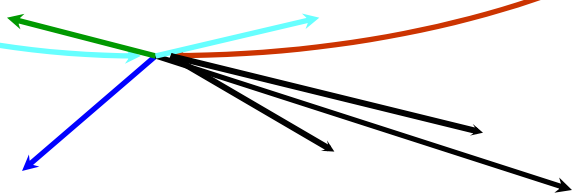
From the Tevatron to the LHC

Marek Zieliński



DOE site visit, 11 August 2004

Transition to LHC Physics

- Expertise from a working Tevatron experiment!
  - ➔ Tracking and b-tagging
  - ➔ Calorimetry, jet and electron ID
  - ➔ QCD studies (see next)
  - ➔ Top-quark physics (analyses discussed by J. Cammin)

- Towards LHC
  - ➔ Prepare for discovery of new physical phenomena
  - ➔ Hands-on expertise with CMS software and analysis at start
  - ➔ Active participation in the LHC Physics Center at Fermilab (LPC)

- Specific example – $t\bar{t}H$ associated production
  - ➔ Important discovery mode for low-mass Higgs
  - ➔ Exploit experience with top and jet physics
  - ➔ Tevatron is the best place to learn about $t\bar{t}$+jets background

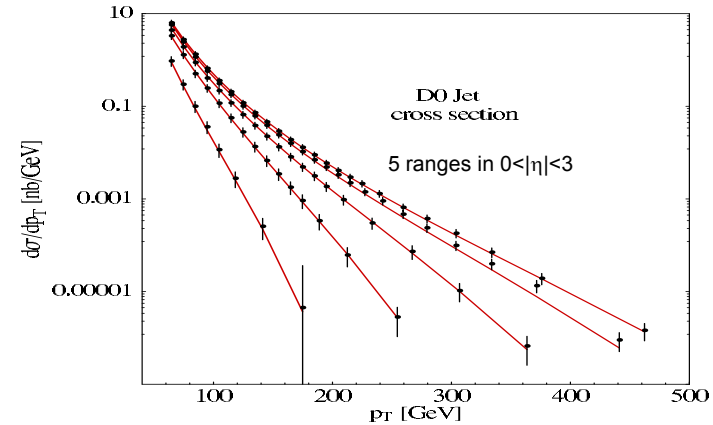
Exploiting the Tevatron Experience: QCD

- Measurements at hadron colliders require good understanding of QCD effects
  - ➔ Explore "hard" perturbative QCD (pQCD) with high-p_T jets
    - ❖ NLO and NNLO pQCD calculations
    - ❖ Parton distributions
    - ❖ Running of α_s
  - ➔ Investigate radiation using dijet angular distributions
    - ❖ Compare data with pQCD
    - ❖ Verify/tune Monte Carlo generators
    - ❖ Connect to Underlying Event/Min Bias studies
  - ➔ Study multiple hard radiation with W/Z+jets
    - ❖ Strong connection to top-quark and Higgs physics
    - ❖ Matrix Element ↔ Parton Shower interplay
    - ❖ Parton↔jet matching issues

Jets: Testing Hard QCD

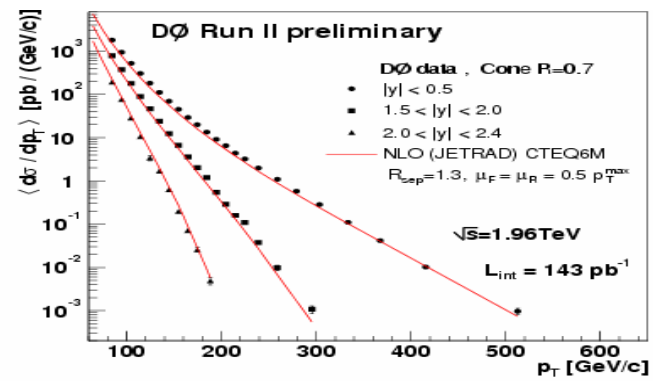
- DØ's Run I jet cross section
  - ➔ Still the strongest constraint of the large-x gluon distribution
    - ❖ Ingredient of the CTEQ and MRST global fits
  - ➔ Used in calculations of hard QCD processes at the Tevatron and in predictions for LHC

Run I



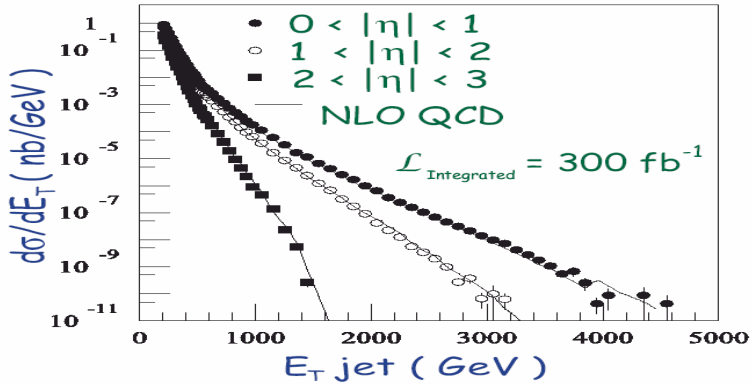
- Current Run II status -- DØ result:
  - ➔ First corrected Run II cross section for forward jets
  - ➔ Originated with the central inclusive jet cross section – G. Davis' thesis
  - ➔ M. Begel and M. Zieliński contribute to the extended analysis

Run II



- LHC will examine QCD jet production at multi-TeV scales
  - ➔ Expect >4•10^6 events with E_T>1 TeV!
  - ➔ Important for evaluation of backgrounds to other processes
  - ➔ Evidence for departures from pQCD?

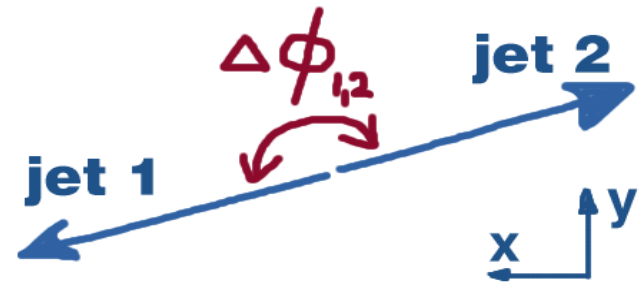
LHC



Testing QCD Radiation with Dijets

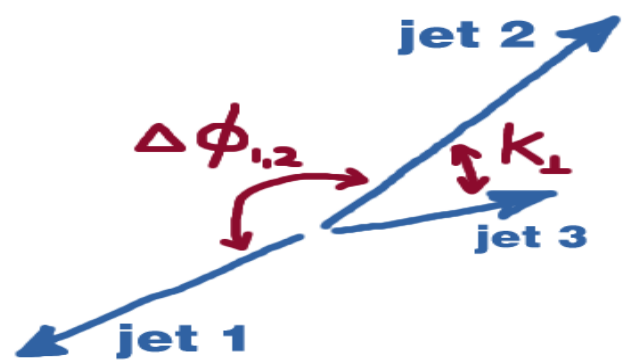
- Proper description of radiative processes is crucial for measurements and searches for New Physics at Tevatron and LHC
- A clean and simple way to study QCD radiation is through its impact on angular correlations
- In 2→2 scattering, partons emerge back-to-back. Radiation introduces decorrelation in ΔΦ between the two leading partons/jets
- Our DØ ΔΦ analysis is directly sensitive to QCD radiation
  - ➔ Begel and Zieliński are primary authors
  - ➔ Results are near submission for publication

Dijet production at lowest-order pQCD



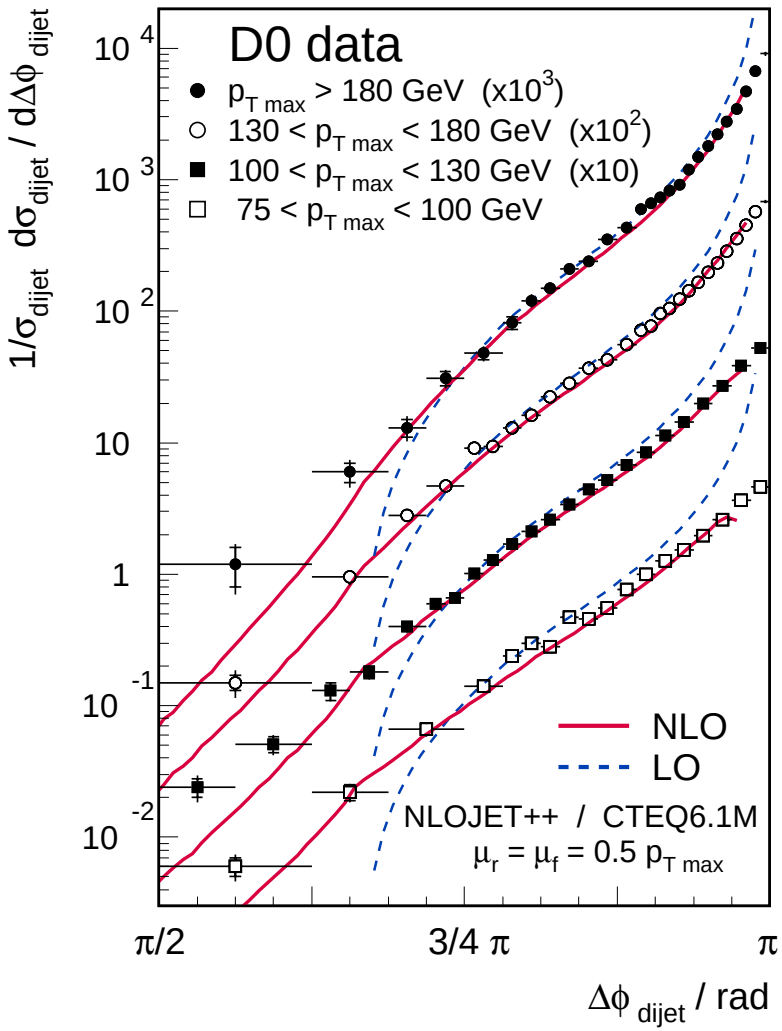
Transverse plane

3-jet production at lowest-order pQCD



ΔΦ: Comparison to Fixed-Order pQCD

$$\frac{1}{\sigma_{\text{dijet}}} \cdot \frac{d\sigma_{\text{dijet}}}{d\Delta\Phi}$$

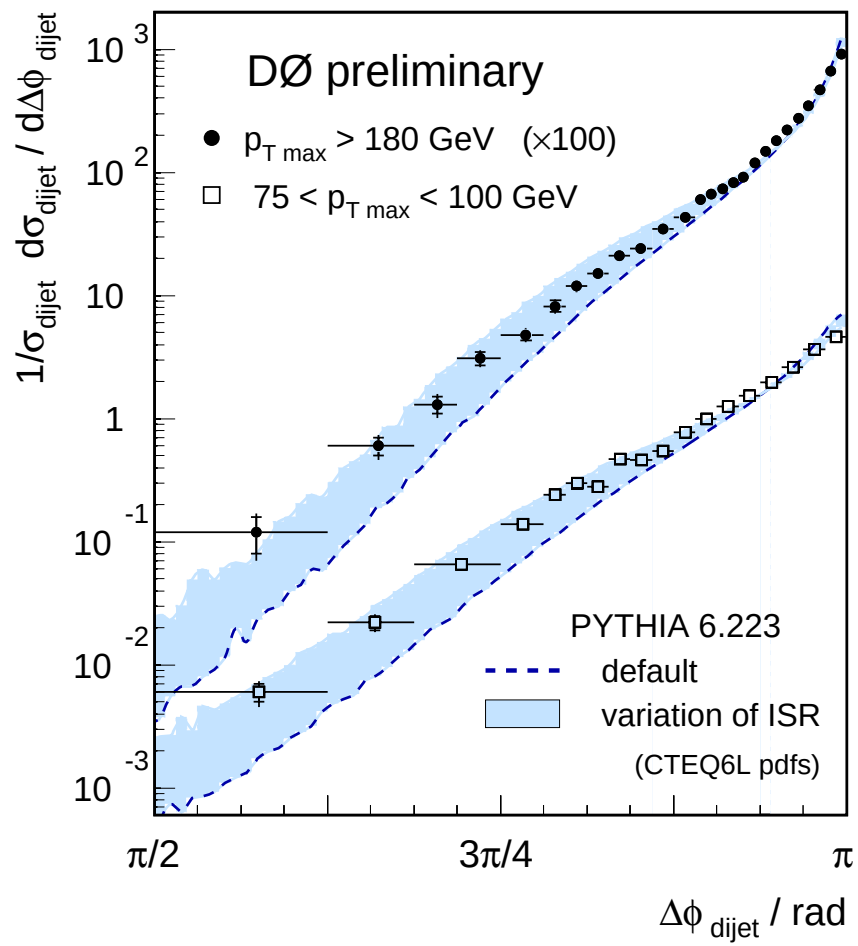


- Advantages of ΔΦ distribution:
  - ➔ Sensitive to QCD radiation
  - ➔ No need to reconstruct any other jets
  - ➔ Reduced sensitivity to jet energy scale
- Leading order (dashed blue curve)
  - ➔ Limited success
    - ❖ Divergence at ΔΦ = π
    - ❖ No phase-space at ΔΦ<2π/3
- Next-to-leading order (red curve)
  - ➔ Good description by "NLOJET++" (except at extreme ΔΦ values)

Begel, Zieliński

ΔΦ: Comparison to Parton-Shower Monte Carlo's

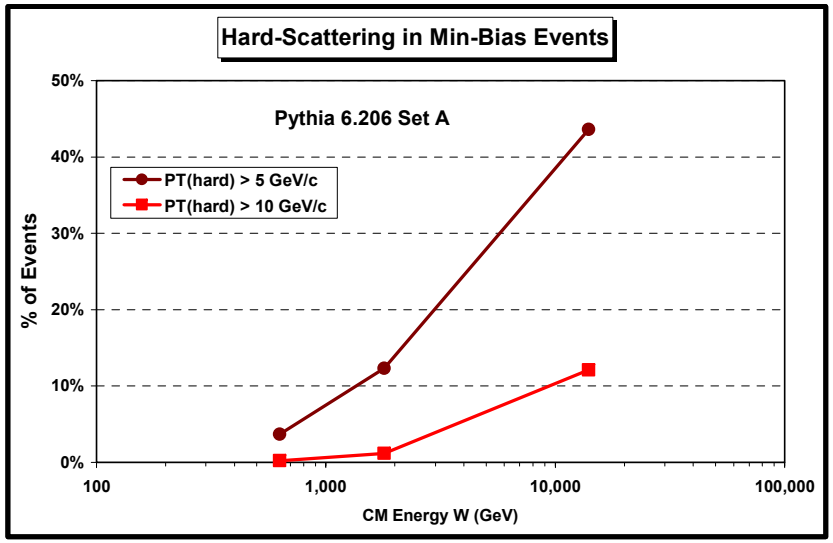
- Radiation generated via parton showers in Pythia
- Default settings – lower edge of band
  - ➔ Dependence too steep
  - ➔ Underestimates small ΔΦ
- CDF Tune A – upper edge of band
  - ➔ Higher level of initial state radiation
  - ➔ Better description of ΔΦ
- More Pythia tuning will be done, with emphasis on extrapolation to LHC



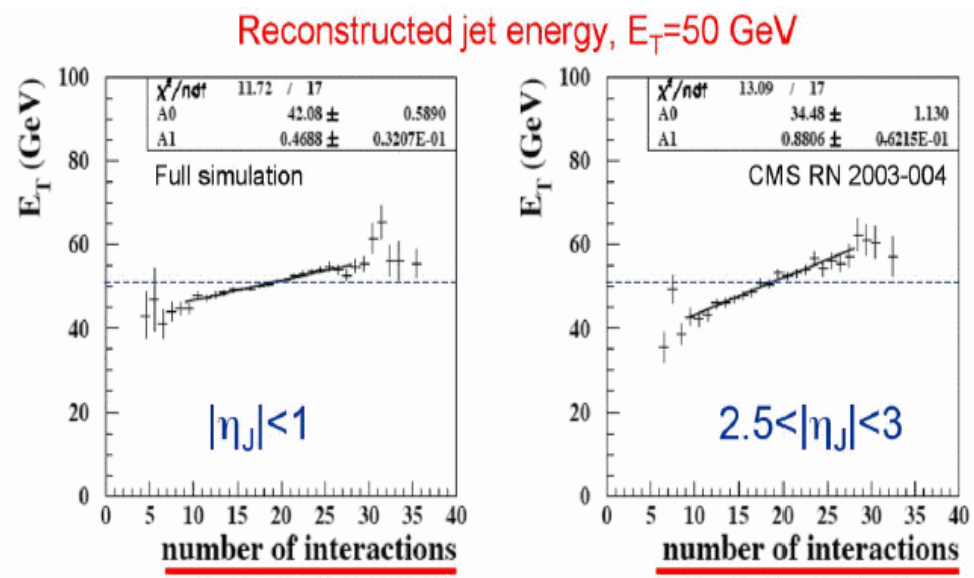
Begel, Zieliński

Impact on Jet Studies at LHC

- At LHC, expect up to ~20 interactions per crossing on average
- Tuned Pythia predicts that 12% of these interactions result from hard scatters with P_T(hard)>10 GeV/c
  - ➔ Significant energy contribution from extra events to jets from the primary event of interest

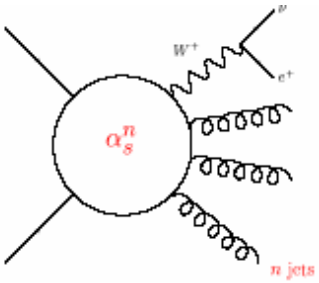


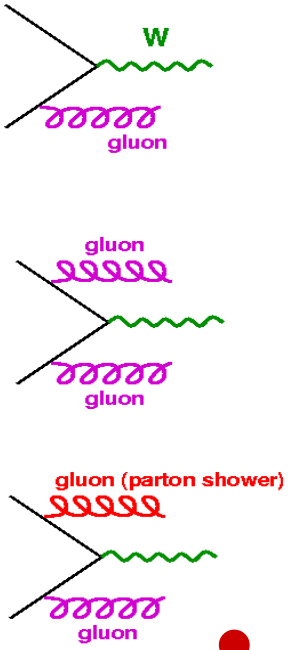
- To get good jet energy resolution, must correct for multiple interactions
  - ➔ Final corrections will be determined from data
  - ➔ However, algorithms should be developed beforehand using Monte Carlo → will benefit from improved understanding of Tevatron data
  - ➔ This is to be studied within the LPC JetMET group (Zieliński et al.)



Electroweak Bosons + Jets

- A good testing ground for QCD
  - ➔ W/Z+n jets ~α_s^n at lowest order





  - ➔ Perturbation theory should be reliable
    - ❖ heavy boson ↔ large scale
  - ➔ NLO calculations available for up to 2 jets

- W+jets, Z+jets
  - ➔ Important backgrounds for other physics channels
    - ❖ Top, Higgs,…

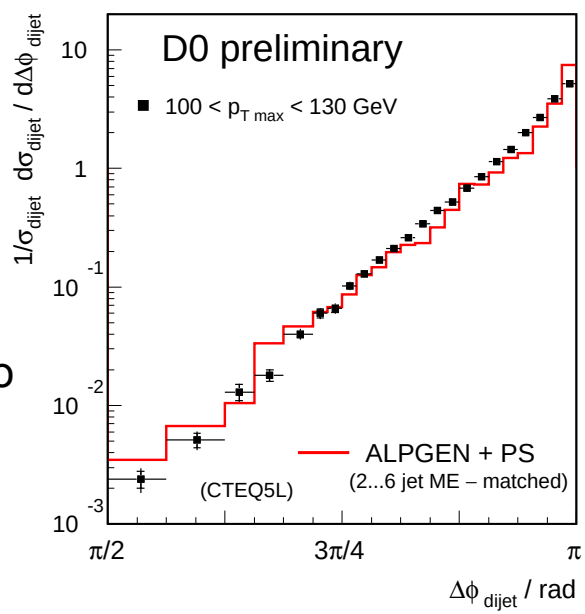
- Development of Monte Carlo tools
  - ➔ NLO generators
    - ❖ MCFM, MC@NLO,...
  - ➔ Multi-parton generators
    - ❖ Alpgen, MadGraph,…
  - ➔ Combining Parton-Shower and Matrix Element techniques to avoid "double counting"
    - ❖ Prescriptions by Mangano, Catani et al for parton↔jet matching
  - ➔ Tuning of Monte Carlo parameters important for comparisons to data

- All these aspects are being investigated at the Tevatron and will benefit LHC physics
- We use these tools for Top Monte Carlo at DØ (Begel, Zieliński)

Simulations for Top Physics at DØ

- We have provided Monte Carlo simulations of the Top signal and background processes
  - ➔ M. Zieliński co-led the Monte Carlo subgroup for the past two years
  - ➔ Begel, S.-J. Park and Zieliński contribute to DØ Alpgen Studies
  - ➔ Begel provided essential improvements to the infrastructure for producing samples, and implemented Mangano's parton↔jet matching (with assistance from Zieliński)

Matching applied to the ΔΦ distribution



- A few details of the Monte Carlo procedures
  - ➔ Alpgen for: $t\bar{t}$, Wjjjj, Wjjj, Wjj, Wj, Zjj, Zj, WWjj, WWj, WW…
    - ❖ overall, hundreds of samples
  - ➔ Pythia or Herwig for parton showering and fragmentation
  - ➔ Tauola for tau-decays
  - ➔ EvtGen for decays of B-states

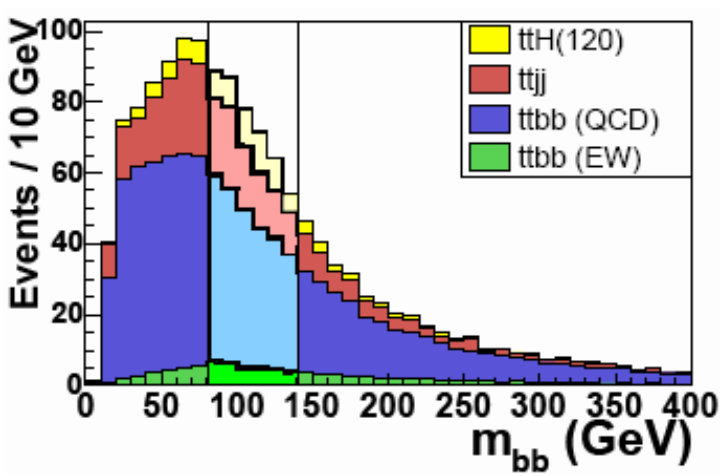
… a "cutting edge" technology has been developed

- Further verification of generators is becoming increasingly crucial as precision of the measurements improves

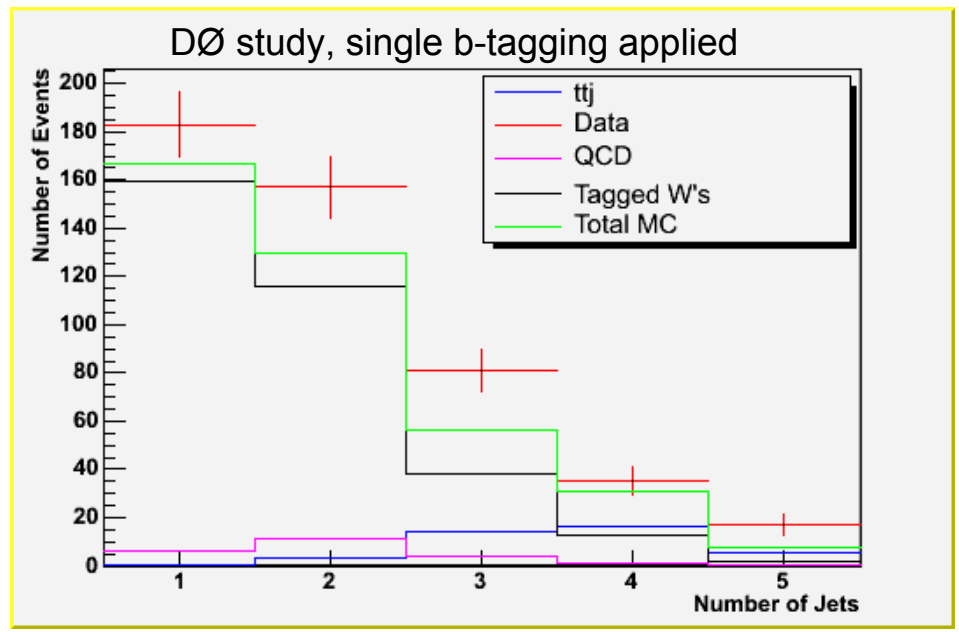
Exploiting the Tevatron Experience: Top

- Re: $t\bar{t}H$ associated production
  - ➔ Important discovery mode for low-mass Higgs
  - ➔ Determine top Yukawa coupling
  - ➔ Benefit from experience with top and jet physics
    - ❖ $t\bar{t}$+jets is the primary background
    - ❖ Tevatron is the best place to understand it and calibrate MC tools in the absence of signal

LHC, $t\bar{t}H$ signal and background



- Work in this direction started this summer
  - ➔ Begel and Zieliński provided Monte Carlo samples
    - ❖ $t\bar{t}$+jets, W + up to 6 jets
  - ➔ E. Groves (with help from A. Khanov) working on comparisons with DØ data



$t\bar{t}H$ at LHC

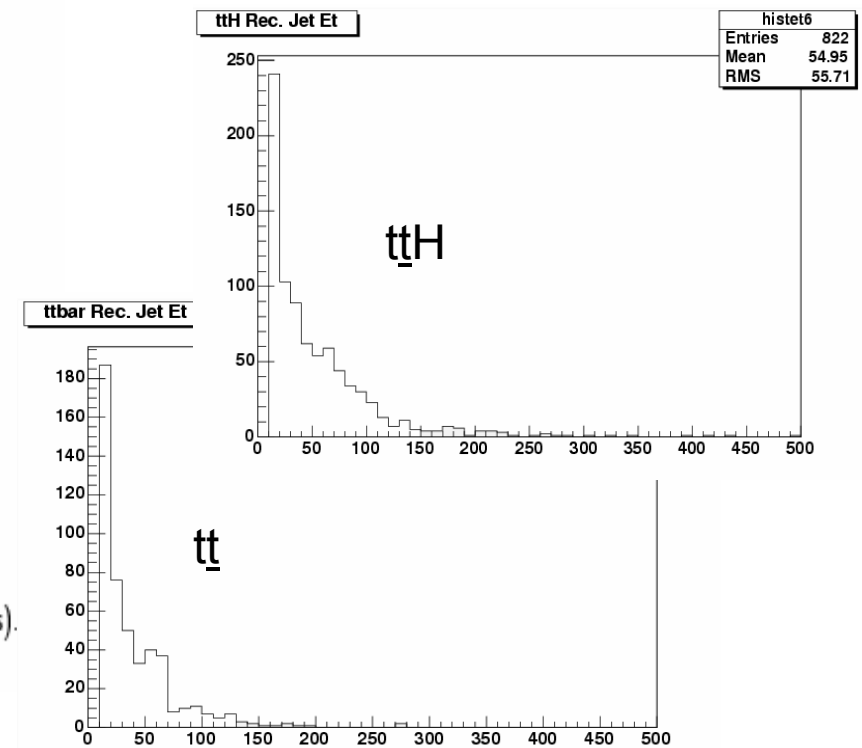
- A big uncertainty: normalization of predictions for $t\bar{t}H$, $t\bar{t}b\bar{b}$, $t\bar{t}jj$ (J. Cammin, see below)
  - ➔ Tevatron studies of $t\bar{t}$+jets data can help a lot!

	CMS	ATLAS
Structure function	CTEQ4L	CTEQ5L
Q^2_{QCD}	m_H^2 for $t\bar{t}H$, $t\bar{t}Z$	$(m_t + m_H/2)^2$
	$m_t^2 + \left(p^2_{T\,t_1} + p^2_{T\,t_2} + p^2_{T\,q_1} + p^2_{T\,q_1}\right)/4$ for $t\bar{t}q\bar{q}$	for all but $t\bar{t}jj$
	LO cross sections in pb	
$t\bar{t}H(100)\times BR_{H\to b\bar{b}}$	1.09	0.69
$t\bar{t}H(115)\times BR_{H\to b\bar{b}}$	0.65	0.43
$t\bar{t}H(130)\times BR_{H\to b\bar{b}}$	0.32	0.24
$t\bar{t}b\bar{b}$	3.3 (see text)	8.6
$t\bar{t}jj$	507	474
CMS: $t\bar{t}Z$	0.65	
ATLAS: $gg\to Z/\gamma/W\to t\bar{t}b\bar{b}$		0.9

Table 17: Settings and cross sections in the CMS and in the current ATLAS analysis (no K factors).

Large differences due to choices of parton cuts and QCD scales

- Work started on full CMS simulation of $t\bar{t}$+jets and $t\bar{t}H$ processes
  - ➔ Summer students J. Dolen and C. Justus
  - ➔ First results for jet E_T:

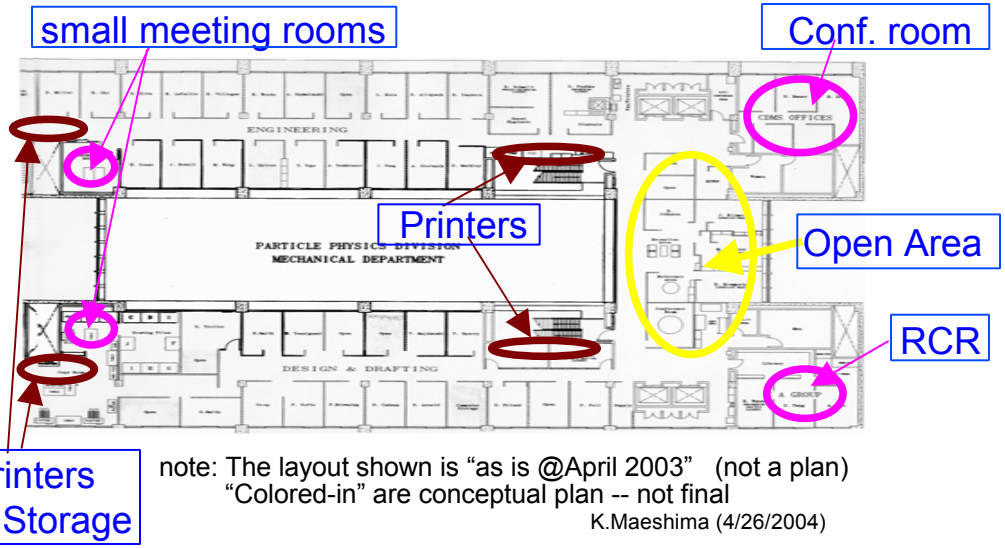


Our Vehicle towards LHC: The LPC

- LPC: The LHC Physics Center at Fermilab
  - ➔ Established in April 2004 by M. Witherell and D. Green
  - ➔ Led by A. Yagil and S. Eno
  - ➔ "A center of excellence within the US for LHC physics"
  - ➔ A place for workshops, conferences, training of scientists
  - ➔ A way to help a graceful transition between the Tevatron and LHC

Main Goals of the LPC

- Attract a critical mass of people to develop software tools for CMS
  - ➔ Reconstruction, particle identification, physics analysis
  - ➔ Local group of experts to work within existing CMS structures ("PRS")
  - ➔ "One-stop shopping" for questions on analysis
- Establish remote control room (RCR) for running the experiment and controlling quality of data
- Provide a physical location and computing infrastructure
  - ➔ Our students, Groves, Dolen and Justus, were among first users of the LPC space on 11th floor of HiRise!



note: The layout shown is "as is @April 2003" (not a plan)
"Colored-in" are conceptual plan -- not final
K.Maeshima (4/26/2004)

LPC Involvements

- Working groups
  - Calorimetry/jets/MET (see later), co-led by Zieliński
  - Muon
  - e/gamma
  - Tracking, co-led by Khanov
  - Framework code/tools
  - Trigger
  - Simulation
- Synergy between calorimetry and tracking: e.g., can use tracking information to improve resolution for jets and MET
- A series of workshops in 2004
  - JetMet, January
  - Muon, April
  - Tracking, August
    - co-organized by R. Demina and Khanov
  - CMS 101, September
  - TeV4LHC, September
    - Demina is convener of the "Physics Landscape" subgroup
    - Zieliński has been invited to convene a QCD subgroup

  …we are actively participating!
- Demina serves on the LPC Advisory Board

Goals for the LPC Working Groups

JetMET: Zieliński
Tracking: Khanov

- Form a center at Fermilab for USCMS software expertise
  - ➔ Data
    - ❖ Where it is, how to get it, how to analyze it
    - ❖ Controlling data in C++
  - ➔ Software
    - ❖ Understanding and contributing to the reconstruction software
    - ❖ All levels, from reconstruction to the root tree and beyond
  - ➔ Analysis tools and techniques
    - ❖ Simulations, event displays, corrections for reconstructed objects
- Work in coordination and cooperation with CMS PRS groups
  - ➔ LPC groups are intended as working groups, NOT a forum to present and approve physics analyses
- Prepare USCMS for analysis of first CMS data
  - ➔ Gain understanding of LHC physics issues
  - ➔ Prepare for possible discovery of any new phenomena

JetMET Group: Just Starting Up

- Conveners
  - ➔ Robert Harris (CMS & CDF) rharris@fnal.gov
  - ➔ Marek Zieliński (CMS & DØ) marek@fnal.gov
- Meetings
  - ➔ Bi-weekly
  - ➔ Agenda available from agenda.cern.ch
- Web page
  - ➔ http://www.uscms.org/scpages/general/users/lpc_jetmet/lpc_jm.html
  - ➔ Current information on data, software and getting started in JetMET
- Mailing List
  - ➔ lpc_jetmet@fnal.gov

JetMET at LPC

JetMET
LPC JetMET
PRS JetMET

Getting Started
JetMet UAF Tutorial
UAF Getting Started

Software
CMS Code Browser
ORCA Class Structure
JetMET RootMaker

Data
CMS Production
DC04 Data at FNAL

Activities
Map of Jets Package
FAMOS for Jets
Jet Corrections
Pictures
Examples

JetMET Working Group at LPC

A developing center for USCMS expertise in JetMET data, software and analysis tools.

Conveners

Robert Harris, Fermilab, rharris@fnal.gov , 630-840-4932.
Marek Zielinski, Rochester, marek@fnal.gov , 630-840-2373.

Meetings: Alternate Thursdays at 9:30 a.m. in WH2NW

- Agenda Server
- Meeting Minutes

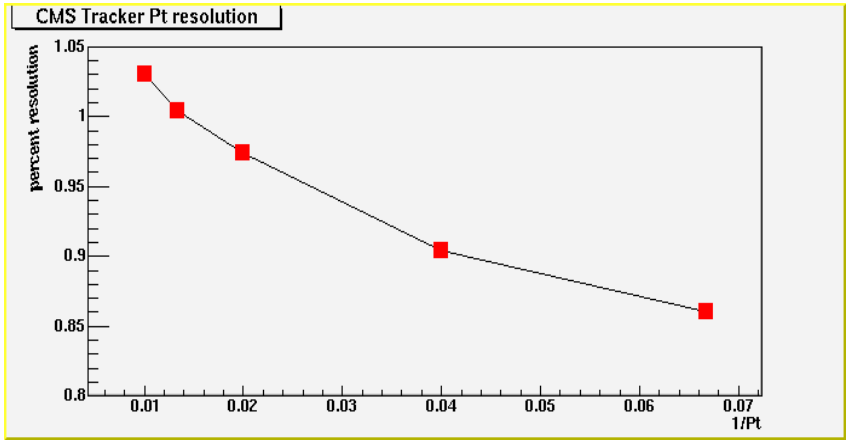
Mailing Lists

- lpc_jetmet@fnal.gov: JetMET working group at LPC. How to subscribe. (hint: MYLIST = lpc_jetmet).
- cms-jetsmet@listbox4.cern.ch: PRS JetMET

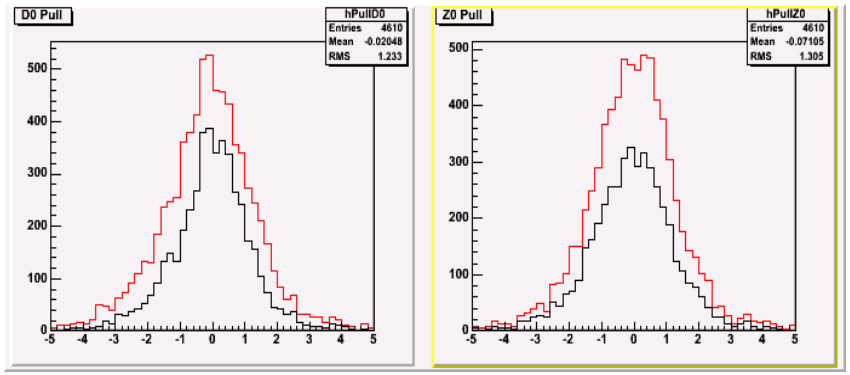
Last updated July 26, 2004 by Robert Harris

Starting LPC Tracking Group

- Tracking group co-lead by Khanov
- Information on the Web, linked from LPC page
  - ➔ Goals and plans
  - ➔ Minutes of the meetings
  - ➔ Links to data samples, code, results, Q&A
- Weekly meetings
- Contacts with CERN experts
- Series of workshops
  - ➔ first was August 3-4, 2004



Study of the CMS tracker momentum resolution



Tests of track reconstruction quality
(pulls for impact parameter and z-position)

Conclusions and Outlook

- We have established a realistic program for a coherent transition from the Tevatron to the LHC era

- We are increasing involvement in the activities of the LHC Physics Center at Fermilab
  - ➔ Build on our technical expertise in calorimetry and tracking
  - ➔ Leverage our physics involvements at DØ to benefit and prepare for the LHC program
    - ❖ Focus on QCD and Top measurements that help improve the understanding of issues at the LHC
    - ❖ At Tevatron, verify and tune Monte Carlo tools needed for LHC
    - ❖ Continue the LHC $t\bar{t}H$ study, measure the $t\bar{t}j$ production at DØ to provide more realistic predictions for $t\bar{t}H$ background rates
    - ❖ Expand collaboration with theorists at Fermilab and Rochester (L. Orr and D. Rainwater)

- We plan to be ready for LHC physics on Day One!