



# ATLAS physics results and analyses crafted at HEP ANL

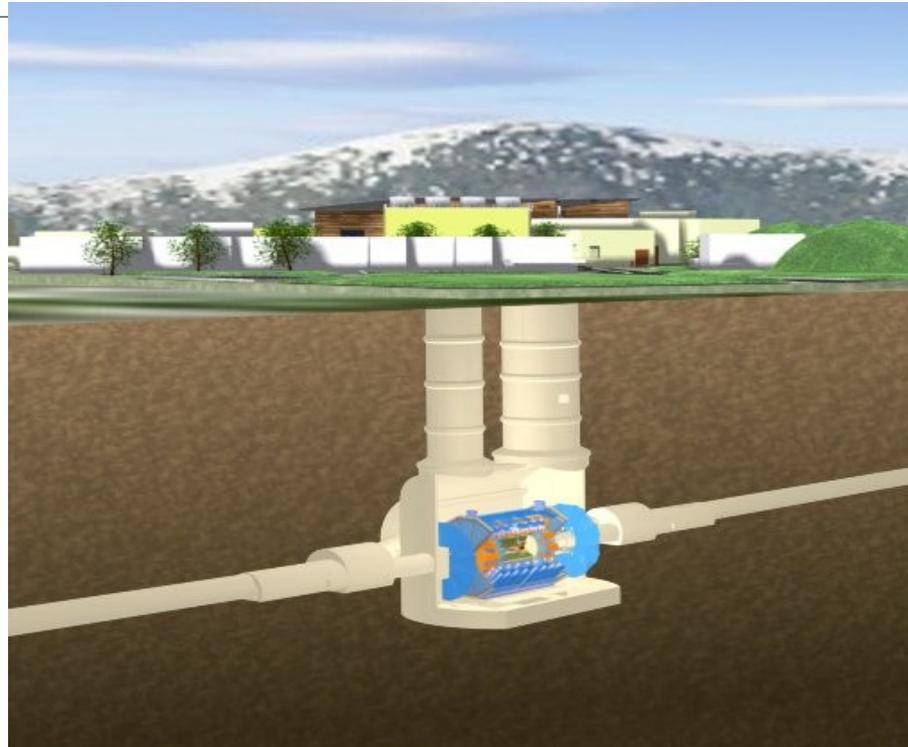
Past Present **Future**



**S.Chekanov (HEP/ANL)**

DOE review

May 2011





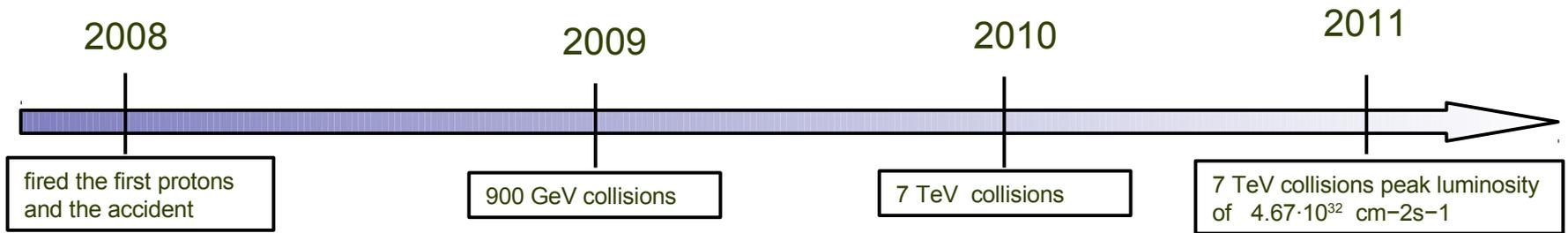
***“Study the past, if you would divine the future”***

Confucius  
551 BC





# From first beam to high-luminosity runs



- Analysis preparation
- Setting up computer infrastructure (Tier3) and analysis tools

- Physics with early data
- Detector-performance studies
- Preparation for high-energy high-intensity beams

- First publications with major contributions from ANL
- Setting up software tools for high-pT / search program

## ■ People (2008-2011):

- **6 senior ANL physics**
- **4 ANL Pos.Docs:**
  - L.Asquith, B.Salvachua, E.Torregrosa (until 2010) S.Paramonov (ANL Named Fellow)
- **6 students affiliated with ANL:**
  - C.Suhr (NIU), S.Norberg (Oklahoma), A.Yurkewicz (Stony Brook), B.Martin (MSU), S.Cole (NIU), R.Calkins (NIU)
- **5 ANL summer students** (J.Boomsma, N.Gardner, C.Levy, Z.Epstein, A.Johnson)
- **Plus short-term ASC visitors (not included in this summary)**





# Preparation & setting up analysis environment

2008-2010

- ✓ **Contribution to Jet/missET performance group**
  - ✓ J.Proudfoot – convener
  - ✓ Jet calibration task force note (E.Torregrosa etc.)
    - MC based Jet Energy Scales (B.Salvachua etc).
  - ✓ Software validation. Jet energy scale studies using gamma+jet (S.C.)
- ✓ **Contribution to Egamma performance group (R.Blair, L.Price, S.C.)**
  - Studies of background for direct photons (R.Blair, L.Price, S.C.)
- ✓ **T.Le Compte is a convener of the Standard Model group**
- ✓ **Designed a Tier3 computer farm (R.Yoshida, S.C.)**
- ✓ **Developed analysis packages & tutorials during 5 analysis Jamborees**
- ✓ **Several analysis packages (cosmic muons studies and general search program)**

Success depends upon previous preparation, and without such preparation there is sure to be failure. *Confucius*

## ATLAS notes with >50% contribution from ANL:

ATL-COM-PHYS-2009-042  
ATL-COM-PHYS-2009-128  
ATL-COM-GEN-2009-016  
ATL-COM-PHYS-2009-158  
ATL-COM-PHYS-2009-162  
ATL-COM-PHYS-2011-239

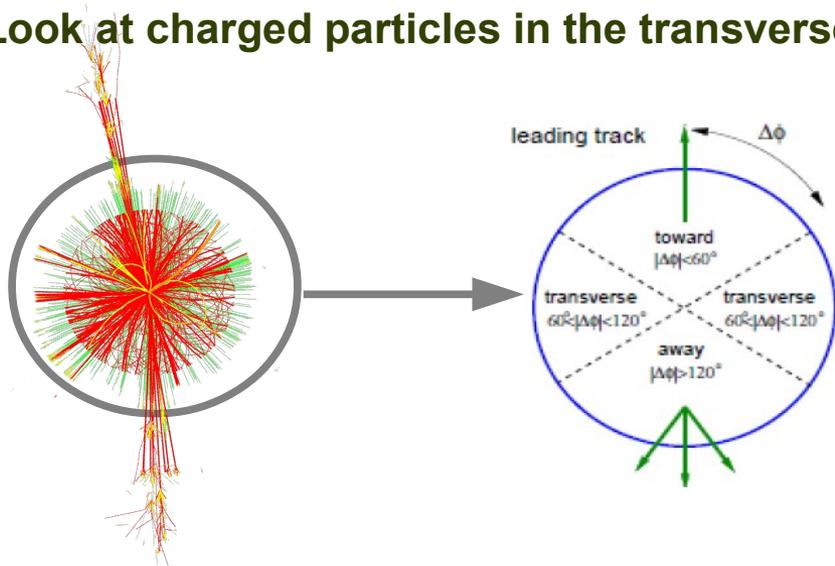
ATL-COM-SOFT-2009-023  
ATL-COM-PHYS-2009-619  
ATL-PHYS-PUB-2009-082  
ATL-COM-PHYS-2009-233  
ATL-COM-PHYS-2010-805  
ATLAS-COM-CONF-2011-063 + ....





# Early measurements with new data (2010)

- ✓ First thing first. Need to understand the underlying event
  - Does not require large luminosity & high energy
- ✓ Look at charged particles in the transverse region!



ANL:

- complete second analysis
- alternative bin-by-bin unfolding

$|\Delta\phi| < 60^\circ$  as **Toward**

$60^\circ < |\Delta\phi| < 120^\circ$  as **Transverse**

$|\Delta\phi| > 120^\circ$  as **Away**

- Track-based underlying event measurements in pp collisions at 7 TeV with the ATLAS Detector at the LHC  
**ATL-COM-PHYS-2010-237**
- Using bin-by-bin corrections for track-based underlying event measurements in pp collisions at 900 GeV  
**ATL-COM-PHYS-2010-165**
- Track-based underlying event measurements in pp collisions at 900 GeV with the ATLAS Detector at the LHC  
**ATL-COM-PHYS-2010-164**

Impacts every high-precision measurement. Monte Carlo simulations should be tuned





# Early measurements with 900 GeV and 7 TeV data

Information | References (23) | Citations (8) | Files | Plots

## Measurement of underlying event characteristics using charged particles in pp collisions at $\sqrt{s} = 900\text{ GeV}$ and 7 TeV with the ATLAS detector.

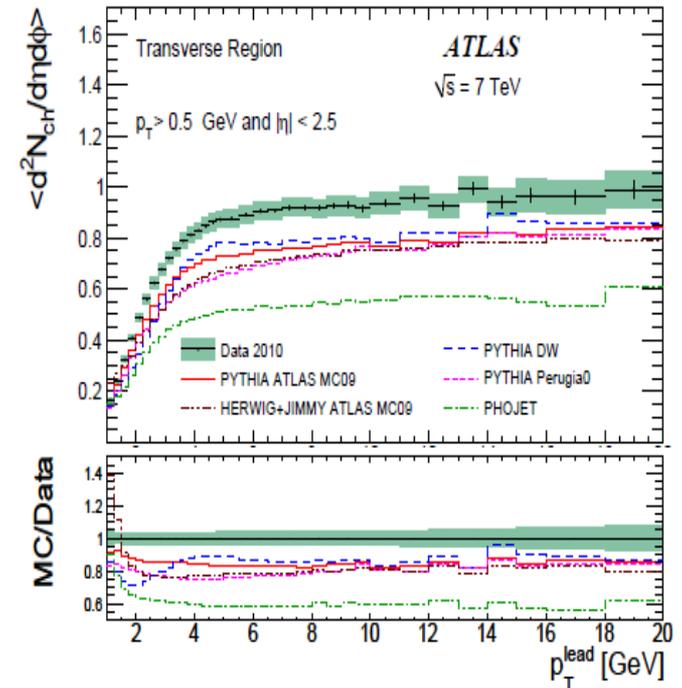
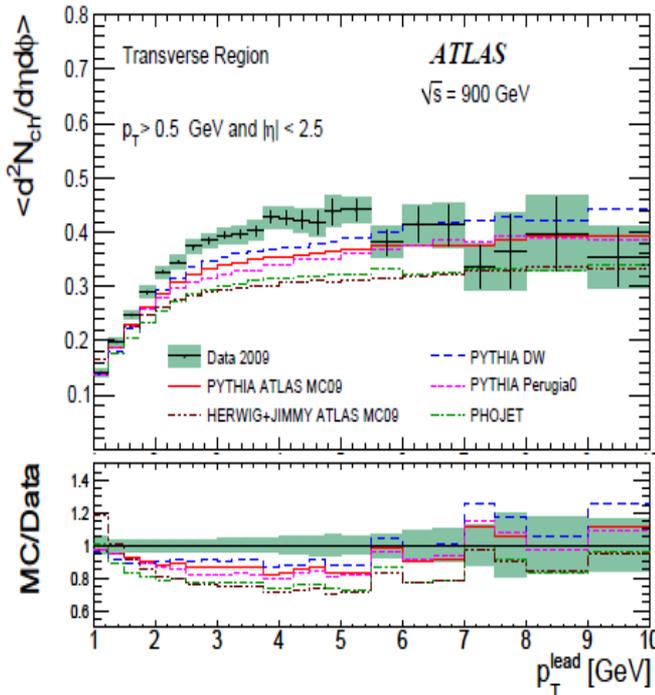
Atlas Collaboration (Georges Aad (Freiburg U) et al.) [Show all 3070 authors.](#)

Dec 2010  
36 pp. e-Print: [arXiv:1012.0791 \[hep-ex\]](#)

**Abstract:** Measurements of charged particle distributions, sensitive to the underlying event, have been performed with the ATLAS detector at the LHC. The measurements are based on data collected using a minimum-bias trigger to select proton-proton collisions at center-of-mass energies of 900 GeV and 7 TeV. The 'underlying event' is defined as those aspects of a hadronic interaction attributed not to the hard scattering process, but rather to the accompanying interactions of the rest of the proton. Three regions are defined in azimuthal angle with respect to the highest- $p_T$  charged particle in the event, such that the region transverse to the dominant momentum-flow is most sensitive to the underlying event. In each of these regions, distributions of the charged are measured. The data show a higher underlying Monte Carlo models tuned to pre-LHC data.

**Keyword(s):** [INSPIRE: charged particle](#) | [mu Coll](#) | [transverse](#) | [Monte Carlo](#) | [multiplicity](#) | [particle: transverse momentum](#) | [correlation](#) | [transverse momentum: momentum spectrum theory](#) | [experimental results](#) | [900: 7000 Ge](#)  
**Note:** \* Temporary entry \*

Soft QCD is more complicated than we thought!  
All Monte Carlo models fail  
Need to be tuned for high-precision measurements

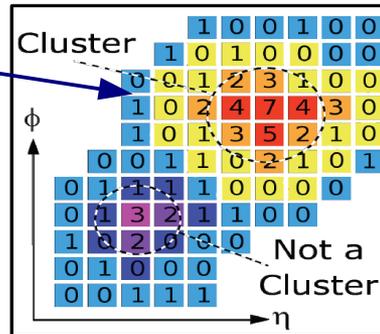
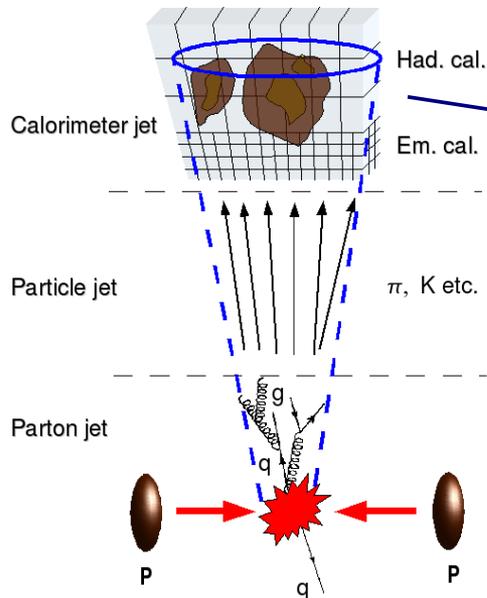




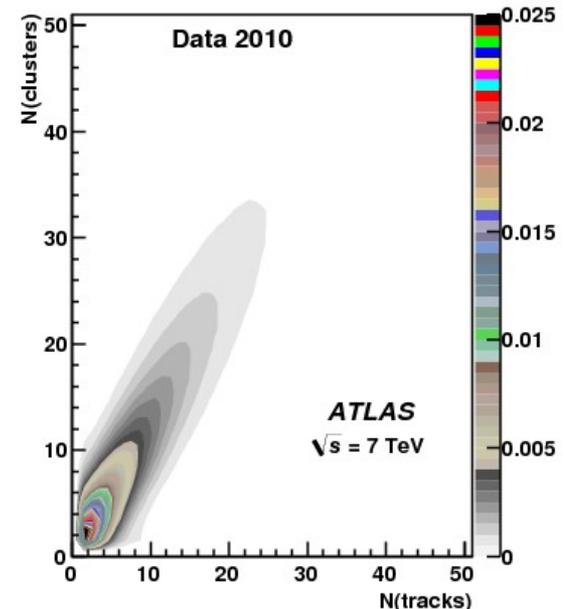
# Towards a complete final state

- Measurements using calorimeters have some advantages:
  - Sensitive to a complete final state including neutrals (extra ~40%)
  - Many high-precision jet measurements are based on energy deposition, and calorimeter-based UE studies can be directly used for such measurements
- Calorimeter UE can take advantage of unique ATLAS calorimeter:
  - 190k channels for electromagnetic & hadronic calorimeter

Excellent transverse and longitudinal segmentation allows reconstruction of “topological” clusters in 3D which are closely related to single particles (on average)

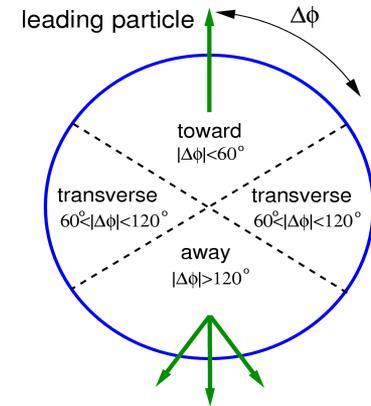
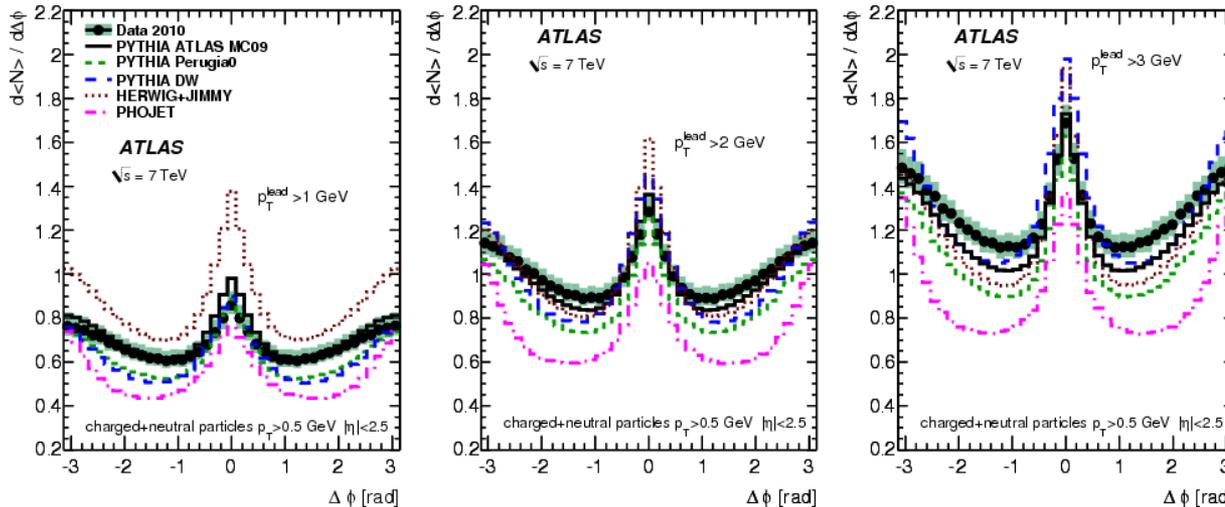


Perfect Cluster  $\leftrightarrow$  particle association





# Particle densities as a function of $\Delta\phi$



Eur. Phys. J. C (2011) 71: 1636  
 DOI 10.1140/epjc/s10052-011-1636-z

THE EUROPEAN  
 PHYSICAL JOURNAL C

Regular Article - Experimental Physics

**Measurements of underlying-event properties using neutral and charged particles in  $pp$  collisions at  $\sqrt{s} = 900$  GeV and  $\sqrt{s} = 7$  TeV with the ATLAS detector at the LHC**

The ATLAS Collaboration\*  
 CERN, 1211 Geneva 23, Switzerland

Received: 10 March 2011 / Revised: 7 April 2011  
 © CERN for the benefit of the ATLAS collaboration 2011. This article is published with open access at Springerlink.com

**Abstract** We present first measurements of charged and neutral particle-flow correlations in  $pp$  collisions using the ATLAS calorimeters. Data were collected in 2009 and 2010 at centre-of-mass energies of 900 GeV and 7 TeV. Events

UE measurements are performed using the mental environment and reconstructed object the calorimeter-based measurements. The fir of the ATLAS calorimeter allows the defini

All Monte Carlo models fail  
 Distributions are used as input to  
 tune MC modes

ANL contribution: ~100%

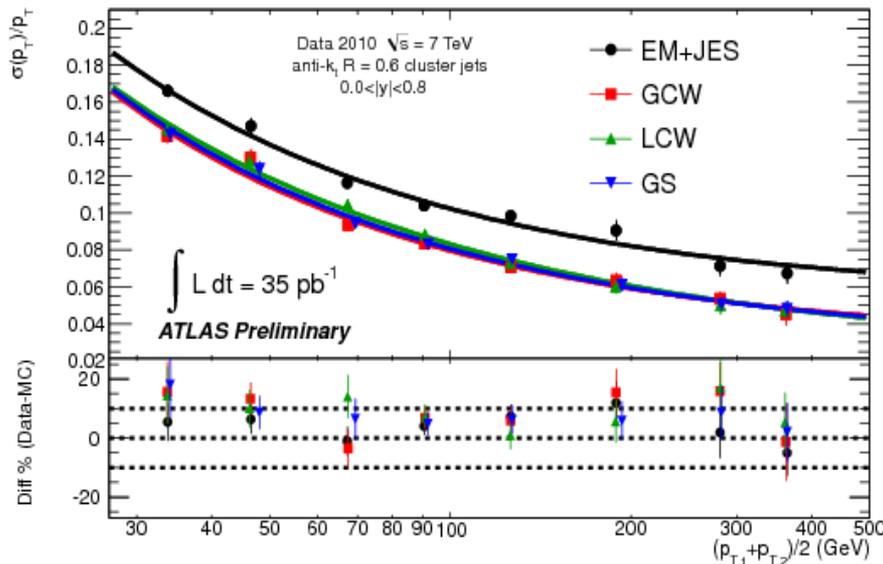
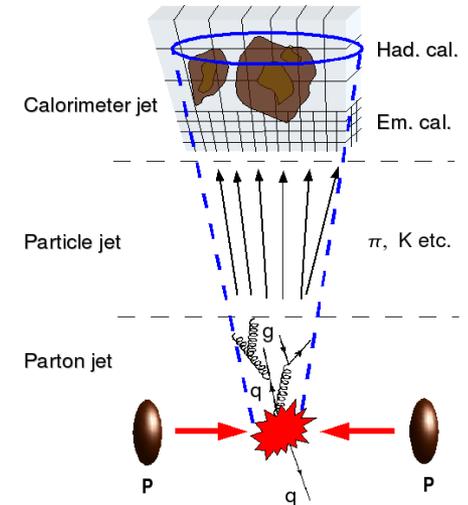
Done at ANL Tier3 & written here.  
 Most talks – remotely with CERN





# Jets

- Jets are sensitive probe of many aspects of pQCD:
  - matrix elements at LO+Parton Showers and NLO QCD
  - parton density function (PDF's), running  $\alpha_s$
  - refine our understanding of soft QCD
  - important for searches beyond SM



## Global-Cell Weighting technique

### Corrects for:

- Non-compensation
- Energy losses: dead material, crack regions, etc
- MC dependent (depends on cell energy density and calorimeter technology)

ATL-COM-PHYS-2010-304  
 ATL-PHYS-INT-2009-050  
 ATL-COM-PHYS-2009-385





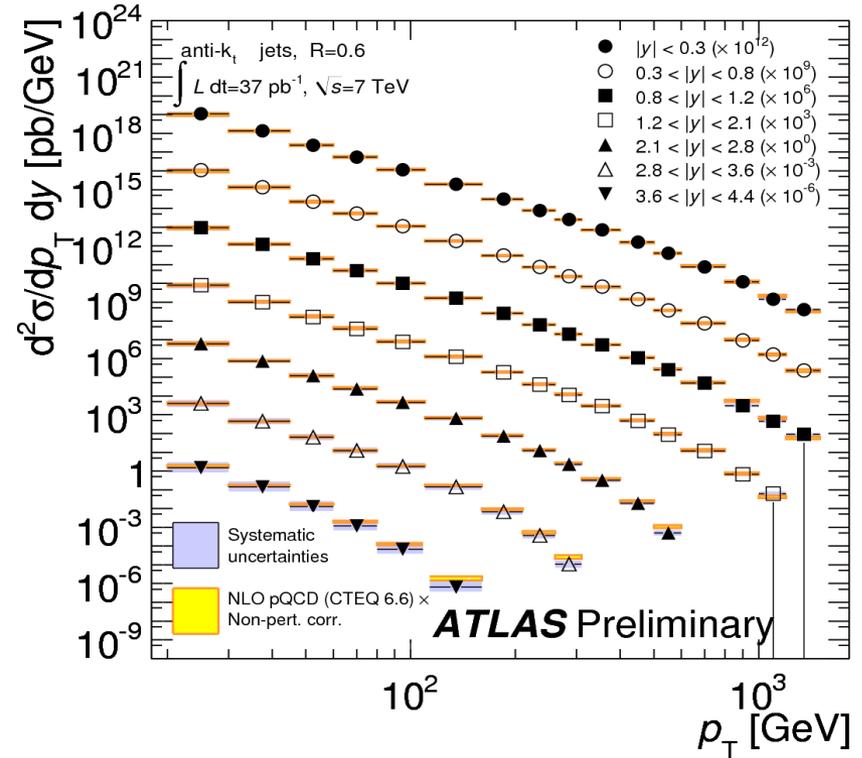
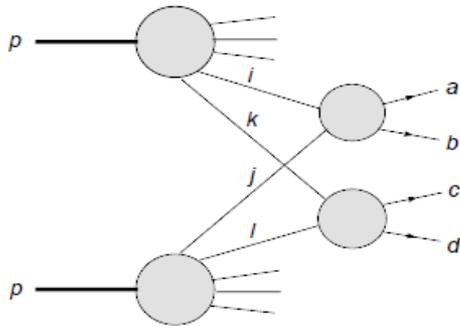
# ANL contribution to inclusive jet measurements

Participated in 2 ATLAS measurements  
(summer 2010 and spring 2011)

ATL-PHYS-INT-2010-119  
ATLAS-CONF-2011-047  
ATLAS-COM-CONF-2011-052:  
CONF note at 38 pb-1

work on GRL, event selection and jet cleaning,  
removing of LAr noise burst above 2 TeV

Pioneering new studies on double-parton  
scattering using  $\gamma+3j$  (done at Tevatron) and  
2b+2j channel (new channel!)



- Impacts multijet cross sections, Higgs & new physics searches
- Directly affects underlying-event models in MC generators
  - bridges MC parameters to a point of reality!
  - less parameters, simpler tunes

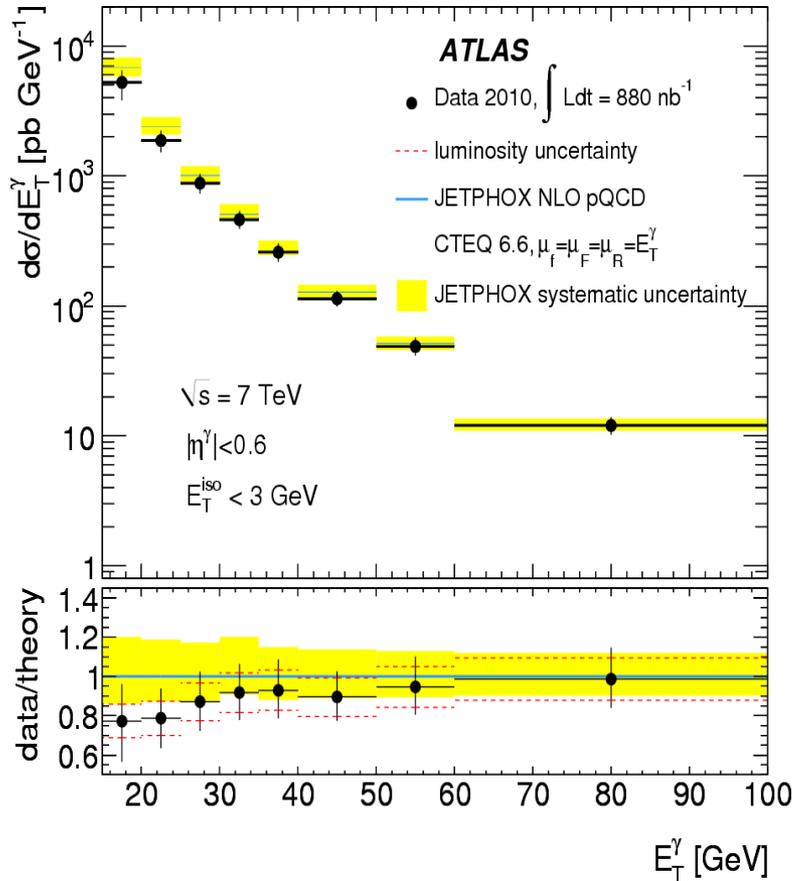




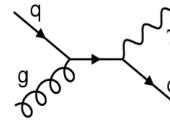
# Direct photon production

ATLAS arXiv:1012.4389

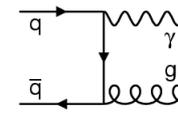
- ANL contributed to several notes on direct photons which eventually made up to a final ATLAS paper



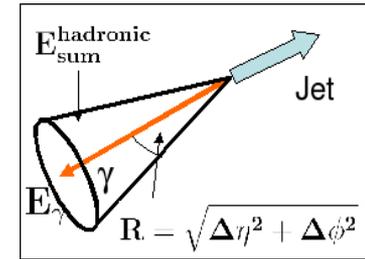
Good agreement with NLO QCD & CTEQ6.6



~90%



~10%



Theoretical Predictions for Measurements of the Inclusive Isolated Photon Cross Section in pp Collisions at s=7 TeV  
 ATL-COM-PHYS-2010-805

The measurement of the cross section for the inclusive production of isolated prompt photons in pp collisions at a center-of-mass energy s = 7 TeV  
 ATL-COM-PHYS-2011-239.

PHYSICAL REVIEW D **83**, 052005 (2011)

**Measurement of the inclusive isolated prompt photon cross section in pp collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector**

G. Aad *et al.*\*  
 (ATLAS Collaboration)

(Received 20 December 2010; published 18 March 2011)

A measurement of the cross section for the inclusive production of isolated prompt photons in pp collisions at a center-of-mass energy  $\sqrt{s} = 7$  TeV is presented. The measurement covers the pseudorapidity ranges  $|\eta^\gamma| < 1.37$  and  $1.52 \leq |\eta^\gamma| < 1.81$  in the transverse energy range  $15 \leq E_T^\gamma < 100$  GeV. The results are based on an integrated luminosity of  $880 \text{ nb}^{-1}$ , collected with the ATLAS detector at the Large Hadron Collider. Photon candidates are identified by combining information from the calorimeters and from the inner tracker. Residual background in the selected sample is estimated from data based on the observed distribution of the transverse isolation energy in a narrow cone around the photon candidate. The results are compared to predictions from next-to-leading-order perturbative QCD calculations.

DOI: 10.1103/PhysRevD.83.052005 PACS numbers: 14.70.Bh

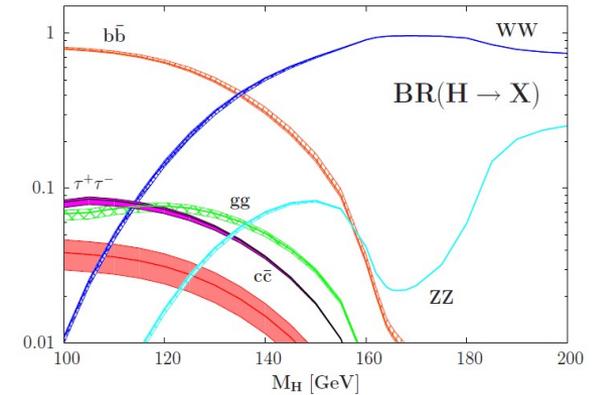




# From QCD to high-pT EWK sector

- Simpler environment to test SM
- W and Z cross sections are among the first measurements
  - <1% precision measurement after for 1 fb<sup>-1</sup> (this year!)
- Main channel for Higgs hunting (and main background!)
- Precise test of NNLO QCD, probing PDF
- Experimental view:
  - Establishing experimental procedure for calibration, trigger, alignment, luminosity and finally a gateway to probe SM at highest CM energies

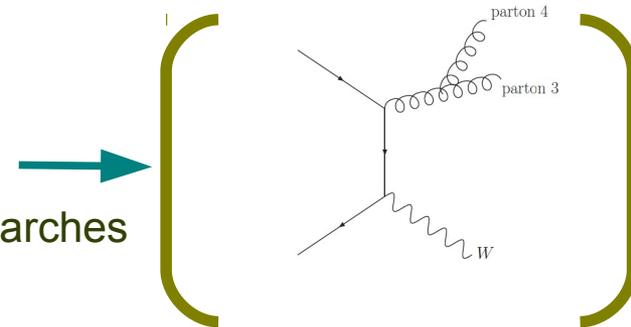
J.Baglio, A.Djouadi arXiv:1012.0530



Contributions to W+jets, WZ final state, Z+missET .. measurements  
(NIU, Santa Cruze ASC-affiliated visitors)

## W+jet measurements:

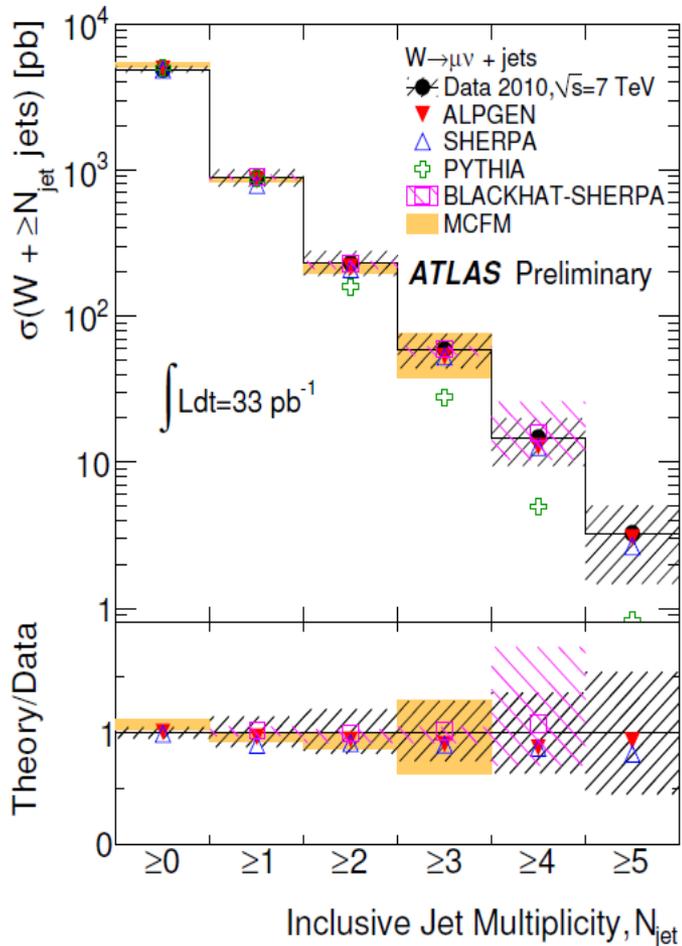
- Constrain measurements to well-known physics
- Precise test of QCD matrix elements & PDF
- Important background for top-antitop, single-top, Higgs searches





# W+jet measurement

- ~ 50% contribution to published ATLAS paper
- ~ Leading the effort to publish CONF note and new paper using all 2010 data



Phys.Lett.B698:325-345,2011

Measurement of the production cross section for W-bosons in association with jets in  $pp$  collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector

The ATLAS Collaboration

- ATLAS-COM-CONF-2011-063
- ATL-COM-PHYS-2011-280
- ATL-COM-PHYS-2011-141
- ATL-COM-PHYS-2010-1008
- ATL-COM-PHYS-2010-977

Done at ANL:

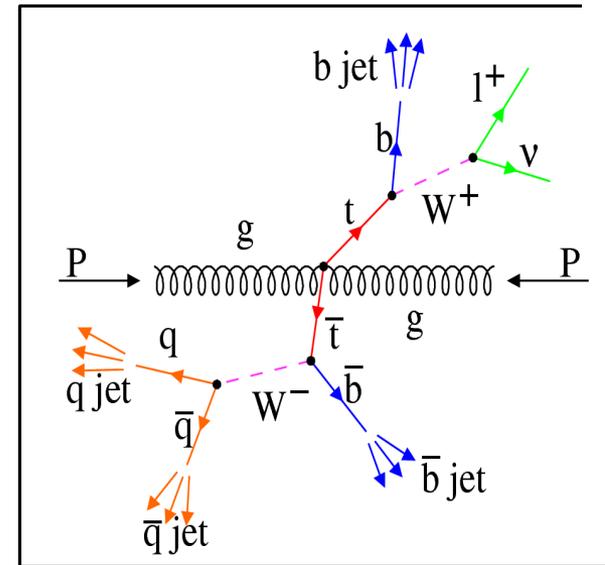
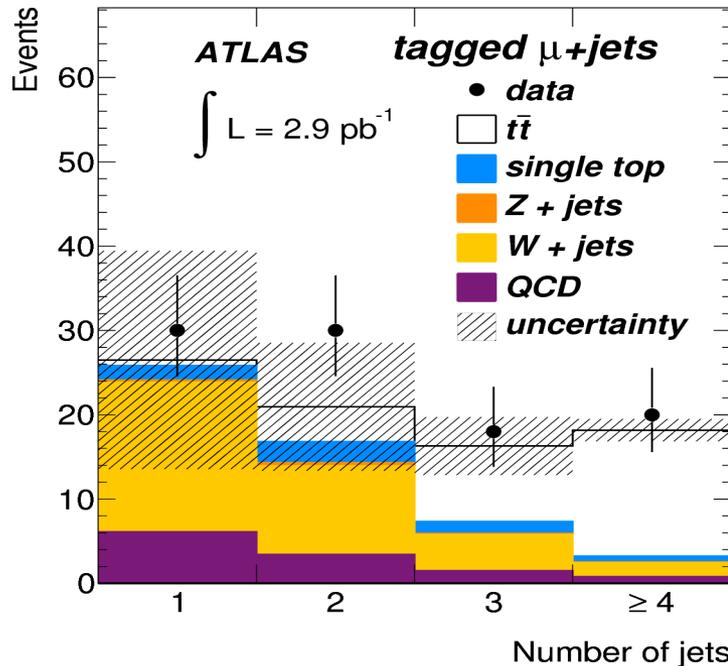
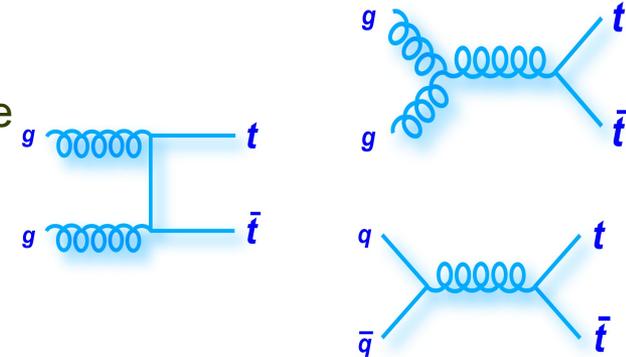
- Muon channel (+ systematics)
- Blackhat-Shepra comparison





# Top rediscovery

- Discovered in 1995 at Tevatron
- The most massive fundamental particle which completes the third generation of the SM quarks
- The most likely place for new physics to show up?



- NIU students affiliated with ASC (semileptonic top decays & single top)
- boosted tops (see next)







# From high-precision SM measurements to searches

Higgs searches

Searches for new TeV scale particles

Large  $p_T$   
 $M < \text{TeV}$  Higgs

TeV-mass particles  
(large Lorentz boost)

Looking at  $\gamma\gamma$ ,  $ZZ$

Looking at almost any  
possible combination

Searches for  
boosted particles  
using jet shapes  
and jet substructure

Generic searches in  
invariant-mass distributions  
up to N-body decays

Decays products are inside a “fat” jet

Decays products are well resolved

Very recently: Searches for “Compressed SUSY”:  
Many interesting event signatures falling into both categories:  
when we resolve decays as one jet or as separate decay products

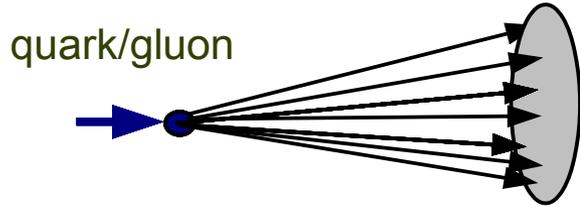




# Searches for boosted objects

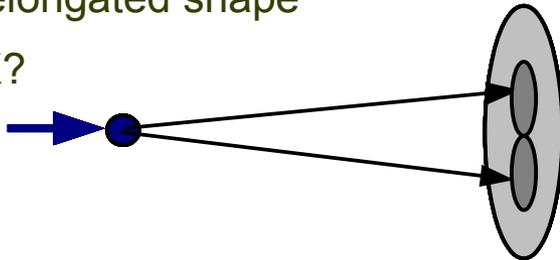
Hard interaction is always associated with extra QCD radiation

## Jet profiles



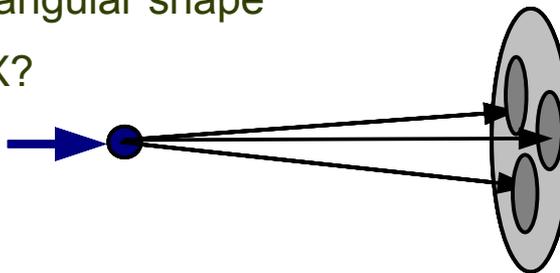
“elongated shape”

X?

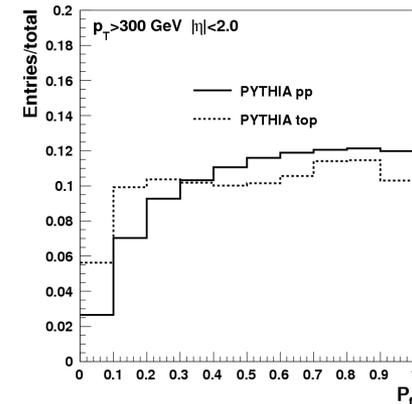
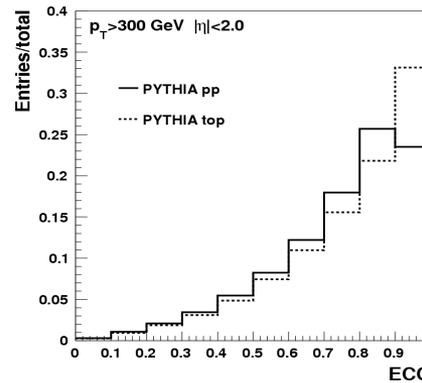
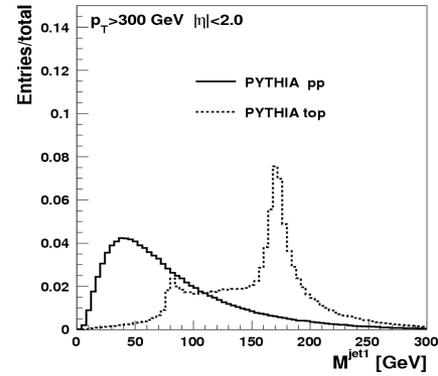


“triangular shape”

X?



Example:  
boosted top



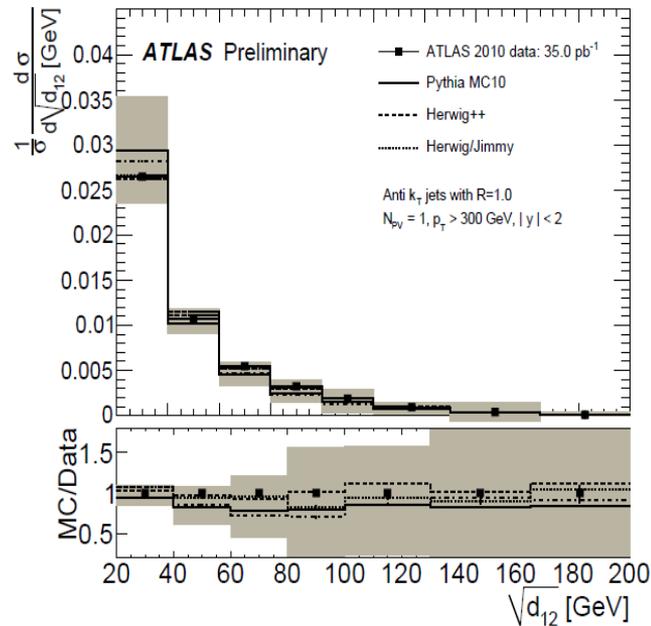
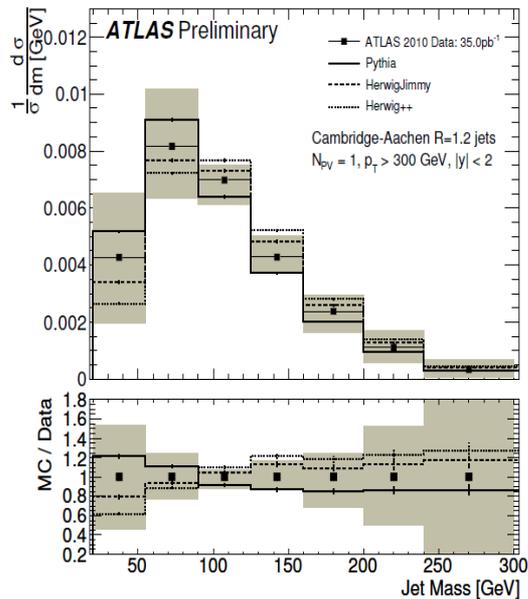
(very little correlation with jet mass)





# ANL effort to measure jet shapes

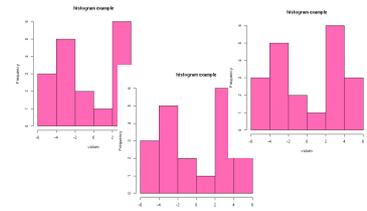
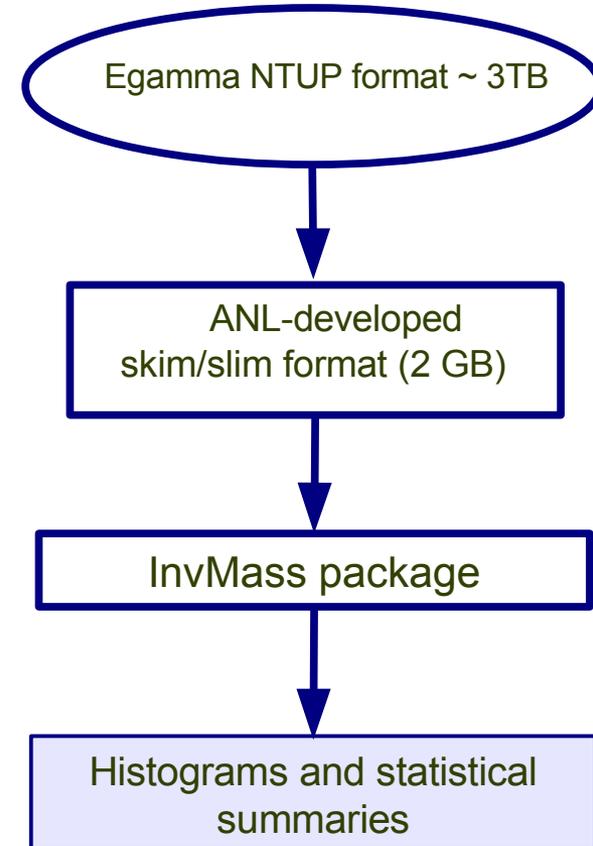
- Tools are in place: <http://atlaswww.hep.anl.gov/asc/statshape/>
  - S.C., J.Proudfoot (2010) Phys. Rev. D81 (2010)
  - S.C., C.Levy, J.Proudfoot, R.Yoshida, Phys. Rev. D81 (2010) 114038
- Significant ANL contribution to jet-mass studies using “fat” jets
  - ATLAS-COM-CONF-2011-084
- Leading data-analysis effort to understand jet shape using 2010
  - ATLAS conf. Note and paper draft are in preparation
- Looking at jet shapes and jet masses for new 2011 data





# General searches. “Early alert system”

- Look at all possible mass combinations
- Reconstructing 6 particles/jets:
  - electrons, muons, Z, gamma, jets, missET
- Reconstruction & automatic peak-identification:
  - 21 invariant masses for 2-body decays
  - 56 invariant masses for 3-body decays
  - 126 invariant masses for 4-body decays
- Analyze invariant masses as data arrive
- Most recent analysis was based on  $200 \text{ pb}^{-1}$ 
  - Several excited peaks
  - Proven a good tool to find misreconstructions





# Future directions and the strategic plan

## ▪ High-pT physics

- *Targeted outcome:*
  - SM cross sections and searches beyond TeV scale
- *Means to achieve:*
  - jets &  $\gamma$  measurements beyond TeV-scale
  - measurements and searches involving large missing ET

“Energy frontier”

## ▪ Rare phenomena with multiple low-pT objects

- *Targeted outcome:*
  - Higgs.
  - softQCD effects, double parton scattering (need large statistics!)
  - New particles and phenomena beyond SM.
- *Means to achieve:*
  - Multijets, multiple  $\gamma$ , WZ, WW etc.
  - General searches

“Intensity frontier”

## ▪ High-precision EWK/QCD measurements

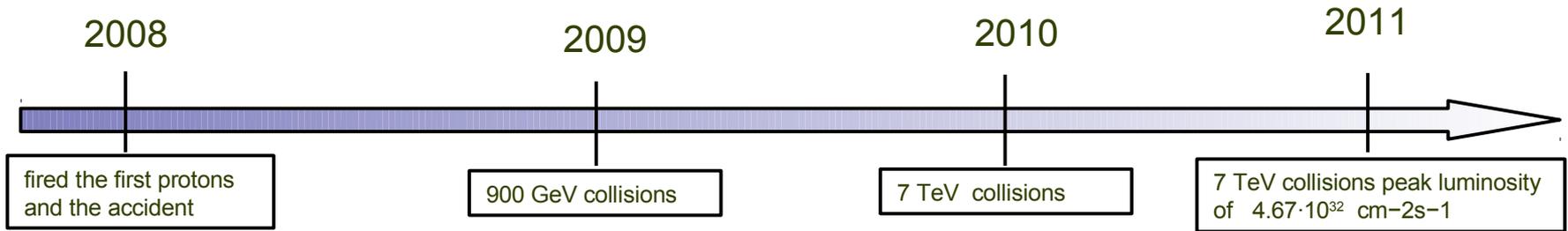
- *Targeted outcome:*
  - High-precision SM cross sections
- *Means to achieve:* W+jet, Z+jet,  $\gamma$ +jet, single top cross sections

“High-precision frontier”





# Summary: ANL involvement in data analysis



## SM QCD

- soft QCD: UE studies, multiplicity measurements
- Hadronic jets: (calibration, inclusive jets, double-parton scattering and jet shapes)
- Direct photons
- Electroweak QCD: W+jets, WZ, Z+missET

## Searches for Higgs and new physics

- general searches
- boosted particles (H, Z' etc)
- Compressed SUSY

Weekly analysis meetings organized by G.Blazey (NIU)





# Backup. ANL summer students (2009-2010)

- A.Jonson
  - Currently author of ATLAS W+jet paper
  - Presentations to ATLAS working groups
- C.Levy
  - Developed JetShape public library <https://atlaswww.hep.anl.gov/asc/statshape/>
  - Integrated to the ATLAS code
  - S.C., **C.Levy**, J.Proudfoot, R.Yoshida, Phys. Rev. D81 (2010) 114038
- J.Boomsma
  - Wrote the general-search program (slide 19)
  - Author of ATLAS note on this subject
  - Presentation to the ATLAS analysis group
- Z.Epstein
  - Work on Ks cross sections using 900 GeV data
  - Presentation to ATLAS analysis groups
- N.Gardner
  - Work on understanding of cosmic muons in TileCal (no data at that time!)
  - Presentations to ATLAS working groups

