A Tutorial on CDF Muon Identification

Tom LeCompte

Argonne National Laboratory

CDF Bottom Group Meeting

27 July 2001

Outline

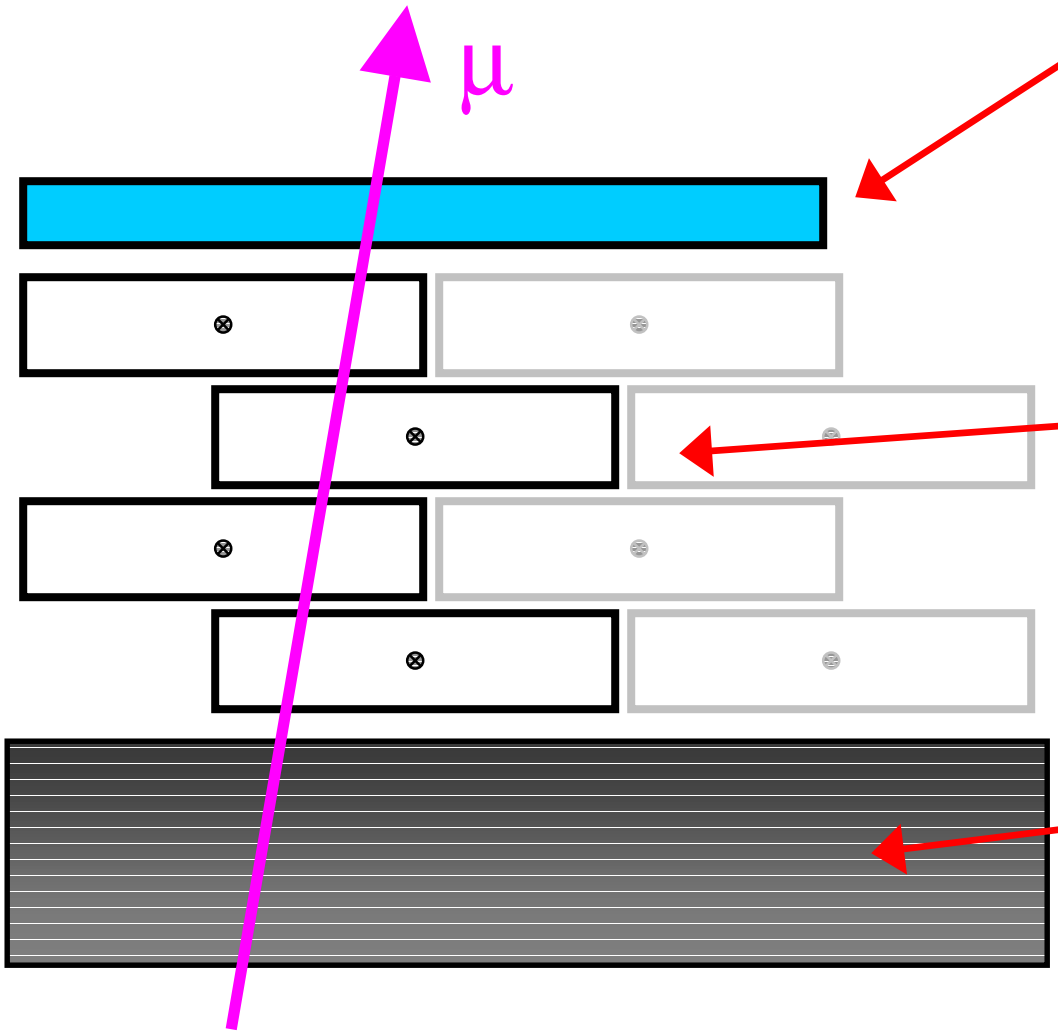
- Muon Detection in a Nutshell
- Geography of the Muon Detectors
  - An introduction to the alphabet soup
- What the muon system tells you offline
- Introduction to triggering

Caveat: This is intended as an introduction. It's not complete, and there are places where I oversimplify. Think "Halliday and Resnick" – it doesn't cover relativity, and it doesn't cover quantum mechanics, but that doesn't mean it's not useful.

Muon Detection 101

- **There is no such thing as a muon detector.**
  - A “muon detector” is a charged particle detector behind lots of material.
    - The material acts to absorb hadrons.
    - Anything left “must be a muon”.
    - Muon purity can be improved by increasing the amount of absorber.
      - **This costs money (steel is not cheap, especially after you assemble it into a shape useful for the detector).**
      - **This ranges out low momentum muons – for central muons, this imposes a p_T cut.**
  - This fact drives much of our design choices and backgrounds…more later in the talk.

A Prototypical Muon Detector System

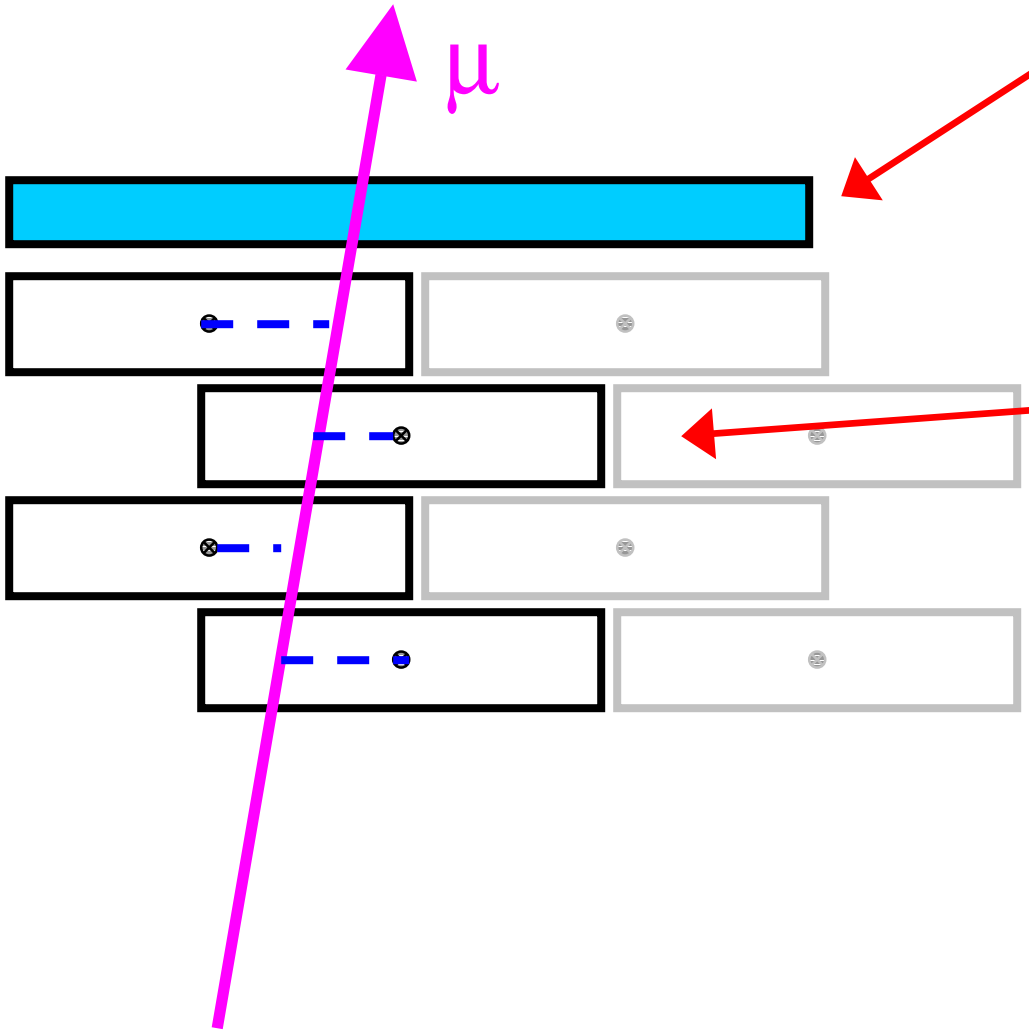


A scintillation counter

A "stack" of four single-cell drift chambers

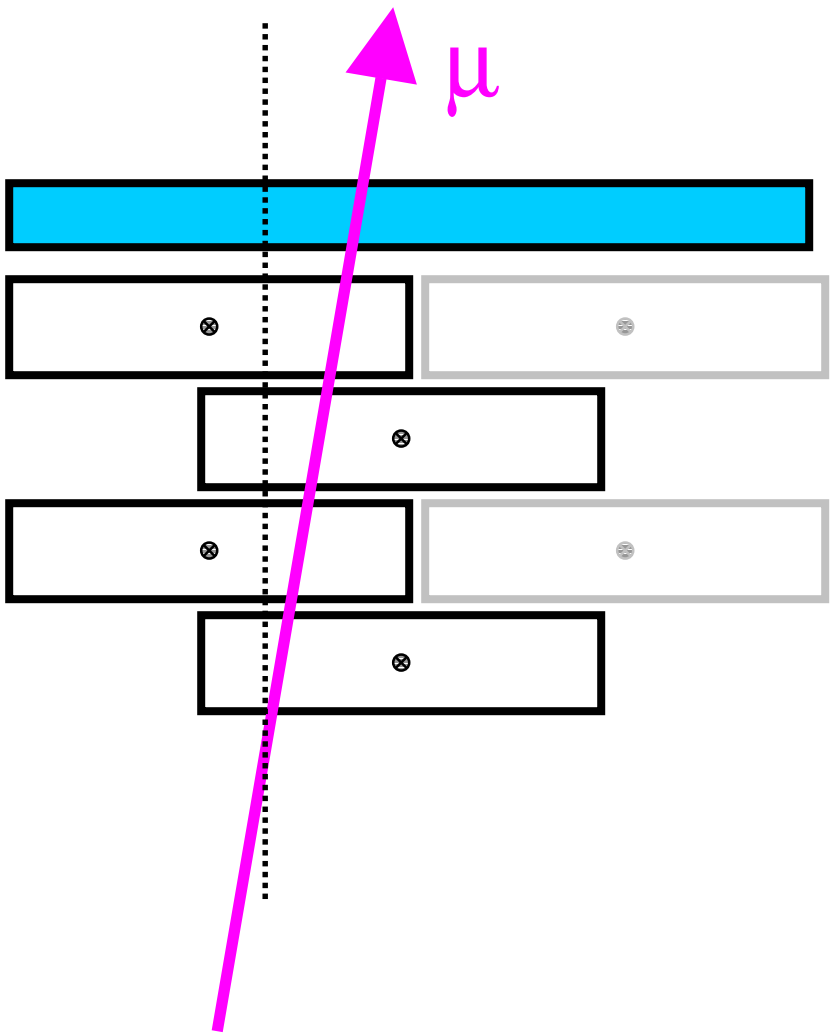
A steel absorber

Detector Measurements



- Scintillator:
  - Time of Flight
  - Light produced (not used)
- Chambers
  - Drift times from the wires (blue dashes):
    - Allows extraction of “stub” position and angle from radial
    - See next slide
  - Charge deposited on each wire

"Stub" Parameters

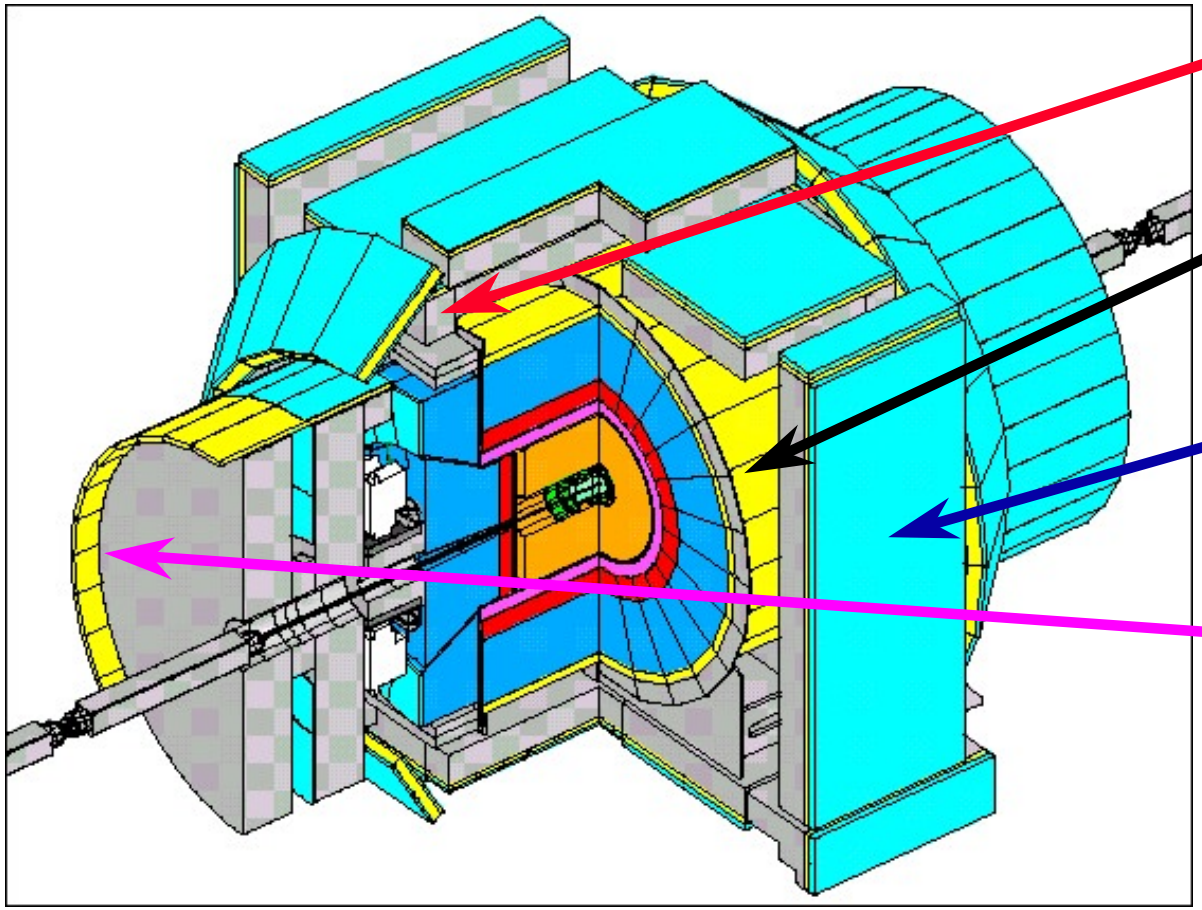


- A "stub" is a short track in the muon detectors.
- Position of the stub in the r-ϕ plane (x)
- (Sometimes) position of the stub in the r-θ plane (z)
- Slope of the stub with respect to radial (x')
  - This is proportional to ~1/p_T
  - Sometimes z' is available, but it's unlikely to be very helpful
- t_0 from the counters

Muon Backgrounds

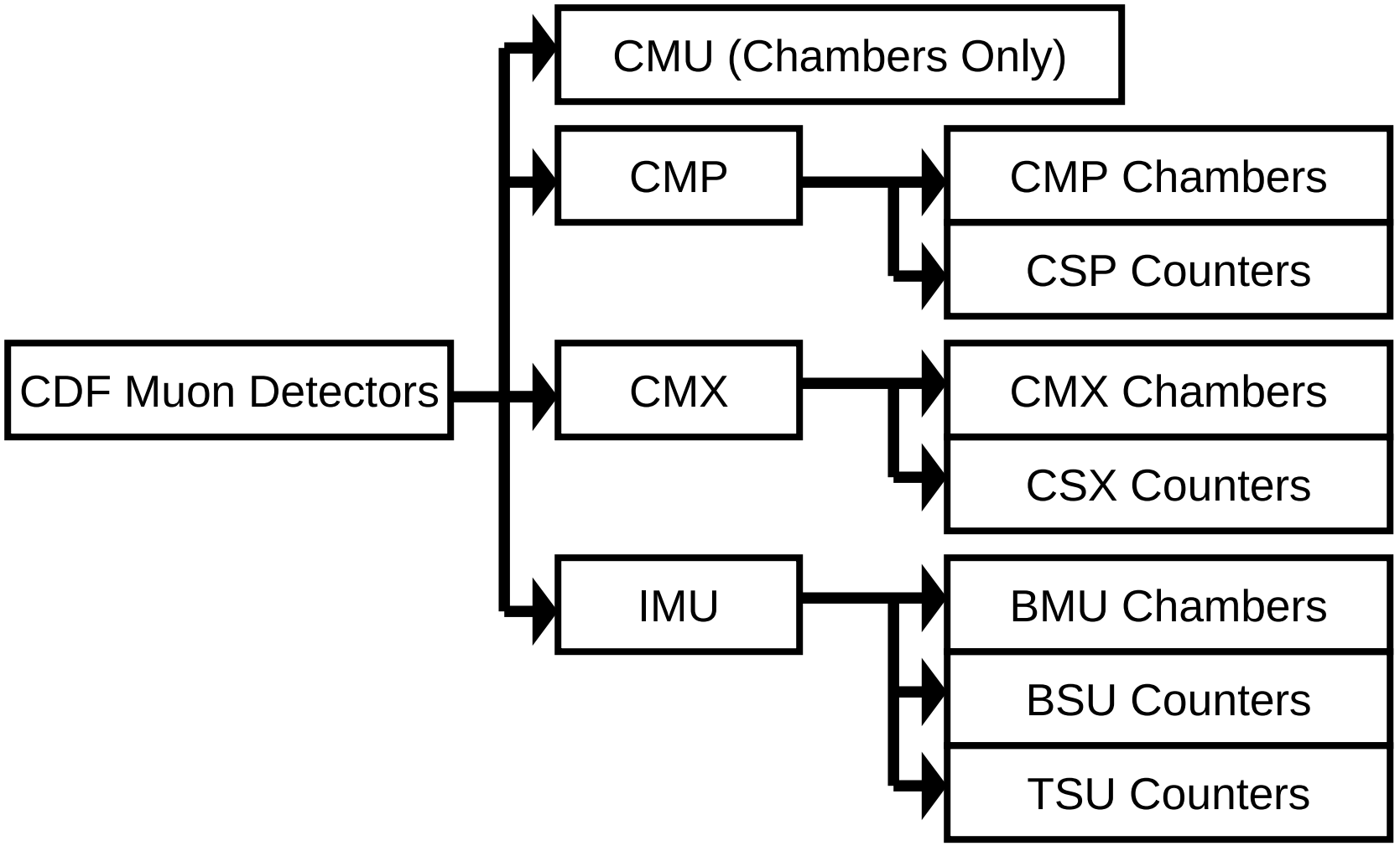
- Hadrons
  - Not many hadrons will mimic a muon, but there are a **LOT** of hadrons
  - Punch-Through
    - Often separated into the cases where the hadron doesn't interact and where it survives the interaction(s). Sometimes you will hear the term "sail-through".
  - Decays In Flight
    - Muons from decays of pions and kaons
    - I have argued, sometimes successfully, that these should not be called "fake muons". They are real muons, simply not from a source we are interested in. "Background" is a better term than "fake".
- Cosmic Rays
  - More of an issue with rare event searches than with *B*'s
- Secondary particles (see CMX section)

Basic Geography

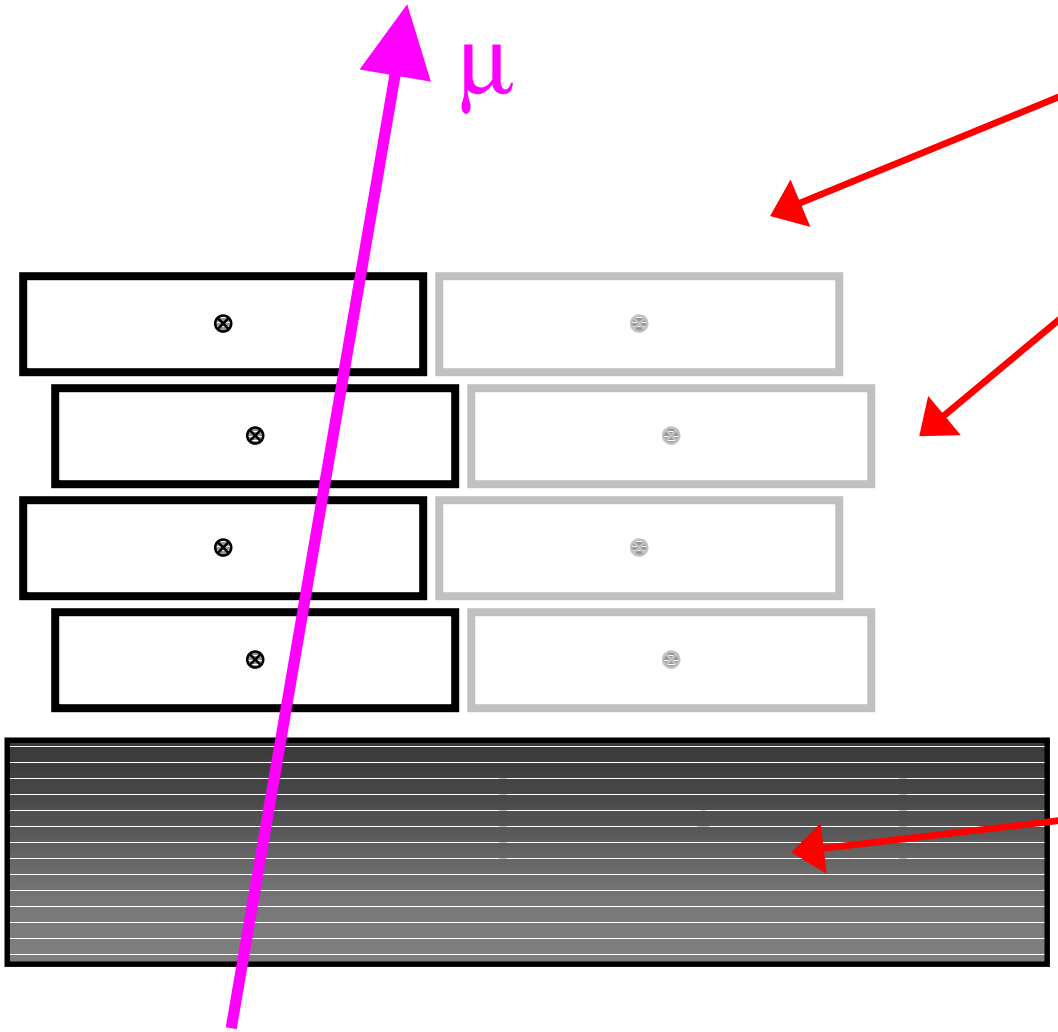


- **C**entral **M**uon eXtension
- Central **MU**on chambers
- **C**entral **M**uon uPgrade
- **I**ntermediate **MU**on

Muon Hierarchy



Central Muon Chambers (CMU)



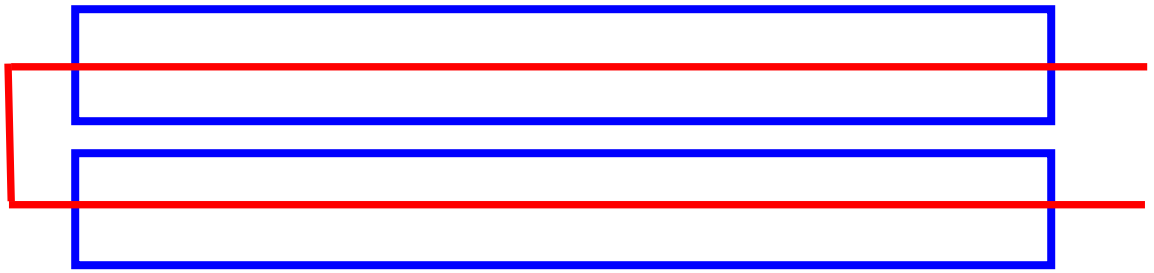
- No scintillation counter
- A “stack” of four single-cell drift chambers
  - Note that the “stagger” is less than half a cell
  - Adjacent cells are ganged together
- Absorber is the central calorimeter

The Real CMU

- 144 chamber stacks
  - 2304 chambers
- Now are inside the central arches, out of view

Installation of CMU

CMU Ganging



- Adjacent chambers in ϕ are ganged together
- The CMU wire is resistive stainless steel
- This allows us to locate the stub's position based on charge division

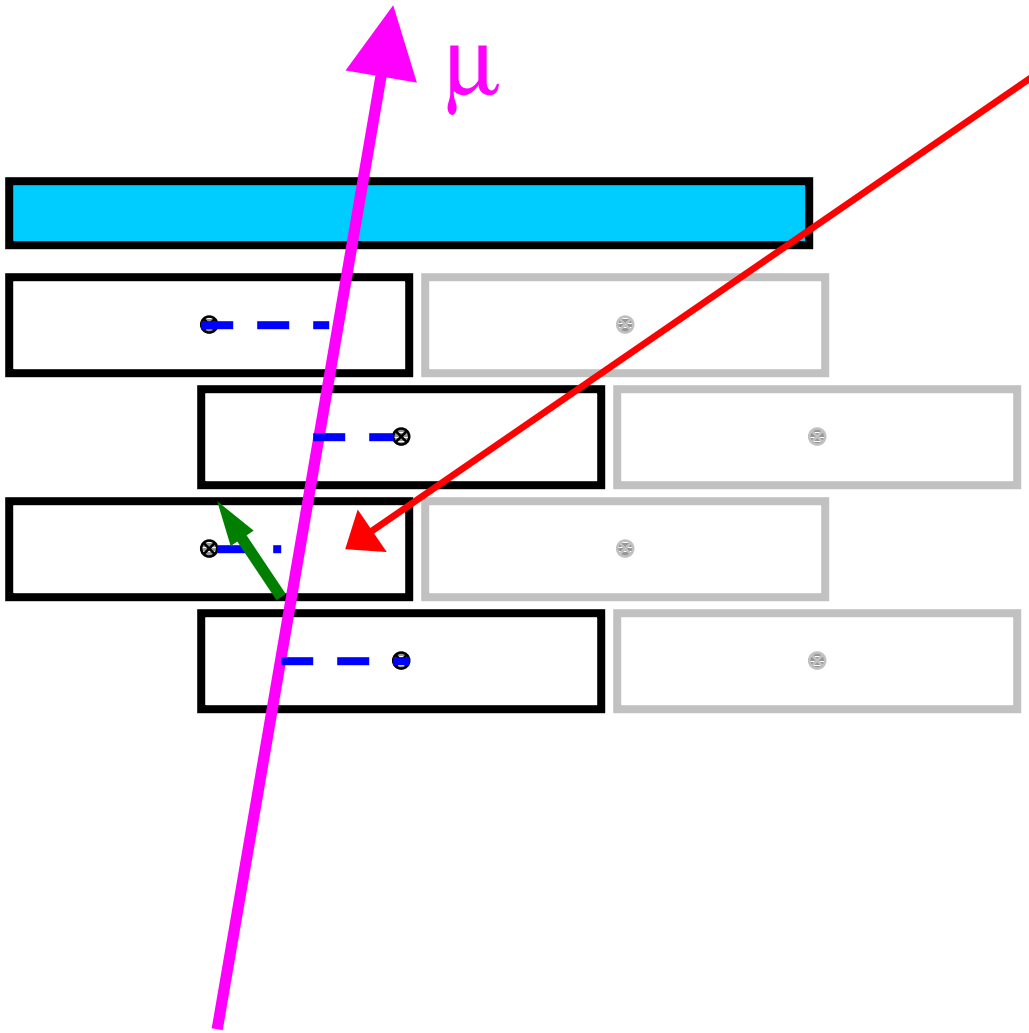
$$z(\mu) \approx z_0 \frac{Q_1 - Q_2}{Q_1 + Q_2}$$

  - actually, we use time-over-threshold to encode charge

CMU Details

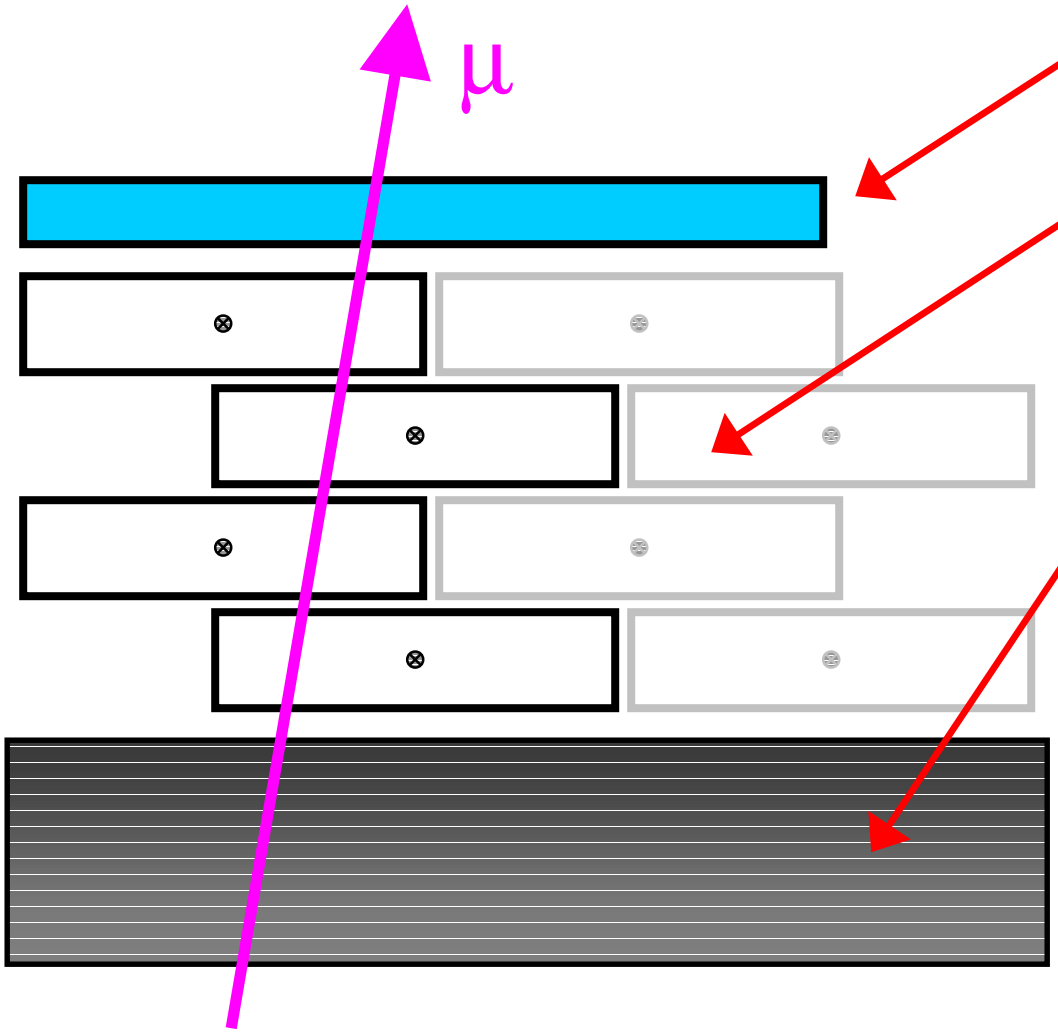
- 2304 chambers
  - Each stack of 4 covers 1.2 degrees
  - Maximum drift time about 800ns
    - Longer than one crossing!
- Available information:
  - *x* and *z* positions of the stub
  - Corresponding slopes of the stub (z slope resolution poor)
    - *x* slope degraded by delta rays ~10% of the time
  - No scintillator, so there is no timing information
- Behind 4.7λ of material
  - Punchthrough is a significant background

Delta Rays



- Here a δ-ray is produced in the second chamber
- It can mask the muon hit
  - Easier to do in the past when we had single hit TDCs
- Apart from degrading the stub because of a wrong hit, a δ –ray can also foul the pattern recognition
  - For example, it could cause the fit to use a different (and incorrect) choice for the L-R ambiguity

CMP/CSP



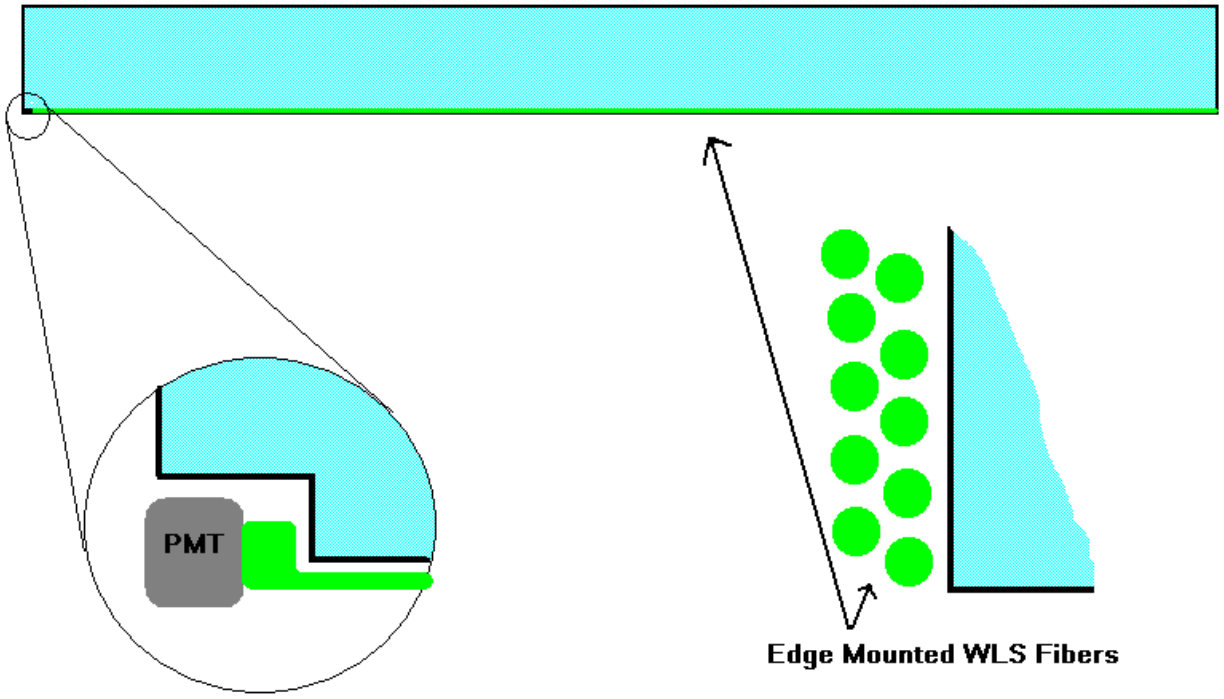
- CSP counter
- A stack of four single-cell drift chambers
  - ½ cell staggered
- Additional steel absorber
  - Top and bottom uses the magnet return yoke
  - North and south use 2 foot thick steel walls

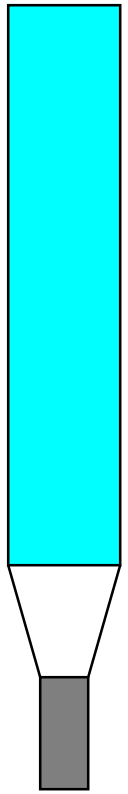
CMP/CSP Details

- ~1200 chambers.
  - Each stack of 4 covers 6 inches. Because of the geometry (CMP is a box), this doesn't correspond to anything simple in terms of ϕ or η.
    - Also, an "η gap" is opened up at various ϕ locations
  - Maximum drift time about 1700ns
- ~300 counters
  - Each counter has the width of two stacks, but is half as long: provides crude *z*-information (east or west)
- Available information:
  - *x* position of the stub – no *z* position (other than E or W)
  - *x* slope of the stub
    - So far as I know, this has never been used, because the orientation of the chamber stack with respect to the muon trajectory is made complicated by the box geometry
  - Crossing identified with the scintillator timing

Muon Counter Design

50% of counters use this WLS design





(Even the conventional design has a row of WLS fibers – this was done to improve the light yield as the counters aged)

The remainder use a conventional design

The Effect of the CMP

- When requiring CMP confirmation to a CMU muon, the purity increases by a factor of 10
  - Why not 20? That's what we calculated before we built the CMP. The error we made was that we didn't consider "mixed" punch-through and decays in flight: where the hadron punches through CMU and then decays en route to the CMP. (There is enough space to park a Genie lift)

- The p_T threshold increases from 1.4 GeV to between 2.0 and 2.2 GeV, depending on position

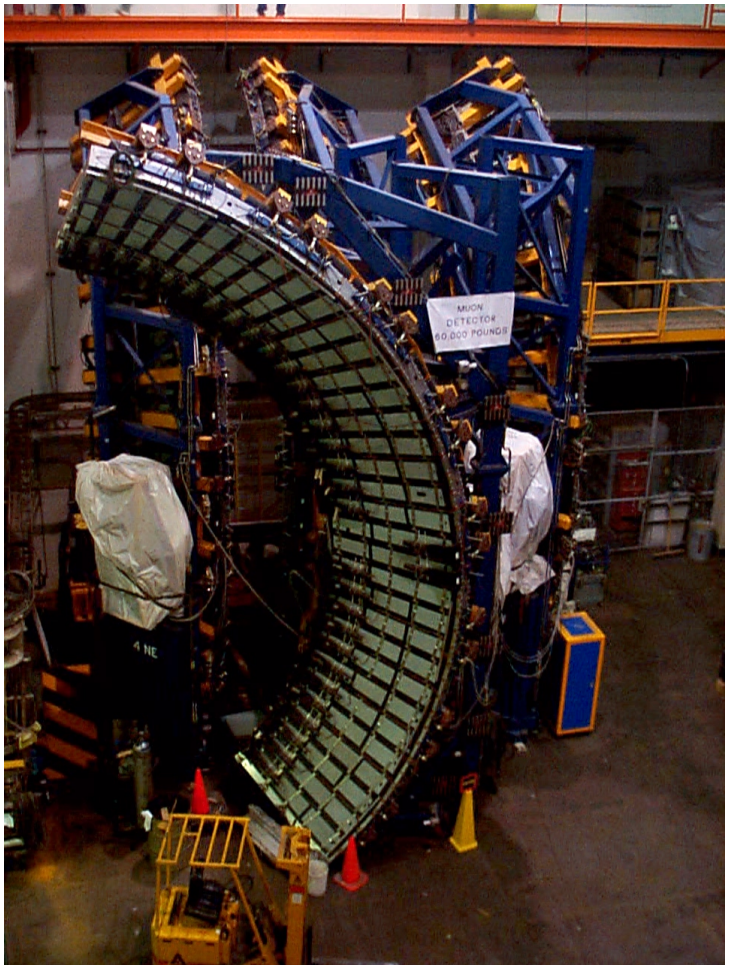
The CMX

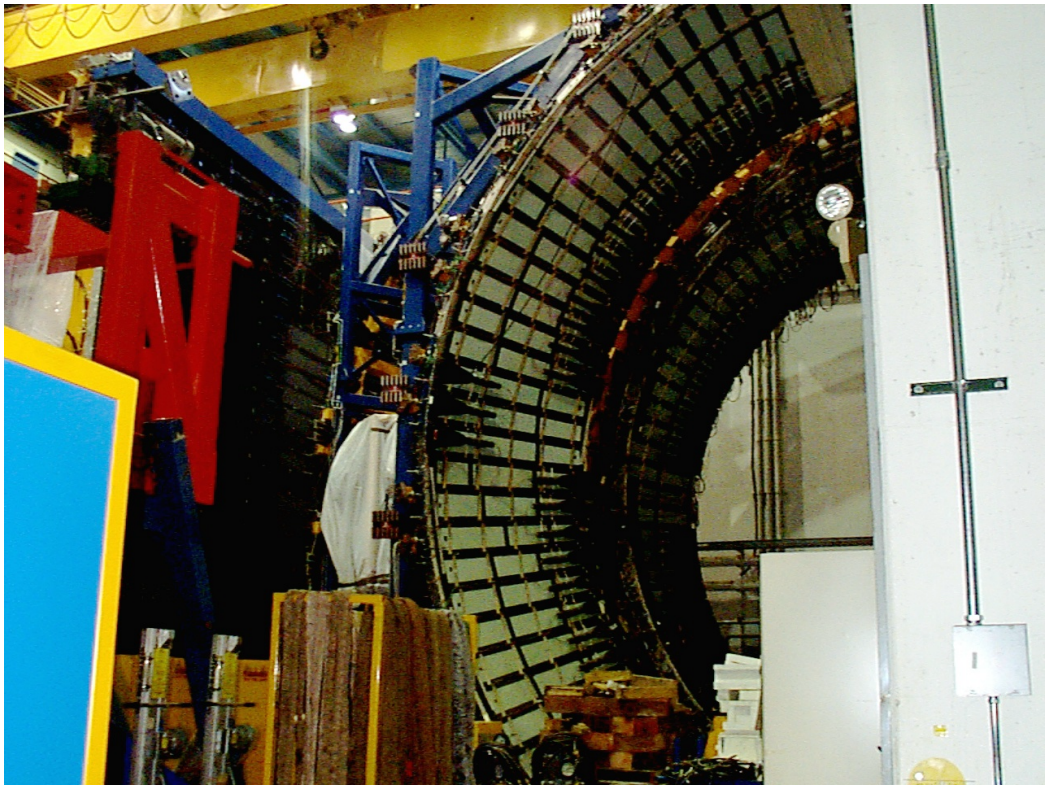
- CMX chambers are identical to the CMP, except
  - They are shorter
  - They are arranged in a frustum of a cone, rather than a box
  - They have two scintillators rather than one, and they runs the length of the chambers
- They are attached in several structures in CDF:
  - The four arches (covering from the floor level to within 15 degrees of the top)
  - The “keystone” covering the top 30 degrees on the west side.
    - There is no space on the east side because of the magnet control dewar
  - The 90 degrees at the bottom, called the “miniskirt”
    - In four 10 degree and four 30 degree pieces
    - A gap at the very bottom for personnel and silicon cooling access.
- They cover the eta range from 0.6 to 1.0

CMX/CSX Details

- ~2170 chambers.
  - Maximum drift time about 1700ns (same as CMP)
- 324 counters
  - Each chamber stack is sandwiched between two counters (1/2 cell staggered). The miniskirt arrangement is different because of space restrictions.
- Available information:
  - *x* and *z* position of the stub
    - *z* position is done with stereo – see next slide
  - corresponding slopes of the stub
  - Excellent scintillator timing
    - Mean timing allows timing to within about 3 ns. This allows us to do time-of-flight to reject particles that did not come from the primary interaction.
- p_T threshold varies with position, from 1.4 to about 1.8 GeV

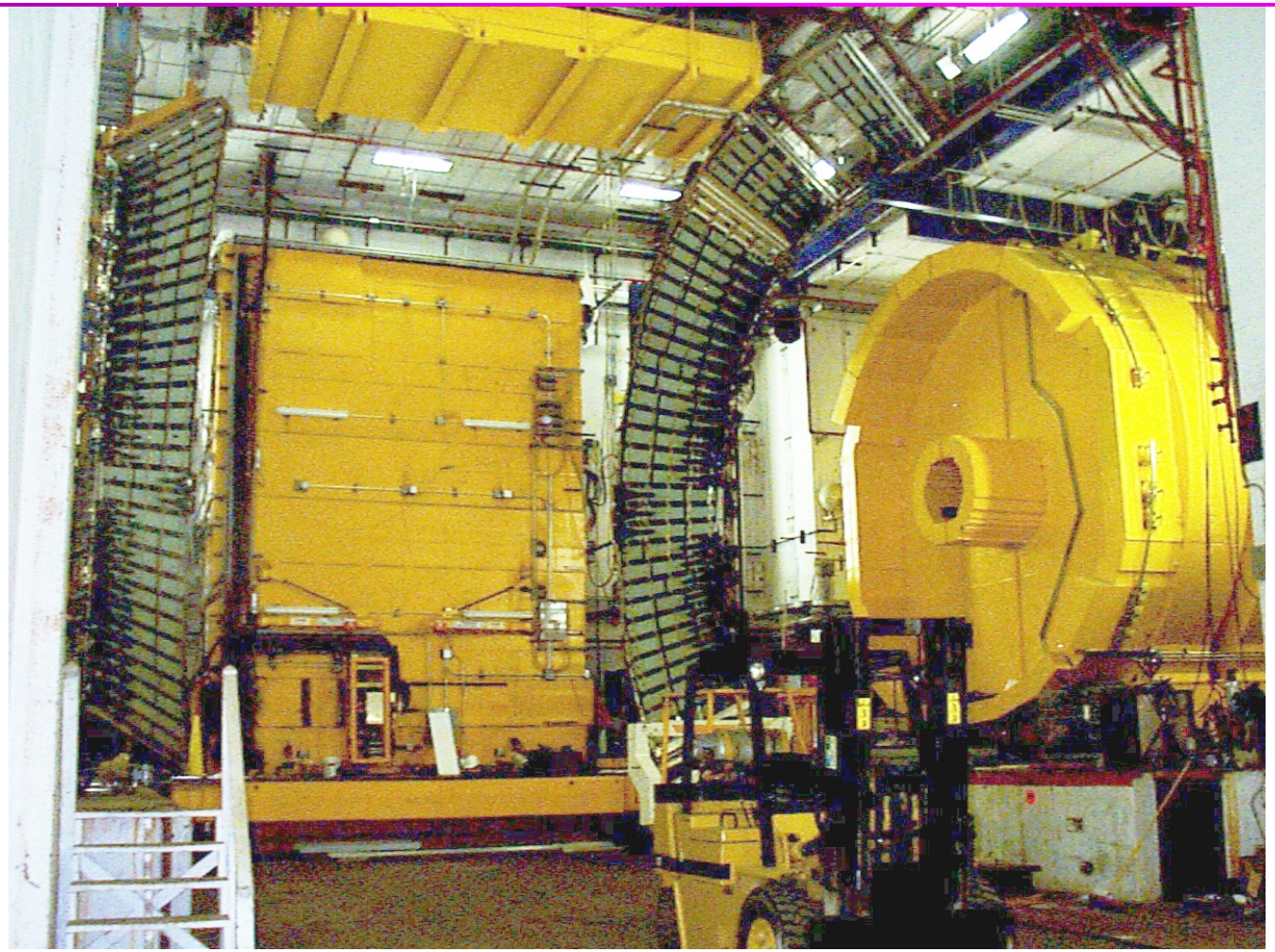
CMX Arches

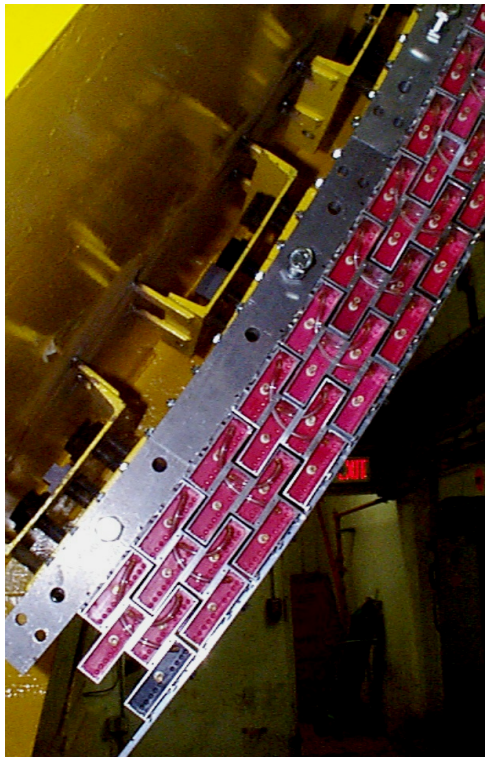




CMP North Wall is in the background

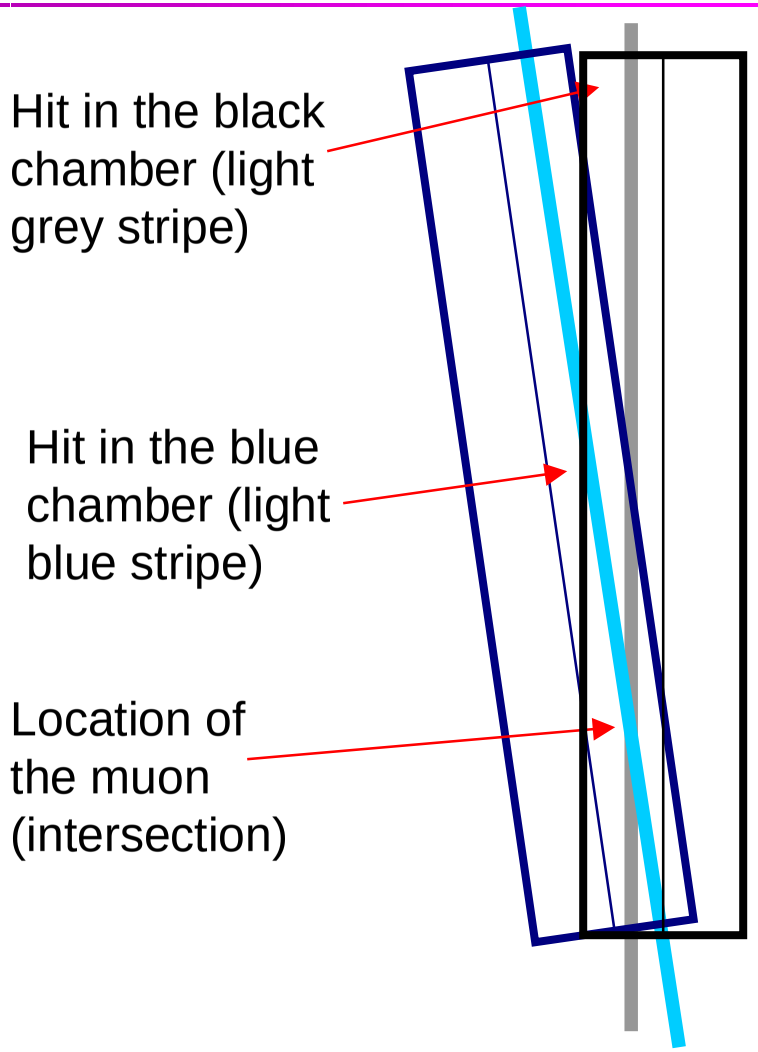
CMU, CMP and IMU





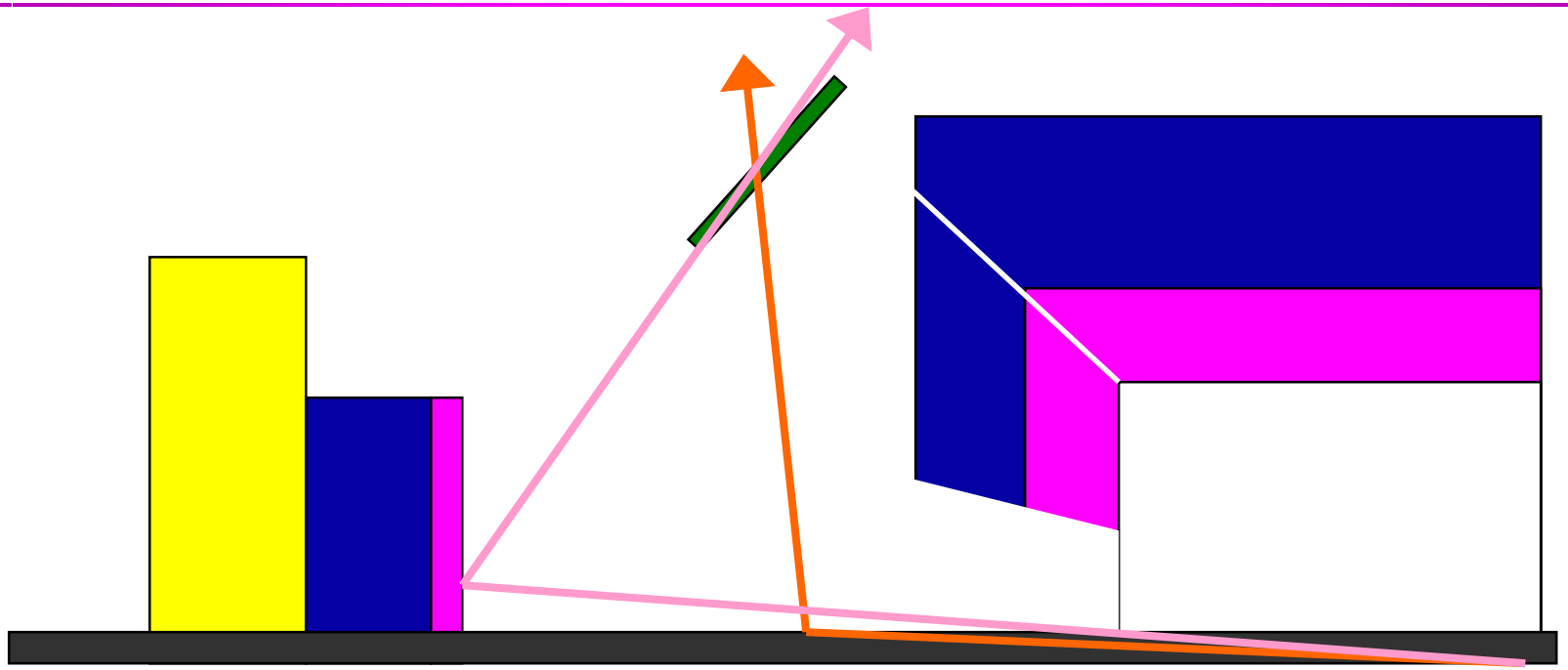
IMU Chambers
(similar to CMP/X)

CMX Stereo/z-view



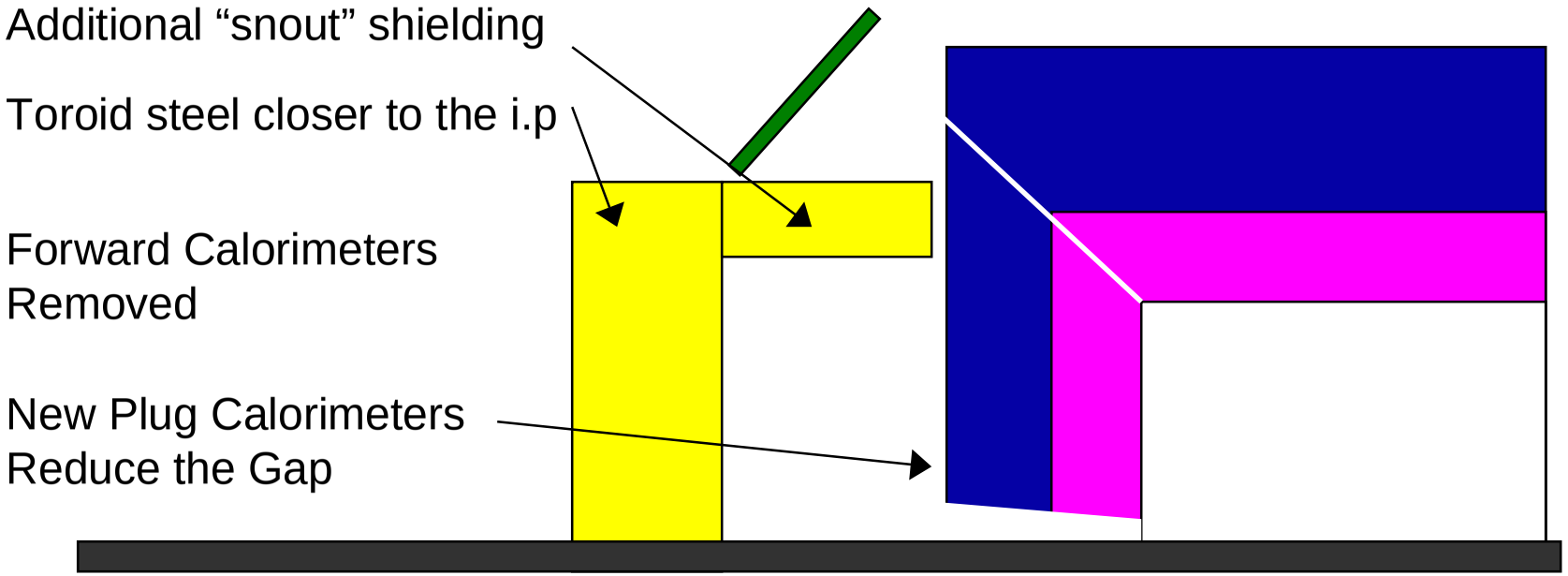
- The CMX is on a cone, so adjacent chambers are not parallel. This allows one to use stereo to find the z-position (and in principle, slope) of a stub.
- Because of the small angle (of order a degree) this method is extremely sensitive to the details of the drift model and other position fine-tuning.

Run I CMX Background



- The background was due to secondary particles that hit the CMX, not primary muons.
  - The path and thus flight time was longer, so scintillator timing was able to reject this background

Run II Improvements



- Monte Carlo calculations suggest that the background will be a factor 77 smaller. This is probably overoptimistic, since there may be other sources that were hard to see on top of the Run I background.

The IMU

- The IMU will be discussed in detail in a future talk.
- What you need to know is
  - It covers from η=1.0-1.5
  - There is a lot of steel (800 tons!) which makes the p_T threshold high (about 2.1 GeV, with some variation)
  - Getting a large number of J/ψ's was never a priority in its design. We felt that if there was enough bandwidth to get a lot of IMU dimuons, it made more sense to lower thresholds in the central region. This was due to the COT's tracking coverage.
  - Flavor tagging central *B*'s with an IMU muon was a priority, however.

Triggering

- This is a subject worthy of its own talk.
- Level 1
  - We can combine one or more of the following
    - Chamber stubs: CMU, CMX, IMU (with a slope/p_T cut) or CMP (presence only)
    - Scintillators: CSX, CSP, BSU, TSU (identifies which beam crossing caused the interaction, and some TOF is possible to reject secondary interactions and cosmic rays)
    - Tracks: XFT tracks, either long ($\eta < 1.0$ or short $\eta < 1.2$). A p_T cut can be applied, and the timing of these tracks also identify which crossing produced the tracks
  - As an example, a J/ψ trigger might require two low p_T stubs plus one XFT track pointing at each stub
- Level 2
  - Collateral damage from the TDC crisis. There is no muon Level 2 now, or in the near future
- Level 3
  - Anything you can do offline, you can do in Level 3

Final Thoughts

- The CDF muon system has obviously evolved over time, and many of the developments were driven more by “how can we improve what we have” rather than “what would we build if we started from scratch”.
  - I am available to give talks on this development anywhere where the climate is better than Chicago’s.
  - That makes things a little more confusing than they would otherwise be.
- Nevertheless, I think we have the finest muon system anywhere
  - This is not just parental pride – I invite comparisons
  - What we have is very well suited for *B* physics
  - However, it’s going to take some effort to understand and characterize the new features and abilities of this system – volunteers are sorely needed: please come to the Wednesday muon software meetings!