



Validation Results from Geant4.10.4.ref09

Status of FTF and QGS

Julia Yarba, Fermilab

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General Information

- Focus: hadron production in hadron-nucleus interactions at intermediate (if applicable) or high energies (test19, test47)
- Regression: 10.4.p02, 10.4.ref07, 10.4.ref08
- Results are mainly presented as χ^2/NDF
 - χ^2/NDF is often “bad” (same for other models)
 - MC results are considered “better” if χ^2/NDF is smaller than the one of **10.4.p02** by a factor of 1.5 or more (or “worse” if χ^2/NDF goes the other way around)
 - In some cases χ^2/NDF is “very bad” – those are “flagged”
 - I know that other approach(es) are being suggested/considered; will make it a priority to get more familiar with those and hopefully to incorporate into the validation procedure in the near future
- Selected plots included for illustrative purpose
- All results from ref09 are uploaded to DoSSiER
- NOTE: list of experimental datasets in backup

Color Code of Results in the Tables

- **“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”**

Status of FTF

- Obviously, there is a number of changes as compared vs 10.4.p02
 - Better agreement with thin target data is expected in some areas...
 - ... but not necessarily everywhere
 - We have discussed it earlier in the 10.4 development cycle
 - <https://indico.cern.ch/event/702280/contributions/2895765/attachments/1600608/2539512/G4HAD-Feb14-2018-v2.pdf>
- Quite stable across development cycle 10.4.refXX
- Only small fluctuations are observed in modeling hadron-nucleus interactions in the intermediate energy range
- Modeling of antiproton production in hadron-nucleus interactions in the intermediate energy range is “gone” (and is “stable” at that)
- As of 10.4.ref09, some changes are observed in modeling production of kaons and Lambda in proton-nucleus interactions at higher energies, e.g. 31 GeV/c proton on C (NA61)

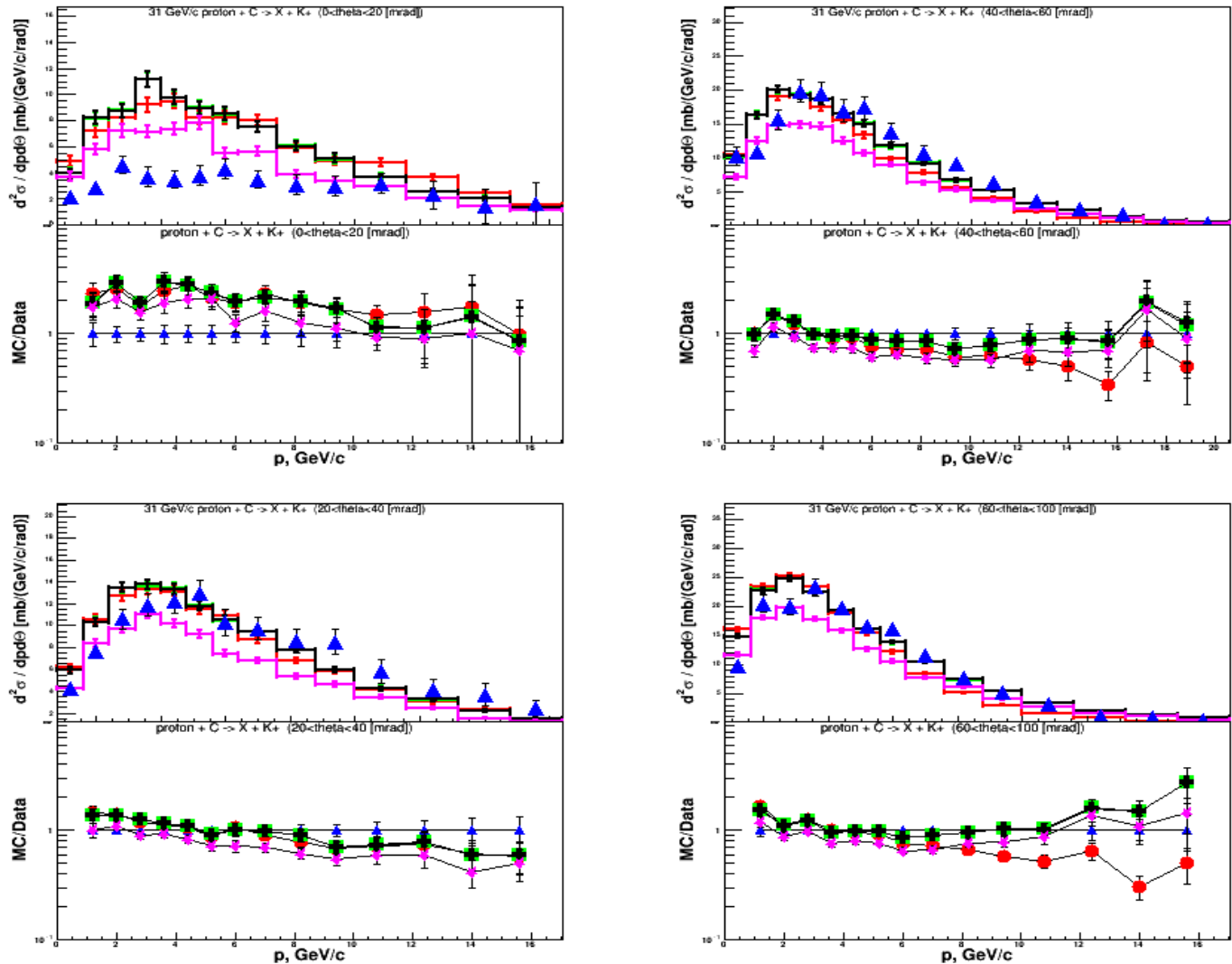
FTFP: 31GeV/c proton on C --> hadrons
chi2/NDF calculated vs NA61 data

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	7.37	23.24	23.27	25.26
pi-	5.55	23.73	23.71	(27.07)
K+	6.93	6.53	6.51	5.64
K-	7.30	7.58	7.53	6.32
K0s	2.05	2.05	2.09	2.25
Lambda	8.91	4.58	4.59	(7.15)
proton	73.81	39.24	39.23	45.37

NOTE-1: Changes in modeling charged kaon production look better numerically. Whether they “look good” in visual inspection may depend on the point of view; selected plots included for illustration (10.4.ref09 is **magenta**)

NOTE-2: Numerically, slight trend to (further) degradation is observed in modeling pi- production but it does not clearly show in visual inspection.

FTFP: 31GeV/c proton + C \rightarrow K⁺ ; data NA61 (I)



MC vs NA61 Data; χ^2 /NDF calculated over ALL theta bins

χ^2 /NDF = 6.93177 for geant4-10-04-patch-02

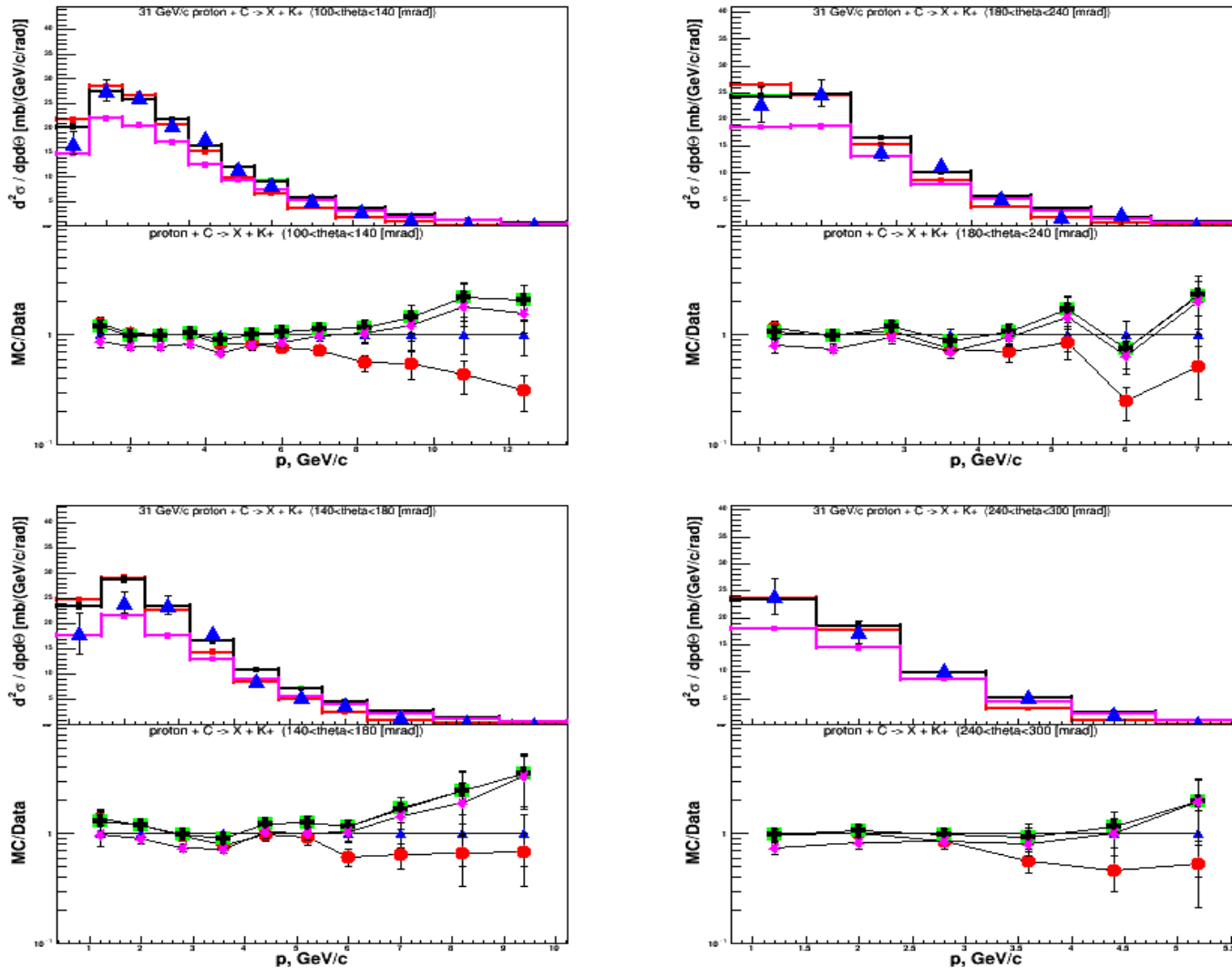
χ^2 /NDF = 6.53209 for geant4-10-04-ref-07

χ^2 /NDF = 6.50799 for geant4-10-04-ref-08

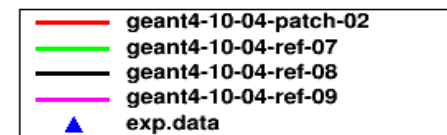
χ^2 /NDF = 5.64186 for geant4-10-04-ref-09



FTFP: 31GeV/c proton + C \rightarrow K $^+$; data NA61 (II)

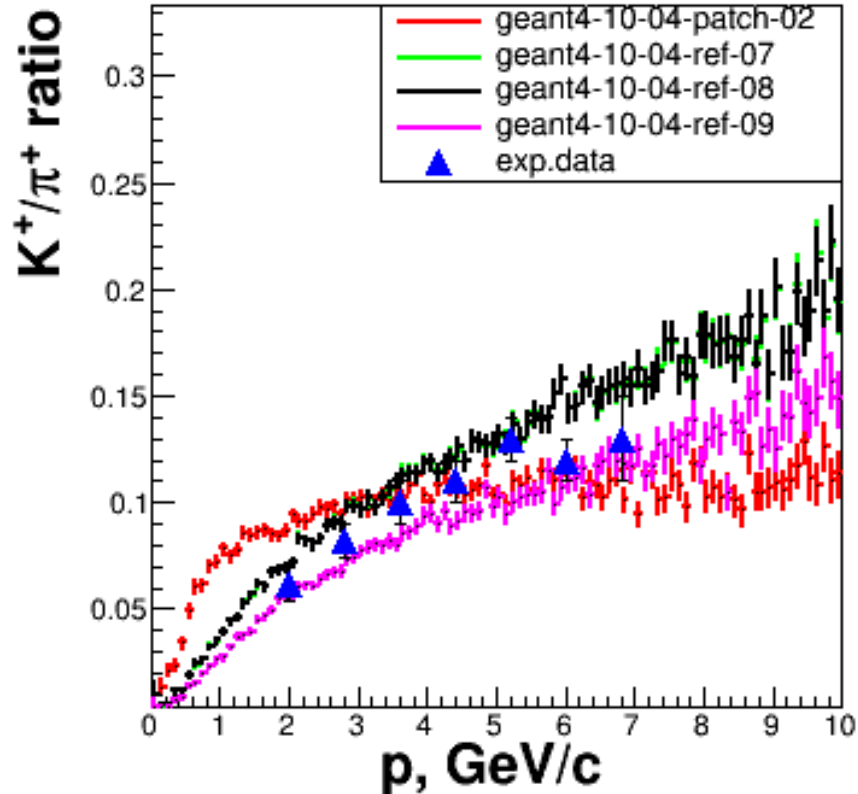


MC vs NA61 Data; χ^2 /NDF calculated over ALL theta bins
 χ^2 /NDF = 6.93177 for geant4-10-04-patch-02
 χ^2 /NDF = 6.53209 for geant4-10-04-ref-07
 χ^2 /NDF = 6.50799 for geant4-10-04-ref-08
 χ^2 /NDF = 5.64186 for geant4-10-04-ref-09

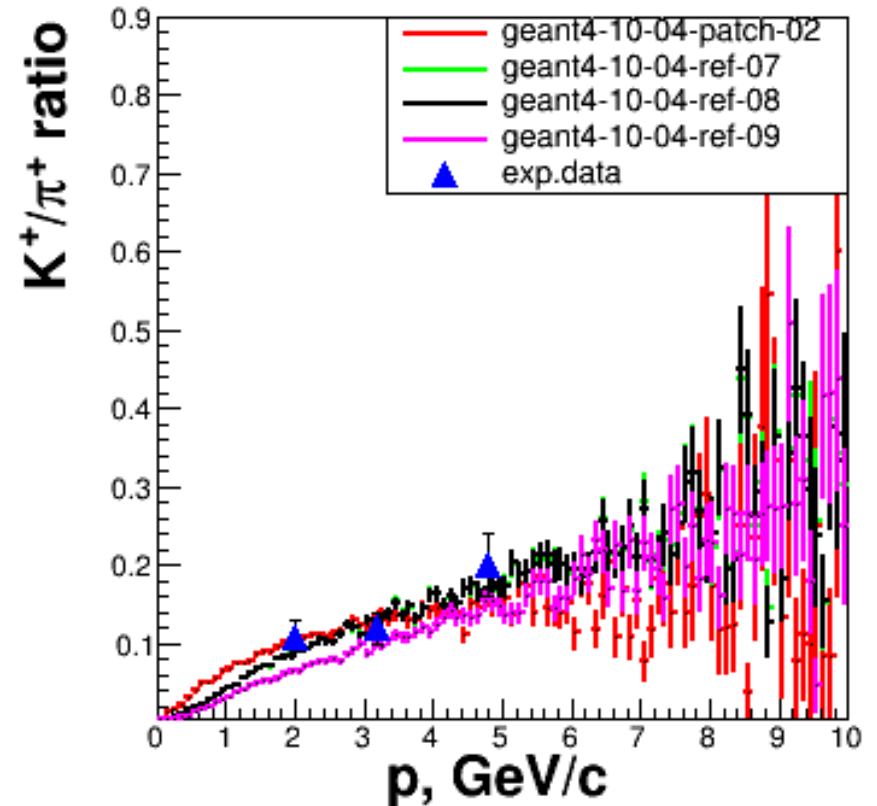


FTFP: 31GeV/c proton + C \rightarrow K^+/π^+ ; data NA61

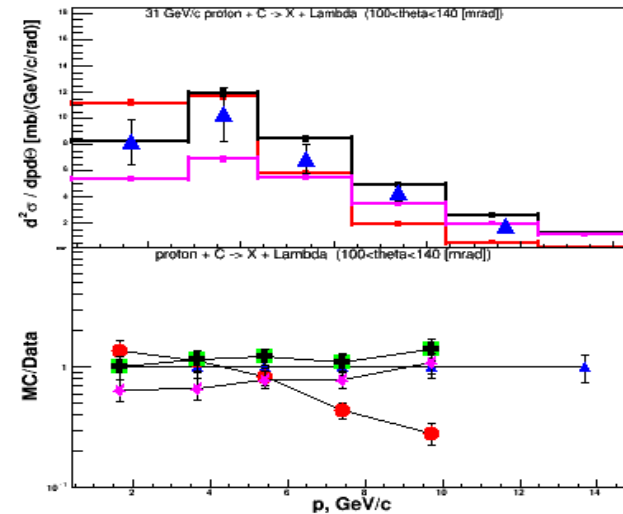
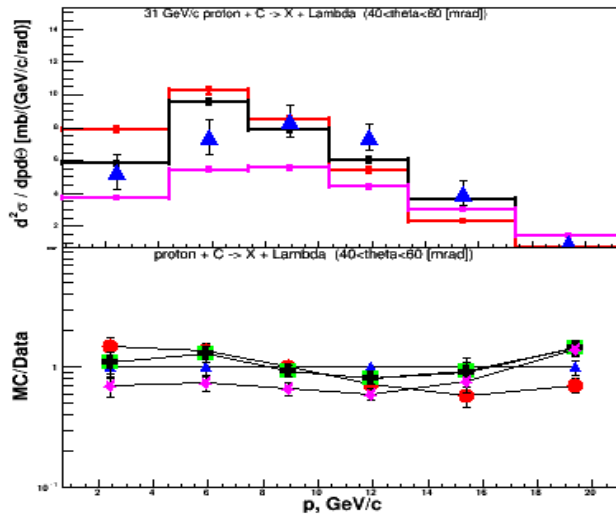
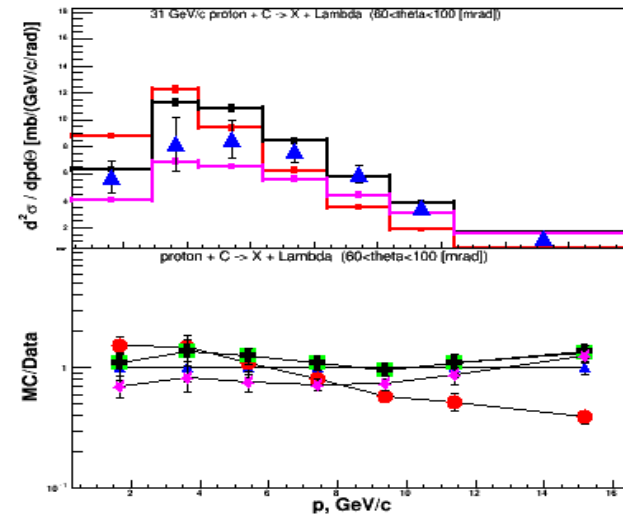
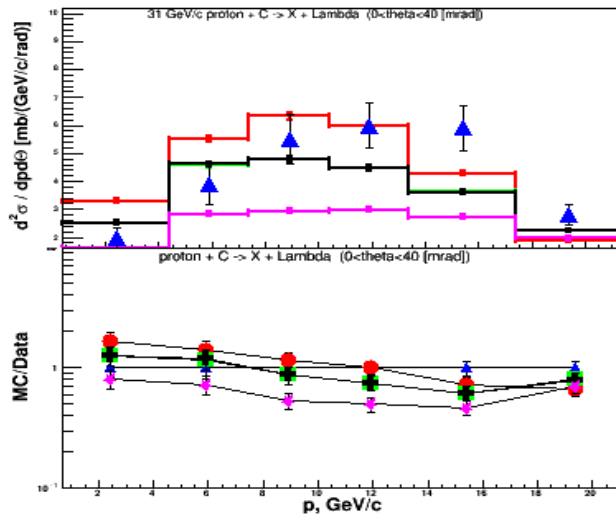
proton + C, K^+/π^+ ($20 < \theta < 140$ (mrad))



proton + C, K^+/π^+ ($140 < \theta < 240$ (mrad))



FTFP: 31GeV/c proton + C -> Lambda ; data NA61 (I)



MC vs NA61 Data; χ^2/NDF calculated over ALL theta bins

$\chi^2/\text{NDF} = 8.90839$ for geant4-10-04-patch-02

$\chi^2/\text{NDF} = 4.58098$ for geant4-10-04-ref-07

$\chi^2/\text{NDF} = 4.59572$ for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 7.14851$ for geant4-10-04-ref-09



Status of QGS

- Obviously, there is a number of changes as compared vs 10.4.p02
 - Model is currently in development and re-tuning
 - We have discussed it earlier in the 10.4 development cycle
 - <https://indico.cern.ch/event/702280/contributions/2895765/attachments/1600608/2539512/G4HAD-Feb14-2018-v2.pdf>
- Relatively stable up to 10.4.ref08
- Multiple changes are observed in 10.4.ref09

QGSP: 158GeV/c proton on C --> hadrons
chi2/NDF calculated vs NA49 data

dN / dxF

<pt> vs xF

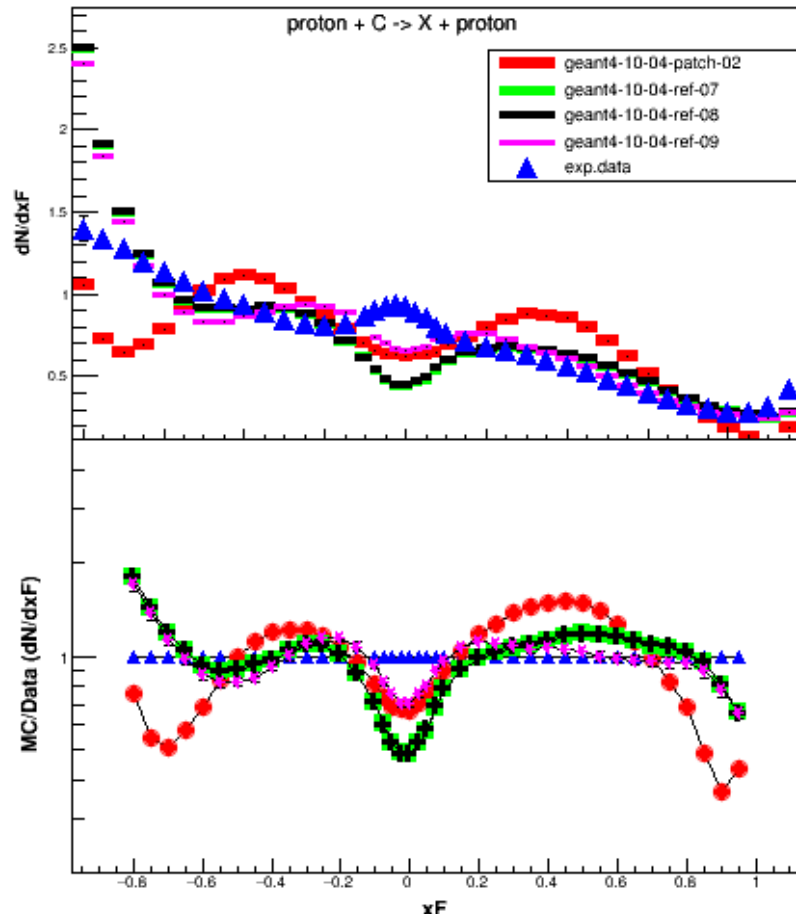
	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	107.79	82.95	83.15	74.96	20.53	2.86	2.77	(5.12)
pi-	99.76	31.37	31.45	99.41	18.59	3.24	3.35	2.50
proton	88.93	62.27	62.26	24.96	115.01	44.20	44.10	58.07
antiproton	665.87	70.94	71.93	90.88	14.92	7.28	7.59	137.17
neutron	9.37	9.62	9.53	5.36				

d2sigma / dxF dpT

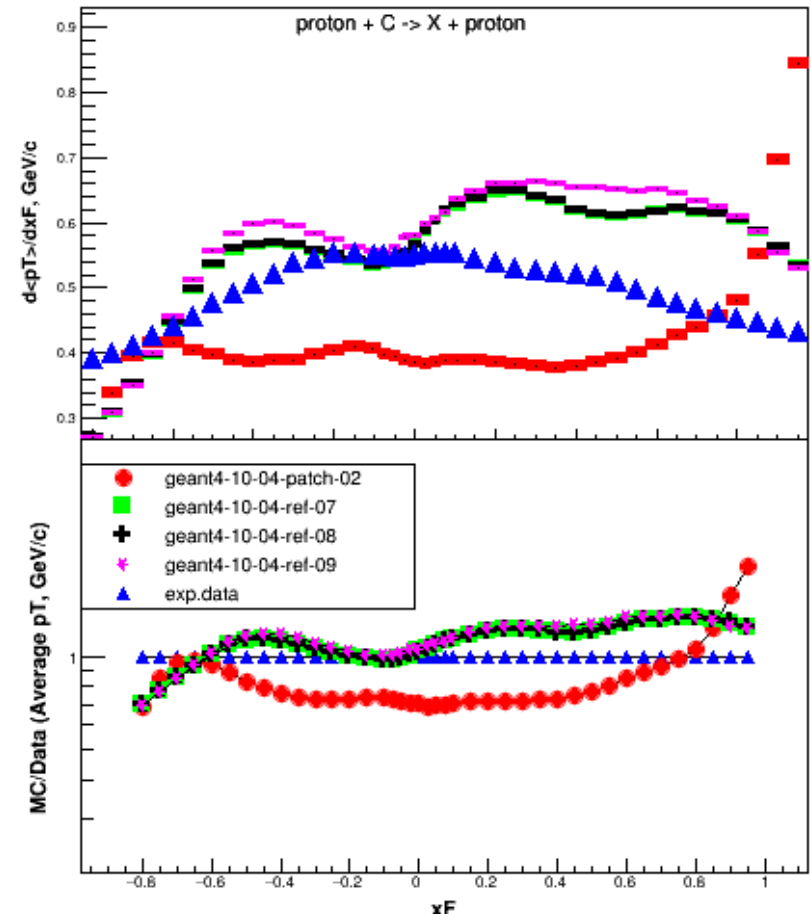
	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	55.34	24.23	24.16	(28.57)
pi-	51.17	15.05	15.14	(24.69)
proton	54.41	33.36	33.23	(28.99)
antiproton	N/A	N/A	11.01	(21.96)

NOTE: While many chi2 values in 10.4.ref09 still show an improvement over 10.4.p02, several of them indicate some trend to degradation, e.g. modeling of antiproton production or multiplicity spectrum of pi-

QGSP: 158 GeV/c proton + C -> proton; data NA49

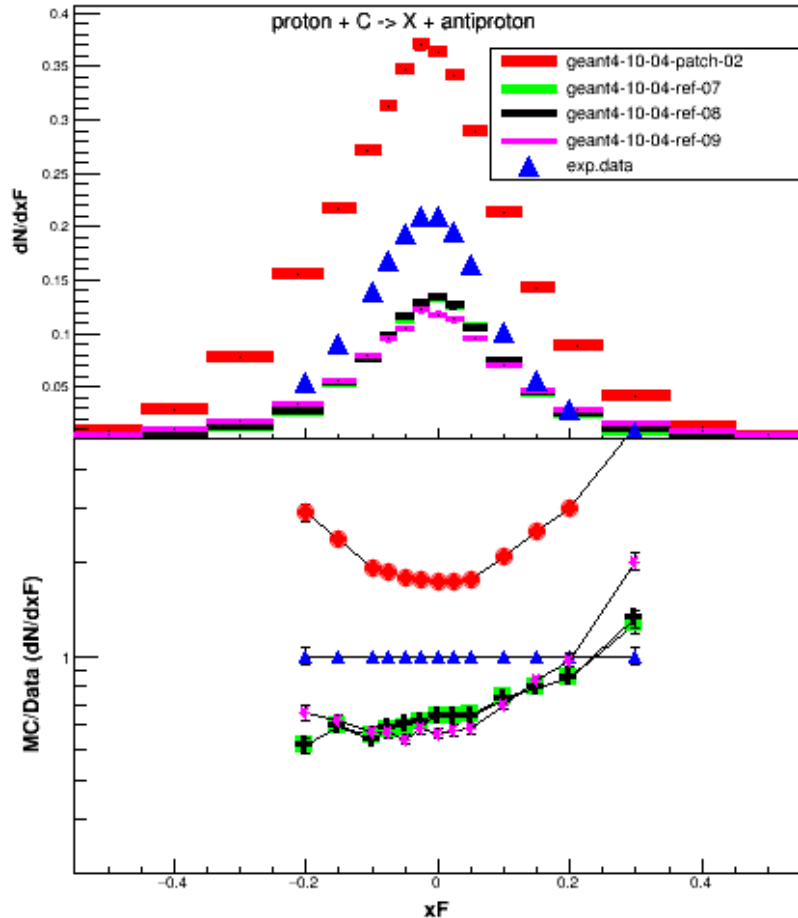


$\chi^2/\text{NDF} = 88.9319$ for geant4-10-04-patch-02 vs NA49 Data
 $\chi^2/\text{NDF} = 62.269$ for geant4-10-04-ref-07 vs NA49 Data
 $\chi^2/\text{NDF} = 62.2632$ for geant4-10-04-ref-08 vs NA49 Data
 $\chi^2/\text{NDF} = 24.9588$ for geant4-10-04-ref-09 vs NA49 Data

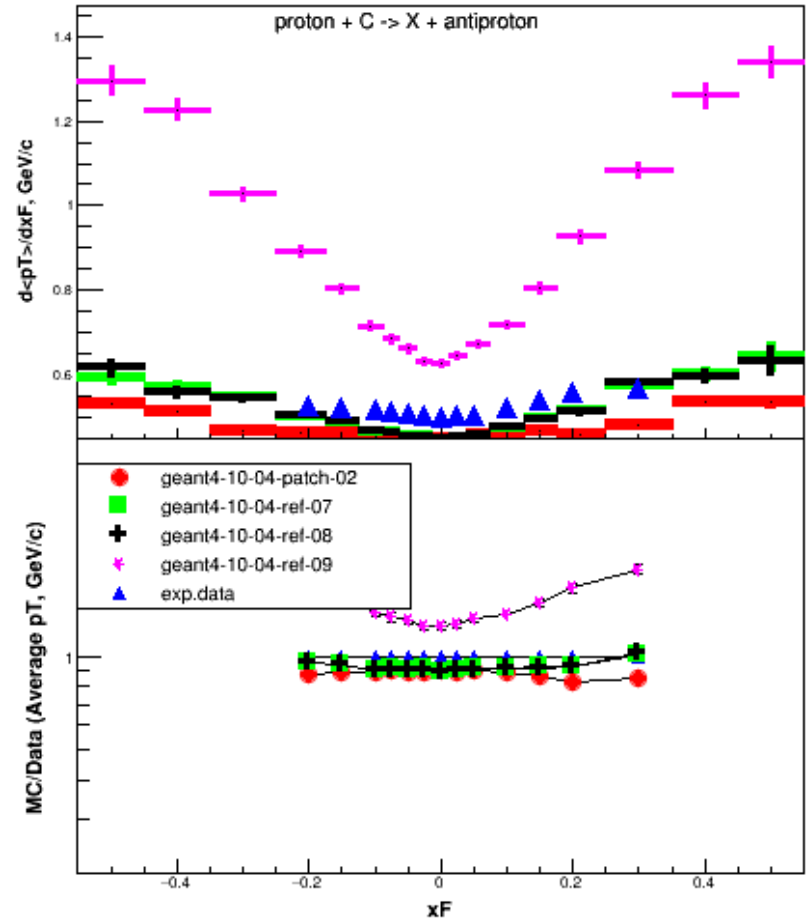


$\chi^2/\text{NDF} = 115.016$ for geant4-10-04-patch-02 vs NA49 Data
 $\chi^2/\text{NDF} = 44.2002$ for geant4-10-04-ref-07 vs NA49 Data
 $\chi^2/\text{NDF} = 44.1065$ for geant4-10-04-ref-08 vs NA49 Data
 $\chi^2/\text{NDF} = 58.0729$ for geant4-10-04-ref-09 vs NA49 Data

QGSP: 158 GeV/c proton + C -> antiproton; data NA49



$\chi^2/\text{NDF} = 665.87$ for geant4-10-04-patch-02 vs NA49 Data
 $\chi^2/\text{NDF} = 70.9395$ for geant4-10-04-ref-07 vs NA49 Data
 $\chi^2/\text{NDF} = 71.935$ for geant4-10-04-ref-08 vs NA49 Data
 $\chi^2/\text{NDF} = 90.8788$ for geant4-10-04-ref-09 vs NA49 Data



$\chi^2/\text{NDF} = 14.9243$ for geant4-10-04-patch-02 vs NA49 Data
 $\chi^2/\text{NDF} = 7.28314$ for geant4-10-04-ref-07 vs NA49 Data
 $\chi^2/\text{NDF} = 7.59413$ for geant4-10-04-ref-08 vs NA49 Data
 $\chi^2/\text{NDF} = 137.172$ for geant4-10-04-ref-09 vs NA49 Data

chi2/NDF calculated vs SAS M6E data (“Barton data”)

QGSP: 100GeV/c proton on C --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	5.27	14.59	14.48	(7.56)
pi-	4.33	1.53	1.55	(5.94) (consistent w/NA49 benchmark)
K+	2.34	6.53	6.97	(8.62)
K-	1.08	0.89	0.91	0.86 (large errors on exp.data)
proton	32.56	3.93	3.98	(5.38) (mainly consistent w/NA49, NA61 benchmark)
antiproton	12.91	0.50	0.50	(0.93) (large errors on exp.data)

QGSP: 100GeV/c proton on Cu --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	5.61	11.40	11.81	(5.47)
pi-	2.19	1.18	1.14	7.76
K+	1.10	3.76	3.38	(4.62)
K-	1.14	1.02	0.79	1.08 (large errors on exp.data)
proton	37.51	2.22	2.04	(3.16)
antiproton	5.98	0.25	0.31	(0.54) (large errors on exp.data)

QGSP: 100GeV/c proton on Pb --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	7.03	9.61	9.58	4.51
pi-	1.12	1.56	1.55	11.14
K+	1.66	2.97	3.24	4.57
K-	0.64	0.59	0.60	0.66 (large errors on exp.data)
proton	35.99	3.26	3.12	(3.87)
antiproton	1.04	0.61	0.63	0.78 (large errors on exp.data)

chi2/NDF calculated vs SAS M6E data (“Barton data”)

QGSP: 100GeV/c pions on C --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	7.41	11.67	11.68	10.95
pi-	14.19	17.60	17.52	15.64
K+	19.38	22.40	22.27	18.32
K-	20.20	2.47	2.67	(1.88) (large errors on exp.data)
proton	5.96	14.82	14.92	(16.52)
antiproton	26.22	4.07	3.98	3.57 (large errors on exp.data)

QGSP: 100GeV/c pions on Cu --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	7.72	8.34	7.51	7.65
pi-	17.61	17.03	17.61	14.54
K+	22.66	25.97	25.97	19.86
K-	19.06	2.61	3.36	3.52 (large errors on exp.data)
proton	4.75	12.15	10.95	11.78
antiproton	25.23	2.11	1.36	2.36 (large errors on exp.data)

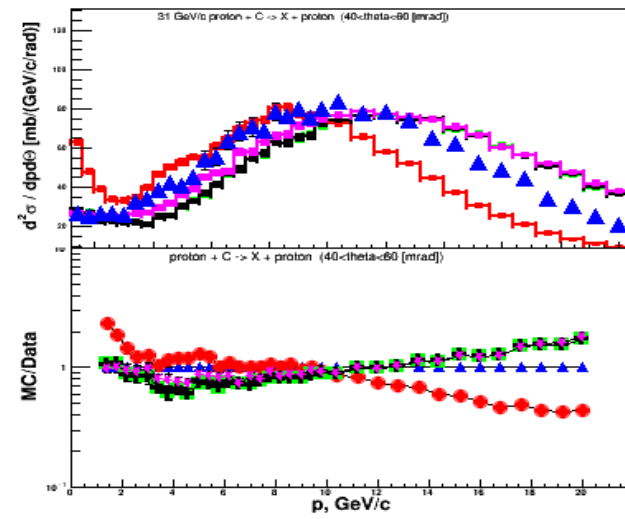
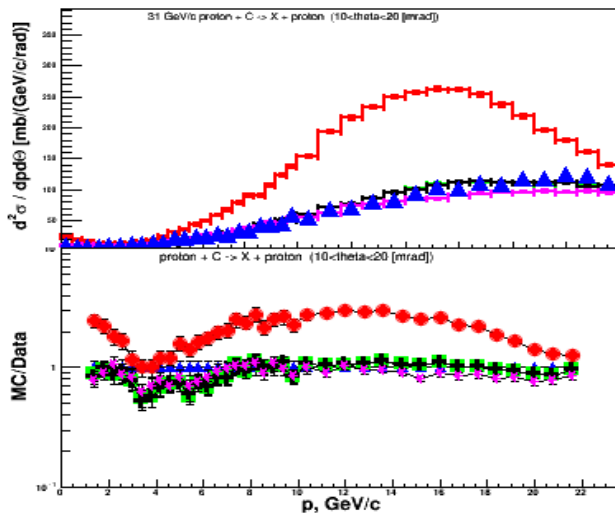
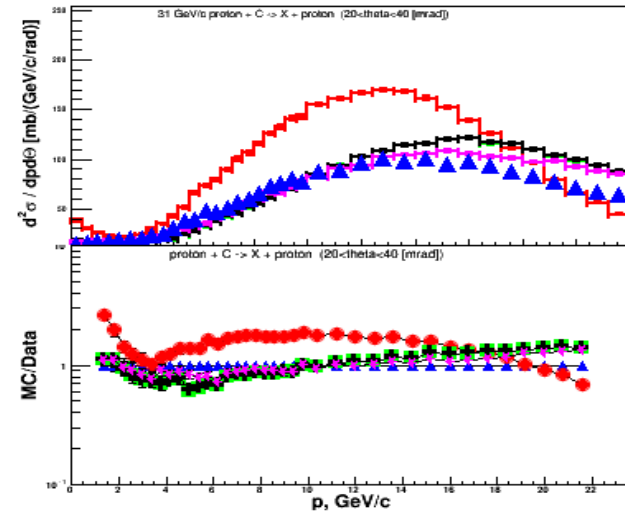
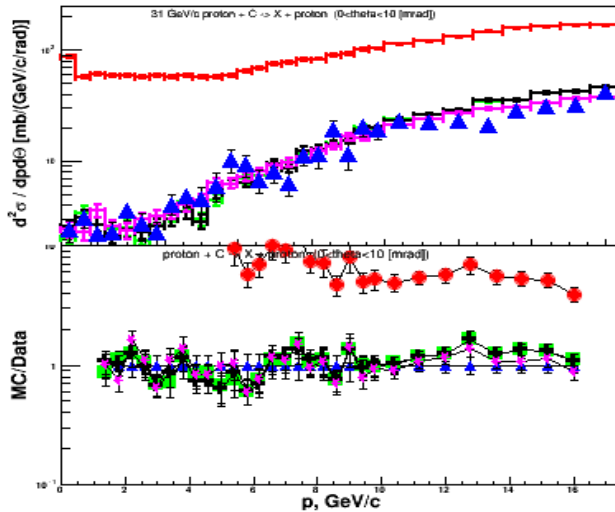
QGSP: 100GeV/c pions on Pb --> hadrons

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	8.92	7.56	7.12	6.75
pi-	12.88	14.46	14.39	12.40
K+	14.26	15.89	15.39	12.47
K-	8.18	2.12	1.85	2.27 (large errors on exp.data)
proton	1.68	7.54	7.99	8.71
antiproton	6.04	4.21	4.18	4.26 (large errors on exp.data)

QGSP: 31GeV/c proton on C --> hadrons
chi2/NDF calculated vs NA61 data

	10.04.p02	10.04.ref07	10.04.ref08	10.04.ref09
pi+	66.50	13.46	13.45	(16.55)
pi-	72.67	11.32	11.31	(13.43)
K+	55.90	8.88	8.99	(10.05)
K-	16.71	10.79	10.52	10.81
K0s	10.48	5.47	5.44	5.19
Lambda	14.18	15.06	15.19	21.65
proton	155.98	15.07	14.97	(12.68)

QGSP:31 GeV/c proton + C -> proton; data NA61 (I)



MC vs NA61 Data; χ^2/NDF calculated over ALL theta bins

$\chi^2/\text{NDF} = 155.98$ for geant4-10-04-patch-02

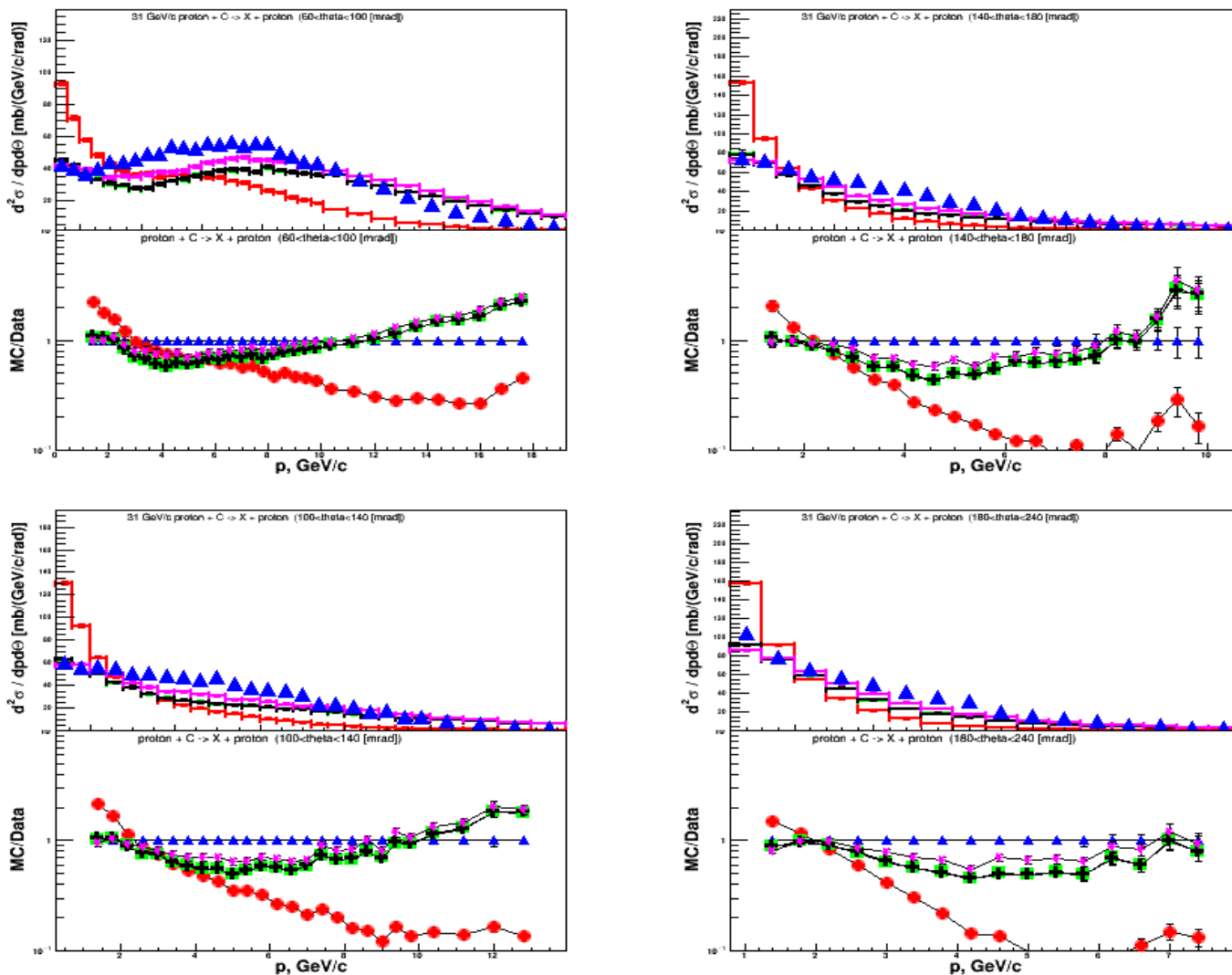
$\chi^2/\text{NDF} = 15.0698$ for geant4-10-04-ref-07

$\chi^2/\text{NDF} = 14.9739$ for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 12.6796$ for geant4-10-04-ref-09



QGSP: 31 GeV/c proton + C -> proton; data NA61 (II)



MC vs NA61 Data; χ^2/NDF calculated over ALL theta bins

$\chi^2/\text{NDF} = 155.98$ for geant4-10-04-patch-02

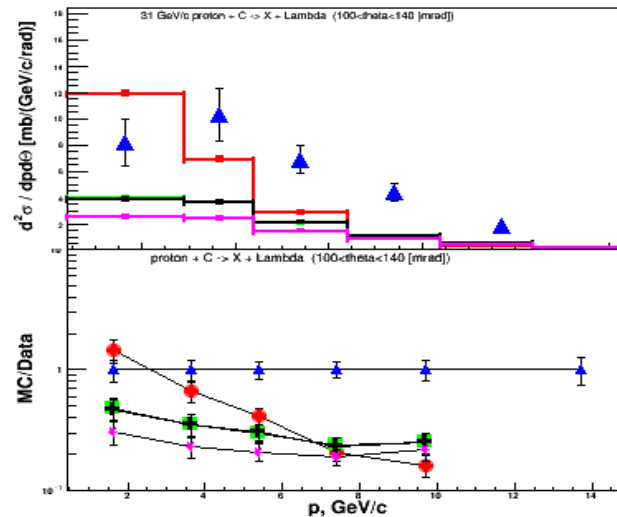
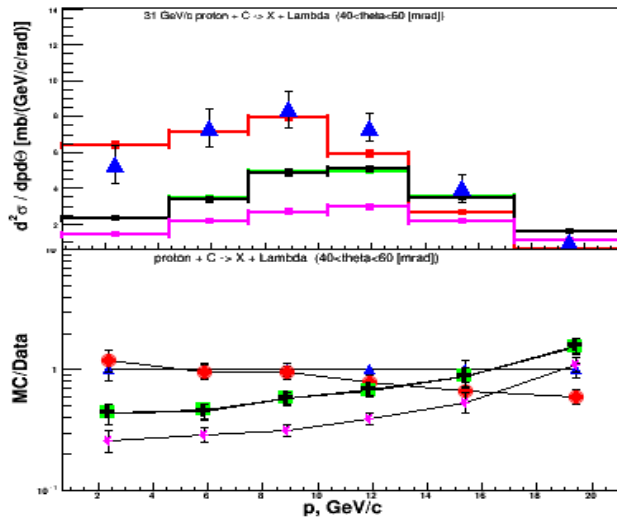
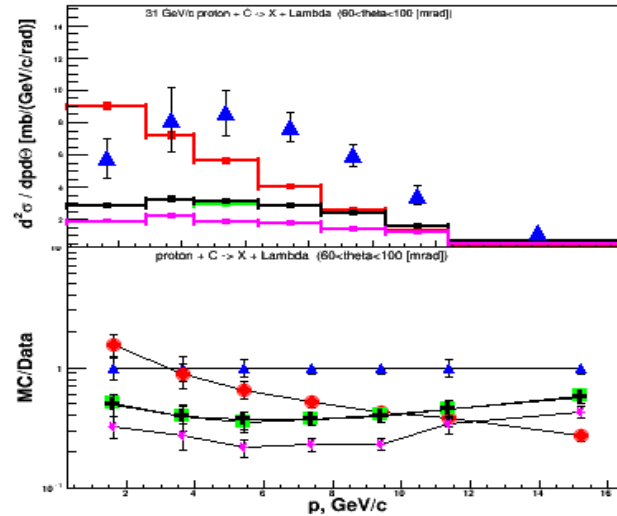
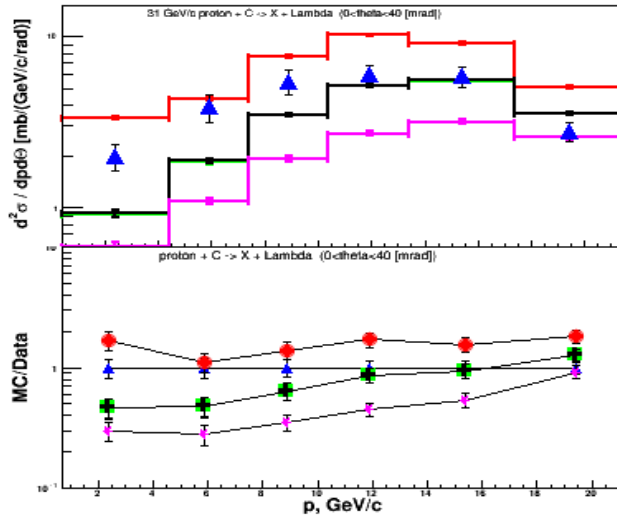
$\chi^2/\text{NDF} = 15.0698$ for geant4-10-04-ref-07

$\chi^2/\text{NDF} = 14.9739$ for geant4-10-04-ref-08

$\chi^2/\text{NDF} = 12.6796$ for geant4-10-04-ref-09



QGSP: 31 GeV/c proton + C \rightarrow Lambda; data NA61



MC vs NA61 Data; χ^2 /NDF calculated over ALL theta bins
 χ^2 /NDF = 14.1847 for geant4-10-04-patch-02
 χ^2 /NDF = 15.0575 for geant4-10-04-ref-07
 χ^2 /NDF = 15.1951 for geant4-10-04-ref-08
 χ^2 /NDF = 21.6535 for geant4-10-04-ref-09



Summary of FTF and QGS

- For most part, FTF has been stable through 10.4.refXX development cycle
 - It is different from 10.4.p02 and is expected to give better agreement with thin target data in a number of areas but not necessarily everywhere
 - Modeling of production of antiprotons in hadron-nucleus interactions at intermediate energies is “gone”
- Some changes in modeling production of charged kaons and Lambda have been observed in 10.4.ref09
- QSG is being re-designed and re-tuned
 - In a number of areas it gives better agreement with thin target data, e.g. modeling of proton production in hadron-nucleus interactions, but not everywhere
- It has been stable up to 10.4.ref08 but a number of non-negligible changes are observed in 10.4.ref09; some of these changes are negative, in particular:
 - Modeling of pi- production at energies > 100 GeV
 - Modeling of antiproton production at energies > 100 GeV

BACKUP SLIDES

Experimental Data (all are for thin target)

- NA49:
 - <https://spshadrons.web.cern.ch/spshadrons>
- “Barton data” (SAS M6E):
 - D.S. Barton et al., Phys.Rev.**D27** (1983) , p.2580
- NA61 (Run2009):
 - N. Abgrall et al., Eur.Phys.J.**C76** (2016) , p.84
- HARP (if applicable):
 - 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 (if applicable):
 - Yu.D.Bayukov et al., Preprints ITEP-148-1983 and ITEP-172-1983;
Sov.J.Nucl.Phys. 42 116, 1985