



# Validation Results from Geant4.10.4.ref08 Status of Bertini, including some of its “custom” features

Julia Yarba, Fermilab

Geant4 Hadronic Group Meeting

Oct. 17, 2018

# General Information

- Focus: hadron production in hadron-nucleus capture processes or interactions at intermediate energies (test19, test47, test48)
- Regression: 10.4.p02, 10.4.ref05, 10.4.ref07
- Results are mainly presented as  $\chi^2/\text{NDF}$ 
  - $\chi^2/\text{NDF}$  is often “bad” (same for other models)
  - MC results are considered “better” if  $\chi^2/\text{NDF}$  is smaller than the one of **10.4.p02** by a factor of 1.5 or more (or “worse” if  $\chi^2/\text{NDF}$  goes the other way around) – this approach is subject to questions/suggestions/criticism, but we need some “border line”
  - In some cases  $\chi^2/\text{NDF}$  is “very bad” – those are “flagged”
- Selected plots included for illustrative purpose
- All results from ref08 are available in DoSSiER

# Experimental Data

(all are for thin target)

- HARP:
  - M. Apollonio et al., Nucl. Phys. A821 118, 2009
  - M. Apollonio et al., Phys.Rev.C80 065207, 2009
  - M. Apollonio et al., Phys.Rev.C80 035208, 2009
  - M.G. Catanesi et al., Phys.Rev.C77 055207, 2008
- ITEP771:
  - Yu.D.Bayukov et al., Preprints ITEP-148-1983 and ITEP-172-1983;  
Sov.J.Nucl.Phys. 42 116, 1985
- pi- capture:
  - R.Madey et al., Phys.Rev.C25, 3050 (1982)

# Color Code of Results

- **“Better”** (chi2/NDF improves by factor of 1.5 or more, regardless of the absolute value)
- **“Worse”** – opposite to “Better”
- **“Somewhat better”** (chi2/NDF improves by factor of 1.1 but no more than 1.5)
- **“Somewhat worse”** – opposite to “Somewhat better”
- **“Neutral”** (chi2/NDF within 1.1 vs the other version)
- **“Always bad”**

**Bertini: proton on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

10.04.p02 10.04.r05 10.04.r07 10.04.r08 10.04.p02 10.04.r05 10.04.r07 10.04.r08

pi+

FW	3.46	3.48	3.57	3.41	6.71	6.67	6.59	6.57
LA	15.10	15.71	15.94	15.09	22.84	24.38	25.12	23.09
Total	13.64	14.19	14.39	13.63	18.93	20.08	20.62	19.08

pi-

FW	3.77	3.72	3.52	4.17	9.17	9.16	7.71	8.34
LA	3.77	3.83	3.95	3.71	17.07	18.32	18.68	17.85
Total	3.77	3.82	3.90	3.76	15.46	16.45	16.44	15.91

**Bertini: proton on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

10.04.p02 10.04.r05 10.04.r07 10.04.r08 10.04.p02 10.04.r05 10.04.r07 10.04.r08

pi+

FW	16.29	16.31	16.23	15.85	22.41	22.71	23.4	22.66
LA	24.89	26.94	27.47	24.82	20.75	24.24	25.31	21.84
Total	22.33	23.78	24.13	22.15	21.25	23.78	24.73	22.09

pi-

FW	38.61	38.07	29.77	31.41	31.84	31.06	26.16	25.91
LA	26.05	28.07	27.93	26.18	24.55	28.01	28.55	26.66
Total	29.62	30.91	28.45	27.67	26.76	28.93	27.83	26.43

**Bertini: pi+ on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	17.94	17.13	17.18	17.31	32.93	32.78	32.84	33.59
LA	30.04	54.72	54.89	28.45	33.42	49.64	49.69	32.06
Total	27.98	48.32	48.47	26.55	33.27	44.74	44.78	32.51
pi-								
FW	5.48	4.98	5.01	5.72	31.41	25.23	25.60	41.28
LA	36.12	36.32	36.42	40.52	33.11	32.97	32.99	38.04
Total	30.9	30.99	31.07	34.6	32.61	30.72	30.84	38.99

**Bertini: pi+ on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	30.33	28.75	28.75	28.34	4.57	4.29	4.31	4.29
LA	24.04	30.13	30.36	22.76	20.92	23.68	23.88	20.03
Total	26.02	29.69	29.85	24.53	15.76	17.55	17.70	15.06
pi-								
FW	19.83	19.92	19.94	25.13	3.92	4.46	4.45	4.9
LA	15.78	18.48	18.82	19.6	8.42	9.92	9.87	9.41
Total	17.01	18.92	19.16	21.28	7.02	8.23	8.19	8.01

**Bertini: pi- on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	11.32	12.89	12.8	11.49	21.67	20.16	20.12	20.18
LA	37.01	39.72	39.79	36.39	31.87	32.56	32.80	29.85
Total	32.64	35.15	35.19	32.15	29.03	29.12	29.28	27.17
pi-								
FW	35.37	30.63	30.53	33.16	52.05	41.85	41.77	49.07
LA	32.85	60.3	60.16	33.77	31.34	45.24	45.07	32.72
Total	33.28	55.25	55.11	33.67	37.37	44.26	44.11	37.47

**Bertini: pi- on Be -> pions**

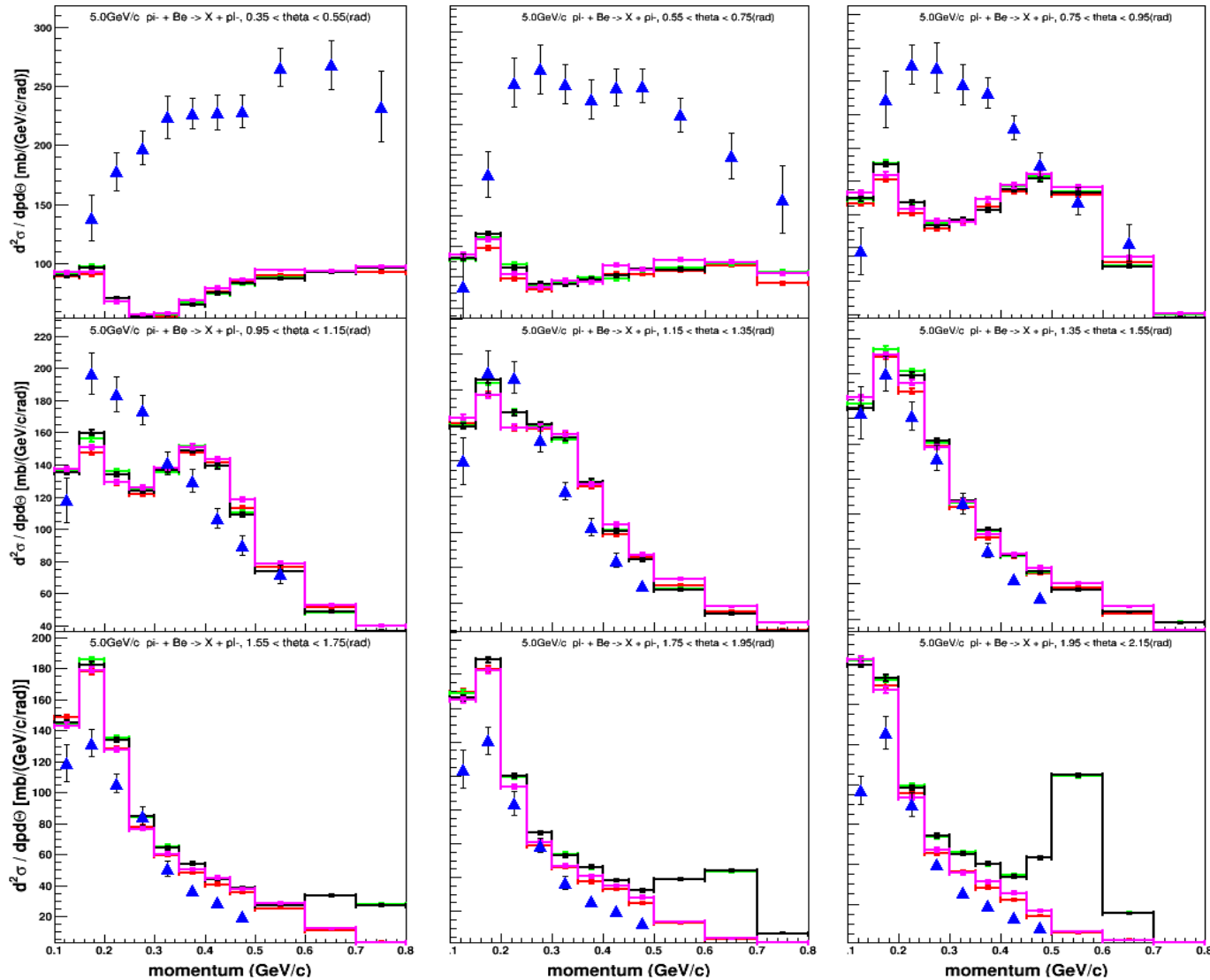
**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	26.65	27.32	27.30	27.75	13.39	13.74	13.71	14.28
LA	25.56	30.47	30.60	26.43	29.14	34.08	34.11	29.07
Total	25.9	29.49	29.58	26.84	24.26	27.78	27.79	24.49
pi-								
FW	43.46	45.71	45.73	44.31	25.18	23.05	22.97	23.31
LA	37.48	47.61	47.3	36.65	52.18	56.5	55.74	47.91
Total	39.37	47.01	46.81	39.07	43.65	45.93	45.39	40.14

# 5GeV/c pi- on Be → pi- + X at LA; data from HARP



bertini vs HARP Data;  $\chi^2/\text{NDF}$  calculated over LA theta bins

$\chi^2/\text{NDF} = 31.3451$  for geant4-10-04-patch-02

$\chi^2/\text{NDF} = 45.2463$  for geant4-10-04-ref-05

$\chi^2/\text{NDF} = 45.0753$  for geant4-10-04-ref-07

$\chi^2/\text{NDF} = 32.7164$  for geant4-10-04-ref-08





**Bertini: proton on Ta -> pions**

**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	0.37	0.4	0.41	0.37	1.12	<b>1.27</b>	<b>1.32</b>	1.06
LA	15.62	15.53	15.73	15.66	<b>35.56</b>	<b>37.66</b>	<b>38.07</b>	<b>36.25</b>
Total	13.59	13.51	13.69	13.62	27.72	29.37	29.70	28.24
pi-								
FW	1.45	<b>1.04</b>	<b>1.24</b>	1.4	3.42	<b>2.80</b>	<b>2.72</b>	3.24
LA	7.15	6.64	6.74	7.24	24.99	24.84	24.95	26.32
Total	6.62	6.12	6.23	6.69	20.41	20.16	20.23	21.43

**Bertini: proton on Ta -> pions**

**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	1.12	<b>1.43</b>	<b>1.48</b>	1.12	7.84	<b>9.23</b>	<b>9.79</b>	8.49
LA	<b>48.62</b>	<b>53.93</b>	<b>54.34</b>	<b>49.18</b>	<b>51.59</b>	<b>61.29</b>	<b>61.7</b>	<b>52.27</b>
Total	33.35	<b>37.06</b>	<b>37.35</b>	33.73	<b>37.77</b>	<b>44.85</b>	<b>45.31</b>	<b>38.45</b>
pi-								
FW	23.55	<b>19.17</b>	<b>16.11</b>	<b>18.94</b>	34.17	<b>29.51</b>	<b>25.15</b>	<b>28.03</b>
LA	<b>45.77</b>	<b>50.49</b>	<b>47.59</b>	<b>49.1</b>	<b>51.16</b>	<b>56.77</b>	<b>52.32</b>	<b>53.78</b>
Total	<b>39.9</b>	<b>42.21</b>	<b>39.27</b>	<b>41.13</b>	<b>45.8</b>	<b>48.16</b>	<b>43.74</b>	<b>45.65</b>

**Bertini: pi+ on Ta -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	59.61	42.13	43.36	55.05	22.22	22.06	21.94	22.24
LA	27.9	54.62	55.11	26.71	47.68	63.22	63.36	46.76
Total	33.3	52.49	53.11	31.53	40.27	51.25	51.31	39.62
pi-								
FW	3.19	3.38	3.32	3.1	13.18	11.1	10.66	16.35
LA	21.98	22.32	21.86	24.34	33.69	36.13	36.28	38.01
Total	18.79	19.1	18.7	20.72	27.73	28.85	28.83	31.72

**Bertini: pi+ on Ta -> pions**  
**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	15.48	16.68	16.86	15.36	2.97	3.43	3.43	3.07
LA	40.16	53.47	53.86	42.36	16.14	19.01	19.19	16.77
Total	32.37	41.85	42.18	33.84	11.98	14.09	14.21	12.44
pi-								
FW	19.94	19.30	19.51	25.71	2.02	2.44	2.48	2.35
LA	26.60	31.42	31.07	33.03	13.61	11.63	11.31	14.06
Total	24.62	27.82	27.63	30.85	10.02	8.78	8.57	10.43

**Bertini: pi- on Ta -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	1.73	2.22	2.13	1.81	8.85	7.99	8.15	8.29
LA	20.28	20.84	20.73	19.76	53.38	54.72	54.49	52.1
Total	17.12	17.67	17.56	16.7	40.42	41.13	41.01	39.36
pi-								
FW	12.55	6.79	7.01	11.34	19.31	15.32	15.52	18.42
LA	19.85	35.32	35.69	20.91	38.24	51.82	51.61	40.18
Total	18.61	30.47	30.81	19.28	32.73	41.20	41.11	33.85

**Bertini: pi- on Ta -> pions**  
**chi2/NDF calculated vs HARP data**

**8 GeV/c**

**12 GeV/c**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
pi+								
FW	19.9	22.03	22.2	21.25	26.55	30.54	30.86	29.83
LA	42.49	48.97	48.86	45.06	47.69	54.93	55.06	50.37
Total	35.35	40.46	40.44	37.54	41.02	47.23	47.42	43.88
pi-								
FW	25.97	29.76	29.69	26.71	29.86	36.68	36.79	32.14
LA	39.09	55.12	54.8	44.95	55.56	68.93	68.47	60.33
Total	34.95	47.11	46.87	39.19	47.44	58.74	58.47	51.42

**Bertini: 1.4GeV/c pi- on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

**Carbon (C)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	7.57	8.73	8.71	10.01	23.71	7.07	6.62	5.5
neutron	10.62	6.24	6.27	9.53		NO DATA		

**Bertini: 1.4GeV/c pi+ on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

**Carbon (C)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	20.31	12.42	12.43	16.52	2.85	11.02	11.21	6.09
neutron	4.02	4.17	4.22	5.21	13.40	11.67	11.77	10.48

**Bertini: 1.4GeV/c proton on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

**Carbon (C)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	9.54	6.6	6.45	6.76	2.63	4.05	3.99	4.07
neutron		NO. DATA			3.59	3.68	3.52	3.17

**Bertini: 5GeV/c pi- on nucleus -> proton/neutron**

chi2/NDF calculated vs ITEP771 data

**Carbon (C)**

**Copper (Cu)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	7.62	11.08	11.16	8.44	50.06	62.56	63.06	33.98
neutron	8.49	6.01	5.97	6.69	17.22	30.6	30.64	17.76

**Lead (Pb)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	40.55	36.83	34.72	20.16	46.54	37.04	36.99	22.94
neutron	24.93	35.82	35.82	25.78	29.27	39.32	40.05	29.36

**Bertini: 5GeV/c pi+ on nucleus -> proton/neutron**

chi2/NDF calculated vs ITEP771 data

**Carbon (C)**

**Copper (Cu)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	19.42	12.01	12.03	13.56	17.25	62.67	61.85	29.44
neutron	3.89	3.48	3.48	4.48	15.77	17.81	17.97	11.7

**Lead (Pb)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	15.58	39.54	39.28	17.7	19.02	43.38	43.31	24.1
neutron	29.44	34.24	33.84	26.31	38.38	46.31	45.66	34.63

**Bertini: 7.5GeV/c proton on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

**Carbon (C)**

**Copper (Cu)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	18.95	11.72	10.58	13.87	38.58	82.99	86.92	50.01
neutron	3.73	3.7	3.89	3.66	22.47	26.02	26.99	17.67

**Lead (Pb)**

**Uranium (U)**

	10.04.p02	10.04.r05	10.04.r07	10.04.r08	10.04.p02	10.04.r05	10.04.r07	10.04.r08
proton	56.73	88.08	88.51	55.15	50.98	74.24	73.35	44.99
neutron	35.31	41.77	42.16	30.59	49.96	58.08	57.68	43.98

**Bertini:** capture of pi- on nucleus -> neutron

chi2/NDF calculated vs ITEP771 data

Carbon (C)

Nitrogen (N)

	10.4.p02	10.4.r05	10.4.r07	10.4.r08	10.4.p02	10.4.r05	10.4.r07	10.4.r08
neutron	74.15	33.51	33.45	31.5	50.07	21.19	21.26	28.42

**Bertini:** capture of pi- on nucleus -> neutron

chi2/NDF calculated vs ITEP771 data

Oxygen (O)

Aluminum (Al)

	10.4.p02	10.4.r05	10.4.r07	10.4.r08	10.4.p02	10.4.r05	10.4.r07	10.4.r08
neutron	82.19	38.00	37.78	27.56	48.90	25.23	25.14	22.72

**Bertini:** capture of pi- on nucleus -> neutron

chi2/NDF calculated vs ITEP771 data

Copper (Cu)

Lead (Pb)

	10.4.p02	10.4.r05	10.4.r07	10.4.r08	10.4.p02	10.4.r05	10.4.r07	10.4.r08
neutron	44.90	22.20	22.14	21.77	48.30	24.09	24.54	25.4

**Bertini:** capture of pi- on nucleus -> neutron

chi2/NDF calculated vs ITEP771 data

Tantalum (Ta)

	10.4.p02	10.4.r05	10.4.r07	10.4.r08
neutron	50.05	27.55	25.41	35.09

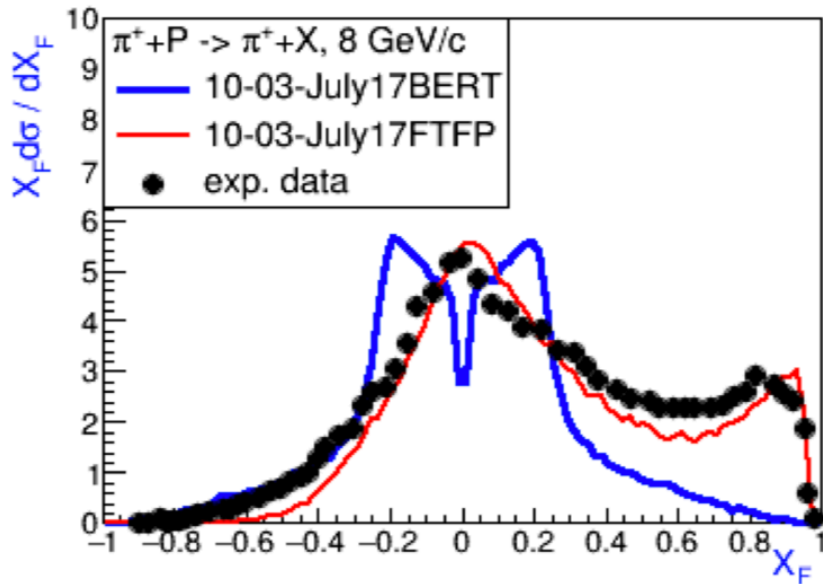
**GENERAL NOTE:** Shapes of the spectra still look a bit "funny"

# Summary – Bertini as of ref08

- Pion production in the intermediate energy range (3-12GeV/c):
  - Proton beam – the situation is fairly **neutral (stable)**
  - Pion beam – ref08 seems to **repair** some of the issues introduced since ref04/05 and present through ref07; in particular, unphysical peaks are gone in momentum spectra for pion+A → same sign pion at LA
- Proton/neutron production in the intermediate energy range (1.4-7.5GeV/c)
  - In a number of areas ref08 seems to repair or at least reduce deviations from the data introduced in ref04/ref05 and present through ref07
- Neutron production in pi- capture process has **improved** in terms of chi2 starting from ref05 and through ref08 (although the shapes of the spectra remain a bit “funny”)
- Overall, the quality of Bertini as of ref08 seems to improve
- Some of the Bertini-simulated spectra remain a concern as they do not agree with the data very well



# Using Kopylov Phase Space Generator in Bertini - Way to Improve MC/Data Agreement ?



- Plot is courtesy of Vladimir U., showing issues in the Bertini-generated  $x_F$  spectrum
- Per Dennis W., the problem is in the Bertini native phase space generator
- Alternatively, Bertini has Kopylov phase space generator which is OFF by default but is run-time configurable (through a UI and/or env.variable)

- Dennis has asked me to run a selected validation apps on Bertini+KopylovPH, and to benchmark vs HARP data, to see if it brings MC closer to the data
  - Proton or pion beam of 3, 5, 8, or 12 GeV/c
  - Be, Cu, Ta targets (C and Pb can be added as well)
- I also did some of the ITEP771 ones
  - 5 GeV/c pion or 7.5 GeV/c proton on C, Cu, Pb
  - Can also add 1.4 GeV/c beam and U target (limited time / short notice)

**Bertini: proton on Be -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	3.41	3.46	6.57	9.25
LA	15.09	11.84	23.09	17.43
Total	13.63	10.79	19.08	15.45

pi-

FW	4.17	1.63	8.34	3.28
LA	3.71	3.39	17.85	6.37
Total	3.76	3.17	15.91	5.74

**8 GeV/c**

**12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	15.85	30.99	22.66	47.11
LA	24.82	19.15	21.84	23.72
Total	22.15	22.67	22.09	30.82

pi-

FW	31.41	17.9	25.91	30.03
LA	26.18	7.69	26.66	10.72
Total	27.67	10.59	26.43	16.58

**Bertini: proton on Cu -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	1.87	1.65	14.34	14.36
LA	19.59	24.66	39.98	38.51
Total	17.58	22.04	33.20	32.13

pi-

FW	0.33	0.27	25.92	6.0
LA	4.72	4.08	32.69	24.63
Total	4.36	3.77	31.15	20.39

**8 GeV/c**

**12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	12.95	26.35	23.31	48.6
LA	56.37	54.39	51.73	55.74
Total	42.53	45.45	42.75	53.48

pi-

FW	45.96	20.42	22.78	18.85
LA	46.46	31.38	44.72	38.14
Total	46.31	28.19	37.79	32.04

**Bertini: proton on Ta -> pions**  
**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	0.37	<b>0.48</b>	1.06	<b>2.11</b>
LA	15.66	<b>18.83</b>	<b>36.25</b>	<b>35.34</b>
Total	13.62	<b>16.38</b>	28.24	<b>27.77</b>

pi-

FW	1.40	<b>0.93</b>	3.24	<b>1.96</b>
LA	7.24	6.53	26.32	<b>18.09</b>
Total	6.69	6.01	21.43	<b>14.67</b>

**8 GeV/c**

**12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	1.12	<b>2.7</b>	8.49	<b>14.72</b>
LA	<b>49.18</b>	<b>45.12</b>	<b>52.27</b>	<b>53.47</b>
Total	33.73	31.49	<b>38.45</b>	<b>41.23</b>

pi-

FW	18.94	<b>11.54</b>	28.03	<b>22.03</b>
LA	49.1	<b>34.51</b>	<b>53.78</b>	<b>49.55</b>
Total	41.13	<b>28.44</b>	<b>45.65</b>	<b>40.86</b>

**Bertini: pi+ on Be -> pions**

chi2/NDF calculated vs HARP data

**3 GeV/c****5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	17.31	<b>15.87</b>	33.59	<b>33.87</b>
LA	28.45	<b>11.44</b>	32.06	<b>15.9</b>
Total	26.55	<b>12.19</b>	32.51	<b>21.13</b>

pi-

FW	5.72	<b>7.14</b>	41.28	<b>18.25</b>
LA	22.76	<b>14.16</b>	38.04	<b>7.62</b>
Total	24.53	<b>19.55</b>	38.98	<b>10.72</b>

**8 GeV/c****12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

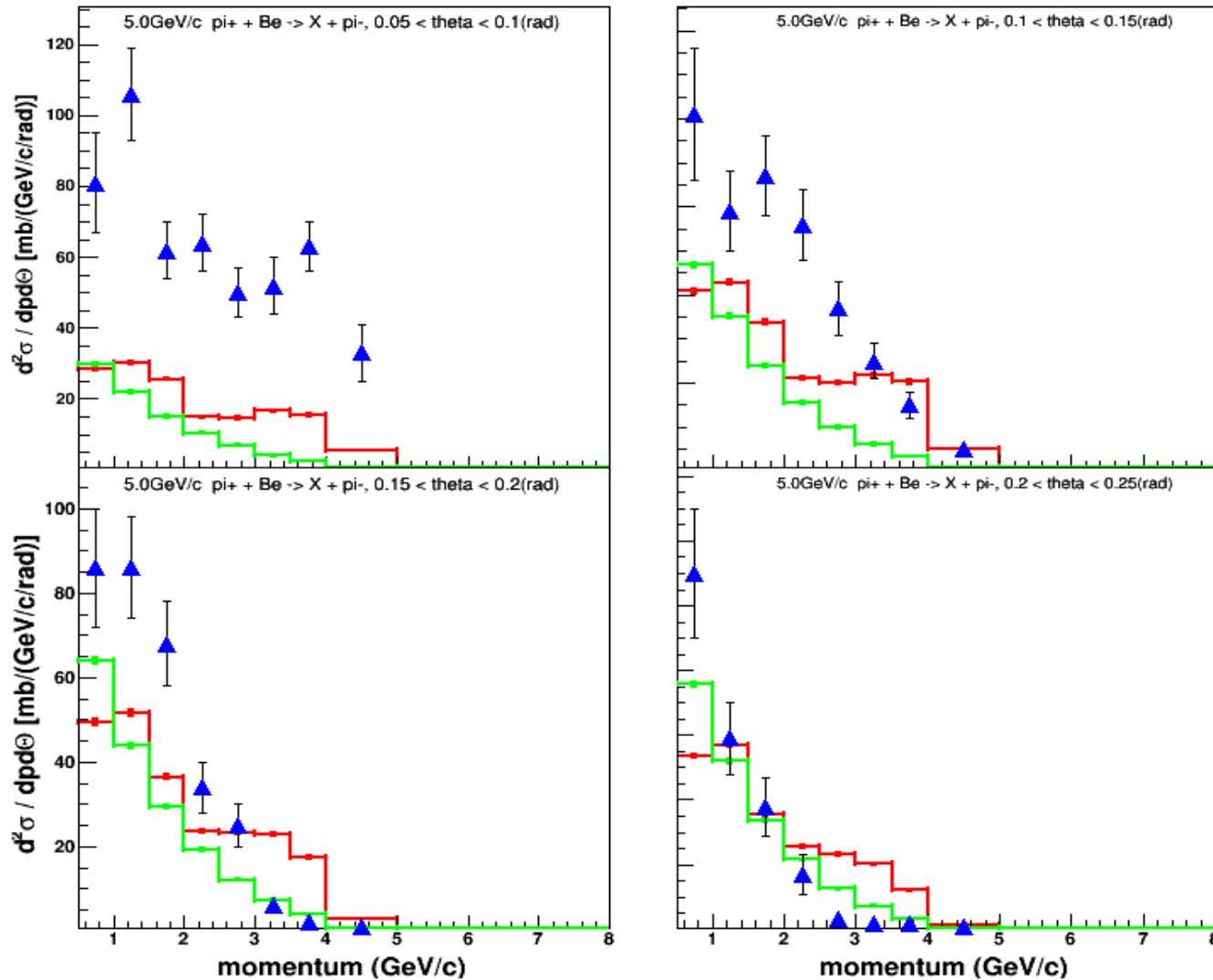
pi+

FW	28.36	<b>31.21</b>	4.29	<b>9.02</b>
LA	22.76	<b>14.16</b>	20.03	<b>9.45</b>
Total	24.53	<b>19.55</b>	15.06	<b>9.31</b>

pi-

FW	25.13	<b>21.57</b>	4.9	<b>7.38</b>
LA	19.6	<b>7.90</b>	9.41	<b>3.35</b>
Total	21.28	<b>12.05</b>	8.01	<b>4.6</b>

# 5GeV/c pi+ on Be -> pi- + X, at FW; data from HARP



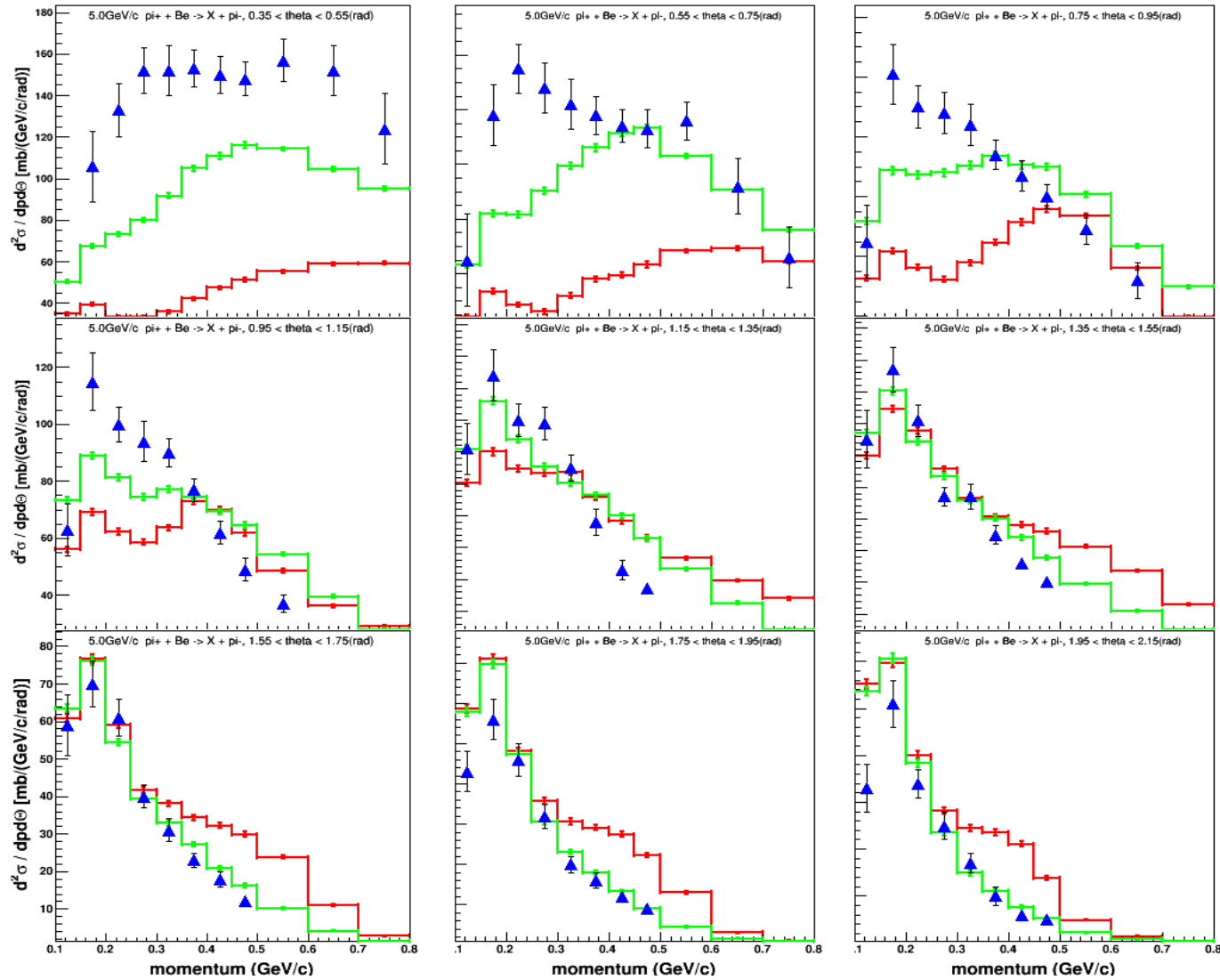
bertini vs HARP Data;  $\chi^2/\text{NDF}$  calculated over FW theta bins

$\chi^2/\text{NDF} = 41.2799$  for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 18.2507$  for Bertini-KopylovPHGen



# 5GeV/c pi+ on Be -> pi- + X, at LA; data from HARP



bertini vs HARP Data;  $\chi^2/\text{NDF}$  calculated over LA theta bins  
 $\chi^2/\text{NDF} = 38.0451$  for geant4-10-04-ref-08  
 $\chi^2/\text{NDF} = 7.62745$  for Bertini-KopylovPGen



**Bertini: pi+ on Cu -> pions**

chi2/NDF calculated vs HARP data

**3 GeV/c****5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	21.18	<b>12.24</b>	<b>45.56</b>	<b>44.13</b>
LA	28.49	<b>24.92</b>	<b>51.73</b>	<b>45.89</b>
Total	27.25	<b>22.76</b>	<b>49.94</b>	<b>45.38</b>

pi-

FW	2.86	<b>3.74</b>	24.15	<b>18.93</b>
LA	22.53	<b>13.17</b>	46.92	<b>29.01</b>
Total	19.19	<b>11.57</b>	40.27	<b>26.08</b>

**8 GeV/c****12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	12.11	<b>12.33</b>	2.35	<b>4.71</b>
LA	<b>41.2</b>	<b>44.51</b>	13.14	<b>15.24</b>
Total	32.02	<b>34.35</b>	9.73	<b>11.91</b>

pi-

FW	25.41	<b>21.47</b>	2.16	<b>3.16</b>
LA	<b>38.81</b>	<b>30.25</b>	9.55	9.94
Total	34.58	<b>27.48</b>	7.22	7.8



**Bertini: pi+ on Ta -> pions****chi2/NDF calculated vs HARP data****3 GeV/c****5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	55.05	<b>17.48</b>	22.24	<b>23.47</b>
LA	26.7	<b>23.64</b>	<b>46.76</b>	<b>41.16</b>
Total	31.53	<b>22.59</b>	<b>39.62</b>	<b>36.02</b>

pi-

FW	3.1	<b>4.38</b>	16.35	<b>11.74</b>
LA	24.34	<b>14.0</b>	38.01	<b>21.13</b>
Total	20.72	<b>12.36</b>	31.71	<b>18.4</b>

**8 GeV/c****12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

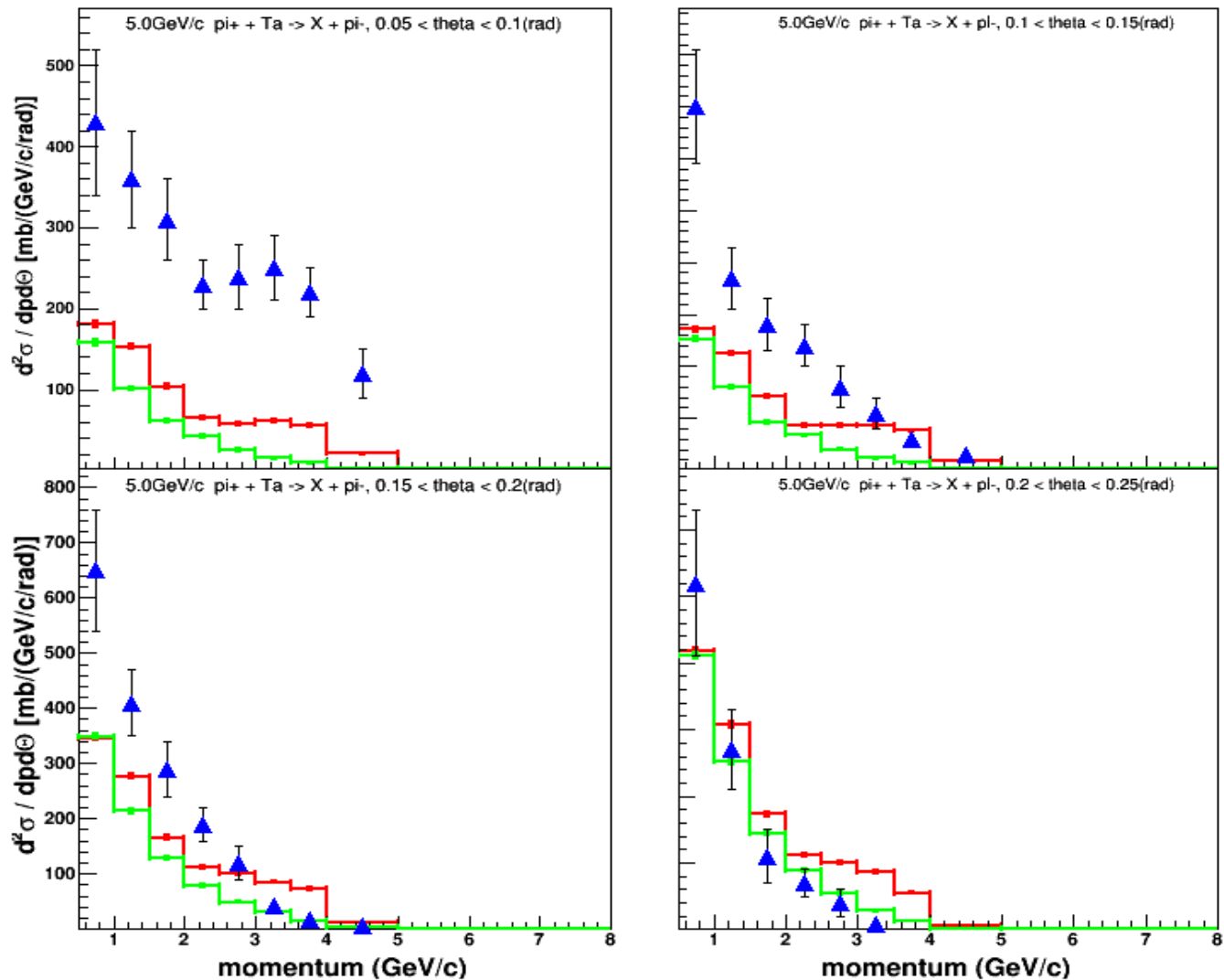
pi+

FW	15.36	<b>18.04</b>	3.08	<b>4.53</b>
LA	<b>42.36</b>	<b>40.73</b>	16.77	<b>17.61</b>
Total	33.84	<b>33.57</b>	12.44	<b>13.48</b>

pi-

FW	25.71	<b>23.25</b>	2.35	<b>3.38</b>
LA	33.03	<b>22.52</b>	14.06	<b>13.5</b>
Total	30.85	<b>22.74</b>	10.43	<b>10.36</b>

# 5GeV/c pi+ on Ta -> pi- + X, at FW; data from HARP



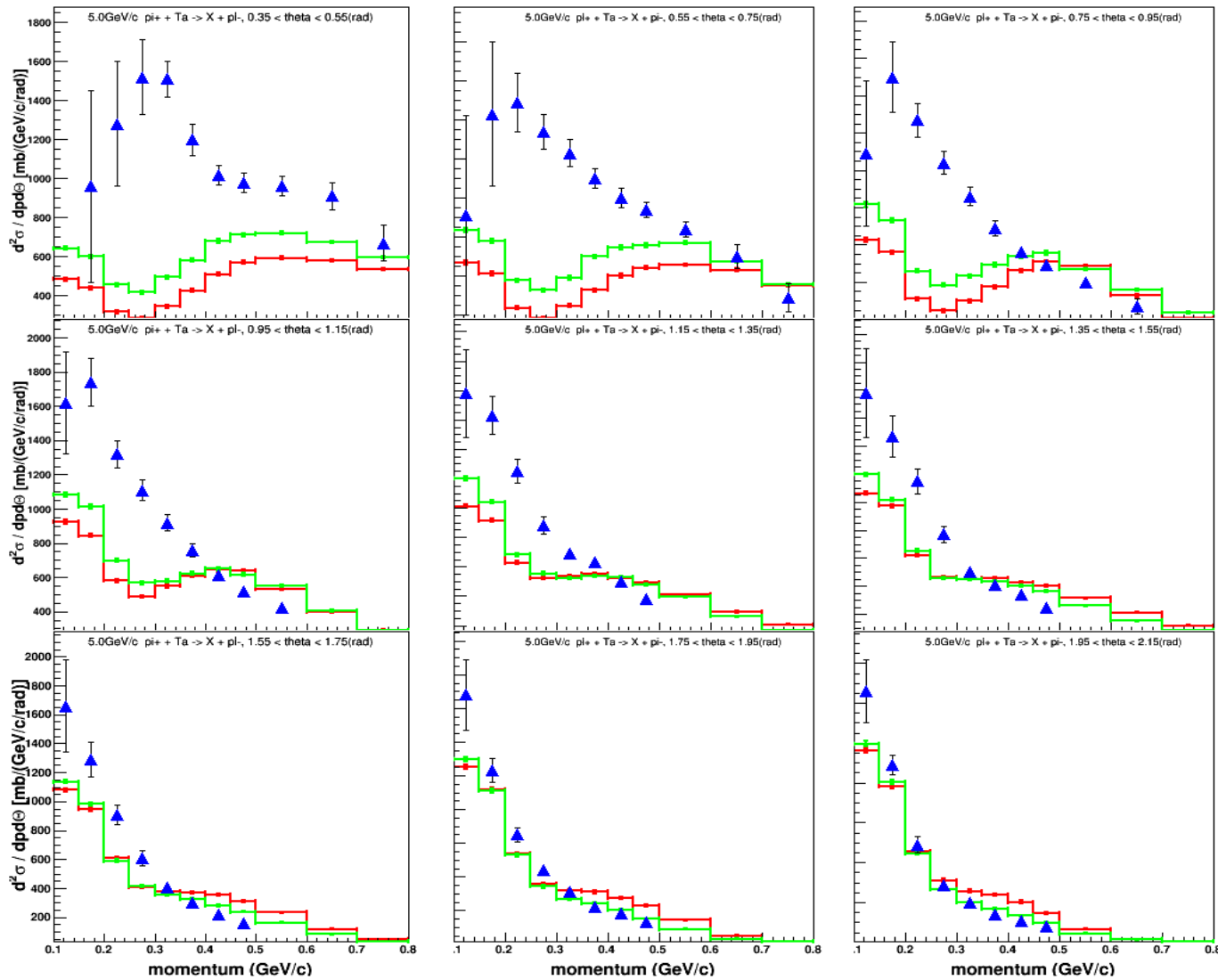
bertini vs HARP Data;  $\chi^2/\text{NDF}$  calculated over FW theta bins

$\chi^2/\text{NDF} = 16.3501$  for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 11.7378$  for Bertini-KopylovPHGen



# 5GeV/c pi+ on Ta -> pi- + X, at LA; data from HARP



bertini vs HARP Data;  $\chi^2/\text{NDF}$  calculated over LA theta bins  
 $\chi^2/\text{NDF} = 38.0141$  for geant4-10-04-ref-08  
 $\chi^2/\text{NDF} = 21.1336$  for Bertini-KopylovPHGen



**Bertini: pi- on Be -> pions****chi2/NDF calculated vs HARP data****3 GeV/c****5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	11.49	<b>14.72</b>	20.18	<b>29.46</b>
LA	36.39	<b>14.77</b>	29.85	<b>11.16</b>
Total	32.15	<b>14.76</b>	27.16	<b>16.25</b>

pi-

FW	33.17	<b>27.49</b>	<b>49.07</b>	<b>57.92</b>
LA	33.77	<b>10.52</b>	32.71	<b>9.66</b>
Total	33.67	<b>13.41</b>	37.47	<b>23.7</b>

**8 GeV/c****12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	27.75	<b>42.13</b>	14.28	<b>50.82</b>
LA	26.43	<b>15.1</b>	29.07	<b>16.75</b>
Total	26.84	<b>23.47</b>	24.49	<b>27.3</b>

pi-

FW	<b>44.31</b>	<b>60.52</b>	23.31	<b>71.7</b>
LA	<b>36.65</b>	<b>14.36</b>	47.91	<b>12.93</b>
Total	<b>39.07</b>	<b>28.93</b>	40.14	<b>31.49</b>

**Bertini: pi- on Cu -> pions**

**chi2/NDF calculated vs HARP data**

**3 GeV/c**

**5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	8.21	<b>10.32</b>	12.25	<b>19.6</b>
LA	33.92	<b>26.99</b>	35.77	<b>28.2</b>
Total	29.54	<b>24.15</b>	29.4	<b>25.87</b>

pi-

FW	23.08	<b>17.71</b>	32.96	<b>39.97</b>
LA	29.3	<b>21.83</b>	31.86	<b>23.98</b>
Total	28.24	<b>21.13</b>	32.18	<b>28.63</b>

**8 GeV/c**

**12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	25.91	<b>42.37</b>	20.86	<b>40.68</b>
LA	26.56	<b>24.41</b>	23.34	<b>26.65</b>
Total	26.35	<b>29.97</b>	22.57	<b>30.99</b>

pi-

FW	<b>36.6</b>	<b>54.39</b>	24.98	<b>43.7</b>
LA	32.84	<b>31.97</b>	<b>43.71</b>	<b>39.2</b>
Total	34.0	<b>38.92</b>	<b>37.79</b>	<b>40.62</b>

**Bertini: pi- on Ta -> pions****chi2/NDF calculated vs HARP data****3 GeV/c****5 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	1.81	<b>1.39</b>	8.29	<b>11.71</b>
LA	19.76	<b>16.95</b>	<b>52.1</b>	<b>45.0</b>
Total	16.7	<b>14.3</b>	<b>39.36</b>	<b>35.31</b>

pi-

FW	11.35	<b>4.94</b>	18.42	<b>22.58</b>
LA	20.91	<b>15.24</b>	<b>40.18</b>	<b>29.4</b>
Total	19.28	<b>13.49</b>	33.85	<b>27.42</b>

**8 GeV/c****12 GeV/c**

10.04.r08

Bertini-KopylovPH

10.04.r08

Bertini-KopylovPH

pi+

FW	21.25	<b>30.8</b>	29.83	<b>68.69</b>
LA	<b>45.06</b>	<b>40.02</b>	<b>50.37</b>	<b>47.24</b>
Total	<b>37.54</b>	<b>37.11</b>	<b>43.88</b>	<b>54.01</b>

pi-

FW	26.71	<b>38.93</b>	32.13	<b>55.16</b>
LA	<b>44.95</b>	<b>37.23</b>	<b>60.32</b>	<b>53.94</b>
Total	<b>39.19</b>	<b>37.77</b>	<b>51.42</b>	<b>54.33</b>

**Bertini: 5GeV/c pi- on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

	<b>Carbon (C )</b>		<b>Copper (Cu)</b>		<b>Lead (Pb)</b>	
	10.04.r08	Bertini-KopylovPH	10.04.r08.	Bertini-KopylovPH	10.4.r08	Bertini-KopylovPH
proton	8.44	<b>7.18</b>	33.98	<b>43.42</b>	20.16	<b>24.9</b>
neutron	6.69	<b>6.73</b>	17.76	<b>22.43</b>	25.78	<b>31.02</b>

**Bertini: 5GeV/c pi+ on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

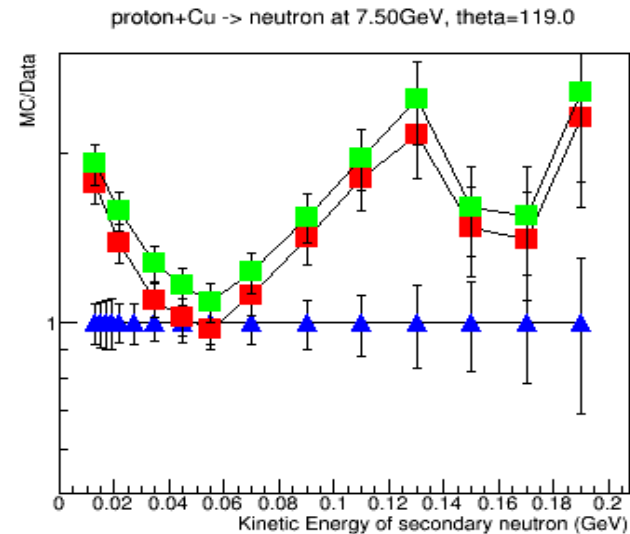
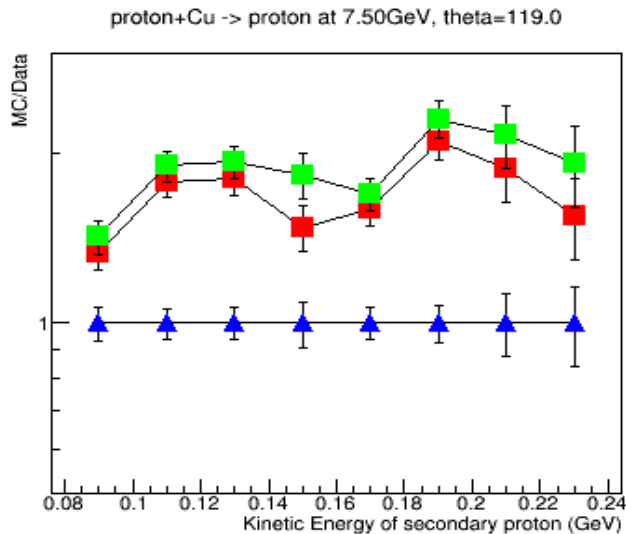
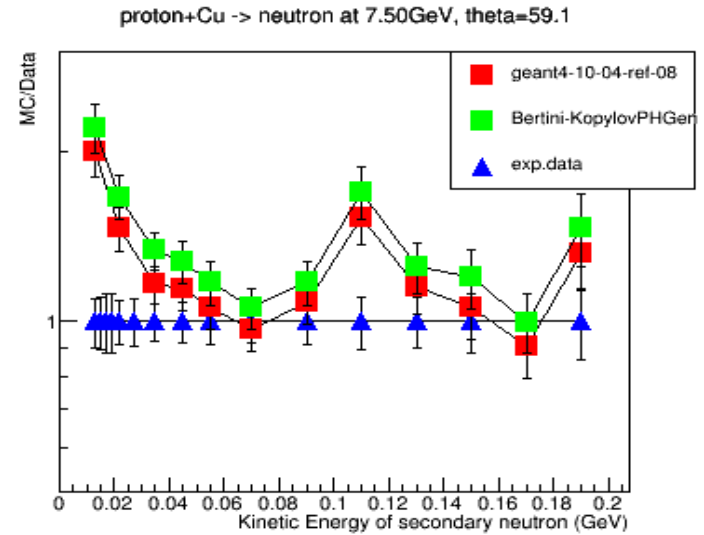
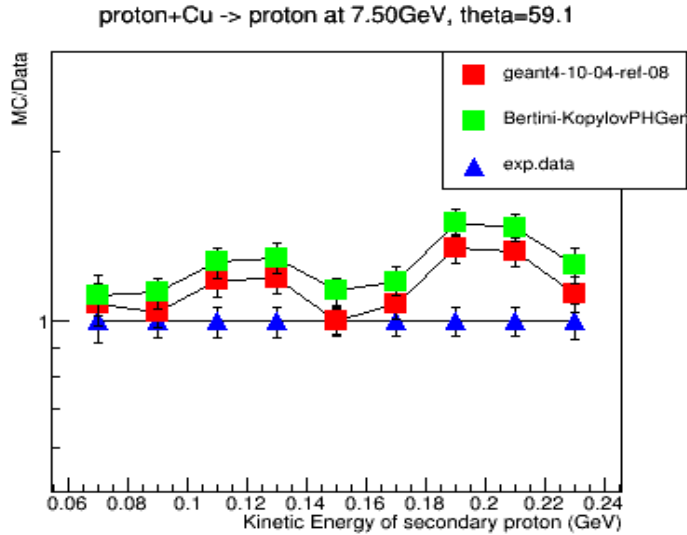
	<b>Carbon (C )</b>		<b>Copper (Cu)</b>		<b>Lead (Pb)</b>	
	10.04.r08	Bertini-KopylovPH	10.04.r08.	Bertini-KopylovPH	10.4.r08	Bertini-KopylovPH
proton	13.56	<b>13.53</b>	29.44	<b>33.71</b>	17.7	<b>21.2</b>
neutron	4.48	<b>4.3</b>	11.7	<b>15.58</b>	26.31	<b>29.11</b>

**Bertini: 7.5GeV/c proton on nucleus -> proton/neutron**

**chi2/NDF calculated vs ITEP771 data**

	<b>Carbon (C )</b>		<b>Copper (Cu)</b>		<b>Lead (Pb)</b>	
	10.04.r08	Bertini-KopylovPH	10.04.r08.	Bertini-KopylovPH	10.4.r08	Bertini-KopylovPH
proton	13.86	<b>13.69</b>	<b>50.01</b>	<b>70.56</b>	<b>55.15</b>	<b>72.73</b>
neutron	3.66	<b>4.15</b>	17.67	<b>30.24</b>	30.59	<b>45.66</b>

# 7.5 GeV/c proton on Cu -> proton/neutron; data from ITEP771



## bertini vs (ITEP) Data

$\chi^2/\text{NDF} = 50.0134$  for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 70.557$  for Bertini-KopylovPHGen

## bertini vs (ITEP) Data

$\chi^2/\text{NDF} = 17.6703$  for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 30.2454$  for Bertini-KopylovPHGen



# Summary – Bertini with Kopylov Phase Space Generator

- Use of Kopylov phase space generator in Bertini does improve a number of spectra of secondary pions produced in hadron-nucleus interactions, especially at large angle (LA)
  - In some cases use of Kopylov phase space generator negatively affects forward (FW) spectra of secondary pions from h+A
  - But we should bear in mind that HARP data on FW particle production are not always of perfect quality, some have large errors
- The trend to (overall) improvement kind of “fades” with increasing energy
  - We have to remember that Bertini is formally valid up to 10 GeV
- It also becomes harder to judge the trend as the target nucleus gets heavier
- Use of Kopylov phase space generator in Bertini seems to be pulling simulated spectra of secondary protons/neutrons from h+A slightly away from data
- Overall, use of Kopylov phase space generator in Bertini is an interesting option; perhaps other Bertini parameters can be tweaked in combination with Kopylov generator, to see if further improvement of the MC results is feasible