Boost 2010 Summary

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Introduction: The Boost Workshop

Follow up from Boost 2009, continuing themes: LHC produced objects can be highly boosted, define interesting channels/final states in which new techniques can provide additional physics reach.

Mixing talks and ideas from Experimentalists and Theorists.

- Repeated Idea (1): "Hey Experimentalists! Talk to your local theorist, he's got some good ideas."
- Repeated Idea (2): "Hey Theorists! Our data isn't public and you can't look at it, but here's a little taste to whet your appetite."

Total of 63 participants and 37 talks. Content and figures from multiple sources – Thanks to all of them

Outline

What Are We Talking About

Large amount of physics probed with boosted objects:

- Heavy particles (e.g., Z' or W') can produce highly boosted final states when decaying to lighter SM particles
- Light particles (H) are boosted in some small fraction of events, but the signature is distinct enough to see over typical backgrounds.

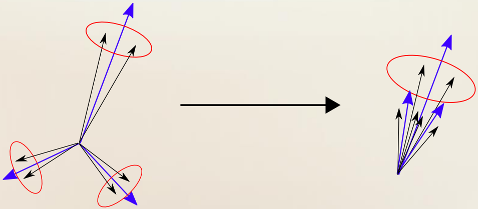
Leptonic Final States:

- High precision tracking $\rightarrow$ resolve final states with highly collimated leptons

Hadronic Final States:

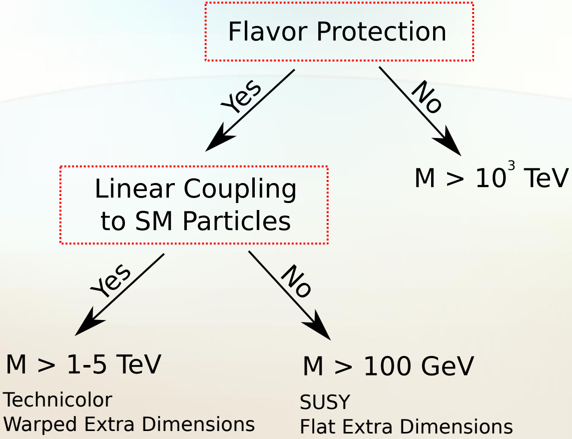
- Can reconstruct ≥ 2 hadrons as one jet
- Structure of merged jets can give clues on origin

In either case, final state involves highly collimated objects:



Models and Phenomenology

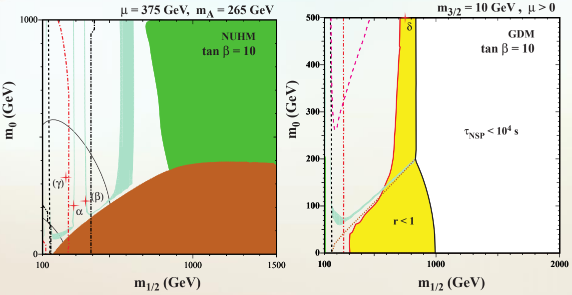
How Light Can New Physics Be?



Boosted SUSY

Produce SM particles (W,Z,h,t) in SUSY decays, large SUSY masses result in boosted SM final states.

- $\tilde{q}_L \rightarrow q\tilde{\chi}_2^0 \rightarrow q\ell^\pm\tilde{\ell}^\mp \rightarrow q\ell^\pm\ell^\mp\tilde{\chi}_1^0$
- $\tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0 \rightarrow qq'\tilde{\chi}_1^0$
- $\chi_2^0 \rightarrow Z\tilde{\chi}_1^0$ ($\rightarrow \ell^+\ell^-\tilde{\chi}_1^0$, or $\rightarrow q\bar{q}\tilde{\chi}_1^0$)
- $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0 \rightarrow b\bar{b}\tilde{\chi}_1^0$



For example, two models, Non-Universal Higgs Mass (left) and Gravitino Dark Mass (right), allowed regions for $m_{1/2}$ and m_0 show how heavy the particles can be.

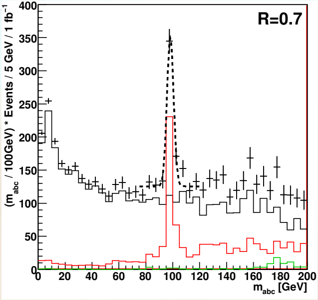
Branching Ratios to SM bosons can be close to 100%, large production of signal

RPV SUSY

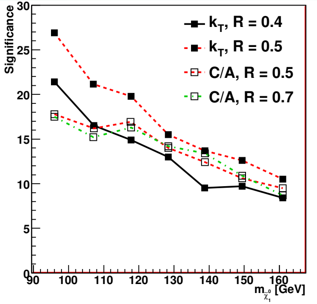
In R-parity violating SUSY, the (N)LSP can decay promptly into 2-4 quarks.

- Decays to $\tilde{\chi}^0_1 \rightarrow qqq$ are notoriously difficult to reconstruct
- 20 possible combinations for 6 jets

Inclusive analysis picking one very hard jet with two mergers: Combining the neutralino candidate with the extra hard jet gives an estimate of the squark mass.



Jet mass distribution for the C-A algorithm for QCD, SUSY, and other backgrounds



Estimated sensitivity for 1 fb^{-1} as a function of $\tilde{\chi}^0_1$ mass for various jet algorithms and R sizes.

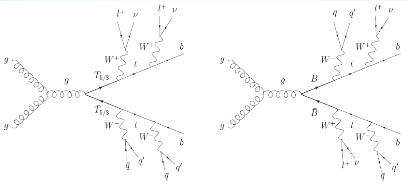
Boosted techniques will be crucial for reconstructing SM particles from SUSY cascade decays

Warped Extra Dimensions

Very patient and engaging speaker – especially given that half the audience was gone, watching the US play soccer.

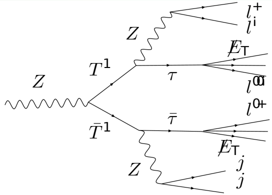
In Warped Extra Dimensions, new physics couples linearly with stronger coupling to heavier SM particles (eg. t, H, V_L)

Can produce new light vector-like quarks that decay to top and longitudinal vector bosons or Higgs.



Very early discovery at LHC possible with: $\mathcal{L} \sim 0.16$ - 1.9 fb^{-1}

Can also happen for τ



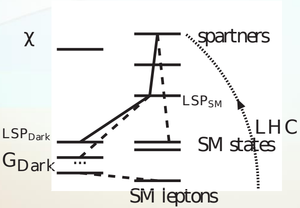
In this case, produces very collimated leptons from the τ and $t\bar{a}u$, but requires more luminosity ($\mathcal{L} \sim 10$ fb^{-1}).

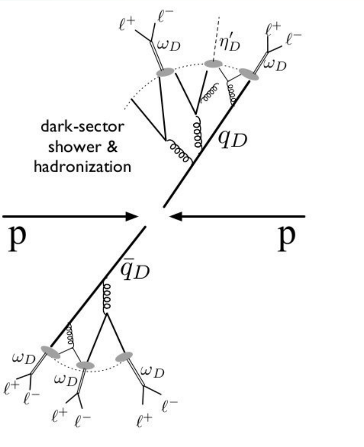
With more data ($\mathcal{L} \sim 300$ fb^{-1}), can start to probe new wide resonances, decaying into tops.

Dark Sector

Assume that the Dark Matter is the result of a Dark Sector (rather than single stat, a la WIMP). Could explain recent string of astrophysical anomalies.

Could be that SUSY is also hidden by this sector:





Decays from DM to SM could occur via SUSY cascade.

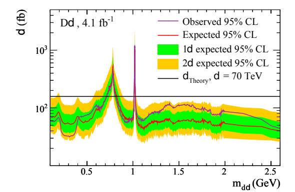
Showering in the dark sector can affect final state: Result is boosted pairs of leptons from the strongly coupled mediator.

Results and Prospects

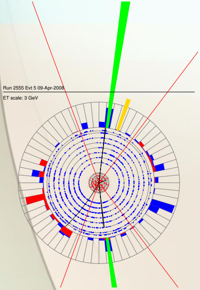
Tevatron Results

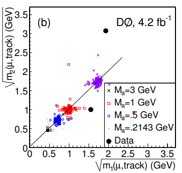
Primarily focusing on lepton final states (partially due to relative coarseness of Calorimeter)

Light pseudo-scalar production in Higgs decays: Search for back-to-back collinear muon pairs (or taus if $m_a > 2m_\tau$).

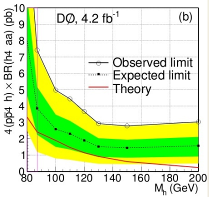


SUSY chargino production with "dark" sector decays to boosted lepton pairs: Trigger on hard photon, match tracks to muon or EM clusters.





MC event display of $H \to aa \to \mu\mu\mu\mu$ and the 2D plot of the invariant masses.



Limits for $H \to aa \to \mu\mu\tau\tau$ versus higgs mass.

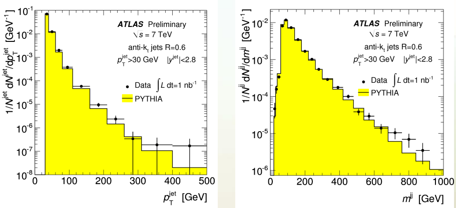
LHC Prospects: ATLAS

ATLAS has the most finely segmented EM calorimeter in any hadron collider experiment, excellent testing-ground for jet techniques.

Number of planned searches sharing a common feature: the jet substructure is investigated in order to suppress light QCD background.

- $W \to qq'$, $Z \to q\bar{q}$
- SUSY with hadronic final states
- Vector boson scattering
- $H \to b\bar{b}$
- top quark resonances
- Lepton Jets

Study jets in early data:



Dijet mass spectrum from the first high-p_T jets at ATLAS

Jet substructure studies are ongoing in multiple analysis groups. Questions to be resolved with respect to how well the variables will be modeled.

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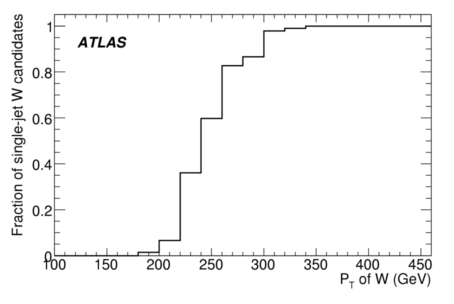

Fraction of single-jet W candidates as a function of W p_T.

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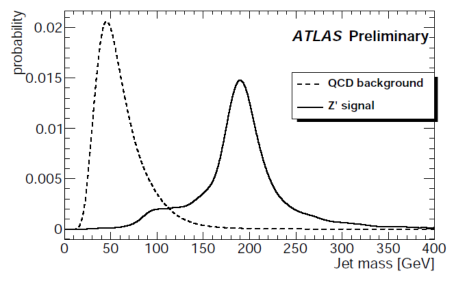
Many heavy particles decaying to top quark pairs are predicted



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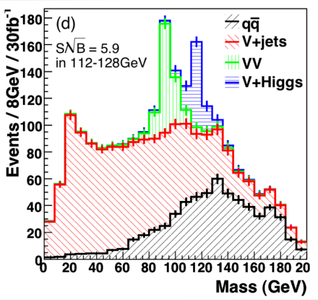
Likelihood ratio from PDFs of variables, including jet substructure.

Jet substructure studies are ongoing in multiple analysis groups. Questions to be resolved with respect to how well the variables will be modeled.

LHC Prospects: CMS

Similar list of aims and goals from CMS.

- Leptonic Final States
  $q^* \rightarrow Zq \rightarrow eeq$ and Dark Matter photon decay
- Boosted Higgs: VH, $(H \rightarrow b\bar{b})$
- Semileptonic top: $t \rightarrow bl\nu$
- Hadronic top: $t \rightarrow bqq'$



Highly collimated decay products producing a single jet. Ongoing work to show this idea will work with the CMS detector.

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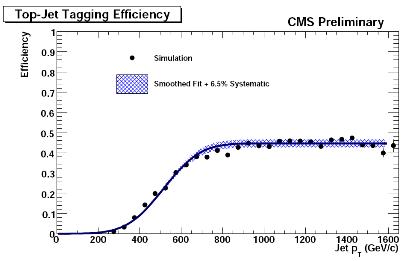

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  $q^* \to Zq \to eeq$ and Dark Matter photon decay
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Top Tagging algorithm: decompose C-A hard jets, looking for two hard parent clusters, and yielding 3-4 sub-jets.

Efficiency ∼46%, with ∼ 1.5% fake rate.

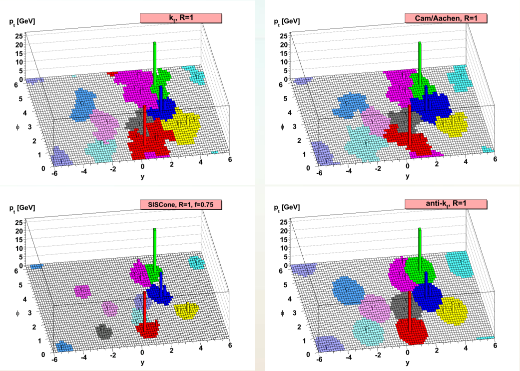
Good sensitivity at high M_{tt}

Doing More With Jets

Jet Reconstruction Algorithms

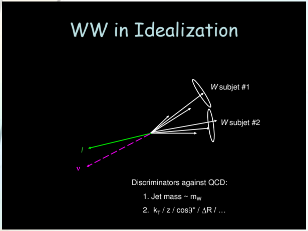
Lots of work already goes into relating how signals in the detector (as experimentalists think about it) or partons (as theorists think about it) are reconstructed as jets.

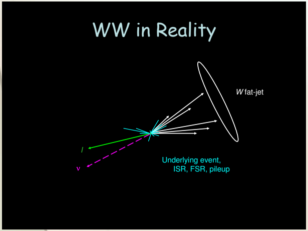
Cone algorithms identify energy flow, whereas sequential combinations identify jet particles.

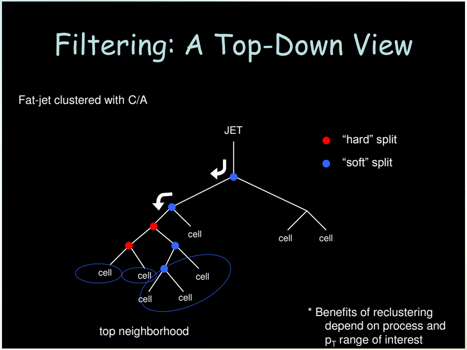


- k_T groups closest objects considering lowest p_T first
- SisCone is a Seedless Infrared Safe Cone jet algorithm
- Cambridge/Aachen sequentially merges nearest neighbors
- Anti-k_T groups highest p_T objects first

Grooming Jets



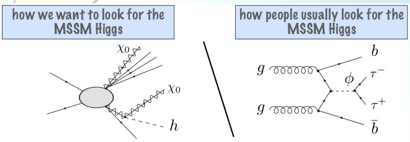




Make use of the history and structure elucidated by sequential algorithms:

- Filtering: Discard "soft" splits, recluster "hard" splits with refined R
- Pruning: Redo clustering of "fat" jet, vetoing distant or asymmetric mergings
- Trimming: Recluster sub-jet with tiny R, rejecting soft jets

MSSM Higgses w/ Jet Substructure



- Large cross section for heavy Sparticles which can cascade decay to the higgs.
- Higgs must be light ($m_h \lesssim 130$ GeV) and tend to decay to boosted $b\bar{b}$

SUSY events are busy w/ lots of extra high-p_T partons from decays of $\tilde{q}/\chi^{\pm,0}/t$.

Look at fat jets:

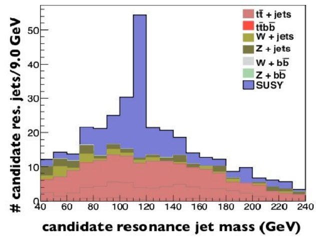
1 undo clustering $j \to j_1 + j_2$

2a if a mass drop, keep $j_2 =$ constituent, $j_1 \to j$, goto 1

2b otherwise $j_1 \to j$, goto 1

3 continue until $p_{T,j} < 30$ GeV

Higgs candidate = two b-tagged constituents with the most similar p_T



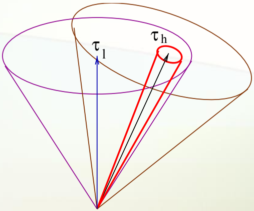
Under ideal conditions, could be the first h discovery mode with $\mathcal{L} \sim 10\text{fb}^{-1}$ (before $h \to \gamma\gamma$ or $h \to \tau\tau$)

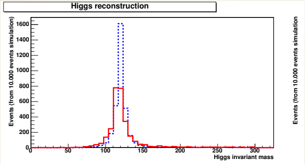
Boosted Light Higgs From TeV Scale Resonance

Investigate case of $Z' \to Z(h \to \tau^+\tau^-)$ for light higgs.
Small BR (compared to $b\bar{b}$) but much cleaner, and τs are boosted.

Mutually isolated lepton and τ:

- Find hardest track in iso cone of lepton
- Remove cone around track and recalculate iso of lepton
- If lepton now passes, calculate isolation of "would be τ"
- If both the lepton and τ now pass isolation, consider them "mutually isolated."





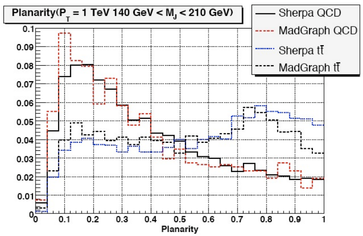
ideal measurement of momenta, no MET mismeasurement and distributions are smeared (according to CMS TDR formula), MET calculated as a sum of leading reconstructed (and smeared) objects.

- 85% of all leptonic Zs are reconstructed
- Of these, 95% of all dileptonic Higgses are reconstructed
- 65% reconstruction for the semi-leptonic events

Maybe this analysis is possible in the $Z \to jj$ channel, requires further background study.

Massive High p_T Jets at CDF

First systematic study of jet substructure for high-p_T jets

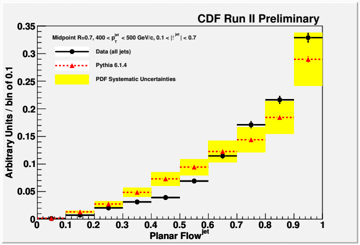


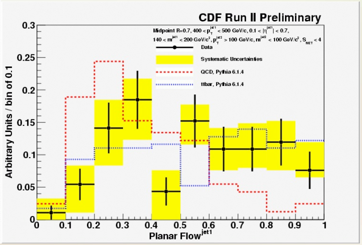
QCD Jets are broad and democratic so calculate an energy flow tensor:

$$I_w^{kl} = \frac{1}{m_J} \sum_i w_i \frac{p_{i,k}}{w_i} \frac{p_{i,l}}{w_i}$$

$$P_f = \frac{4\det(I_w)}{\mathrm{tr}(I_w)^2}$$

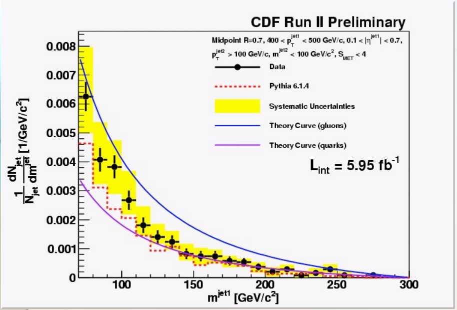
In these preliminary di-jet results, CDF observes a deviation at large masses.





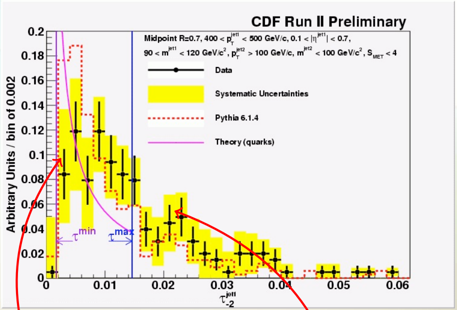
Massive High p_T Jets at CDF

Jet Mass – High mass region



Data nicely interpolates between quark and gluon jet functions consistent with mostly quark case!

Angularity – $\alpha_a = -2\sum_i w_i\theta_i^4$



rise → clear sign of 2 body description!

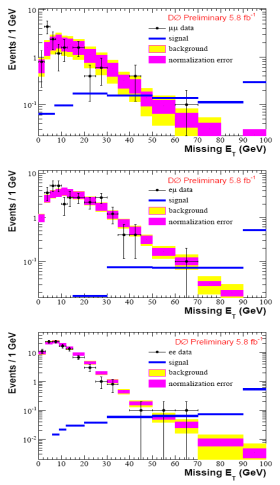
tail is due to merged jets

Lepton Jets

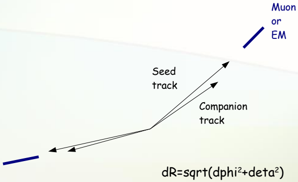
New Tevatron Limits

New results from the Tevatron: Direct dark-photon production from a dark sector with SUSY.

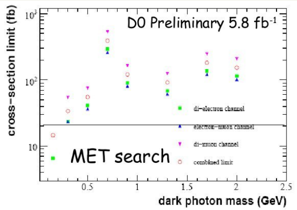
- Rate could be large (no mixing ϵ)
- At least two lepton jets per event
- Large $\not{E}_T$ from the $\tilde{\chi}$

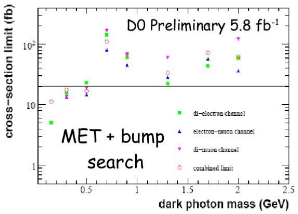


Selection by mix of isolated lepton and track candidates, gets around selection inefficiencies.



Background modeled by data with reversed isolation. Normalization performed in data with $\not{E}_T < 15$ GeV



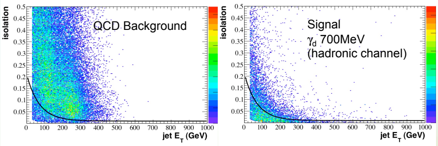


Preliminary LJets at CMS

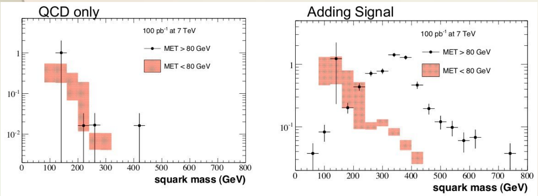
Similar analysis from CMS:

- Feasibility studies, signal + background simulated with Madgraph, detector simulated with PGS 4.
- Select events with $\geq$ 4 jets and at least one isolated lepton-jet.

Exploit the isolation dependence on jet E_T:



Use MET distribution in QCD events selected with no lepton jets to predict events with exactly one lepton jet. Then do the same for two lepton jets.

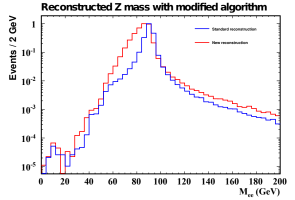


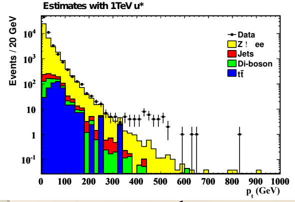
Reconstruct two jet + l-jet masses (pick pairing that gives closest masses), average the two.

Boosted $Z^0 \rightarrow ee$ at CMS

Model independent search for new heavy resonances decaying to $Z^0 + X$
(thesis work, not CMS approved!)

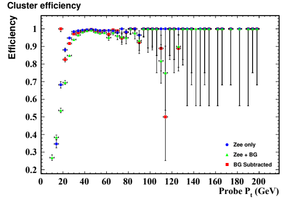
Revamp classic e clustering algorithms for Bremsstrahlung from two close-by electrons.

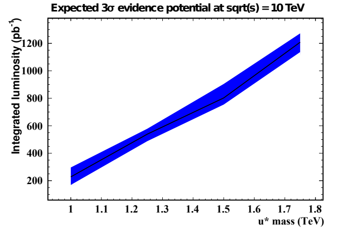




Signal + Background for 200 pb^{-1} of pseudo-experiments

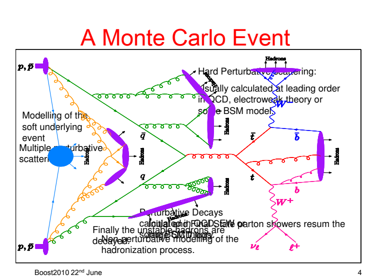
Estimates with sideband technique: high efficiency after turn-ons.

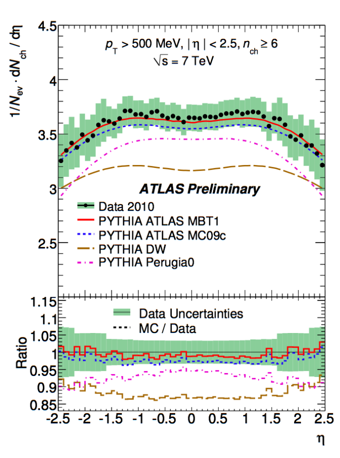




Supporting Tools

Simulation for LHC





Many years of simulating LEP → simulation of the radiation in the decay of a colour neutral boosted object should be pretty reliable.

Less experience with simulating heavy coloured particles. Will need to:

- retune parameters
- improve the perturbative physics

Fastjet and Spartyjet

During the Hadronic Workshops, tutorials on the use of FastJet (http://www.lpthe.jussieu.fr/ salam/fastjet/) and SpartyJet (http://www.pa.msu.edu/ huston/SpartyJet/SpartyJet.html)

FastJet

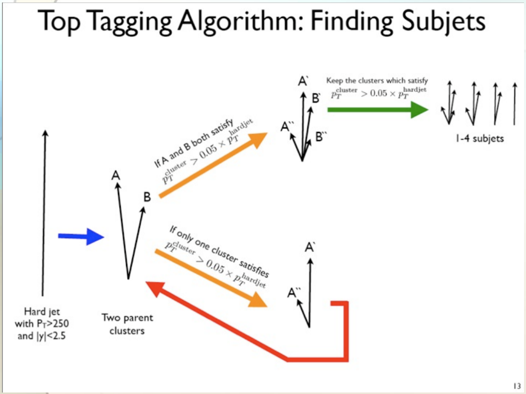
- A tool for jet finding
- Many standard algorithms implemented
  - kT, Cambridge/Aachen, anti-kT (built-in)
  - SISCone, PxCone, JetClu, MidPoint, D0 RunII Cone, ATLAS and CMS Cones (plugin)
- Easy mechanism for user-supplied plugins
- Growing set of FJ-based tools
  - JHTopTagger, filtering, CA subjet finding, CMTopTagger (add-ons), BDRS Higgs search (built- in)

SpartyJet

- A tool for jet analysis
- Wraps around jet finding in FastJet
- Support for many input formats
  - StdHEP, HepMC, LHE, ROOT trees, several ASCII formats
- Output to simple ROOT files, explorable with increasingly powerful GUI
- Analyses consist of chains of JetTools
  - Very simple plug-and-play
  - Growing list of tools available

For example, during workshop, demonstrated running "grooming" on $t\bar{t}$ events, compare mass distribution, then subjet mass distribution after mass cut

Top Tagging



Many papers on top tagging in 08-10: jet mass + something extra. (eg. Johns Hopkins top tagger)

Very tunable: Pick your top efficiency and fake rate!

Rough results for top quark with $p_t \sim 1$ TeV

	"Extra"	eff.	fake
[from T&W]	just jet mass	50%	10%
Brooijmans '08	3,4 k_t subjets, d_{cut}	45%	5%
Thaler & Wang '08	2,3 k_t subjets, z_{cut} + various	40%	5%
Kaplan et al. '08	3,4 C/A subjets, z_{cut} + θ_h	40%	1%
Ellis et al. '09	C/A pruning	10%	0.05%
ATLAS '09	3,4 k_t subjets, d_{cut} MC likelihood	90%	15%
Chekanov & P. '10	Jet shapes	60%	10%
Almeida et al. '08–'10	Template + shapes	13%	0.02%
Plehn et al. '09–'10	C/A MD, θ_h/Dalitz [busy evs, $p_t \sim 300$]	35%	2%

Conclusions

- Tough to condense 4 days of talks into < 1 hour. I hope I've kept you entertained.
- Entering the era of boosted physics. Signal from heavy new resonances are best viewed with a boosted mindset, and even light states can benefit from boosted techniques.
- New analysis techniques are being developed, many of which are already being collected within unified analysis frameworks. Half the work has already been done for you!
- Regions of phase-space already being probed (excluded) by the Tevatron. More can be expected with the full 9 fb^{-1} dataset, but lots will remain to be done at the LHC.
- Proceedings from the workshop are planned for early September. Talks with much more detail than I could muster are already available online on the workshop agenda: http://indico.cern.ch/conferenceTimeTable.py?confId=74604#20100622
- Plenty of physics to be seen with early data!