

Jets at LHC in the presence of 2011 and 2012 pile-up



BOOST 2013

Salvatore Rappoccio
(State University of New York at Buffalo)

12 Aug 2013



Caveat



- This is intended as a “teaser” for the rest of the week’s talks related to pileup
- There is a plethora of quantitative information coming your way, this will only “guide the eye”



Bibliography

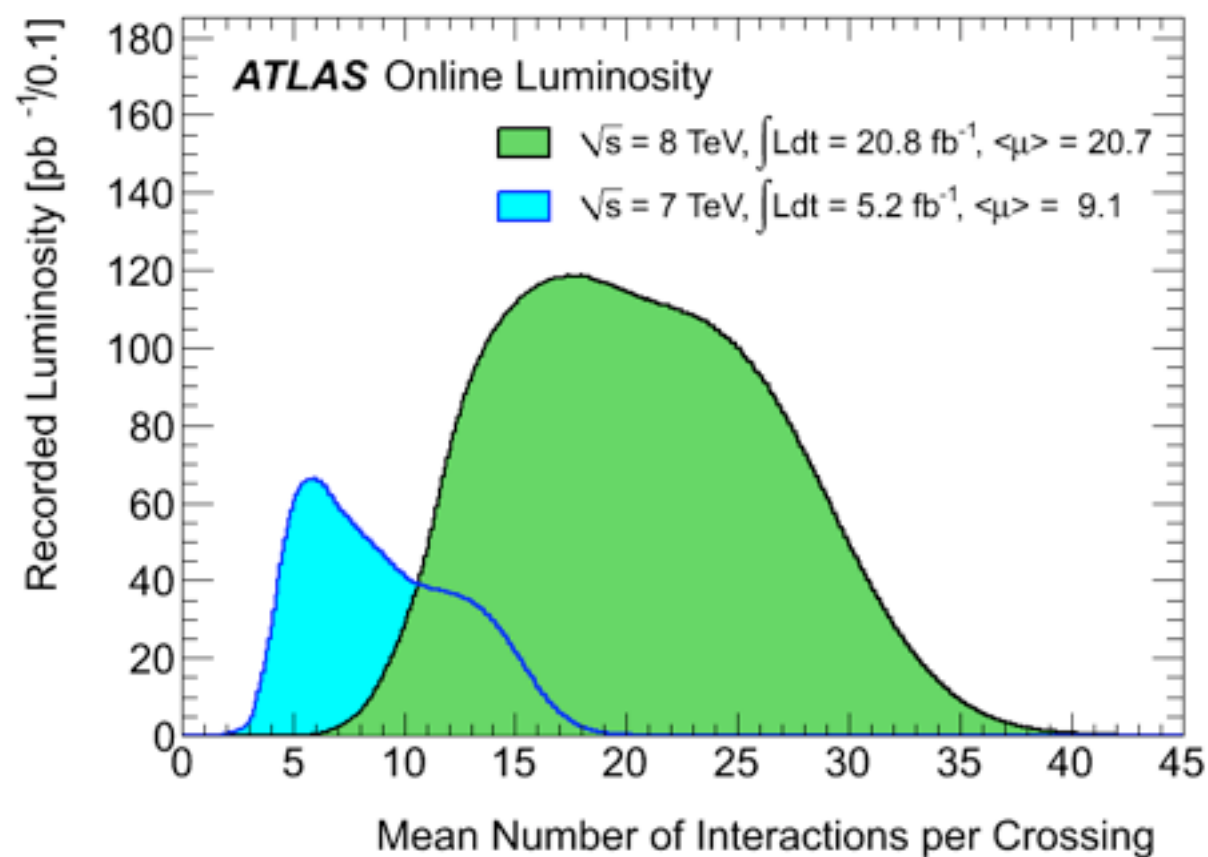
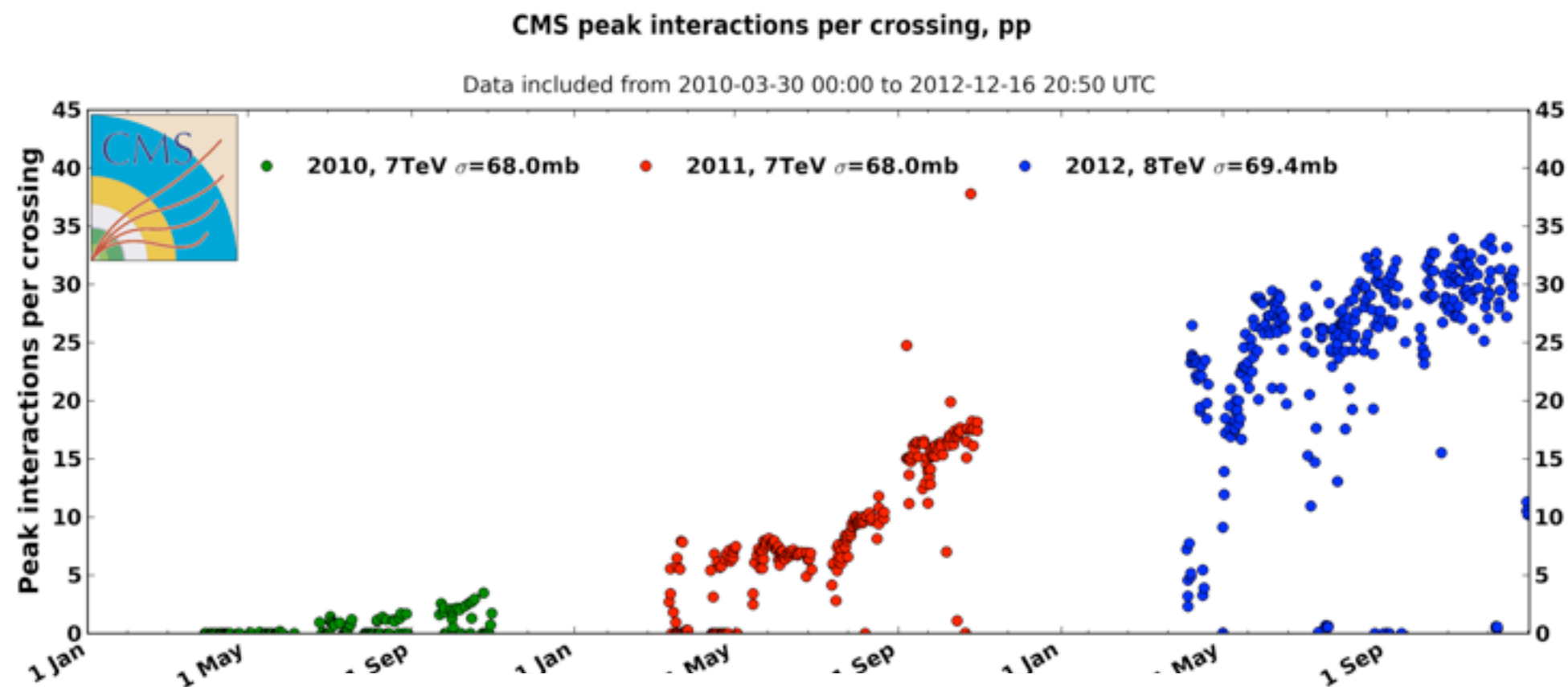


- <http://inspirehep.net/record/1202489>
- <http://inspirehep.net/record/1224539>
- <http://inspirehep.net/record/1239348>
- <http://inspirehep.net/record/1192920>
- <http://inspirehep.net/record/919443>
- <http://inspirehep.net/record/1202489>
- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetEtmisApproved2011PileupOffsetAndJVF>
- <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME2013JEC>
- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetEtmisApproved2013JESUncertainty>
- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TileCaloPublicResults>
- <https://twiki.cern.ch/twiki/bin/view/CMS/HcalDPGApprovedResults>



Luminosity in Run 1

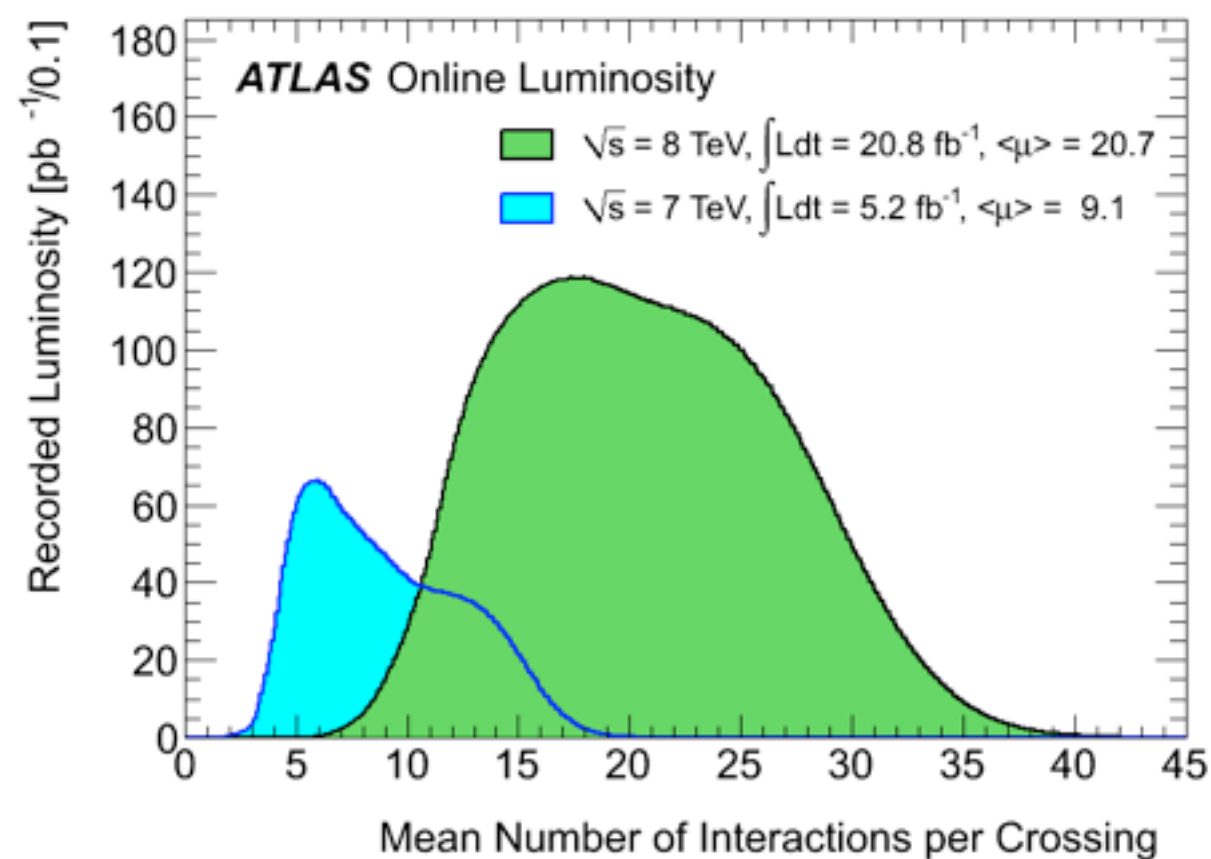
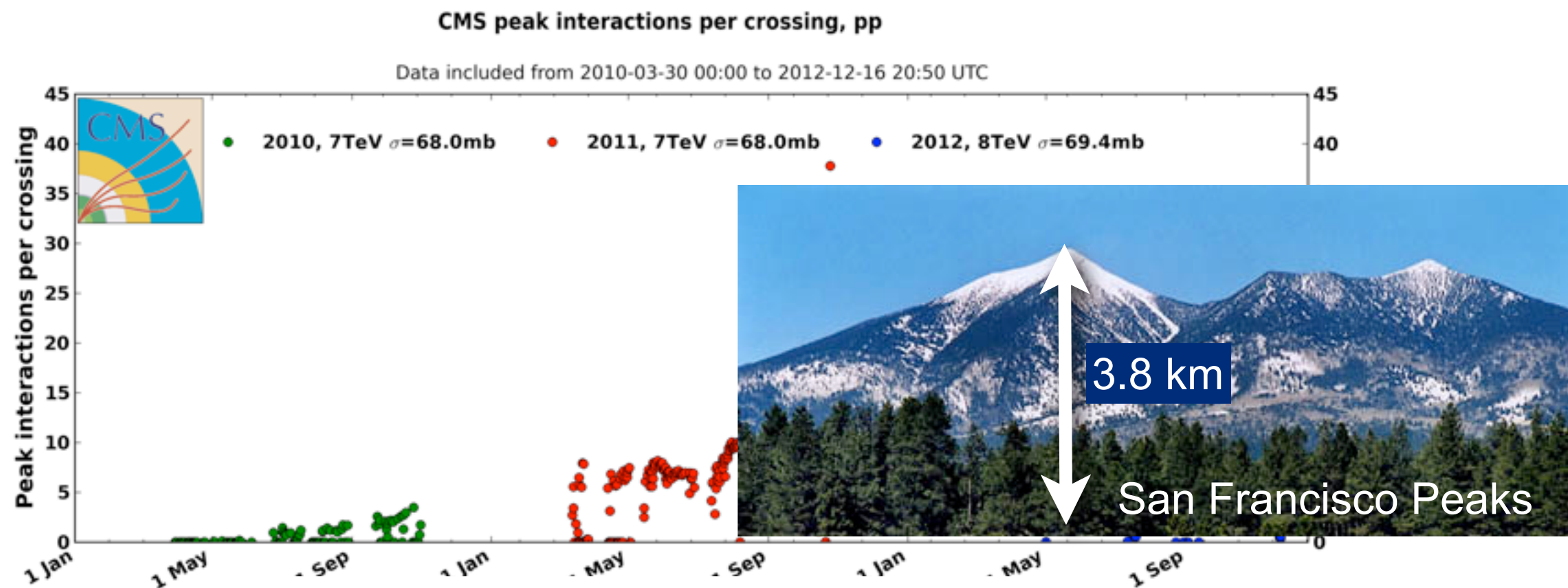
August 12-16
BOOST 2013





Luminosity in Run 1

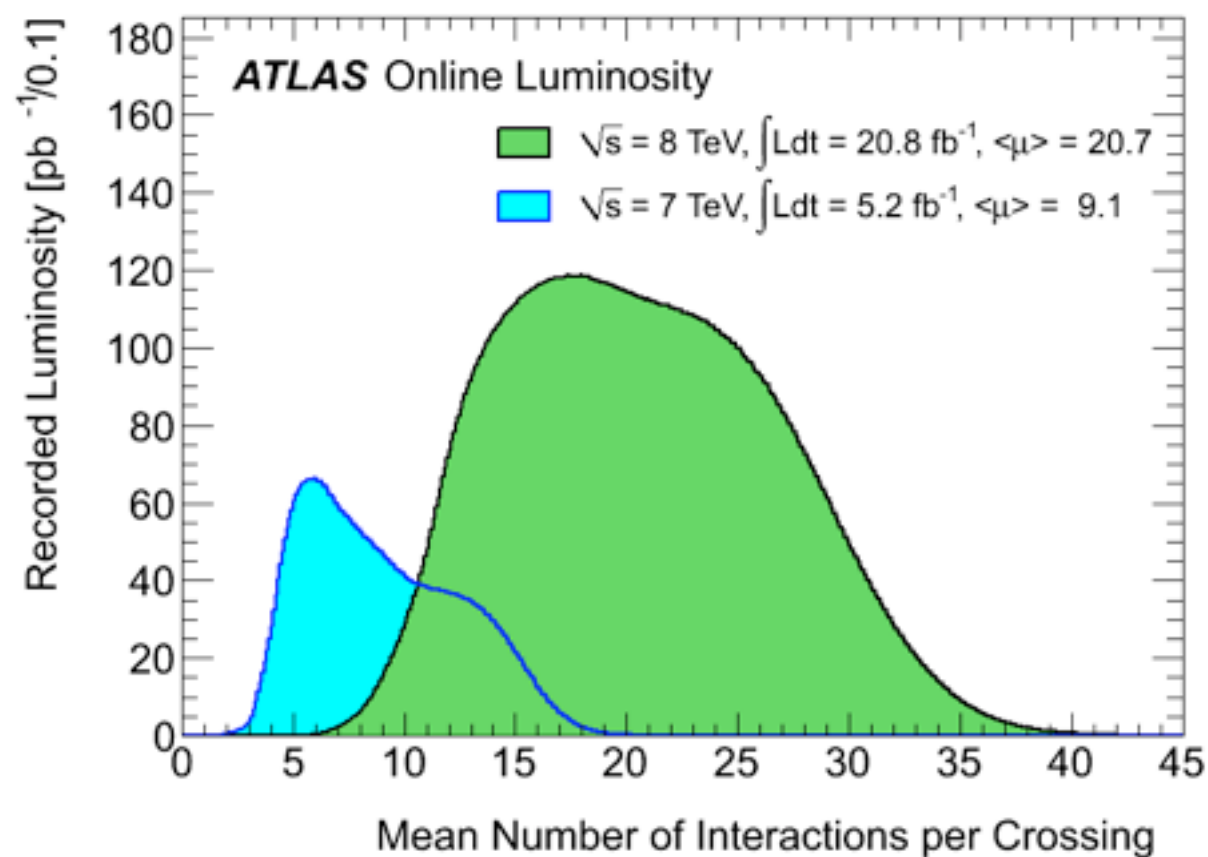
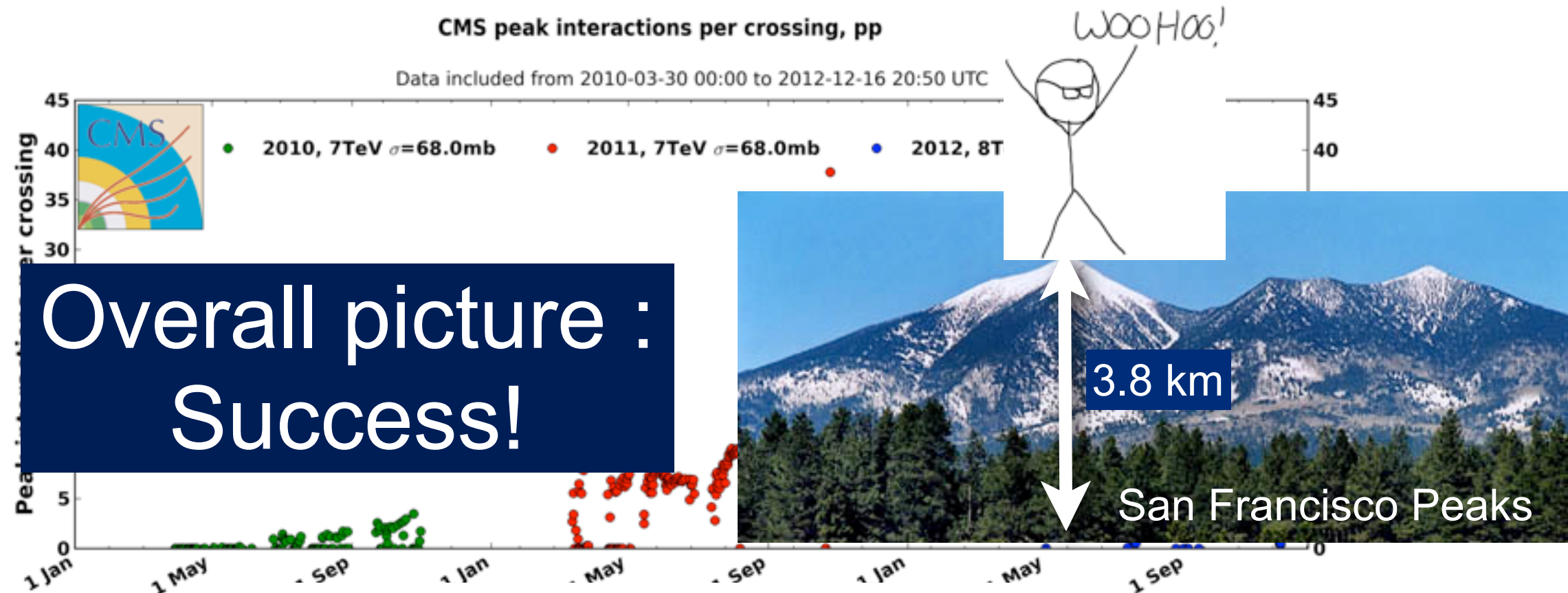
August 12-16
BOOST 2013





Luminosity in Run 1

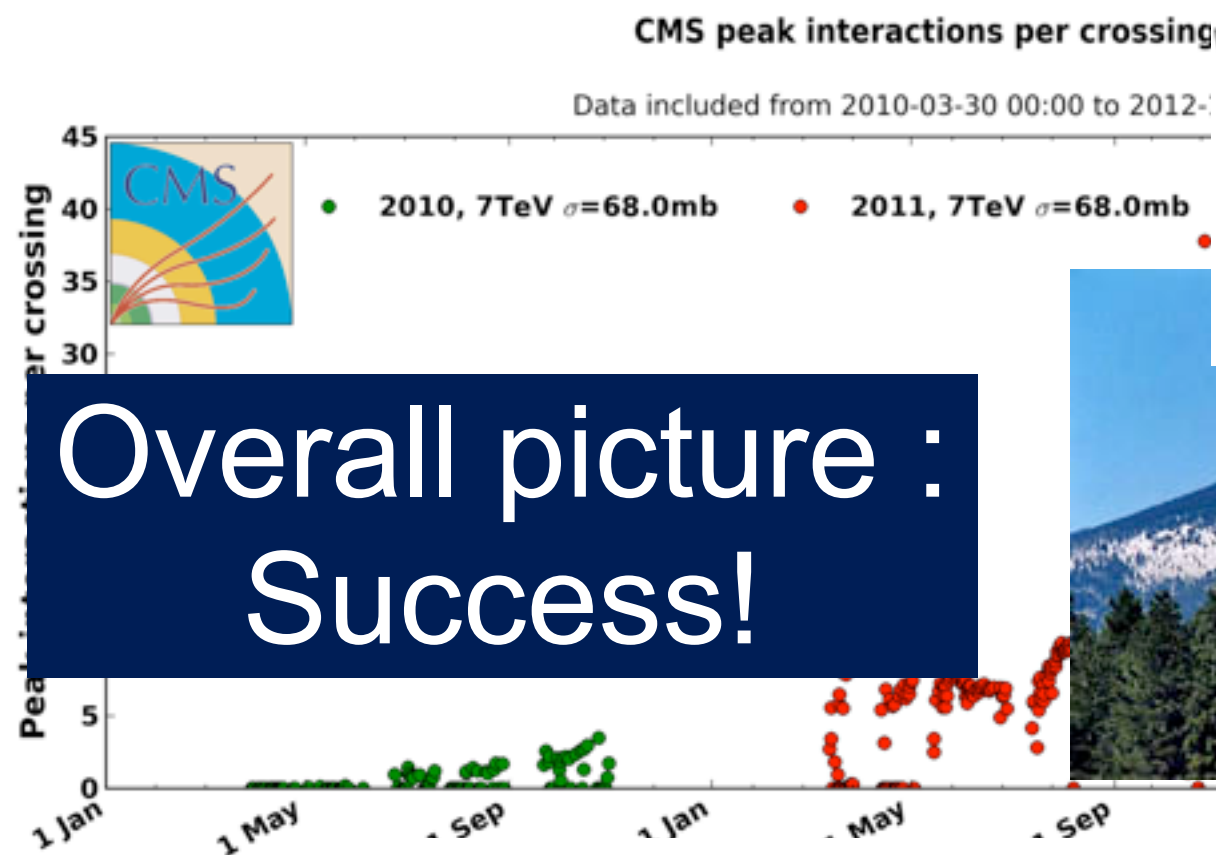
August 12-16
BOOST 2013



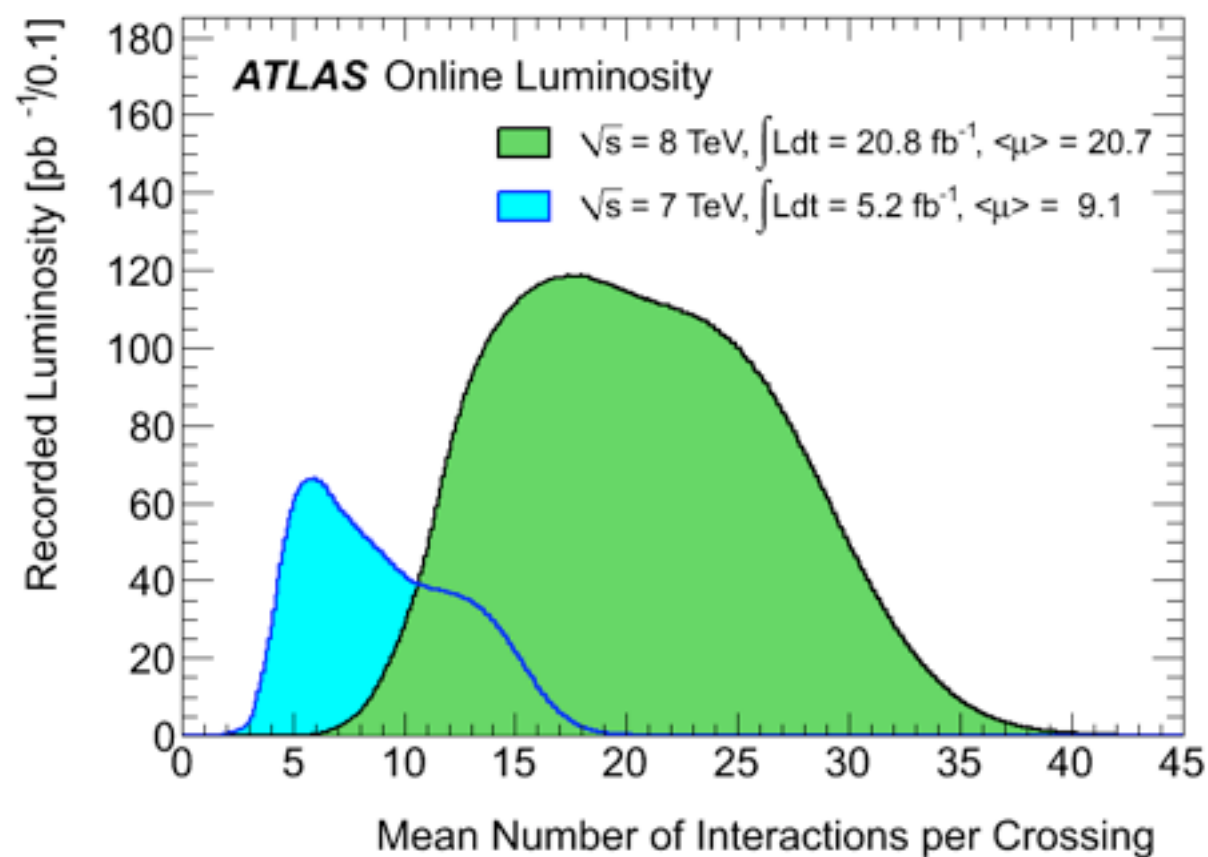


Luminosity in Run 1

August 12-16
BOOST 2013



(Apologies to
Randall Monroe)





Luminosity in Run 3

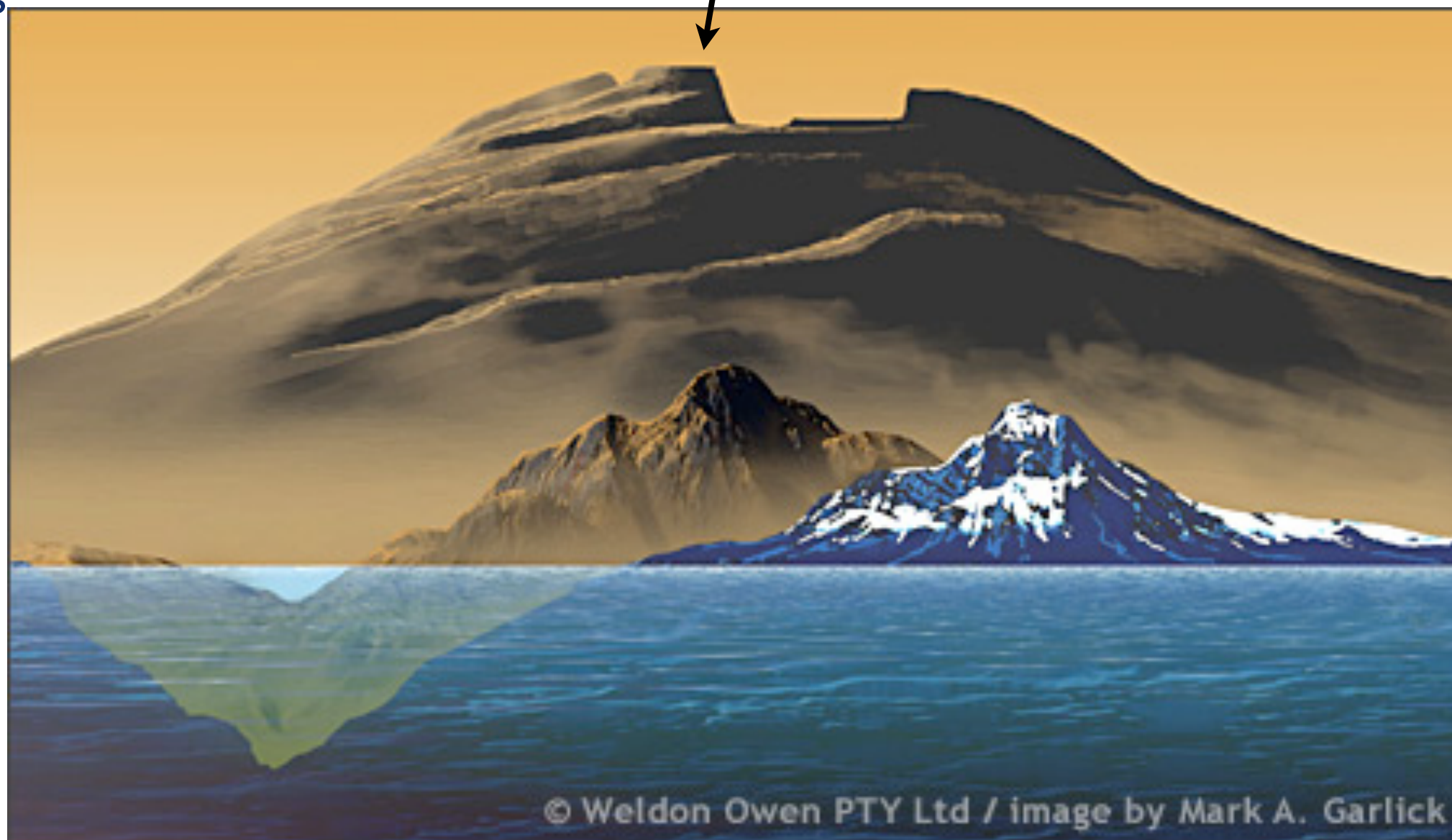
August 12-16
BOOST 2013

2012 Pileup

HL-LHC Pileup

Olympus Mons

San Francisco Peaks



Oh my.



12 Aug 2013

© Weldon Owen PTY Ltd / image by Mark A. Garlick



Luminosity in Run 3

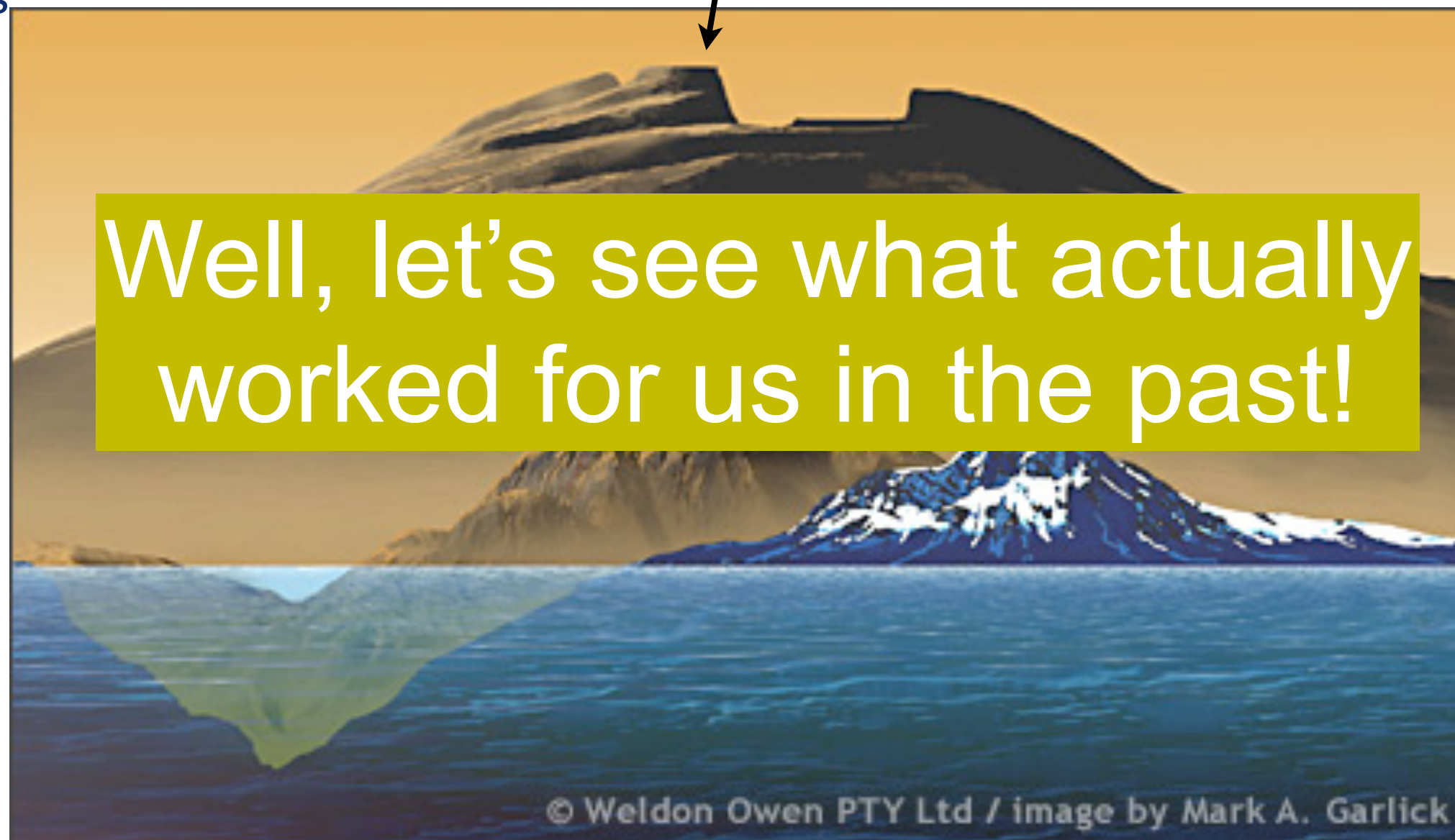
August 12-16
BOOST 2013

2012 Pileup

HL-LHC Pileup

Olympus Mons

San Francisco Peaks



12 Aug 2013



How did we manage?

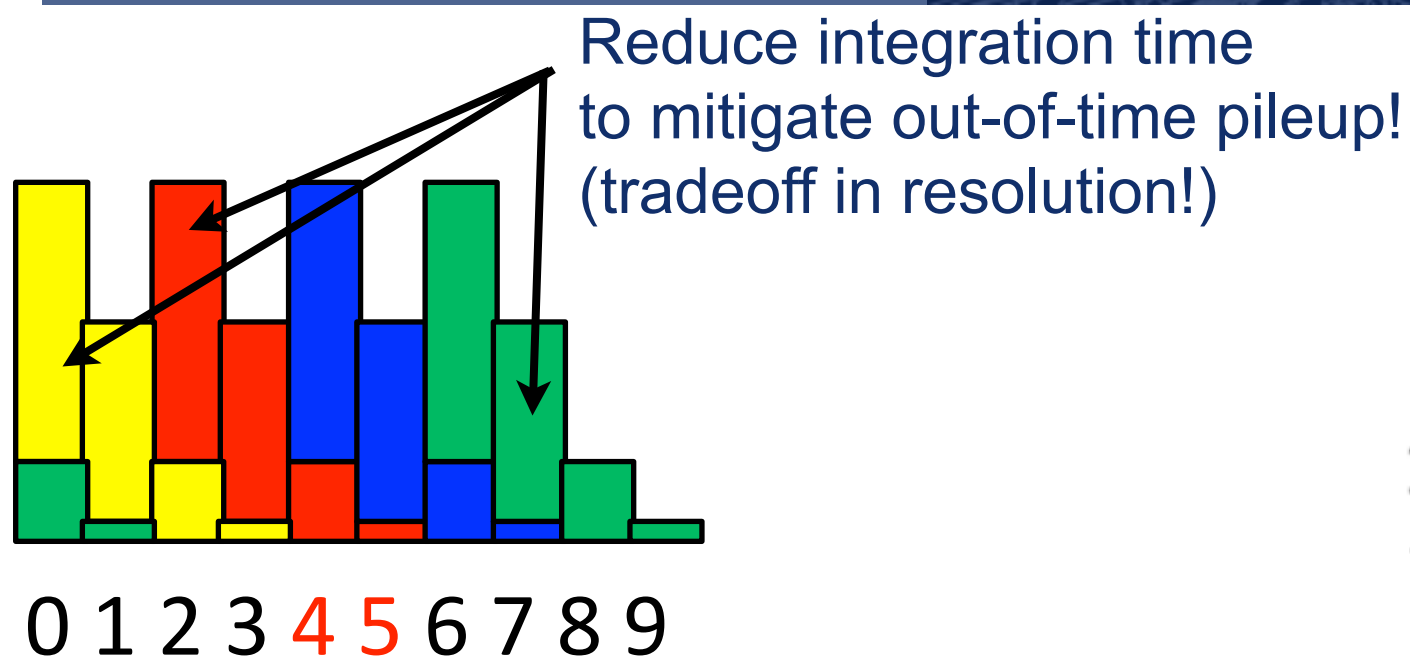
August 12-16
BOOST 2013

- Detector-level selections
- Jet areas
- Tracking information
- Jet shapes
- Grooming

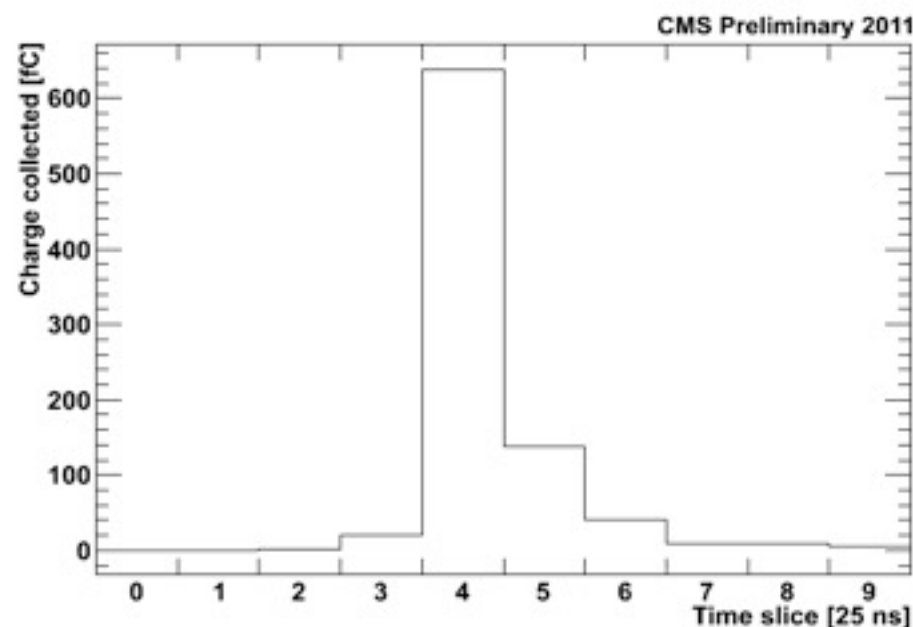


How did we manage? Detector Selections

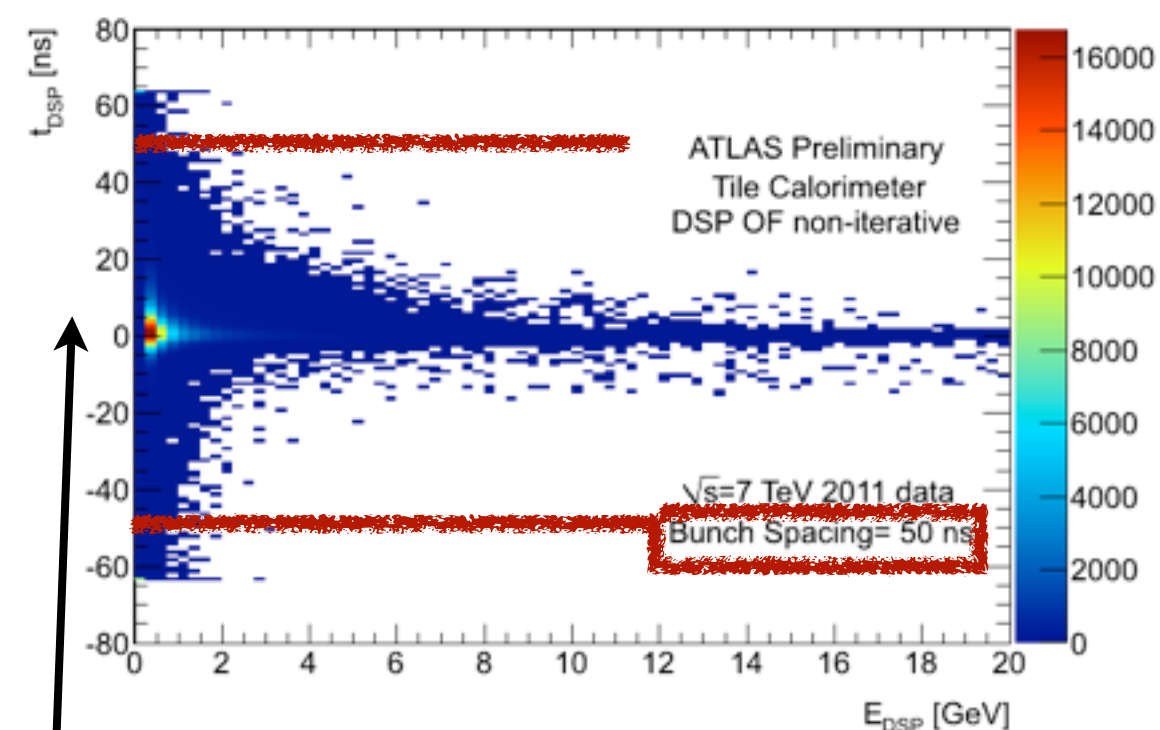
August 12-16
BOOST 2013



CMS HCAL Charge Collection
versus 25 ns “slice”



ATLAS timing vs energy



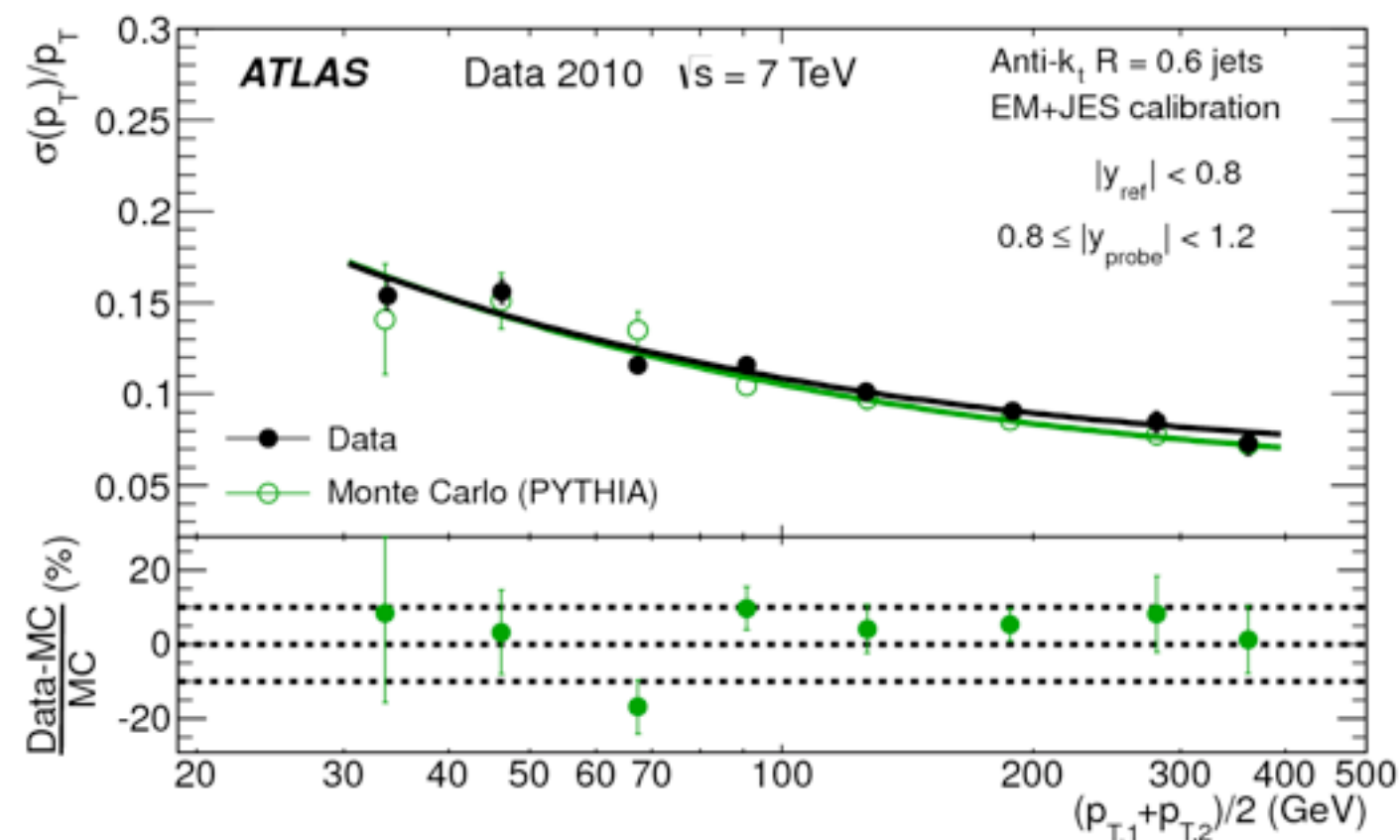
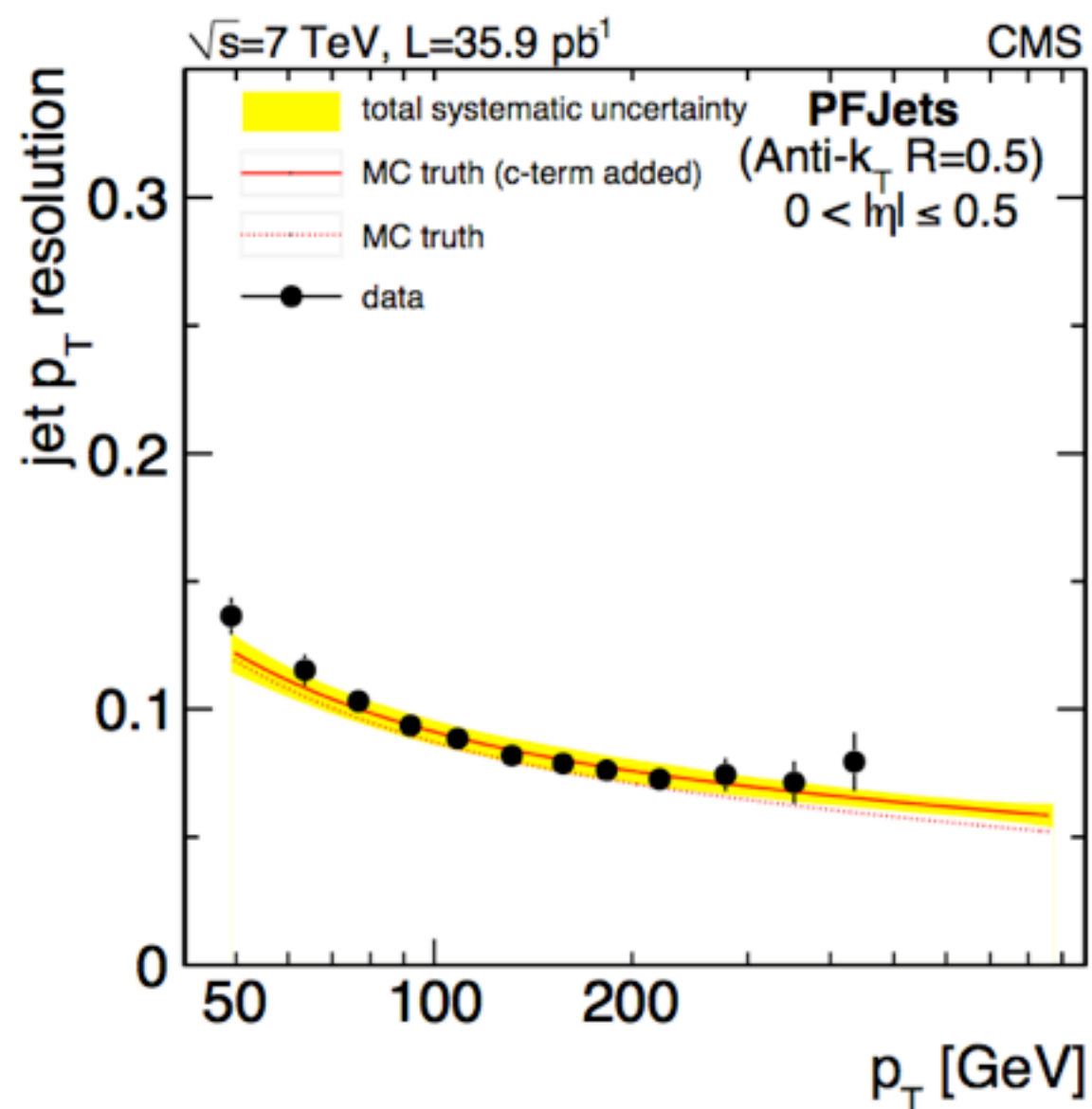
Separately read out channels with
different phase to reduce OOT pileup



Detector selections : Did it work?

August 12-16
BOOST 2013

- Detector resolutions for both ATLAS and CMS below 15% for low pileup, but degrades as you get more





How did we manage? Jet Areas

August 12-16
BOOST 2013

See talks from Jesse Thaler and Gavin Salam!

Information References (17) Citations (245) Files Plots

Pileup subtraction using jet areas

Matteo Cacciari, Gavin P. Salam (Paris, LPTHE)

Jul 2007 - 10 pages

Phys.Lett. B659 (2008) 119-126
DOI: [10.1016/j.physletb.2007.09.077](https://doi.org/10.1016/j.physletb.2007.09.077)
LPTHE-07-01
e-Print: [arXiv:0707.1378](https://arxiv.org/abs/hep-ph/0707.1378) [hep-ph] | [PDF](#)

Abstract: One of the major challenges for the LHC will be to extract precise information from hadronic final states in the presence of the large number of pileup, that occur simultaneously with any hard interaction. We propose a novel technique, based on jet areas, that can be used with any jet algorithm for which a jet area can be defined. It is data driven, does not require any model for the pileup, and is effective for all processes. We test its effectiveness for some key processes and find that it works well for the Tevatron, low-luminosity LHC and LHC heavy-ion collisions.

Keyword(s): INSPIRE: [p.p. inclusive reaction](#) | [jet](#) | [hadronic interaction](#) | [momentum correction](#) | [luminosity high](#) | [background](#) | [Z boson production](#) | [top mass](#) | [W boson](#) | [inclusive reaction](#) | [top pair production](#) | [W mass](#) | [scattering heavy ion](#) | [numerical calculations](#) | 1960-14000 GeV-cms 5500 GeV-cms/nucleon

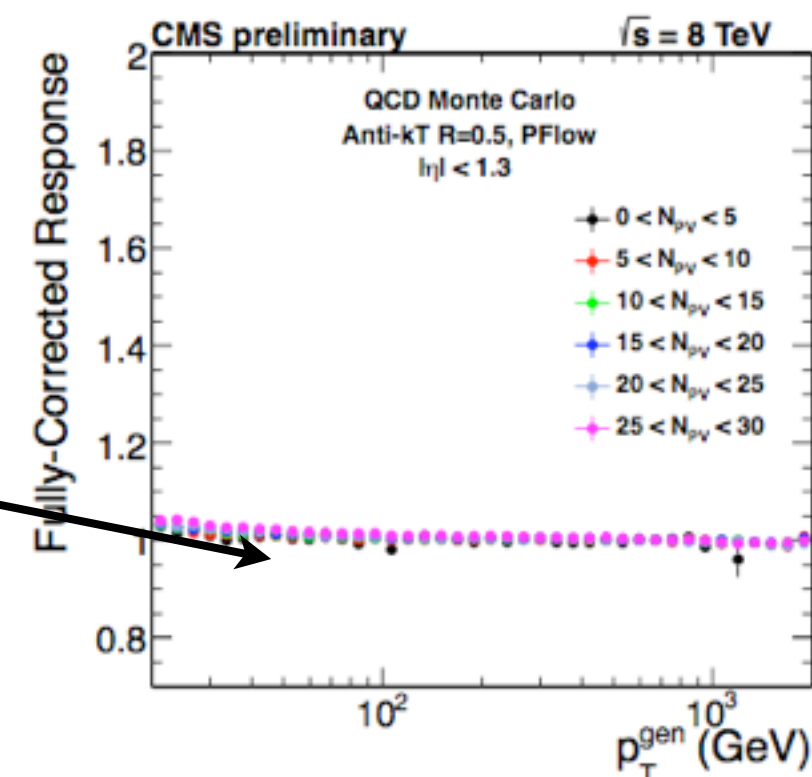
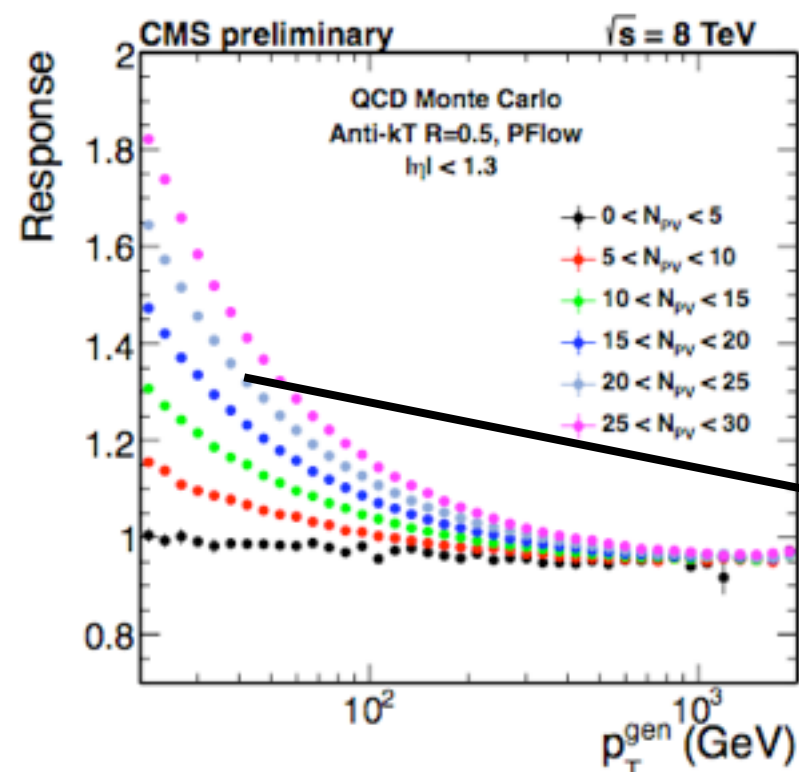
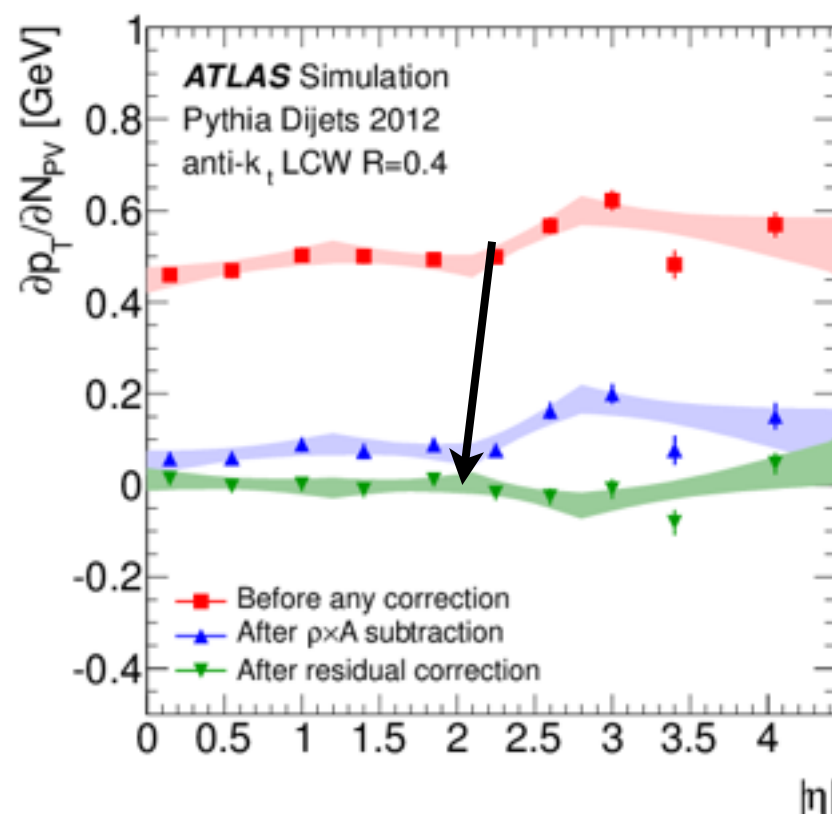
Record created 2007-07-10, last modified 2013-07-03

The critical bit is here :

$$\Delta p_t = A\rho \pm \sigma\sqrt{A} - L, \quad \langle L \rangle = \mathcal{O}\left(\alpha_s \cdot A\rho \ln \frac{p_t}{A\rho}\right)$$

Uncorrected Jets with PU

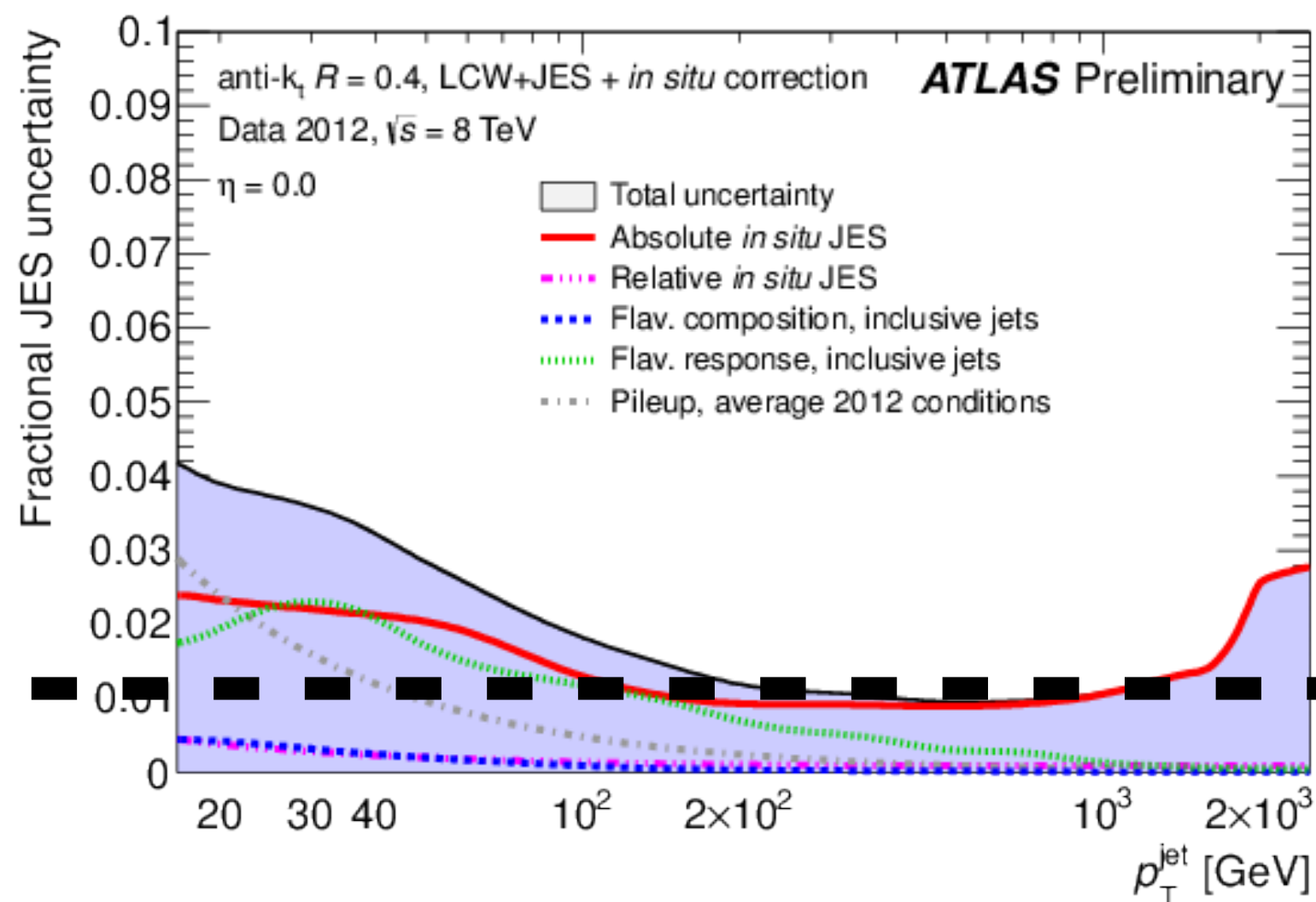
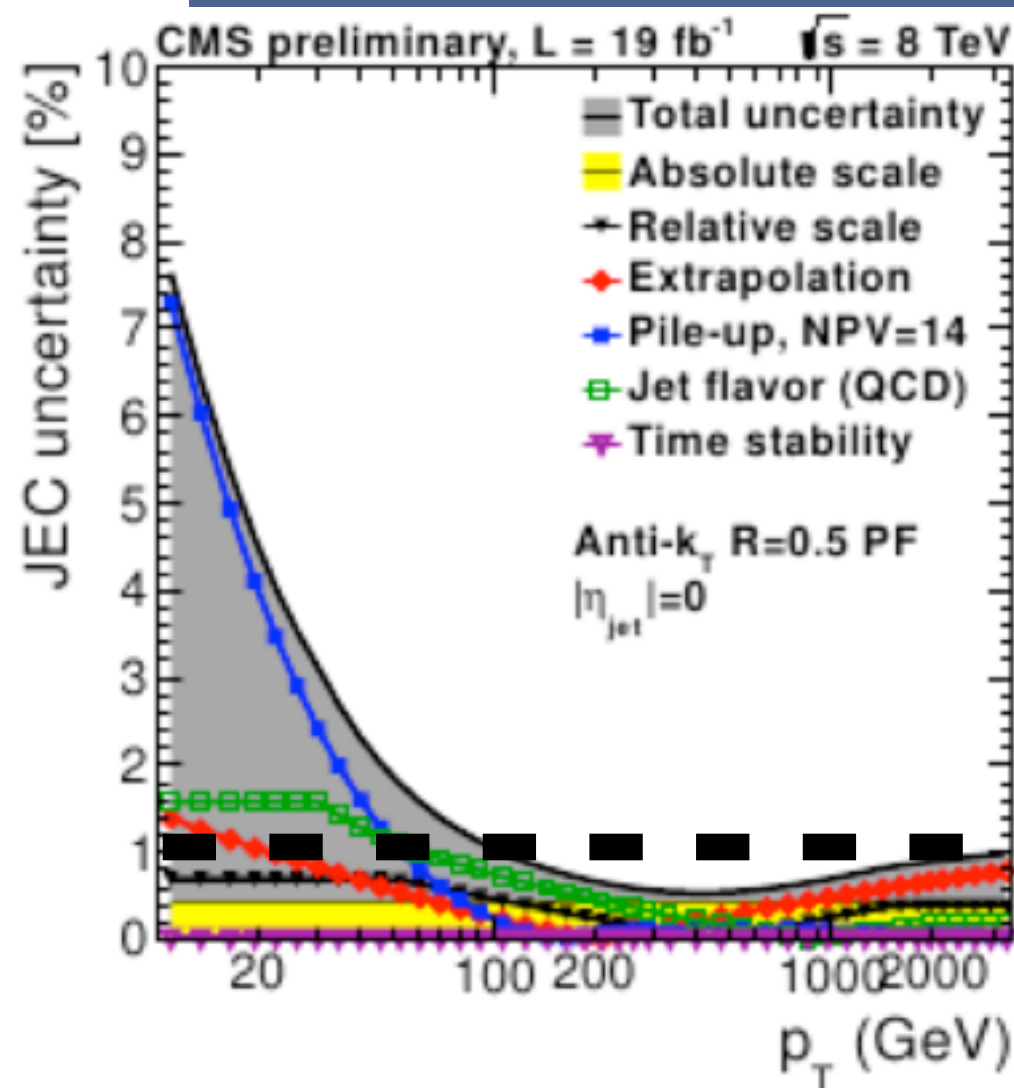
PU+MC truth corrected





Jet areas : Did it work?

August 12-16
BOOST 2013



- Correct jets with the rho*Area method
- Overall jet energy uncertainty reduced to 1% for $p_T > 100 \text{ GeV}$
- Pileup uncertainty subdominant for $p_T > 25 \text{ GeV}$!

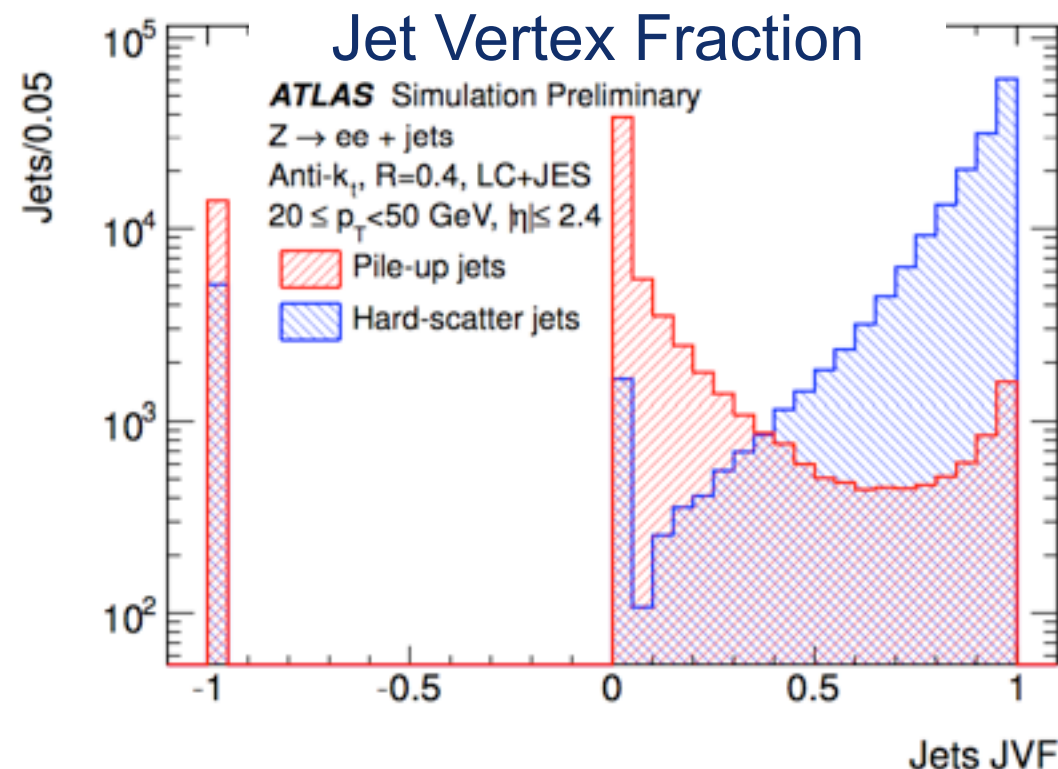
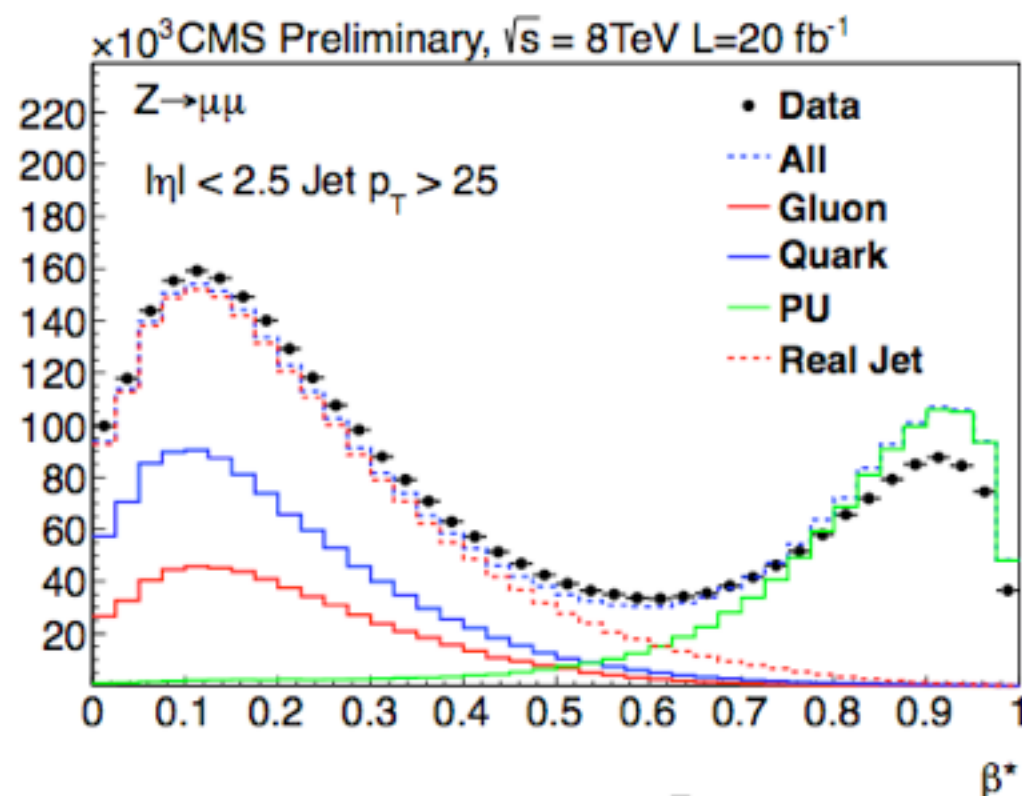


How did we manage? Tracking

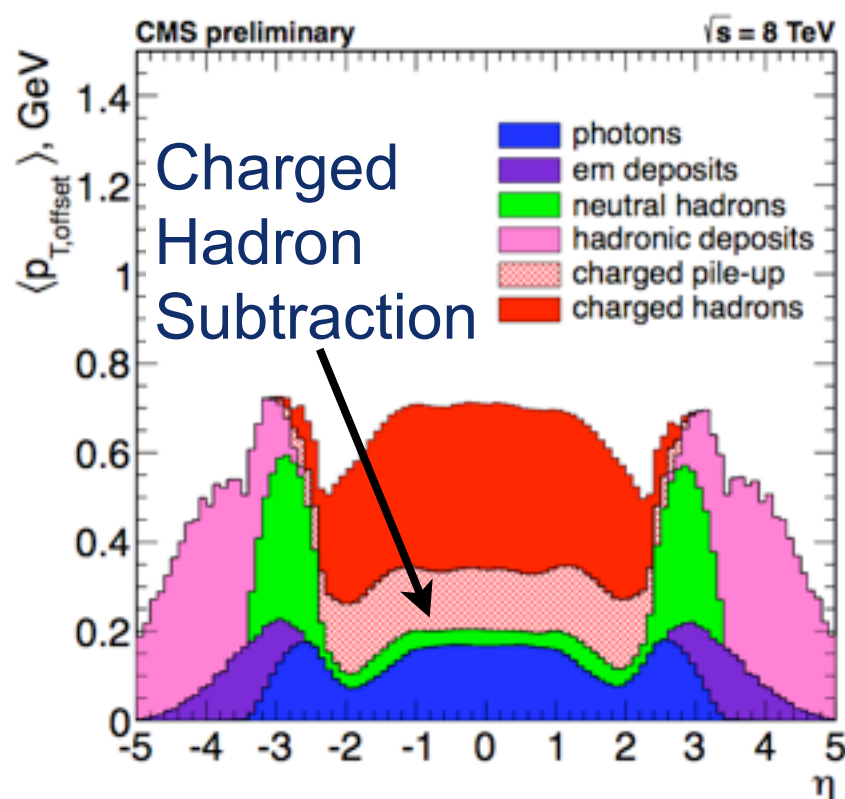
August 12-16
BOOST 2013

$$\beta^* = \frac{\sum_{i \in \text{other PV}} p_{Ti}}{\sum_i p_{Ti}}$$

Events



See talks by
Sven Menke,
Phil Harris,
Wouter
Waalewijn!



Tracks from
leading PV

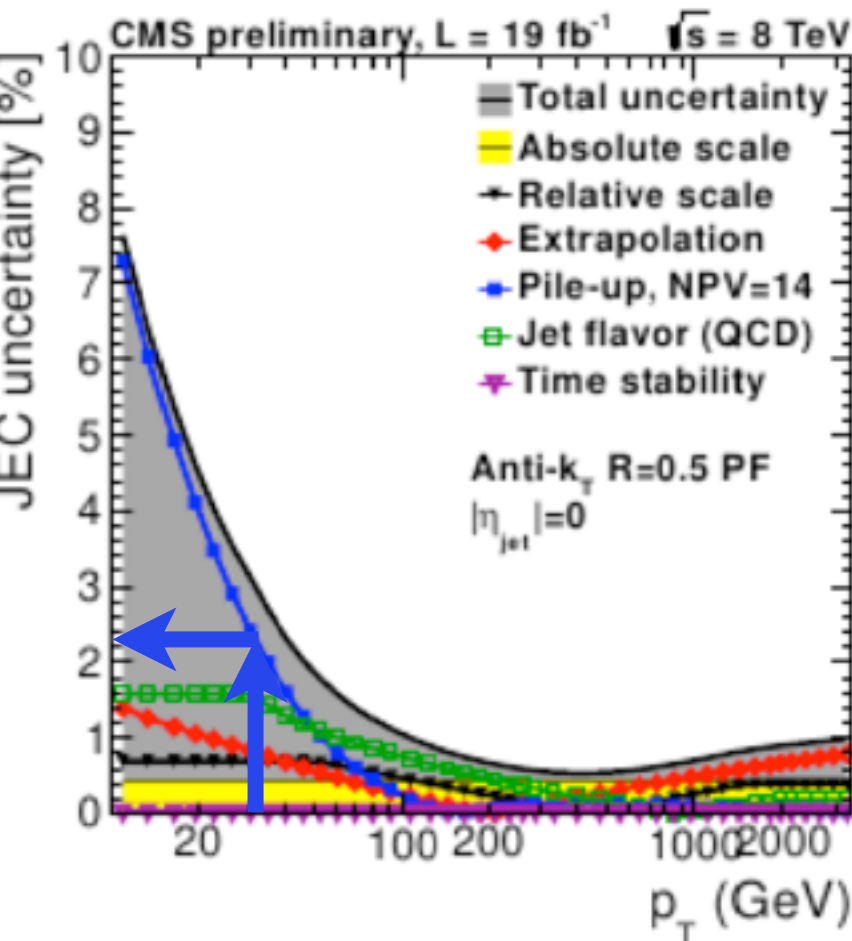
Tracks from
pileup



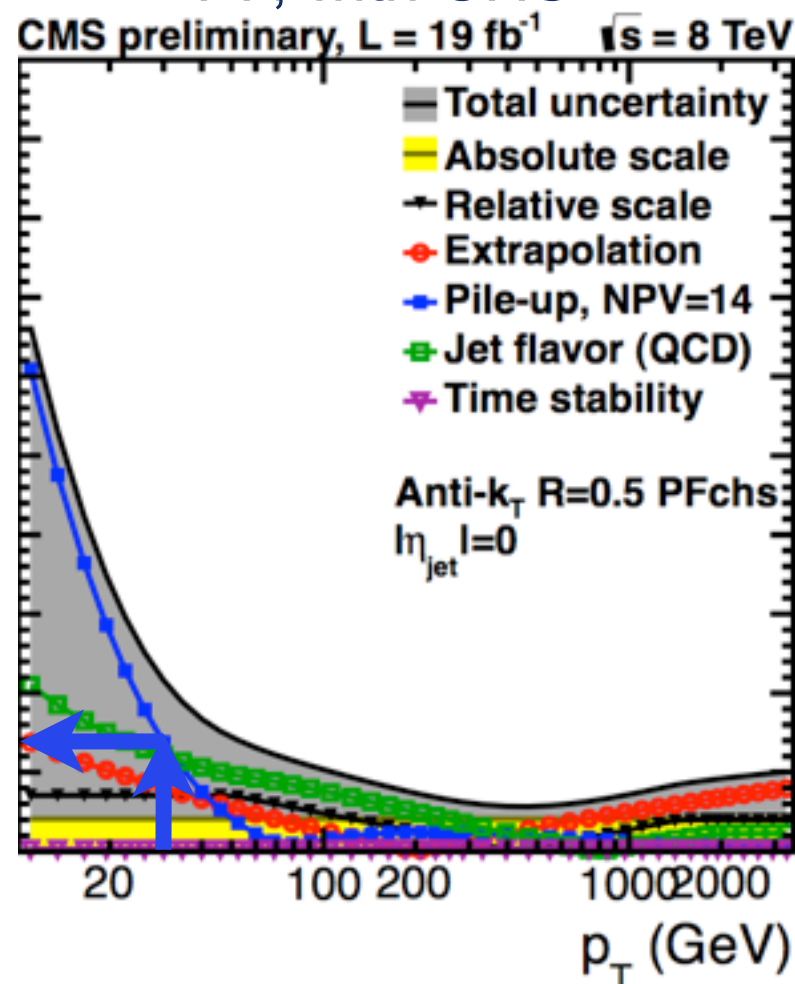
Tracking : Did it work?

August 12-16
BOOST 2013

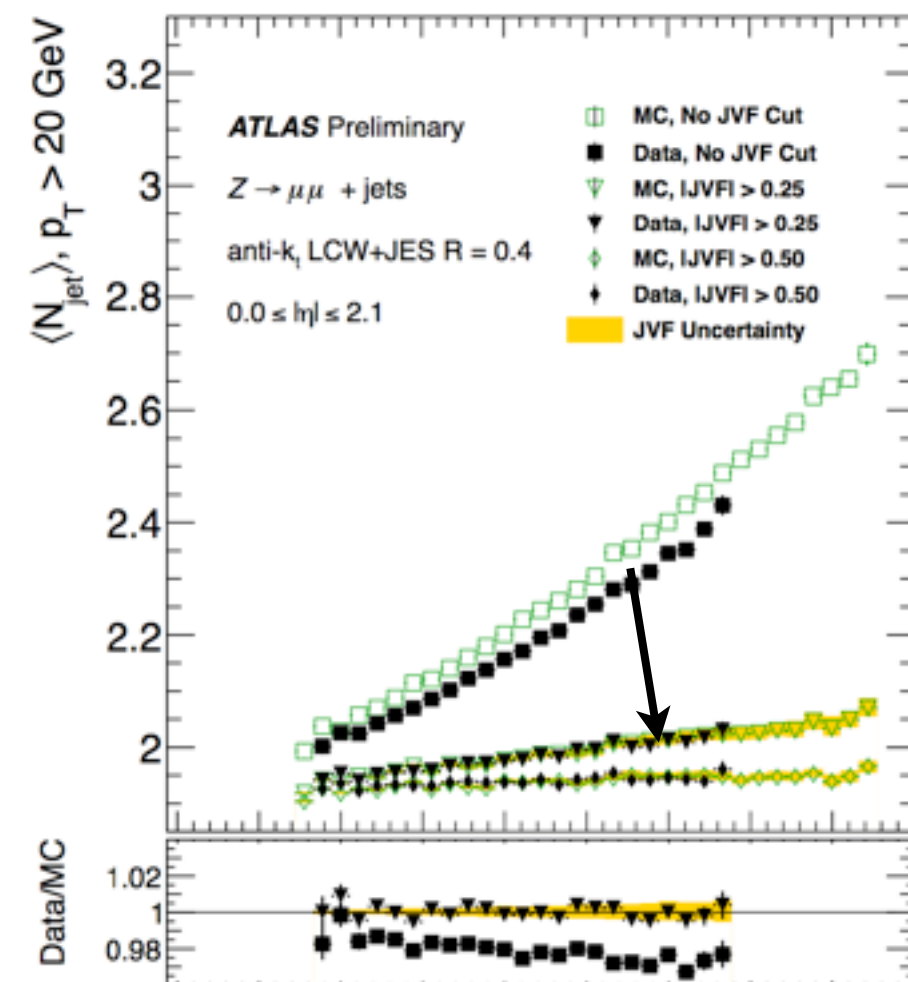
PF, no CHS



PF, with CHS



JVF

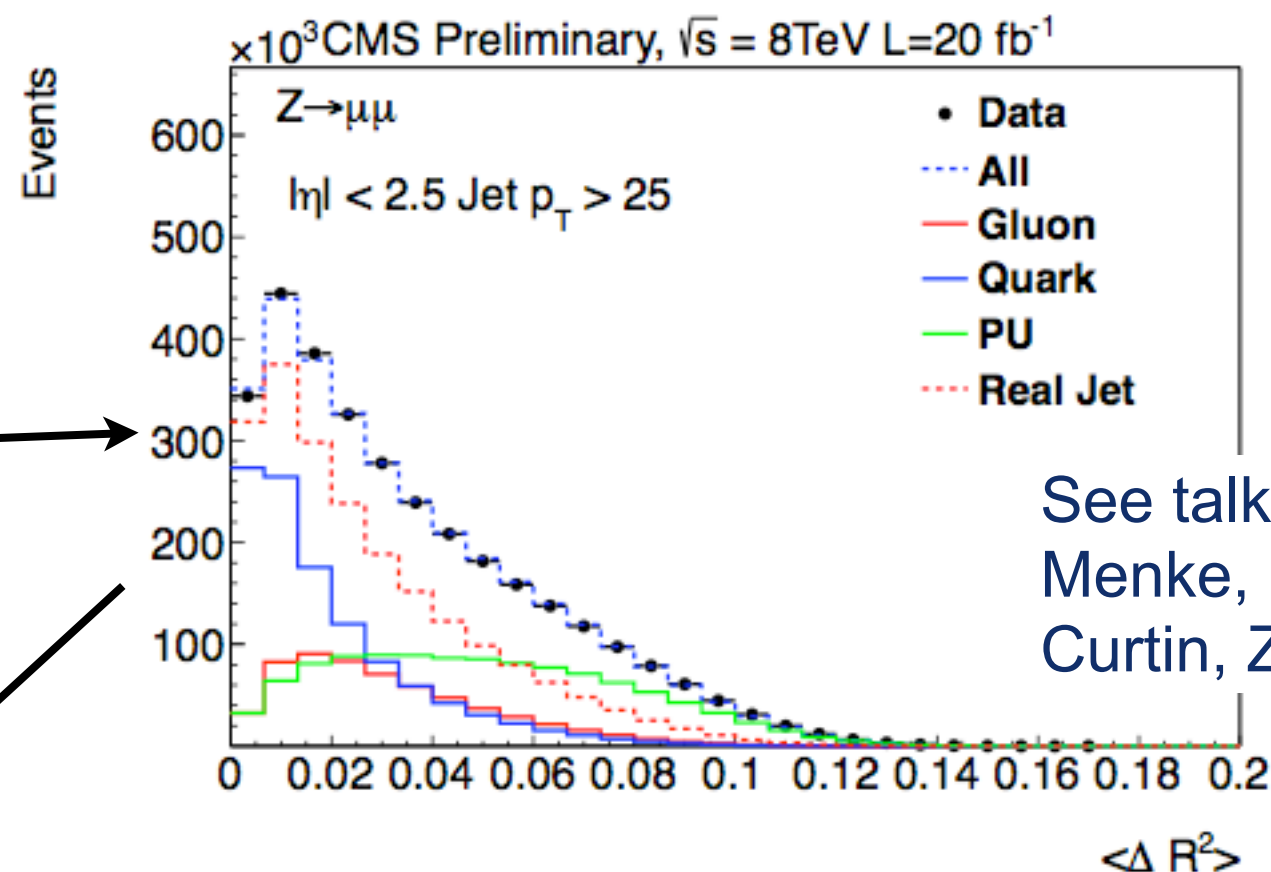
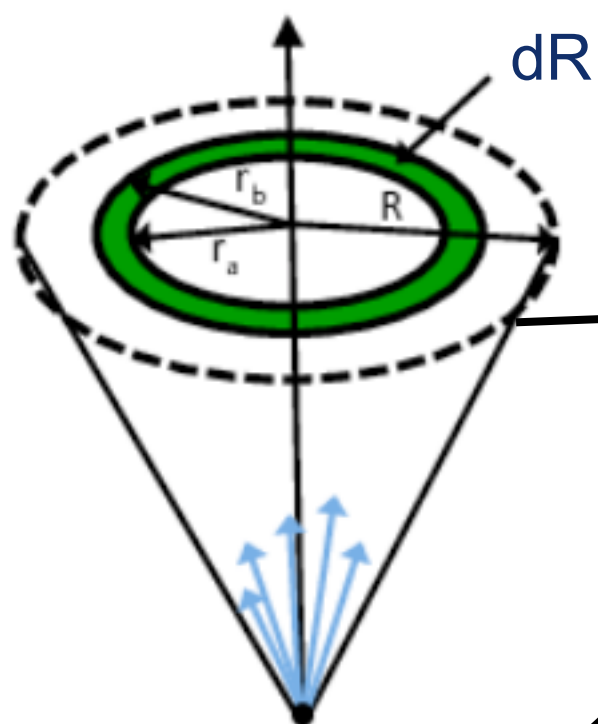




How did we manage? Shapes

August 12-16
BOOST 2013

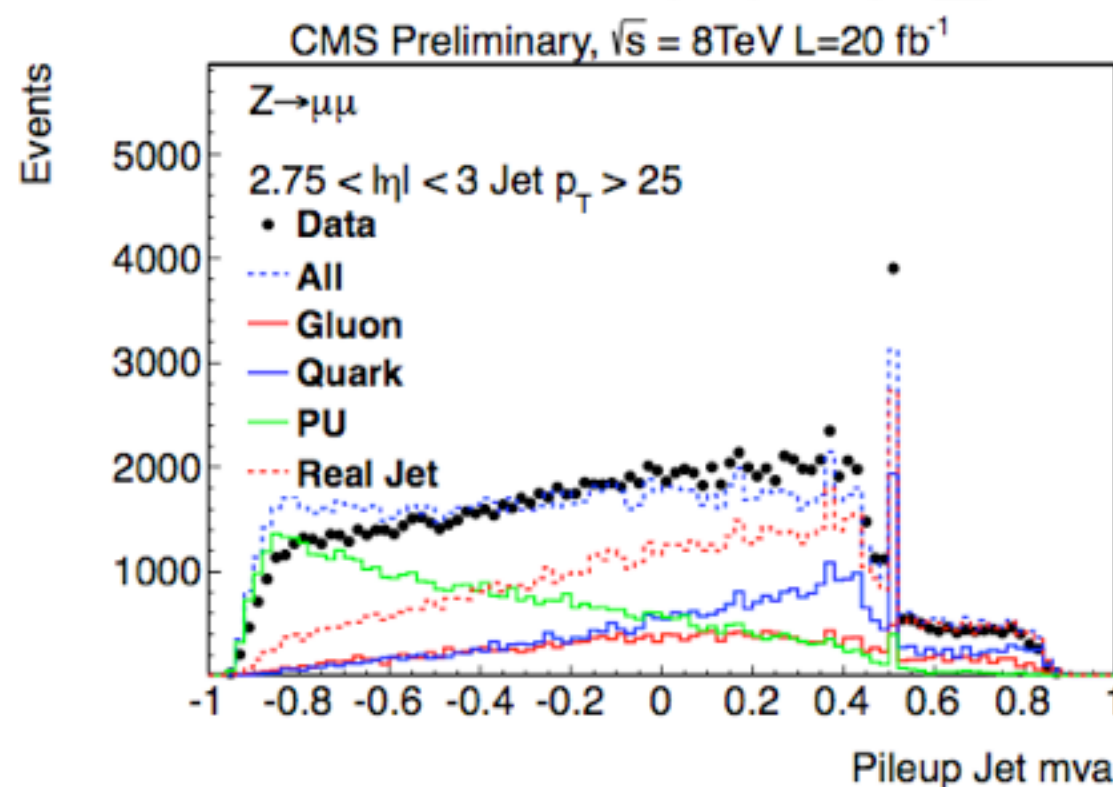
Use shape of jets vs
shape of PU



See talks by Sven
Menke, Phil Harris, David
Curtin, Zhenyu Han!

- $\langle \Delta R^2 \rangle$
- $p_T^A(\Delta R)$
- N_{charged}
- N_{neutrals}
- p_T^D

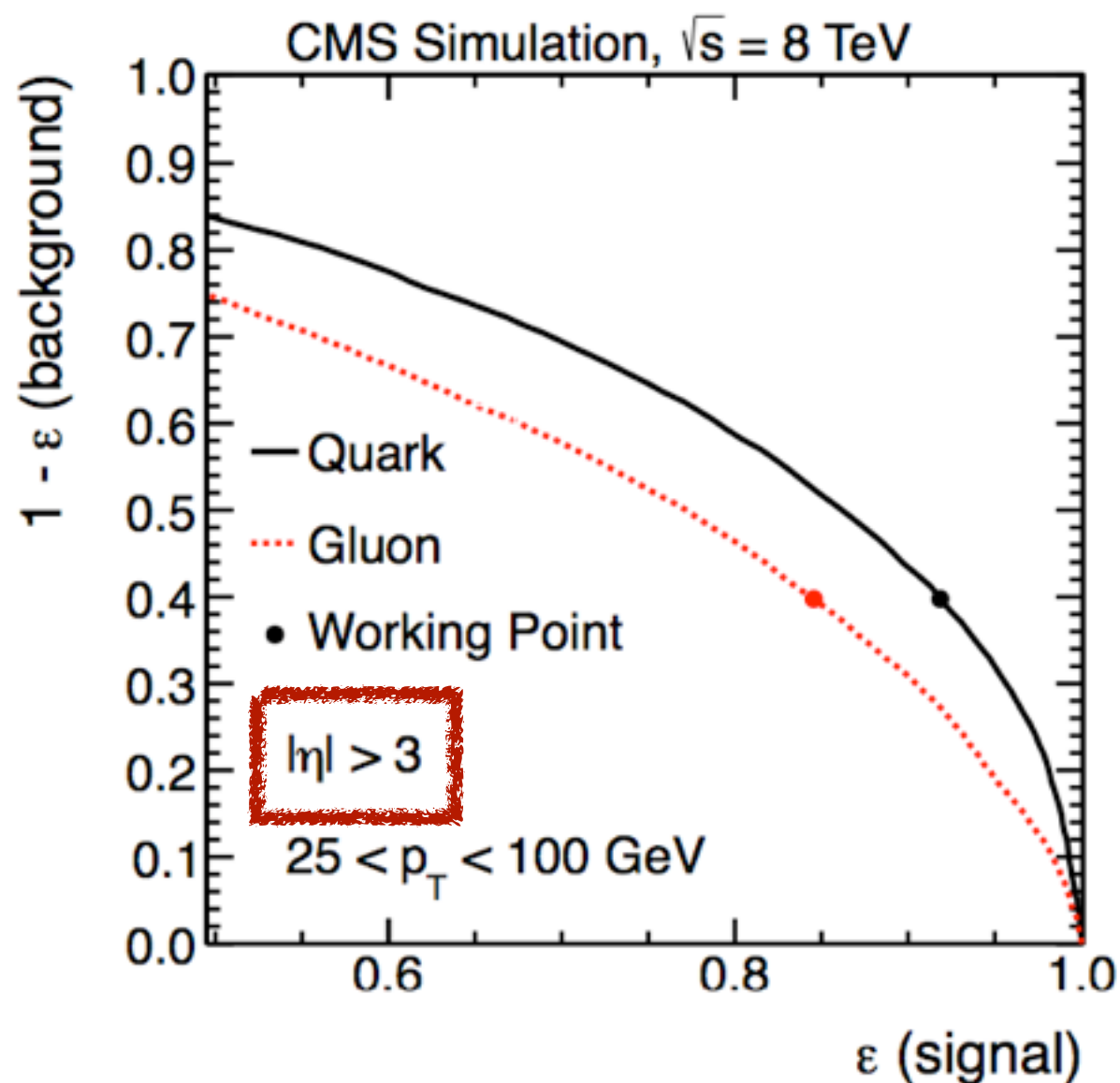
MVA





Shapes : Did it work?

August 12-16
BOOST 2013



- Can get mileage out of shapes to discriminate pileup jets even without tracking!
- Useful for forward jets!
 - VBF tagging
 - Was used in Higgs discovery



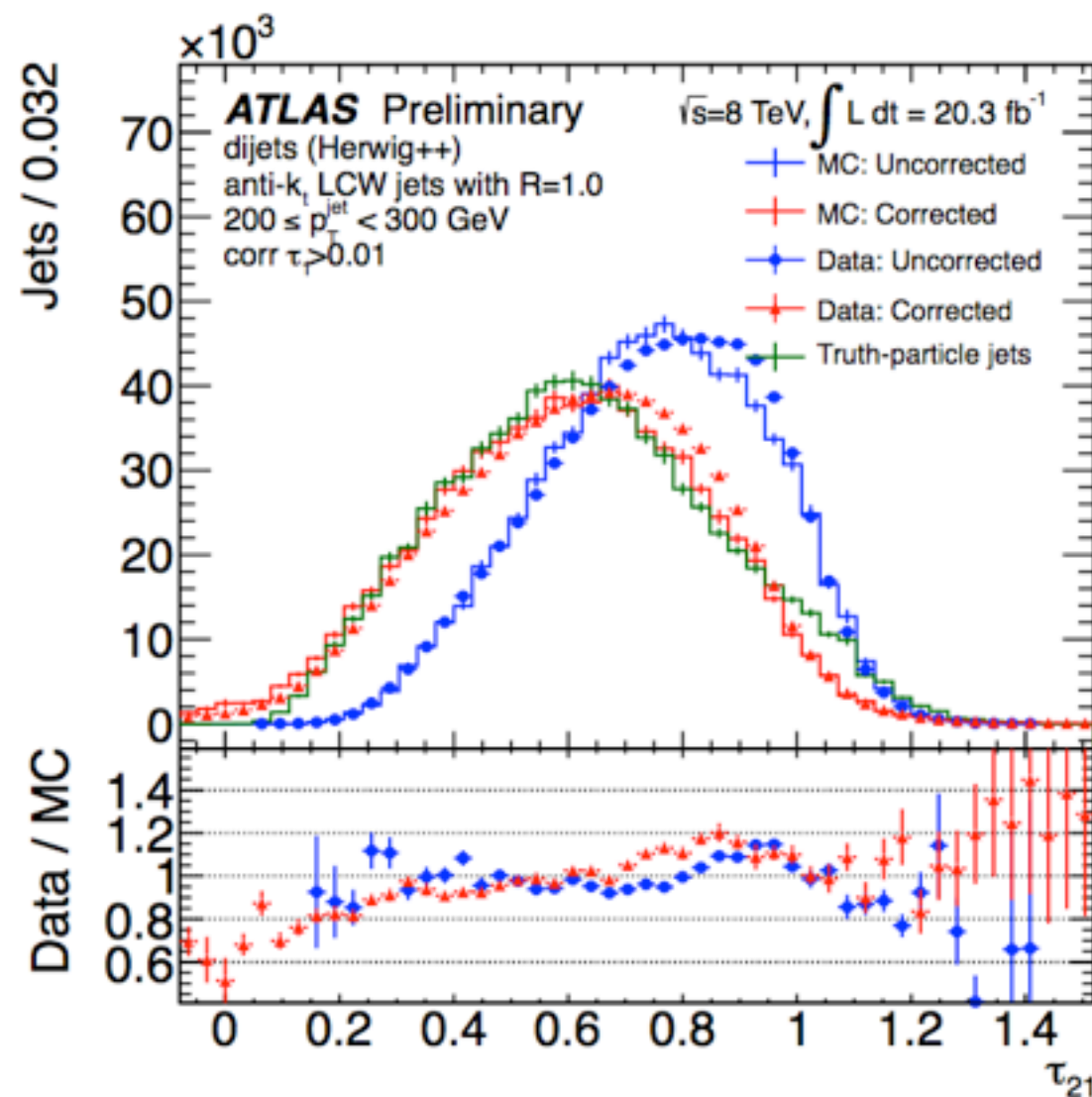
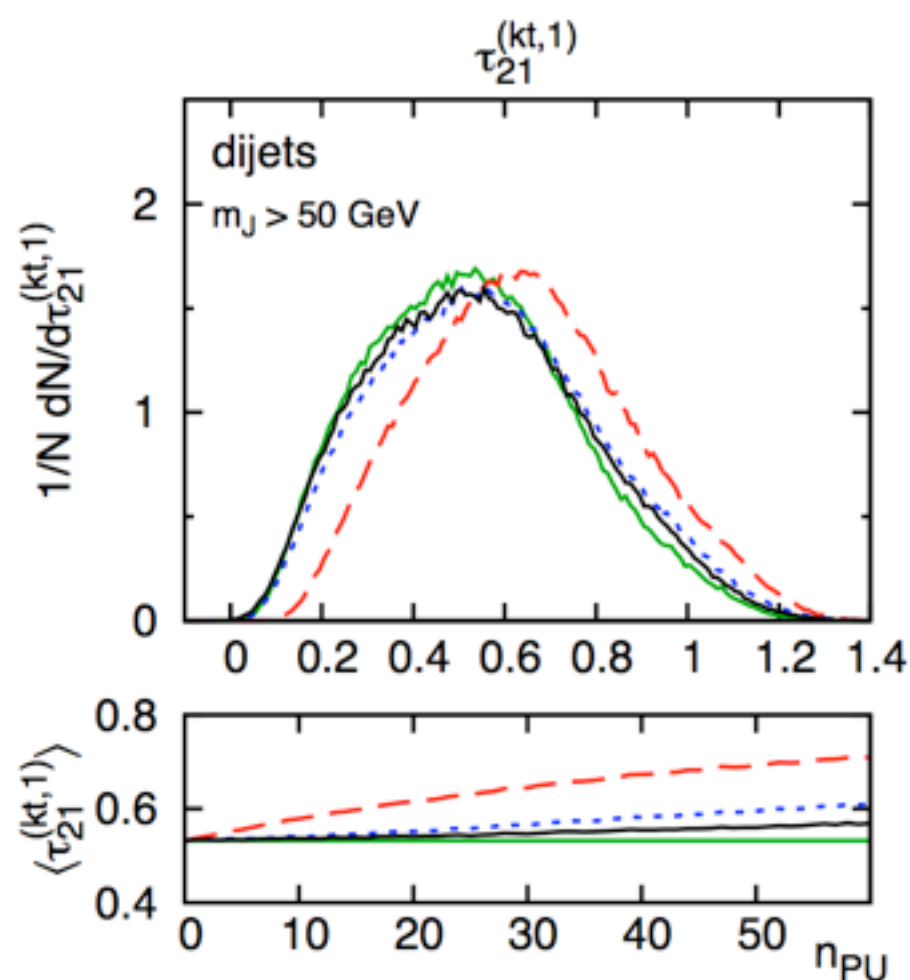
How did we manage? Shapes

August 12-16
BOOST 2013

- Can also correct shapes for pileup directly!

$$P_{\mu, \text{corr}}^{\text{jet}} = P_{\mu}^{\text{jet}}(\rho = \rho_0, g_t = -\rho_0 \cdot A_g) = P_{\mu}^{\text{jet}} - \rho_0 \cdot A_{\mu}^{\text{jet}}$$

$$A_{\mu}^{\text{jet}} = \frac{1}{v_g \langle g_t \rangle} \sum_{i \in g} g_{\mu, i},$$



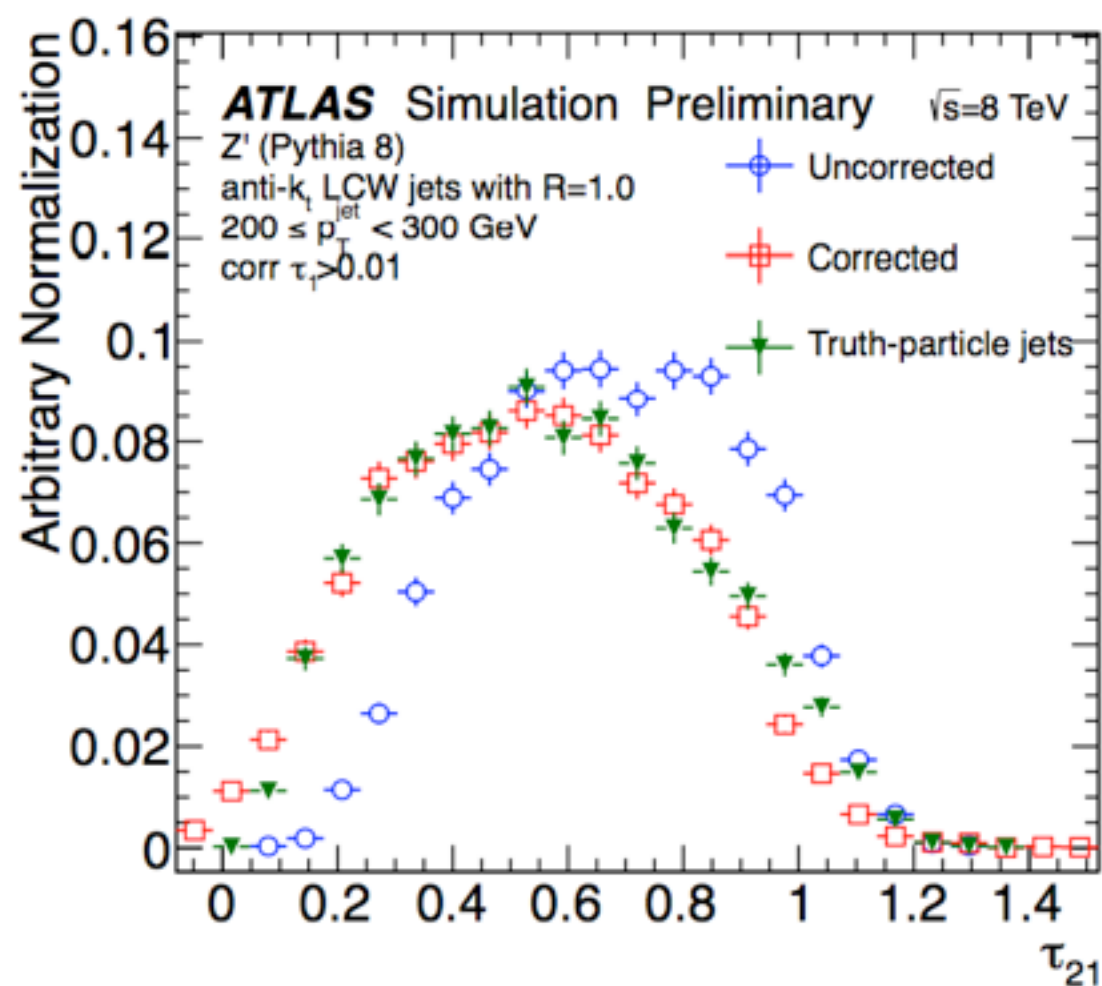
(a) Low p_T : 200-300 GeV



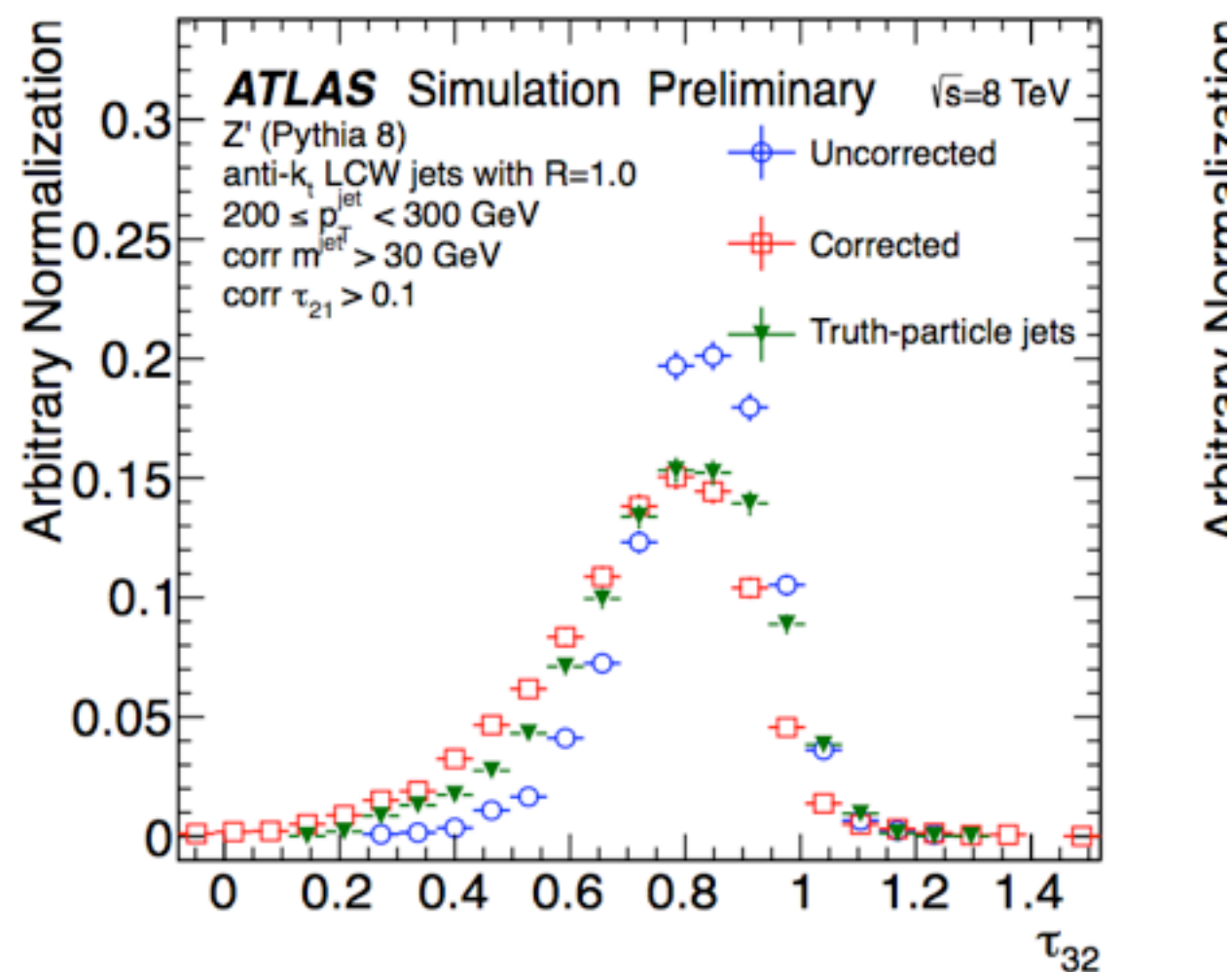
Shapes : Did it work?

August 12-16
BOOST 2013

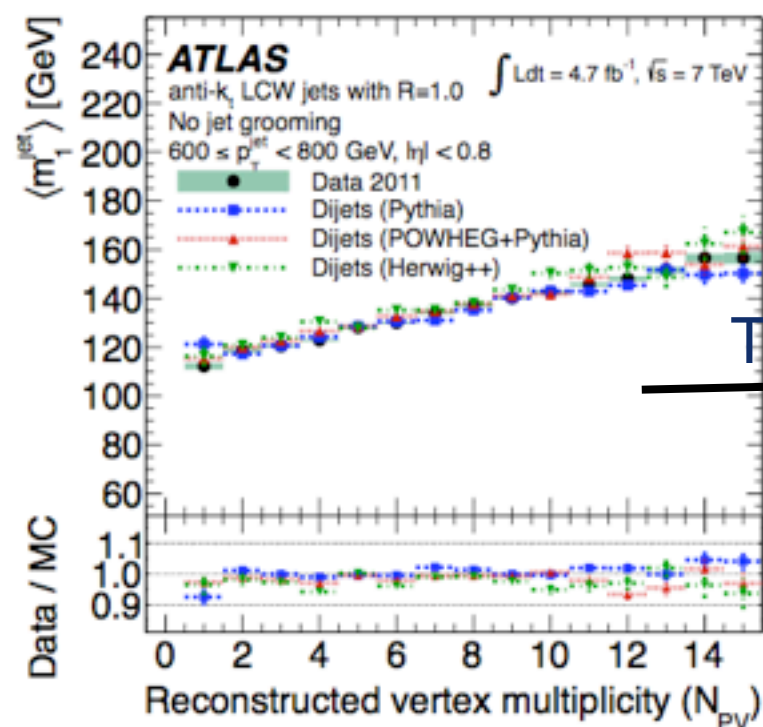
Boosted tops



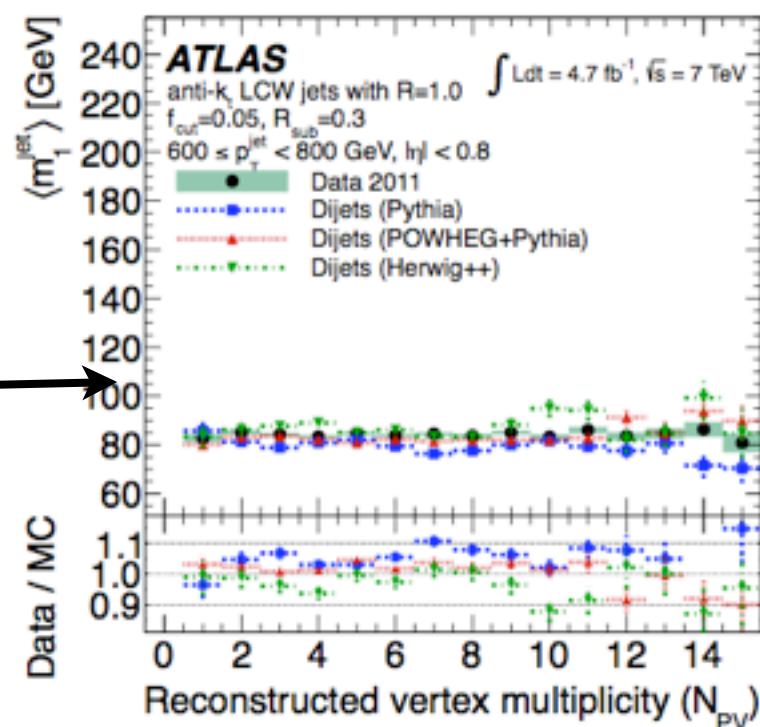
(a) Low p_T : 200-300 GeV



(a) Low p_T : 200-300 GeV

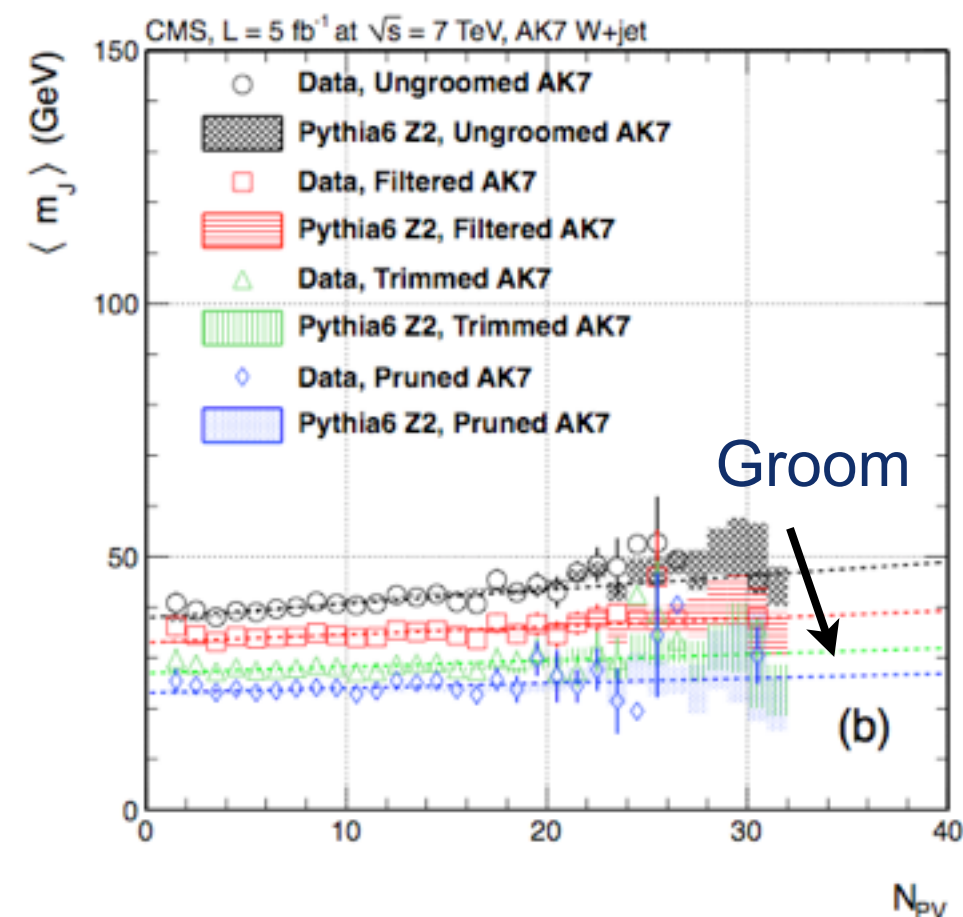


(a) anti- k_t , $R = 1.0$: Ungroomed

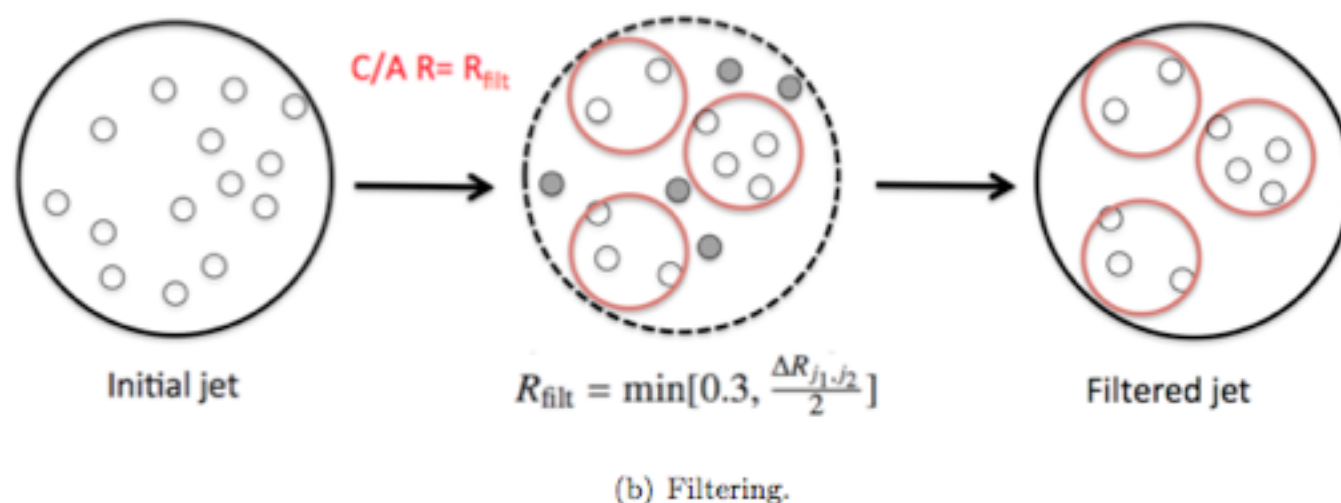


(b) anti- k_t , $R = 1.0$: Trimmed

Trim



Groom



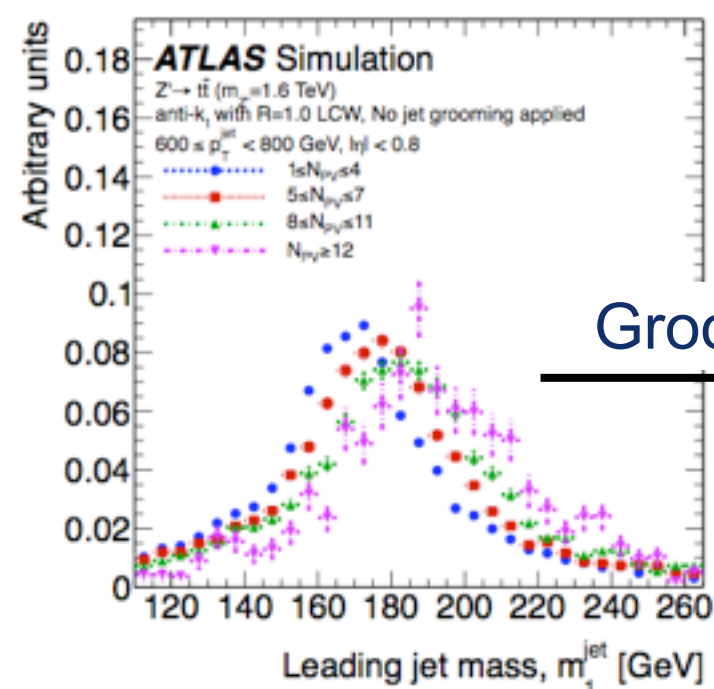
See talks by Sven Menke, Phil Harris, Jesse Thaler, Gavin Salam, Simone Marzani, Matt Low, Andrew Larkowski!



Grooming : Did it work?

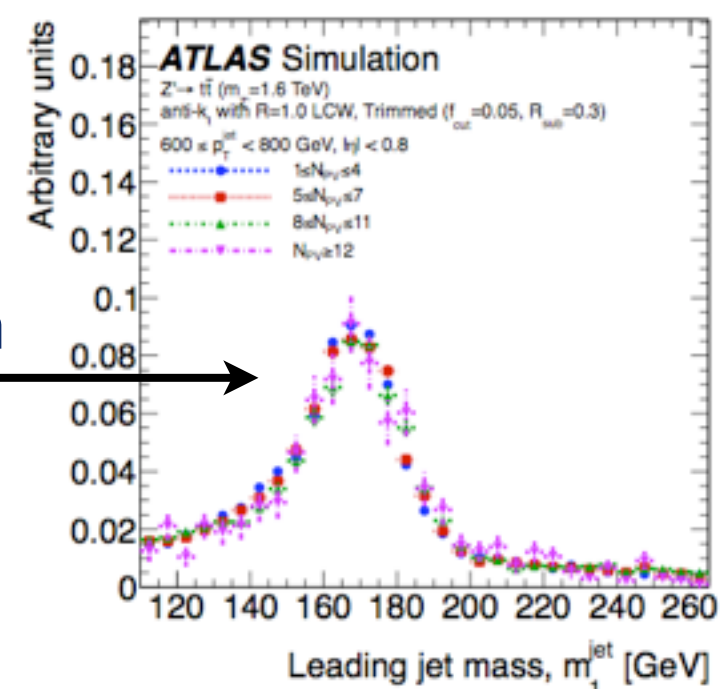
August 12-16
BOOST 2013

- Largely mitigated PU-dependence of jet mass
- Reduced overall QCD backgrounds for substructure

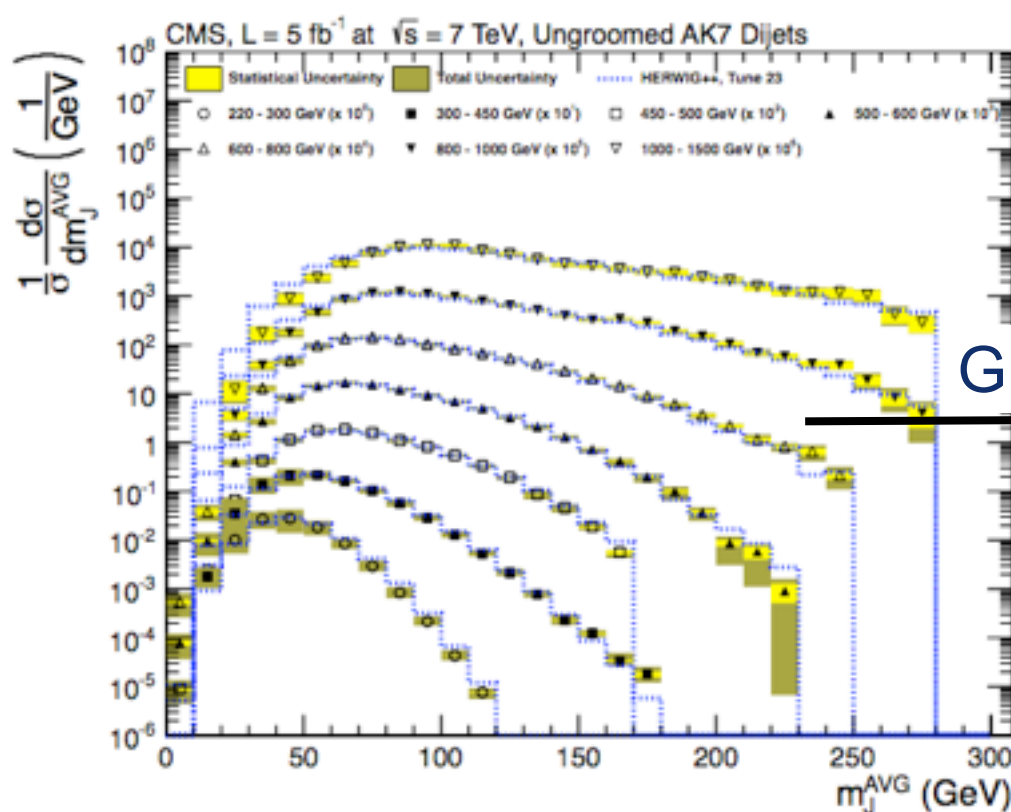


(c) Z' : anti- k_t , $R = 1.0$: Ungroomed

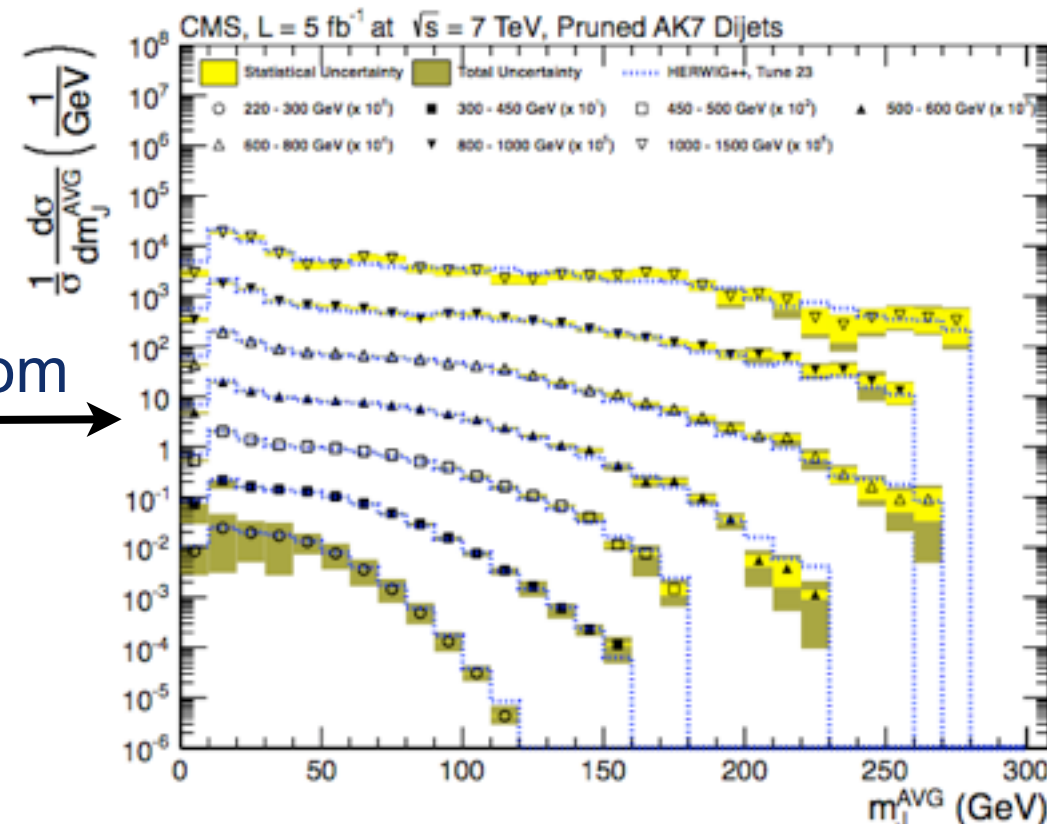
Groom



(d) Z' : anti- k_t , $R = 1.0$: Trimmed



Groom

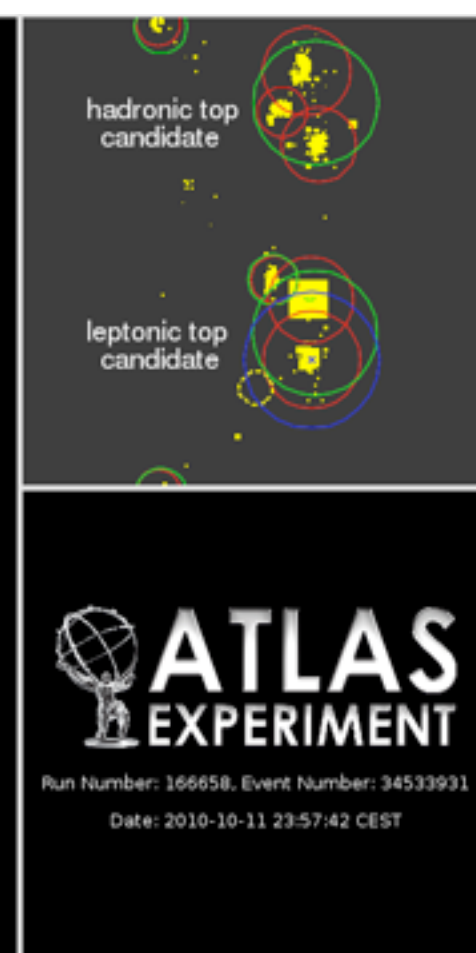
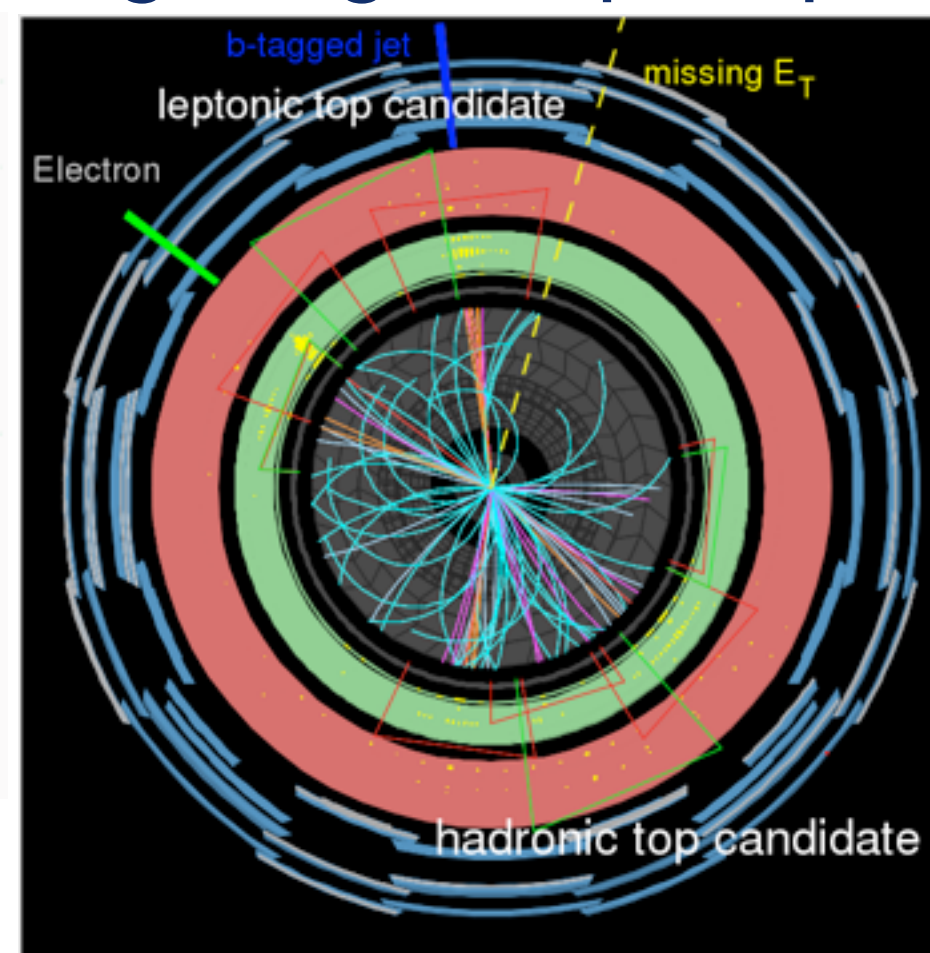
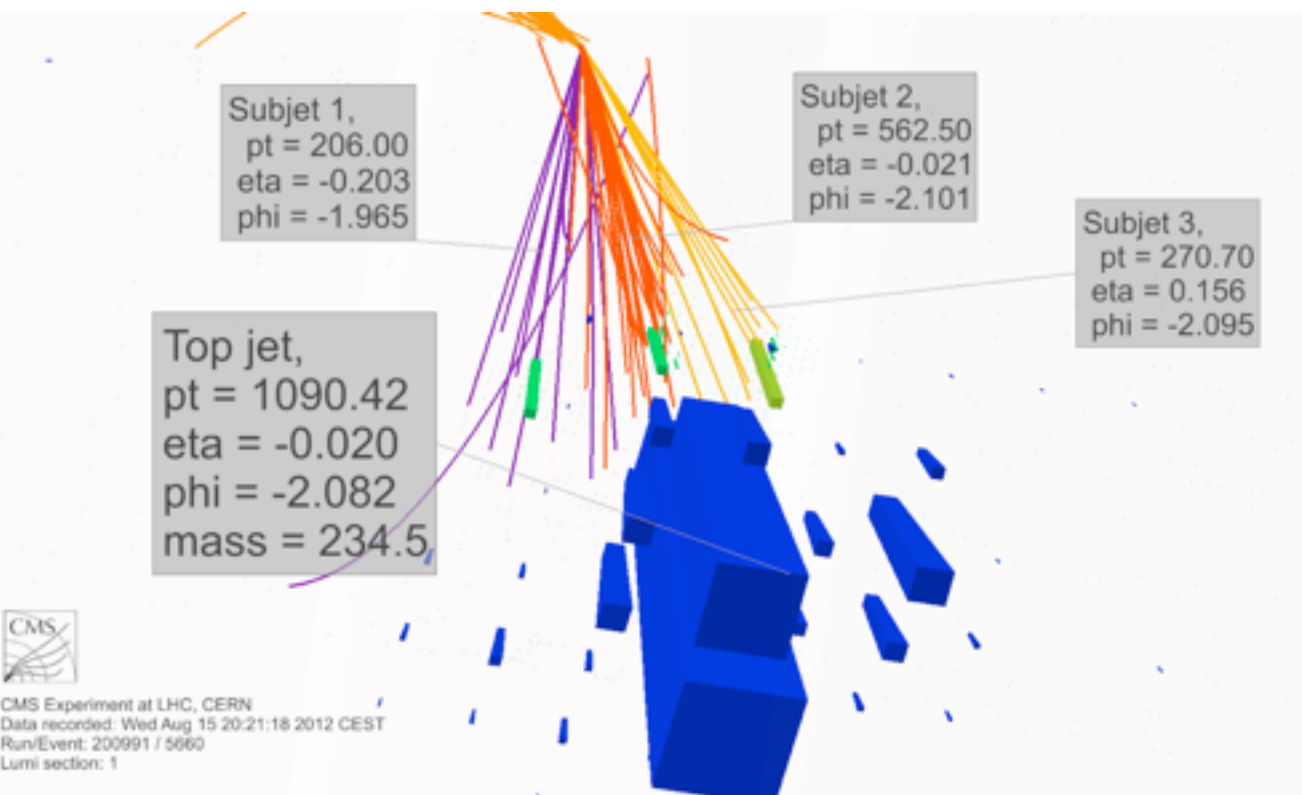




Grooming : Did it work?

August 12-16
BOOST 2013

- And of course, just look at the title of this conference
- Wouldn't exist without mitigating the pileup!

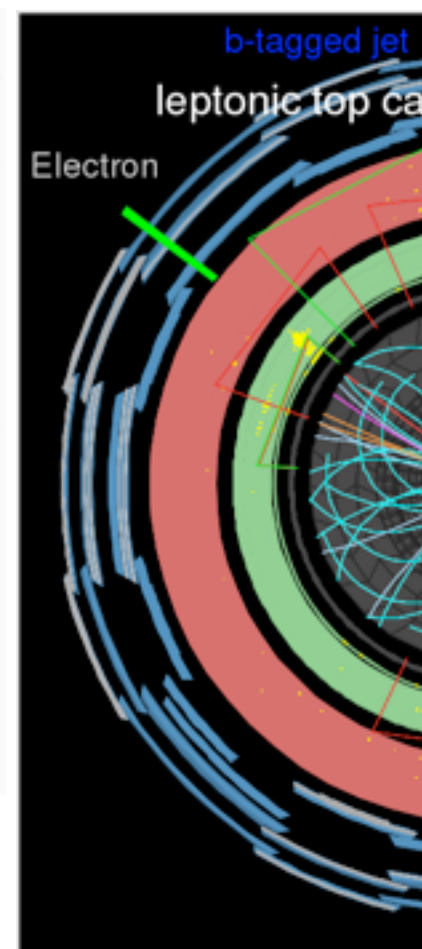
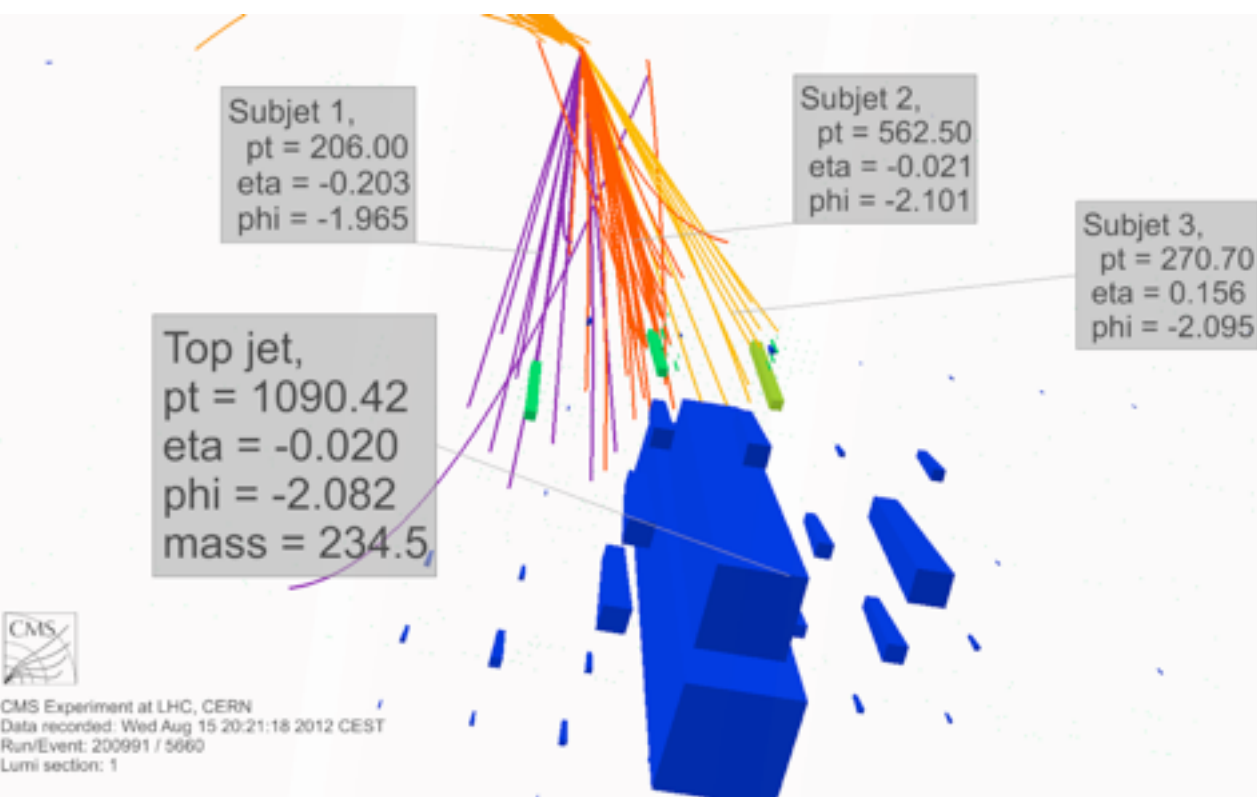




Grooming : Did it work?

August 12-16
BOOST 2013

- And of course, just look at the title of this conference
- Wouldn't exist without mitigating the pileup!



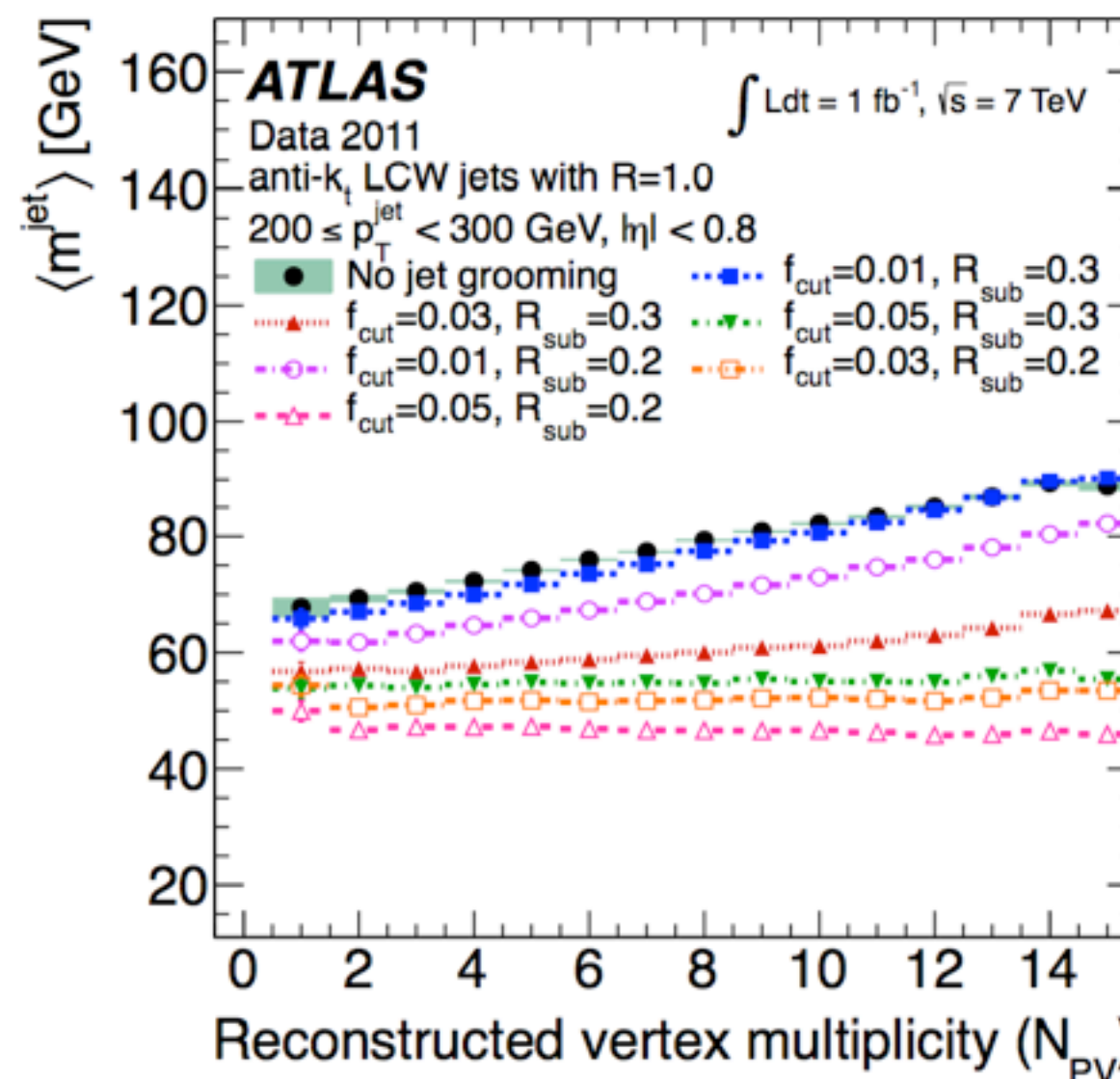
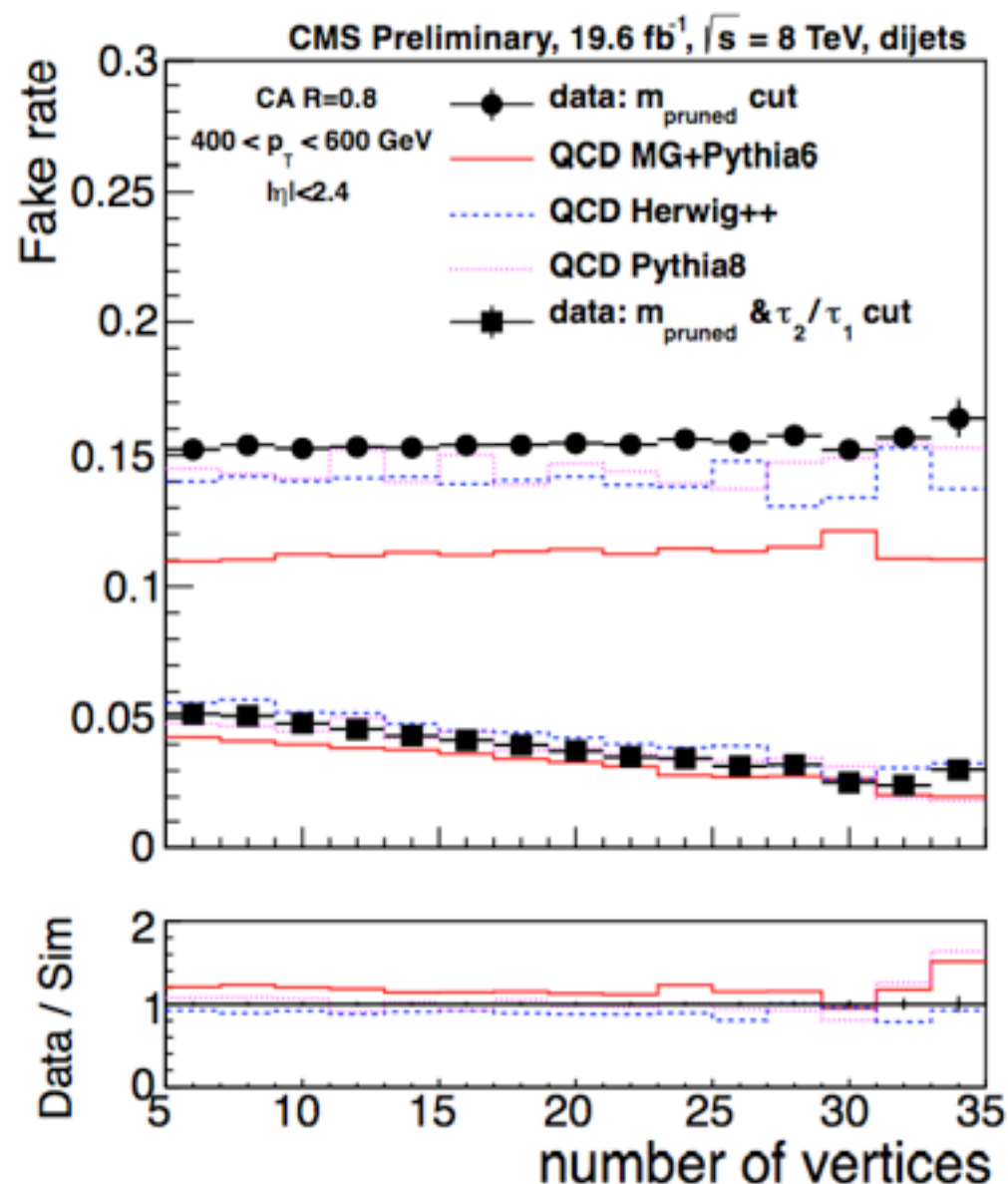
And it was apparently delicious too,
or so Emily told me ;)



Grooming : Did it work?

August 12-16
BOOST 2013

- First questions at BOOST and elsewhere was whether it would work at all
- Expectation was that it would be more sensitive to pileup than “standard” jet stuff
- Now we’ve actually seen that it is LESS sensitive!
- Currently more limited by theoretical (PS) uncertainties than PU
 - This won’t last for long

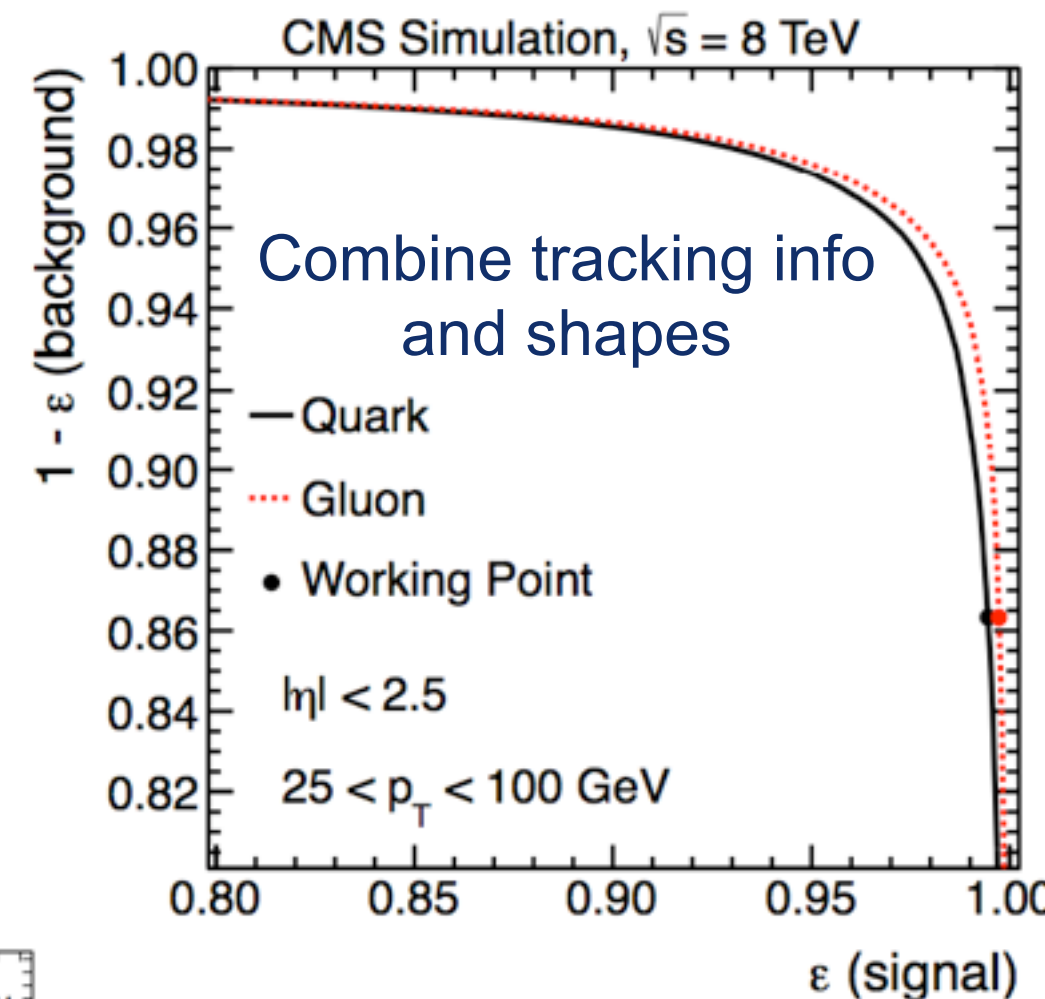




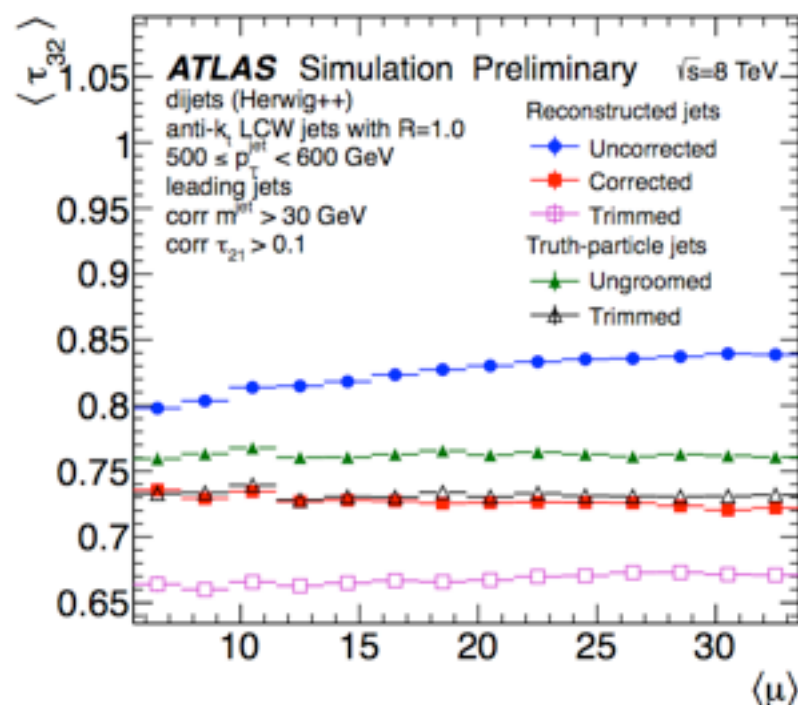
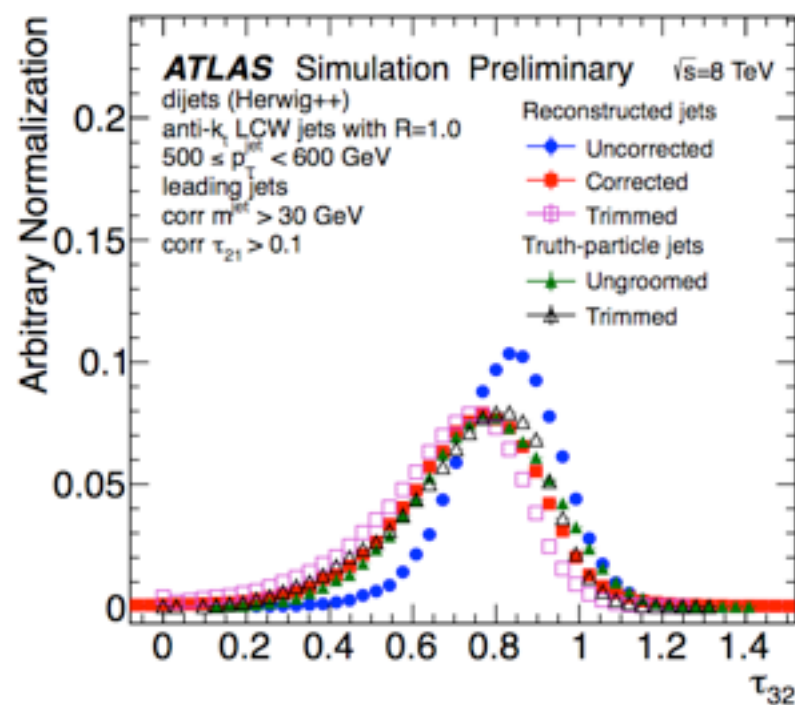
Putting information together!

August 12-16
BOOST 2013

- There is no such thing as “too much pileup mitigation”
- Constant battle for which we must all be continually vigilant
- Adding ideas together will be an excellent way forward!



Grooming compared to shapes

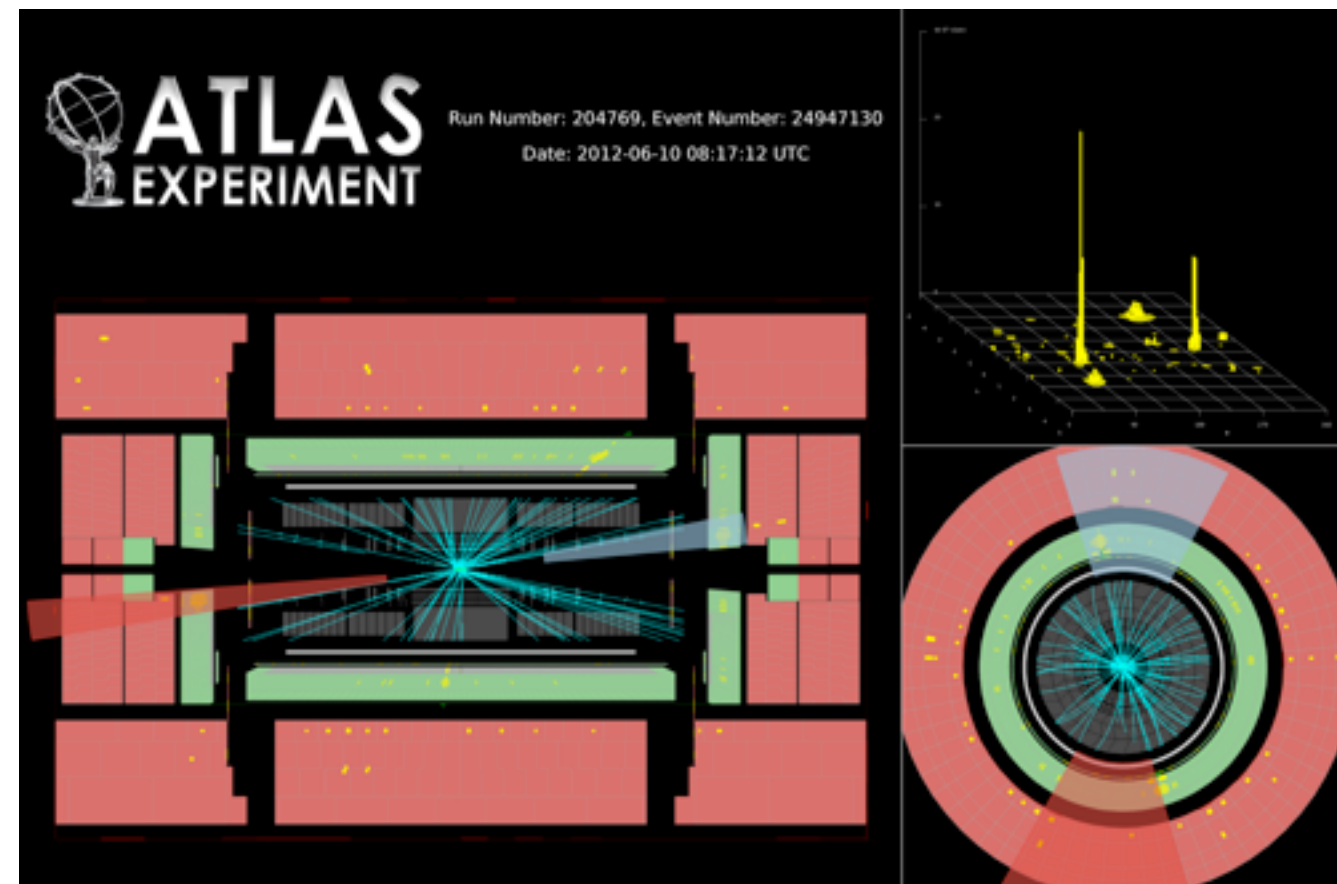
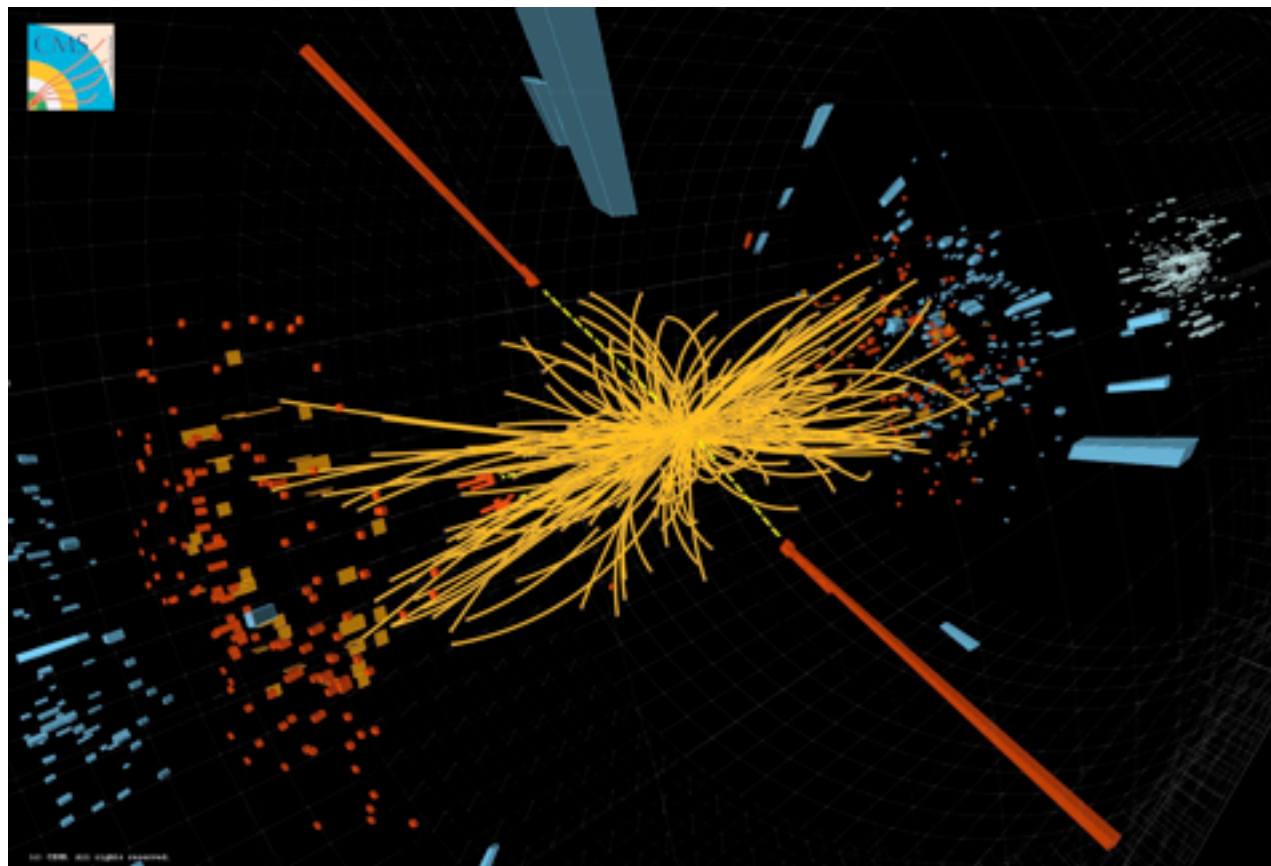




Jets and Pileup : Did it work?

August 12-16
BOOST 2013

- Most of these strategies were used in the Higgs discovery
- They were all used in one of the 500+ ATLAS/CMS papers
- No one expected to get this far as it is



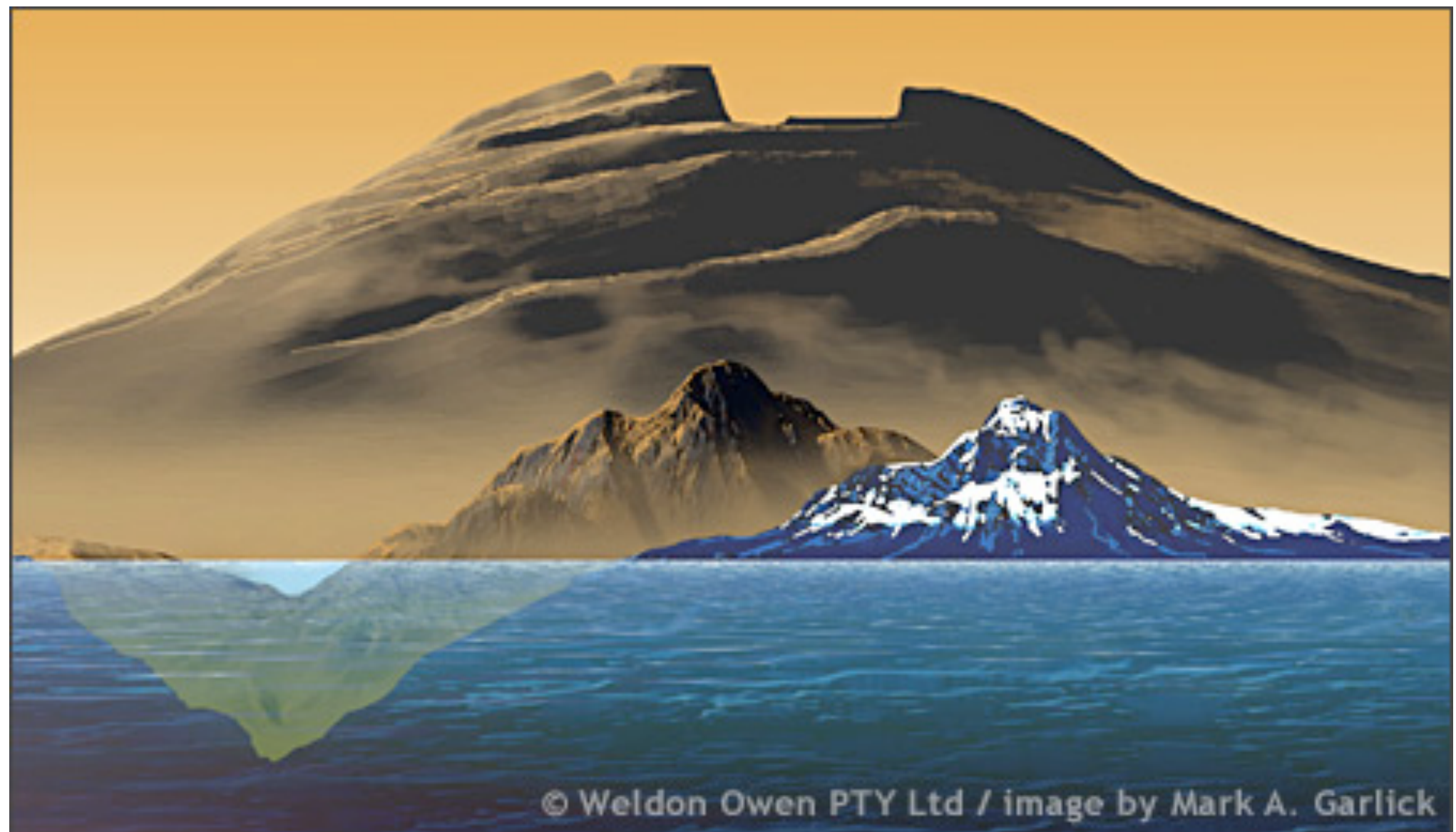
So yeah... there's that



Prospects

August 12-16
BOOST 2013

The trick is to get it to work with 2-10x the pileup!
Should we lose heart?





Prospects

August 12-16
BOOST 2013





Prospects

August 12-16
BOOST 2013



12 Aug 2013