Exploring the use of EPOS as particle generator for pp collisions at NICA energies

Katherin Shtejer Díaz

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EPOS

Energy conserving quantum mechanical multiple scattering approach, based on **P**artons (partons ladders), **O**ff-shell remnants, and **S**plitting of parton ladders.

Unified formalism based on a combination of:

- Gribov – Regge theory
  - Focusses on the soft aspects of the particle collisions.
  - Describes multiple interactions using “Pomerons” representing an elementary interaction.
- Parton model
  - Introduces quarks and gluons giving a more precise description of interactions.
  - Uses QCD and QED descriptions to calculate cross sections of parton jets.
  - Parton production represented by Lund model strings.

Strengths:

- Consistent treatment of soft and hard scattering.
- Hard processes are introduced in a natural way without arbitrary assumptions (no artificial cuts)
- Energy conservation is considered in both, particle production and cross section calculation.
- Hydrodynamical evolution is done event by event.
- Treatment of participants and remnants ensures the energy conservation.

Where to find EPOS?

There is common user interface to several models, used for air shower simulations "Cosmic Ray Monte Carlo" which includes cosmic rays and non cosmic ray event generators.
EPOS (1.99 and LHC) is one of them: https://web.ikp.kit.edu/rulrich/crmc.html

The interface provides different output formats: Les Houches, ROOT or HepMC

Input:

Example of generation command:

```
bin/crmc -o hepmc -S10 -n1000  -m1
                          -i2212 -I2212
```

`-o hepmc`	……	Output can be uncompressed (`hepmc`) or compressed (`hepmc.gz`)
`-S10`	……	$\sqrt{s_{NN}}$ = 10 GeV (center of mass energy)
`-n1000`	……	1000 pp collisions
`-m1`	……	model EPOS1.99 (`-m0`= EPOS-LHC)
`-i2212 I2212`	……	pp collision is the default (it can be omitted)

Basic structure of the output information

Output:

- Header lines

```
HepMC::Version 2.06.09
HepMC::IO_GenEvent-START_EVENT_LISTING
```

- Line Keys

- **E**: general event information (ev. number, signal process ID, number on vertices in event, etc)
- **U**: Momentum and position units (GEV, MM)
- **C**: GenCrossSection information (pb)
- **H**: Heavy Ion information (# of hard scatt., projectile and target participants, # of NN collisions, **impact parameter (fm)**, azimuthal angle of event plane, nucleon-nucleon inelastic cross section)
- **V**: GenVertex information (vertex ID, four vector “x, y, z, t”, etc)
- **P**: GenParticle information (**PDG id**, four vector “**px**, **py**, **pz**, E”, generated mass, **status code defining if is FS particle**, decayed particle, incoming beam particle, etc.)

- Footer line

```
HepMC::IO_GenEvent-END_EVENT_LISTING
```

MpdRoot interface for the EPOS model

Proposed generator class: `MpdEPOSGenerator.cxx` `MpdEPOSGenerator.h`

```
MpdEPOSGenerator::MpdEPOSGenerator()
```

→ Constructor

```
MpdEPOSGenerator::MpdEPOSGenerator(const char *filename="crmc_epos199.hepmc.gz")
{
   fgzFile = gzopen(filename,"rb"); // zlib
   if (!fgzFile) {printf("-E- MpdEPOSGenerator: can not open file: %s\n",filename); exit(1);}
   printf("-I- MpdEPOSGenerator: open %s\n",filename);

   fPsiRP=0.;
   fisRP=kTRUE;     frandom = new TRandom2();
   frandom->SetSeed(0);
 };
```

→
- Opening output file from EPOS model
- Initialization of reaction plane angle to be randomly sampled

```
MpdEPOSGenerator::~MpdEPOSGenerator()
```

→ Destructor

```
Bool_t MpdEPOSGenerator::ReadEvent(FairPrimaryGenerator *primGen)
{
     ……..
     Reading ascii file line by line

     Loop for event
         … Here the impact parameter (fb) is read …
         FairMCEventHeader *eventHeader = primGen->GetEvent();
         if (eventHeader && (!eventHeader->IsSet()))
          {
             eventHeader->SetB(fb);   eventHeader->MarkSet(kTRUE);  eventHeader->SetRotZ(fPsiRP);
          }
           Loop for vertices in the event

                  Loop for particles from each vertex
                  … Here FS particles are selected…
                      - Reading ipdg, px, py, pz per particle

                        Adding particles to simulation: primGen->AddTrack(ipdg, px, py, pz 0., 0., 0.);
};
```

→ Reading events and adding particles to the simulation

Monte Carlo simulations

Minimum bias inelastic collisions were generated at energies $\sqrt{s_{NN}}$ = 6 - 25 GeV, with:

- EPOS-1.99 (10^5 events)
- HSD-4.0 (10^5 events)
- UrQMD-3.4 ($5x10^4$ events)

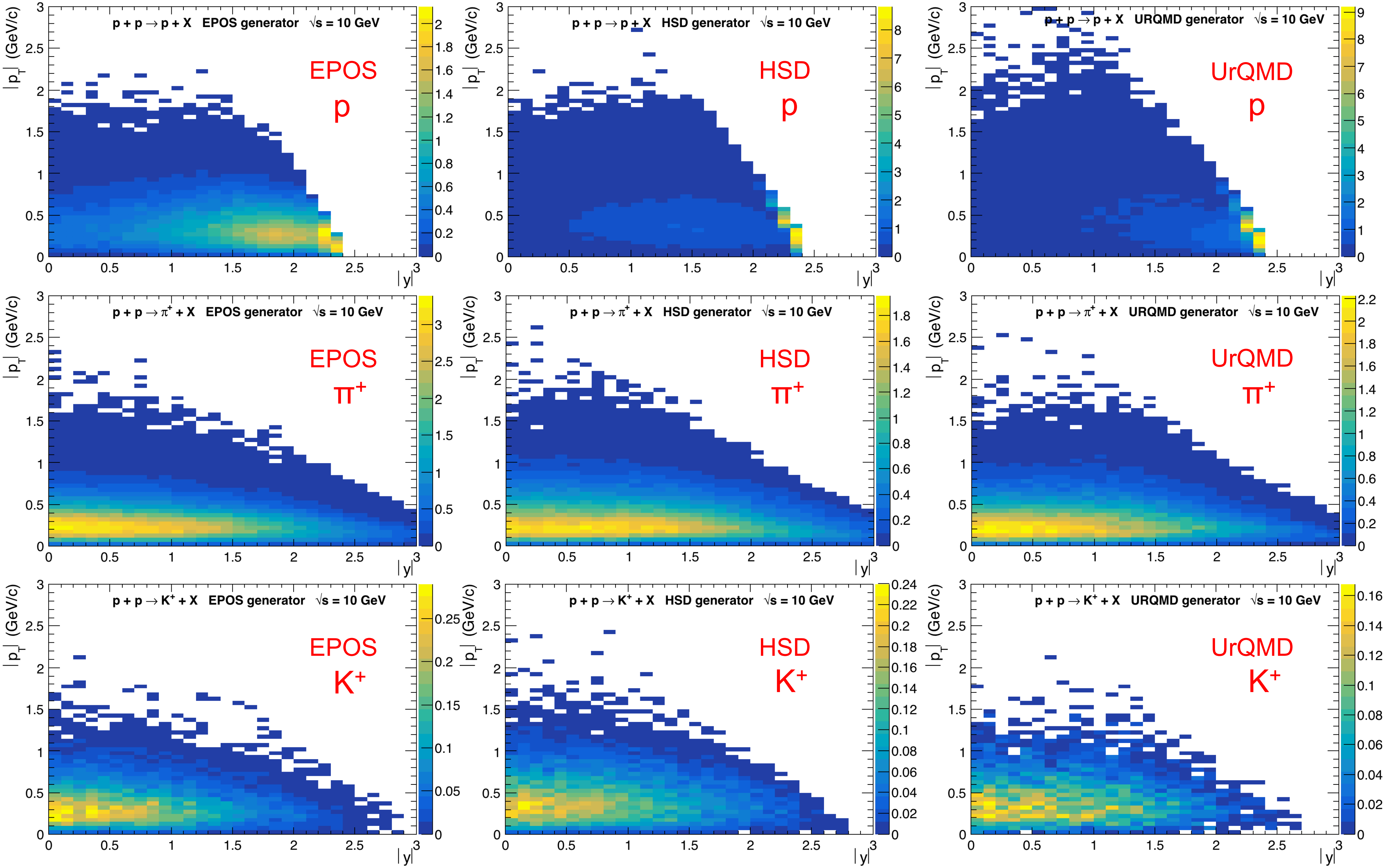
Monte Carlo:

- MCTrack branch was analyzed with MPDRoot.
- Only FS primary particles [(1)]
- Geant3 based on the geometry stage I.

[(1)] Final state particle: is the particle that is not further decayed by the generator. It can also be unstable particles that are to be decayed later.

Monte Carlo simulations with generators: EPOS, HSD, UrQMD

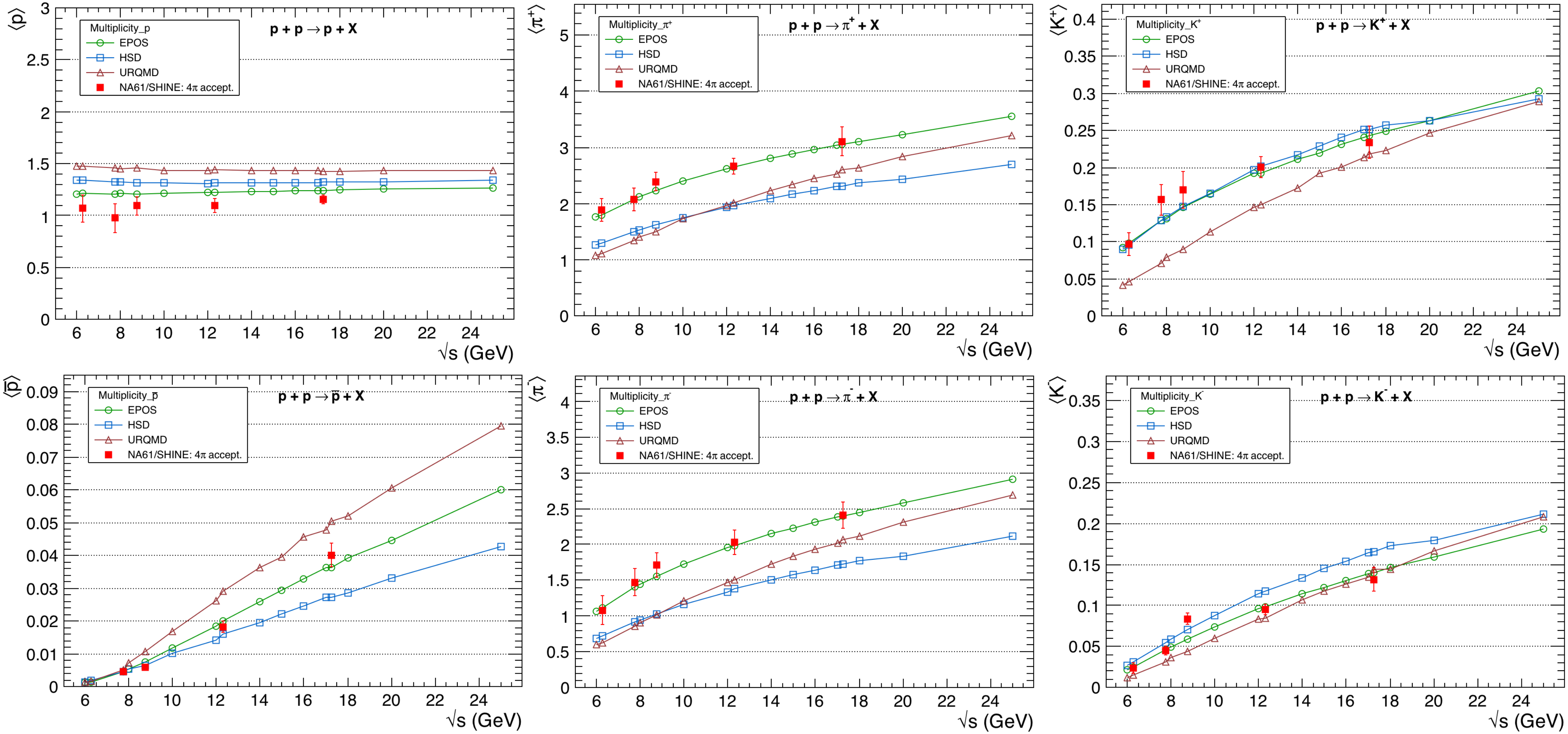
Phase space y vs. p_T of p, π^+, K^+, $\bar{p}$, π^-, K^-, produced in pp collisions at $\sqrt{s_{NN}}$ = 10 GeV



Monte Carlo simulations with generators: EPOS, HSD, UrQMD

Energy dependence of mean multiplicity of p, π^+, K^+, $\bar{p}$, π^-, K^-, produced in pp collision

The mean number of produced particles per inelastic event was calculated from rapidity distributions.

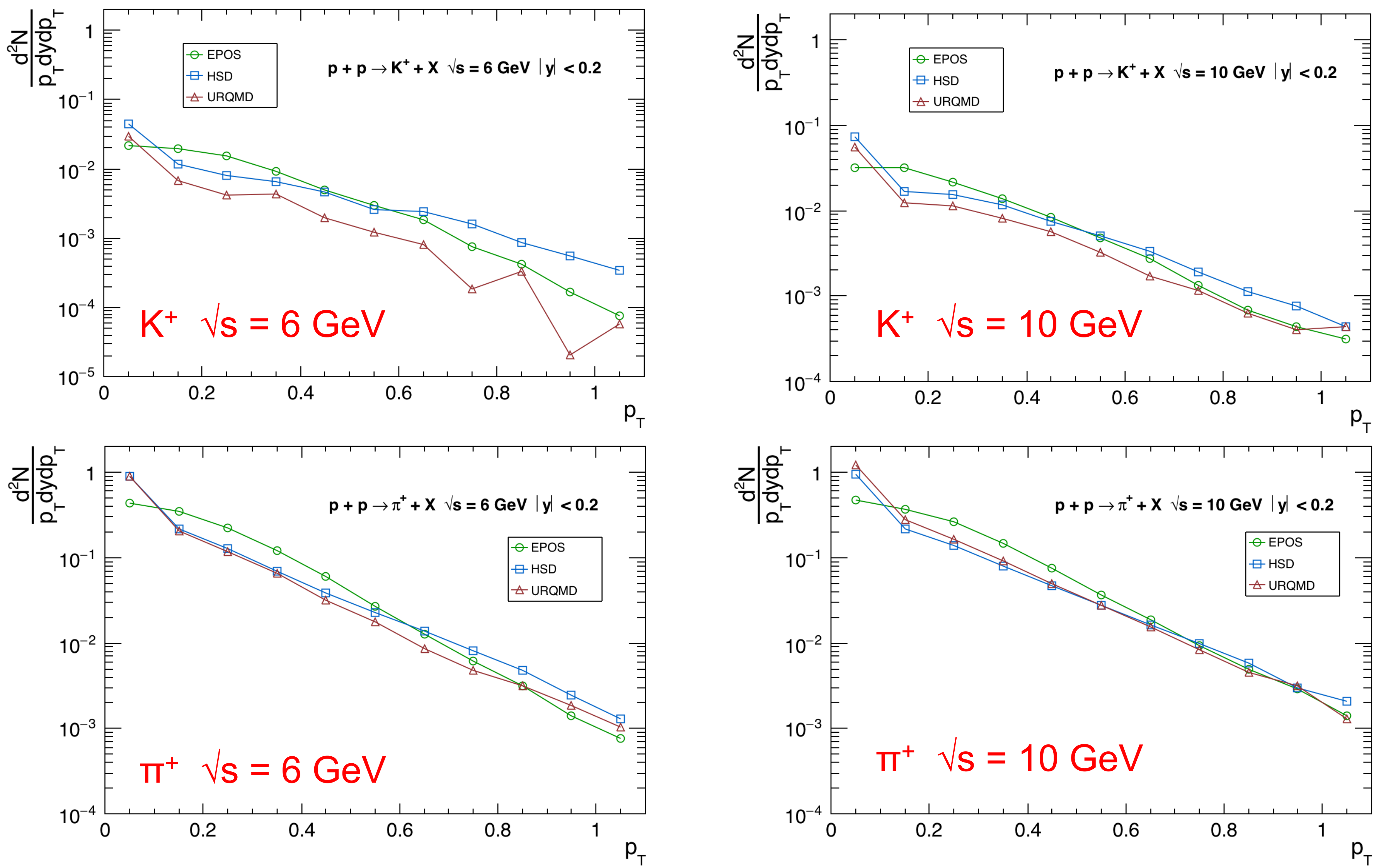


From MC simulations with MPDRoot, can be seen that EPOS describes better the particle multiplicity measured at SPS energies from NA61/SHINE experiment.
With HSD the pion multiplicity is lower and the kaon multiplicity is higher than the same predictions from the other models.

[1] Experimental values from NA61/SHINE at SPS energies, represents 4π multiplicities. These data were published in *Eur. Phys. J. C (2017) 77:671* (Tables 4 and 5). https://link.springer.com/content/pdf/10.1140/epjc/s10052-017-5260-4

Monte Carlo simulations with generators: EPOS, HSD, UrQMD

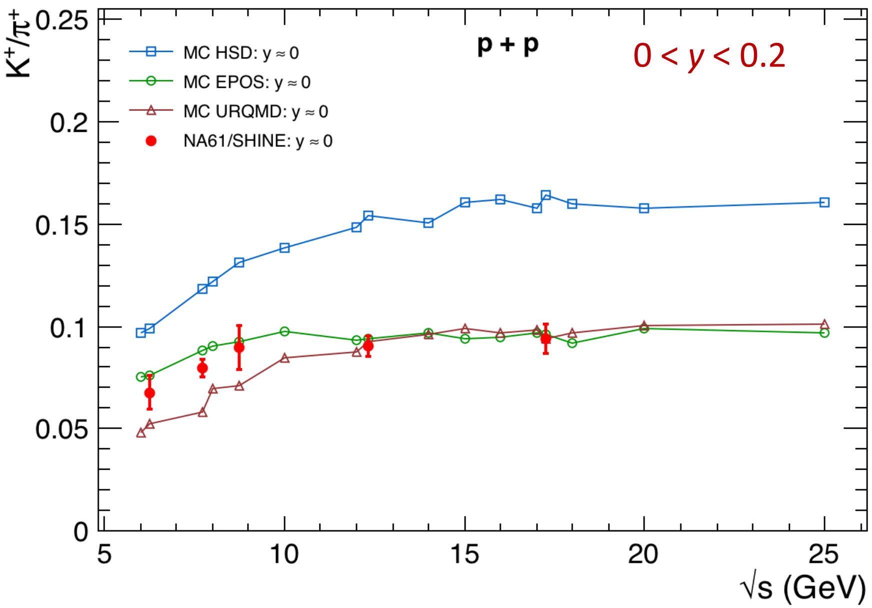
pT spectra for K^+ and π^+ at mid-rapidity |y| < 0.2

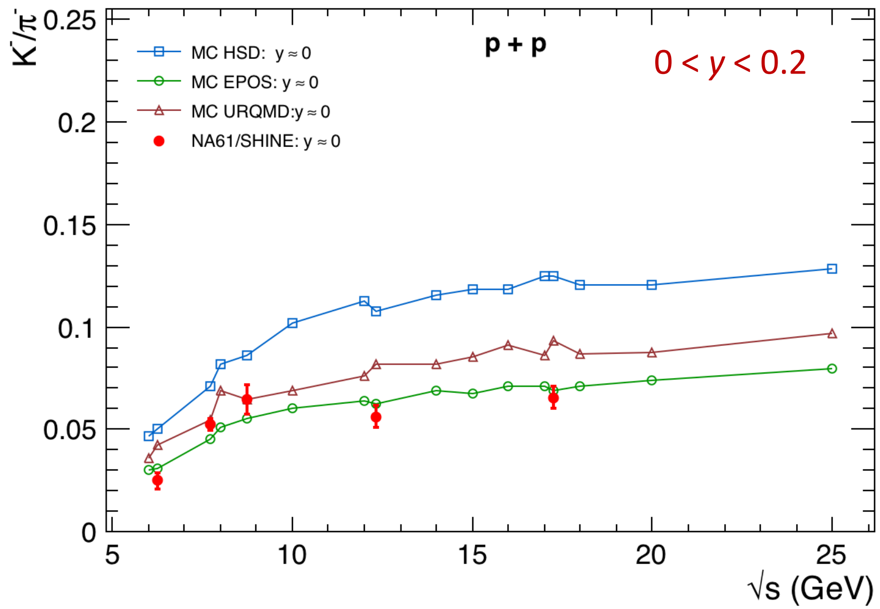


At mid-rapidity EPOS predicts more K^+ and π^+ for 0.1 GeV/c < pT < ~0.6 GeV/c than HSD and UrQMD

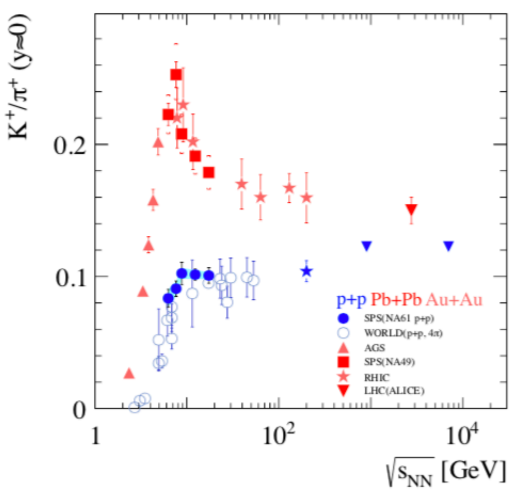
Monte Carlo simulations with generators: EPOS, HSD, UrQMD

Ratio $K^{\pm}/\pi^{\pm}$ ("horn") as signal of deconfinement.

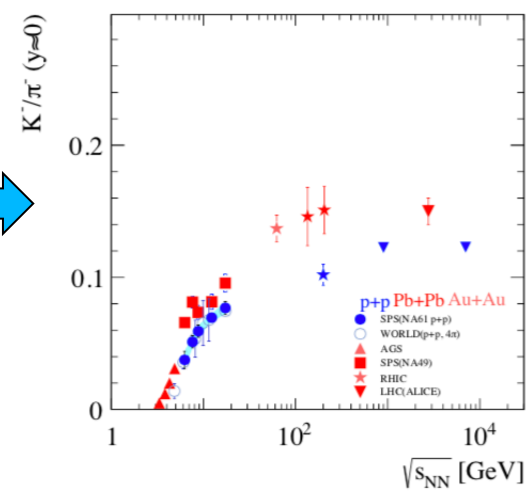




The kaon-to-pion ratio predicted by MC in MPD with EPOS generator at mid-rapidity, describes better the experimental data from NA61/SHINE. With HSD the pion multiplicity is lower and the kaon multiplicity is higher than the same predictions from the other models.



Ratio $K^{\pm}/\pi^{\pm}$ comparison between pp inelastic collisions and Pb-Pb / Au-Au central collisions

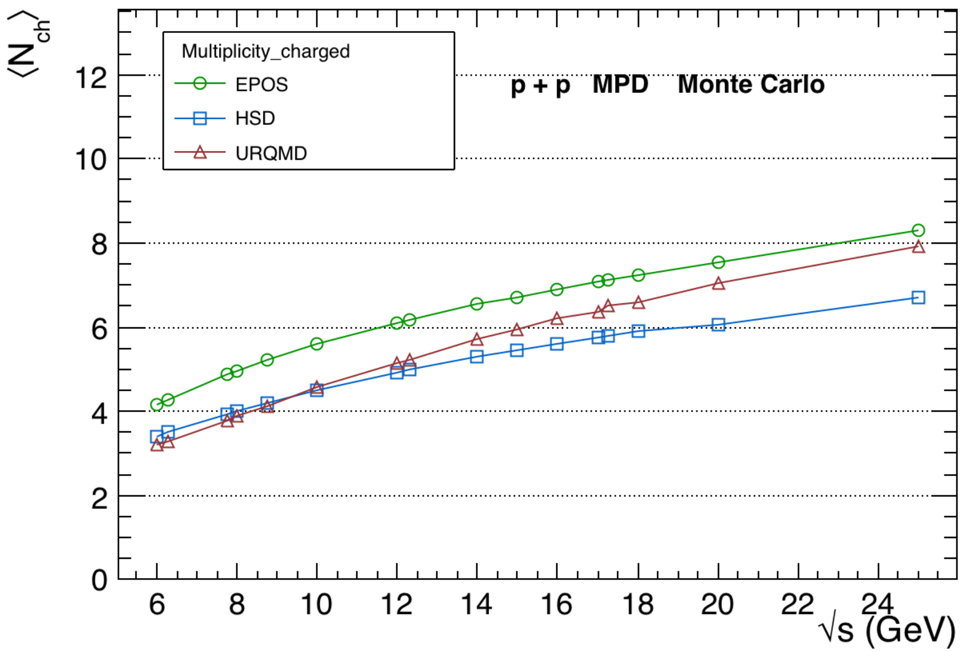


(1) Experimental values from NA61/SHINE at SPS energies were obtained from the data corresponding to the first bin of the rapidity spectra published in *Eur. Phys. J. C (2017) 77:671* (Fig. 34). The experimental data can be found in: https://dx.doi.org/10.17182/hepdata.79533

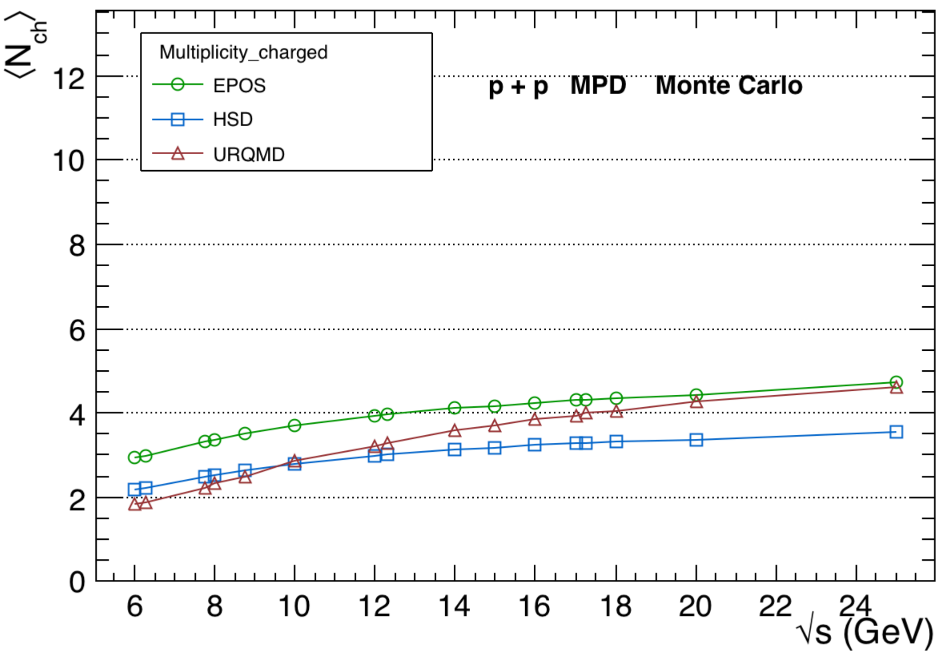
Monte Carlo simulations with generators: EPOS, HSD, UrQMD

Energy dependence of mean multiplicity of $\mathbf{p} + \boldsymbol{\pi}^+ + \boldsymbol{K}^+ + \overline{\boldsymbol{p}} + \boldsymbol{\pi}^- + \boldsymbol{K}^-$, produced in pp collision.

Considering all Monte Carlo tracks



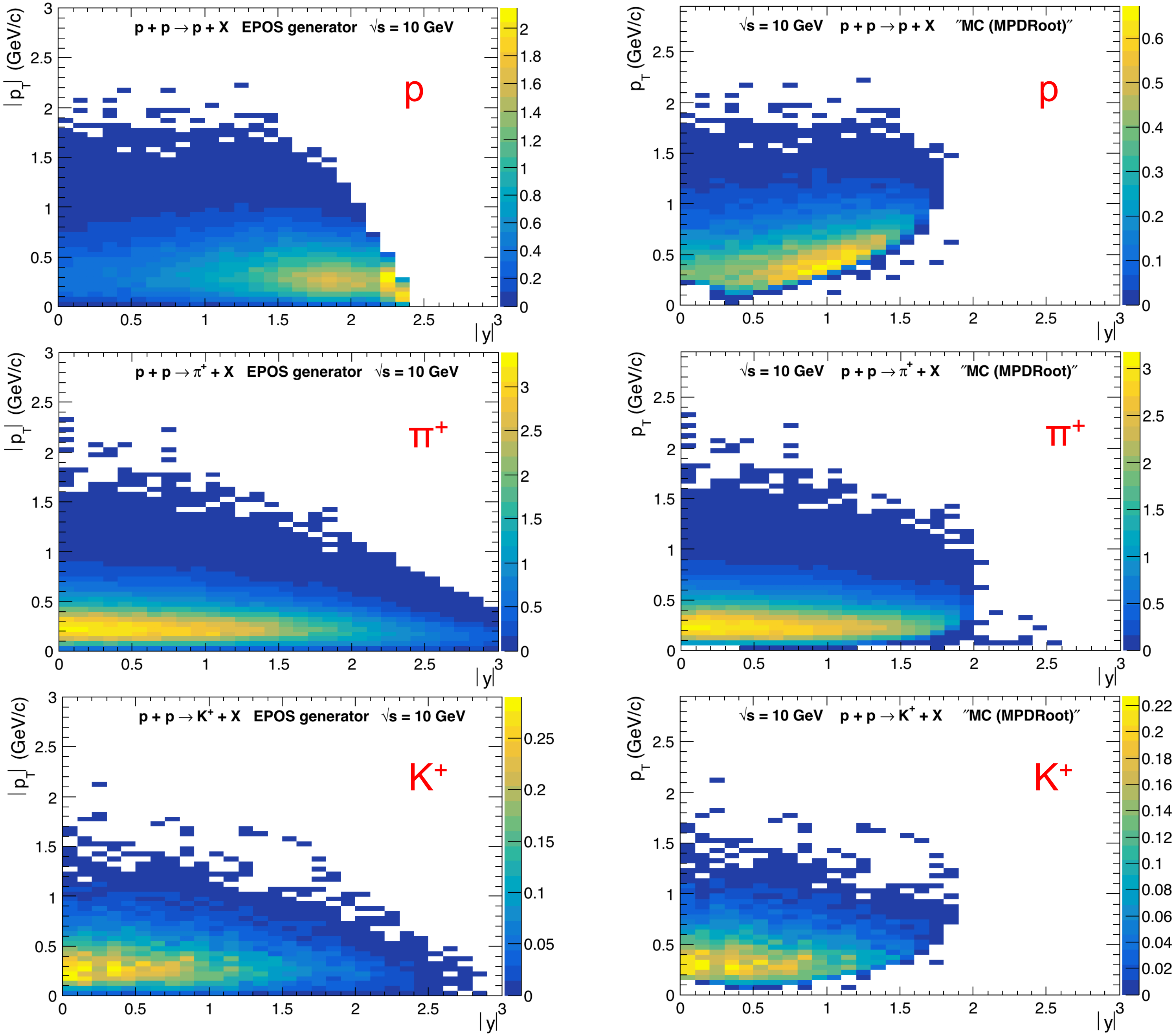
Only MC tracks which have the corresponding track reconstructed in TPC



Phase space y vs. p_T $\sqrt{s_{NN}}$ = 10 GeV

Considering all MC tracks

Only MC tracks which have the corresponding track reconstructed in TPC



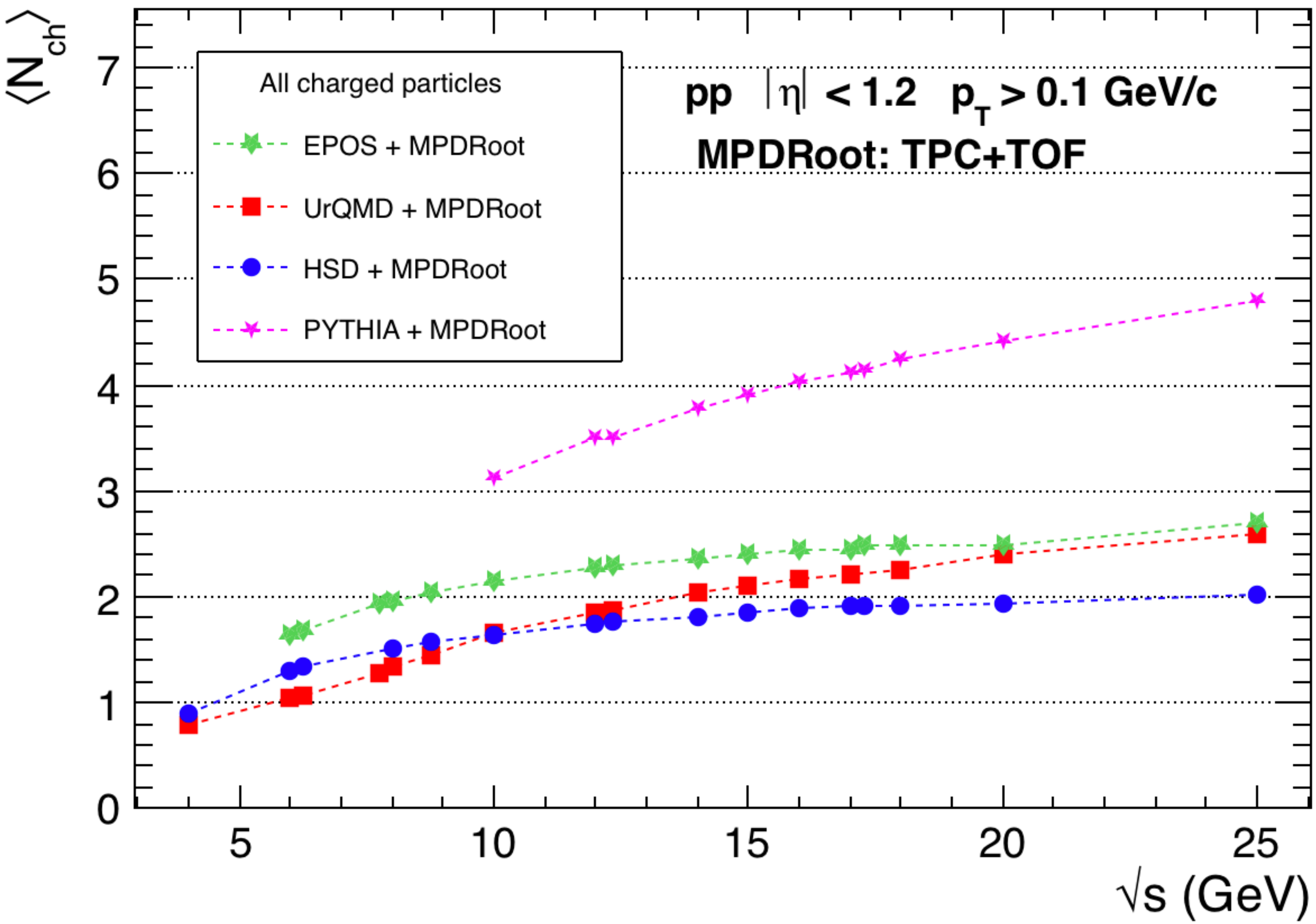
Apart from the TPC acceptance limitations, a large number of particles with low p_T are not reconstructed and consequently will be lost or reconstructed/measured with very low efficiency.

Protons and kaons are more affected.

Around 0.1% of charge particles are lost count the MC multiplicity for $p_T > 0.1$ GeV/c. This p_T cut-off is the value at which the tracking efficiency is 50%).
eg. from 1million produced particles 1000 will be lost.

Correction factors, by using a good generator, will be needed for low p_T effect and other factors affecting multiplicity, Available models to study pp collisions are currently under investigation to define its possibilities as particle generator at the energies available in NICA.

Mean multiplicity of all charged particles in MPD (TPC+TOF). Here the models EPOS, UrQMD, HSD and PYTHIA were used as generators.



- EPOS-1.99
- HSD-4.0
- UrQMD-3.4
- Pythia-8.215

EPOS-1.99 is a strong candidate as it best describes the NA61/SHINE experimental data.
Eur. Phys. J. C (2017) 77:671

SUMMARY

- EPOS generator is ready to be committed to the MpdRoot!

- For pp collisions at center of mass energies until 25 GeV/c, EPOS1.99 describes quit well the experimental data.

- EPOS model provides the possibility to study different observables and its event-by-event fluctuations, not only for elementary collisions like proton – proton, but also for heavy ion collisions.

- EPOS-LHC was tuned with the collisions at LHC, while EPOS1.99 needs to be further tested at lower energies, like the energies obtained in SPS, and NICA in the next future.