Tevatron, DØ And Top Physics

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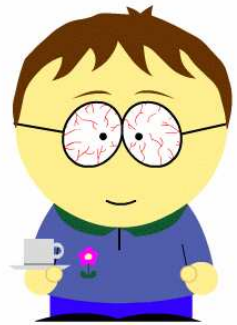
21st December 2005

Outline

- **Tevatron and the DØ Experiment.**
- **Student's Point of View.**
- **QCD and Top Quark.**
- **Kinematics of the $t\bar{t}$ Final State.**



It's about circles – Fermilab Aerial View

- Collider experiments CDF and DØ, theory and accelerator divisions, US CMS, LHC dipoles production...
- Fixed target beam line, neutrino experimets (MiniBoone, Minos, ...).
- Fast neutron therapy, outreach (Lederman science center).

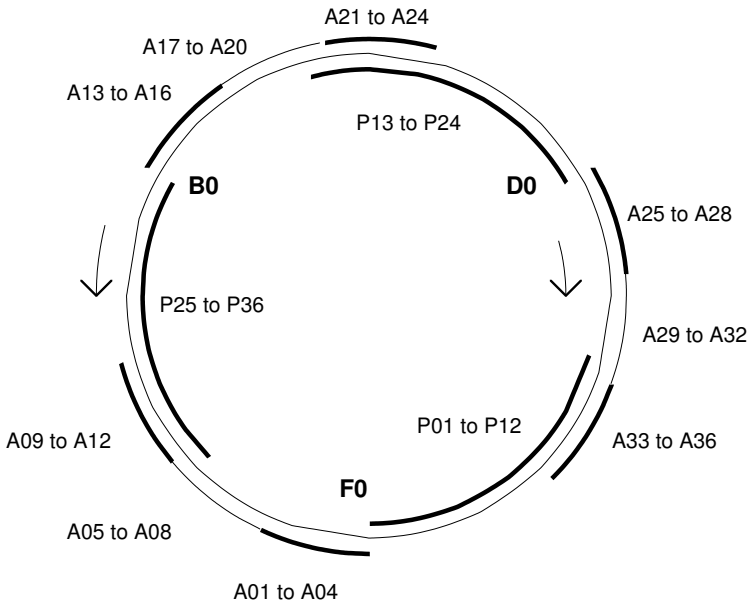
Tevatron

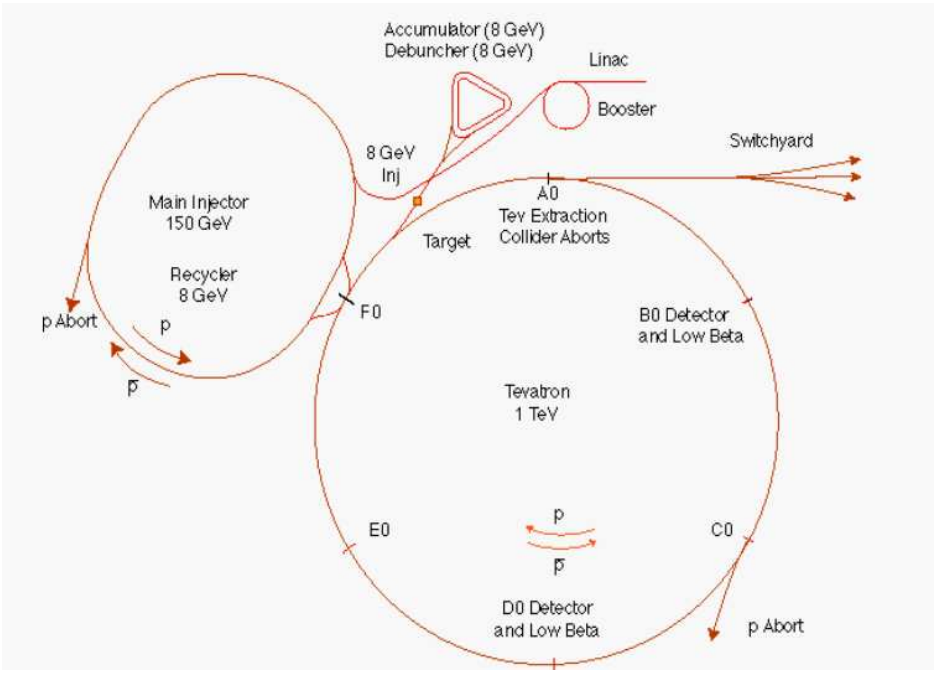
- **Run I:** 1992-1996, 3500 ns bunch spaceing, 120 pb^{-1} integrated luminosity, $\sqrt{S} = 1.8\,\mathrm{TeV}$.

- **Run II:** Accelerator complex in Fermilab was extended by the the Main Injector, a brand new $150\,\mathrm{GeV}$ proton synchrotron.
- Run IIa: 2001-2006, more than 1 fb^{-1}.
  Run IIb: 2006-2009; expect 4-8 fb^{-1} in total.
  (Electron cooling, $\bar{p}$ stack increase)

- $E_{\mathrm{beam}} = 980\,\mathrm{GeV}$, filling time 0.5 h, acceleration in 86 s.
- Typical beginning of store luminosity: $10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  (LHC goal is 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$).

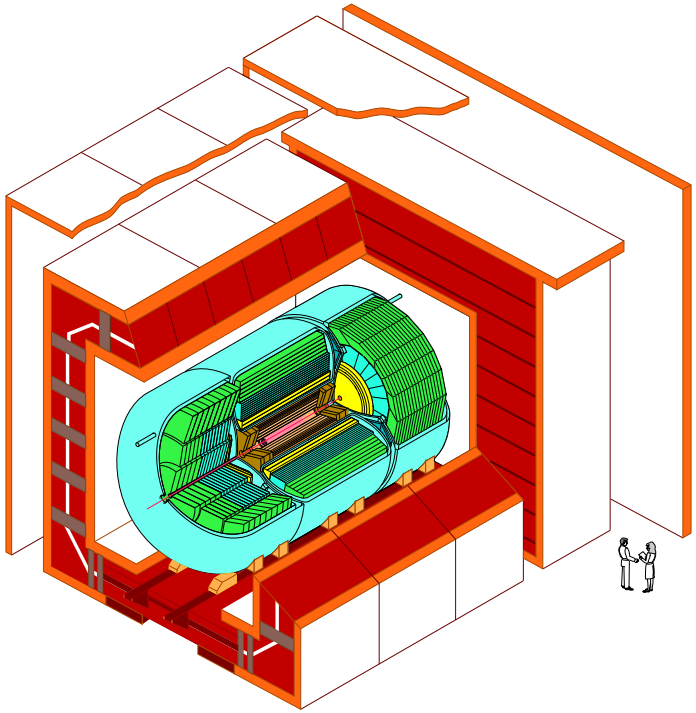
Tevatron Layout





- **Circumference: 6.28 km, c.m.s. energy 1.96 TeV**, hexagonal lattice symmetry.
- Bunches: $p \times \bar{p}$: 36×36, each 3×12 (12 bunches in a superbunch)
- Revolution frequency: 47713 Hz, Revolution time: 21 μs.
- RF frequency 53.104 MHz, RF "bucket" time separation: 18.8 ns $\Rightarrow$ **bunch spacing 396 ns**. . . 119 m;-)

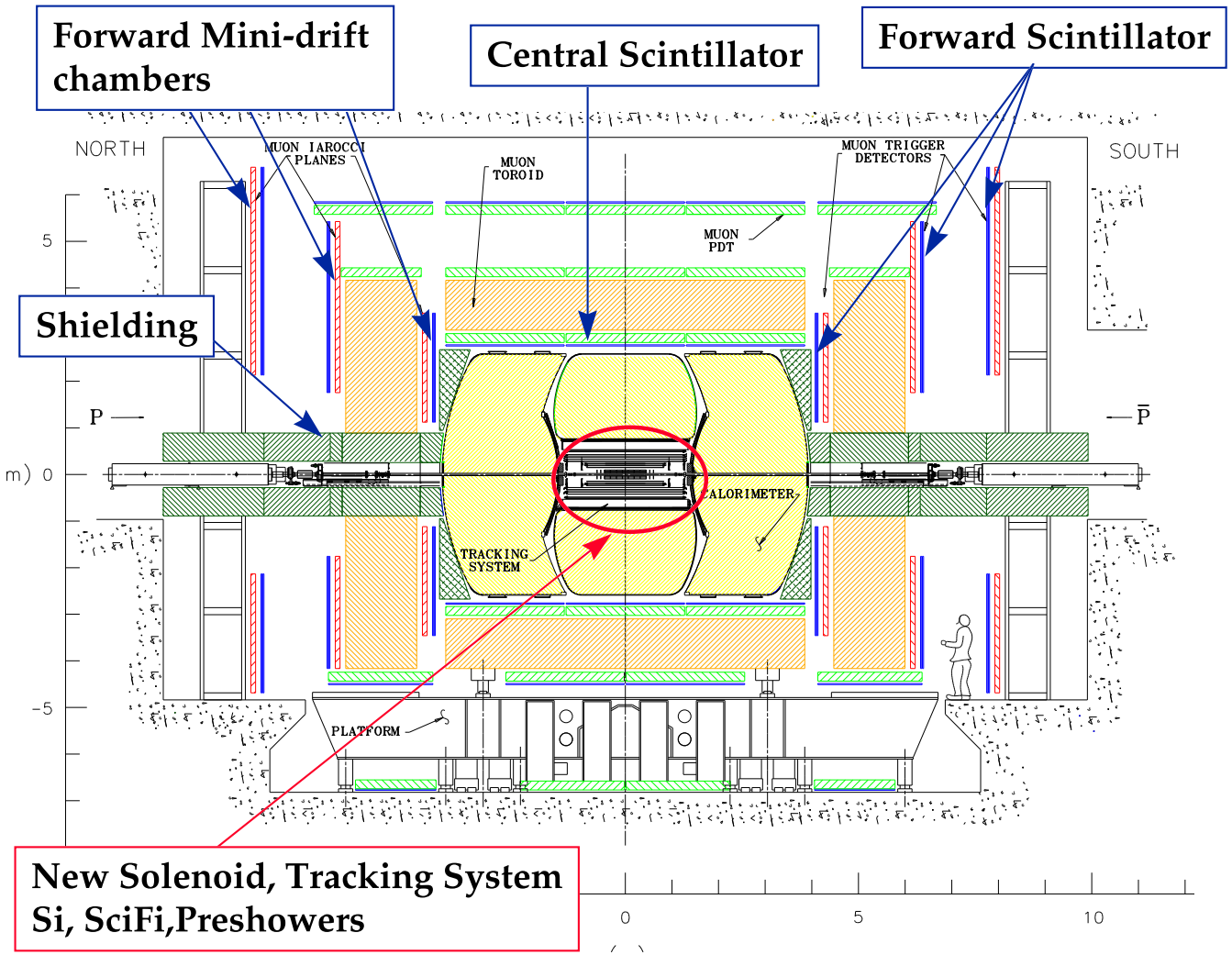
DØ Detector



DØ Detector

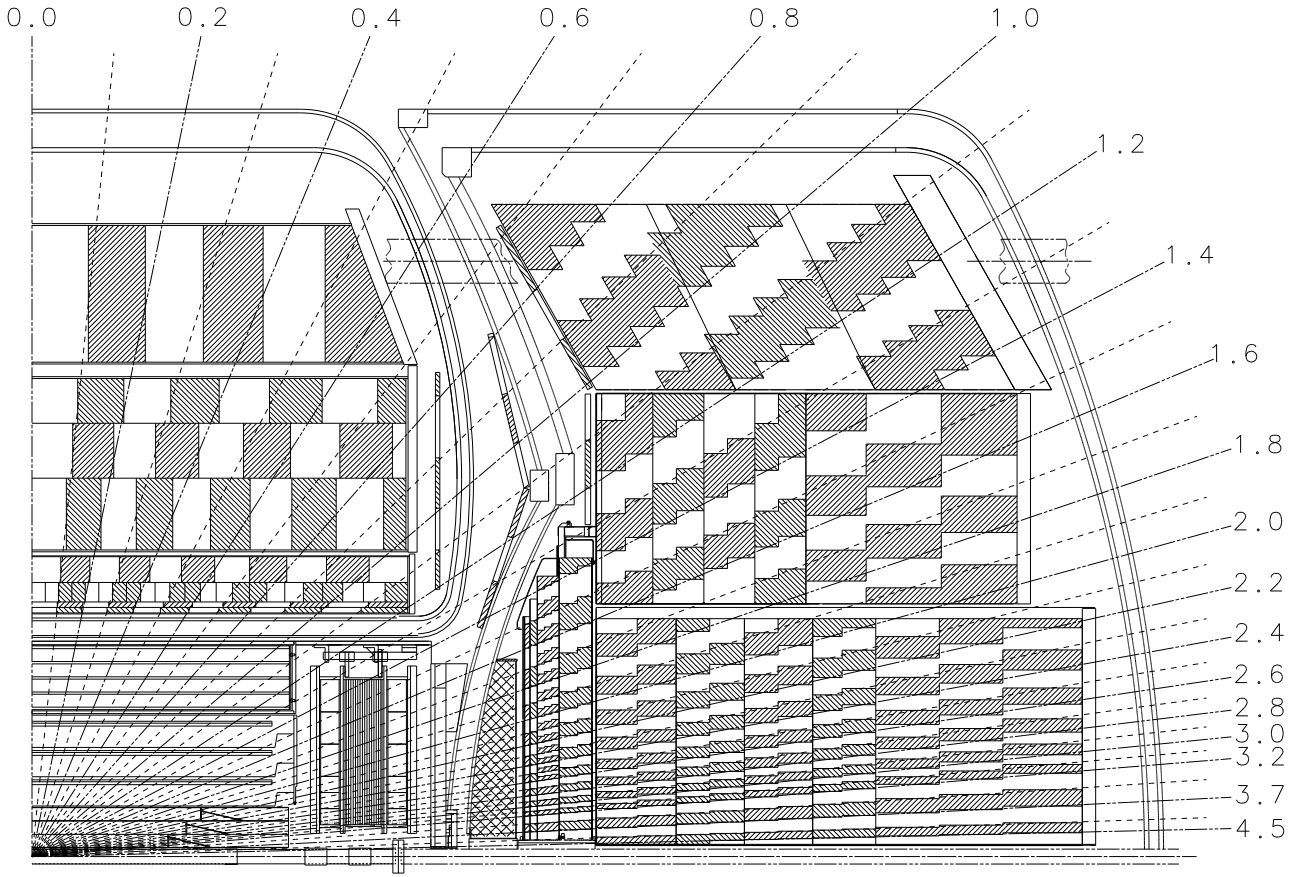
- Proposed 1983, major upgrades for Run II.
- 2T Solenoid, Silicon and fibre tracker, Calorimeter, Muon chambers, Toroid, Forward proton detector.

DØ Upgrade



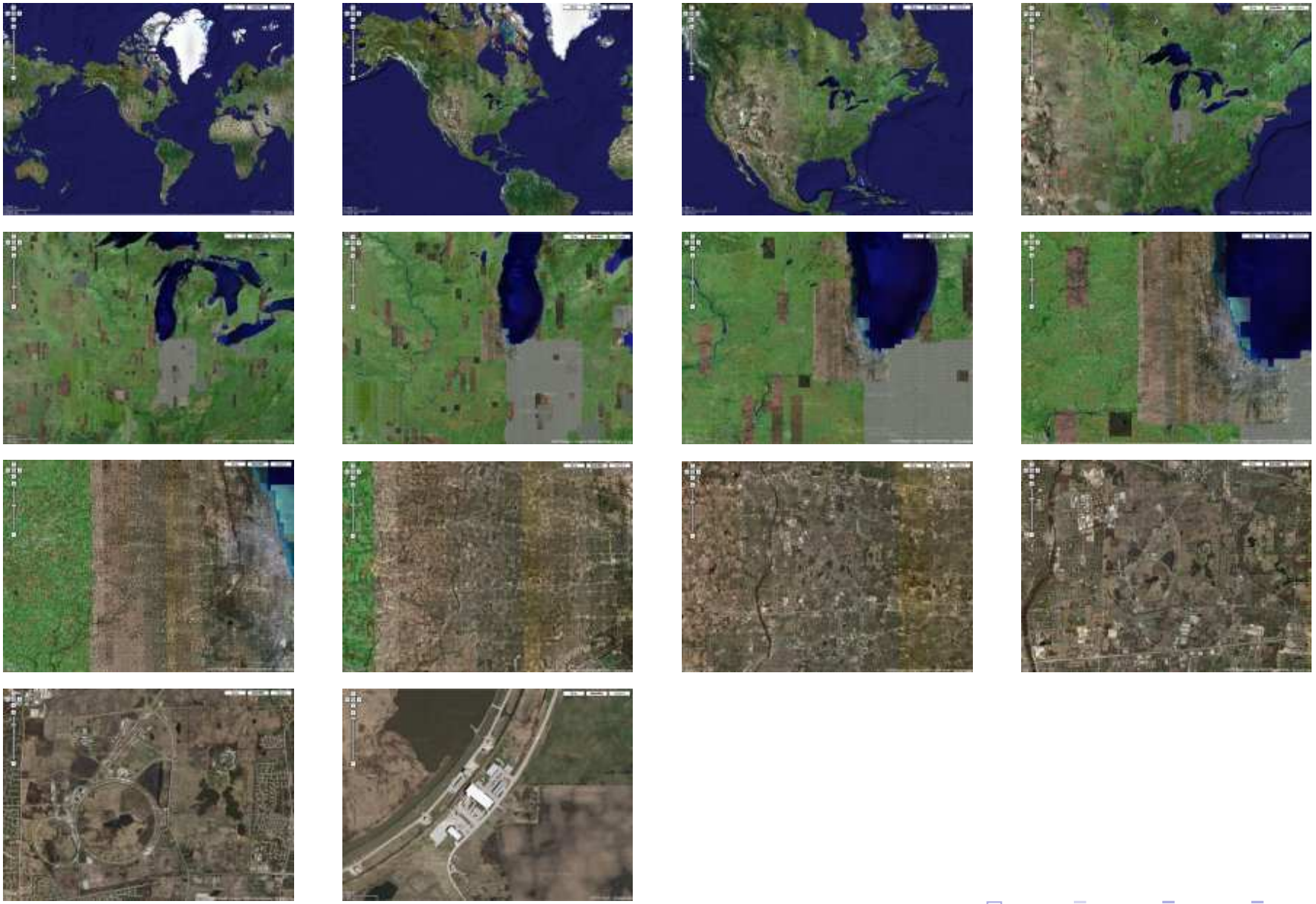
D0 Upgrade

DØ Calorimeter



- Sampling Liquid Argon + Uranium, nearly compensating, $e/\pi \approx 1.05$.
- New electronic, shorter integration time, shorter bunch crossing, nonlinearities;-)

Going to Fermilab. . . Method I



Going to Fermilab. . . Method II









How does it work in Fermilab?

- DØ is a collaboration of 679 people from 89 institutions (Atlas: $\approx$ 2000 members?:-).
- **Object Identification Groups:** Jets, EM's, μ's, Tracks, τ's, B-ID...
- **Physics Groups:** QCD, Top ($t\bar{t}$, single top), Electroweak, Higgs, New Phenomena, B-Physics
- Our **Czech Group:-)**
  3+3 students:
  - MFF: Vlasta Hynek, Olda Kepka, J.K.
  - ČVUT: Zdeněk Hubáček, Roman Otec, Petr Vokáč.

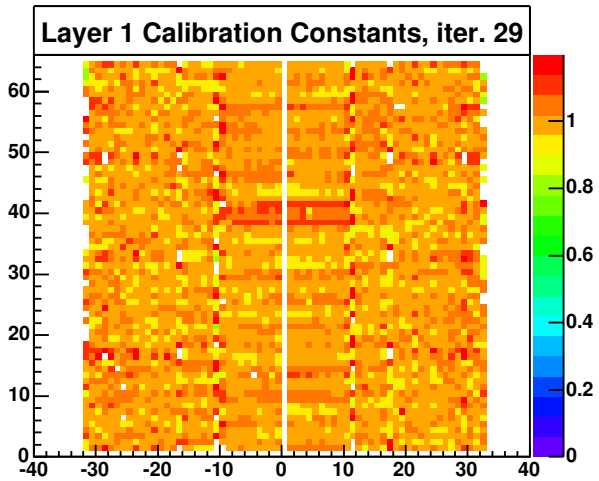
  2 postdocs: Karel Soustružník (MFF), Saša Kupčo (FzÚ).
  2 bosses (M.L., V.Š.)
- To become an author, one has to spend 1 year for DØ and provide 6 months of service tasks for the collaboration.
- Serve shifts at the detector;-)
- So what do we do there? ;-)

Service Work

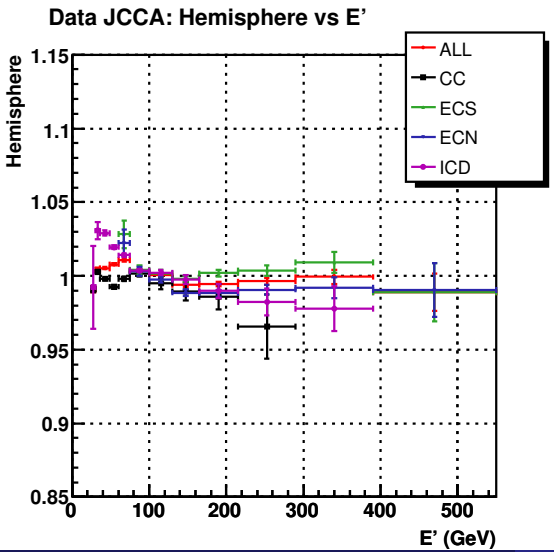
- The idea is to contribute to an area one will use in the PhD analysis.
- The advantage of working on Top: you need almost everything: jets, tracks, primary (interaction point) and secondary (b-jets) vertices, electrons, muons, perhaps taus, missing E_{T} (and photons, J/ψ...needed for Jet Energy Scale anyway;-)
- Pick topic carefuly, don't get involved in doomed projects;-)
- Ask people around, in the place: stays in Fermilab are invaluable.
- My choice:
  - Jet Energy Scale tests with γ/Z + jets.
  - Hadronic Calorimeter Calibration (ϕ-intercalibration).
- **What is it good for:**
  - Contribution for the whole collaboration.
  - Learning software skills, working closely in groups.
  - Learning from others, data analysis techniques.
  - Understanding the detector and data.

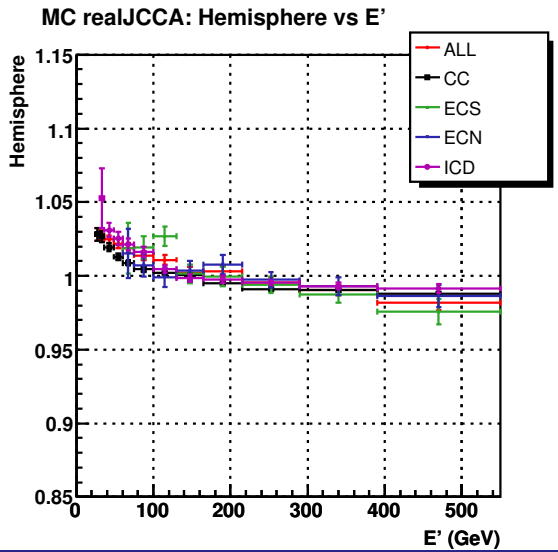
Service Work

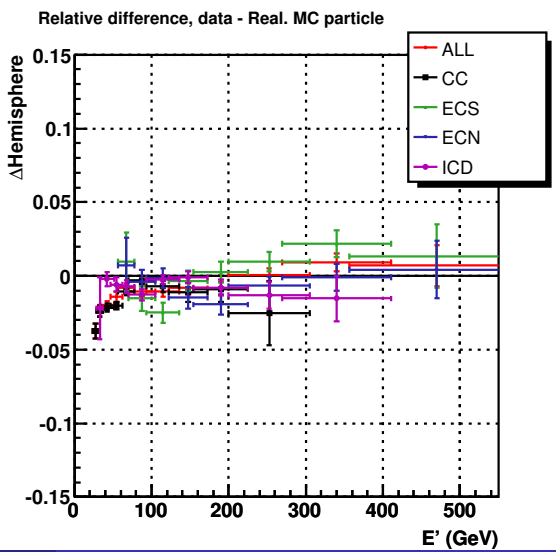
- **Hadronic Calorimeter Calibration:**
- Equalise the response in the azimuthal angle ϕ using the symetric E-flow the detector should see (unpolarised beams.
- Illustration of calibration constants for a particular layer, areas corresponding to highly nonuniform modules visible.



- **Jet Energy Scale Closure tests:** comparing p_{T} balance in Data and Monte Carlo particle jets.





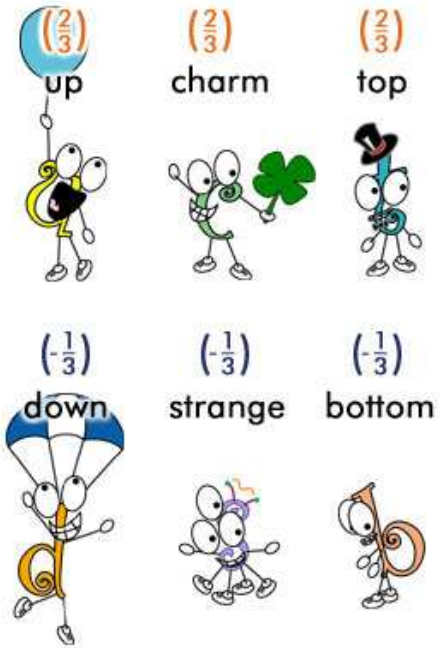


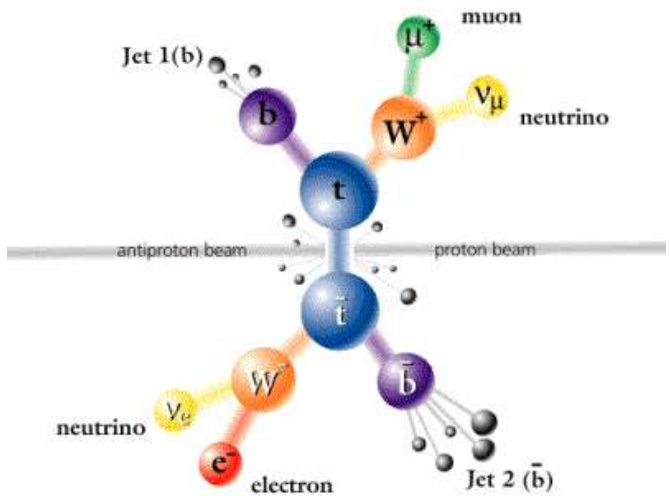
So . . . What physics can we do at hadron collider?

- Higgs ($\gamma\gamma$, $b\bar{b}b\bar{b}$, charged, SUSY . . .)
- New phenomena (ED, SUSY, MSSM, black holes, gravitons . . .)
- B-physics (B_s, J/ψ, $\mathcal{CP}$ violation . . .)
- **Top:** just turned 10 years, but so far only a few properties explored (cross section, mass, W helicity), new recent measurements of BR light q/b and top charge.
  Run II "To do": observe single top production.
  Top width only at Linear Collider, but we can study kinematics to understand top as a background source at LHC.
- Electroweak (W mass, width, forward–backward asymmetry, lepton couplings to Z, VV productions. . .)
- **"Good–Old QCD":**
  pQCD started to be tested on a precison level!
  And there's also the diffraction (DØ's Roman Pots).

Top Quark

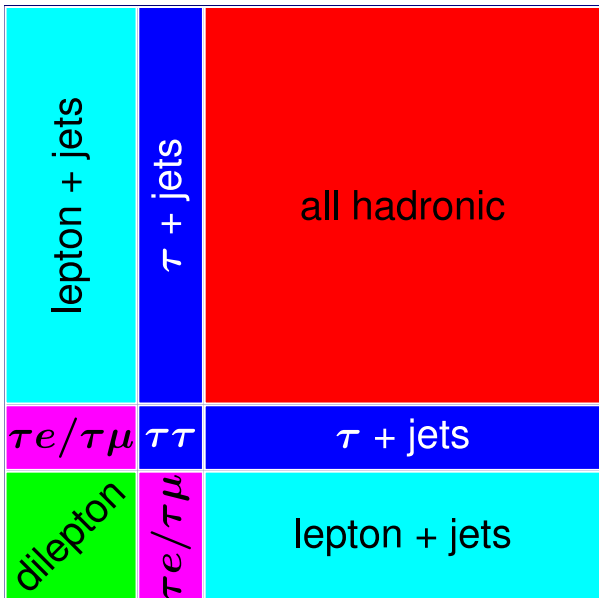
- Top is the heaviest elementary particle at the moment!
- Large mass may relate it to the mechanism of EWSB, it's the only particle of the mass around the Higgs vacuum expectation.
- Large mass gives important corrections to Higgs mass, enters CP violation via loop diagrams (flavour physics, CKM).
- Top Quark is a nice QCD and EW laboratory! (cross section, decay, BR's, kinematics, searches for new physics, couplings . . .)

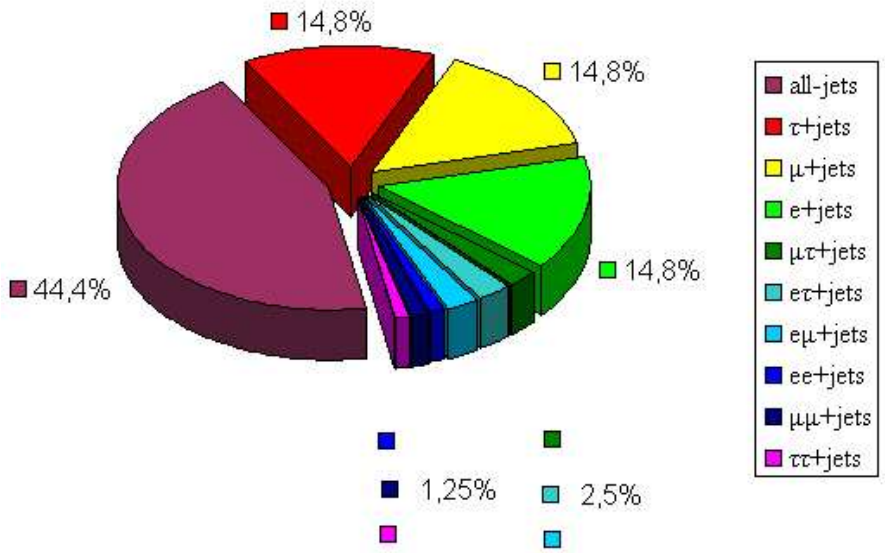




Top Quark Decay

- We have the process $p\bar{p} \rightarrow t\bar{t} + X \rightarrow bW^+\bar{b}W^- + X$.
- $t \rightarrow Wb$, further decay of W either to quarks ($\Rightarrow$ jets) or lepton+neutrino.
- We expect ideally 6 jets in the all jets channel, 4 jets in lepton+jets channel and 2 b-jets in dilepton channels.





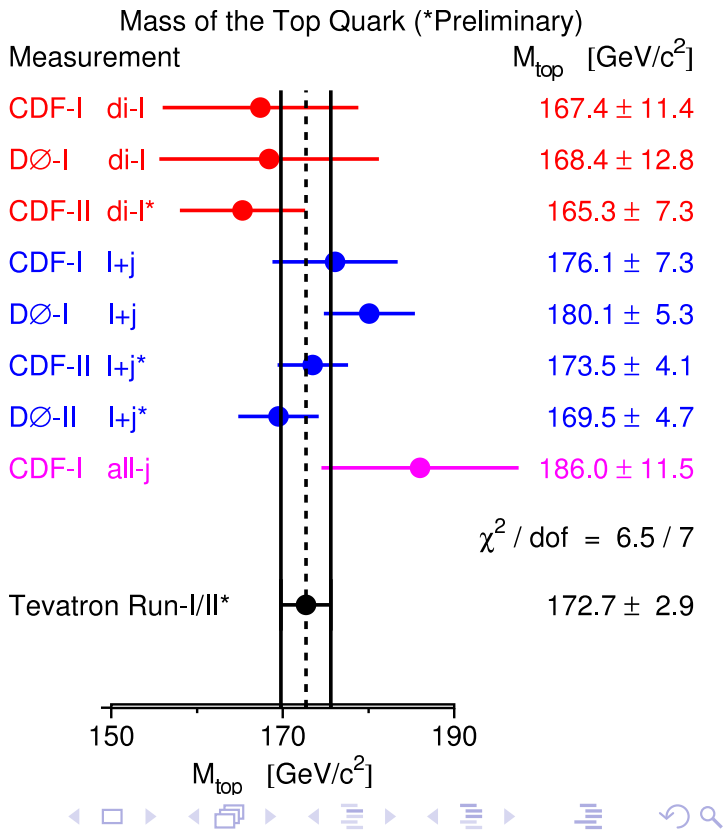
(M. Begel graphics;-)

The Story of the Top Quark Mass

World averages (both experiments combined):

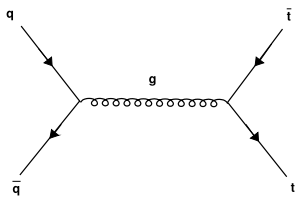
- 2003: **174.3 ± 5.1** GeV (Run I)
- 2004: **178.0 ± 4.3** GeV (New DØ Run I l+jets: 180 ± 5.3 GeV)
- Current world average? – hep-ex/0507091.
  2005: **172.7± 2.9** GeV (accuracy of 1.7%).

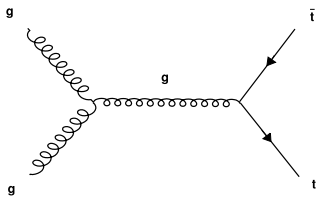
- Run I and preliminary Run II.
  Both CDF and DØ.
- Systematics dominated.
- Best CFD measurement involve simultaneous in-situ Jet Energy Scale fit using m_W.
  CDF l+jets: $173.5^{+3.9}_{-3.8}$ GeV.
  DØ l+jets: 169.5 ± 4.7 GeV.
- No Run II mass in alljets channel yet, only recently published DØ Run I.

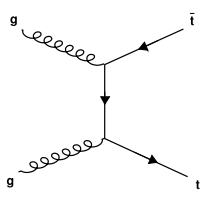


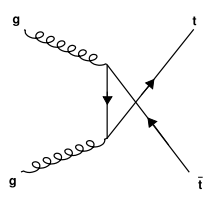
Top Quark and QCD I

- In $t\bar{t}$ system, we deal with a **multijet environment!** the W mass in $t\bar{t}$ events.
- Top decays weakly, but $t\bar{t}$ **production happens via the strong interaction:-)**
- At Tevatron, $q\bar{q}$ initial state dominant (85%), gg important at LHC (90%), problem of large **uncerntainties on gluon PDF's** while Top will be an **important background** for new physics.
- In $t\bar{t} + nj$ processes also qg initial state and corresponding PDF's enter the game.
- Problematic treatment of additional jets in event reconstruction.





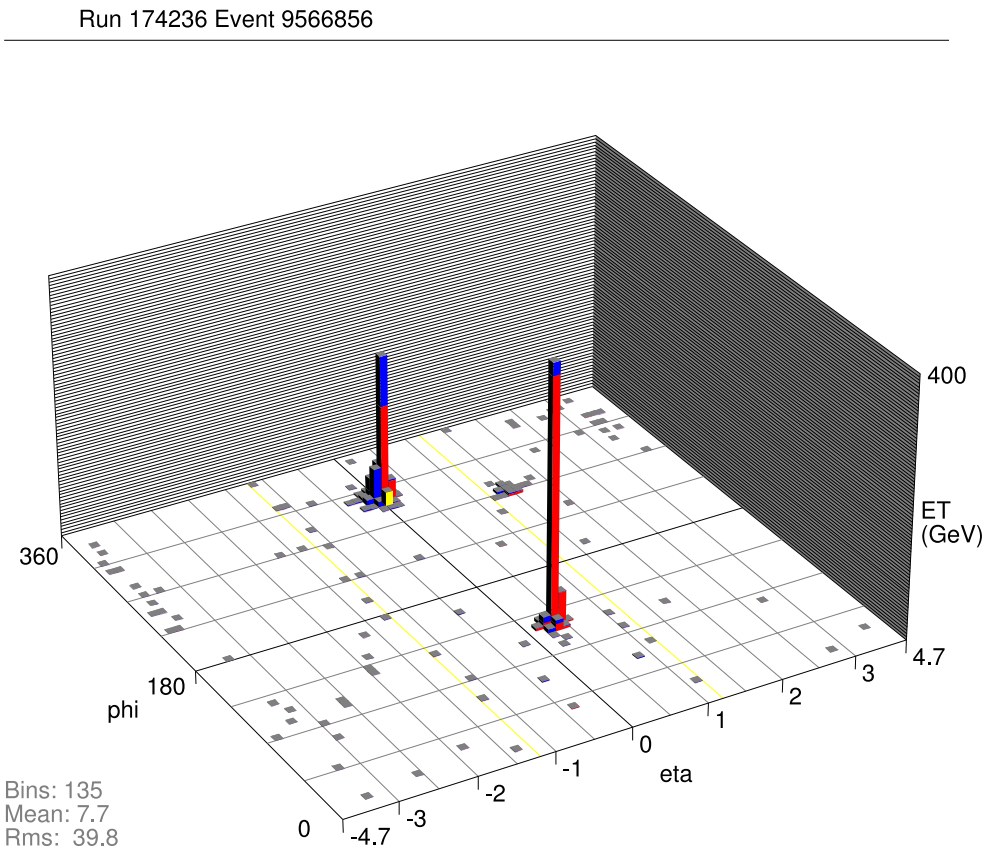


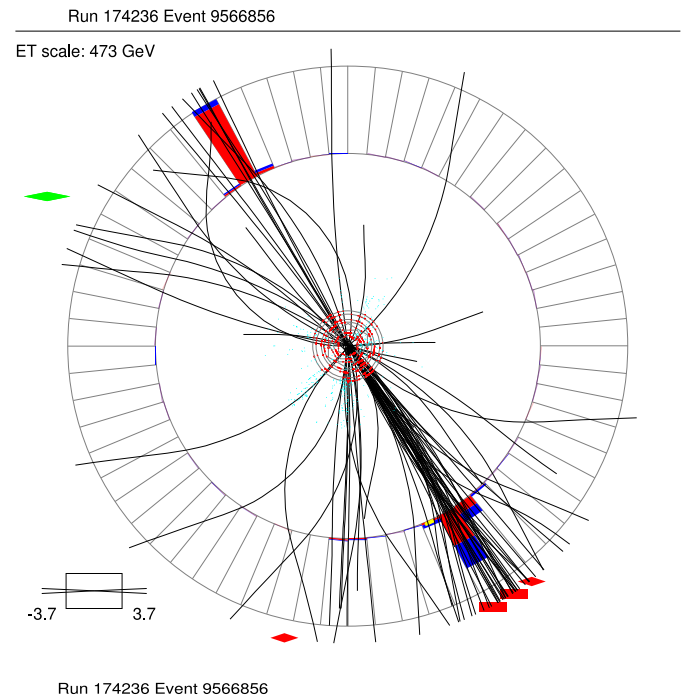


Top Quark and QCD II

- **Top quark does not hadronise**, it has almost no time to radiate: it brings direct infomation about the parton final state!
- It has a **distinct signature**, observing decay products one can fully reconstruct the event.
- **Final state systematics is completly different to QCD** measurements, still it's like a dijet system.
- There should be observable differences related to heavy quark production (two large scales present, scale choice, resummation).
- Jet Energy Scale uncertainties are the main systematics to most Top Quark related measurement.

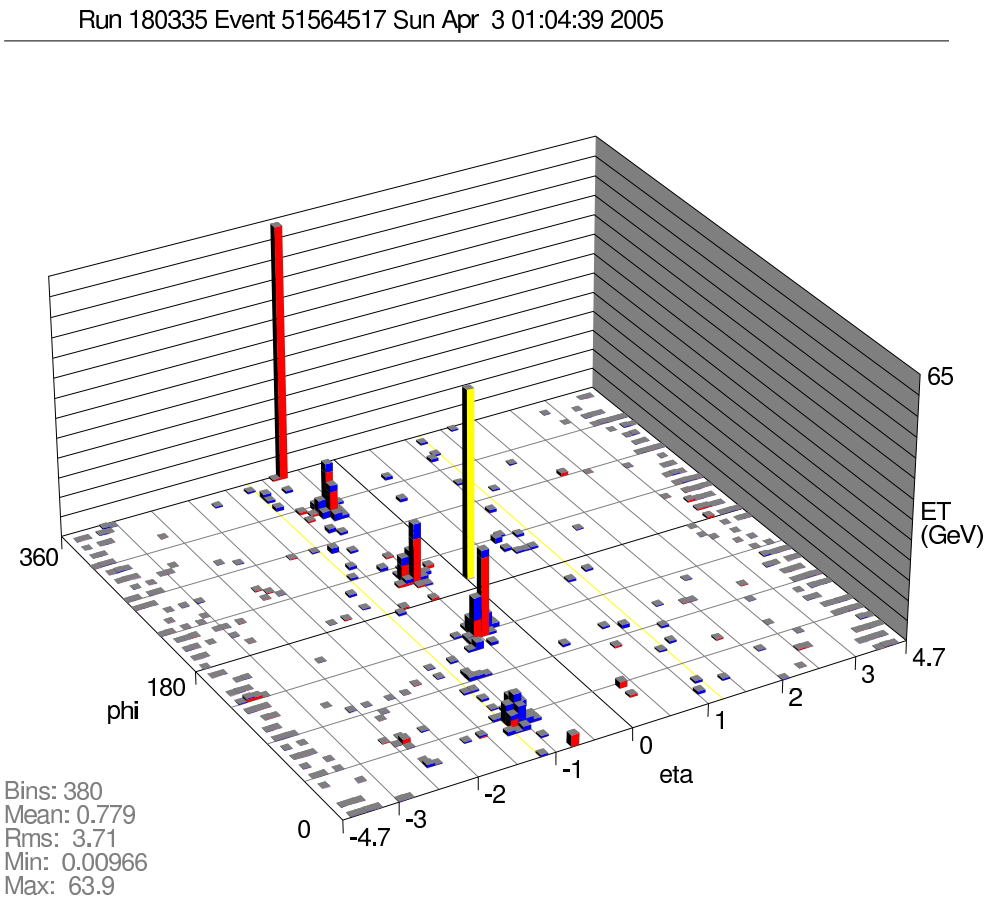
What does it look like: QCD, Highest p_T Dijet Event

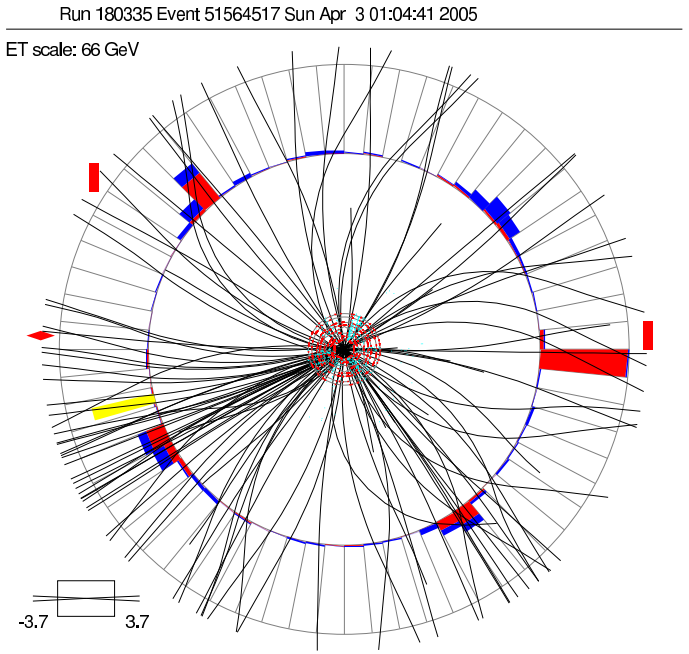


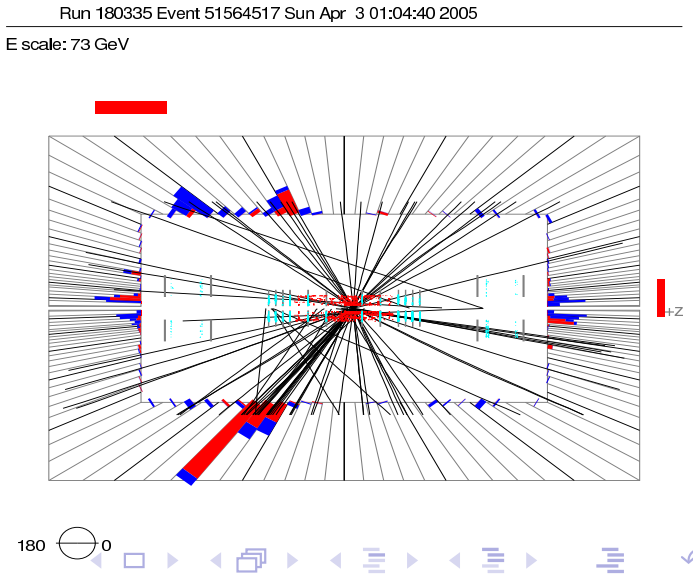


	1st jet	2nd jet
p_T	631 GeV	560 GeV
y_{jet}	0.14	-0.17
ϕ_{jet}	2.10	5.27
$M_{jj} = 1208$GeV		

What does it look like: Top, $t\bar{t}$ e+jets Event, 1 SVT b tag.



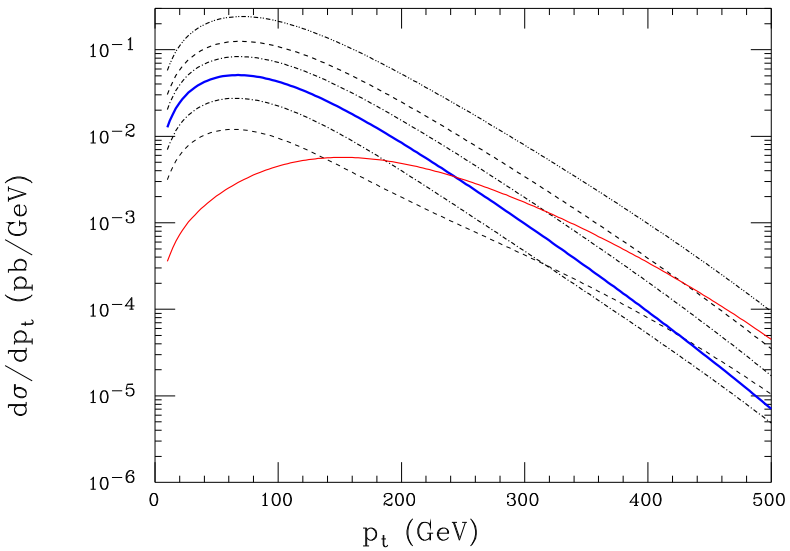




- EM cluster energy
- Hadronic energy
- Missing transverse energy

Some more motivation for studying $t\bar{t}$ kinematics

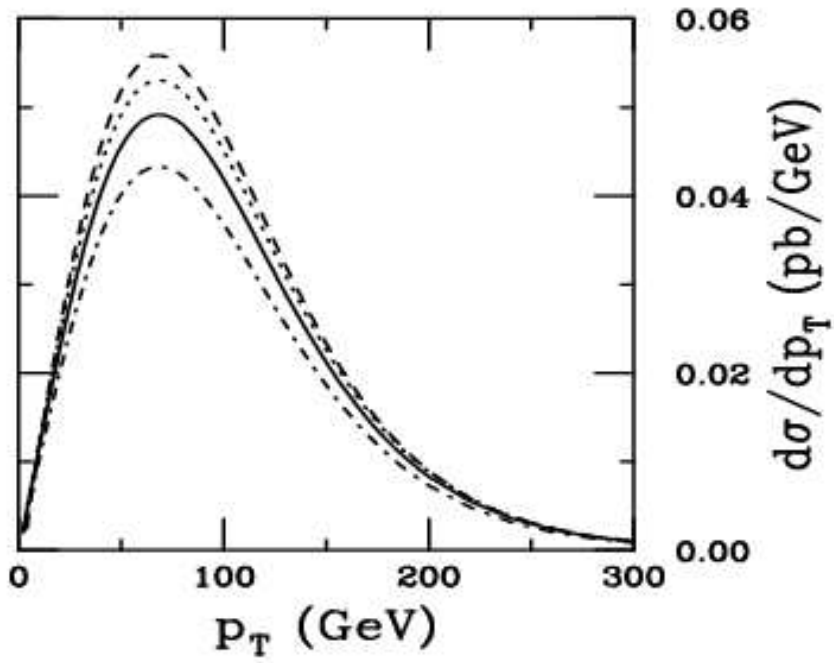
- We would like to know more about the Top quark!
- All kinematical distributions related to the $t\bar{t}$ final state are sensitive to new physics (resonances, couplings) and higher order QCD effects.
- Almost any QCD observable from e.g. dijet studies can also be studied in the $t\bar{t}$ system with completely different systematics.
- We can also probe radiation and parton system boost effects, our Monte Carlo understanding...



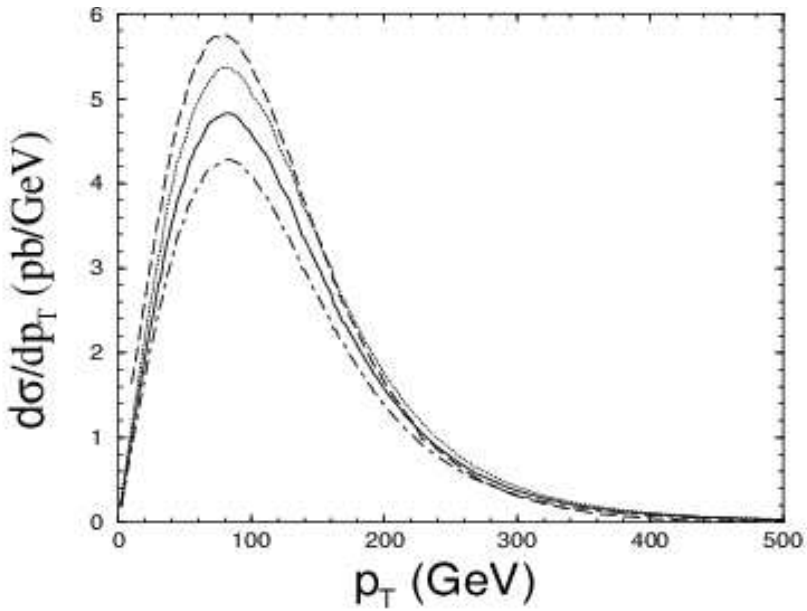
T.G.Rizzo, `ArXiv hep-ph/9902273`
Top p_T:

- blue – SM,
- red – Maximal Top anomalous chromomagnetic moment.

Theory Top p_T Predictions



Tevatron



LHC

- Top p_T spectrum $\frac{d\sigma}{dp_T}$ is a first–hand QCD variable and has not been measured yet at DØ.
- N. Kidonakis and R. Vogt, Phys. Rev. D 68, 114014 (2003), hep-ph/0308222

Analysis Outline: $t\bar{t}$ Kinematics in lepton+jets channel.

- Investigate and compare MC $t\bar{t}$, $t\bar{t}j$ and $t\bar{t}jj$ samples, their fractions taken from LO Alpgen predictions (0.55, 0.31, 0.14).
  Problems with phase space double counting...
- Assume QCD-like and W+jets backgrounds.
- Identify b jets looking at secondary decay vertices of b hadrons (b-tagging): possible due to long mean life ($B^{\pm}$ $c\tau \approx 500$ μs).
- Preliminary data – MC comparison plots in combined l+jets channel.
- Lepton here is e or μ, or leptonicaly decaying τ.

- Focus on the following variables of interest:
  - Hadronic Top p_T and η
  - $t\bar{t}$ system p_T and η
  - $\Delta\phi$ of the two Top quarks...

The Method

- Kinematics of the lepton+jets final state is not fully known due to the undetected neutrino.
- We approximate the neutrino p_{T} by $\not\!\!E_{\mathrm{T}}$.
- In order to fully reconstruct the $t\bar{t}$ event and improve resolution, a constrained kinematic fit is performed.
- We constrain both W masses and the top mass (175 GeV/c^2) and minimize a χ^2 expression based on measured and fitted variables.
- We use b-tagged events and best χ^2 solution of up to 12 jet permutations (reduced when b-taged).
- Understanding of additional jets in the event is essential for combinatorial background as well as for effects on distributions themselves.

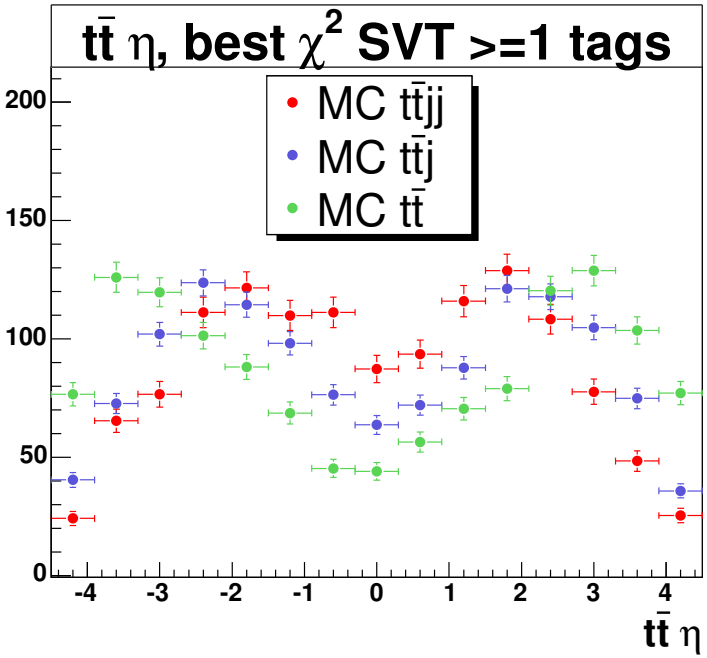
Datasets and Event Selection

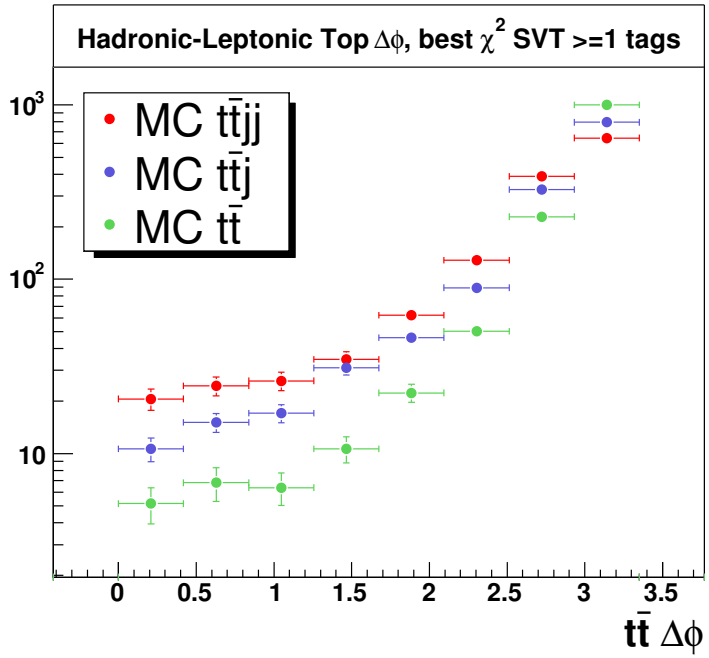
- Work closely follows DØ b-tag cross section analysis in the l + jets channel (preselection, background types, tagging efficiencies).

- Secondary Vertex Tagged DØ Run II datasets
  - 226.3 pb^{-1} in e+jets
  - 229.1 pb^{-1} in μ+jets

- Require the following preselection:
  - At least 4 jets with $p_{\mathrm{T}} > 15\,\mathrm{GeV}$, $|\eta| < 2.5$.
  - Lepton $p_{\mathrm{T}} > 20\,\mathrm{GeV}$.
  - $\not\!\!E_{\mathrm{T}} > 20\,\mathrm{GeV}$.
  - Veto another tight lepton in the event.
  - Fit $\chi^2 > 0$, best $\chi^2 < 20$.

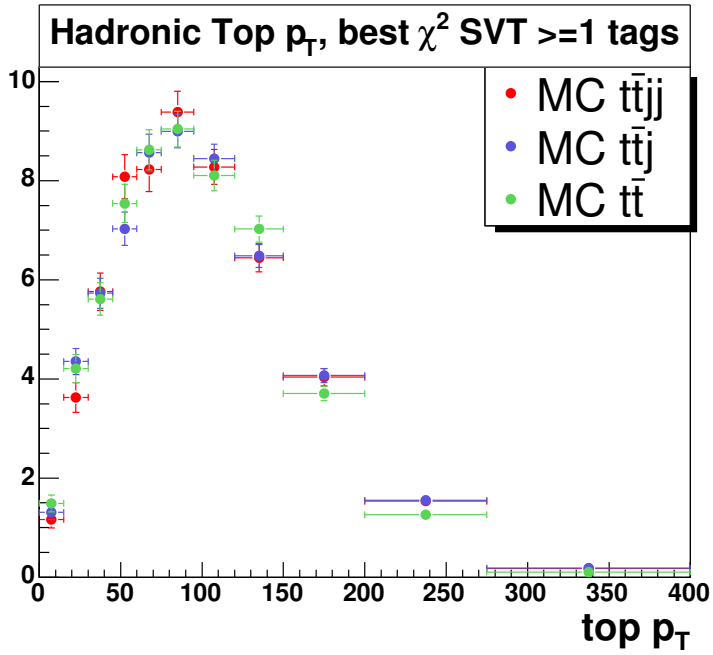
Monte Carlo Comparison for Additional Generated Jets I

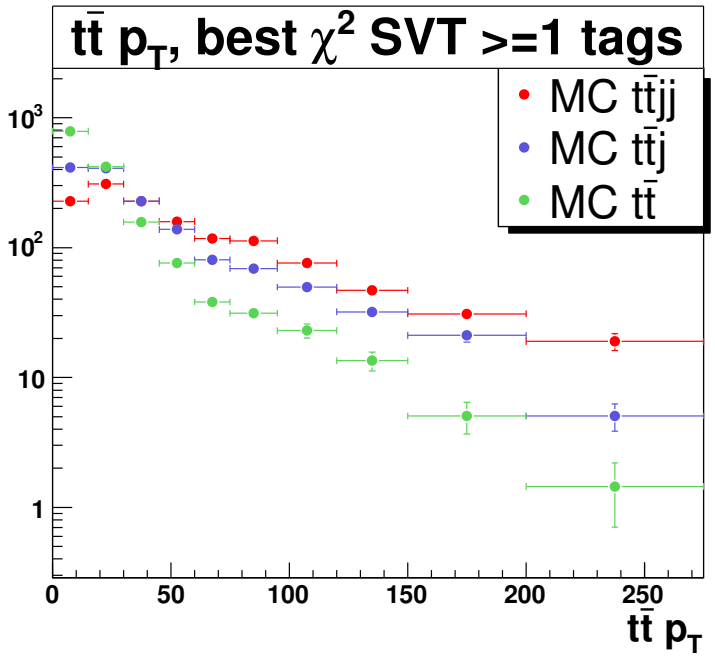




- $t\bar{t}$ system η and $\Delta\phi$ in the e+jets channel.
- Extra jets spoil $t\bar{t}$ back-to-backness.
- η distributions sensitive to $t\bar{t}$ system boost, softly radiated partons making the system more forward-like.
- $t\bar{t}$, $t\bar{t}j$ and $t\bar{t}jj$ important for understanding data distributions.

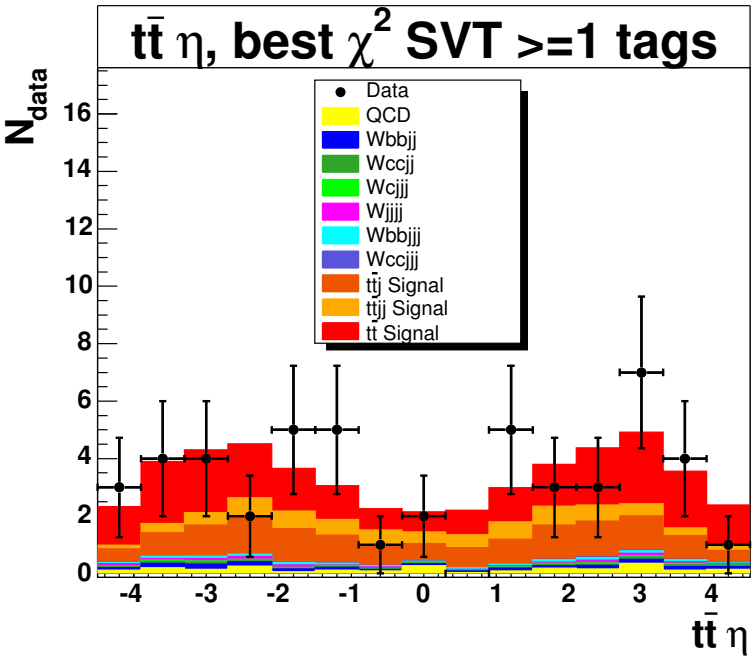
Monte Carlo Comparison for Additional Generated Jets II

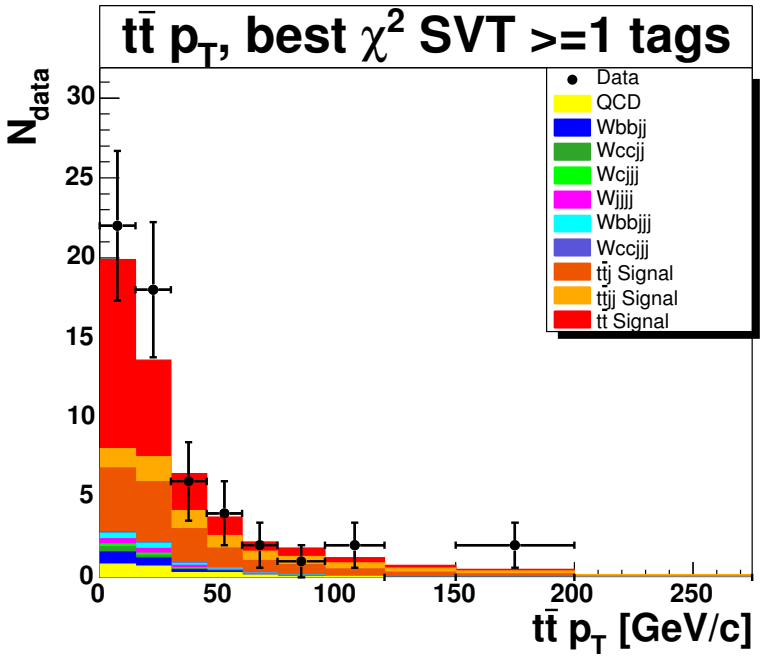




- Hadronic Top and the $t\bar{t}$ system p_T in the e+jets channel.
- $t\bar{t}$ spectrum is broader as expected, however, the effect on individual Top p_T seems to be negligible.
- If confirmed, Top p_T insensitivity to radiation makes it promising for new physics searches!

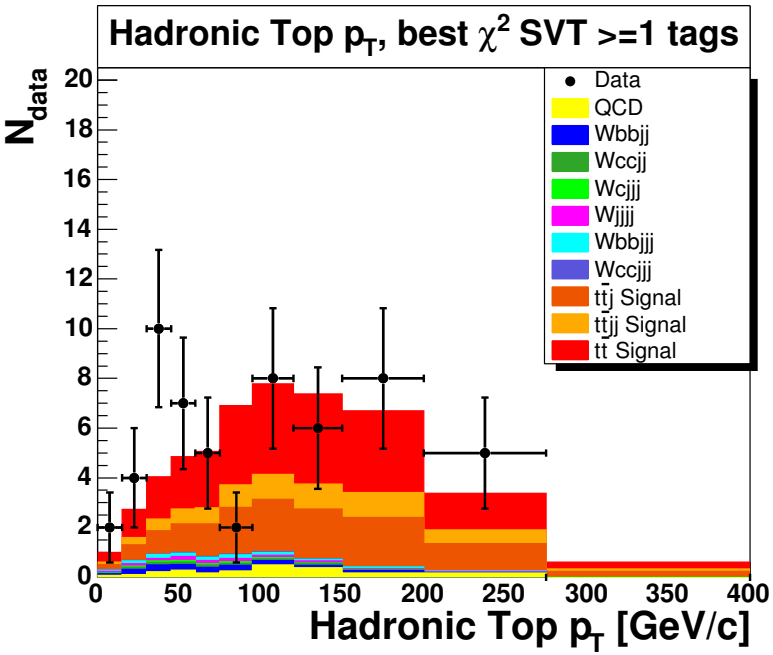
Data – MC Plots I, ≥ 1 Tags, Best χ^2.

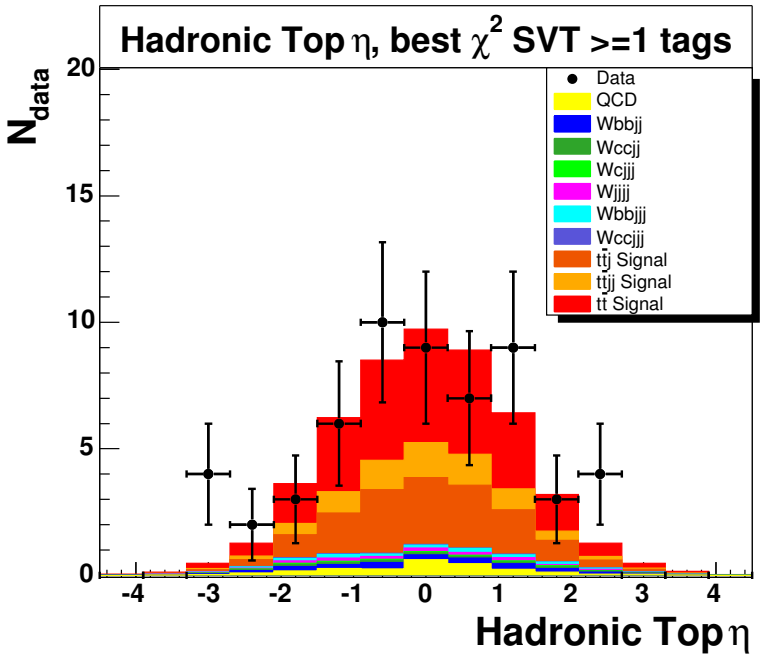




- Plots of $t\bar{t}$ system η and p_T in the combined l+jets channel.
- Variables sensitive mainly to radiation effects.
- Number of events not divided by (variable) bin width.

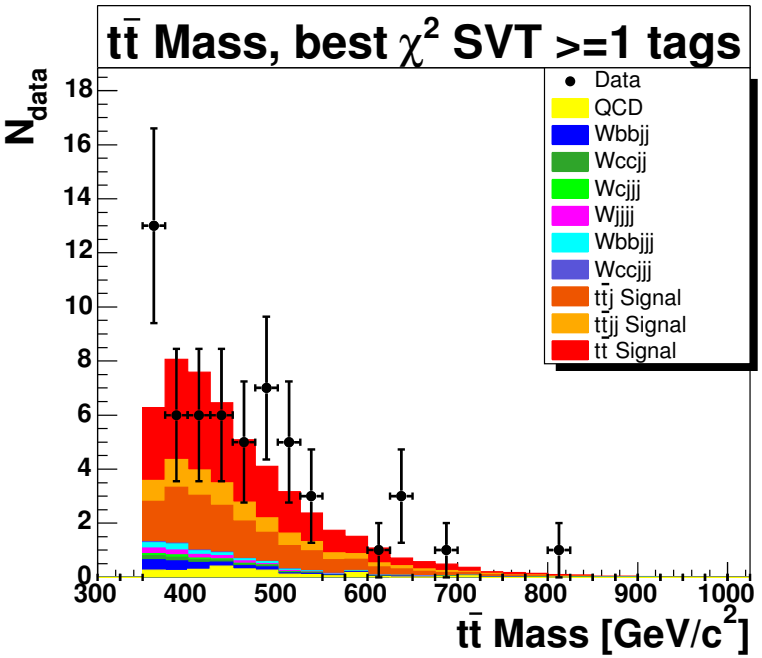
Data – MC Plots II, ≥ 1 Tags, Best χ^2.

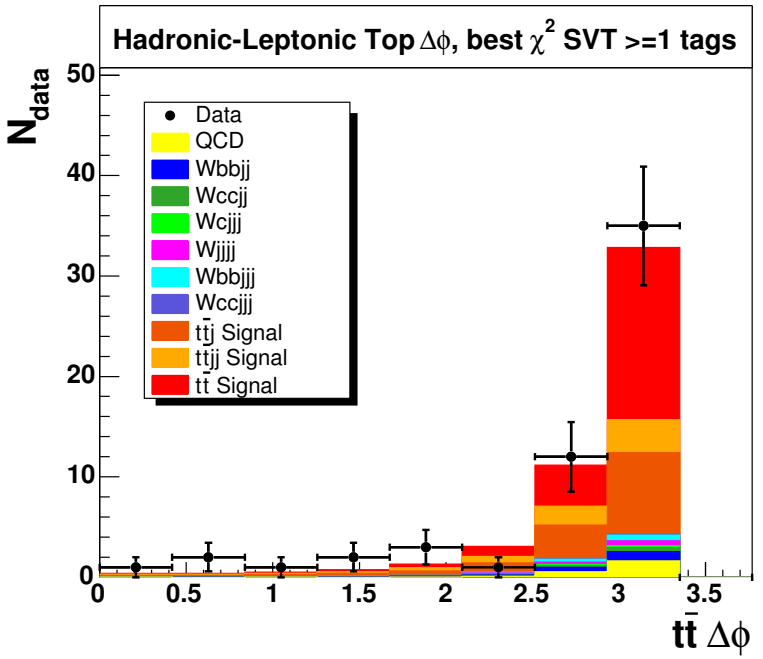




- Plots of hadronic Top p_T and η in the combined l+jets channel.
- High purity $t\bar{t}$ events closely related to any new physics!
- Low p_T behaviour to investigate, new Jet Energy Scale available soon:-)
- Number of events not divided by (variable) bin width.

Data – MC Plots III, ≥ 1 Tags, Best χ^2.





- $t\bar{t}$ system mass is the place to search for new physics.
- $\Delta\phi$ between the two top quarks is sensitive to both hard and soft emissions (at opposite ends of the spectrum) and tests pQCD.

Conclusions

- A preliminary look at various kinematical distributions related to the $t\bar{t}$ system in the tagged $l+$ jets channel.
- Potential to disentagle new physics effects from NLO QCD.
- Further understanding of preselection cuts which shape the phase space is needed to fully aim e.g. the Top p_{T} spectrum measurement.
- More serious techniques to subtract combinatorial background and to perform the unsmearing of the spectrum from detector resolution under development (just after I finish work for Jet Energy Scale:-)
- Reasonable agreement is reached in data – MC plots while MC with additional jets bring useful knowledge of the system kinematics.
- New DØ b-tagging (reaches goals of Tevatron Higgs sensitivity Study:-), new JES.
- With now available 1 fb^{-1} data on tapes, this is an exciting subject to explore with the DØ Run II detector:-)