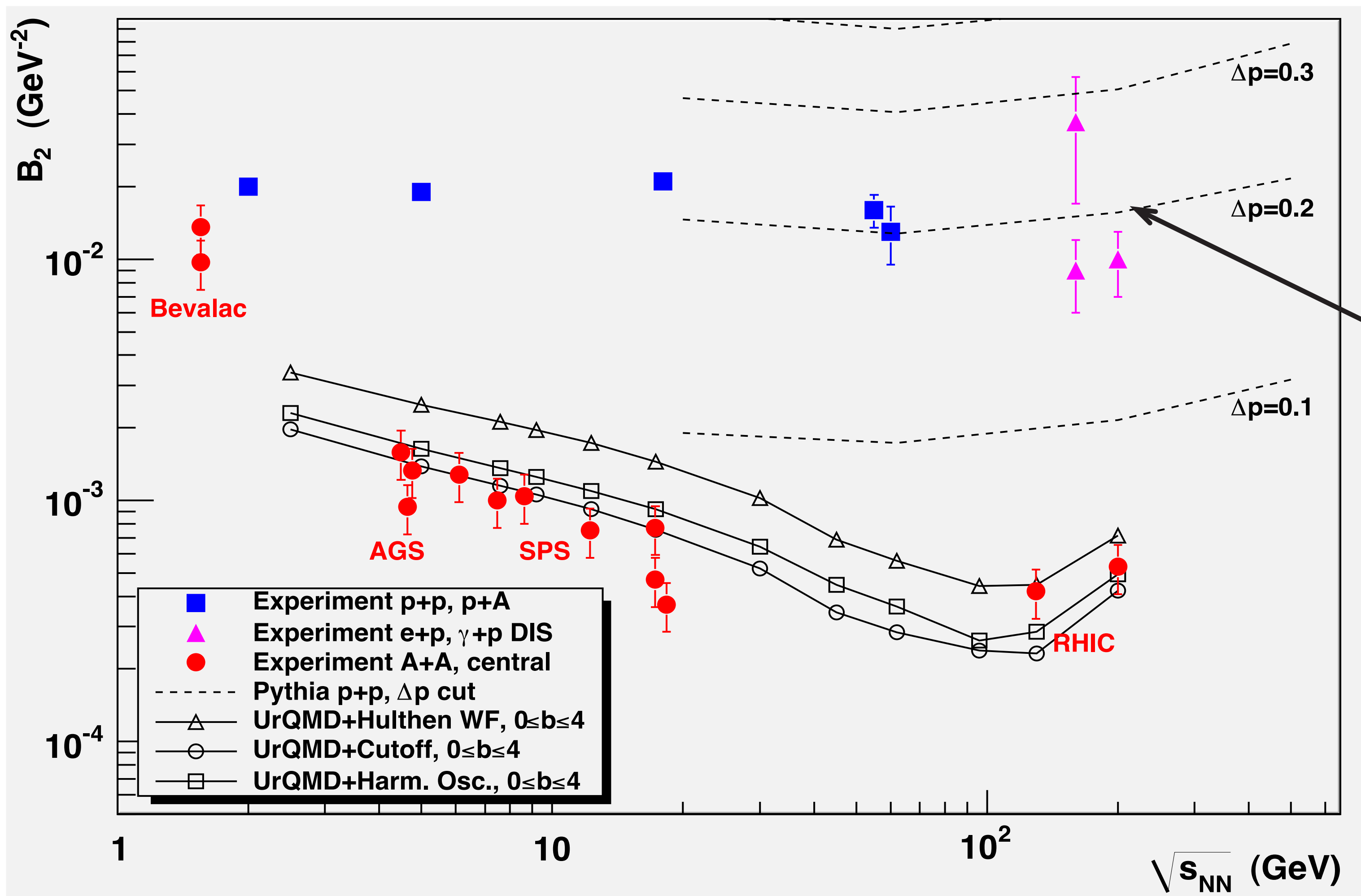
Light Nucleus Production in p+p & d+Au

W.J. Llope
Rice University
☆ Analysis Meeting, Austin, TX
1/12/2010

Existing Results on B_2

$B_A = \sigma_A / [\sigma_N]^A$ where the cross-sections are evaluated at same momentum

$B_A = d/p^2$ where cross-sections are formed at same P_T/A & y=0, Δy=1.0

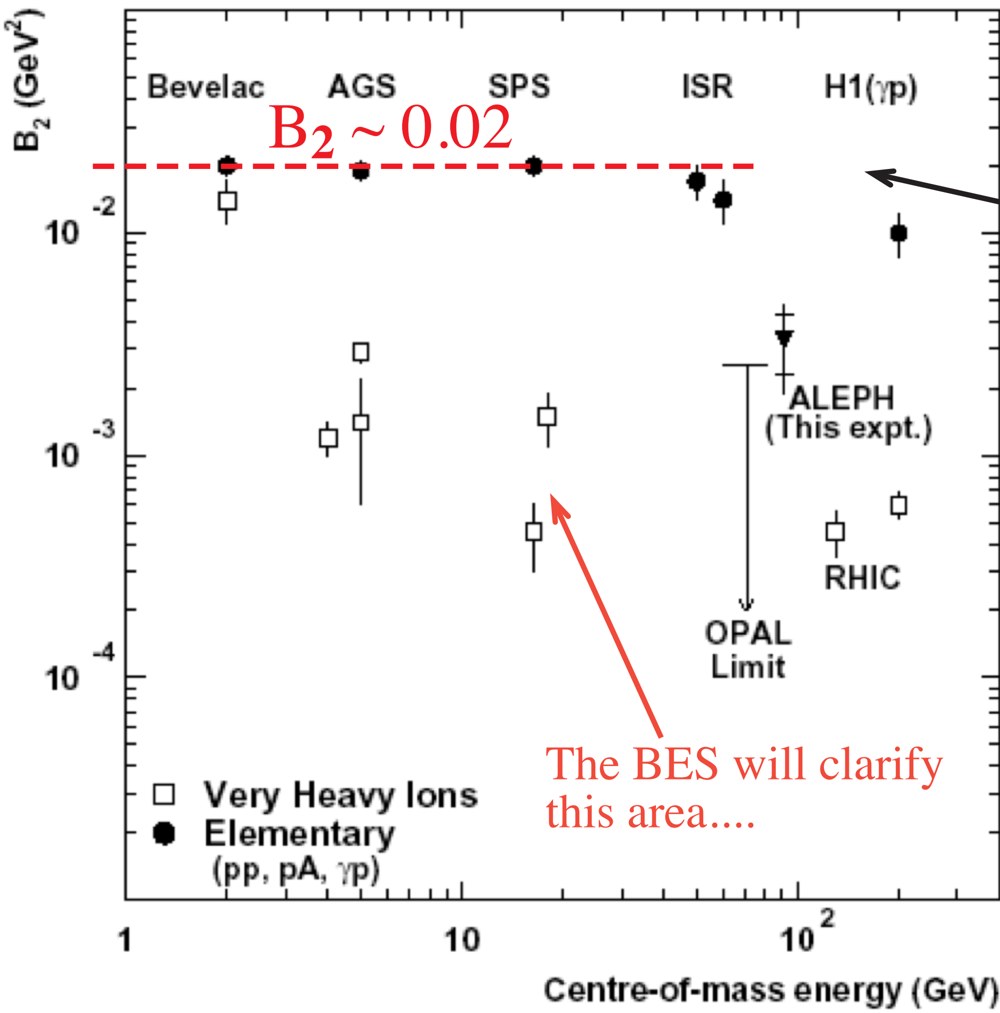


where's the RHIC results?

deuterons relative to protons is largest in □elementary collisions□...

¥°factor of ~40 larger than in A+A according to the trend (blue squares)

¥°essentially independent of $\sqrt{s_{NN}}$ ... also unlike A+A



T. Sloan, GDR Meeting Paris April 2006
http://www.lpta.univ-montp2.fr/GDR/documents/reunion2_2006/sloan.ppt

where does the RHIC data fall?

...we have p+p @ 62, 200, & 500 GeV
& d+Au @ 200 GeV

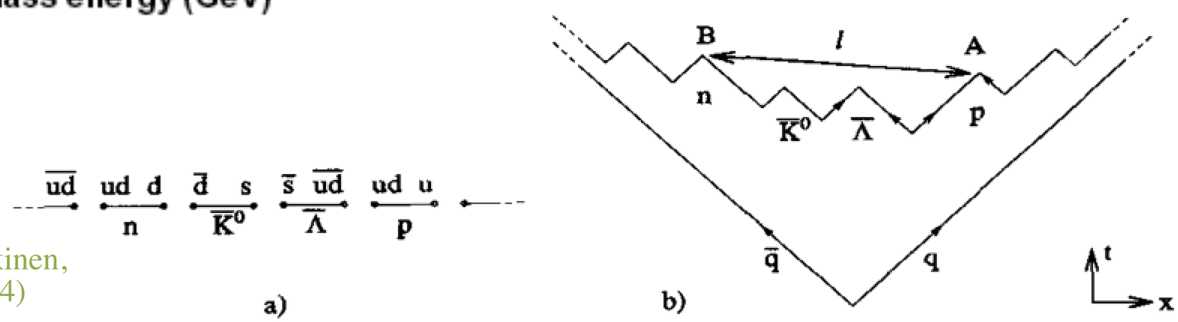
Conventional Wisdom:

p+p: several strings stretched between 2 hadrons
→ B2 ~ 0.02

γ+p: fewer strings
→ B2 ~ 0.01

e+e: only one string
→ B2 ~ 0.003

A+A: lots of strings, but strong rescattering kills all d□s except those that form very late
→ B2 ~ 0.0003



Gosta Gustafson, Jari Haikkinen,
Z. Phys. C 61,683-687 (1994)

Fig. 3a, b. a Possible string breakup process with a *pn* pair. **b** Space-time structure of the breakup

Why B_A ?

$$\frac{d^3N_A}{d^3p_A} = B_A \left[\frac{d^3N_p}{d^3p_p}\right]\left[\frac{d^3N_n}{d^3p_n}\right] \sim B_A \left[\frac{d^3N_p}{d^3p_p}\right]^2$$

$$\frac{d^3N_x}{d^3p_x} = \frac{1}{2\pi P_T}\frac{1}{N_{ev}}\frac{d^2N_x}{dP_T dy}$$

B_A (GeV^2) is related to the source "size" at freeze-out.

$$B_A = \frac{2S_A+1}{2^A} R_{np}^N \begin{cases} \frac{1}{N!Z!}\left[\frac{4\pi p_o^3}{3\gamma m_p}\right]^{(A-1)} & \text{Das Gupta \& Mekjian} \\ A^{3/2}\left[4\pi\frac{\nu_A\nu}{\nu_A+\nu}\right]^{\frac{3}{2}(A-1)} & \text{Sato \& Yazaki} \end{cases}$$

S_A	composite spin	p_o	coalescence momentum cutoff
N,Z,A	composite neut, prot, mass number	ν_A	composite Gaussian size (1/fm^2)
R_{np}	n/p ratio in entrance channel ($\equiv$1)	ν	source Gaussian size (1/fm^2), $R_{rms}=\sqrt{3/(2\nu)}$
m_p	proton mass		
γ	composite Lorentz factor		

deuterons......

$$B_2 = \frac{3}{4}\left[\frac{4\pi}{3}\frac{p_o^3}{\gamma m_p}\right] = \left[\frac{\pi p_o^3}{\gamma m_p}\right] \rightarrow p_o = \sqrt[3]{\frac{\gamma m_p B_2}{\pi}}$$

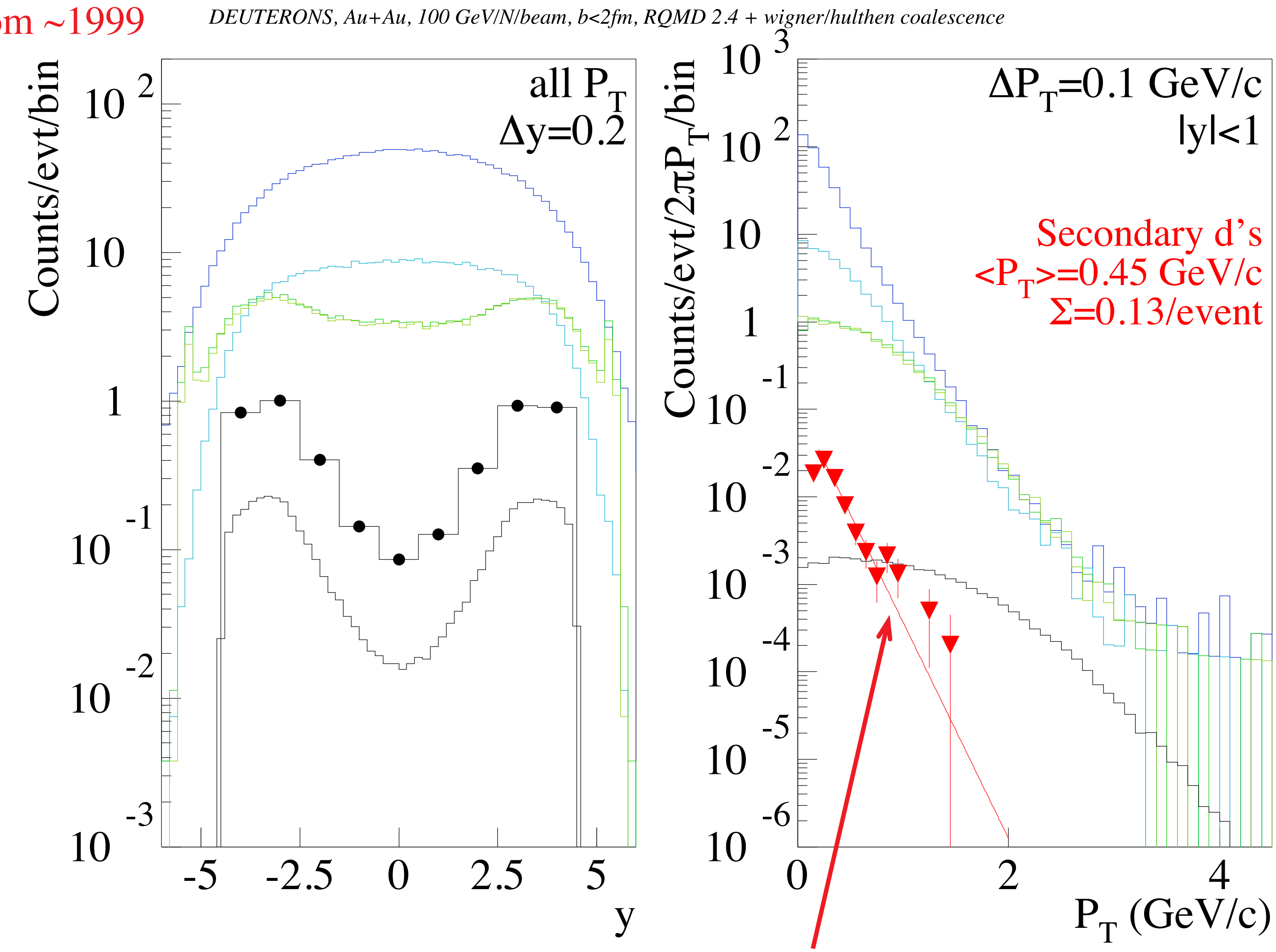
$$R^3 = \frac{9\pi^2}{2}(\hbar c)^3\frac{m_d}{m_p^2}\frac{1}{B_2} \quad \text{(hard sphere)} \qquad \left[Note: \frac{4\pi p_o^3}{3} = \frac{(2\pi)^3}{V}\right]$$

...evaluate for B_2=0.02 GeV^2.....
$p_o = 0.180$ GeV $\quad R = 3.3$ fm $\quad (R_d^{rms}=2.1$ fm$)$

similar but alternative interpretations: Scheibl&Heinz, Llope&Pratt *et al*...

Significant spallation backgrounds are well-known....

from ~1999



background d calculation by Dave Hardtke

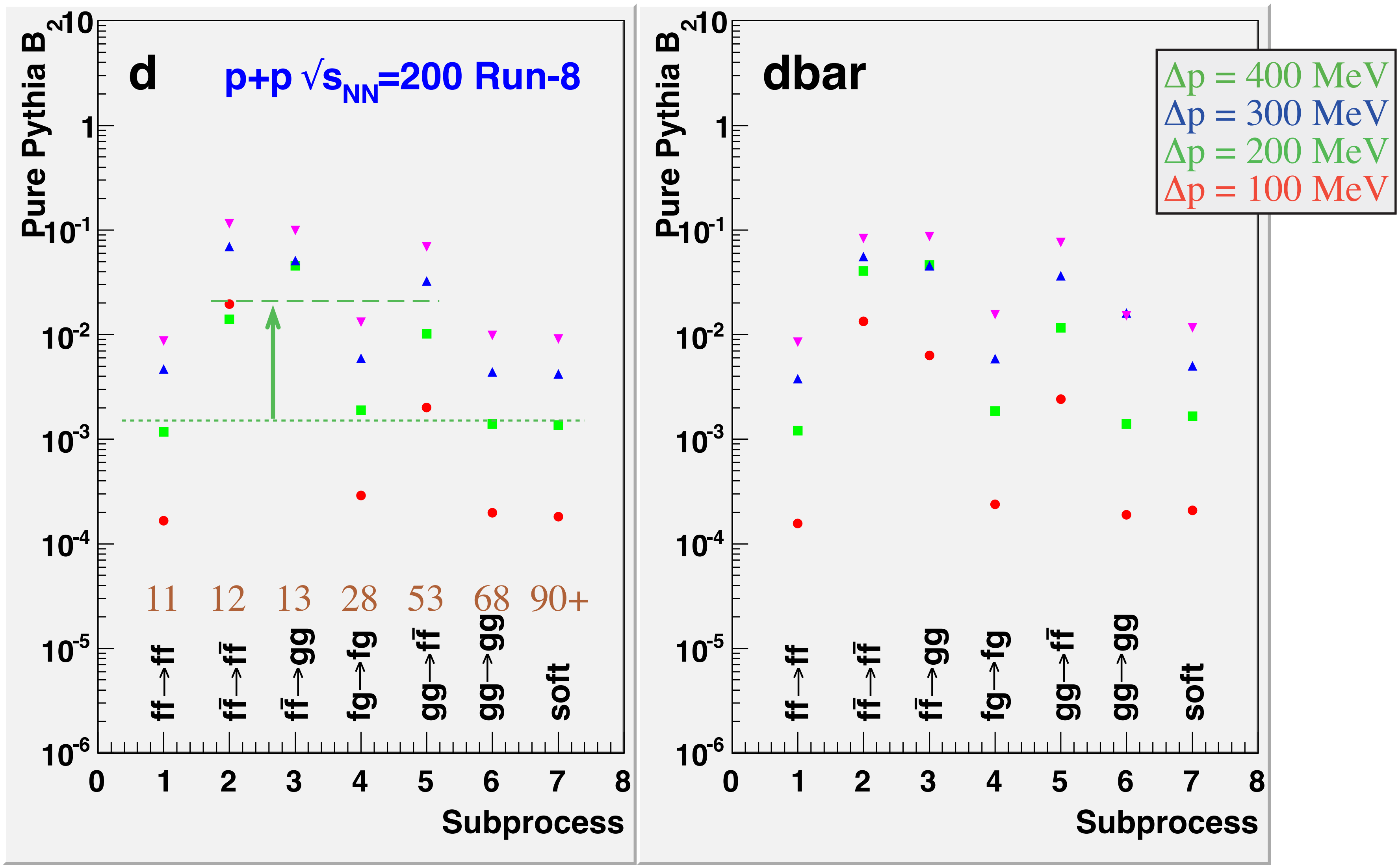
see also J. Nystrand, DIS2004, nucl-ex/0409006

Thus, concentrate on antinucleus production (much cleaner signal)....

Coalescence Afterburner + pure Pythia events.....

define Δp - the relative momentum cutoff for p+n pair forming a deuteron (k = Δp/2)

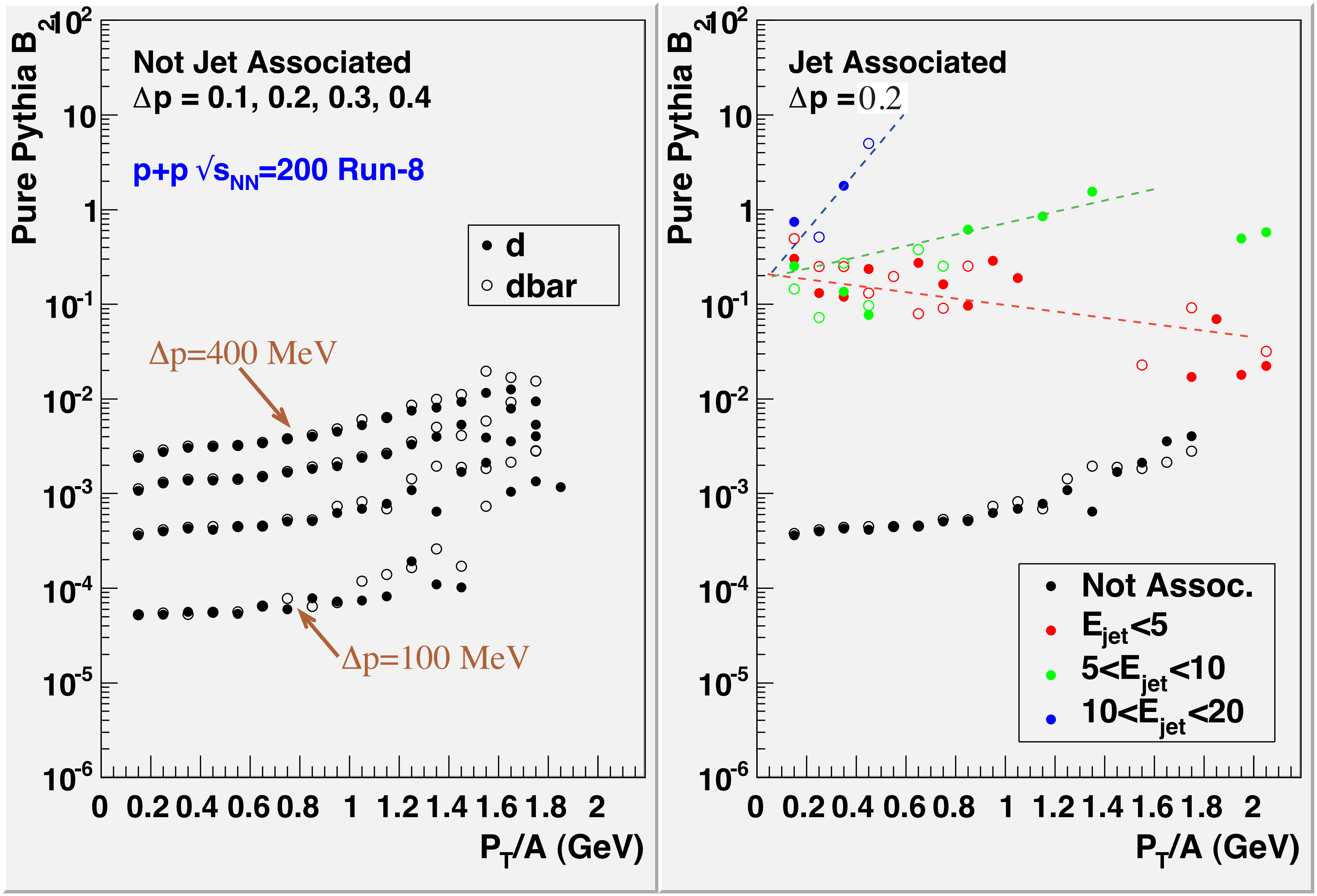
Δp ~ 120-140 MeV implied by earliest Bevalac A+A results...
(somewhat larger value required to match existing p+p data - see previous pages)



Factor ~10 differences in d/p^2 depending on Pythia subprocess......

Jets and deuteron production.....

use Pythia's PYCELL (simple seeded cone) to find jets....



B2 values hugely increased in Jets... (and also increase with the jet energy?)

Goals:

- ~~learn how to use ☆ MuDsts & offline software...~~
- ~~investigate DCA-type cuts to suppress spallation backgrounds...~~
  - track densities are relatively low...
  - primary vertex not as precisely defined...
- extract cross-sections and coalescence parameters for d and t production & compare to:
  - trends implied by the existing lower-energy data....
  - UrQMD or Pythia calculations with coalescence afterburner...
- Include direct Jet-finding & investigate fragment production mechanisms...

Data:

Run-6	p+p	$\sqrt{s_{NN}} = 62$ GeV	4.8 M events
Run-8	p+p	$\sqrt{s_{NN}} = 200$ GeV	36.1 M events
Run-8	d+Au	$\sqrt{s_{NN}} = 200$ GeV	75.8 M events

Cuts:

Require that a Primary Vertex was found...

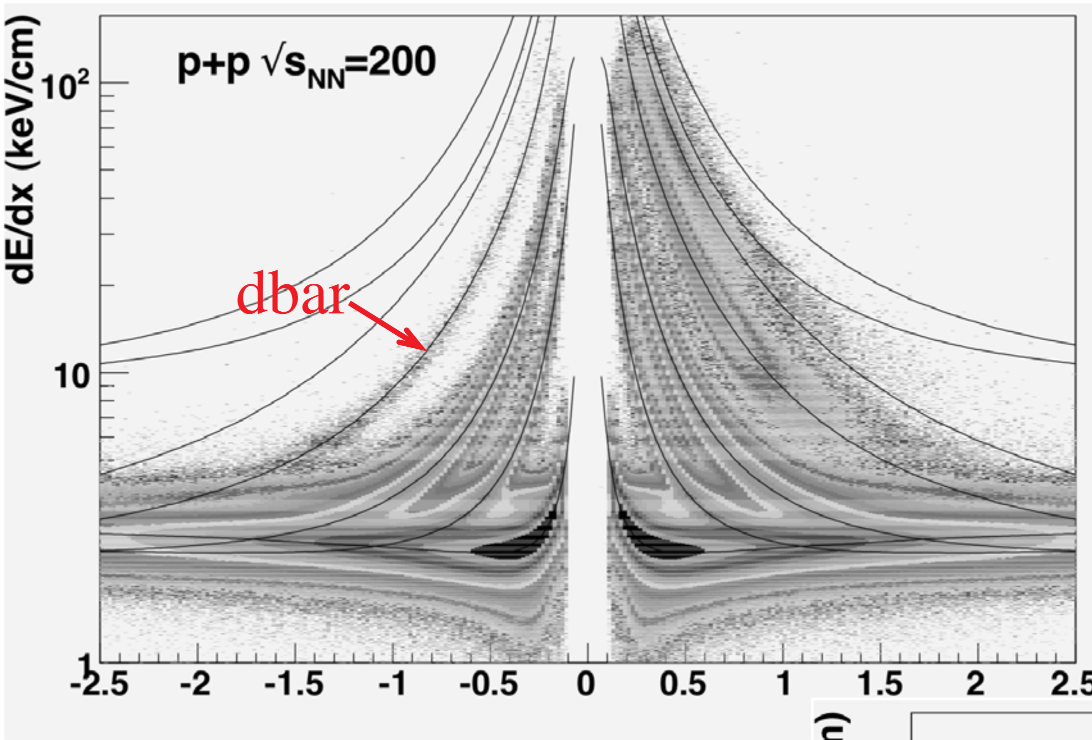
Nfitpts > 15, Nfitpts/Nhitsposs > 0.52, DCAglobal < 1.0cm

Presently, use only TPC dE/dx for PID....

A.S.A.P....

Include PID from the significant TOF coverage in the Run-9 data....

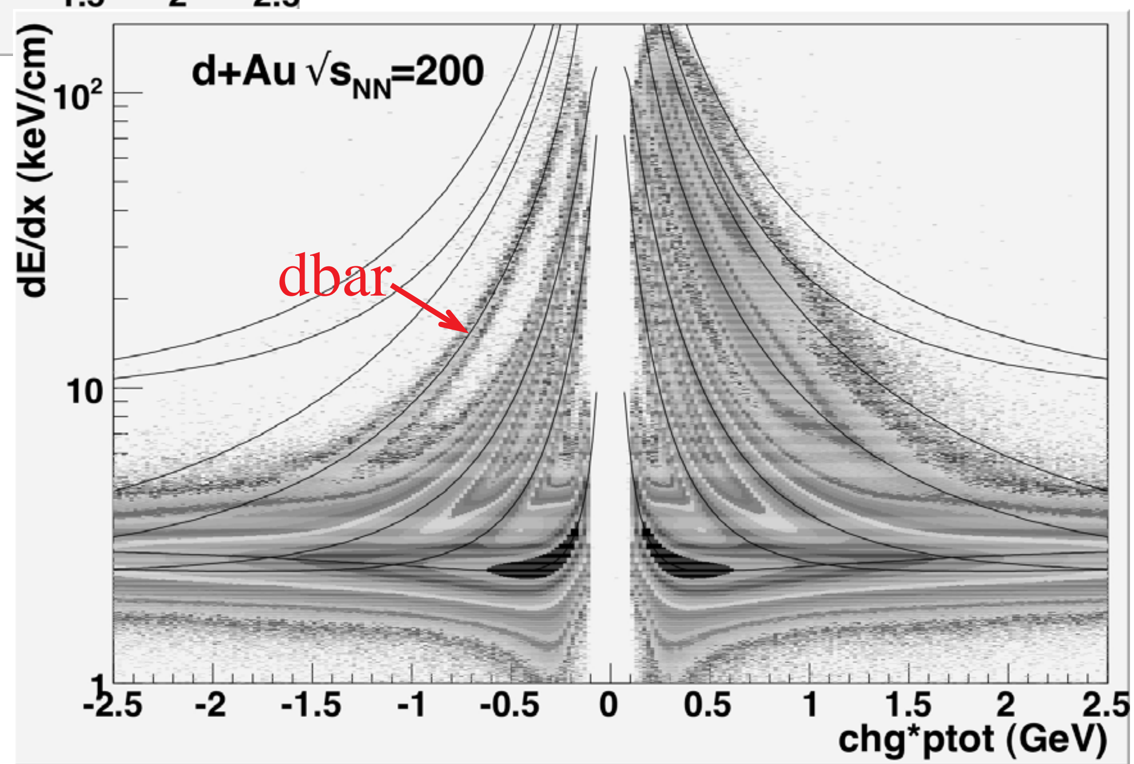
Produce plots for the Run-9 $\sqrt{s_{NN}} = 500$ GeV data....



d/dbar is huge... (spallation in ☆)

Significant dbar signal in our
p+p and d+Au data.....

Some tbars and He-3's too...
(hard to see here though)

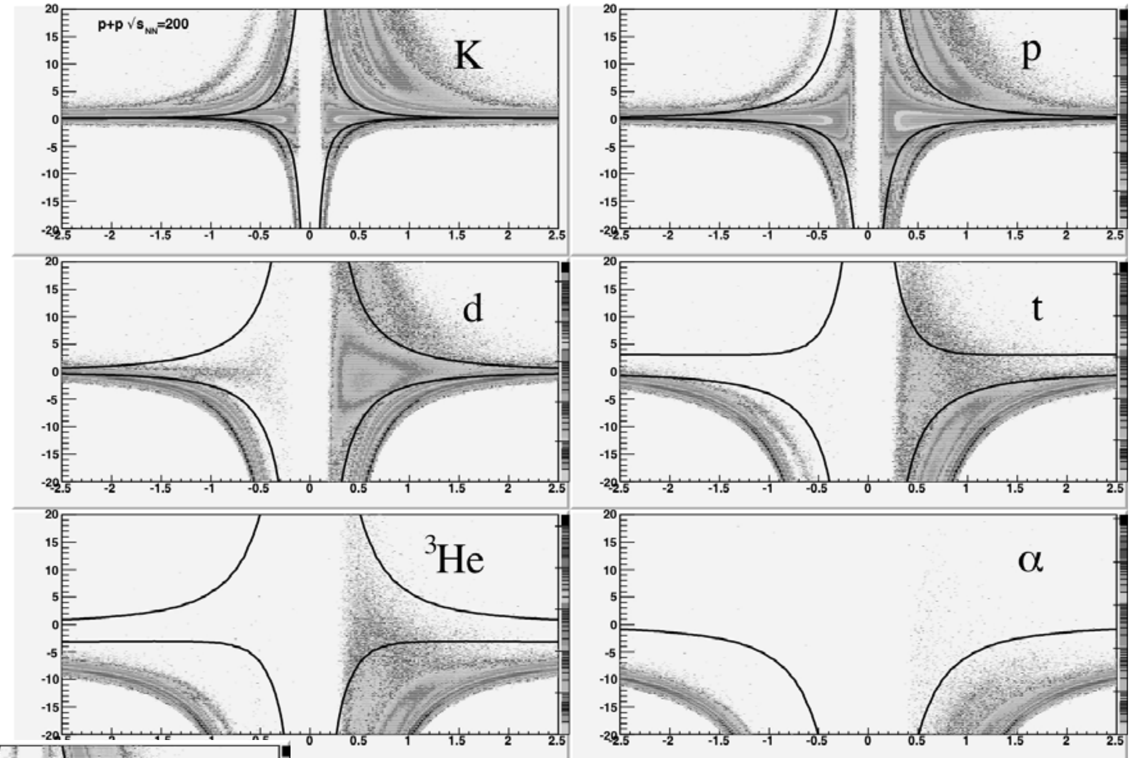


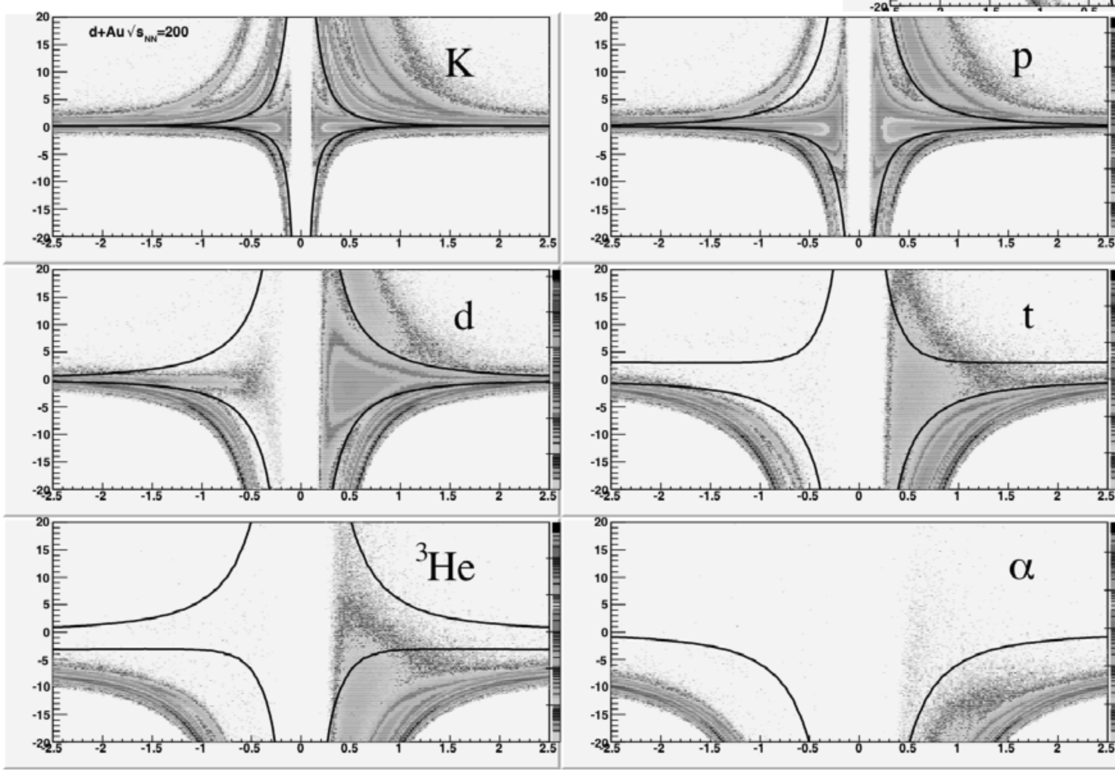
At present, simply do the PID
by "Splitting the differences"
of the dE/dx curves....

Momentum cut-offs used:

- p → 1.0 GeV
- d → 1.5 GeV
- t → 2.0 GeV

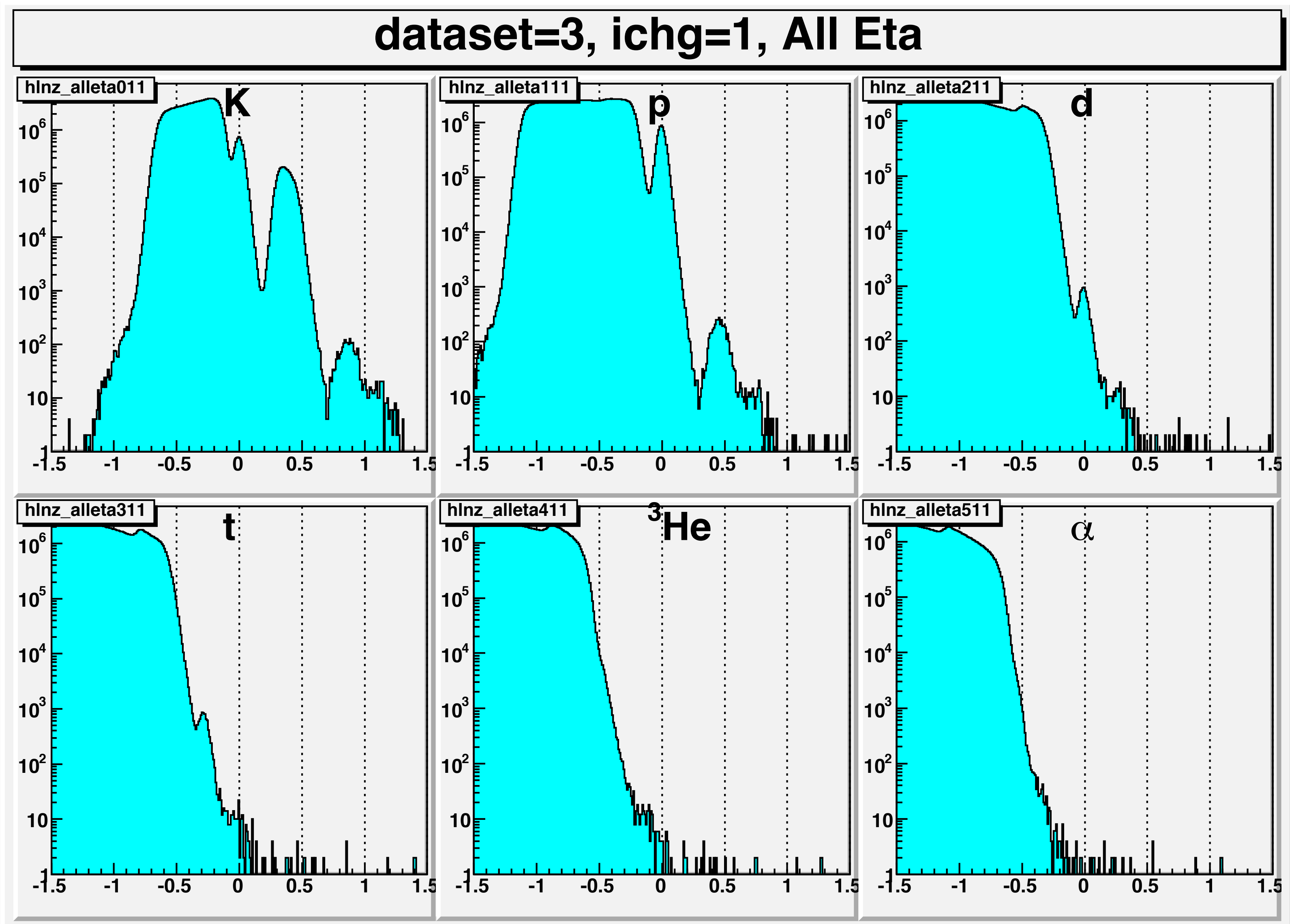
...fairly crude at the moment
& can be improved (next pages)
& TOF will help a lot too





Antiparticle Z = ln (dE/dx meas / dE/dx pred)

p+p, 200 GeV, Run-8

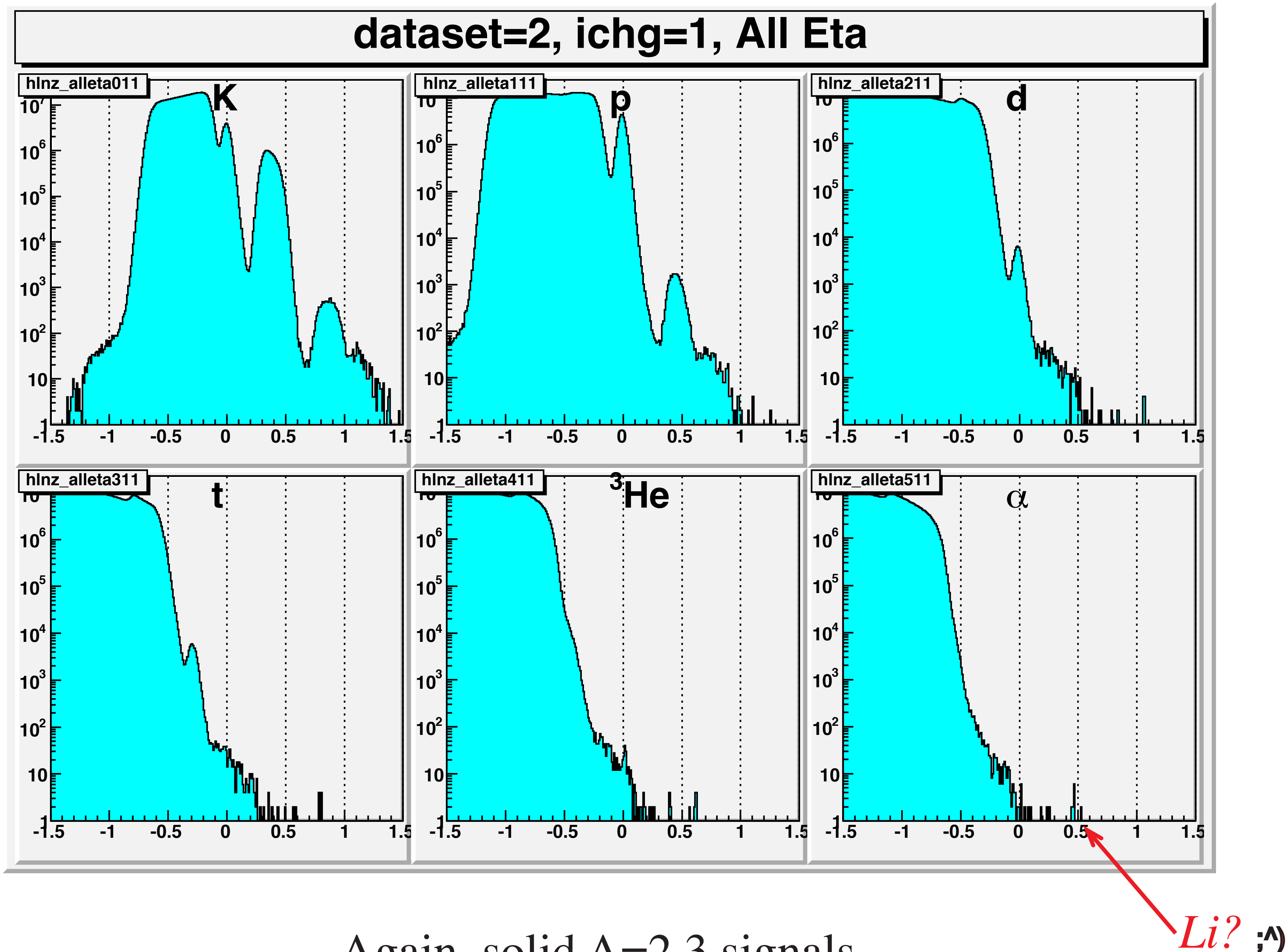


Solid dbar and tbar signals....

tbar and anti-3He would be a "first observation" in p+p...

Antiparticle Z = ln (dE/dx meas / dE/dx pred)

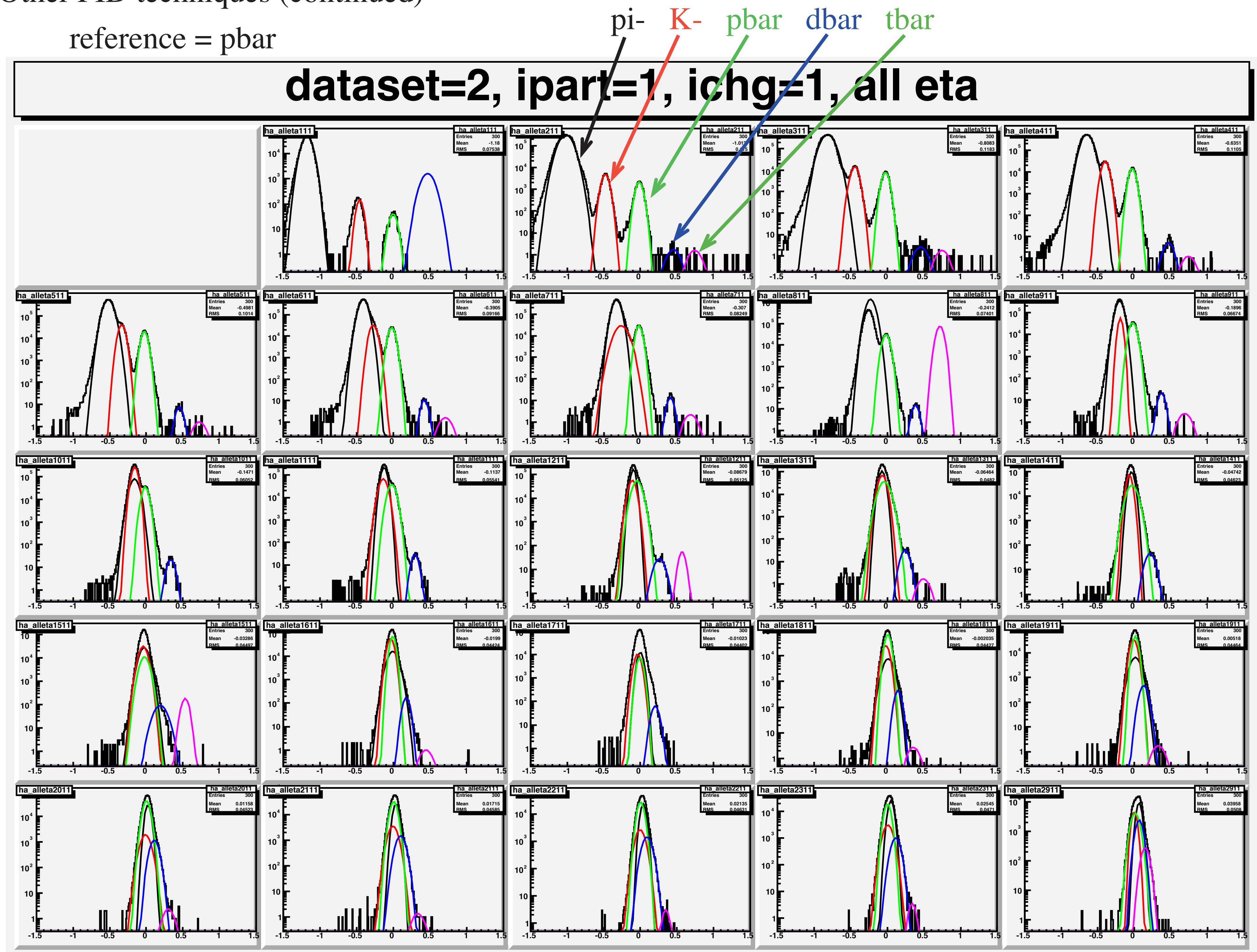
d+Au, 200 GeV, Run-8



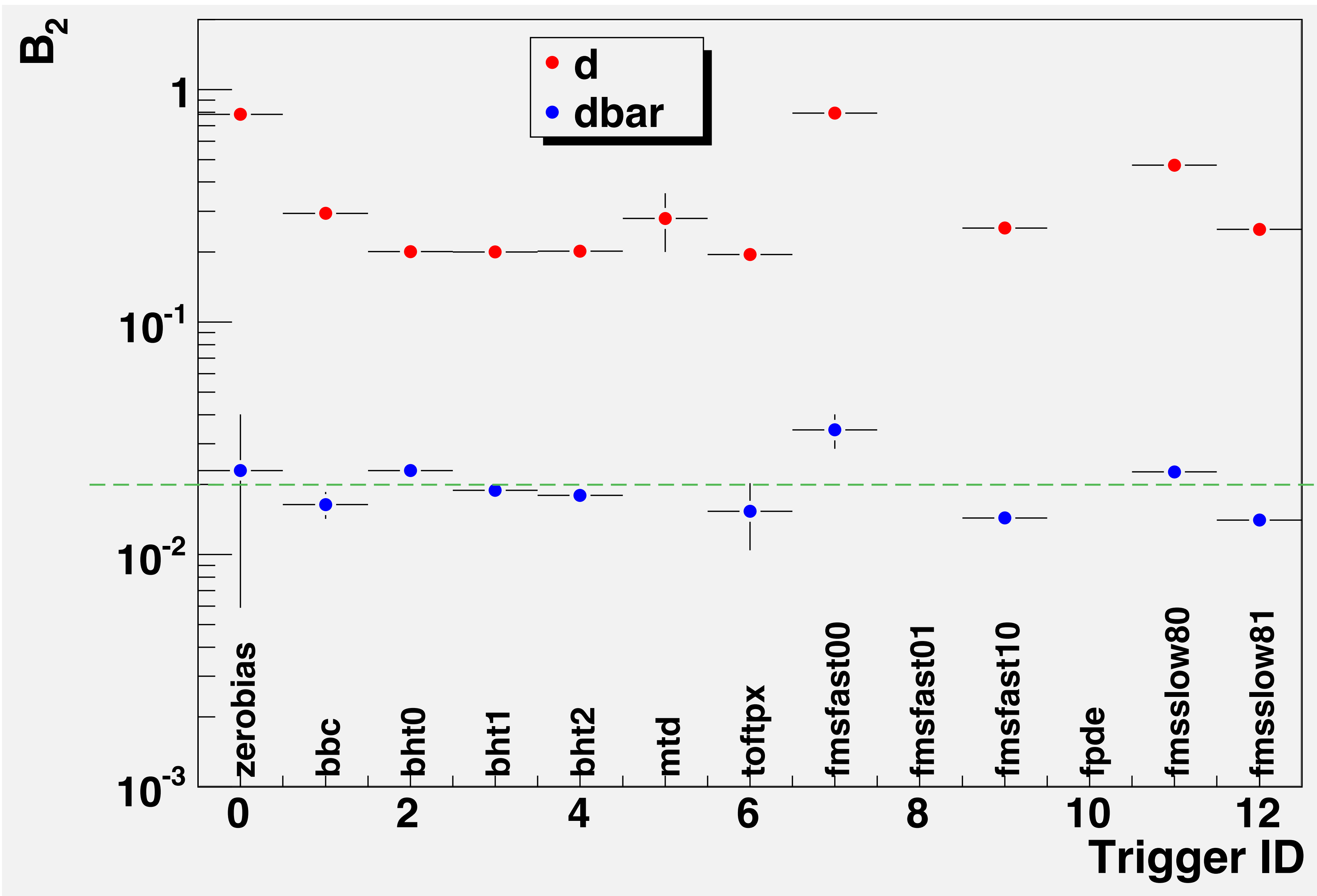
Again, solid A=2,3 signals....

Other PID techniques (continued)

reference = pbar



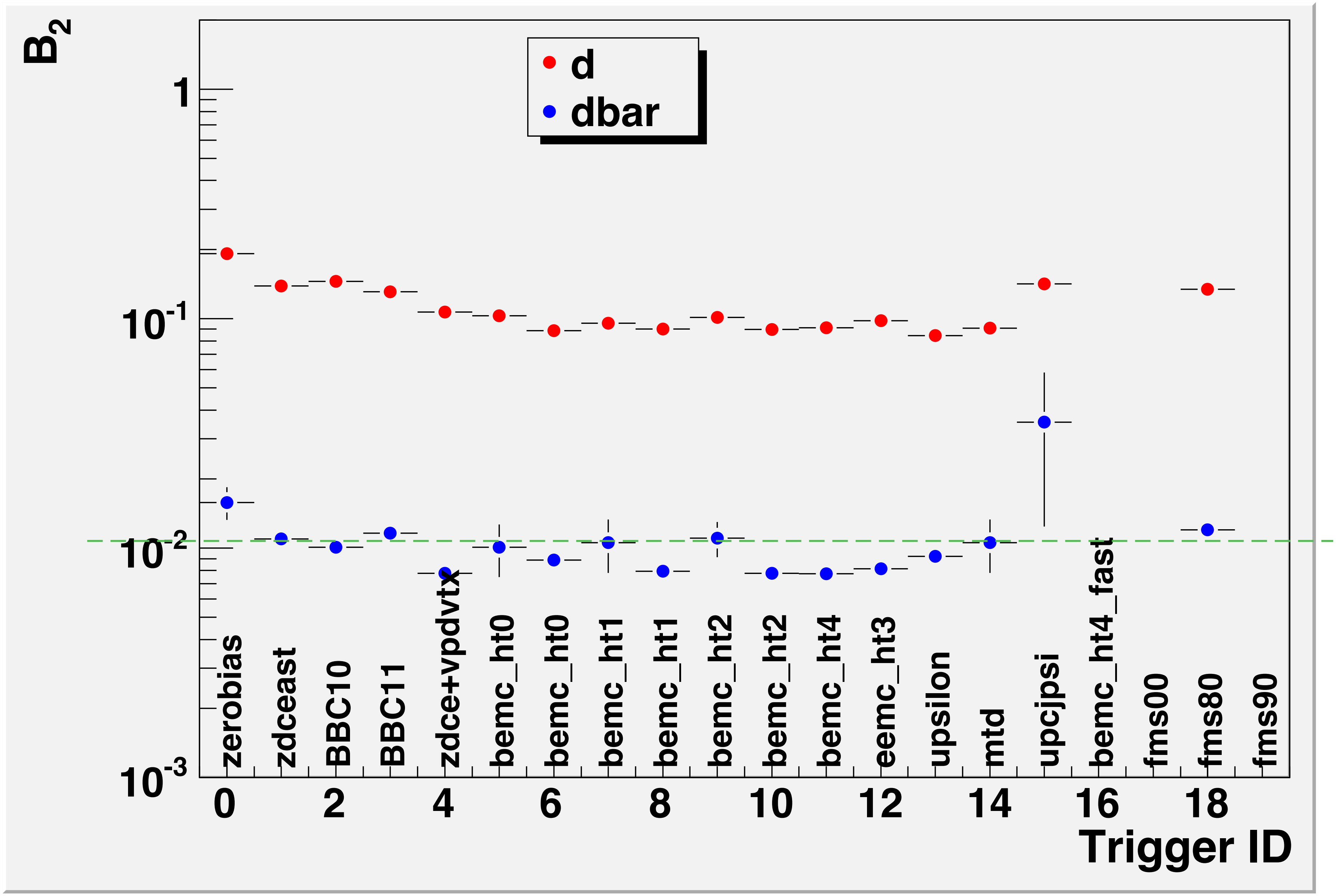
Run-8 p+p 200 GeV



...very close to that in the lower-energy p+p data: B2 ~ 0.02 GeV^2

....implies hard sphere R ~ 3.3 fm

Run-8 d+Au 200 GeV



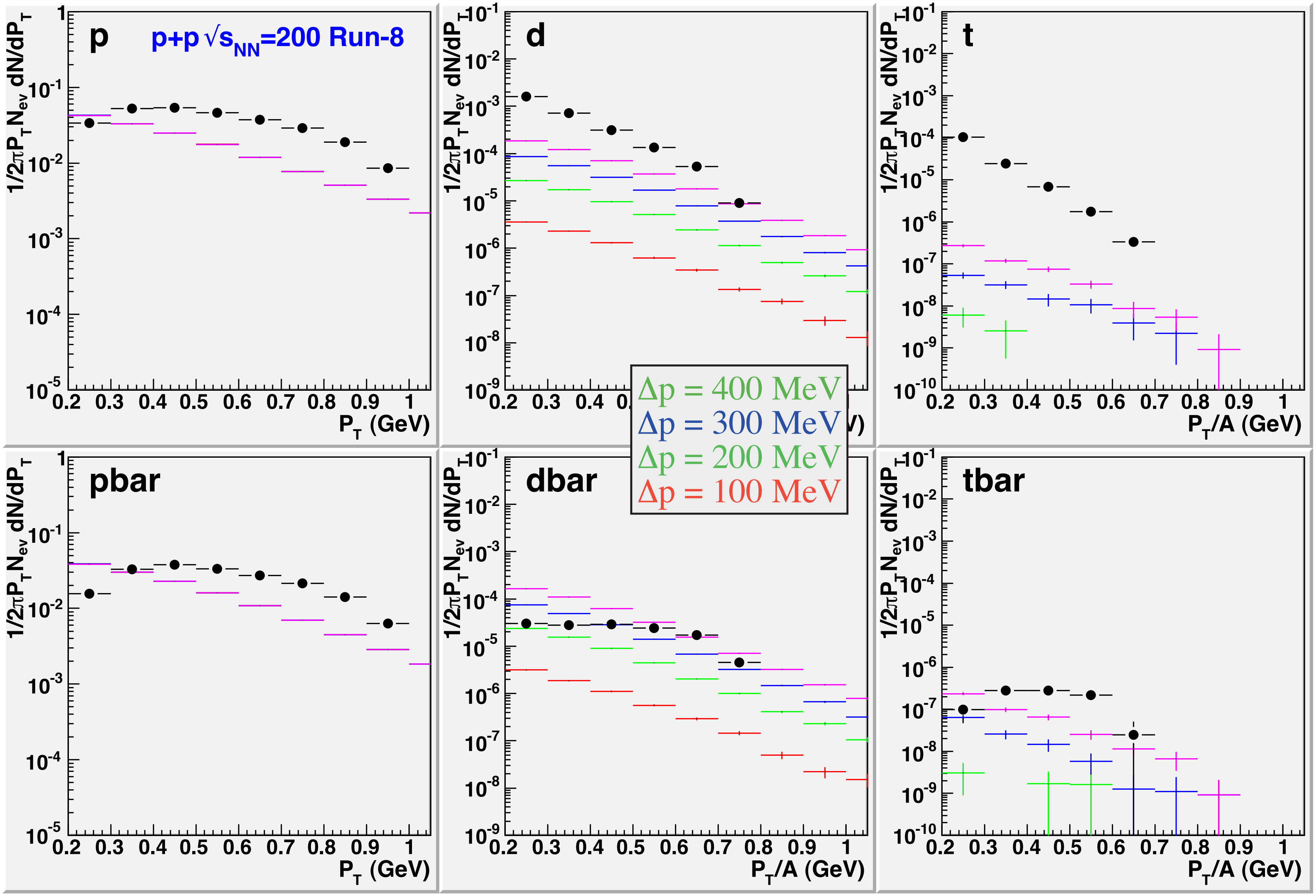
....Here B2 ~ 0.01 GeV^2

R ~ 4.2 fm

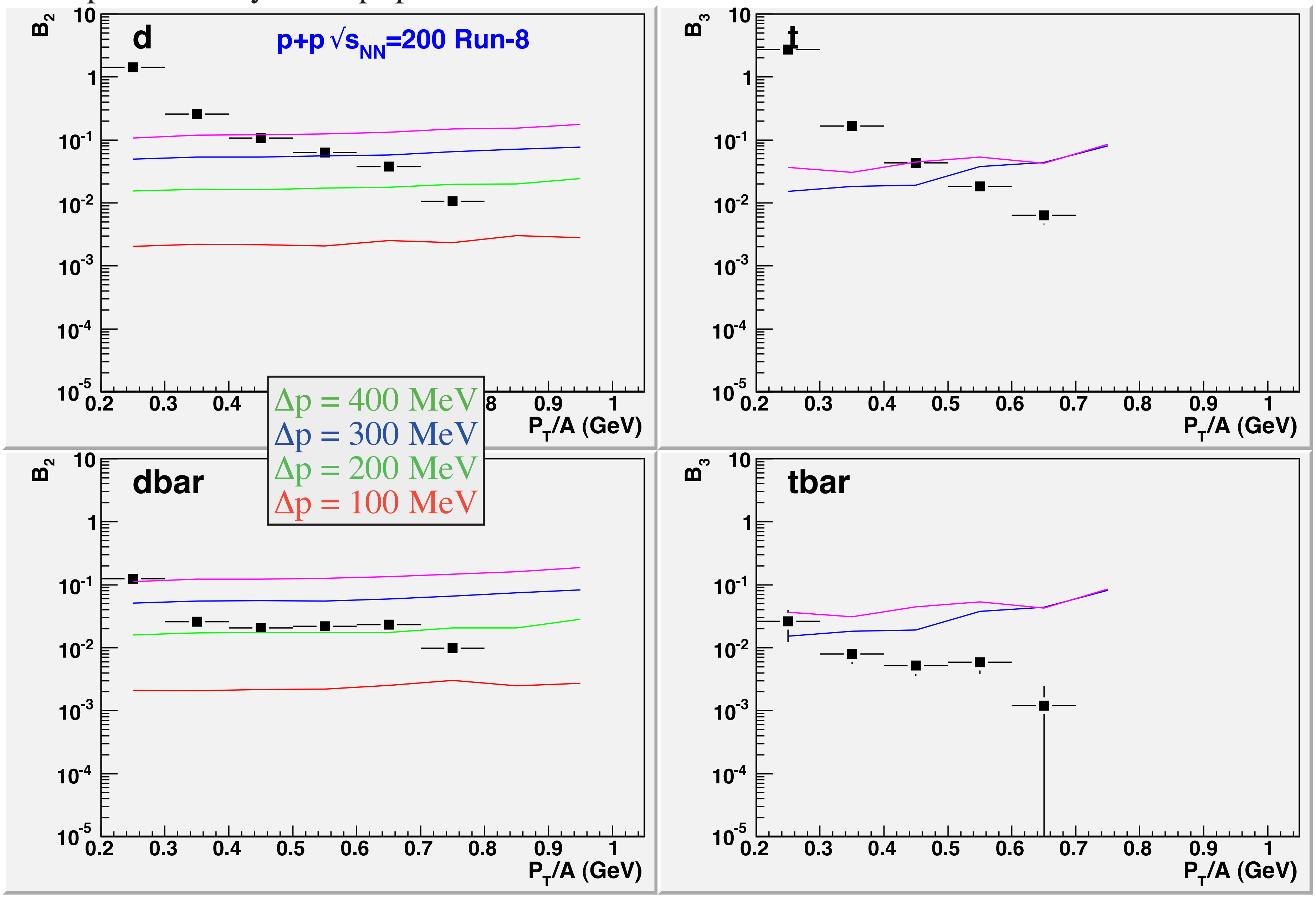
Comparison to Pythia -- p+p 200 GeV

....use Δp cut dynamically to form nuclei

Notes: no Eff., Abs., or F.D. corrections...
DCAglobal < 1.0cm...
Hyperon weak decays turned off in Pythia...
tritons from d+n not p+n+n...

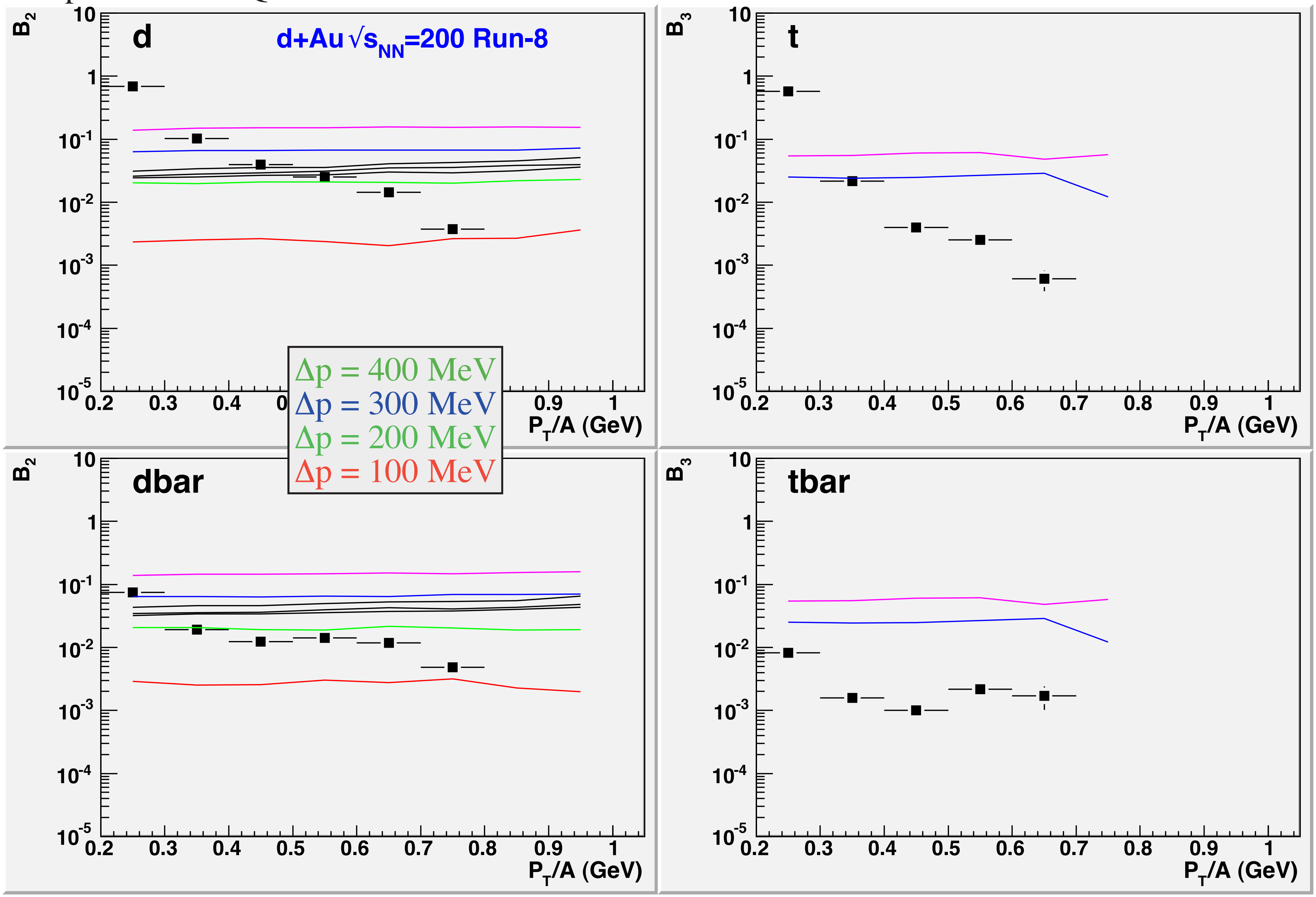


Comparison to Pythia -- p+p 200 GeV



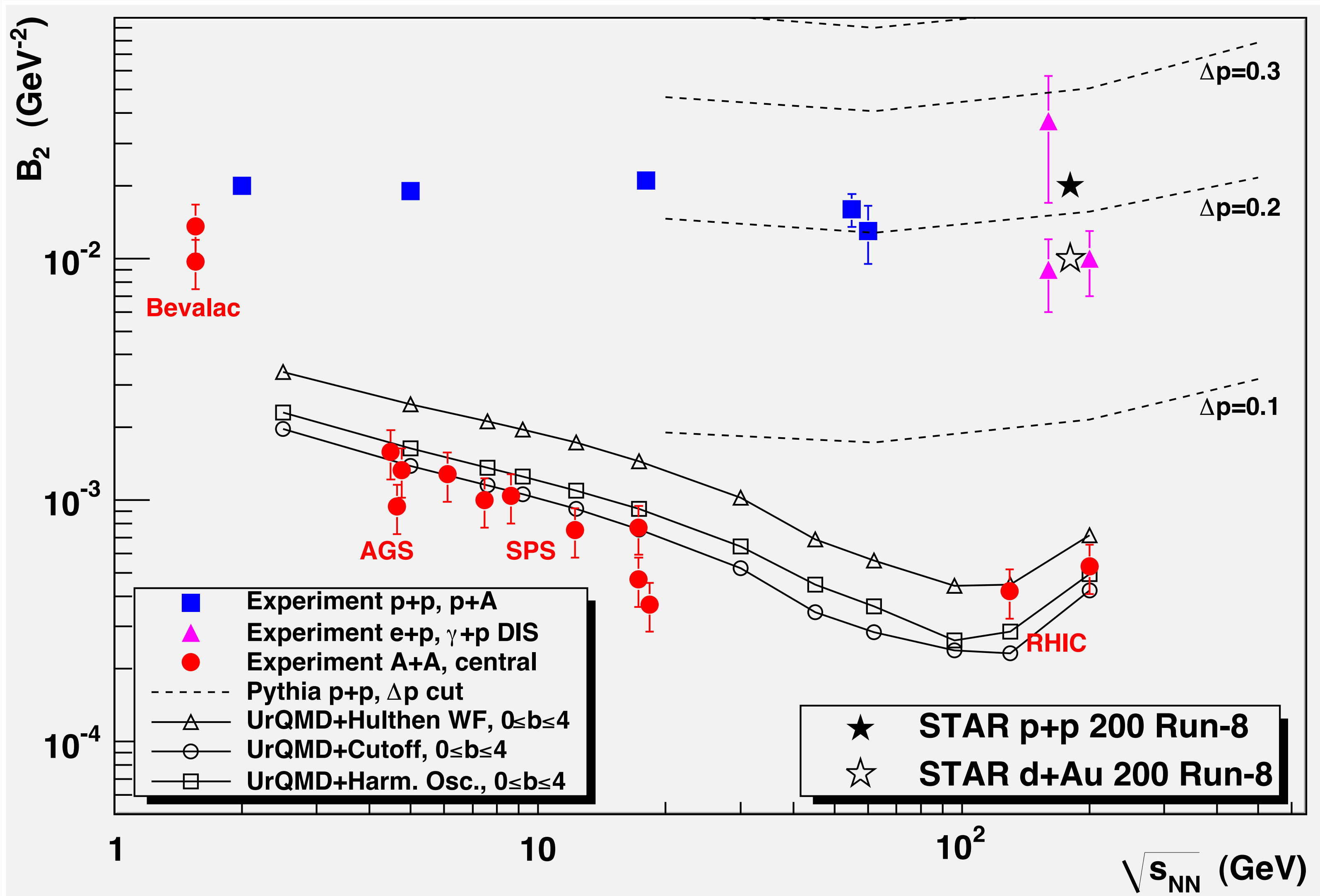
experimental dbar B_2 implies Pythia Δp Dynamic Cutoff ~ 210 MeV...
consistent with coalescence assumptions! ($B_2 \sim 0.02 \rightarrow p_o \sim 180$ MeV)

Comparison to UrQMD -- d+Au 200 GeV



dbar B2 implies Δp ~ 180 MeV for d+Au, 200 GeV

Comparisons to world's data.....



Summary* so far:	Experiment	Coalescence Picture:	Pythia+Δp
p+p, 200 GeV, Run-8:	$B_2 = 0.02\ GeV^2$	$R \sim 3.3$ fm, $p_o \sim 180$ MeV	$\Delta p \sim 210$ MeV
d+Au, 200 GeV, Run-8:	$B_2 = 0.01\ GeV^2$	$R \sim 4.2$ fm, $p_o \sim 150$ MeV	$\Delta p \sim 180$ MeV

(*) No tracking & PID efficiency, absorption, or feeddown corrections yet!

Light nucleus production & Jets in p+p and d+Au....

Plot proton & deuteron cross-sections and B_A values separately for

- events in which no jet(s) reconstructed...
- tracks not associated with a Jet...
- tracks associated with a Jet...

"UE"

"Jet"

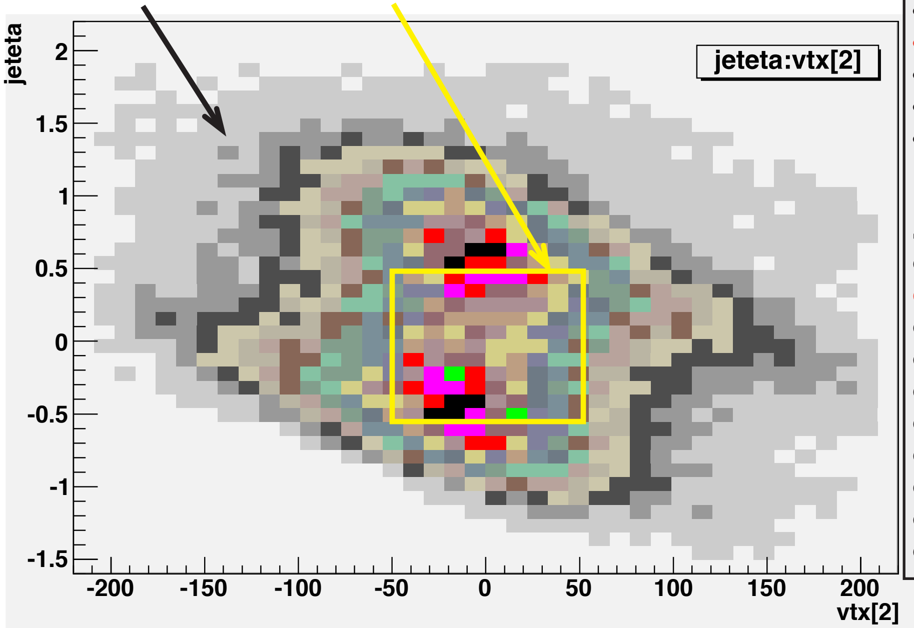
Does B_A depend on UE vs Jets?

Different nucleus production mechanisms?

Are R & p_o different?

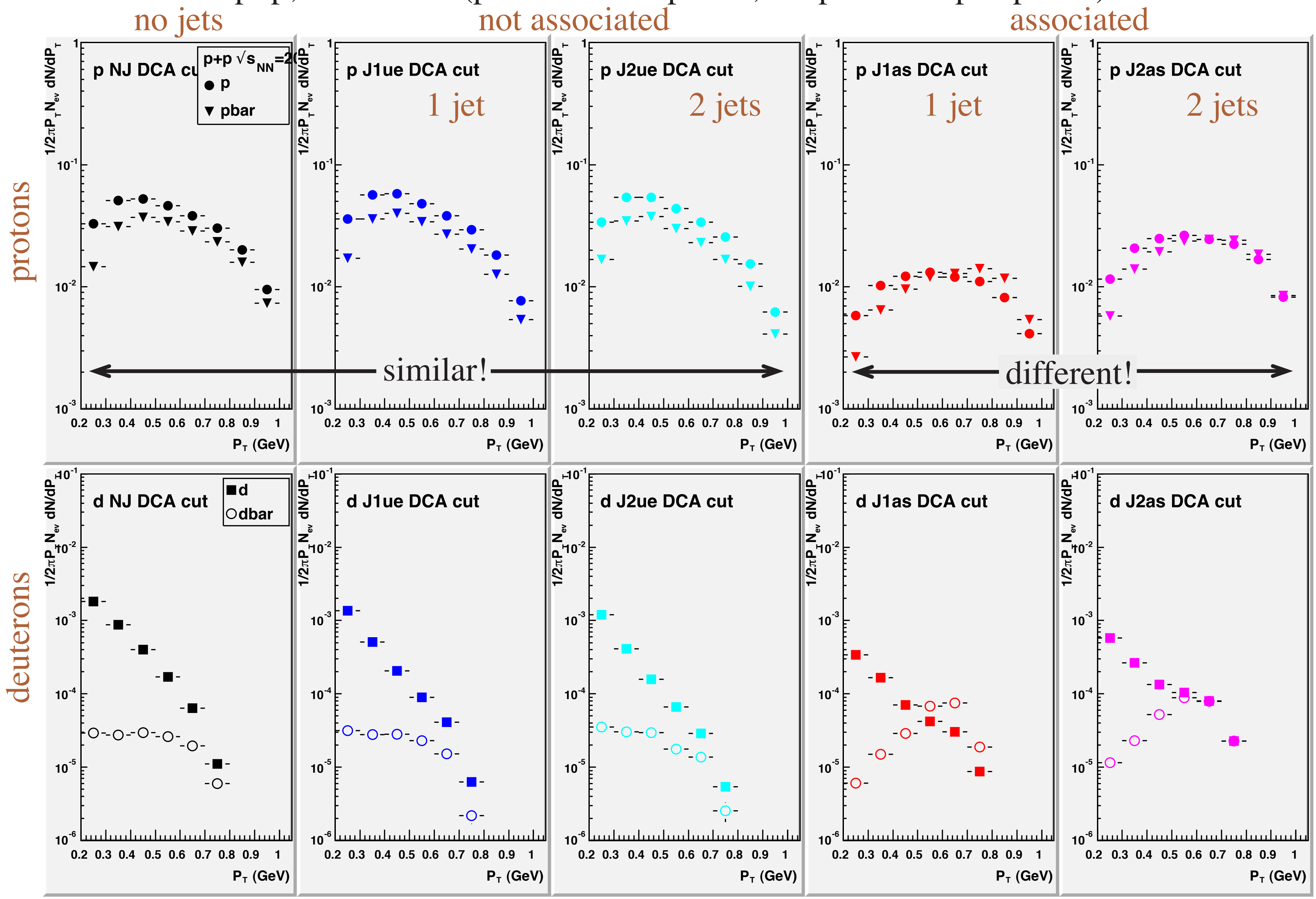
(thanks to Renee, Ilya, and David for helpful comments!)

All Jets MR Jets




```
StppAnaPars* anapars = new StppAnaPars();
anapars->setFlagMin(0);         // track->flag() > 0
anapars->setNhits(12);          // track->nHitsFit()>12
anapars->setCutPtMin(0.2);      // track->pt() > 0.2
anapars->setAbsEtaMax(2.0);     // abs(track->eta())<2.0
anapars->setJetPtMin(3.5);
anapars->setJetEtaMax(100.0);
anapars->setJetEtaMin(0);
anapars->setJetNmin(0);
//
//---- Setup the cone finder for measured particles
StConePars* cpars = new StConePars();
cpars->setGridSpacing(105, -3.0, 3.0, 120, -pi, pi);
cpars->setConeRadius(0.7);
cpars->setSeedEtMin(0.5);
cpars->setAssocEtMin(0.1);
cpars->setSplitFraction(0.5);
cpars->setPerformMinimization(true);
cpars->setAddMidpoints(true);
cpars->setRequireStableMidpoints(true);
cpars->setDoSplitMerge(true);
cpars->setDebug(false);
```

Cross-sections -- p+p, 200 GeV (particle: solid points, antiparticle: open points)

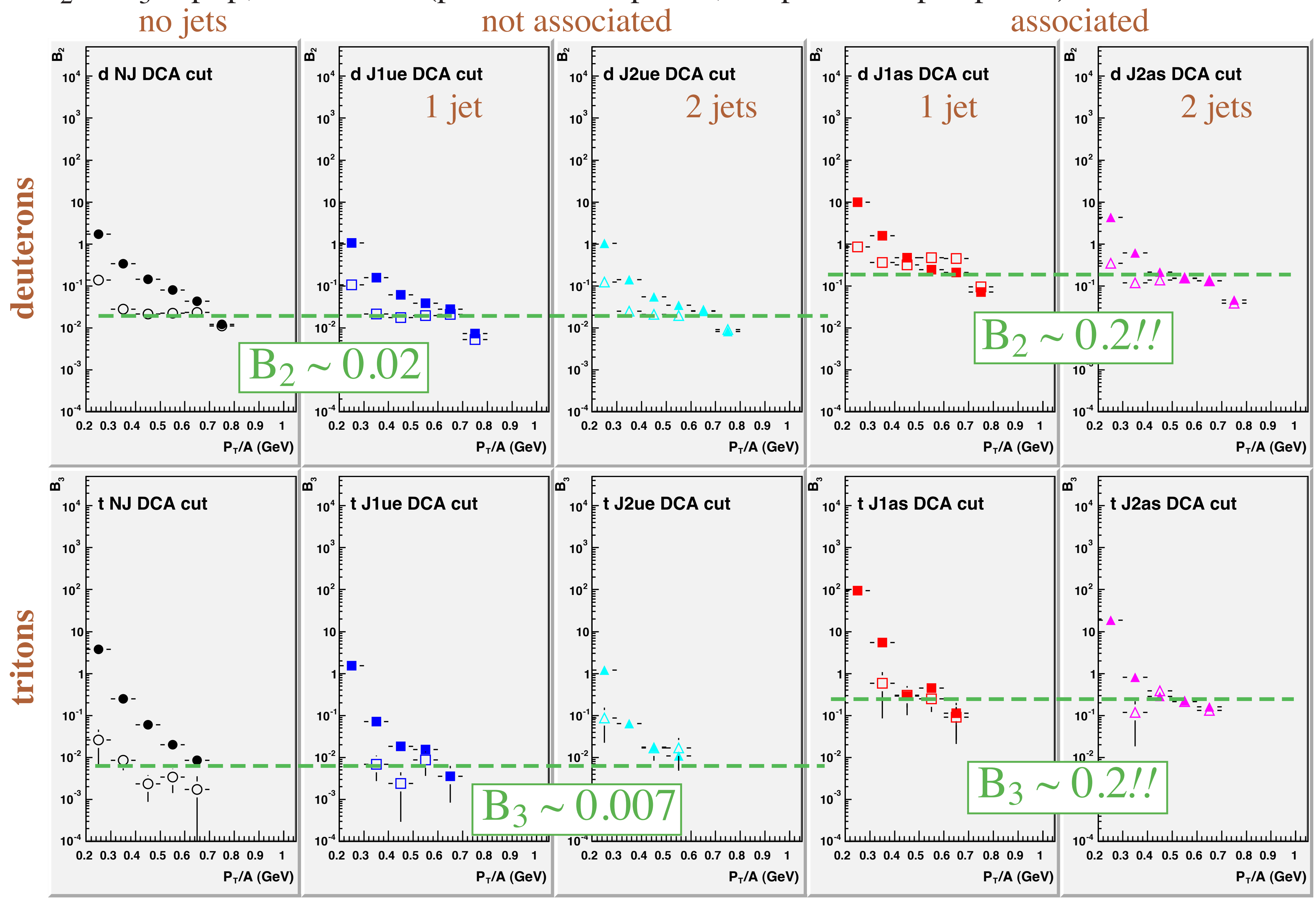


NJ, J1ue, J2ue are very similar. J1as & J2as are different!

particle and antiparticle cross-sections "meet" above $P_T \sim 1$ GeV (spallation!)

pbar & dbar cross-sections considerably harder for in-jet compared to not in-jet

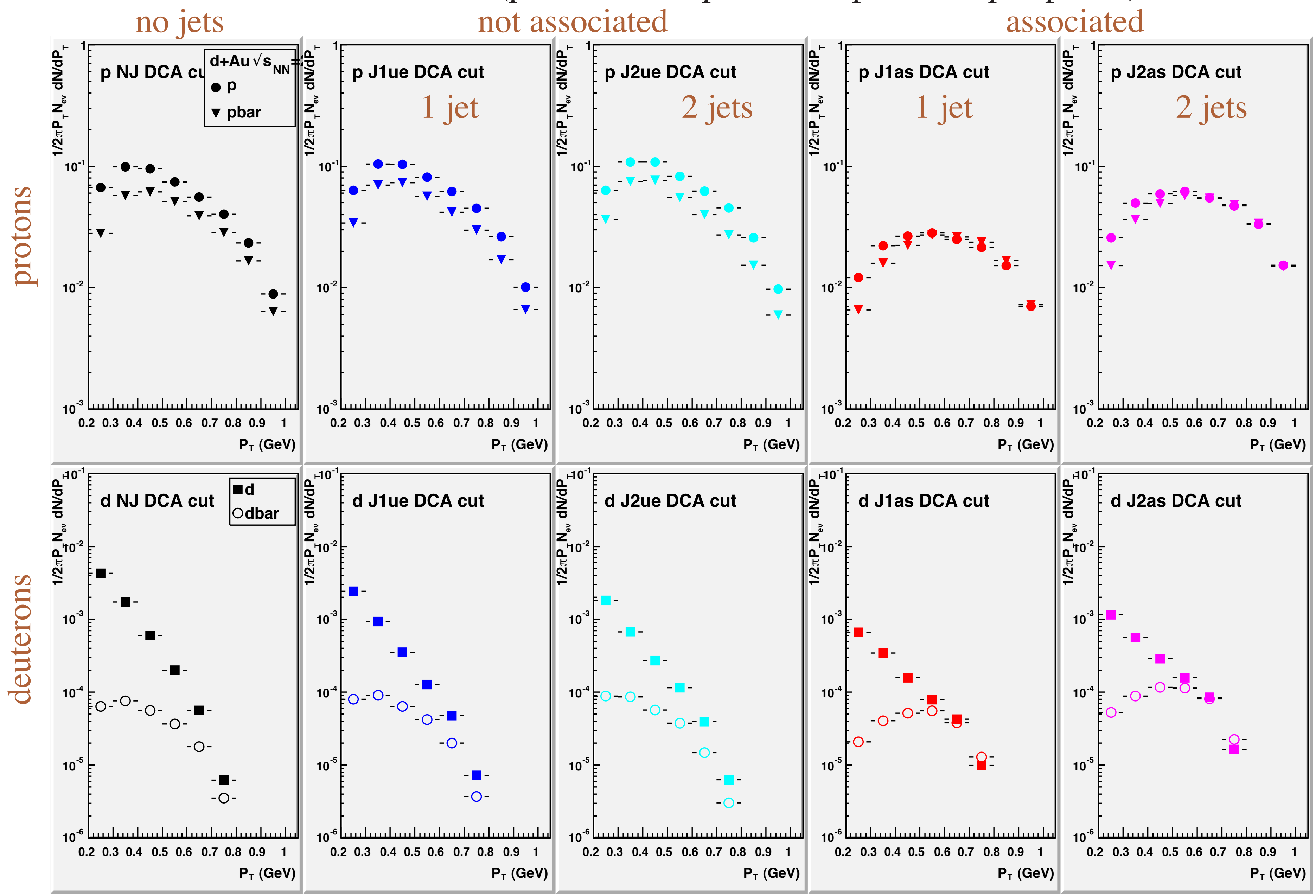
B_2 & B_3 -- p+p, 200 GeV (particle: solid points, antiparticle: open points)



B_2 & B_3 significantly larger (factor>10) for in-Jet particles....

antiparticle B_2 and B_3 essentially flat for increasing P_T/A

Cross-sections -- d+Au, 200 GeV (particle: solid points, antiparticle: open points)

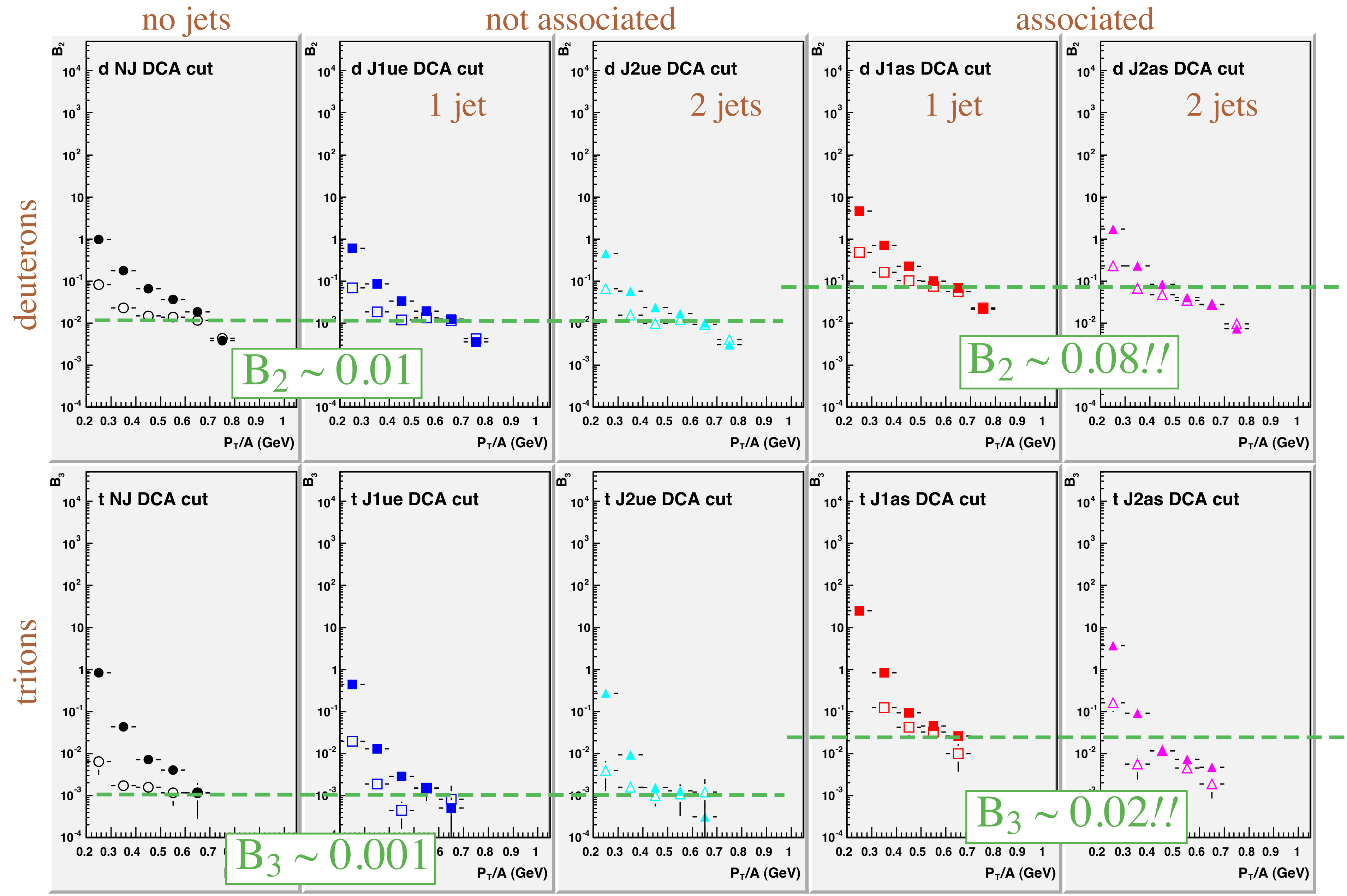


NJ, J1ue, J2ue are very similar. J1as & J2as are different!

particle and antiparticle cross-sections "meet" above $P_T \sim 1$ GeV (spallation!)

pbar & dbar cross-sections considerably harder for in-jet compared to not in-jet

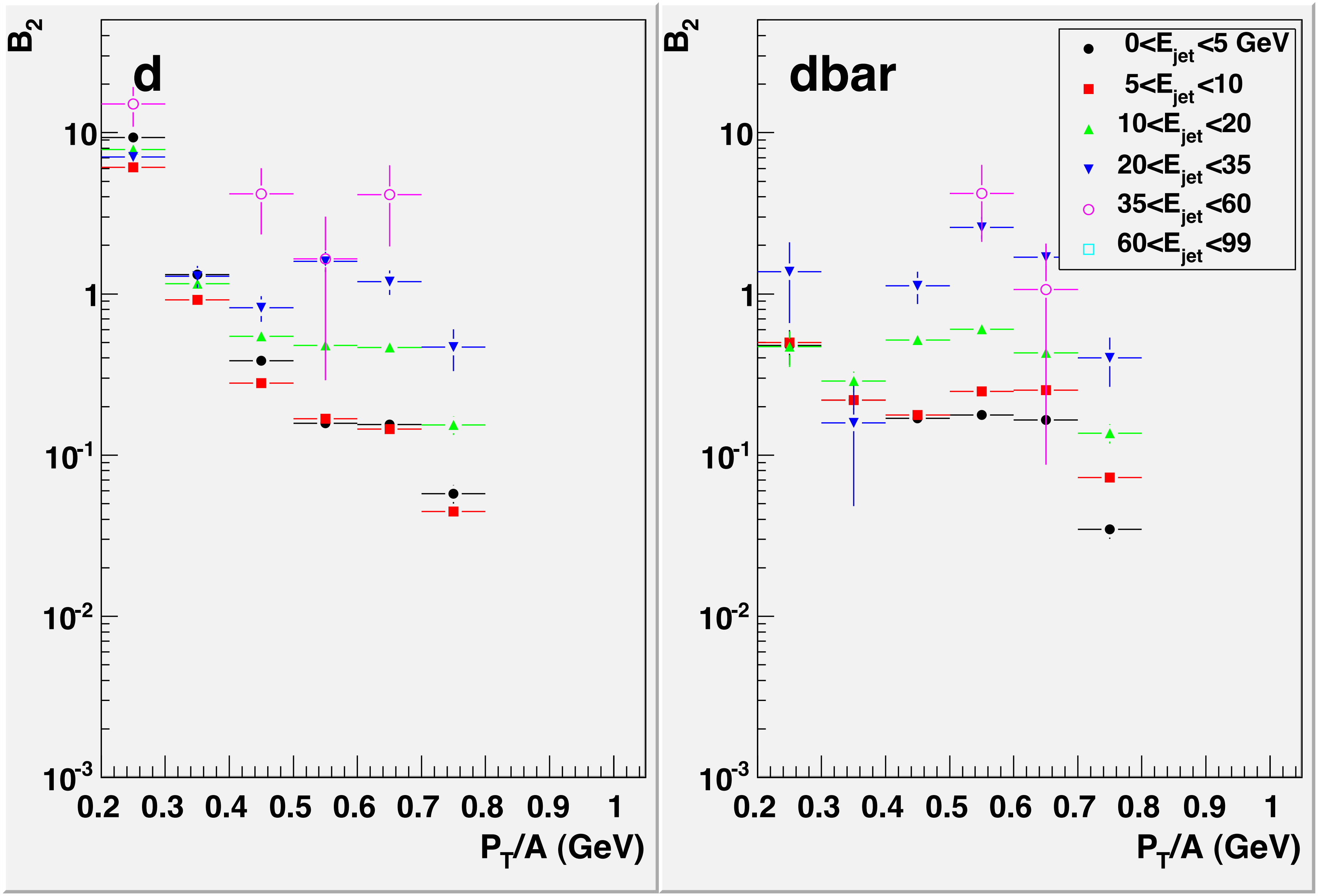
B_2 & B_3 -- d+Au, 200 GeV (particle: solid points, antiparticle: open points)



B_2 & B_3 significantly larger for particles associated with Jets
B_2 and B_3 falling with increasing P_T/A

B_2 for jet-associated particles now gated on Jet Energy -- **p+p 200 GeV**

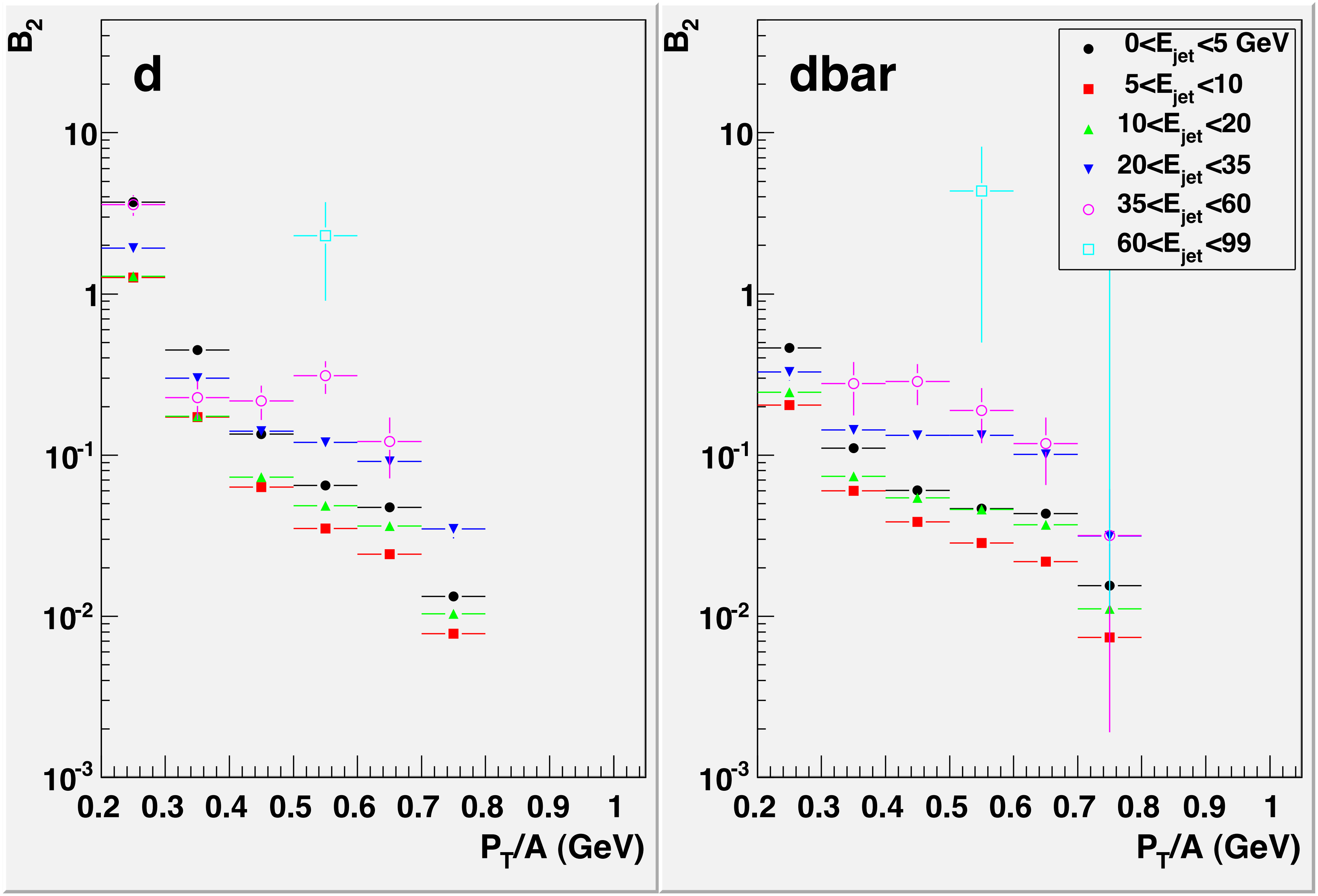
Here - "All Jets" and d/p^2 formed for y=0 & Δy=1.0



B_2 for in-Jet particles increases with jet-energy....

B_2 for jet-associated particles gated on Jet Energy -- **d+Au 200 GeV**

Here - "All Jets" and d/p^2 formed for y=0 & Δy=1.0



Another intermediate summary*.........

(*) No tracking & PID efficiency, absorption, or feeddown corrections yet!

Inclusive....

Data set	Experiment	Coalescence Picture:	Pythia+Δp
p+p, 200 GeV, Run-8:	$B_2 = 0.02\ GeV^2$	$R \sim 3.3$ fm, $p_o \sim 180$ MeV	$\Delta p \sim 210$ MeV
d+Au, 200 GeV, Run-8:	$B_2 = 0.01\ GeV^2$	$R \sim 4.2$ fm, $p_o \sim 150$ MeV	$\Delta p \sim 180$ MeV

In-Jet ("Jet") vs Not-In-Jet ("UE") particles....

(B_A values just "by eye" from prev plots)

Data set		Experiment	Coalescence Picture:	Pythia+Δp
p+p, 200 GeV, Run-8:				
	UE	$B_2 = 0.02\ GeV^2$	$R \sim 3.3$ fm, $p_o \sim 180$ MeV	$\Delta p \sim 210$ MeV
	Jet	$B_2 \sim 0.2\ GeV^2$	$R \sim 1.5$ fm, $p_o \sim 39$ MeV	
	UE	$B_3 \sim 0.007\ GeV^2$	$R \sim 1.7$ fm	
	Jet	$B_3 \sim 0.2\ GeV^2$	$R \sim 1.0$ fm	
d+Au, 200 GeV, Run-8:				
	UE	$B_2 = 0.01\ GeV^2$	$R \sim 4.2$ fm, $p_o \sim 150$ MeV	$\Delta p \sim 180$ MeV
	Jet	$B_2 \sim 0.08\ GeV^2$	$R \sim 2.1$ fm, $p_o \sim 29$ MeV	
	UE	$B_3 \sim 0.001\ GeV^2$	$R \sim 2.3$ fm	
	Jet	$B_3 \sim 0.02\ GeV^2$	$R \sim 1.4$ fm	

B_2 values from inclusive data are the same as those when reconstructing jets but looking only at particles not associated with the Jet(s).

B_2 values for "in-Jet particles" (for all reconstructed STAR jets using default parameters) are an ~order of magnitude higher than the inclusive B_2 values.

In the coalescence picture, this implies
    "freeze-out" radii that are a factor of ~2 smaller
and
    cut-off momentum parameters that are a factor of ~5 smaller
than the values obtained for inclusive particles or
the particles not associated with jets in jet-found events ("UE").

When subsequently gating the p,d,t cross-sections on the reconstructed Jet Energy:
    the B_2 values increase with increasing jet energy....

→ deuterons are more probable (w.r.t. protons) in jets compared to inclusive events...
→ deuterons are more probable (w.r.t. protons) in HE jets compared to LE jets...

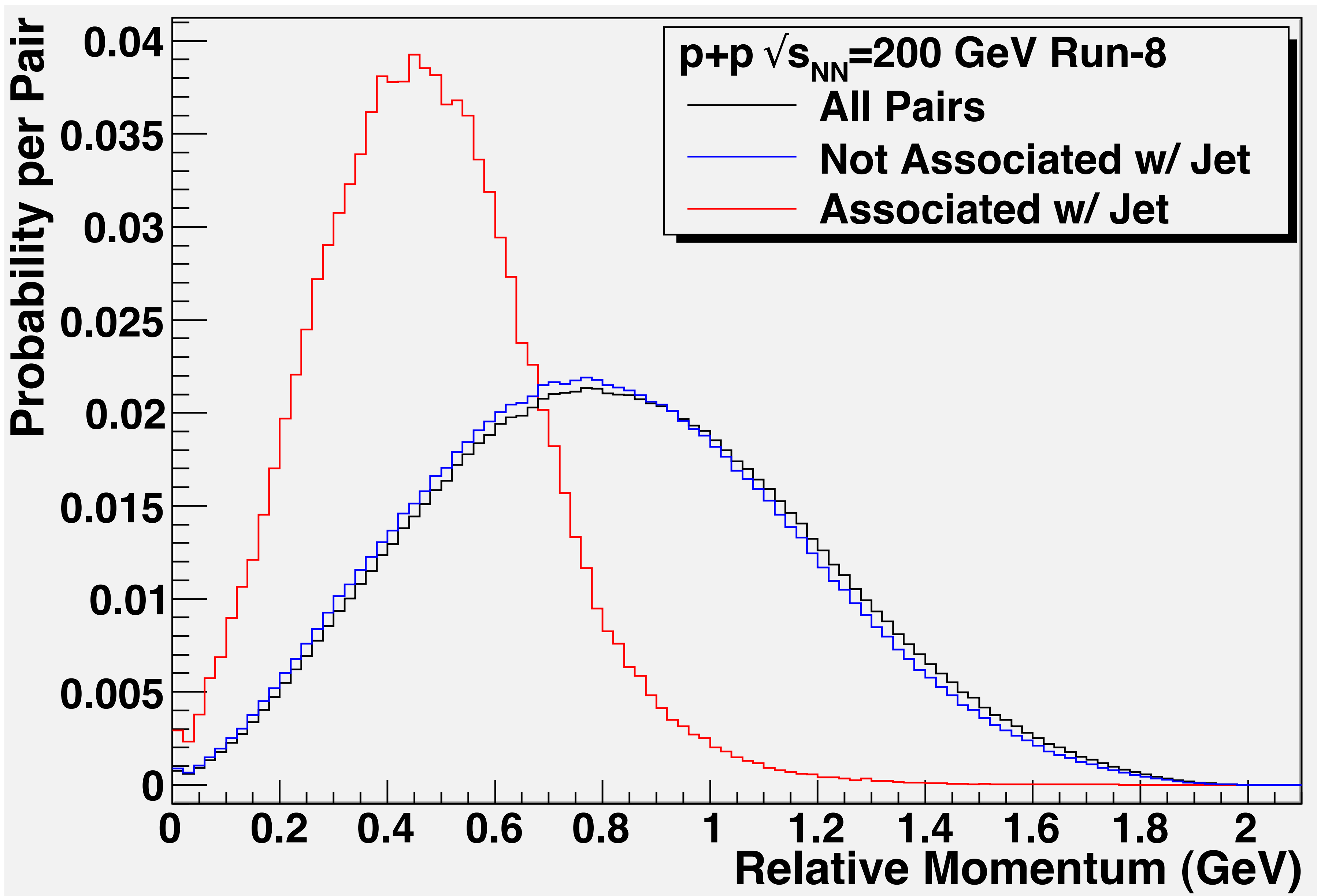
Present mental picture is thus.... (comments?)
    jets produce sprays of nucleons that are highly correlated in direction....
    enhanced correlation focusses nucleons in phase space (just like flow does in HI collisions!)...
    this focussing enhances the probability that two nucleons fall into a light nucleus state...
        and (also just like flow), increases B_2 values & suppresses the apparent source radii...

    and as jet radii decrease with increasing jet energy, then B_2 should increase w/ Jet-E....

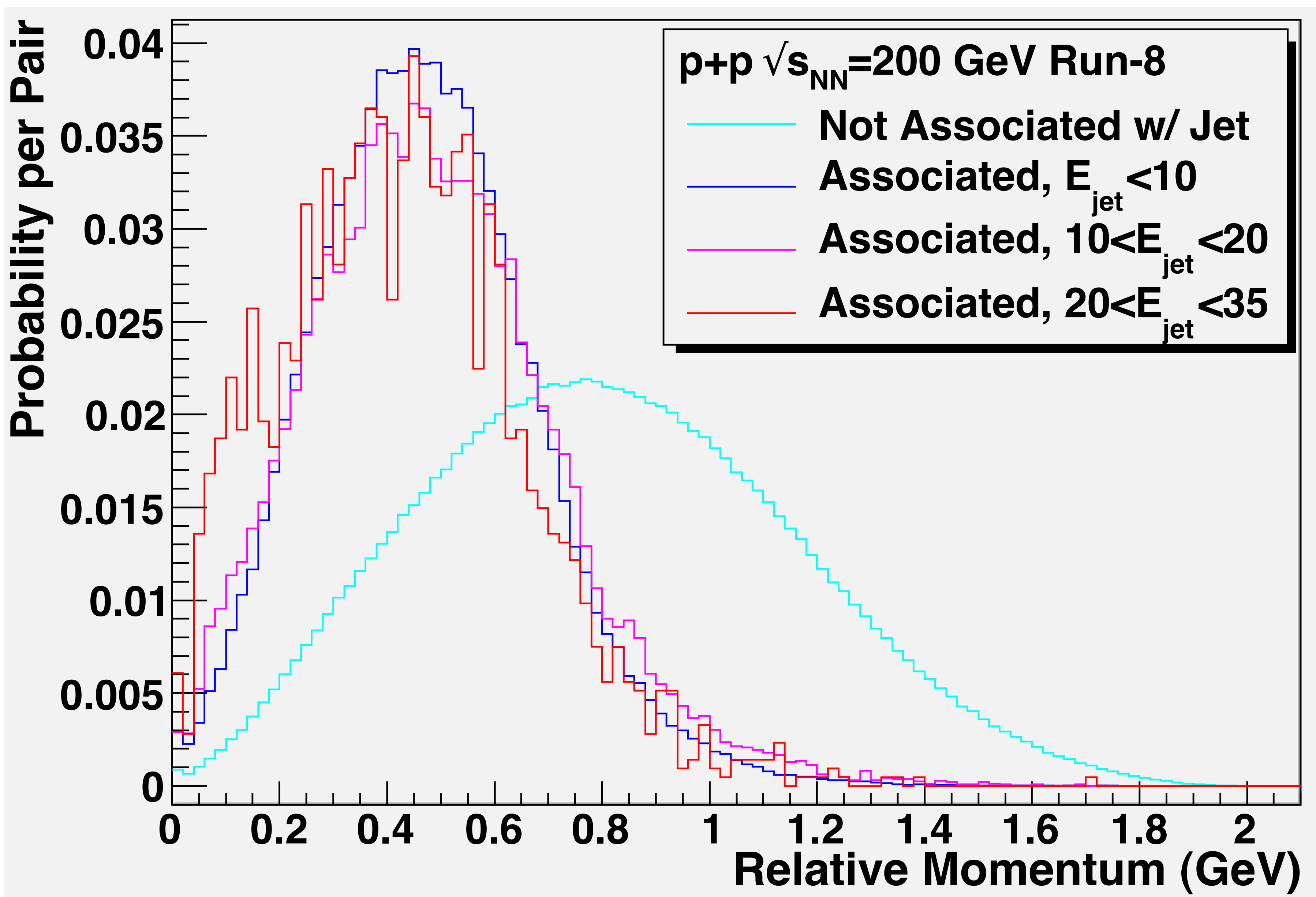
To look into this further, look at 2 "proton" (p or pbar) 3D relative momentum differences
    in inclusive events and in-jets in these same data sets....

Pair Normalized 2 "proton" relative momentum distributions

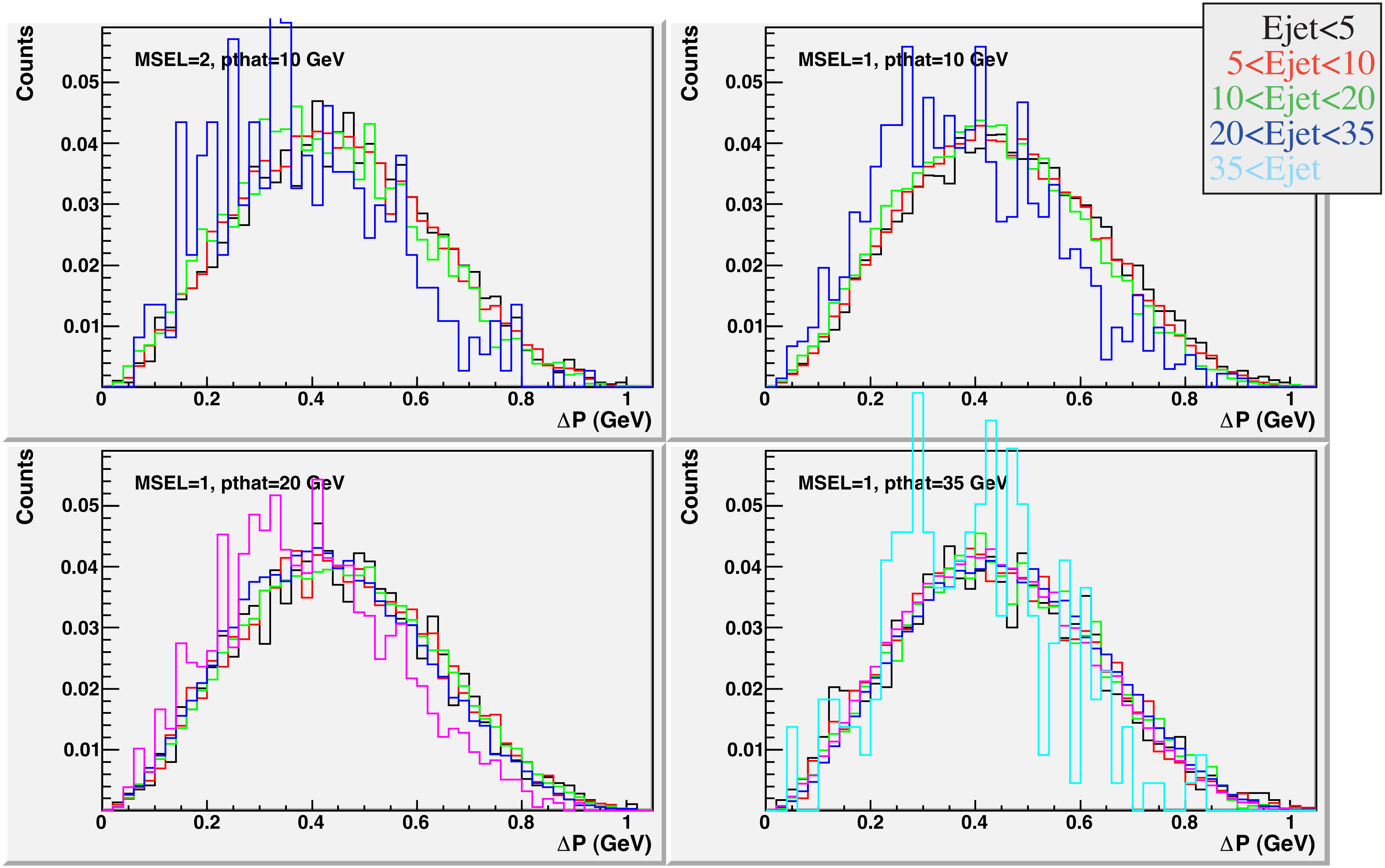
max Δp is 2.0 GeV due to dE/dx PID cut



Pair Normalized 2 "proton" relative momentum distributions, now gating on Jet Energy

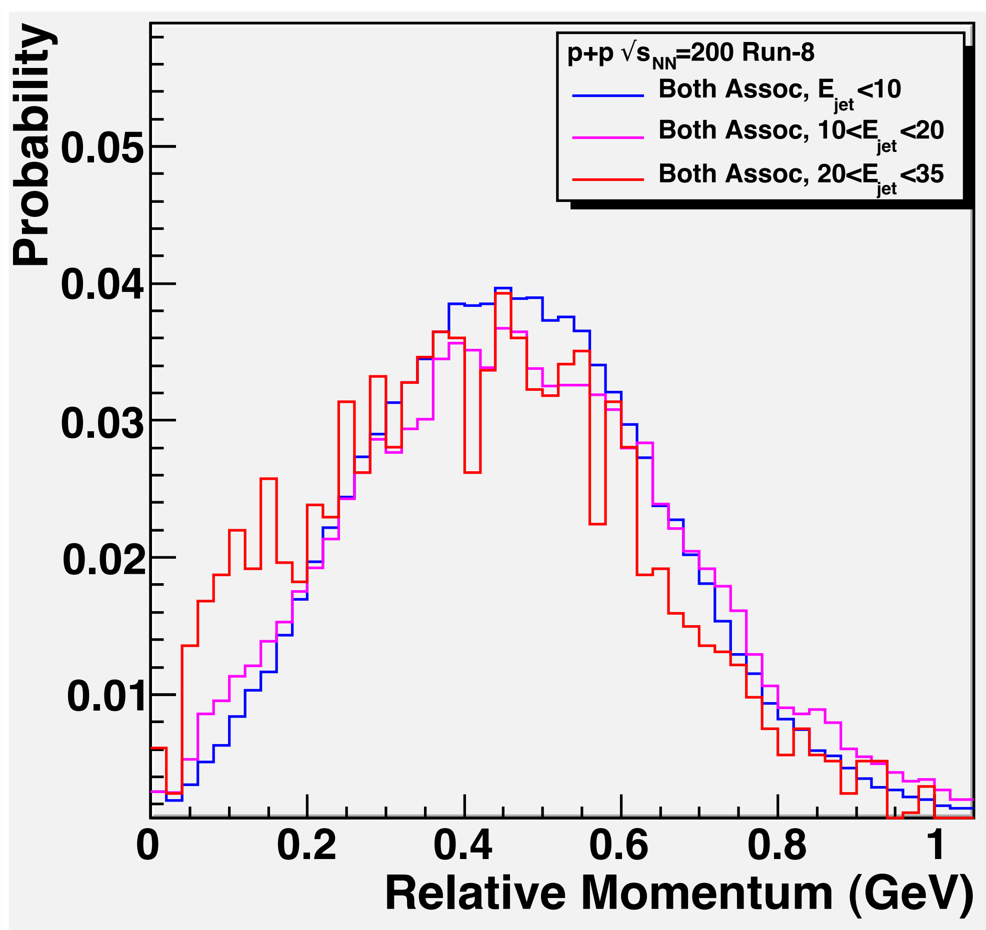


two in-jet p/pbar relative momentum probability distributions from Pythia (jets using PYCELL)

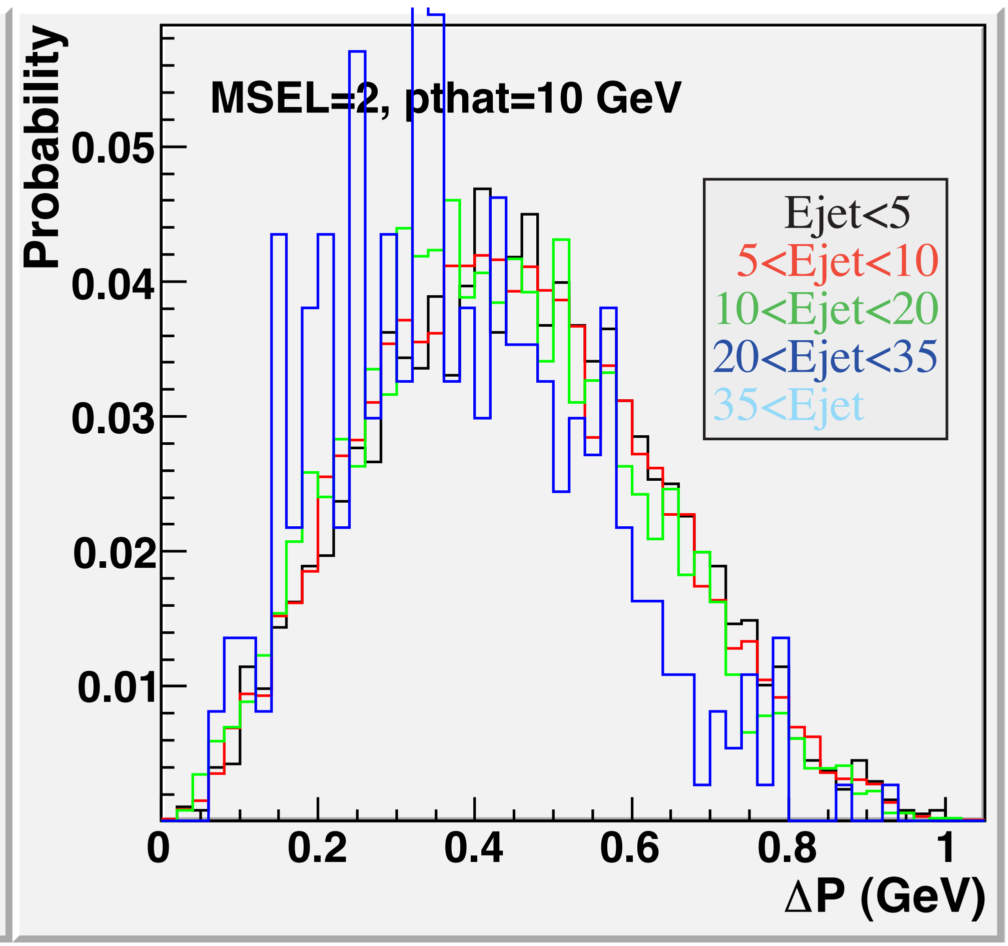


Pythia generally reproduces the observed "focussing" of 2 protons w/ increasing Ejet
...dependence on "pthat," CKIN(3), not understood yet though....

Experimental (p+p 200 GeV Run-8)



Pythia



(sorry about the colors)

Next Steps.....

- Run-9 with TOF PID .... extends P_T/A reach!
- double check B_A from other PID techniques in run-8 (Z_{dedx}, Stat ID in (η,p) bins *etc*)
- CORRECTIONS!!
  - tracking efficiency (from embedding)
  - PID efficiency (from data)
  - absorption correction...
  - feeddown correction...
  - spallation correction...

Absorption

geant does not have an engine for light nucleus dissociation/annihilation etc...

get the density profile of STAR from geant

simulate & calculate the pbar annihilation

scale this to the light nucleus annihilation...

Feeddown ("subtract" protons from Λ, Σ, decays...)

method 1: measure Λ, Σ spectra directly, then simulate contribution to measured p spectra

method 2: plot DCA dists from simulated primordial protons and those from Λ, Σ decays

Spallation (for nuclei only - no contribution to antinuclei)

proton yield = [(pbar yield, dca<3cm)/(pbar yield, dca<1cm)] * (p yield, dca<1cm)

Christof Struck Ph.D. Thesis 2003 (Au+Au data)

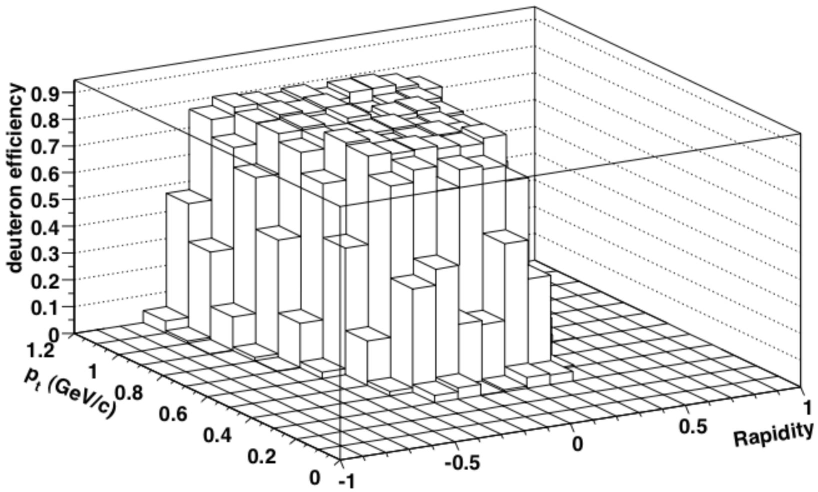


Figure 6.12: Deuteron reconstruction efficiency as a function of transverse momentum and rapidity.

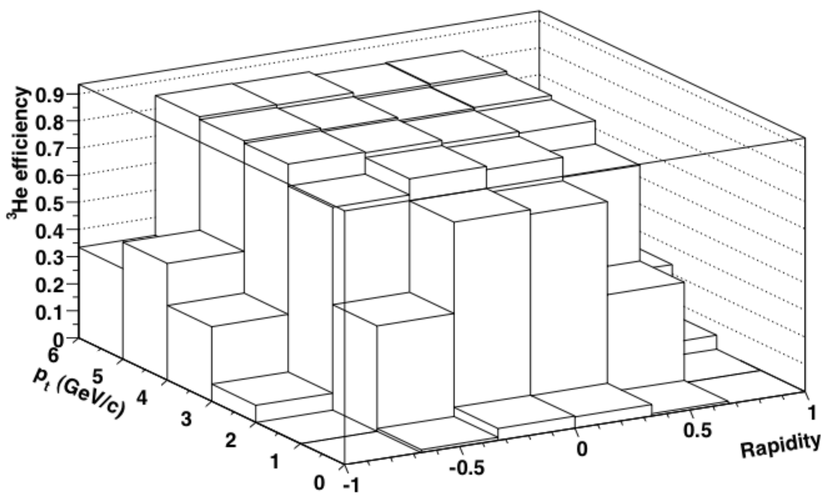
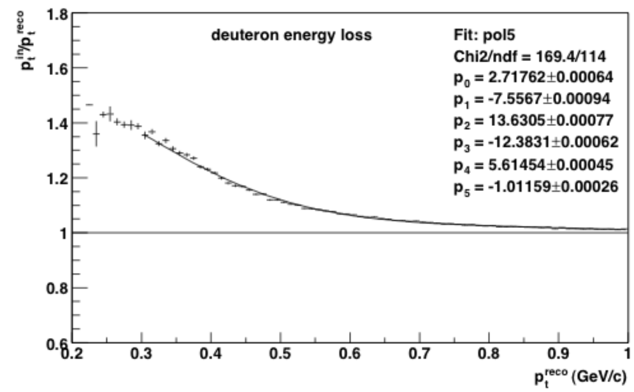
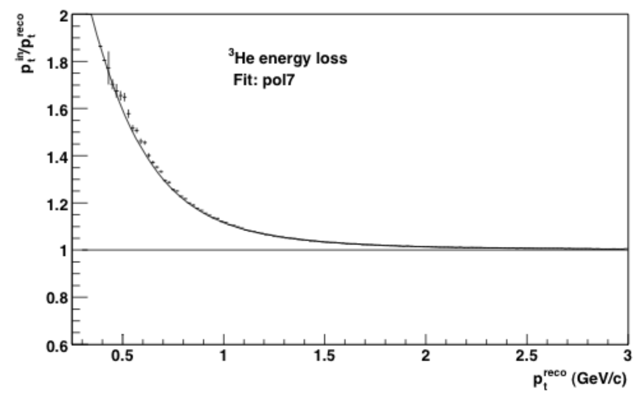


Figure 6.13: ^{3}He reconstruction efficiency as a function of transverse momentum and rapidity.



(a)



(b)

Figure 6.5: Energy loss correction: Ratio of input to reconstructed transverse momentum p_t^{in}/p_t^{rec} as a function of p_t^{rec} for d (a) and ^{3}He (b).

Christof Struck Ph.D. Thesis 2003 (Au+Au data)

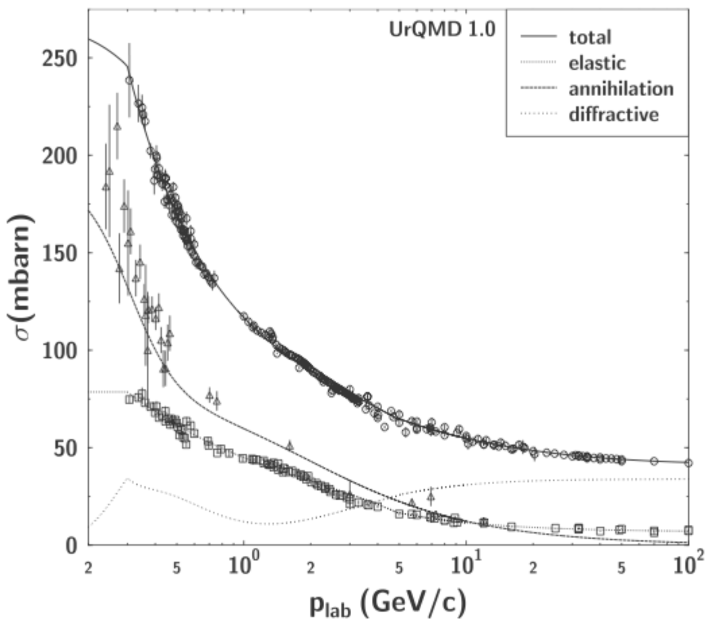


Figure 6.14: Antiproton/proton total, elastic and annihilation cross section. Lines show the parametrizations used in UrQMD [58].

for $\bar{p}$, get detector density distribution from geant and use known cross-sections...

$$abs(p) = 1 - e^{-\sigma_{anni}\,\rho_t\, p\,/\,p_t}$$

$$\sigma_{anni} = 1.2\,\sigma_{total}\,/\,\sqrt{s}$$

$$\sigma_{total} = 120\,p^{-0.65}$$

$$abs^{\bar{p}}_{corr}(p) = exp[\frac{0.089}{\sqrt{1+\gamma}}\,p^{-0.65}\,\frac{p}{p_t}]$$

where ρ_t is the transverse density profile

for light fragments, only σ_{anni} changes...
so, use this pA→AA scaling:

$$\sigma_{inel}(A=2,3) = (\sqrt{(2)}, 2)\;\sigma_{inel}(p)$$

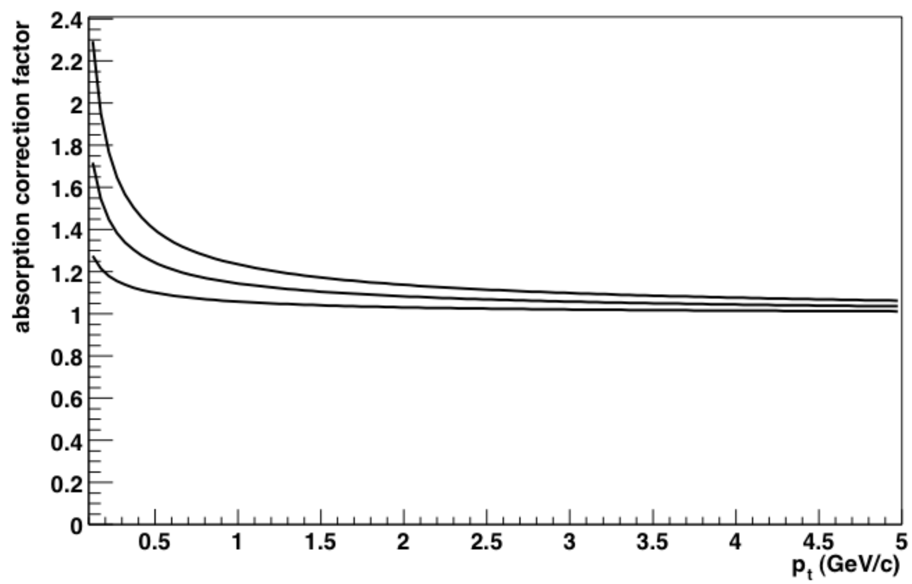


Figure 6.15: Absorption correction factor at mid-rapidity as a function of transverse momentum for $\overline{p}$ (lower curve), $\overline{d}$ (middle curve) and $^3\overline{He}$ (upper curve).

Haidong Liu Ph.D. Thesis 2007 (Au+Au data)

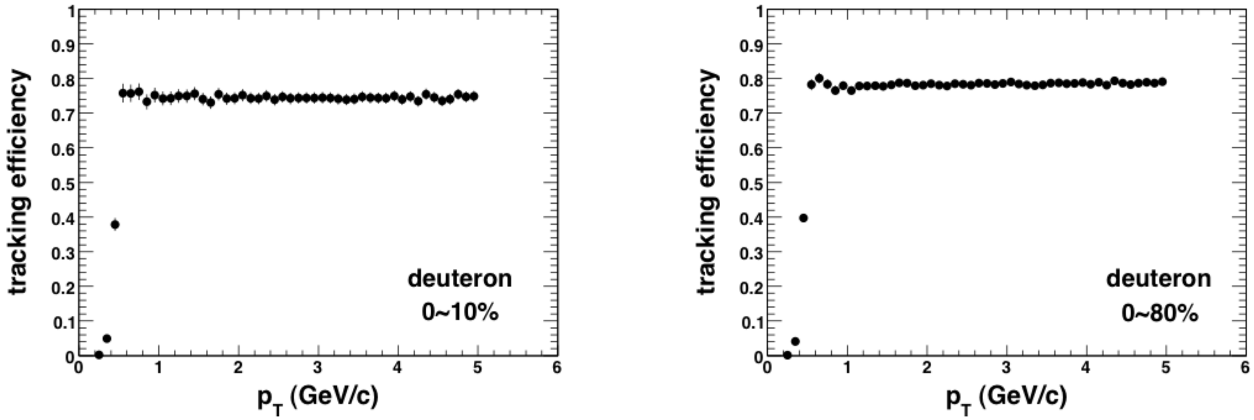


Figure 3.15: Deuteron tracking efficiency as a function of p_T. The left panel is for 0-10% centrality and the right panel is for 0-80% centrality.

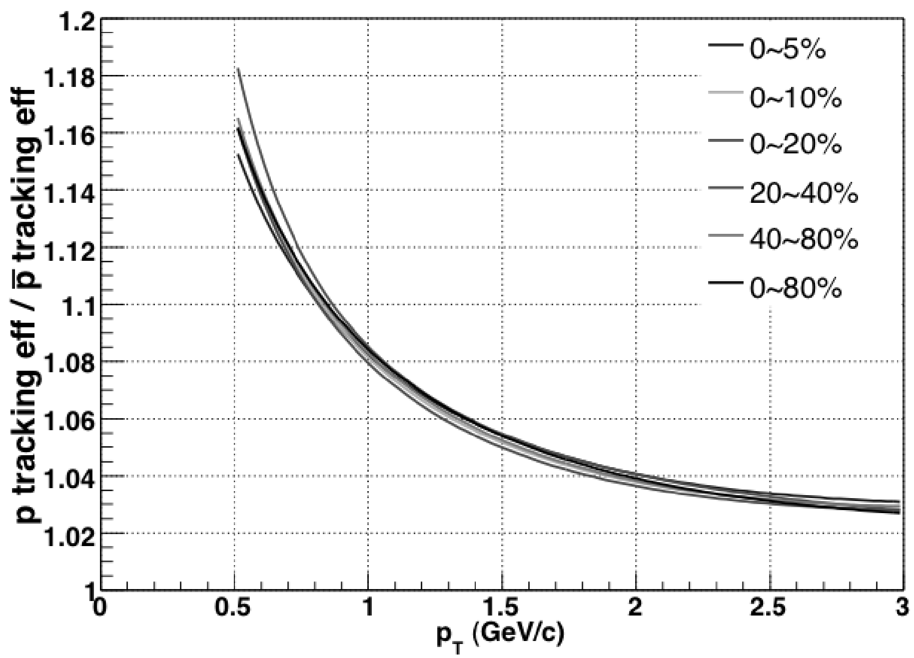


Figure 3.16: p tracking efficiency over $\bar{p}$ tracking efficiency as a function of p_T in different centrality bins.