GP Report

1. process
2. analysis clarifications
3. important questions
   - will not cover everything

Doug Glenzinski (Fermilab)
Mark Kruse (Duke)
Kevin Pitts (UIUC)

Process

- concerns of all the reviewers and questions from collaborators taken very seriously
- Specific to the reviewers, we've spent time with Matt, Pasha, Luciano and Aseet
  - the minutes of those meetings have been posted to the GP web page
  - based on these discussions GP generated a set of additional requests to the authors

Process

- **The web page has been updated with:**
  - Questions and answers from the collaboration
  - Numerous plots
- **We have attempted to prioritize studies and replies**
  - first concentrate on questions and concerns of the analysis presented
  - further checks/demonstrations of the NP conjecture have been given lower priority
- **Based upon questions, GPs made a set of requests**
  - answers and plots on web page
  - we followed up with some additional requests

Analysis Summary

- CDF 8891 b-bbar cross section
- CDF 9230 this analysis

- Use trigger path: B_BBAR_TWO_CMUP3
  - L1: L1_TWO_CMU1.5_PT1.5
  - L2: L2_CMUP1.5_PT3_&_CMU1.5_PT1.5(later DPS)
  - L3: L3_BBAR_TWO_CMUP3
    - two CMUP muons pT > 3 GeV
    - Mass(μμ)>5 GeV

Sub-samples

- QCD sample defined as events where both muons pass "tight" SVX cuts (hits on L00 and L0).
  - Sample used in b-bbar cross section analysis
  - Sample composition well known
  - Efficiency for this sample is 24.4%

- Ghost sample defined as:

  total sample – QCD/0.244 ≈ total sample – 4*QCD

- Total sample: 743006
- QCD sample: 589111±4829 (estimate 221564±11615 bbbar)
- Ghost sample: 153895±4829
  - 25% of the ghost sample is ~38k events

Ghost Sample

- The efficiency of the tight SVX selection in the dimuon data is ε=0.1930±0.0004 instead of ε=0.244±0.002
  - Predicted efficiency (ε=0.244±0.002) from J/ψ (weighted)
    - This value was used in b-bbar cross section paper. Uncertainty (0.002) comes from J/ψ statistics and reweighting
  - measured efficiency (ε=0.1930±0.0004) from this data sample.
  - Low efficiency must be coming from denominator $\Rightarrow$ additional background [ghost]
- Initial estimate ~40% of ghost sample is QCD
  - from decay-in-flight estimated from QCD MC
  - but d_0 shape doesn't look exclusively like DIF
- Number of additional, non-μ tracks (p_T>2 GeV) in 36.8° cone around trigger muon:
  - 2.7 tracks in Ghost
  - 1.3 tracks in QCD

Analysis Summary

- **Ghost events are observed to have the following characteristics**
  - **When making no silicon requirements, ghost yield comparable to b-bbar yield**
  - **The d_0 distribution of the trigger muons has a tail that extends well beyond the point hf is expected to contribute**
  - **For the trigger muons, the ratio SS/OS is about two times larger in Ghosts than for QCD**
  - **At this stage, entire Ghost contribution could be accounted for by decays-in-flight (DIF) if**
    - **DIF normalization off by x2.5 *and* d_0 tails off by x10**

Comment

- **Questions and studies regarding the analysis focus on the source/cause of the Ghost sample.**
  - **Its existence seems well-established in this analysis.**
- **This is an important point. Regardless of the source of the Ghost sample, it very likely explains several of the effects the authors listed:**
  - **Discrepancies in**
    - **the *b* cross-section**
    - **chi-bar**
    - **Low mass dileptons**
- **This analysis is interesting/important independent of the source of the Ghost sample**

Control Samples

- **Measure fake muon punch-through rates from $D^0 \rightarrow K^- \pi^+$**
  - Events from two-track and μSVT trigger paths
  - Fake rate independent of silicon criteria
  - Fake rate constant with track multiplicity (statistics to check only up to 3 extra tracks)

- **Do not see large muon impact parameters in the following samples:**
  - Additional muons in QCD events
  - Muons in $\mu + D^0$ events (highly enriched in B)
  - Upsilon$\rightarrow \mu^+ \mu^-$ events

- **Measure correct lifetimes for:**
  - Inclusive $B \rightarrow \mu X$ events with tight SVX cuts
  - K_S events (tracking at large d_0) w/no SVX cuts

Questions About Tracks

- **Are large d_0 tracks real?**
  - Si pattern recognition failures?
  - COT pattern recognition failures?
  - Si hit usage? Si χ^2?
  - COT hit usage? COT χ^2?
  - Split tracks due to DIF?

- **Conclusion: large d_0 measurements are real. They cannot be explained by reconstruction failures or detector effects.**

Si Tracking [1]

- Pasha's studies show four specific features [CDF9375]:
  - Number of Si hits on prompt tracks in the GHOST22 sample is significantly higher than for large d_0 tracks [Fig. 1.]
  - The SVX χ^2 for large impact parameter tracks is larger than for prompt tracks. [Fig. 2.]
  - The probability for finding additional axial hits in layers outside the innermost hit layer is lower for d_0 tracks than for prompt tracks. [Fig. 3.]
  - The probability for finding a stereo hit in the same ladder where an axial silicon hit is found is observed to be lower for d_0 tracks tracks than for prompt tracks. [Fig. 3.]
- Furthermore, Pasha observes these same effects when comparing prompt tracks with large impact parameter tracks in JET50 data.
- The authors of the analysis concur with Pasha's findings (plots from the authors can be found on the GP web page.)

Si Tracking [2]

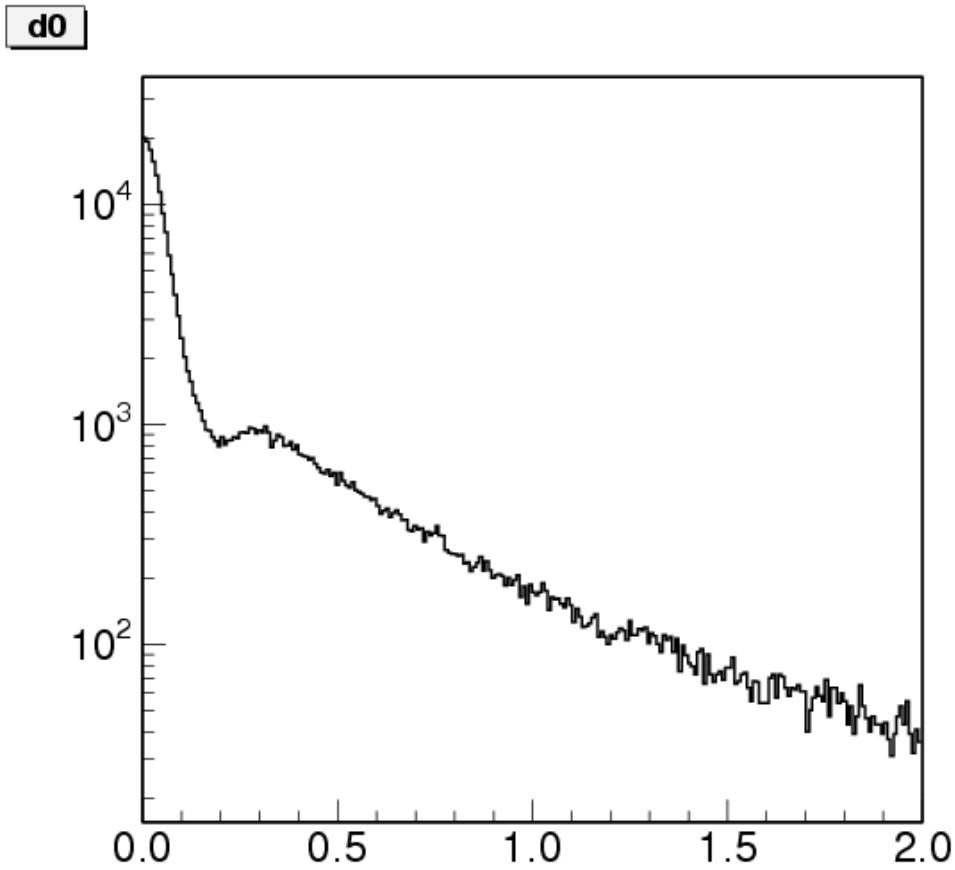
- Known physics signatures with large d_0 e.g. K_S decays) are observed to have misassigned silicon hits and worse Si χ^2
- Matt Herndon reprocessed the Ghost22 sample using COT only tracking and observed a virtually identical d_0 distribution.
  - Perhaps not surprising because there is a limit (<100μm) that silicon hits can pull tracks.
- Half of the Ghost sample consists of muons with no Si information.

- Conclusion: low silicon hit usage and poor SVX fit quality is not generating large d_0 tracks. It is a feature that would be present in either signal or background.

COT Tracking [1]

- COT d_0 resolution (no Si) is ~100μm
- High d_0 tails seen in COT only tracks.

d_0 distribution for COT only Ghost sample.



COT Tracking [2]

- Tracking environment in majority of ghost events not dense. Not counting muons, CDF 9230 reports
  - average of 2.7 tracks (p_T>2GeV) in a 36.8° cone for ghost events
  - average of 1.3 tracks in a 36.8° cone for QCD events.
- Aseet and Matt scanned some events and found no obvious failures of COT tracking
  - Difficult to make quantitative statements on this.
- Pasha reported 20% larger COT χ^2 for large d_0 tracks (Ghost and JET)
  - Likely to reflect differences in HL and SL tracking algorithms.
- Authors show that K_S lifetime properly measured (non-trigger tracks)
  - Indicates good tracking efficiency at high d_0

COT Tracking [3]

- **Upsilon and J/ψ muons do not show d_0 tail**
  - **If tracks mismeasured, must also affect p_T and cause loss of signal event.**
- **Muons in $B \rightarrow \mu D^0$ events also do not show d_0 tail.**
  - **Sample from μ-SVT trigger (μ not an SVT track)**
  - **Concern regarding p_T mis-measurement less of a factor**

- **Conclusion: there is a real sample of tracks at large impact parameter. These are not generated by COT or SVX pattern recognition failures.**

d_0 tails in Jet 20

- Large impact parameter tails seen in inclusive tracks in jet samples. [see Pasha's talk]
  - From CDF9375: "Although the underlying cause of the tails is yet to be understood…we expect the tails in the d_0 distributions for JET20 tracks to result from various detector and reconstruction effects: decays of the long-lived particles (K_S, Λ), secondary strong interactions in the tracker material, photon conversions, effects of the COT pattern recognition etc."
  - The sample composition of Jet 20 tail is not known.
  - Comparing muons in Ghost22 to tracks in Jet20
  - Jet20 not necessarily "Ghost-depleted"
- Tails also seen in Jet 20 MC (see Luciano's talk)
- CDF 9230 has attempted to account for the following contributions:
  - Decay in flight (QCD MC), long-lived particles (data), cosmics (data), secondary interactions (HF MC)

- Conclusion: There are known sources of real tracks at large d_0. Most of these sources are hadrons (K_S, Λ, interactions, DIF) and they clearly contribute to both Jet20 and Ghost samples. The presence of large d_0 tracks in the Ghost sample is not alone an indicator of new physics. [Hadron vs. muon is tied to fake rate question.]

Luminosity Profile

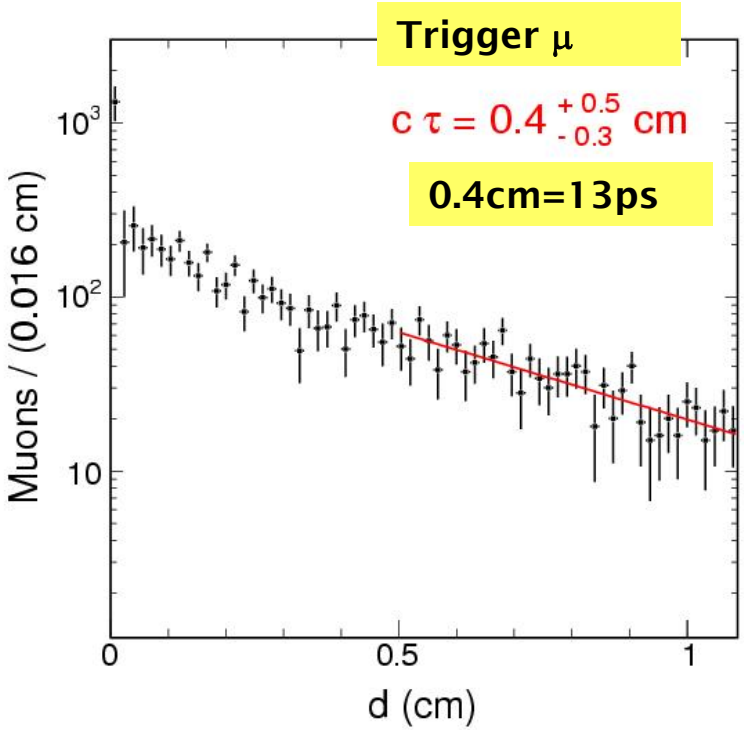
- Sample acquired on b-bbar dimuon trigger
  - Fixed PS=1 for first 742 pb^{-1}(cross section paper)
  - On DPS for last 1400 pb-1 of data.
    - DPS turns on well below 2E32 $cm^{-2}s^{-1}$
    - Average $\mathcal{L}$ for the sample <1E32 $cm^{-2}s^{-1}$
- Authors have verified that the rate Ghost events versus QCD events is constant over time.
  - Plots on web page show number of vertices in ghost and QCD samples.
- Conclusion: luminosity profile and multiple interactions are not responsible for observations.

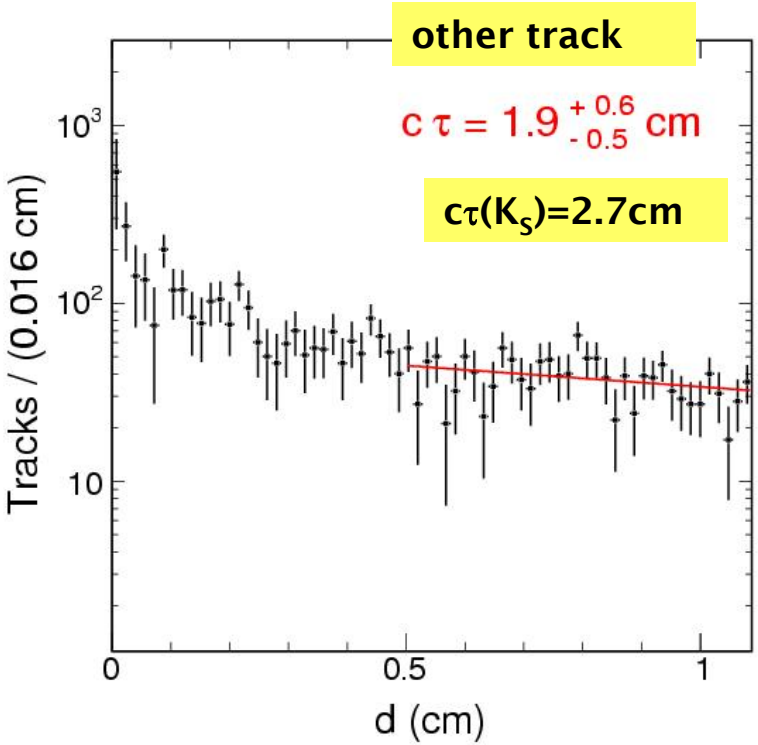
Trigger Bias

- XFT linker patterns include beamspot assumption
  - XFT d_0 resolution ~mm $\Rightarrow$ inefficient for very large d_0 tracks.
  - This is shown in the author's K_S study
    - Trigger muon d_0 distribution shows much steeper slope than untriggered leg.
  - Also observed as a difference between d_0 distribution in trigger and additional muons.
  - Large d_0 tracks introduce d_0-p_T correlation in XFT, should be removed by offline p_T cut.
- Dimuon mass cut (>5 GeV) in trigger removes possibility of μ-μ correlation effects in trigger
- Conclusion: effect not generated by trigger.

K_S Study

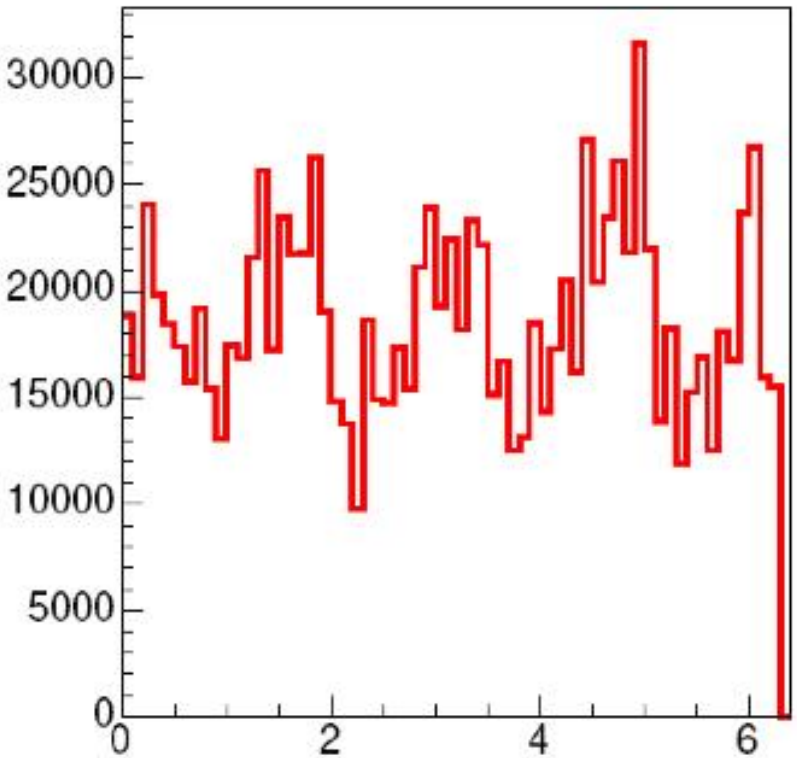
- Take trigger m, vertex it with other tracks in the event. Reconstruct K_S.
- Look at impact parameter of K_S daughters
  - Trigger μ has slope consistent with ~20ps
  - Unbiased track has slope consistent with K_S lifetime.

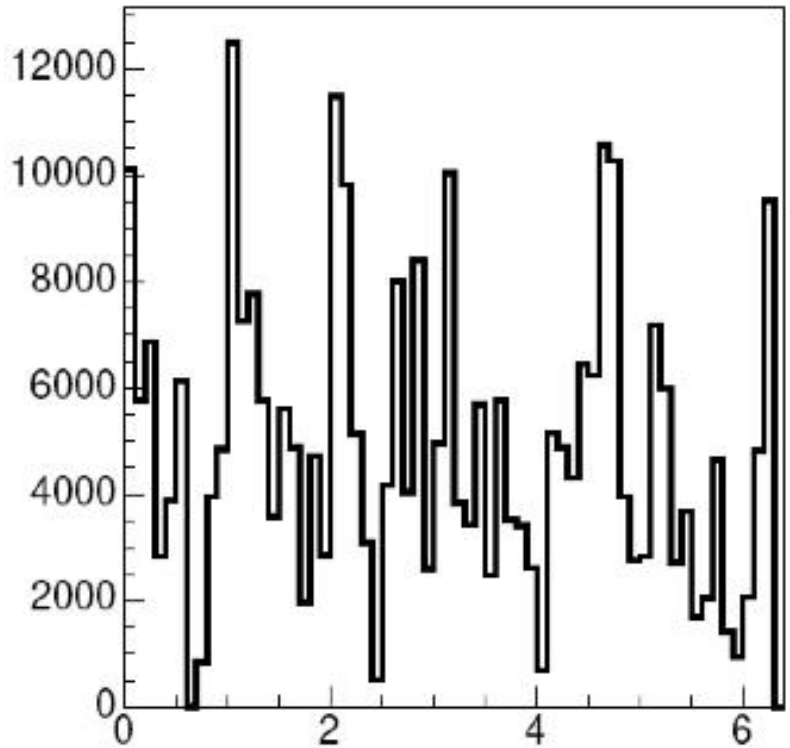




Geometry, Material, Interactions

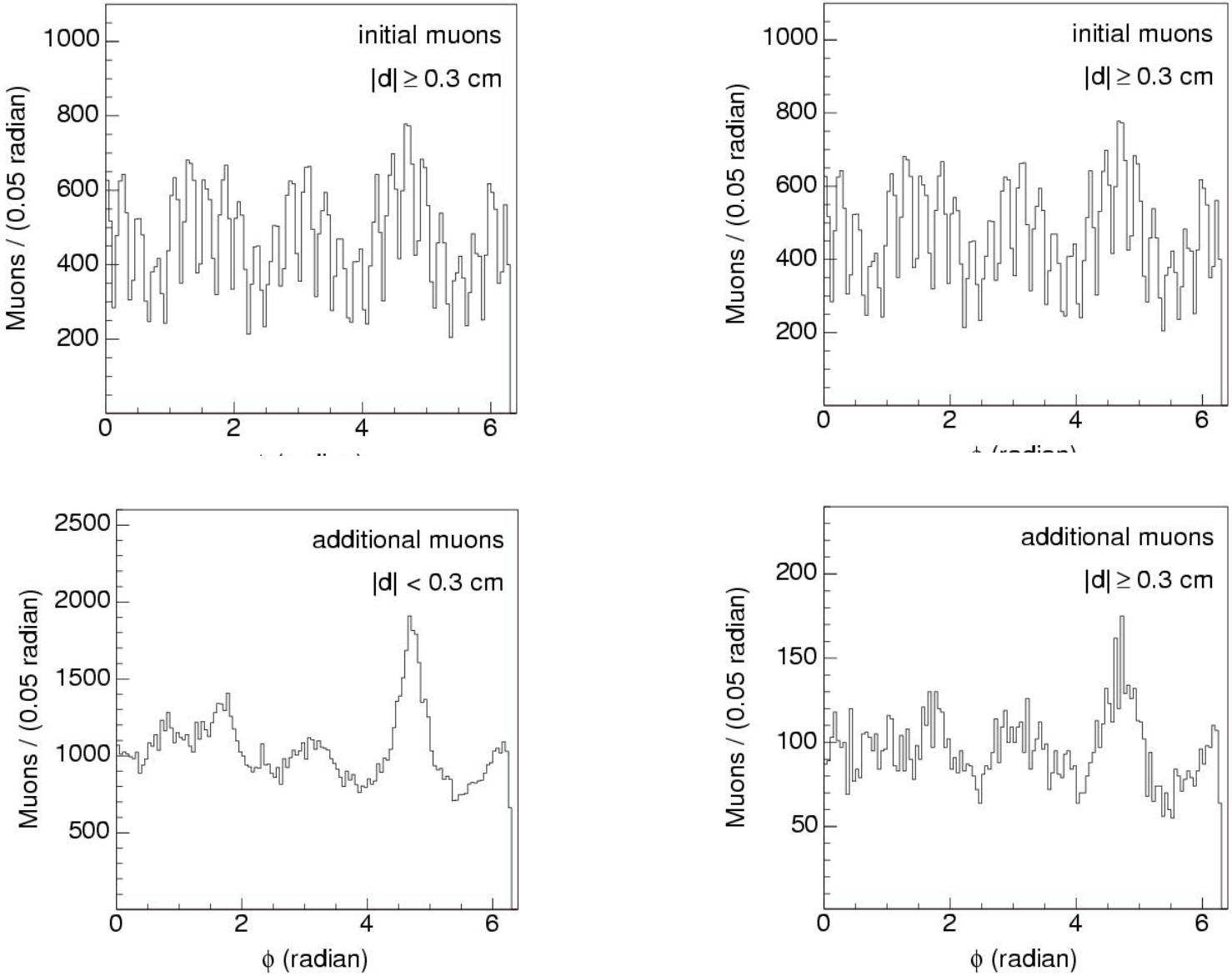
- **Phi distributions for trigger muons:**
- **QCD** **Ghost**





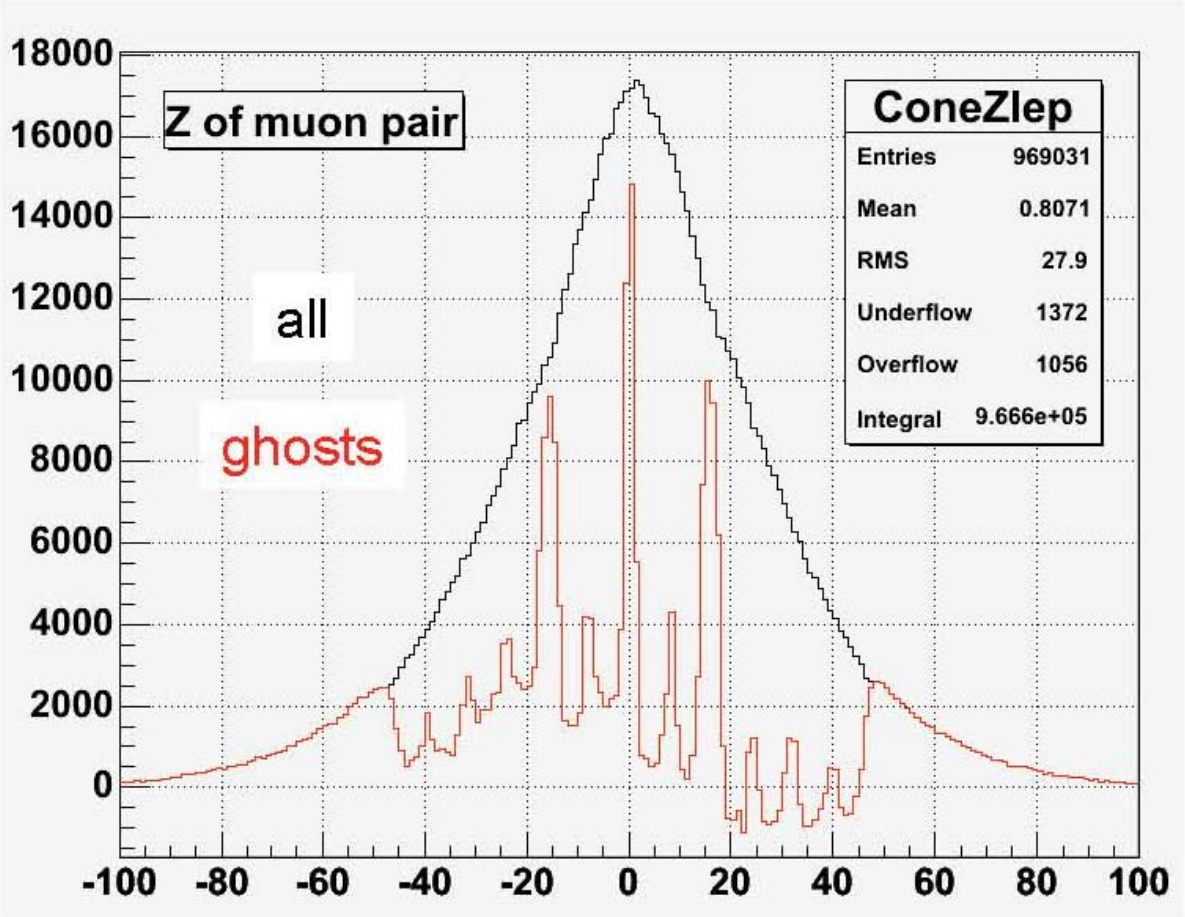
Geometry, Material, Interactions

- **Phi distributions for trigger and extra muons split by d_0:**



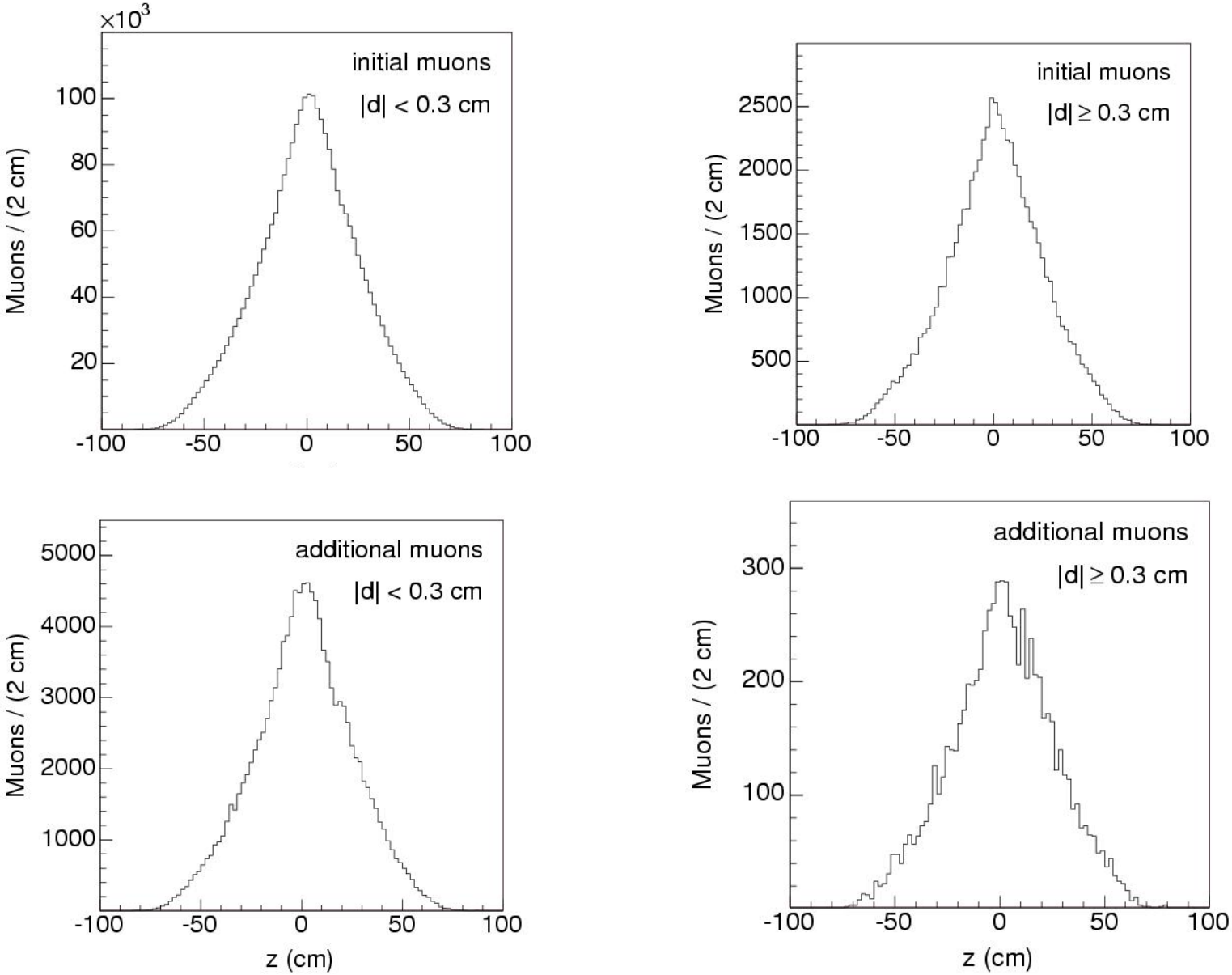
Geometry, Material, Interactions

- **From Luciano's talk last week:**



ghost = ~ all – 4 x (tight SVX component)

Geometry, Material, Interactions

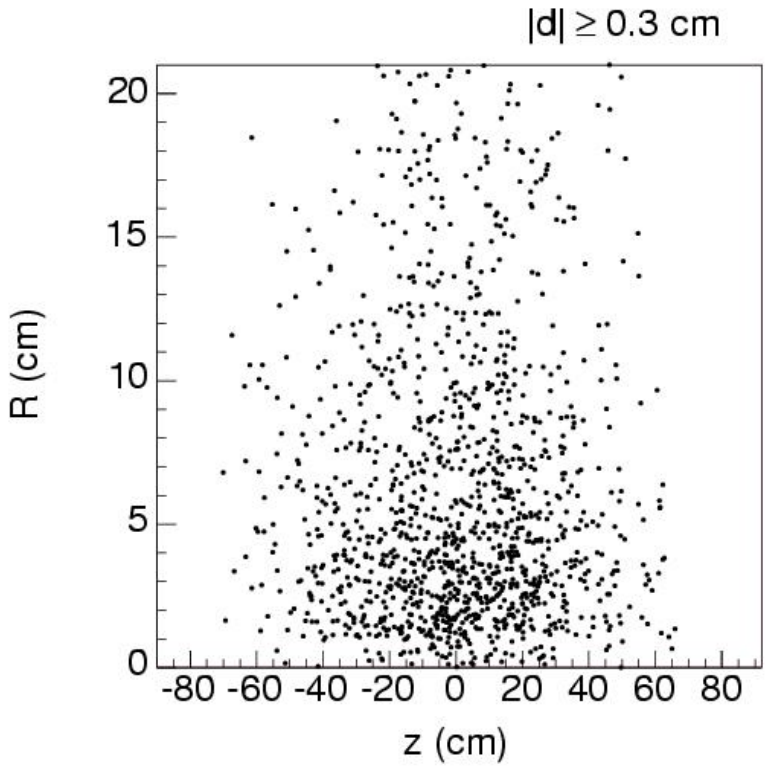


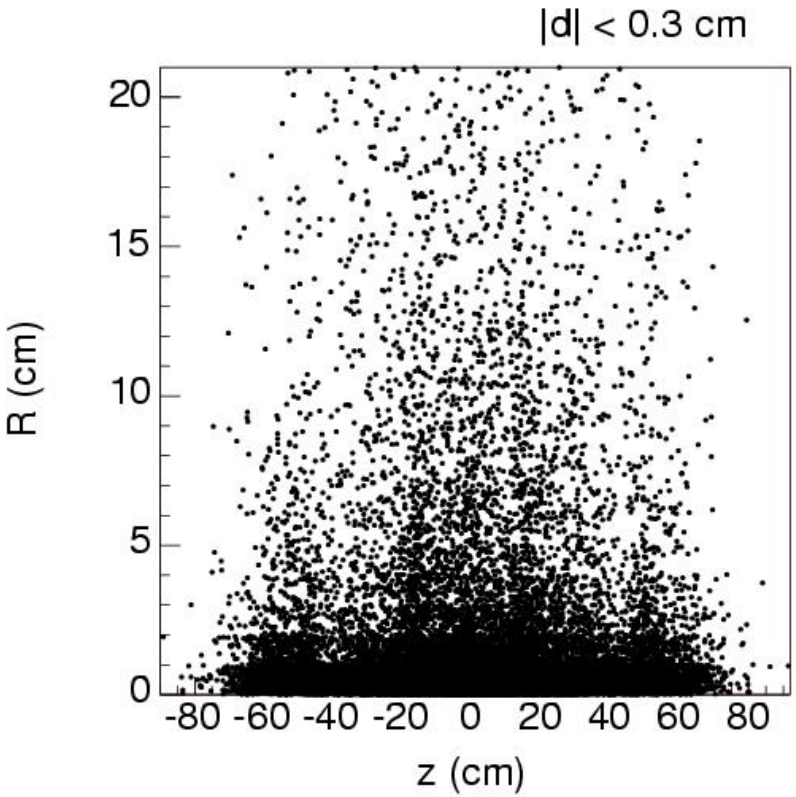
Geometry, Material, Interactions

- **Reminder:**
  - QCD: both muons have hits in L00 and L0
  - Ghost: all – QCD/0.244 ≈ all – 4xQCD
- **By construction, the ghost sample will reflect the geometry of the detector, particularly the silicon.**
  - If no Ghost excess, phi and z_0 plots will still show structure, but integral will be zero.

Geometry, Material, Interactions

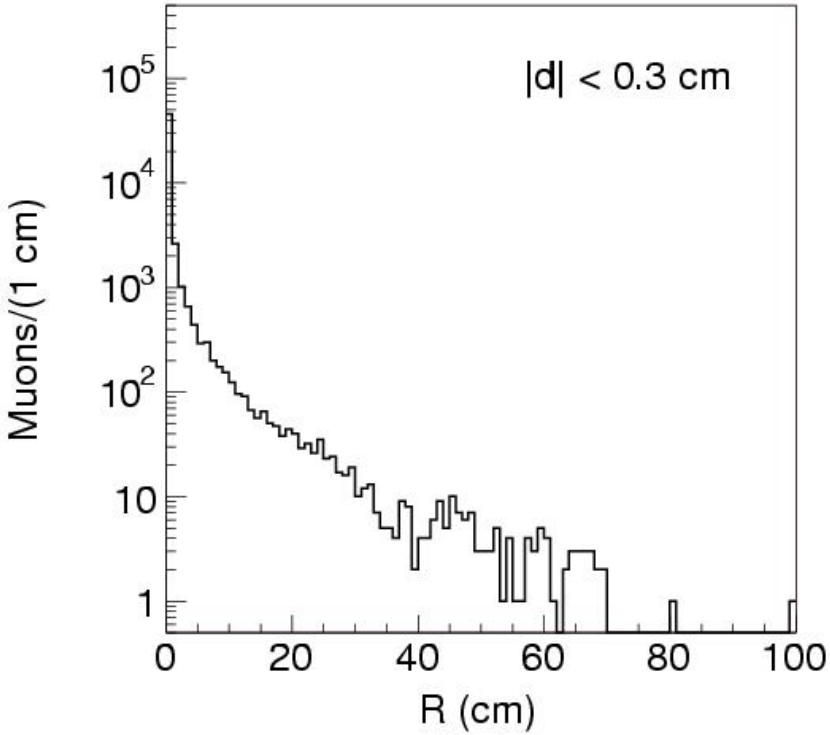
- **Structure could additionally be indicative of interactions in material.**
  - **e.g. Do the high d_0 muons come from the SVX cooling pipes or COT inner can?**
- **Vertex muon pairs in cone:**

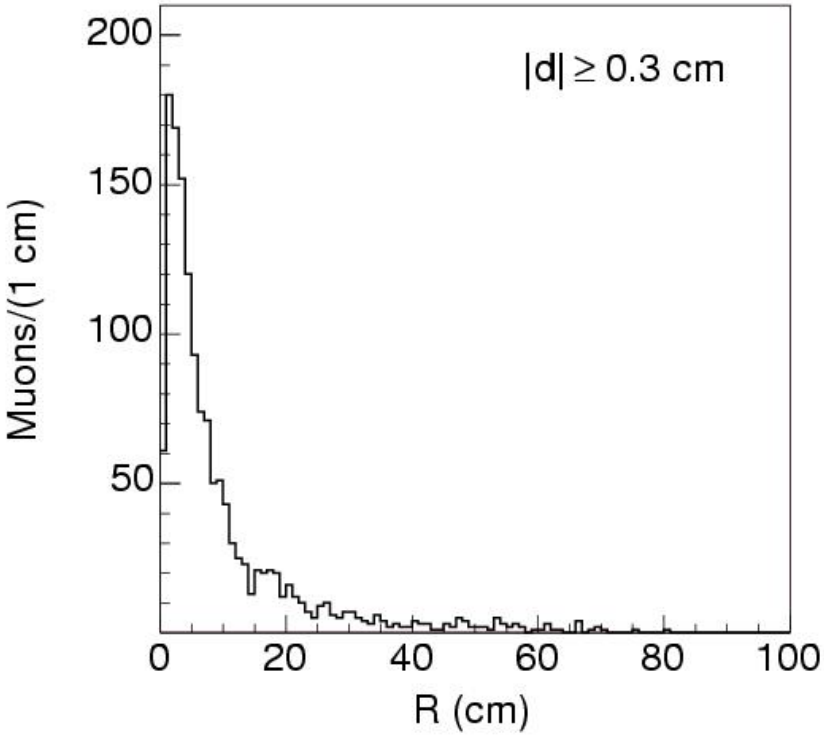




Geometry, Material, Interactions

- **Structure could additionally be indicative of interactions in material.**
  - **e.g. Do the high d_0 muons come from the SVX cooling pipes or COT inner can?**
- **Vertex muon pairs in cone:**
  - **Projections of previous r-z plots**





Hyperon decays

- **Measure fake muon punch-through rates from $D^0 \rightarrow K^- \pi^+$**
  - **Events from two-track and μSVT trigger paths**
  - **Fake rate independent of silicon criteria**
  - **Fake rate constant with track multiplicity (statistics to check only up to 3 extra tracks)**
- **Use Herwig MC (all 2→2) to estimate decay-in-flight (DIF)**
  - **MC includes hyperon decays**
  - **Difficult to assess uncertainty on this estimate.**
  - **Authors state that DIF could explain the entire large d_0 excess.**

- **Recent check: reconstruct K_S and Λ where one of the daughter tracks has punched through. See signals in both cases.**

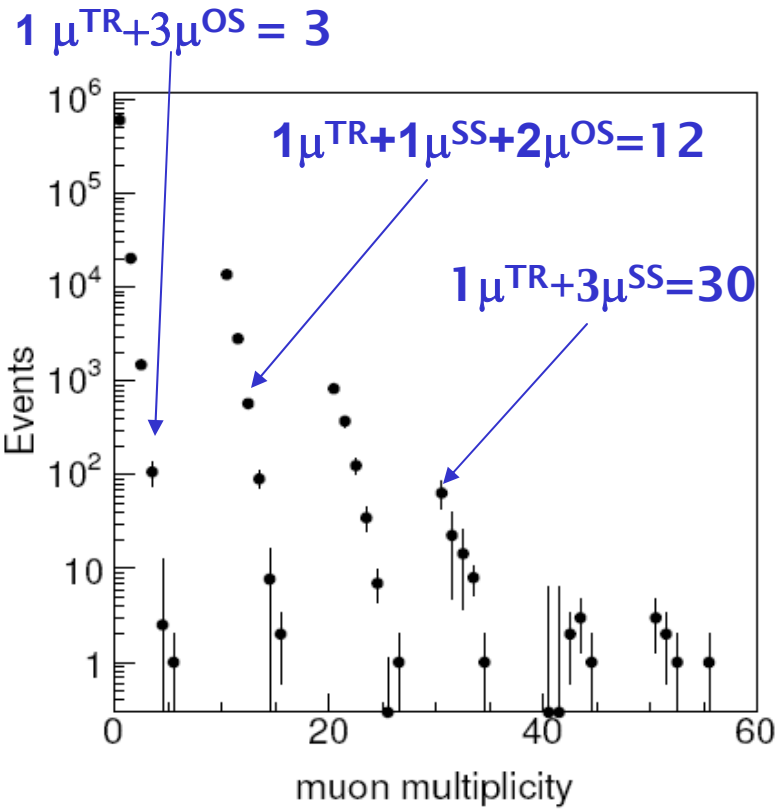
Analysis Summary

- As an additional discriminant, 9230 looks for additional muons in the event and finds
  - Rate in Ghosts about a factor of four larger than in QCD
  - The d_0 distribution of the additional muons in Ghosts also has a tail that extends well beyond expected hf contribution
  - The invariant mass between a trigger-muon and an additional-muon is well modeled in the QCD sample, but not in the Ghost sample

Additional muons

- **Ask for an additional muon in the event**
  - Should suppress hadronic events triggered by DIF or punch-through, so expect ε to recover to a value close to 24.4%.
  - Instead, see ε=0.166, as measured directly from dimuon data sample.
  - Low efficiency must be coming from denominator $\Rightarrow$ even more unexpected background.
- **Muon counting (correct for fakes)**
  - See extra muons in 9.4% of Ghost events
  - See extra muons in 2.1% of QCD events
- **Muon counting (CMUP only)**
  - See extra muons in (1.64±0.08)% of Ghost events
  - See extra muons in (0.40±0.01)% of QCD events
- **Additional observation**
  - See some events with very high μ multiplicity in ghost
  - See no events with >3 μ in QCD events
- **Impact parameter**
  - See large d_0 tail in additional muons in ghost events.
  - Do not see large d_0 tail in additional muons in QCD events.

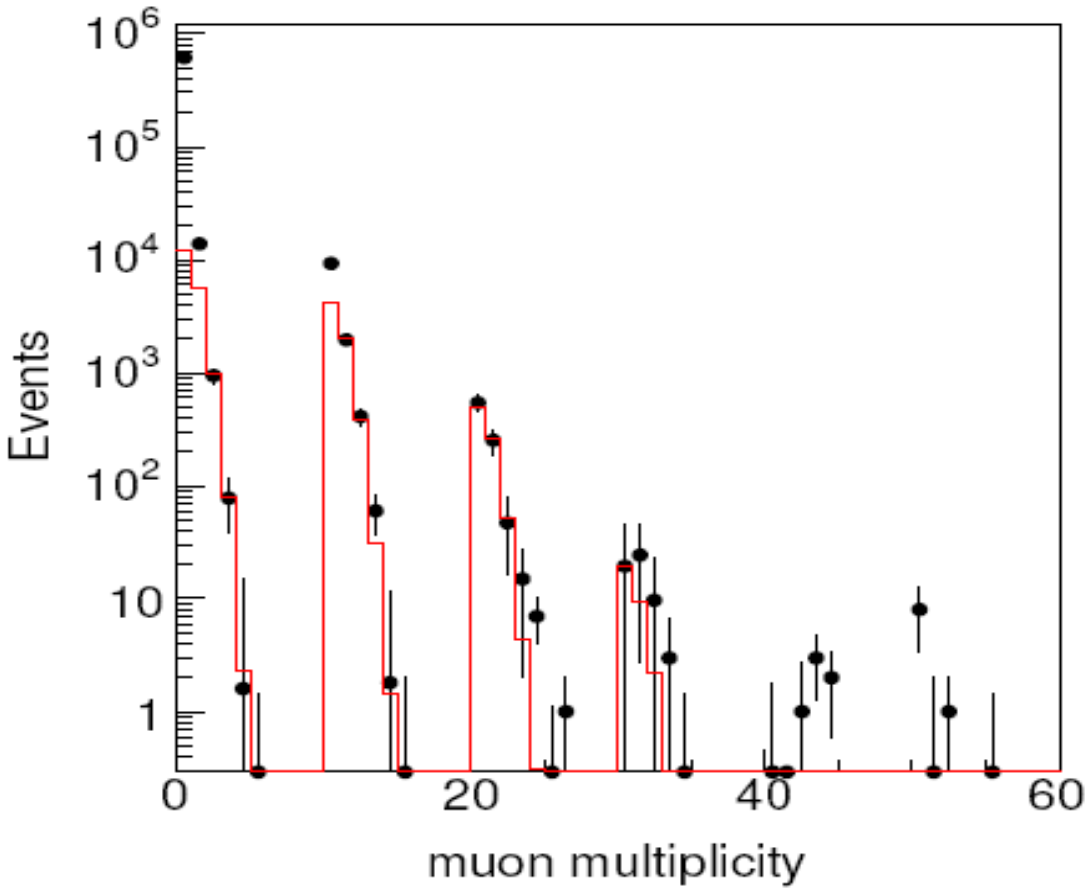
additional muon multiplicity



- **Plot is muons in a single cone in Ghost sample.**
- **Counting additional muons (not trigger muon) in a single cone.**
- **Relative to trigger μ**
  - **OS μ: +1**
  - **SS μ: +10**
- **Example:**
  - **Trigger μ^+, find 2 μ^+ and 1μ^- in cone: plot in bin 21**

In average, a multiplicity increase of one unit corresponds to a population decrease of 7

additional muon multiplicity



Fake <u>muons</u> removed assuming tracks are π.

(e.g. Cone with 1 trigger and 2 SS muons = 20 and is found to have 1 fake muon, then it becomes 1 trigger plus 1 SS $\mu \Rightarrow$ 10)

Points are after subtraction, negatives not shown. Integral above 40 is 0.

Toy Monte Carlo: 8 $\tau \rightarrow \mu$ with BR=0.174 and ε_μ =0.883 and ε_{kin} =1

4 τ^+ +4 τ^- – toy MC, normalized to data for bins >=11,

accounts for approximately 13200 (5%) of the ghost events

Fake Muons

- **The anomaly reported in this analysis is primarily in the rate of additional muons.**

- **In our opinion, the question of muon fake rates and their applicability to the ghost sample is the <u>crucial</u> question regarding the anomalous nature of the ghost sample.**

Fake muons

- From the $D^0 \rightarrow K\pi$ sample, the authors calculate a "per track" punch through probability for kaons and pions. [DIF assessed separately]
- The D^0 sample is checked for a track multiplicity dependence up to 2.6 tracks.
  - Recall the Ghost sample averages 2.7 <u>extra</u> (non-μ) tracks.
- Question: Can the rate of additional muons be explained by an inappropriate application of the per track fake rate?
  - *e.g.* If the Ghost events are really dijets, then perhaps the fake muon rate depends upon jet E_T and cannot be done on a per track basis.
  - And if calorimeter energy leakage causes one fake muon, it's more likely to cause additional fake muons.

Fake muons: What we know

- "per track" technique used in CDF9320:
  - Has been used in many other analyses.
  - Authors correctly predict muon yield in QCD sample.

- CDF 9375 uses Δx and $\Delta\phi$ to attempt to asses the fraction of fake muons in the Ghost22 sample. (see Pasha and Matt's talks)
  - They conclude:
    - "purity of the GHOST22 CMU-only and CMP-only muons is very low, possibly consistent with zero"
    - "purity of the GHOST22 CMUP muon sample is estimated to be below 50%"

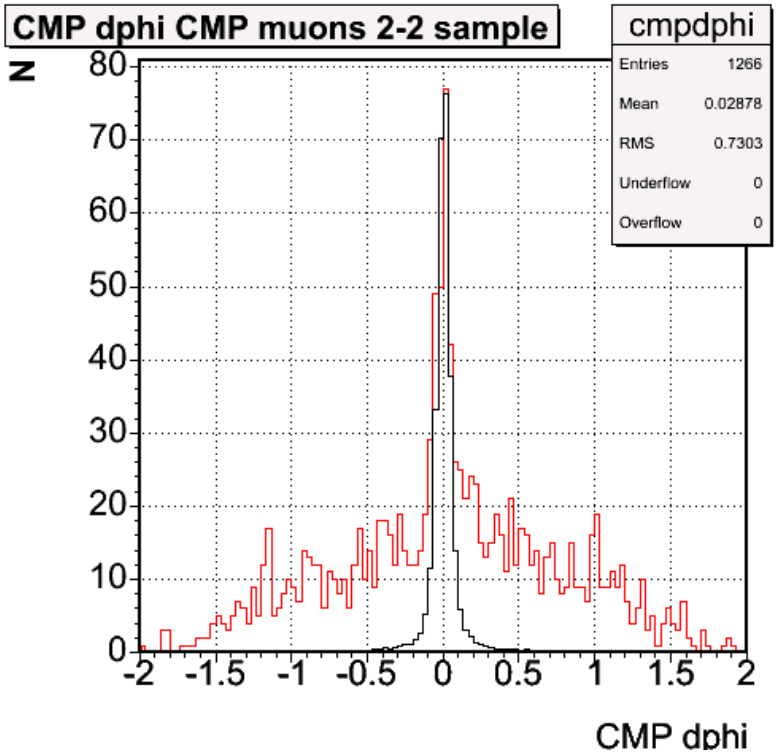
    based upon $\Delta\phi$ shapes from J/ψ events. Assume that wide component all fake.
  - Like D^0, J/ψ are isolated. (both cases: ~80-85% from prompt charm)

- Based upon their per track fake rate calculations, the authors estimate that 60% of the Ghost22 events contains one or more fake muons.

- SLT analysis did not perform correction for correlated fakes.
  - Using double-tags, CDF 9083 Saw 23% effect in Jet20 and $SumE_T$, no effect in Jet50, 70, 100.
  - SLT selection more sophisticated than selection used in CDF9320

CMU Muon Quality

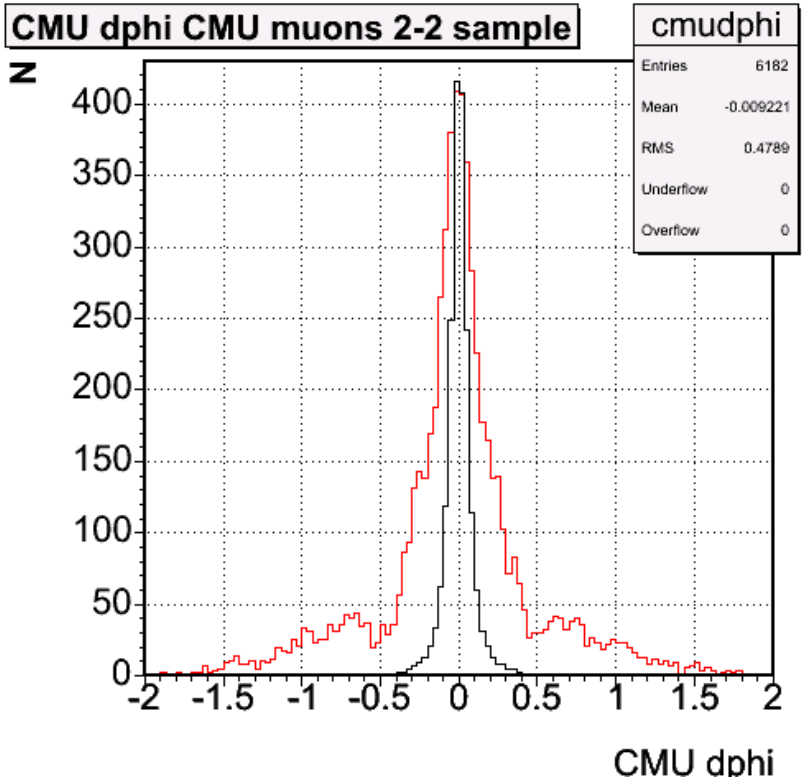
- Compare $\Delta\phi$ track-stub matching of CMP muons

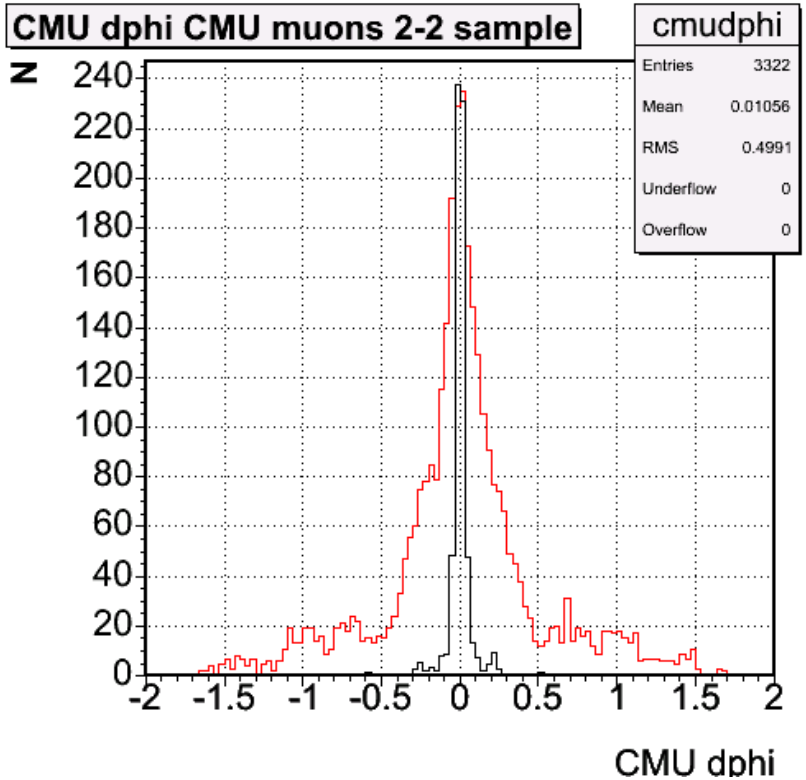


- 2-2 sample red and J/ψ black.
- 2-2 muons have significantly broader $\Delta\phi$. ~75% distribution probably fake

CMU Muon Quality

- Compare $\Delta\phi$ track-stub matching of CMU muons

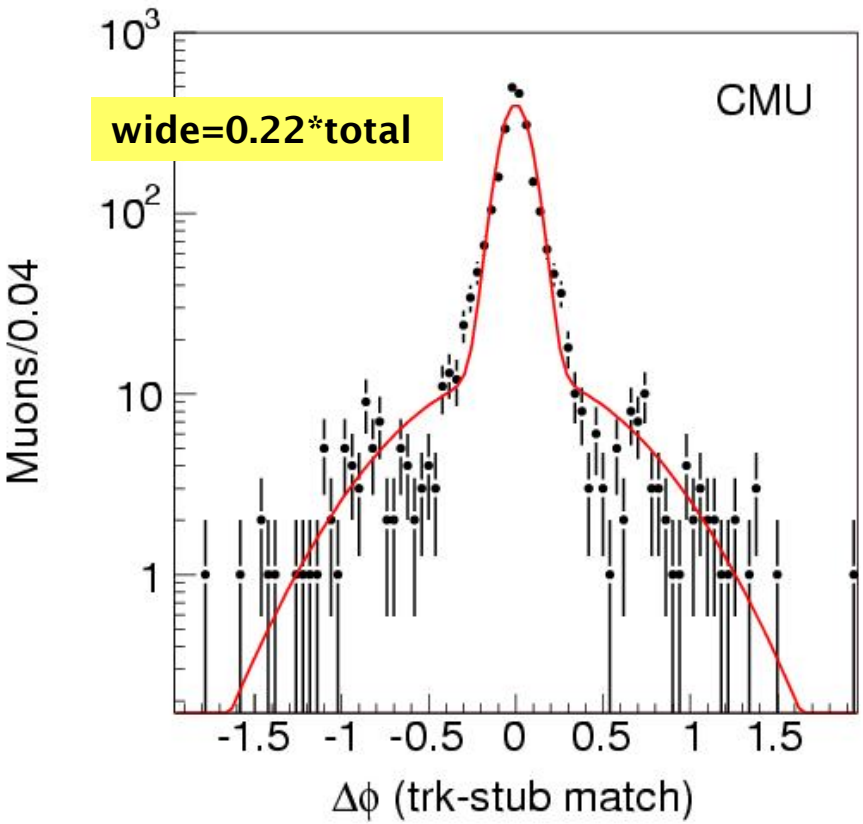


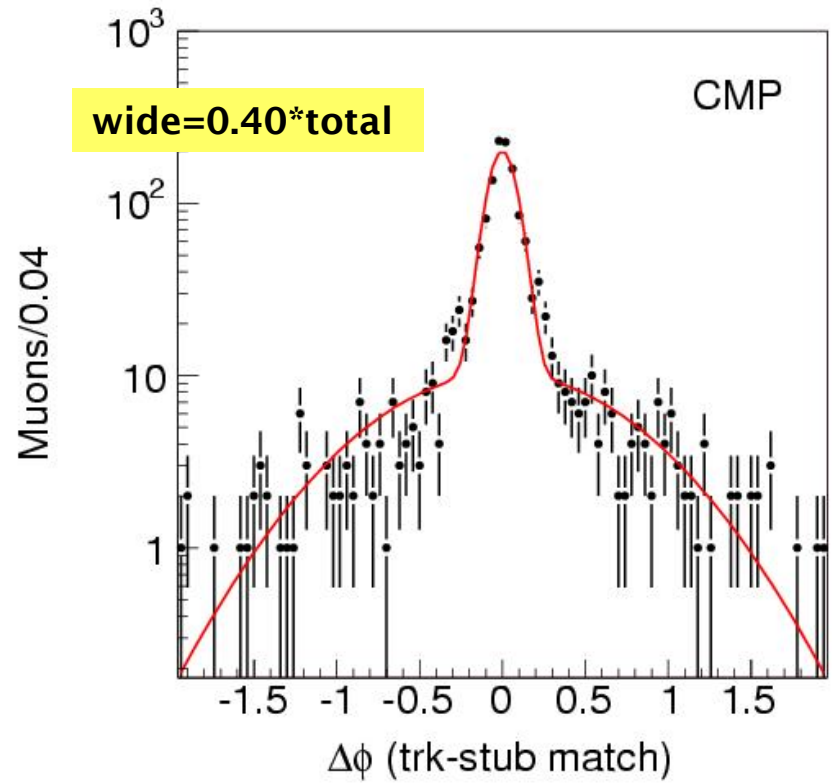


- 2-2 sample red and J/ψ black.
- Divide into <3GeV and >3GeV(enough to reach the CMP)
- ~75% distribution probably fake for <3GeV
- ~90% distribution probably fake for >3GeV. 70% fake for all muons

Fake Muons

- **Authors look for J/ψ in their sample.**
  - **Pair trigger muon with additional μ.**
  - **See about 5000 J/ψ, ~1000 with 2nd μ CMU and ~600 with 2nd μ CMP only.**
  - **Use sideband subtraction, look at $\Delta\phi$**
    - **Tails indicate that single gaussian insufficient to model $\Delta\phi$ distribution**





Correlations

- **Concern regarding correlated fakes. Two potential sources of correlation:**

1. **First track points at a crack (⇒fake muon), nearby tracks more likely to point at a crack (⇒additional fake muons)**
   - **If real, would depend upon track multiplicity and separation**

2. **Leakage from a jet provides hits in muon systems. Many stubs formed from random hits, tracks matched to stubs.**
   - **If real, would depend upon Jet E_T (higher E_T⇒more leakage⇒more stubs⇒higher correlation)**

Correlations

1. First track points at a crack (⇒fake muon), nearby tracks more likely to point at a crack (⇒additional fake muons)
   - If real, would depend upon multiplicity and track separation

- Authors attempted to implement η dependent and ϕ dependent fake rate corrections.
  - Applied track-by-track, this would account for cases where multiple tracks are pointing at cracks.
  - They observed an overall drop in the fake rate of about 5% using this technique.
  - Some regions (cracks) have a higher fake rate, but effect compensated by other regions with lower fake rate.

Correlations

2. Leakage from a jet provides hits in muon systems. Many stubs formed from random hits, tracks matched to stubs.
   - If real, would depend upon Jet E_T (higher E_T, higher correlation)

- The authors correctly predict the rate of muons in QCD events.
  - The QCD sample has contribution that extends to high E_T
  - What is the mechanism that permits fake muon correlations in the Ghost sample and suppresses it in the QCD sample?

Where does μ the excess come from?

- Table shows μ multiplity in ghost sample after fake correction.
  - My numbers are approximate.
- Total of 32800 muons, which is 4.5x more than expected in QCD events.
  - i.e. expect about 7300 μ

# of additional muons per cone	# cones	# muons =cones* μ/cone
1	23192±713	23192
2	3422 ± 238	6844
3	756 ± 105	2268
4	126 ± 47	504
	total # extra μ	32800

- If we argue that high μ multiplicity cones come from correlated fakes, and decide to ignore all cones with more than 1 additional μ, we still have 23192 μ where we expect 7300.
- Events with 2, 3 and 4 additional muons are important to the multi-τ hypothesis, they account for about 30% of the muon excess.

Summary of muon excess

- Low and high multiplicity events contribute to the excess of additional muons observed in the ghost sample.

- Authors account for fakes on a per track basis as has been done in other analyses.
  - Disagreement between authors and reviewers regarding muon fake rate in Ghost 22 sample.
    - Reviewers see tails in $\Delta\phi$ and Δx distributions
    - Authors show that these tails are sample-dependent

Conclusion

- Seems clear to us that there is an excess of events in this analysis whose sample composition is not understood.

- This excess very likely explains several effects suggested by the authors: discrepancies in *b* cross-section, chi-bar, and low mass dileptons and is worth publishing.

- We believe the crucial question regarding the excess has to do with fake muons.
  - Many checks have been performed.
  - Some work ongoing