A BTeV perspective on semileptonic and rare/forbidden decays

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BTeV

Goal: High-statistics study of decays of hadrons containing b and/or c quarks.

Basic idea

- Two-arm spectrometer in C0 region of Tevatron
- Forward coverage (10 mrad $<\theta<$ 300 mrad, 1.9 $<\eta<$ 5.3)

Advantages

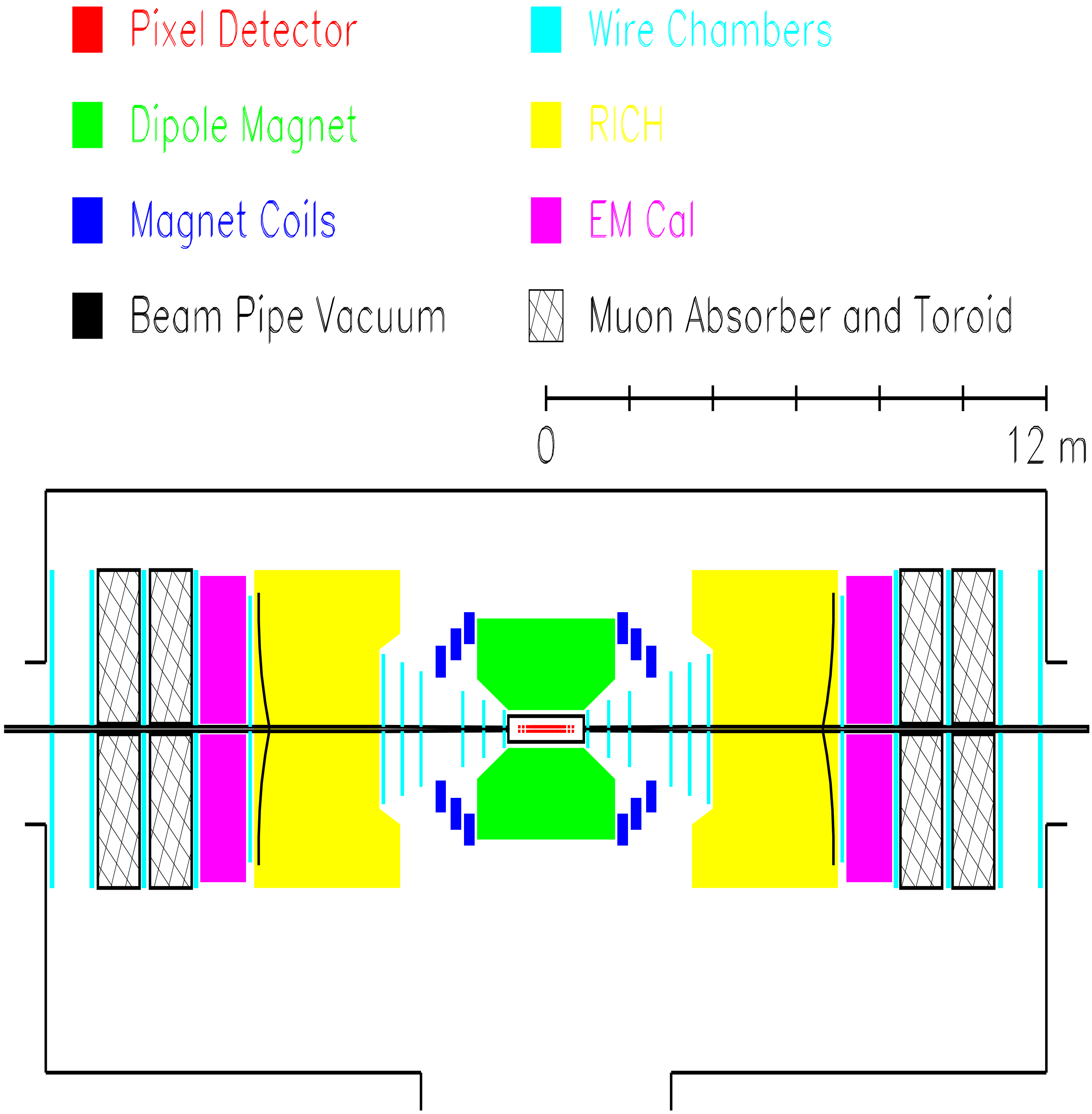
- Forward produced $\Rightarrow$ higher momentum
  - Larger vertex seperation
  - Less multiple Coulomb scattering
  - Better lifetime resolution
  - Better hadronic ($\pi/K/p$) particle ID (can use Čerenkov)
- Both b particles usually in same spectrometer
- Better than e^+e^- because $p\bar{p}$ gives higher cross section and B_s, B_c and b-baryons

Disadvantages

- Beam related background more difficult in forward region
- Less coverage
- Not hermitic
- Worse than e^+e^- because $p\bar{p}$ is dirtier and no beam energy constraint

Spectrometer

BTeV: Horizontal Section at y=0



Spectrometer

1 1.6 T, 3.2 m dipole magnet on interaction region

2 Silicon pixel detectors

- 50 μm $\times$ 400 μm pixels
- 10 cm $\times$ 10 cm transverse with 1.2 cm $\times$ 1.2 cm beam hole
- 31 triplets (or doublets) seperated by 3.2 cm
- 42 million pixels for triplets (analog readout)

3 Forward tracker

- Straw tubes
  - Diameter = 4 mm
  - Resolution $\sim$150 μm / plane $\Rightarrow$ $\delta p/p \sim 0.5\%$–1.0%
  - 7 stations/arm, 3 views/station, 3 planes/view
  - Beam hole = 5 cm $\times$ 5 cm to 24 cm $\times$ 24 cm
  - 78,132 straws, 118,464 channels
- Silicon strip detectors
  - First 3 straw stations have strips in center
  - 2 double-sided (4 views) 100 μm pitch Si strips / station
  - Cover 24 cm $\times$ 24 cm with 5 cm $\times$ 5 cm hole
  - 57,600 channels (binary readout)

4 RICH (Ring Imaging Čerenkov Counter)

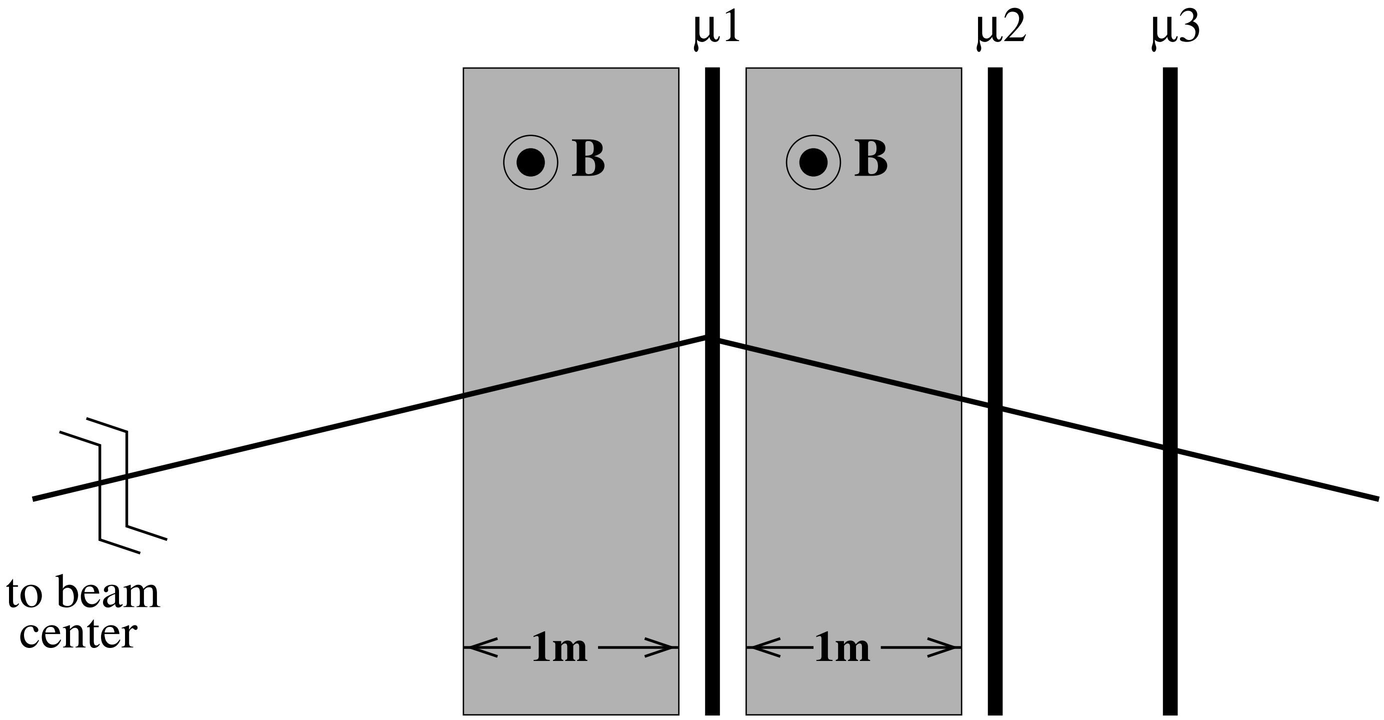
- Would like >4 σ seperation of $\pi/K/p$ from 3 – 70 GeV
- C_4F_{10} gas and aerogel combine to meet this requirement
- 92000 multianode PMTs gives 320,000 channels

5 Calorimeter

- Required to be rad hard and have good resolution
- 10-20,000 $PbWO_4$ $2.47 \times 2.47 \times 22$ cm^3 crystals/arm
- 25 radiation lengths, 1 interaction length
- Resolution $\sim 0.55\% + 1.6\%/\sqrt{E}$ (CMS study)

6 Muon detector

- Required to be rad hard, low occupancy and useable in a Level 1 trigger
- 2 1 m iron filters (magnetized as toroids) per arm – required for sufficient resolution to trigger.
- 1 cm diameter stainless steel tubes with 30 μm gold-plated tungsten wire operating in the proportional region
- 1 cm tubes $\Rightarrow$ low occupancy
- 3 stations per arm (1 between ($\mu1$) and 2 downstream of filters ($\mu2$, $\mu3$)) – momentum from $\mu2/\mu3$ slope – beam spot/bend center slope with confirmation from $\mu1$



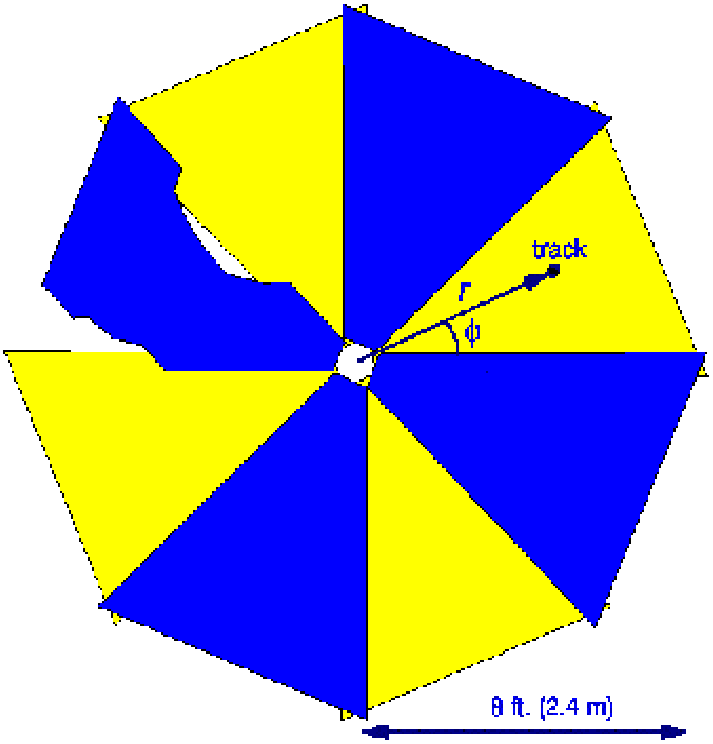
3 views per station ⇒ space-point position, reduced ambiguities

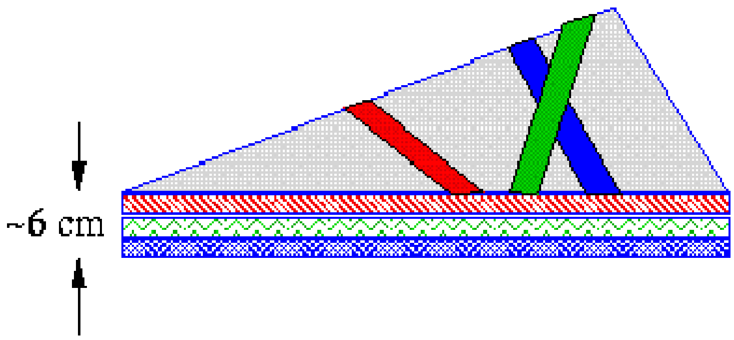
2 layers per view ⇒ redundancy and eliminate gaps

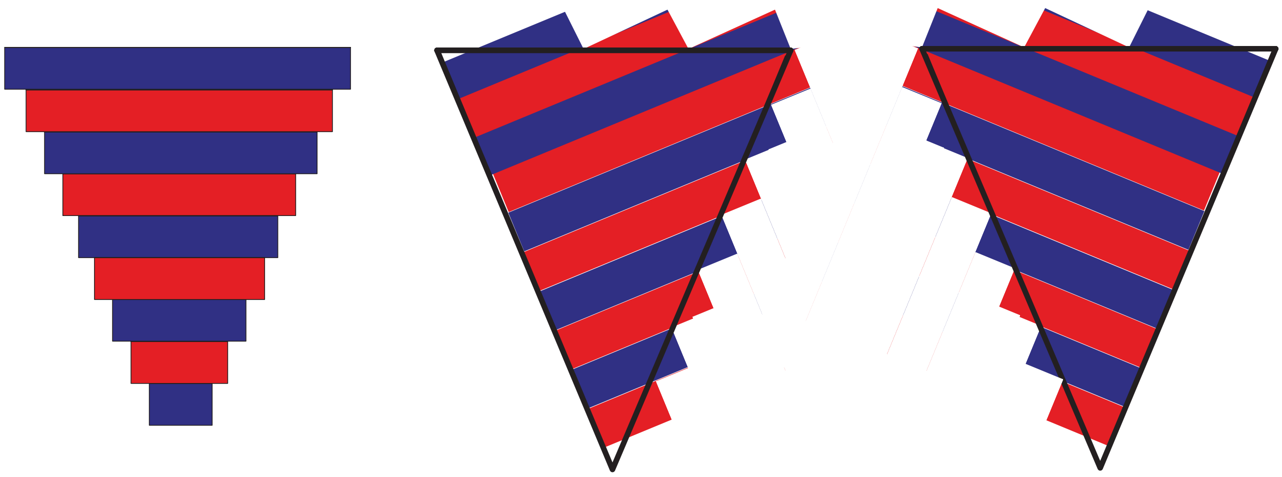
Arranged in octants ⇒ modular, constant occupancy vs r

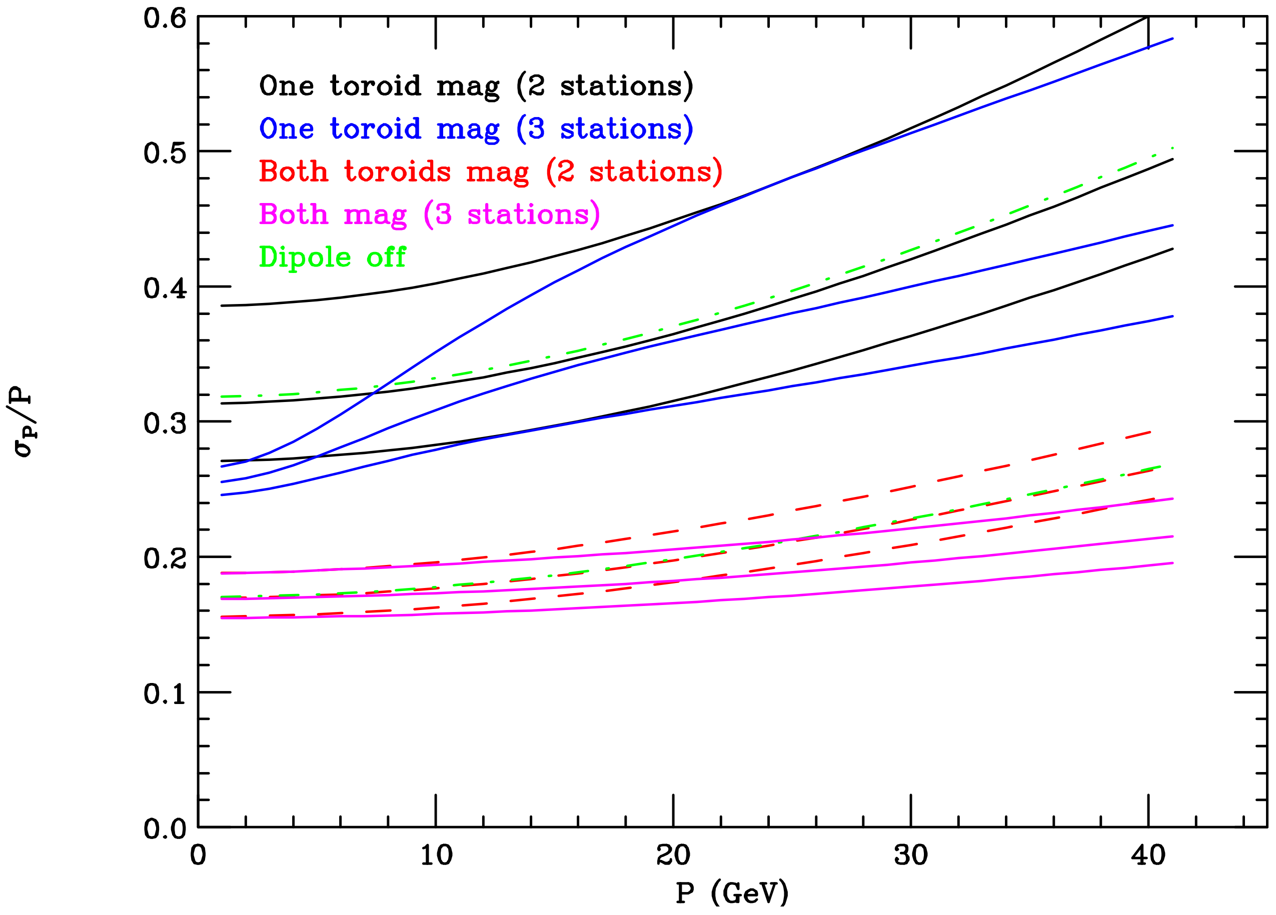
Gas = $Ar/CF_4/CO_2$ (88%/10%/2%) ⇒ fast (90 μm/ns)

35,000 tubes per arm readout with Penn ASD-Q chips (binary), no TDC



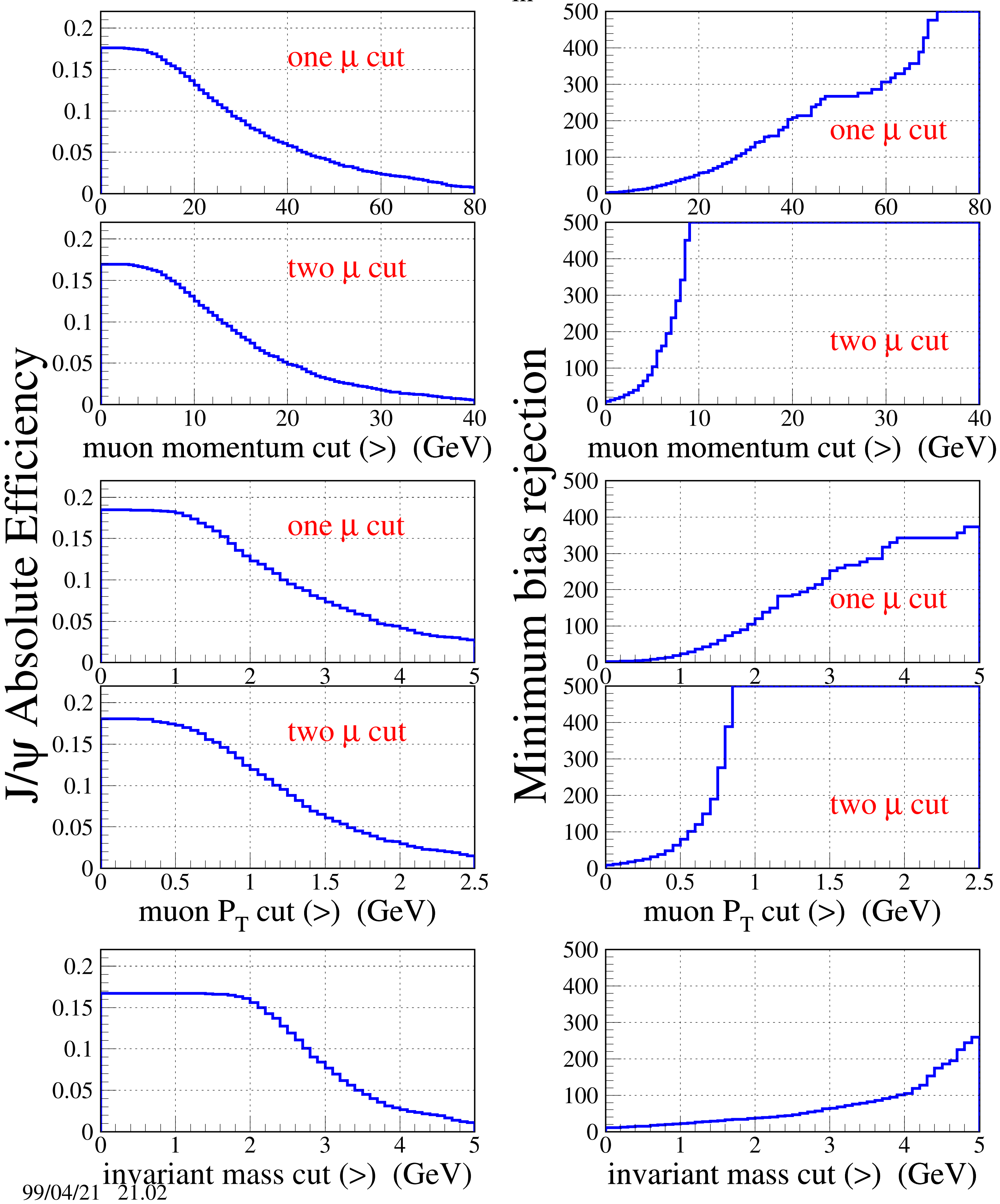




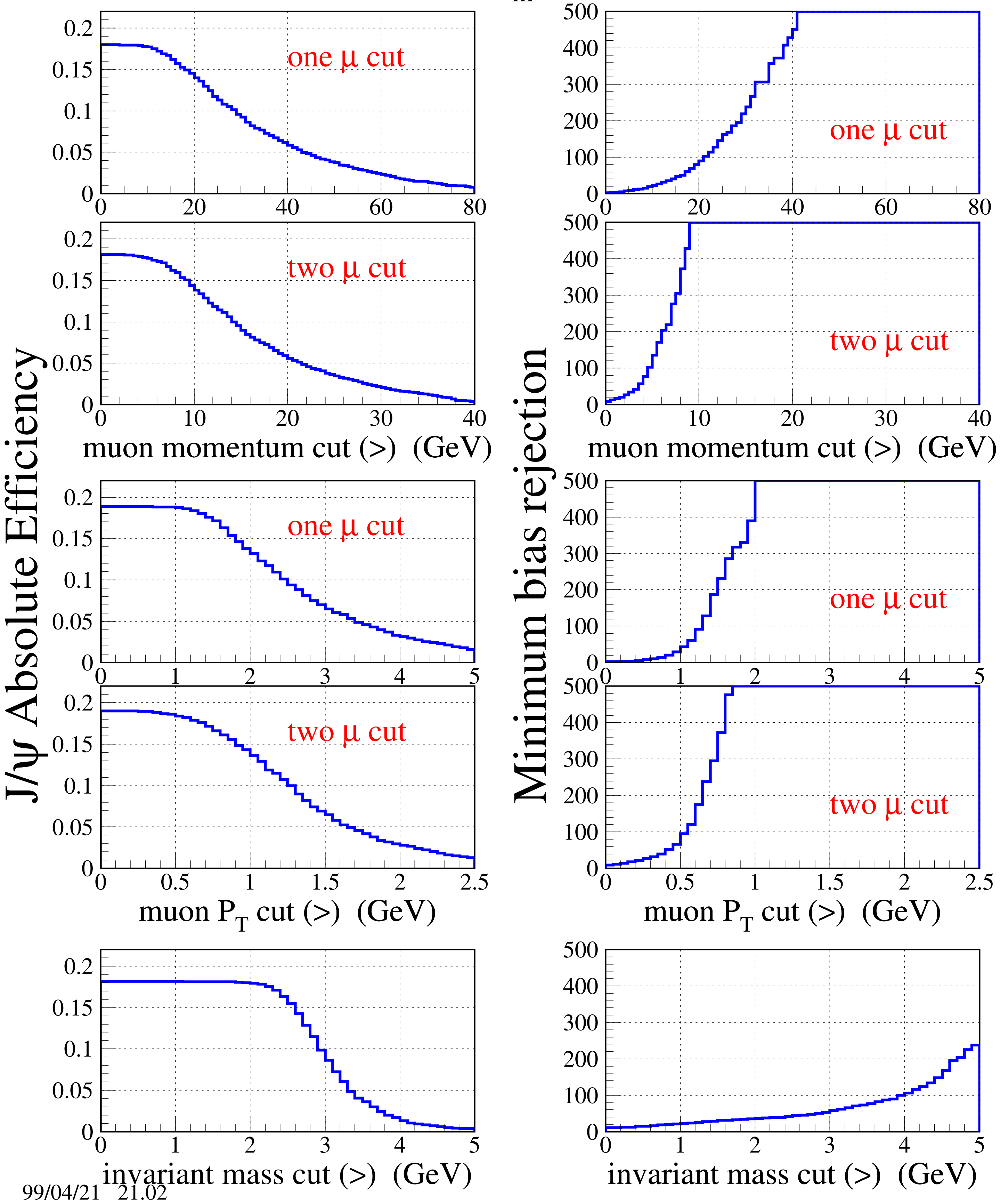


Momentum resolution for 1 and 2 toroids.

Efficiencies and rejections for r_{in}=20cm, 1 toroid muon detector



Efficiencies and rejections for r_{in}=20cm, 2 toroid muon detector



Trigger/DAQ

- Data readout every beam crossing (132 ns)
- Buffered until Level 1 is finished
- Level 1
  - Must provide $>$100:1 rejection of min bias
  - Should be $\gtrsim$ 50% efficient
  - Vertex trigger
  - Dimuon trigger
  - Combination loose vertex and high-p_T muon trigger?
  - Electron triggers?
- Level 2 and 3 triggers reconstruct more data and offer more refined triggers (rejection = 5-10 each)
- Full reconstruction at end of Level 3
- Write out 50 kB DST at $\sim$3 kHz
- Store 800 TB/year @ L=2$\times$10^{32}

Monte Carlo status

- PYTHIA generator and MCFAST detector simulation
- Other generators and GEANT simulation possible
- Detector resolution, secondary interactions, conversions, MCS included
- e (μ) ID is simply calorimeter (muon detector) acceptance
- Background from light quark physics interaction (min bias)
- No background from beam effects (scraping)
- No hadronic punch-through to muon detectors
- No random noise implemented except in pixels

Monte Carlo studies

$B^- \to K^-\mu^+\mu^-$ (SM BR = $4.0 \pm 1.5 \times 10^{-7}$)

- Cuts applied
  - Good vertices
  - K: p>4 GeV, RICH ID
  - μ: p>5 GeV, μ ID
  - L/$\sigma_L > 7$
  - B point back to primary < 2.5 σ
- Obtain $\sim$ 2.5% efficiency
- Trigger efficiency $\sim$ 80% (dimuon), 50% (vertex)
- Backgrounds from any combination of π/K decays/punchthrough, B semileptonic decay(s), charm semileptonic decay(s).
- Assume 2 B semileptonic decays is primary background
- 1 event out of 10^5 survives (need more statistics)
- With SM BR $\Rightarrow$ S/B = 1/3

No semileptonic studies have been done.

Discussion of modes

- Semileptonic decays
  - $B \to X\ell\nu$
    - ∗ Seems easiest at e^+e^- machines with cleaner environment and beam energy constraint for missing ν
    - ∗ No studies done for BTeV yet
  - $B_s, B_c, \Lambda_b \to X\ell\nu$
    - ∗ Not possible at e^+e^- machines, only Tevatron (until LHC)
    - ∗ No studies done for BTeV yet
- Rare/Forbidden decays
  - b-hadron $\to X\ell\ell, \ell\ell$
    - ∗ Better stats than e^+e^- colliders
    - ∗ Two leptons, fully reconstructed $\Rightarrow$ "easy"
    - ∗ Can search for new physics

My (and BTeV's?) Goal

Accurate estimate of signal and background for various rare and semileptonic decays

Requirements to achieve the above

- Better particle ID simulation (including pattern recognition and efficiency)
- More accurate backgrounds (including hadronic punch-through and beam spray)
- A "real" analysis of the semileptonic modes (including reconstructing the ν momentum, investigating our q^2 resolution and obtaining form factors)
- Lots of computer time to run the signal and background simulations
- An investigation of triggers to allow an efficient collection of these decays