BSM Searches and Upgrades of the ATLAS experiment

Rui Wang (王睿)
Argonne National Laboratory

Seminar at IHEP
September, 2018

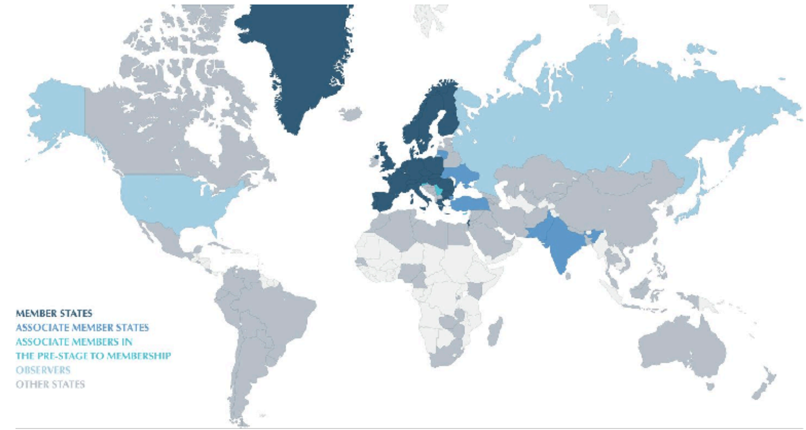
www.anl.gov

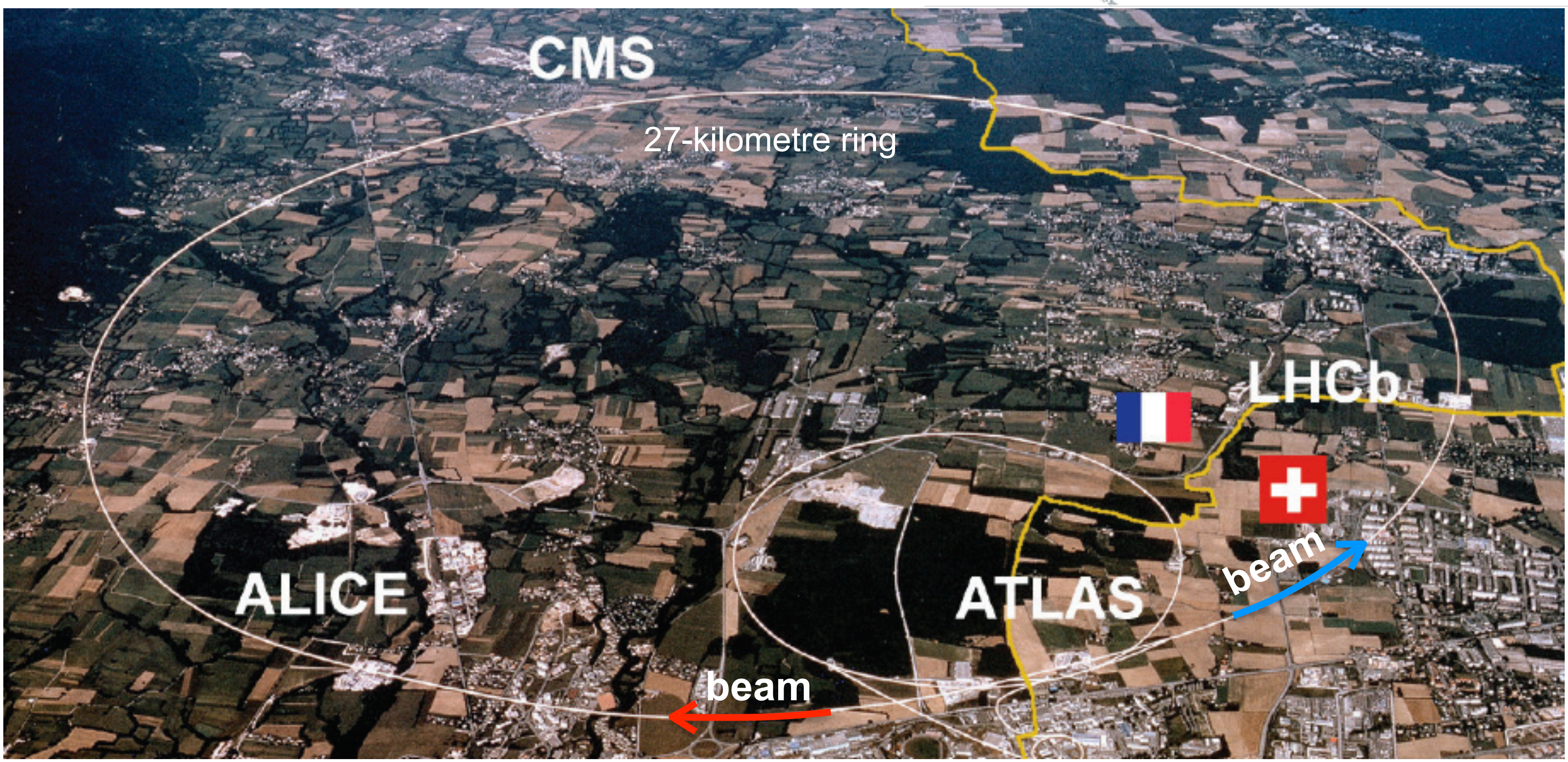
ATLAS EXPERIMENT

Argonne NATIONAL LABORATORY

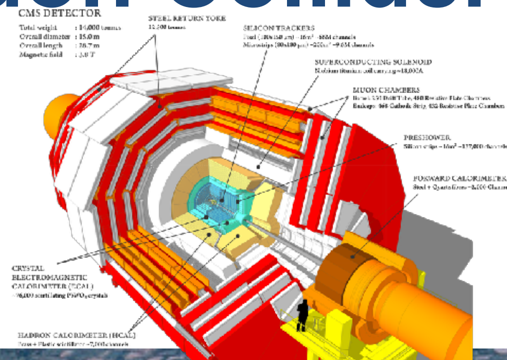
Large Hardon Collider

The world's largest and most powerful particle accelerator
First started up on 10 September 2008

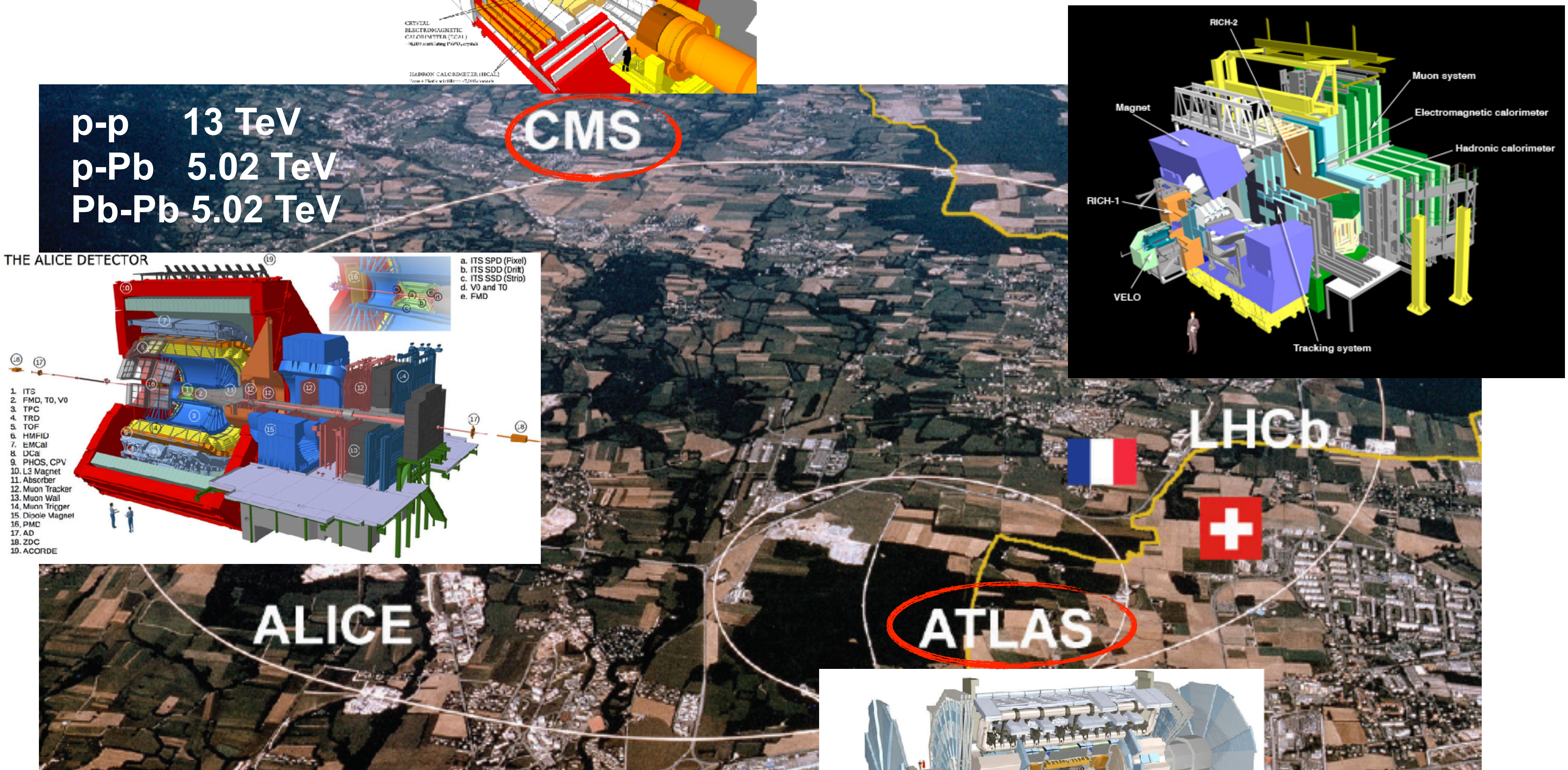


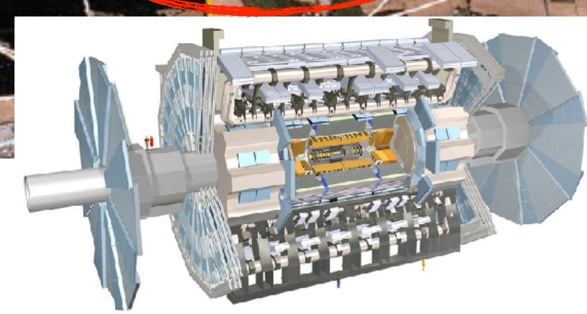


Large Hardon Collider



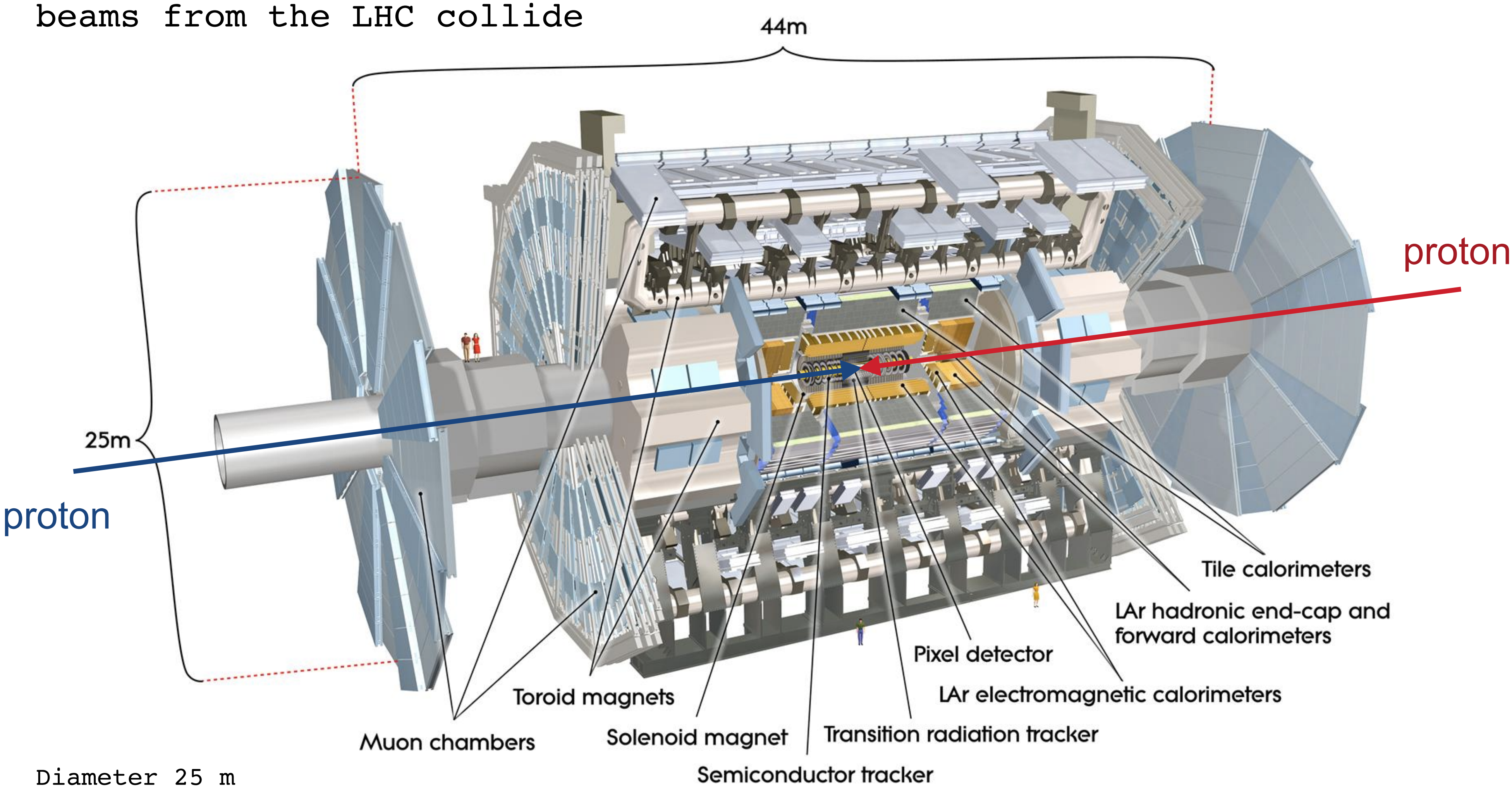
CMS & ATLAS – designed for discover new physics





A Toroidal LHC ApparatuS (ATLAS) detector

The ATLAS detector consists of a series of very large concentric cylinders and disks around the interaction point where the proton beams from the LHC collide

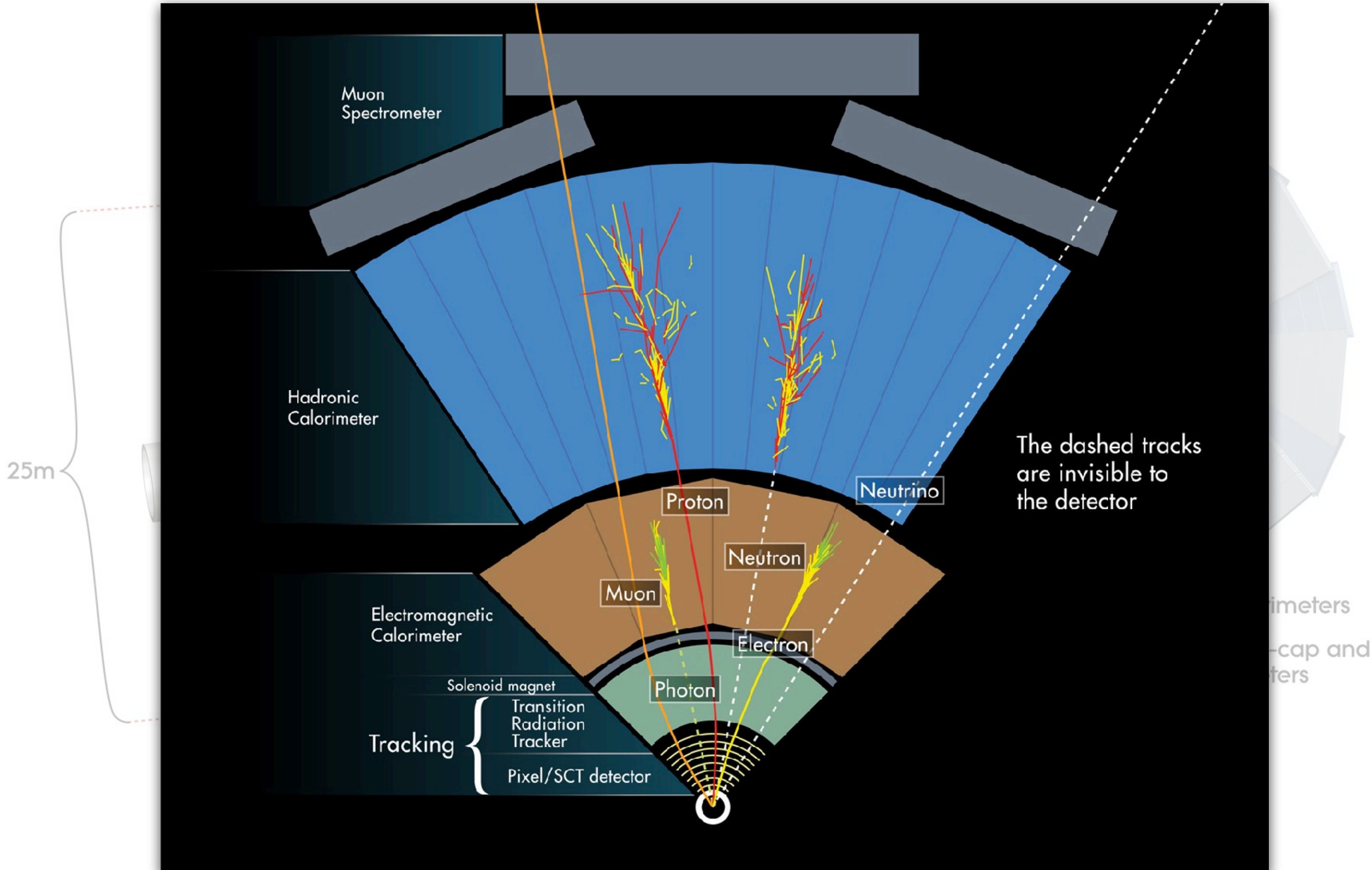


Diameter 25 m
Barrel toroid length 26 m
Toroid End-cap end-wall Chamber span 46 m
Overall weight 7000 Tons

General propers detector

A Toroidal LHC ApparatuS (ATLAS) detector

Different Particle leave signatures in different part of the detector

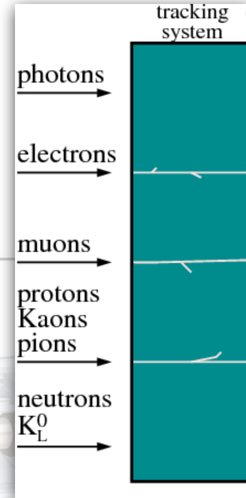


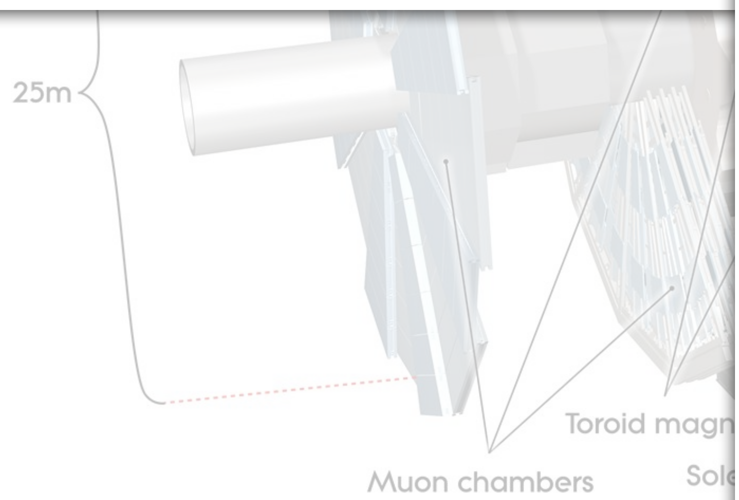
Argonne NATIONAL LABORATORY

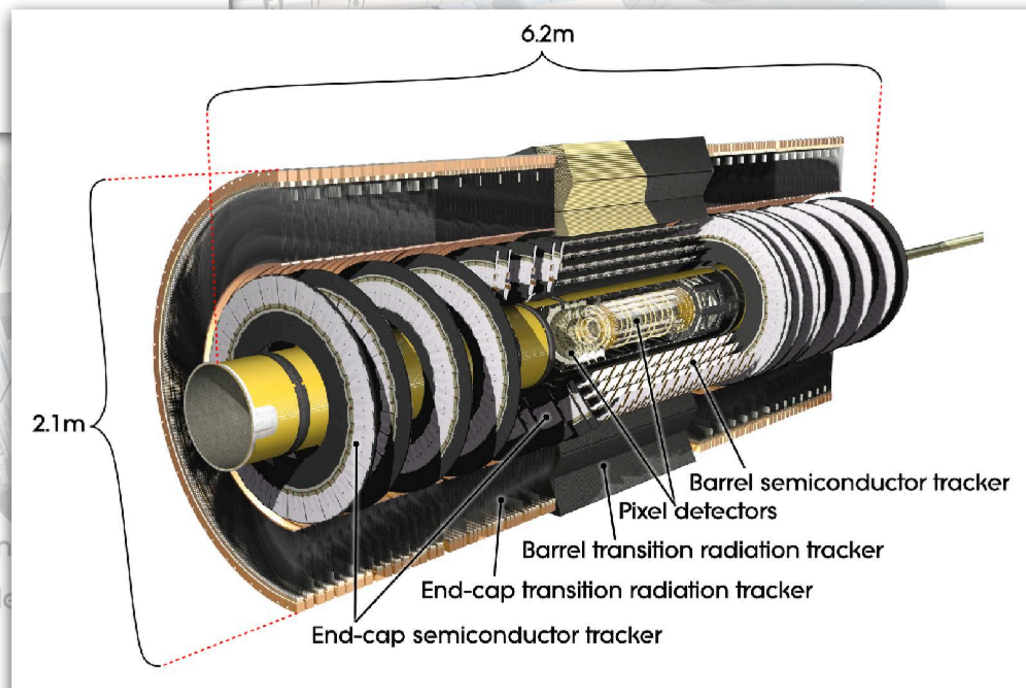
ATLAS — Inner tracker

Inner Traker (|η|<2.5, B=2T):

- Track reconstruction of charged particles
- Momentum reconstruction
- *Vertex finding*
- *b-tagging*
- *Particle identification*



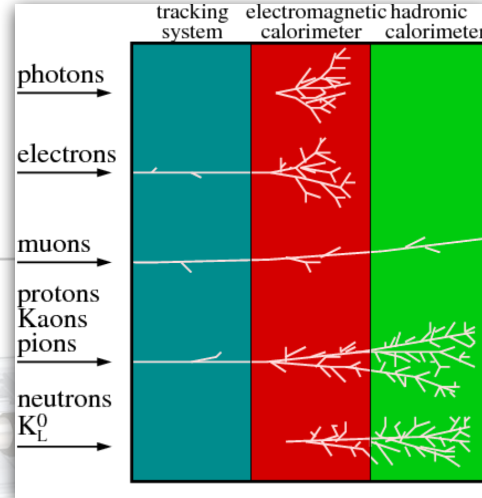


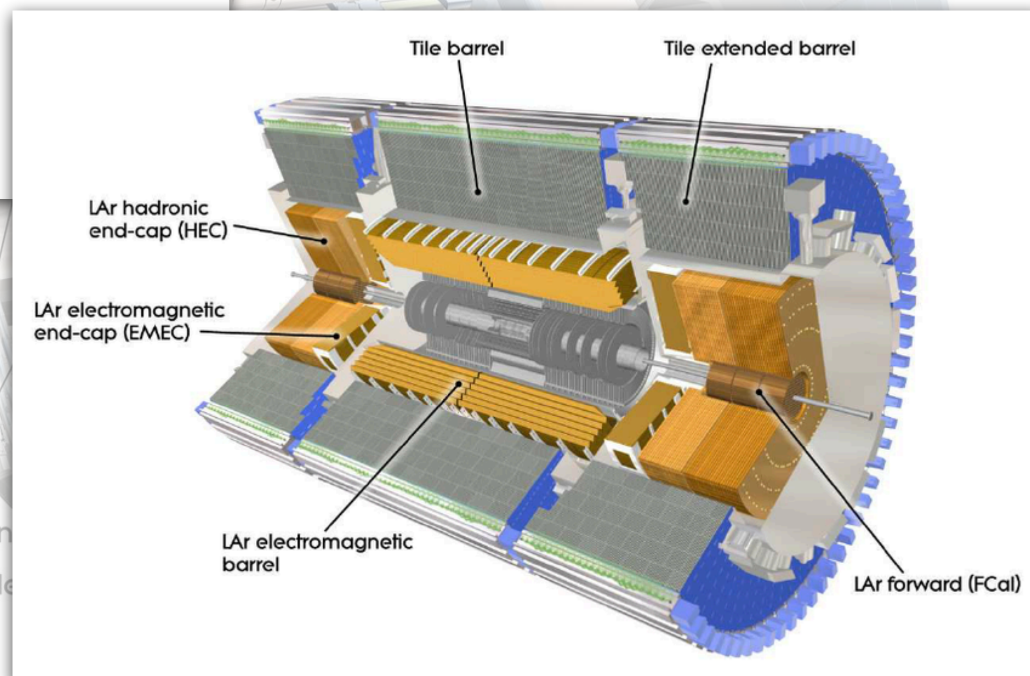


ATLAS — Calorimeter

Electromagnetic calorimeter ($|\eta|<3.2$) & Hadronic calorimeter ($|\eta|<5$):

- Energy deposition measurement
- *Photon, electron identification*
- *Photon, electron trigger*
- *Jet reconstruction*
- *Jet trigger*

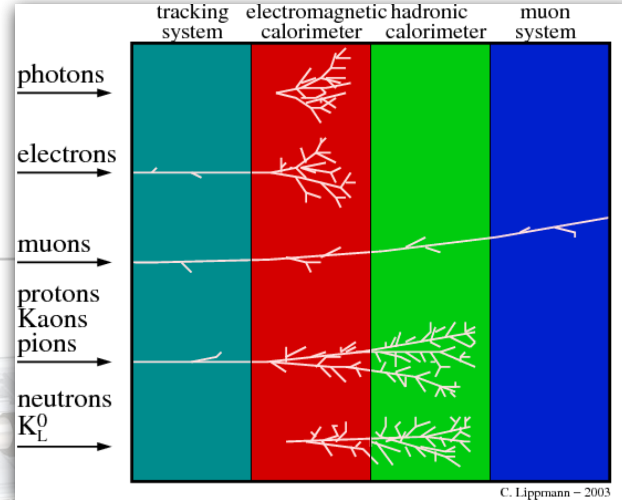


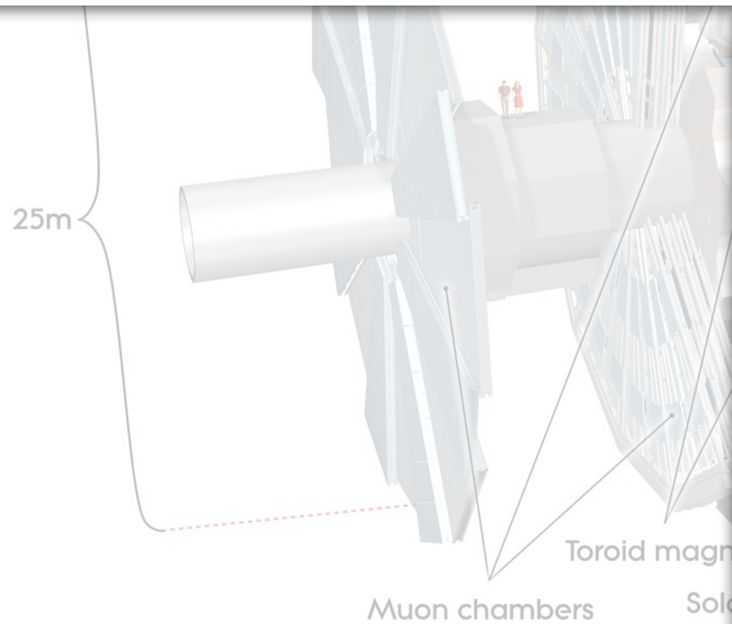


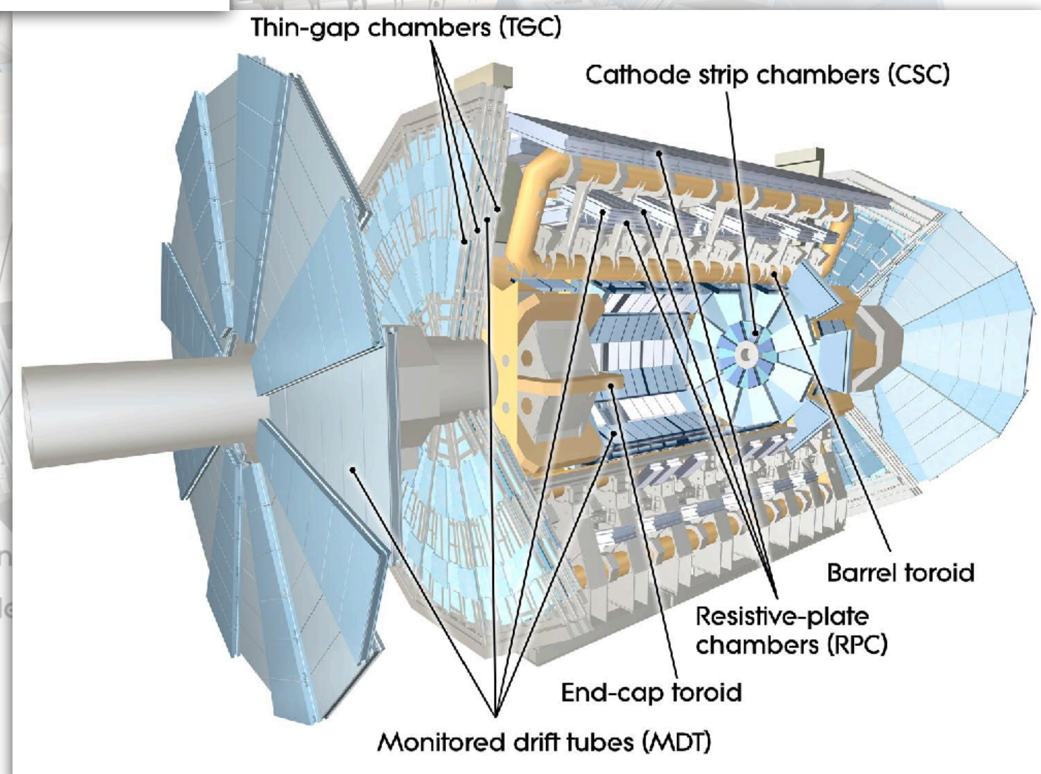
ATLAS — Muon detector

Muon Spectrometer ($|\eta|<2.7$):

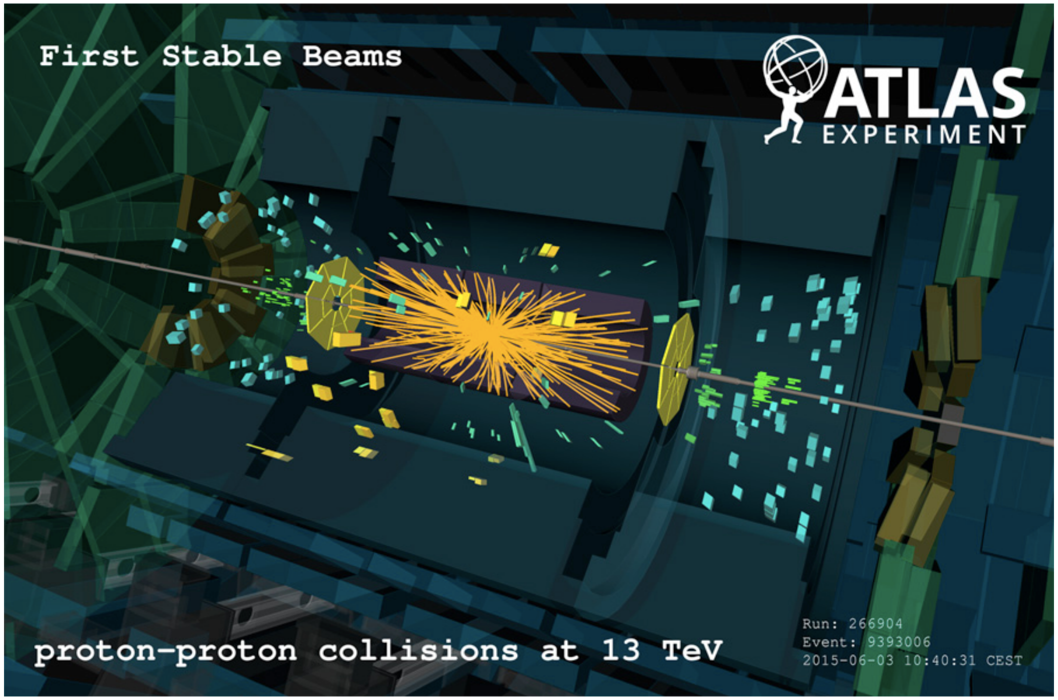
- Muon reconstruction
- Muon momentum measurement
- Muon identification
- *Muon trigger*







ATLAS TDAQ



40 MHz

Level 1

100 kHz

HLT

~1000 Hz

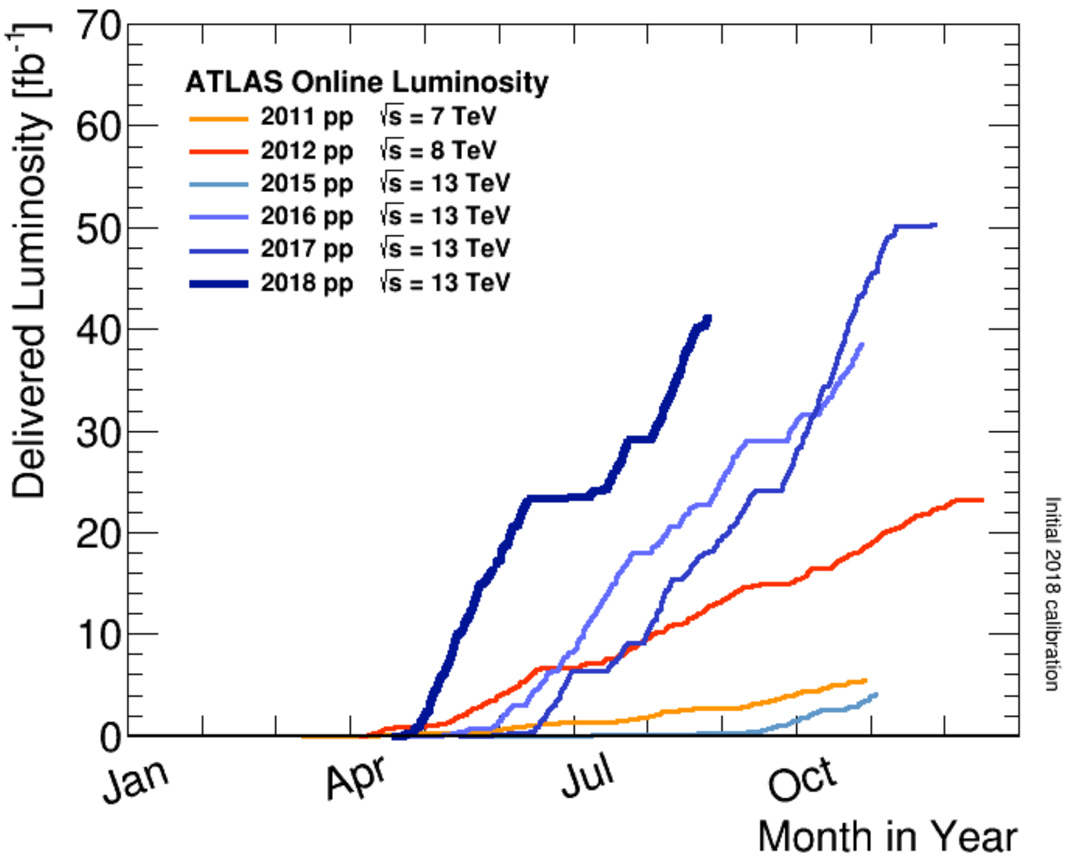
http://phdcomics.com/

Level 1 — Hardware based Level 1 trigger

HLT — Software-based High Level Trigger

Data taking

Excellent data taking efficiency and quality



> 100 fb^{-1} delivered and recorded at 13 TeV

Run 2 (13 TeV) recorded

- 2018: 39.1 fb^{-1} (96.6%)
- 2017: 46.8 fb^{-1} (93.6%)
- 2016: 35.9 fb^{-1} (93-95%)
- 2015: 3.7 fb^{-1} (87.1%)

Run 1 (7-8 TeV) recorded

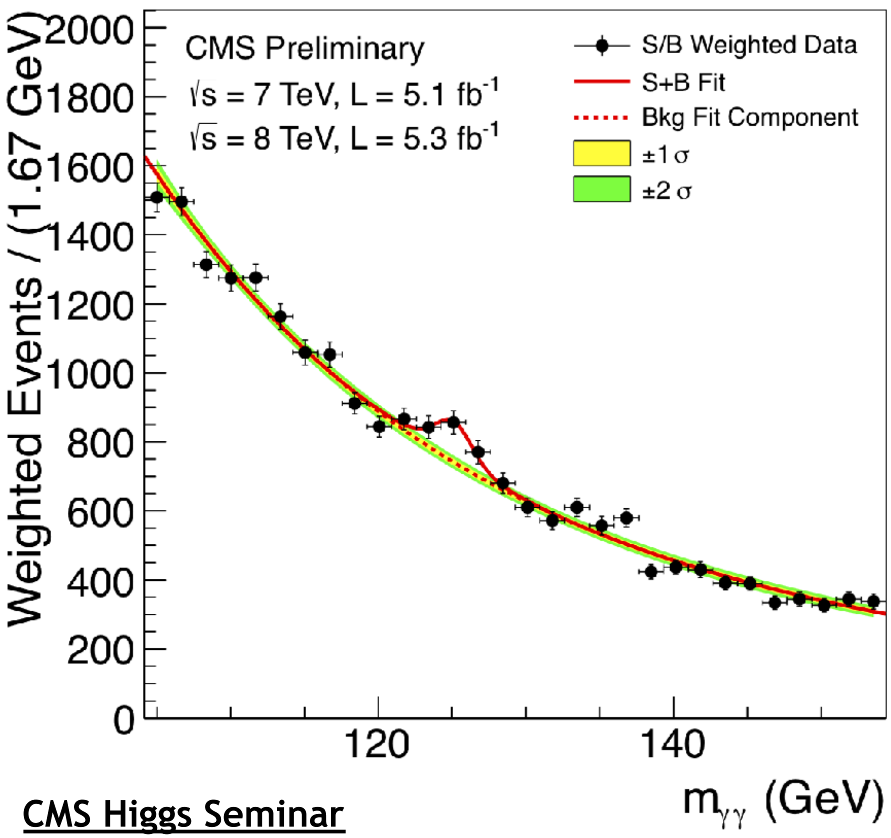
- 2012: 21.3 fb^{-1} (95.9%)
- 2011: 5.23 fb^{-1} (94%)

Higgs discovery

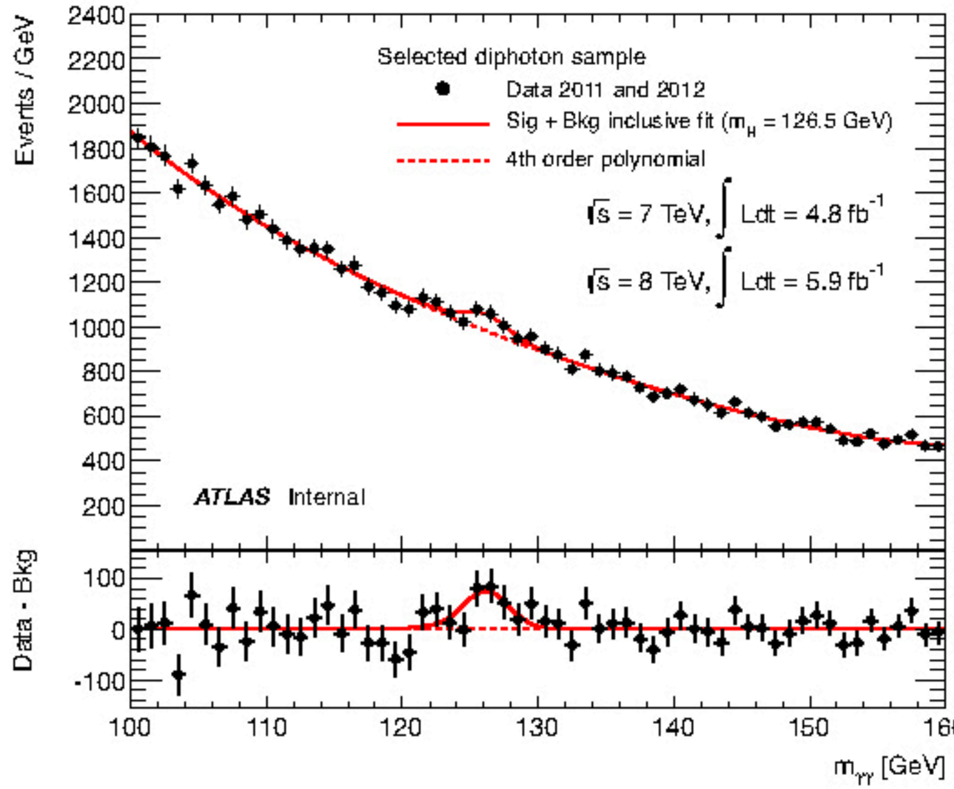
On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider announced they had each observed a new particle in the mass region around 126 GeV – *The Higgs boson*

Higgs discovery

On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider announced they had each observed a new particle in the mass region around 126 GeV – ***The Higgs boson***



CMS Higgs Seminar

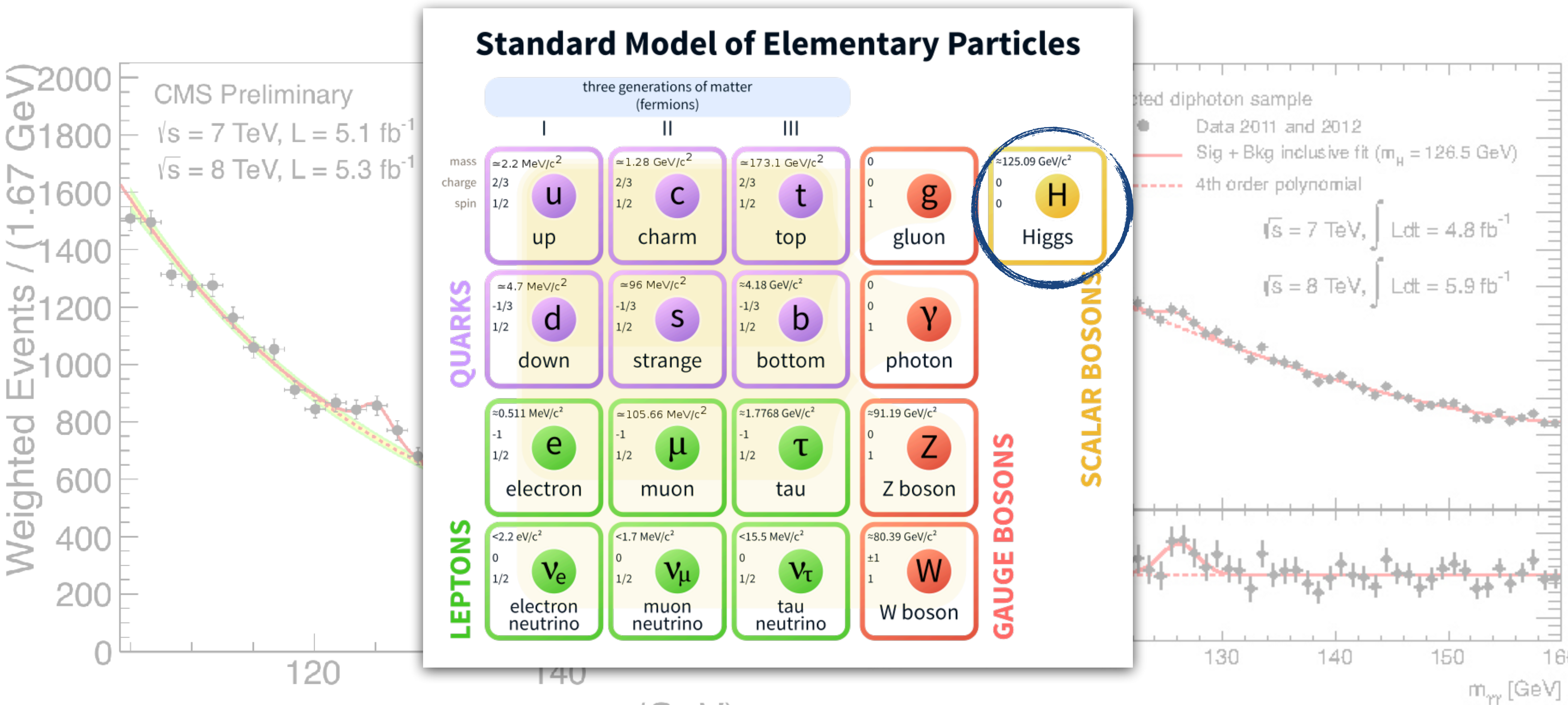


ATLAS Higgs Seminar

Argonne NATIONAL LABORATORY

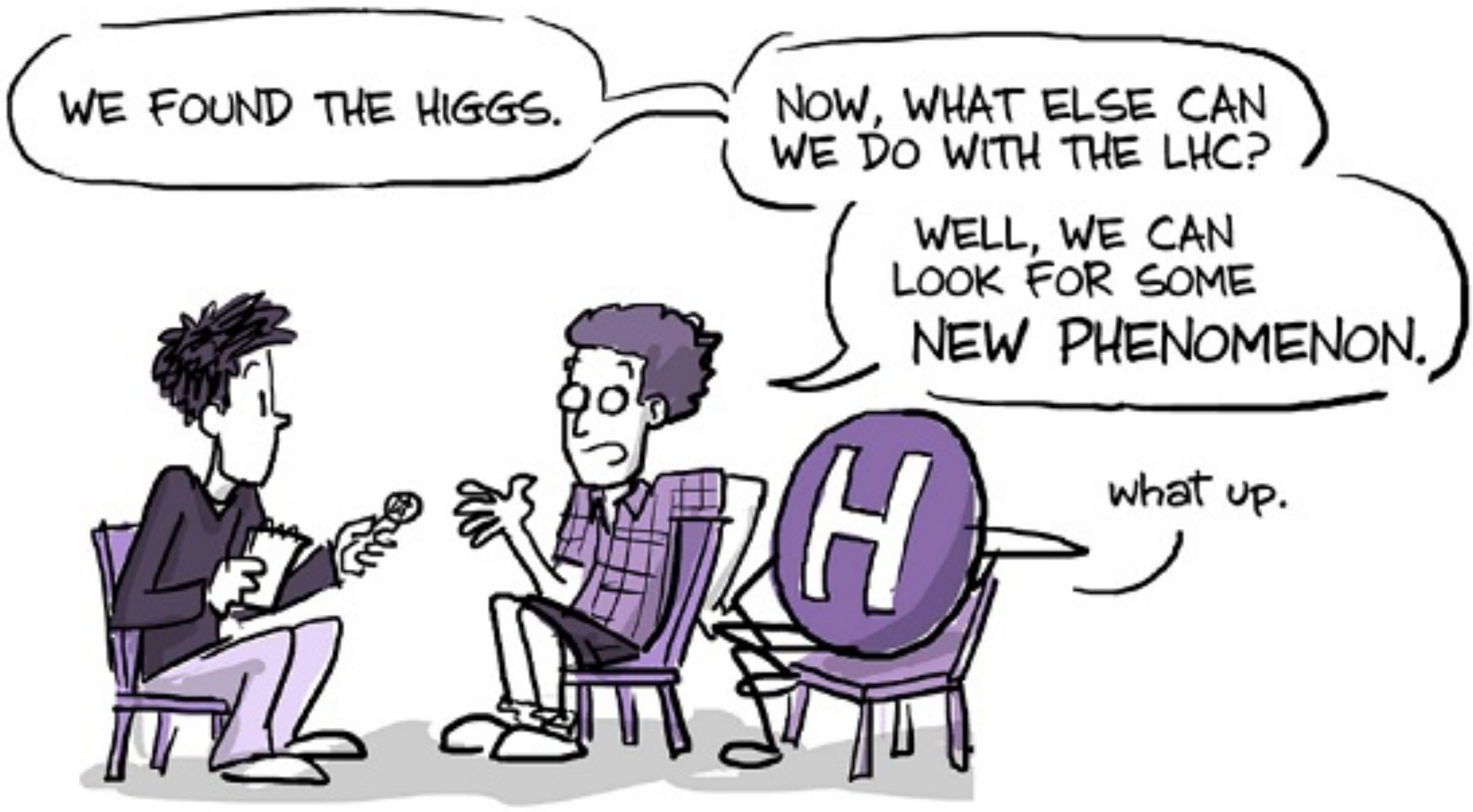
Higgs discovery

On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider announced they had each observed a new particle in the mass region around 126 GeV – ***The Higgs boson***



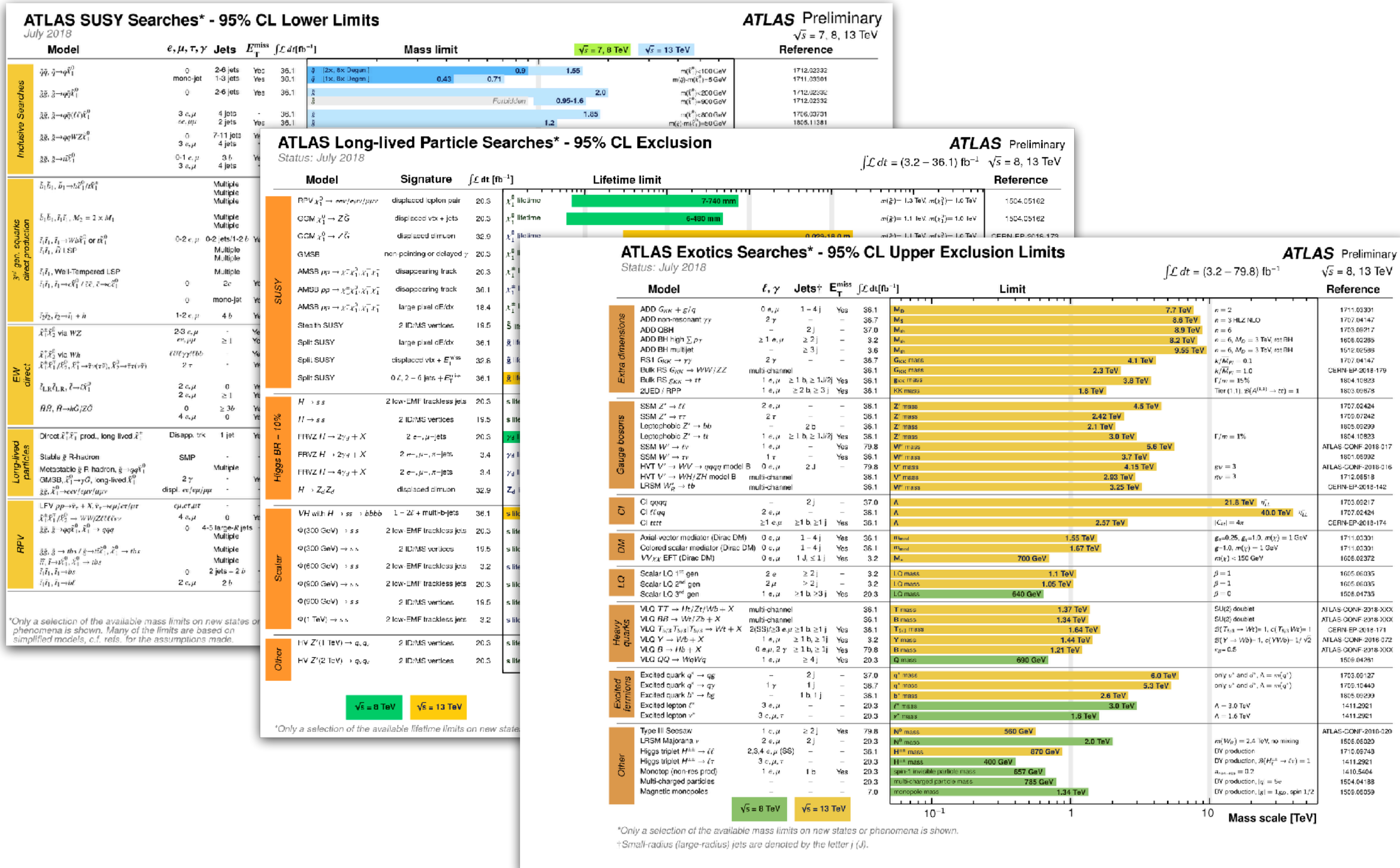
CMS Higgs Seminar ATLAS Higgs Seminar

Moving forward



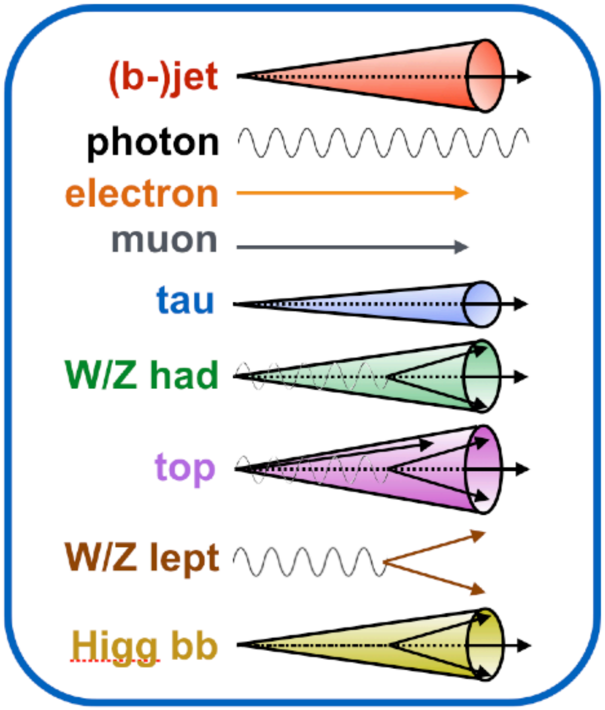
http://phdcomics.com/

Searching for new physics

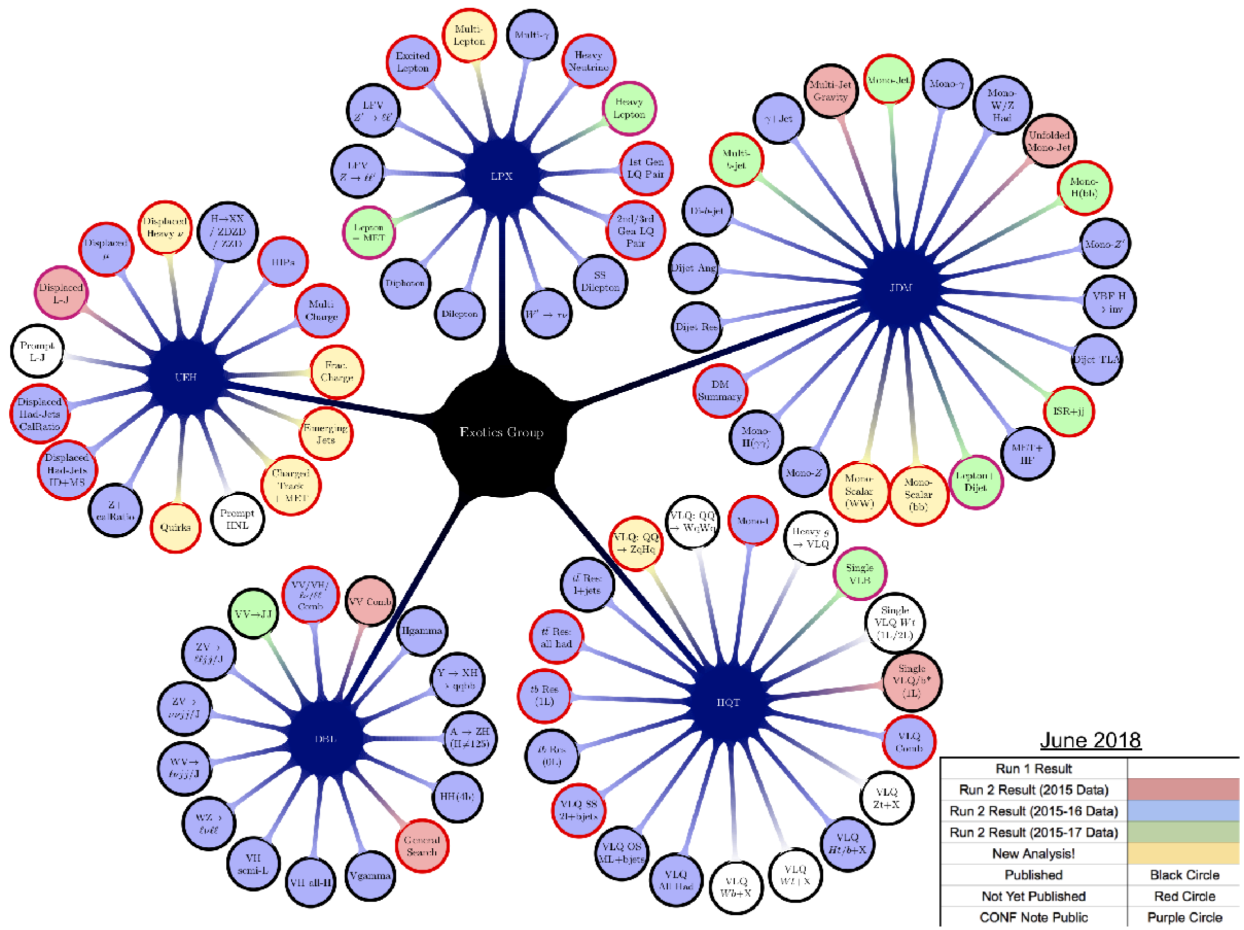


Exotics search — signature-based

Scan phase space for all possible signatures and be as much model-independent as possible



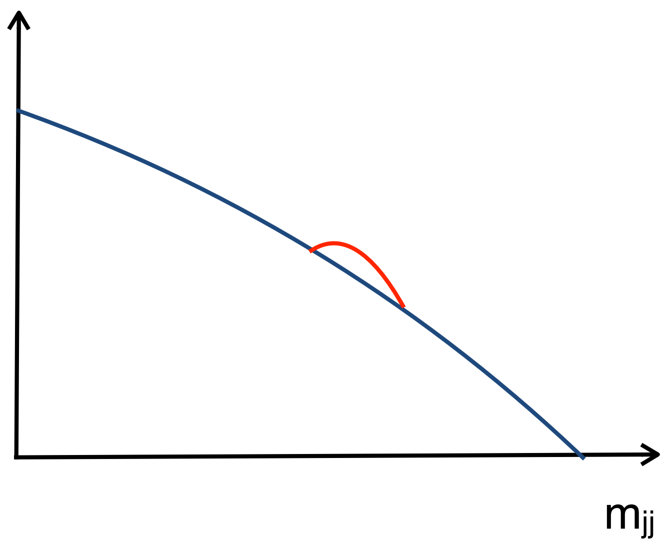
Daniele del Re



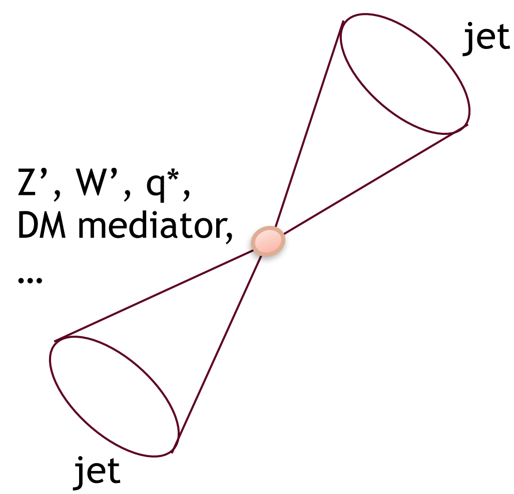
Argonne NATIONAL LABORATORY

di-jet resonance search

- Di-jet final states are "classic signatures" to search for NP with strong interactions
  - Searching for signatures in the di-jet mass spectrum (m_{jj})
    - Narrow resonance
    - Very high mass event
  - New Gauge Boson Z' & W', excited quark, DM mediator and ……



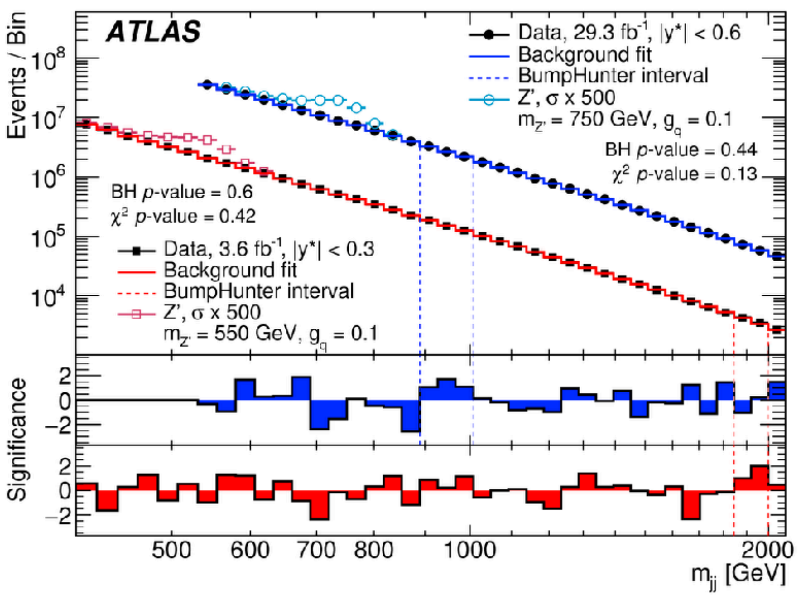
Looking for derivations on smoothly falling background



Argonne NATIONAL LABORATORY

di-jet resonance search

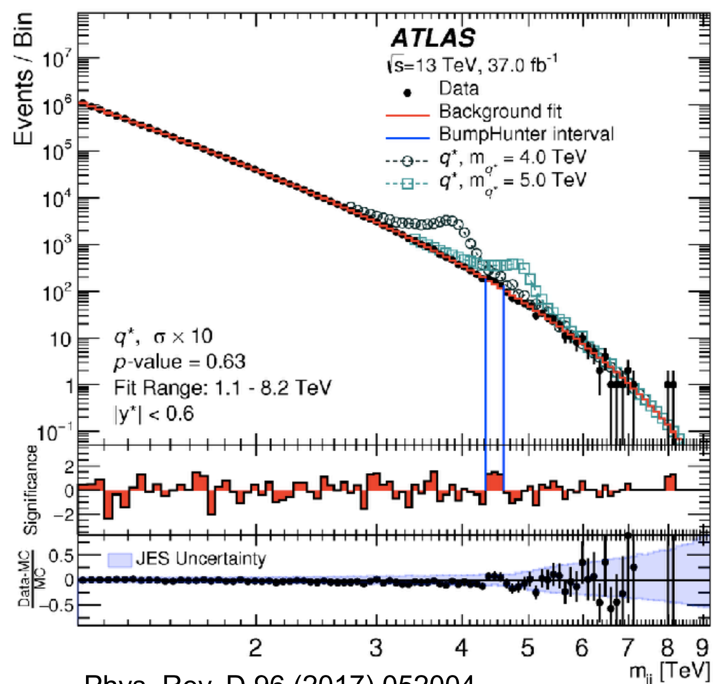
- Collect events using fully efficient single jet trigger
  - L1 single jet trigger (low mass region) & HLT single jet trigger (high mass region)
  - m_{jj} threshold limited by jet trigger threshold
  - Reject QCD multi-jet by cutting on $y^* = (y_{jet1} - y_{jet2})/2$ of the di-jet system
    - QCD multi-jet normally have large y*



Phys. Rev. Lett. 121 (2018) 081801

$p_{T,\gamma(jet)}$ > 155 (420) GeV, $p_{T,fat\ jet}$ > 200 (450) GeV, |y*| < 0.3 (0.6), 0.4 TeV < m_{jj} < 2 TeV

+

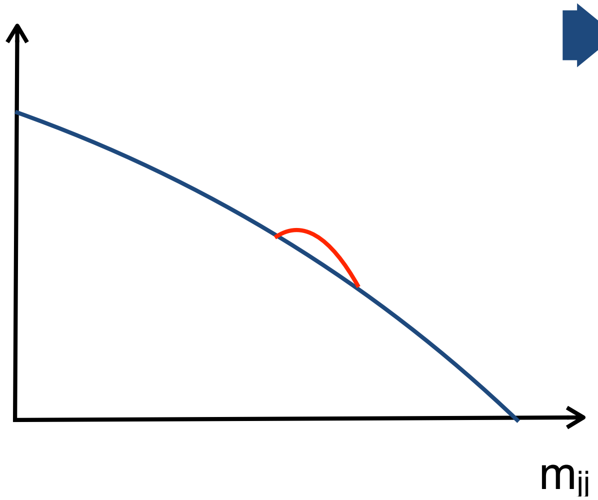


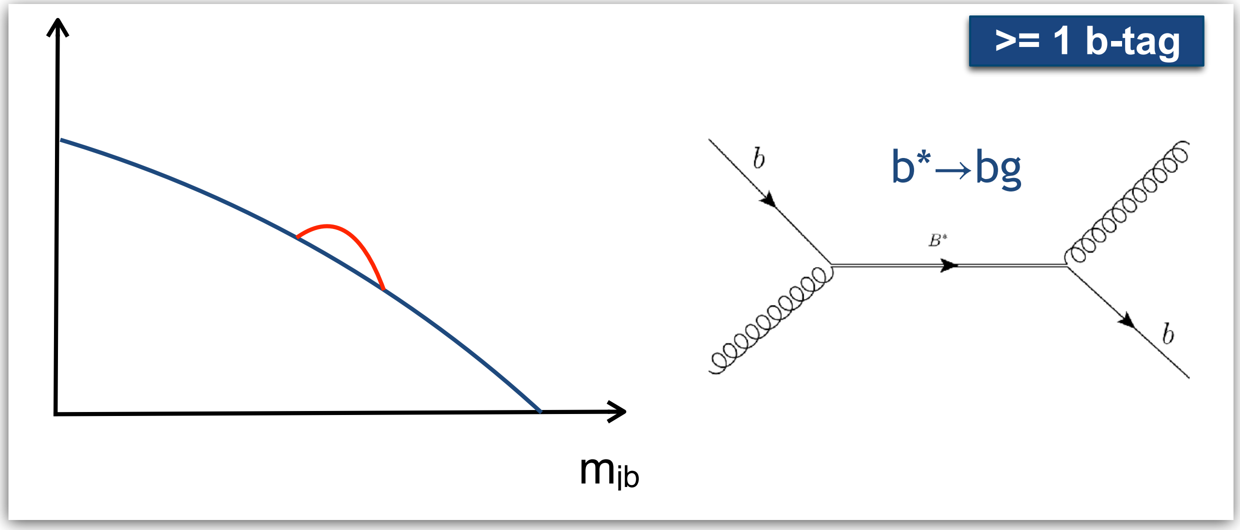
Phys. Rev. D 96 (2017) 052004

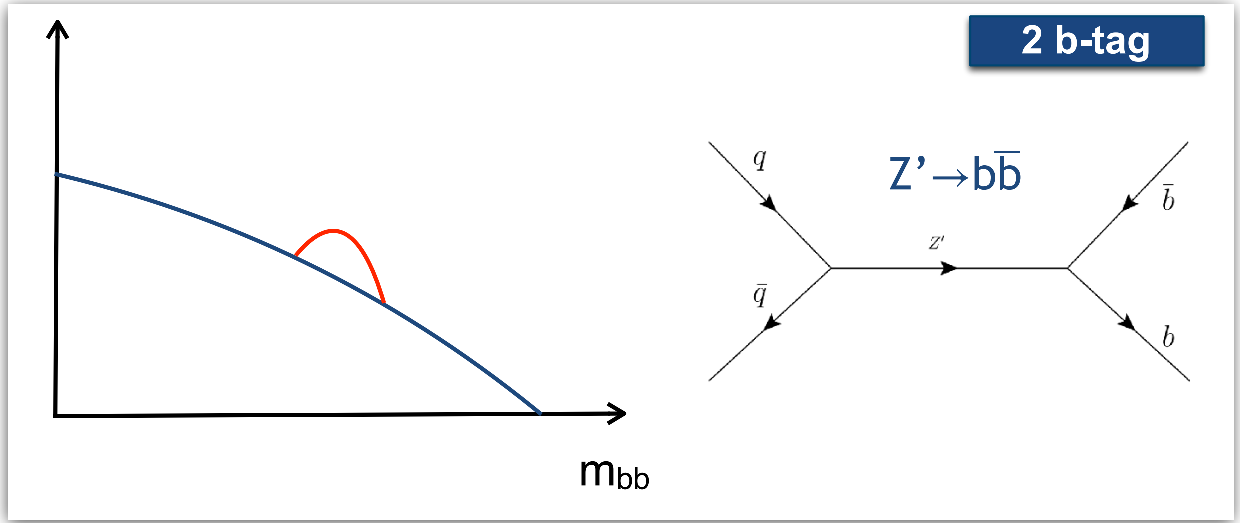
$p_{T,1}$ ($p_{T,2}$) > 440 (60) GeV, |y*| < 0.6
1.1 TeV < m_{jj} < 9 TeV

di-jet resonance search with b-tagging

- Some predicted particles prefer to decay into $b\bar{b}$ or bg rather than the light quarks
  - Tag the b jet(s) -> increase the sensitivity!



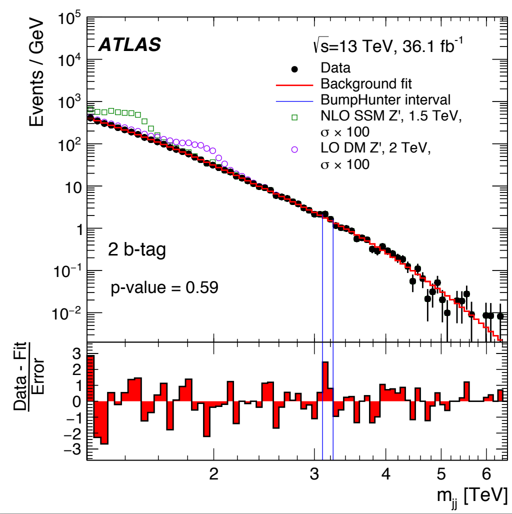


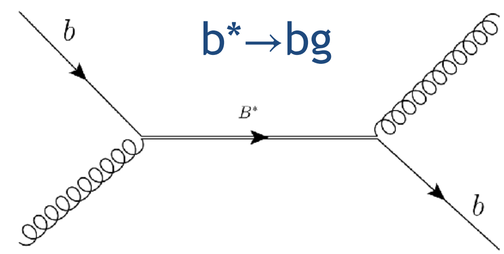


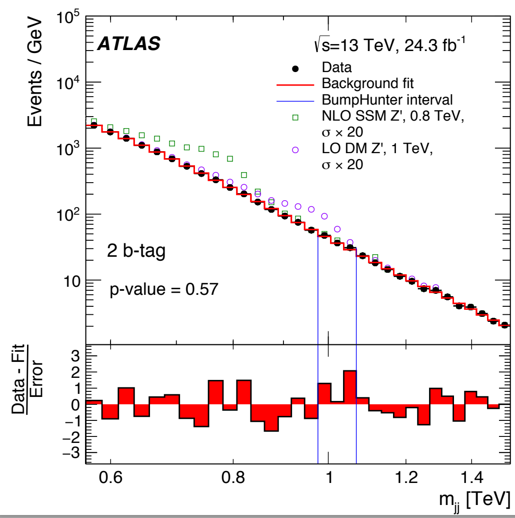
di-b-jet resonance search

- HLT double b-jet trigger (low mass region) & HLT single jet trigger (high mass region)

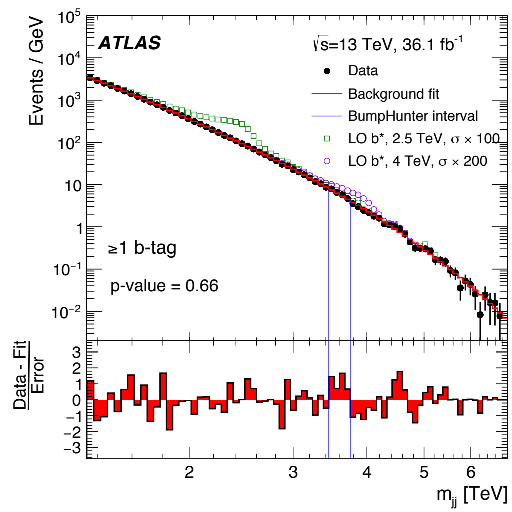
>= 1 b-tag



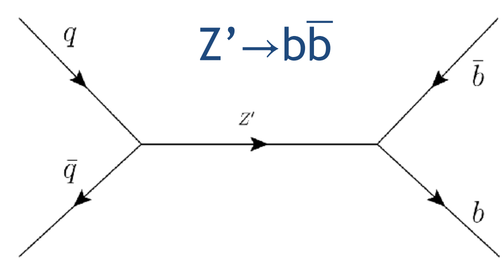




+



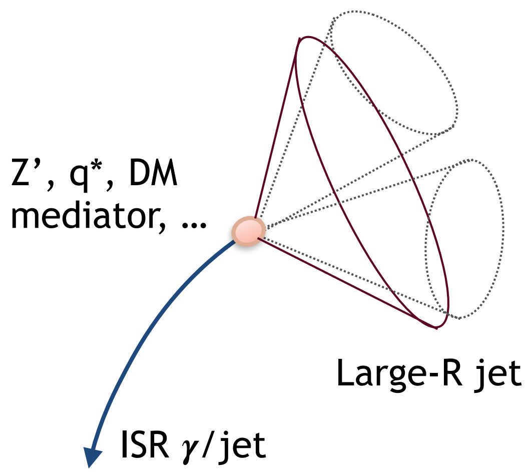
2 b-tag



di-jet + ISR search

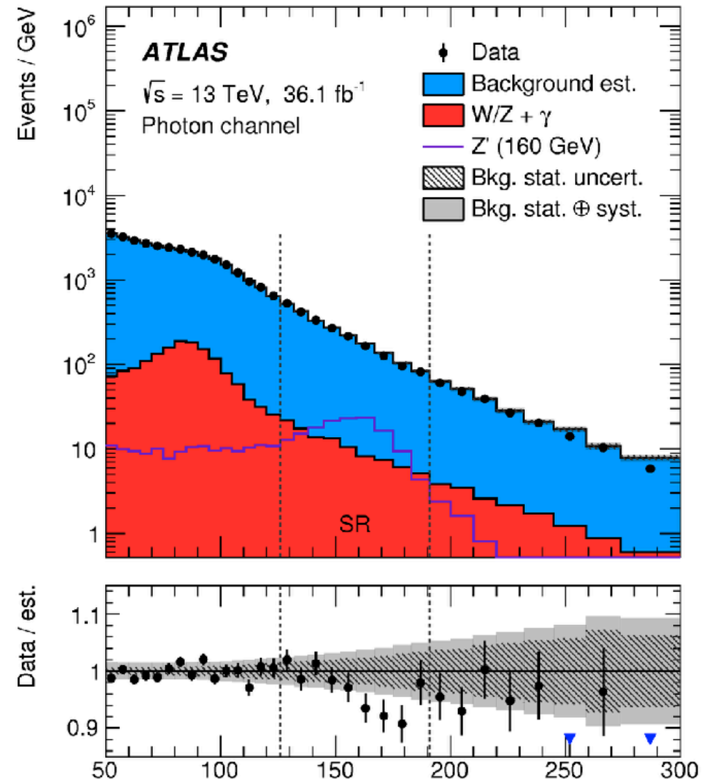
- NP may hide in the low mass region which has not been well explored
  - Collect event using triggers on other objects: ***photon***, electron, muon and …

di-jet + ISR search (boost)



Tagging events via ISR γ/jet

For ISR with large p_T, the two jets from resonance decay are merged into a single large-R jet



EXOT-2017-01

Photon channel

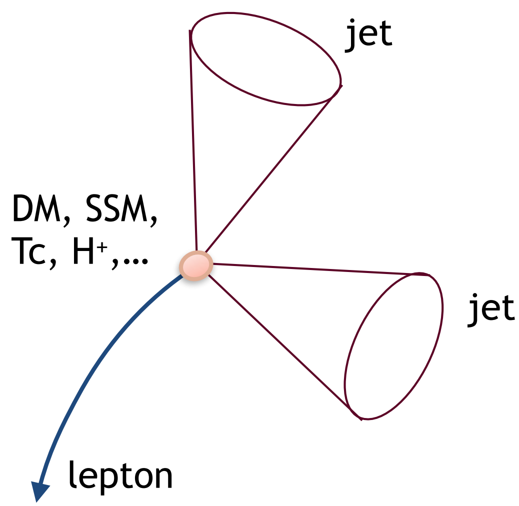
$p_{T,\gamma}$ > 155 GeV, $p_{T,\text{Large-R jet}}$ > 200 GeV,

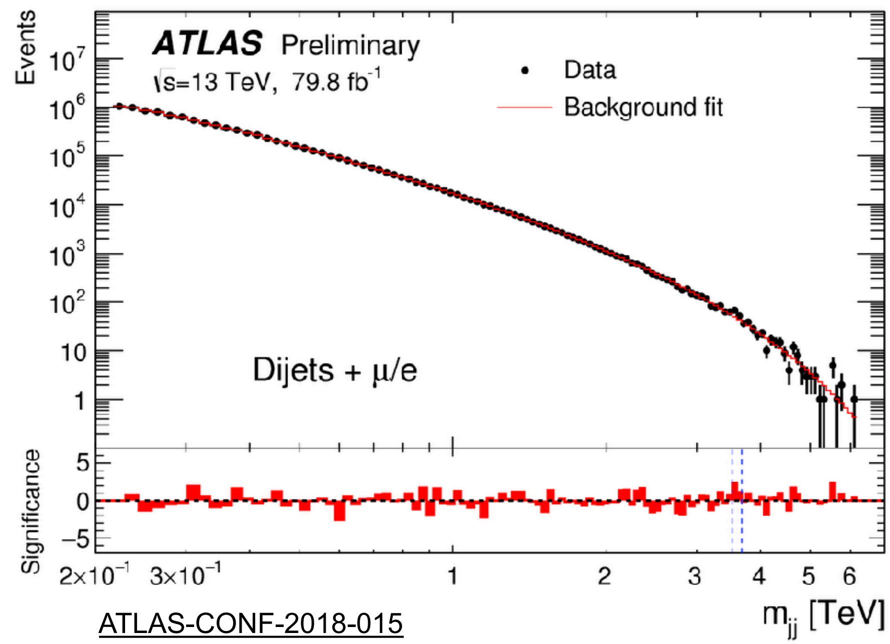
50 MeV < $m_{\text{Large-R jet}}$ < 300 MeV

Lepton + di-jet search

- NP may hide in the low mass region which has not been well explored
  - Collect event using triggers on other objects: photon, ***electron***, ***muon*** and …

Lepton + di-jet search





ATLAS-CONF-2018-015

Tagging events via lepton from associated production

For lepton with small p_T, the two jets from resonance decay are well separated

Lepton + di-jet search

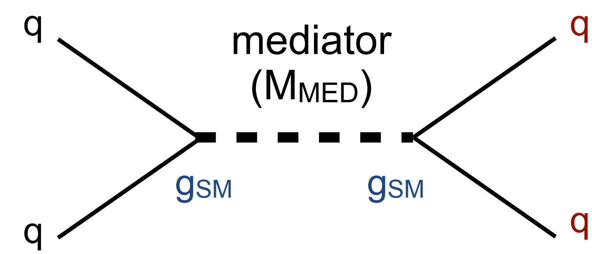
$p_{T,e(\mu)}$ > 60 GeV, Isolated

$p_{T,\,jet}$ > 20 GeV,

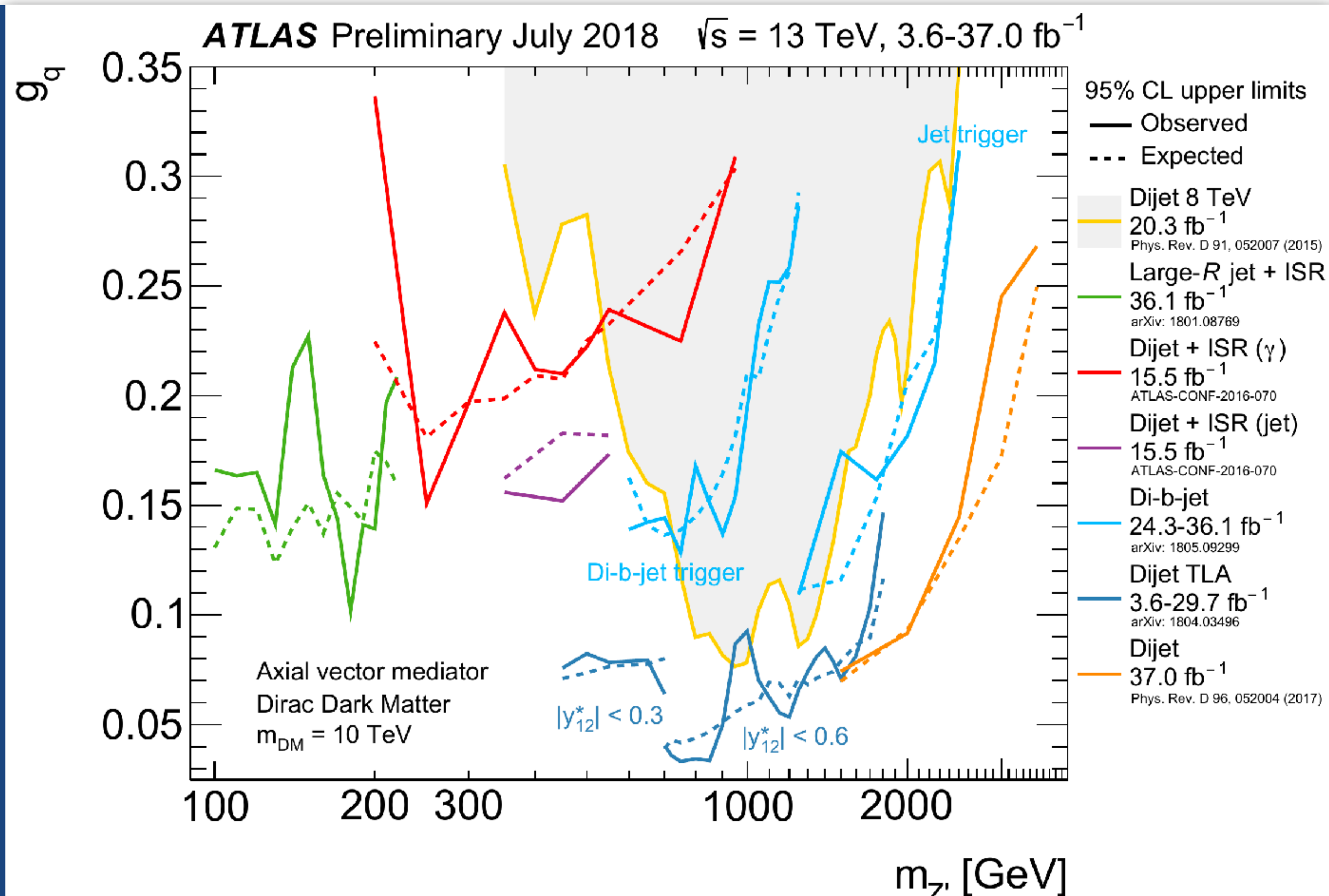
216 MeV < m_{jj} < 6 TeV

Result of di-jet searches

Dark matter simplified model



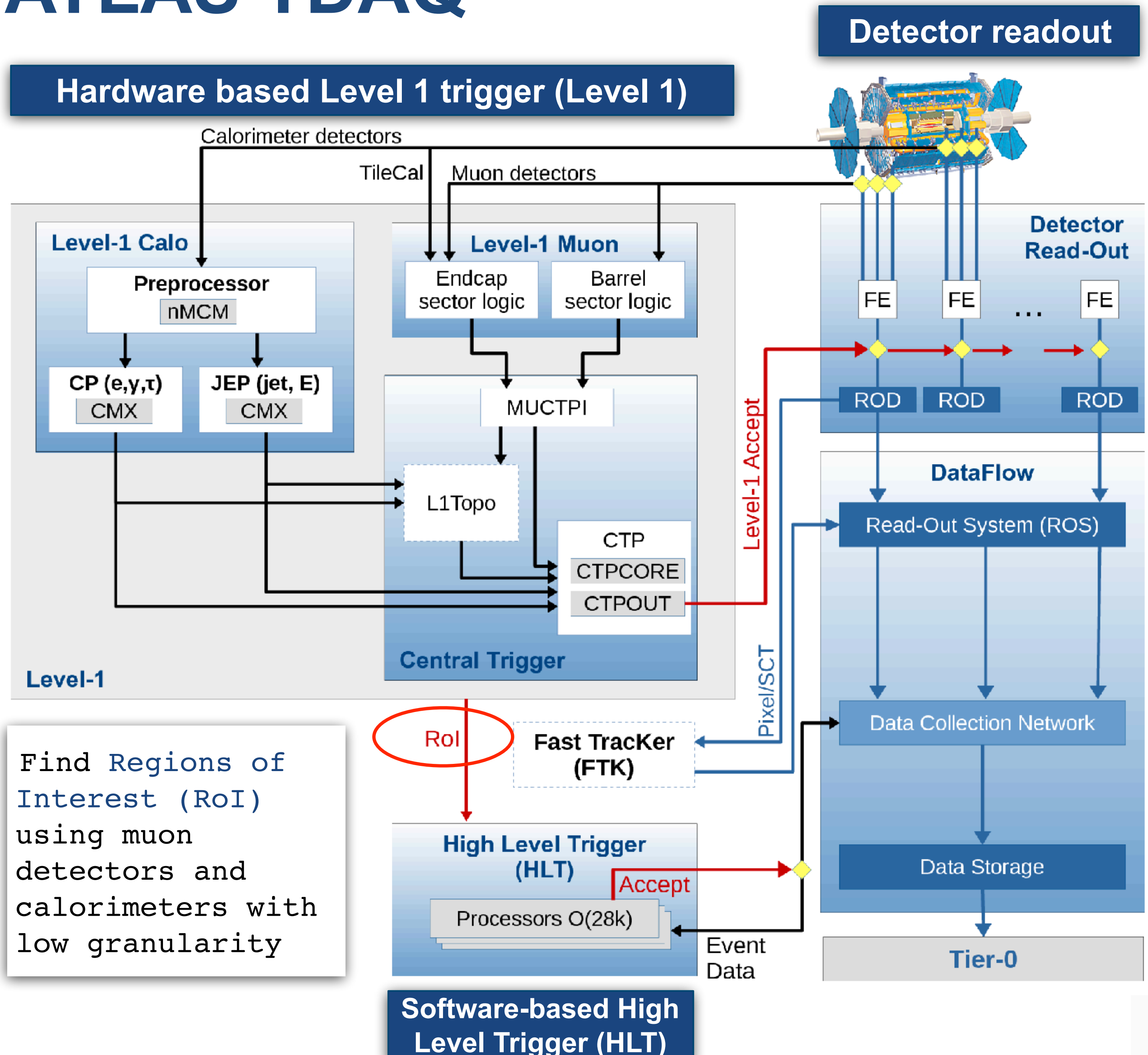
Dark matter to SM quark coupling



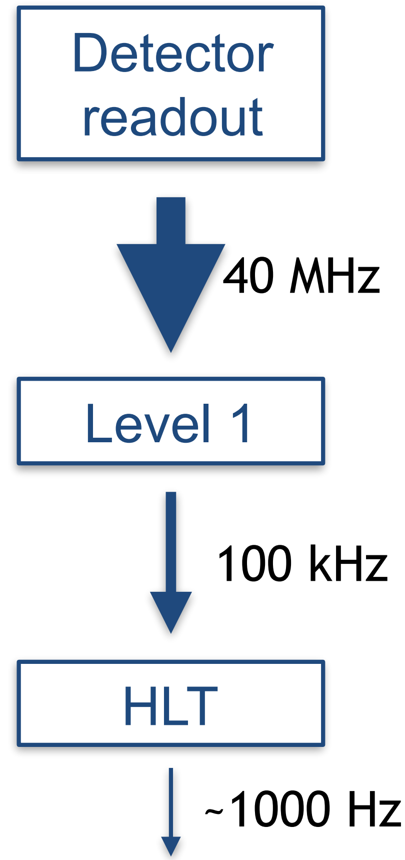
Dark matter mediator mass

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/

ATLAS TDAQ



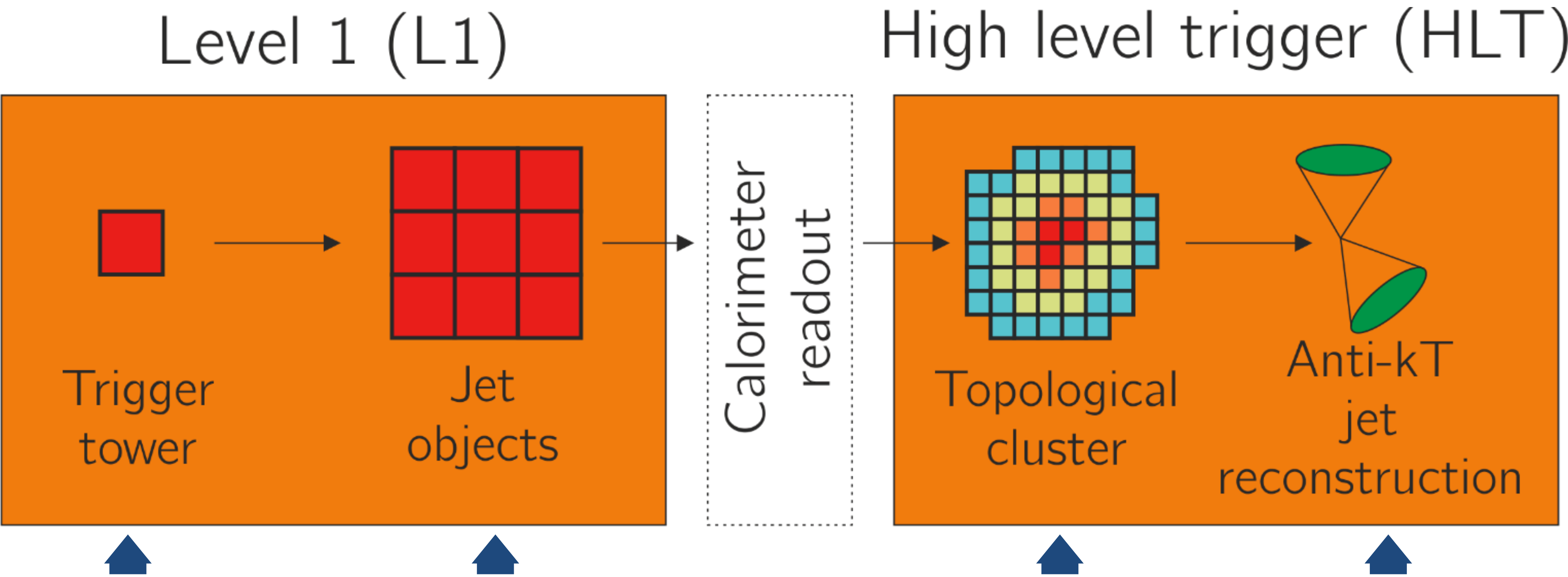
Find Regions of Interest (RoI) using muon detectors and calorimeters with low granularity



http://phdcomics.com/

Jet reconstruction and triggering

- Built from calorimeter information to capture collimated showers of particles
- Defined by the reconstruction algorithm (anti-kT) and their radius (R) in the eta-phi plane



Built from calo (0.2x0.2 in size)

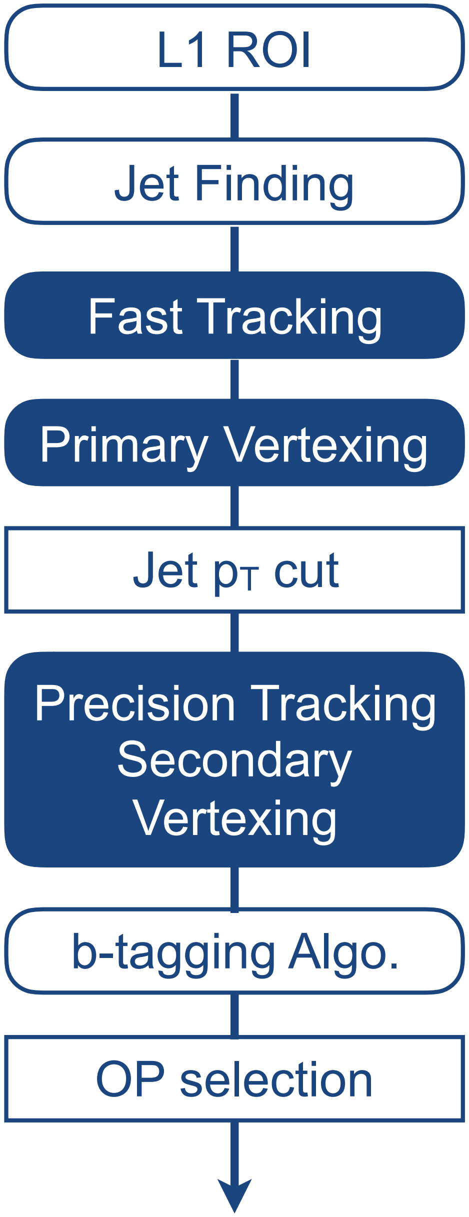
Defined by sliding window algo, creating Region of Interest (ROI)

Exploiting signal/noise ratio

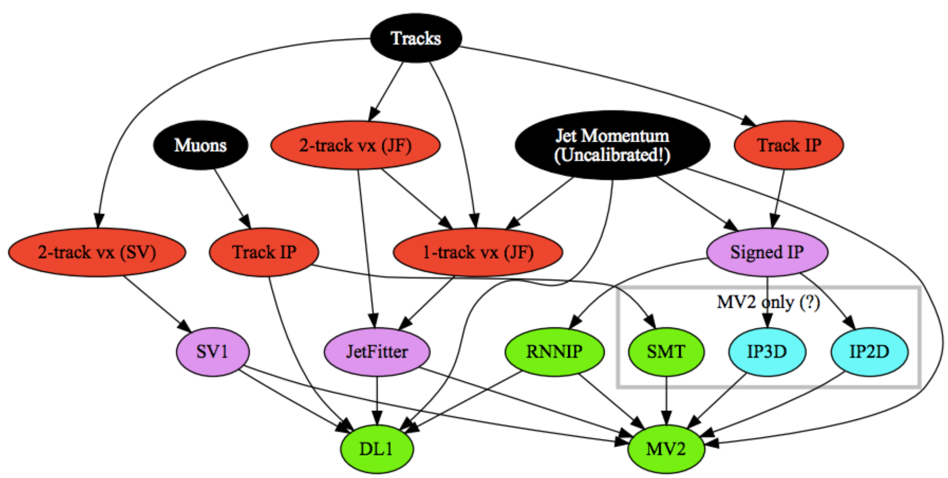
Jet algorithm

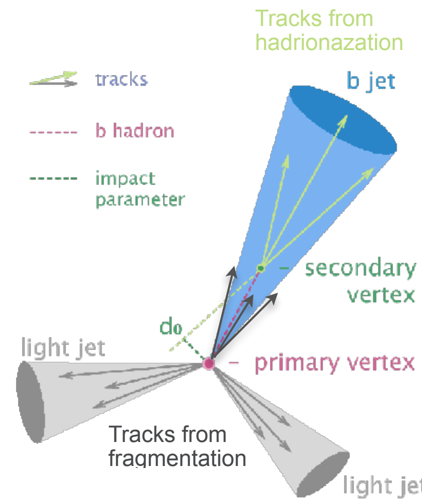
Herjuno Nindhito' LHCP poster

b-jet triggering



- b-tagging: identifying jets that have a b-hadron in it
  - Simple taggers (SV, JetFitter, IP, …) use track and jet informations directly
  - **Combined taggers** (MV2, DL1) take account the output of the simple tagger as well as the track and jet informations



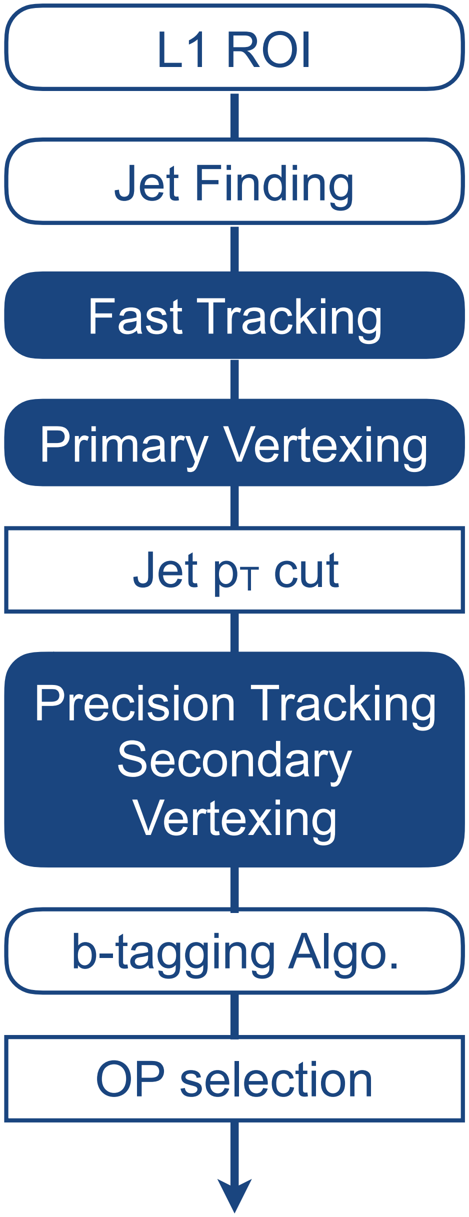


▸ Includes vertexing, distilling, likelihoods, and **BDTs or NNs**

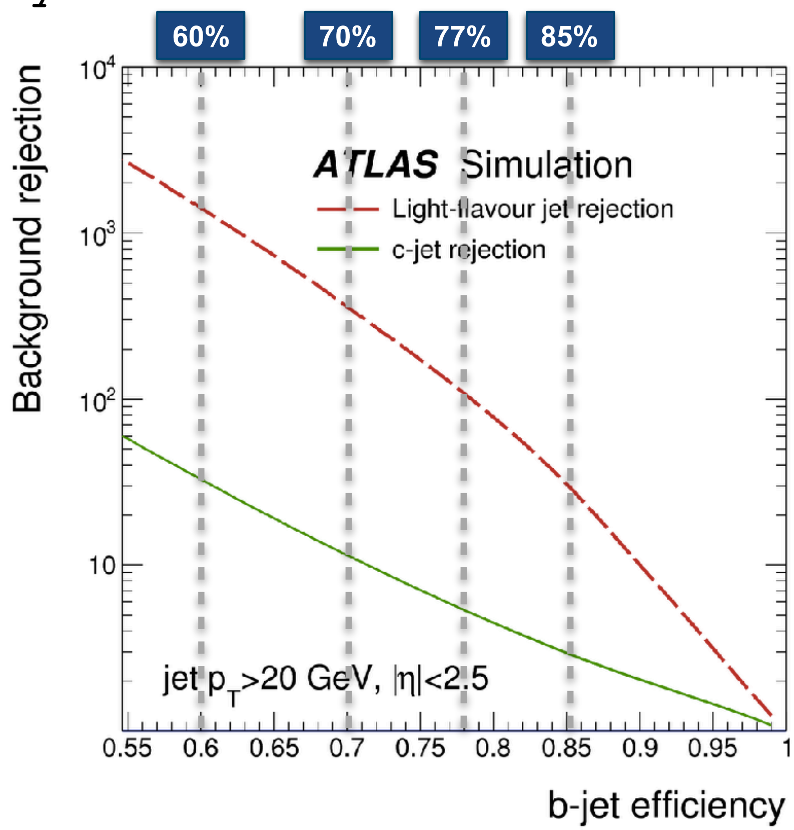
MV2 (Run2): Boosted decision tree

DL1 (2017): Deep Neural Network

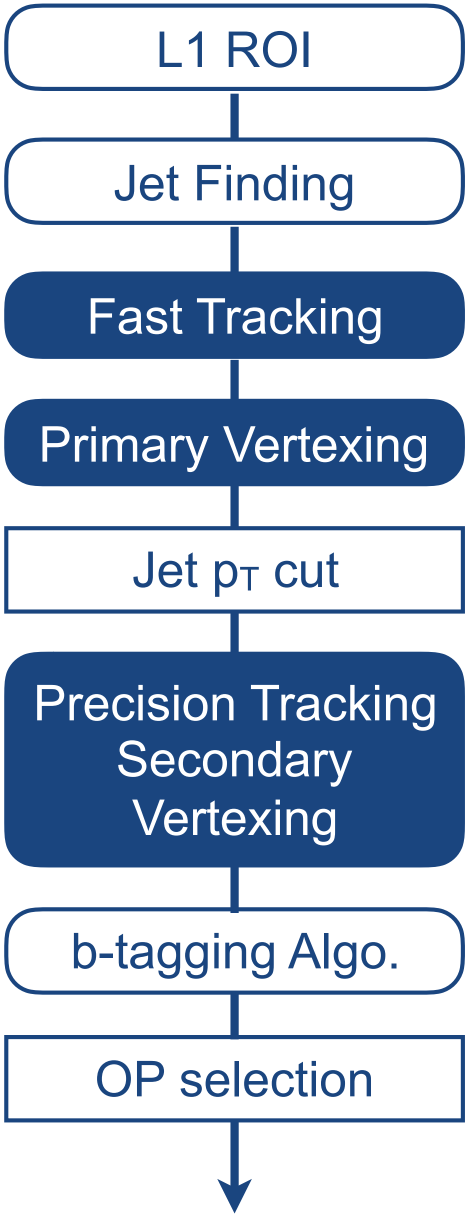
b-jet trigger



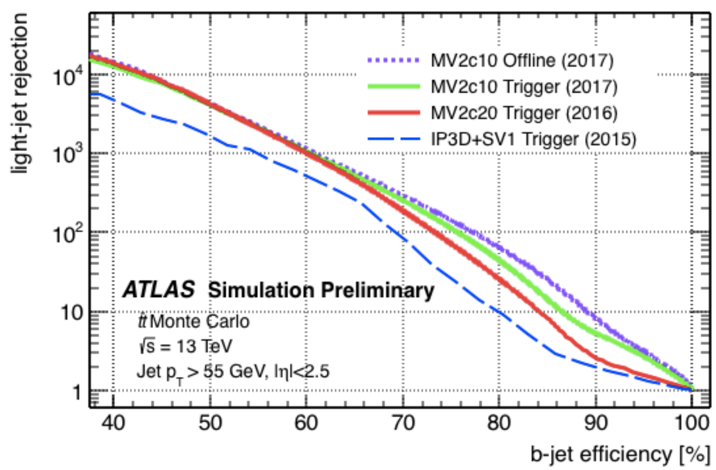
- b-jet tagging efficiency are evaluated using a high purity ttbar data sample
- Operation points are defined based on **integrated (Fixed)** / p_T-dependent (Flat) b-jet tagging efficiency



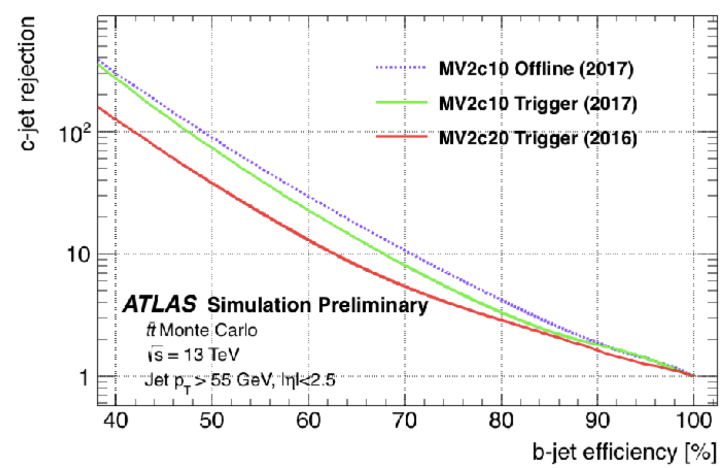
b-jet trigger



- Code/Algorithms are in common for online b-tagging and offline b-tagging
  - Training is performed on different objects : Trigger Jets (online) vs Calibrated Jets (offline)
  - OPs are not fully correlated between online and offline

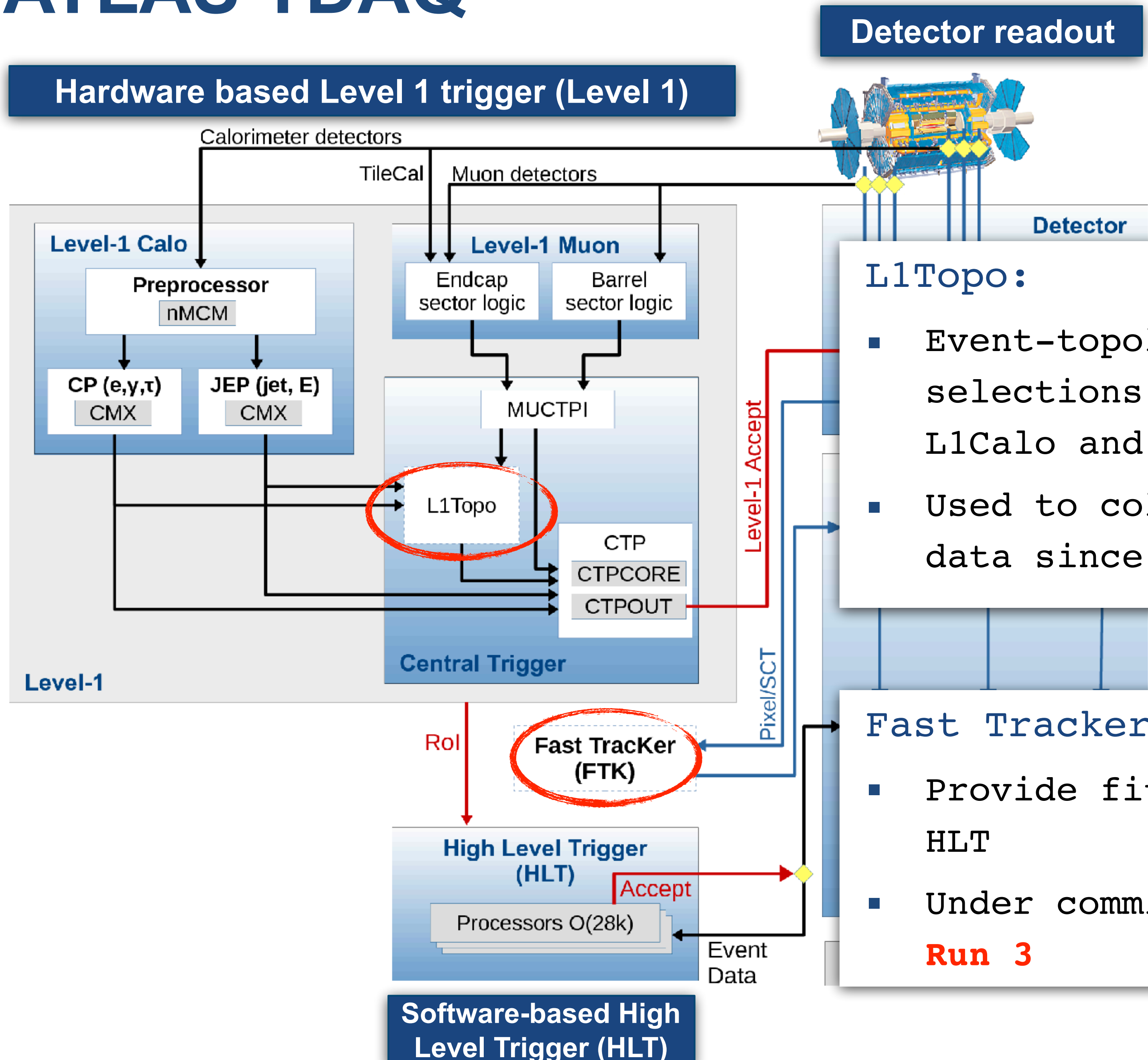


light-jet rejection vs b-jet efficiency



c-jet rejection vs b-jet efficiency

ATLAS TDAQ



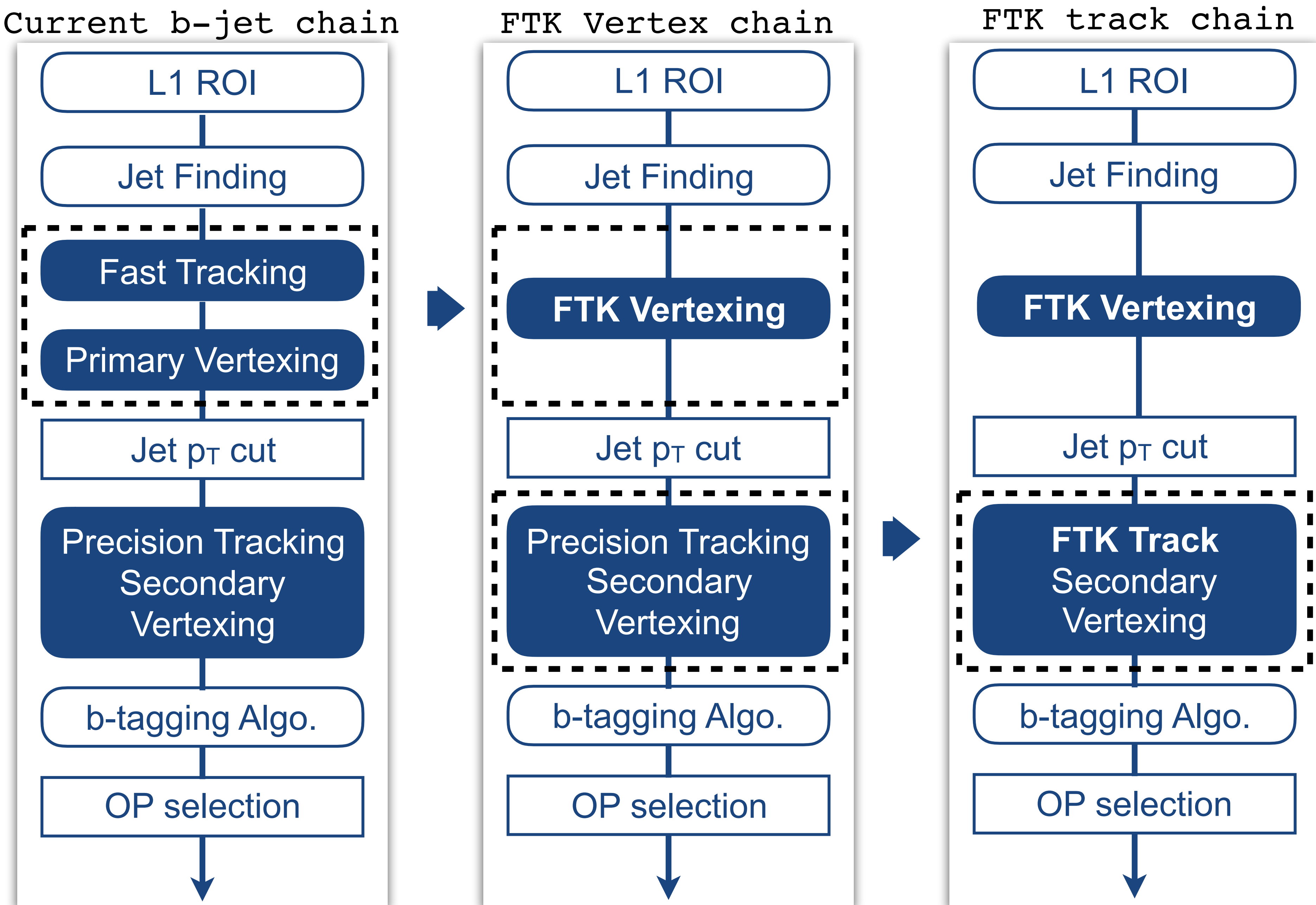
L1Topo:

- Event-topology-based selections based on L1Calo and L1 Muon inputs
- Used to collect physics data since 2017

Fast Tracker (FTK):

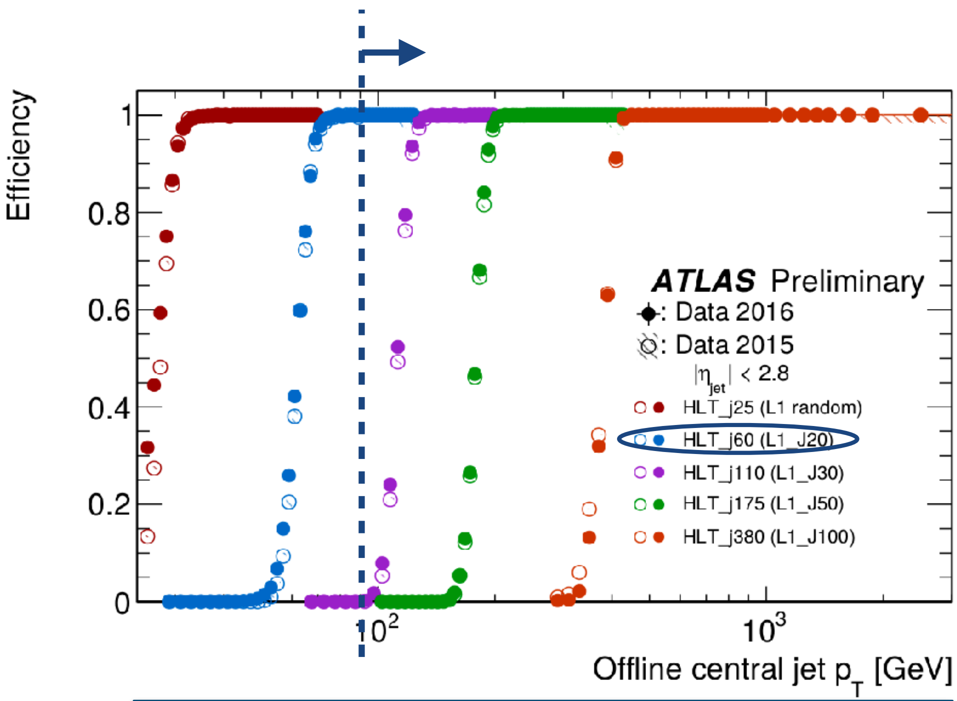
- Provide fitted tracks to HLT
- Under commissioning for **Run 3**

b-jet triggering with FTK tracks

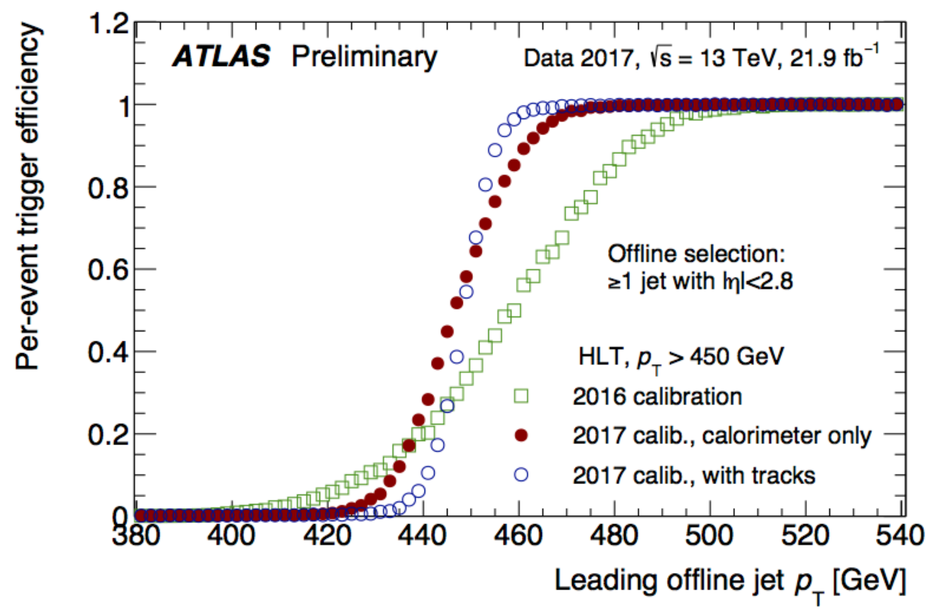


Jet trigger performance

- Trigger efficiency turn on curves indicate the relative resolution difference between HLT and offline jets
  - eg. HLT_j60 is fully efficient for offline jets with pT > 90 GeV
- Sizable performance gain on resolution from combining calorimeter and tracking information, using HLT tracks (computed for current b-jet triggers)

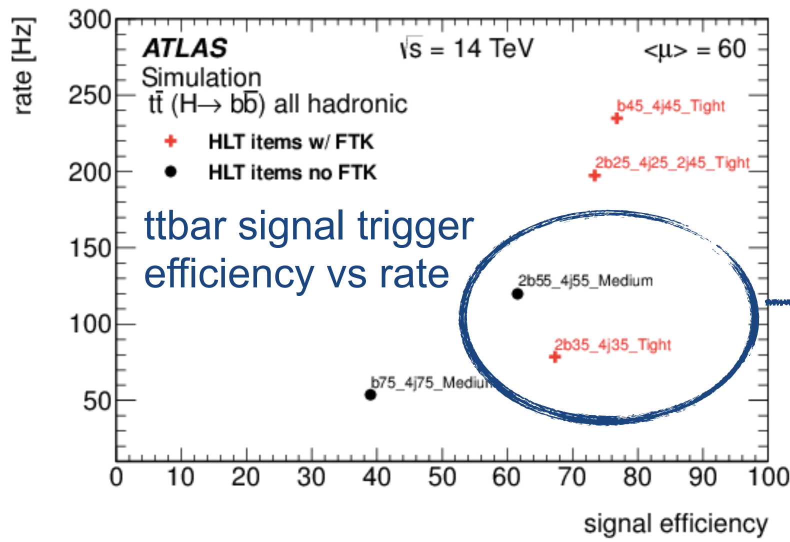


Turn on curves for single-jet trigger with R=0.4 for 2015 & 2016 data



Turn on curves for single-jet trigger with R=0.4 using three different sets of calibrations in 2016 & 2017 data

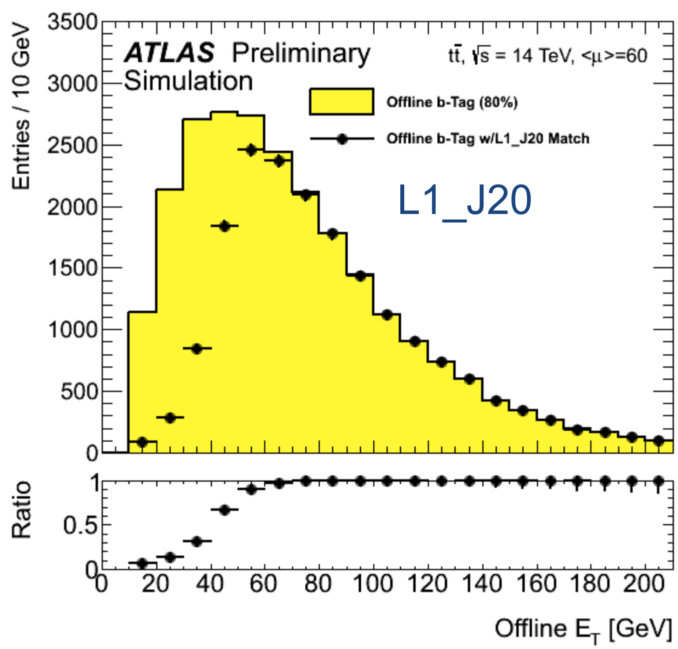
b-jet triggering with FTK tracks

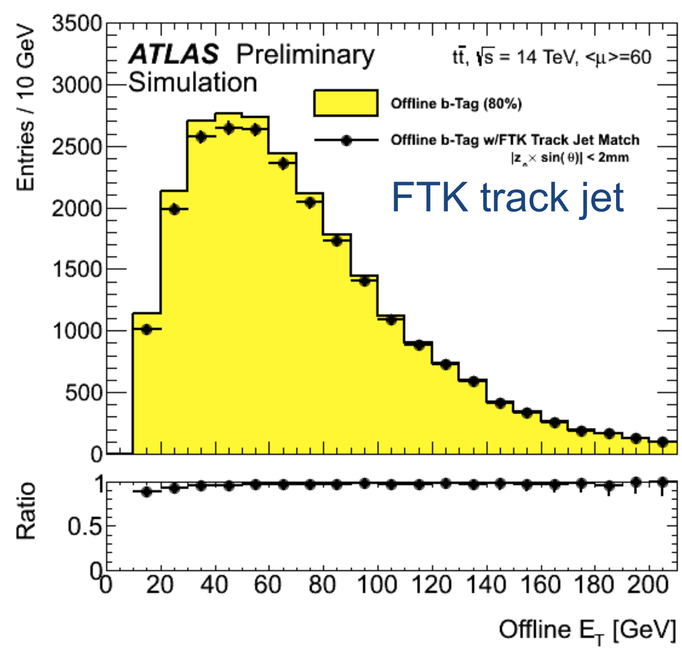


With FTK tracks, b-jet trigger can go to lower E_T threshold while still keep the rate acceptable

Better signal efficiency and lower rate with tighter OP (more low E_T jets)

Gain low mass signal sensitivity by using FTK tracks

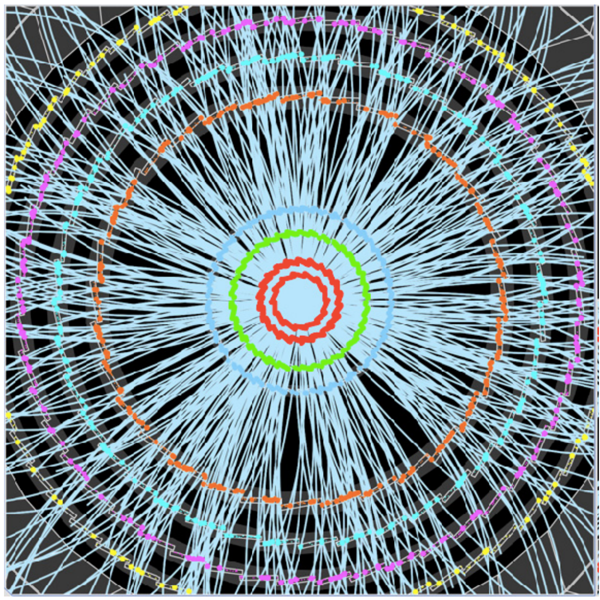




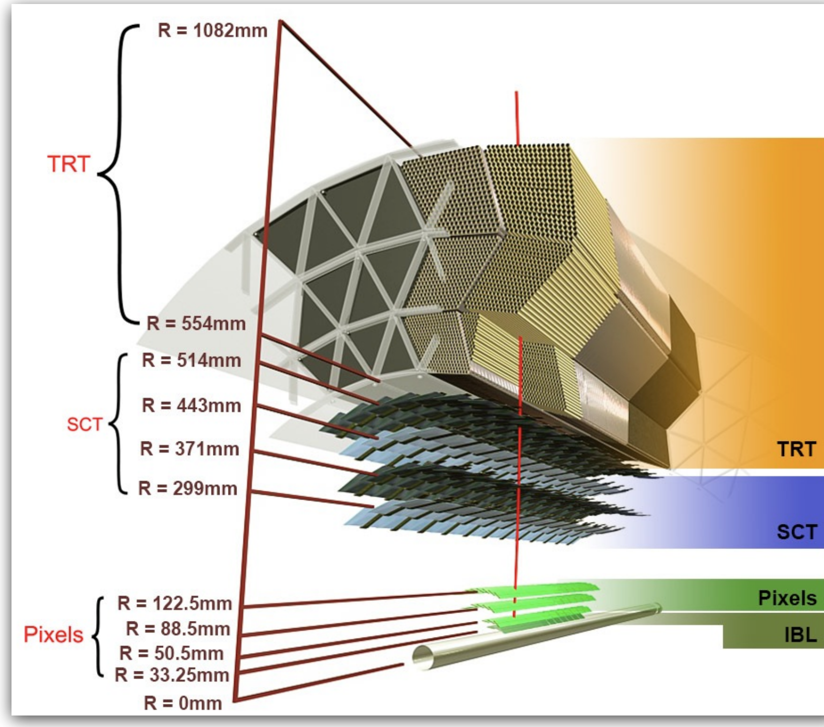
Highly efficient triggering on low E_T b-jets using FTK track jet

Fast TracKer (FTK)

Do offline liked tracking in the full detector volume for each event with in ~0.1 ms



Tracks



40 MHz

Level 1

100 kHz

All hits in IBL, Pixel and SCT

p_T > 1 GeV

FTK

FTK tracks

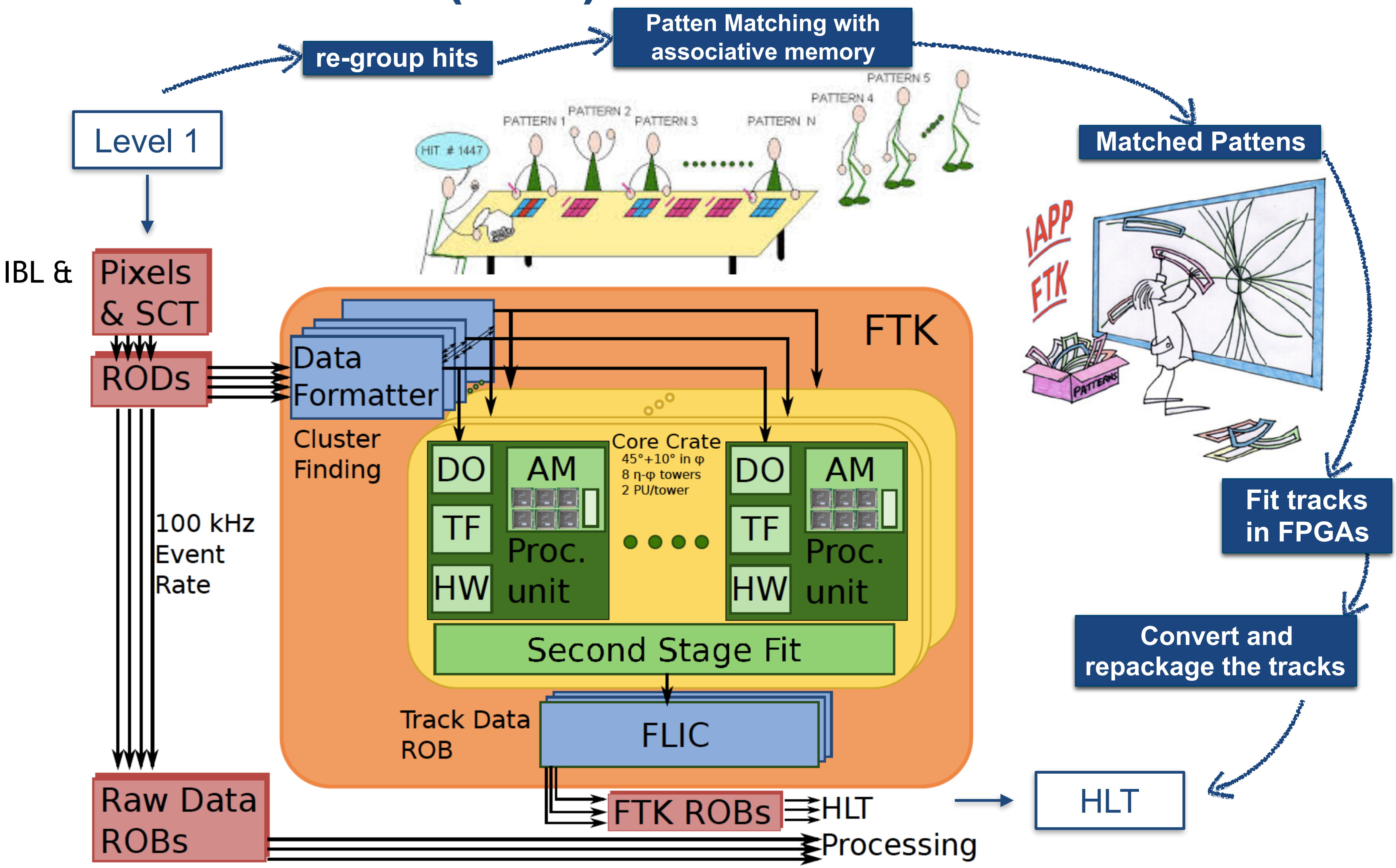
100 kHz

HLT

~1000 Hz

**Offline track reconstruction for the full tracking volume requires about 10s / event*

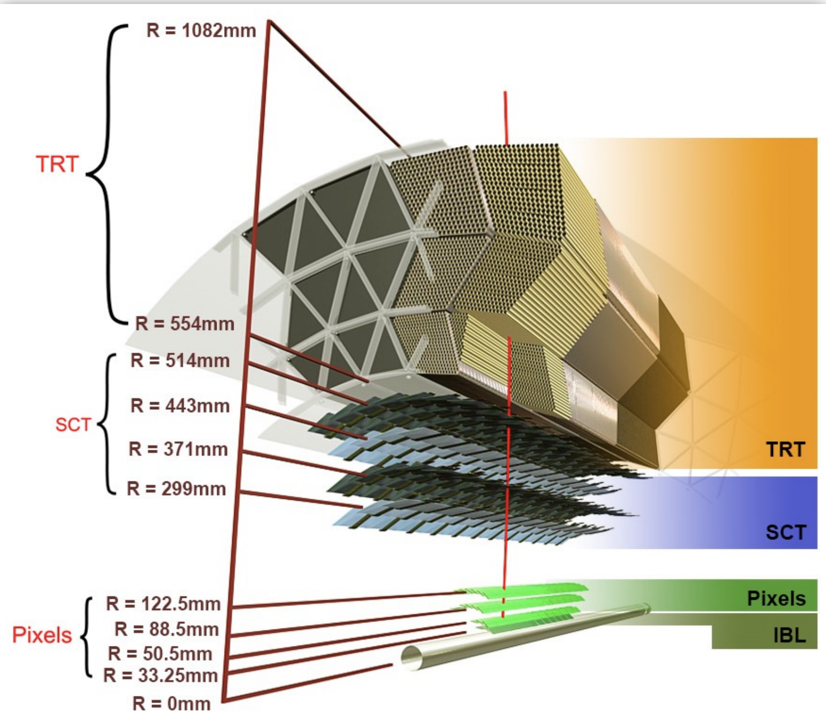
Fast TracKer (FTK)

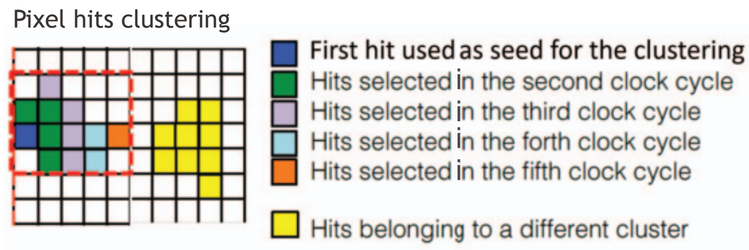


IM — hit clustering

IM (Input mezzanine)

- Input from Inner tracker + hit clustering
- Receive hit information @ 100kHz L1 trigger rate
- Total 128 boards





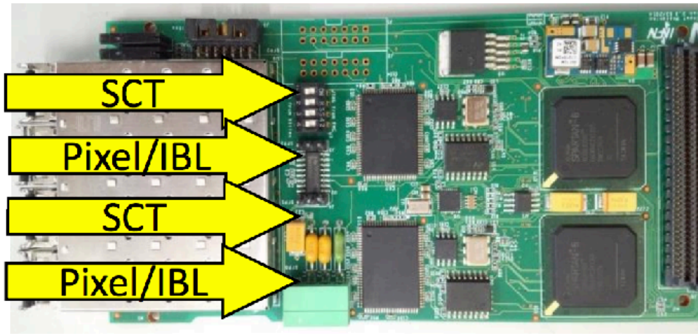
SCT hits:

- 8 layers
- 1 coordinate

Pixel+IBL hits:

- 4 layers
- 2 coordinate

4 input fibers + 2 FPGAs



ATCA (Advanced Telecommunication Computing Architecture) mezzanine card

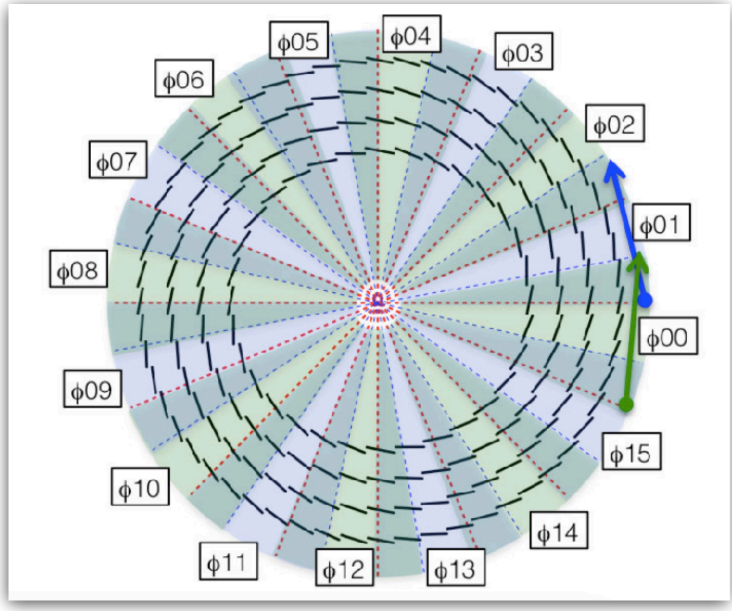
DF — Parallelize hits

DF (Data Formater)

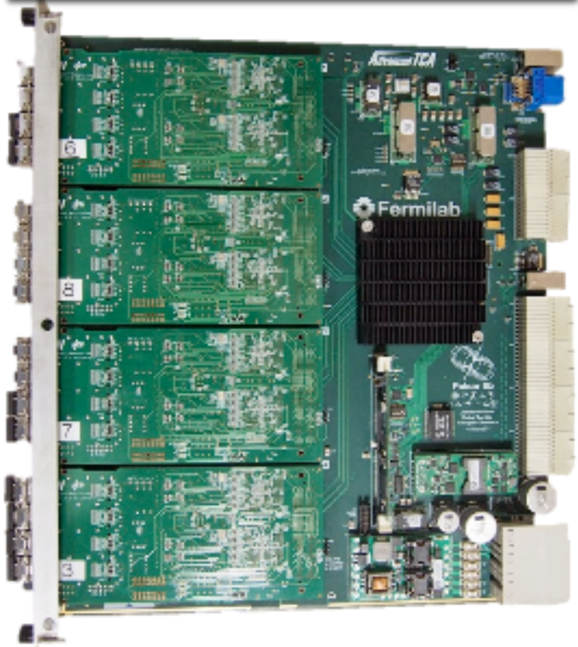
- Organizing clustered data into towers
- Total 32 boards (4 ATCA shelves)

Parallelize hits:

- Divide the detector into 64 overlapping η-φ towers (4x16)
- Access appropriate ID data via ATCA full mesh 40 Gbps backplane (intra-shelf) and fibre links (inter-shelf)
- Send data from each tower to separate processing units



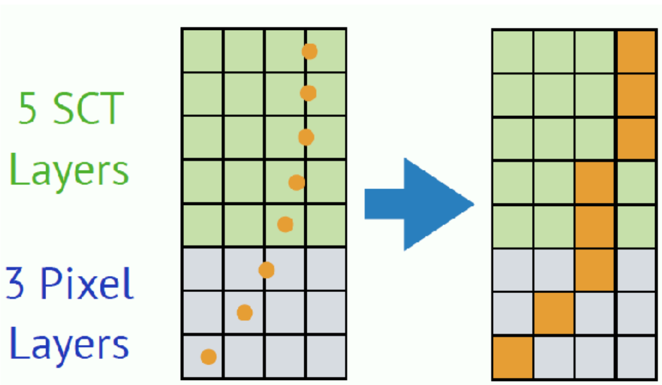
DF board with 4 IM on it



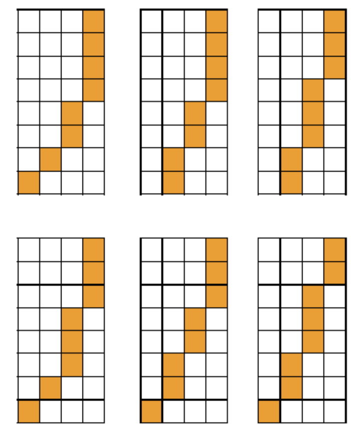
ATCA (Advanced Telecommunication Computing Architecture) mezzanine card

Processing unit — patten matching + fit

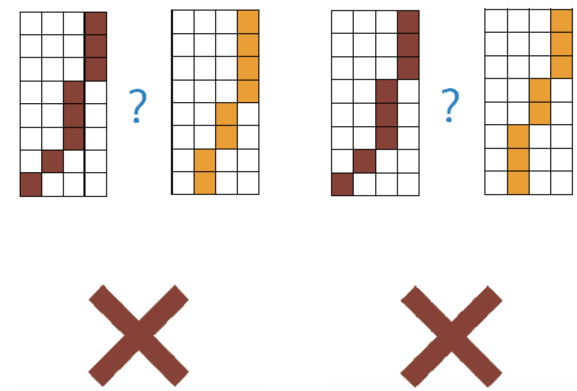
Divide each layer into coarse chunks

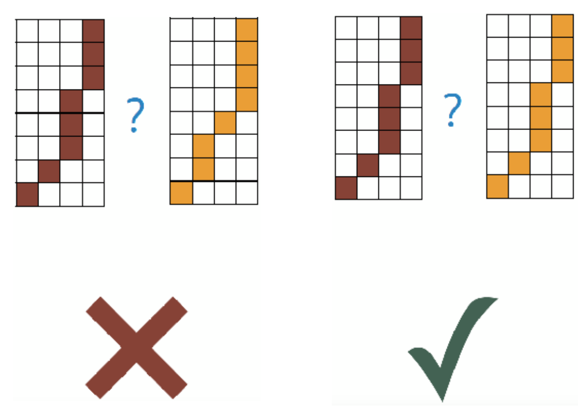


Define patterns of these chunks that correspond to tracks

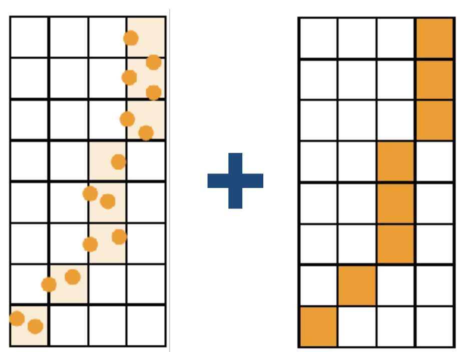


Compare fired patterns to a stored bank of track-like patterns

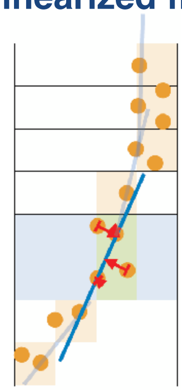




For matched patterns, retrieve all full resolution hits

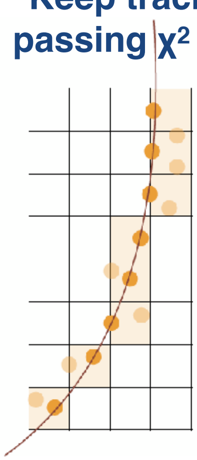


Perform a linearized fit



$$\chi^2 = \sum_{i}^{8} \sqrt{\Delta x_i^2 + \Delta y_i^2}$$

Keep tracks passing χ^2 cut

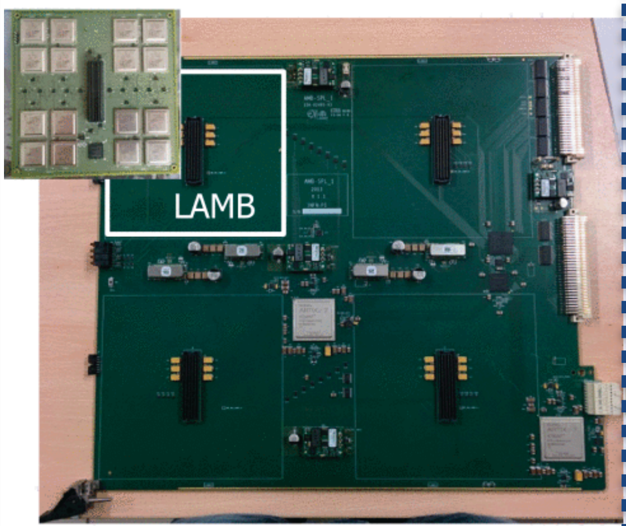


Processing unit — AMB&AUX

AMB (associative memory board)

- Matching clusters to predefined patterns
- 128 AMBs with 4*16 AM chips each

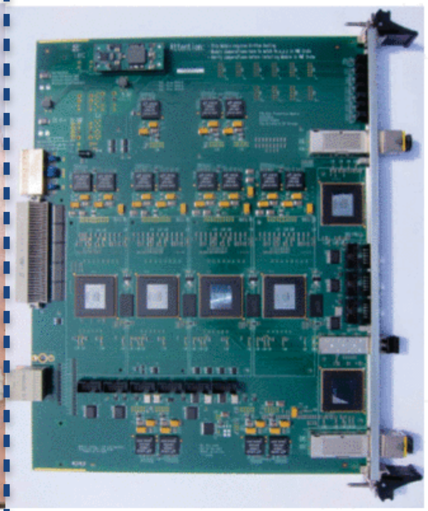
- Events are loaded on the AMB serial link processor at a maximum rate of 100 kHz corresponding to a maximum input bandwidth of 1.6 GB/s
- Each board can read out up to an average rate of 8000 matched patterns per event, for a maximum output bandwidth of ~3.2 GB/s.



AMB with 4 little AMBs (16 AM chips each) on it

AUX (Auxiliary card)

- 8-layer 1st stage track fitting
- Total 128 boards



2 input FPGAs + 4 processing FPGAs

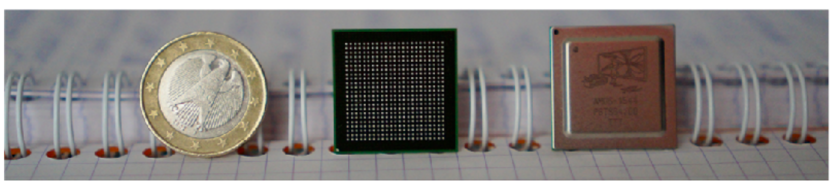
- Receives hits from the DF boards (up to 6 Gb/s)
- Stores the hits and sends them to the AMB with coarser resolution
- Receive matched pattens from address AMB and retrieve all the hits
- Fit 8-layer hits

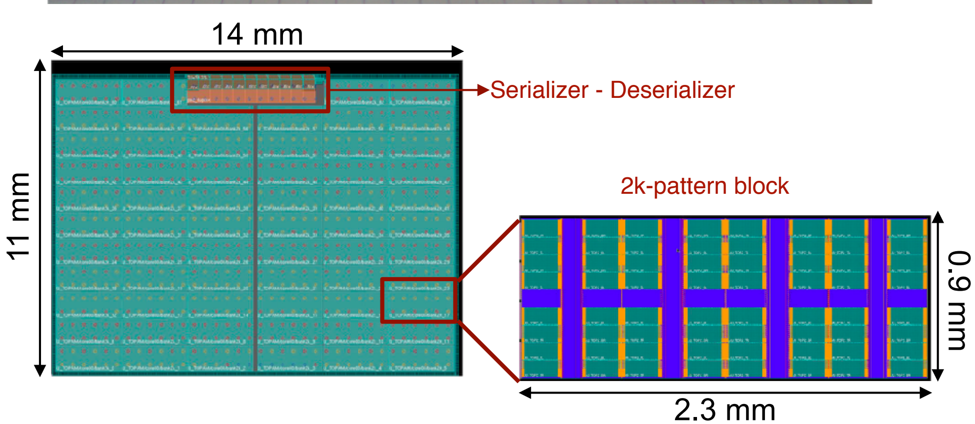
Customized VME cards

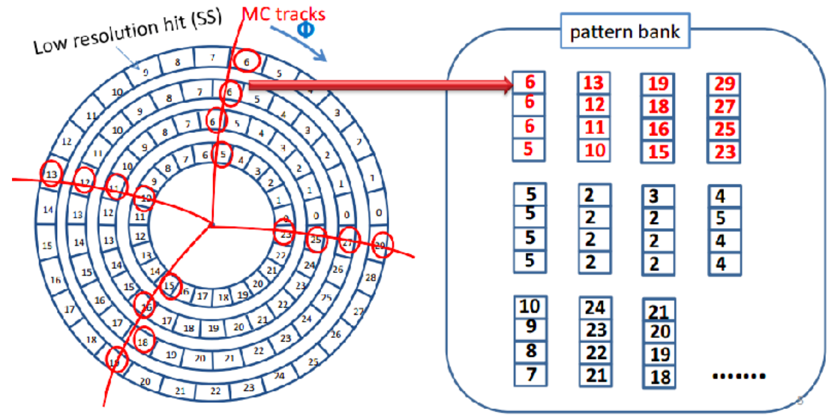
Processing unit — AM chips

AM (associative memory) chip

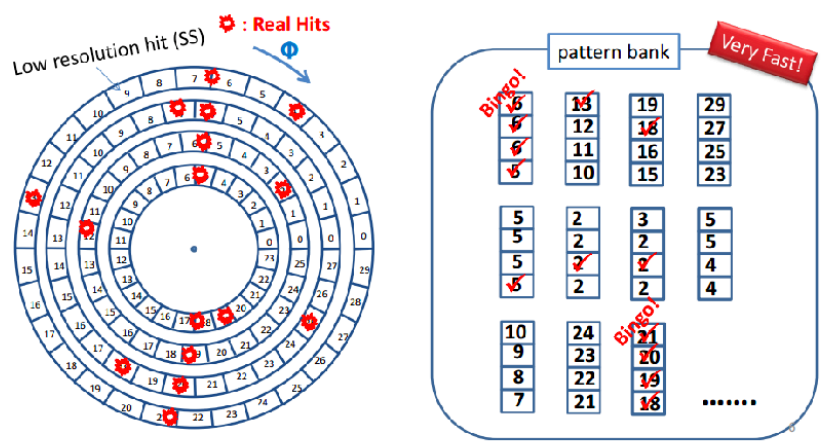
- Custom designed ASIC using 65nm technology
- Content Addressable Memory (CAM) with 128000 patterns / chip (1 billion in system)
- Low voltage (1.2 V) / low power (3 W)
  - Energy usage: 2.3 fJ / comparison / bit
  - Important effort, to minimize heat
- Stores the pre-calculated tracks and makes bit-wise comparisons







All possible patterns determined from simulation



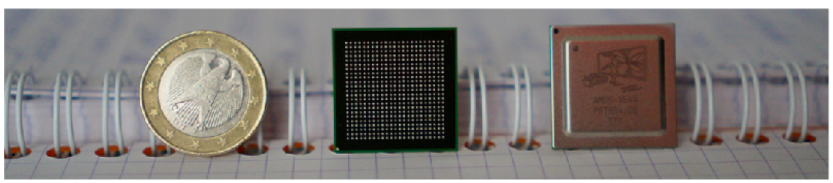
Custom associative memory (AM) chips are used to compare hits to O(10^9) patterns simultaneously

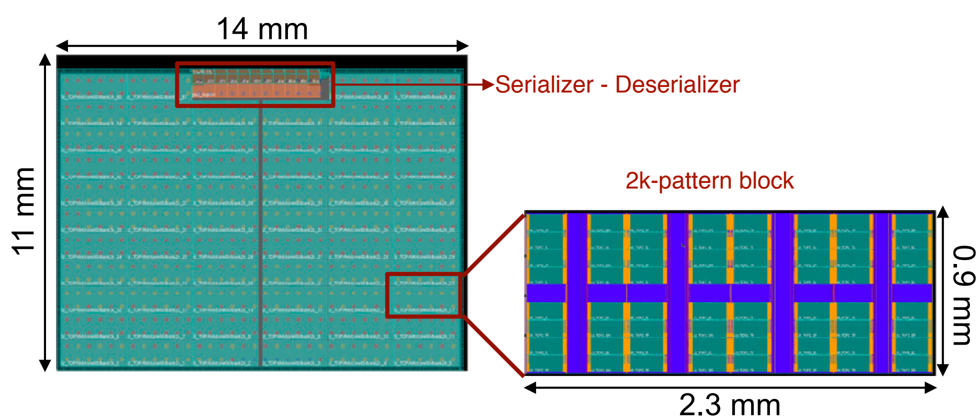
Argonne NATIONAL LABORATORY

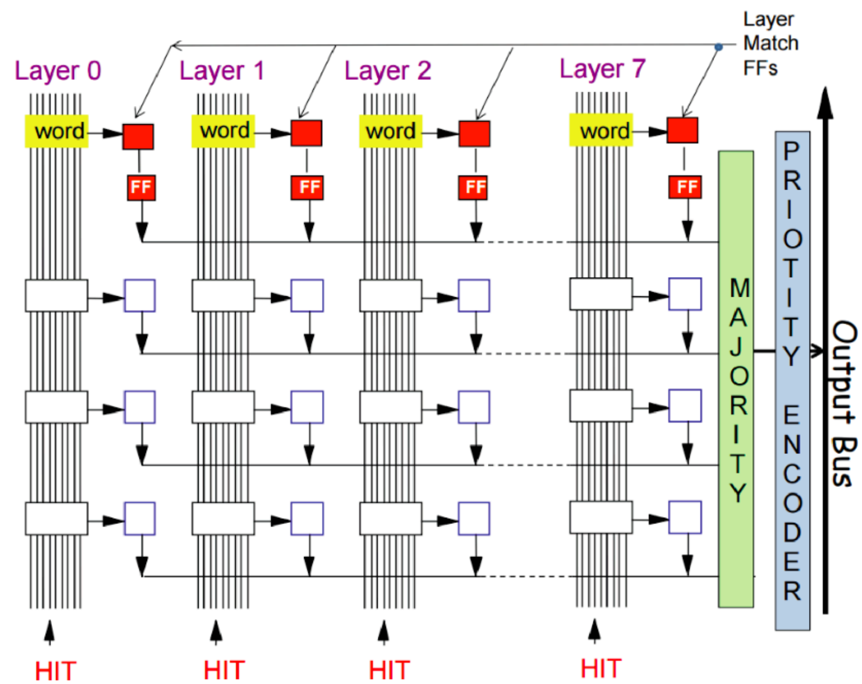
Processing unit — AM chips

AM (associative memory) chip

- Custom designed ASIC using 65nm technology
- Content Addressable Memory (CAM) with 128000 patterns / chip (1 billion in system)
- Low voltage (1.2 V) / low power (3 W)
  - Energy usage: 2.3 fJ / comparison / bit
  - Important effort, to minimize heat
- Stores the pre-calculated tracks and makes bit-wise comparisons





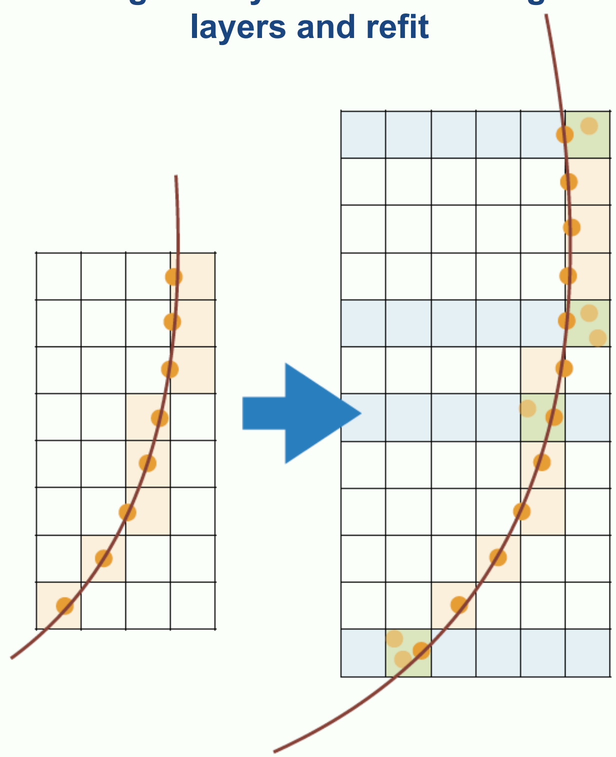


SSB — track fitting

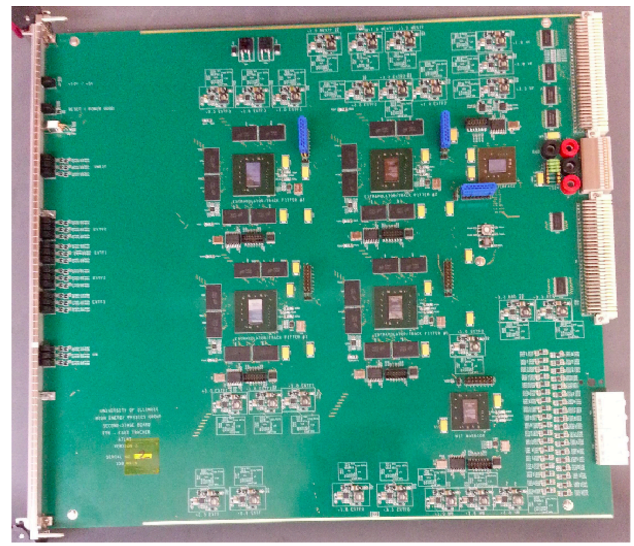
SSB* (Second Stage Board)

- 8-layer to 12-layer extrapolation + 12-layer fit
- Total 32 boards

- Receives 8-layer data from 4 AUX cards
- Receives IBL and stereo SCT hits from DF (2 towers)
- Extrapolates 8-layer fits, retrieving candidate hits to use in the 12-layer track fitting
- Performs 12-layer fit
- Retrieves intra- and inter-crate SSB 12-layer tracks, removing duplicates
- Merges FTK data and outputs to FLIC



SSB Main board



Customized VME cards

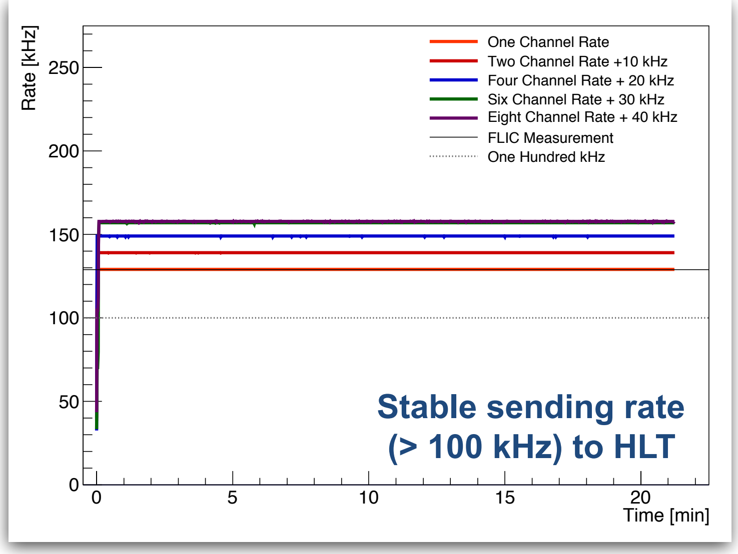
Argonne NATIONAL LABORATORY

FLIC — data reformatting

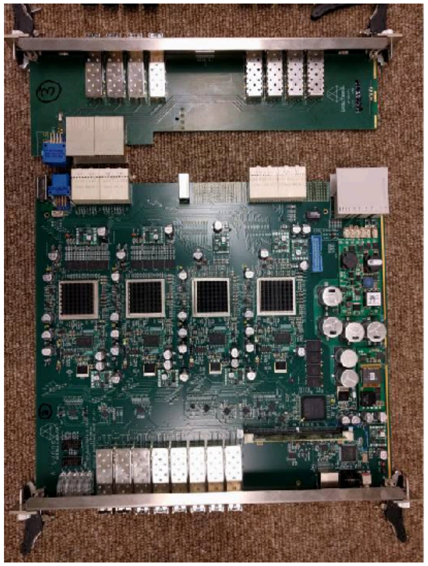
FLIC (FTK to Level-2 Interface Card)

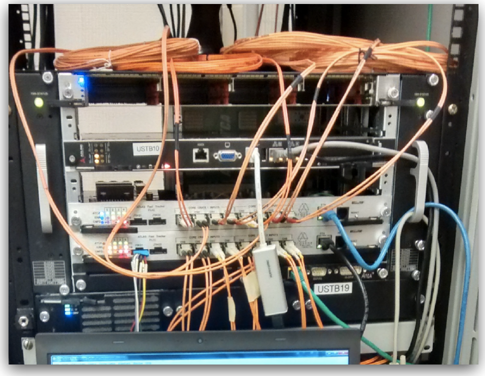
- Reformat hits & track data for HLT
- Total 2 boards + 1 ATCA processor blade

- Receive data from 1/16th of the detector per channel (2 SSB)
- Baseline: 300 tracks per event @ 100 kHz
- Convert FTK identifiers to ATLAS global identifiers using SRAM lookup
- Repackage event record into standard ATLAS format
- Communicate with HLT
- Duplicate data through fabric FPGA to ATCA Blades for monitoring and processing via backplane



2 processing FPGAs + 2 fiberic FPGAs





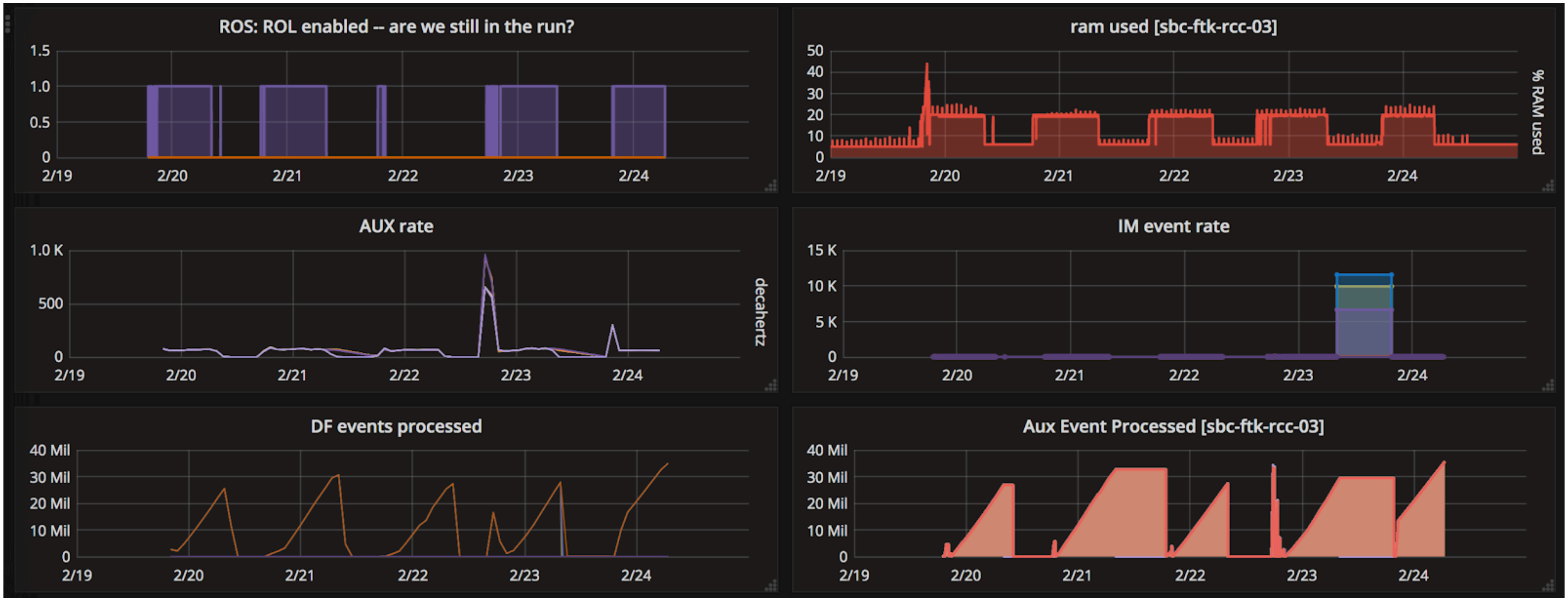
2 FLICs in ATCA shelf together with ATCA blade

Customized ATCA (Advanced Telecommunication Computing Architecture) board

FTK status

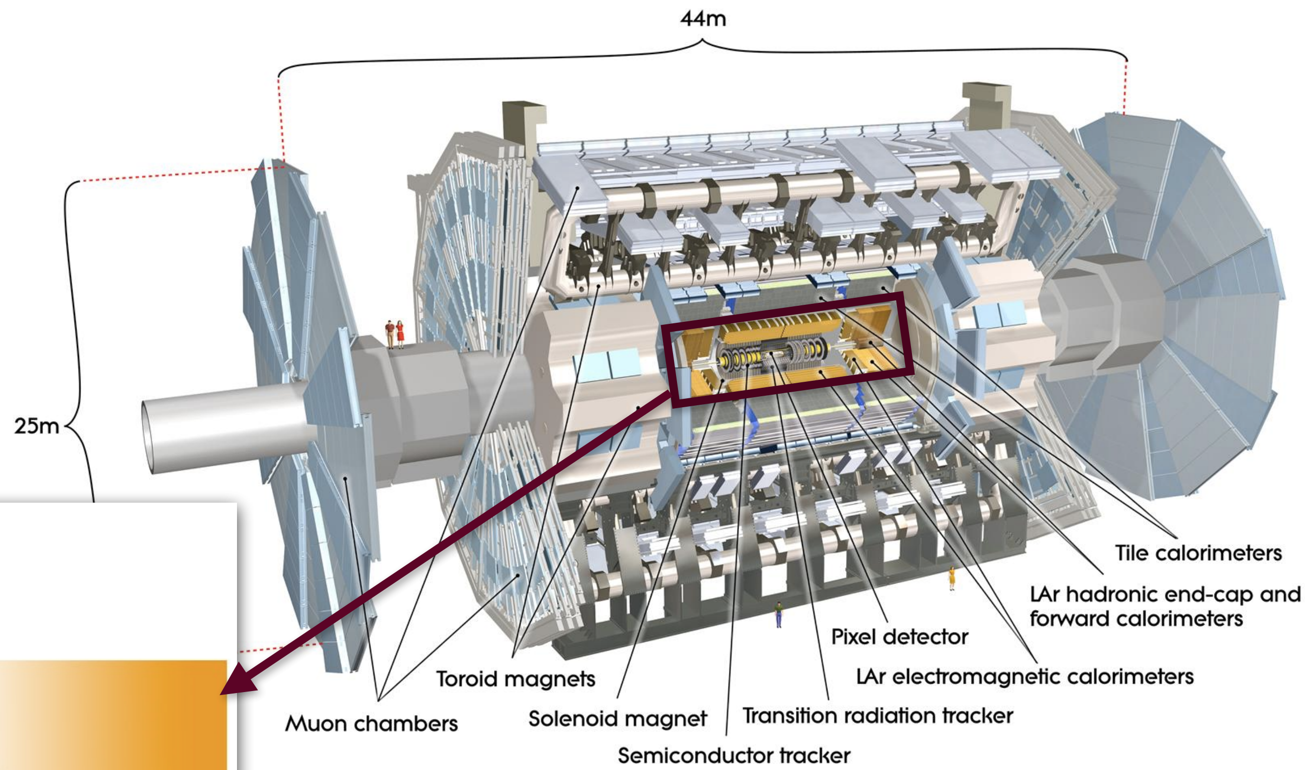
- Part of the system has been integrated with ATLAS in Feb 2018
  - FTK triggers are in the 2018 physics menu
    - Prescaled L1 triggers: L1MU_FTK, L1MU6_FTK, L1FTK-J(topo), L1FTK-EM(topo)
- Full system is under commissioning, to be ready for Run 3

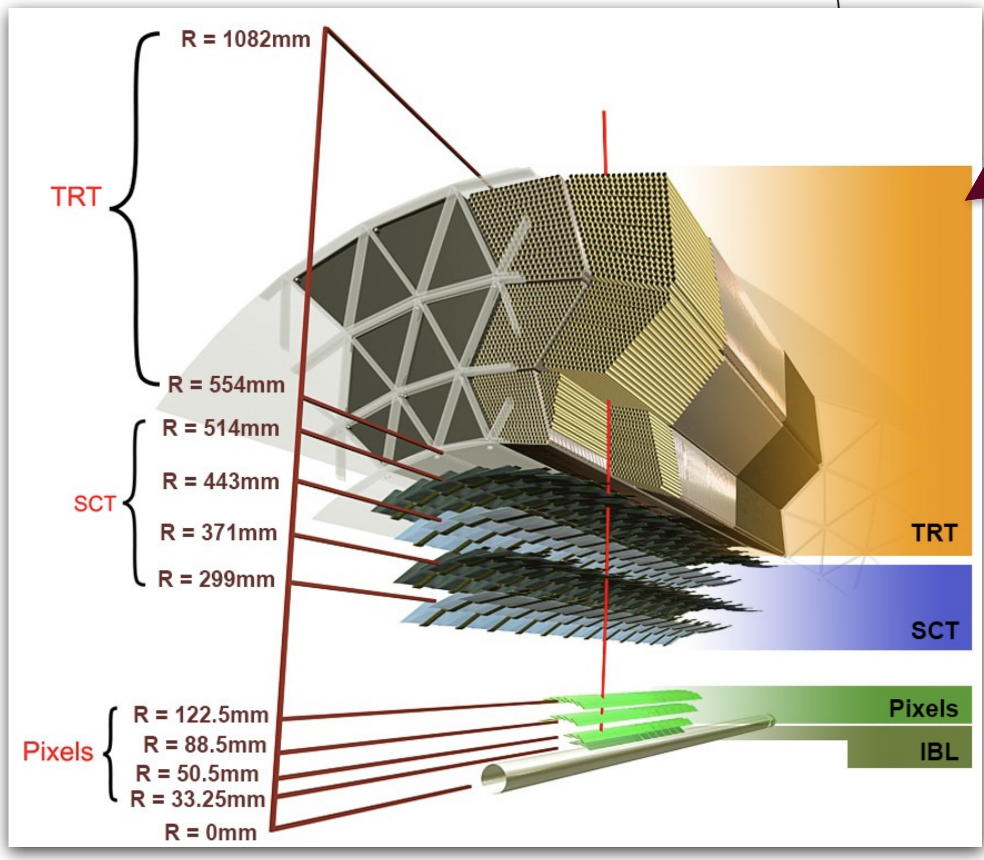
Grafana Dashboard for FTK monitoring



Argonne NATIONAL LABORATORY

Inner tracker



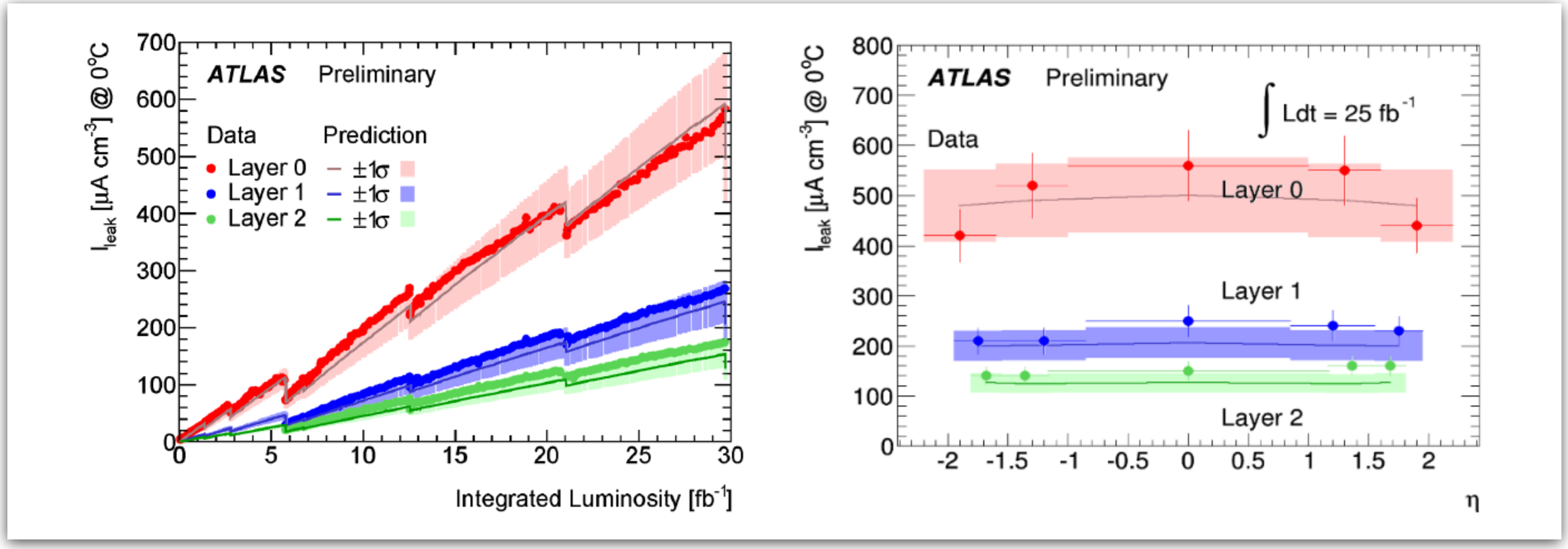


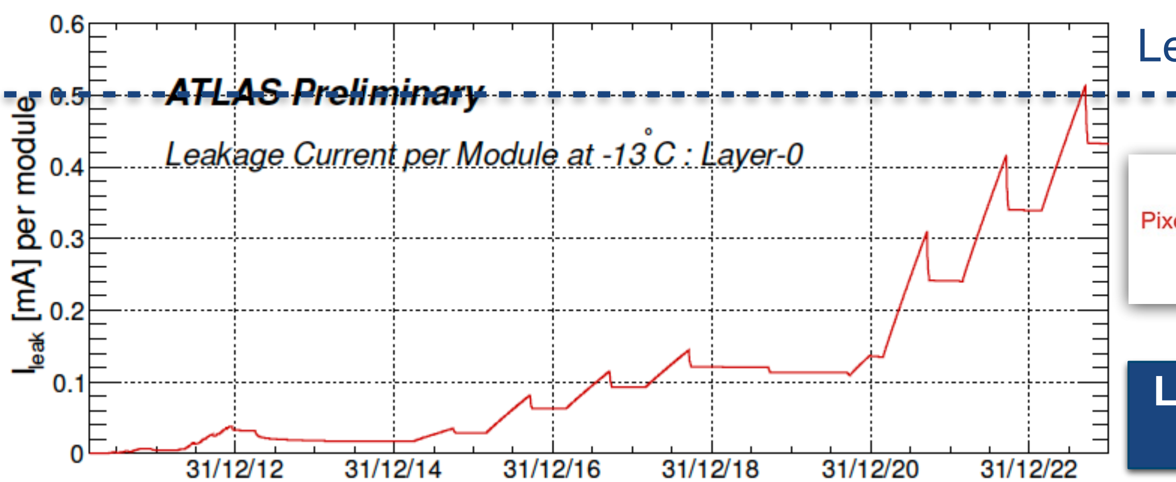
Inner tracker

- Insertable B-Layer (IBL)
- Pixel detector (Pixel)
- Semiconductor tracker (SCT)
- Transition radiation tracker (TRT)

Inner detector lifetime

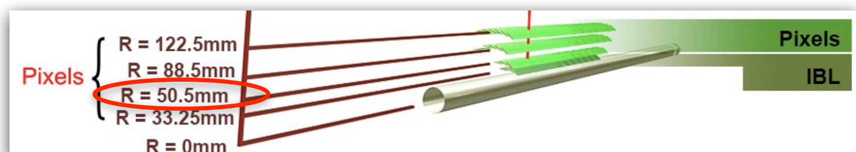
Good agreement between I_{leak} monitoring and MC simulation





ATL-INDET-PUB-2014-004 Date [dd/mm/yy]

Leakage current limitation (0.5 mA)

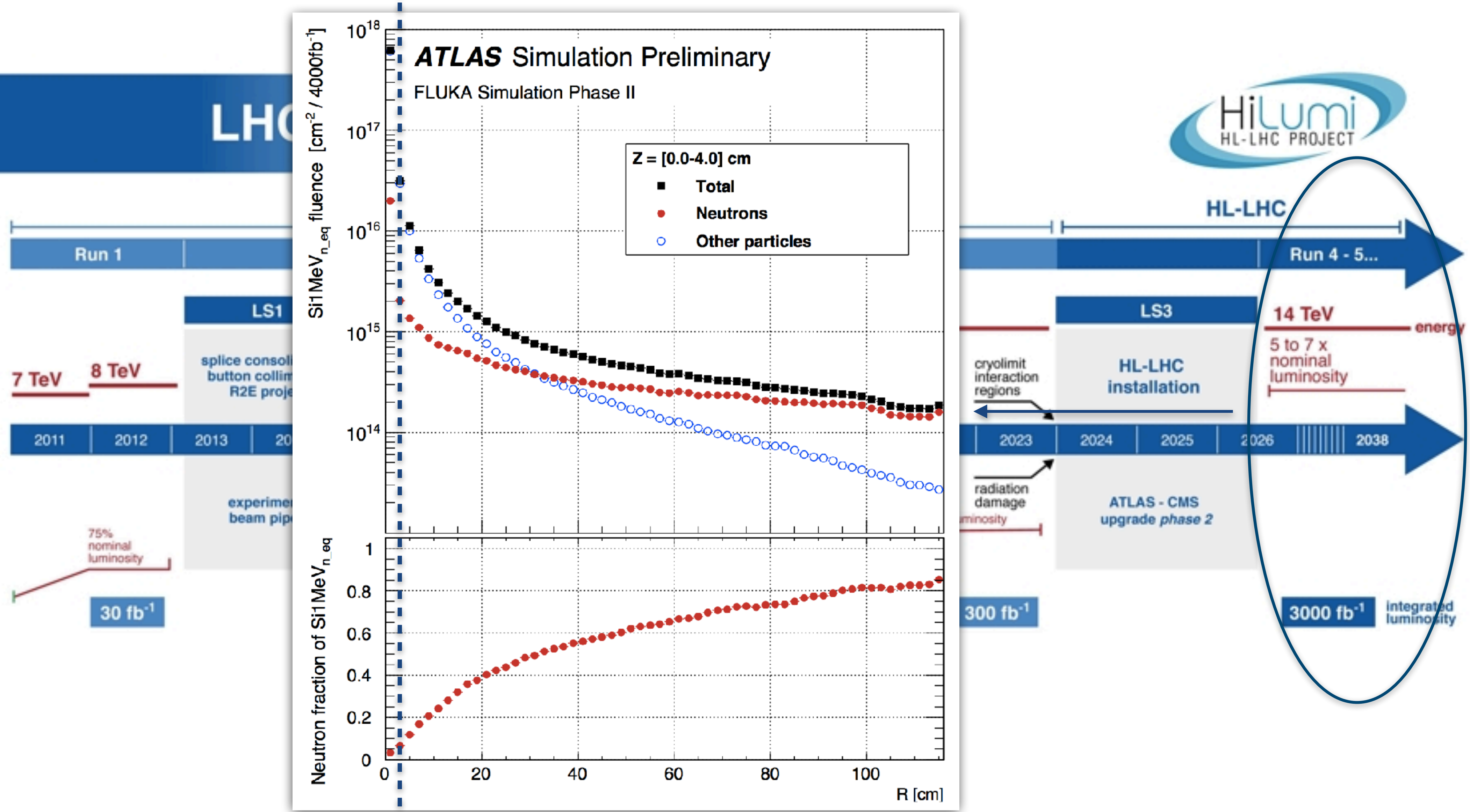


Layer-0 can survive until 2023 / 450 fb^{-1} if operate at -13^{o}C

LHC upgrade plan

Inner Tracker upgrade (ITk)

LHC upgrade plan



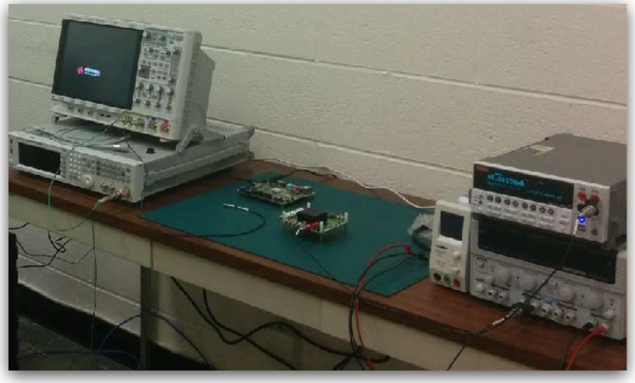
Radiation up to $2 \cdot 10^{16}$ MeV n_{eq}/cm^2 for IBL region

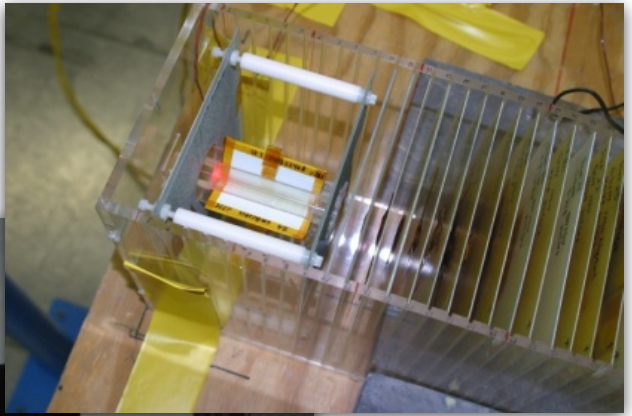
Argonne NATIONAL LABORATORY

R&D

Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

- Sensors, readout chips, cables and other device need to be irradiated and tested
  - Lab testing
    - Source
    - Laser
    - Pulse injection
  - Testbeam
    - 800 MeV proton beam at Los Alamos National Lab
    - 4 GeV electron beam at DESY
    - 24 GeV proton beam at CERN
    - 120 GeV proton beam at Fermilab
    - …

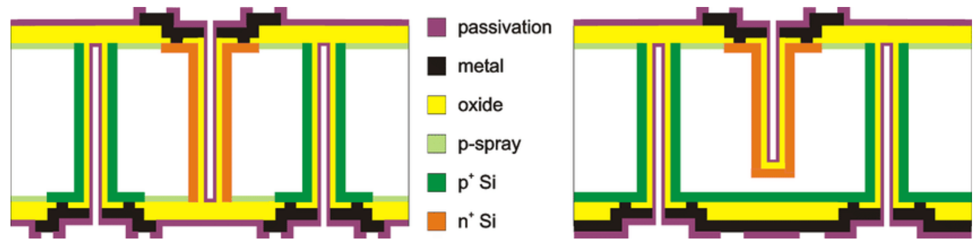




R&D

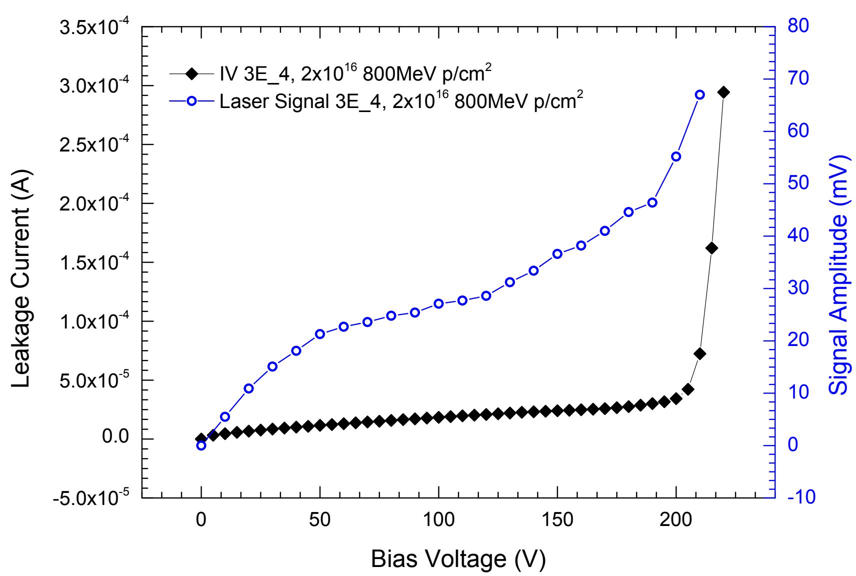
Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

- Different sensor technologies been investigated
  - 3D silicon sensor
    - Successfully used in IBL
    - Radiation hard design



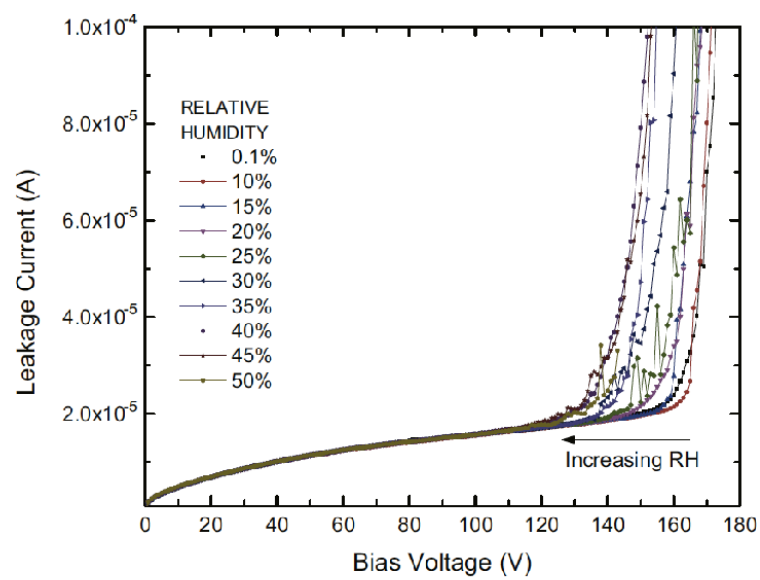
Sensor characterization

I_{leak} and signal Amp vs V_b



Nuclear Instruments and Methods in Physics Research A 685 (2012) 98–103

I_{leak} vs V_b under different humidity

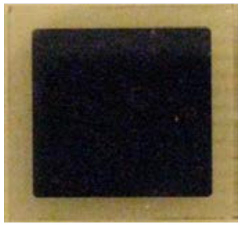


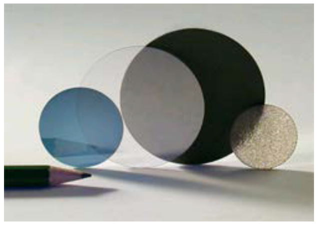
Nuclear Instruments and Methods in Physics Research A 785 (2015) 1–4

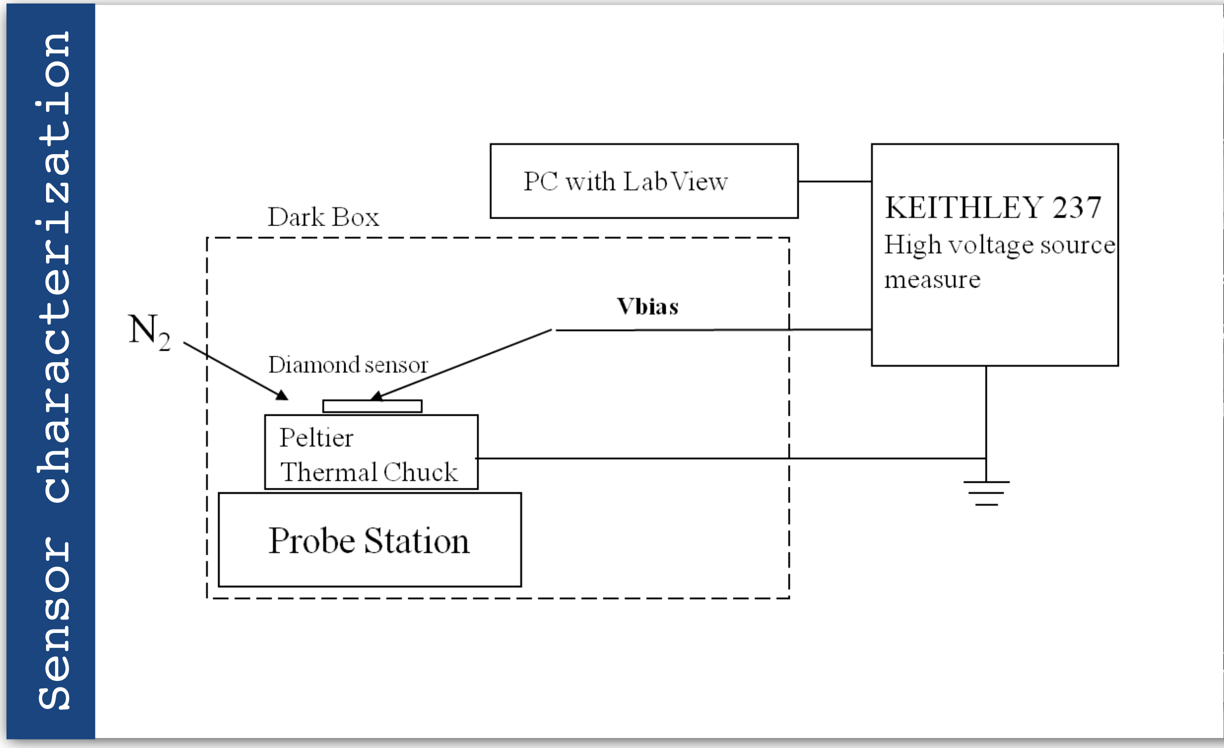
Sensor characterization

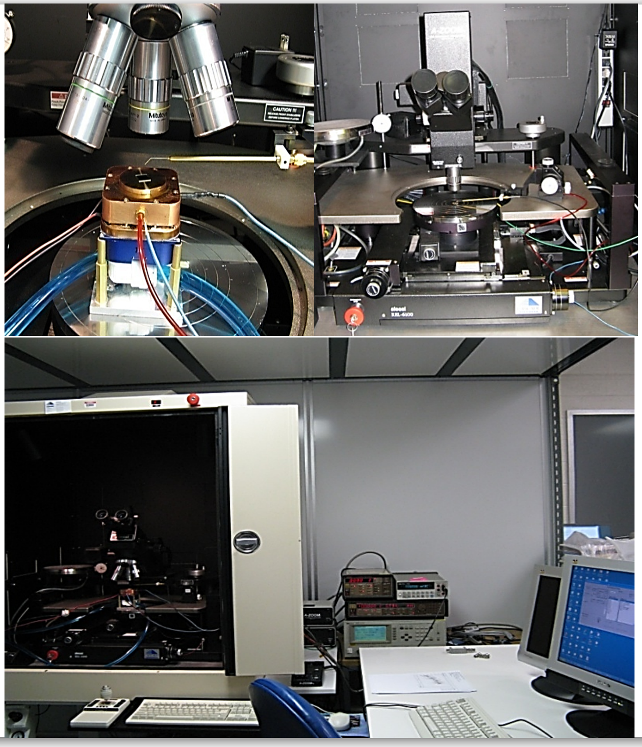
Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

- Different sensor technologies been investigated
  - Diamond sensor
    - Used in beam monitoring (DBM)
    - Extremely radiation hard







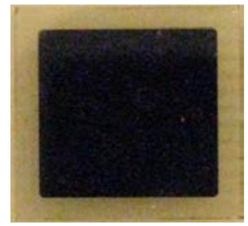


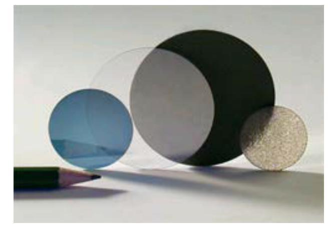
Argonne NATIONAL LABORATORY

R&D

Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

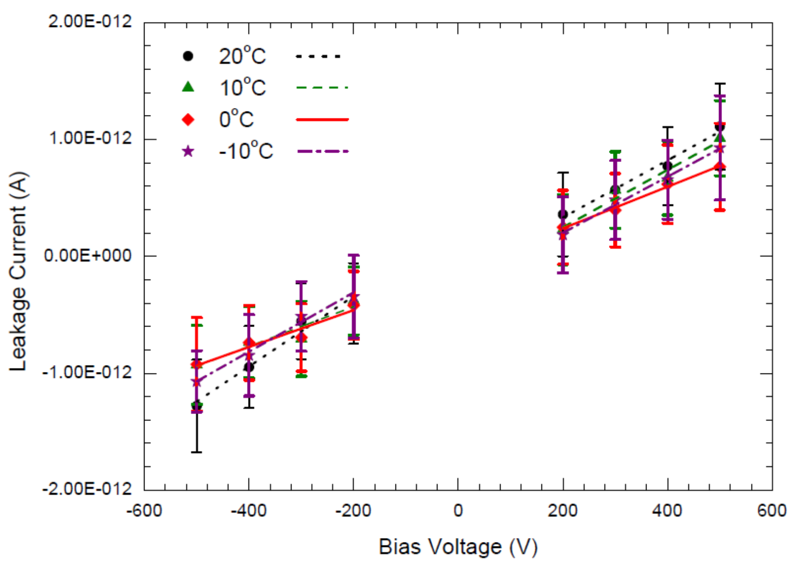
- Different sensor technologies been investigated
  - Diamond sensor
    - Used in beam monitoring (DBM)
    - Extremely radiation hard



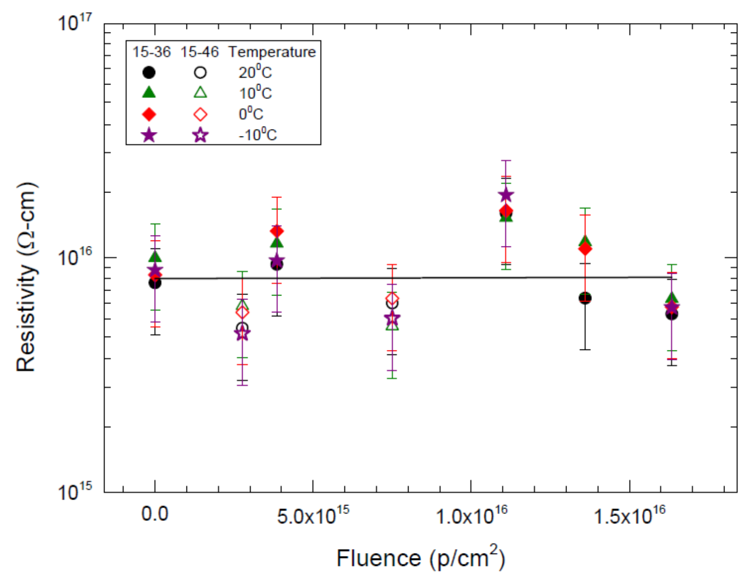


Sensor characterization

I_{leak} vs V_b under different temperature



Resistivity under different temperature

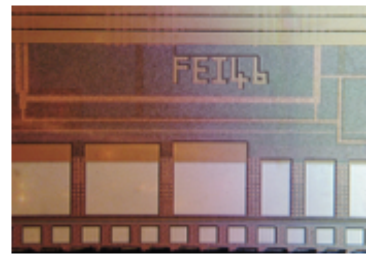


Nuclear Instruments and Methods in Physics Research A 735 (2014) 610-614

Module characterization

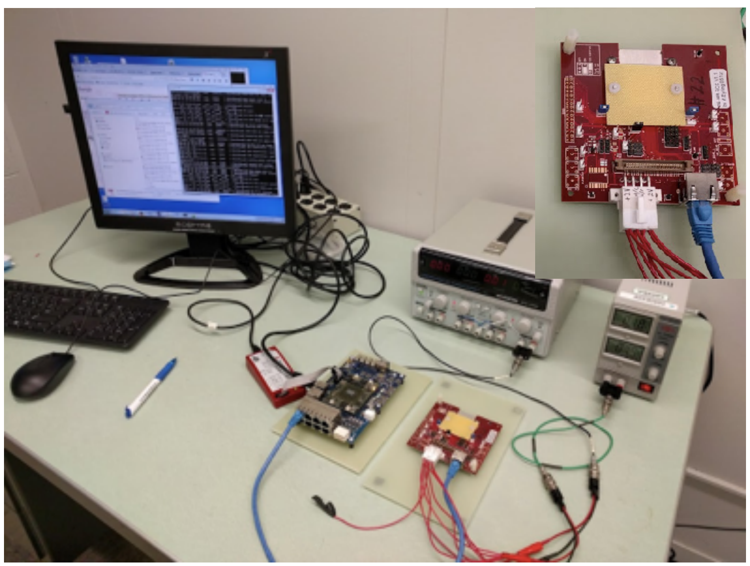
Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

- Sensors, readout chips, cables and other device need to be irradiated and tested
  - FEI4b pixel sensor readout chip
    - Currently used for IBL



module characterization

Test stand — in lab



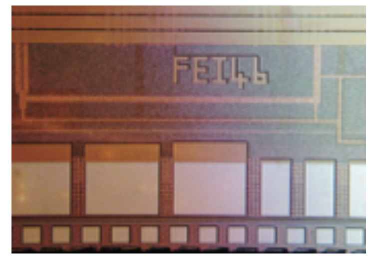
Telescope — Fermilab test beam

180nm CMOS

Module characterization

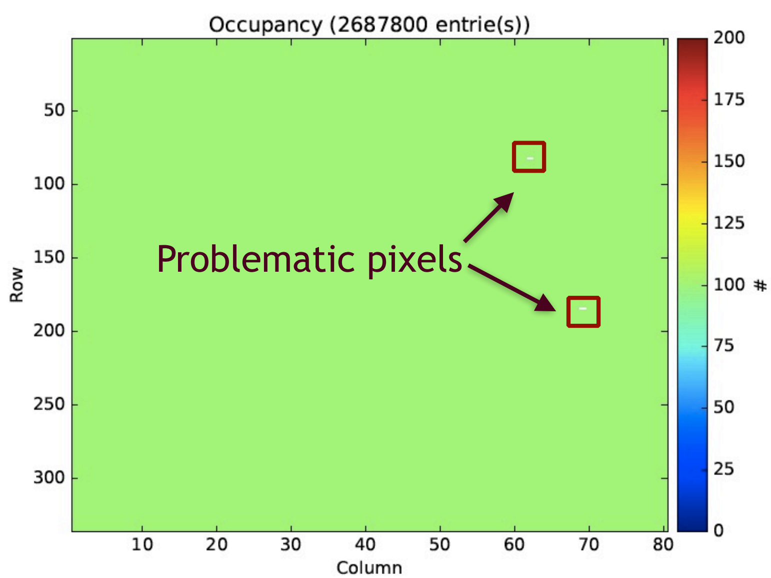
Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

- Sensors, readout chips, cables and other device need to be irradiated and tested
  - FEI4b pixel sensor readout chip
    - Currently used for IBL

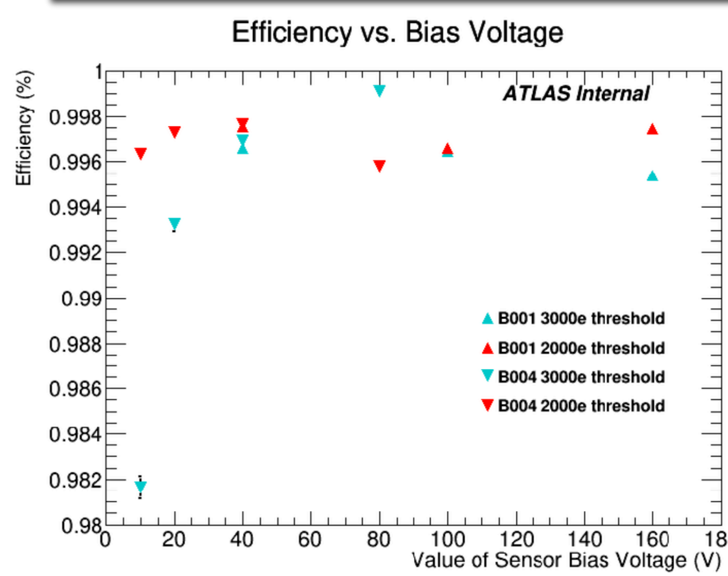


module characterization

Occupancy map (noise only)



Hit efficiency vs V_b with different thresholds



180nm CMOS

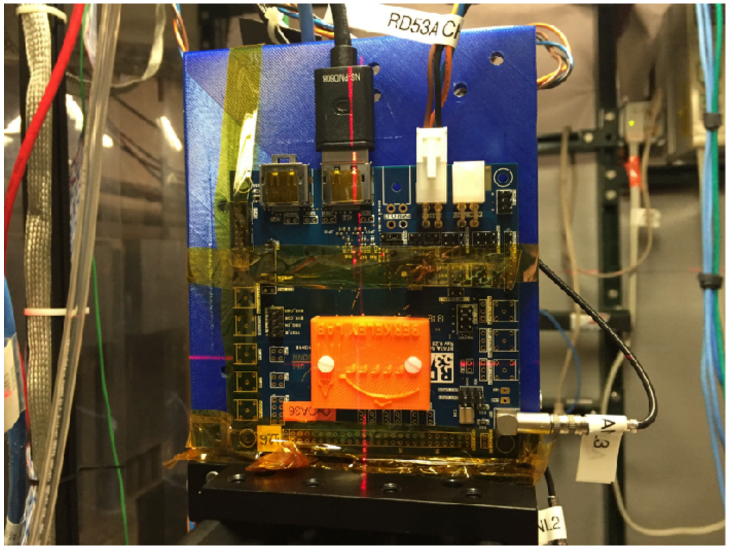
Module characterization

Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

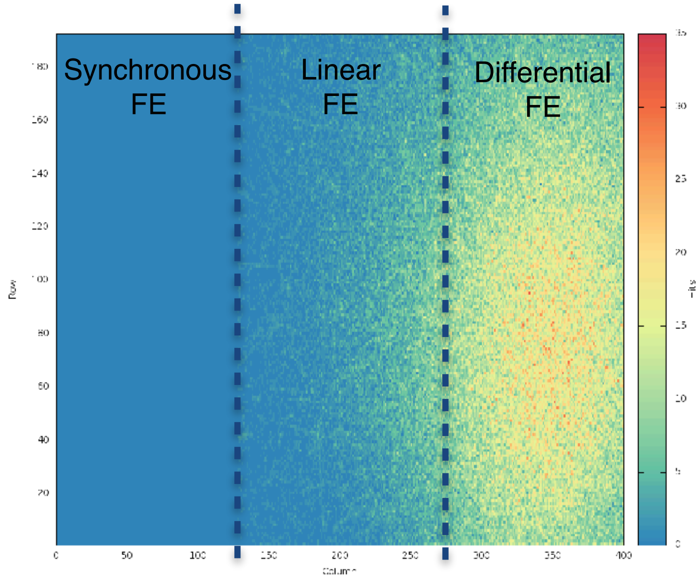
- Sensors, readout chips, cables and other device need to be irradiated and tested
  - RD53A readout chip
    - Designed for ITK readout

module characterization

RD53A module



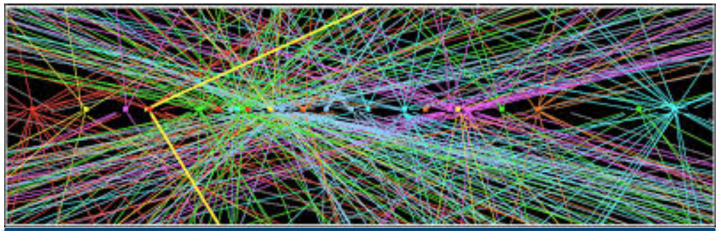
Hit Occupancy map



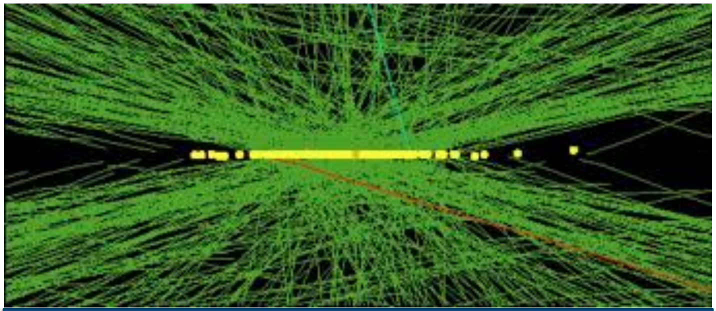
65nm CMOS

HL-LHC

HL-LHC era will be challenging with high pileups



Current LHC: ~25 vertices



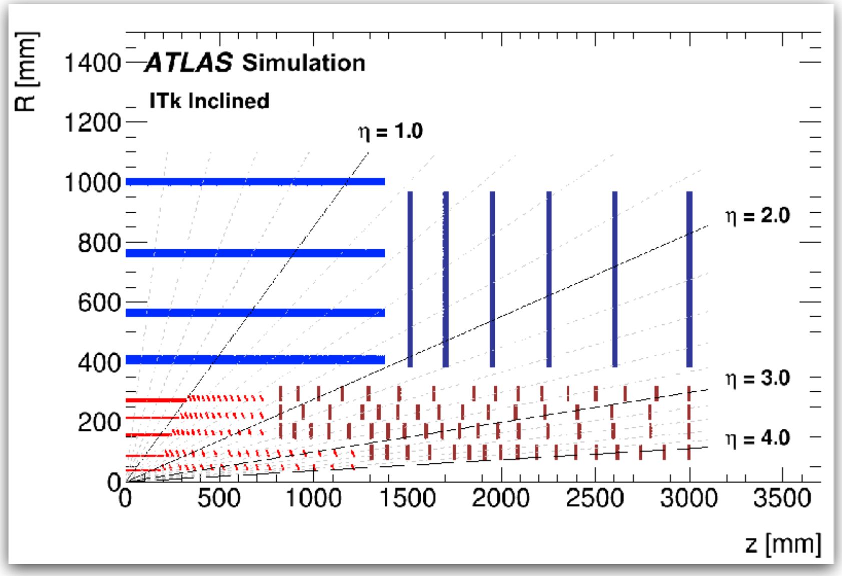
HL-LHC: ~200 vertices

Operational parameters:

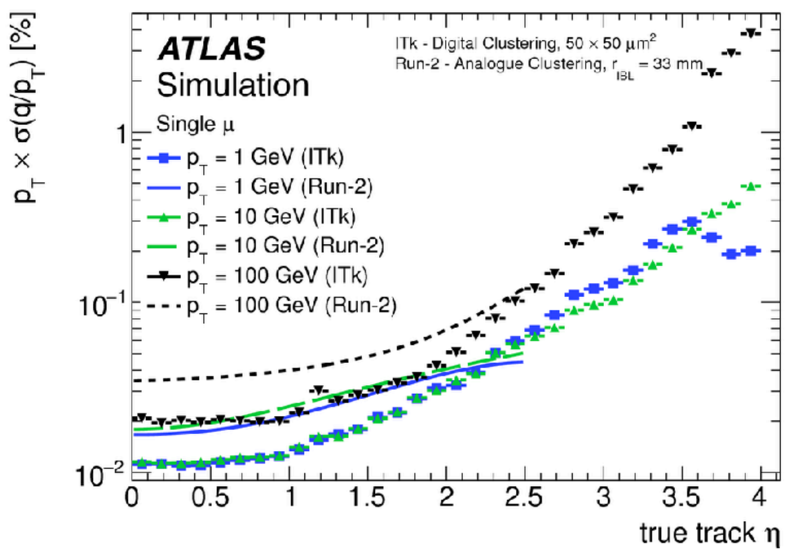
- Center of mass energy: $\sqrt{s}$ = 14 TeV
- Instantaneous luminosity: 5.0×10^{34} $cm^{-2}s^{-1}$
- Average interactions per bunch crossing: $\langle\mu\rangle = 200$
- Integrated luminosity: 3 ab^{-1}

ITk performance

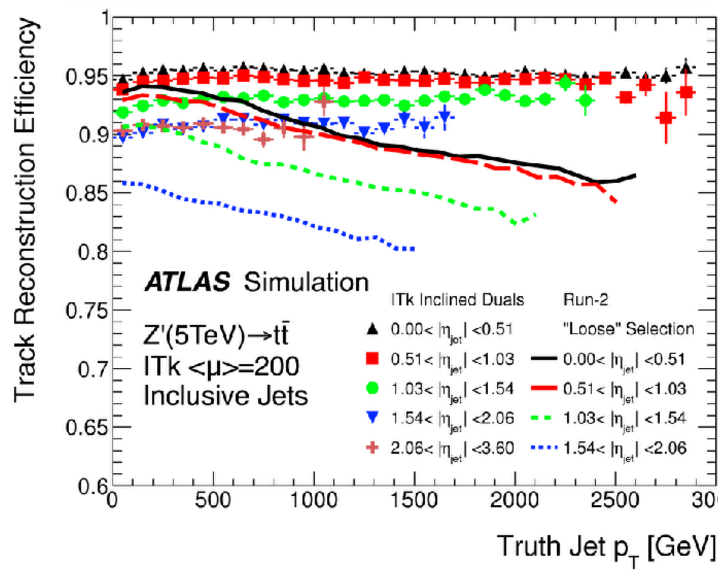
- Lots of improvement comparing to Run 2
  - Better track parameter resolution
  - Enhanced reconstruction efficiency for tracks in jets
  - Higher b-tagging efficiency and rejection power
  - …



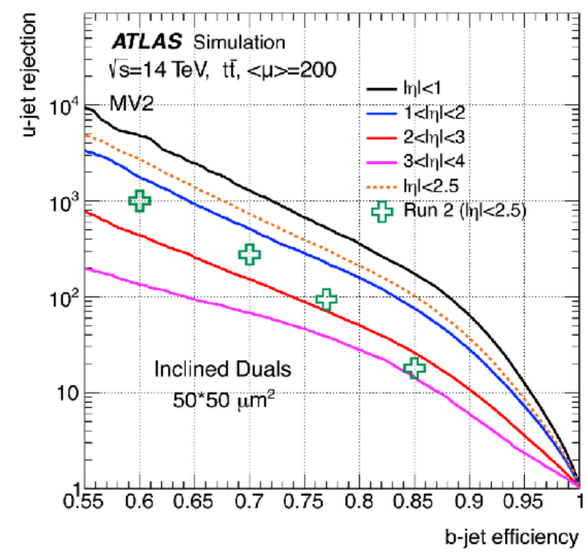
Track parameter resolution in p_T



Recon. efficiency for tracks in jets



MV2 tagger



Argonne NATIONAL LABORATORY

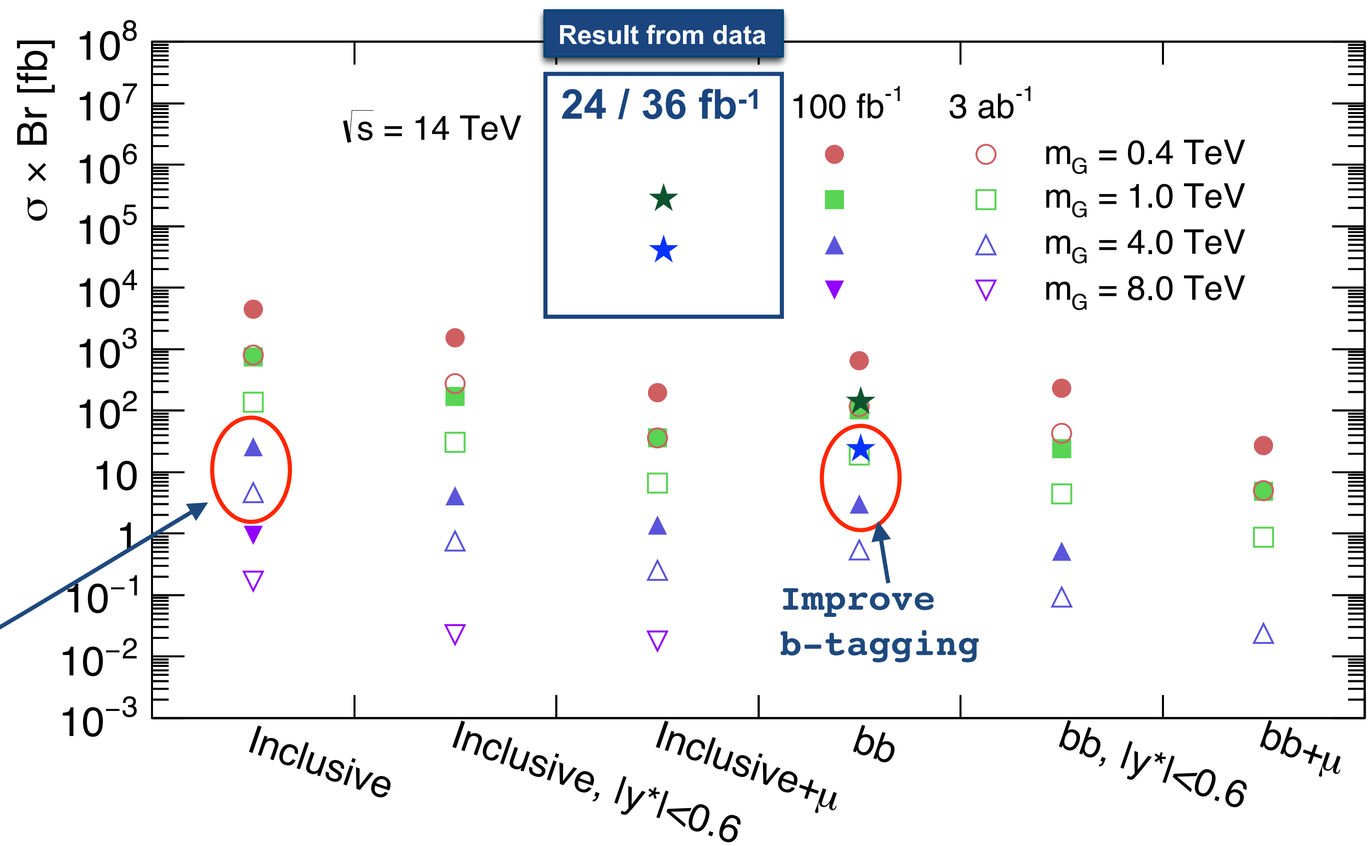
di-jet searches at HL-LHC

Great physics program is foreseen with 3ab-1

When luminosity Increases from 100 fb-1 to 3 ab-1, it gives ~10 times better exclusive limit on the cross section * Br

eg. blue filled triangle vs blue open triangle

- Inclusive di-jet at 4 TeV



Exclusion limits of Gaussians ($\sigma_G / M_G = 10\%$) of various di-jet searches

Argonne NATIONAL LABORATORY

Summary and outlook

ATLAS at full speed on upgrade to cope with that

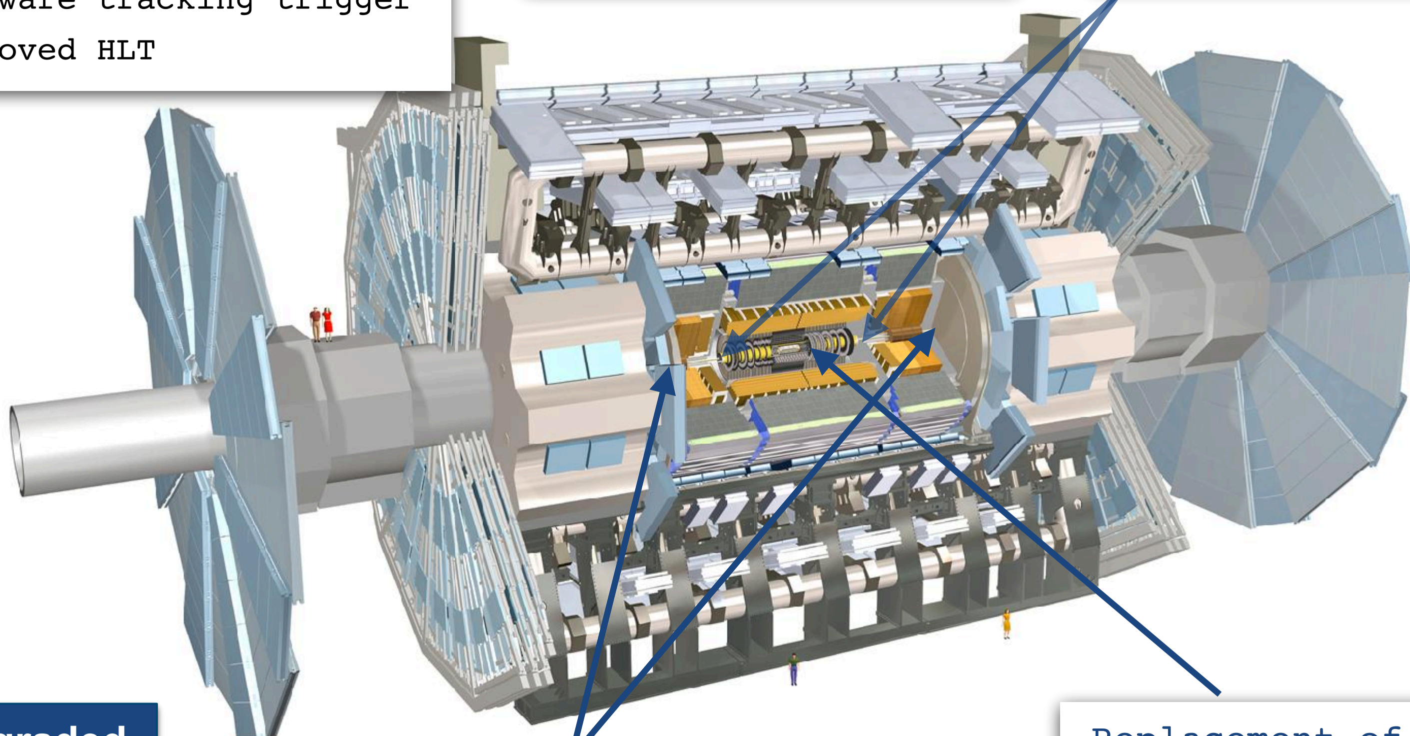
Upgraded TDAQ system

- L0 @ 1MHz
- Access to full calorimeter granularity
- Hardware tracking trigger
- Improved HLT

Electronics Upgrade

- LAr calorimeter
- Tile Calorimeter
- Muon system

High Granularity Timing Detector (HGTD) $2.4 < |\eta| < 4$



The upgraded ATLAS phase II detector

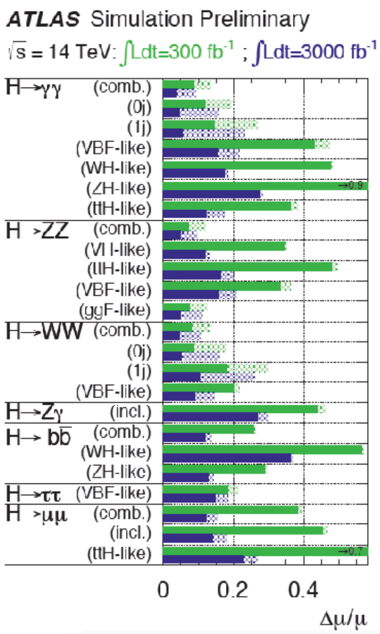
New Muons chambers in the inner Barrel region

Replacement of the Inner Detector by ITk (All silicon tracker up to $|\eta| = 4$)

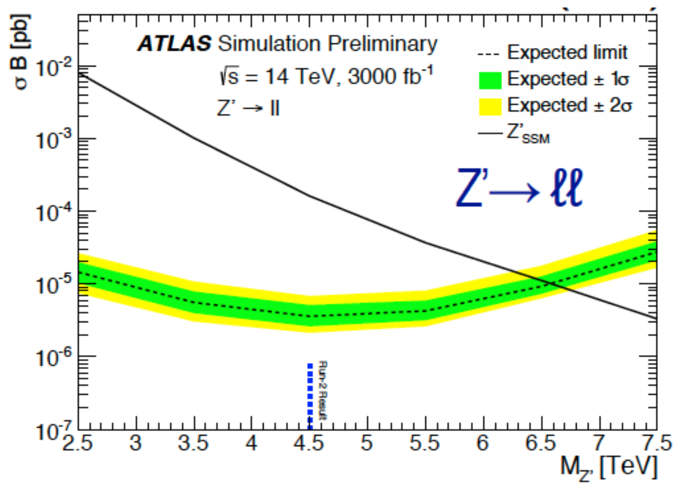
Summary and outlook

Great physics program is foreseen with 3ab-1

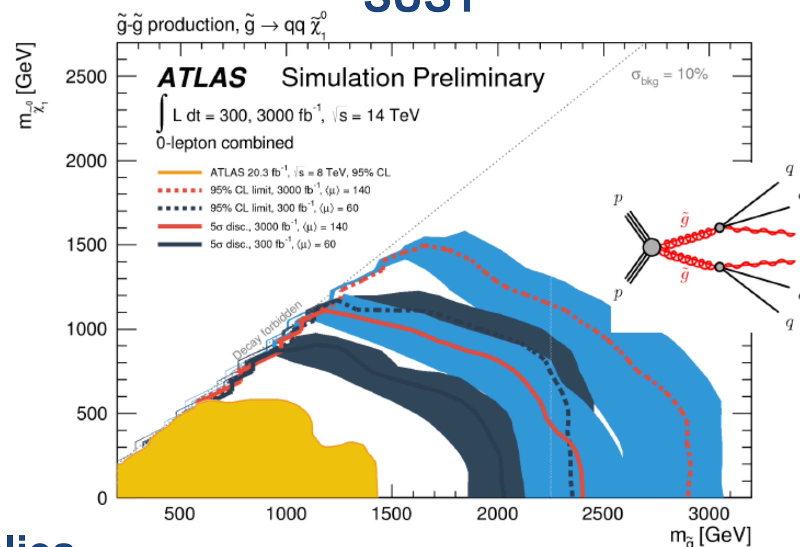
Higgs coupling



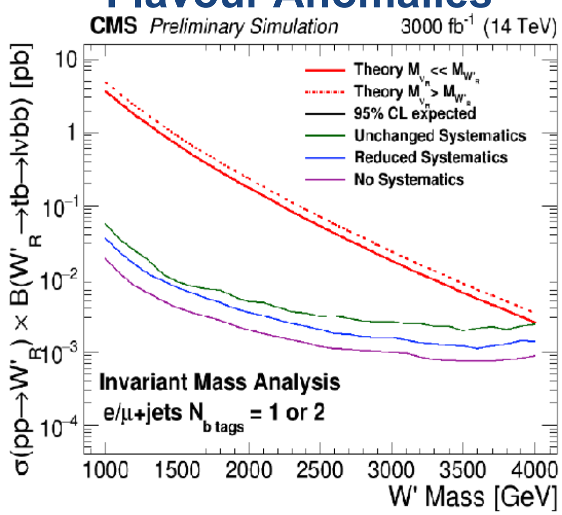
Resonances search



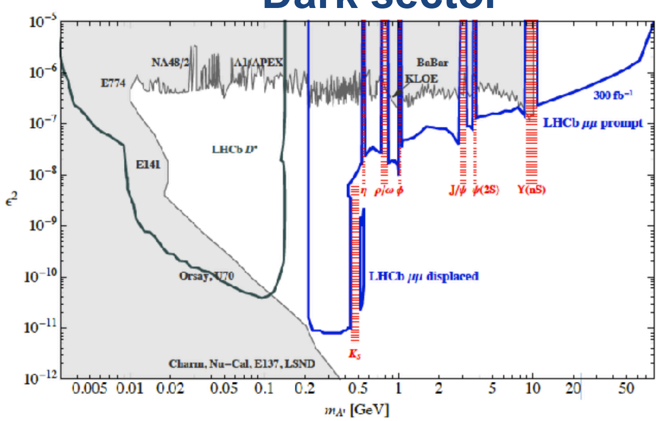
SUSY



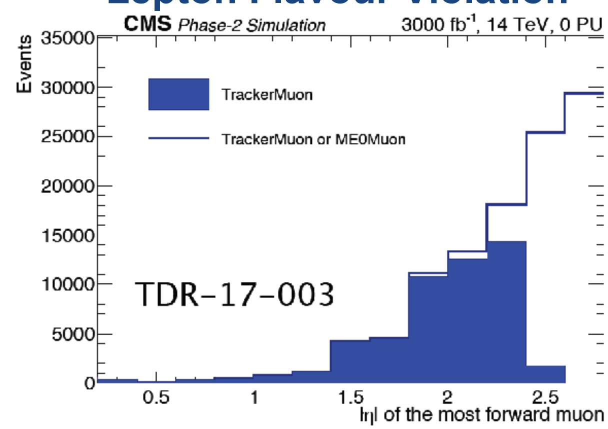
Flavour Anomalies



Dark sector



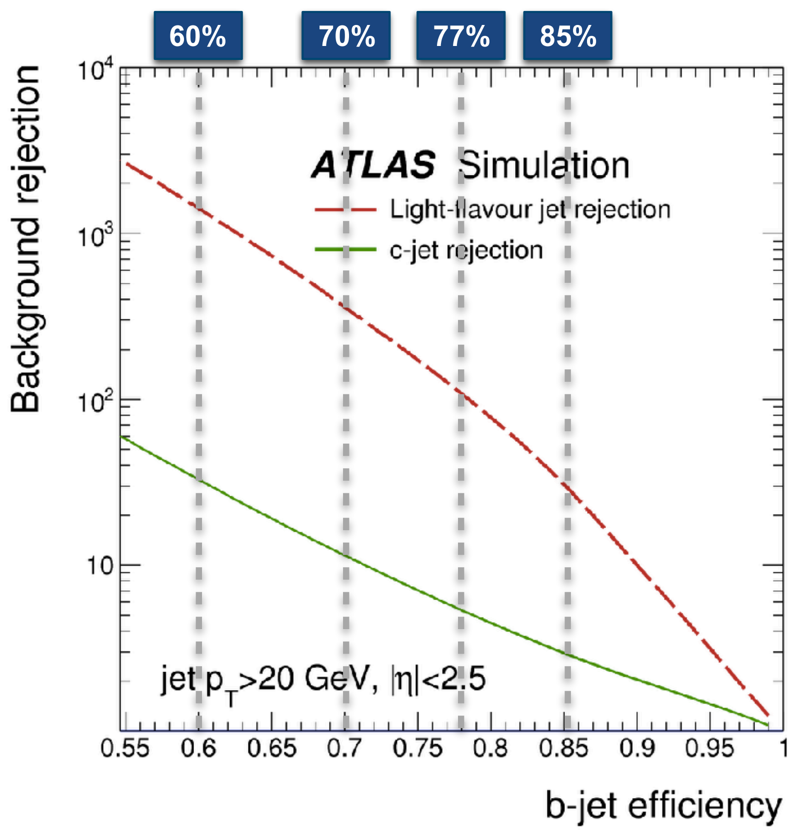
Lepton Flavour Violation



Backup

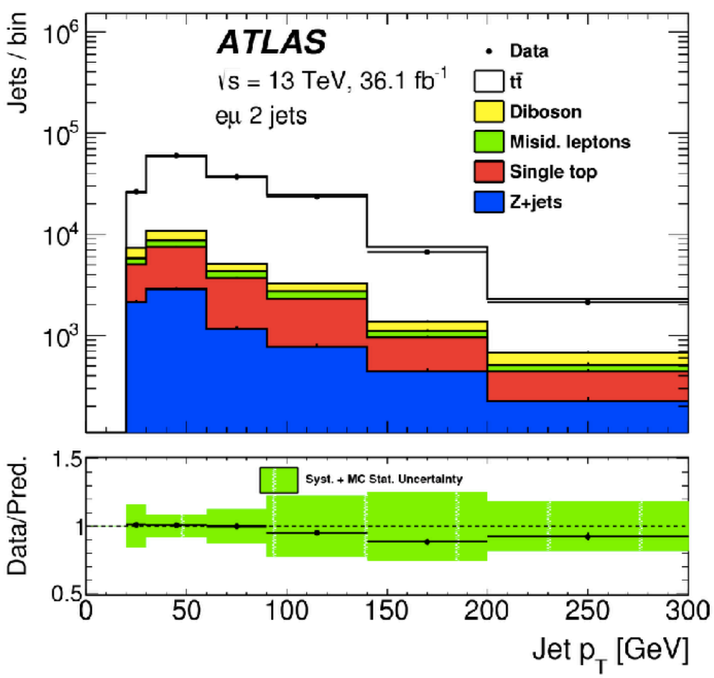
b-tagging OP definition

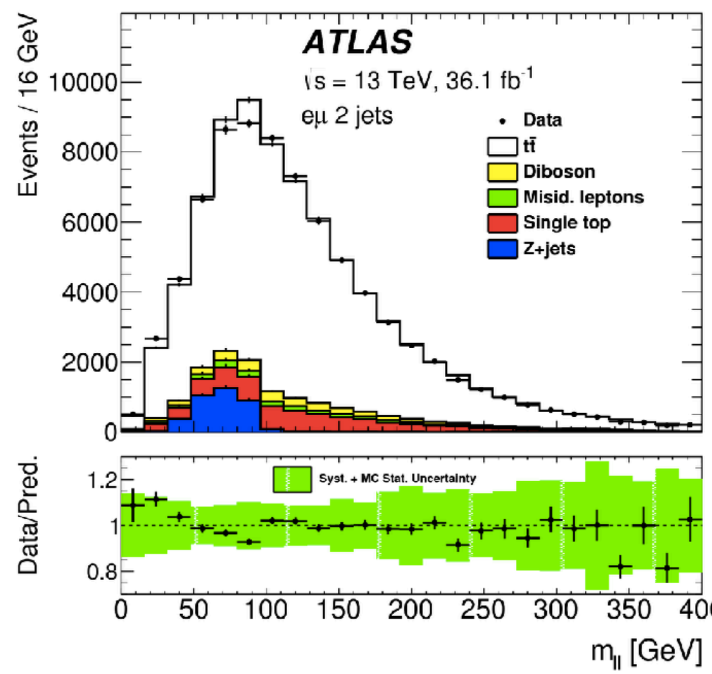
- b-jet tagging efficiency are evaluated using a high purity ttbar data sample
- Operation points are defined based on **integrated (Fixed)** / p_T-dependent (Flat) b-jet tagging efficiency



Offline b-tagging calibration

- b-jet calibration is done using high purity ttbar sample
- Including track impact parameter resolution (dominate), the fraction of poorly measured tracks, the description of the detector material, and the track multiplicity per jet
  - 0.01mm bias in track transverse impact parameter leads to ~25% increase in light jet mistag rate
- measured using data for jet p_T< 300 GeV and are extrapolated to jet p_T> 300 GeV using MC simulation





di-b-jet search — selections

High mass search

- 2015+2016 data, 36.1fb^{-1}
- Single jet trigger
- Leading jet p_T > 430 GeV, $|\eta|$< 2
- Sub-leading jet p_T > 80 GeV, $|\eta|$< 2
- $|y^*|$<0.8 (reject QCD background)
- m_{jj} > 1.2TeV
- >=1 b-tag & 2 b-tag (85% Fixed OP)

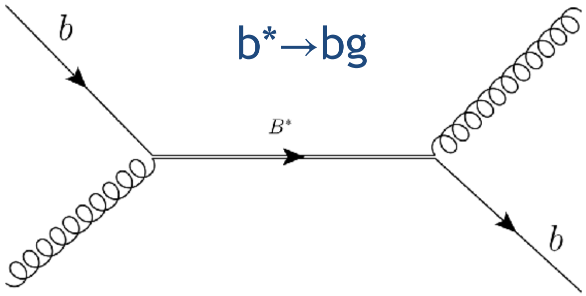
Low mass search

- 2016 data, 24.3fb^{-1}
- Double b-jet trigger
- Leading jet p_T > 150 GeV, $|\eta|$< 2
- Sub-leading jet p_T > 80 GeV, $|\eta|$< 2
- $|y^*|$<0.6 (reject QCD background)
- 0.57 TeV < m_{jj} < 1.5 TeV
- 2 b-tag (70% Fixed OP)

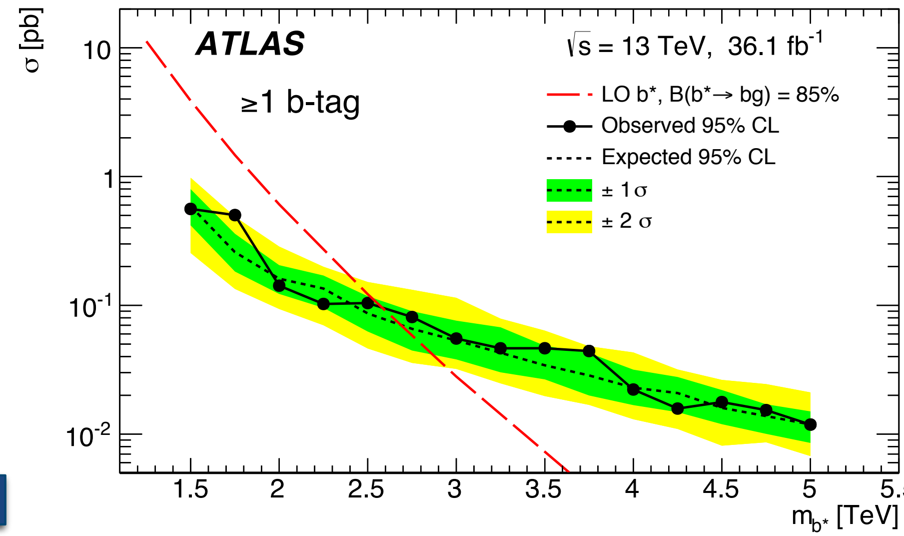
Benchmark model limit

With A*ε corrected

b* is excluded at 2.6 TeV

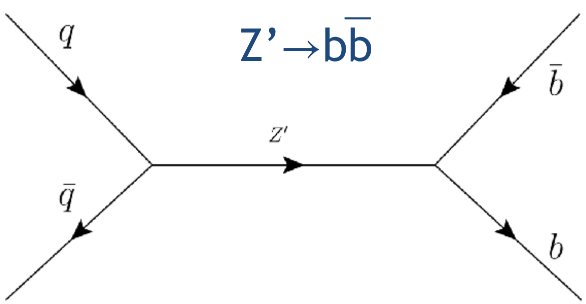


>= 1 b-tag

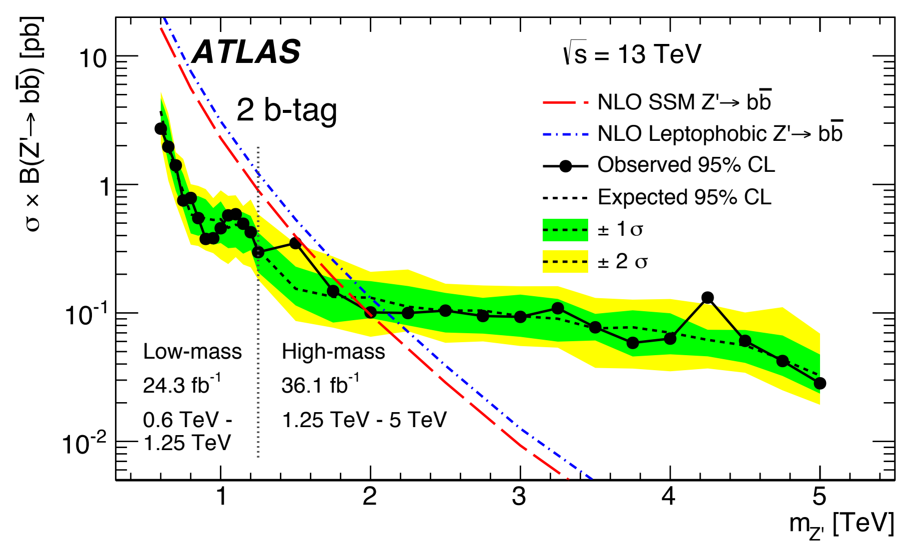


SSM Z'->bb is excluded at 2 TeV

Leptophobic Z'->bb is excluded at 2.1 TeV



2 b-tag



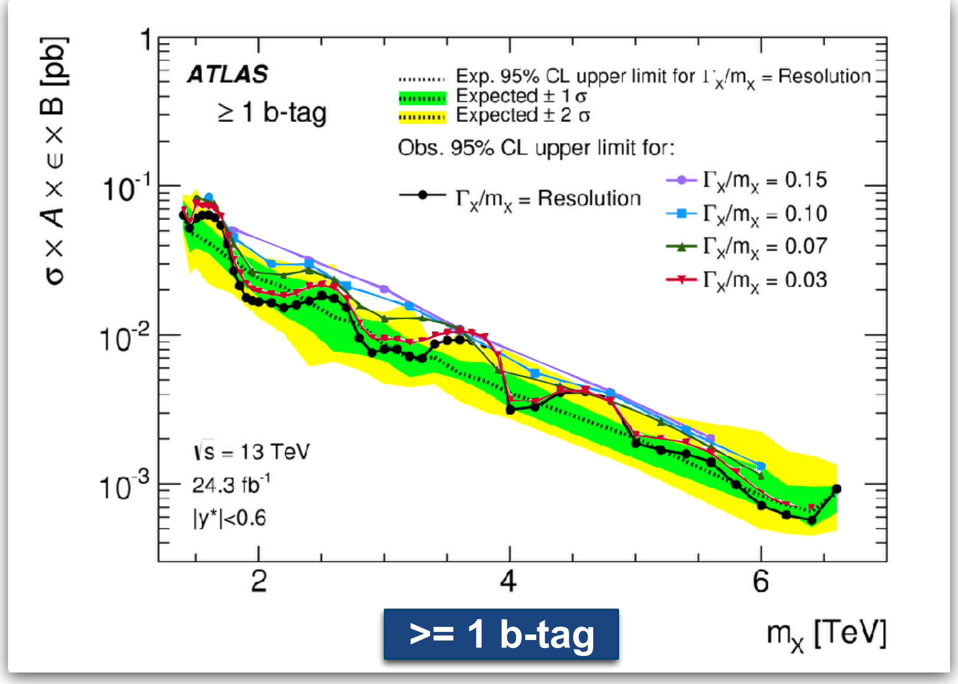
Better limit is picked in the overlap region for combination

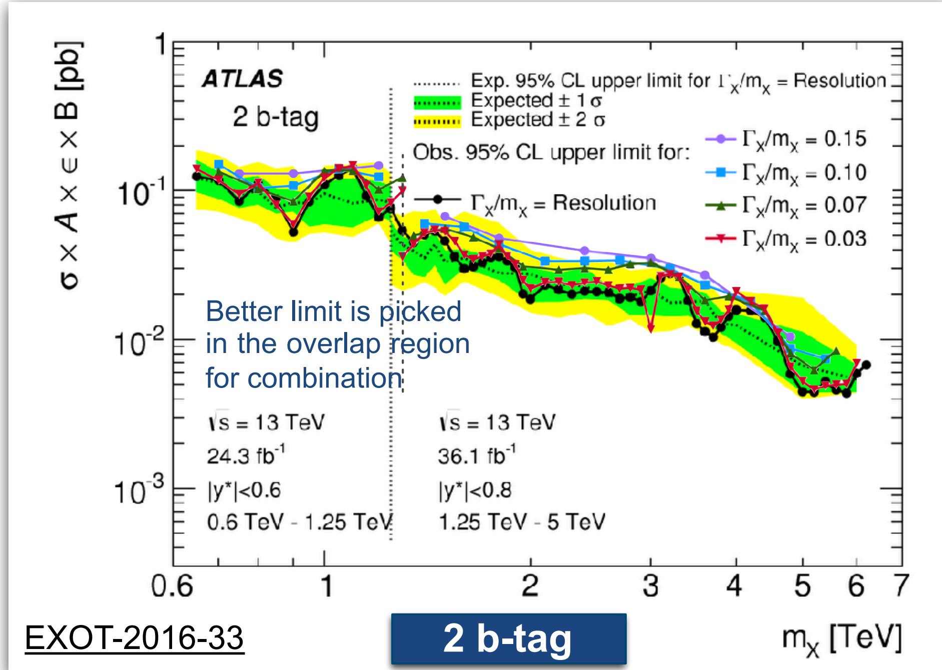
EXOT-2016-33

Gaussian limits

- There are many signal candidates other the b* and Z' which are picked as benchmarks
- These signals can be approximated by an Gaussian shape after reconstruction
- 95% CL. upper limits are set on Gaussian shapes with widths of detector resolution, 3%, 7%, 10% and 15% relative to the signal mass
- Useful in reinterpretation

With b-jet trigger and offline b-tagging efficiency corrected





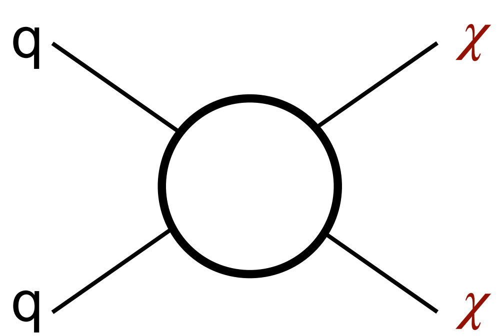
EXOT-2016-33

DM models used at ATLAS

1507.00966
details in Wendy Taylor's talk

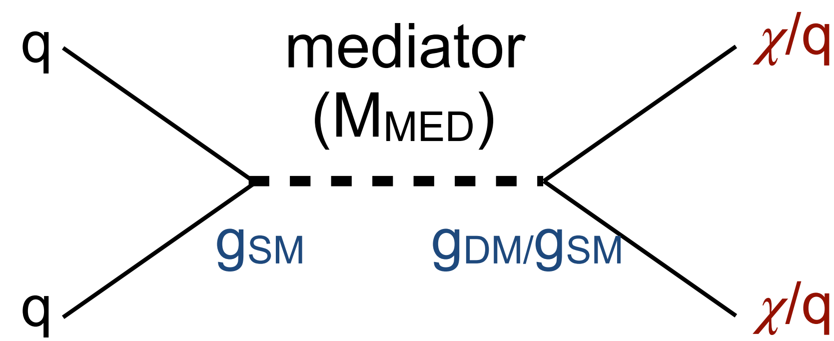
Effective field Theory

- m_{DM}, M*, underlying coupling type, DM types
- Valid when mediator of the interaction between SM and DM particles are very heavy



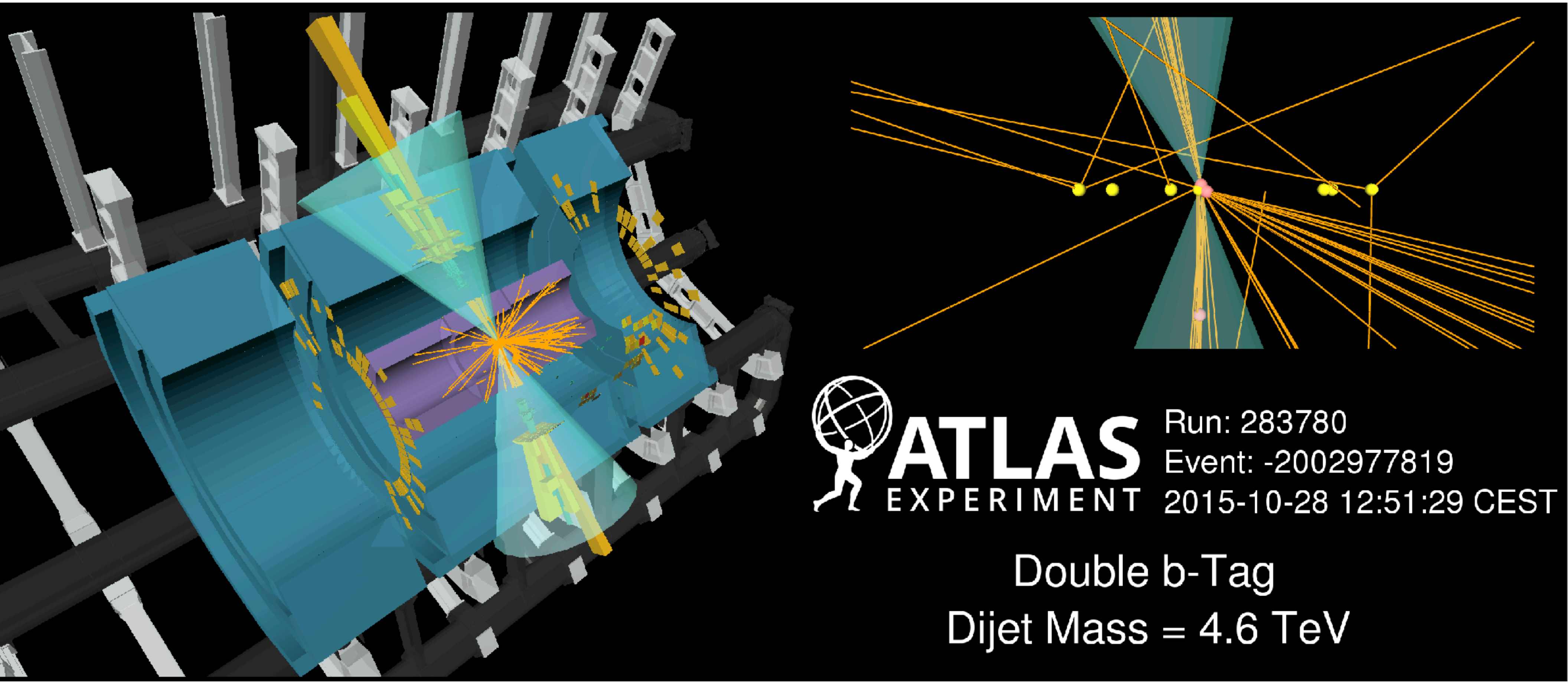
Simplified model

- Standardized for ATLAS&CMS Run2
- Relatively light mediator (TeV-scale)
- Mediator has minimal decay width
- Minimal flavor violation
- Minimal set of parameters
  - Coupling structure, M_{MED}, m_{DM}, g_{SM} (g_q), g_{DM}



LHC DM forum and working group
— Antonio Boveia's talk

2 b-tagged dijet event with highest mass

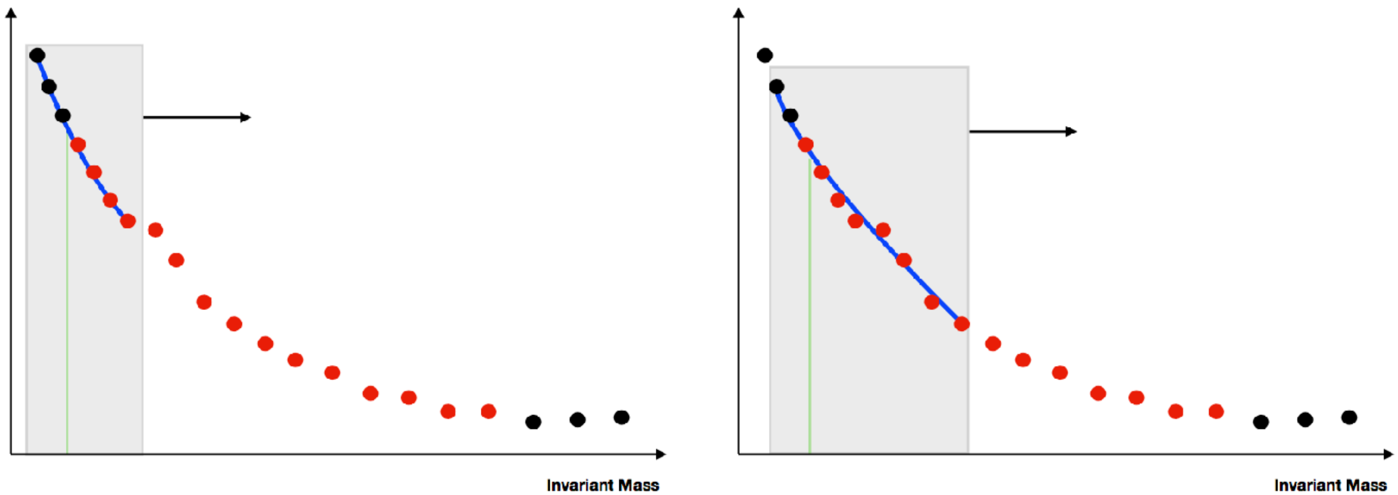


SWiFt — Concept

- Fit data distribution in small, over-lapping windows using dijet functions
  -> smaller windows allow functions to model data well

- Sliding Window Fits is a resonance search method
  -> performs likelihood ratio based local p-value search: model-dependent
  -> sets 95% CL limits using profiled likelihood method
  -> creates background estimation over full mass range using new technique

- In Full SWiFt method, SWiFt background is used to calculate global p-values, expected 95% CL limits from pseudo-experiments
  -> **To perform a model-independent search, SWiFt background used with BumpHunter**



SWIFT — Window Selection

- Biggest question: how do you pick window sizes ?

  -> Answer: “Pick the largest window that gives good background-only fits”

  -> Multiple ways of doing this. Evolution of the process:

  1) Require background-only fit in each window to pass a combination of goodness-of-fit measures
     - High Mass Dijet Analysis: Chi2/NDF, KS and Wilks p-value
     - Dibjet Analysis: Chi2 p-value and a looser Wilks p-value

  2) Use global Chi2 p-value by comparing complete SWiFt background and data
     - Trigger Level Analysis

  3) Require Chi2 p-value for each window to be the best
     - Automatically scan range of windows & pick one with the best Chi2 p-value for the background-only fit
     - Allows the window size to grow and shrink depending on how well the fit does
     - New SWIFT code uses this method

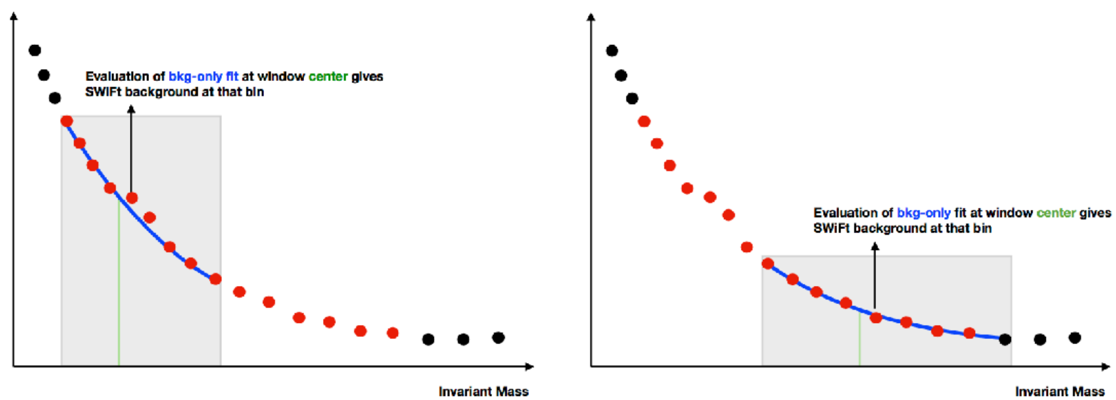
- Once window sizes are picked, a background estimation is produced using the SWIFT background method

SWiFt Background

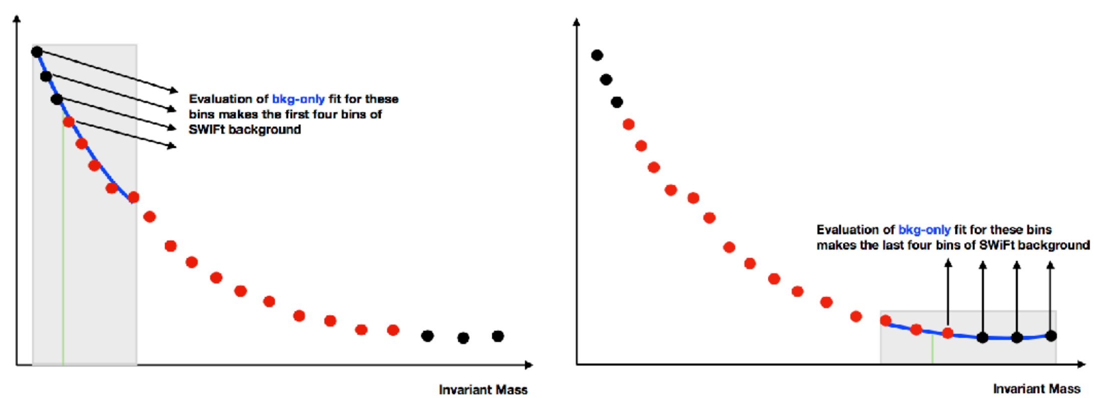
- SWiFt background making procedure:
  -> Use a background-only function: eg. 3 parameter dijet function
  -> In each window, evaluate background-only fit at window center
  -> Obtain bkg estimation for that bin
  -> For first & last windows, in addition to the window centers, evaluate background-only fit at edge bins
  -> stitch together bin-by-bin bkg

- At the end of the slide, the SWiFt background is produced

Intermediate Windows



First and Last Windows



SWiFt Background – Uncertainties

- There are two uncertainties considered on the background:

1) Statistical: accounts for the uncertainties on the background fit parameters

-> Evaluated using pseudo-experiments (PEs) from the SWiFt background

-> From each PE, a SWiFt background is produced

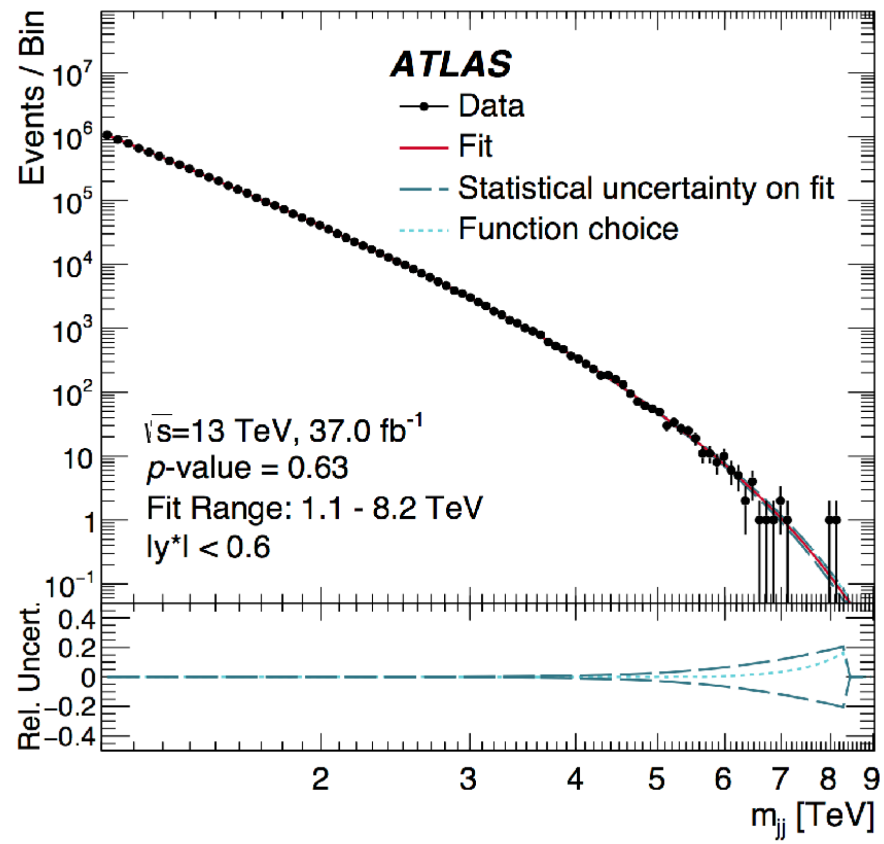
-> Uncertainty: RMS of bkgs from PEs in each mass bin

2) Function Choice: accounts for the difference in bkg if an alternate function was used

-> Evaluated using PEs from the SWiFt background

-> From each PE, two SWiFt backgrounds are produced: one using the nominal bkg function and another using an alternate bkg function

-> Uncertainty: Mean difference of nominal and alternate in each bin

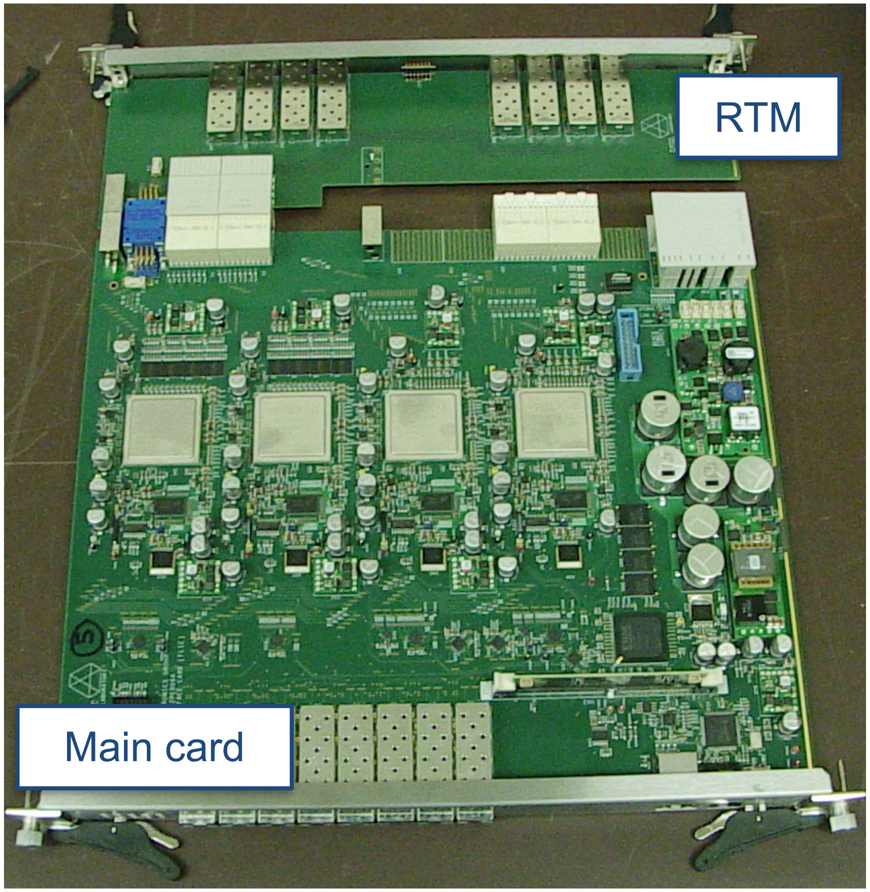


Argonne NATIONAL LABORATORY

FTK Level-2 Interface Crate (FLIC)

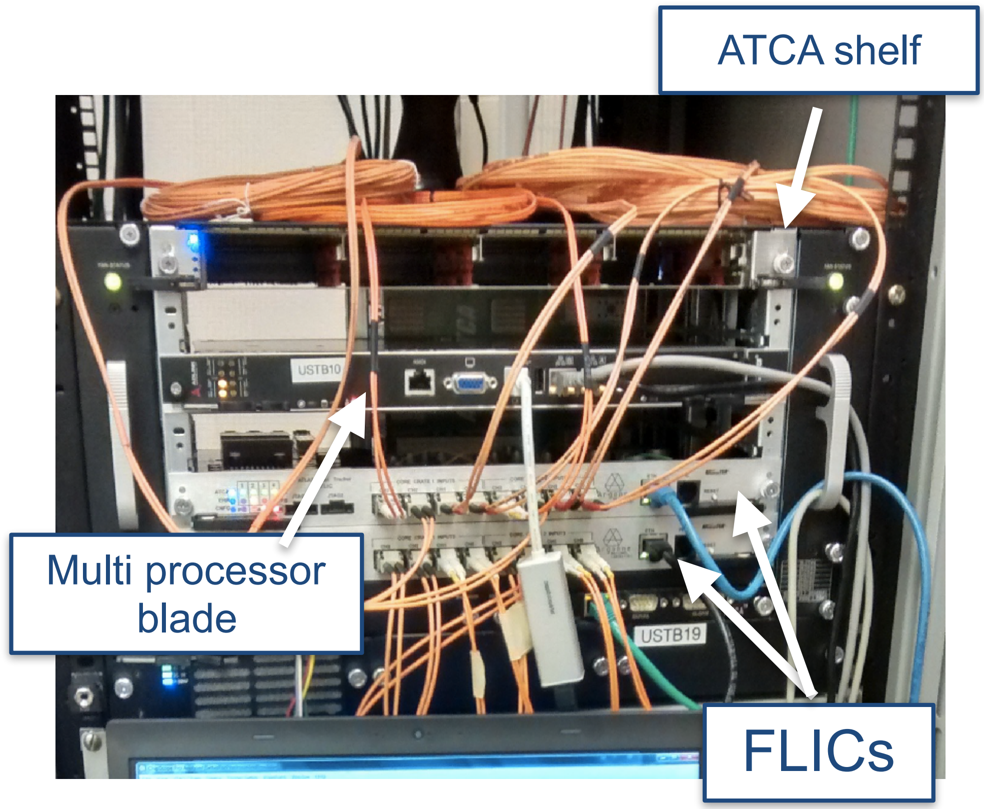
- FLIC is the final component of the FTK
- Receive event records from upstream FTK system, 1/16th of the detector per channel
  - Full bandwidth output from the FLIC to HLT
    - Baseline: 300 tracks per event @ 100 kHz
- Convert FTK identifiers to ATLAS global identifiers using SRAM lookup
- Repackage event record into standard ATLAS format
- Communicate with HLT
  - Sends records
  - receives xoff signal and propagates it upstream to FTK
- Monitoring and Processing on ATCA Blades via backplane

RTM — Rear Transition Module



ATCA

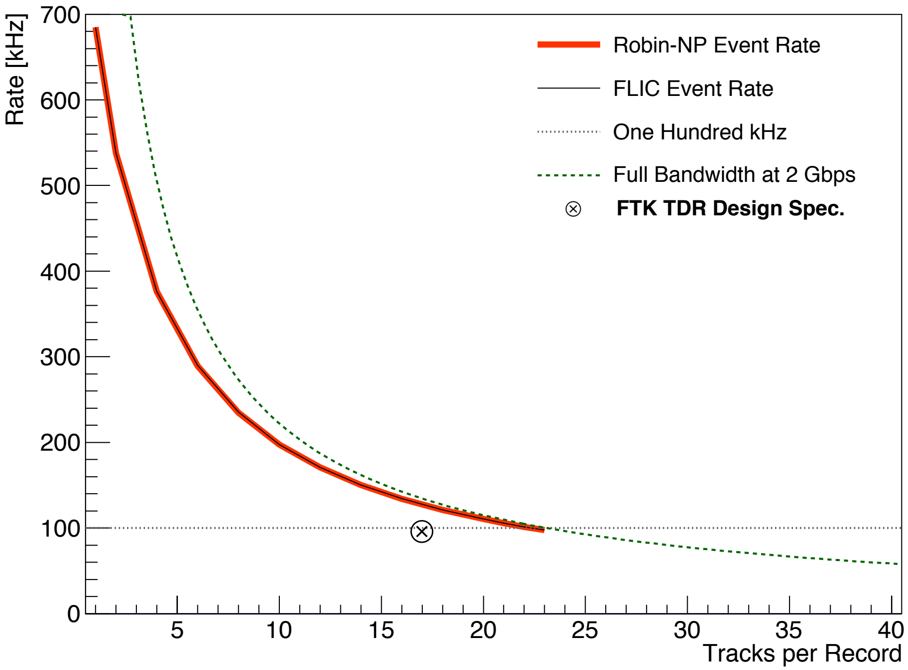
- Advanced Telecommunication Computing Architecture (ATCA) for data acquisition
  - Each FLIC implements four 10 Gb Ethernet channels
  - Allows for data distribution to up to four commercial processor blades
  - For trigger processing and complex data quality monitoring
    - ATCA shelf allows data from either FLIC to any blade
  - Data transfer to blades occurs in parallel with flow-through data processing

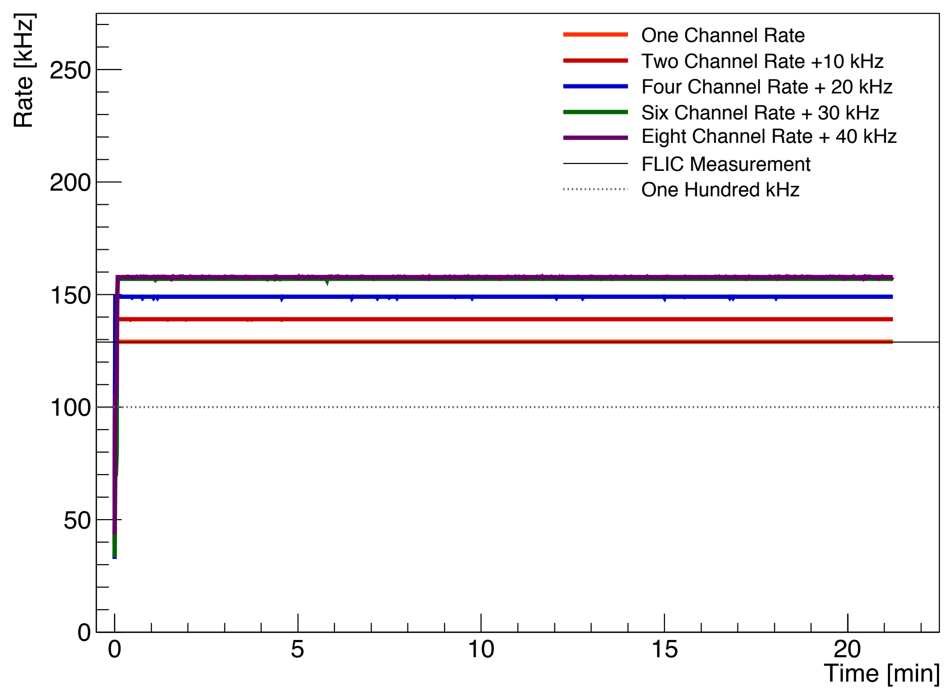


PERFORMANCE - EVENT SENDING TO HLT

- FLIC sending constant bandwidth to HLT
  - Size of event record varies with number of tracks
- Sending 200 MB/s of data to HLT using one channel
- Running above design spec, no limitation on the total data rate of the FTK system

- Full system test running at design specification
  - Running above 100 kHz
  - Testing with constant event record size to the HLT
  - No effect from parallel channels

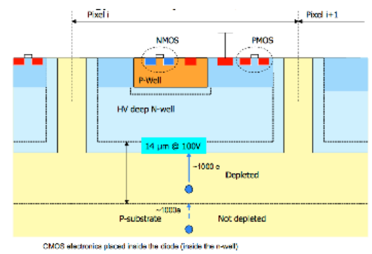


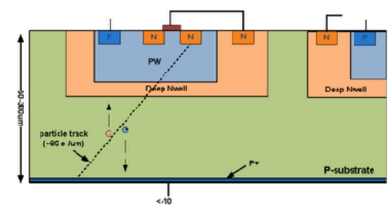


Module characterization

Lots of R&D work to find new material, technology and design that can improve the resolution under the harsh radiation environment

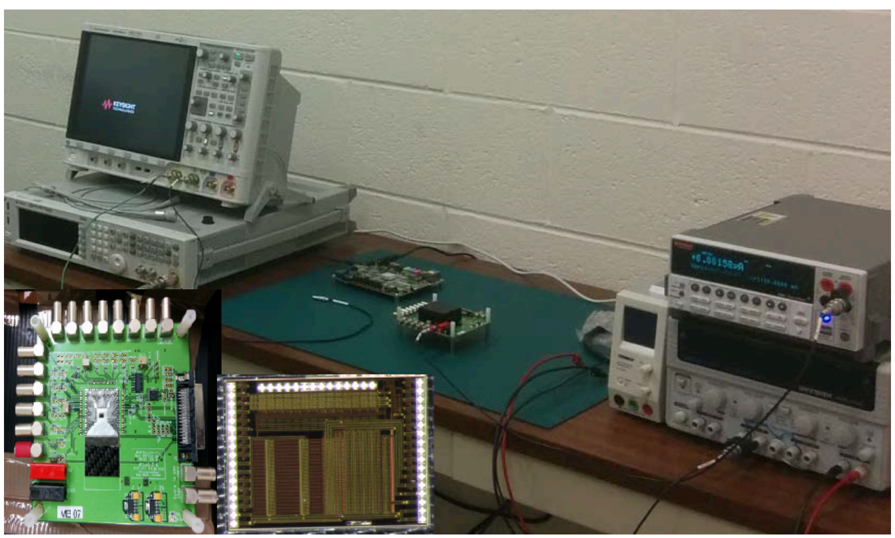
- Different sensor technologies been investigated
  - CMOS silicon sensor
    - Much smaller pixel size and thickness, modularized
    - Industrialized production



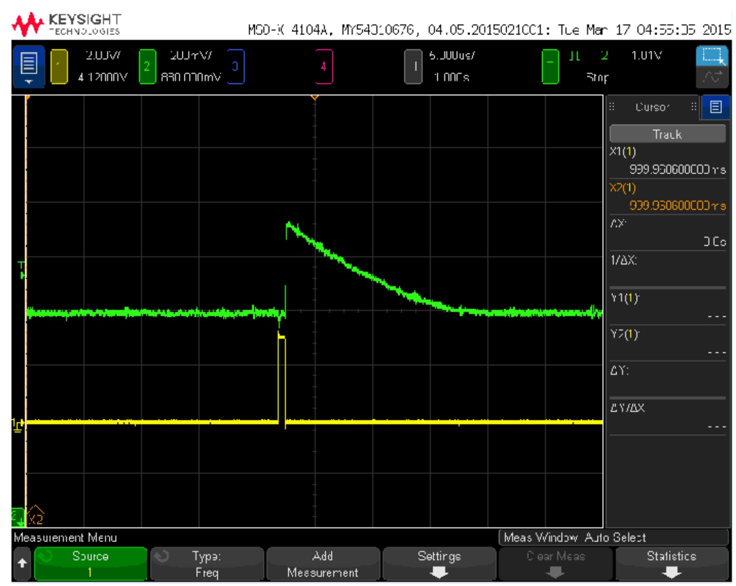


module characterization

Test stand — in lab



Inject pulse & output signal



350nm CMOS

Argonne NATIONAL LABORATORY

arXiv:1710.09484

MC sample

- 10 M CPU hours (10 days) on supercomputers at NERSC

- 100 billion events are generated in each of these three categories:
  - Light jet QCD including bb production (exclude $t\bar{t}$)
  - Vector and scalar boson production that includes the W, Z and H^0 boson processes
  - tt and single top quark production
- The combined Monte Carlo dijet mass spectrum provides a better precision than will be achievable for data at 3 ab^{-1}
- LO order Pythia8 generation with the
- default parameter settings and the ATLAS A14 tune for minimum-bias events
- 14 TeV and 27 TeV for the HL-LHC and HE-LHC

http://www.nersc.gov/