Title: Closing Summary Talks

Date: Feb 23, 2013 11:15 AM

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Abstract:

PI-Workshop:

Application of Jet Substructure to New Physics Searches

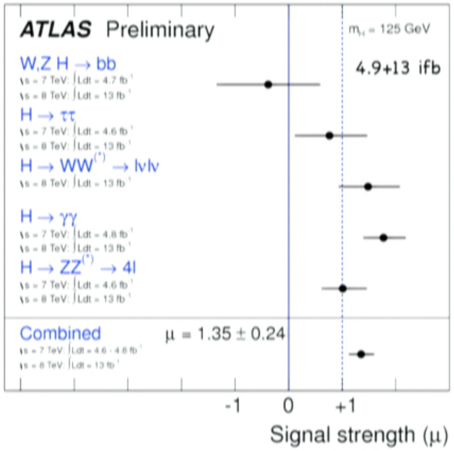
Michael Spannowsky

University of Durham

Where are we at the moment?

4th of July,
Higgs-like boson discovery after prediction 50 years earlier

Huge international success!



Couplings quite SM like...

"Jet substructure is the only field where you can actually do something new"

(experimentalist)

→ Mass of Higgs nice for jet substructure community

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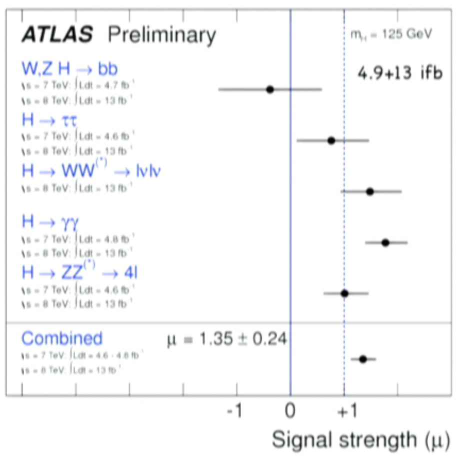

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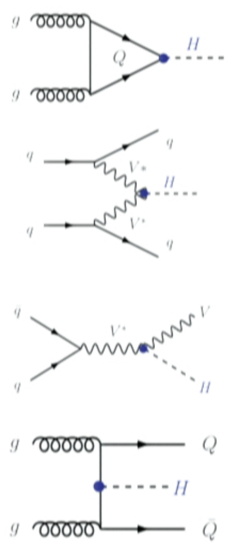
For Higgs measurement we need cross correlation between many channels:



production	decay
$gg \to H$	ZZ
qqH	ZZ
$gg \to H$	WW
qqH	WW
$t\bar{t}H$	$WW(3\ell)$
$t\bar{t}H$	$WW(2\ell)$
inclusive	$\gamma\gamma$
qqH	$\gamma\gamma$
$t\bar{t}H$	$\gamma\gamma$
WH	$\gamma\gamma$
ZH	$\gamma\gamma$
qqH	$\tau\tau(2\ell)$
qqH	$\tau\tau(1\ell)$
$t\bar{t}H$	$b\bar{b}$
WH/ZH	$b\bar{b}$ (subjet)

assumed: $\Gamma_H = \Sigma_{SM}\Gamma_i \quad \Gamma_i \sim g_d^2$

[Lafaye, Plehn, Rauch, Zerwas, Duehrssen (2009)]

Decay into spec. channel

Production

$$\sigma \cdot BR \propto g_p^2 \frac{g_d^2}{\Gamma_H}$$

Sum of all possible decays

- Every measurement affected by production and decay

Uncertainty of all coupling measurements driven by total width, i.e. channel with largest BR: H-> bb

Hbb difficult but can use new techniques, i.e. Jet substructure!

	Measurement incl. BDRS			only $t\bar{t}H$, $H \to b\bar{b}$ (no BDRS)		
	σ_{symm}	σ_{neg}	σ_{pos}	σ_{symm}	σ_{neg}	σ_{pos}
Δ_{WWH}	± 0.24	-0.21	$+0.27$	± 0.33	-0.24	$+0.43$
Δ_{ZZH}	± 0.31	-0.35	$+0.29$	± 0.59	-0.33	$+0.64$
Δ_{ttH}	± 0.53	-0.65	$+0.43$	± 0.48	-0.56	$+0.41$
Δ_{bbH}	± 0.44	-0.30	$+0.59$	± 0.78	-0.43	$+0.84$
$\Delta_{\tau\tau H}$	± 0.31	-0.19	$+0.46$	± 0.39	-0.20	$+0.60$
$\Delta_{\gamma\gamma H}$	± 0.31	-0.30	$+0.33$	± 0.33	-0.33	$+0.33$
Δ_{ggH}	± 0.61	-0.59	$+0.62$	± 0.66	-0.48	$+0.82$

- Huge improvement from boosted Higgs analysis
- also for non-b decay modes due to better knowledge of total width

→ To reduce uncertainty for all coupling, need to measure b and t coupling

→ Jet substructure the right topic at the right time
(reflected by age structure of workshop participants)

Field of jet substructure changed (matured?) over recent years:

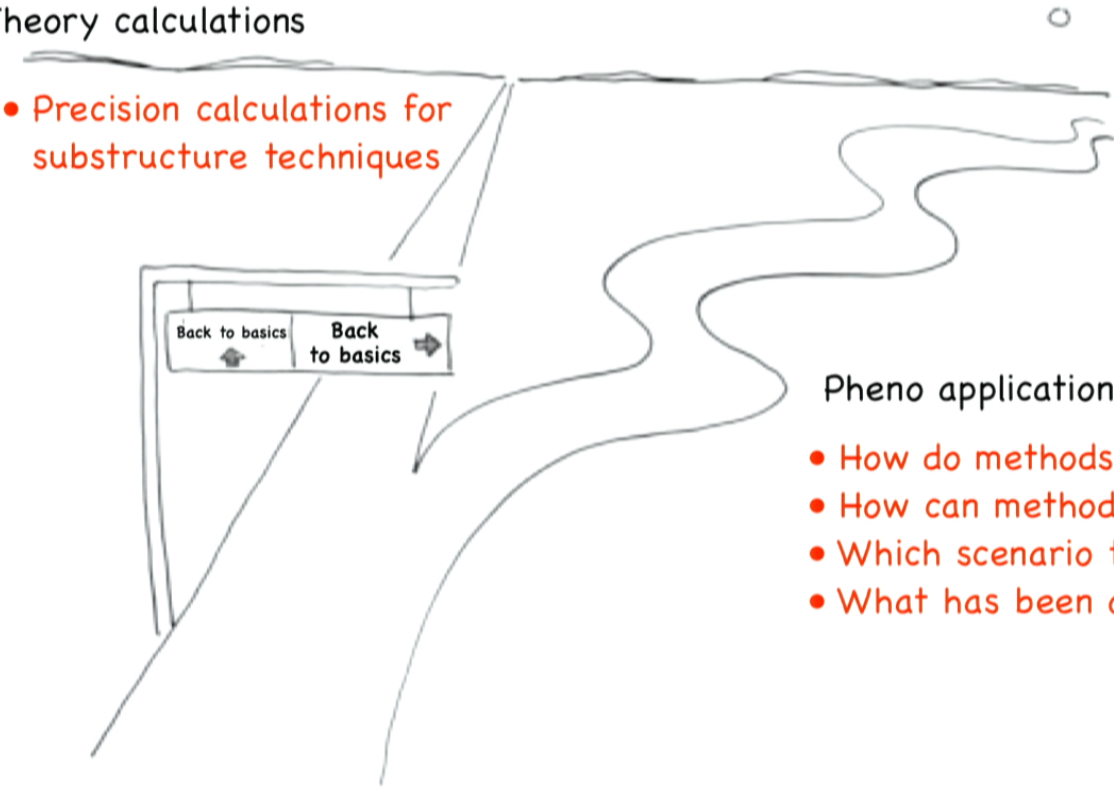
Ideas older (see Mike Seymour's early work) but tremendous growth only since 2008

2009/2008	• First reconstruction techniques • Theory-study of high-profil pheno searches • New objects (lepton jets)	PHENO initiated
2010/2011	• Many Higgs/BSM/top studies • First exp. results. e.g. jet mass measurement for boosted jets • More methods to reconstruct objects	PHENO EXP
2012	• Many experimental results • Many techniques tested on data • Strong efforts in calculating jet observables, e.g. mass	THEO EXP
2013	Our workshop	"Back to basics" (Gavin)

Theory questions in focus of workshop

Theory calculations

- Precision calculations for substructure techniques



Pheno applications and methods

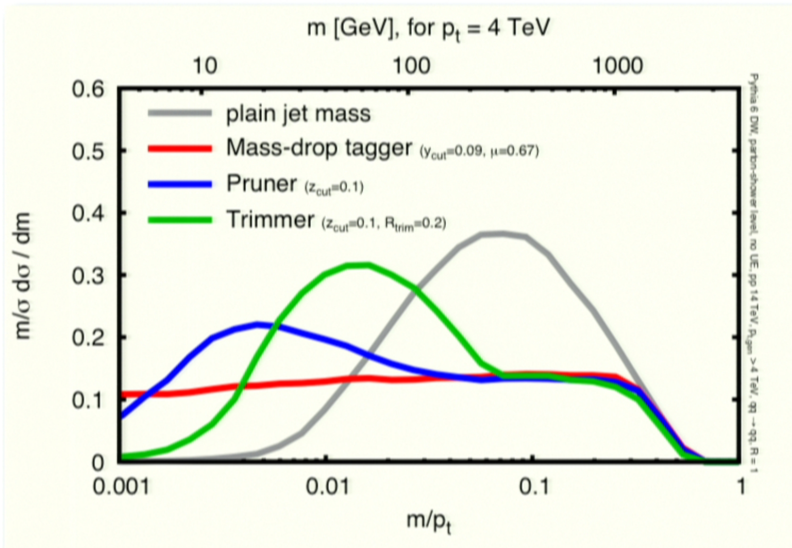
- How do methods compare?
- How can methods be improved?
- Which scenario to study?
- What has been overlooked?

Hopefully roads meet behind horizon...

Analytic calculations for grooming techniques

The "right" MC study can already be instructive
(testing on background [quark] jets)

[Salam]



But only for a limited range of masses

Grooming techniques can have surprising/unwanted features

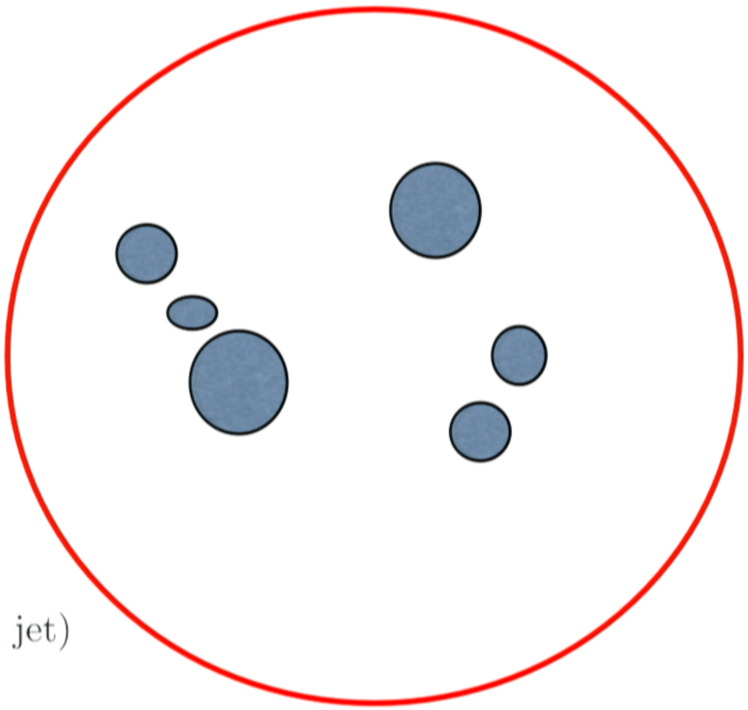
Pruning

Based on 2 conditions

If both hold true veto merging,
eg. recombination is wide angle and asymmetric

$$z = \frac{\min(p_{T,i}, p_{T,j})}{|\vec{p}_{T,i} + \vec{p}_{T,j}|} < z_{\rm cut}$$

$$\Delta R_{ij} > D_{\rm cut} = M(\text{fat jet})/P_T(\text{fat jet})$$



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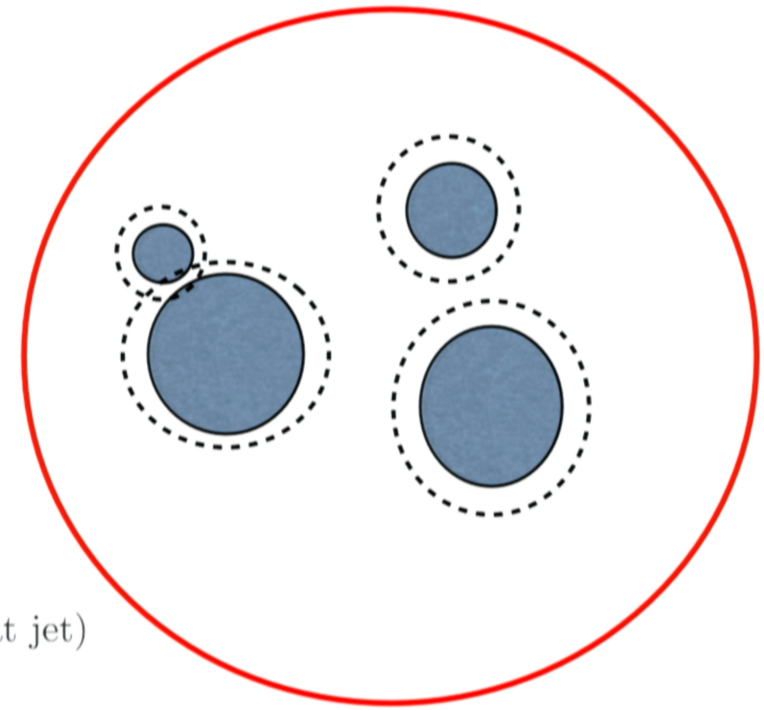

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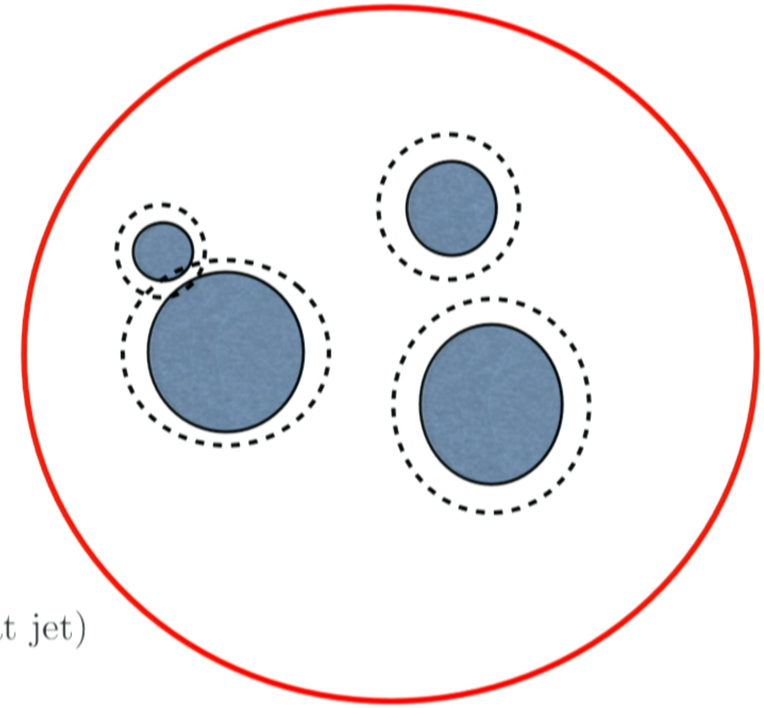

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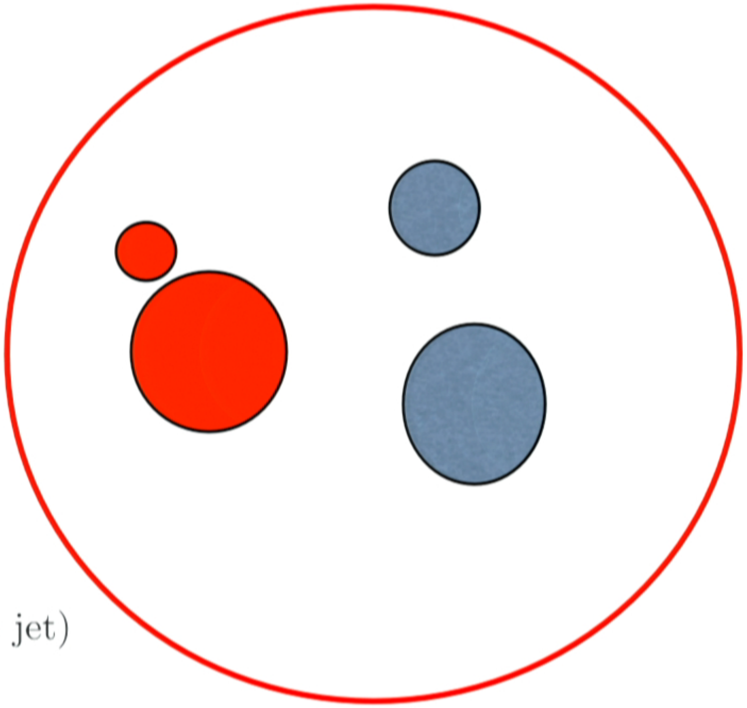

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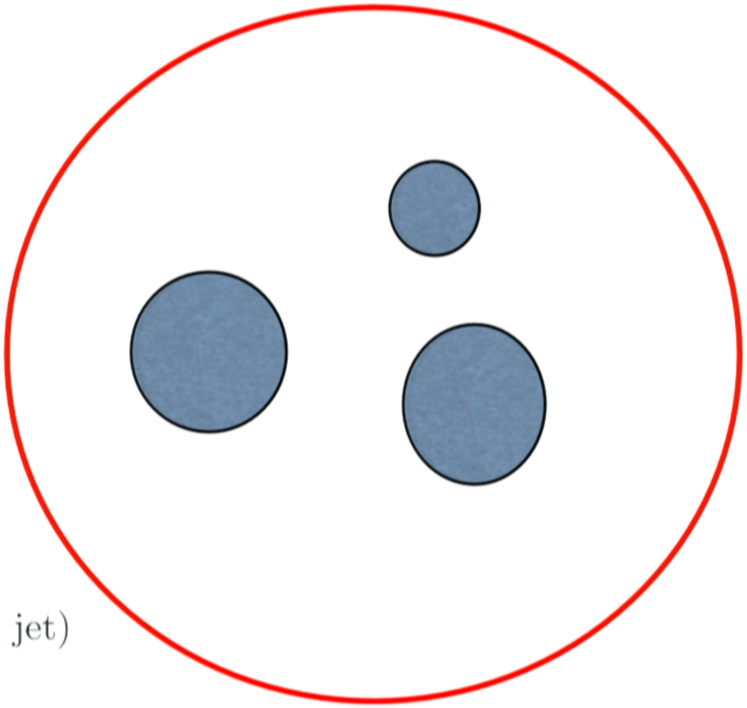

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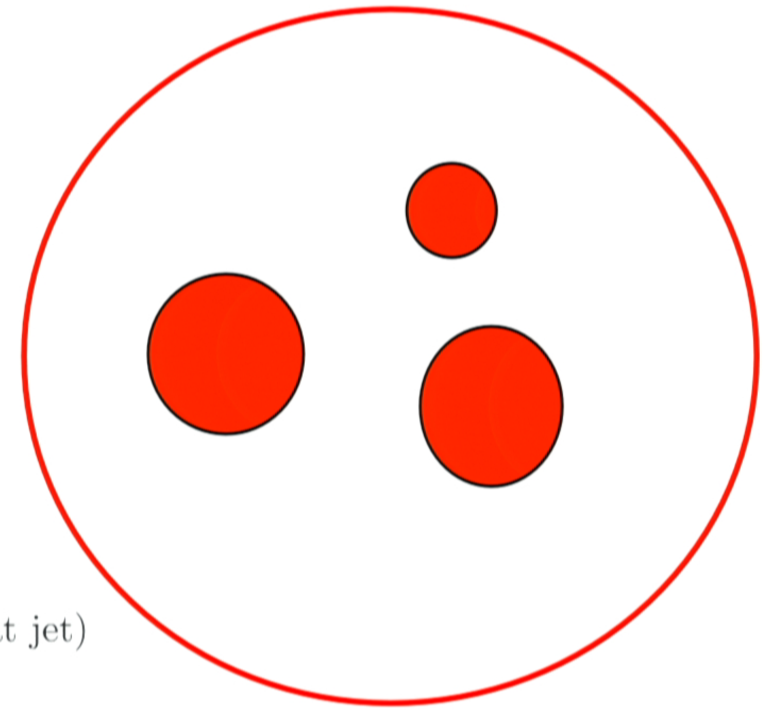

Soft wide-angle radiation can change mass and Dcut

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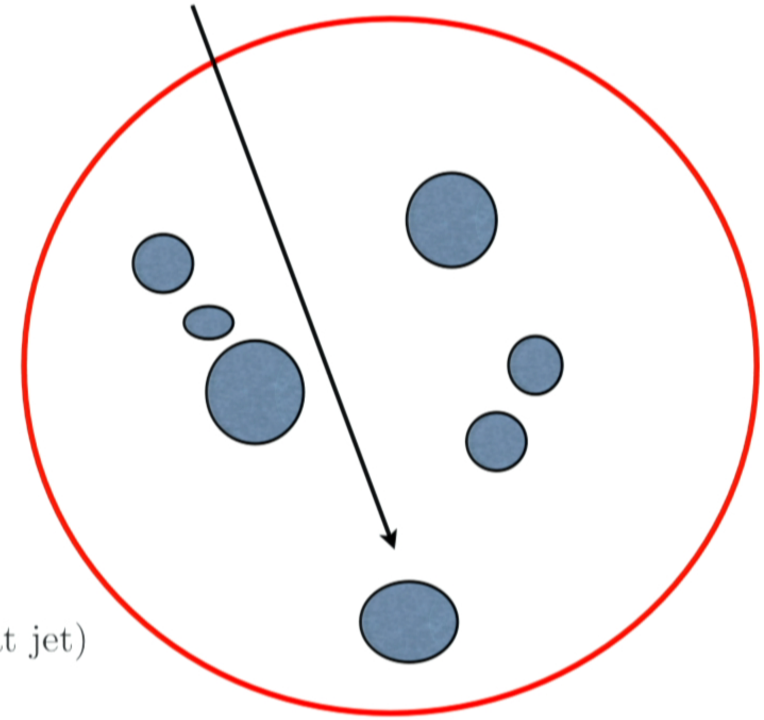

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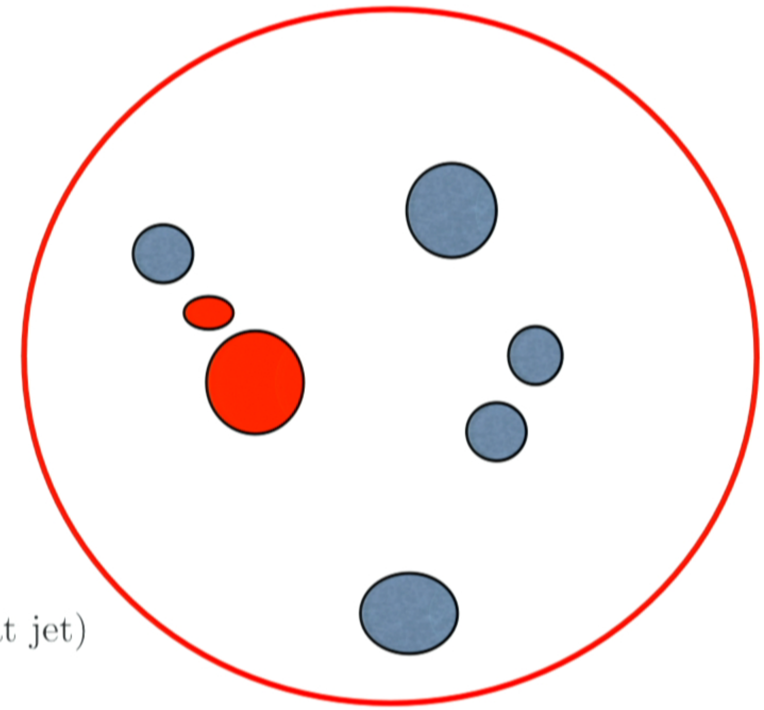

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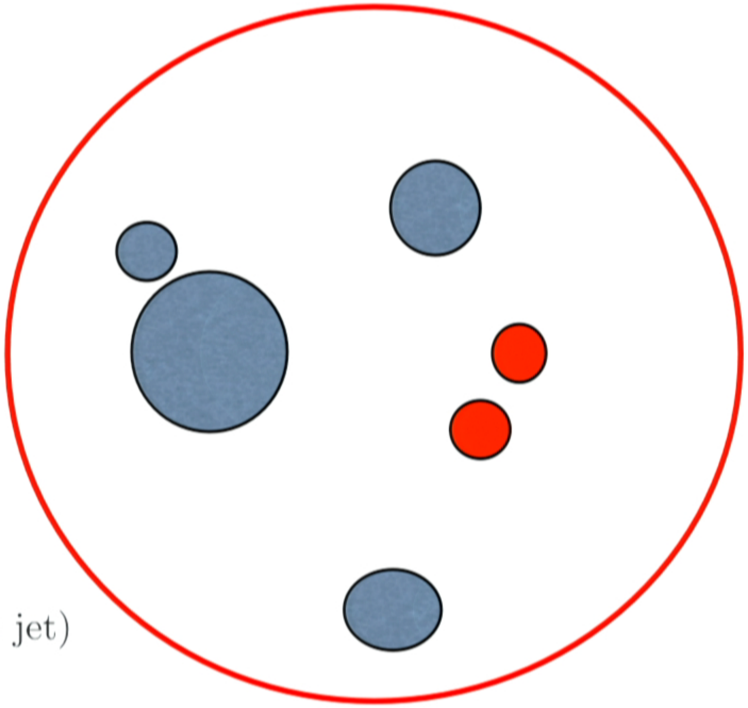
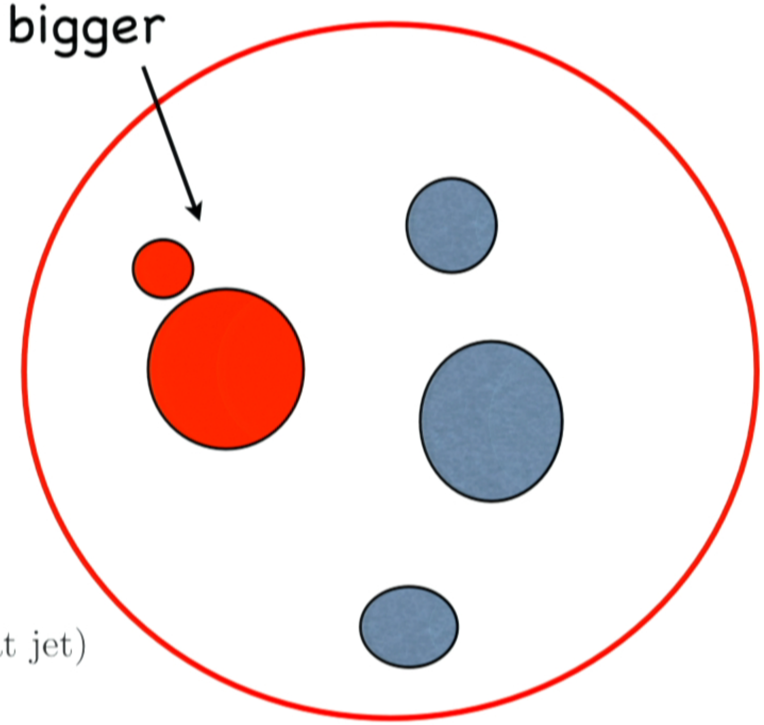


Pruning

Dcut now bigger



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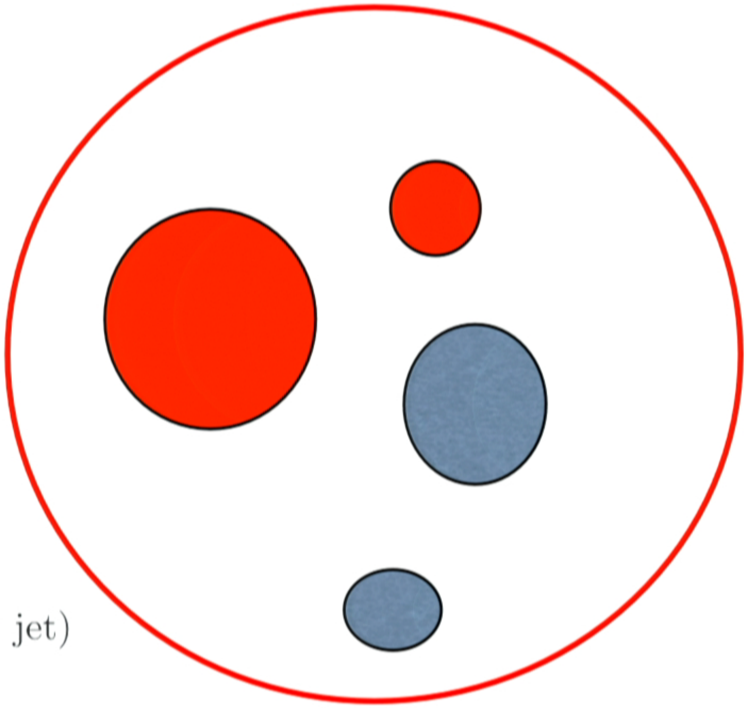

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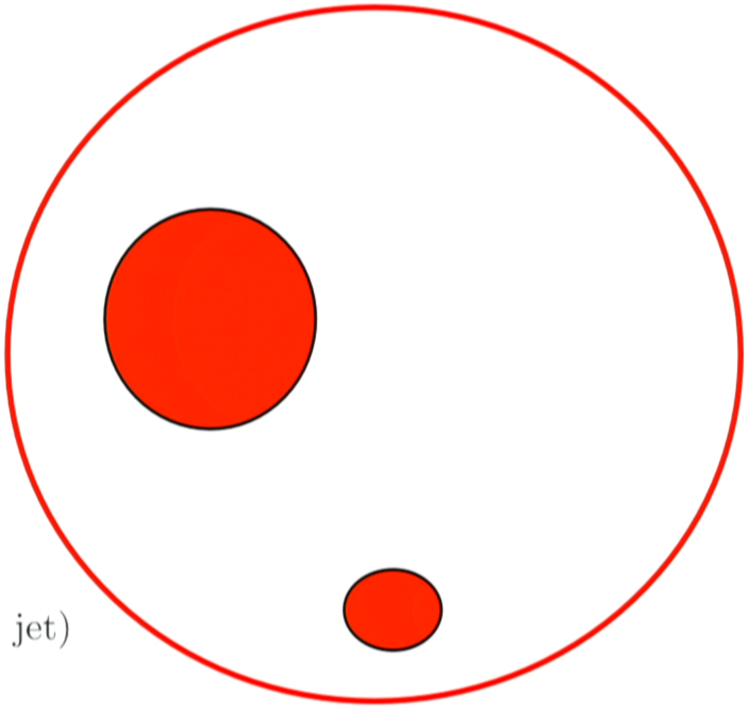

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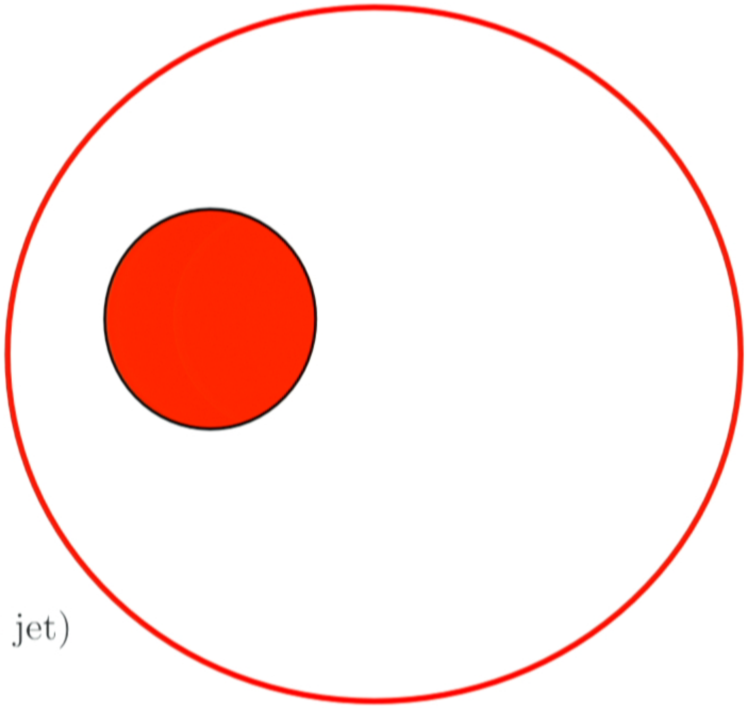
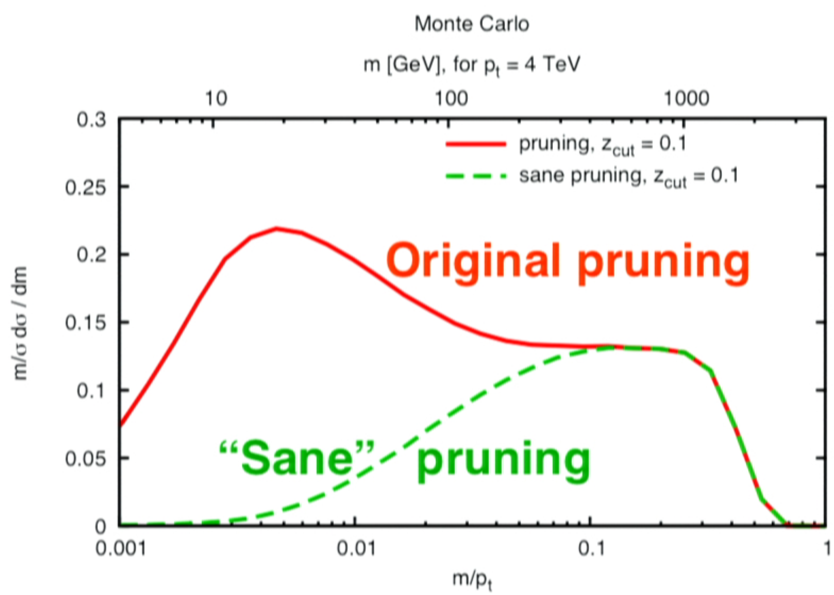


A simple fix: “sane” pruning

Require at least one successful merging with $\Delta R > R_{prune}$ and $z > z_{cut}$

Change groomer to tagger based on theory calculation



“sane” pruning is effectively placing an isolation cut on radiation around the tagged object

Gavin Salam (CERN) Jet substructure: back to basics @ PI, February 2013 15

Theory calculations lead to development of tagger (see also N-subjettiness)

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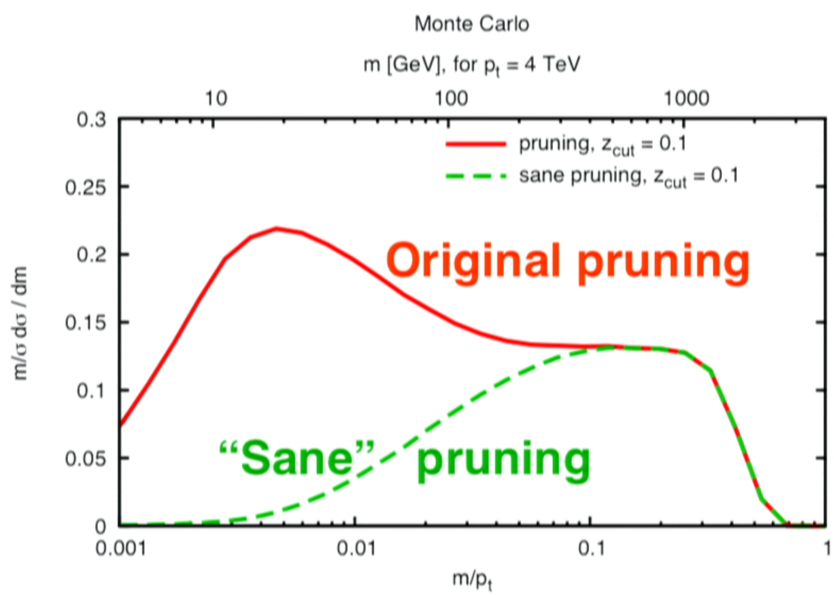

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Workshop driven by goal to
collect, categorize and compare

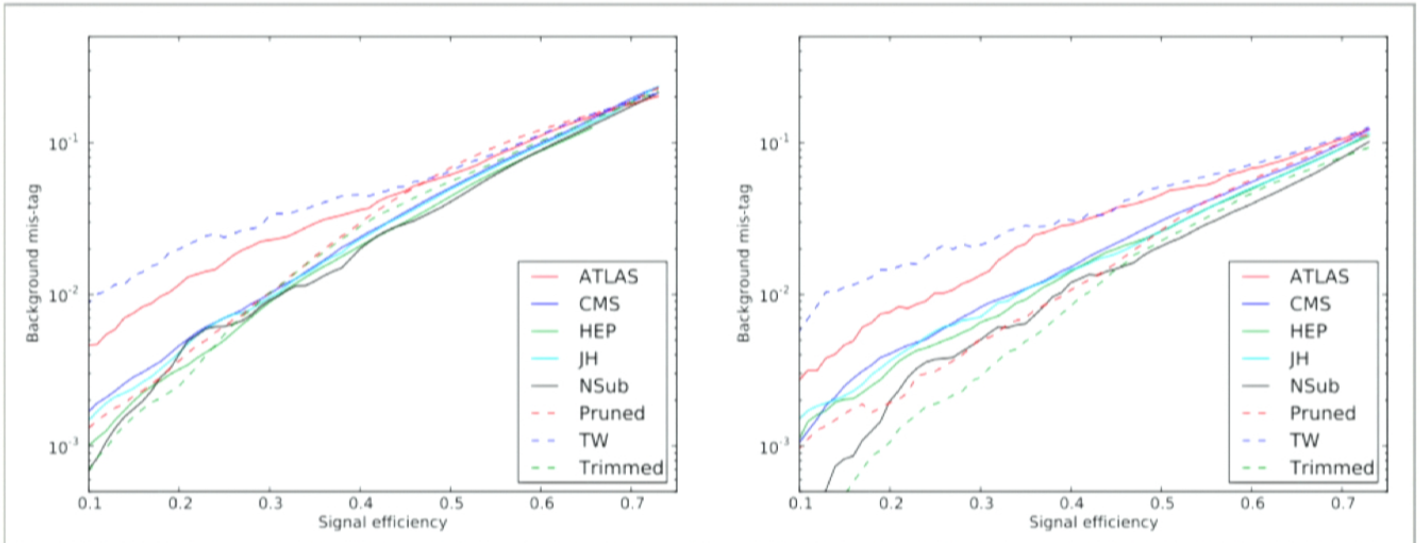
Liantao's discussion session

		Well understood	pile-up subtraction	theory	application
sub-jets ↑	y-splitter	yes			everything
	BDRS	yes		some	everything
	Hopkins, HEPTop W-tagger	yes			boost top, W
	jet-mass, groomed	yes	good	a lot of work	everything
	angularity	yes	good	some	
	planar flow	yes	?	some	
shapes ↓	nsub: τ_{ij}	yes	good	some	t, W, more

	Well understood	pile-up subtraction	theory	application
$n_{charge\text{-}track}$	yes			
width	yes			
angularity	yes	yes		
color flow				
angular correlation function				
Event subjettiness				
shower deconstructin top-tag			some	
jet charge			some	
Qjet				

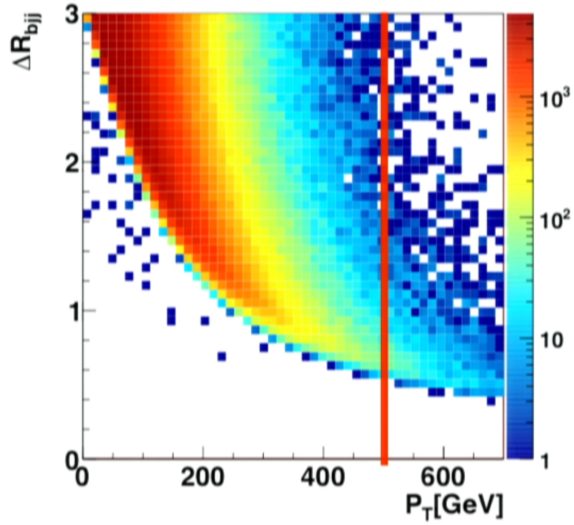
Liantao's discussion session

Many top taggers, are they all the same?



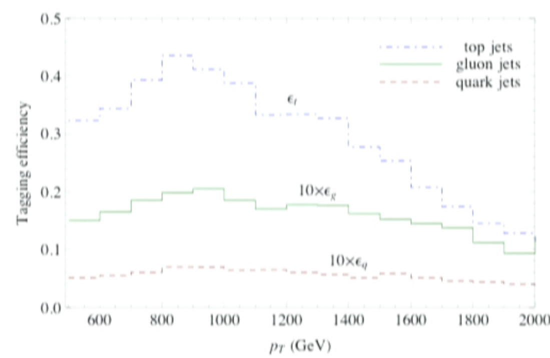
Performance very similar...

Many top taggers, are they all the same?



We chose to test them in the simplest scenario... Shouldn't be surprised to find little difference

low pT, bigger cone and large hadronic activity in event are game changer



[Kaplan, Rehrman, Schwartz, Tweedie]

Workshop driven by goal to collect, categorize and compare

Physics cases which should be studied:

- high multiplicity jets
- quark vs gluon tagging (Dependent on superstructure?)
- SUSY scenarios, e.g. RPV
- Challenging SM processes, e.g. VH with H->gg or cc
- Resolved vs boosted, impact of event-color flow on reconstruction efficiency
- Electroweak states from cascade/elw decays

Is it really useful to independently
collect, categorize and compare
pheno-applications and reconstruction methods?

Contra:

- Many methods were designed for specific scenarios
- Performance of methods not always independent of event super structure, e.g. hadronic activity, color...

Pro:

- Application dependent component might render categorization and comparison infeasable

A categorization which takes into account

purpose and technique

could be

hypothesis tester vs BSM discoverers

(maximum information approach) (agnostic discriminator)

A categorization which takes into account purpose and technique could be hypothesis tester vs BSM discoverers

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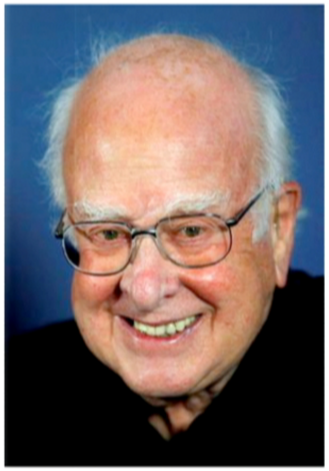
If you know what to look for hypothesis tester should be most sensitive,
e.g. Higgs discovery/measurements:



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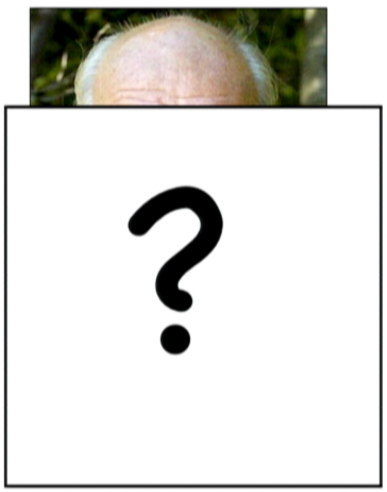

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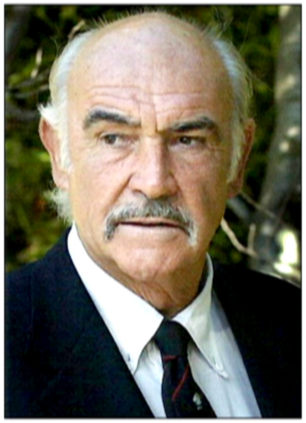

[Sean Connery]

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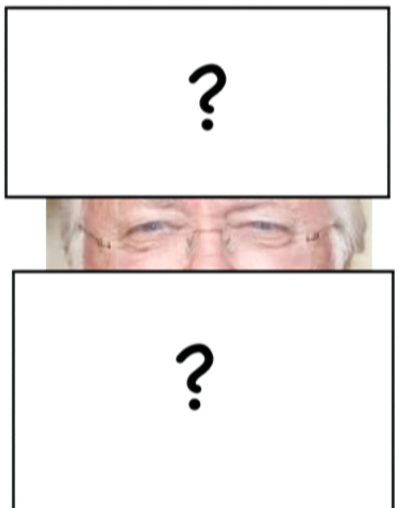

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[Richard Attenborough]

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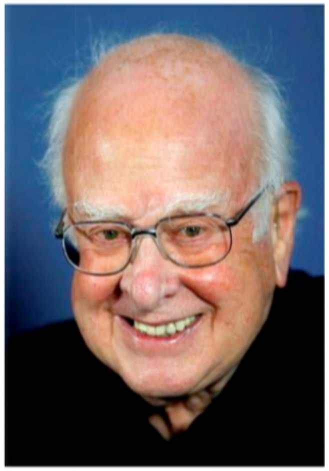
Taking all features into account prevents mixup with impostors



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BSM discoverers use simple observables which induce as little bias as possible. However, several of these observables can be combined...

Eg. a number of bald guys with glasses is interesting enough

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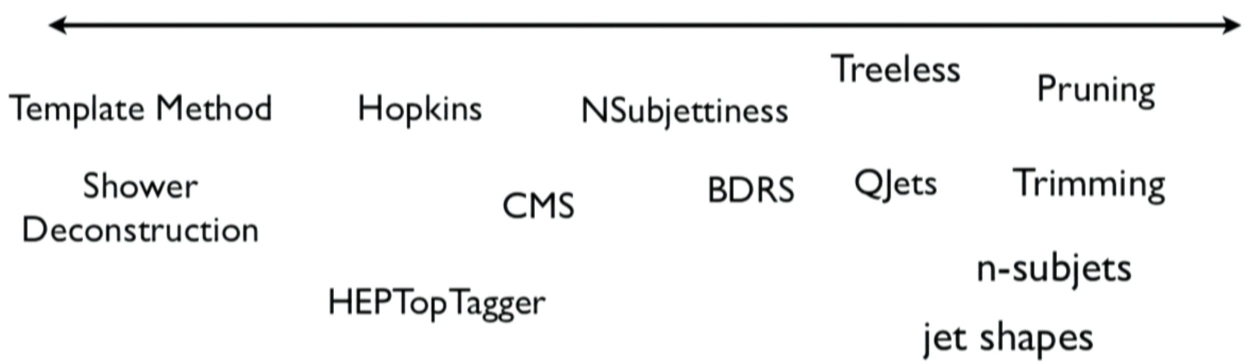

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Template Method

Shower Deconstruction

Hopkins

HEPTopTagger

CMS

NSubjettiness

BDRS

Treeless

QJets

Pruning

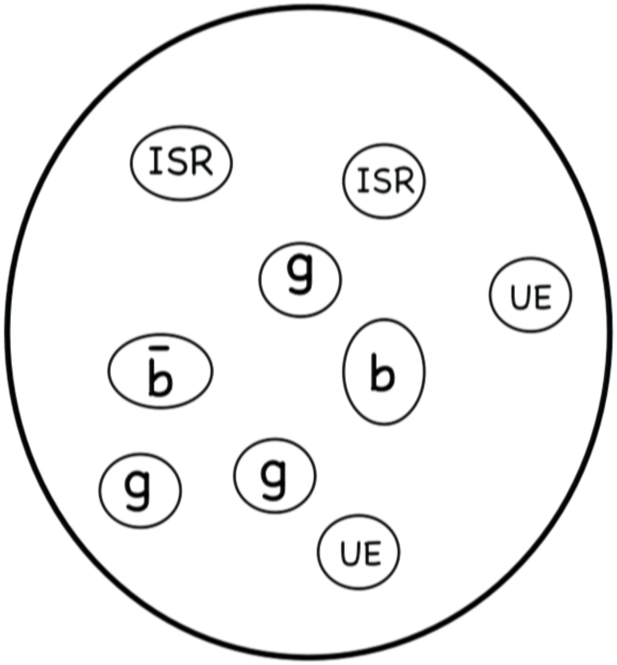
Trimming

n-subjets

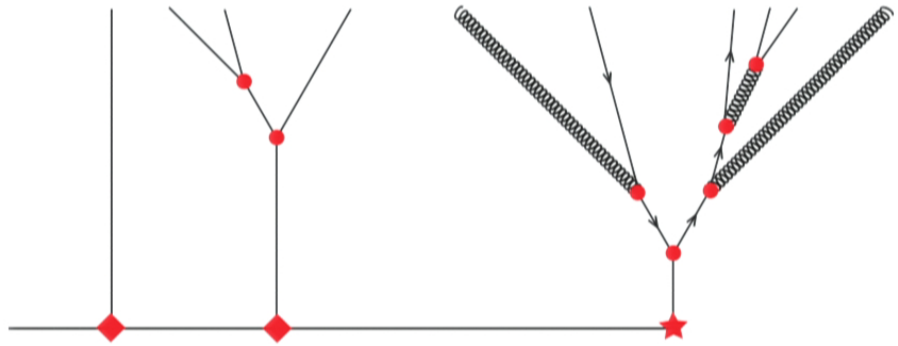
jet shapes

Peter asked me to show SD

Fat jet: R=1.2, anti-kT



microjets
R=small, kT

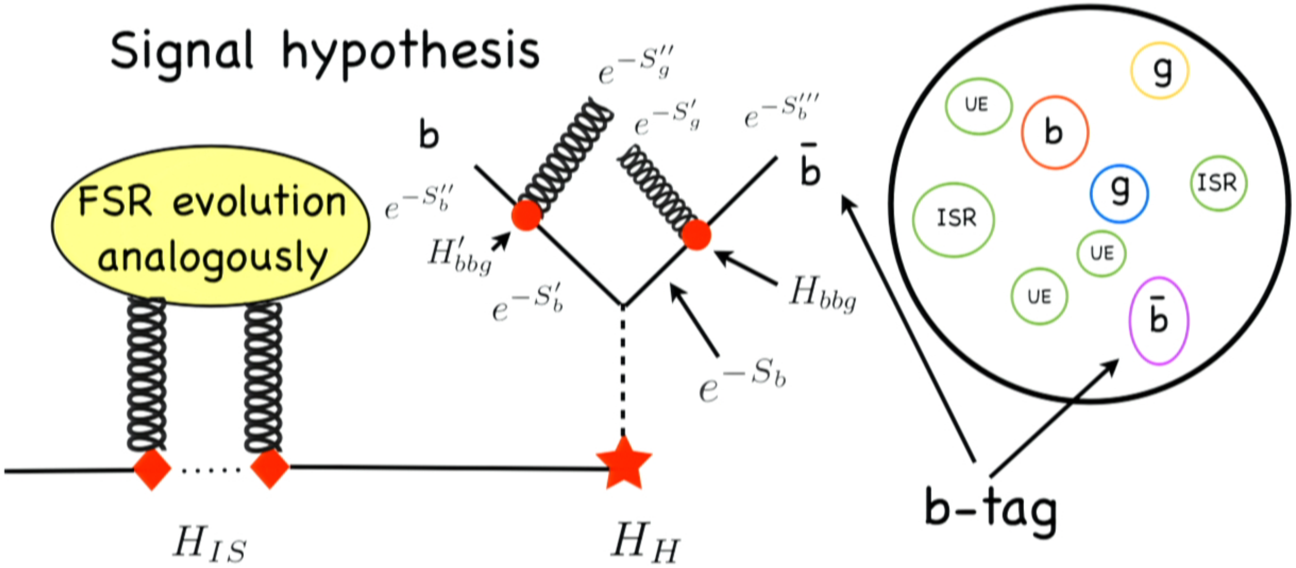


Build all possible shower histories

signal vs background hypothesis based on:

- Emission probabilities
- Color connection
- Kinematic requirements
- b-tag information

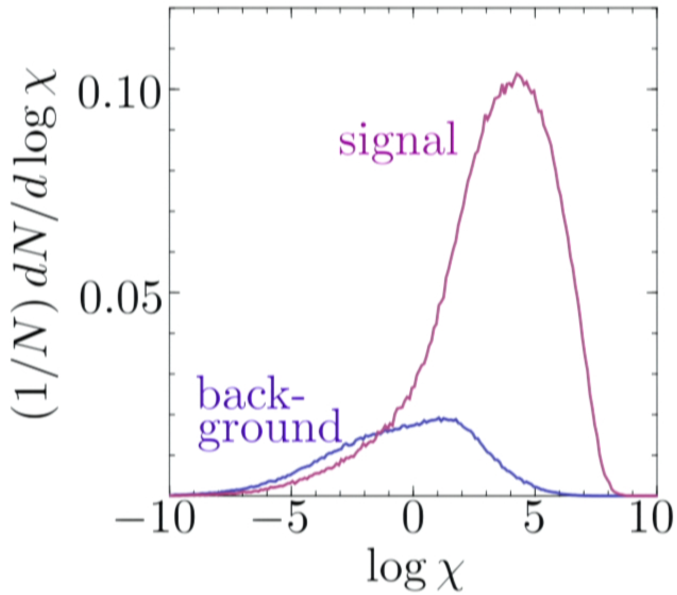
Signal hypothesis



Wrapping up all factors gives weight for shower history

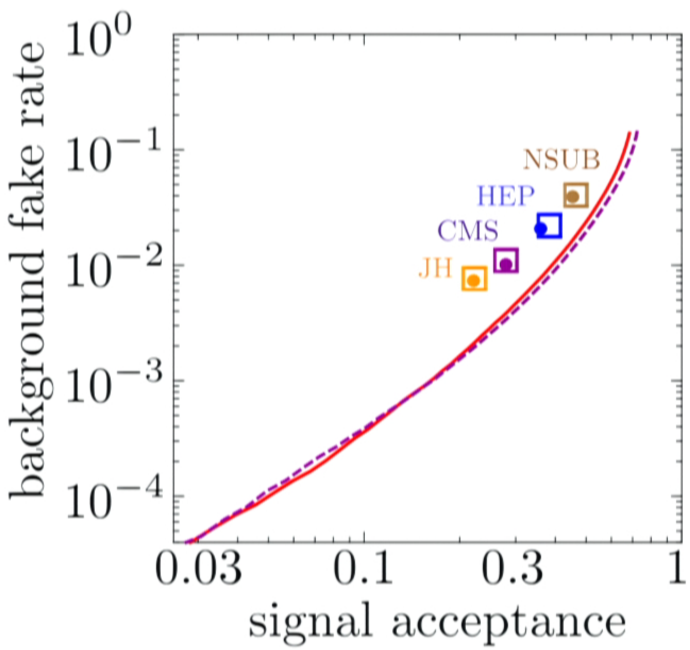
$$\chi = \frac{\sum_{ISR/Hard}\left(\sum_i \mathrm{ISR_i} \times \sum_j \mathrm{Signal_j}\right)}{\sum_{ISR/Hard}\left(\sum_i \mathrm{ISR_i} \times \sum_j \mathrm{Backg_j}\right)}$$

Here $\mathrm{Signal_1} = \mathrm{H_H H_{split} e^{-S_{split}} H_{bbg} e^{-S_b'} e^{-S_b'''} e^{-S_g'} H'_{bbg} e^{-S_b''} e^{-S_b} e^{-S_g''}}$

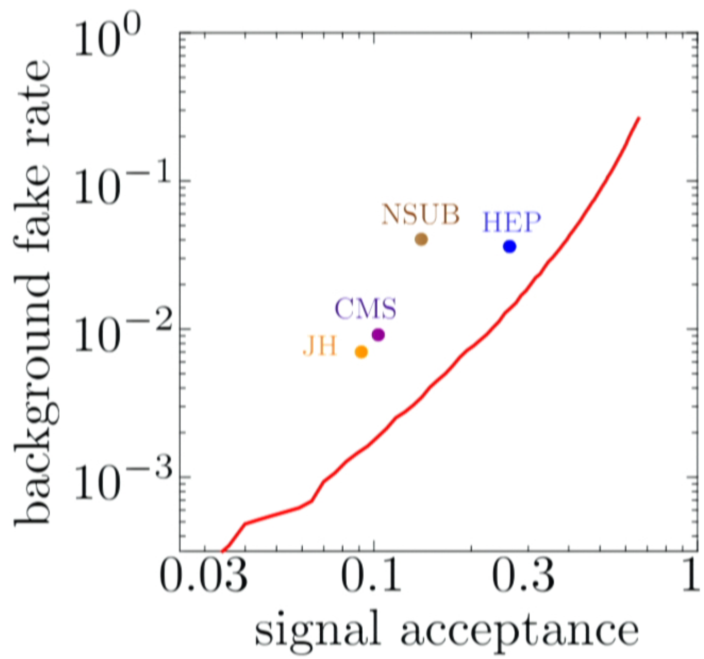

(1/N) dN/d log χ
0.10
0.05
signal
back-
ground
−10
−5
0
5
10
log χ

Input for SD: small jets with R=0.2 and pT>5.0 GeV

fat jet pT>500 GeV and R=1.0:

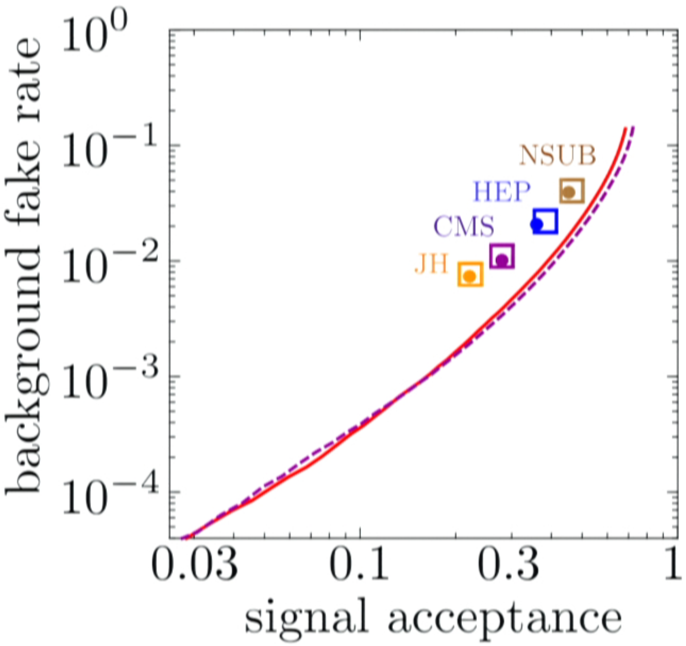


fat jet pT>200 GeV and R=1.5:

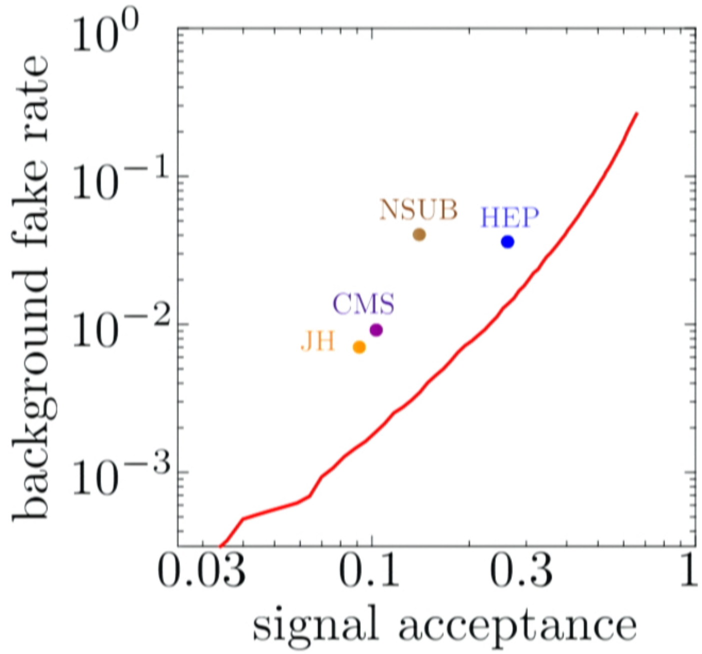


Input for SD: small jets with R=0.2 and pT>5.0 GeV

fat jet pT>500 GeV and R=1.0:



fat jet pT>200 GeV and R=1.5:



Apply BSM discoverer (N-subjets) to all-hadronic final state

If $m_j < m_{cut}$, j is a subjet

If not, uncluster last step

If $R_{j1j2} < R_{cut}$, j is a subjet

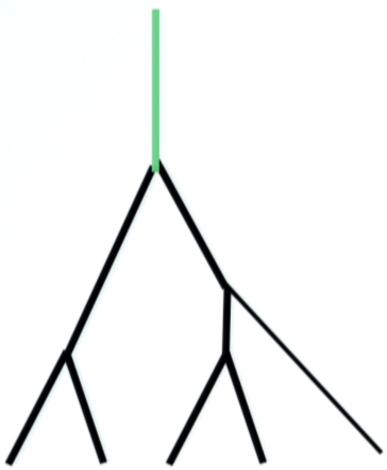
If $p_{T\,j2} < y_{cut}\, p_{T\,j}$, j2 throw out

If $p_{T\,j2} < p_{T\,cut}$, j2 throw out

Iterate

Subjet Counting

by reversing the CA tree



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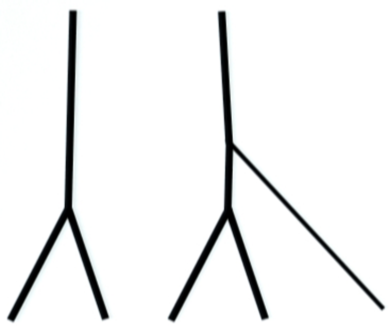

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Iterate

3 Subjets

Subjet Counting

by reversing the CA tree

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If not, uncluster last step

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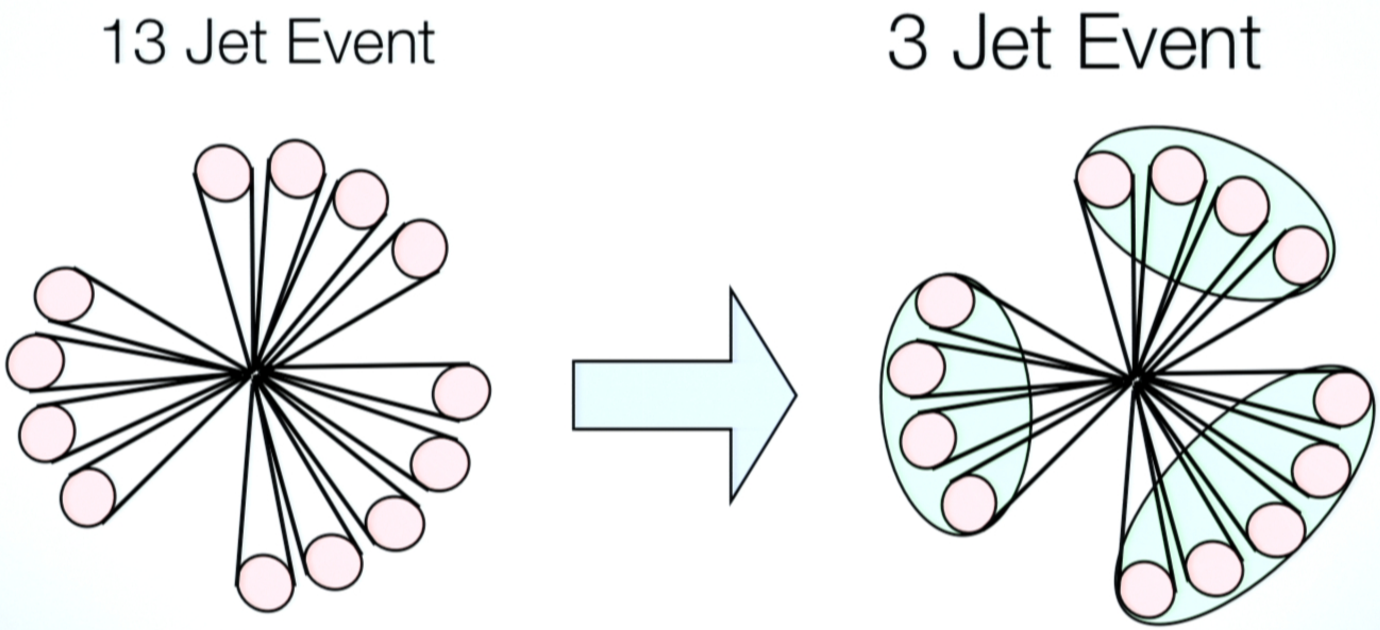
If $p_{T\,j2} < p_{T\,cut}$, j2 throw out

Iterate

3 Subjets

[Wacker]

High multiplicity final states will appear as multiple fat jets, but with unusual fat jets



[Wacker]

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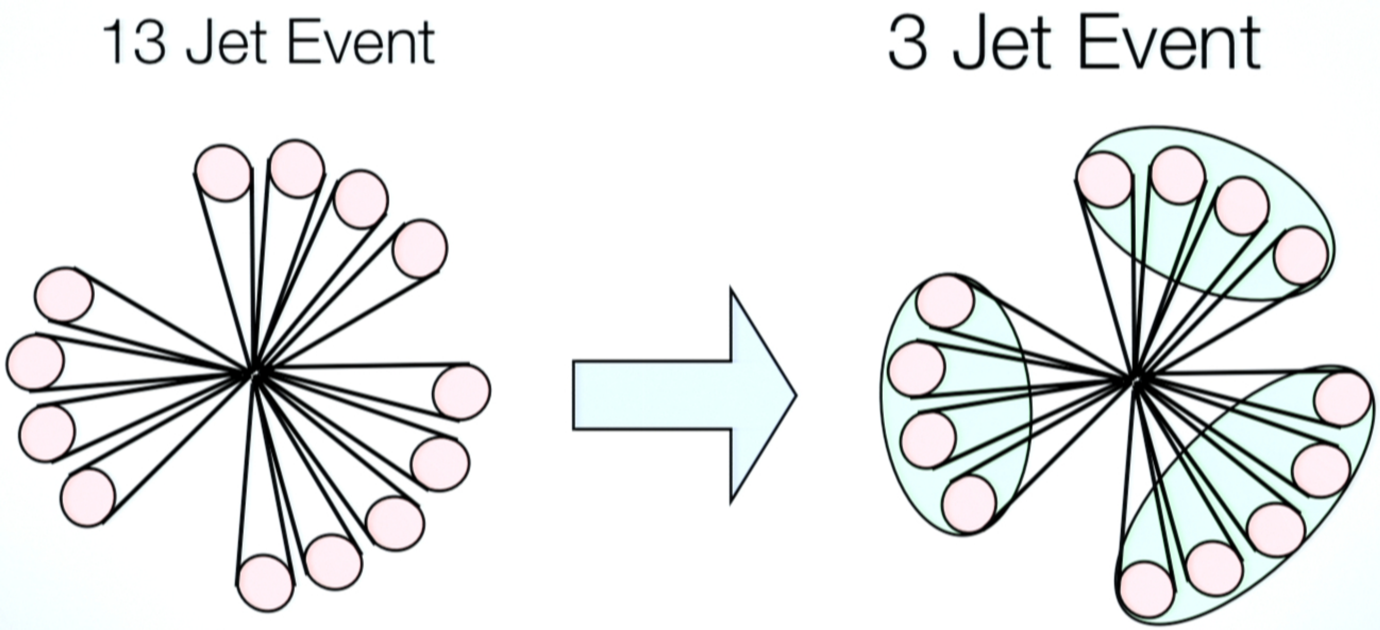
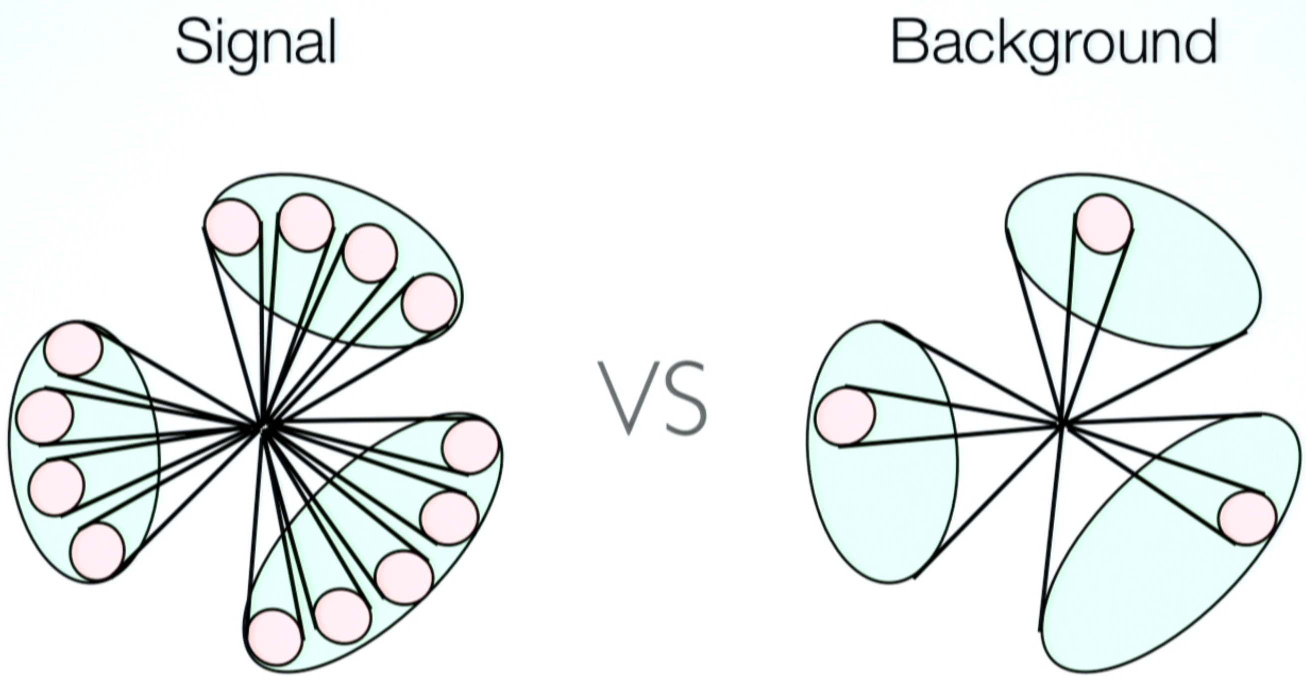


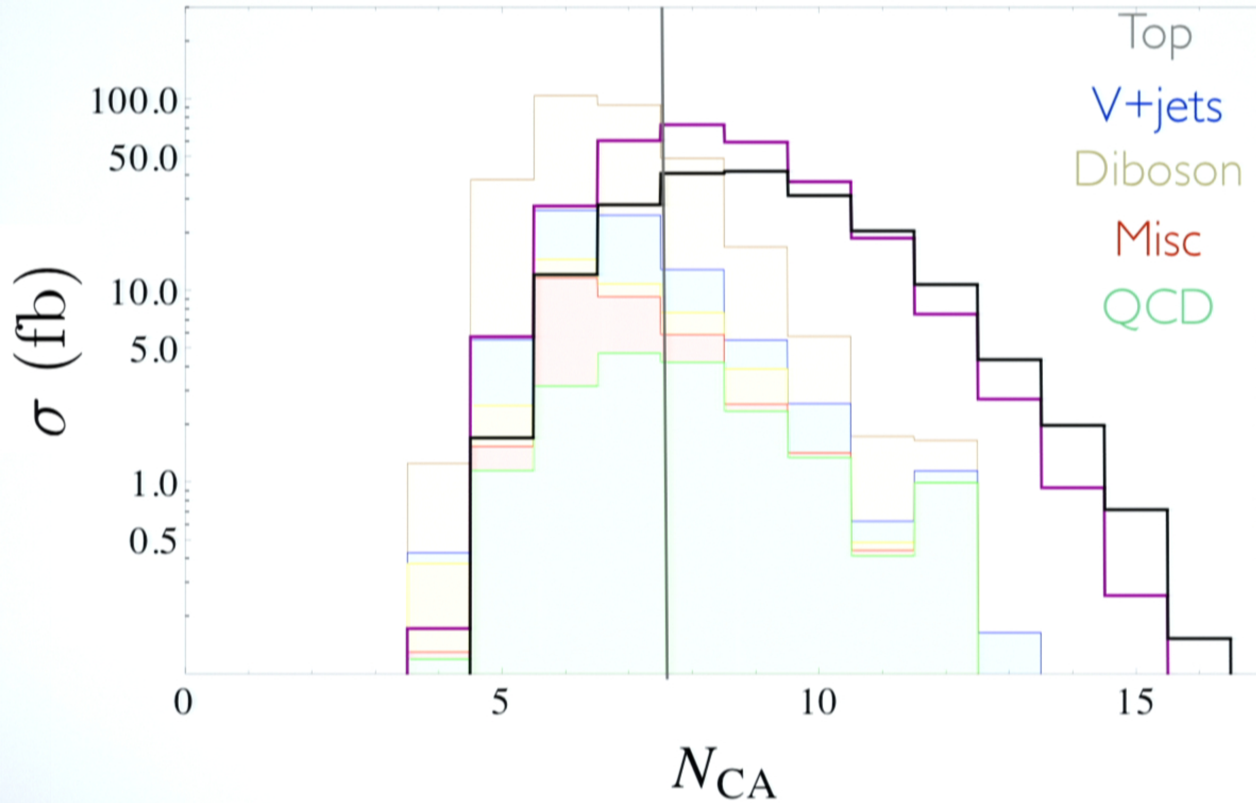
DISCOVERY PROCESS



4 Fat Jets, p_T > 100 GeV

After $\not{E}_T > 150$ GeV & M_J > 280 GeV

N_J Distribution



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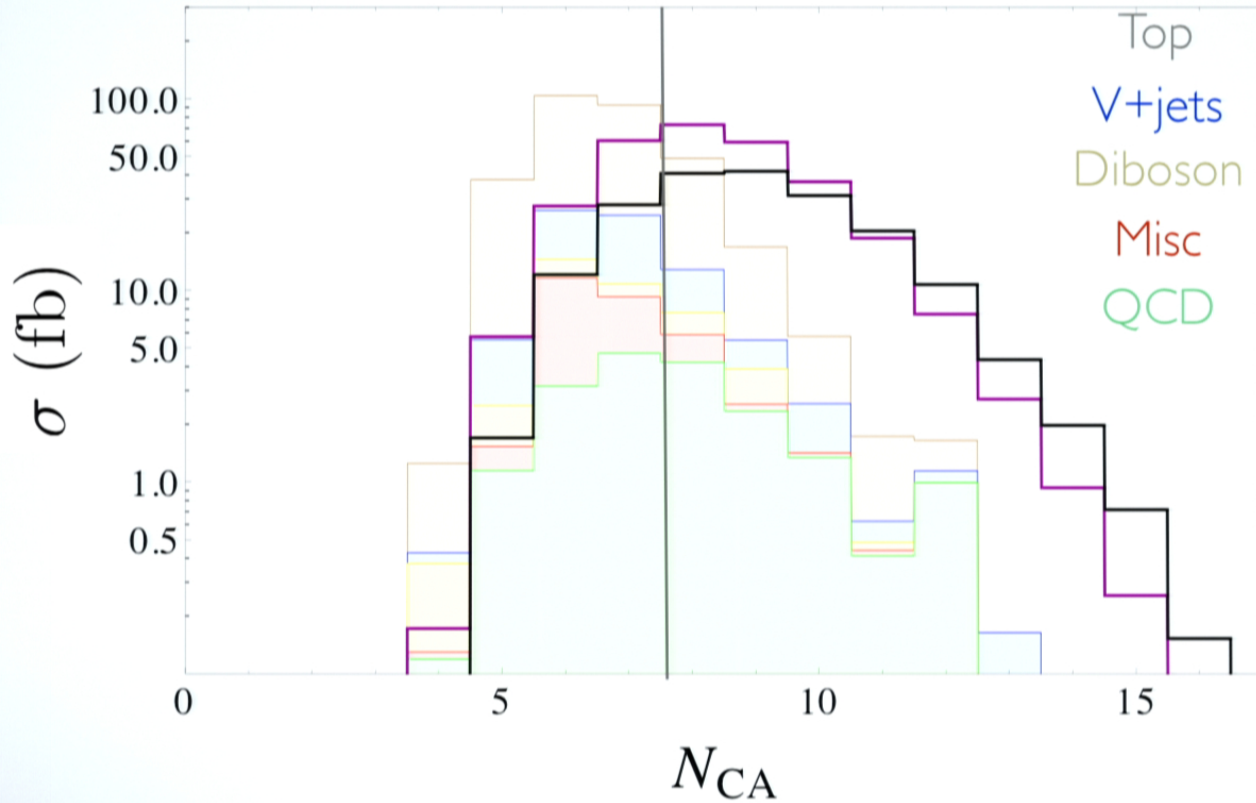

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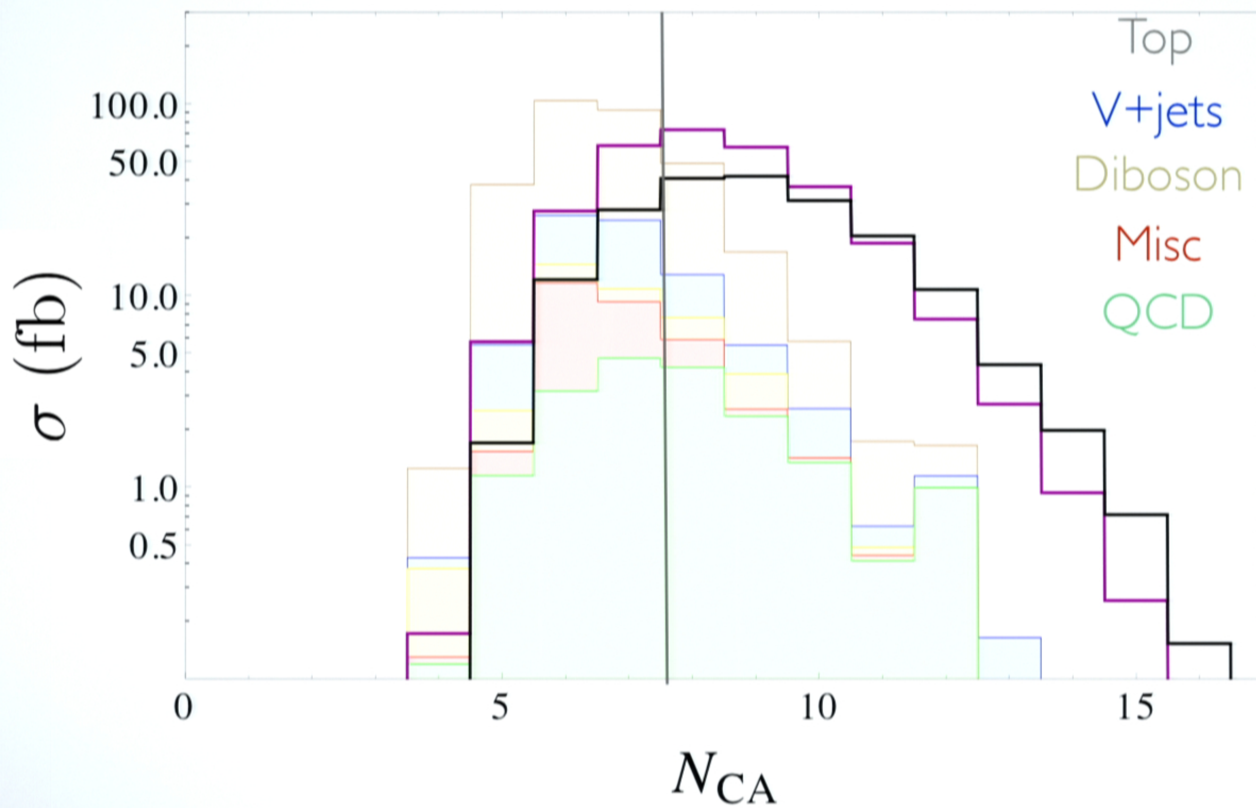


Summary

Jet substructure community is small, but young and energetic -> thus remarkably active

Back to basics!

Let's not forget to help searching for new physics
but make sure at the same time
to improve our theoretical understanding of tools

Experimental Considerations for Jet Substructure Reconstruction and Application in Searches

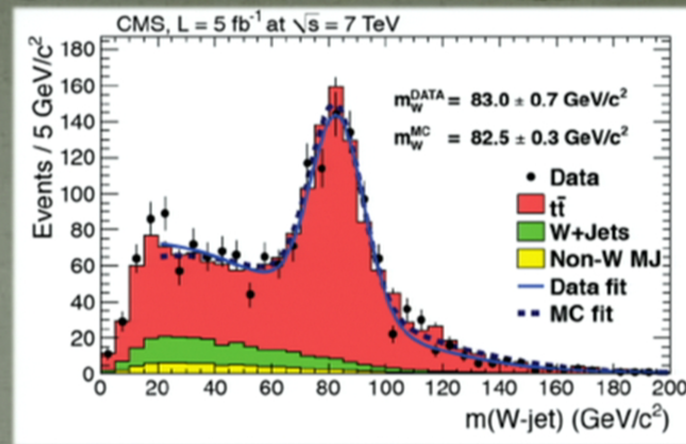
Peter Loch
University of Arizona

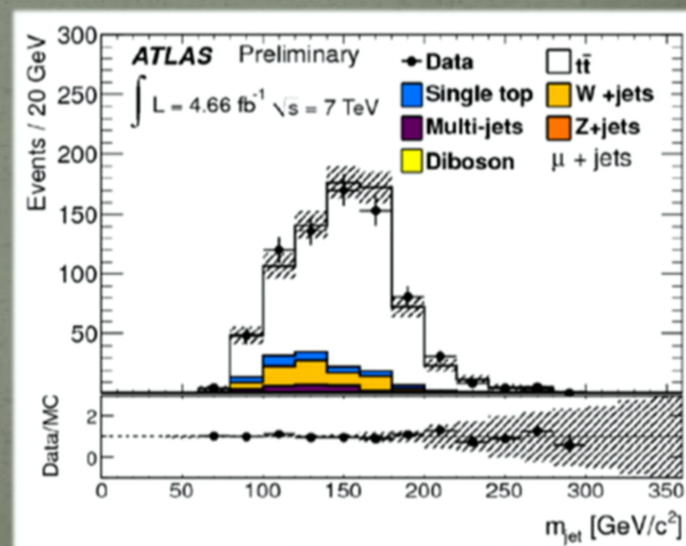
This talk…

- Basic performance of substructure techniques in data
  - For top/W tagging performance and usage in searches, see Marcel's and Andreas' talk
- Sensitivities to understanding/modeling the "soft event" in 2011/2012 running
  - Tuning – you get out what you put in?
  - Pile-up (minimum bias) and underlying event (parton shower and multiple parton interactions)
- More energy and more lumi in 2015
  - Pile-up in ATLAS & CMS
  - Detector aspects of suppressing pile-up in jet shapes, mass and subjets
  - Testing sub-structure related variables
- Conclusions

Using substructure in the experiment

- Definitively a way to go…
  - Hadronic W tagging
  - Top tagging
  - Shifting background jet masses out of signal regions
- Increasing signal significance
  - Access “boosted” regimes where resolved signal reconstruction becomes problematic
  - Shifting background out of signal regions – e.g., QCD jet masses in pruning
  - Using substructure in fat jets to explore sub-jet correlations – reduction of combinatorics etc.

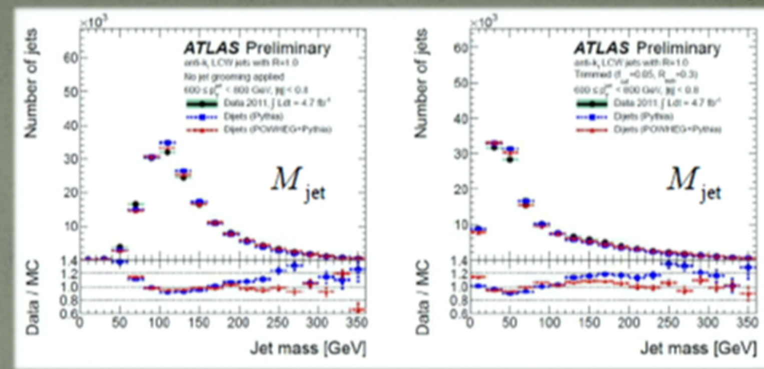




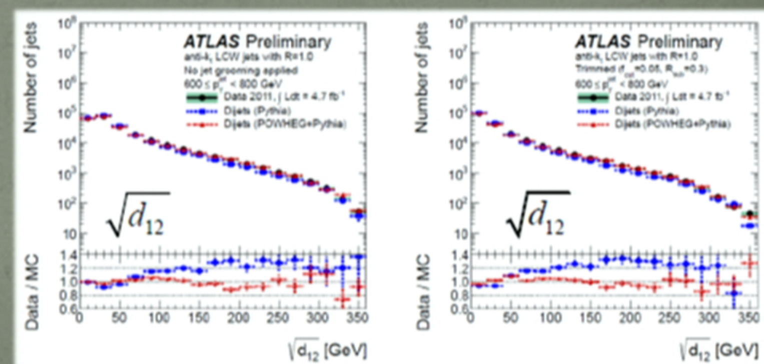
Understanding the measured subjet features

ATLAS-CONF-2012-065

- Goes surprisingly well…
  - Jet masses
  - Splitting scales
- Comparisons to LO and NLO generators
  - Jet masses
  - Splitting scales
  - N-subjetiness
- MC describes features well



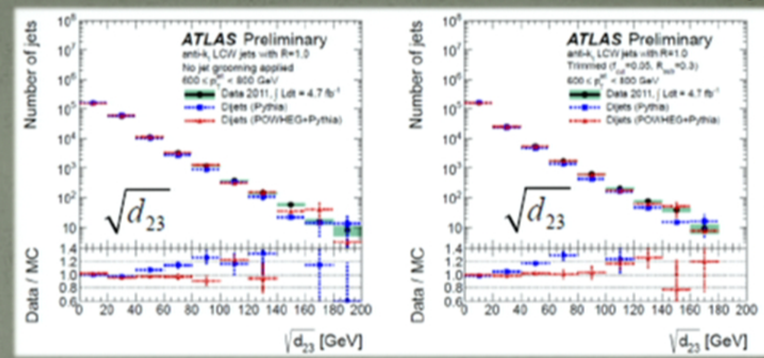
Anti-kt R = 1.0, ungroomed (left), trimmed f=0.05, R_{filt} = 0.3 (right)



Understanding the measured subjet features

ATLAS-CONF-2012-065

- Goes surprisingly well…
  - Jet masses
  - Splitting scales
- Comparisons to LO and NLO generators
  - Jet masses
  - Splitting scales
  - N-subjetiness
- MC describes features well
  - But that may not be a complete surprise…



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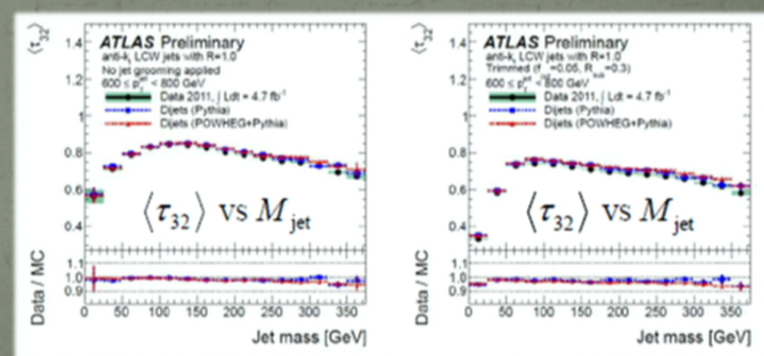

Soft physics tuning

- Description of non-perturbative features of p-p collisions important for e.g. jet shapes and pile-up modeling
  - Parton shower
  - Soft collisions
- Characterized by absence of models
  - Simple parameterization of (soft) radiation patterns observed in data
  - Energy scaling and pT cut-offs
  - Fragmentation and hadronization, FSR from LEP
- Often stressing parameterizations
  - Combined underlying event (PS, MPI) and MinBias (MPI) not always possible at sufficient quality
    - Not in PYTHIA6
    - PYTHIA8 seems to work (ATLAS tune A2)
- Note: we can only tune to unfolded distributions of observables!
- ATLAS performed 4-stage tuning with 2010 data (cleanest!)
  - (1) flavor production in fragmentation functions (LEP data)
  - (2) FSR and fragmentation (LEP data)
  - (3) ISR and primordial kT (ATLAS jet data)
  - (4) MPI tuning (ATLAS jet data for UE, ATLAS MinBias data for Pileup)
- Note that (1)-(4) are UE tunes while (4) can also include a MinBias tune
  - ATLAS provides two different tunes
- MinBias tune validation for 2012
  - Dedicated low mu run
- Both UE and MB tuning are relevant for substructure observables sensitive to small signals
  - Parton shower features
  - Pile-up features

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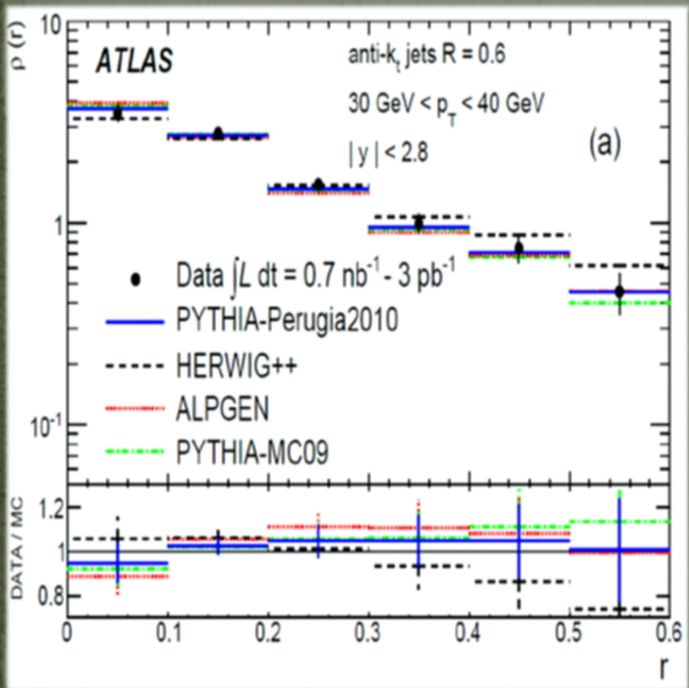
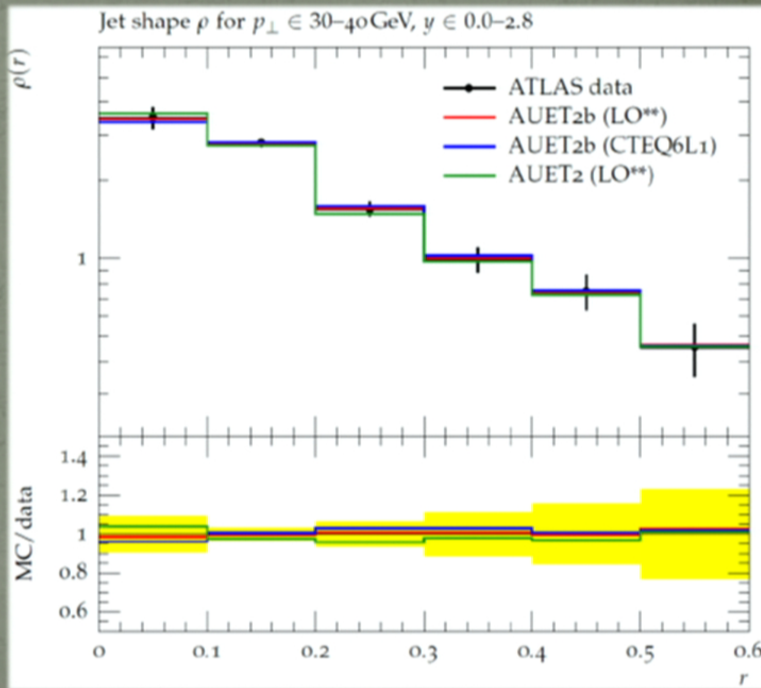
ISR and Primordial kT Tuning (UE)

(Phys.Rev.D83:052003,2011)



Before tuning to LHC data

(ATL-PHYS-PUB-2011-009)



After tuning to LHC data

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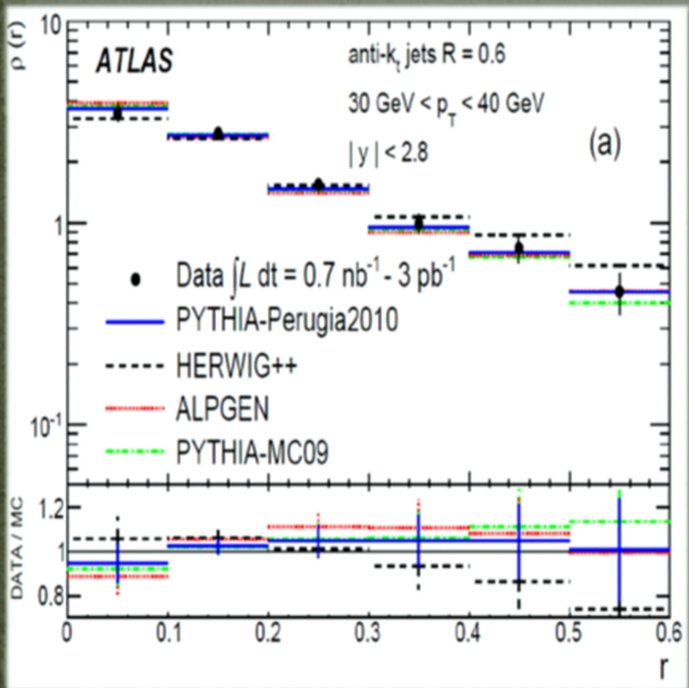

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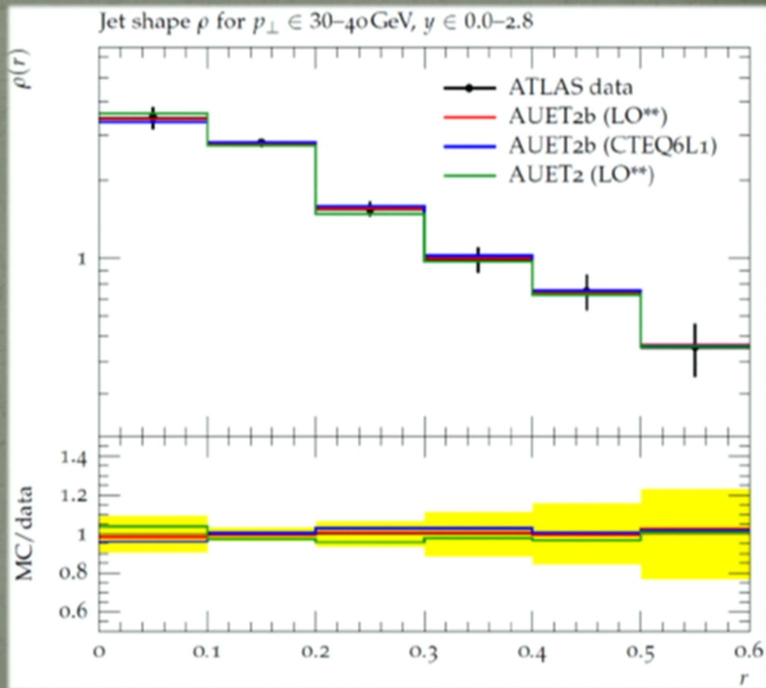
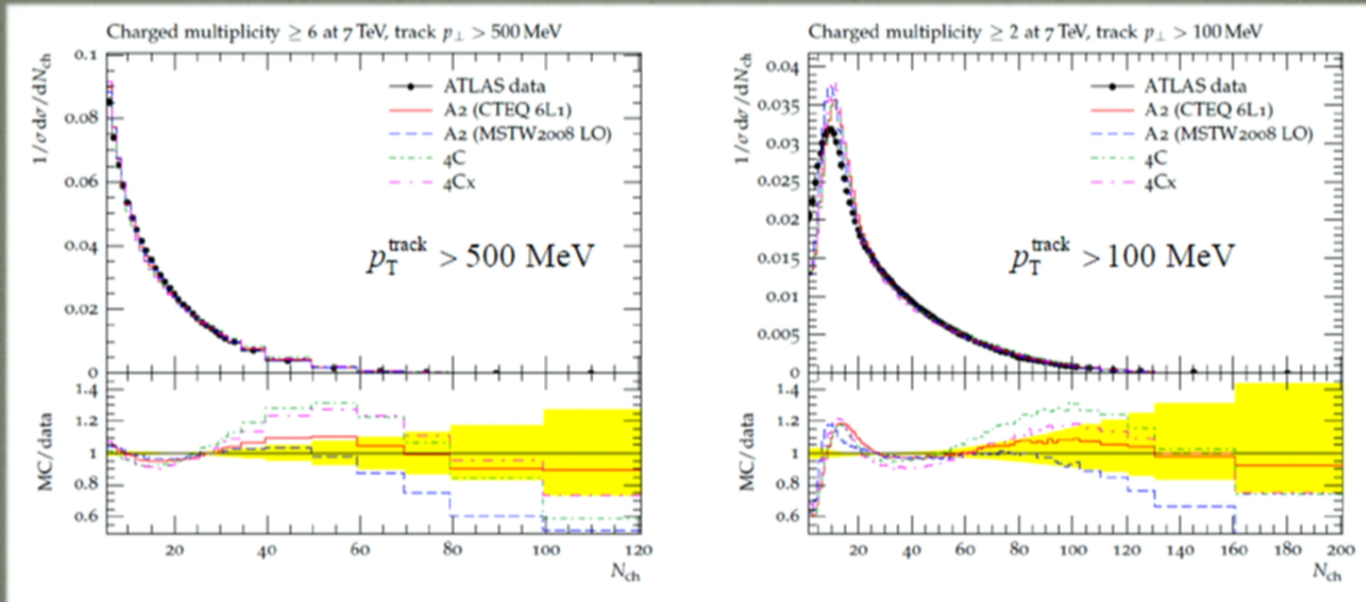


After tuning to LHC data

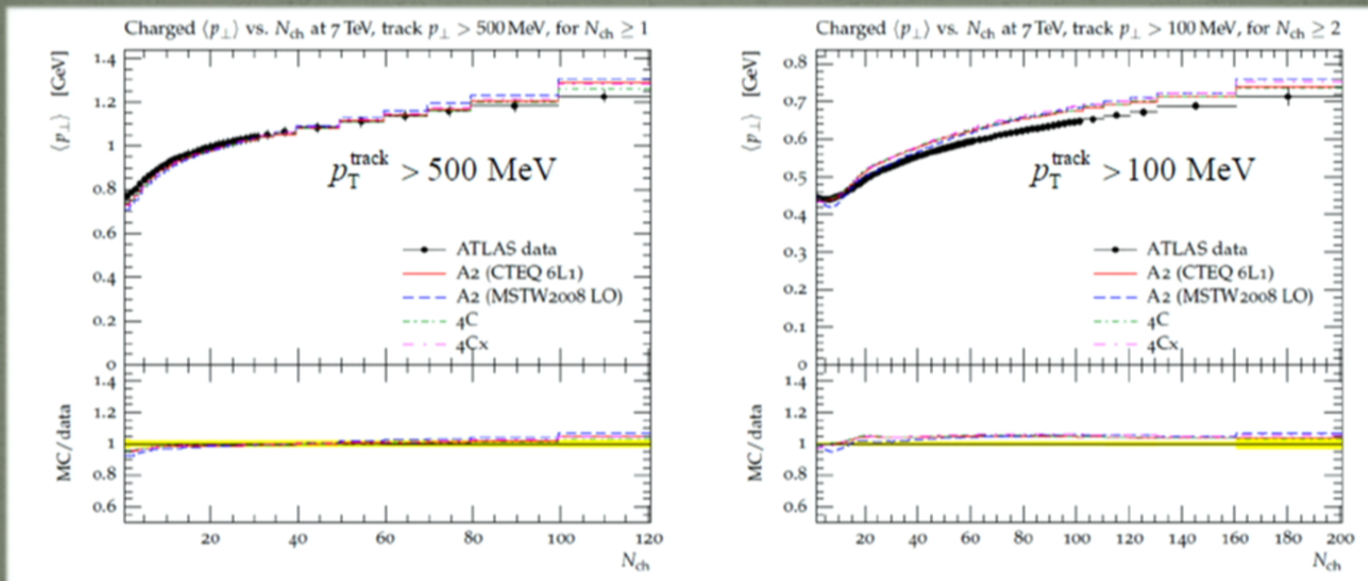
MinBias tuning features: charged multiplicities

(ATL-PHYS-PUB-2012-003)



MinBias tuning features: average pT versus charged multiplicities

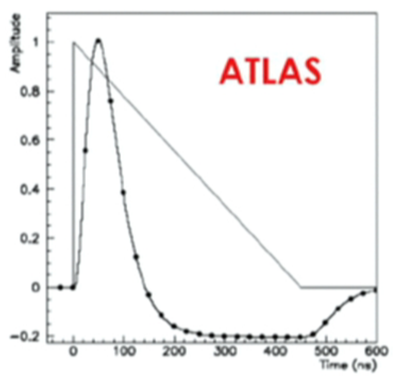
(ATL-PHYS-PUB-2012-003)

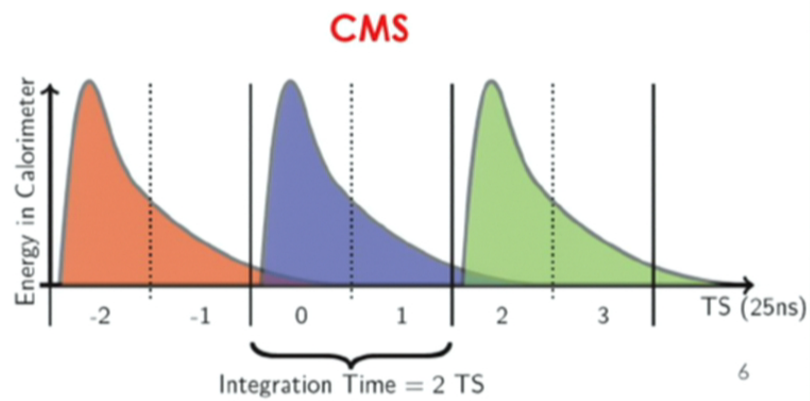


Pileup

(A. Schwartzman, talk at "**Joint Snowmass-EuCARD/AccNet-HiLumi LHC meeting 'Frontier Capabilities for Hadron Colliders 2013**', February 21, 2013)

- **ATLAS LAr calorimeter has a very large integration time relative to bunch spacing:**
  - **Out-of-time** pile-up contributions
  - bi-polar shape compensates, on average, for both in-time and out-of-time pile-up, but out-of-time effects vary significantly within sub-detectors (eta-dependence)
  - ATLAS needs both in-time and out-of-time pile-up corrections
  - No directly handle on event-by-event out-of-time contribution
    - Cannot reduce out-of-time *fluctuations*
- **CMS is mostly insensitive to out-of-time pile-up:**
  - 2 time-slices (TS) for integration





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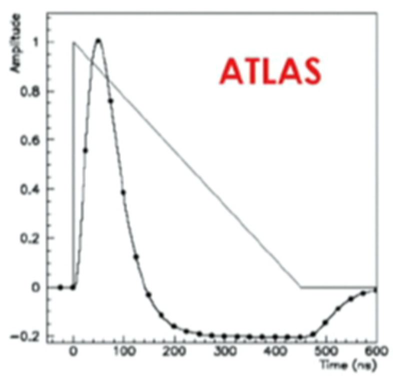

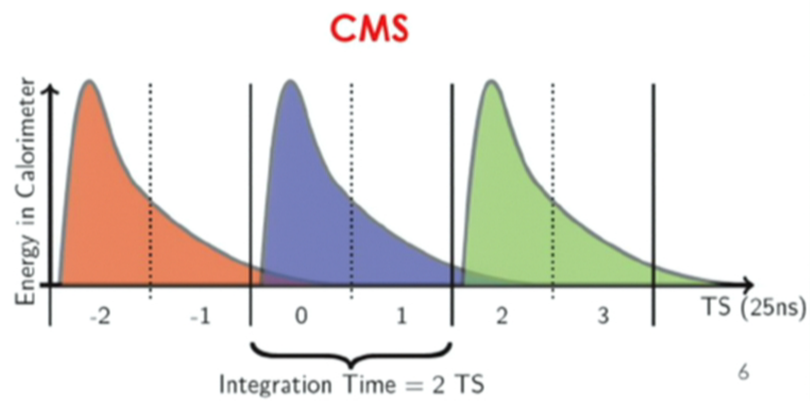

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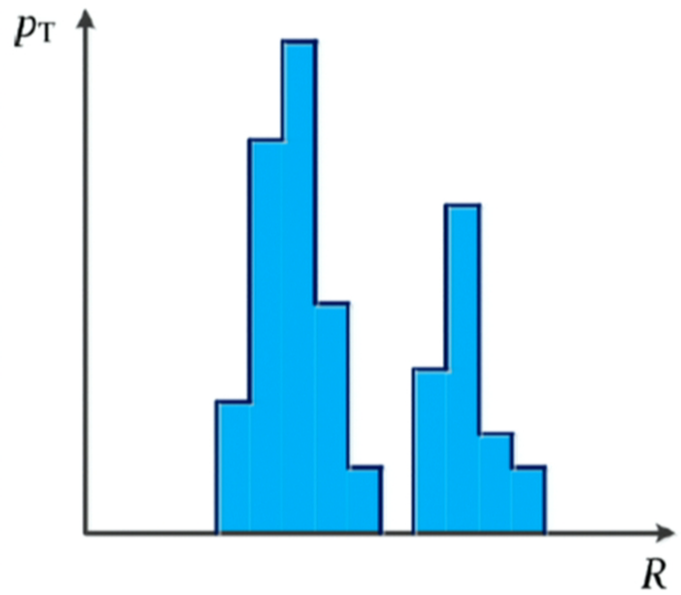
Schematic view on pile-up – and a naïve way of dealing with it…



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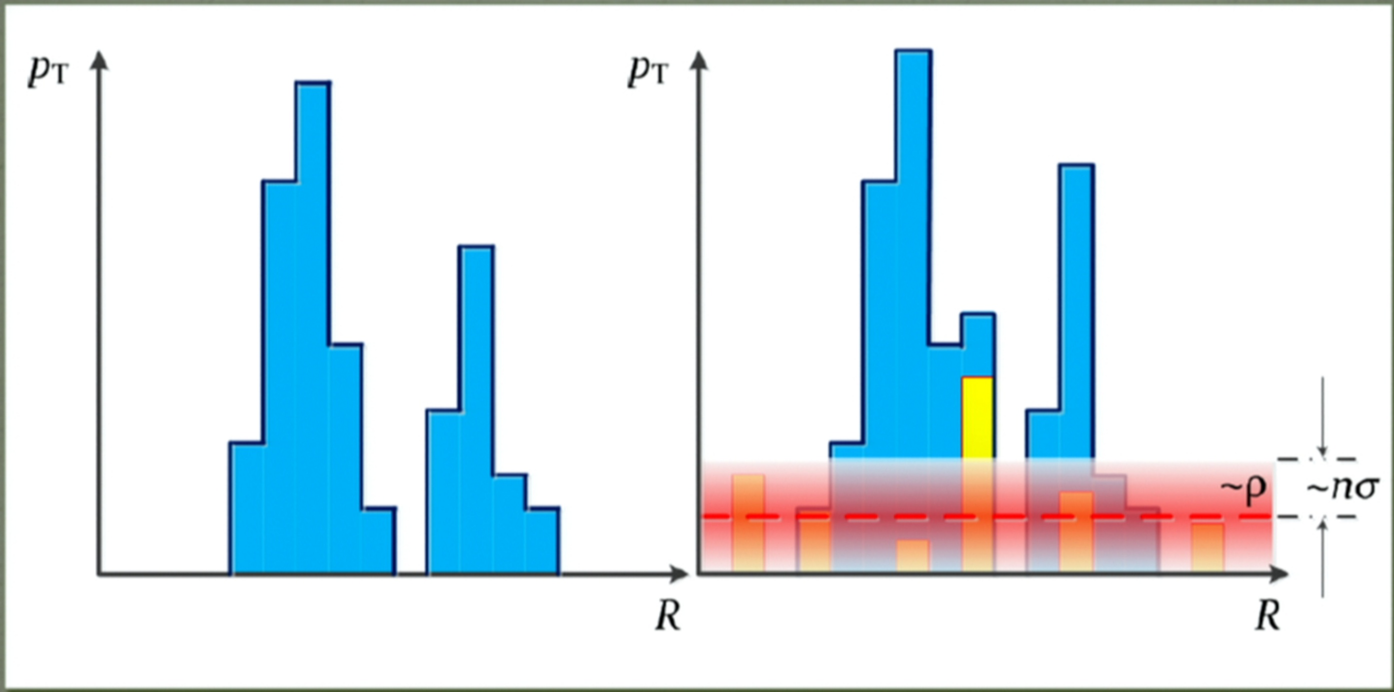
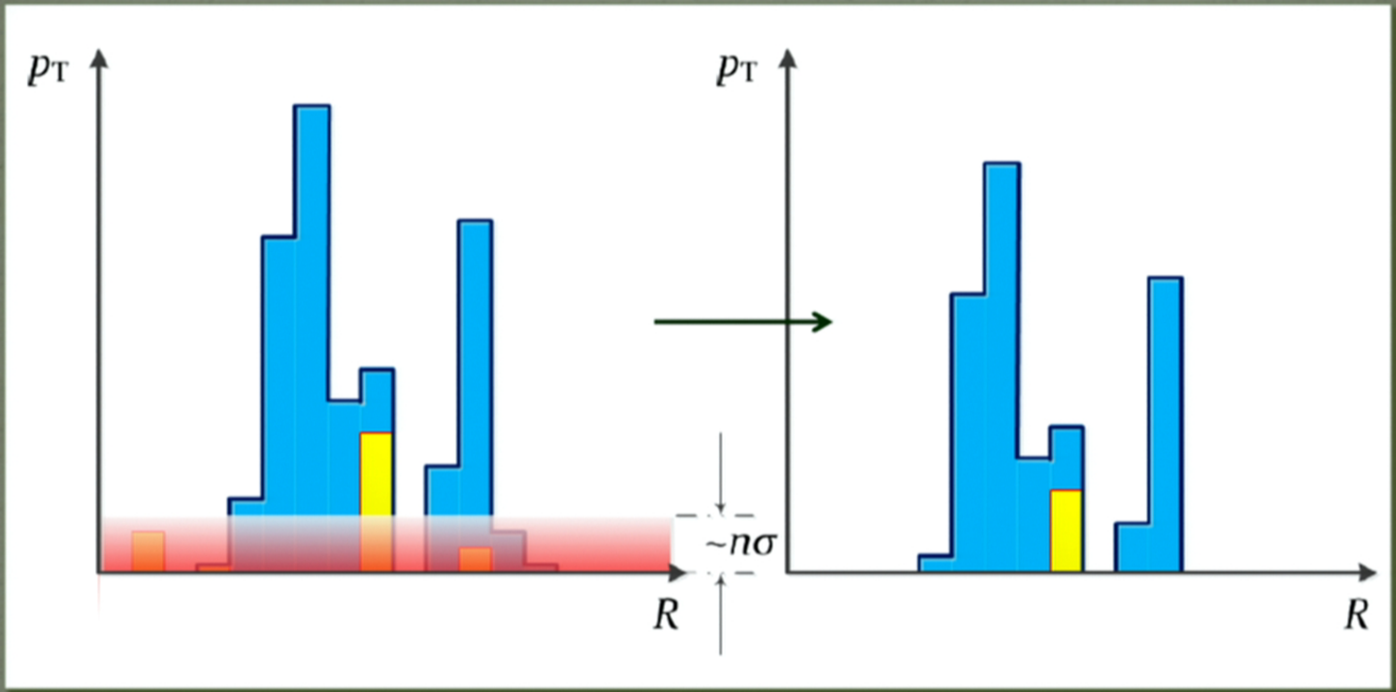


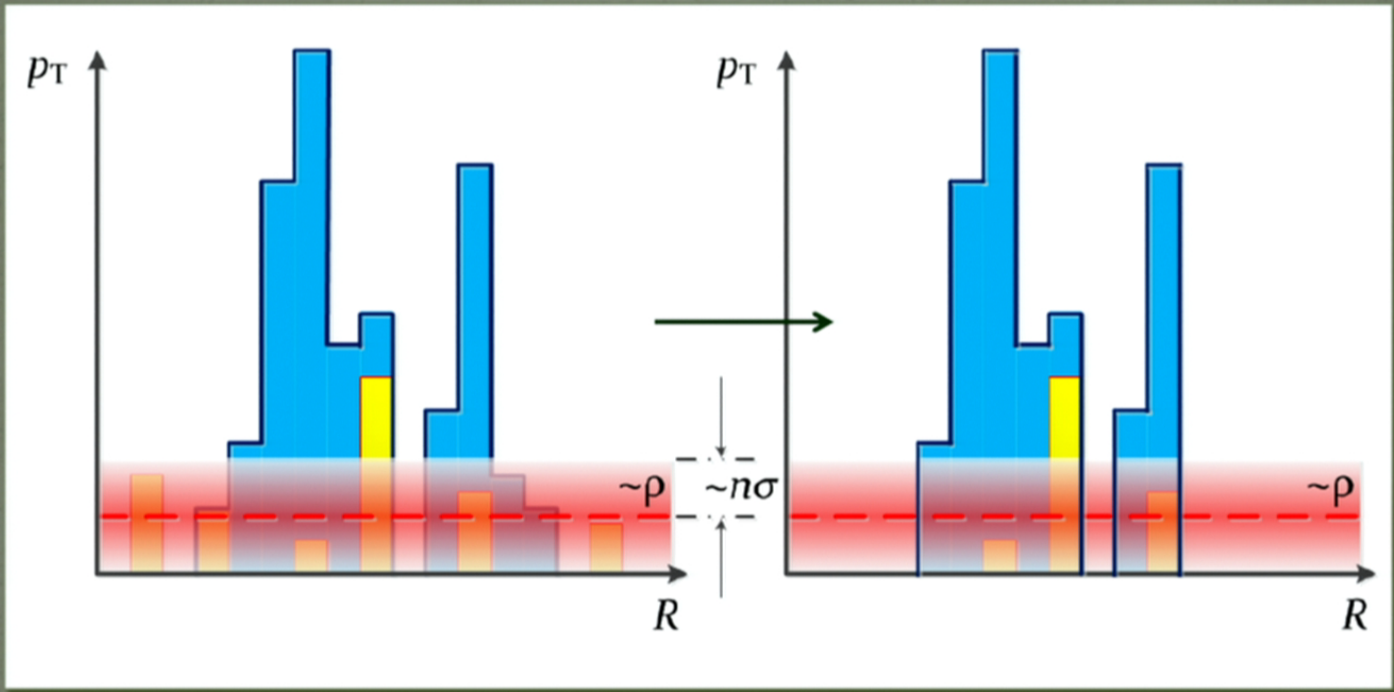
Add pileup at a level corresponding to ρ with local fluctuations σ

Schematic view on pile-up – and a naïve way of dealing with it…



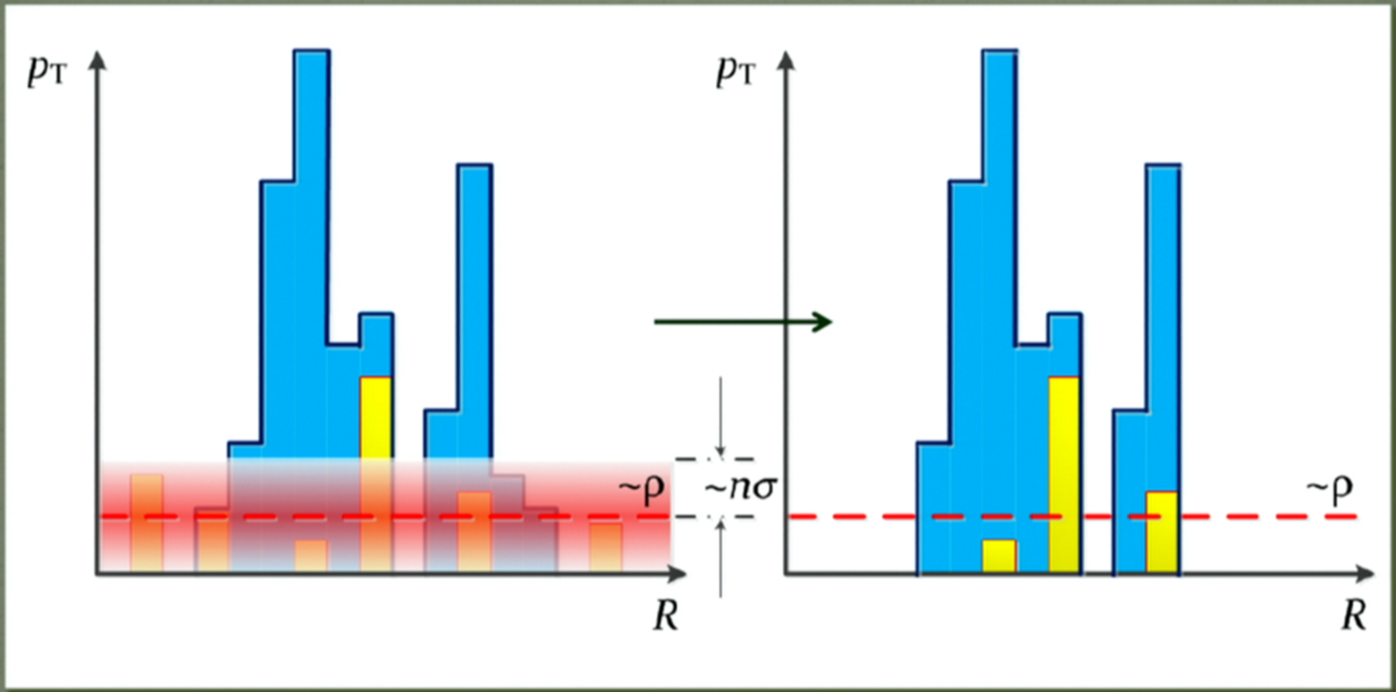
Subtract baseline and apply "noise cut" (cut method)

Schematic view on pile-up – and a naïve way of dealing with it…



Select signals above noise (filter method)

Schematic view on pile-up – and a naïve way of dealing with it…



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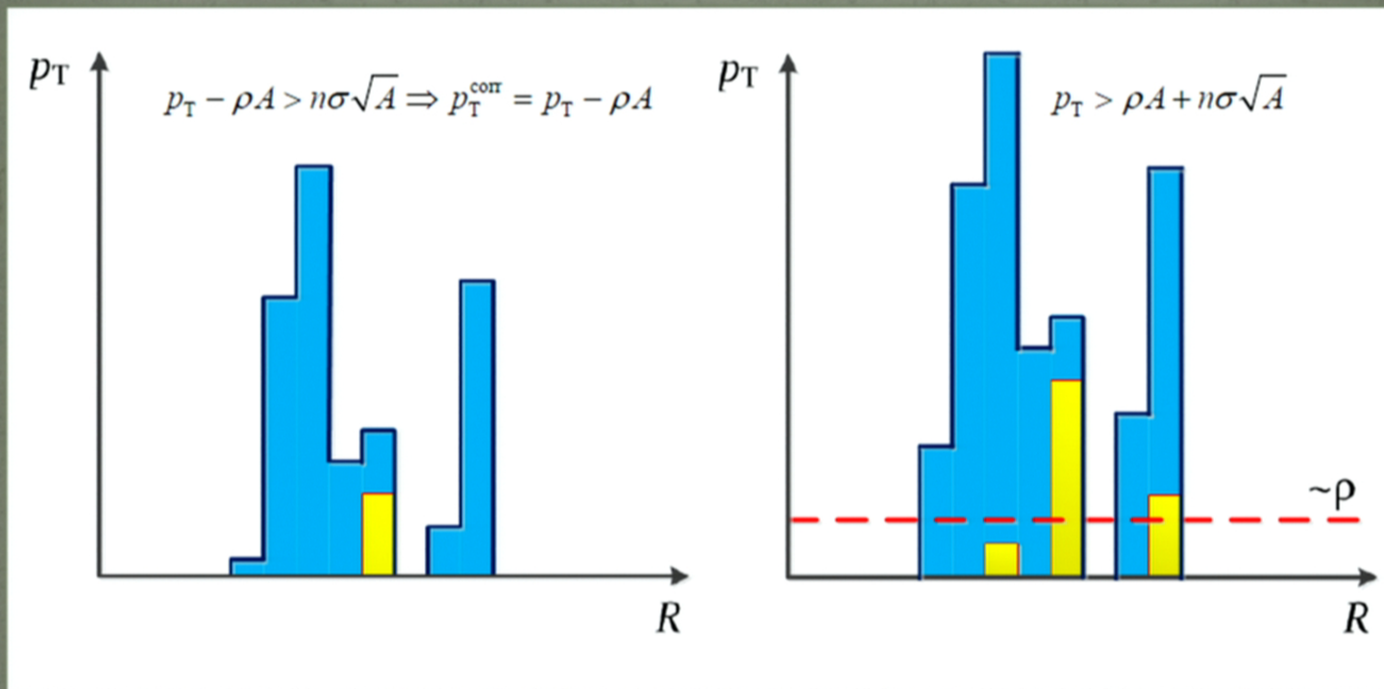


Detector level pile-up suppression (1)

- Pile-up is an experimental condition typically adding energy
  - Ideally to be addressed at the level of signal reconstruction
  - Corrections need to suppress signal baselines (in-time pile-up) and the corresponding global (event-by-event) fluctuations
  - Corrections ideally should suppress local fluctuations from signal history (out-of-time pile-up) – provide stable signal at smallest possible (distance/energy) scales with high likelihood to be "true"
- Naïve noise-cut like corrections are likely too hard for substructure
  - Presence of hard signals in a (sub)jet suggest that close-by soft signals are valid/important/"true"… (e.g., generated by small angle radiation…)
  - Group of smallish signals in close proximity may indicate relevant signals – we tried very hard to keep coherent detector noise down!
  - Topological considerations appropriate – jet grooming techniques!

Detector level pile-up suppression (2)

- First step of trimming provides well motivated signal collection
  - Small R jet finder follows topology/transverse energy flow inside jet
  - Connects small signals with close-by larger signals
- Initially constructed small R jets can be evaluated with respect to pile-up baseline and noise
  - Keep only those above threshold without modifying their pT (selection only)
  - Keep only those above threshold but subtract baseline pT as given by transverse energy density and small jet area
- Both approaches have been tested at particle level
  - Les Houches 2011 (Soyez, Francavilla, PL,...)

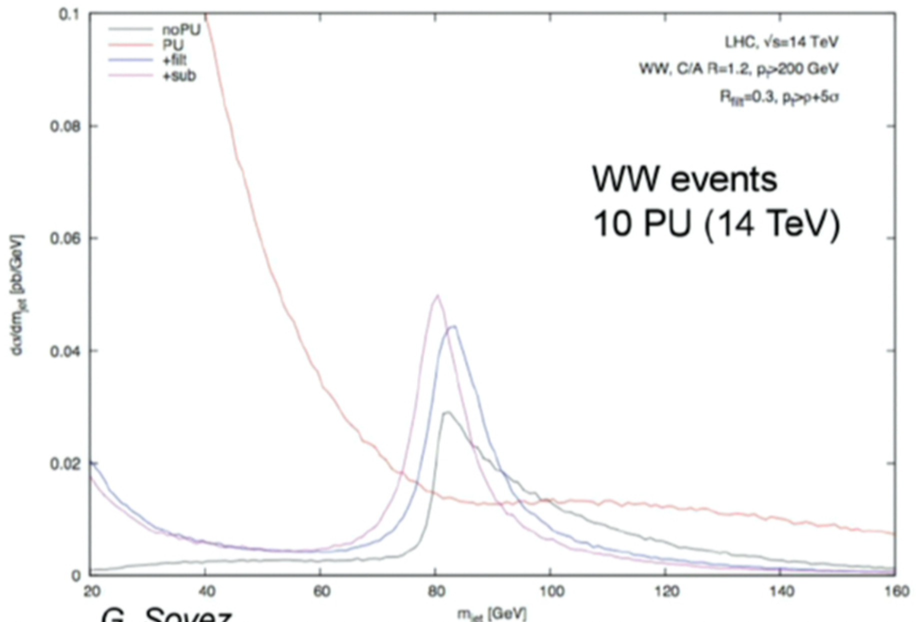
Trimming based pile-up suppression

Start with big jet : C/A, R=1.2

→ Recluster (R_{filt}= 0.3)

→ Keep only sub-jets with $p_T > \rho A + 5\sigma\sqrt{A}$

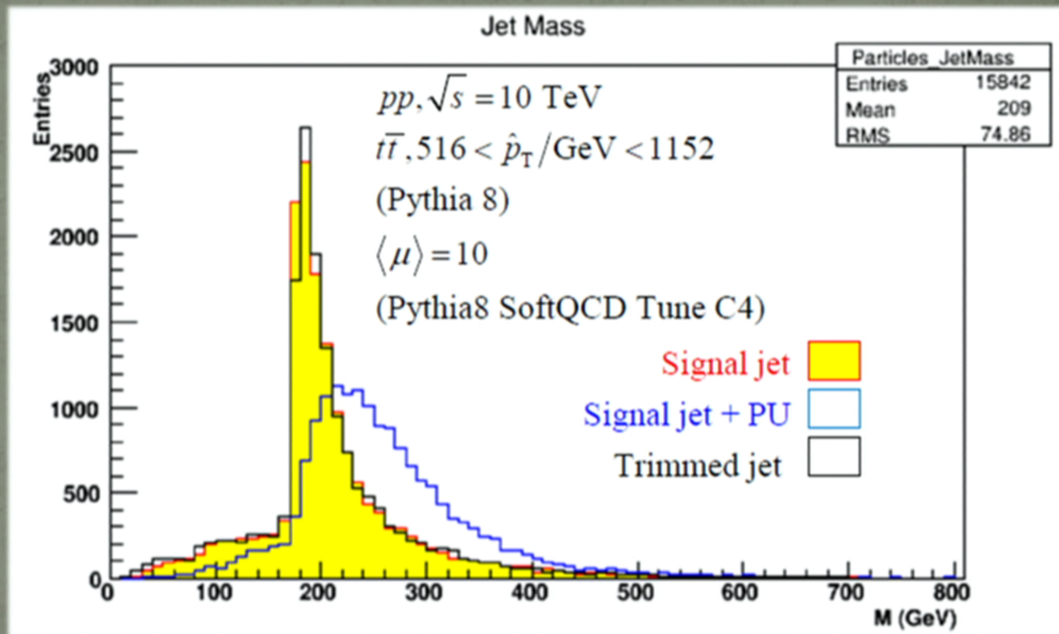
→ Keep only subtracted sub-jets with $p_T > 5\sigma\sqrt{A}$



G. Soyez

R_{filt}, n_{filt}, p_T^{cut} being optimised

Top mass tagging



$K_T, R = 1.2$

Trimming, $R_{\text{filt}} = 0.3$

$p_T^{\text{subjet}} > \rho A^{\text{subjet}} + 3\sigma\sqrt{A^{\text{subjet}}}$

Trimming based pile-up suppression

Start with big jet : C/A, R=1.2

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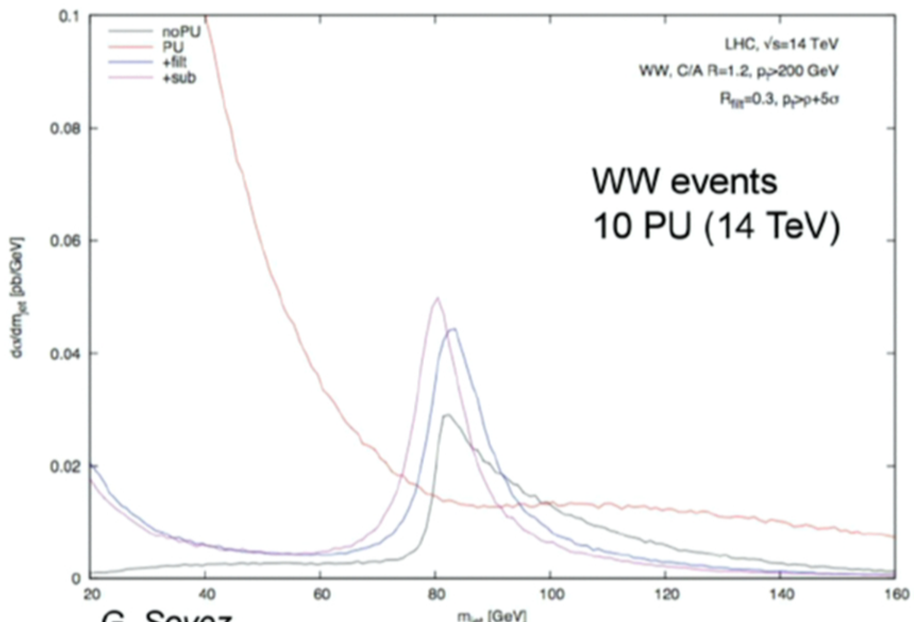
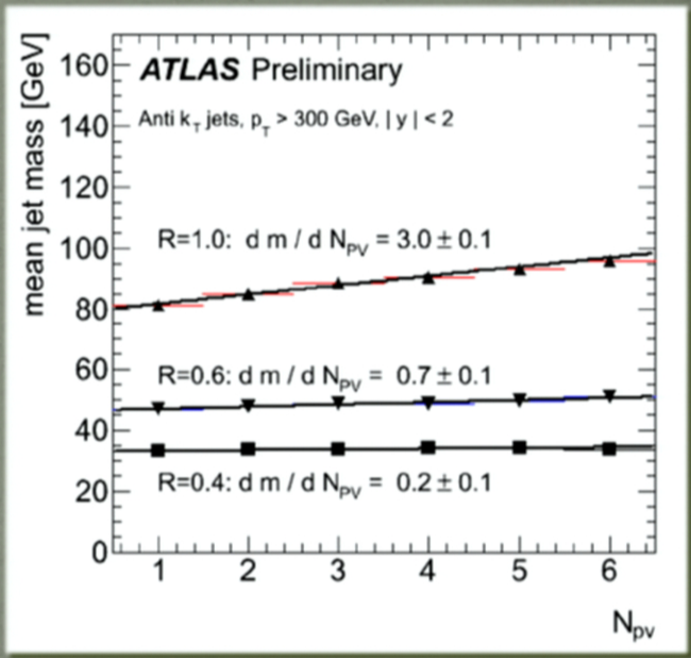


G. Sovez

R_{filt}, n_{filt}, p_T^{cut} being optimised

Experimental observations

- Jet mass good test bed
  - Effect of in-time pile-up in 2010 data in ATLAS – clean (no out of time pile-up)
- Grooming techniques can mitigate pile-up effects
  - Also change the global mass –scale – dedicated calibration!



Other experimental considerations

- Evaluation of tagger performances
  - It is not obvious that ATLAS and CMS can be directly compared with respect to tagging performance – different effects of pile-up, very different fluctuations in basic signals, different reconstruction cuts…
  - Comparisons and optimizations within one experiment is of course possible
- Can we get the detectors more out of the way?
  - Correction/unfolding of principal observables before substructure analysis?
  - Unfolding hard to imagine (is based on distributions)
  - Correction procedures may suffer from reliable/stable "truth" reference – especially for small signals
  - Clearly unfolding can be done at the level of distributions of scoring variables
- Some concerted effort would be nice…
  - Likely not much manpower/interest in the collaborations, but a few dedicated people will do!

New taggers or additional tagger configurations?

- Shower deconstruction deserves a harder look
  - Need to understand effect of pile-up/corrections on deconstruction and evaluation variable
  - Control of systematics not too obvious – need to find a very well modeled and simulated control region and understand extrapolation to other phase space locations
  - Some activity in ATLAS at least
- Qjet
  - Interesting approach – but not clear how to establish systematic uncertainties
- Focus on substructure observables most stable against loss of small signals
  - Increasing luminosity will increase reconstruction thresholds (e.g., minimum pT for tracks, topo-cluster noise thresholds…)
  - Evaluation of taggers at particle level should include scenarios with acceptance limitations for individual particles (pT > 500 MeV/1 GeV – magnetic field, dead material, reconstruction thresholds – detectors are intrinsically IR unsafe and collinear instable at some small scale)

Killing observables*

- Correlations
  - It seems many observables are just slight variations of the same underlying dynamics – the jet mass and (not entirely independent) pT
  - It would be nice find the set which has the largest de-correlated components – additional information content, increased sensitivity
  - Carefully designed BDTs?
- Experimental concerns
  - We cannot really measure e.g. 2-dim correlation matrix – systematics are extremely hard to control (errors in each bin can be 100% correlated)
  - Maybe we can translate uncertainties into groups of nuisance parameters with different correlations
  - Not completely deterministic as nuisance correlations may require assumptions – often only two options (0 and 100%)

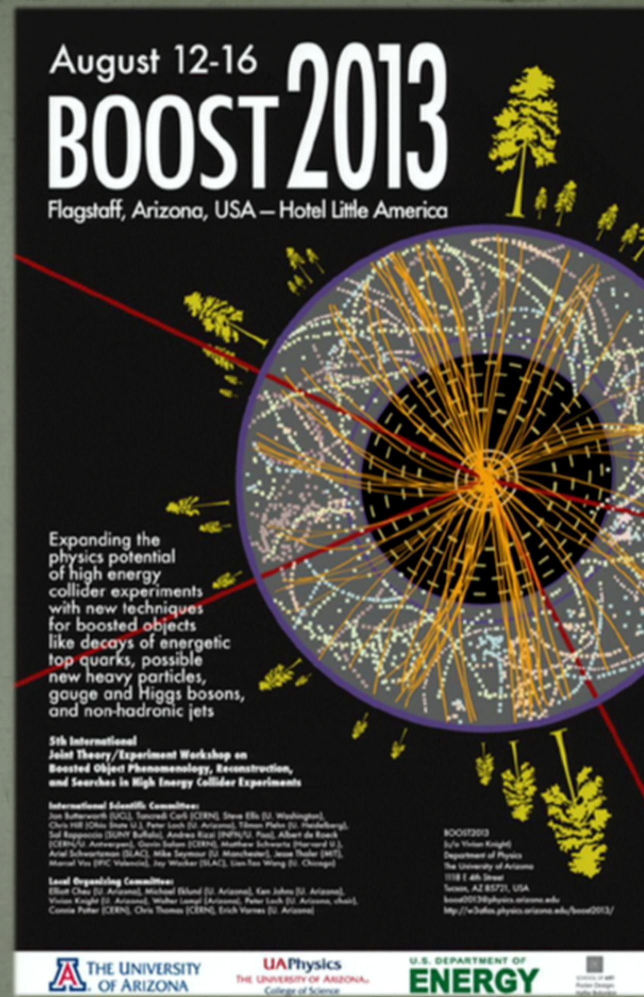
*just remembered killing tunes at Les Houches 2011

Link to phenomenology

- It is great to have all these various algorithms, but…
  - Need some focus/guidance on best performance for given final state/search goal including some experimental limitations early on…
  - … we need to get together whenever needed and see if we can get some realistic estimates before embarking on long and resource heavy projects with potentially little to now gain (e.g., this workshop, BOOST, Les Houches,…)
- Better test beds – simple detector models?
  - Some smearing and acceptance models for ATLAS/CMS-like detector (they are not that different in many respects related to jet substructure analysis) – PGD etc.

Last but not least…

- BOOST2013 is coming!
  - August 12-16, 2013 – Flagstaff, Arizona, USA
  - First bulletin next week
  - Registration and webpages go live within the next two weeks



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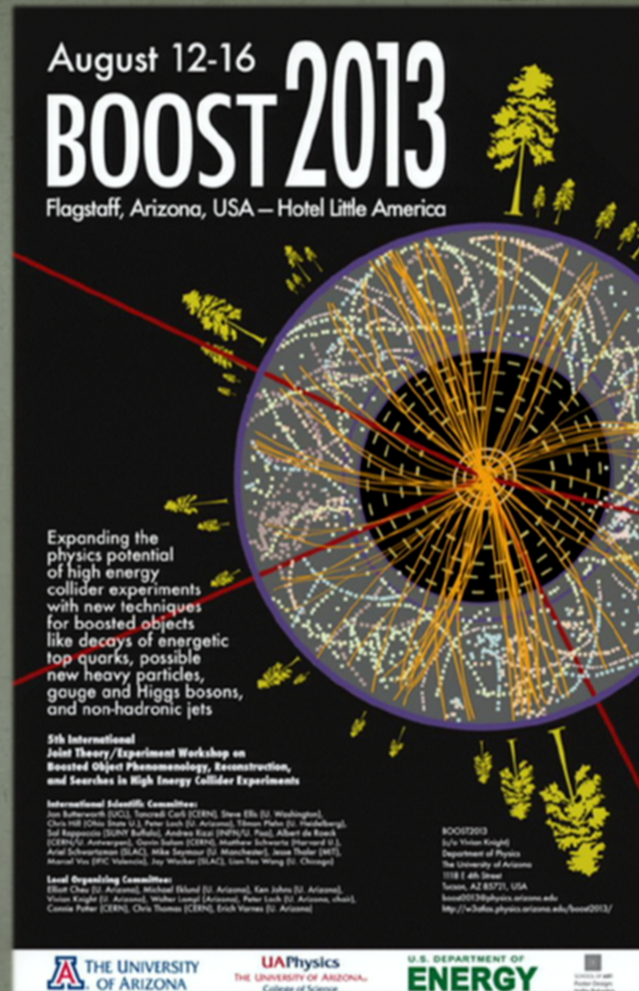

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And of course…

- Many thanks to the organizers, advisors, and sponsors for this very nice and interesting workshop!
    - Brian, Eder, David, Natalie, Phillip & everybody who helped getting us here – thank you very much!

Peter Loch (University of Arizona)