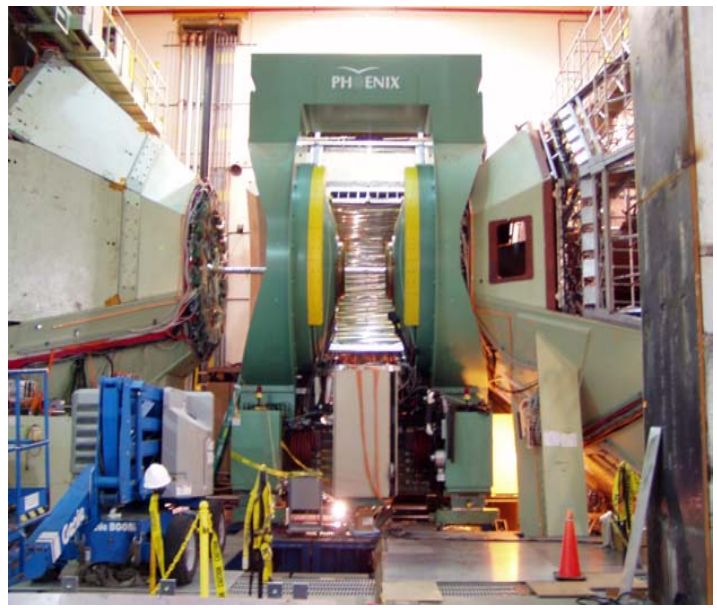
# Status Report on the PHENIX Muon Spectrometers

*Mike Leitch, P-25*

- **History of Muons in PHENIX**
- **Muon arms: Commissioning & Performance**
- **Plans for the Au-Au run in 2004 and beyond**

PHENIX μ Arms



# Brief History of Muons in PHENIX

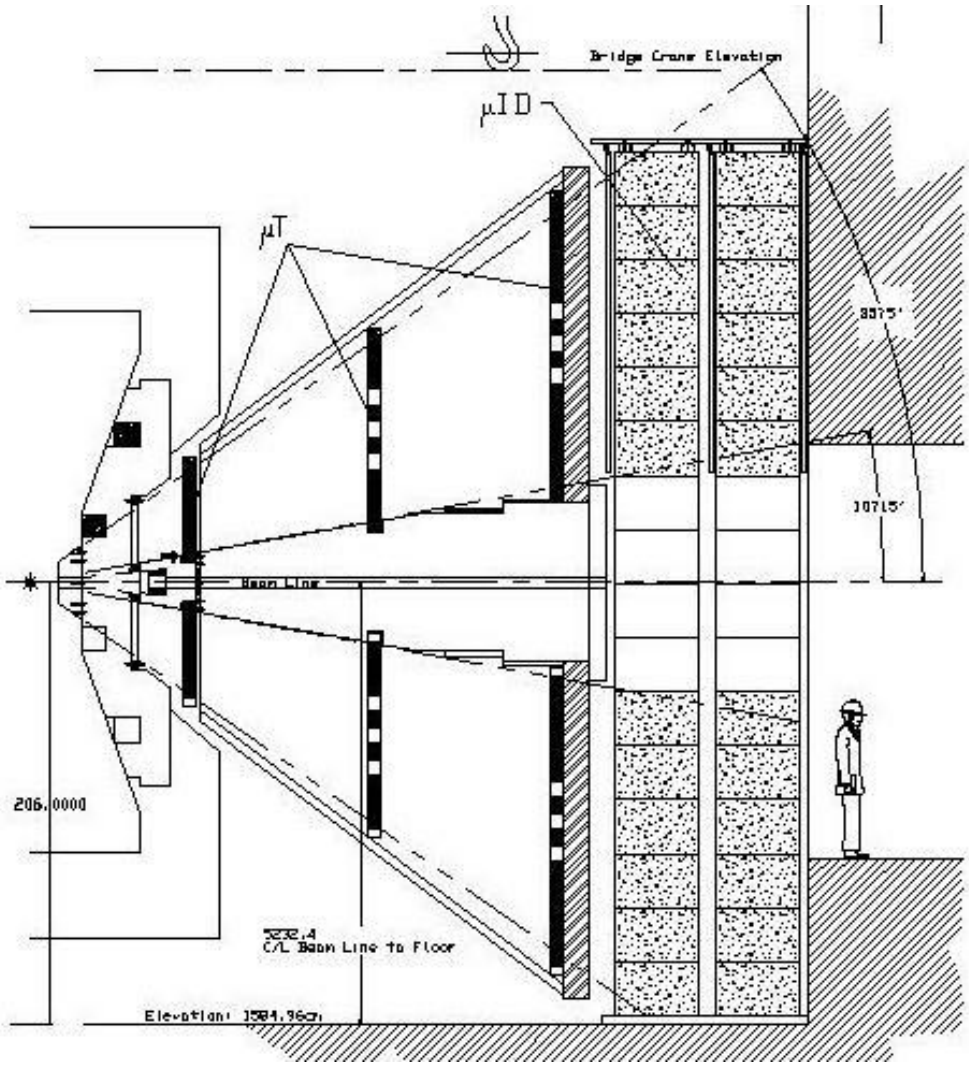
- 1990: LANL decision to enter RHIC, FNAL E789 + CERN NA44/HELIOS (Jacak, Leitch, McGaughey, Moss)
- 1991: Dimuon proposal, first and last PAC review: PHENIX rises from the ashes, concept of piston magnet for muons
- 1992: PHENIX CDR approved but Deferred Muon instrumentation!
- 1993: Redefined MUID detector concept, concrete → steel, huge number of pads → hodoscope style
- 1994: Japanese join : bring RHIC spin & South muon arm
- 1996: AEE funding for North arm
- 1998: Both MUID built by ORNL
- 1999: start MUTR South construction
- 2001: 1st run with South muon arm - 200 GeV Au-Au & p-p
- 2002: North arm installed
- 2003: 1st run with both arms – 200 GeV d-Au & p-p
- 1st J/Ψ paper from RHIC submitted to Physical Review Letters July 8 2003!

# Cast of Participants

*Glenn Young*
*CD4 review*

- Magnet/Steel
  - LANL, RIKEN, LLNL, BNL, PNPI
- Detectors
  - Muon Tracker
    - LANL, UNM, NMSU, ACU, Yonsei, Seoul, Korea U, BARC, Kangnung, Tokyo I.T., RIKEN, Myongji
  - Muon Identifier
    - ORNL, RIKEN, CIAE, UT, Kyoto, Tokyo IT, KEK, Peking U.
- Engineering & Safety
  - BNL, PNPI, LANL
- Electronics
  - Muon Tracker
    - LANL, Orsay, Palaiseau, Nantes, Clermont-Ferrand, Saclay, Cyclotron Lab Korea
  - Muon Identifier
    - ORNL, UT
- Triggering
  - ISU/AmesLab, ORNL, Columbia, LANL
- Software
  - LANL + everyone else

# PHENIX CDR, Jan. 1993




One Muon Arm with Drift Chambers and Concrete Absorbers.

Design adapted from Dimuon Proposal.

# CDR Muon Physics Program

| Quantity to be Measured | Category* | Physics Objective |
|---|---|---|
| $e^+e^-$, $\mu^+\mu^-$ | | |
| • $\rho \to \mu^+\mu^- / \rho \to \pi\pi$, $d\sigma/dp_\perp$ | BCD | Basic dynamics ($T$, $\tau$, etc.,) for a hot gas, |
| $\omega \to e^+e^- / \omega \to \pi\pi$, $d\sigma/dp_\perp$ | | transverse flow, etc. |
| • $\phi$-meson's width and $m_{\phi \to e^+e^-}$ | QGP | Mass shift due to chiral transition (C.T.) |
| $\phi \to e^+e^- / \phi \to K^+K^-$ | QGP | Branching ratio change due to C.T. |
| $\phi$-meson yield ($e^+e^-$,$\mu^+\mu^-$) | ES | Strangeness production ($gg \to s\bar{s}$) |
| • $J/\psi \to e^+e^-, \mu^+\mu^-$ | QGP, QCD | Yield suppression and the distortion |
| $\psi' \to \mu^+\mu^-$ | | of $p_T$ spectra due to Debye screening |
| $\Upsilon, \to \mu^+\mu^-$ | | in deconfinement transition (D.T.) |
| • $1 < m_T(l^+l^-) < 3$ GeV | ES, QGP | Thermal radiation of hot gas, and |
| (rate and shape) | | effects of QGP |
| • $m_{l^+l^-} > 3$ GeV $\to \mu^+\mu^-$ | QCD | $A$-dependence of Drell-Yan, and |
| | QGP | thermal $\mu^+\mu^-$ |
| $e\mu$ coincidence | | |
| • $e\mu$, $e(p_T > 1$ GeV/c) | QCD, QGP | $c\bar{c}$ background, charm cross section |

* BCD = Basic collisions dynamics. ES = Thermodynamics at early stages.
QGP = Effect of QGP phase transition. QCD = Study of basic QCD processes.

# CDR Muon Arm Event Yields

Table 1: Phenix Muon Arm Accepted events per RHIC Year

| RESONANCE | Min. bias Au + Au | Min. bias p + Au |
|---|---|---|
| $\rho \to \mu^+ + \mu^-$ | 1,100,000 | 920,000 |
| $\phi \to \mu^+ + \mu^-$ | 500,000 | 420,000 |
| $J/\psi \to \mu^+ + \mu^-$ | 1,730,000 | 1,060,000 |
| $\psi' \to \mu^+ + \mu^-$ | 24,200 | 14,700 |
| $\Upsilon \to \mu^+ + \mu^-$ | 4920 | 1400 |
| Drell-Yan $\to \mu^+ + \mu^-$ | | |
| 2 GeV | 216,000 | 87,000 |
| 4 GeV | 30,000 | 12,000 |
| 6 GeV | 6600 | 2600 |
| 8 GeV | 1800 | 740 |
| $D\overline{D} \to \mu^+ + \mu^- + X$ | | |
| 2 GeV | 360,000 | 215,000 |
| 4 GeV | 32,000 | 20,000 |
| 6 GeV | 2600 | 1600 |
| $D\overline{D} \to e + \mu + X$ | 620,000 | 370,000 |

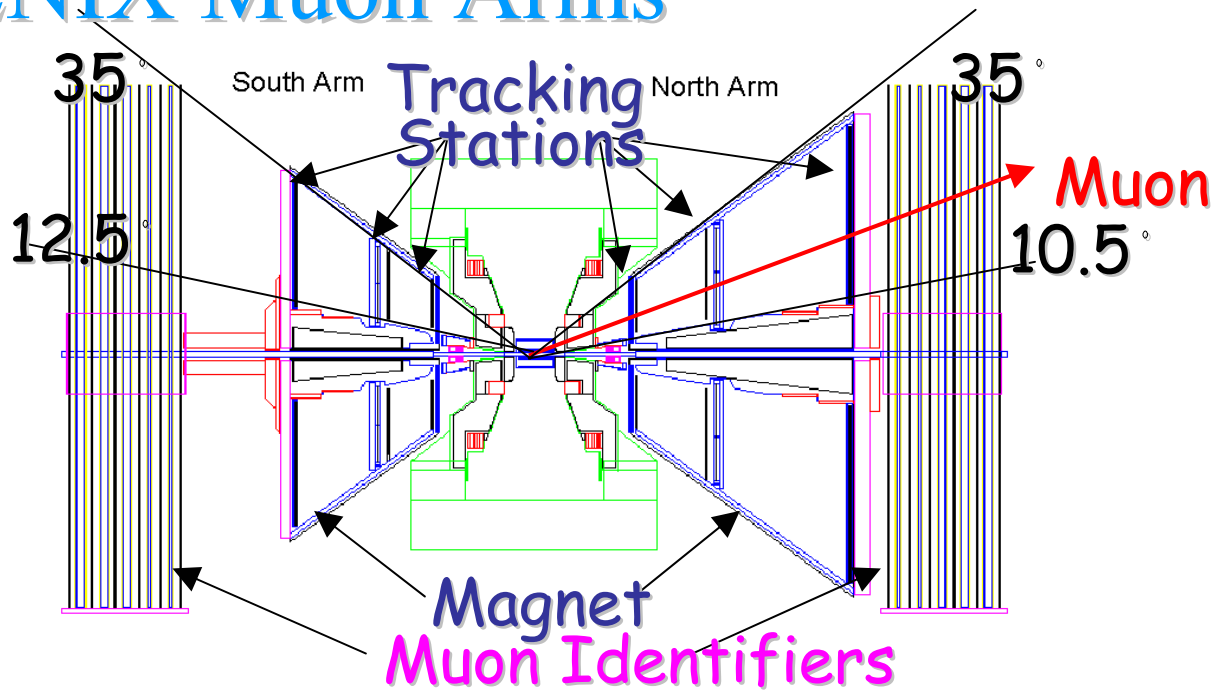
**$10^6$ J/ψ !**

Charm dominates the continuum below 5 GeV.

Yields were computed for 10X RHIC Blue Book Luminosity, per 37 week RHIC Year. Essentially a 10 year program.

# PHENIX Muon Arms

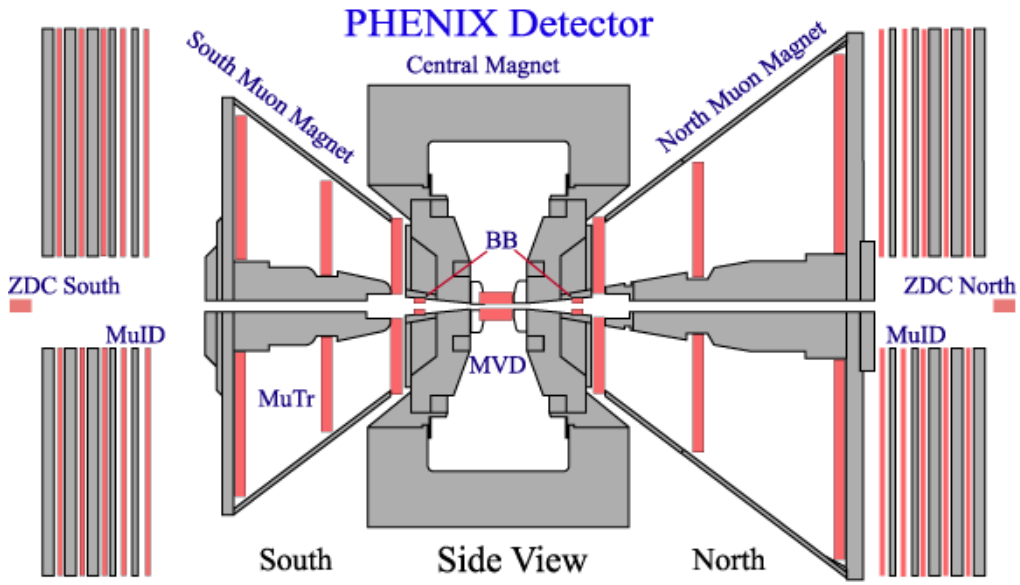
2 Muon Trackers =
2x3 stations
2 Muon Identifiers
= 2x5 planes




South Arm:
Began operations
in 2001-2002 run.

North Arm:
Installed in 2002, run for 2003
d-Au & p-p run.

Acceptance : $1.2 < |\eta| < 2.4$, $\Delta\Phi = 2\pi$
Muon minimum momentum ~ 2 GeV/c




South Muon Arm

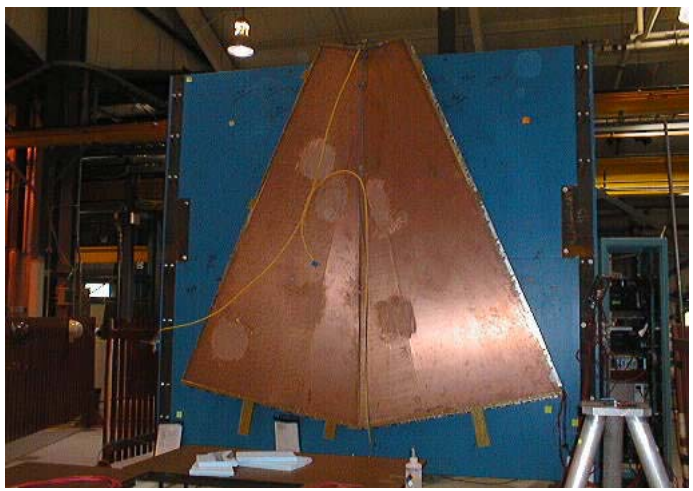

North Muon Arm

# North Chambers and Mechanics

- Tracking chambers – designed at LANL and built by us & collaborators
- Largest operating cathode-strip detectors in the world!

Station 1 Quadrant

Station 2 Octant



Station 3 Octant

Station 2 Support Structure

# Front-End Electronics (FEE) Installation and Commissioning

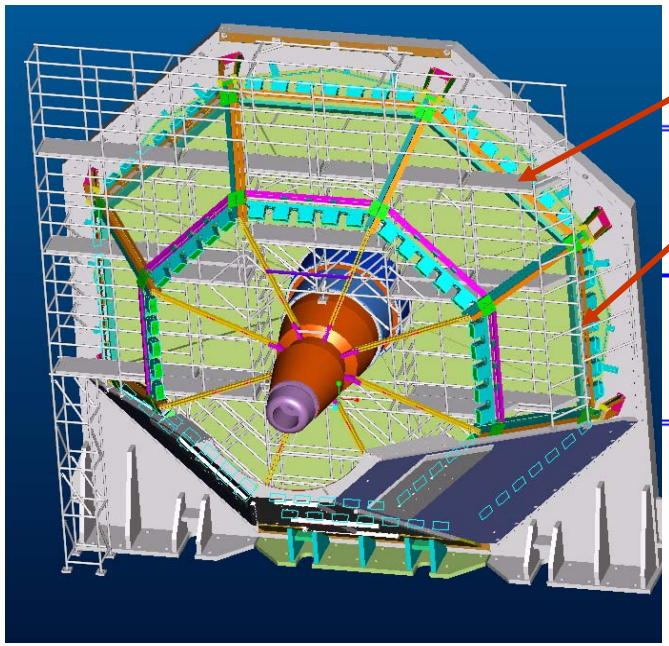
- FEE led, built & installed by LANL for South arm
- Extensive repairs of South FEE made in 2002 shutdown.
- Copy with minor modifications built & installed in North arm with strong contribution from French

Electronics being assembled

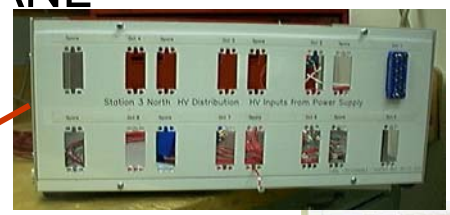
And installed

# Other LANL North Arm FEE Contributions

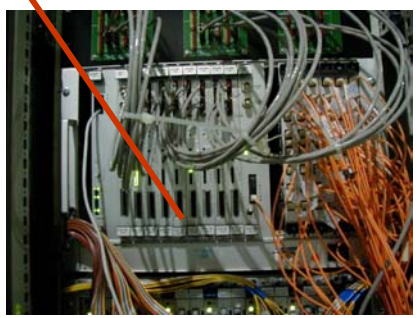
- Mechanical support designed and overseen at LANL, built at NMSU
- Calibration system
- Optical Fiber<-->Copper electronics system
- HV Distribution system designed and built at LANL
- Rack and cable layout completed at LANL



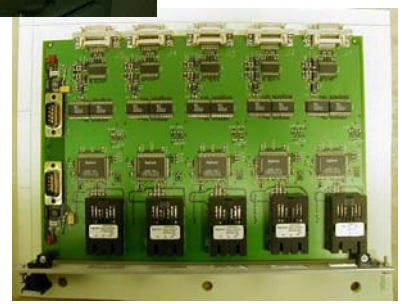
North Magnet Layout and FEE Support Structures



HV dist.

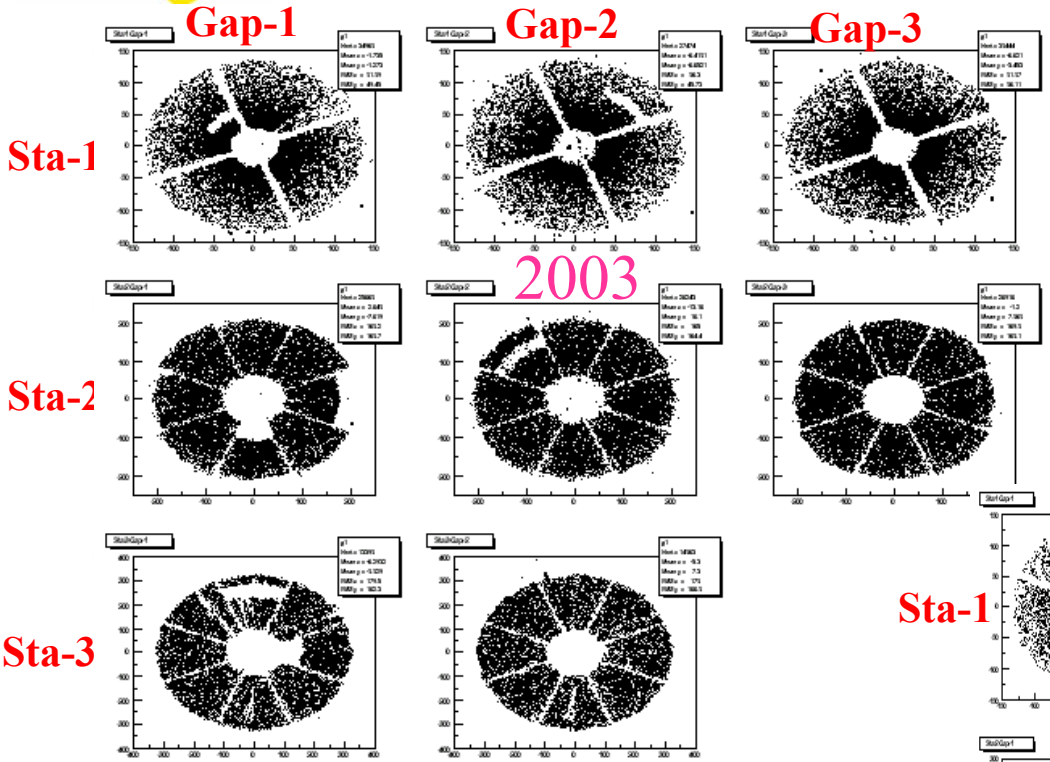


Calibration System



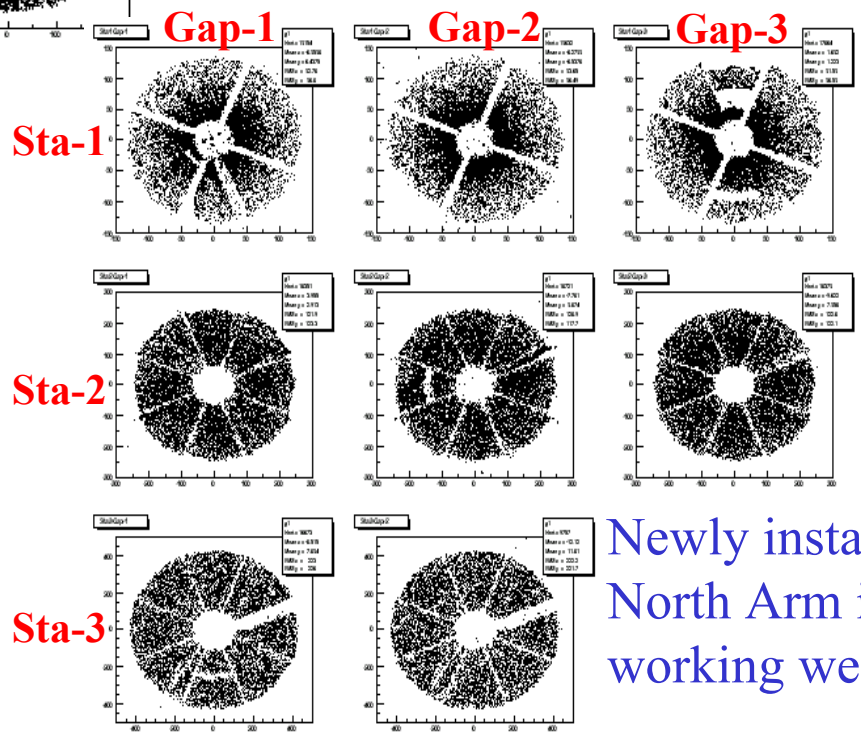
Optical ↔ Copper Translation System

Physics




Radiographs of active area for South arm in run-II. (Three stations with 3 or 2 gaps each)

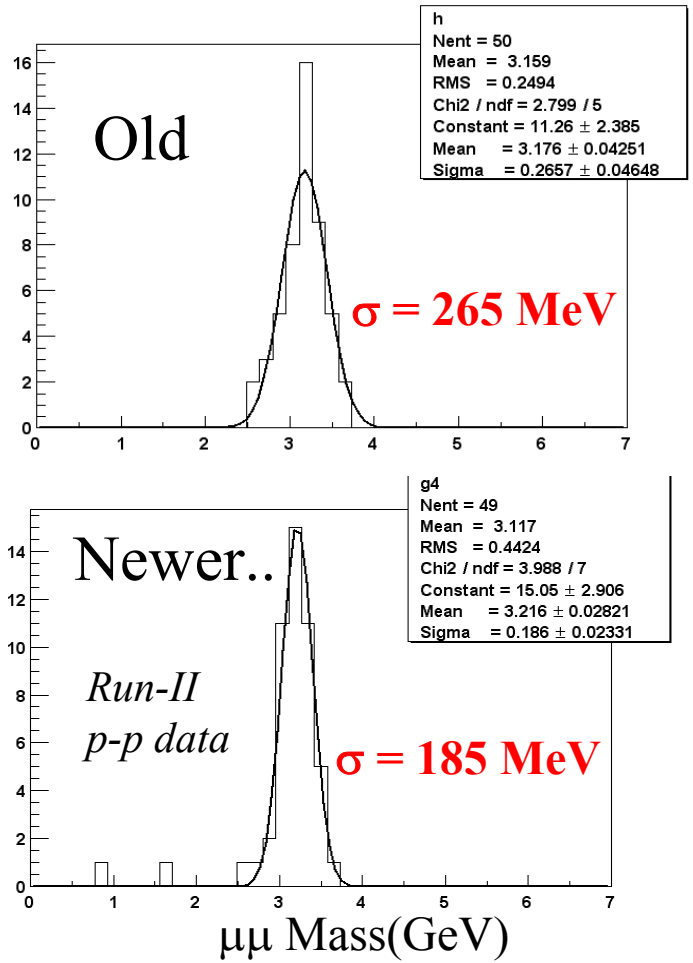
Vast improvement for present (run-III) after extensive repairs to electronics and HV during shutdown




Newly installed North Arm is working well

# Tracking/pattern recognition progress led by LANL

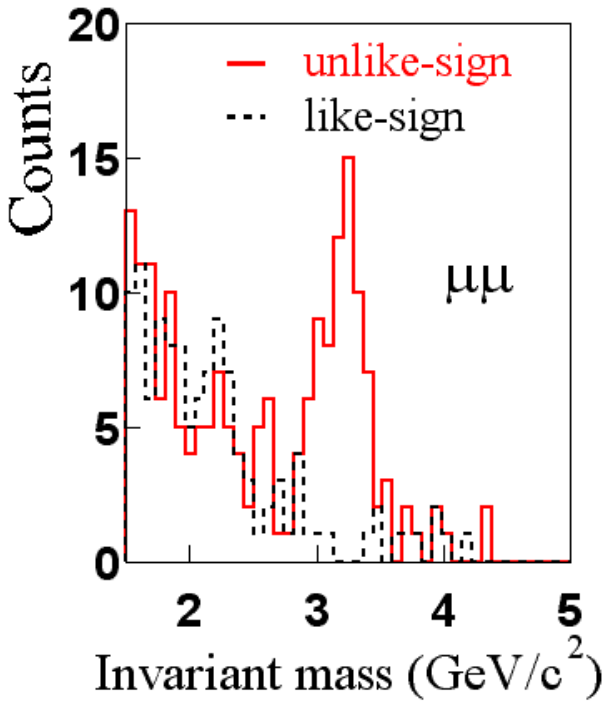
**(We wrote the original code and have led all developments)**



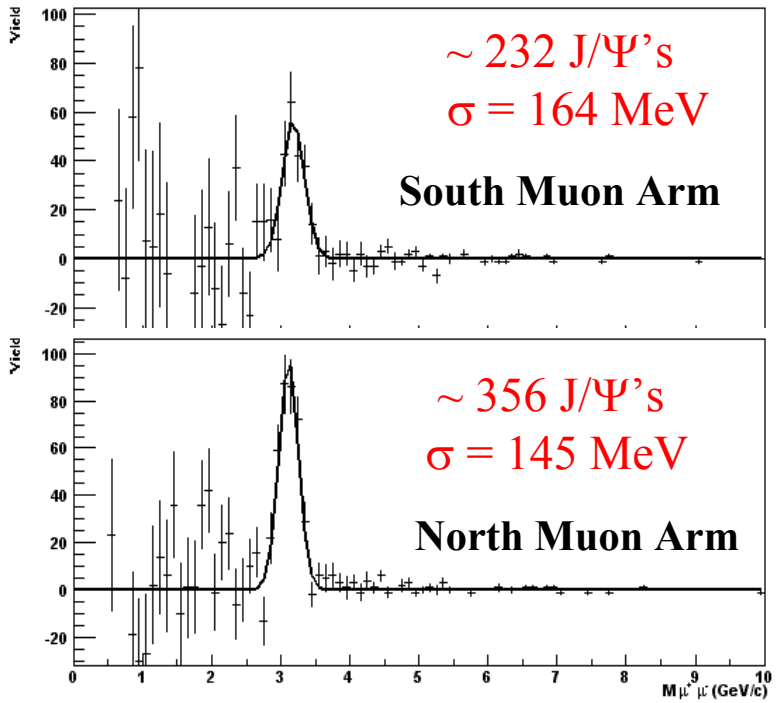

- **Factor of ~1.8 more J/Ψ's for p-p from tuning of pattern recognition software**
  - Better handling of skipped planes
  - Corrections for swapped cables
  - Better projections between stations
  - Important for p-p (not just Au-Au)
  - Realistic sigma's for points in each plane
- Mixing with real events to determine efficiencies more reliably
- Mass resolution and acceptance now agree between simulations and data
- snapshot of J/Ψ during above development at left
- **Final p-p J/Ψ has ~140 MeV resolution (see next page)**

# Run-2 to Run-3

Our total di-muon sample from Run-2 pp with ~65 J/Ψ's




**New results from d-Au collisions should shed light on the question of shadowing for gluons, as well as provide a baseline for high-luminosity Au-Au measurements in the next RHIC run.**




Dimuon Mass (GeV/c)

# Expectations & Plan for 2003-2004 Au-Au Run ("Run4")

- Expected luminosity for ~15 weeks production
  - 315 $\mu b^{-1}$ level-2 trigger sampled & 116 $\mu b^{-1}$ minimum-bias
  - (40% RHIC eff., 50% PHENIX eff., ±30 cm $Z_{vertex}$ cut )
- 3 level-2 triggers: $J/\Psi \rightarrow \mu\mu$, $J/\Psi \rightarrow ee$, high-$p_T$ photons/$\pi^0$'s
  - 20 msec/evt/level-2 trig on 180 CPU level-2 processor farm
  - Need ~1/40 rejection, but only cut at highest rates
  - Filter events which pass level-2 cuts to small (~10%) output stream
  - ~10% of total data size (~37 Tb) would take ~6 weeks to analyze on 300 cpu's (as opposed to ~1 year for total minimum-bias data sample)
- 315 $\mu b^{-1}$ level-2 events would give ~ 15,000 $J/\Psi \rightarrow \mu\mu$
  - ($\sigma_{AuAu}$ = 50 mb, $\alpha$ = 0.92, no shadowing, no QGP )
  - ($Acceptance_{\mu\mu}$ ~ 3%, $e_{\mu\mu}$ ~ 50% )
  - Expect also ~264 $\Psi'$ & ~9 $\Upsilon$ (need higher luminosity for these!)

***"Melting the Nucleus" - Science Now – 13 June 2003***

"Jet quenching was a strong hint, but scientists wanted to perform another test. This time, instead of smashing gold atoms with gold atoms, they smashed gold atoms with much, much lighter deuterium atoms. The idea was that the collision should look pretty much the same, jets and all, but this less energetic collision shouldn't be enough to melt the nucleus. Without a plasma around, the jets should not be quenched. And they weren't.

The new evidence, spreading by word of mouth, is being greeted with enthusiasm. "It looks convincing," says Karel Safarik, a physicist at CERN in Geneva. Nevertheless, RHIC scientists are still loath to claim they have created a quark-gluon plasma. Late this fall, they'll begin looking for other subtle signatures, such as the destruction of particles known as J/Ψs. That may well put the matter to rest."

***Comments from Tony Frawley - PHENIX Level-2 Coordinator:***

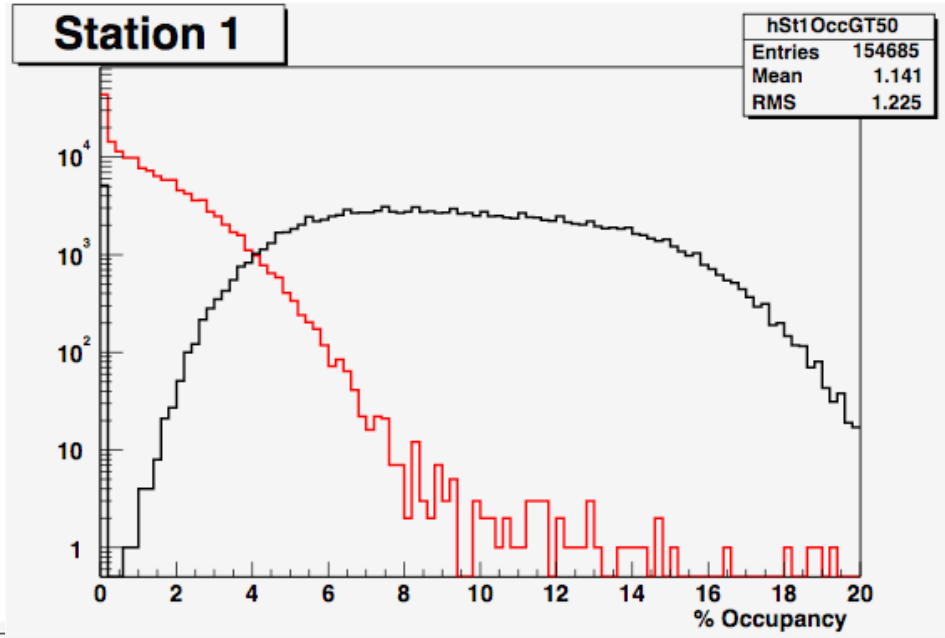
I believe that it will be crucial for us to know half-way through Run 4 how many J/ψ we are taking. There will be a **lot** of pressure to stop running full energy AuAu and do something else towards the end of the run.

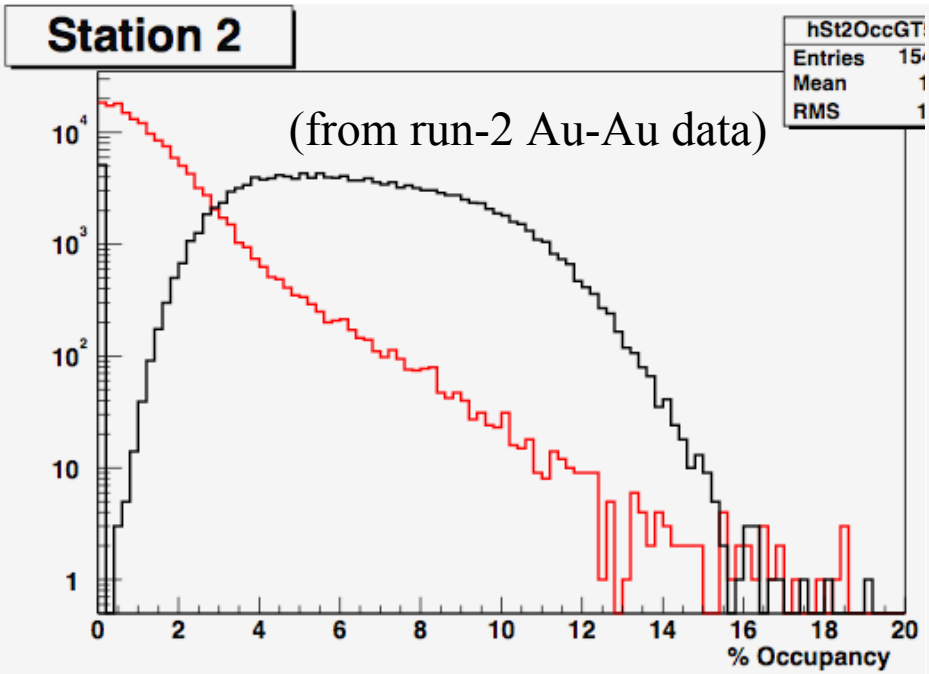
# Summer 2003 Shutdown Muon Related Work

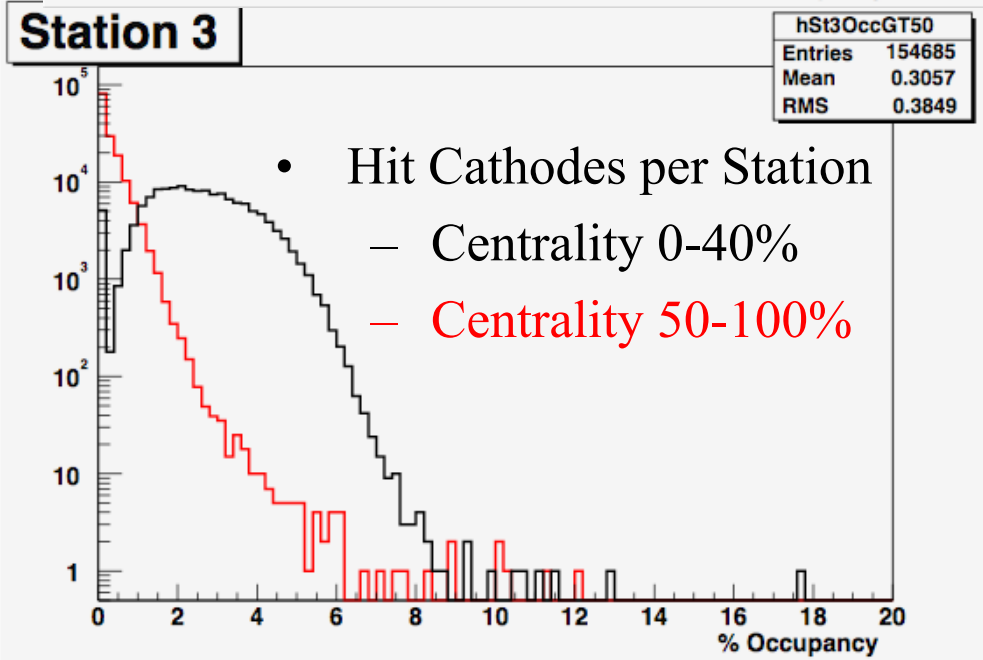
- Muon arms
  - FEE repairs to eliminate duplicated channels (~1%) & a few dead channels
  - Repair high-voltage channels that draw large currents (~12/arm channels out of ~800 total channels)
  - Use anode pulsing scheme to identify scratched cathode problems & deal with them in software
  - Improve automatic calibration procedures
  - New gas system to achieve better stability
- Shielding in tunnels to reduce beam scrape backgrounds which forced us to not turn on muon arms for the beginning of many stores in Run-3
- Commission new level-1 trigger with much higher modularity then old "BLT" version in order to achieve higher selectivity at level-1
- Tune offline software pattern recognition for higher occupancy Au-Au collisions

# MuTr Occupancy vs Centrality for Au-Au

Pattern recognition software needs tuning to improve efficiency and cleanliness for higher-occupancy Au-Au events. E.g. ghost track elimination, removal of outlier hits from tracks, better alignment, etc.



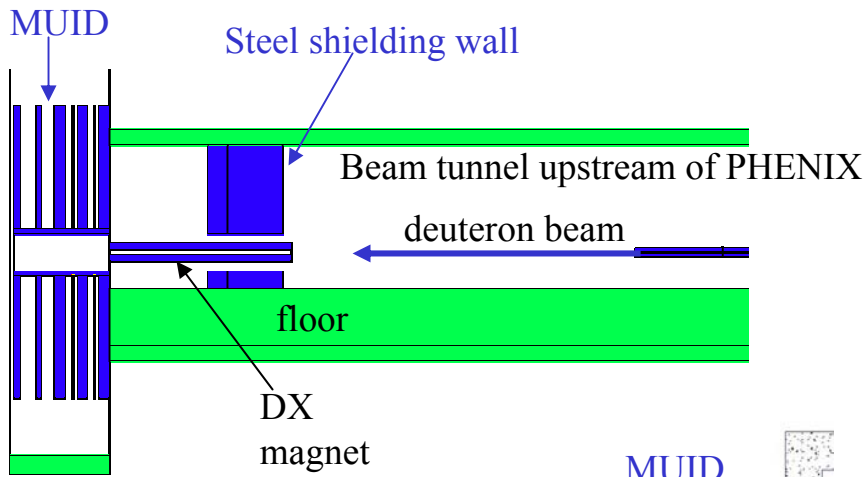



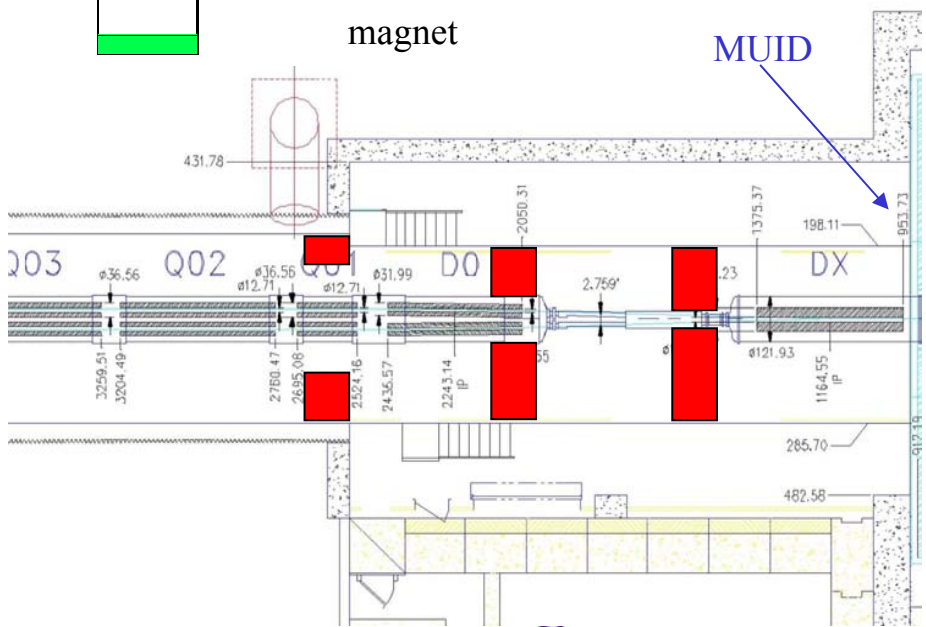




- Hit Cathodes per Station
  - Centrality 0-40%
  - Centrality 50-100%

# Shielding from large beam backgrounds

- High currents and trigger rates in muon identifier (MUID) forced us to use deeper (higher momentum) muon triggers and often to keep the muon arm(s) off at the beginning of the store when the background rates were largest → loss of efficiency and systematic checks
- Primary culprit is particles scraping somewhere along the ring, falling out of orbit, and showering in the beampipe upstream of the MUID
- Will install 4-foot steel walls in the tunnels upstream of PHENIX on both sides (just upstream of DX magnet)
- RHIC also putting in more collimation



# Looking Ahead

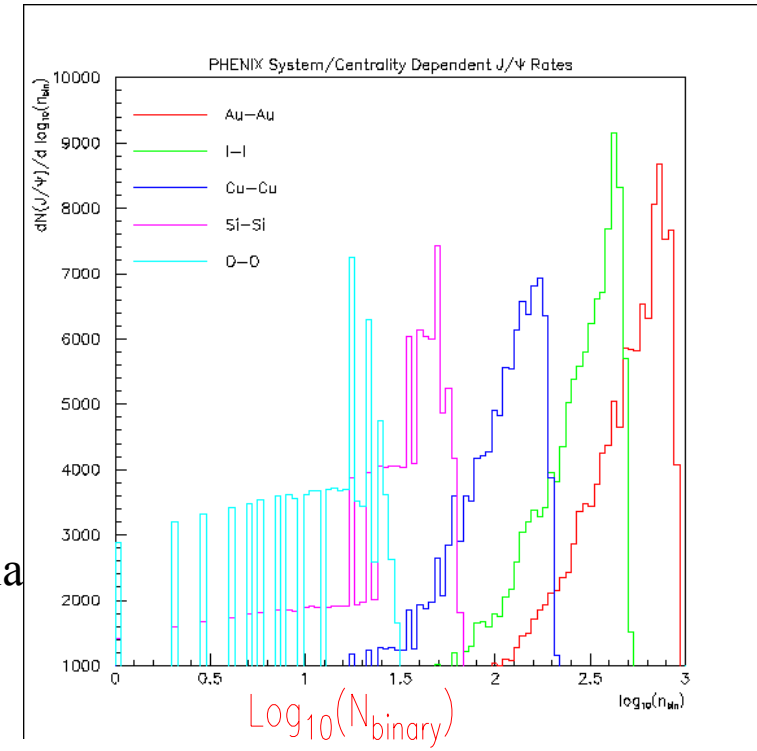
Runs 4, 5, 6 ... :

(Subject to the usual caveats about surprises and flexibility):

- Au-Au
  - Major goal: First definitive measurement of J/Ψ production systematics
  - Also: direct photons, γ+"jet", light vector mesons, continuum, ...
- Polarized protons
  - Major goal: First definitive measurement of ΔG via $\pi^0$ channel
  - Also: beginning of spin physics with rare probes (direct photons, J/Ψ, open charm)
- Light ions
  - Full exploration of J/Ψ production versus "$N_{binary}$" ~ A(b)*A(b) via a series of shorter(?) runs with light ions

N.B.: The complexity of species available at RHIC is *unprecedented for a collider*

➡ *unprecedented scheduling challenge*




| Species | Number of J/Ψ's (0.6 R.Y. - AuAu, 0.1 R.Y. - others) |
|---|---|
| OO | 1.15E+05 |
| SiSi | 1.44E+05 |
| CuCu | 1.56E+05 |
| II | 1.73E+05 |
| AuAu | 1.79E+05 |

# Backup Slides

# Luminosity in RHIC Runs to Date

- Run-1:
  - Au-Au at 130 GeV
    - Expectation: 20 $\mu b^{-1}$
    - Reality : ~ 1 $\mu b^{-1}$
    - Output: 11 publications (to date; 1 pending)
- Run-2:
  - Au-Au at 200 GeV
    - Expectation: 300 $\mu b^{-1}$
    - Reality : ~ 24 $\mu b^{-1}$
    - Output: 4 submissions (to date; 8 others pending)
  - p-p at 200 GeV
    - Expectations: 3 $pb^{-1}$
    - Reality : 0.15 $pb^{-1}$
    - Output: 1 submission (to date; 1 other pending)
- Run-3:
  - d-Au at 200 GeV
    - Expectation: 10 $nb^{-1}$
    - Reality: : 2.7 $nb^{-1}$
    - Output: 1 submission (to date)
  - p-p at 200 GeV
    - Expectation: 3 $pb^{-1}$
    - Reality : 0.35 $pb^{-1}$
    - Output: TBD

Shortfall: factor of 20

Shortfall: factor of 8

Shortfall: factor of 20 (∞)

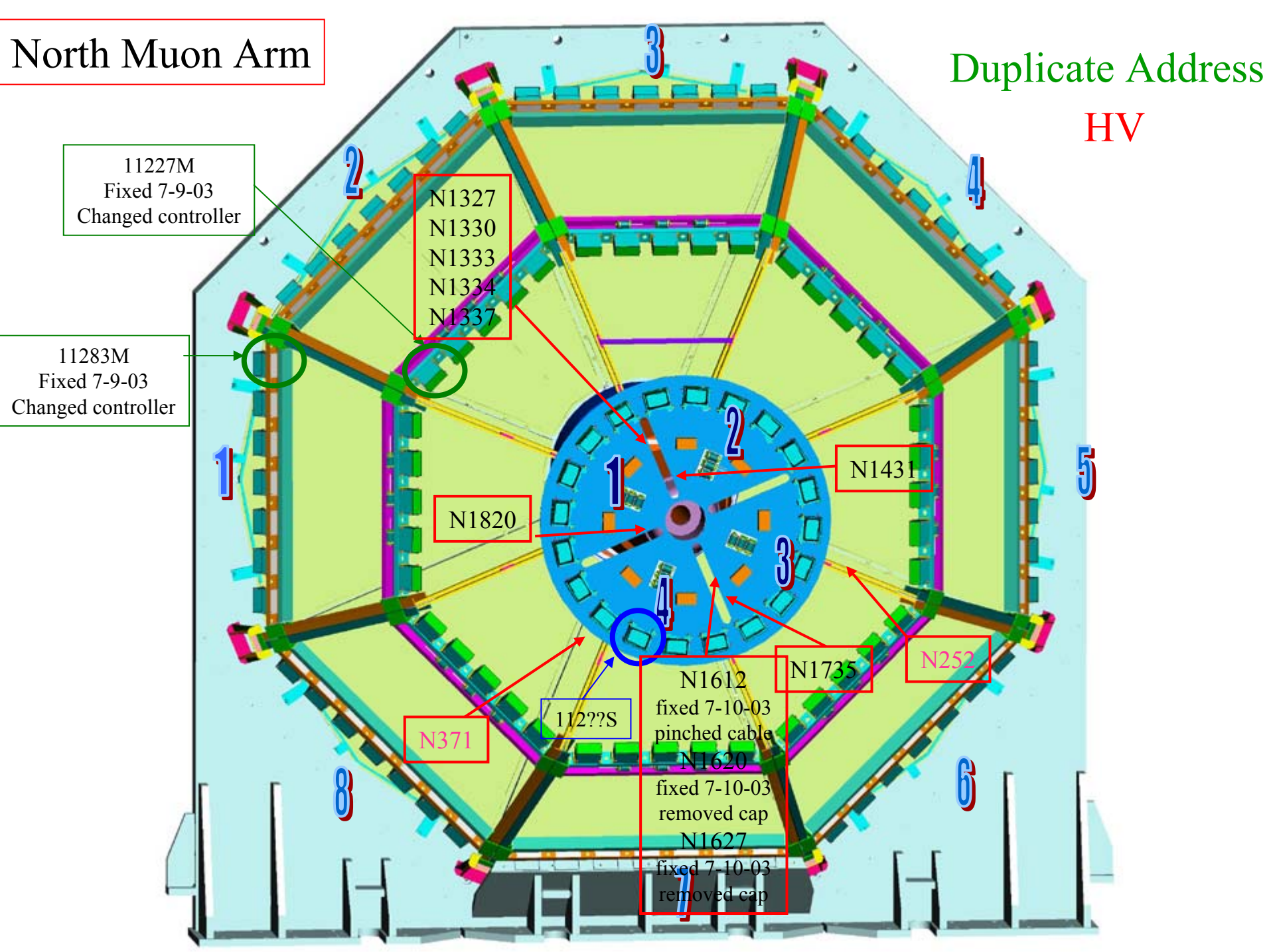
Shortfall: factor of 4

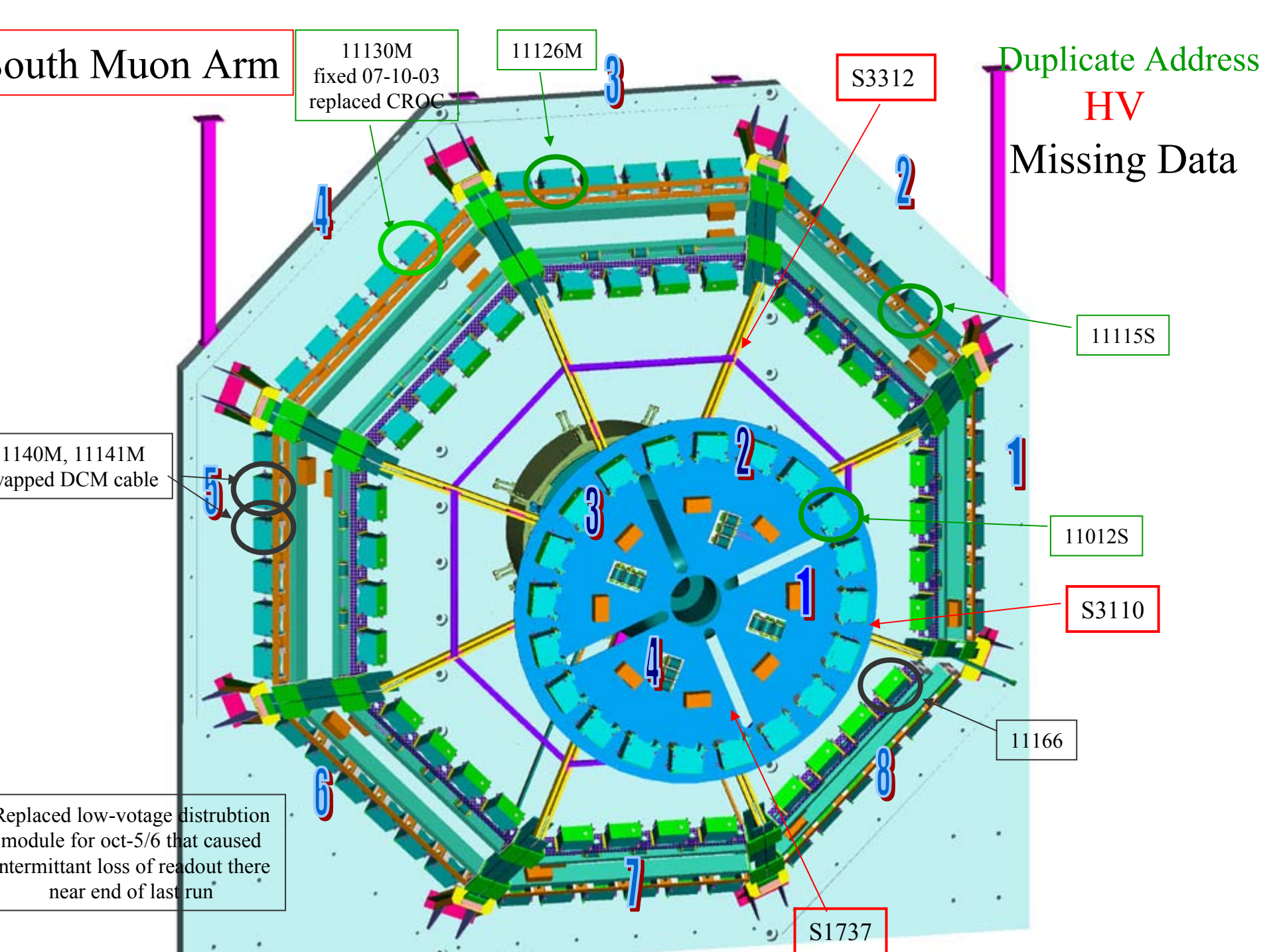
Shortfall: factor of 9 (30-60)

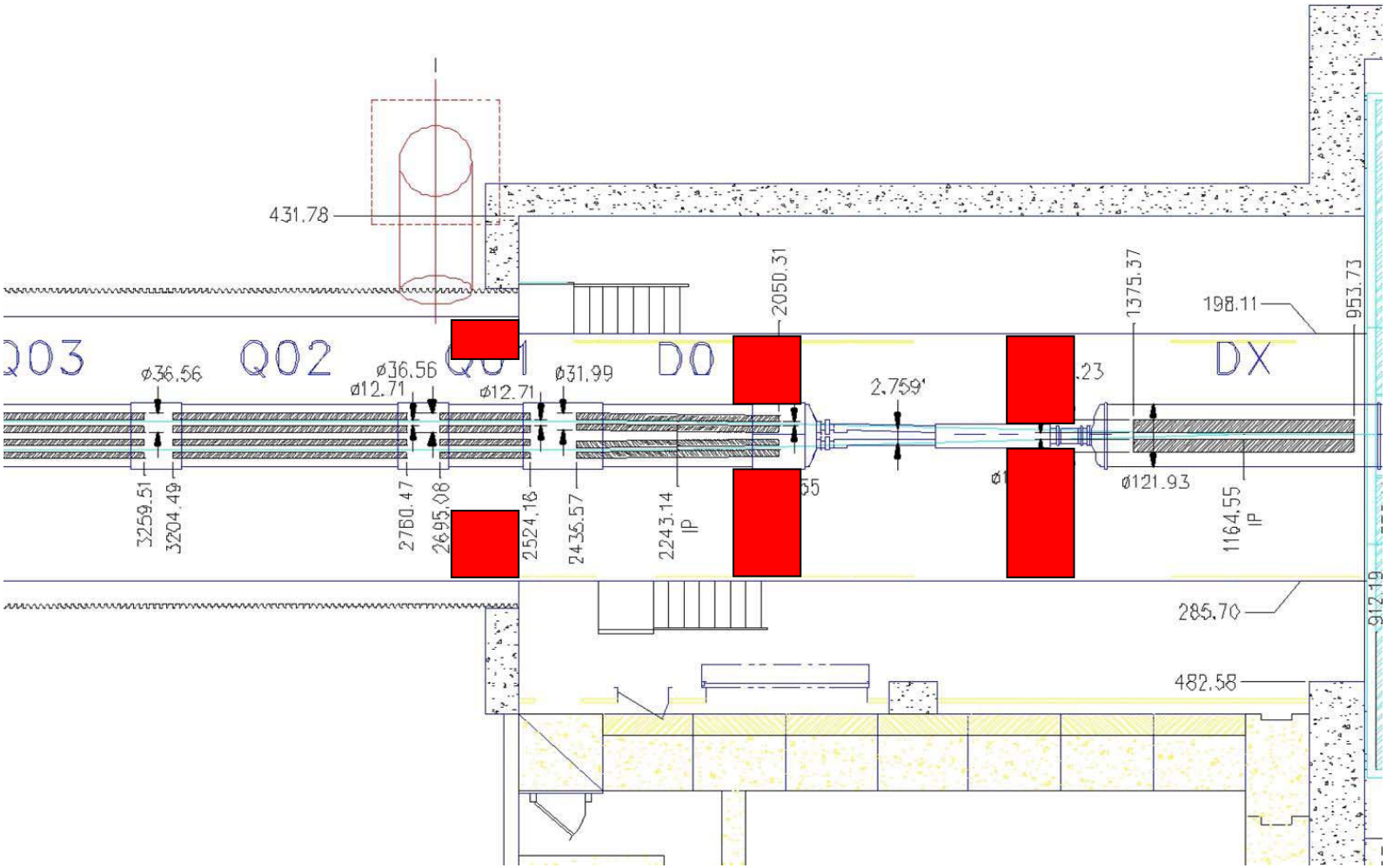
# North Muon Arm

Duplicate Address

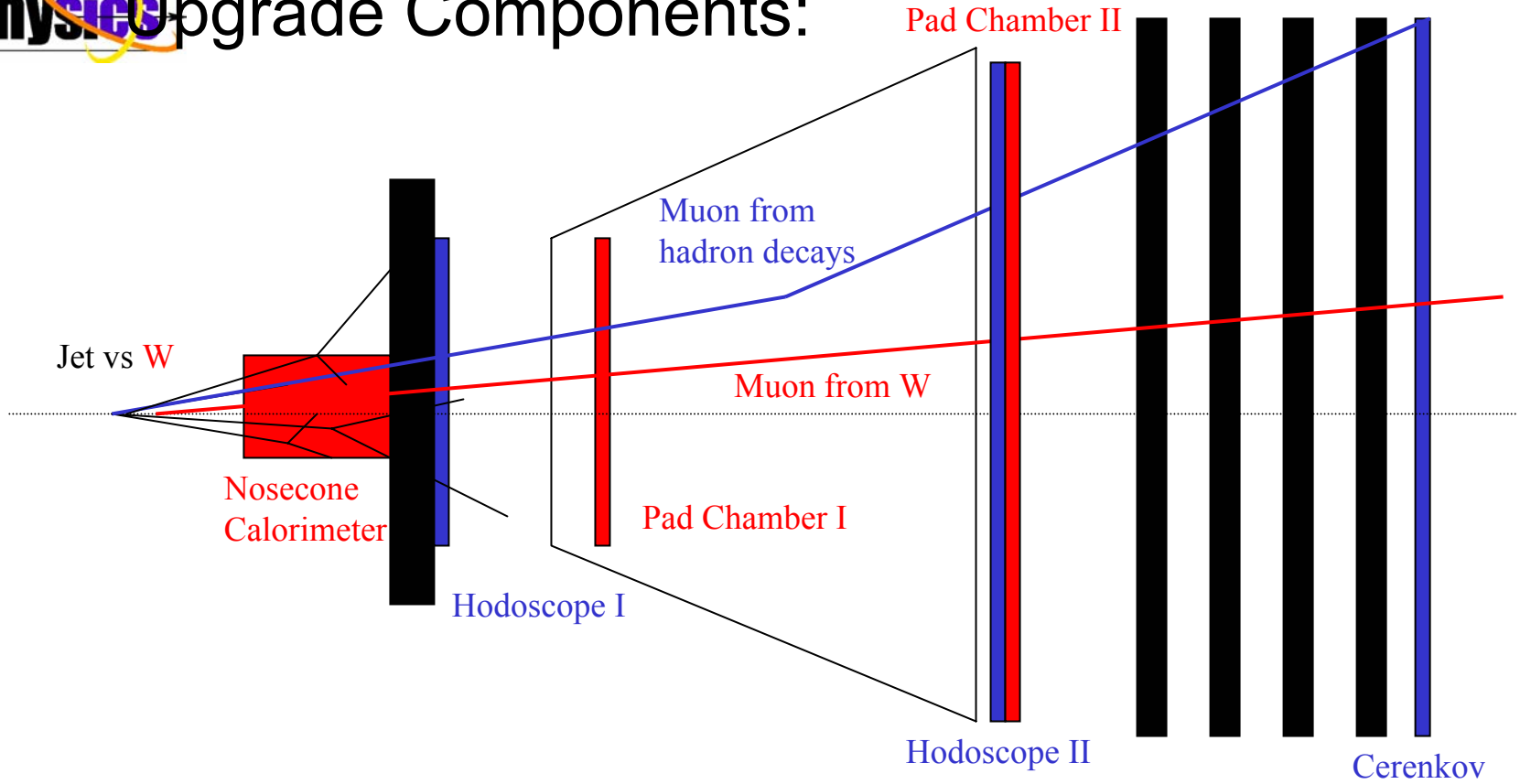
HV

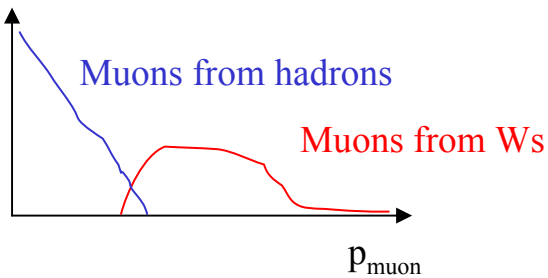



South Muon Arm
11130M
fixed 07-10-03
replaced CROC
11126M
S3312
Duplicate Address
HV
Missing Data
11115S
11140M, 11141M
swapped DCM cable
11012S
S3110
11166
Replaced low-votage distrubtion
module for oct-5/6 that caused
intermittant loss of readout there
near end of last run
S1737


431.78
2050.31
1375.37
198.11
953.73
Q03
Q02
Q01
D0
DX
ø36.56
ø12.71
ø36.56
ø12.71
ø31.99
2.759'
.23
ø121.93
3259.51
3204.49
2760.47
2695.08
2524.16
2435.57
2243.14
IP
1164.55
IP
285.70
912.19
482.58

# Physics Upgrade Components:




Nosecone calorimeter -> dA: low x,
pp: W-tag, b-tag

Pad Chambers+uID -> high momentum lepton and di-lepton trigger for pp, AA

hodoscopes+uID -> pp: W-tag

Cerenkov+uID -> AA: $\Upsilon$ trigger, beam gas rejection
pp: W-tag