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Analysis note: d-Au Minimum bias cross sections.

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I. Introduction and purpose:

The purpose of this note is to determine the PHENIX integrated luminosity for Run III d-Au data by measuring the absolute cross section of the BBLVL1 trigger. While we are at it, we determine the STAR experiment's luminosity also.

During Run III PHENIX recorded 12M events with the trigger

(1) zdcs||zdcn>10 geV

in addition to the traditional PHENIX min bias trigger

(2) BBCLVL1>0

The STAR experiment during Run III used as its principal min bias trigger the selection

(3) ZDCS>10 GeV

(we use throughout the nomenclature "S"=Au beam forward direction).

For our purposes knowing the corresponding cross section for the min bias trigger is of interest because this trigger was scaled throughout the run and is used as a reference for all other measurements of cross sections.

It might be expected that by properly correcting (2) for BBC hit efficiency we would arrive at the same geometrical cross section for (2) as for (3) when we calculate the “total inelastic cross section” from a Glauber model treatment.
On the other hand, as was pointed out by Kopeliovich in ref. 1, trigger (3) is more inclusive than (2) since, for a component of the inelastic pp cross section-single diffraction dissociation- the latter has efficiency close to 0.

Since ref. 1 also calls into question other aspects of PHENIX and STAR's Glauber model prescription it is worthwhile measuring our trigger cross sections directly.

II. Calibration cross section:

Photodissociation of the deuteron has been well studied since the 1930's (when it was first measured by Maurice Goldhaber at the Cavendish) and its dependence on incident photon energy is known to high accuracy. In ref. 2 Klein and Vogt apply the Weizsacker-Williams method to calculate the corresponding photodissociation cross section in d-Au collisions at RHIC energy. They also note that hadronic diffraction contributes at the level of 140 mb to the breakup cross section bringing the total cross section for the experimentally clean

(4) d+Au->n+p+Au

reaction to 1.38 barns with an estimated uncertainty of less than 5%.

This calculation is relatively straightforward ("textbook"). More so for example than calculating the PHENIX BBC efficiency. And certainly much simpler than calculating the accelerator luminosity from machine parameters. And not insignificantly…. it is available in a refereed scientific journal.

For these reasons we propose adoption of the photodissociation process as the basis for PHENIX luminosity.

III. Experimental Overview:

The subsystems relevant for this analysis are

-ZDCS & ZDCN
-SMDS & SMDN
-FCLS & FCLN
-the BBC

The signature for reaction (4) is

-(**) 100 GeV energy in ZDCN
-(**) 100 GeV energy in FCLN
cut #1=no energy in either ZDCS or FCLS
-cut #2= BBC multiplicity <1
-cut #3=DC track multiplicity<1
and hit multiplicity in PC1,PC2,PC3 <1

(**) – in the event selection used below we use only the ZDCN Energy distribution (and not the FCLN Energy distribution). Dissociation candidates are extracted from events in ZDCN distribution satisfying above cuts #1-3.

The ZDC energy response vs neutron impact position is well known (from testbeam) and the SMD is used to validate assumptions about the angular distribution (and therefore acceptance) of neutrons.

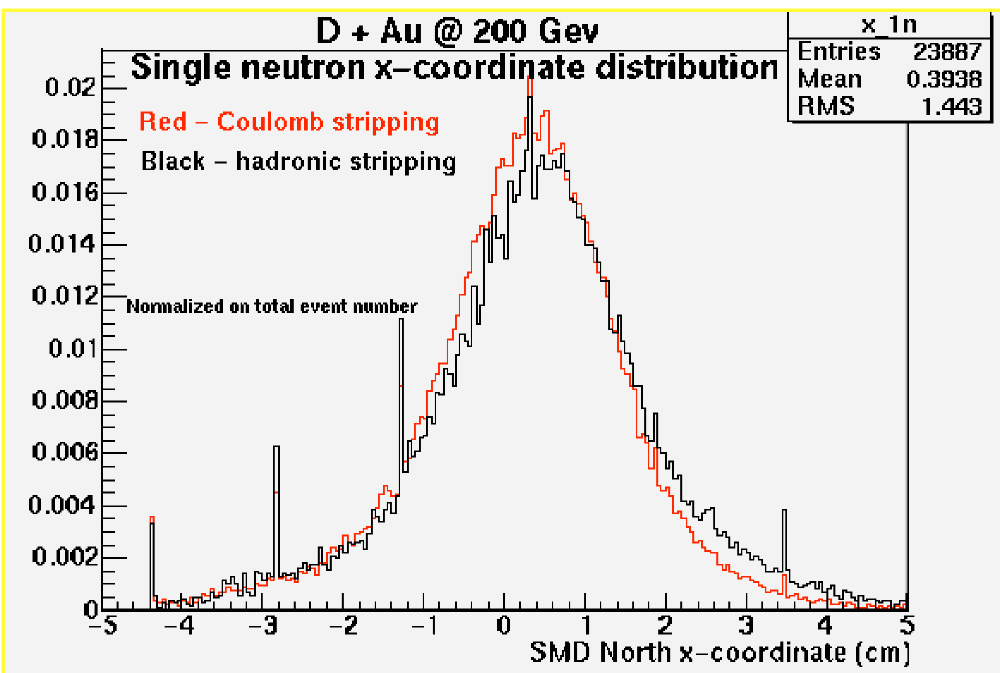
Fig. 1 shows the impact distribution of neutrons in the North ZDC as measured by the SMD in the x (horizontal) coordinate. Two classes of events are shown:

-(in red) is the distribution for reaction(4)-photodissociation candidates

-(in black) is the distribution for inelastic collisions with a “neutron tag”

The distributions are essentially identical. It should be kept in mind that the current SMD algorithm is non-linear at the edges of the detector since it uses the energy weighted centroid and doesn’t account for shower leakage. Nevertheless we see that the neutron angular distribution is not significantly broader than inferred from the CD Bonn model discussed below. (The “spikes” in distributions originate from events with total energy deposition in single scintillator strip of the SMD hodoscope). The offset of the distributions reflects the offset of the deuteron beam which depends on the d+Au run conditions.

Fig. 1: Measured x distribution of neutrons in ZDCN.



IV.Data Set:

We used primarily 3 runs:
(#75549) with the following statistics:

		Prescale
Total events	1.070M	
ZDCS*N	0.308M	161
ZDCSIIN	0.317M	1000
BBCLVL1>0,no vertex	0.161M	1000

(#76864) with

		Prescale
Total events	0.928M	
ZDCS*N	0.278M	161
ZDCSIIN	0.285M	1000
BBCLVL1>0,no vertex	0.141M	1000

And (#76995) with

		Prescale
Total events	0.563M	
ZDCS*N	0.172M	161
ZDCSIIN	0.175M	1000
BBCLVL1>0,no vertex	0.089M	1000

The Runs #76864 and #76995 have essentially identical collision vertex distributions and have been combined for final results. Run #75549 has different beam steering conditions (collisions vertex distribution has a shift of ~10 cm) and have been used for cross checks only.

Events with negative values for number of “fired” phototubes in BBC as well as negative values of energy deposition in ZDC have been removed from analysis. The fraction of such events was 0.05% and they has been ignored.

During runs of interest the “fast clear” procedure for FCL ADC has been performed during beam crossings #15,16,17. Events from these beam crossings have been removed from the analysis as well as events from “empty” beam crossings (even number) and “abort beam” gaps. Removal of events from “empty” beam crossings is an important procedure since ZDCS*N triggers, generated by hits of ZDCs from “back side” by beam halo particles, just occupy these crossings. In doing so we also reduce the rate of possible fake ZDCSIIN triggers from beam halo particles.

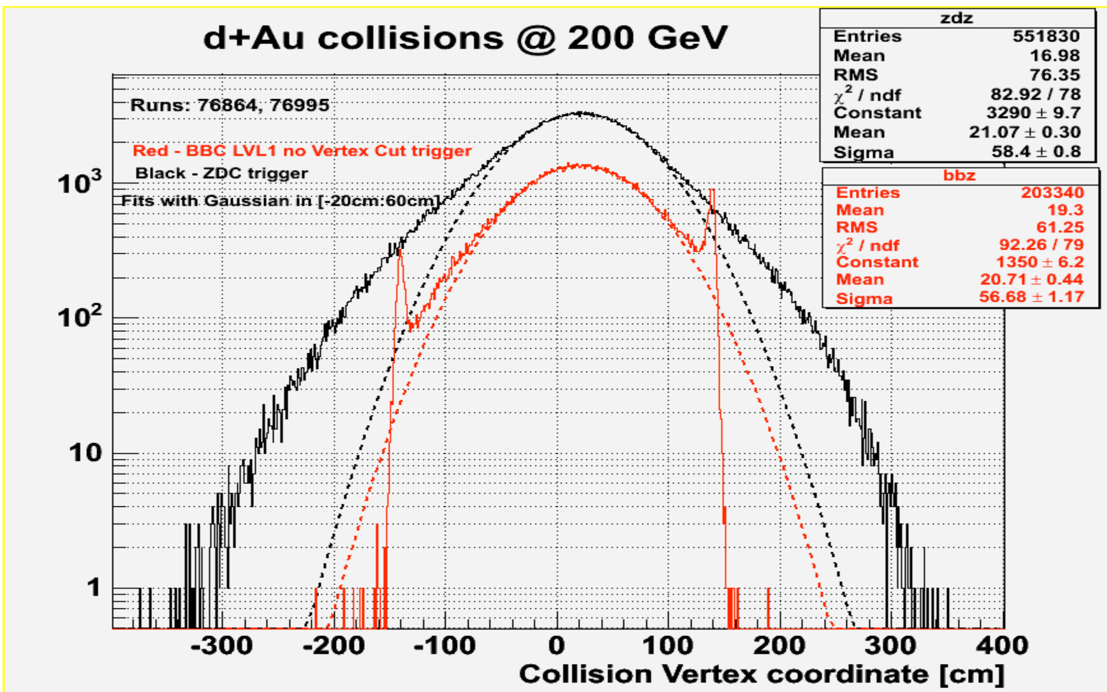
We also used a group of short runs taken during a vernier scan to measure the luminosity dependence (ie Beam-gas background) for the dissociation candidates. These runs are:71738-71744,71746,71749. During these runs horizontal displacement of beams varied from -0.75mm to +1mm

V.Interaction Vertex Dependence:

The ZDC SIIN trigger efficiency doesn't depend on the location of the interaction vertex whereas the BBCLVL1 efficiency deteriorates beyond lZ_vertexl~40 cms.

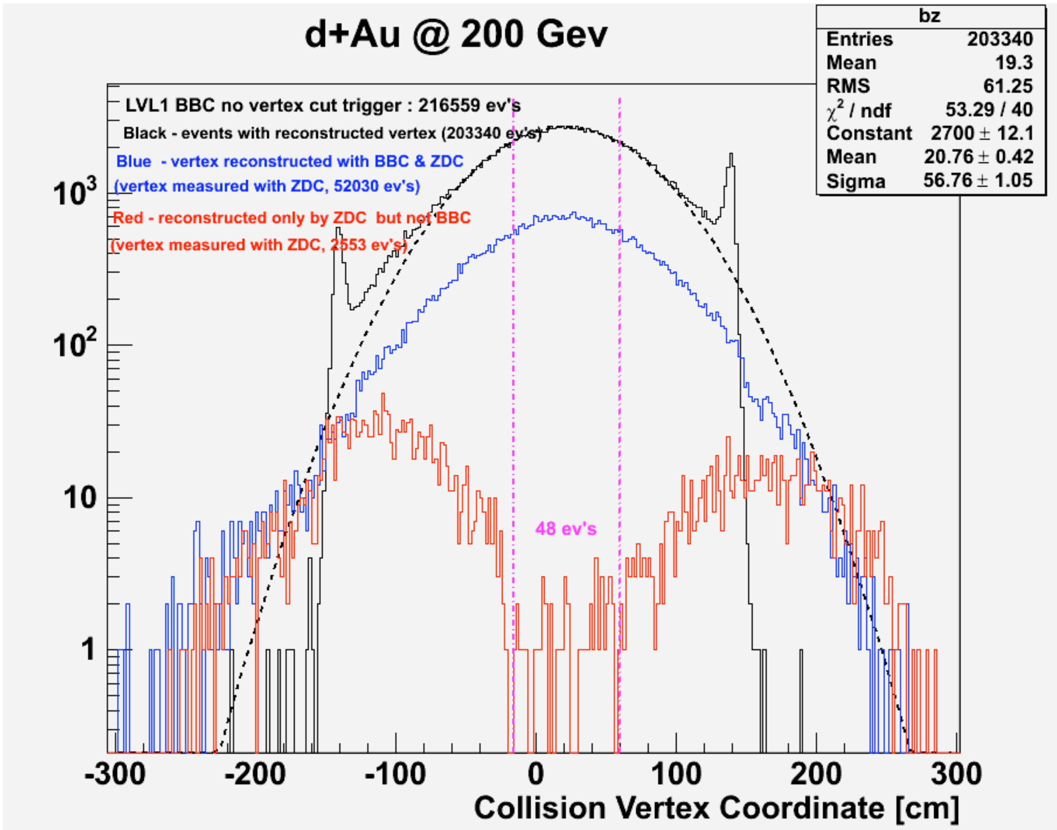
The ZDC and BBC vertex distributions are shown in Fig. 2 .

Fig. 2 Vertex distribution of BBLVL1 events(red) and ZDC SIIN events (black).



The BBC vertex distribution is calculated from BBCLVL1(no vertex cut) triggers and the ZDC vertex distribution is from ZDC NIIS triggers. It is necessary to note, that only 94% of events, triggered by the BBCLVL1(no vertex cut) trigger, have a reconstructed collision vertex and this effect should be taken into account. In reality the “off-line” reconstruction efficiency depends on collision vertex position, as is demonstrated in Fig. 3, where we plotted reconstructed ZDC vertex distributions for an event sample with a reconstructed BBC vertex, and also where reconstruction with the BBC failed.

Fig. 3. Collision vertex distribution reconstructed with BBC (black). Blue histogram shows vertex distribution reconstructed with the ZDC. The red one is the vertex distribution for events in which BBC reconstruction failed.



It is clear that BBC vertex reconstruction efficiency is good in the central region, between BBC arms, and degrades toward the detector positions. It is important to note that most of beam-gas generated events (background) are concentrated in regions of the "horns" in the BBC vertex distribution. Taking this into account, we will consider the BBC vertex distribution in the range of +/- 40 cm around of peak position (~20 cm) only, as indicated by vertical lines on the plot.

To estimate the unbiased number of BBCLVL1 events in the full range of collision vertices (see Fig.2 with ZDC vertex distribution) we multiplied the number of BBCLVL1 events in the range [-20cm:+40cm] by the ratio of ZDC N*S events in the full range to that in the [-20cm:+40cm] range:

$$N_{BBCLVL1} = 99676 * (421550/185251) = 226819 \text{ events}$$

We don't try to correct this number for the BBC reconstruction efficiency since it is already absorbed in the estimate for BBCLVL1 trigger efficiency in Ref.4. The "feed down" correction due to different experimental vertex resolutions for the BBC and ZDC, was accumulated in a multiplicative factor for $N_{BBCLVL1}$, which was found to be small:

$$F_{feed\ down} = 1.008 \pm 0.002$$

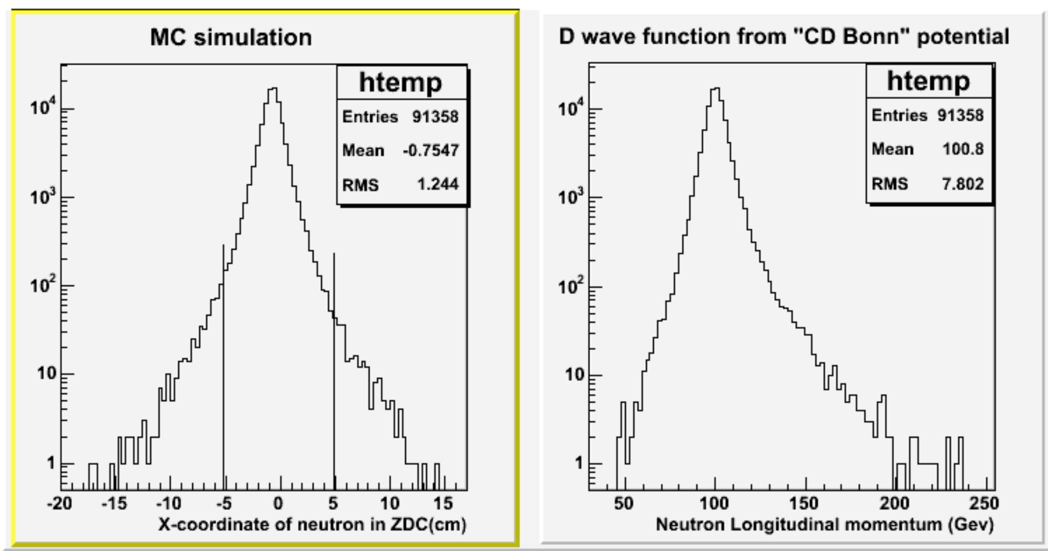
The final number of BBCLVL1 events is 226819 * 1.008 = 228634 (+/-0.5%).

<u>VI.Neutron Acceptance in the ZDC:</u>

The neutron wave function was modeled using the "CD Bonn potential" of ref. 3.

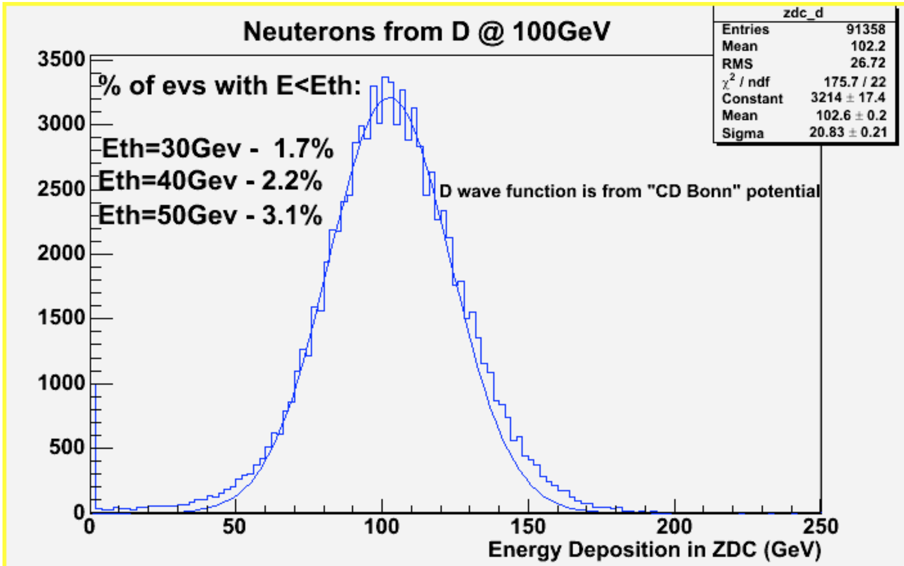
Using this input, angular and energy distributions of dissociation neutrons in PHENIX were calculated and are shown in fig.4. In these calculations the d-beam offset was taken into account explicitly.

Fig.4 Simulation of n impact position and energy using "CD Bonn" wavefunction as input.



Full simulation, including detector response is shown in fig. 5. We see from the figure that we expect ~3% of events to have ZDCN energy less than 50GeV.

Fig. 4. Simulated ZDCN energy distribution including ZDC response.

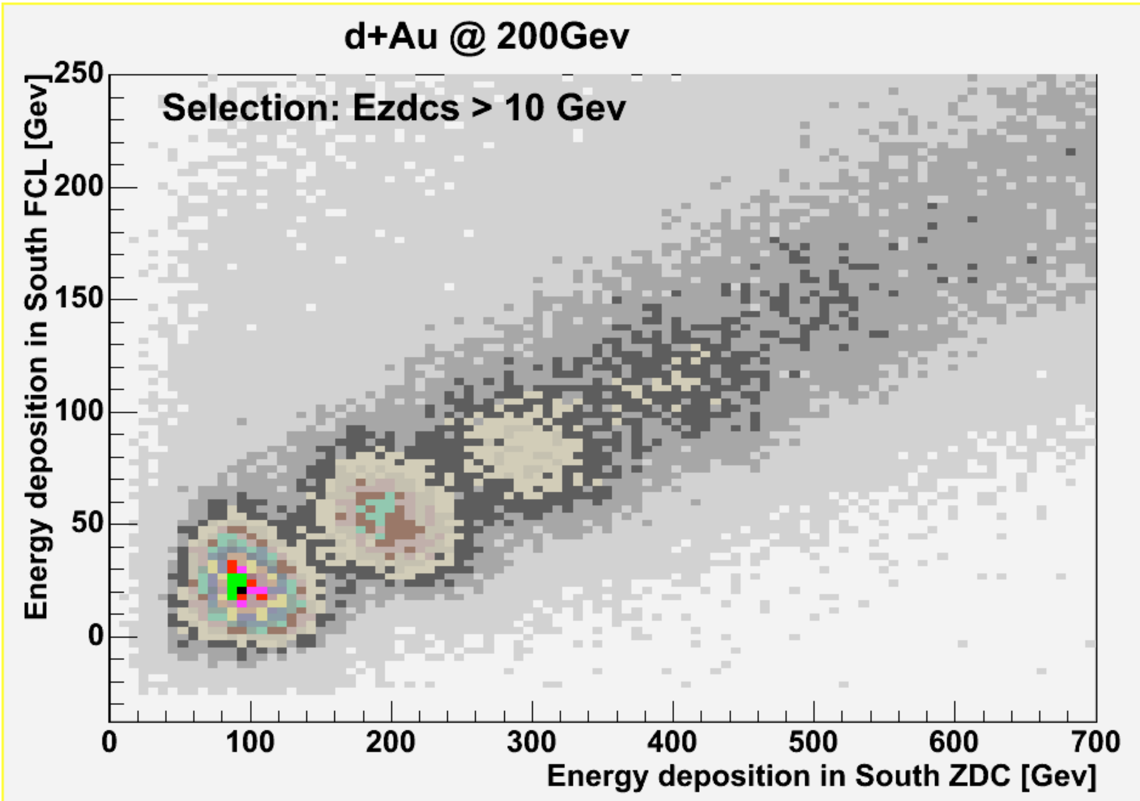


In real life we have "cross talk" between the ZDC and FCL in the energy response of the detectors. It is clearly demonstrated in the scatter plot on the left panel of Fig.6. Roughly, a 100 Gev neutron, absorbed in the ZDC, injects ~27 Gev of equivalent energy into FCL (with an r.m.s. spread ~13 Gev). On the other hand a 100 Gev proton, absorbed in FCL, injects ~7 Gev of energy in the adjoining ZDC (with an exponential distribution). These cross talk effects can be obtained from the experimental data and have been used to correct for event losses due to cuts on energy in ZDCN. For a 50 Gev cut on energy deposition in ZDCN for deuteron dissociation events we estimated these losses as (2.5+/-0.5)% of good events.

The correction will be applied where needed.

The energy scale for FCLN was established from a fit of FCLN response to 100 Gev protons, obtained from experimental data. But for establishing a correct energy scale for FCLS, the cross talk between ZDCN->FCLN was utilized . Just for illustration, Fig.6 demonstrates the correlation in the responses of FCLS and ZDCS with a beautiful neutrons separation.

Fig.6. Energy deposit correlation between South arms of FCL and ZDC for ZDC NIIS triggers and energy cut E_{zdcs} >10Gev.



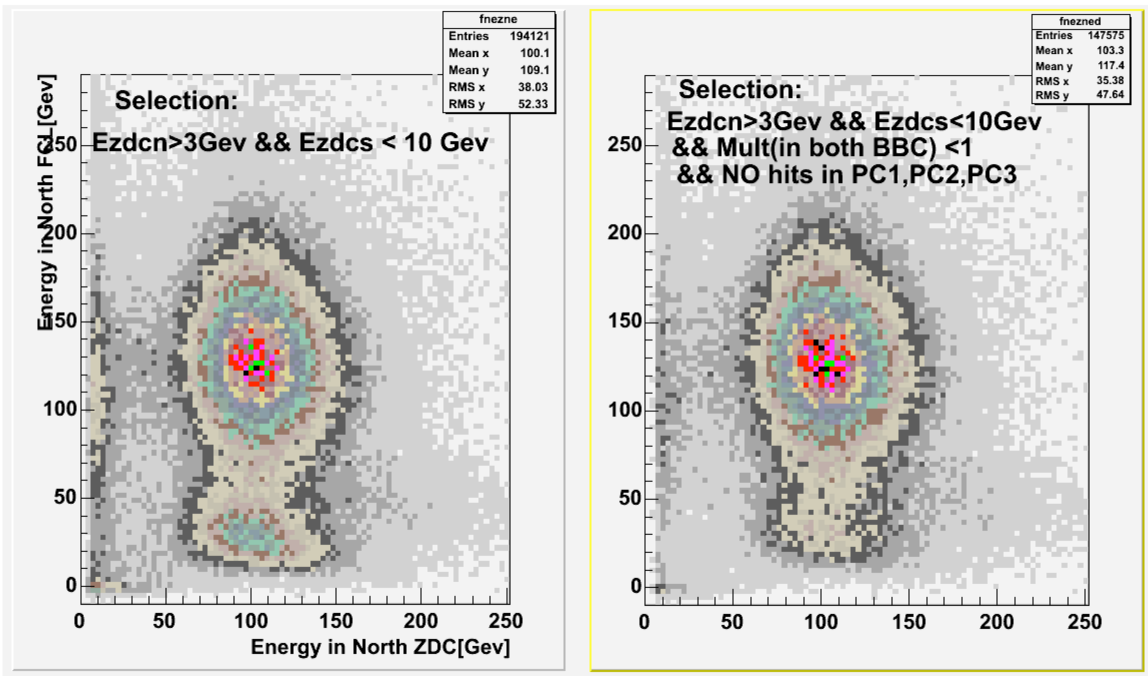
VIII.Photodissociation data sample:

It is well known that a fraction of d-Au inelastic collisions have a beam energy neutron in the north arm. These events have been used to select a "neutron tagged " set of peripheral events in the d-Au centrality analysis. To calculate the d-Au dissociation cross section we need to eliminate contamination from these inelastic collisions by applying cuts#1-3 for reaction (4) given above.

The left panel of Fig. 7 shows a scatter plot of ZDCN and FCLN energy depositions for events in the ZDCNIIS data sample. A minimal cut has been placed on the ZDCN energy(>3GeV) and ZDCS energy (<10 Gev). A clear signal is seen for the majority of candidates for reaction (4) but there is also a significant number of events with a full energy neutron in the ZDCN and negligible energy in the FCLN and vise versa - a full energy proton in the FCLN and negligible energy in the ZDCN.

In the right panel we show the same distribution after vetoing on activity in the South arm ZDC and FCL as well as the BBC, PC1,PC2,PC3. Vetoing on activity in the BBC, PC1,PC2,PC3 significantly reduces the number of events with energy deposit in a single detector (ZDCN or FCLN) only.

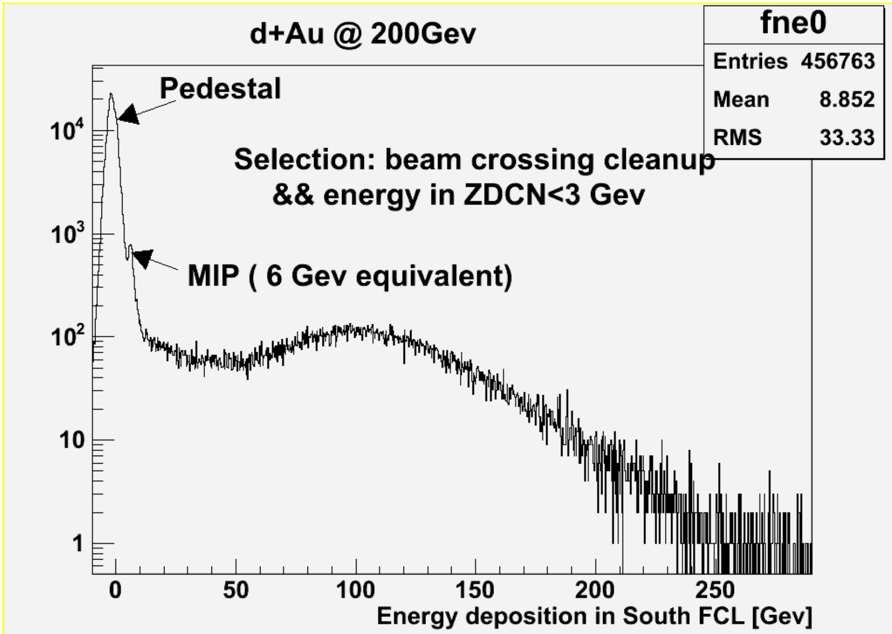
Figure 6: NORTH arm FCL versus ZDC energy deposit.



Proton measurements are significantly cruder than the neutron case. Whereas the neutron distribution is well contained in the ZDC, the proton impact distribution is broadened by a significant momentum dispersion at this location. Tails of this distribution intercept a fair amount of accelerator hardware (flanges,etc) and a fraction of the beam envelope simply misses the active volume of the FCAL. In contrast there is only 0.25” of steel upstream of the ZDC.

In Fig.8 we show response of FCLN for events with negligible energy deposition in the ZDCN (<3 Gev). It demonstrates “MIP” signals from 100 Gev protons, which traverse FCLN without interaction, as well as a broad peak from 100 Gev proton showers. The most important feature here is the low energy “shoulder” in the energy distribution (<~50Gev) . It originates from environmental conditions, discussed above. Since ~(20-25)% of 100 Gev protons encountered large energy losses, it is hard to account for this effect with good confidence by simply applying cuts on energy deposition in the FCLN.

Fig.8. Energy deposition in North FCL for events with negligible energy deposition in the neighbor ZDCN.



We therefore select "golden" D-dissociation events with the following cuts:

ZDCSIIN trigger && E_{zdcn}>50 && E_{ZDCS}<10 && E_{FCLS}<40

This sample consist of 164450 events. As will be shown below, 3+/-0.3% of these events originate from beam-gas collisions.

The effects of additional cuts on activity in the BBC and central arm detectors are demonstrated below:

Successive cuts:		# of events left
&& (bbcn+bbcs)<1	-	150840
&& ndc<1 -	-	150139
&& (bbcn+bbcs)<1&&npc1<1&&npc2<1&&npc3<1	-	136201

The effect of these clean-up cuts varies from 8% up to 18%. It is a large effect and there is no real criterion where to stop. Definitely in applying them we remove real D-dissociation events due to background events which generate hits in BBC, DC, PC detectors. For PC detectors, the electronic noise may play an important role too. We should expect that events, which were removed by the "clean-up" procedure to have some signature in comparison with "clean" events. This is clearly demonstrated in Fig.9 where we plot total energy deposit in North ZDC and FCL for removed and "clean" events for different "clean-up" cuts. Fig.9b demonstrates importance of fake hits in PC from electronic noise.

Fig.9a.

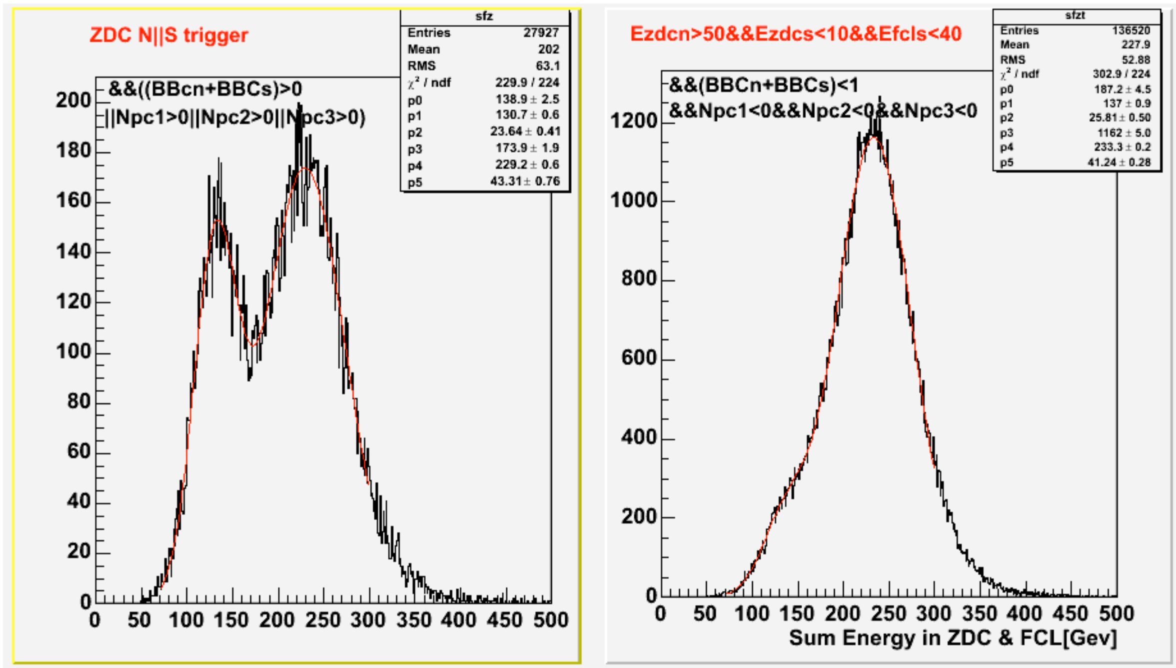
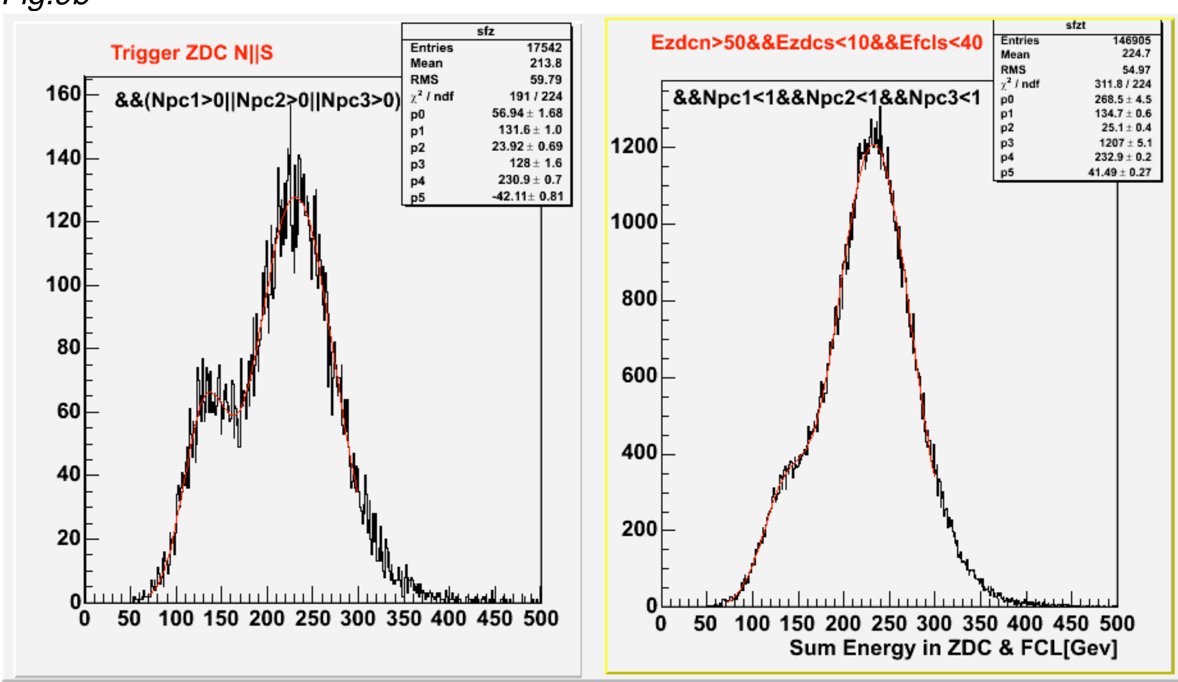


Fig.9b



To estimate the correct number of deuteron dissociation events we use the following procedure. As an approximate template for the total energy distribution for ***REAL*** D-dissociation events we will use the experimental distribution for events after clean up cuts. After appropriate normalization this template is used to subtract good events from the cut sample. Strictly speaking, this is an iterative procedure. But in our case, already the first iteration should provide us with an accuracy of better than ~ 0.1* 0.1 = 1%.

Practically we implemented this correction procedure as follows:
The total energy distributions for “cut” and “clean” event samples were fitted with a sum of 2 Gaussians in the energy range [70Gev:290Gev]. In general the fits are very good (see ie Fig.9). The subtraction procedure is reduced in this case to a multiplicative factor for “clean” events, which is the ratio of constants for high end Gaussians for “cut” and “clean” samples. The error estimates are from propagation of fit errors.

Below are results of this correction procedure for two extreme cuts on hits multiplicity in BBC and central arm detectors:

Successive cuts:	# of ev’s left	Correction	Corrected #
&& (bbcn+bbcs)<1	- 150840 -	1.0418+/-0.0010	157149
&&npc1<1&&npc2<1&&npc3<1	- 136201 -	1.1497+/-0.0018	156951

The different combinations of cuts on BBC ,DC andPC hit multiplicities produce identical results. As a final estimate for the number of deuteron dissociation events we used 157149.

Potentially, up to 50% of beam-gas backgrounds can produce hits in the BBC or in central arm detectors and good events will be removed by the clean up procedure. We assume the maximum case and assign a 100% error for this assumption. So, we will subtract 1.5+/-1.5 % from the estimated number of “deuteron dissociation” events.

We should correct our sample for losses of (2.5+/-0.5)% due to the selection cut E_{zdcn}>50 Gev and finally get

N(d->n+p) = 157149*0.985/0.975= 158761 (+/- 1.7%)

As a by-product of our procedure we will be able to get a precise estimate for the real response shape of the FCAL to 100 Gev protons after de-convolution of ZDC cross talk.

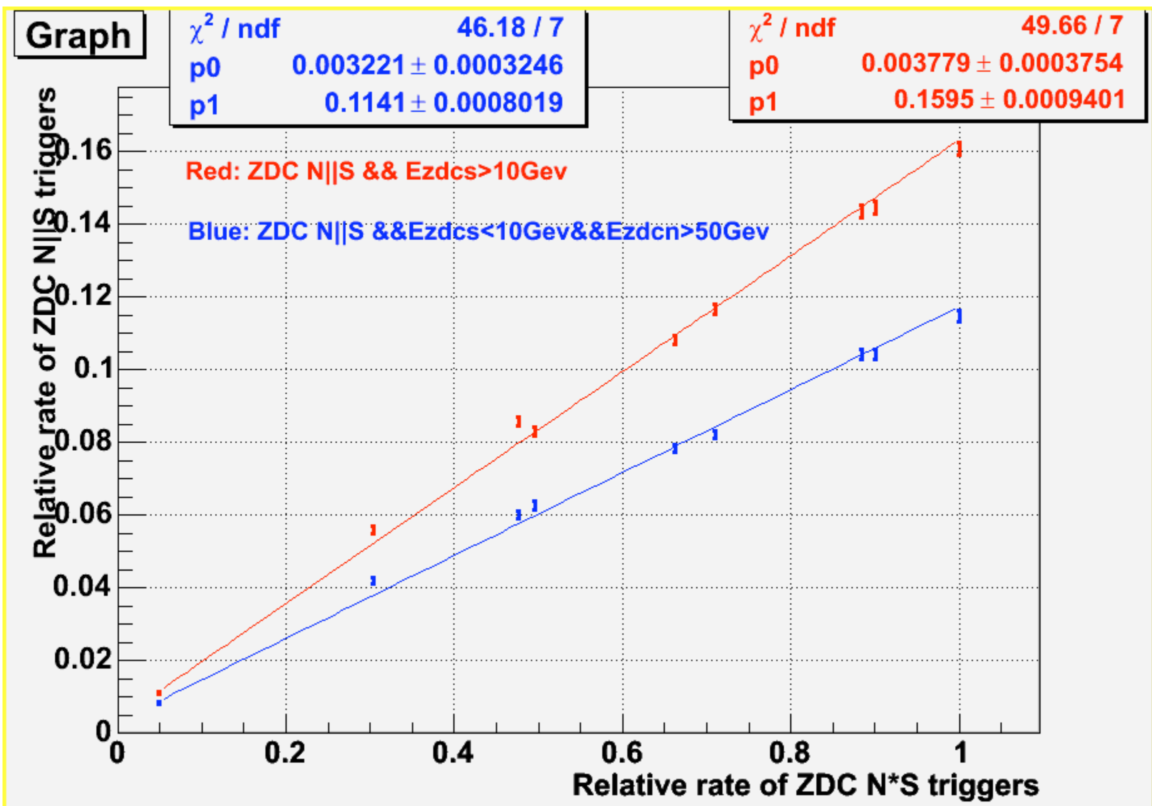
Correcting for Beam-gas background:

To measure the beam-gas fraction in each class of events we plotted the event yield versus luminosity (proportional to the ZDCN*S coincidence rate) in the “Vernier scan” runs. Since the beam currents are unchanged during these runs while the beam overlap is varied, the extrapolation to Luminosity=0 measures directly the beam-gas background fraction. Fig.10 shows the dependence of relative rates for triggers ZDCNIIS with E_{ZDCS} >10Gev (upper curve) and triggers ZDCNIIS with E_{ZDCN} >50Gev and E_{ZDCS} <10Gev on the relative rate of ZDCN*S triggers. Normalization of the rates was based on the maximum ZDCN*S rate.

During these “Vernier scan” runs the ZDCNIIS trigger was suppressed by a factor of 22.5 relative to the ZDCN*S trigger. The ratio of intercept parameter to slope parameter will provide us with estimates of beam-gas fractions in the trigger selections of interest. From the fits we conclude that the fraction of beam-gas events in the quoted ZDCNIIS triggers are:

ZDCNIIS and E_{ZDCN} >50Gev and E_{ZDCS} <10Gev: (3.0+/-0.3)%
ZDCNIIS and E_{ZDCS} >10Gev: (2.4+/-0.3)%

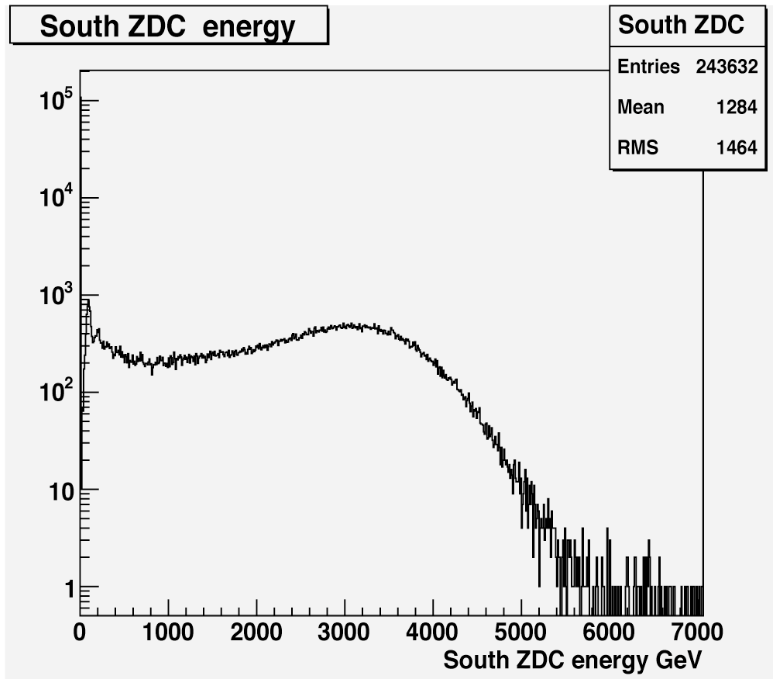
*Fig. 10. Relative ZDCNIIS trigger rates and rate versus relative ZDCN*S trigger rate.*



ZDCS events:

This class of events was used as an alternate minimum bias trigger for dAu. It was the primary min-bias trigger of the STAR experiment. The distribution of energy in ZDCS is shown in fig. 11. Since the average neutron multiplicity is quite large we can neglect correction for neutron acceptance discussed above.

Fig. 11: ZDCSouth Energy distribution (note 1 and 2 n peaks at 100, 200 GeV, see also fig.5).



There are 243,371 (242,842) events satisfying E_{ZDCS}> 10 GeV (E_{ZDCS}> 50 GeV) out of the 430,739 ZDCSIIN triggers. After subtracting beam-gas background we have 237043 (+/-0.3%) events.

Results and Conclusion:

We can now calculate the effective cross sections for the different min-bias triggers based on the (input) cross section of
σ (d->n+p)= 1.38 b (+/-5%)

First we have
σ (ZDCS)= N(ZDCS)* σ(d->n+p)/N(d->n+p)= 237043/158761*1.38
= 2.06 (+/-1.7% +/- 5.0 %) barns
where the second error is due to theoretical uncertainty in σ (d->n+p).

Secondly we find:
σ (BBC)= N(BBC)* σ(d->n+p)/N(d->n+p)= 228634/158761*1.38
= 1.99 (+/-1.6% +/- 5.0 %) barns

Finally we calculate a corrected cross section which uses as input the HIJING estimate of the BBC efficiency in dAu inelastic events (Ref.4)

ε_{MB}(|Z|<30cm) = 0.872 +/- 0.014

σ (BBC-corrected)=1.99/0.872= 2.282 (+/-1.8% +/- 5.0 %+/-1.6%) barns

where first error is experimental, the second one is the theoretical error on the d->np dissociation cross section and the last one is from the uncertainty in the HIJING calculation for BBC minimum-bias trigger efficiency.

How to use these results:

The BBC trigger cross section for use in normalizing dAu luminosity is exactly the quantity σ (BBC)=1.99 barns. However it should be kept in mind that this is calculated for |z_vertex|<40 cms. Typically, with the usual vertex distribution we find that this cross section is reduced by 94% if one considers the full z_vertex distribution for a normalization sample. But the correct procedure is to determine directly the size of this correction by comparing ZDC to BBC vertex distributions.

Similarly σ (ZDCS)=2.06 barns is the correct normalization to use for the STAR min-bias trigger sample. For these data Z_vertex corrections can be ignored.

Finally the quantity σ (BBC-corrected)= 2.28 barns is probably the correct quantity to compare with Kopeliovich's calculation/prediction since he doesn't estimate a BBC detector inefficiency. It can also be compared with David d'Enterria's calculation in ref. 5 of σ(d+Au)=2.32+/-0.18 barns.

The Bibliography:

Ref.1: B.Kopeliovich "Transparent Nuclei and Deuteron-Gold Collisions at RHIC" Phys.Rev. C68 (2003) 044906 and nucl-th/0306044

Ref. 2 S.Klein and R. Vogt, "Deuteron Photodissociation in Ultraperipheral Relativistic Heavy-Ion on Deuteron Collisions"
Phys.Rev. C68 (2003) 017902 and nucl-ex/0303013

Ref 3: R.Machleidt, "High-precision, charge-dependent Bonn nucleon-nucleon potential", PRC, vol.63, 024001, 2001

Ref 4: K.Homma, " **Study of BBC trigger efficiencies based on HIJING simulations for d+Au analysis** ", PHENIX AN211, 2003

Ref.5 David d'Enterria PHENIX AN381
d+Au nuclear cross-section from PHENIX Glauber MC including Au neutron "skin"