FTF validation for antiproton-proton interactions

A. Galoyan, V. Uzhinsky 27.11.2018

1. History of anisotropy in Pbar-P annihilation

2. Differential cross sections of binary channels: PbarP->Λ Λbar, PbarP-> ΛΣbar, ΣΛbar, PbarP->K+K-, PbarP->π+π- in FTF of Geant4 10-04-Ref-09

3. Λ , Ks0 production cross sections in Pbar-P interactions in FTF

4. Kinematical distributions of Λ, K0 production in Pbar-P interactions in FTF of Geant4 10-04-Ref-09. Problems

4. Pbar-P annihilation at rest in FTF of Geant4 10-04-Ref-09

5. Description of annihilation channels in FTF of Geant4 10-04-Ref-09
New annihilation channels were added in test22/PbarPchan

6. Cross sections of 2, 4, 6, 8 prong events in Pbar-P-interactions in FTF

Conclusion and Plans

History, anisotropy in annihilation

Date: Wed, 13 Jun 2018 05:25:41 +0200
From: Johannes Stoessl stoessl@hawaii.edu To: dwright@slac.stanford.edu, Vladimir.Uzhinskiy@cern.ch
Subject: Pion distributions from proton-antiproton annihilations in Geant4

The ultimate goal of the GAPS experiment, which is a detector payload scheduled for a long distance balloon flight in the Antarctic is to perform a measurement of hadronic antimatter in Cosmic Rays. Anti-deuterons are of special interest, and constraints on their fluxes will help to constrain the parameter space for dark matter models where up to this date only very limited constraining data exist.

We are currently studying low energy anti-proton annihilations with hydrogen using Geant4, which is the reason why we are reaching out to you. We are working with the latest patch 10.4p2 as well as the previous one, 10.4p1. No significant differences have been seen, so in the following we will concentrate on patch level 10.4p1.

Within our studies, we use the FTFP_BERT_HP physics list to shoot a beam of 10(50) MeV anti-protons on a hydrogen target. In general, we would expect an isotropic emission pattern for the pions. The distributions of the z-component of the pion momentum however reveal a clear dependence independent of the primary momentum, and show different shapes for each of the three pion species.

Sincerly,
Achim

On Wed, Jun 13, 2018 at 11:35 PM Alberto Ribon <Alberto.Ribon@cern.ch> wrote:

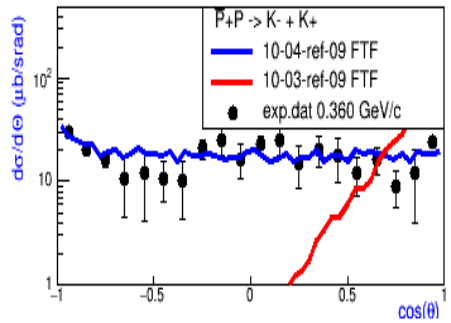
> Dear Johannes,
> I confirm that Vladimir's fix to improve the isotropy of annihilation at rest in FTF, made in November 2017, is included in the public release G4 10.4, and related patches (patch-01 and patch-02).

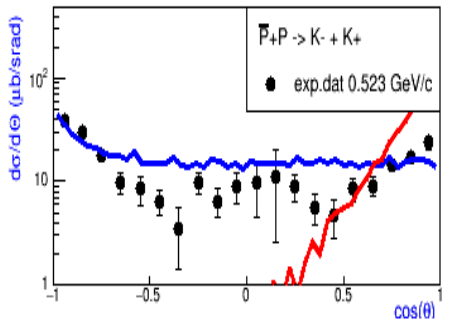
On 06/19/2018 06:27 AM, Alberto Ribon wrote:

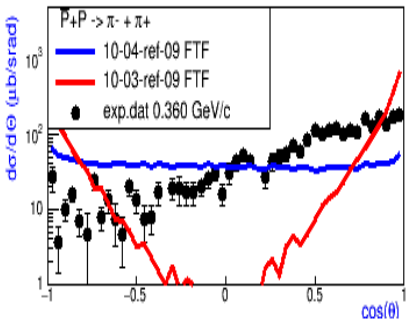
> Dear Johannes,
> Vladimir managed to improve the FTF annihilation and now the cos(theta) distribution appears flat in our tests.

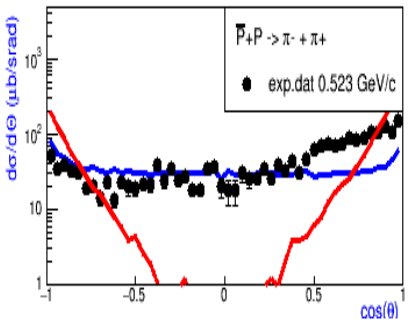
Date: Sat, 30 Jun 2018 02:19:42 +0200
From: Johannes Stoessl <stoessl@hawaii.edu>
Dear all,
thank you very much Vladimir and Alberto for the patch. It works well for us and fixes the anisotropy problem we discussed.

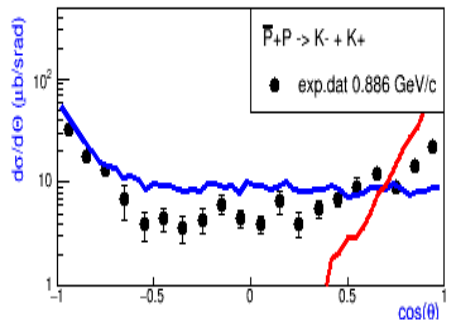
Differential Cross Sections of PbarP->K+K- and π+ π- at various initial energies (cms angle distributions) FTF with rotating strings

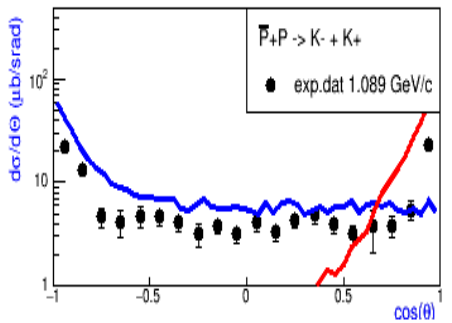


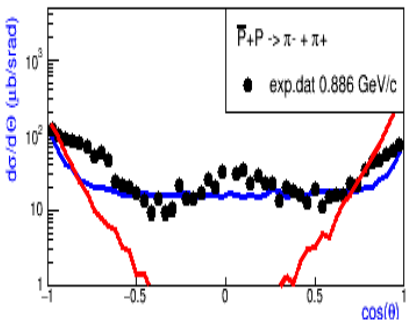


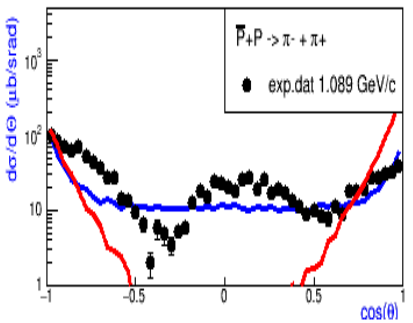


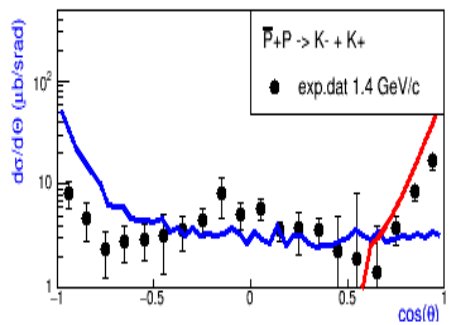


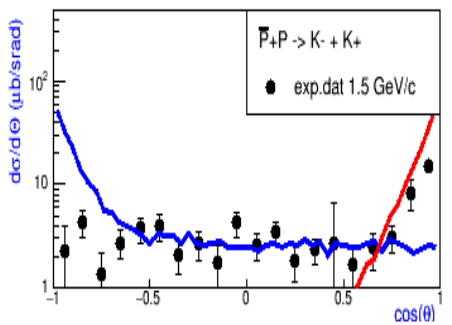


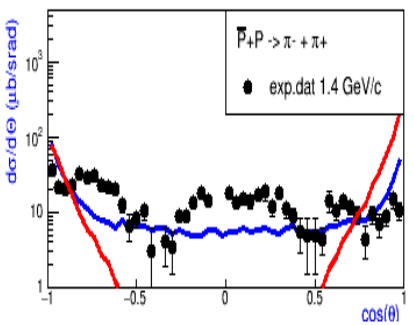


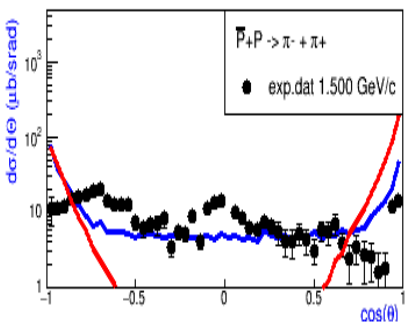






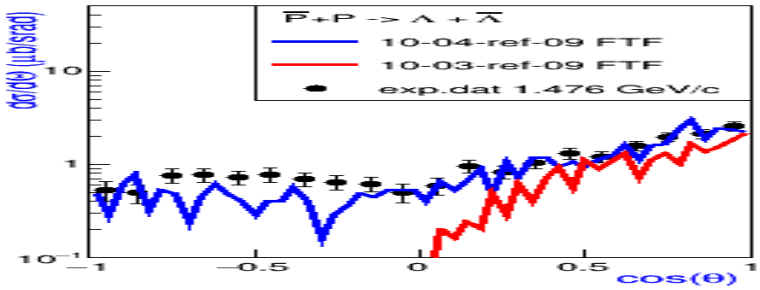


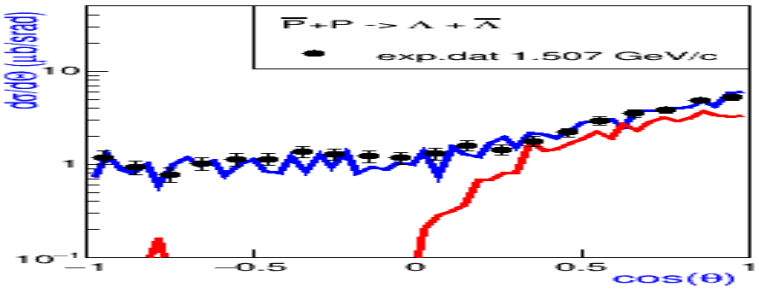


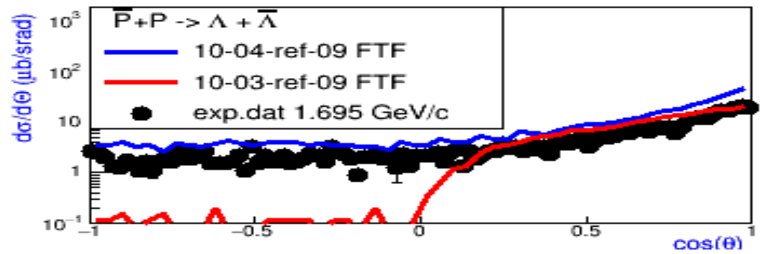


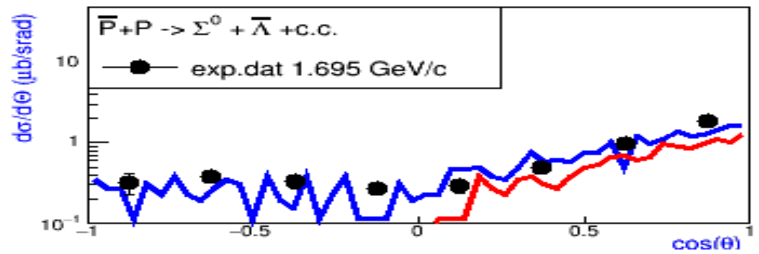
Subdirectory test22/PbarHyperonV is updated for testing of FTFP for strange particle production in PbarP interactions at various momenta.

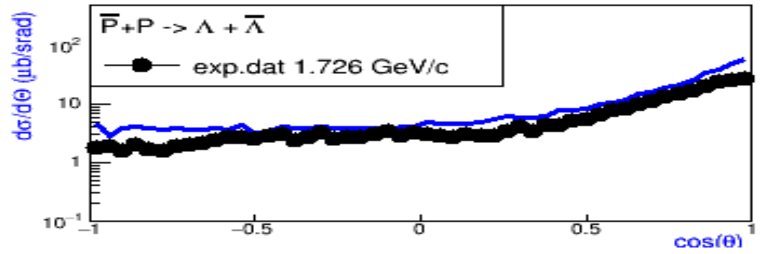
Differential Cross Sections of PbarP->ΛΛbar and ΣΛbar +c.c. at low momenta (cms angle distributions) FTF with rotating strings

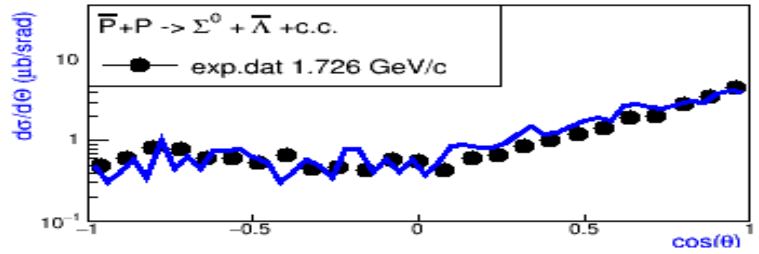


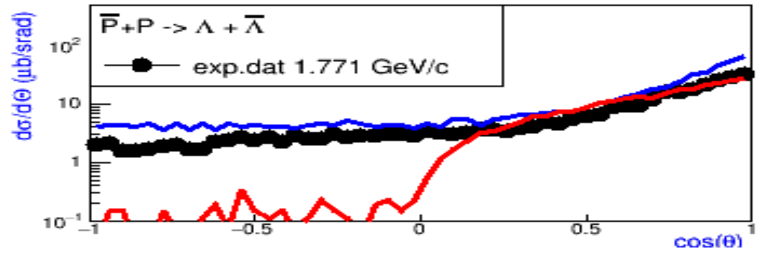


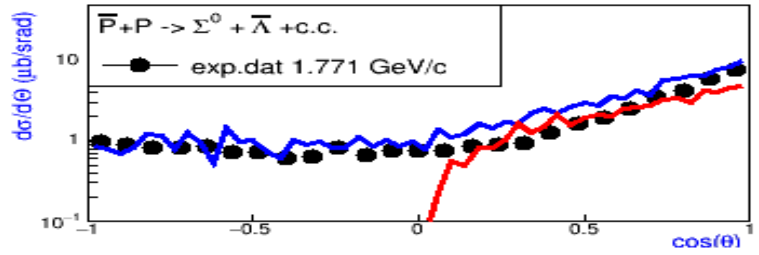








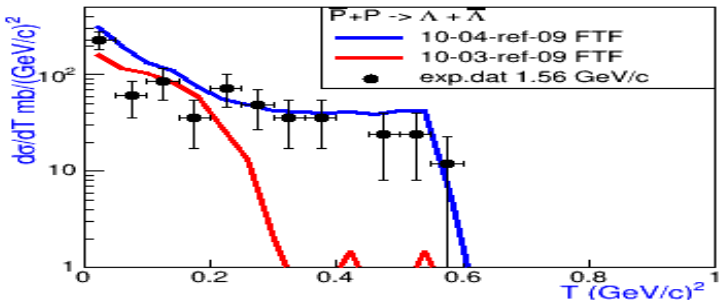


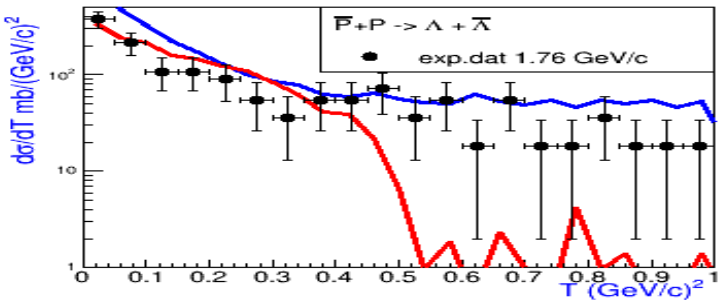


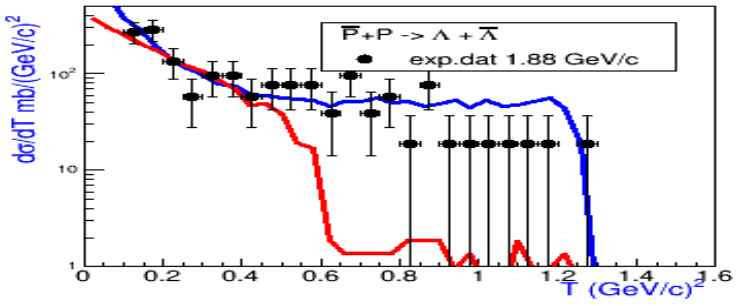
Exp. data: P.D. Barnes et al., Phys. Rev., C54. N6 (exp. PS185 at LEAR)

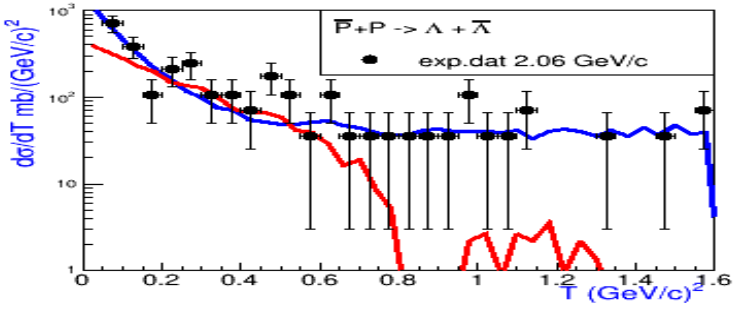
Differential Cross Sections of PbarP->ΛΛbar at various initial energies (transfered momentum distributions) FTF with rotating strings

Exp. data: B. Jayet et al., Nuov. Cim. A45, 371 (1978)

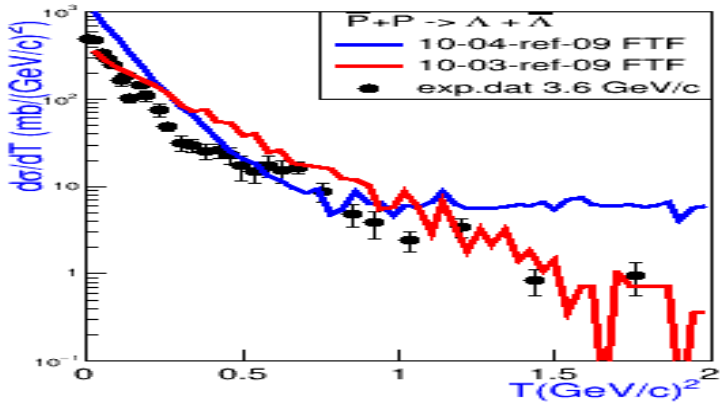


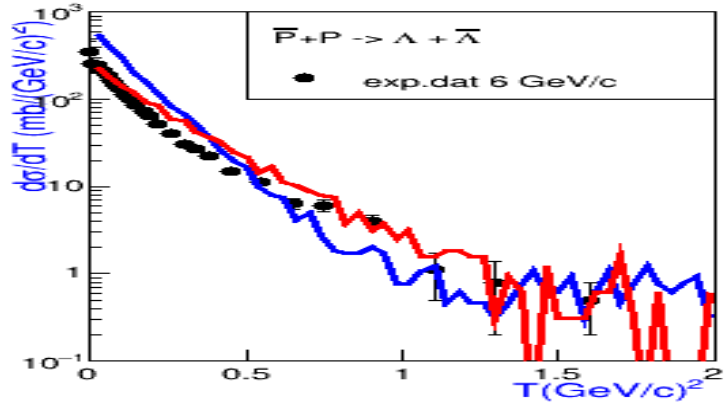






Differential Cross Sections of PbarP->ΛΛbar at Plab= 3.6 and 6 GeV/c

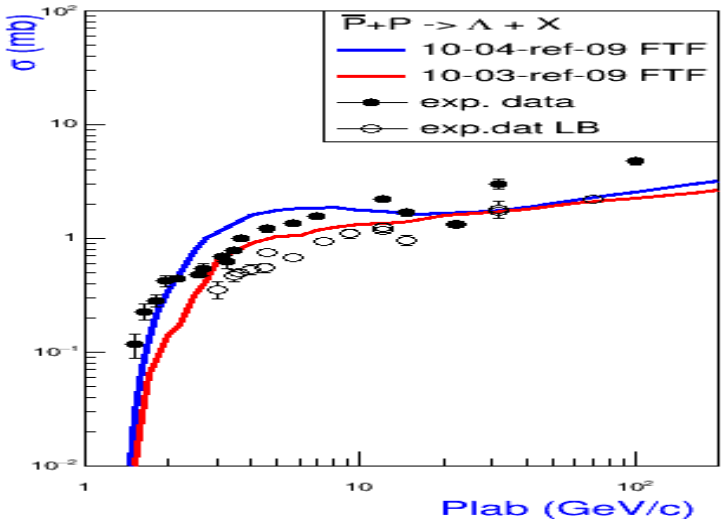


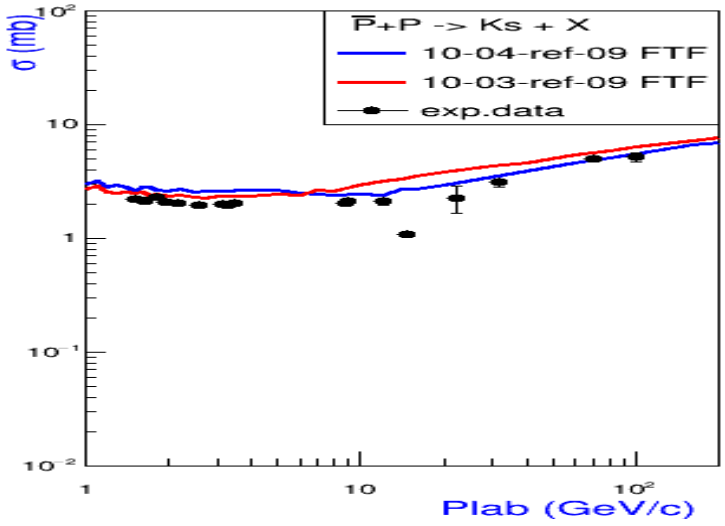


Exp. data: H. Becker et al., Nucl. Phys. B141 48 (1978)

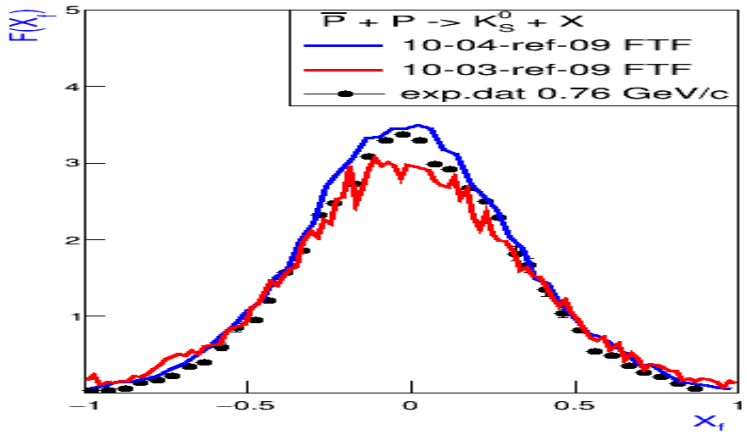
Test 22/PbarHyperonV Strange particle production in PbarP - interactions

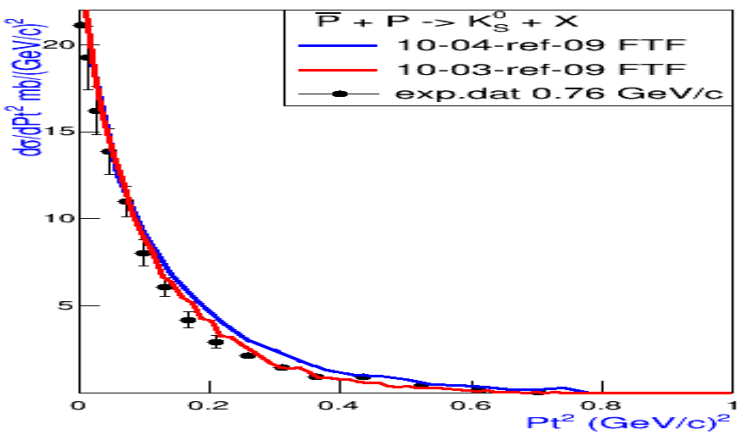
Inclusive Cross Sections of PbarP->Λ+X and PbarP->Ks^0+X processes





Kinematic distributions of Ks^0 produced in PbarP interactions at 0.76 GeV/c

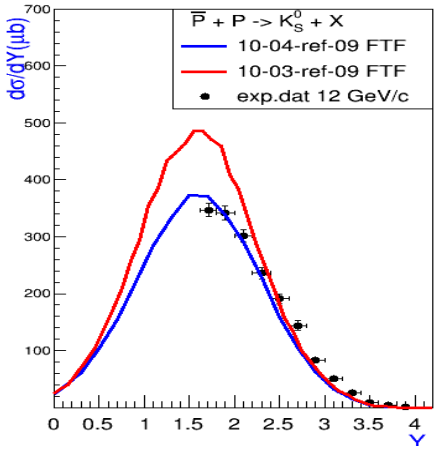


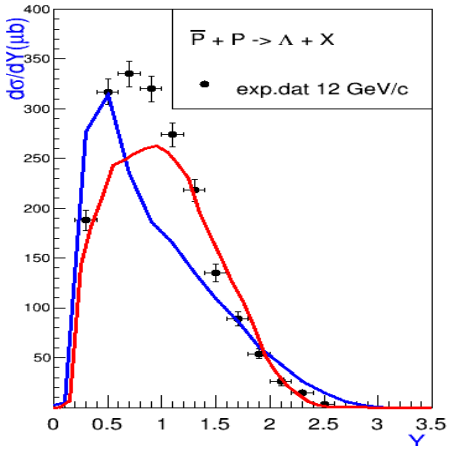


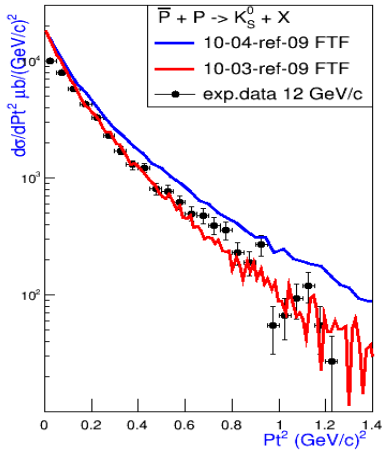
Exp.data: A.M. Cooper et al., Nucl.Phys.B 136, 1978, P.365

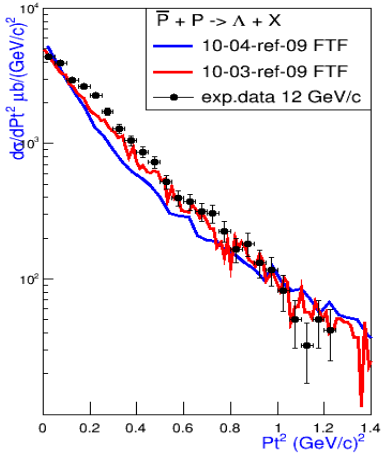
Test 22/PbarHyperonV Strange particle production in PbarP - interactions

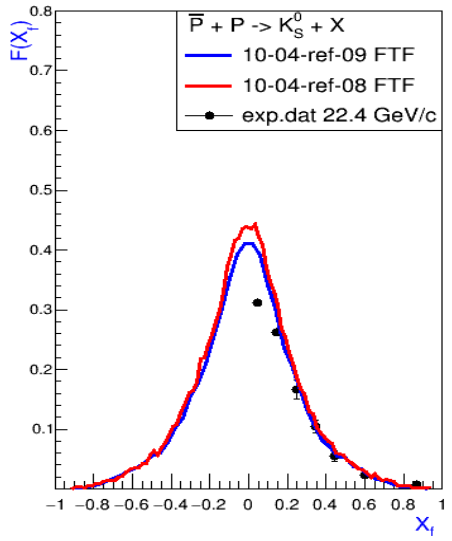
We consider in folder test22/PbarHyperonV kinematic properties of strange particle production in PbarP interactions at various energies: 3.6, 12, 8.8, 22.4, 32, 100 GeV/c. In Ref: 10-04-ref-09 kinematic distributions of Λ and Λbar became worse than 1 year ago

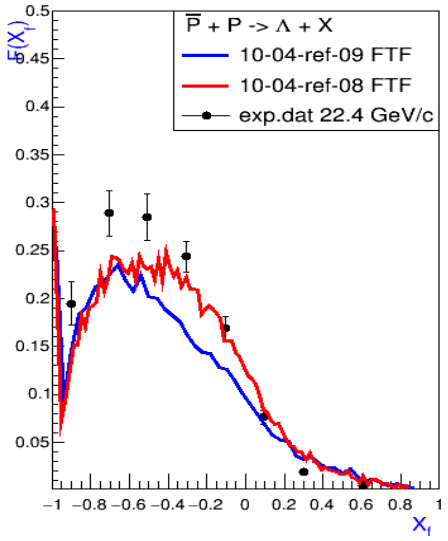


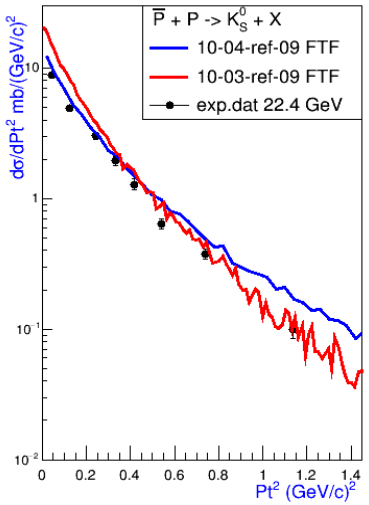


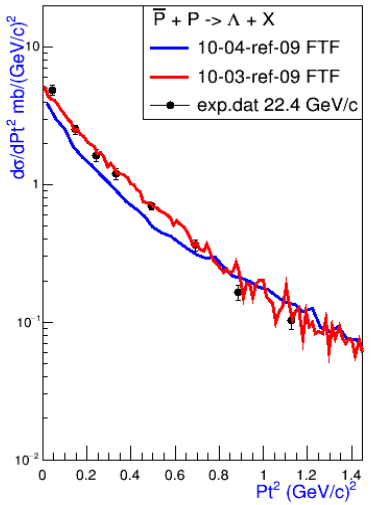






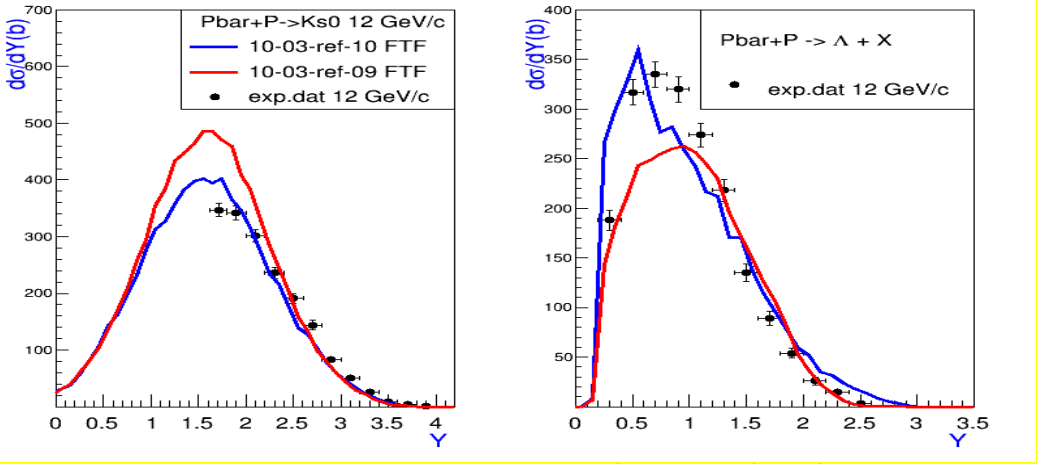


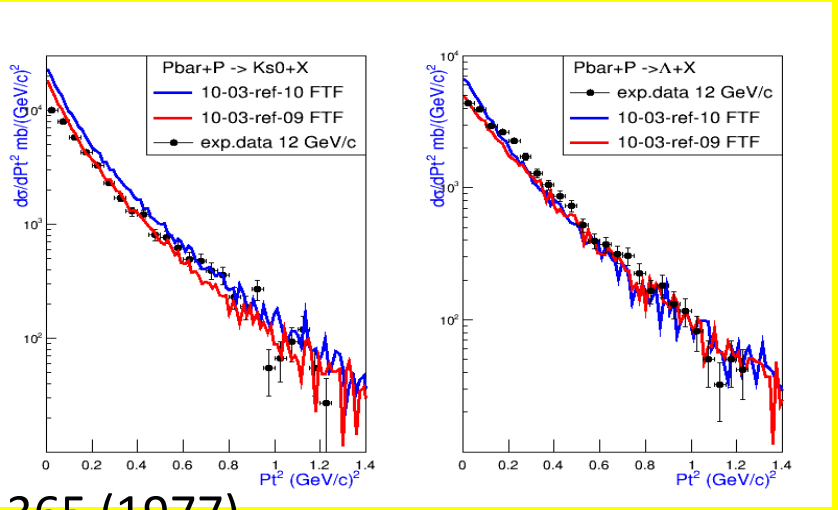




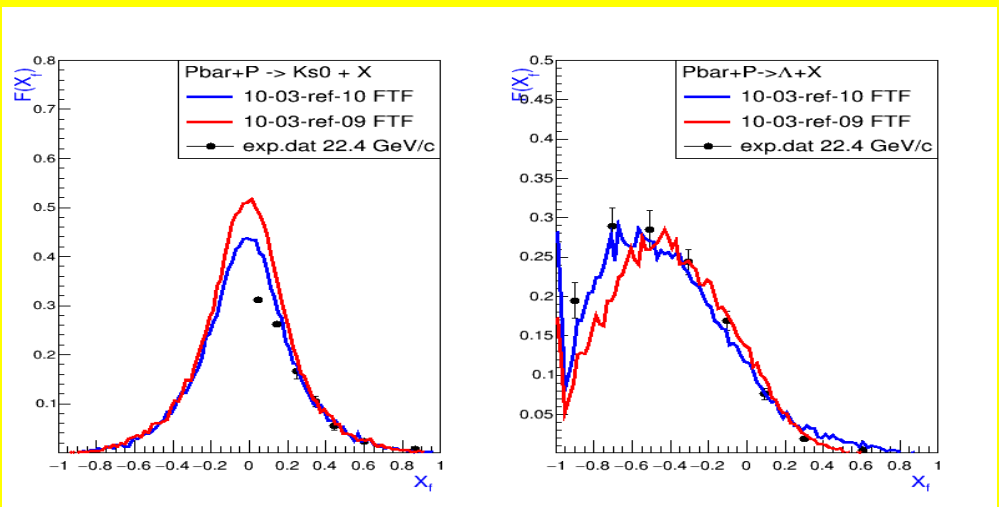
November 2017: Validation of FTF model for strange particle

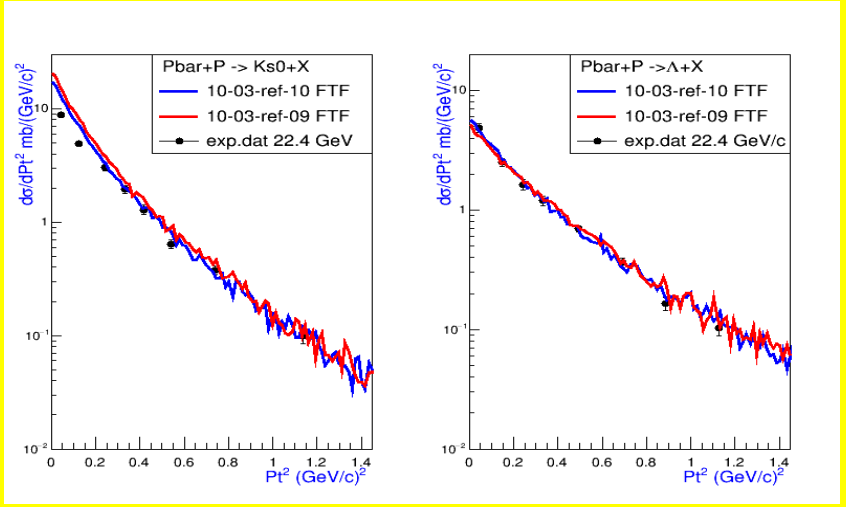
Kinematic distributions of Λ and Ks^0 produced in PbarP interactions at Plab=12 GeV/c and 22.4 GeV/c





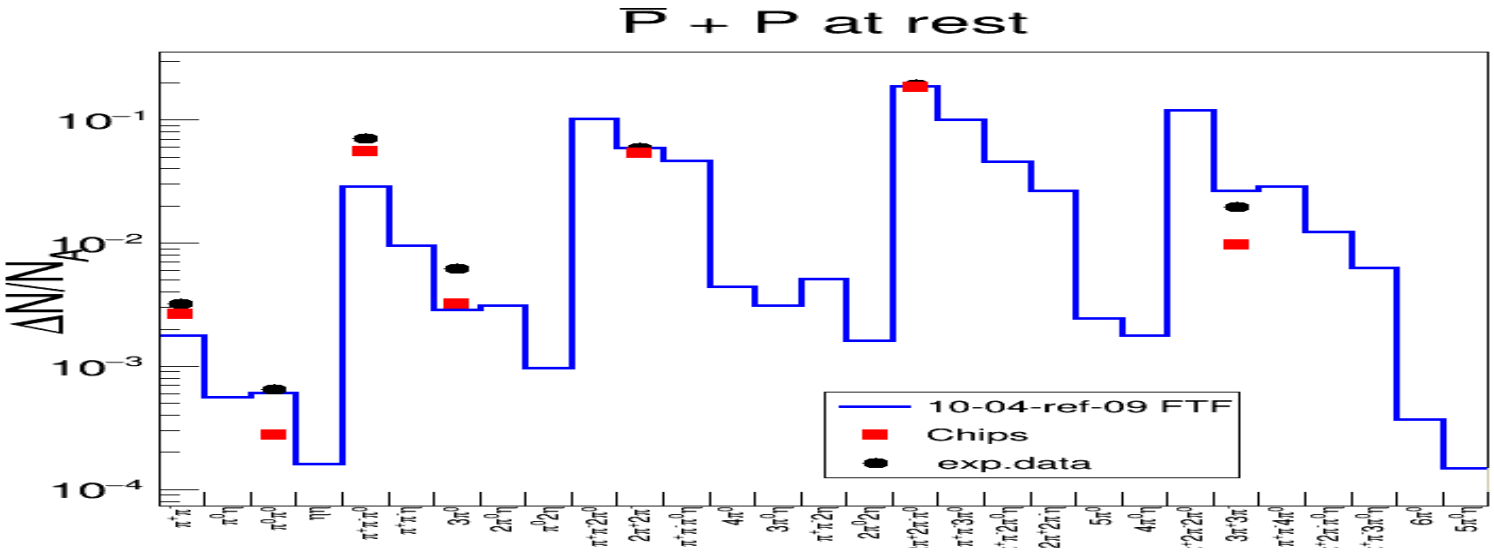
Exp data: D. Bertrand et al., Nucl. Phys. B 128 365 (1977)

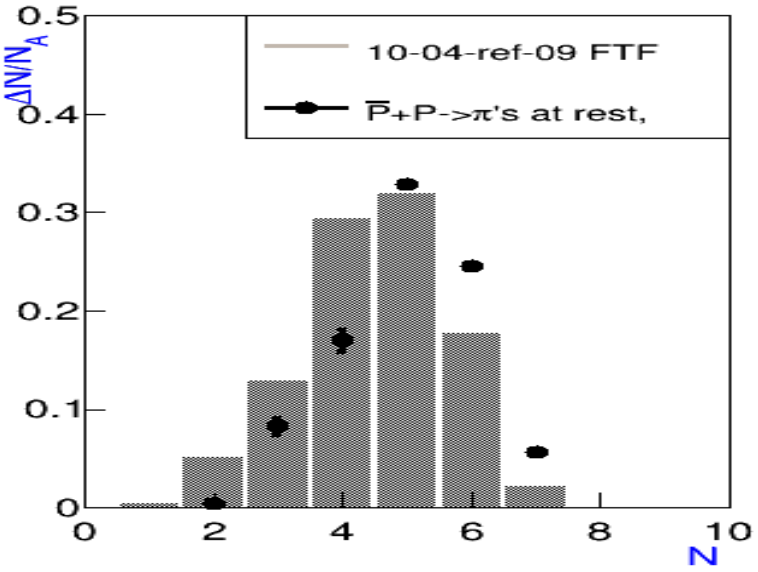


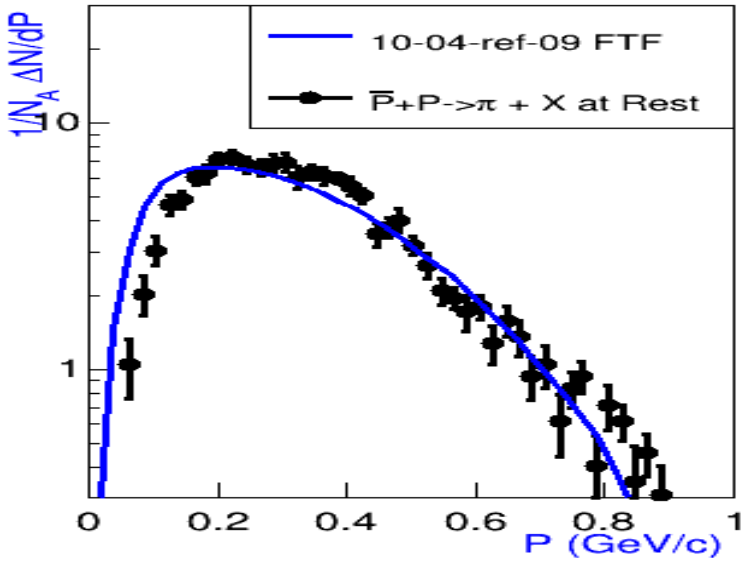


Exp data: B.V. Batyunya et al., Z. Phys.C 25 213 (1984)

Antiproton-proton annihilation at rest



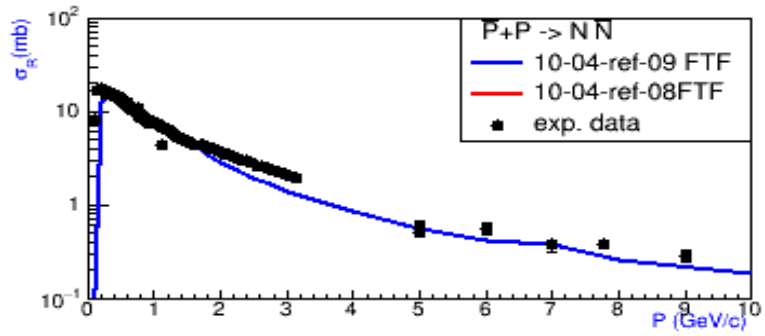


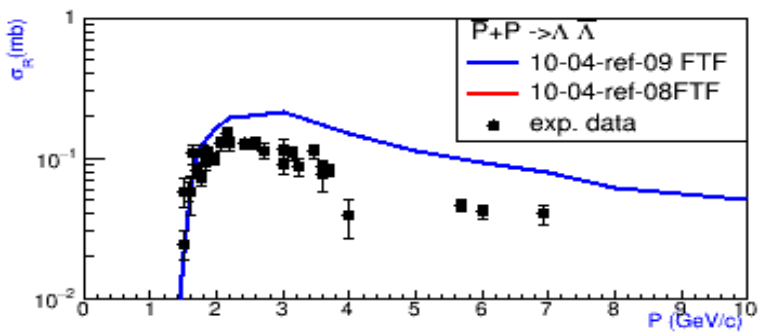


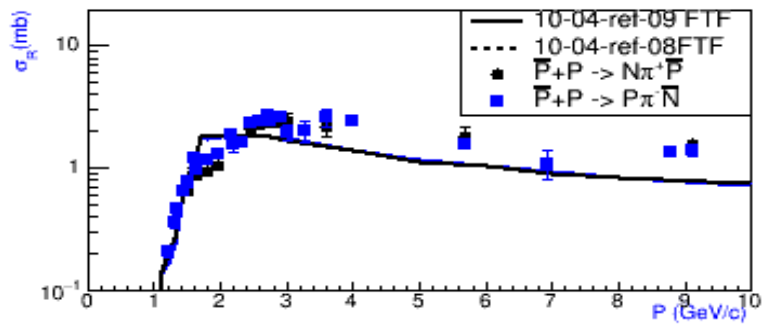
Corresponding scripts for calculations of Pbar-P at rest and visualization of results of comparison with exp.data are added in folder test22/PbarPchan

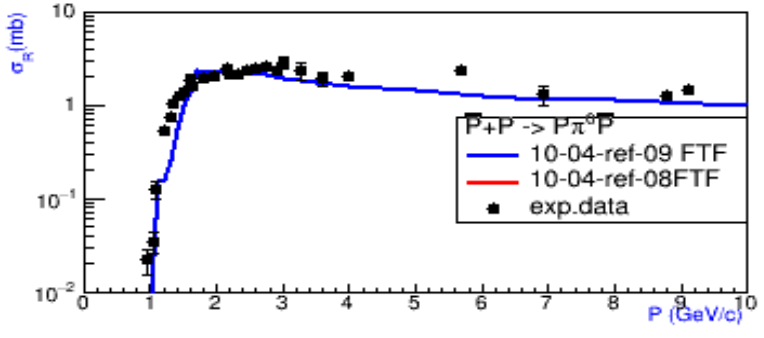
New annihilation channels were added in test22/PbarPchan

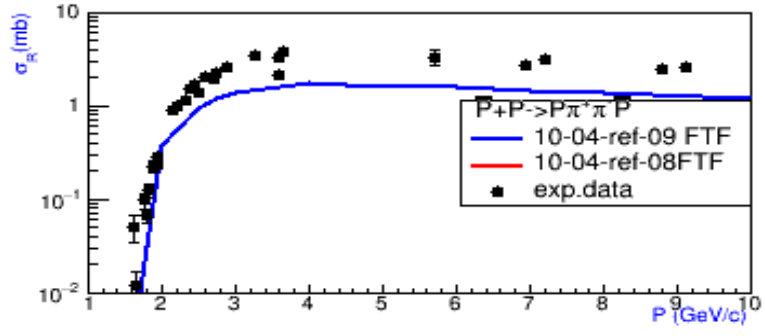
Main Pbar-P channels with baryons in final states were considered

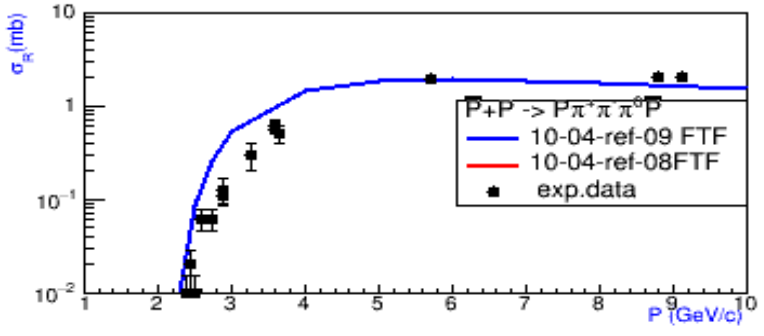






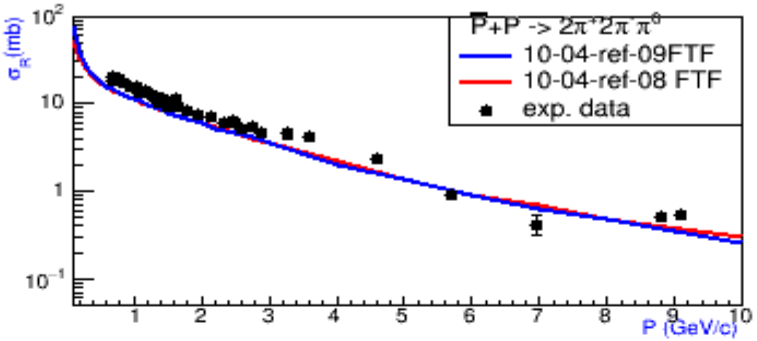


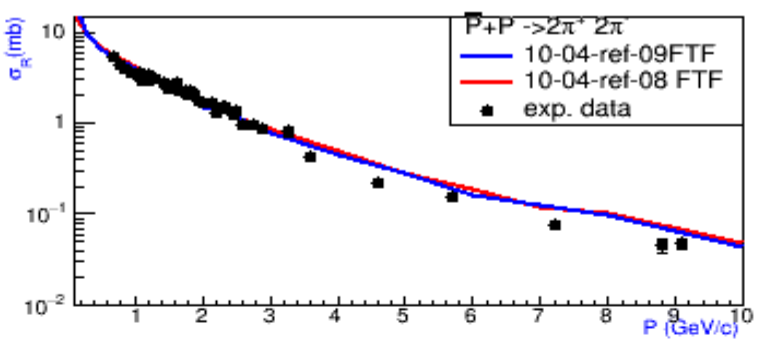


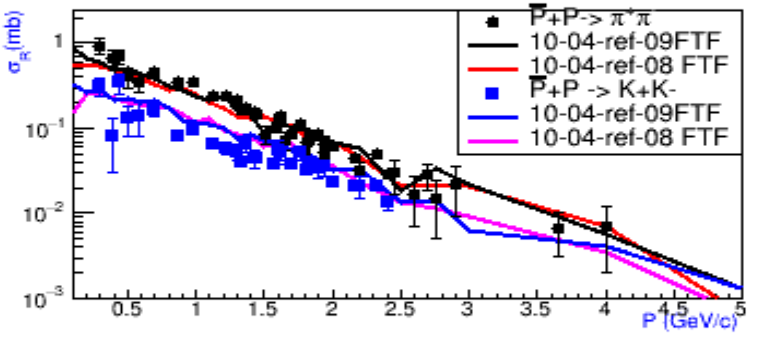


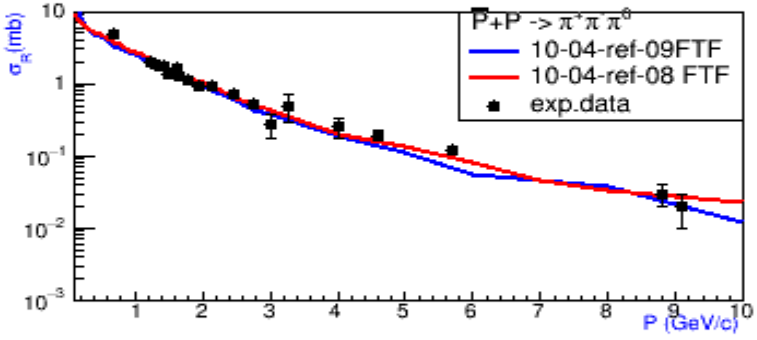
New annihilation channels were added in test22/PbarPchan

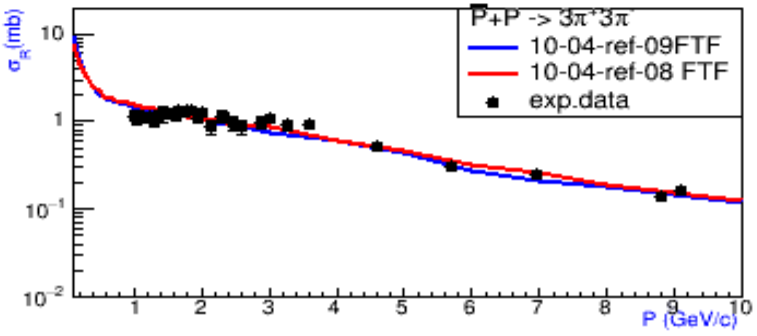
Main annihilations Pbar-P channels without baryons in final states considered

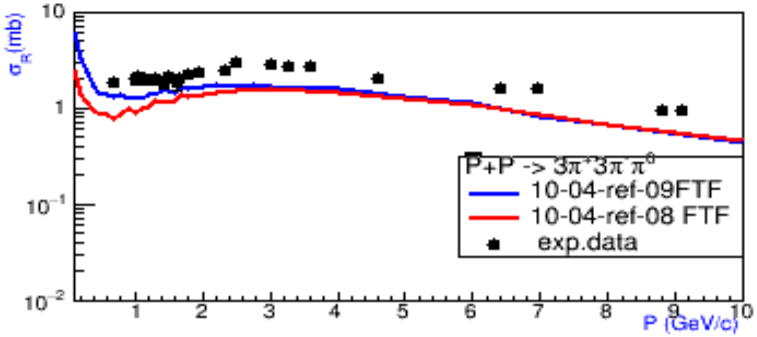








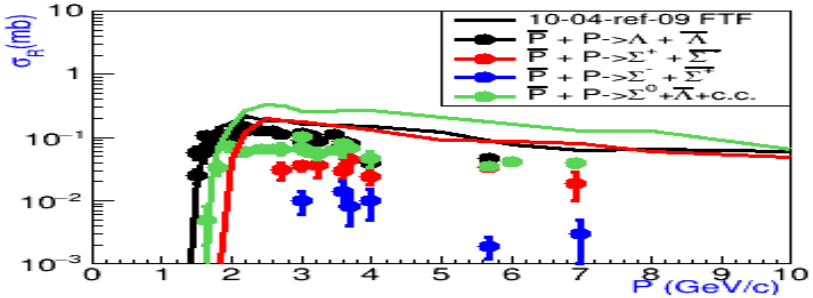


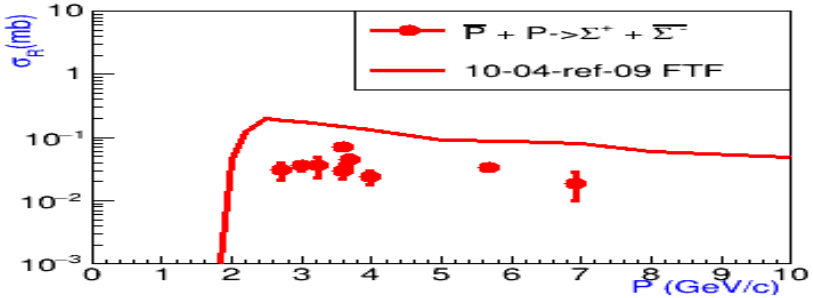


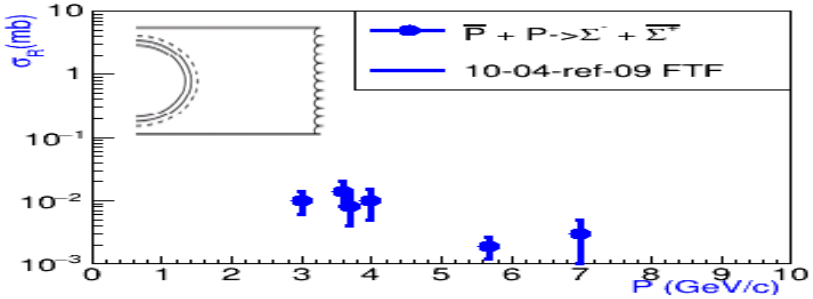
New annihilation channels were added in test22/PbarPchan

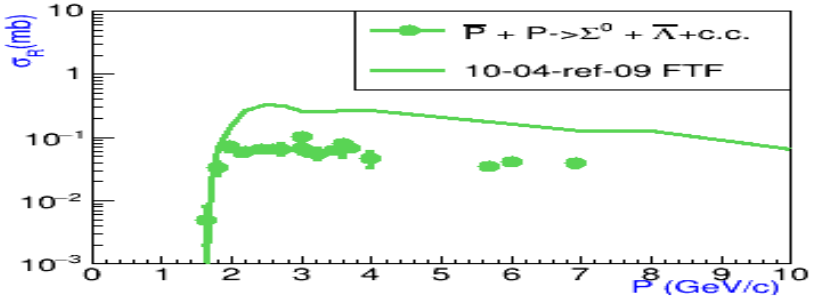
2 and 3 particle channels: PbarP -> Σ+Σ-bar, Σ-Σ+bar, Σ0Λbar, Σ0bar Λ Λπ0Λbar, Σ+π-Λbar + c.c. , Λ K0 Nbar +c.c.

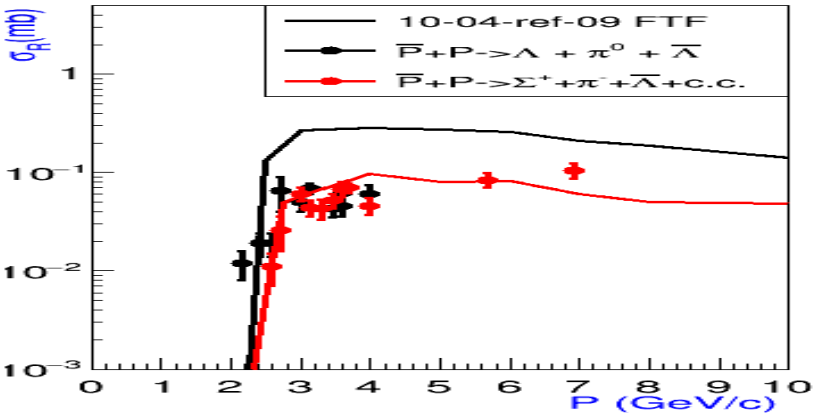
Landolt-Bornstein, Vol.12, "Total Cross –Sections for Reactions…"

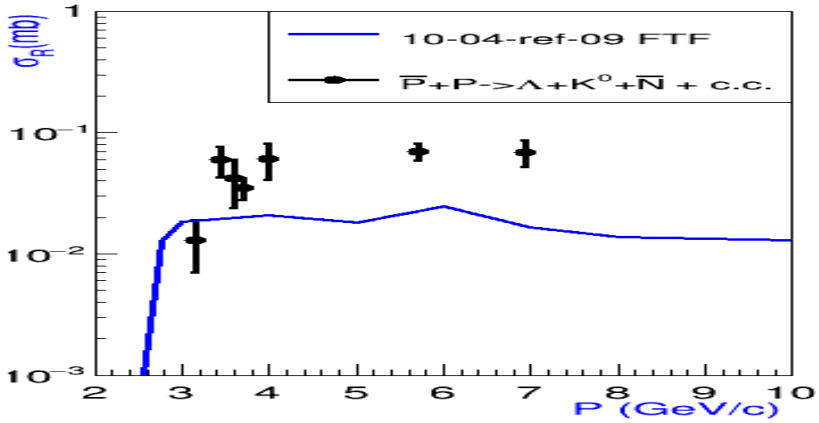






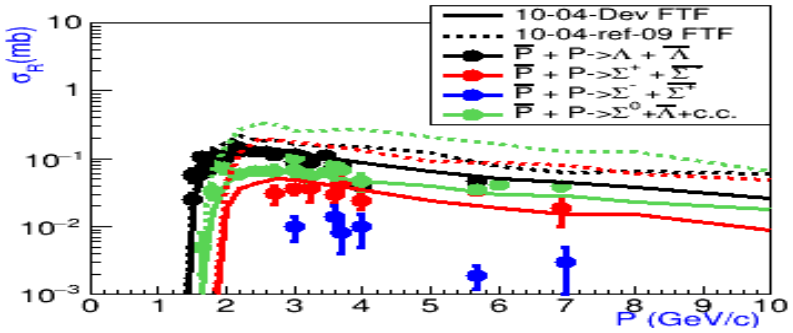


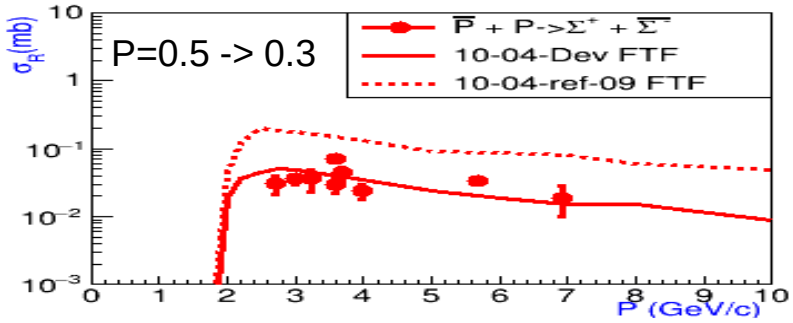


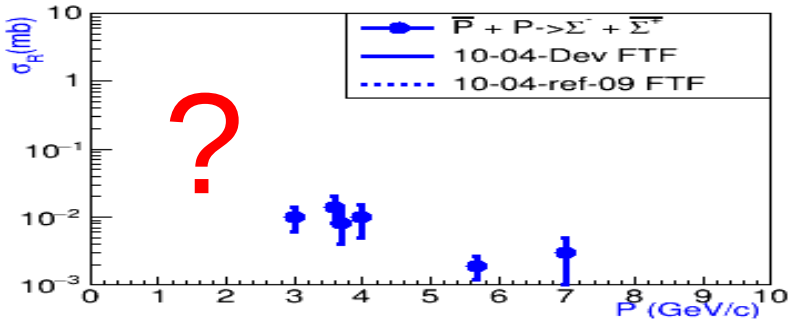


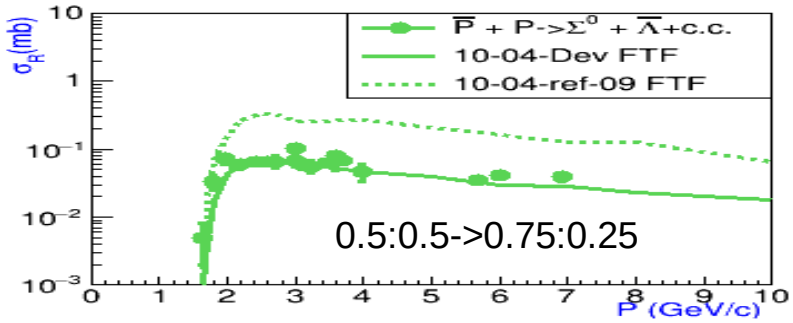
New annihilation channels were added in test22/PbarPchan

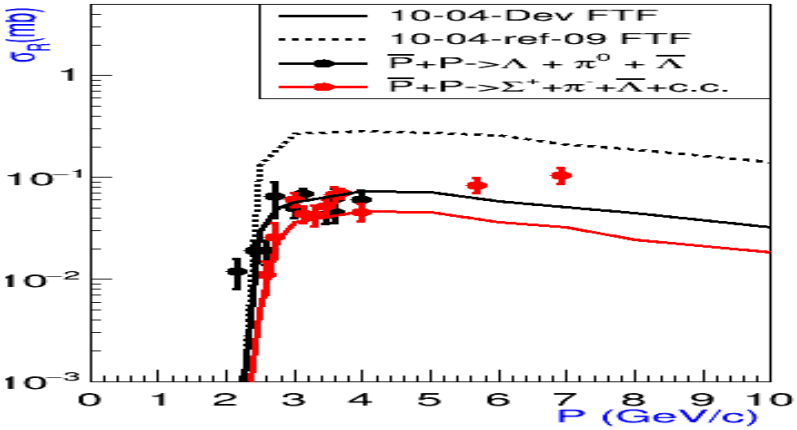
2 and 3 particle channels: PbarP -> Σ+Σ-bar, Σ-Σ+bar, Σ0Λbar, Σ0bar Λ Λπ0Λbar, Σ+π-Λbar + c.c. , Λ K0 Nbar +c.c. (after improving of)

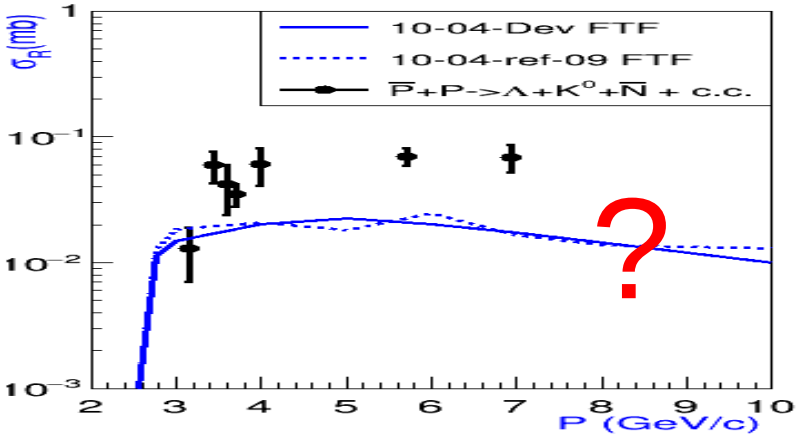






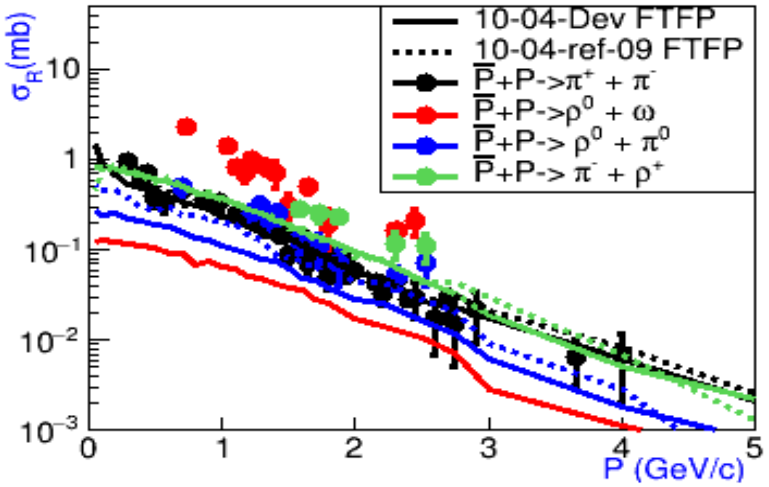


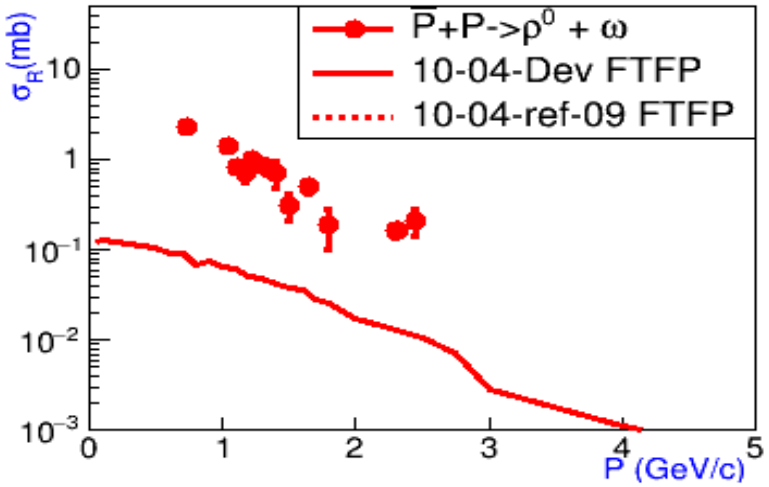


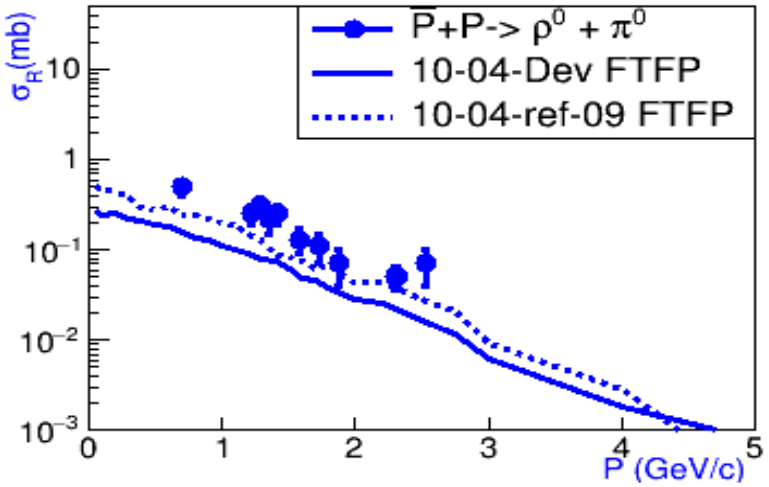


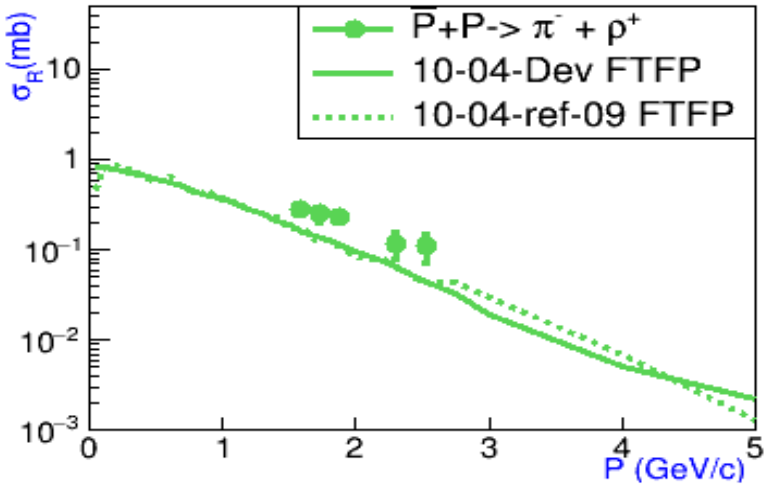
New annihilation channels were added in test22/PbarPchan

2 particle channels: PbarP -> ρ0ω, ρ0π0, π-ρ+.
They are compared with PbarP ->π+π-





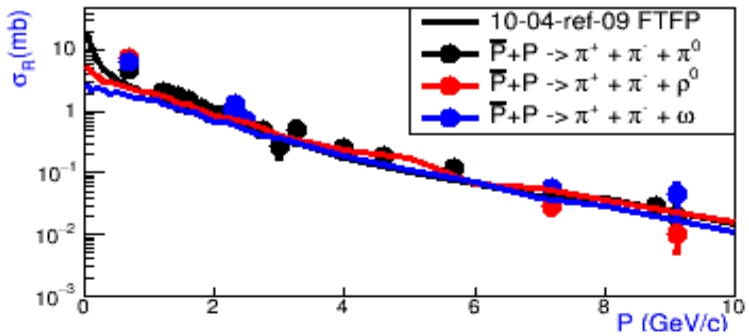


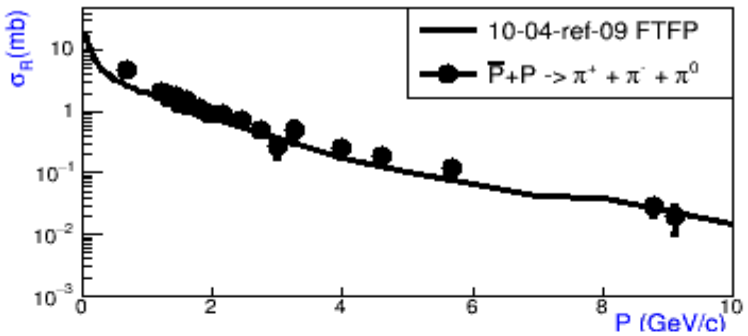


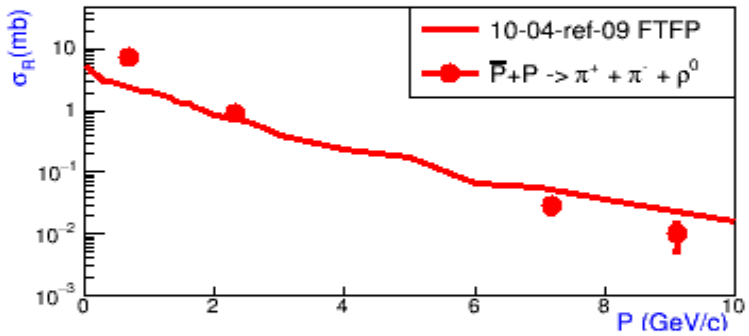
In FTF 10-04-Ref09 channel PbarP -> ρ0ω is absent (bug). We have fixed the bug.

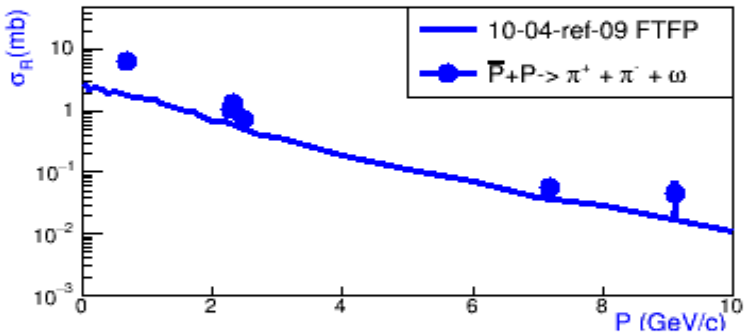
New annihilation channels were added in test22/PbarPchan

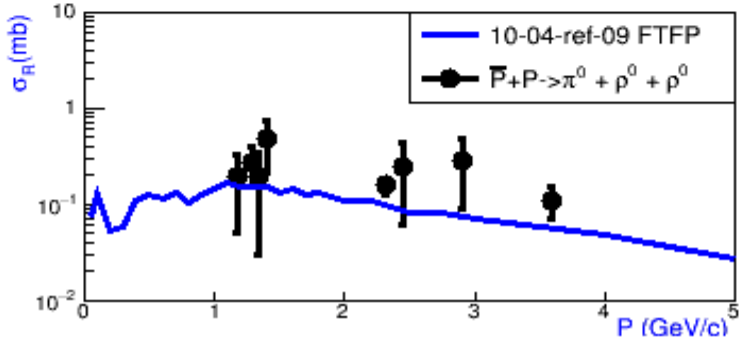
3 particle channels: PbarP -> π+π-ρ0, π+π- ω, compared with π+π- π0
3 particle channels: PbarP -> π0 2ρ0, π- ρ+ ρ0 + c.c.

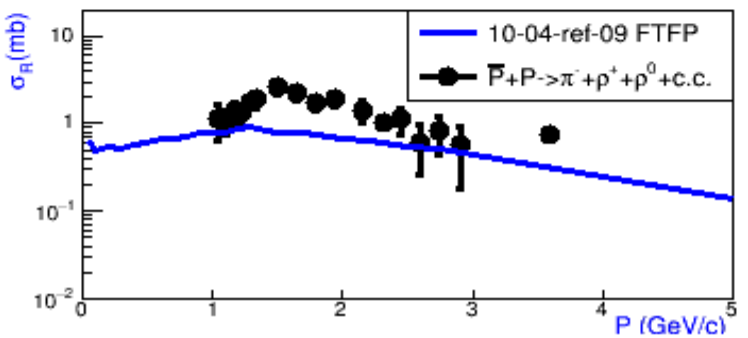






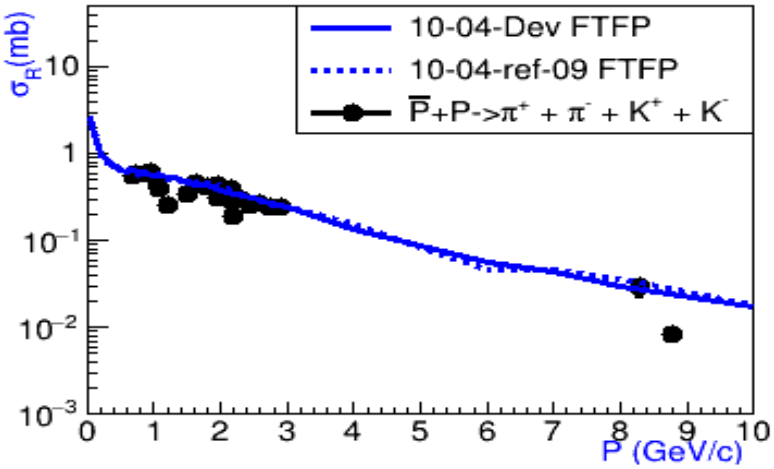


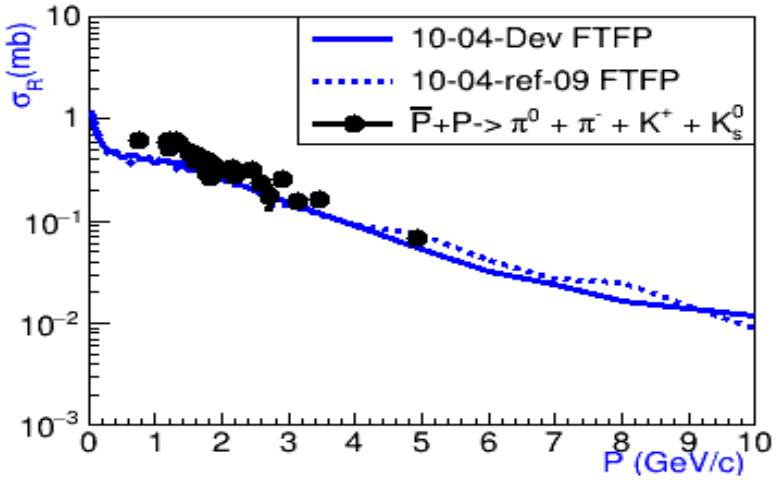


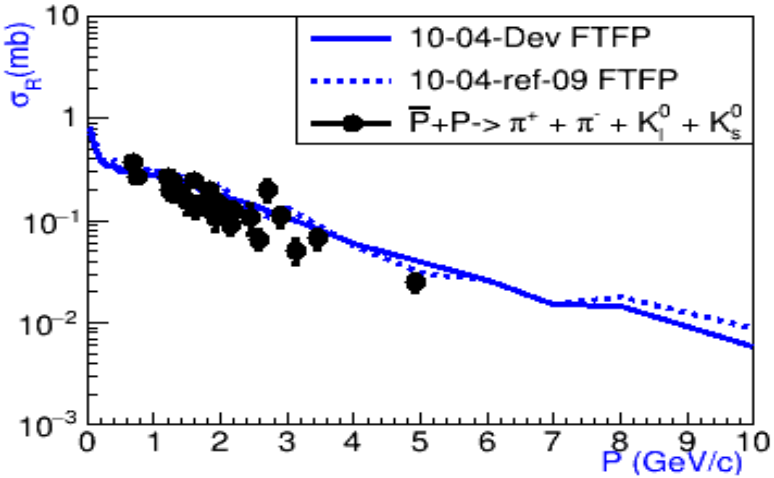


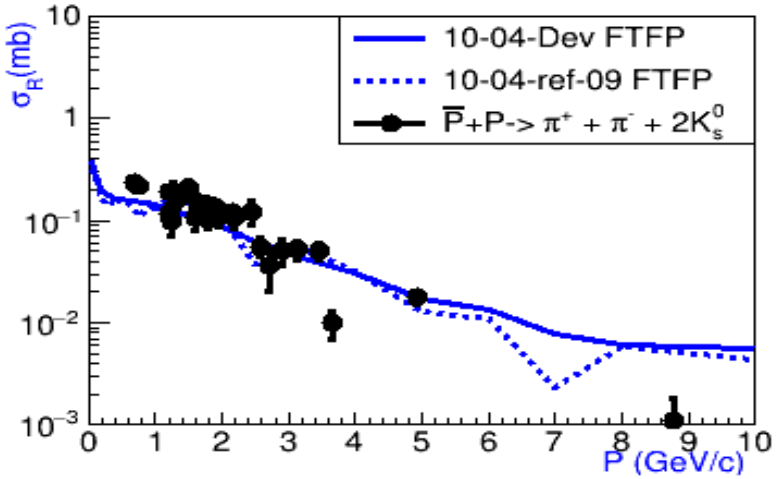
New annihilation channels were added in test22/PbarPchan

4 particle channels: PbarP -> π+ π- K+ K-, π0 π- K+Ks0, π+ π- Kl0 Ks0, π+ π- 2Ks0.





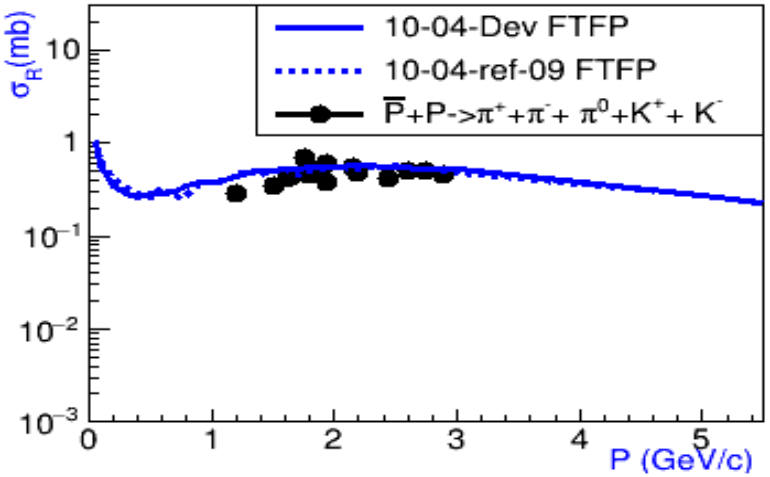


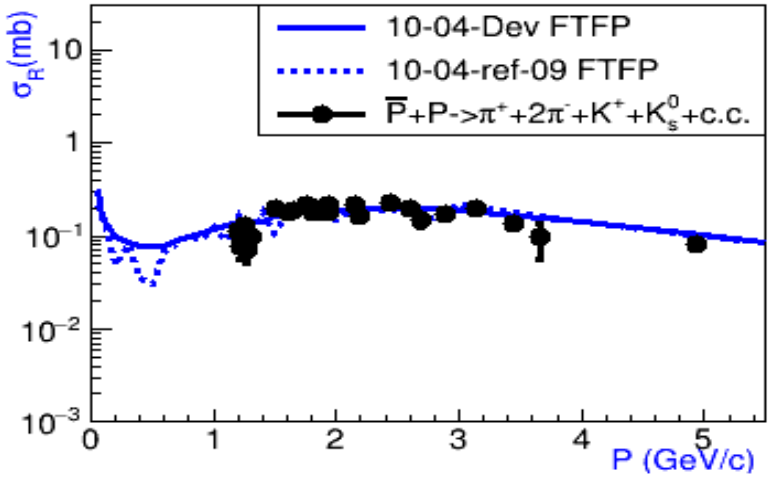


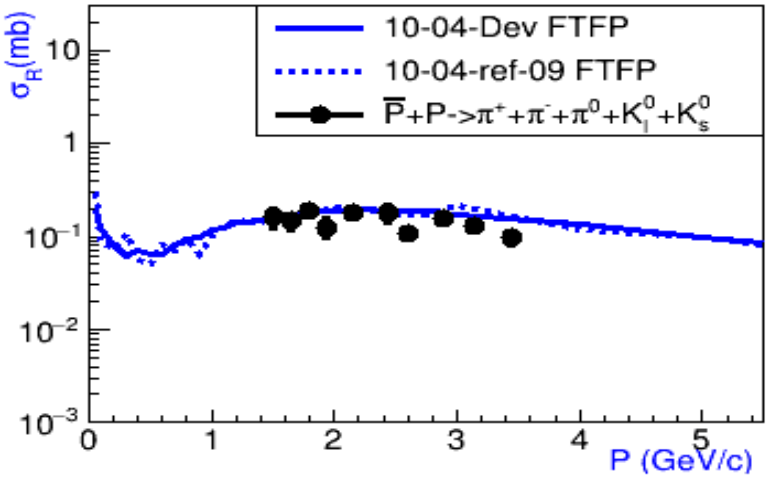
Landolt-Bornstein, Vol.12, "Total Cross –Sections for Reactions…"

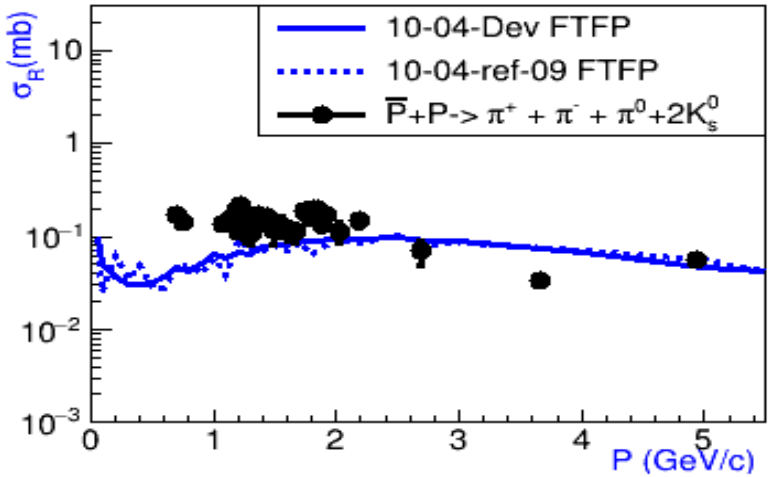
New annihilation channels were added in test22/PbarPchan

5 particle channels: PbarP -> π+ π- π0 K+ K-, π+ 2π- K+Ks0, π+ π- π0 Kl0 Ks0, π+ π- π0 2Ks0. **test22/PbarPchan**



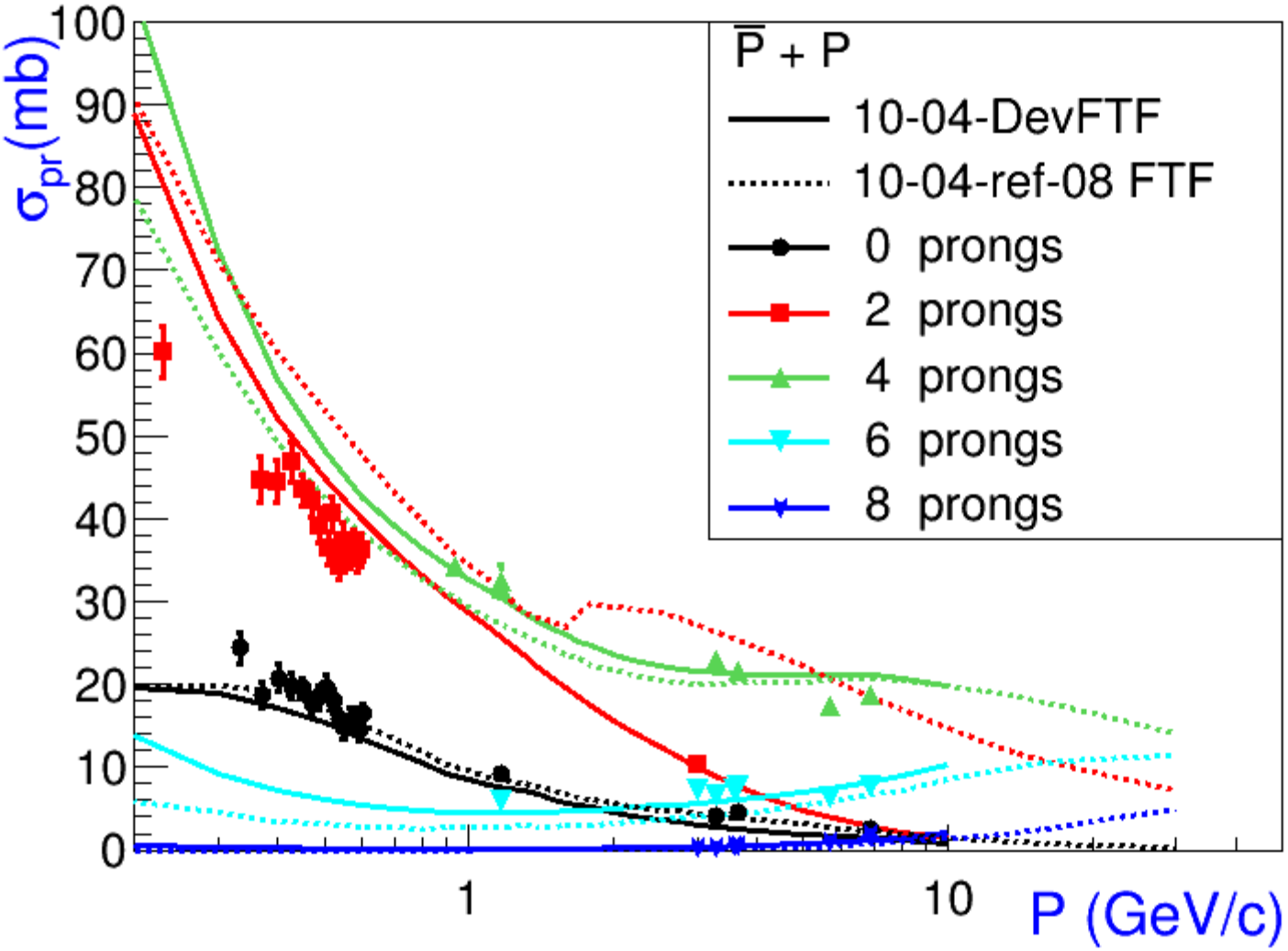






Landolt-Bornstein, Vol.12, "Total Cross –Sections for Reactions…"

Cross sections of 2, 4, 6, 8 prong events in Pbar-P-interactions



Conclusion

1. Isotropy of particle emission at Pbar-P annihilation at rest is recovered.

2. The change does not reflect on differential cross sections of binary reactions:
   Pbar-P -> ΛΛbar , PbarP-> π+π-, PbarP->ΣbarΛ +c.c. and Pbar-P -> K+K- .
   Reasonable description of exp. data is reached in the FTF model with rotating strings

3. Essential distortion of rapidity, Xf and Pt distributions of Λ-hyperons is observed in FTF version of G4-10-04-ref09.

4. New Pbar-P reaction channels are included in the validation folder: test22/PbarPchan
   Standard string fragmentation model parameters are changed for description of the new channel cross sections. Good agreement between modified FTF calculations and exp. data are reached for many new channels.

5. Modified FTF reproduces well topological cross sections of Pbar-P interactions.

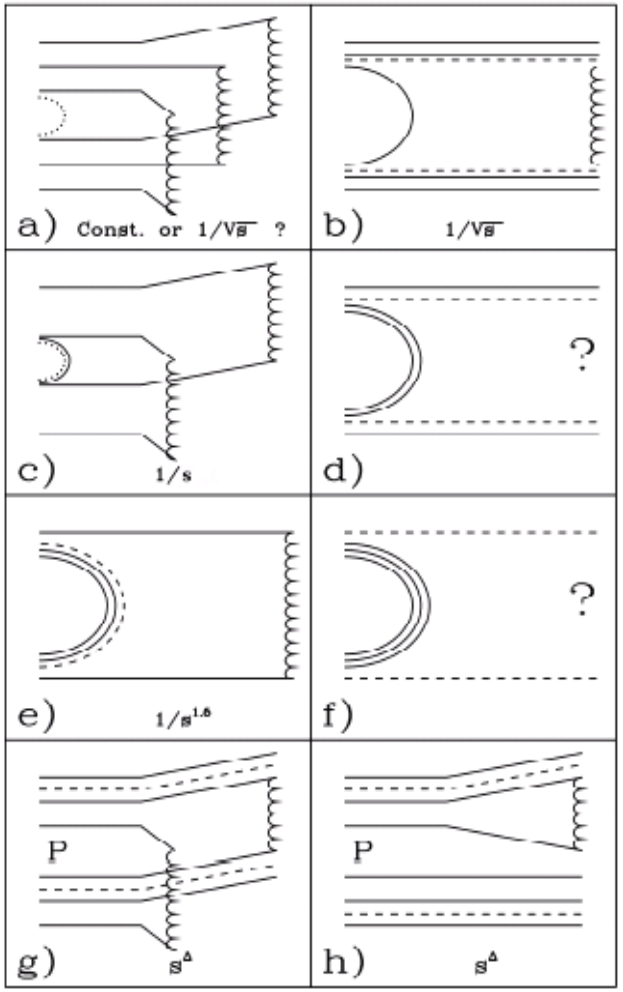
Plans:

It is needed to improve multiplicity distributions of π-mesons at Pbar-P annihilation at rest .
It is very important to improve kinematical spectra of Λ, Λbar hyperons.
produced in Pbar-P interactions at various initial momenta.
More verification and validation are required.

New annihilation channels were added in test22/PbarPchan

Landolt-Bornstein, Vol.12, "Total Cross –Sections for Reactions…"

2 particle channels: PbarP -> ΣΣbar, Σλbar, ρω, ρπ.
3 particle channels: PbarP ->πππρ, ππω , ΛπΛbar, ΣπΛbar, Λ K0 Nbar, π2ρ
4 particle channels: PbarP -> 2π 2K . 5 particle channels PbarP -> 3π 2K



Cross sections of Pbar-P processes in FTF

$$\sigma_a = \frac{25}{\sqrt{s - 4m^2}} \quad (mb)$$

$$\sigma_b = 15.65 + 700 * (2.172 - \sqrt{s})^{2.5} \quad (mb), \quad \sqrt{s} \le 2.172 \quad (GeV)$$

$$\sigma_b = 34/\sqrt{s} \quad (mb), \quad \sqrt{s} > 2.172 \quad (GeV)$$

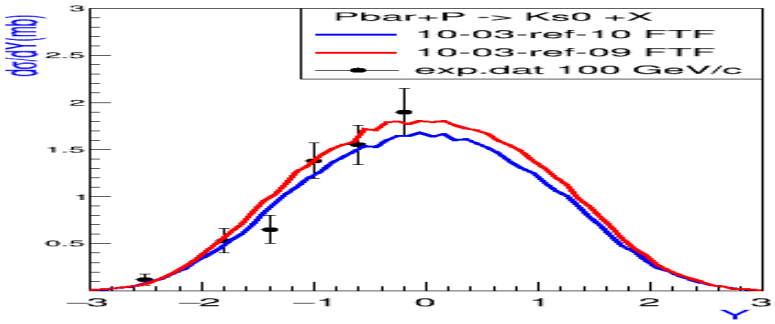
$$\sigma_c = \frac{2}{\sqrt{s - 4m^2}} \left(\frac{m_p + m_t}{s} \right)^2 \quad (mb)$$

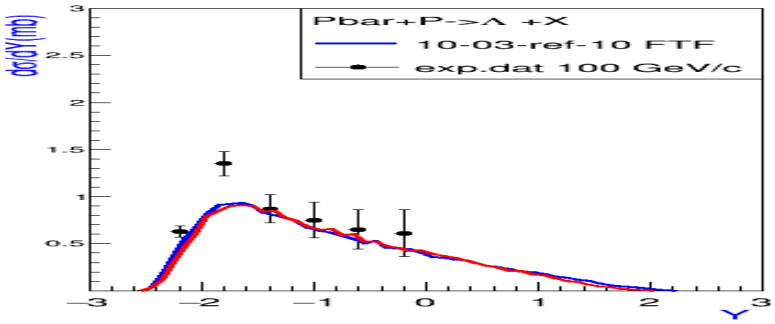
$$\sigma_e = 140/s \quad (mb)$$

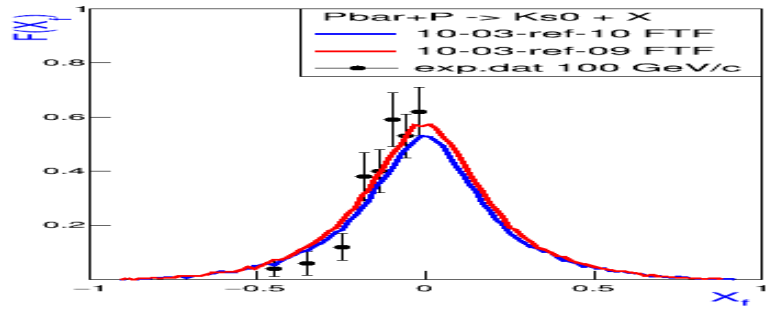
$$\sigma_{FTF} = 35 * (1. - 2.1/\sqrt{s}) \quad (mb)$$

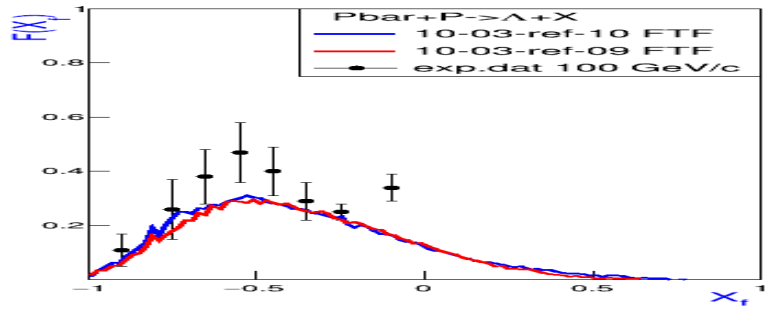
Strange particle production in PbarP - interactions at high energies

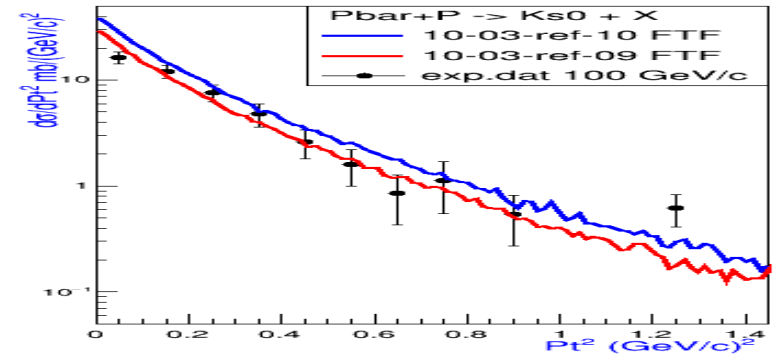
Kinematic distributions of Λ and Ks^0 produced in PbarP interactions at Plab=100 GeV/c

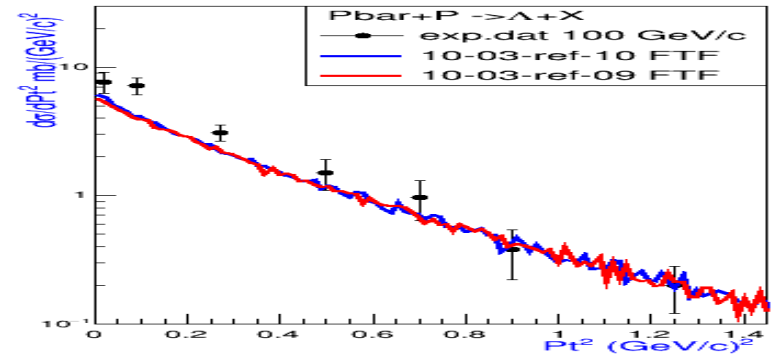










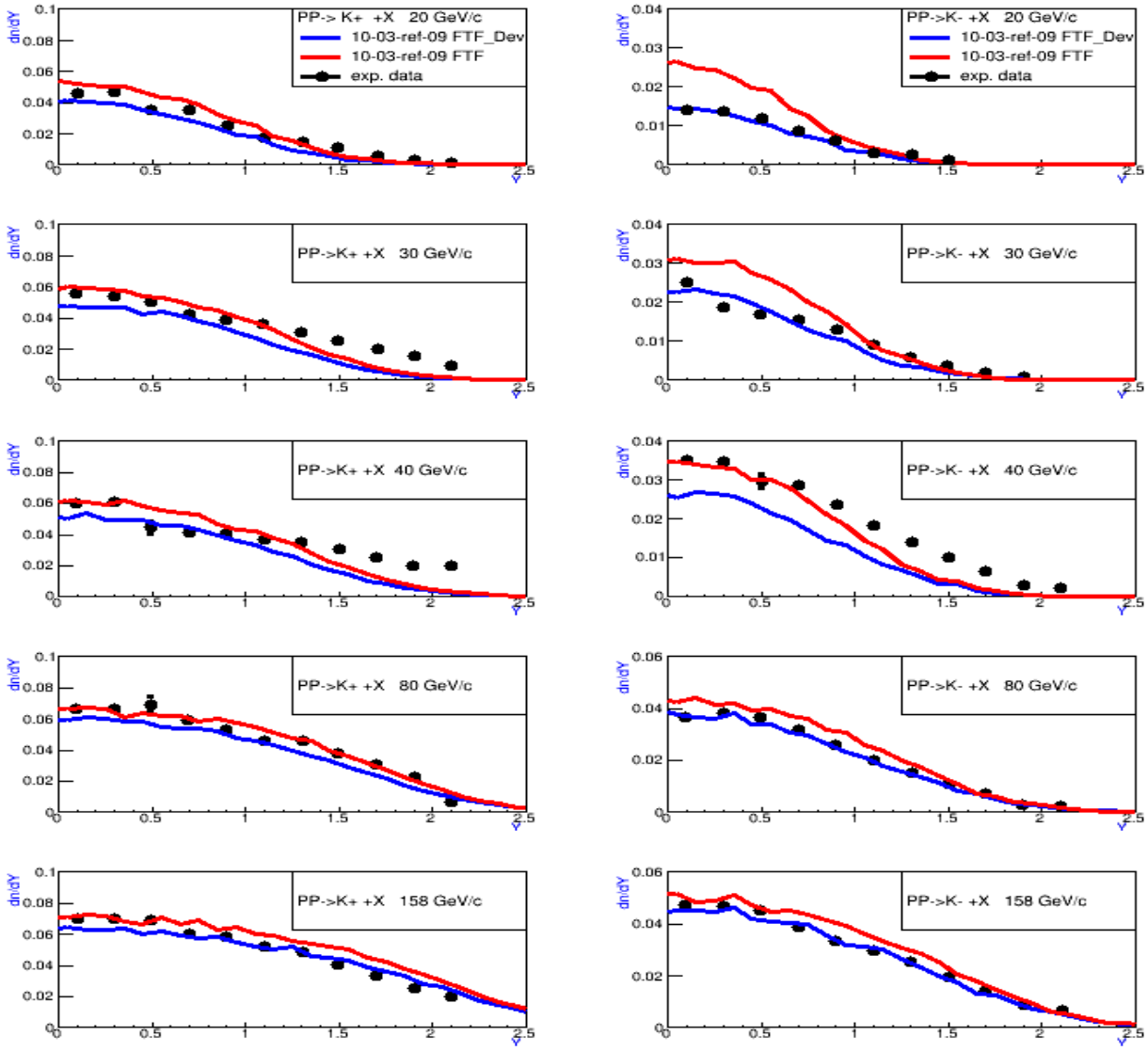


Exp data: D.R. Ward et al., Phys. Lett. 62B 237 (1976)

K+ and K- production in PP-interactions at Plab>= 20 GeV/c

NA61/SHINE Collaboration Eur.Phys.J. C77 (2017) no.10, 671

Measurements of π±, K± , p and p¯ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS.



Probability of strange q-qbar production at final string decay is changed. New probability is chosen:

$$P_{\bar{s}\ s} = 0.108 \left[1 - \left(\frac{m_{th}}{M_{str}}\right)^4\right]$$