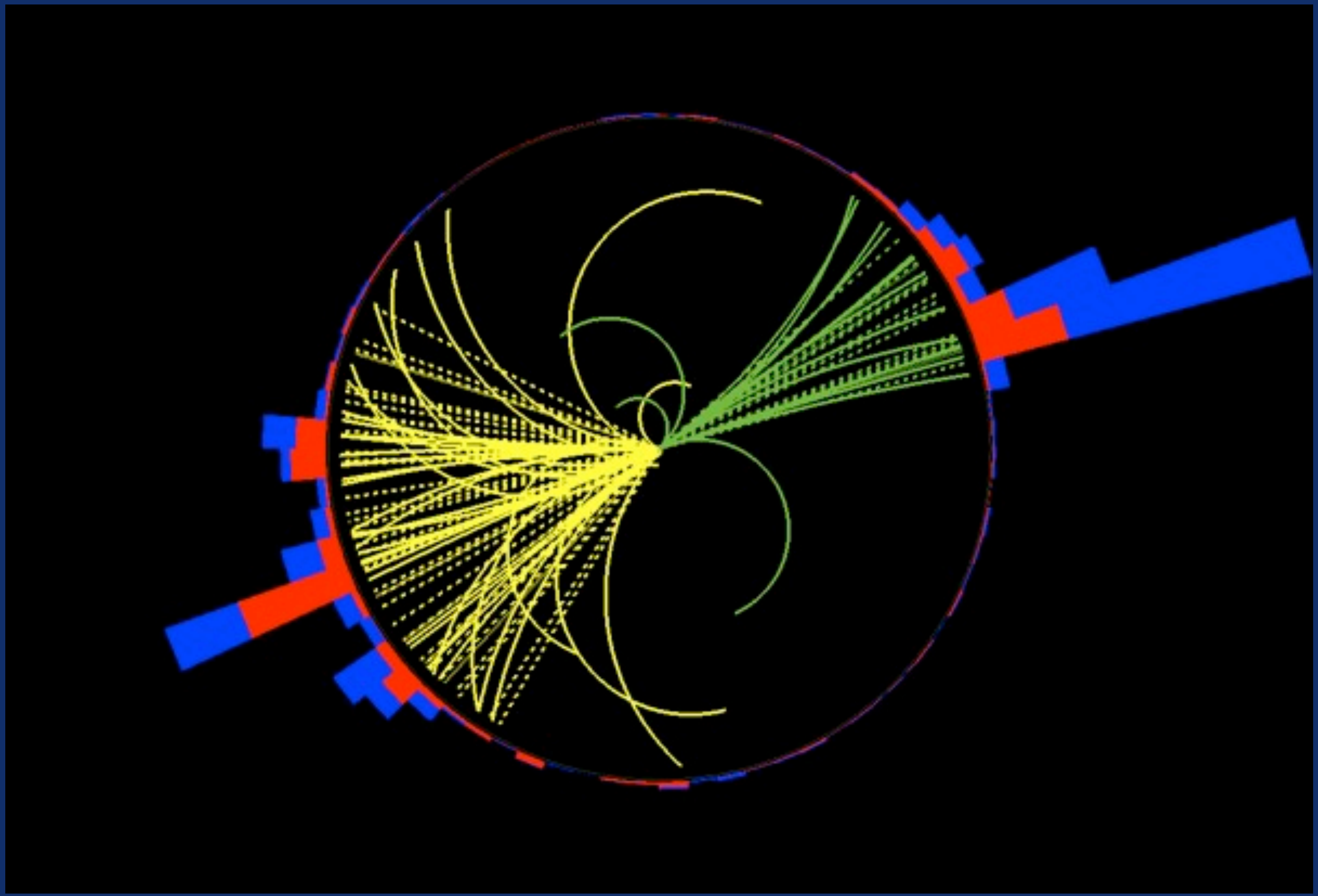
Measurement of the top pair invariant mass distribution at 7 TeV and search for New Physics

Salvatore Rappoccio (JHU)
for the CMS Collaboration

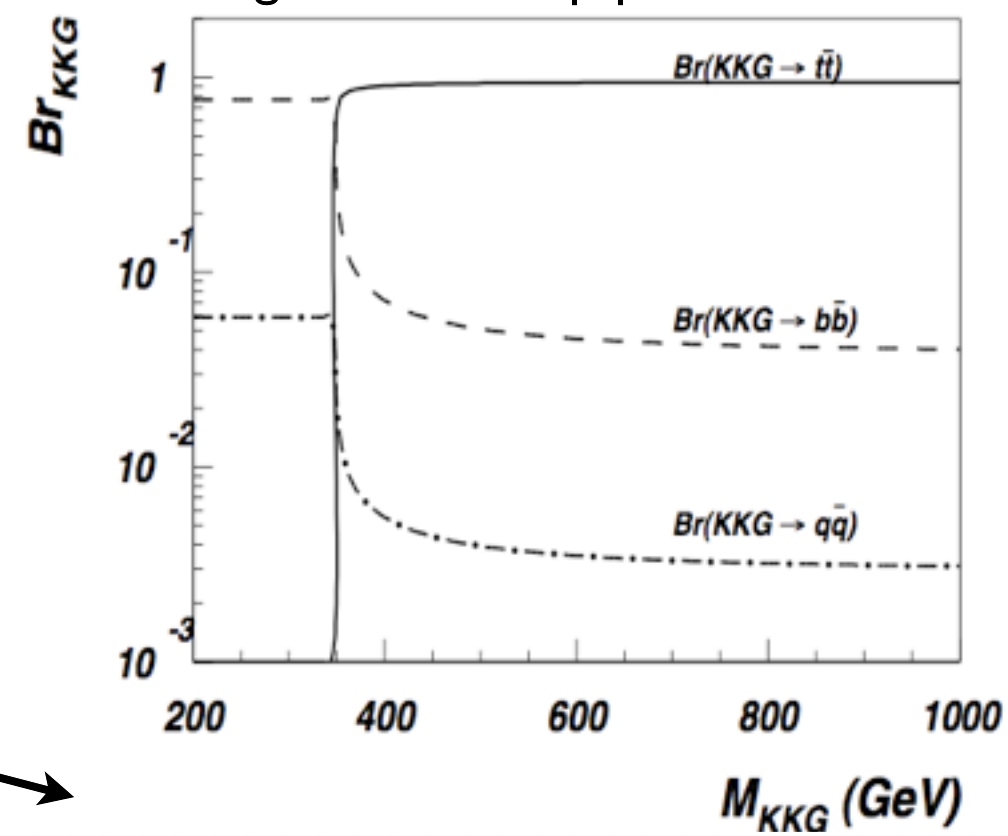


11 August 2011

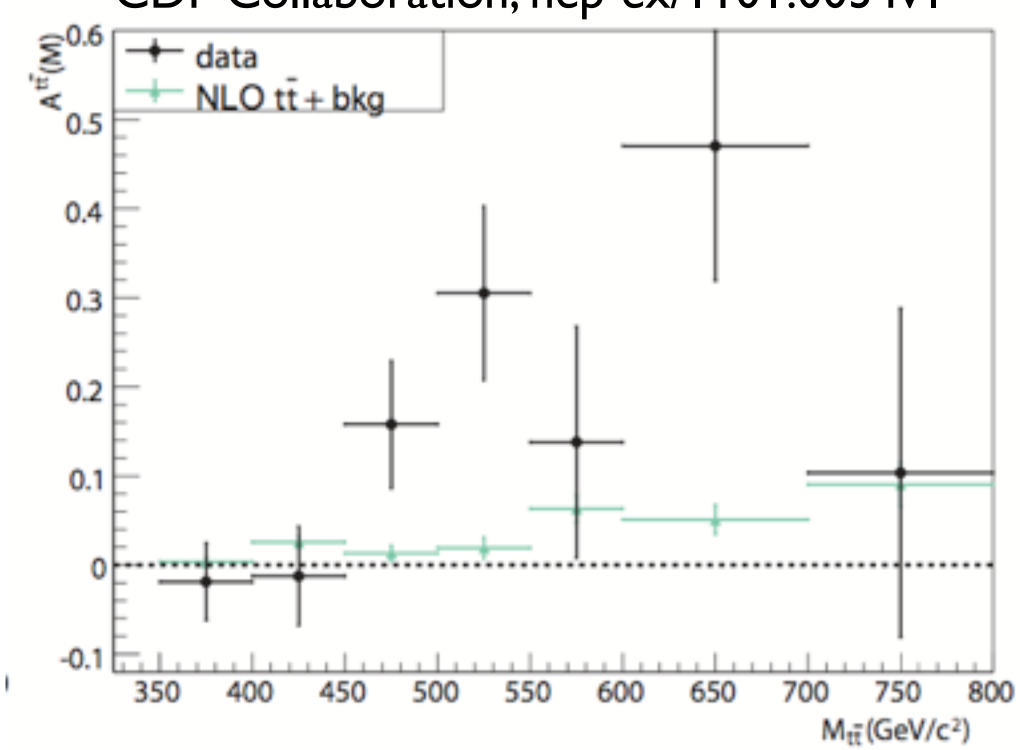
Motivation

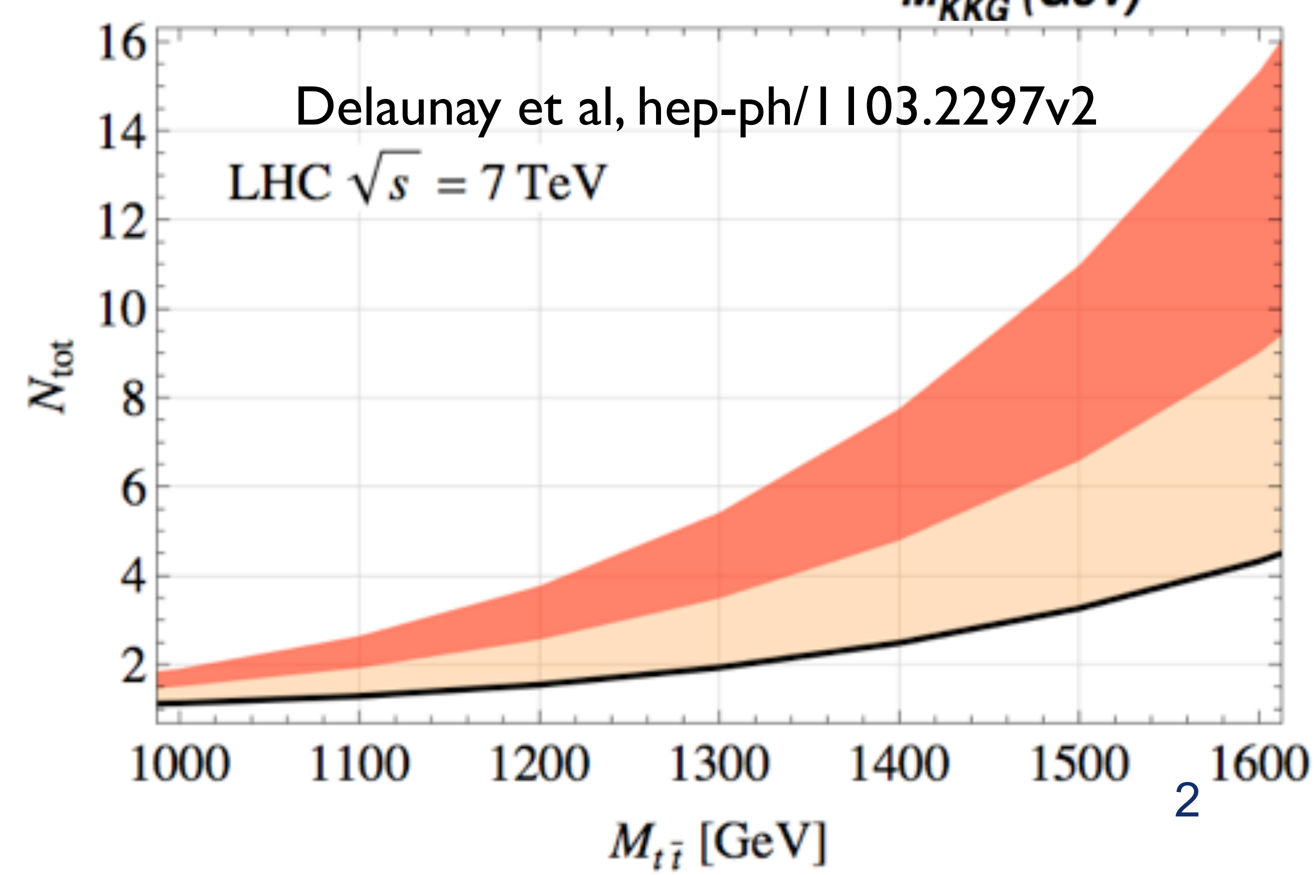
- Solution to hierarchy problem often involves ttbar in the final state
- Top forward/backward asymmetry at Tevatron possibly explained by hard interaction, visible in ttbar invariant mass spectrum

Agashe et al, hep-ph/0612015v1



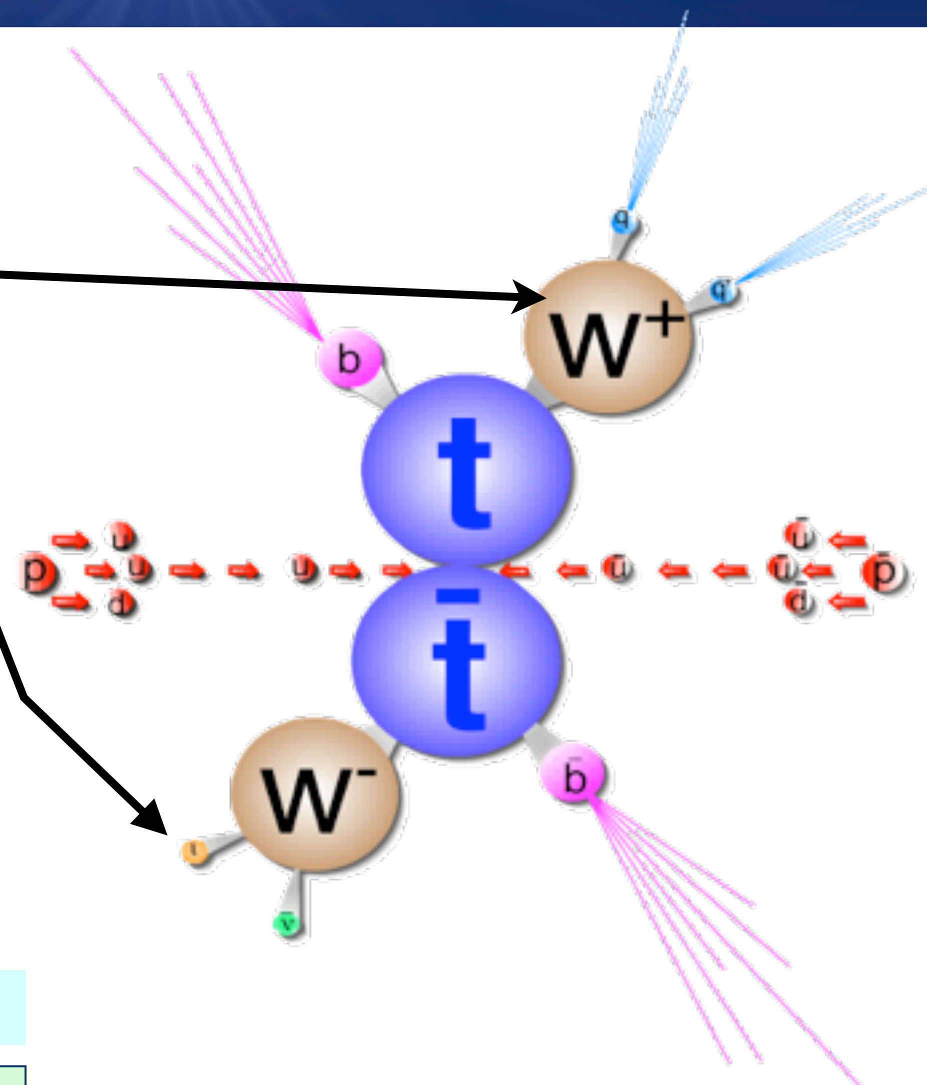
CDF Collaboration, hep-ex/1101.0034v1

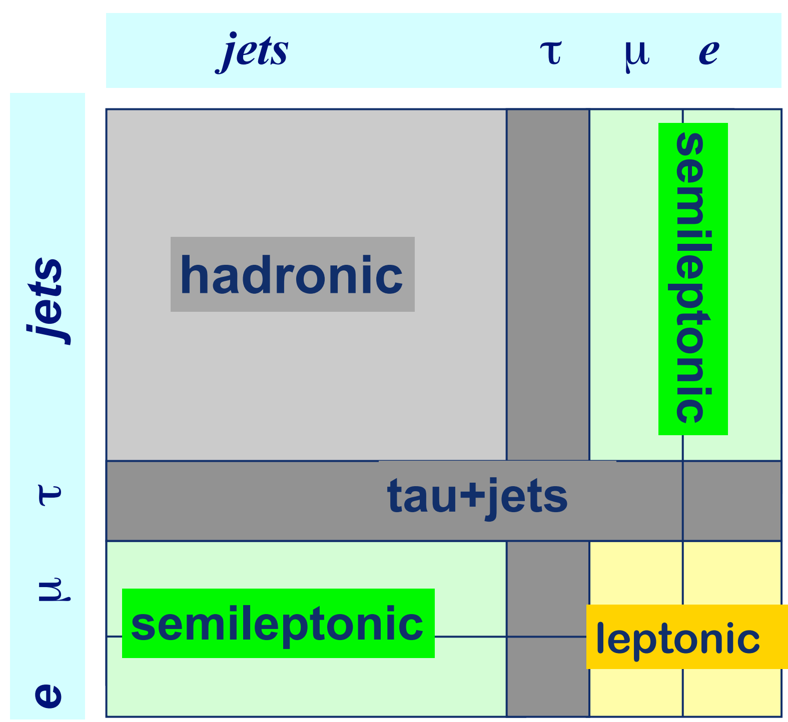




Strategy

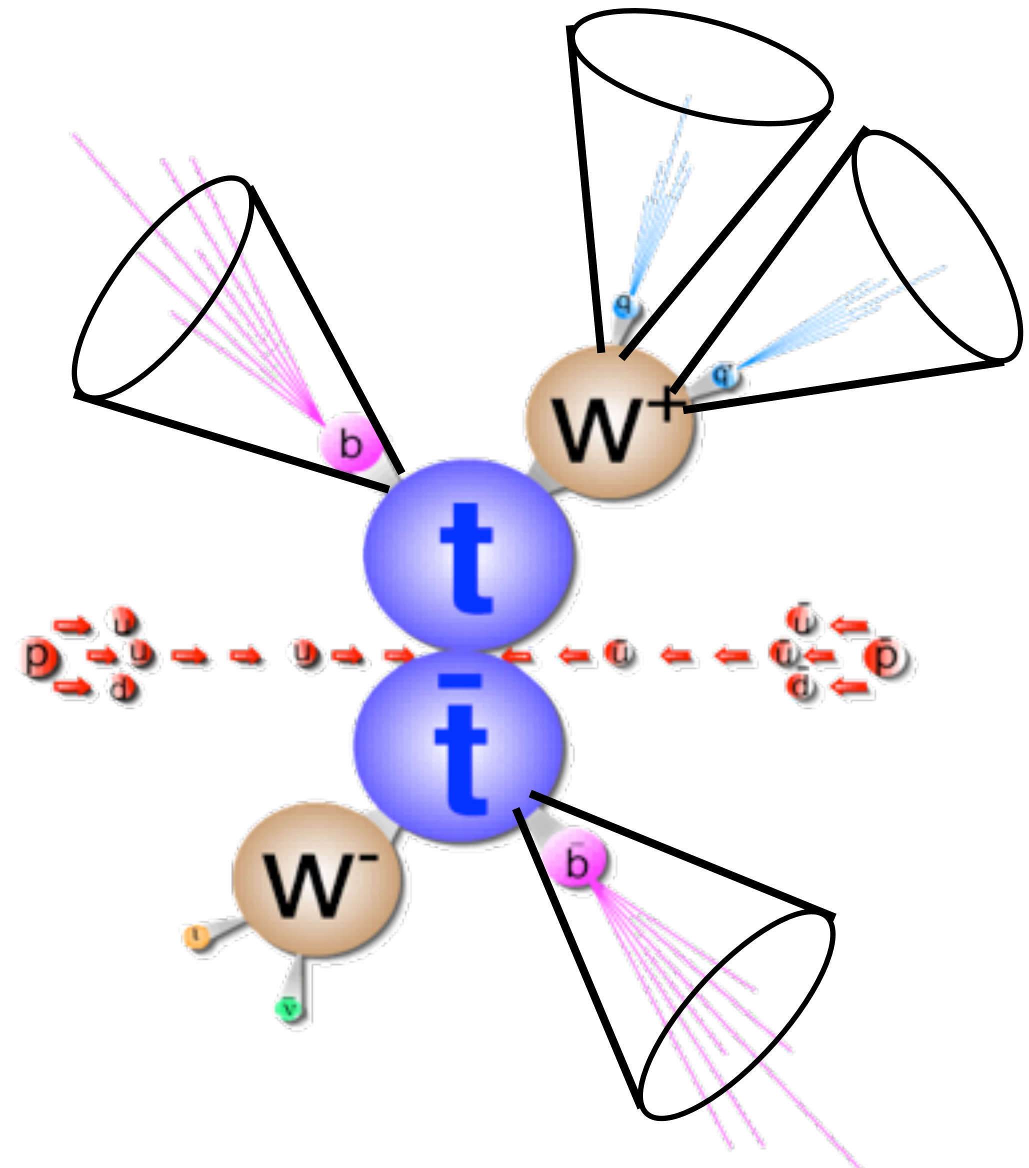
- Characterize ttbar decays based on the decays of the W
- All channels have good sensitivity in different kinematic regimes
  - Fully leptonic analysis
  - Semileptonic analysis
  - **New!!!** All-hadronic analysis





Strategy

- Traditional "parton-to-jet" assignment is useful, but breaks down at high energy
  - Generic feature of hadronic final states
- Need to use new technology from **jet substructure**!



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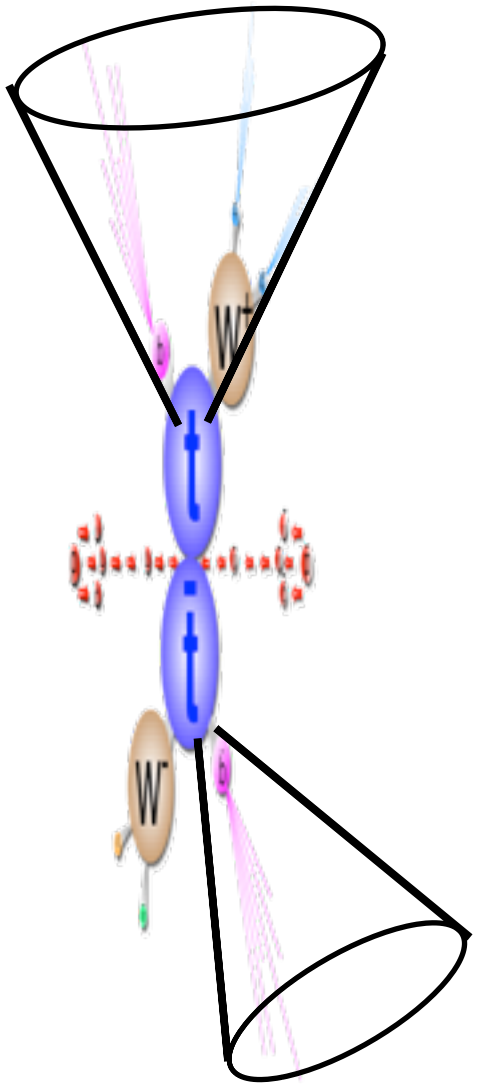

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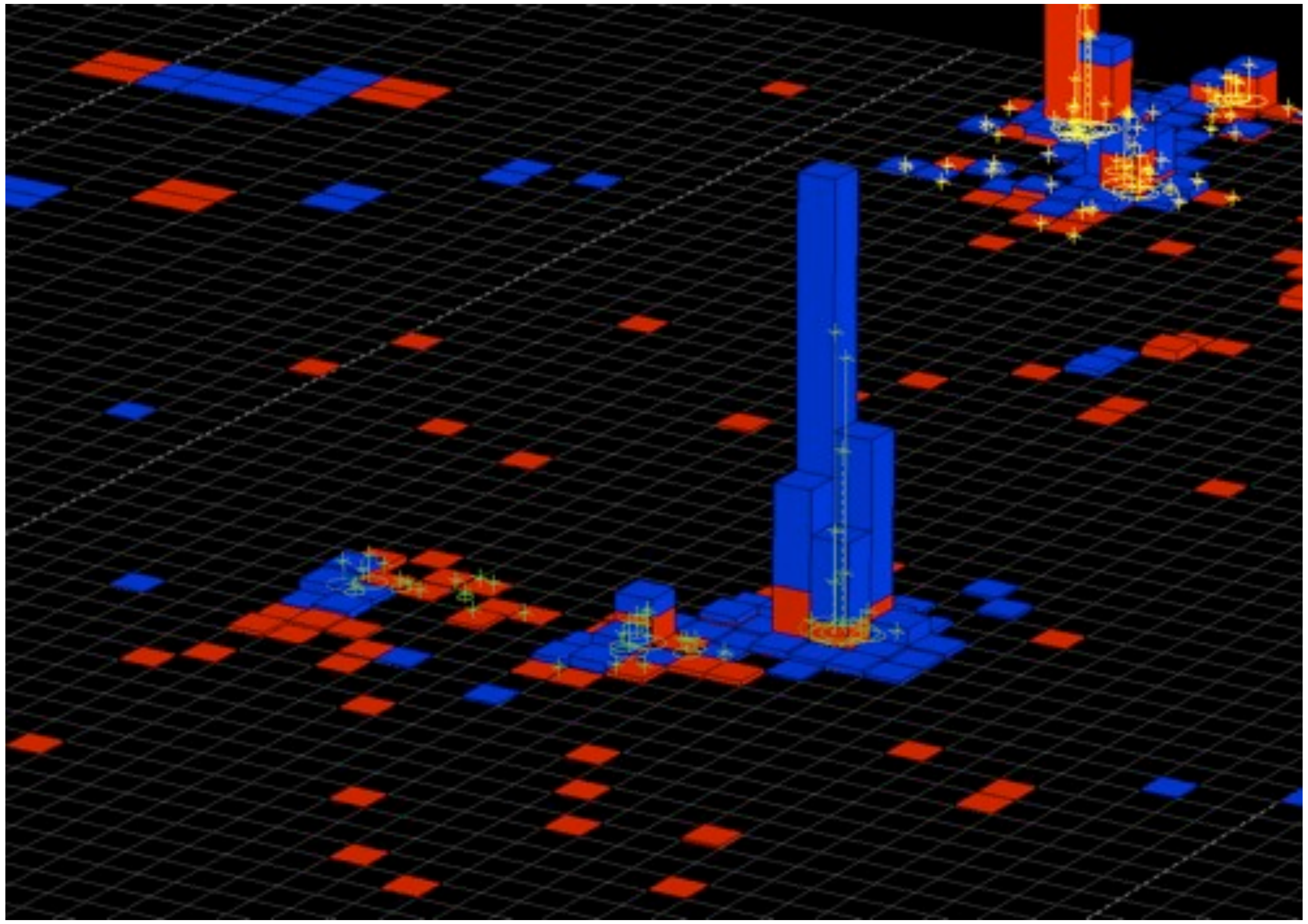
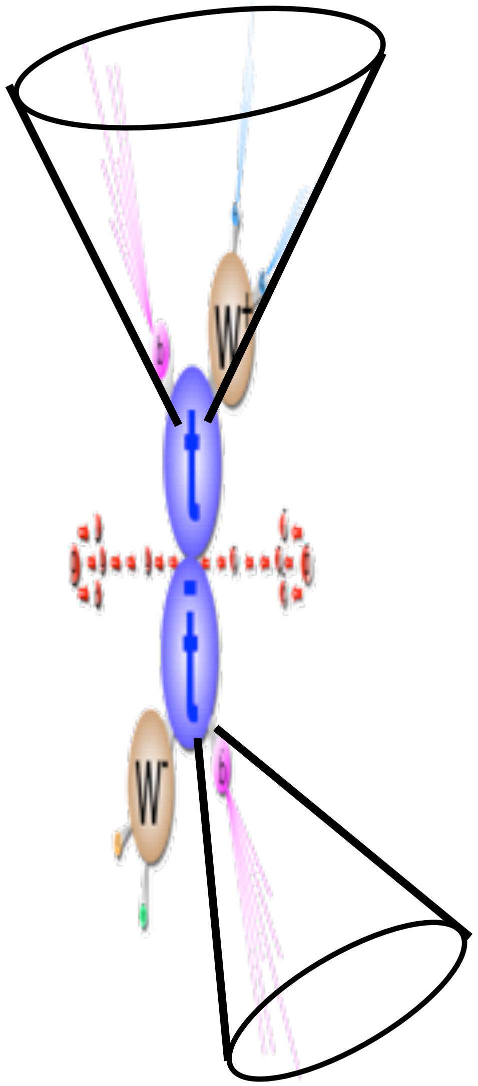




Experimental Overview

(3.8T)

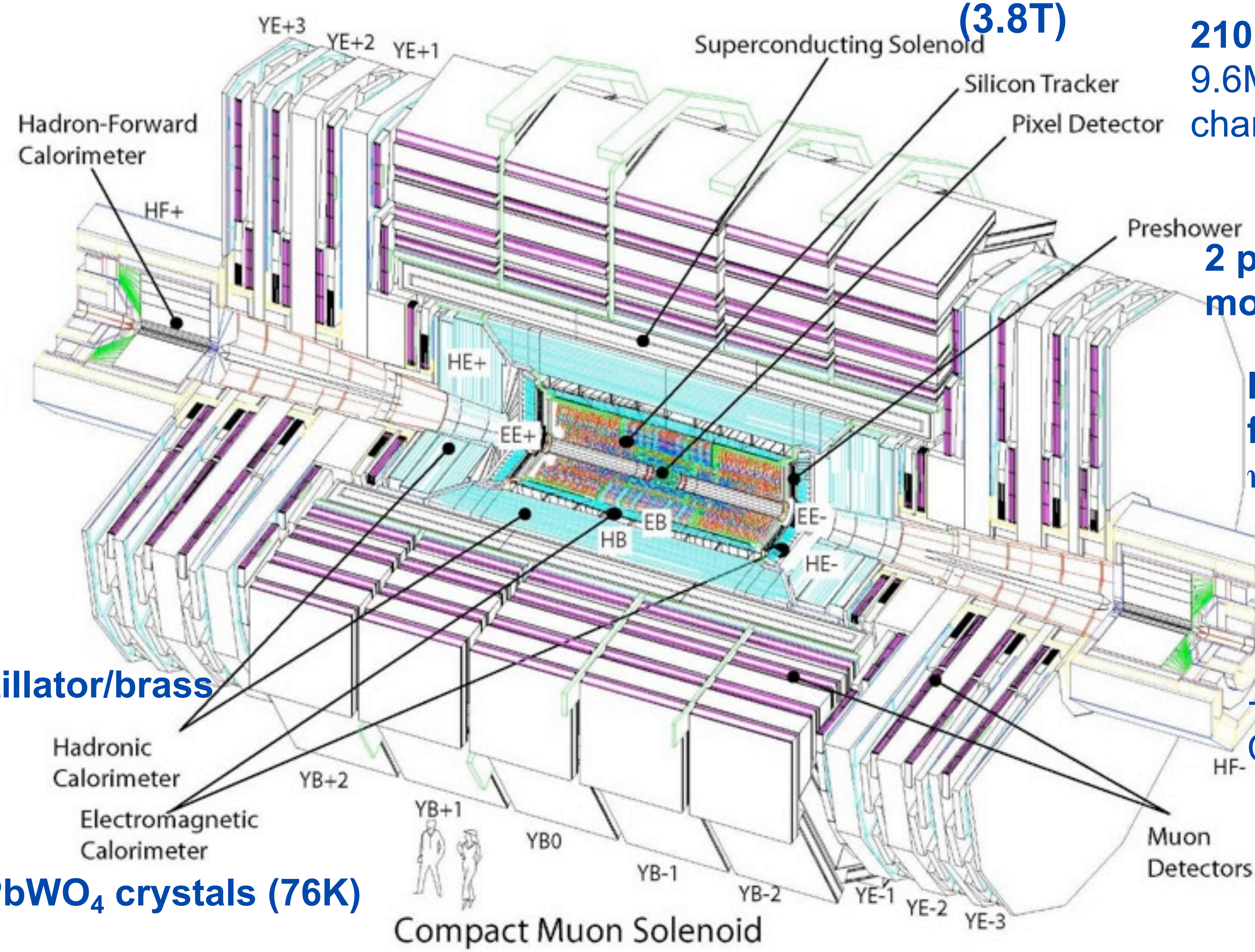
210 m² of silicon sensors: 9.6M (Str) & 66M (Pix) channels

2 planes of silicon modules for ECAL

Iron / Quartz fiber fwd calorimeter, 3<|η|<5;

+ Castor, 5<|η|<6.55

+ Zero Degree Calorimeter



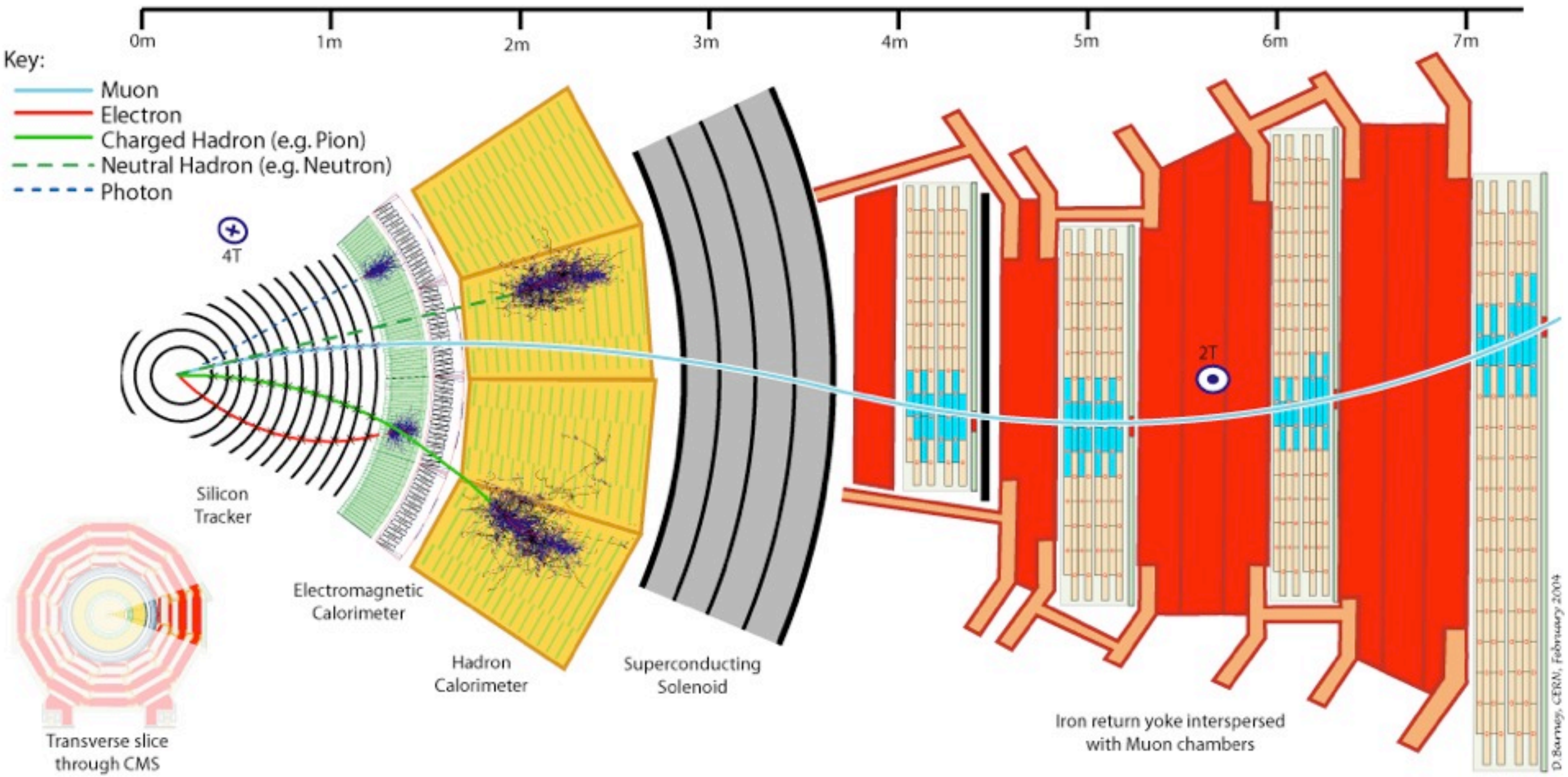
Scintillator/brass

$PbWO_4$ crystals (76K)

Cathode Strip Chambers, Drift Tubes, Resistive Plates

Experimental Overview

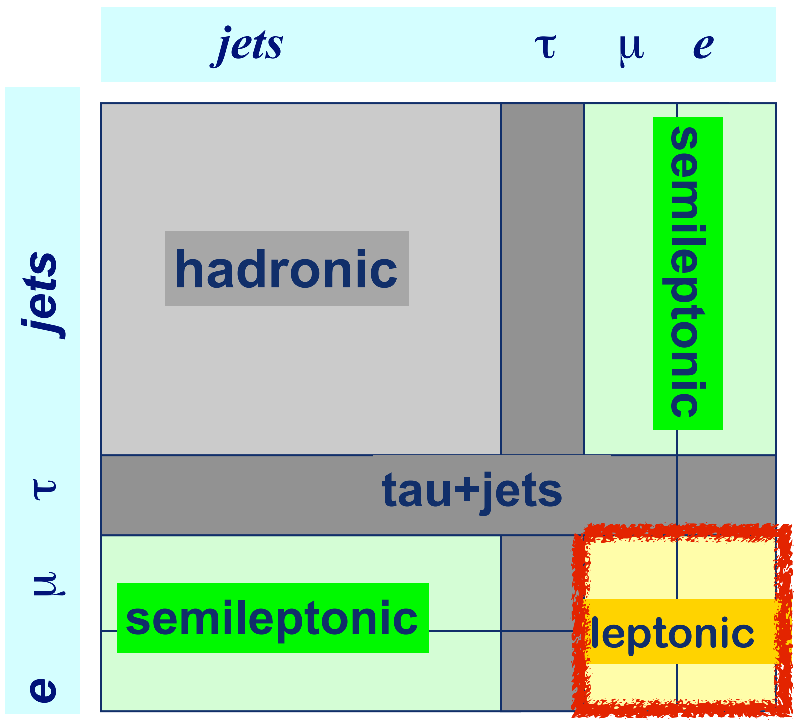
Classify objects into 5 categories



"Holistic" approach to reconstruction at CMS: Particle flow!

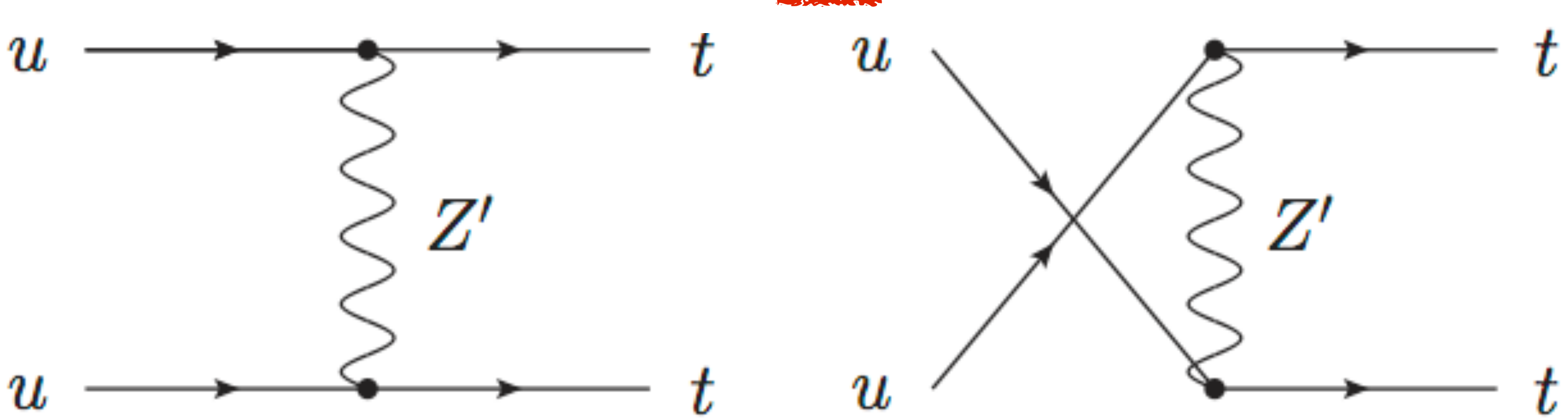
Fully Leptonic Analysis

- Reinterpretation of SUSY same-sign dilepton search
  - hep-ex/1104.3168, JHEP 1106:077,2011
- Examine e + mu, e + e, and e + mu final states, 36 pb^{-1}
- Possible explanation for top A_{FB} anomaly at Tevatron involve Flavor Changing Neutral Current (FCNC) Z' exchange
  - cf Berger et al (hep-ph/1101.5625v2)
- Examine same-sign tt search in dilepton channel
- Formulated in terms of the right-handed coupling f_R
- Left-handed coupling is constrained by B_d mixing



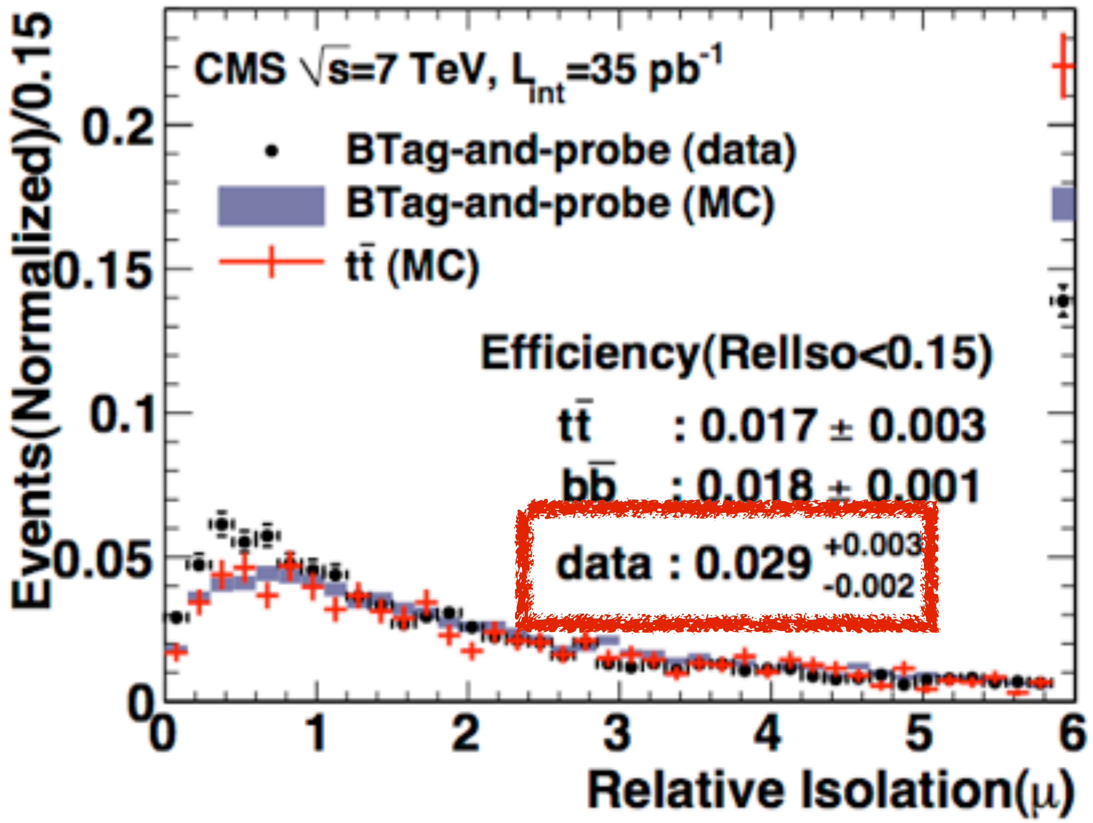
hep-ex/1106.2142
CMS-PAS-EXO-11-065

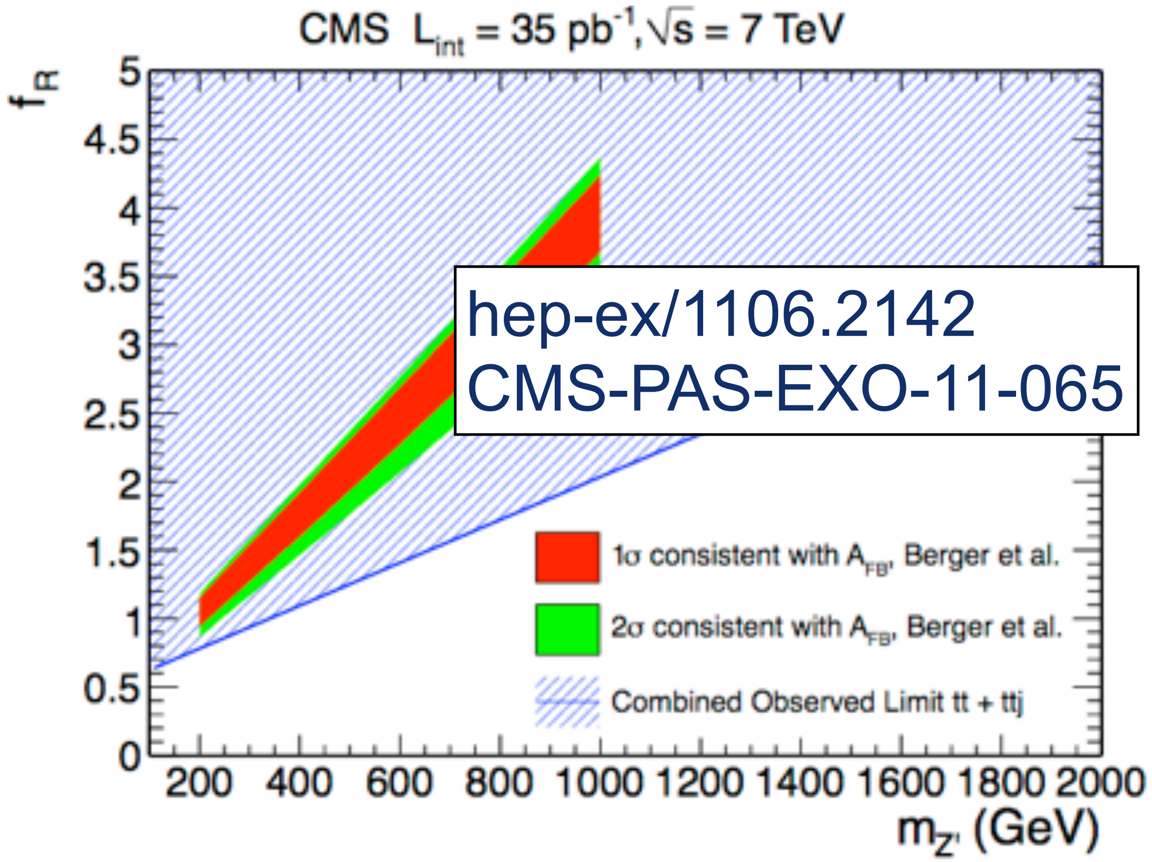
$$\mathcal{L} = g_W \bar{u}\gamma^\mu (f_L P_L + f_R P_R) t Z'_\mu + \text{h.c.},$$



Fully Leptonic Analysis

- Require >=1 e or mu
  - p_T > 20 GeV
  - Both have positive charge (pp -> tt)
  - >=2 jets with p_T > 30 GeV
- Data-driven background
  - Dominated by ttbar
    - One true prompt W lepton, one from semileptonic b-decay
  - Use btagged sideband regions (btag + probe) to determine backgrounds
- Main systematic uncertainties : lepton selection (12%), jet energy scale (8%)
- Observe 2 events
- Expect 0.9 +- 0.6
- Interpret limit in terms of f_R and $m_{Z'}$
- Disfavors the Z' interpretation of the top A_{FB}

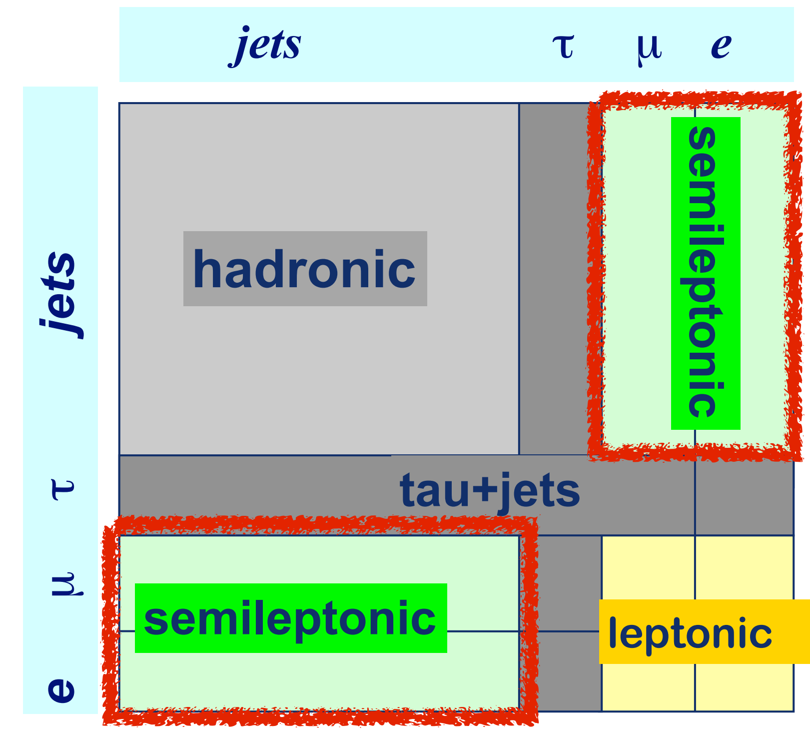




hep-ex/1106.2142
CMS-PAS-EXO-11-065

Semileptonic Analysis

- Examine e/mu + jets final states, 36 pb^{-1}
- Require
  - Exactly 1 e,mu with p_T > 30,20 GeV
  - >= 3 jets, p_T > 30 GeV
  - MET > 20 GeV
- Categorize events into categories (4 for each lepton type):
  - 3 jets, >=1 btag (one bin)
  - >=4 jets, 0/1/2 btag (three bins)
- Perform kinematic fit with ttbar mass hypothesis



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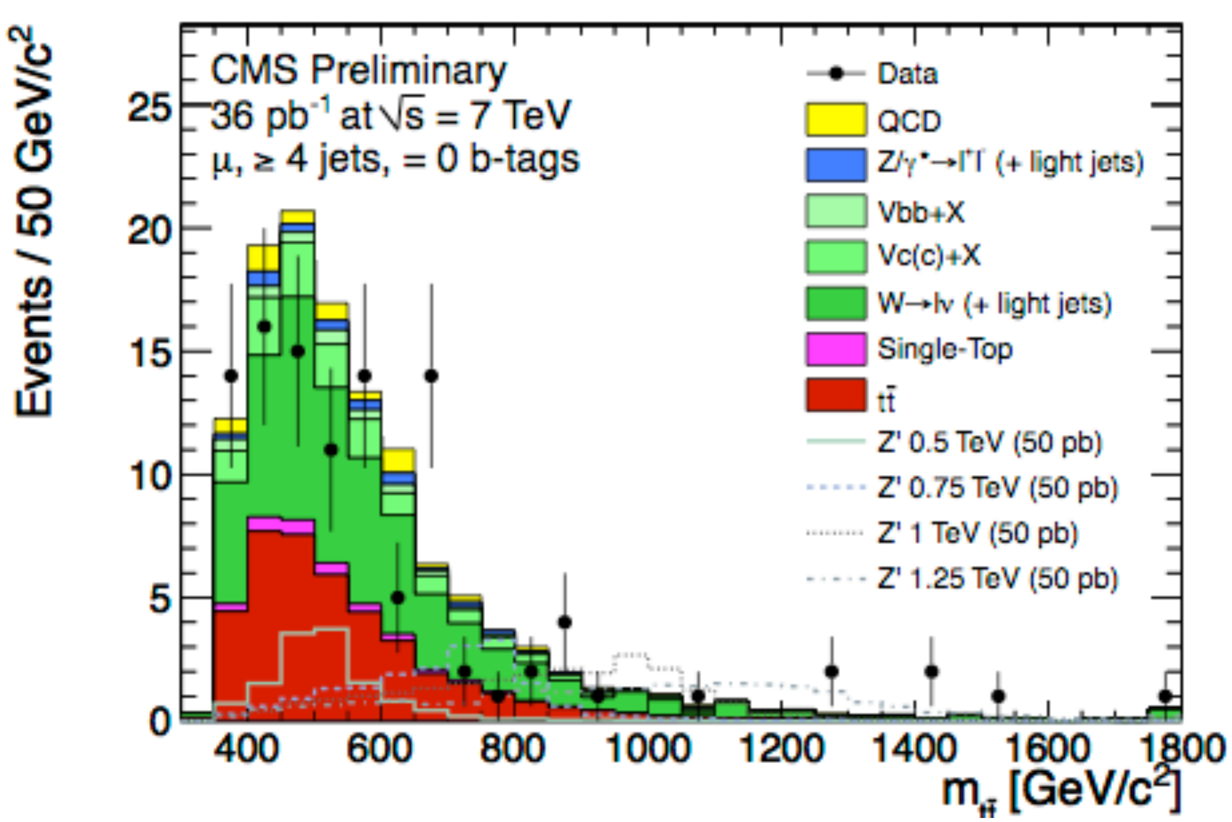
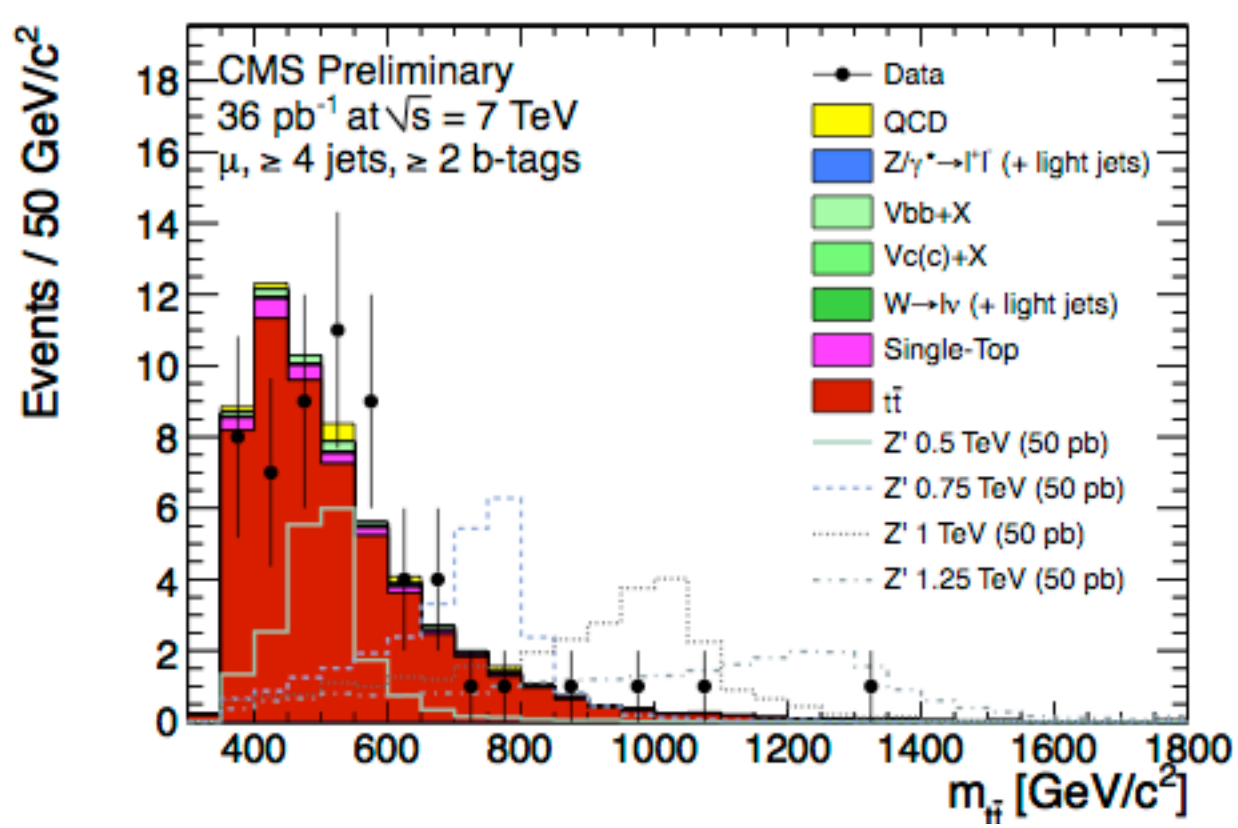
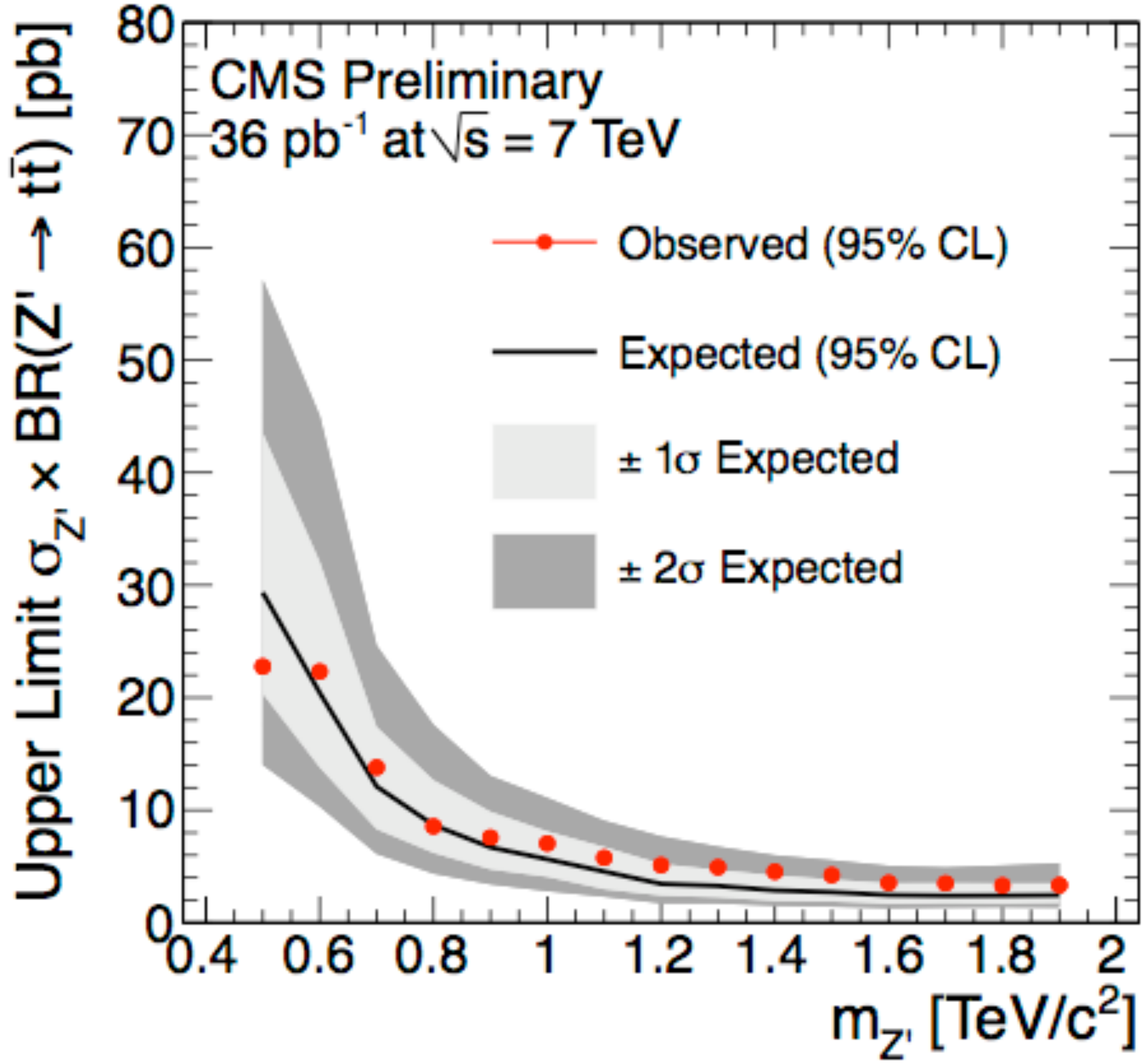




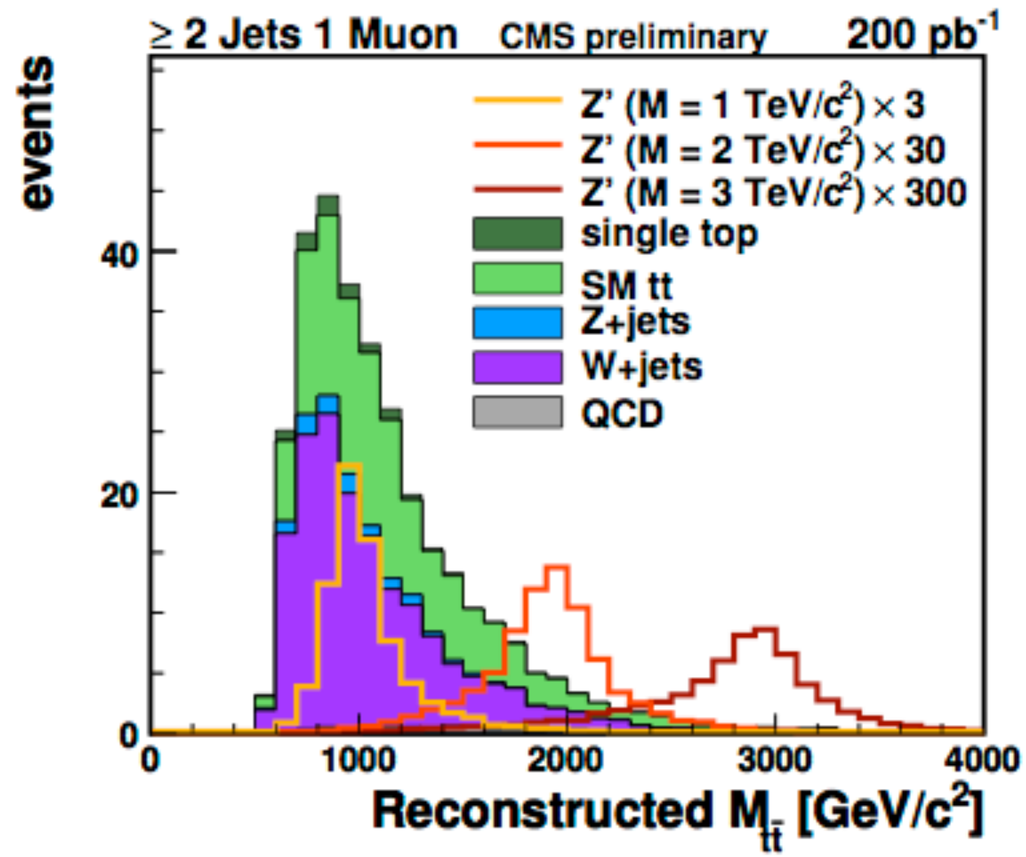
- Backgrounds are:
  - QCD multijets (from data)
  - W+Jets (from MC)
  - TTbar + Jets (from MC)
- Good agreement between data and MC, no excess seen
- Set limit with Bayesian technique (using Markov Chain MC integration to integrate over nuisance parameters)



Semileptonic Analysis

- The traditional jet/parton assignment in the previous analysis breaks down for high mttbar
- Need to employ other techniques to handle cases with merged jets!
- Developed a technique that relaxes lepton isolation and N_{jet} requirements to maintain high efficiency at high mttbar
- Measurement underway, expected sensitivity from MC is better at high mttbar

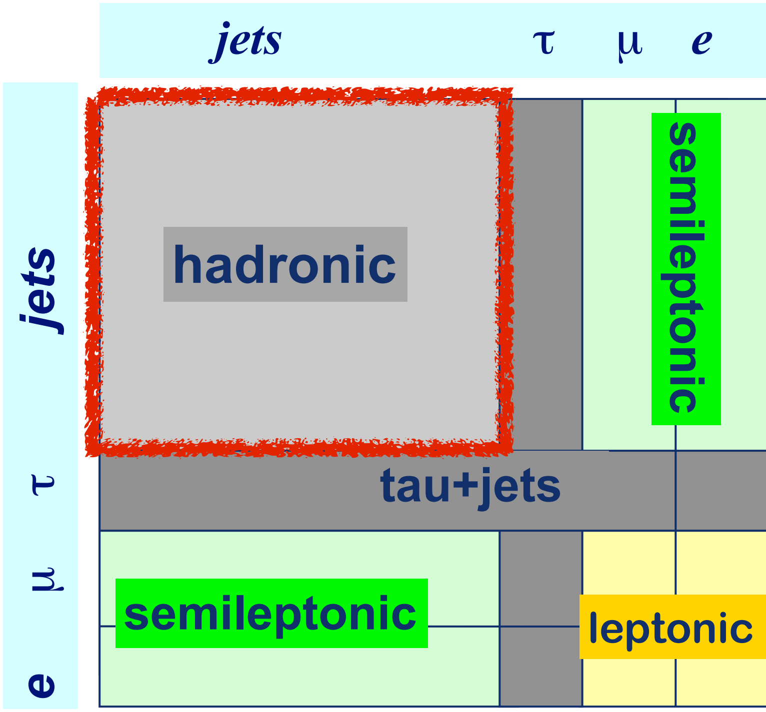
CMS-PAS-EXO-09-008



Monte Carlo Study
at 10 TeV,
expect measurement soon

All-Hadronic Analysis

- **New result with 0.9 fb^{-1}!**
- All-hadronic final state has largest BR (44%) but also lowest S/B (1/5 or 1/10)
- However, recent techniques in **jet substructure** opens this channel for the case of boosted top quarks!



W mass from jets in semileptonic sample

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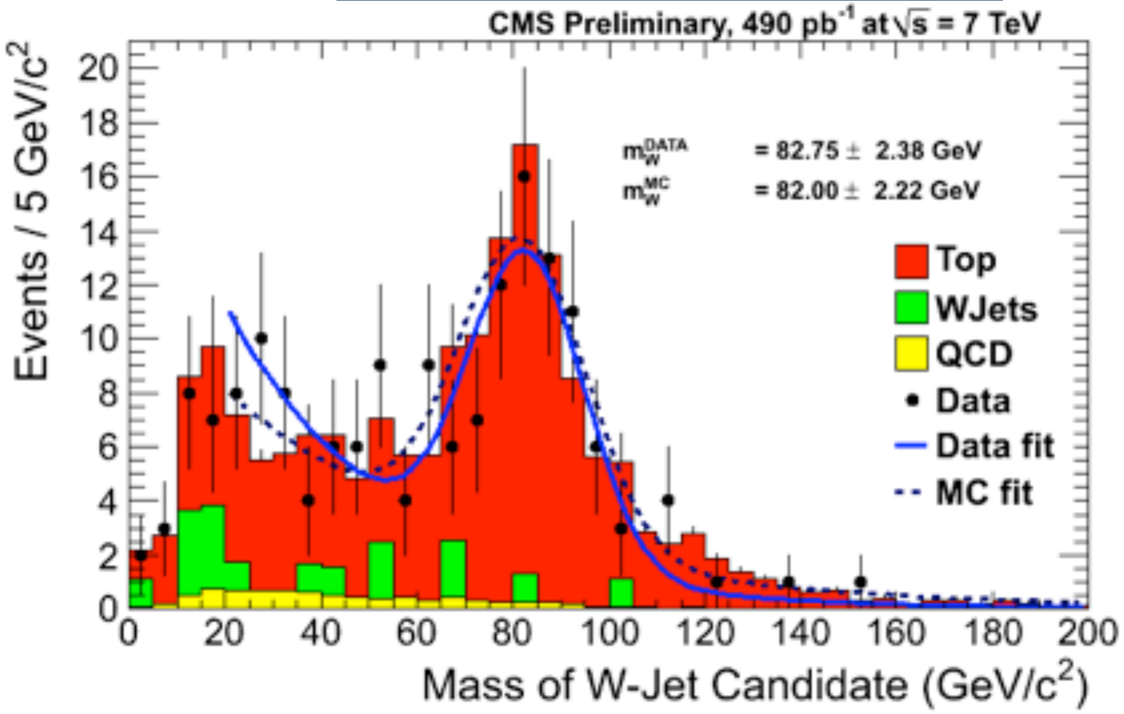
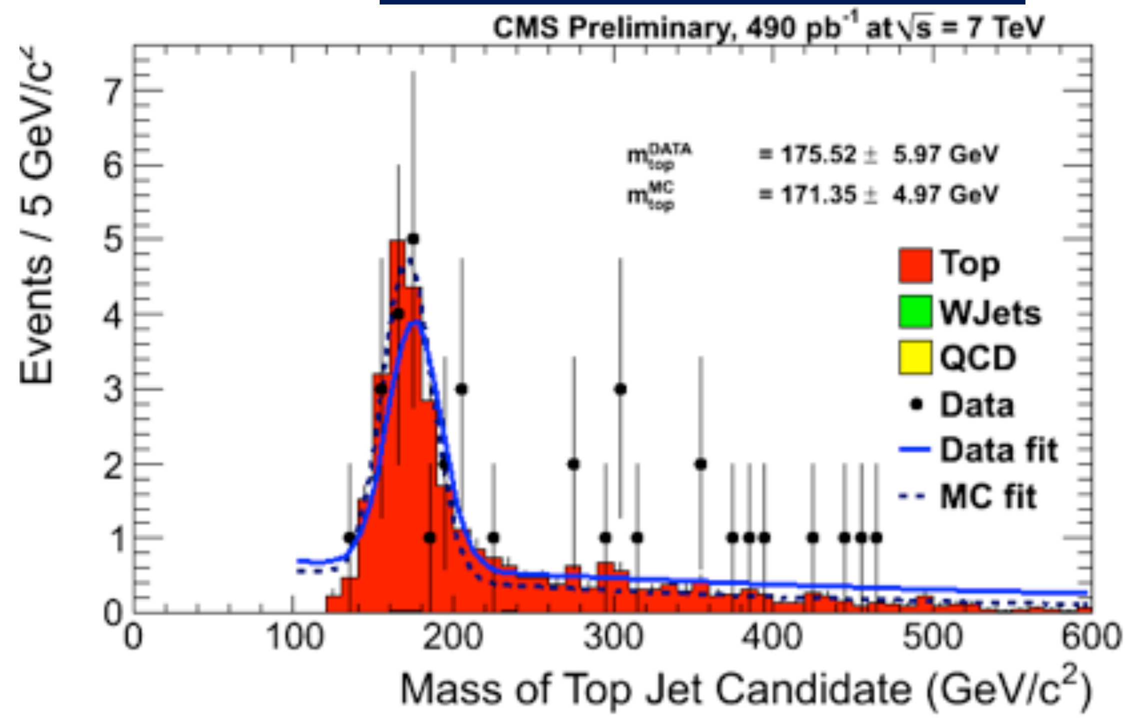
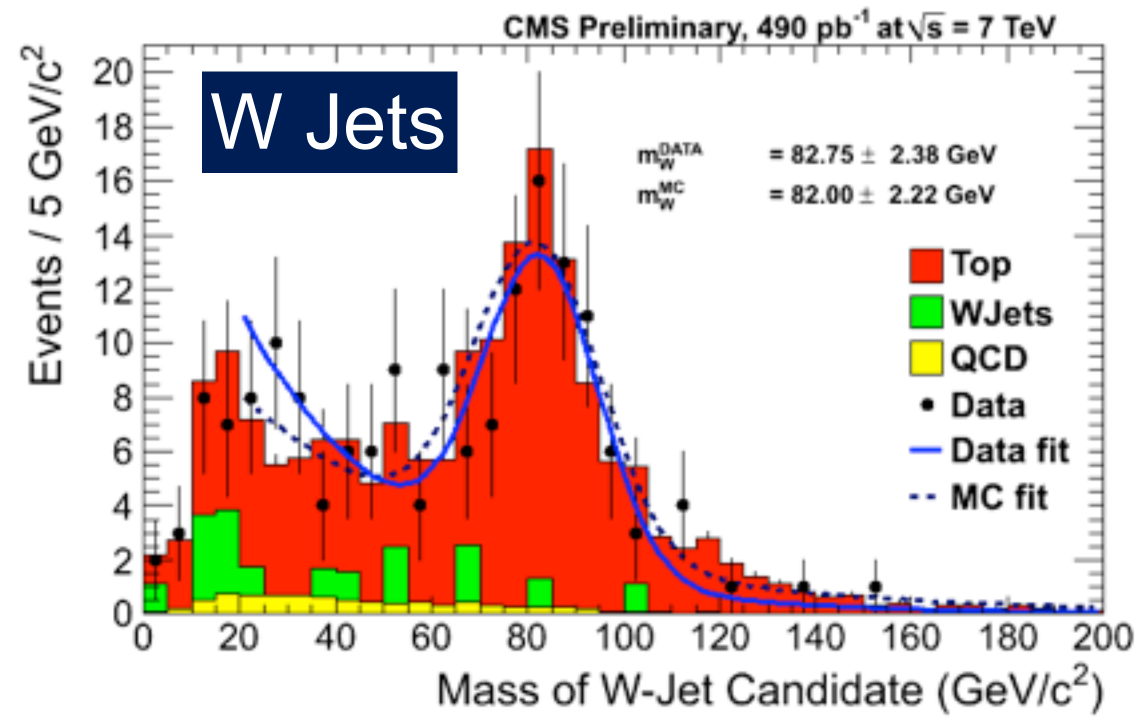
Add Closest Jet to form top candidate

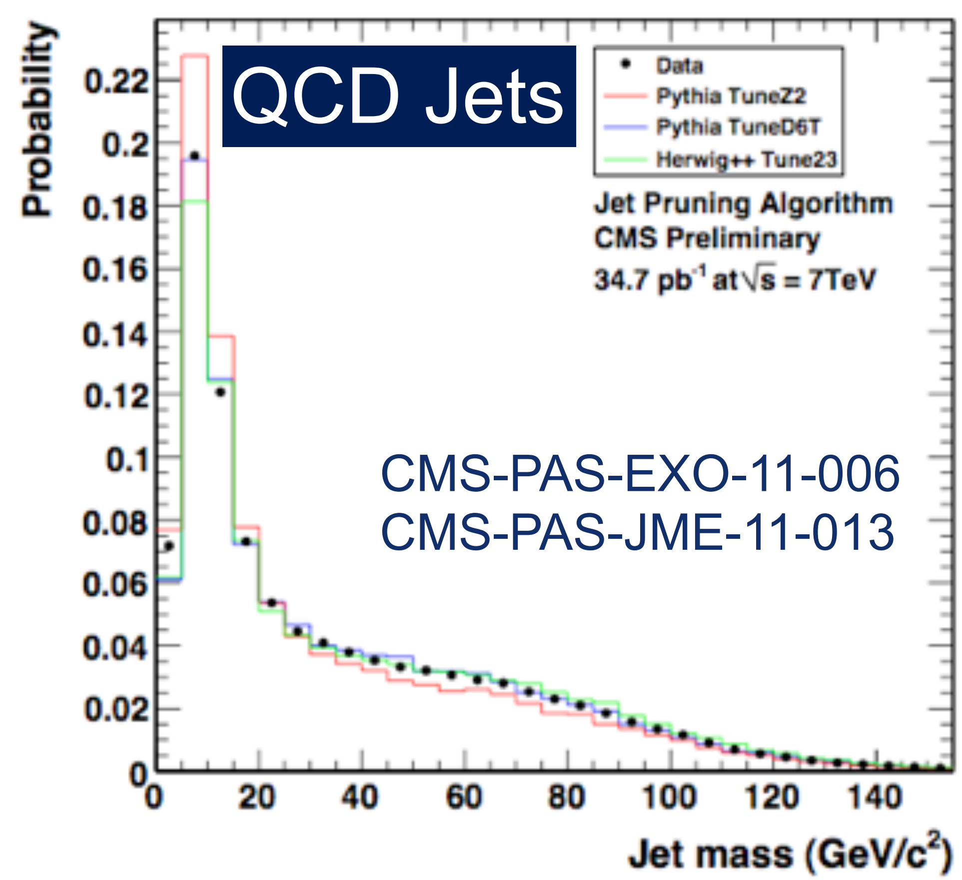




All-Hadronic Analysis

- Jet Substructure
  - Uses the principle that jet masses are different for QCD and "merged" jets from a resonance
- Plethora of new tools, we've used these:
  - "BDRS" Subjet/filter technique
    - Butterworth et al: Phys.Rev.Lett. 100:242001,2008, arXiv:0802.2470v2
  - JHU "top tagger"
    - Kaplan et al: Phys.Rev.Lett. 101:142001,2008, arXiv:0806.0848
  - University of Washington "jet pruning"
    - Ellis et al: Phys. Rev. D80 (2009) 051501, arXiv:0903.5081





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Top Tagging Details

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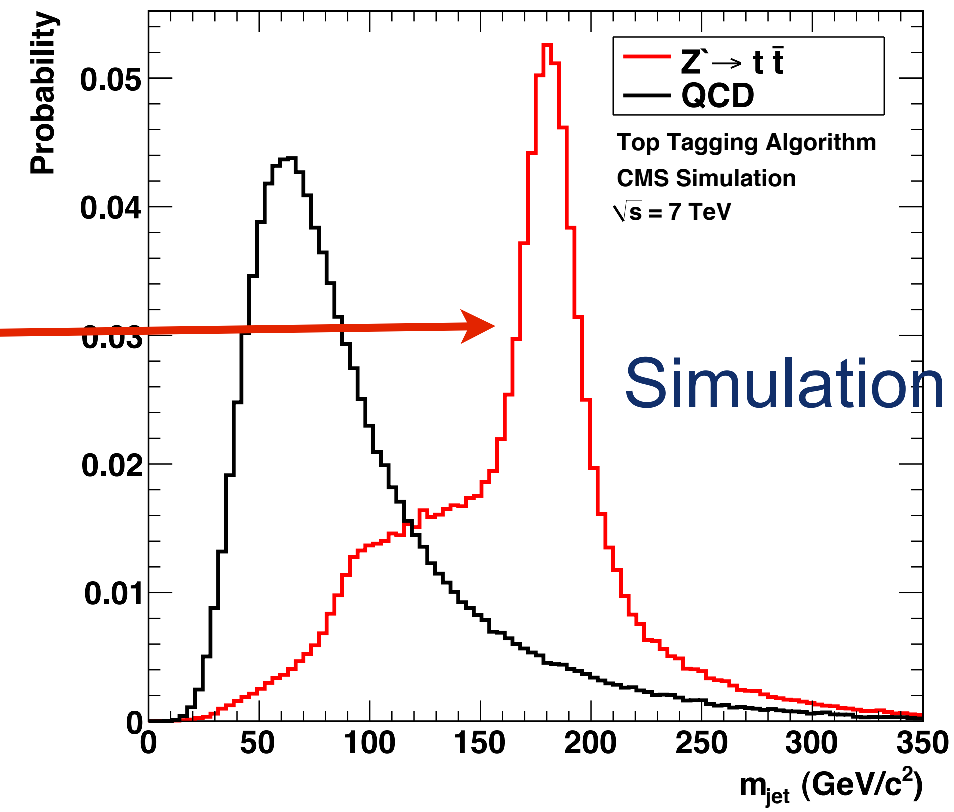
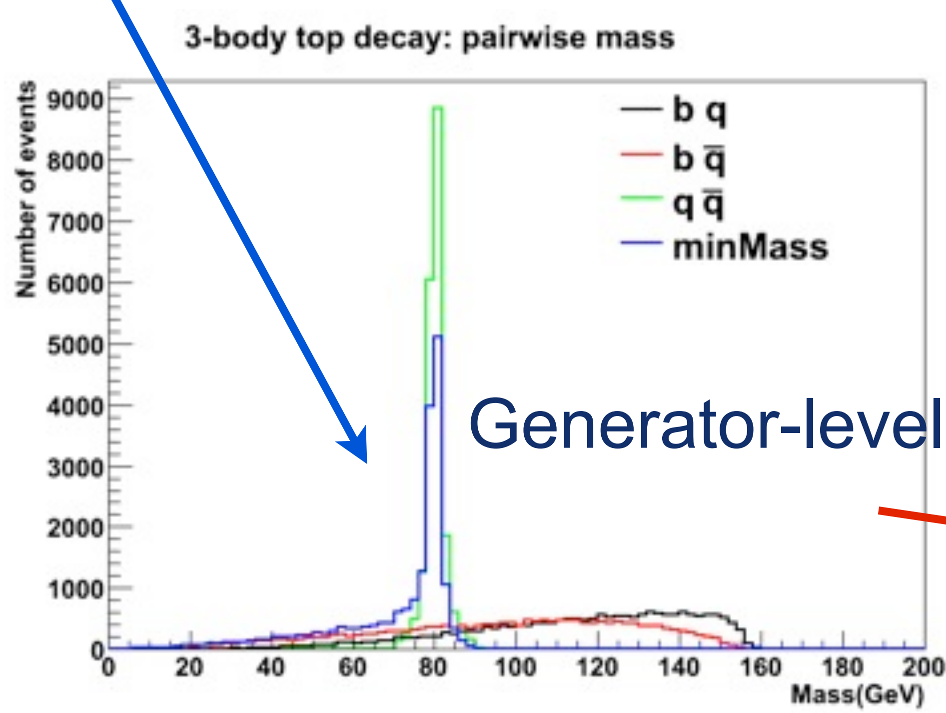
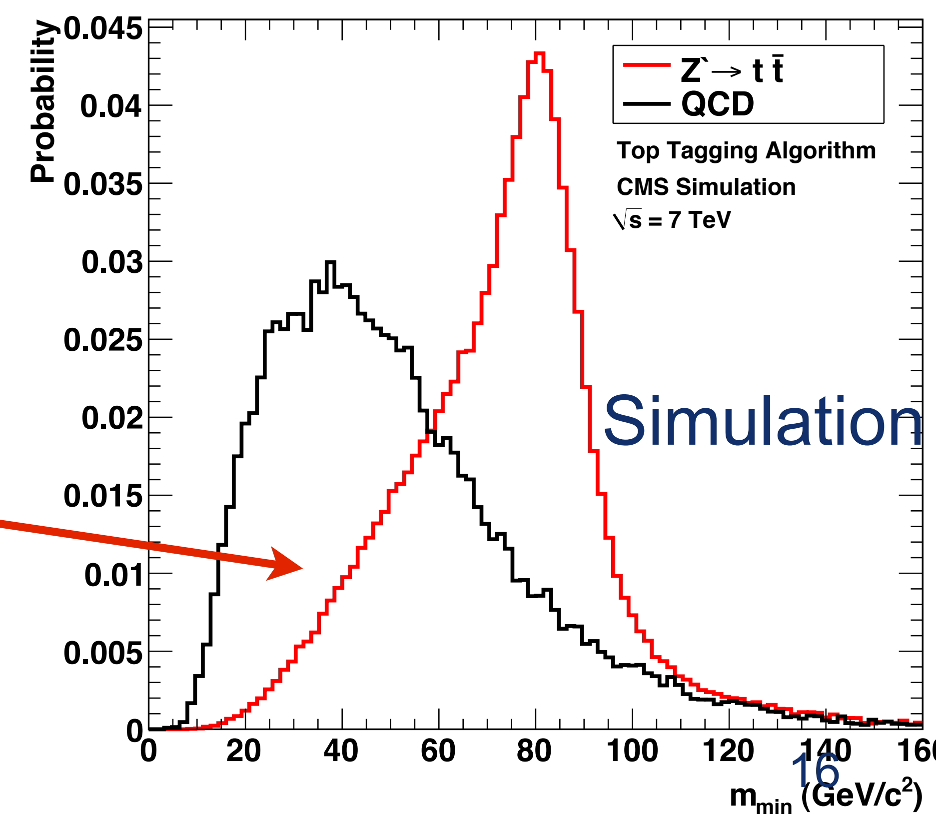
- Discriminating variables:
  - Number of subjets: 3 or 4
  - Top Mass: Approximated by jet mass
    - Mass in 100-250 GeV/c^2
  - W Mass: Approximated by min pairwise mass
    - Min mass > 50 GeV/c^2



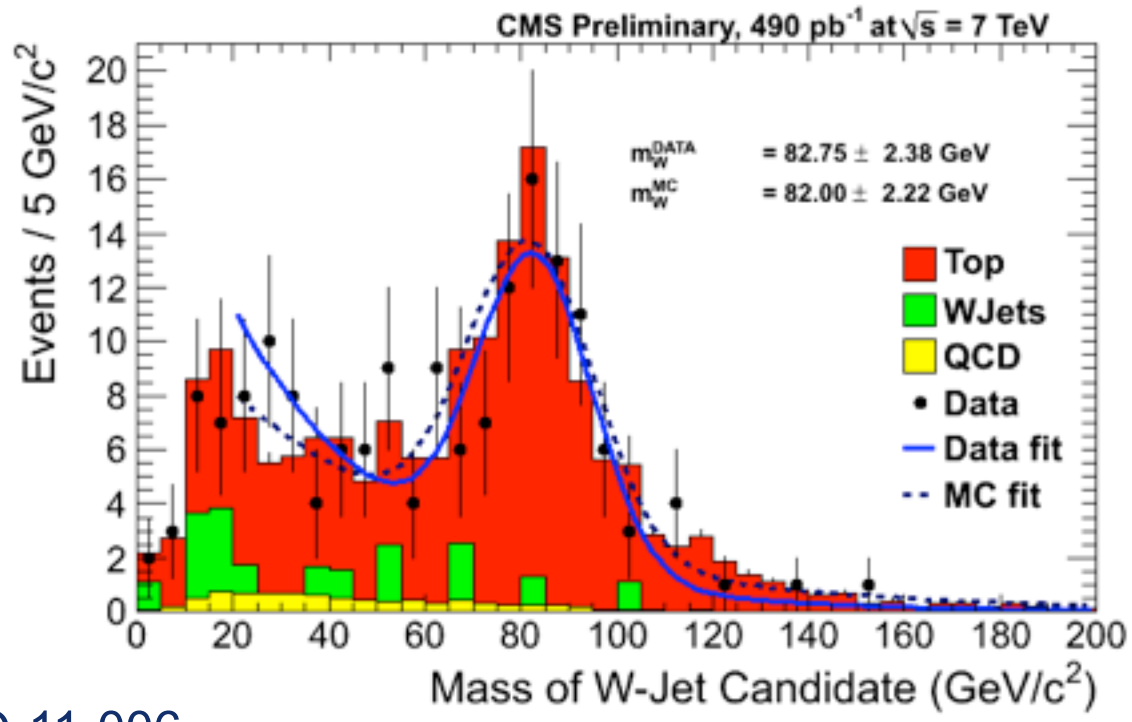
$$m_{\min} = \min[m_{12}, m_{13}, m_{23}]$$





W Tagging Details

- Can compute ratio of efficiencies in data and MC
  - Completely statistically dominated, will improve with more data!
- Combined selection:
  - 60 < Mjet < 100
  - Mass Drop < 0.4
- Combined efficiencies:
  - Data: 28%
  - MC : 30%
- Evaluate "data-to-MC scale factor":
  - SF = 0.93 +- 0.13



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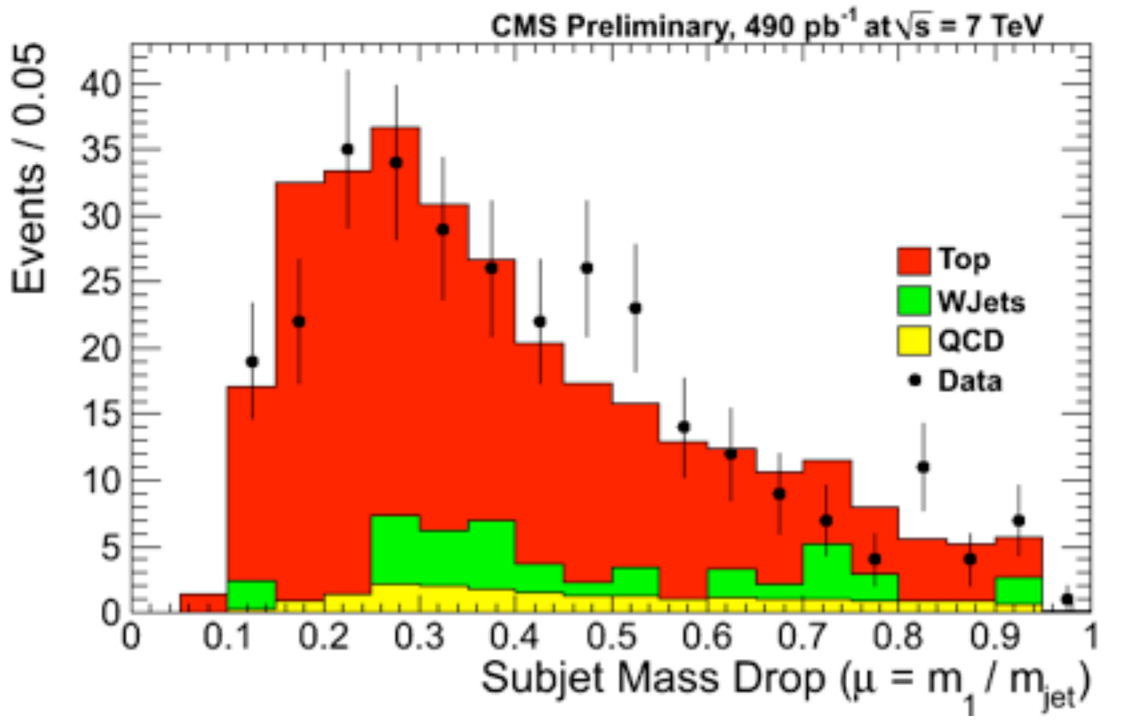

Monday, August 8, 2011

All-Hadronic Analysis

- Fully merged, "type 1" : JHU top tagger
- Partially merged, "type 2" : U of W jet pruning with BDRS mass drop as a "W tagger"

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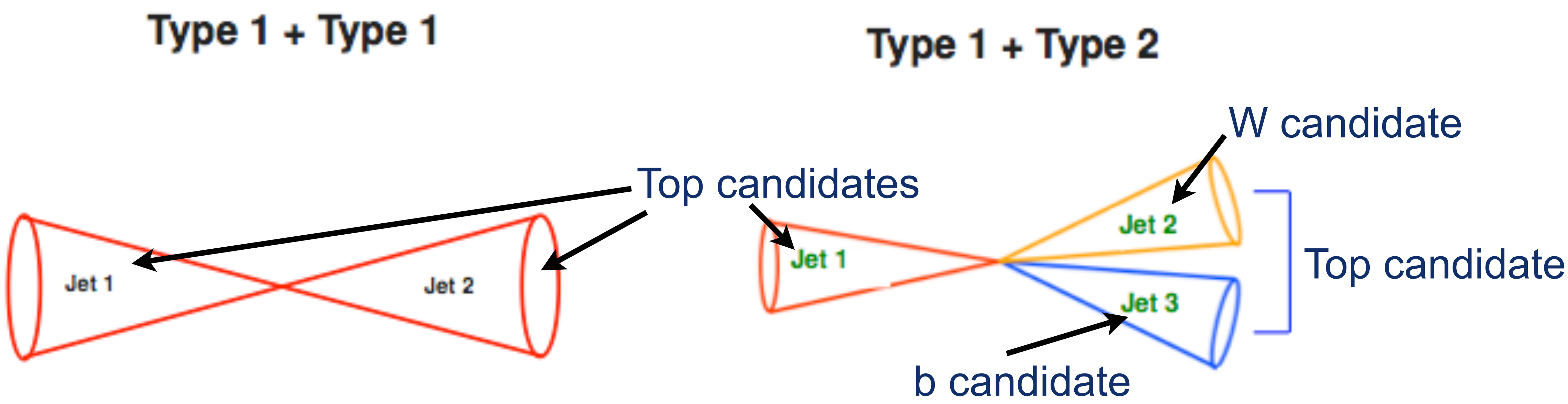

- 2 jets, p_T > 350 GeV
- Both jets are top tagged

- Not type 1 + 1
- Jet 1 pT > 350 GeV, top tagged
- Jet 2 pT > 200 GeV, W tagged
- Jet 3 pT > 30 GeV, form top mass with jet 2

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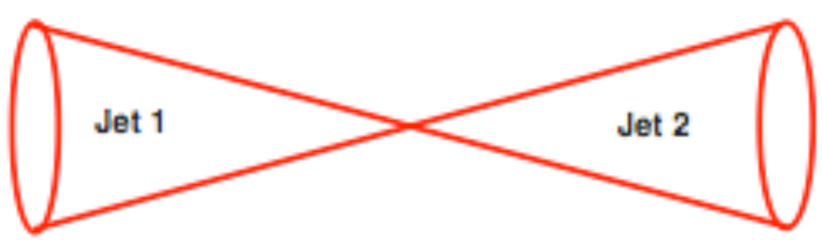
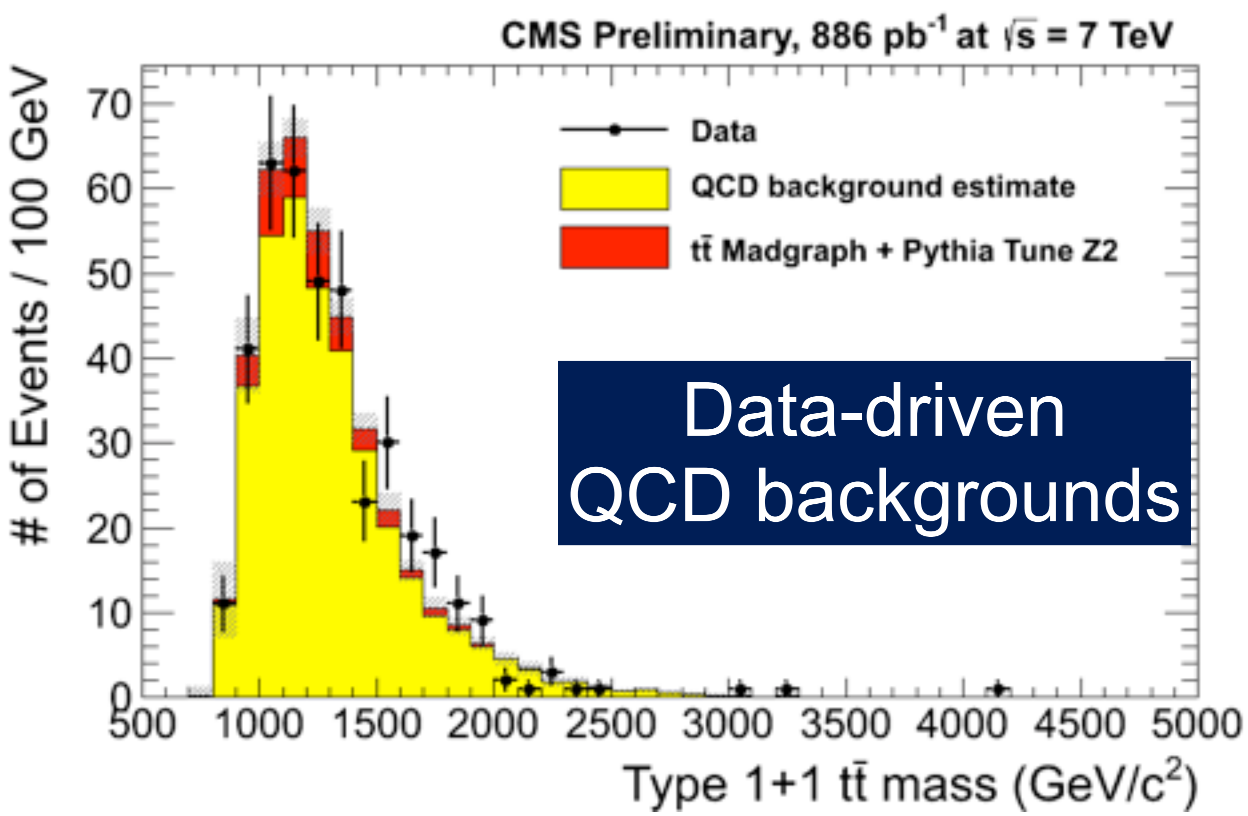
Type 1 + Type 1

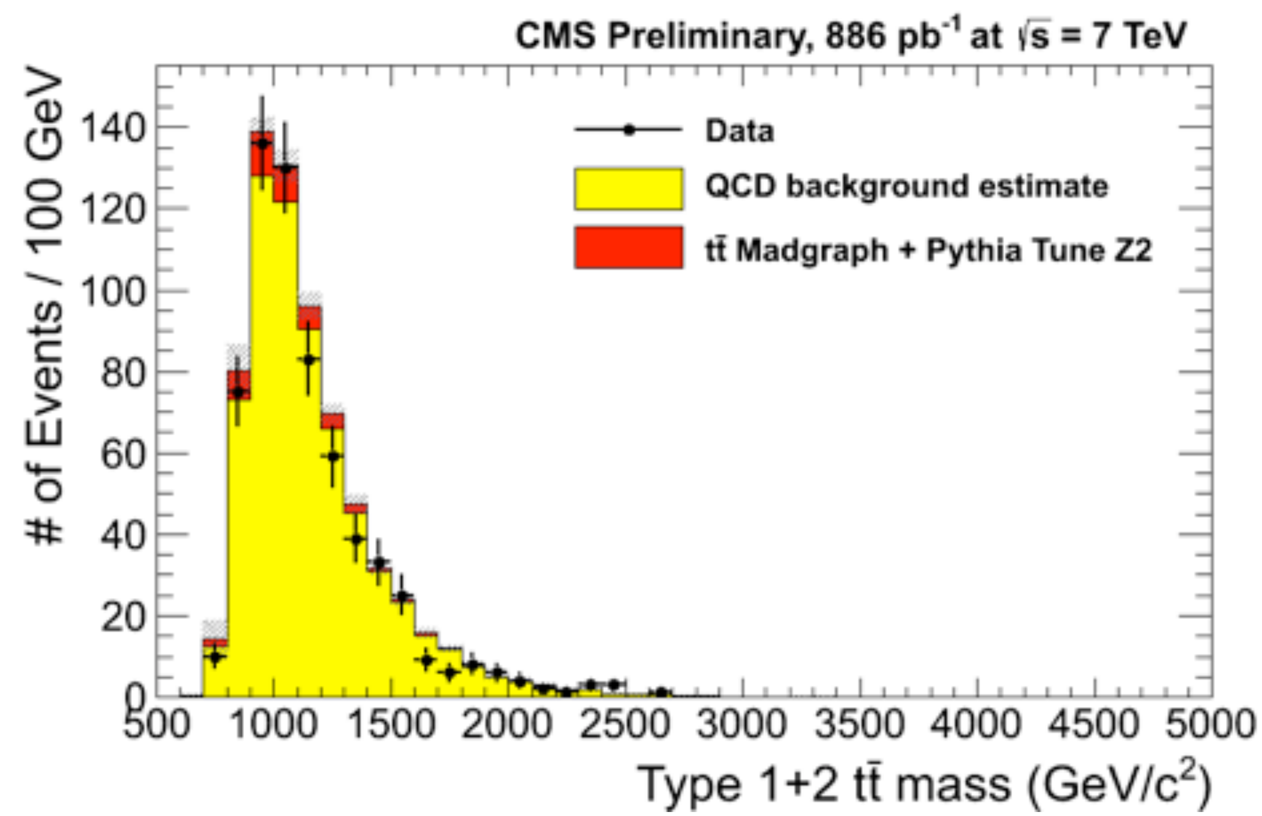


Type 1 + Type 2

b candidate



Data-driven
QCD backgrounds



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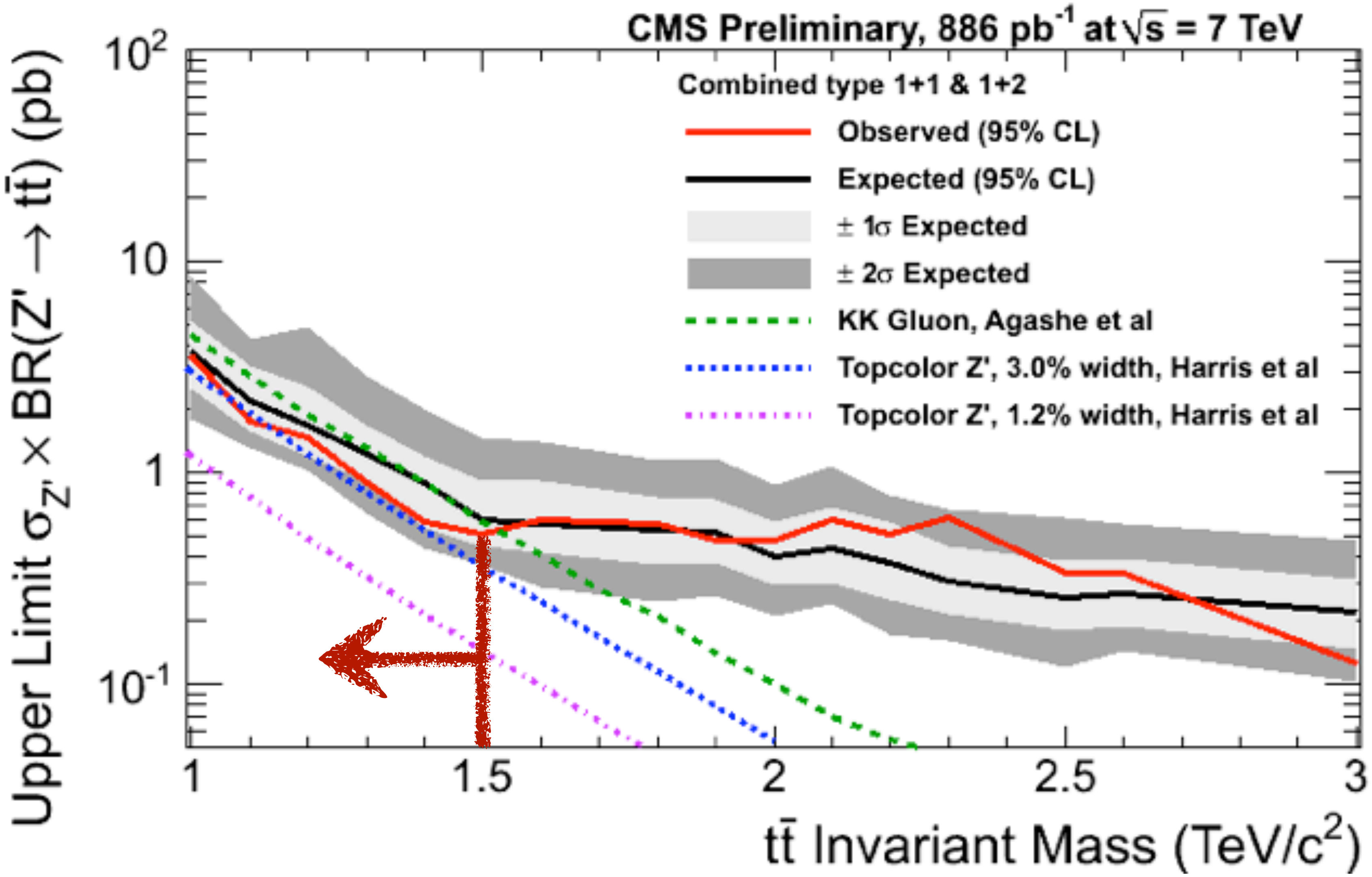
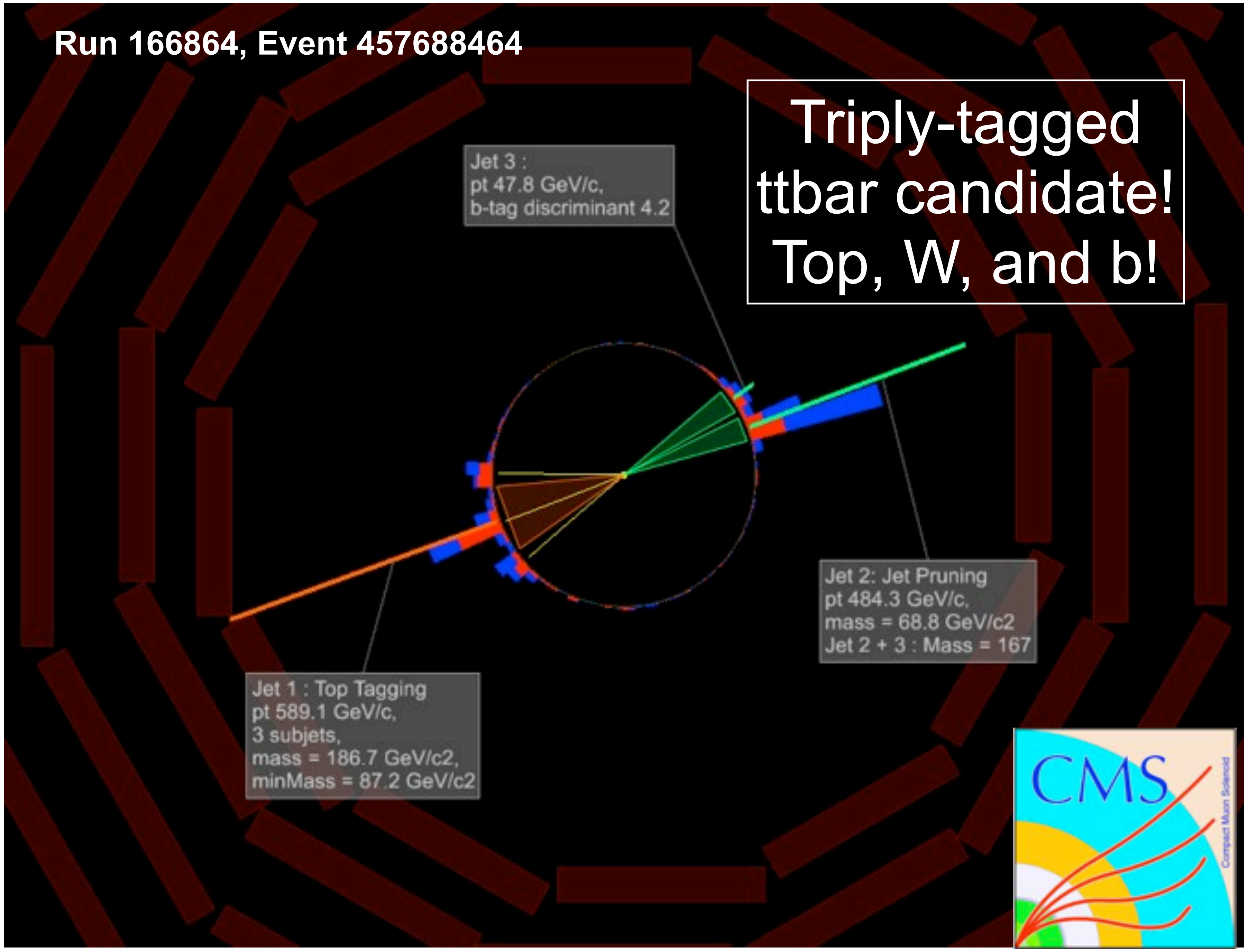
- Perform counting experiment in signal windows
- Exclude KK gluons with M in range 1.0-1.5 TeV



All-Hadronic Analysis



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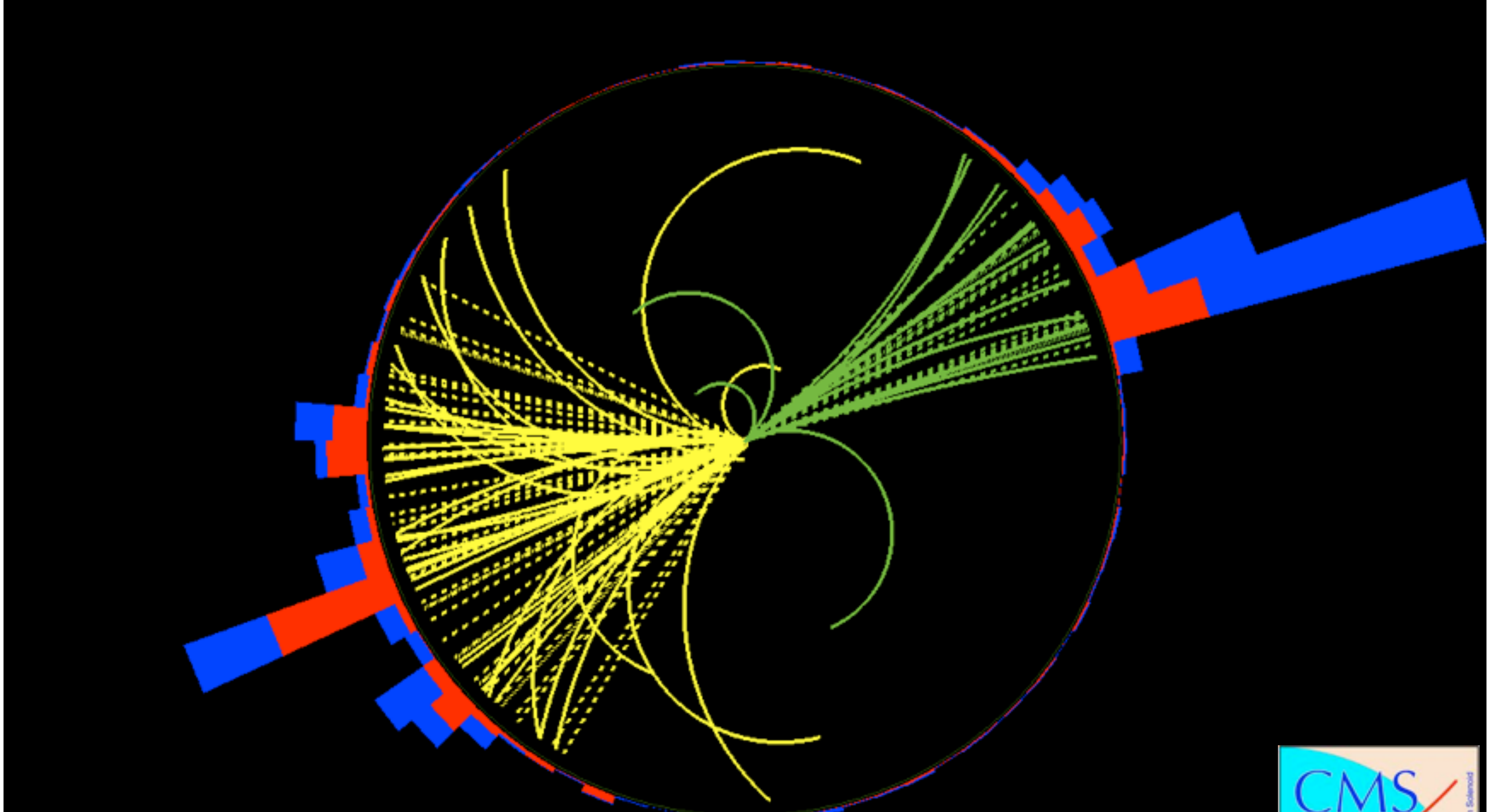
All-Hadronic Analysis



Particle Flow Reconstruction aids in jet substructure enormously!

Conclusions

- Starting to limit new physics models decaying into ttbar
- Extending Tevatron limits
- Making use of new tools in jet substructure
- More updates to 1 fb^{-1} are on the way!

Backups

Top Tagging Details

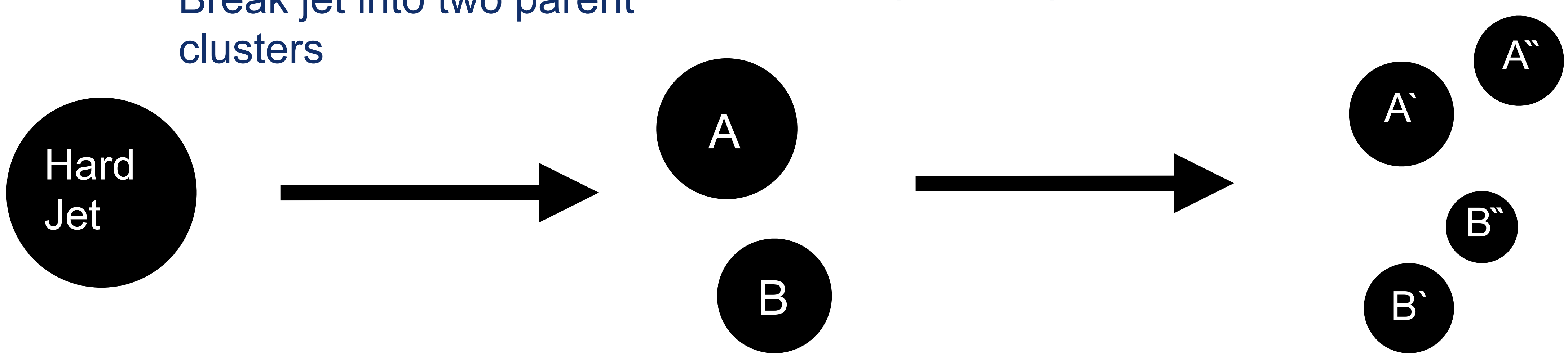
- Based on Kaplan et al. (arXiv:0806.0848)
- Cluster particle flow candidates using Cambridge Aachen
- Reverse the clustering sequence in order to find substructure
- Subjets must satisfy two requirements
  - Momentum fraction criterion: $pTsubjet > 0.05 \times pThard\ jet$
  - Adjacency criterion: $\Delta R(A, B) > 0.4 - 0.0004 \times pT$
- Iterative process - throw out objects that fail momentum fraction cut and try to decluster again
- Then use :
  - Jet Mass ~ Top mass
  - Minimum mass pairing of subjets ~ W mass

Removes soft clusters

Removes wide angle clusters

Primary Decomposition:
Break jet into two parent clusters

Secondary Decomposition
Repeat on parent clusters

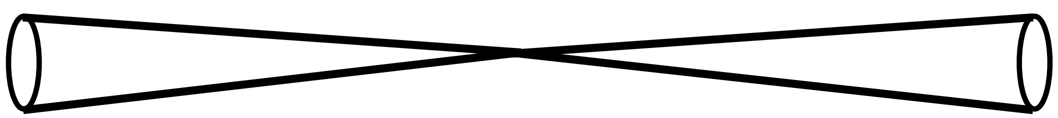


Require >= 3

Top Tagging Mistag Rate From Data

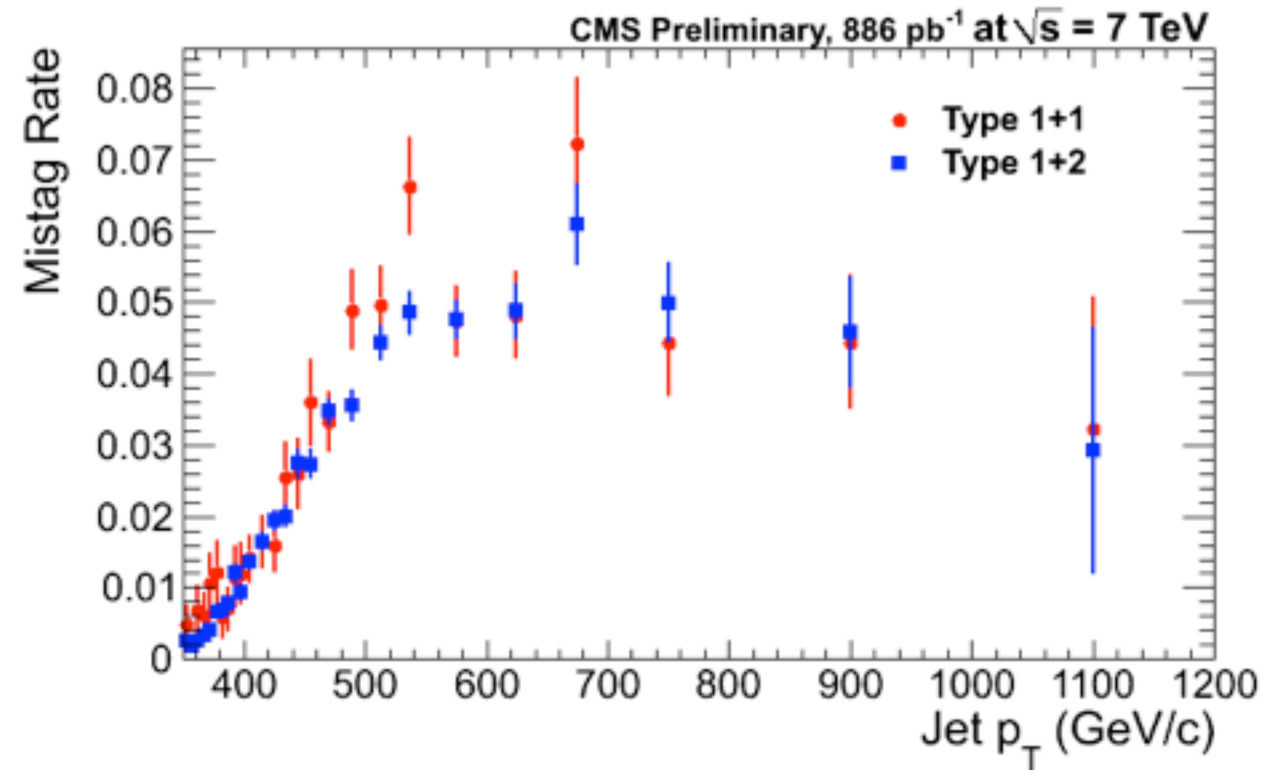
CMS-PAS-EXO-11-006

- Anti-tag and probe method
  - Randomly select one jet, check if its tagged
  - If the random jet is vetoed, the opposite jet is the probe jet



Anti-tagged jet (mass<140 or mass >250 or minmass<50 or nsubjets <3)

Probe jet



$$\text{Mistag Rate} = \frac{\text{Number of probe jets that are tagged}}{\text{Number of probe jets}}$$

* Type 1 + 1 = Dijet events, with mass requirement

* Type 1 + 2 = Trijet events

Jet Pruning Details

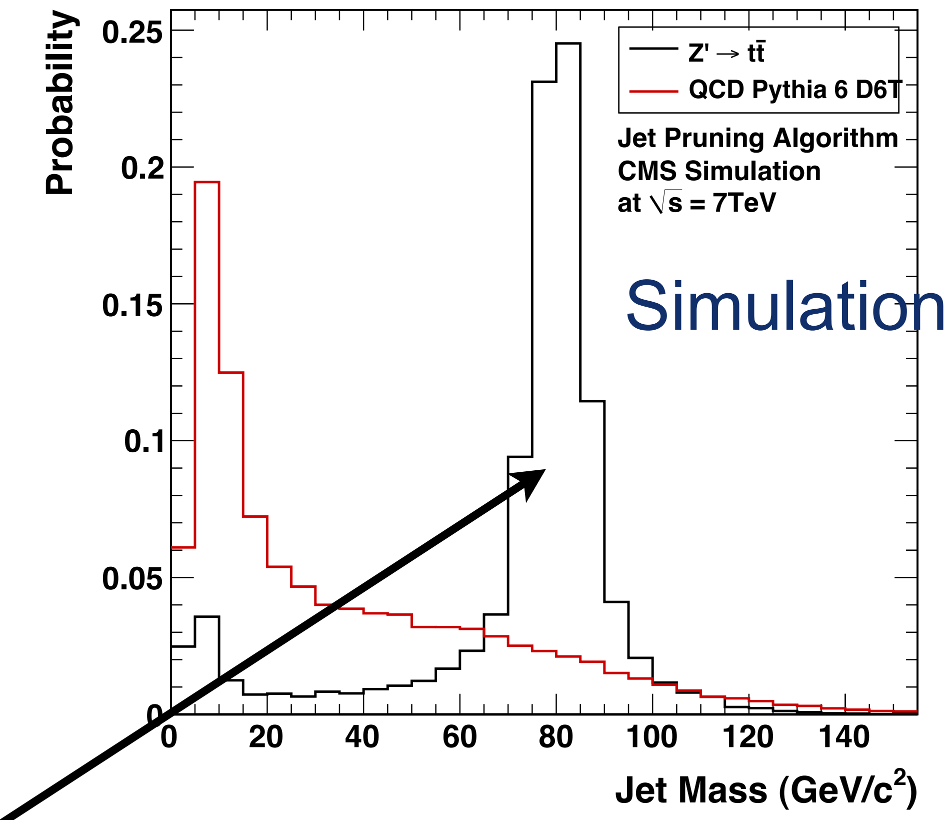
- Ellis et al. (arXiv:0903.5081)
- Improves mass resolution by removing soft, large angle particles from the jet
- Recluster each jet, requiring that each recombination satisfy the following:

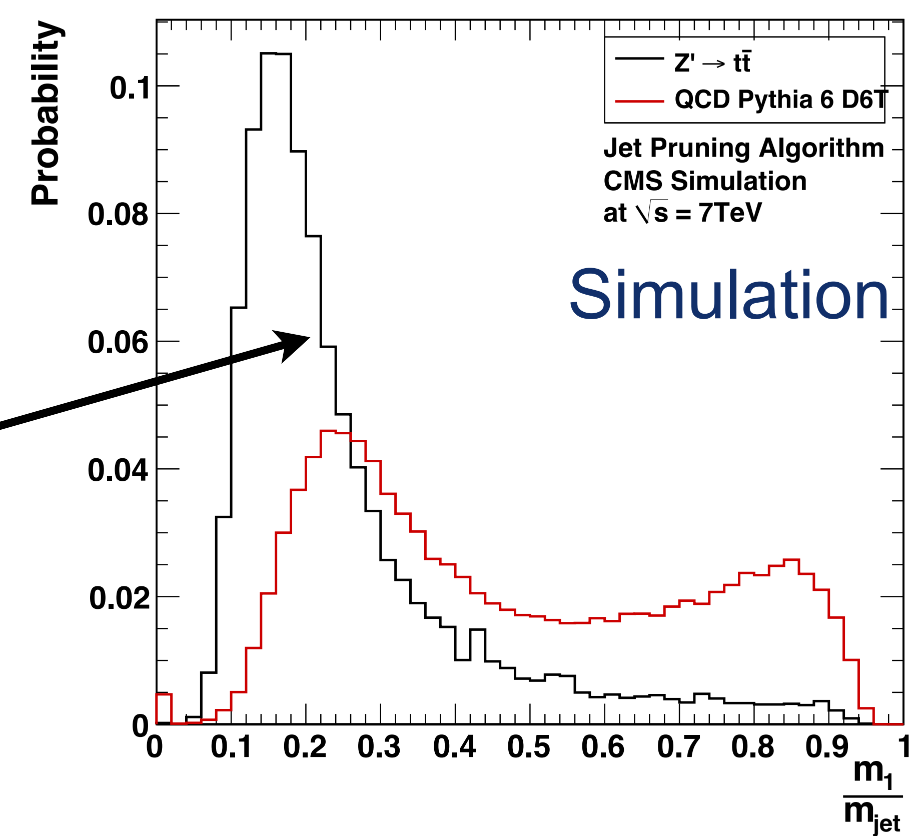
$$\frac{\min(p_{T1}, p_{T2})}{p_{Tp}} > 0.1$$

$$\Delta R_{12} < 0.5 \times \frac{m_{\rm jet}}{p_T}$$

- For W tagging, require:
  - Jet mass in 60-100 GeV/c2
  - Mass drop (mu) < 0.4

$$\mu = \frac{m_{j1}}{m_j}$$

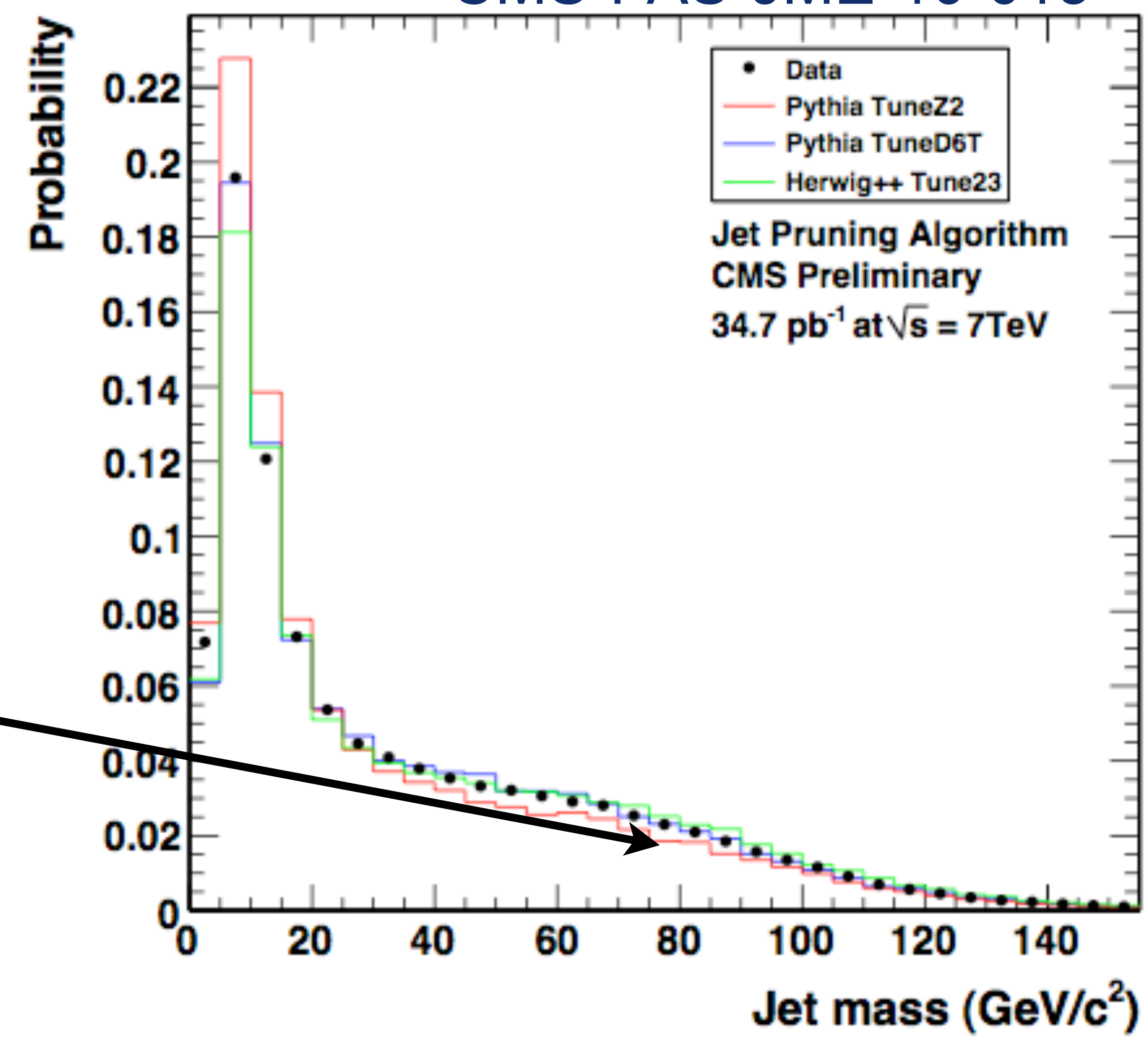




Pruned Jet Mass

- Very good agreement between MC and data jet mass!
- Strong dependence on PS model and tune, but all very good in “signal region” for interesting particles (high jet mass)

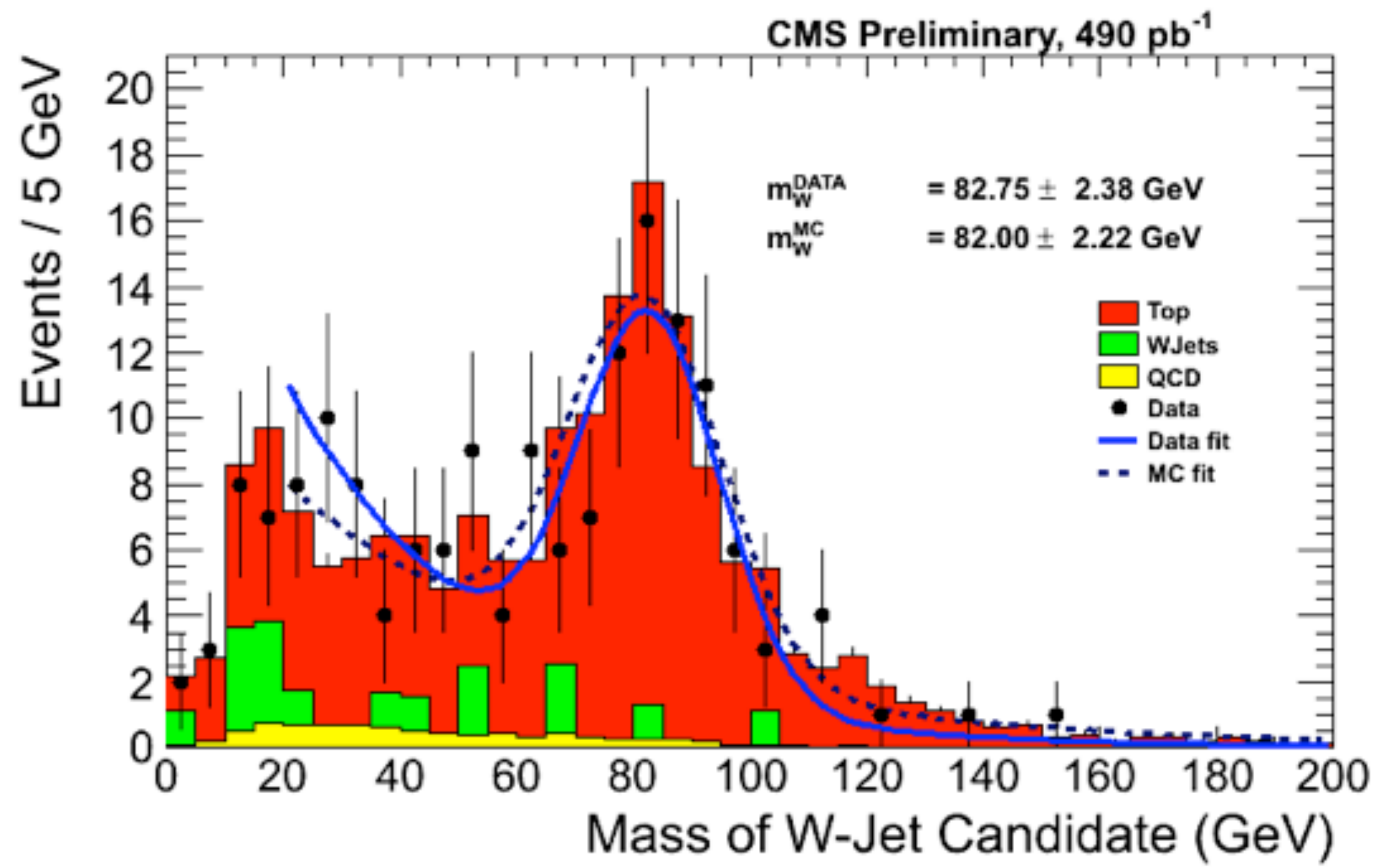
CMS-PAS-JME-10-013



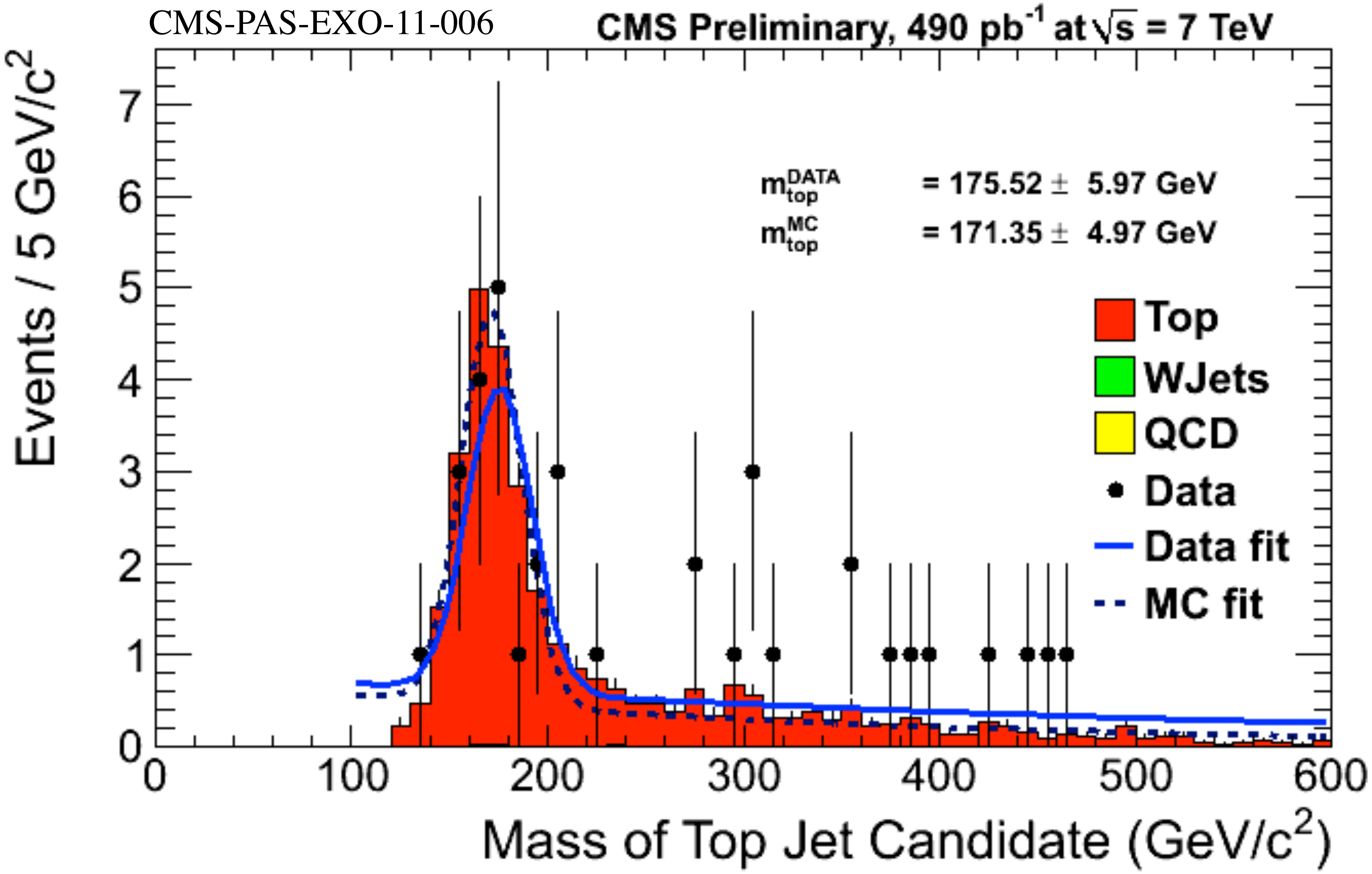
W Mass in Semileptonic Sample

- **Standard candle : Find a W peak in jet masses!**
  - **Examine boosted semileptonic ttbar**
  - **Require >=1 btag**
  - **Look at mass of W-jet candidates**
  - **Nice clear W peak from within jets!**
  - **Also observe good data to MC agreement**

CMS-PAS-EXO-11-006



Top Mass in Semileptonic Sample



- Take events in the W window (60-100)
- Combine with closest jet, form top mass
- Very clear top signal, can even be used to measure top mass!

Top Tagging Details

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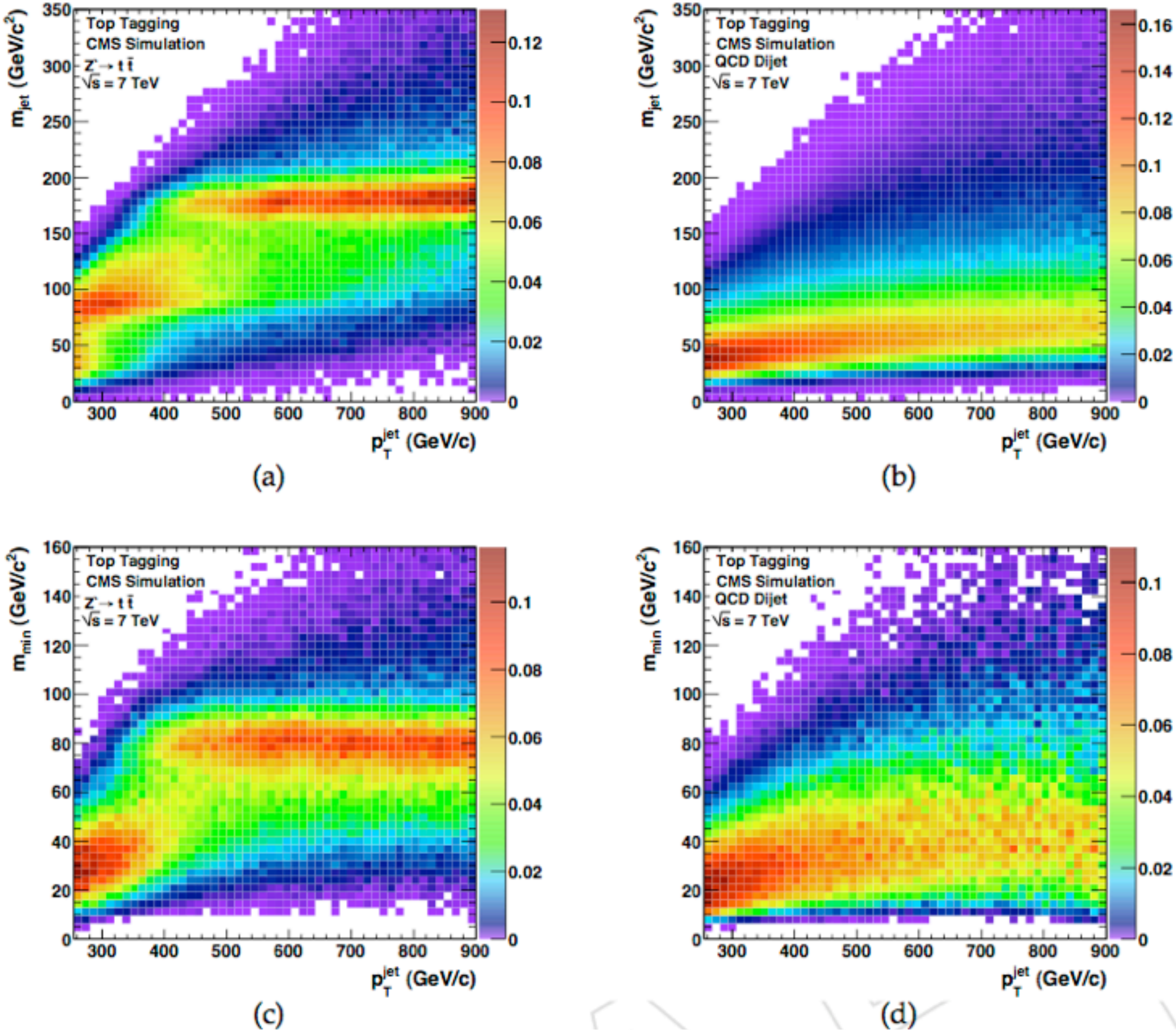


Jet Mass

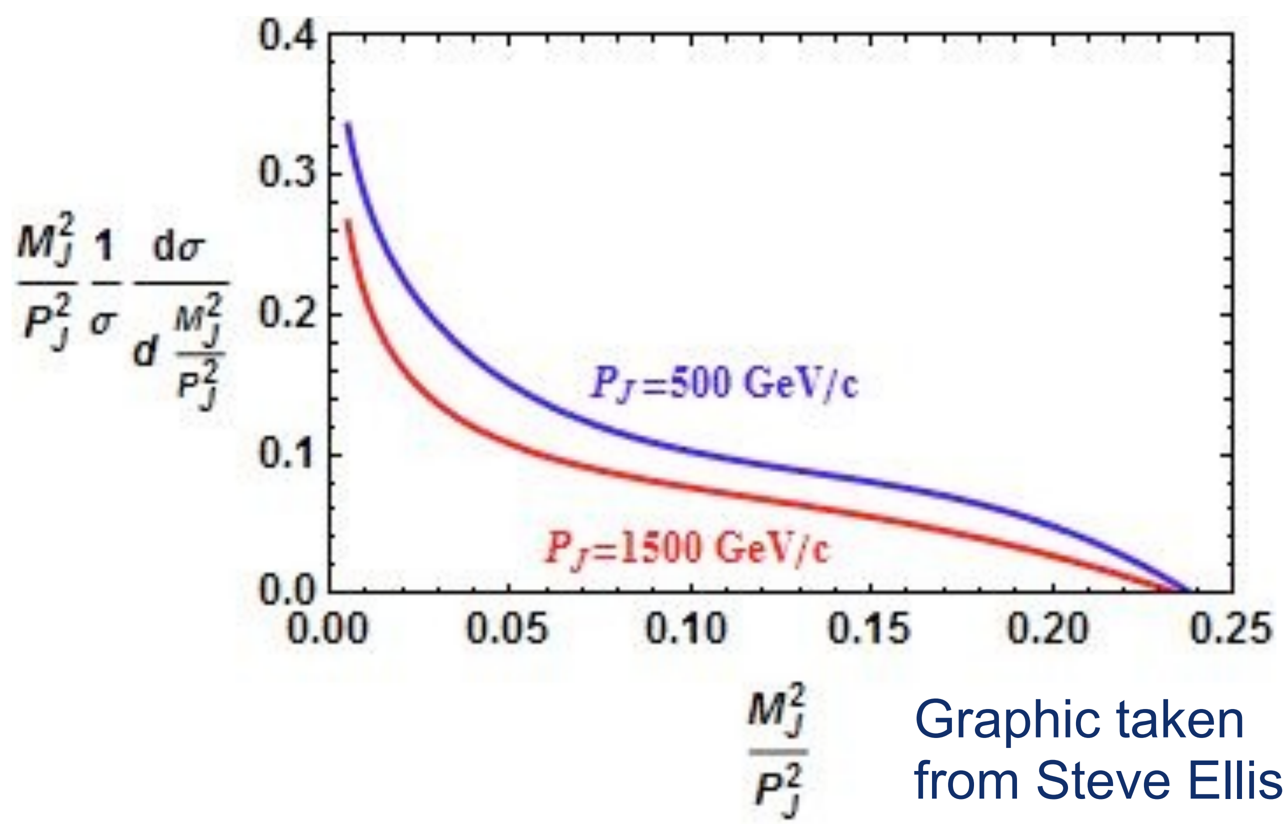
- What's the typical mass scale of QCD?
  - See e.g. Ellis et al (arXiv:0712.2447v1)

Finite-size effects from cutoff

Scales ~linearly with momentum

Log. divergence at low mass

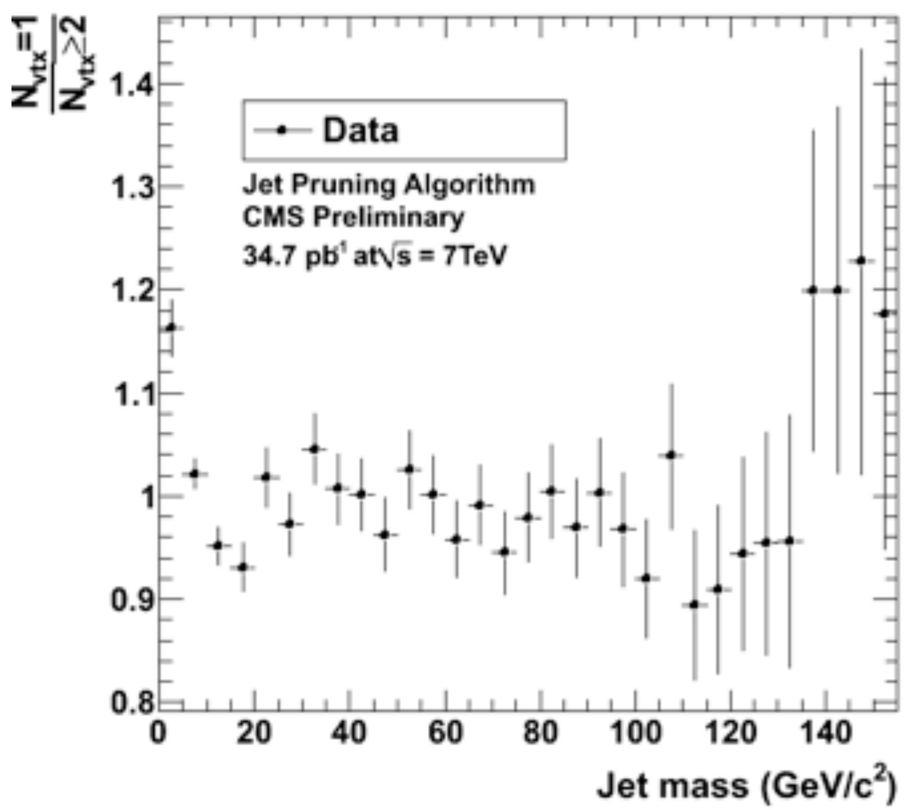
$$\langle M_J^2 \rangle_{NLO} \simeq \overline{C}\left(\frac{p_J}{\sqrt{s}}\right) \alpha_s\left(\frac{p_J}{2}\right) p_J^2 R^2,$$



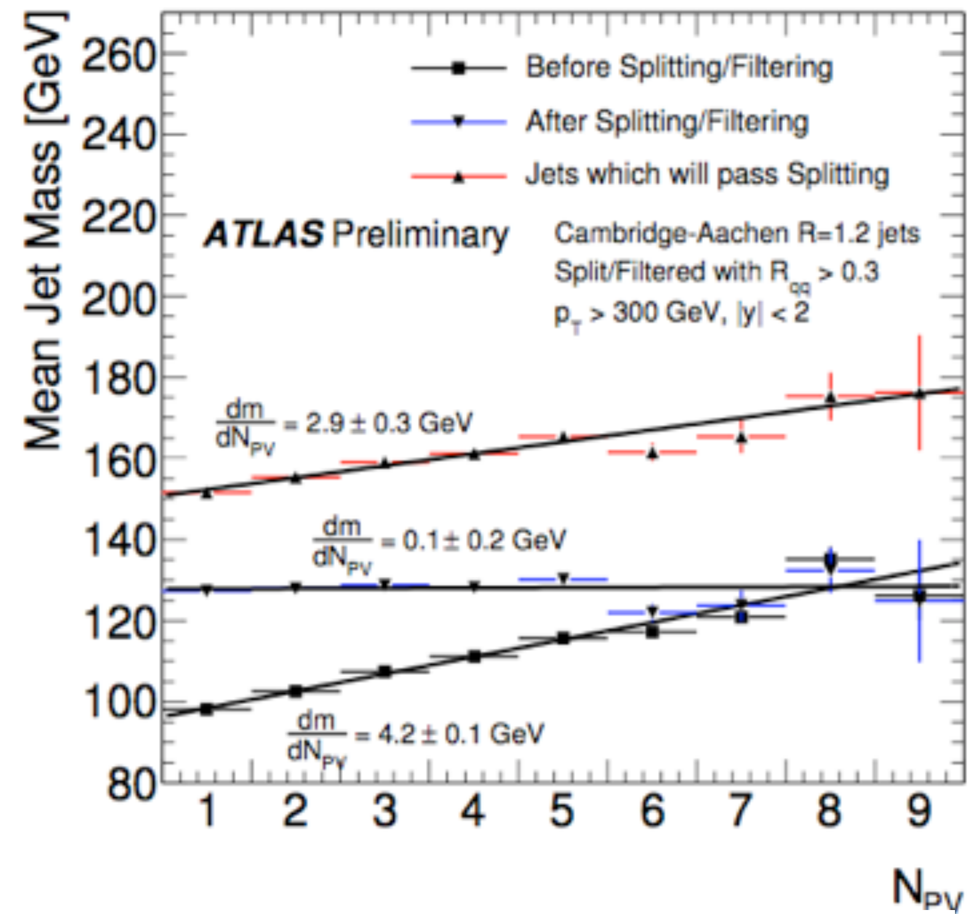
Graphic taken from Steve Ellis

Pileup Dependence

CMS-PAS-JME-10-013



ATLAS-CONF-2011-073



- Some pileup dependence seen, but largely mitigated by substructure tools!