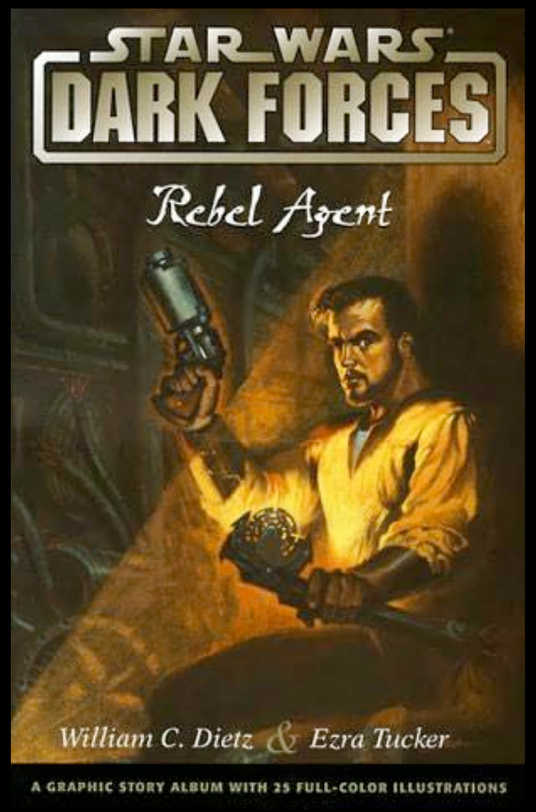
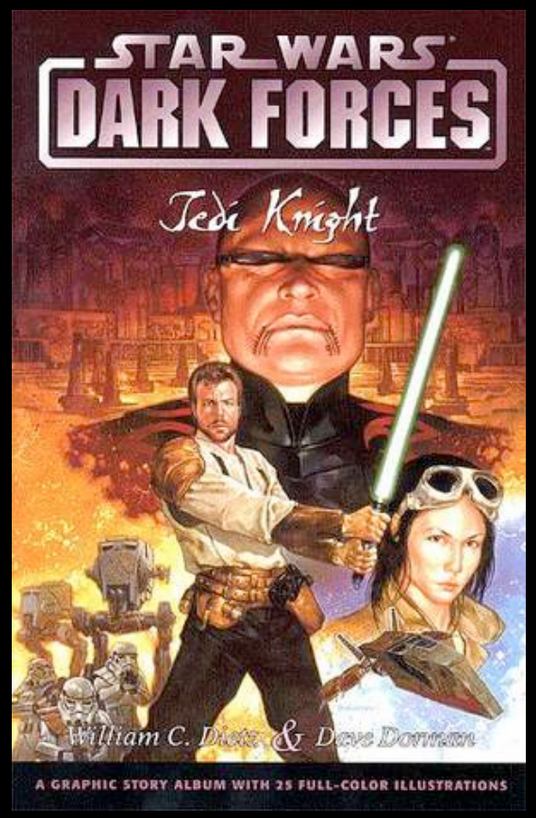
Search Strategies for Multilepton Jets at the Tevatron

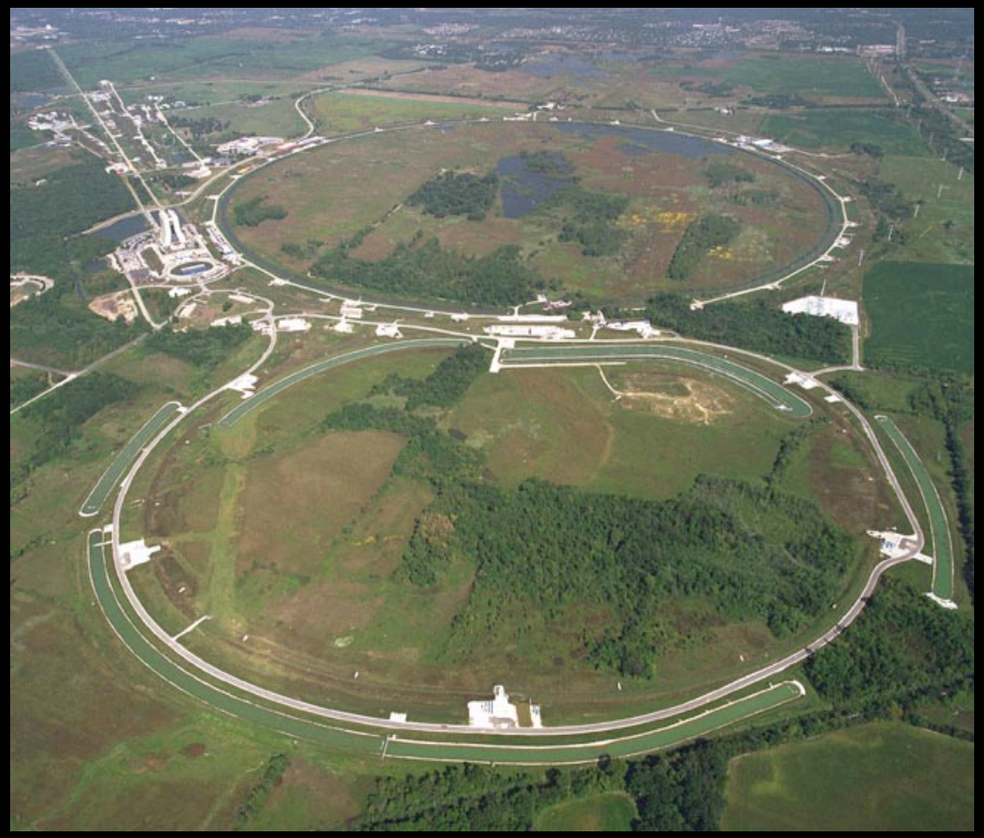


Chris Hays, Oxford University

SLAC, 26 September 2009



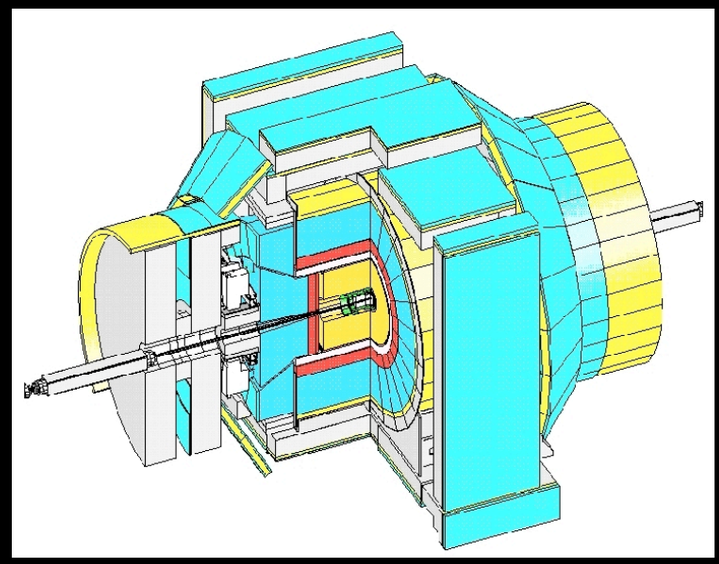
Lepton Jets at the Tevatron

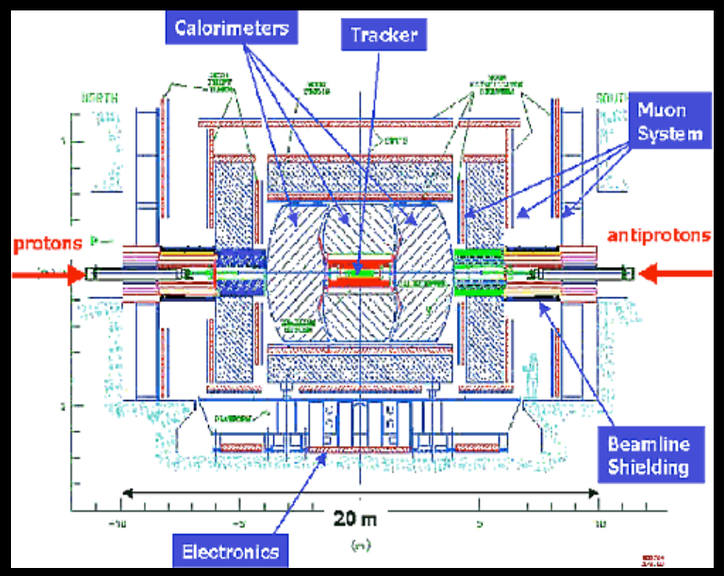


Fermilab Tevatron in Batavia, Illinois

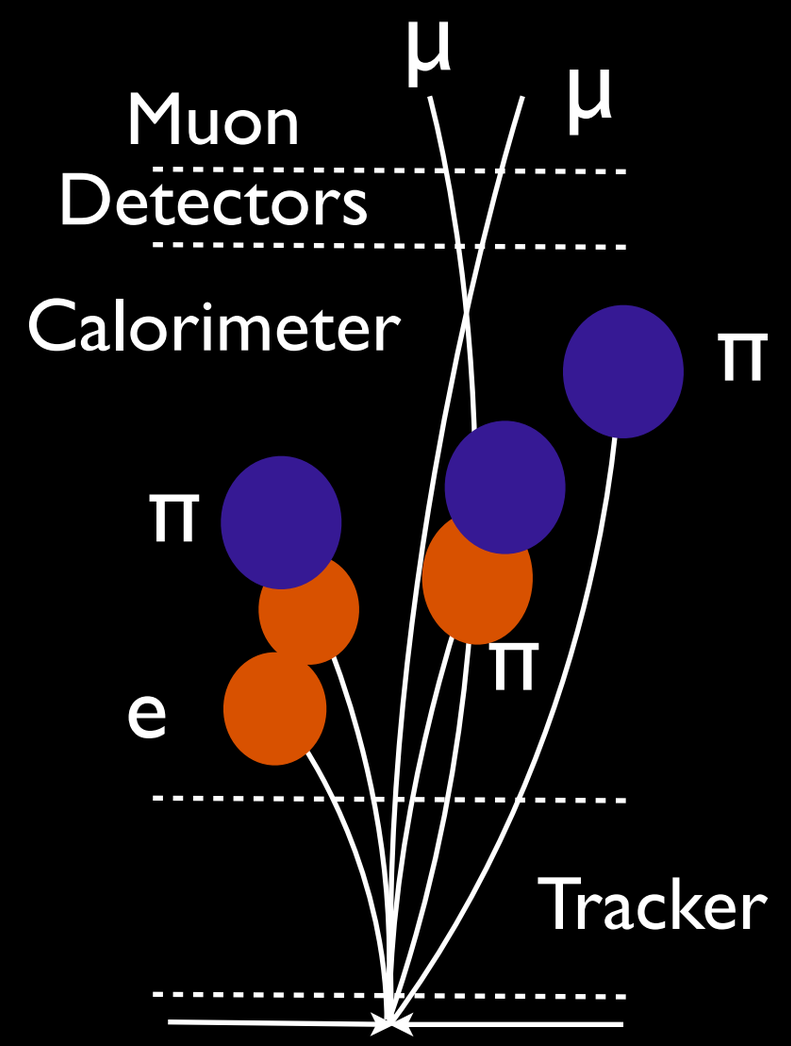
$\sqrt{s}$ = 1.96 TeV $p\bar{p}$ collisions

CDF Detector





DØ Detector

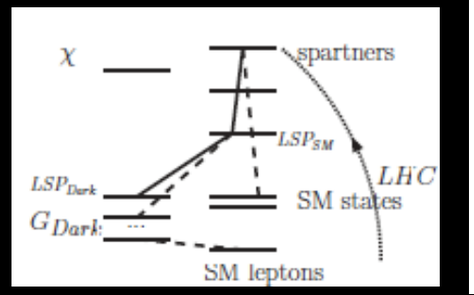


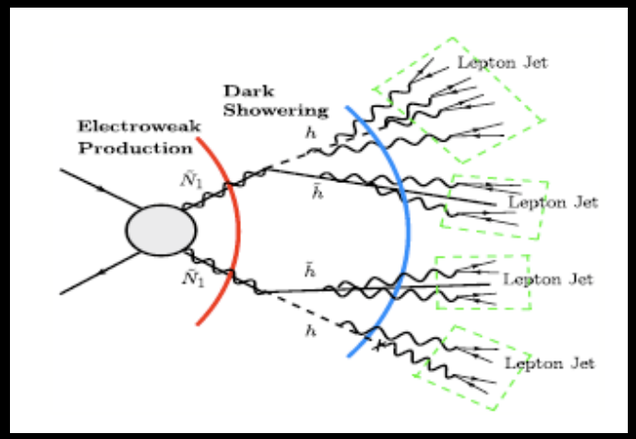
Lepton Jet

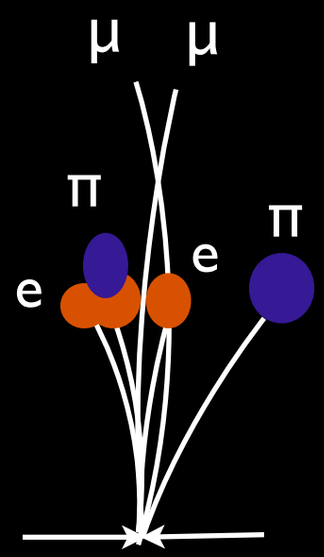
≥2 collinear leptons

Sources of Lepton Jets

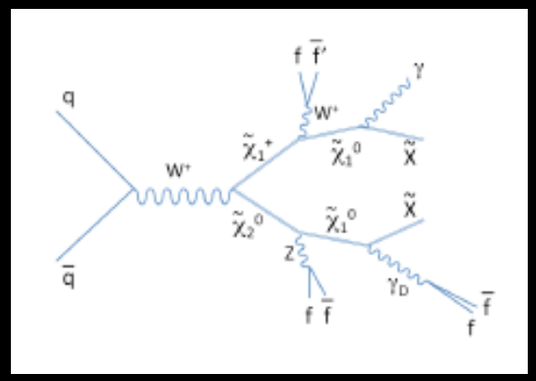
- New physics
  - Dark particles

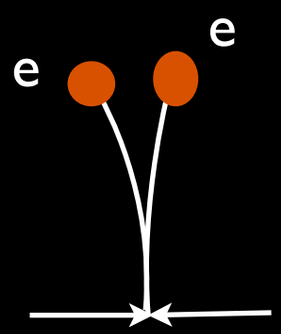




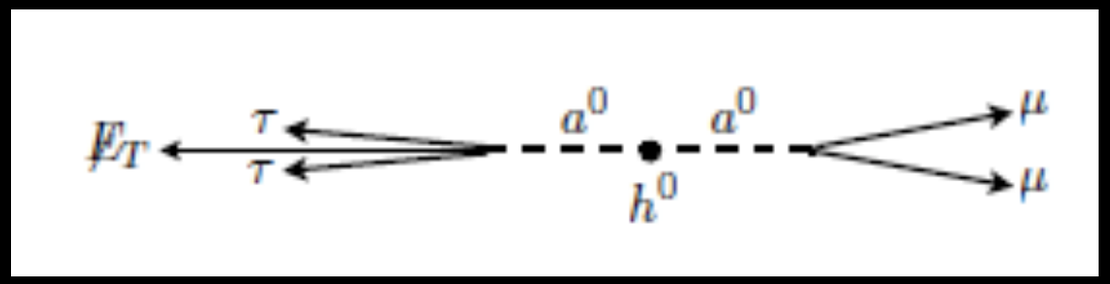


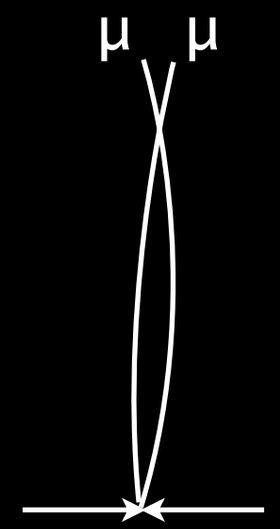
  - Dark photons





- Higgs decay to pseudoscalars

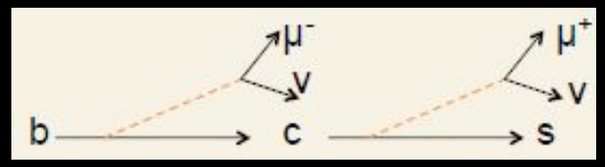




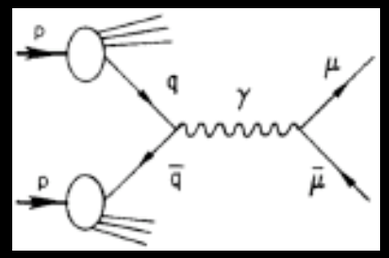
- Anything with high mass decaying through a low-mass state

Sources of Lepton Jets

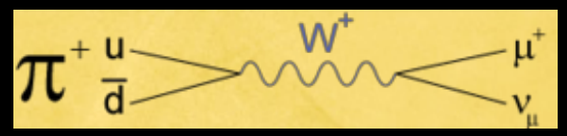
- Standard model
  - Sequential B-hadron decays

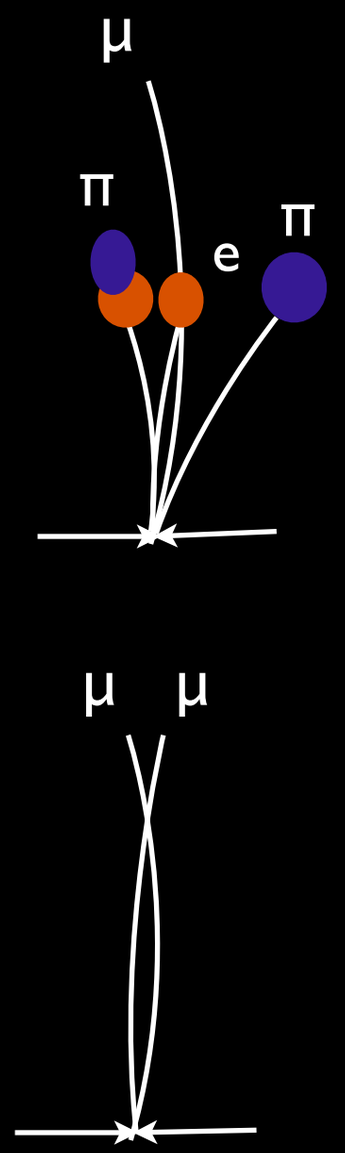


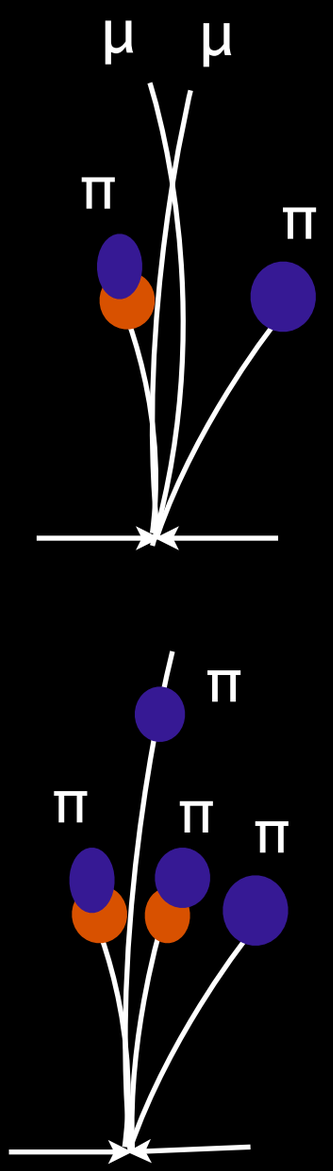
  - Light hadron resonance decays
  - Drell-Yan



  - Hadron punch-through
  - Any combination of sail-through or π, K, B, D, W, Z decays

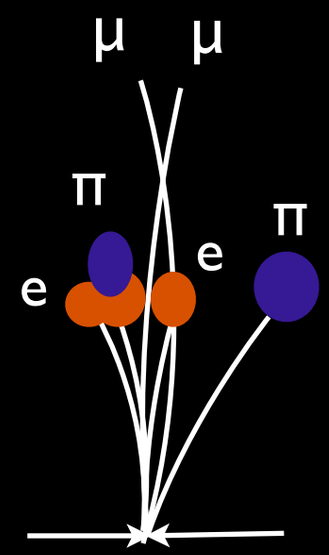


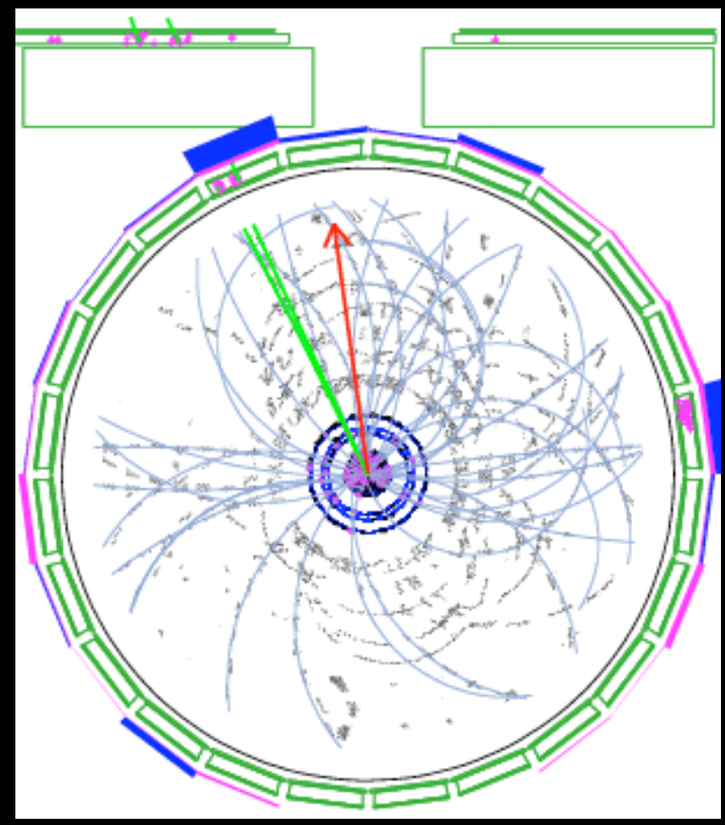




Searching for Lepton Jets

- Signatures
  - Electrons, muons, hadrons?
- Trigger
  - Two low-p_T or one high-p_T electron or muon
- Identification
  - Tracker, calorimeter, muon system
- Backgrounds
  - Data- and MC-based estimates
- Optimization
  - Maximizing sensitivity and believing an excess





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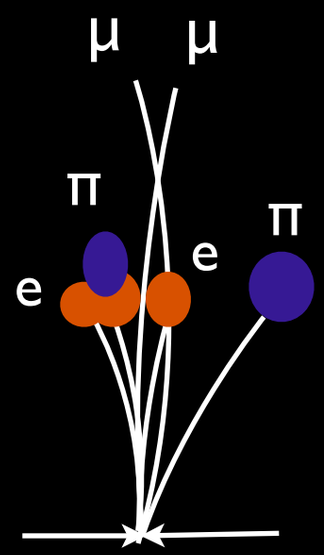
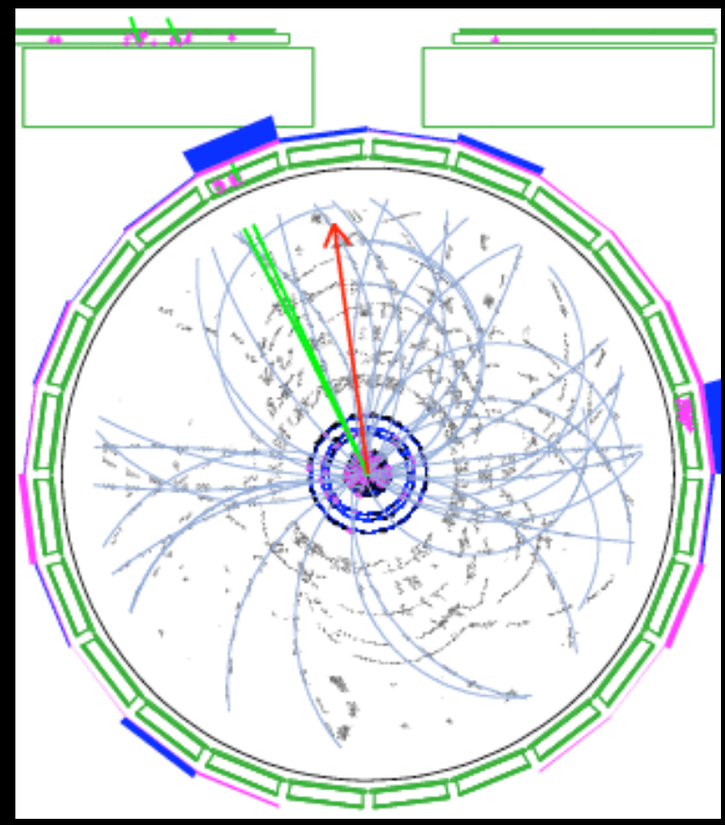
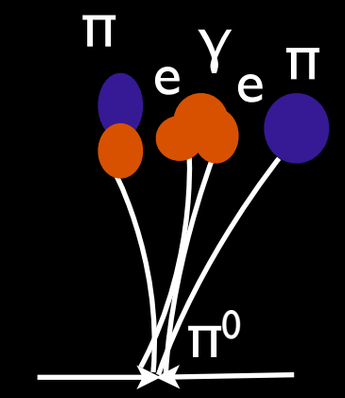


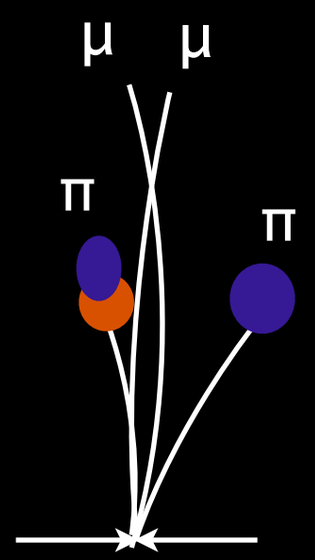


Signatures

- Multielectrons
  - Challenge to distinguish from $\pi \rightarrow \gamma\gamma$ background
    - Conversions produce electron pairs



- Multielectrons and multimuons
  - $\pi \rightarrow \gamma\gamma$ background again an issue
    - Allowing additional hadrons affects identification and measurement



- Multimuons
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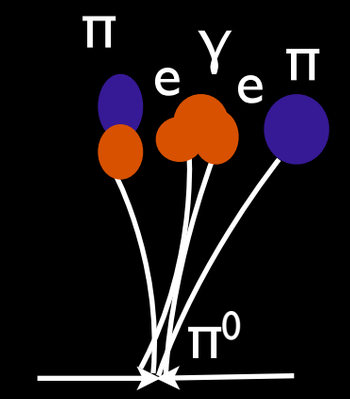

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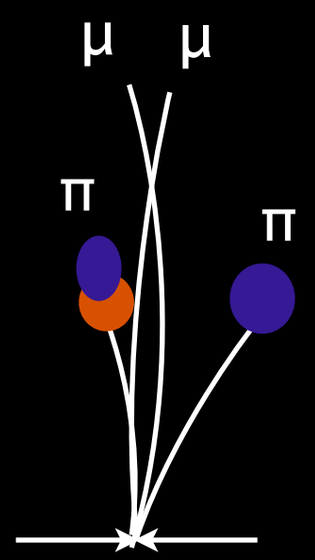

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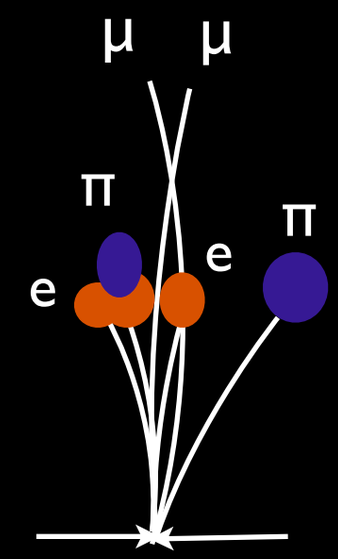
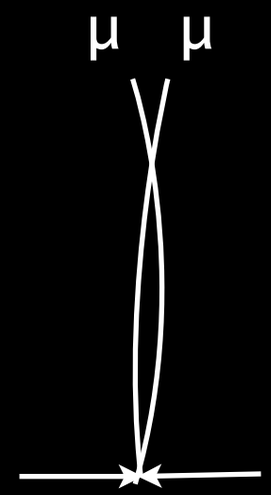
Signatures

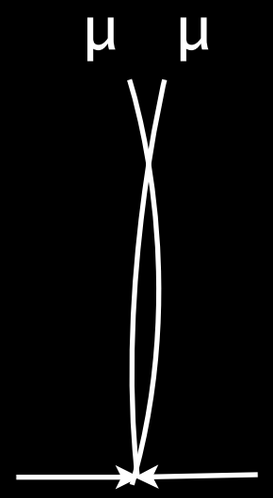
- Inclusive multimuons
  - Generic search sensitive to any source of lepton jets
    - Understand all sources of background



- Inclusive isolated multimuons
  - Focus on lepton-only jets
    - Significantly reduce hadronic background



- Isolated multimuons + lepton or photon
  - Significantly reduce all backgrounds
    - More model specific



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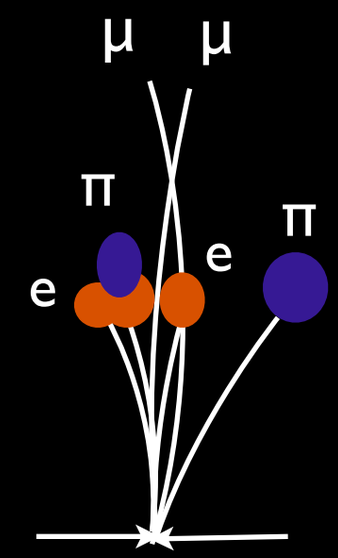

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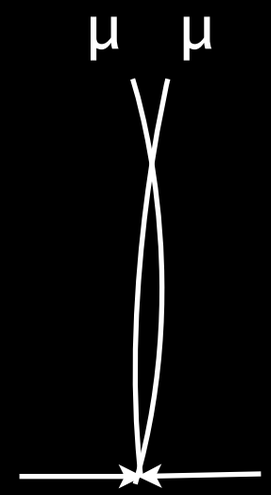

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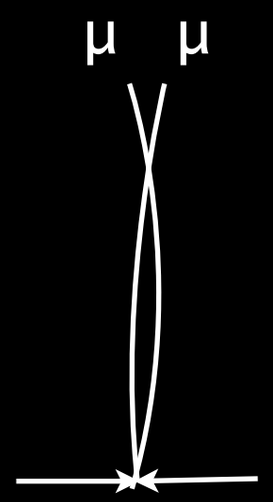

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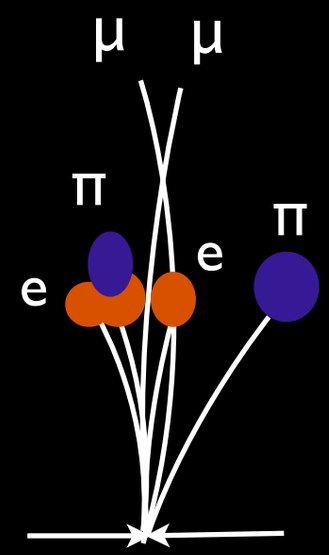

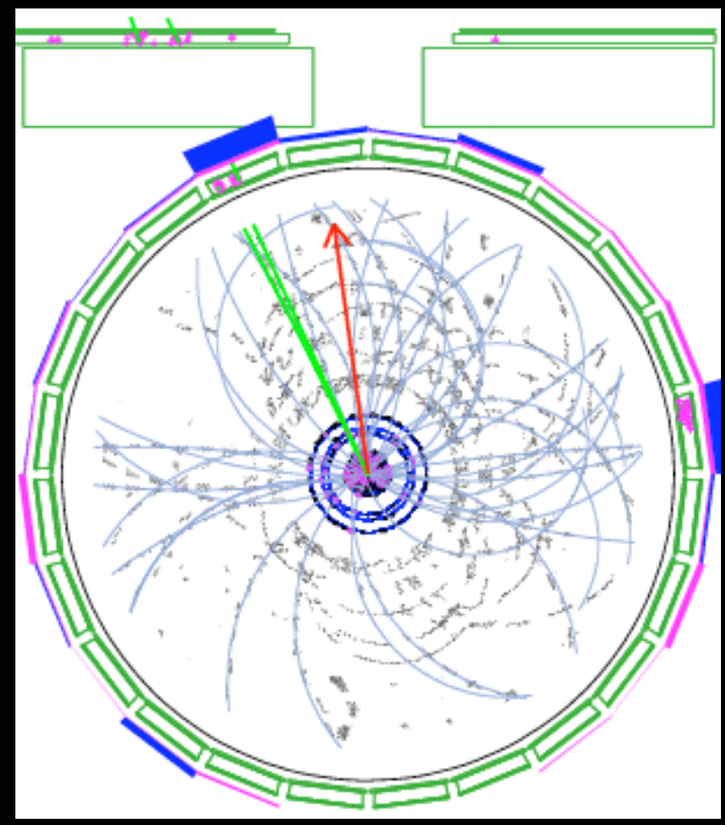

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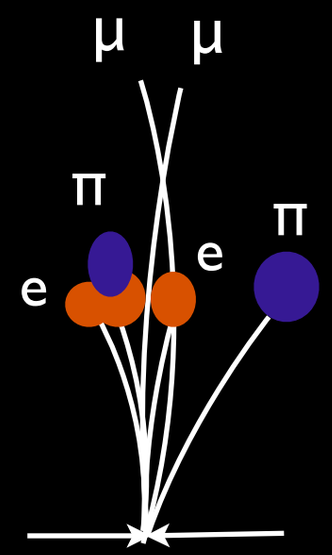

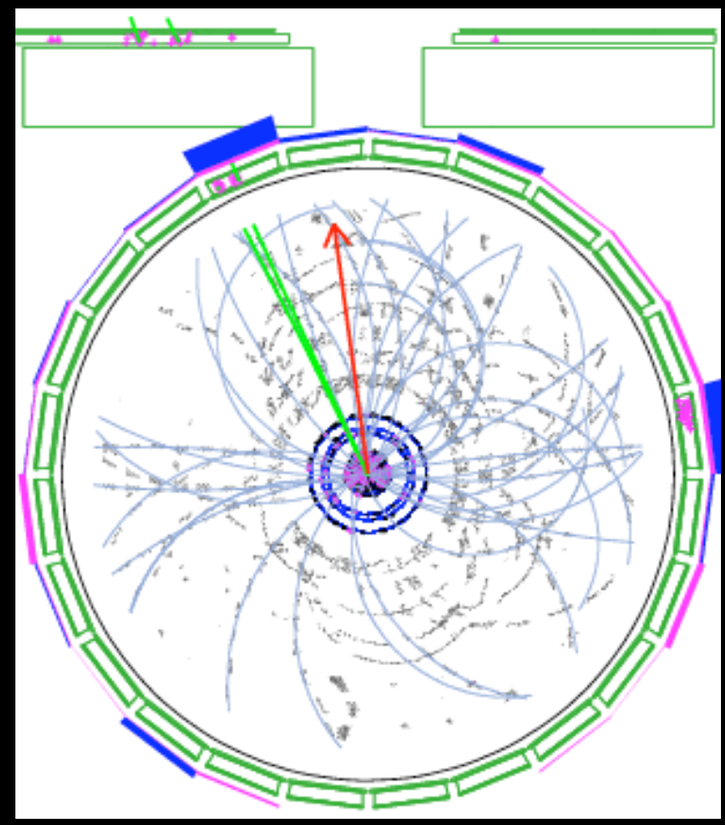

Trigger

- High-p_T single muon trigger:
  - p_T > 18 GeV in the trigger at CDF
  - Maximizes geometric acceptance; reduces kinematic acceptance
- Mid-p_T dimuon trigger:
  - Increases kinematic acceptance (p_T > 8, 4 GeV at CDF)
  - Need to understand correlated trigger efficiencies
- Low-p_T dimuon trigger:
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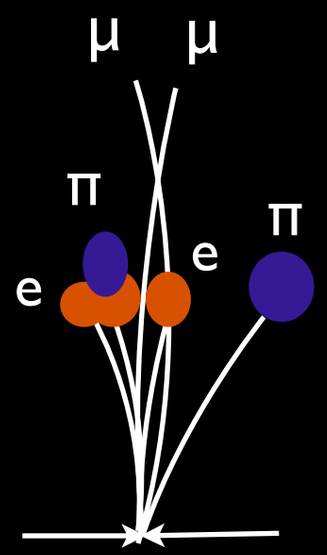

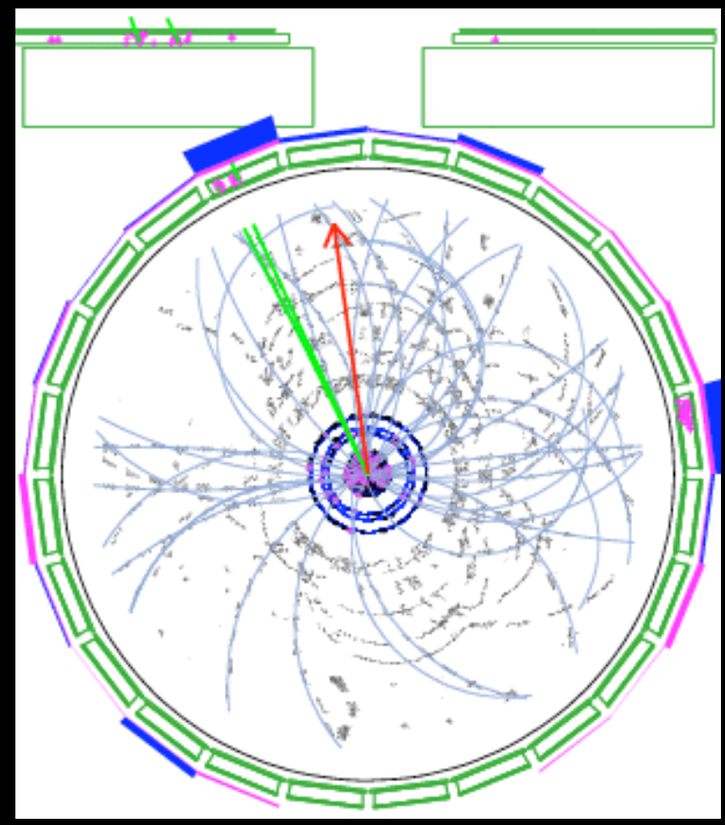

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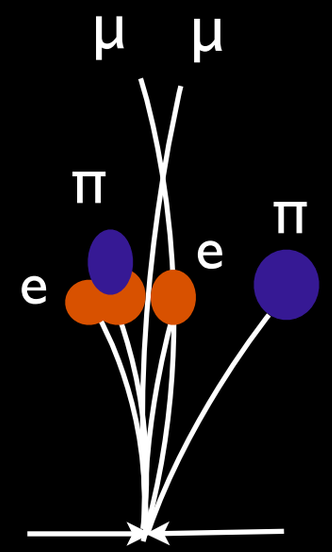
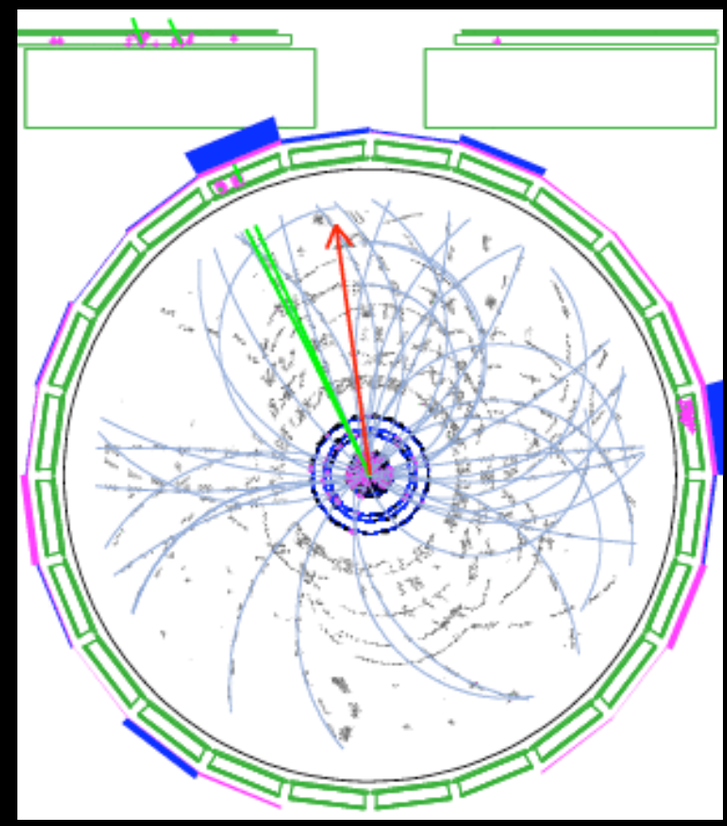
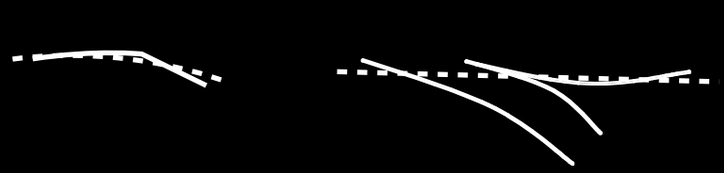
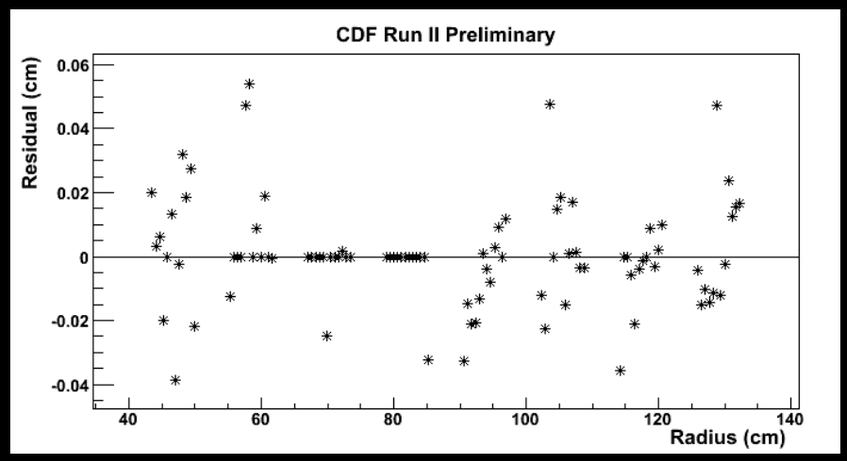




Tracker Identification

- Generic tools
  - Hit usage and track quality requirements
    - Silicon hit requirement reduces sensitivity to long-lived sources ($c\tau$ > 1 cm)
  - Hit pattern requirements
    - Identify and remove kinks from π/K decays in flight





- CDF-specific
  - Silicon detector covers r < 40 cm, outer tracker 40 - 140 cm
    - No bias from outer-tracker hit requirements for $c\tau$ < 40 cm
  - Good track reconstruction in jet environment
    - Minimal bias from a χ^2 requirement

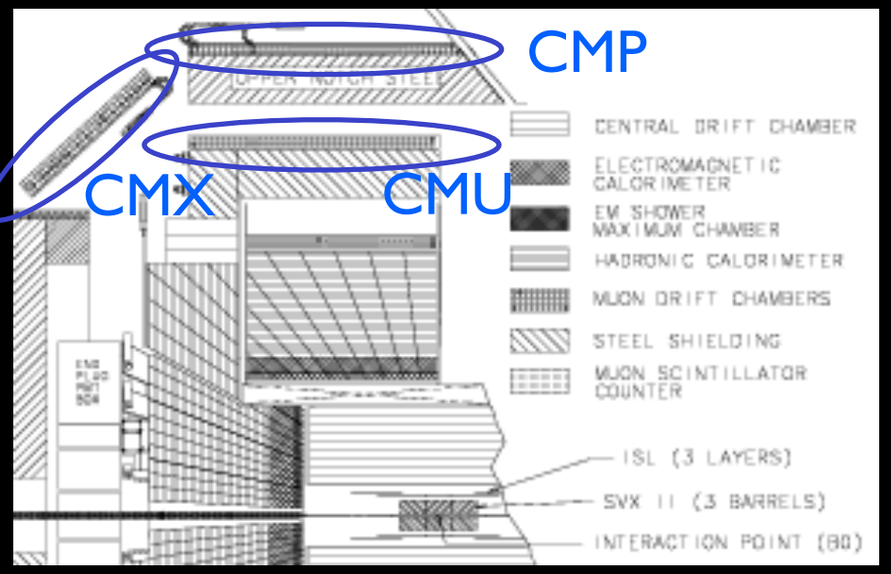
Calorimeter Identification

- General issues
  - Standard muon identification removes surrounding hadrons
    - Traversed towers consistent with minimum ionizing particle (upper energy cutoff)
    - No significant energy deposition in surrounding towers (can also use tracks)
    - Generic search should allow hadrons in jet

- CDF-specific
  - Little longitudinal segmentation to identify punch-through
  - Requirements would be hard to model for signal with hadrons
  - Ideally make no calorimeter requirements

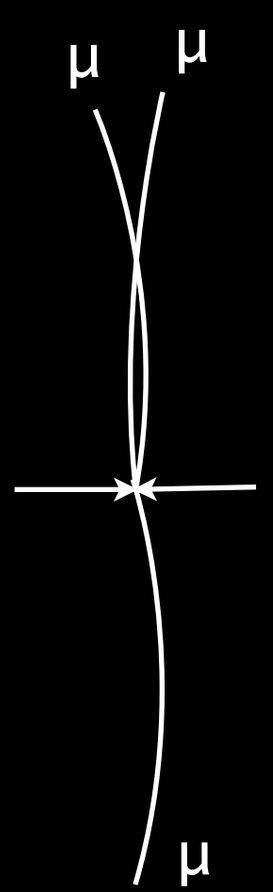
Muon Identification

- General issues
  - Muon system focus of muon-jet identification
    - Quality of muon track
    - Quality of match to inner detector track
  - Least potential for bias in separating muons from hadrons
- CDF-specific
  - Good rϕ, modest z matching quality
    - Multiple scattering weakens requirement at low p_T
  - CMP significantly reduces punch-through (covers $|\eta| < 0.6$)
    - Range-out affects muons with $p_T \lesssim 3$ GeV



Low-p_T Multimuon Search

- CDF muon-jet identification
  - Tracker:
    - Default COT reconstruction requirements (4 of 8 superlayers with 5 of 12 hits)
    - Default silicon reconstruction (hits added if in search road)
  - Muon system:
    - Two trigger muons (p_T > 3 GeV)
    - Additional muon p_T > 2 GeV within cosθ < 0.8 cone of a trigger muon
    - Require CMU, CMP, or CMX stub for all muon candidates
    - Default rϕ matching to track (CMU: 30 cm, CMP: 40 cm, CMX: 30 cm)



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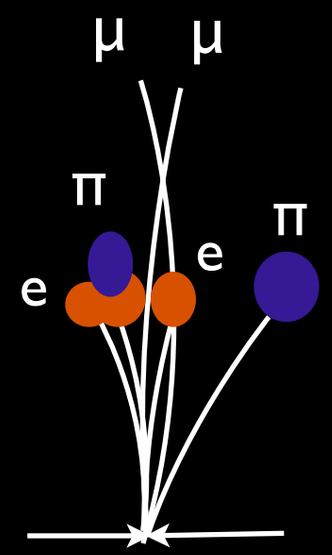
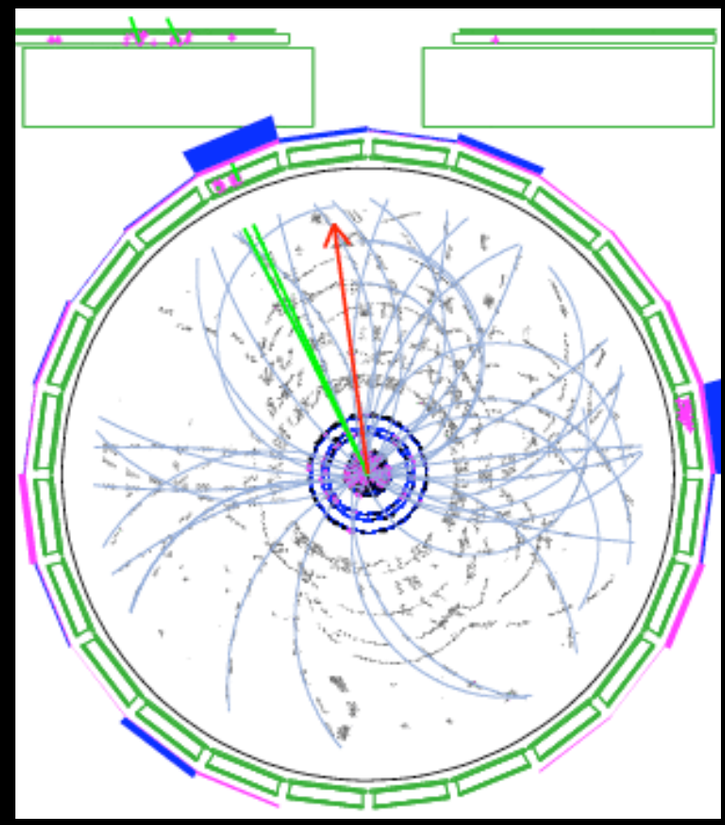
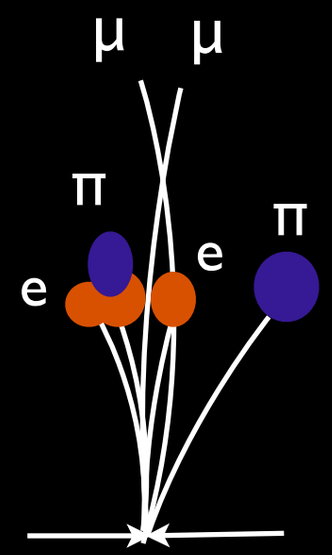
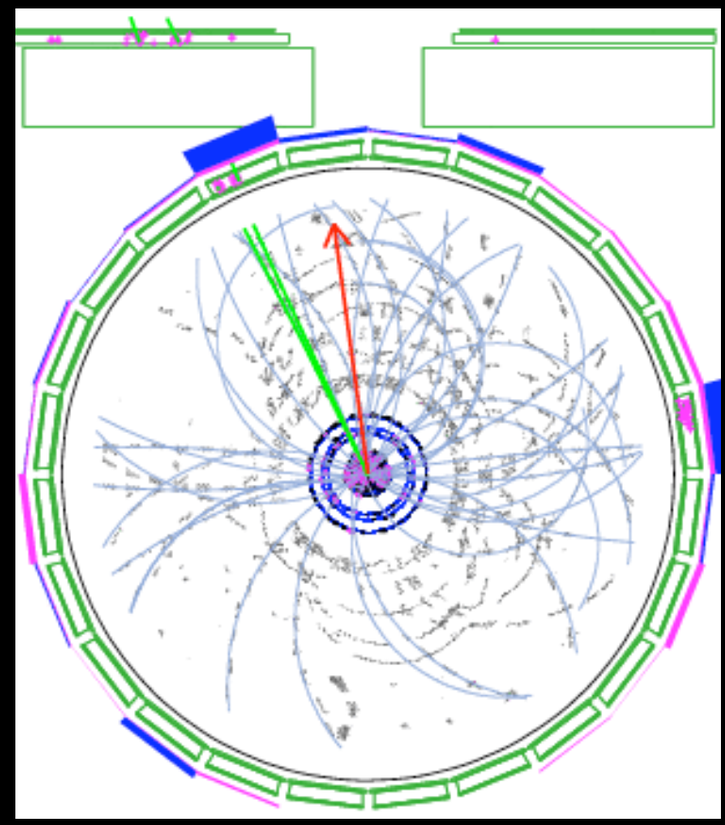




Searching for Lepton Jets

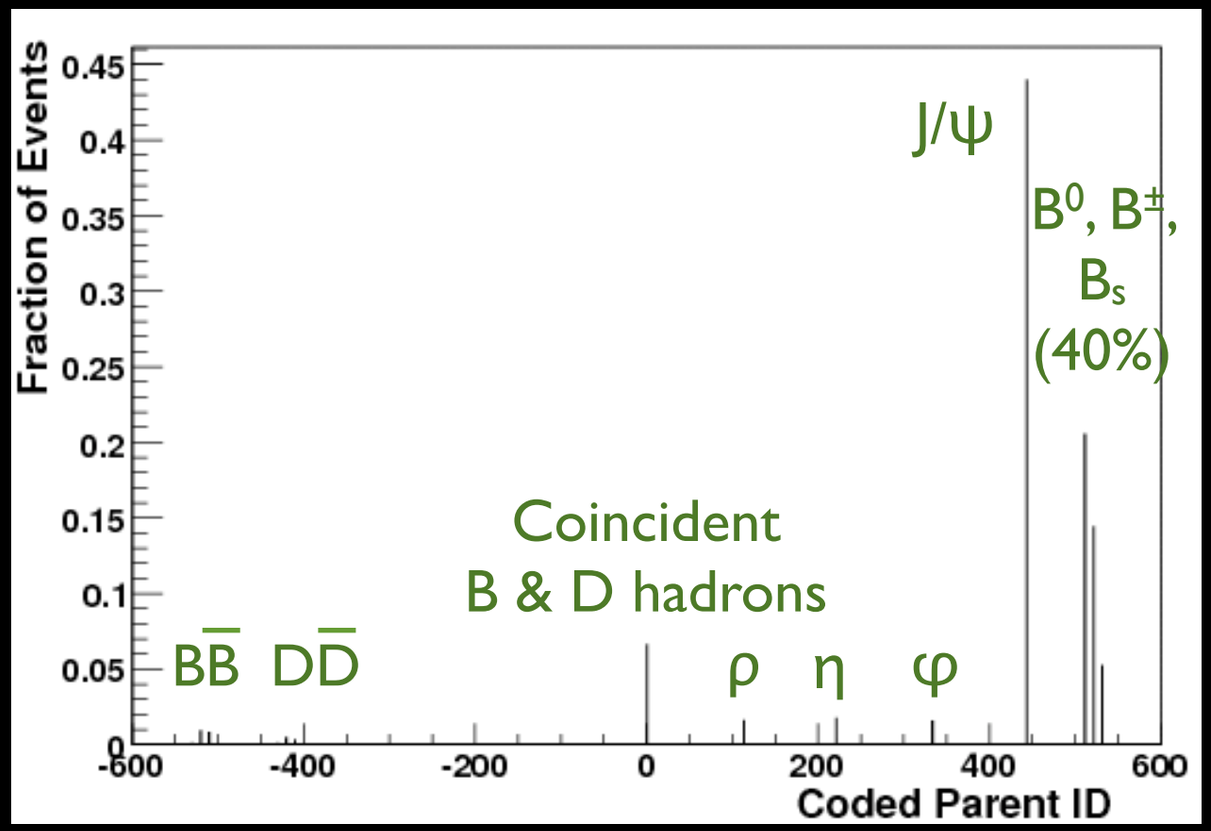
- Signatures
  - Inclusive multimuons
- Trigger
  - Two low-p_T or one high-p_T muon
- Identification
  - Tracker and muon system
- Backgrounds
  - Data- and MC-based estimates
- Optimization
  - Maximizing sensitivity and believing an excess





High-p_T Muon Backgrounds

- Heavy flavor sequential decays & hadron decays to dimuons
  - Can model with PYTHIA inclusive jet production ($p_T \gtrsim 15$ GeV)
    - Includes gluon splitting to heavy flavor
  - Ideally normalize with reconstructed B-hadrons
    - More statistics with J/ψ but direct color-octet production difficult to predict

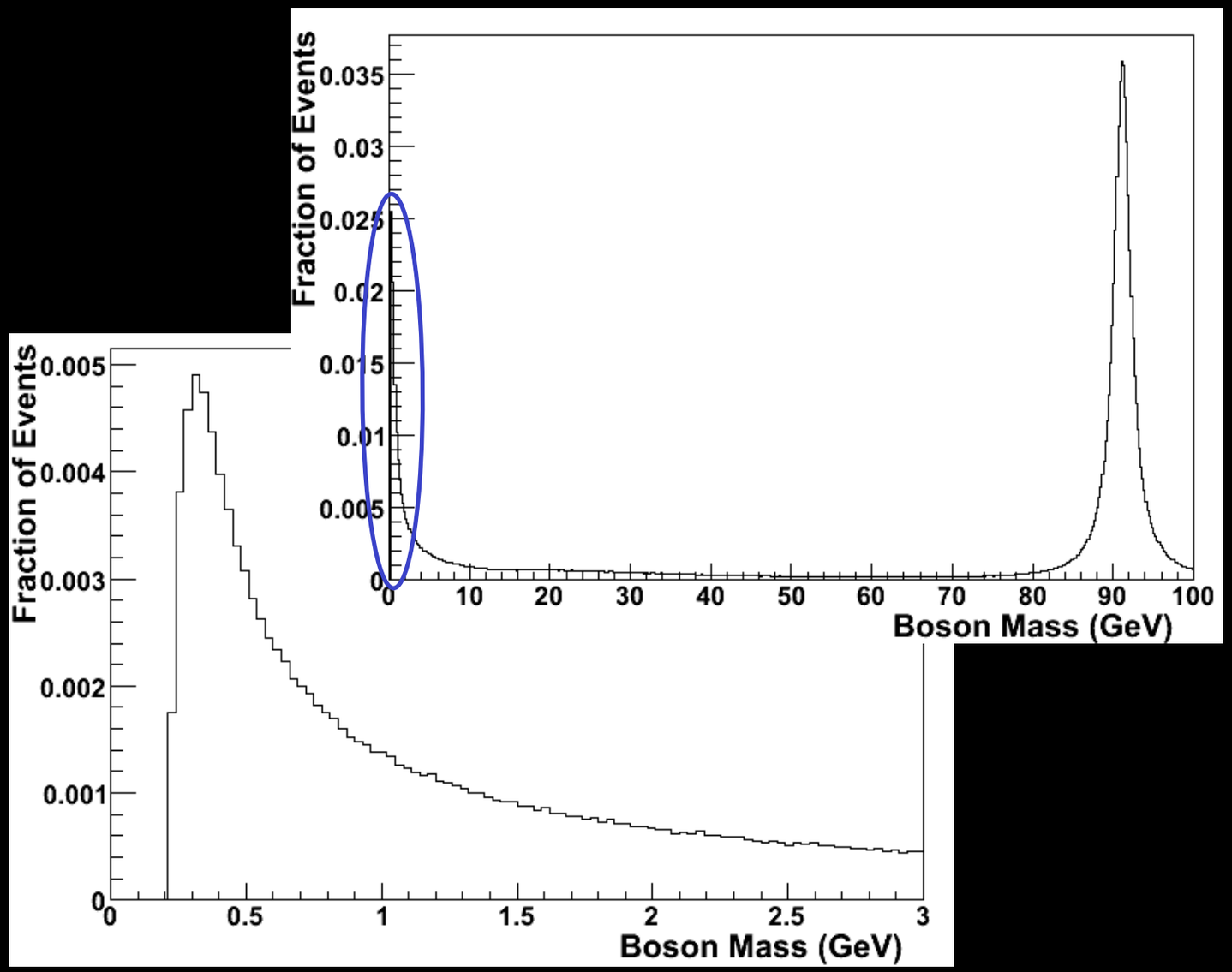


PYTHIA sources of dimuons with $p_T > 20$ GeV and 3 GeV within ΔR cone of 0.5

QCD processes with $p_T > 13$ GeV

High-p_T Muon Backgrounds

- Drell-Yan
  - Can model with PYTHIA
  - Normalize using Z boson production



PYTHIA Drell-Yan production of dimuons with p_T > 20 GeV and 3 GeV

High-p_T Muon Backgrounds

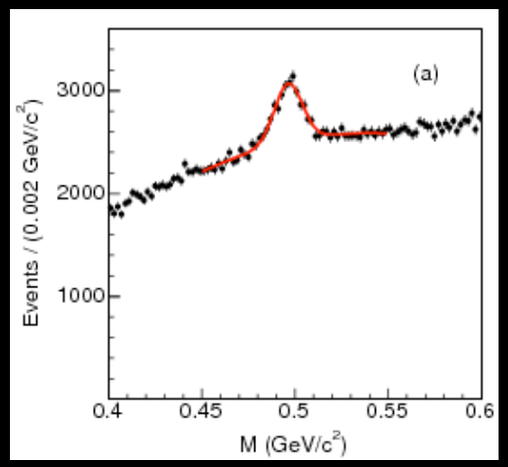
- Coincident muons from hadron / gauge-boson decays
  - Can make tight requirements on a high-p_T muon
  - Then apply a data-based 'fake' rate to the low-p_T muon
    - Assumes source of two muons is uncorrelated
    - Can extract fake rate from a trigger without muon requirement (jet, track, collision)

- Correlated muon candidates from punch-through hadrons
  - Most pernicious background
    - Do not expect accurate prediction from detector simulation
    - Data-based rates could be contaminated by signal
    - Can study using reconstructed hadron resonances

Low-p_T Muon Backgrounds

- Heavy-flavor decays, Drell-Yan, π/K decays and punch-through
  - Estimated in a cross-section measurement
    - MC prediction: Heavy-flavor, Drell-Yan
    - Data prediction (D→Kπ): light hadron sources (30%)
  - Measurement consistent with theory (data/theory = 1.20 ± 0.21)
    - Makes tight silicon track requirements
  - Search extrapolates to no-Si tracks using measured efficiencies
    - MC-based correction for K/π decays to muons
    - Data study of K→ππ punch-through to estimate rate of additional muon candidates

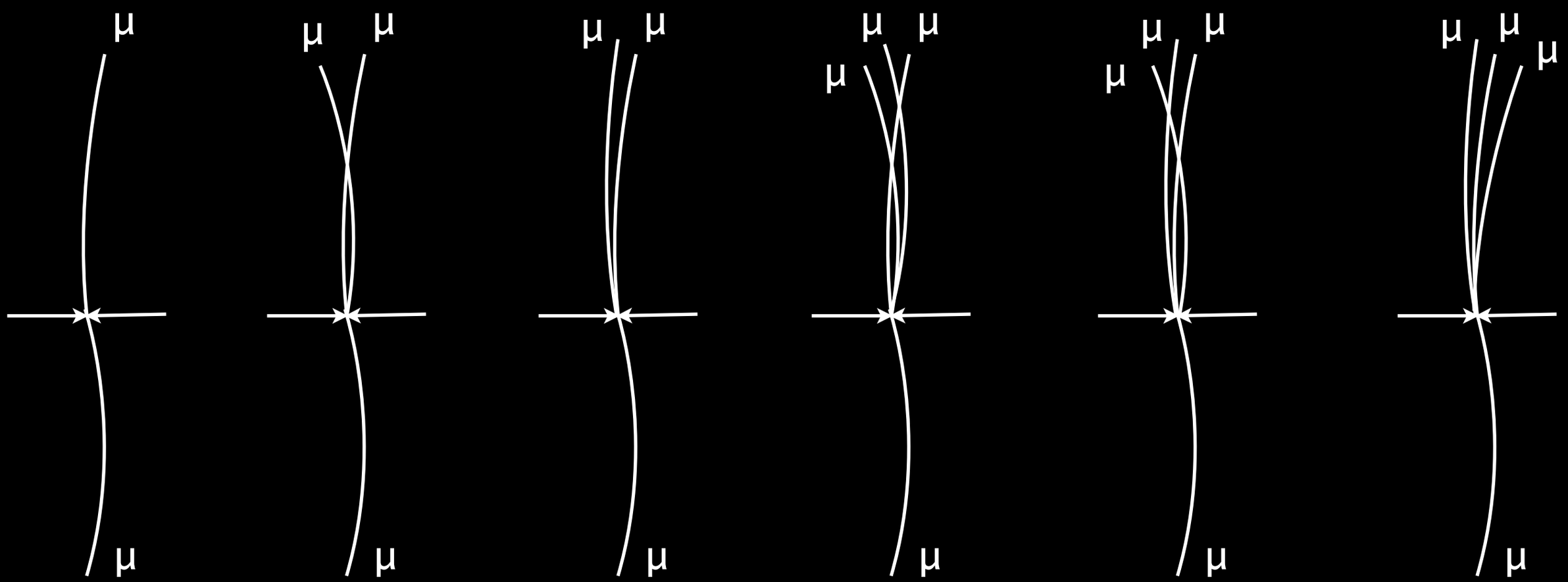
CDF Collaboration, PRD 77, 072004 (2008)



Mass of muon + track with p_T > 0.5 GeV

Low-p_T Muon Multiplicity

- CDF observes excess of multimuon events over background
  - Numbers after background subtraction



620k events
σ_{vis} = 300 pb

14k events
σ_{vis} = 7 pb

9k events
σ_{vis} = 4 pb

0.9k events
σ_{vis} = 0.4 pb

2k events
σ_{vis} = 0.9 pb

0.5k events
σ_{vis} = 0.3 pb

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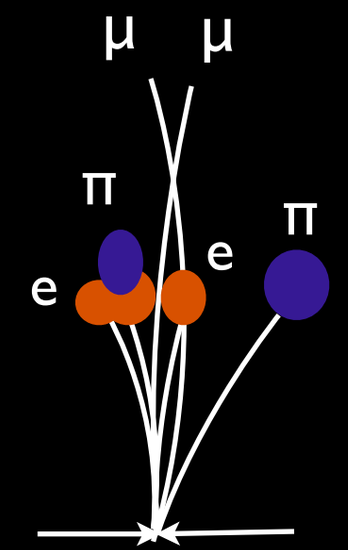

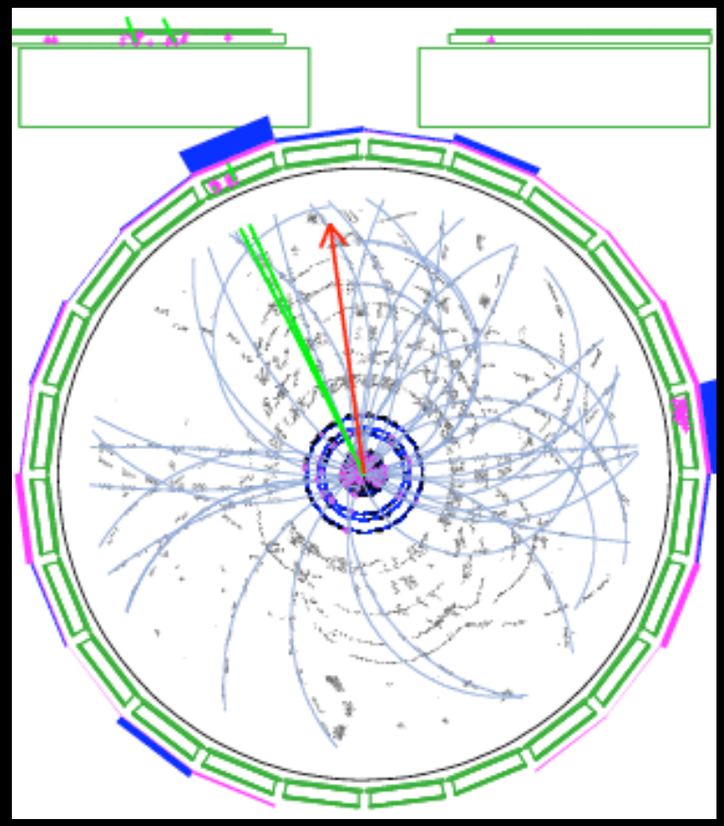

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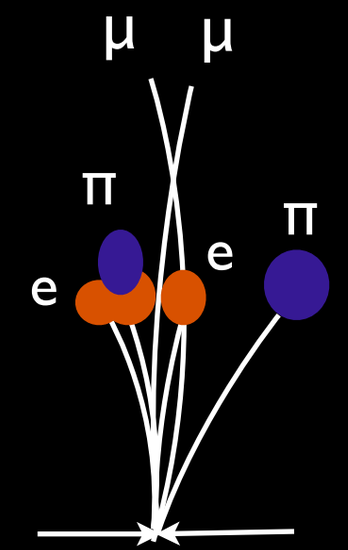

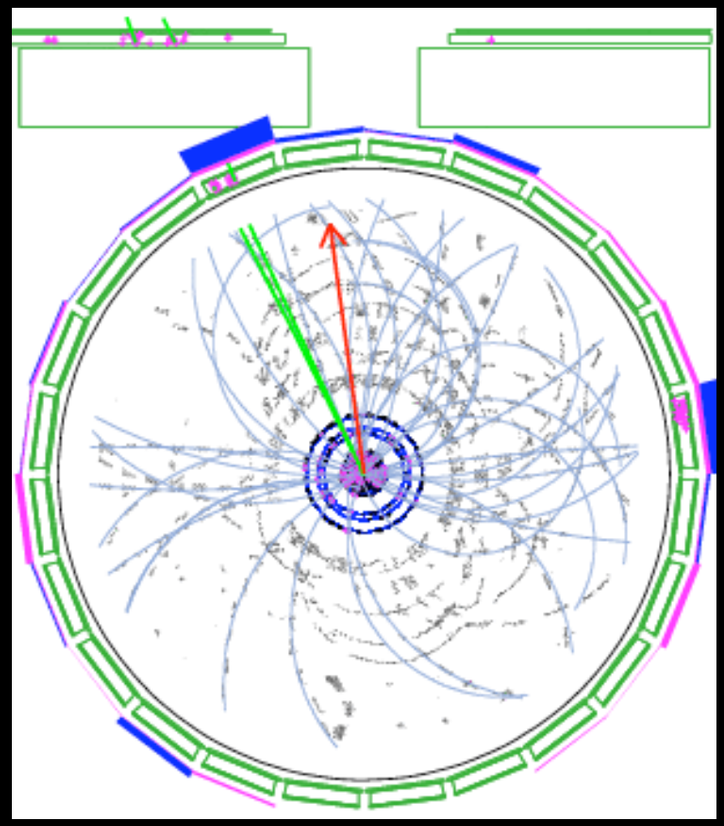

Optimization & Observation

- Steps for probing and believing a non-SM hypothesis
  - Perform a generic search for non-SM lepton-jet production
  - Demonstrate robustness of an excess
    - Observe in independent data samples
    - Loose and tight identification requirements
    - Multiple methods of background estimation
    - Test predictions with control samples
  - Test new physics hypotheses
    - Optimize for presence or absence of hadrons in lepton jet
    - Study event topology, lepton multiplicity and kinematic distributions
    - Confirm with independent detector with different systematics

Summary

- Lepton-jet searches have various motivations
  - New physics models with Higgs and dark matter implications
  - Several observations not yet explained by the Standard Model
- Many challenges to such a search
  - Most generic search extends to the limits of detector capabilities
- Tevatron detectors probing these final states
  - Interesting initial results
  - Multiple studies ongoing with different strategies