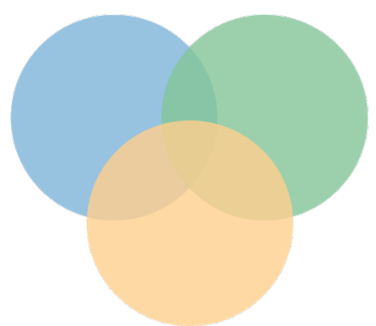
Search for dark matter mediator using a **Trigger-Object Level Analysis** with the ATLAS detector

by

Claire Antel

(Kirchhoff Institute for Physics, Heidelberg)

on behalf of the ATLAS collaboration



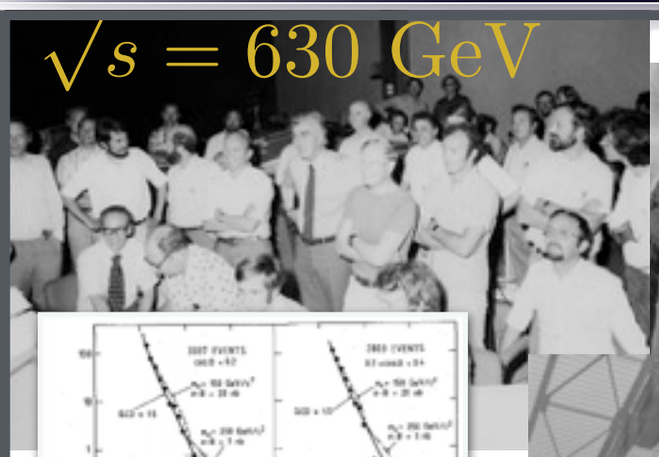
DM@LHC, Heidelberg

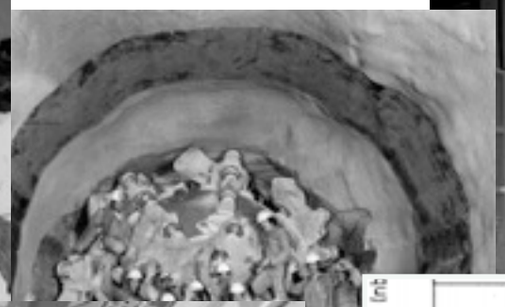
5th April 2018

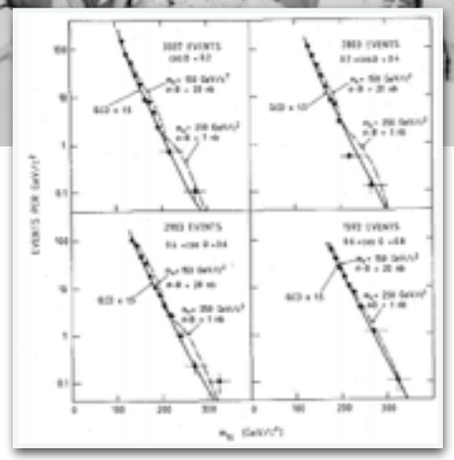
Kirchhoff-Institut für Physik

Introduction: Dijet searches through the ages

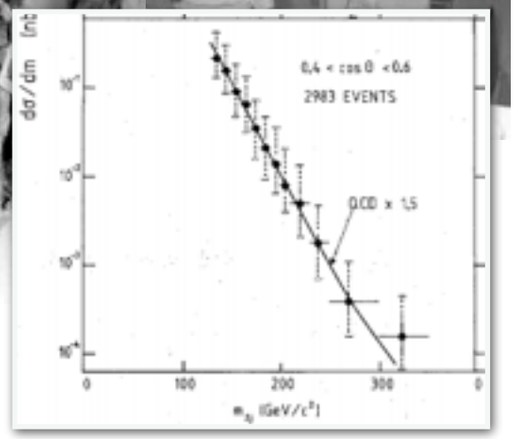
$\sqrt{s} = 630$ GeV



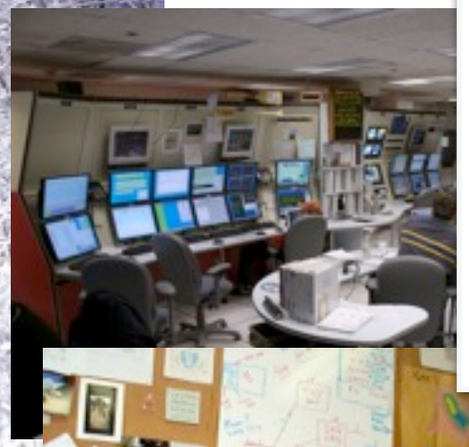


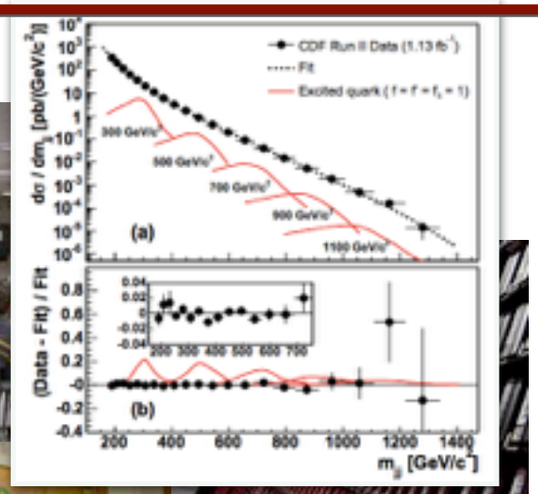


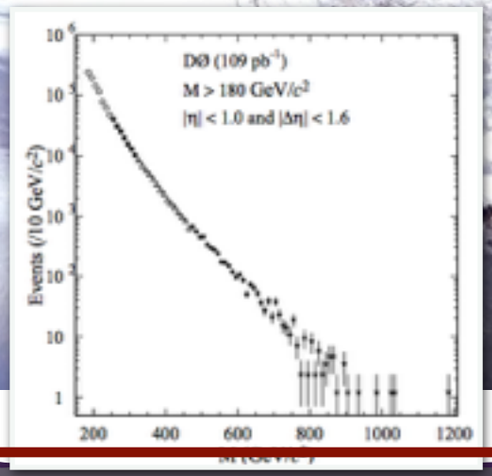
UA1, UA2 at SPS



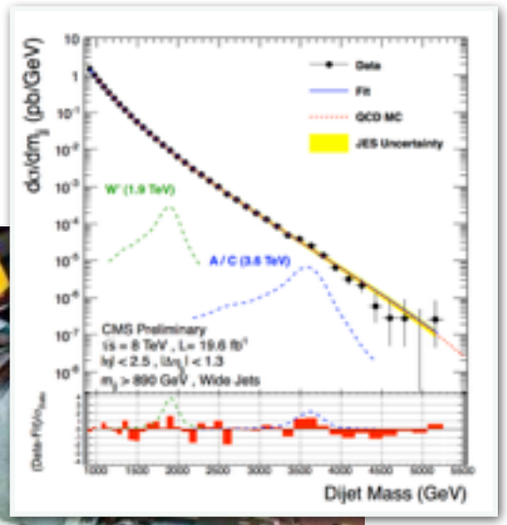
CDF, D0 at Tevatron

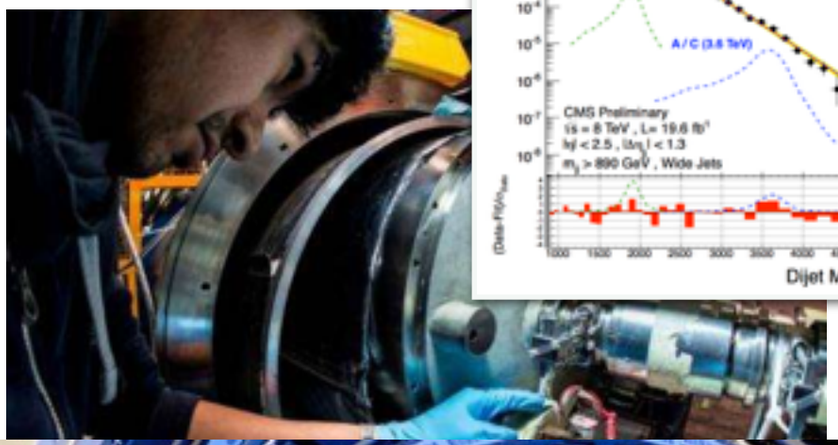


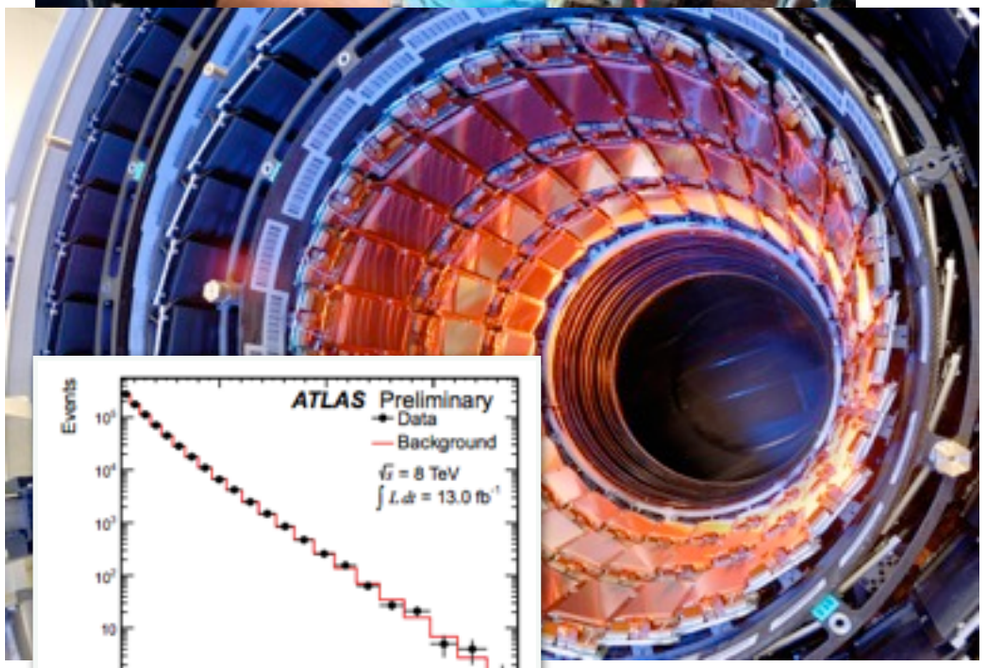




ATLAS, CMS at LHC







$\sqrt{s} = 8$ TeV

Phys. Rev. D 88, 035021

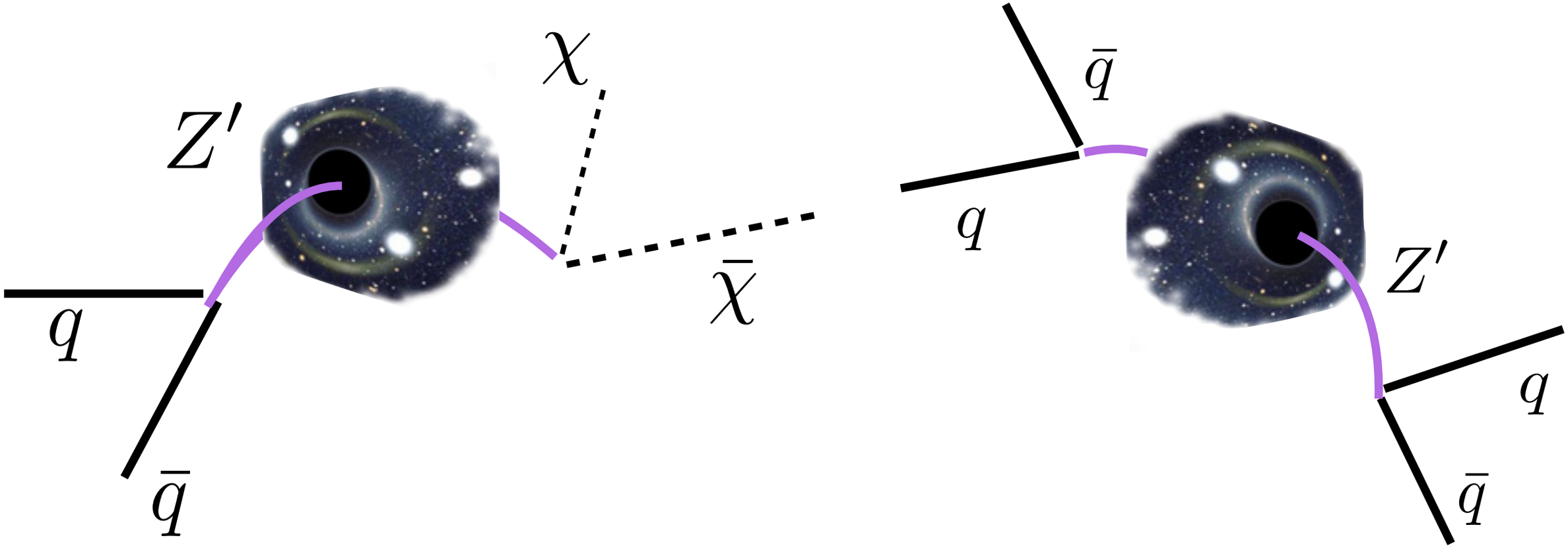
$\sqrt{s} = 1.96$ TeV

Introduction: Dijet Search in a simplified DM Model

- **Dijet resonance searches** have been conducted in the QCD rich environments of hadron colliders for the past 4 decades.

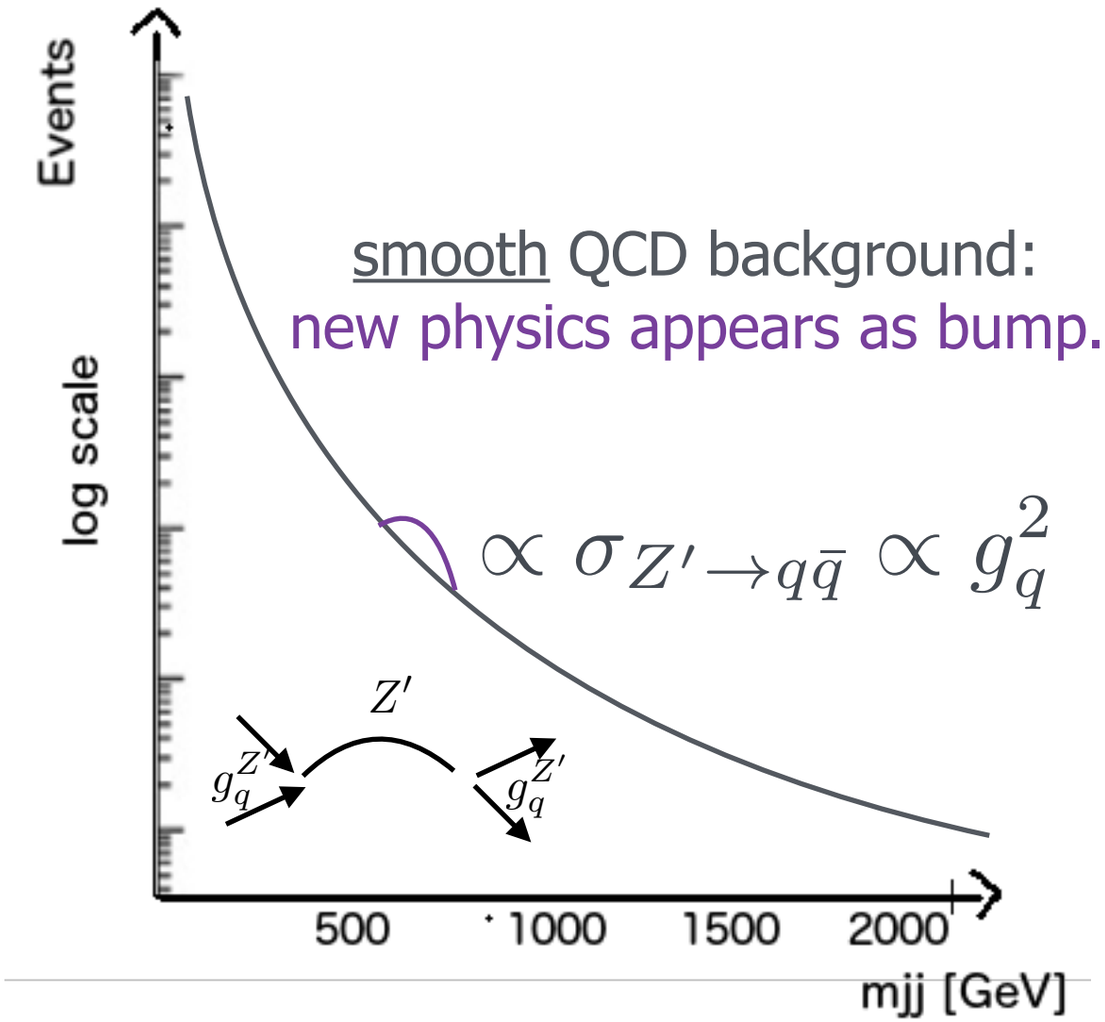
- **Motivation:** What can be produced from quarks…

- … can also decay back to quarks.



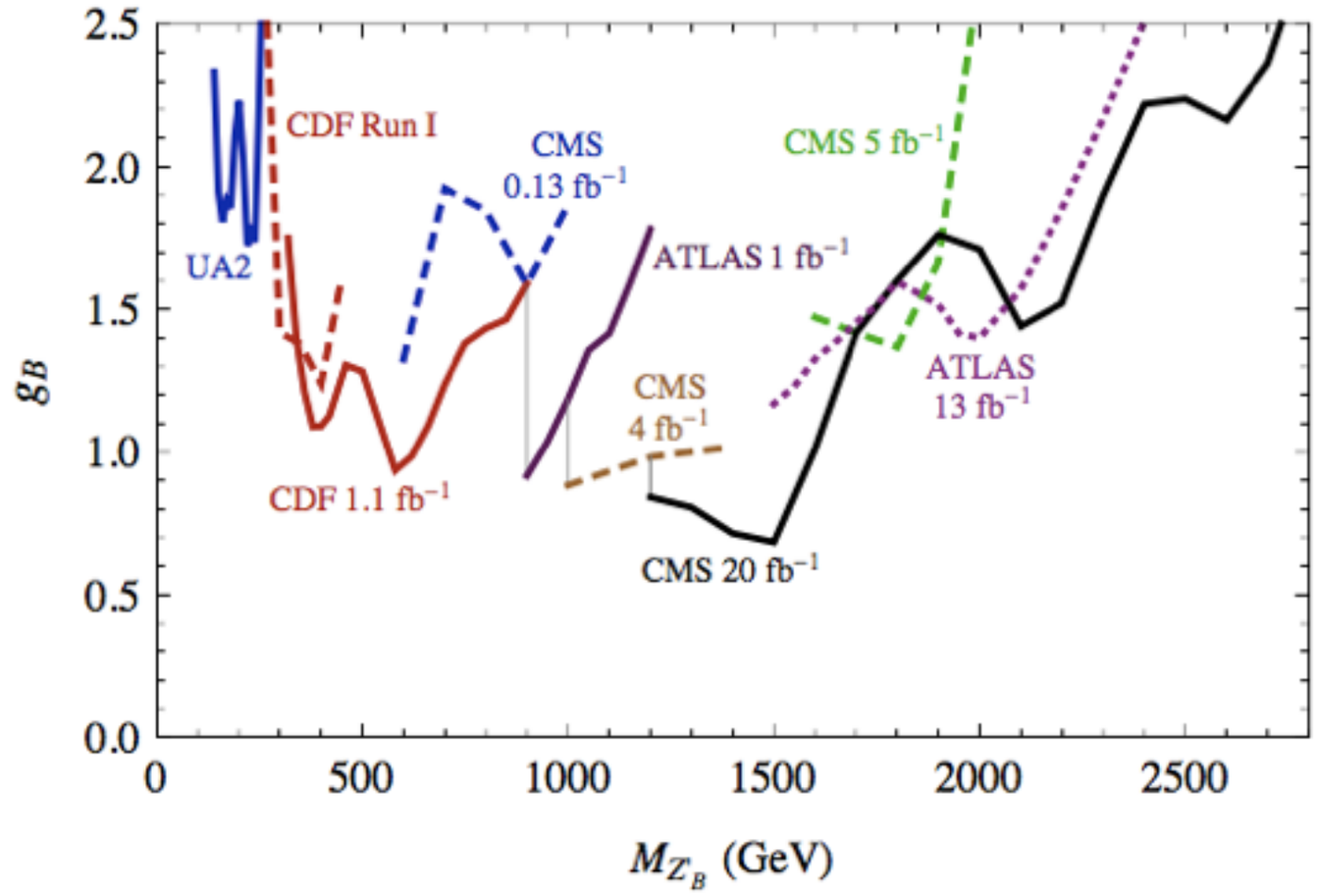
Z' - dark matter (axial-)vector mediator

Introduction: Dijet Search in a simplified DM Model



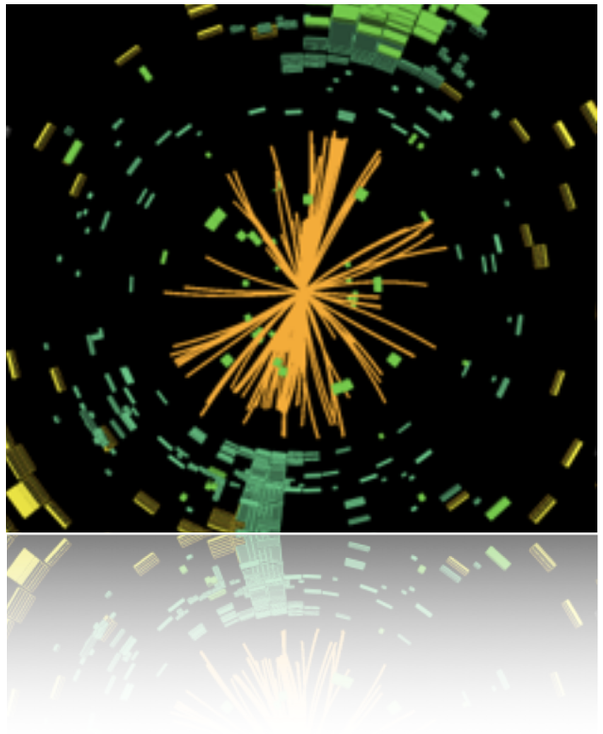
Z' -
dark matter (axial-)vector mediator

- Non-detection of a resonance at the mjj mass: limits on mediator couplings to quarks for mediator mass in range.



Coupling-mass mapping of dijet peak searches, Bogdan A. Dobrescu and Felix Yu
Phys. Rev. D 88, 035021 – Published 26 August 2013; Erratum Phys. Rev. D 90, 079901 (2014)

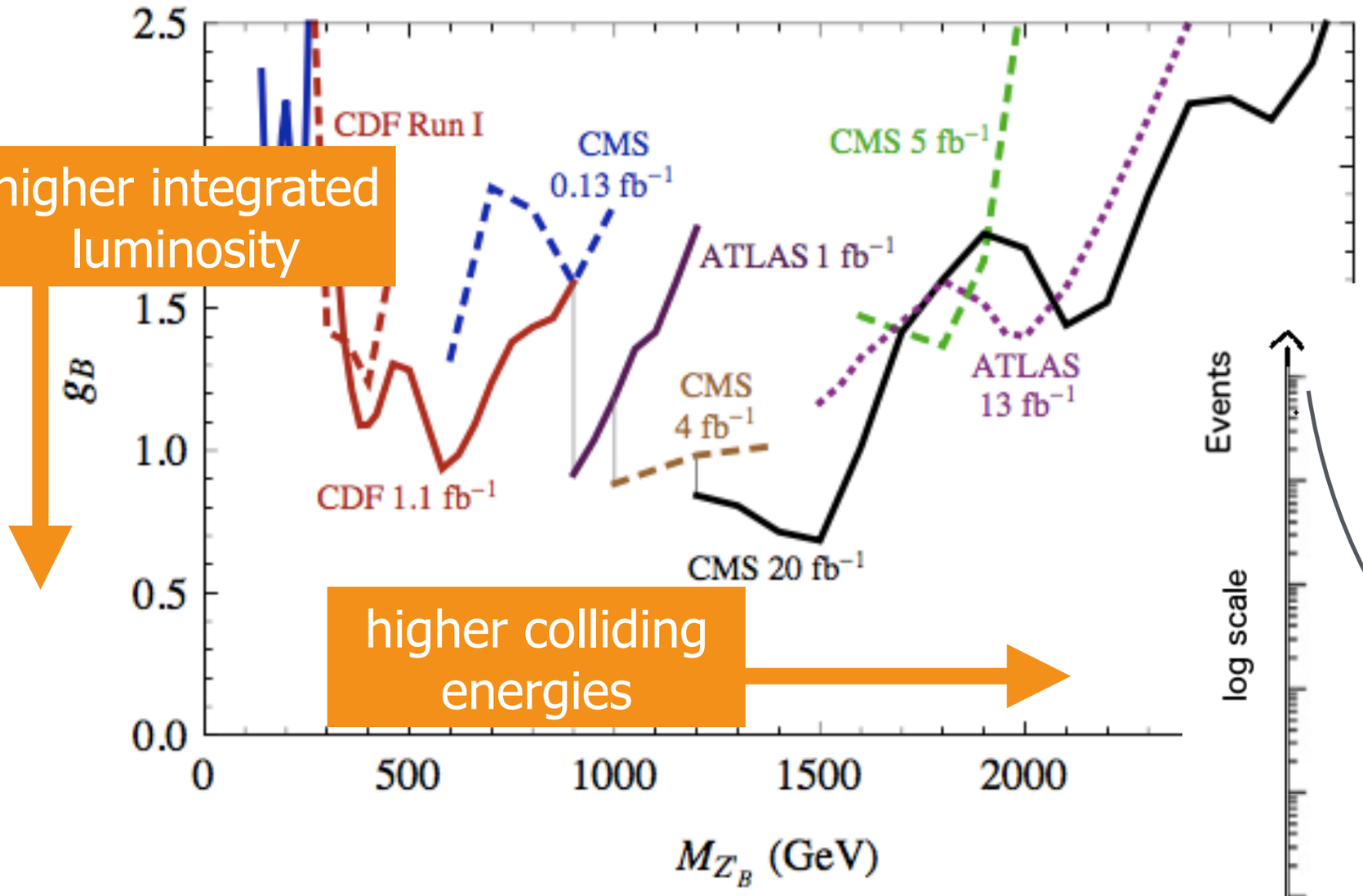
Triggering at the LHC

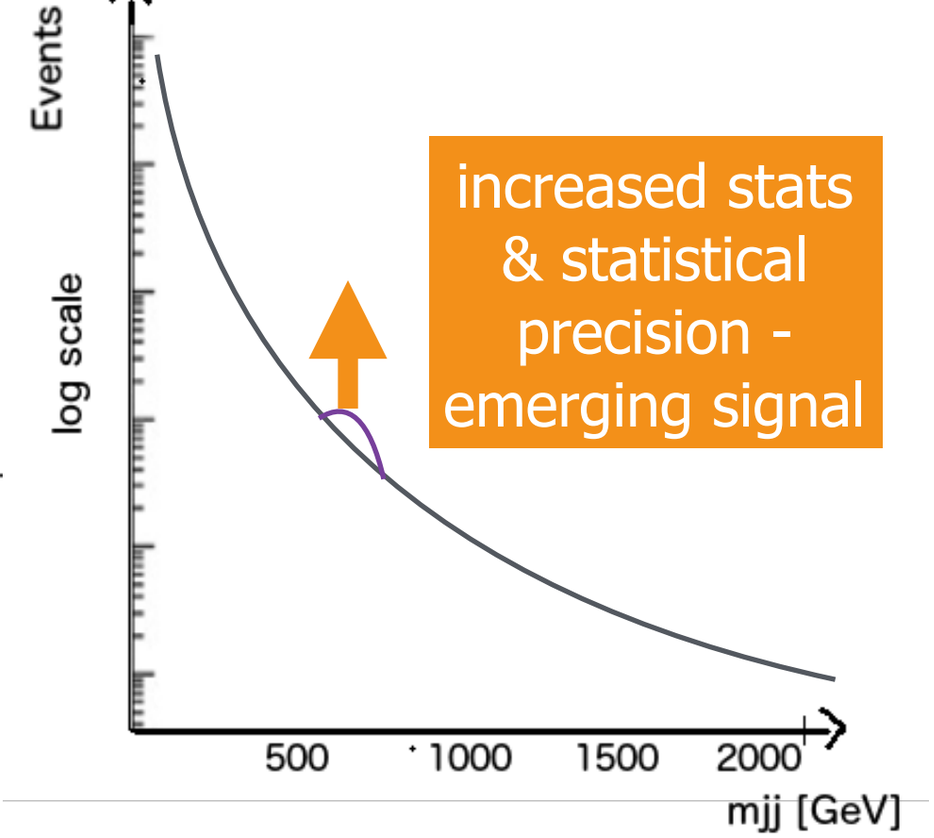


Ideal Detector

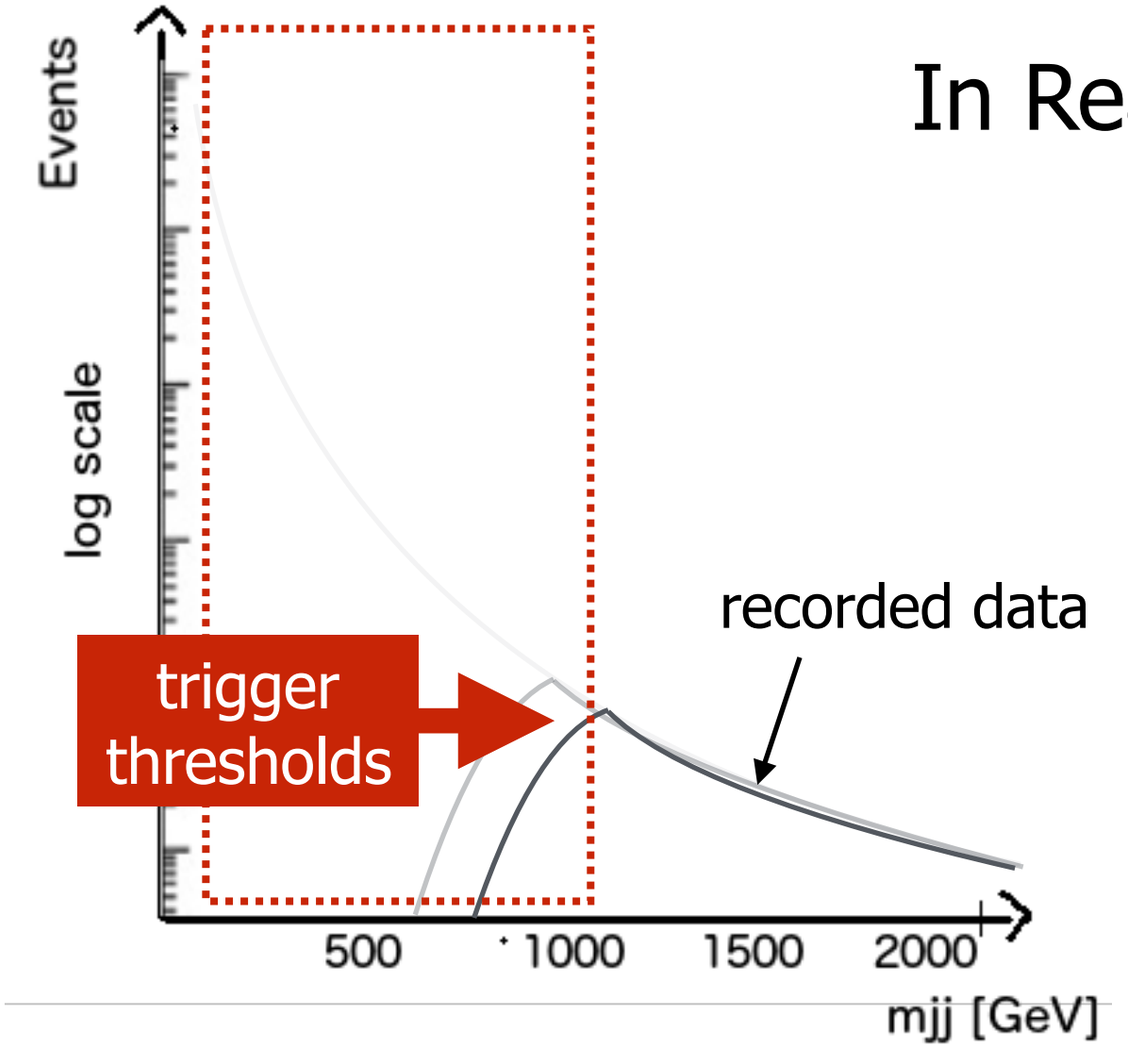
Tighter limits with ...

higher integrated luminosity

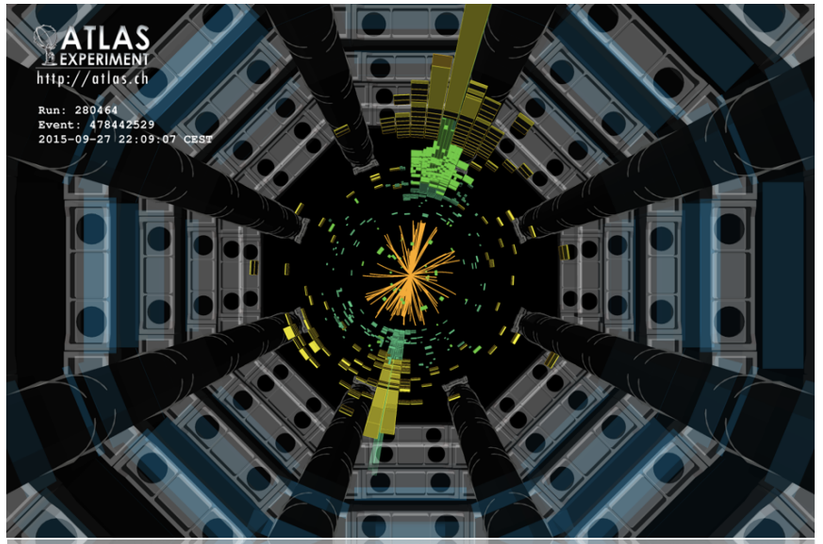


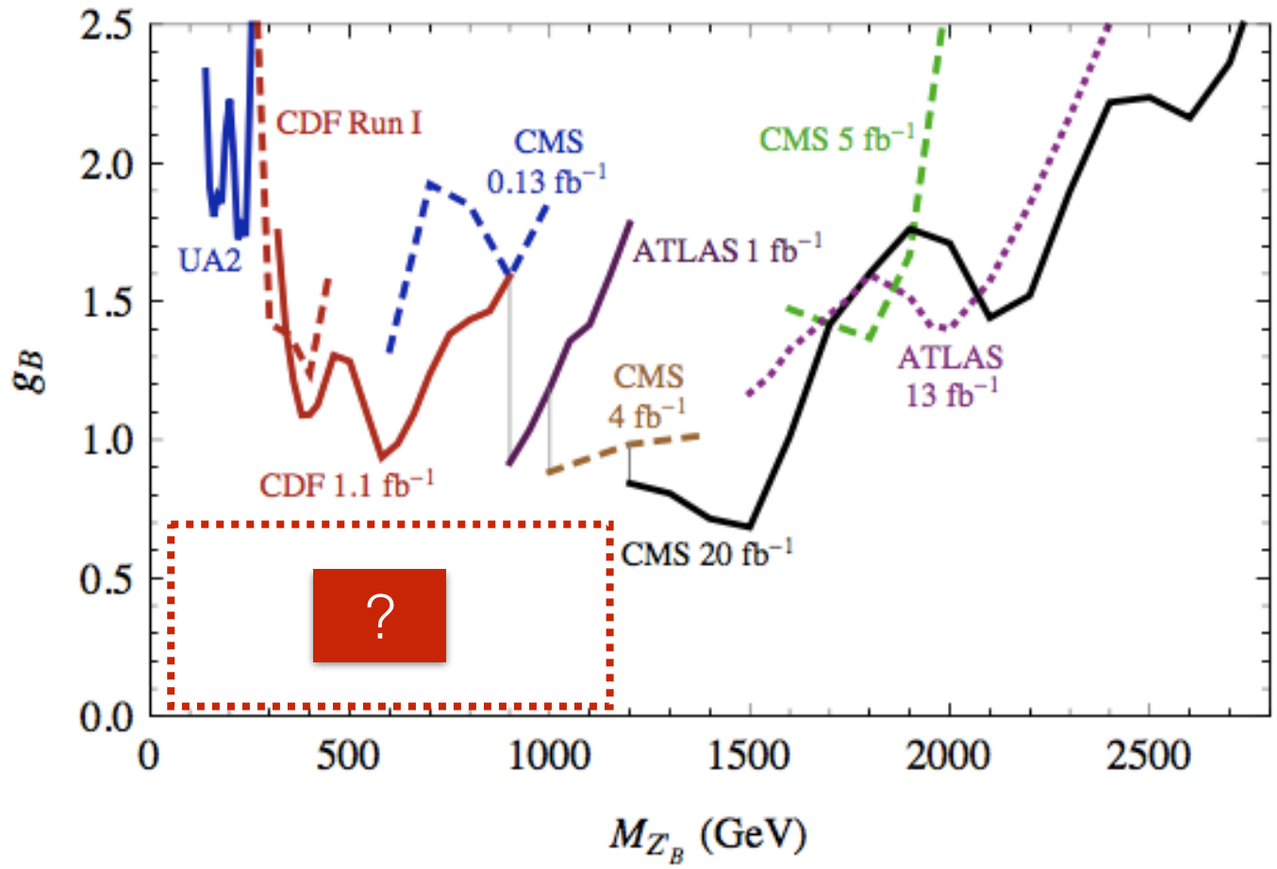


Triggering at the LHC



In Reality





- Trigger reality:
  - higher instantaneous luminosity; increased trigger rates.
  - raise trigger thresholds as data processing limits reached.

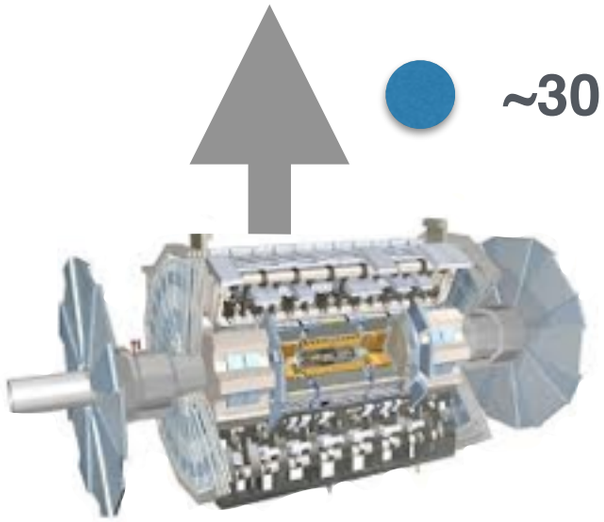
Physics (Jet) Data Recording at the LHC

ATLAS
2-Tier Trigger
System

conventional
data stream

offline pT
[GeV]

Recorded data:
entire detector
information for "offline"
jet reconstruction



Single Jet
Trigger rate

~30 Hz

420

HLT
j380*

~0.03 kHz

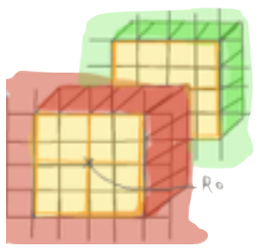
Trigger
requirement:
1 HLT jet above
pT threshold

220

Level-1
J100*

~3 kHz

Trigger requirement:
1 L1 Jet above pT
threshold



40 MHz collision rate

* 2016 triggers

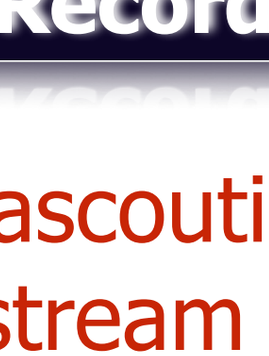
Physics (Jet) Data Recording at the LHC

Datascouting stream

offline pT [GeV]

no HLT trigger threshold

Recorded data: High-Level Trigger Jets (from calorimeter information)



~3 kHz

Single Jet Trigger rate

Datascouting event size ~ **0.5%** main physics event size

very low trigger bandwidth allows decreased trigger constraints

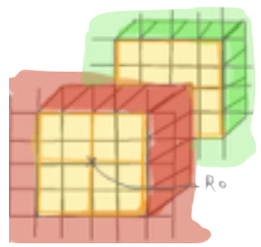
220

Level-1 J100*

~3 kHz

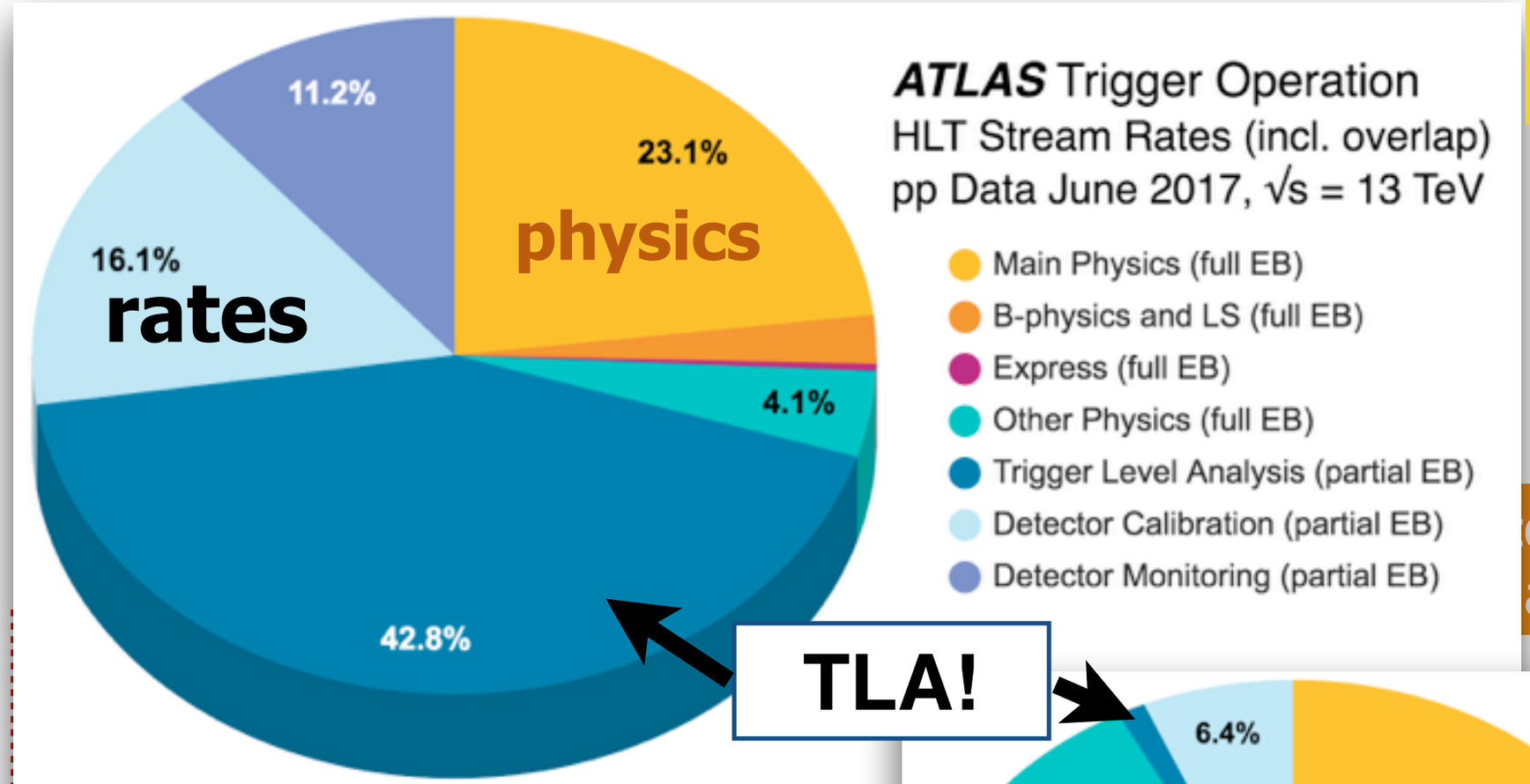
40 MHz collision rate

Trigger requirement: 1 L1 Jet above pT threshold



* 2016 triggers

Physics (Jet) Data Recording at the LHC



ATLAS Trigger Operation
HLT Stream Rates (incl. overlap)
pp Data June 2017, √s = 13 TeV

- Main Physics (full EB)
- B-physics and LS (full EB)
- Express (full EB)
- Other Physics (full EB)
- Trigger Level Analysis (partial EB)
- Detector Calibration (partial EB)
- Detector Monitoring (partial EB)

TLA!

TLA ~2 x normal physics data taking rate

Single Jet Trigger rate

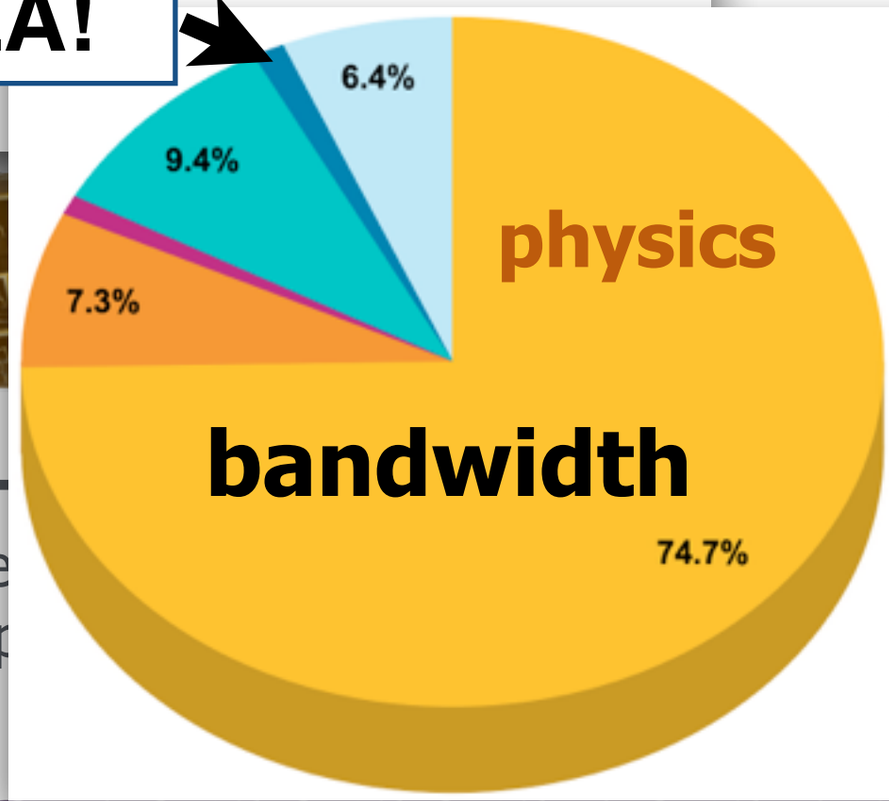
outing event size ~
ain physics event size

threshold

Recorded data:
High-Level Trigger Jets

220

Trigger requireme
1 L1 Jet above p
threshold



ATLAS Trigger Operation
HLT Output Bandwidth
pp Data June 2017, √s = 13 TeV

- Main Physics (full EB)
- B-physics and LS (full EB)
- Express (full EB)
- Other Physics (full EB)
- Trigger Level Analysis (partial EB)
- Detector Calibration (partial EB)

Trigger-Object Level Analysis (TLA)

Analysis Components

event cleaning

trigger jet calibration

mjj spectrum, varying bin width

data-driven background estimate

bump search

observed excess: evidence/discovery of new particle

limit setting

axial-vector Z' mediator

gaussian signals of varying widths

Trigger-Object Level Analysis (TLA)

Analysis Components

event cleaning

trigger jet calibration

mjj spectrum, varying bin width

data-driven background estimate

rely on smoothly falling background

bump search

observed excess: evidence/discovery of new particle

limit setting

axial-vector Z' mediator

gaussian signals of varying widths

Challenges

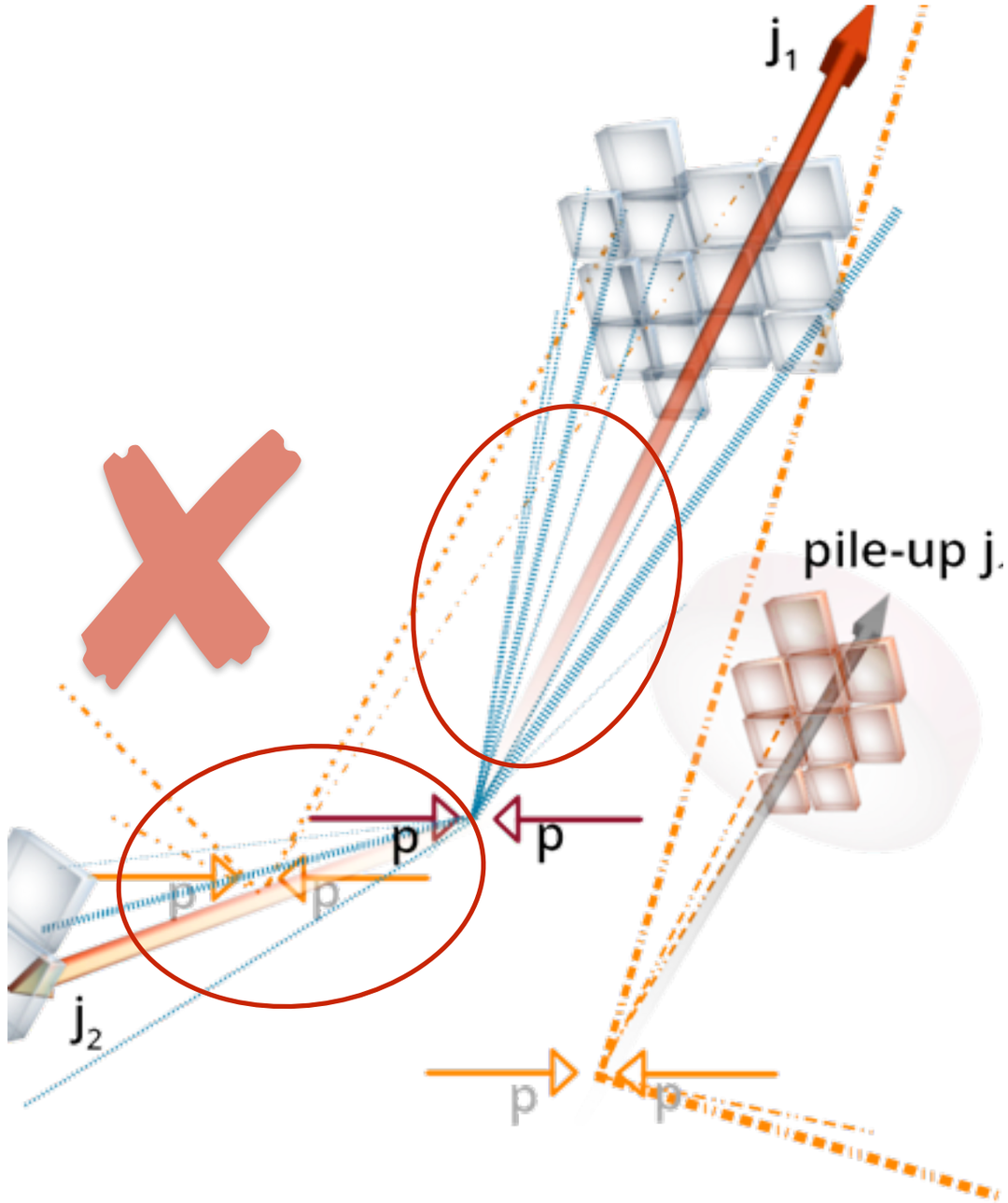
full detector info cannot be exploited, little handle on pile-up.

high statistical precision: unprecedented sensitivity to detector/calibration-induced fluctuations.

Trigger Jet Calibration

(see back-up for full calibration chain)

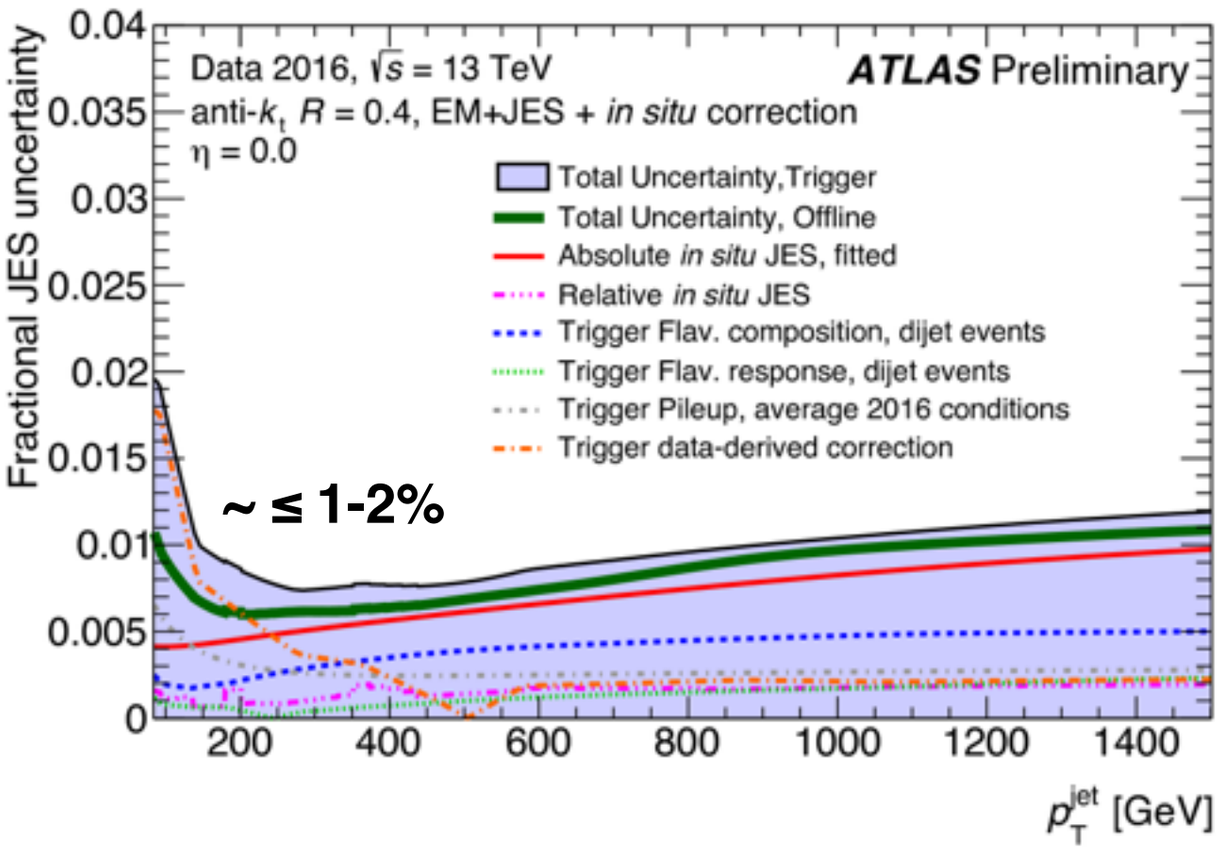
- Challenge: **no tracking information -> dedicated calibration.**



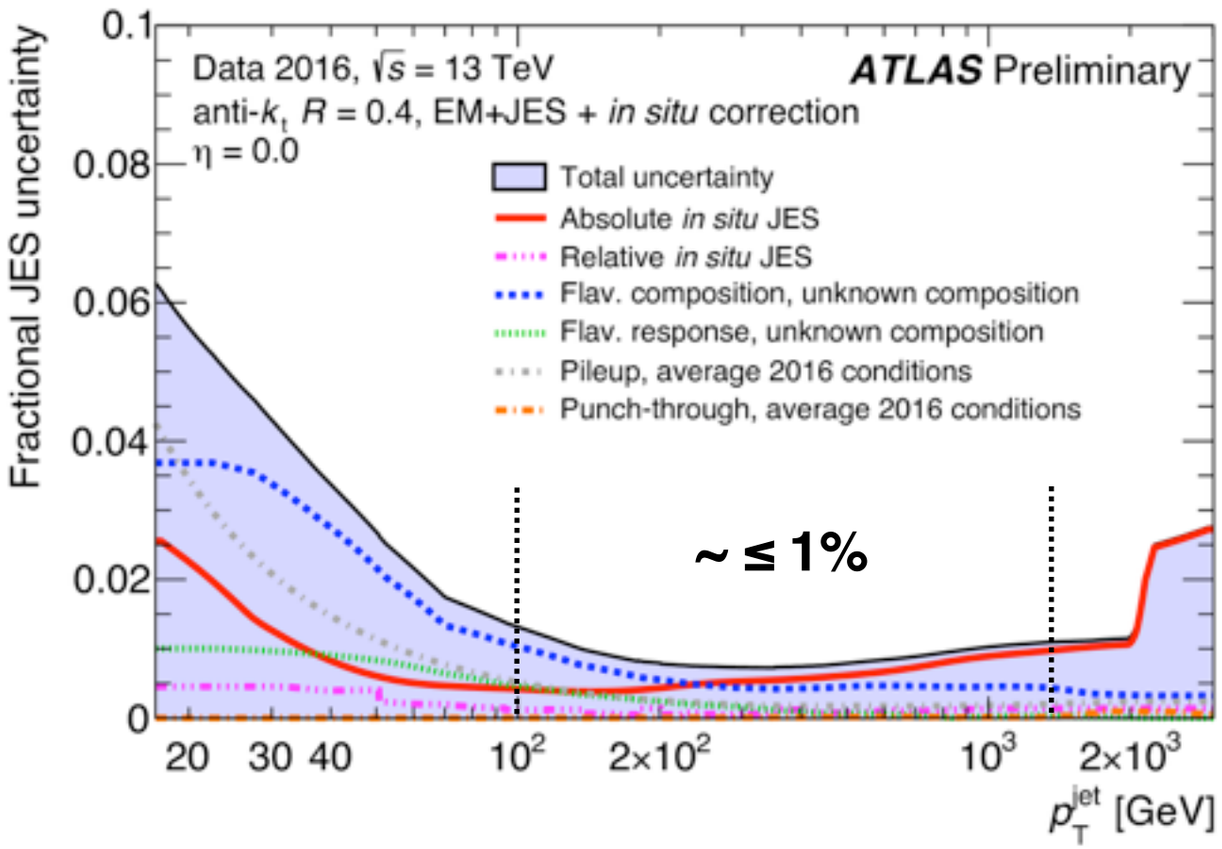
Trigger Jet Calibration

- Challenge: **no tracking information -> dedicated calibration.**
- Successfully achieved a **similar precision** for trigger jets compared to offline jets.

Trigger



Offline

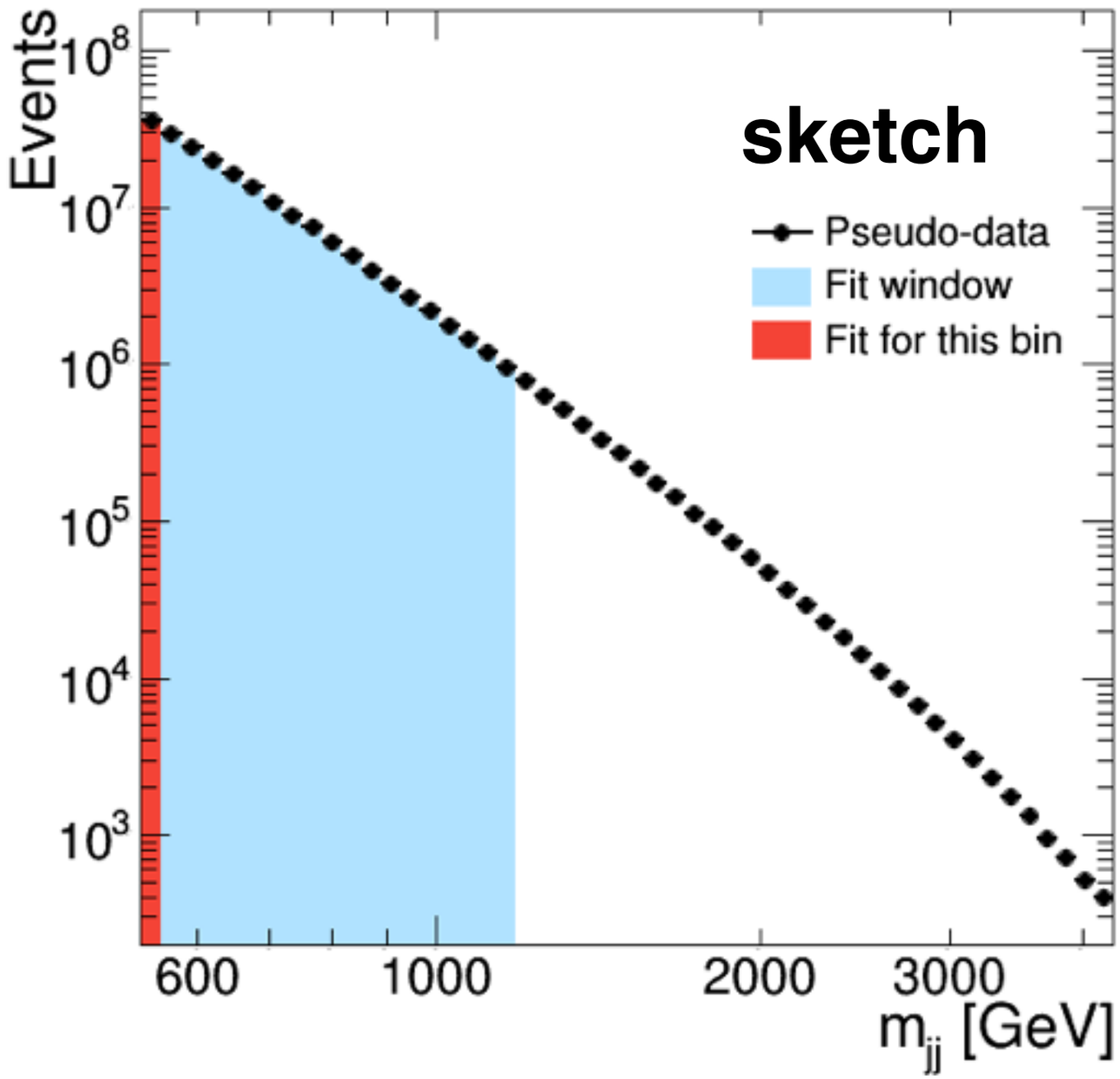


- Trigger-to-offline jet energy ratio within 0.05%.

Data-Driven Background Estimation

SWiFT - Sliding Window Fit

(more detailed description of SWIFT
Phys. Rev. D 96, 052004 (2017))

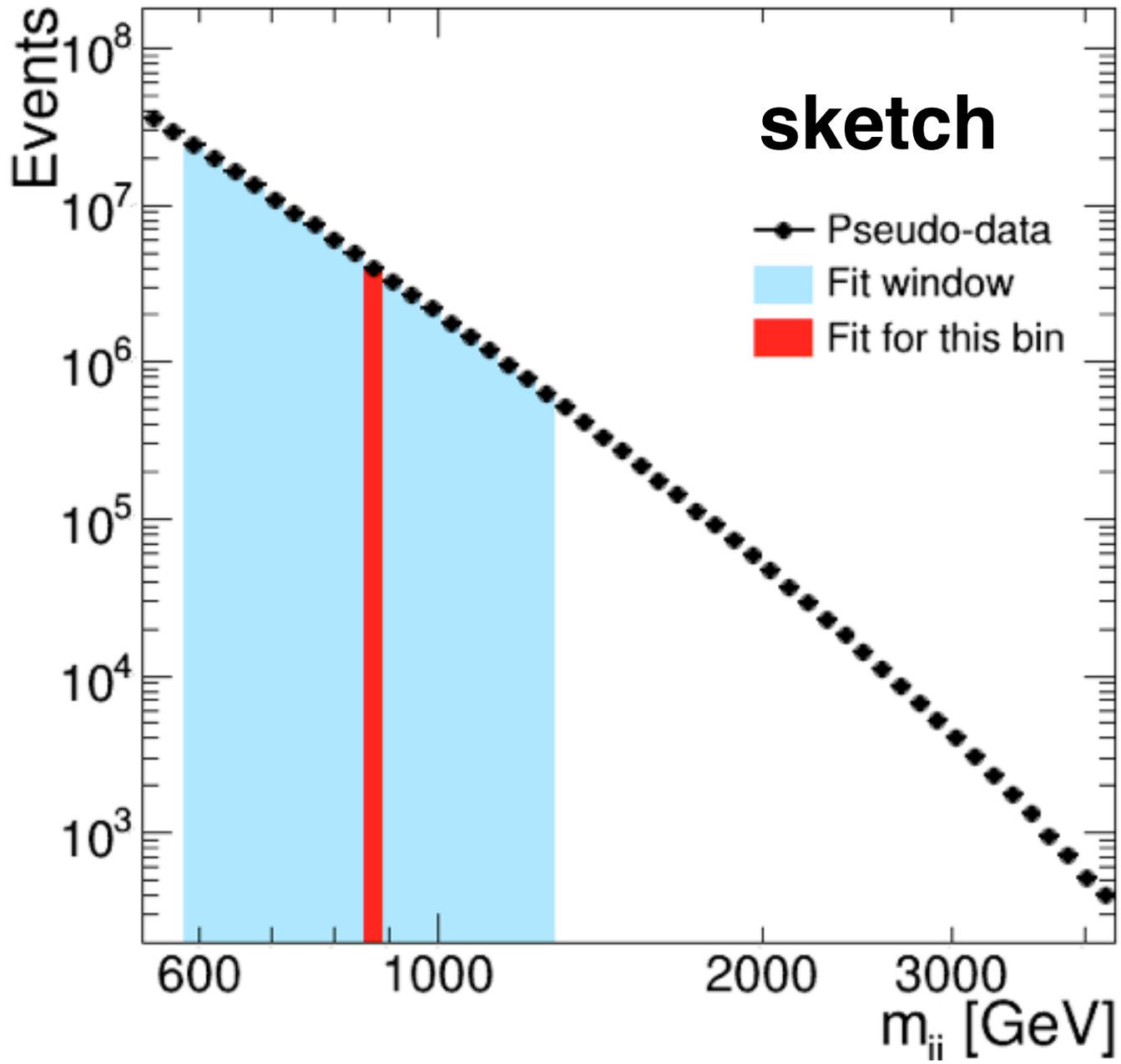


- A fit of the mjj spectrum performed within a ‘sliding window’: window width is fixed.

Data-Driven Background Estimation

SWiFT - Sliding Window Fit

(more detailed description of SWIFT
Phys. Rev. D 96, 052004 (2017))

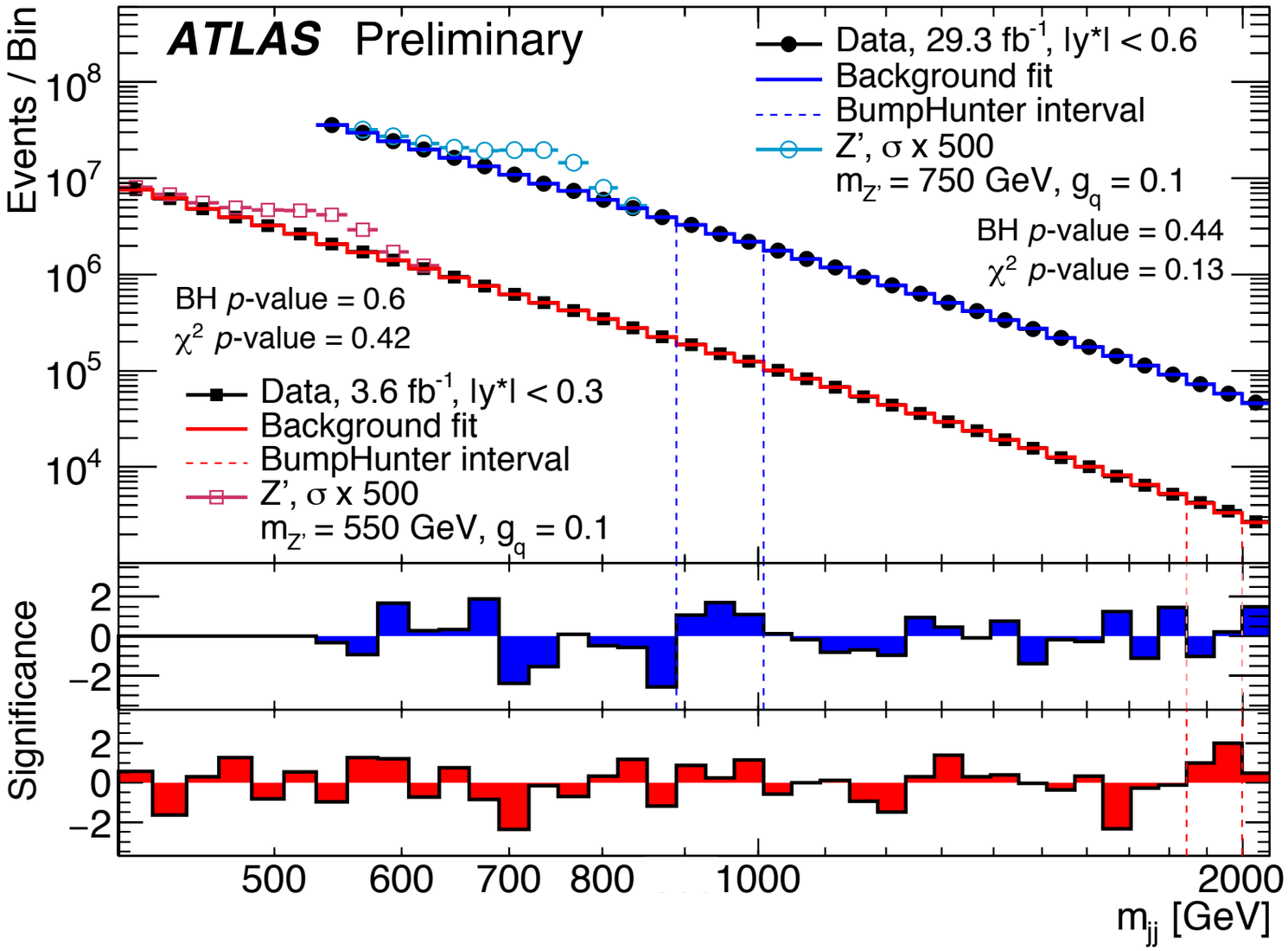


- A fit of the mjj spectrum performed within a 'sliding window': window width is fixed.

Bump Search

- Is there an excess over background estimate?

signal region (1):
3.6/fb
Level 1 J75 Trigger
|y*|<0.3



signal region (2):
29.3/fb
Level 1 J100 Trigger
|y*|<0.6

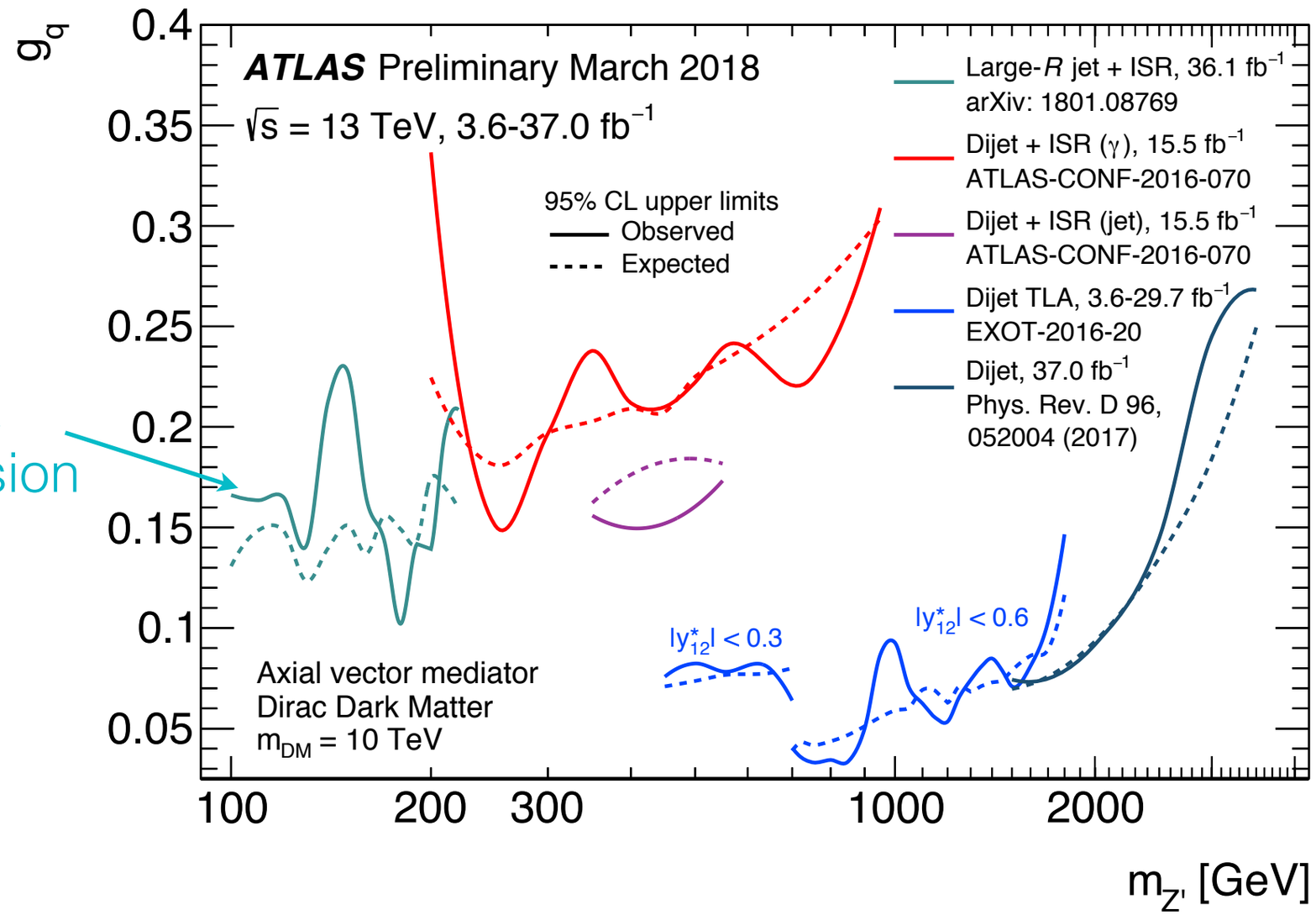
* $y* = \frac{(y_1 - y_2)}{2}$

- most discrepant region 887-1007 GeV with global significance of 0.16 σ.
- Thus, no significant excess observed.

Summary Plot

dijet search overview @
ATLAS+ CMS:
Sarah Malik's talk on Tuesday

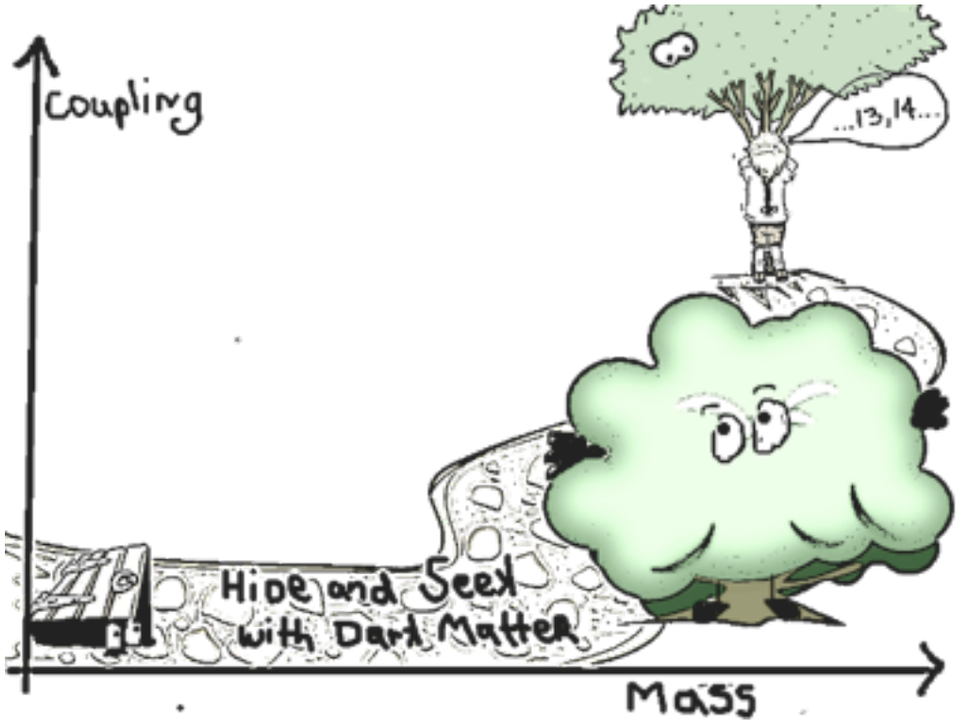
Merve's talk
earlier this session



- Numerous other analyses developed to tackle trigger limitation:
  - dijet + ISR, boosted dijet + ISR: low mass reach
- TLA's forte: statistically powerful -> limit setting to lowest coupling.

In Summary

- The ATLAS Trigger-Object Level Analysis is a low-mass dijet search, which
  - Tackles trigger limitations by taking on calibration challenges.
  - Unprecedented statistical precision: high sensitivity to fluctuations. May soon face underlying QCD complexities?



NEW

EXOT-2016-020

  - 2016 13 TeV 29.3/fb results:
    - No excess found
    - Limits set for masses 450-1800 GeV on
      - Quark couplings in an axial-vector Z' mediator model.
      - $\sigma \times \mathcal{A} \times \mathcal{B}.\mathcal{R}.$ for Gaussian signals of various widths.
- Closing gaps in mediator mass - quark coupling landscape.

Back-up Slides

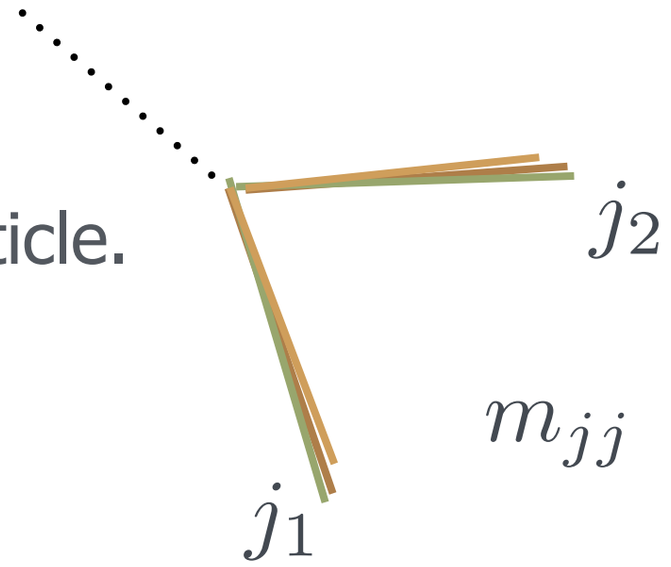
Trigger-Object Level Analysis (TLA)

Analysis Framework

- Analysis objects from **Datascouting stream**.
- A **dijet search** for a new Dark Matter mediator particle.
- <u>Event selection:</u>

$$2 \text{ jets}, pT > 85 \text{ GeV}$$

$$|\eta_j| < 2.8$$



signal region (1)

L1 Jet Trigger: **J75**

$$\text{leading jet } p_T > 185 \text{ GeV}$$

$$|y*| < 0.3 \text{ *}$$

$$400 \text{ GeV} < m_{jj} < 2080 \text{ GeV}$$

$$\mathcal{L} = 3.6 fb^{-1}$$

signal region (2)

L1 Jet Trigger: **J100**

$$\text{leading jet } p_T > 220 \text{ GeV}$$

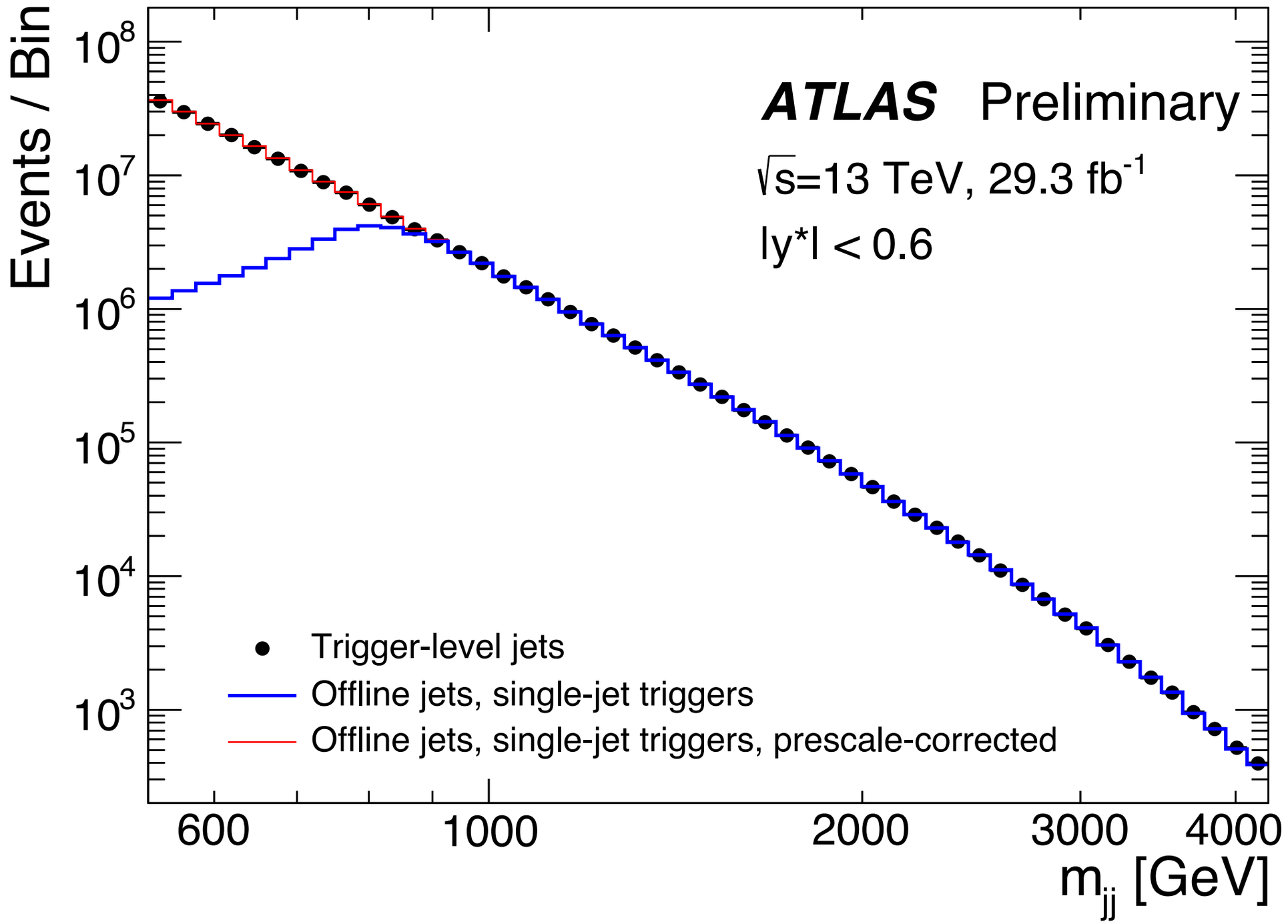
$$|y*| < 0.6 \text{ *}$$

$$531 \text{ GeV} < m_{jj} < 2080 \text{ GeV}$$

$$\mathcal{L} = 29.3 fb^{-1}$$

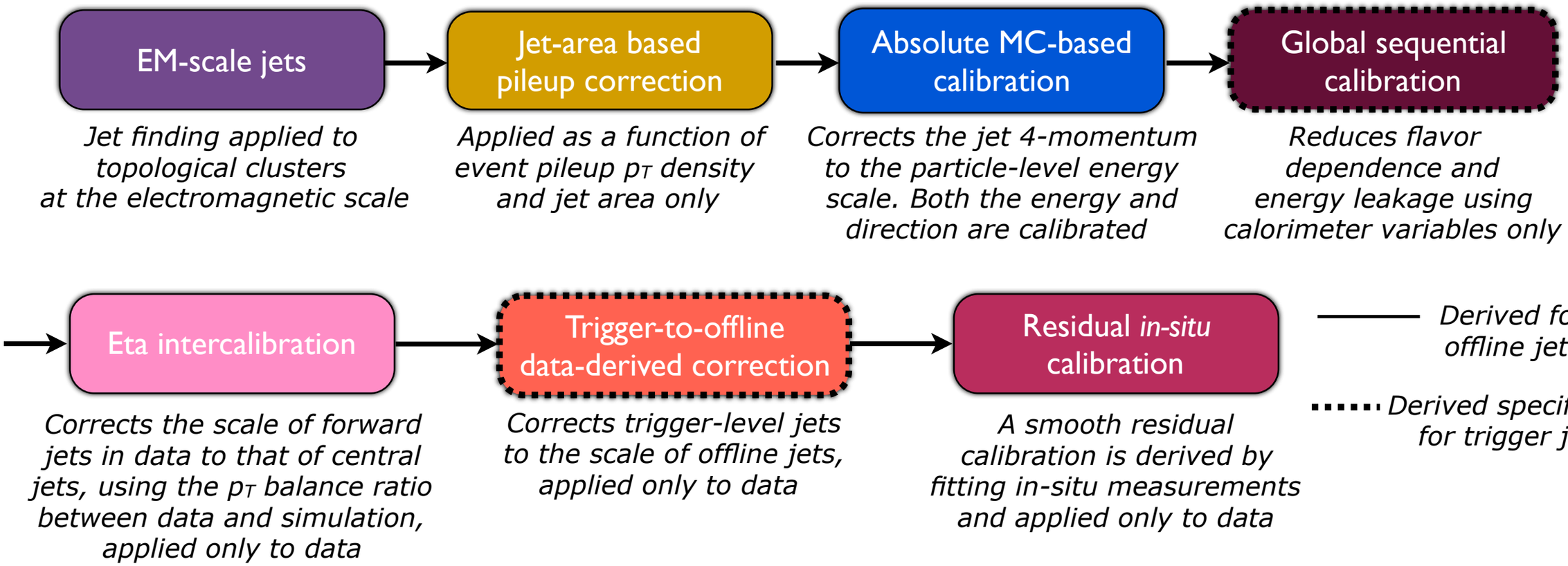
* $y* = \frac{(y_1 - y_2)}{2}$

All Single Jet "Offline" data versus TLA recorded data



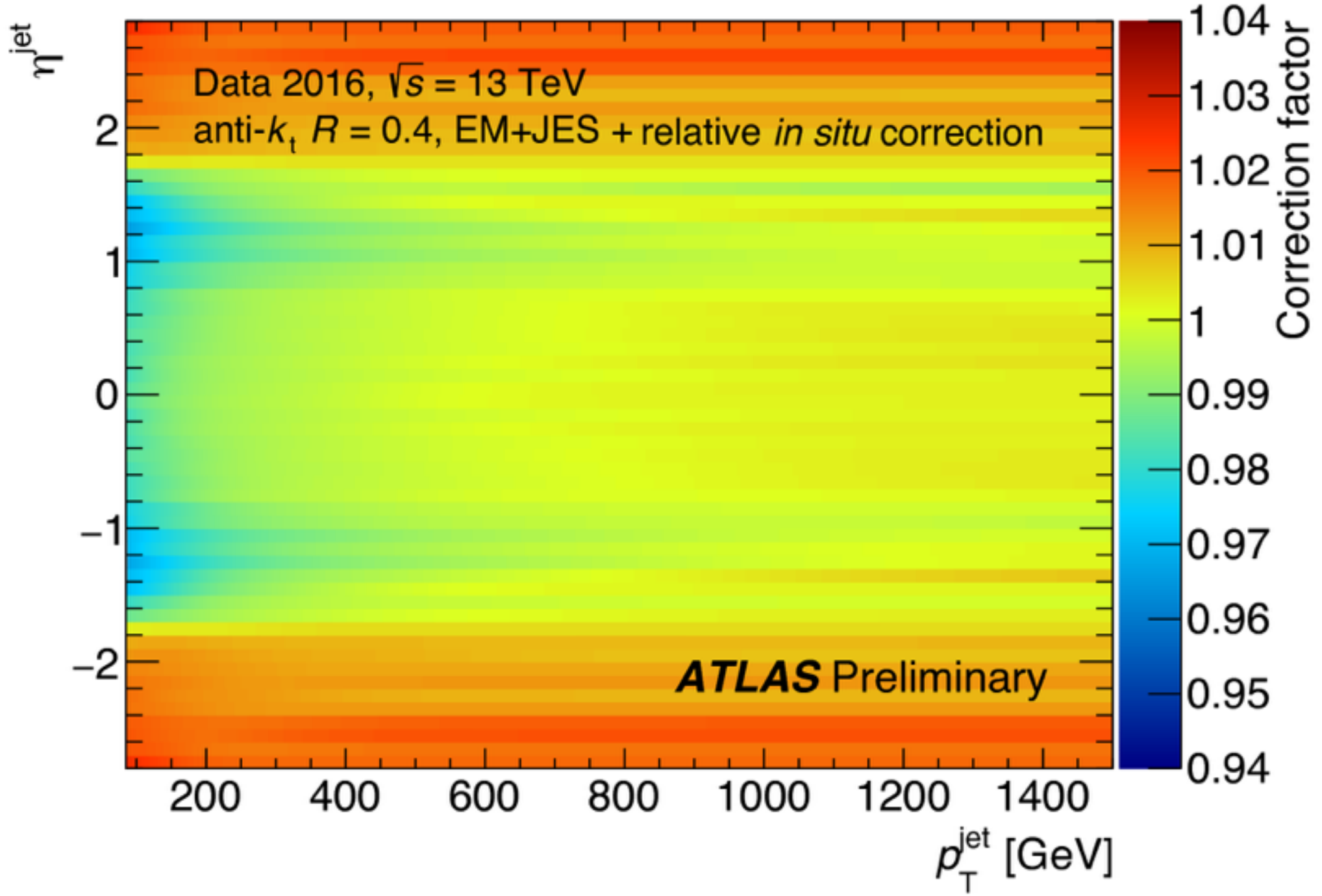
Trigger Jet Calibration

- **dedicated jet calibration** as don't have full detector information - mainly **no tracking information**.



- **Final calibration:**
  - Trigger-to-offline jet energy ratio within 0.05%.
  - Min. 3.5% (max. 4.5%) jet energy scale uncertainty for |eta|<0.8 (1.0<|eta|<1.5) jets.

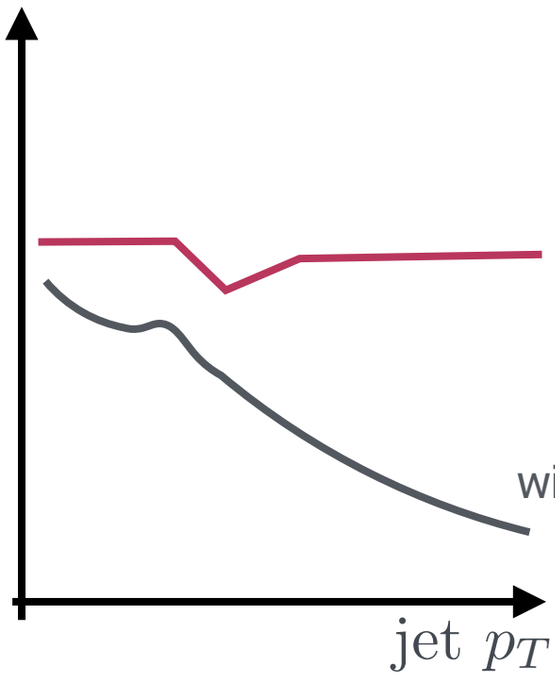
Correction Factors: Trigger->Offline Jets

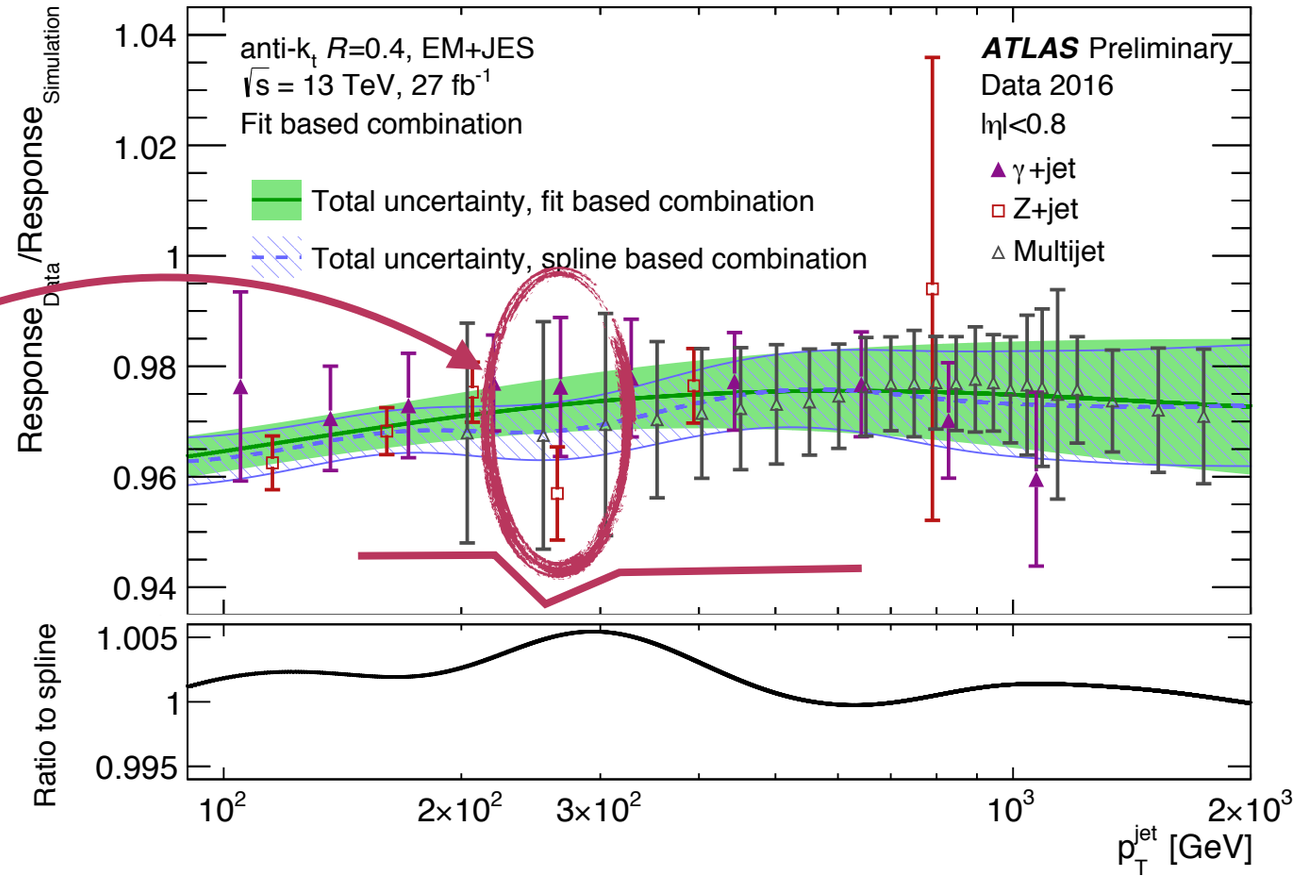


Trigger Jet Calibration

- **Need to watch out for localized fluctuations!**

  .. as can be induced by bumps in the calibration:

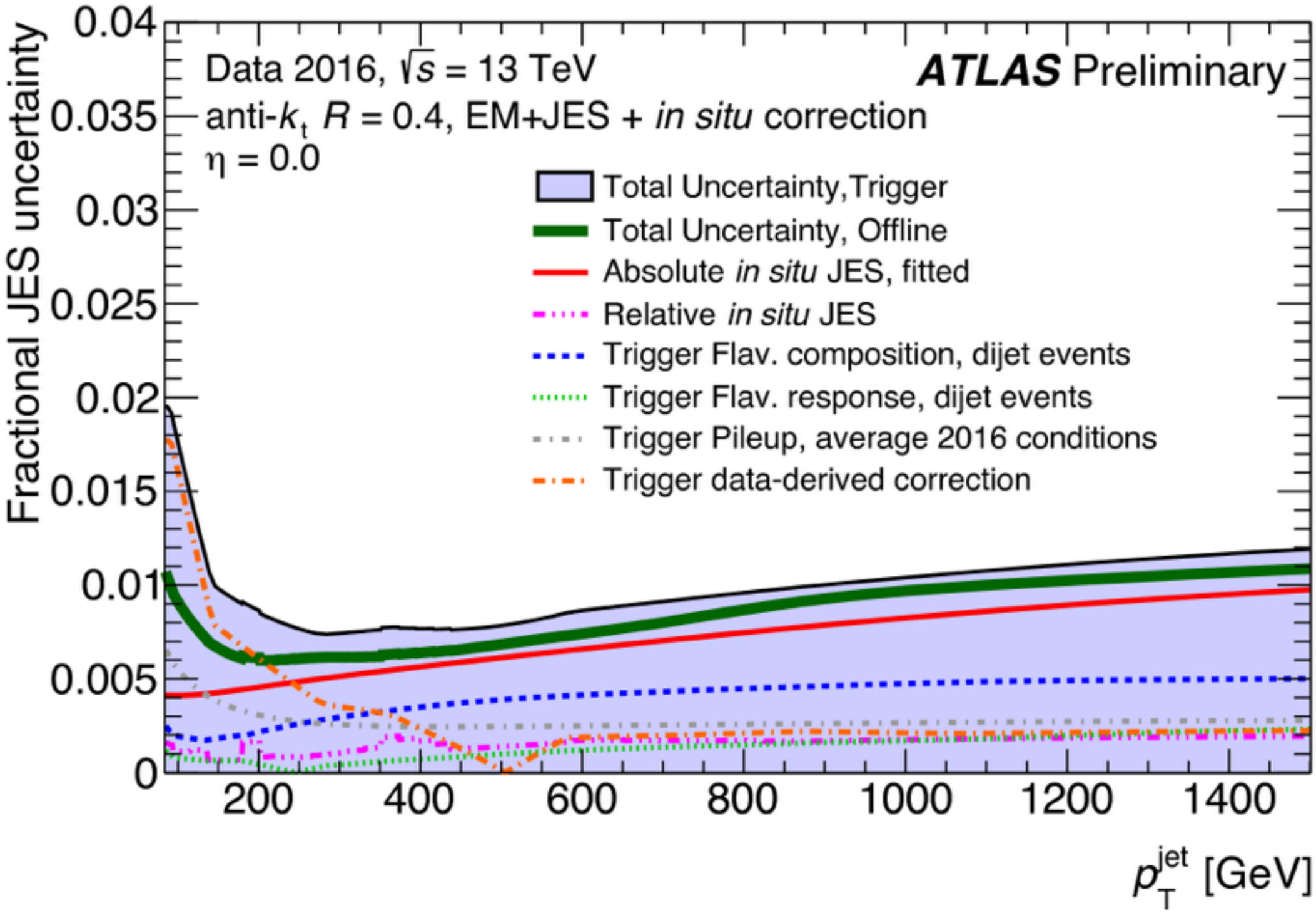




- The **residual in-situ calibration** initially not sufficiently smooth.

- replaced a spline-based combination method (dashed line, used offline) with a polynomial fit method (solid line) to smoothen calibration factors.

JES uncertainties for Trigger Jets



Data-Driven Background Estimation: more detail

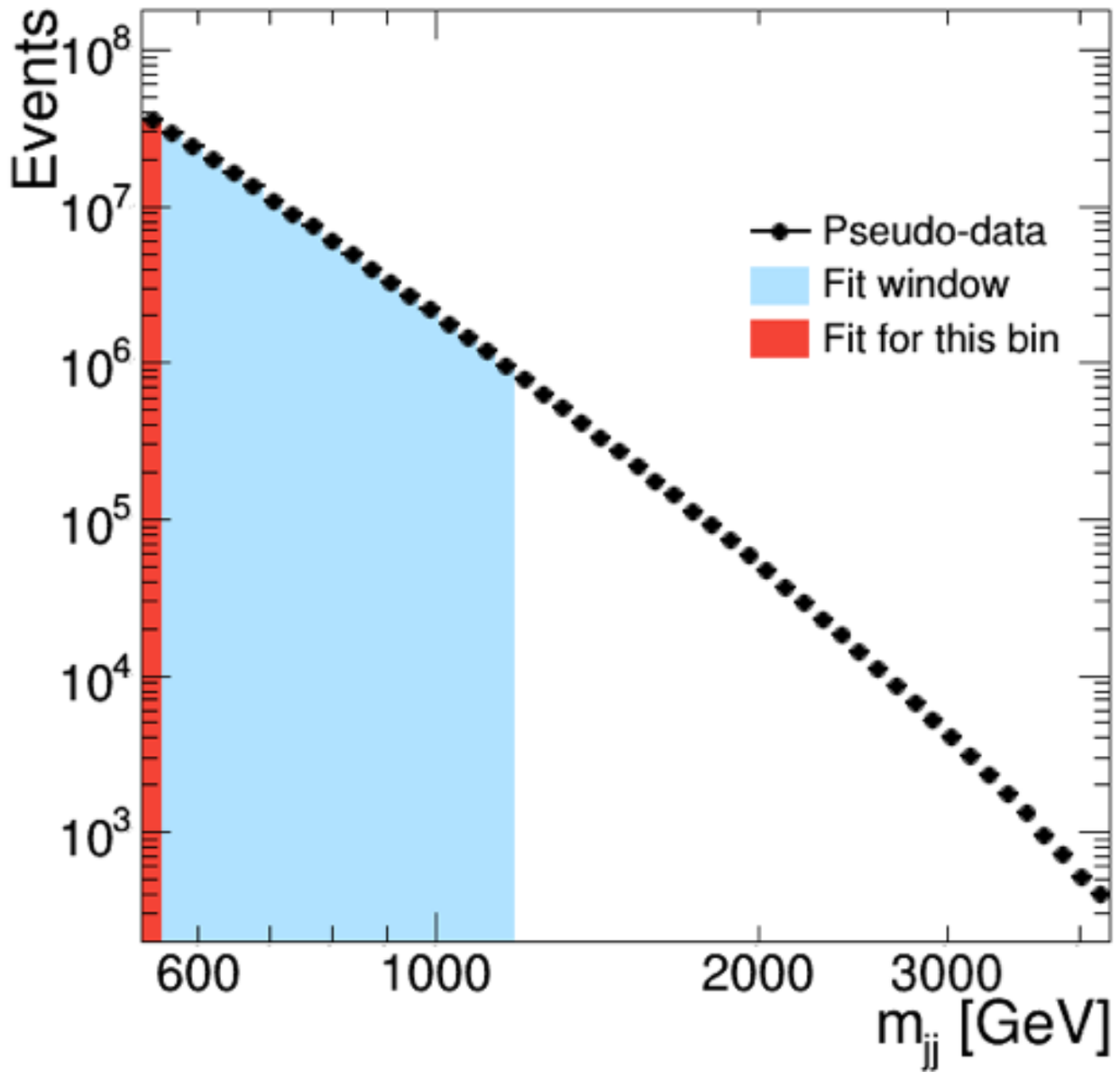
SWiFT - Sliding Window Fit

- A fit of the mjj spectrum performed within a 'sliding window': window width is fixed.
- background estimates in all windows collated.
- starting at widest window width, find 2 good fit functions*:

  1) bg estimate, 2) systematic uncertainty

- good fit:

$$\chi^2 \text{ p-value} > 0.05$$



* final selected function for signal region (2): $f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 lnx+p_5 lnx^2}$ (see back-up for all considered functions)

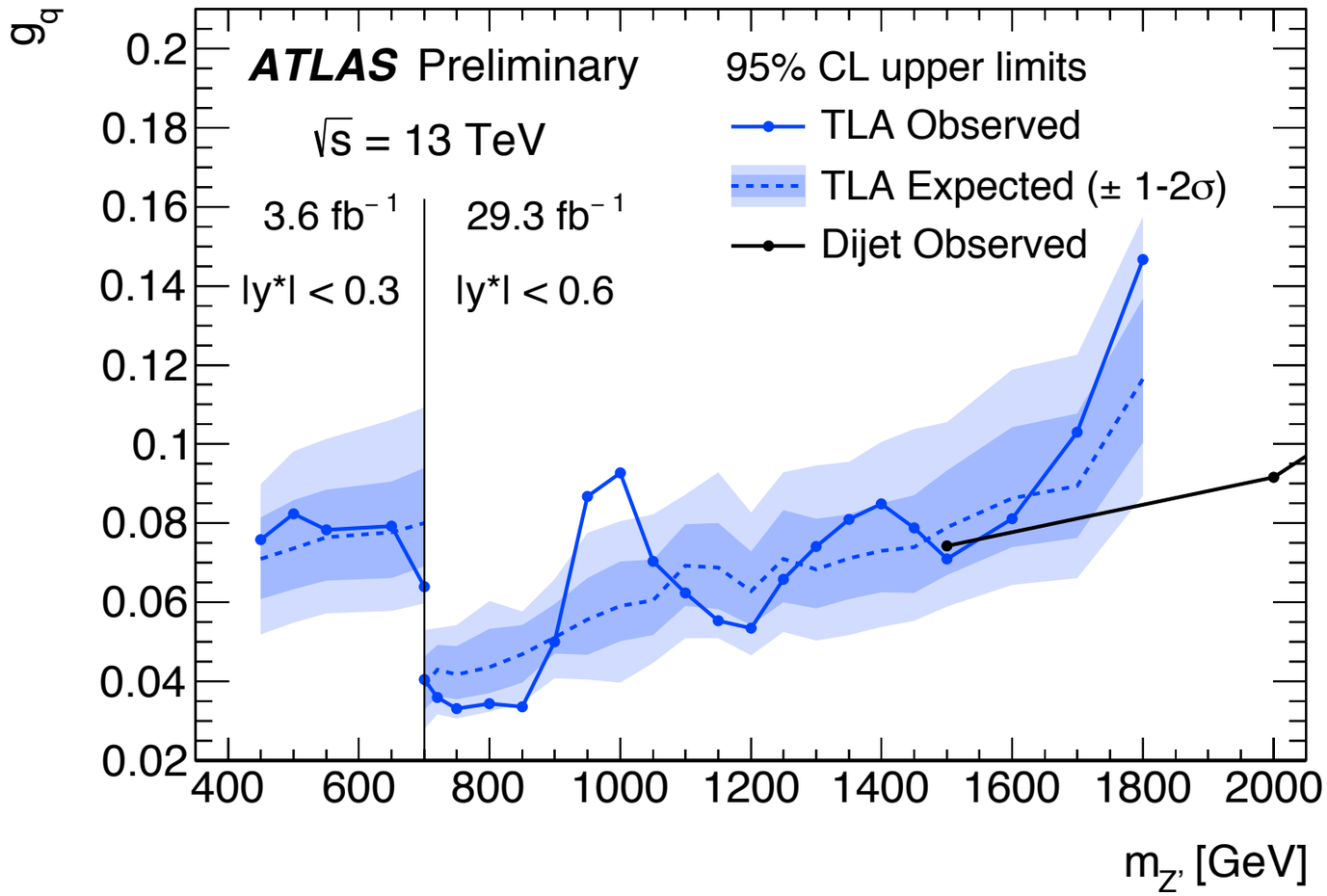
Functional Forms

- considered functional forms for background estimation in SWIFT:
  - 5-param function: $f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 lnx+p_5 lnx^2}$
  - 4-param function: $f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 lnx}$
  - 4-param "UA2" function: $f(x) = \frac{p_1}{x^{p_2}} e^{-p_3 x - p_4 x^2}$

Limit Setting

leptophobic axial-vector Z’ simplified Dark Matter model*

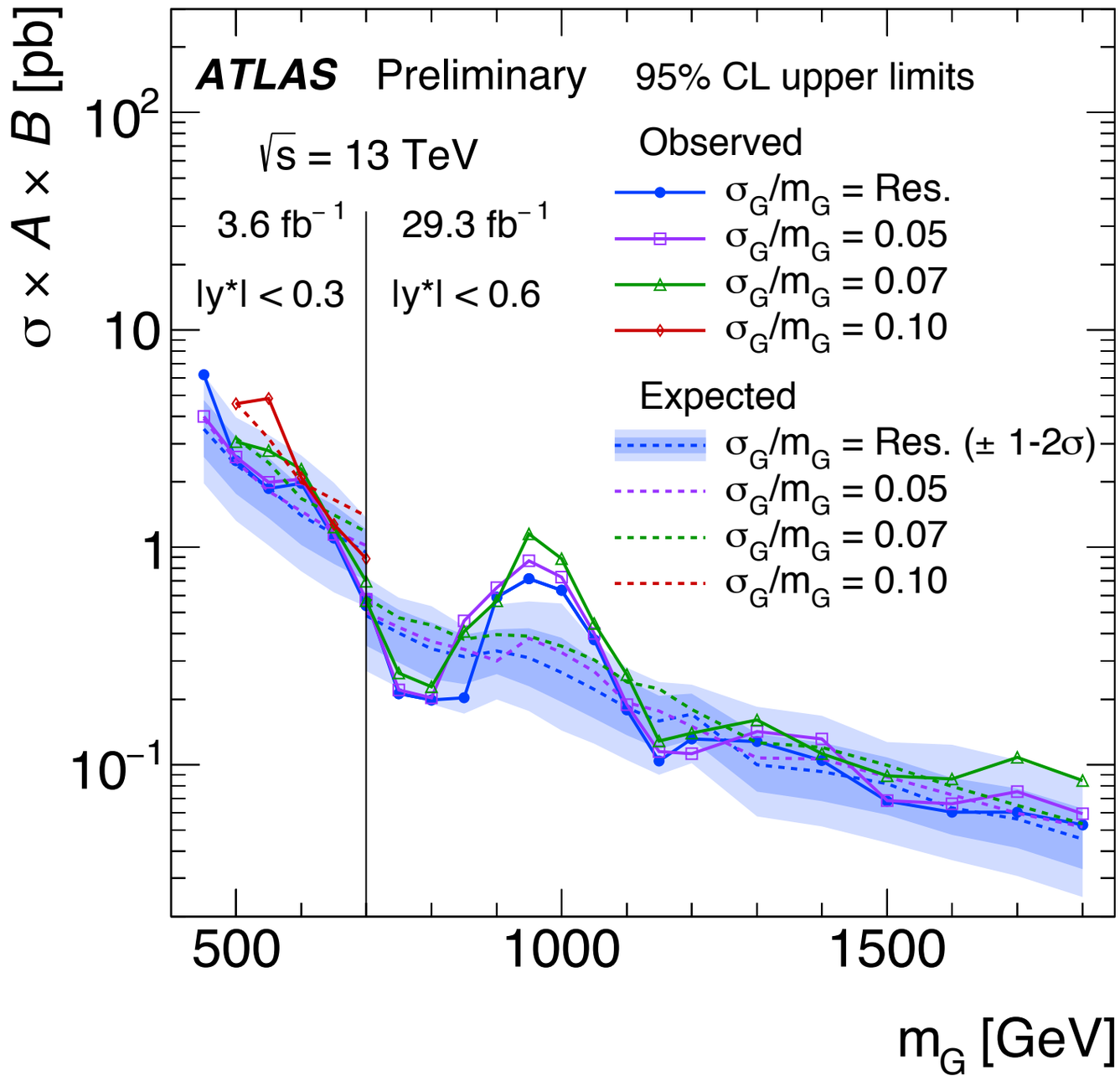
- No significant excess found. How far can we exclude our Z’ model?



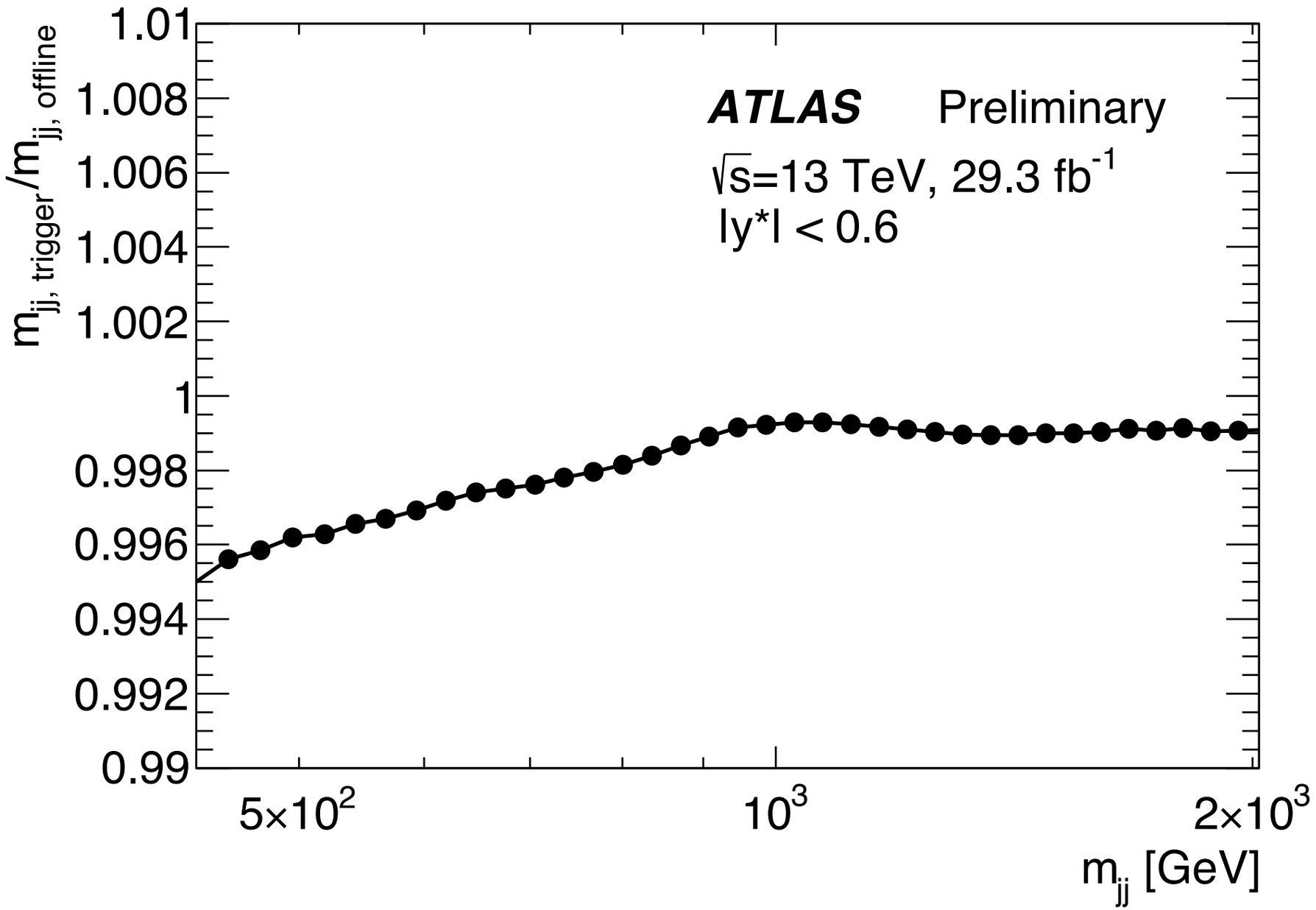
- New coupling limits down to as low as ~0.04.

*D. Abercrombie et al., Dark matter benchmark models for early LHC Run-2 searches: Report of the ATLAS/CMS Dark Matter Forum, 2015, arXiv: 1507.00966 [hep-ex]

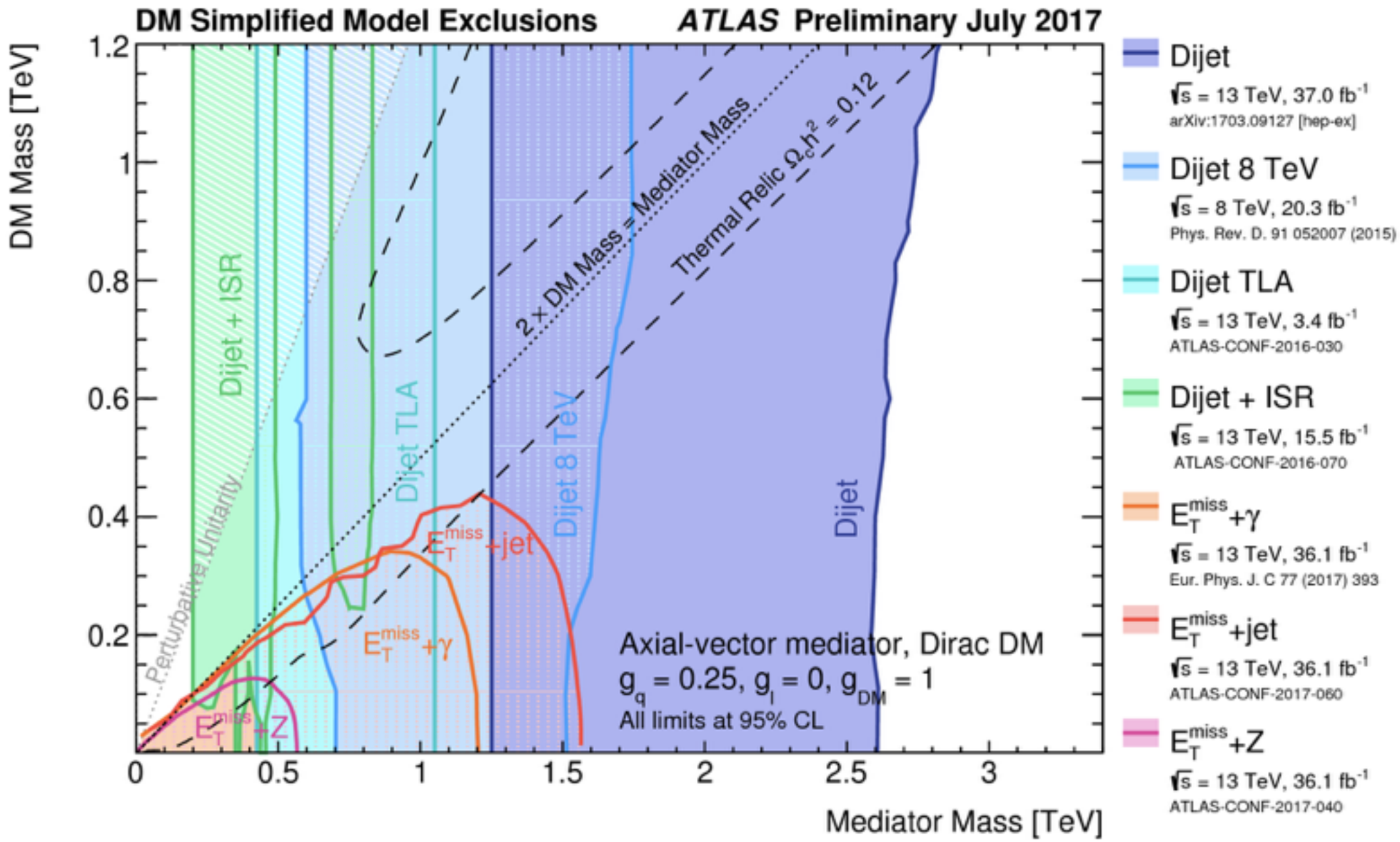
Limits on Gaussian Signals



Mass Resolution for Trigger Jets

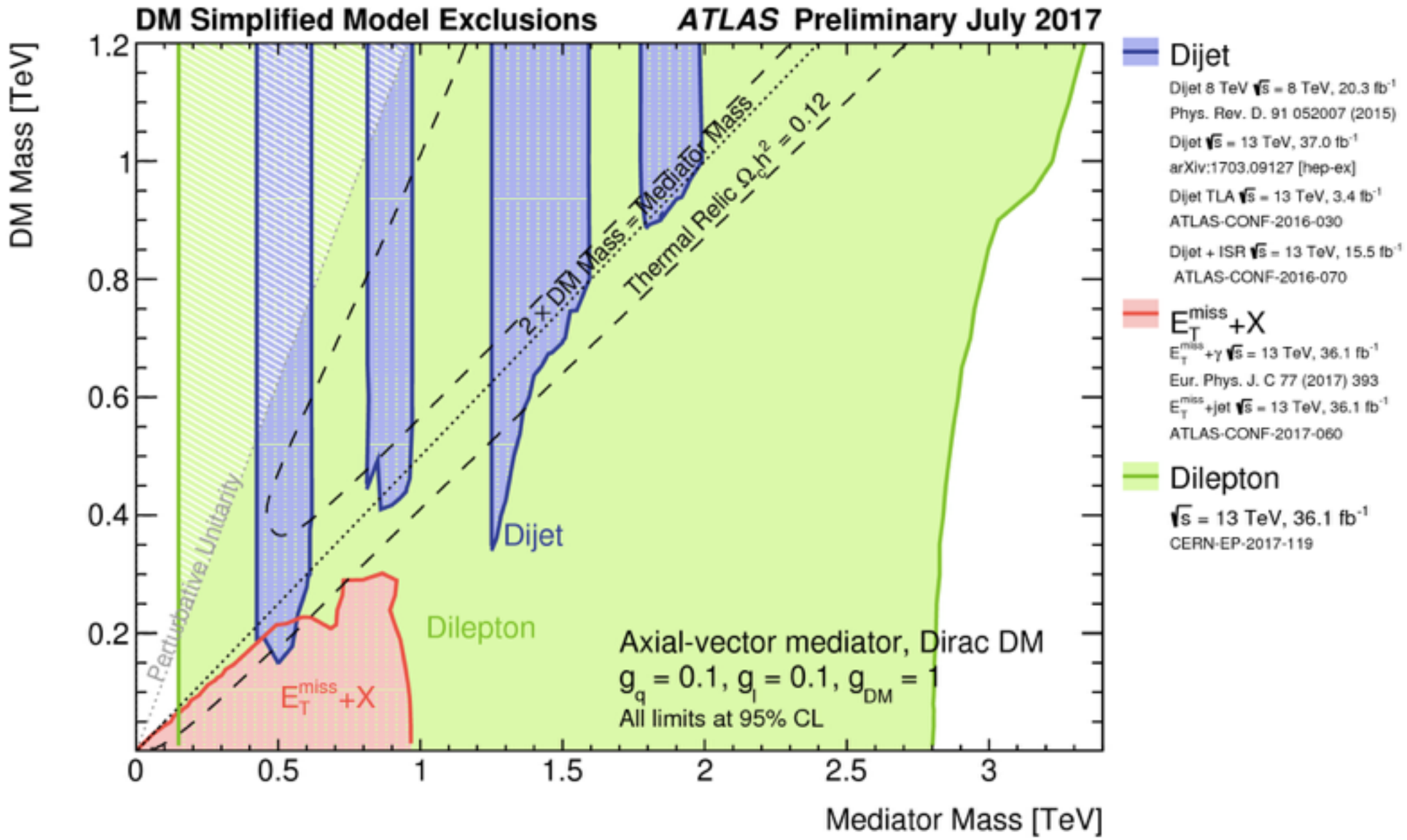


Summary Plot: DM mass - mediator mass plane



- Not updated for latest TLA and Dijet+ISR results.

Summary Plot: DM mass - mediator mass plane



- Not updated for latest TLA and Dijet+ISR results.