Prospects for Systematic d-Au studies with PHENIX

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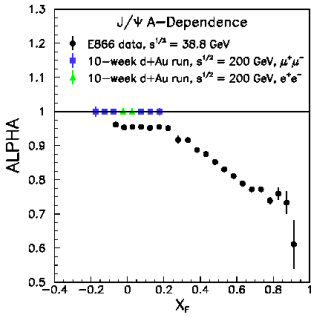
for the PHENIX Collaboration

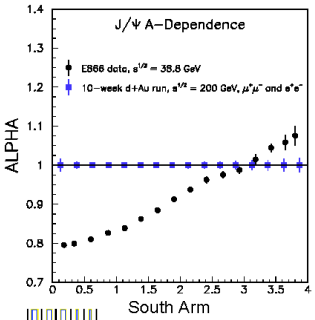
Unique Time/Unique Opportunity

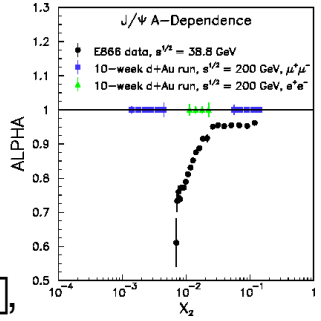
- First time in (short) history of H.I.C. when entire field is focused on p(d)-A for a year
  - Common understanding that p(d)-A is essential for quantitative study of A-A re: QGP
  - Studies of cold nuclear matter interesting in their own right
- Opportunity exists for systematic measures that rely less on theoretical propositions
- Use this time to understand numerous physics signals
- In this talk I'll outline some of the PHENIX plans for d-Au studies, focusing primarily on centrality definition techniques

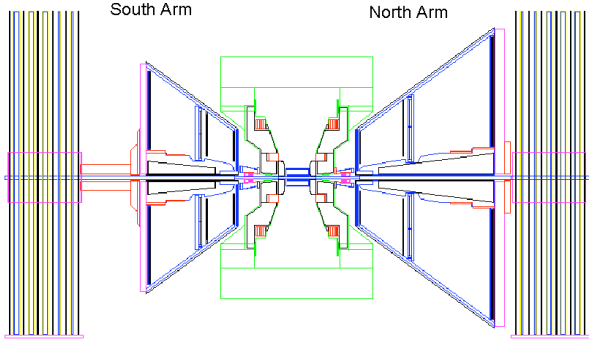
PHENIX and d-Au

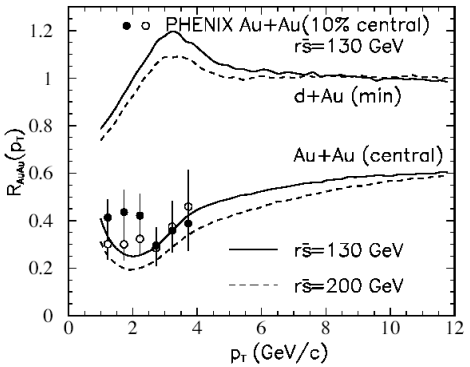
- The baseline PHENIX detector is COMPLETE!
- With the upcoming d-Au run, this detector can be used to measure
  - High p_T hadrons: jet suppression vs. parton saturation
  - J/□ production over a wide kinematic range: nuclear shadowing at small x
  - Open charm from high p_T leptons
  - Cold nuclear medium effects on □, □
  - Variety of hadronic observables:
    - E_T, N_{ch}, HBT
- While many theoretical predictions can be differentiated with min-bias distributions, systematic studies require global event characterization











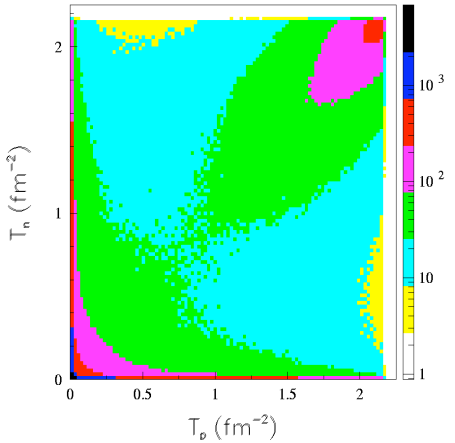
Wang & Wang PRL89 (2002) 162301

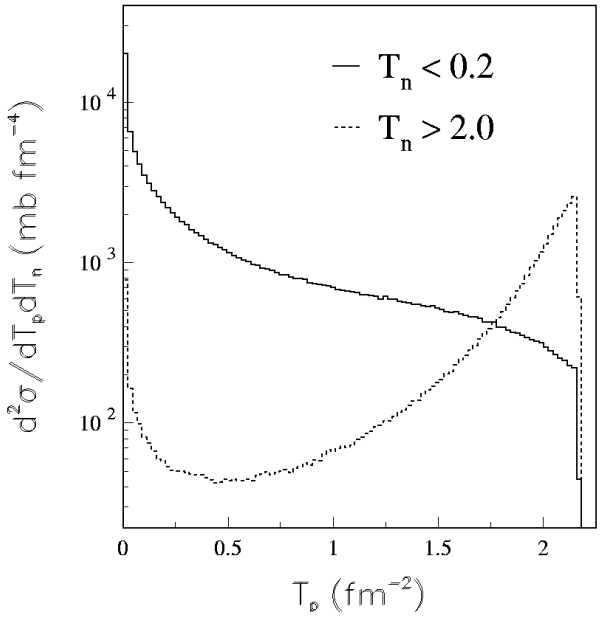
Q: is p-A d-A?

- A1: No
- A2: Yes

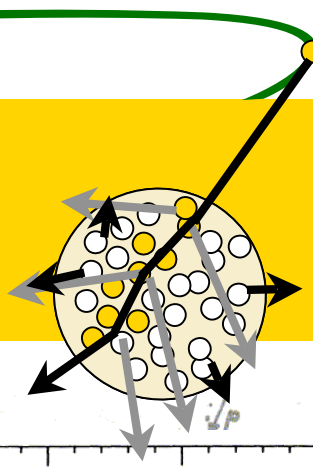
- Study (by B. Cole) of thickness function (T) seen by p & n in deuteron
  - Monte Carlo deuteron using Hulthen wave function
- For central neutron proton distribution mostly central
- For peripheral, peripheral
- But long tails due to deuteron size

- How can we trigger on collision conditions?





Shades of grey



- True systematic comparison with minimum of theoretical meddling requires N_{binary} dial
- How
  - Variety of d-A combinations?
    - Trivial to do in fixed target experiments
    - Unrealistic at RHIC
  - Particle multiplicity or E_T?
    - Difficult to disentangle biases
    - E.g. $N_{\square}$ multiplicity vs. E_T
    - Problem exacerbated for low multiplicity environment of d-A
  - Grey particles
    - "Knock-out" nucleons – forward biased
    - More sensitive, less biased, independent measure of centrality
  - Black particles
    - Evaporation nucleons -- isotropic
    - Also related to centrality (but less so)

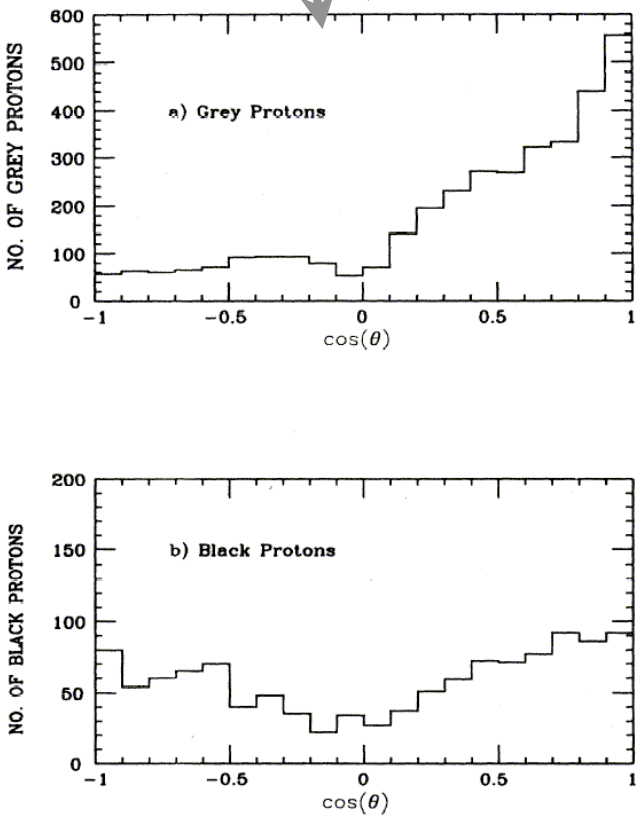
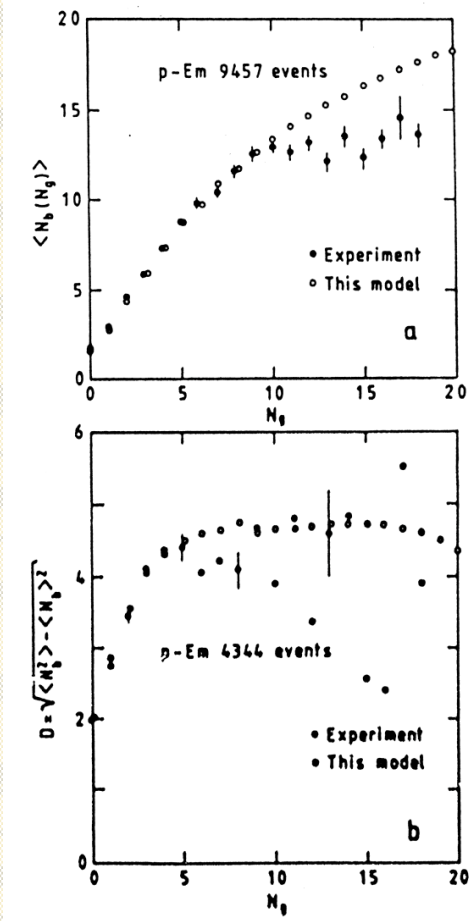
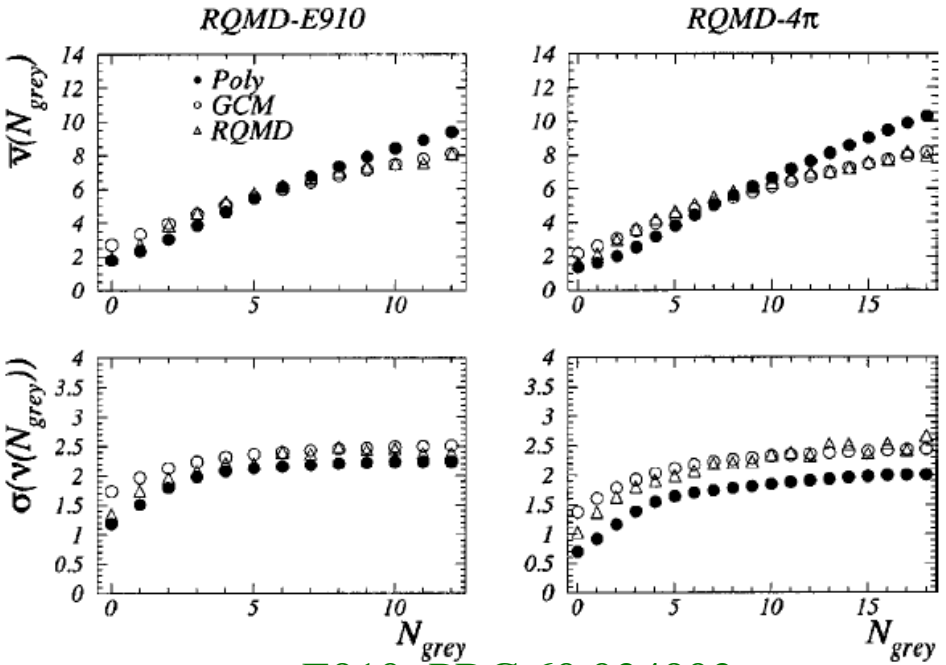


FIG. 2. Angular distribution of identified protons with respect to the beam direction for (a) grey protons with momentum >0.3 GeV/c and (b) black protons with momentum <0.3 GeV/c.

N_{grey}/N_{black} relations

Stenlund & Otterlund
NPB198 407





E910: PRC 60 024902

- Physical picture:
  - N_{grey} directly related to N_{binary}
  - N_{black} related to excitation of nucleus (N_{grey})

Previous Uses of Grey Protons

Multiplicity vs N_{binary}
NA5 PRD29 (1984) 2476.

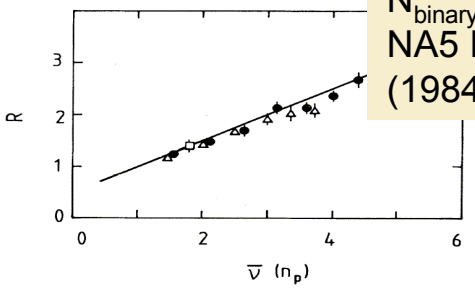
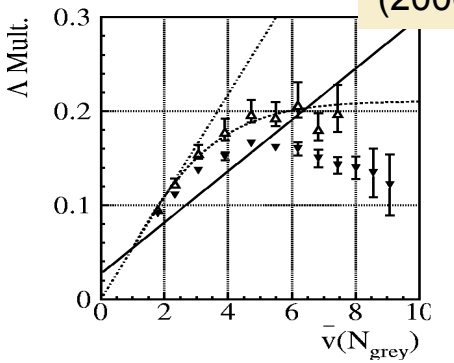
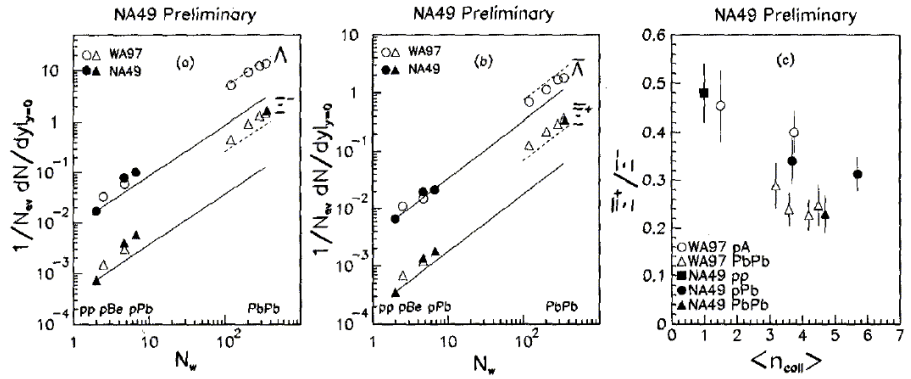


FIG. 4. The ratio $R = \langle n \rangle_{pA} / \langle n \rangle_{pp}$ versus the average number $\overline{\nu}(n_p)$ of projectile collisions for pXe (circles), pAr (triangles), and pNe (squares) collisions. A line of the form $R = 0.5[\overline{\nu}(n_p)+1]$ is shown for comparison.

Strangeness E910 PRL85 (2000) 4868



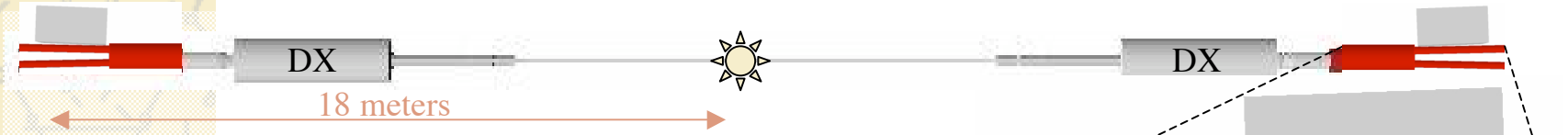


Strangeness at CERN NA49 PRL85 (2000) 4868

Figure 3. Mid-rapidity yields as a function of number of wounded nucleons for (a) baryons (b) antibaryons (c) $\bar{\Xi}^+/\Xi^-$ ratio at mid-rapidity

And where are they located at RHIC?

Tagging centrality/collision flavor



- On nucleus side:
  - ZDC measures only evaporation (black) neutrons (by design)
  - Beam pipe shadows grey neutrons
  - Larger calorimeter on Au side can measure grey protons
- On deuteron side:
  - ZDC can tag on p-A like collisions
  - Addition of small proton calorimeter can trigger on n-A like collisions
- Interesting side notes:
  - Same detector on Au side can be used in p-A
  - Combination of both detectors can trigger on 200GeV n-n collisions should RHIC every run d-d.

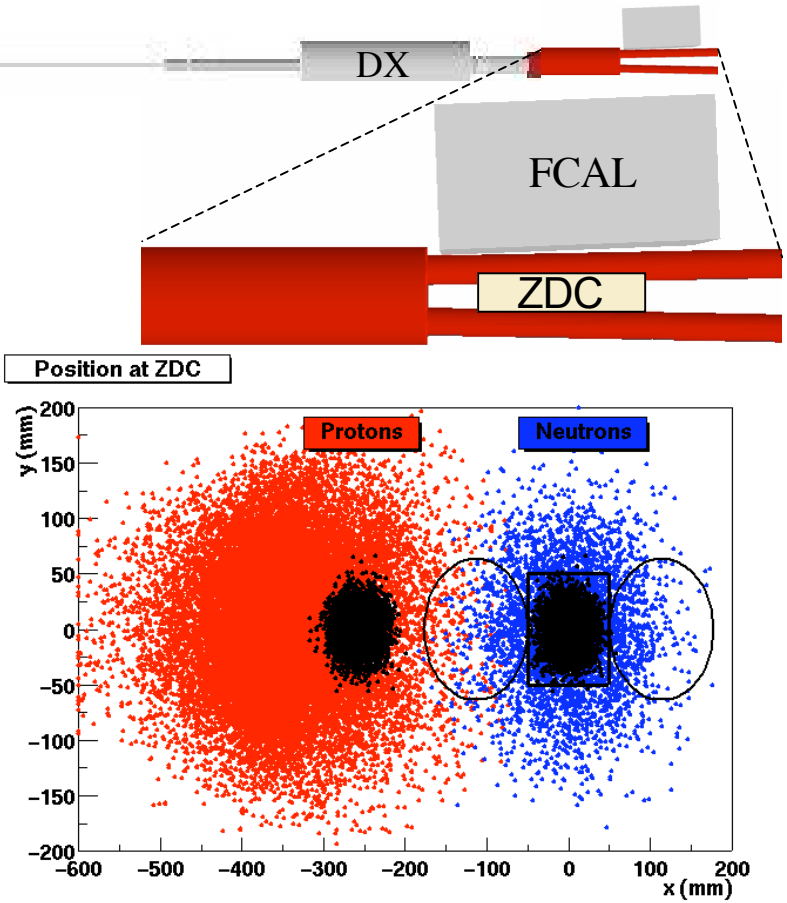
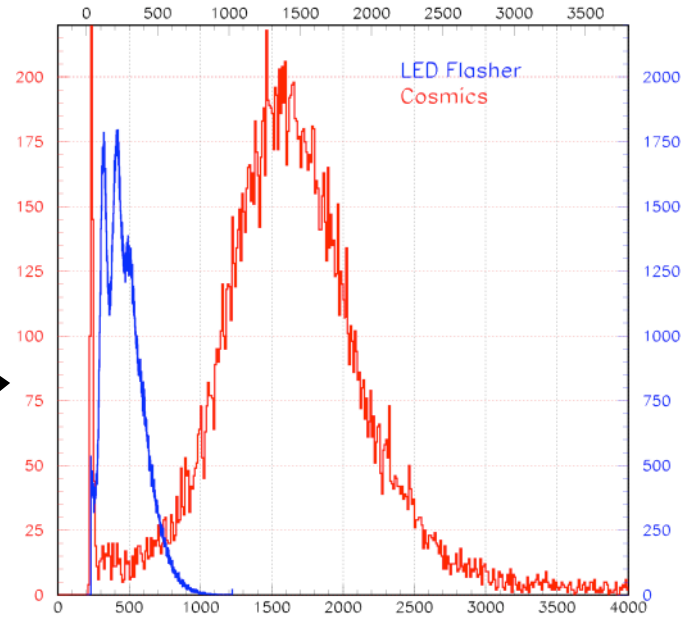


Fig: Distribution of black and grey nucleons at ZDC position with no scattering. [Protons look wider in y due to relative statistics thrown.]

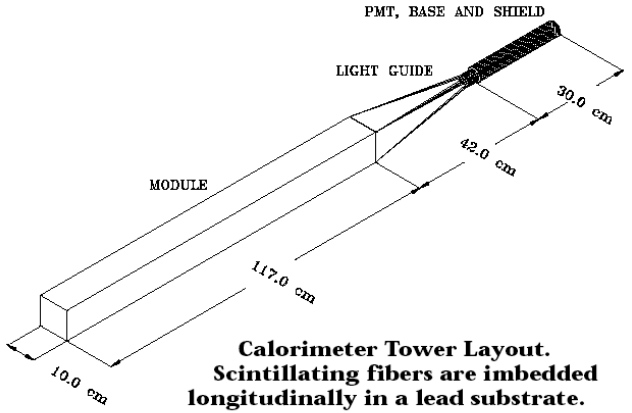
Born in the Bahamas

- Needed working calorimeter on short order
- @ 18th Winter Workshop:
  - Mentioned idea to measure forward protons in d-A collisions to several participants -- searching for quick detector solution
  - Encouraged (by Rene) to consider 864 hadron calorimeter
- Over the course of the next couple months we
  - Found the modules (eek!)
  - Tested them (aah!)

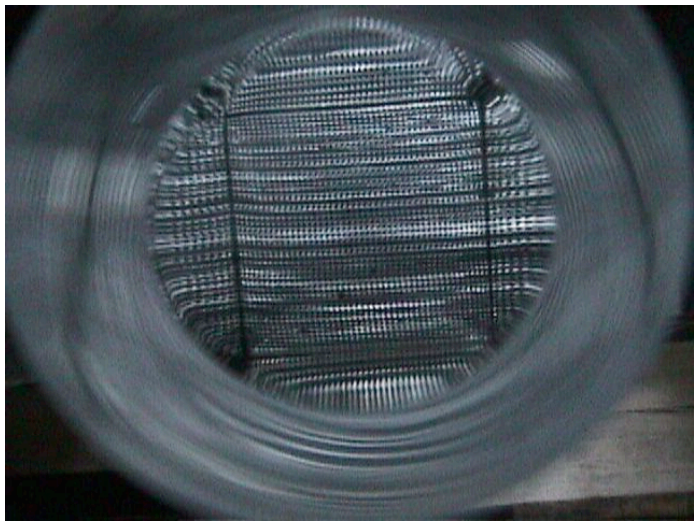


Detector Specifics

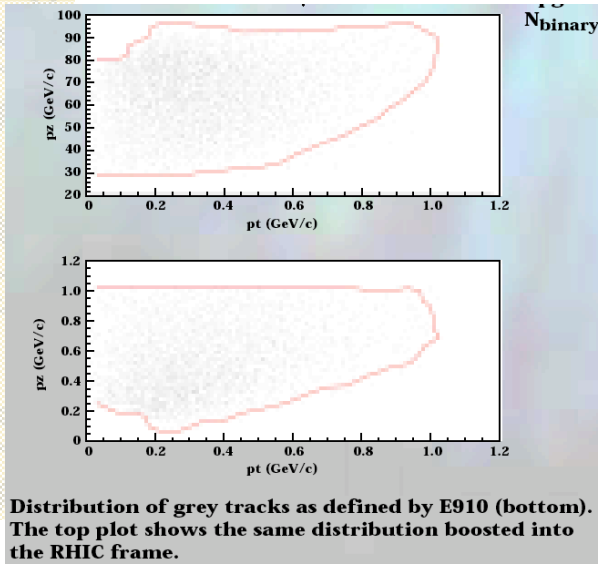
- >700 Pb-Sci modules
  - 10cmx10cm face
  - 117cm long
  - Scintillating fibers along length in grooves of Pb
  - 47x47 array
  - Best energy resolution: 35%/sqrt(E)
- E864: NIM A406 (1998) 227



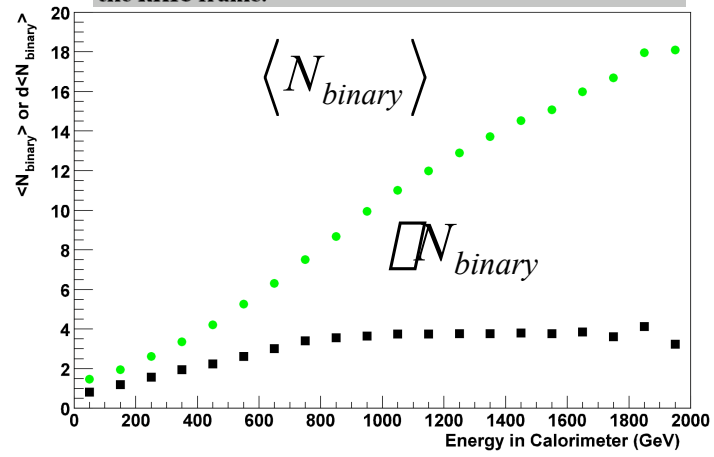
Calorimeter Tower Layout. Scintillating fibers are imbedded longitudinally in a lead substrate. The light readout proceeds through a tapered lucite light guide with a single photo-multiplier tube per tower[8].



Expected Sensitivity

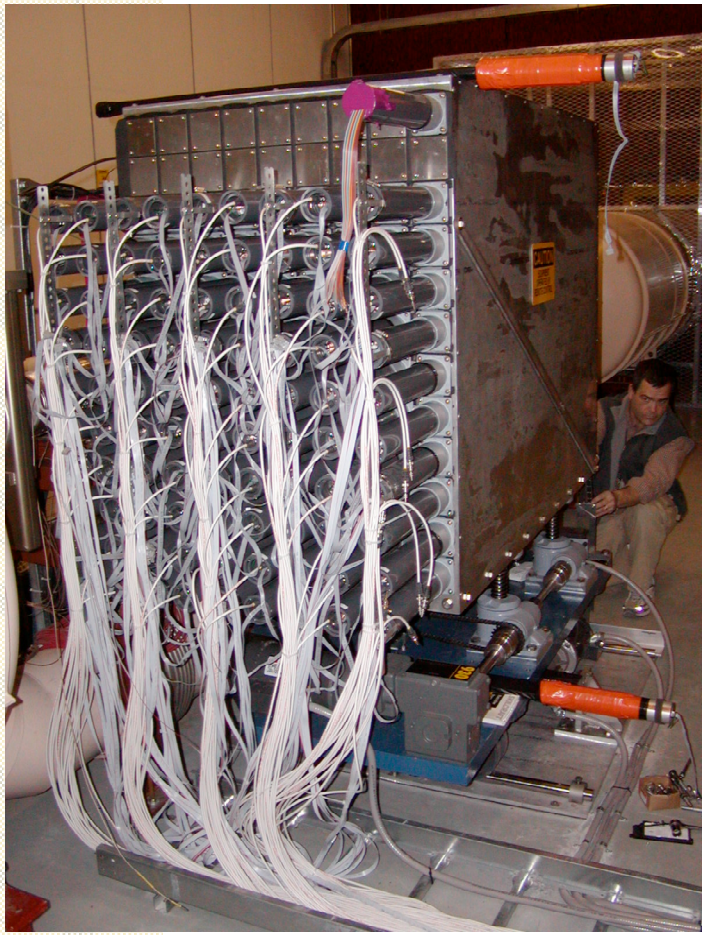


Distribution of grey tracks as defined by E910 (bottom). The top plot shows the same distribution boosted into the RHIC frame.



- Throw d-Au collisions with simple Glauber model ==> determine N_{binary}
- Use E910/Stenlund-Otterlund measurements to determine
  - $N_{grey}(N_{binary})$
  - $N_{black}(N_{grey})$
- Take raw grey/black definition from E910 ntuple -- boost to RHIC energies
- Simple MC including
  - All beam components
  - One big block of Pb-Sci for calorimeter
- N_{binary} resolution very similar to E910.

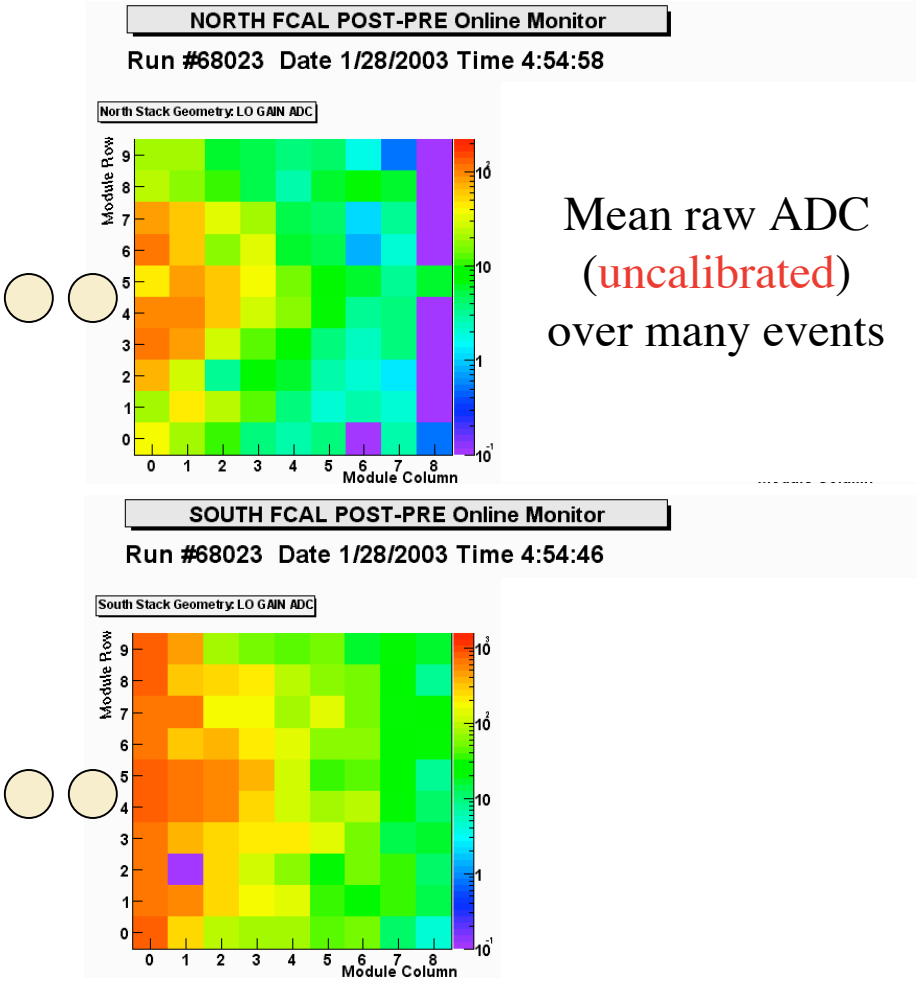
From Vision to Reality



- Detector instrumented in PHENIX
- Array of 9x10 modules centered at beam pipe
  - Cockroft-Walton on tube base -- only supply LV
  - Signals into identical electronics as the PHENIX Emcal
    - Low and high (x16) gain readout
    - Low gain tuned for beam, high gain still good for cosmics
  - Array remotely moveable for calibration
    - That's 12 tons within 1/2cm of the beam pipe…
- Nearly identical detector built by PHOBOS

First Results

- The detector is in, working, and taking data.
- South detector (Au) is run at lower PMT gain than north (d)
  - Don't compare absolute scales of top figure to bottom
- As expected: proton shower much more contained than black/grey distribution
- Blacks predominantly contained to first couple columns, greys distributed over rest of calorimeter



Mean raw ADC (uncalibrated) over many events

The Present and the Future

- Detailed simulations of detector response
- Precise calibration of modules
  - With comics and beam
- Shower reconstruction
  - To improve N_{binary} resolution
- N_{binary} analysis
  - Full event characterization includes intelligent use of FCAL, ZDC, BBC, etc.
- Publish
- Sleep

Collaborators:

- The results of this work are well-nigh impossible without the work of a large number of collaborators

- However, those individuals who contributed directly to this small part of PHENIX for a significant fraction of their time are:
  - Jane Burward-Hoy (LANL), Nathan Grau (ISU), Mike Heffner (LLNL), Gerd Kunde (LANL), Ron Soltz (LLNL), Ray Stantz (FAU), SCJ (LLNL)
- We also enjoy a strong collaborative relationship with the PHOBOS PCAL group:
  - Nigel George, Corey Reed, George Stephans

Extra slides:

Deuteron Wave Function

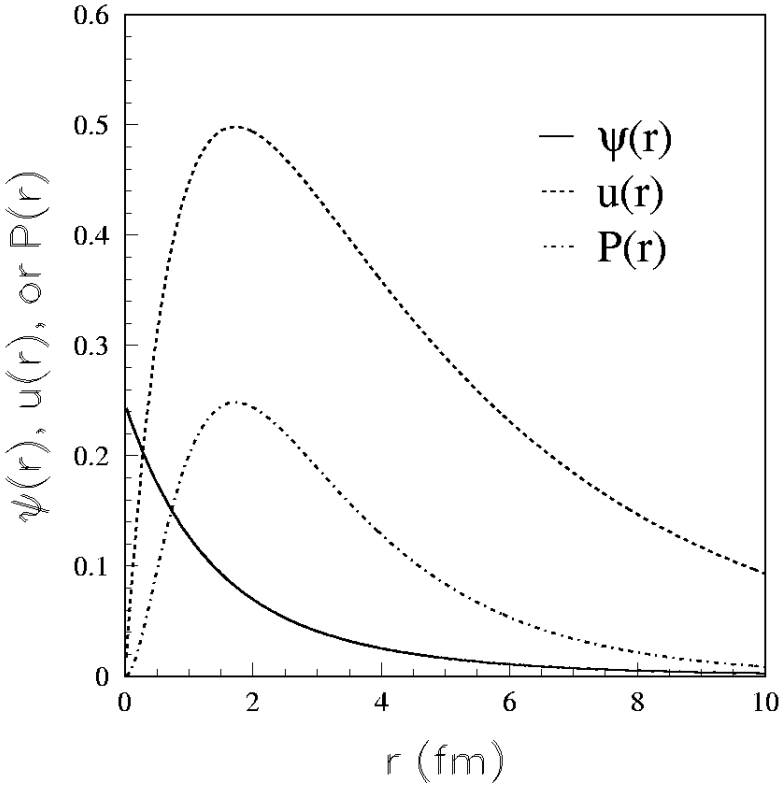
Hulthen wave function

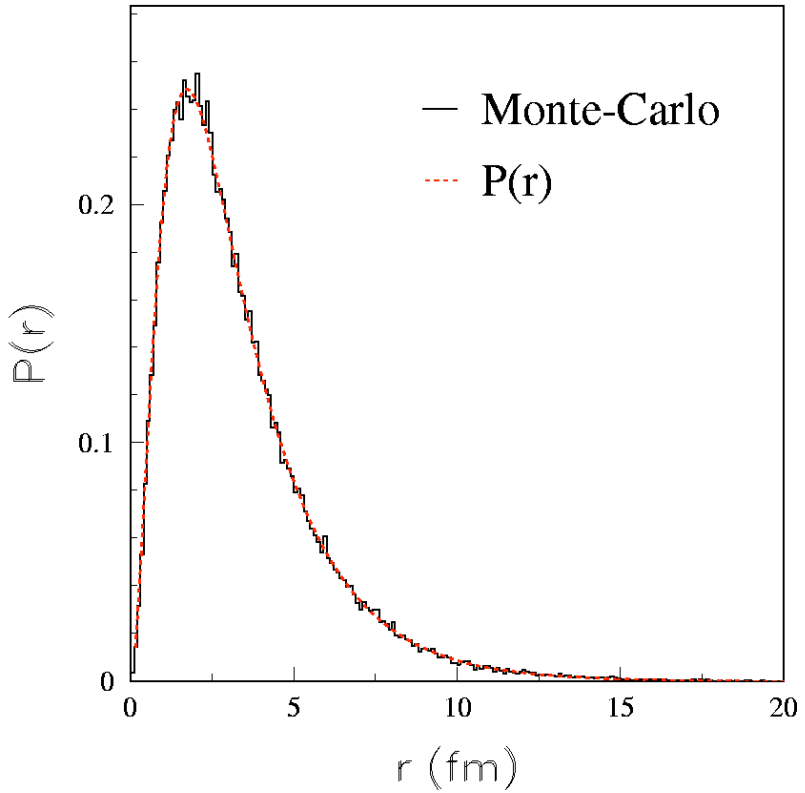
- I have started with the Hulthen wave function for the deuteron because it is trivial to Monte-Carlo.
  - $\psi(r) = \frac{1}{\sqrt{2\pi}} \frac{\sqrt{ab(a+b)}}{b-a} \frac{\left(e^{-ar} - e^{-br}\right)}{r}$
  - $P(r) = 4\pi r^2 \psi^2(r) = \frac{2ab(a+b)}{(b-a)^2}\left(e^{-2ar} + e^{-2br} - 2e^{-(a+b)r}\right)$
  - This probability distribution can be represented as the convolution of three exponential distributions
    - $P_1(r) = 2ae^{-2ar}$
    - $P_2(r) = 2be^{-2br}$
    - $P_3(r) = (a+b)e^{-(a+b)r}$
  - To Monte-Carlo P(r): $r = -\left[\frac{1}{2a}\ln(ran()) + \frac{1}{2b}\ln(ran()) + \frac{1}{a+b}\ln(ran())\right]$

Slide stolen from B.A. Cole 31 May 2002

Hulthen Wave Function -- Results

- a & b can be specified w/ equivalent energies, $E_a = \hbar^2 a^2 / m$.
  $\Rightarrow$ E_a=2.22, E_b=59.8 MeV $\Rightarrow$ 1/a = 4.38 fm, 1/b = 0.85 fm.
- Below I plot the wave-function & related distributions and a comparison of Monte-Carlo and P(r).





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