Title: Gearing For Boosts in Run 2

Date: Mar 17, 2015 01:00 PM

URL: http://pirsa.org/15030100

Abstract: <p>With the increase of the center-of-mass energy from 8 TeV
 to 13 TeV for LHC Run 2, the probability for boosted topologies will
 become even higher than in Run 1. This also comes with a large
 increase in pileup from the increased luminosity. This talk
 investigates the state of the art of boosted algorithms and grooming
 techniques, addresses shortcomings and possible improvements, and
 discusses hot-topic items that will be interesting early on in Run 2.</p>

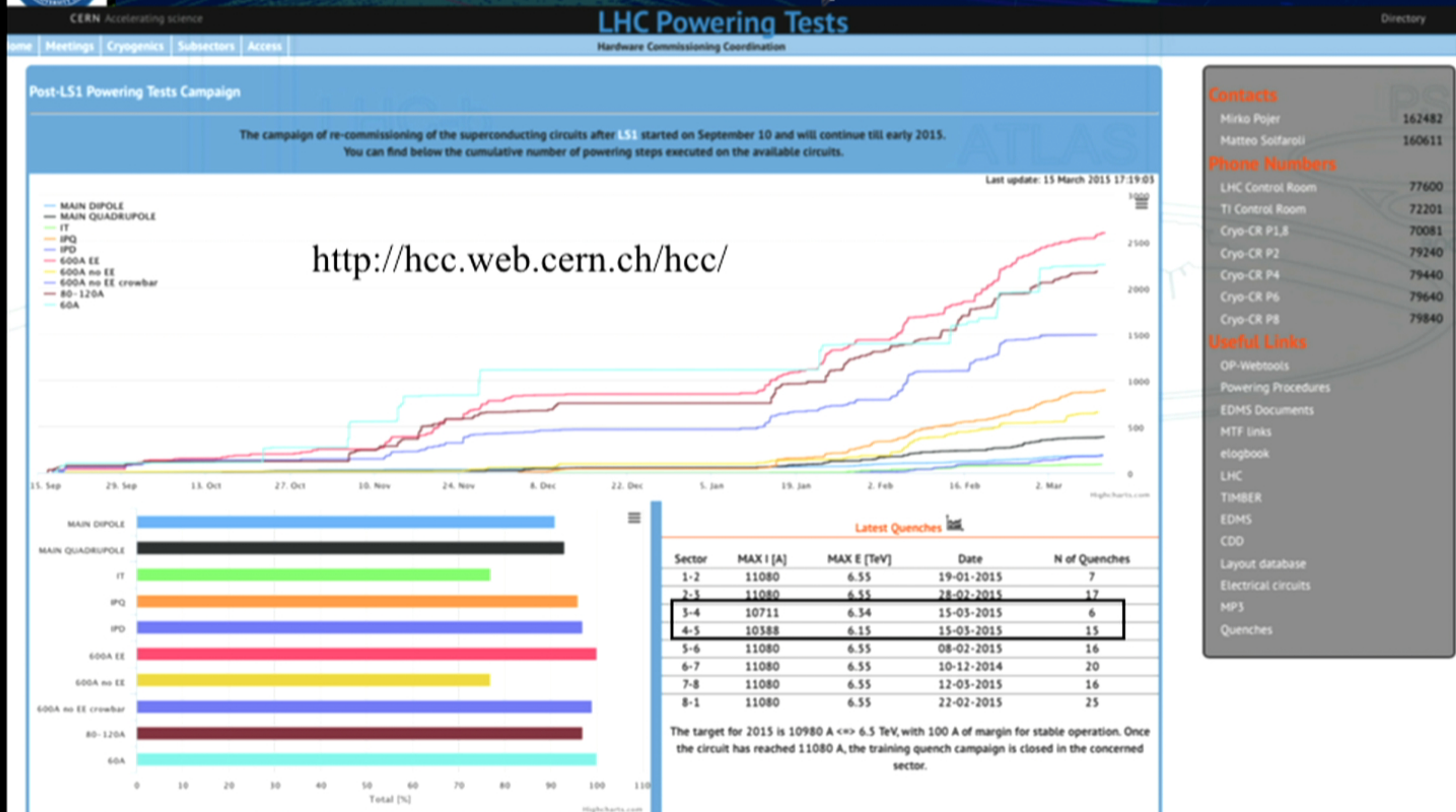
Fine Print

- I'm a member of CMS, so for lack of time I will focus there
  - Instead of "motivation, theory, experimental work" I will present the field as a whole (but not everything)
  - May seem a little chaotic, but there is a lot of cross-feed!

- I'm also an experimentalist, so I cannot always answer all theory questions but will attempt as best as I can

- There are a huge plethora of things to present. I will present those that form a bit of a coherent story that is now well-understood

Run 2 Is Upon Us!



Sector	MAX I [A]	MAX E [TeV]	Date	N of Quenches
1-2	11080	6.55	19-01-2015	7
2-3	11080	6.55	28-02-2015	17
3-4	10711	6.34	15-03-2015	6
4-5	10388	6.15	15-03-2015	15
5-6	11080	6.55	08-02-2015	16
6-7	11080	6.55	10-12-2014	20
7-8	11080	6.55	12-03-2015	16
8-1	11080	6.55	22-02-2015	25

The target for 2015 is 10980 A <=> 6.5 TeV, with 100 A of margin for stable operation. Once the circuit has reached 11080 A, the training quench campaign is closed in the concerned sector.

First beams in all of LHC : 25-March!
ONE WEEK FROM TOMORROW!!!!!

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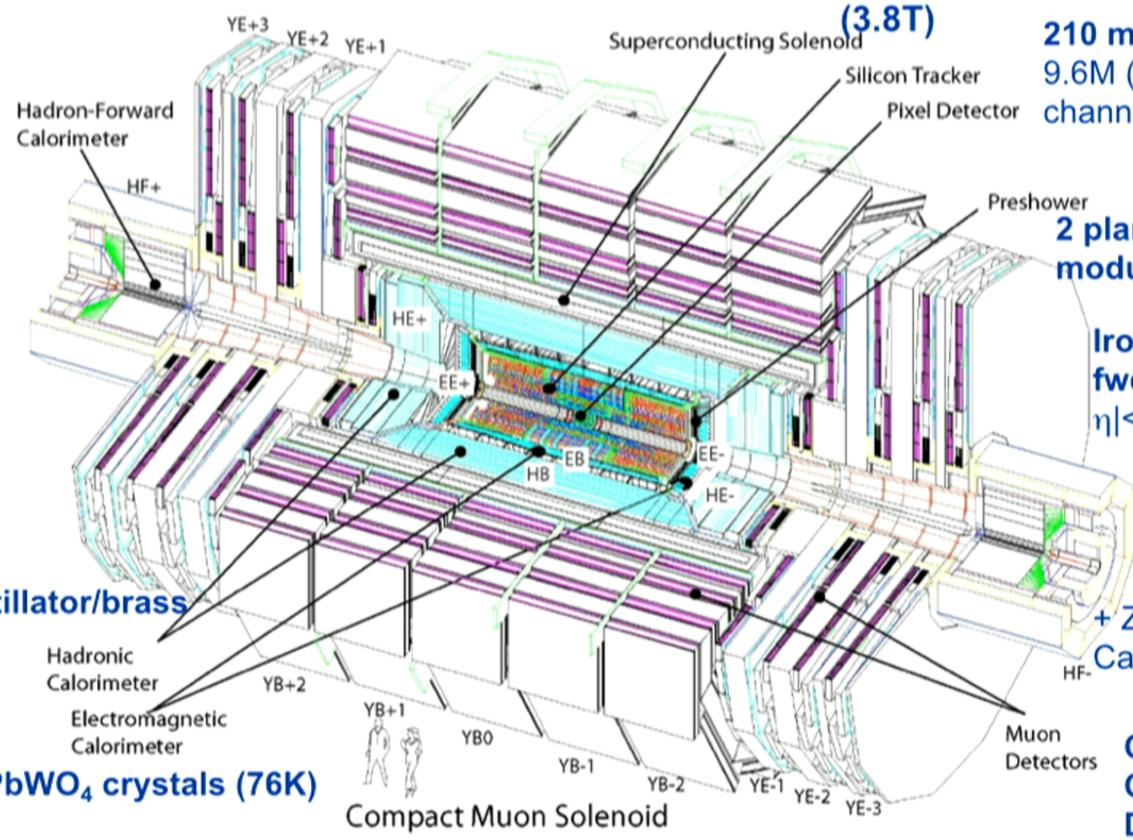

(3.8T)

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

2 planes of silicon modules for ECAL

Iron / Quartz fiber fwd calorimeter, $3<|\eta|<5$;

+ Castor, $5<|\eta|<6.55$

+ Zero Degree Calorimeter

Scintillator/brass

$PbWO_4$ crystals (76K)

Cathode Strip Chambers, Drift Tubes, Resistive Plates

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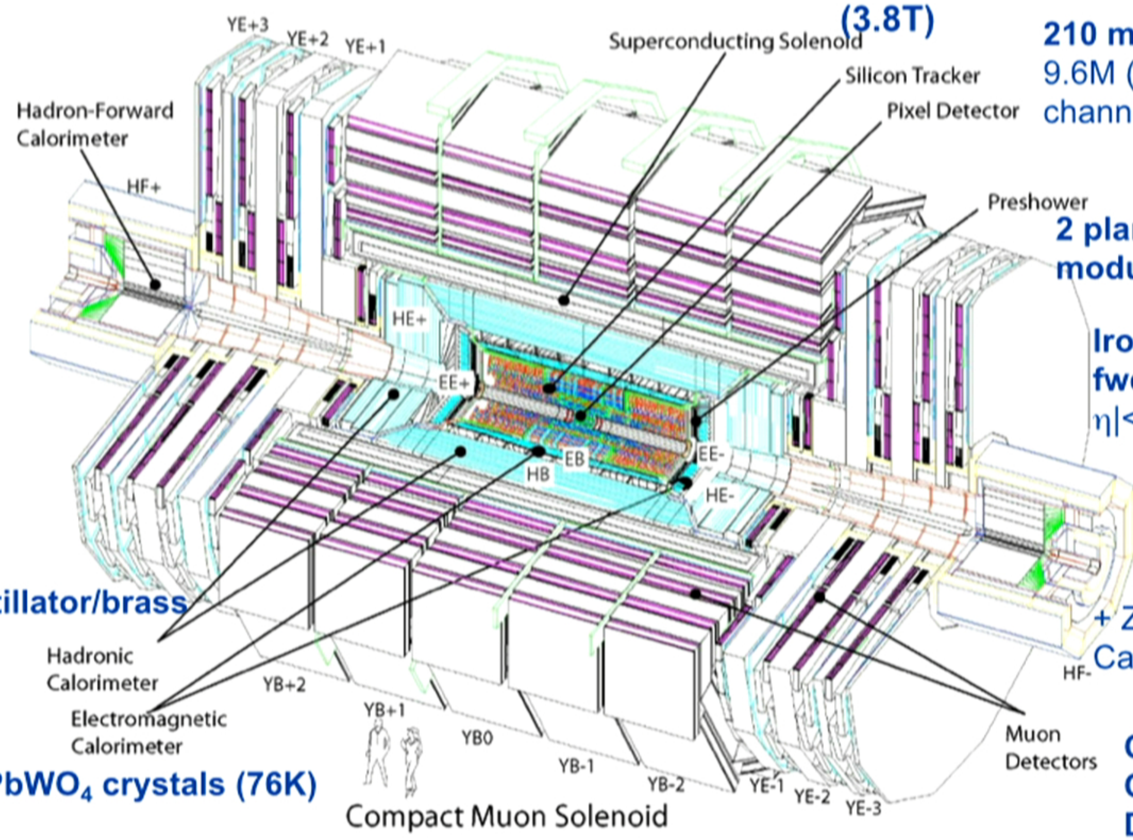

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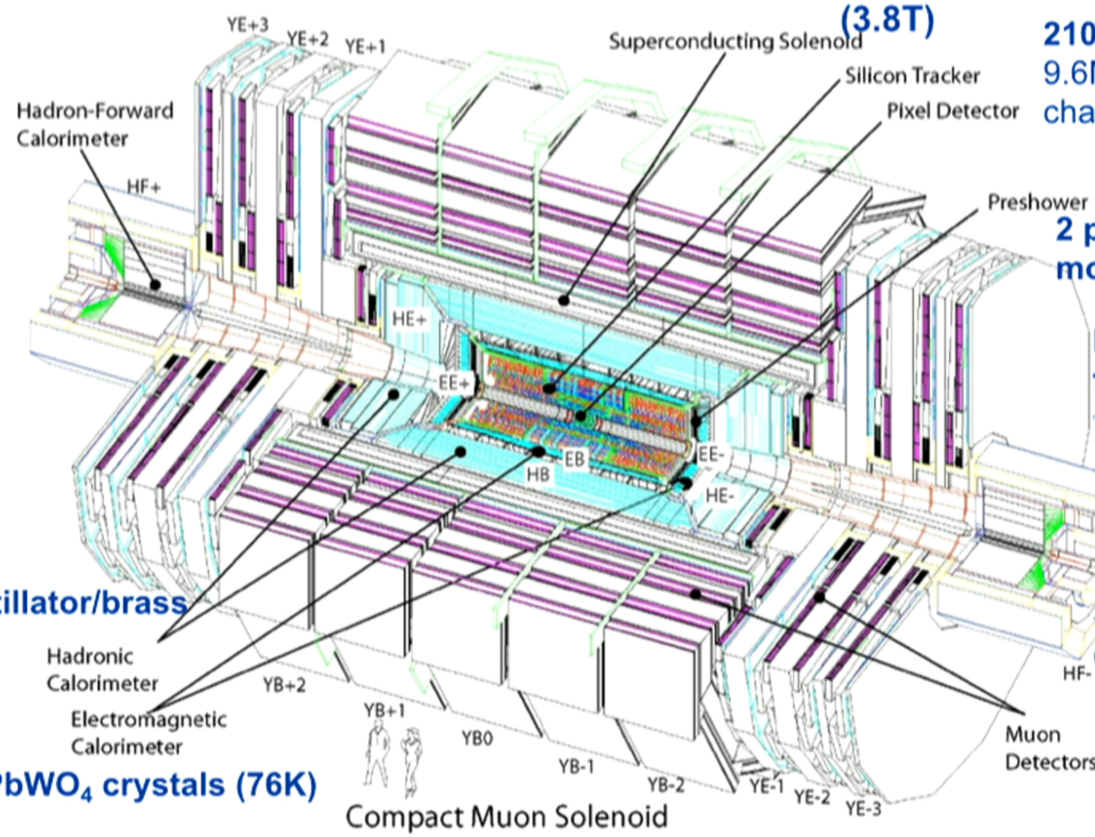

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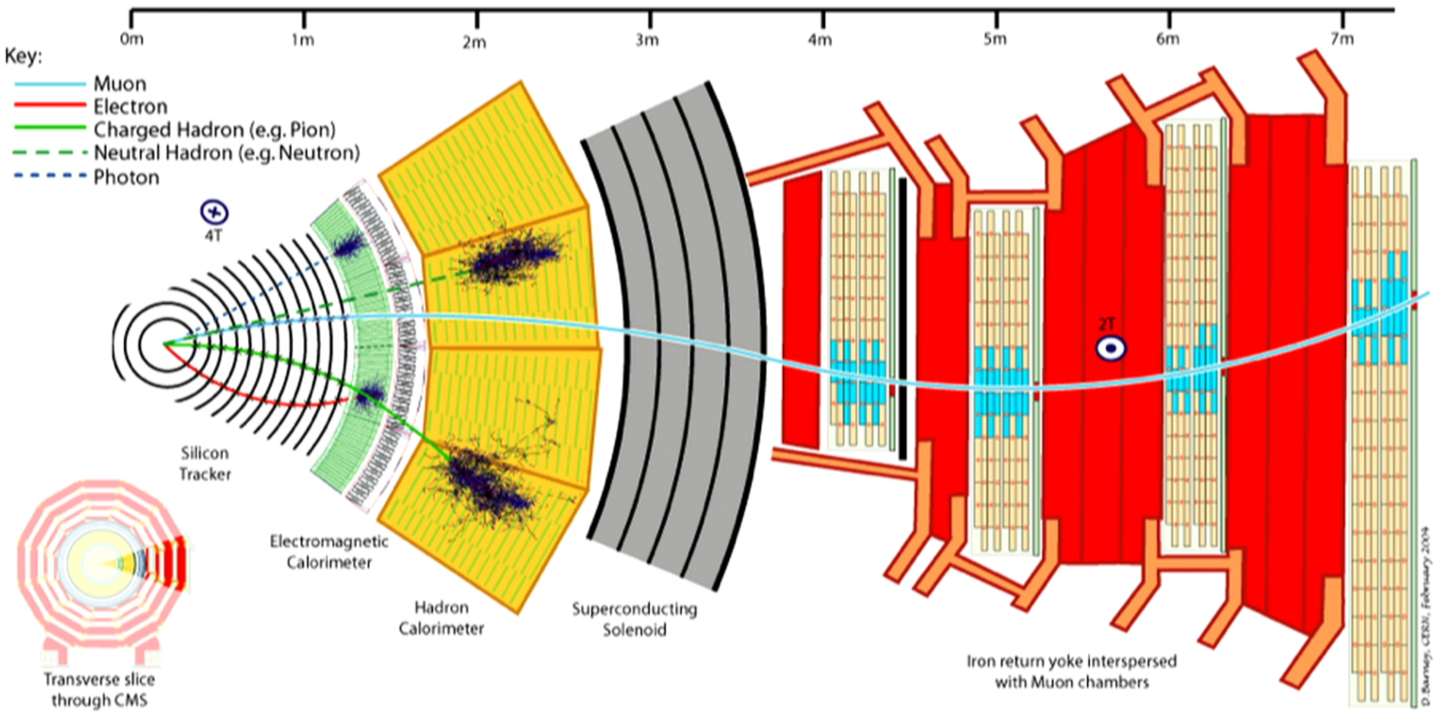
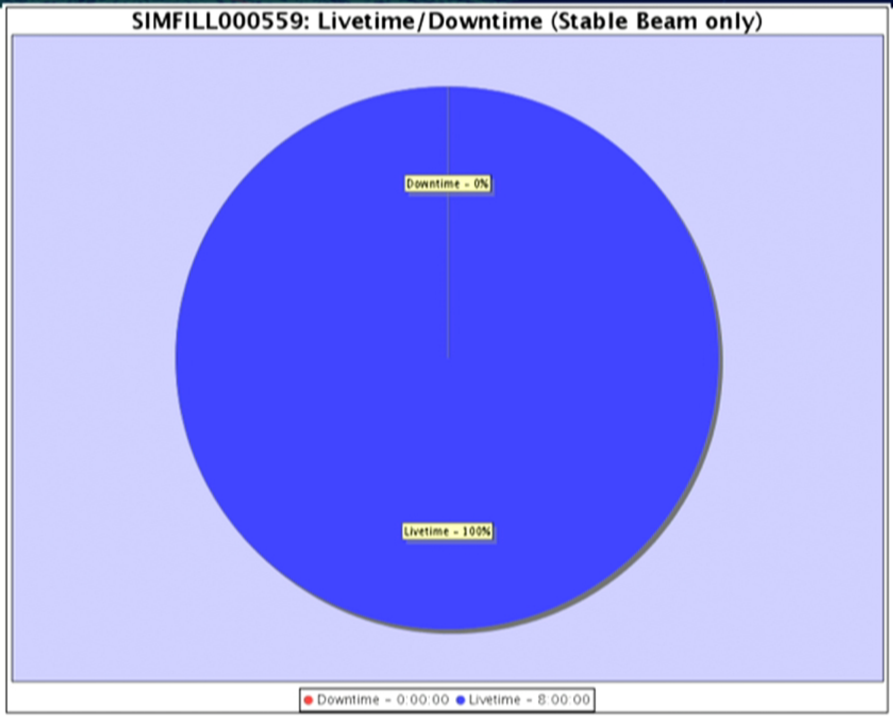
Run 2 Is Upon Us!

Classify objects into 5 categories



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

Run 2 Is Upon Us!



- CMS happily taking cosmic-ray data
- Turning on the magnet Thursday

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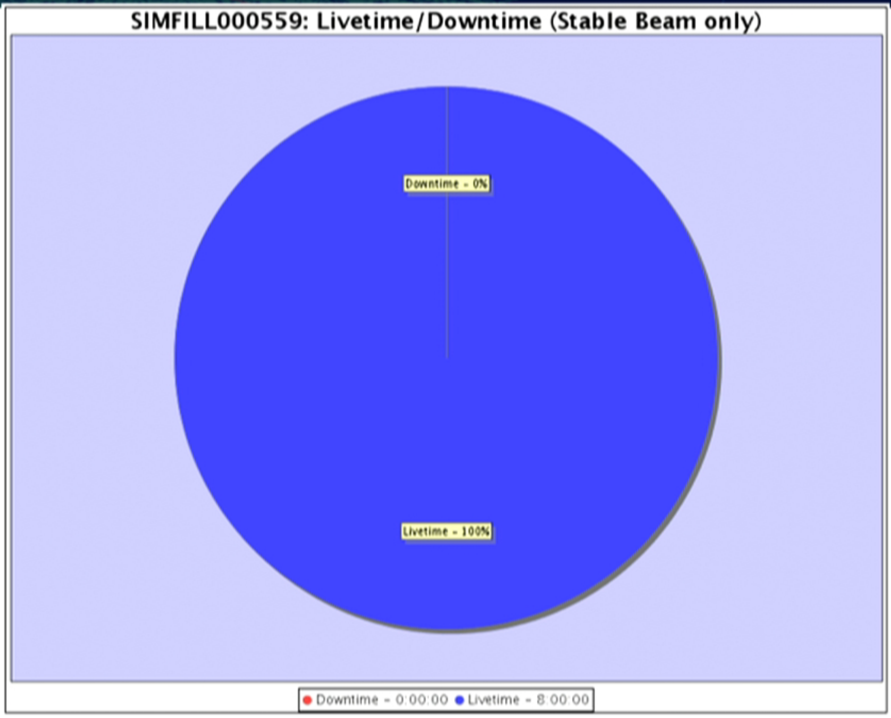

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Saturday Night Live never knew what hit them

#RestartLHC

17 March 2015

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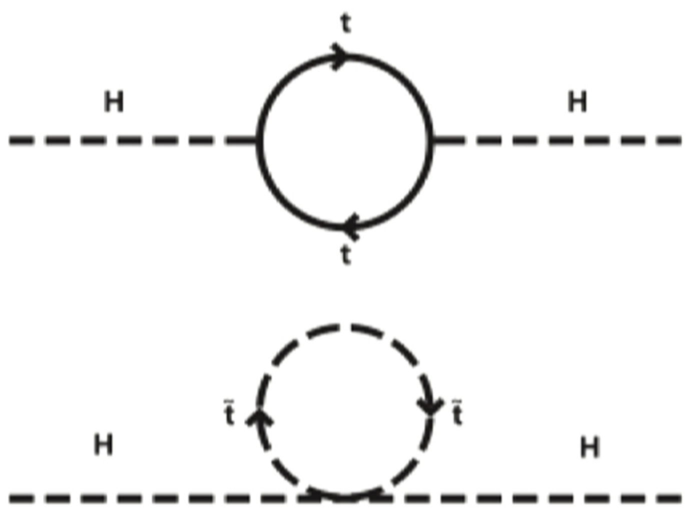
17 March 2015

Is Naturalness a Thing?

- Is mH = 125 GeV an accident or a necessity?
  - Hierarchy problem



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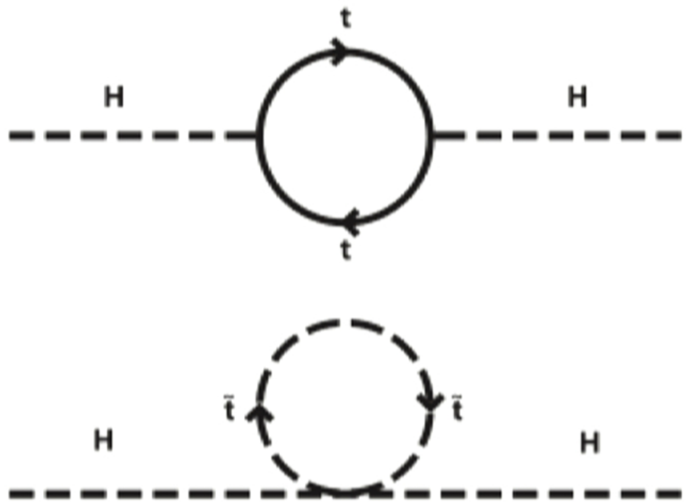

Is Naturalness a Thing?

- The search is on…

12

Is Naturalness a Thing?

- Note : This isn't a doom-and-gloom talk
- We did discover something awesome, so we still have something to keep us busy for **~20 years**

- About "naturalness", remember Stephen Crane :

> A man said to the universe:
> "Sir, I exist!"
> "However," replied the universe,
> "The fact has not created in me
> A sense of obligation."

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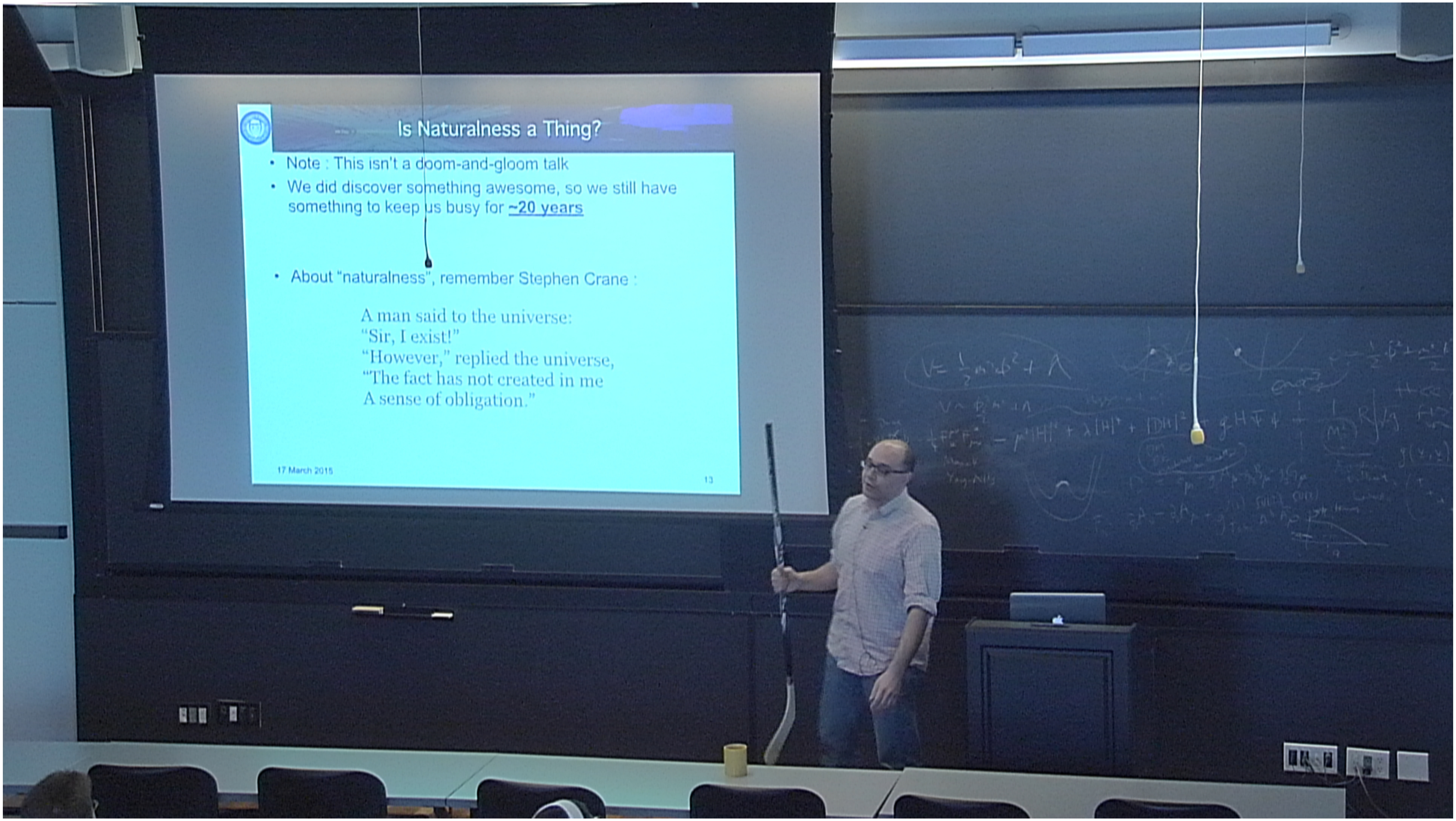
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17 March 2015
13

Assume Naturalness is a Thing

- The space of natural solutions to the hierarchy problem is enormous
- I will not focus on most of it
  - All interesting, all difficult, and all may bear fruit

H. Murayama

- Today is about models that result in particles with **high Lorentz boosts**
  - "High Lorentz boost" means $\gamma = E/m > 2$

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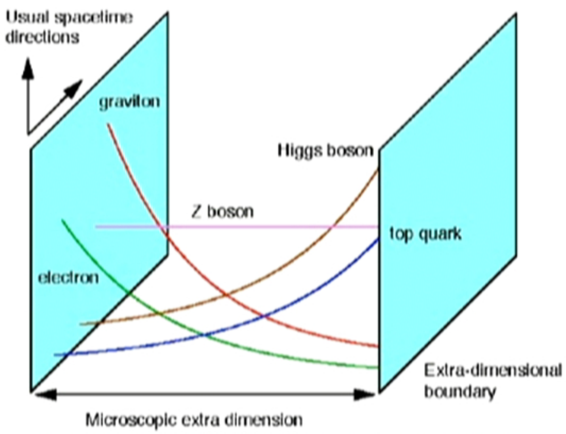
Assuming Naturalness is a thing, does boost matter?

- Compositeness
- Extra dimensions



http://www.pha.jhu.edu/~morris/jhu_hep/theory.html

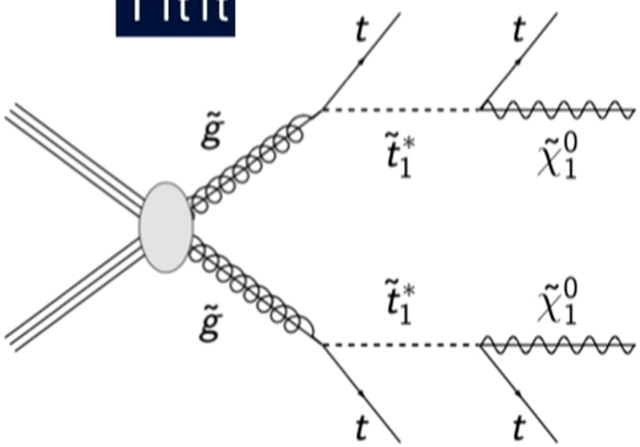
Heavy resonances and vector-like quarks

Example :
Agashe, Belyaev, Krupovnickas, Perez, Virzi
Phys.Rev. D77 (2008) 015003

$$M = 2\,TeV \Rightarrow$$
$$\gamma_{top} \sim 5, \gamma_W \sim 13$$

- SUSY

T1t1t



Lots of kinematics,some boosted!

Example :
J. Alwall, P. Schuster, N. Toro
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$$m_{\tilde{g}} = 1.0\,TeV,$$
$$m_{\tilde{t}} = 0.3\,TeV$$
$$\Rightarrow \gamma_{top} \sim 4$$

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15

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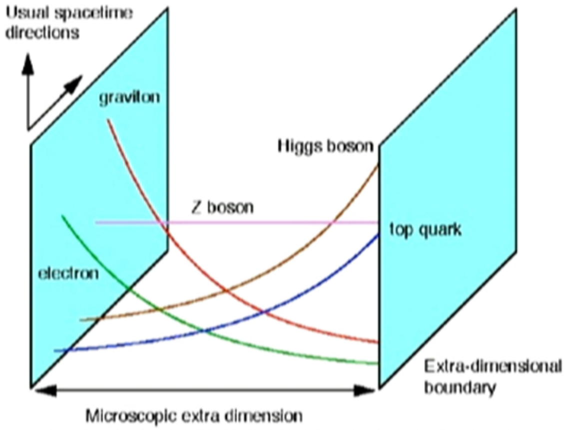

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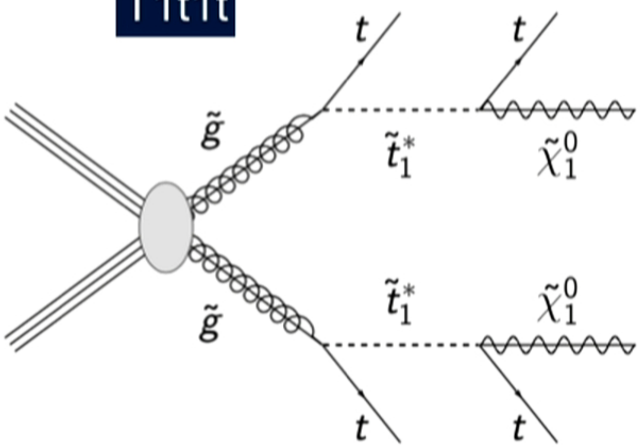

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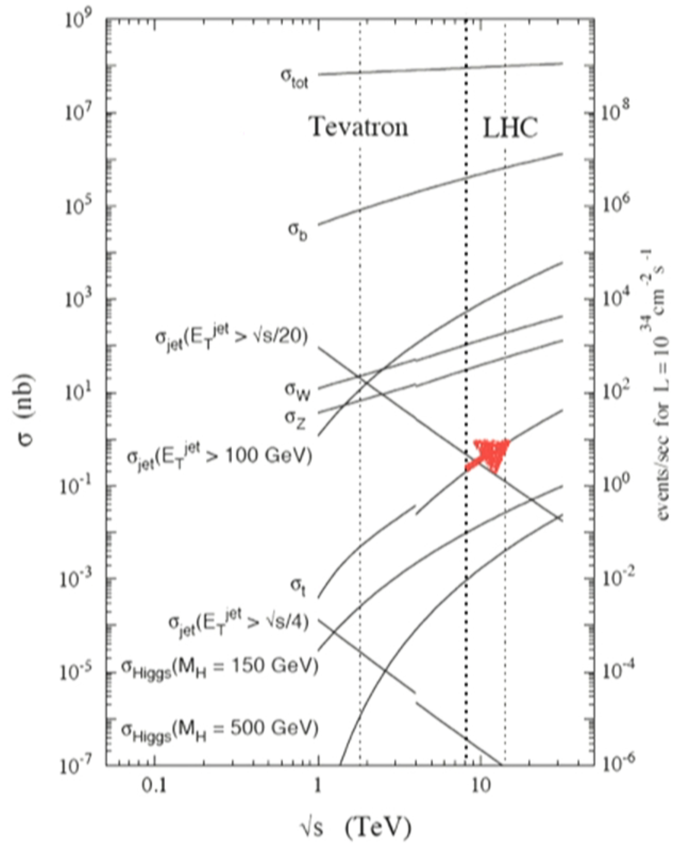
LHC : All about that boost!



Increase E from 8 TeV to 13 TeV :
2.4 times higher fraction of
SM boosted tops!

800k tops in 1 fb-1
10k boosted tops in 1 fb-1

#DoubleTheEnergyDoubleTheFun

'Bout That Boost

10^9

cmsTopTagPFJetsCHS

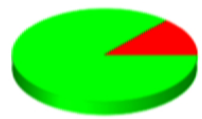
10^7 *Physics/B2G*

Summary

10^5 *15 comparisons:*

- success: 86.7% (13)
- fail: 13.3% (2)

10^3 To the DQM GUI...



Sample:

RELVALRSKKGLUON_M3000GEV_13

Run1 and Run2:

1 - 1

Releases:

- CMSSW_7_4_0_pre1-MCRUN2_73_V5-v1
- CMSSW_7_4_0_pre2-MCRUN2_73_V7-v1

Statistical Test (Pvalue threshold):

- CHI2 (1E-05)

σ (nb)

10^1

10^{-1} *Failing Comparisons*

10^{-3}

10^{-5}

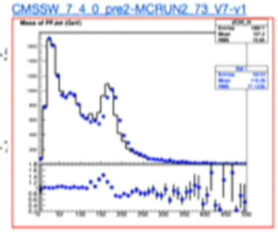
10^{-7}

pfJet_m

Chi2: 2.73E-26

CMSSW_7_4_0_pre1-MCRUN2_73_V5-v1

CMSSW_7_4_0_pre2-MCRUN2_73_V7-v1

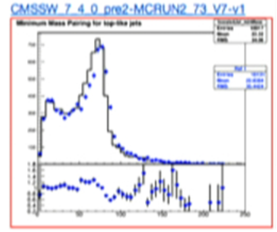


boostedJet_minMass

Chi2: 1.19E-14

CMSSW_7_4_0_pre1-MCRUN2_73_V5-v1

CMSSW_7_4_0_pre2-MCRUN2_73_V7-v1



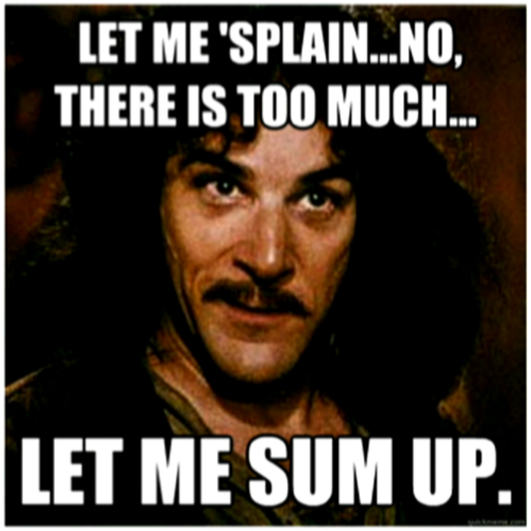
V to 13 TeV :
fraction of
tops!

1 fb-1
s in 1 fb-1

oubleTheFun

(Boosted tops are in our DQM)

‘Bout That Boost



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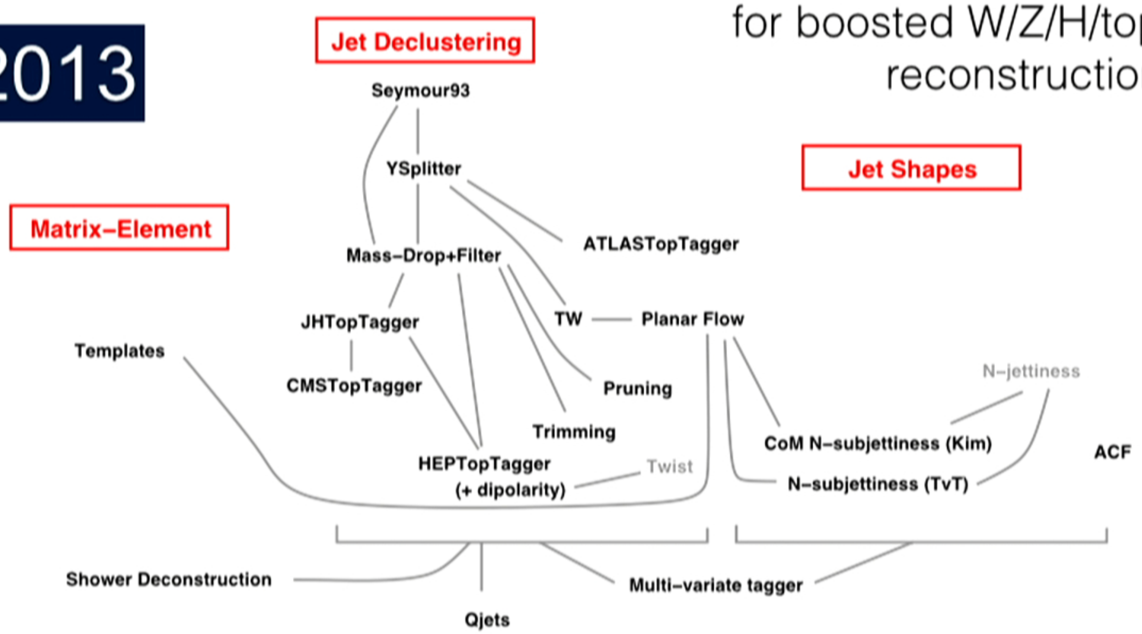
- S.D. Ellis, J. Huston, K. Hatakeyama, P. Loch, M. Tonnesmann, Prog.Part.Nucl.Phys. 60 (2008) 484-551
- This list is by no means exhaustive
- If you can read this, you have passed your eye exam. Congratulations.

'Bout That Boost

Very active research field

Some of the tools developed
for boosted W/Z/H/top
reconstruction

2013

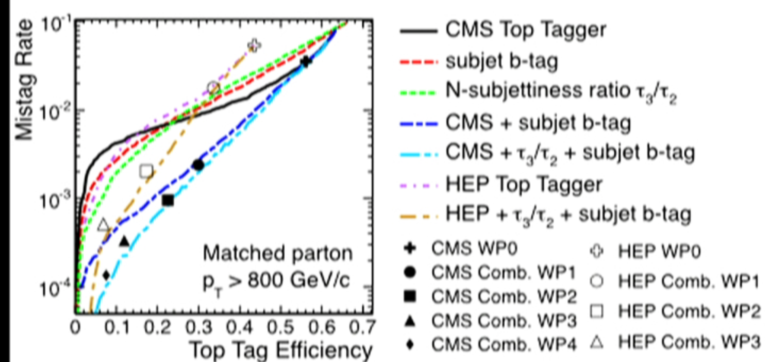


apologies for omitted taggers, arguable links, etc.

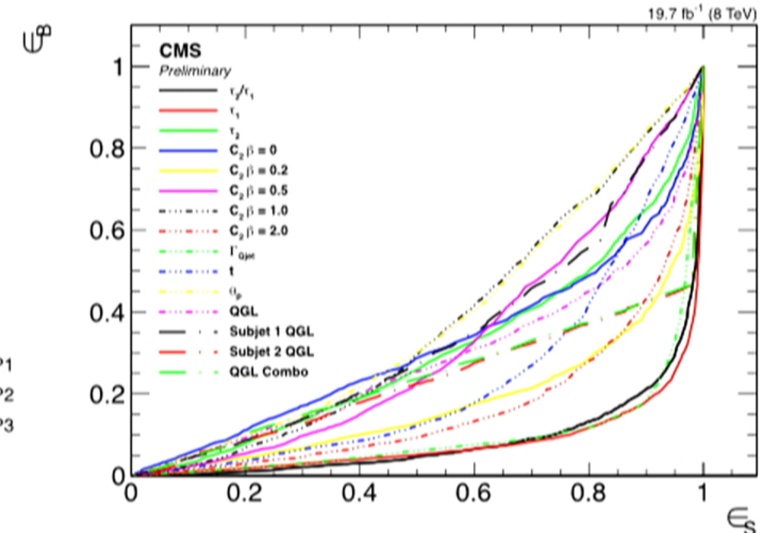
Gavin Salam (CERN) Jet substructure @ CMS substructure workshop, April 2013 3

'Bout That Boost

Top tagging



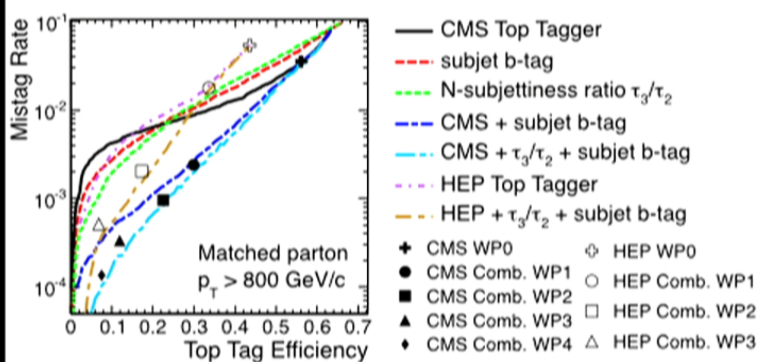
V/H tagging



That's a lotta taggers.

'Bout That Boost

Top tagging



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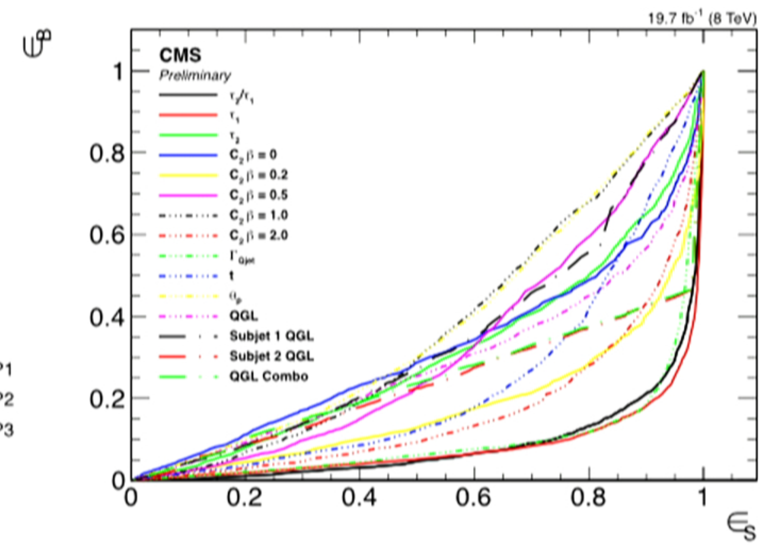

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Jet Analytics

- First need to understand jet mass

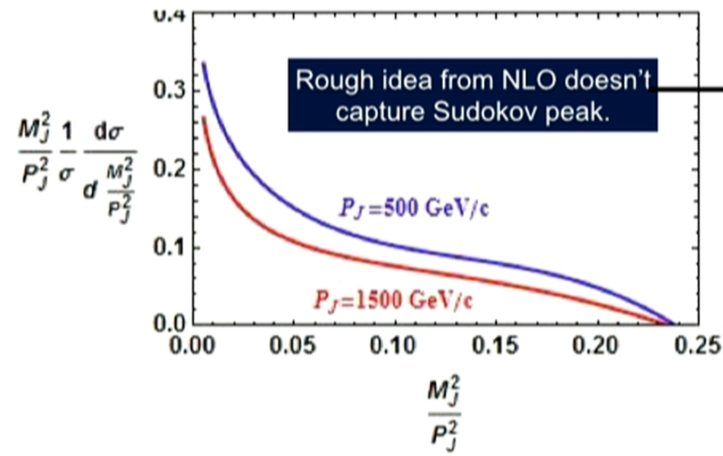
At NLO :

Finite-size effects from cutoff

Scales ~linearly with momentum

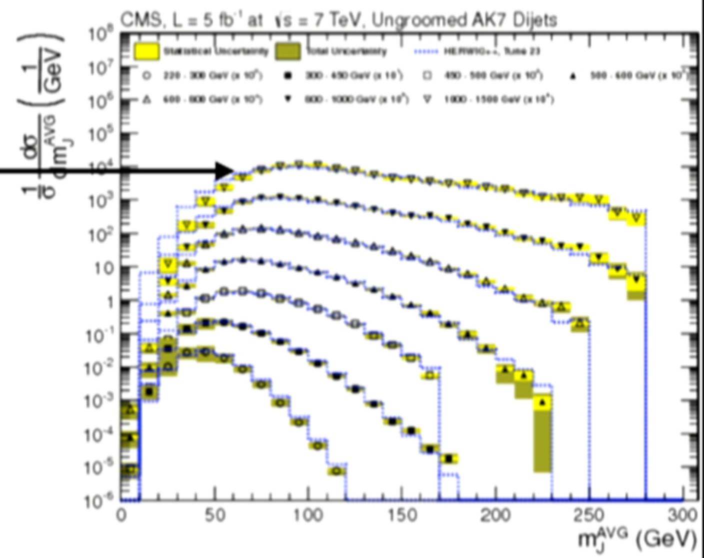
Log. divergence at low mass

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



Rough idea from NLO doesn't capture Sudokov peak.

Good prediction of jet data from MC



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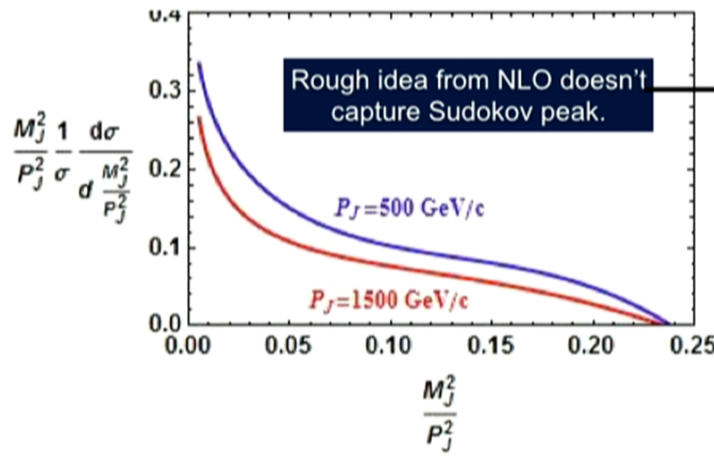

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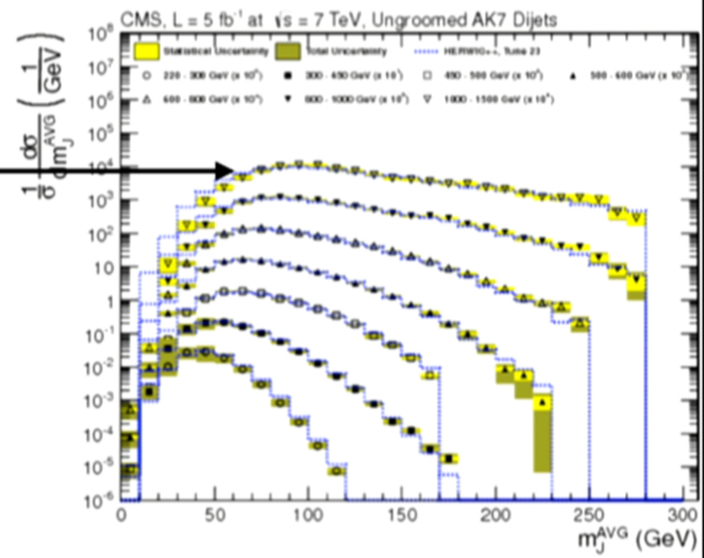

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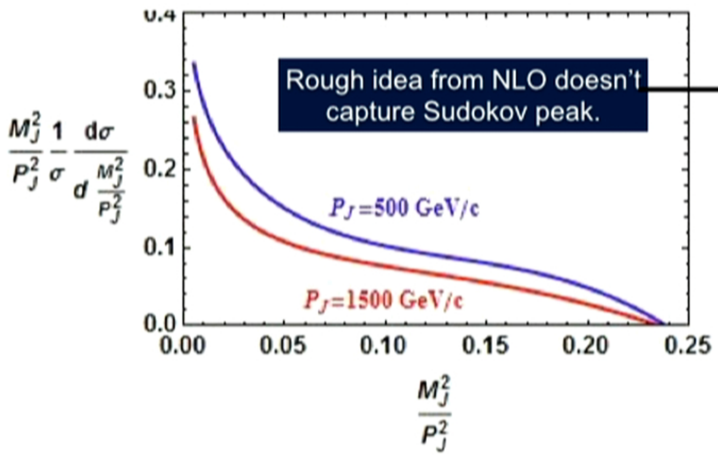

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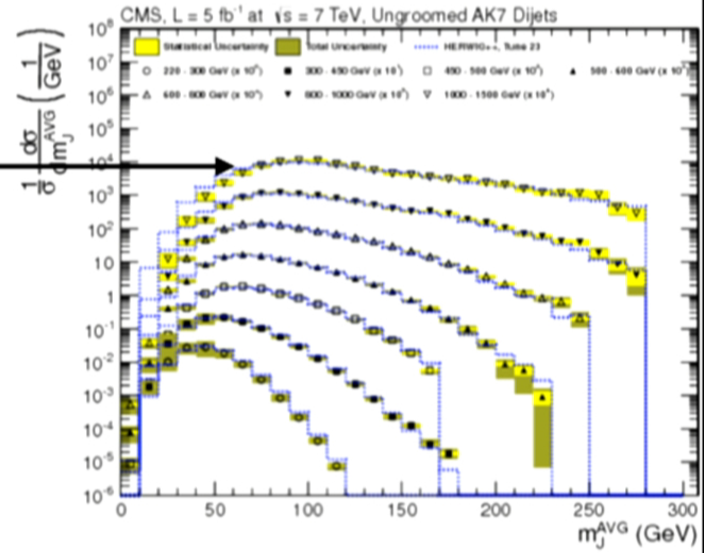

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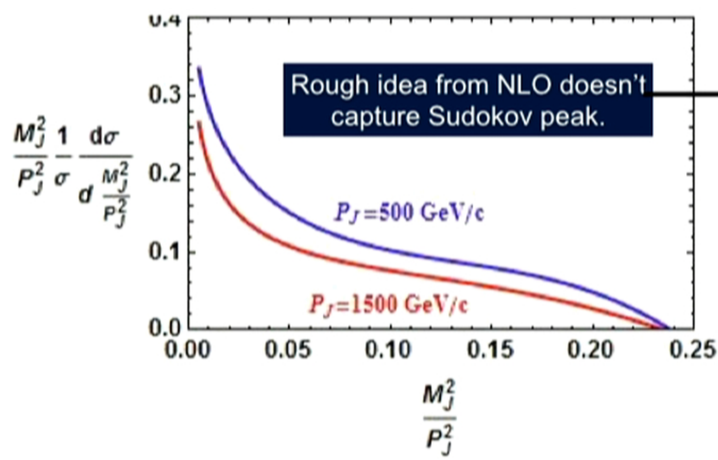

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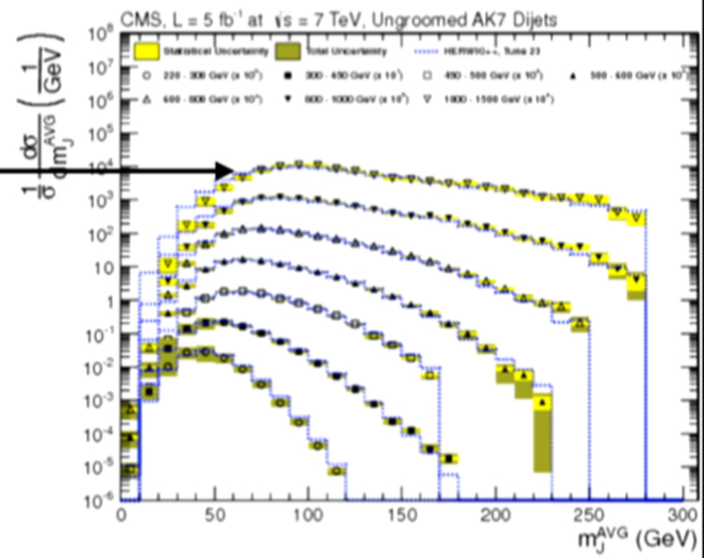

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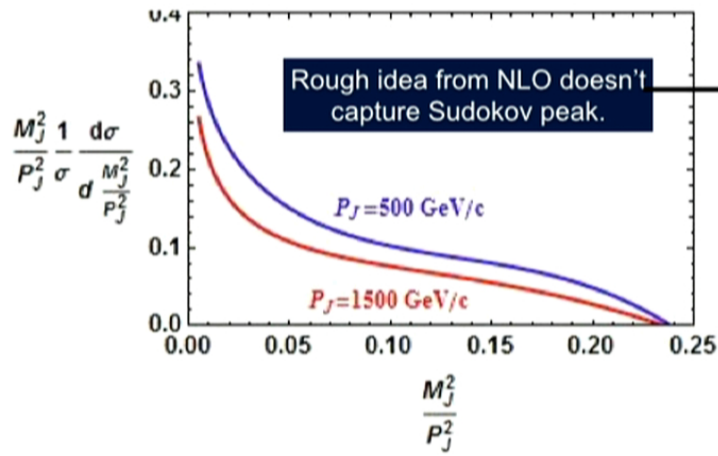

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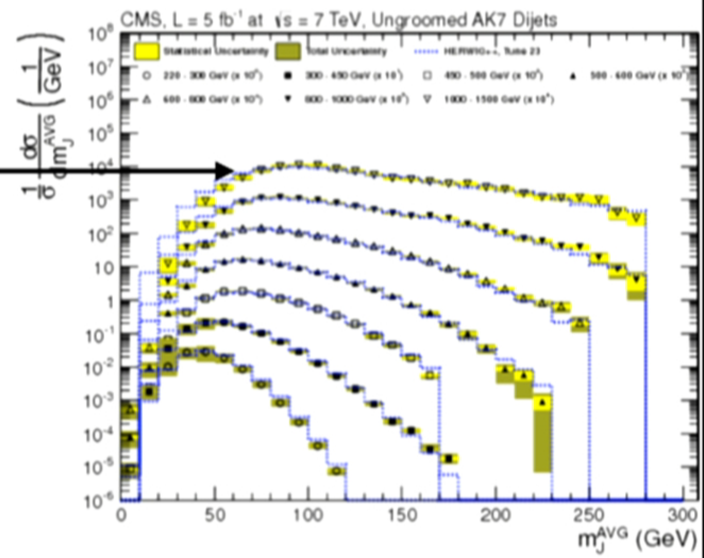

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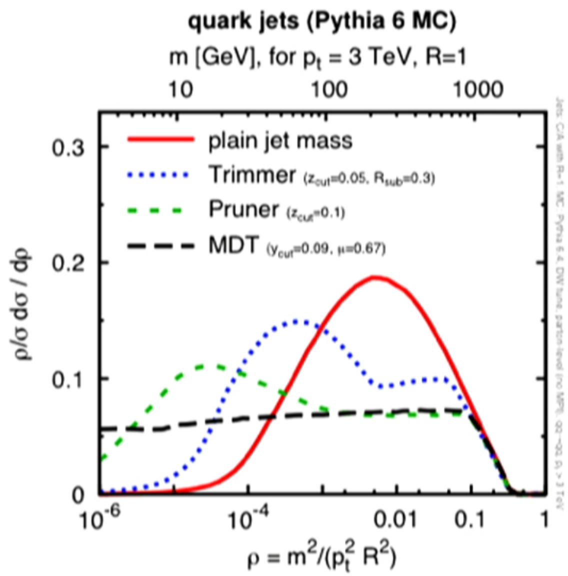
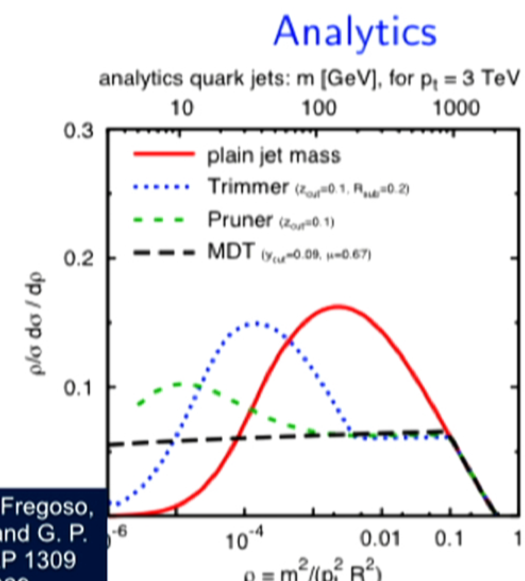
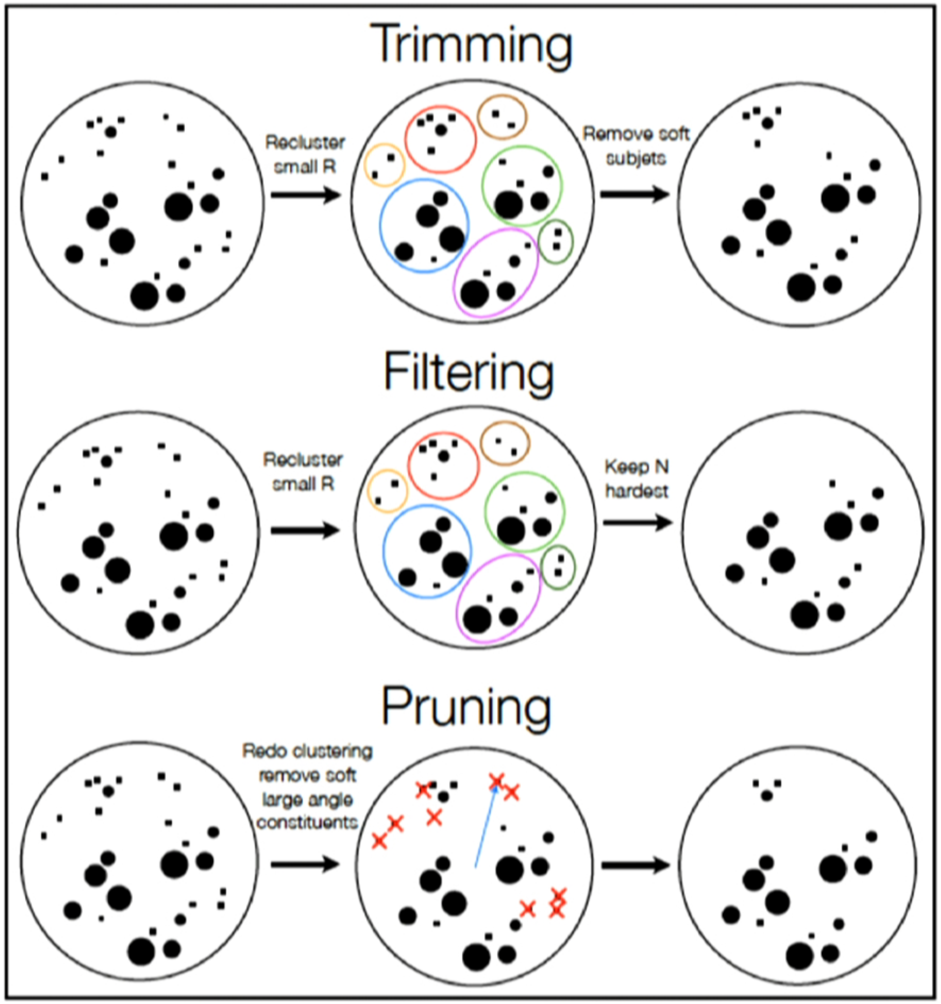
Slide from G. Soyez





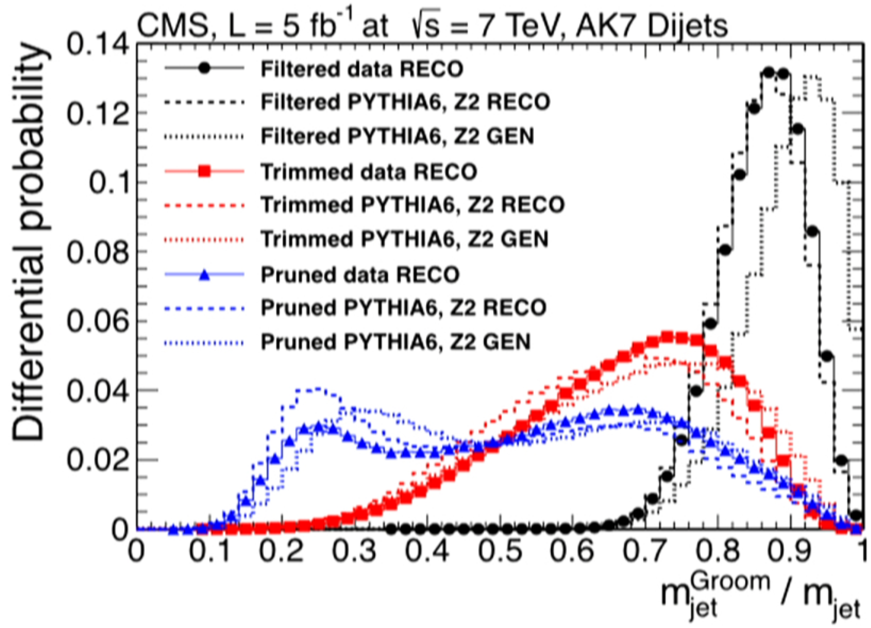
Dasgupta, A. Fregoso, S. Marzani, and G. P. Salam, JHEP 1309 (2013) 029,

Jet Grooming



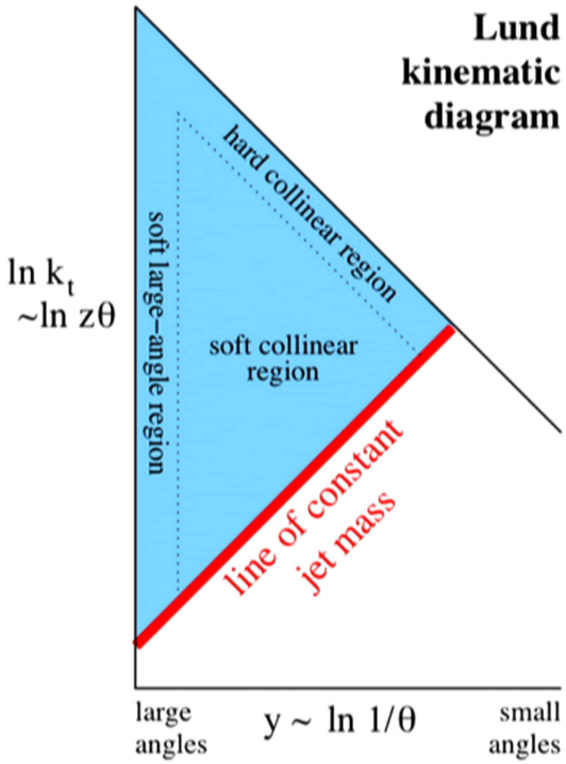
Jet Grooming

- Synopsis : They All Work.



Jet Grooming Analytics

- What are groomers doing?



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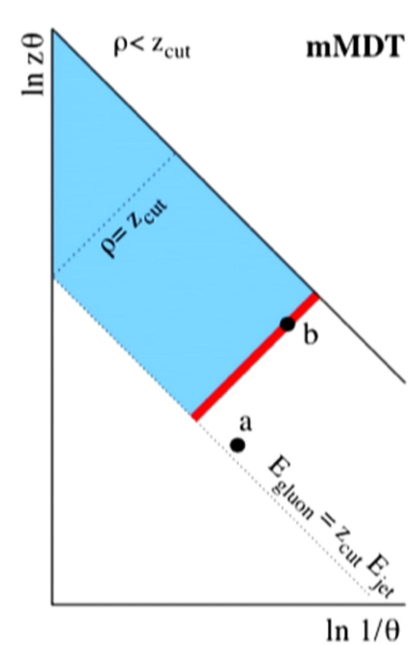

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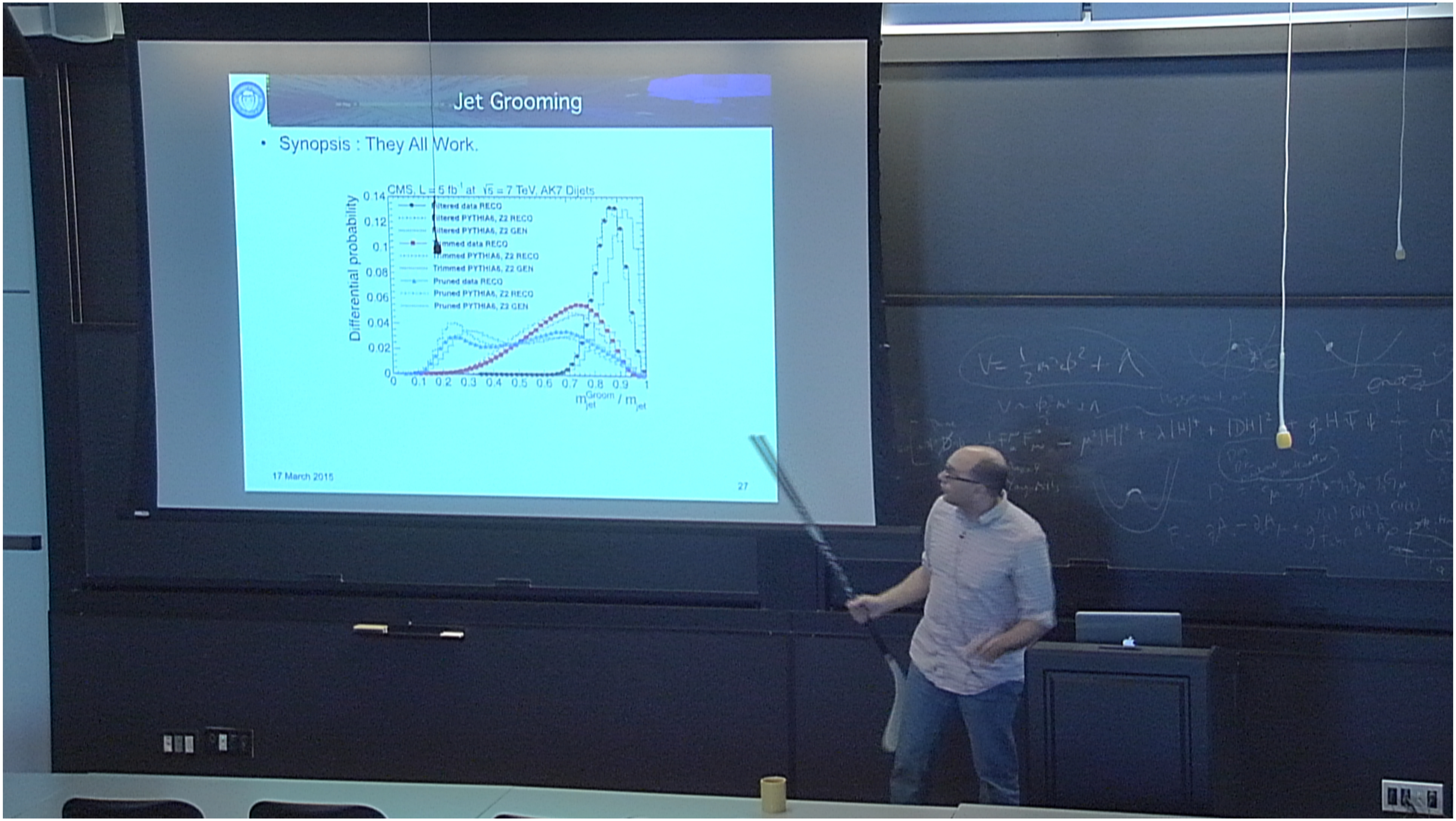
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CMS, L = 5 fb⁻¹ at √s = 7 TeV, AK7 Dijets
Differential probability
17 March 2015
27

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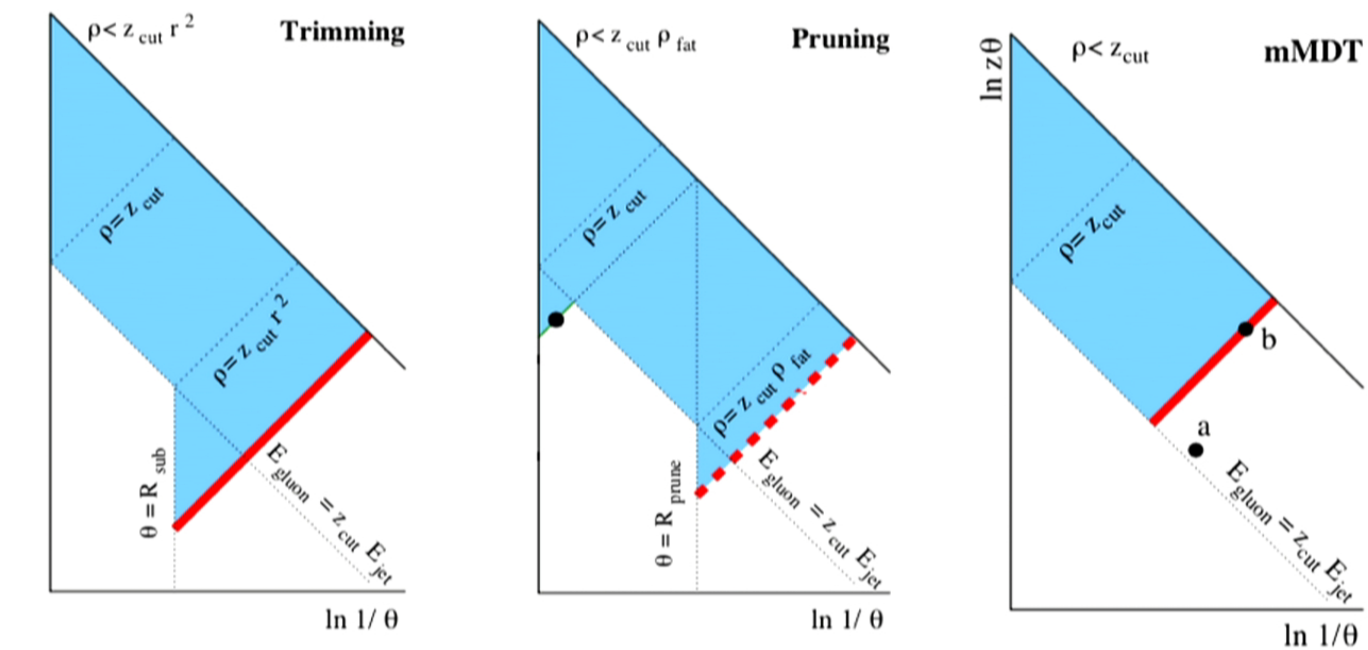

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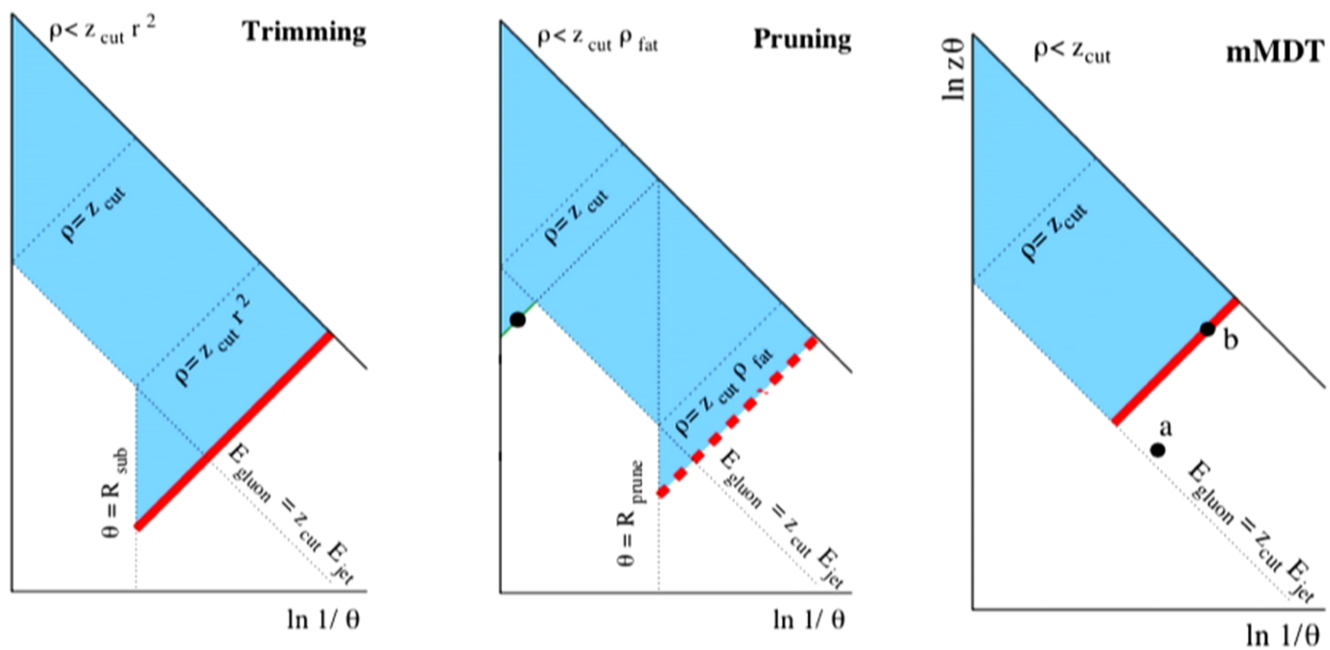

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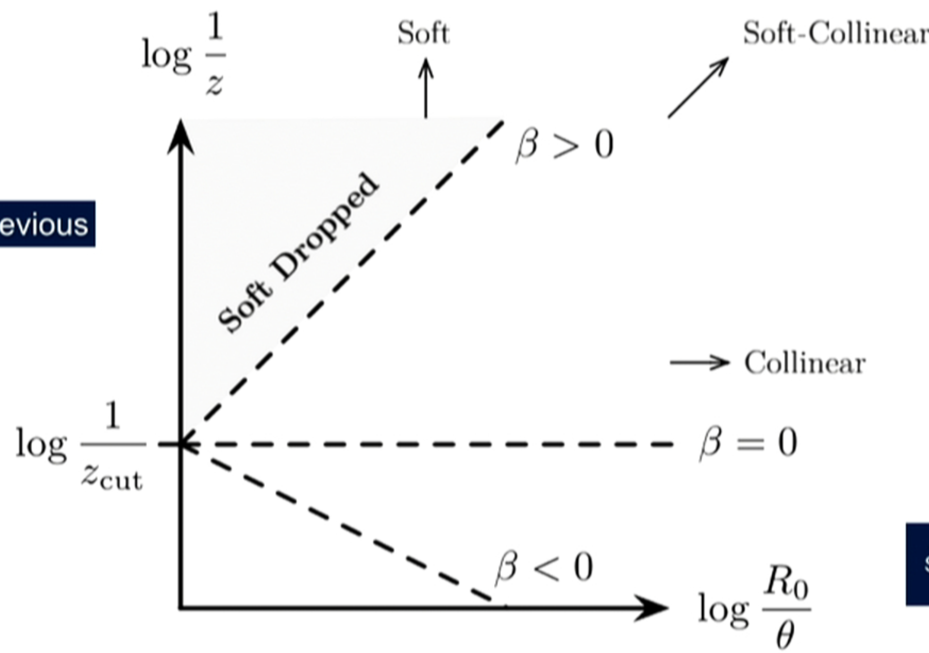
Jet Grooming Analytics

- Understanding gained from jet analytics even gives new and better ways to groom and tag!

Note : y-axis now 1/previous



A. Larkoski, S. Marzani, G. Soyez, J. Thaler,JHEP 1405 (2014) 146

Soft drop : "simple" behavior in this plane, with tunable parameter for many algorithms!

Jet Grooming Analytics

- Soft drop :
  - Undo last stage of C/A clustering, label subjets j1,j2
  - If :

$$\frac{min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0} \right)^{\beta}$$

    then j is soft dropped
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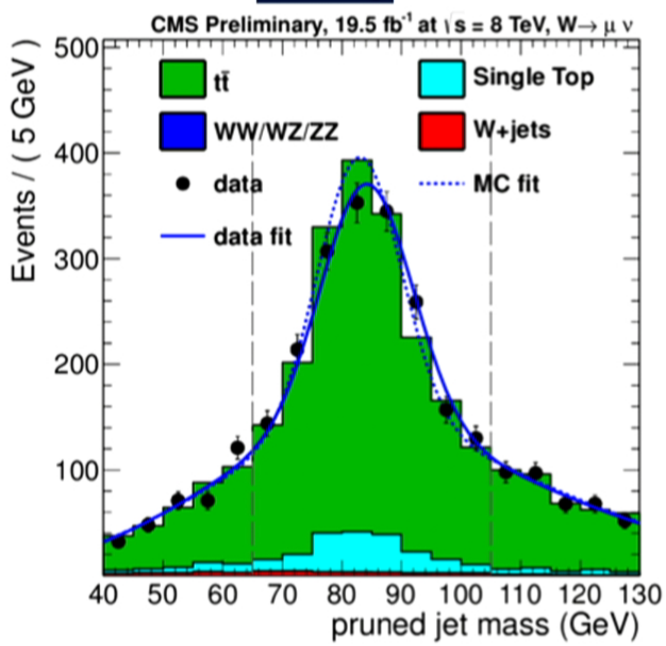
Pruning



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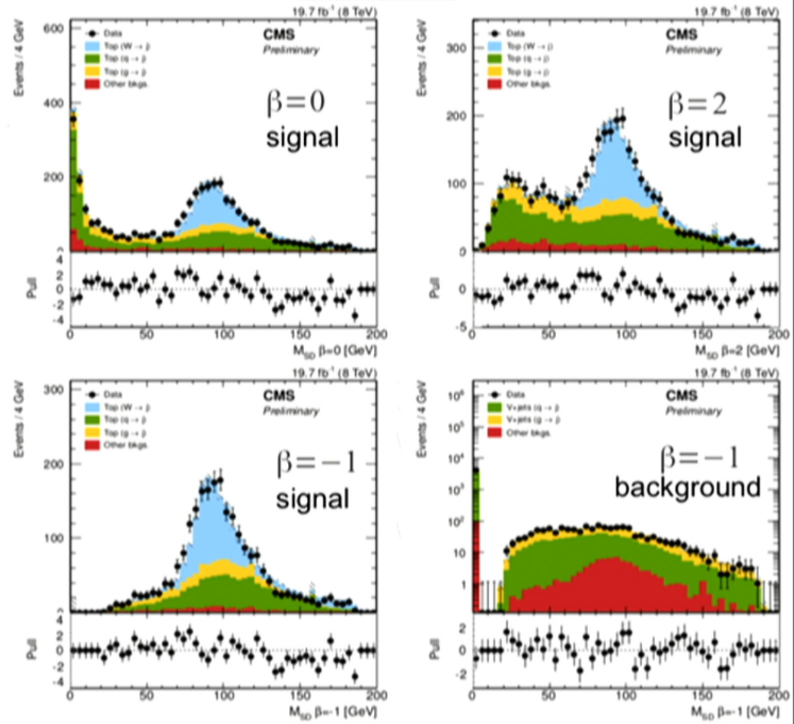

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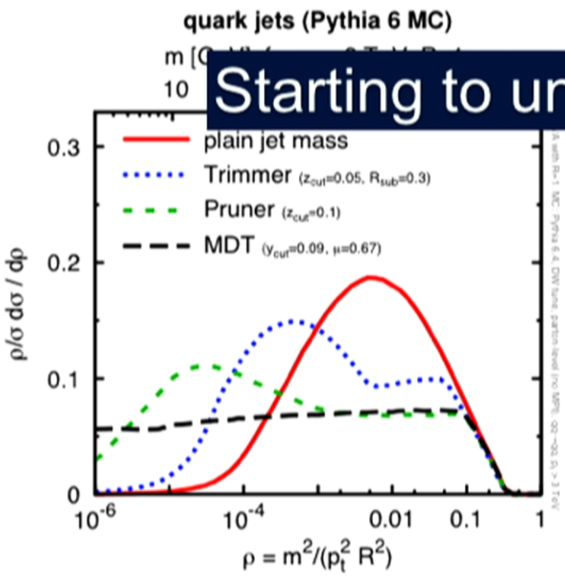
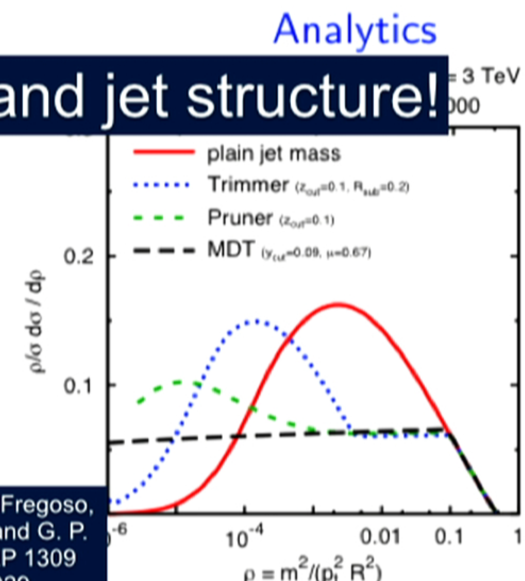


Starting to understand jet structure!



Dasgupta, A. Fregoso, S. Marzani, and G. P. Salam, JHEP 1309 (2013) 029,

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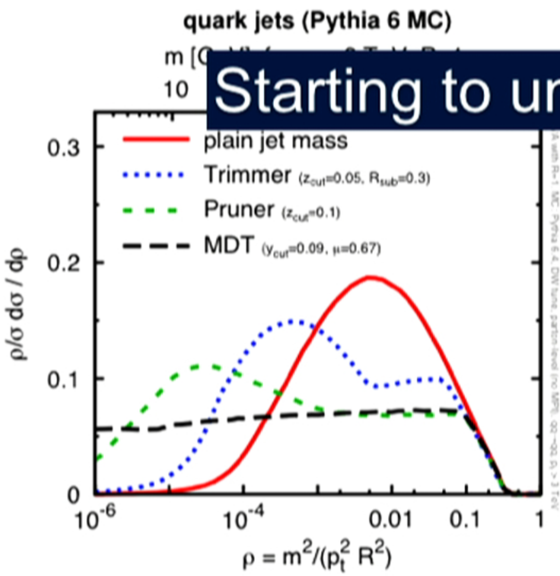

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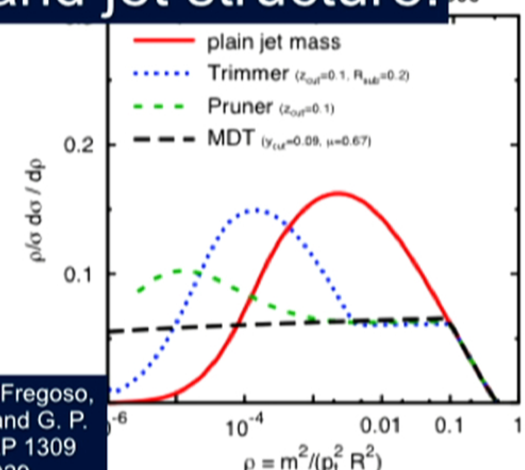

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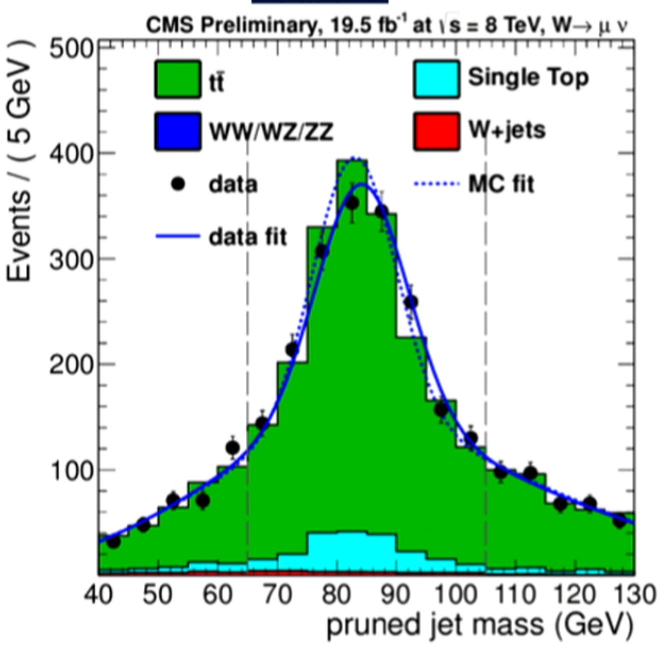

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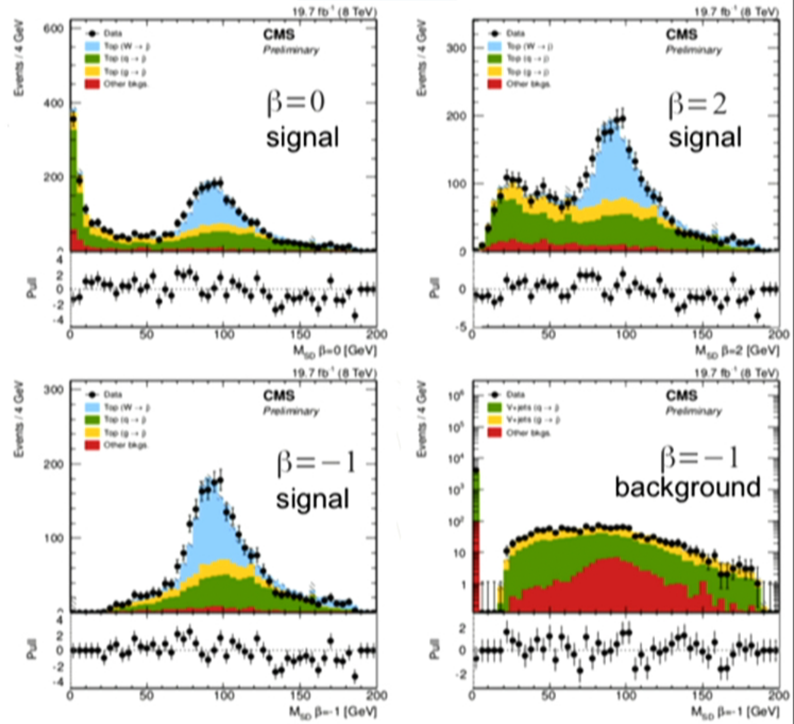
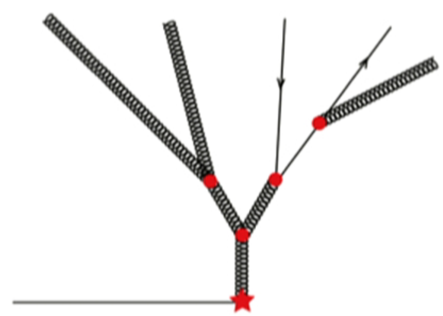
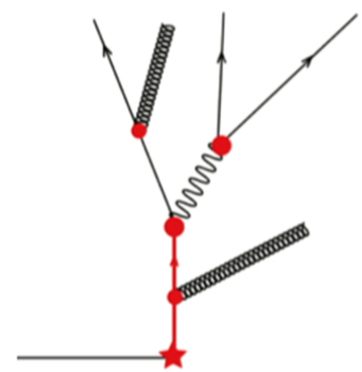


Top Tagging Analytics : Shower Deconstruction

- Make "microjets" out of CA jet constituents
- Keep at most 9 microjets with pt > ptmin
- Approximate probability for observed particles to satisfy a "signal-like" shower, or a "background-like" shower
- Construct likelihood and compare





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Coming soon for CMS!

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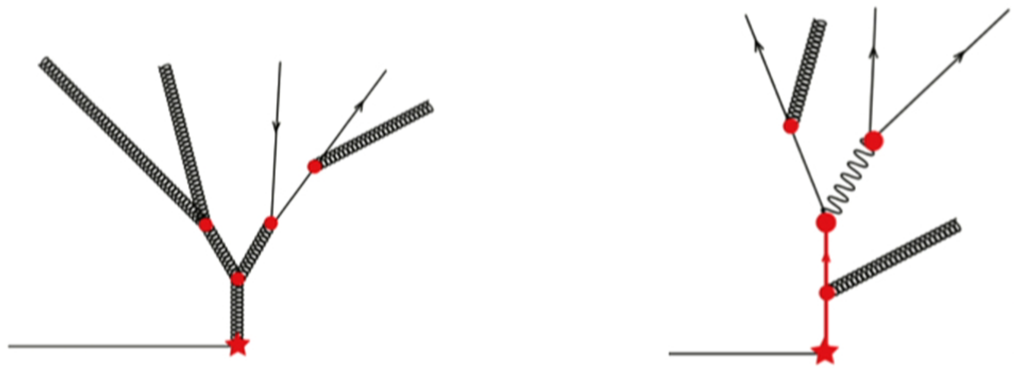

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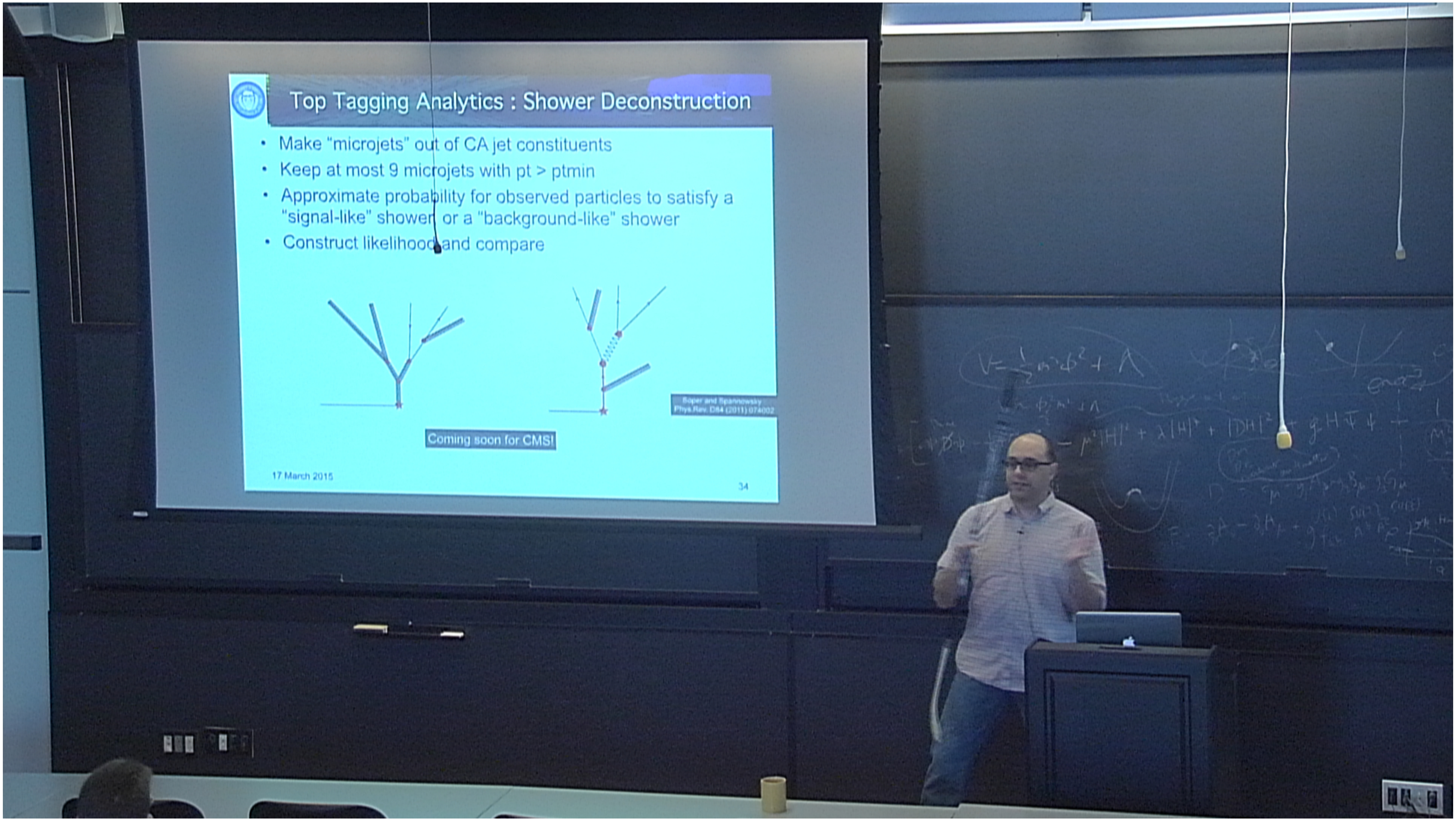

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17 March 2015
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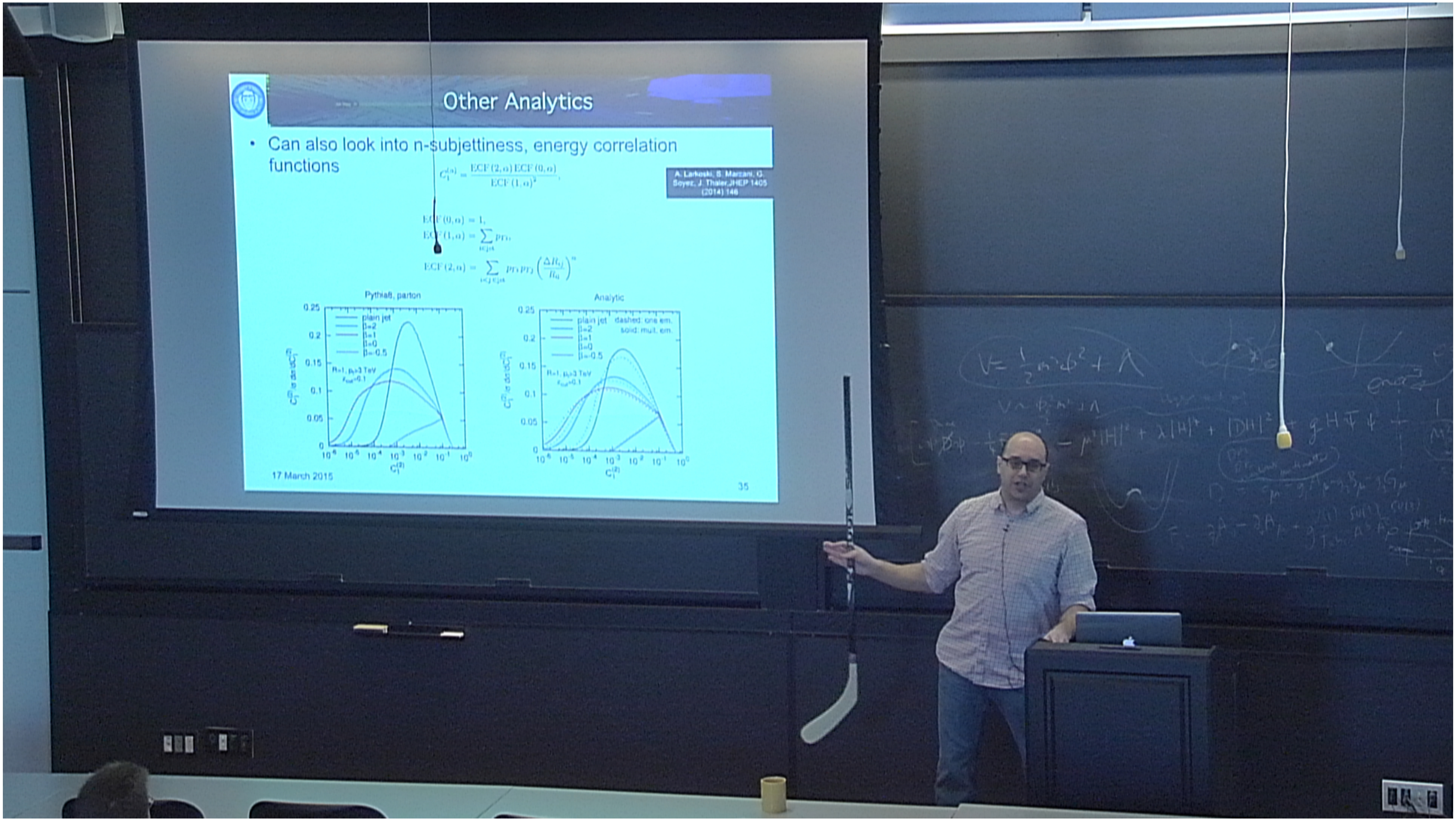

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• Can also look into n-subjettiness, energy correlation functions
$C_1^{(\alpha)} = \frac{\mathrm{ECF}(2,\alpha)\,\mathrm{ECF}(0,\alpha)}{\mathrm{ECF}(1,\alpha)^2}$,
A. Larkoski, S. Marzani, G. Soyez, J. Thaler,JHEP 1405 (2014) 146
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Pythia8, parton
Analytic
plain jet
β=2
β=1
β=0
β=-0.5
dashed: one em.
solid: mult. em.
17 March 2015
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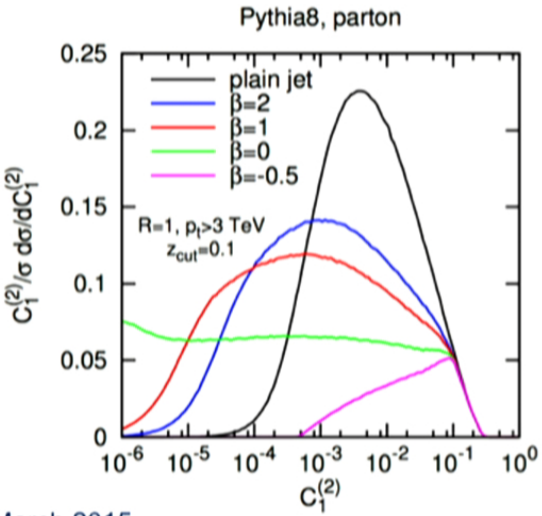

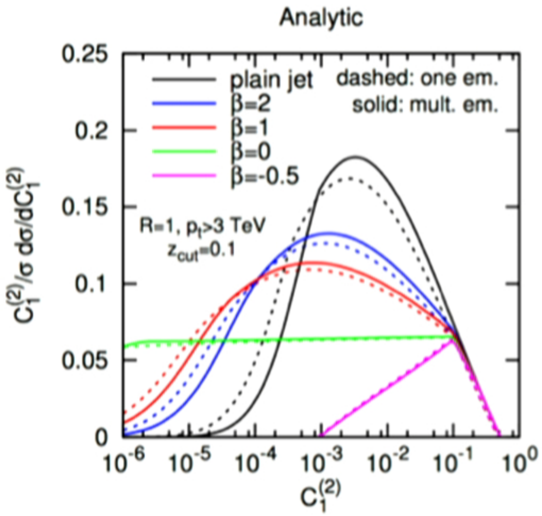

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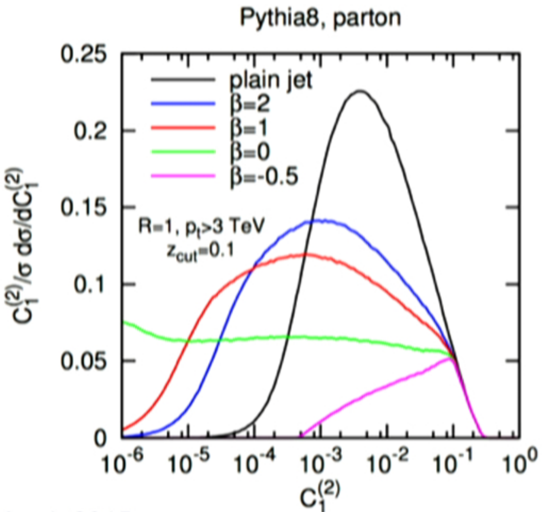
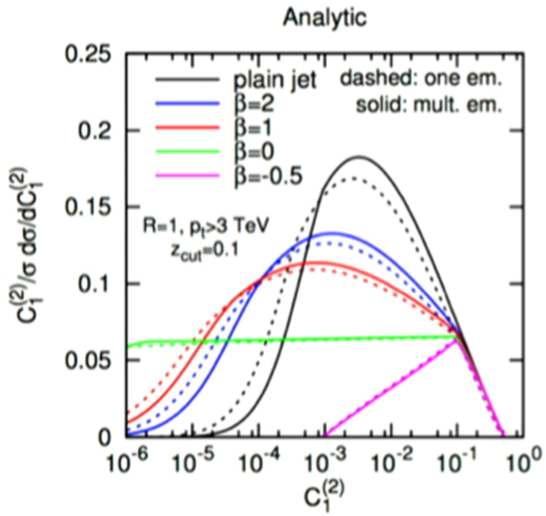
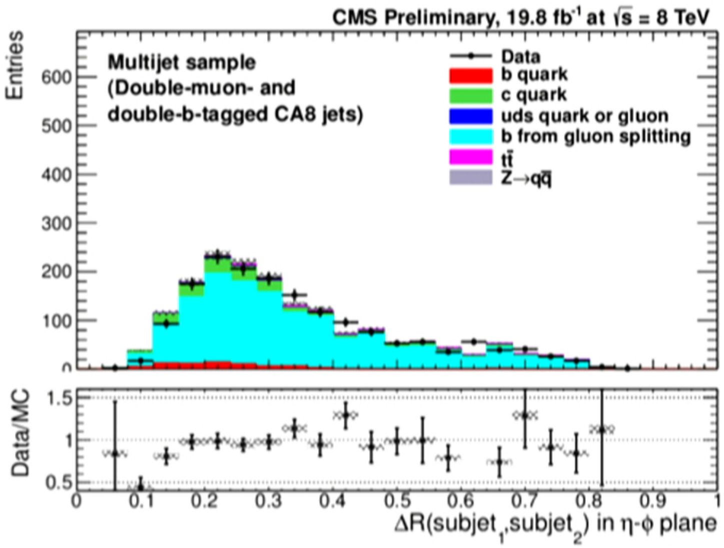
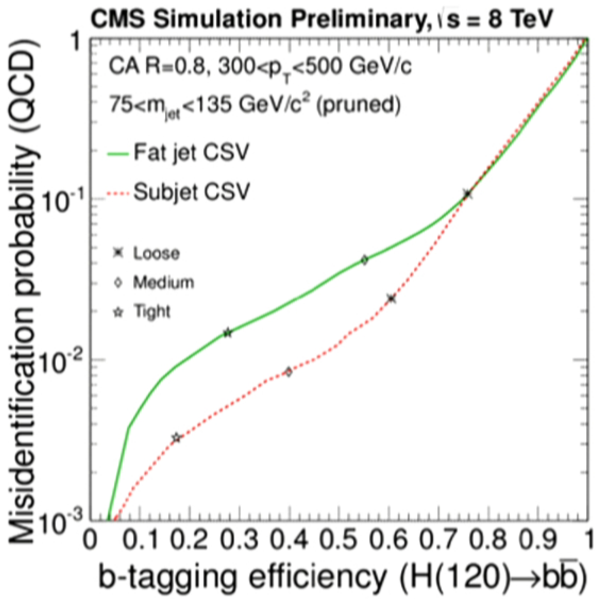




Bottoms in Boosted Jets

- Calibrate with gluon splitting to b-bbar
- Excellent performance by b-tagging subjets!





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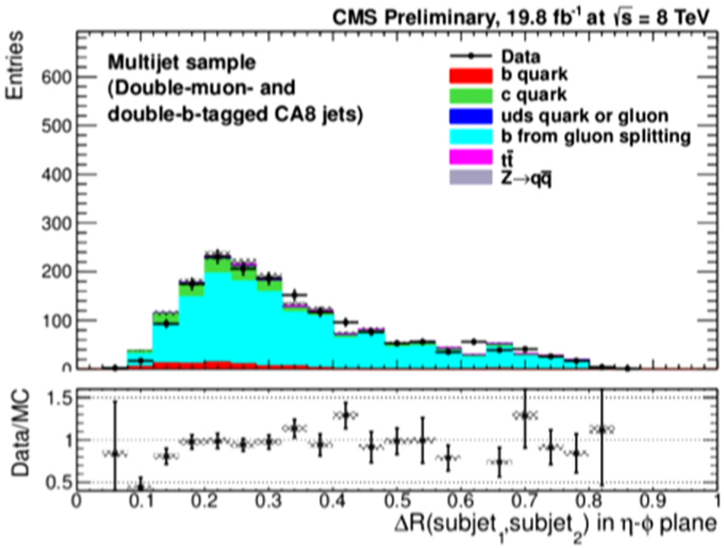
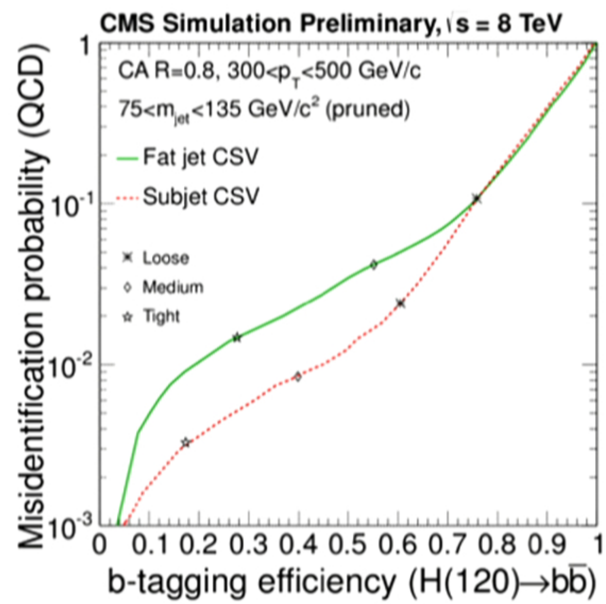
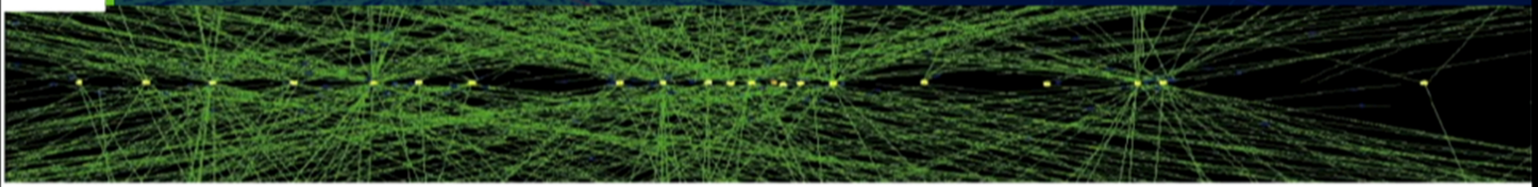




LHC : Luminosity and Pileup



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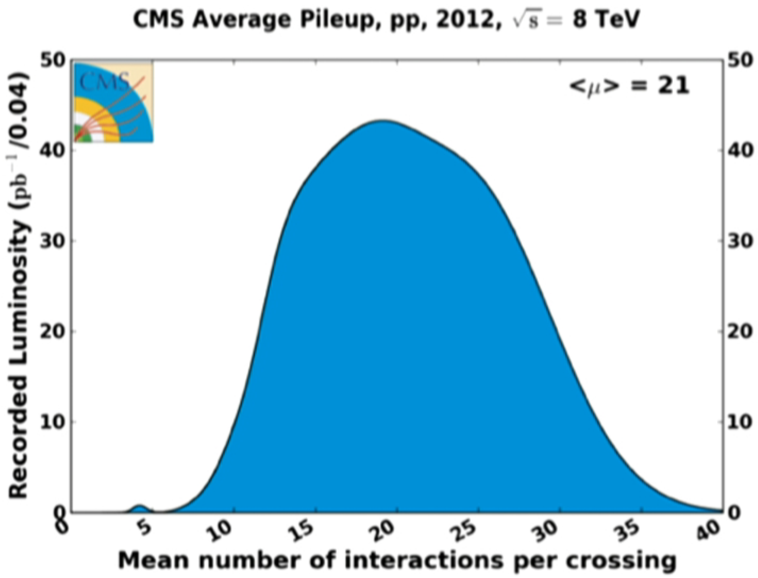

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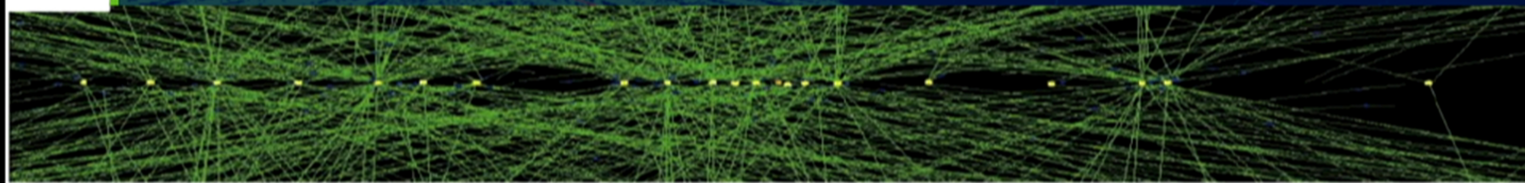

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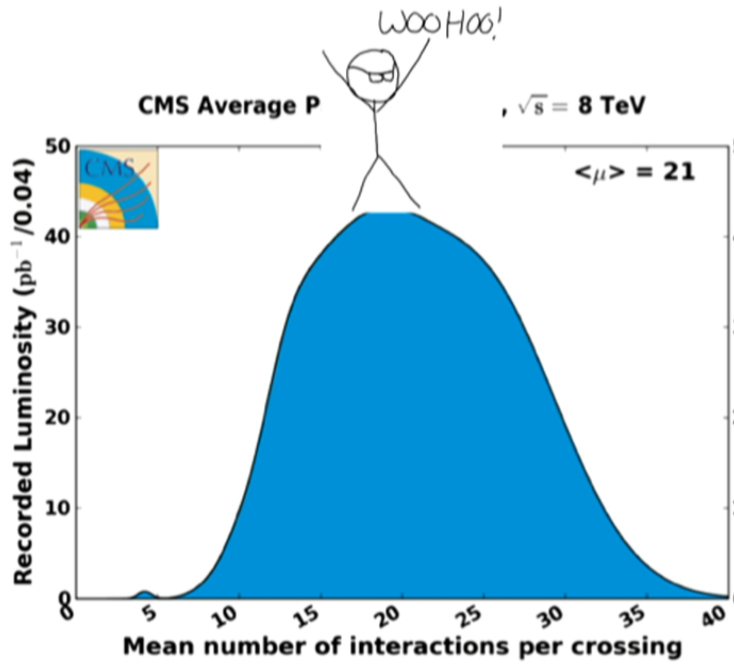
Overall picture : Success!

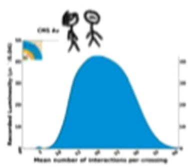


LHC : Luminosity and Pileup

HL-LHC Pileup

Run 1 Lumi profile.

Oh my.



Run 3 Lumi profile.

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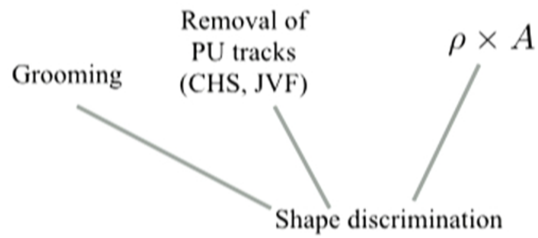
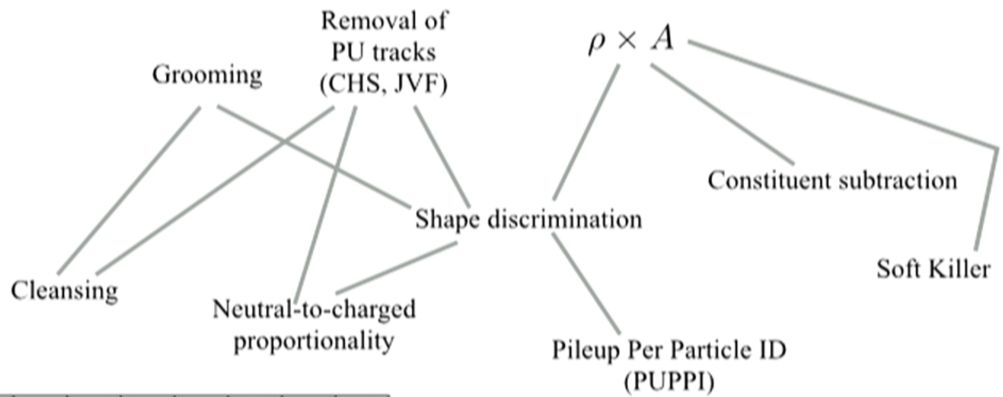
New Pileup Mitigation Techniques

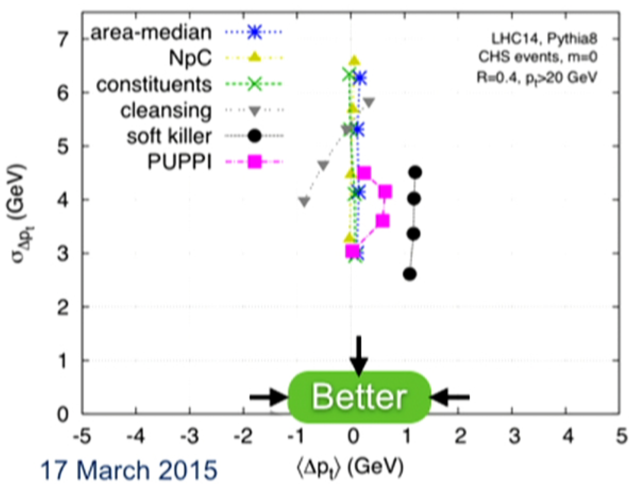
- Run 1 : Set the baseline



New Pileup Mitigation Techniques

- Run 2 : Kick it up a notch





From pileup mitigation workshop at CERN

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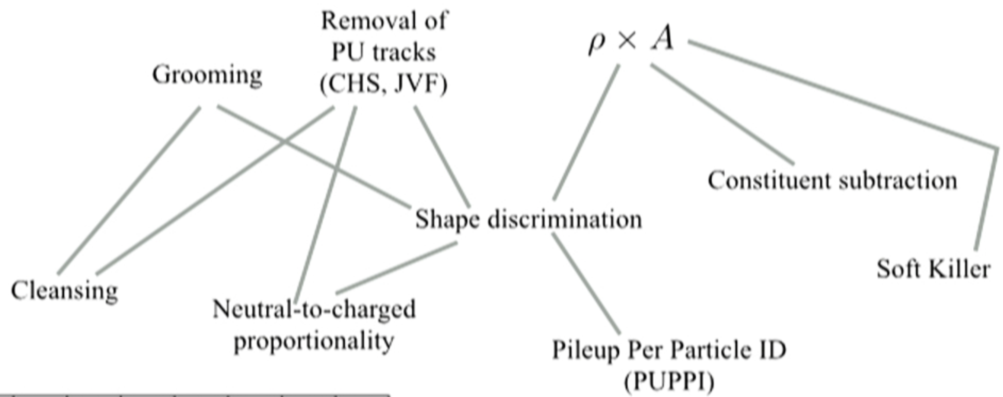

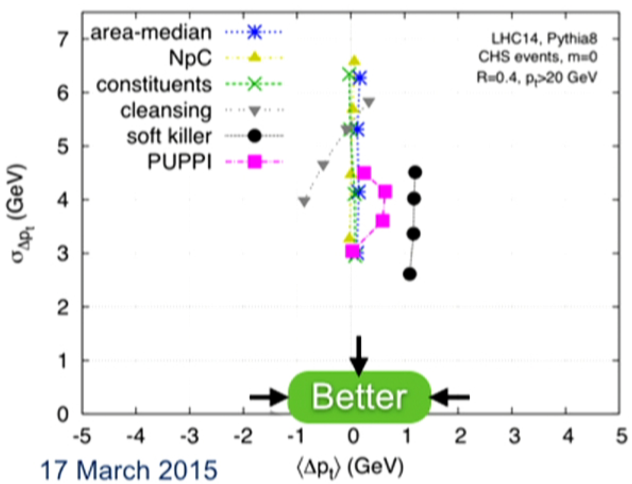

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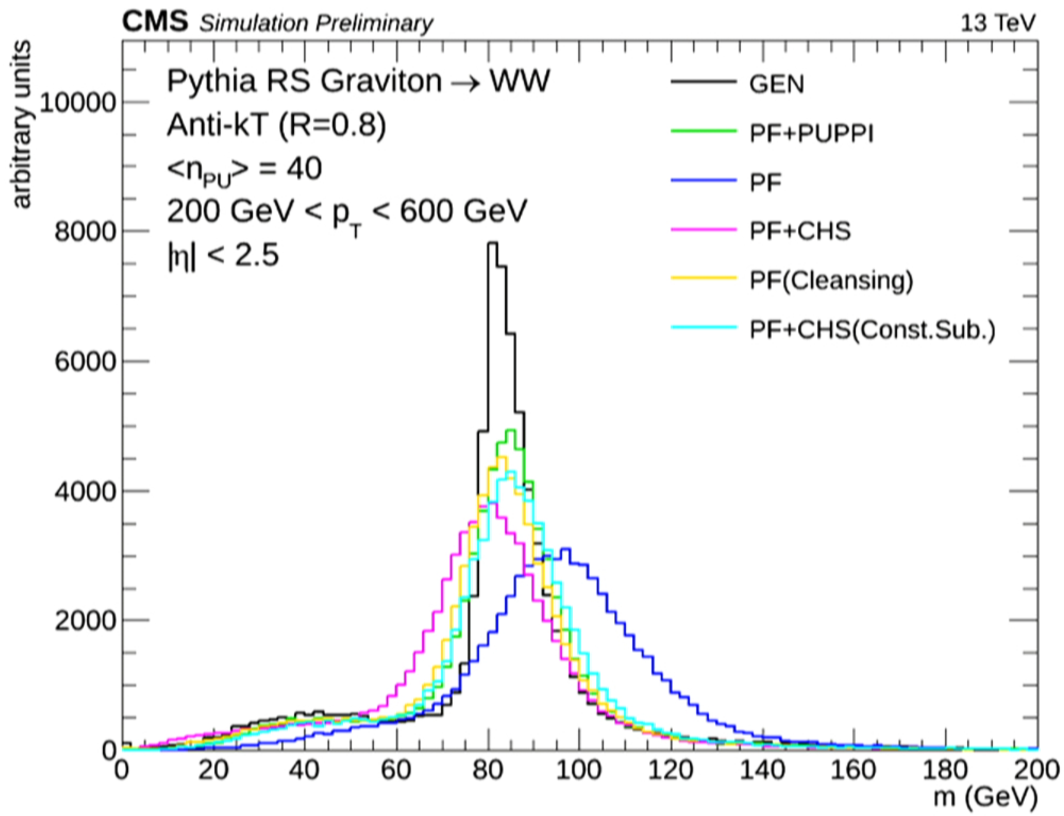

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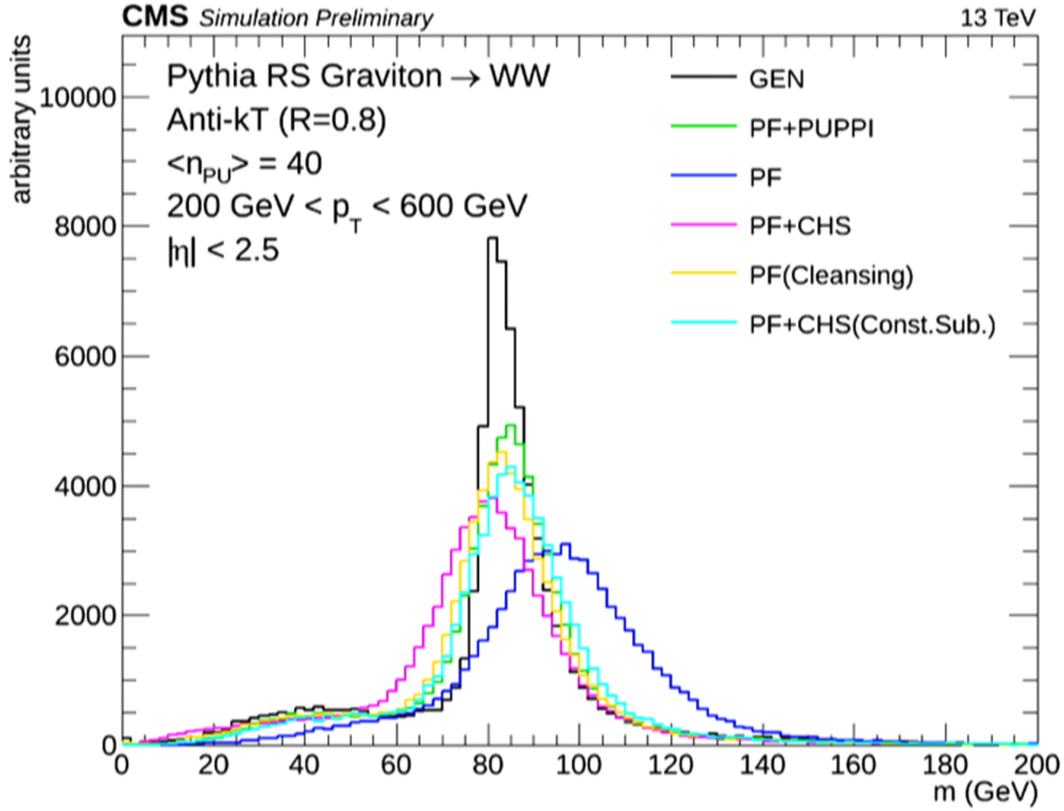

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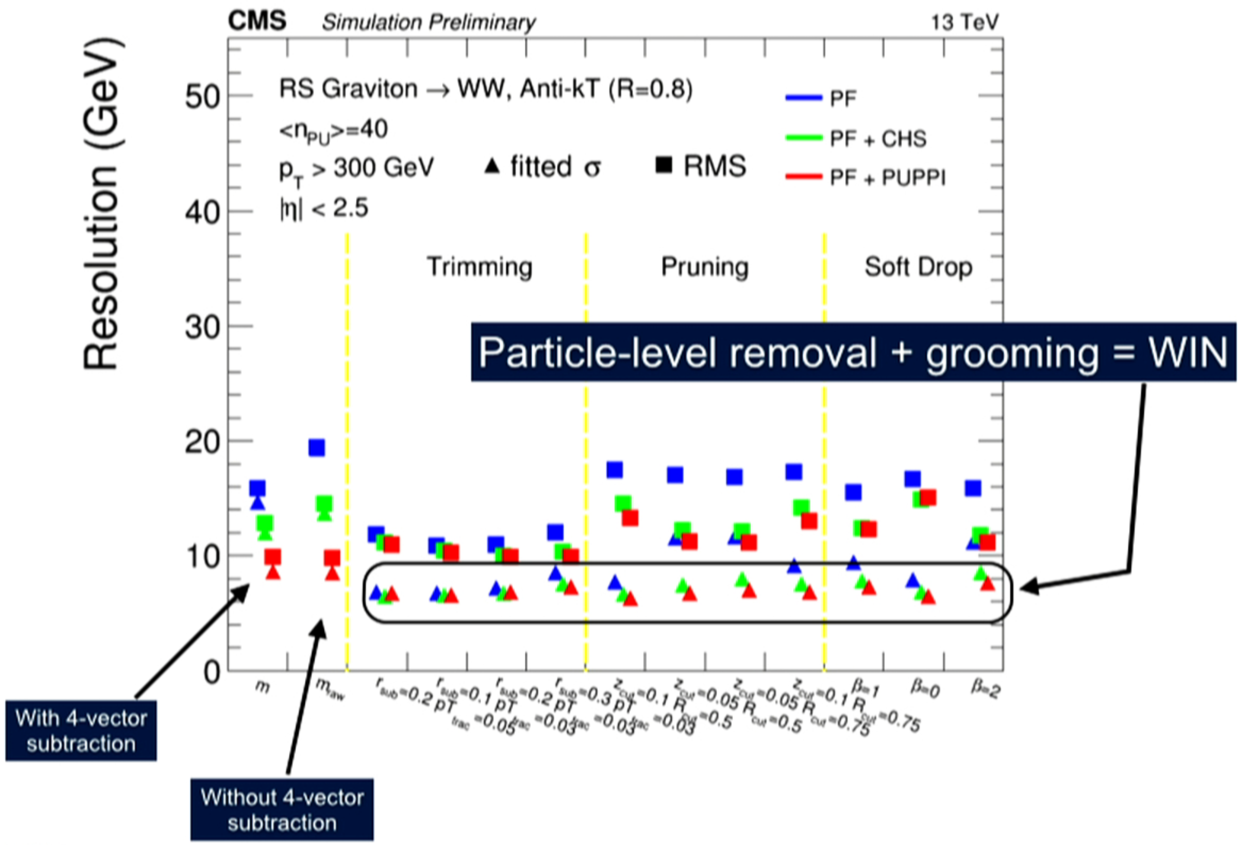
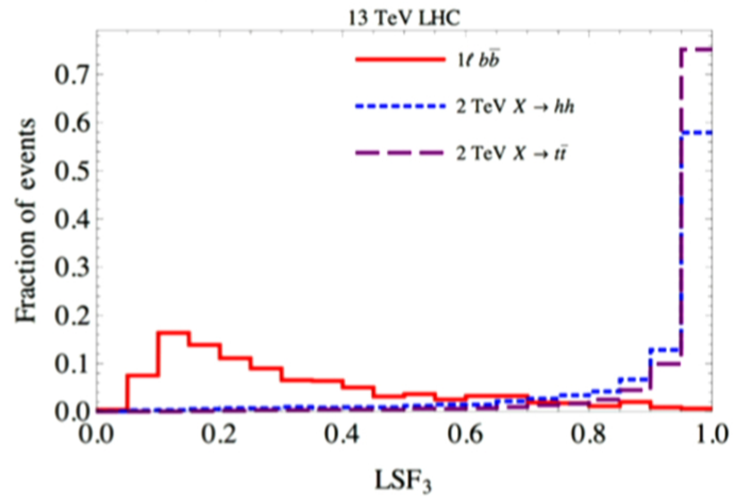


Other Boosty Stuff

- Leptons need special treatment too!
  - Isolation? What isolation!
    - Special triggers, special reconstruction, special isolation
- Lepton subjet fraction
  - (Brust, Maksimovic, Sady, Saraswat, Walters, Xin, arxiv:1410.0362v2)

Fraction of subjet momentum carried by lepton



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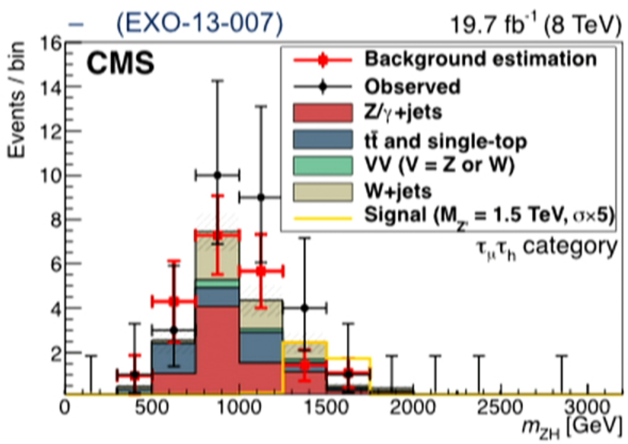
  - (EXO-13-007)



Need to add tau channels to tab searches!

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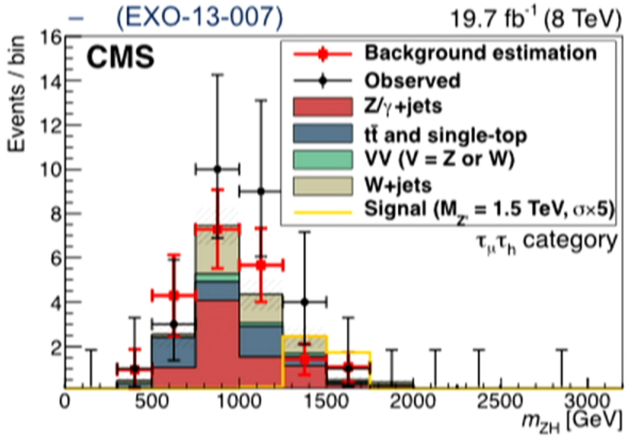

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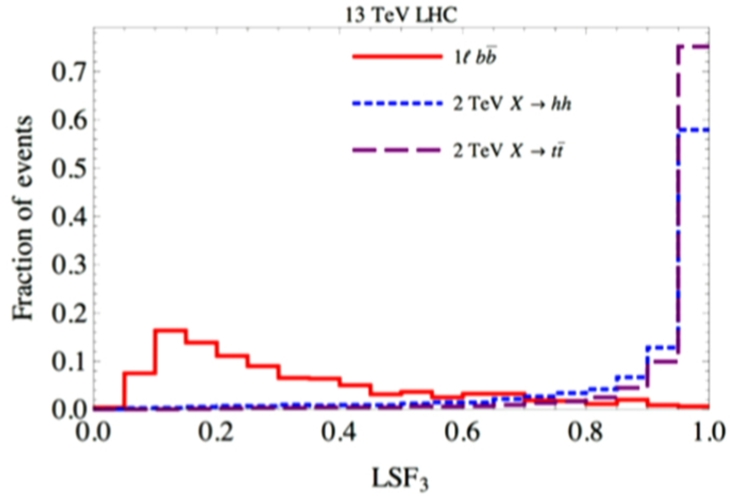

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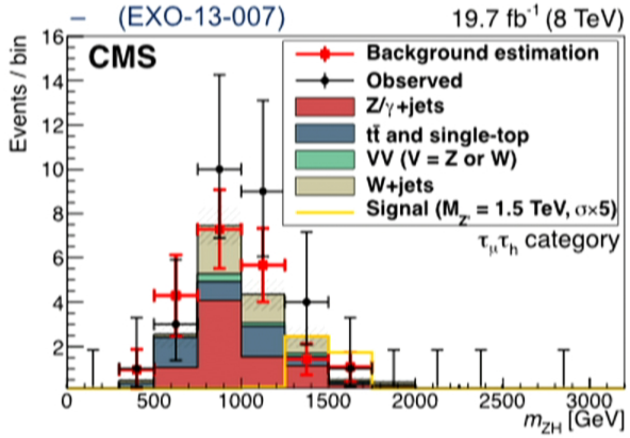

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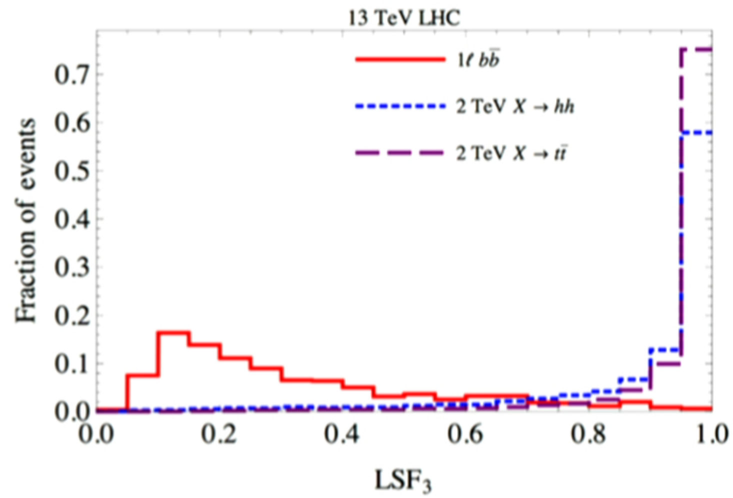
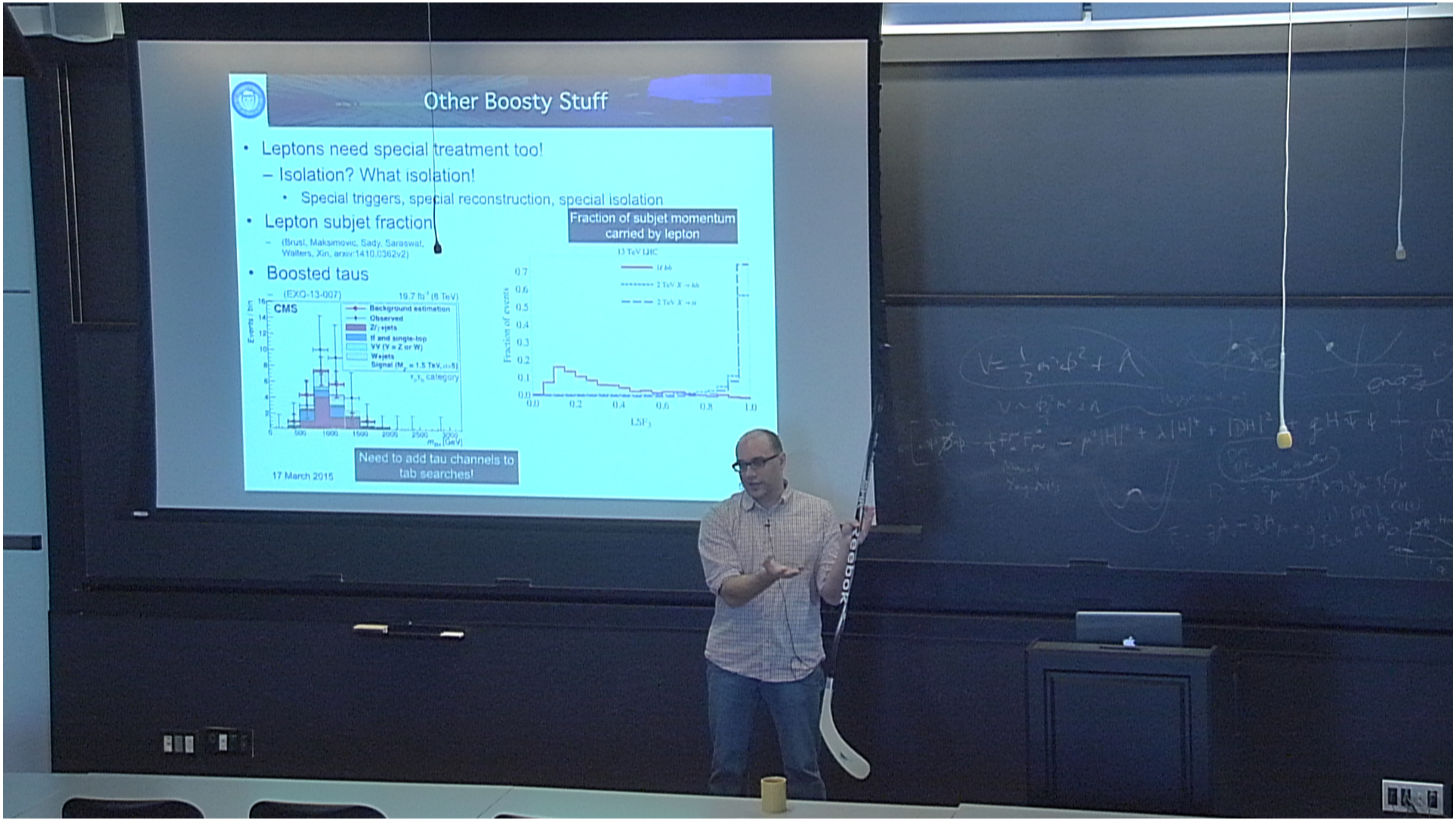
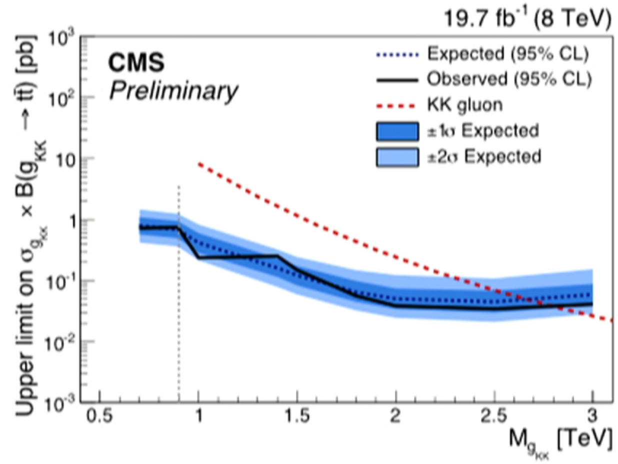


Need to add tau channels to tab searches!


Other Boosty Stuff
• Leptons need special treatment too!
– Isolation? What isolation!
• Special triggers, special reconstruction, special isolation
• Lepton subjet fraction
– (Brust, Maksimovic, Sady, Saraswat, Walters, Xin, arxiv:1410.0362v2)
• Boosted taus
– (EXO-13-007)
Fraction of subjet momentum carried by lepton
CMS
Background estimation
Observed
Need to add tau channels to tab searches!
17 March 2015
Reebok

Run 1 Wrap-ups

- Hot off the press :
  - Run 1 Legacy Z'->ttbar search (CMS-B2G-13-008)



- Coming soon :
  - Run 1 HH, HV

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  - VV sees a bit of an excess at 1.8 TeV (~1.5-2 sigma)
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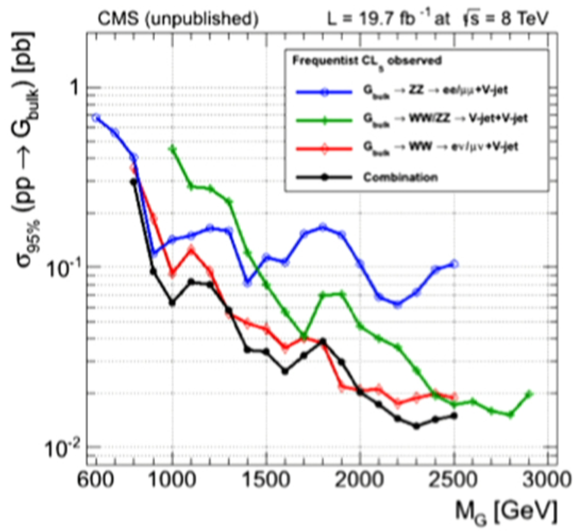

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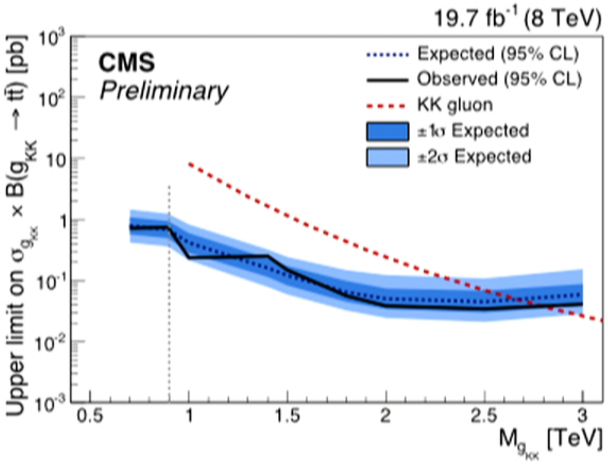

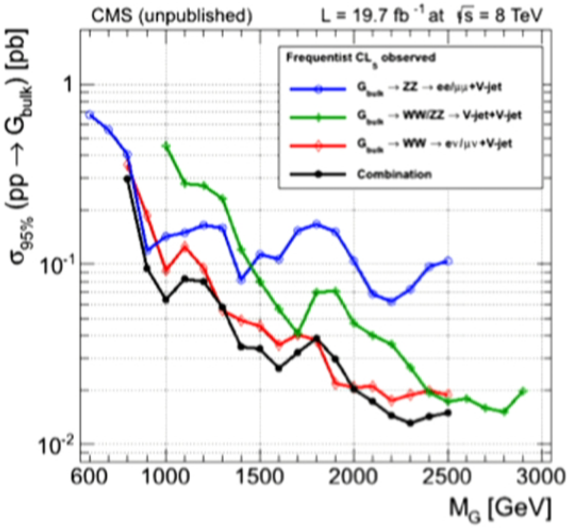

17 March 2015

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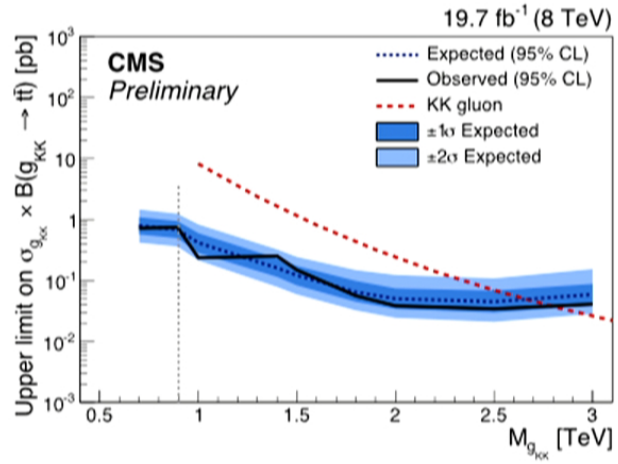

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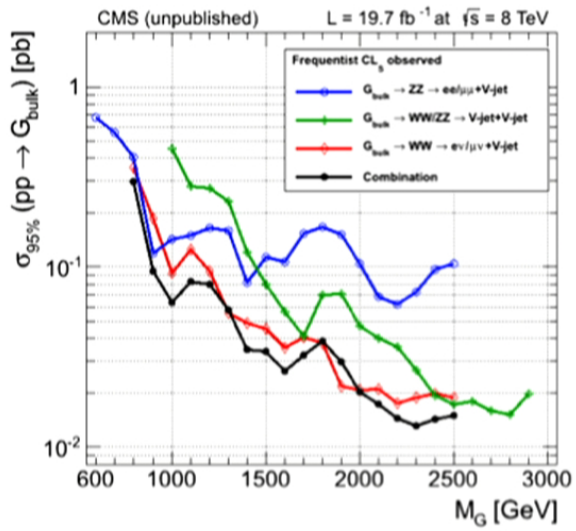

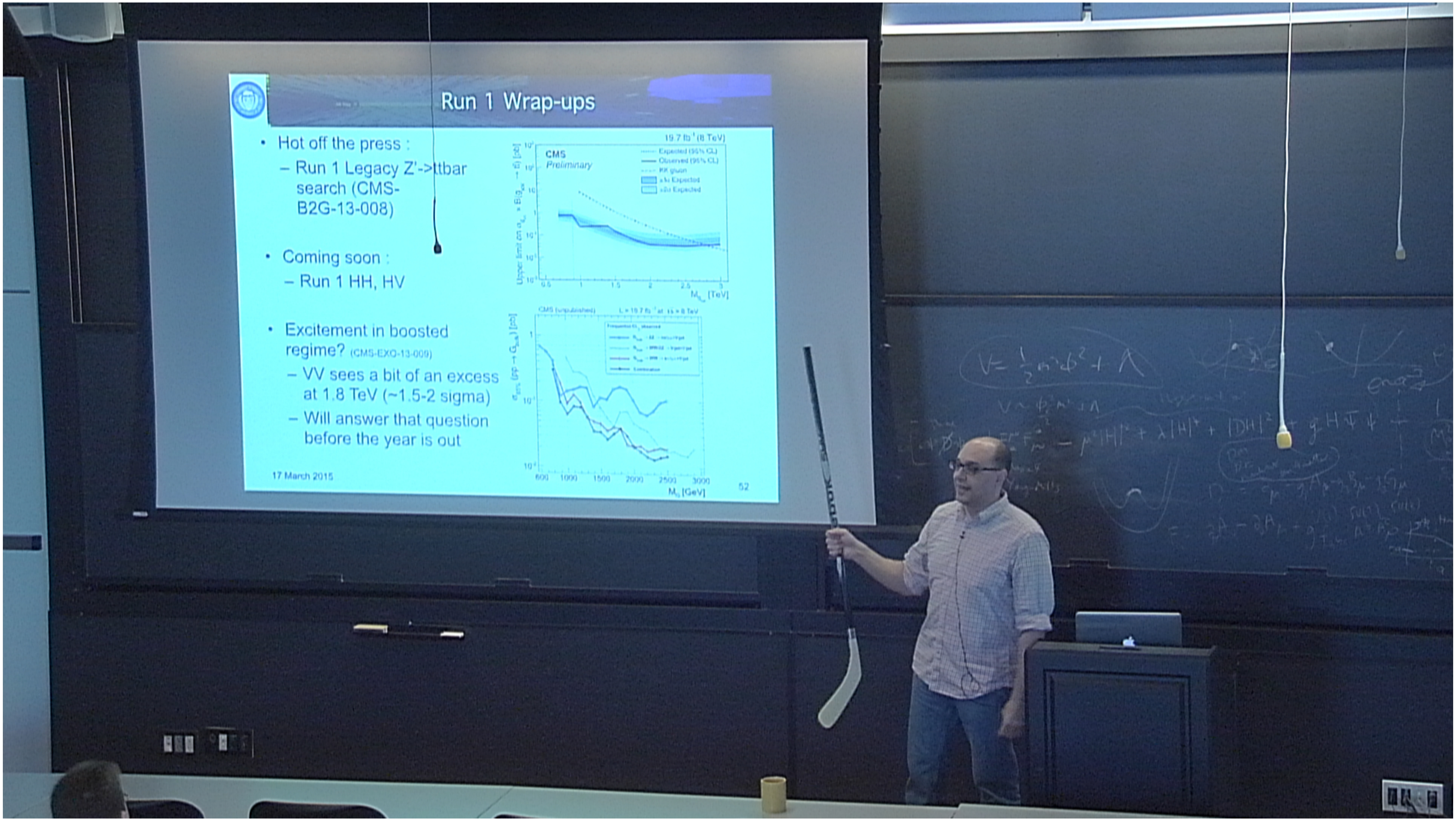

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17 March 2015
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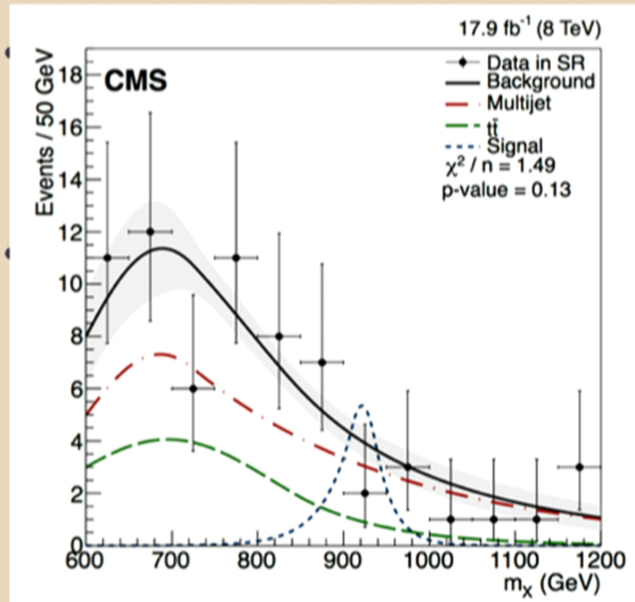
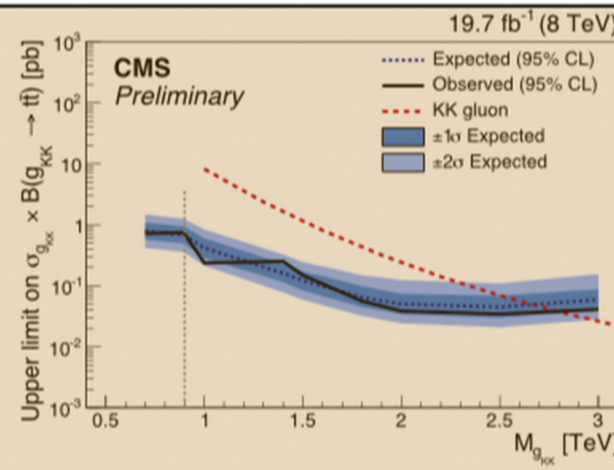
CMS
Preliminary
19.7 fb⁻¹ (8 TeV)
M [TeV]
M [GeV]

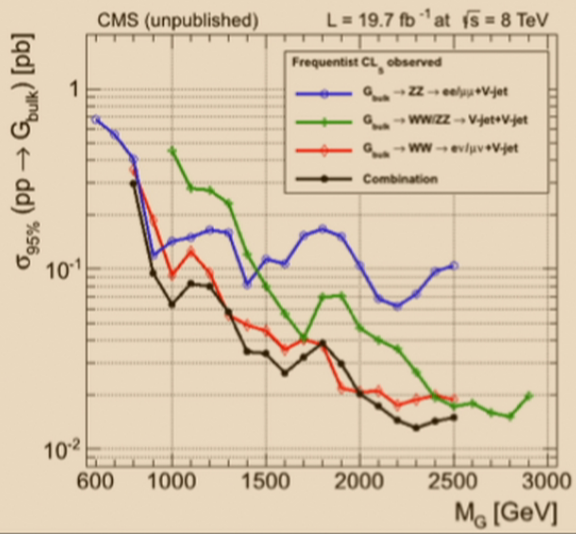
Run 1 Wrap-ups

- Hot off the press :
  - Run 1 Legacy Z'->ttbar search (CMS-

Update (11:00 PM last night) : CMS HH result submitted







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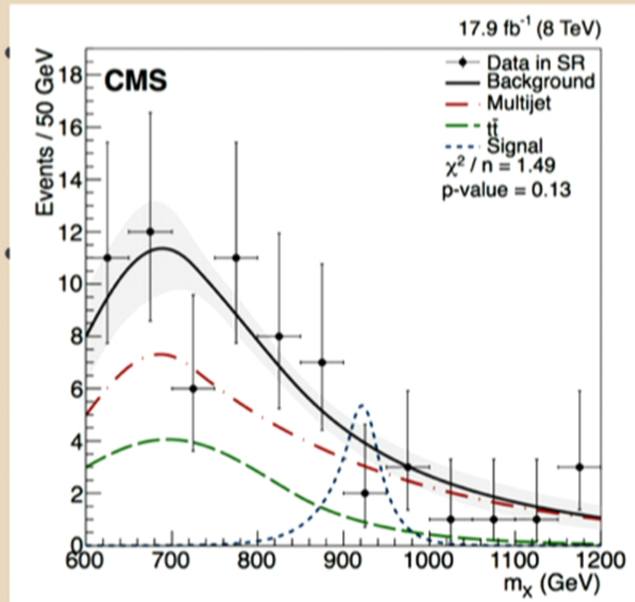

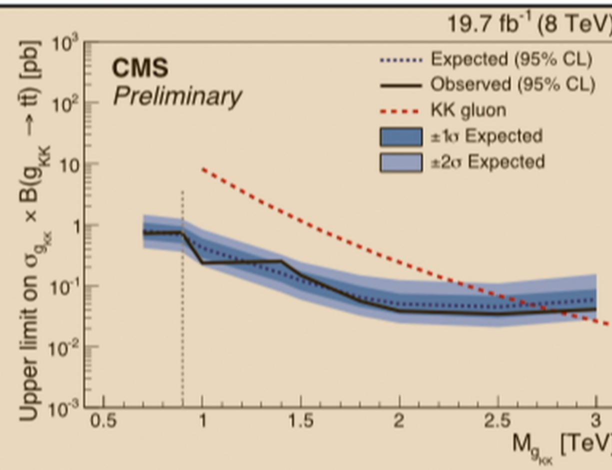

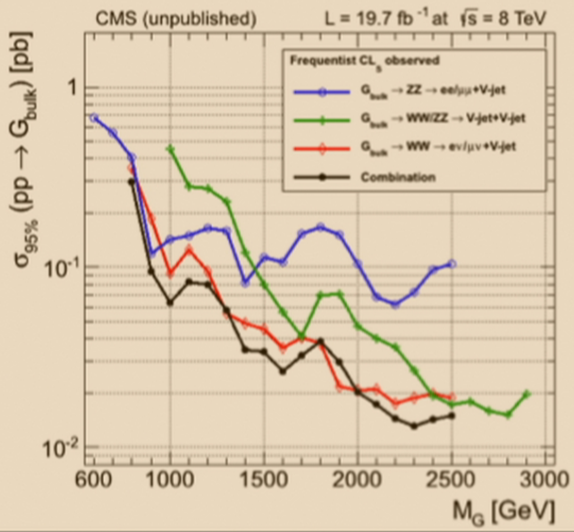

17 March 2015

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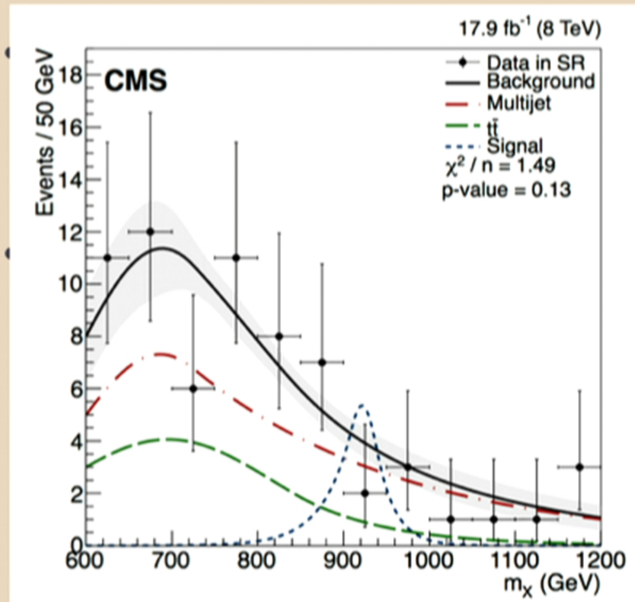

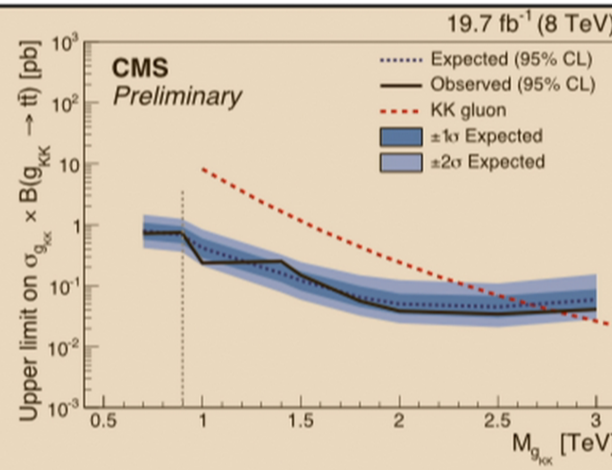

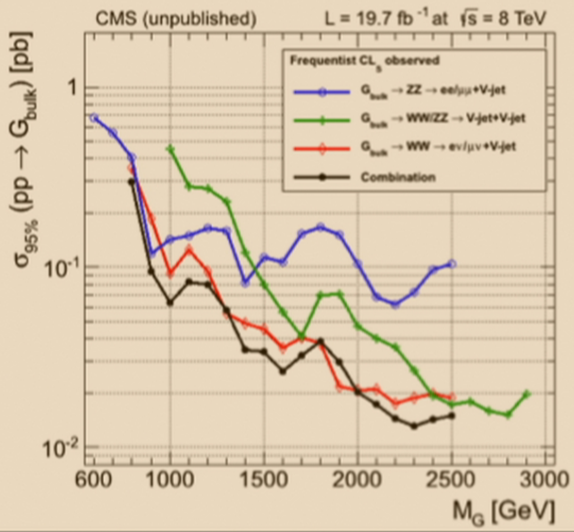

17 March 2015

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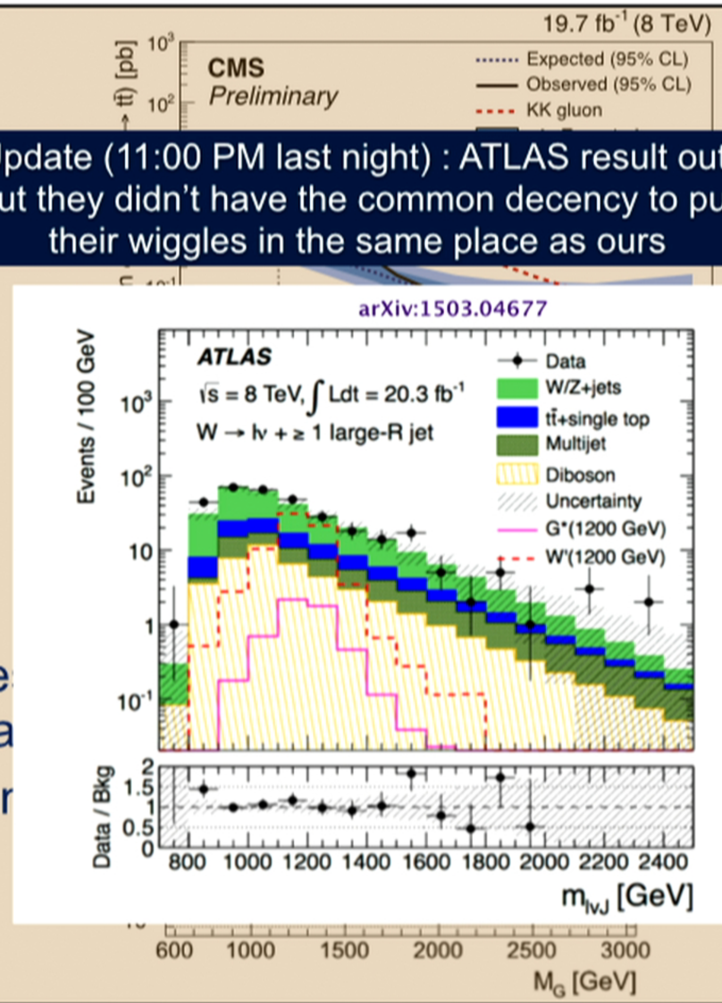

Update (11:00 PM last night) : ATLAS result out, but they didn't have the common decency to put their wiggles in the same place as ours

- Coming soon :
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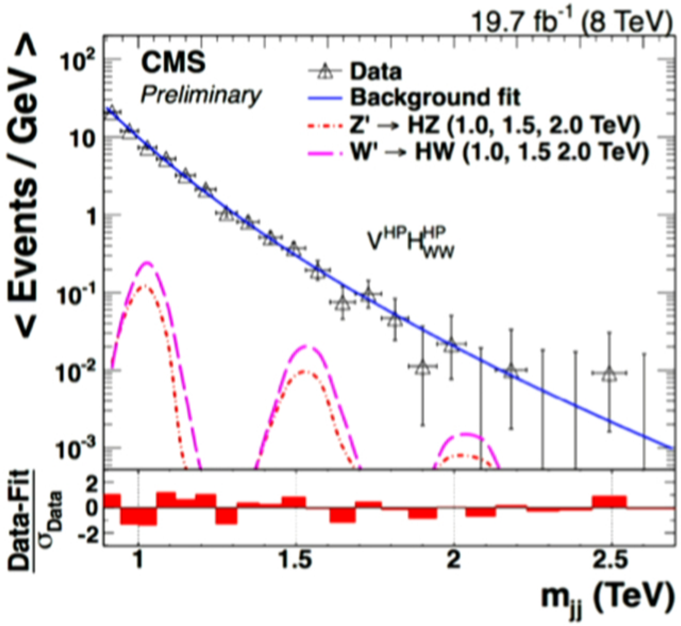
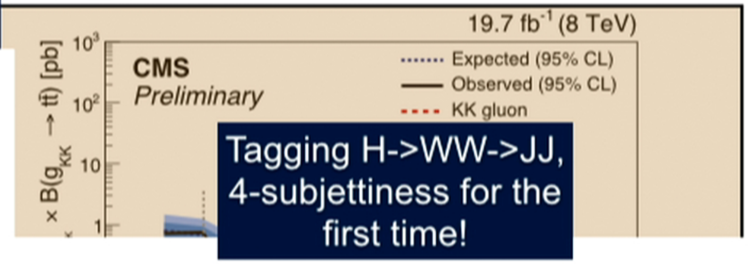
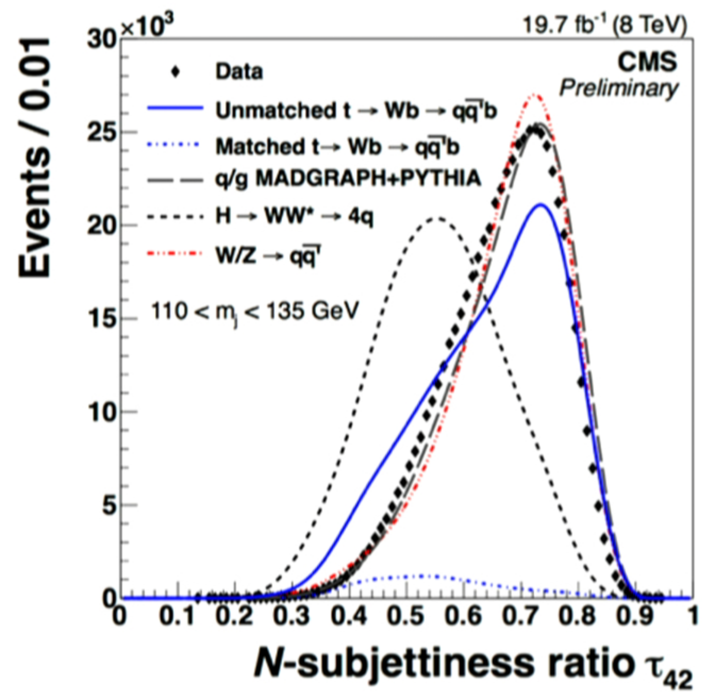
Run 1 Wrap-ups

Update (2:00 AM last night) : HV results public







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17 March 2015

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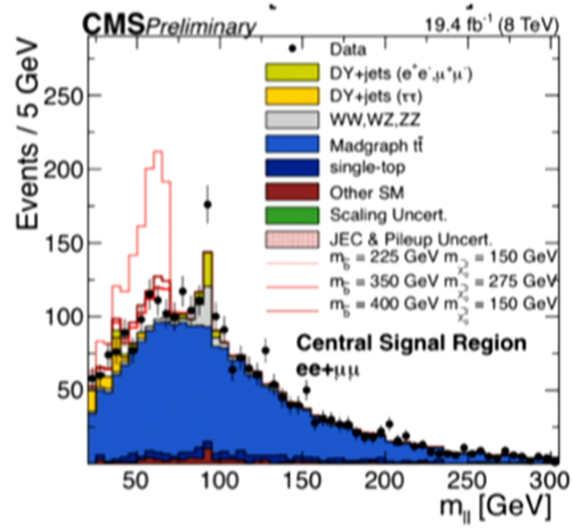
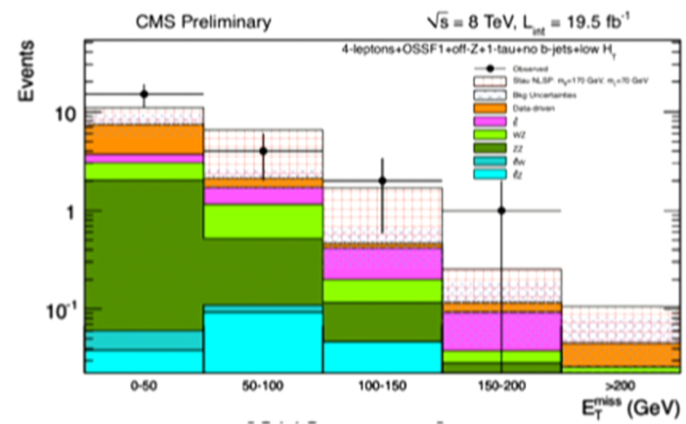
- A few other small excesses :
- SUSY-12-019
  - “The Edge”
  - OS dileptons +
    - >=2 jets + MET > 150 GeV
    - >=3 jets + MET > 100 GeV
- SUS-13-002
  - 4 leps, 1 tau, off-Z-peak, no b-jets, HT < 200 GeV
- EXO-12-041, EXO-13-008
  - eejj only (no mumujj)
  - Very little overlap between the two selections, yet small excesses in each





17 March 2015

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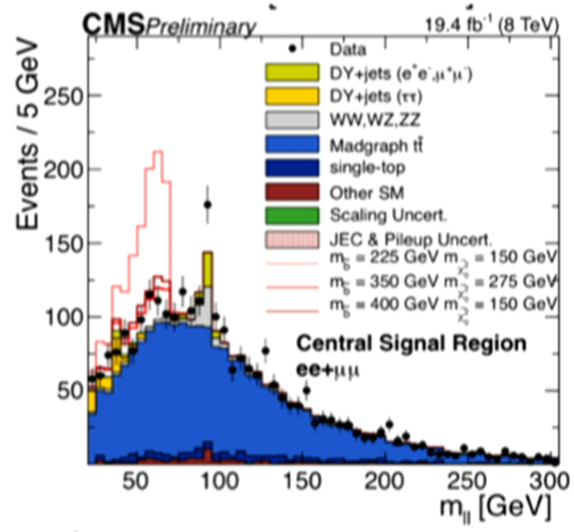

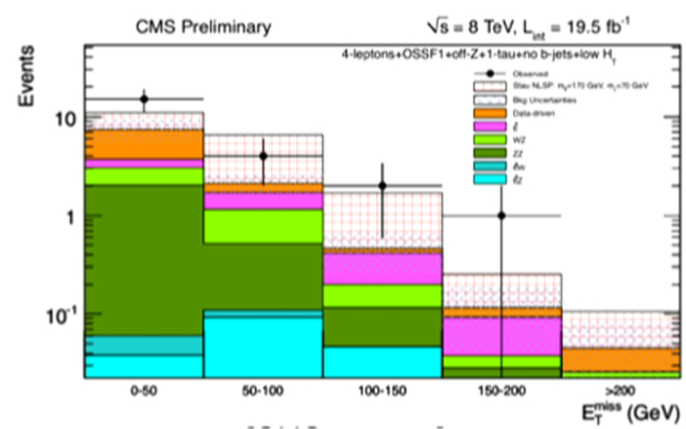

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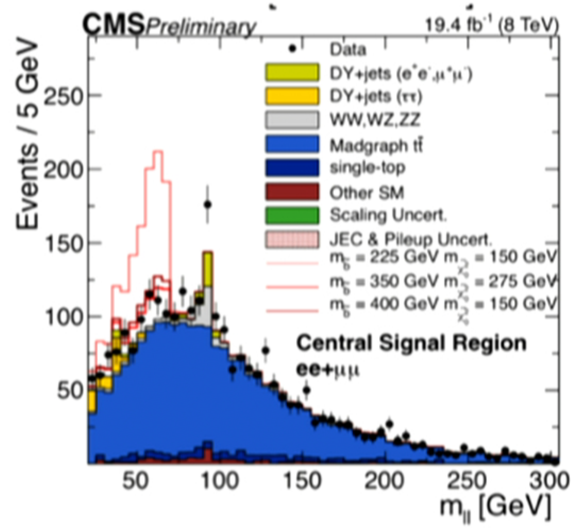
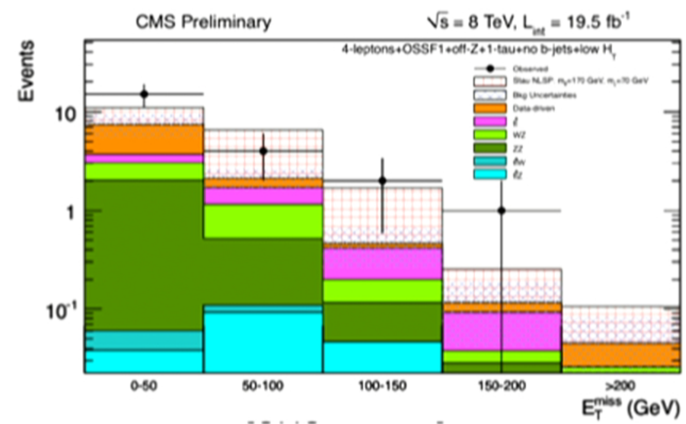




17 March 2015

Run 2 Startup

- V/H taggers
  - Startup :
    - Soft drop + nsubjettiness (pruning will remain as a cross-check too)
    - For H : +subjet b-tagging

- Top Taggers
  - Startup :
    - CMS "combined" tagger (JHU +nsubjettiness+subjet b-tagging)
    - HEP tagger+subjet b-tagging

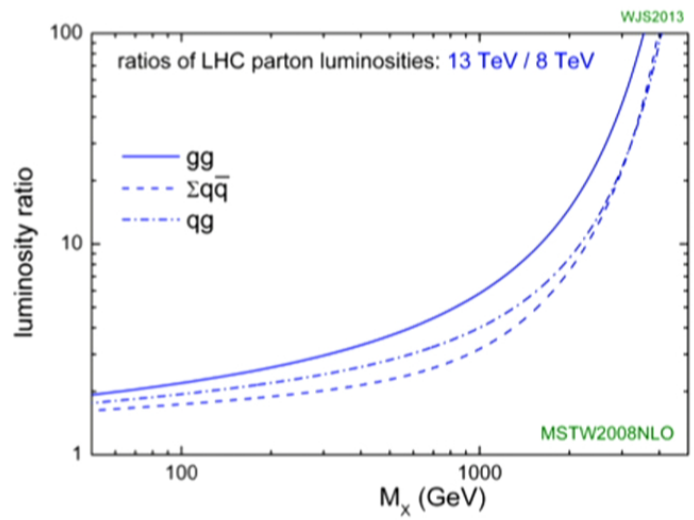
- Under development :
  - Multi-R top-tagger
  - Shower deconstruction
  - Subjet QGL
  - MVAs

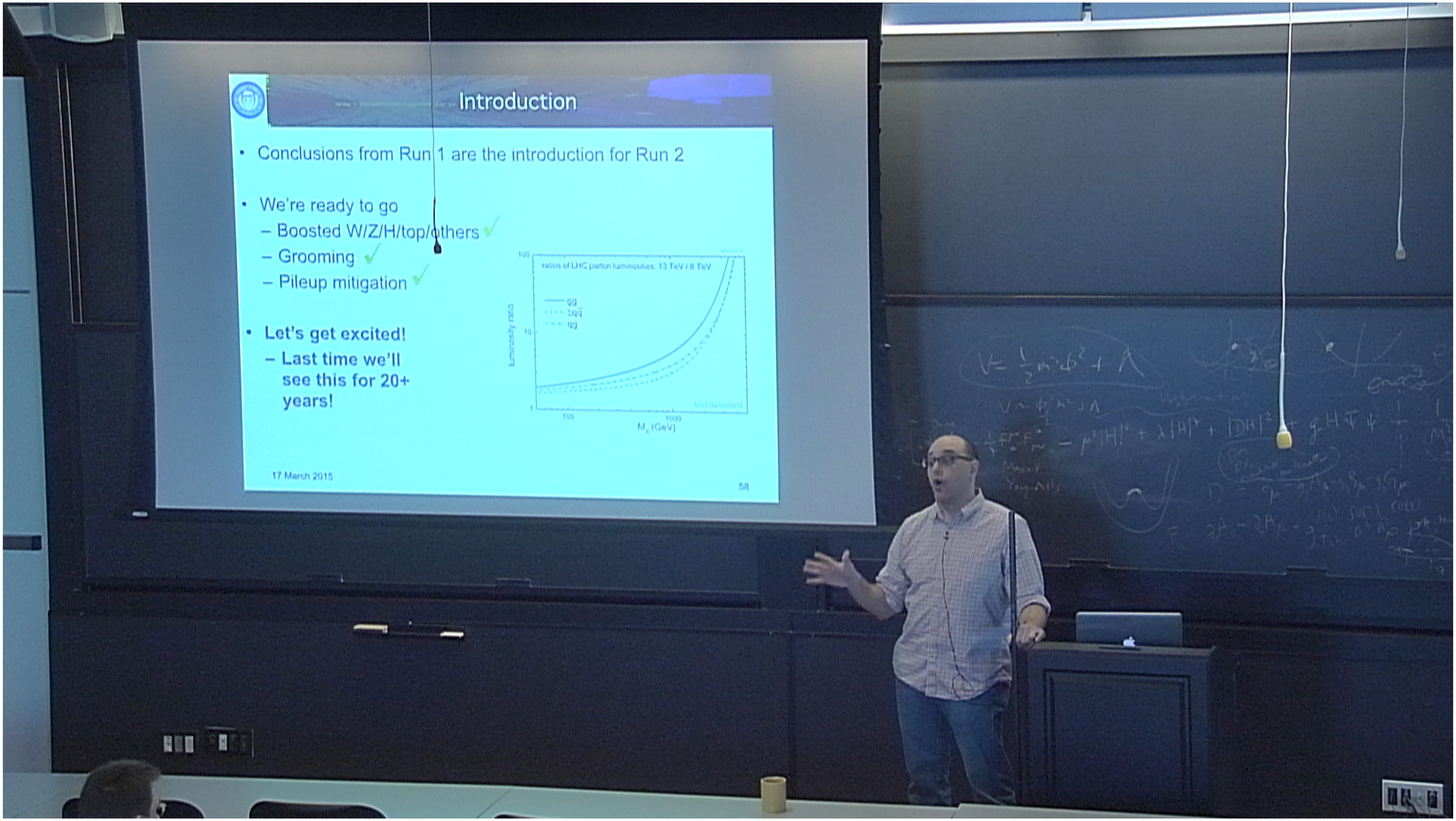
Introduction

- Conclusions from Run 1 are the introduction for Run 2

- We're ready to go
  - Boosted W/Z/H/top/others ✓
  - Grooming ✓
  - Pileup mitigation ✓

- **Let's get excited!**
  - **Last time we'll see this for 20+ years!**

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ratios of LHC parton luminosities: 13 TeV / 8 TeV
luminosity ratio
17 March 2015
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