ATLAS jet triggers and trigger-level analysis

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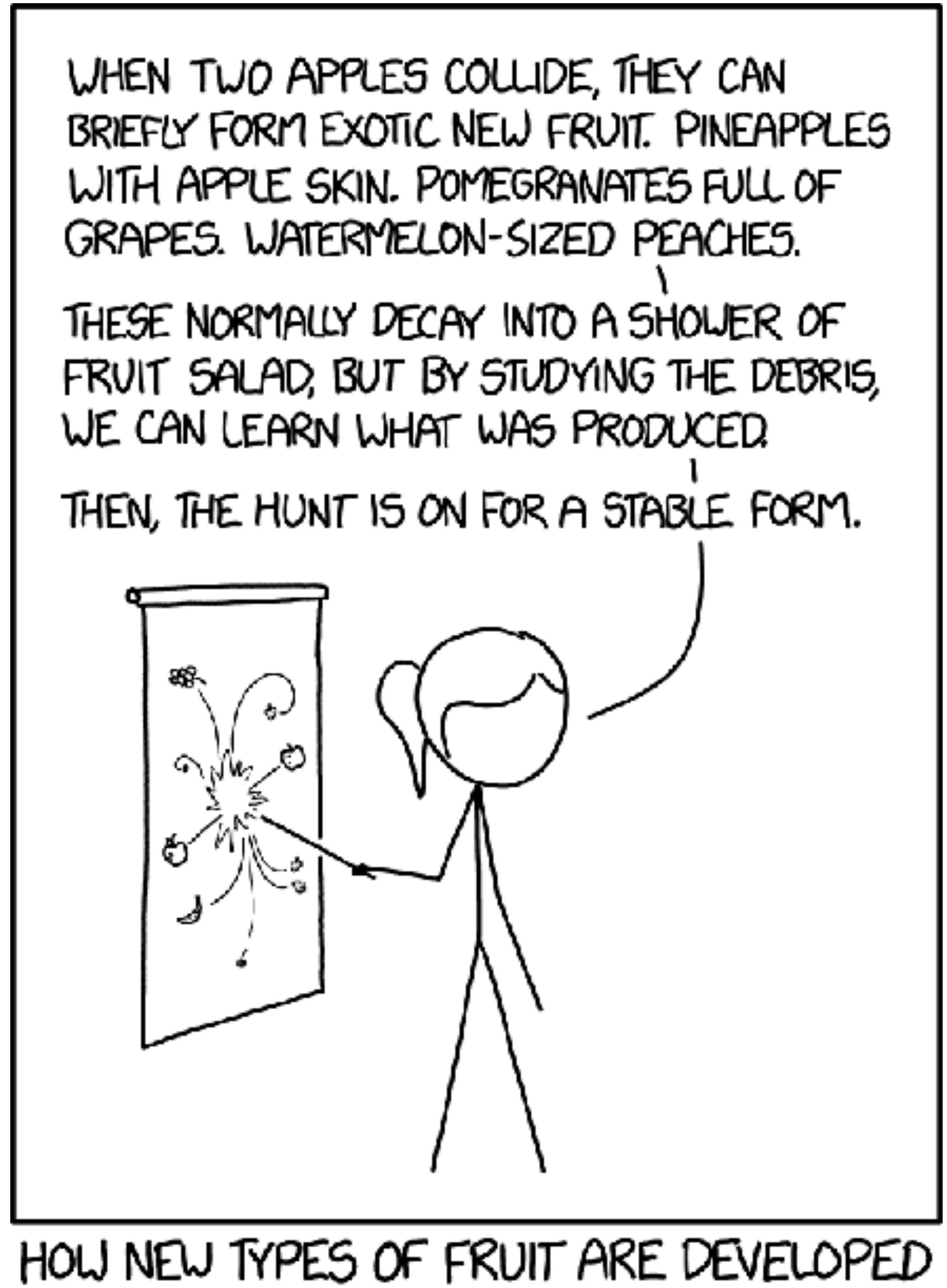
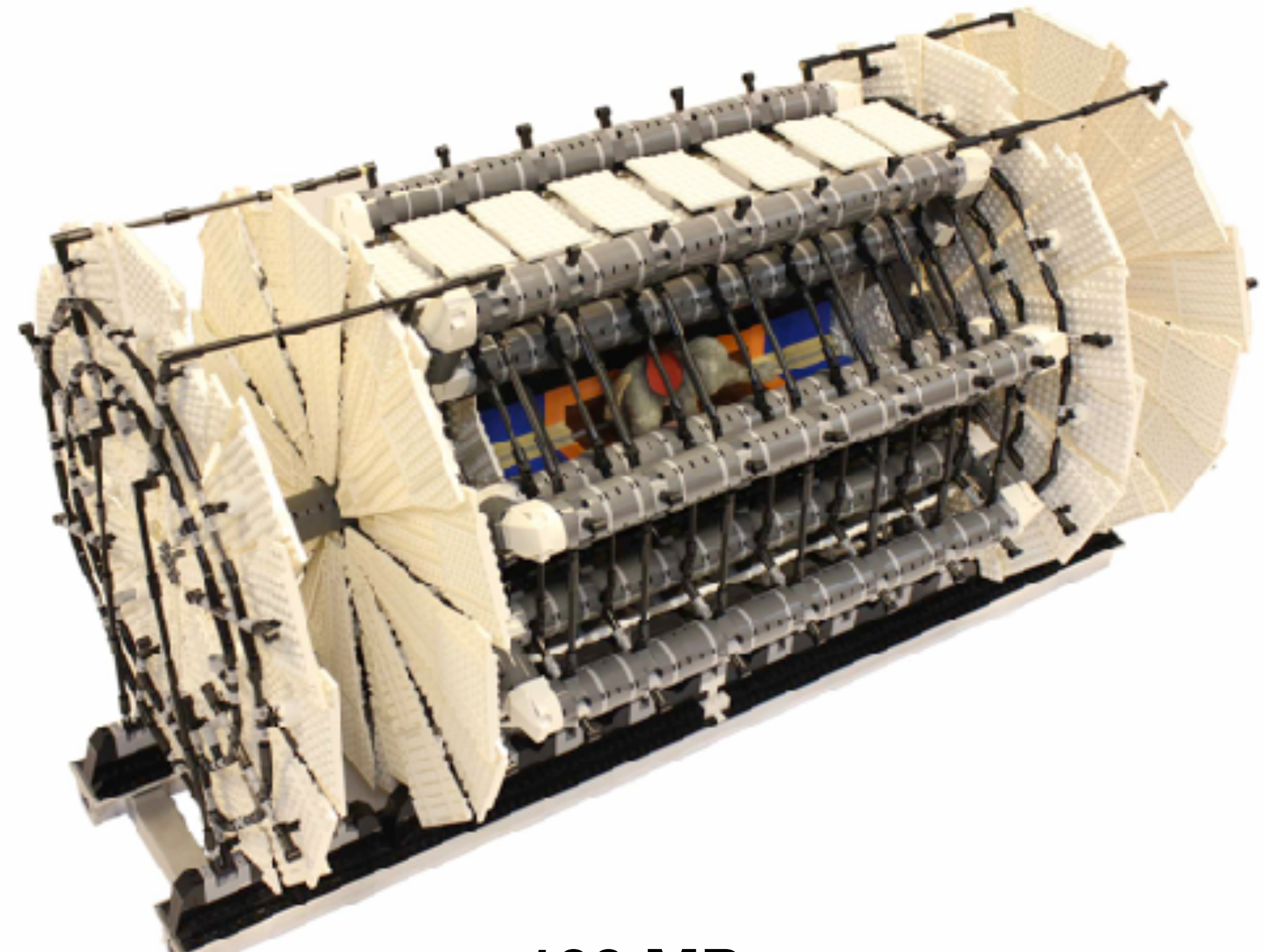
Lund University
Uppsala, 24.04.19



https://xkcd.com/1949/

ATLAS vs a smartphone



100 MP

https://arxiv.org/abs/1303.7367

~10 MP

- Can’t record everything: capabilities of readout electronics, enormous storage
- Solution: prime for readiness, press the shutter button during an interesting event

When to press the shutter button?

- Some things don't linger very long

Big blue sea

https://www.youtube.com/watch?v=H2zLvWeyiJY

- When will something interesting happen?
- How to record something after it's happened?

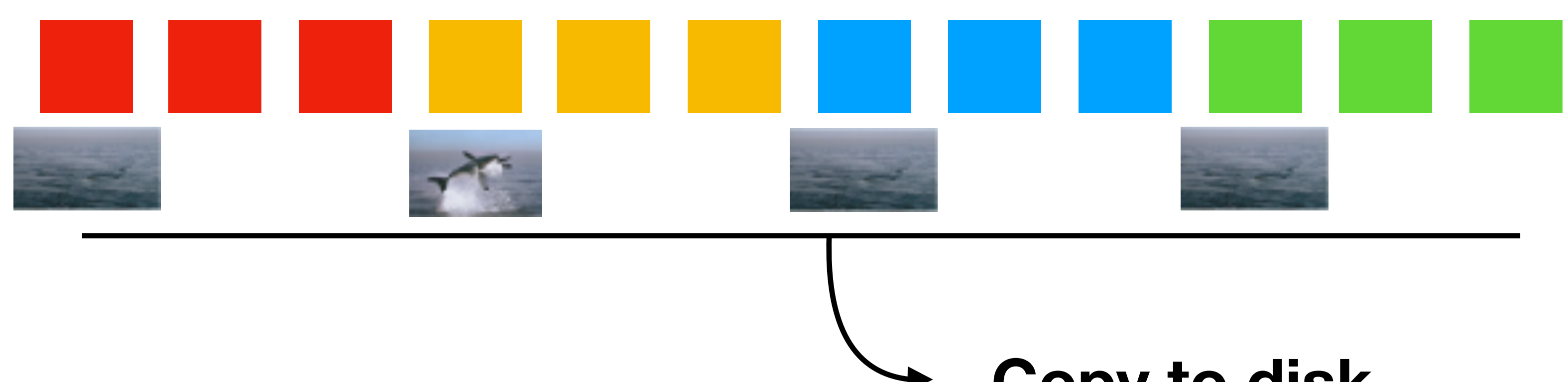
Memory and pipelines

Internal memory: space for N frames

“one in, one out” pipeline memory

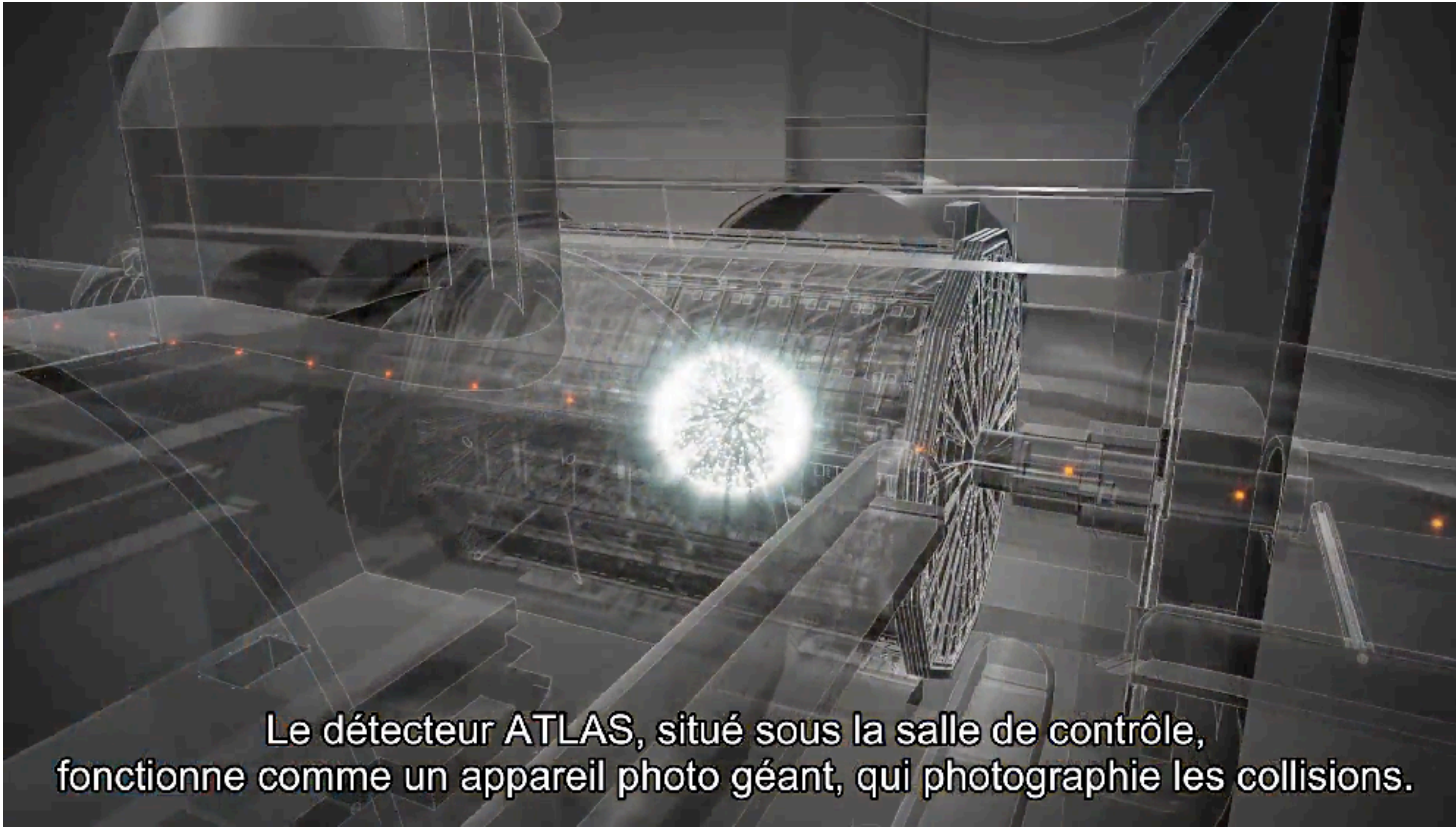
Something happened! Record the past N frames

“Trigger”



Copy to disk

High-speed photography



https://videos.cern.ch/record/2033743

Similar across HEP

Method

Target material volume

Put it somewhere where interesting things might happen

Where do backgrounds come from?

How to mitigate?

Trigger records:

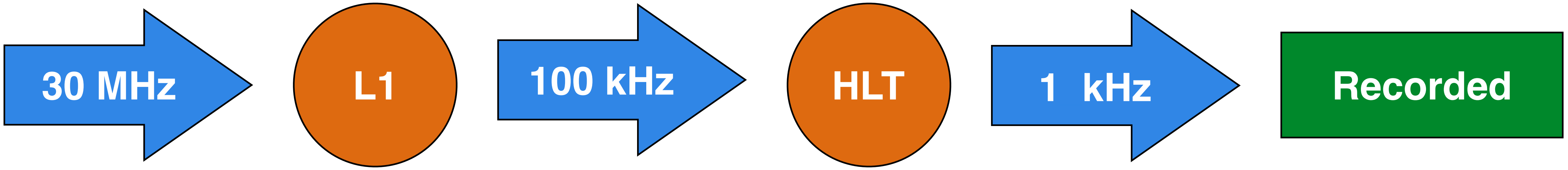
What to trigger on?

Method	Direct DM Detection
Target material volume	Xe tank
Put it somewhere where interesting things might happen	Anywhere :-)
Where do backgrounds come from?	The sky / radioactive things
How to mitigate?	put underground and shield
Trigger records:	~everything that happens

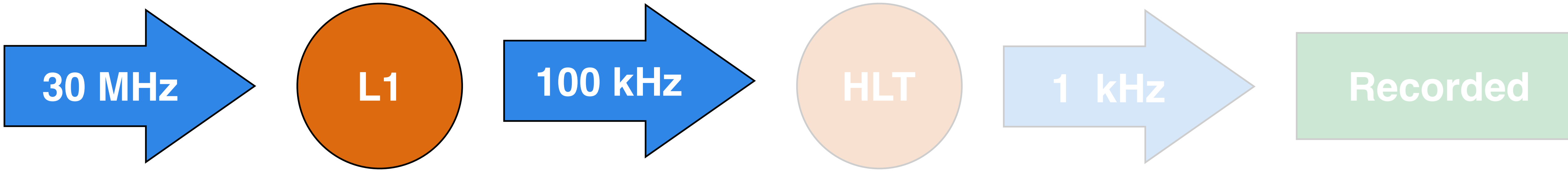
What to trigger on?

Method	Direct DM Detection	Collider experiment
Target material volume	Xe tank	Ar / Fe in calorimeters
Put it somewhere where interesting things might happen	Anywhere :-)	Near colliding LHC beams
Where do backgrounds come from?	The sky / radioactive things	The colliding LHC beams…
How to mitigate?	put underground and shield	“boring” QCD tends to give low-p_T jets
Trigger records:	~everything that happens	only high-p_T events

ATLAS trigger system

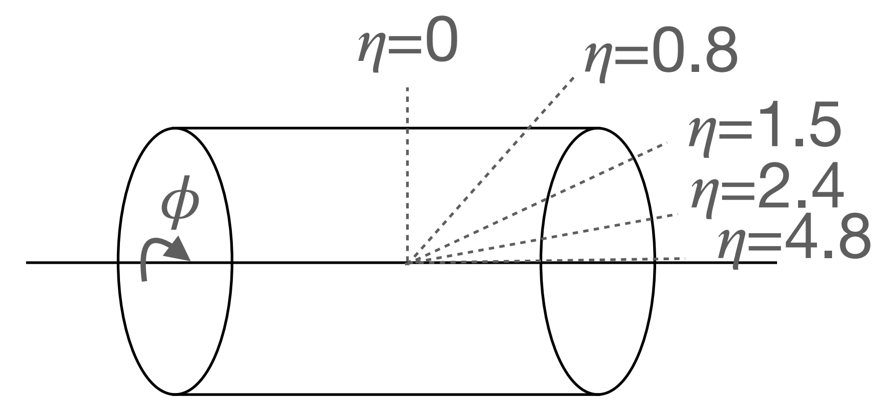


ATLAS trigger system



Limitations:

detector readout

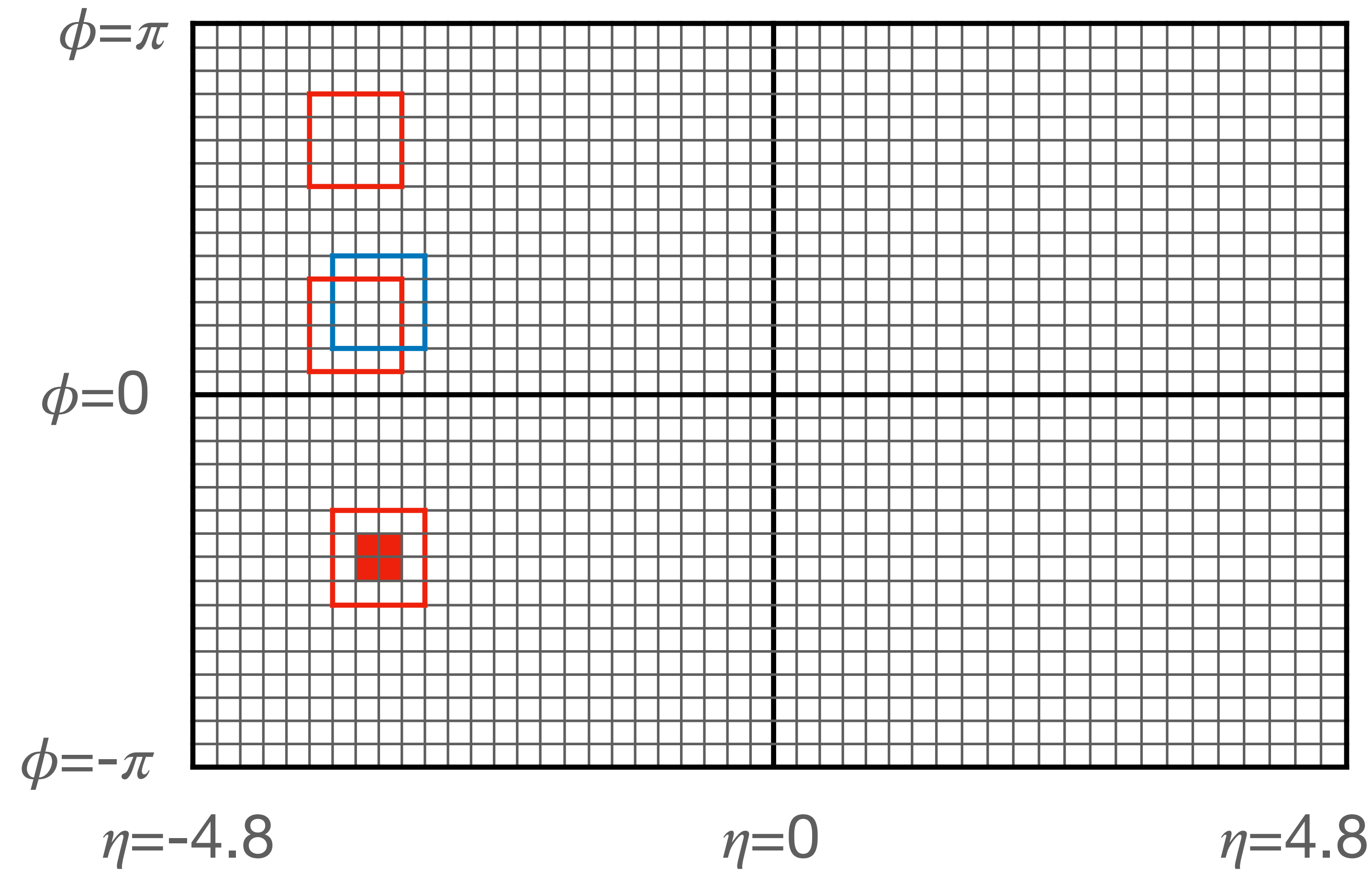


2.5 μs latency
(100 bunches)
-> electronics in
detector cavern

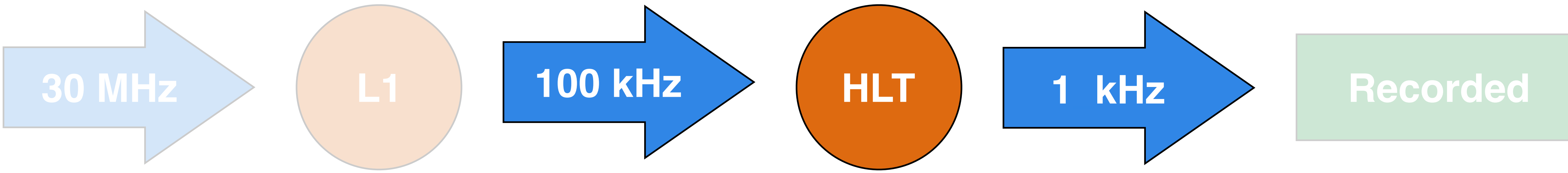
Square windows in η-ϕ

Step across with
large granularity

Simple local
maximum algorithms

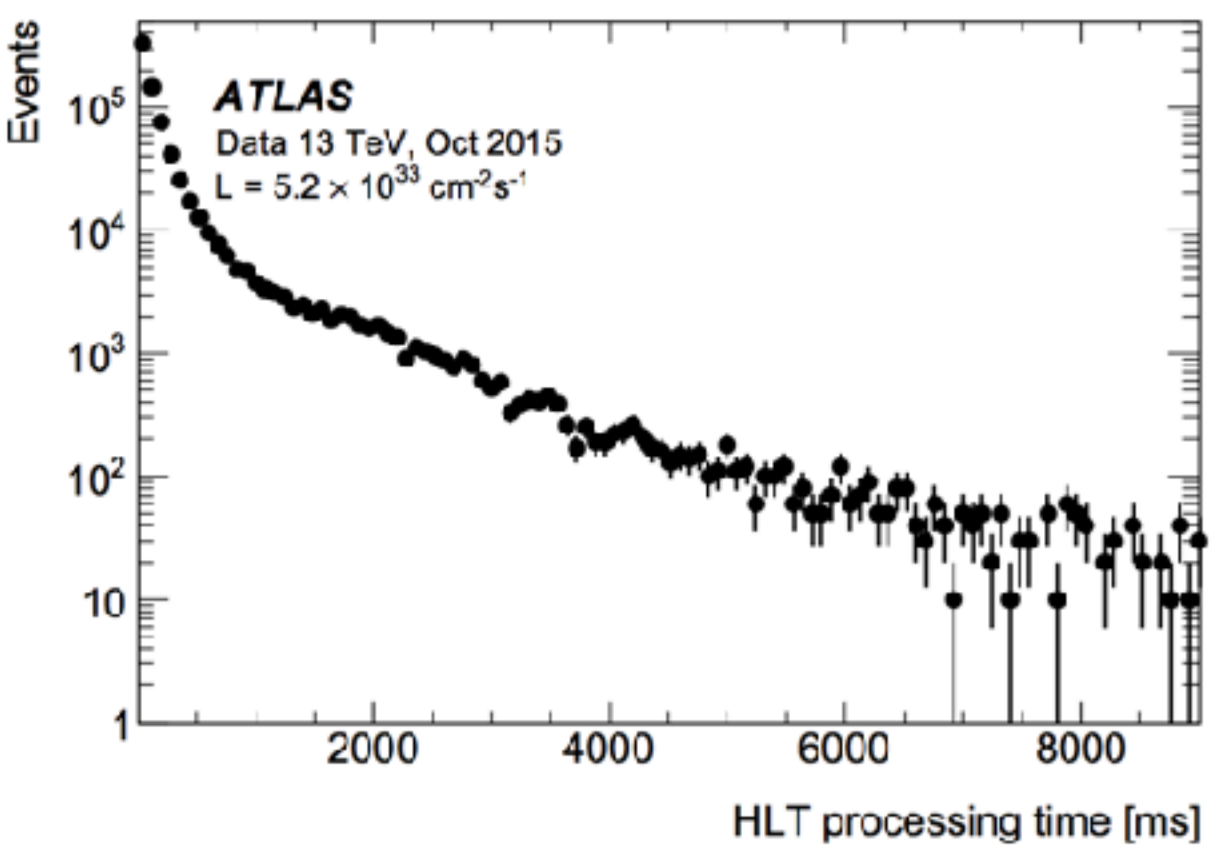


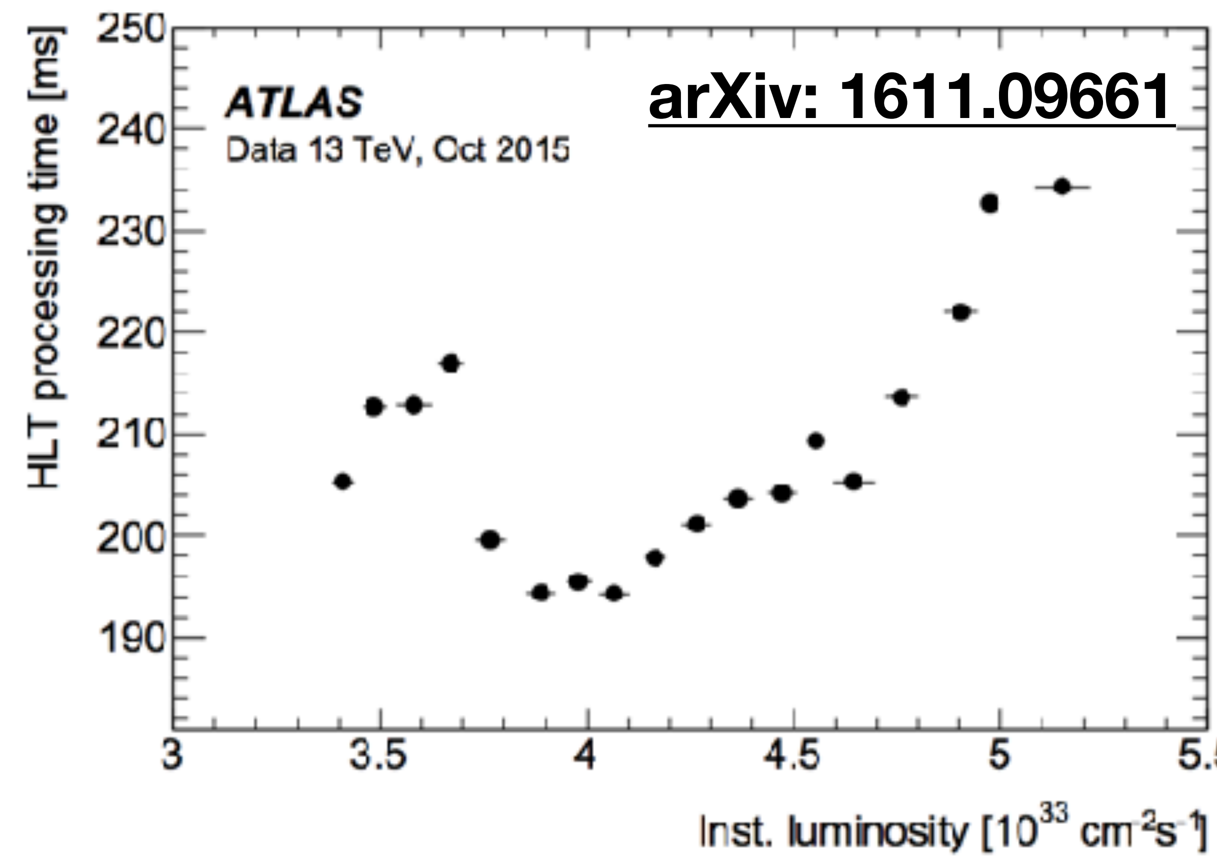
ATLAS trigger system



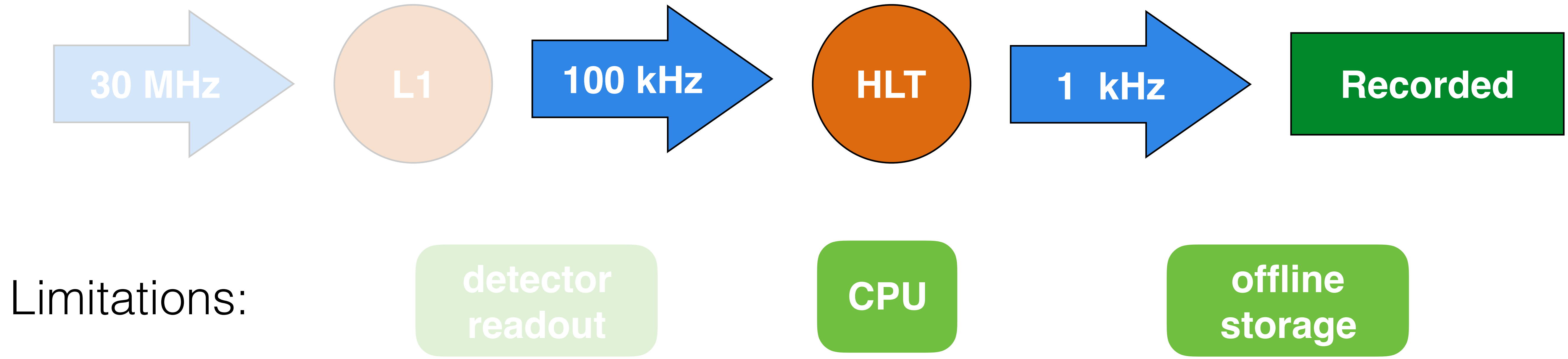
Limitations: detector readout | CPU

- Read out close to full detector information from pipelines
- Large computer farm to reconstruct 'objects' (electrons, muons, jets, photons) in ≤ 1 s (on average)



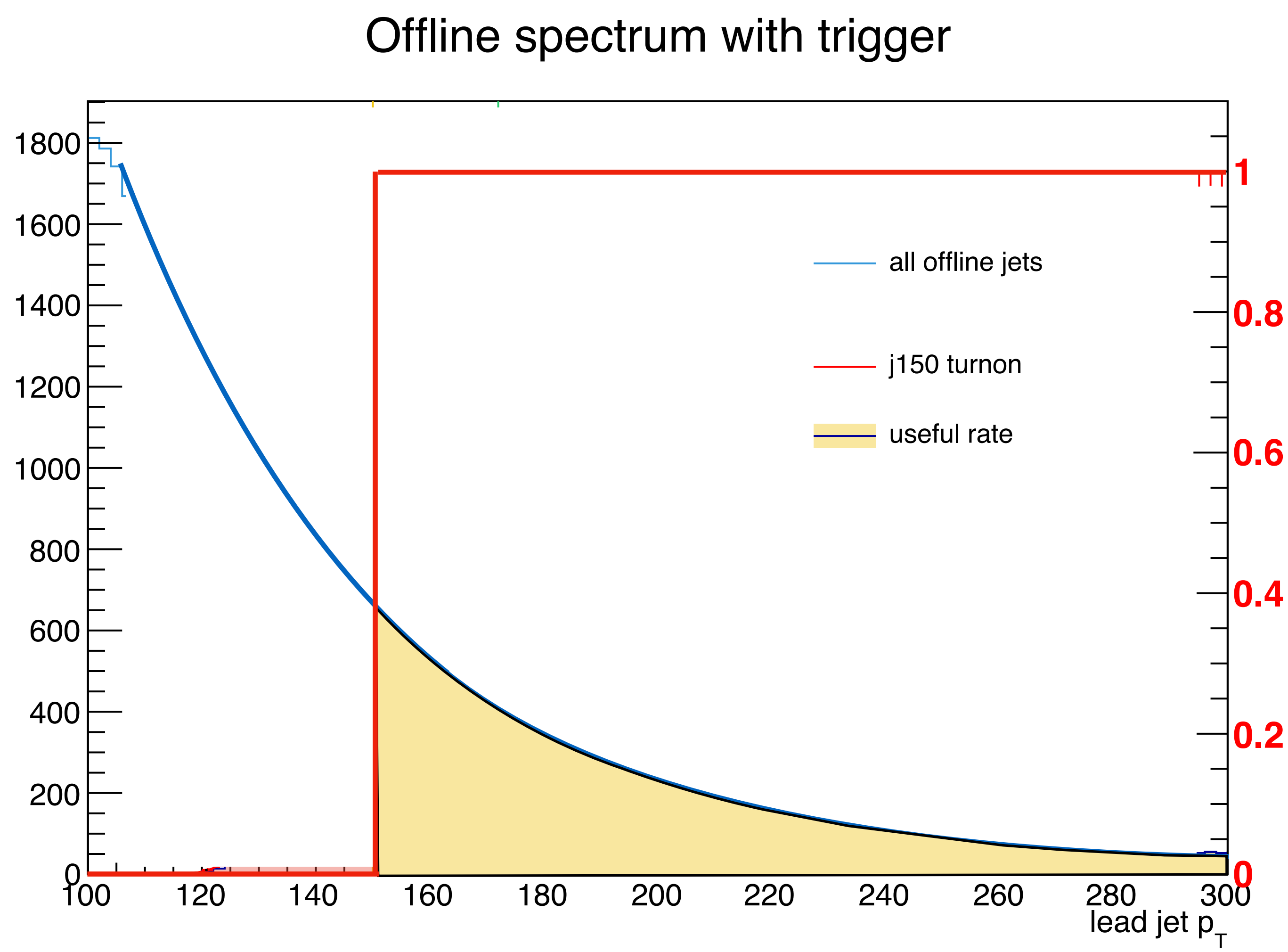


ATLAS trigger system



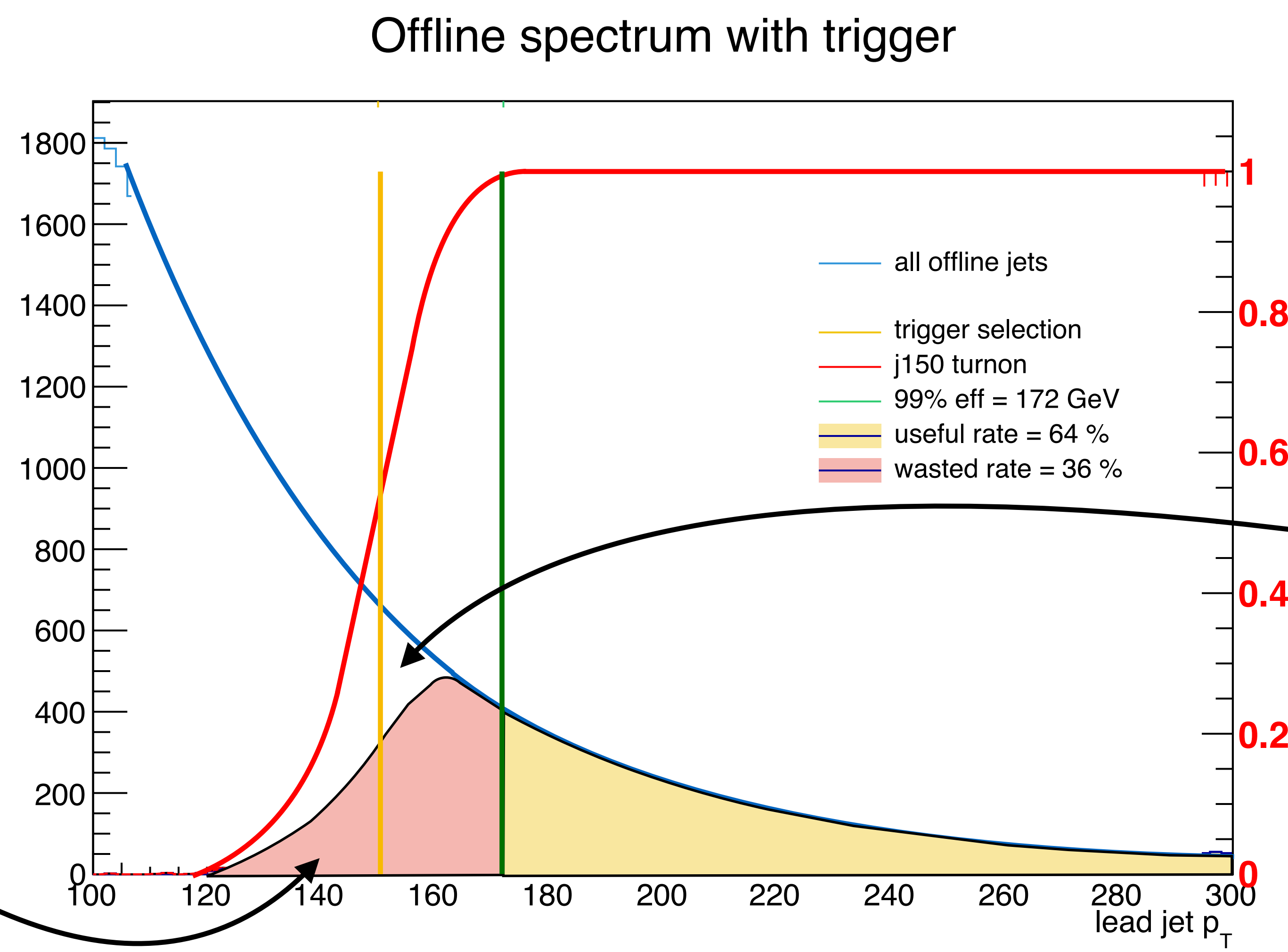
- Total selected rate limited to ~ 1000 Hz by offline storage
- Precision of reconstruction limited by available CPU in the HLT farm
- ATLAS as a whole decides priorities for data recording: do we want lower momentum electrons, or more events with missing transverse momentum?

Jet pT spectrum



- Steep drop-off in rate with pT -> choosing higher threshold reduces trigger rate

Jet pT spectrum

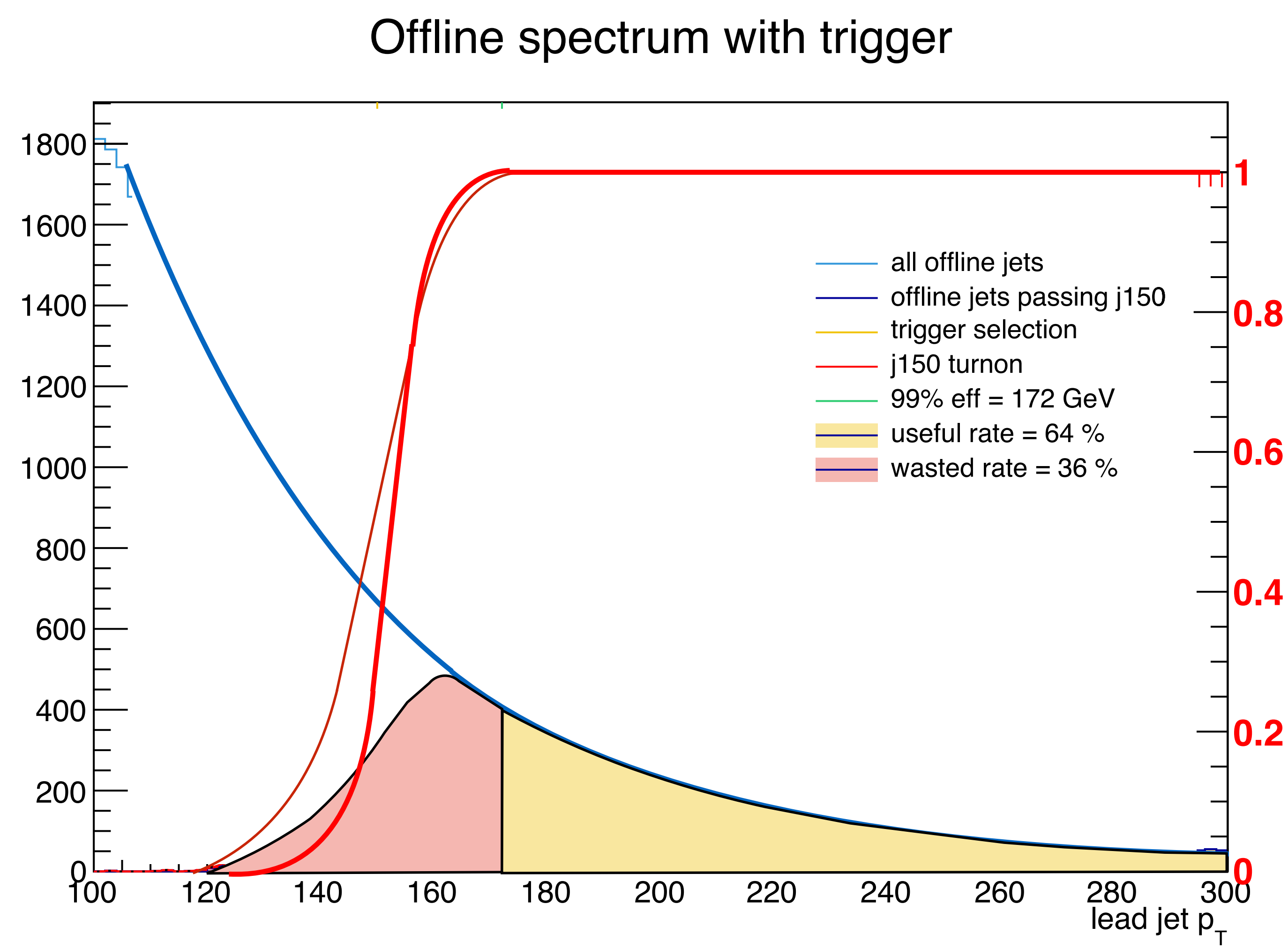


Trigger pT higher than offline pT: record event that we are not interested in

Trigger pT lower than offline pT: do not record event that we are interested in

- Steep drop-off in rate with pT -> choosing higher threshold reduces trigger rate
- HLT != offline (what we usually analyse) -> smear
- Usually only use events above 95 or 99% efficiency -> can "waste" a fairly high fraction of events

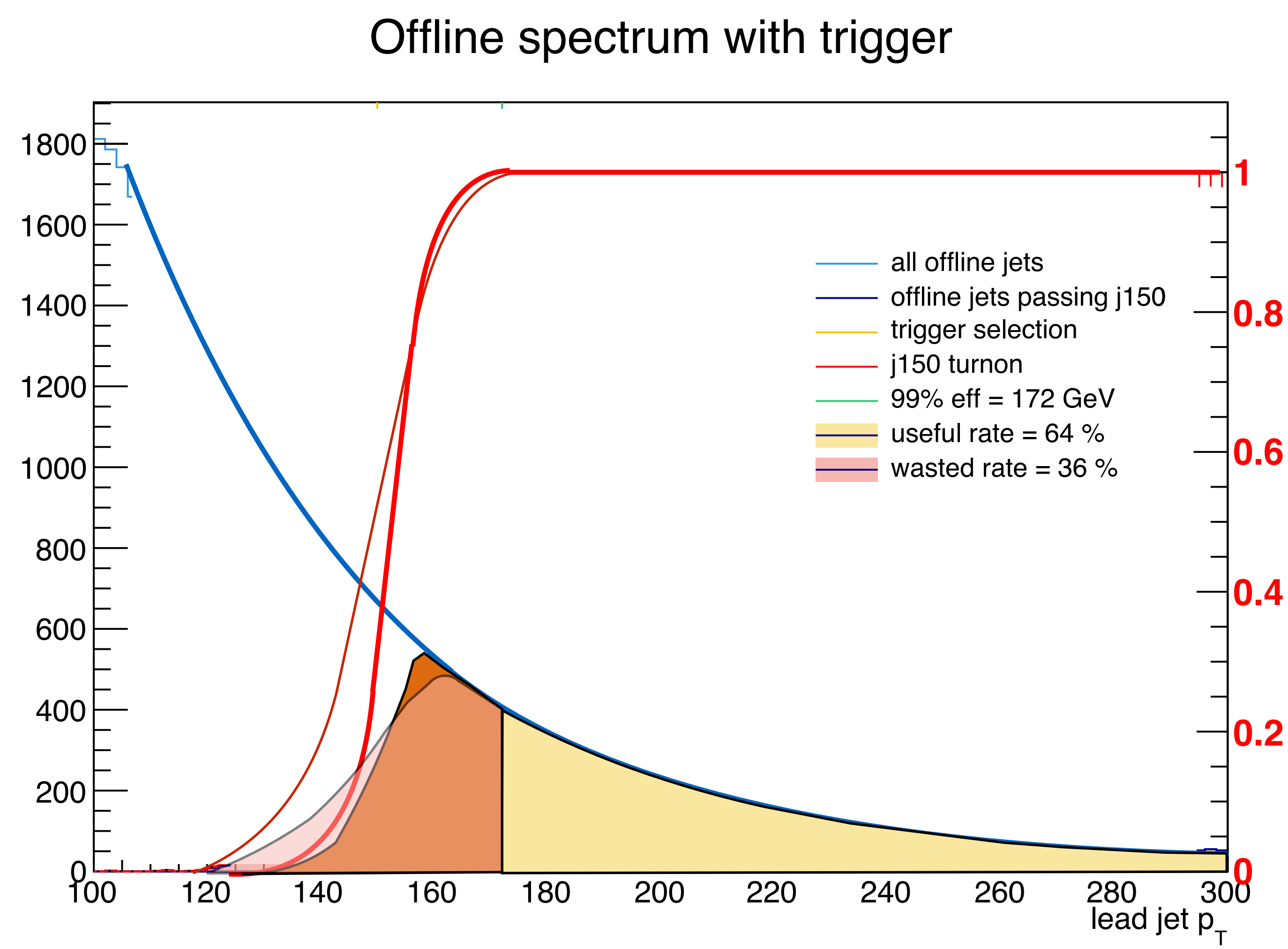
Jet pT spectrum



- But, if I improve the resolution, then…
  - The turnon will sharpen

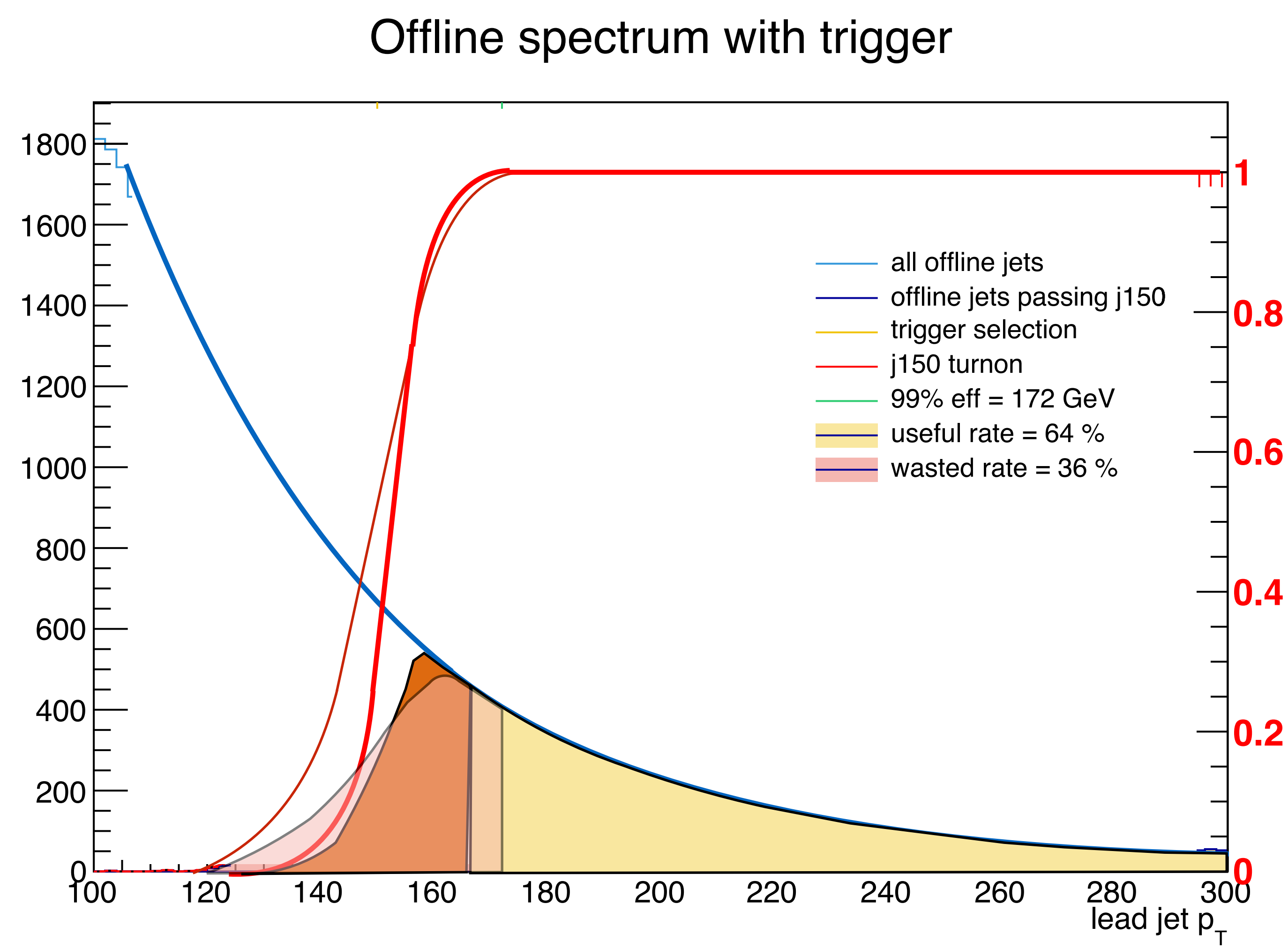
Jet pT spectrum

- So, if I improve the resolution, then…
  - The turnon will sharpen
  - The recorded spectrum will match better



Jet pT spectrum

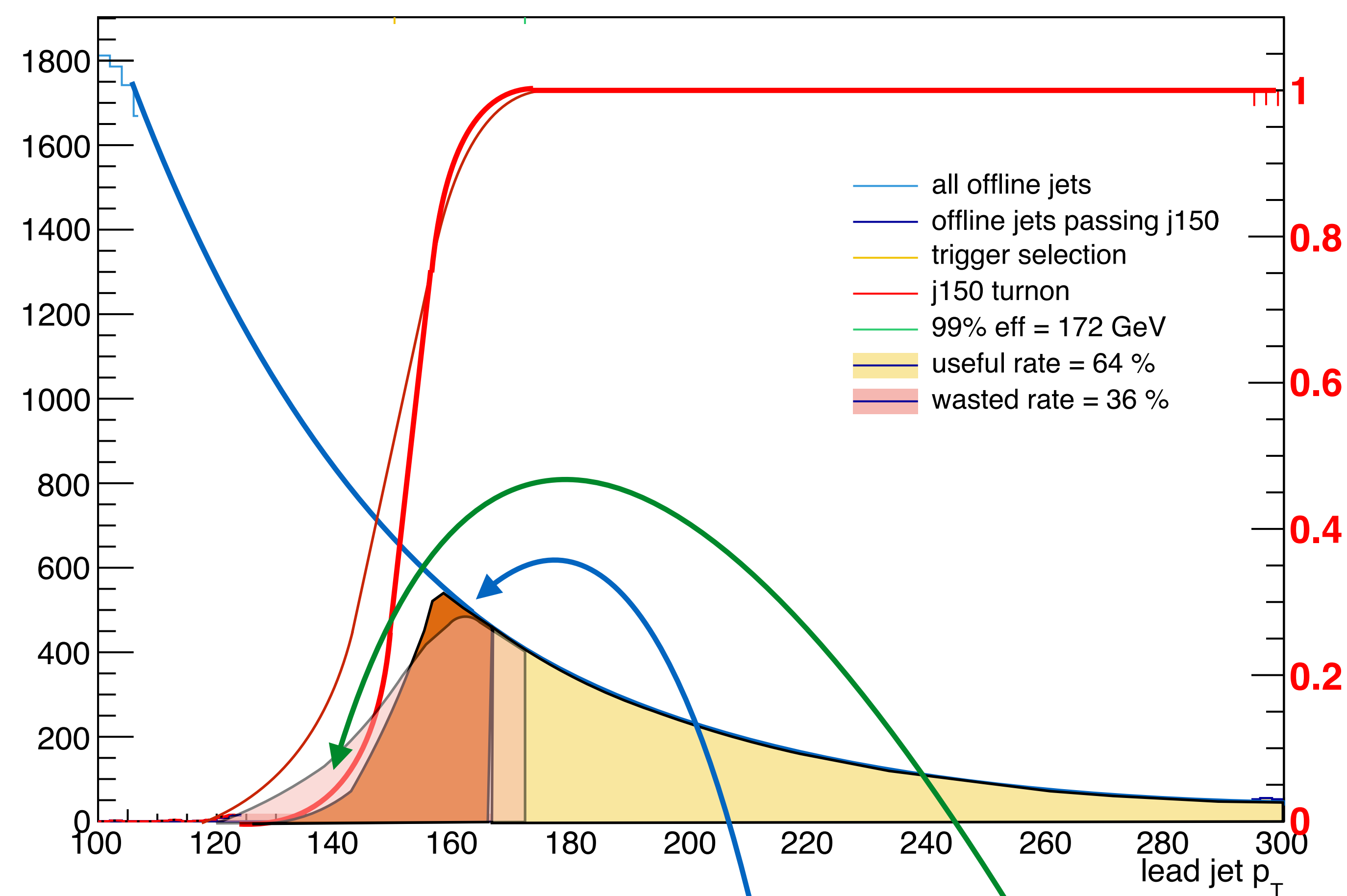
- So, if I improve the resolution, then…
  - The turnon will sharpen
  - The recorded spectrum will match better
  - The 99% eff. point moves left



Jet pT spectrum

- So, if I improve the resolution, then…
  - The turnon will sharpen
  - The recorded spectrum will match better
  - The 99% eff. point moves left
  - More useful rate :-)

Offline spectrum with trigger



- The total rate may increase or decrease
  - Depends on shape of resolution before and after, and p_T spectrum
  - May have to shift trigger threshold to get equal rate as before (but guaranteed to have more useful rate either way)

Jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area Residual	Remove contributions from pileup
Jet Energy Scale correction		Restore hadronic energy
Global Sequential Correction	Calo-only with tracks	Reduce flavour (quark / gluon) dependence
In-situ eta intercalibration		Corrects detector effects along eta to central region
In-situ JES correction		Calorimeter response corrected to MC truth scale

Applied to?

Offline

Jet calibration

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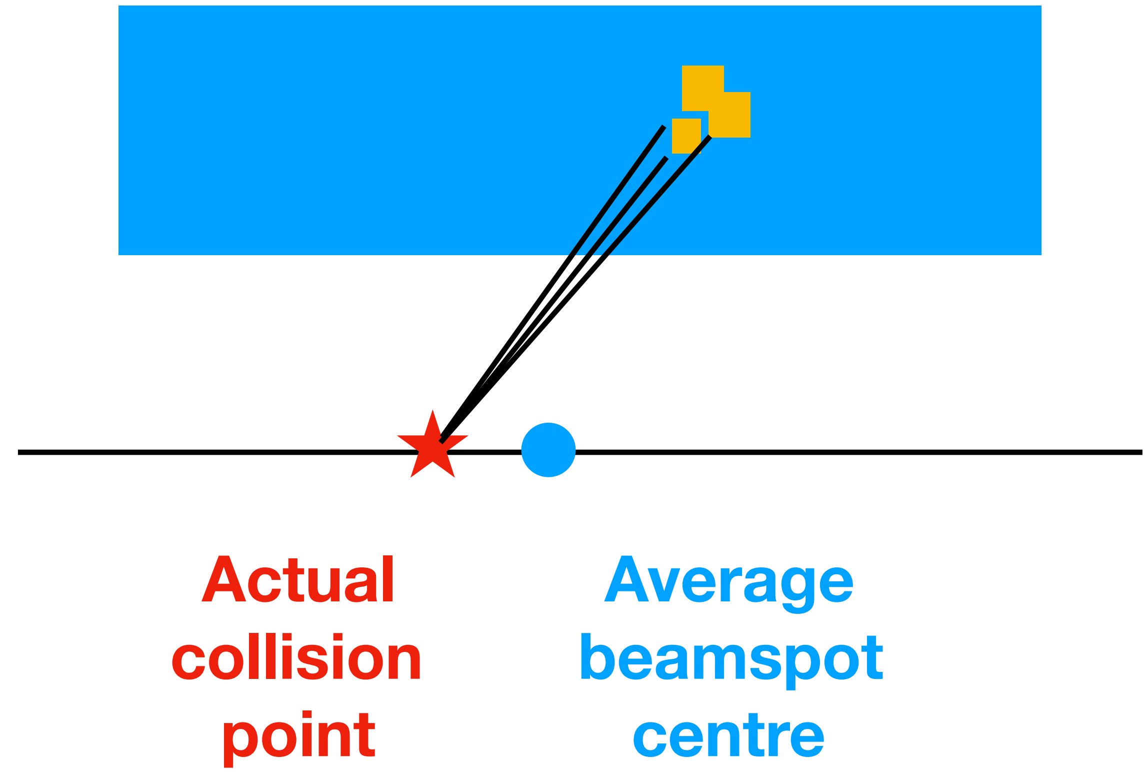
Applied to?

Offline



Jet calibration

Calibration	Purpose
Origin correction	Move jet origin to vertex
Pileup subtraction (**Jet area** / Residual)	**Remove contributions from pileup**
Jet Energy Scale correction	Restore hadronic energy
Global Sequential Correction (Calo-only / with tracks)	Reduce flavour (quark / gluon) dependence
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Applied to?

Offline

Pileup -> low-E deposits ~ isotropically distributed

Sum up energy to get an average pileup density, ρ

Subtract ρ*A, the area of the jet

Jet calibration

Calibration	Purpose
Origin correction	Move jet origin to vertex
Pileup subtraction: Jet area / Residual	Remove contributions from pileup
Jet Energy Scale correction	Restore hadronic energy
Global Sequential Correction: Calo-only / with tracks	Reduce flavour (quark / gluon) dependence
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Applied to?

Offline

Pileup -> low-E deposits ~ isotropically distributed

Sum up energy to get an average pileup density, ρ

Subtract ρ*A, the area of the jet

This isn't perfect, so fix the dependence on the number of pp collisions:

- that happened in this event
- That are happening on average at that moment

Jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area Residual	Remove contributions from pileup
Jet Energy Scale correction		**Restore hadronic energy**
Global Sequential Correction	Calo-only with tracks	Reduce flavour (quark / gluon) dependence
In-situ eta intercalibration		Corrects detector effects along eta to central region
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Applied to?

Offline

Simulate collisions and jets: if I have a quark or gluon of a given pT in a given position, what will ATLAS measure?

Jet calibration

Calibration	Purpose
Origin correction	Move jet origin to vertex
Pileup subtraction (Jet area / Residual)	Remove contributions from pileup
Jet Energy Scale correction	Restore hadronic energy
Global Sequential Correction (Calo-only / with tracks)	**Reduce flavour (quark / gluon) dependence**
In-situ eta intercalibration	Corrects detector effects along eta to central region
In-situ JES correction	Calorimeter response corrected to MC truth scale

Applied to?

Offline

Gluon jets tend to be wider since they radiate more -> behave slightly differently, want to correct for this

Jet calibration

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Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area Residual	Remove contributions from pileup
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In-situ eta intercalibration		**Corrects detector effects along eta to central region**
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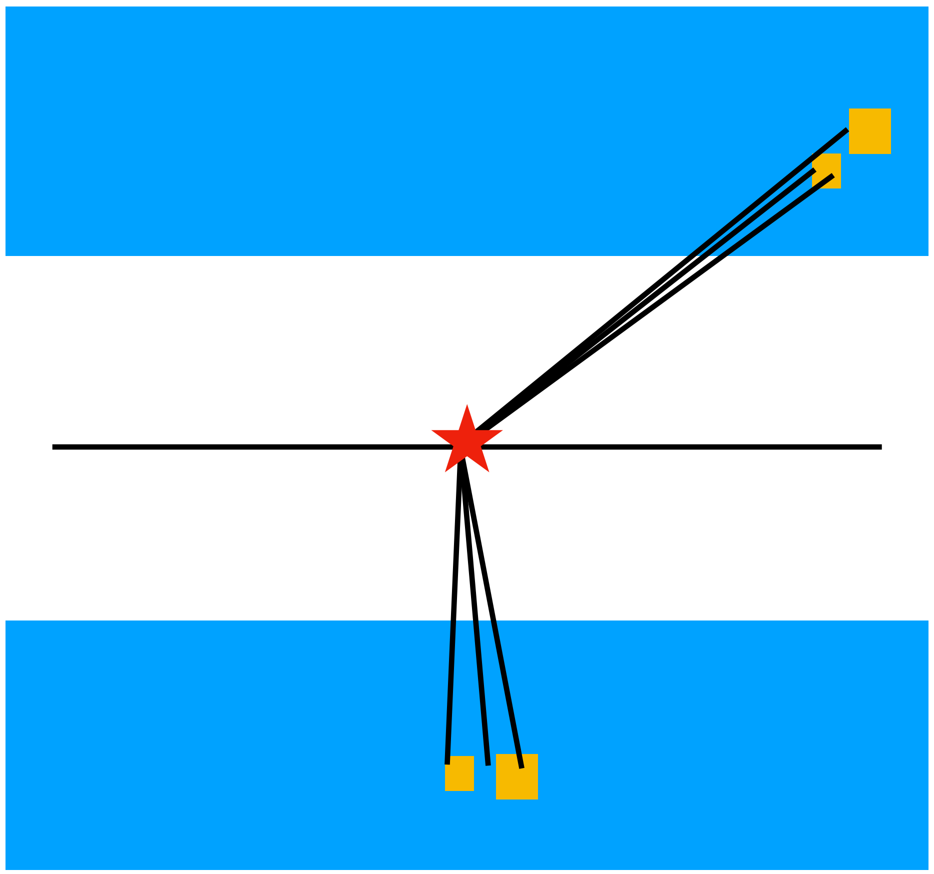
Applied to?

Offline



We trust the middle of the detector best -> balance forward jets against central ones, correct simulation mismodelling of forward region

Jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area Residual	Remove contributions from pileup
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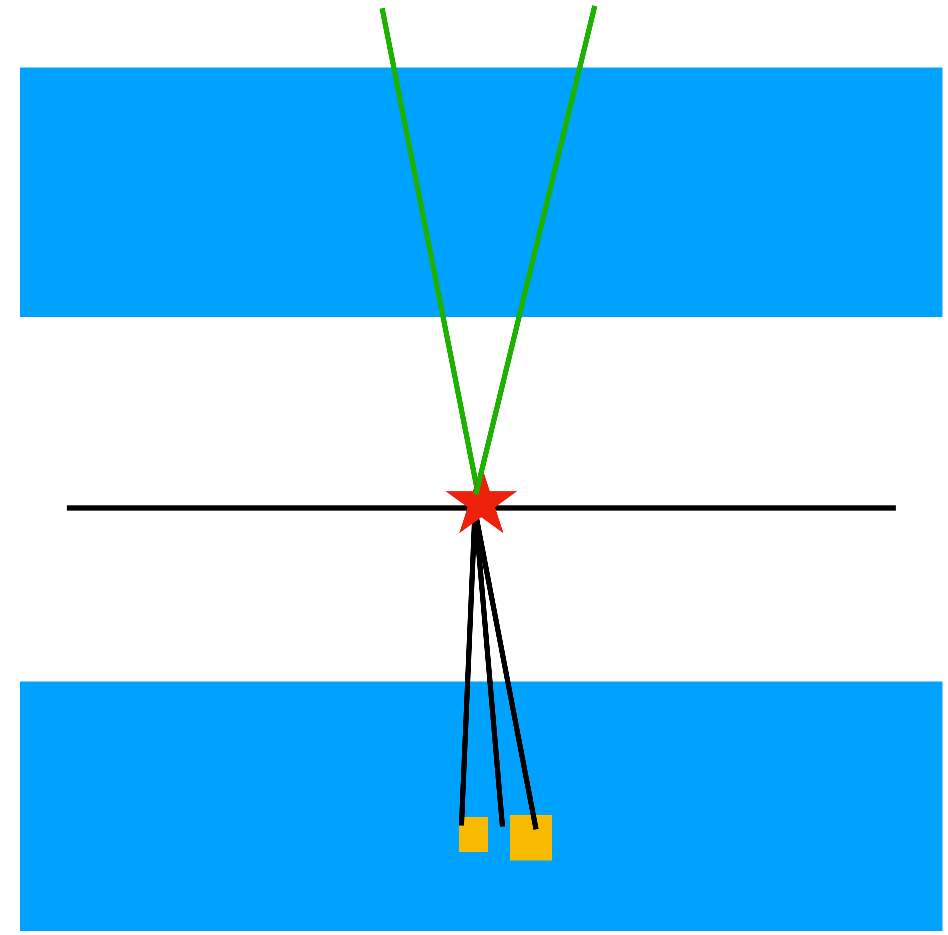
Applied to?

Offline



We can measure muons very well -> balance Z->mumu against a central jet to make a final correction

Trigger jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area	Remove contributions from pileup
	Residual	
Jet Energy Scale correction		Restore hadronic energy
Global Sequential Correction	Calo-only	Reduce flavour (quark / gluon) dependence
	with tracks	
In-situ eta intercalibration		Corrects detector effects along eta to central region
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Applied to?

Offline

- Start with offline calibration chain

Trigger jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
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Applied to?

- Offline and HLT (2015 and 2016)
- Offline only - not implemented in time

- Start with offline calibration chain
- No GSC or in-situ in 2015/16 data (developed using 2015 data!)

Trigger jet calibration

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area / Residual	Remove contributions from pileup
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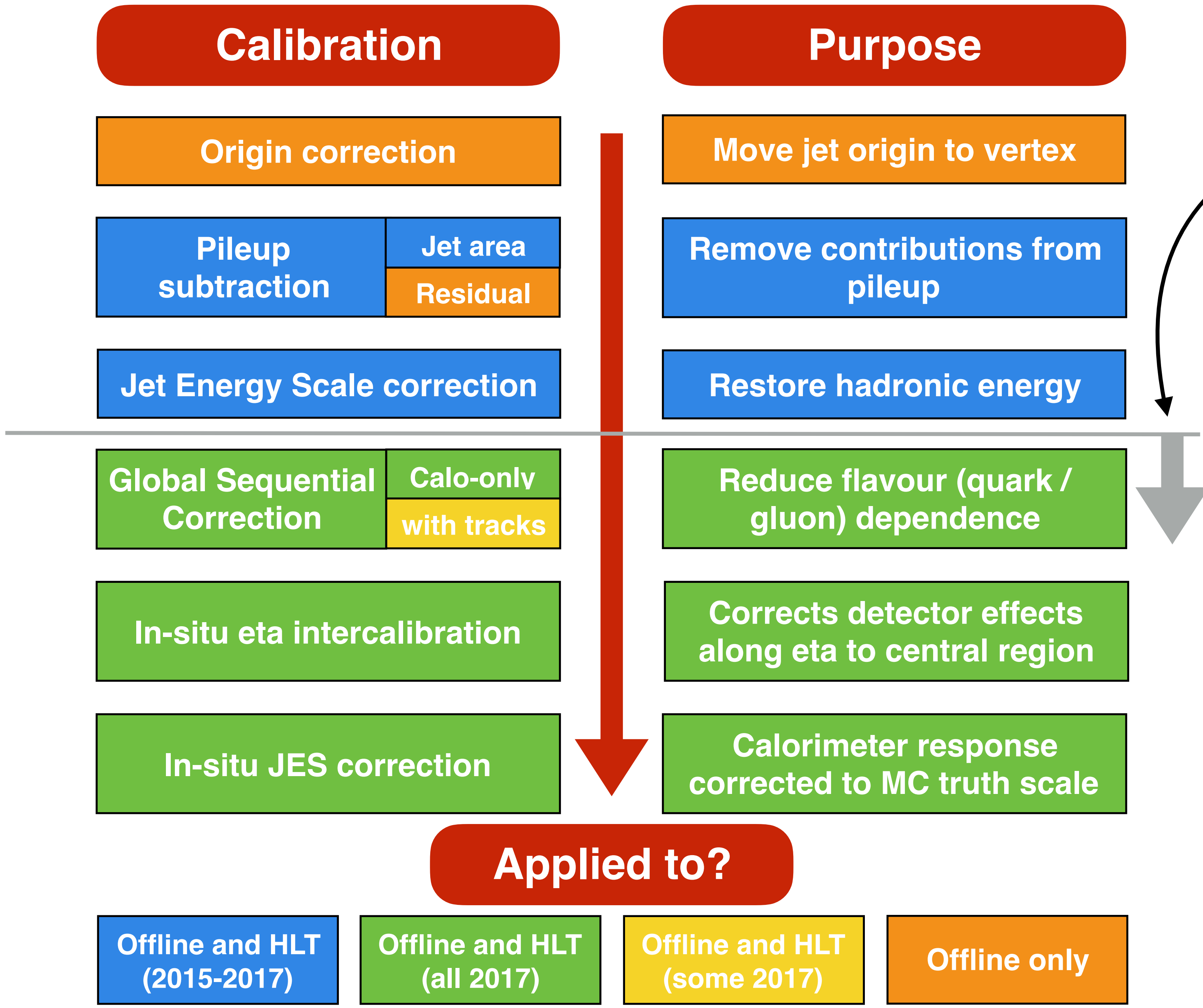
Applied to?

Offline and HLT (2015 and 2016)	Offline only - not implemented in time	Offline only - needs tracks

Status in 2015 and 2016 data

- Start with offline calibration chain
- No GSC or in-situ in 2015/16 data (developed using 2015 data!)
- Also: no tracks!
    - very CPU intensive in ATLAS trigger -> infeasible to run full tracking

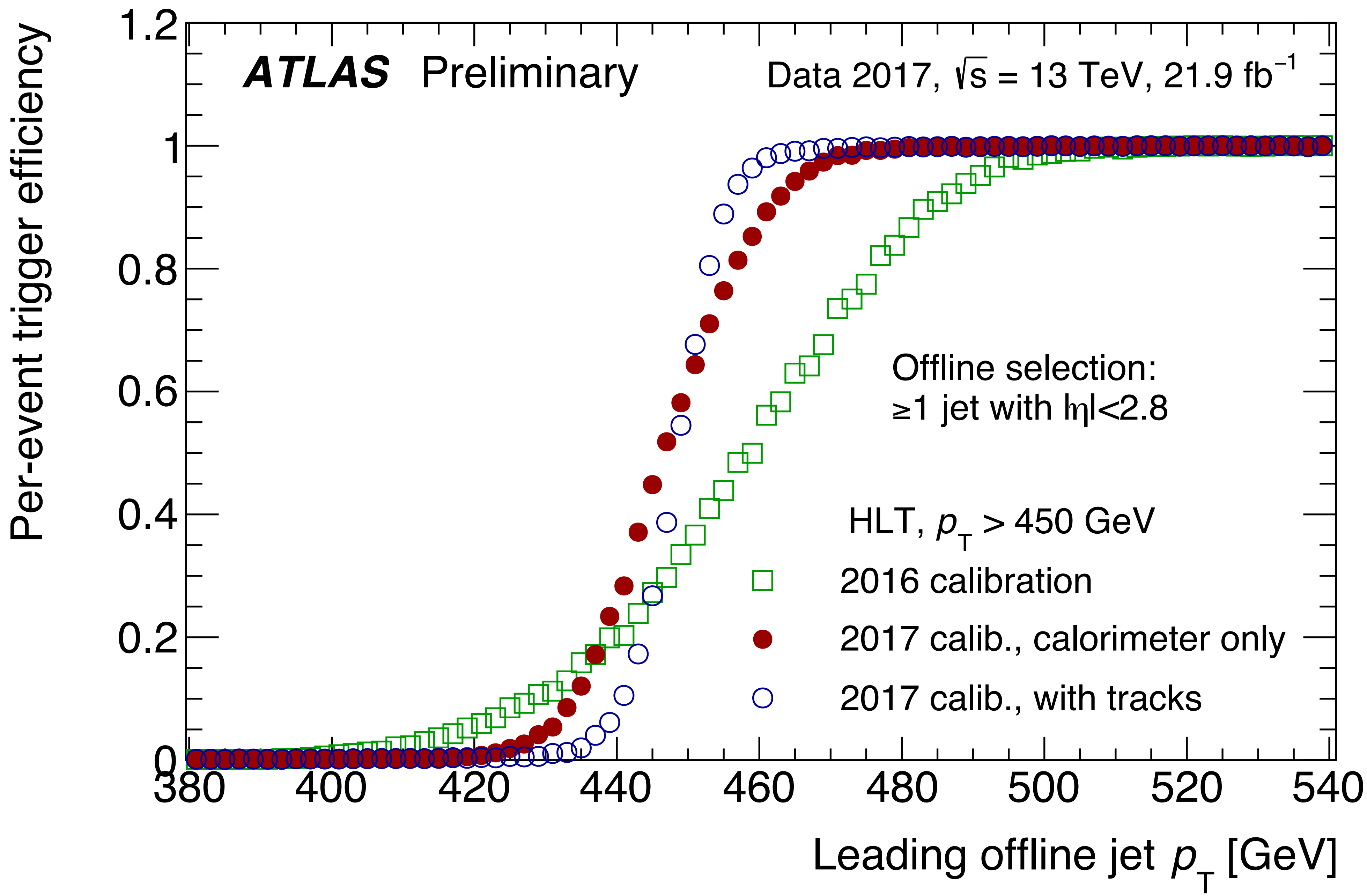
Trigger jet calibration



Status in 2017 and 2018 data

- New in 2017
  - Apply partial GSC and in-situ calibrations to all trigger jets
  - Some HLT tracking in jets is possible within CPU constraints - can apply GSC to some trigger jets

Jet trigger over run 2

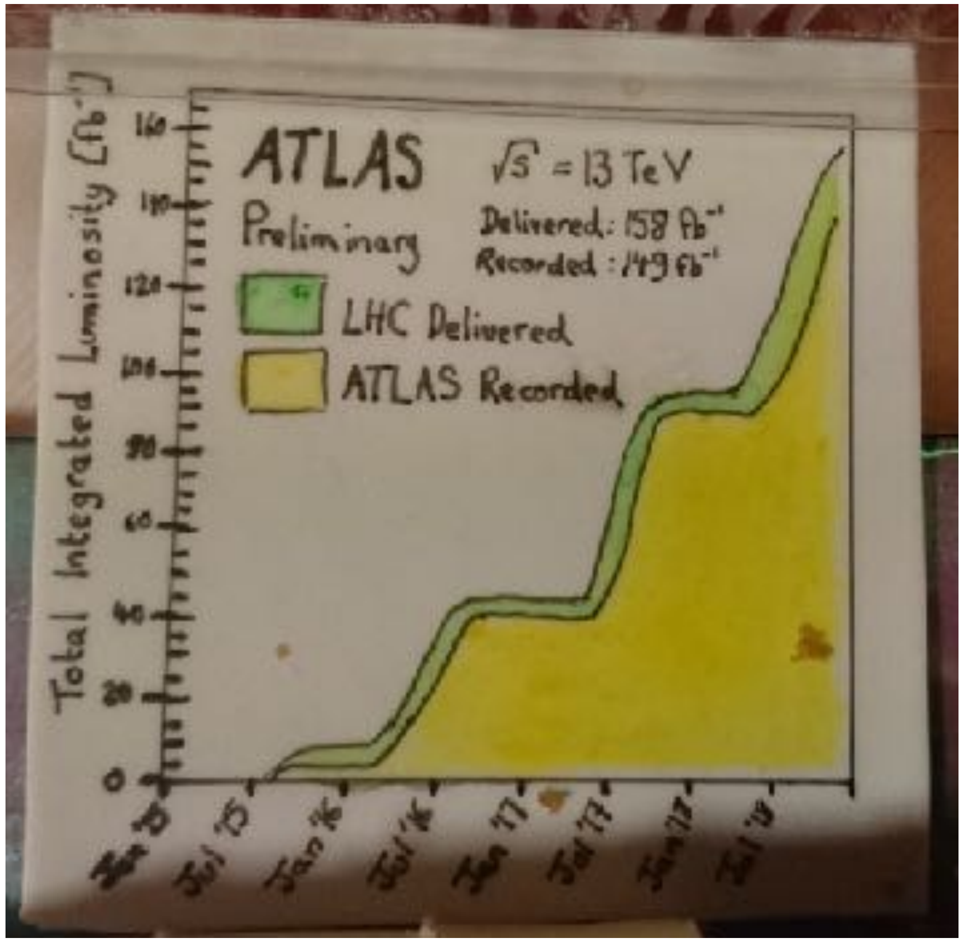


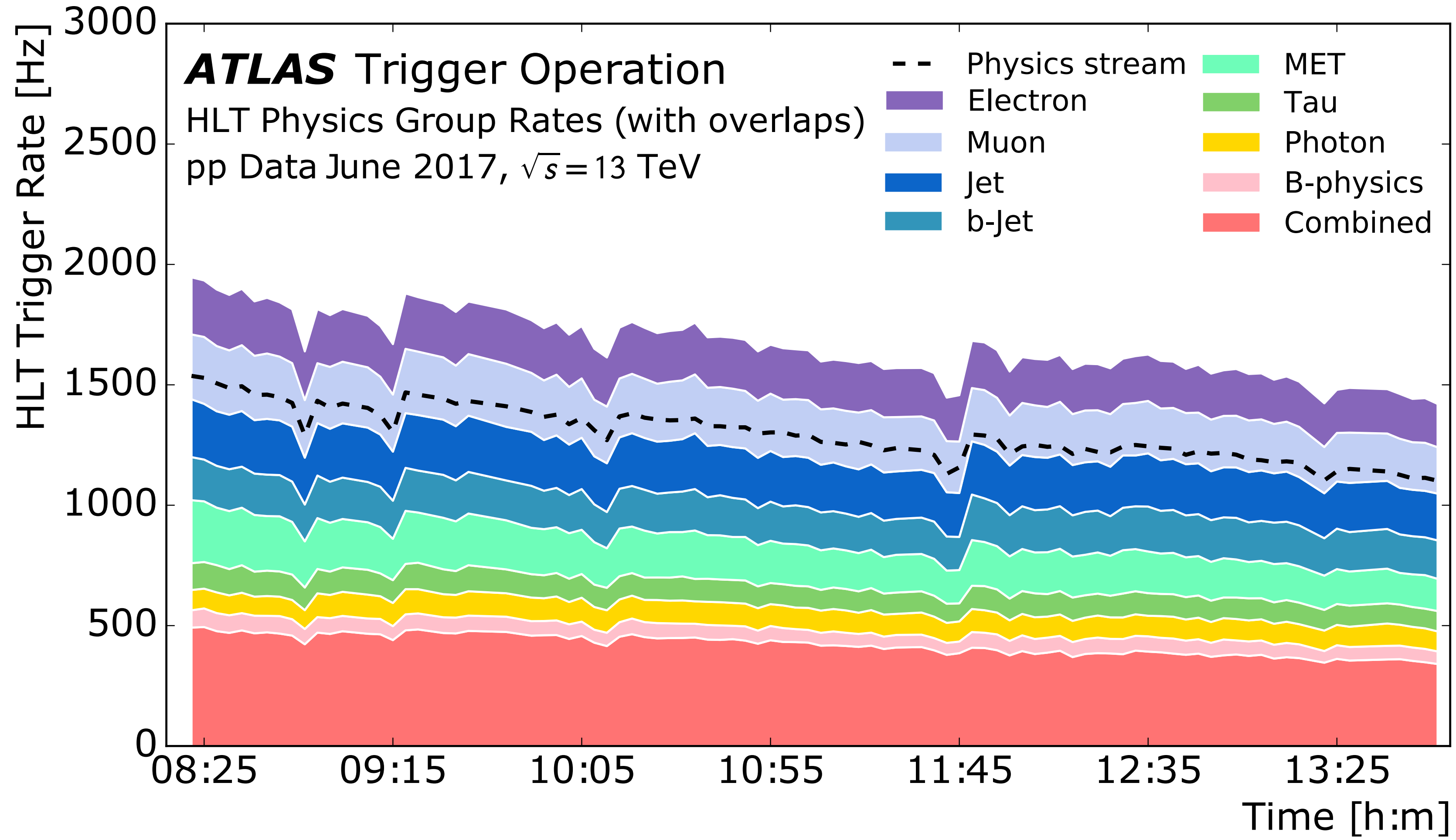
- Update calibration to catch up with offline developments
- Use limited tracking available at the HLT (for b-tagging) to further improve calibration

Jet trigger over run 2

year	L / 10^{34} cm^{-2} s^{-1}	jet p_T threhsold	single jet trigger rate	offline turnon
2015	0.5	260	18	400
2016	1.2	380	38	420
2017 & 18	1.7	420	33	435

What to do with my jet triggers?

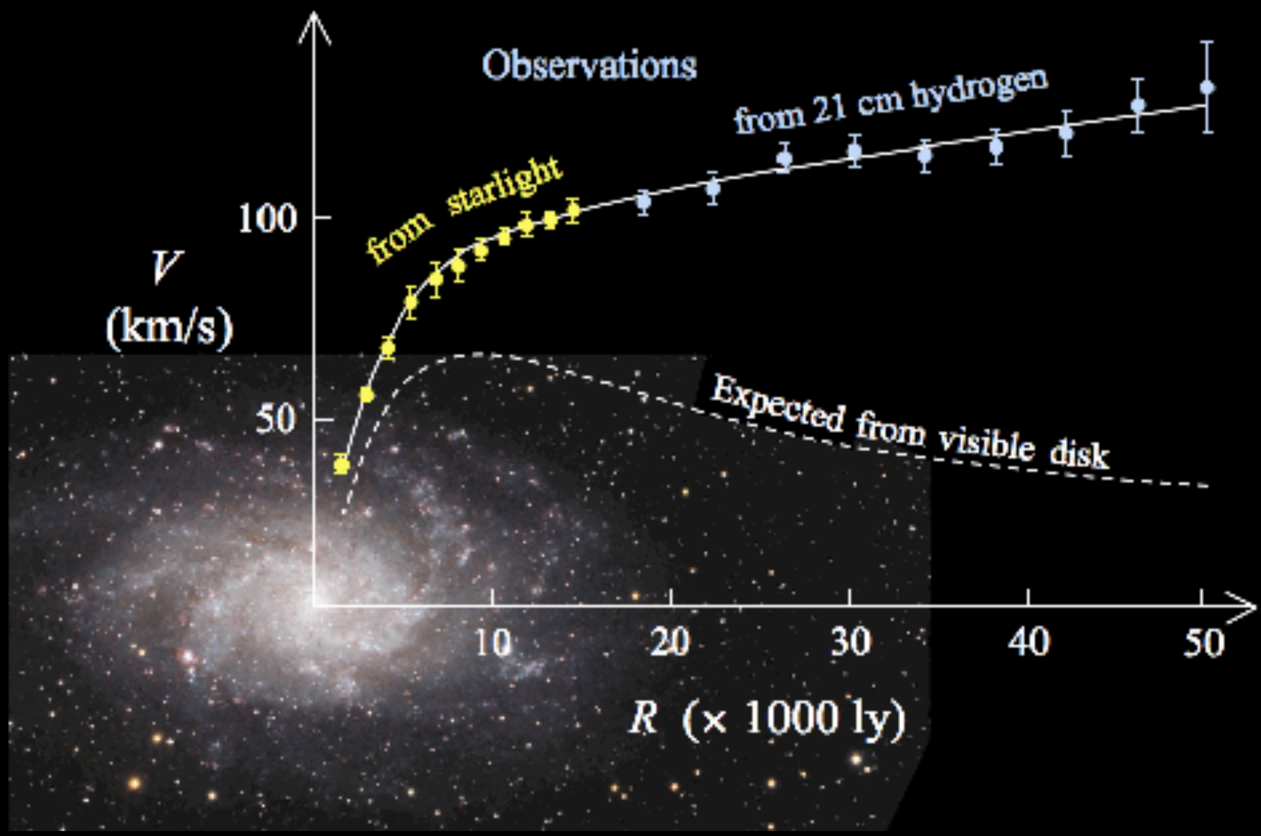


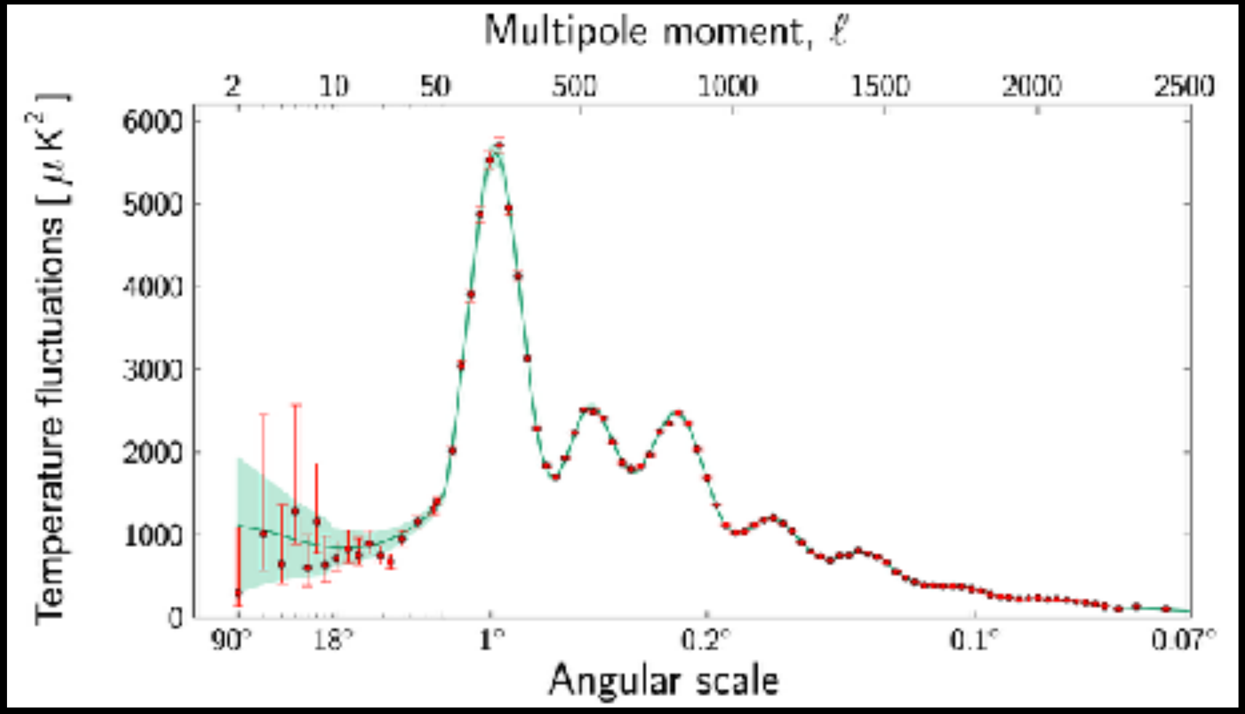


Katharine Leney

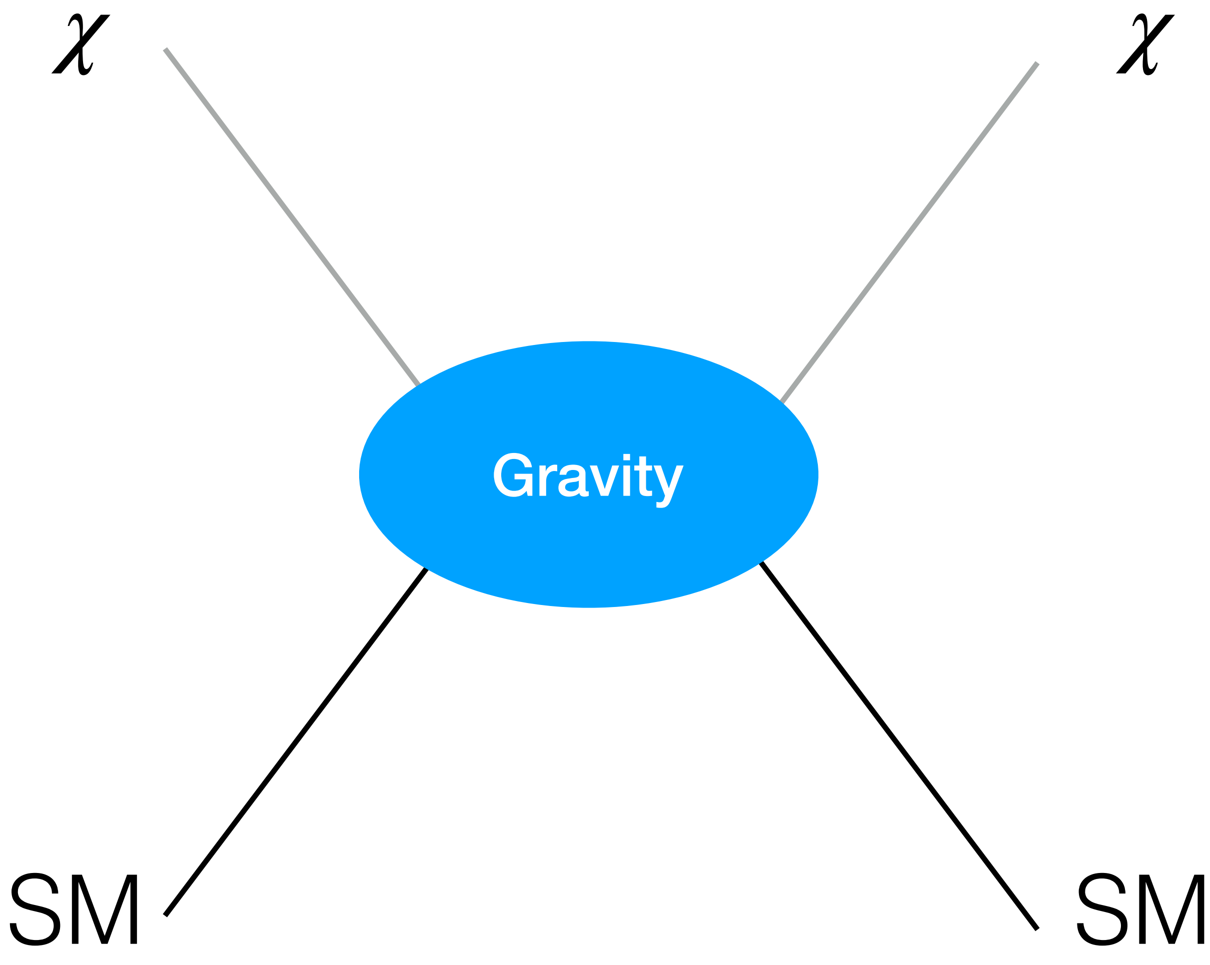
- ATLAS collected lots of data in run 2
- A decent fraction was from jet triggers (~15%)
- What do we do with it?

One thing: Dark Matter

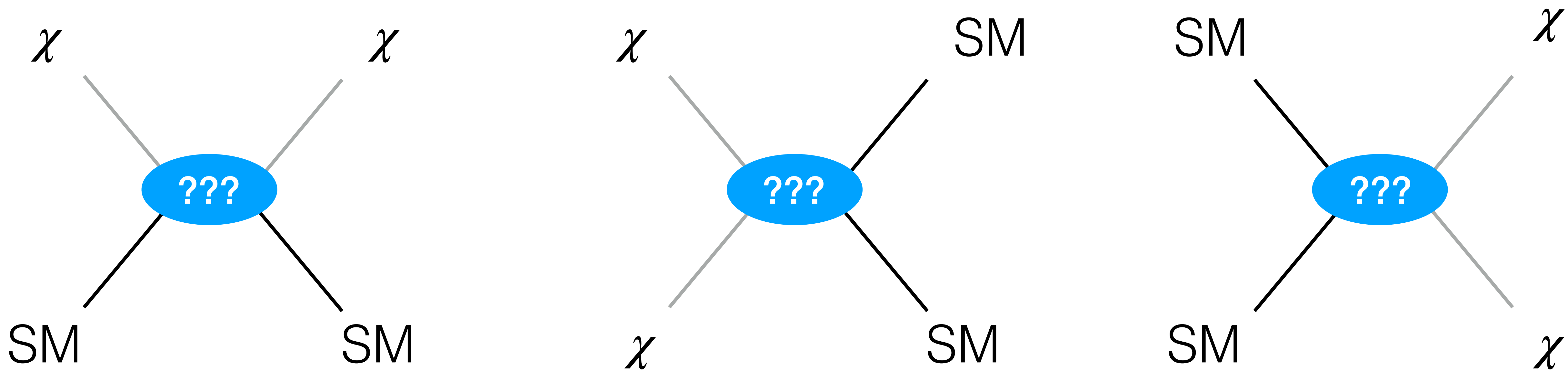




We think this happens…

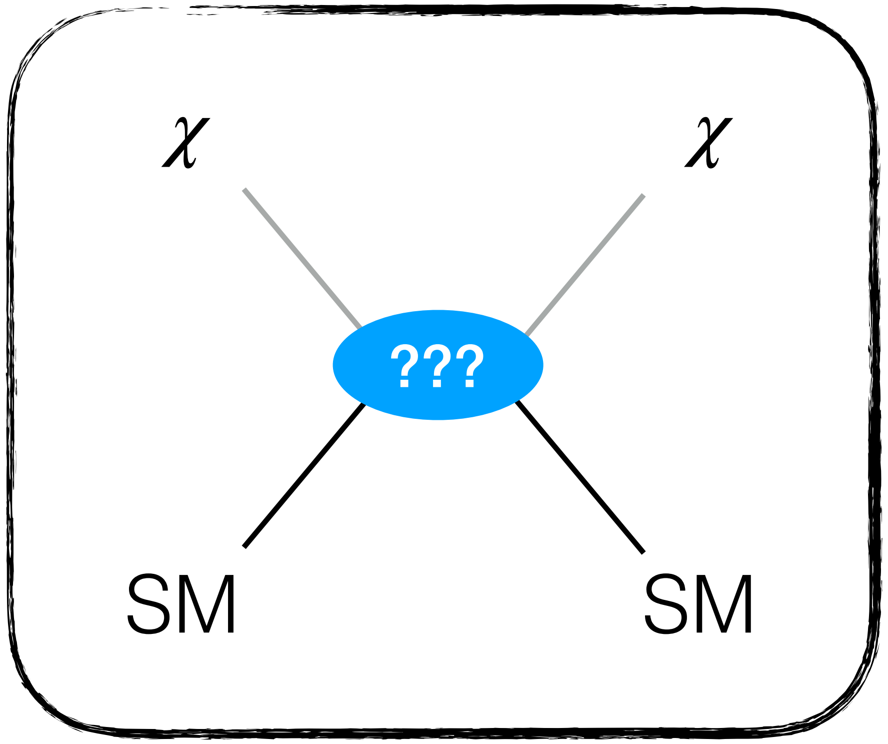


… so these might too?

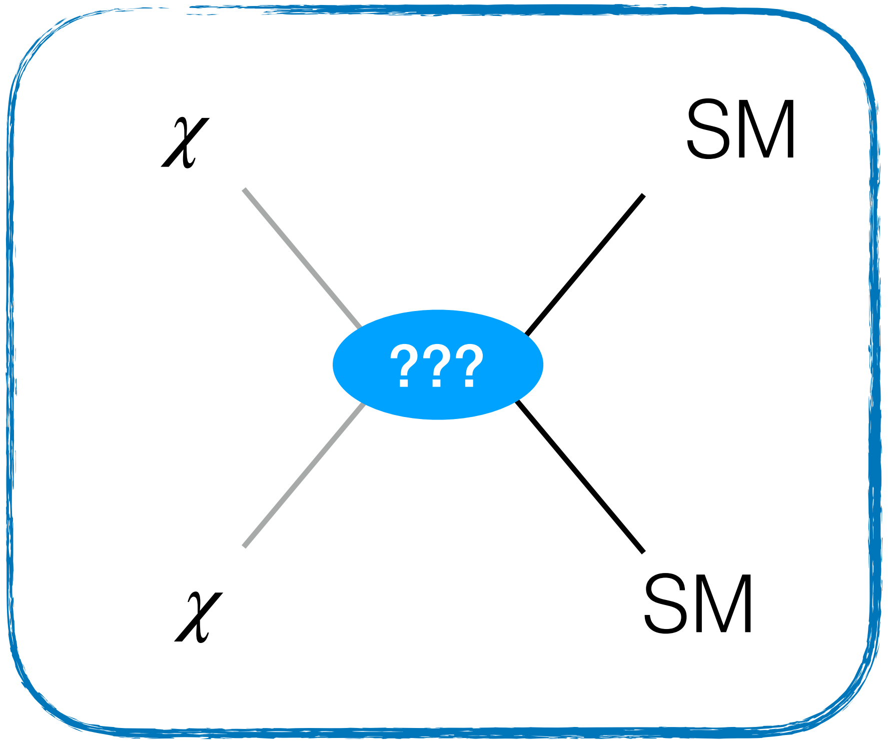


= **Electromagnetic** ✗
Strong ✗
Weak-strength ?

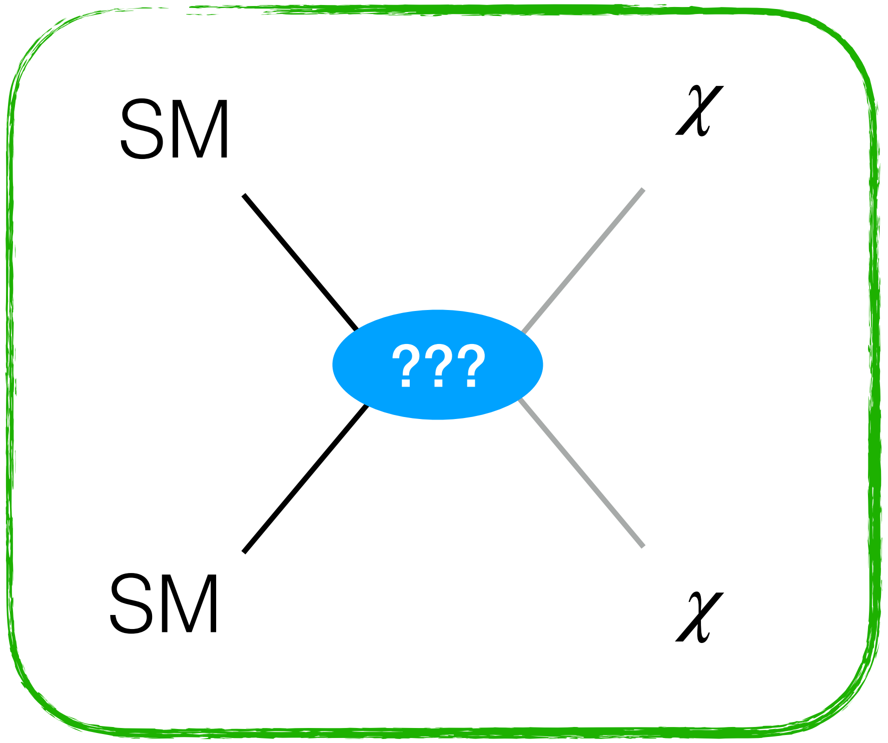
How to search for them



Direct detection

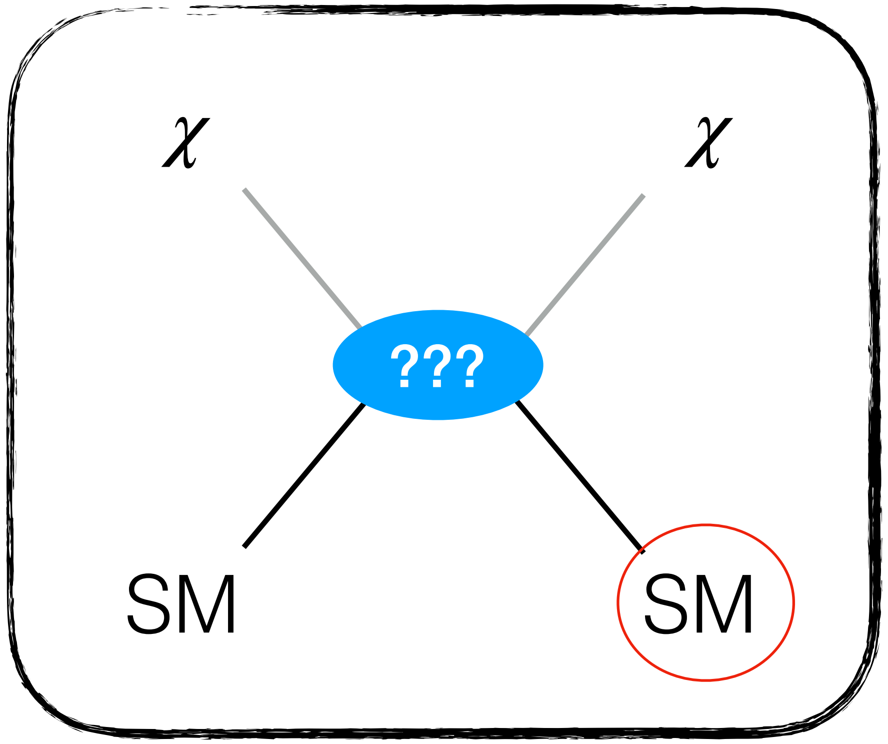


Indirect detection

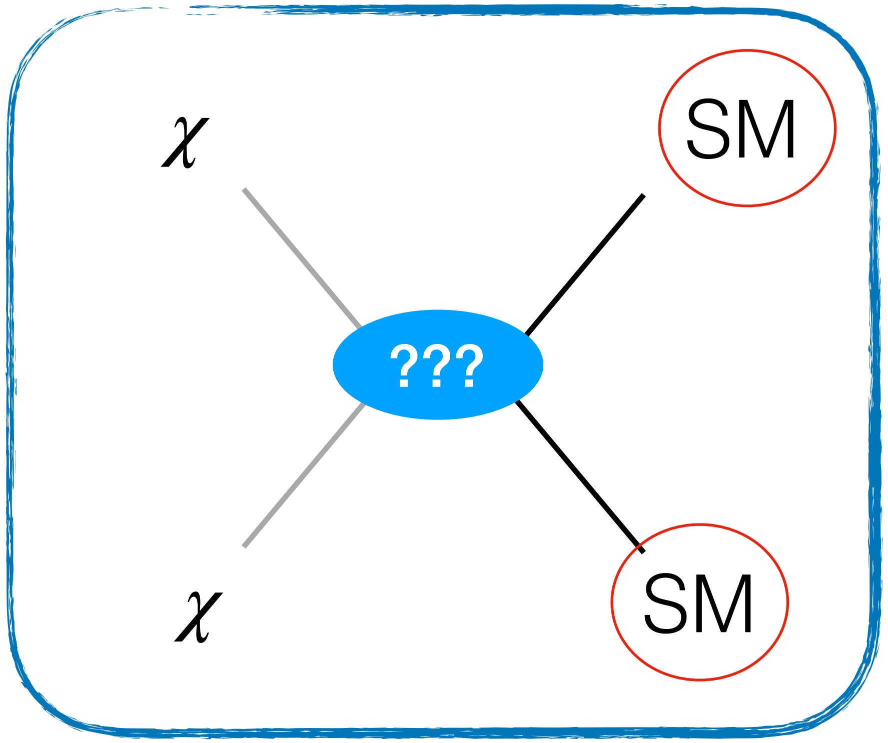


Collider production

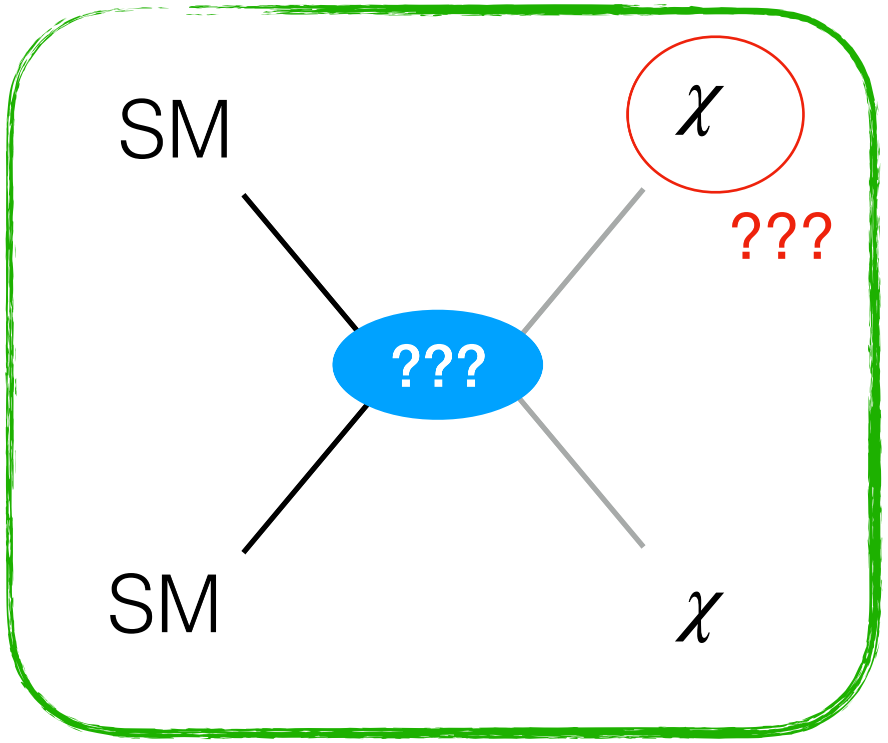
How to search for them



Direct detection



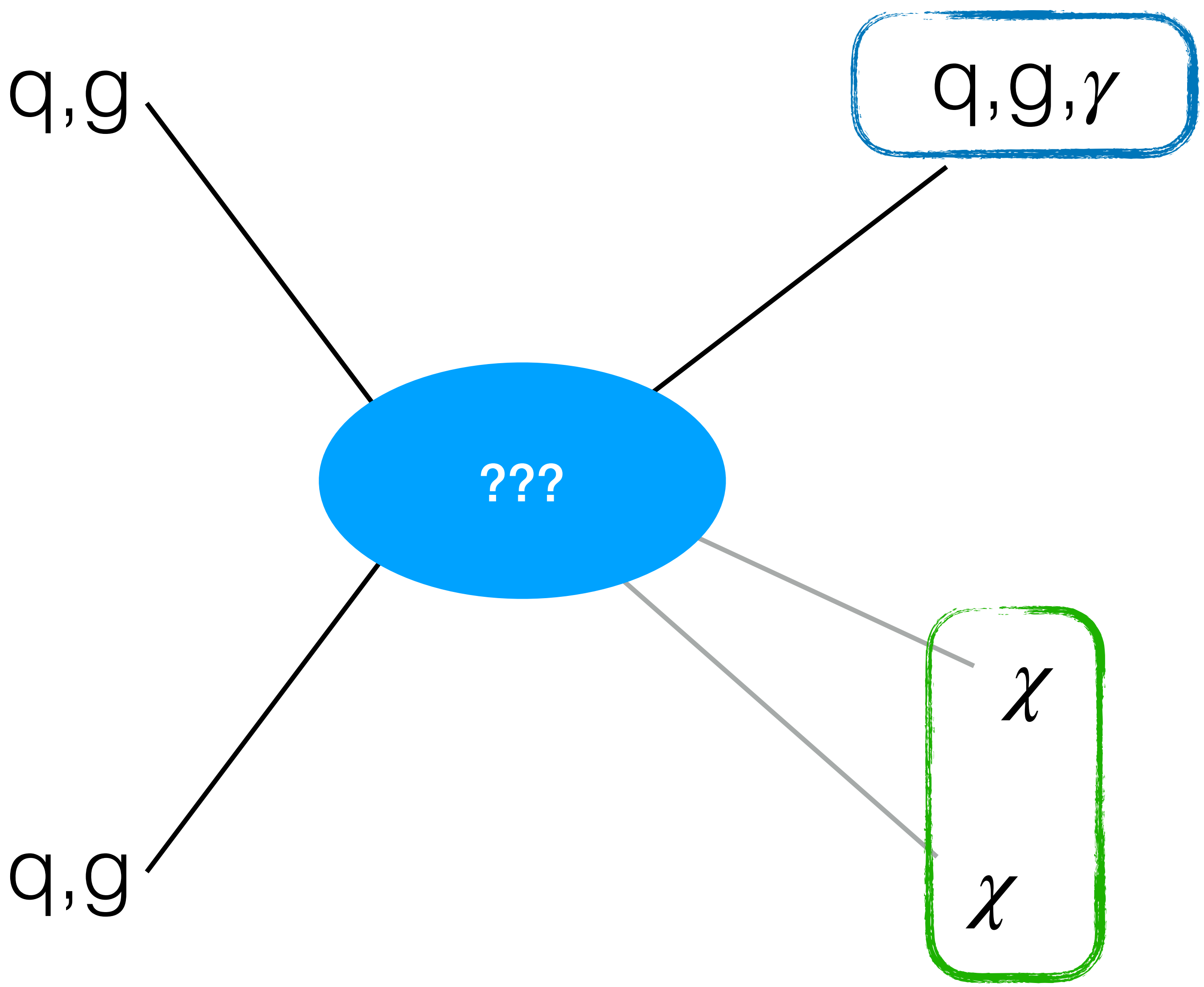
Indirect detection



Collider production

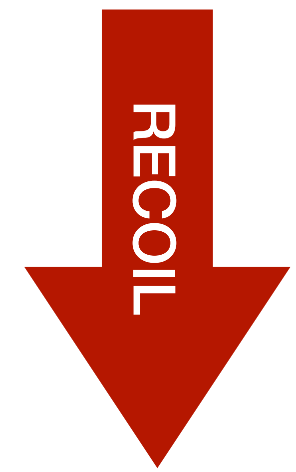
How do I search for nothing?

Option 1: require something to happen!

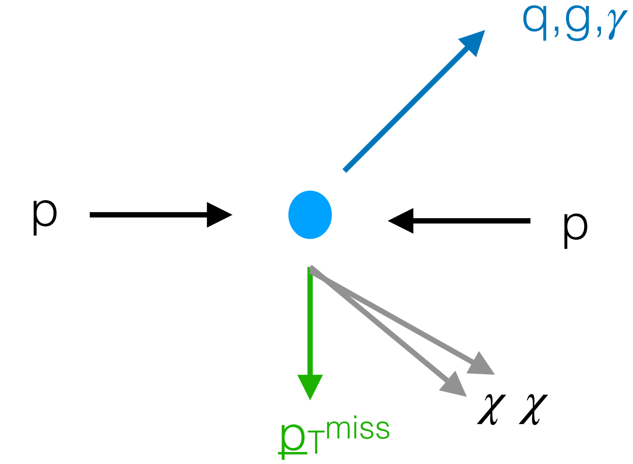


In a hadron collider, "SM" initial state = quarks and gluons

We can see this

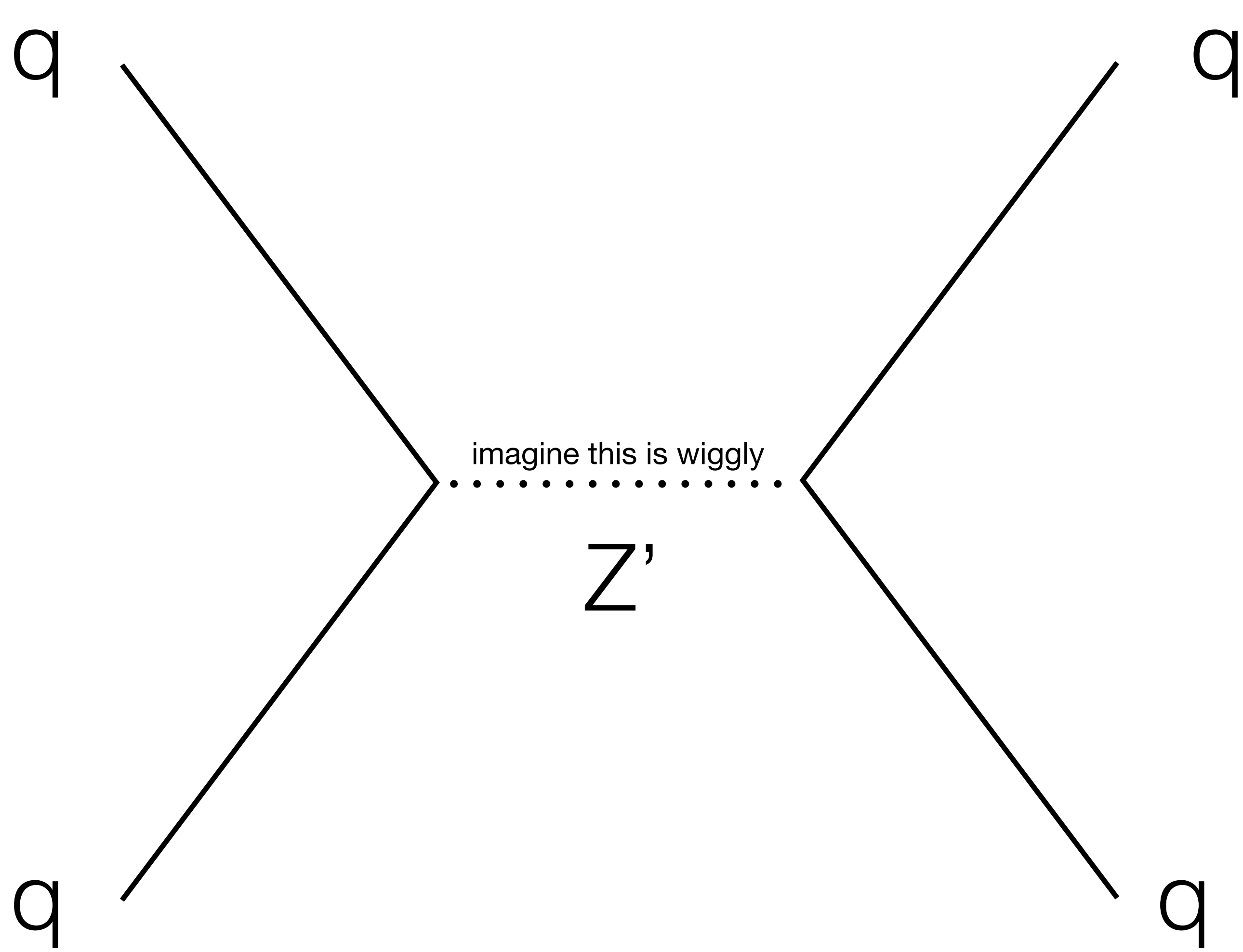


Which also allows us to notice this

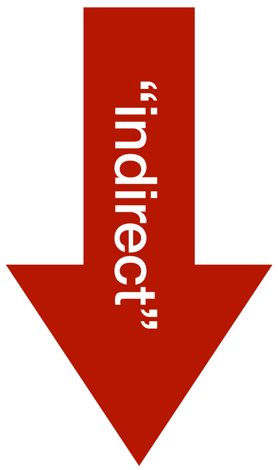


"Mono-X searches"

Option 2: dark matter? What dark matter?



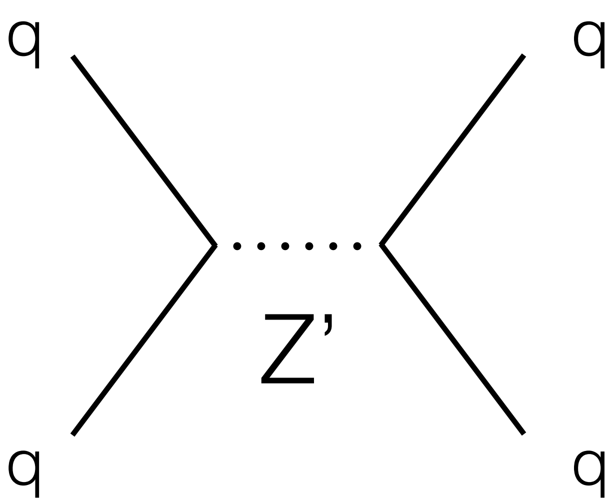
If there is a mediator that couples to quarks and DM…



… then we can forget about the DM and look for the mediator

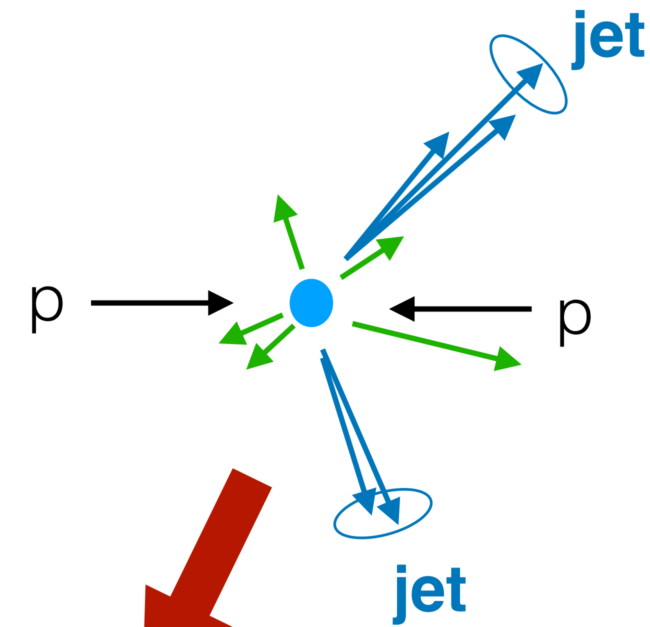
"Dijet* resonance searches"

One of many things: dijet resonance search

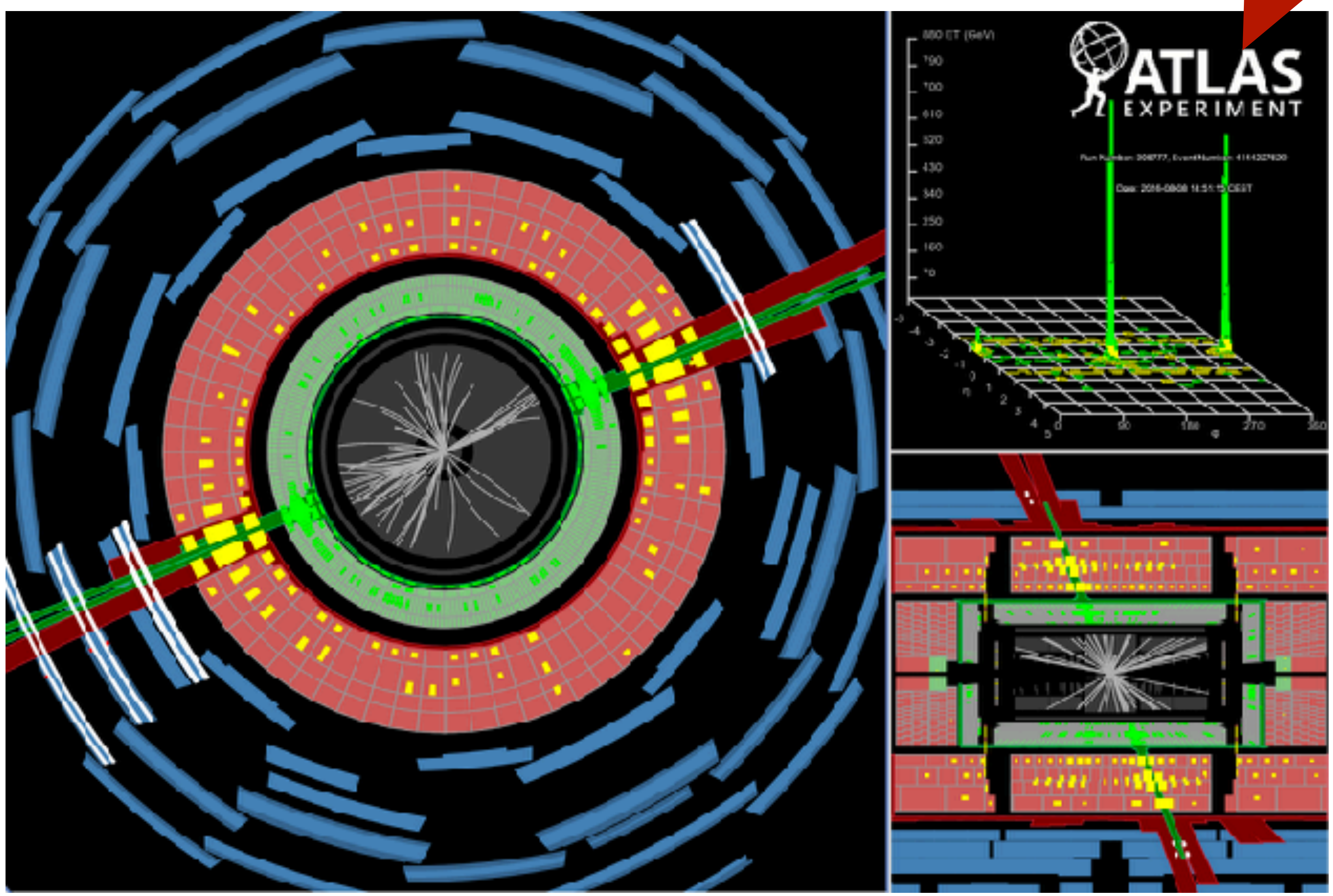


hadronisation of final state quarks

“pile-up” - simultaneous p-p interactions



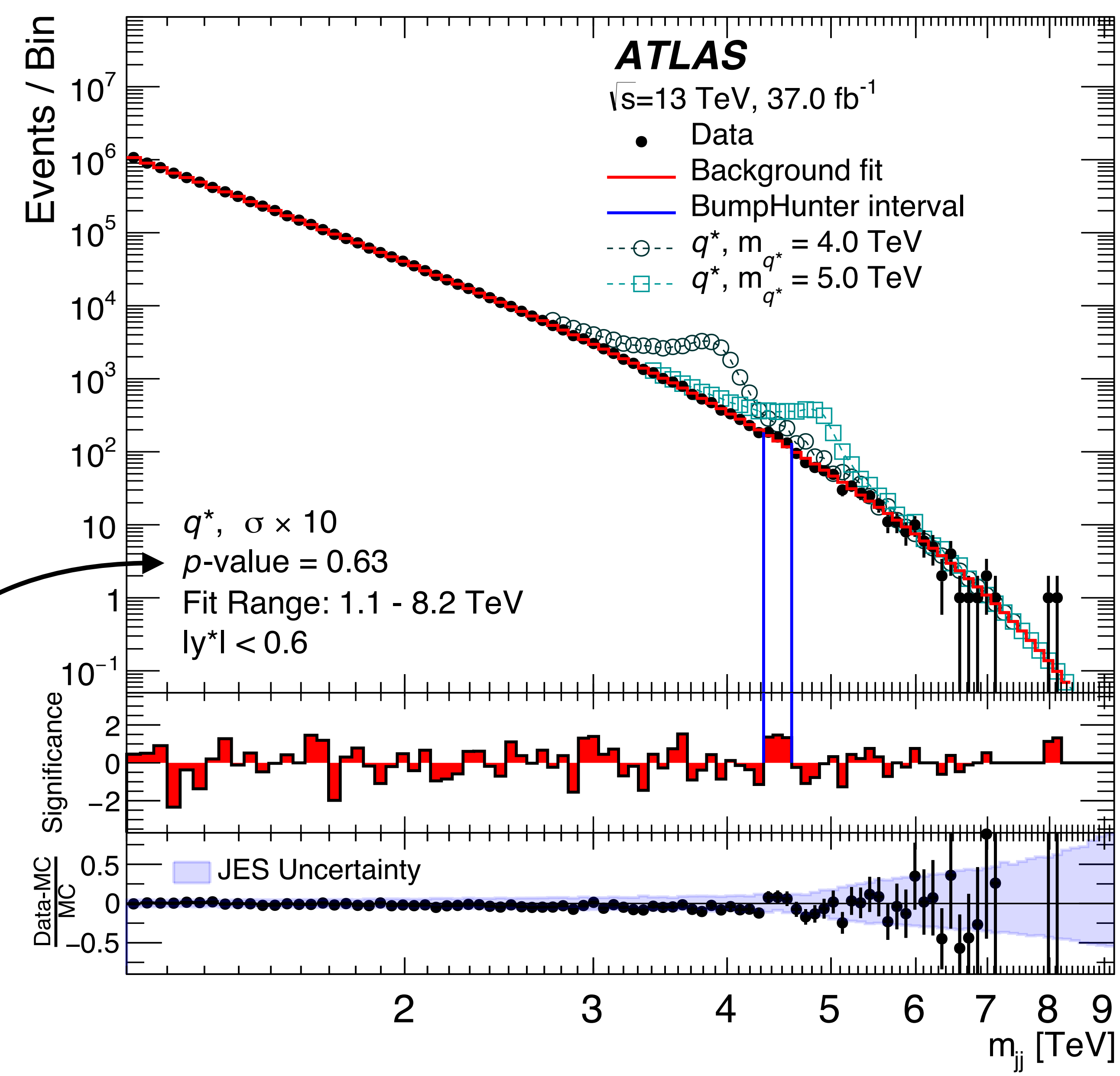
highest-mass dijet event in 2016
$p_T(j1,j2) = 3.79$
$m_{jj} = 8.12$ TeV



Bump hunting

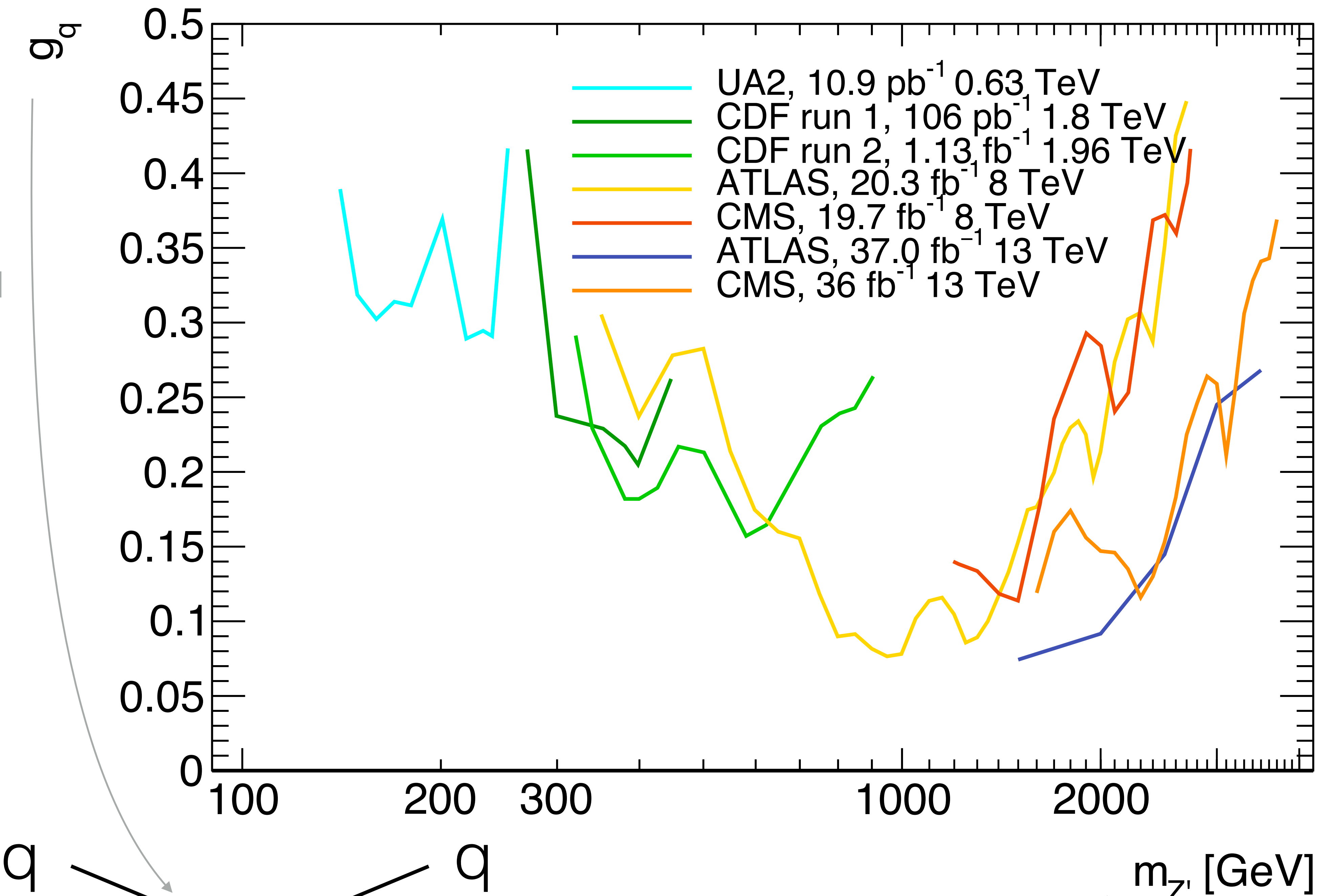
- QCD is hard…
- BUT also smooth :-)
- It is hard to predict exactly what shape the background should have, but we don't need to - fit to functional forms partly ad-hoc, partly inspired by QCD
- p-value < 0.05 => there is something there with 95% confidence
- p-value > 0.05 => there is not something there

Functional form
$f(x) = p_1(1-x)^{p_2} x^{p_3}$
$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$
$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x * p_5 \ln x^2}$
$f(x) = \frac{p_1}{x^{p_2}} e^{-p_3 x - p_4 x^2}$

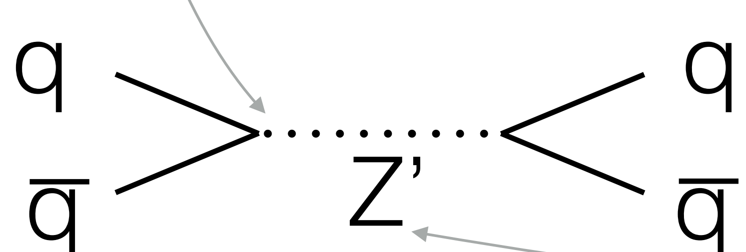


Dijet search limits

What limits these searches?

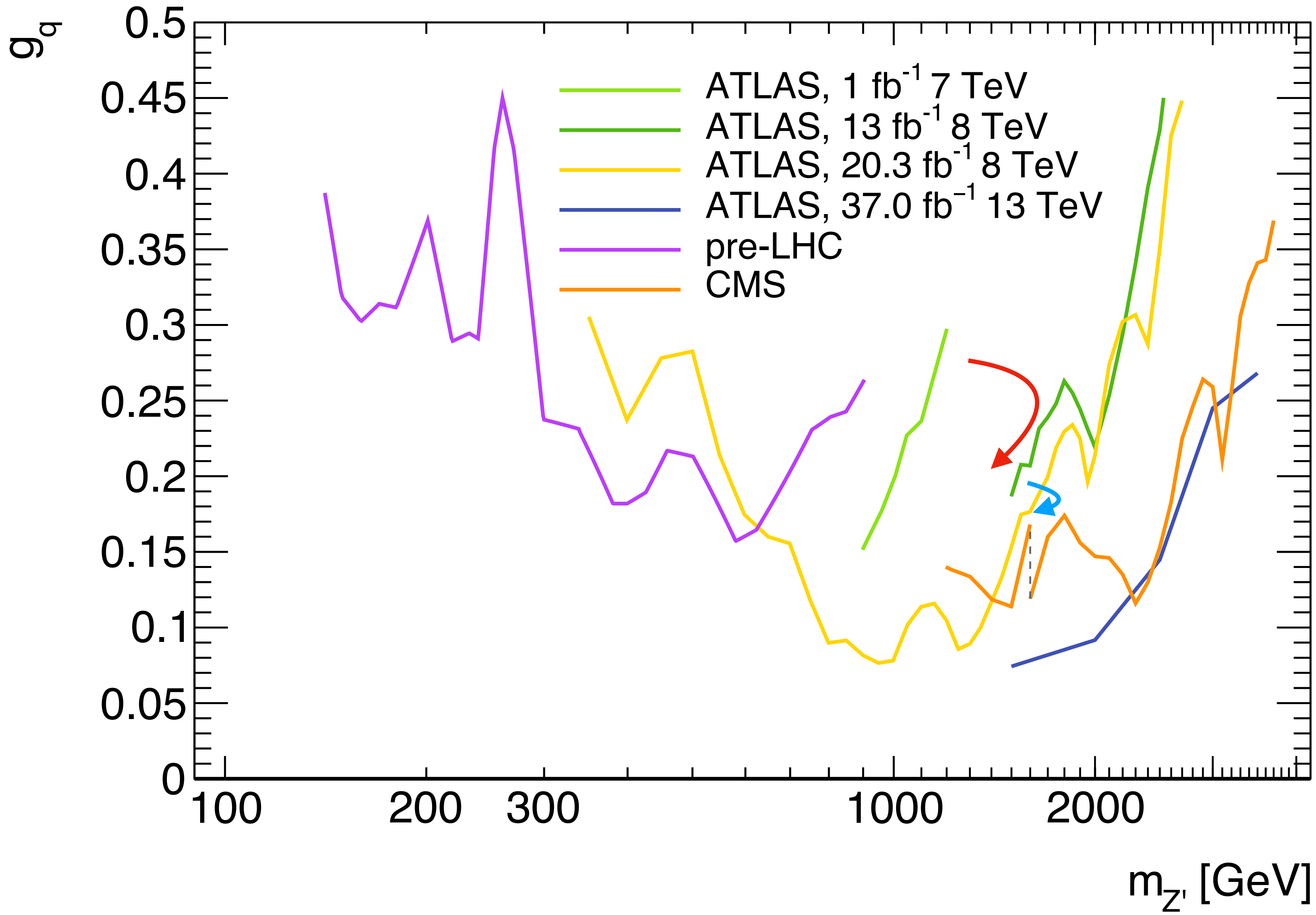


g_q = Z' - q coupling



$m_{Z'}$ = mediator mass

Limits on the limits: stat precision



amount of data

- statistical power ~ $N^{1/2}$

=> cross-section sensitivity ~ $N^{1/2}$

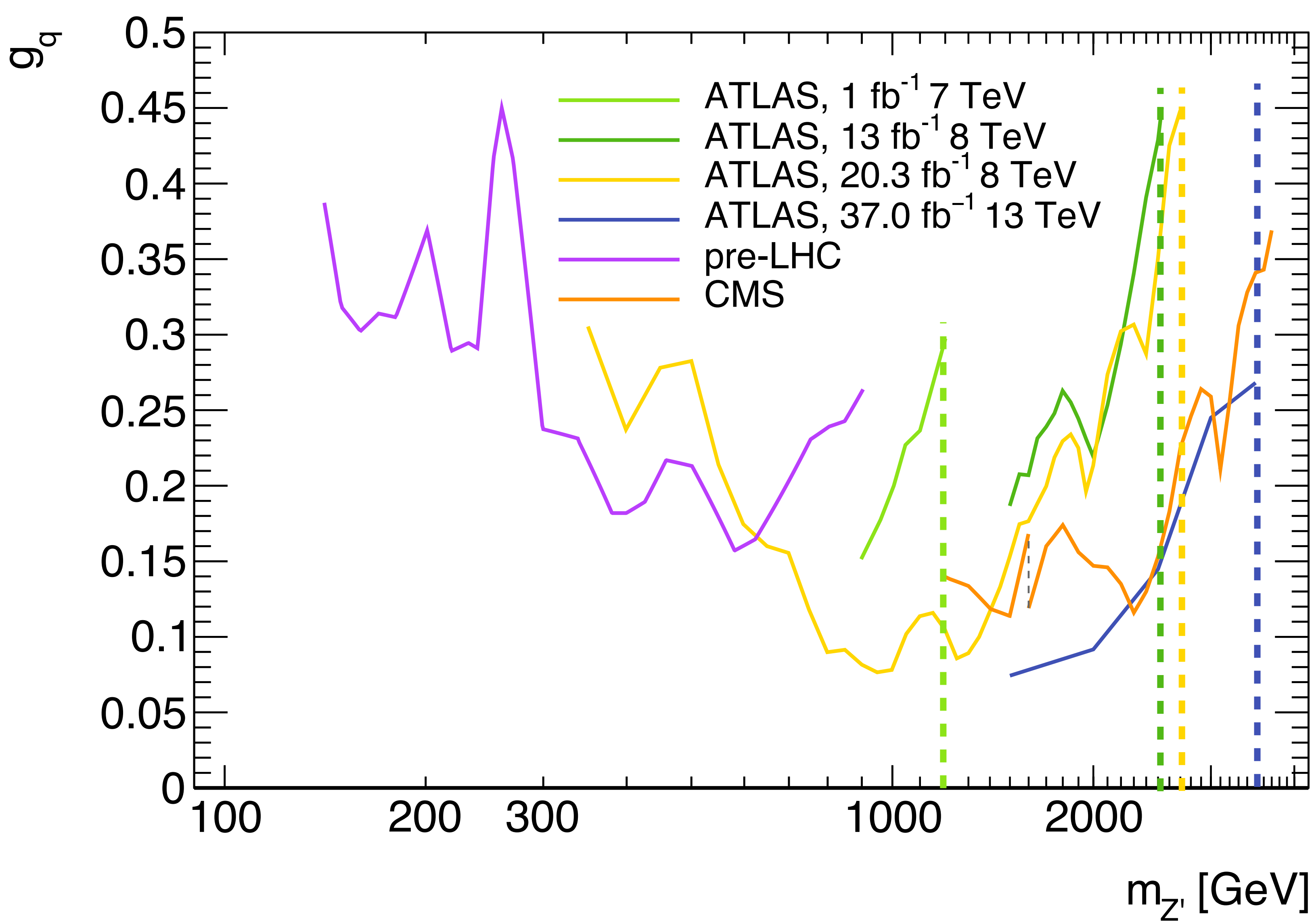
- cross-section ~ g_q^2

=> g_q sensitivity ~ $N^{1/4}$

$(13/1)^{1/4} = 1.9$

$(20/13)^{1/4} = 1.1$

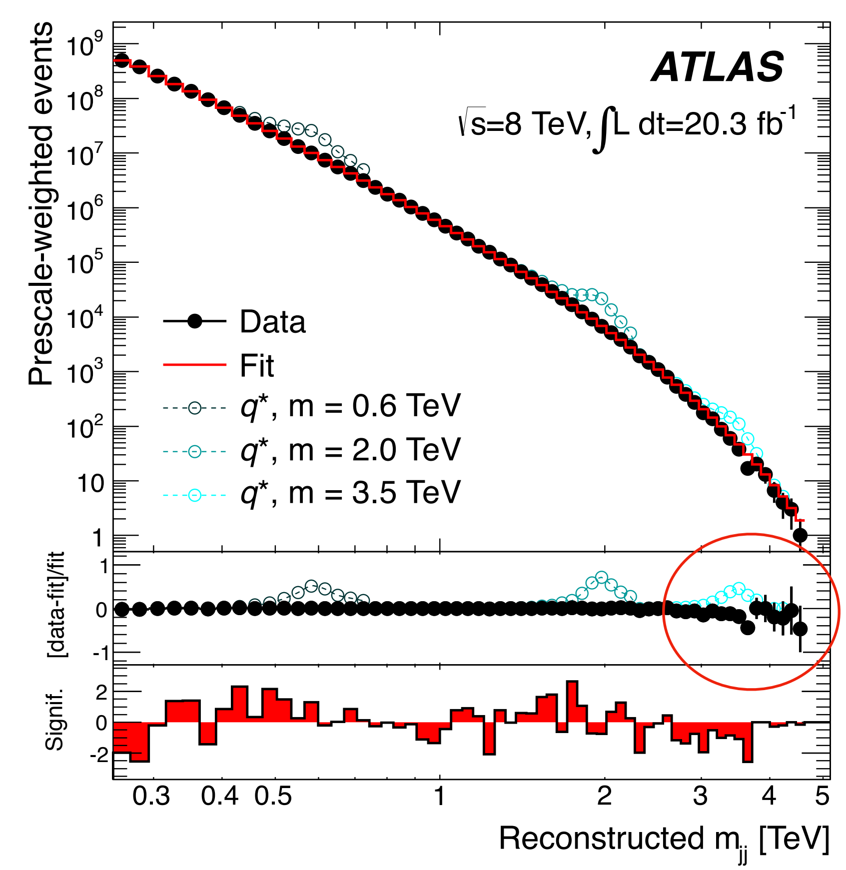
Limits on the limits, spectrum endpoint



amount of data

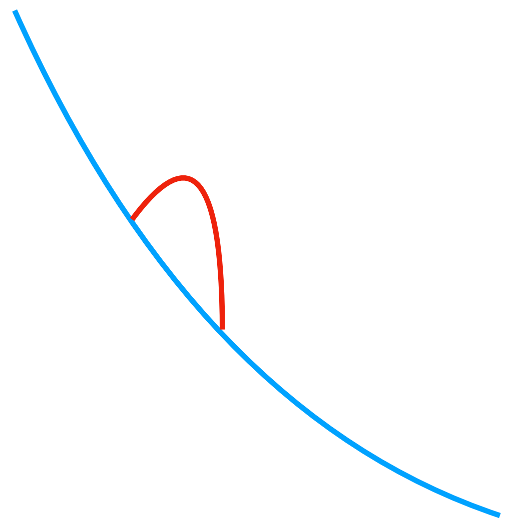
- run out of events at top end of spectrum
- need to fit beyond signal to be sensitive

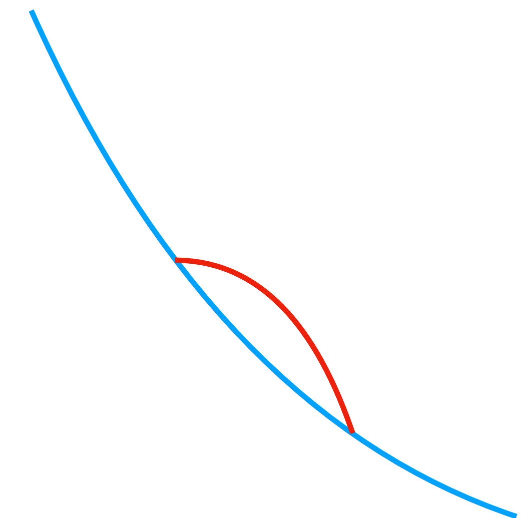
=> can't set limits beyond a certain point



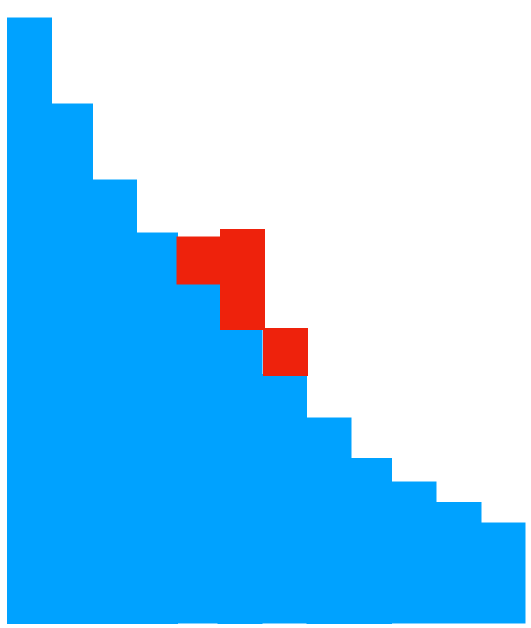
Limits on the limits: m_{jj} resolution

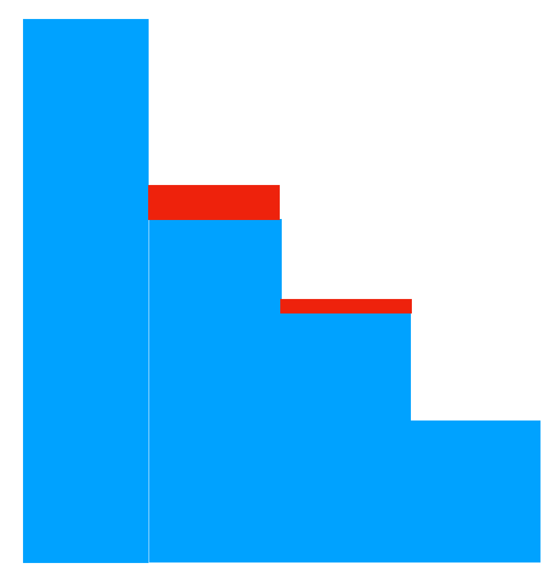
Good resolution | **Bad resolution**



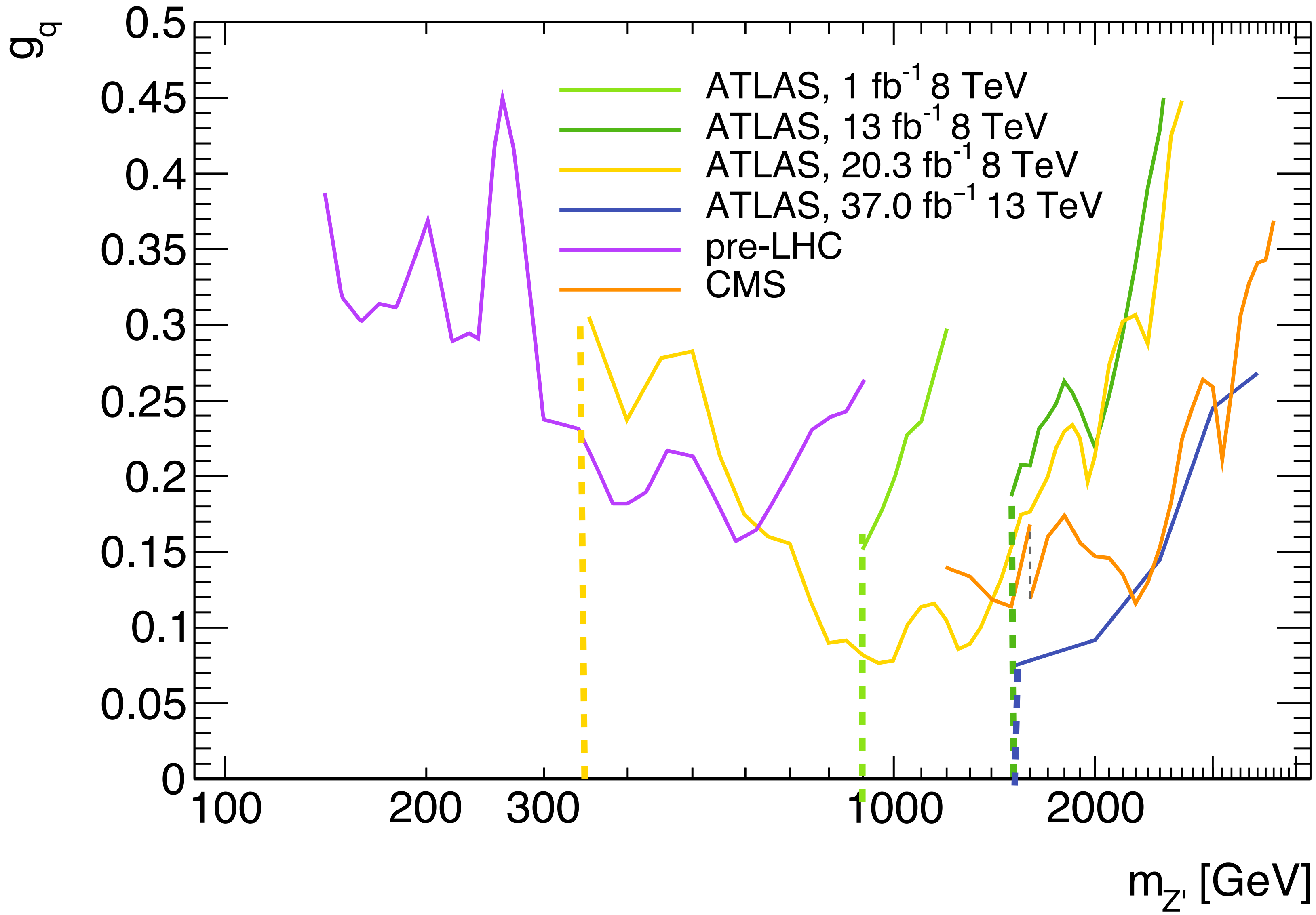


Bad resolution: signal smears out, covers wider m_{jj} range, trying to extract same number of signal events from more background events





Limits on the limits, spectrum start

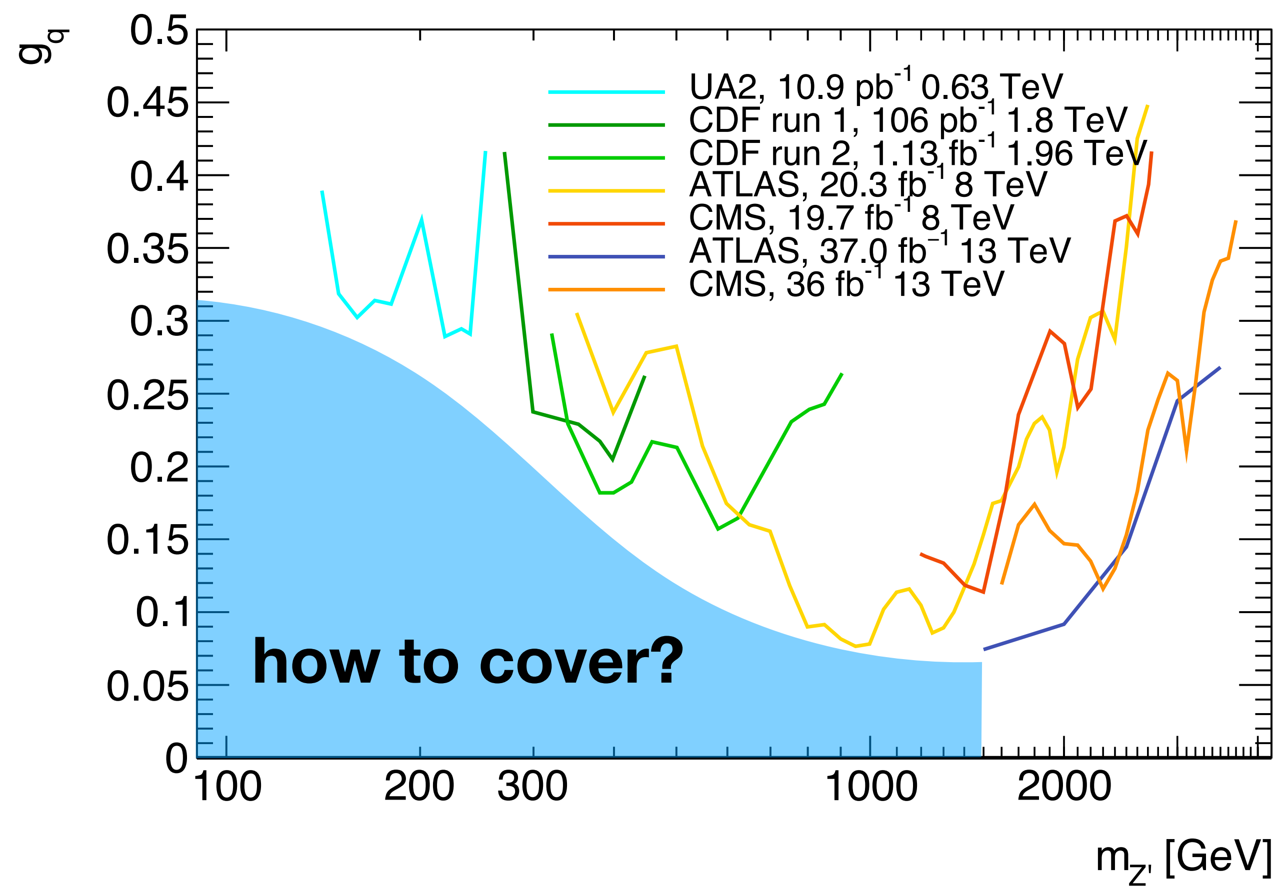


what causes this?

- aside from 20.3 fb^{-1} line, creeping to the right…
- Increase in trigger thresholds

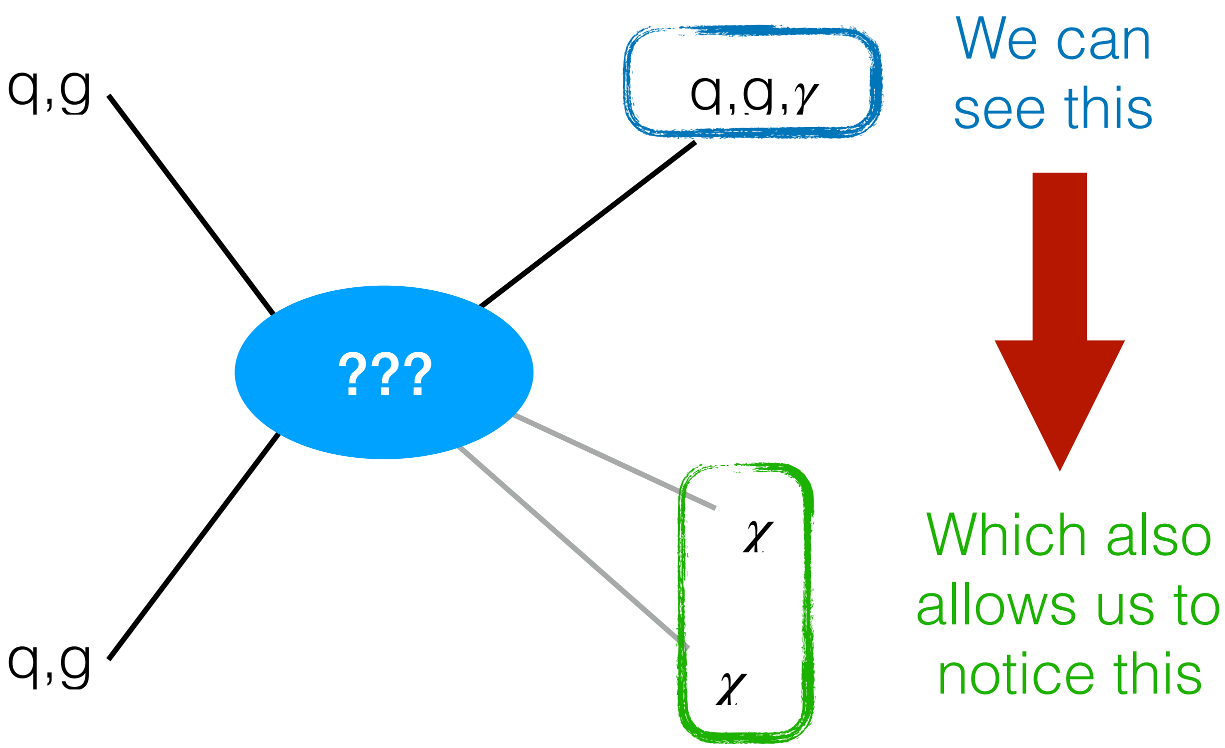
Limits on the limits, summary

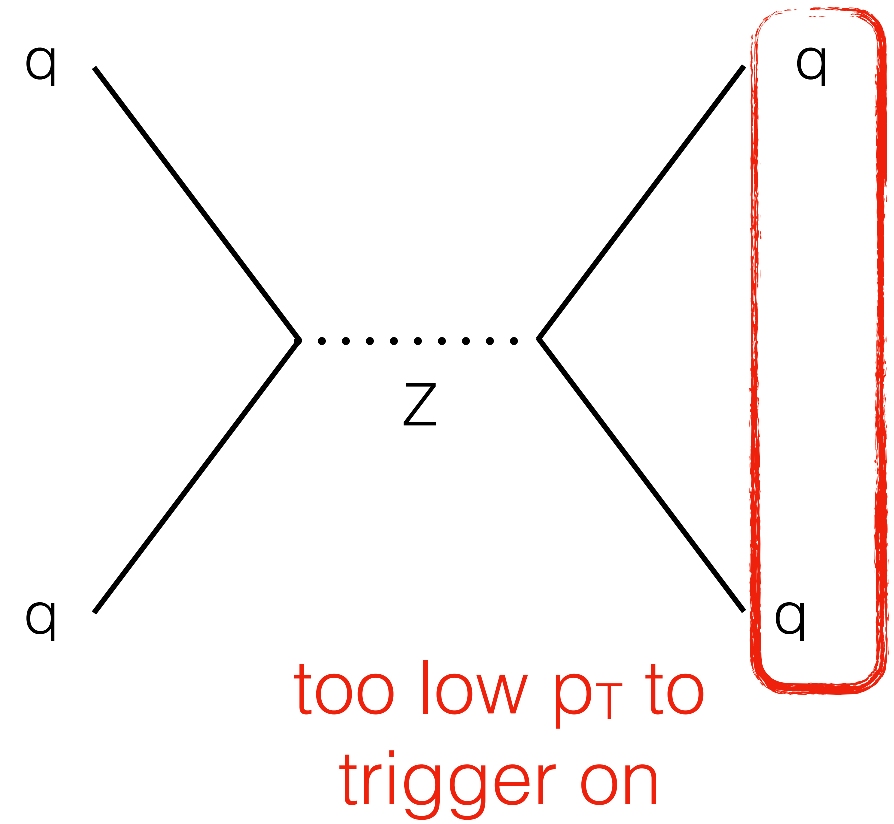
- Statistical precision
  - Collect more data
  - Rapidly diminishing returns, g_q limit ~ $\int L^{1/4}$
  - Have a bit of a wait now!
- Spectrum endpoint
  - See above
- m_{jj} offline-truth resolution
  - We're working on it :-)
- Trigger thresholds -> offline jet p_T selection
  - Improved performance mitigates, but isn't going to help enough



Need a new approach!

1: borrow tricks





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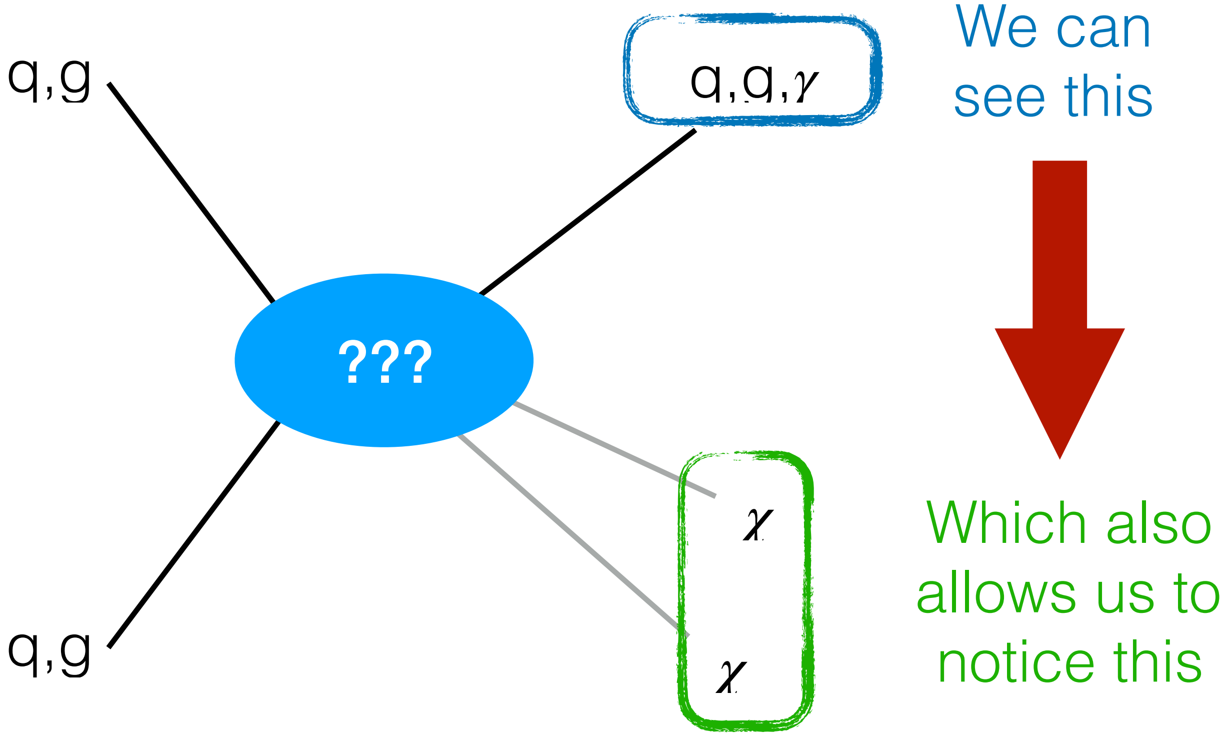
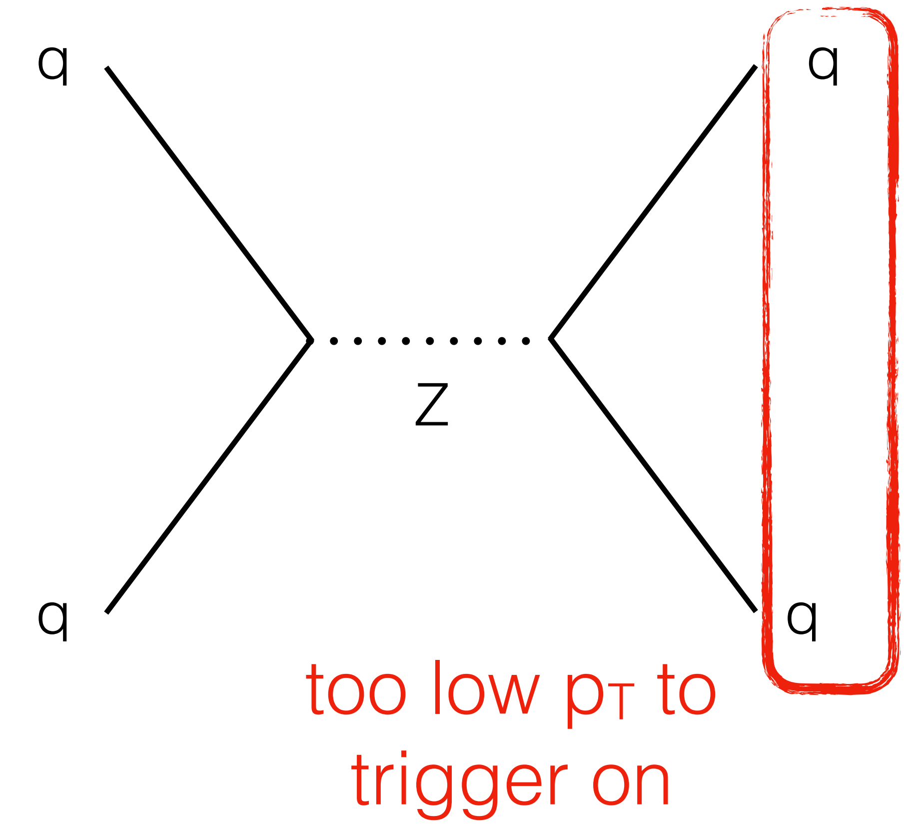
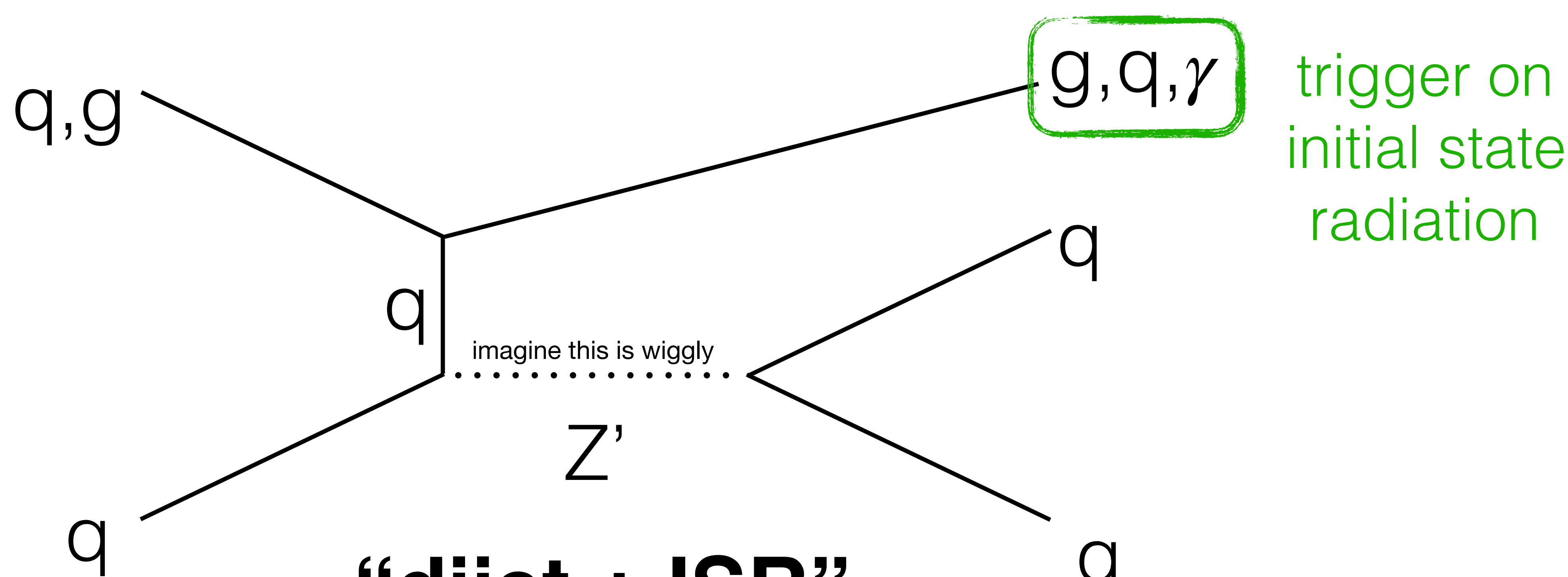


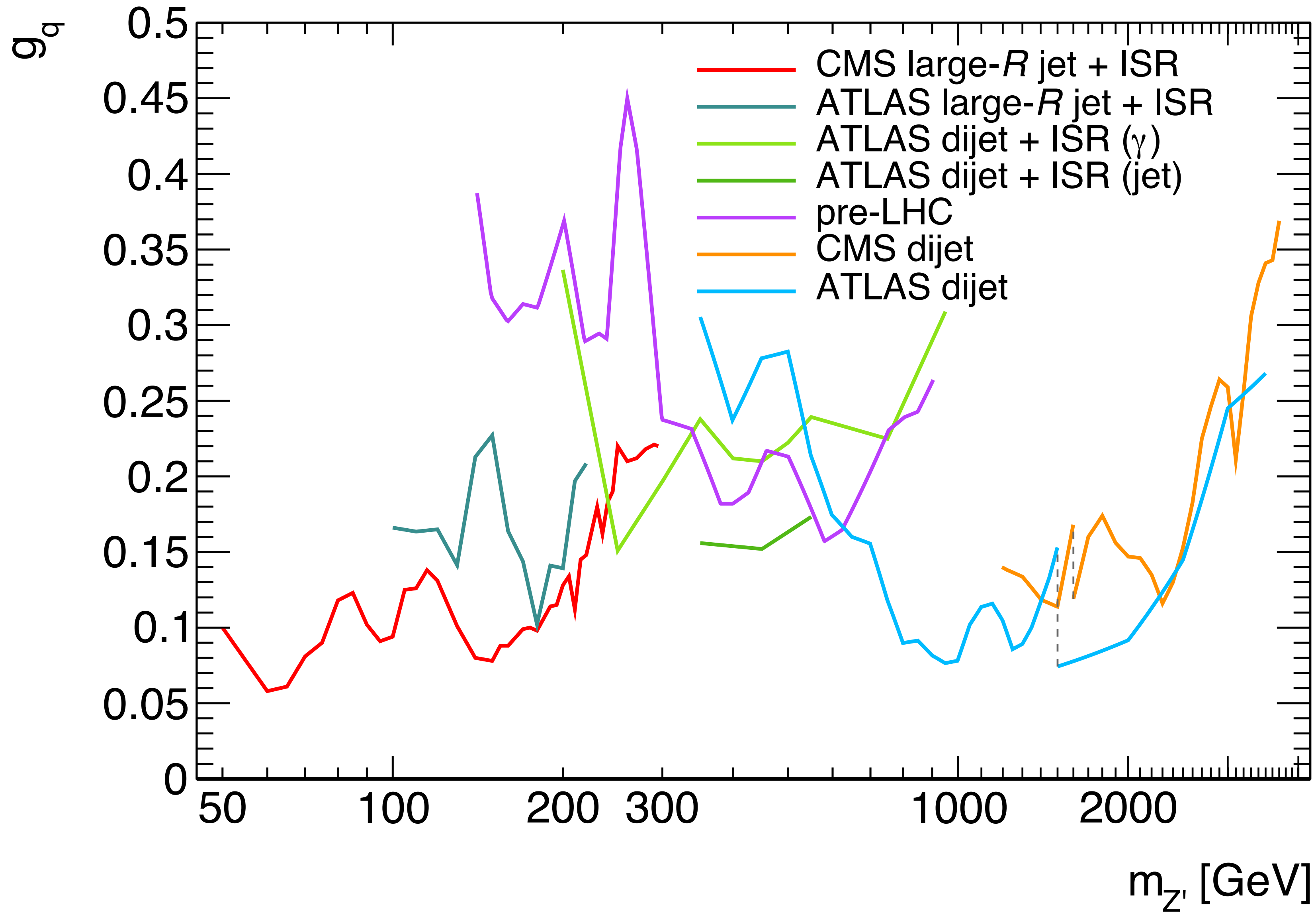




“dijet + ISR”

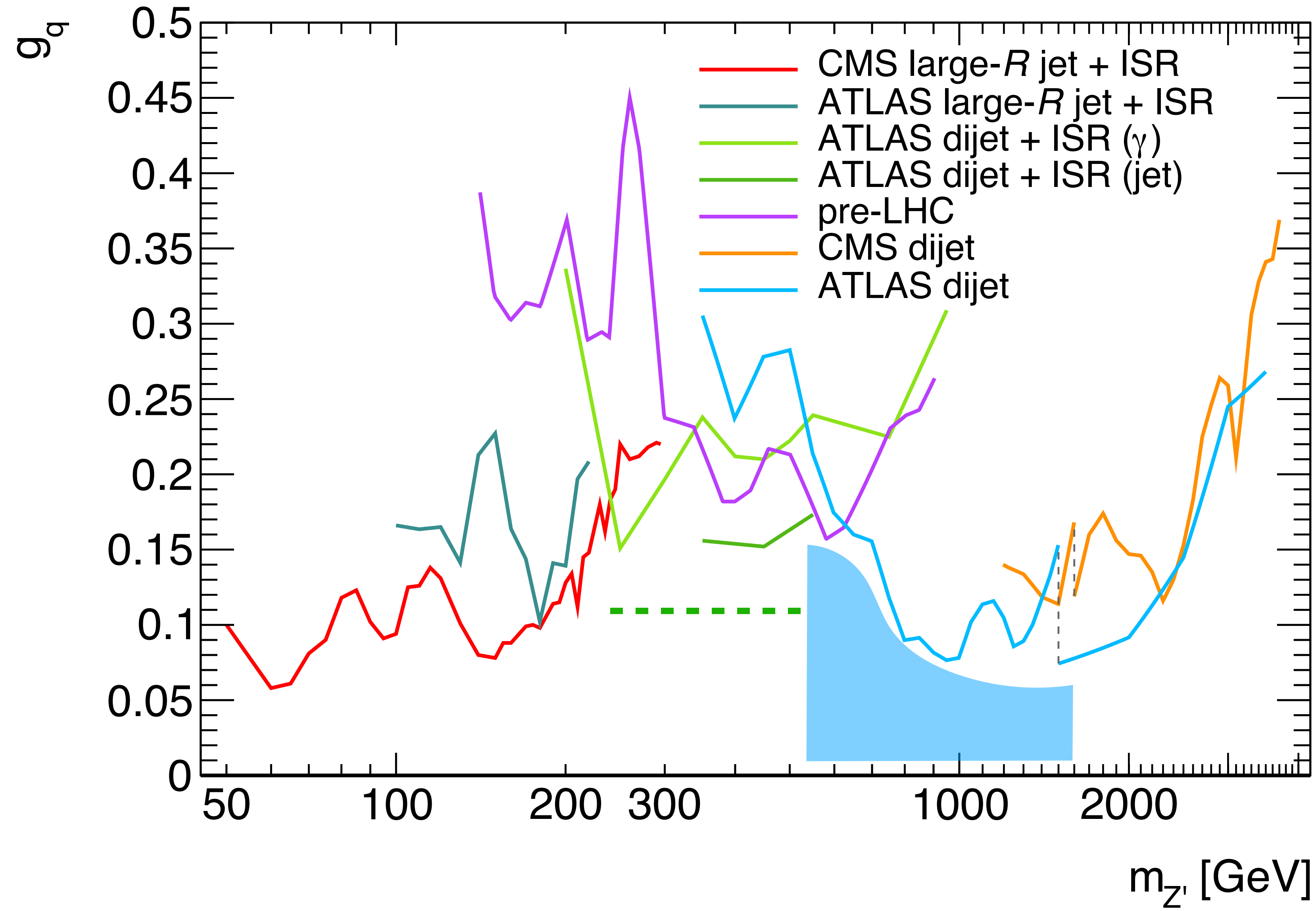
Dijet + ISR variants

- ISR: jet or photon
  - jet: more frequent ($\alpha_{QCD} > \alpha_{EM}$)
  - photon: trigger thresholds lower
  - jet: combinatorics cause loss of acceptance (is ISR always lead jet?)



- What happens to the recoiling system?
  - Higher mass Z’ -> qq hadrons resolved -> two small-radius jets
  - Lower mass Z’ -> qq hadrons merge -> one large-radius jet

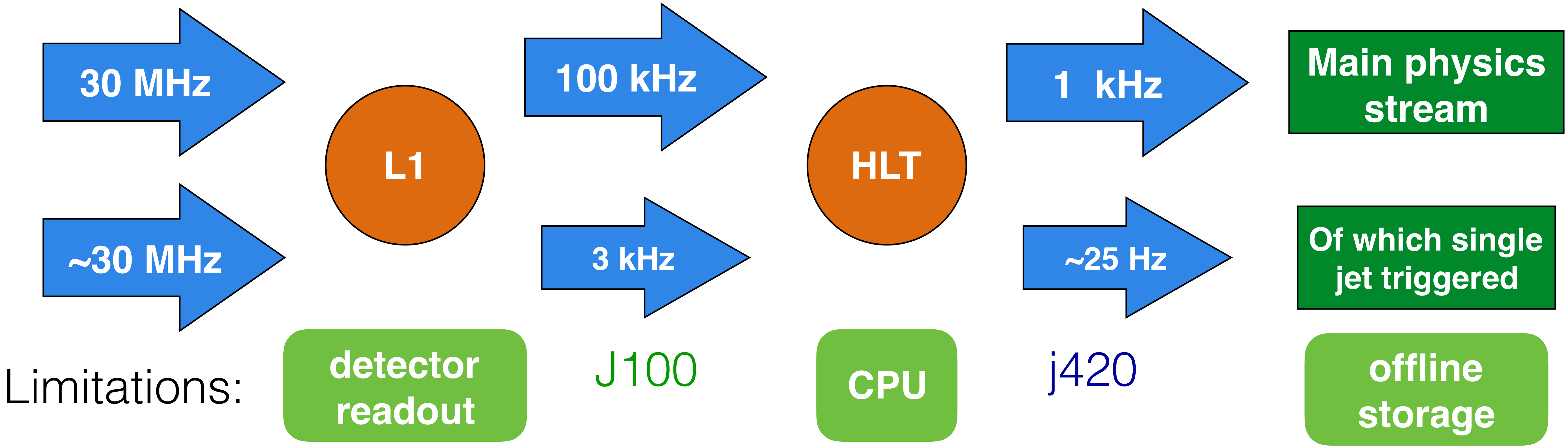
Still have a gap



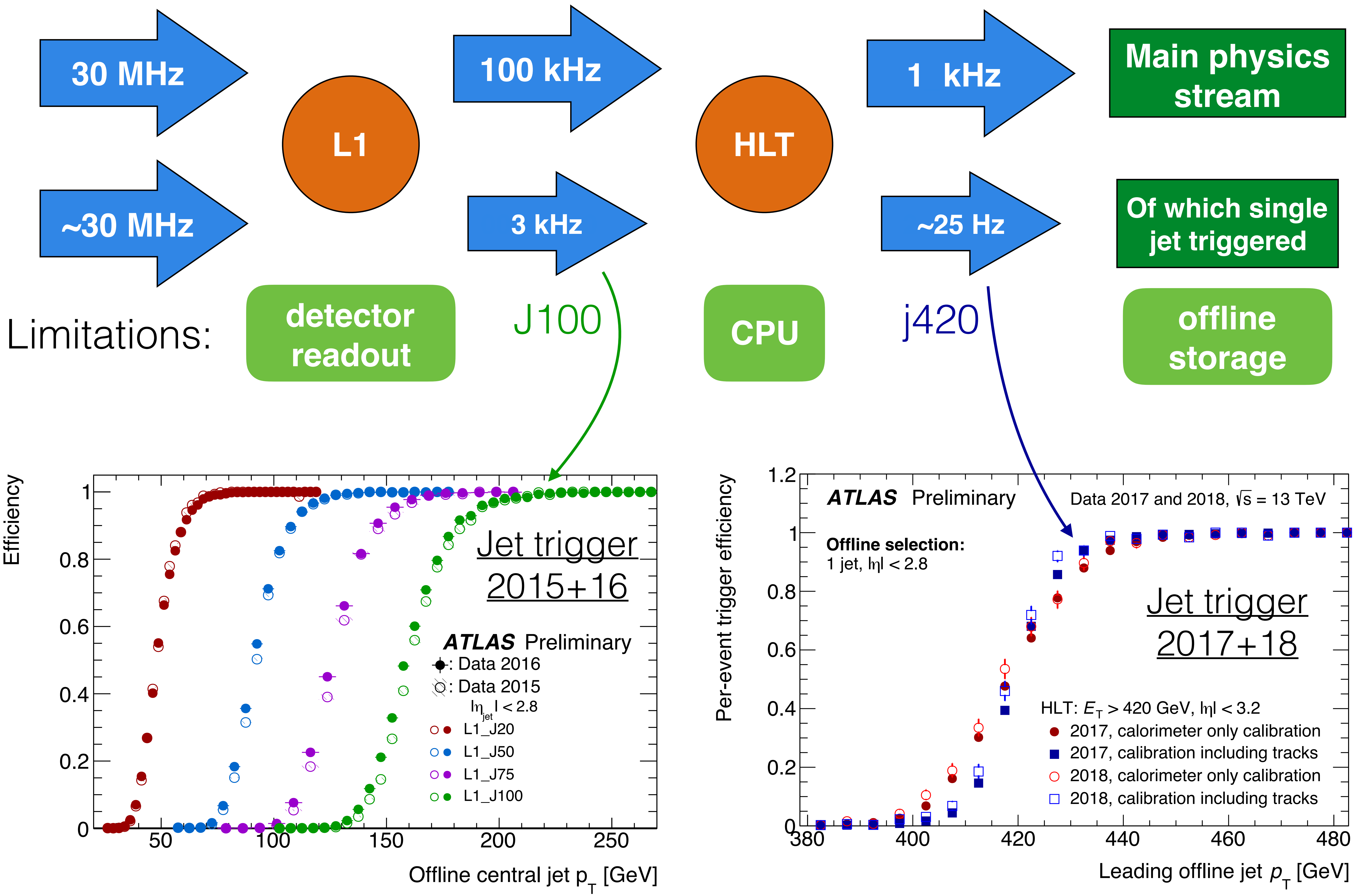
- Still struggle to improve things between 500 and 1500 GeV

Need another new idea

Revisit limitations



Revisit limitations

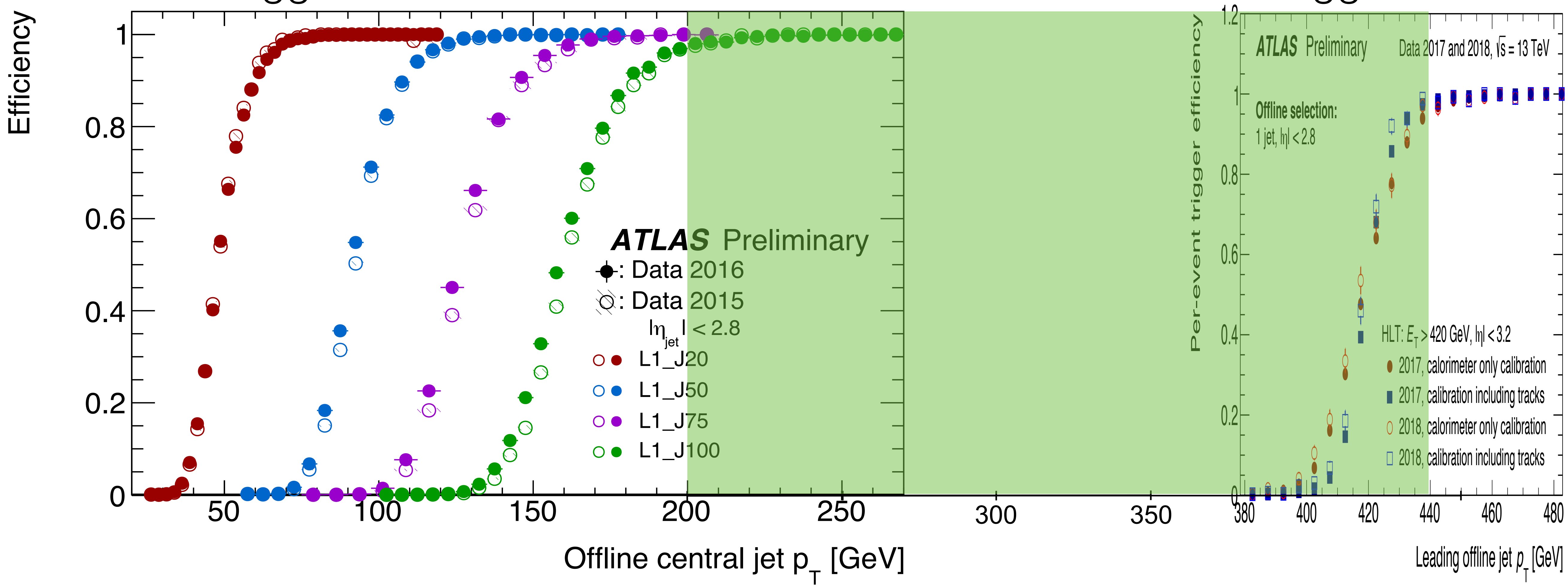


Opportunity

- Now with L1 and HLT turnons on the same x axis scale
- Every event in the green shaded region (~200 - 440 GeV) has full HLT jet reconstruction, but is thrown away because we don't have space to store the full event
- Taking inspiration from LHCb and CMS: record partial events

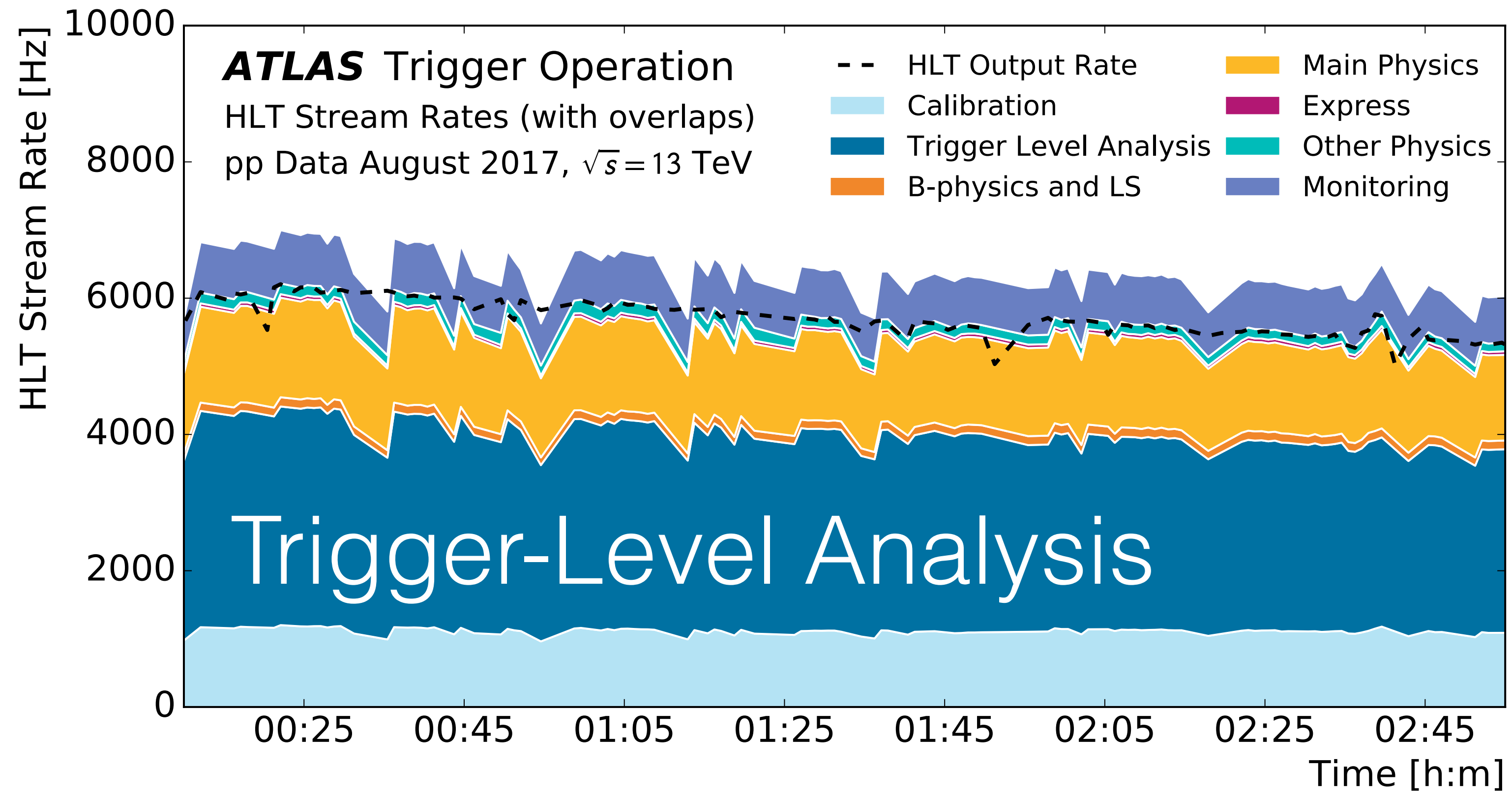
Jet trigger 2015+16

Jet trigger 2017+18

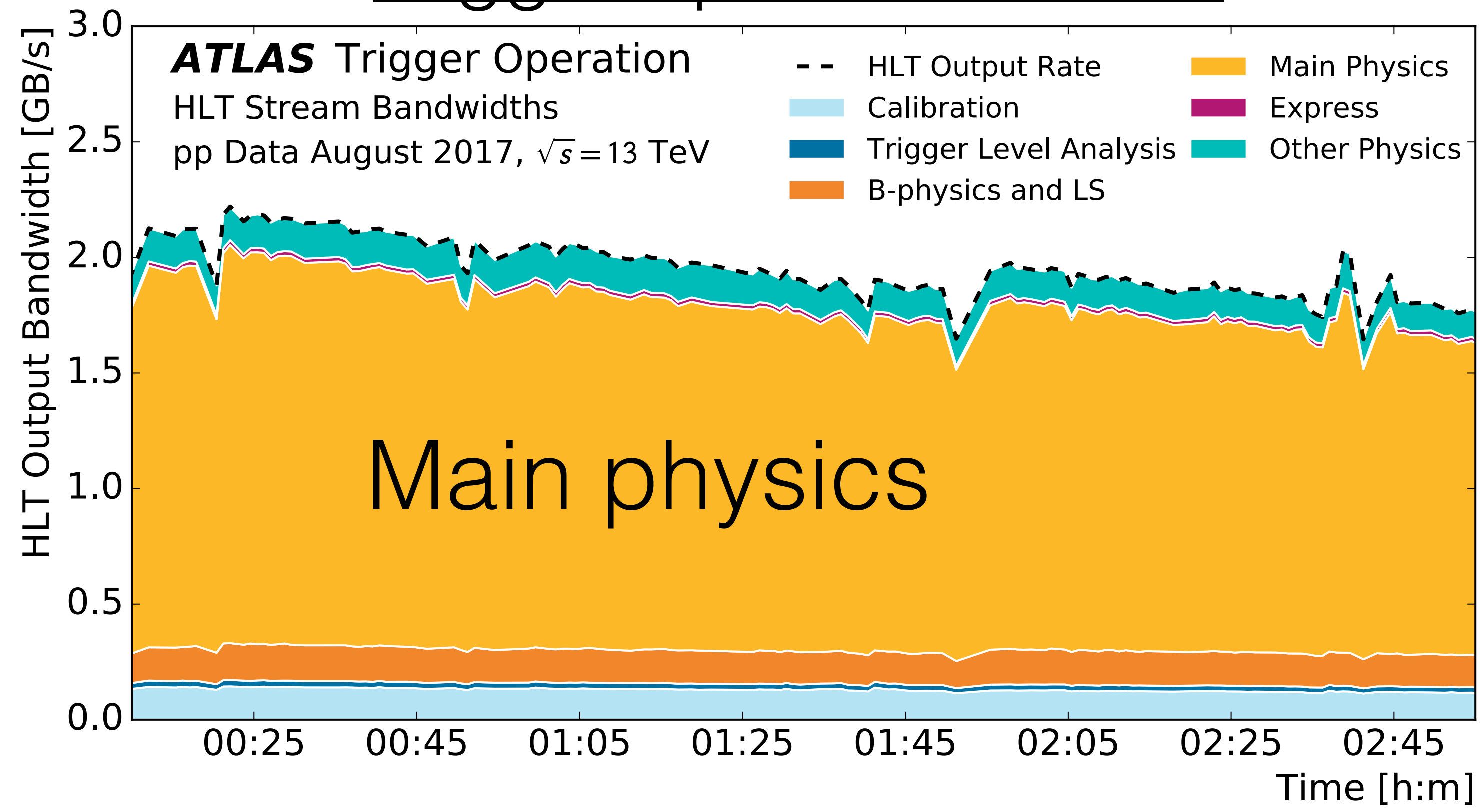


“Trigger-Level Analysis”

- Store only HLT jet 4-vectors and some summary info
  -> tiny event size (0.5% of full size)
- Allows all events passing unprescaled L1_J100 to be recorded to disk
- Very large event rate, tiny bandwidth impact

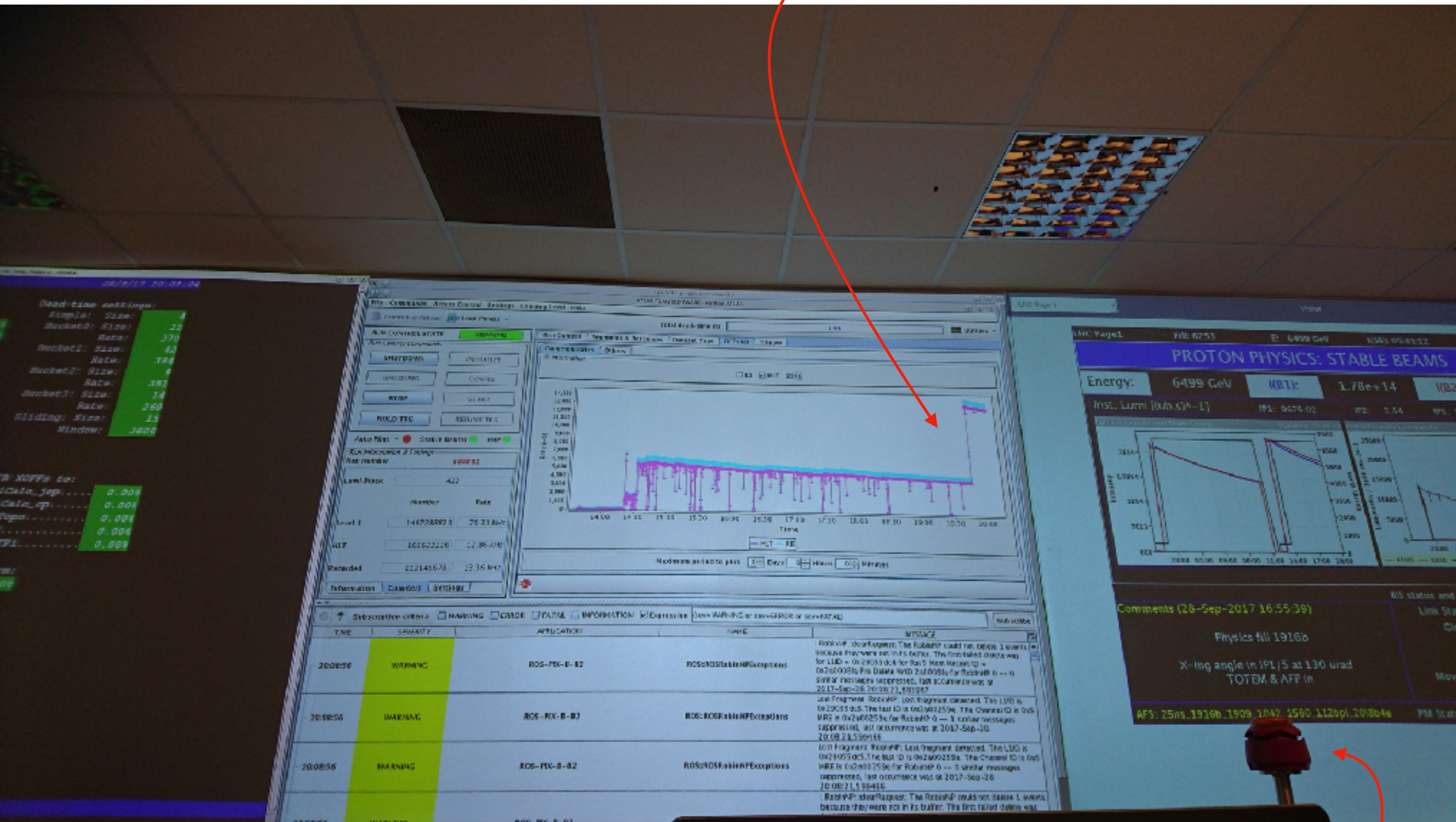


Trigger operations 2017



In real life

TLA!



Out of sight: confused shift leader

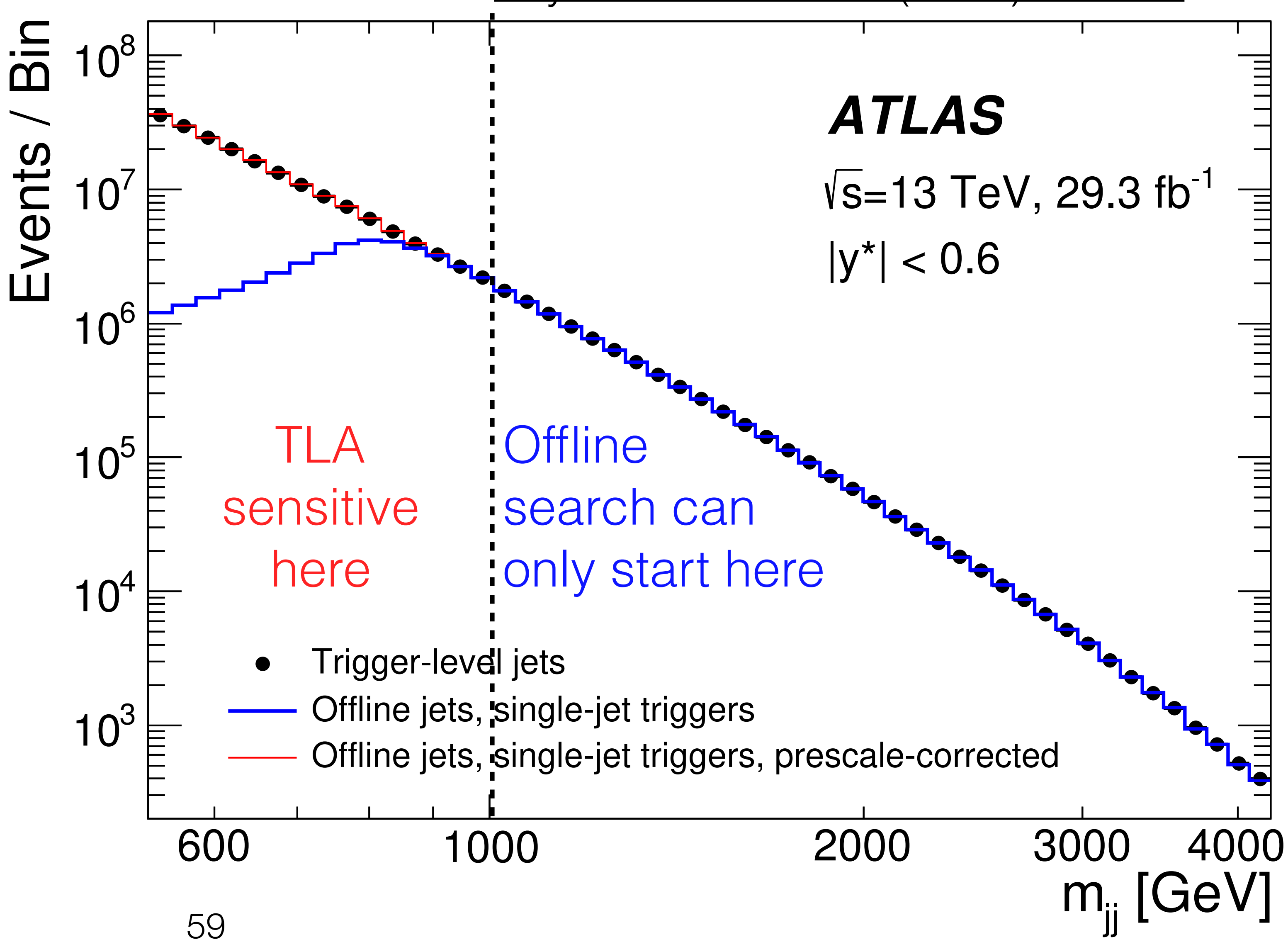
Do not press this

The payoff

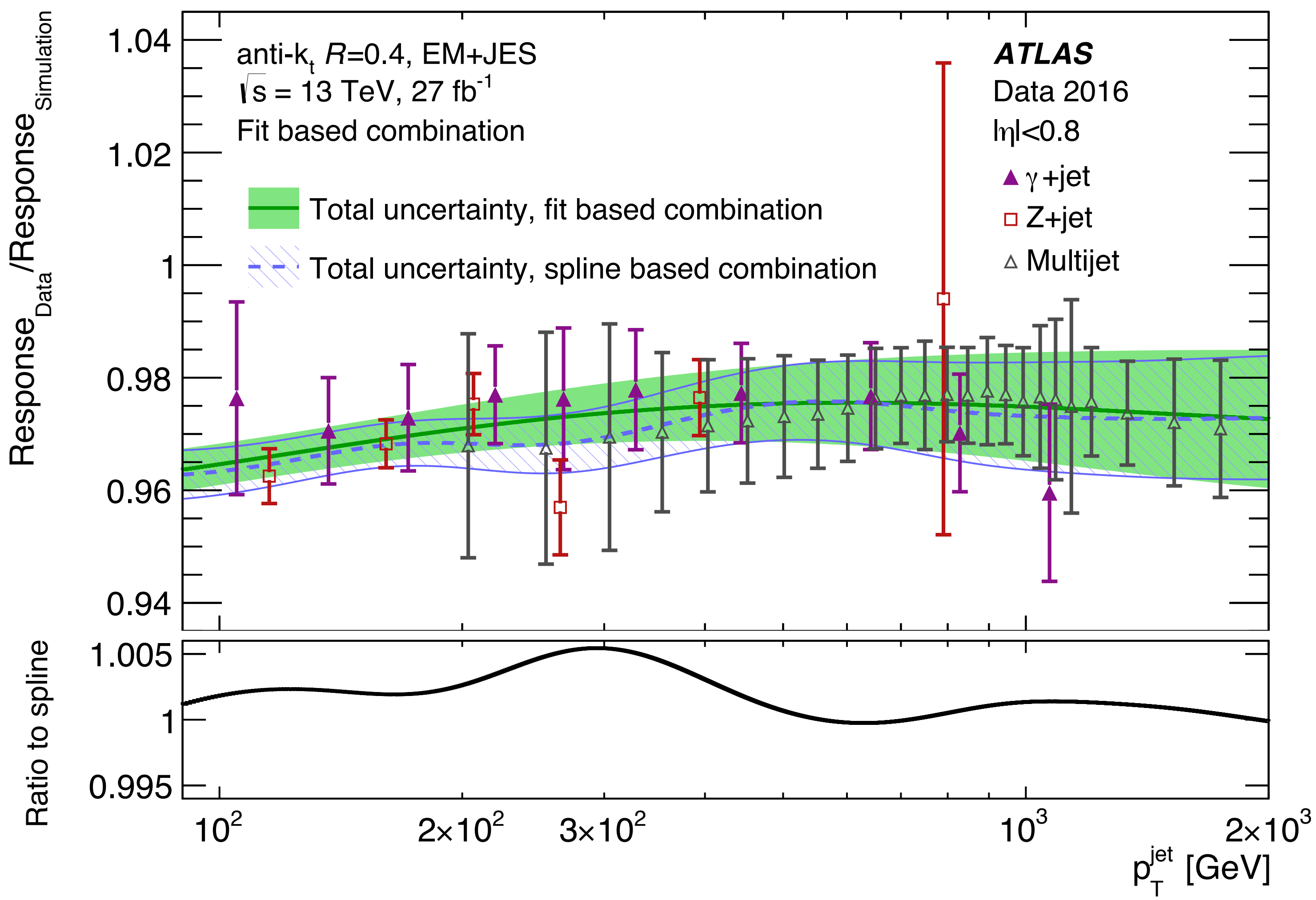
	“‘“standard” dijet	TLA
lead jet p_T >	440	220
sublead jet p_T >	60	85
m_{jj} >	1100	520

Phys. Rev. Lett. 121 (2018) 081801

4x10^7 events in first bin in 29.3 fb^{-1} of 2016 data



Downside: too much data!



Statistical precision of calibration dataset << statistical precision of TLA dataset

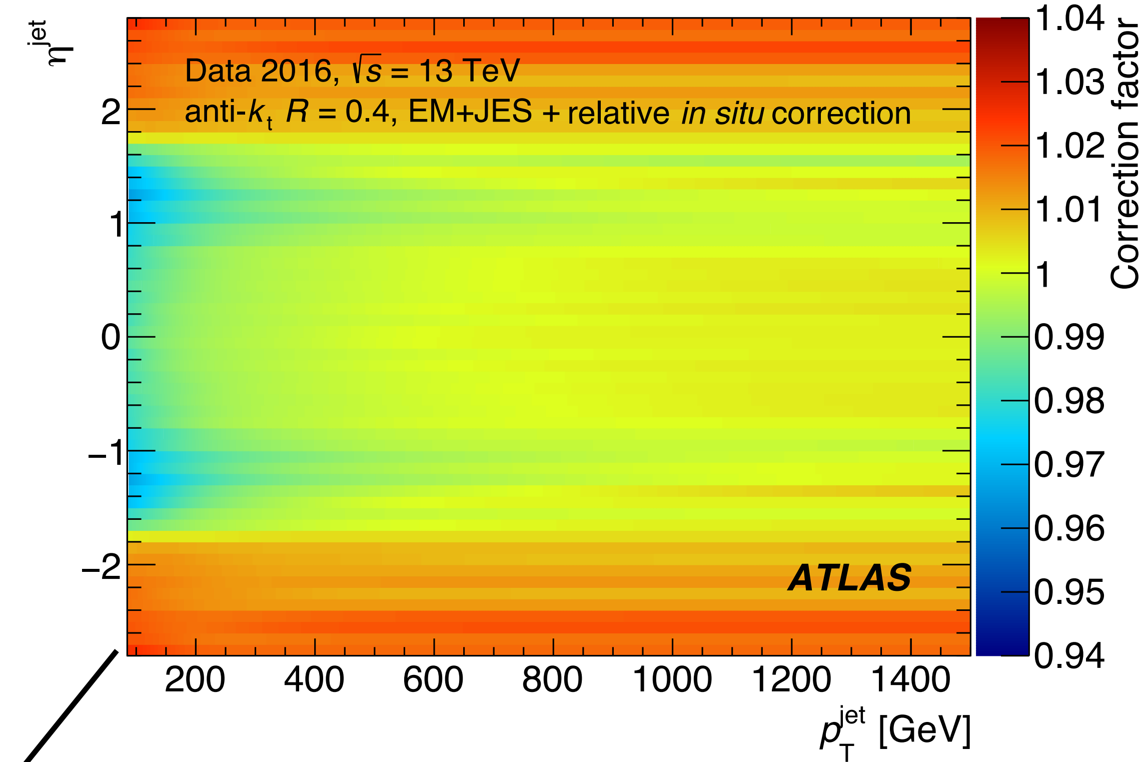
Custom "in-situ" step to ensure smoothness - statistical fluctuation in normal spline-based combination leads to bump in p_T and hence m_{jj}

Problem 2: no tracks

Calibration		Purpose
Origin correction		Move jet origin to vertex
Pileup subtraction	Jet area	Remove contributions from pileup
	Residual	
Jet Energy Scale correction		Restore hadronic energy
Global Sequential Correction	Calo-only	Reduce flavour (quark / gluon) dependence
	with tracks	
trigger - offline scale factor		Corrects residual differences (binned in p_T and eta)
In-situ eta intercalibration		Corrects detector effects along eta to central region
In-situ JES correction		Calorimeter response corrected to MC truth scale

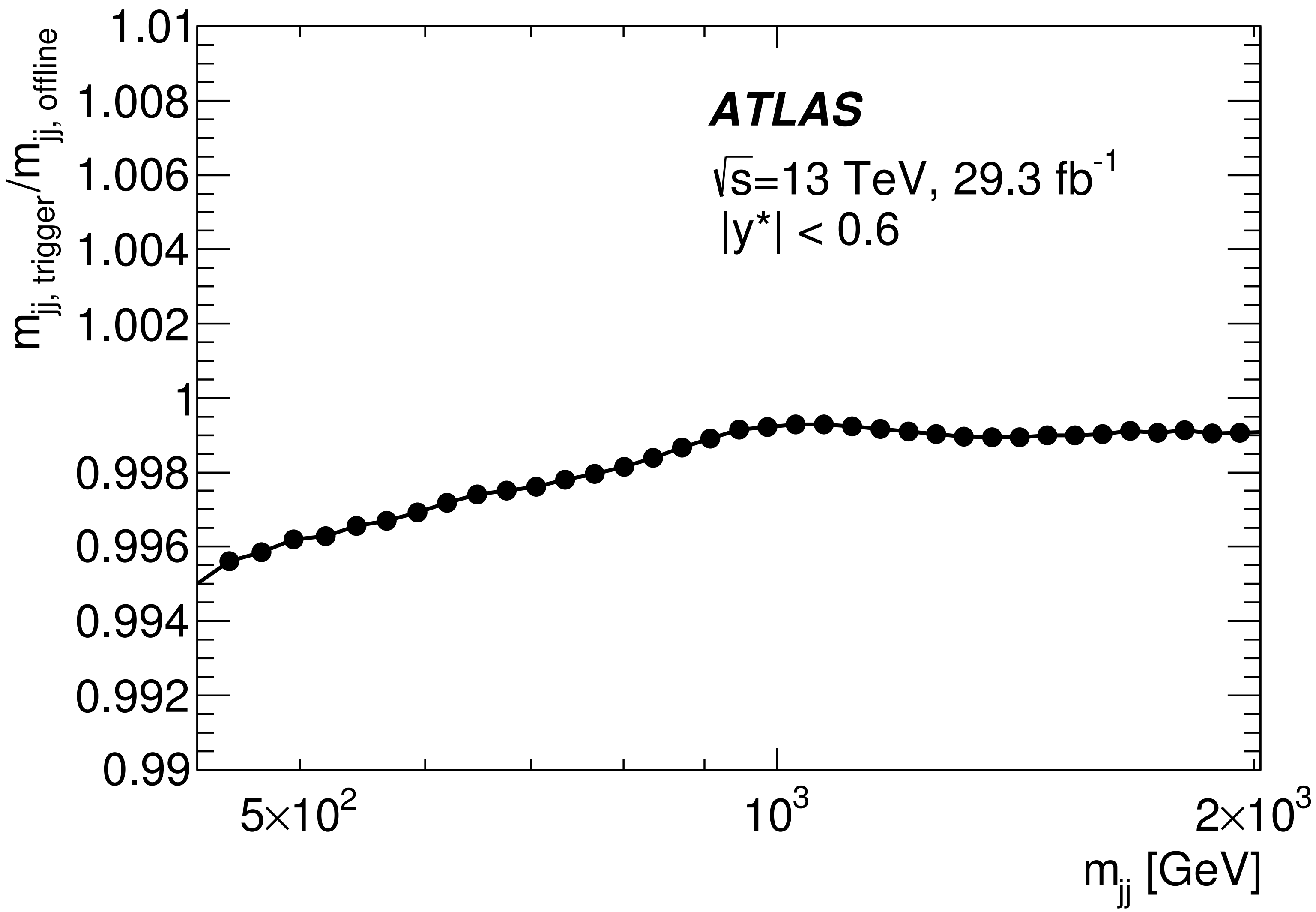
Applied to?

Offline and TLA	Modified for TLA	Extra for TLA	Offline only



- Write out sufficient information to be able to redo calibration offline
- Some parts rederived since TLA data lacks eg track information

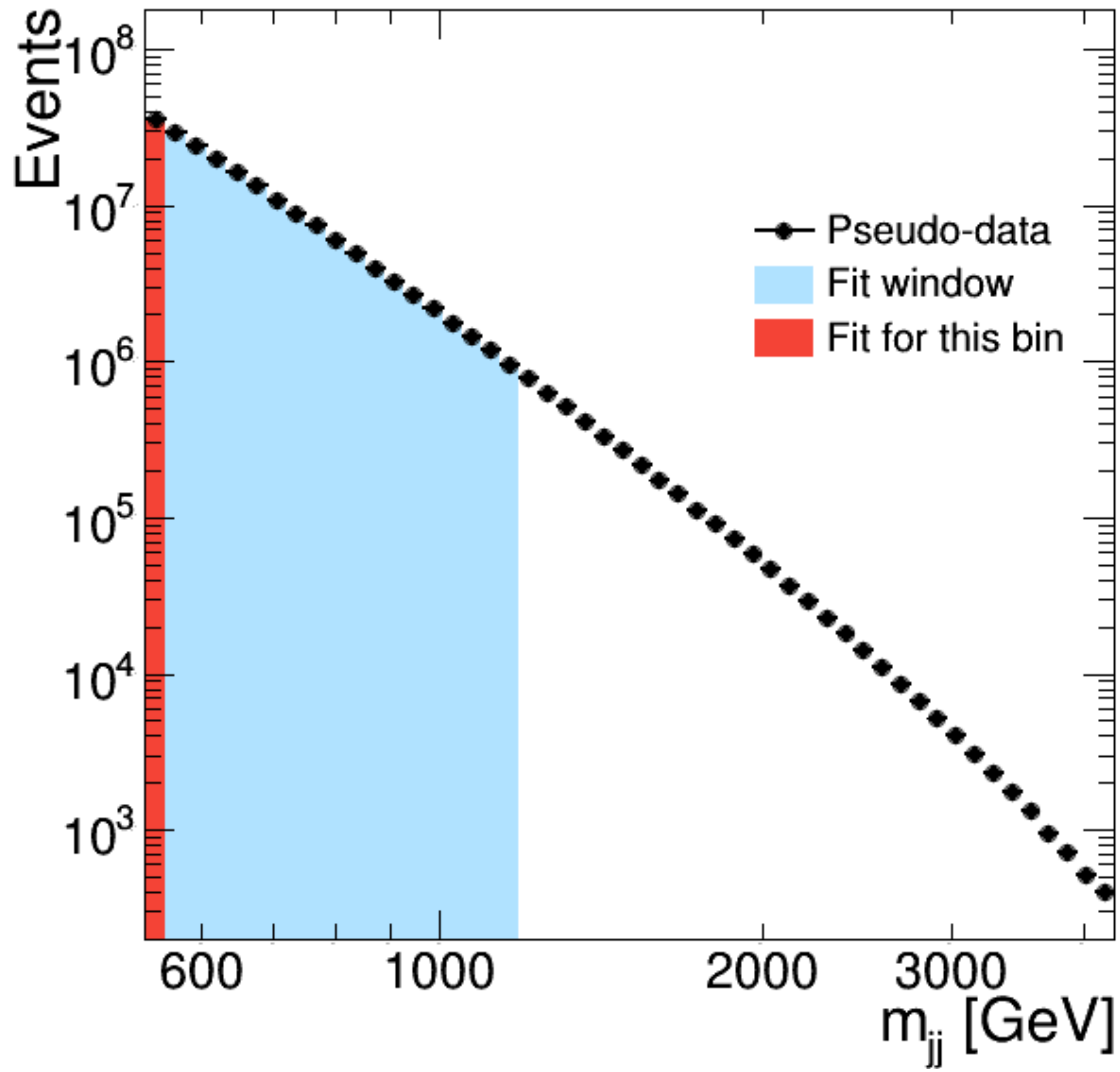
TLA trigger jet calibration



Excellent trigger : offline agreement

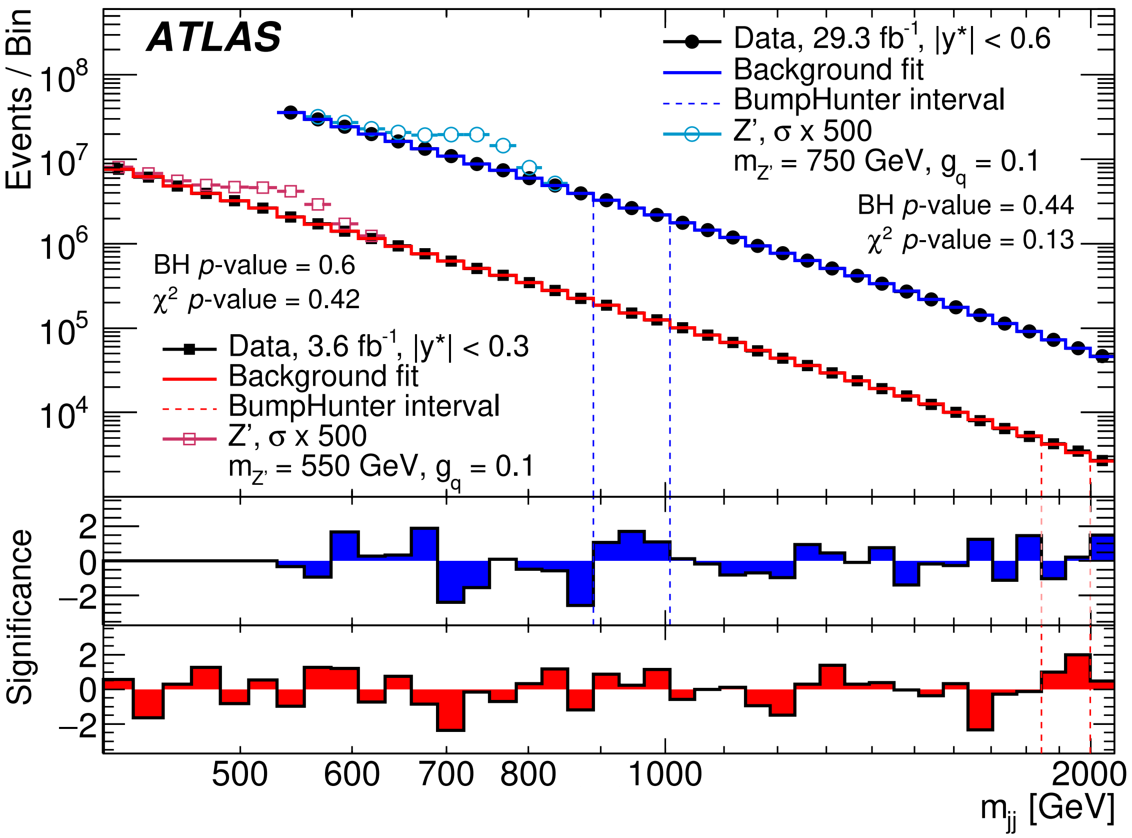
Fitting

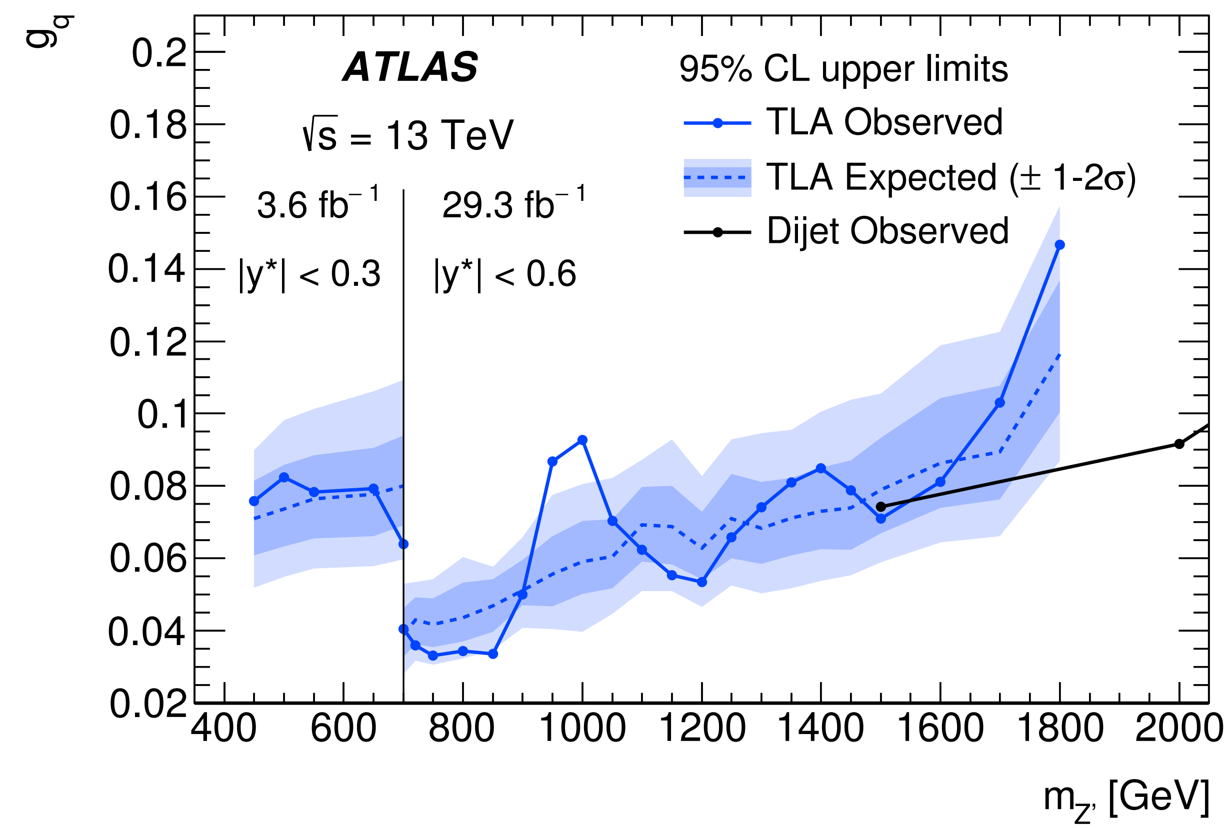
- Very large number of events -> very little scope for QCD to deviate from functional form
- Could not fit whole mjj range with a single parameterisation
- Solution: fit sub-ranges



End result

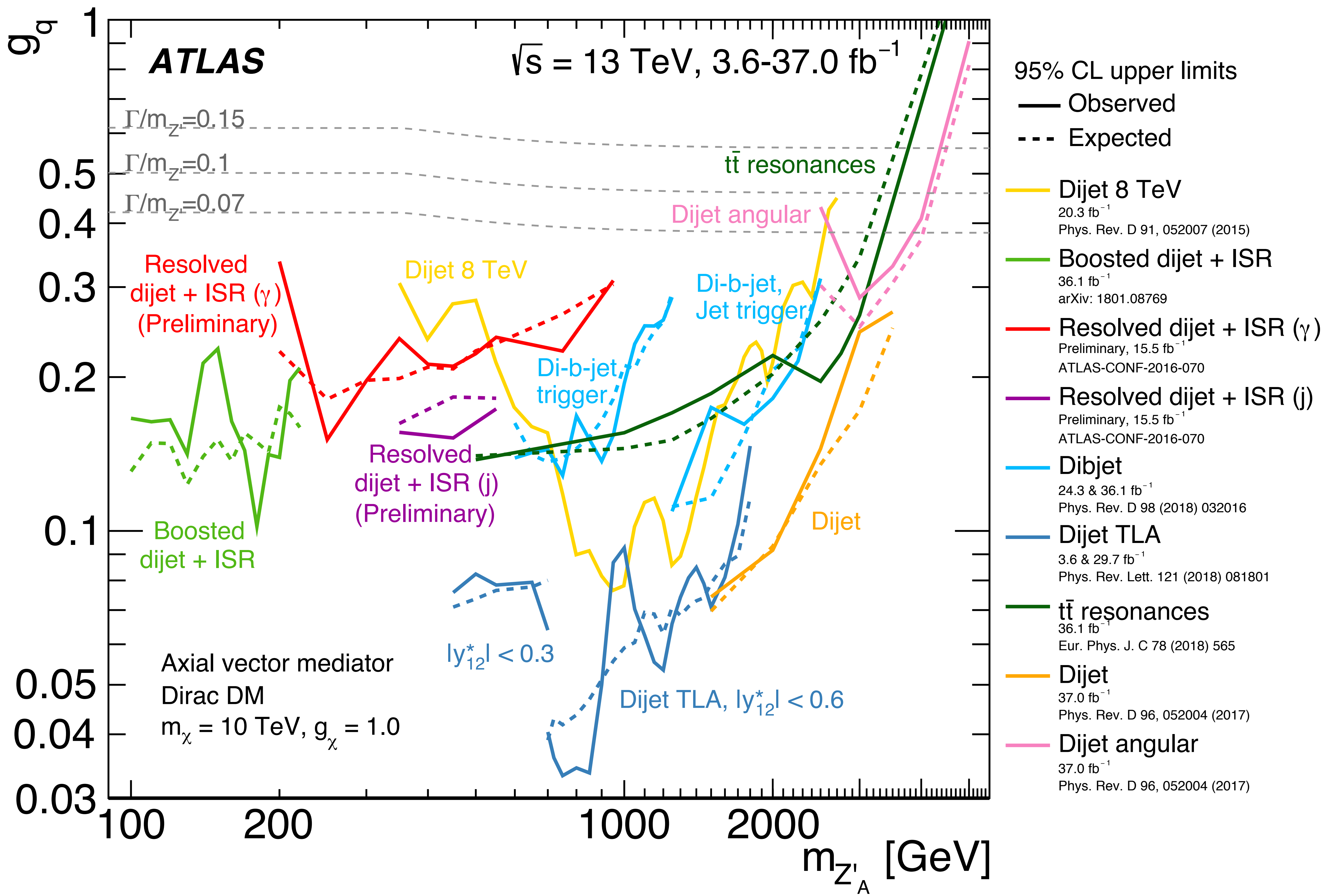
- Similar sensitivity to conventional dijet resonance search at 1.5 TeV
- Can go much lower in $m_{Z'}$
  - 450-700 GeV using dedicated signal region with L1_J75 for some of 2016





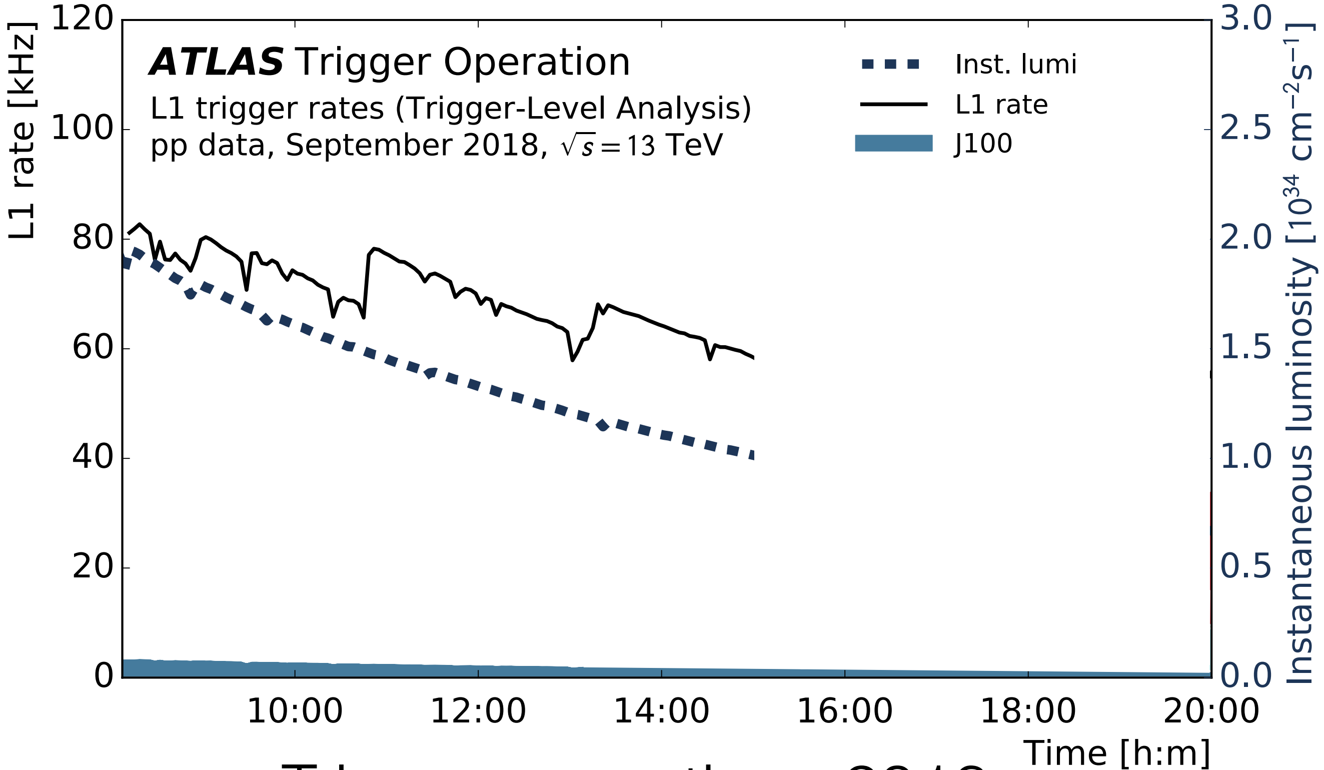
End result

arxiv: 1903.01400



Rest of run 2

- TLA is not a license to ~~print money~~ write out everything
- Most significant limitation is the total L1 rate
- However, this falls significantly over a fill as instantaneous luminosity decreases
- Limited scope for utilisation by other triggers, since they remain bound by the total bandwidth averaged over the fill



Trigger operations 2018

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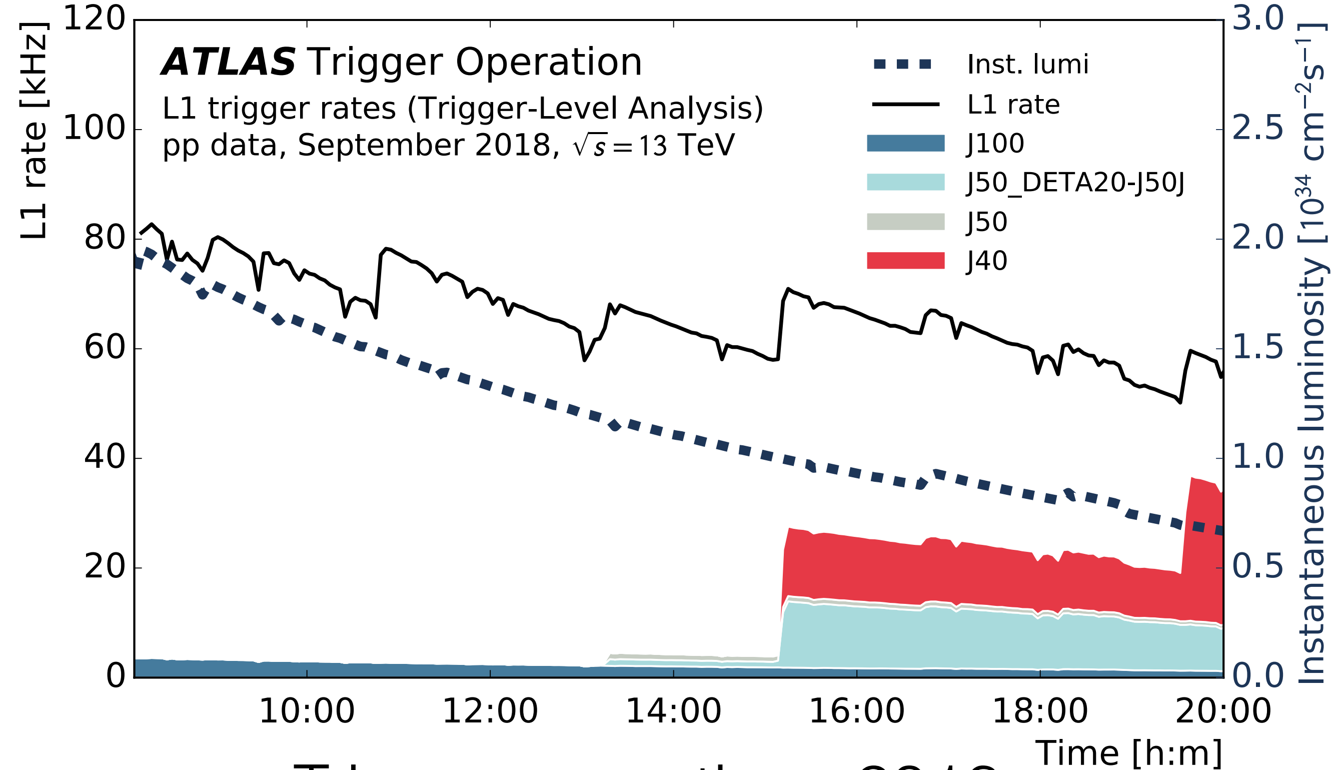

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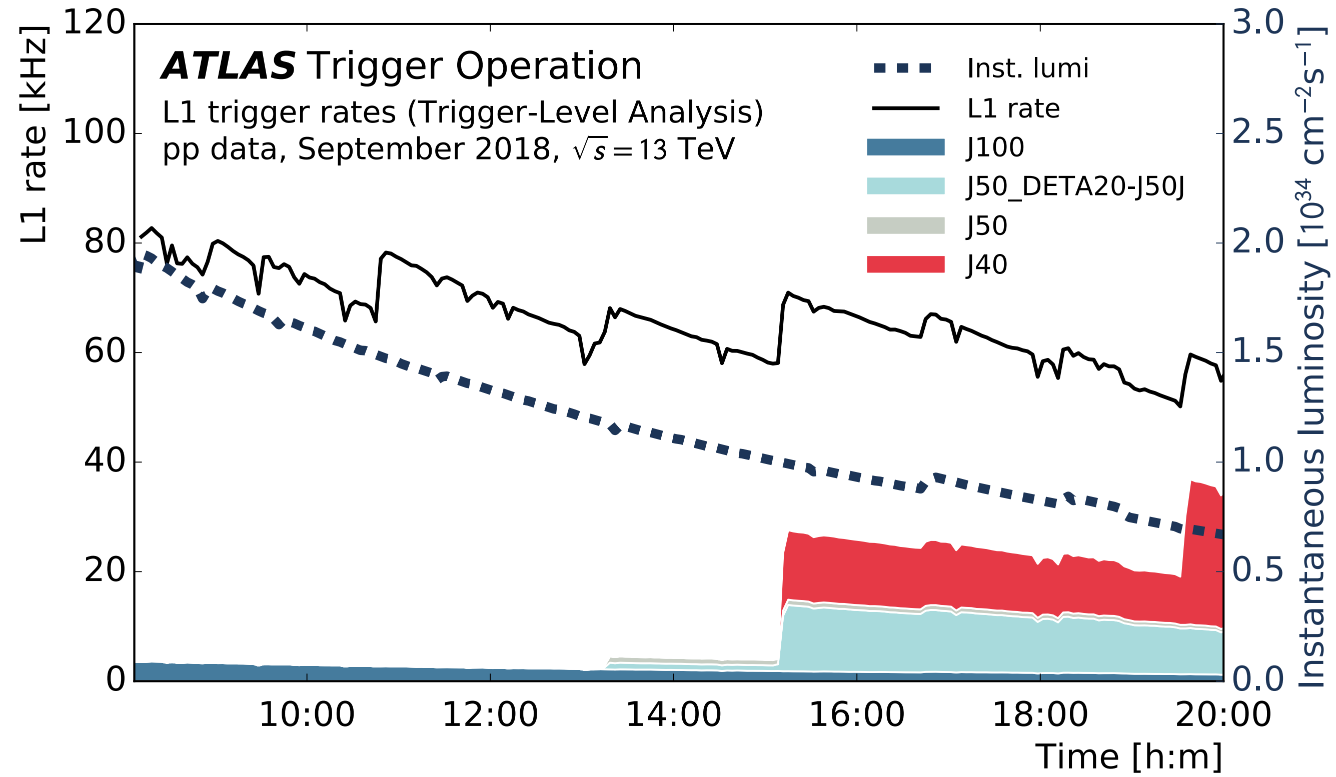
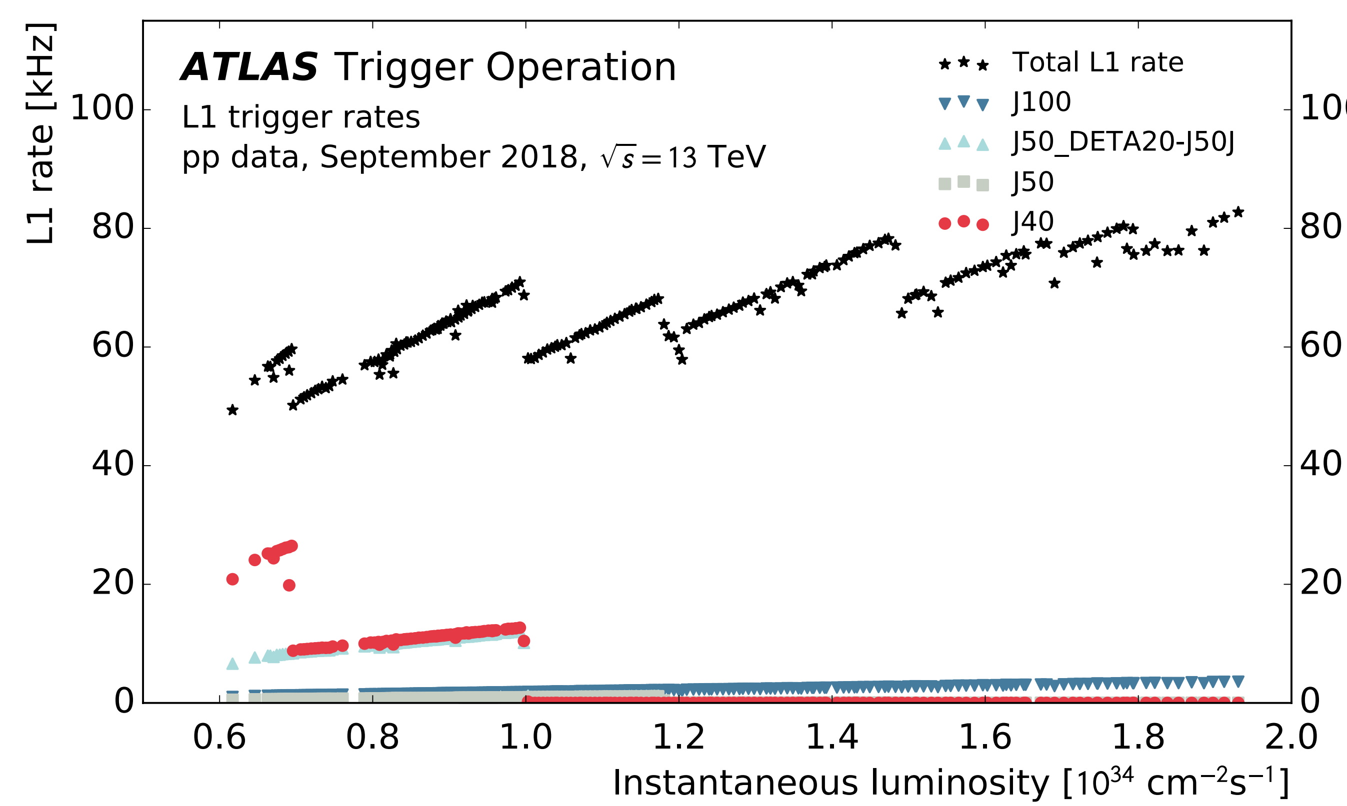


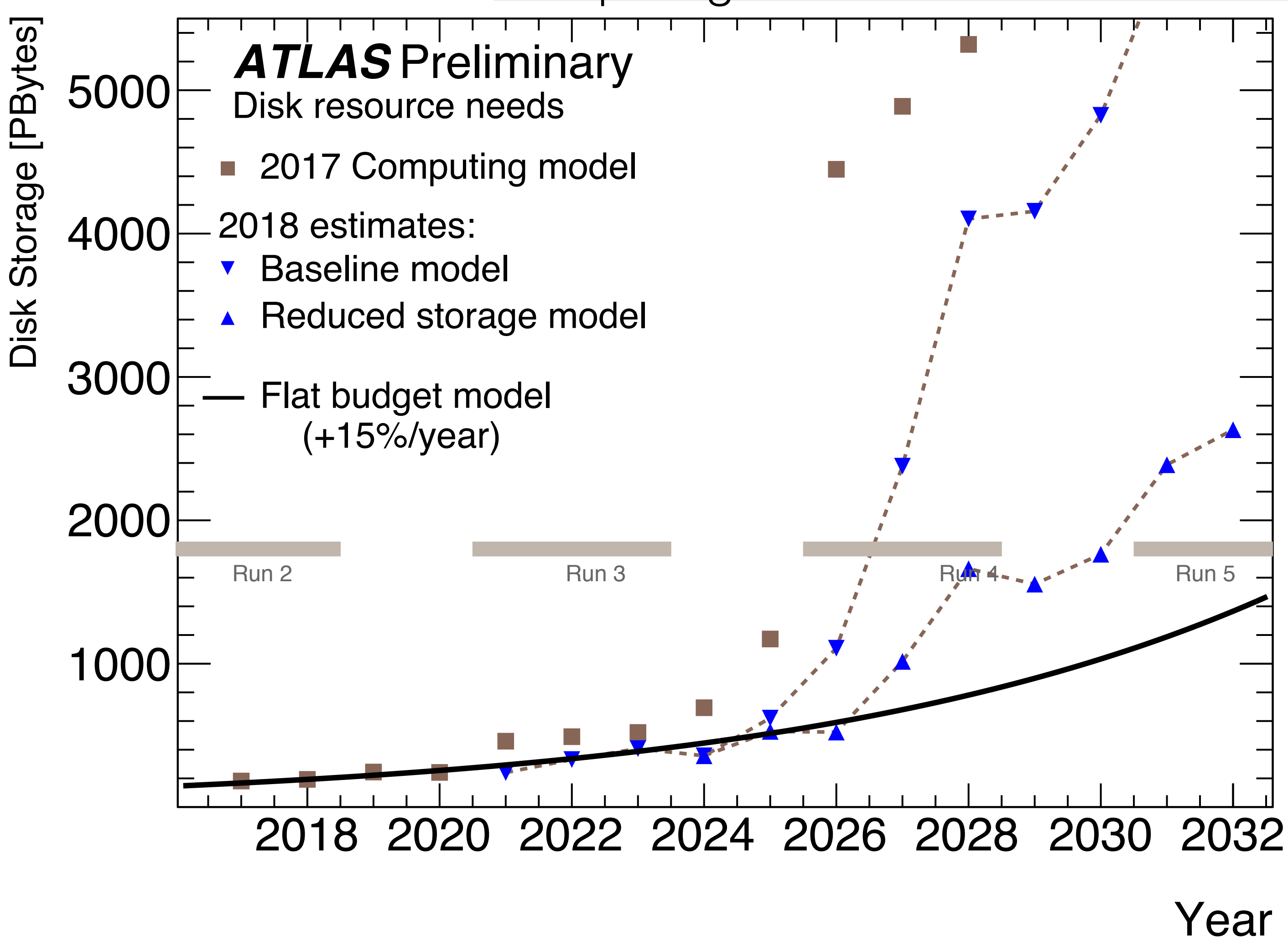
Trigger operations 2018



Beyond

- Various trigger hardware and software improvements under development and installation: FTK, e/j/gFex, NSW
- Will likely run at higher instantaneous luminosity on average than in run 2
- Storage pressures will remain and likely worsen
- Run 2 was the “proof of concept”, Run 3 can be “full commissioning” (with a large helping of interesting physics!) to prepare for the step-change of Run 4 when radical solutions might be necessary

ComputingandSoftwarePublicResults



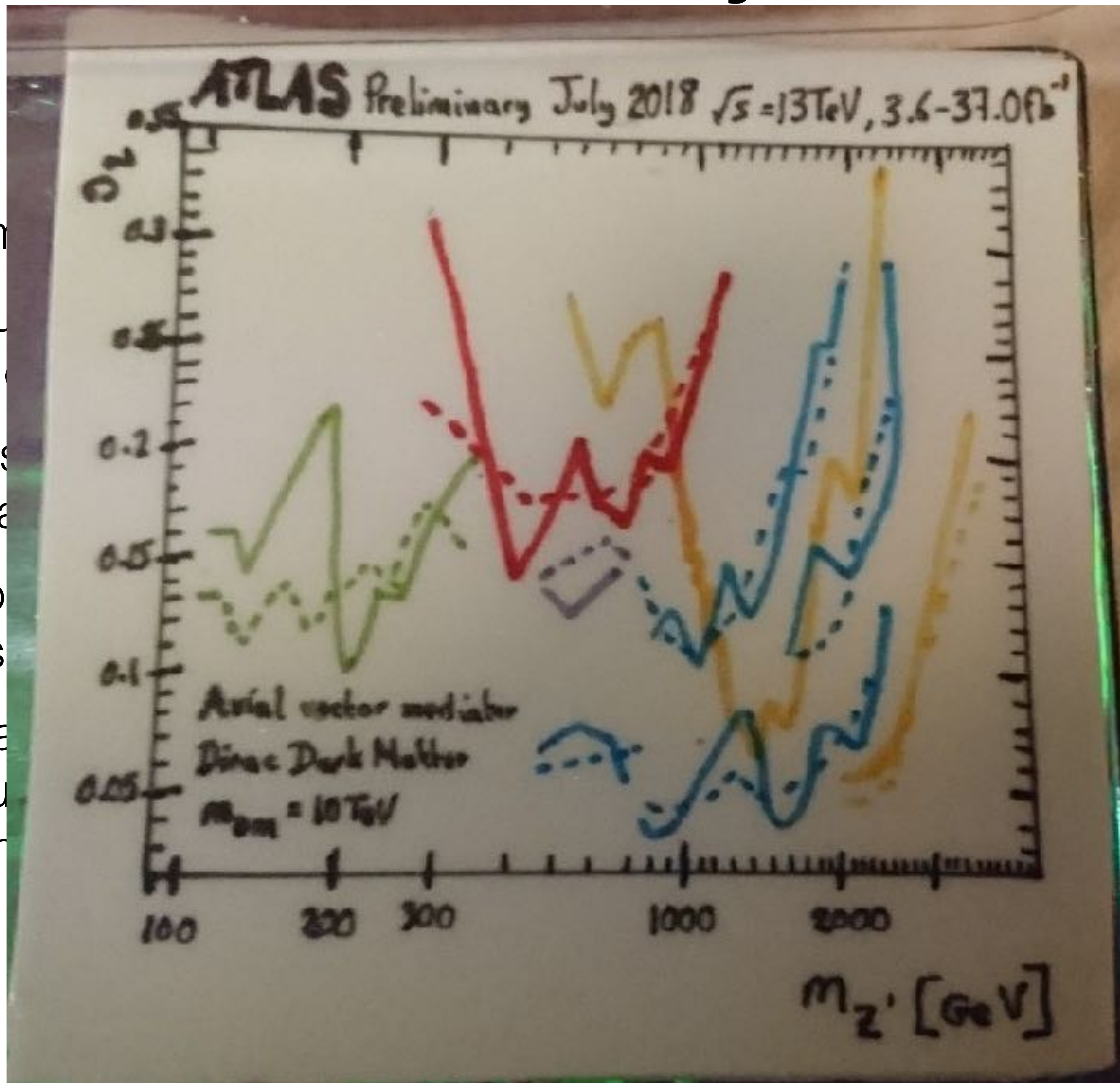
White paper

- Details on future outlook to be found in ATL-DAQ-PUB-2017-003, a complement to the HEP Community White Paper on Software trigger and event reconstruction
- New L1 hardware (jFex, gFex)
  - Expect improved L1 performance -> lower rate for TLAs
  - Possibility for TLAs to be performed with L1 objects - histograms filled at 30 MHz!
- New “L1.5” hardware (FTK (run 3), HTT and HGTD (beyond))
  - Tracking or timing information for the majority of trigger jets -> pile-up suppression and reduction of quark/gluon response differences
  - Potential to expand TLA beyond jets for dijet resonance searches (do more with jets, record more than just jets)
- Some possibilities to do some jet calibration with TLAs
  - Improved HLT calibration, equalising the response of central and forward jets

Summary

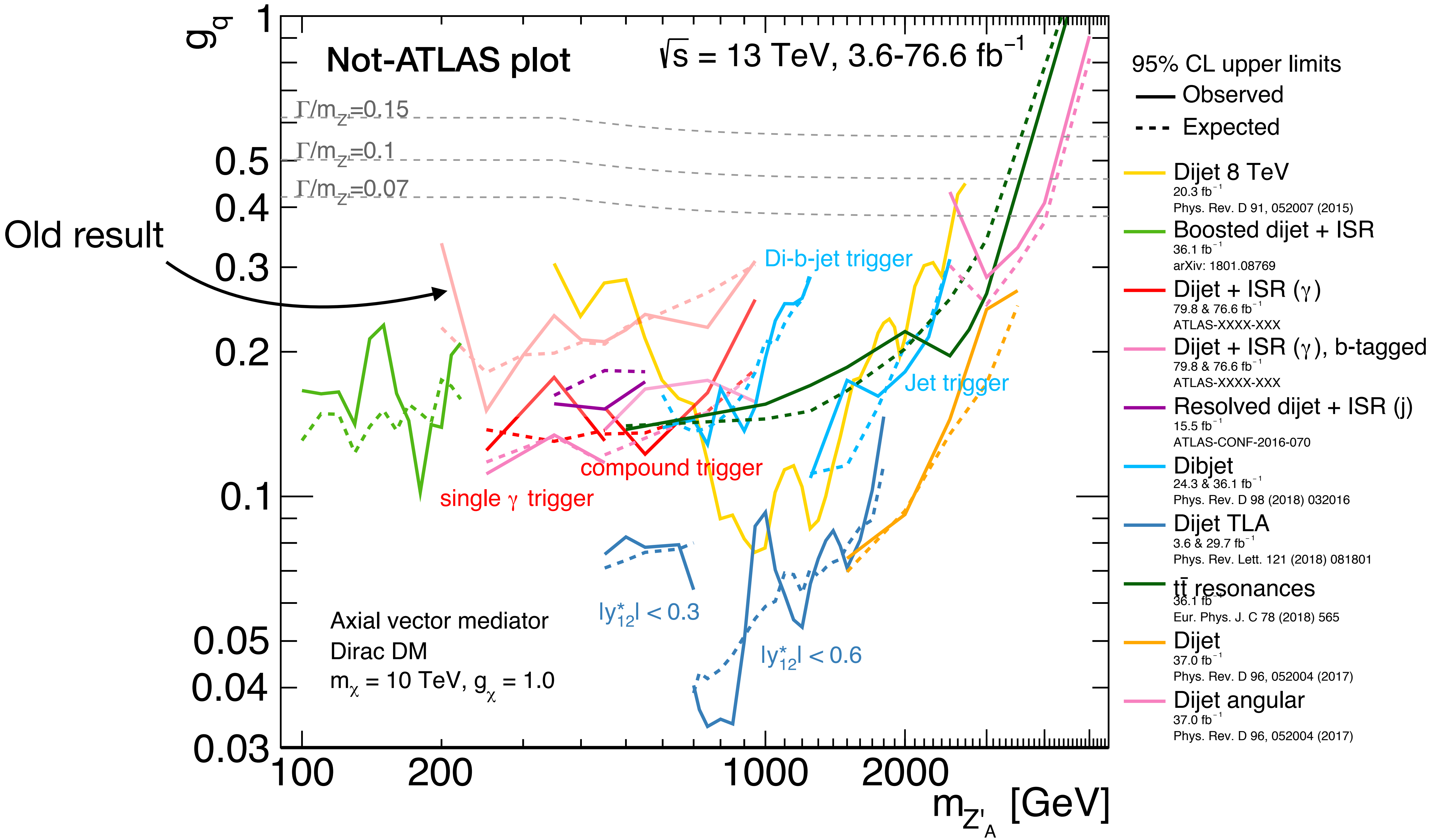
- Trigger systems are a crucial part of high-energy physics experiments: they decide what data we record for analysis
- Continuous improvements of these triggers are key to keeping pace with energy and instantaneous luminosity increases at the LHC
- HLT jets can be used for analysis below trigger thresholds through use of a special data stream
- This comes with several challenges, but they’ve been overcome successfully
- Hardware and software upgrades over LS2 have the potential to lead to a much more capable trigger system, and a wider set of trigger-level analyses, in run 3: we’ve got 1.5 years to make it happen :-)

Summary



- Trigger … experim…
- Continu… ng pace with en… HC
- HLT jets … rough use of a…
- This co… ome succes…
- Hardwa… al to lead to a mu… rigger-level ar… en :-)

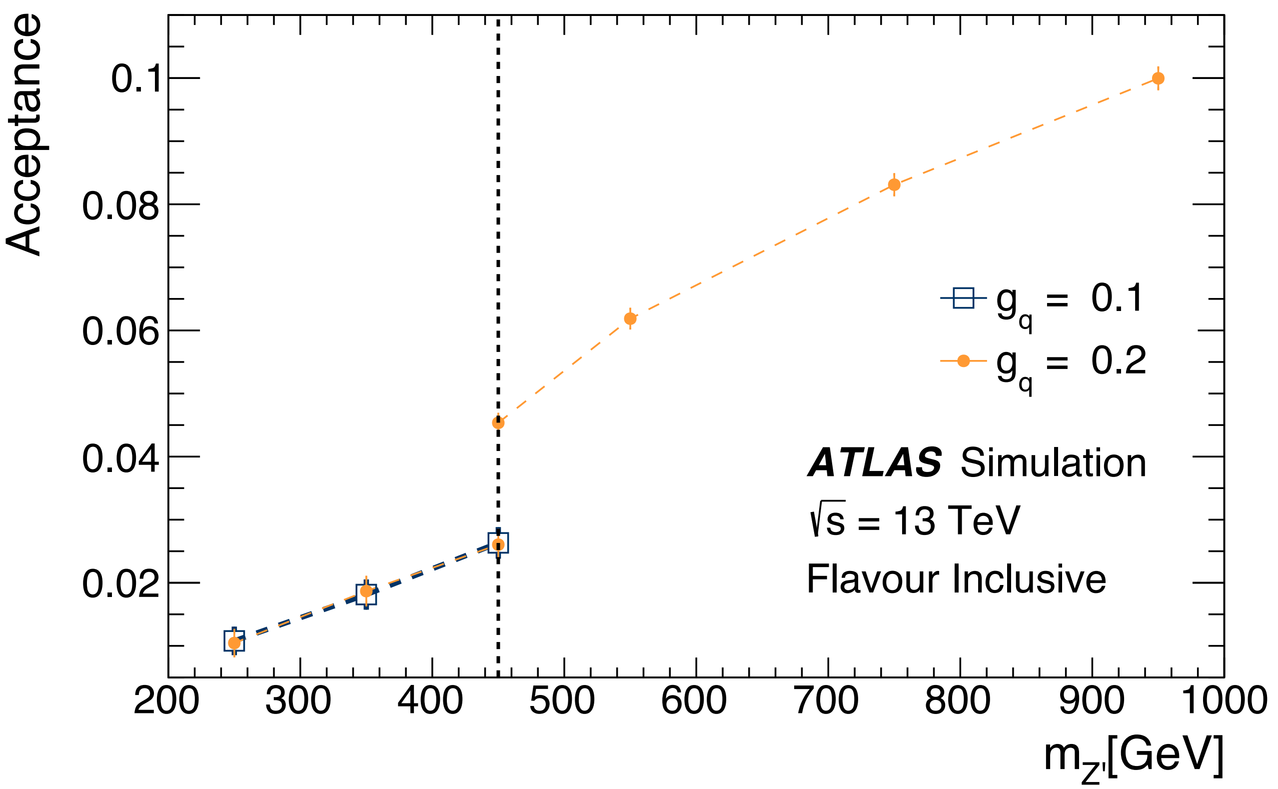
Dijet + ISR

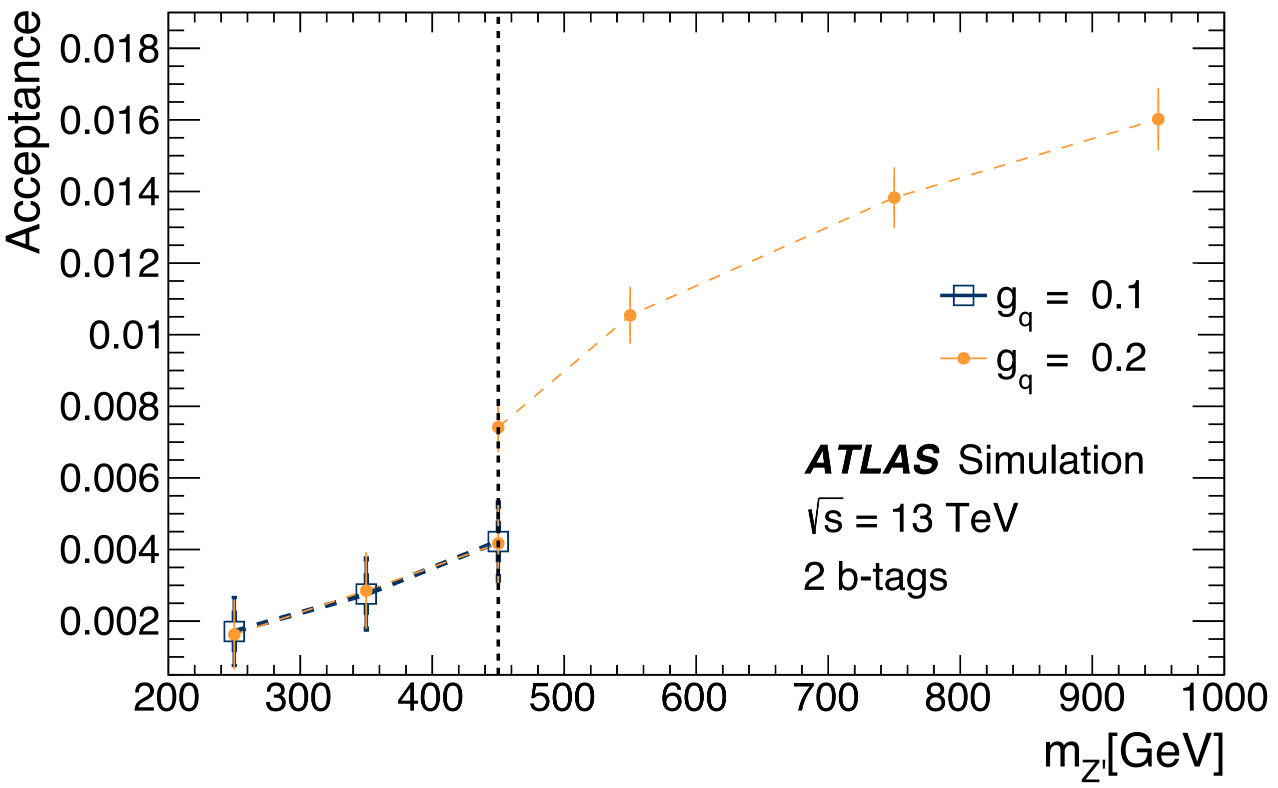


- New result submitted in January, updating photon ISR channel
- Interesting interplay between b-tagged and inclusive

Dijet + ISR

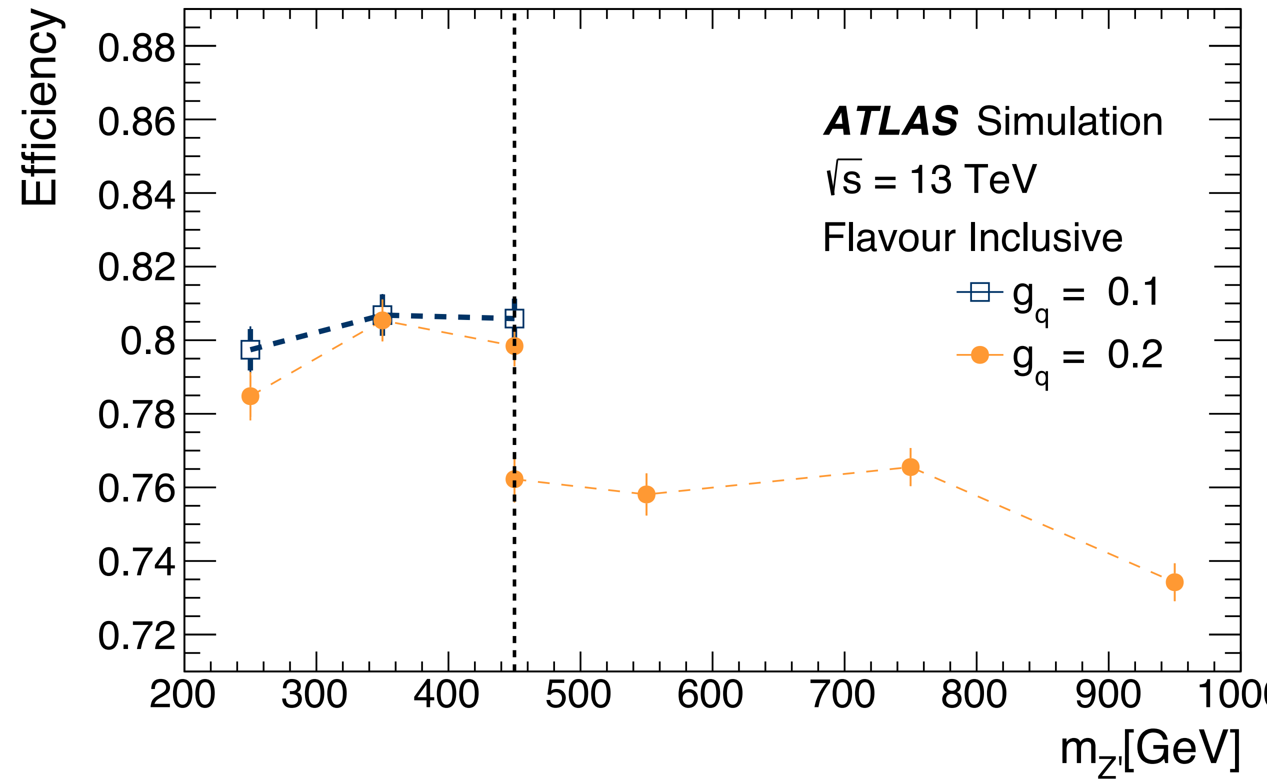
- Sensitivity ~ S/sqrt(B)
- $S_b = S_i/6$
- $B_b << B_i/6$



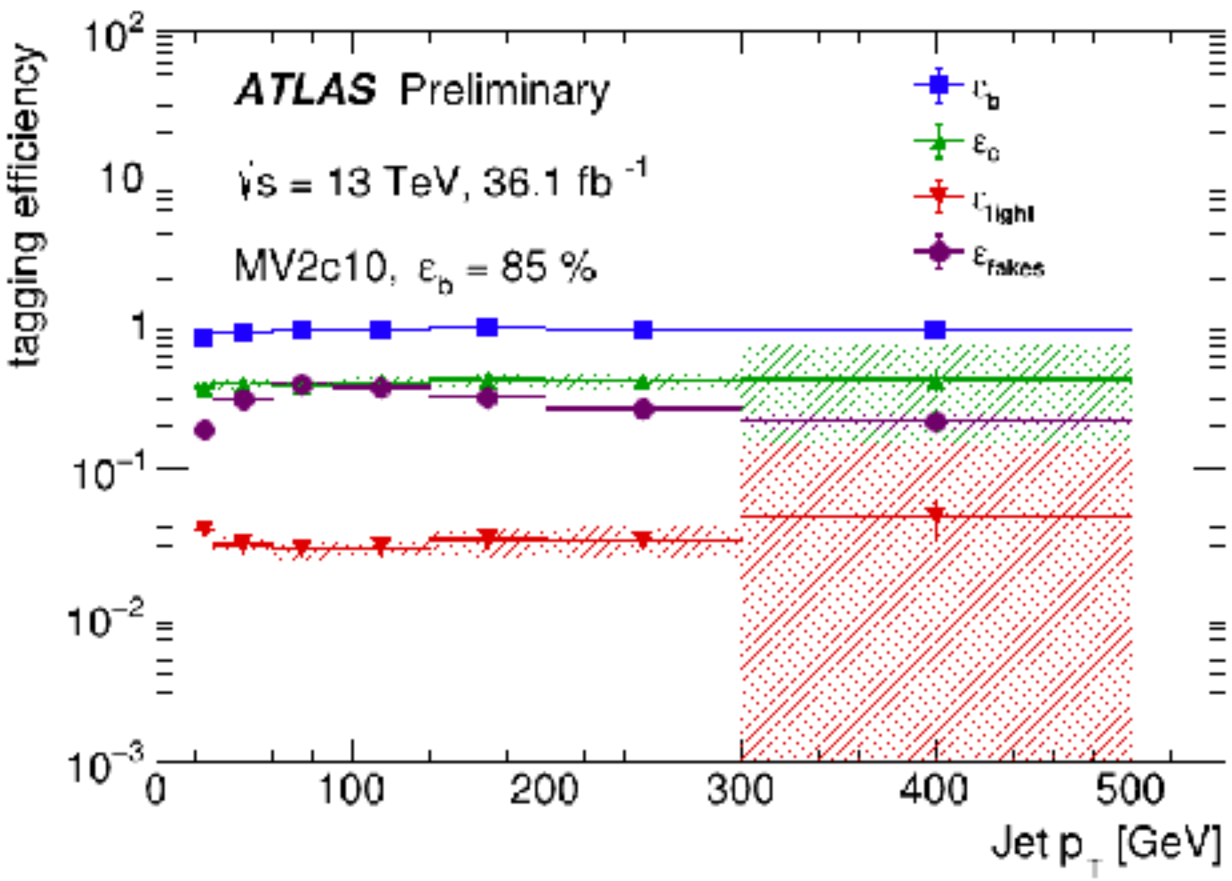


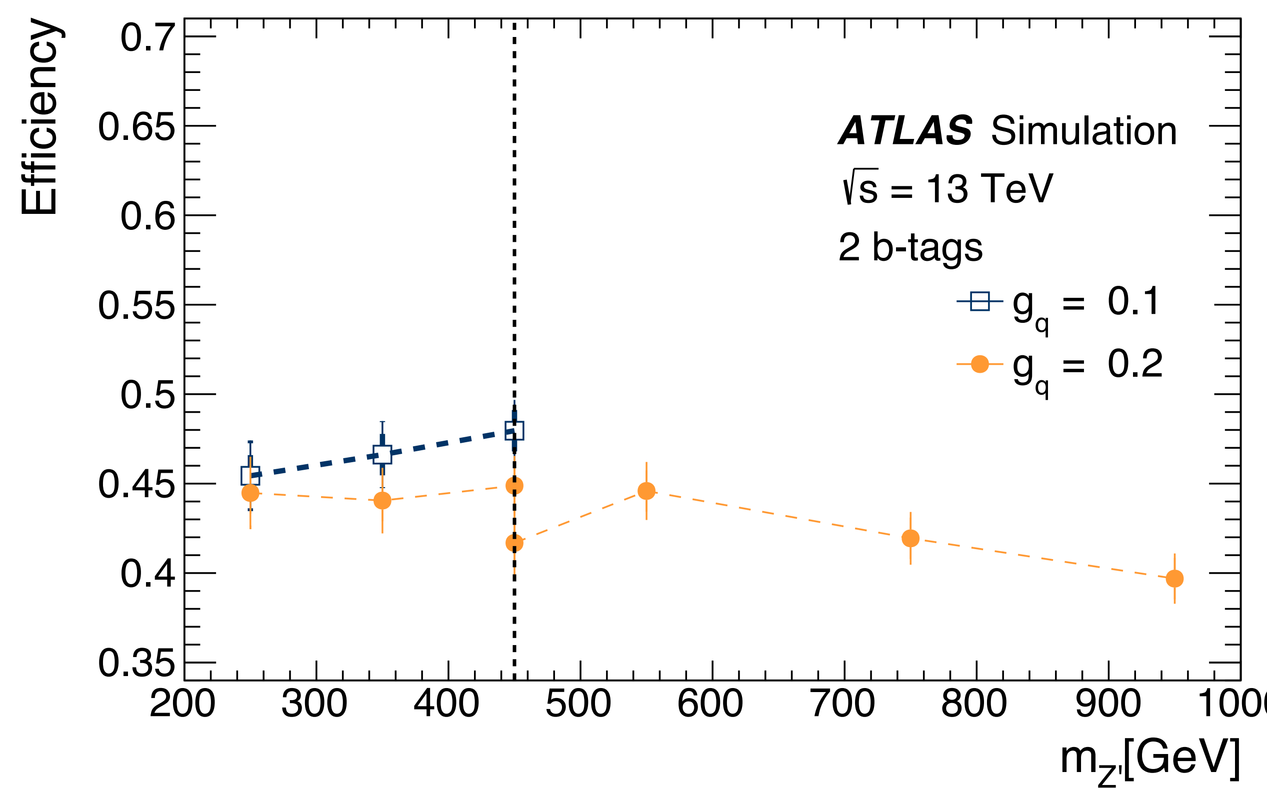
Dijet + ISR

- Modified by b-tagging efficiency (reduces S_b) and light- and charm-jet mistagging rate (increases B_b)
- These are p_T dependent -> impact varies across $m_{Z'}$

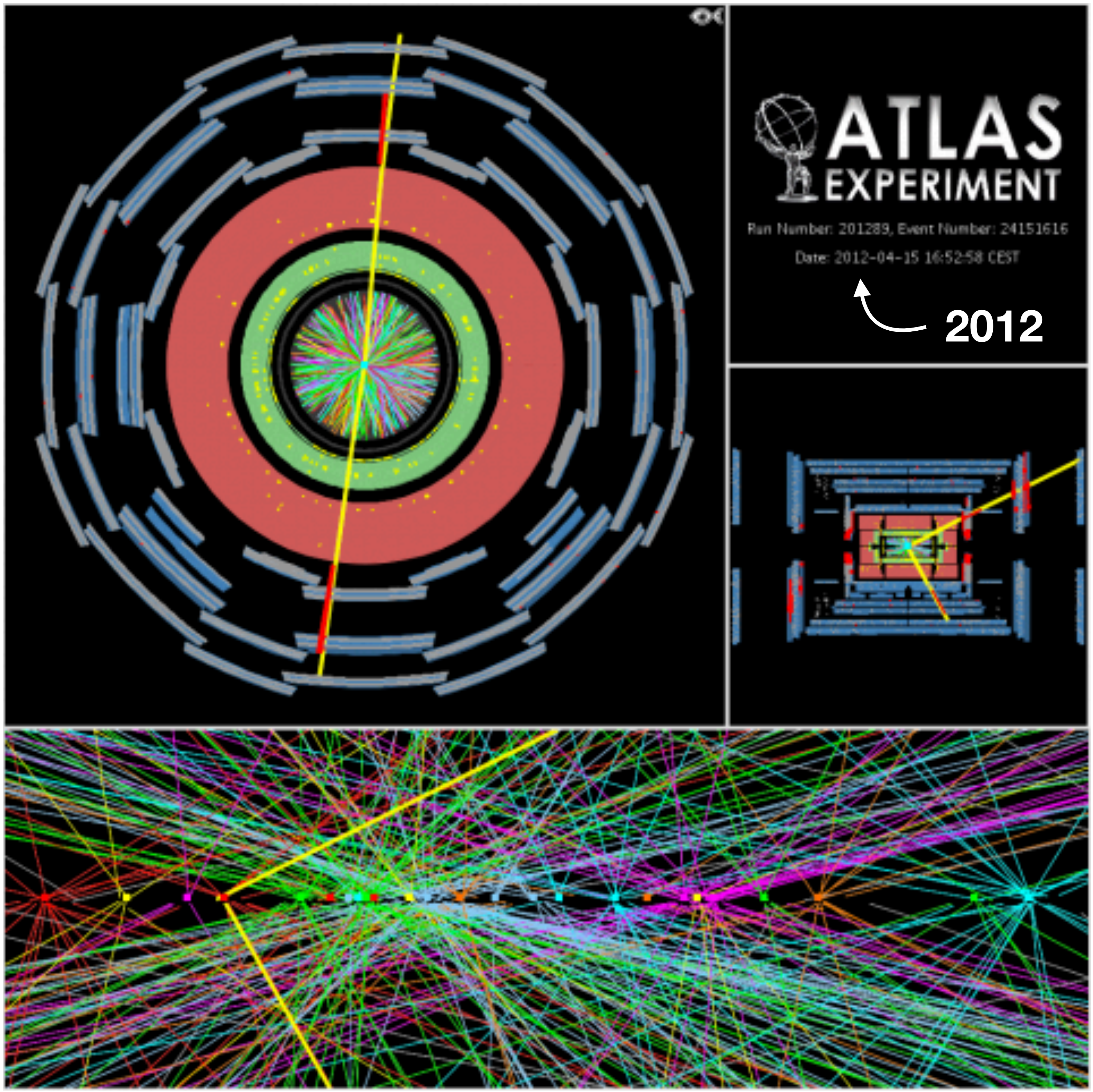


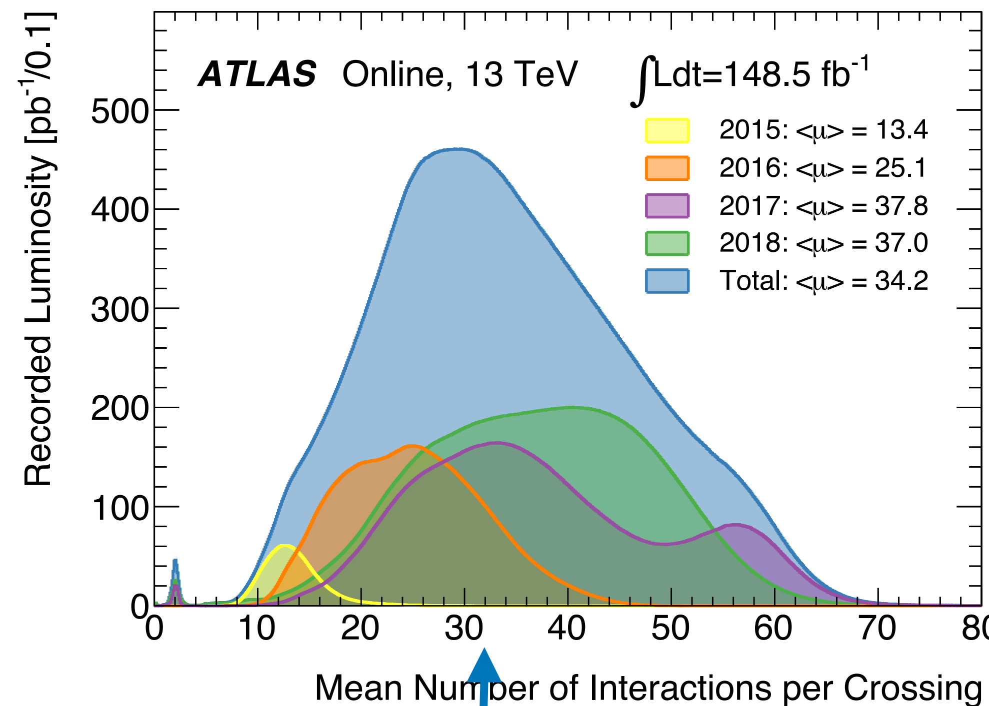
ATLAS-CONF-2018-045





Looking for nothing - inside rather a lot





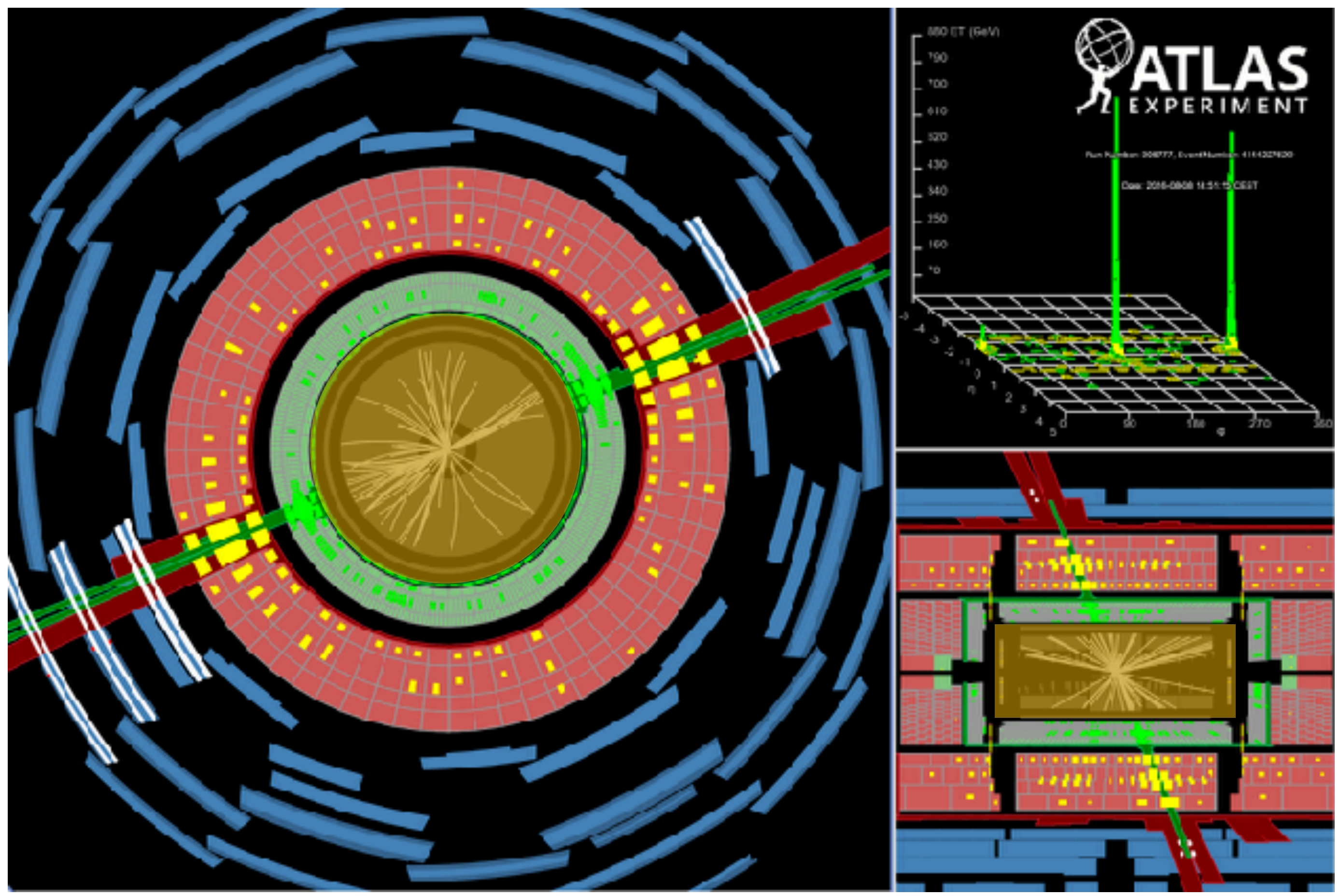
ATLAS

Inner detector

- Si pixels and strips and gas straws
- measures tracks left by charged particles
- reject pileup
- correct origin of jet

Muon system

- Various technologies
- Track charged particles escaping calorimeter
- Corrections to high-energy jets



EM calorimeter

- Liquid Ar / lead
- EM energy absorption
- Part of jet energy - primarily charged hadrons

Hadronic calorimeter

- Steel / scintillator
- Hadronic energy absorption
- Part of jet energy - neutrals and remaining charged

ATLAS

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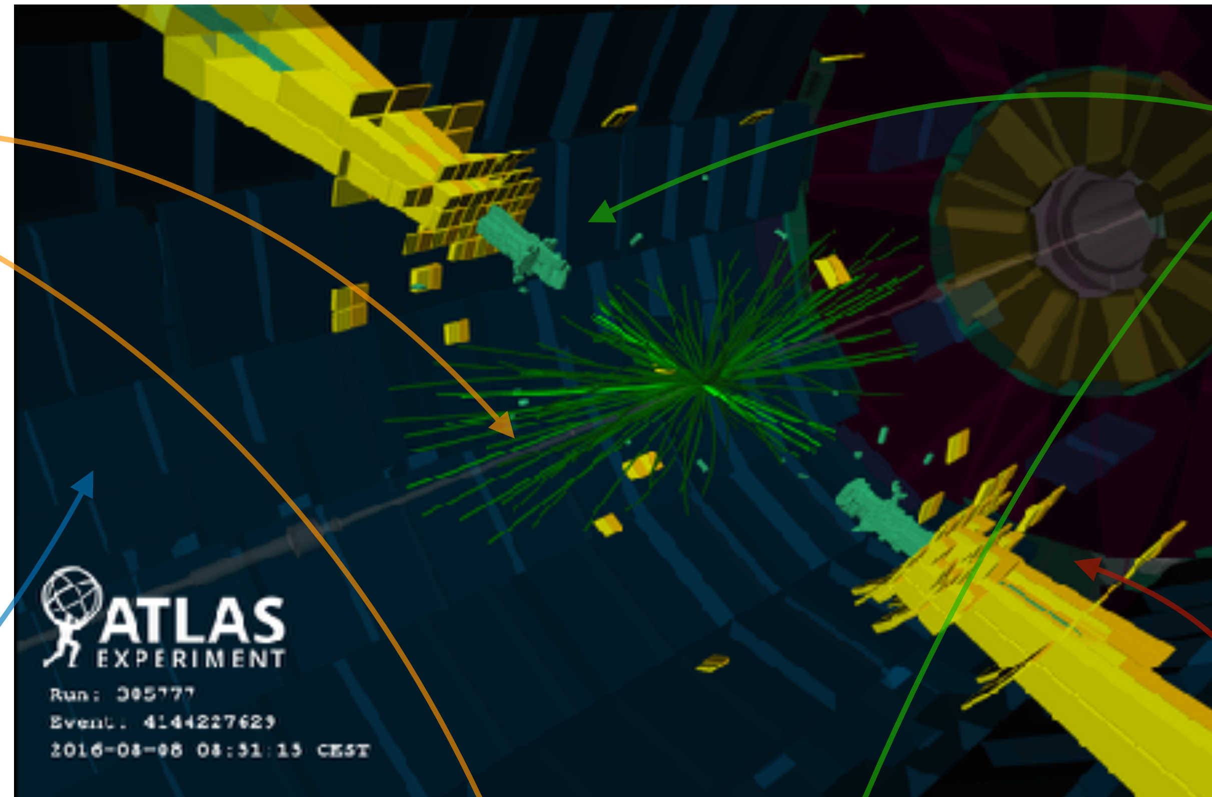

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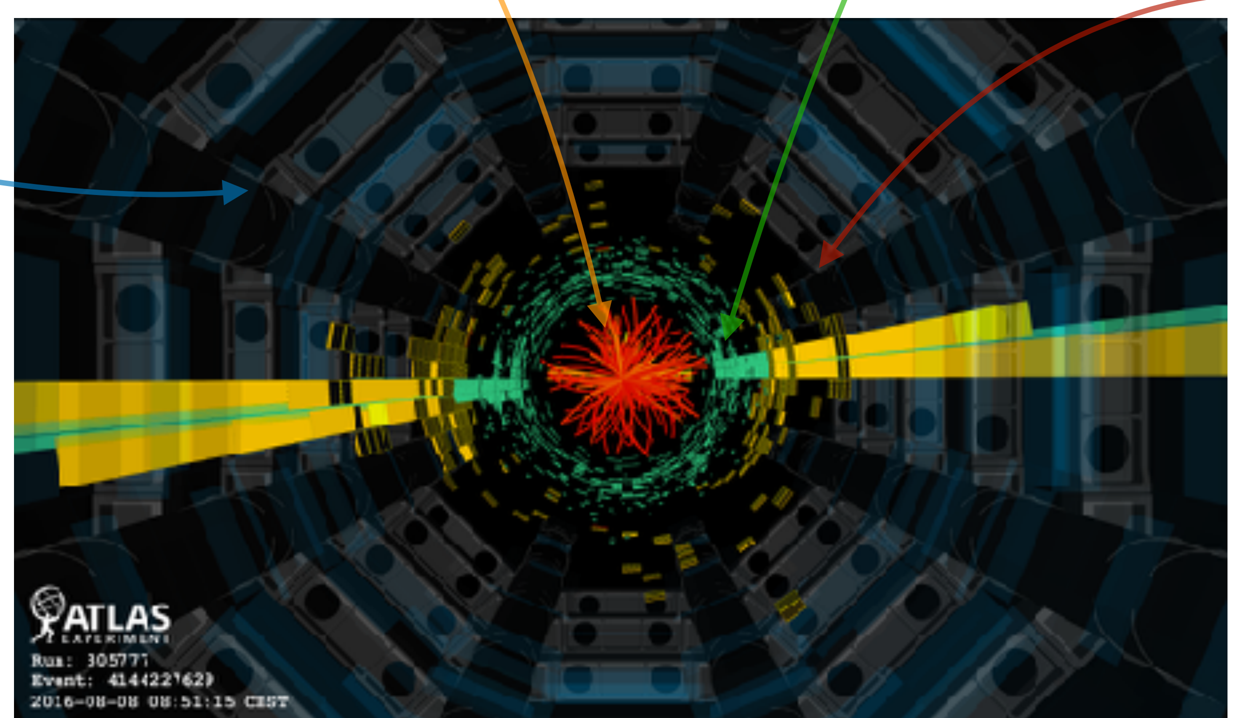


Hadronic calorimeter
- Steel / scintillator
- Hadronic energy absorption
- Part of jet energy - neutrals and remaining charged

Topoclustering

Topo-cluster Formation

Peter Loch
UAPhysics
THE UNIVERSITY OF ARIZONA
College of Science

Calorimeter cell signals are collected into topological clusters

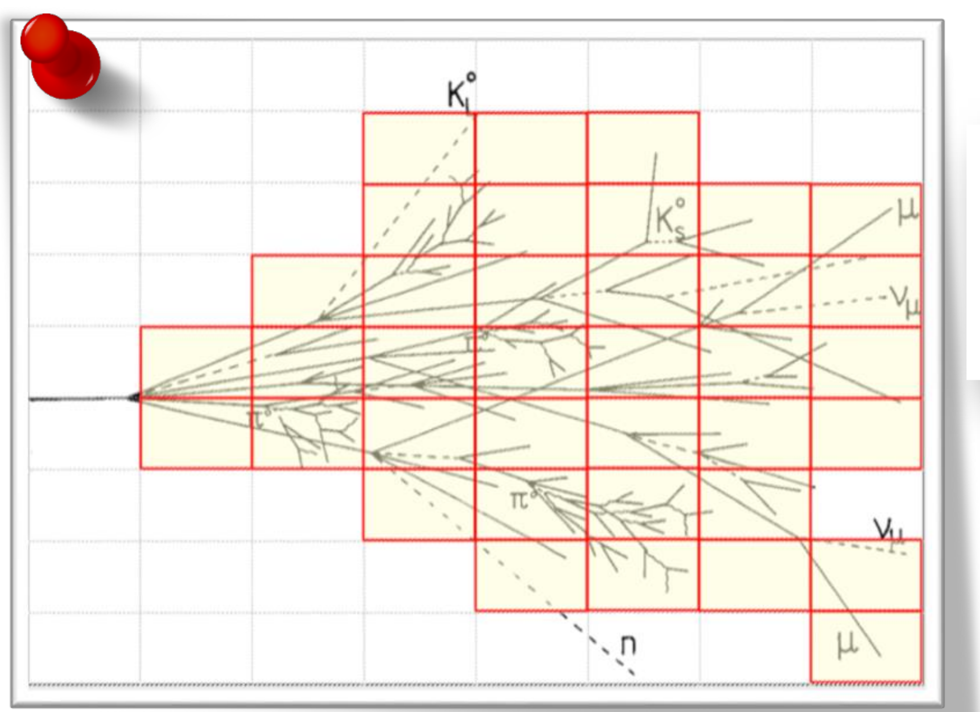
Collects signals from individual or close-by particles into 3-dim *energy blobs*

- Connect cell signals following spatial signal significance patterns using seed and growth control, + envelope
- Default 4-2-0 configuration ($S = 4$, $N = 2$, $P = 0$)

$$\left|E_{\text{cell}}^{\text{EM}}\right| > S\,\sigma_{\text{noise,cell}}^{\text{EM}}$$

$$\left|E_{\text{cell}}^{\text{EM}}\right| > N\sigma_{\text{noise,cell}}^{\text{EM}}$$

$$\left|E_{\text{cell}}^{\text{EM}}\right| > P\sigma_{\text{noise,cell}}^{\text{EM}}$$



$$\sigma_{\text{noise}} = \begin{cases} \sigma_{\text{noise}}^{\text{electronic}} & < 2011 \\ \sqrt{\left(\sigma_{\text{noise}}^{\text{electronic}}\right)^2 + \left(\sigma_{\text{noise}}^{\text{pile-up}}\right)^2} & \end{cases}$$

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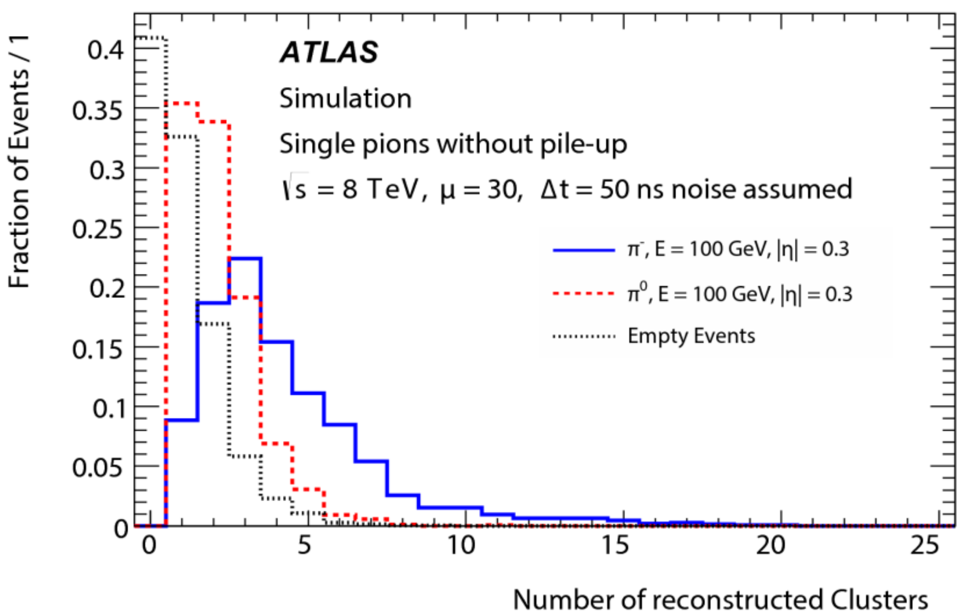
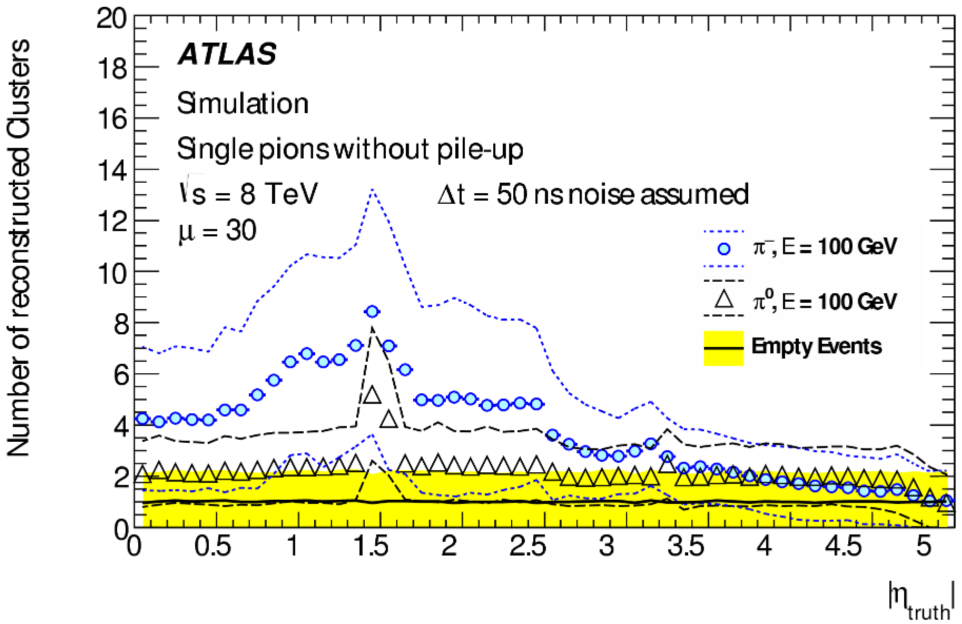
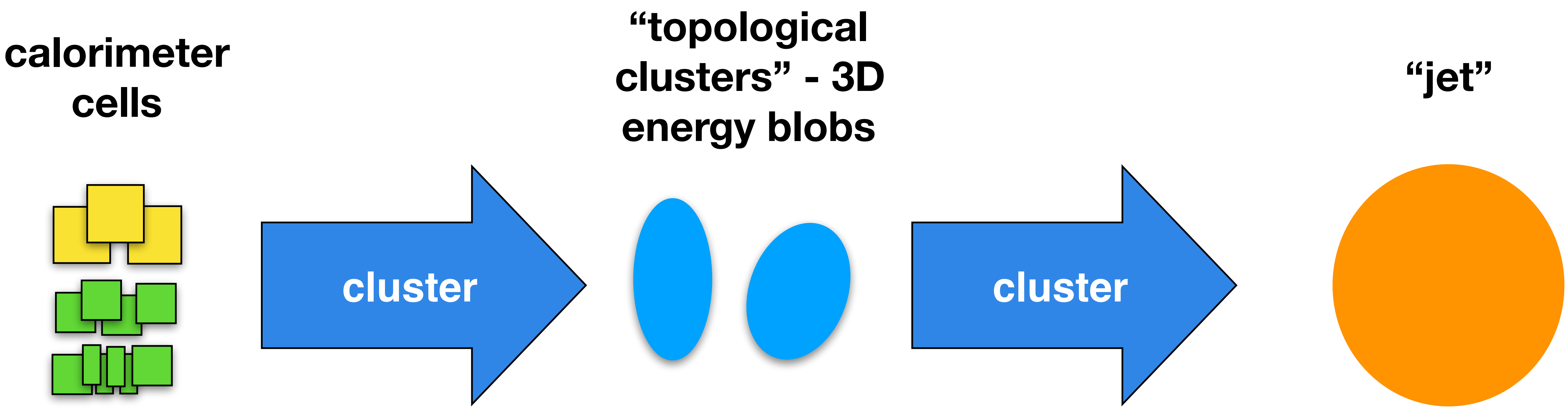
  - Connect cell signals following spatial signal significance patterns using seed and growth control, + envelope
  - Default 4-2-0 configuration ($S = 4$, $N = 2$, $P = 0$)
- Applies splitting between local signal maxima
  - Splitting typically guided by high granularity (EM) calorimeter
  - EM showers typically generate one cluster – compact shower development
  - Hadronic showers can generate more than one cluster – macroscopic distances between inelastic interactions





Jet reconstruction



- Seed from cells with S/N > 4
- Grow with cells S/N > 2
- Split local maxima (EM calorimeter)

- Sequentially merge topoclusters
- Start from highest E_T
- Size controlled by 'radius' parameter, $\Delta R = \Delta\eta \oplus \Delta\phi = 0.4$
- End with a 2D object - ~ circular in η-ϕ (except when touch)

Jet calibration

- Built from raw energy recorded by calorimeter
- **sampling** calorimeters -> don't record all the energy
- Also have energy deposits from other p-p collisions in same event

Jet calibration

jet → Origin correction → Jet area-based pile-up correction → Residual pile-up correction

Origin correction: *Changes the jet direction to point to the hard-scatter vertex. Does not affect E.*

Jet area-based pile-up correction: *Applied as a function of event pile-up p_T density and jet area.*

Residual pile-up correction: *Removes residual pile-up dependence, as a function of μ and N_{PV}.*

- Built from raw energy recorded by calorimeter
- **sampling** calorimeters -> don't record all the energy
- Also have energy deposits from other p-p collisions in same event

look at average p_T density of event in the calorimeter, subtract this approximated pileup contribution

Jet calibration

jet → **Origin correction** → **Jet area-based pile-up correction** → **Residual pile-up correction**

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→ **Absolute MC-based calibration** → **Global sequential calibration** → **Residual *in situ* calibration**

Absolute MC-based calibration: *Corrects jet 4-momentum to the particle-level energy scale. Both the energy and direction are calibrated.*

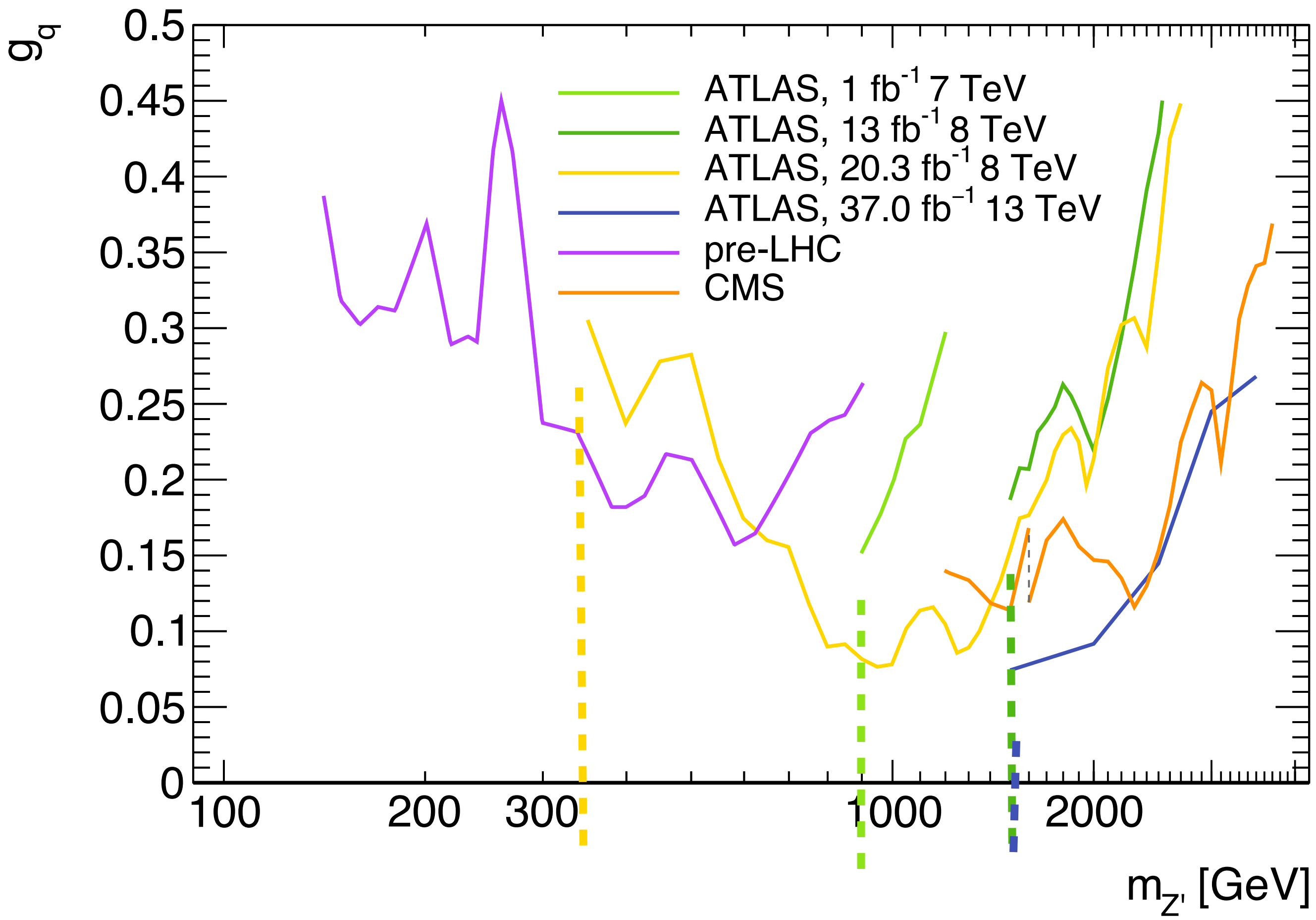
Global sequential calibration: *Reduces flavor dependence and energy leakage effects using calorimeter, track, and muon-segment variables.*

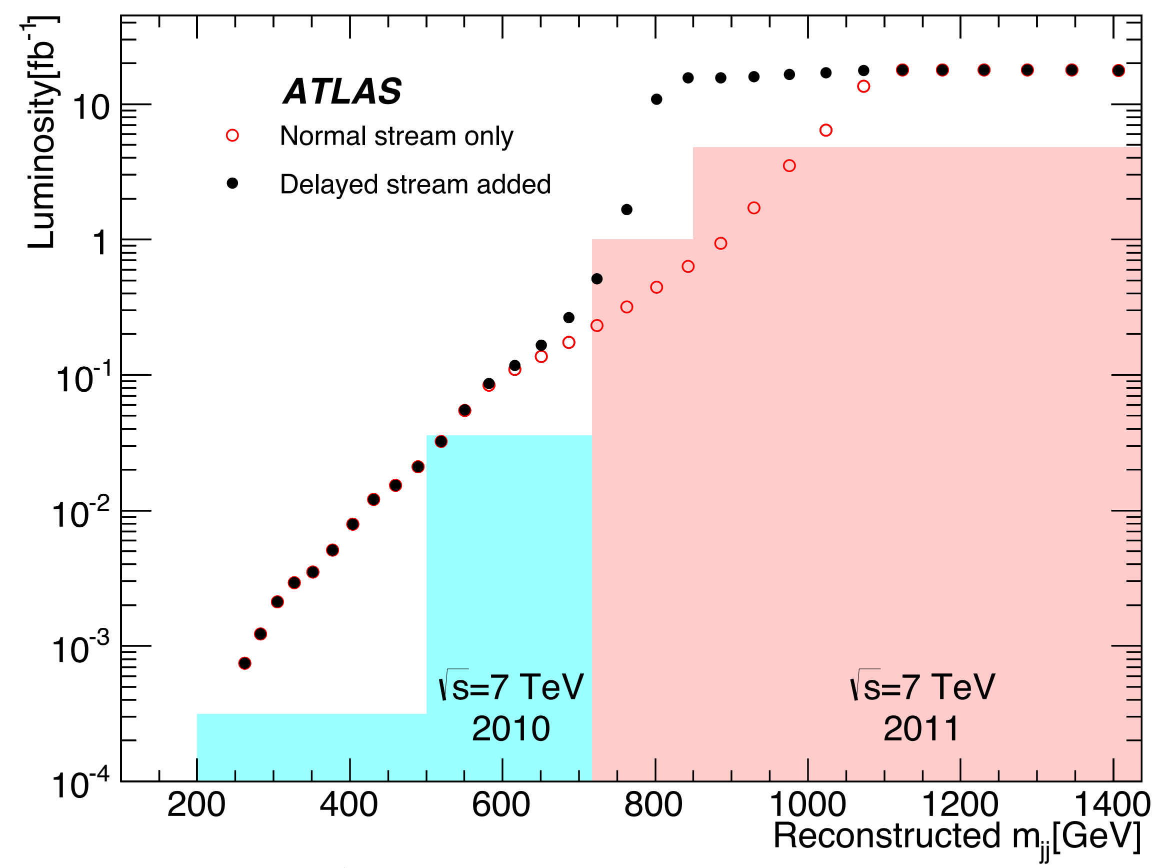
Residual *in situ* calibration: *A residual calibration is derived using in situ measurements and is applied **only to data**.*

at this point, have only discriminated based on event pileup and jet origin, η and p_T. We have more information than this!

final corrections to get back to "truth" scale

8 TeV 20.3 fb^{-1} triggers





prescaled single jet triggers plus delayed stream

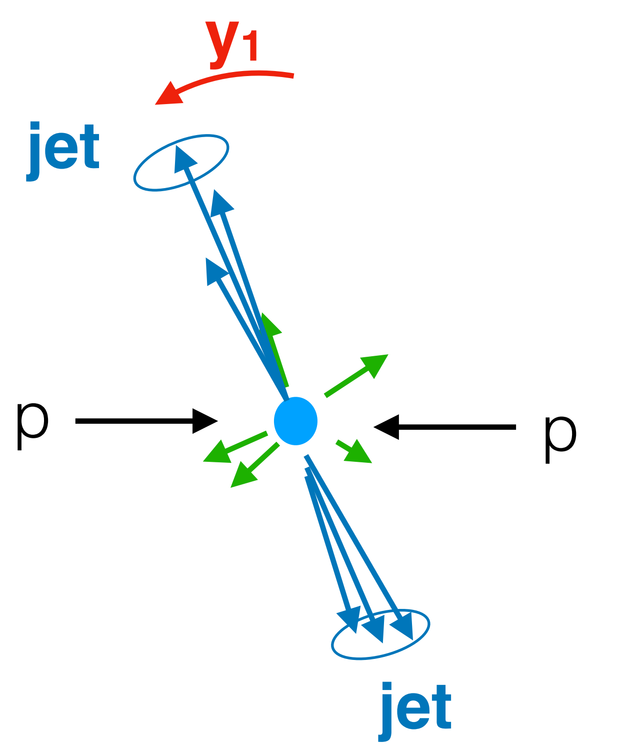
Analysis	L / 10^{34} cm^{-2}	trigger threhsold	offline cut	mjj start
1 fb^{-1} 7 TeV 2011	~1	180	~300	717
13 fb^{-1} 8 TeV 2012	~0.6	360	various	1000
20.3 fb^{-1} 8 TeV 2012	~0.7	complex	complex	complex
37 fb^{-1} 13 TeV 2015-6	~0.3-1.2	380	440	1100

J75: exploiting the Kinematics

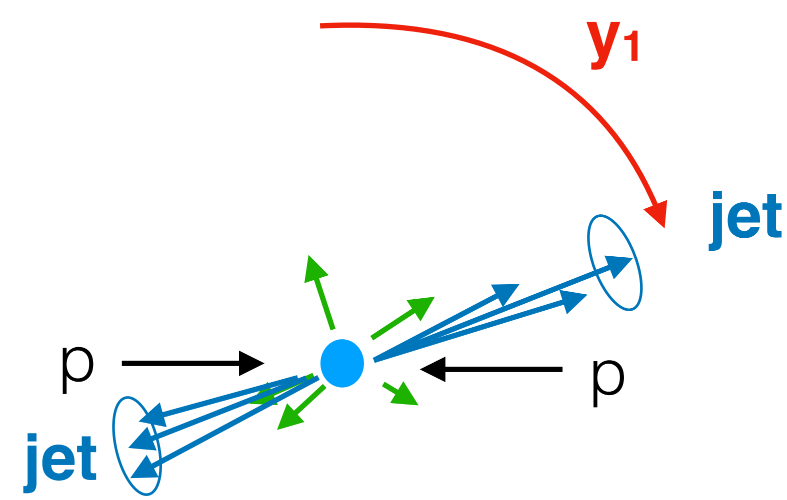
both use $|y^*| < 0.6$

$y^* = {}^1/_2\,(y_1 - y_2)$

Imagine a centrally produced Z':
i.e. quarks back to back, $y_1 = -y_2$, $y^* = y_1$



small Δy, large p_T



large Δy, small p_T

Imposing $|y^*|<0.3$ => higher $<p_T>$ from given Z' mass
=> sensitive to lower Z' mass for given p_T (**394** vs 443)
(signal and background both lose a factor of ~ 2-3)