E917

Stopping and Baryon Density at the AGS

Can we quantify proton rapidity distributions?

DNP- Williamsburg,VA

Oct. 6, 2000

Richard Seto for the E917 Collaboration

Proton distributions – Getting the baryon density

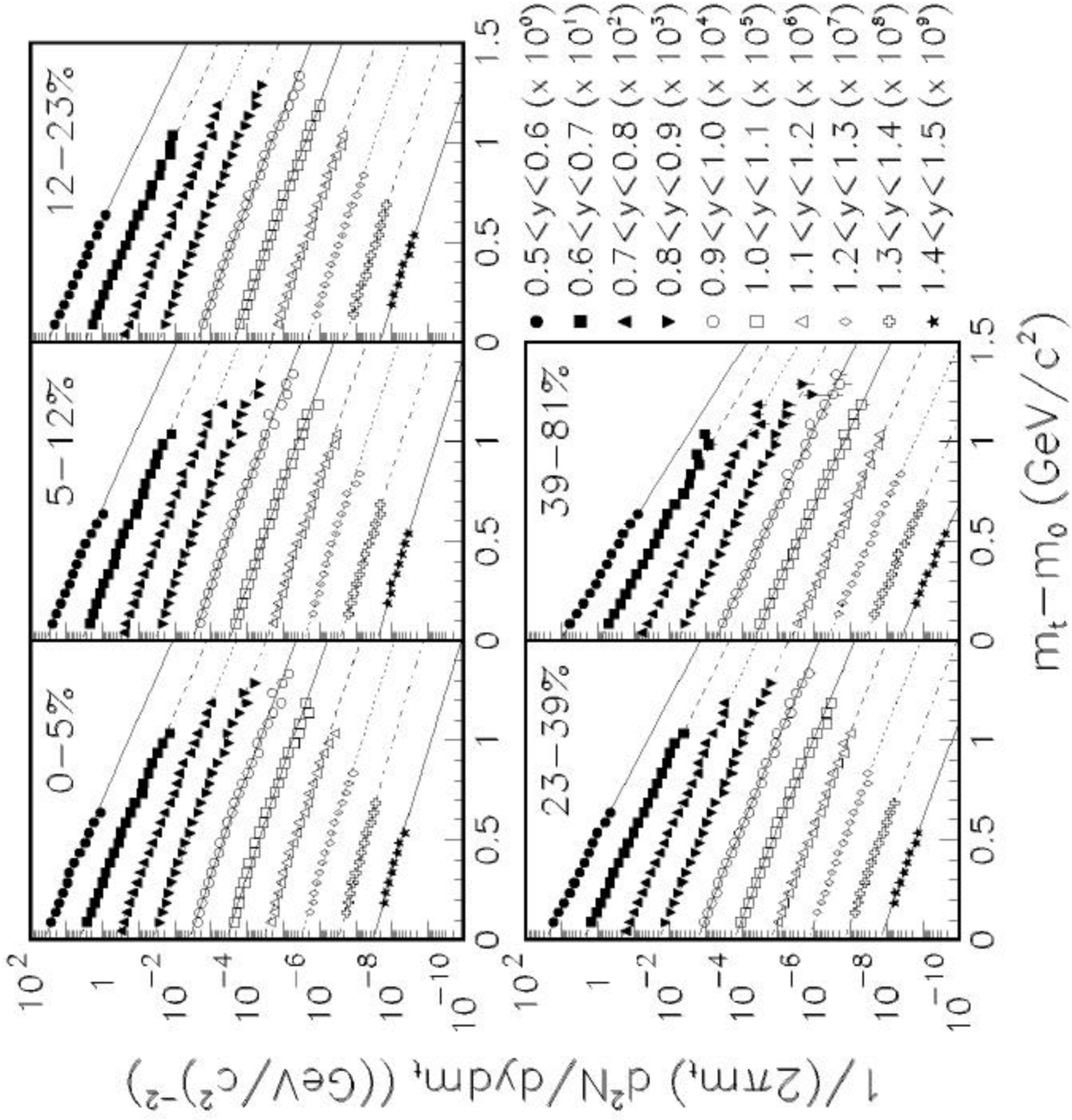
- Need: Concepts not so clearly defined
  - Lots of "stopping"
  - Local equilibration
- Energy Regimes
  - Mechanisms of Stopping/Transparency
    - Low energy (E_{beam}<700 MeV/c=200 MeV KE)
      - Cross section is all elastic
    - 200 MeV-2GeV KE (~2GeV/c) - GSI
      - Inelastic cross sections kick in
    - 2GeV-100 GeV : AGS to CERN
      - Total CS stays flat ~ 40mb
      - Inelastic CS becomes dominant
    - QCD regime Ebeam>100 GeV : CERN to RHIC
      - Q^2>1GeV^2 (distance ~0.3fm, 200Mev-fm/ 0.3 ~1GeV)
      - α_s~0.3 so coupling constant is getting small and gets smaller as Q^2 gets larger
      - ⇨Hence transparency increases with energy
      - CERN and RHIC (mostly RHIC)
      - Development of baryon free rapidity plateau
    - I argue that the relevant stopping (ie. To make large ρ_B) reaches a peak somewhere between GSI and CERN as the inelastic channels open up, but α_s is still large
    - an additional requirement aside from stopping will be local thermal equilibrium

Rapidity loss, pA vs AA

- In pA collisions (AGS to FNAL energies) the rapidity loss seems to be ~1 indep of beam energy
- We see that the rapidity loss increases with beam energy ~y_{Beam}
- Some numbers
  - $N_{coll}=\rho_0\sigma R$=.16*4.*7=4.5 Collisions in gold
  - Formation time of pions ~ 200 MeV-fm/140 MeV ~ 1 fm
  - Passage time of proton thru AU 2R/gamma
    - 14/5(AGS)~3 fm
    - 14/14(100GeV) ~ 1fm
  - $\sigma(\pi\text{-p})\sim\sigma(\text{p-p})\sim$30-40mb
- In p-A fewer particles are produced and the collisions is essentially between p and Au
- In Au-Au initial collision produces particles and subsequent collisions (either secondary collisions of protons since there are 5 collisions, or other incoming protons collide with a larger volume of matter. The number of secondary particles produced per collusion depends on the energy, hence effectively the target becomes more dense

➔ More rapidity loss in Au-Au collisions

E917 Proton Spectra 8GeV



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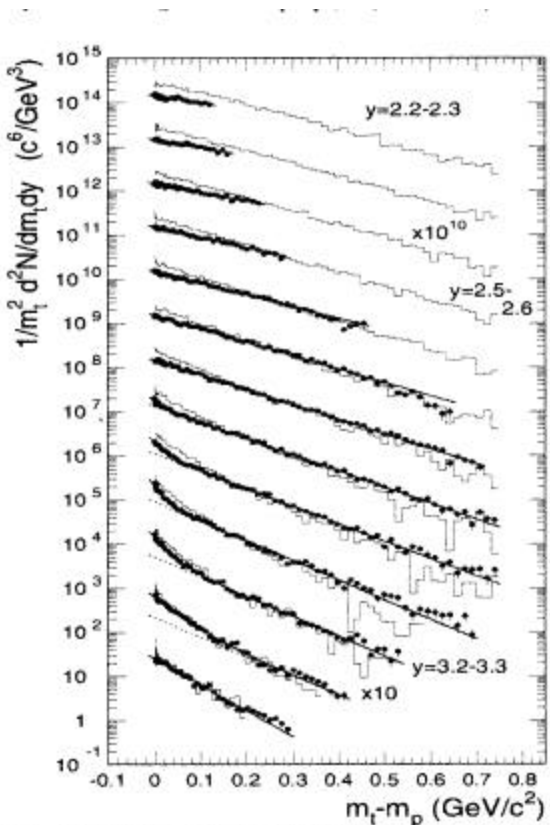
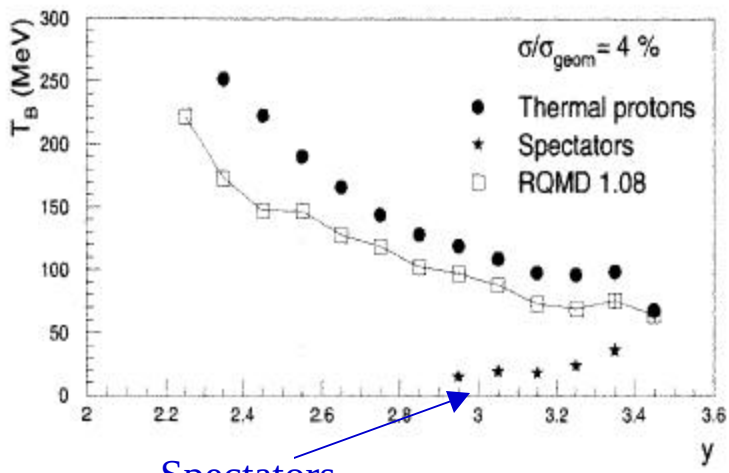
E877 Protons

- Assume that spectators are not in E917 acceptance
  - E877 protons - high rapidity > 2.3 (beam=3.14)
    - 4% central data
    - low T component at high y-spectators
    - Spectator peak at y>3 (<0.3)
- non-central collision

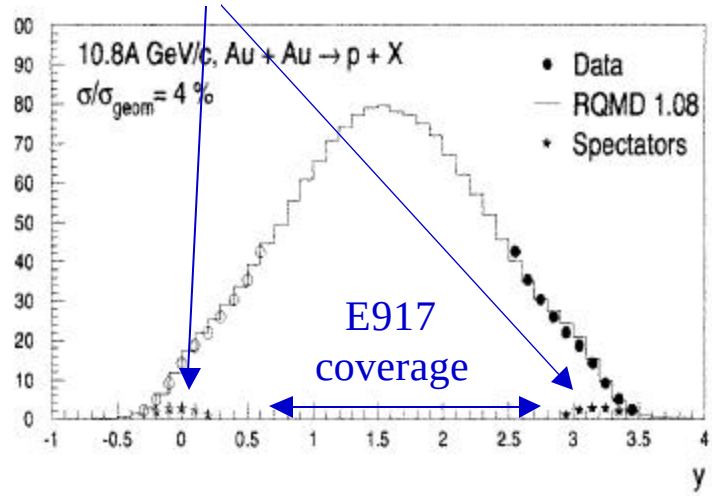
  ➔ collision of two smaller systems

E877 Protons





Spectators



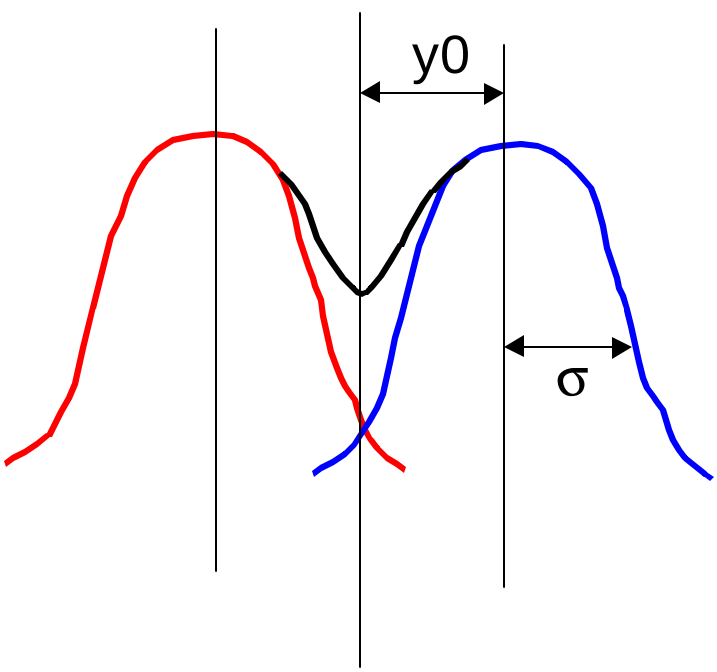
E917 coverage

Fitting to a double gaussian

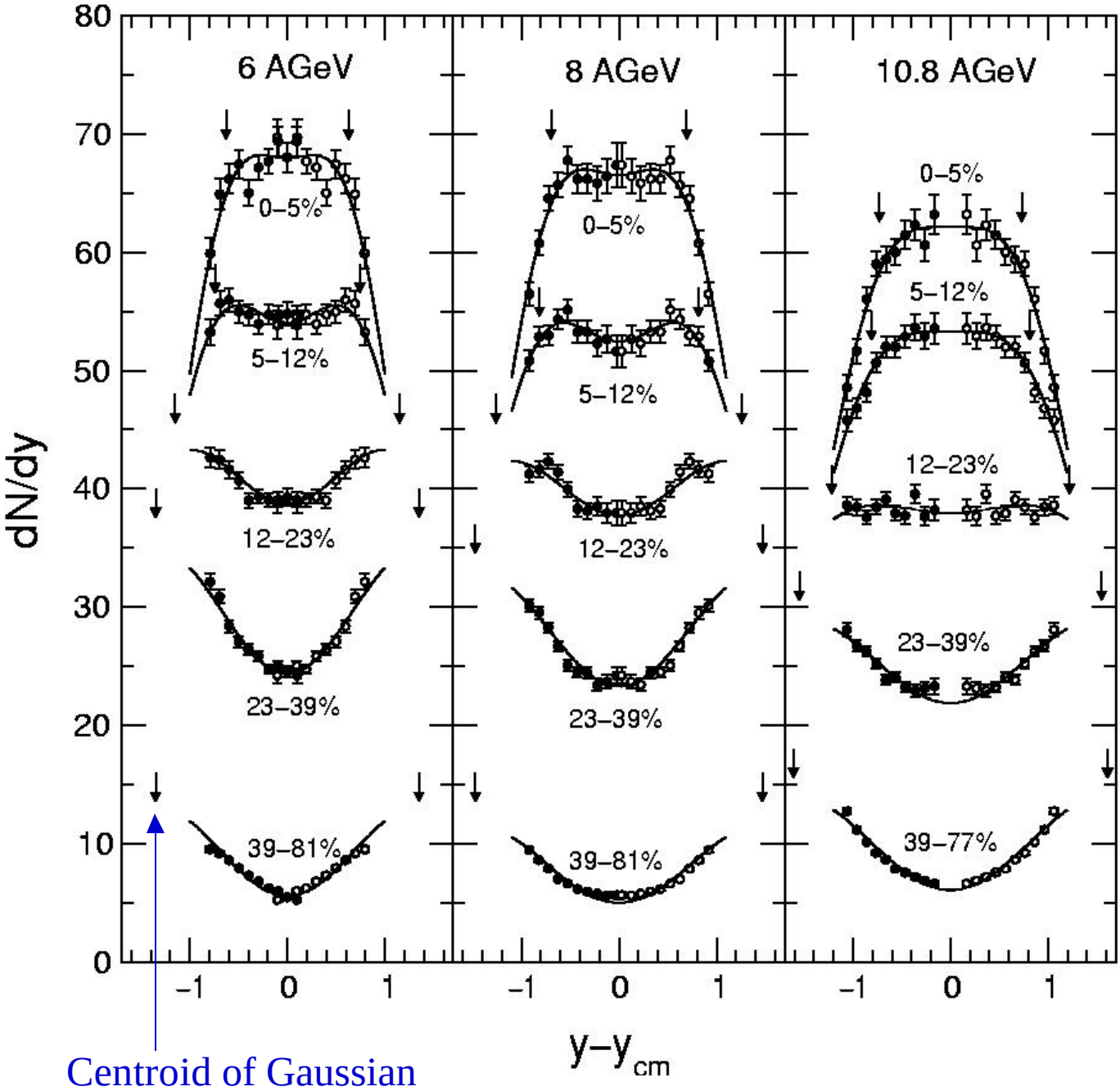
- fit dN/dy protons to a double gausian reflected around y=0

$$\frac{N_0}{s\sqrt{2p}}e^{-\frac{(y-y_0)}{2s^2}}+\frac{N_0}{s\sqrt{2p}}e^{-\frac{(y+y_0)}{2s^2}}$$

- Three free parameters N_0, y_0, and s.
- The value of y_0 must be less than y_{cm}.
- For the most peripheral (transperant) collisions, $y_0 = y_{cm}$



Fits to rapidity distribution



0-5%

N_p=75

E	*N*	*Y0*	*s*	*int*	*Y0/ycm*	*fiso*	*y0/σ*
6	88	.63	.61	79	.47	.48	1.04
8	96	.70	.66	84	.47	.45	1.05
11	94	.73	.73	83	.45	.44	1.01

5-12%

N_p=66

E	*N*	*Y0*	*s*	*int*	*Y0/ycm*	*fiso*	*y0/σ*
6	84	.74	.67	67	.55	.43	1.10
8	89	.82	.74	72	.55	.41	1.11
11	89	.81	.98	81	.50	.42	1.01

12-23%

N_p=52

E	*N*	*Y0*	*s*	*int*	*Y0/ycm*	*fiso*	*y0/σ*
6	96	1.15	0.94	56	.85	.38	1.22
8	103	1.26	1.03	59	.86	.35	1.22
11	96	1.22	1.13	61	.76	.36	1.08

23-39%

N_p=22

E	*N*	*Y0*	*s*	*int*	*Y0/ycm*	*fiso*	*y0/σ*
6	81	1.35	0.94	40	1.	.317	1.44
8	83	1.47	1.03	41	1.	.304	1.43
11	79	1.55	1.13	41	.963	.297	1.37

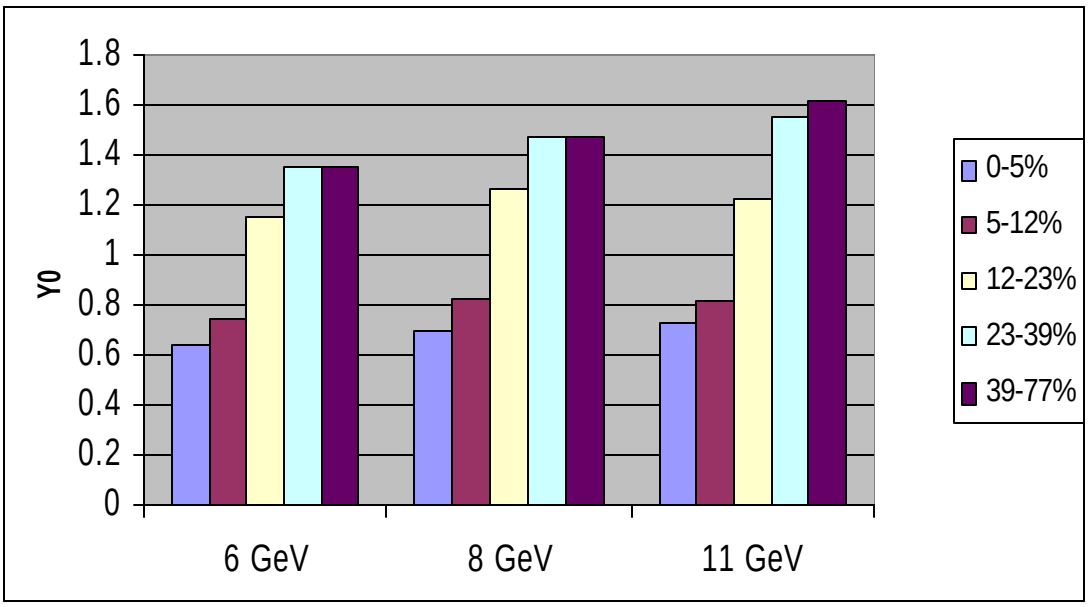
39-80%

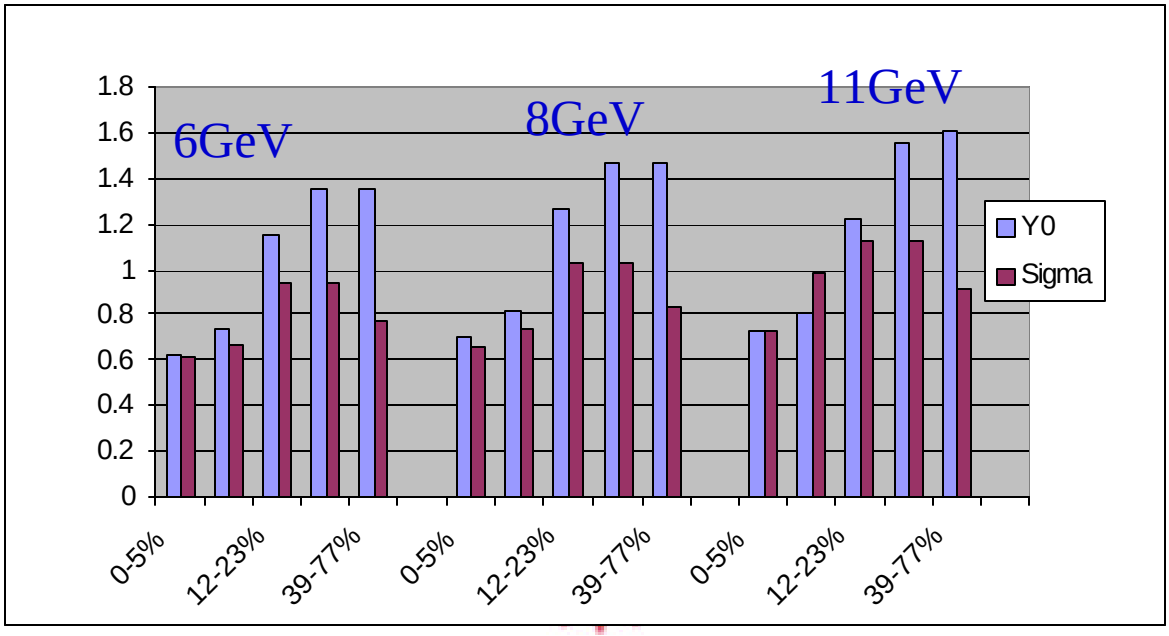
N_p=5

E	*N*	*Y0*	*s*	*Int*	*Y0/ycm*	*fiso*	*y0/σ*
6	25	1.35	0.77	13	1.	.22	1.76
8	24	1.47	0.84	12	1.	.21	1.75
11	32	1.61	0.92	16	1.	.20	1.75

Trends - centrality

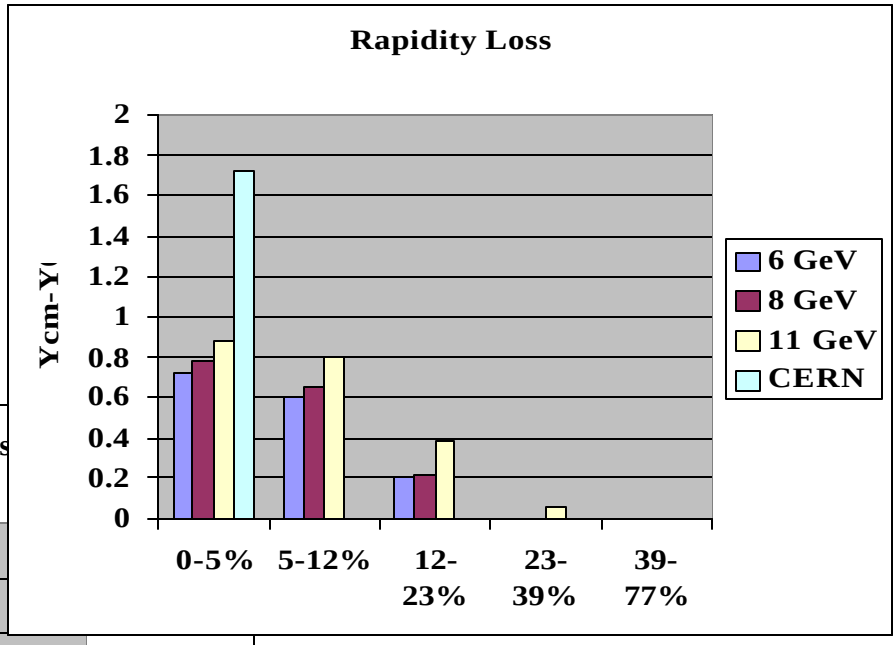
- As centrality gets less y_0 gets larger
  - When it reaches y_{cm} , ♦ narrows
  - This is what you would expect if transparency increases to more peripheral events
    - Note: All error bars < 2%

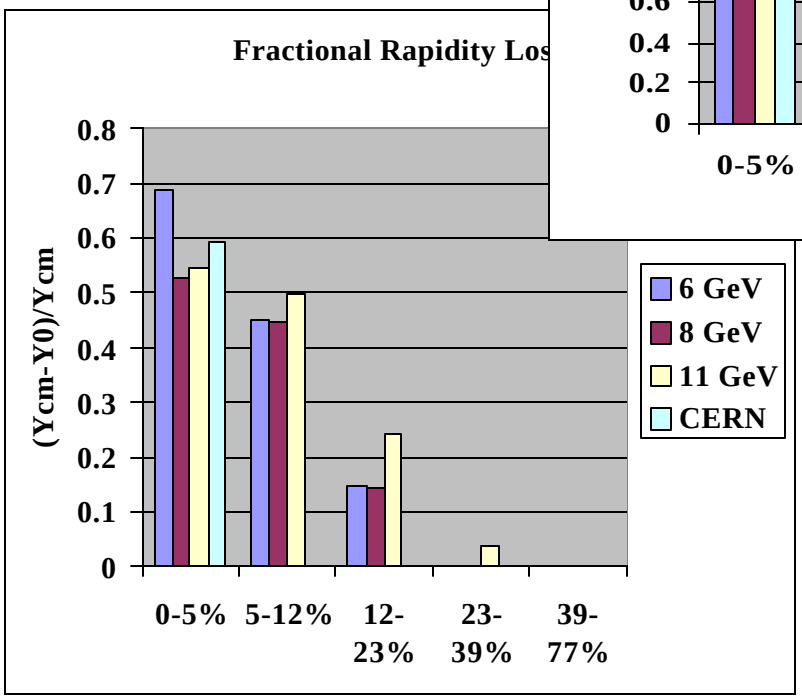




Trends: Energy Dependence

- As the energy increases the rapidity loss increases (ycm-y0)
- fractional rapidity loss (ycm-y0)/ycm seems to be ~constant





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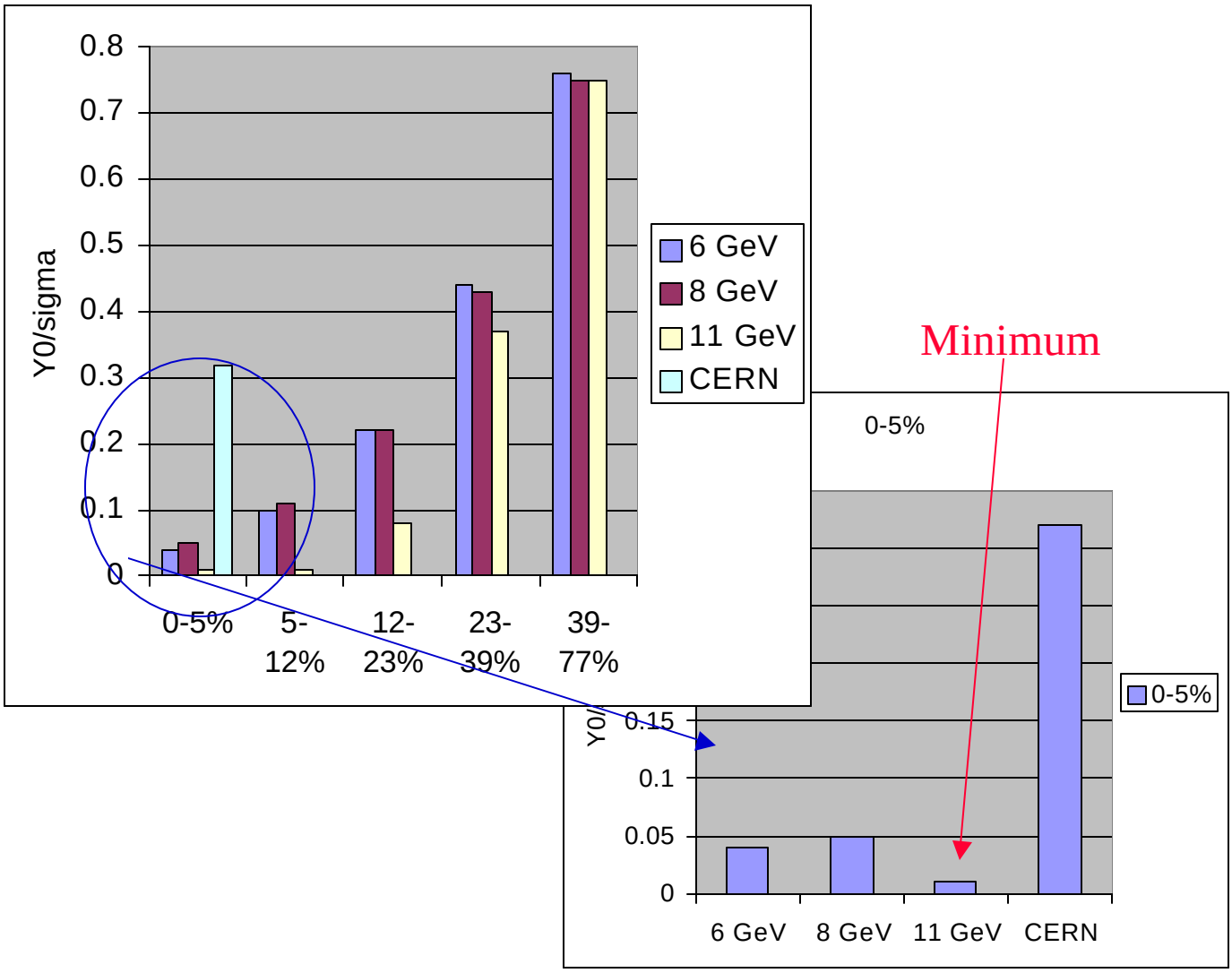
The Baryon Density

- High baryon density requires
  - system in local thermal equilibrium
    - Lots of baryons in small volume of space coordinates
    - Lots of baryons in a small volume of momentum coordinates
      - If two nuclei whiz past each other, the baryon density is momentarily very high but this is not the situation we want
- Look at quantity $s=y_0/\sigma$ ~ a measure of homogenaity
  - The smaller this quantity is, the close to a system in local thermal equilibrium we have.
    - If we have a peripheral collision or perfect transparency then s is large
    - If we have complete stopping and a thermal system then s is small.
    - If we have a situation of a rapidity plateau then the relevant y_0 is that of the produced baryons and again s is small.

Our data

- The minimum value of S=Y0/sigma : most central events
- S reaches a minimum for our 11 GeV central. (1.035,1.050,1.007,1.32(CERN))
  - CERN's value is large because the original baryons are not part of the equilibrated system. The produced particles left in the wake of the nuclei make up the equilibrated baryon-free system. A similar situation should exist at RHIC



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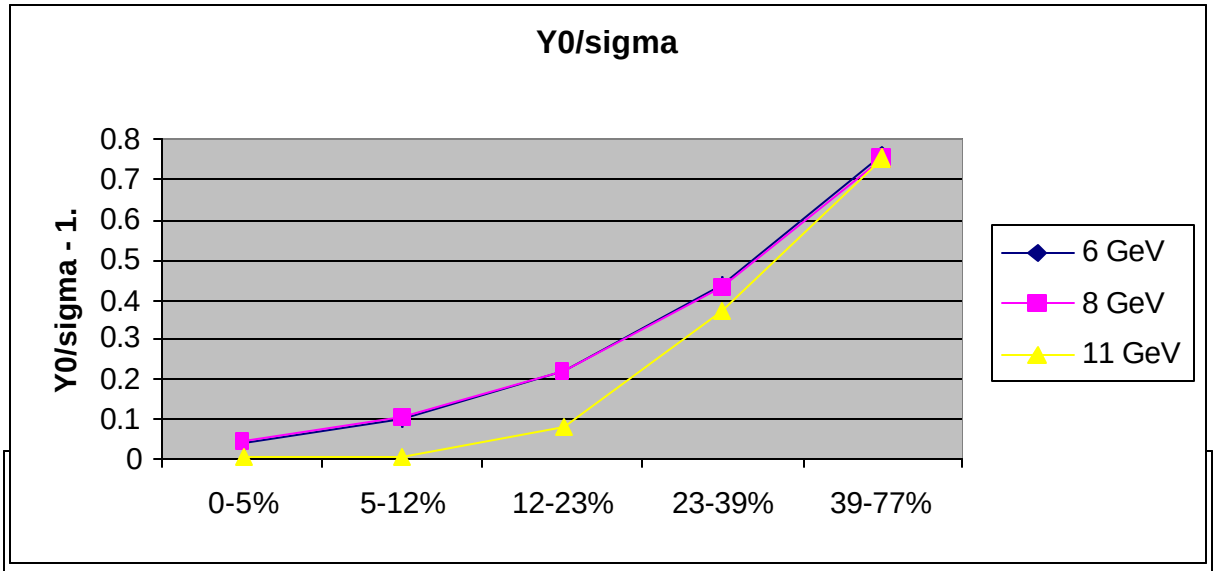
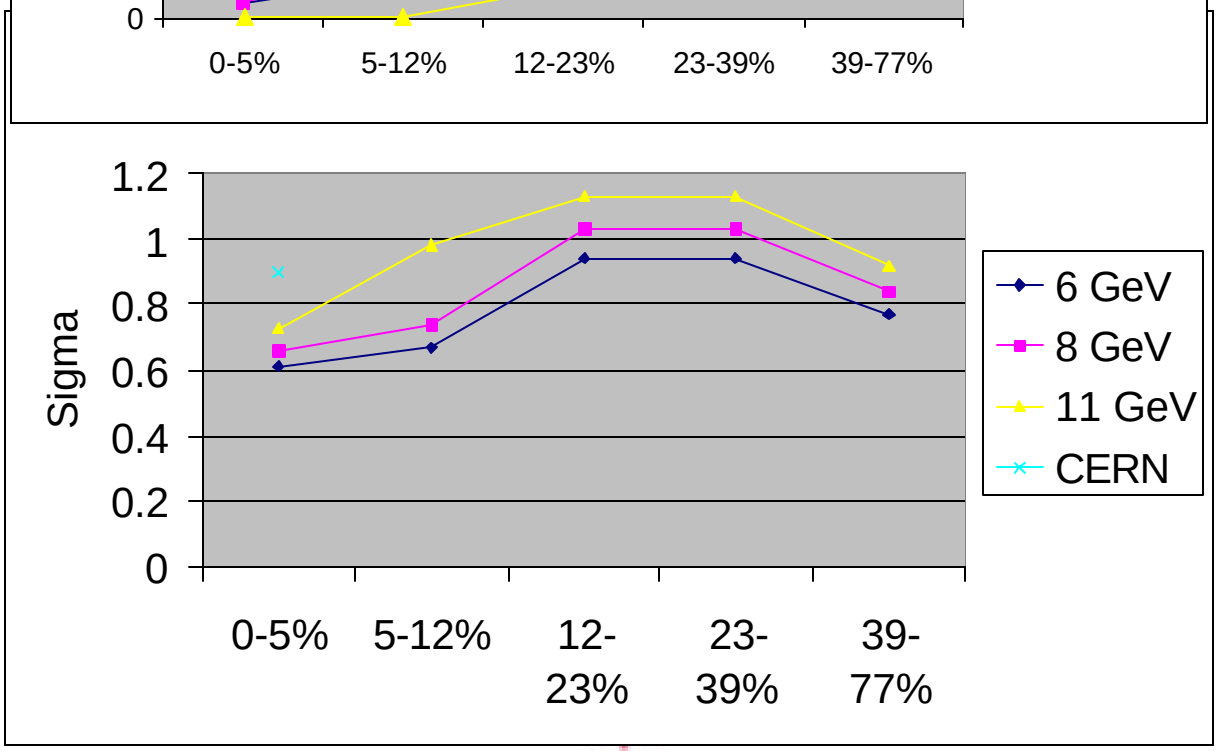

Y0/sigma
Y0/sigma - 1.
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-5%
5-12%
12-23%
23-39%
39-77%
6 GeV
8 GeV
11 GeV


Sigma
1.2
1
0.8
0.6
0.4
0.2
0
0-5%
5-12%
12-23%
23-39%
39-77%
6 GeV
8 GeV
11 GeV
CERN

Transparency

- Longitudinal Explosion or Transparency?
  - Look as a function of centrality –
    - If complete stopping and longitudinal explosion, then we expect to see, some non-central bin to be the narrowest.
    - Doesn't look as if there is a stopping then explosion

    ➔ Transperancy
      - Or at least full stopping occurs only in the most central bin

Conclusions

- I had hoped to come up with some model independent way of calculating the baryon density (in space) knowing the baryon density in rapidity. (Will we ever know?)
- More mundane conclusions
  - Y0 ("stopping") increases with centrality
  - Y0 increases with energy
    - Y0/ycm ~ constant
  - Y0/sigma ~ measure of homogeneity ~ local equilibration
  - Non-isotropic distribution comes from transparency

N	88.300	95.800	93.700	85.000
y0	0.628	0.695	0.730	1.190
sigma	0.607	0.662	0.725	1.600
err N	0.729	0.624	0.576	1.000
err y0	0.006	0.007	0.008	0.100
err sigma	0.001	0.002	0.001	0.100
integral	77.920	84.183	83.121	72.630
y0/ycm	0.465	0.473	0.453	0.408
sigma/ycm	0.450	0.450	0.450	0.549
rel curv	-0.191	-0.233	-0.026	0.175
ycm-y0	0.722	0.775	0.880	1.725
ycm-y0/ycm	0.535	0.527	0.547	0.592
avy	0.600	0.657	0.708	1.256
ycm-avy	0.750	0.813	0.902	1.659
ycm-avy/yc	0.556	0.553	0.560	0.569
avy 1 exp	0.659	0.721	0.779	1.392
ycm-avy	0.691	0.749	0.831	1.523
ycm-avy/yc	0.512	0.509	0.516	0.523
av(y**2)	0.00634	0.00703	0.00832	0.03047
av(y**2)/yc**2	0.00348	0.00326	0.00321	0.00359
temps	0.207	0.222	0.237	0.000
fiso	0.484	0.452	0.439	0.000

N	83.800	89.300	89.300	0.000
y0	0.743	0.815	0.811	0.000
sigma	0.674	0.736	0.807	0.000
err N	0.817	0.691	0.614	2.018
err y0	0.008	0.008	0.009	-1.999
err sigma	0.002	0.001	0.001	0.000
integral	68.319	72.548	74.807	0.000
y0/ycm	0.550	0.554	0.504	0.000
sigma/ycm	0.499	0.501	0.501	0.000
rel curv	-0.474	-0.418	-0.015	inf
ycm-y0	0.607	0.655	0.799	2.915
ycm-y0/ycm	0.450	0.446	0.496	1.000
avy	0.635	0.693	0.733	nan
ycm-avy	0.715	0.777	0.877	nan
ycm-avy/yc	0.529	0.528	0.545	nan
avy 1 exp	0.695	0.758	0.807	nan
ycm-avy	0.655	0.712	0.803	nan
ycm-avy/yc	0.485	0.484	0.499	nan
av(y**2)	0.00797	0.00893	0.00983	nan
av(y**2)/yc**2	0.00437	0.00413	0.00379	nan
temps	0.202	0.218	0.233	0.000
fiso	0.434	0.410	0.415	0.000

N	96.400	103.000	96.300	0.000
y0	1.150	1.260	1.220	0.000
sigma	0.943	1.030	1.130	0.000
err N	1.640	1.480	1.280	2.018
err y0	0.016	0.016	0.020	-1.999
err sigma	0.002	0.002	0.001	0.000
integral	55.912	59.409	60.564	nan

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0-5%

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5-12%

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	0-5%	5-12%	12-23%	23-39%	39-77%											
	0.63	0.74	1.15	1.35	1.35											
	0.7	0.82	1.26	1.47	1.47											
	0.73	0.81	1.22	1.55	1.61											
	1.19															
	0-5%	5-12%	12-23%	23-39%	39-77%											
	0.61	0.67	0.94	0.94	0.77											
	0.66	0.74	1.03	1.03	0.84											
	0.73	0.98	1.13	1.13	0.92											
	0.9															
	0-5%	5-12%	12-23%	23-39%	39-77%											
	0.63	0.74	1.15	1.35	1.35											
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	0.73	0.81	1.22	1.55	1.61											
	0.73	0.98	1.13	1.13	0.92											
ι	0-5%	5-12%	12-23%	23-39%	39-77%											
	1.04	1.1	1.22	1.44	1.76											
	1.05	1.11	1.22	1.43	1.75											
	1.01	1.01	1.08	1.37	1.75											
	1.32															
	0-5%	5-12%	12-23%	23-39%	39-77%	--	0-5%	5-12%	12-23%	23-39%	39-77%	–	0-5%	5-12%	12-23%	23-39%
	0.63	0.74	1.15	1.35	1.35	0	0.7	0.82	1.26	1.47	1.47	0	0.73	0.81	1.22	1.55
	0.61	0.67	0.94	0.94	0.77	0	0.66	0.74	1.03	1.03	0.84	0	0.73	0.98	1.13	1.13
ι	0-5%	5-12%	12-23%	23-39%	39-77%											
	0.04	0.1	0.22	0.44	0.76											
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	0.01	0.01	0.08	0.37	0.75											
	0.32															
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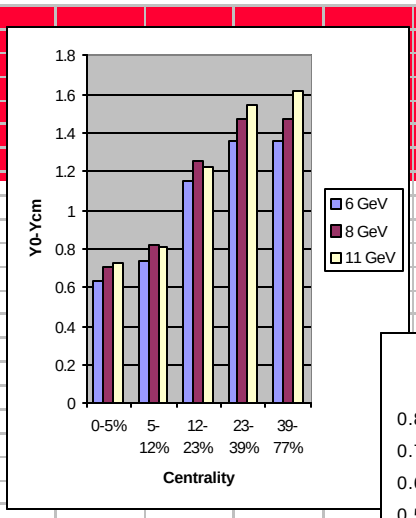
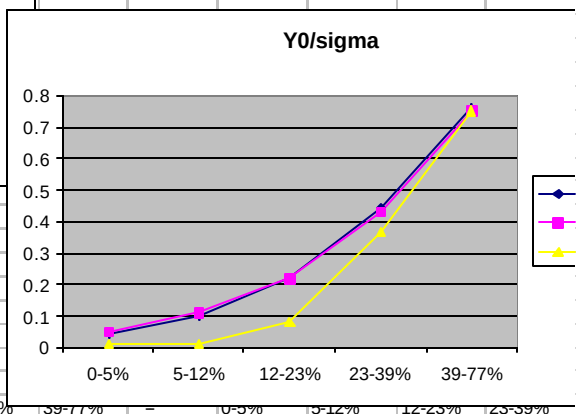
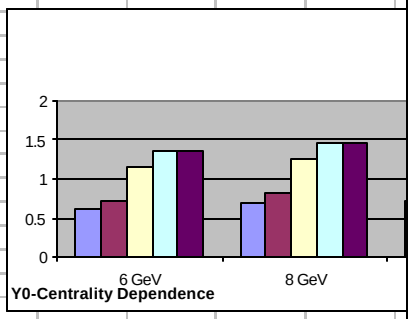
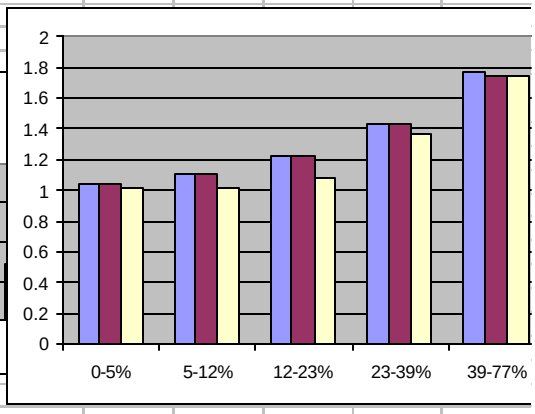
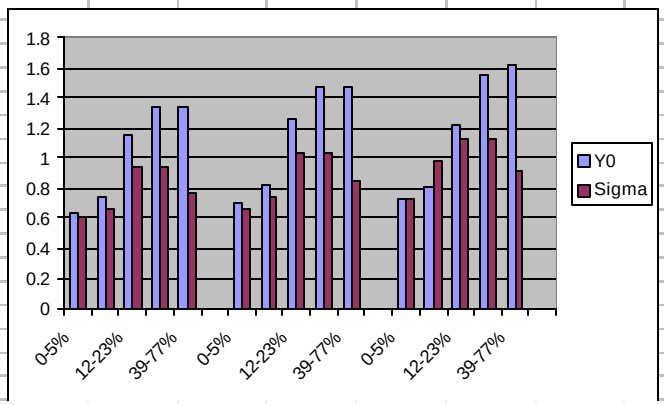
	0.722	0.607	0.2	0	0											
	0.775	0.655	0.21	0	0											
	0.88	0.799	0.39	0.06	0											
	1.725															
Y	0-5%	5-12%	12-23%	23-39%	39-77%											
	0.687619	0.45	0.148	0	0											
	0.527	0.446	0.143	0	0											
	0.547	0.496	0.242	0.037	0											
	0.592															
s	0-5%	5-12%	12-23%	23-39%	39-77%											
	1.183607	0.90597	0.212766	0	0											
	1.174242	0.885135	0.203883	0	0											
	1.205479	0.815306	0.345133	0.053097	0											
	1.916667															











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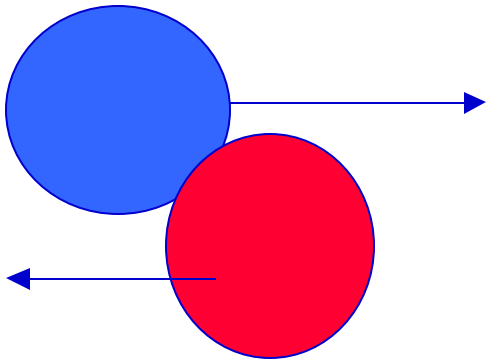
Comment on shapes

- To first order non-central collisions are like collisions of smaller nuclei.
- But this is not completely true since non-central collisions are really collusions of two partial spheres



This gives a flatter shape – E802 Si+Al

presumably like our peripheral bin has a double bell shape. Our peripheral bin has a different shape since thick parts of the projectile go through thin parts of the target

- centrality classes correspond to
  - f=0.95,0.84,0.66,0.28,0.06
  - n_p=75,66,52,22,5
  - Integral follows trend so model makes sense