# Light (Anti)Nucleus Production in 7.7-200 GeV Au+Au collisions in the STAR Experiment

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Outline:

Quick overview of major directions of this analysis

- Fragment spectra in p+p collisions
  - $B_2$ and source radii (first measurement at RHIC)
  - UE vs in-Jet differences, & dependence on Jet Energy (first measurement anywhere)
- Fragment production in BES
  - antinucleus production cross-sections and $B_2$ at low root-s (first measurement anywhere)
  - source radii from $B_2$ vs $P_T$ & $\sqrt{s_{NN}}$ (some RHIC results at high-$\sqrt{s_{NN}}$, but not at BES/SPS energies)
    - direct comparison to HBT (existing results from SPS, but not RHIC)
  - (anti)baryon density vs $\sqrt{s_{NN}}$ (significant extension in $P_T$ using TOF, and in $\sqrt{s_{NN}}$ in BES data)
- Direct comparison to models (urqmd 2.3/3.3p1, AMPT, Pythia)
  - millions of events (from SUG@R & davinci) + coalescence

Major effort recently has been on all the corrections

| | |
|---|---|
| Absorption | (STAR-standard parameterization) |
| Feeddown | (full starsim+bfc simulations) |
| Reconstruction | (embedding) |
| TOF Matching | (from data itself) |

PID Method revised!

…an astoundingly rich data set from an awesome detector!

Datasets Analyzed with the same code:

| | | | |
|---|---|---|---|
| 11 = p+p | 62GeV | run-6 | no TOF |
| 12 = d+Au, | 200GeV | run-8 | no TOF |
| 13 = p+p | 200 GeV | run-8 | no TOF |
| 14 = p+p | 500 GeV | run-9 | partial TOF |
| 15 = p+p | 200 GeV | run-9 | partial TOF |
| 16 = Au+Au | 200 GeV | run-10 | full TOF |
| 17 = Au+Au | 62.4 GeV | run-10 | full TOF |
| 18 = Au+Au | 39 GeV | run-10 | full TOF |
| 19 = Au+Au | 7.7 GeV | run-10 | full TOF |
| 20 = Au+Au | 11.5 GeV | run-10 | full TOF |
| 23 = Au+Au | 19.6 GeV | run-11 | full TOF |
| 25 = Au+Au | 27 GeV | run-11 | full TOF |

# Dynamic Coalescence Simulations and Experimental Goals

| Data | Nev | pythia | ampt | ampt(SM) | urqmd2.3 | urqmd3.3p1 |
|---|---|---|---|---|---|---|
| pp 200 Run9 | 183M | 653M | | | | |
| AuAu 200 Run 10 | 51.4M | | 84k | 73k | 663k | 136k |
| AuAu 62.4 Run 10 | 48.2M | | 248k | 246k | 636k | 256k |
| AuAu 39 Run 10 | 37.9M | | 328k | 298k | 836k | 236k |
| AuAu 27 Run 11 | 46.2M | | 759k | 696k | 1.74M | 390k |
| AuAu 19.6 Run 11 | 27.8M | | 1.02M | 690k | 1.73M | 410k |
| AuAu 11.5 Run 10 | 15.5M | | 456k | 280k | 1.84M | 492k |
| AuAu 7.7 Run 10 | 4.8M | | 984k | 708k | 4.92M | 2.74M |

Experimental Goals:

- Cross-sections for p, d, t versus $P_T$ and $P_T/A$
  - dramatic extension in $P_T$ compared to previous STAR results given TOF and BES energies
  - in p+p, cross-referencing of tracks in jets to jet energy, angles, etc
- Coalescence ratios: $B_A$ vs $P_T/A$
  - interpretable in terms of source homogeneity volumes
- Spectra ratios: d/p & t/p vs $M_T/A$
  - (net baryon density)

Theory:

- 6-D Dynamic Coalescence using various models…. Pythia, AMPT, UrQMD
- Source radii directly from $B_A$ vs $P_T/A$…. several prescriptions & compare to HBT

Event Cuts:

$|Z_{vtx}|<50$, $R_{vtx}<2$, $|\eta_{asym}|<5$, $|\eta_{asymTOF}|<5$, $N_{tofmatch}>5$
refmult centrality
minimum bias trigger in st_physics stream

Track Cuts:

flag=301, $N_{hitsfit}/N_{hitsposs}>0.52$
"cuts set1": $N_{hitsfit}>15$, $N_{hitsdedx}>10$, gldca<2
"cuts set2": $N_{hitsfit}>25$, $N_{hitsdedx}>15$, gldca<1
TOF: matchflag>0, |ylocal|<1.8, $\beta>0$

PID as of Kolkata Meeting:

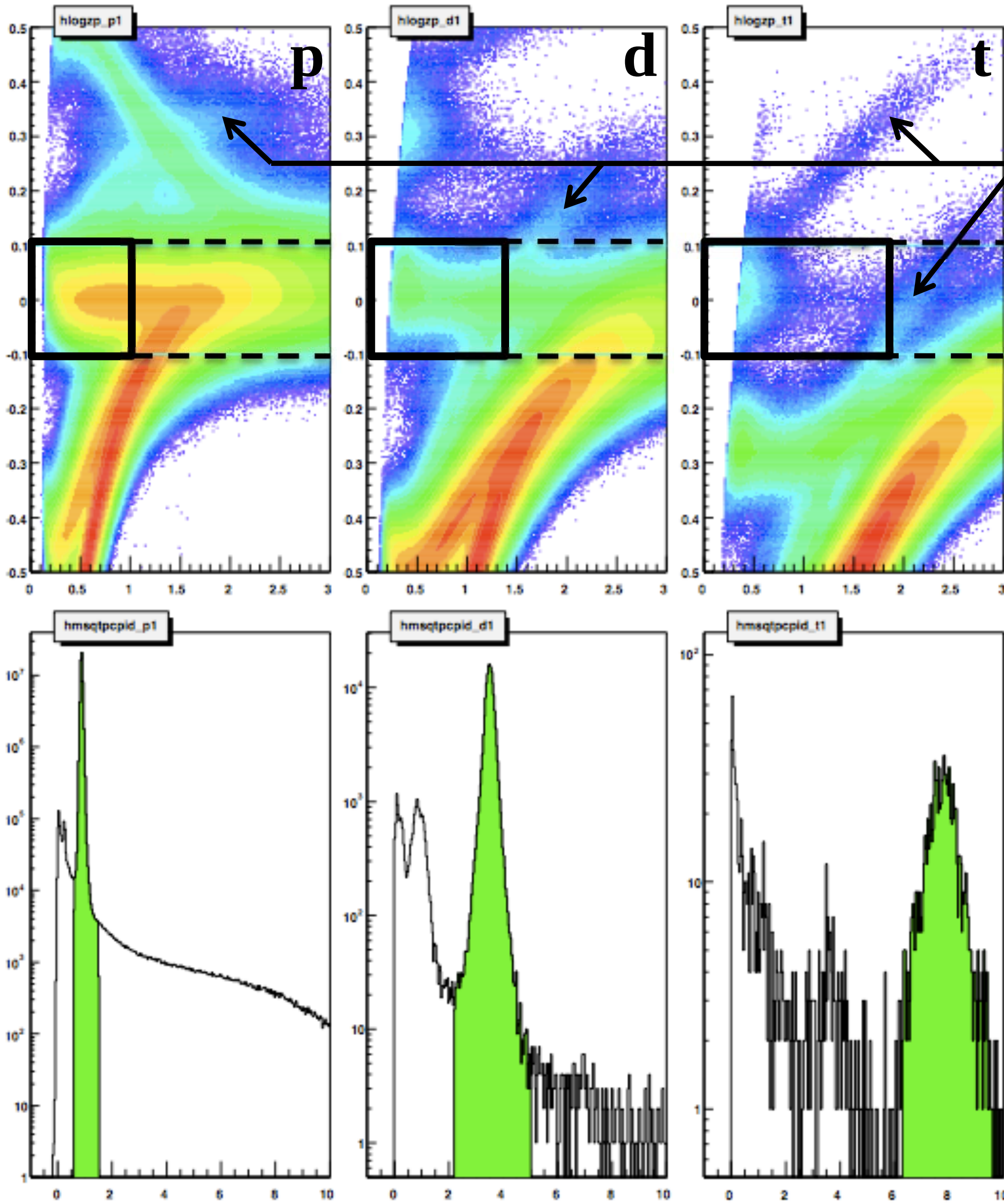
"dE/dx-TOF": log-Z cut on POI, p<0.9 (p), p<1.3 (d), p<1.7 (t)
if TOF info exists (~65-70%), require that $M^2$ is consistent with POI
full efficiency but mom'n limited, uses TOF to clean up dE/dx where possible

"dE/dx+TOF": log-Z cut on POI, no momentum upper limit
require TOF info exists, and require that $M^2$ is consistent with POI
65-70% as efficient, but much wider mom'n reach

now - "direct fits": weighted TH3D's (y,pt,Z) and (y,pt,$M^2$) – major improvements!

# Older PID method, and why it's **no good**…

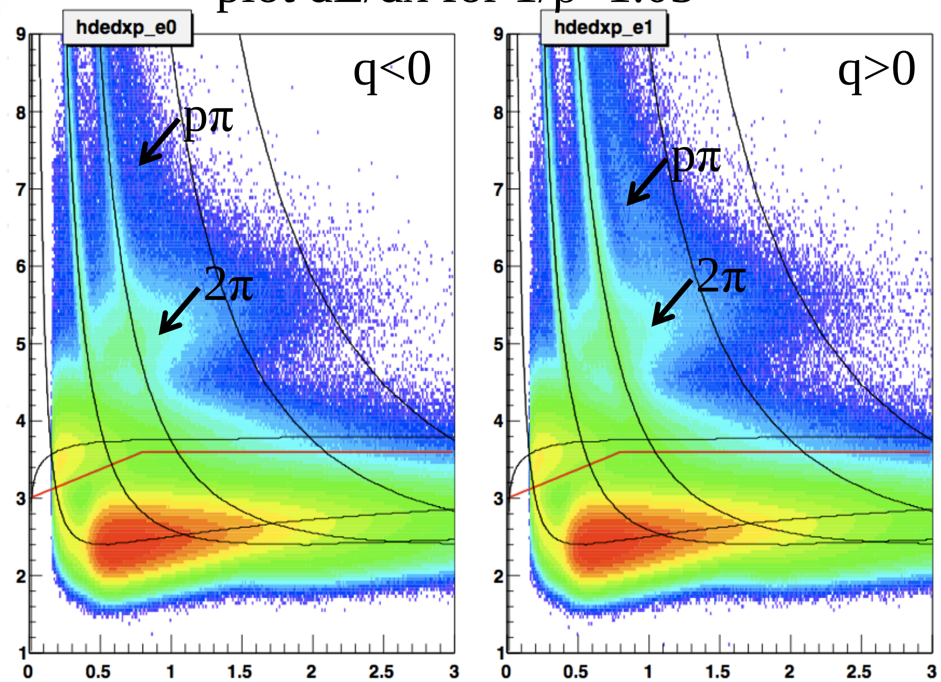
Z = log[dE/dx(track)]/[dE/dx(Bichsel)] *vs.* momentum…




what's this junk?

It's merged tracks!

plot dE/dx for $1/\beta<1.03$




rate can be large compared to Abar rate!

TOF kills these quite effectively…

Corrections:

**absorption (applied in pDST analysis)**

pbar handled by geant/embedding

Abar cannot be done w/ geant, need to use an empirical approach

**feeddown (applied in post-pDST analysis)**

simulation/reconstruction of full events from some model

not applying here (for reasons that will become clear shortly)

but I've increased the stats by a factor ~3 since last talk…

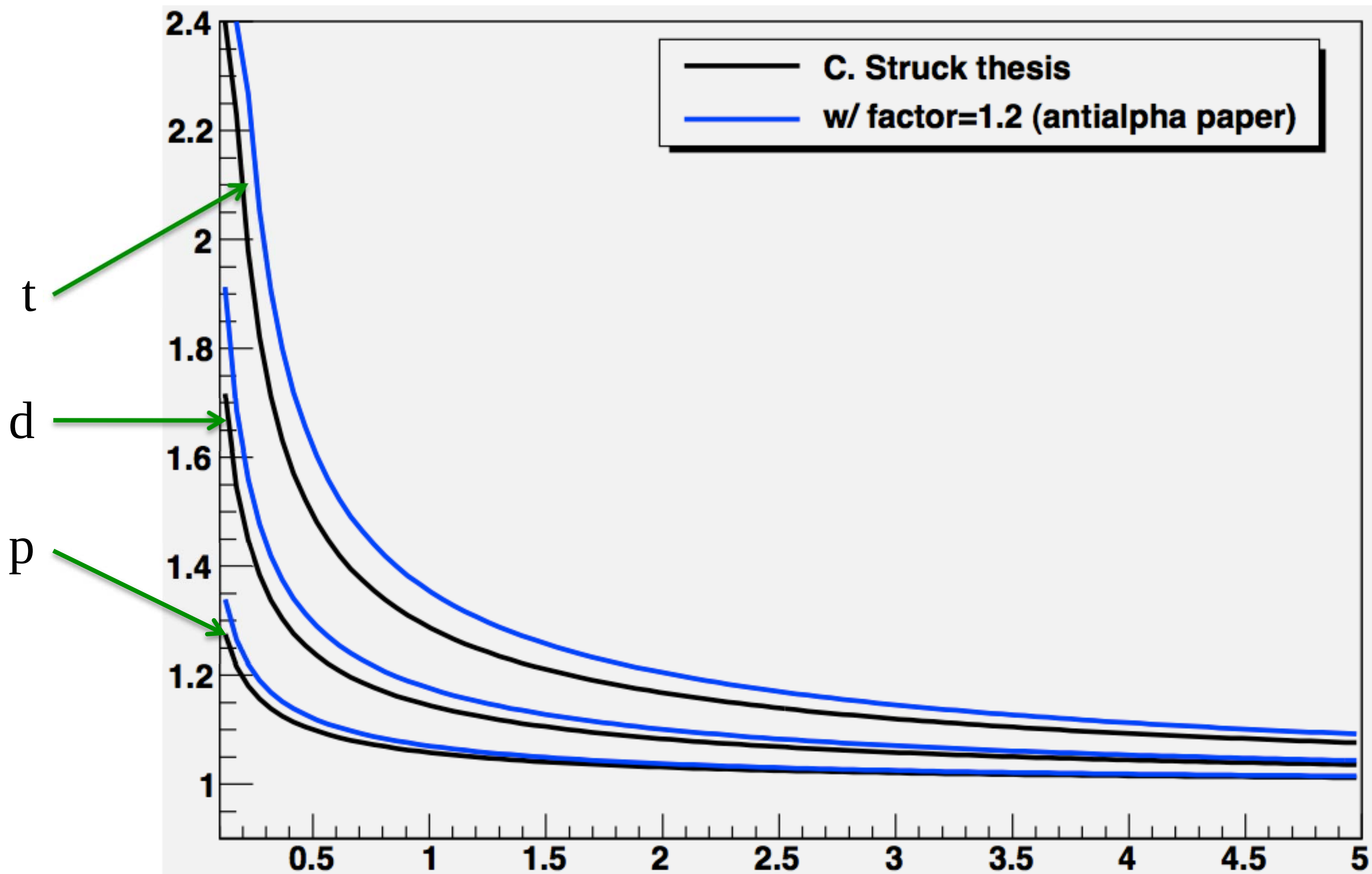
**reconstruction efficiency (applied in pDST analysis)**

embedding, almost done. reproduced in new SLXX_emb libs

**TOF matching efficiency (applied in pDST analysis)**

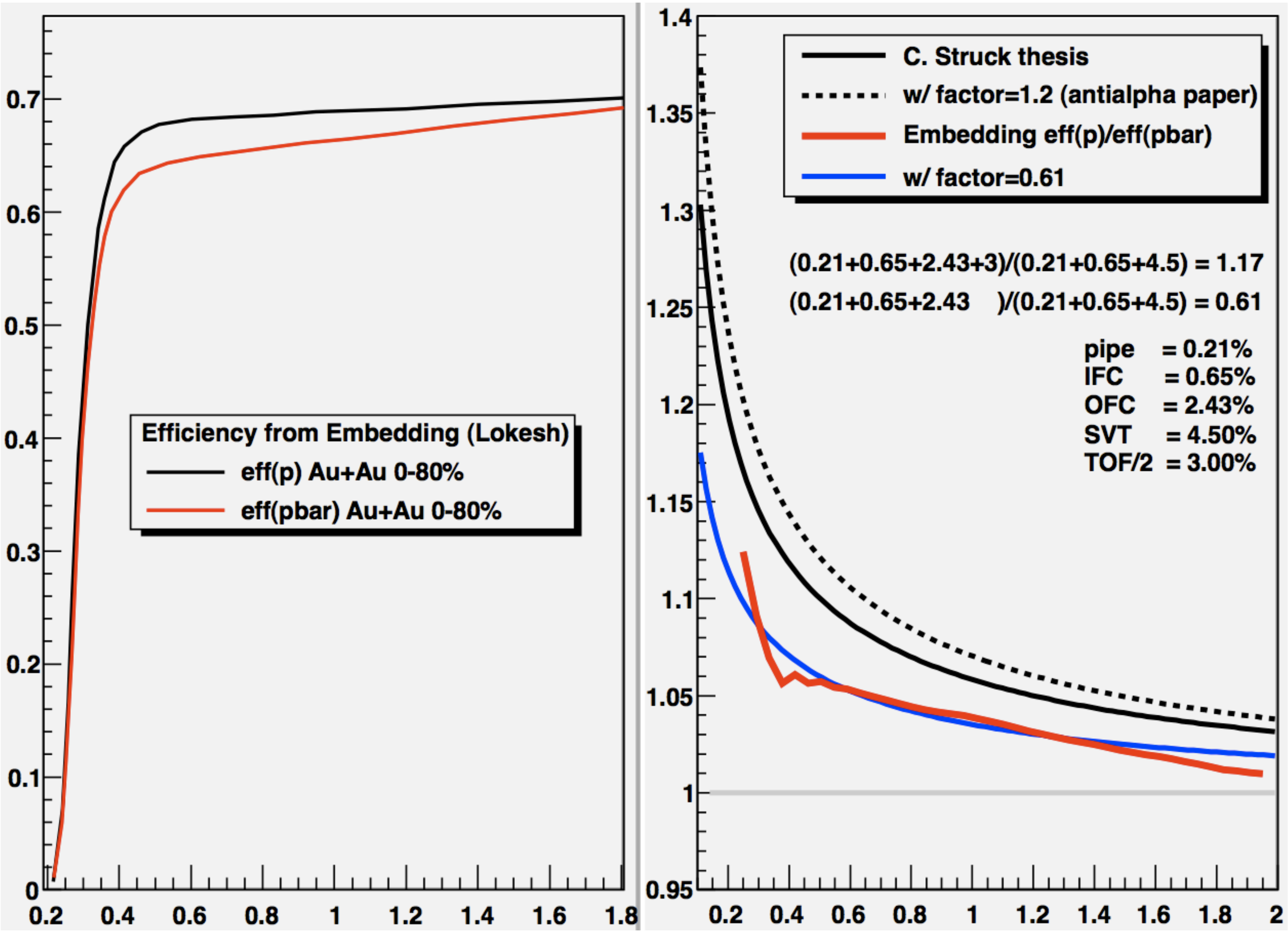
# Absorption

geant does not know how to interact antinuclei w/ arbitray materials
so use prescription described in Christof Struck's thesis…
same prescription used in recent antialpha paper after scaling the materials
(remove SVT, add half-depth of TOF)



# Absorption

geant *does* know how to interact pbars, so one can test the absorption prescription using embedding data!



# Feeddown (as of Kolkata – statistics have been improved & 19.6 GeV added)

UrQMD 3.3p1

starsim & Y2010c

- geom repairs
- realistic $\sigma_{Zvtx}$

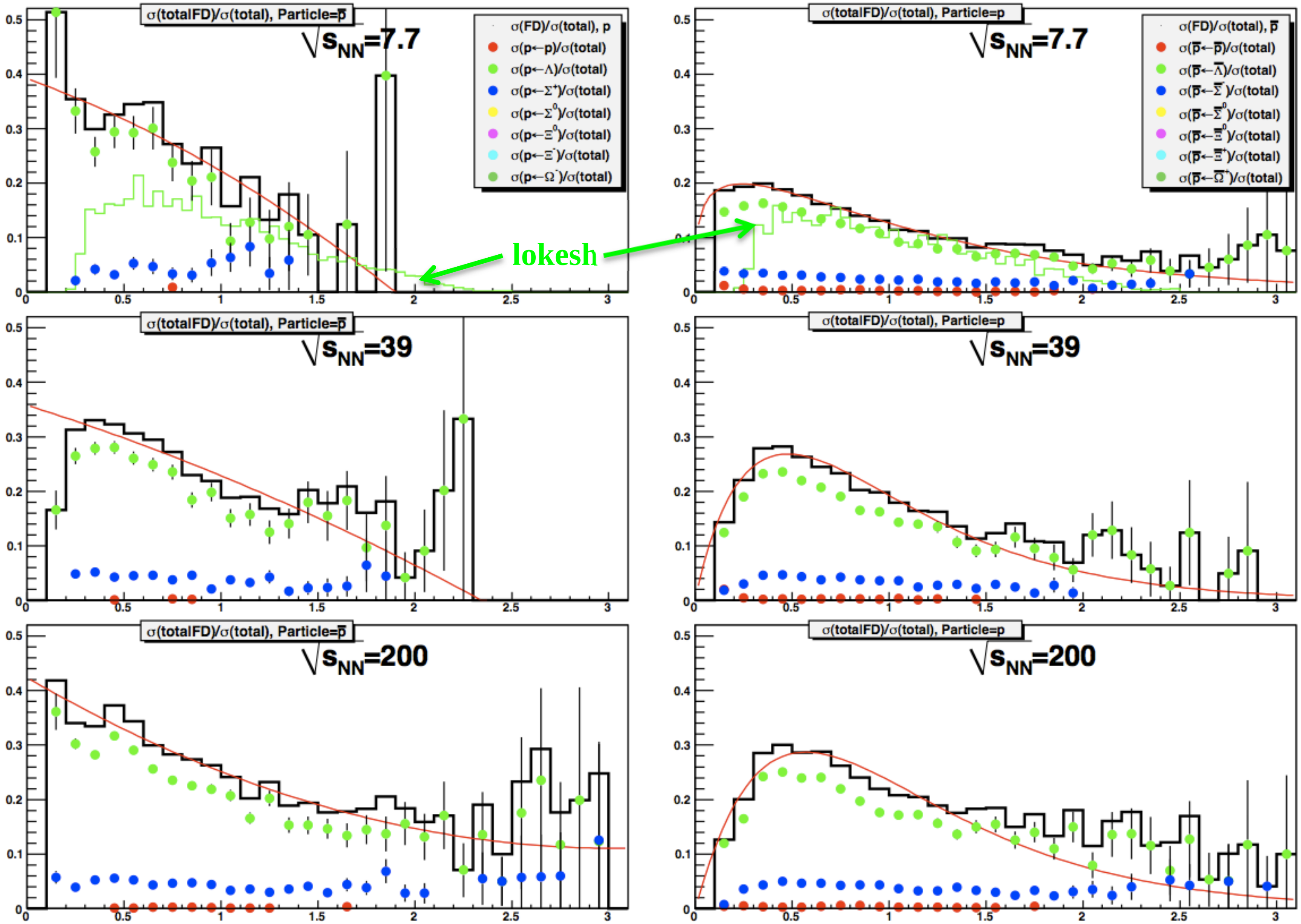
bfc.C

- TpcRS
- MiniMcMk

TpcRS is **slow**

but most realistic…

no dE/dx fudging!




Uncovered problems in trs

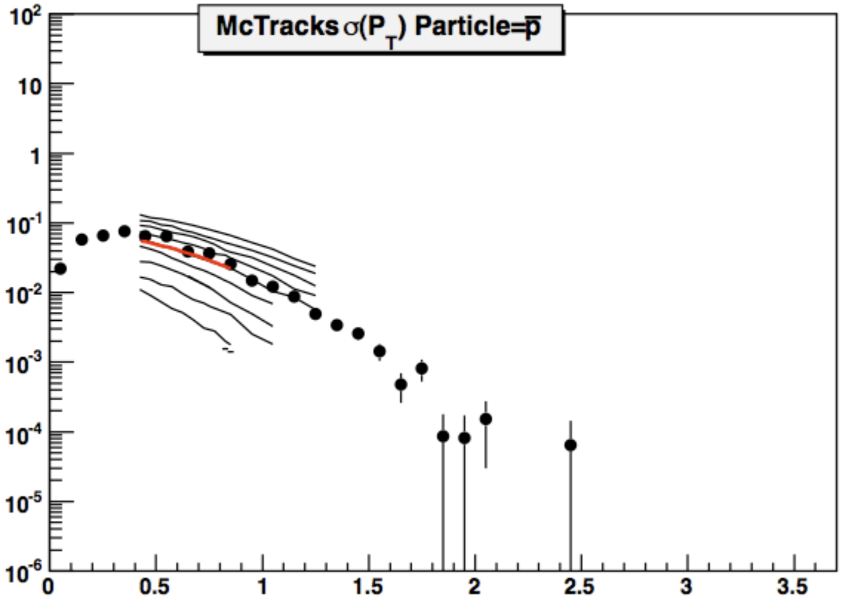
- unknown species was given a geantID=0, and then no energy loss, and then no rec. tracks

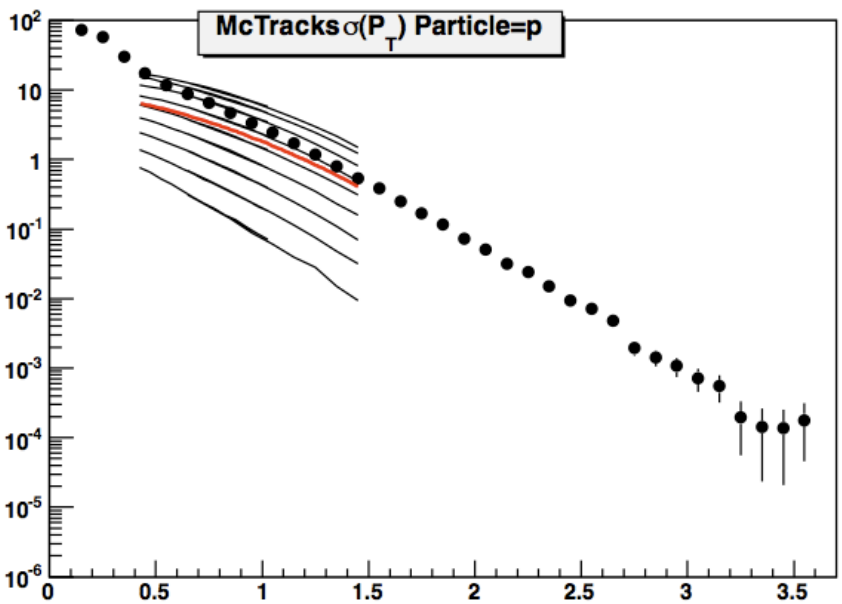
Fix entailed changes to trs and StarClassLibrary to properly include light antinuclei…

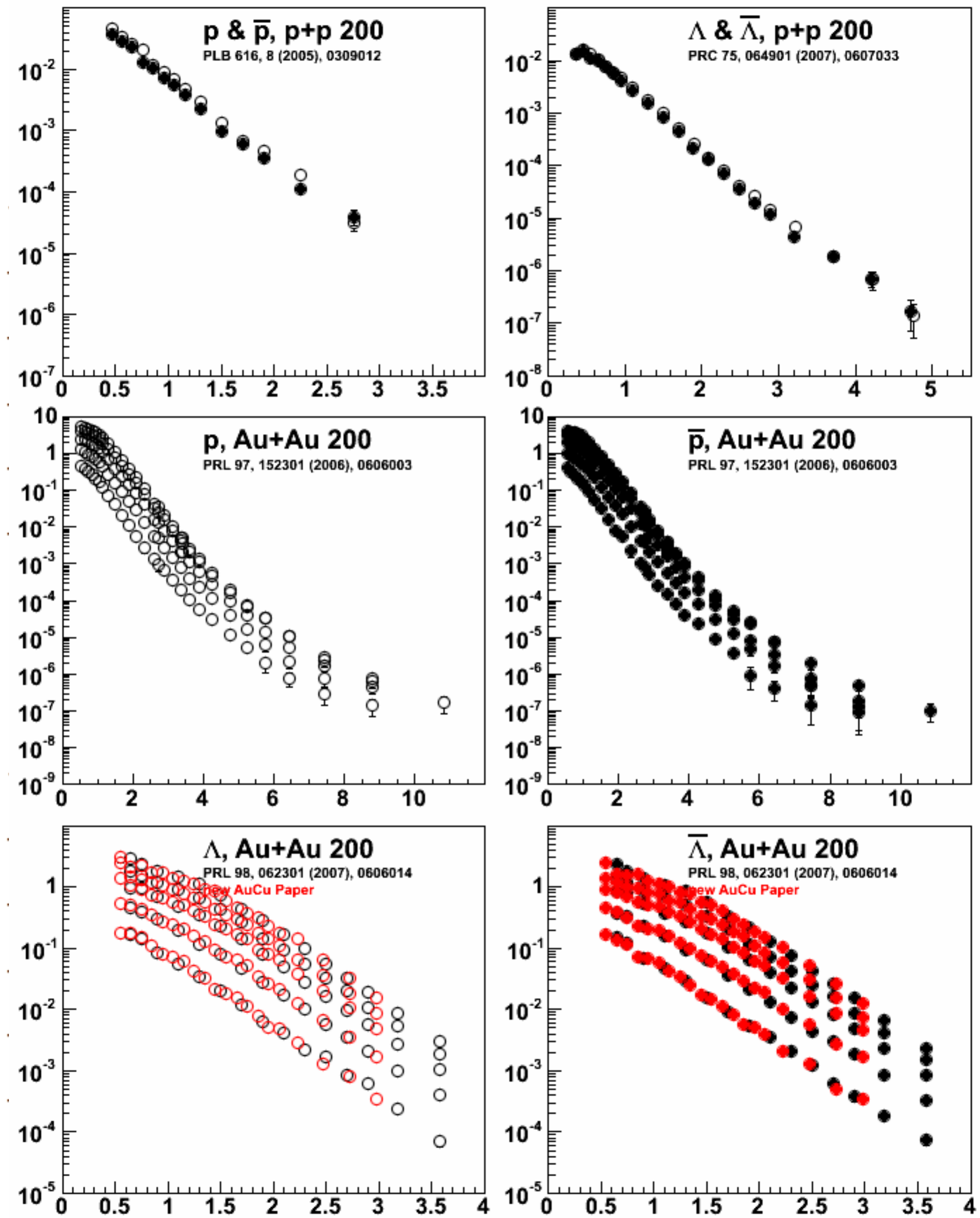
- see RT Ticket #2157.

# Feeddown (comparison to Lokesh's result based on Λ embedding)

Might need the measured cross-sections to check the UrQMD ratios…..



# Reconstruction Efficiency from Embedding

Lots of technical problems in many different codes….
(many thanks to Hiroshi, **Xiangli, Geraldo, Xianglei**, Gene, Jason, & Victor!)

| | |
|---|---|
| dbar in p+p, 200 GeV, run-9 | DONE |
| dbar in Au+Au, 200 GeV, run-10 | DONE |
| tbar in Au+Au, 200 GeV, run-10 | DONE |
| d in Au+Au, 200 GeV, run-10 | DONE |
| pbar in Au+Au, 39 GeV, run-10 | DONE |
| dbar in Au+Au, 39 GeV, run-10 | DONE |
| tbar in Au+Au, 39 GeV, run-10 | DONE |

OOPS! These were done in incorrect libraries. Comparison to the newly available SLXX_emb shows different glDCA distributions

these have been reproduced…
dbar in p+p 200 run-9 still in progress…

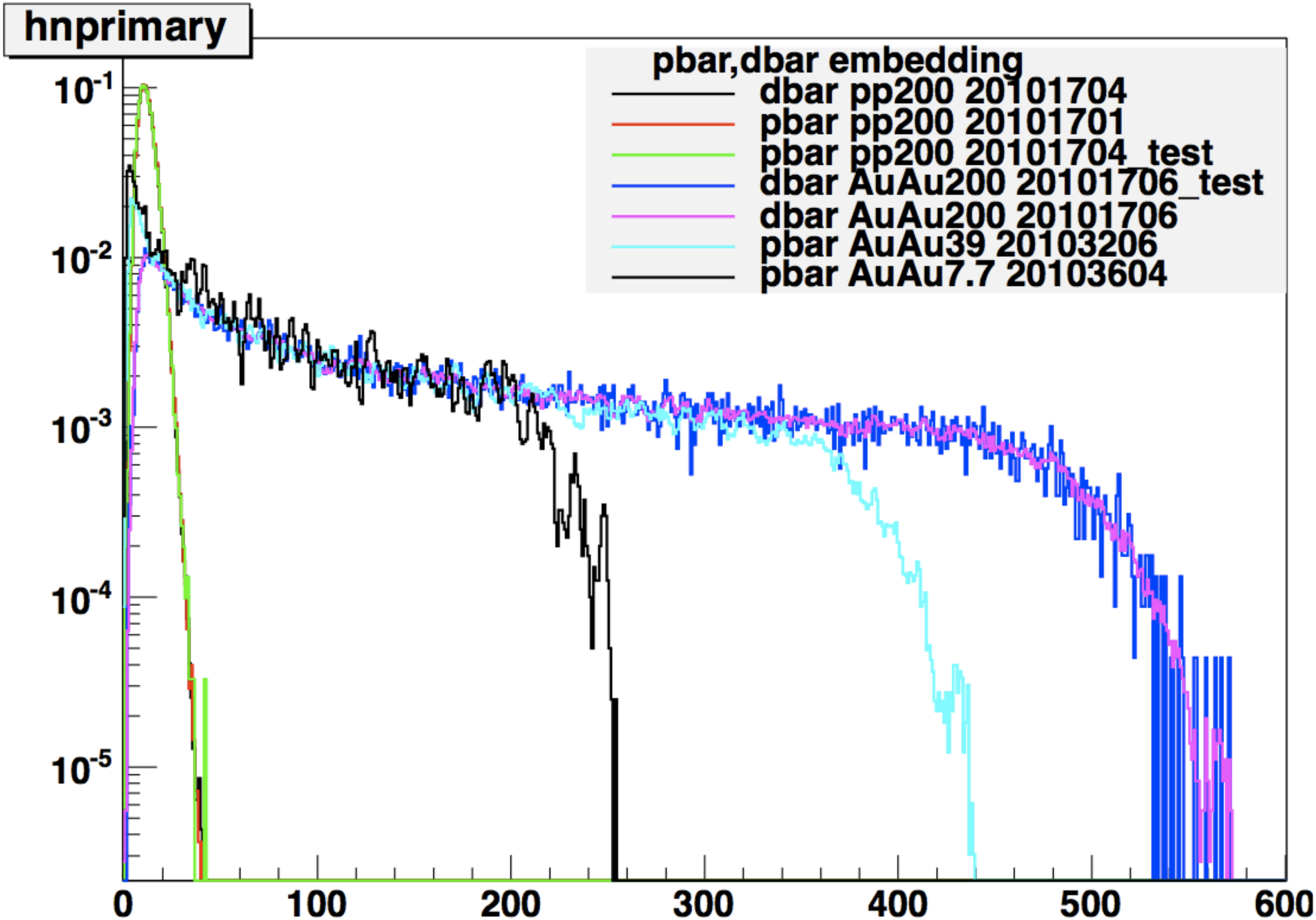
"saving" last two requests (will likely be dbar in p+p 200 and 500)
these two are waayyy at the back in the bus now…

I also found some existing embedding productions laying around….

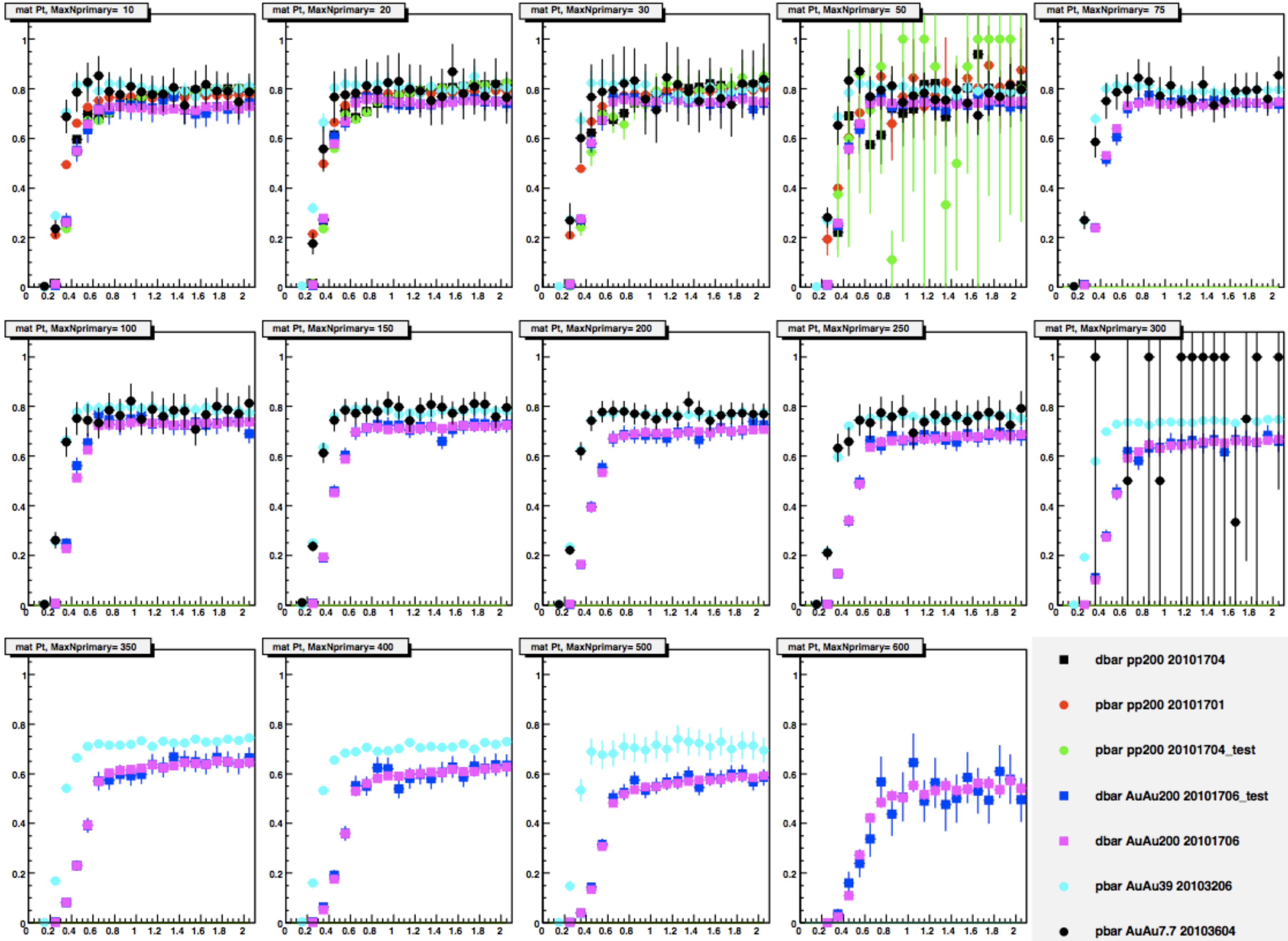
| | | | |
|---|---|---|---|
| pbar | p+p | 200GeV | 20101701 |
| pbar | Au+Au | 39GeV | 20103206 |
| pbar | Au+Au | 7.7GeV | 20103604 |

…Waiting patiently for p and pbar in AuAu 200 Run-10 jetcorr requests (Kolja Kauder)
I've QA'd the test samples and they look fine.

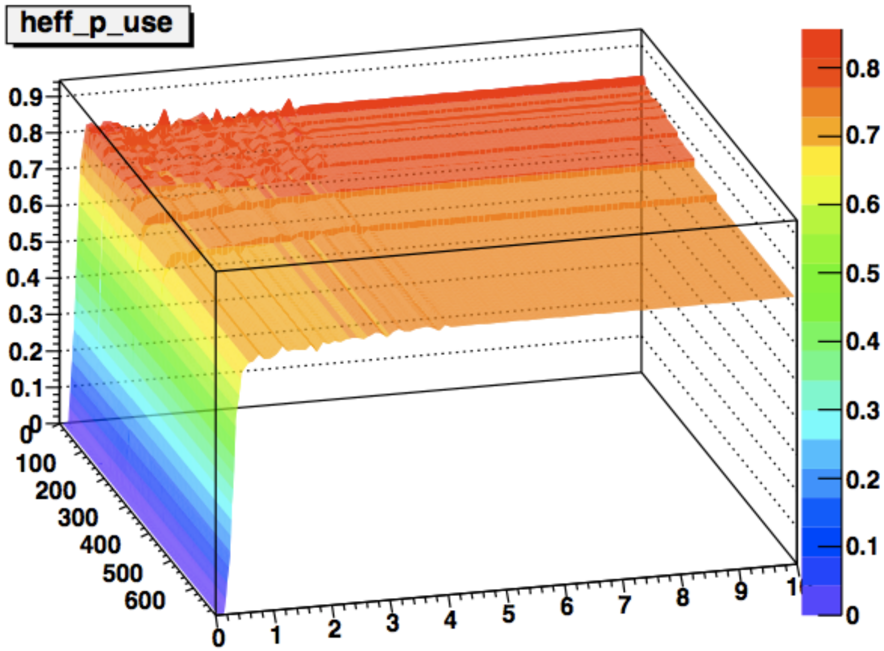
# Embedding

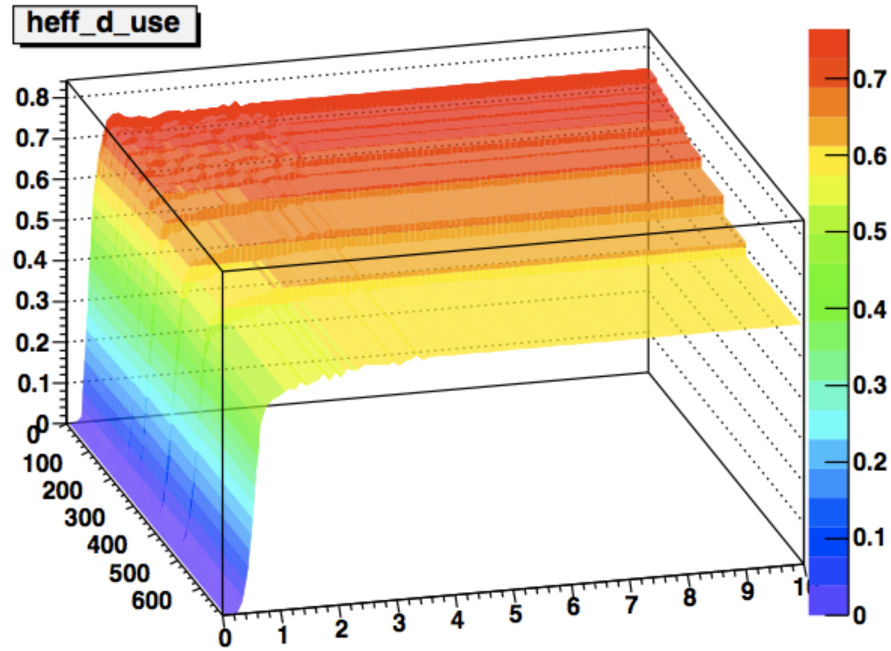

hnprimary
pbar,dbar embedding
dbar pp200 20101704
pbar pp200 20101701
pbar pp200 20101704_test
dbar AuAu200 20101706_test
dbar AuAu200 20101706
pbar AuAu39 20103206
pbar AuAu7.7 20103604
10-1
10-2
10-3
10-4
10-5
0
100
200
300
400
500
600

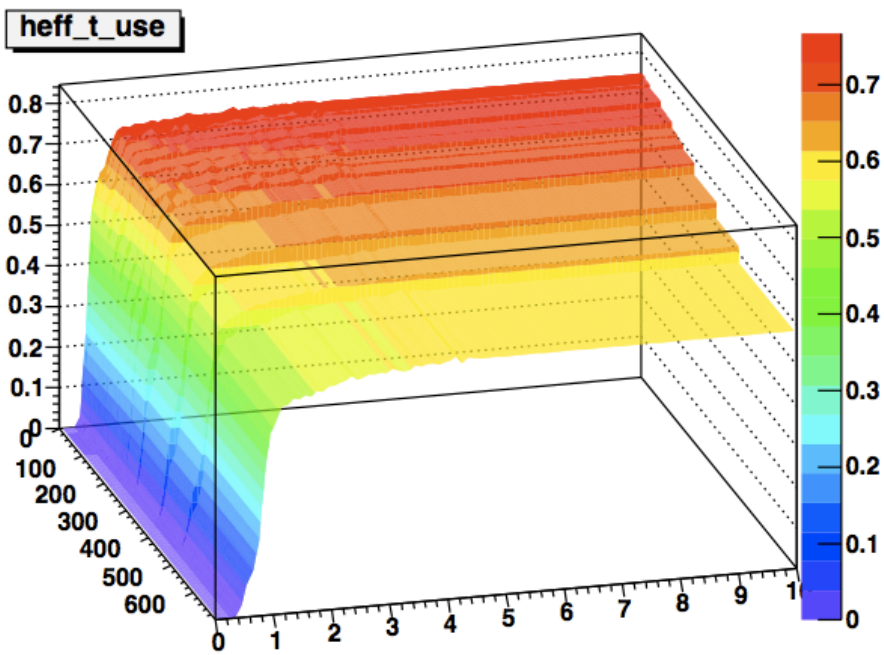
# Embedding


mat Pt, MaxNprimary= 10
mat Pt, MaxNprimary= 20
mat Pt, MaxNprimary= 30
mat Pt, MaxNprimary= 50
mat Pt, MaxNprimary= 75
mat Pt, MaxNprimary= 100
mat Pt, MaxNprimary= 150
mat Pt, MaxNprimary= 200
mat Pt, MaxNprimary= 250
mat Pt, MaxNprimary= 300
mat Pt, MaxNprimary= 350
mat Pt, MaxNprimary= 400
mat Pt, MaxNprimary= 500
mat Pt, MaxNprimary= 600
dbar pp200 20101704
pbar pp200 20101701
pbar pp200 20101704_test
dbar AuAu200 20101706_test
dbar AuAu200 20101706
pbar AuAu39 20103206
pbar AuAu7.7 20103604

# Embedding



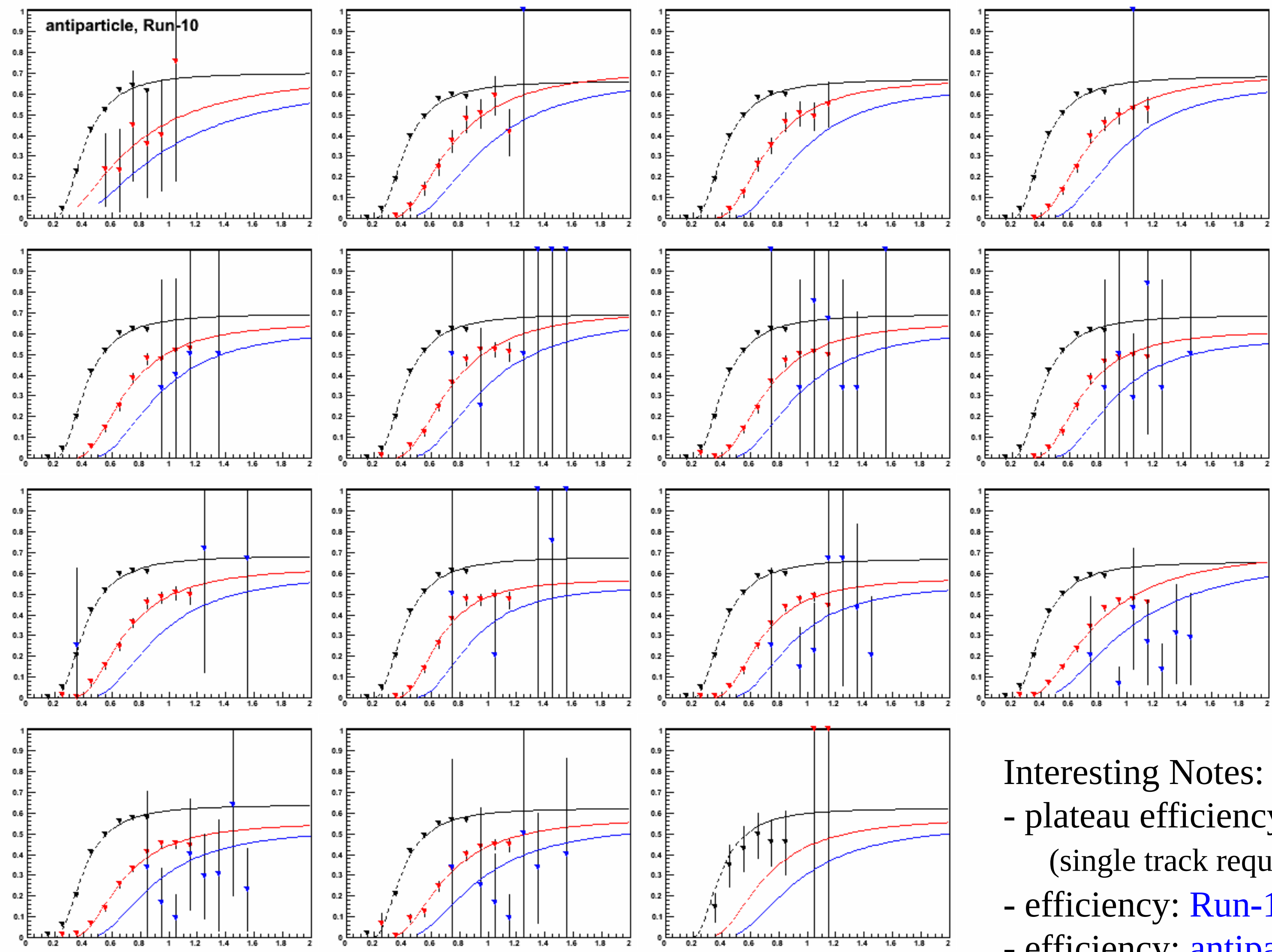

Embedding results converted into "look-up table" vs $P_T$ and refmult for pbar,dbar,tbar.

right now use 200 GeV embedding for all refmult
will use 39 GeV for root-s <= 39 GeV (sector 20!) soon…

p,d,t efficiencies w.r.t. pbar,dbar,tbar handled with absorption correction function (tested directly for protons, *e.g.* pg. 8)

# TOF Matching

1σ cut on dE/dx, then plot probability there is a TOF match for this track *vs.* $P_T$….




different boxes are refmult bins (same as for embedding)

p d t

heavier particles start matching to TOF at higher $P_T$

results in 3×2×3 functions vs $P_T$…

(p,d,t) (+,-) (run9,10,11)

Interesting Notes:

- plateau efficiency decreases with refmult
  (single track requirement in BTofMatchMaker)
- efficiency: Run-11 > Run-10
- efficiency: antiparticle < particle
  (absorption in OFC, TPC rail, TOF box)

# New PID Approach

Previous PID approach – set hard cuts on Z or $M^2$ and calculate cross-sections on the fly…

PRO: Simpler analysis code…

CON: Difficult to control contamination…

CON: Impossible to remove merged tracks…

For the xsec, ratios, radii *etc* using this PID approach, see:

`http://wjllope.rice.edu/~WJLlope/-myPublications/Kolkata_Llope_nuclei.pdf`

Now using a much more detailed PID approach….

Analysis code fills 3*2*2 TH3Ds (3 POIs – p,d,t, & 2 charges, & 2 weights)

for minbias, and each of sixteen 5%-wide centrality bins

for each observable (“weight” is counts or cross-section vs $P_T$, vs $P_T/A$, vs $M_T/A$)

and for two PID approaches (Z, $M^2$)

x = $P_T$, $P_T/A$, or $M_T/A$ in 0.1 GeV bins from 0 to 5.0

y = rapidity assuming the POI mass, dy=0.2 bins from -0.5 to 0.5

z = Z or $M^2$

w = 1/2/pi/W/dW/dy, where dW=0.1 & W=$P_T$, $P_T/A$, or $M_T/A$

or w = 1 (needed for error bars for direct counting of tbar and dbar at low root-s)

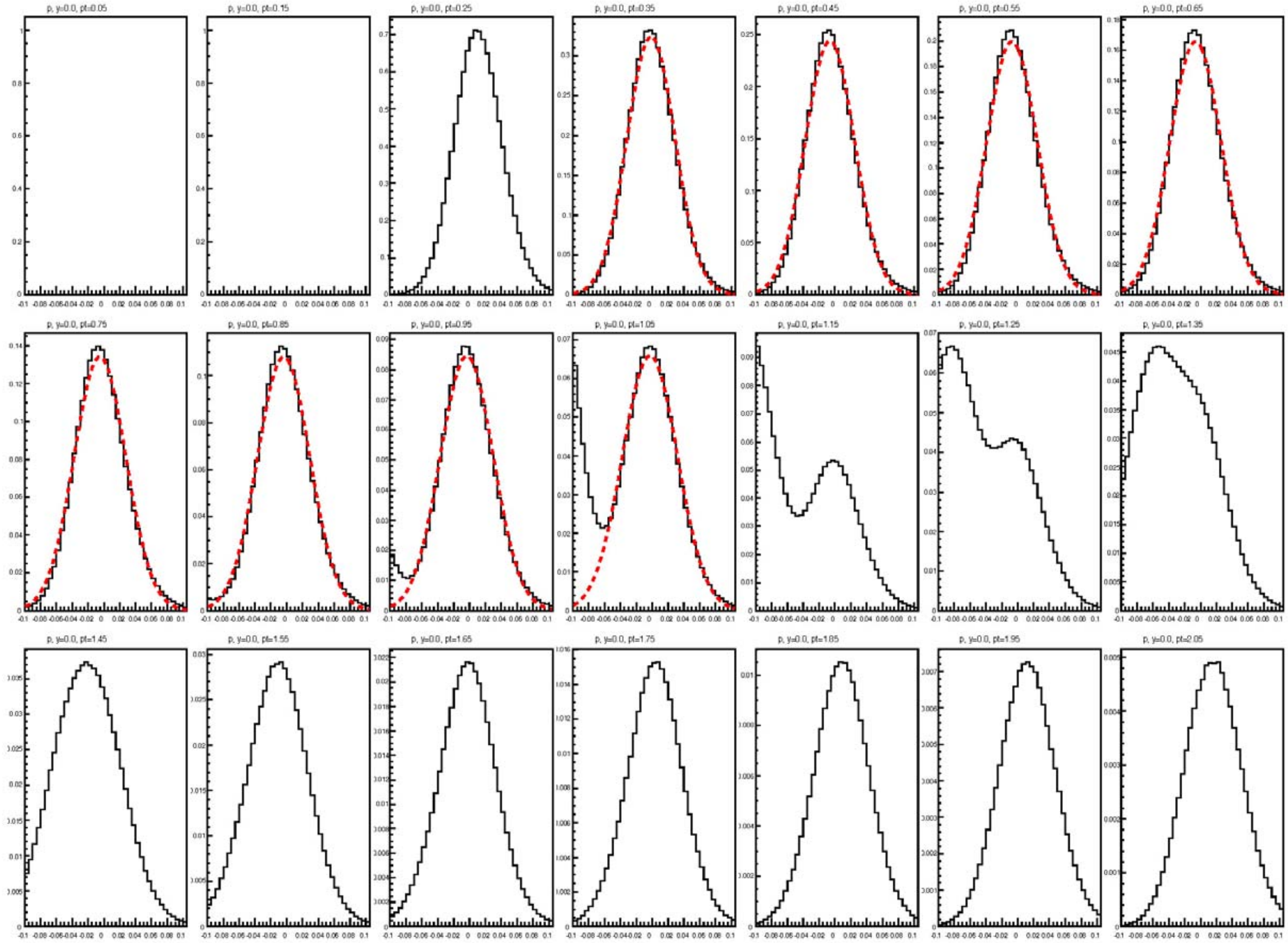
Then project each TH3D bin into a TH1D, fit a Gaussian, then get `Integral` and `IntegralError`

Power Moves: Do **NOT** use “L”, “B”, and **MUST**: `hist->GetSumw2()->Set(0); hist->Sumw2();`

New PID method works significantly better, as expected…

# Example of New PID approach for root-s = 39 GeV

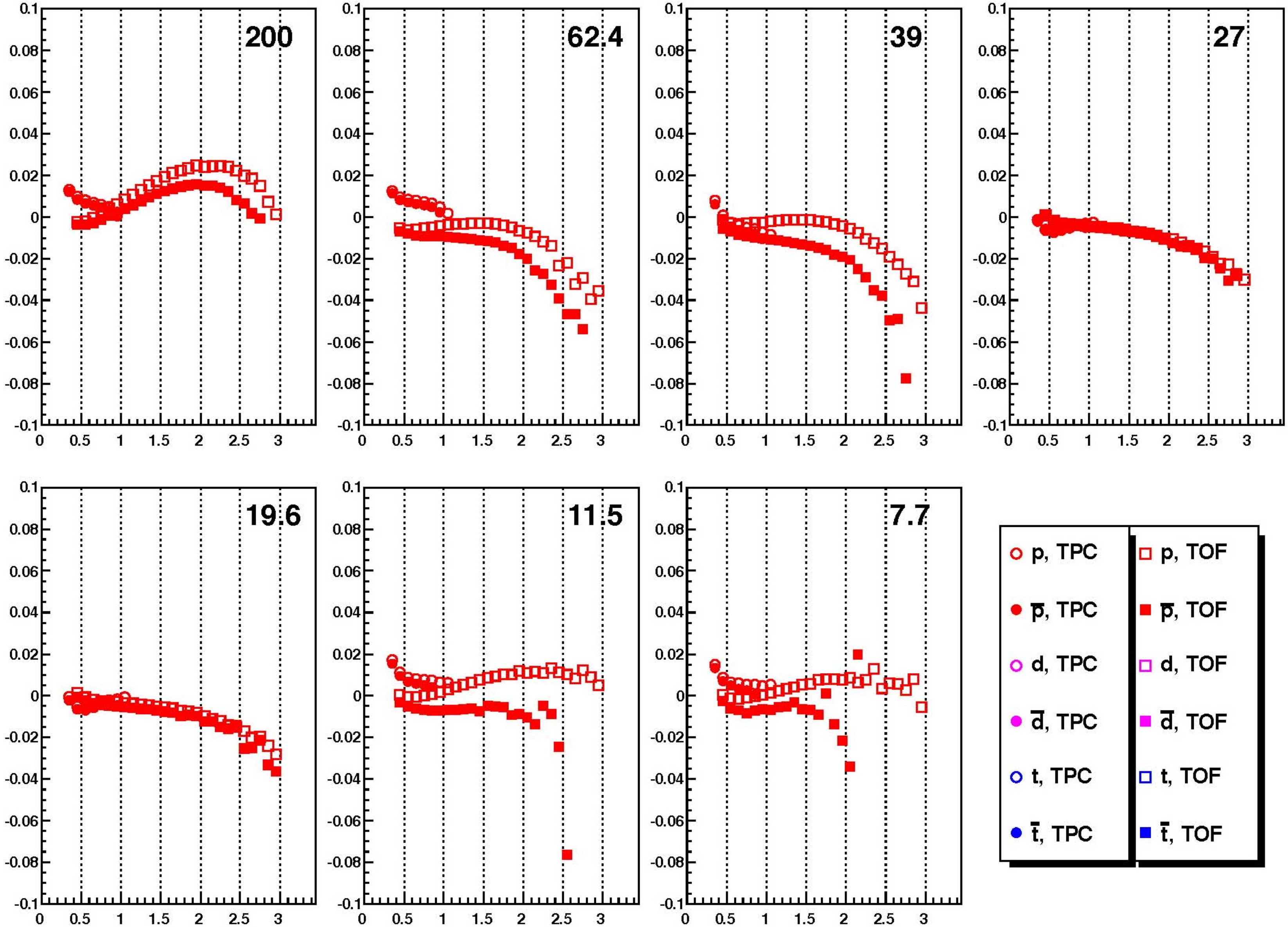
p, d, t…. here -0.1<y<0.1, minbias…. each frame is a 0.1 GeV-wide $P_T$ bin



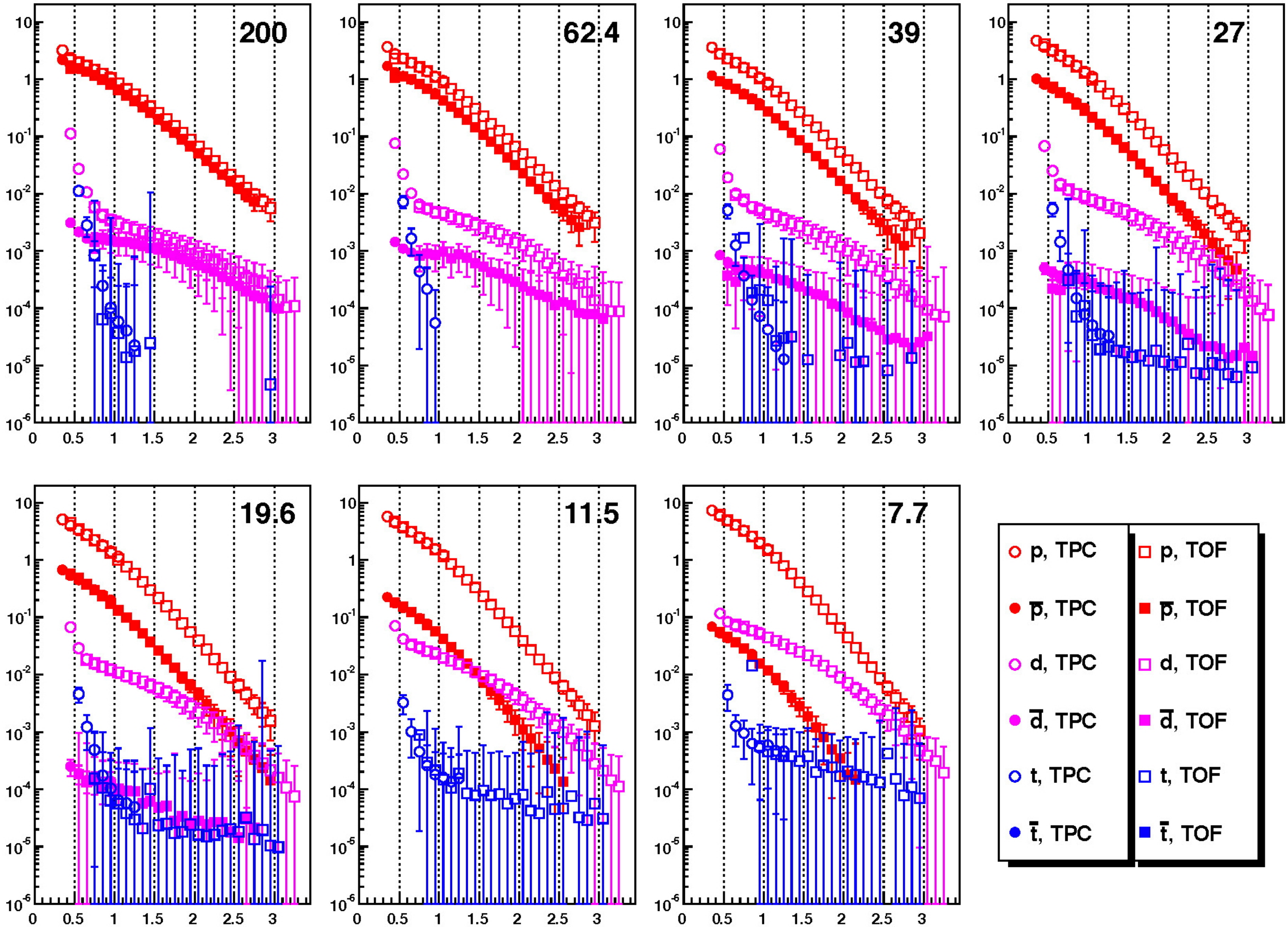
Allowed $P_T$ ranges carefully set for pos/neg, TPC/TOF, for each of 7 root-s values

# Interesting trends from the resulting fit parameters (protons)

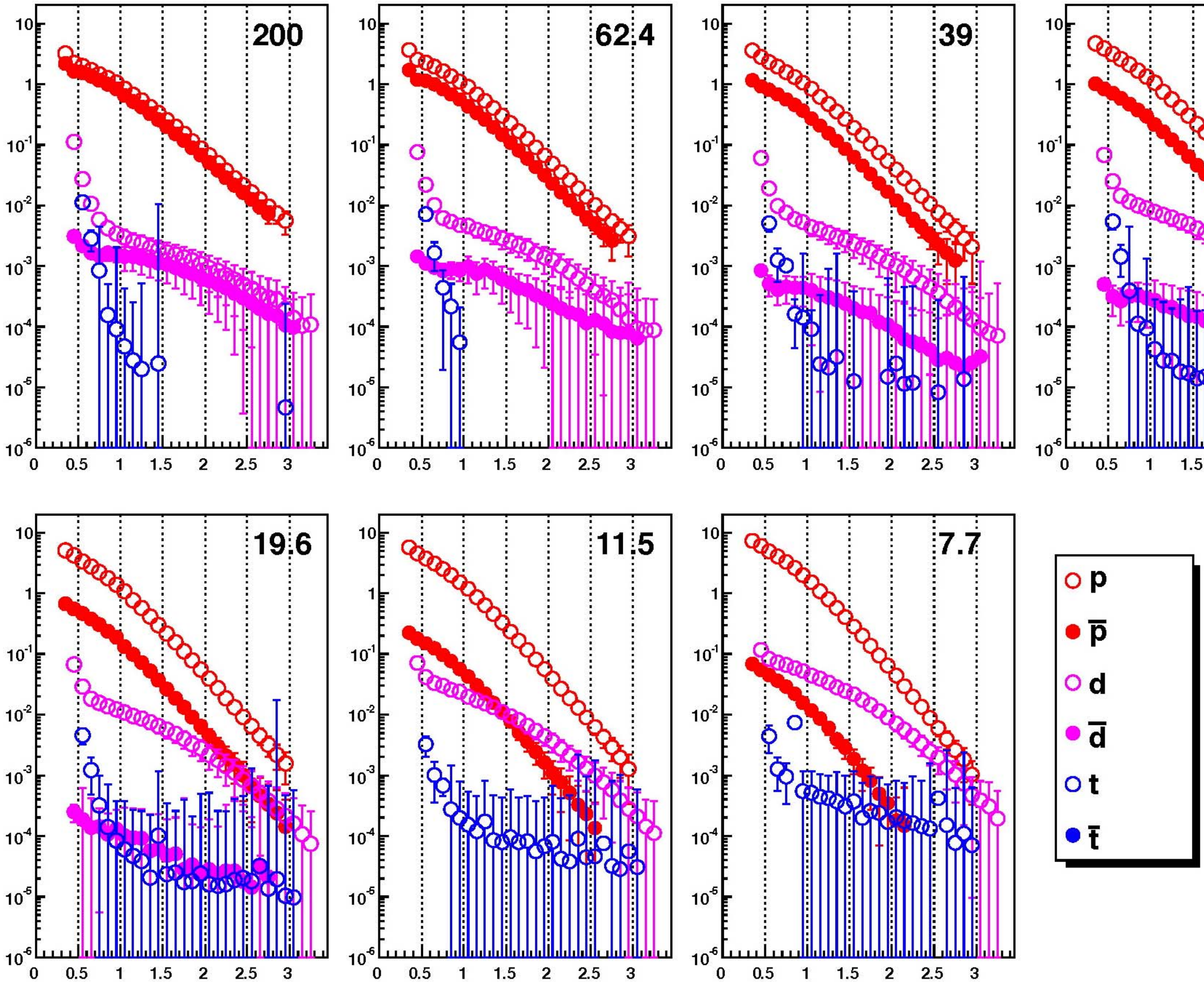
avg Z (TPC), & avg $M^2$-$M_0^2$ (TOF) vs $P_T$ for protons…



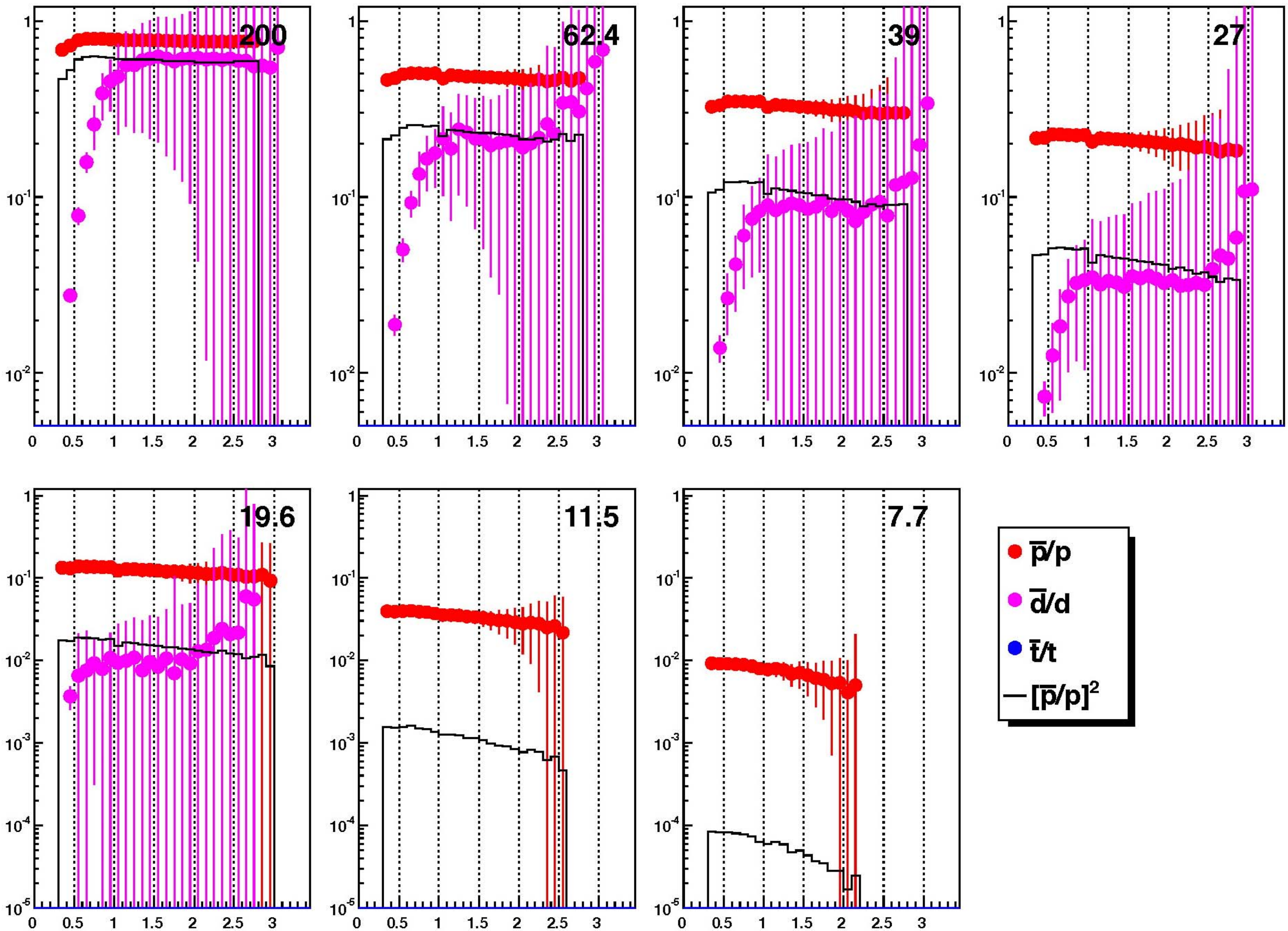
# Cross-sections vs $P_T$, $|y|<0.1$, min-bias



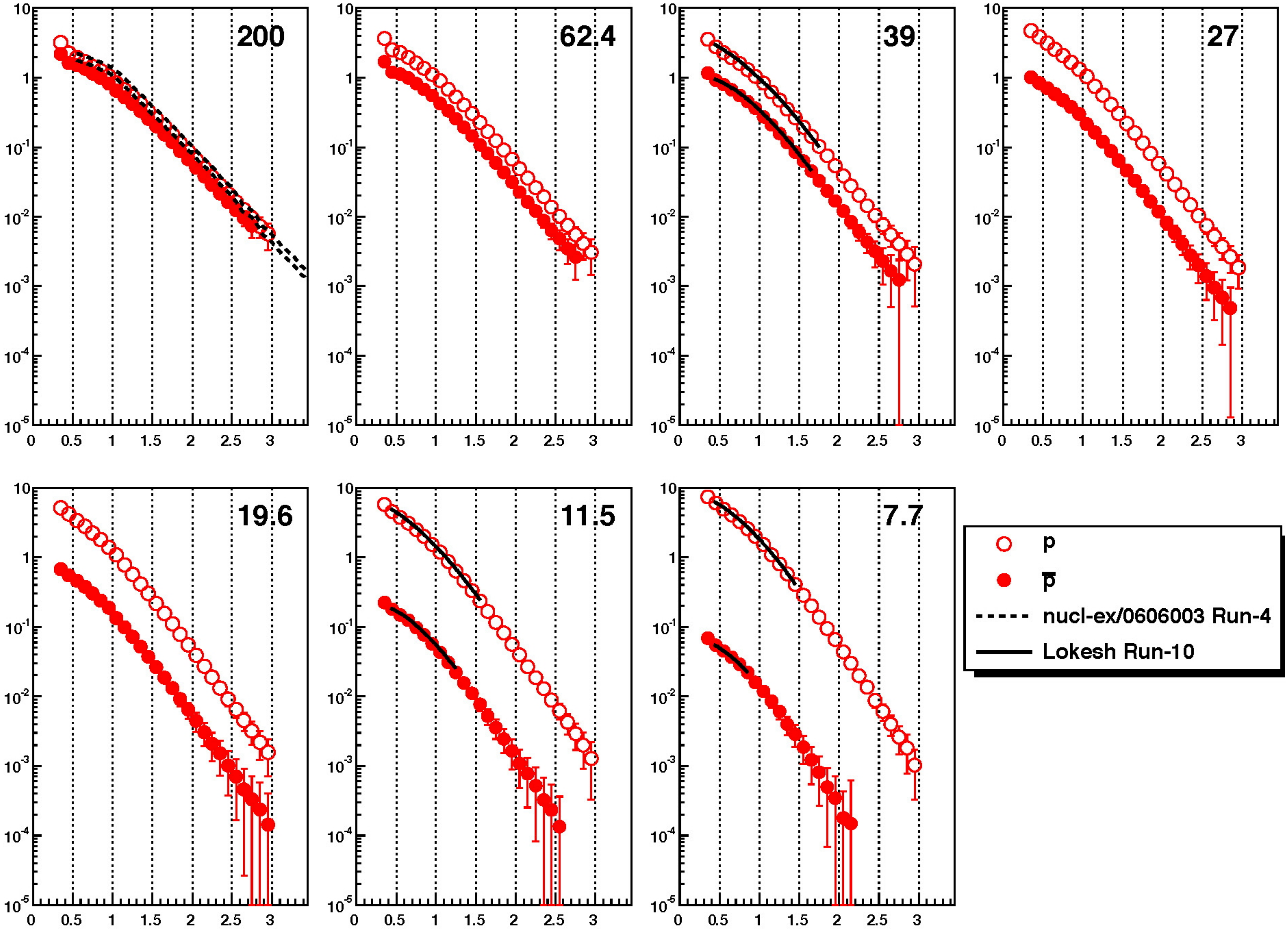
# Final cross-sections vs $P_T$, |y|<0.1, min-bias



# pbar/p, dbar/d, and (pbar/p)$^2$ vs $P_T$, |y|<0.1, min-bias



# Comparison of my (anti)protons to Lokesh's (anti)protons



# QM2012 Poster Abstract

http://www.star.bnl.gov/HyperNews-star/protected/get/startalks/2130.html

Light (anti)nucleus production in $\sqrt{\rm s_{\rm NN}}$$=$7.7-200 GeV Au$+$Au collisions in the STAR Experiment

W.J. Llope for the STAR Collaboration

In the dense and high-temperature systems formed in relativistic heavy-ion collisions, final-state composites - light nuclei and antinuclei - are formed close to the freeze-out hypersurface. Their spectra, compared to those of the constituent (anti)nucleons, can be described by picturing the formation process as the coalescence of a number of nucleons that are close to each other in phase space. This makes the composite spectra sensitive to the distribution of the constituent nucleons in phase space. It also implies a sensitivity of the spectra to the local densities and flow velocities of the source. In the coalescence picture, specific ratios of these spectra provide information on the baryon densities and homogeneity volumes. The STAR experiment has collected data from Au$+$Au collisions at seven beam energies, $\sqrt{\rm s_{\rm NN}}$, ranging from 7.7 to 200 GeV. The spectra for (anti)protons, (anti)deuterons, and (anti) tritons at mid-rapidity, and the source information inferred from these spectra, will be presented and compared to several dynamic coalescence models.

# Summary

Embedding results pretty much in hand (I want to see Kolja's p&pbar jobs though)
Feeddown simulations continuing (factor ~3 increase in stats since Kolkata mtg)
New PID approach avoids contamination and merged tracks
Comparisons of my protons to Lokesh's looks *much* better, basically dead-on

Just need to run the PID fitting code over the remaining (already-available) TH3D's
- up to 16 centrality bins, all 5 rapidity bins
- *vs* $P_T/A$ (towards $B_2$ then $R_G$), & *vs* $M_T/A$ (towards baryon density)
- apply newest feed-down corrections (much better statistics compared to Kolkata)
- compare to huge samples of dynamic coalescence results (see previous talks)

The resulting corrected cross-sections lead to
$B_A$ ratios and source radii, comparison to pp HBT ($\Phi_{RP}$-dependence?)
d/p ratios and baryon densities…
source density profiles, degree of equilibration, …

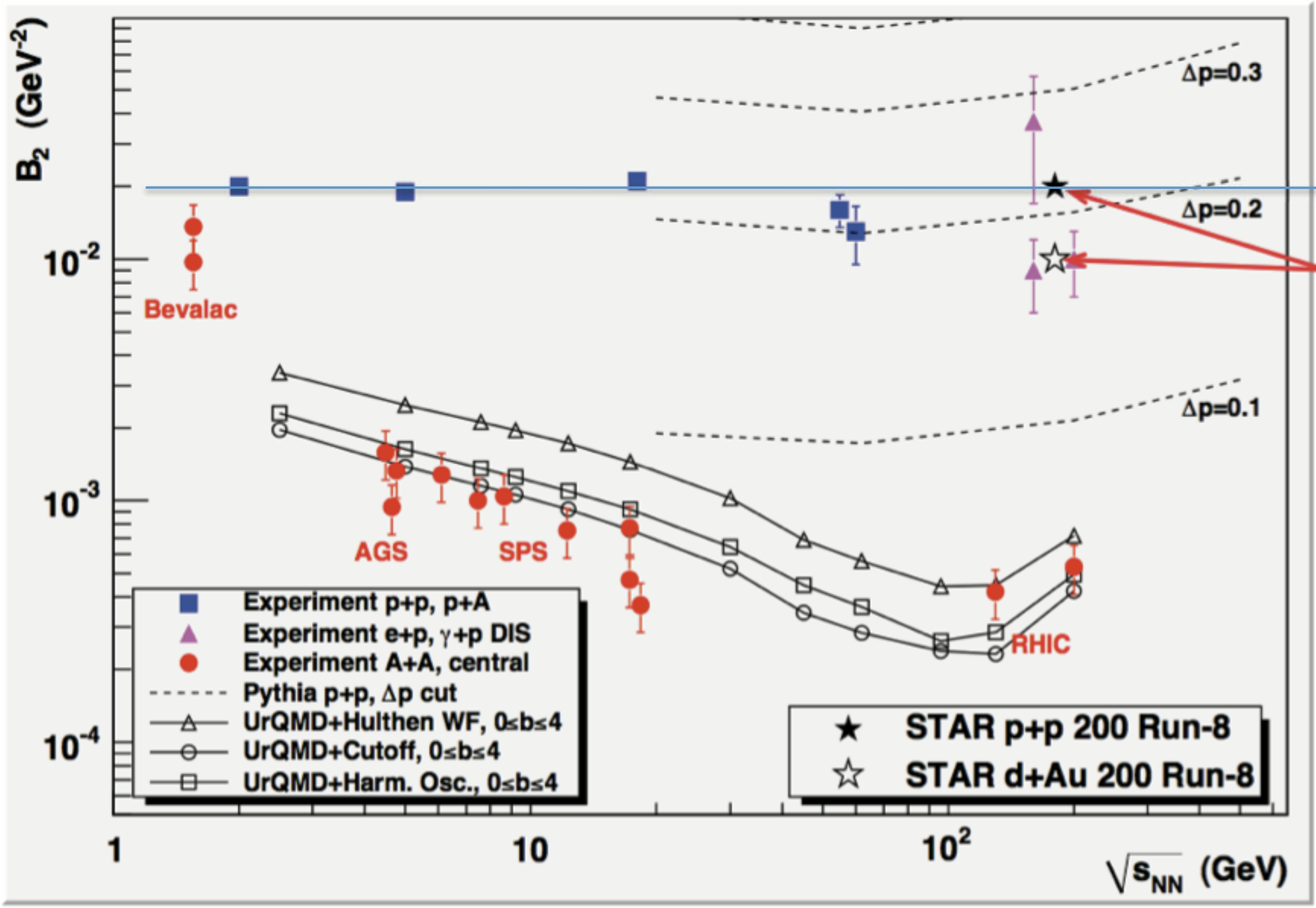
Getting very close now…

widest & most detailed vs root-s measurement in a single & wide acceptance…
first measurement of spectra & $B_A$ for antinuclei at low end of SPS range…
first observation of dependence of $B_2$ on jet energy in p+p…
direct comparisons to source information at FO from HBT…

# backup

# World's Data on $B_2$ in various entrance channels

Comparisons to world's data.....




$B_2 \sim 0.02$

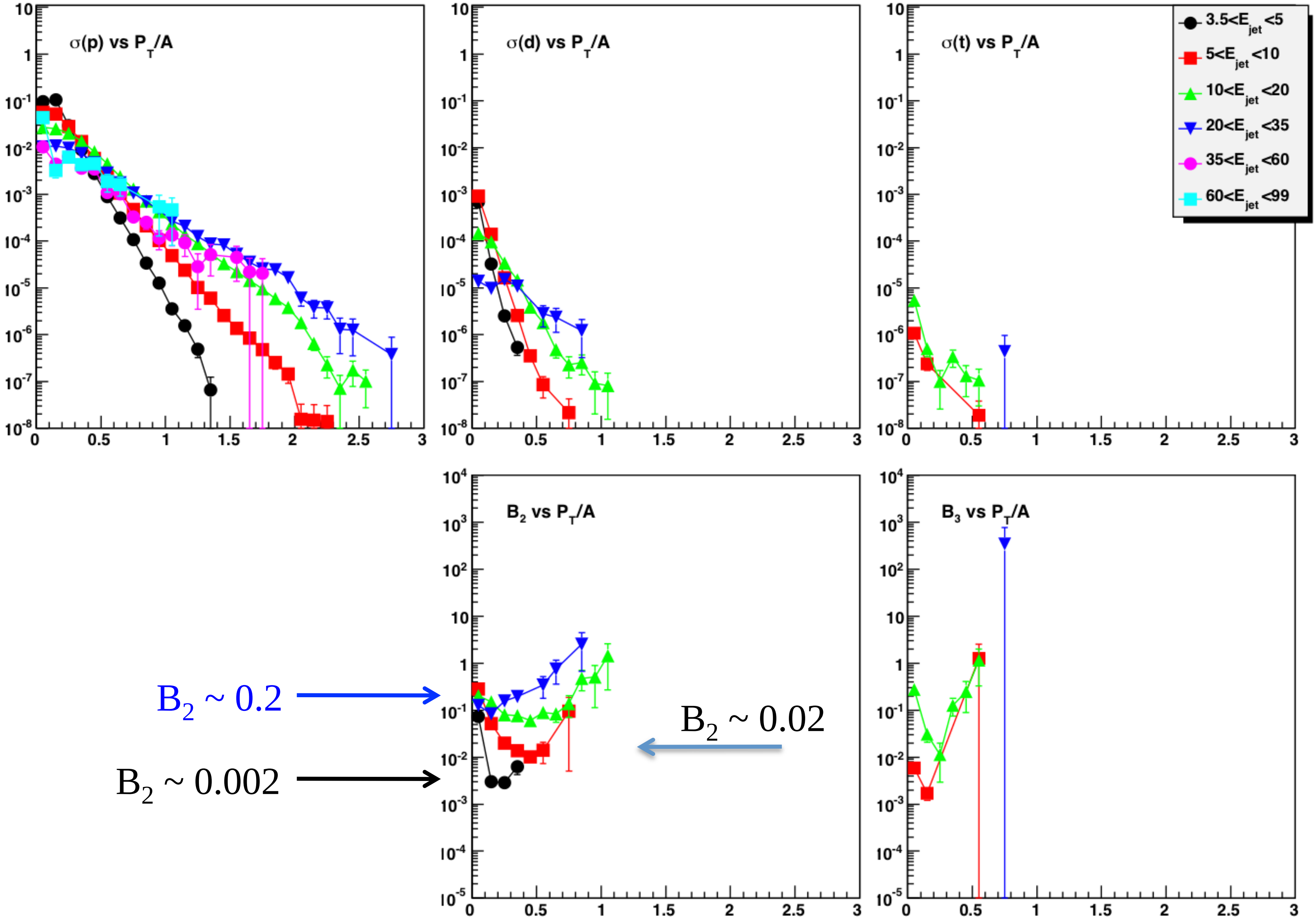
**my results (uncorrected)**

but PT lower limit to avoid inefficiency

These are the run-8 points, p+p will be superceded by run-9 (lots of TOF)

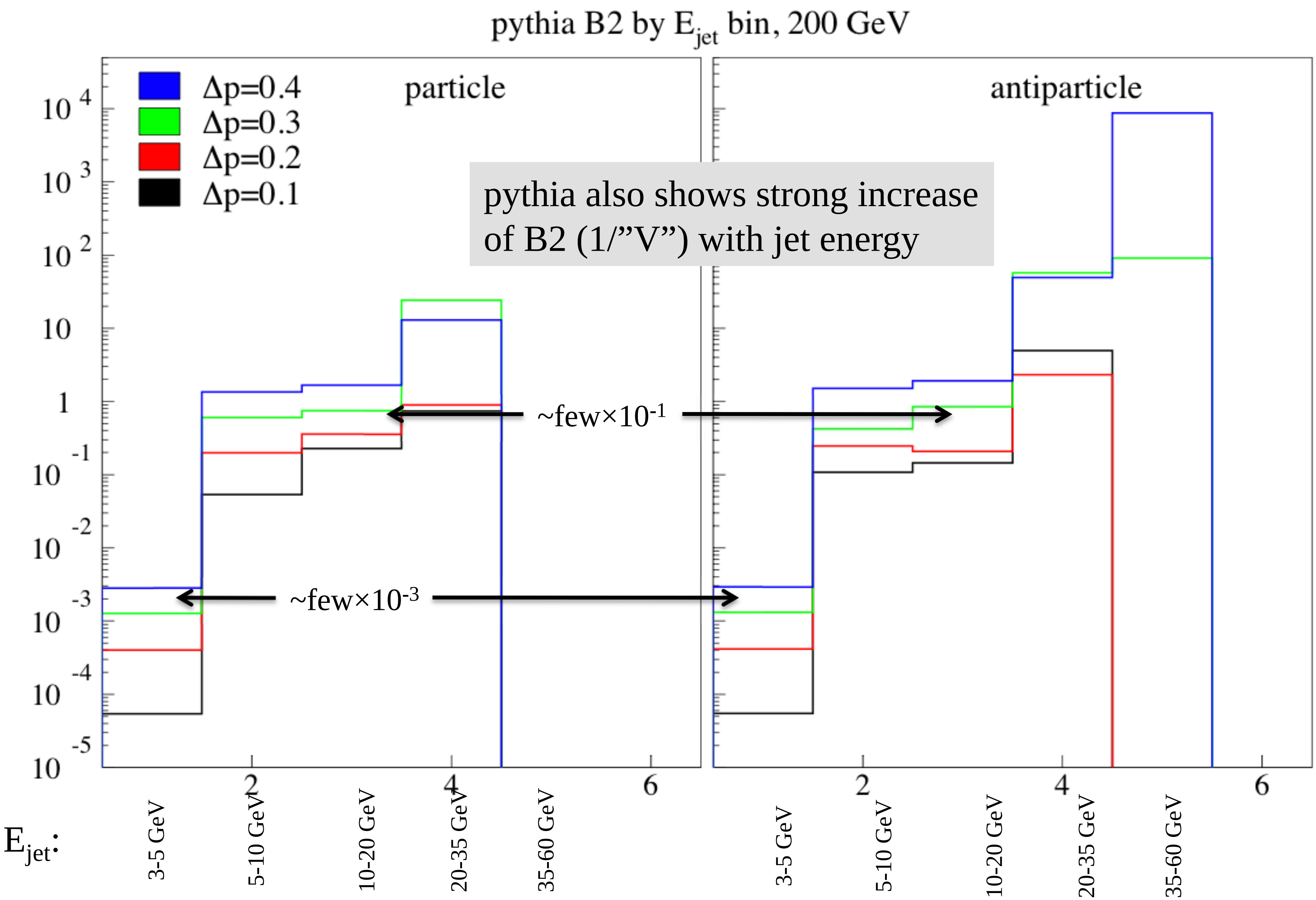
| Summary* so far: | Experiment | Coalescence Picture: | Pythia+Δp |
|---|---|---|---|
| p+p, 200 GeV, Run-8: | $B_2 = 0.02$ GeV$^2$ | R ~ 3.3 fm, $p_o$ ~ 180 MeV | Δp ~ 210 MeV |
| d+Au, 200 GeV, Run-8: | $B_2 = 0.01$ GeV$^2$ | R ~ 4.2 fm, $p_o$ ~ 150 MeV | Δp ~ 180 MeV |

# Dependence of $B_2$ for p,d in Jets vs Jet energy

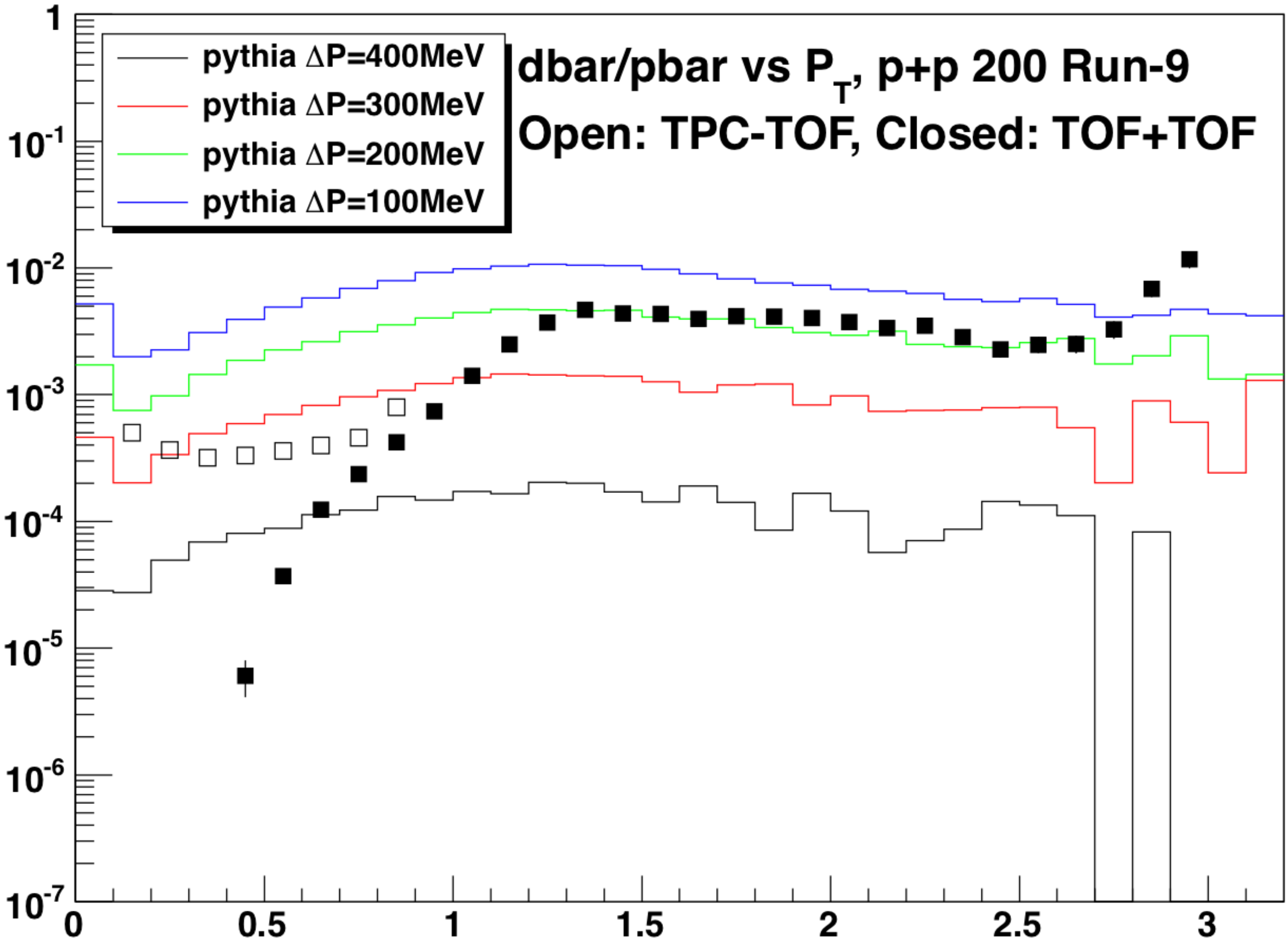



strong increase in $B_2$ (strong decrease in "source volume") with inc. $E_{jet}$

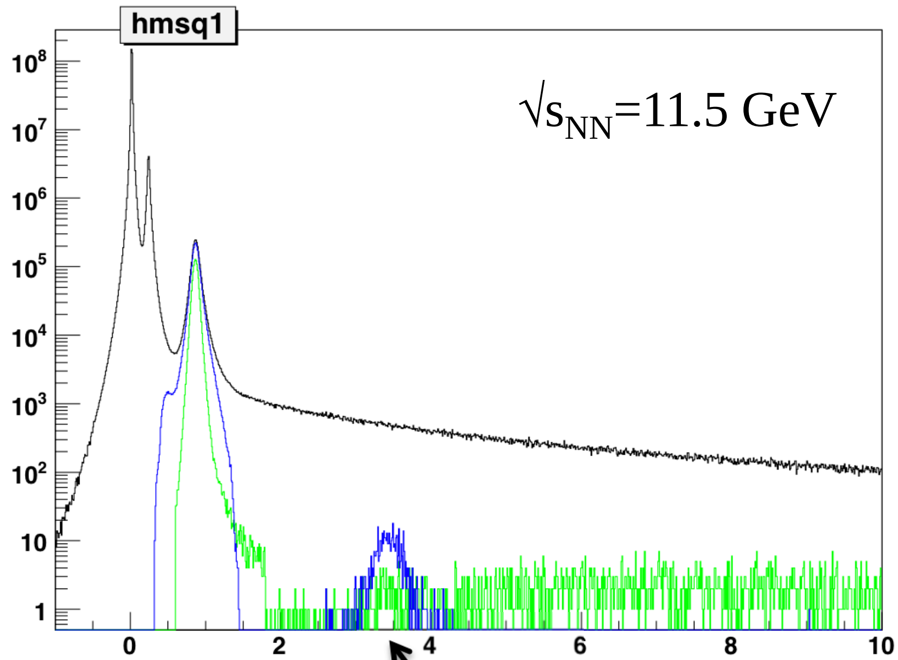
# Dependence of $B_2$ for p,d in Jets vs Jet energy, from Pythia



# $B_2$ from Data and from Dynamic Coalescence on Pythia events

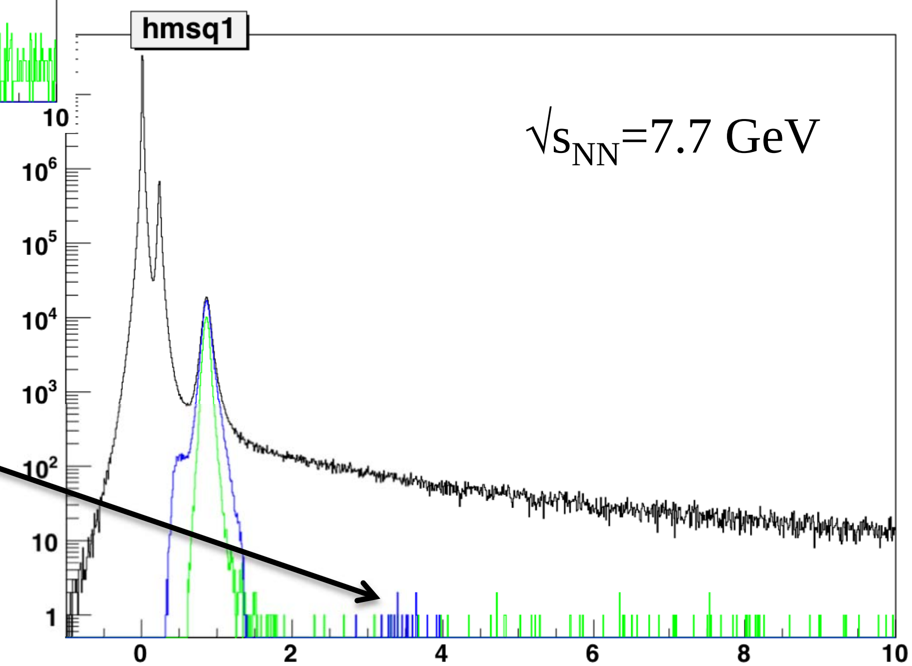


# Antinucleus Production at very low (~SPS) root-s

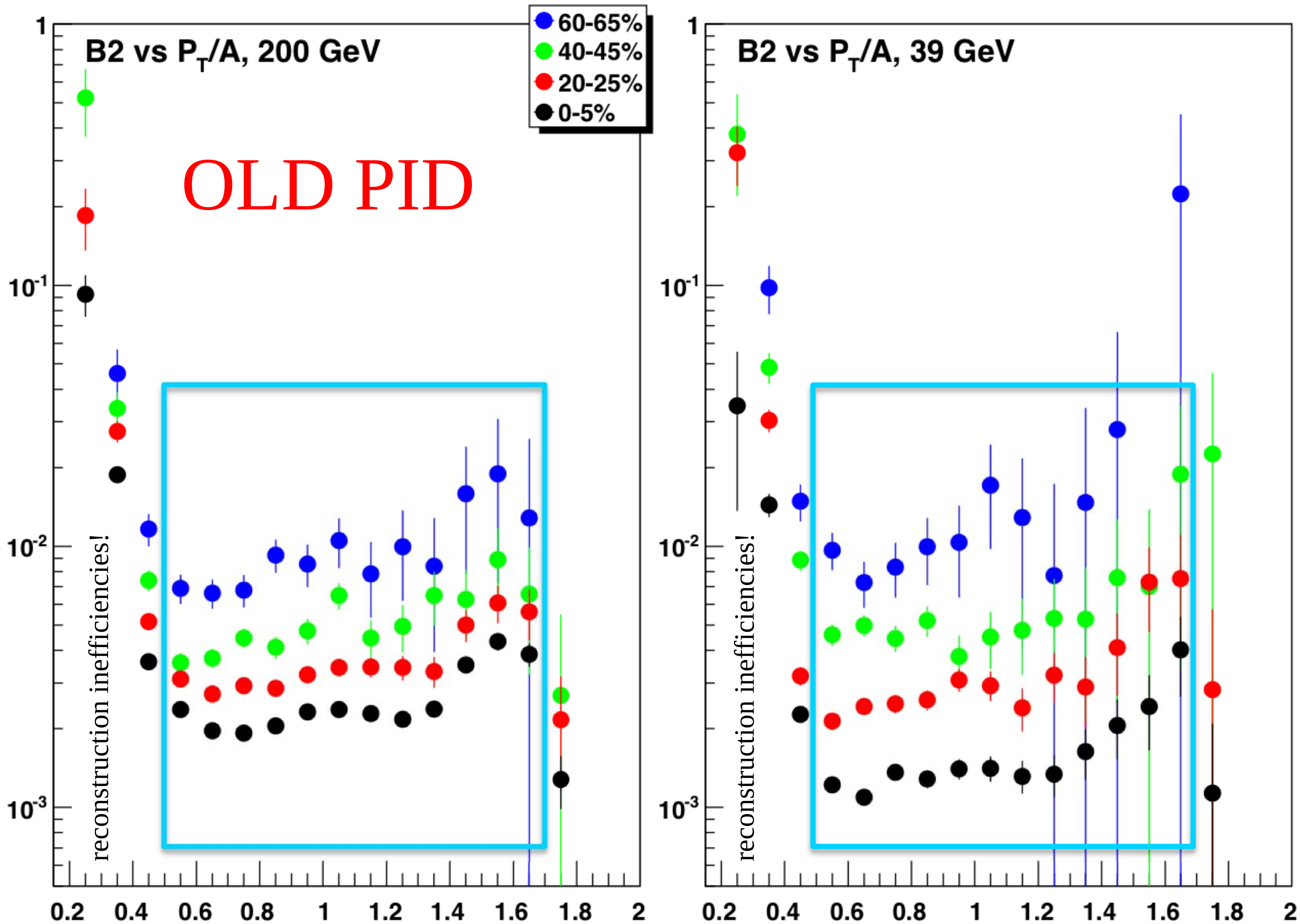



dbar spectra, and dbar/pbar & $B_2$ ratios at these very low root-s values not reported by any of the SPS experiments

dbar!



# $B_2$ vs $P_T/A$ vs centrality

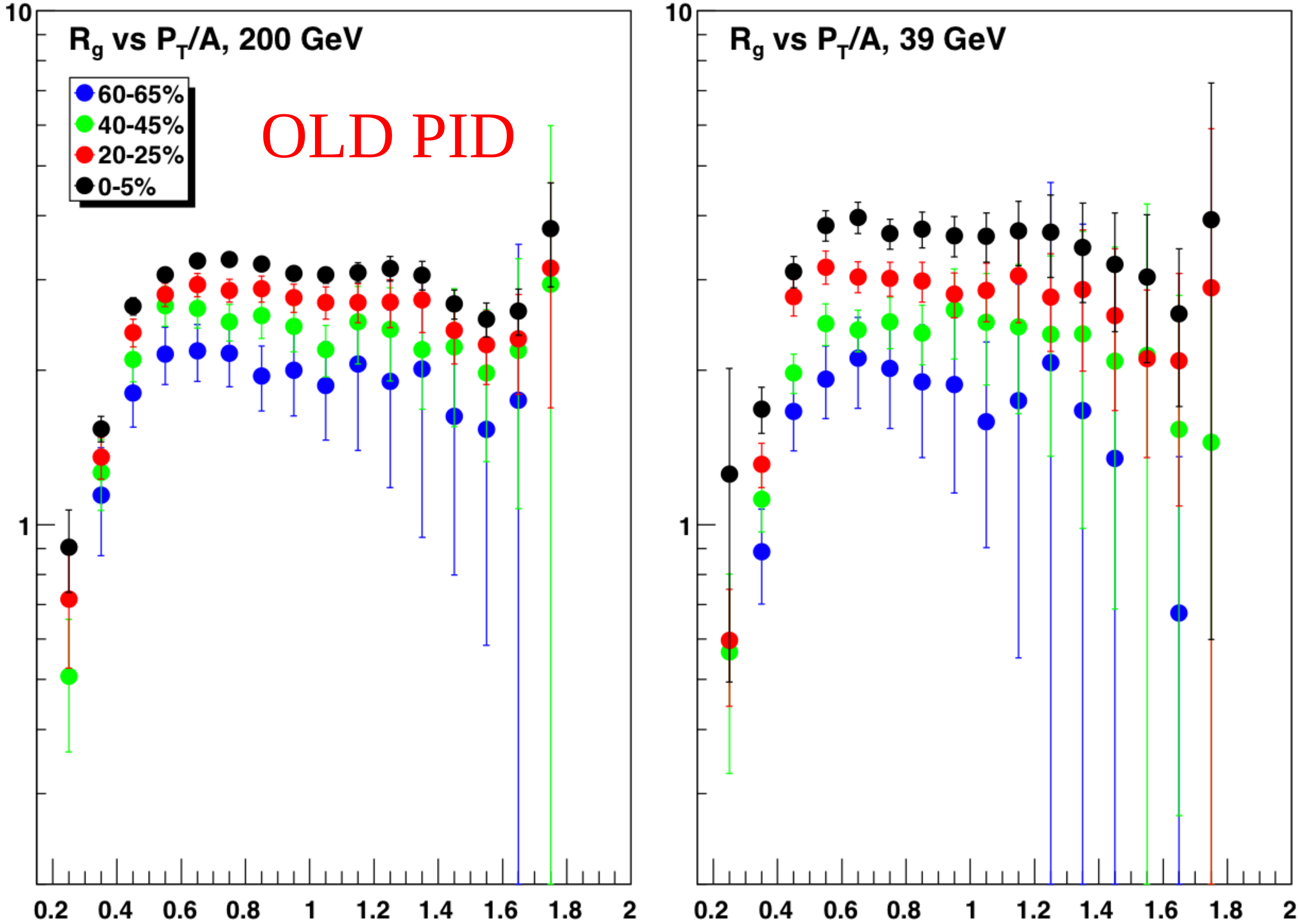



B2 increases ("V" decreases) as collisions get more peripheral

# Source Radius at freezeout from $B_2$ values

hard-sphere $R = 2.2R_G$

conversion of $B_A$ into $R_G$ done via WJL *et al.*, PRC **52**, 2004 (1995).



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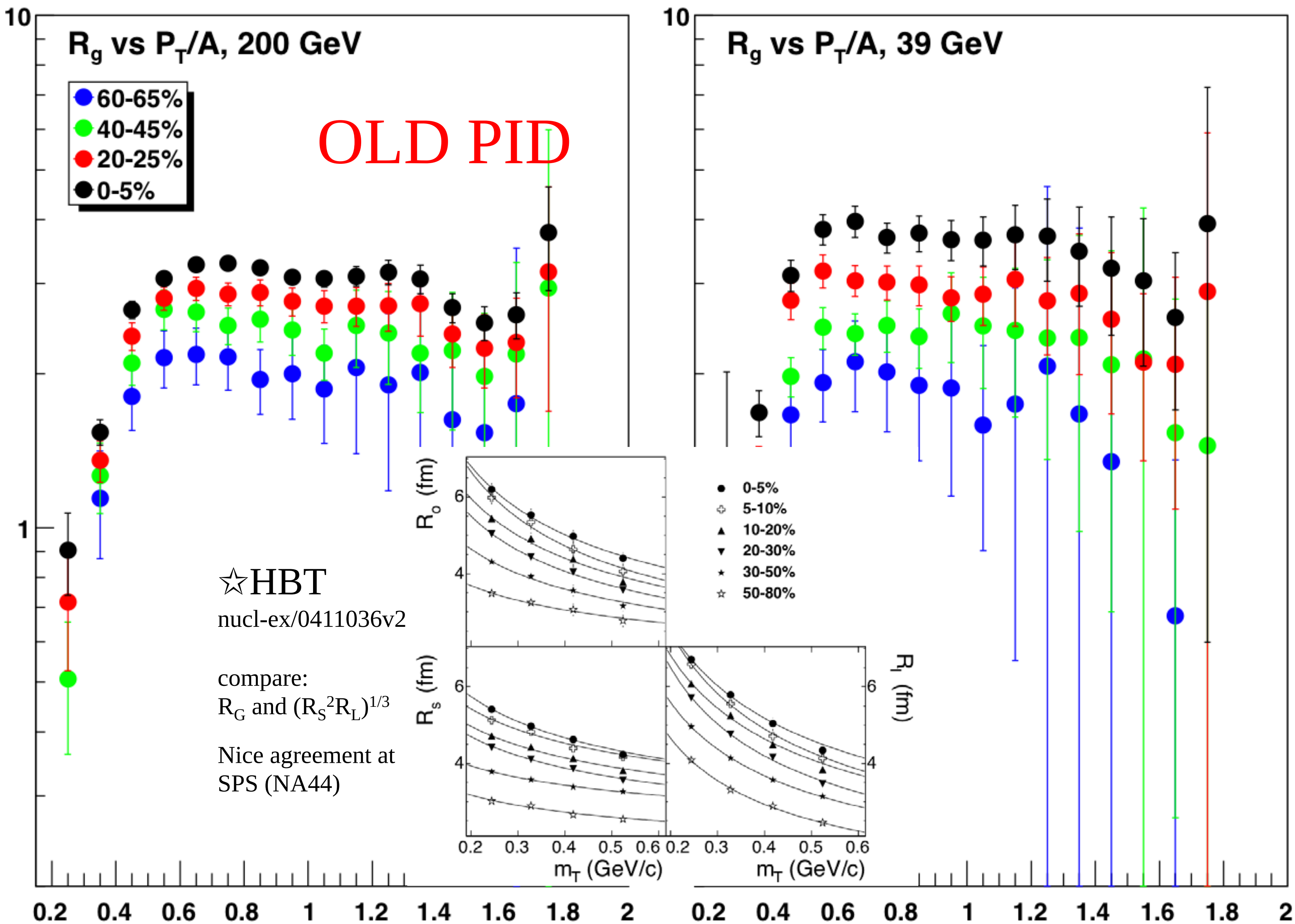
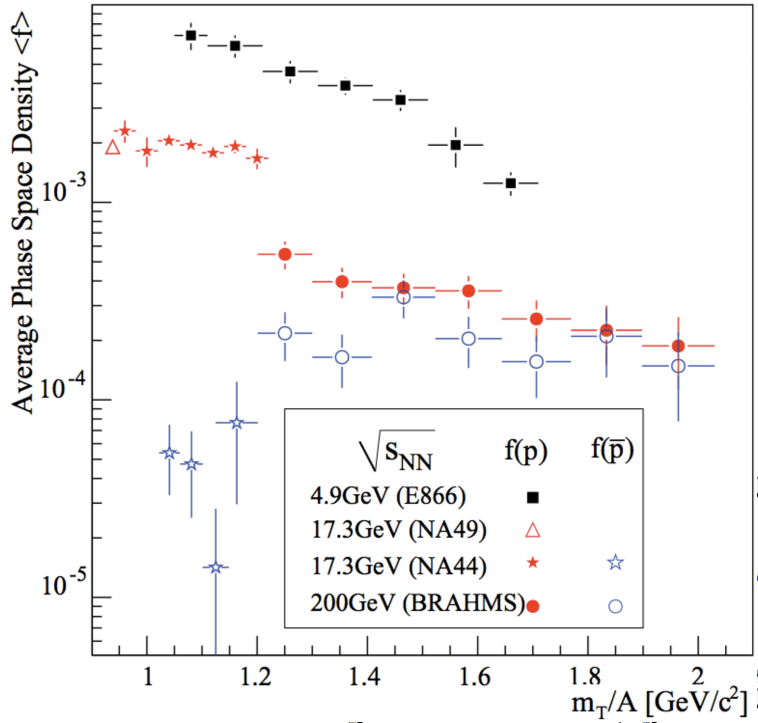


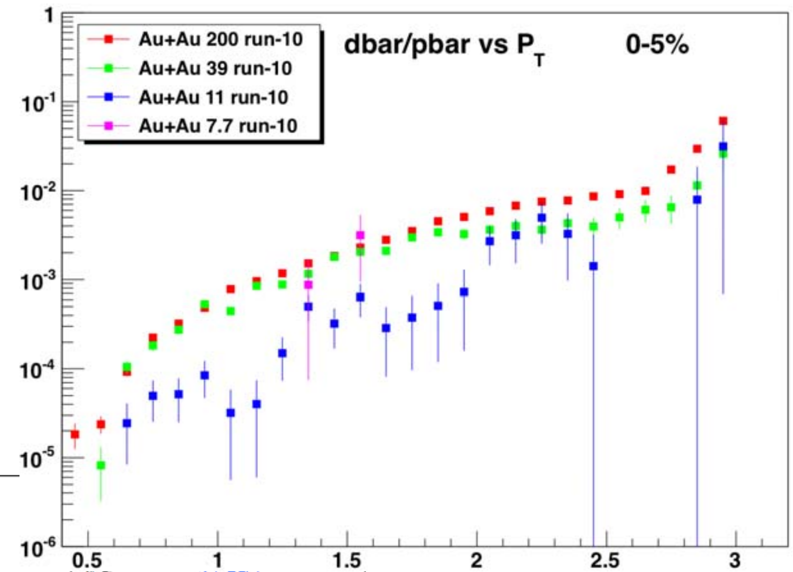

☆HBT
nucl-ex/0411036v2

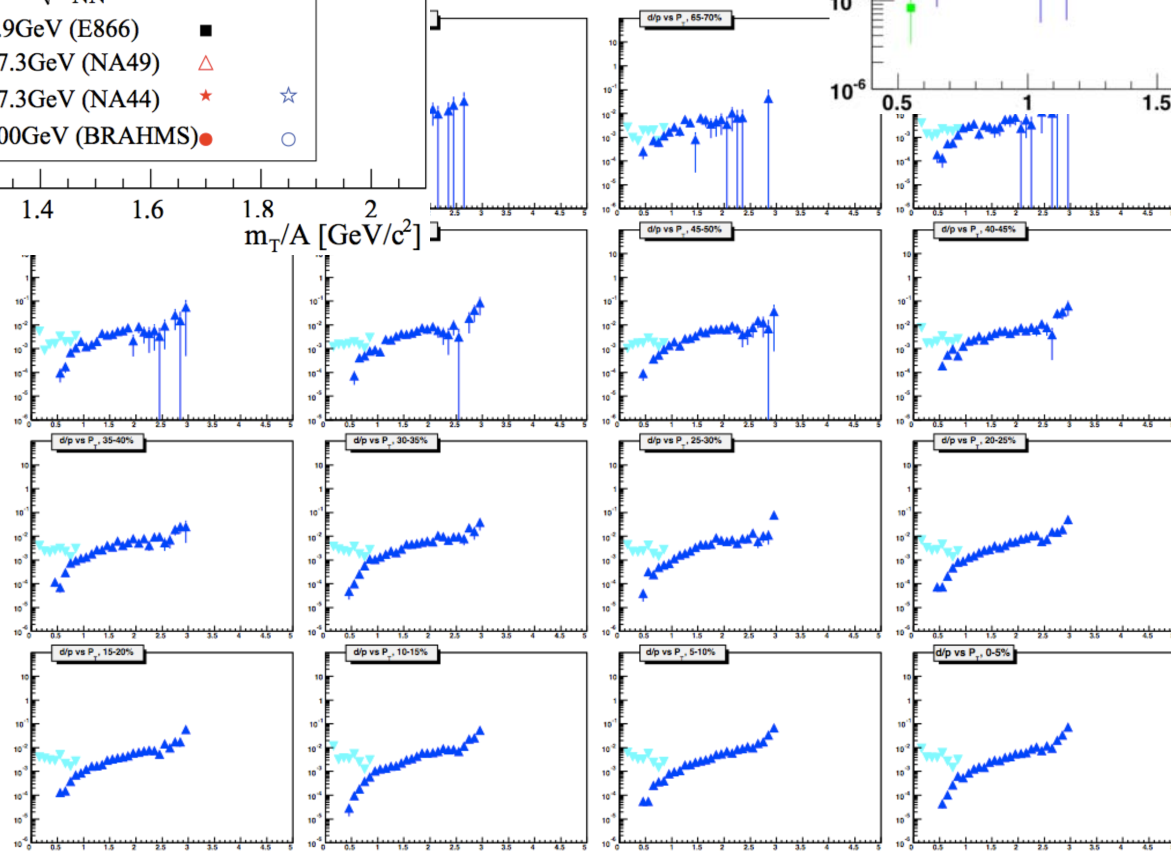
compare:
$R_G$ and $(R_S{}^2R_L)^{1/3}$

Nice agreement at SPS (NA44)

# Baryonic Phase Space Density (d/p with a simple prefactor)

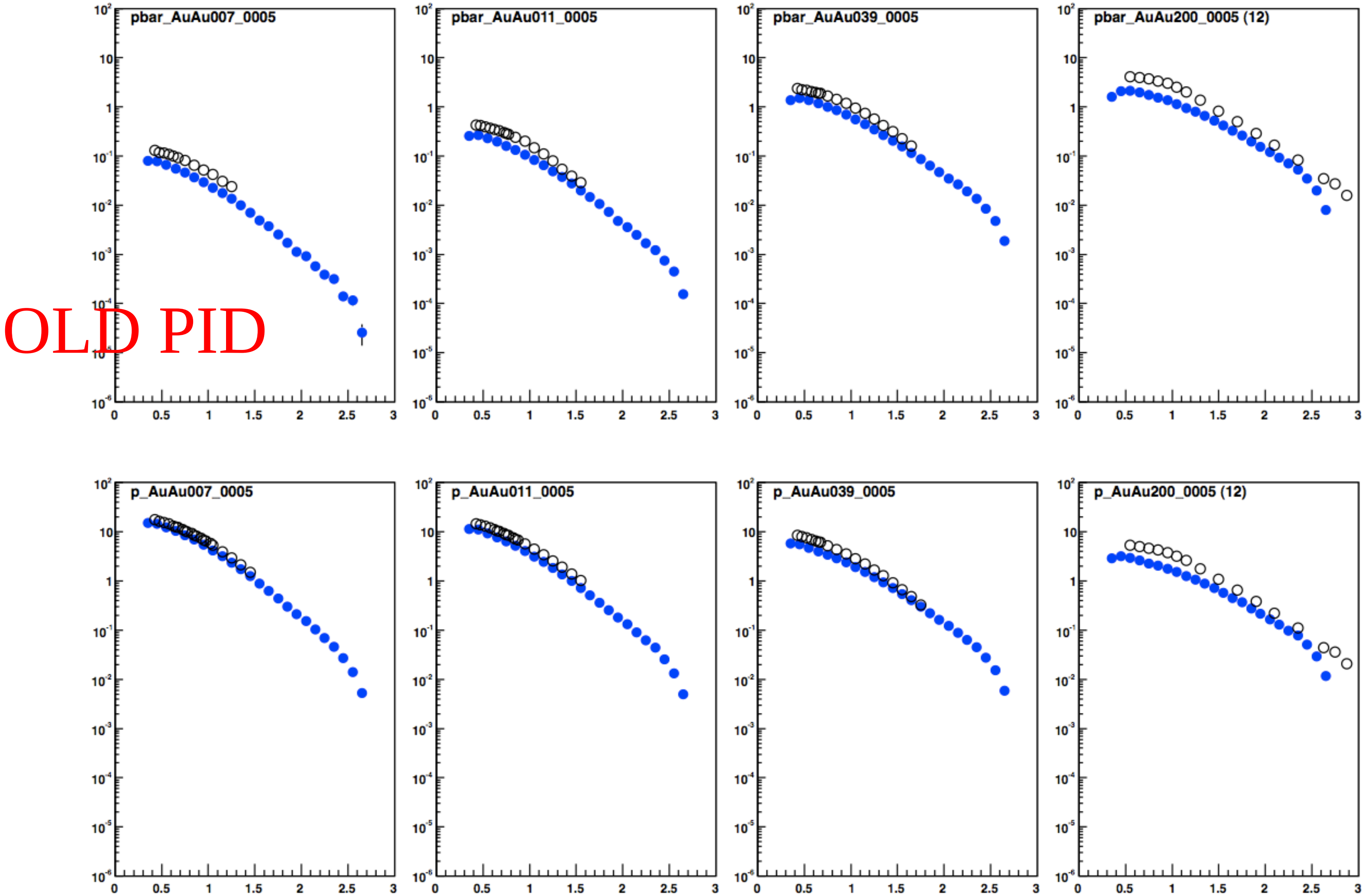


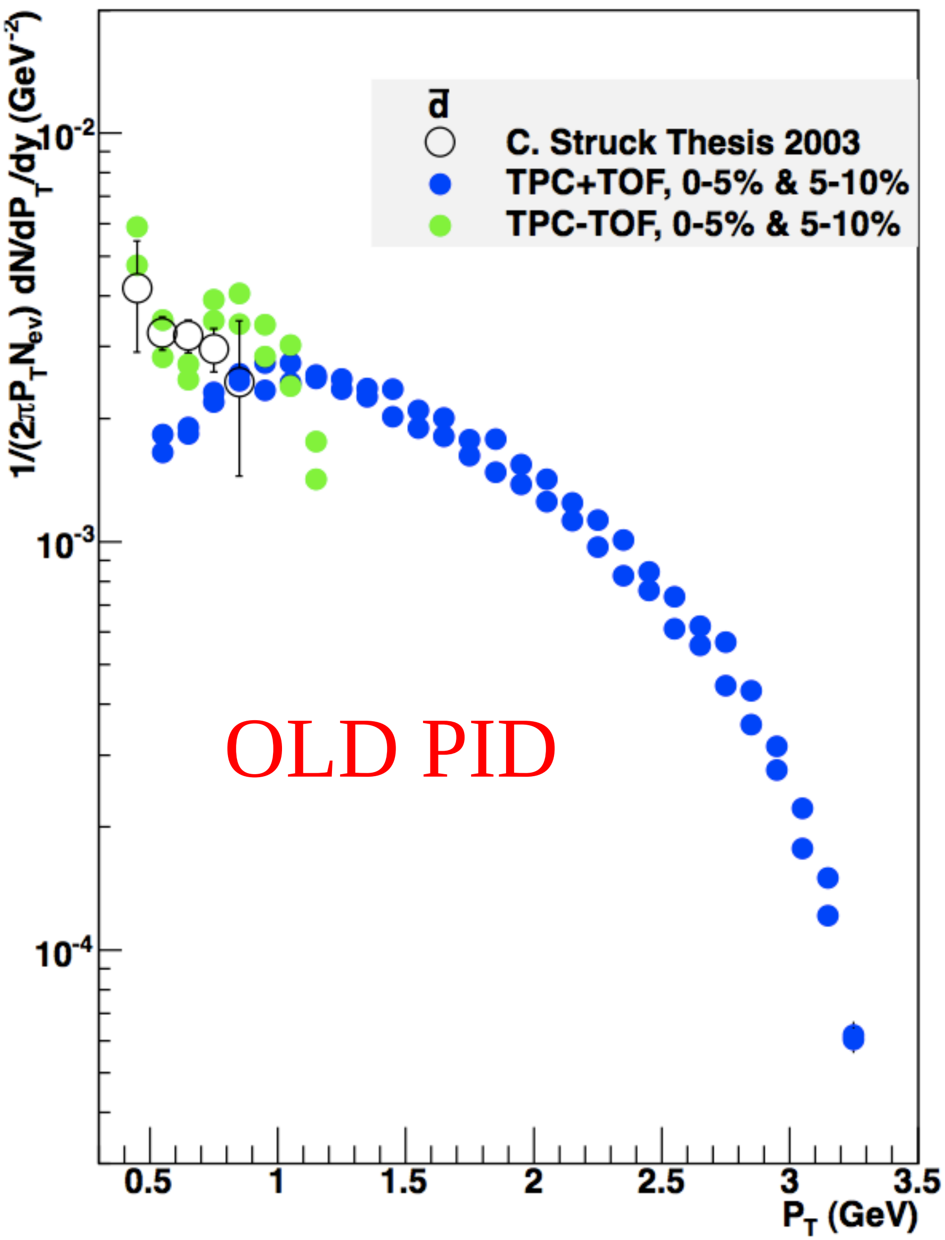
OLD PID

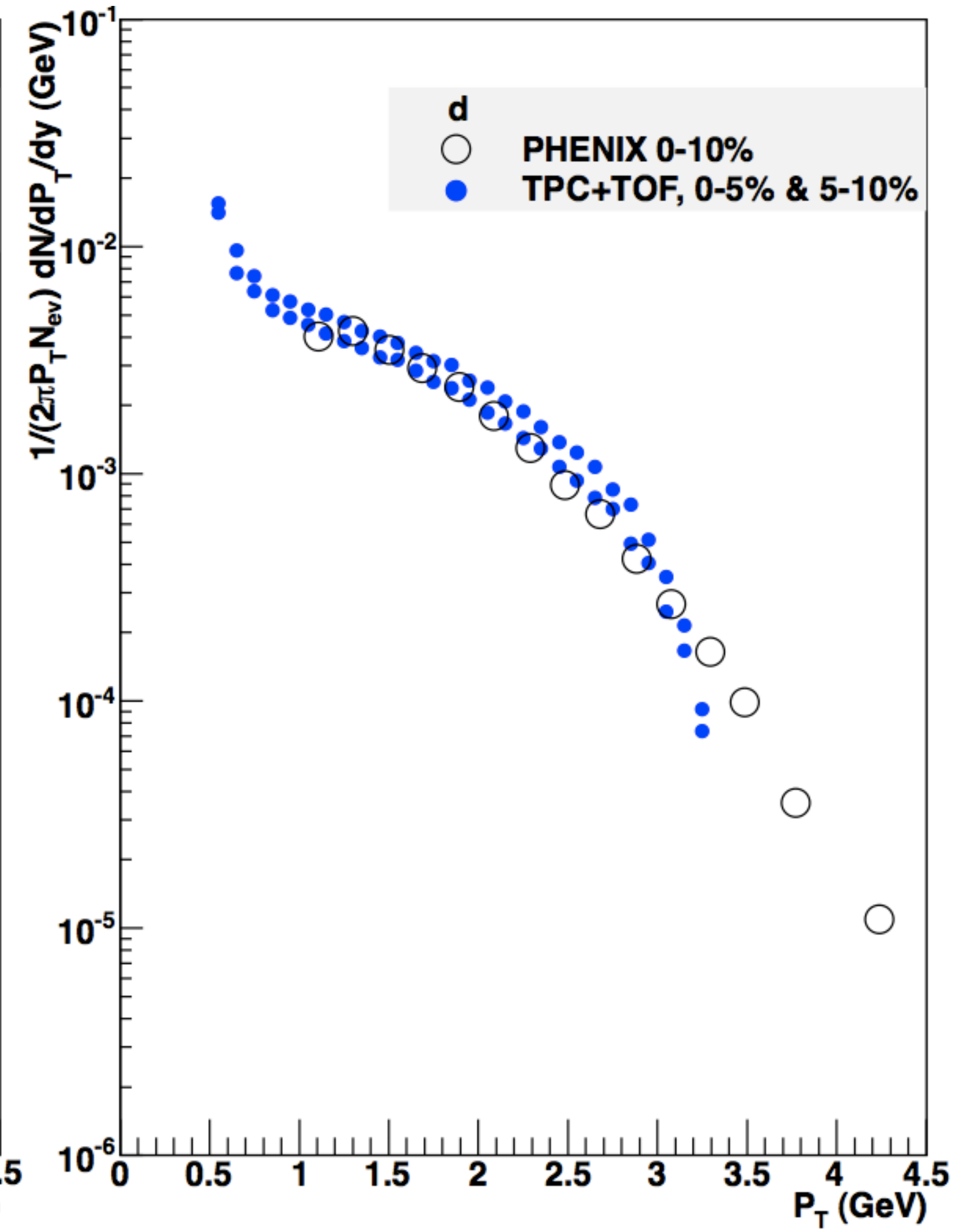
# Comparison to Lokesh's protons



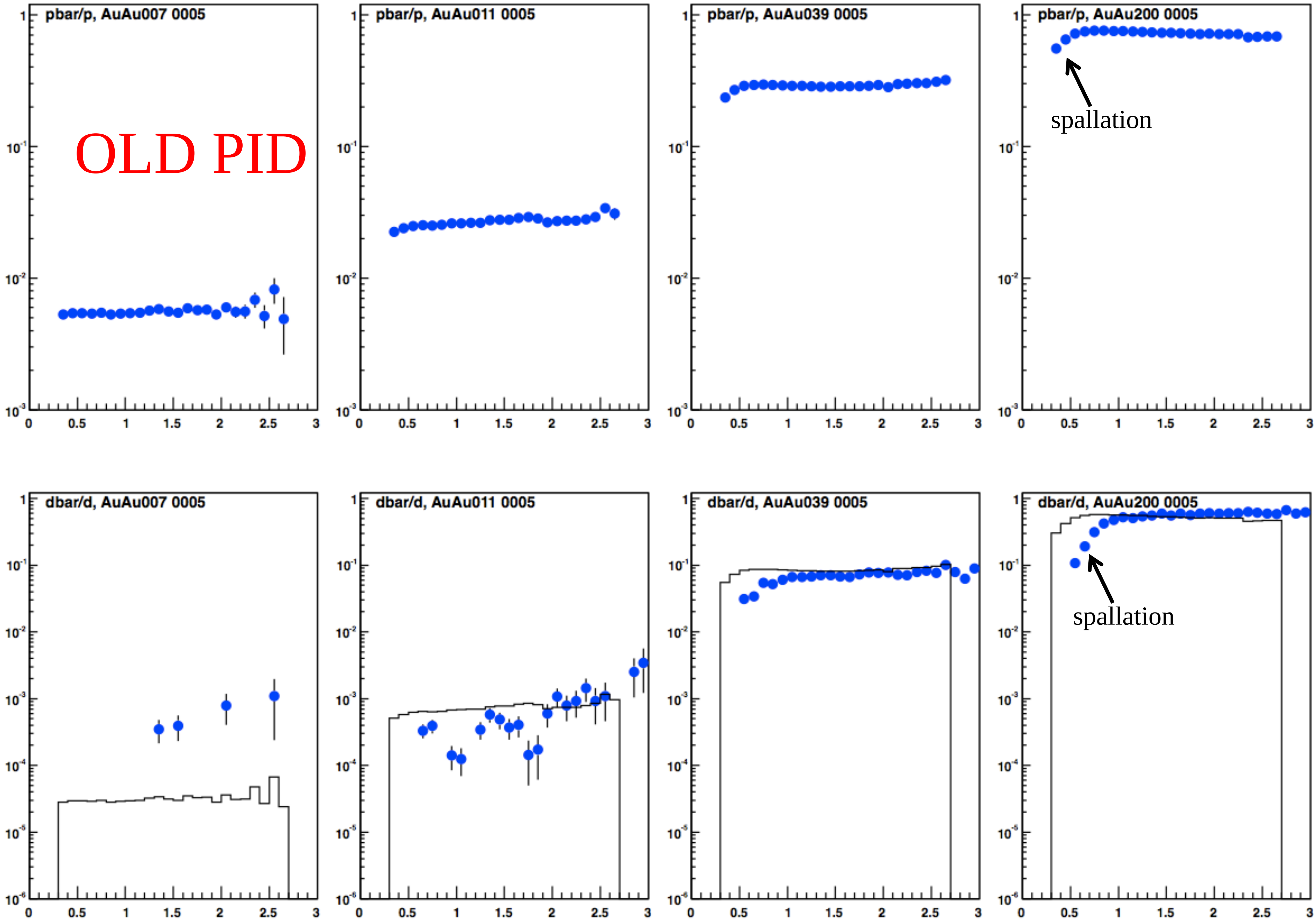

Lokesh's xsecs are not feeddown corrected, mine are.
My FD-uncorrected protons are dead on top of lokesh's p's, my pbar's ~20% less…

# Comparison to published d's and dbar's

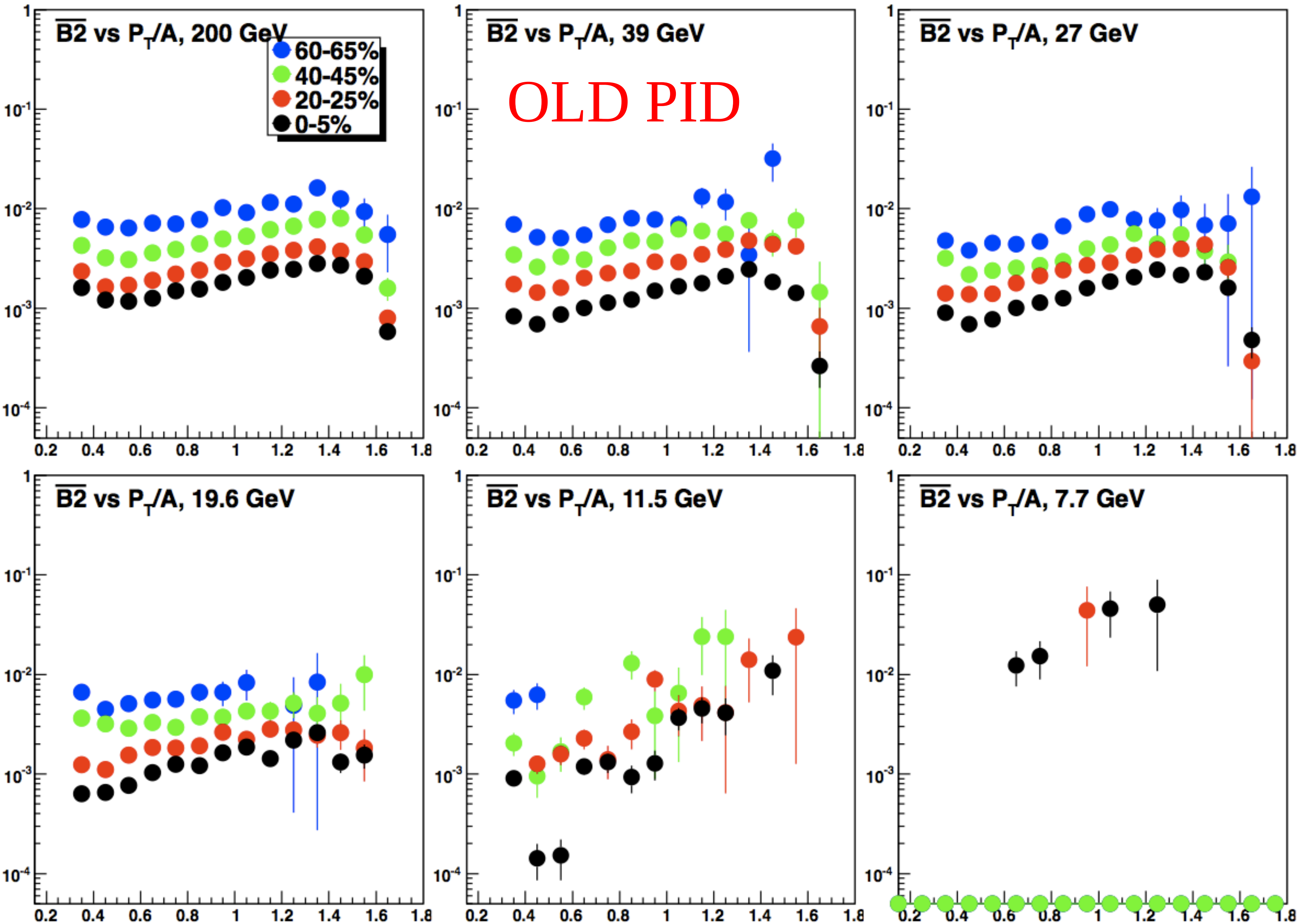


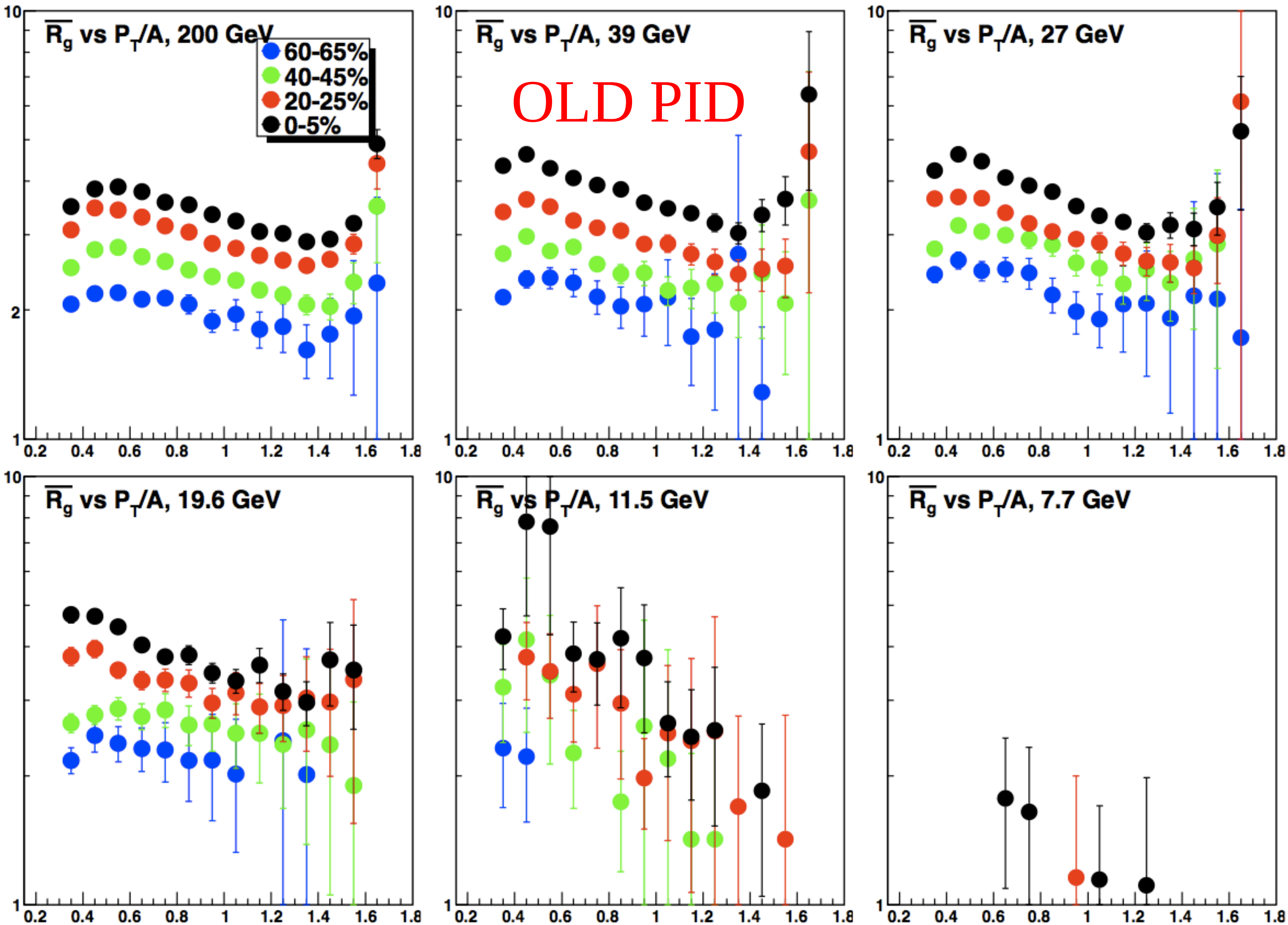
# Ratio checks motivated by coalescence arguments



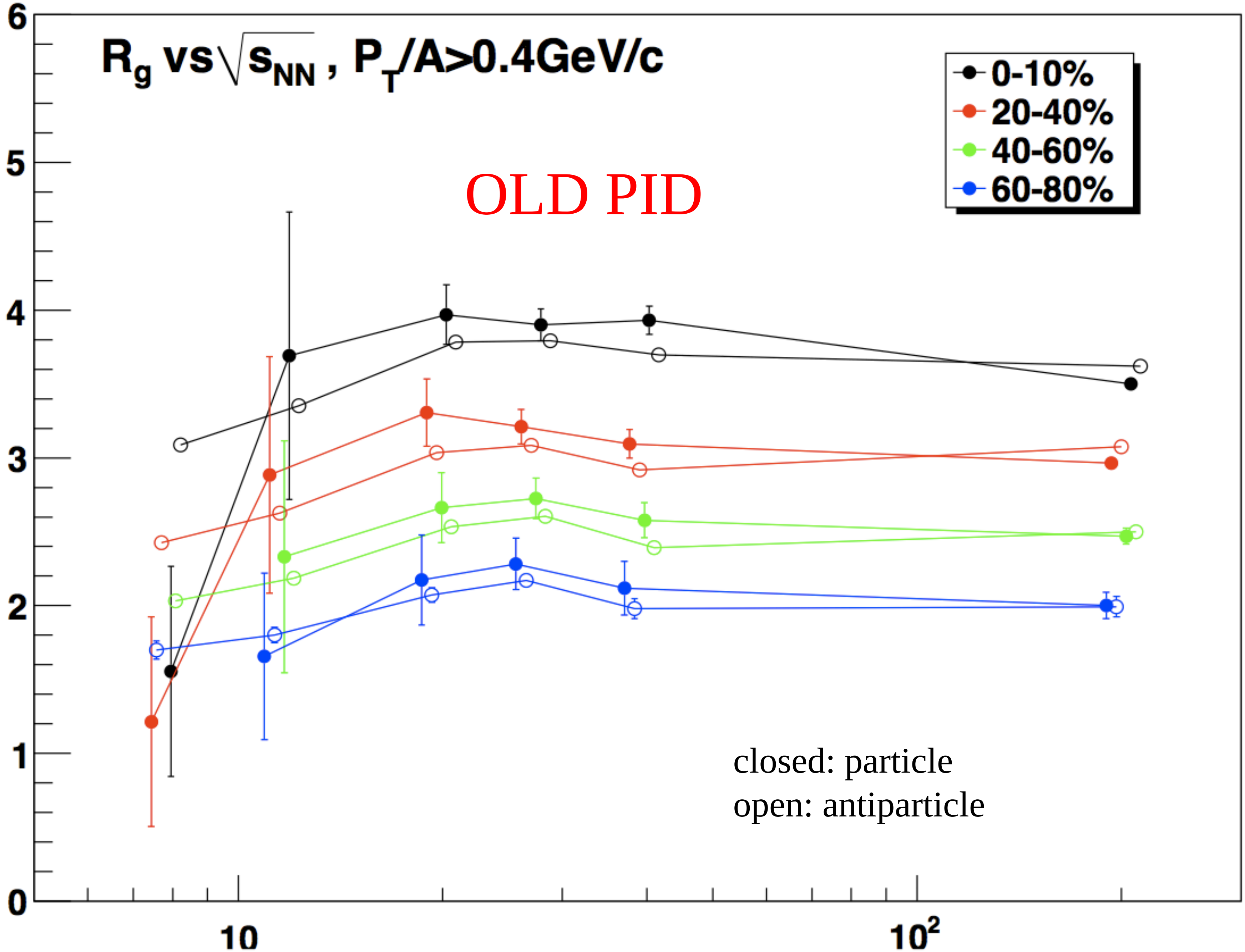
# $B_2$ vs $P_T/A$ by $\sqrt{s_{NN}}$ and centrality



# $R_G$ vs $P_T/A$ by $\sqrt{s_{NN}}$ and centrality



## $R_G$ vs $P_T/A$ by $\sqrt{s_{NN}}$ and centrality



# dbar/pbar vs. $P_T$, comparison to Pythia+coalescence