Polaroid jetography

an album of jet physics measurements and searches at the ATLAS experiment

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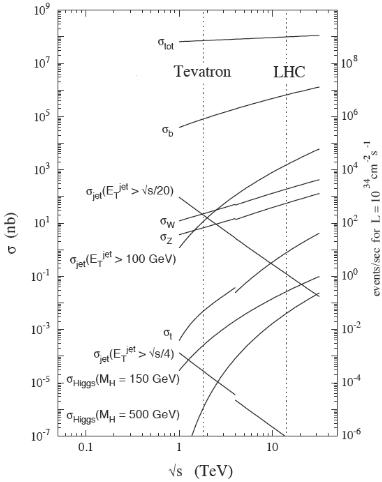
HEP Seminar, University of Virginia - 17/09/13

Introduction

Why jets?

Large **Hadron** Collider:
quark and gluon ($\rightarrow$ jet) factory

1. Use jets for measurements:
   understand QCD (backgrounds), test reconstruction and calibration performance
2. Use jets for searches:
   probes for new physics



Why jetography?

Main message of the day:
there's **many ways** to make a jet
(see G. Salam's primer)

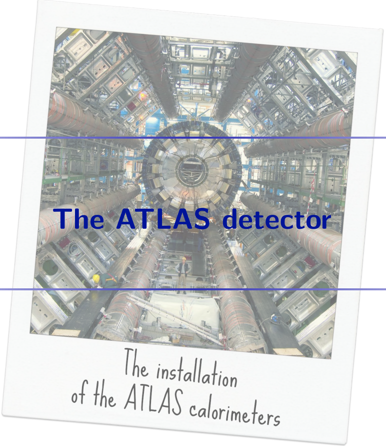
Why polaroid?

I only have limited time...
This talk: **quick snapshots** of large ATLAS jet physics program

Outline

Overview of **jet reconstruction**: jet finding, calibration, performance
Selected ATLAS results on **jet physics**: measurements and exotics searches

The ATLAS detector

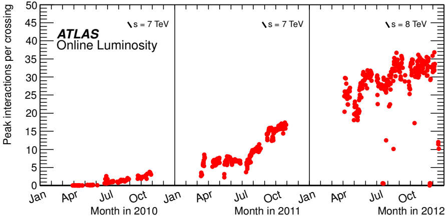


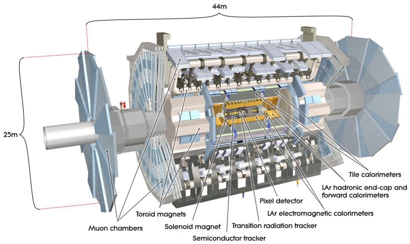
The ATLAS Detector in 2012

Excellent performance of the LHC and of the ATLAS experiment:
5 and 21 fb^{-1} of pp data recorded in the **7 and 8 TeV runs**
+ heavy ion / $p - Pb$ data (not covered here)
263 papers published, 530 public notes and counting

ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.5%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.3 fb^{-1} of recorded data.

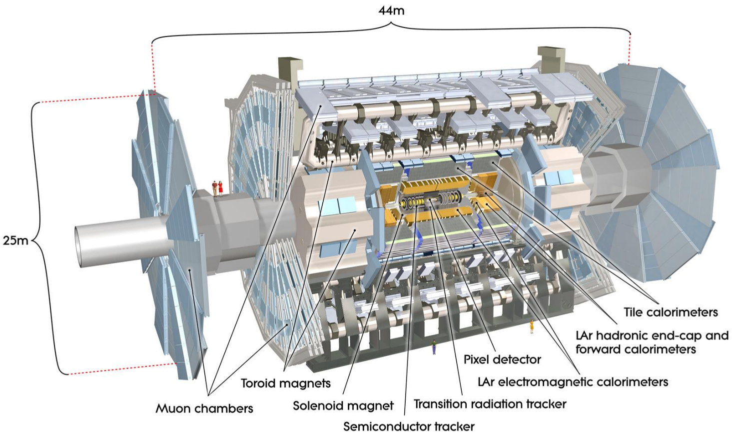




2012 challenge: high luminosity

- Multiple interactions per bunch crossing
  → optimize trigger, object reconstruction

The ATLAS Detector



For the measurements described in this talk: inner detector, calorimeter system

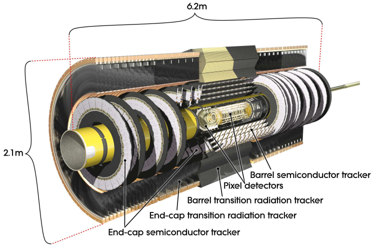
The ATLAS inner detector and calorimeters

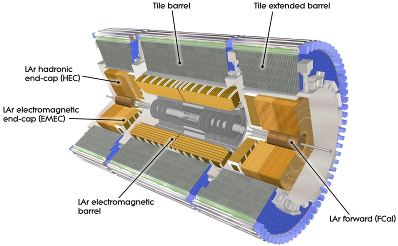
Inner detector

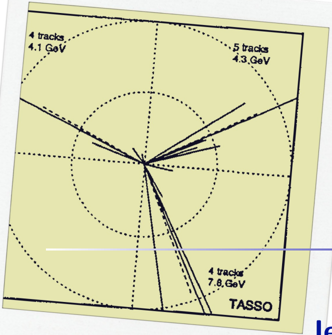
- Pixel detectors, semiconductor tracker (SCT), transition radiation tracker
  - $\approx$ 87M readout channels, coverage up to $|\eta| < 2.5$
  - Immersed in 2T magnetic field from solenoid

Electromagnetic and hadronic calorimeters

- Subsystem technology and granularity $\leftrightarrow$ shower characteristics
  - **transverse** and **longitudinal** sampling
  - very fine granularity: $\approx$ 200 000 *readout cells* up to $|\eta| < 4.9$
- Energy deposits grouped in noise-suppressed **3D topological clusters**
  noise definition includes pile-up and electronic noise







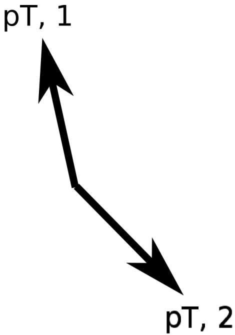
One of the first observed gluon jets

Jet algorithms: basics

Chaos from order, order from chaos?

A high-p_T dijet event: how we see it

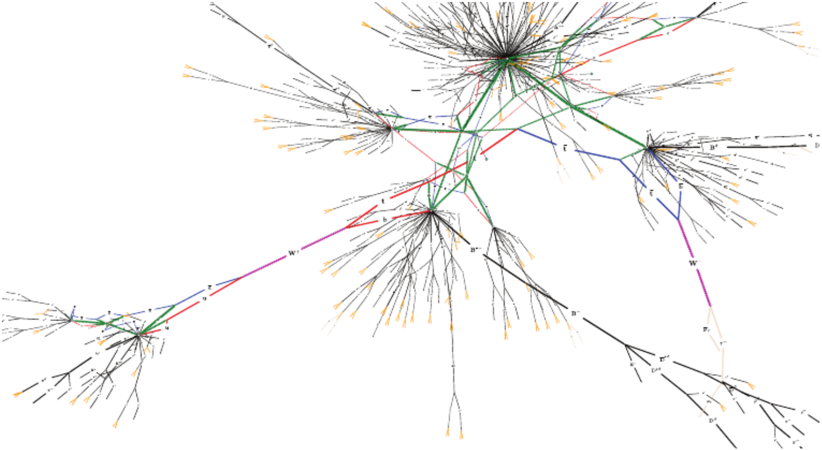
...from the back of an envelope...



Chaos from order, order from chaos?

A high-p_T dijet event: how we see it

...according to QCD from a MC generator...

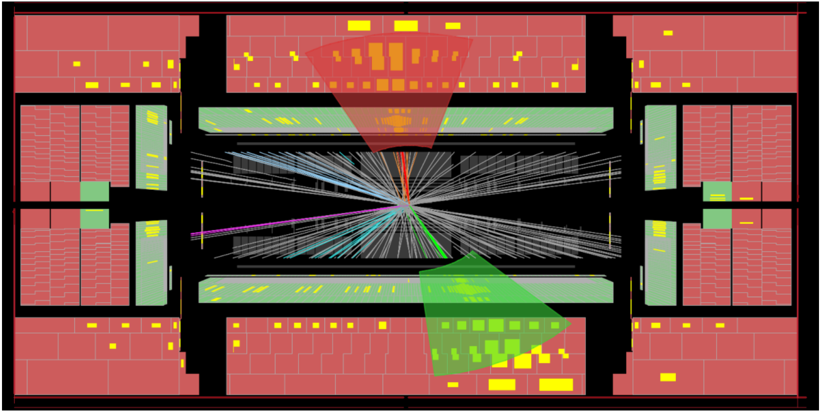


I cheated: this is a semileptonic $t\bar{t}$ event from MCViz, but you get the idea

Chaos from order, order from chaos?

A high-p_T dijet event: how we see it

...in the ATLAS calorimeter...

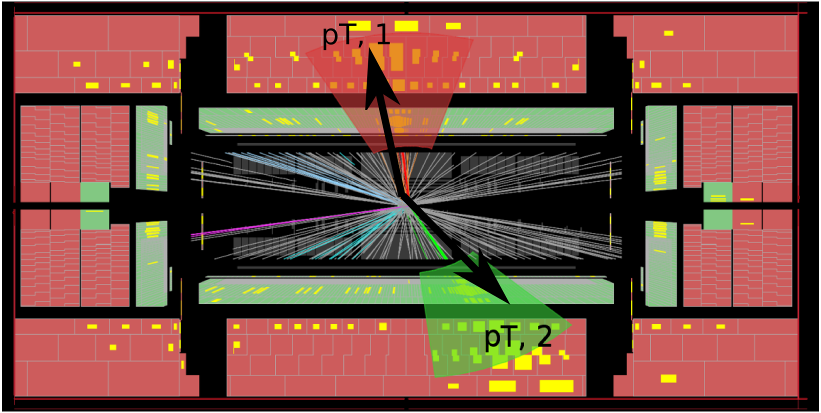


Note: some 'cleaning' already performed: **ATLAS topological clustering algorithm**

Chaos from order, order from chaos?

A high-p_T dijet event: how we see it

...after applying a **jet algorithm**.

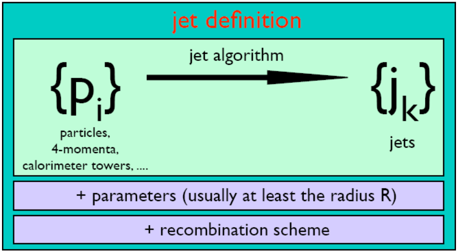


Need **algorithms** to define **jets** out of underlying constituents

Jet algorithms: basics

Goal: kinematics of jet ↔ kinematics of underlying physics objects
Use a **jet algorithm** to cluster objects into a jet

Les Houches 2007 proceedings, arXiv:0803.0678



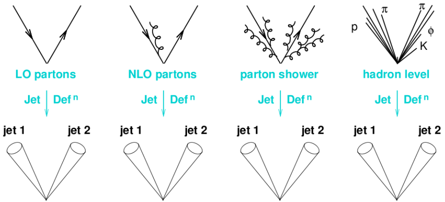
From M. Cacciari, MPI@LHC08

Apply same jet definition
to objects on different levels:

1. Partons
2. Particles
   → Truth Jets
   (only particles from the hard scattering)
3. Calorimeter objects
   (ATLAS: Towers, Topoclusters)
   → Reconstructed Jets
4. Tracks
   → Track Jets

Jet algorithms: basics

Goal: kinematics of jet ↔ kinematics of underlying physics objects
Use a **jet algorithm** to cluster objects into a jet



From G. Salam, MCNet School 2008

Apply same jet definition
to objects on different levels:

1. Partons
2. **Particles**
   → Truth Jets
   (only particles from the hard scattering)
3. **Calorimeter objects (ATLAS: Towers, Topoclusters)**
   → Reconstructed Jets
4. **Tracks**
   → Track Jets

Wishlist for jet finding algorithms

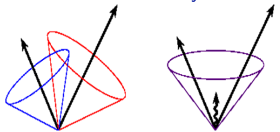
No right jet algorithm

Different processes ↔ different algorithms / parameters
(we'll see more of this later...)

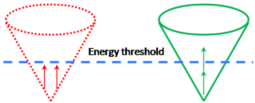
Requirements:

1. Theoretically well behaved → no α_s dependence of jet configuration:

Infrared safety



Collinear safety

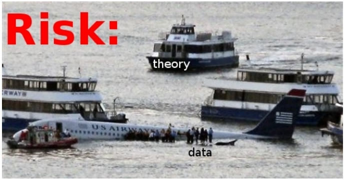


2. Computationally feasible → fast

3. Detector independent

More safety warnings

Crucial to analyse data
with **infrared / collinear safe**
jet algorithm!



Theory matters:

Among consequences of IR unsafety:

	Last meaningful order			Known at
	JetClu, ATLAS cone [IC-SM]	MidPoint [IC_{mp}-SM]	CMS it. cone [IC-PR]	
Inclusive jets	LO	NLO	NLO	NLO ($\rightarrow$ NNLO)
$W/Z + 1$ jet	LO	NLO	NLO	NLO
3 jets	**none**	LO	LO	NLO [nlojet++]
$W/Z + 2$ jets	**none**	LO	LO	NLO [MCFM]
$m_{\rm jet}$ in $2j + X$	**none**	**none**	**none**	LO

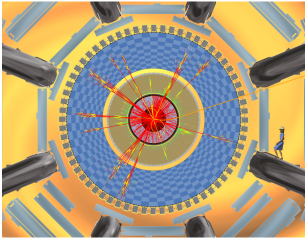
NB: \$30 – 50M investment in NLO

From G. Salam, MCNet School 08

Implementation of jet algorithms

Goal: kinematics of jet $\leftrightarrow$ kinematics of underlying physics objects
Use a **jet algorithm** to cluster objects into a jet

Basic algorithm: event display + physicist



"Everyone knows a jet when they see it"
Note: don't try this at home when the LHC is running

...but what is really needed for communicating results:

1. full specification of algorithm and parameters $\rightarrow$ how to group objects
2. recombination scheme $\rightarrow$ how to merge objects characteristics
3. treatment of overlapping jets (if any) $\rightarrow$ how to avoid double counting

Jet algorithms available in ATLAS

Cone-based algorithms

- Cone in $y-\phi$ space around object momentum vector
- **Jet =** objects in cone

Available on the (ATLAS) market:

- ATLAS Cone **unsafe!**
- Seedless Infrared Safe Cone (SISCone)

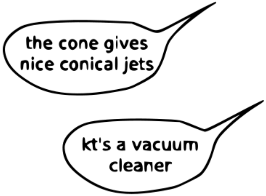
Sequential recombination algorithms

- Group objects based on minimum relative *distance*
- **Jet =** grouped objects

Available on the (ATLAS) market:

- K_t
- Cambridge-Aachen
- Anti-K_t

What algorithms for data?



From G. Salam, MCNet School 2008

Sequential recombination algorithms (k_t-like)

Algorithm specification: k_t

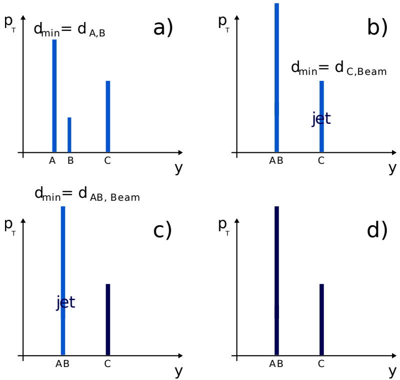
- $d_{i,j} = min(p^2_{T,i}, p^2_{T,i}) \frac{\Delta R^2}{D^2}$;
  $d_{i,Beam} = p^2_{T,i}$
- **D** : algorithm parameter (≈ weight for angular distance ΔR)
- Iterate:

1. For every pair of objects i, j calculate $d_{min} = min(d_{i,j}, d_{i,beam})$
2. **If** $d_{min} = d_{i,j}$ recombine objects
   Else i is a jet, remove it from list [a]

- Recombination starts from **soft** objects

[a] ATLAS default: inclusive algorithm

Idea:



Sequential recombination algorithms (k_t-like)

Algorithm specification: Cambridge-Aachen

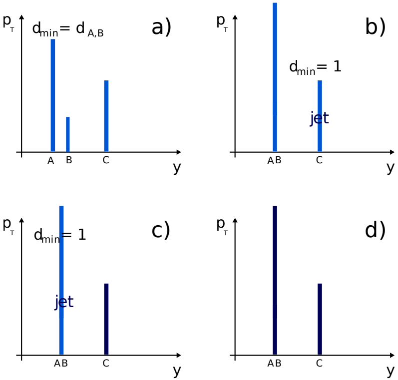
- $d_{i,j} = \frac{\Delta R^2}{D^2}$; $d_{i,Beam} = 1$
- **D** : algorithm parameter
- Iterate:

1. For every pair of objects i, j calculate $d_{min} = min(d_{i,j}, d_{i,beam})$
2. **If** $d_{min} = d_{i,j}$ recombine objects
   Else i is a jet, remove it from list [a]

- **Distance-based** recombination

[a] ATLAS default: inclusive algorithm

Idea:



Sequential recombination algorithms (k_t-like)

Algorithm specification: Anti-k_t

- $d_{i,j} = min(\frac{1}{p_{T,i}^2}, \frac{1}{p_{T,i}^2})\frac{\Delta R^2}{D^2}$;
  $d_{i,Beam} = \frac{1}{p_{T,i}^2}$
- **D** : algorithm parameter
- Iterate:

1. For every pair of objects i, j calculate $d_{min} = min(d_{i,j}, d_{i,beam})$
2. **If** $d_{min} = d_{i,j}$ recombine objects
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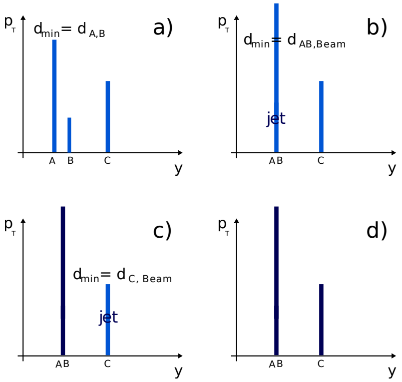
- Recombination starts from **hard** objects

[a] ATLAS default: inclusive algorithm

Idea:



Sequential recombination algorithms (k_t-like)

Algorithm specification: Anti-k_t

- $d_{i,j} = min(\frac{1}{p_{T,i}^2}, \frac{1}{p_{T,i}^2})\frac{\Delta R^2}{D^2}$;

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[a] ATLAS default: inclusive algorithm

Is it safe?

Yes, by construction:

- Collinear, infrared safe
  soft particles recombined

Sequential recombination algorithms (k_t-like)

Algorithm specification: Anti-k_t

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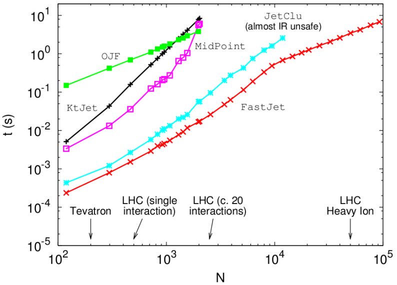
   Else i is a jet, remove it from list [a]

- Recombination starts from **hard** objects

[a] ATLAS default: inclusive algorithm

Is it fast enough?



Time needed to cluster N particles vs N

Yes

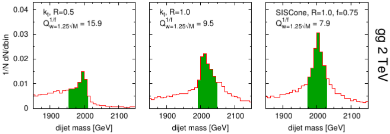
What jet algorithm and parameters?

Decision: choice of jet algorithm distance parameter (R)
"It's all fun and games until someone loses a hard constituent"

Example figures from original jetography paper arXiv 0810.1304:
Quantifying the performance of jets, *G. Salam, J. Rojo, M. Cacciari*

Advantages of wider distance parameters (large-R):

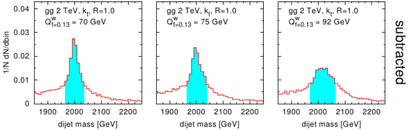
- Captures more QCD radiation:
  → Smaller non-perturbative corrections when comparing data to theory
  → Better mass resolution for dijet resonances



Dijet mass for resonance decaying into two gluons: improvement in resolution when increasing radius

Disdvantages of wider distance parameters (wider jets):

- Captures more of anything else:
  → extra energy not from hard scattering (calorimeter noise, other pp collisions)

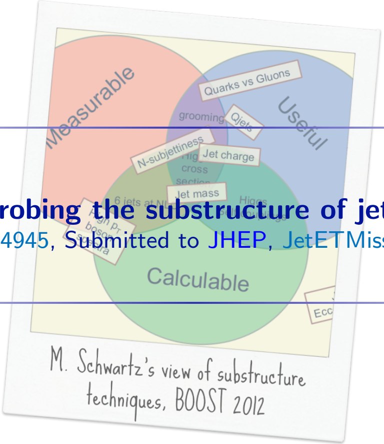


Dijet mass for resonance decaying into two gluons, large-radius: deterioration in resolution when increasing pile-up as in left to right plot

- with large kinematic boost, decay products of heavy objects more collimated
  ...can we use this to our advantage?

Probing the substructure of jets

[ATLAS arXiv 1306.4945, Submitted to JHEP, JetETMiss WG public results]



Jet substructure

When to make fat jets:

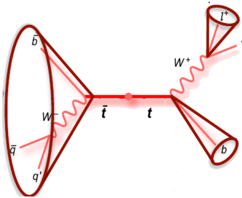
When more objects (e.g. from a decay) are collimated due to kinematic boost:

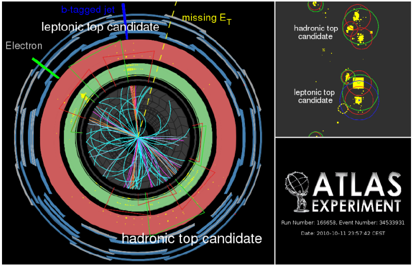
- collect everything in a large-R (**fat**) jet
- probe substructure of this large-R jet (e.g. sub-jets)

How to use fat jets:

- exploit **jet grooming** techniques to:
  - separate QCD jets from jets from boosted objects decays (background rejection)
  - make jets more resilient to radiation/pile-up
- use **jet mass** as a handle for mass of heavy object (e.g. W, or top)

Example: boosted top candidate

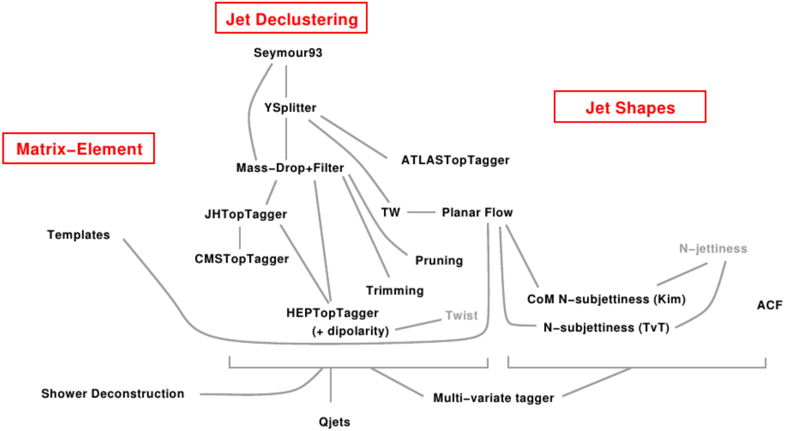




[ATLAS-CONF-2011-073]

Jet substructure is an active field...

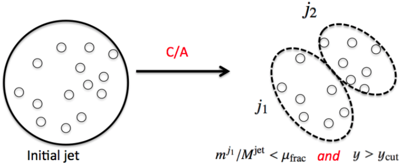
From G. Salam's closing talk at BOOST2012



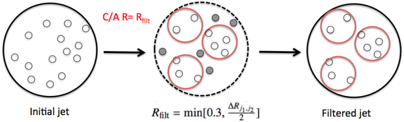
apologies for omitted taggers, arguable links, etc.

A famous substructure technique: mass-drop filtering [arXiv 0802.2470]

1. Find Cambridge/Aachen R=1.2 jets
2. Undo last step of jet algorithm and obtain two proto-jets $(j1, j2)$
3. Only keep C/A jets where:
   - significant difference between original jet and $j1$: $m^{j1}/m^{C/A\ jet} < \mu_{frac}$
   - symmetric splitting between $j1, j2$: $y = \frac{min[(p_T^{j1})^2, p_T^{j2})^2]^2}{m^{C/A jet}} \Delta R^2_{j1,j2} > y_{cut}$

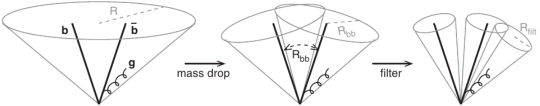


4. Recluster constituents of the jet using C/A with distance parameter=R_{filt}, only keep three hardest subjets



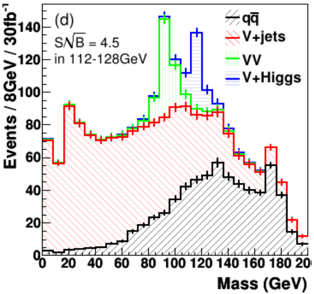
A famous substructure technique: mass-drop filtering [arXiv 0802.2470]

It could be useful for Higgs decay in $b\bar{b}$ (overwhelming background):



Frequently Asked Questions

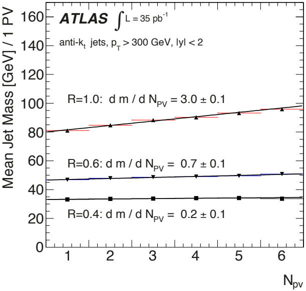
- *Is it really useful for boosted Higgs?*
  We'll know at the LHC @ 14 TeV
- *Is it useful for ATLAS analyses?*
  Yes, we'll see this later



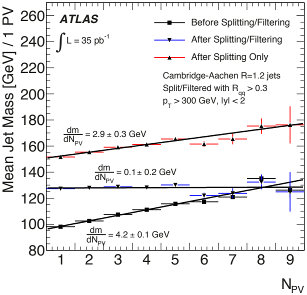
Substructure techniques in presence of pile-up

Original aim of **jet filtering** algorithms [arXiv 0802.2470]:
"filter away UE contamination while retaining hard perturbative radiation from the Higgs decay products"

Impact of pile-up for anti-k_T jets as a function of R



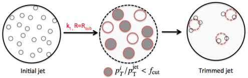
Impact of pile-up for C/A jets R=1.2, before and after filtering



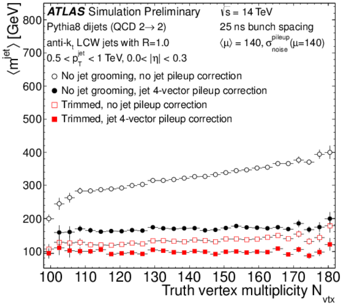
Technique can be employed to reduce impact of pile-up

Substructure techniques in presence of more pile-up

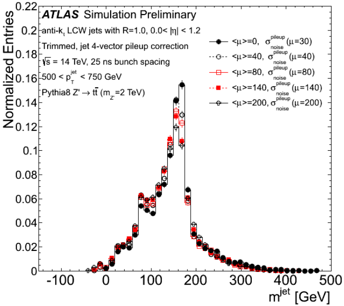
High-luminosity LHC (14 TeV, after Run-II): number of additional interactions (μ) could go up to 140 and more
$\Rightarrow$ will jet substructure techniques still work?



Simulated impact of pile-up on QCD jet mass for R=1.0 anti-k_T jets



Simulated impact of pile-up on $Z' \to t\bar{t}$ jet mass for R=1.0 anti-k_T jets

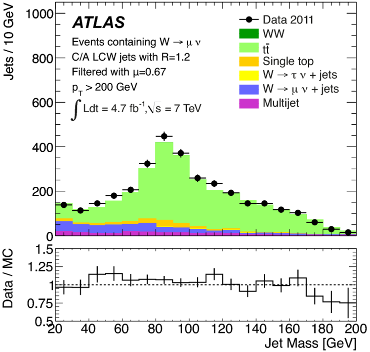


Need both trimming and pile-up correction, but it will work!

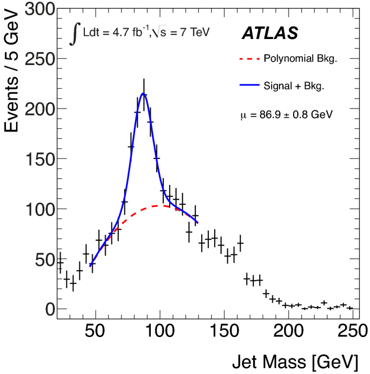
Jet mass measurements

Mass of single fat, groomed jet: handle on mass of heavy boosted objects
⇒ a well known standard candle can be used to set mass scale in data

Mass distribution for C/A split/filtered jets in $W \to l\nu$, with $p_{T,W} > 200$ GeV

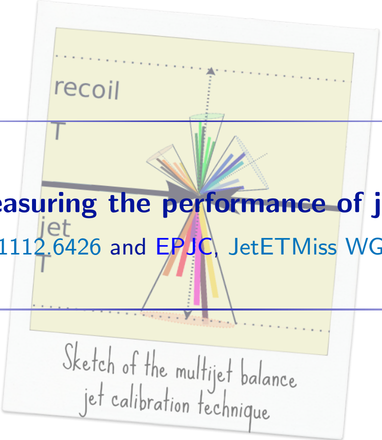


Fit to the W mass distribution in 2011 data



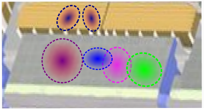
Measuring the performance of jets

[ATLAS arXiv 1112.6426 and EPJC, JetETMiss WG public results]



Recap: jet reconstruction in ATLAS - jet finding

Energy deposits in calorimeters



ATLAS Calorimeters

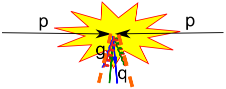
⇒

Jet reconstruction

jet finding

calibration

⇒



$$\{p_i\} \xrightarrow{\text{jet algorithm}} \{j_k\}$$

particles
4-momenta
Topoclusters

jets

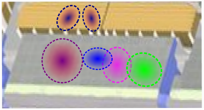
Many **alternative jet finders** can be found (e.g. k_T family/Cambridge, SISCone, ...)

Group objects in **jet** with **jet algorithm**
→ ATLAS default: **Anti-**k_T

- Aggregative algorithm, combines pairs of constituents sequentially
- Combination depends on jet p_T, angular distance in (η, ϕ)
- Algorithm clusters highest energy constituents first
- High p_T Anti-k_T jets have regular shapes, stable under pile-up

Jet reconstruction: calibration

Energy deposits in calorimeters



ATLAS Calorimeters

⇒

Jet reconstruction

jet finding

calibration

⇒

Measure **energy** from **readout signal**

$\longrightarrow$ **EM / hadronic calibration**

$\{ADC\}$ —to electromagnetic scale→ **EM calibration** $\{E^{EM}\}$

$\{E^{EM}\}$ —to jet energy scale→ **HAD calibration** $\{E^{JES}\}$

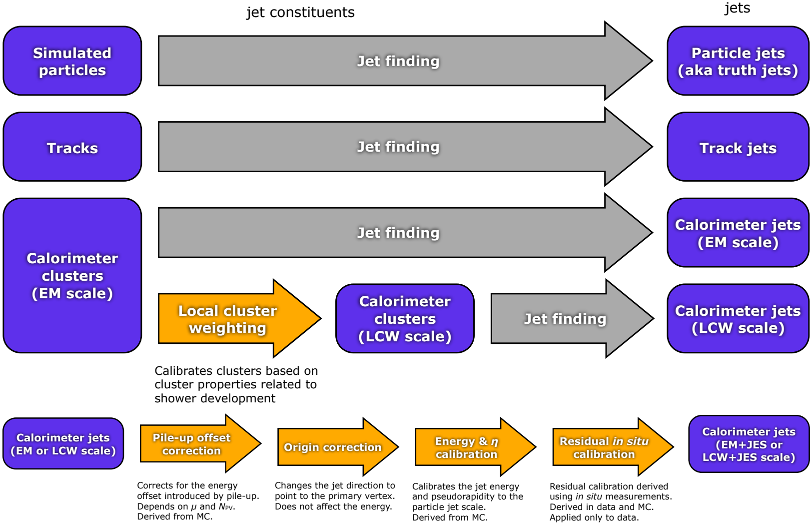
Calorimeter jet response corrected for:

- **Non-compensating** calorimeters
- **Inactive** material
- **Out-of-cone** effects

Further calibration steps:

- **pile-up correction** to remove extra energy from multiple interactions
- correction based on **in-situ balance** techniques (e.g. γ+jet)

Jet finding and calibration in ATLAS



Note: origin correction not applied in 2012

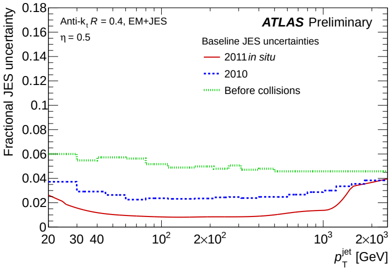
Jet energy scale uncertainty in ATLAS

Estimate JES uncertainties using:

- In-situ techniques ($\gamma - jet, Z - jet$, multijet balance, track vs calorimeter jets)
- single particle uncertainties from test beam convoluted to jets (high-p_T)
- p_T balance in dijet events (forward JES uncertainty)
- Different MC generators (jet flavor and topology uncertainty)

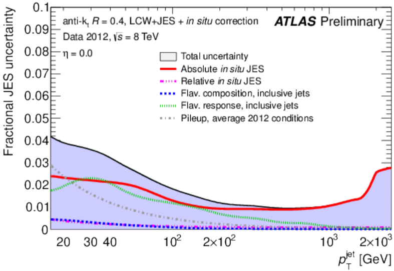
Comparison: before collisions → 2011 (with in-situ correction)

<6.5 → 1% for central jets, p_T=200 GeV
<10 → 9% for more forward jets



Overall JES uncertainty for 2012

As low as 1% for central jets, p_T =250 GeV



Jet energy scale uncertainty correlations

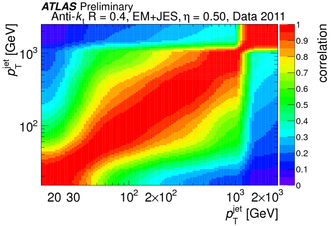
Treatment of correlated experimental uncertainties:

- ATLAS has **o(60) jet energy scale nuisance parameters**:
  set of uncertainty sources, each correlated bin-to-bin, uncorrelated among themselves
- Propagation through analysis allows quantitative theory comparisons, meaningful inclusion in PDF fits, combinations with other experiments

Components:

- pile-up uncertainties
- uncertainty sources from in-situ techniques: systematic and statistical
- high-p_T (single particle) uncertainties
- flavor and topology uncertainties
- $b-$jet uncertainties

In-situ correlation matrix (2011):



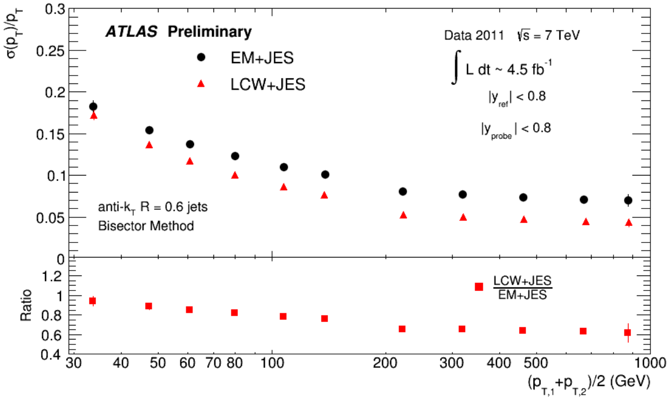
How can an analysis propagate 60 uncertainty sources separately? (they could, it just takes a long time...) ⇒ **Nuisance parameter reduction technique:**

Fewer nuisance parameters, still retaining information on correlations and category for combination with other experiments (e.g. uncertainty from detector effects, MC modeling effects...)

Jet energy resolution

Jet energy resolution: reflects intrinsic fluctuations of reconstructed jet energy from *true* jet energy

Two independent in-situ techniques to estimate JER and compare to MC



Up to 30% improvement if using the more refined calibration technique

Measuring the Standard Model with jets

Jet triggers

The ATLAS trigger system

- 3-tier system (Level-1, Level-2, Event Filter)
- Reduces data intake from ≈ o(10) MHz to ≈ 300 Hz
- Jet triggers: allow for rejection of fakes at L2, anti-k_T jets at the event filter

ATLAS jet triggers (Summer 2011):

1. Minimum Bias Scintillators (MBTS)
2. Single-jet triggers (central and forward)
3. Multijet triggers
4. Topology based triggers
5. Combination triggers

[ATL-DAQ-PROC-2011-034]

Trigger chains currently running unprescaled	Thresholds L1 (GeV)	Thresholds L2 (GeV)	Thresholds EF (GeV)	Rates for 1×10^{33} cm^{-2}s^{-1} L1 (Hz)	L2 (Hz)	EF (Hz)
Inclusive single-jet chains						
1 central jet	75	95	240	275	160	2.8
1 forward jet	75	95	100	3.9	1.1	0.6
Inclusive multi-jet chains						
3 central jets	3×50	3×70	3×75	12	4.9	4.2
5 central jets	5×10	5×25	5×30	60	7.9	3.0
Topological and combination chains						
1 central "fat" jet, anti-k_T $R = 1.0$	75	95	240	275	160	2.7
2 forward jets with $\Delta\eta > 5$	2×30	2×50	2×55	2.2	<0.5	<0.5
1 central jet + E_T^{miss}	50 + 20	70 + 20	75 + 45	711	338	20
1 central jet with $H_T > 350$	75	95	100	275	160	11

Jet triggers

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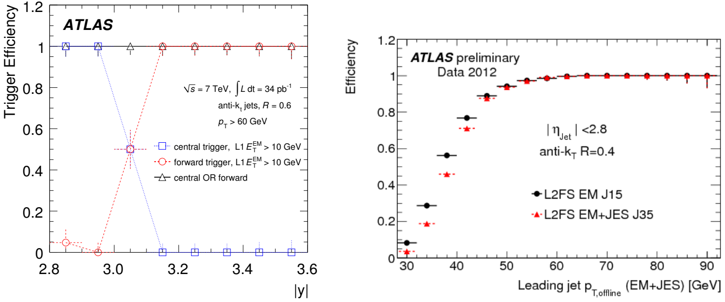


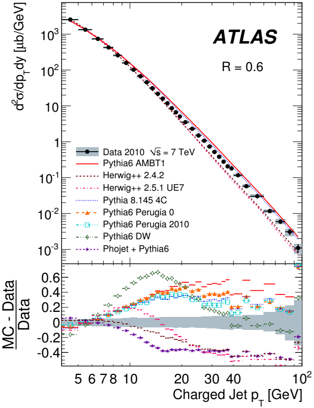
(a) Trigger combination for 2010 inclusive jet cross-section in the transition region between two trigger systems

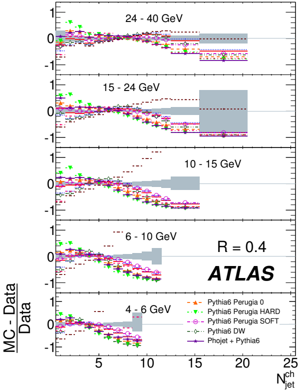
(b) Example of jet trigger efficiency curves for Level-2 in 2012

Low-momentum jets and non-perturbative QCD

Measure **properties of low-momentum jets** using jets reconstructed from **tracks** : probe non-perturbative QCD from minimum bias to jet structure at higher p_T

[ATLAS arXiv 1107.3311, PRD]





Track-jet cross-section and charged particle multiplicity, anti-k_T R=0.6

Jet fragmentation and shape

Probe **internal jet structure** with measurements of **charged particles** inside the jet: jet fragmentation function and transverse jet profile

[ATLAS arXiv 1109.5816, EPJC]

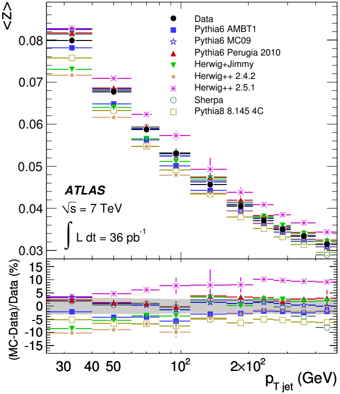
Measurement of
jet fragmentation function:

probability of charged particle carrying momentum fraction z

$$z = \frac{\mathbf{p_{jet}} \cdot \mathbf{p_{ch}}}{\mathbf{p_{jet}}}$$

Sensitivity to:

- Fragmentation models: benchmarks for simulation
- Non perturbative hadronisation effects



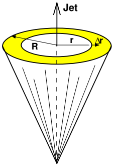
Jet fragmentation and shape

Probe **internal jet structure** with measurements of **charged particles** inside the jet: jet fragmentation function and transverse jet profile

[ATLAS arXiv 1109.5816, EPJC]

Measurement of integrated jet shape:

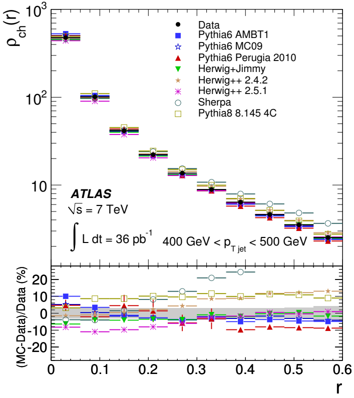
density of ch. particles around jet axis



Sensitivity to:

- Fragmentation models: benchmarks for simulation
- Non perturbative hadronisation effects

No MC model describes both jet fragmentation and jet profile

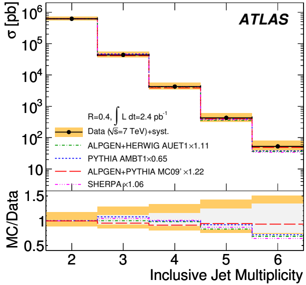


Inclusive jet, dijet and multijet cross section

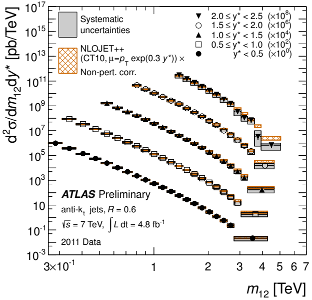
Jet production: dominant high p_T process at LHC

- Probe perturbative QCD at small distances
- Understand dominant background for many analyses
- Early testing ground for jet calibration and performance
  very first measurements: 17 nb^{-1} [ATLAS arXiv 1012.4389, EPJC]
  [ATLAS-CONF-2010-084]

Multijet cross section:
[ATLAS arXiv 1107.2092, EPJC]



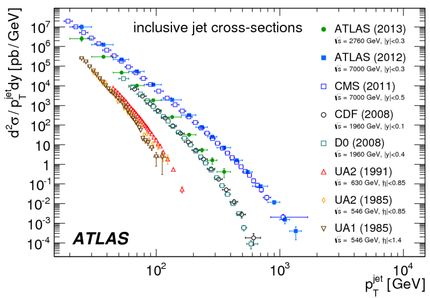
Dijet double-differential cross section,
[ATLAS CONF-2012-021]



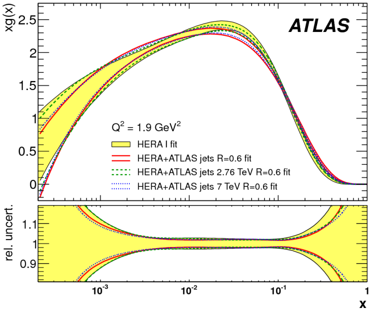
Jet cross sections: 7 TeV and 2.76 TeV

Measure jet cross sections at two center of mass energies (7 and 2.76 TeV): exploit uncertainty correlations, use **both** datasets as input for PDF fits

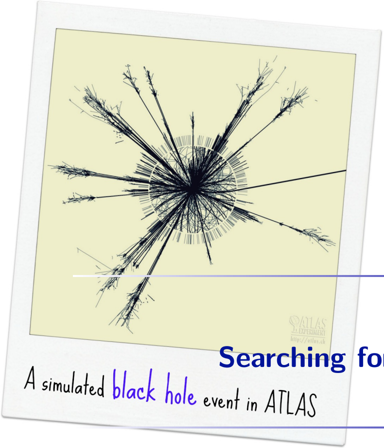
[ATLAS arXiv 1304.4739,EPJC]



Qualitative comparison of jet cross sections for various experiments



Effect of 7 and 2.76 TeV fits on gluon PDF (ATLAS+HERA data only)

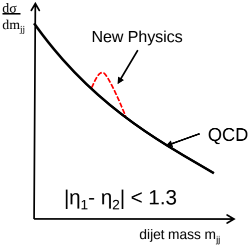


Searching for new phenomena with jets

Overview of dijet searches

Searches in the dijet mass spectrum

- Select high m_{jj} events (m_{jj} >1000 GeV)
- Fit QCD background from data using smooth function: $f(x) = p_1(1-x)^{p_2} \cdot x^{p_3 + p_4 \log x}, x = m_{jj}/\sqrt{s}$
- Look for discrepancies using BumpHunter [1101.0390]
- If no surprises, test models → set limits:
  - **Benchmark**: excited quark (q^*) production [PRD]
  - Color octet model [JHEP]

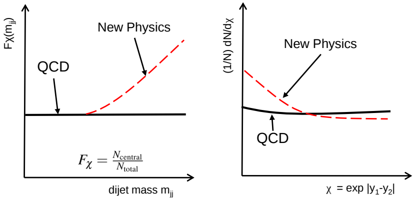


[F. Ruehr, LPCC Workshop on Higgs/BSM]

Overview of dijet searches

Searches in dijet angular distributions

- Select high m_{jj} events (m_{jj} >850 GeV)
- Look for excesses above QCD at high scattering angles
- Use $F_{\chi}(m_{jj}) = \frac{N_{central}}{N_{total}}$ to resolve evolution of angular shape in fine mass bins
- Use normalised $\chi = e^{|y_1 - y_2|}$ distribution for angular shape in wide mass bins
  - **Benchmark**: Contact Interactions
  - Quantum Black Holes [JHEP]

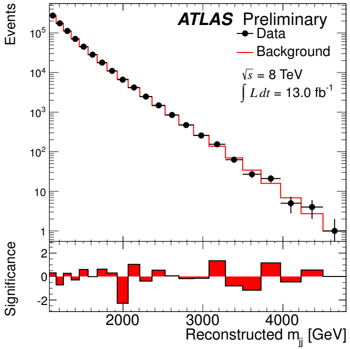


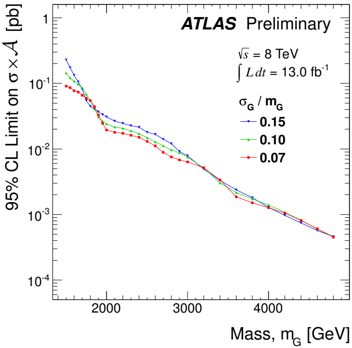
[F. Ruehr, LPCC Workshop on Higgs/BSM]

Searches in the dijet mass distribution

[Search for dijet mass resonances: ATLAS-CONF-2012-148]

- Look for resonances above smooth background in central dijet mass spectrum: none found
- Set 95% C.L. limit on $\sigma \times A$ for excited quark model (m(q*) $<$ 3.84 TeV)
- Include model-independent limits on Gaussian resonances of varying width





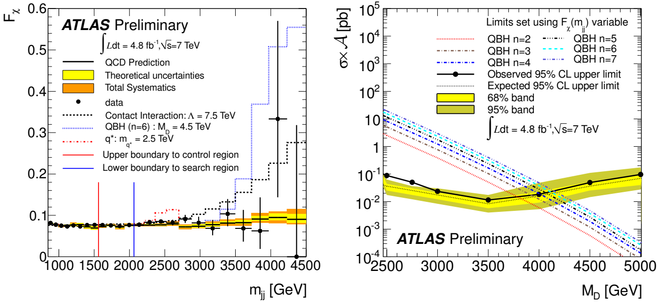
No evidence of new phenomena with more than half of the 8 TeV dataset
Consistence with good agreement of SM measurement of m_{jj} with QCD at 7 TeV

Searches in dijet angular distributions

[ATLAS-CONF-2010-056]

$$F_\chi(m_{jj}) = \frac{N(|y*| < 0.6)}{N(|y*| < 1.7)}$$ distribution, with QCD prediction superimposed

with 95% C.L. limit on Quantum Black Holes model as a function of Planck mass



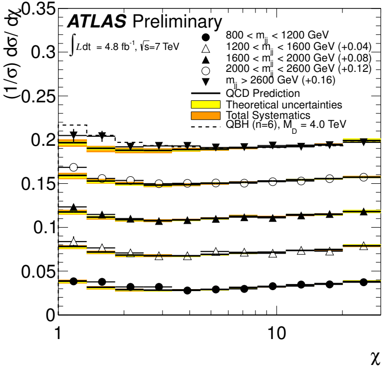
(a) (b)

No evidence of new phenomena with 7 TeV dataset
Consistent with good agreement of SM jet measurements with QCD

Searches in dijet angular distributions

[ATLAS-CONF-2010-056]

The $\chi = \exp(|y_1 - y_2|)$ distribution, with QCD prediction superimposed with summary table for 95% C.L. limits

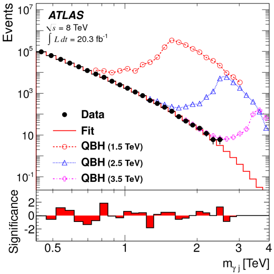


Model, and Analysis Strategy	95% C.L. Limits (TeV) Expected	Observed
Excited quark, mass of q^*		
Resonance in m_{jj}	3.09	3.35
Resonance in $F_\chi(m_{jj})$	2.97	2.58
Colour octet scalar, mass of s8		
Resonance in m_{jj}	1.94	1.94
Quantum Black Hole for $n = 6$, M_D		
$F_\chi(m_{jj})$	4.14	4.11
11-bin χ , $m_{jj} > 2.6$ TeV	4.23	3.96
Contact interaction, Λ, destructive interference		
$F_\chi(m_{jj})$	8.2	7.6
11-bin χ , $m_{jj} > 2.6$ TeV	8.7	7.8

No evidence of new phenomena with 7 TeV dataset
Consistent with good agreement of SM jet measurements with QCD

Searches in the γ+jet invariant mass spectrum

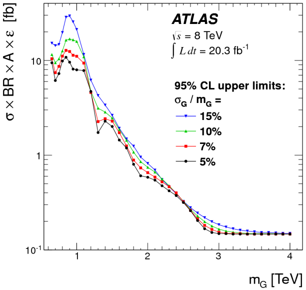
- Select central high p_T γ-jet events ($p_{T,\gamma}, p_{T,jet}$ >125 GeV)
- Build $\gamma - jet$ invariant mass
  Reject background using calorimeter isolation/topology
- Fit background from data using smooth function, look for discrepancies using BumpHunter [1101.0390]



No evidence of new phenomena in entire 8 TeV dataset

[ATLAS arXiv 1309.3230, sub. to PRD]

- No surprises → set limits on benchmark models:
  - Excited quarks (q*)
  - Quantum Black Holes
  - Hypothetical Gaussian γ−jet decay signal (mass m_G, width σ_G)

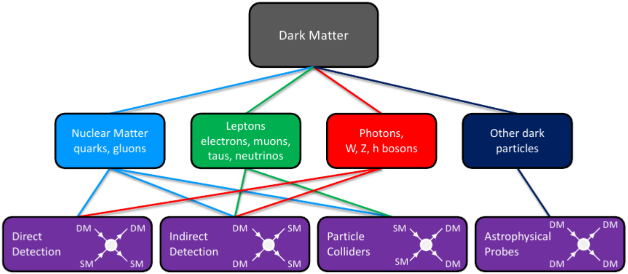


Searches for dark matter in mono-X+MET

From cosmological and astroparticle experiment observations:

≈ 95% of the universe is (directly or indirectly) evident but unexplained:
dark matter and **dark energy**

[arXiv 1305.1605]



Synergy needed with other experiments for dark matter detection
in space and in labs

Searches for dark matter in mono-X+MET

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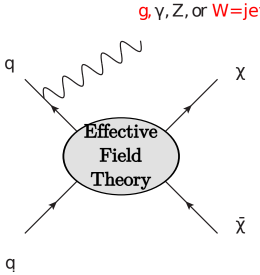


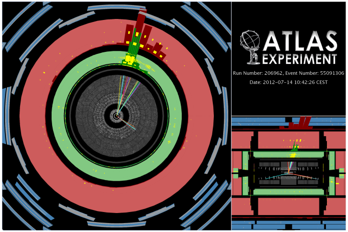
LHC experiments have a shot at finding a particle candidate for **dark matter**:
dark matter interacts gravitationally ⇒ could it interact **weakly**?

- Specific, UV-complete theories: e.g. SUSY, with Lightest Supersymmetric Particle as DM candidate → optimise sensitivity for certain models
- Simplified models: e.g. effective theory encompassing interaction between SM and DM particles → less sensitive but more generic

Searches in the monojet final state

[Search for new physics in monojet: ATLAS CONF-2012-147]

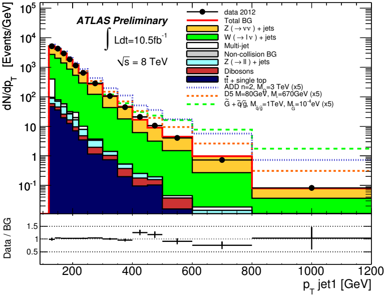
- Select events with large jet p_T and missing transverse momentum



- Background estimation: use transfer factors from control regions in data
- Counting experiment: hope to observe excess of events above jet p_T and missing transverse momentum thresholds
- Set model-independent limits ($\sigma \times A$), limits on Large Extra Dimensions, WIMPs, Gravitinos

No significant excess over background in 10 fb^{-1}

- Data, background and example signals in one of the signal regions



Errors on plot are statistical only

- 8 TeV analysis limited by modelling uncertainties

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[Search for new physics in monojet: ATLAS CONF-2012-147]

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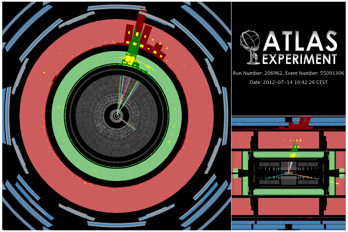

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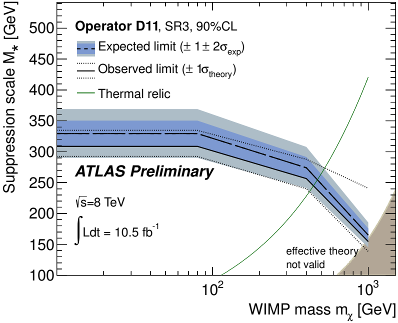
No significant excess over background in 10 fb^{-1}

- Limits on WIMP scalar operator D11



Caveat: validity of effective theories at colliders
→ Theory/experiment collaborations to ensure complementarity of DM searches

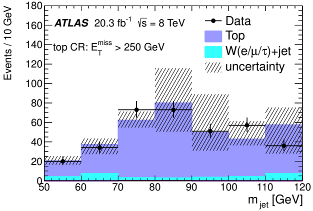
- Higgs entering searches: reinterpretation in terms of H→ invisible BR (and vice-versa: H→ inv. reinterpreted as limits on WIMPs)

Searches in mono-W final state

If dark matter has opposite-sign couplings to up and down quarks
→ preferential radiation of W boson

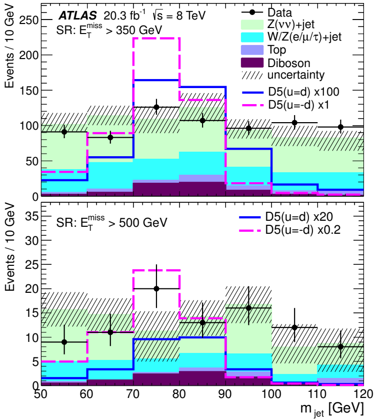
[Search for dark matter in mono-W: ATLAS arXiv-1309.4017, Submitted (yesterday) to PRL]

- Select events with C/A split/filtered jet, with mass around W peak (**hadronic W**) + missing transverse momentum



- Main background estimation technique: similar to monojet (transfer factors)
- Look for excess over number of estimated events: no excess found in whole 8 TeV dataset

- Data, background and hypothetical signal



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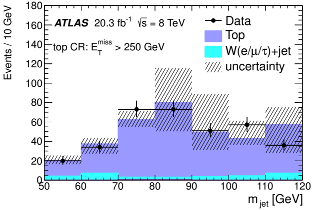
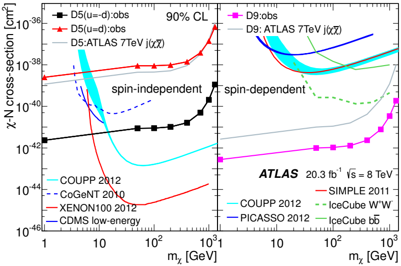


- Main background estimation technique: similar to monojet (transfer factors)
- Look for excess over number of estimated events: no excess found in whole 8 TeV dataset

- Limit on dark matter-nucleon cross section, compared to other experiments



- Also available: limit on *Higgs to invisible* branching ratio ($\sigma_{inv}/\sigma_{tot\ SM} \lesssim 1.6$)

Conclusions and outlook

A wealth of **jet results** produced by **ATLAS** in **2011 7 and 8 TeV** dataset: more precision measurements and searches in the pipeline

Jet algorithms and performance:

- No *one fits all* jet algorithm: **complexity of jets** can be exploited (e.g. jet **substructure**)
- Good understanding of the **jet energy scale** and **resolution** in ATLAS data throughout the LHC Run-I

Standard Model jet measurements:

- **Good agreement** of data and **pQCD**
- Effort ongoing to deliver ATLAS data for constraining PDFs/theory/MC models

Searches with jets:

- **No evidence** of new phenomena in jet final states
- **Exclusion limits** set on exotic models

Conclusions and outlook

A wealth of **jet results** produced by **ATLAS** in **2011 7 and 8 TeV** dataset:
Expect **much more** with the **13 TeV** data:
let's prepare for the excitement of **dijet searches** in 2015!

Thanks for your attention!