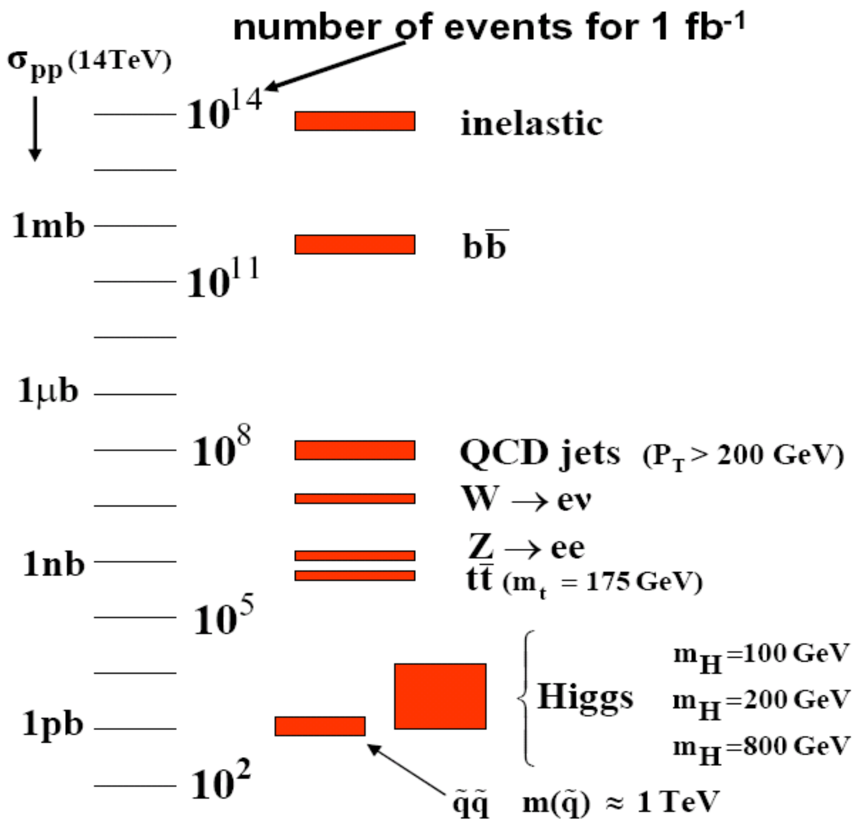
Early ATLAS Physics at the LHC



NSERC ATLAS Review
13-15 December 2007

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University of Victoria

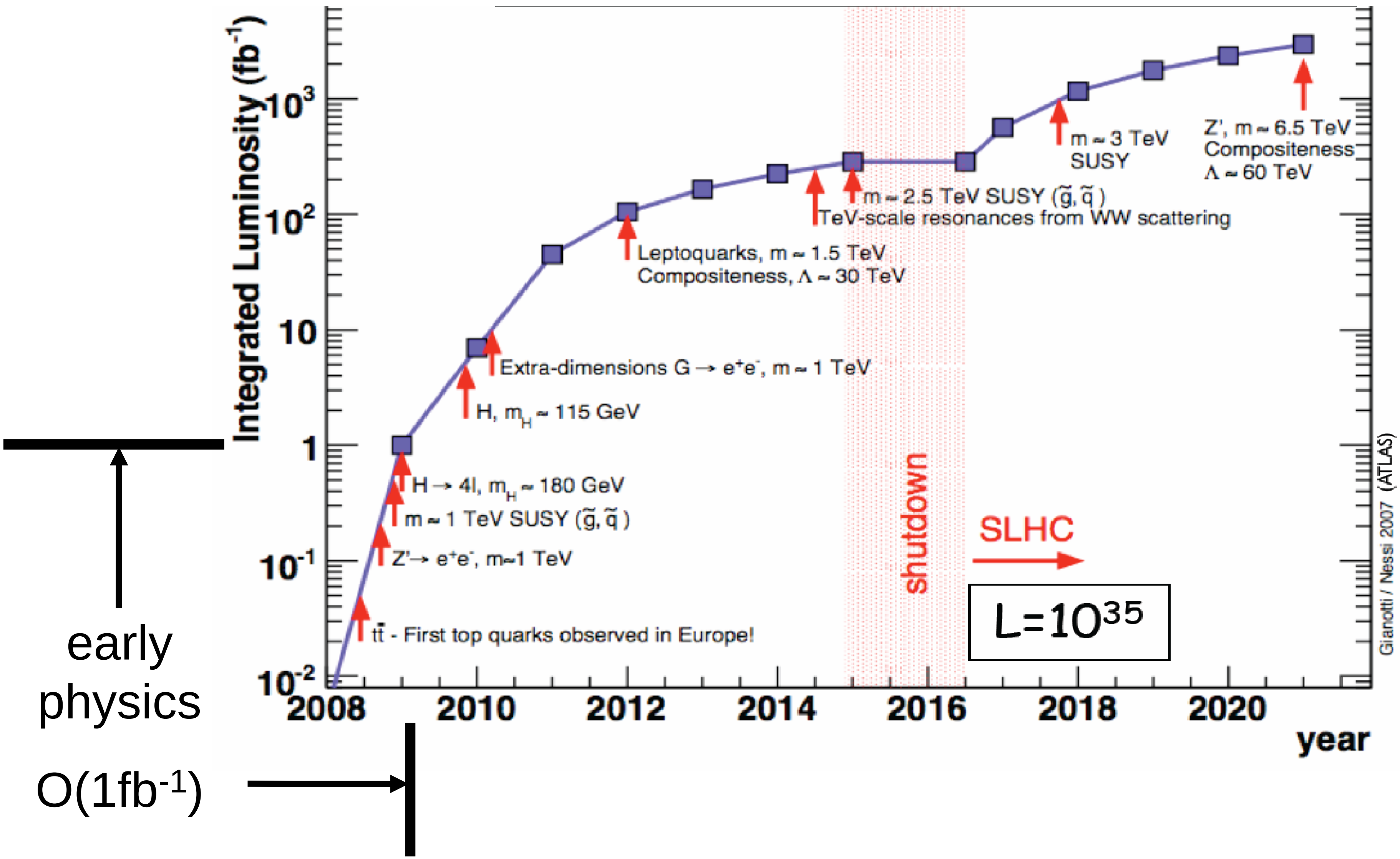
Getting ready for first LHC collisions

- ATLAS has very ambitious performance goals
  - driven by physics requirements
  - needs time and effort to control the detector at required level
  - final understanding of detector only achievable with LHC collisions
- Pressure to extract results as soon as possible
  - competition with other experiments
  - feedback signs of new physics to HEP community for planning
- Exploit time available before collisions to understand the detector enough to take advantage of the very first data
  - beam tests
  - detector and computing commissioning
  - preparation of calibration and analysis strategies

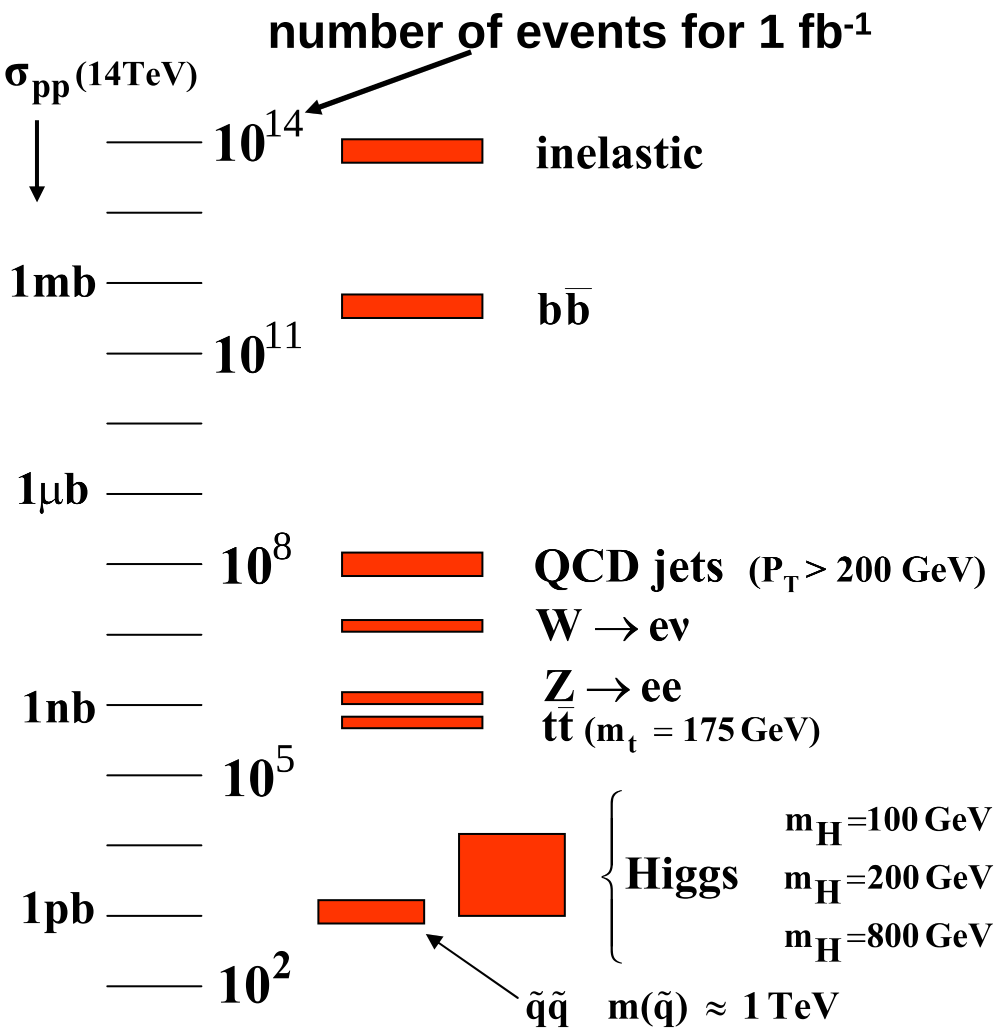
Initial conditions

- Assume the ATLAS detector installed
- Assume good knowledge of the detector
  - many years of simulation and (combined) beam test studies
  - commissioning at low and high rates
    - electronics pulser systems
    - cosmic rays: detector timing and alignment
    - first injections (beam gas collisions / beam halo muons): more specialized alignment work
- Expected detector performance at first collisions
  - EM calorimeter response uniformity ~1%
  - Hadronic calorimeter response uniformity 2 to 3%
  - $\gamma/e/\mu$ energy scale 0.5 to 2%
  - Jet energy scale <10%
  - Tracker alignment (in $R\varphi$ plane) 20 to 200 μm

LHC luminosity profile and physics reach



LHC PP Cross Section



- Assume total pp cross section known to ~1% from the TOTEM experiment
- Typical cross sections:

Process	σ
$W \to e\nu$	15 nb
$Z \to ee$	1.5 nb
$\bar{t}t$	800 pb
$\bar{b}b$	500 μb
$\tilde{q}\tilde{q}$ ($m_{\tilde{q}}$ =1 TeV)	1 pb
Higgs (m_H =0.8 TeV)	1 pb

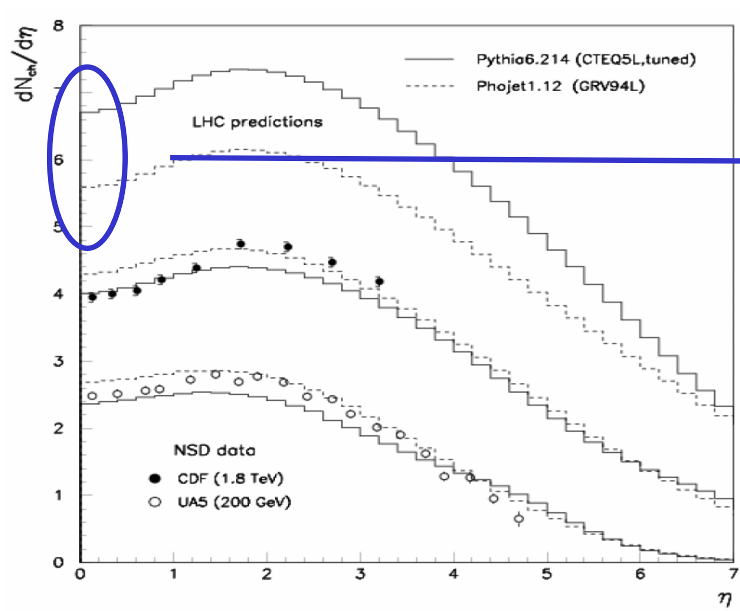
Strategy for first interactions

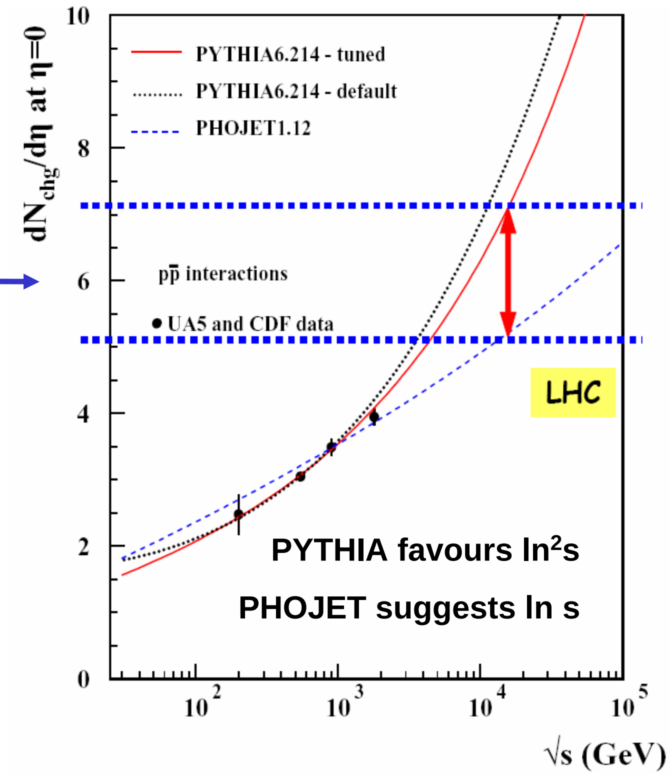
- First use of in-situ calibration
  - understand and calibrate detector and trigger in-situ using well known physics samples
- Understand basic SM physics at 14 TeV
  - first checks of Monte Carlo simulations
  - first look at minimum bias events, jet distributions, parton density functions constraints; W, Z, top cross sections; top mass
  - understand detector signatures
- The road to discovery
  - understand SM backgrounds to searches
    - in particular missing E_T distribution
  - focus on robust signatures that could reveal new physics without a complete knowledge of the detector response
    - for example, hunt for mass bumps where more than one sub-detector contribute to the signal

Minimum-bias events

- One of the very first measurements
  - Modelling of pileup event crucial for high p_T studies
  - extrapolating from Tevatron to LHC
  - in principle, only requires a few days of data
    - should be done at low luminosity
  - energy dependence of dN/dη ?

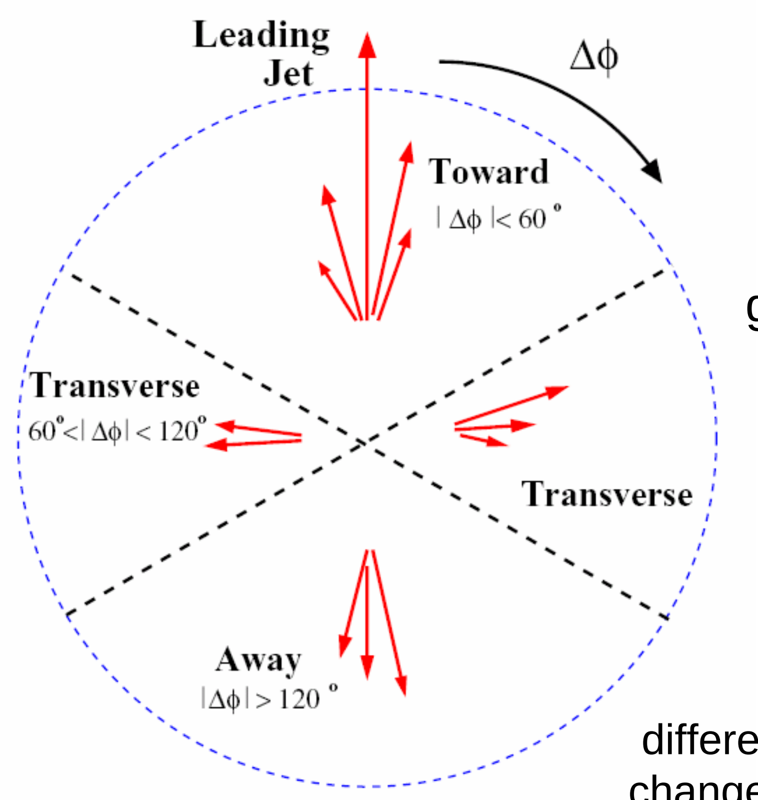
charged particle density at $\eta = 0$





Underlying event

- Also one of the very first measurements
  - Modelling of underlying event crucial for high p_T studies
- Look at tracks in the region transverse to jet activity



select $N_{\text{jets}} > 1$ $p_T^{\text{jet}} > 10$ GeV $|\eta_{\text{jet}}| < 2.5$

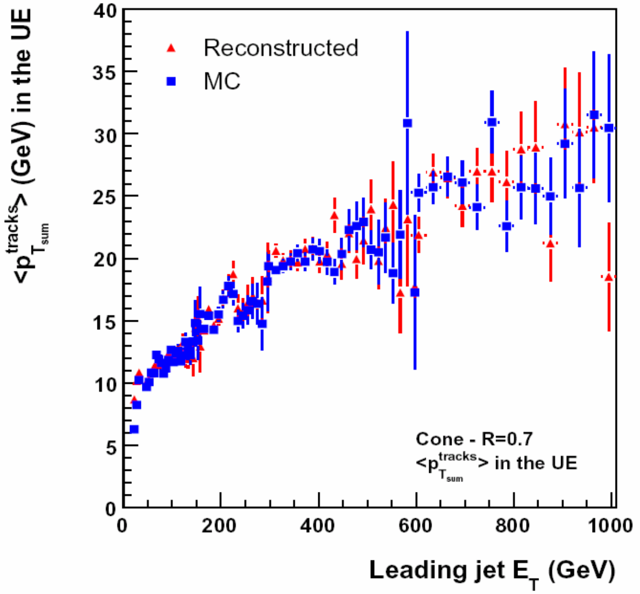
$p_T^{\text{track}} > 1$ GeV $|\eta_{\text{track}}| < 2.5$

good agreement between generated and full reconstruction

Can be used to tune simulations

different UE models can change the reconstructed top mass by up to 5 GeV

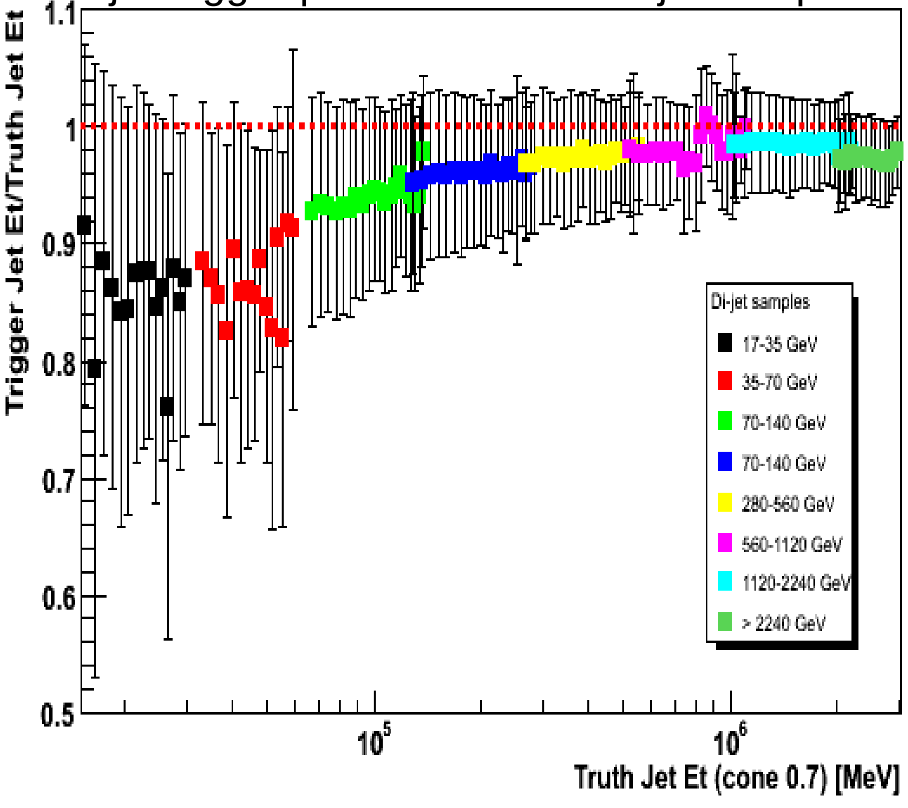
$\langle p_{T\text{sum}}^{\text{tracks in UE}} \rangle$ vs $p_T^{\text{leading jet}}$



Trigger studies

- Triggering on interesting events is one of the greatest challenges at a hadron collider
  - CSC studies must be trigger-aware
- Canadian goups lead the efforts to characterize the trigger performance, in particular jet reconstruction
  - involved in performance optimization of HLT algos
  - developed tool to make it possible to estimate trigger rates in a consistent and uniform way to help with menu development.
  - in charge of rate calculation and menu development for all ATLAS

jet trigger performance on di-jet samples



Trigger menus development

- Example trigger menu for 10^{31} $cm^{-2}s^{-1}$ (under development)
  - tool developed to simulate an entire trigger menu
  - estimate trigger rates including prescales
    - for different signatures and different trigger level (L1, L2, EF)
  - compute overlap between signatures
    - tune trigger stream definition

Signature	L1 rate (Hz)	HLT rate (Hz)	Physics addressed
Minimum bias	Up to 10000	10	Pre-scaled trigger item
e10	8000	20	$b, c \to e, W, Z$, Drell-Yan, $t\bar{t}$
2e5	12000	3	Drell-Yan, $J/\psi, \Upsilon, Z$
γ20	300	6	Direct photons, γ-jet balance
2γ15	100	1	Photon pairs
μ10	110	10	$W, Z, t\bar{t}$
2μ4	15	15	B-physics, Drell-Yan, $J/\psi, \Upsilon, Z$
$\mu 4 + J/\psi(\mu\mu)$	1000	< 1	B-physics
j100	9	9	QCD and other high-p_T jet final states
4j23	17	17	Multi-jet final states in pass-through mode at HLT
τ20i + xE30	5000 (see text)	10	$W, t\bar{t}$
τ20i + e10	130	0.2	$Z \to \tau\tau$
τ20i + μ6	20	0.1	$Z \to \tau\tau$

Trigger streams

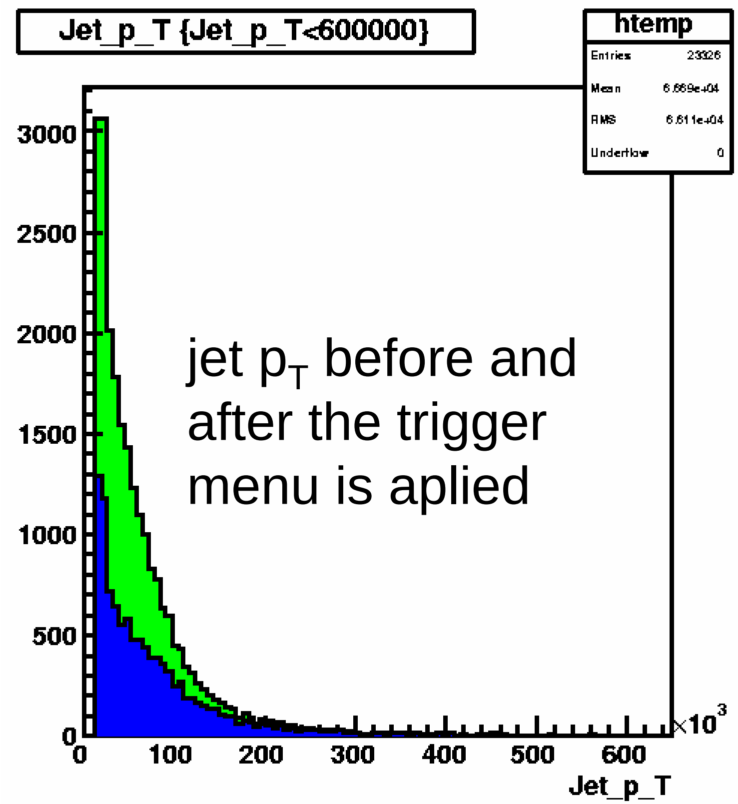
Correlation matrix between different physics stream

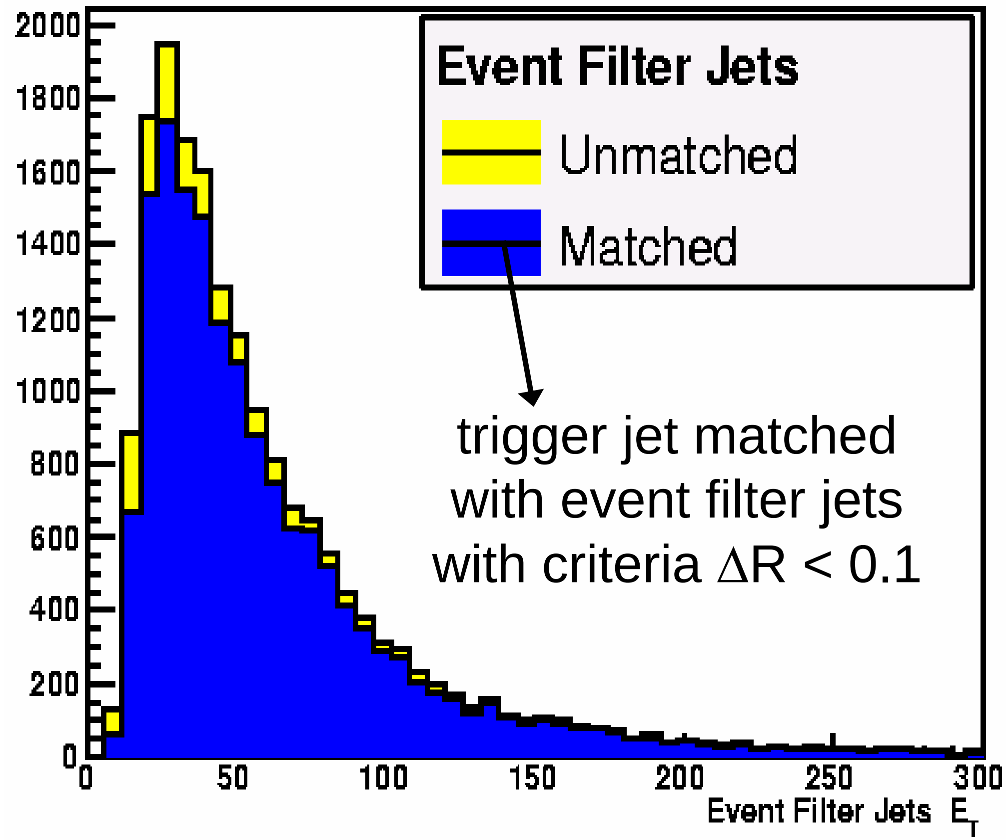
Streams Overlap = $N(S_x + S_y) / N(S_y)$								
Stream x / y	combined	jets	egamma	tauEtmiss	express	muons	bphysics	minbias
combined	-	0.27932	0.14925	0.20814	0.18834	0.14923	0.04452	0.00001
jets	0.13278	-	0.03811	0.11754	0.15706	0.00446	0.01015	0.00001
egamma	0.12130	0.06516	-	0.04370	0.06691	0.00578	0.00601	0.00001
tauEtmiss	0.15003	0.17822	0.03876	-	0.07478	0.00619	0.01006	0.00001
express	0.00140	0.00245	0.00061	0.00077	-	0.00055	0.00017	0.00006
muons	0.12276	0.00772	0.00585	0.00707	0.06041	-	0.07155	0.00001
bphysics	0.08531	0.04092	0.01418	0.02674	0.04347	0.16665	-	0.00001
minbias	0.00007	0.00016	0.00008	0.00009	0.10003	0.00009	0.00004	-

- allows to tweak the definition of the different streams to minimize overlap, yet ensure that physicists can quickly and easily have access to the data they will need on day 1.

Trigger algorithms for H^+

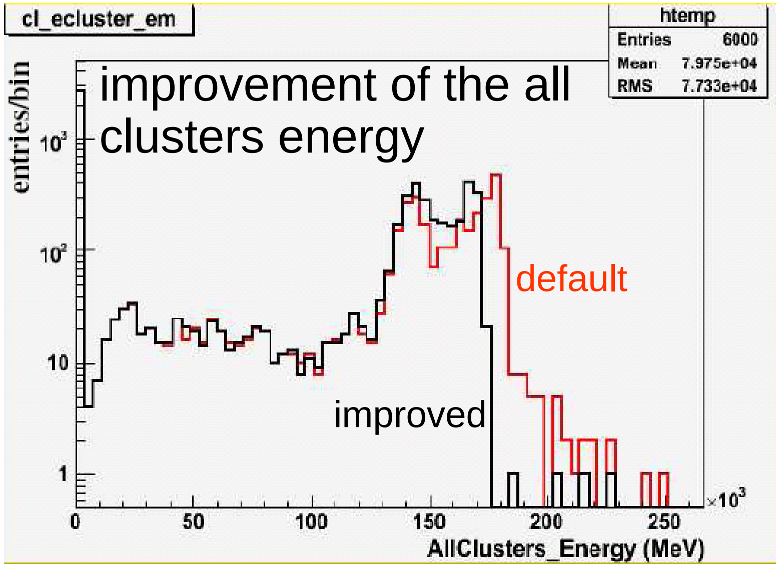
- Develop a general trigger strategy for for the many different production modes, decay channels and possible H+ masses
  - example for $t \rightarrow bH^+ \rightarrow b\tau\nu$, where $\tau \rightarrow$ hadrons and M_H = 110 GeV

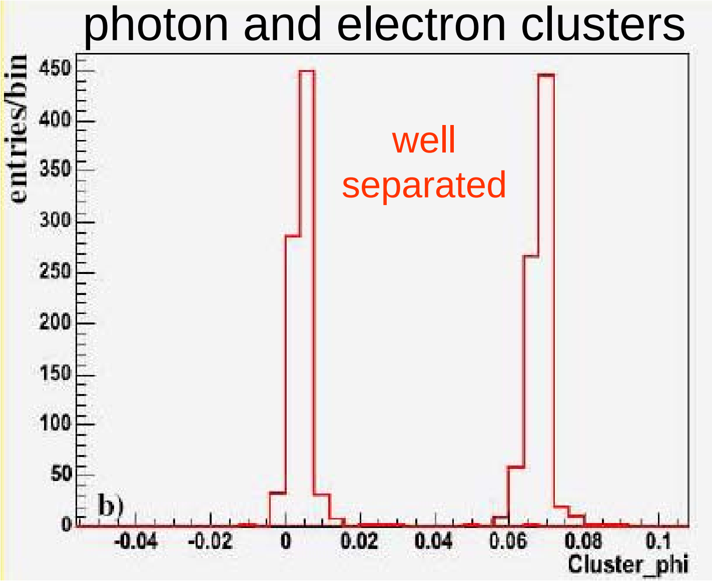




EM clustering algorithm

- EM calorimeter cell clusters are essential parts of the photon and electron reconstruction
  - Special clustering algorithms has been developed
- Recent important improvements
  - better pre-clustering logic
  - handling of energy sharing between overlapping clusters
  - tested on tagged photon test beam on EM calorimeter





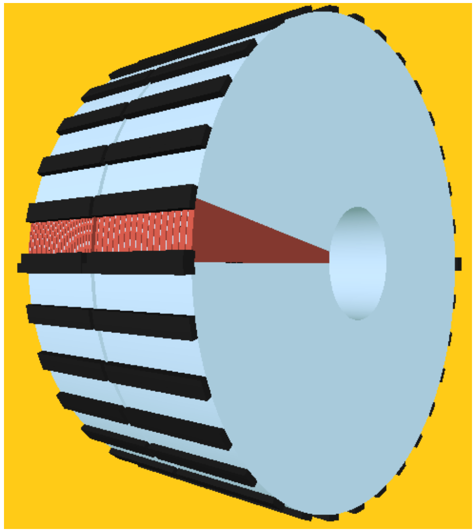
Calorimeter hadronic scale calibration

- Calibrate calorimeter to particle jet energy
- Prefered method is local hadronic calibration
  - identify energy deposits (topological clusters)
  - parametrize cell energy weights for clusters
    - use measurement of energy density
    - requires cluster classification (EM, Hadronic, other)
  - provide calibrated topoclusters
    - used as building blocks for other objects, as jets, missing E_T
- Relies heavily on simulation
  - test beam results also used (with some limitations)
  - in-situ validation involves jets, taus, isolated pions
- Look for correlations between various jet observables
  - data and MC-only observables
    - attempt to validate MC observables used in calibration procedure
- Next workshop in March 2008

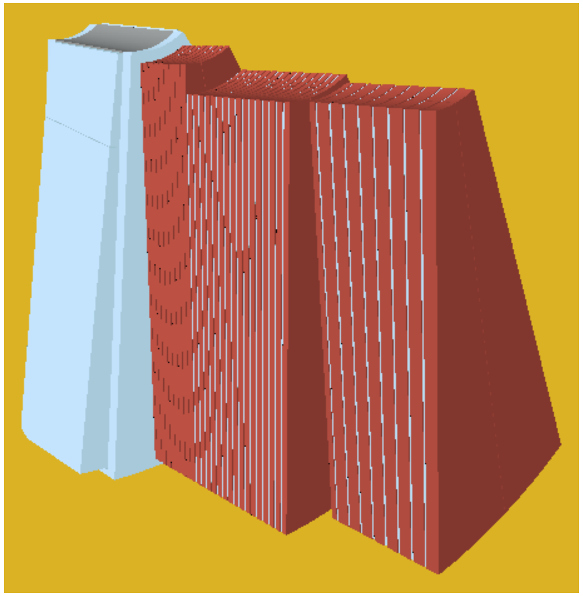
Hadronic Endcap Calorimeter simulation

- Big effort to improve the simulated geometry
  - separate from and rear wheels
  - each HEC modules are constructed separately
    - beam test simulations can now share same code as ATLAS
  - many geometrical improvements
    - affects the proper simulation of dead material in front of TILE

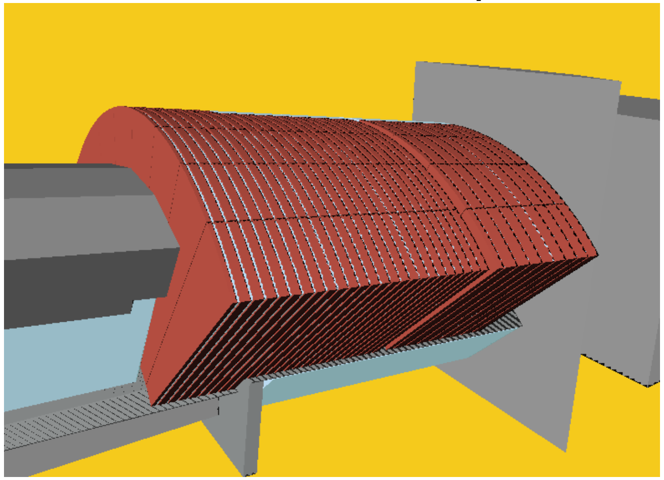
HEC ATLAS setup



HEC-EMEC 2002
beam test setup



HEC-EMEC-FCAl 2004
beam test setup

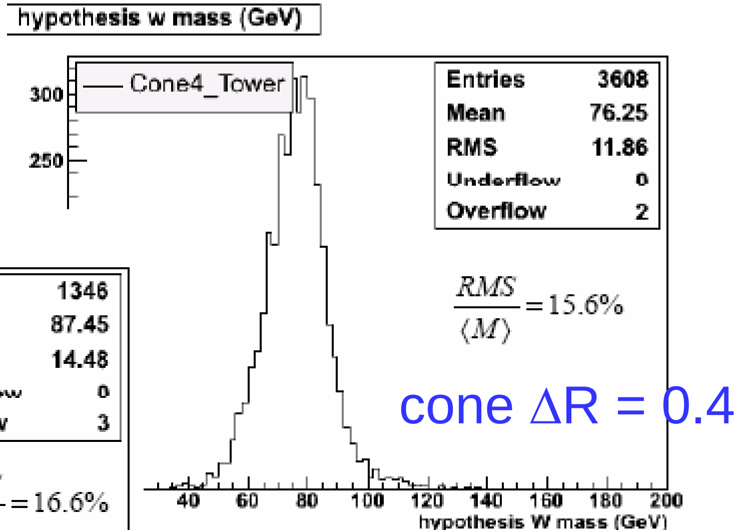


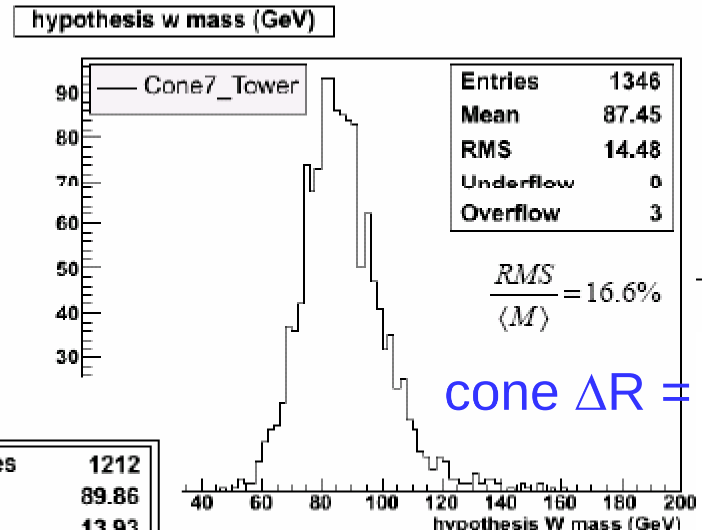
Optimal Jet Finder studies

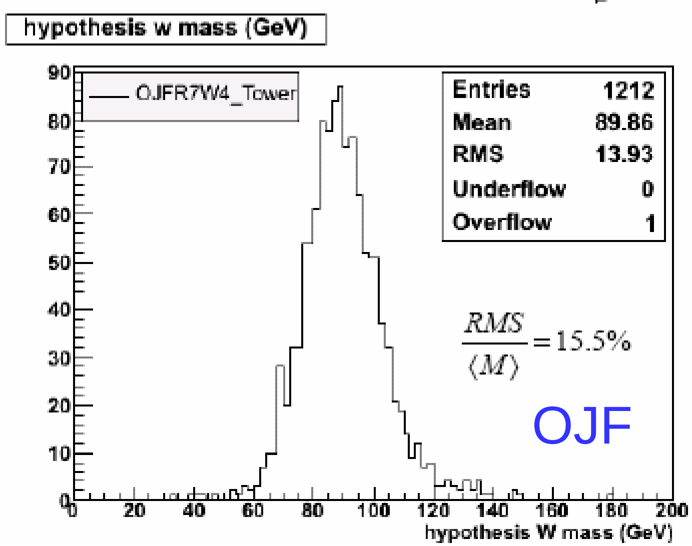
- Study of the Optimal Jet Finder algorithm
  - jet configuration obtained through the minimization of an event shape-like variable
  - which depends on the reconbination matrix z_{aj}
    - fraction of the a^{th} particle energy going into the j^{th} jet
  - some energy can be left out of the jet formation
- implementation now available in Athena
  - preliminary studies are encouraging
    - W and top mass reconstruction in ttbar events
  - robustness studies under way
    - uniqueness of minimization outcome
    - small changes in input kinematics
    - presence of pileup and detector imperfections

Optimal Jet Finder studies

- comparison of W mass reconstruction in hadronic top decays

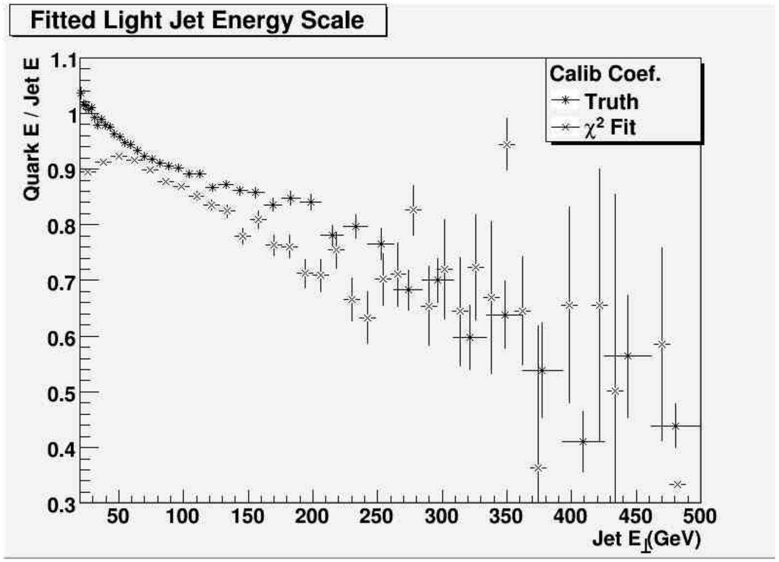






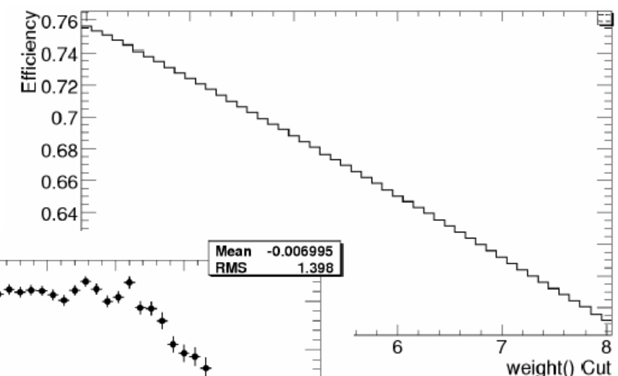
In-situ jet energy scale calibration

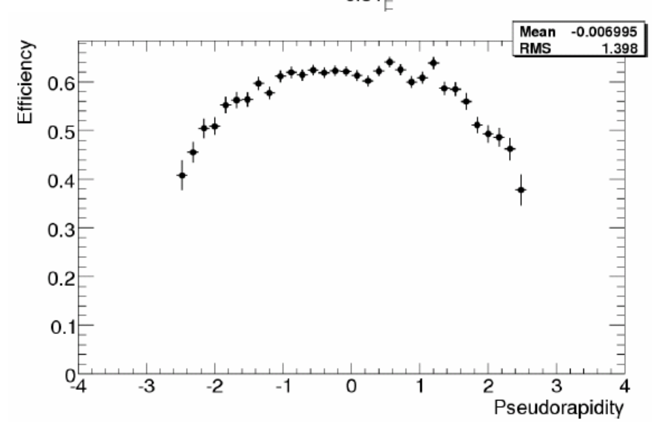
- use semi leptonic (e/μ) ttbar events
  - good purity; use hadronic decay of one top
- various methods are being studies
  - iterative method and W mass constraint
    - light quark jet energy scale
  - kinematic fit method with W and top mass constraints
    - light quark and b quark jet energy scale
  - bootstrapping method to extend calibration to higher energy jets
- study systematics
  - hadronisation
  - underlying event
  - pileup
  - channel dependence



b-jet tagging studies

- important for analysis with b-jet(s) in the final state
  - in particular from top and Higgs decay
  - reduce combinatorics and QCD backgrounds
- different tagging algorithms have different efficiencies
  - b-tag efficiency, c-tag efficiency, lighter quark tag efficiency
- b-tagging performance depends on physics channel
  - different optimizations
- studies focus on
  - secondary vertex in jet reconstruction (BtagVrtSec, JetFitter)
  - in-situ use of ttbar events (available early: σ = 833 pb)
  - compared working point for data and simulation

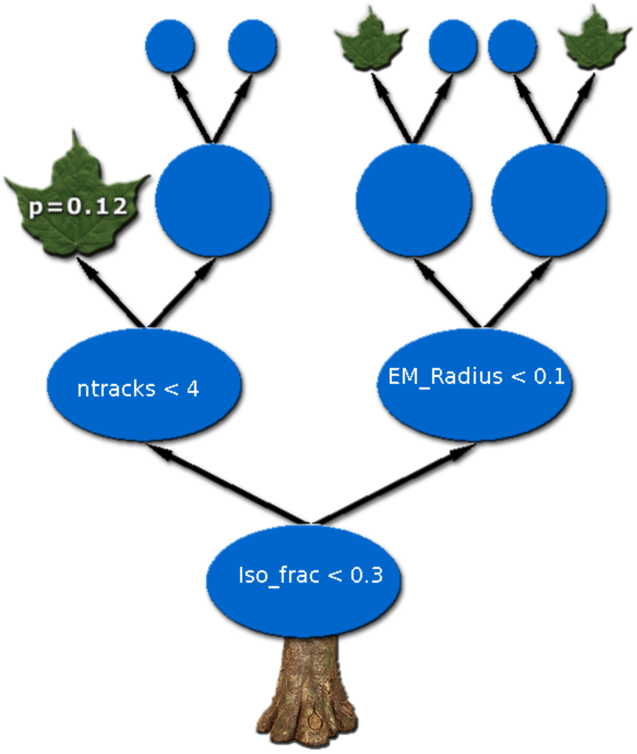




b-tag efficiciency studies for fully hadronic ttbar decays

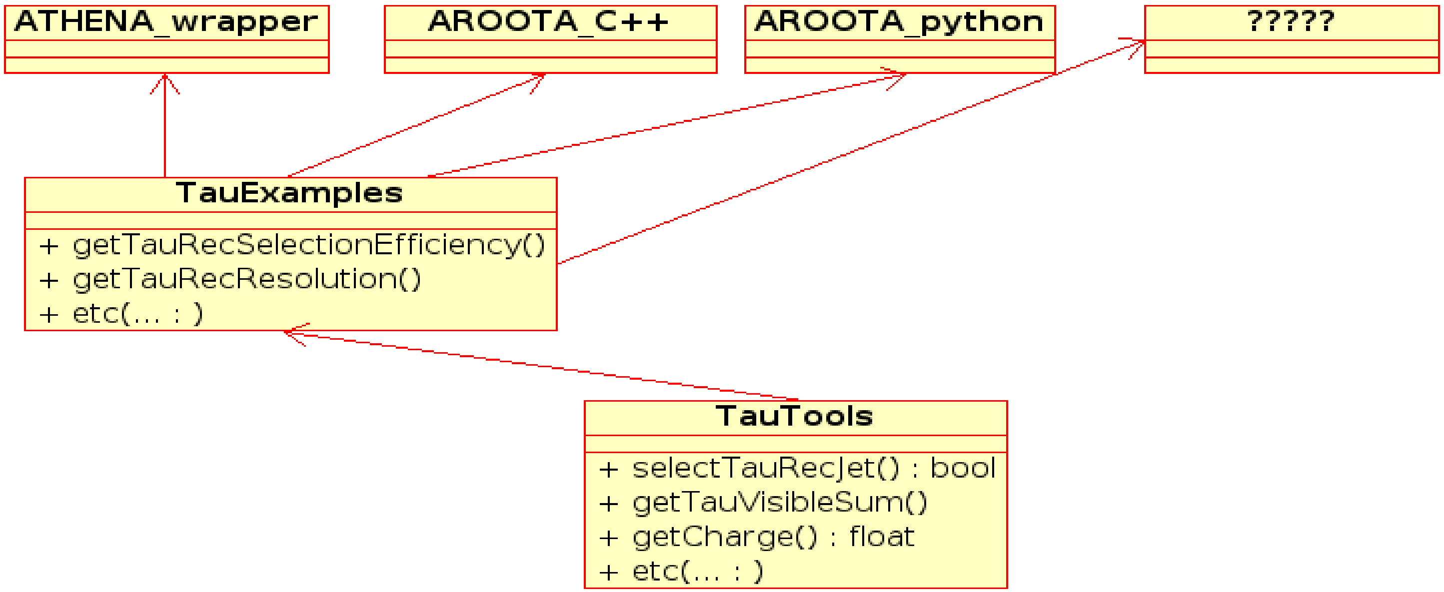
Tau identification

- Study the use of Boosted Decision Trees for tau ID
  - decision tree
    - cut-based algorithm
    - maximize signal and background separation using best variable at each node
    - construct tree with purity assigned to terminal “leaves”
    - output a classifier for testing phase related to purity of node
  - boosted
    - weights of misclassified events increased
    - retrain to construct a “forest” of boosted trees
    - classifier a weighted average over forest
  - boosted decision tree
    - powerful MV technique
    - fast training
    - flexible variable lists
    - understandable algorithm



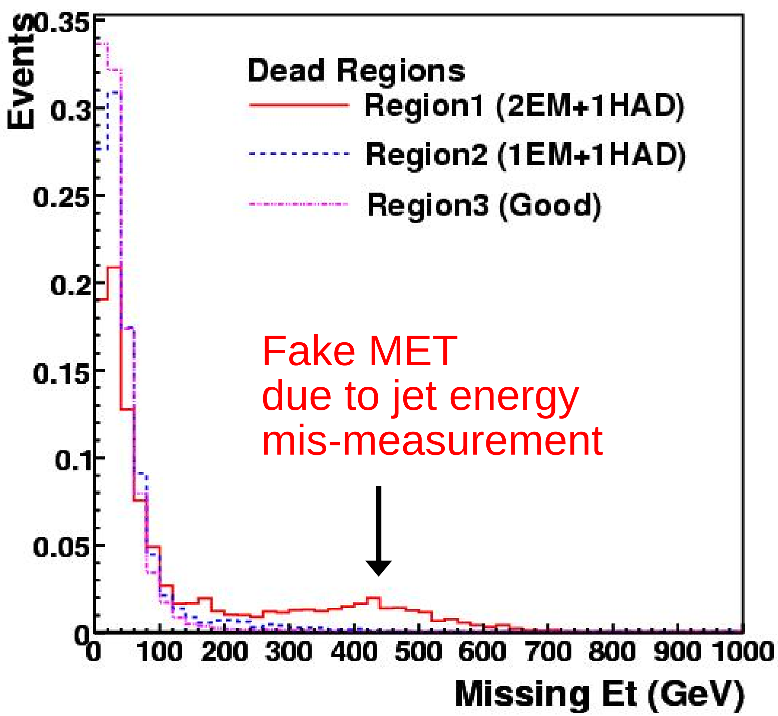
Tau identification software tools

- Design of modular software tools for tau identification
  - to help coping with data format changes with early data
  - for tau performance studies and MC sample validation
  - tools designed to be independent of analysis framework and also provide a means to standardize the tau selections
- Tools currently available in two analysis environments
  - Standalone Athena
  - AthenaROOTAccess (direct ROOT access of DPD's, AOD's)



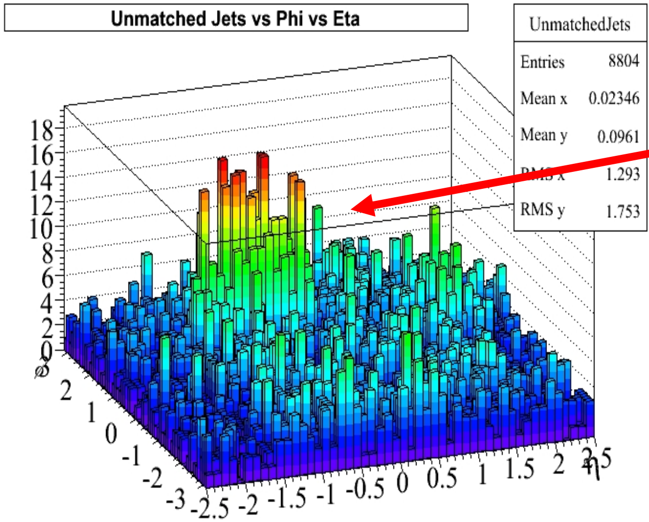
Fake Missing E_T studies

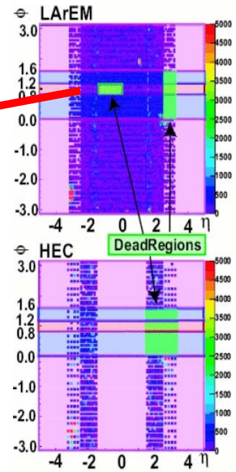
- Missing E_T is an important signature for new physics
  - detector imperfections can fake missing E_T
  - in particular dead (or sick) calorimeter regions
- Study fake missing E_T using jet kinematics
- use γ + jet events with early data
  - γ energy reconstruction well calibrated in-situ with $Z \rightarrow ee$
  - jet E_T should be balance by the γ E_T
  - large cross section compared to Z + jet
- Different methods available
  - use jet EM fraction
  - compare trackJet E_T and jet E_T
    - clusters, towers, cells
- Promising
  - cuts fake large (> 400 GeV) missing E_T events down to a few %
  - cuts are about 80% efficient at keeping events with no fake missing E_T



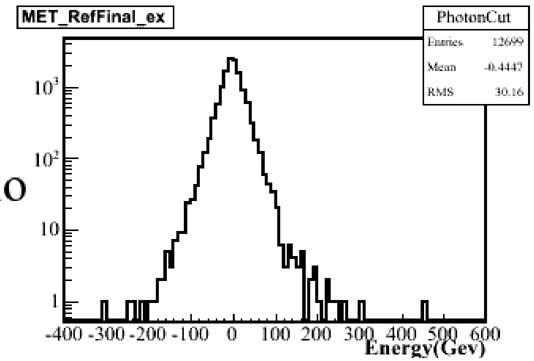
Fake Missing E_T studies

- Use cell killer tools to simulate problems

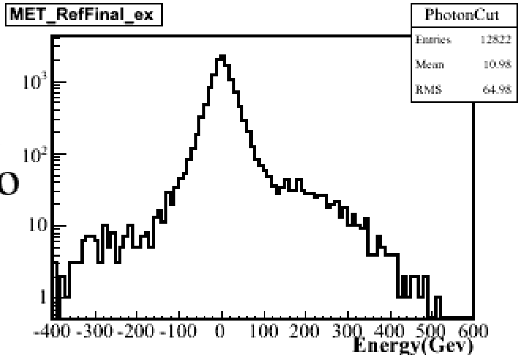




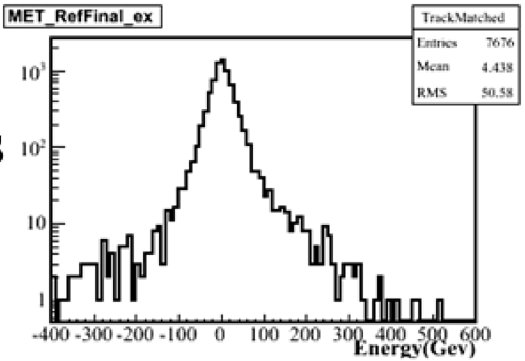
Normal Monte Carlo



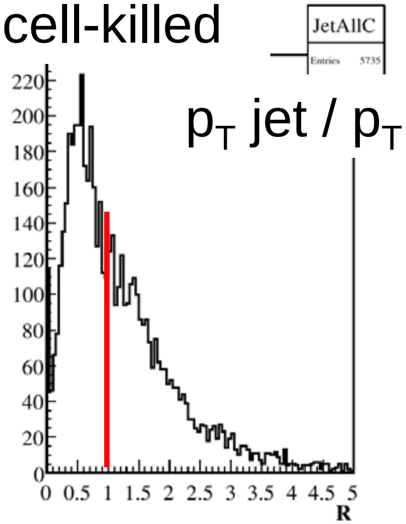
Cell Killed Monte Carlo



after cuts

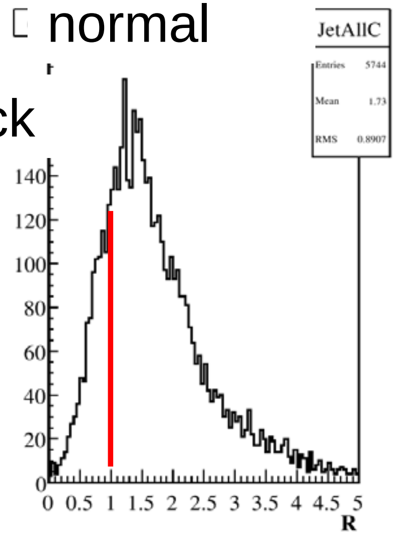


cell-killed



p_T jet / p_T track

normal

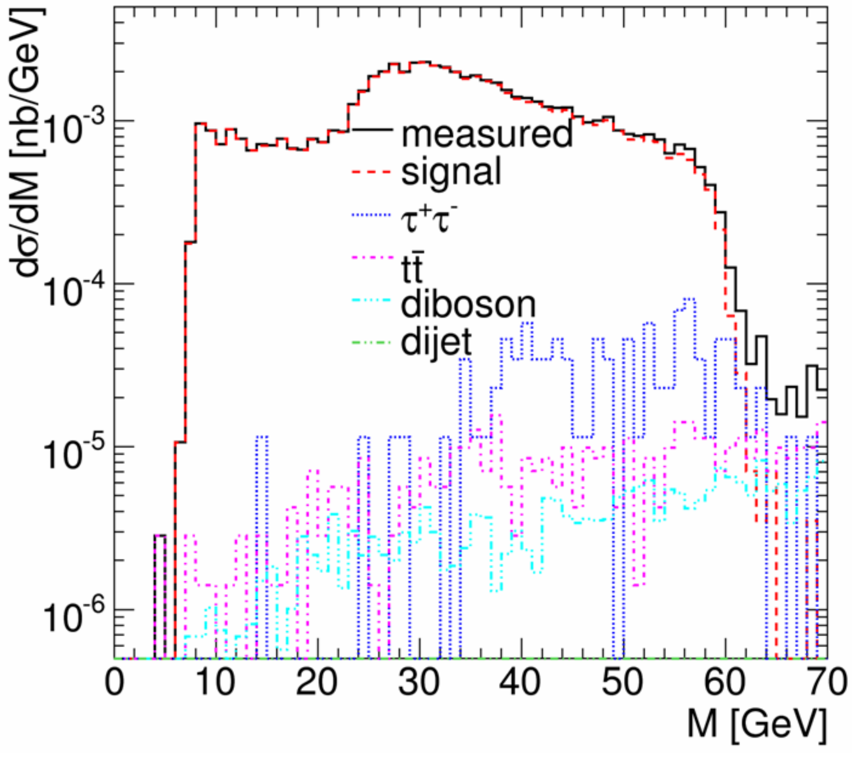


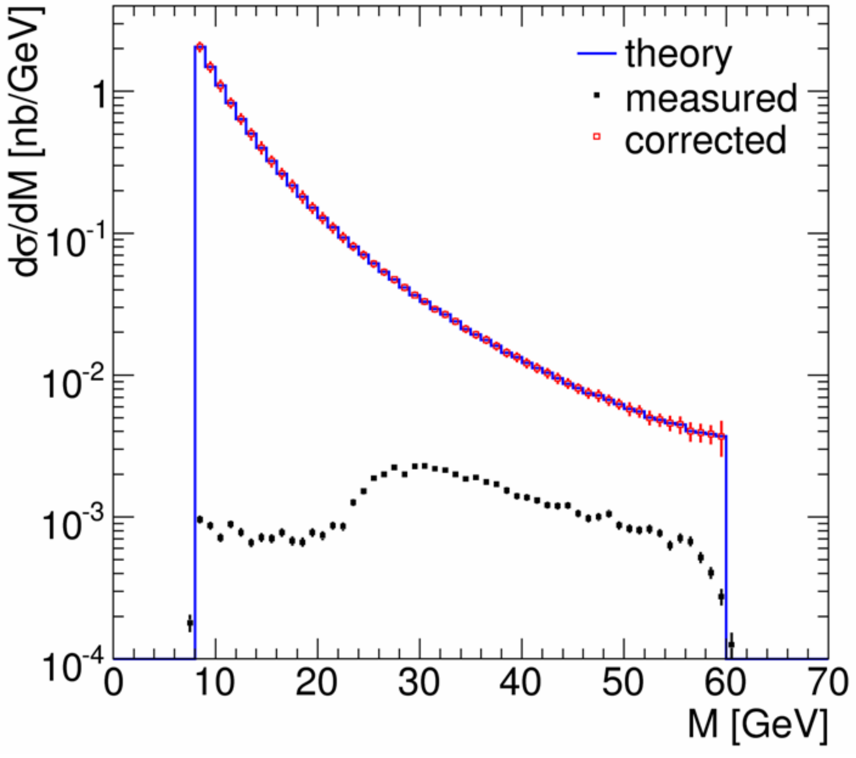
Low mass e^+e^- Drell-Yan pairs and PDFs

- Drell-Yan e^+e^- (and $\mu^+\mu^-$) pairs is one of the key processes that will be studied at the start of the LHC
- The LHC will probe down to $x \approx 5 \times 10^{-5}$ for $|\eta| \leq 2.5$ and down to $x \approx 3 \times 10^{-4}$ for $|\eta| \leq 1.0$
- Drell-Yan events can be used to constrain parton density functions
  - 1 fb^{-1} of data is enough to start improving PDFs at low x for $|\eta| \leq 2.5$ while at least 4 fb^{-1} is needed for $|\eta| \leq 1.0$
    - taking data with 2e15i trigger (10^{-33} $cm^{-2}s^{-1}$ menu).
    - less data will be enough for lower threshold (and lumi) menus

Low mass e^+e^- Drell-Yan pairs and PDF's

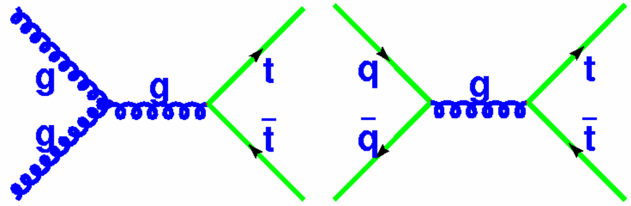
- M_{ee} spectrum for 284 pb^{-1}
  - as measured with backgrounds
    - need more work on di-jet
  - corrected
    - background subtracted
    - trigger and selection efficiency





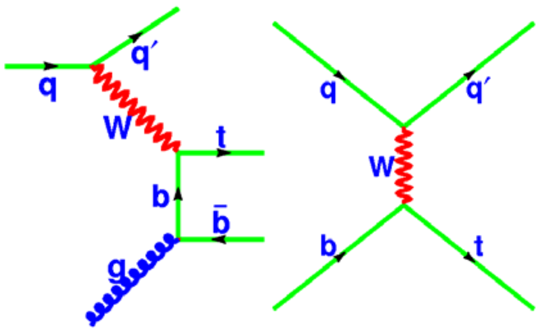
Top Quark Production

LHC is a top factory...

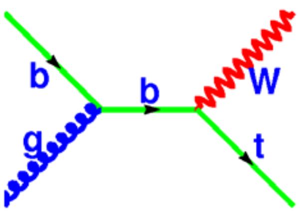


$t\bar{t}$ production = 833 pb Nucl. Phys B 529 (1998) 524

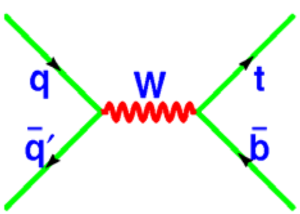
≈ 10^6 $t\bar{t}$ pairs produced for 1 fb^{-1}



Wg fusion ≈ 245 pb



Wt production ≈ 60 pb



W* channel ≈ 10 pb

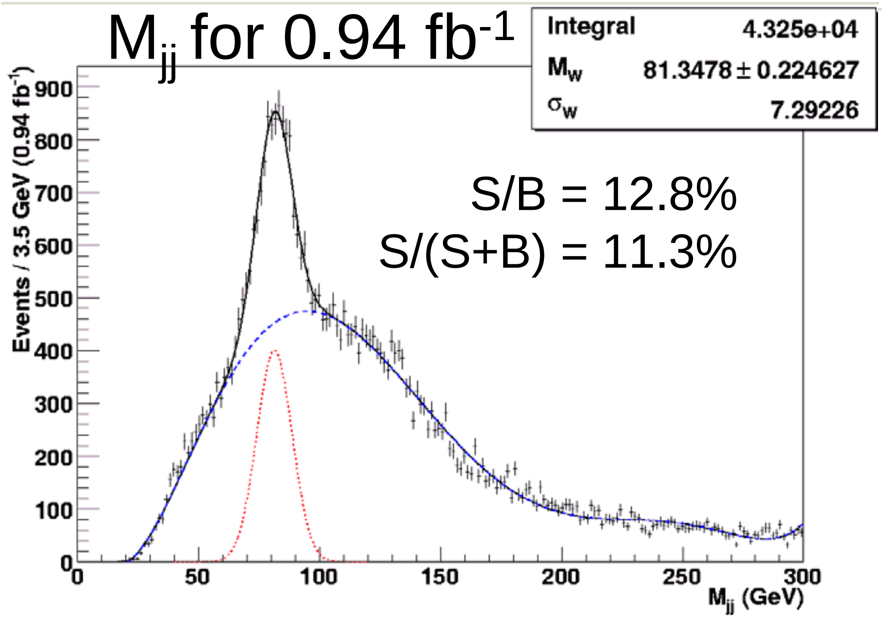
Electroweak single top production

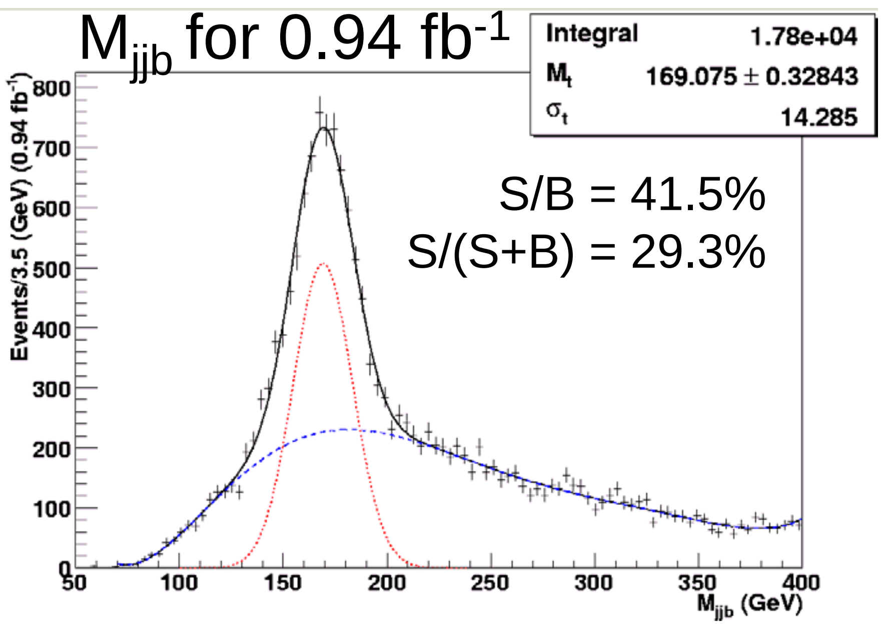
Early top analysis

- Reconstructed top mass, without b-tagging
  - aim at extremely simple and robust selection criteria
- Event selection ("commissioning cuts")
  - one isolated e or μ with $p_T > 20$ GeV
  - at least 4 jets with $p_T > 20$ GeV
  - at least 3 jets with $p_T > 40$ GeV
  - missing $E_T > 20$ GeV
  - selection efficiency: 13%
- hadronic top hypothesis selection
  - jet triplet with highest scalar p_T sum is the hadronic top
  - jet pair in hadronic top with highest scalar p_T sum is the W

Early top analysis

- Reconstructed top and W mass
  - no mass constraints, no jet recalibration
  - here only combinatorics background

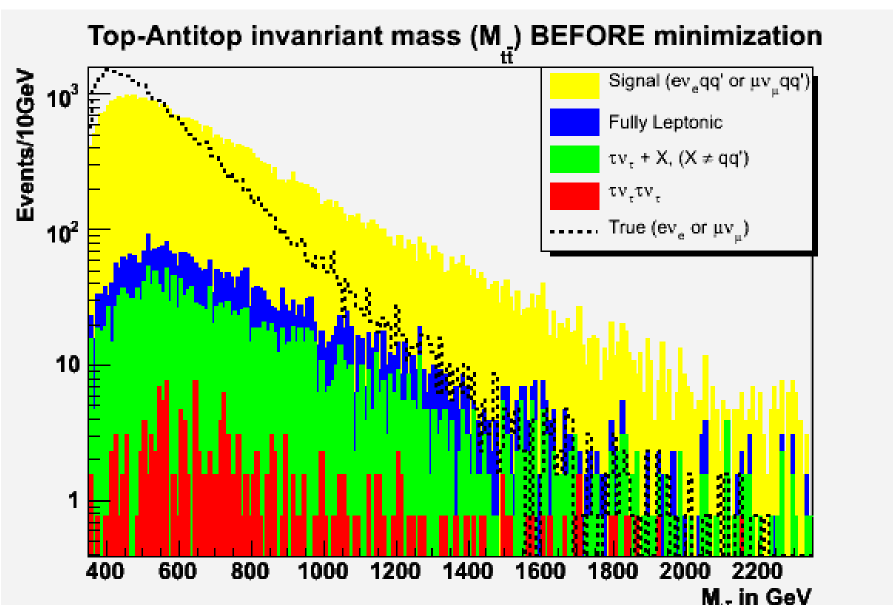


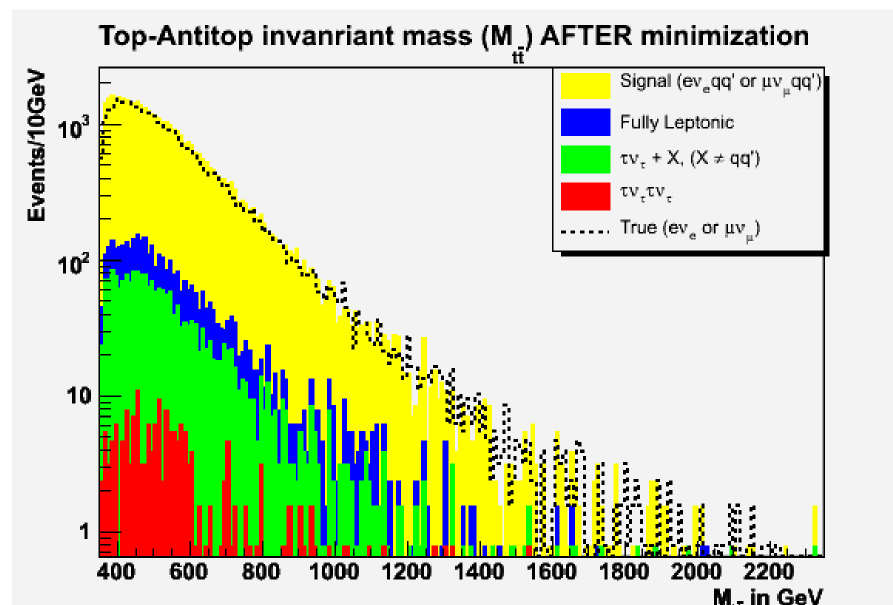


- good semileptonic sample quickly available
- top mass systematics limited
  - top mass MC input: 175 GeV $\rightarrow$ output: 169 GeV
  - needs b-jet calibration

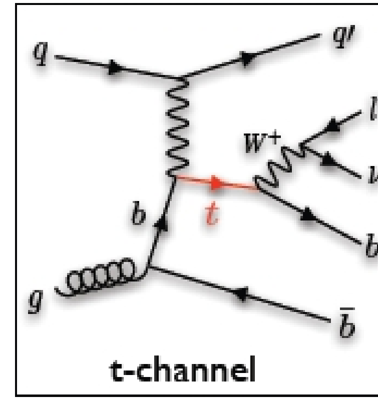
ttbar invariant mass spectrum

- Search for new physics in ttbar resonance
  - use commissioning top selection
  - minimize a χ^2 with W and top mass constraints for both tops
    - needs knowledge of jet energy and missing E_T resolutions
    - allow to vary the 4 jet energies, missing E_T, $p_{z\nu}$
    - obtain hypothesis that way
  - study robustness and accuracy of M_{ttbar} reconstruction
    - include backgrounds



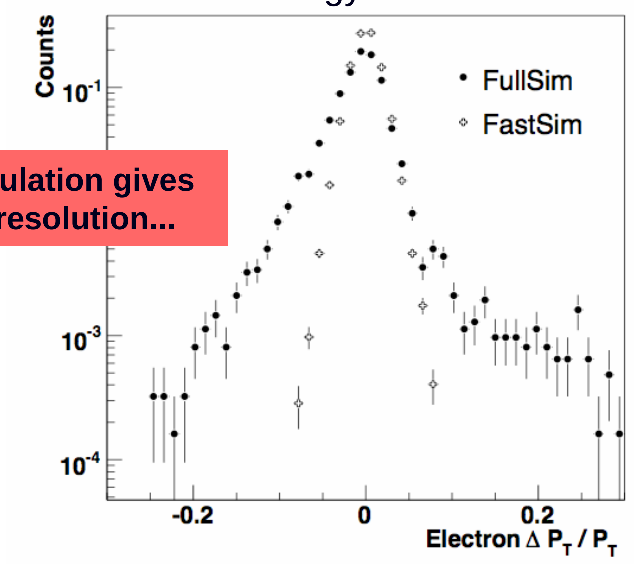


single top studies



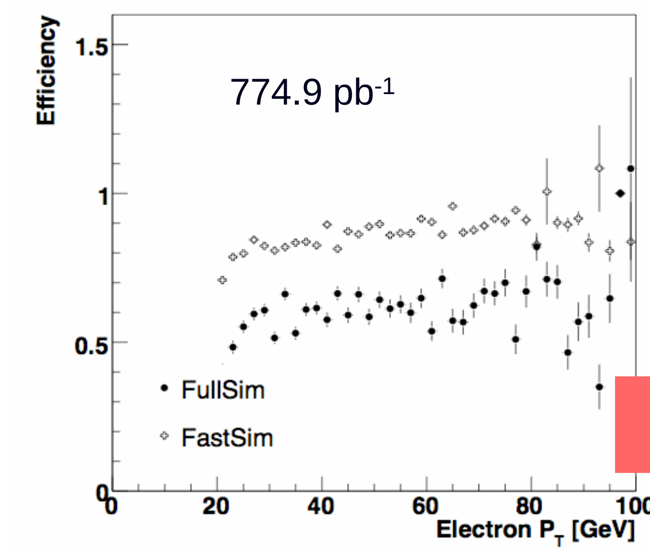
- focus on t-channel
- comparing full and fast simulation

electron energy resolution



fast simulation gives better resolution...

electron reconstruction efficiency



fast simulation has higher efficiency...

- parton density function uncertainty
  - effects on event selection efficiency

ε(CTEQ6) = (2.5 ± 0.5) % ε(MRST2001E) = (2.4 ± 0.5) %

light SUSY top

- focus on same sign top pair production from gluino decay
  - gluinos are Majorana particles: $\tilde{g} \rightarrow t\tilde{t}_1^*$ or $\bar{t}\tilde{t}_1$ same probability
  - gluino pair production and decay into same sign top pair

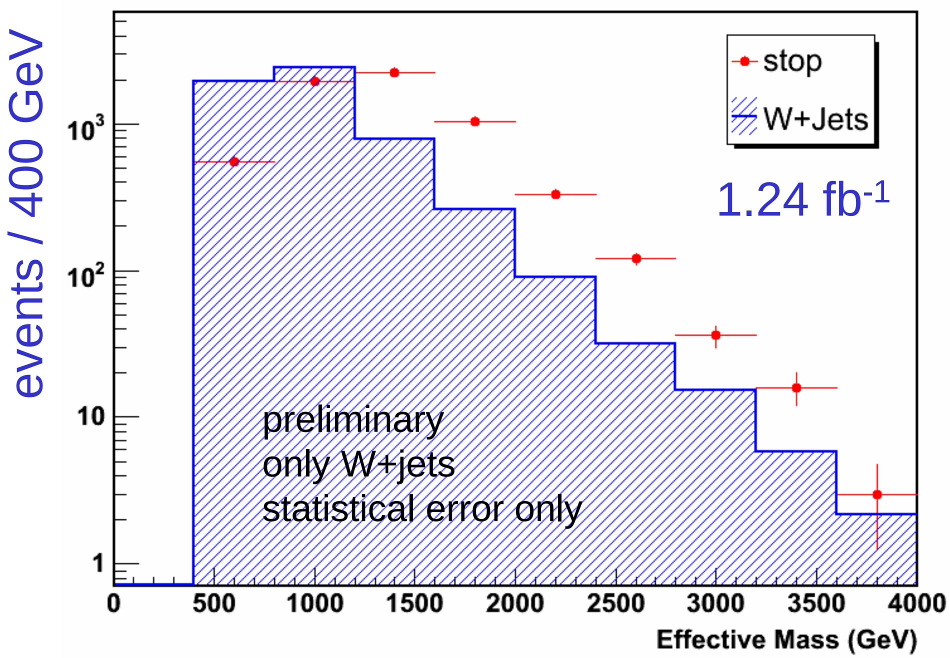
$$\tilde{g}\tilde{g} \rightarrow t\bar{t}\,\tilde{t}_1\tilde{t}_1^*,\, tt\,\tilde{t}_1^*\tilde{t}_1^*,\, \bar{t}\bar{t}\,\tilde{t}_1\tilde{t}_1$$ and $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

$$\tilde{g}\tilde{g} \rightarrow bb\,l^+l^+\ (\text{or}\ \bar{b}\bar{b}\,l^-l^-) + \text{jets} + E_T^{\text{miss}}$$ signature

- inclusive search
  - look for excess in M_{eff}

$$M_{\text{eff}} = E_T^{\text{miss}} + \sum_i p_{T,i}^{\text{jet}}$$

  - SM backgrounds
    - ttbar
    - W+jets, Z+jets
    - QCD jets
    - WW, WZ, ZZ

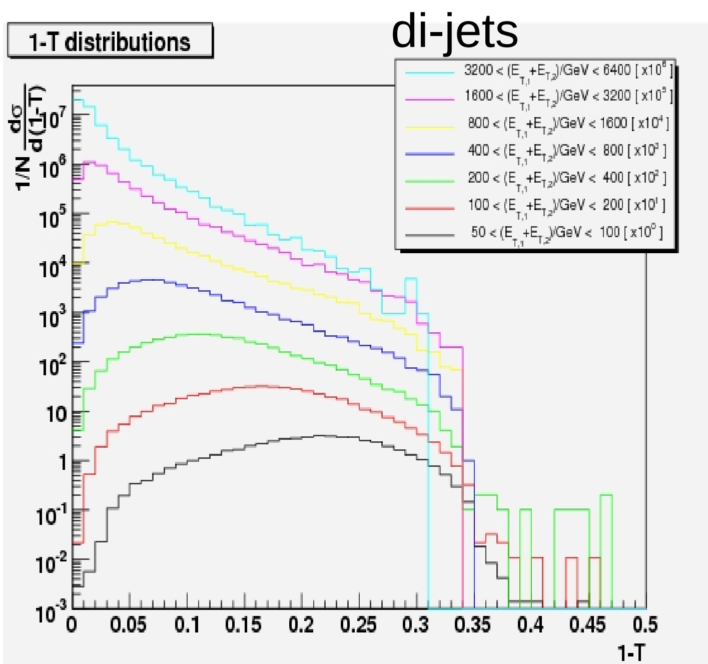


QCD event shapes

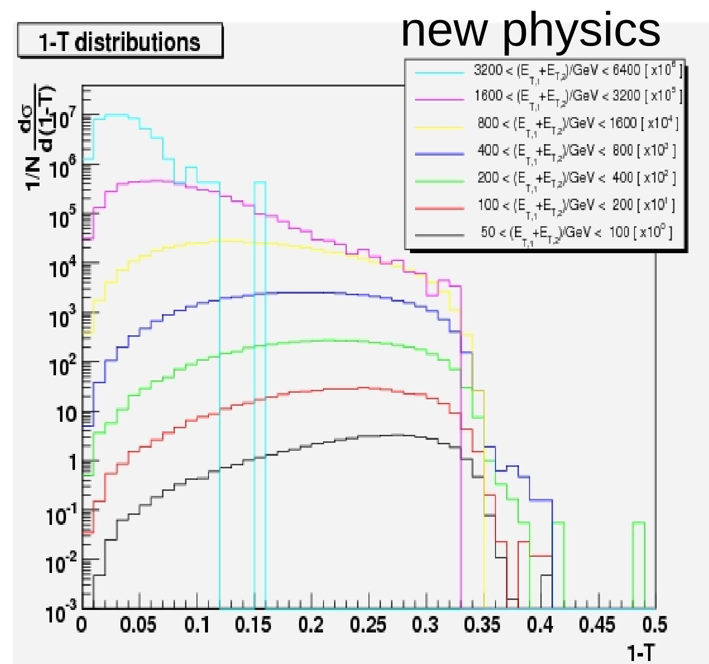
- **Event shape variables under investigation**

$$T_{\perp,g} = \max_{\vec{n}_\perp} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \vec{n}_\perp|}{\sum_i |\vec{p}_{\perp,i}|}$$

  - special event shape variables for pp collision
  - allow complementary event classification to jets, missing E_T
    - may be a way to be sensitive to new physics in early data
  - for example: thrust



higher $p_T \rightarrow$ more "jetty"



heavier particles $\rightarrow$ more 3-jet-like

List presented Dec 2006

Topic	Institute
QCD di-jets	Victoria
SM top physics	Carleton
Hadronic top pair decays	Victoria
Anomalous top production	Victoria
Inclusive SUSY; fake / instrumental $\not{E}_T$	TRIUMF, Victoria, Toronto
SUSY end-point search	Carleton
Higgs in SUSY decays	Victoria
Two-electron finder for Drell-Yan, Z'	Victoria
Z' or strong interaction resonance in τ channel	Montréal, Toronto, TRIUMF
Black holes	Alberta, TRIUMF
ADD extra dimensions	Toronto
Randall-Sundrum graviton search	Regina, Toronto
Trigger-aware charged Higgs	McGill
Lepton identification and fake rate studies	Toronto

- This list is increasing steadily: new students, research associates, etc.

QCD event shapes and underlying event	Victoria
τ/jet separation and fake rate studies	Regina
W' and Z' studies	Regina

Analyses in Canada for early physics

- This list is increasing steadily: new students, research associates, etc.
  - performance and signature studies: essential at LHC and ATLAS turn on
  - physics channels: early physics

- Performance and general signatures

Trigger Menu development for start-up and early physics	McGill: Dufour, BV
Triggers for charged Higgs physics (CSC HG10)	McGill: Potter
Event Filter jet trigger performance	McGill: Santamarina, BV
L2 Forward Jet trigger commissioning and performance	McGill/Carleton: Schram
Hadronic calorimeter Monte Carlo description	Victoria: Fincke
tau identification (tau/jet separation, etc) (CSC)	SFU: Godfrey, Rani, Stewart, DO
	Toronto: Mazini, Rezvani, Fatholazedah, Dhaliwal, BO
b-jet tagging	Toronto: Guo, Ma, PS
	Victoria: Berghaus, (Edmonds), ML
calorimeter hadronic energy scale calibration	Victoria: Seuster, ML, RM
E/p calorimeter calibration using single hadrons (CSC J8)	Alberta: Lu, DG
in-situ jet energy scale calibration using ttbar events	Victoria: Berghaus, Lessard, ML
in-situ calibration using photon+jet	SFU: Spreitzer, Schouten, MV
detector effects in missing E_T reconstruction (CSC Etmis)	Toronto: Gibson, RT
	TRIUMF: Ishizawa, IT
	Victoria: Courneyea, RKK, RM
optimal jet finder algorithm (CSC J5)	Victoria: Lelas, Seuster, ML, RM
EM clustering algorithms (CSC CALO1)	Victoria: Lelas
radiation environment in forward region using Medipix	Montreal: CL

Analyses in Canada for early physics

- Physics channels (many more in the full luminosity physics talk)

low mass Drell-Yan and PDF (CSC SM2 SM7)	Victoria: Ince, RKK
$Z \to \tau\tau$ in early data	SFU: Stewart, DO
	Toronto
minimum bias events and underlying event	TRIUMF: Moraes
	Toronto: BO
commissioning top physics	Carleton, McGill, Victoria
top cross section	Carleton: Heelan, GO
high p_T top quark	McGill
	Victoria: Lessard, ML
resonance in ttbar mass spectrum	Victoria: Lessard, ML
single top (CSC T8)	Carleton
	SFU: Schouten, MV
	Toronto: Tardif, WT
fully hadronic top (CSC T9)	Victoria: (Edmonds), Seuster, ML, RM
WH, ZH with $H \to \gamma\gamma$ (needs 30 fb^{-1})	Montreal
QCD event shapes	Victoria: Seuster
QCD background to SUSY (CSC SUSY 3)	Toronto: Rosenbaum, RT
	TRIUMF: Ishizawa, IT
	Victoria: Courneyea, RM
Quark compositness	Victoria: Berghaus, ML
di-jet resonances	Toronto: Cheung, PS
high p_T jet signatures	Toronto: Deviveiros, PS
t' search	Toronto: Beare, WT
Technicolour	Montreal
light SUSY top from gluino pair and same sign tops	Carleton: Yang, Archambault, GO
Black holes	Alberta: Hakobyan, DG

- Jet, missing E_T data quality: Rolf Seuster (Victoria)
- Jet validation: Pier-Olivier Deviveiros (Toronto)

Comments and Conclusions

- We are aggressively getting ready for first collisions
  - take advantage of our ATLAS detector expertise
  - ATLAS Canada computing in fast progress
  - we need to increase our presence at CERN
- Canadian involvement in early physics analyses
  - broad range of interests
    - trigger
    - jets, leptons, missing E_T signatures
    - SM processes
    - first search for evidence of BSM physics
  - integrated in ATLAS working groups
  - strong involvement in CSC notes production
  - frequent regional Canadian meetings