LAr Phase-1 upgrade demonstrator and resonance searches in the dilepton final state at the ATLAS experiment

Journées de Rencontre des Jeunes Chercheurs 2017
Instrumentation session

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LAPP / CNRS

27th November 2017

The ATLAS experiment

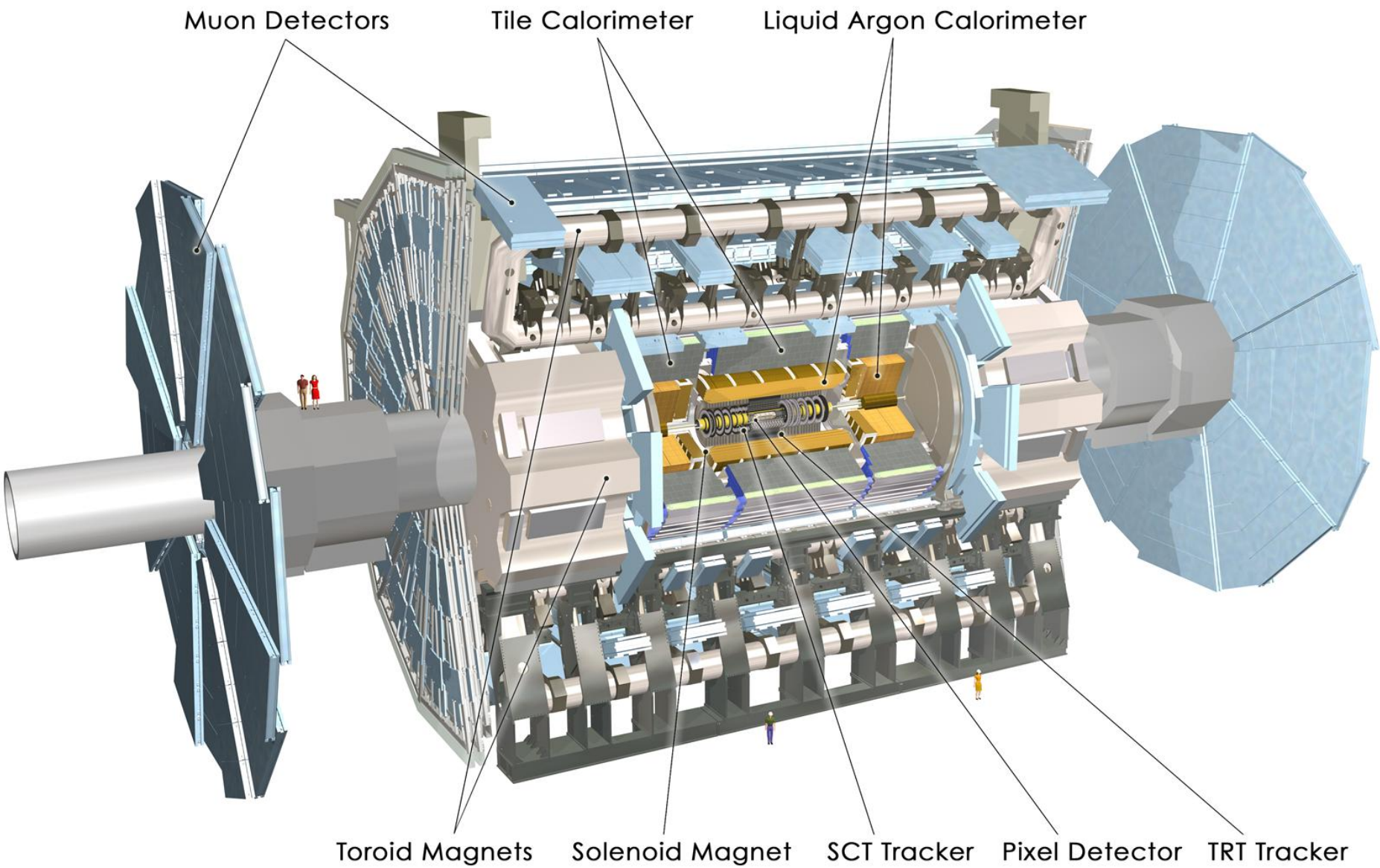
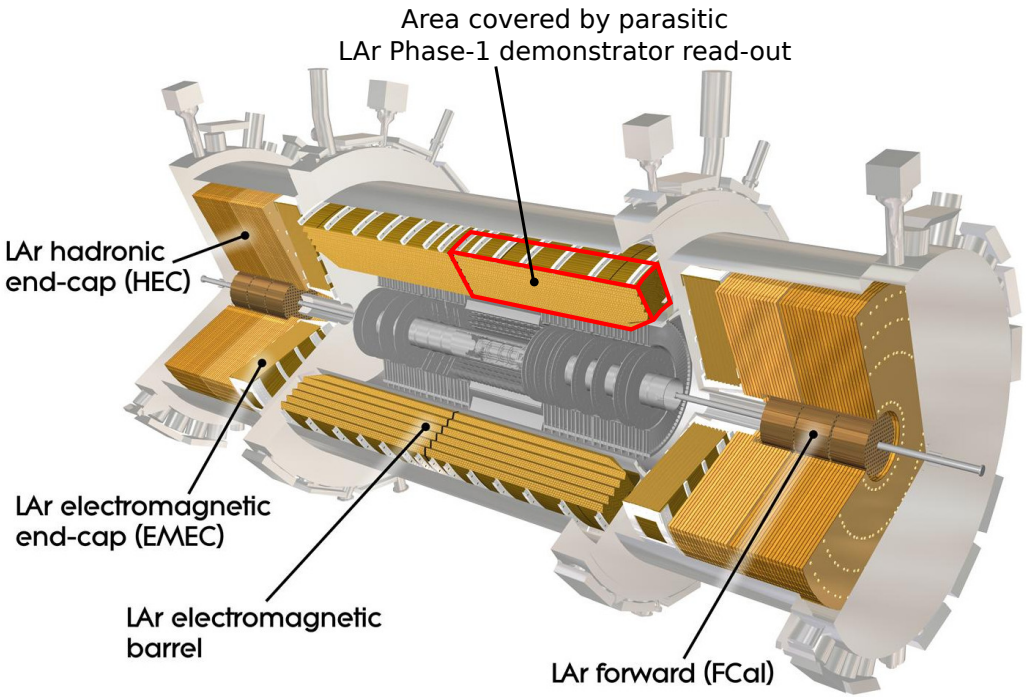


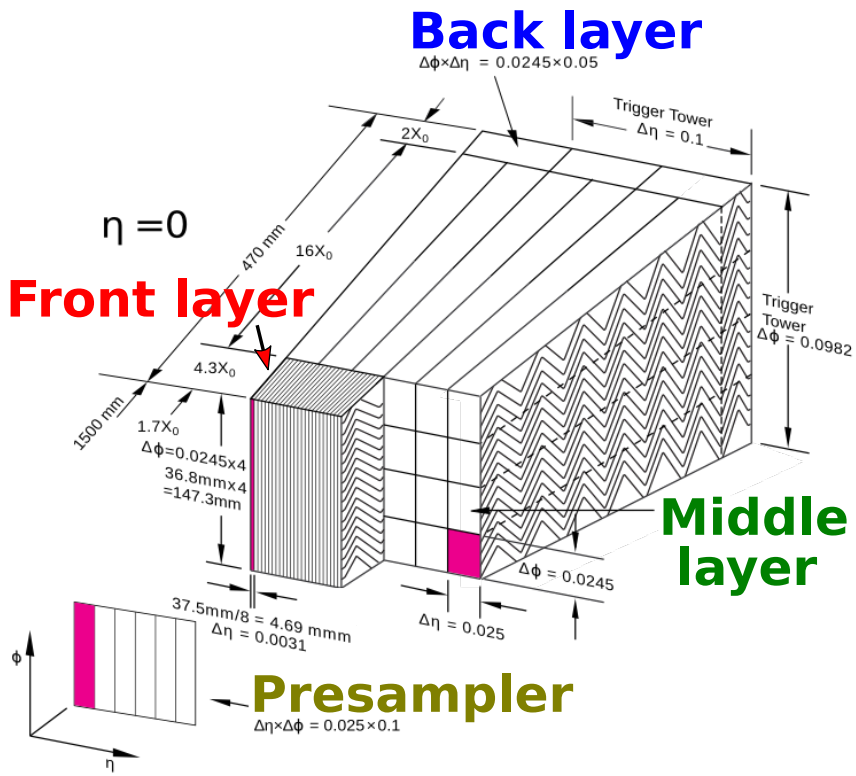
Figure from CERN CDS

Upgrade of the trigger system: LAr Phase-1 upgrade demonstrator

ATLAS LAr calorimeter

- Electromagnetic (EM) and hadronic endcap/forward calorimeter
  - Measures energy of various physics objects (e, γ, jets, τ, ...)
- Absorbers (e.g. lead in the barrel) are used to let particles loose energy
- Ionization signal is created in layers of liquid Argon (LAr)





Figures from LAr detector status

Trigger system

- LHC collision rate too high to record all events
  - Need to be selective → trigger

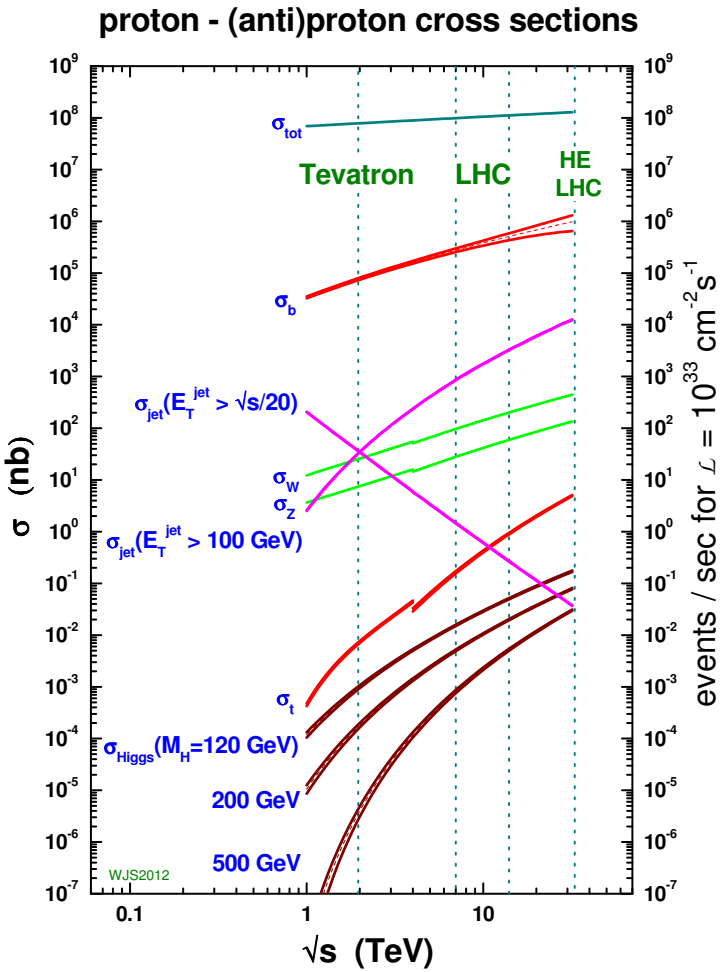
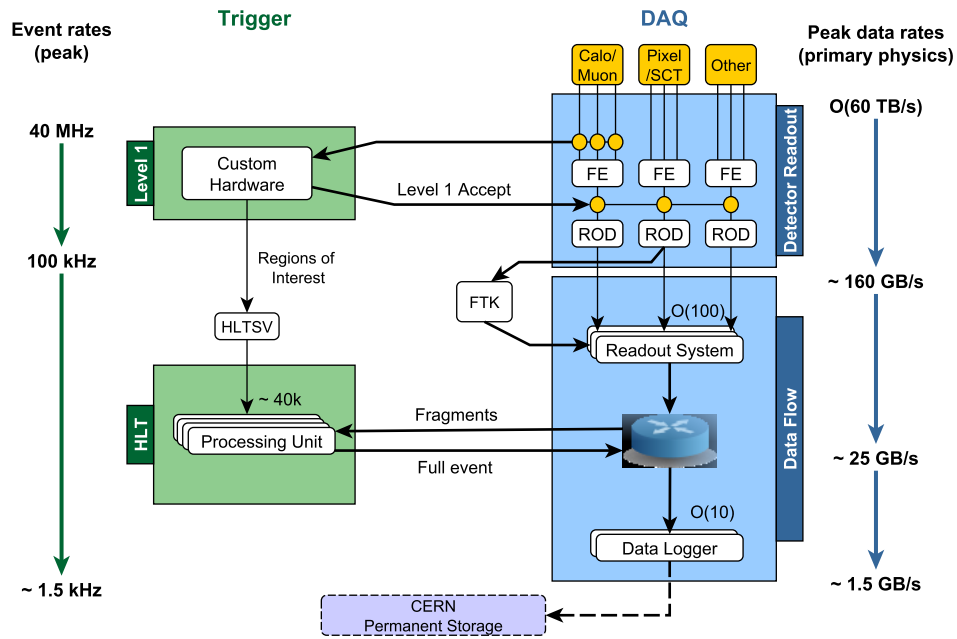


Figure from James Stirling



ATLAS trigger system overview

Figure from ATLAS DAQ public plots

Phase-1 Upgrade boundary conditions

- Expected LHC parameters in Run-3
  - $\times 2$ higher instantaneous luminosity than in 2017
- ATLAS status
  - Level-1 (hardware) trigger limited to $100\,\mathrm{kHz}$ until end of Run-3
    $\rightarrow$ out of this: $20 - 30\,\mathrm{kHz}$ for single EM trigger
    $\rightarrow$ need more complex selection with luminosity increase
  - Currently trigger has limited granularity $\rightarrow$ Phase-1 Upgrade

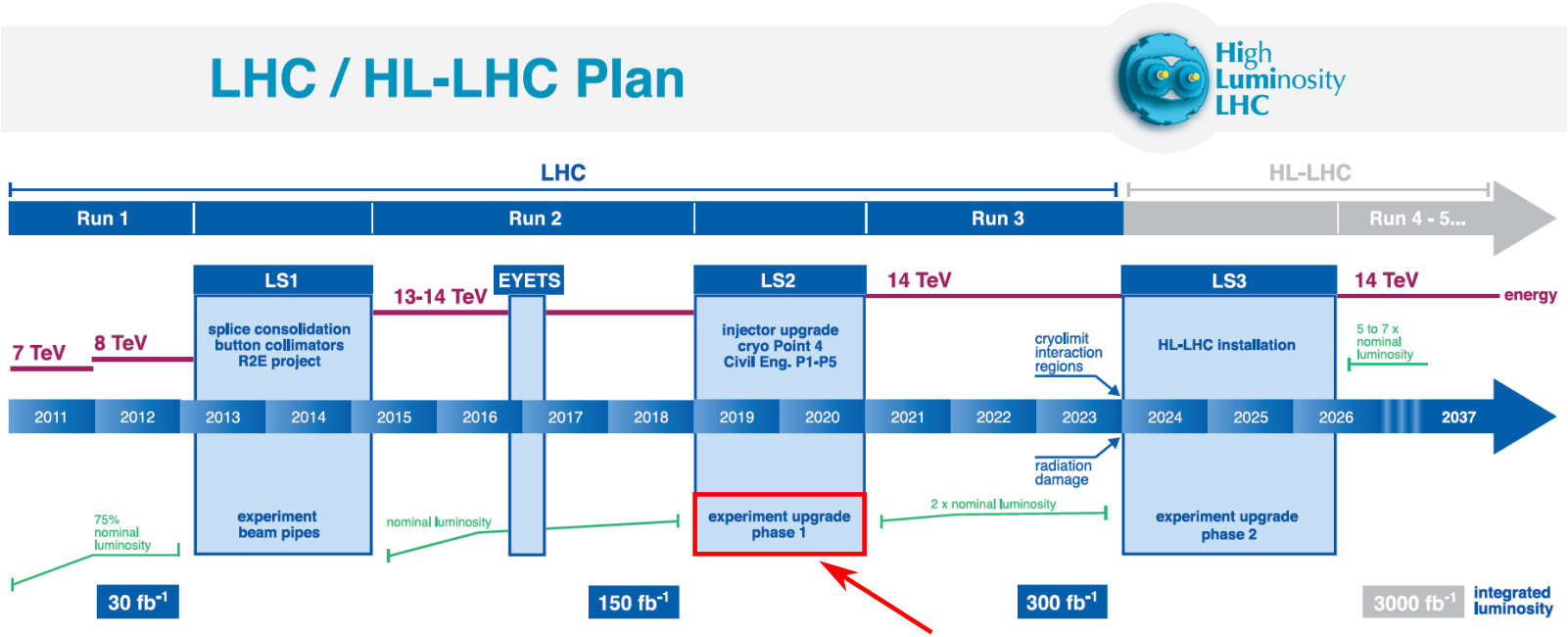
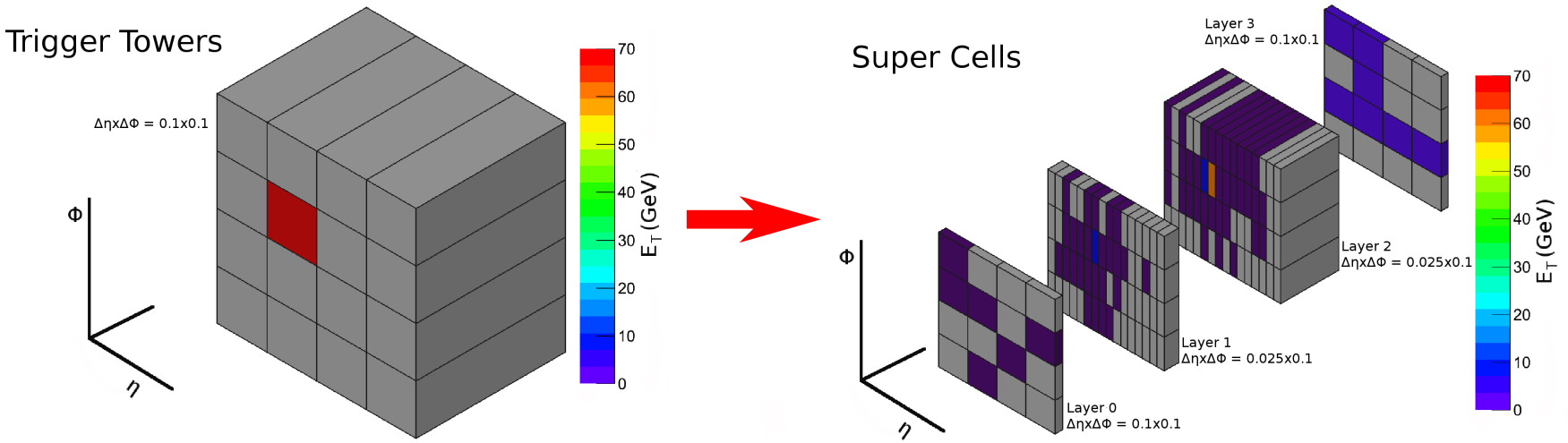


Image from https://hilumilhcds.web.cern.ch/about/hl-lhc-project

Trigger readout: From Trigger Towers to Supercells

- Cannot process full cell granularity on Level-1 calorimeter trigger level
  - Currently based on $5.4\,\mathrm{k}$ trigger towers

Current: Trigger Towers **After upgrade: Supercells (SCs)**



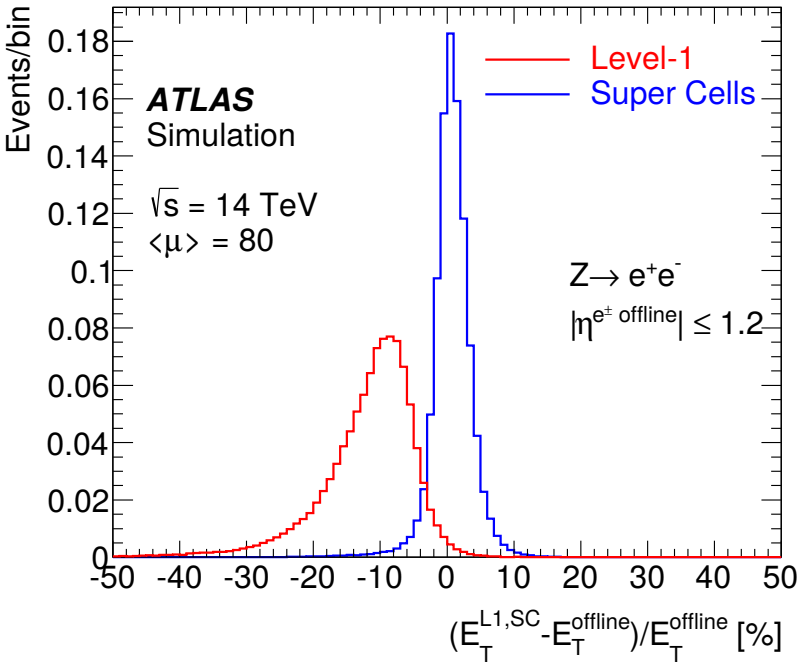
Example of $70\,\mathrm{GeV}$ electron shower

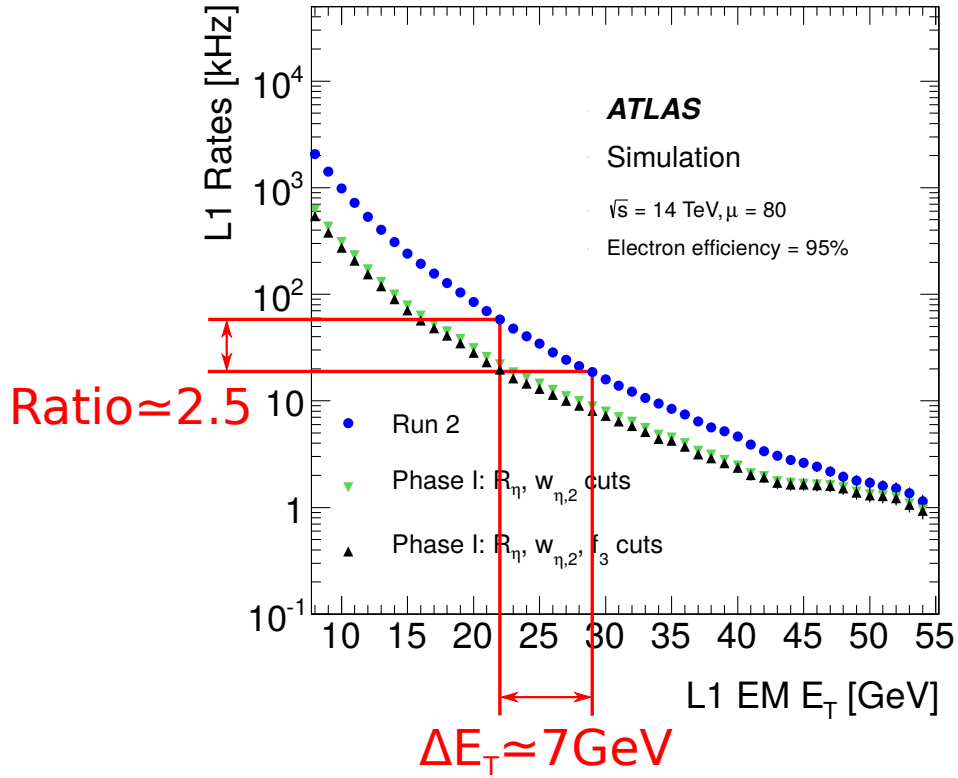
Figure from ATLAS LAr Phase-1 Upgrade TDR

- $34\,\mathrm{k}$ supercells (SCs) after upgrade
  - Consist of $4-8$ LAr cells in the barrel ($110\,\mathrm{k}$ cells available in total)
  - Will provide higher granularity, better resolution and longitudinal shower information
- Partial exchange and extension of electronics needed

Expected performance gains

- Current criteria at Level-1 hardware trigger: Energy and isolation
  - Improving energy measurement helps to reduce rate
    $\rightarrow$ can cut closer to desired E_{T} threshold
  - Additionally: finer granularity and layer information
    $\rightarrow$ more information about shower development
    $\rightarrow$ can be used to distinguish between electrons and jets





Figures from ATLAS LAr Phase-1 Upgrade TDR

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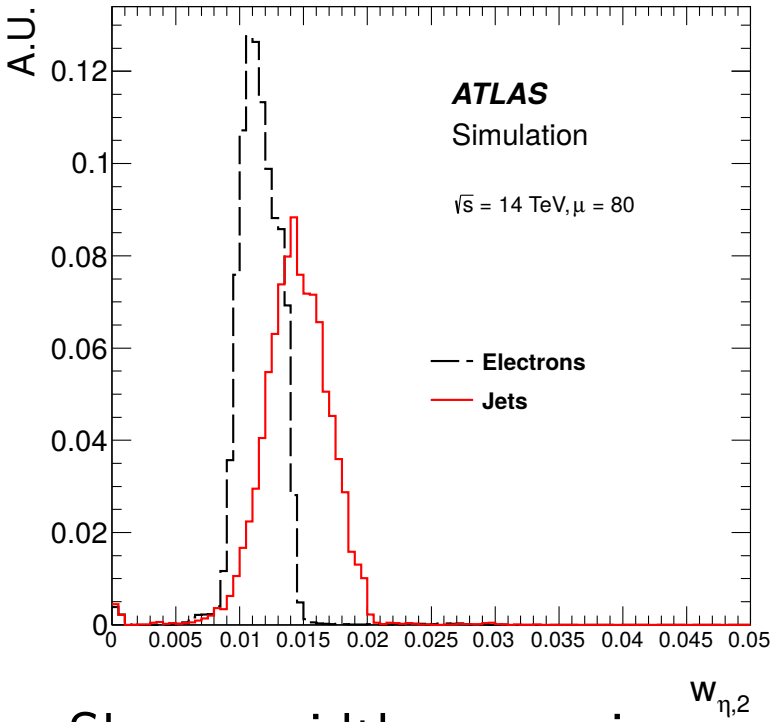
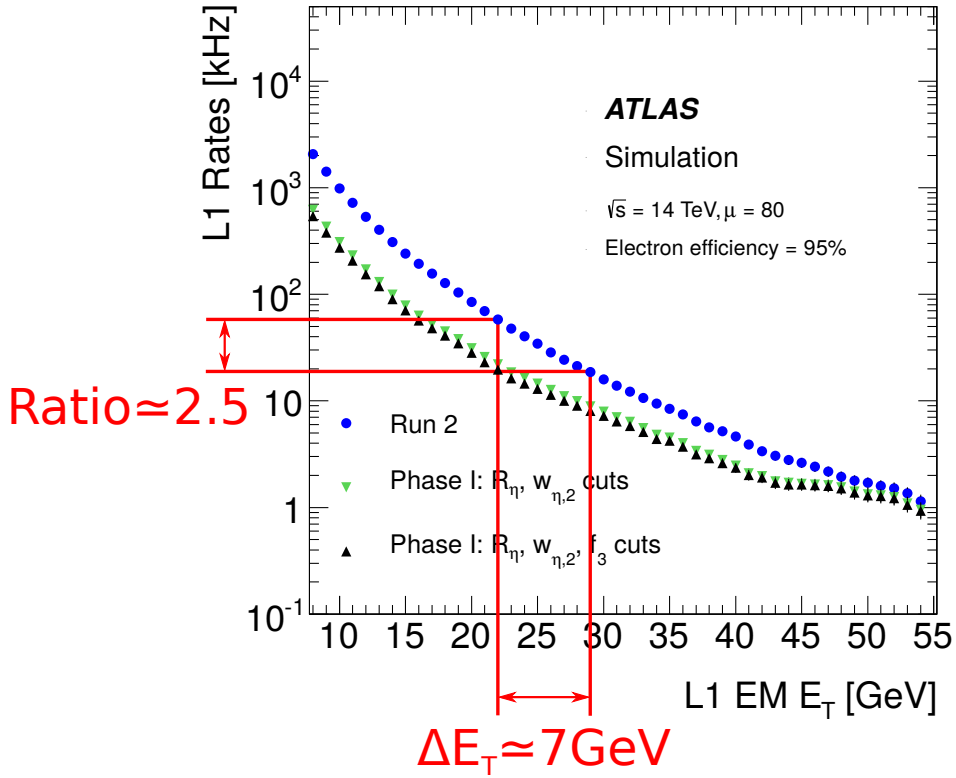


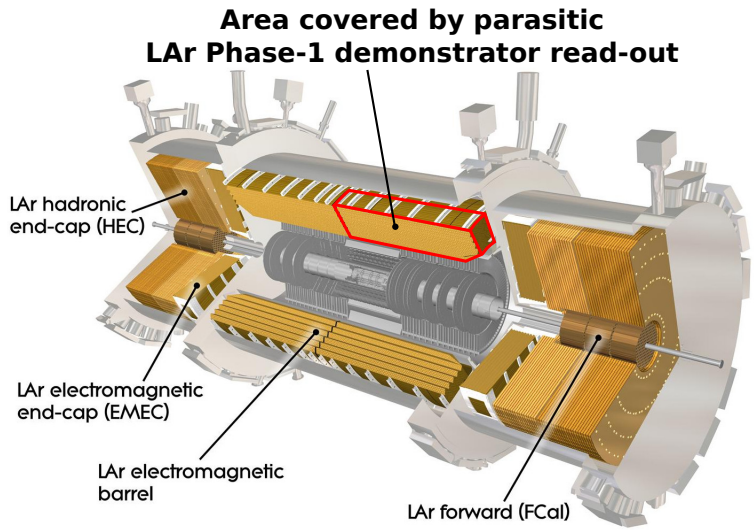
Shower width comparison

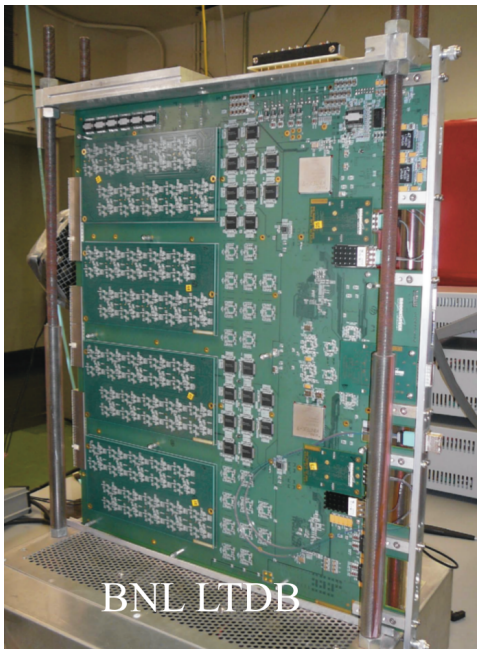


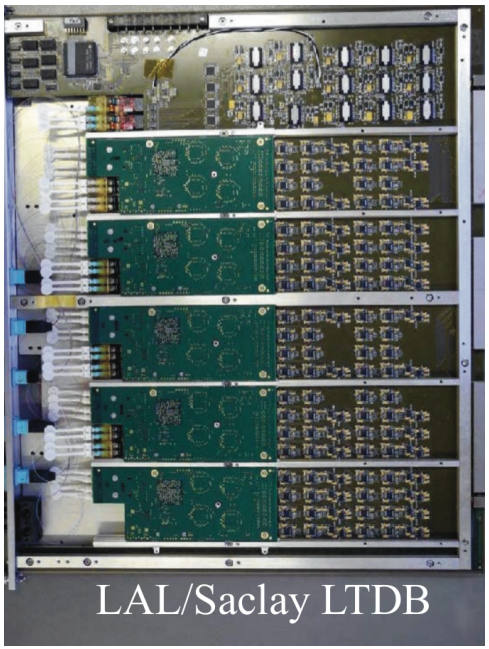
Figures from ATLAS LAr Phase-1 Upgrade TDR

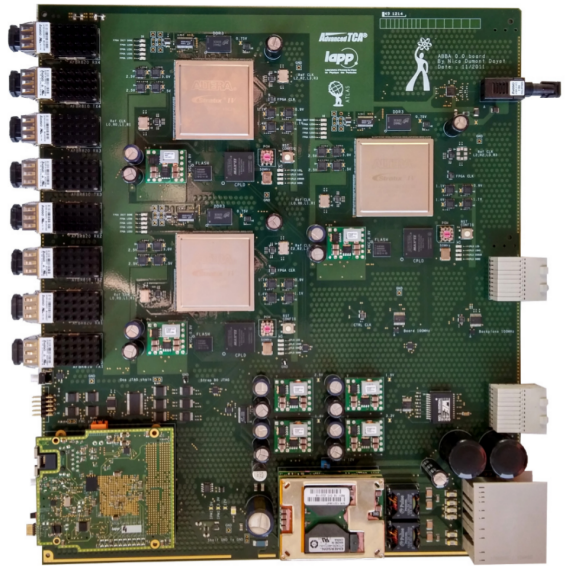
Demonstrator for LAr Phase-1 upgrade electronics

- In-situ demonstrator installed in ATLAS
  - Available since July 2014
  - Part of LAr barrel, covering a region of $9\pi/16 < \varphi < 11\pi/16$ and $0 < \eta < 1.52$
  - Allows to collect data and validate energy reconstruction under LHC conditions
- Pre-prototype of Phase-1 electronics



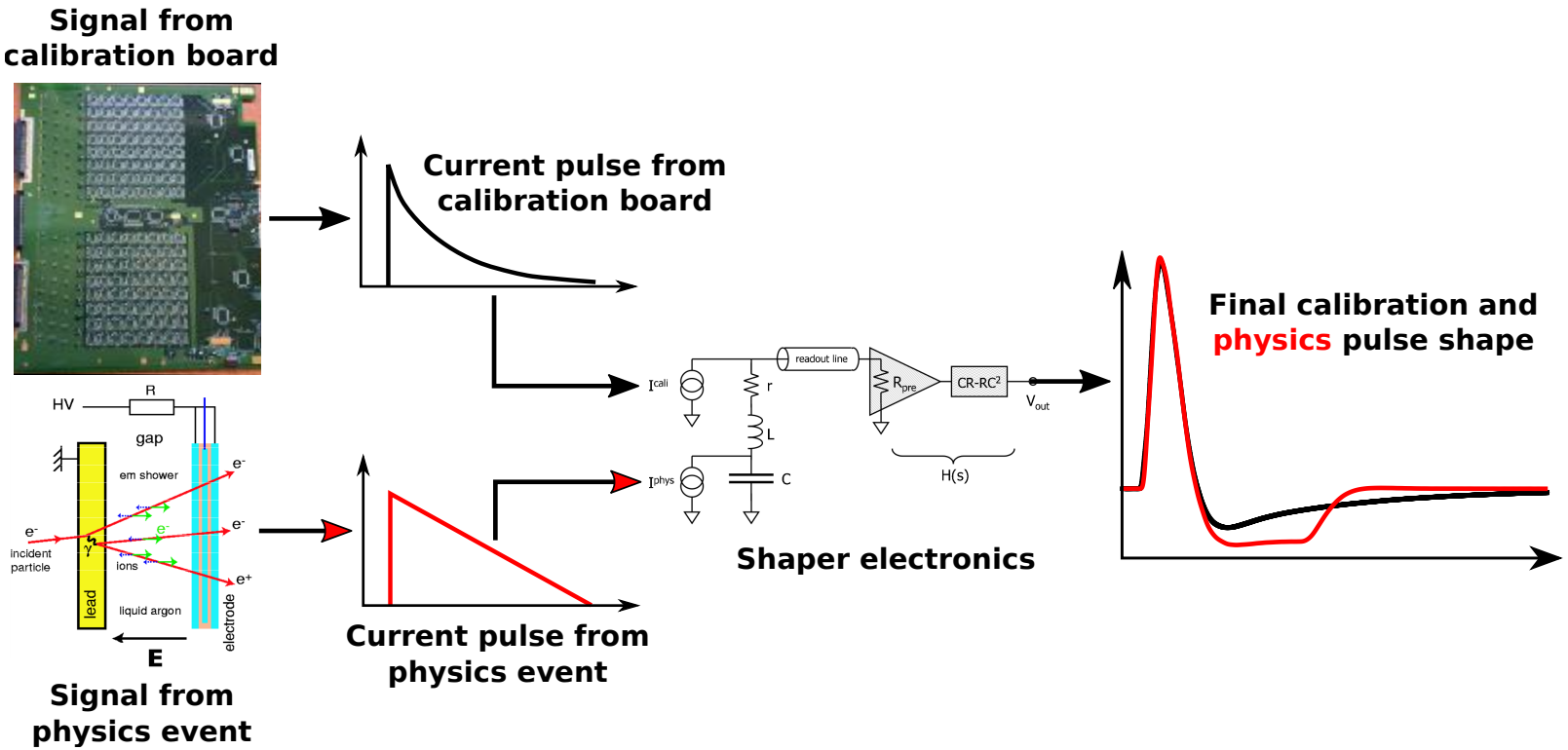

BNL LTDB


LAL/Saclay LTDB


ABBA board

Calibration electronics of the LAr detector

- Need to calibrate demonstrator system before further data analysis
  - Cell energy unknown $\rightarrow$ need $\mathrm{ADC} \rightarrow \mathrm{MeV}$ conversion



- Can inject known signals with calibration board
  - Allow to derive $\mathrm{ADC} \rightarrow \mathrm{MeV}$ conversion factor
  - Need correction due to different pulse shape of physics signals

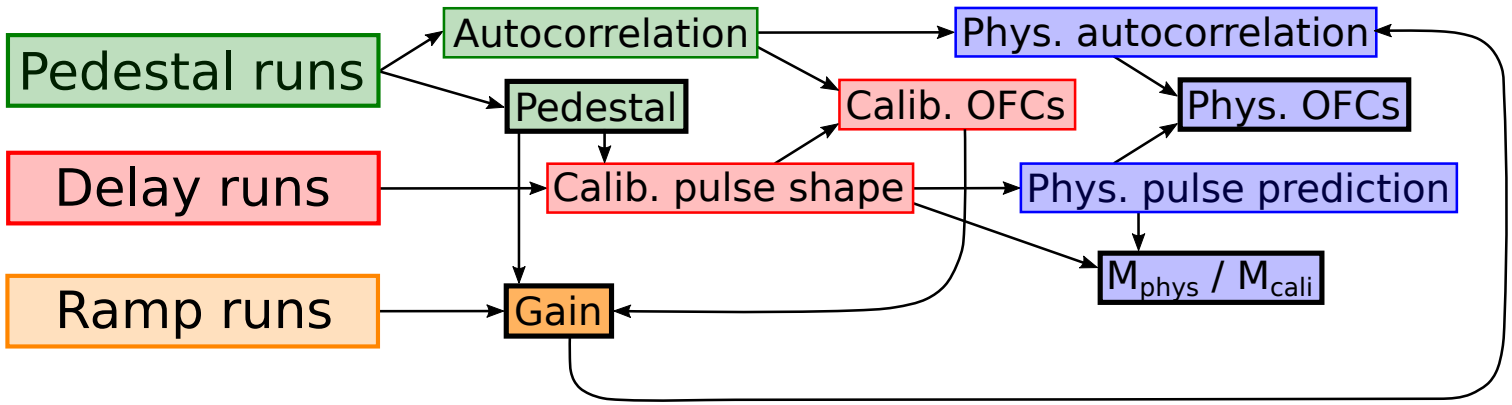
Calibration procedure

- Calibration carried out by performing three types of runs
  - Pedestal runs obtain baseline ADC value and noise autocorrelation
  - Delay runs allow precise sampling of pulse shape
  - Ramp runs relate ADC counts to an injected current
- Runs are encoded in so-called pulsing patterns ($\rightarrow$ next slide)

Pulse samples — Optimal filtering coefficients (OFCs)

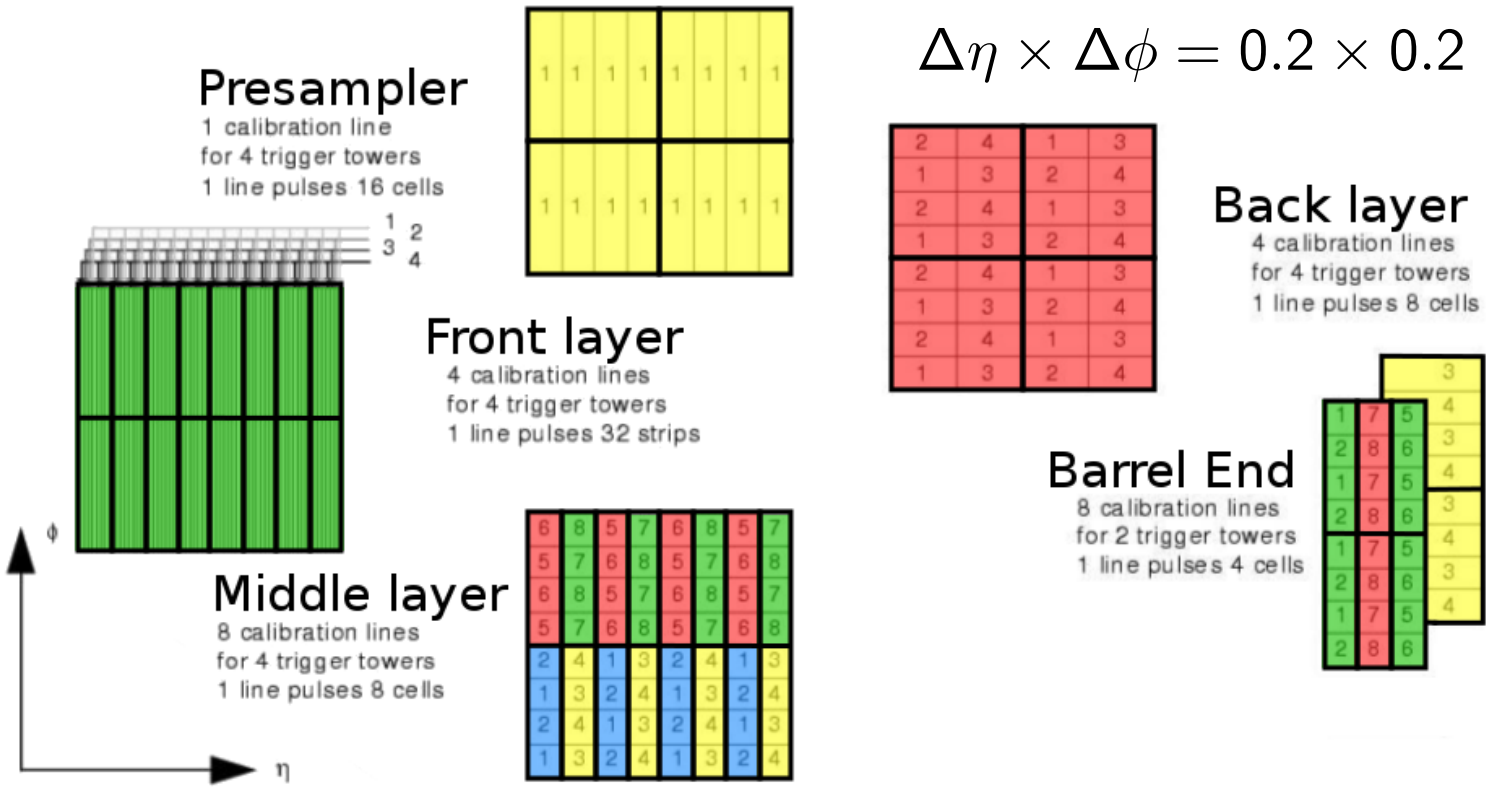
$$E_{\text{cell}} = \left(\sum_{i}^{N_{\text{samples}}} (s_i - p)\, a_i \right) \cdot G_1 \cdot \left(\frac{M_{\text{phys}}}{M_{\text{cali}}} \right)^{-1} \cdot F_{\text{DAC}\rightarrow\mu\text{A}} F_{\mu\text{A}\rightarrow\text{MeV}}$$

Energy — Pedestals — ADC to DAC — Sampling fraction — Calibration board



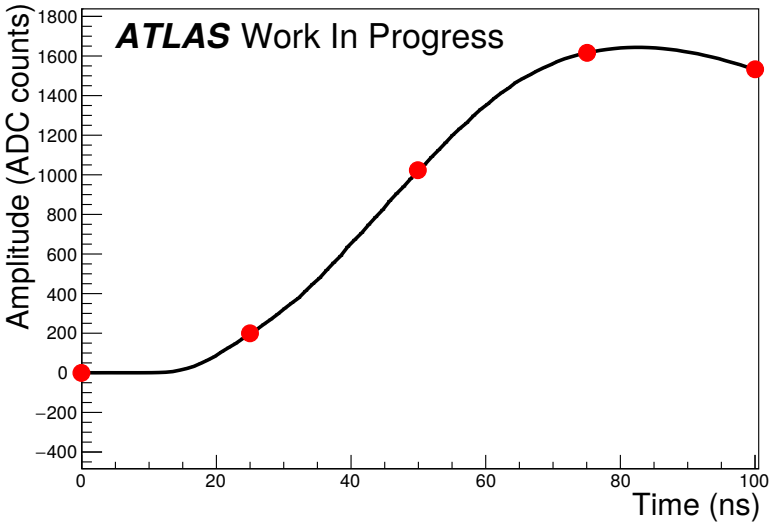
Calibration patterns

- Developed special pulsing pattern for supercells
  - General calibration cabling scheme developed for cells (i.e. do not want to pulse nearby cells to measure the cross-talk)
  - Need to pulse all cells in supercell at the same time
  - Trying to minimize impact of cross-talk between supercells

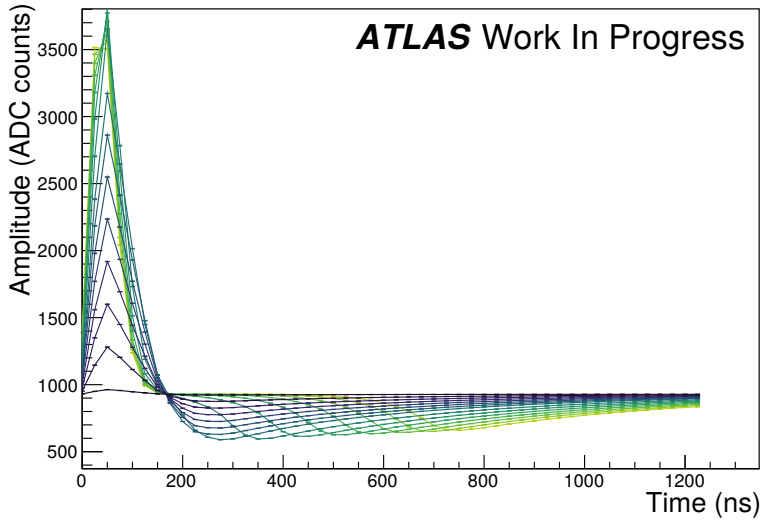


Demonstrator calibration

- Calibration data-taking
  - Measured the data mostly "by-hand" at CERN
  - Need to ensure good data quality to be able to calibrate all SCs
- Calculation of calibration coefficients
  - Processing of data done within Athena framework of ATLAS



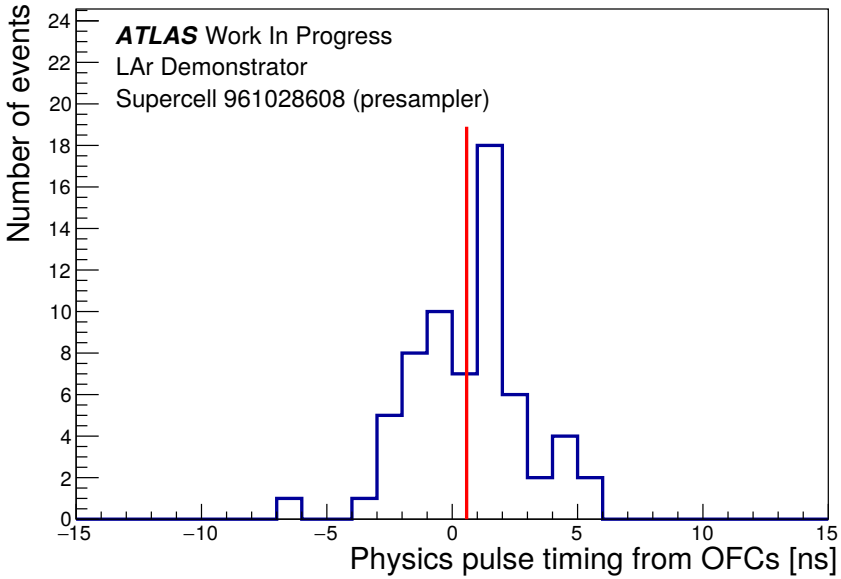
Calibration pulse shape with example of measurements



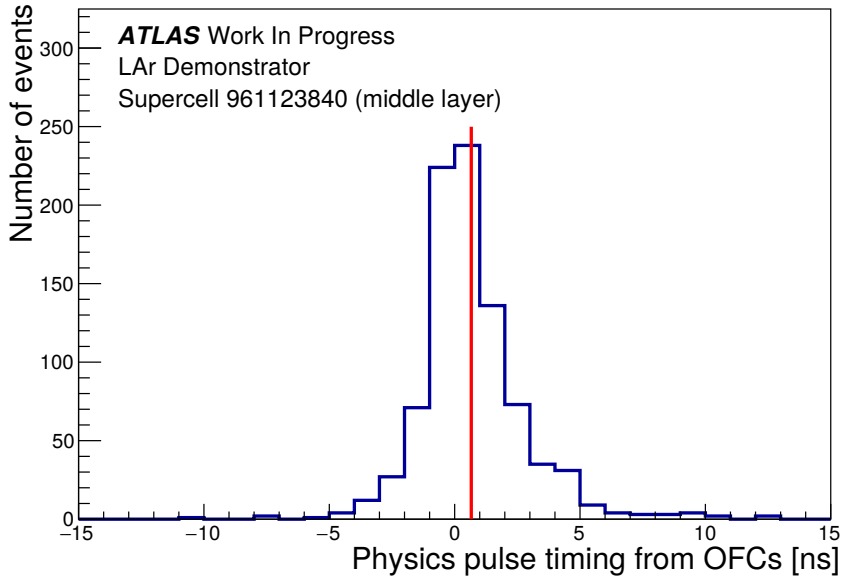
Pulse shapes with increasing amplitude from a ramp run

Timing alignment

- Crucial for trigger: Provide right timing for event consistent with the LHC bunch crossing (every 25 ns)
- Timing with respect to reference calculatued using OFCs a_i and b_i: $A = (\sum_i^{N_{\text{samples}}}(s_i - p)a_i)$ and $At = (\sum_i^{N_{\text{samples}}}(s_i - p)b_i)$
- Final timing distribution well aligned when using proper reference
  - Width small enough to identify bunch-crossing



Presampler example



Middle layer example

Energy correlation

- Comparison done between E_{SC} and $\sum_{\mathrm{SC}} E_{\mathrm{cells}}$
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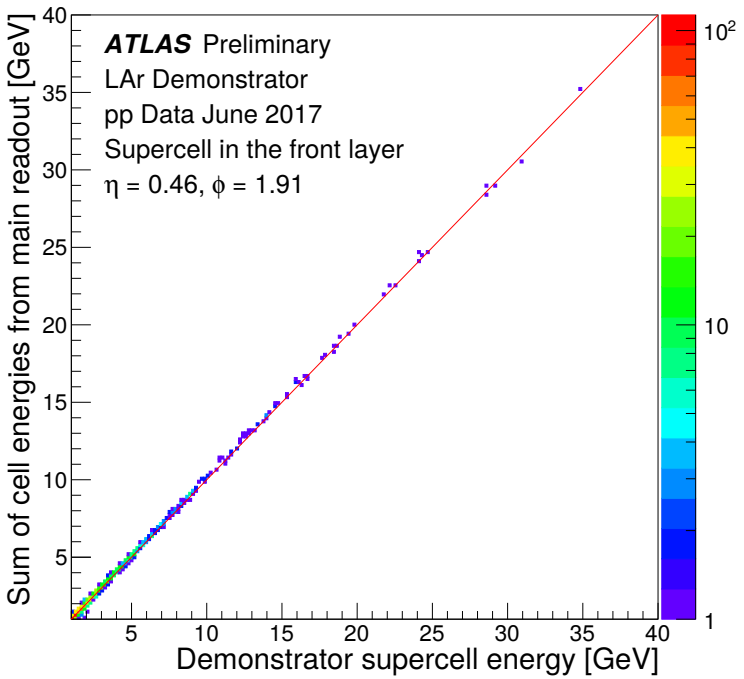
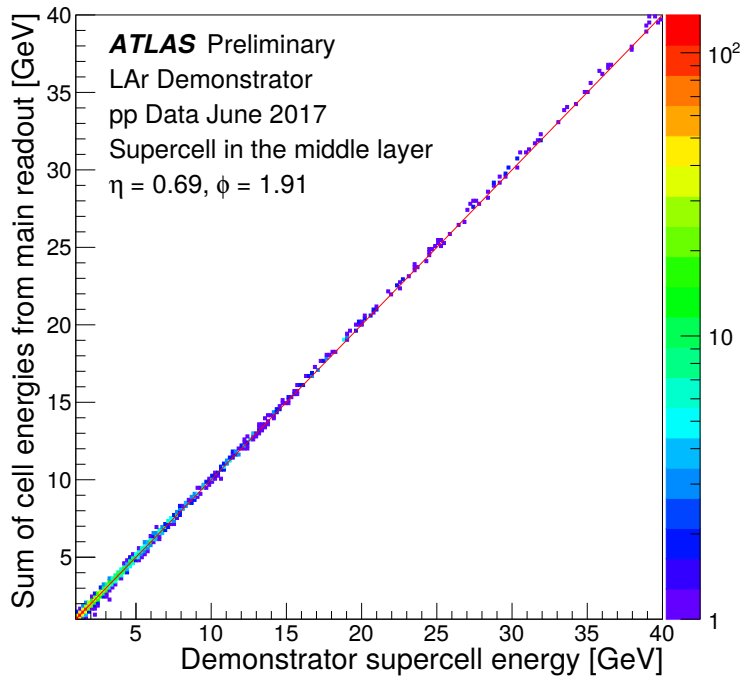
- Good agreement of my calibration with main readout can be observed
  - Perfectly sufficient for trigger purposes



Front layer

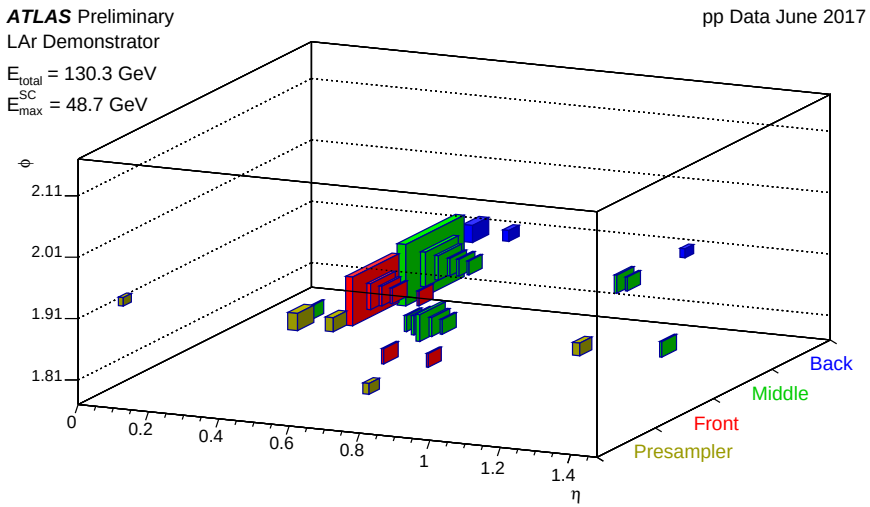


Middle layer

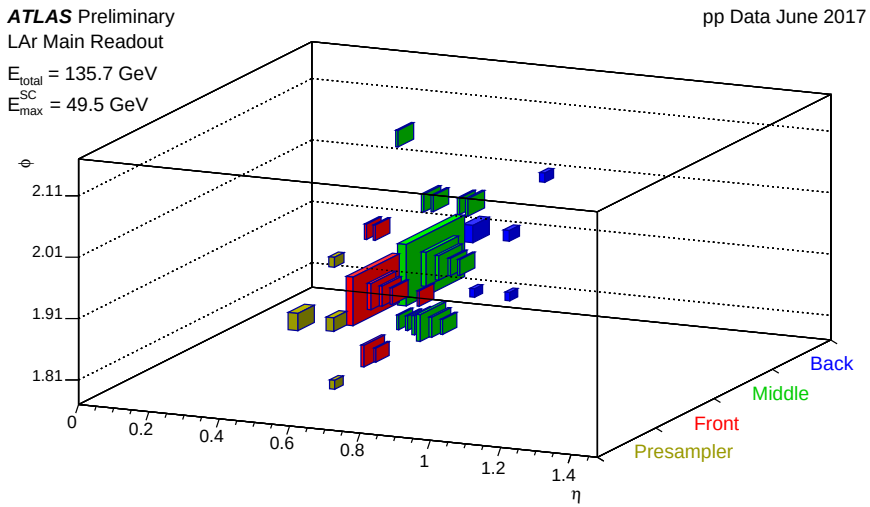
Figures from summary page for LAr Phase-1 Upgrade public plots

Event displays

- Demonstrator physics data collected in parallel to LAr main read-out
  - Can compare with summed main read-out cells → dummy supercells
  - Event displays allow to visualise shower development
- Highest supercell energy in event, $E_{\mathrm{max}}^{\mathrm{SC}}$, typically within $\sim 5\%$
- Total plotted energy, E_{total}, typically within $\sim 10\%$



Demonstrator read-out



Main read-out "supercells"

Figures from summary page for LAr Phase-1 Upgrade public plots

Search for dilepton resonances

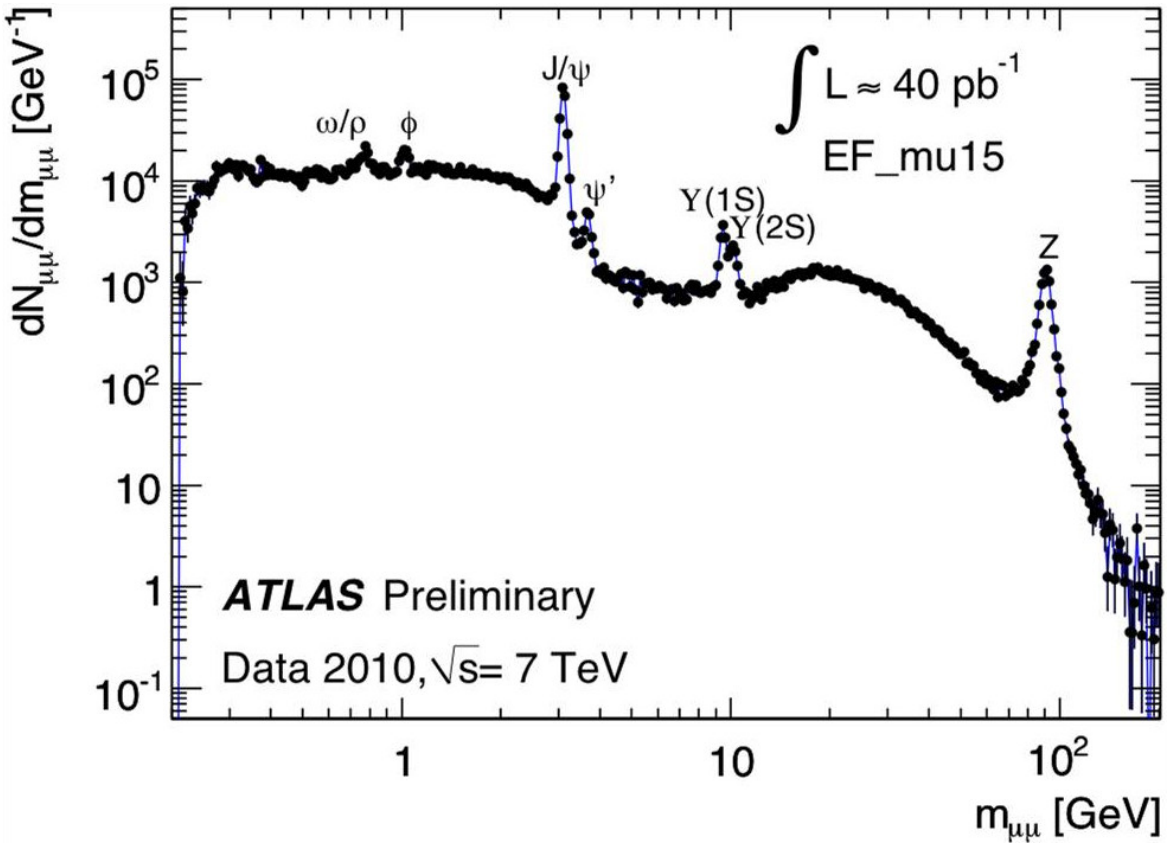
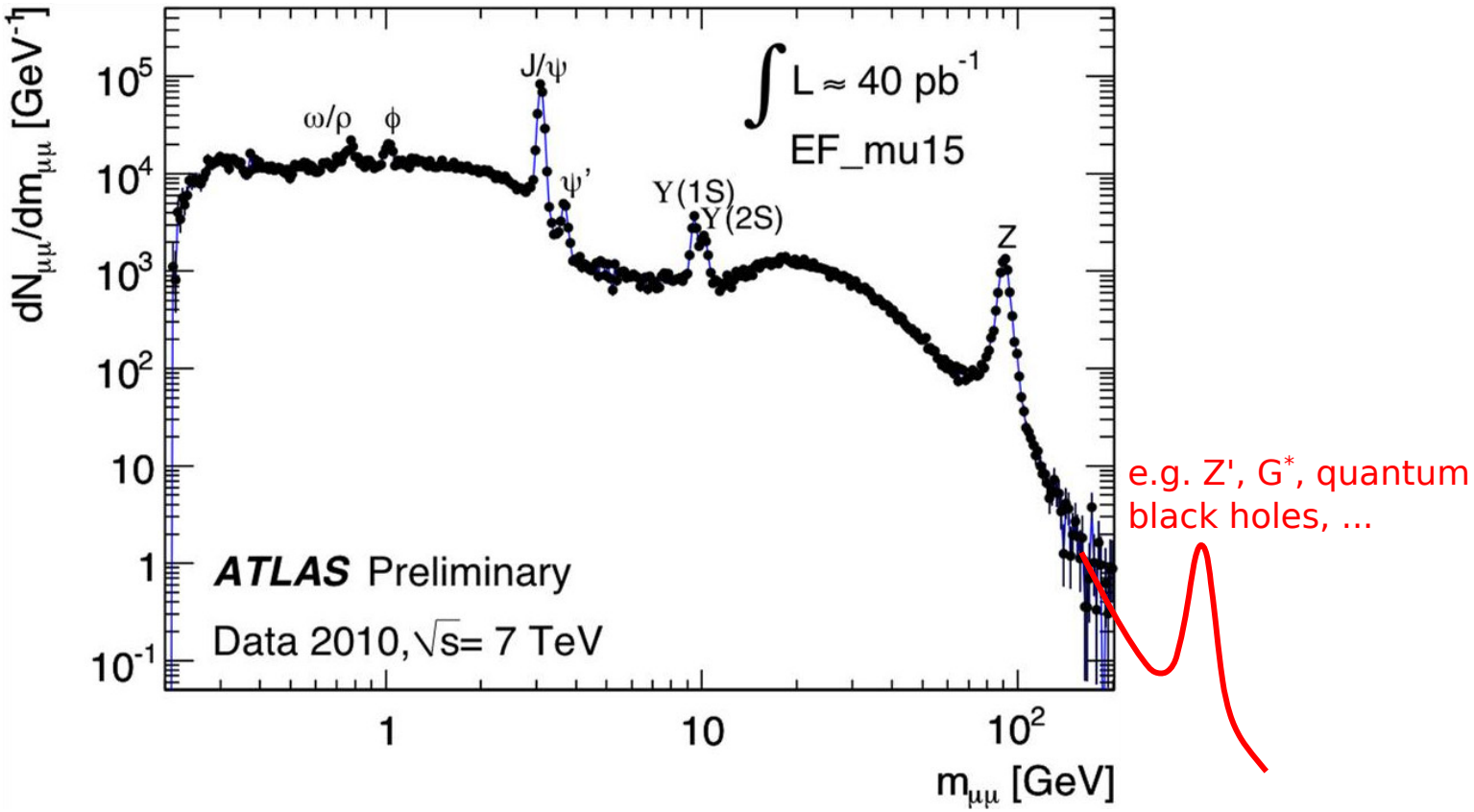


Figure from ATLAS Preliminary Figures from 2010 Collision Data at 7 TeV

New energy frontiers unveiled new resonances in dileptons (e.g. J/ψ, Z)

New phenomena could be hiding...



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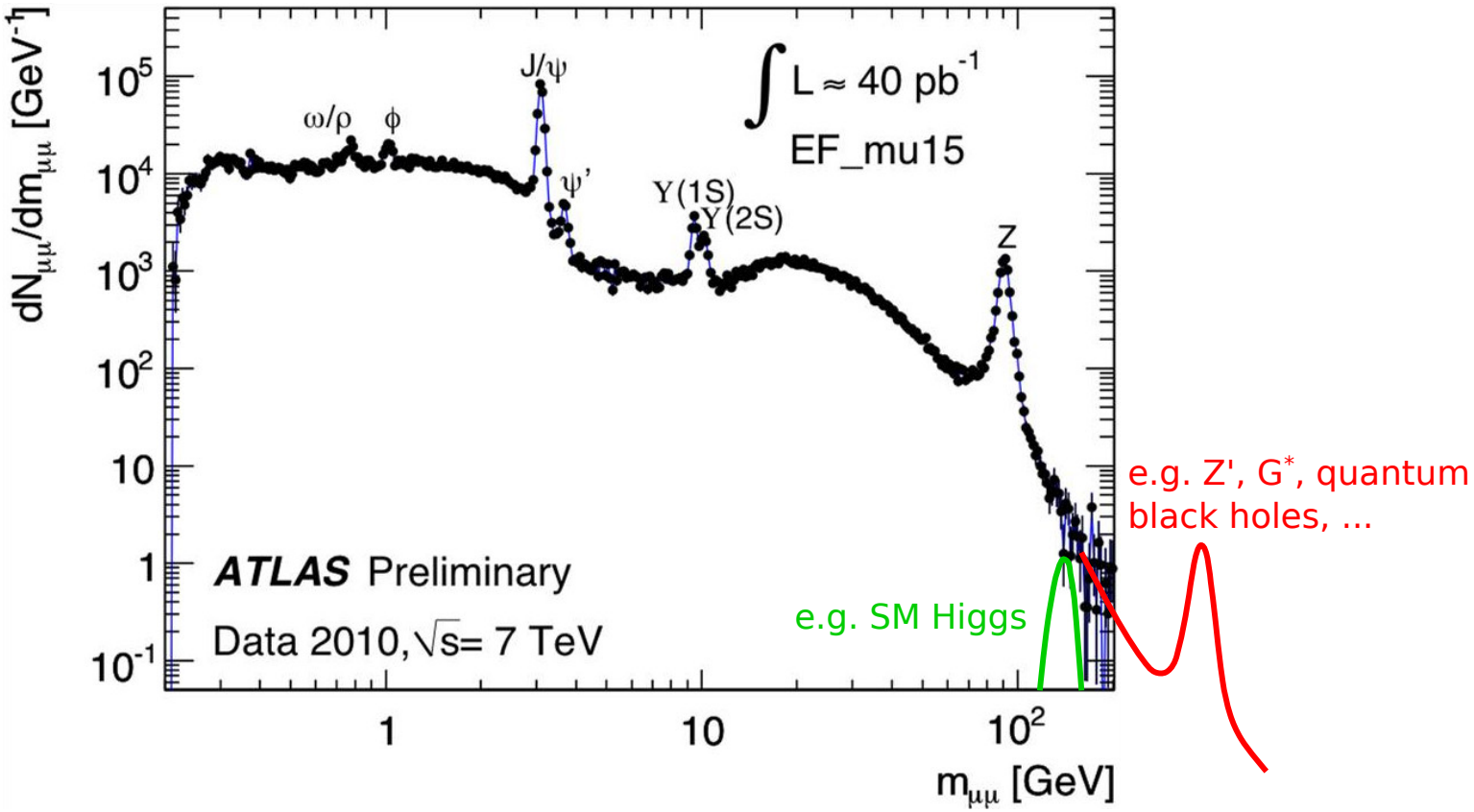

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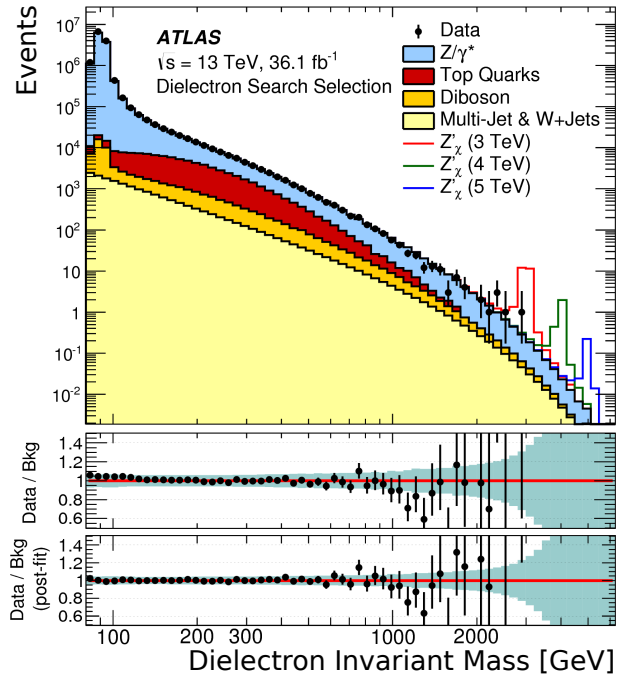
New energy frontiers unveiled new resonances in dileptons (e.g. J/ψ, Z)

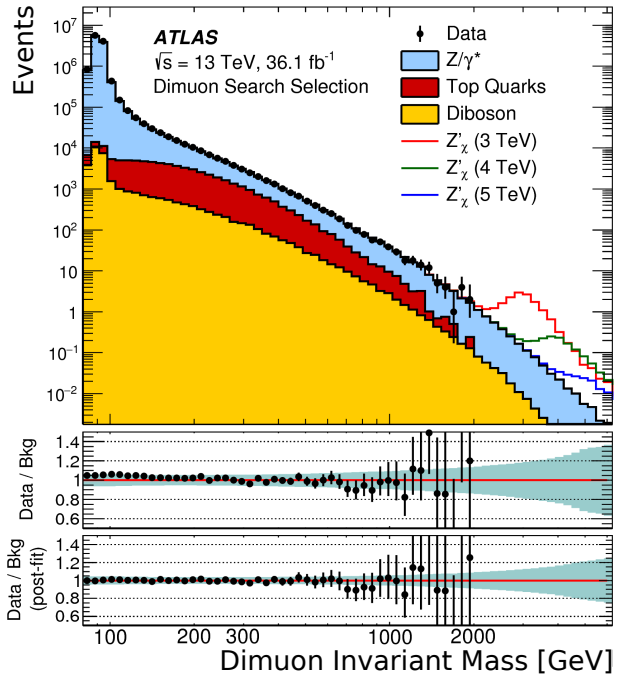
New phenomena could be hiding at higher masses or lower cross-sections

Search for dilepton resonances

- Part of the ATLAS exotics program
  - Fast search for an excess above the DY-dominated spectrum
- Inclusive selection to keep independent of model
  - $\geq$ 2 same flavour charged leptons with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and loose isolation
  - Only in muon case opposite charge required



Dielectron mass spectrum



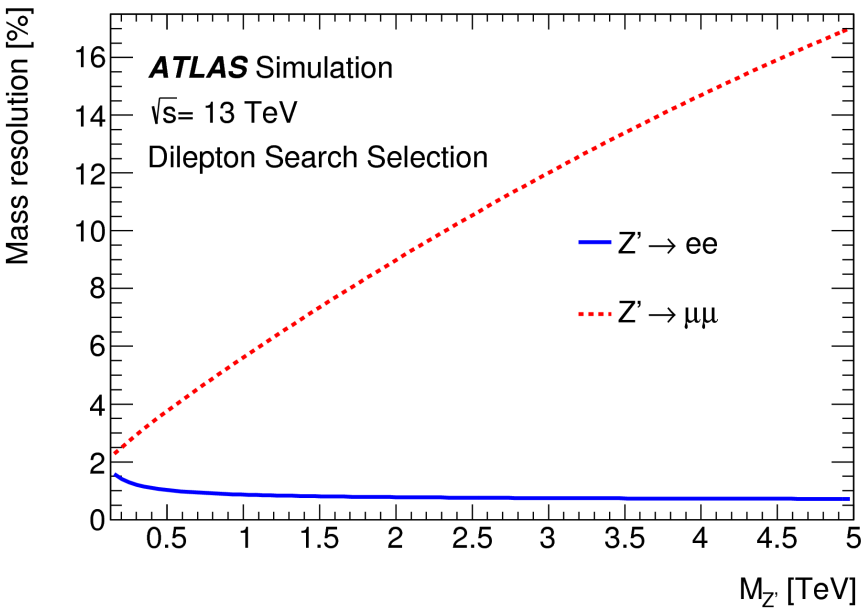
Dimuon mass spectrum

Figures from JHEP 10 (2017) 182

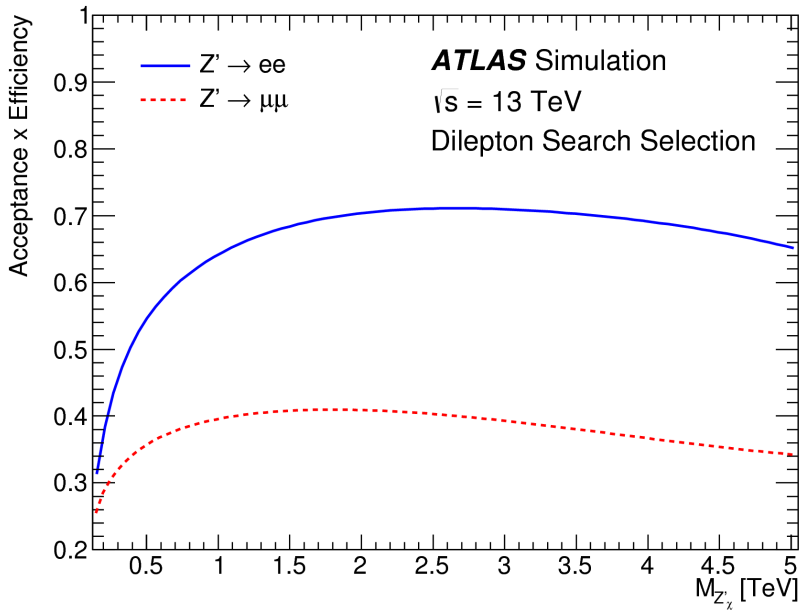
- Backgrounds: Drell-Yan (Z/γ^*), $t\bar{t}$, dibosons and QCD/W+jets
  - Diphoton background contribution estimated to be negligible

Channel comparison

- Electron channel yields stronger limits than muon channel because of
  - Better mass resolution
  - Higher acceptance and efficiency



Obtained mass resolution

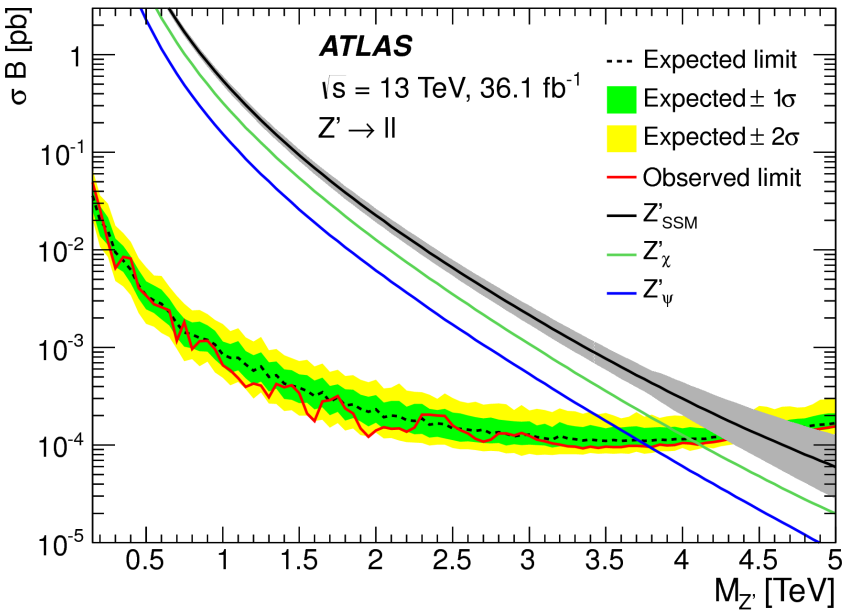


Final acceptance × efficiency curve

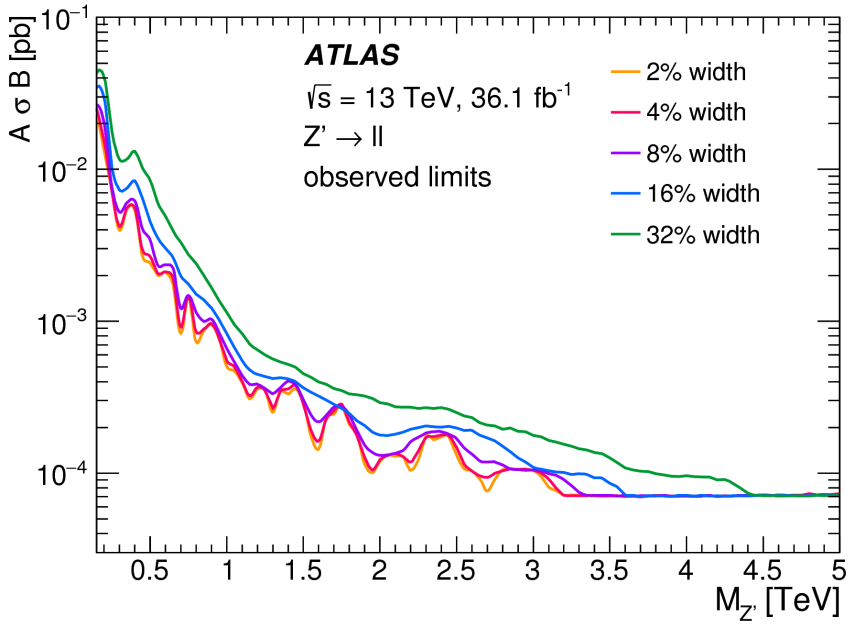
Figures from JHEP 10 (2017) 182

Theoretical motivation and obtained limits

- Various models predict new dilepton resonances
  - Z'_{SSM} has the same properties as the Z boson, but higher mass
  - More physical models e.g. E_6 symmetries in grand unified theories
  - Results can be reinterpreted into Gravitons, black holes, dark matter, ...
- Analysis using $36.1\,\mathrm{fb}^{-1}$ excluded Z'_{SSM} until pole-mass of $4.5\,\mathrm{TeV}$
  - Paper published in JHEP (JHEP 10 (2017) 182)
  - Previous ATLAS result: $4.05\,\mathrm{TeV}$ (using $13.3\,\mathrm{fb}^{-1}$, cp. here)
  - Most recent CMS result: $4.0\,\mathrm{TeV}$ (using $13.0\,\mathrm{fb}^{-1}$, cp. here)



Obtained cross-section limits



Observed generic limit

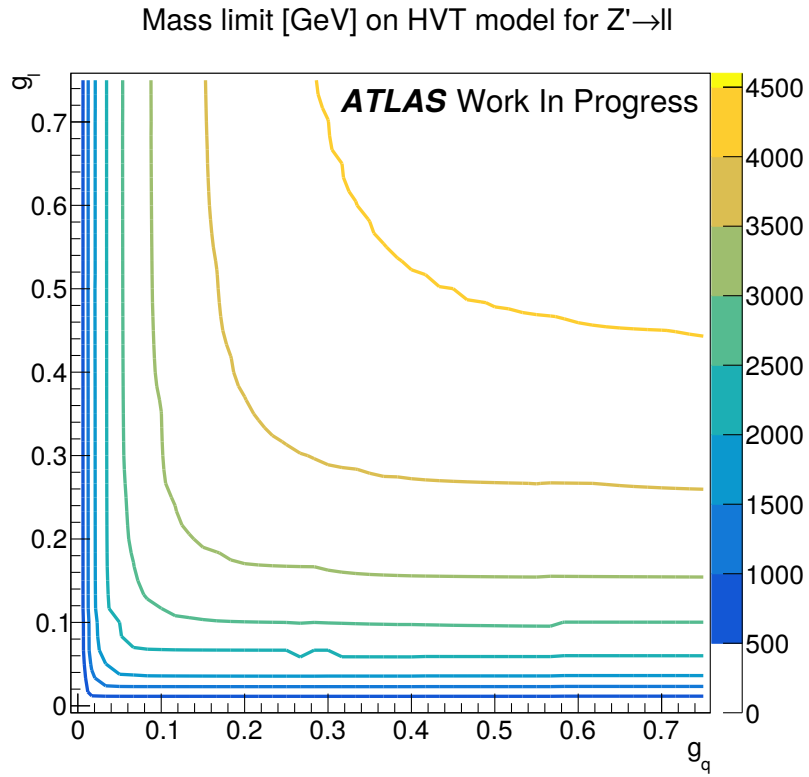
Figures from JHEP 10 (2017) 182

Reinterpretation in heavy vector triplet model

- W'/Z' heavy vector triplet (HVT)
  - g_l and g_q are the couplings to leptons and quarks
  - Coupling to Higgs field described by g_ϕ
  - Allows to compare to other channels such as dibosons, $\tau\tau$, $l\nu$
- Used generic limits to calculate Z'-only results in HVT model

$$\mathcal{L}_{\mathcal{W}} = -\frac{1}{2}[D_\mu \mathcal{W}_\nu]^a[D^\mu \mathcal{W}^\nu]_a + \frac{1}{2}[D_\mu \mathcal{W}_\nu]^a[D^\nu \mathcal{W}^\mu]_a + \frac{\mu^2}{2}\mathcal{W}_\mu^a \mathcal{W}_a^\mu$$
$$+ g_2 \mathcal{W}_\mu^a \mathcal{W}_a^\mu \phi^\dagger \phi - g_l \mathcal{W}_a^\mu \bar{l}_i \gamma_\mu \frac{\sigma^a}{2} l_i - g_q \mathcal{W}_a^\mu \bar{q}_i \gamma_\mu \frac{\sigma^a}{2} q_i$$
$$- \left(i g_\phi \mathcal{W}_a^\mu \phi^\dagger \frac{\sigma^a}{2} D_\mu \phi + \text{h.c.} \right) + \frac{1}{2} g_W \epsilon_{abc} \mathcal{W}_\mu^a \mathcal{W}_\nu^b W_{\mu\nu}^c$$

Lagrangian of HVT model



Limit plot from reinterpretation

Summary and outlook

Summary and outlook

- LAr Phase-1 upgrade demonstrator
  - Performed calibration of the system
  - Comparison with the main readout shows good agreement
  - Results available as public plots (see here)
  - New demonstrator will be installed in 2018

- Search for dilepton resonances
  - Presented analysis of 2015/16 data (JHEP 10 (2017) 182)
    $\rightarrow$ excluded Z'_{SSM} until pole-mass of $4.5\,\mathrm{TeV}$
  - Reinterpretation of ATLAS limits in HVT model

Backup

Energy correlation

- Comparison done between E_{SC} and $\sum_{\mathrm{SC}} E_{\mathrm{cells}}$
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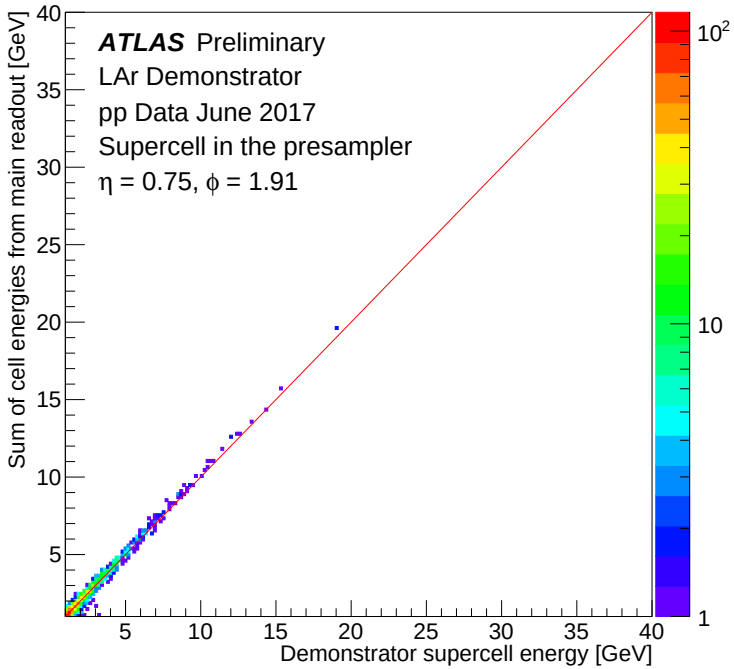
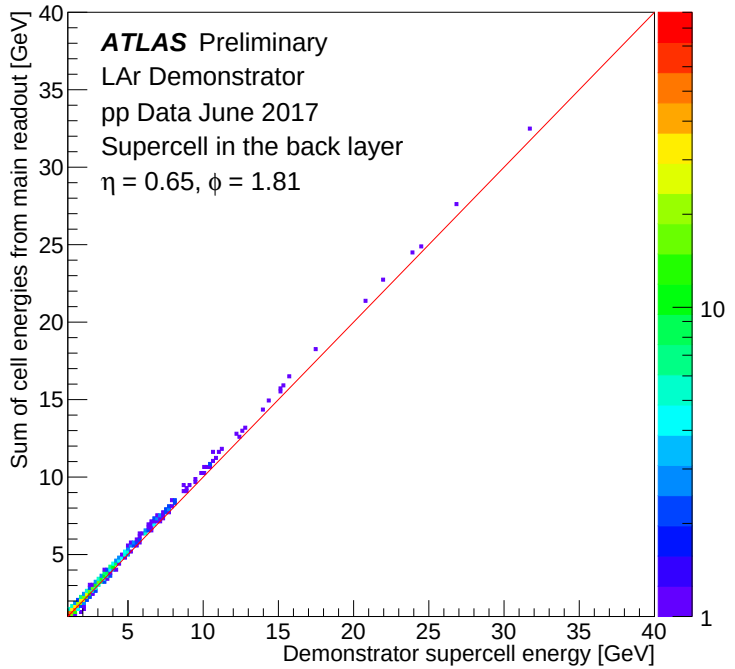


Presampler



Back layer

Figures from summary page for LAr Phase-1 Upgrade public plots