ATLAS
UPGRADE PROJECTS

Federico Meloni

UNIVERSITÄT
BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Upgrade goals and motivations

Successful Run 1: Higgs discovery, plenty of other results

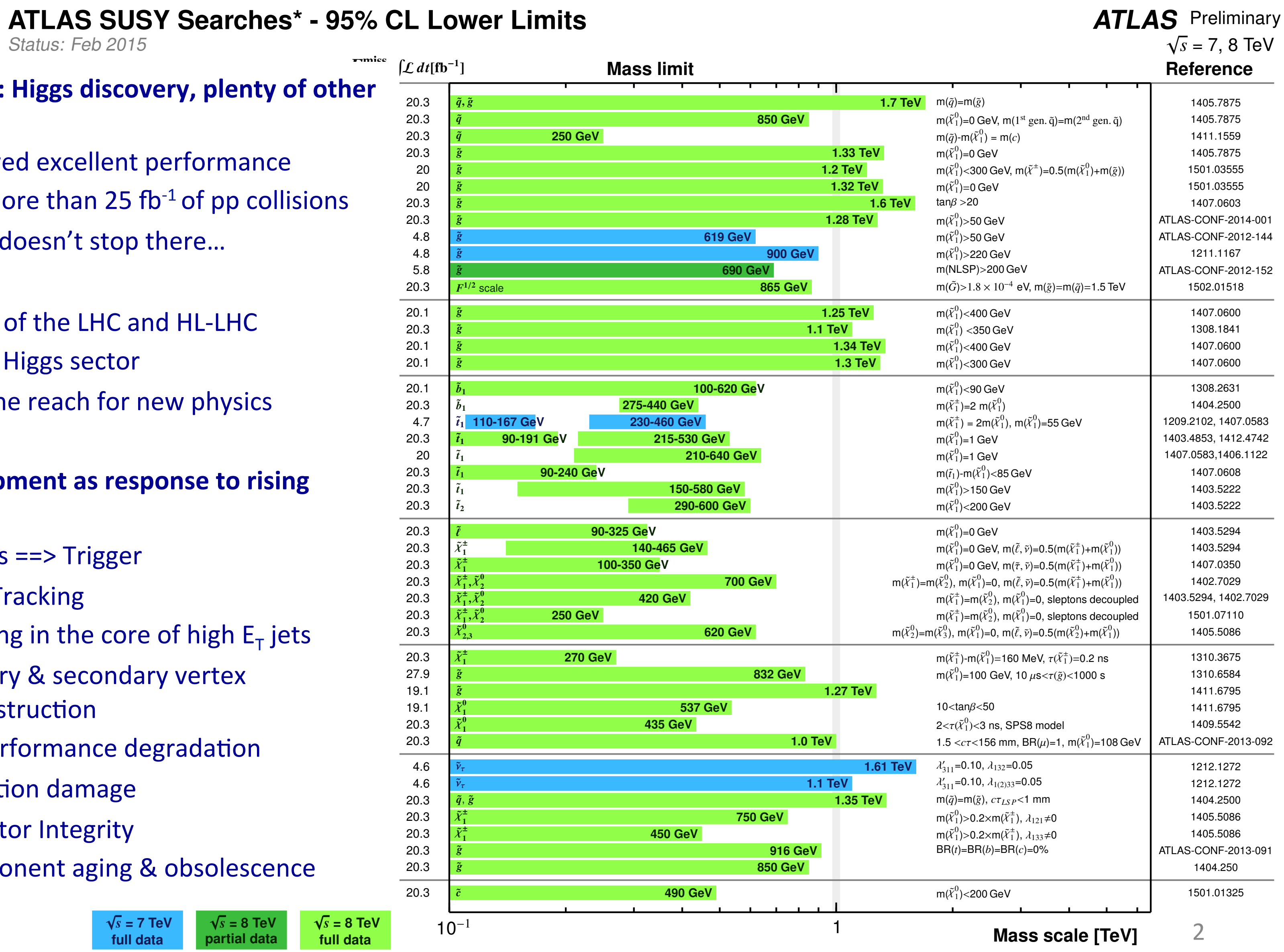
- ATLAS showed excellent performance
- Recorded more than 25 fb^{-1} of pp collisions
- But physics doesn't stop there…

Physics potential of the LHC and HL-LHC

- Probing the Higgs sector
- Extending the reach for new physics

Detector **development as response to rising luminosity**

- Higher Rates ==> Trigger
- Pileup ==> Tracking
  - tracking in the core of high E_T jets
  - primary & secondary vertex reconstruction
- Detector performance degradation
  - Radiation damage
  - Detector Integrity
  - Component aging & obsolescence



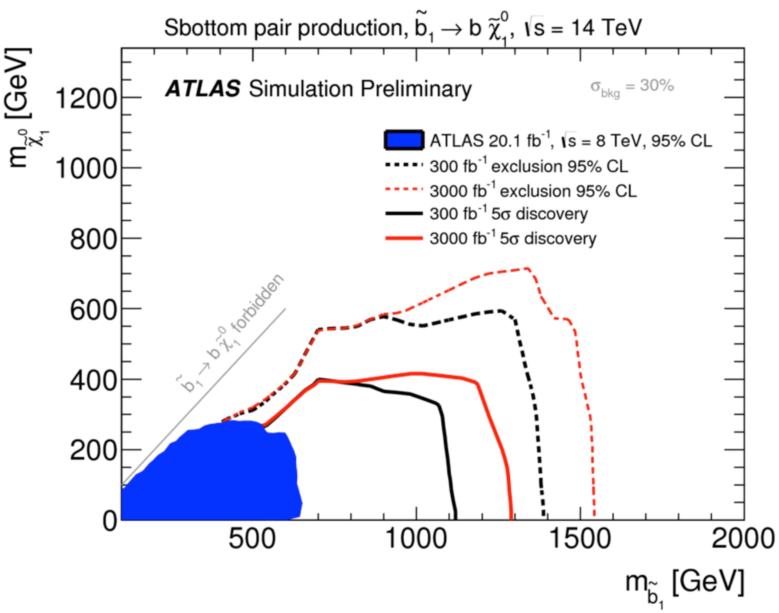
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Upgrade goals and motivations

NEW PHYSICS

SUSY

- Squarks and gluinos 1-1.5 TeV
- SUSY particle properties

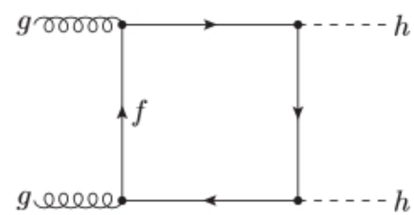


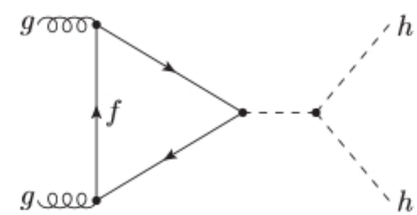
3-5 TeV W’ and Z’ properties

Look for strongly coupled scalars

HIGGS BOSON

- Measure σ x B
- Ratio of H couplings to fermions
- Low rate Higgs couplings
- Self-couplings
- Dynamics of EWSB



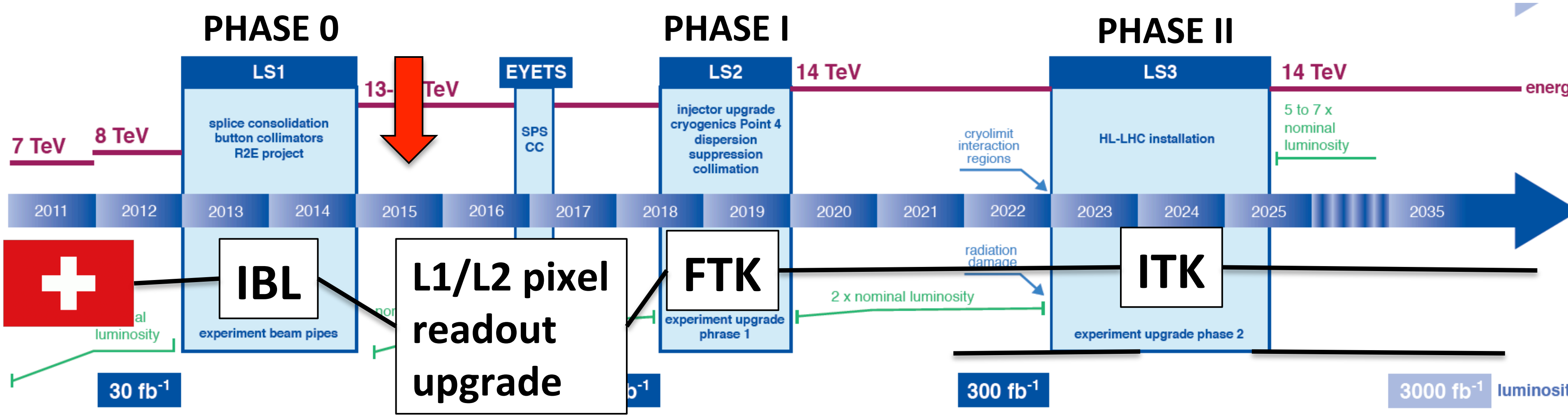


O(1000 fb^{-1}) required to carry out the physics program

ATLAS Upgrades overview

System	Phase 0 Upgrades	Phase I Upgrades	Phase II Upgrades
Tracking	• IBL pixels • Pixel new services		• Replace pixel/SCT/TRT with all-Silicon tracker
Lar Calo	• new LV power supplies	• finer granularity to L1Calo	• full granularity digital readout at 40 MHz to L1Calo • replace forward calorimetry
Tile Calo	• new LV power supplies		• completely replace electronics - digital signals to L1 • improved mechanics
Muons		• NSW endcap muon system	• replace readout electronics - precision (MDT) to L1
TDAQ	• topology at L1 • Fast TracKer (FTK) • L2/Evt Filter/Evt Builder on one CPU	• new L1Calo • NSW in L1Muon • continued FTK	• move to L0/L1 architecture • add tracking to L1 (L1Track) • more use of commodity hardware in HLT/DAQ

LHC timeline



From **LHC** to **HL-LHC**

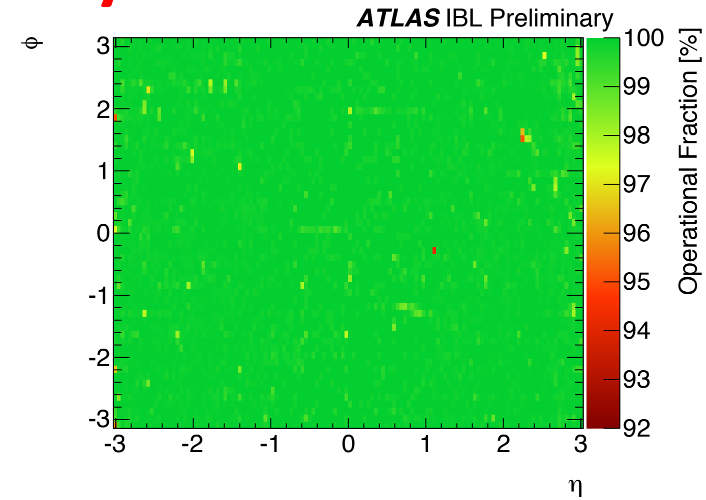
- Instantaneous luminosities x5 – Particle densities x5-10
- Integrated luminosity x10 – Radiation damage x10
- Increased overlap of pp events (pile up x3-5)

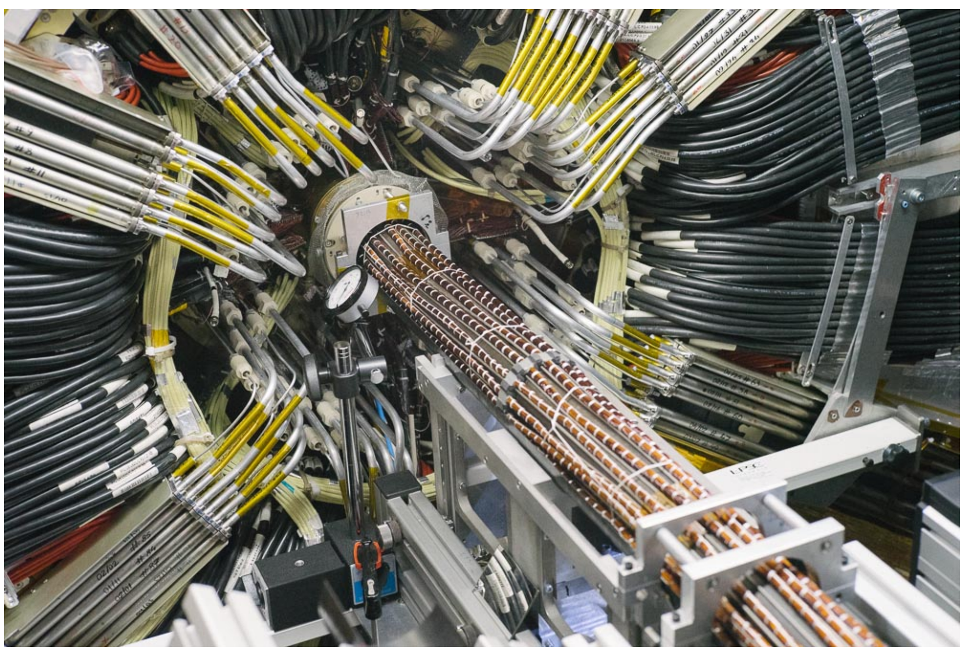
Phase 0 highlights

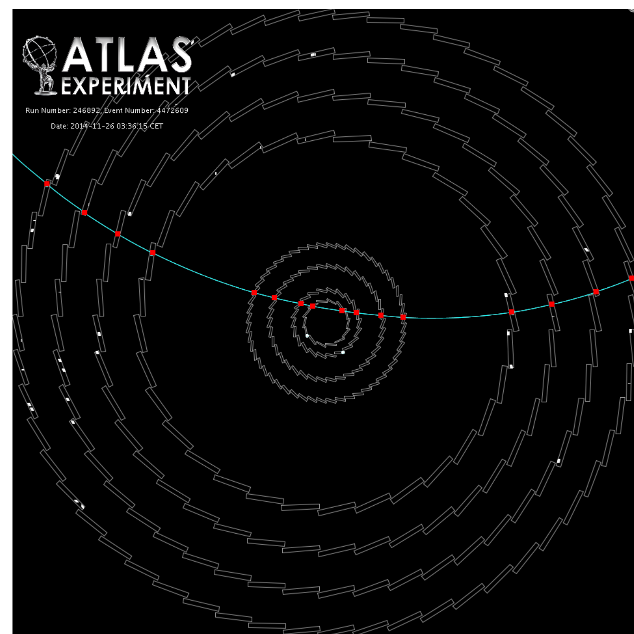
The Insertable B-Layer

Additional 4th **pixel sensor layer**

- Close to interaction point (33 mm)
- Significant **improvement to tracking**: vertex reconstruction, impact parameter resolution
- The detector **has ~0.1 % dead pixels**!



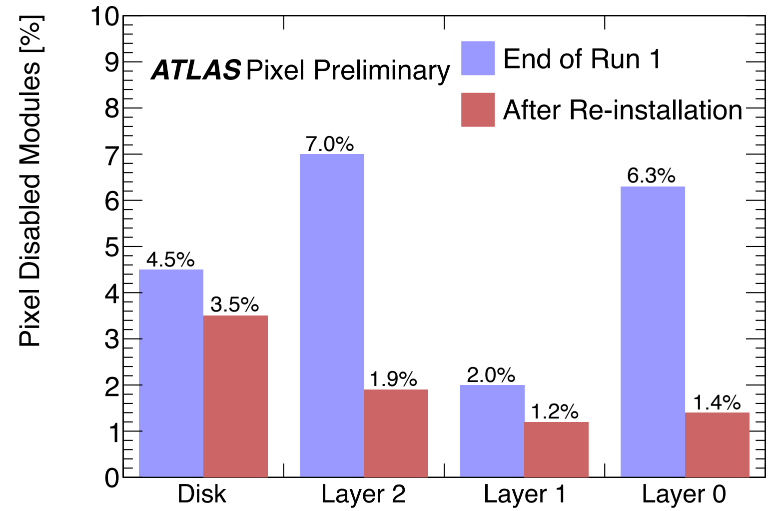




Phase 0/1 highlights

Pixel consolidation

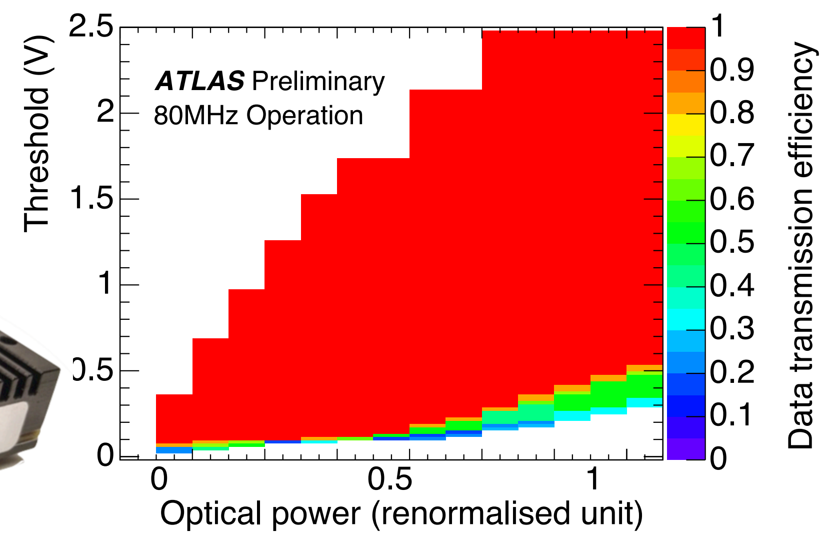
- On-detector services replaced
- Repaired all accessible failures (~98% modules working)
- Optical electronics moved to off-detector location for improved accessibility
- Power supply system upgraded



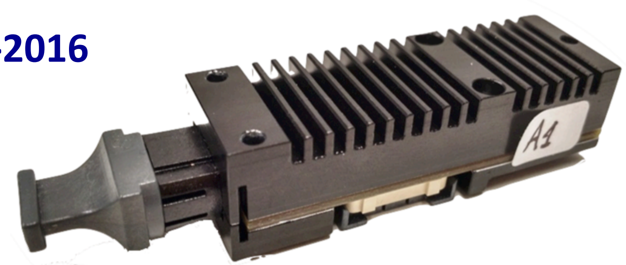
Readout upgrade

Occupancy increase foreseen in run II operation **is problematic** at Run I read out speed

- An **upgraded readout chain** is needed for the two external pixel layers
- The IBL readout system offers optimal bandwidth
- Compatibility between the on-detector and off-detector electronics needed the **design of a custom optical recevier**



Installation in 2015-2016



Phase 1 goals

LHC – 14 month shutdown –

- consolidation of injector chain
- peak luminosity = 2 x 10^{34} cm^{-2} s^{-1}

		hase I Upgrades	Phase II Upgrades
			• Replace pixel/SCT/TRT with all-Silicon tracker
Lar Calo	• new LV power supplies	• finer granularity to L1Calo	• full granularity digital readout at 40 MHz to L1Calo • replace forward calorimetry
Tile Calo	• new LV power su		ics
Muons			
TDAQ	• topology at L1 • Fast TracKer (FTK • L2/Evt Filter/Evt Builder on one CF		

ATLAS

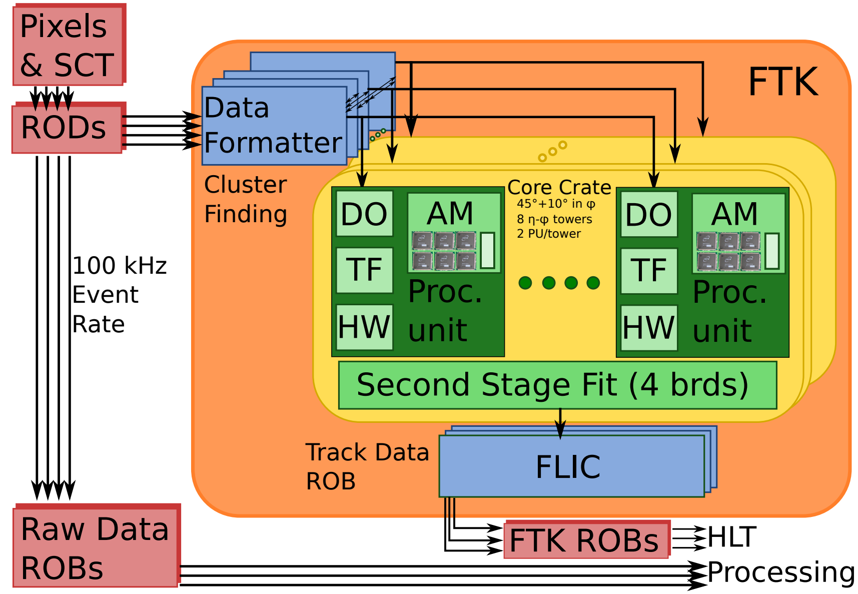
Phase 1 LOI (CERN-LHCC-2011-012)

- Physics goals (Higgs, SUSY, etc) require ability to **trigger on low p_T** (~20 GeV) **leptons** - difficult with current ATLAS configuration at Phase I due to rates
- Forward trigger chambers limit muon trigger thresholds
- Similar limits for EM trigger
- All the **upgrades compatible with Phase II**

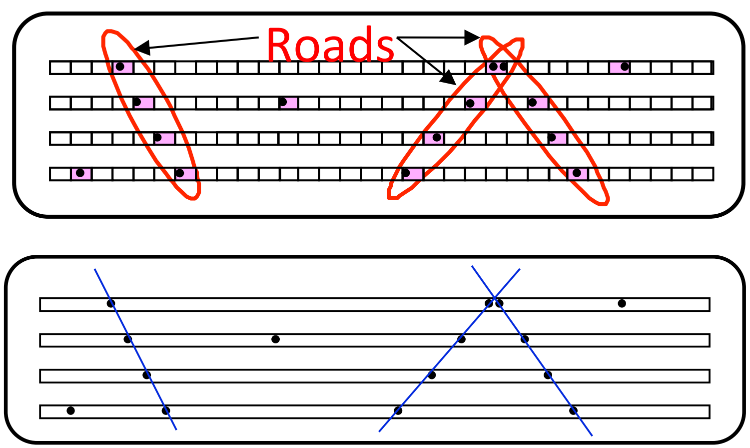
Fast TracKer

Fast track reconstruction for events passing the L1 trigger.

- Crucial to **improve QCD rejection in b-jets and τ signatures**
- Hardware based pattern recognition and fitting (1 fit/ns)
- **1 billion patterns (roads)** stored (AM Chip 06 hold 128k patterns / chip)
- Provides input to the HLT
- Installation started, with modular usage ramp up (full coverage in 2018).

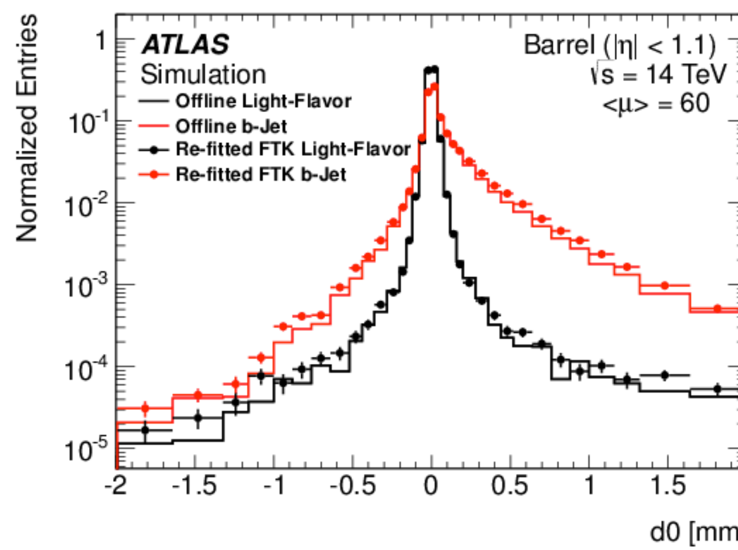


TWO STEP TRACK FITTING



1) Pattern Recognition

2) Track fit in full resolution of the hits



Muon and Calorimeter upgrades

New Small Wheels: reduce fake rates and keep precision at high rate

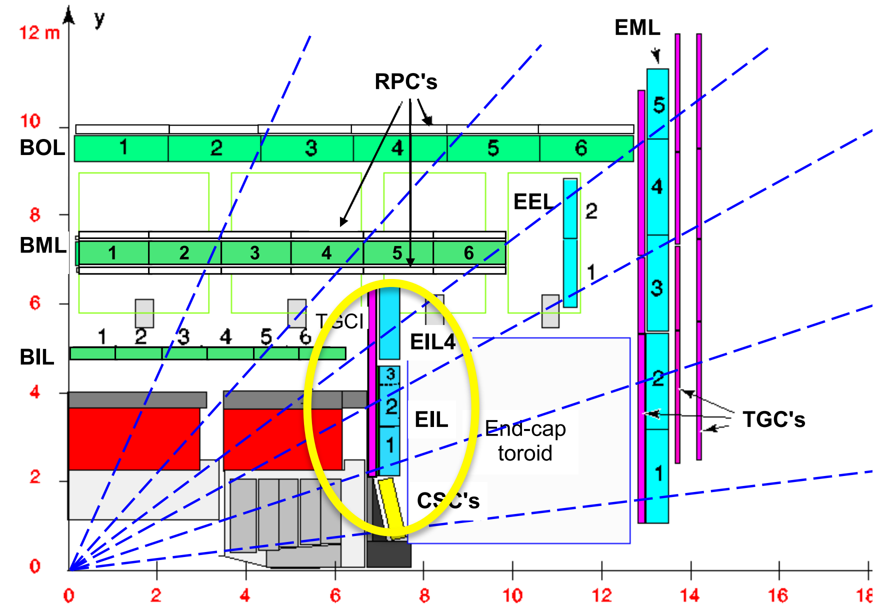
- Improved muon tracking from |η|>1.3
- Resolution < 100 μm

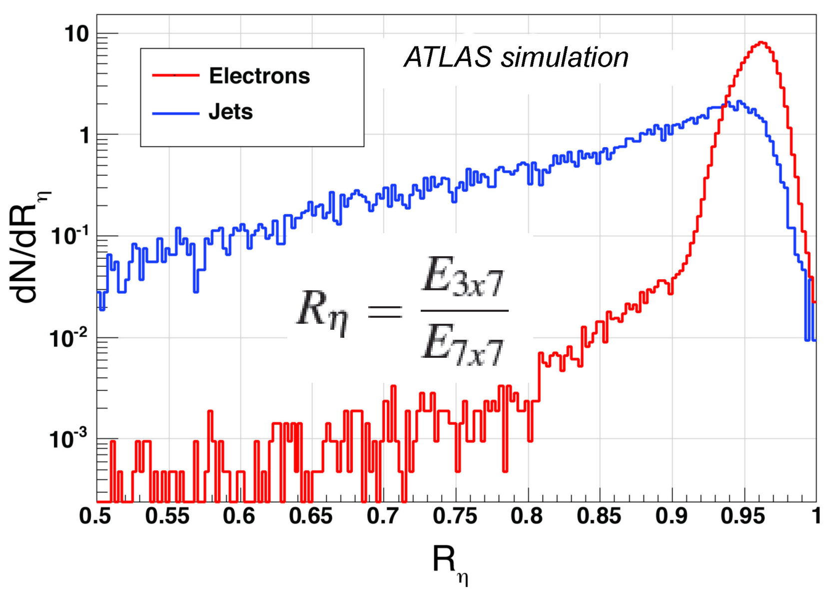
Micromegas (1200 m^2)

- Precision tracking
- High rate capable

Small-strip thin gap chambers (1200 m^2)

- Triggering with timing from bunch ID
- Proven technology





Level 1 Calorimeter Trigger

- Improve granularity
- Requires new trigger electronics

- Better discrimination between electrons and jets with the use of topological information

Phase 2 goals

LHC – 18 month shutdown –
- use of crab cavities for luminosity leveling
- peak luminosity = 5 x 10^{34} $cm^{-2}s^{-1}$

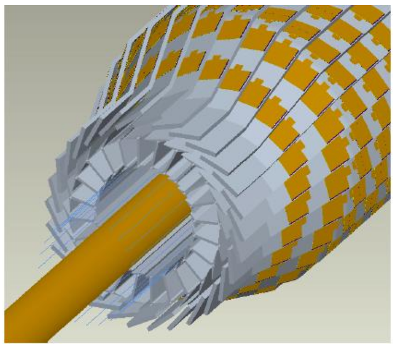
		...hase I Upgrades	Phase II Upgrades
			• Replace pixel/SCT/TRT with all-Silicon tracker
Lar Calo	• new LV power supplies	• finer granularity to L1Calo	• full granularity digital readout at 40 MHz to L1Calo • replace forward calorimetry
Tile Calo...			• completely replace electronics - digital signals to L1 • improved mechanics
Muons		...on	• replace readout electronics - precision (MDT) to L1
TDAQ	...Builder on one CPU		• move to L0/L1 architecture • add tracking to L1 (L1Track) • more use of commodity hardware in HLT/DAQ

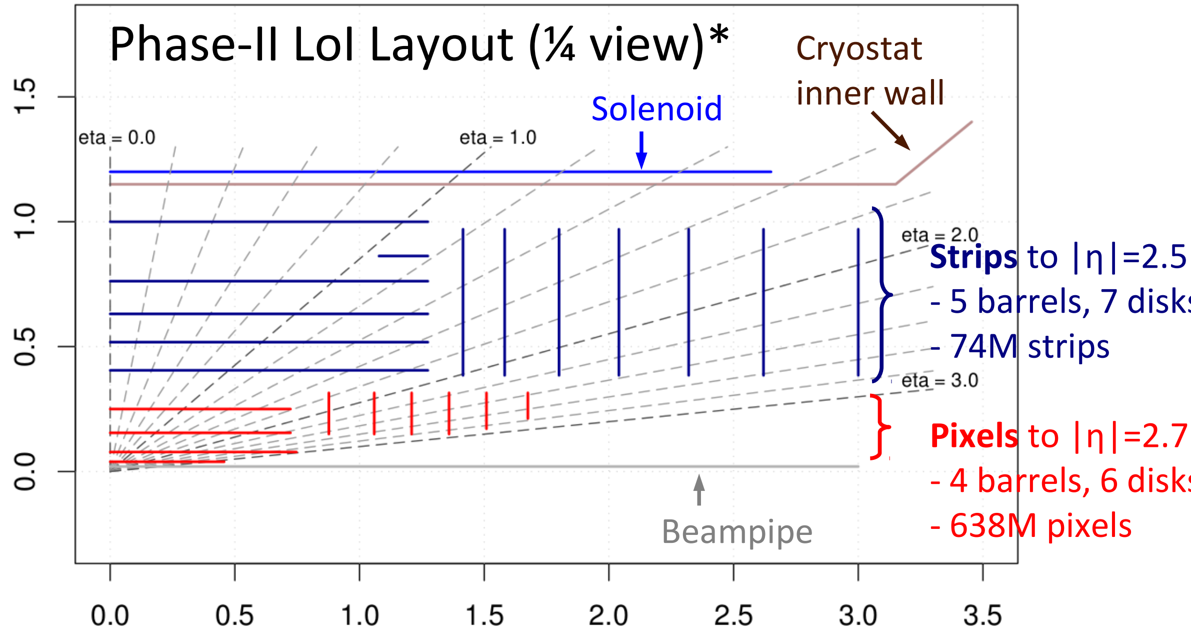
ATLAS
Phase 2 LOI (CERN-LHCC-2012-022)

- Detectors must cope with both **high instantaneous and high integrated luminosity**
- Still evaluating options required for Phase II detector upgrades

Phase 2 Tracking Detector

Possible Pixel sensor arrangement





* snapshot – still under development

Phase-II Tracker Goals

- Good/Robust Pattern Recognition: 11 measurement planes
- Good Track Location at LAr Calorimeter: 1 mm resolution in z
- High muon efficiency and resolution: 20% improvement in H->μμ mass resolution
- Efficient b-jet tagging: light jet rejection factor of 400 for 65% efficiency

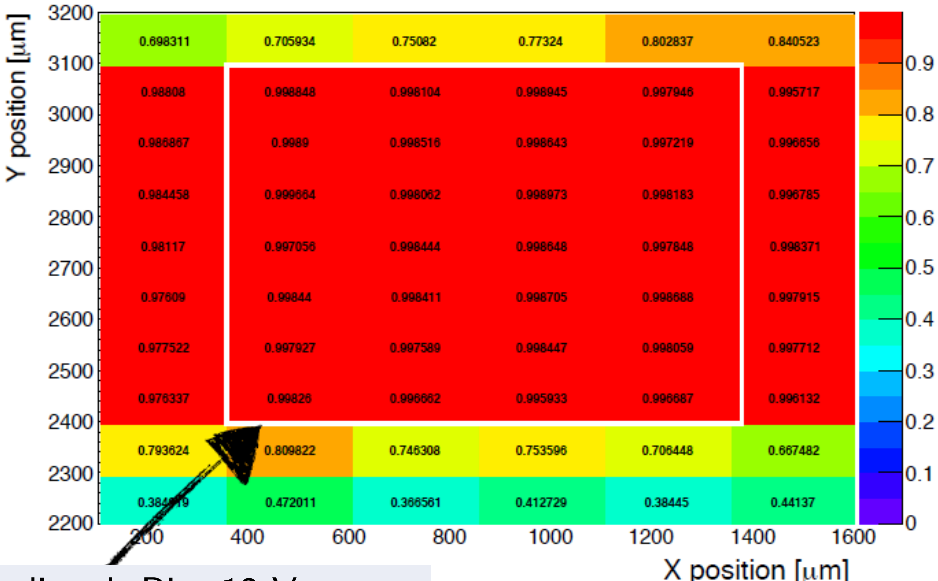
Development of novel silicon sensors

New silicon sensors are being developed for the Phase 2 Tracker

- **HV-CMOS is a family of CMOS processes** where addition are made in order to allow High-Voltage (~ 100V) to be used in the circuitry.

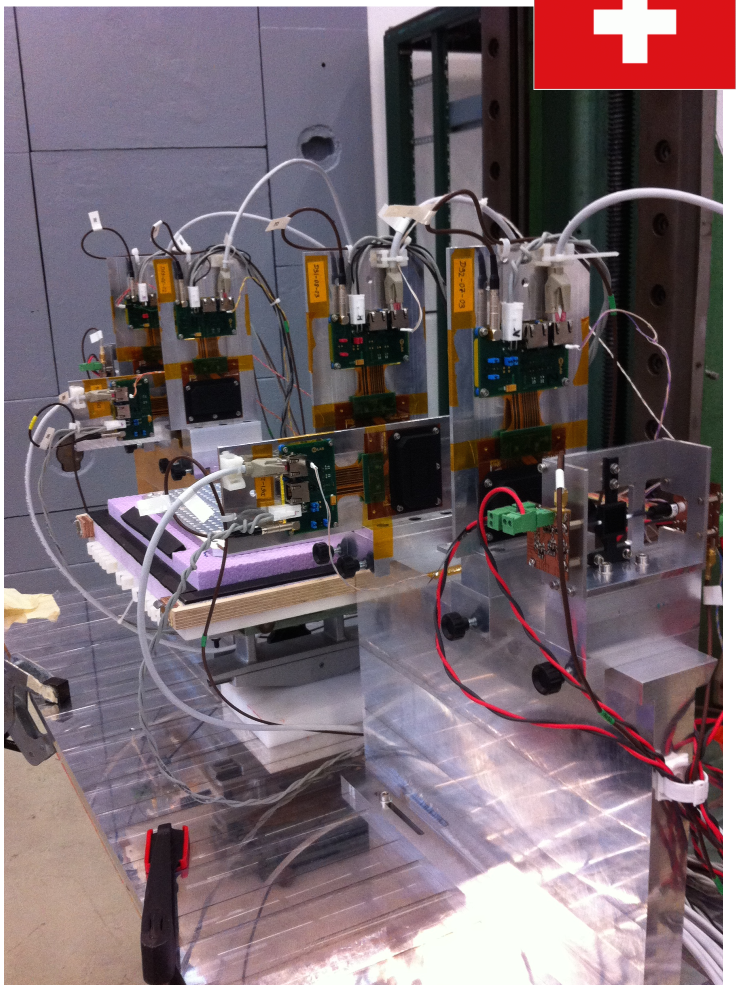
Why use this technology for HEP?

- Large-scale, low-cost production possible.
- Possibility to integrate full electronics in-pixel



unIrradiated -Bias 12 V
Th 0.84 V

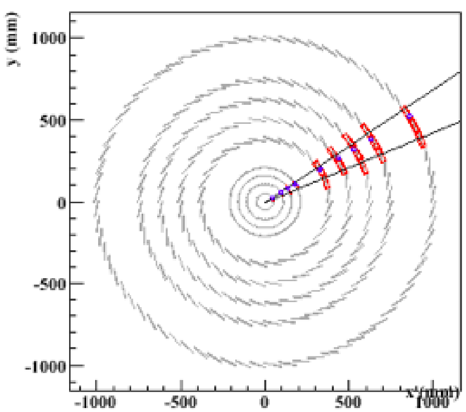
Eff 99.7%

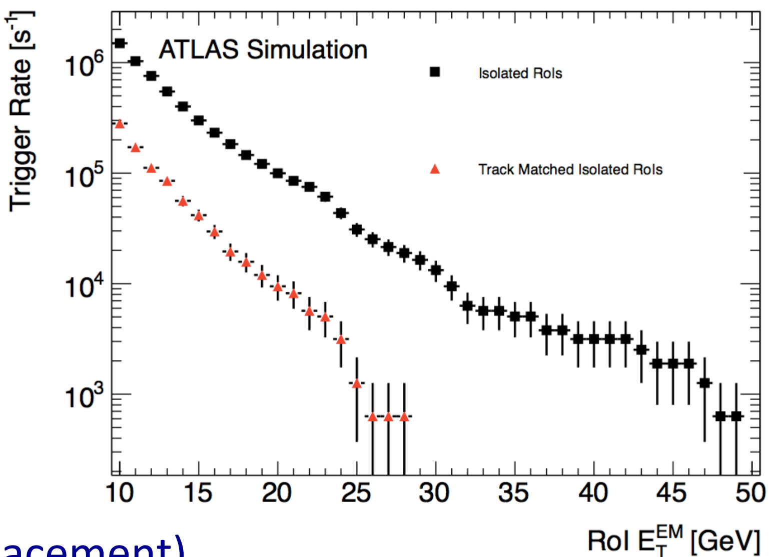


Phase 2 L1 track trigger

Evolution of FTK for Phase II

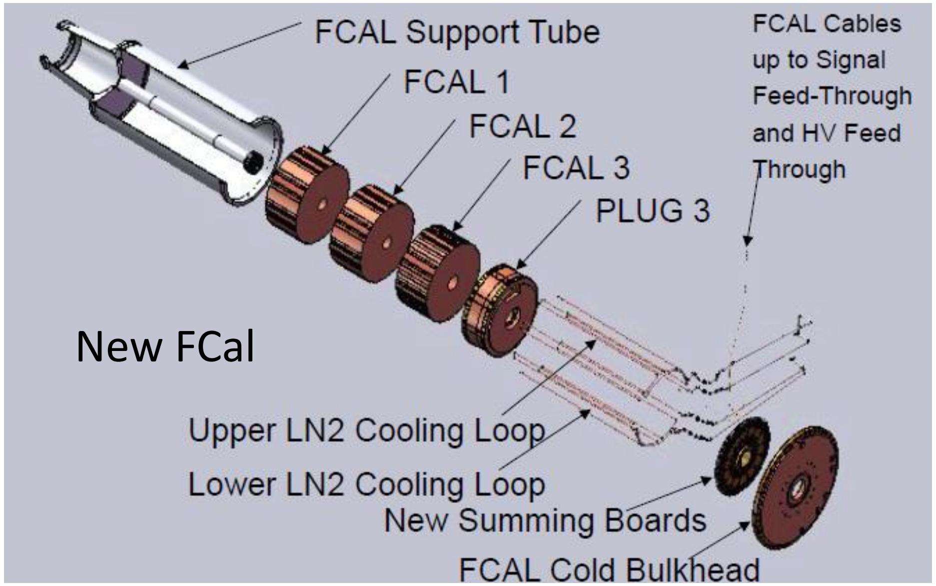
- **Regional readout** at L0 and L1
  - Calorimeter and Muons could provide region of interest (ROI)
  - Inner tracker is read out and hardware trigger confirms presence of a track candidate
  - Needs additional data stream in front end chip

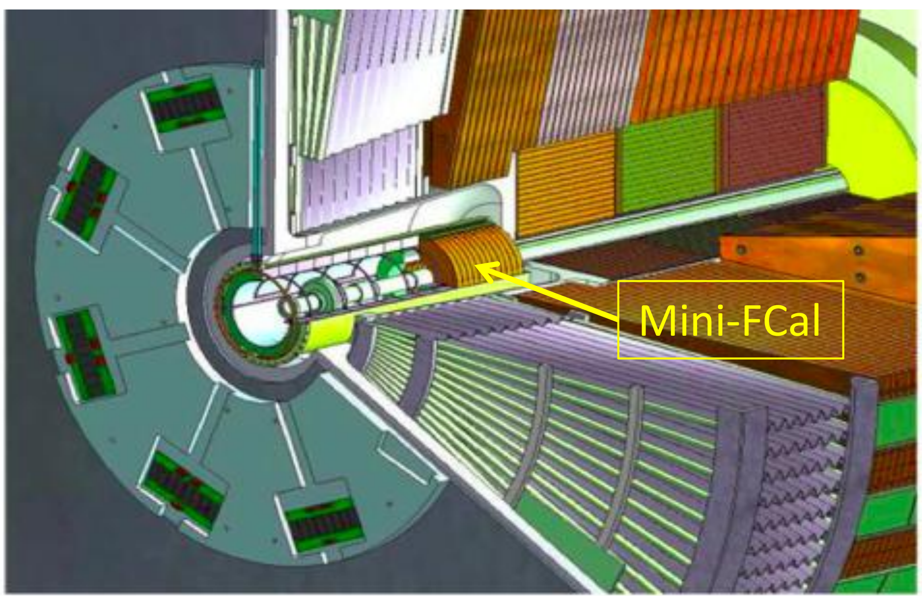




- **Self seeded** stand alone
  - Use paired modules (omit stereo placement)
  - Read out only coincident modules (high p_T)

Phase 2 Calorimeter upgrades





Forward Calorimeter (Fcal)

- potential problems with overheating and signal loss in Forward Calorimeter
- At high intensity beam heating could cause Liquid Argon to boil

Complete replacement

- New detector with smaller gaps
- New cold electronics for HV distribution
- New cooling loops

Installation of a small calorimeter in front of the current FCal: Mini-FCal

- Reduces energy and ionization in FCal to acceptable levels
- Mini-FCal baseline is copper plate calorimeter with Diamond detector.

Outlook

Exciting physics program with 300fb^{-1} and 3000fb^{-1}

- Search for new particles and measurements of Higgs properties

Technical challenges ahead

- High radiation environment
- High rate of pile up and occupancy
- High trigger rates

LHC and all 4 experiments have coherent plans to perform upgrade of systems.

- This talk was only a brief summary only a part of the ATLAS upgrade effort
- The Swiss institutes are giving crucial contribution to both Phase I and Phase II activities

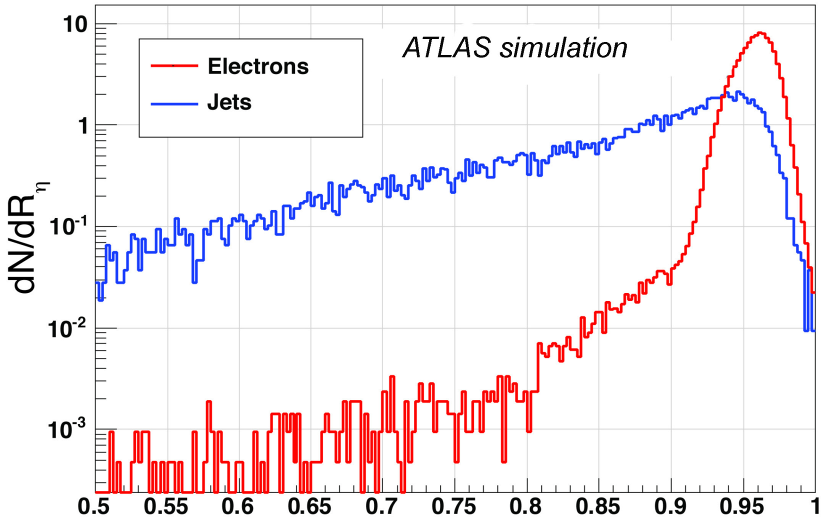
BACKUP

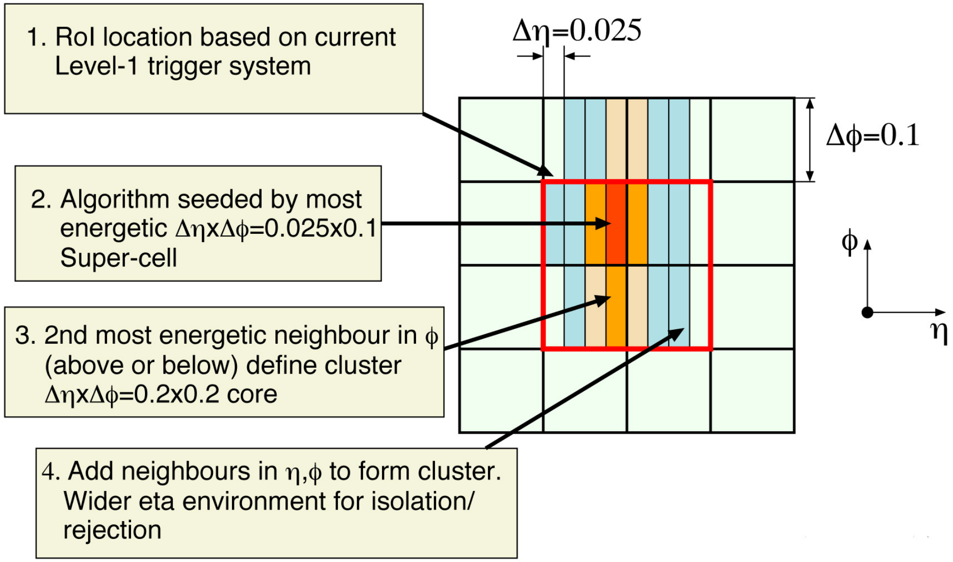
Calorimeter L1 Trigger Upgrade

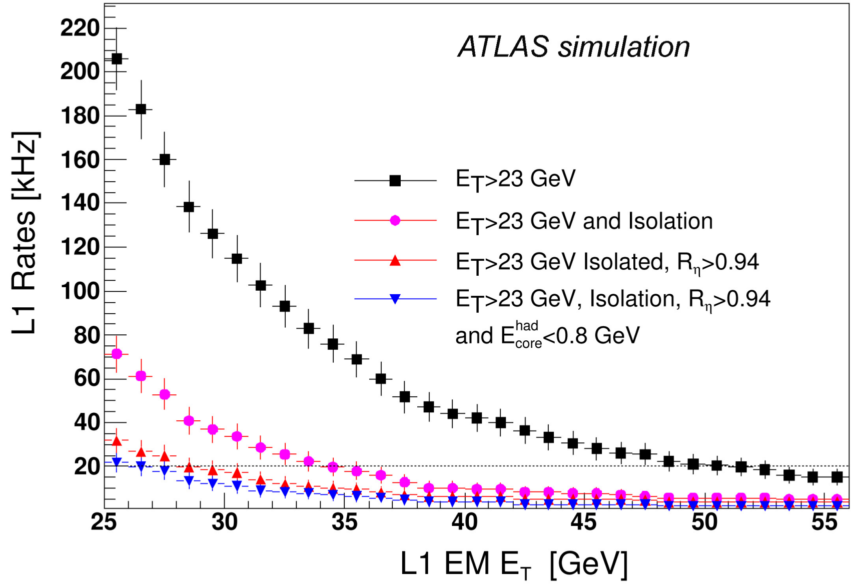
Improve granularity of trigger

- Requires new trigger electronics
- Better discrimination between electrons and jets with the use of topological information

$$R_\eta = \frac{E_{3x7}}{E_{7x7}}$$

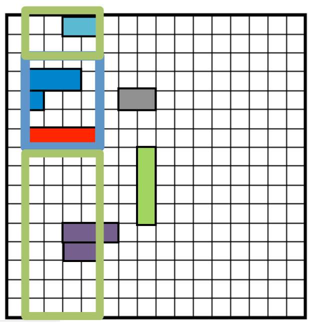




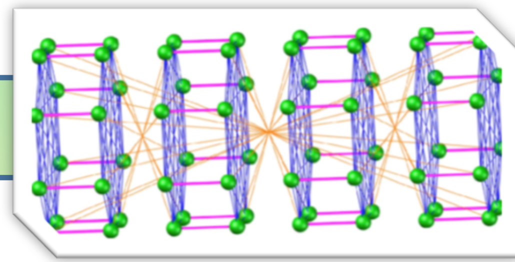


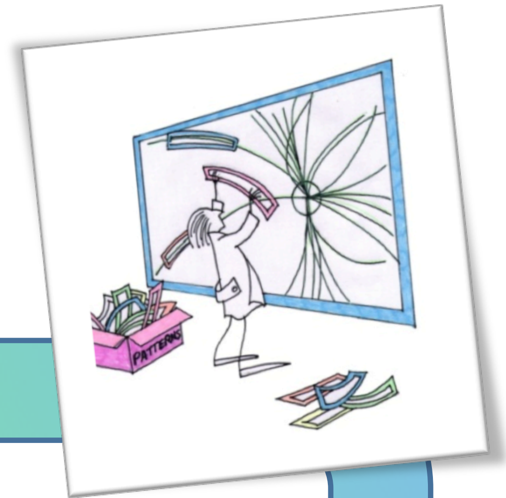
FTK Main Algorithms

FTK has a custom clustering algorithm, running on FPGAs

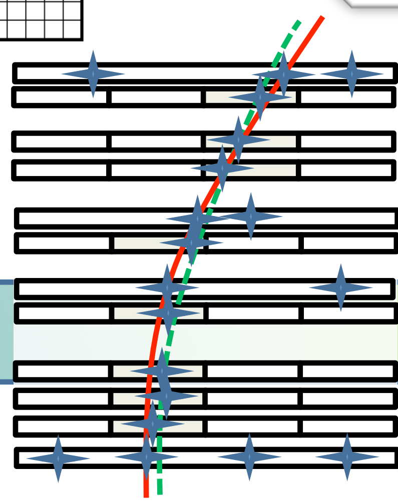


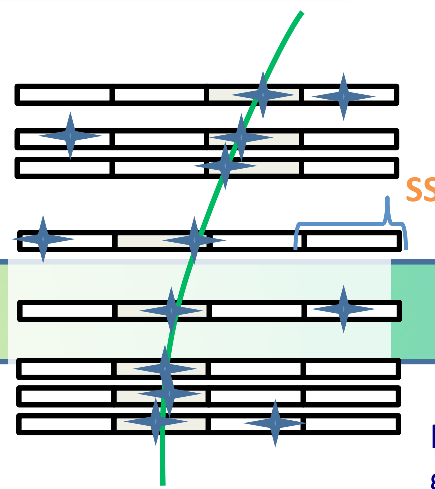
The data are geometrically distributed to the processing units and compared to existing track patterns.





Pattern matching limited to 8 layers: 3 pixels + 5 SCTs.
Hits compared at reduced resolution.





Good 8-layer tracks are extrapolated to additional layers, improving the fit

$$p_i = \sum_j C_{ij} \cdot x_j + q_i$$

Full hits precision restored in good roads.
Fits reduced to scalar products.