# New Physics at CDF?

## A Halloween "ghost" story.

Study of multi-muon events produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

arXiv:0810.5357 (31 Oct 08)


Flip Tanedo


4 November 2008

CIHEP Collider Club

# Hype

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**New Type of Particle May Have Been Found**

Posted by kdawson on Monday November 03, @06:33PM
from the outside-the-pipe dept.

An anonymous reader writes

"The LHC is out of commission, but the Tevatron collider at Fermilab is still chugging along, and may have just discovered a new type of particle that would signal new physics. New Scientist

nature

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Published online 3 Nove
doi:10.1038/news.2008.

News

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**Has new physics been found at the ageing Tevatron?**

18:55 03 November 2008
NewScientist.com news service
Anil Ananthaswamy

IOP A community website from IOP Publishing

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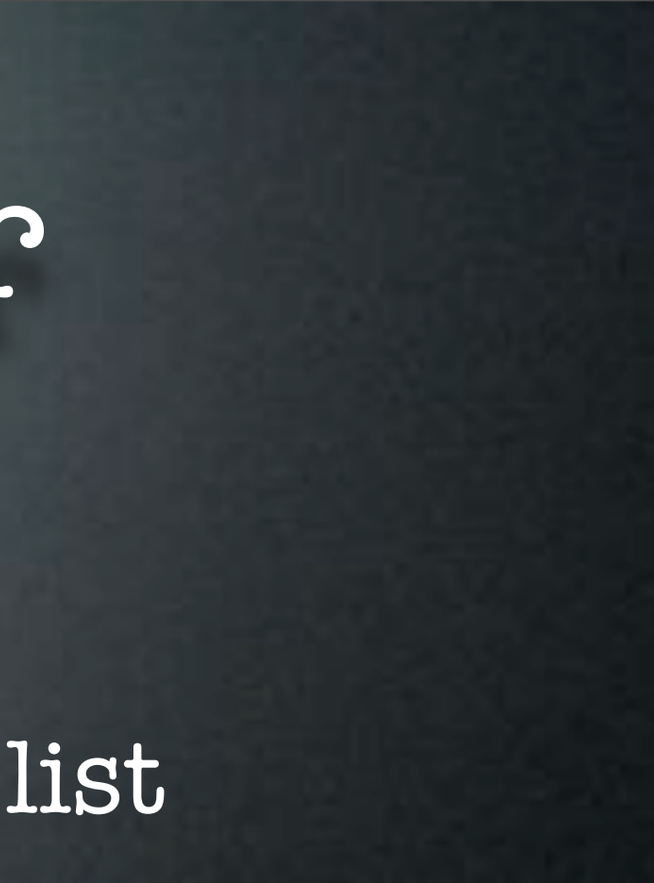
Nov 3, 2008

**Fermilab 'ghosts' hint at new particles**

# Caveat Emptor

- This is a controversial result
- Only 2/3 of CDF on the author list
- Lots of hype from blogs, etc.
  Latched on to Nima-Neal DM hype
- Work in progress.
- I don't have the answers.
  Maybe you do.




Happy Halloween

# *I'll tell you a story.*

Then you tell me what kind of story it was.

- **True story**?
  Actually a potential signal of new physics

- **Fairy tale**?
  Signal turns back into a pumpkin at midnight

- **Morality play**?
  Not literally true, but teaches us lessons

Johannes Pumpkin is burning to find out if the CDF anomaly is new physics!

# $b\bar{b}$ inconsistencies

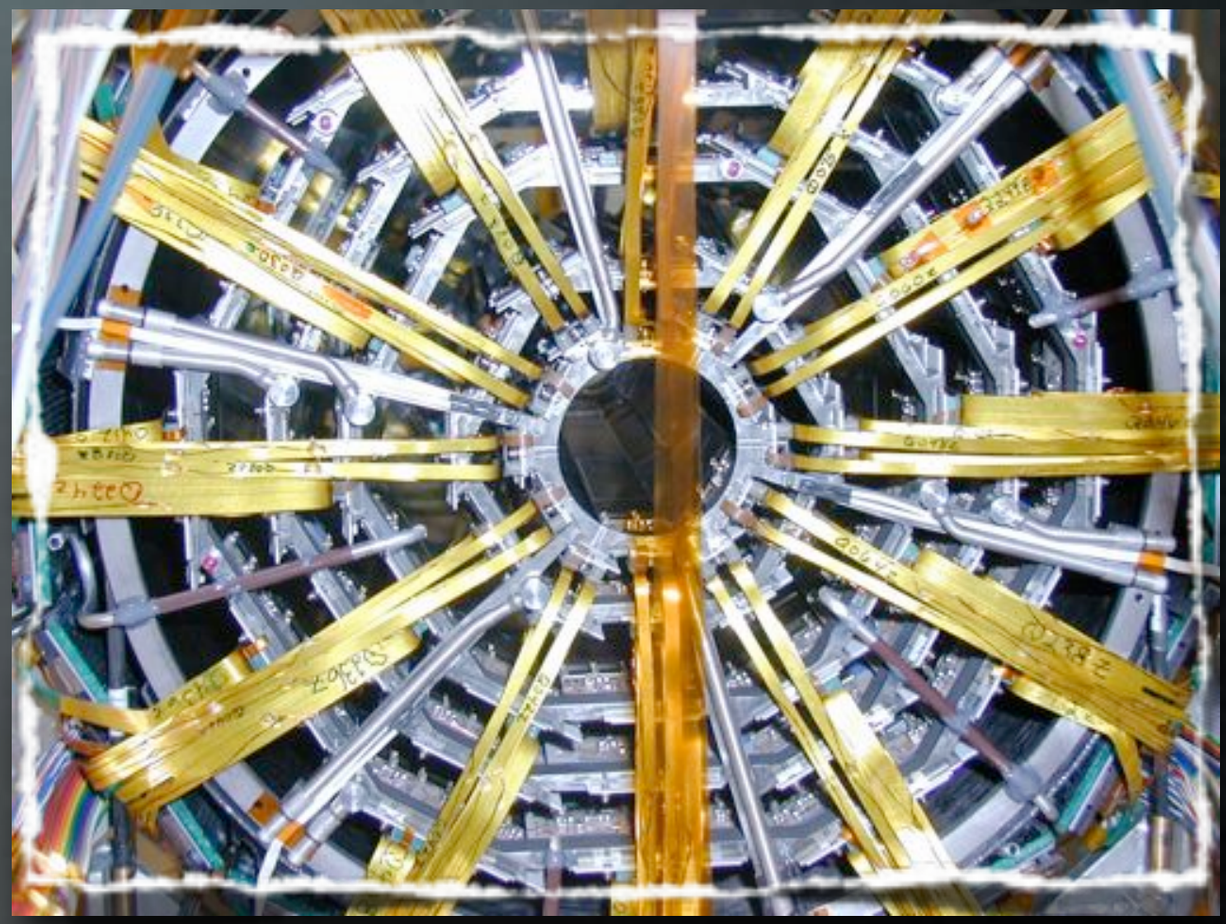
- $R_{2b} = (\sigma_{b\bar{b}})_{\mathrm{exp}}/(\sigma_{b\bar{b}})_{\mathrm{NLO}}$ should be ≈ 1
  - R = 1.15 ± 0.21 when using 2nd'ry vertex ID
  - R = 3.0 ± 0.6 when using semileptonic decays

- Invariant mass spectrum doesn't fit well with simulation of sequential semileptonic b decays

- Time-integrated mixing probability of b hadrons "significantly larger" than LEP

# New result: R fixed

- Phys. Rev. D 77, 072004 (2008) Measurement of correlated bb production in pp collisions at $\sqrt{s}$ = 1960 GeV
- R = 1.15 ± 0.21
- So what gives?
- Used **tight SVX** selection criteria, muon parents decay within 1.5 cm of beam (cf **loose SVX**)



Silicon Vertex Detector

# The call is coming from ~~inside~~ OUTSIDE the ~~house~~ BEAM PIPE

- Anomalously large number of muons produced **outside** the beam pipe

- “ghost” muons

- Unusual multiplicity of muons in B events
  (historically how they were discovered)

... and that’s why Neve decided to purchase a cell phone

# The call is coming from ~~inside~~ the house

OUTSIDE

BEAM PIPE

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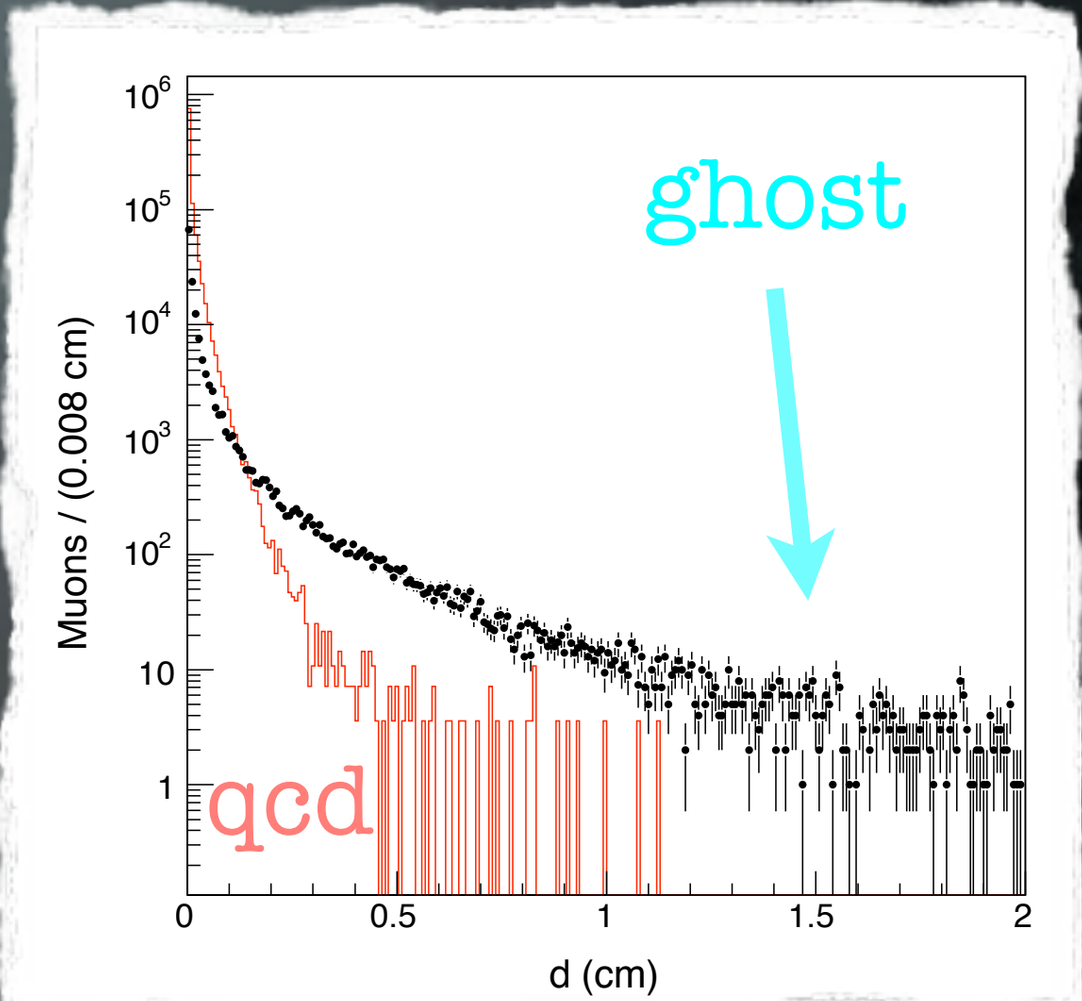


Impact parameter distribution

# “Ghost” Properties

| Type | Total | Tight SVX | Loose SVX |
|---|---|---|---|
| All | 743,006 | 143,743 | 590,970 |
| QCD | 589,111 | 143,743 | 518,417 |
| Ghost | 153,895 | 0 | 72,553 |

- 2x tracks in a 36.8˚cone
- 4x real μ in a 36.8˚cone
- Independent of luminosity, multiplicity of $p\bar{p}$ interactions
- Impact parameter distribution could fit NP with $\tau \approx 20$ ps


Won 2 Oscars

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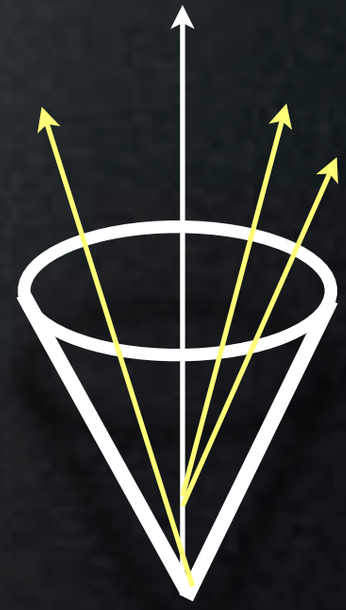

“Lepton Jet”

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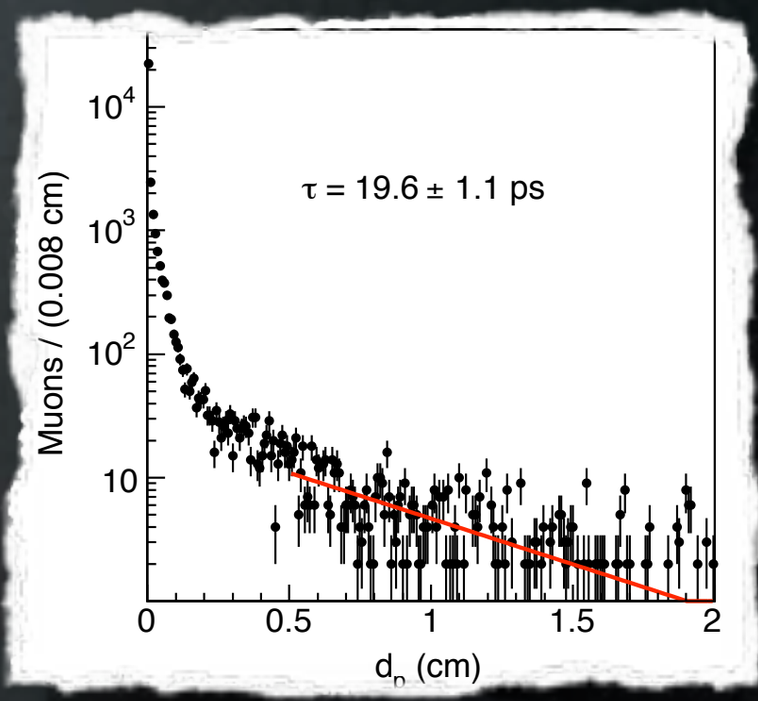


Events with >2 μ

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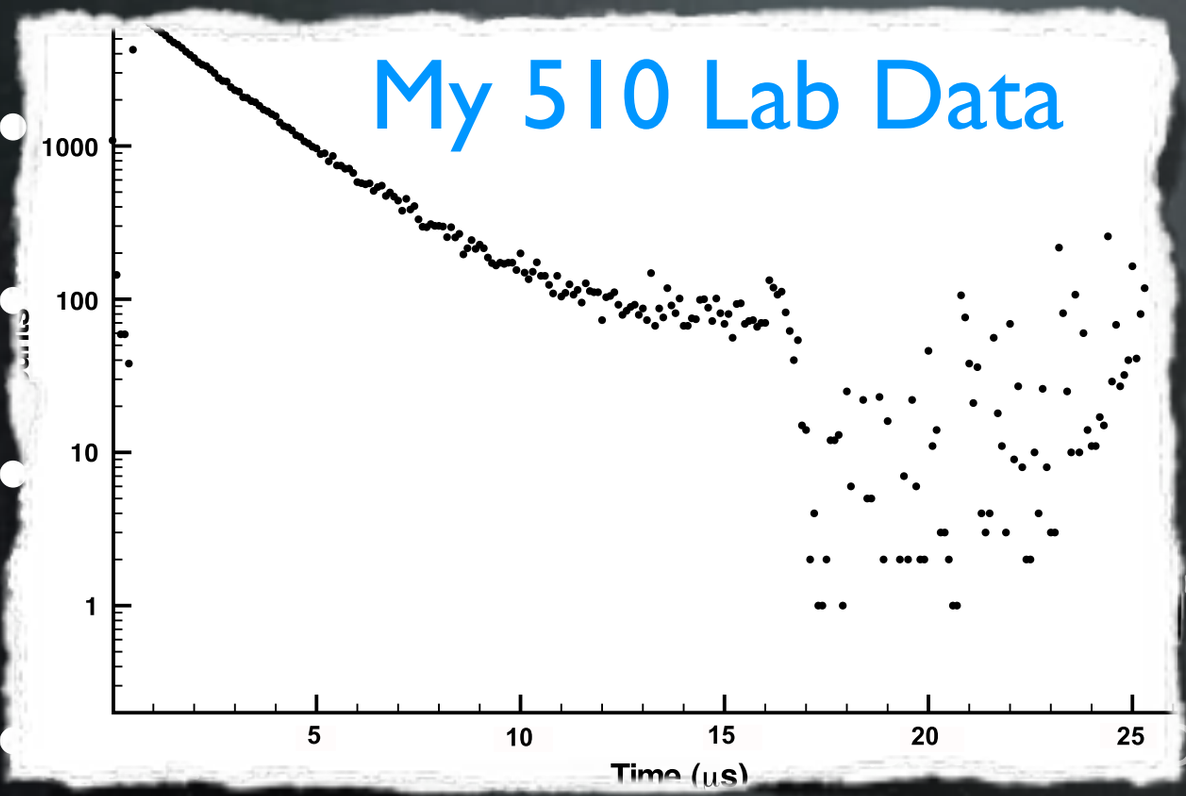
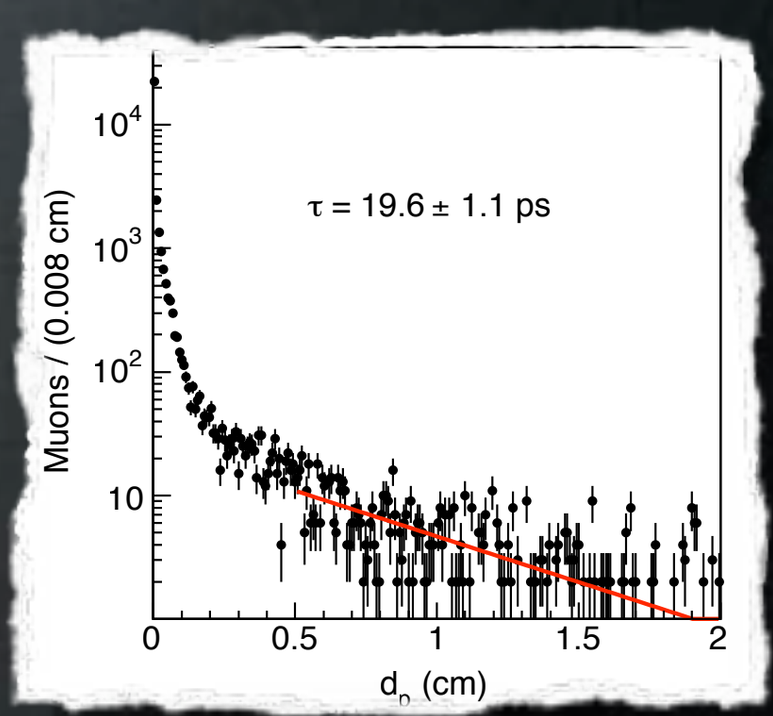



Events with >2 μ

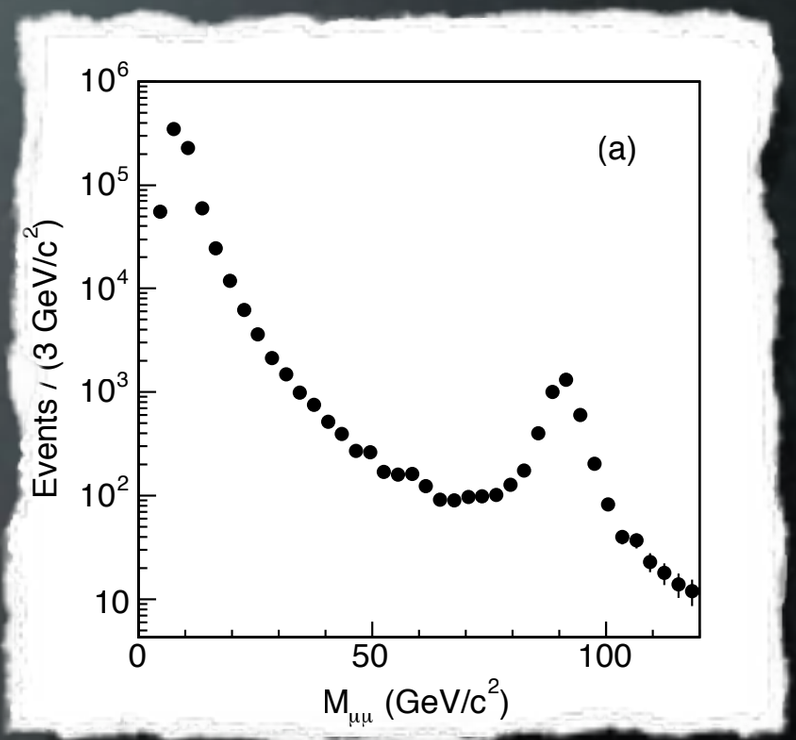
# But is it real?

i.e. can we get rid of it?

# But is it real?

## Could it be ordinary QCD?

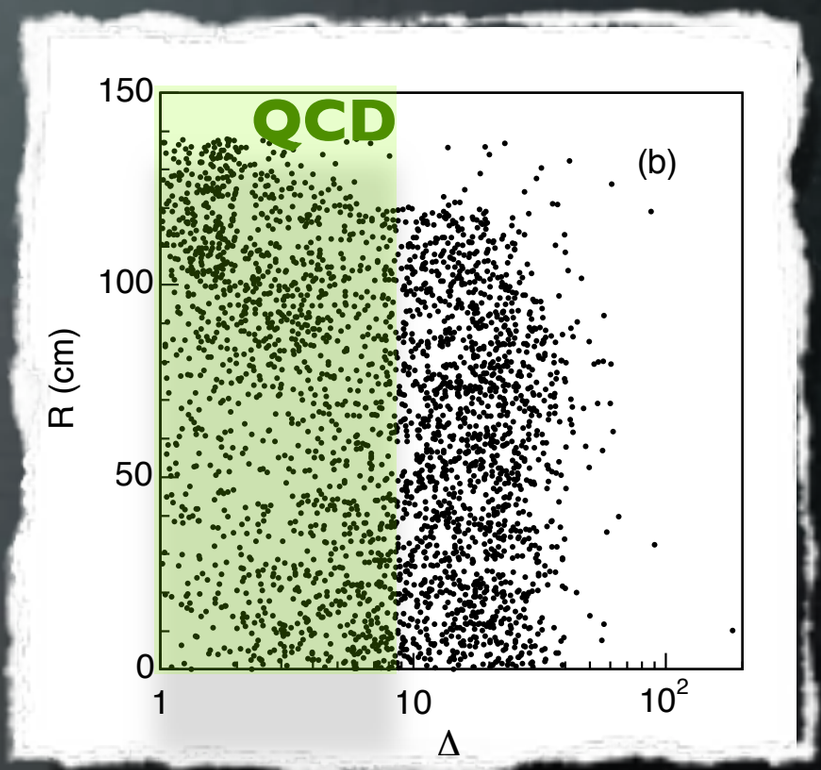
- "QCD" = Drell Yan, $\Upsilon$, $Z^0$, heavy flavor, ...
- We expect 96% of QCD within 1.5 cm of beam
- **Highly boosted hadrons**? Don't see any signature in the invariant mass distribution.
- Can also compare detector efficiencies



# But is it real?

## Could it be in-flight decays of K, π?

- Particles with τ > heavy flavor lifetime
- In-flight decay to μ's lead to misreconstructed tracks
- Simulated with HERWIG
- Can account for **35%** of ghosts, but only **10%** of those with d ≥ 0.5 cm



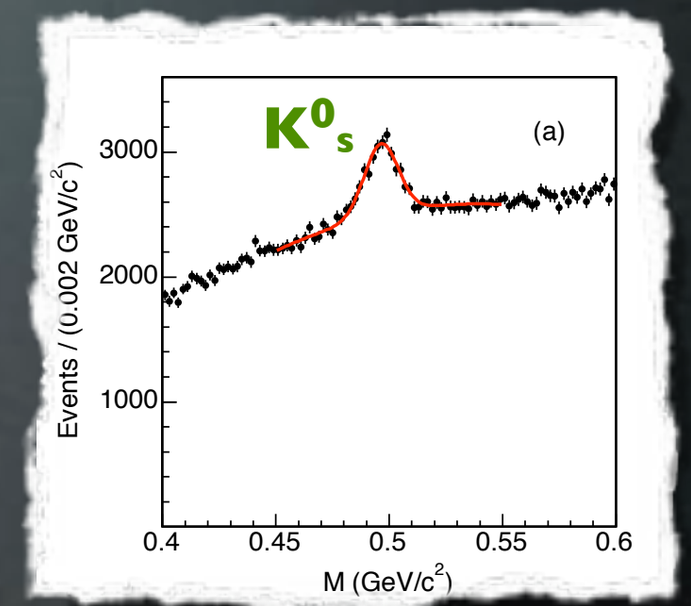

Measure of π, K momentum vs. closest reconstructed tracks

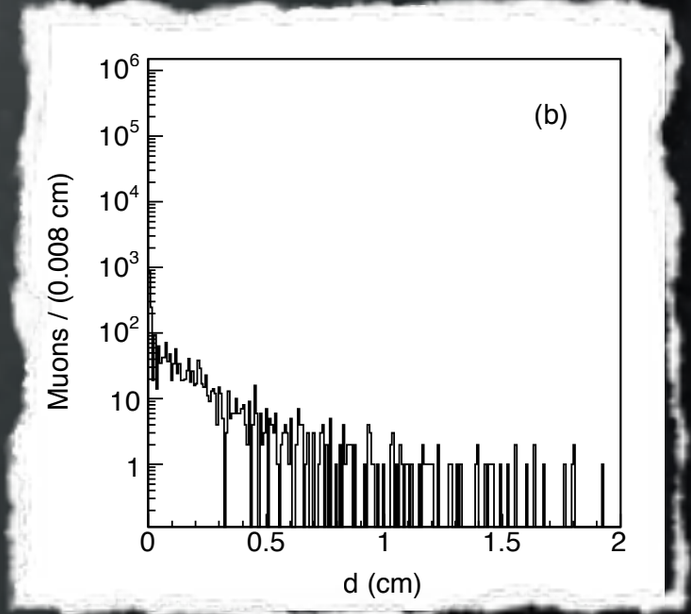
$$\Delta^2 = \frac{1}{3}\frac{\eta^h - \eta^{\text{track}}}{\sigma_\eta^2} + \frac{(\phi^h - \phi^{\text{track}})^2}{\sigma_\phi^2} + (\frac{1}{p_T^h} - \frac{1}{p_T^{\text{track}}})/\sigma_{1/p_T}^2$$

# But is it real?

## Could it be punchthough of $K^0_s$ or hyperons?

- Hadrons from $K^0_s$ and hyperon decay can mimic muons
- e.g. $K^0_s \rightarrow \pi^+\pi^-$
- Explains about **8%** of ghost events



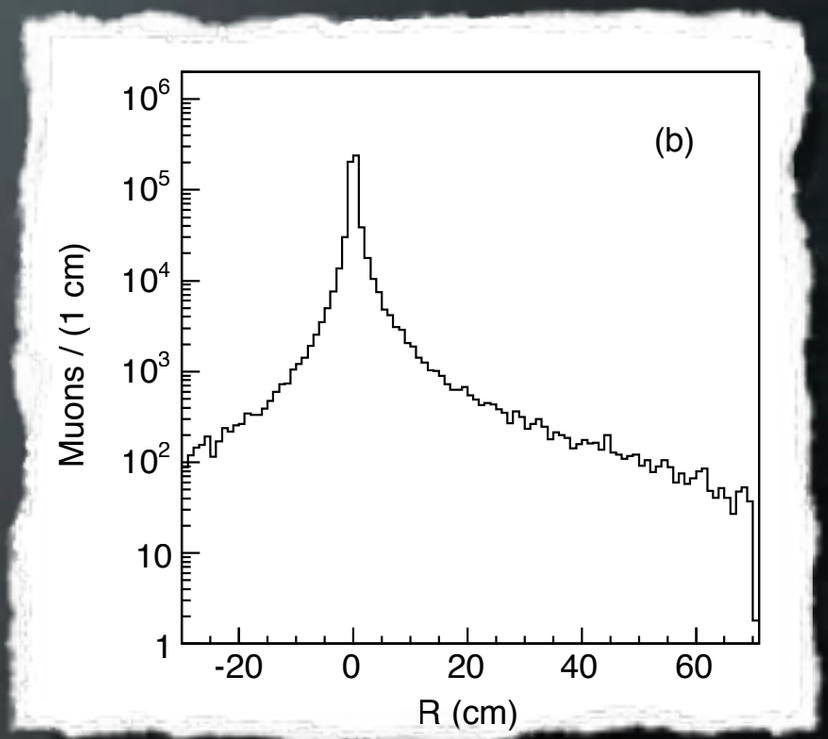




Invariant mass and impact parameter distribution for opposite-sign muons.

# But is it real?

## Could it be secondary interactions?

- Interactions with the detector volume
- e.g. detector support structure
- Signature: spikes in distance to reconstructed vertex
- Appears to be negligible.



# But is it real?

## Does anything else fake multiple muons?

- All of the previous points could plausibly be a conspiracy of Monte Carlos, experiment
- But these backgrounds would not account for the additional number of real muons (2x QCD)
- Apply tight SVX to multi-μ sample,
  - efficiency drops from 0.193 to 0.166
  - QCD fakes have much fewer additional muons, would expect efficiency to increase to 0.244 (QCD expectation)

# But is it real?

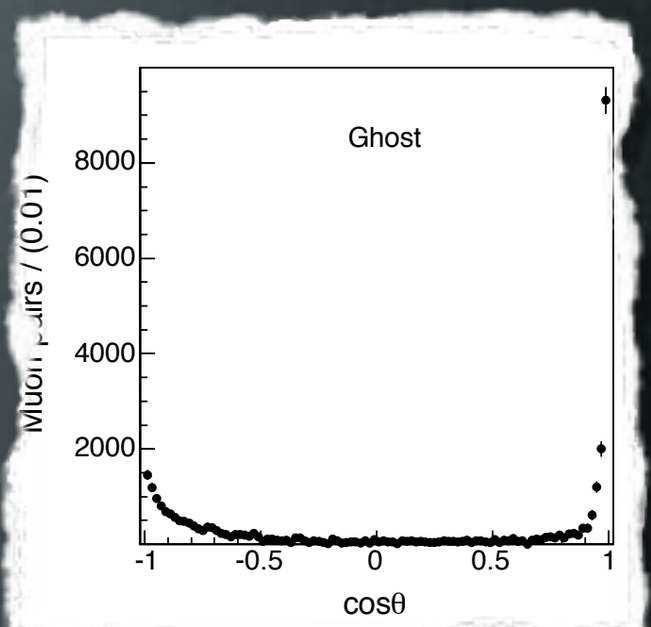
## Does anything else fake multiple muons?

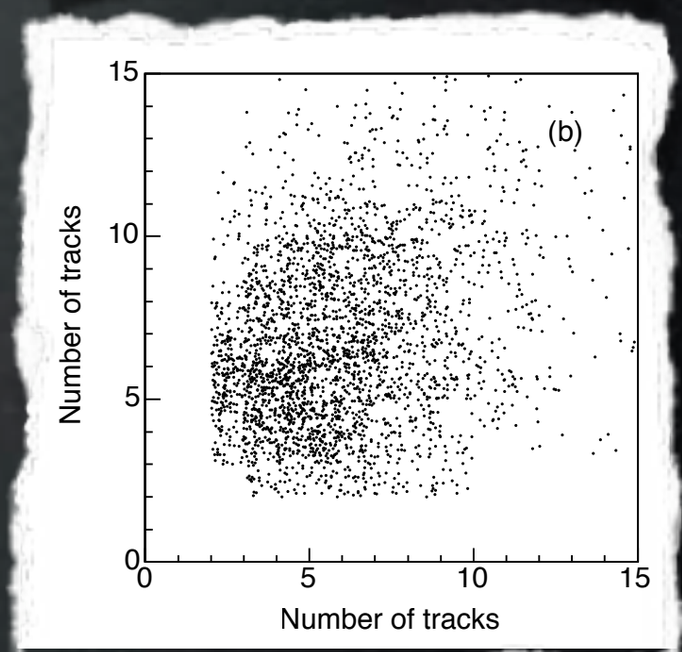
- In a cone with $\cos\theta < 0.8$
  2x as many tracks, 4x μ

- "Surprisingly large number of tracks with $p_T \geq 2$ GeV

- Shapes of impact parameter distribution for 2nd'ry differs from QCD; large tail, like primary μs (correlated)

- Estimate fakes with $D^0$ decays; doesn't match high multiplicity tail of ghosts



# Caveat Emptor II

- When only “best” muon tracks selected, signal significance decreases
- Estimating the fake rate is **hard**
- Tagging events is **hard**; $p_T$ cut only below 3-5 GeV ... muons are relatively **soft**
- Analysis is still ongoing... still a few kinks

# What's next?

- Does **DO** see the same thing?
- B analysis is subtle, don't expect much from the LHC in early years
- B factories?
- Continue **CDF** analysis
  - 1st priority: study electrons

# In one slide...

- CDF **may** have found an excess of high-multiplicity, high-impact parameter muons
- Doesn't seem to be background, but this has **not** yet been ruled out.
- Analysis is **ongoing**.
- Model-building "circus" has already begun (prematurely?)

# Paper trail

- Phys. Rev. D **77** 072004 (2008)
  Main study using tight vs loose SVX

- arXiv:0810.5730
  Model-building paper...