Triggering And Data Acquisition in High Energy Physics

for the Heidelberg GK BSM

Lecture 3/3

27th November 2017

by

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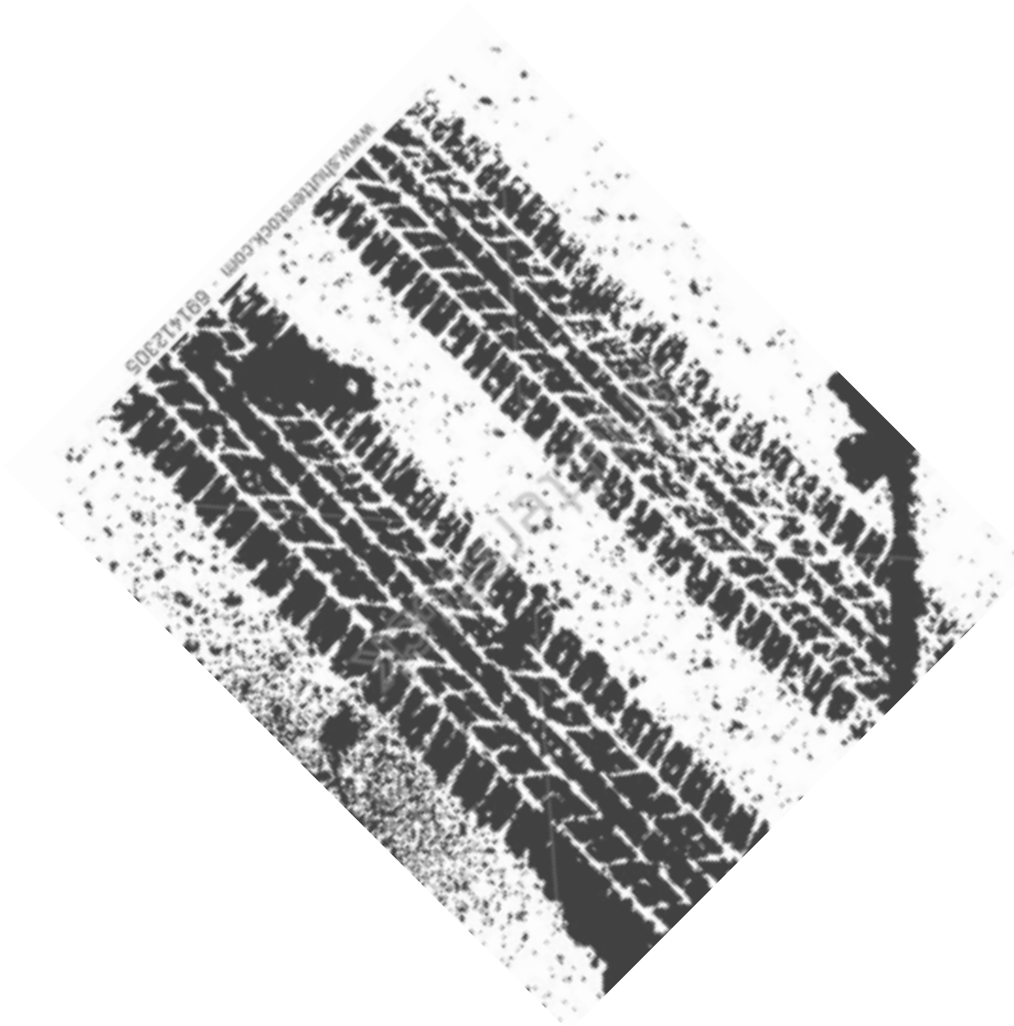
Table of Content



- **Lecture 3 (today):**
  - Tracking at trigger-level and looking for the unusual.

Summary of previous lecture

What is triggered

trigger objects

at L1:
EM, JET, MUON
TAU, MET …

coarse granularity
calorimeter + muon system data

at HLT:
electrons, photons, jets, b-tagged jets, muons, taus, missing energy …

full granularity
calorimeter + muon system data
+ limited tracking information

tracking expensive at trigger level:
huge # of channels
huge combinatorics

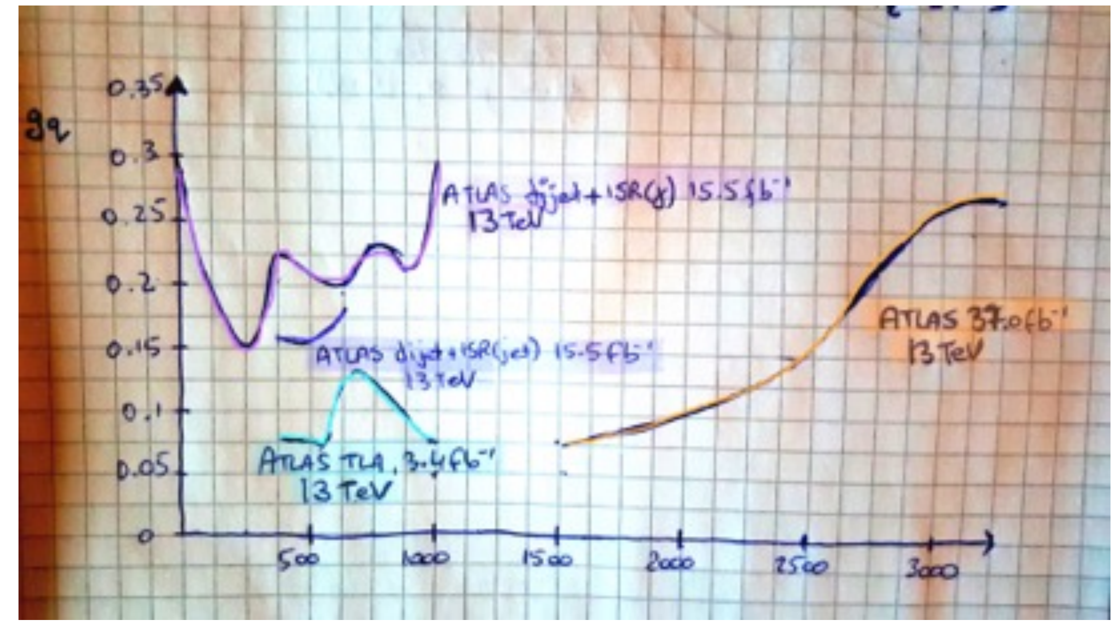
phase space

within detector acceptance

above ET threshold

increasingly being pushed up by pile-up

Trigger Limitations: Dijet analyses



coupling-mass plot for ATLAS Run 2 dijet searches

offline pT [GeV] *

offline jets

offline lead jet pT limit

420 — HLT j380*

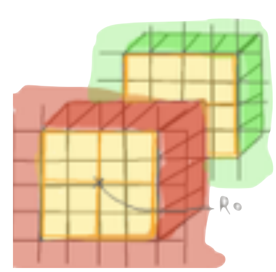
HLT Jets (TLA)

offline + ISR

TLA lead jet pT limit

220 — Level-1 J100*

L1 Jets



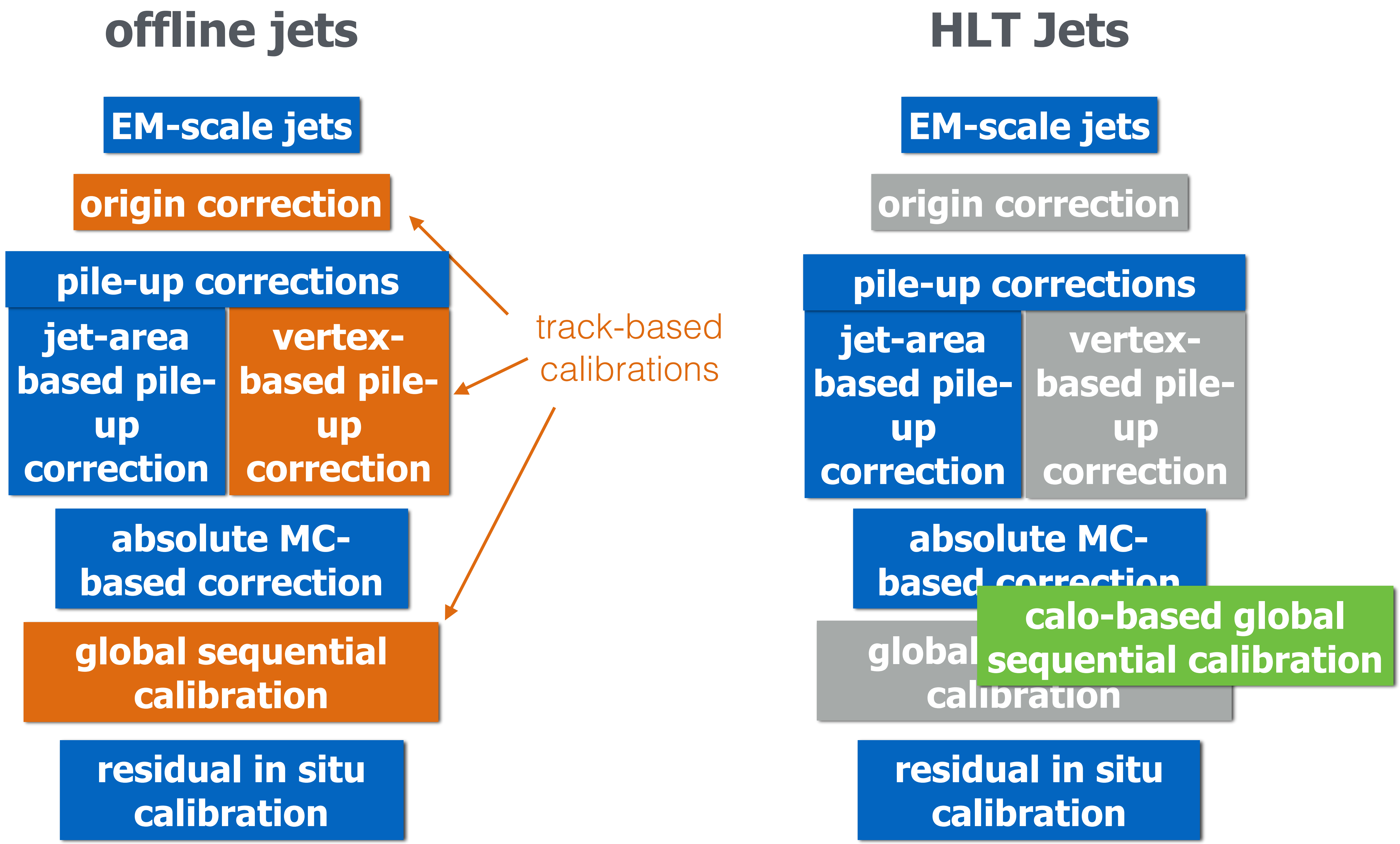
TLA + ISR ?

80

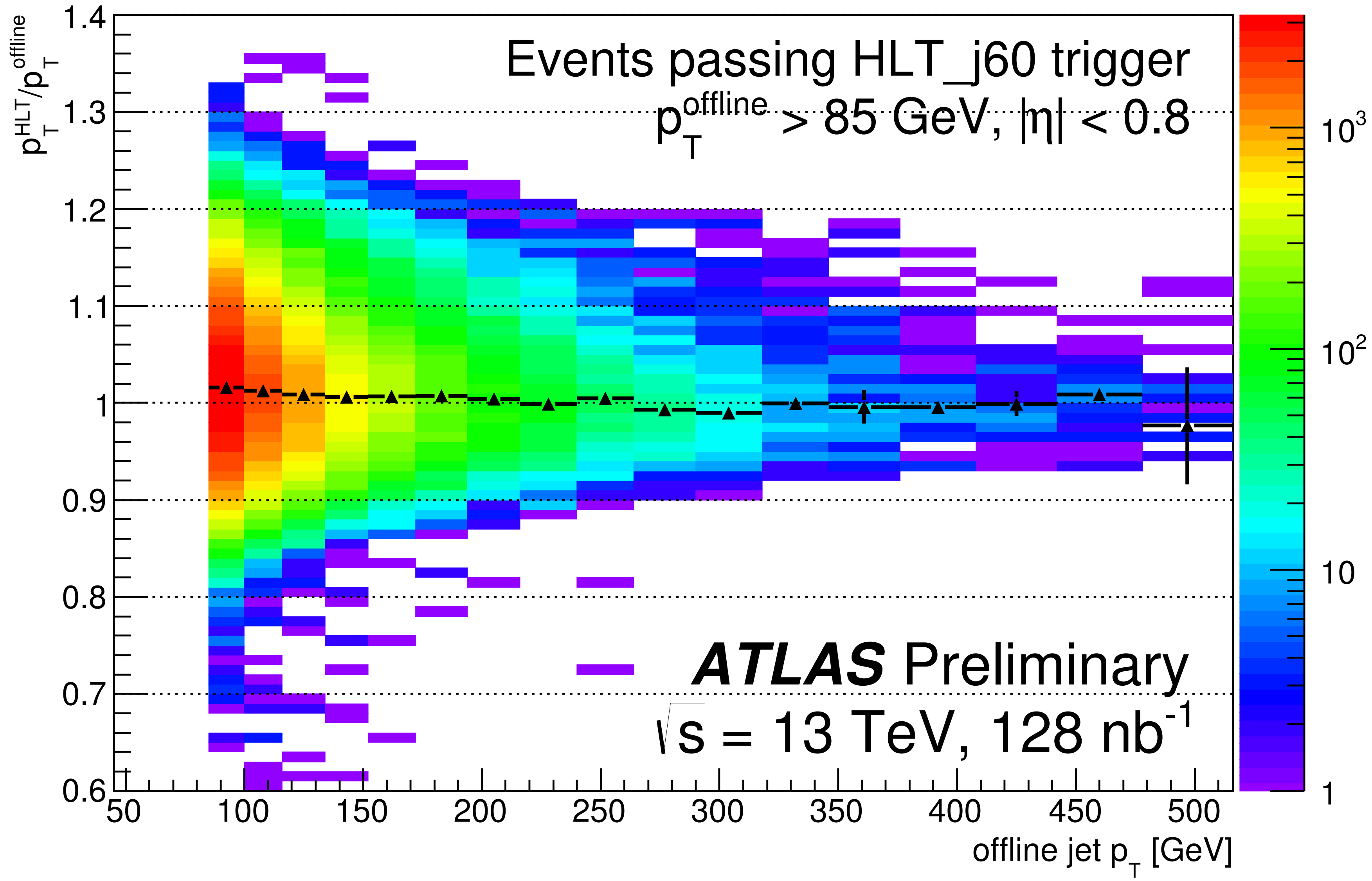
pile-up jets

* 2016 trigger limitations

Why pile-up is a huge issue for TLA

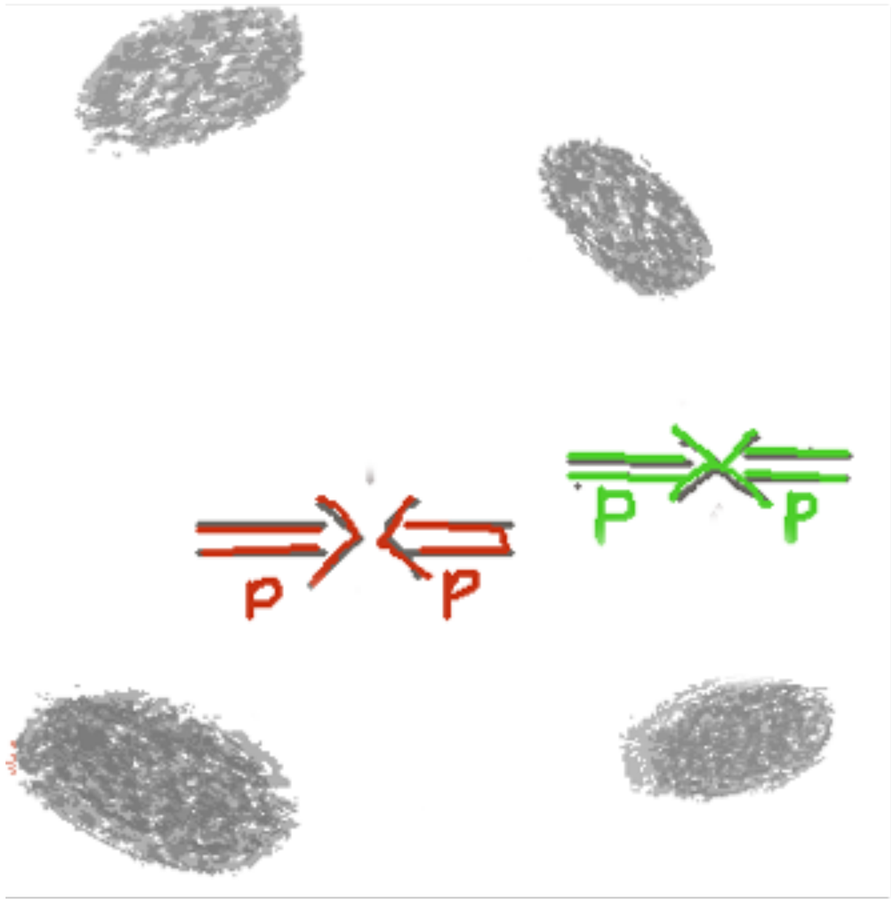


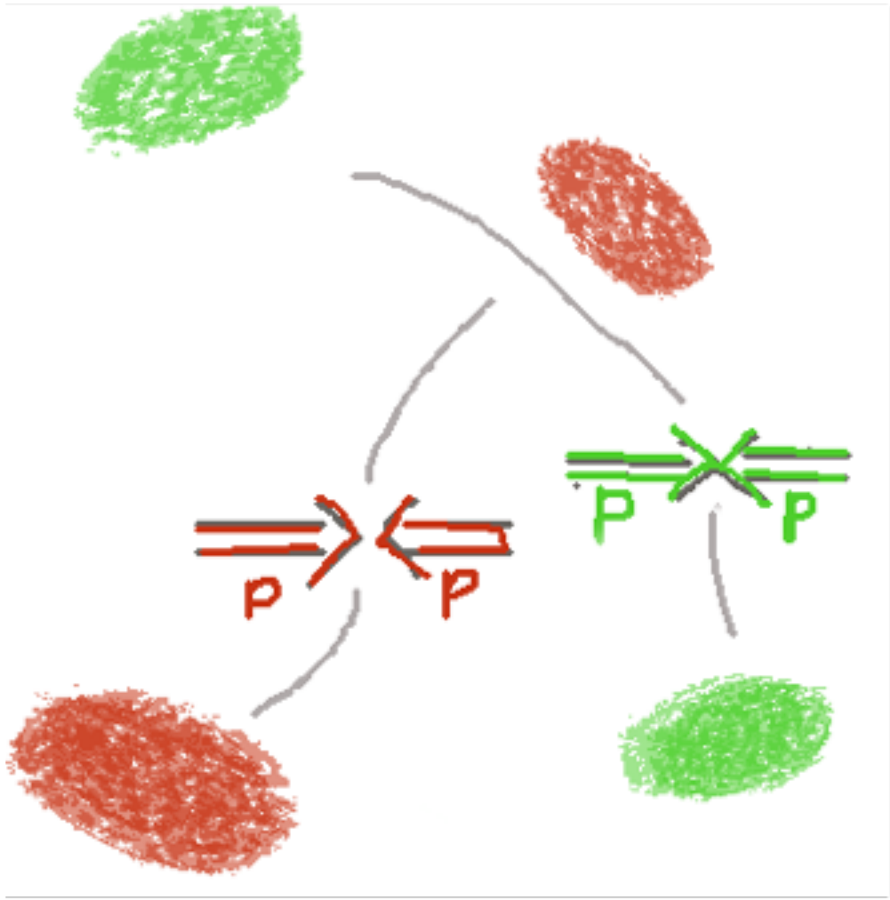
Why pile-up is a huge issue for TLA



- aim for offline-like performance.
- worsening performance at low pT due to pile-up effects we cannot correct for.

Why pile-up is a huge issue for TLA

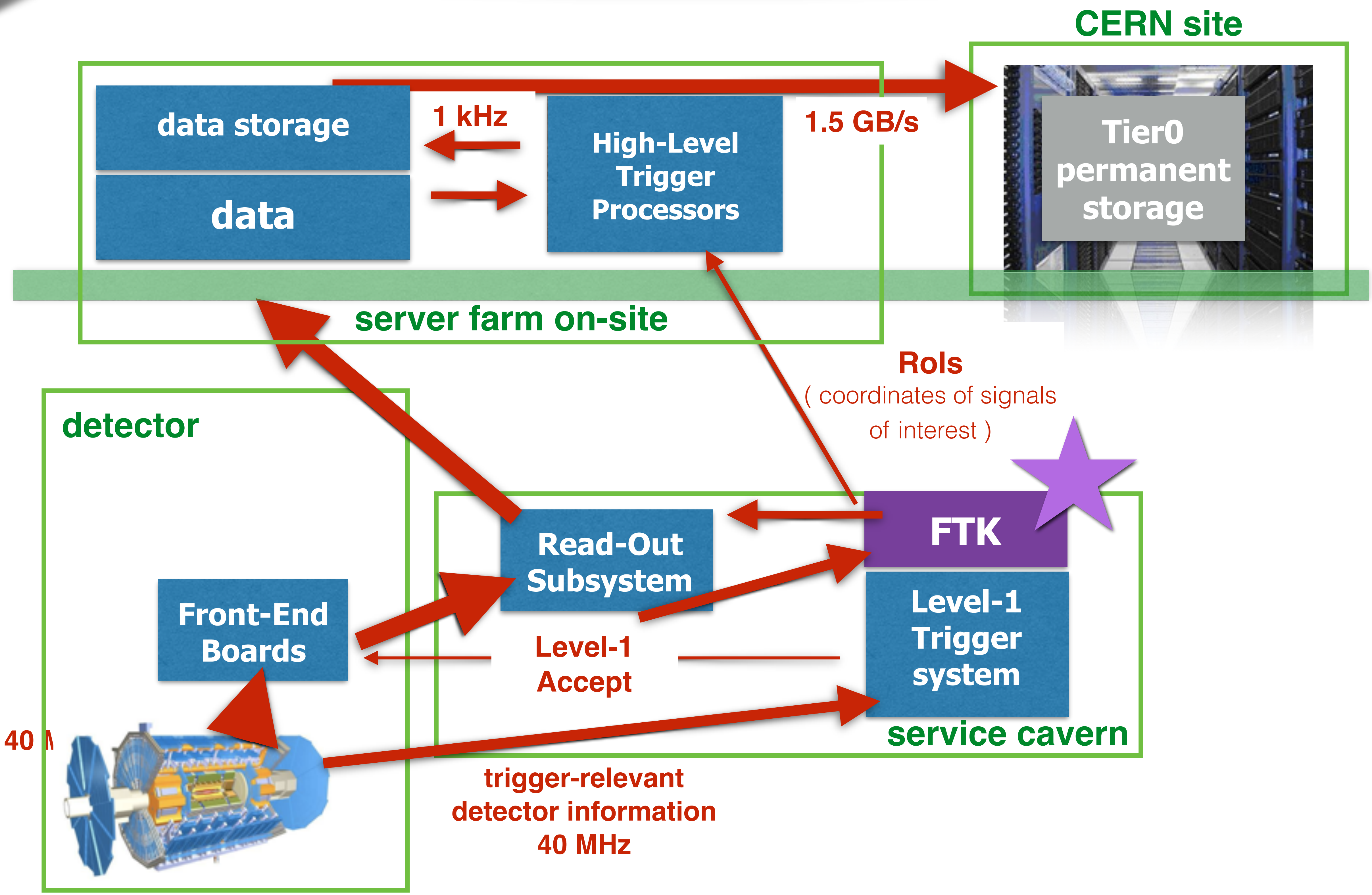




- only way to distinguish hard scatter from pile-up jets: **tracks**.

in commissioning

Fast Tracker (FTK): new hardware for triggering



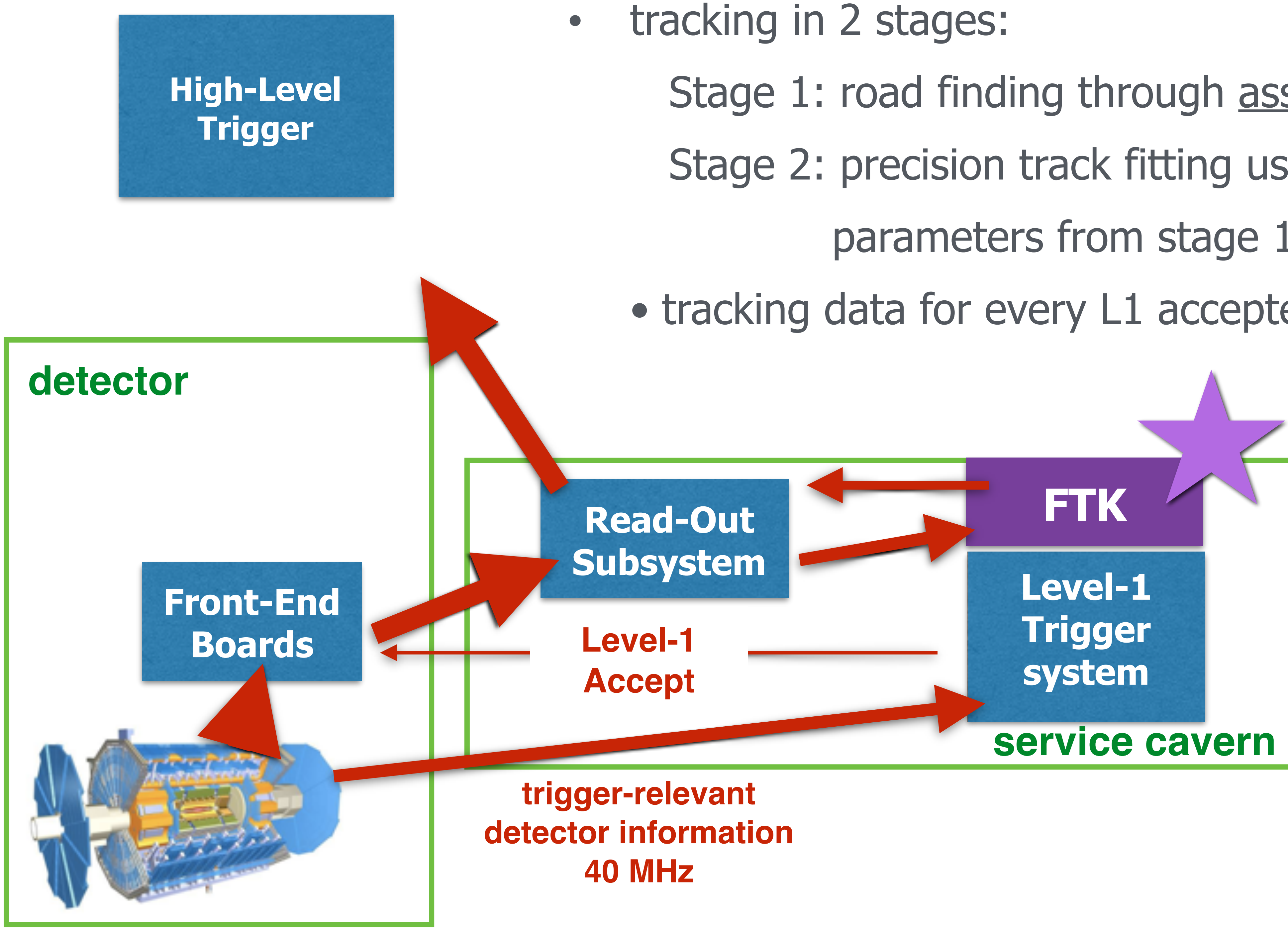
FTK: How it works

- FTK performs fast tacking by:
  - tracking in 2 stages:

    Stage 1: road finding through associative memory

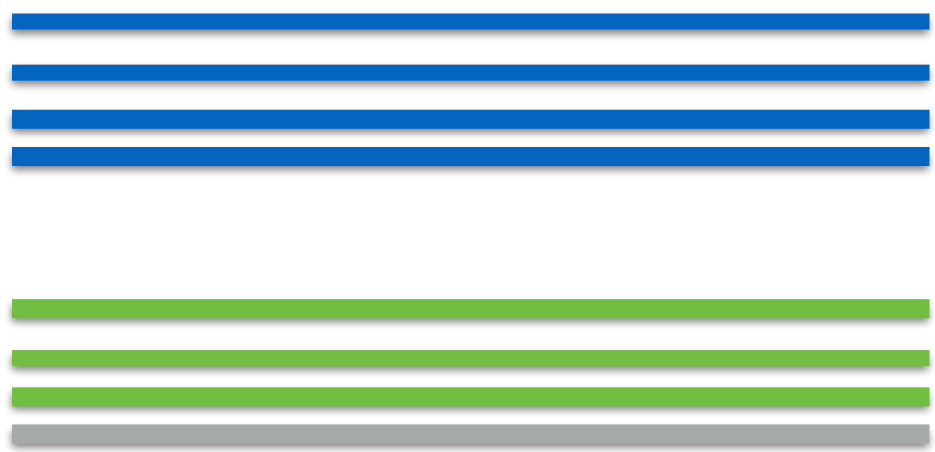
    Stage 2: precision track fitting using

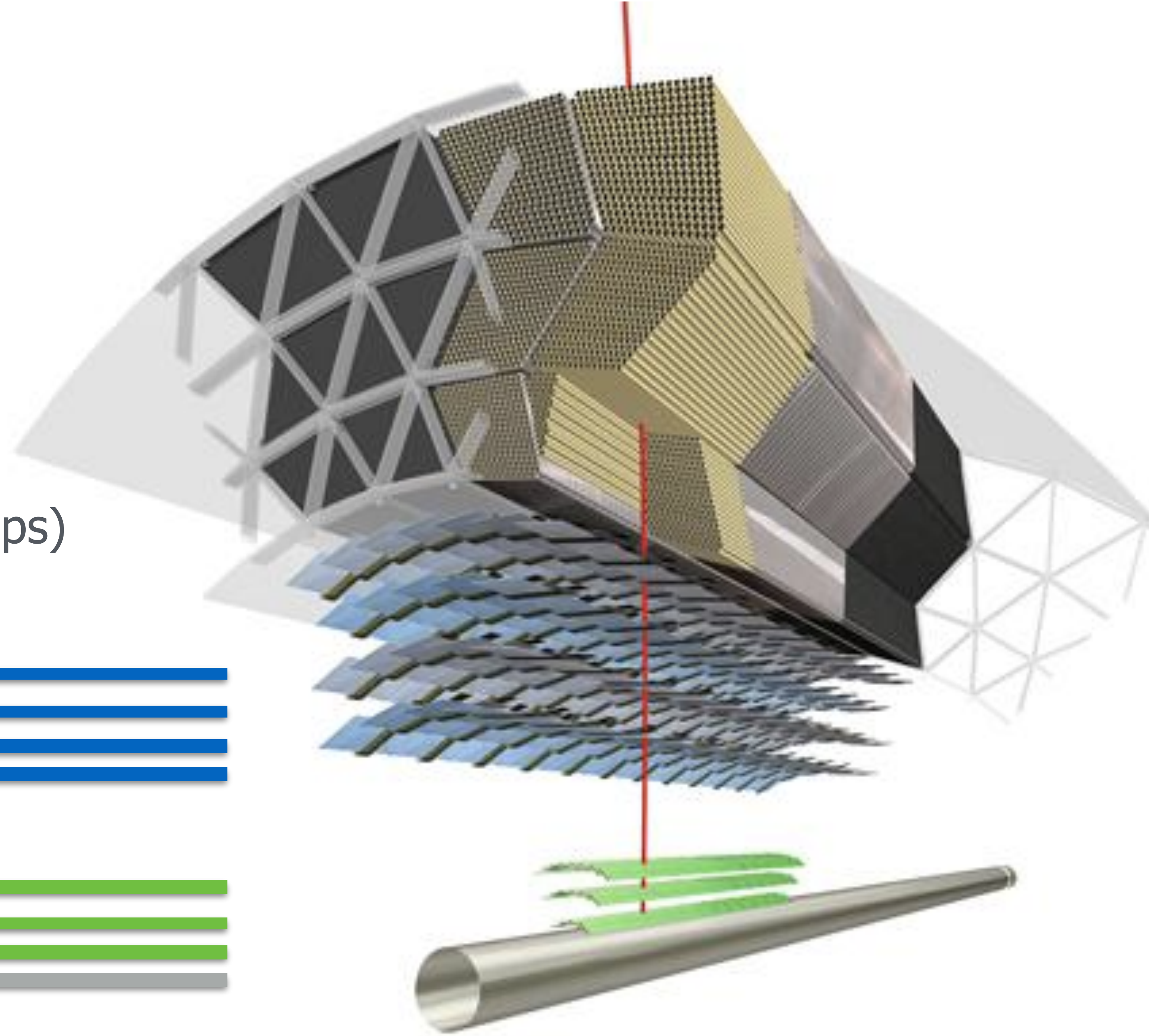
    parameters from stage 1.
  - tracking data for every L1 accepted event.



FTK: How it works

- 1st Stage: uses data from inner 8 tracking layers (silicon pixels + strips)



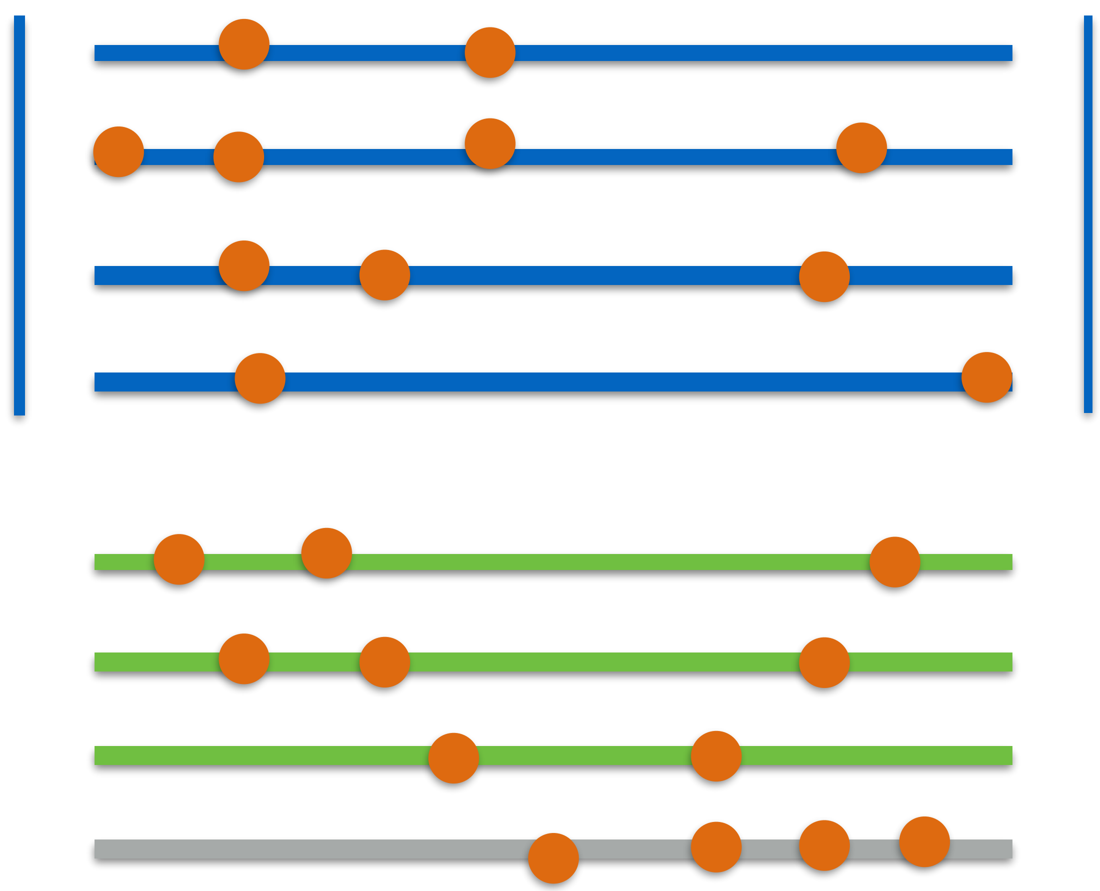


- 1st Stage track (road) identification is what makes FTK work rapidly. It uses the concept of associative memory …

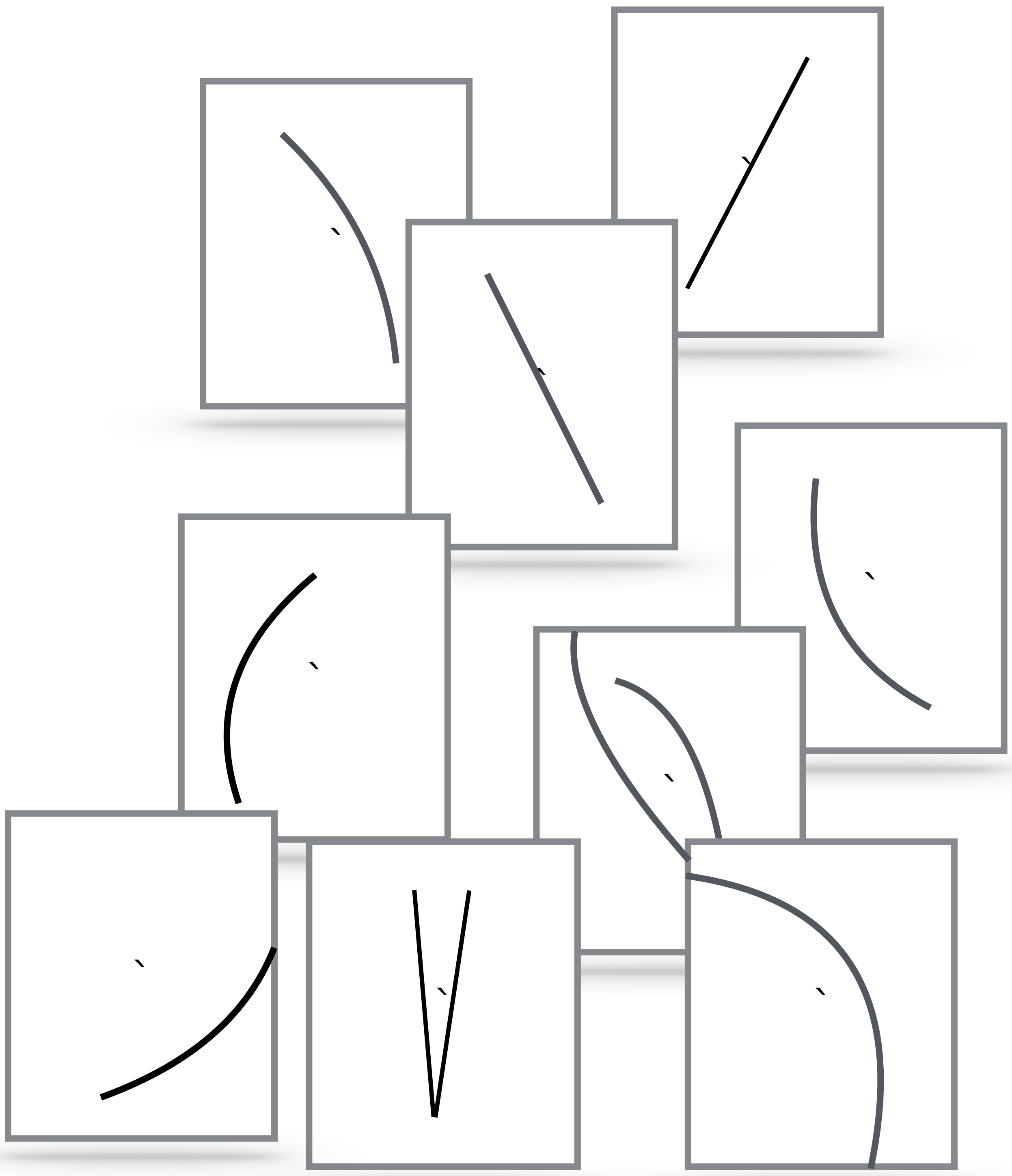
- (<u>not shown here:</u> FTK logic extends to layers in end-cap region.)

FTK: How it works

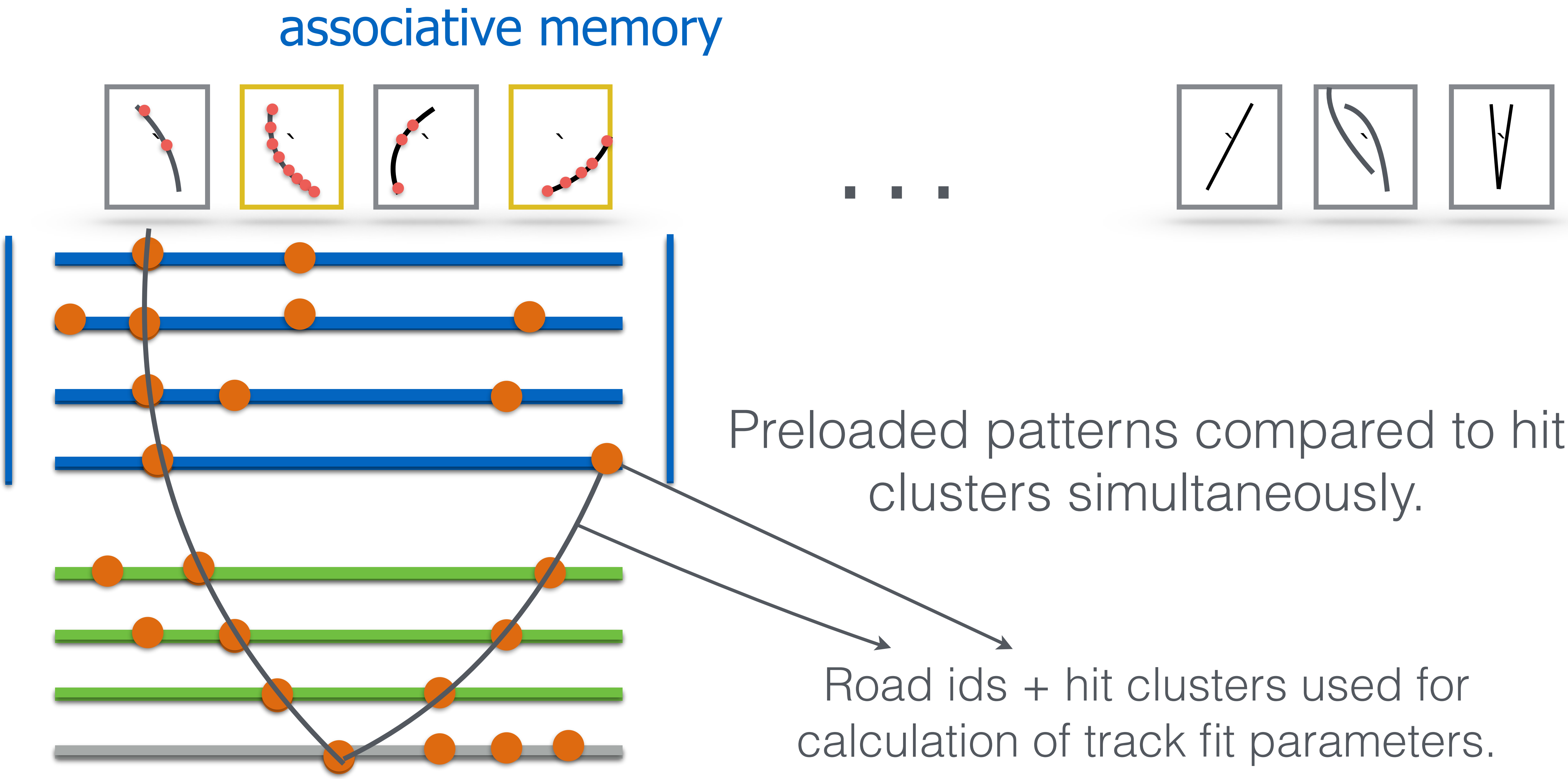
associative memory



pattern bank
(preloaded track patterns)

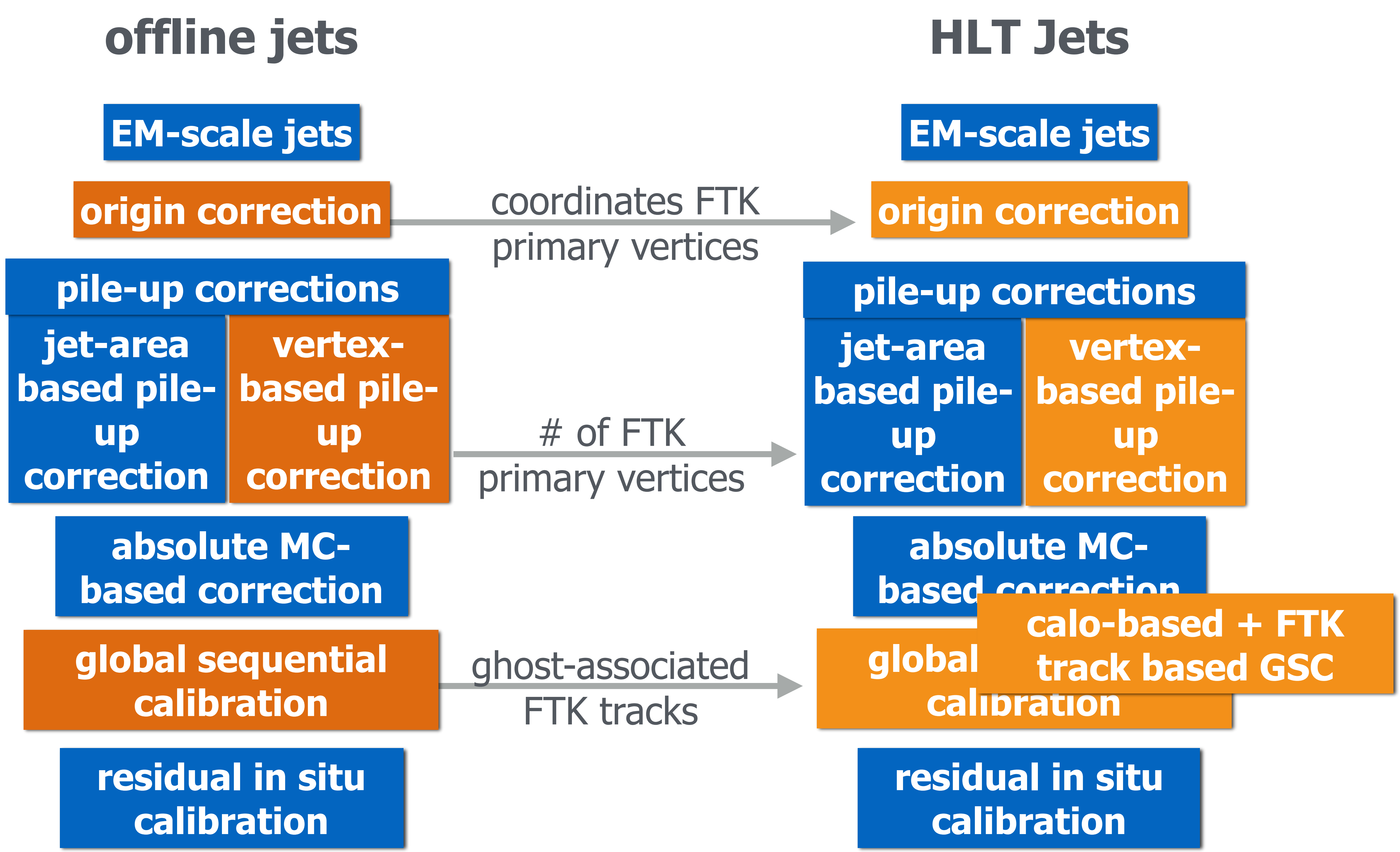


FTK: How it works



- ultra-efficient: 1st stage track finding completes with read-in of last hit.

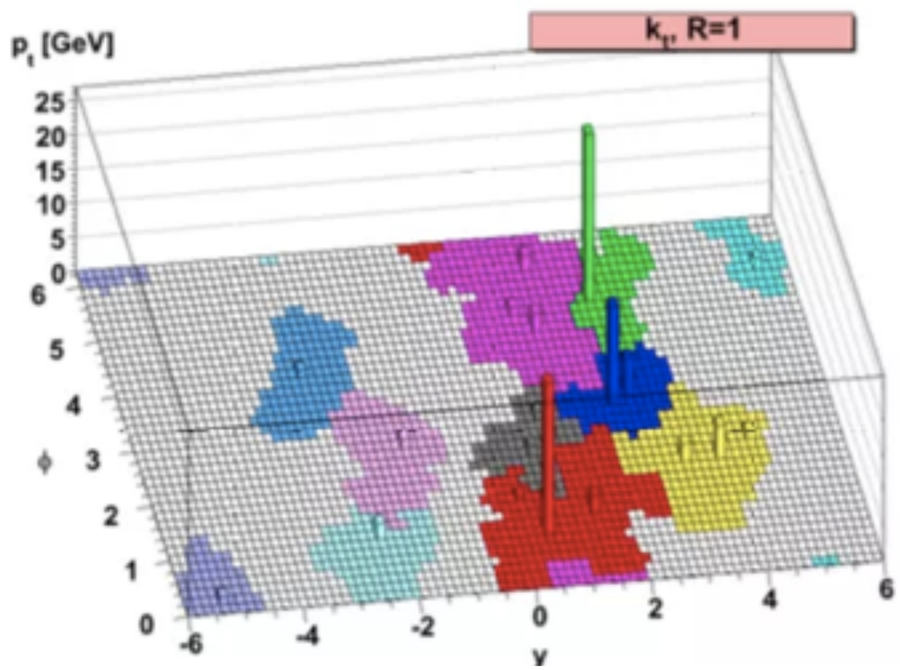
Jet Calibration with FTK

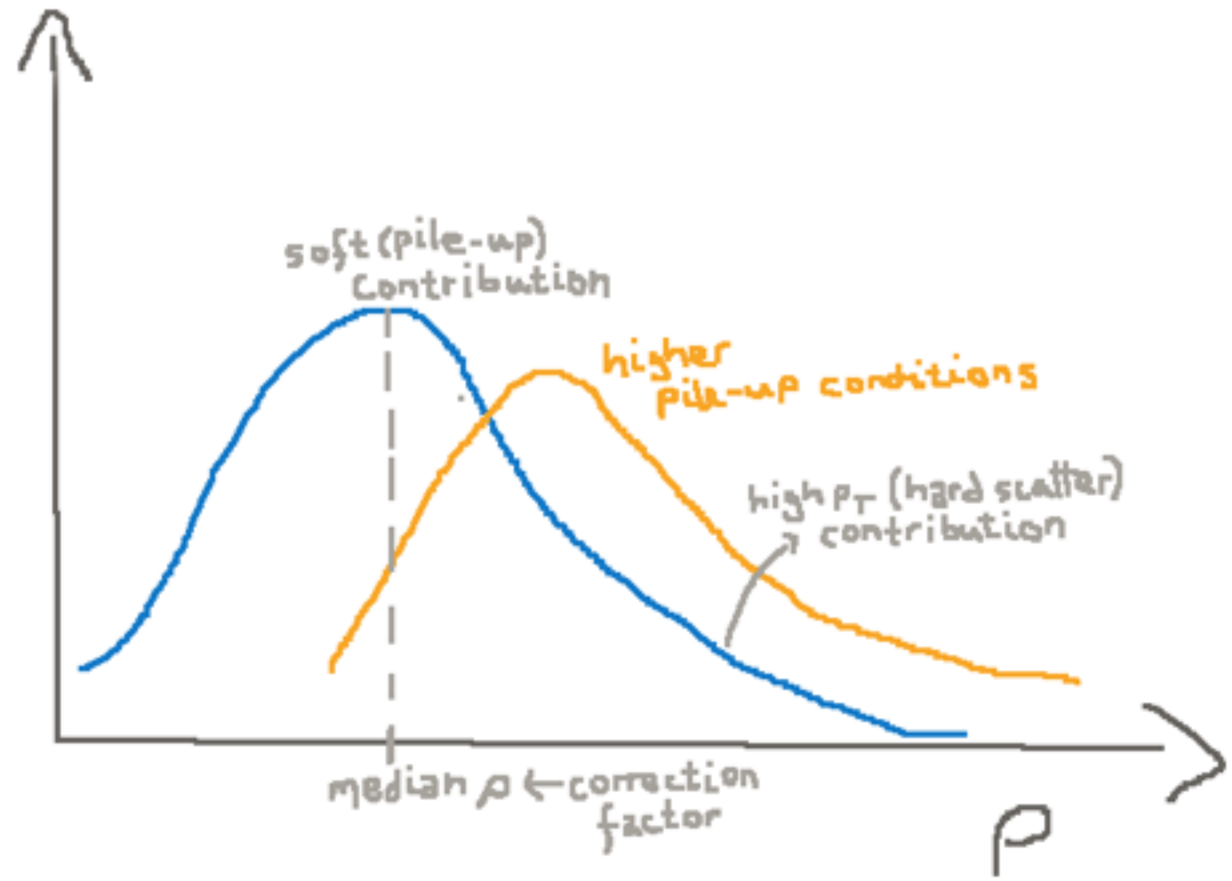


Jet Calibration with FTK

pile-up correction

$$p_T' = p_T - \rho \cdot A_{\text{jet}}$$

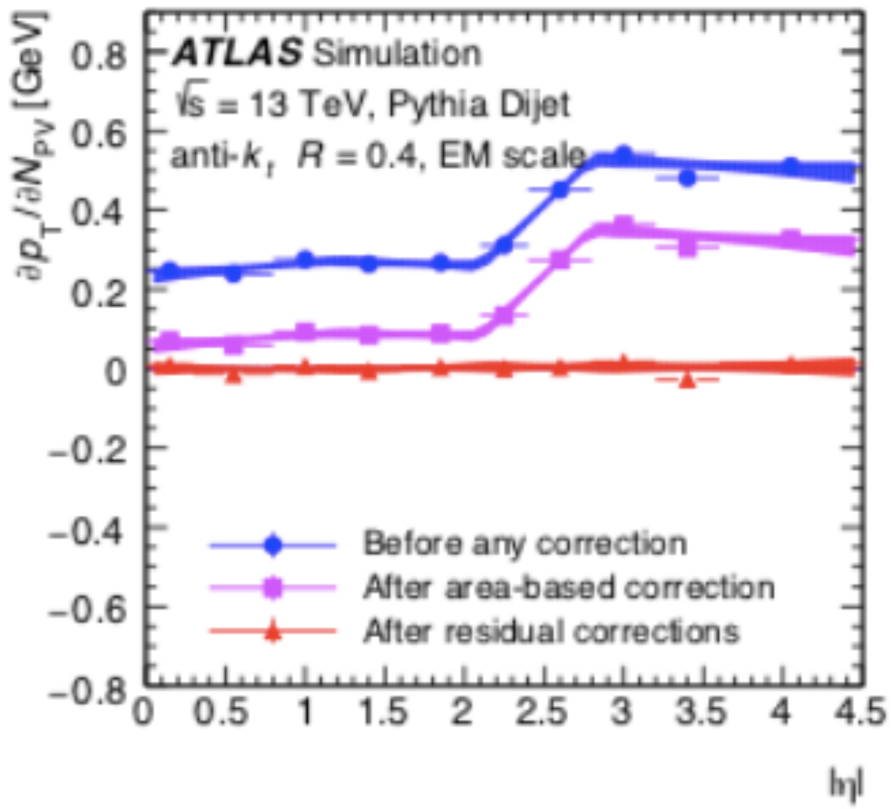




- correction applied event-by-event at HLT to jets.
- **Average pile-up density** estimated using the median of jet pT/ jet area of kT jets, ρ :
  - **kT jets**, as sensitive to soft particles.
  - ρ **median** as density distribution dominated by soft pile-up jets, with tail from hard scatter jets.

Jet Calibration with FTK

pile-up residual correction



$$p_T{}' = p_T - \rho \cdot A_{\mathrm{jet}} - \alpha(N_{\mathrm{PV}} - 1) \cdot$$

does not account for varying pile-up effects in different eta regions.

Further correction dependent on number of pile-up interactions within collision event, defined for eta-bins.

- Derivation of α coefficients based on FTK reconstructed vertices

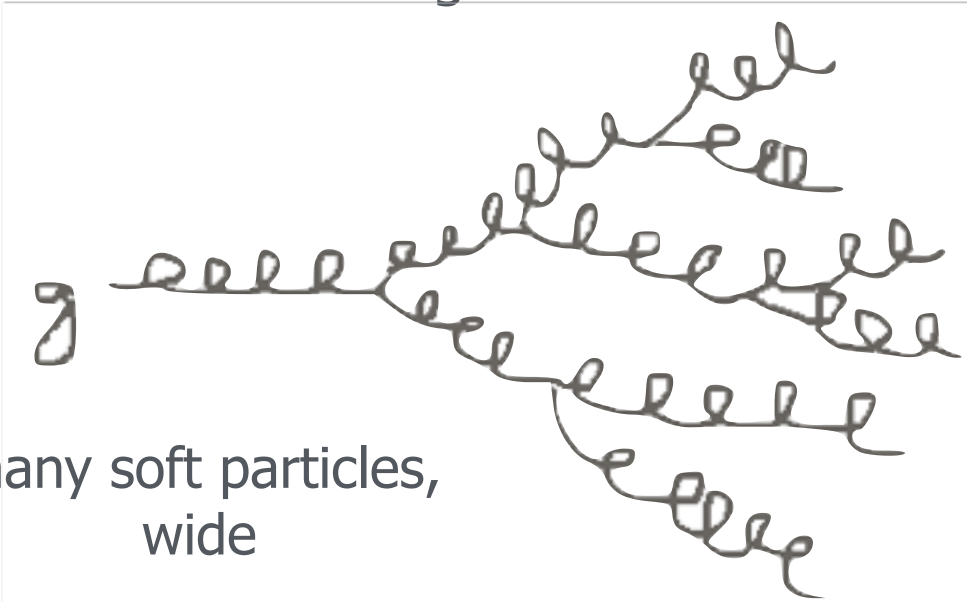
* offline, there is a further residual correction dependent on the mean number of interactions $< \mu >$.

Jet Calibration with FTK

global sequential calibration

- jet properties may fluctuate jet-to-jet , affecting the energy response.
- e.g. different energy response from:
    - quark-initiated versus gluon-initiated jets.
    - energy fraction in EM versus HAD calorimeter versus transition region

high pT tracks, penetrating,
narrow

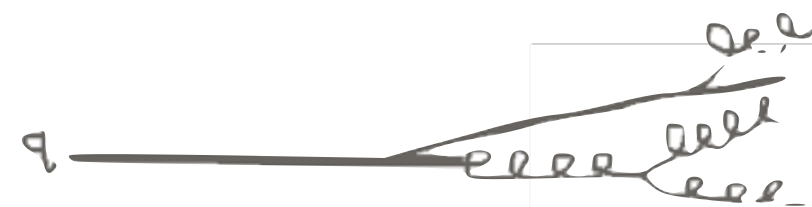


many soft particles,
wide

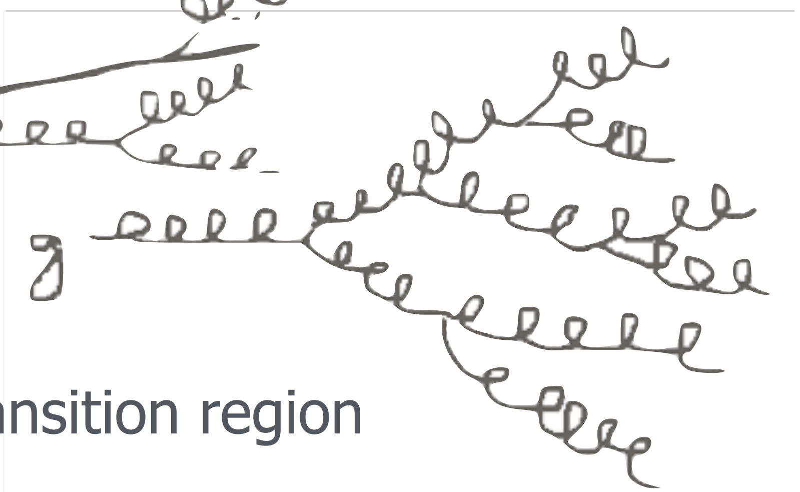
Jet Calibration with FTK

global sequential calibration

- jet properties may fluctuate jet-to-jet , affecting the energy response.
- e.g. different energy response from:



  - quark-initiated versus gluon-initiated jets.



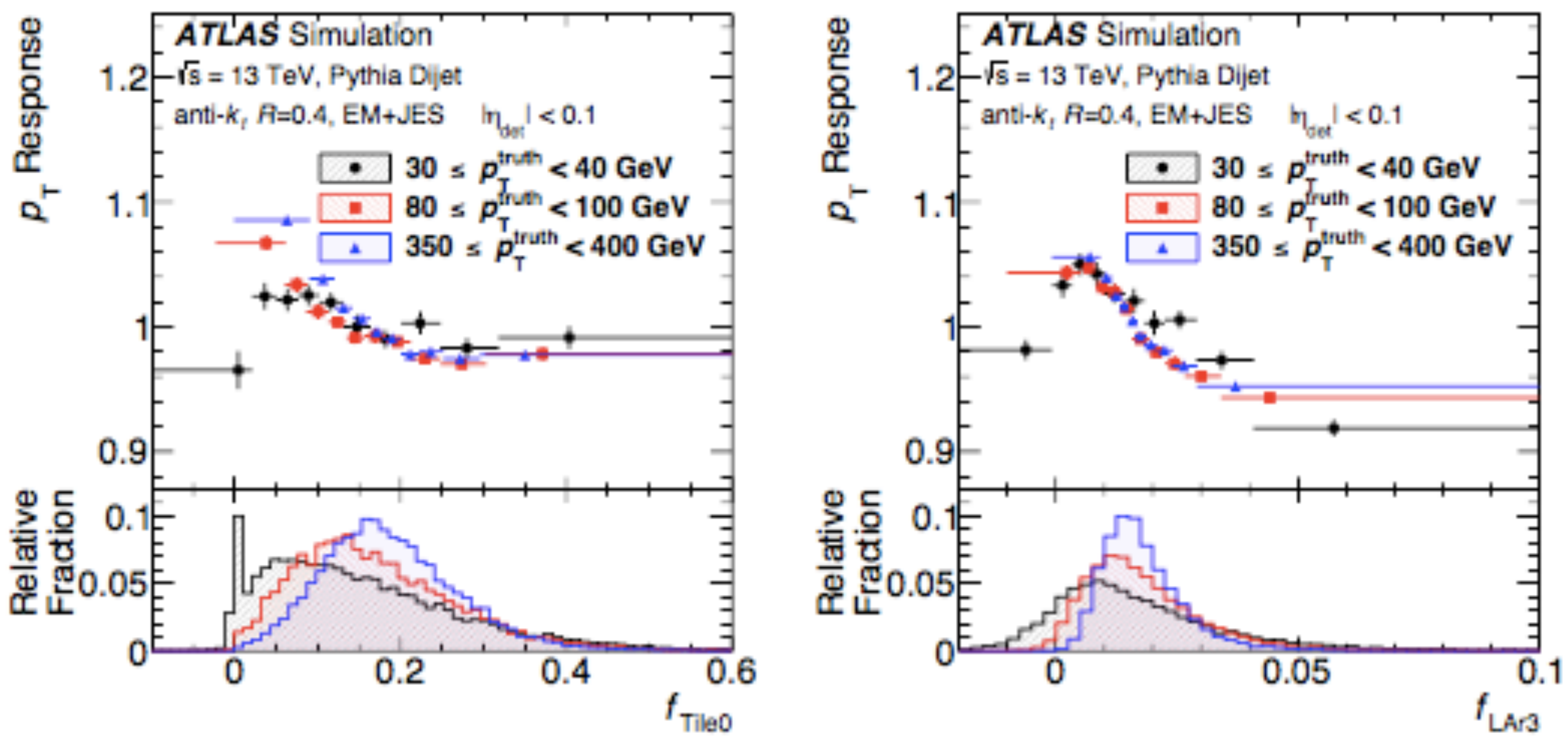
  - energy fraction in EM versus HAD calorimeter versus transition region
- **global sequential calibration** corrects jet pTs based on their measured properties (moments): each correction is applied in sequence.

calorimeter-based moments:
from energy deposits clustered in jet

track-based moments:
from ghost-associated tracks

Jet Calibration with FTK

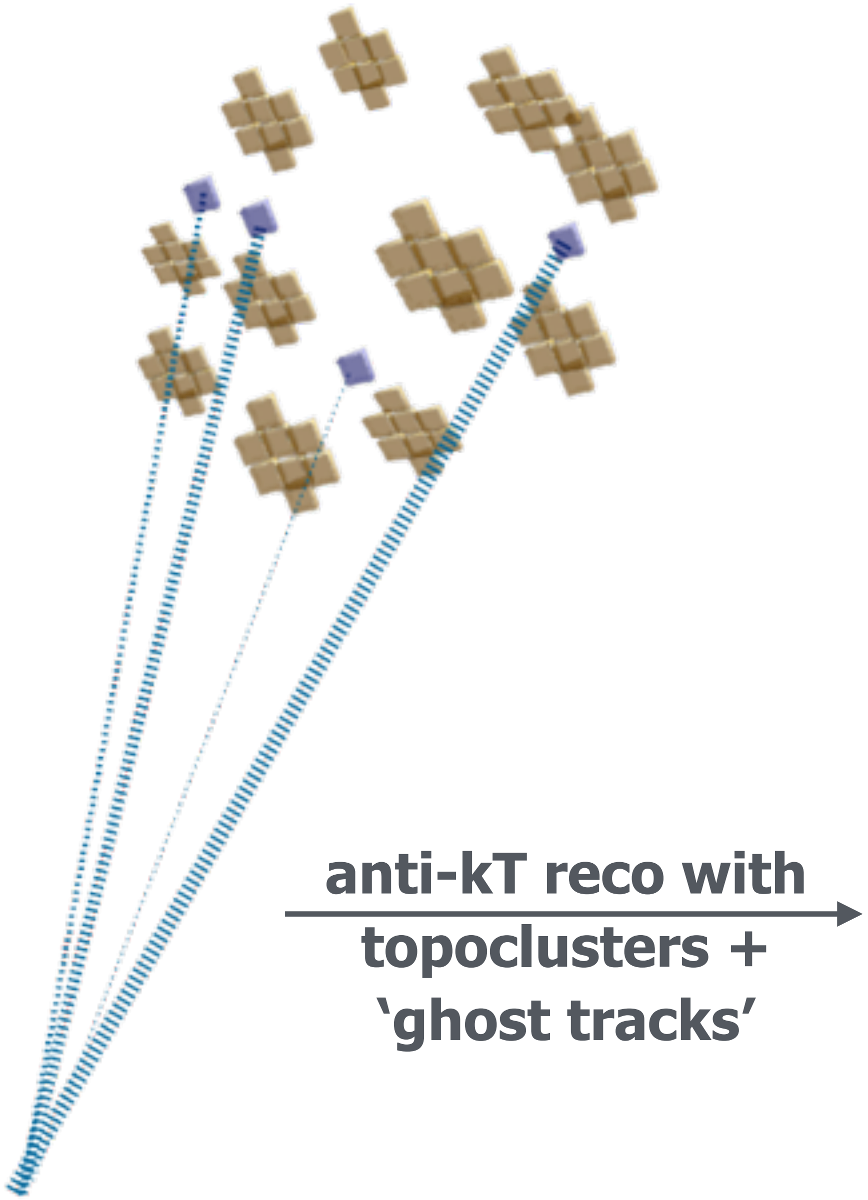
global sequential calibration (for offline jets)



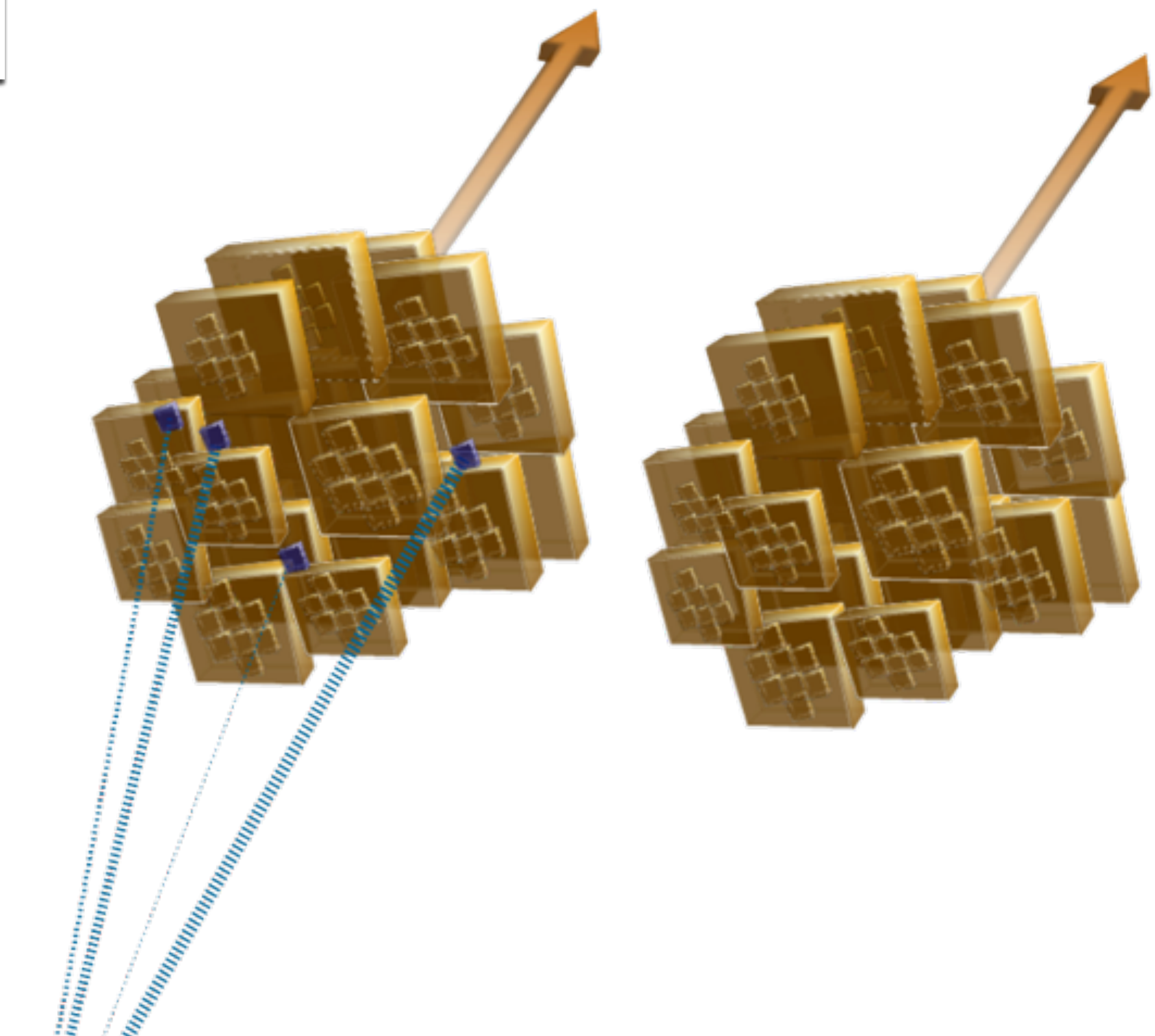
- examples of energy response as function of calo-based jet moments

Jet Calibration with FTK

ghost-association



- tracks are given a pT of ~0.
- 'ghost tracks' + topo clusters -> input to anti-kT algo.

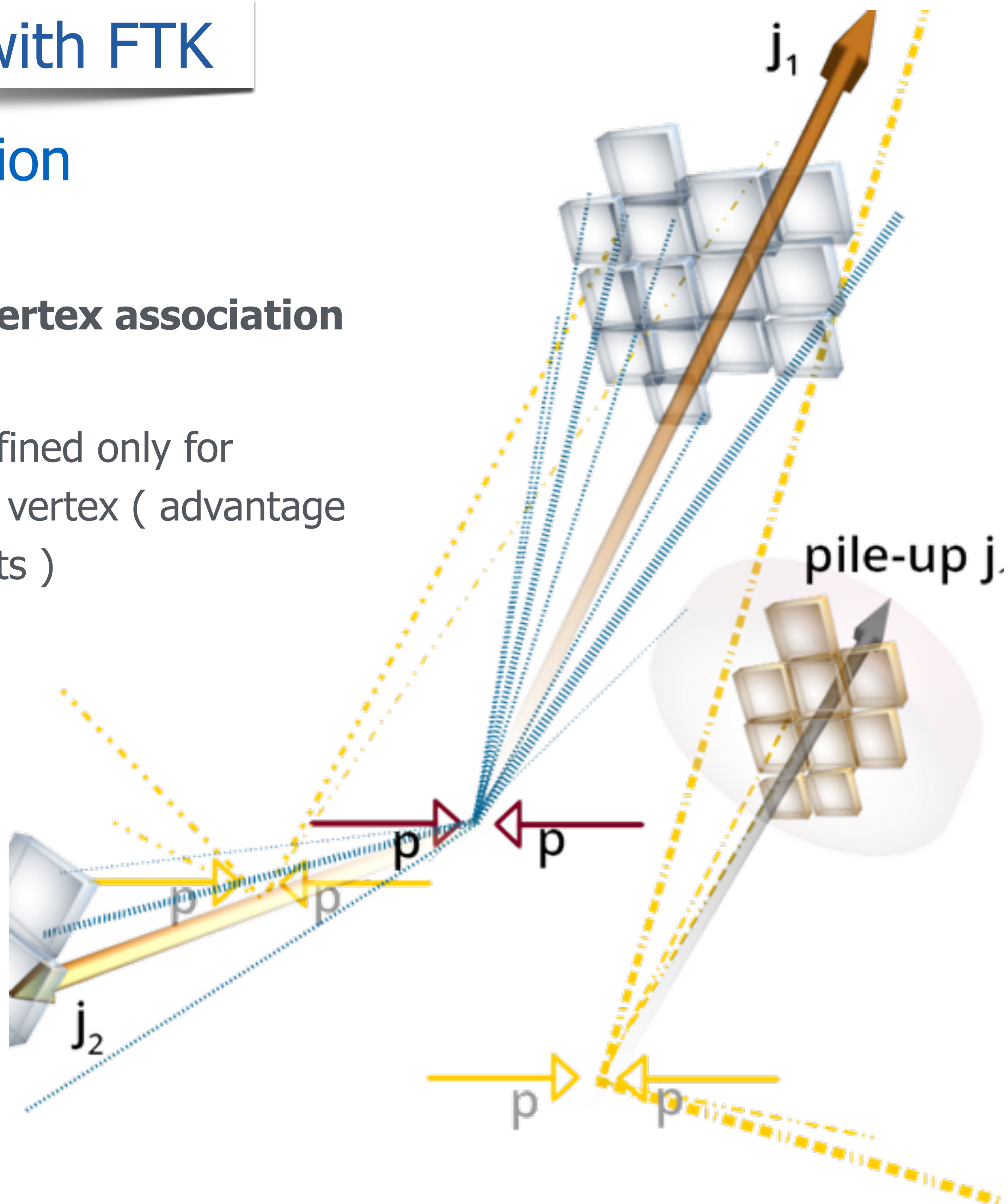


- jets reconstructed with/without 'ghost tracks' look the same.
- However, now can define track properties of ghost-associated jet.

Jet Calibration with FTK

ghost-association

- additionally, **track-to-vertex association** is performed.
- track-moments of jet defined only for tracks from hard scatter vertex (advantage over calo-based moments)



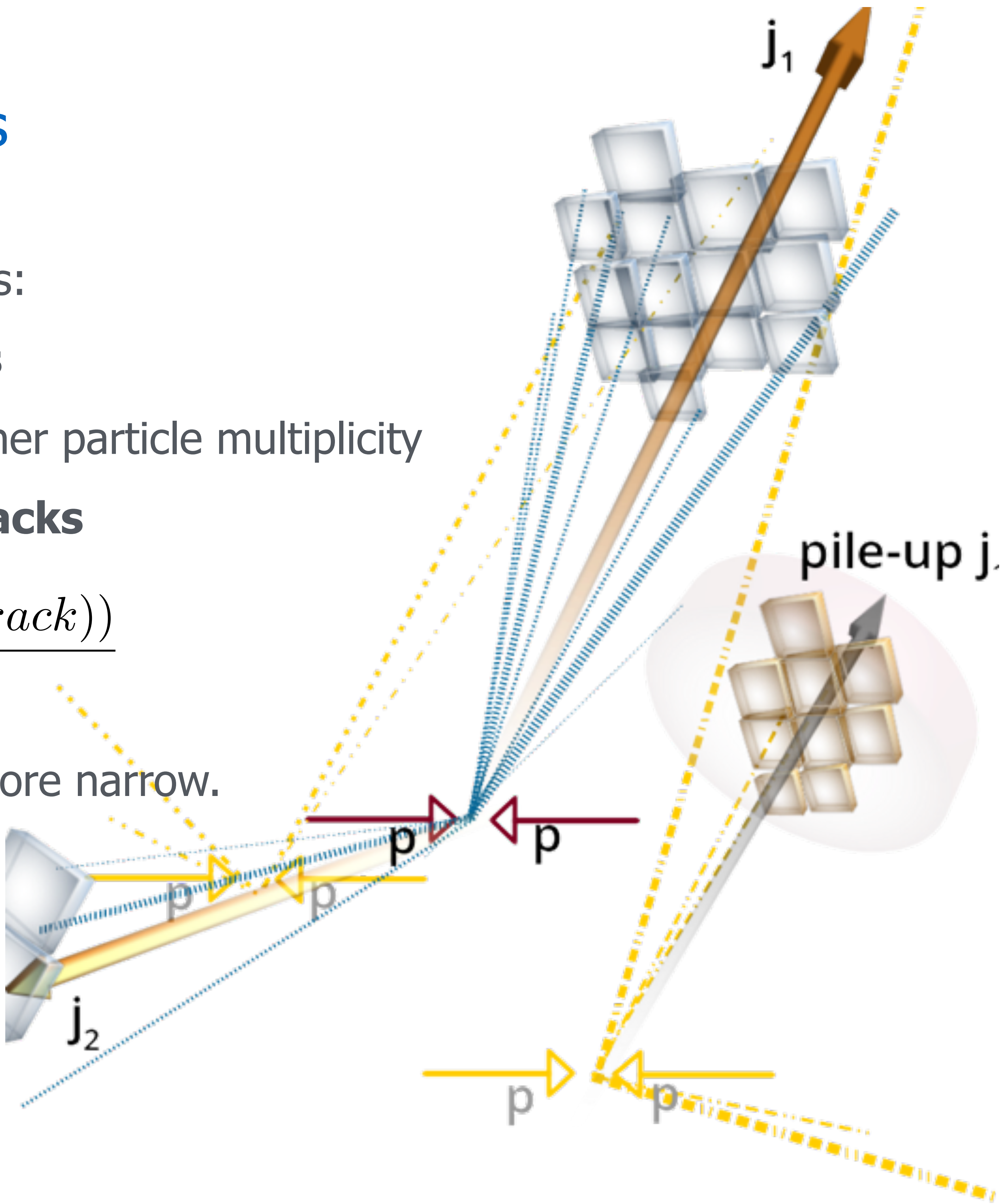
Jet Calibration with FTK

track-based moments

- discriminating track-based moments:
  - **number of associated tracks**
    - gluon-initiated jets have higher particle multiplicity
  - **track width of associated tracks**

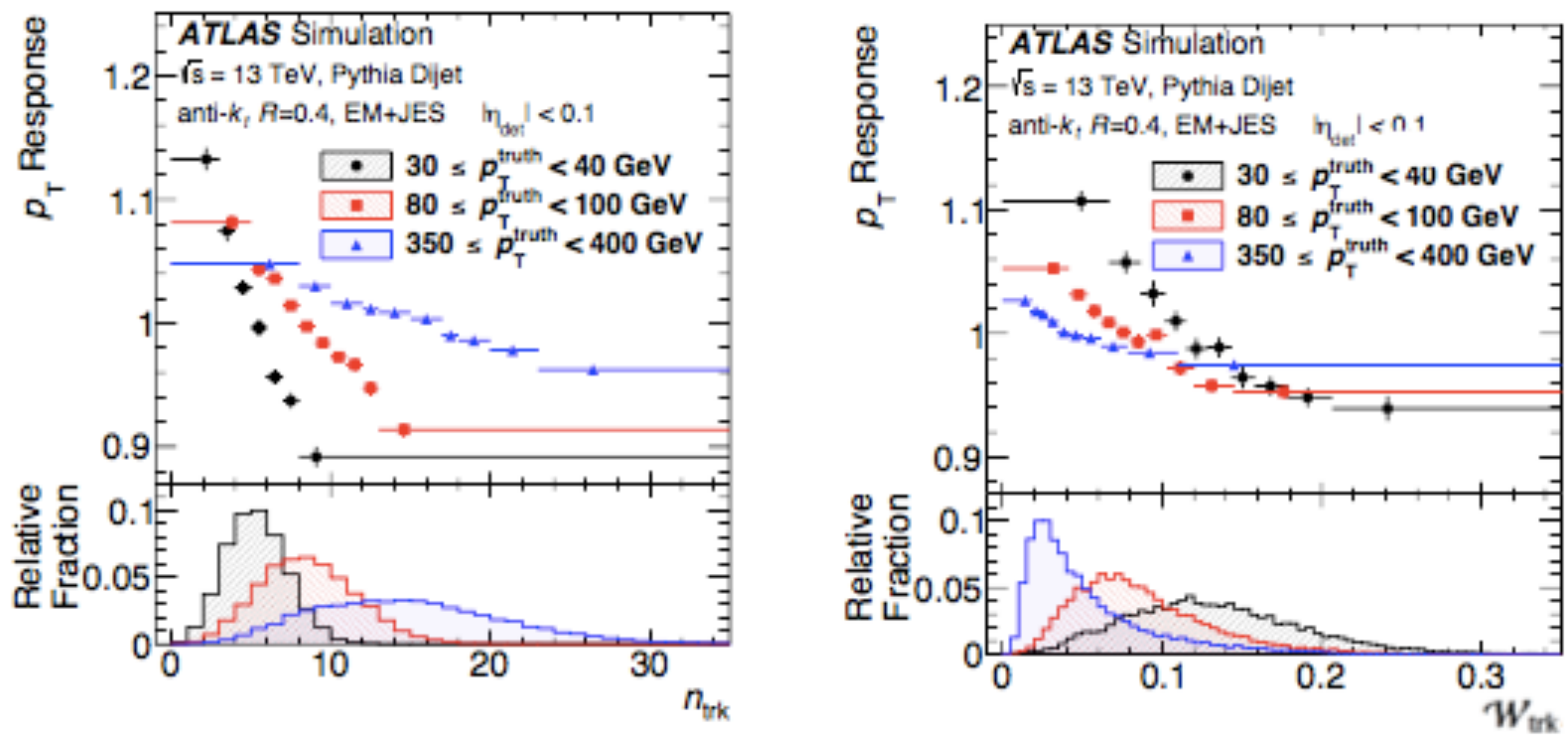
$$\frac{\Sigma(p_{Ttrk} \times \Delta R(jet, track))}{\Sigma p_{Ttrk}}$$

- gluon-initiated jets are more narrow.



Jet Calibration with FTK

global sequential calibration (for offline jets)

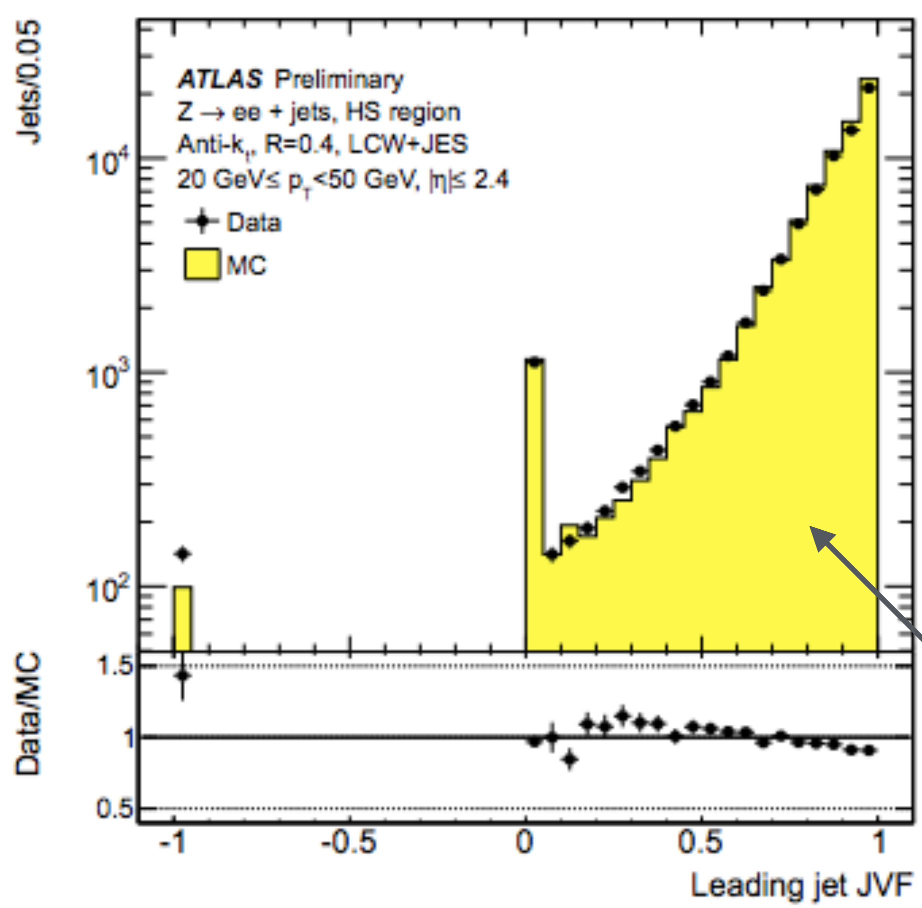


- energy response as function of track-based jet moments for offline tracks.

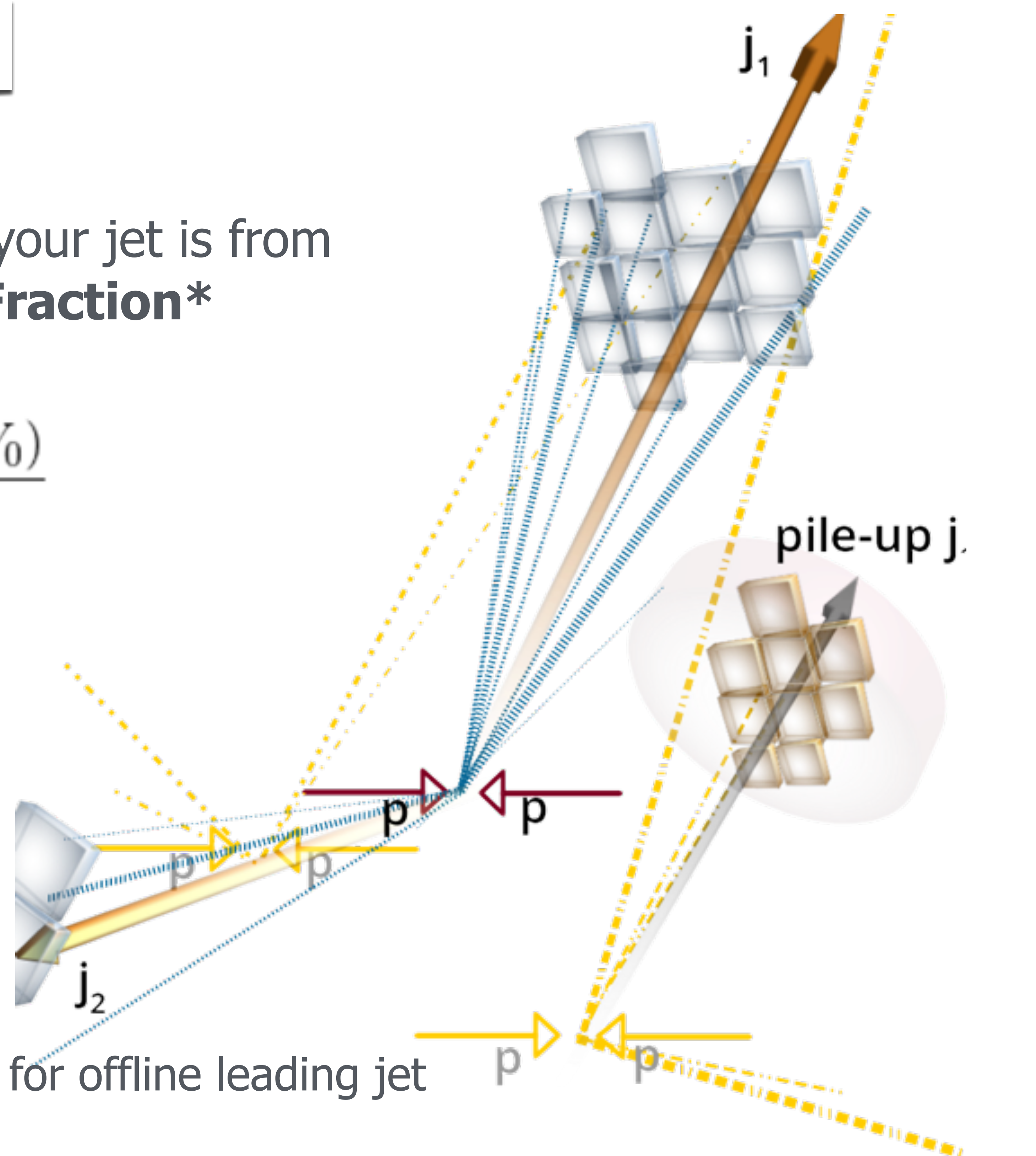
Pile-up rejection with FTK

- simple way to quantify likelihood your jet is from hard scatter vertex: **Jet Vertex Fraction***

$$JVF = \frac{\sum_k p_T^{trk_k}(PV_0)}{\sum_N p_T^{trk_N}}$$

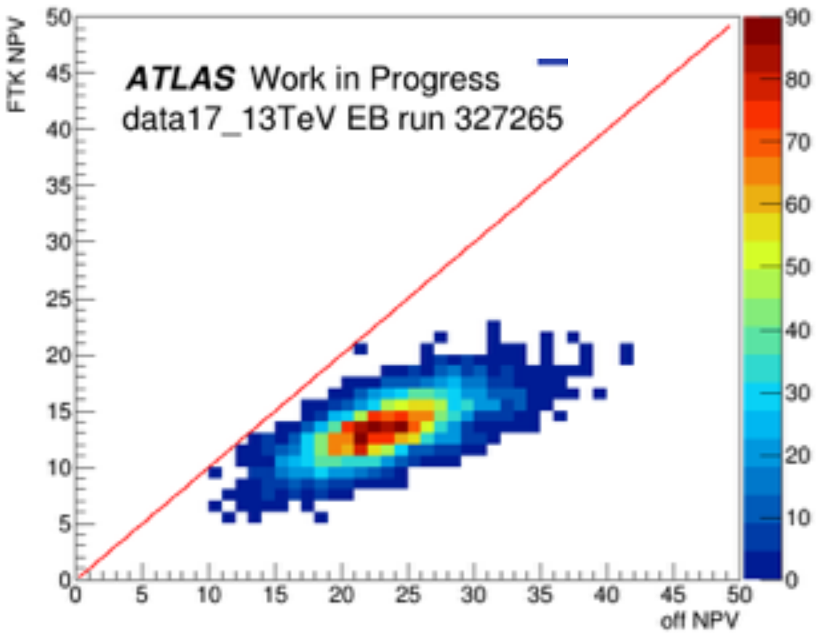


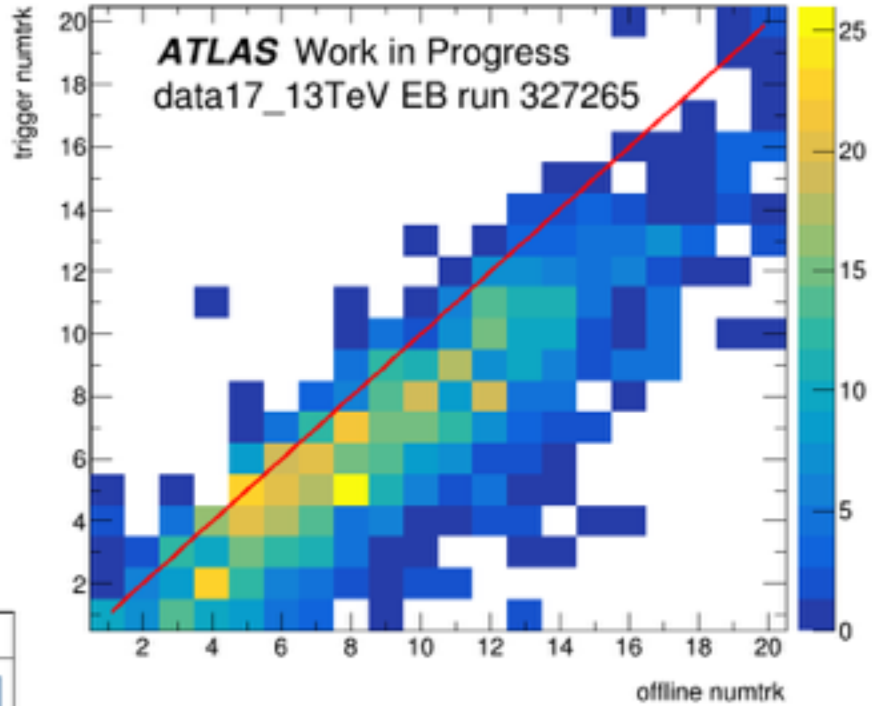
JVF for offline leading jet

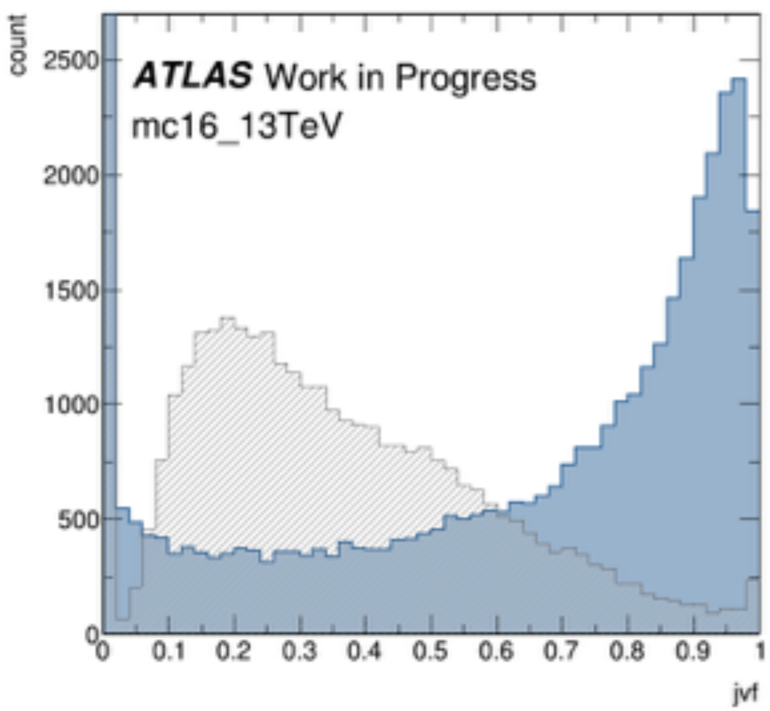


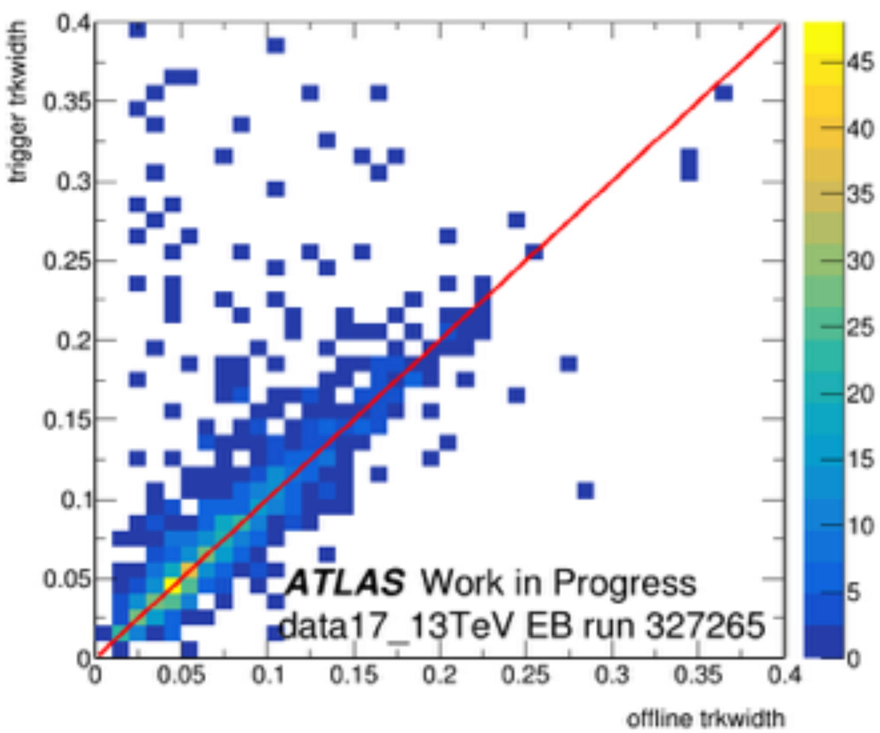
* shape of JVF dependent on number of interactions in event; in actual fact, ATLAS now uses a slightly different hard scatter jet tagger (JVT)

Jet Calibration with FTK





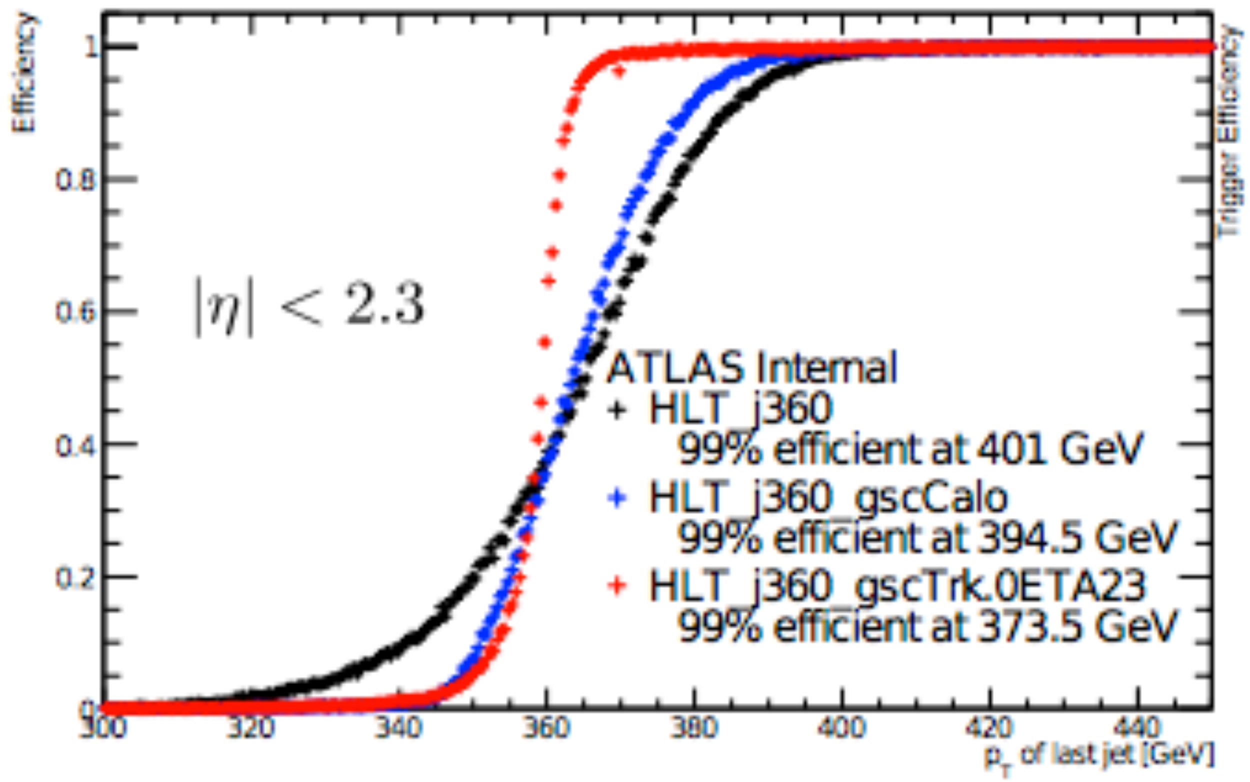




- Calibration coefficients to be rederived - “FTK-dedicated calibration set” - knowing that FTK not fully efficient w.r.t. offline tracks.
- (TLA perfect use case for FTK studies :)

Jet Calibration with FTK

jet trigger turn-on curves



result from precision (not FTK!) tracks

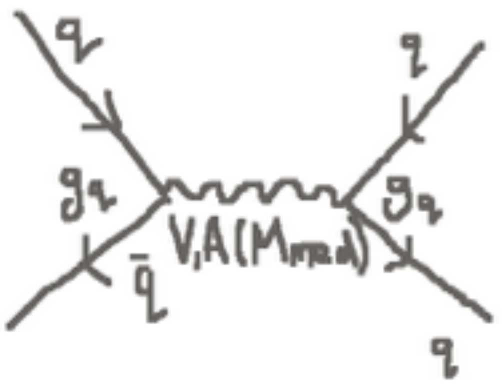
- jet calibrations with FTK will lead to improved trigger efficiencies once loaded online.
  - -> lower pT cut on leading jets.

Further Cool Trigger ideas

No signs of dark matter/other new physics.
Where to look ?

something unusual

general searches

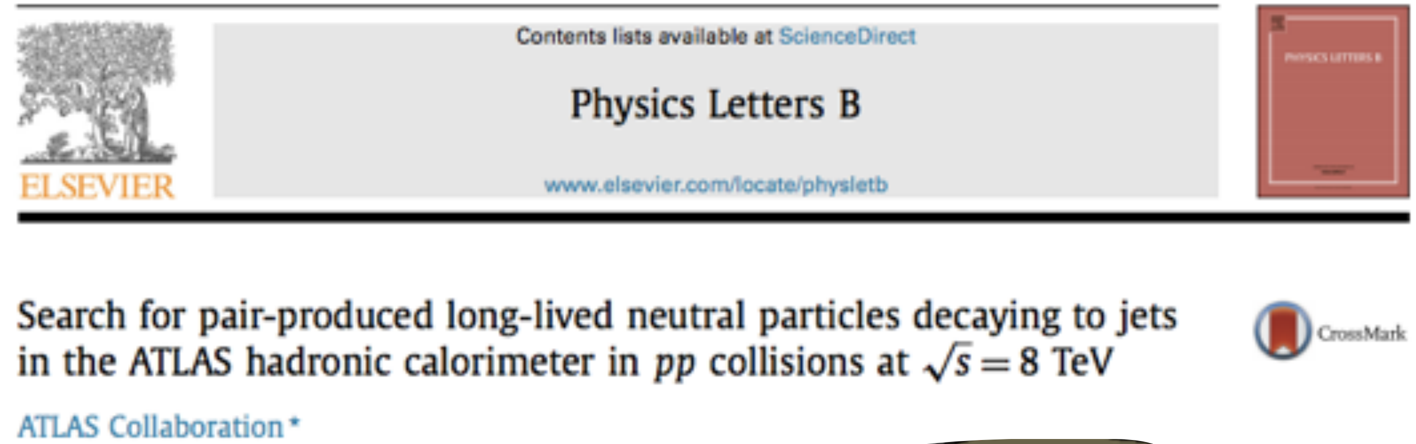


are we triggering
on something unusual ?

e26
2mu14
10j40
j420
mu26
4j100
2e17
xe110
2g20
3j200
j60+btag+xe80

yes !

calo-ratio trigger


Contents lists available at ScienceDirect

Physics Letters B

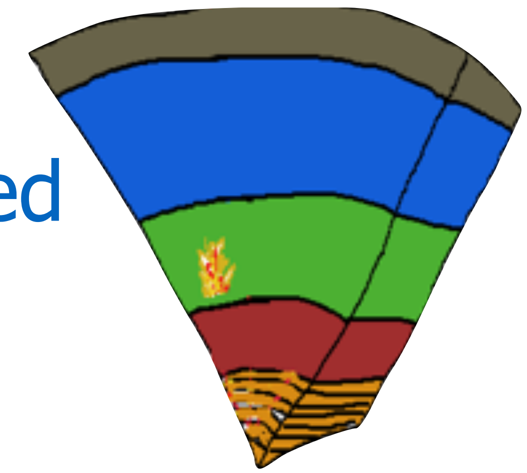
www.elsevier.com/locate/physletb

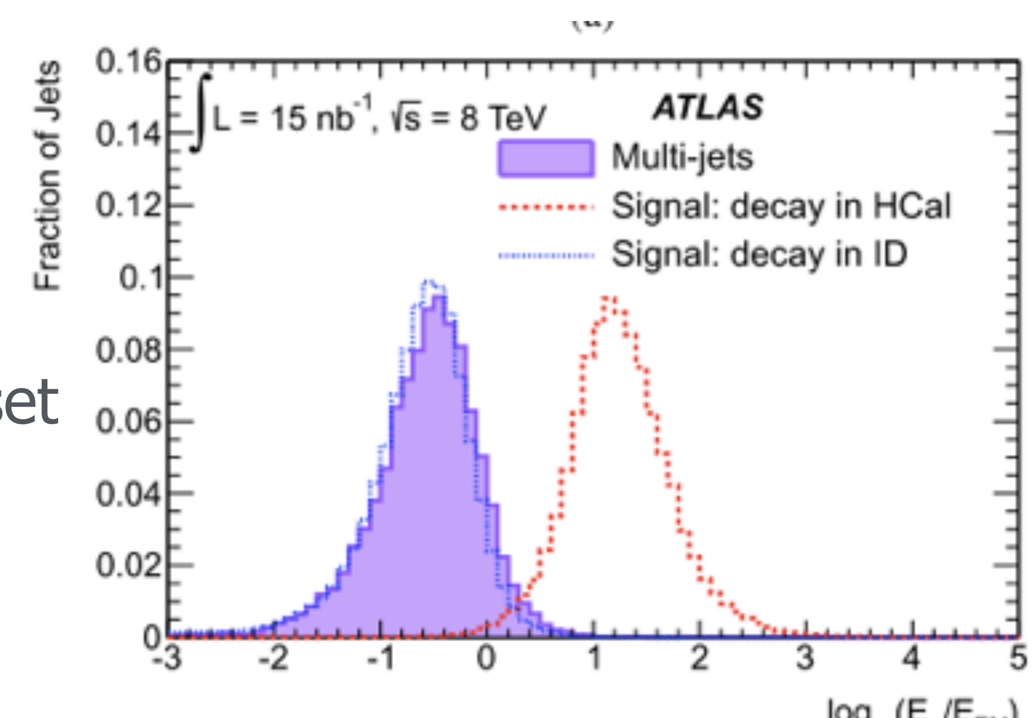
Search for pair-produced long-lived neutral particles decaying to jets in the ATLAS hadronic calorimeter in pp collisions at $\sqrt{s} = 8$ TeV

ATLAS Collaboration *

- implemented since Run 1.
- Trigger
  - narrow L1 Jet > 60 GeV
  - **log(E_H/E_{EM}) > 1.2**
  - HLT jet > 30 GeV
  - no tracks matched to jet.
  - beam-induced background veto: min 4 cells along same Phi as jet with BIB-like timing offset

delayed decay of long-lived neutral particles



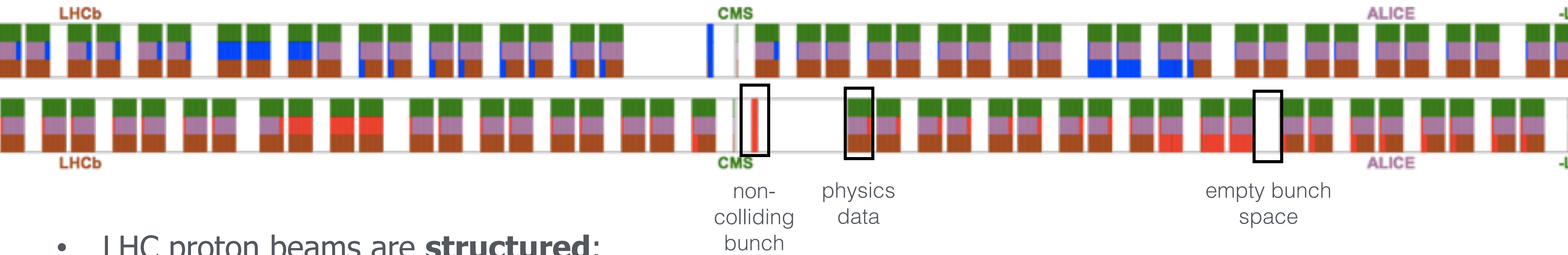


(b)

- trigger rate ~ 20% of HLT jet trigger j400
  - trigger rates can be reduced by targeting all unusual traits of signature.

empty bunch crossings

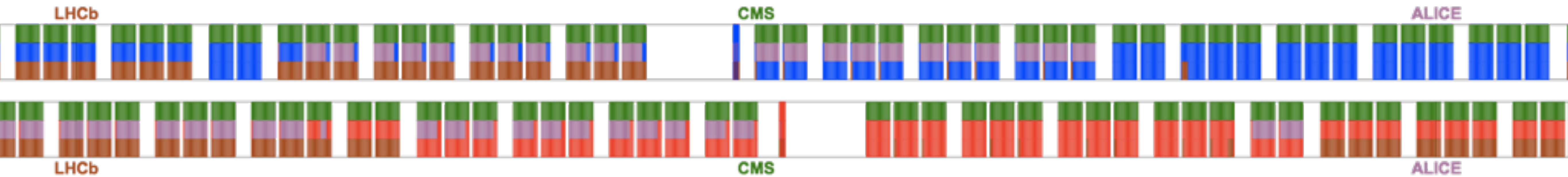
http://lpc.web.cern.ch/cgi-bin/filling_schemes.py



- LHC proton beams are **structured**:
  - proton **bunches**, spaced 25 ns apart, circulate in **batches** in SPS.
  - SPS batch spacing set by SPS injection kicker rise time: min. 200 ns (8 empty bunch spaces)
  - injected into LHC in LHC batches.
  - LHC batch spacing set by injection kicker rise time: 900 ns (36 empty bunch spaces)
  - abort gap of ~119 empty bunch spaces set by beam dump kicker rise time.
- crossing types at interaction points:
  - colliding bunches (physics data)
  - non-colliding bunches (beam background)
  - **empty bunch crossings** → no background ! Look for long-lived particle here?

empty bunch crossings

http://lpc.web.cern.ch/cgi-bin/filling_schemes.py



decay of embedded long-lived particle (R-hadron)

- 'Empty Bunch Crossing' Trigger
  - L1Jet > 30 GeV, HLT jet > 50 GeV, missing ET > 50 GeV
  - **active in empty bunch crossings, 125ns after colliding bunch.**
  - HLT trigger rate < 1 Hz (low activity)

Data period	Delivered luminosity (fb^{-1}) @ energy (TeV)	Recorded empty live time (hours)
Cosmic	0.3 @ 7	125.8
Search	5.0@7 + 22.9@8	389.3
Total	5.3@7 + 22.9@8	515.1

empty bunch crossings

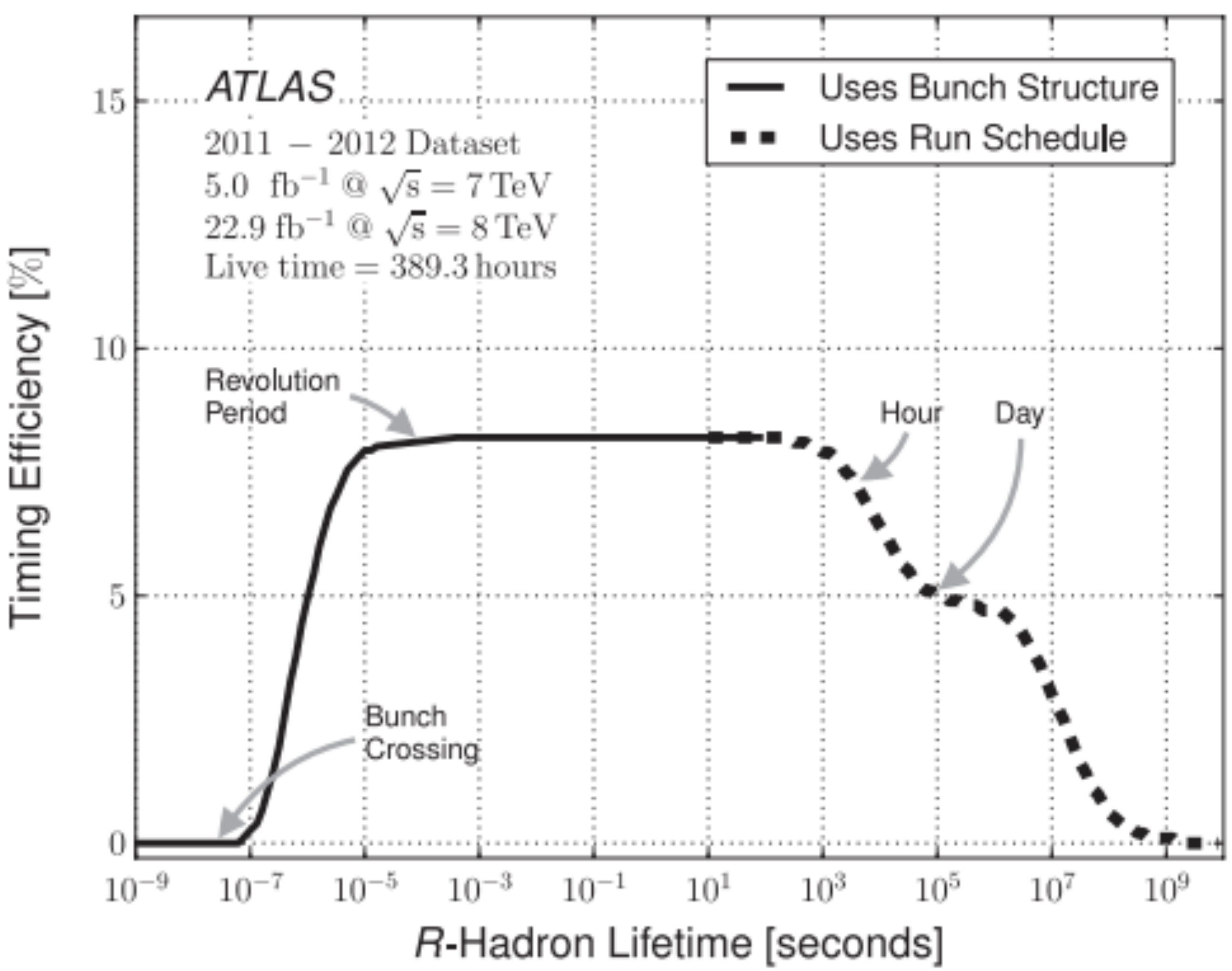
PHYSICAL REVIEW D **88**, 112003 (2013)

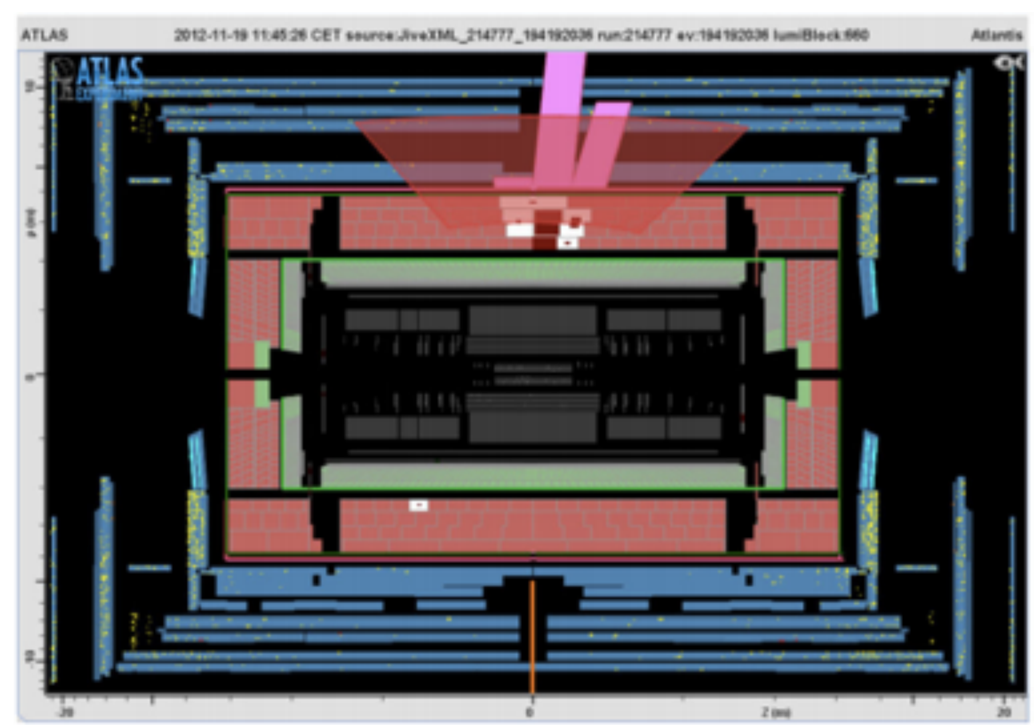
Search for long-lived stopped *R*-hadrons decaying out of time with *pp* collisions using the ATLAS detector

G. Aad *et al.**
(ATLAS Collaboration)
(Received 24 October 2013; published 3 December 2013)

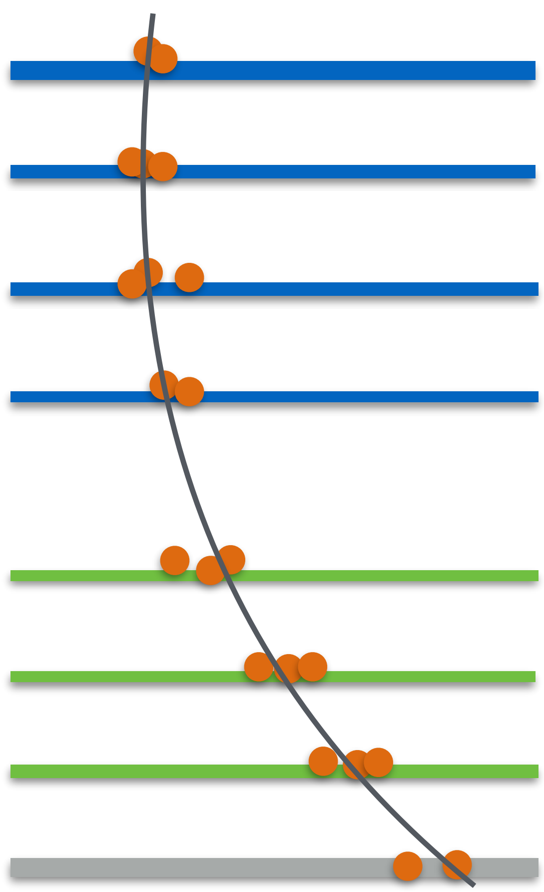
- (long lived) R-hadron reconstruction probability

$$L \times \sigma \times \epsilon_{stopping} \times \epsilon_{recon} \times \epsilon_T(\tau)$$

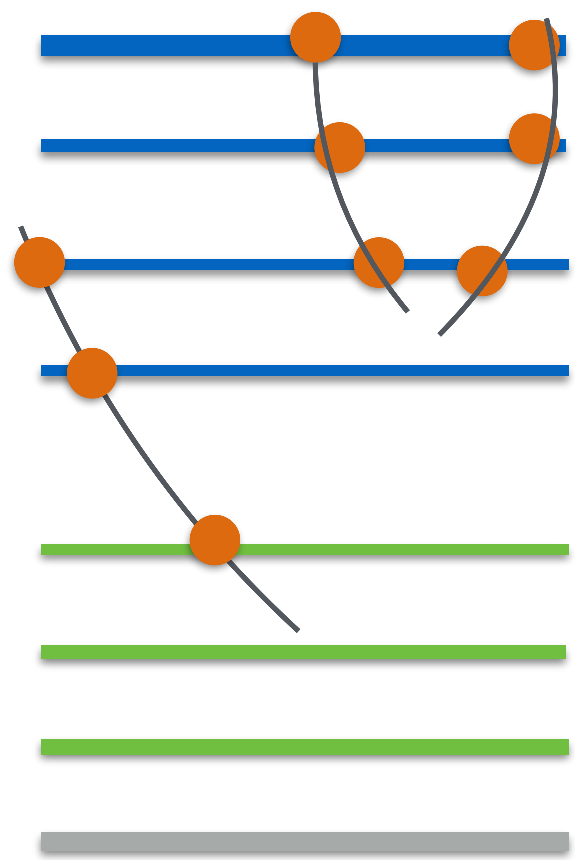




Future ideas: FTK heavy or delayed particles

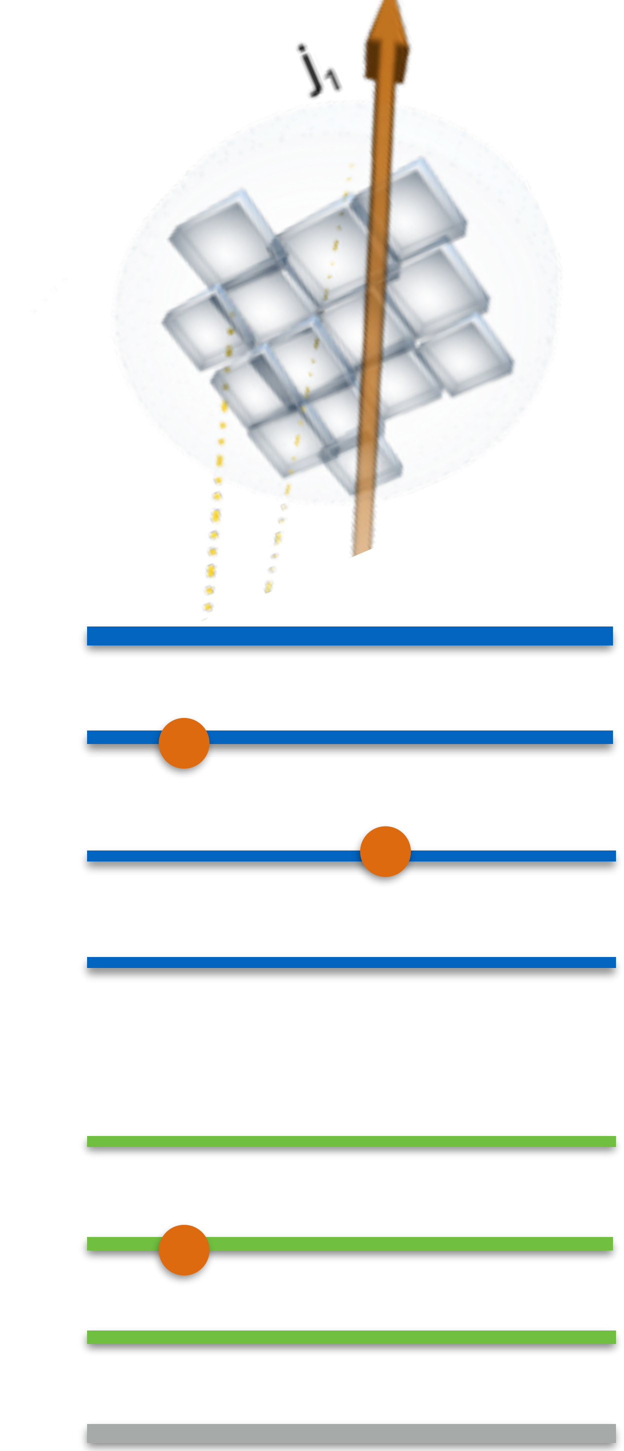


FTK high pT track
as seed
for HLT track with high dE/dx
(R-hadron)



FTK secondary vertex:

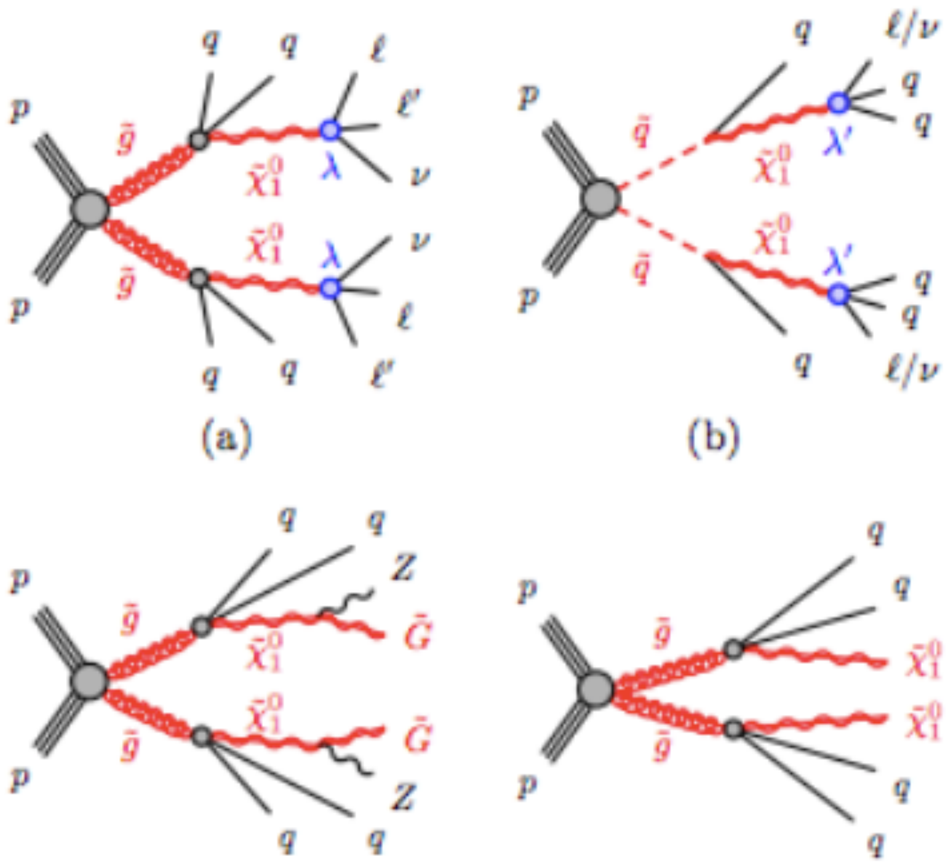
- challenge: requires generation of special ‘delayed particle’ pattern bank - optimise number of patterns based on efficiency vs fake rate



“no FTK track” trigger:
trackless jets

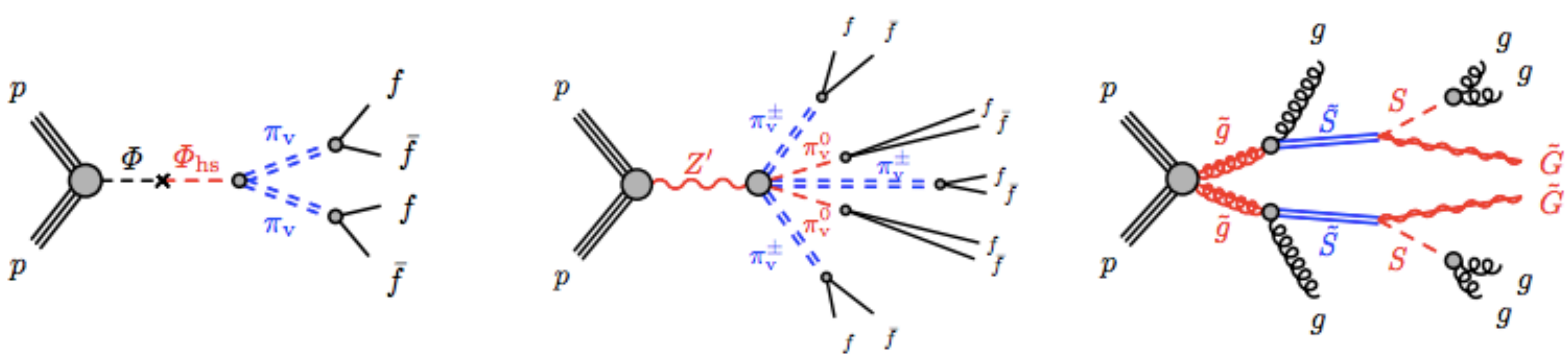
- challenge: calorimeter noise, pile-up (how to suppress rate ?)

displaced vertices



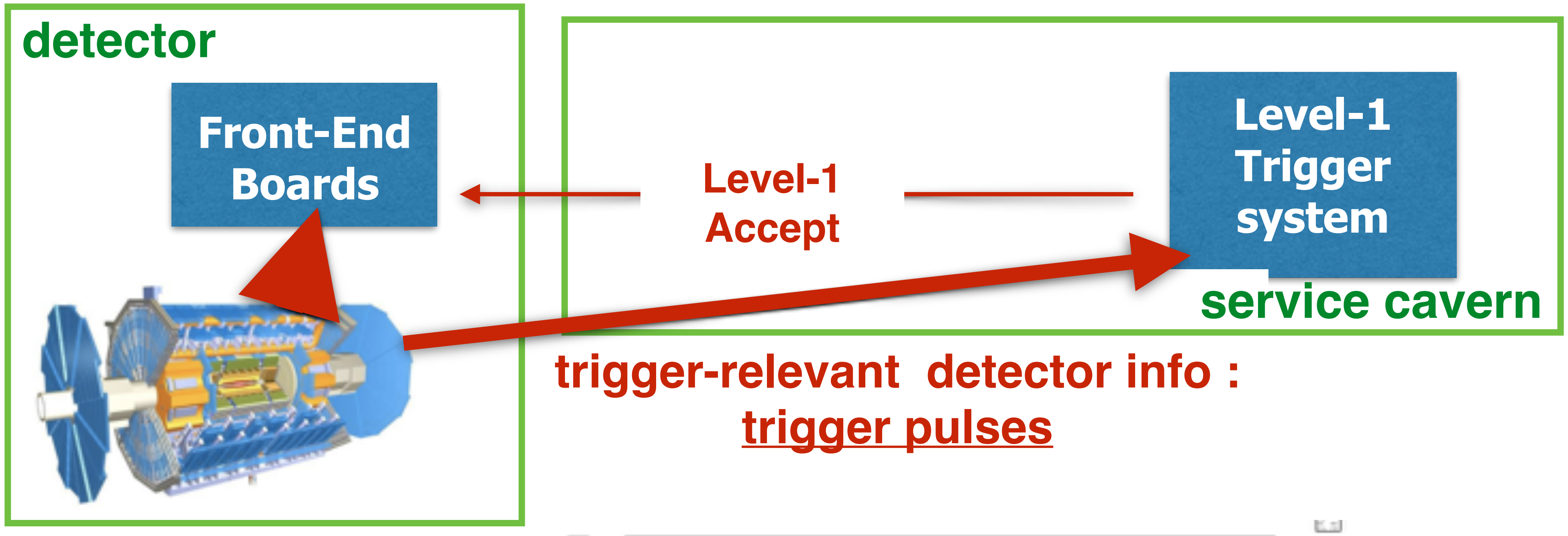
(a) (b) (c) (d)

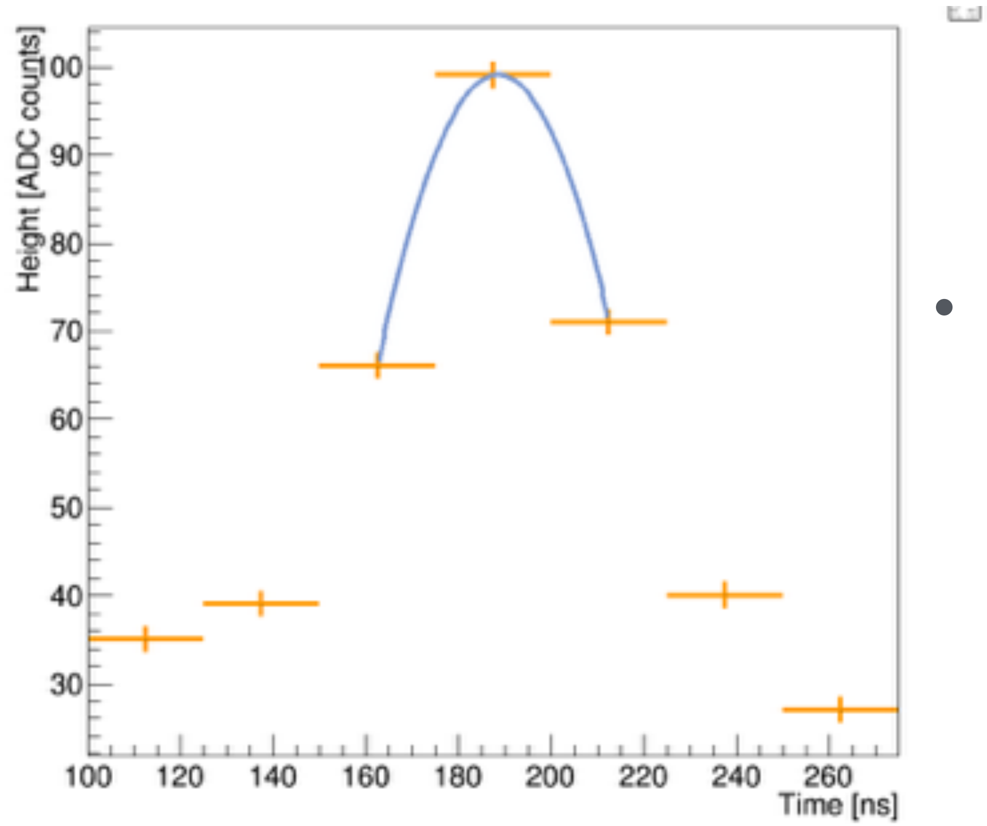
for dedicated FTK pattern bank



(a) (b) (c)

Future ideas: timing of raw pulses

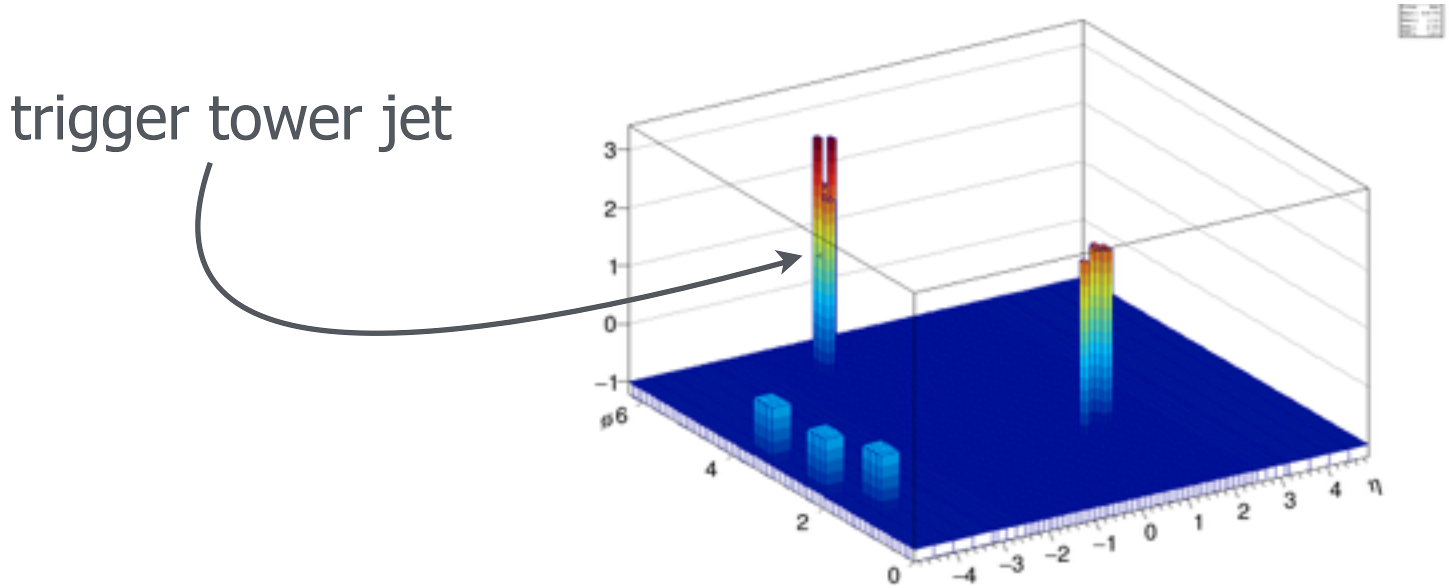


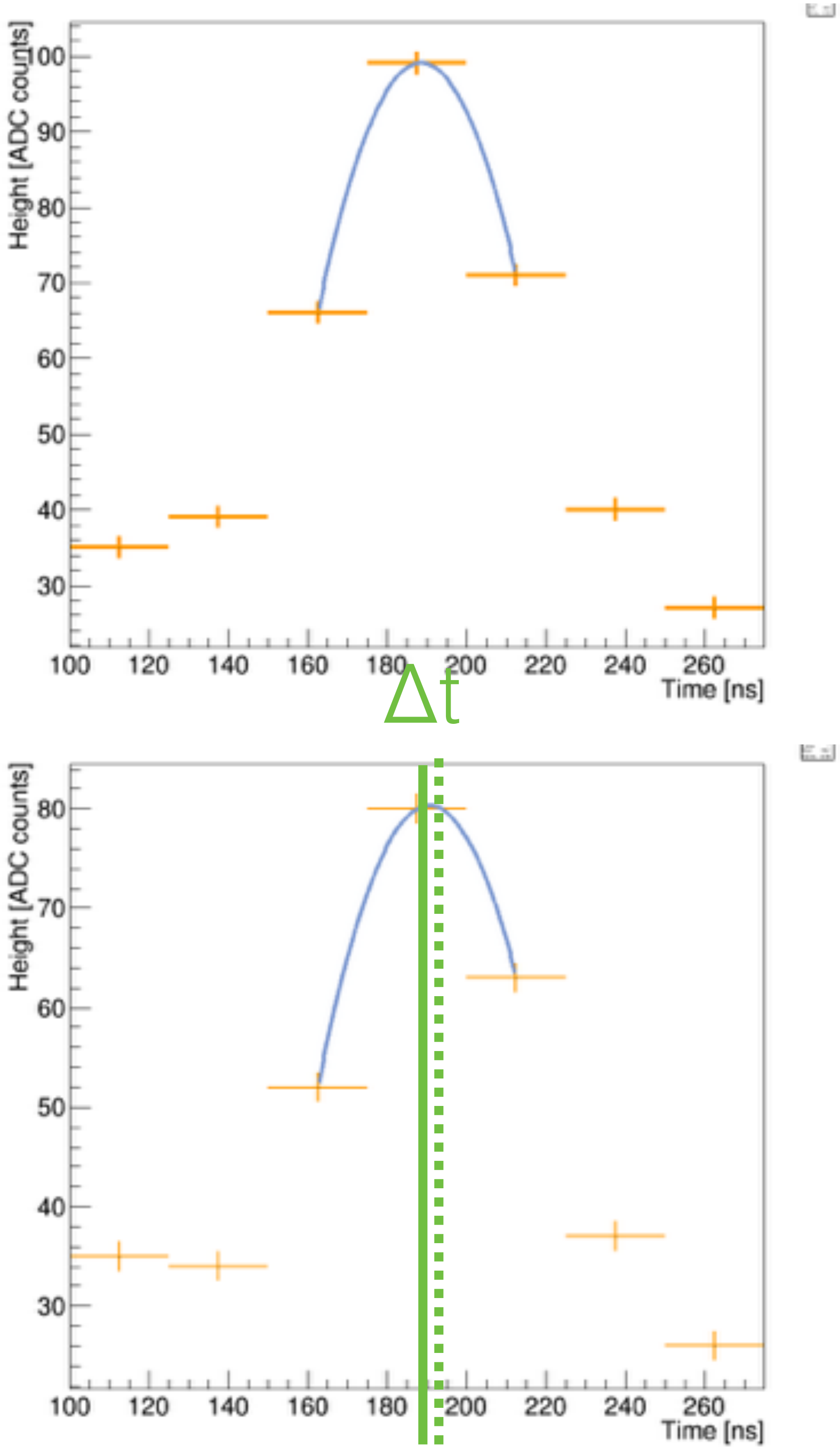


- calorimeter trigger pulses: digitized at 40 MHz.

Future ideas: timing of raw pulses

- reconstruct 'trigger tower' jets at HLT.
- fit to pulse to measure timing offset of trigger towers in 'trigger tower jet'
- trigger on average t_offset > 0 (+ resolution offset).





- **challenges**:
  - beam-induced background, out-of-time pile-up.
  - optimizing sensitivity of timing measurement.

In Summary

Trigger operations are extremely important:

"The trigger does not determine which physics model is right;
only which physics model is left."

No repeats: Running the LHC costs ~ 19 million Euros per year.*

*https://cds.cern.ch/record/2255762/files/CERN-Brochure-2017-002-Eng.pdf

In Summary

Trends though the ages

trigger increasingly **selective**: the more we know, the more becomes background obscuring the signals

cosmic-ray muon: " a new particle of mass intermediate between a proton and an electron "

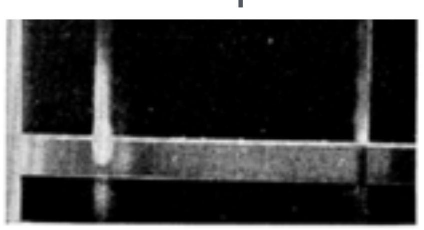
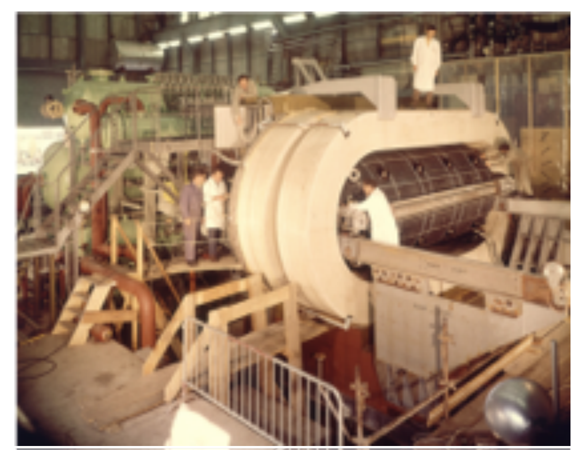
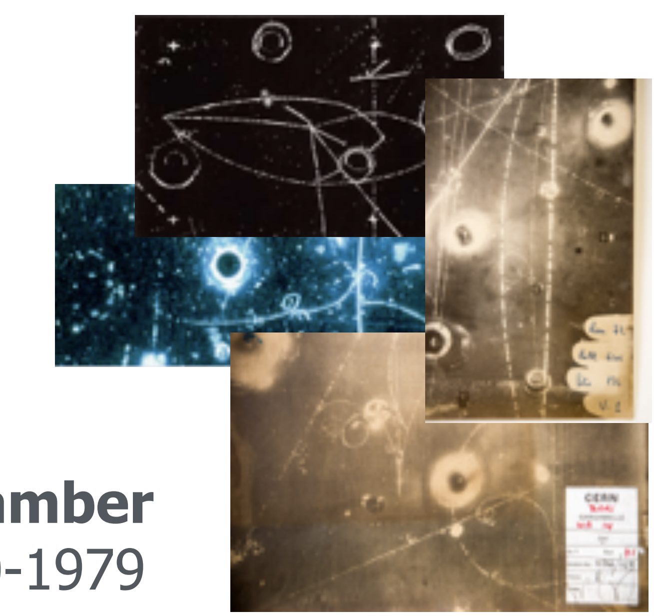


Fig. 3. Track B.

muon discovery 1936



Gargamelle, bubble chamber experiment, CERN, 1970-1979

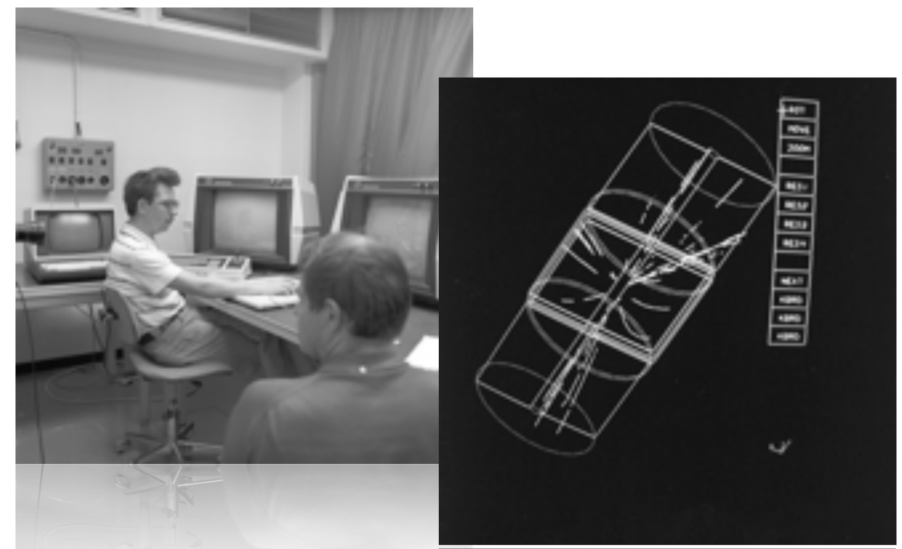


In Summary

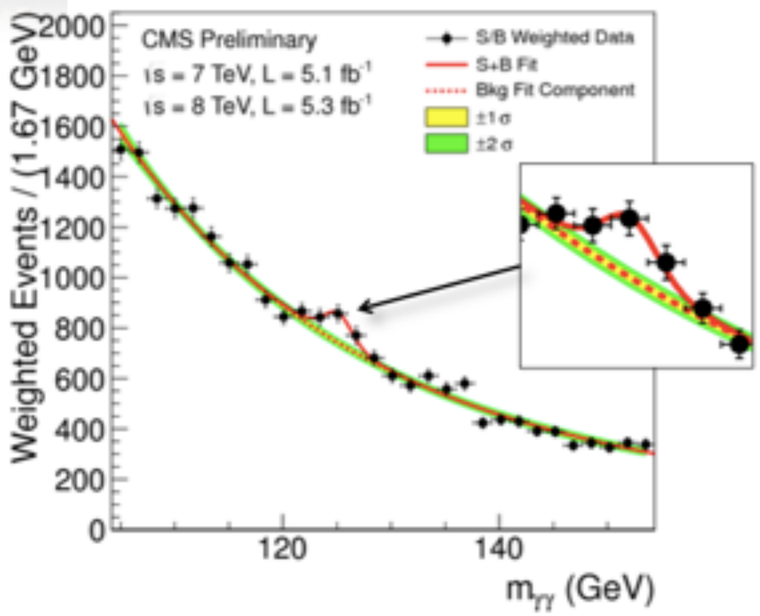
Trends though the ages

digital acquisition essential: discovery through **statistics**

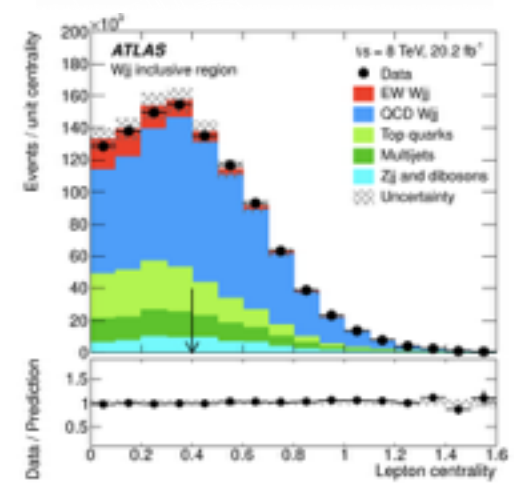
'scanning girl' for Gargamelle



Interactive event display at the Megatek facility for UA1.



Higgs discovery at the LHC



computer analysis: **histograms**.

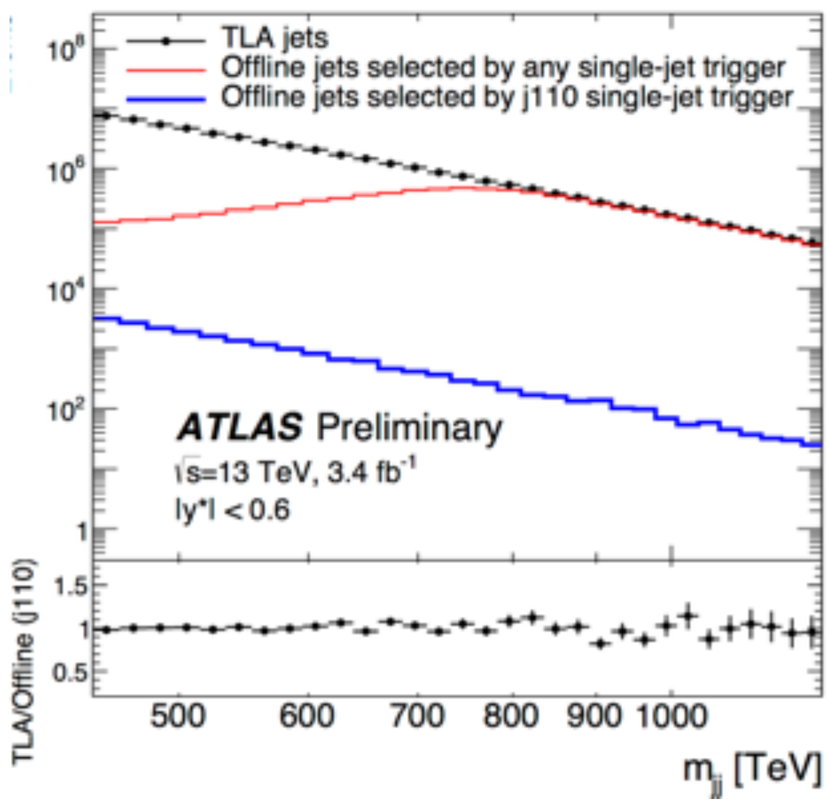
In Summary

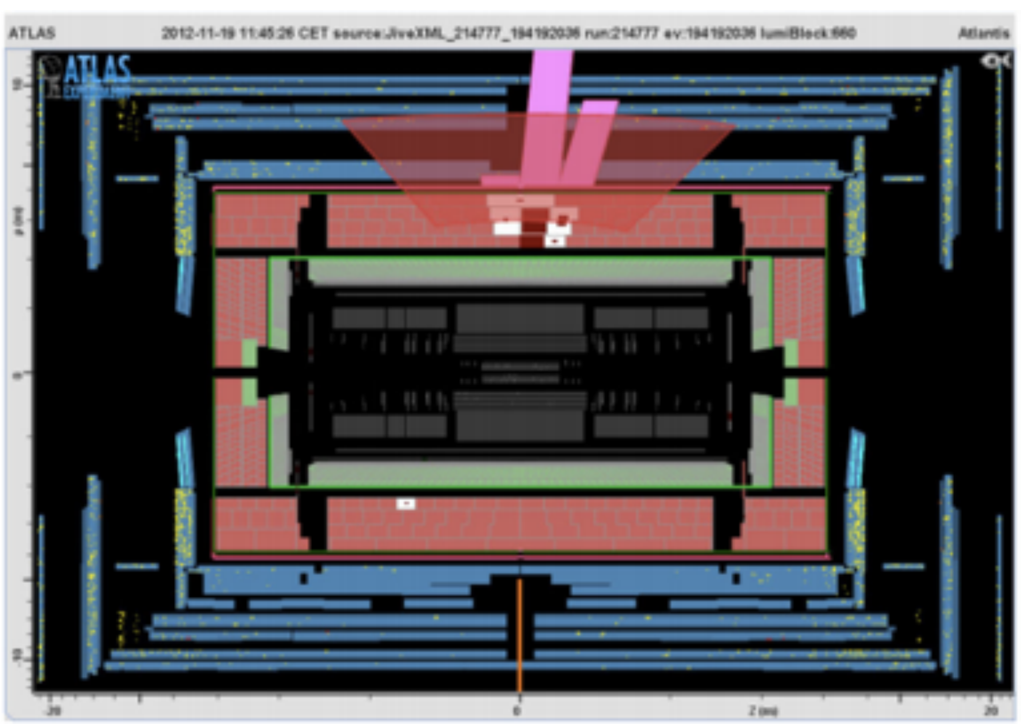
Trends through LHC running

Increasing activity in bunch crossing -> higher thresholds.

No signs of new physics.

'creative' searches: trigger limitation work-arounds, unusual signals



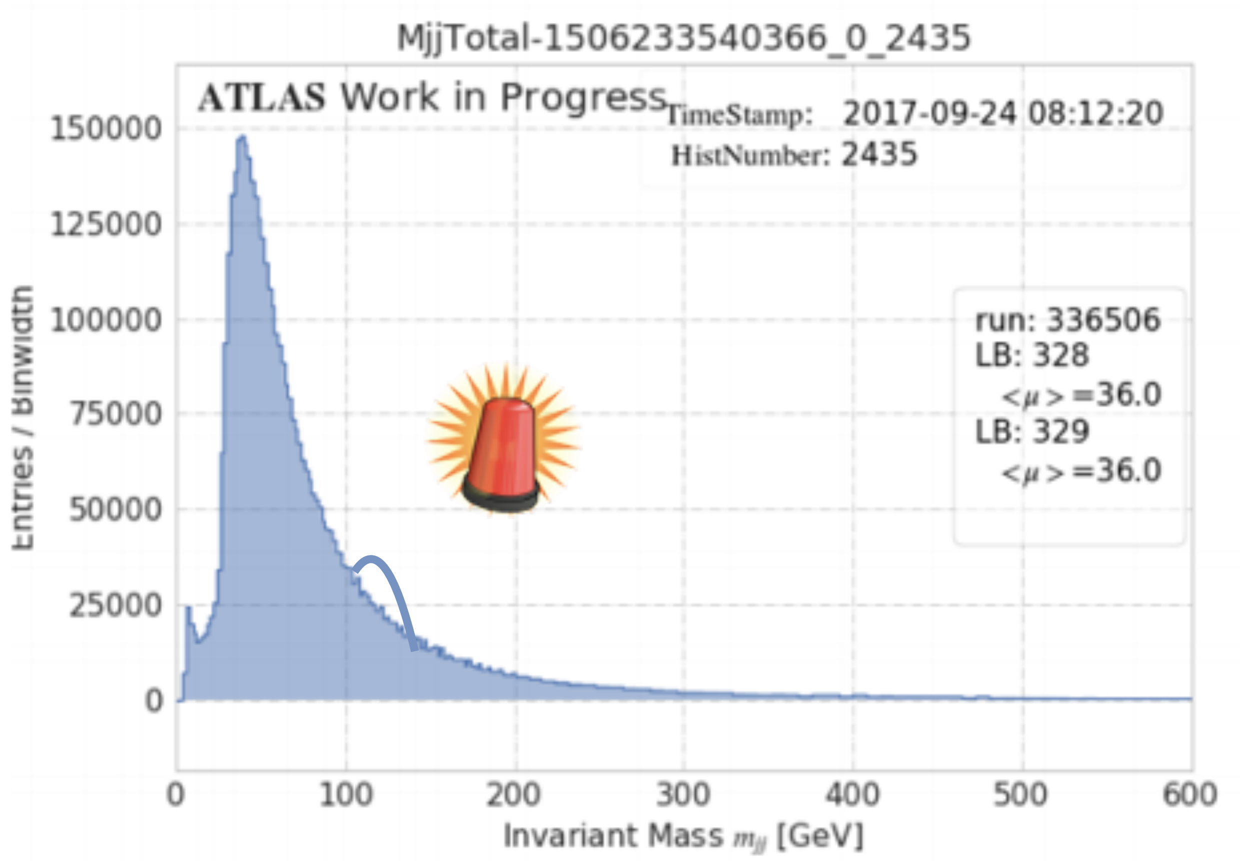


In Summary

Trends at high energy collider experiments

improving reconstruction at trigger-level

calibration moving online



... towards real-time analyses ?