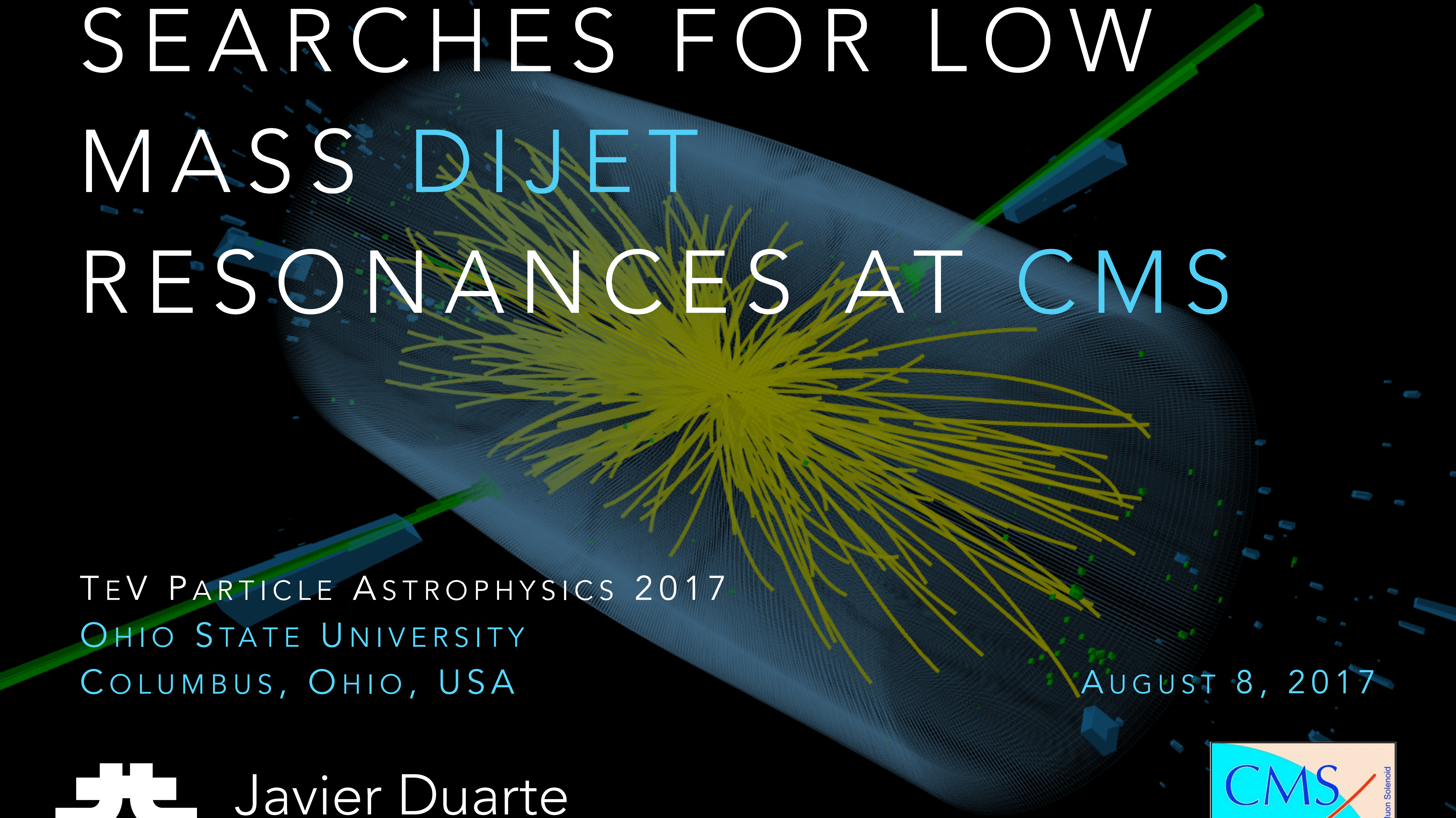
LOW MASS DIJET RESONANCES

SEARCHES FOR LOW MASS DIJET RESONANCES AT CMS



TeV Particle Astrophysics 2017

Ohio State University

Columbus, Ohio, USA

August 8, 2017

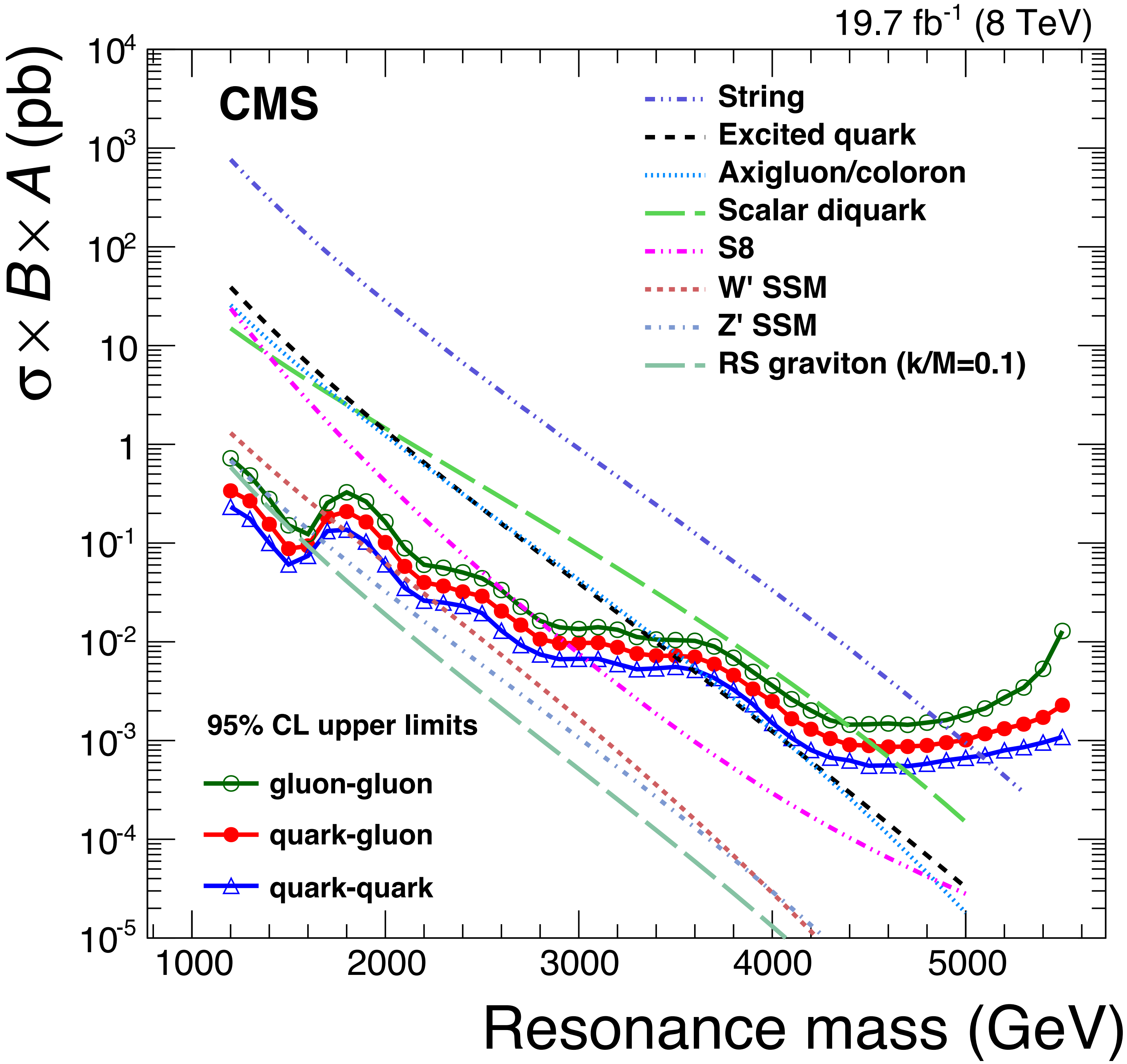
Javier Duarte

Fermilab

arXiv:1501.04198

A LOOK AT THE PHASE SPACE

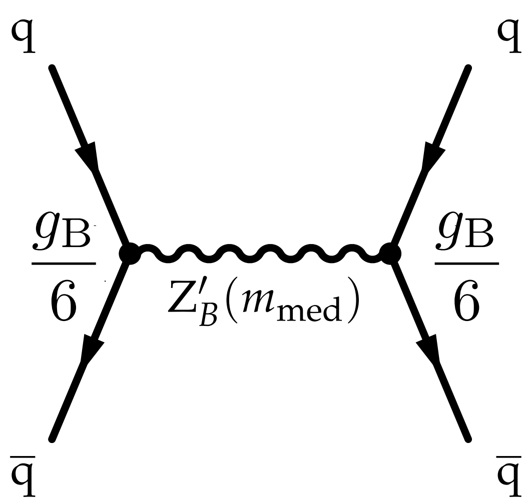
- Classic dijet search (Run 1) targets narrow resonances
- Sensitive to many signal models: axigluons, colorons, W′, Z′, excited quarks, string resonances, RS gravitons, S8 resonances, …
- But every model comes with a cross section assumption: low mass → very large cross section
- Have we really ruled out all possibilities at low mass?



arXiv:1306.2629

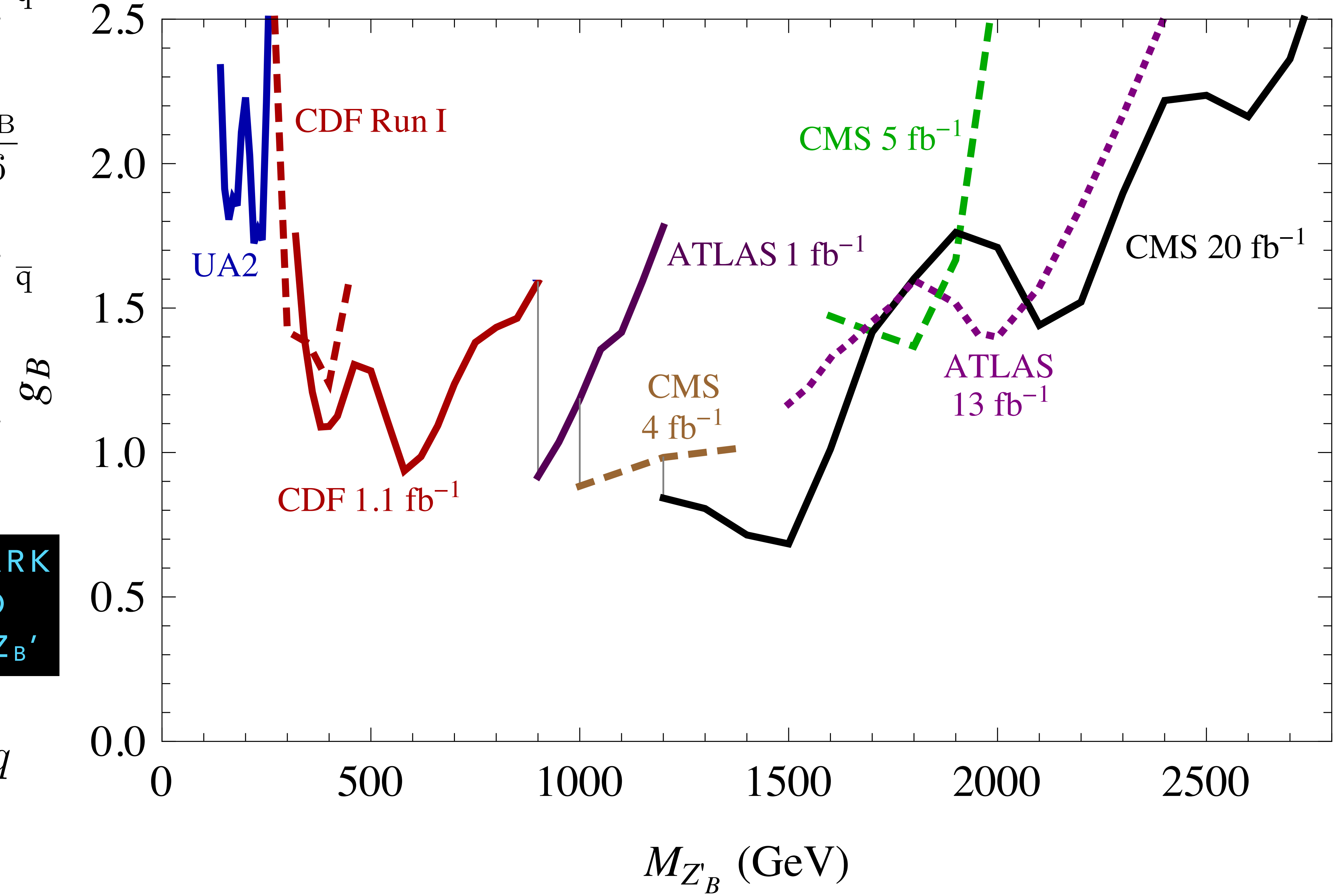
NEW LOOK AT THE PHASE SPACE

- Generic model with a leptophobic Z′ before Run 2



UNIVERSAL QUARK COUPLING TO LEPTOPHOBIC Z_B'

$$\mathcal{L} \propto \frac{g_B}{6} Z'_{B\mu} \bar{q} \gamma^{\mu} q$$



NEW LOOK AT THE PHASE SPACE

arXiv:1306.2629

- Due to trigger thresholds and larger backgrounds, standard dijet search @ LHC explores lower in coupling at higher masses

UNIVERSAL QUARK COUPLING TO LEPTOPHOBIC Z_B'

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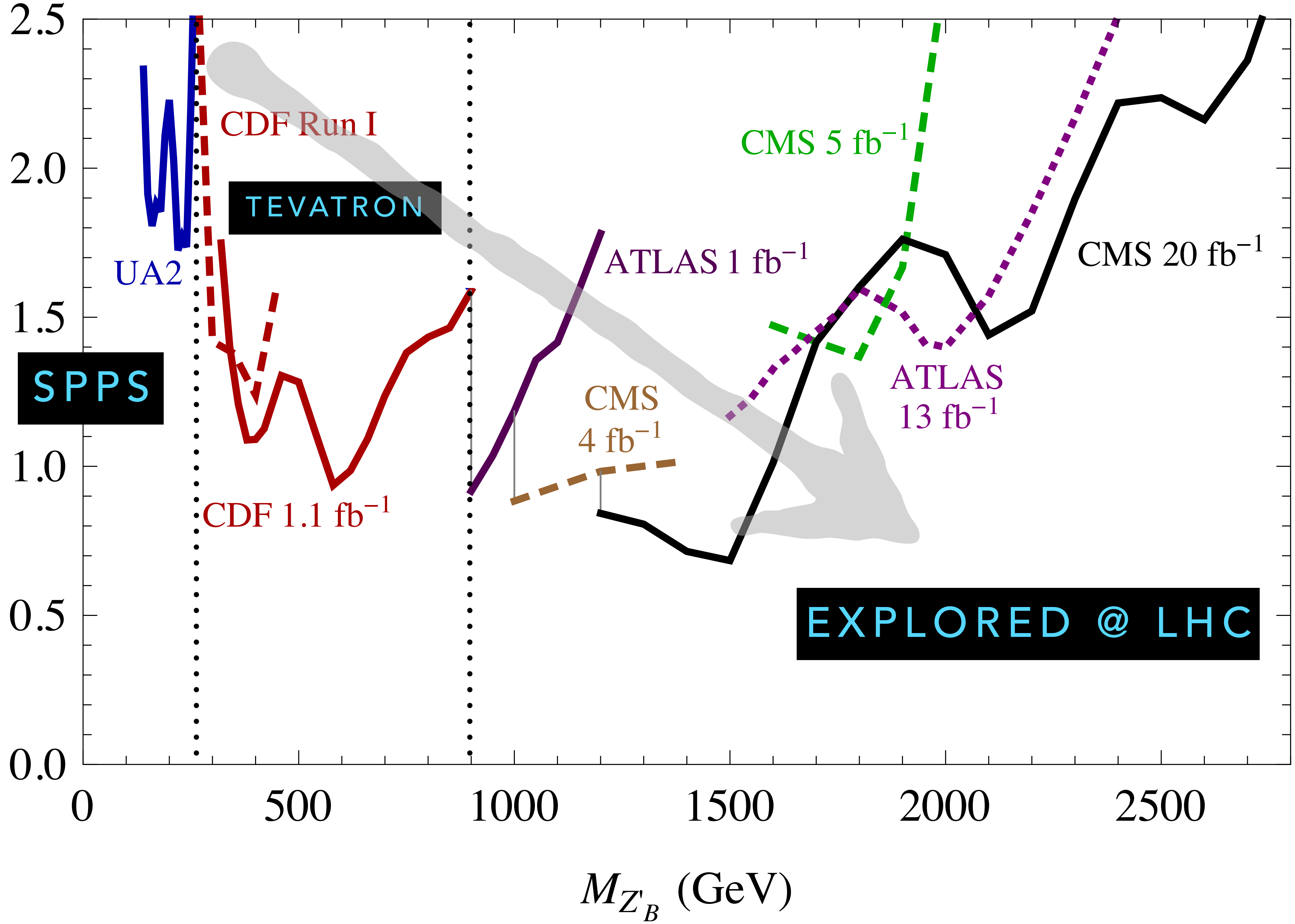
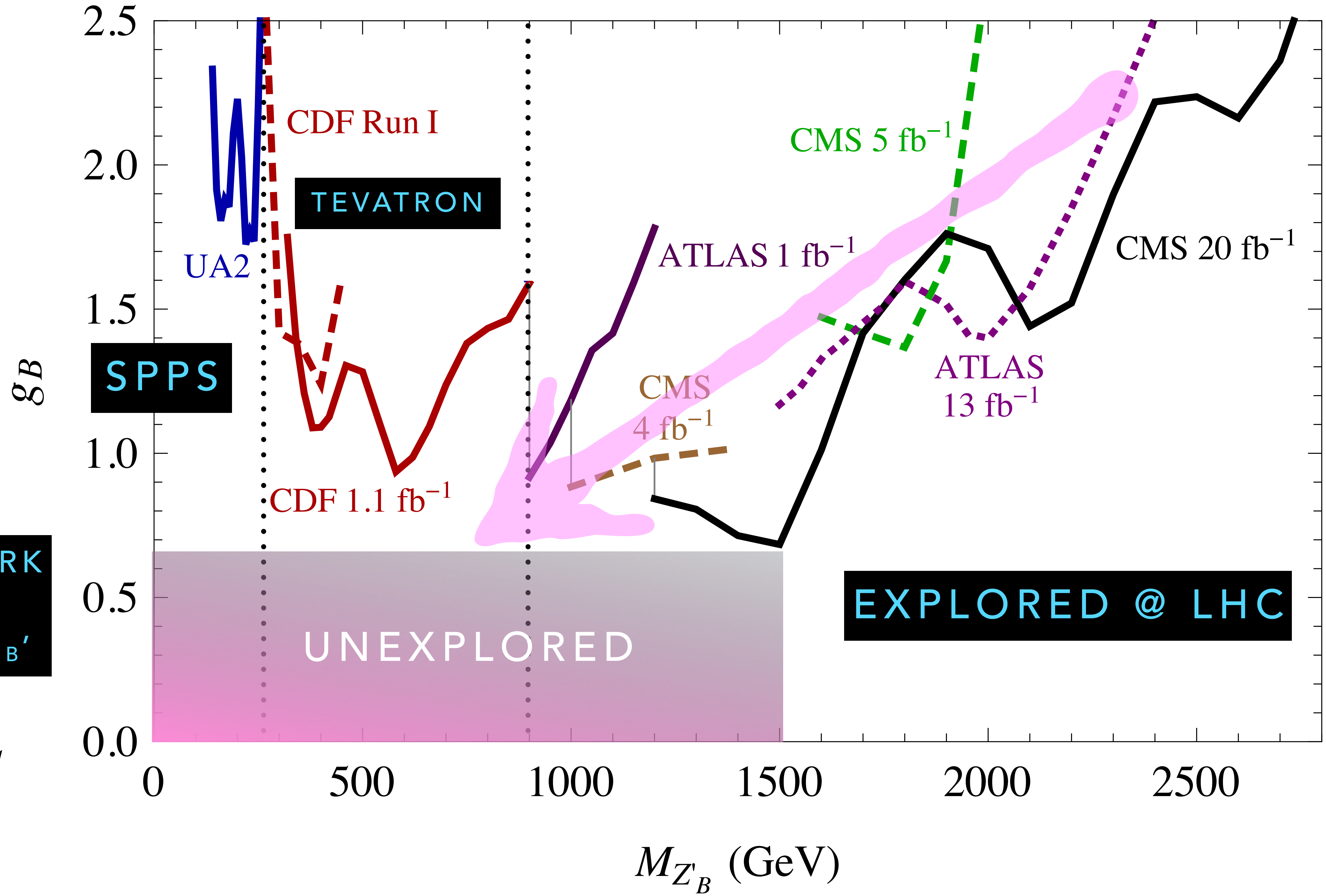


arXiv:1306.2629

NEW LOOK AT THE PHASE SPACE

- How can we go lower in coupling and lower in mass?

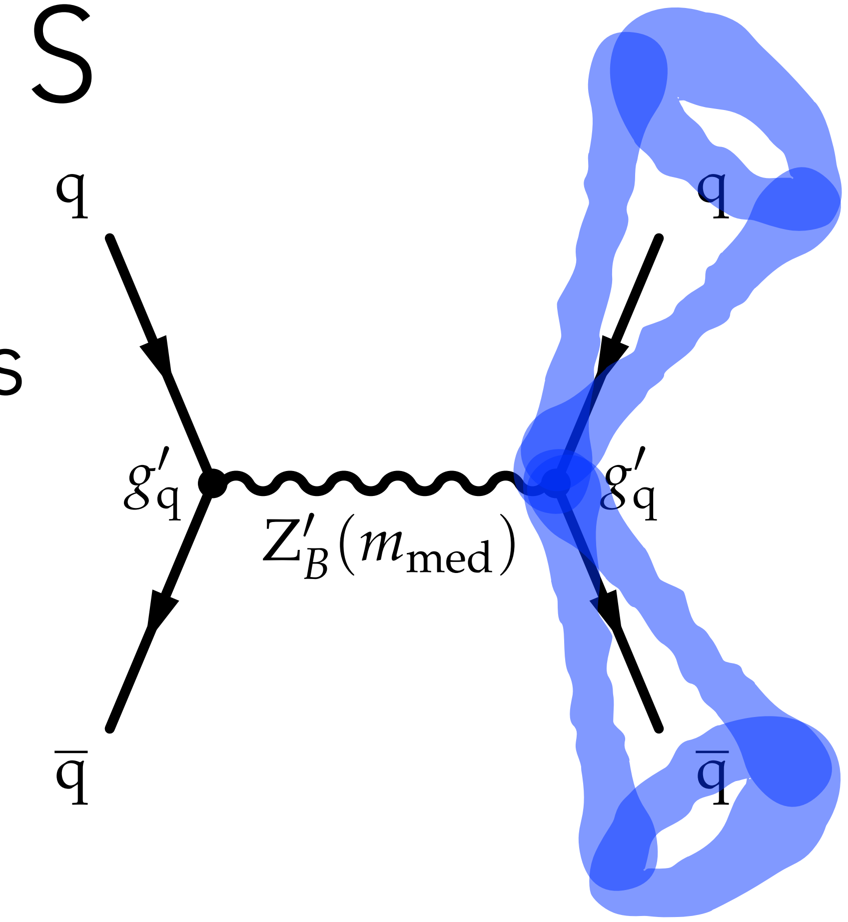


UNIVERSAL QUARK COUPLING TO LEPTOPHOBIC Z_B'

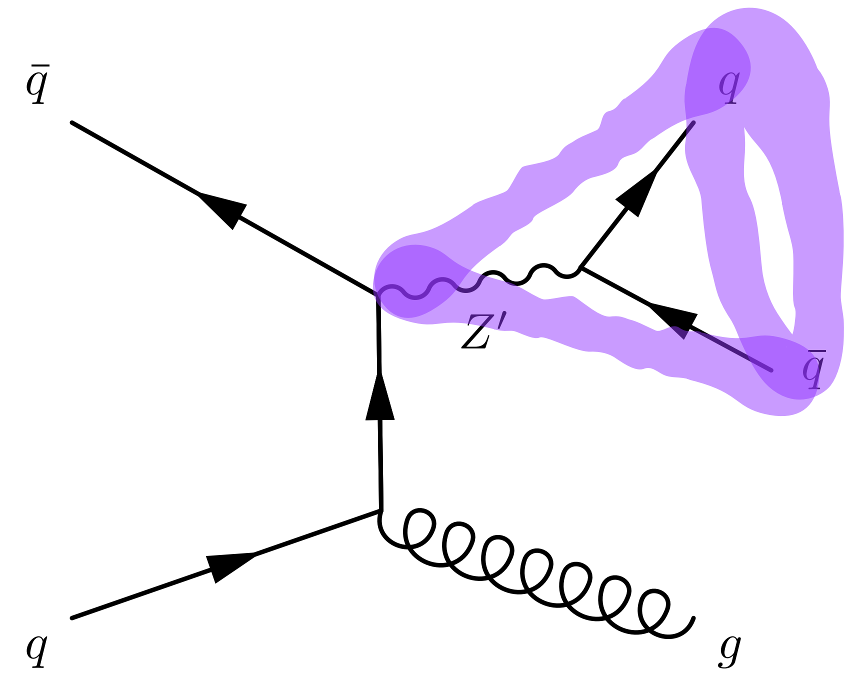
$$\mathcal{L} \propto \frac{g_B}{6} Z'_{B\mu}\bar{q}\gamma^{\mu}q$$

TWO METHODS

- **Data scouting**: lower trigger thresholds by recording only information necessary to perform analysis (to get around data-taking constraints)

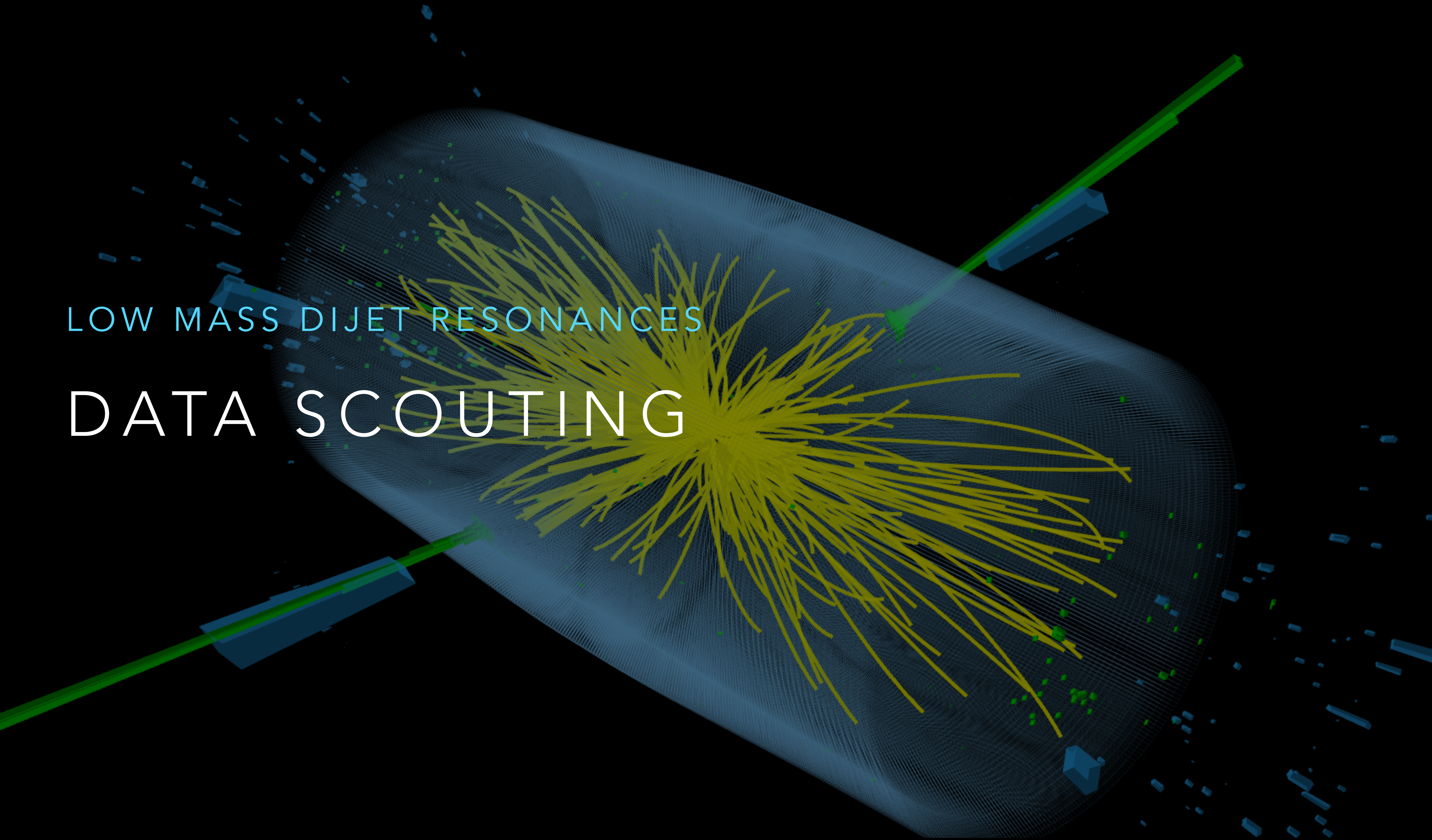


- **Boosted dijets + associated ISR jet**: Use ISR jet to get above the trigger thresholds



LOW MASS DIJET RESONANCES

DATA SCOUTING



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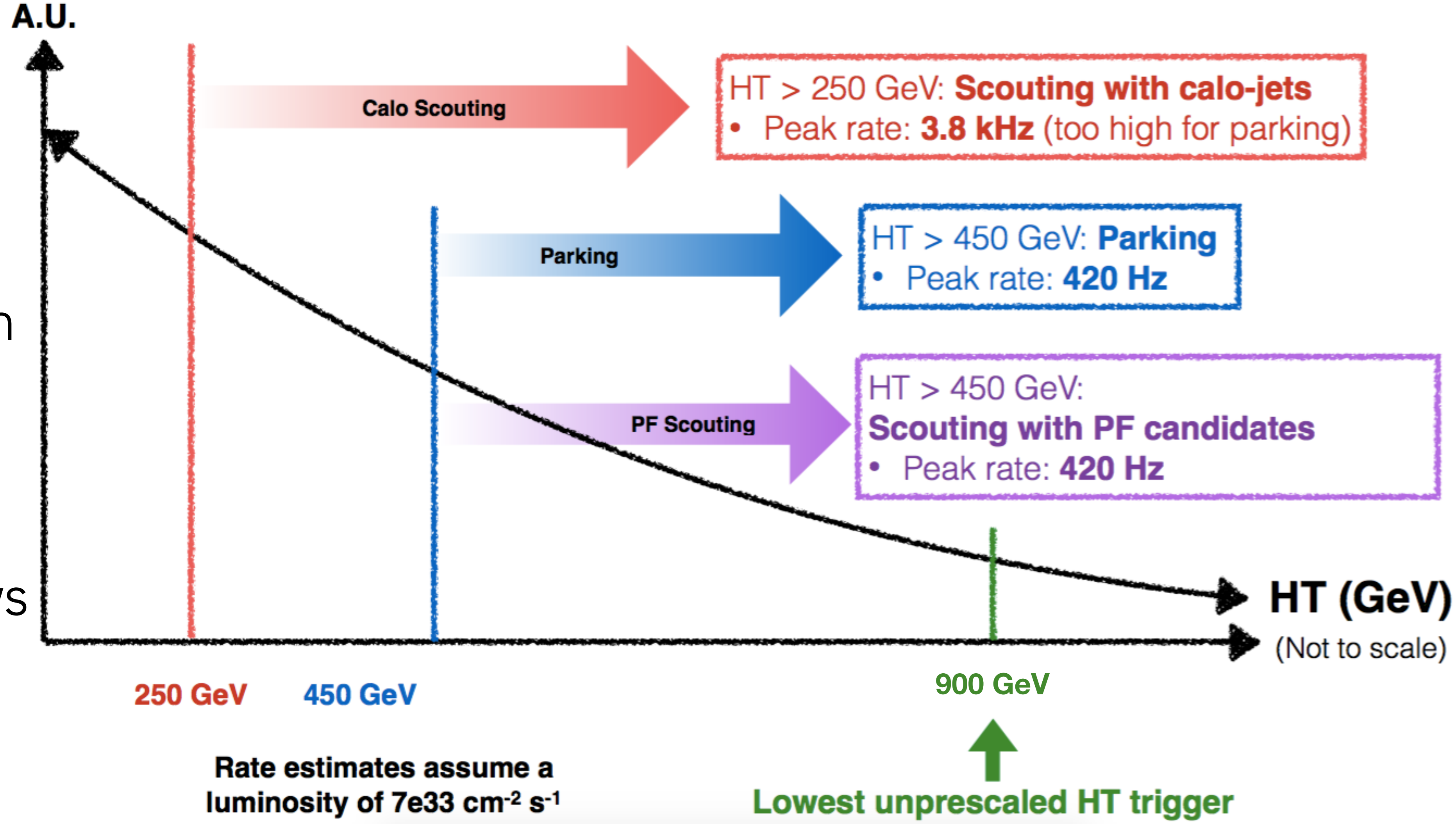
[D. Anderson "Data Scouting at CMS" 2015 IEEE NSS/MIC]

DATA SCOUTING

- How can we trigger below H_T = 900 GeV?
- ***Reconstruct/save*** only necessary information to perform analysis → record more events
- ***Calibrate*** using data stream containing both reduced content and standard content
- "**Calo Scouting**" allows us to get down to **H_T > 250 GeV**

Calo Scouting

4kHz × 1.5 kb



LOW MASS SPECTRUM AND FIT

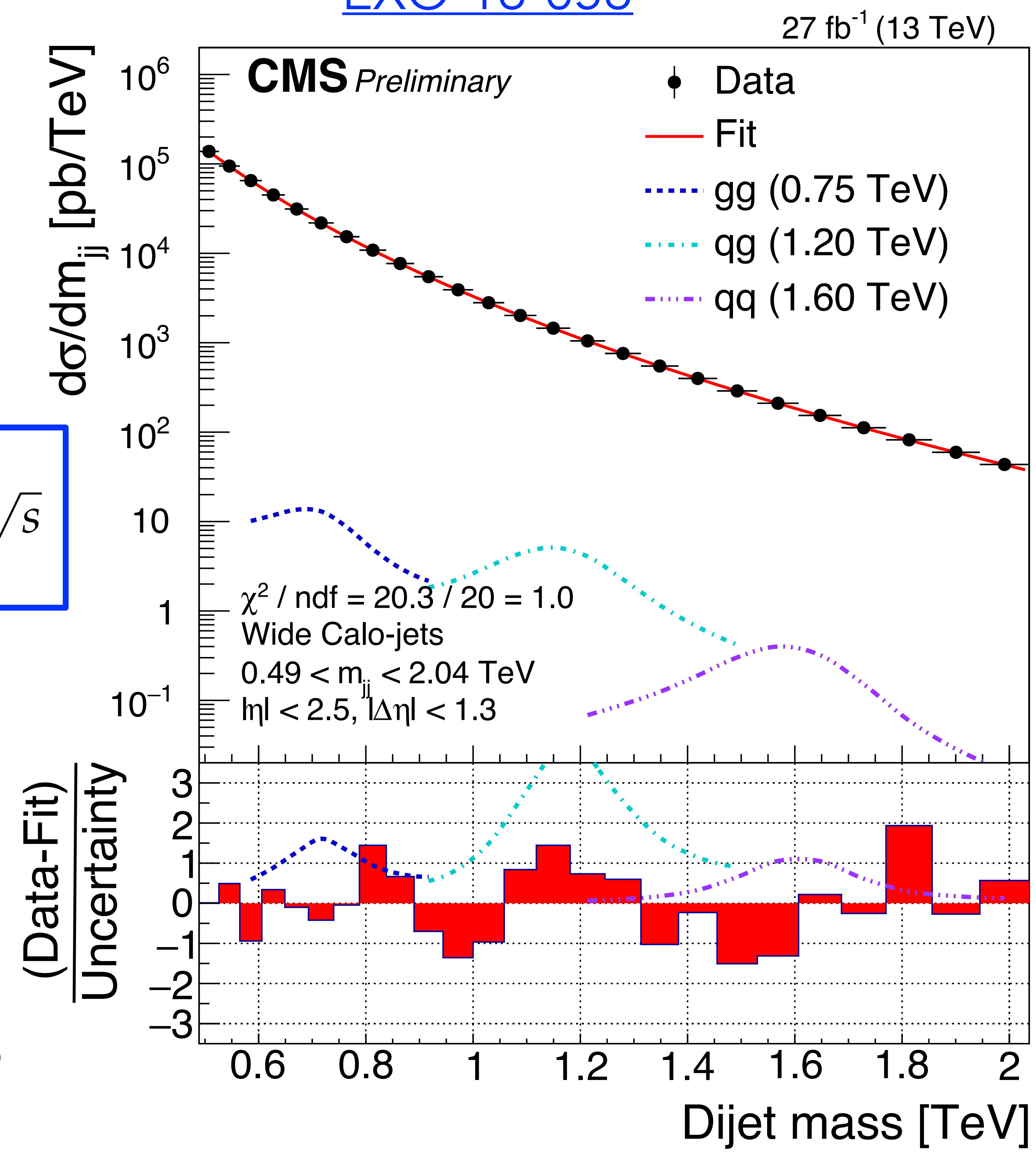
EXO-16-056

- Using "Calo Scouting," **low mass** spectrum* is fit with 5-parameter function above $m_{jj} > 489$ GeV

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)+P_4\ln(x)^2}} \quad x = m_{jj}/\sqrt{s}$$

- χ^2/dof = 1.0
- No evidence for dijet resonance

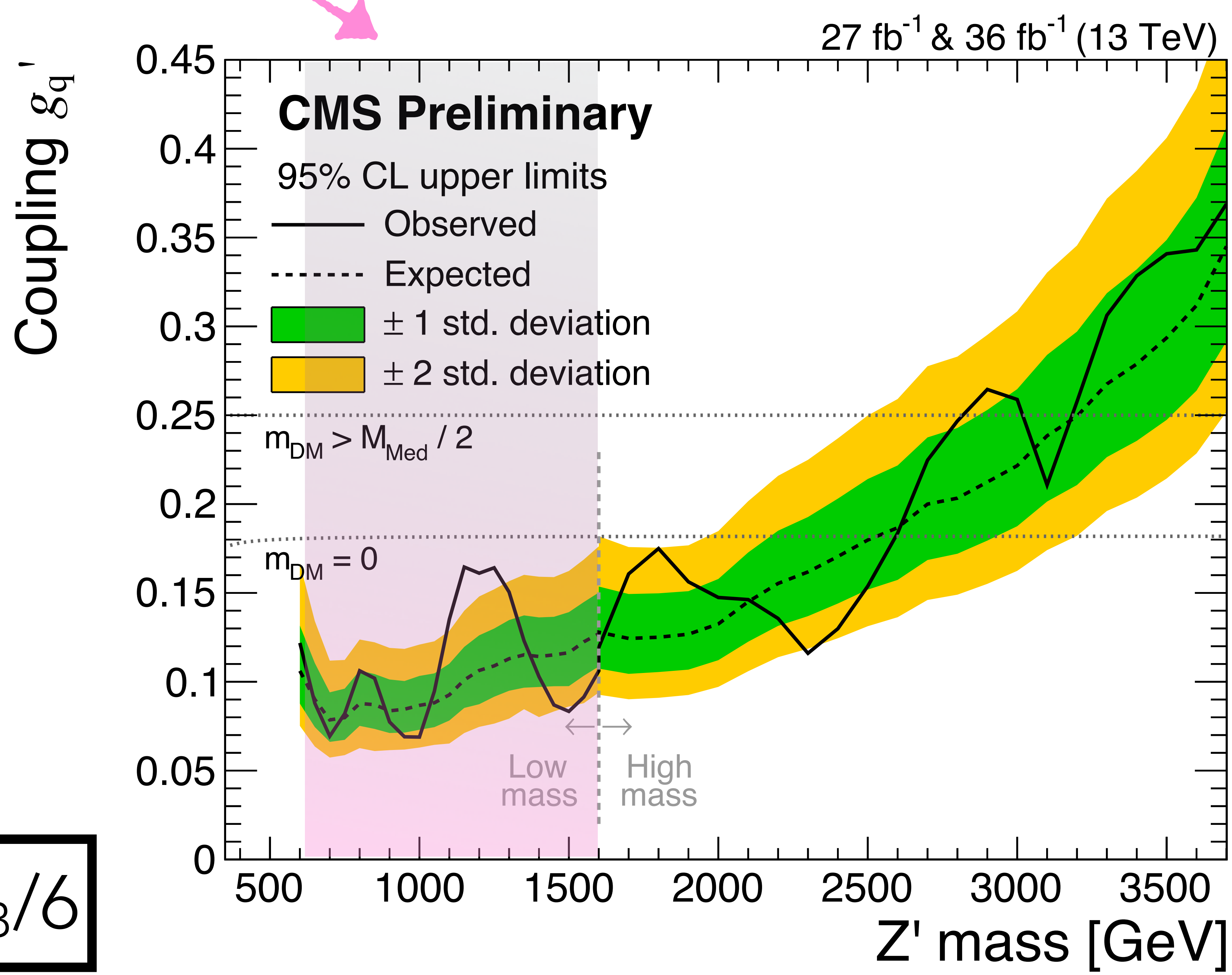
* Note: only the first 27 fb^{-1} is used due to an inefficiency in the L1 jet H_T trigger



LIMITS ON NARROW RESONANCES

EXO-16-056

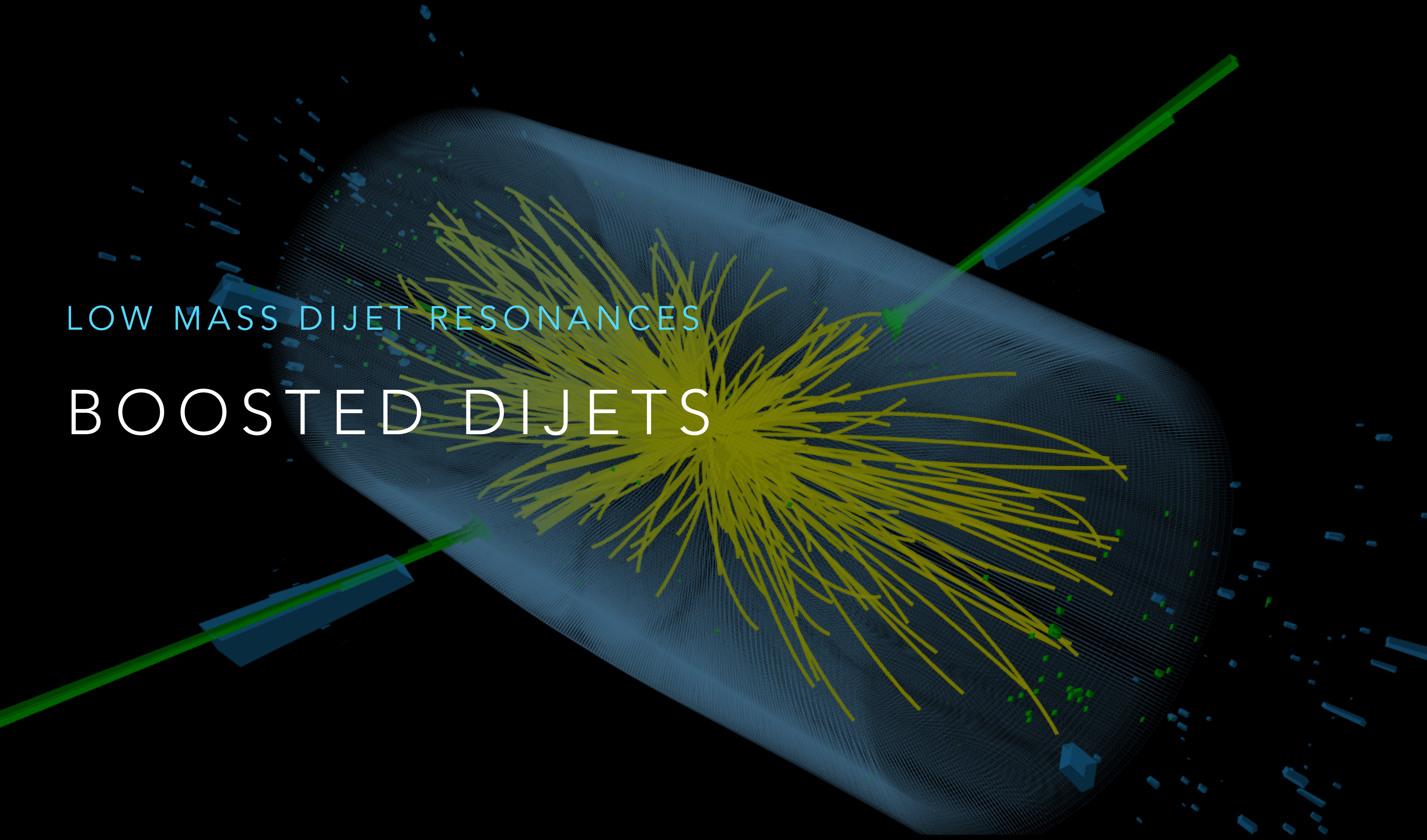
- Expanded CMS reach at low mass



$g_q' = g_B/6$

LOW MASS DIJET RESONANCES

BOOSTED DIJETS



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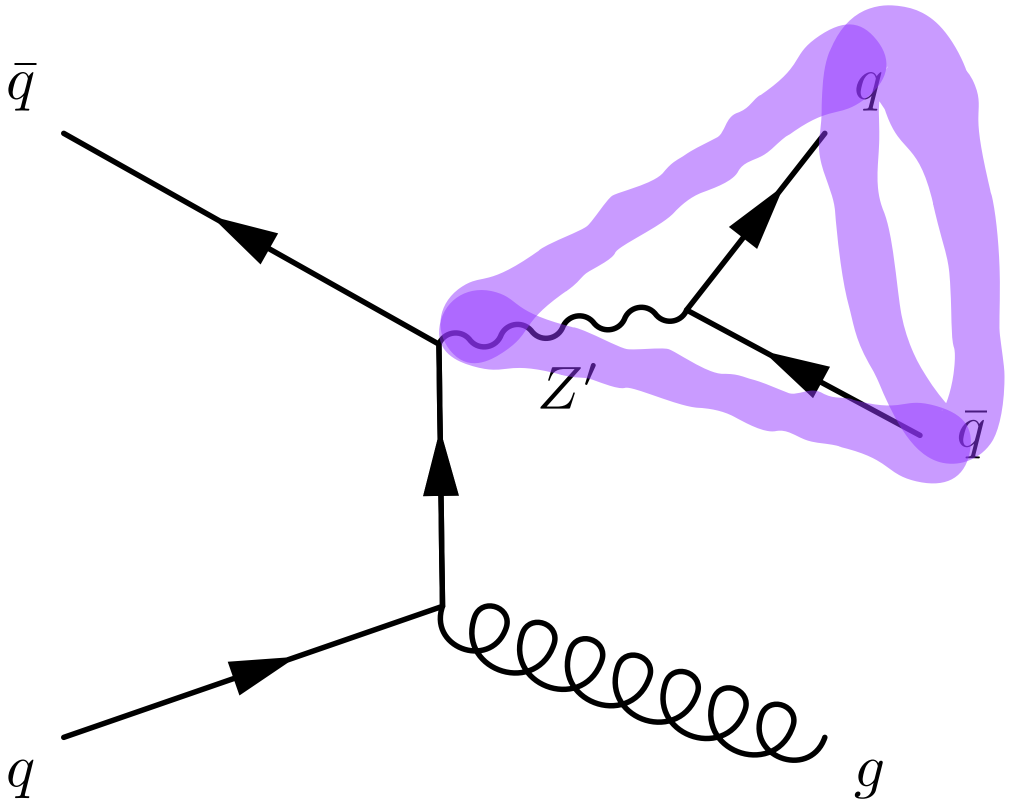
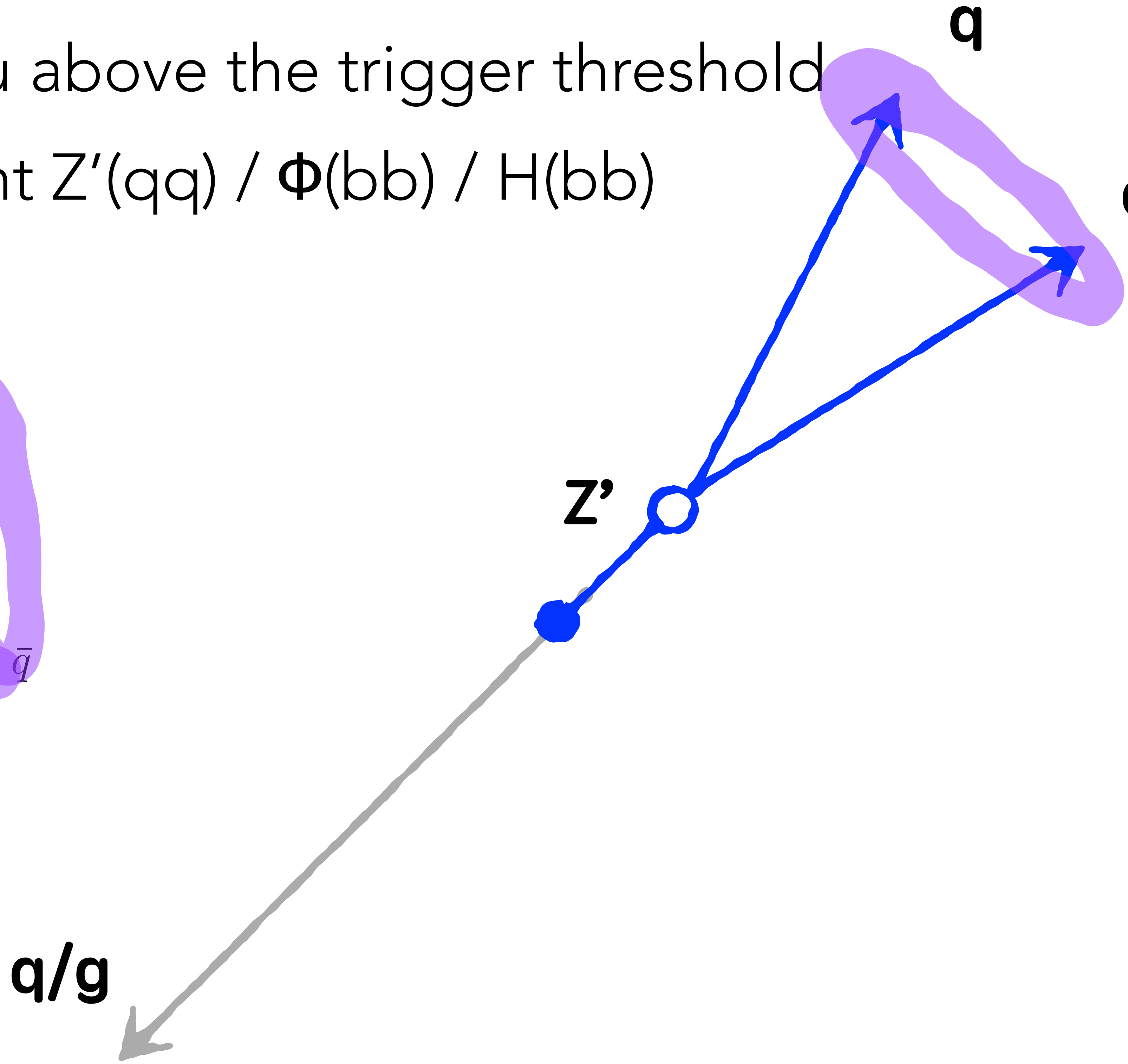
ASSOCIATED ISR JET TOPOLOGY

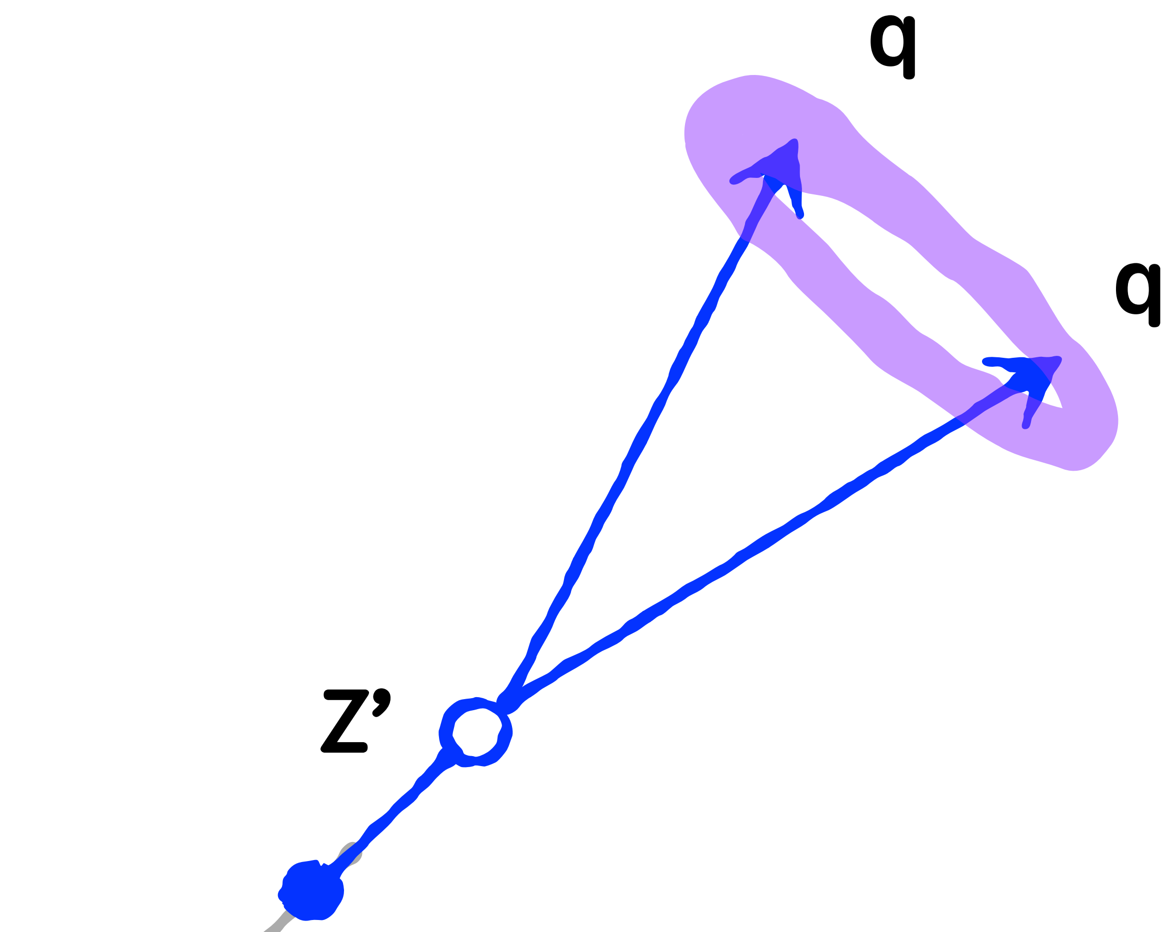
- Use ISR jet to get you above the trigger threshold
- Look for boosted light Z′(qq) / **Φ**(bb) / H(bb) resonance

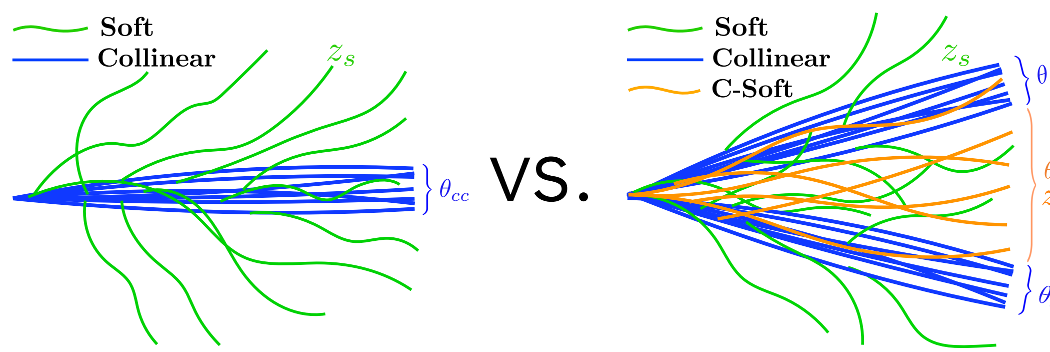




ANALYSIS SELECTION

- Online selection:
  - jet p_T > 360 GeV (m > 30 GeV) or H_T > 900 GeV
- Offline selection:
  - jet p_T > 500 GeV, $|\eta|$ < 2.5
- Substructure selection:
  - Soft drop jet mass > 40 GeV
  - $\mathbf{N^1_2}^{\mathbf{DDT}}$ (5% QCD eff. WP)
- Backgrounds:
  - QCD
  - SM Candles: W/Z + jets

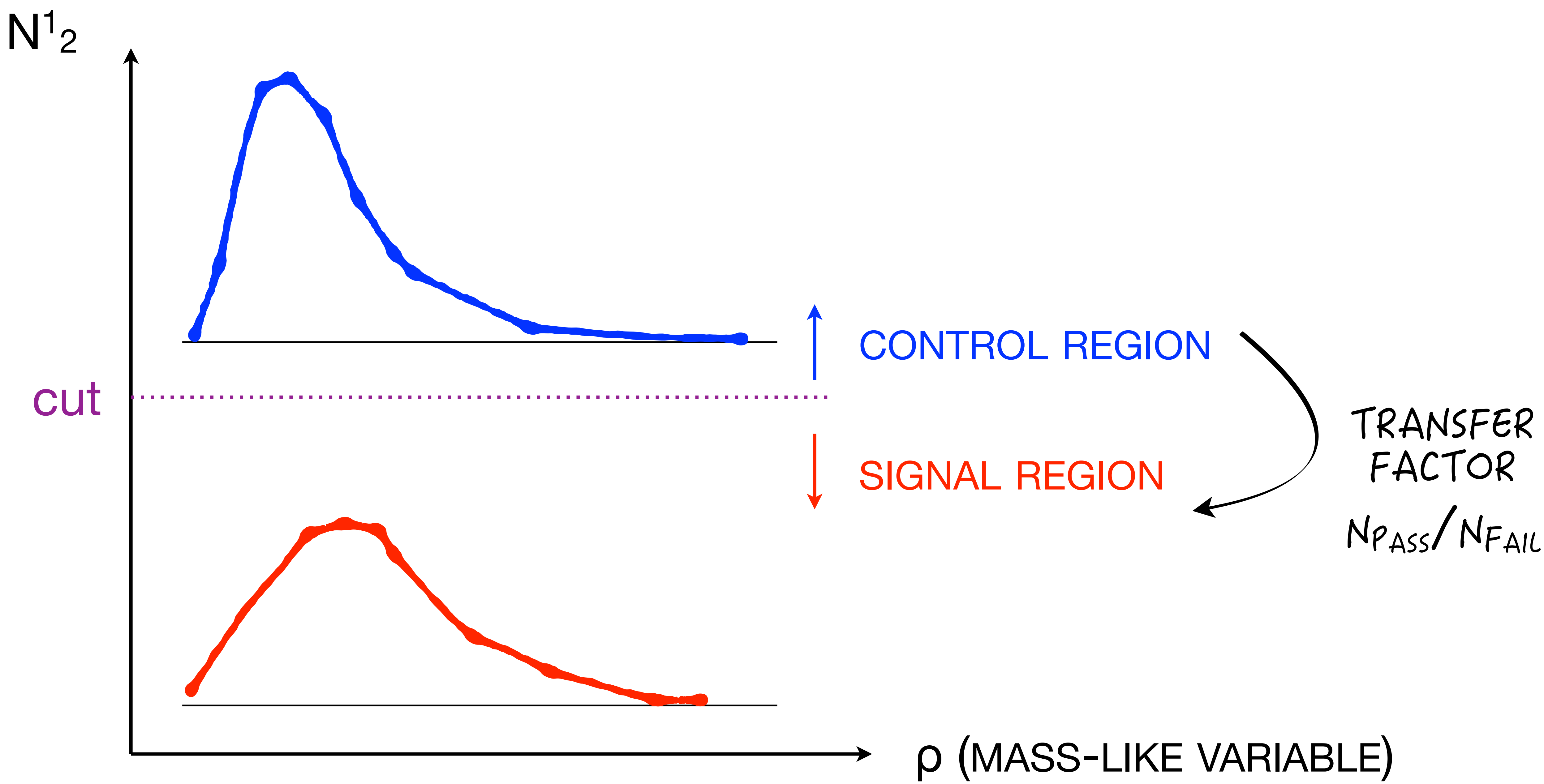




arXiv:1609.07483

SIDEBAND QCD PREDICTION

- Core idea: predict QCD jet mass distribution from failing region
- Problem: cut on N^1_2 sculpts jet mass distribution!

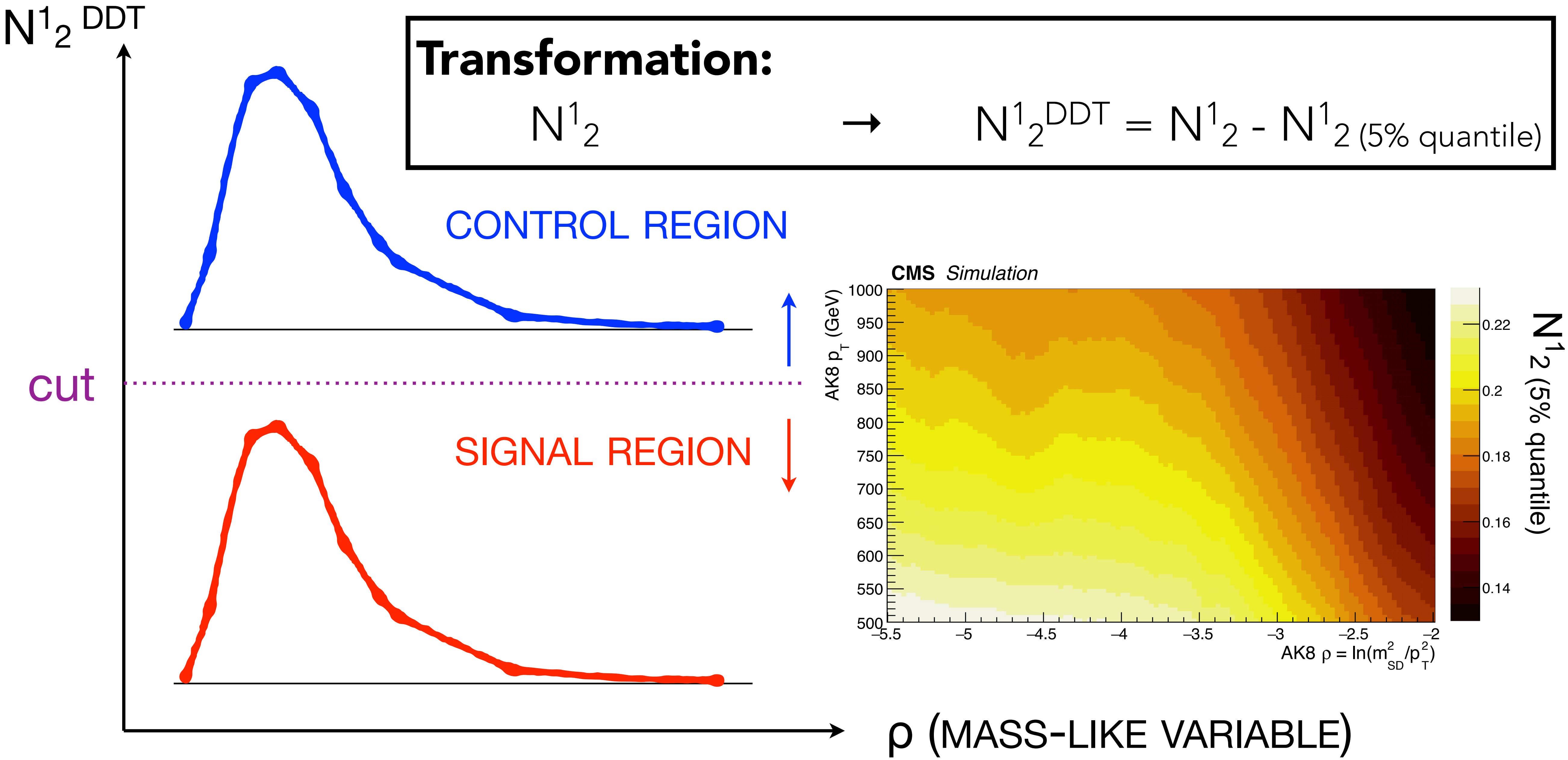


SIDEBAND QCD PREDICTION

- Solution: define new substructure variable intended to be decorrelated from jet mass

Transformation:

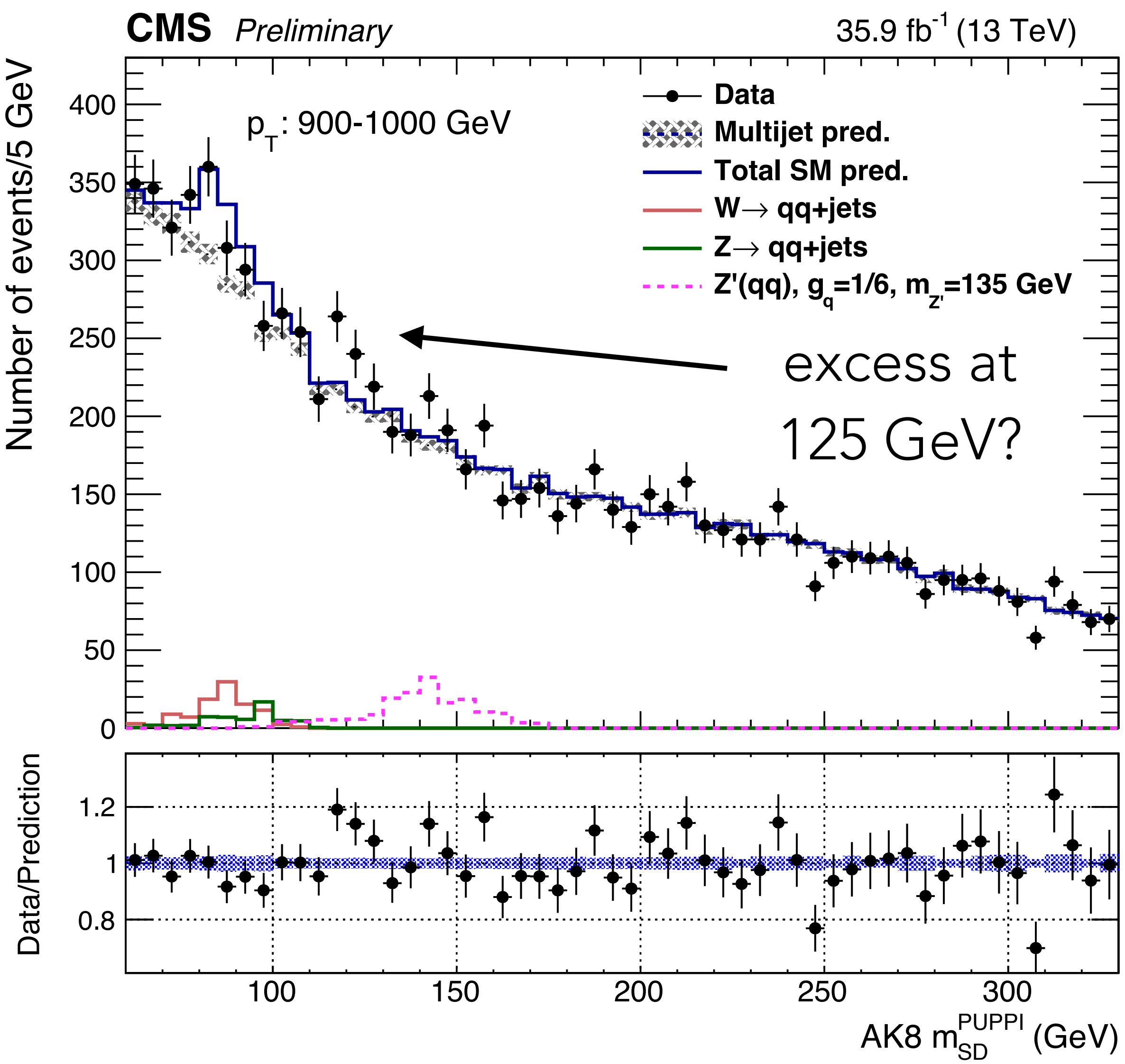
$N^1_2 \rightarrow N^{1,DDT}_2 = N^1_2 - N^1_{2\,(5\%\ \text{quantile})}$



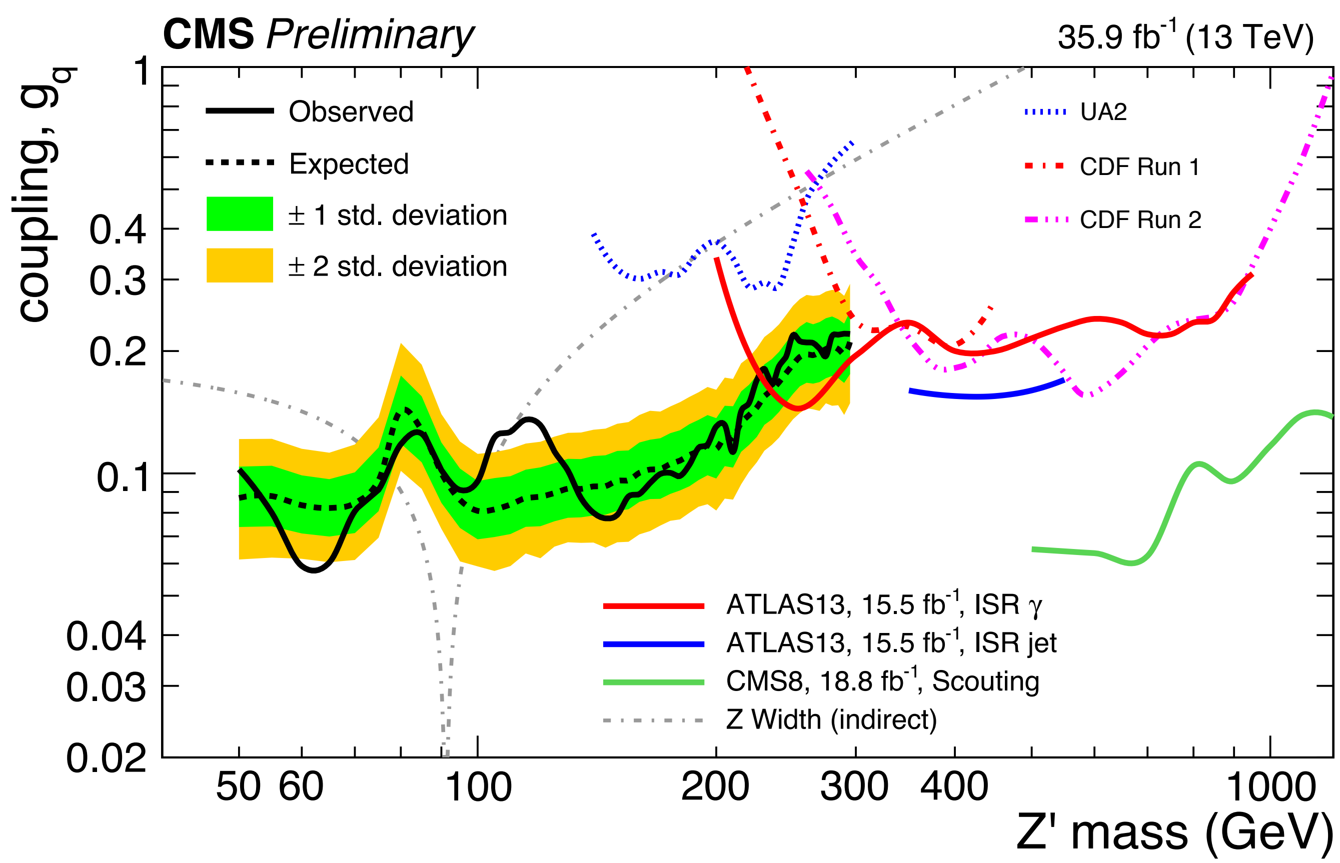
[EXO-17-001](#)

Z′ INTERPRETATION

- Jet mass distribution is fit down to 40 GeV
- Interpretation for resonance masses down to 50 GeV (!)



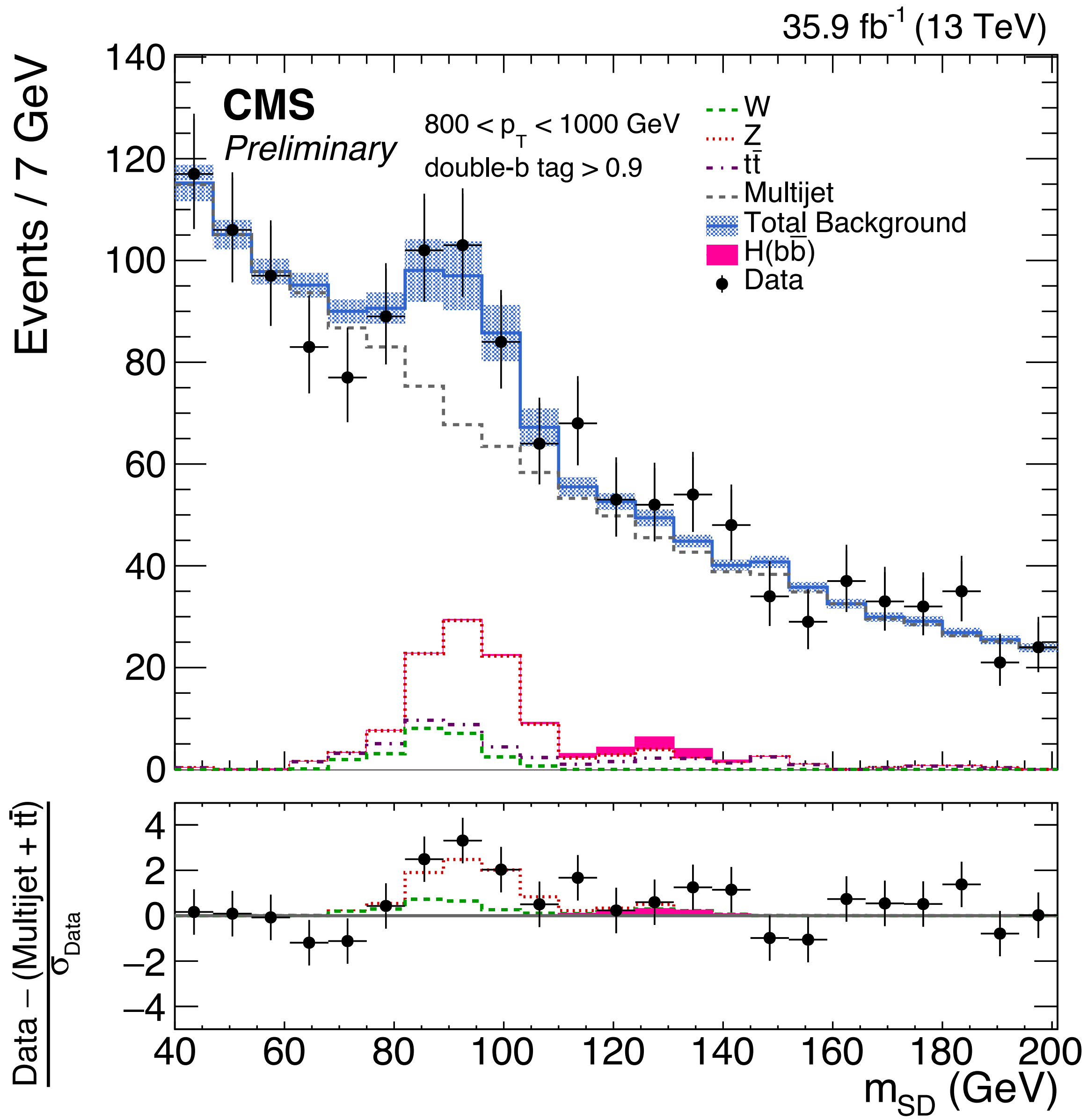
SM candles: W/Z(qq) peak provides
in-situ constraint of Z′(qq) signal systematics



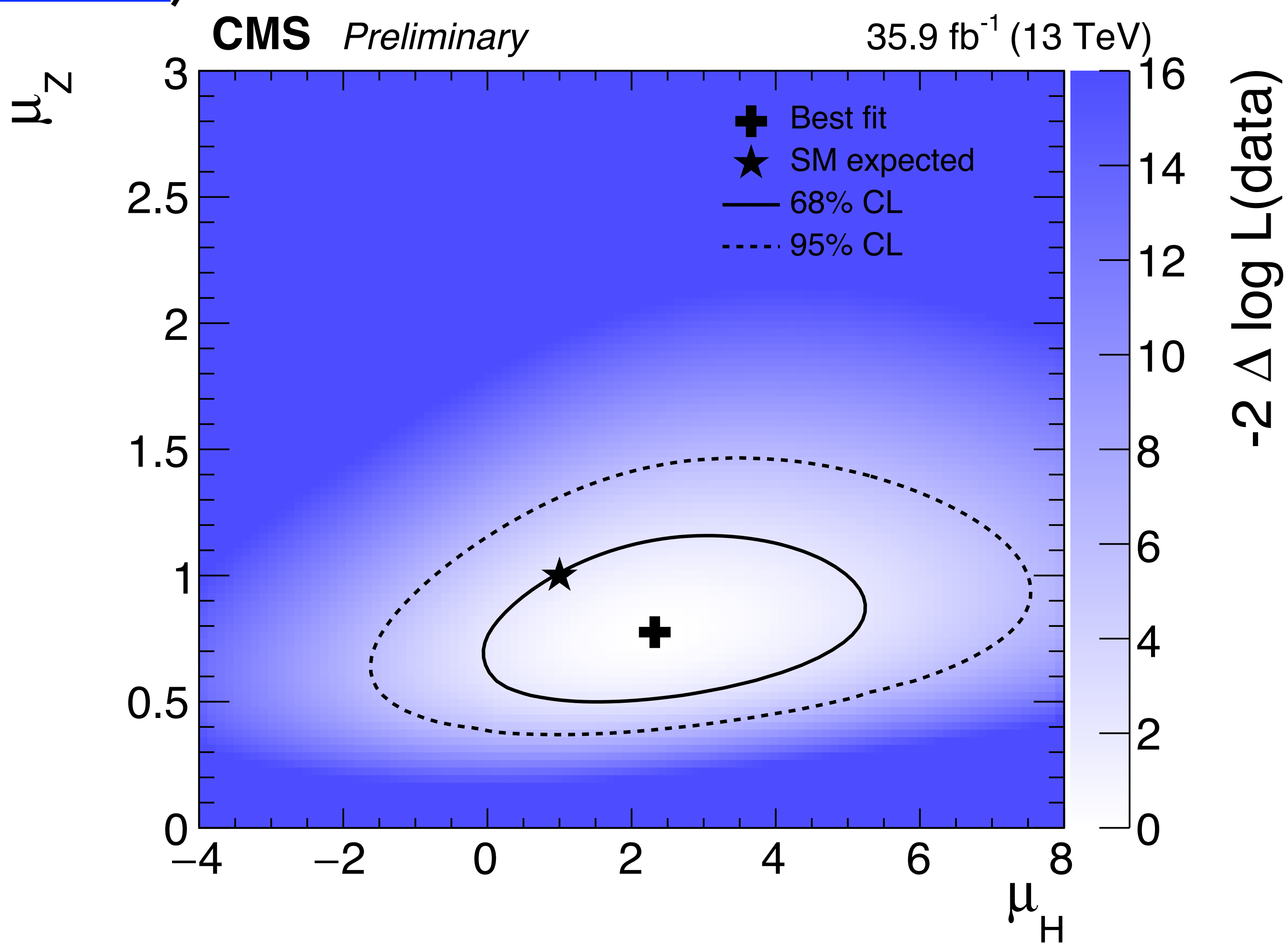
$\boxed{g_q = g_B/6}$

HIGGS TO BB?

- Similar background estimation strategy using CMS double-b tagger (BTV-15-002)



SM candles: Z(bb) peak provides in-situ constraint of H(bb) signal systematics

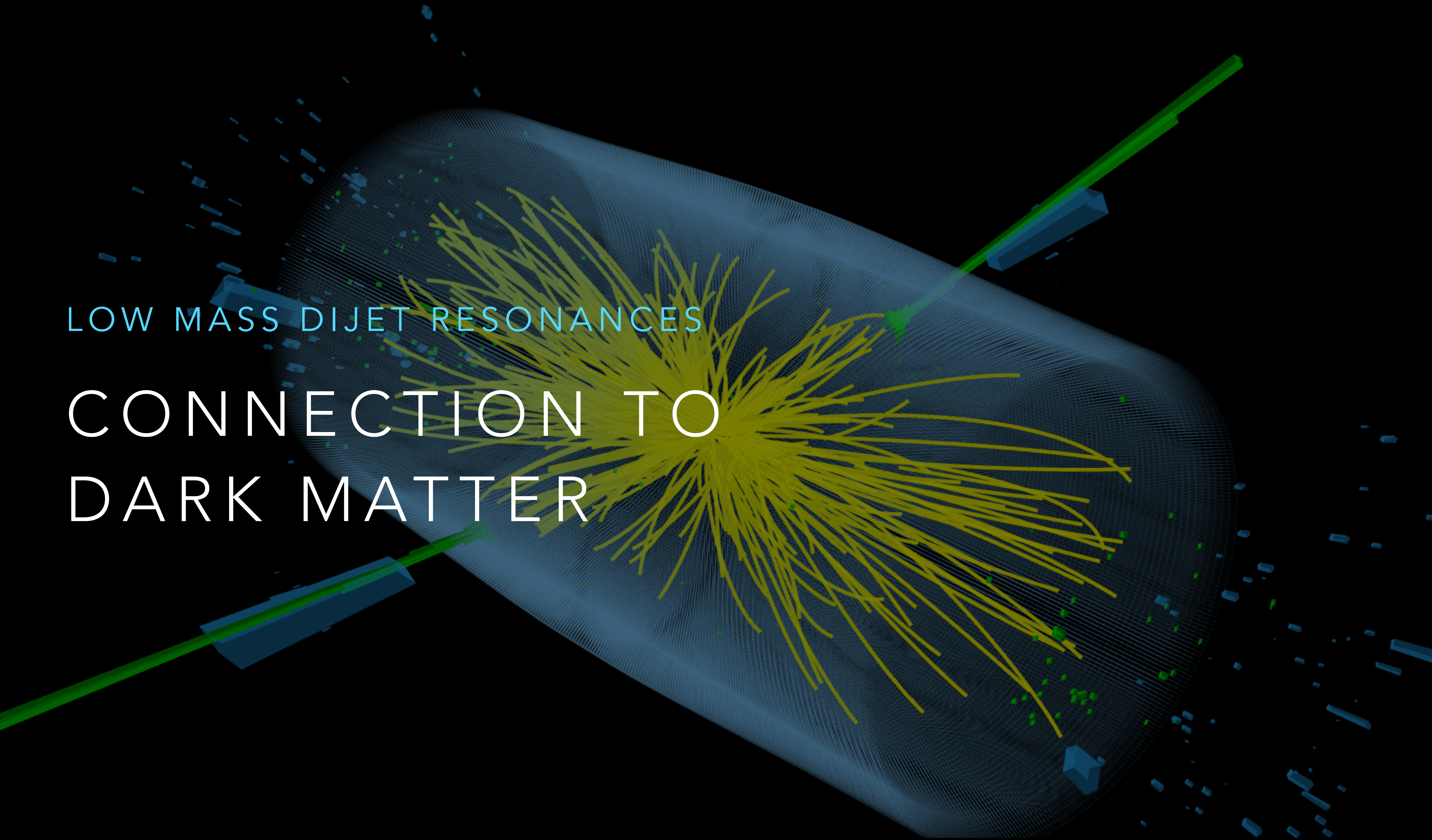


5.1σ Z(bb) — $\mu_Z = 0.78^{+0.23}_{-0.19}$

1.5σ H(bb) — $\mu_H = 2.3^{+1.8}_{-1.6}$

LOW MASS DIJET RESONANCES

CONNECTION TO DARK MATTER



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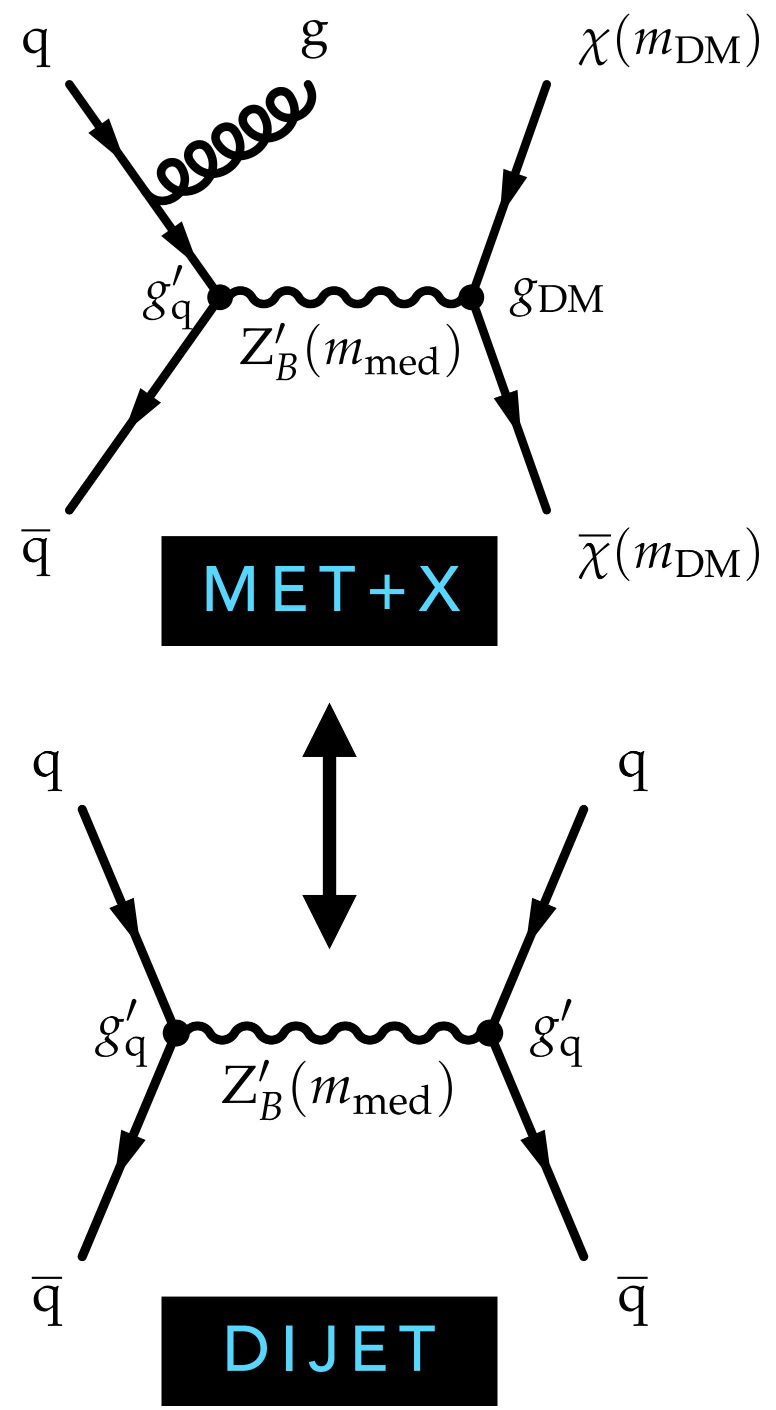
DARK MATTER MEDIATOR

- If our leptophobic Z′ couples to **dark matter** as well **quarks**, then it acts as **mediator** between the dark sector and visible sector (SM)
- How do our limits on the mediator change as we turn on $\mathbf{g_{DM}} > 0$ and $\mathbf{m_{DM}} < m_M/2$?

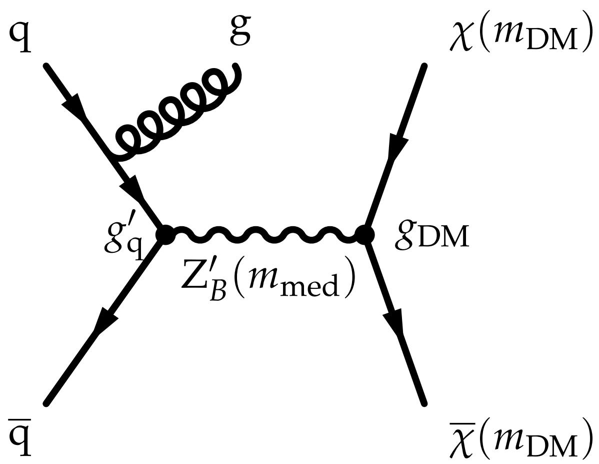
$$\mathcal{L}_{\mathrm{V}} = -\boxed{g_{\mathrm{DM}} Z'_{B\mu} \bar{\chi} \gamma^{\mu} \chi} - \boxed{g'_{\mathrm{q}} \sum_{\mathrm{q}} Z'_{B\mu} \bar{q} \gamma^{\mu} q}$$

4D parameter space: $\mathbf{g_{DM}}$, $\mathbf{g_q}$, $\mathbf{m_{DM}}$, $\mathbf{m_M}$

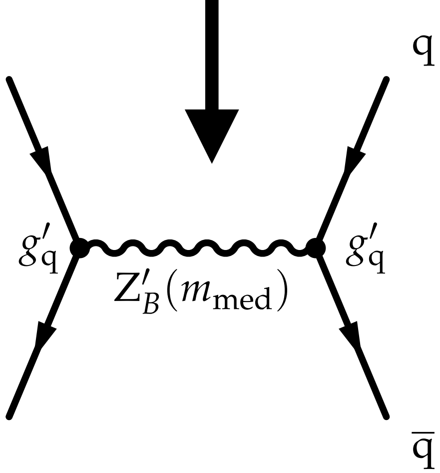


SENSITIVITY TO DARK MATTER

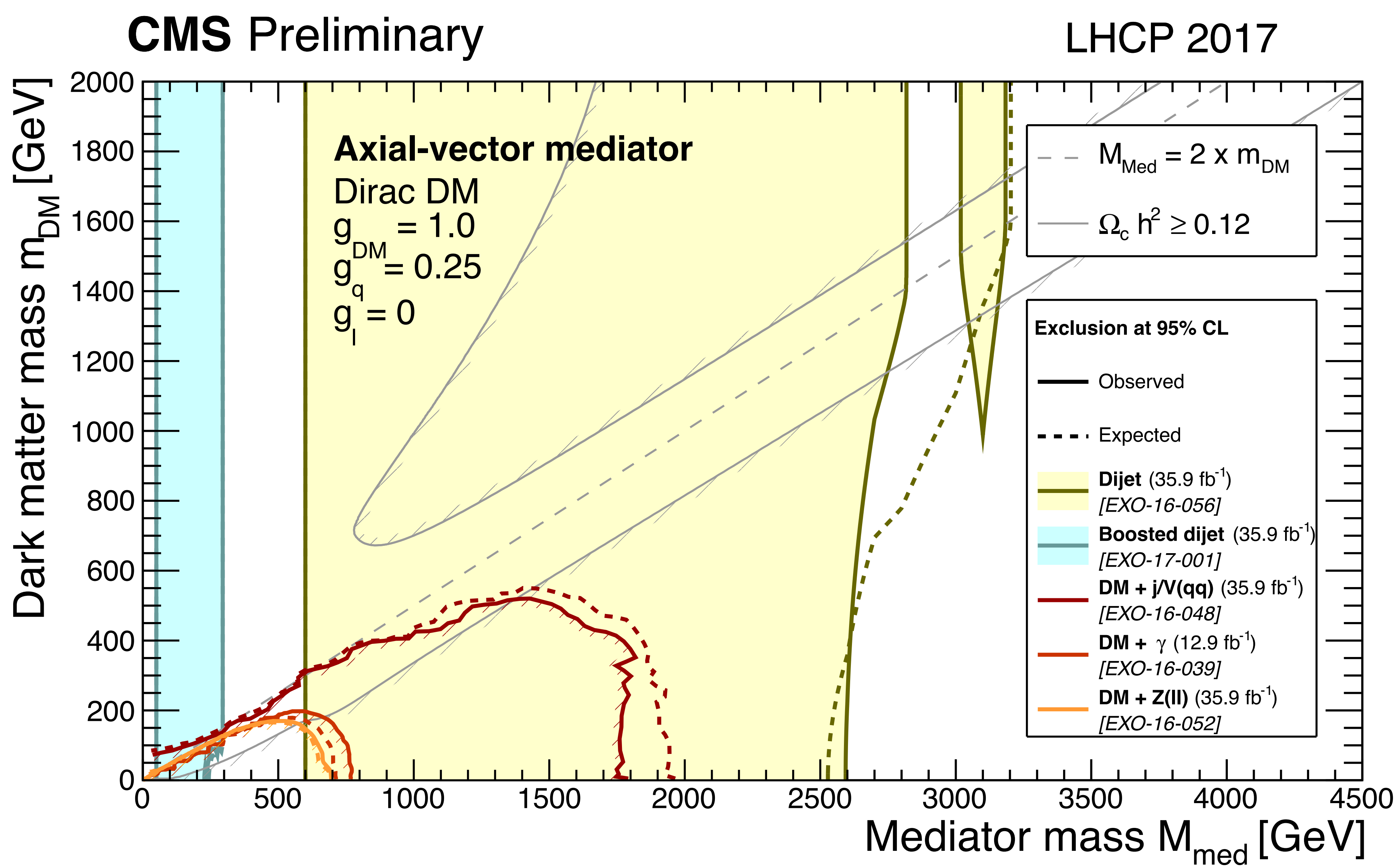
- Sensitive to large range of ***dark matter*** parameter space by looking directly for resonant production of the ***mediator***



MET+X



DIJET



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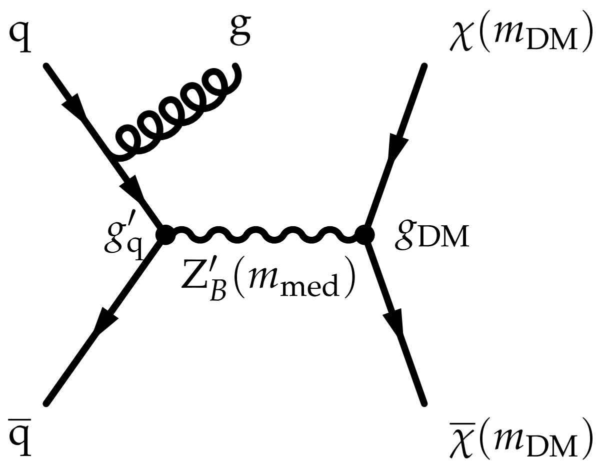

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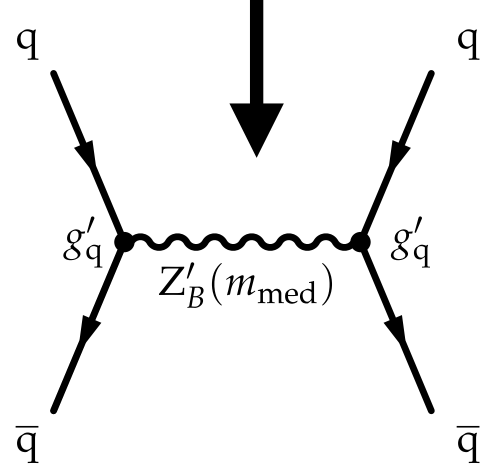
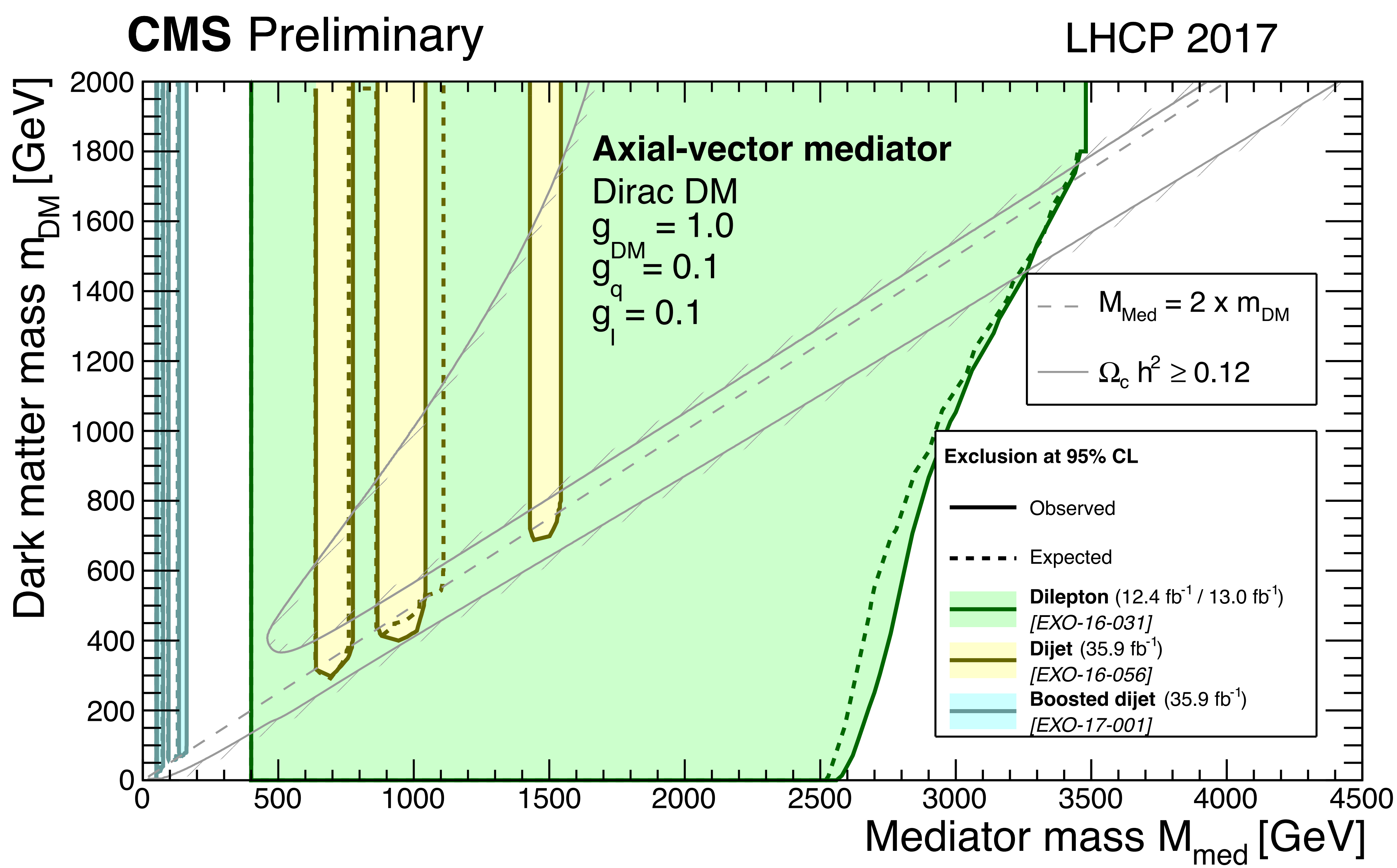
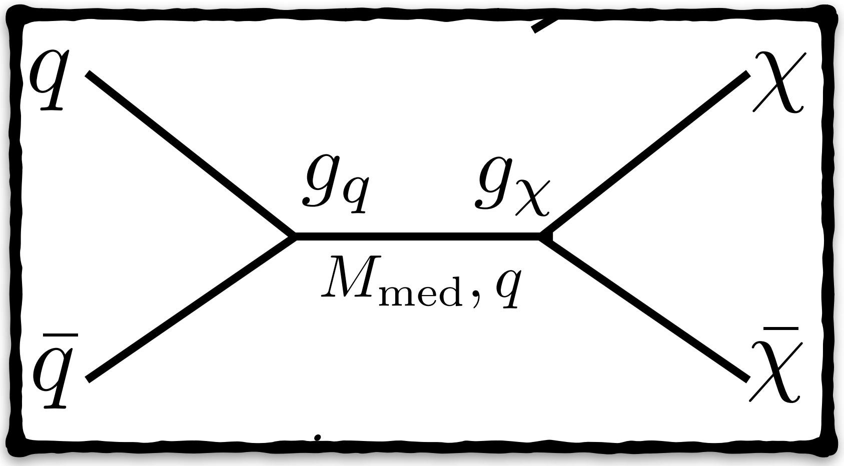


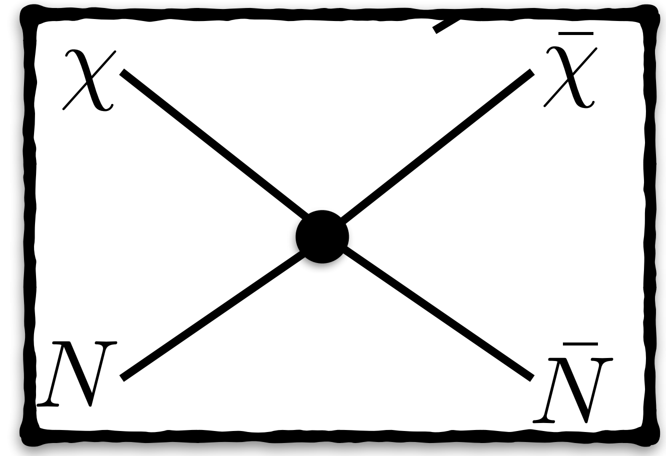
DIJET



SENSITIVITY TO DARK MATTER

- We can convert these limits in the (m_M, m_{DM}) plane into limits in the (m_{DM}, σ_{SD}) plane to compare with ID/DD DM experiments





For axial-vector mediator with universal quark coupling g_q', mediator-nucleon coupling is

$$f^{\rm p} = f^{\rm n} = 0.32 g'_{\rm q}.$$

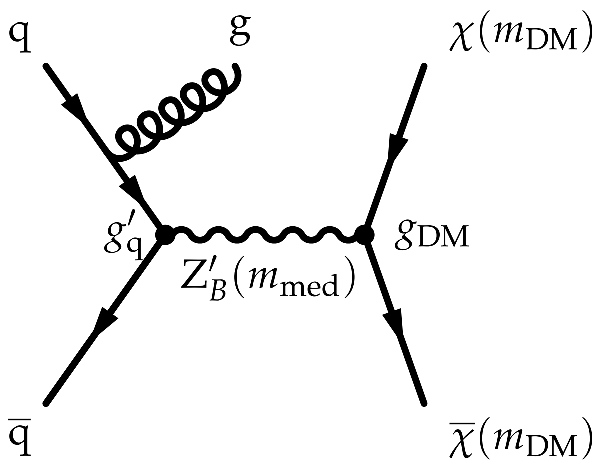
$$\sigma^{\rm SD}_{\rm DM\text{-}p} = \frac{3 f^2(g'_{\rm q}) g^2_{\rm DM} \mu_{\rm N\chi}}{\pi m^4_{\rm med}}$$

$$\simeq 2.4 \times 10^{-42}\,{\rm cm}^2 \cdot \left(\frac{g'_{\rm q} g_{\rm DM}}{0.25}\right)^2 \left(\frac{1\,{\rm TeV}}{m_{\rm med}}\right)^4 \left(\frac{\mu_{\rm N\chi}}{1\,{\rm GeV}}\right)^2,$$

arXiv:1603.04156

SENSITIVITY TO DARK MATTER

- ***Competitive*** with direct detection experiments (depending on the details of the model: couplings, mediator type, etc.)



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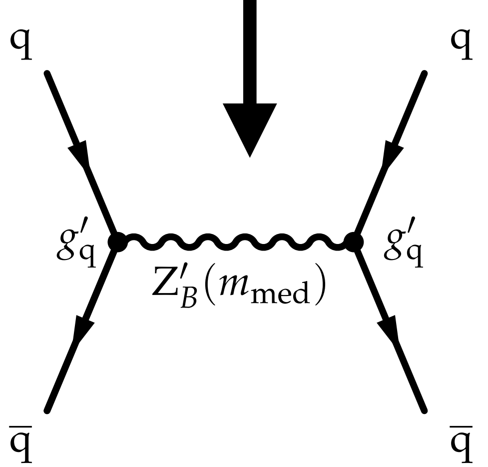
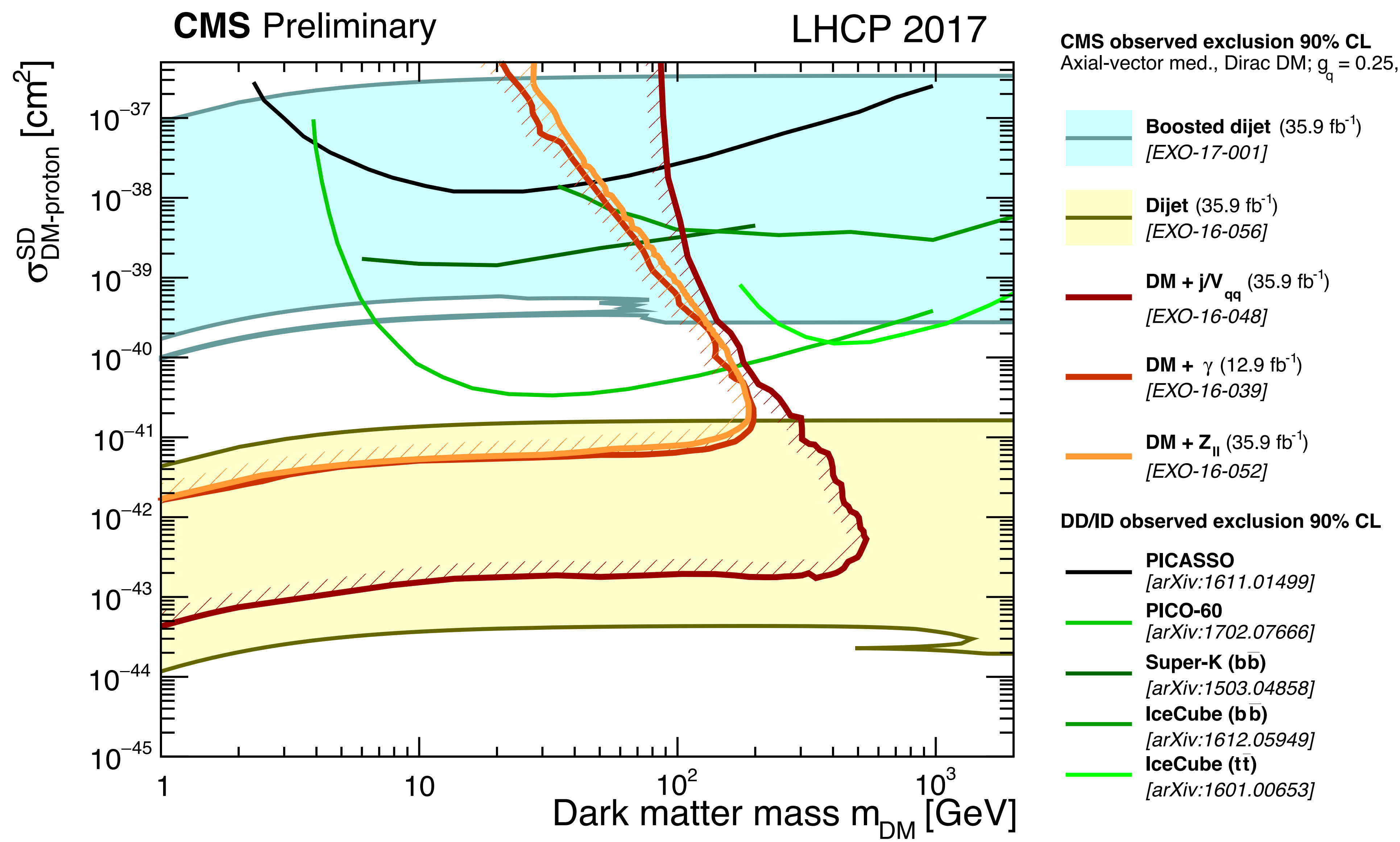
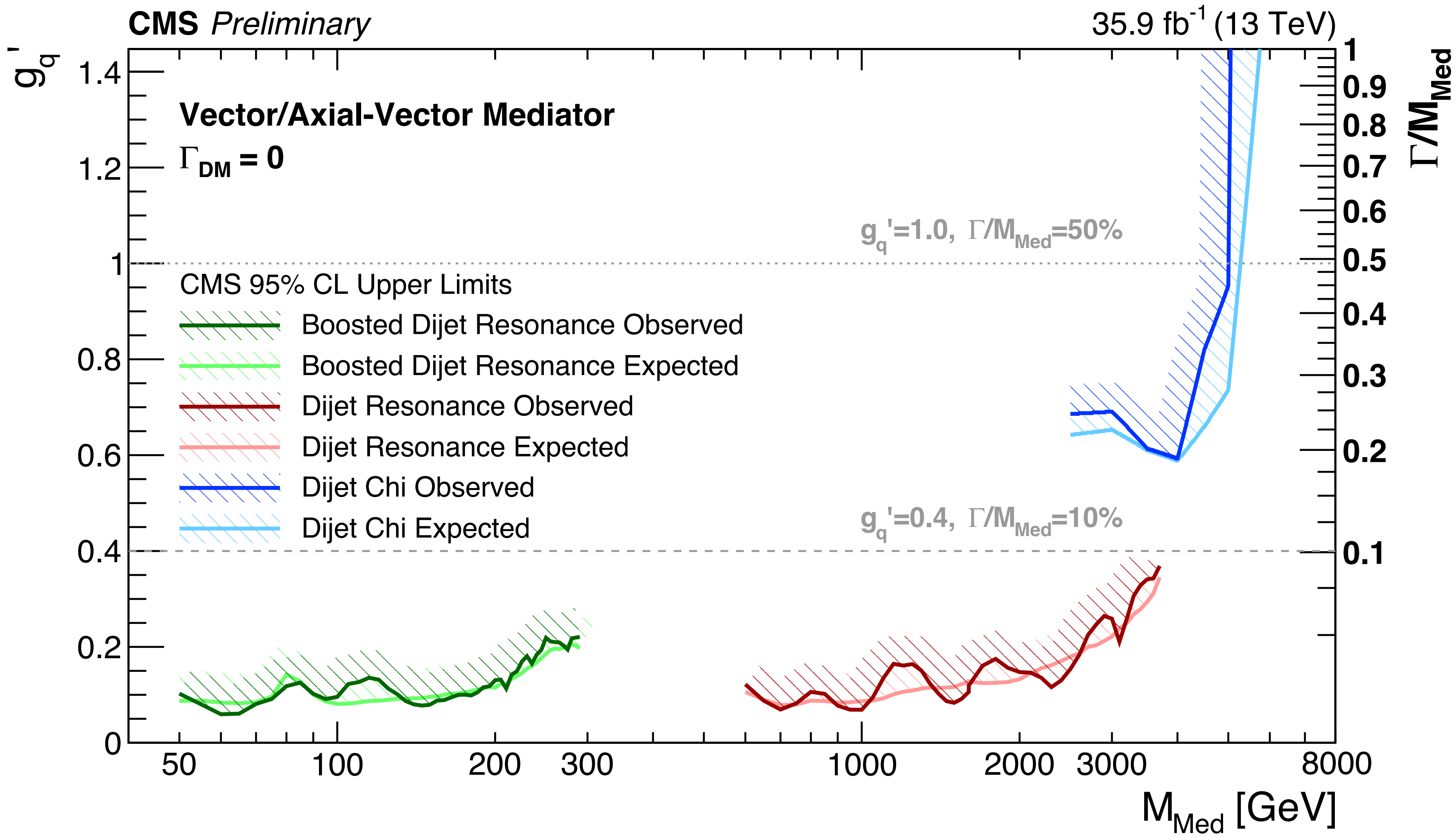


DIJET



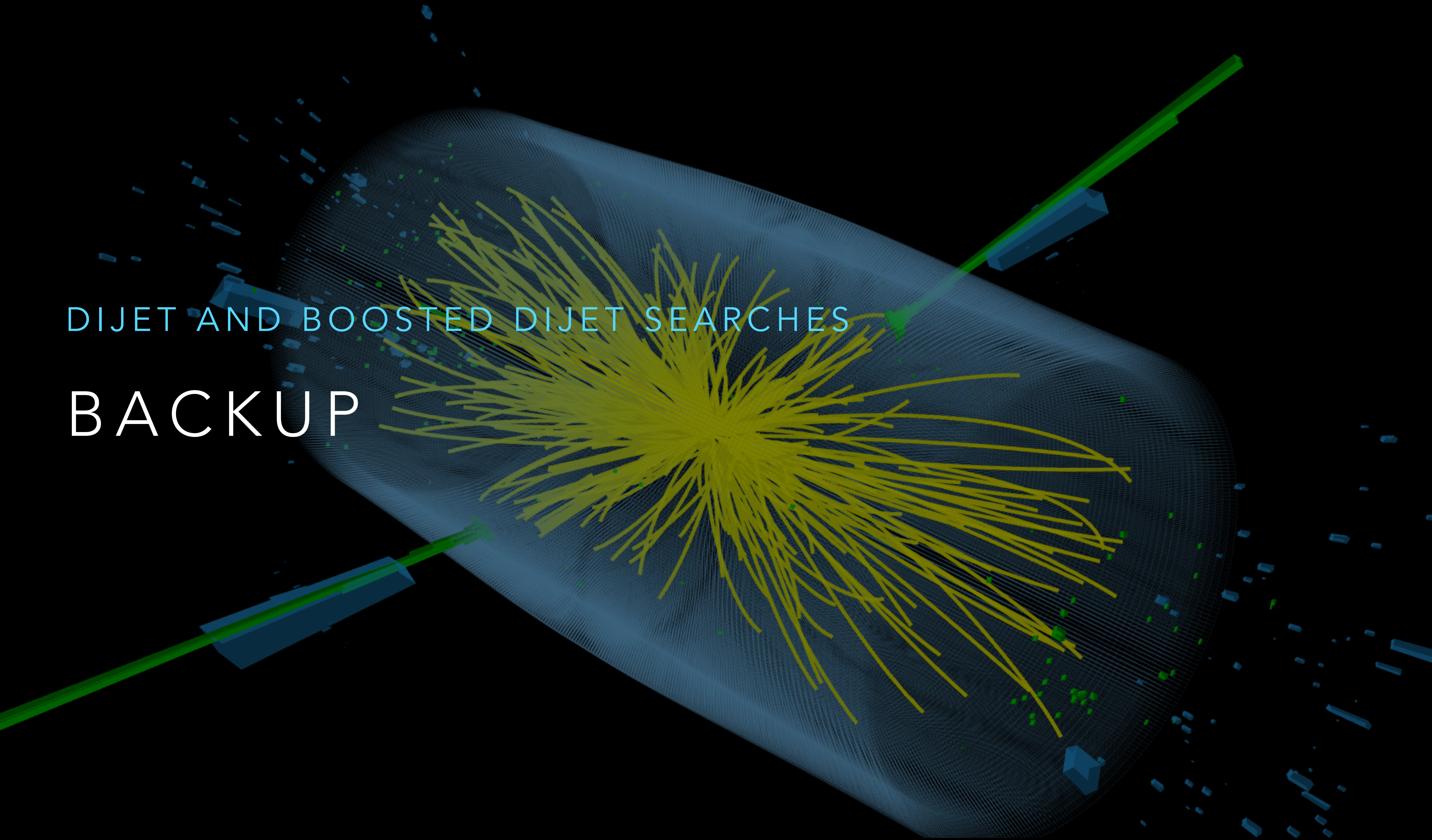
SUMMARY AND OUTLOOK

- 2016 dijet searches at the LHC are probing lower in resonance mass and coupling
- Many complementary searches, new techniques (substructure, decorrelation), and interpretations (DM mediators)
- Limits in DM-nucleon cross section vs. mass plane are competitive with direct detection experiments
- 2017 data taking is already underway!



DIJET AND BOOSTED DIJET SEARCHES

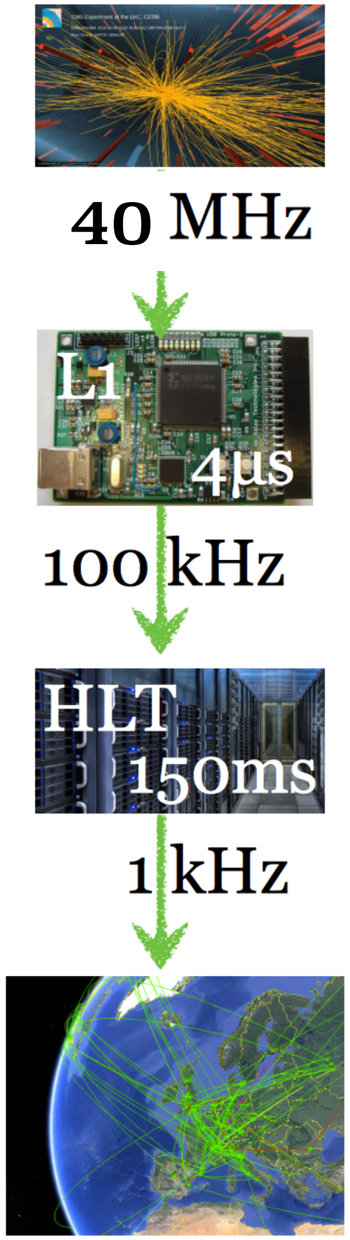
BACKUP



TRIGGER SYSTEM

CMS

- How can we trigger below H_T = 800-900 GeV?
- Two limitations:
  - Bandwidth = event rate × event size limited by read-out of O(100M) detector channels, disk storage, and everyone else's favorite physics channel
  - CPU time limited by computing resources for online reconstruction



H. Brun, LP 2015

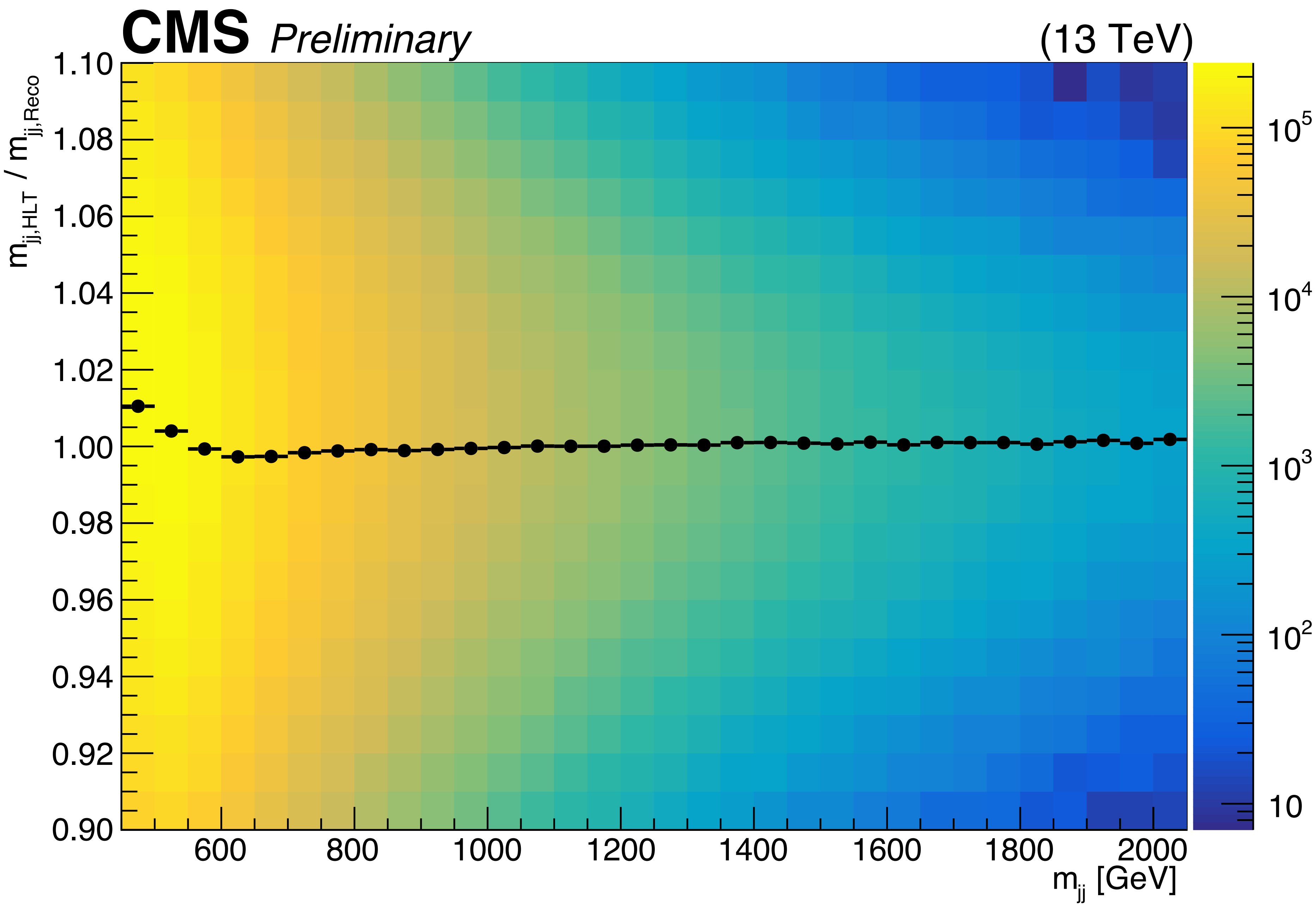
Total Reco.

BW: 1 kHz × 1 MB

CPU time: 150 ms

CALO JET VS PF JET

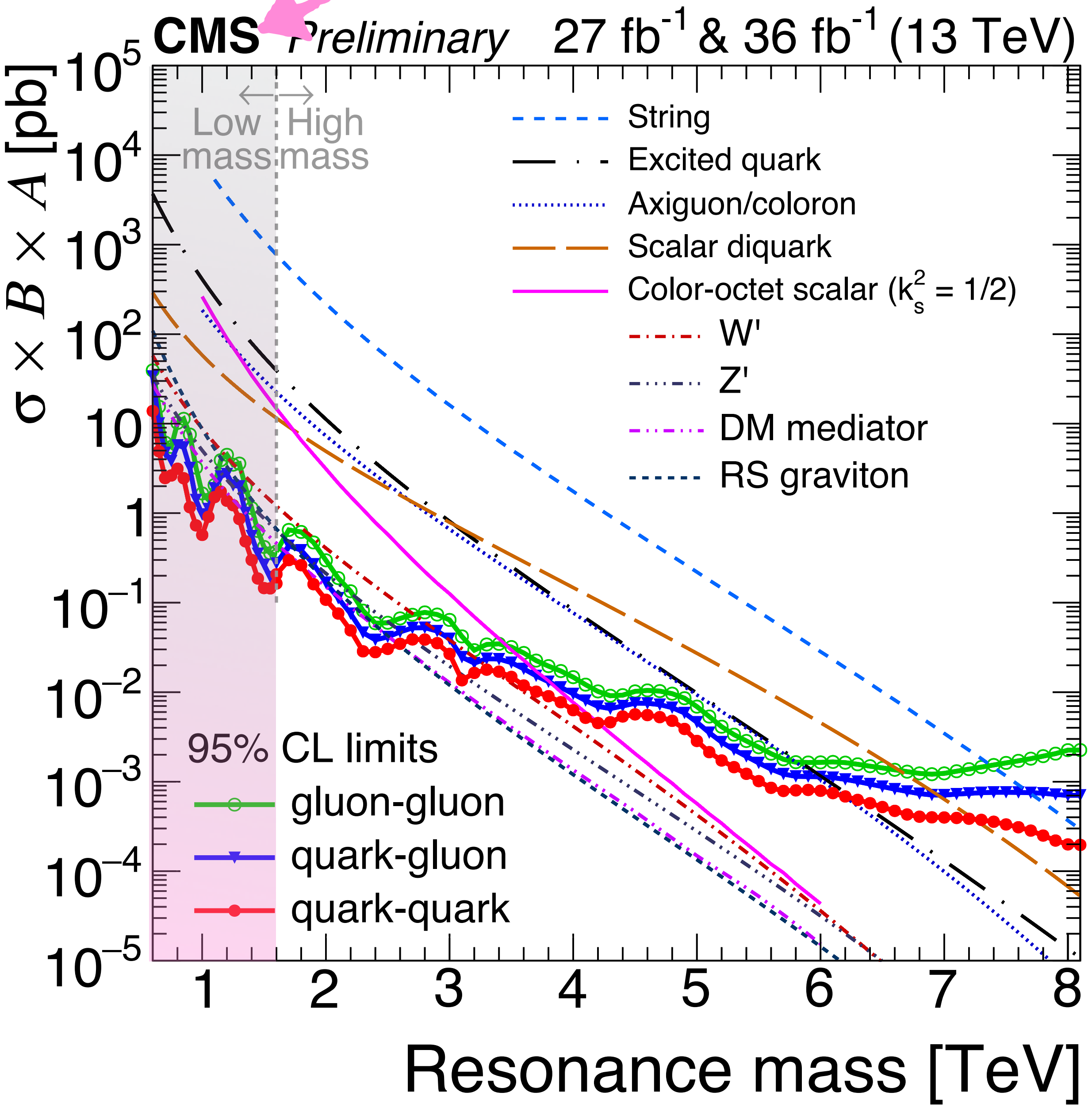
- Ratio of Calo HLT dijet mass to PF RECO dijet mass

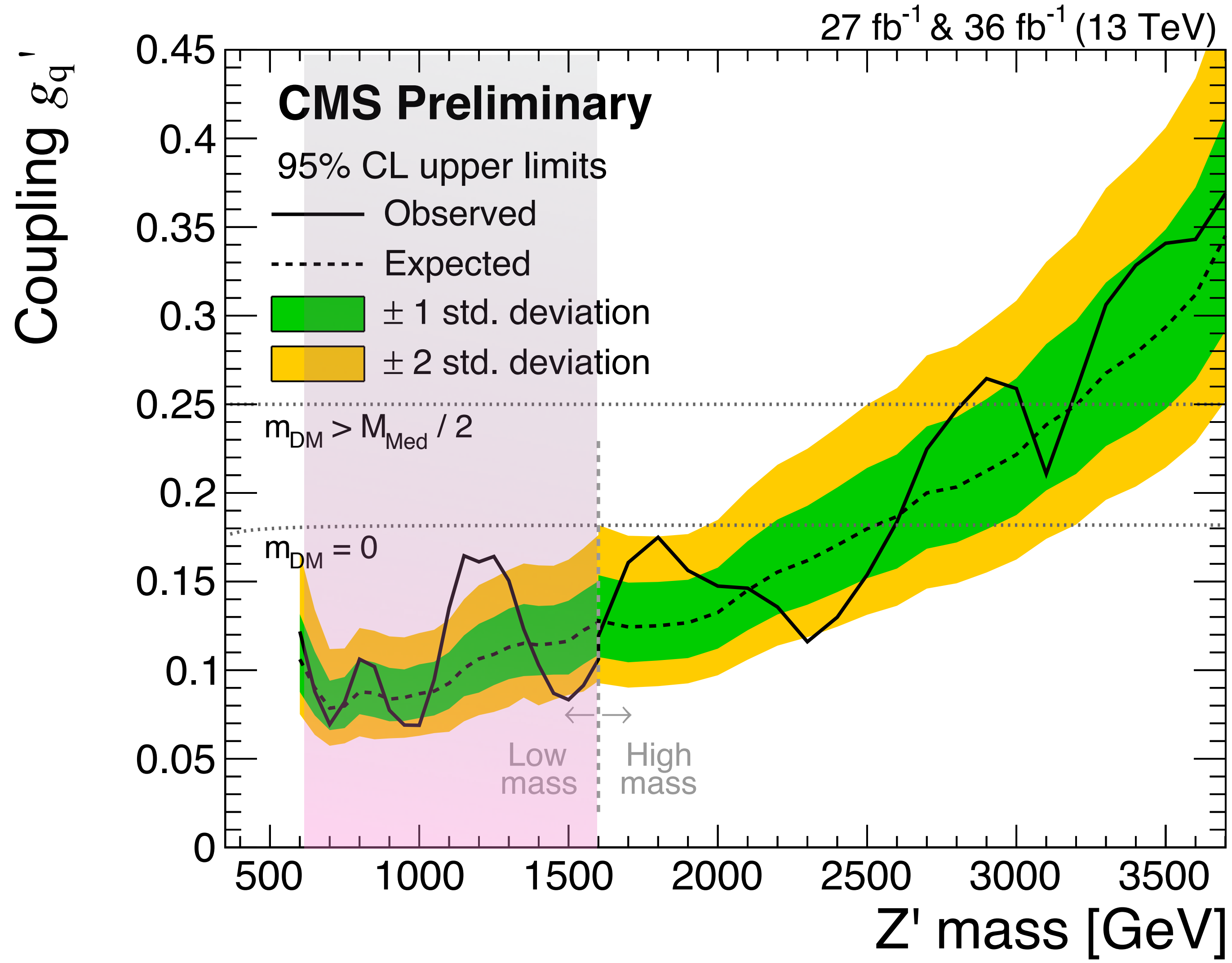


LIMITS ON NARROW RESONANCES

EXO-16-056

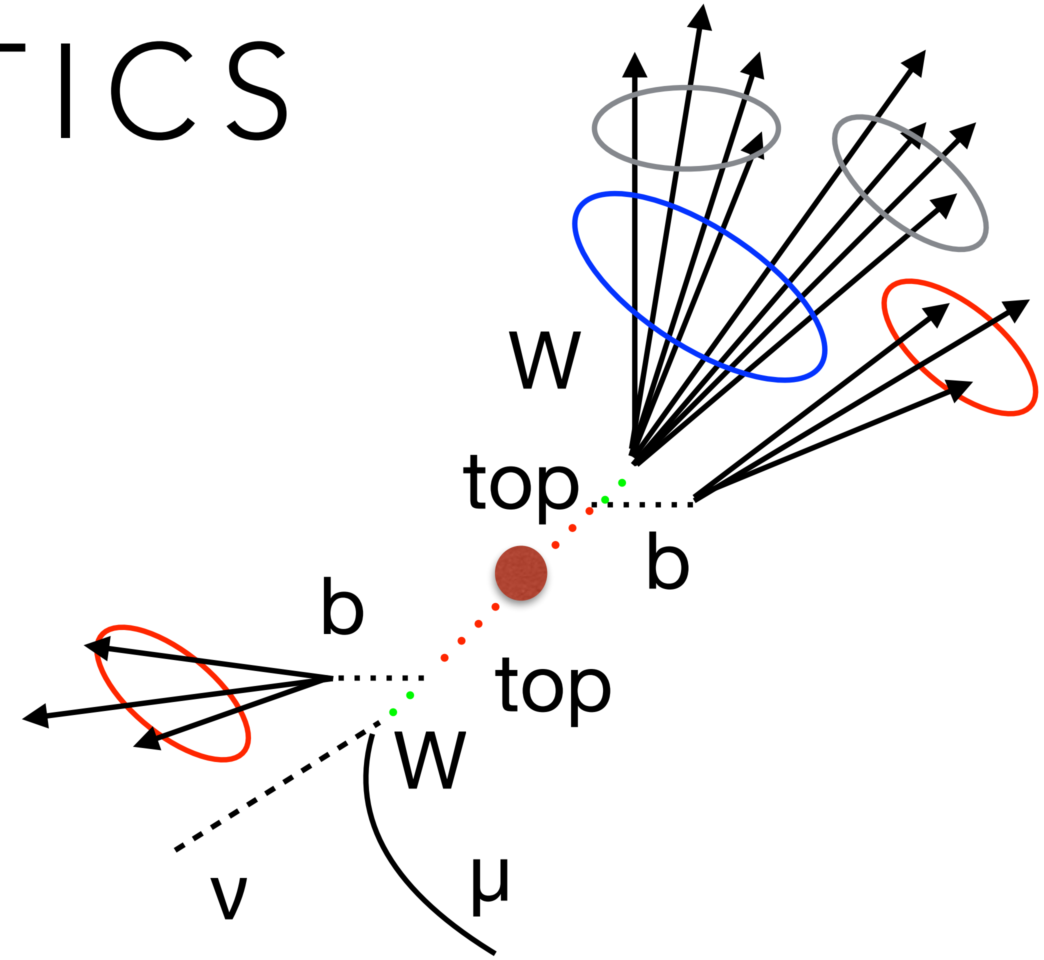
- Expanded CMS reach at low mass



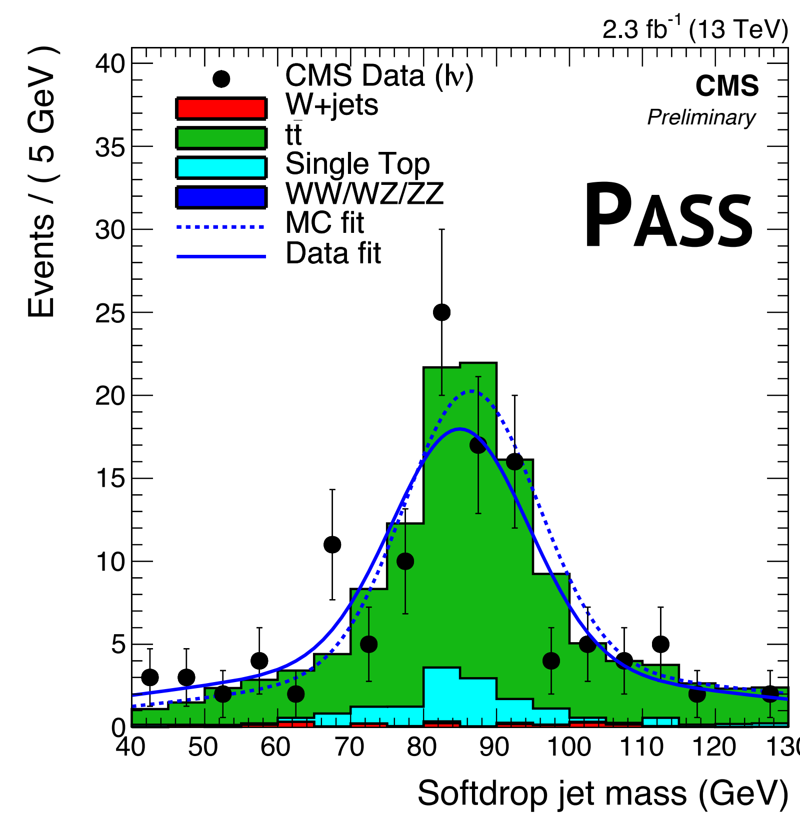


$$\boxed{g_q' = g_B/6}$$

SYSTEMATICS



- Signal systematic uncertainties from merged W sample in semi-leptonic ttbar events (external constraint)
- SM candles: presence of W/Z in final jet mass distribution provides additional in-situ constraint, i.e. W/Z/Z' nuisances are tied together



SENSITIVITY TO DARK MATTER

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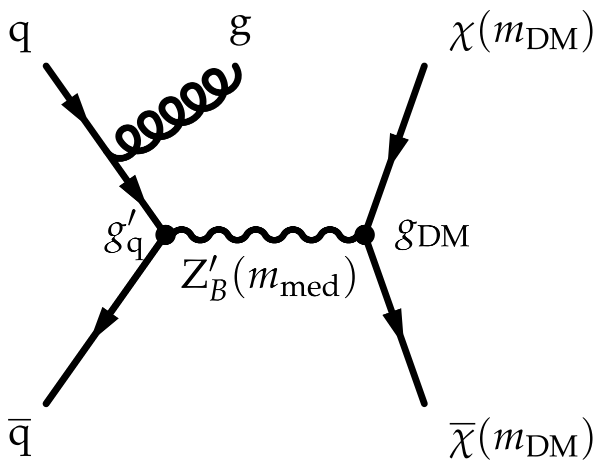

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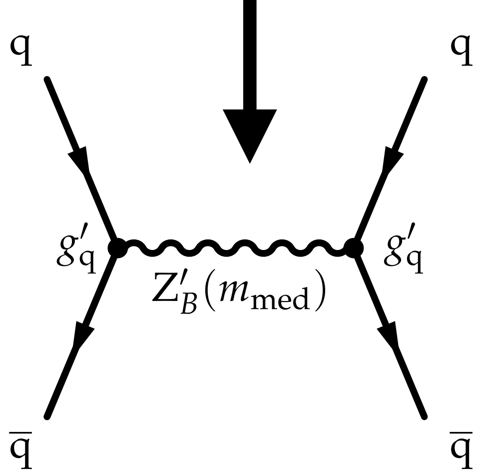
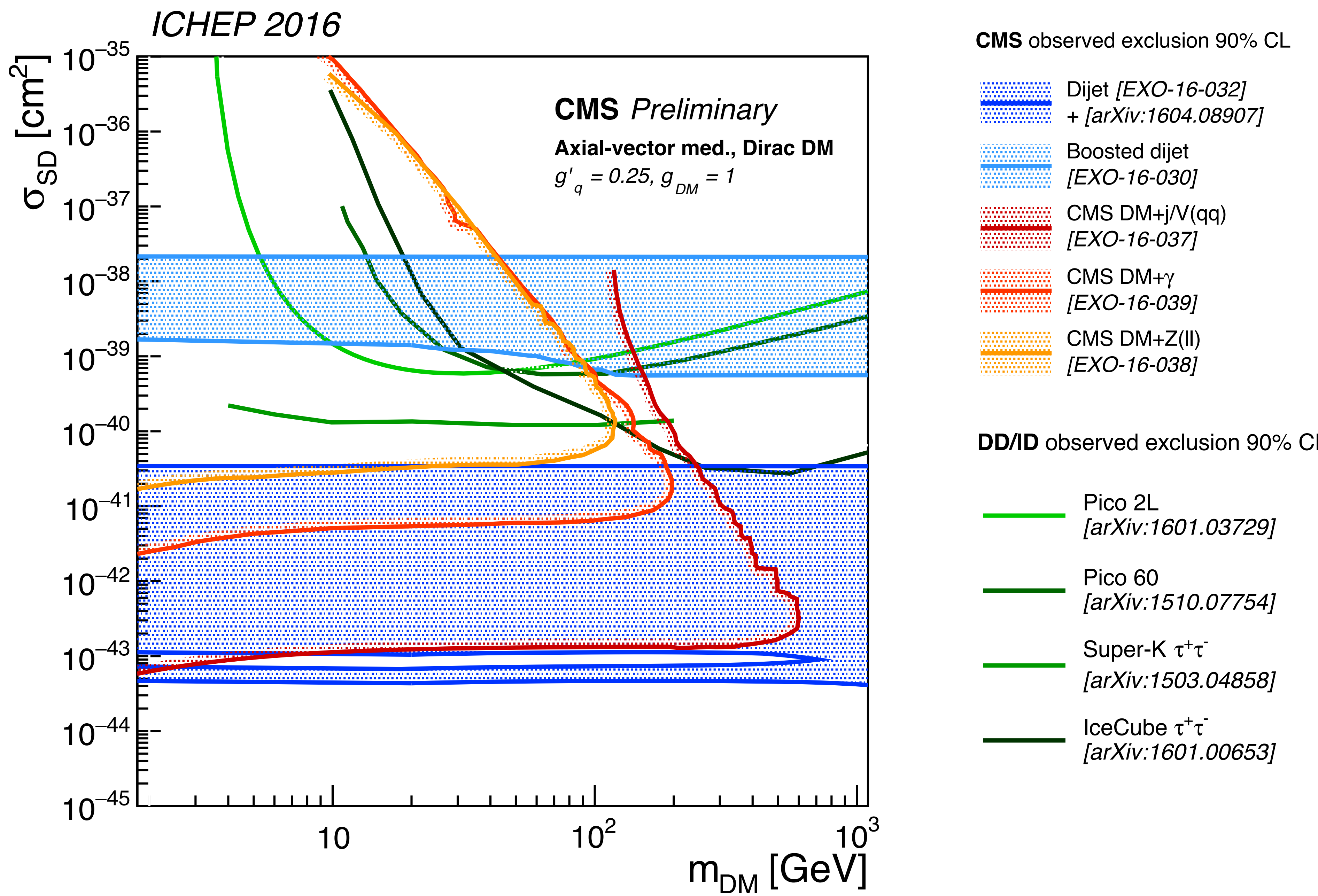
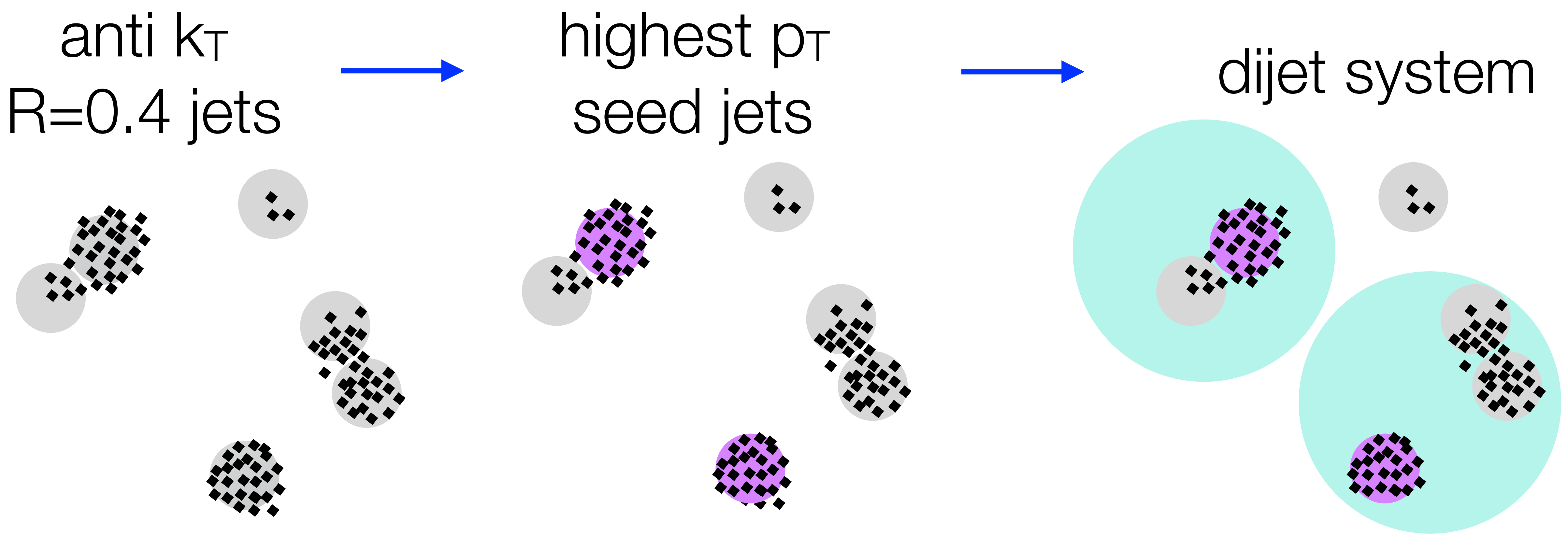


DIJET



WIDE JETS

- Jets initially reconstructed with anti-k_T algorithm with R=0.4
- "Wide jet" algorithm uses two leading jets as seeds
  - Adds neighboring jets to nearest leading jet if within $\Delta R < 1.1$
  - Recover loss in mass response due to radiation



WIDE JETS

- Gluon-gluon resonances are wider than quark-quark resonances due to greater radiation (gluon color factor)
- Mass resolution improved with wide jets even in gluon-gluon case