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Update on Tuning FTF Model Parameters : Preliminary Results from Hadronic Validation test19 and test47, as of Geant4 11.0.r08

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Candidate “tune” for FTF, pion beam (can we call it pion-tune2022-v0 for now?)

- **Results are preliminary, subject to review/verdict by developers**
- **Pion projectile**
  - **MESON_EXCI_E_PER_WNDNUCLN = 58.1 +/- 0.7 (D=40 MeV)**
  - **MESON_NUCDESTR_P1_TGT = 0.001026 +/- 0.00003 * A (D=0.0048*A)**
  - **PION_PROC1_A1 = 5.84 +/- 0.1 (D=5.77)**
  - **PION_PROC1_A2 = -7.57 +/- 0.08 (D=-5.77)**
  - **PION_PROC1_B1 = 0.337 +/- 0.0006 (D=0.6)**
  - **PION_PROC1_B2 = 0.441 +/- 0.0008 (D=0.8)**
- More detailed report on determining this group of parameters:
  - https://indico.cern.ch/event/1156193/contributions/5051173/attachments/2515999/4325623/G4CM-FTFParams-2022_v2.pdf
- NOTE-1: Parameter values from ***fits based on 11.0.r06***
- NOTE-2: ***Tests*** are done ***with 11.0.r08***
- Exercise is mainly based on test19 and test47 (hadronic validation tests)
- Results are presented as chi2/NDF tables

General Remarks on Experimental Datasets

- For **pion beam**, we have more **limited basis for MC-data benchmark** comparing to the proton beam
  - Data on proton and neutron productions only cover values of >~60deg of the polar angle of the secondary; we do not have enough basis to judge MC-data agreement at theta<60deg
  - HARP data on pion production do cover Forward (FW) and Large Angle (LA) regions but the errors on datapoints in the FW region are often large, and a careful evaluation will be needed in the future
  - HARP data on FW proton production also exist but, again, the errors on many datapoints are fairly large
  - A subset of NA61 data for 60 GeV/c pi+ beam was newly added for exploring FTF parameters for the pion projectile, and is NOT part of standard G4 HAD validation infrastructure
  - References in Backup Slides
- In subsequent tables, when chi2 improves or degrades, it does NOT necessarily mean that the effect is uniform across the involved spectra; instead, some MC spectra may move closer to the data while some others will not

ftfp: piplus on Be --> pions
chi2/NDF calculated vs HARP data

3 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	23.4	23.2	23.1	26.7
LA	24.6	22.2	22.4	22.2
Total	24.4	22.4	22.5	22.9
pi-				
FW	3.7	3.7	3.6	3.8
LA	23.6	20.5	20.6	23.1
Total	20.2	17.7	17.7	19.9

5 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	17.7	18.2	18.4	18.5
LA	22.1	19.7	20.1	20.5
Total	20.8	19.3	19.6	19.9
pi-				
FW	9.5	9.7	9.4	9.1
LA	25.4	22.1	23.1	24.1
Total	20.7	18.5	19.1	19.7

8 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	11.9	12.1	12.2	12.1
LA	10.3	9.2	9.4	9.6
Total	10.8	10.1	10.3	10.3
pi-				
FW	8.4	7.2	7.5	7.3
LA	10.8	9.5	10.2	10.8
Total	10.1	8.8	9.4	9.8

12 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	4.2	4.6	4.6	4.2
LA	4.1	3.4	3.6	3.7
Total	4.1	3.8	3.9	3.9
pi-				
FW	2.1	1.9	1.9	1.8
LA	4.6	4.3	4.6	5.0
Total	3.8	3.5	3.8	4.0

ftfp: piminus on Be --> pions
chi2/NDF calculated vs HARP data

3 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	6.0	7.0	6.9	6.7
LA	42.5	36.6	37.2	40.1
Total	36.3	31.5	32.0	34.4
pi-				
FW	55.5	58.1	57.1	63.7
LA	25.9	24.6	24.9	24.5
Total	31.0	30.3	30.3	31.2

5 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	7.0	6.5	6.7	7.4
LA	24.8	21.3	22.2	22.8
Total	19.9	17.2	17.9	18.6
pi-				
FW	24.9	28.0	27.4	28.6
LA	14.5	14.1	14.3	14.7
Total	17.6	18.1	18.1	18.7

8 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	12.4	10.6	10.9	10.7
LA	23.6	20.2	21.1	23.5
Total	20.2	17.3	17.9	19.5
pi-				
FW	21.2	20.4	20.6	20.8
LA	13.2	13.6	14.2	14.5
Total	15.7	15.8	16.2	16.5

12 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	7.8	9.4	8.7	7.7
LA	17.6	14.8	15.5	18.5
Total	14.6	13.1	13.4	15.2
pi-				
FW	28.1	33.4	33.2	28.5
LA	11.9	12.3	12.7	11.7
Total	17.0	19.0	19.2	17.0

ftfp: piplus on Ta --> pions
chi2/NDF calculated vs HARP data

3 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	86.2	86.5	85.5	134.7
LA	14.9	15.0	15.2	19.1
Total	27.0	27.1	27.2	38.8
pi-				
FW	2.6	2.4	2.4	2.7
LA	17.1	13.9	14.3	18.0
Total	14.6	11.9	12.2	15.4

5 GeV/c

	11.0	11.0.r06	11.0.re08	pion-tune2022-v0
pi+				
FW	18.8	20.2	20.2	31.9
LA	23.0	26.0	25.5	26.4
Total	21.8	24.3	23.9	28.0
pi-				
FW	7.1	7.2	7.5	14.3
LA	15.2	14.4	15.0	33.4
Total	12.8	12.3	12.8	27.9

8 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	16.7	17.9	18.1	22.8
LA	13.2	15.5	15.1	9.9
Total	14.3	16.2	16.1	13.6
pi-				
FW	10.9	11.9	11.9	15.7
LA	14.4	15.7	16.3	24.0
Total	13.4	14.5	15.0	21.5

12 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	4.5	4.9	5.0	5.0
LA	5.5	6.3	5.8	4.6
Total	5.2	5.8	5.5	4.8
pi-				
FW	1.4	1.4	1.5	1.5
LA	10.0	11.1	11.3	11.0
Total	7.3	8.1	8.2	8.1

ftfp: piminus on Ta --> pions
chi2/NDF calculated vs HARP data

3 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	1.4	1.8	1.8	5.1
LA	11.0	9.0	9.1	8.7
Total	9.4	7.8	7.9	8.1
pi-				
FW	52.1	51.6	51.8	84.7
LA	45.3	45.7	45.6	43.1
Total	46.5	46.7	46.6	50.2

5 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	6.8	7.0	7.1	19.0
LA	11.4	8.9	8.8	15.1
Total	10.0	8.4	8.3	16.3
pi-				
FW	21.3	23.3	23.2	42.8
LA	80.1	85.6	84.8	78.1
Total	63.0	67.5	66.9	67.8

8 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	8.1	8.4	8.5	11.0
LA	6.2	6.1	6.2	12.4
Total	6.8	6.9	7.0	11.9
pi-				
FW	31.4	33.7	34.0	41.7
LA	86.2	93.6	93.4	72.2
Total	68.9	74.7	74.6	62.6

12 GeV/c

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+				
FW	11.4	11.7	11.9	11.6
LA	7.9	6.5	6.8	12.6
Total	9.0	8.1	8.4	12.3
pi-				
FW	37.2	40.1	40.4	40.0
LA	53.6	58.4	58.2	40.5
Total	48.4	52.6	52.6	40.4

ftfp: 5.0 GeV/c piplus on nucleus --> proton/neutron
chi2/NDF calculated vs ITEP771 data

Carbon (C)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	3.5	5.2	5.7	7.7
neutron	2.0	1.2	1.3	1.9

Copper (Cu)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	6.9	7.5	8.0	11.3
neutron	3.1	3.4	3.1	3.9

Lead (Pb)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	62.5	49.0	49.7	10.7
neutron	200.1	201.2	200.4	19.8

Uranium (U)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	127.4	102.6	103.1	17.7
neutron	363.4	352.7	354.8	41.6

ftfp: 5.00 GeV/c piminus on nucleus --> proton/neutron
chi2/NDF calculated vs ITEP771 data

Carbon (C)

	11.0	11.0 .r06	11.0.r08	pion-tune2022-v0
proton	4.2	7.4	7.3	9.0
neutron	2.9	1.4	1.4	1.8

Copper (Cu)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	13.7	15.8	16.4	19.8
neutron	6.2	5.8	5.8	14.7

Lead (Pb)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	117.8	95.2	95.0	13.0
neutron	126.2	127.2	126.0	15.5

Uranium (U)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
proton	163.3	132.4	133.2	19.6
neutron	168.7	166.2	167.7	19.5

ftfp: 60GeV/c piplus on C --> hadrons
chi2/NDF calculated vs NA61 data

	11.0.r06	11.0.r08	pion-tune2022-v6
pi+	21.5	23.4	13.7
pi-	11.6	12.3	4.7
K+	5.9	5.8	3.6
K-	3.2	3.3	5.8

NOTE: Spectra of secondary charged kaons were NOT (yet) included in the fitting procedure to explore possible “pion-tune2022-v0”. Any improvements or degradation of chi2 related to such spectra are accidental

NOTE: When using the “tune” in simulation, behavior of K+/- spectra in the 0-20mrad theta-bin may look a bit “strange”; plots can be shared with developers, if needed

NOTE: Data on K0s, Lambda, proton production in pi+ on C will be added later

NOTE: Data on Be target will be added later

ftfp: 100GeV/c piplus on C/Cu/Pb --> hadrons
chi2/NDF calculated vs SASM6E data

Carbon (C)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+	36.0	36.1	36.8	24.7
pi-	10.6	9.4	9.5	12.7
K+	13.7	13.1	13.3	11.4
K-	5.3	6.2	6.8	37.4
proton	10.2	10.3	10.8	12.7
antiproton	3.7	3.1	3.0	3.5

Copper (Cu)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+	31.3	32.1	32.7	18.9
pi-	9.1	9.1	9.3	18.2
K+	15.1	15.5	15.9	12.0
K-	7.1	6.4	6.4	34.5
proton	5.7	4.8	6.2	6.9

Lead (Pb)

	11.0	11.0.r06	11.0.r08	pion-tune2022-v0
pi+	31.3	32.1	29.2	14.7
pi-	9.1	8.1	8.1	15.5
K+	9.6	8.9	9.5	6.8
K-	4.1	3.6	4.0	11.2
proton	2.7	2.9	2.9	3.1
antiproton	2.7	3.3	3.0	3.7

NOTE: Spectra from SAS-M6E were NOT included in the fits towards “pion-tune2022-v0” although the contribution of “proc1” at such beam momentum is non-negligible (~6%).
They can be included in the subsequent studies.
The largest “damage” happens to the K- spectra.
As in the case of NA61 benchmark, it might be interesting to look at **individual** distributions of secondary K-.

Summary

- Technically speaking "pion-tune2022-v0" was obtained on the basis of Geant4 11.0.r06 which is not identical to 11.0.r08.
- However, simulated results from 11.0.r08 are **mainly** reasonably close to those from 11.0.r06; thus for the 1st order it is probably fair enough to try "pion-tune2022-v0" on top of 11.0.r08
- If using "pion-tune2022-v0", **in a number of areas** either leaves simulated spectra relatively unchanged or improves MC-to-data agreement
- However, a in some areas it is been observed that the spectra simulated with "pion-tune2022-v0" move somewhat away from the data; examples:
  - Pion production by **3-5 GeV/c pion beam on heavy target(s)**
  - K- production in pion-nucleus interactions
- Expanding collection of data suitable for the study is very important
- At the recent collaboration meeting the question was raised about a possibility to include this "tune" in the upcoming Geant4 release, even if very early in the study. It can be done but we must bear in mind that a lot of work is still needed and its use may bring a number of side effects

BACKUP SLIDES

Experimental data sets used in the study

HARP – 3, 5, 8, 12 GeV/c pion on C, Cu, Pb targets
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
M.Apollonio et al., Phys.Rev.C82 045208, 2010

ITEP771 -- Yu. D. Bayukov et al., Preprints ITEP-148-1983
and ITEP-172-1983; Sov.J.Nucl.Phys. 42 116, 1985

NA61 – 60 GeV/c piplus on C
A. Aduszkiewicz et al. , Phys.Rev.D100 112004, 2019

SASM6E -- 100 GeV/c piplus on C
D.S. Barton et al., Phys. Rev. D27, 2580 (1983)
https://inspirehep.net/record/12592