Unconventional Signatures

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Tuesday, June 7th, 2016

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OUTLINE

- Motivation
- Key Analysis: displaced jets at CMS
- Out-of-the-box strategies: data scouting
- Missing strategies and Longer-term Plans

MOTIVATION

- An easy mistake to make is to assume that unconventional = unmotivated
  - long-lived particles arise naturally in a wide space of plausible models, supersymmetric and otherwise
    - gauge mediation, split, stealth, RPV SUSY, neutral naturalness, dark matter, hidden valleys, etc.
    - long-lived particles arise in solutions to all of the major questions in particle physics today (naturalness, dark matter, flavor, etc.)

- Paucity of evidence for new physics thus far suggests that unconventional signatures are **even more motivated** now than at the start of the LHC

NEUTRAL NATURALNESS

- Assumptions: take 1) the hierarchy problem and 2) the absence of evidence for strongly produced top partners seriously
  - note that top partners need not be charged under SM SU(3), you just need 3 of them with the right Yukawa
  - Various ways to build a model like this (folded SUSY, quirky little Higgs, twin Higgs, etc.)
    - copy (some part of) the SM into a mirror sector, including top partners
    - Higgs mass can be protected at 1-loop
    - top partners are charged under mirror QCD and are either SM singlets or charged under EWK
- Phenomenological consequences:
  - rich dark sector, exotic SM Higgs decays (including invisible and long lived)

Higgs Portal

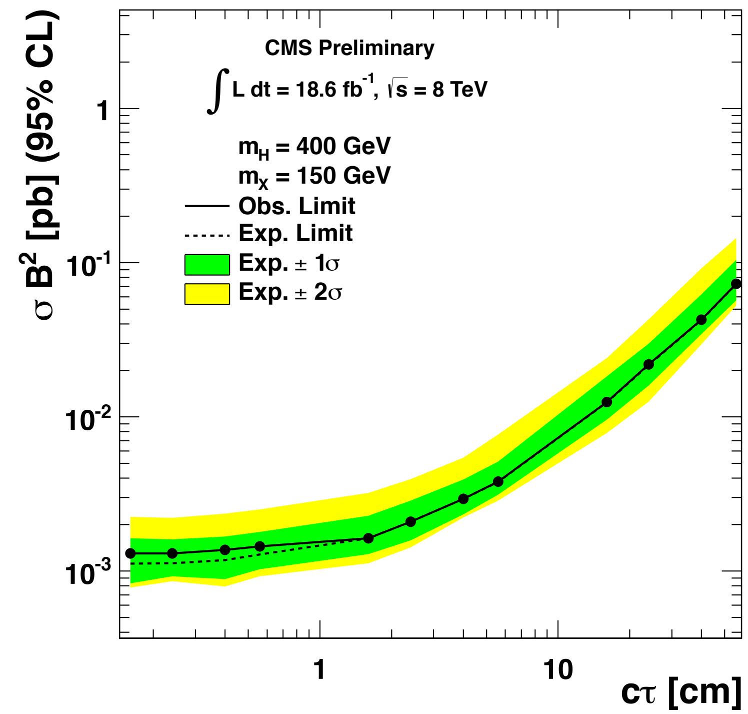
- There is a vast space of models predicting unconventional signatures produced in a variety of modes, but the LHC has a notable competitive advantage: the Higgs boson
  - copiously produced (uniquely at the LHC)
  - naturally large potential decay rates to new physics
    - decay is dominated by the small bottom quark Yukawa ~0.02
    - new hidden sectors can couple to the Higgs via portal operators of low effective dimension

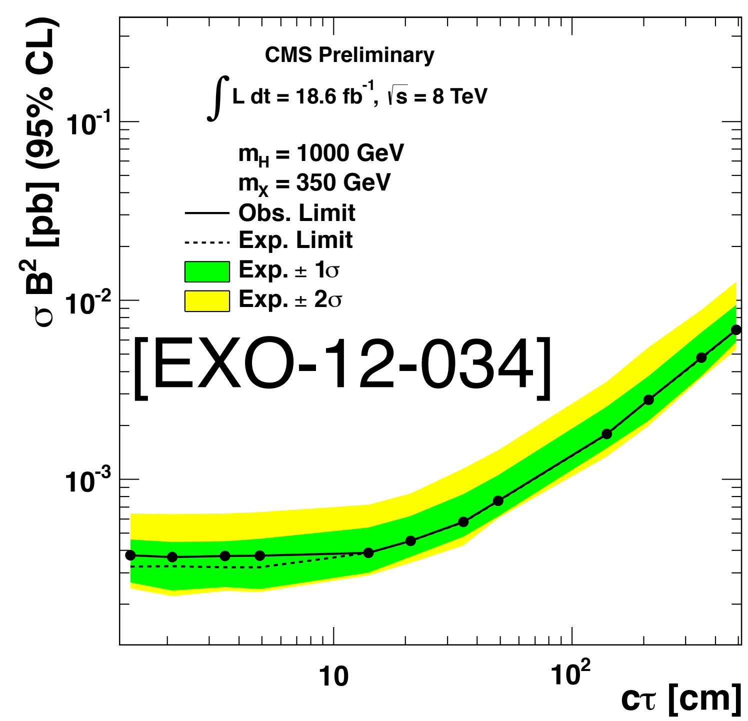
Higgs Portal as a Target

- Unconventional signatures produced through a Higgs boson are **an important target** for searches
  - Many LL searches have relatively low background rates, so going after Higgs production may be difficult but feasible
    - Low production rate (compared to QCD)
    - low p_T make things difficult to trigger
    - various production modes (associated W, Z, VBF, etc.)
- Requires serious thought about **triggers** and background rates
  - Can you trigger on direct production, or do you need to rely on associated production? Even L1 seeds can be constraining
  - Does your reconstruction have sensitivity to low mass, low p_T objects?

RUN I DISPLACED DIJET SEARCH

- Baseline signature
  - H→2X; X→dijets (udscb)
  - where X is long-lived, neutral, spin-0 particle decaying inside the tracker volume
- Selection
  - Scalar sum of the jets transverse momenta H_T > 300 GeV
  - **≥2** jets (p_T>60 GeV, $|\eta|$ < 2) with small number of prompt tracks and prompt energy fraction
  - both jets reconstruct to a **single, displaced vertex**
    - likelihood discriminant determines quality of the vertex and promptness of the jets
    - cut-and-count strategy w/ ~0 background
- Final result: ~fb xs·BR limits for ~mm cτ



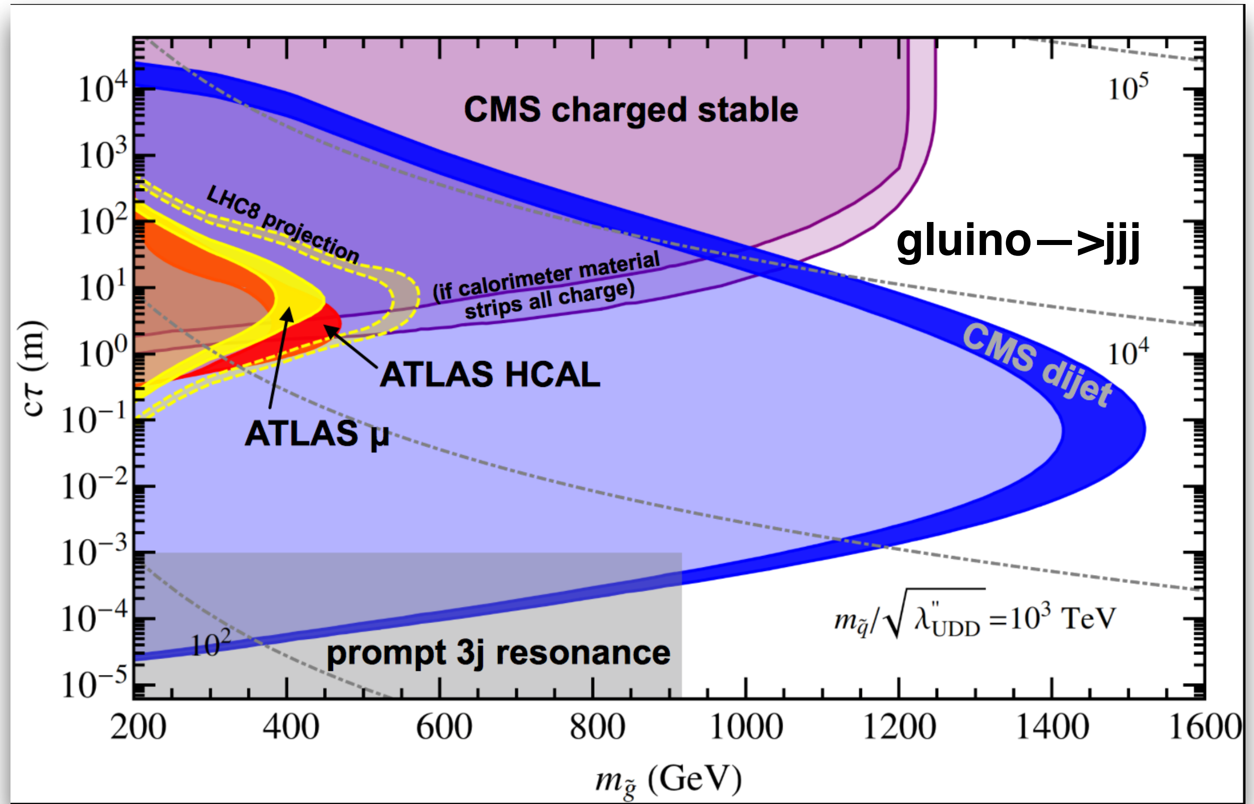


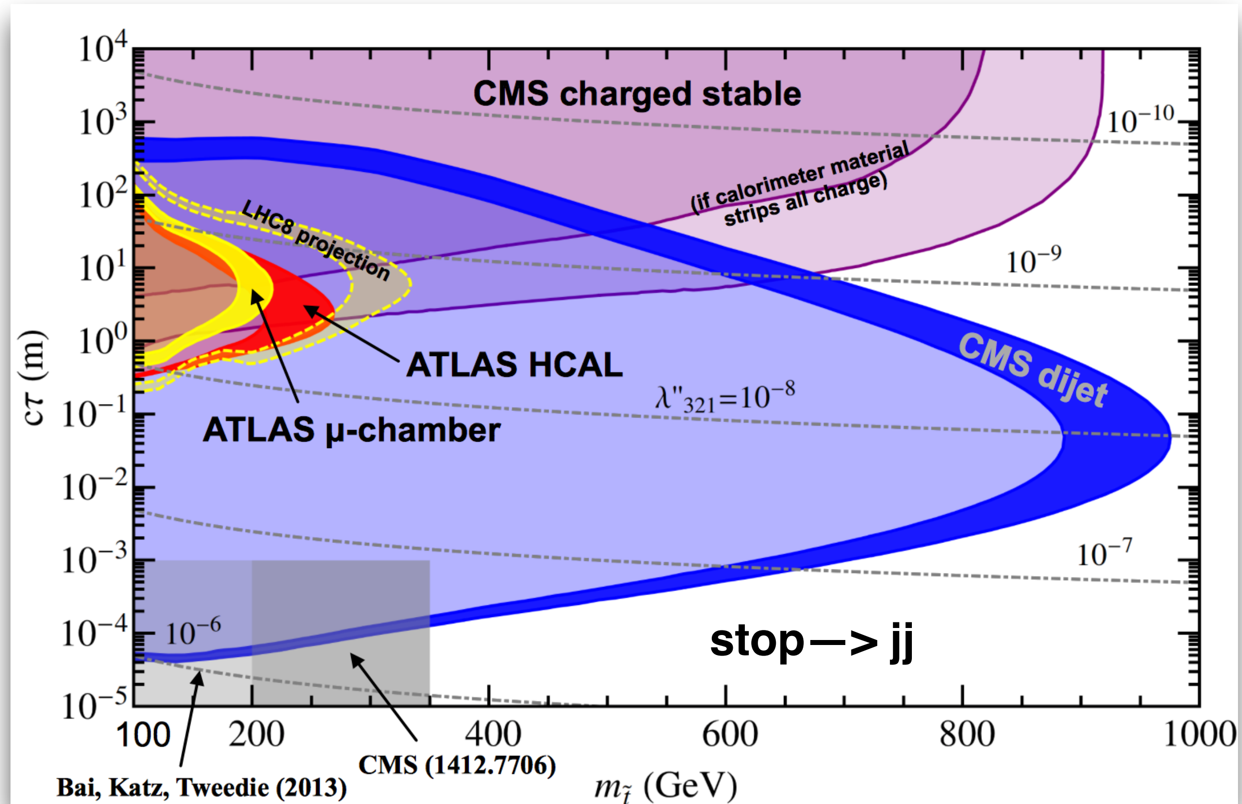
Run I Displaced Dijet Search

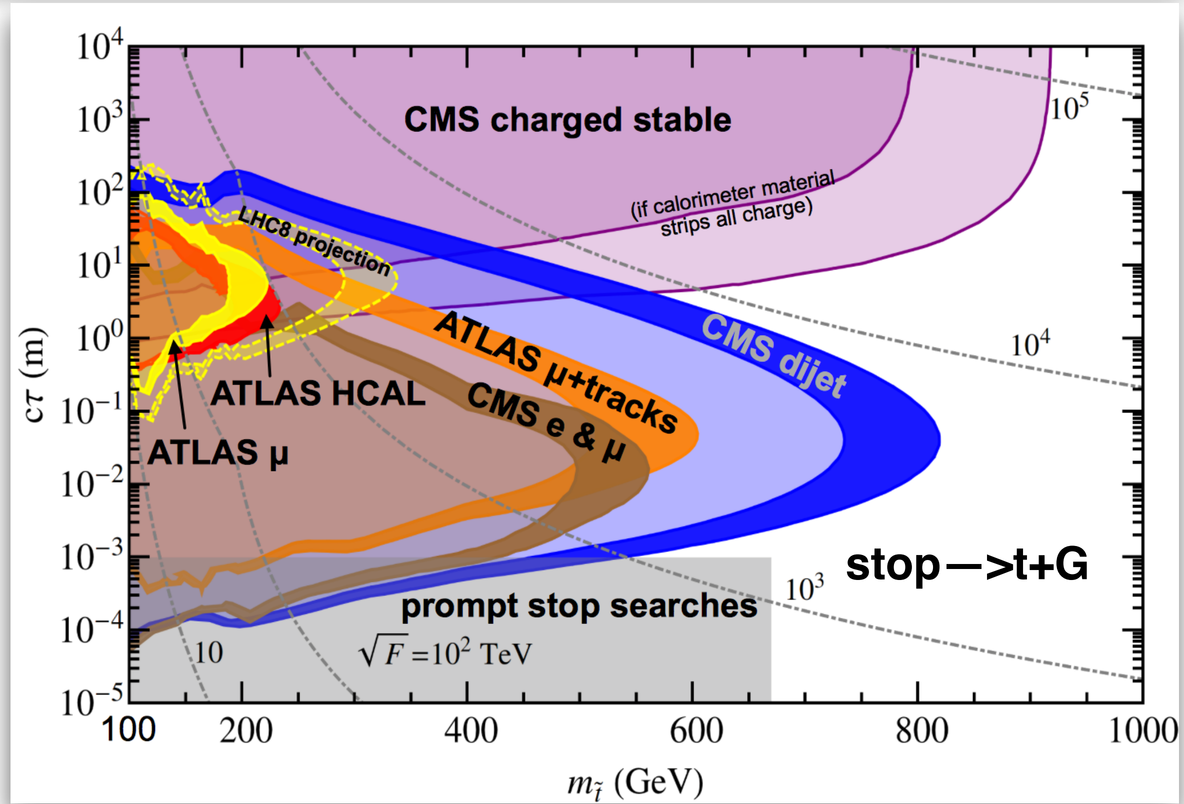
- Why focus on displaced dijet search?
  - It is a powerful search
    - covers many important models involving long-lived objects
    - It has sensitivity to a wide range of lifetimes ctau from 1mm to 1m
  - It takes a minimalistic approach
    - Two "jets" with a common displaced vertex and little prompt energy
    - H_T>300 GeV
  - ~0 backgrounds
    - Essentially a rate limited search: Improvements must be directed towards improving acceptance, not further reducing background

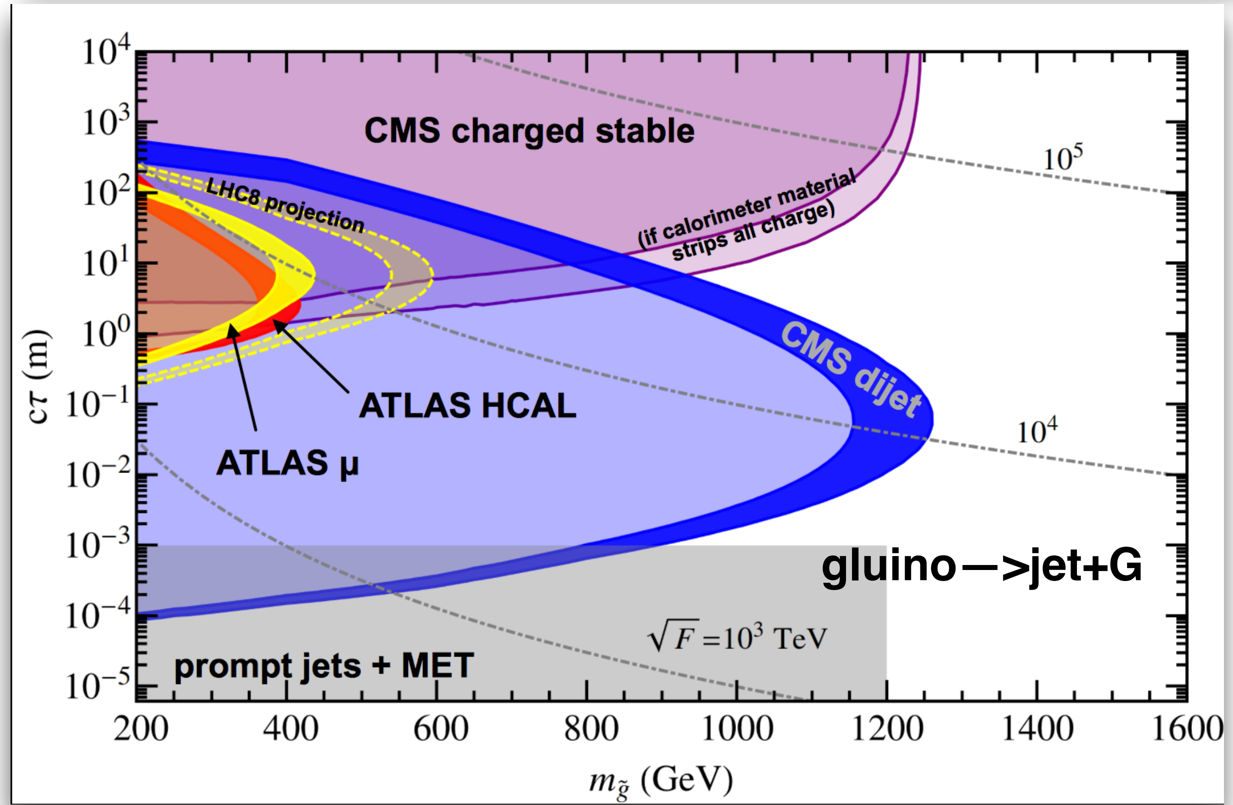
SENSITIVITY

c.f. Liu, Tweedie, JHEP06 (2015) 042







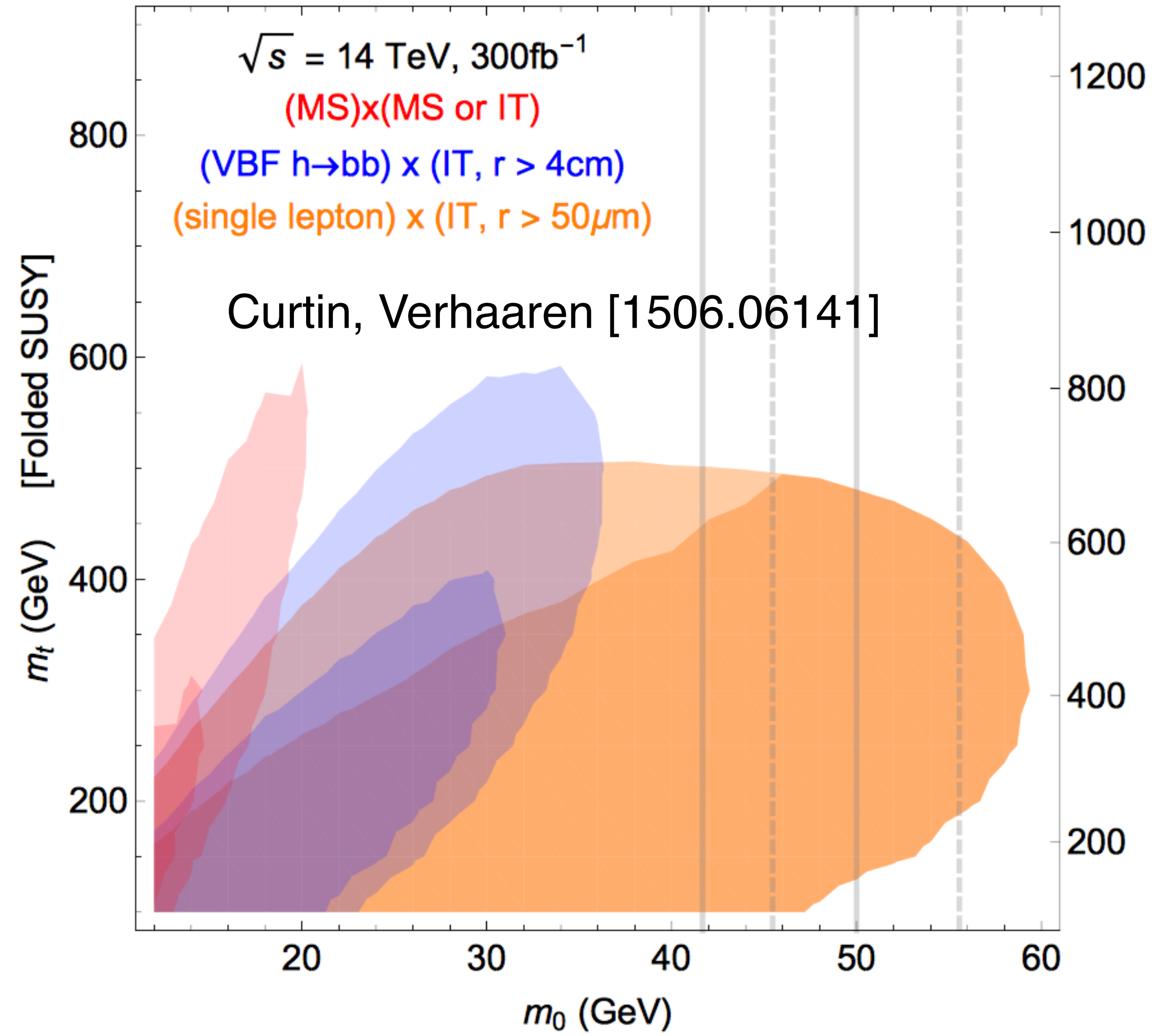


Displaced Dijet Coverage

- Again, this single analysis is transparently very powerful
  - Still, there are places that it lacks coverage
    - it requires two, separated jets from the same vertex
    - H_T>300 GeV
    - reduced sensitivity for lifetimes below 1 mm and above 1 m
- Model dependent improvements by considering different triggers targeting associated production
  - single lepton, dilepton, VBF, MET, etc.
  - LL analyses typically have data-driven methods for the backgrounds (ABCD, etc.) so adapting to different triggers is very easy
- We are also pursuing other analyses that target:
  - shorter lifetimes, longer lifetimes (trackless jets), single displaced jets, looser displaced jet selection, etc.

Where Displaced Dijets Fail

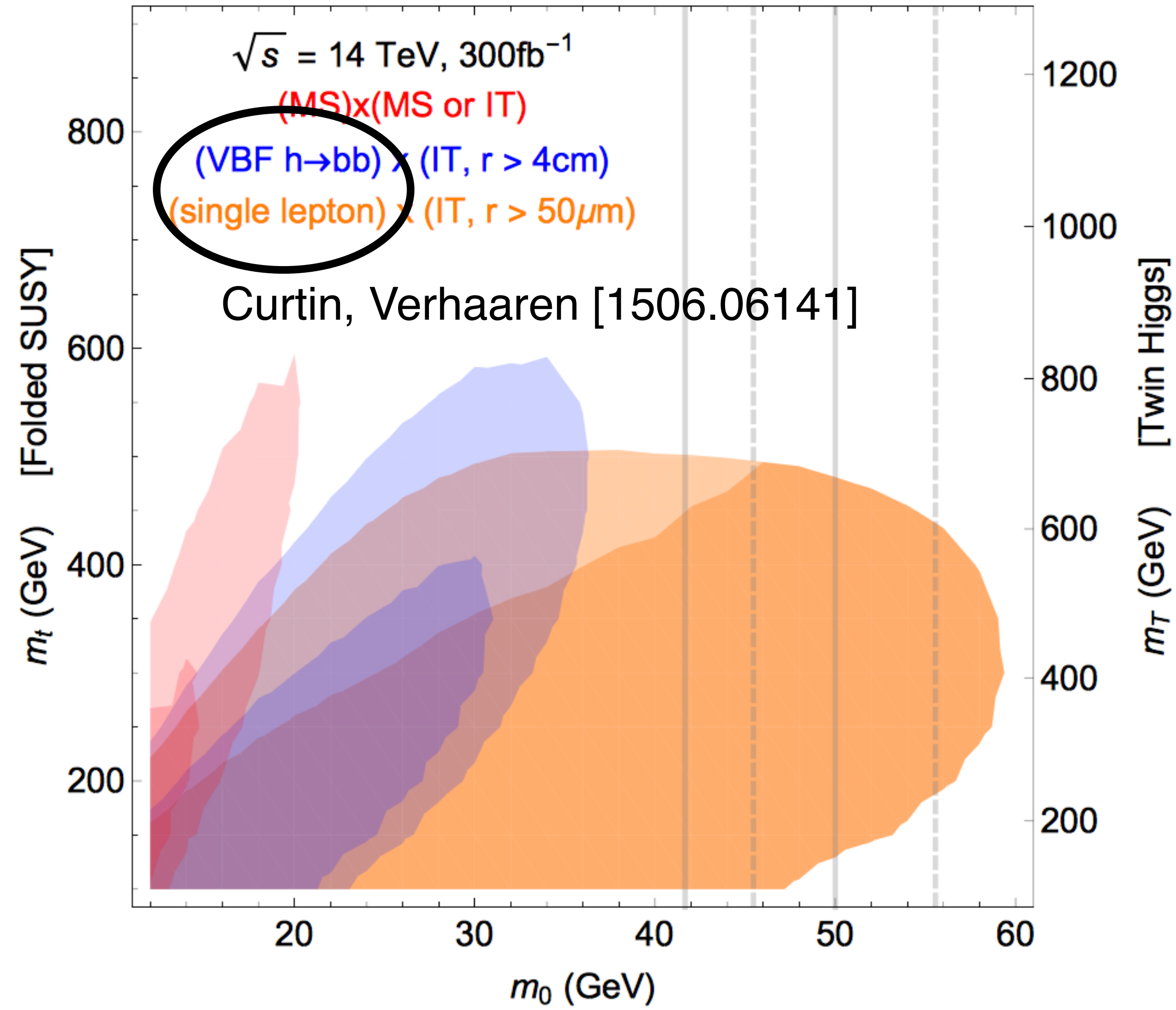
- Search for h(125)→XX→(ff)(ff)
  - X is a 0++ mirror glueball that decays through mixing with h(125)
    - **X preferentially decays to bb or ττ**
  - m_0 and m_T fully specify the X lifetime and h BR to mirror sector (lifetimes from μm on up)
- Shown are expected limits from ATLAS based on three sets of analyses combining various signatures to complete the coverage



- m_0 = mass of the 0^{++} mirror glueball
- m_T = mass of the mirror top partner
- different color regions correspond to the reach of potential ATLAS searches
- shading corresponds to uncertainties on the mirror gluon hadronization
- MS = muon station
- IT = inner tracker vertex

Where Displaced Dijets Fail

- Fantastic coverage of the meaningful/ natural parameter space is possible
  - With 300/fb, LHC can place severe constraints the naturalness of these types of models
  - CMS could have much better sensitivity than ATLAS, but we're currently limited because of the HT>300 GeV threshold!
    - h(125) is accessible in this plot through single lepton and VBF triggers
- CMS has better offline track reconstruction than ATLAS
  - whereas ATLAS has better ECAL/ HCAL pointing



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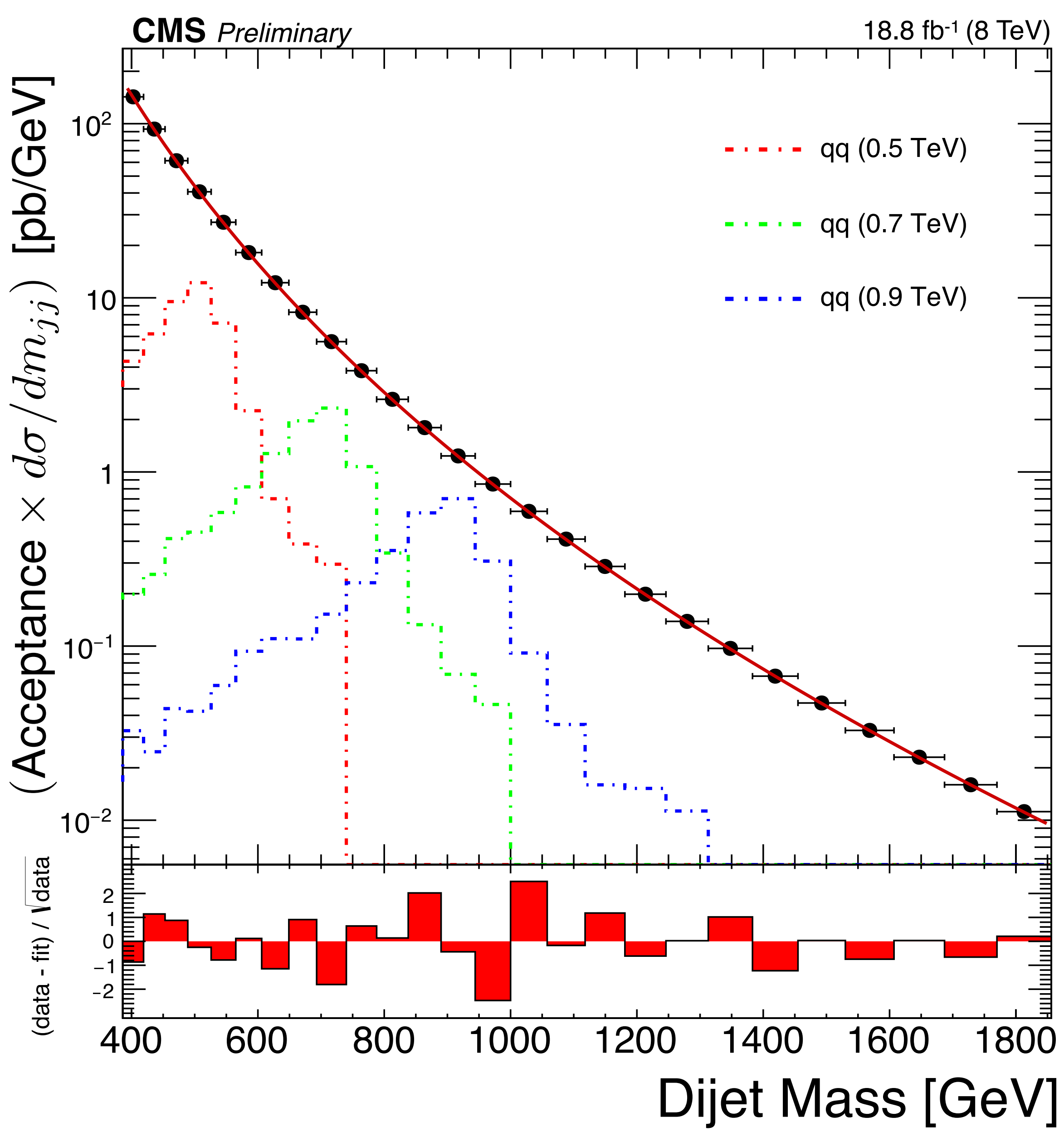
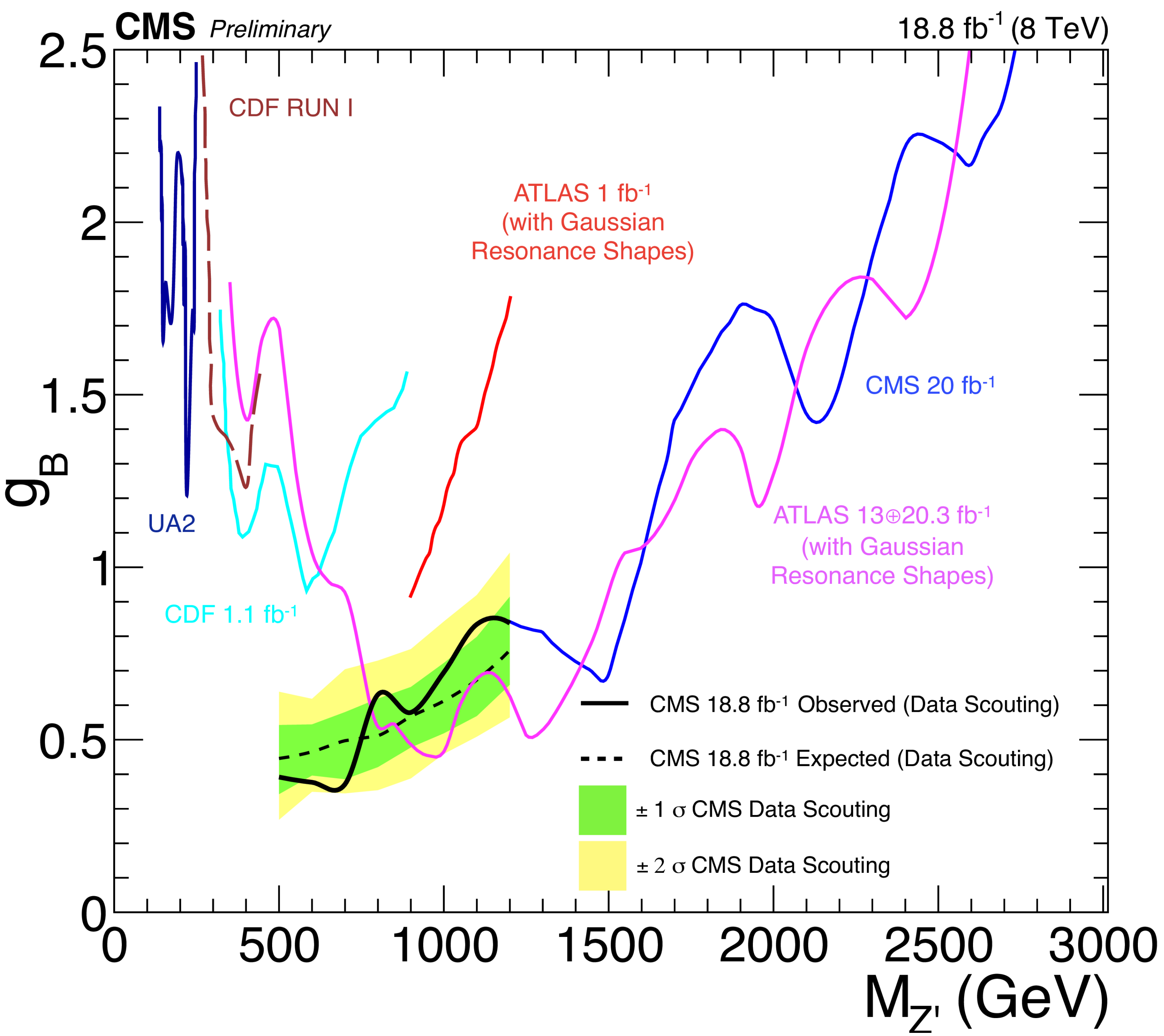
SCOUTING AND PARKING

- Data Scouting
  - HLT processes event rate of 100 kHz from L1 trigger
    - time optimized event reconstruction based on “offline” software
  - Ultimately, the limiting factor is **(event size) x (rate)**
  - Can write a substantially reduced dataset to tape at >kHz rate
    - for instance, keep just four vectors of electrons, muons, jets, etc.
    - we considerable flexibility for what is stored
      - nearly everything available in standard reconstruction can be recorded
      - but what we can do with tracking also has limitations…
- Data Parking (aka “delayed dataset”)
  - Can write up to 1000 Hz of data
    - O(300 Hz) is processed promptly and ready for analyzers to study within days
    - The rest may never be processed, but can be used as a backup in case something is observed in the scouting

Dijet Scouting Data in 2012

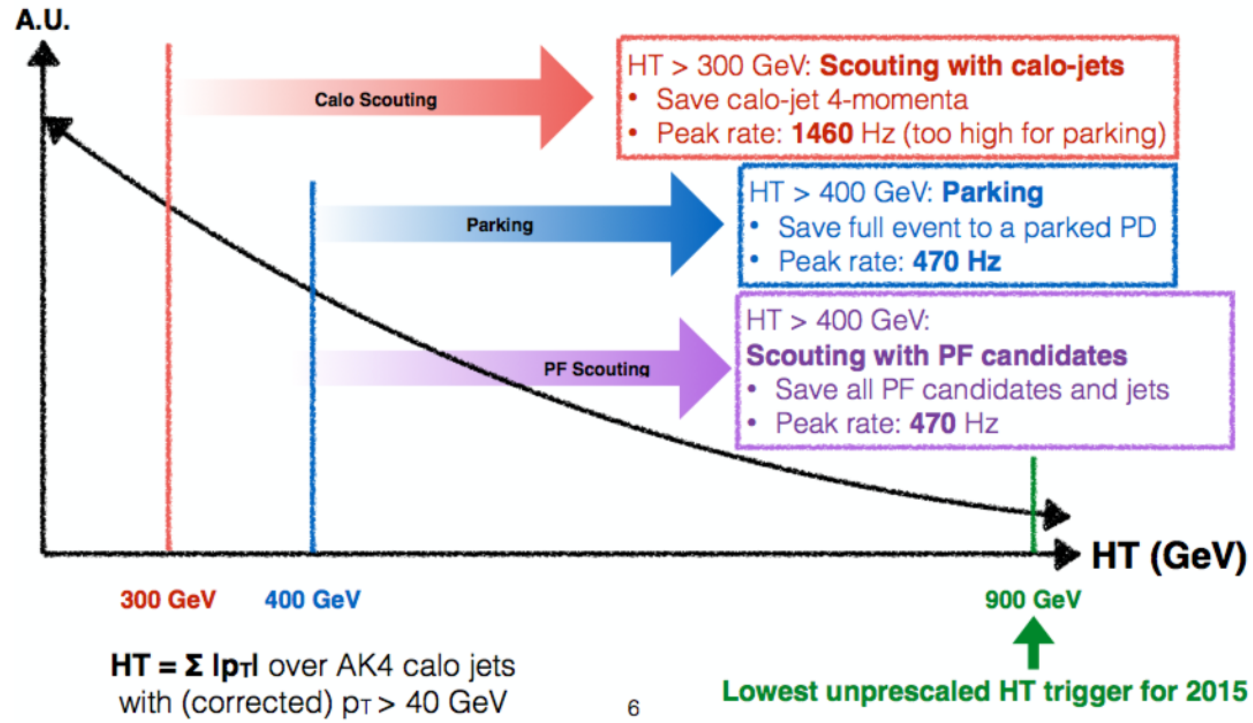
- Standard dijet bump hunt can access resonances as low as 500 GeV in 2012





DATA SCOUTING IN 2015

- Scouting CaloHT dataset: collected data starting October 1 (**1.8/fb**)
  - Events with **HT > 250 GeV**
- Scouting PFHT dataset: collected data starting October 1 (**1.8/fb**)
  - Events with **HT > 450 GeV**
  - Full event content is **parked**
- Scouting PFMuons dataset: collected data starting October 20 (**830/pb**)
  - Events with two muons having **pT > 3 GeV** and **$m_{\mu\mu}$ > 10 GeV**
  - Full event content is **parked**



WHAT IS STILL MISSING?

- Huge parameter space
  - Displaced leptons
    - consider displaced taus
    - look for displaced dileptons with m_{ll}<15 GeV
    - require both vertexed and non-vertexed pairs
  - Displaced photons
    - ATLAS has some competitive advantage here wrt pointing
    - $h(125) \rightarrow \gamma$+MET and $h(125) \rightarrow \gamma\gamma$+MET are important benchmarks
  - Quirks
    - Dedicated tracking is a significant complication
    - Can look for resonances with extra radiation from the P.V.
  - Trackless jets cover transition from vertices in the track to vertices in the muon chambers
    - Trade-off between requiring one displaced object and two displaced objects must be considered carefully

FUTURE

- What can HL-LHC bring? Very high Higgs production rate, but can we trigger?
  - Can the FTK or track-trigger pick up displaced tracks?
- loss of dE/dx for future CMS tracker is a shame
  - Any time you discover new physics you want to characterize it
    - Not having dE/dx is a crucial handle on characterization
  - What can be done with high precision timing?
- other experiments? MilliQan, MoEDAL, SHiP, etc.
  - Well beyond the scope of this talk, but dedicated experiments have considerable interest