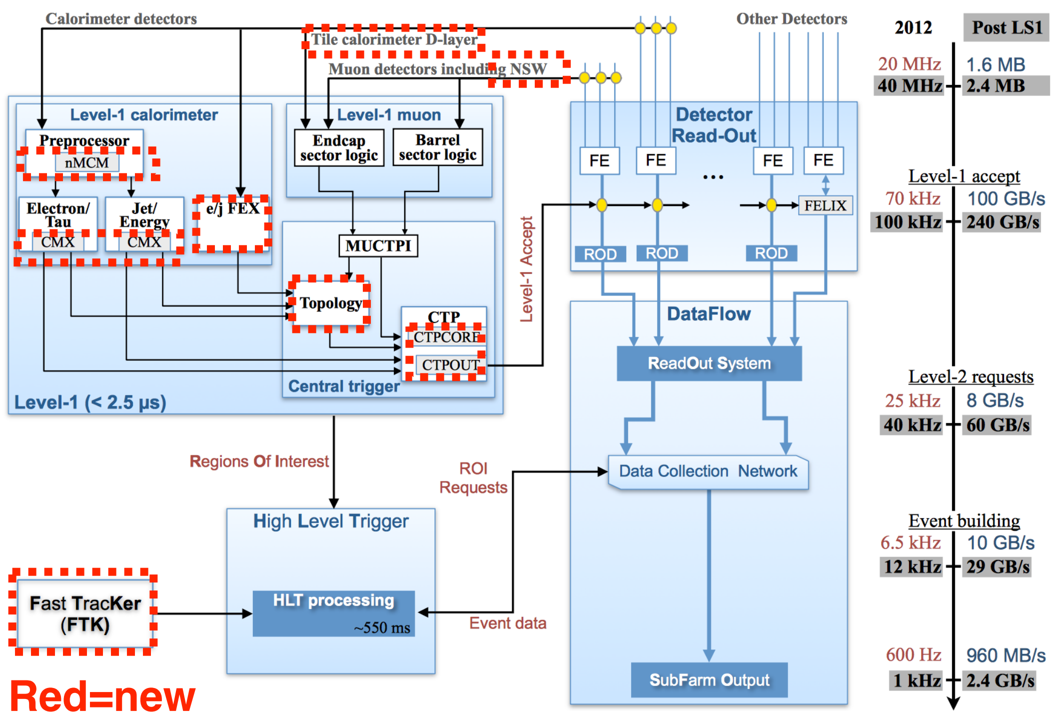


- L1Calo or "SuperCell"
  - **LAr calorimeter**
  - high granularity and longitudinal shower information used at L1
  - higher energy resolution

Low rates restored maintaining low thresholds

Staggered Upgrades: TDAQ in Phase I

- New **Level-1 calorimeter feature extraction processors** will be incorporated to allow the finer granularity data from the LAr Calorimeter to be used to improve:
  - electron, photon, and tau selection
  - **more sophisticated and larger-area algorithms** for jet selection, pile-up corrections, missing momentum reconstruction

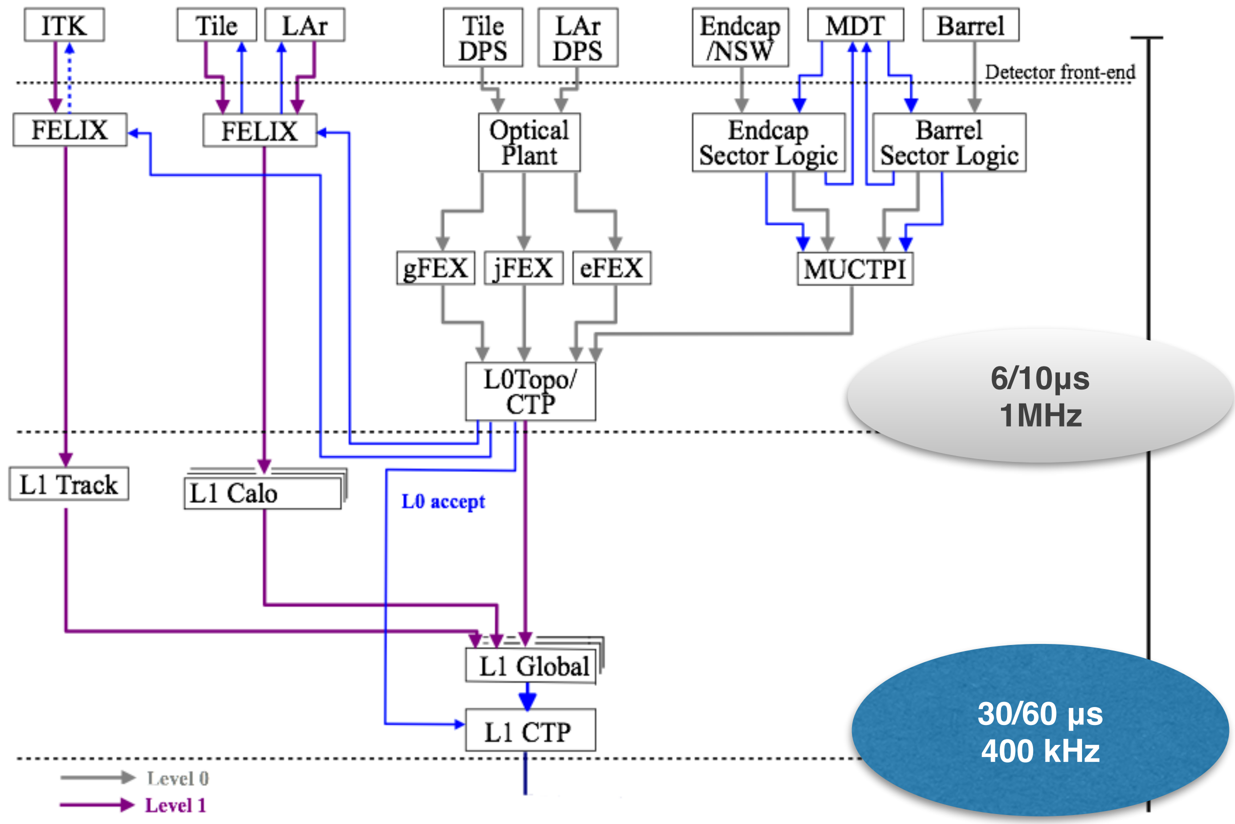


Red=new

Lower thresholds on objects from Higgs decay and **topological selection essential for the program** (*e.g.* further selection of $\Delta\eta < 2.0$, rate reduced by 25% with no loss of VBF Higgs signal)

Staggered Upgrades: TDAQ and L1Track in Phase II

- **A new trigger system is proposed with a 2-step first level hardware trigger**:
  - 1st step, Level-0: calorimeter and muon information for regions of interest
  - 2nd step, Level-1: **regional tracking information**, regional full calorimeter granularity, refined muon selection using muon precision tracking chambers



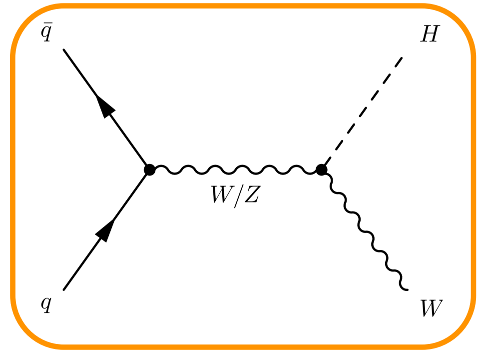
L1Track processes hits from ITK (pixels&strips) to find tracks with $p_T > 4$ GeV using AM (3.2B patterns).

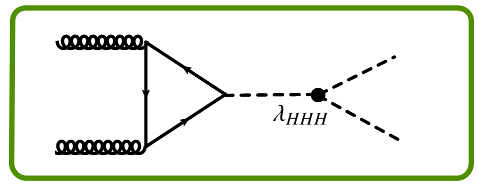
If the pT cut is increased to 8 GeV, the efficiency of hard scatter jets drops from 90 to 60%.

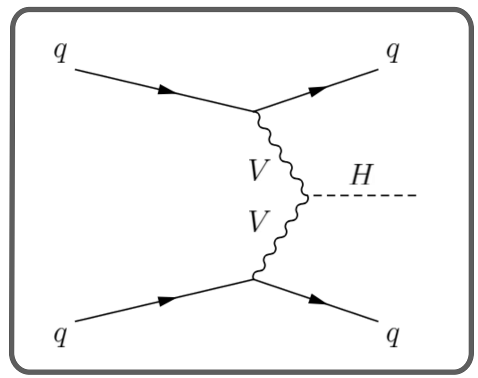
Trigger Menu

The Phase 2 TDAQ upgrade successfully maintains low thresholds

item	Reference		
	p_T Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%
forward e	35	$2.5 - 4.0$	90%
single γ	120	< 2.4	100%
single μ	20	< 2.4	95%
di-γ	25	< 2.4	100%
di-e	15	< 2.5	90%
di-μ	11	< 2.4	90%
$e - \mu$	15	< 2.4	90%
single τ	150	< 2.5	80%
di-τ	40,30	< 2.5	65%
single jet	180	< 3.2	90%
fat jet	375	< 3.2	90%
four-jet	75	< 3.2	90%
HT	500	< 3.2	90%
E_T^{miss}	200	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%







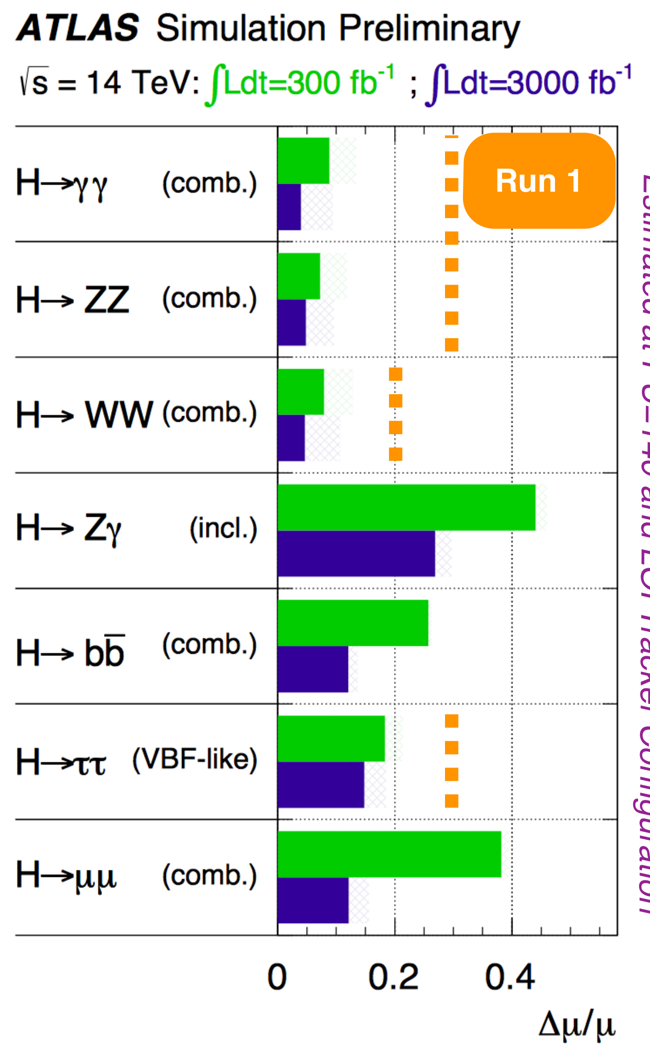
Summary and Conclusions (I)

- The Higgs boson *"offers a unique portal to understanding the laws of Nature and connects several areas of particle physics. […]. The HL-LHC has a compelling and comprehensive program […] of the Higgs properties"*
- Instantaneous luminosities as high as $7 \times 10^{34}/cm^2 s$ and the integrated dose corresponding to 3000/fb are **THE challenge** at the HL-LHC
  - and represent a driver for technological and experimental innovation!
- Essential to the success of the Higgs precision program are detectors capable of an **excellent reconstruction of leptons (including taus), jets, Etmiss, photons, b-jets in presence of 140-200 interactions per bunch-crossing**
  - suppression of jets from pile-up vertices and corrections of the object scale for pile-up induced effects are the key

Summary and Conclusions (II)

- **Tracker** with largest possible η coverage, increased outer radius, small radius of innermost layer, high granularity
- **Calorimetry** with high granularity in the forward region
- **Timing device** in the forward region
- **Trigger system** with excellent signal-to-background discrimination capabilities

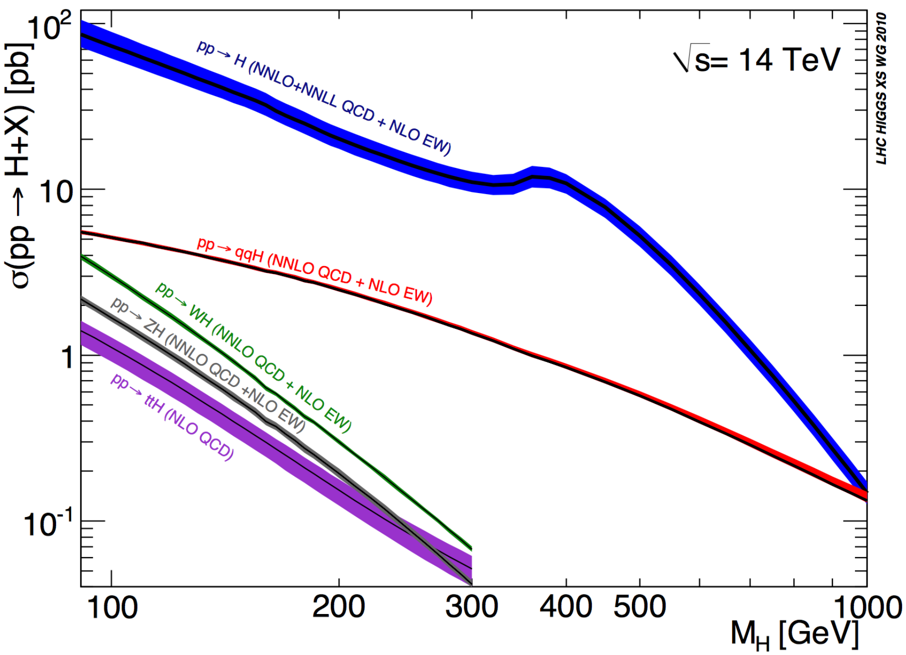
The design of the upgraded ATLAS detector meet these requirements

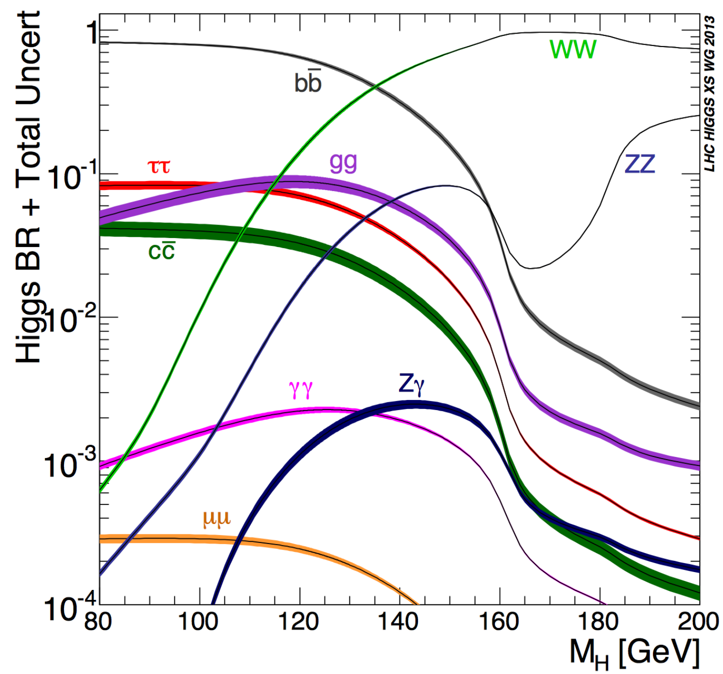


EXPECT TO ACHIEVE A FEW % UNCERTAINTY ON THE BEST MEASURED MODES AND TO OBSERVE RARE MODES

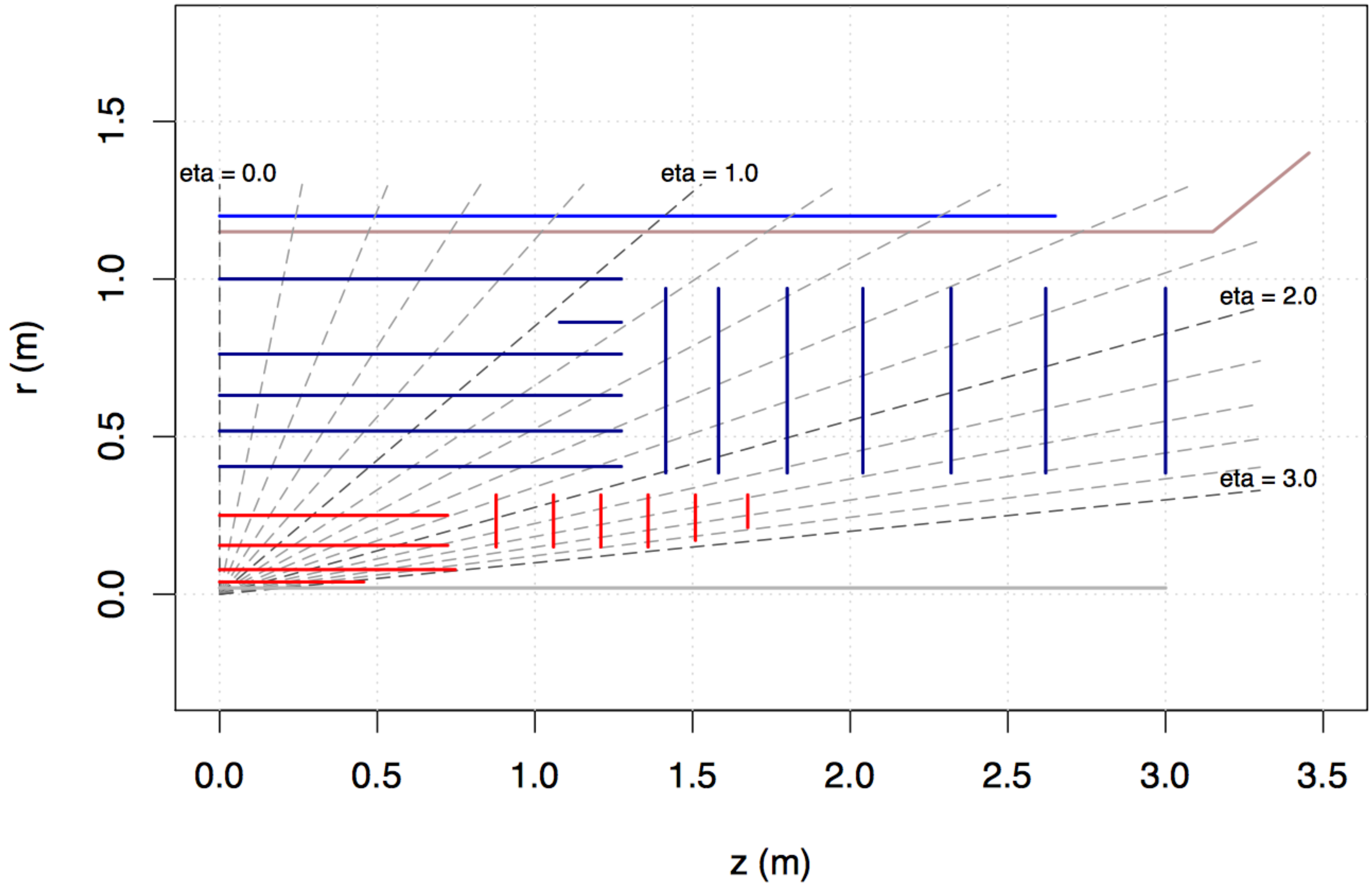
Additional Material

Production Cross-Section and Decay BR

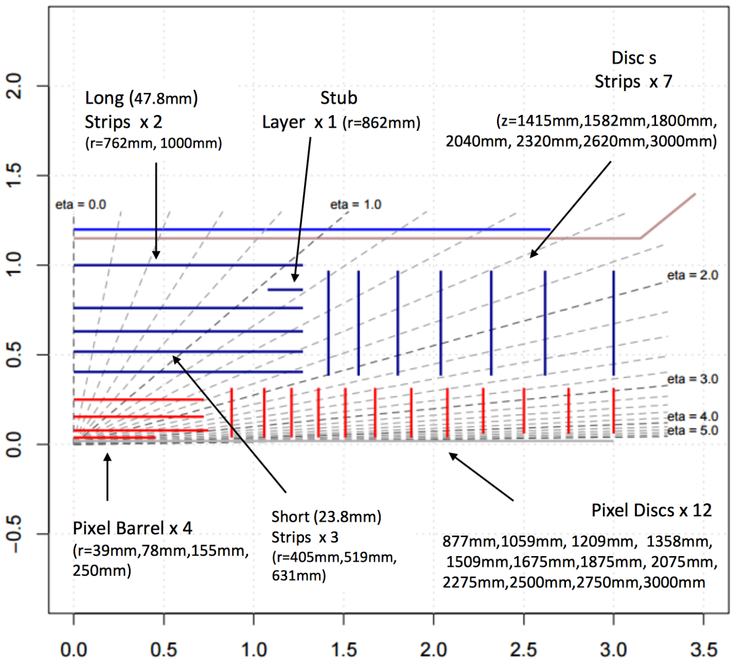


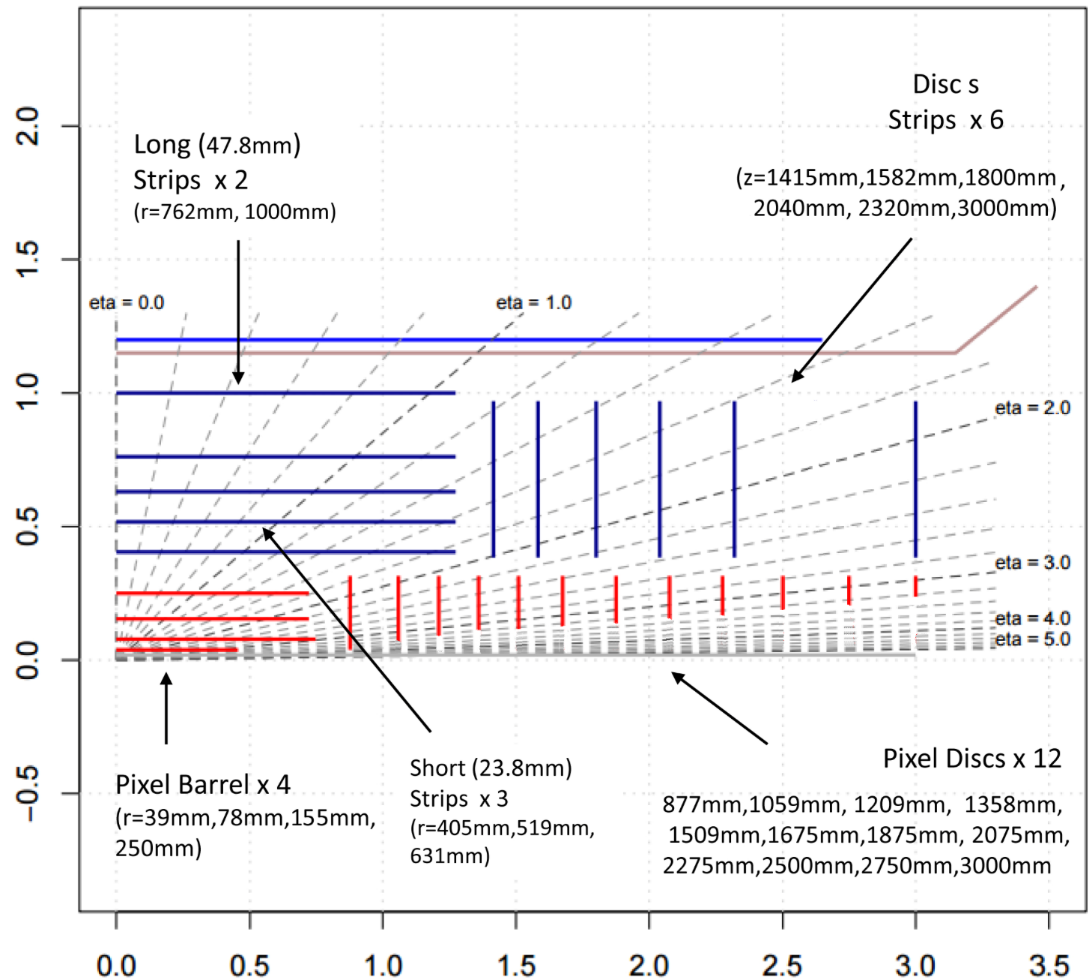


ITK - LOI

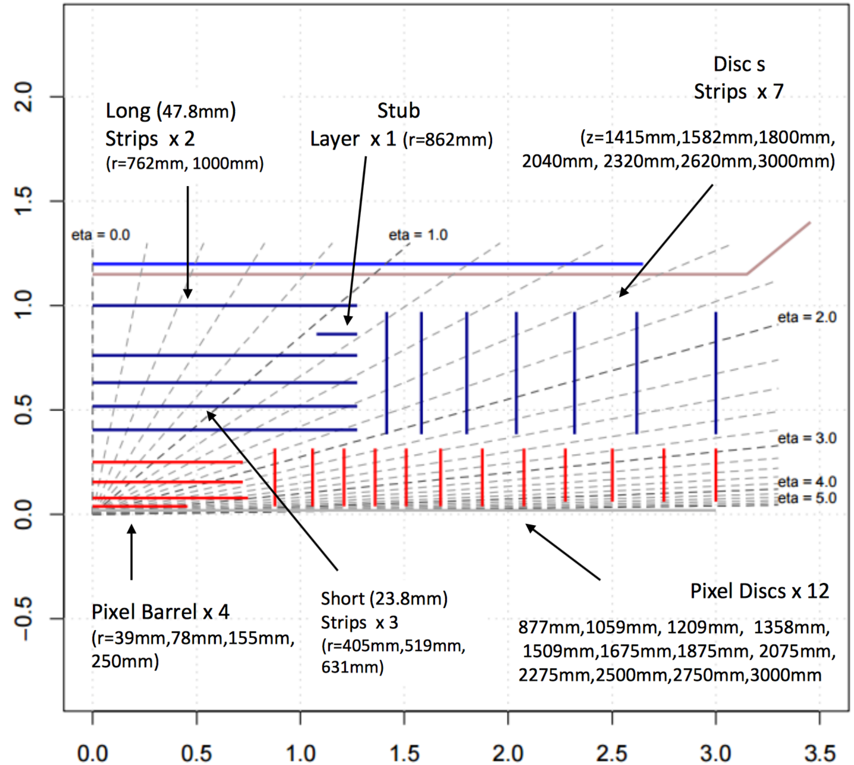


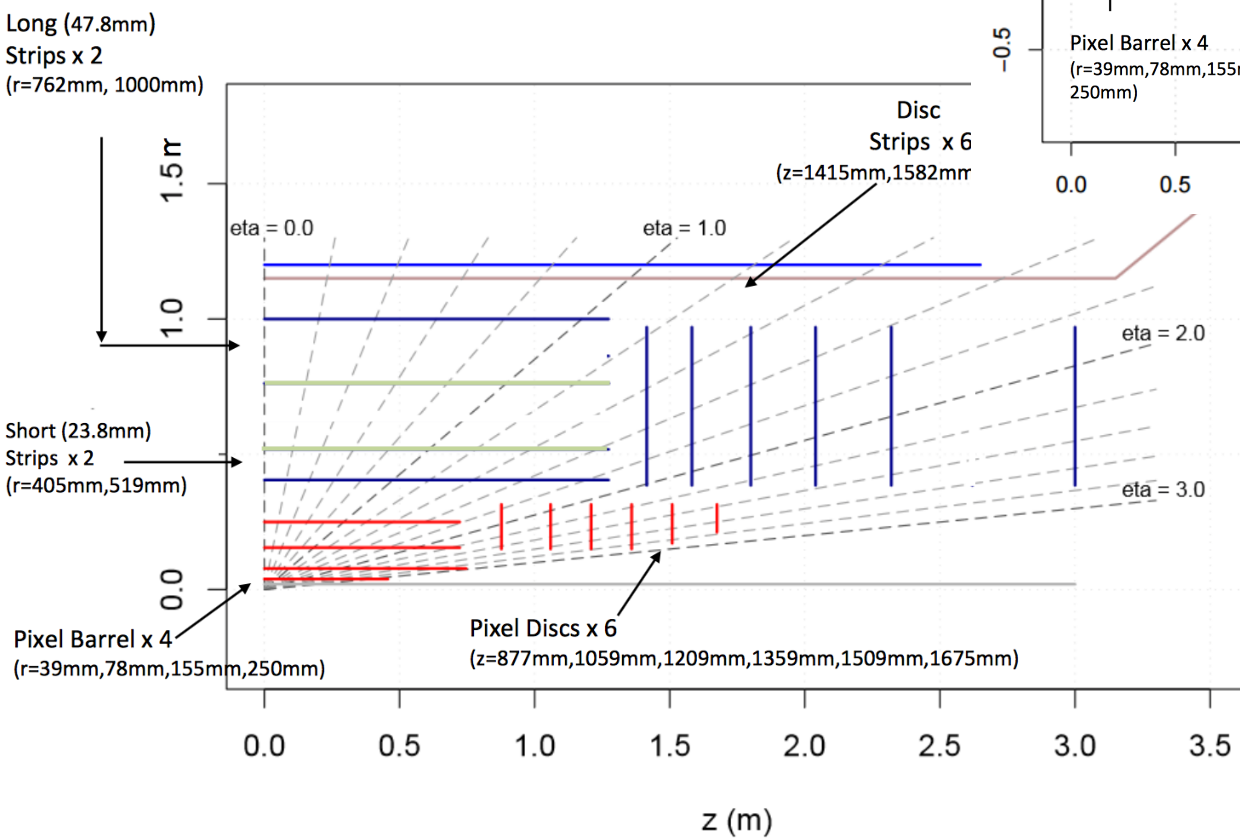
ITK in Reference and Middle Scenario





ITK in Reference and Low Scenario



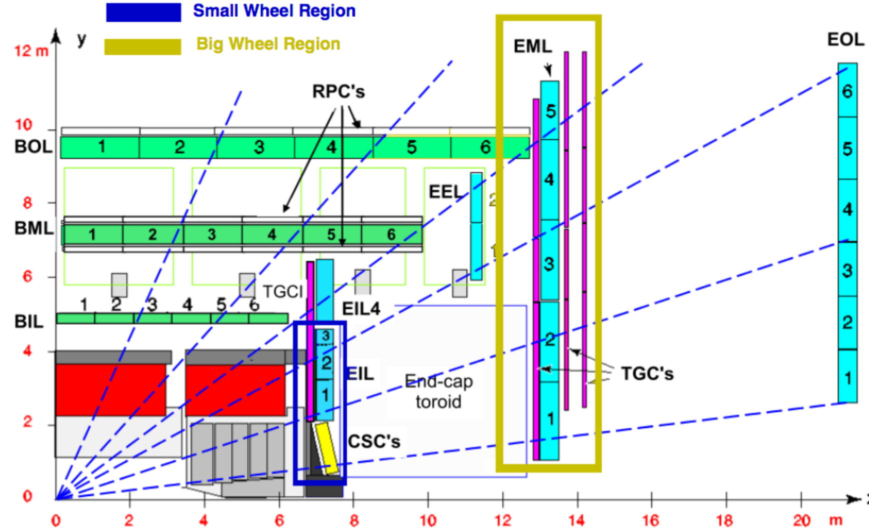


Performance of the Upgraded Trigger System

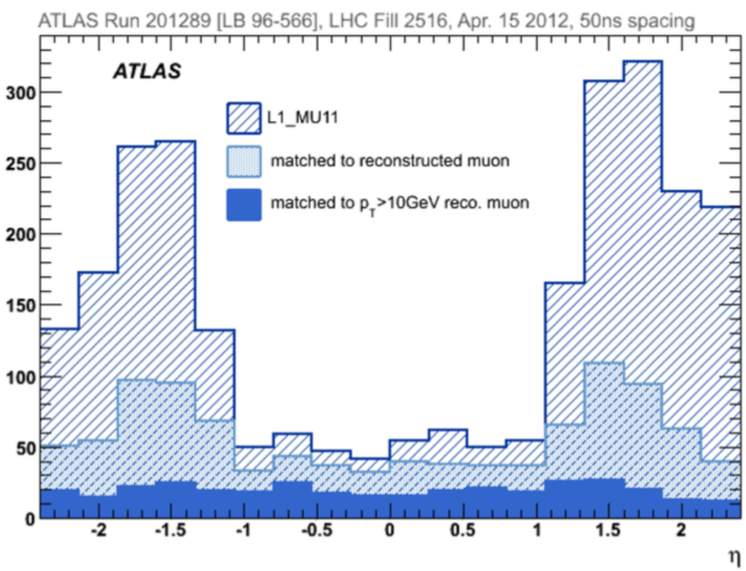
item	Reference			Middle			Low		
	p_T Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%	28	< 2.5	95%	28	< 2.5	91%
forward e	35	$2.5 - 4.0$	90%	40	$2.5 - 3.2$	90%	-	-	-
single γ	120	< 2.4	100%	120	< 2.4	100%	120	< 2.4	100%
single μ	20	< 2.4	95%	25	< 2.4	80%	25	< 2.4	65%
di-γ	25	< 2.4	100%	25	< 2.4	100%	25	< 2.4	100%
di-e	15	< 2.5	90%	15	< 2.5	90%	15	< 2.5	82%
di-μ	11	< 2.4	90%	15	< 2.4	80%	15	< 2.4	65%
$e - \mu$	15	< 2.4	90%	15	< 2.4	84%	15	< 2.4	70%
single τ	150	< 2.5	80%	150	< 2.5	80%	150	< 2.5	80%
di-τ	40,30	< 2.5	65%	50,40	< 2.5	65%	50,40	< 2.5	55%
single jet	180	< 3.2	90%	225	< 3.2	90%	275	< 3.2	90%
fat jet	375	< 3.2	90%	400	< 3.2	90%	450	< 3.2	90%
four-jet	75	< 3.2	90%	85	< 3.2	90%	90	< 3.2	90%
HT	500	< 3.2	90%	600	< 3.2	90%	750	< 3.2	90%
E_T^{miss}	200	< 4.9	90%	225	< 4.9	90%	250	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%	150,175	< 4.9	90%	160,200	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%	225	3.2 - 4.9	90%	275	3.2 - 4.9	90%

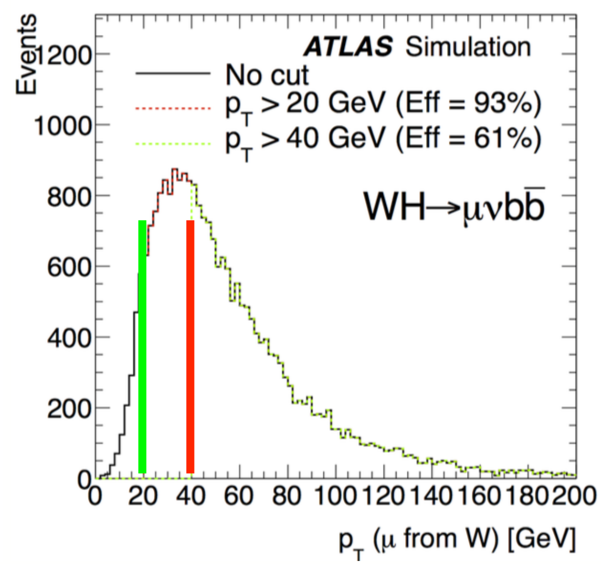
Overview of the New Small Wheel Upgrade

- In the Run1-2, muon end-cap triggers are based on TGC
  - ~90% of the L1 muon triggers in the EC are fakes
- Raising the pT threshold would lead to significant loss of acceptance
- A substantial degradation of tracking efficiency and resolution is expected at high luminosity



CERN-LHCC-2013-006

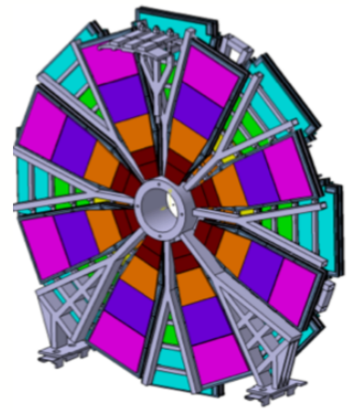


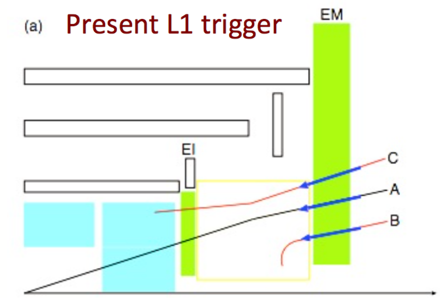


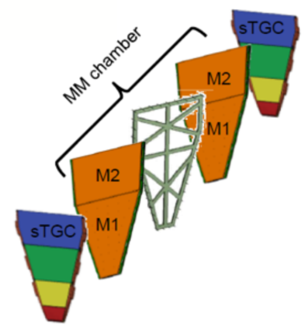
An upgrade of the New Small Wheel is proposed (1.3<|η|<2.7)

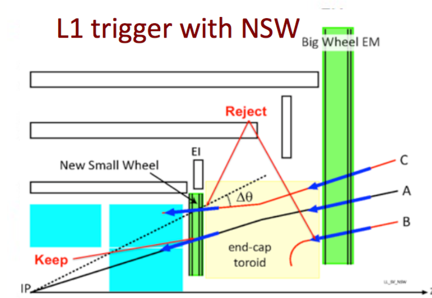
NSW Detector Technology & Performance

- Two (redundant) chamber technologies are adopted
  - TGC (sTGC): primary trigger
    - Single bunch crossing identification capability
      - segment available within 1us, current delay of the Big Wheel
    - Track vectors with <1 mrad angle resolution
    - Space resolution < 100 μm independent of incident angle
  - MicroMega (MM): primary tracker
    - Exceptional precision tracking capabilities
      - position resolution <50 μm or 100 μm per plane
    - High granularity leading to good track separation and to a match to the current system
    - High rate capability due to small gas amplification and small space charge effect







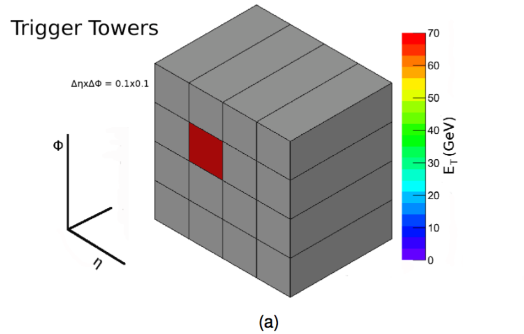


L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3
$p_T > 20$ with NSW and EIL4	17 ± 2

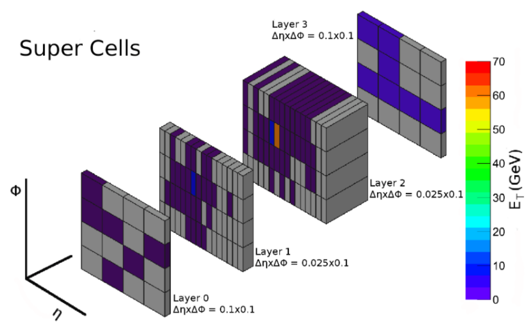
CERN-LHCC-2013-006

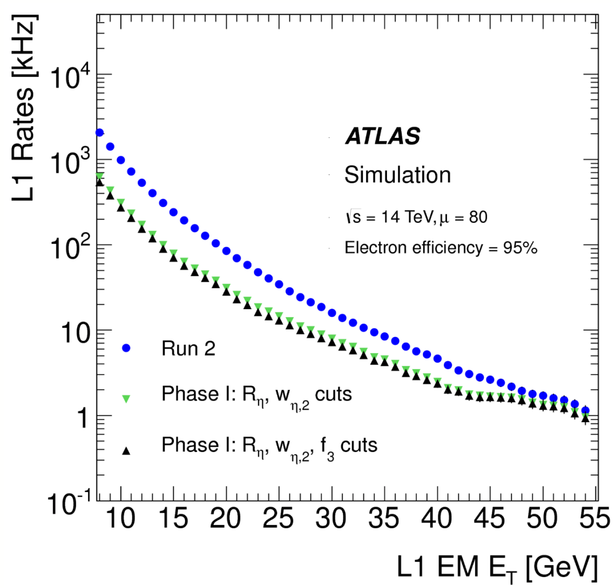
Overview of the L1 Calo Trigger Upgrade

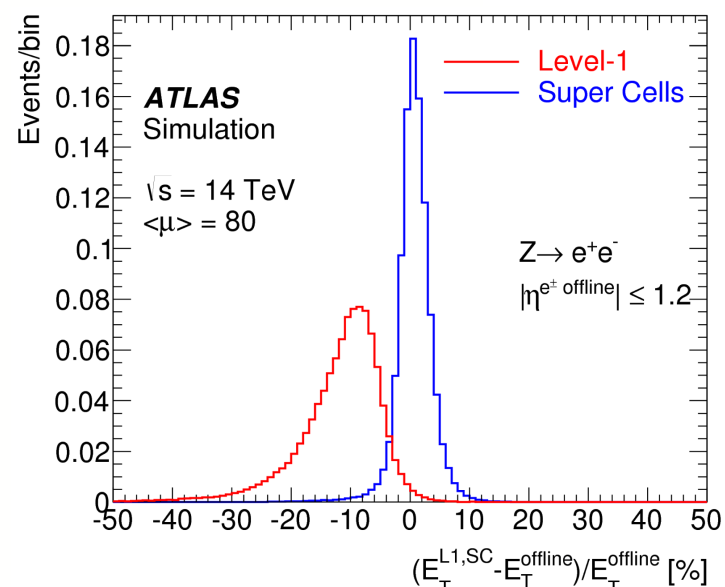
- Current L1 Calo is based on $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ trigger towers
  - needed for photons, electrons, jets, Etmiss
  - used to compute object energy and isolation
  - expecting rates ~270 kHz @ $3 \times 10^{34}/cm^2 s$ >> total L1 rate of 100kHz (for Run 1 thresholds)



- The "SuperCell" upgrade will
  - make high granularity and longitudinal shower information available at L1 (retain transverse energy in each layer instead of summing)
  - will also improve substantially the energy resolution (12 bits in place of 8 of the towers)



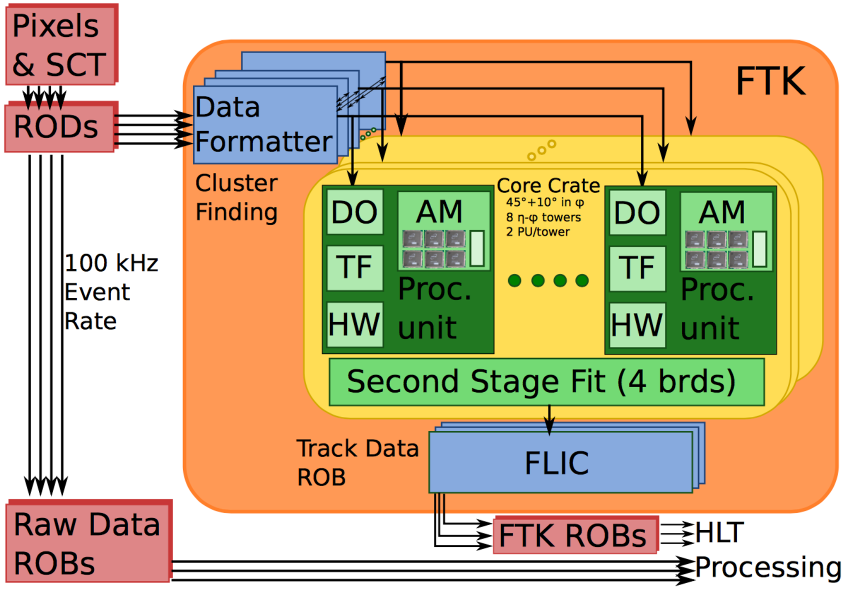




CERN-LHCC-2013-017

Overview of the Fast Tracker Trigger Upgrade

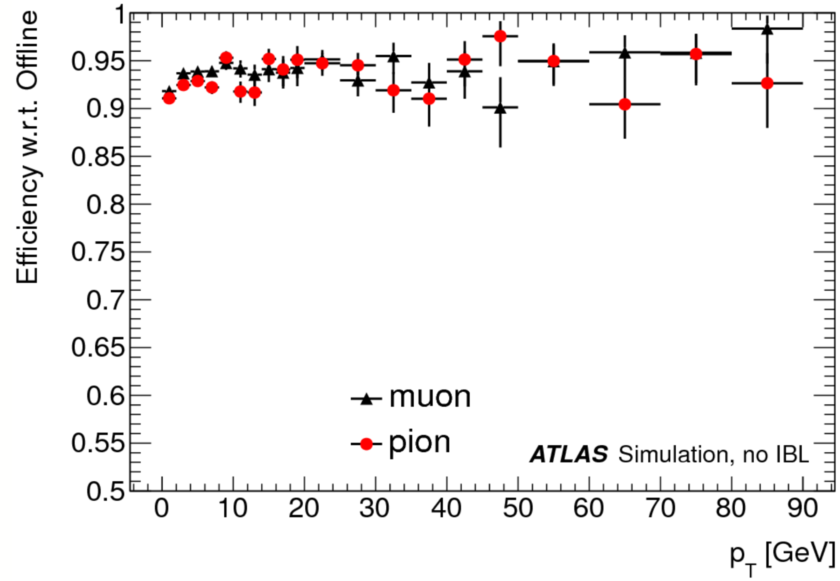
- Tracking information is critical for distinguishing which events triggered by the L1 should be kept
- Current approach based on Region of Interest (ROI) identified by the L1 trigger has limitations
  - there is a limit to either the number or size of ROIs processed by the HLT
  - global event information, such as the location of the hard interaction vertex are very important in challenging environment at high pile-up
- A dedicated, hardware-based track finder (FTK) is proposed to provide *global* tracking information after
- FTK operates in two stages:
  - Stage 1
    - pattern matching performed in custom-designed chips using Associate Memory (AM)
      - information from 8 /12 silicon layers only used for track fit
  - Stage 2
    - Tracks extrapolated into the additional 4 logical silicon layers
    - Precise re-fit with all 12 layers using FPGAs
    - Determination of the Chi2 and helix parameters

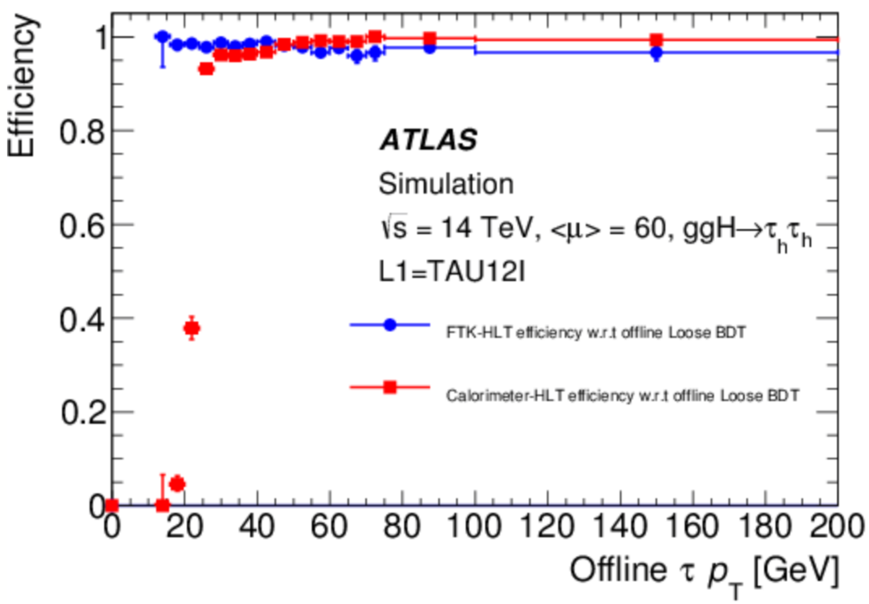


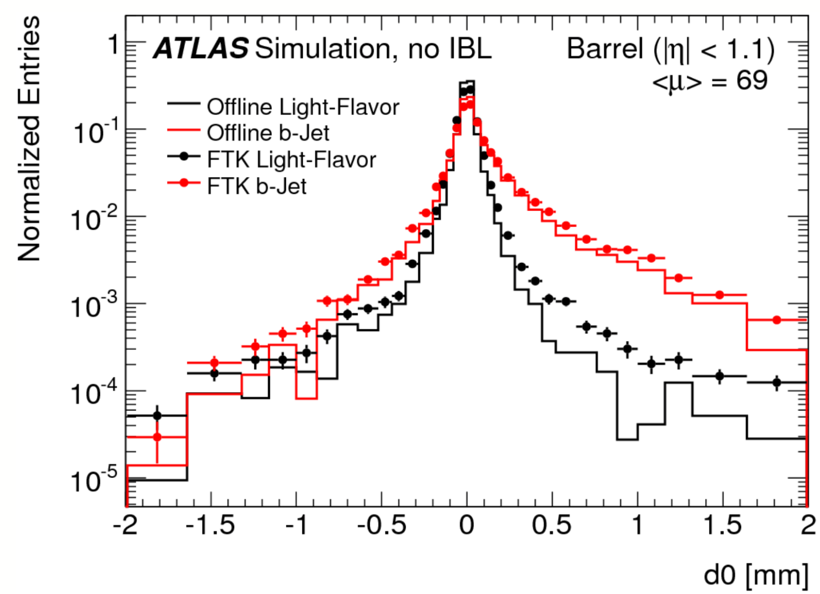
ATLAS-TDR-021

FTK Performance

- FTK is highly parallelized, detector data decomposed into independent regions (64 towers)
  - input to L2 in ~25μs (projection at <mu>=69)
- FTK online track quality and b-tagging efficiency are comparable to offline ones
- Tau trigger efficiency improves significantly
- There is a linear correspondence between the number of FTK vertices and offline vertices vs pile-up







ATLAS-TDR-021