

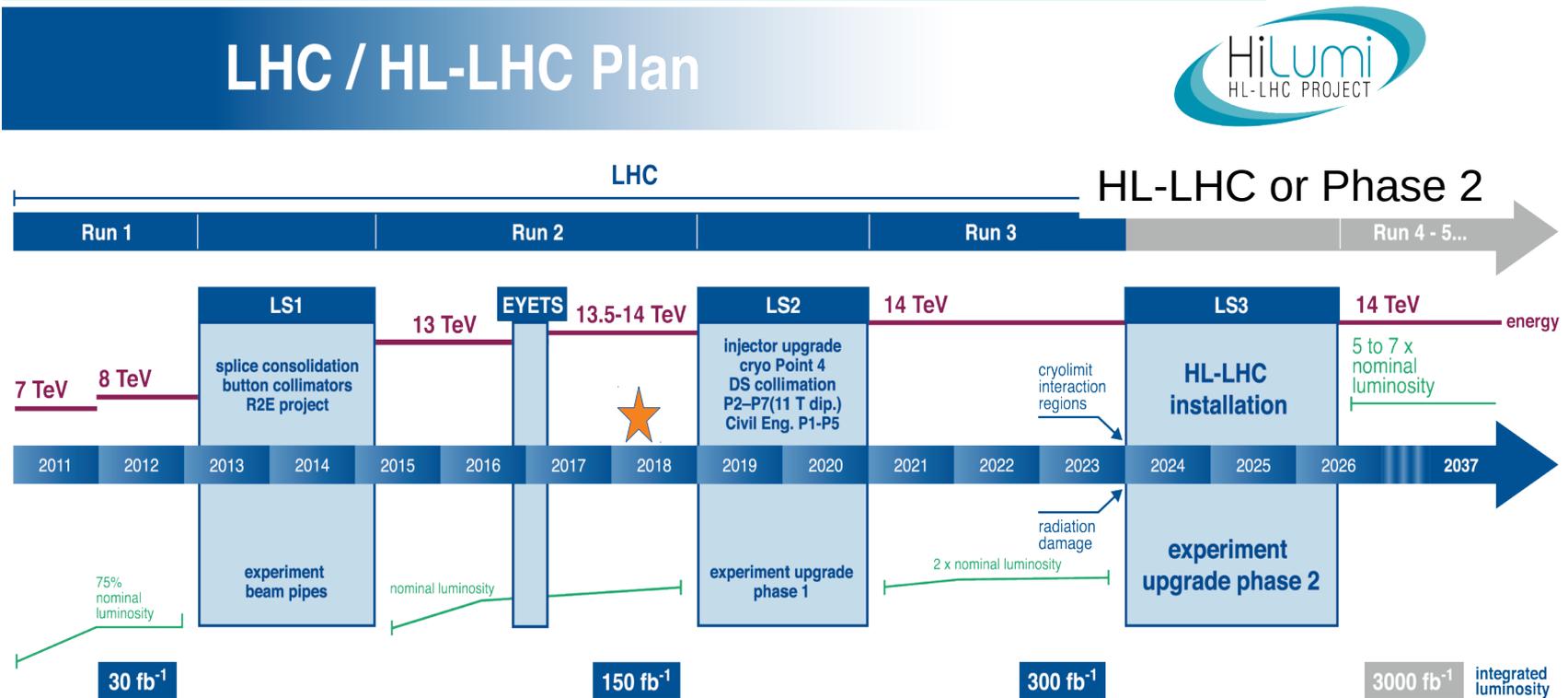
ATLAS@HL-LHC : Detector and Physics goals

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31 May 2018

IRN Terascale Strasbourg

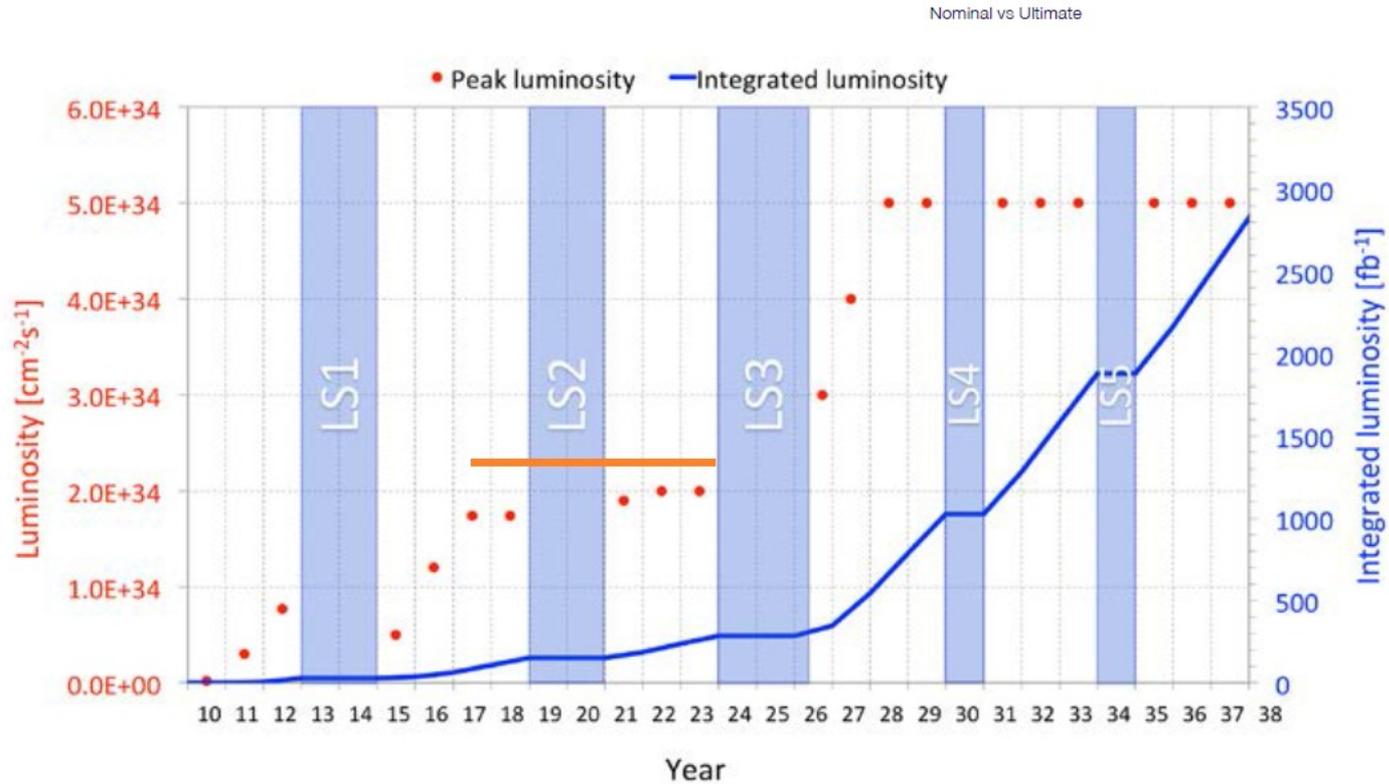




* HL-LHC program : Extend studies beyond current LHC one with x10 in \mathcal{L}

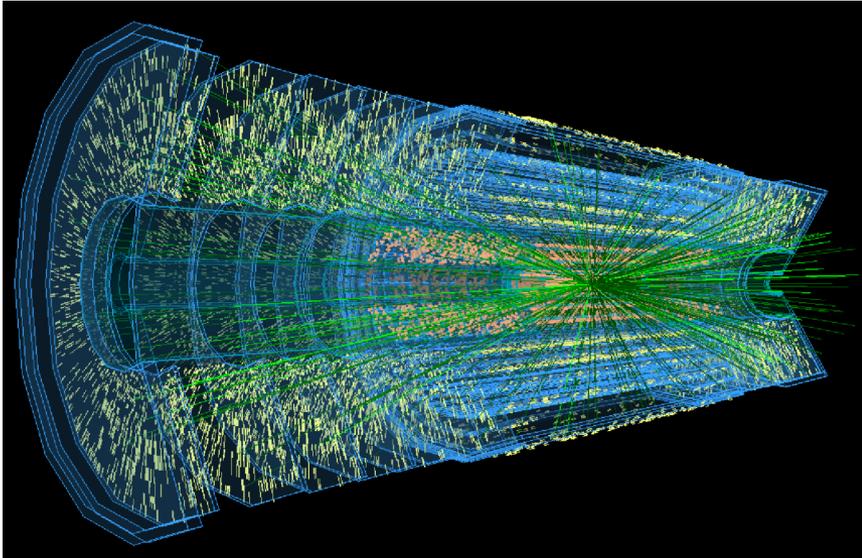
- Precision measurements
- Rare decays
 - Understand Electroweak Symetry Breaking
 - Search for new physics (direct/Indirect)

* Target for ATLAS detector : Maximise the physics outcome with the delivered integrated luminosity adapting to difficult running conditions

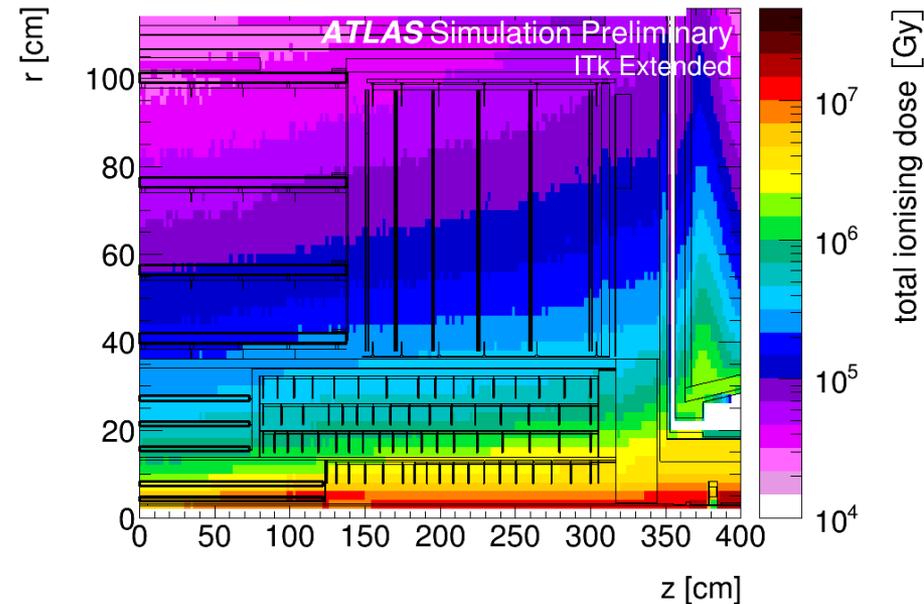


HL-LHC mode	Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	Mean number of interactions per bunch-crossing $\langle\mu_{pU}\rangle$	Integrated luminosity (fb^{-1})
Baseline	5×10^{34}	140	3000
Ultimate	7.5×10^{34}	200	4000

High particle density



High radiation dose



- Replace sub-detector not sustaining integrated radiation dose
- Minimize degradation from pile-up (high granularity, fast timing)
- Improve or maintain current detector performances
- Allow higher event rate to increase trigger acceptance

Calorimeters : LAr + Tile



TDAQ/Trigger

New Inner Tracker (Itk)



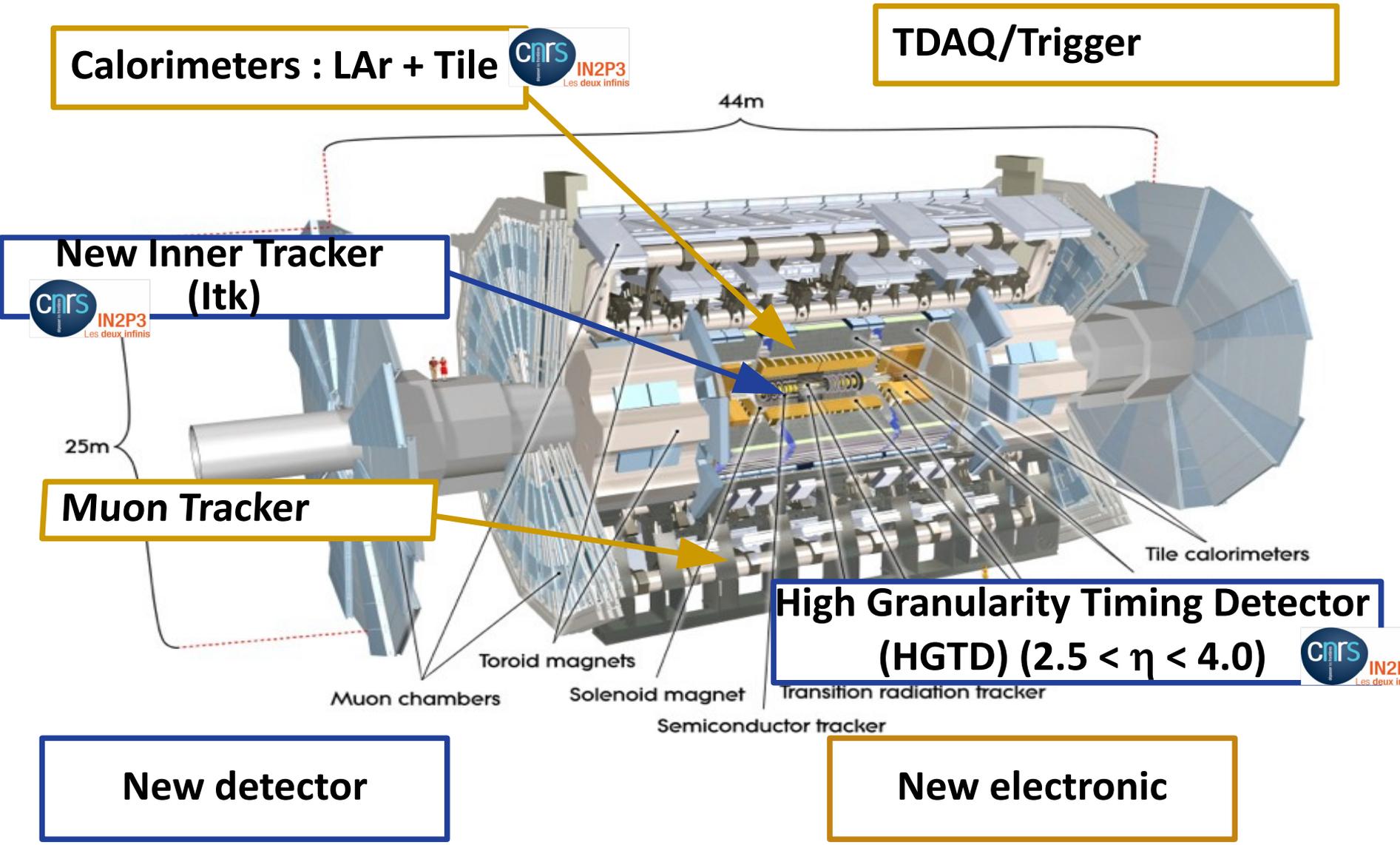
Muon Tracker

High Granularity Timing Detector (HGTD) ($2.5 < \eta < 4.0$)



New detector

New electronic



- * 2017 : Technical Design Report
 - Last optimisation of detectors
 - Technology availability
 - Physics performances
 - Define detector baseline and list remaining options

- * 2017-2019 : High Granularity Timing Detector :Letter Of Intent → TDR

- * 2020 : Software and Computing TDR

* Completely new tracker :

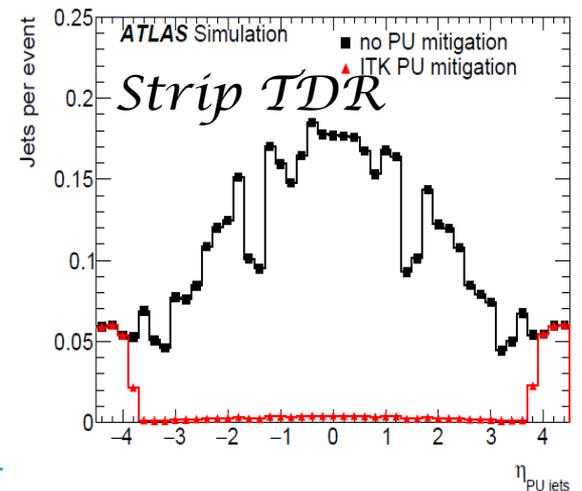
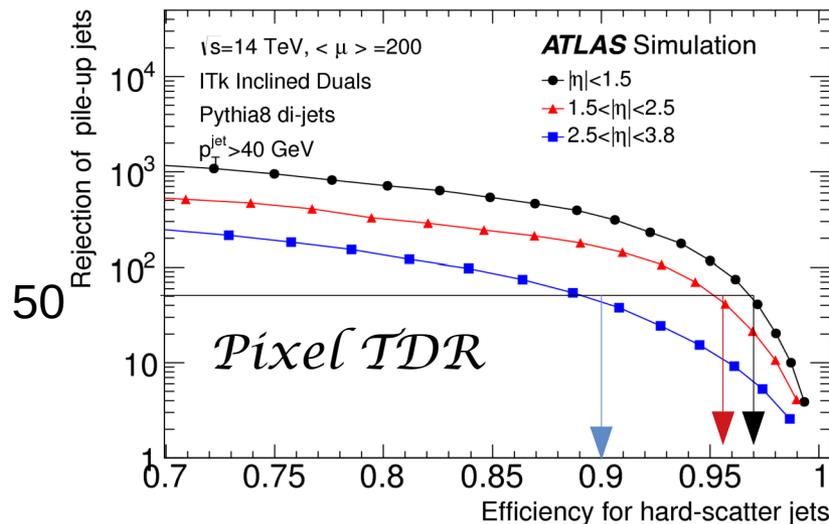
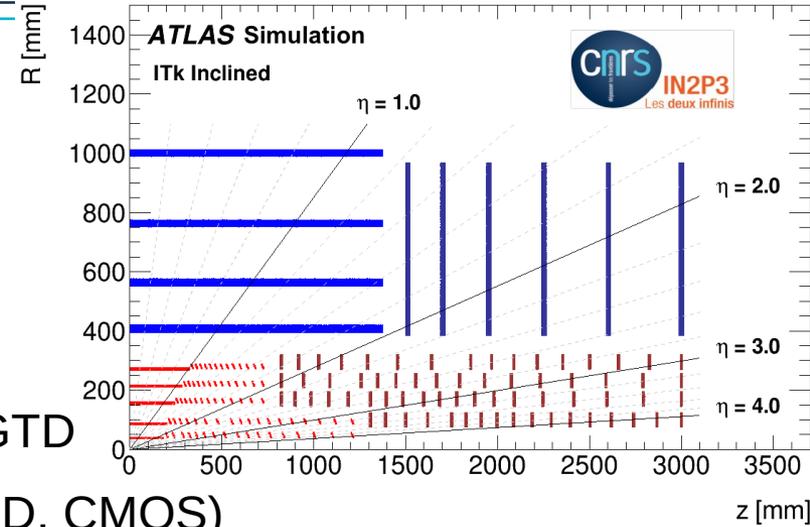
- Full silicon tracker up to $\eta=4$

* Pixel

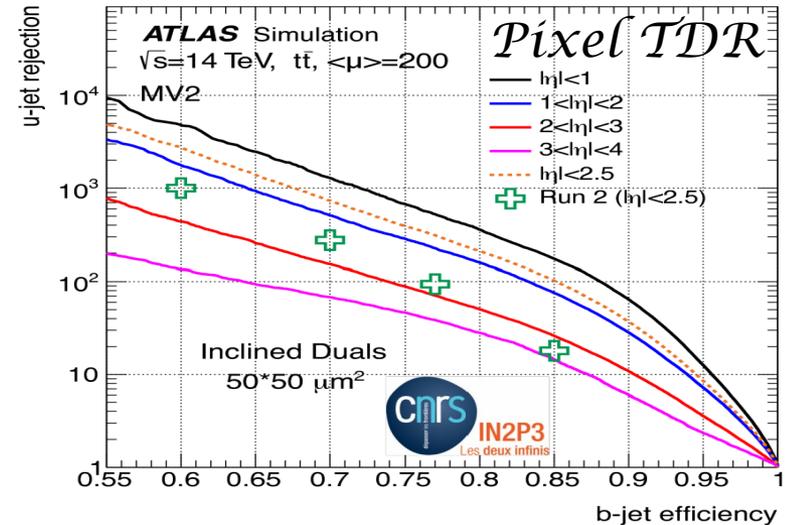
- Pixel peach : $50 \times 50 \mu\text{m}^2$
 - Option: 25 (ϕ) \times 100 (z) reinforced by HGTD
- Still options for sensor technology (Planar, 3D, CMOS)

* PU rejection

- Keep HS jet P_T threshold at same level as Run2 (~ 30 GeV in forward direction)



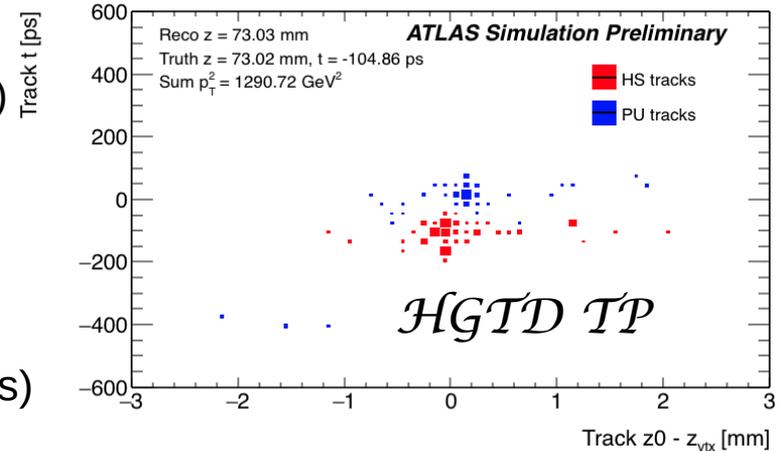
- * B-tagging :
 - Better performances than current Run2
 - Extension to forward direction



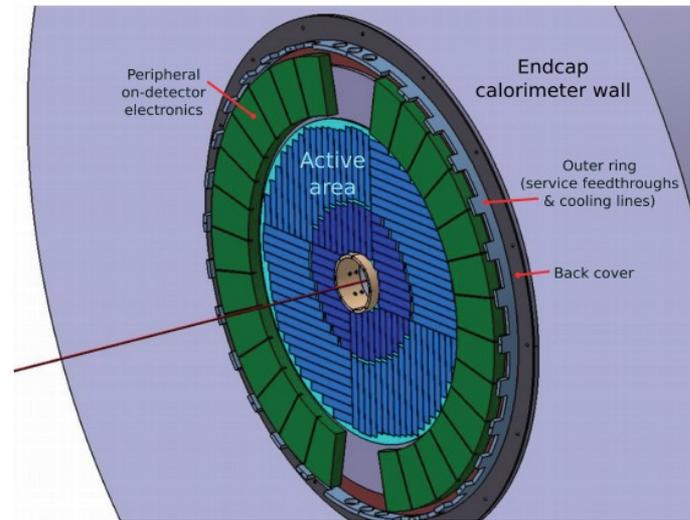
- * Detector production : Interest of IN2P3 labs
 - Mechanics and cooling
 - Electronics : Sensor + Front End
 - Stave equipment and qualification

* Main motivation : Reinforce PU rejection

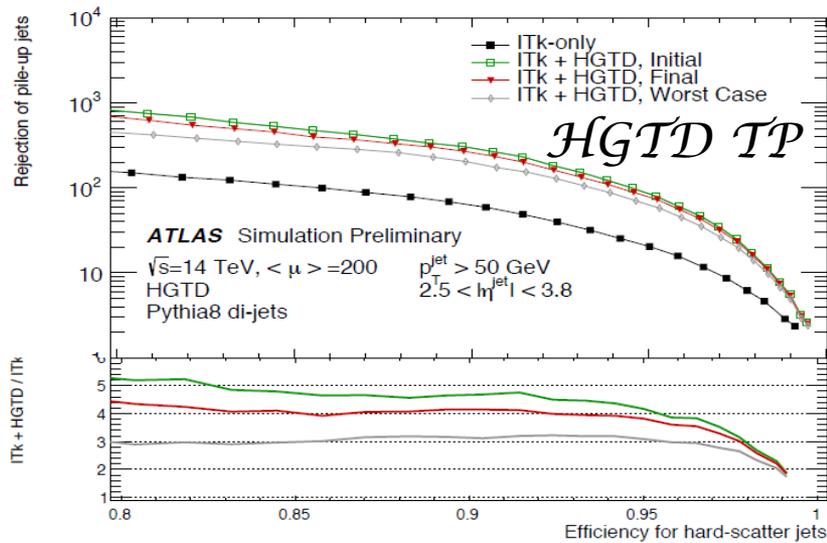
- Tracker : Separate vertices along z ($\sigma(z) \sim 50$ mm)
→ reject vertices distant in z
- HGTD : Separate vertices in time ($\sigma(t) \sim 180$ ps)
→ reject vertices distant in time
(single track resolution : 30 ps)



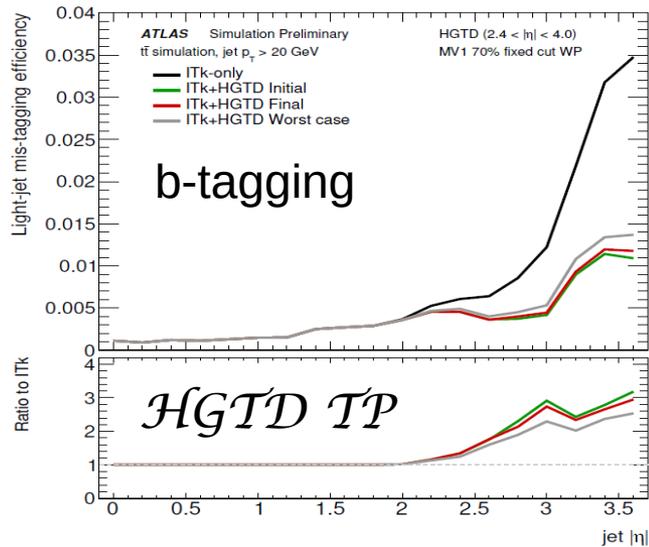
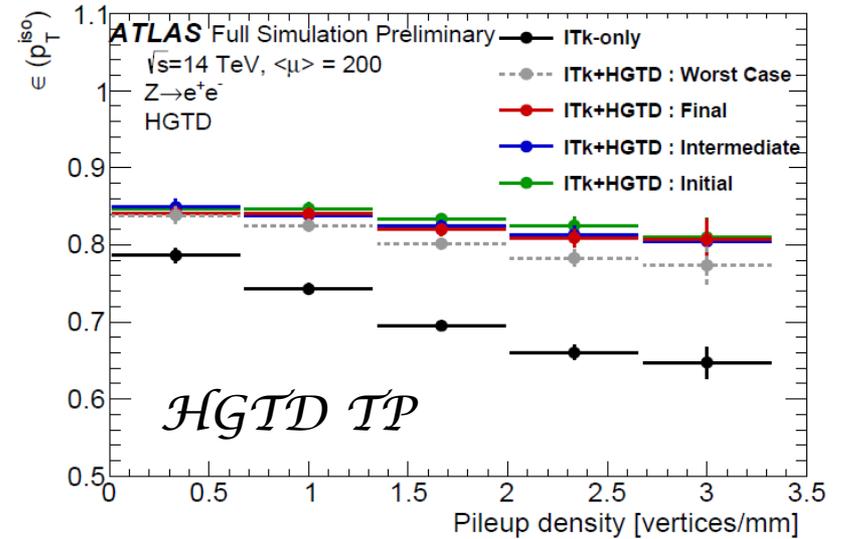
Pseudorapidity coverage	$2.4 < \eta < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	$3435 \text{ mm} < z < 3485 \text{ mm}$
Radial extension:	
Total	$110 \text{ mm} < R < 1000 \text{ mm}$
Active area	$120 \text{ mm} < R < 640 \text{ mm}$
Time resolution per track	30 ps
Number of hits per track:	
$2.4 < \eta < 3.1$	2
$3.1 < \eta < 4.0$	3
Pixel size	$1.3 \times 1.3 \text{ mm}^2$
Number of channels	3.54M
Active area	6.3 m^2



PU jet rejection



Electron isolation



Worst case : 60 ps



Final : Degradation after 4000 fb⁻¹



Detector production : Interest of IN2P3 labs



Mechanics



Asics + electronics

* Objectives and challenges :

- Electron-photon : Precise energy measurement and triggering
- Improve trigger capability (handle finer granularity)
- Increase electronic level of saturation
- Dynamic gain

Layer η range	Presampler		Front		Middle		Back	
	<0.6	>0.6	<0.8	>0.8	<0.8	>0.8	<0.8	>0.8
MIP values [MeV]	—	—	50	35	250	300	—	—
$\mu\text{A GeV}^{-1}$	0.84	2.67	3.16	2.67	3.16	2.67	3.16	
Current electr.								
Preamp. max. current [mA]	1		1		5	10		5
Max. energy [GeV]	1190		375	317	1873	3165		1873 1582
Req. for HL-LHC								
Max. current from 5 TeV Z' [mA]	<0.05	0.51	0.84	0.81	5.36	7.86	0.91	0.90
Max. current from jets [mA]	<0.05	0.23	0.57	0.78	6.78	7.13	1.63	2.42
Max. from both [mA]	<0.05	0.51	0.84	0.81	6.78	7.86	1.63	2.42

LAr TDR

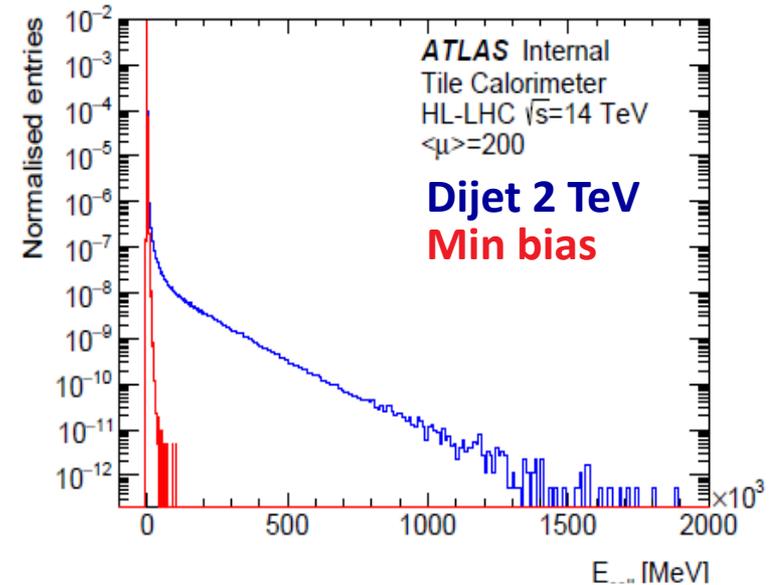
* Electronic upgrade : Interest of IN2P3 labs

- On detector : Full front-end + calibration boards
- Off detector : Lar Signal Processor + backend for triggering

* Objectives and challenges :

- Sustain higher radiation dose
- Simplify readout
- Increase electronic saturation
- Increase granularity
 - PU mitigation

Tile TDR



**Current electronic :
Saturation : 1.2-1.5 TeV**

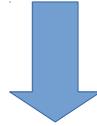
* Electronic upgrade: Interest of IN2P3 lab

- Remote HV power-supply and update distribution among dynode
- Change front-end readout
- Upgrade of calibration laser system

HL-LHC Physics potential

* Limitations :

- Not enough computing resources and software sophistication to make detailed projection
- Not enough expert manpower to run full Run2-like analysis



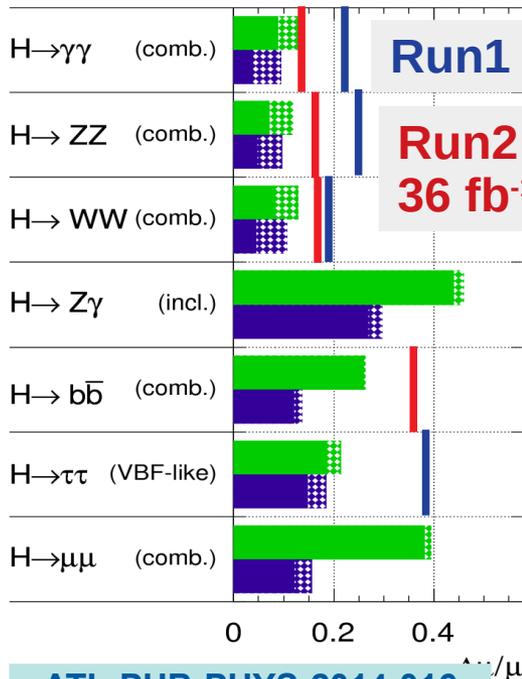
* Approaches :

- Extrapolate Run2 results to 3000 fb⁻¹ @ 14 TeV
 - Pros : Fully benefit from Run-2 optimised tools
 - Cons : Do not take into account benefit from Upgraded detectors and degradation from PU
 - Assumption : Benefit compensates degradation
 - Convolute 'smearing' functions of particles response with truth-level samples
 - Pros/Cons : Opposite to 'Extrapolation'
- Choice depends on channel study

- * HL-LHC : Reach the precision regime for Higgs → Sensitivity to new physics

Signal strength precision
 $\mu = \sigma / \sigma_{SM}$
 from few % level to 10-20 %

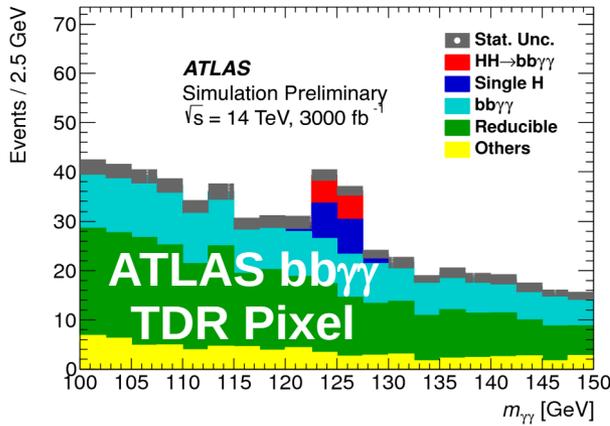
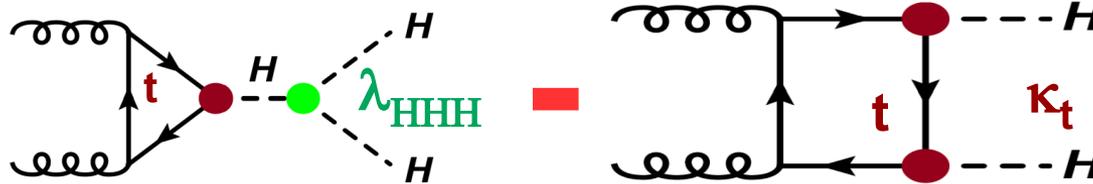
$\sqrt{s} = 14 \text{ TeV}$; $\int Ldt = 300 \text{ fb}^{-1}$; $\int Ldt = 3000 \text{ fb}^{-1}$



- * Based on extrapolation from Run2 data (36 fb⁻¹)
 - Stick to Run2 acceptance
- * Current published precision ~ 300 fb⁻¹ extrapolation from Run1 (stat + syst.)
 - Extrapolation to be redone from Run2
 - Syst. exp./theory have to be adressed
 - VBF precision conservative : Gain from Itk/HGTD extension not included

ATL-PUB-PHYS-2014-016
 +
 Run-1/Run-2 publications
 IRN Terascale, May 2018

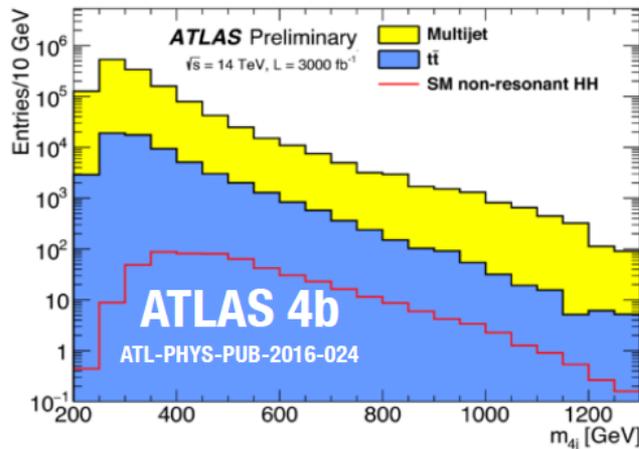
- * HL-LHC : First opportunity to study Higgs self-coupling through HH production



- * Context :

- 120 k HH events produced
- High background (bbbb, bb $\tau\tau$) or low B.R. (bb $\gamma\gamma$)

Channel	ATLAS
HH \rightarrow bbbb	$-4.1 < \lambda_{\text{HHH}} / \lambda_{\text{SM}} < 8.7$ @95 % C.L.
HH \rightarrow bb $\tau\tau$	0.6σ $-4.0 < \lambda_{\text{HHH}} / \lambda_{\text{SM}} < 12.0$ @95 % C.L.
HH \rightarrow bb $\gamma\gamma$	1.5σ $0.2 < \lambda_{\text{HHH}} / \lambda_{\text{SM}} < 6.9$ @95 % C.L. (stat only)
tt(HH \rightarrow bbbb)	0.35σ



- * $HH \rightarrow bb\gamma\gamma$: Naive extrapolation to HE-LHC

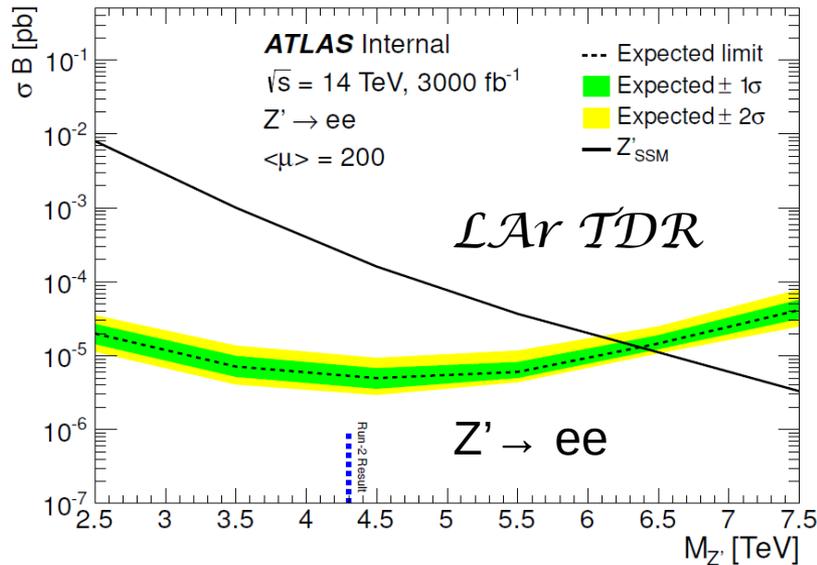
	CMS	ATLAS	LHCb
Couplings Studies	✓✓★	✓✓★	
Differential CrossSections	✓★	✓★	
Width		✓	
CPV	✓★	✓	
Rare Decays	$\mu\mu, cc$	$Z\gamma, J/\psi\gamma, FCNC$ $\mu\mu, \rho\gamma, cc$	Hcc/Hbb
Exotic Decays	LFV; Invisible, DarkSusy; 4jets		
DiHiggs	✓✓★	✓✓★	
Additional Scalars	A-\rightarrowZh, high mass $\tau\tau$, low mass $\gamma\gamma$	$\mu\mu, ZZ, A\rightarrow Zh,$ $\tau\tau, WW$	

Legend: Past Studies, 2017 TDRs, Wishlist for 2018

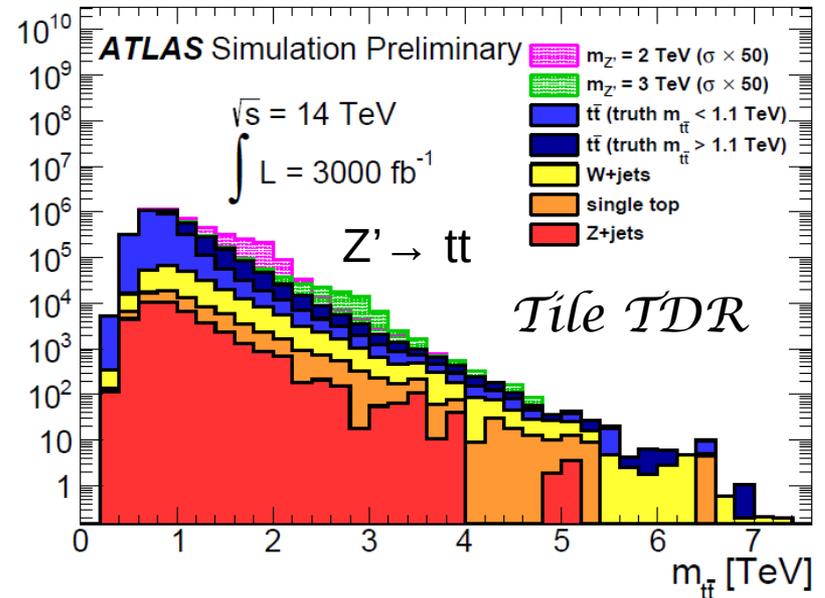
Detailed presentation from J. Stark

* Statistically limited

* Calorimeter linearity critical



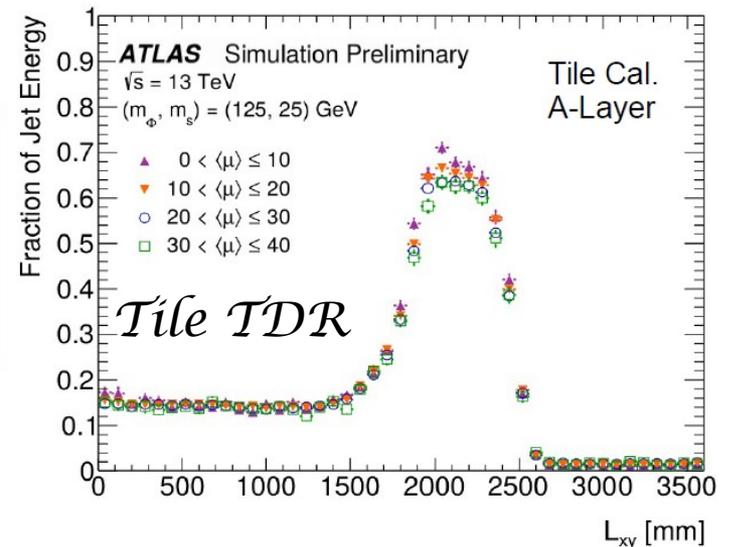
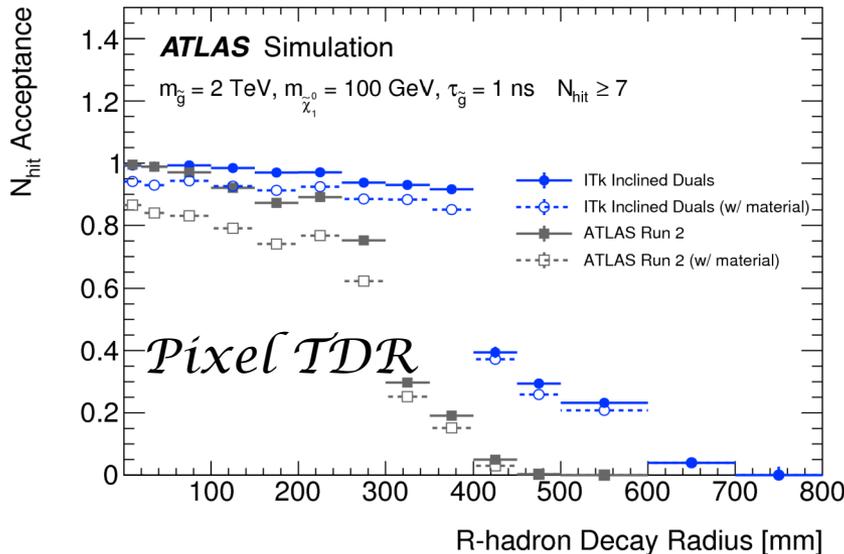
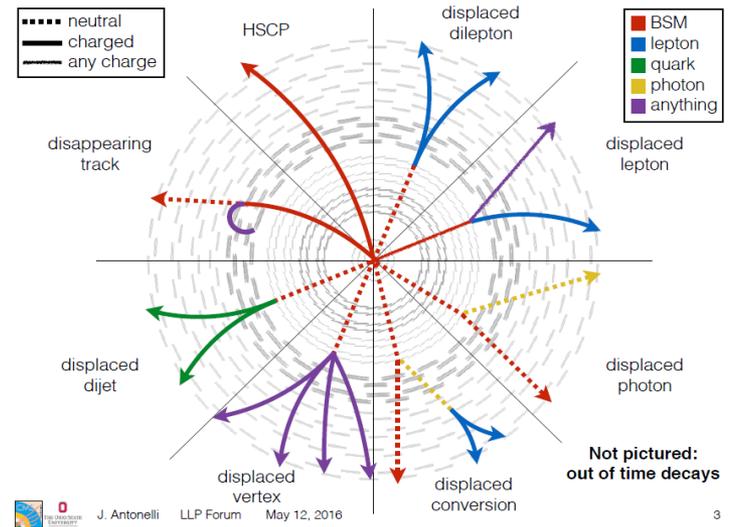
4.4 TeV (36 fb^{-1}) \rightarrow 6.3 TeV (3000 fb^{-1})

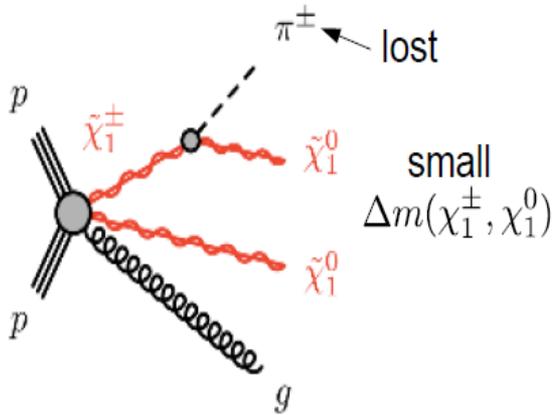


3 TeV (300 fb^{-1}) \rightarrow 4 TeV (3000 fb^{-1})

▶ **Great discovery potential: many NP models predict LLPs**

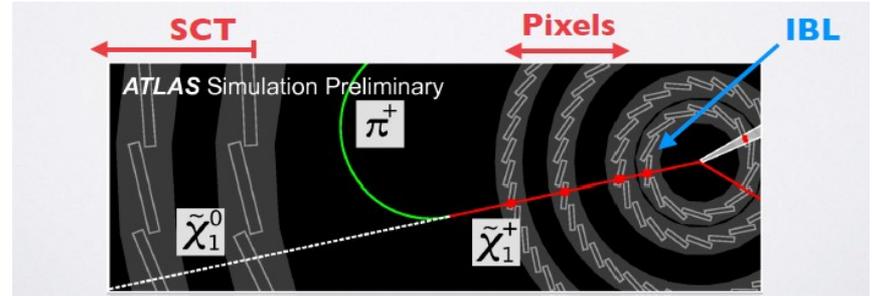
- ▶ small couplings: RPV decays, dark sector coupling
- ▶ small mass-splittings: degenerate next-LSP
- ▶ heavy messengers, split SUSY, hidden valley



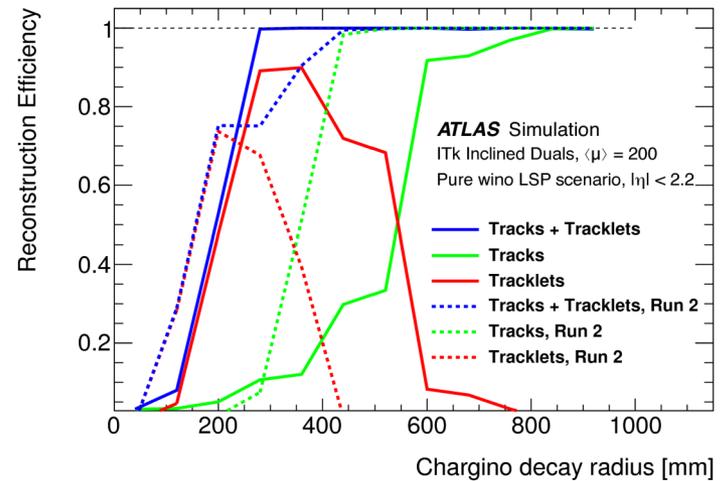
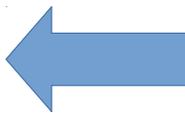
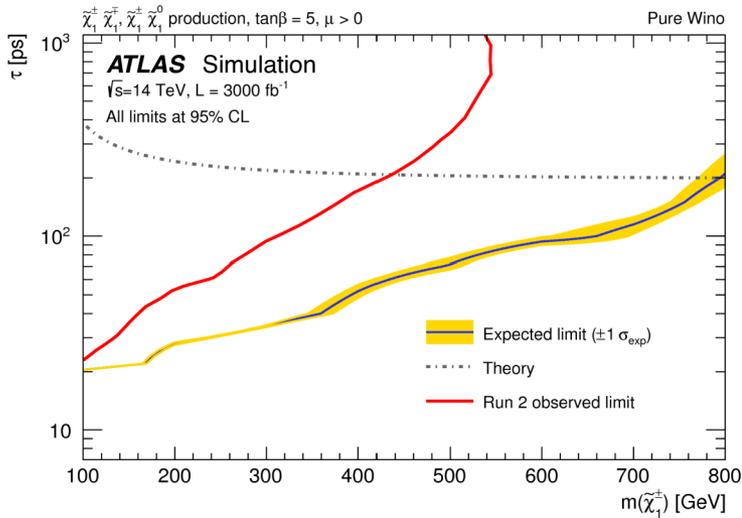


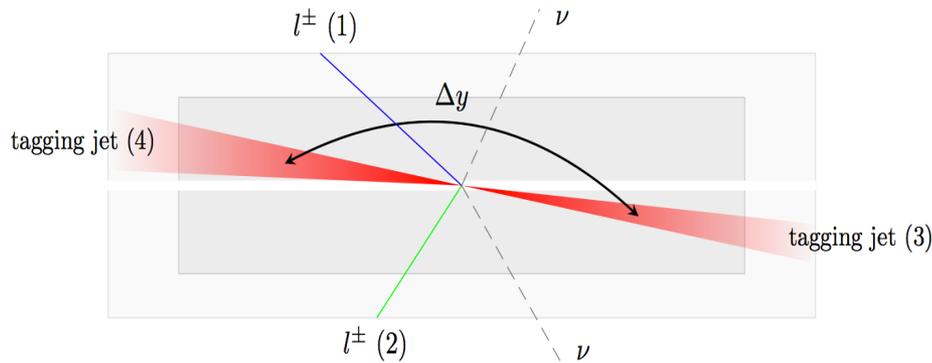
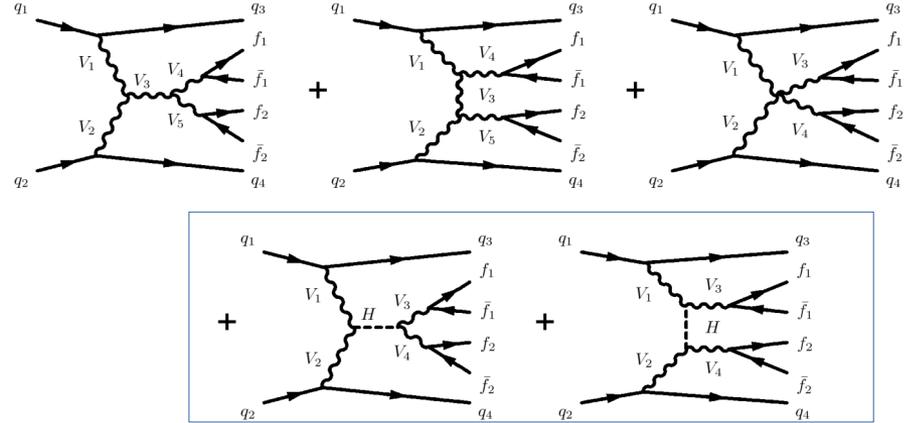
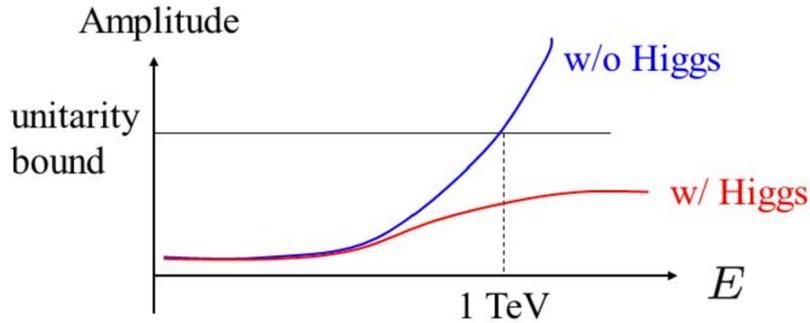
small $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$

$$m(\tilde{\chi}_1^\pm) \sim m(\tilde{\chi}_1^0)$$



Pixel TDR





$W^\pm W^\pm + jj$

Pixel TDR

$$\frac{\Delta\sigma}{\sigma}$$

Without forward tracking

4.5%

With forward tracking

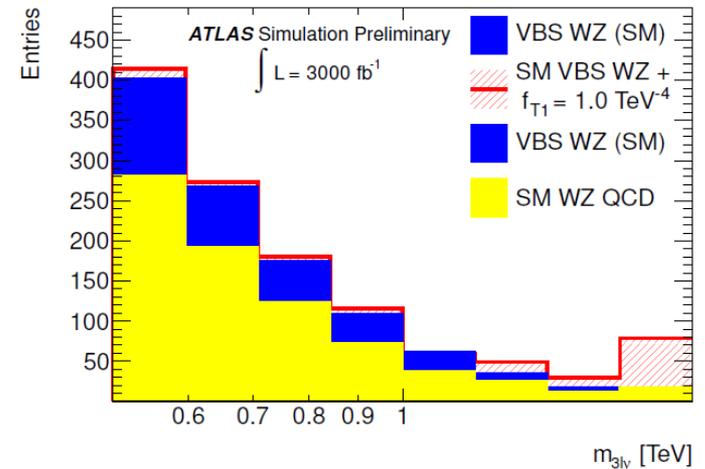
3.9%

+ 15 %

W Z+jj



ATL-PHYS-PUB-2013-006



- * Common document 'LHC experiments + theorists'
- * Previous publications (2013-2014) based on Run1 analysis methods
 - Expect significant gain applying improved Run2 algorithms
 - Exp/theo systematics more critical
 - Many improvements in analysis performance and systematic reduction developed in last 10 years → should continue over coming 20 years

- * Also addressing HE-LHC potential :
 - 15 ab⁻¹ @ 27 TeV (LHC tunnel with 16 T magnets)
 - Extension of 14 TeV analysis assuming same detector performances

- * Timescale :
 - Experiment PUB notes : End summer 2018
 - CERN YR : End autumn 2018

HL-LHC program : Both discovery and precision machine

* Detector upgrades :

- Most TDRs published : Baseline layouts defined but few remaining options still
- Enter in Memorandum of Understanding negotiation for commitments in construction/qualification
- Construction program (2018-2025) :
 - Involving physicists and engineers in all ATLAS-IN2P3 labs

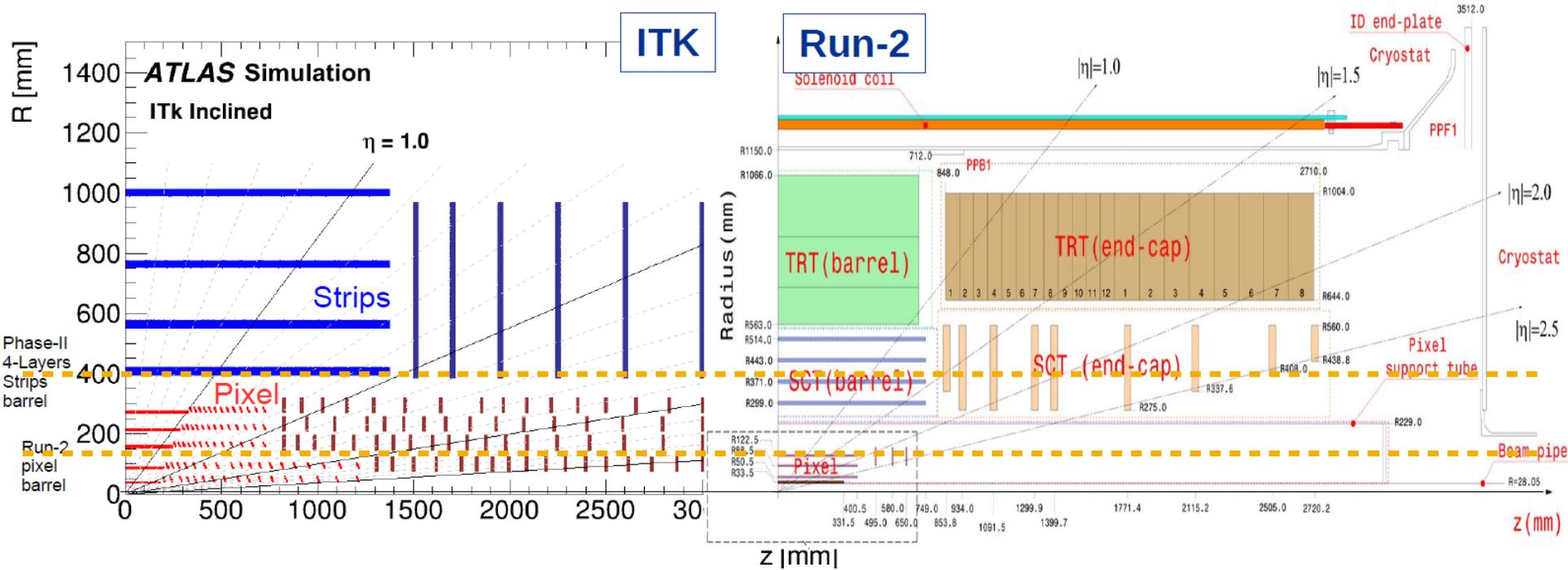
Opportunity to improve expertise in new technologies implemented in large detectors

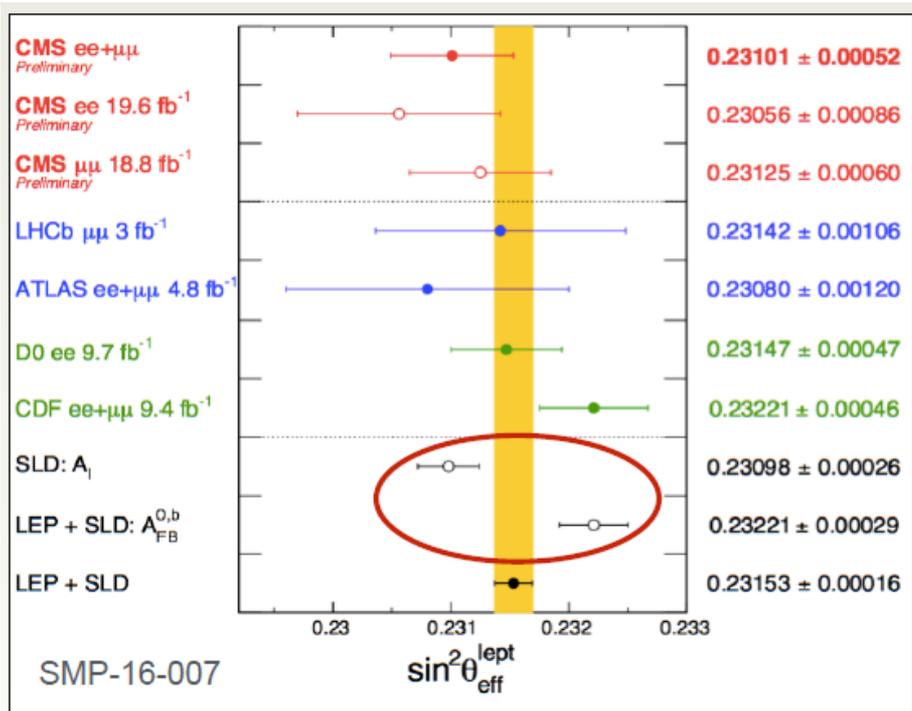
* Physics potential :

- End 2018 : CERN Yellow Report (including HE-LHC) with better precision
- Still opportunities for improvements thanks to new ideas/algorithms (ex : $H \rightarrow c\bar{c}$)

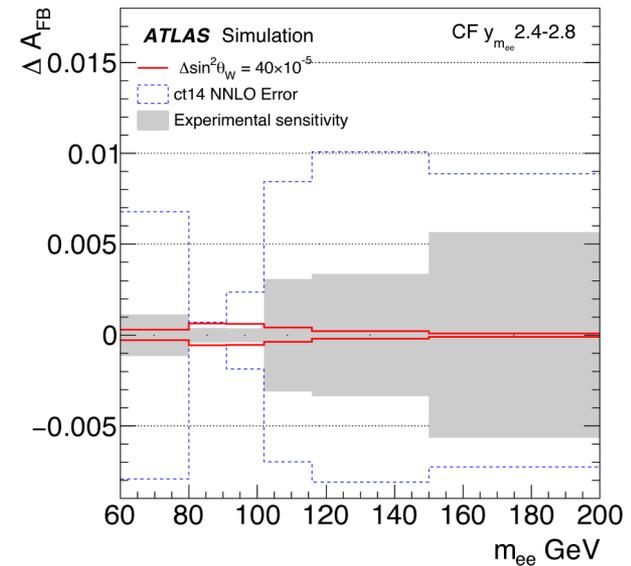
HL-LHC program : Rich physics program for coming 20 years

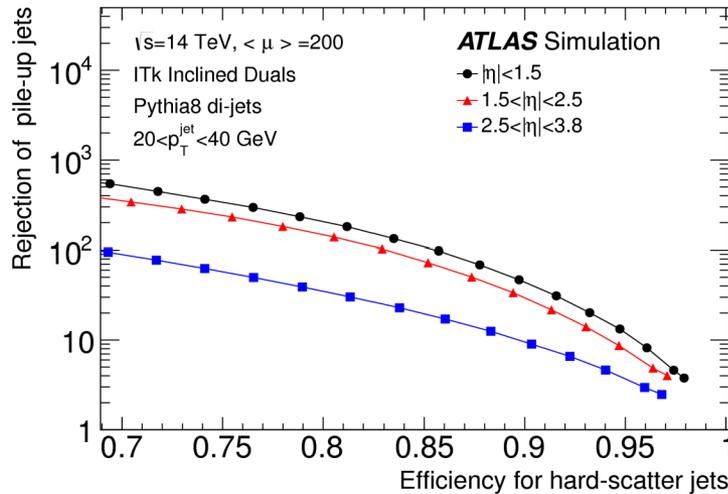
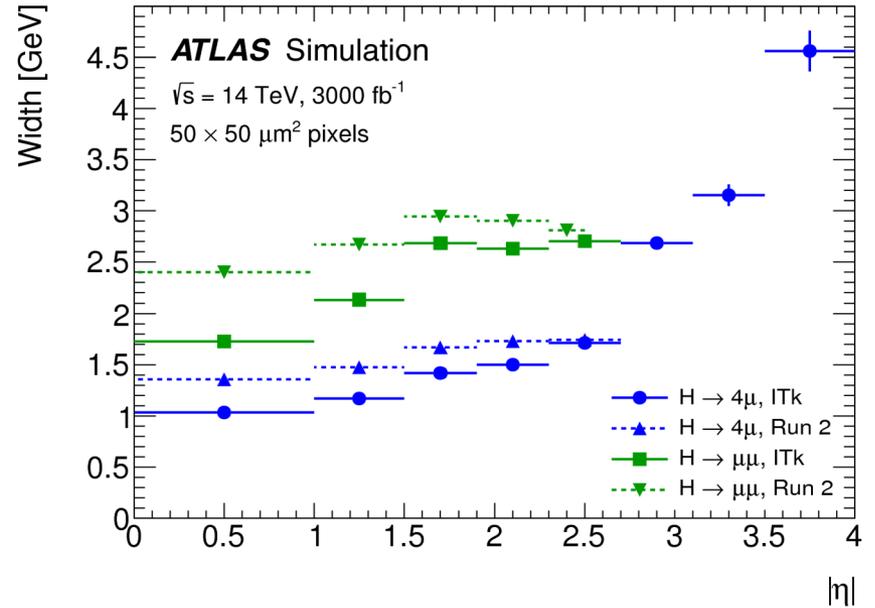
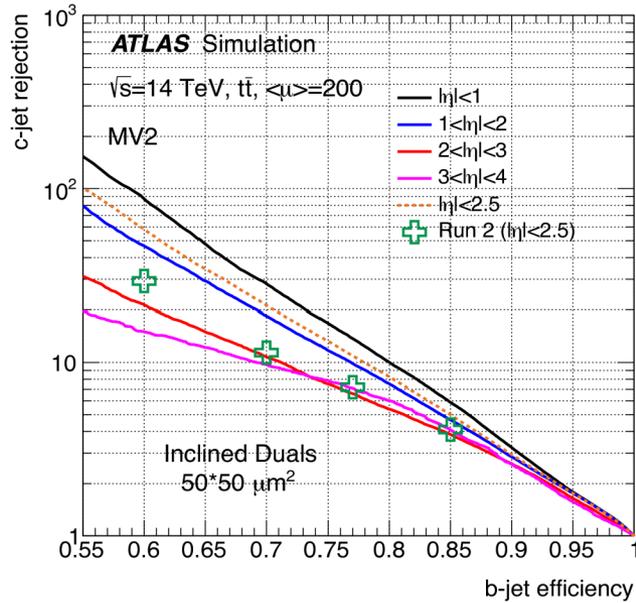
Backup





- Strong consistency test of the SM in global FWK fits
 - $\Delta \sin^2 \theta_W = 16e^{-5} \iff \Delta m_W = 8 \text{ MeV}$
- LEP/SLD discrepancy mandates further investigation





parameter	FCC-hh		HE-LHC	(HL) LHC
collision energy cms [TeV]	100		27	14
dipole field [T]	16		16	8.33
circumference [km]	100		27	27
straight section length [m]	1400		528	528
# IP	2 main & 2		2 & 2	2 & 2
beam current [A]	0.5		1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25
rms bunch length [cm]	7.55		7.55	(8.1) 7.55
peak luminosity [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	5	30	25	(5) 1
events/bunch crossing	170	1k (200)	~800 (160)	(135) 27
stored energy/beam [GJ]	8.4		1.3	(0.7) 0.36
beta* [m]	1.1-0.3		0.25	(0.20) 0.55
norm. emittance [μm]	2.2 (0.4)		2.5 (0.5)	(2.5) 3.75