ATLAS.
Il programma di upgrade per HL-LHC

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101° Congresso Nazionale SIF

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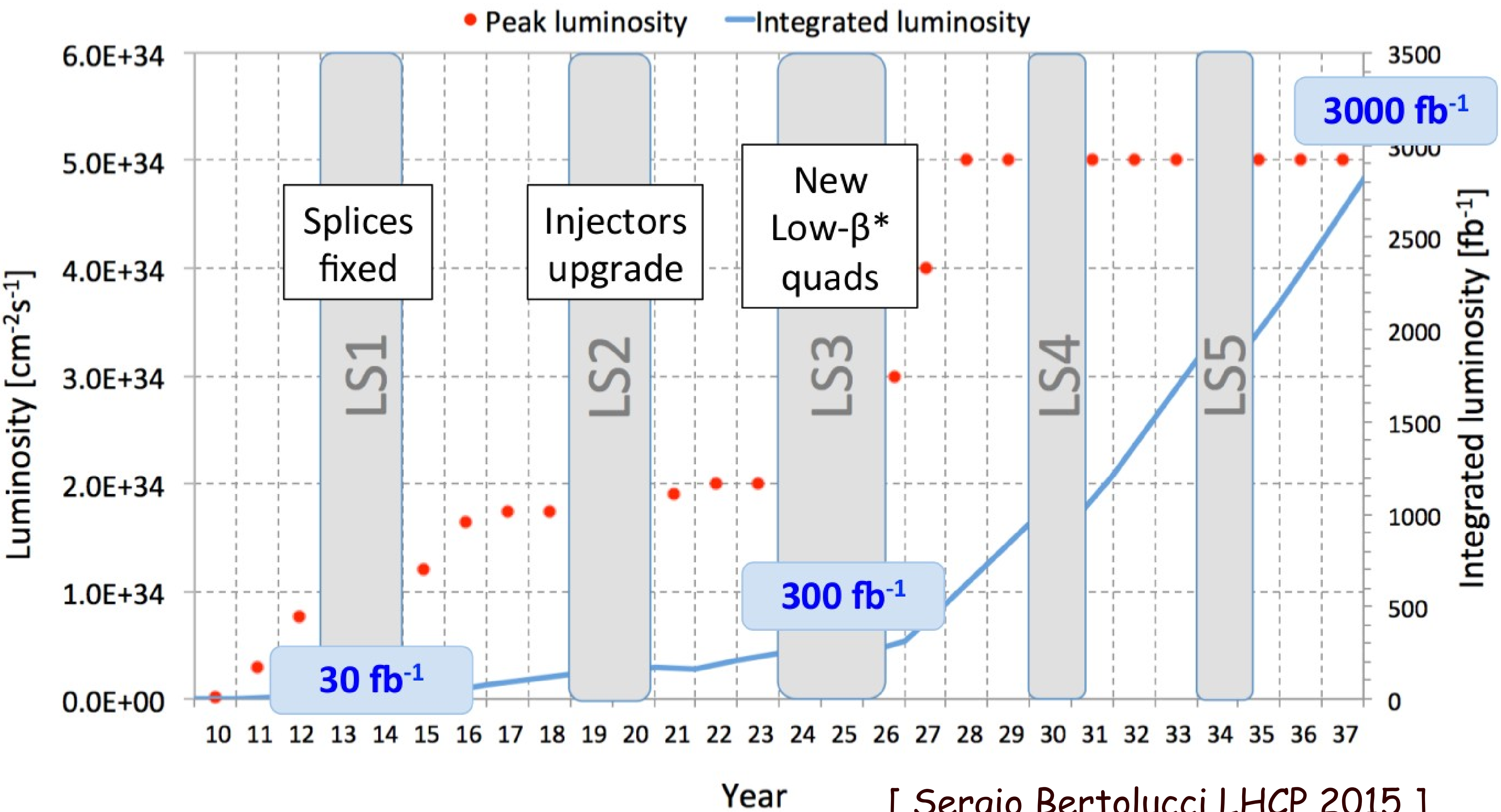
the road to HL-LHC



[Sergio Bertolucci LHCP 2015]

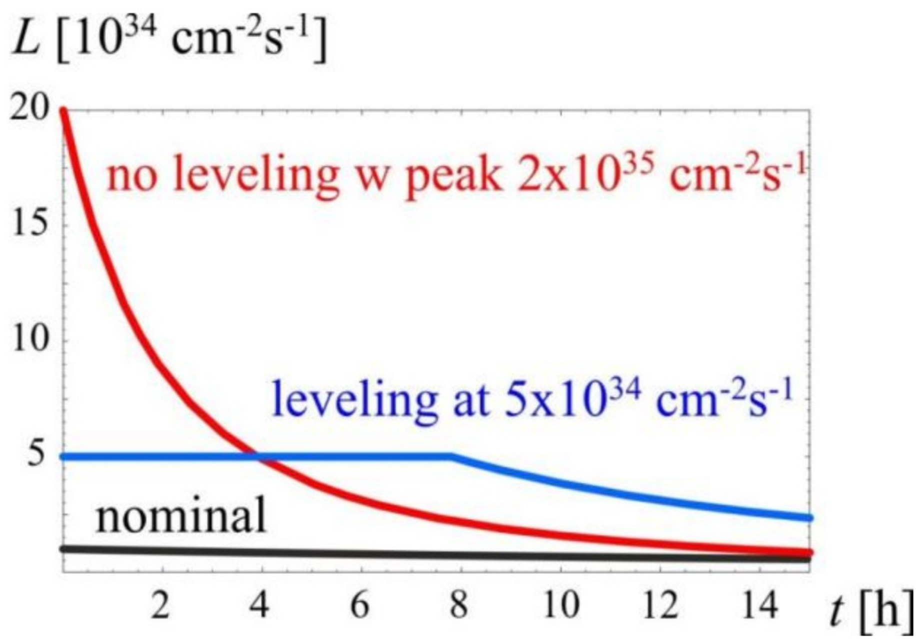
goal: fully exploit the LHC potential

Luminosity Levelling

a) minimize max pile-up

b) provide “constant” luminosity

avoiding high peak luminosit



[Sergio Bertolucci LHCP 2015]

	25 ns	50 ns
p/bunch [10^{11}]	2.0	3.3
Peak lumi [10^{34}]	6.0	7.4
T_{level}@ 5e34 [h]	7.8	6.8
Pile-up @ 5e34	123	247

Design detectors for ultimate performance of $7.5{\times}10^{34}$cm^{-2}s^{-1}

25 ns baseline but 50 ns still alive

<pile up> → ~200 or even ~250

Physics Motivations (not exhaustive)

Address not extreme-kinematics but low cross-section proc.s

→ collect high-statistics sample for:

a. Higgs sector:

1) measurements of SM couplings at the level of few %
2) ttH measurement (assessment of top Yukawa coupling)
3) $H \to \mu\mu$, $H \to Z\gamma$ observation (new rare decays)
4) evidence for HH production (self coupling)

b. EW simmetry breaking: VV scattering (e.g. ssWW)

c. Indirect searches (FCNC in top decays, …)

→ precision measurements as probe for BSM physics

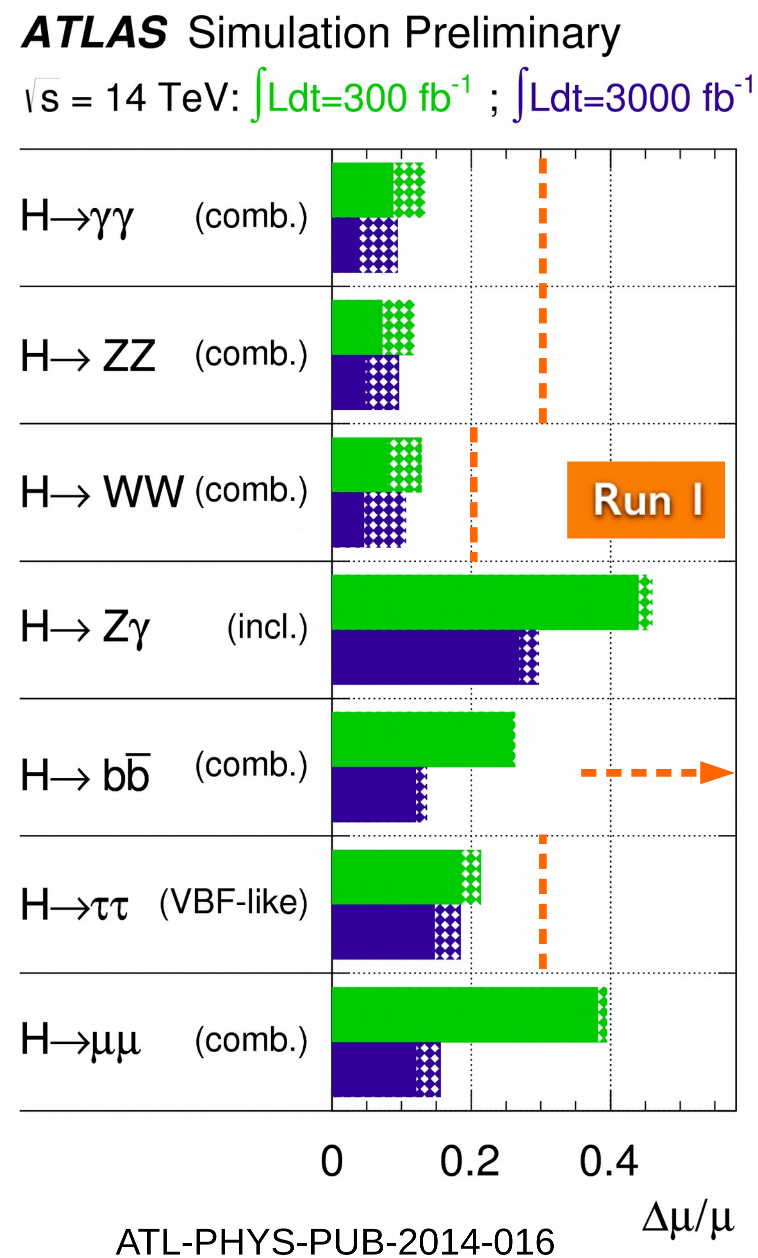
d. Direct searches of BSM physics

Higgs Couplings

LHC can only measure σ x BR.
Evaluate ratio of signal strength to SM value : μ

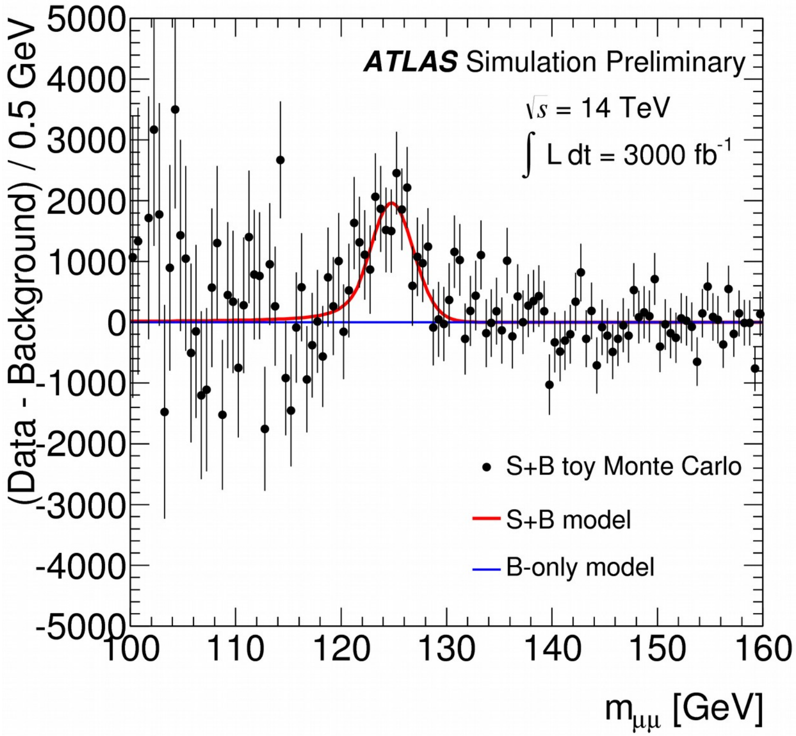
Wanted:

- good sensitivity to all final states
- high efficiency (low trigger thresholds)
- large acceptance (coverage)



Higgs Rare Decays

$H \rightarrow \mu\mu$



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$\mathcal{L}$ [fb^{-1}]	300	3000
Signal significance	2.3σ	7.0σ
$\Delta\mu/\mu$	46%	21%

Test coupling to 2nd generation fermions

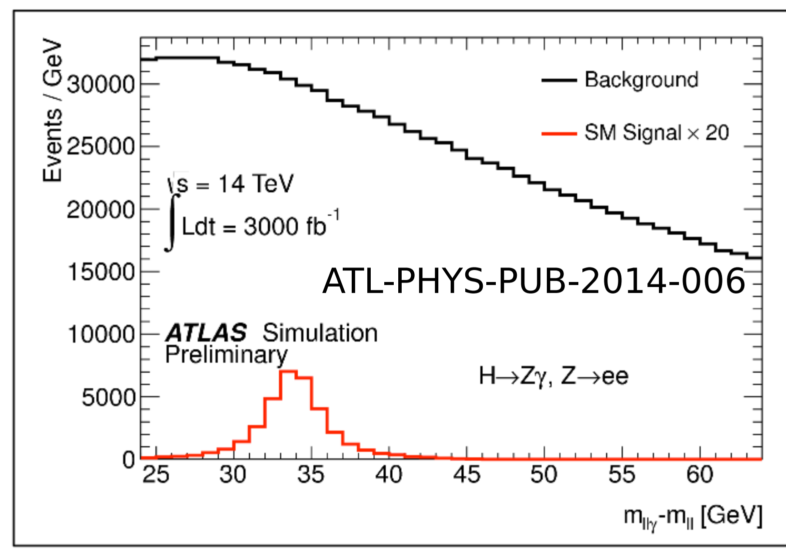
Test lepton flavour violation (can be done?)

$H \rightarrow Z\gamma$

produced via heavy-particle loops

→ possibly sensitive to new physics

observation of SM decay possible (~3.9σ)

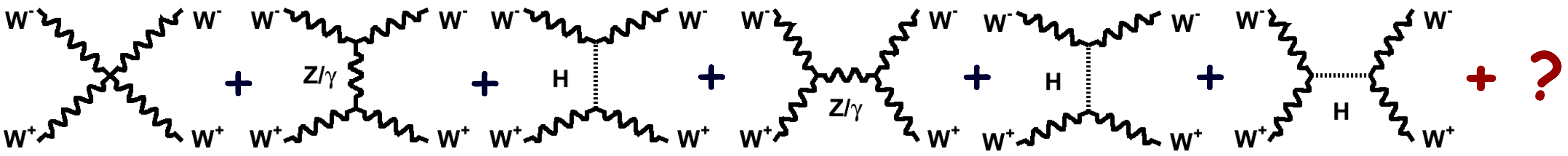


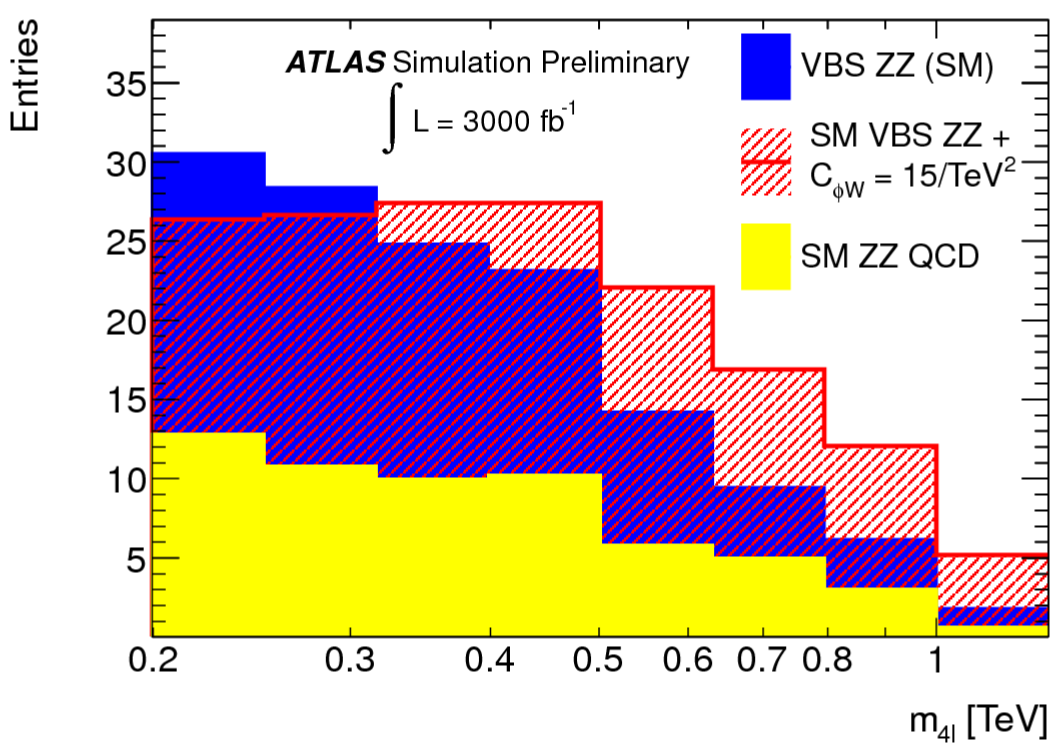
$m_{ll\gamma}$-m_{ll} of signal and background after the full event selection and parameterized lepton and photon reconstruction

Vector Boson Scattering

Confirm that Higgs Boson provides cancellation of divergences at HE

Generic EFT framework: add all possible gauge-invariant boson couplings





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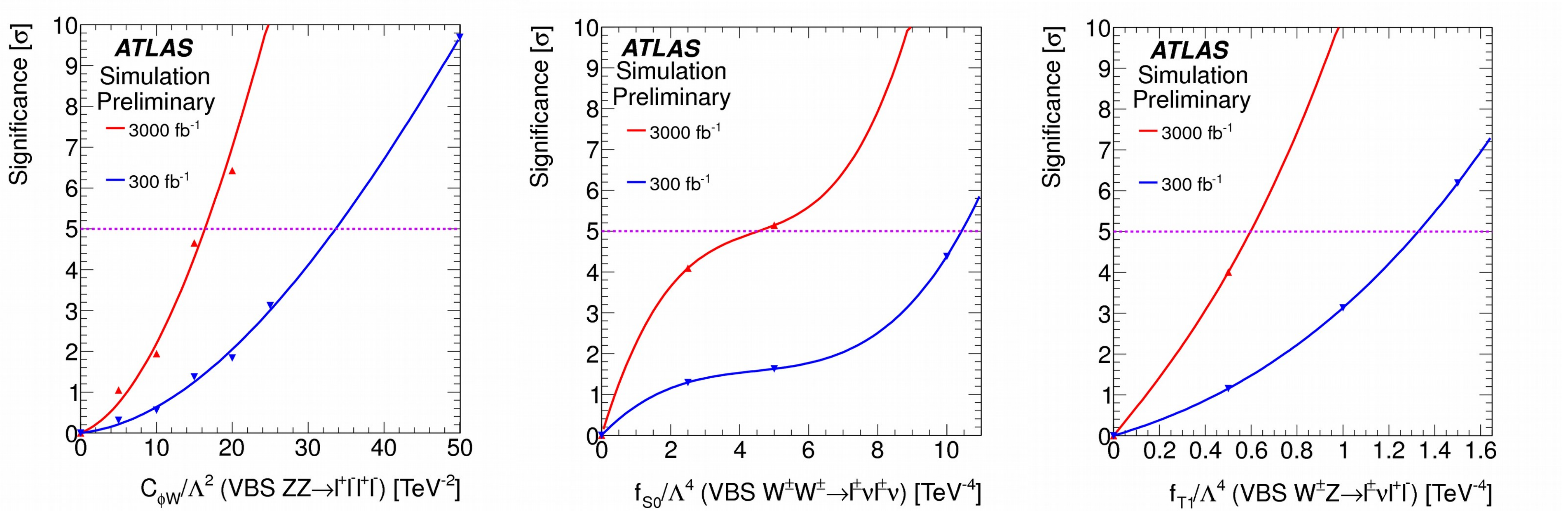
Vector Boson Scattering (2)

Parameterize BSM using higher dimensional operator

ZZ dim-6 operator → $\mathcal{L}_{\phi W} = \frac{c_{\phi W}}{\Lambda^2} \mathrm{Tr}(W^{\mu\nu} W_{\mu\nu}) \phi^\dagger \phi$

ssWW dim-8 operator → $\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4} [(D_\mu \phi)^\dagger D_\nu \phi)] \times [(D^\mu \phi)^\dagger D^\nu \phi)]$

WZ dim-8 operator → $\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} \mathrm{Tr}[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta}] \times \mathrm{Tr}[\hat{W}_{\mu\beta} \hat{W}^{\alpha\nu}]$



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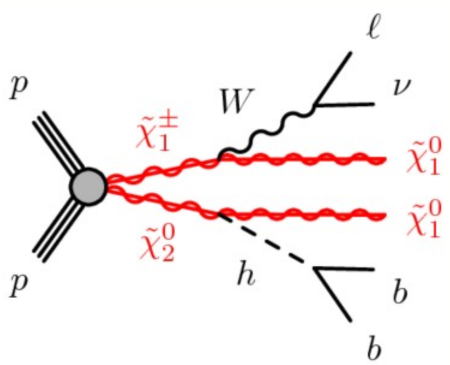
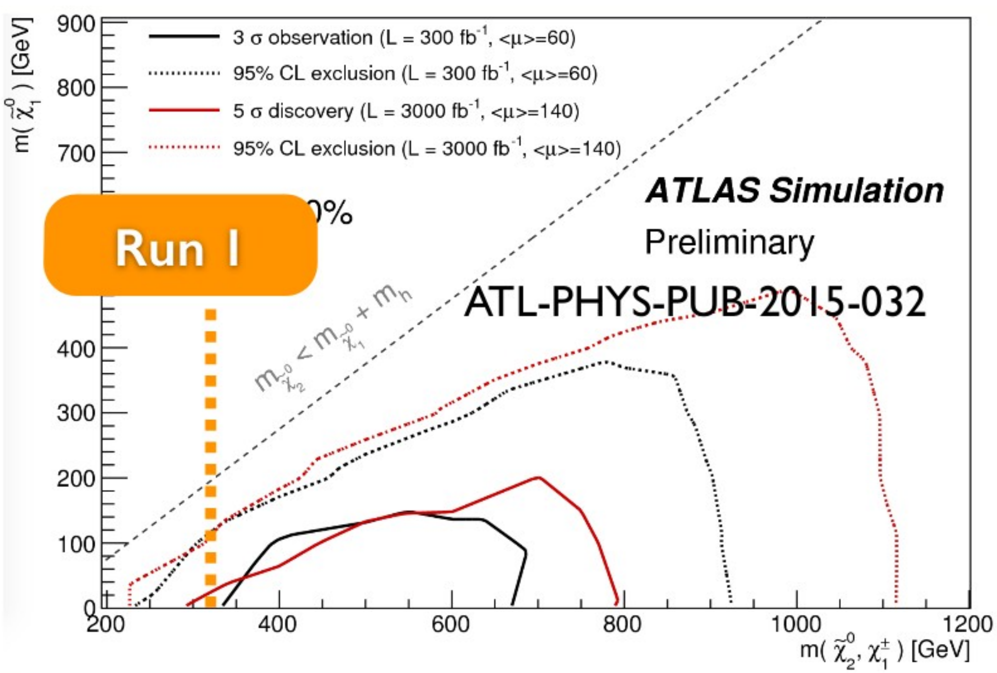
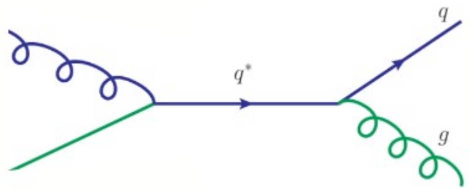
BSM Direct Searches

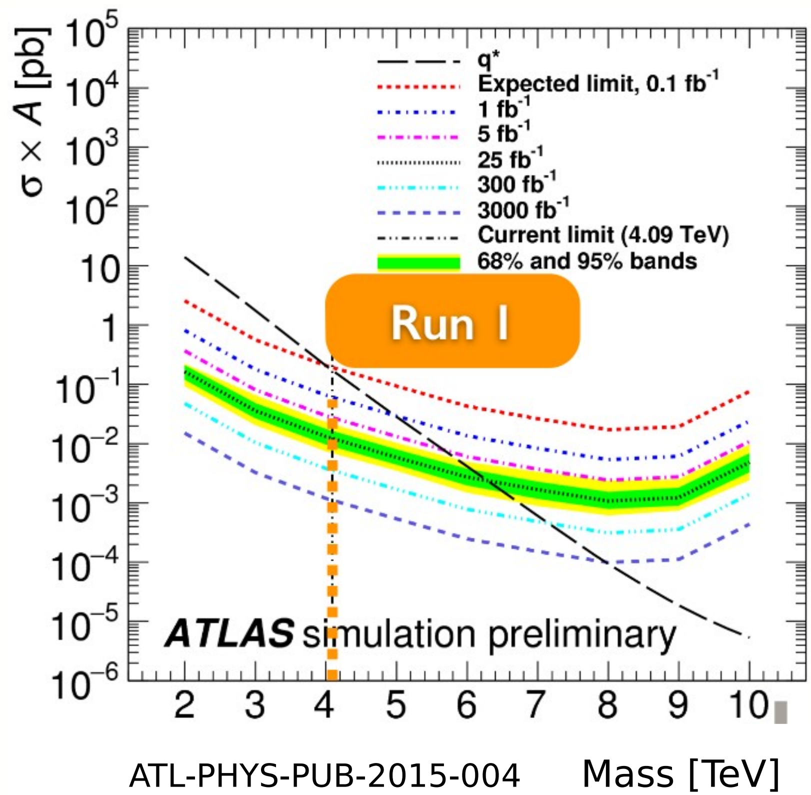
The discovery potential at 14 TeV greatly enhanced at Run 3 and HL-LHC

→ searches for rare SUSY signatures (EWK-inos) and excited quarks







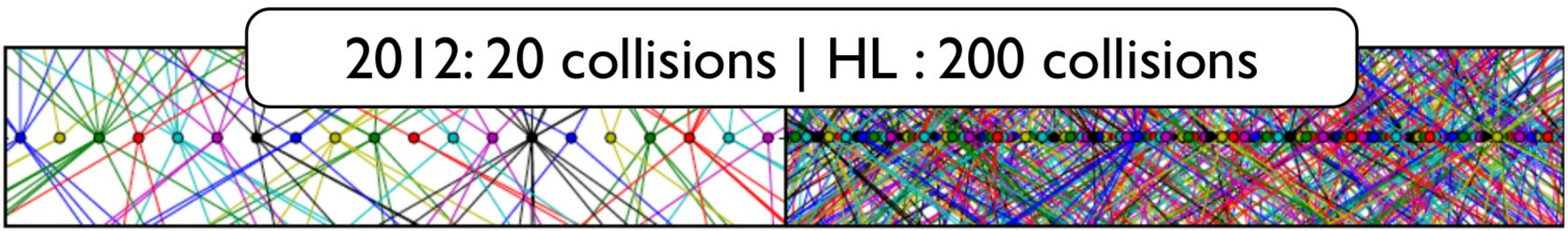


ATLAS Detector

Hard challenge (as usual): high efficiency & acceptance & pileup-rejection with:

- single e/μ (offline) thresholds as low as Run 1 (~20 GeV)
- large comprehensive τ & hadronic channel selections

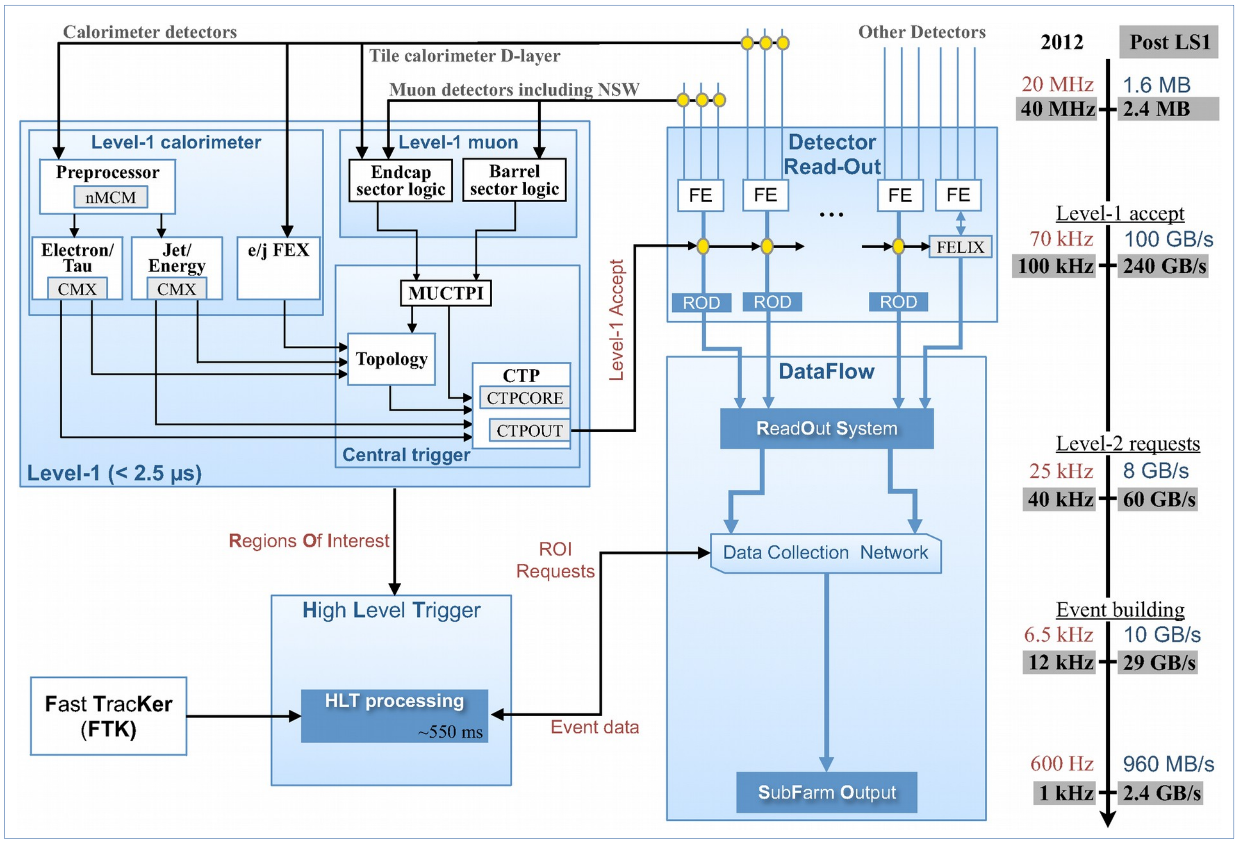
Don't loose any physics opportunity!

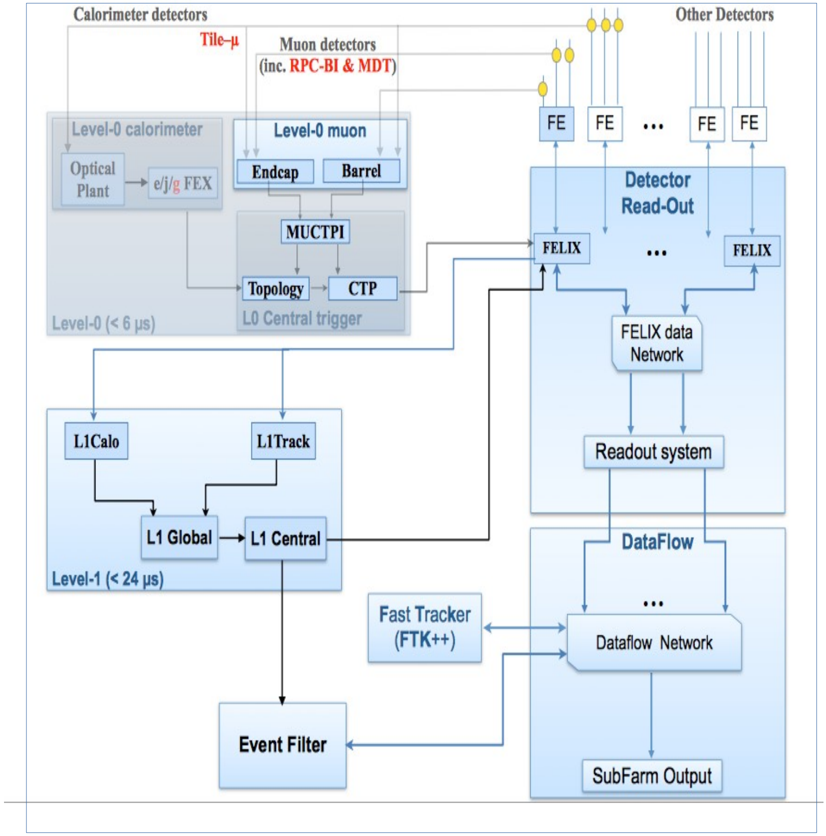


Trigger/DAQ Scheme

1. New (2-step) design of hw trigger: exploit Phase-I (NSW & L1 Calo) upgrades
   - Level-0 [Calo + Muon]: latency ~6/10 μs, rate ~1 MHz, defines R.O.I. for L1
   - Level-1 [Calo + Muon + ITK]: latency ~30/60 μs, rate ~400 kHz, all data readout

2. High-Level software trigger with full fast tracking (FTK++)





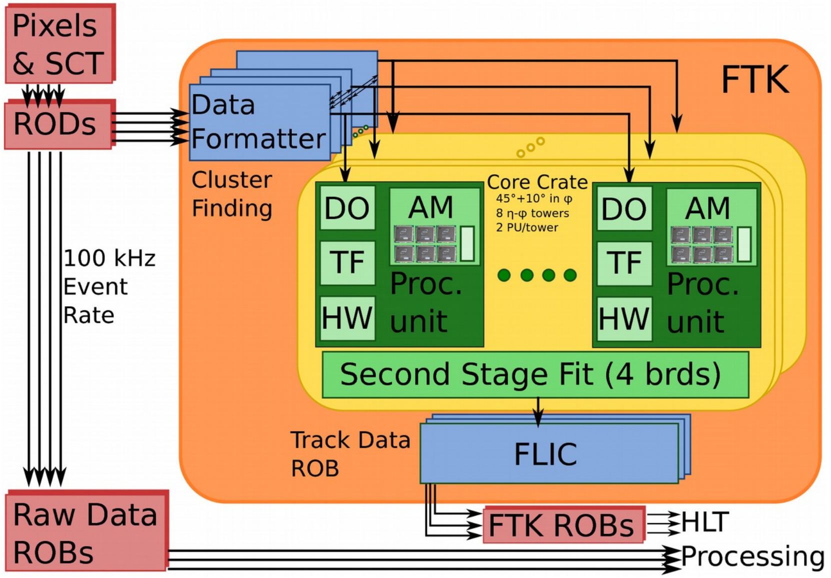
Phase-I → Phase-II

Fast TracKer (FTK)

Highly-parallel: handle 100kHz L1 rate w/ ~25 μs latency

1. fast pattern recognition → associative memories
2. precise fast fitting → FPGA

delivers almost offline-quality data



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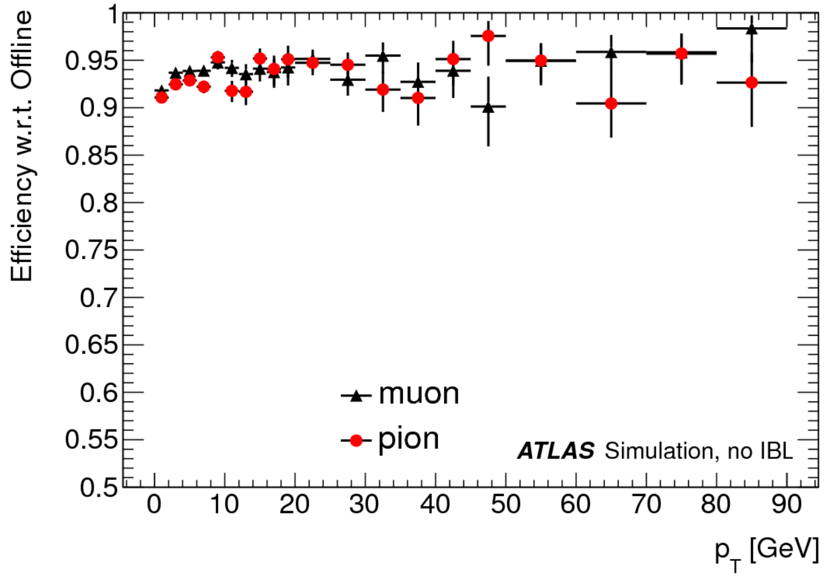
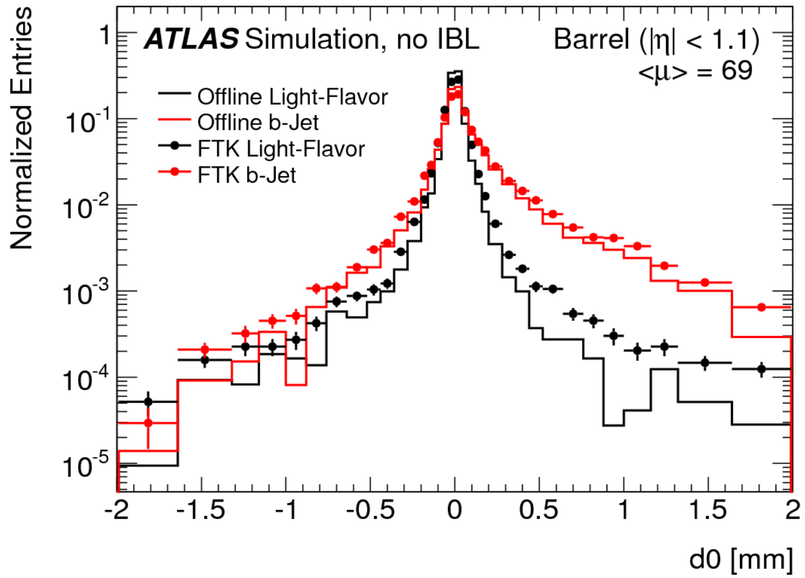
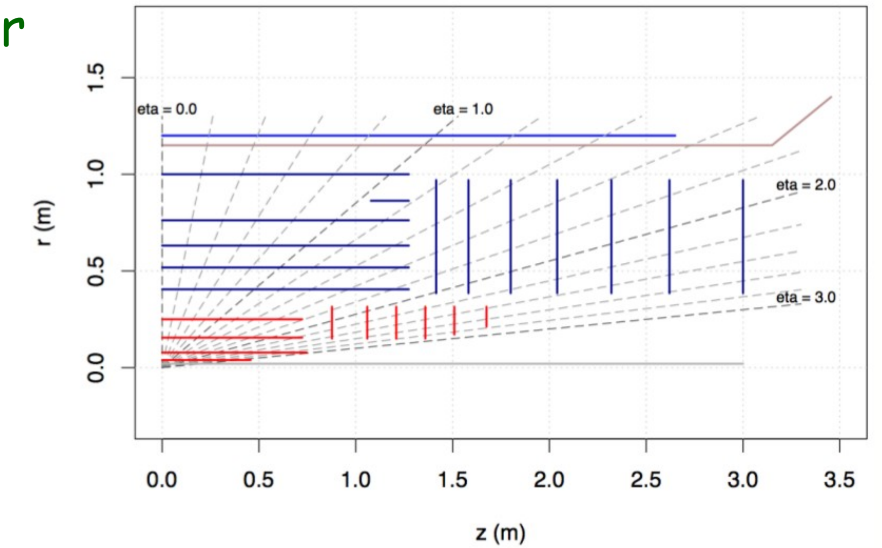




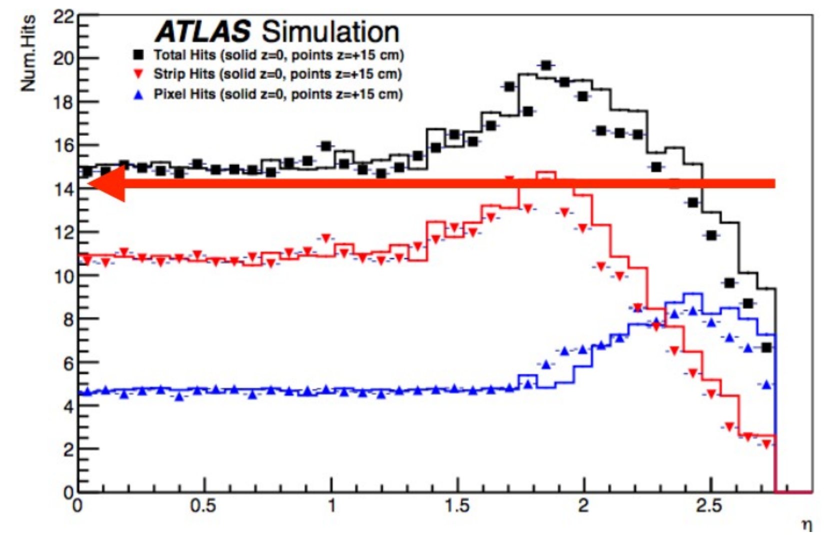
Tracker Upgrade - ITK

Current ID (Pixel, SCT, TRT) → all-silicon tracker to cope with increased pile-up and dose



Both robust tracking and reduced material are critical issues:

- at least 14 hits up to $|\eta| = 2.5$
- $0.7\ X_0$ at $|\eta| = 2.7$
- < 1% occupancy for $\langle\mu\rangle \sim 200$



Different layouts under consideration

LOI:

- Strip tracker: 5 layers, stubs, 7 disks per side
- Pixel tracker: 4 layers, 6 disks

Track parameter $|\eta| < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50

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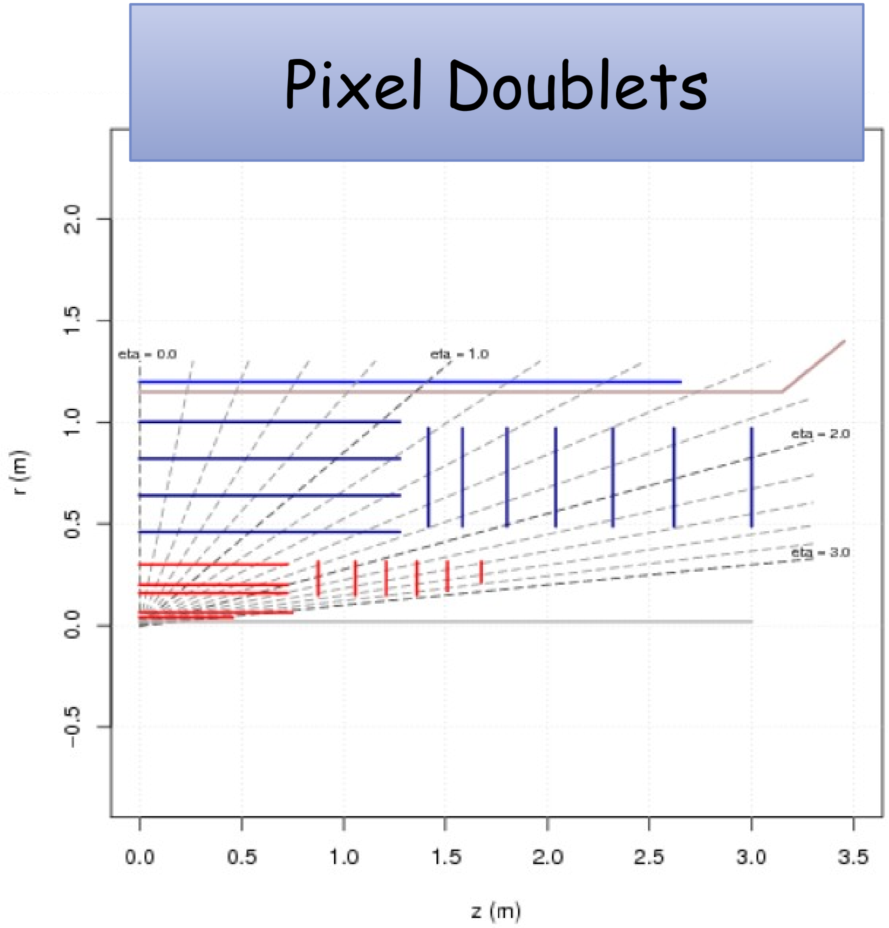
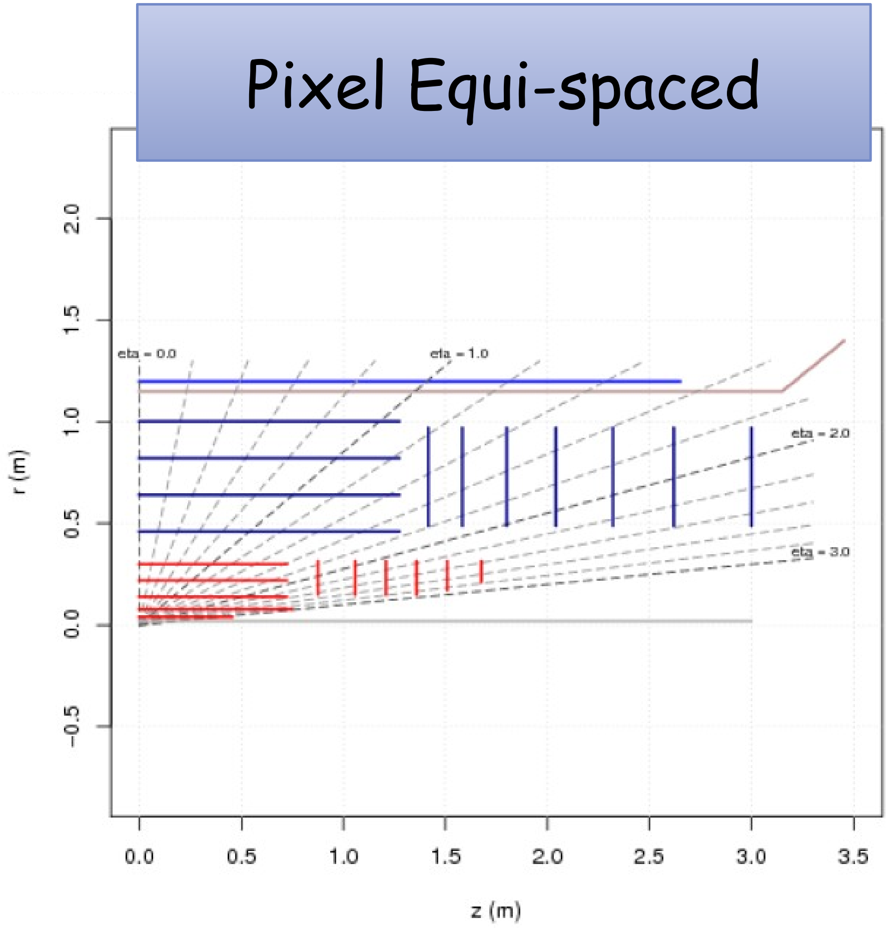
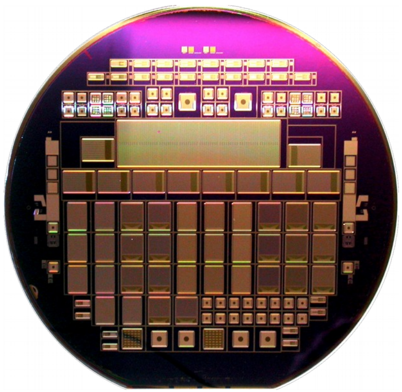
ITK - 5th Pixel Layer

e.g.:





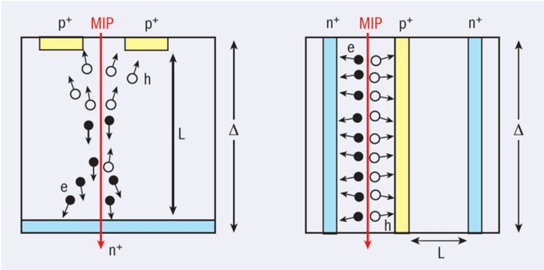
ITK Sensors

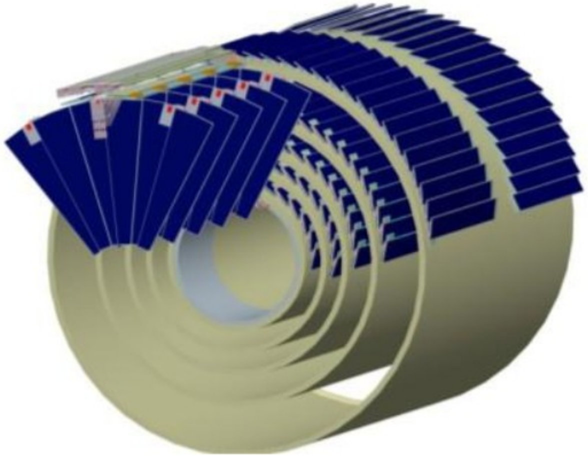


Pixels:

low mass + large bandwidth + low power consumption + sustain fluence of up to 1.4×10^{16} particles/cm^2

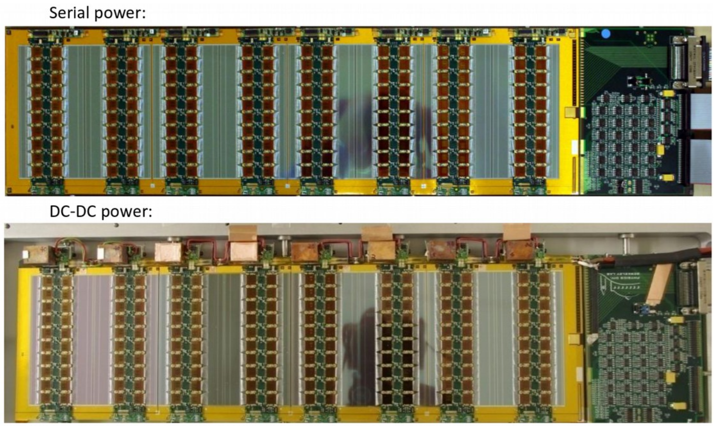
- thin sensors, 50×50 or 25×100 μm^2 pixel size
- n-in-n, n-in-p planar, 3D, diamond sensors
- CMOS technology being explored for larger radii





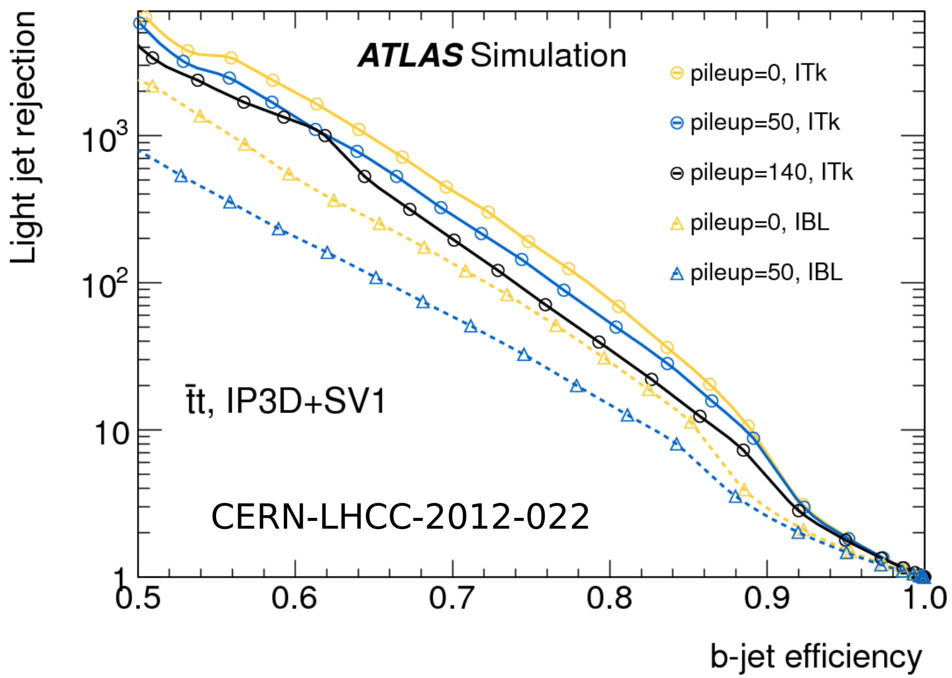
Strips:

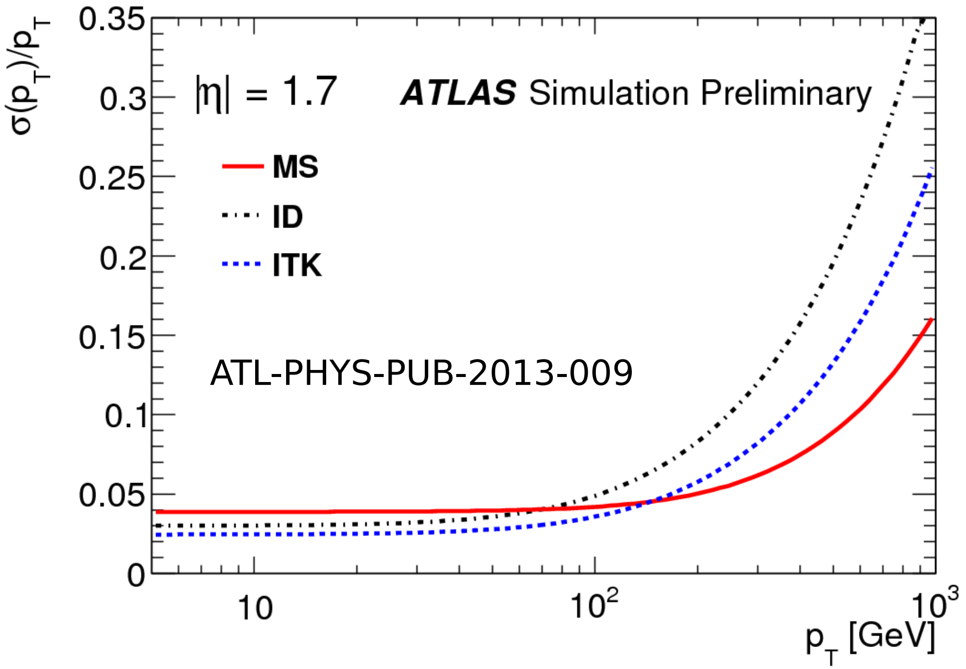
- double-sided layers with axial strip orientation and 40 mrad stereo angle on the back side
- short (~23 mm) and long (~48 mm) strips with ~75 μm pitch in the barrel
- 6 different designs in the EC to accommodate the geometry
- silicon modules directly bonded on a cooled carbon fiber plate



ITK Performances

- B-tagging better with ITK than ID+IBL with <μ> = 0
- Significant improvement (×2) in momentum resolution





Intensive R&D ongoing in order to identify optimal technology choice(s)

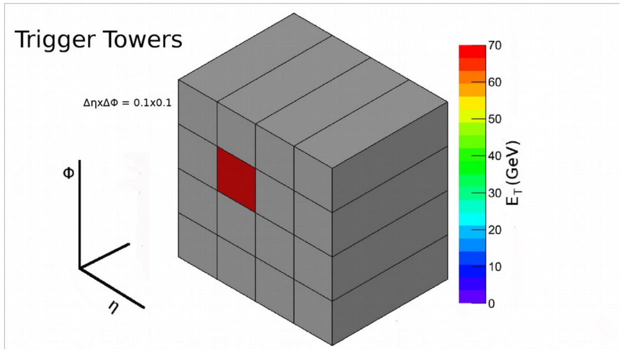
L1 Calo Trigger Upgrade – Phase I

Current L1 Calo based on $\Delta\eta\times\Delta\varphi$=0.1×0.1 trigger towers:

· needed for γ, e, jets, missing E_t

· compute object energy and isolation

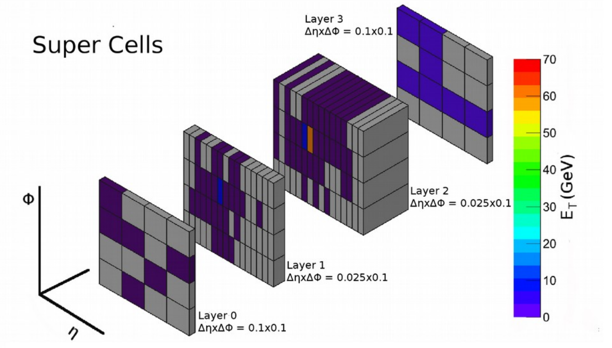
· rates (Run 1 thresholds) ~270 kHz @ 3×10^{34} >> total L1 rate of 100 kHz

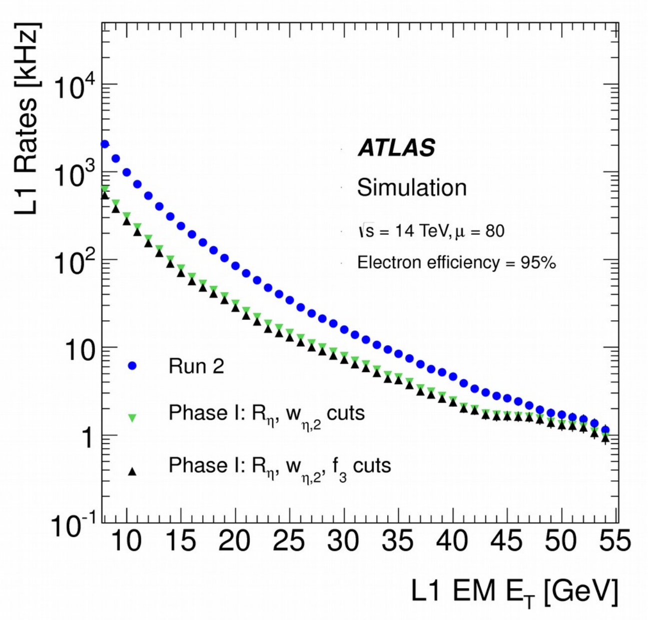


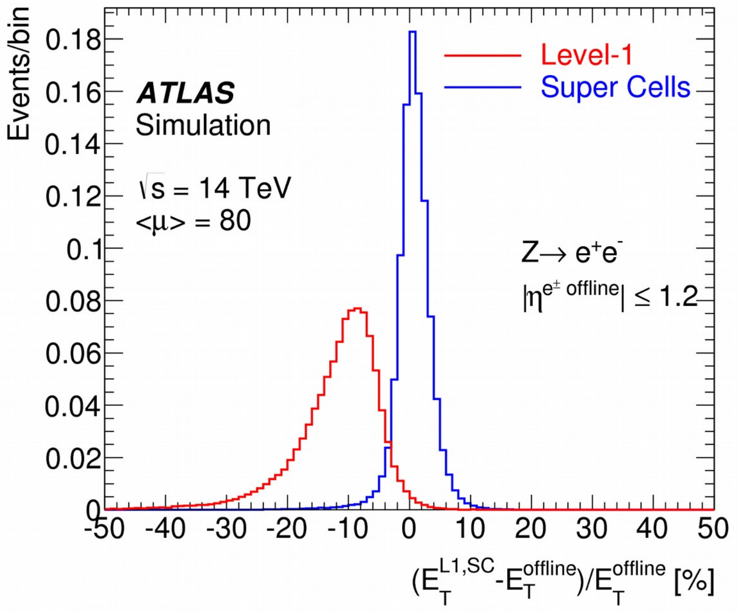
"SuperCell" upgrade:

· high granularity and longitudinal shower information available at L1 (transverse energy in each layer)

· substantially improve energy resolution (12 bits in place of 8)







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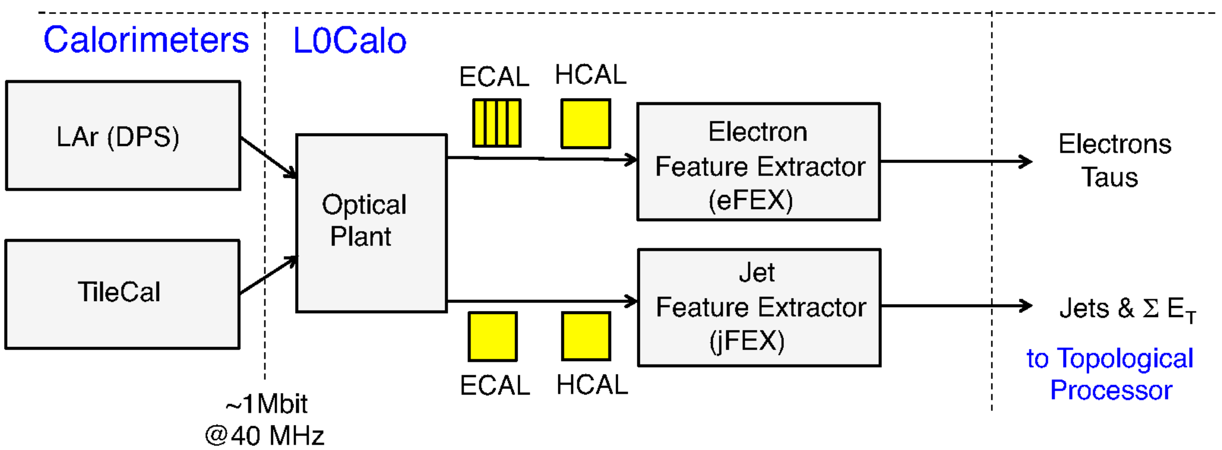
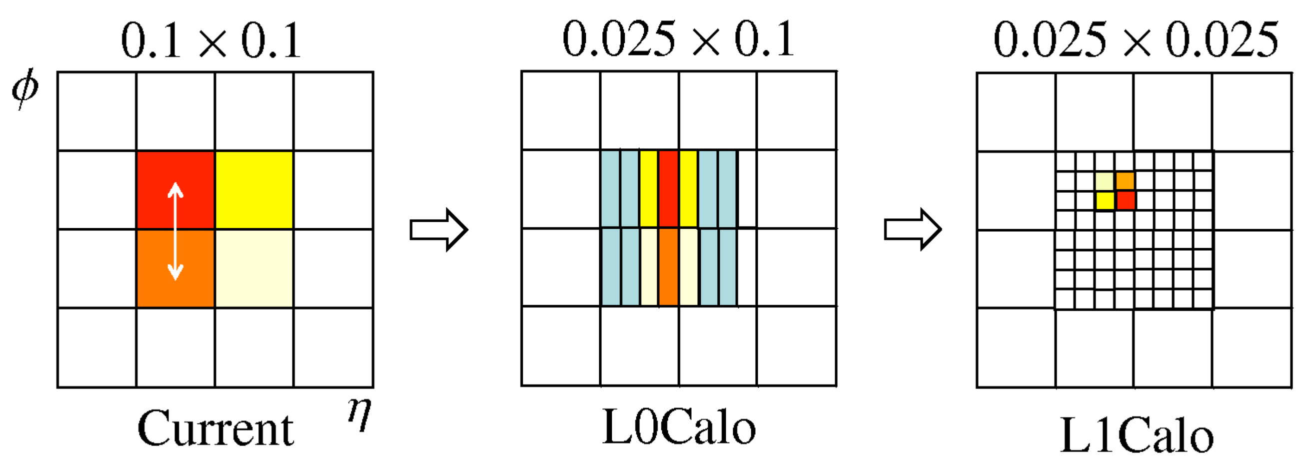
Phase-II Calorimeter Trigger

Block diagram



Granularity



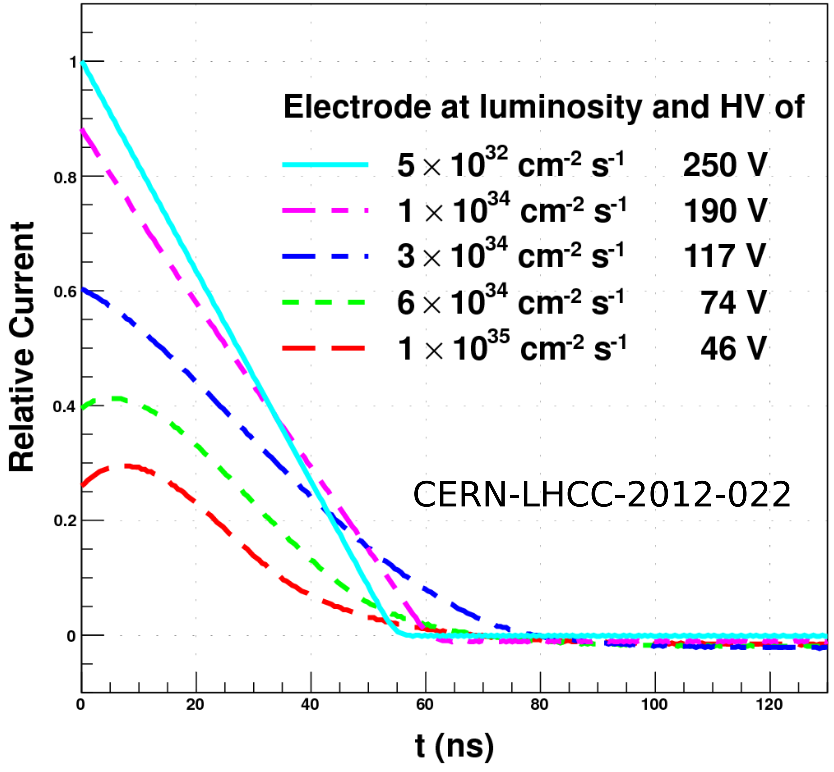
Forward Calorimetry Upgrade

Current FCal made of 3 modules:

a) groups of 4 electrodes ganged together, their signals summed

b) at HL-LHC luminosities:

→ ion build-up, HV sagging, argon bubble formation



FCal 250 μm LAr gap

Two possible upgrade options being considered:

1. sFCal: ~FCal with narrower gaps & removed signal summing & improved cooling

2. miniFCal in front of FCal possible technologies: diamond, silicon, and Cu/LAr

FCal .vs. sFCal

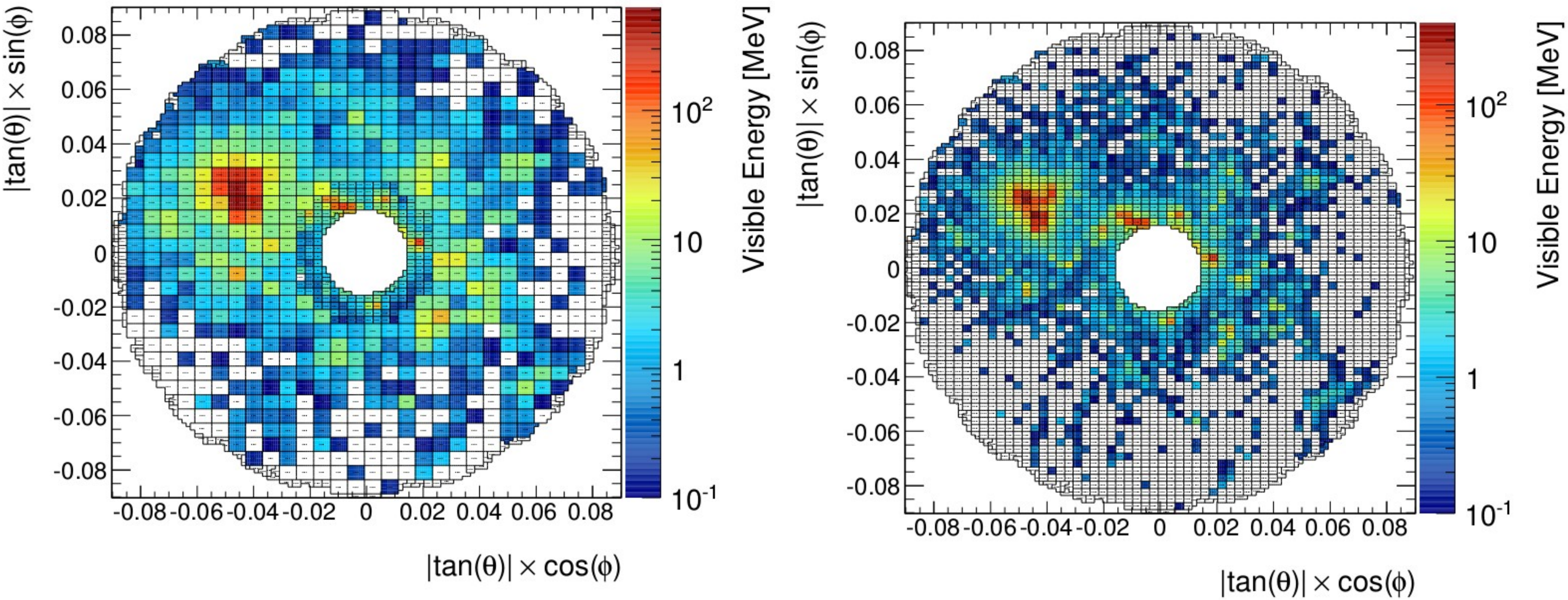
Improved high-granularity version:

→ reduce Lar gaps → no ion build-up

→ lower protection resistors → no HV sagging

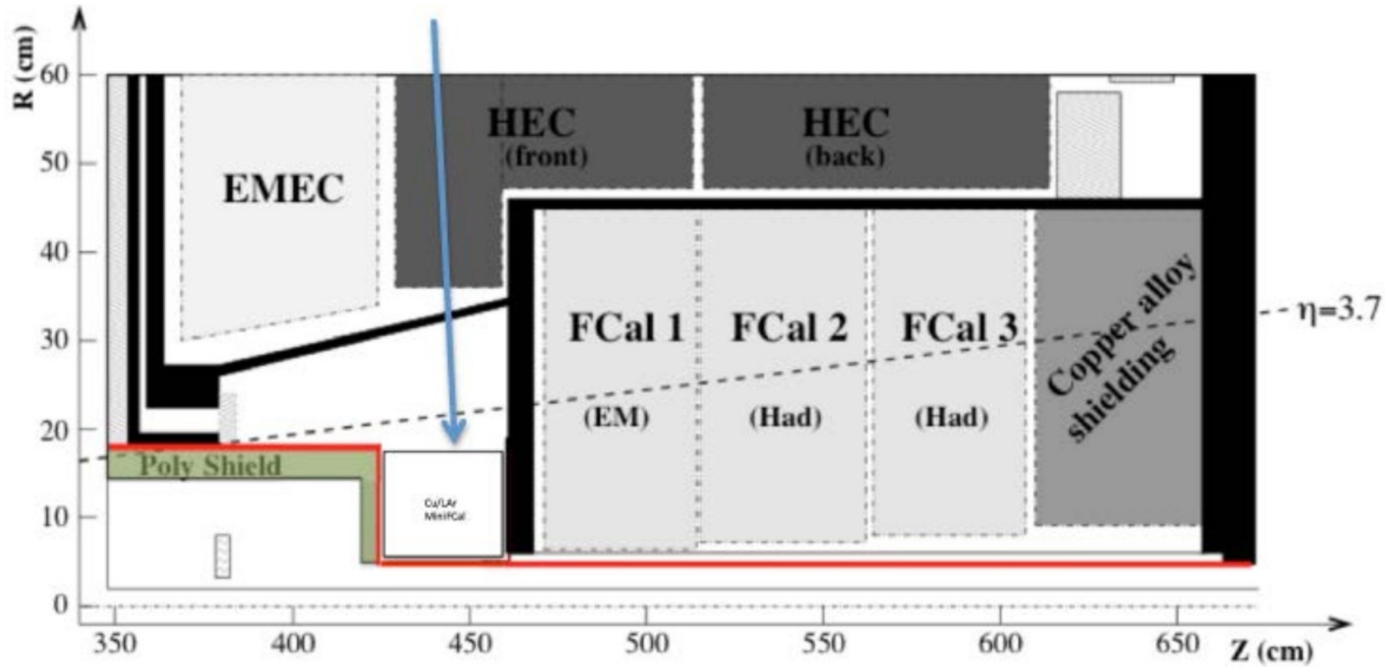
→ cooling loops → no overheating / no bubbles

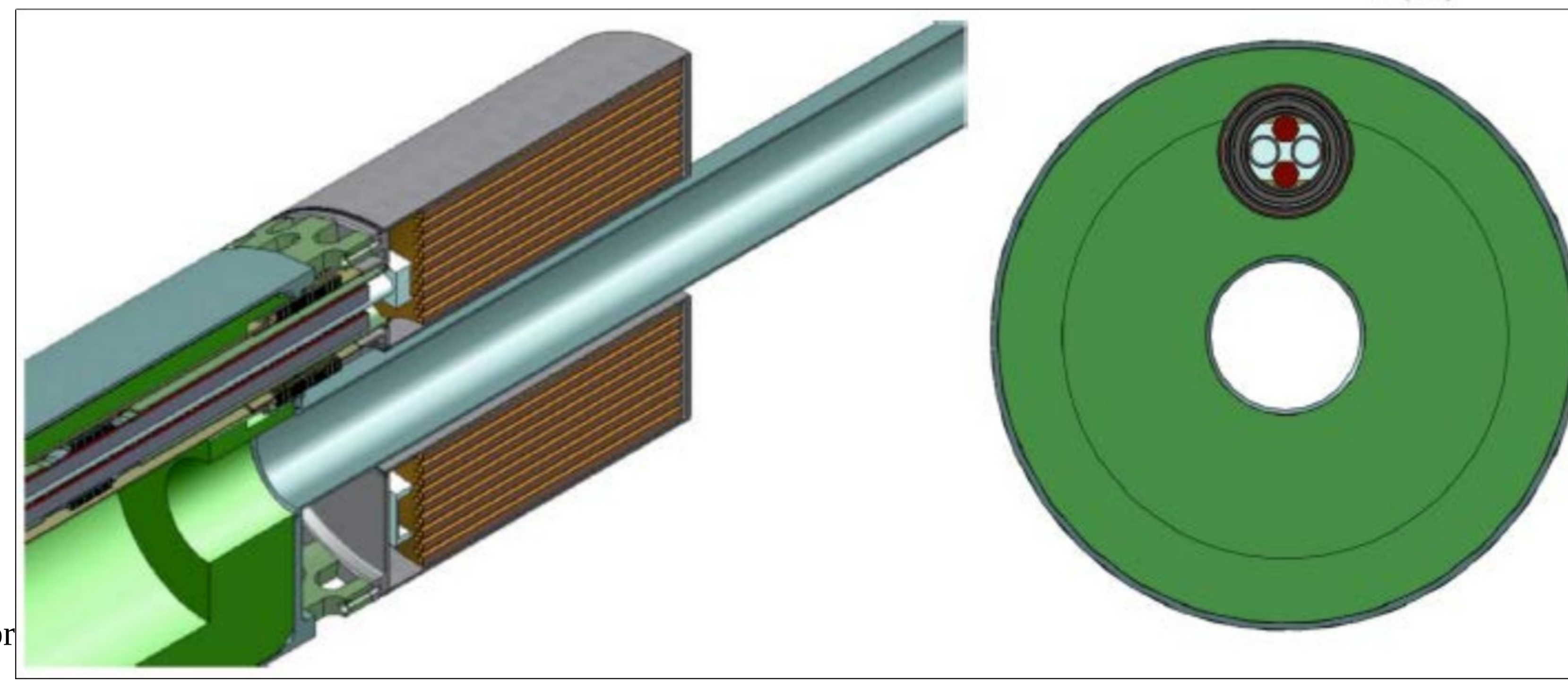
→ remove signal summing → improve pile-up reduction



same jet seen in FCal and in sFCal

miniFCal


R (cm)
60
50
40
30
20
10
0
EMEC
HEC
(front)
HEC
(back)
FCal 1
(EM)
FCal 2
(Had)
FCal 3
(Had)
Copper alloy shielding
η=3.7
Poly Shield
Cu/LAr MiniFCal
350
400
450
500
550
600
650
Z (cm)



Muon Spectrometer Options

Electronics of trigger chambers → replace in any scenario

Precision chamber readout (+ trigger) electronics

→ 100% or ~50% (BM, BO, EM) or ??

* issues for accessing the innermost chambers *

New tracking and trigger (RPC+sMDT) BI chambers:

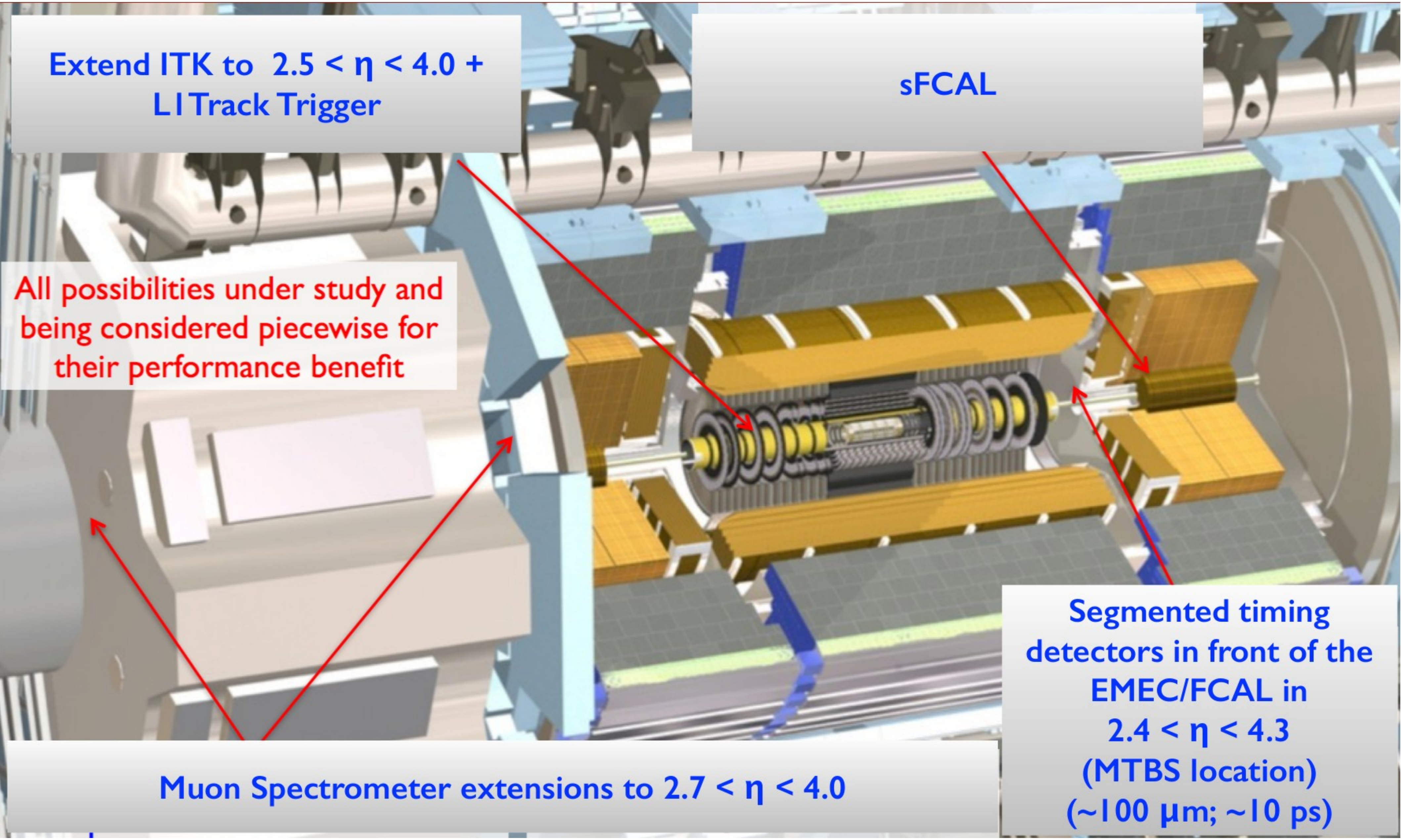
all → half → none

barrel trigger efficiency : ~95% → ~80% → ~65%

(RPC-only trigger)

High-η muon tagger : also under consideration

High-η Extensions



Pile-up Rejection

Pileup jets can be discriminated using the jet charged fraction

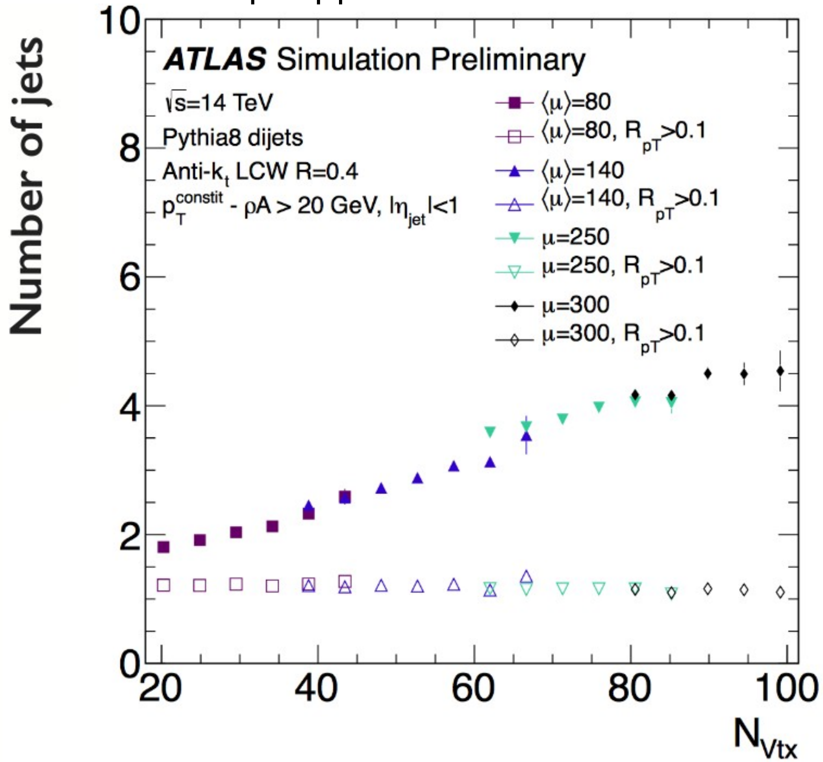
Missing-E_T resolution depends on pileup suppression

→ improves with tracker extension to large eta

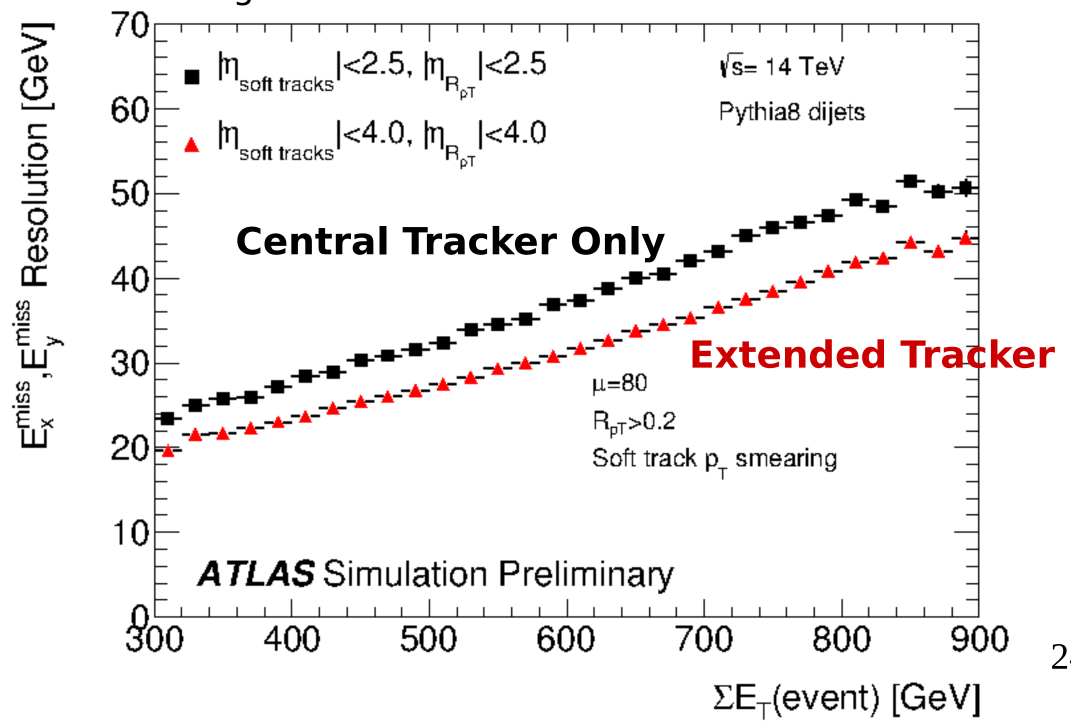
$$R_{pT} = \frac{\sum_k p_T^{trk_k}(PV_0)}{p_T^{jet}}$$

$$\sigma(E^{miss}_{x,y}) = s + k\sqrt{\Sigma E_T}$$

PileupSuppressionECFA2014



LargeEtaECFA2014



Summary and Conclusions

HL-LHC critical to improve measurements and access final states, limited by cross-section and not by kinematics:

a) Higgs: couplings, rare decay final states, self coupling
b) SUSY: light, EW produced neutralinos
c) VBS: anomalous triple and quartic gauge couplings
...

ATLAS has an ambitious upgrade program in order to preserve the current, excellent performance of the detector, despite the incredibly harsh environment:

1. full replacement of the inner tracker
2. large replacement of trigger and readout electronics (and power supplies)
3. upgrades in the calorimeter and muon systems
4. new, segmented, hardware trigger scheme
5. new DAQ/HLT architecture with powerful Tracking Trigger systems

...

Many technical challenges to be overcome and several options on the table: ongoing efforts in R&D and simulations crucial in order to maximize the physics potential

Backup

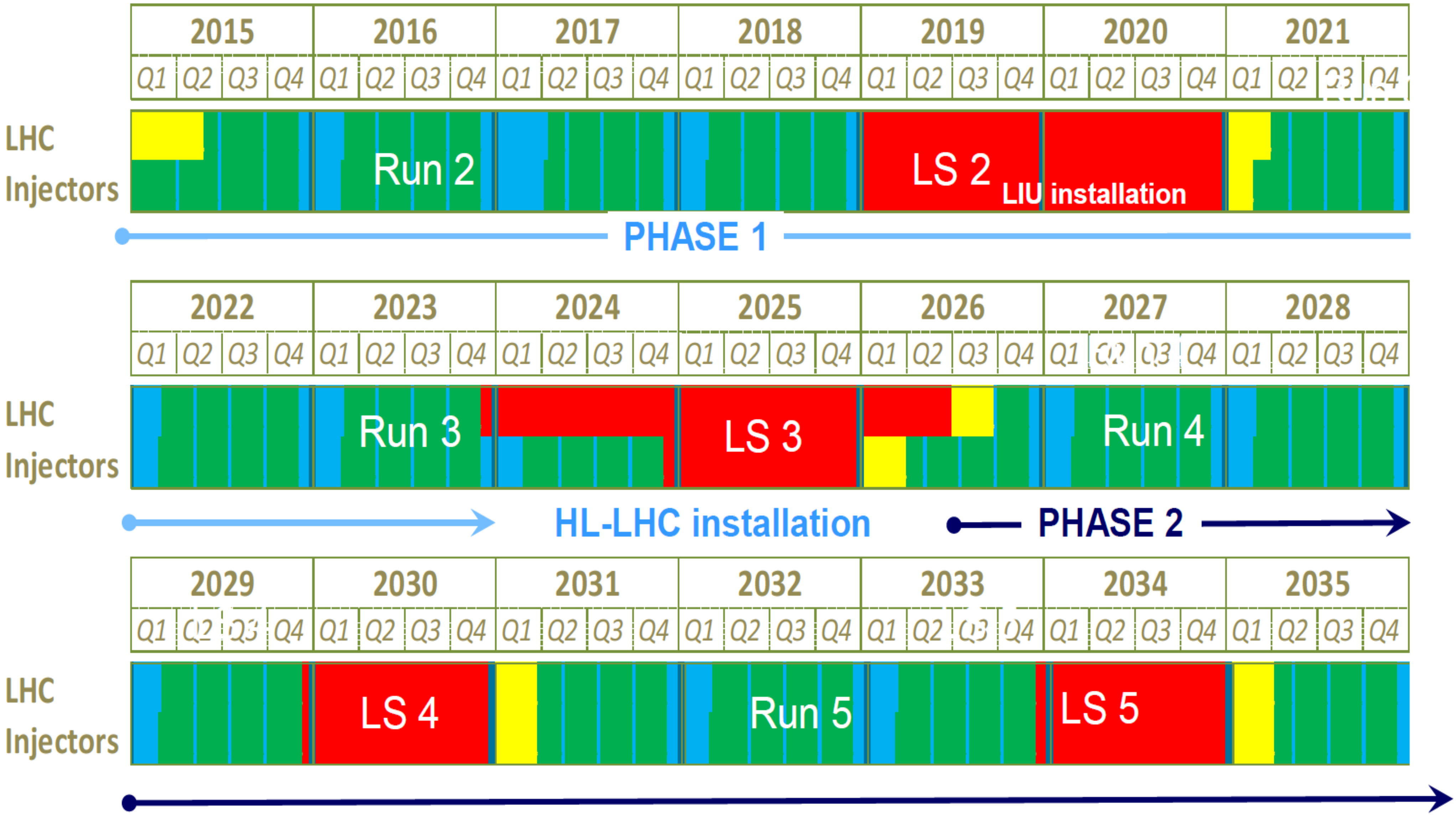
LHC roadmap: according to MTP 2016-2020

LS2 starting in 2019 => 24 months + 3 months BC

LS3 LHC: starting in 2024 => 30 months + 3 months BC

Injectors: in 2025 => 13 months + 3 months BC

- Physics
- Shutdown
- Beam commissioning
- Technical stop



ATLAS Phase 2 - Trigger

Goal (e.g.) : keep single e/μ (offline) threshold ~20 GeV

L1 fase 1 → L0: 1 MHz / 6 μs

~300 [kHz] Jet/MET + ~500 leptons/photons + ~200 taus

L0 & L1Track → L1: 400 kHz / 30 μs

~180 [kHz] Jet/MET + ~160 leptons/photons + ~40 taus

A possible trigger menu

Item	Offline p_T thr. [GeV]	Offline $\|\eta\|$	Level-0 [kHz]	Level-1 [kHz]	Event Filter [kHz]
isolated Single e	22	< 2.5	200	40	2.20
forward e	35	$2.4 - 4.0$	40	8	0.23
single γ	120	< 2.4	66	33	0.60
single μ	20	< 2.4	40	40	2.20
di-γ	25	< 2.4	8	4	0.18
di-e	15	< 2.5	90	10	0.08
di-μ	11	< 2.4	20	20	0.25
$e - \mu$	15	< 2.4	65	10	0.08
single τ	150	< 2.5	20	10	0.13
di-τ	40,30	< 2.5	200	30	0.08
single jet	180	< 3.2	60	30	0.60*
fat jet	375	< 3.2	35	20	0.35*
four-jet	75	< 3.2	50	25	0.50*
HT	500	< 3.2	60	30	0.60*
E_T^{miss}	200	< 4.9	50	25	0.50*
jet + E_T^{miss}	140,125	< 4.9	60	30	0.30*
forward jet**	180	3.2 - 4.9	30	15	0.30*
Total			~1000	~400	~10

Si/W 4D Precision Timing Detector

Recent proposal for a precision Si/W timing detector in front of LAr endcap cryostat [$2.4 < \eta < 4$] with:

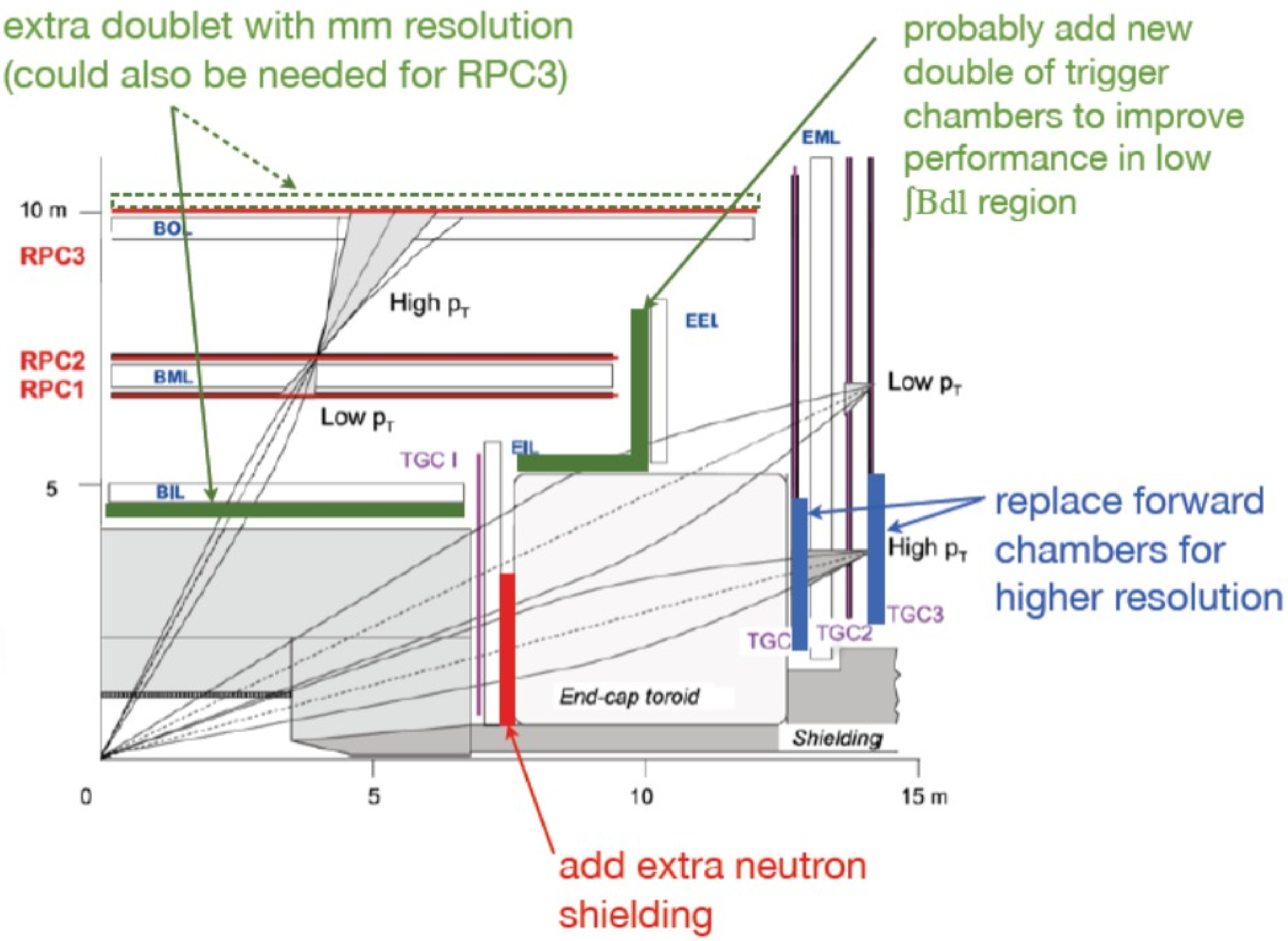
1) high spatial granularity
2) measurement of arrival time of charged particles with ~10 ps timing resolution, to assign them to different vertices

Physics Performance

A list of possible physics channels for benchmark

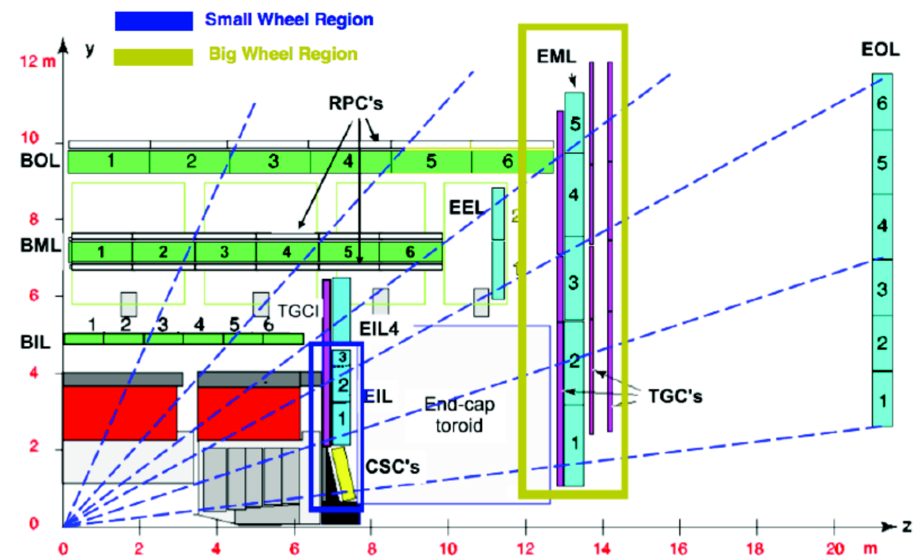
Detector system	Trigger & DAQ		Muon Spec-trome-ter	Inner Trk. / Calorimeter			Inner Trk.		Inner Trk./ Calo.
Object Perf. / Physics process	$\mu^\pm$ Trigger Eff.	$e^\pm$ Trigger Eff.	$\mu^\pm$ p_T Resol.	Pileup rejec-tion	γ Eff.	e-γ Misid.	b-tagging	Fwd. Tracks	E_T^{miss} Perf.
VBF $H \to ZZ^{(*)} \to \ell\ell\ell\ell$	✓	✓	✓	✓					
VBF $H \to \gamma\gamma$				✓	✓	✓			
$H \to \mu\mu$	✓		✓	✓(if VBF)					
$HH \to b\bar{b}b\bar{b}$							✓	✓	
$HH \to \gamma\gamma b\bar{b}$					✓	✓	✓	✓	
SM VBS SS	✓	✓		✓					
BSM $HH \to b\bar{b}b\bar{b}$							✓	✓	
$Z' \to t\bar{t}$	✓	✓	✓				✓		✓
$Z' \to \ell\ell$	✓		✓						
SUSY, $\chi^{0,\pm} \to \ell b\bar{b} + X$	✓	✓	✓				✓		✓

Muon Spectrometer Upgrades

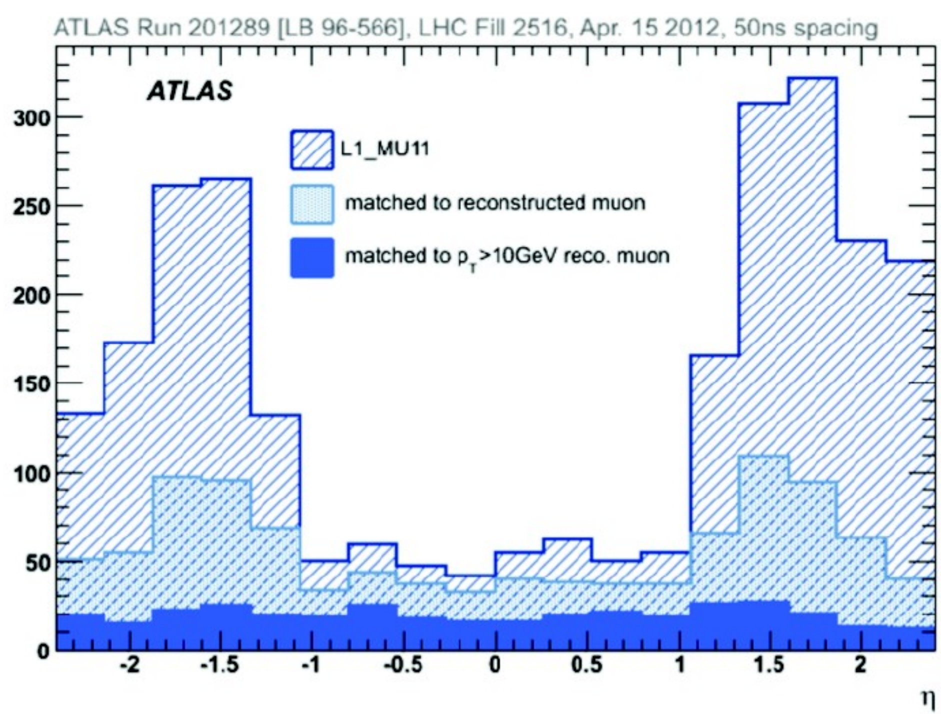


NSW – Phase-I Upgrade

- 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
  - background rates exceeding 15 kHz/cm^2 at high luminosity

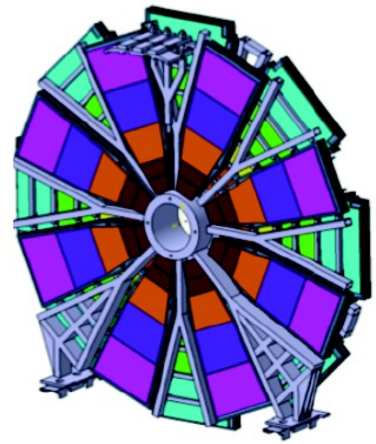


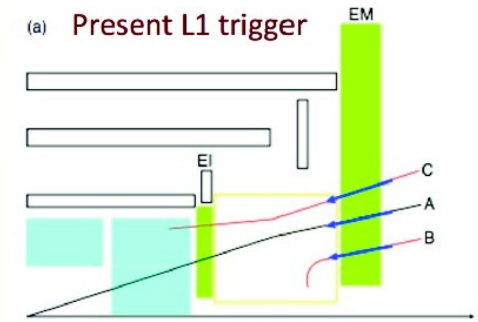
CERN-LHCC-2013-006

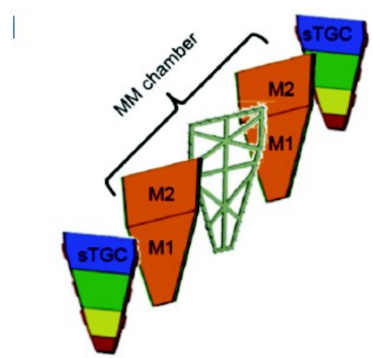


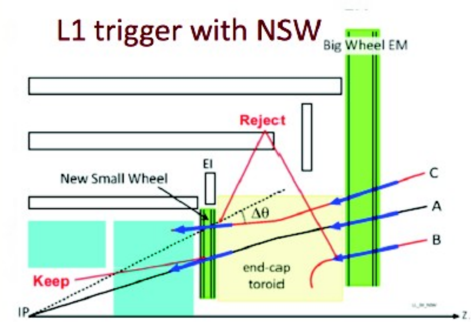
NSW Technology & Performance

- 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