The Forward Calorimeter in PHENIX

Stephen C. Johnson

Lawrence Livermore National Lab

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

You are here with me (I’m sorry)

The Forward Calorimeters are:

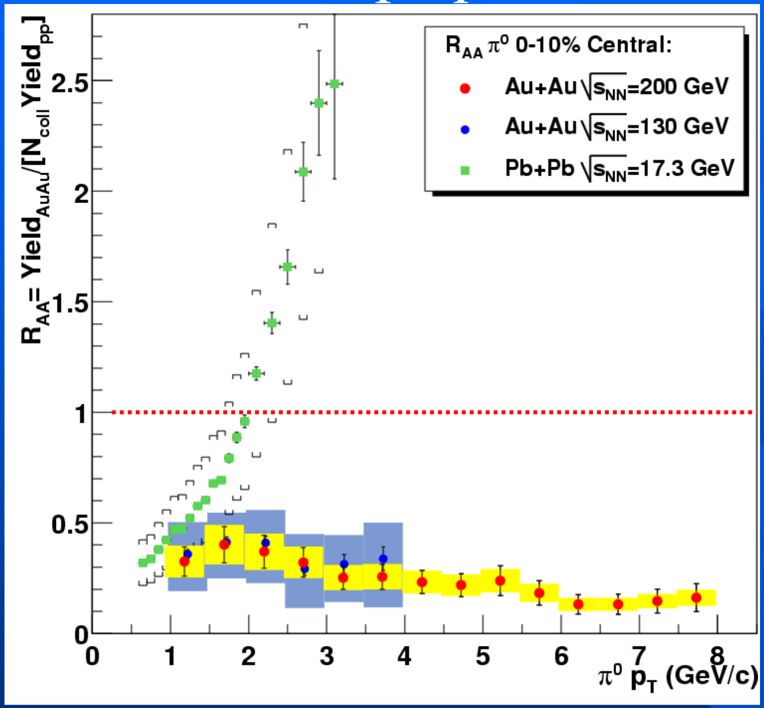
- The newest subsystem addition to PHENIX
- Two 12 ton calorimeters located near the beam pipe, beyond the DX magnets (in the tunnel)
- Conceived to measure centrality in p-A/d-A collisions, but being considered for interesting measures in p-p, d-d, etc.
- The topic of this talk

Outline, an historical review

- Initial thoughts on upgrades
- A need arises:
  - My two favorite measurements in Au-Au
  - the d-Au program needs centrality
- The search for a calorimeter
- Testing, building, spending
- A look at beam
- Calibrations and the current analysis
- The future
  - n-n collisions at 200 GeV
  - Diffractive processes
  - More … ?

A Quark-gluon plasma should be:

Opaque



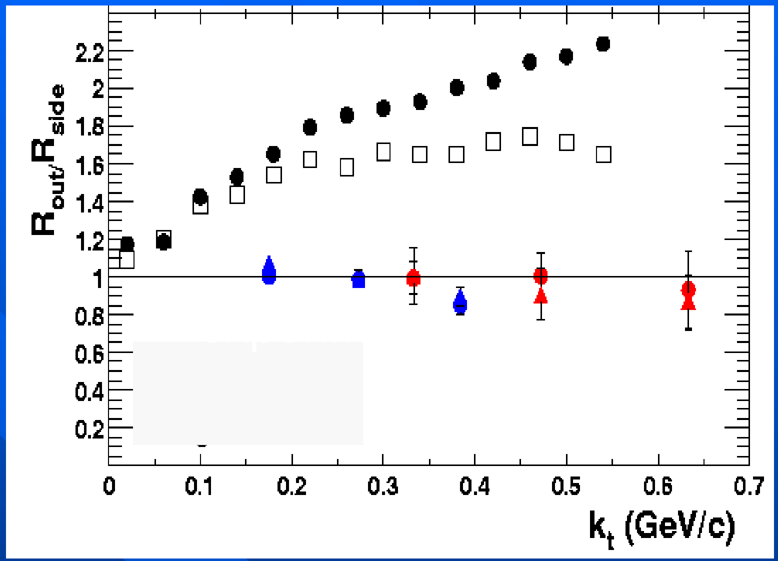
- Measured with yields of high momentum particles.
- Severe deficit from simple scaling consistent with simple plasma scenario

- A jet is expected to lose a tremendous amount of energy as it passes through the plasma
  - ~GeV/fm
  - Suppresses single particle production at high p_T relative to pp
  - Completely consistent with PHENIX measurements
- Plasma is found!
  - Well…CGC condensate also 'predicts'
  - Complicated physics of jet fragmentation
  - Etc. etc.

A QGP should also be:

- In transition from QGP to hadron gas, dramatic change of N.D.F (xx => yy)
  - Large latent heat
  - Long lived system
- Reflected in ratio of HBT radii
  - $R_{side} \sim R_{geom}$
  - $R_{out} \sim \mathrm{sqrt}\{R_{geom}^2+\tau^2\}$
- Results consistent with very short lifetime
- => AuAu collisions are
  - a strange plasma
    - » Doesn't explore full NDF?
  - CGC
    - » No prediction for HBT
  - A completely different beast

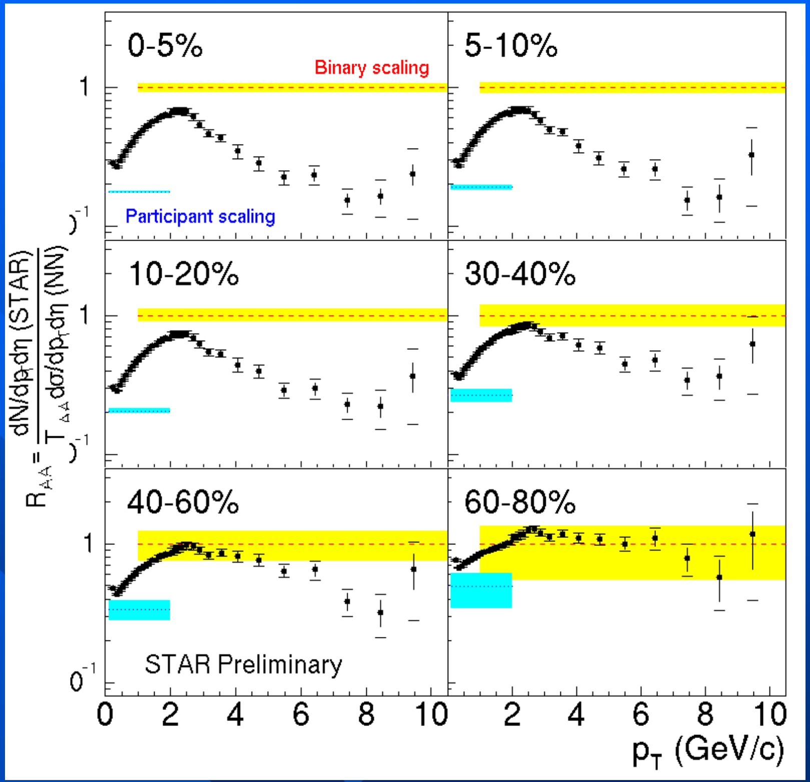
Long-lived



- Measure source size by quantum mechanical interference of identical particles. Difference of radii ~ lifetime.
- Rout/Rside=1 inconsistent with plasma scenario

How to resolve

- I like to believe we work in a field of "exploratory experimentation" **
  - Two stages:
    - » Analytic: from complex to a simpler first principle
    - » Synthetic: showing how complex appearances are related to the first principle
- The pp, dA, and aa runs are meant to fill in our synthetic approach
- We break down the AA into smaller steps as part of analytic stage with centrality definitions



Who ordered that?
Suppression in all but the most peripheral bin??

**See nice article by Ribe and Steinle on Goethe's and Faraday's "exploratory experimentation" in July issue of Physics Today (free on the web)

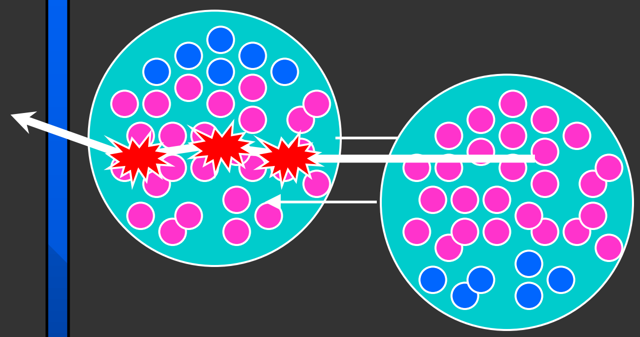
Centrality in p(d)A

Proton-proton → "Hadron Gas"

$N_{participants} = 2$
$N_{binary} = 1$

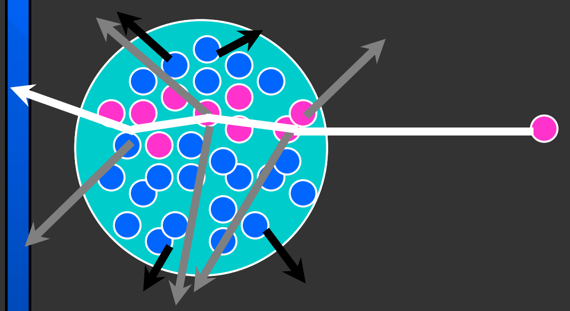
=pp

Nucleus-nucleus → QGP(?) → Hadron Gas



In absence of QGP
AA= N_{binary}*pp??

Proton-nucleus → Hadron Gas

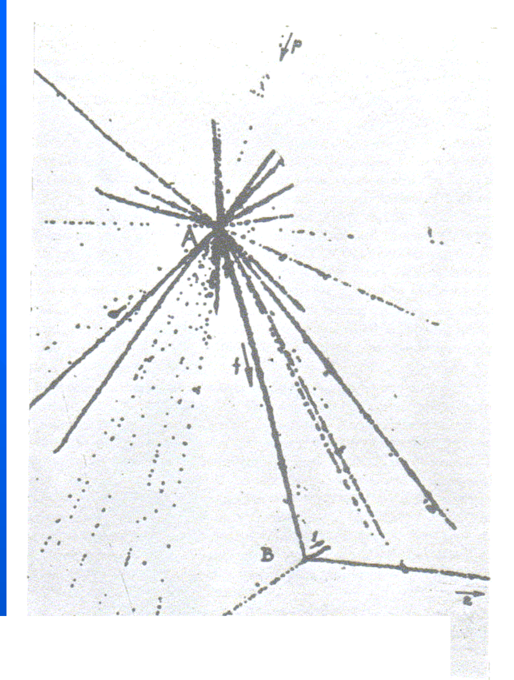


$N_{participants} - 1 = N_{binary} = \nu$

pA(N_{binary})= N_{binary}*pp??

Need to measure grey/black nucleons to determine N_{binary}

N_{grey} dependencies



QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

I. Chemakin, et al.

E910 PRC 60 024902

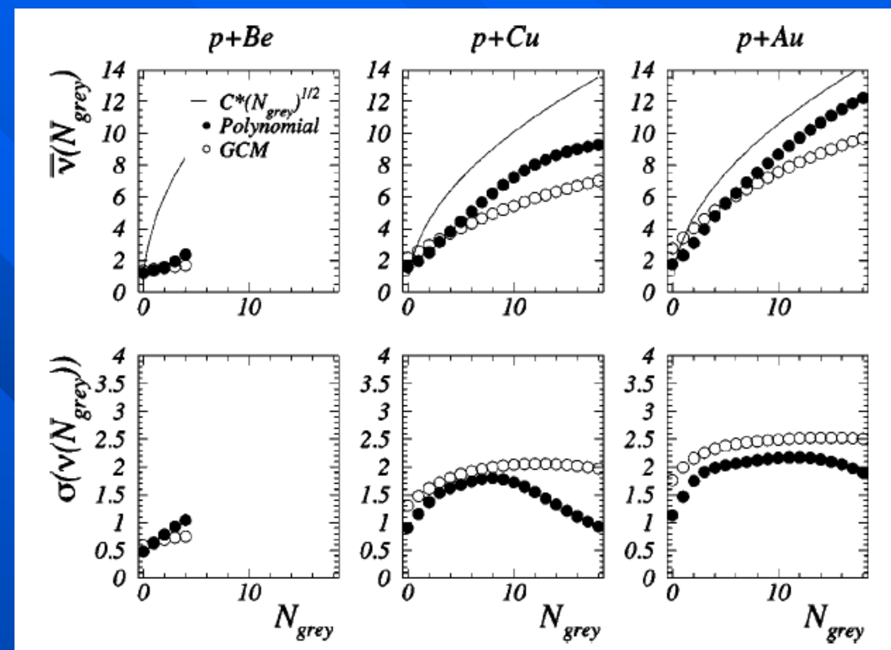


FIG. 12. $\bar{\nu}(N_{\rm grey})$ and $\sigma[\nu(N_{\rm grey})]$ generated from the polynomial model (solid circles) and the GCM (open circles), and $\bar{\nu}(N_{\rm grey})$ according to the $\bar{\nu}^2$ ansatz (solid line) for $p+$Be, $p+$Cu, and $p+$Au.

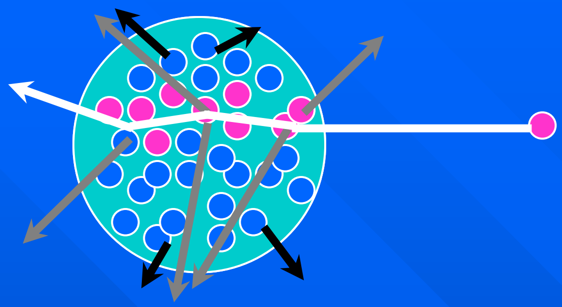
Bubble Spectrometer
D.H. Brick, et al.
PRD39 (`89) 2484

Sample measurement with N_{grey}

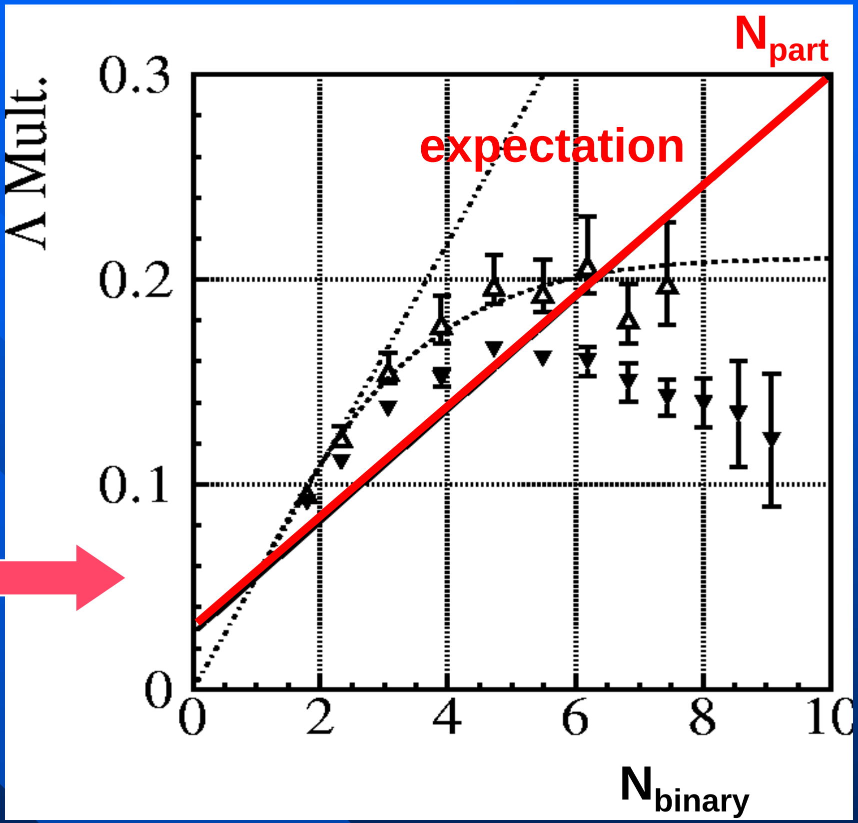
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Busza, et al. PRL 34 (`75)

Binary and participant scaling in pA fails



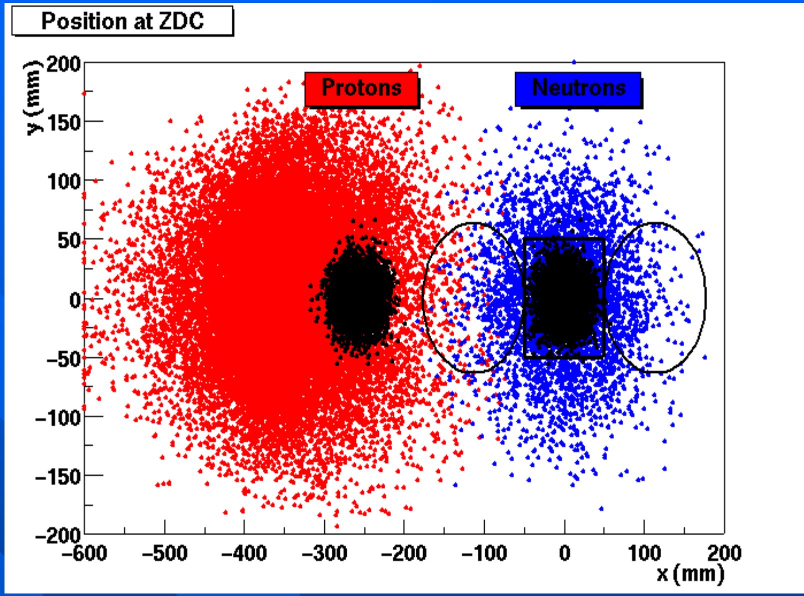
- Best example of physics from pA centrality (with strong contingent of future PHENIXians) is E910 at lower energies (AGS)
  - PRL 85 (2000) 4868
  - PRC 60 (1999) 024902
  - Mystery of ‘strangeness enhancement’ solved by detailed understanding of strangeness production

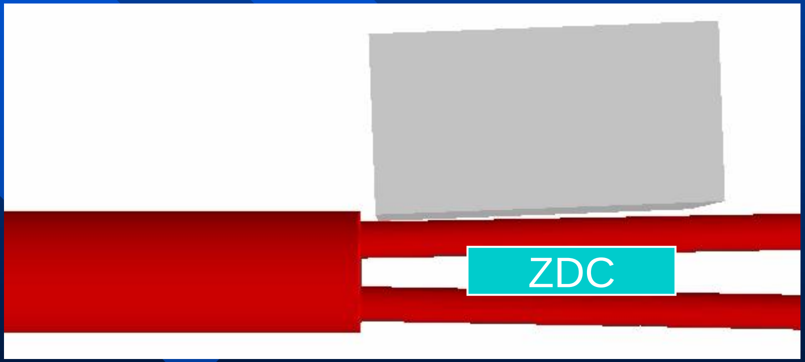


- If you’re here to understand the physics
  - Min bias distribution won’t do it
- Only planning on fitting to a recent theoretician’s model?
  - Min-bias may be fine…

How do we measure grey particles in PHENIX?

- Non-trivial question
  - In high energy collider setting grey particles pass through beam pipe, separating after passing through DX magnet
    - Large amount of material
    - Forward focused energy
  - Appropriate technology: calorimeter





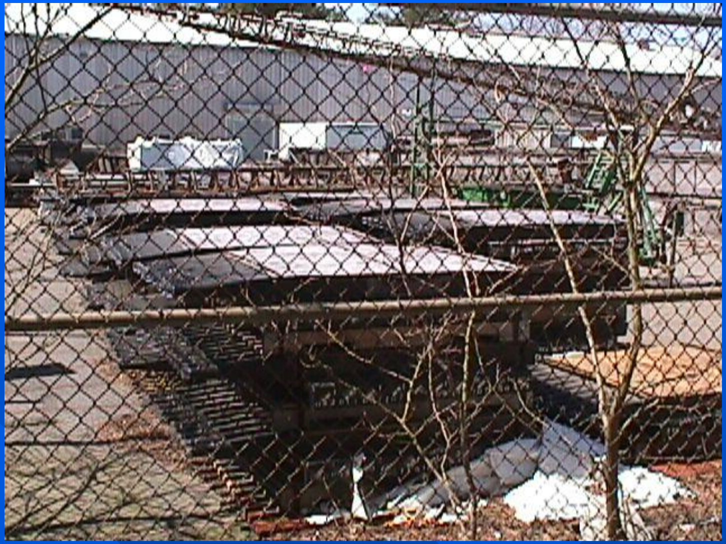
Goldilocks…part I

This calorimeter is too big

And this calorimeter is too small

Goldilocks part II

- This calorimeter is just right
- From E864 (retired AGS experiment)
- Younger, spaghetti-style calorimeter
  - Array of 47x47 fibers
- Very good energy resolution:



$$\partial E / E = 35\% / \sqrt{E} + 3.5\%$$

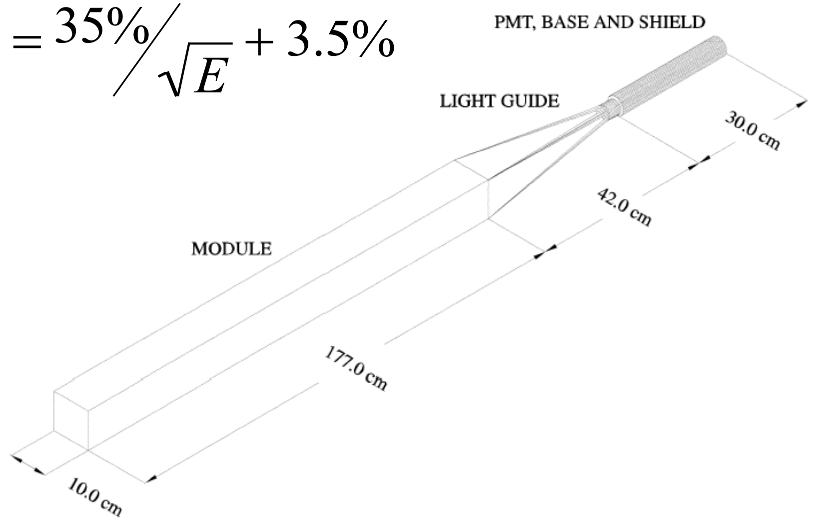
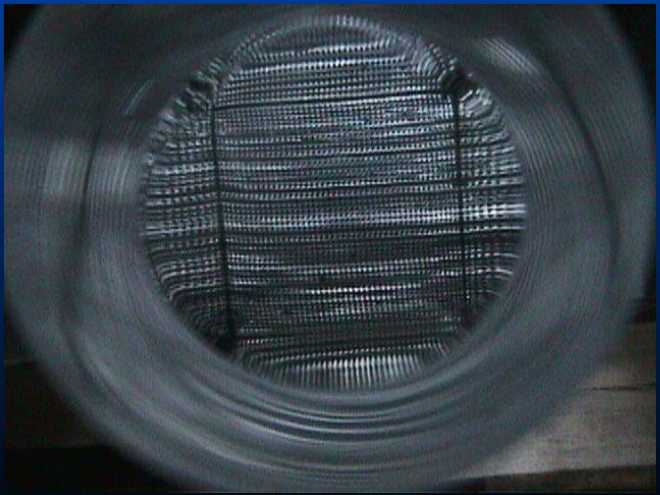
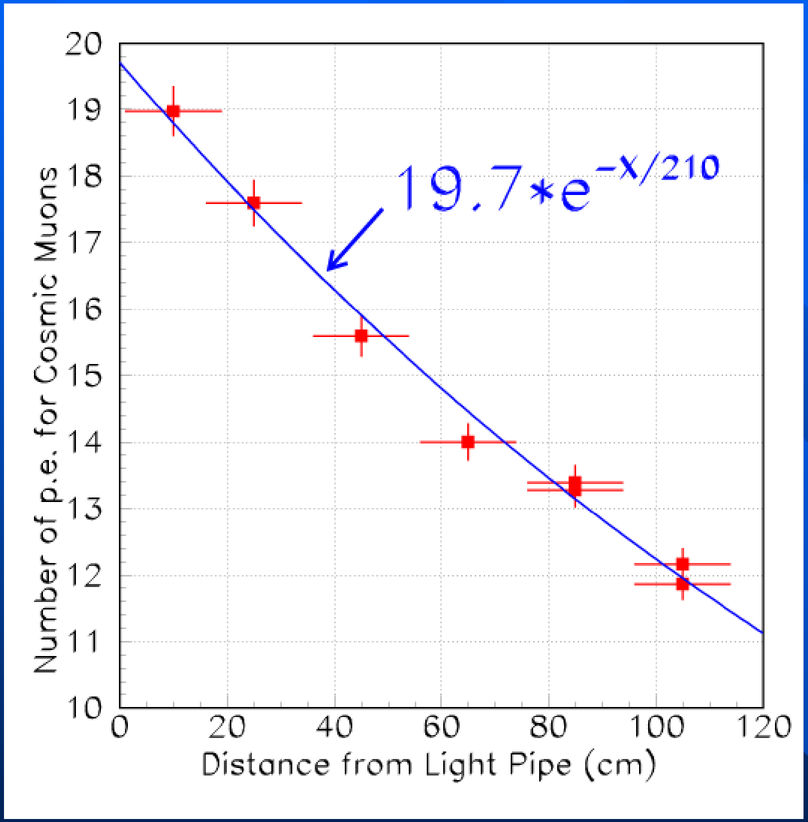


Fig. 3. Calorimeter Tower Layout. Scintillating fibers are imbedded longitudinally in a lead substrate. The light readout proceeds through a tapered lucite light guide with a single photo-multiplier tube per tower.



We can rebuild it …

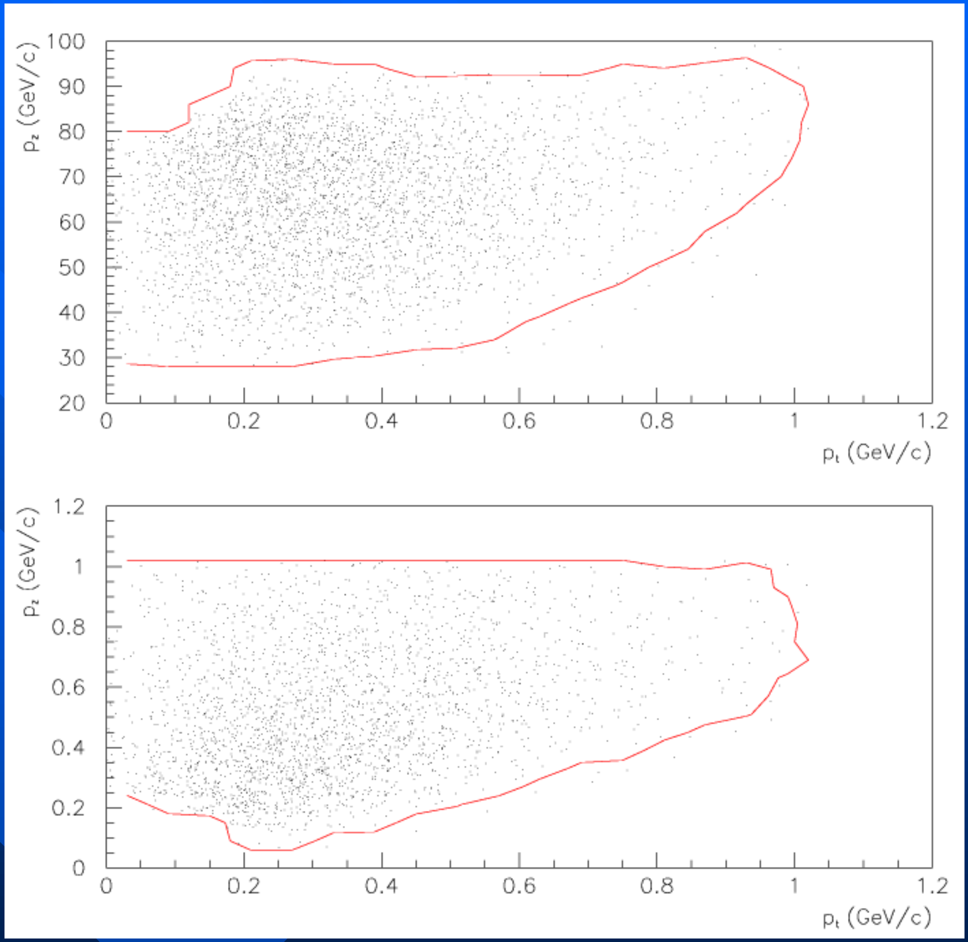


- Study at Yale by Dick Majka and Gerd Kunde show modules are unscathed after several years outside
  - Attenuation of fibers: 200cm
  - #PE/cosmic ~ 20

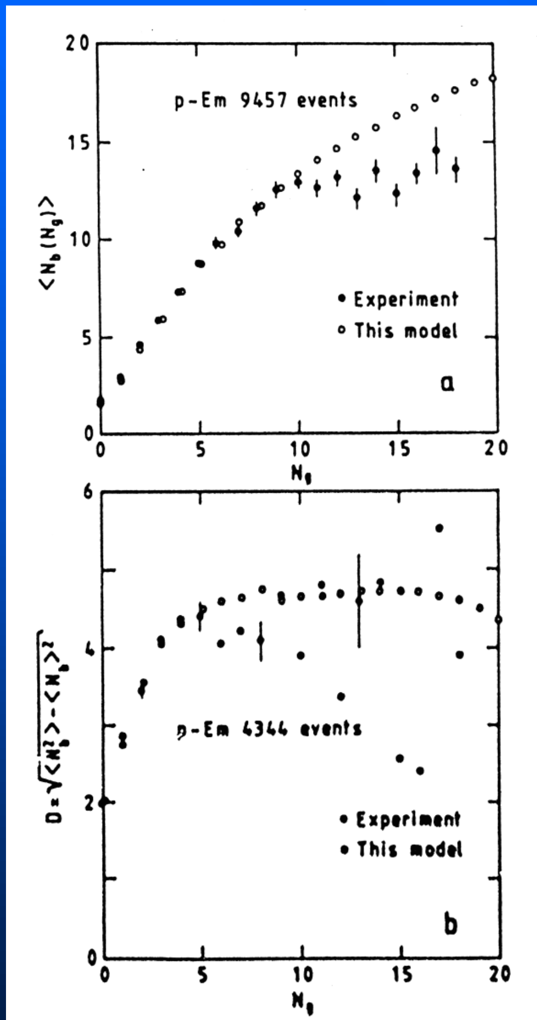
Best guess at N_{grey}/N_{black} model

- Never been measured at RHIC energies
- Assume energy independence of distribution

- Use Glauber model for N_{binary} distribution
- E910 model of N_{binary} vs N_{grey}
- E910 N_{grey} momentum distribution boosted to RHIC beam energy

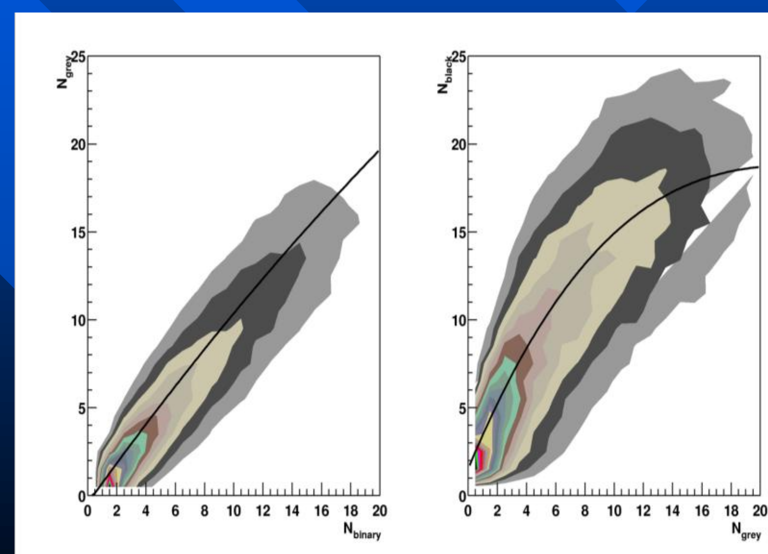


Best guess at N_{grey}/N_{black} model part deux



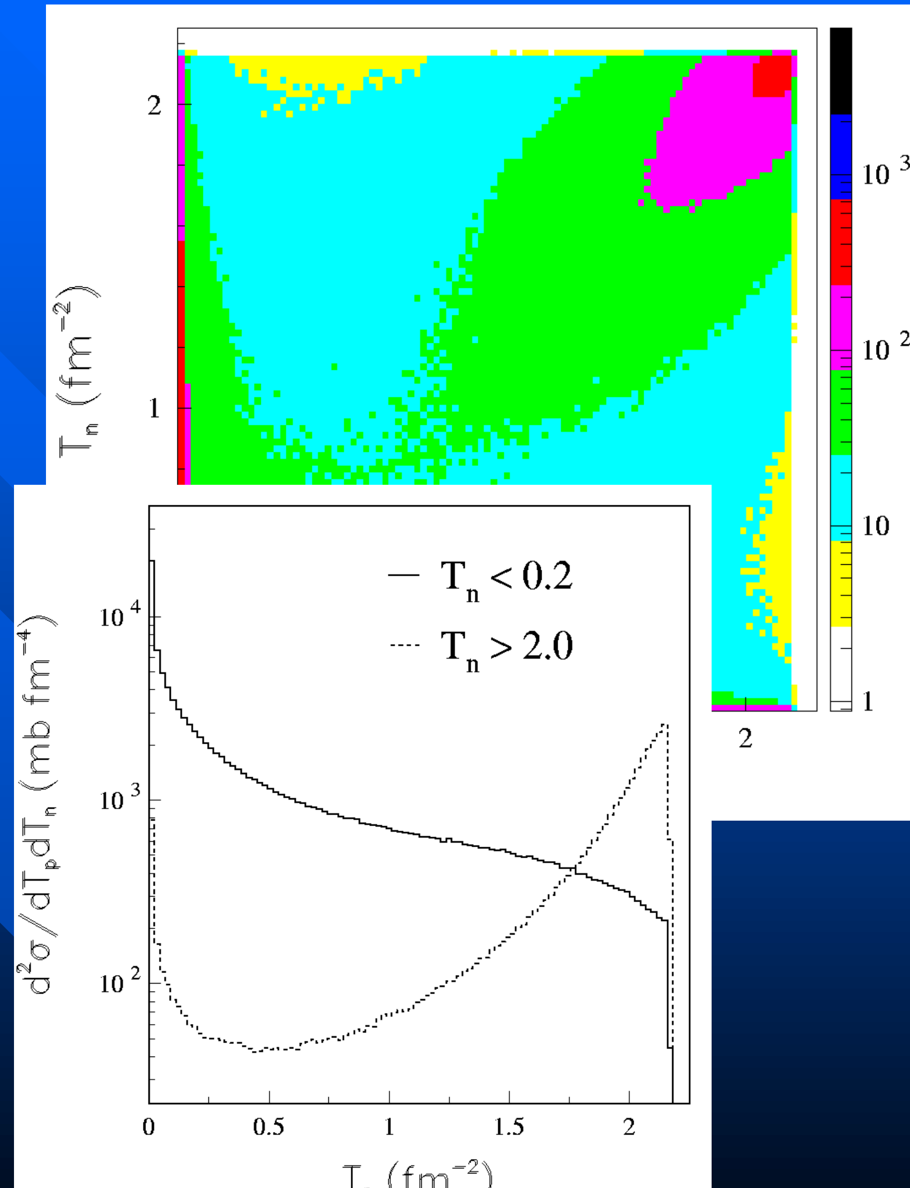
Stenlund & Otterlund,
Nucl. Phys. B198 (1982) 407

- N_{grey} vs N_{black} distribution measured in emulsion experiments
- Final result:

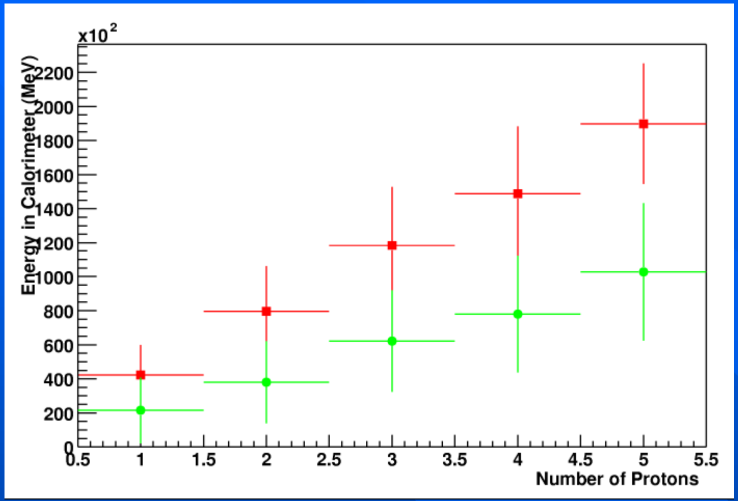


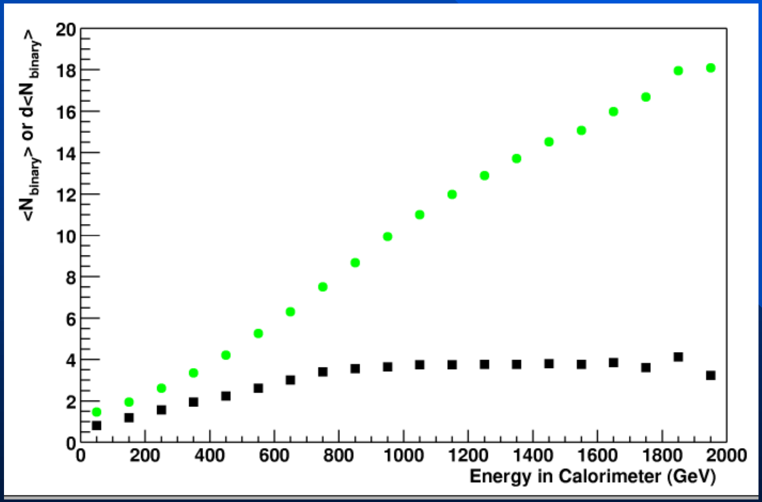
Thickness functions

- I've assumed that a deuteron collisions is approximately two independent collisions.
- Not exactly true:
  - Study by Brian of the thickness function seen by the proton and neutron of a deuteron.



The Punchline

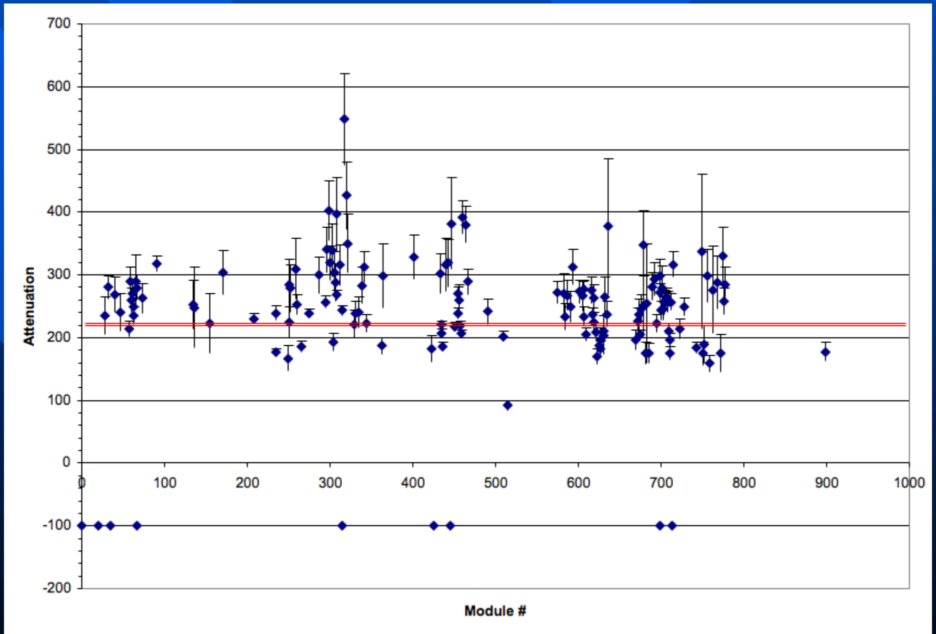




- Roll in expected energy resolution of detector (twice as bad as E864's best result)
- Let's do it!
  - PHOBOS agrees
    - » Emulation is the best form of flattery…

Testing the modules

- Testing station throughout the summer
  - Nathan Grau gets it set up in a couple weeks
  - Ray Stantz (undergrad) finishes setup, tests first stack
  - LLNL group uses setup to test ~2/3 of PHENIX modules
  - PHOBOS tests the next ~1/3



November 2002

The infamous stand

- Non trivial
  - Modules have no lifting point
    - Hermeticity is a good thing…?
  - Stand to hold ~12 tons of Pb
    - And …
  - Move remotely up-and-down/side-to-side
    - For calibration purposes
- To make matters worse:
  - Pb oxide dust found on modules
  - Quick action by BNL safety, PHENIX techs and Pearson’s crew get the modules stacked in a couple weeks

Low voltage and readout

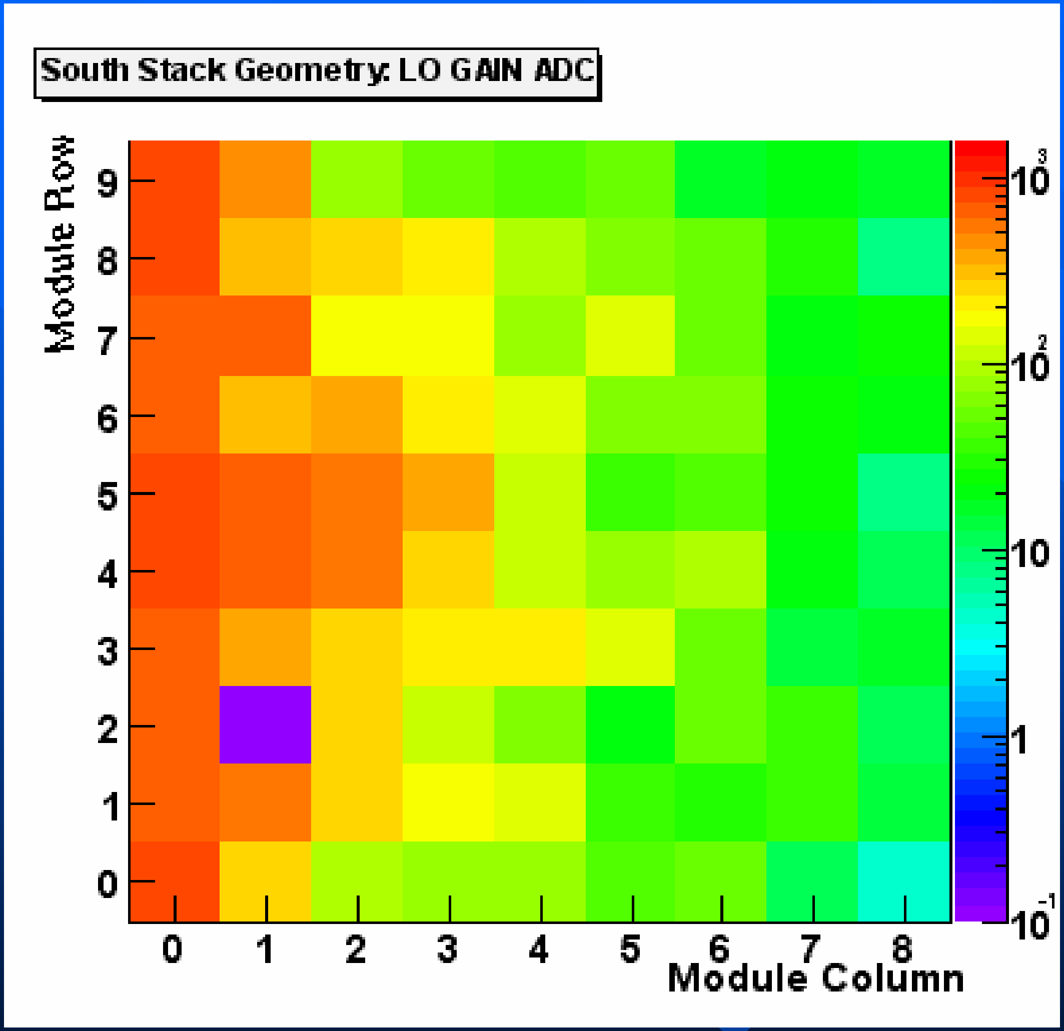
- Cockroft-Walton on the tube base
  - Only supply LV/high current to tube
- Discriminator on baase
  - In E864, disc output used for trigger decision
  - If rate too high and threhold low, base draws too much current
- Readout:
  - Scrounge FEM boards from Emcal
    - » Only need 2x90 channels -- EMC has >15k

Putting it all together

- Why two detectors?
  - First law of government spending*
  - Accelerator couldn't promise which side would be Au
    - » Would you please move that detector for me…?
  - Some interesting measures on d side
    - » Can trigger offline on pA like collisions with FCAL, nA like collisions with ZDC

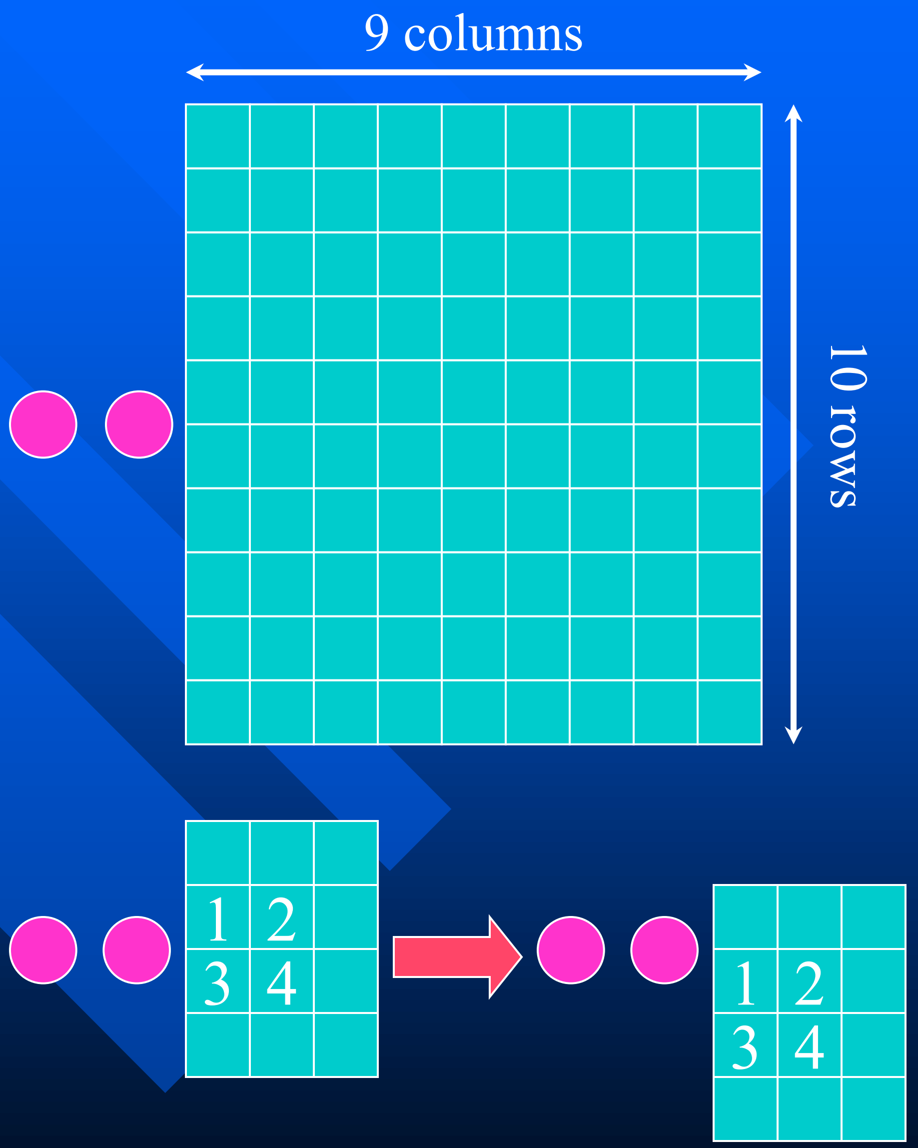
*Why build one when you can build two for twice the cost?

First Data

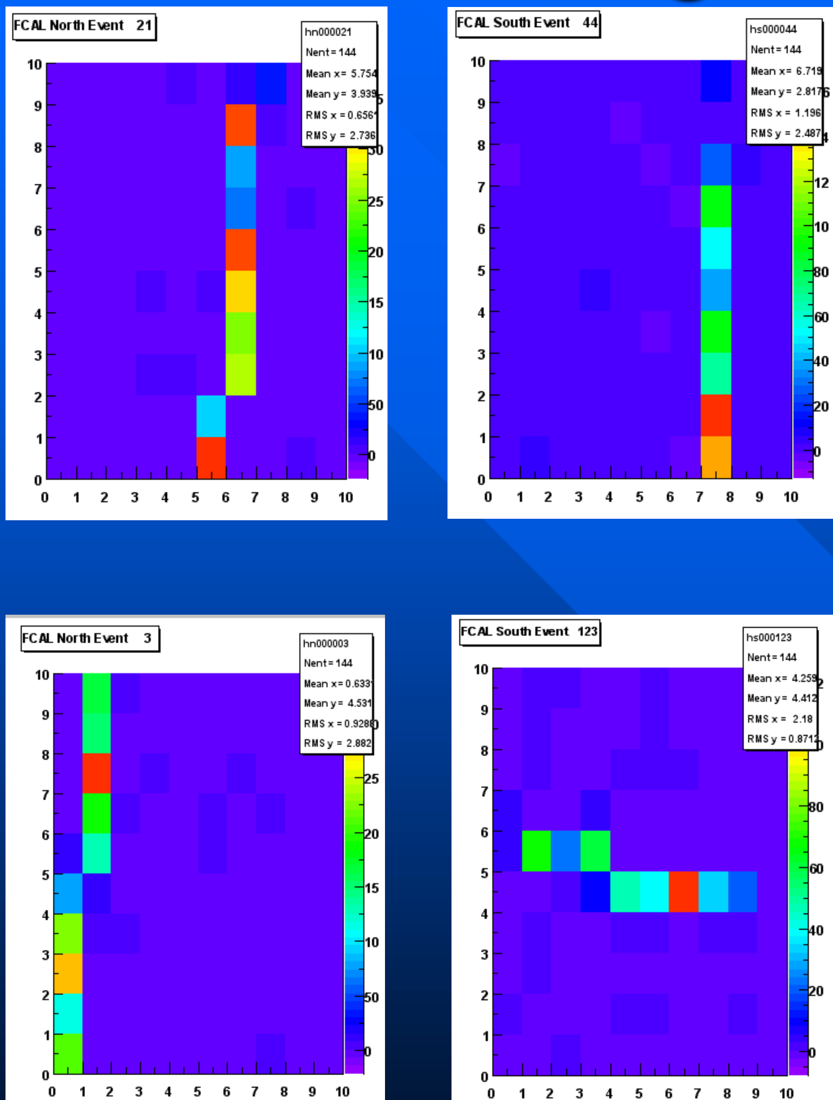

South Stack Geometry: LO GAIN ADC
Module Row
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8
Module Column
10^3
10^2
10
1
10^{-1}

Calibrating the FCAL (more than one handle)

- **Use beam:**
- Move detector one module length up/down/sideways.
  - Same position, same average energy.
- Pros:
  - Using same energy scale as data (no scaling, no non-linearities, etc.)
  - ~Fast (3 min./position)
- Cons:
  - Not perfect: edge modules not shielded
  - Uses precious beam time.
- Result: ran 3 times during d-Au run



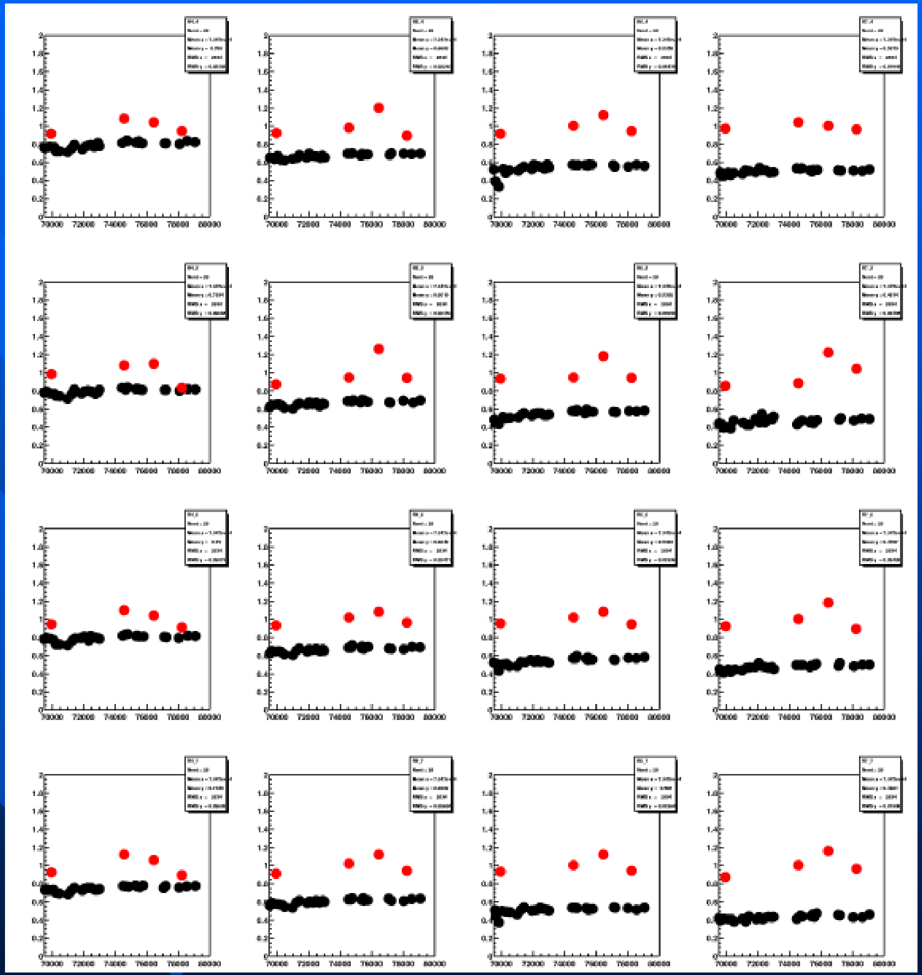
Calibrating the FCAL (handle #2)



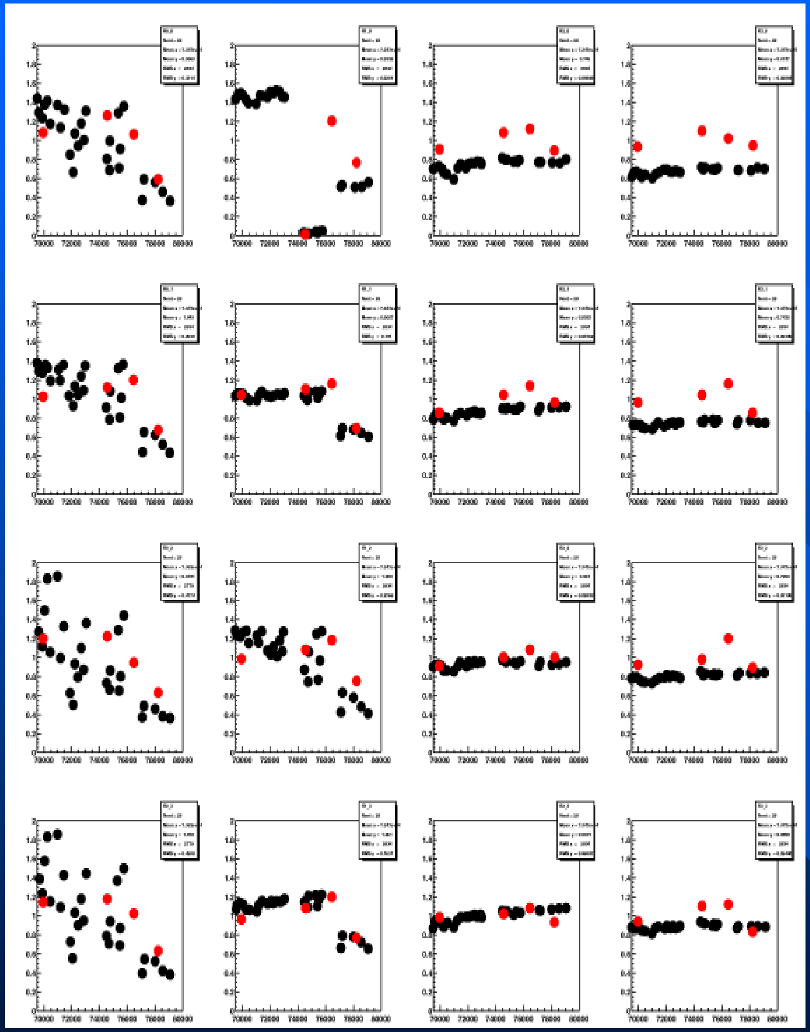
- **Cosmics:**
- FCAL utilizes EMcal FEE with 2x2 (and 4x4) trigger thresholds
  - Set threshold for cosmics
  - Acquire some noise, but fair fraction of cosmics.
  - Simple offline cuts on #towers hit and angle of track
- Pros:
  - Run without beam
- Cons:
  - Must run without beam
  - Different gains than beam
    - Through going μ: ~150MeV
    - Black proton @ 100 GeV
    - Luckily, EMC FEE has low and high gain readout. (~x16)
  - ~30 minutes for enough statistics

Calibrating the FCAL (handle #3)

- **Monitoring:**
- Response of tubes can vary ~10-20% based on T_{tunnel}
- Monitor <E>(channel) for all channels for each run (onlCal)
- Systematic studies ==>



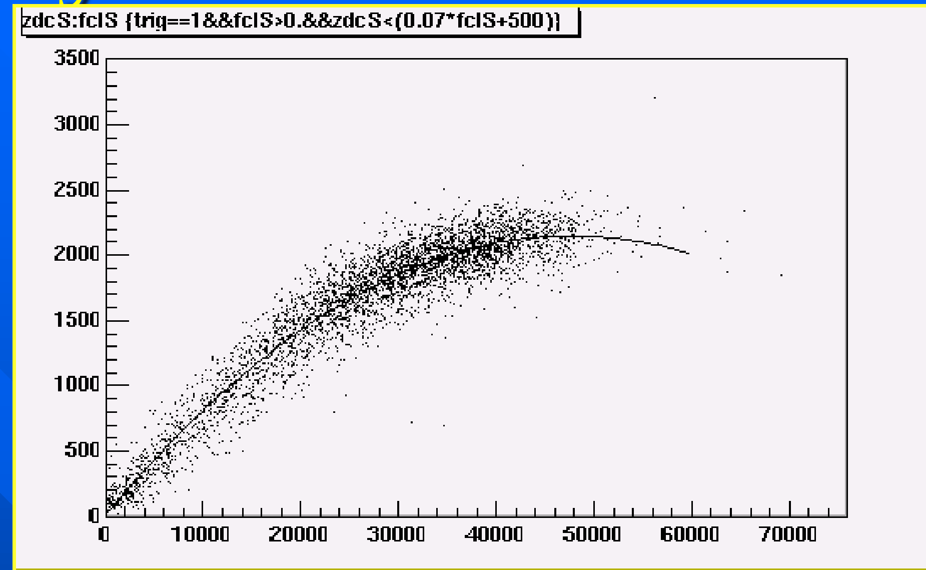
Calibration



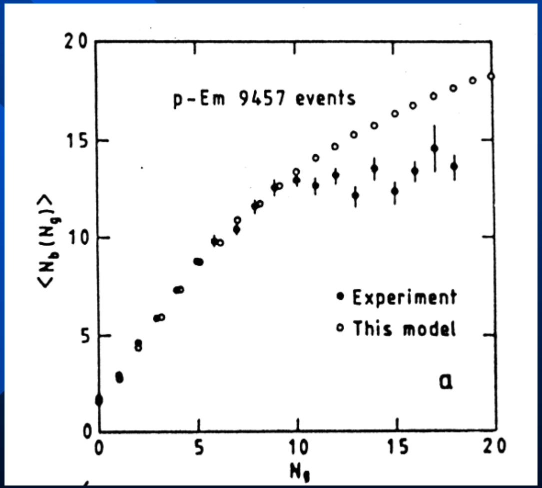
- Trend of cosmics and beam monitoring are consistent
  - Some noise in those modules closest to beam pipe
    - » backgrounds?
  - Steady decline in light output for those modules too
    - » Scintillator damage?

First Physics

- Calibrated detector ZDC vs FCAL ==>
  - FCAL ~ A*N_{grey} + N_{black}
  - ZDC ~ N_{black}
  - Deconvolution of grey from black may clean it up further



Now where have I seen that before…



The Future

- Immediate
  - Finalize calibrations
  - Determine relation between FCAL distribution and N_{grey}
  - Use FCAL in pp run
    - » Polarization monitor physics
      - Asymmetry in neutron peak position for transversely polarized beam: diffractive Δ production? Look for pion in FCAL
- Moderate:
  - Look into scintillator damage, prepare for next run
- Long term
  - Interesting future uses:
  - d-d collisions, offline trigger on two forward protons: nn at root-s = 200 GeV
  - Future pA run?
  - Pp diffractive measures?
    - » Difficult due to material in the way -- roman pots?

The people who make me look good*

- Lawrence Livermore National Lab
  - Mike Heffner, Ron Soltz
- Los Alamos National Lab
  - Jane Burward-Hoy, Gerd Kunde
- Brookhaven National Lab
  - John Haggerty, Steve Boose, Charlie Pearson, Frank Toldo, Martin Purschke, Rob Pisani, …
- Columbia
  - Chun, Chi, Brian
- Iowa State
  - Nathan Grau

* Well, they make me look better at least….