New developments in EPOS

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1 Multiple scattering in EPOS

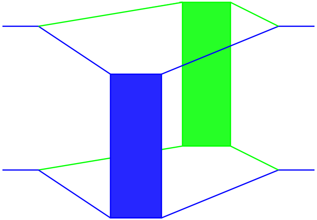
Parton based Gribov-Regge theory. By H.J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, K. Werner. hep-ph/0007198. Published in Phys.Rept. 350 (2001) 93-289.

Be T the elastic (pp,pA,AA) scattering T-matrix =>

$$2s\,\sigma_{\mathrm{tot}} = \frac{1}{\mathrm{i}}\mathrm{disc}\,T$$

Basic assumption :
Multiple "Pomerons"

$$iT = \sum_k \frac{1}{k!}\left\{iT_{\mathrm{Pom}} \times \ldots \times iT_{\mathrm{Pom}}\right\}$$

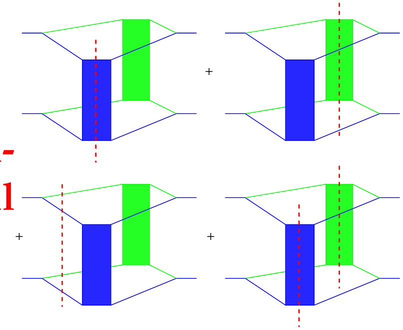


Evaluate

$$\frac{1}{i}\mathrm{disc}\left\{iT_{\mathrm{Pom}}\times\ldots\times iT_{\mathrm{Pom}}\right\}$$

using "cutting rules" :

A "cut" multi-Pomeron diagram amounts to the sum of all possible cuts



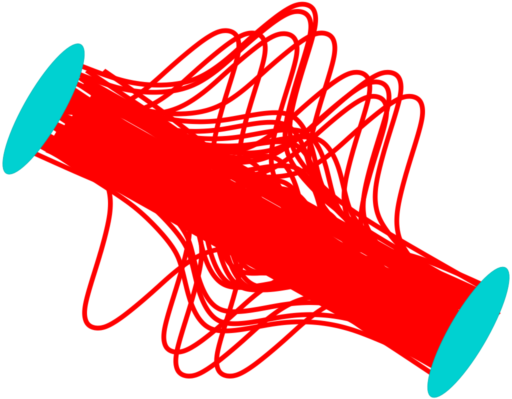
Summing uncut contributions

=> MuScatt weights, high-dim probab. distributions

=> Sampled via Markov chains

High multiplicity pp or AA: Many cut Pomerons

=> Many kinky strings



=> core + corona

core => hydro evolution => statistical decay

2 News

Current activities:

Unification of EPOS LHC & EPOS3

- □ **Implementation of HF**
- □ **Saturation and factorization**
- □ **Statistical hadronization**

- **Core-corona separation (pp,pA,AA)**

- **EPOS 3:**
  - **Hydrodynamic expansion of core**
  - **Statistical decay of fluid**
    (Grand canonical, big systems)

- **EPOS LHC:**
  - **Effective flow, droplet decay**
    (like resonance decay, small systems, small hadron list)

- **"Unification": Microcanonical decay**
  for small and big systems, works for pp and PbPb

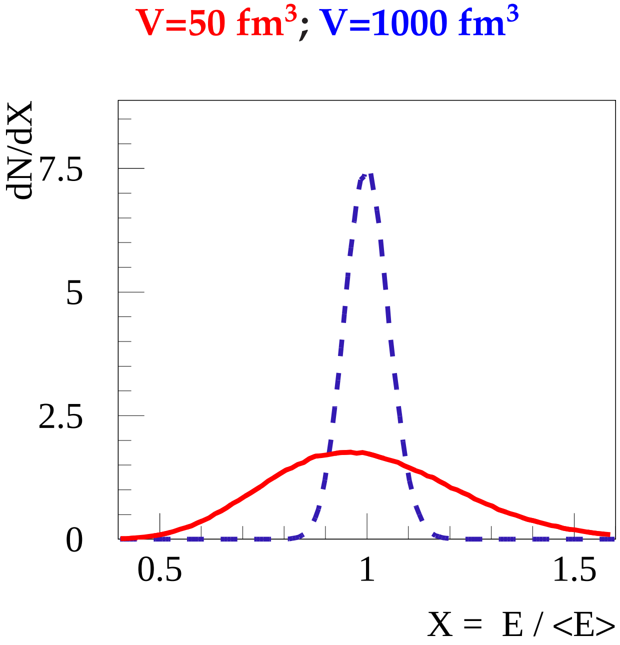
2.1 Microcanonical hadronization of plasma droplets

- **No need to match dynamical part of hydro evolution**

- **Energy and flavor conservation for small systems**

- **Needed to "unify" EPOSLHC and EPOS3**

Grand canonical decay, T = 130 MeV



Microcanonic decay

of given volume in its CMS into n hadrons

$$dP = C_{\mathrm{vol}}\, C_{\mathrm{deg}}\, C_{\mathrm{ident}} \times \delta(E - \Sigma E_i)\, \delta(\Sigma \vec{p}_i) \prod_A \delta_{Q_A, \Sigma q_{A\,i}} \prod_{i=1}^{n} d^3 p_i$$

$$C_{\mathrm{vol}} = \frac{V^n}{(2\pi\hbar)^{3n}}\,, \quad C_{\mathrm{deg}} = \prod_{i=1}^{n} g_i\,, \quad C_{\mathrm{ident}} = \prod_{\alpha \in \mathcal{S}} \frac{1}{n_\alpha!}$$

(n_α is the number of particles of species α, $\mathcal{S}$ is the set of particle species)

Different from decay rate of a massive particle (using LIPS), where asymptotic states are defined over an infinitely large volume (see Becattini et al, EPJC35:243-258,2004). **But $E_i = \sqrt{p_i^2 + m_i^2}$**

Microcanonical decay

$$dP \propto d\Phi_{\mathrm{NRPS}} = \delta(M - \Sigma E_i)\,\delta(\Sigma \vec{p}_i)\,\prod_{i=1}^{n} d^3 p_i$$

- □ Hagedorn 1958 methods to compute Φ_{NRPS}
- □ Lorentz invariant phase space (LIPS) (James 1968)
- □ Hagedorn methods used for decaying QGP droplets (Werner, Aichelin, 1994, Becattini 2003)
- □ 2012 (Bignamini,Becattini,Piccinini) compute Φ_{NRPS} via the Lorentz invariant phase space (LIPS)

- **LIPS method very fast for small n,**
  gets time consuming at large n

- **Hagedorn integral method can be made very efficient at large n (new),** while it is VERY time consuming at small n

- **around $n \approx 30 - 40$ both methods work**
  (=> checks)

Hagedorn integral method

The phase-space integral:

$$\phi_{\mathrm{NRPS}}(M, m_1, \ldots, m_n)$$
$$= (4\pi)^n \int \prod_{i=1}^{n} p_i^2 \, \delta(E - \sum_{i=1}^{n} E_i) \, W(p_1, \ldots, p_n) \prod_{i=1}^{n} dp_i,$$

with the "**random walk function**" ***W*** (angular integral)

$$W(p_1, \ldots, p_n) := \frac{1}{(4\pi)^n} \int \delta(\sum_{i=1}^{n} p_i \times \vec{u}_i) \prod_{i=1}^{n} d\Omega_i$$

New: Very efficient procedures to compute W for large *n* with high precision

We obtain (Werner, Aichelin 94)

$$\phi(M, m_1, \ldots, m_n) = \int_0^1 dr_1 \ldots \int_0^1 dr_{n-1} \psi(r_1, ..., r_{n-1})$$

$$\psi = \frac{(4\pi)^n \, T^{n-1}}{(n-1)!} \prod_{i=1}^{n} p_i \, E_i \, W(p_1, \ldots, p_n),$$

with $z_i = r_i^{1/i}$, $x_i = z_i x_{i+1}$, $s_i = x_i T$, $t_i = s_i - s_{i-1}$,
$E_i = t_i + m_i$, $T = M - \sum_{i=1}^{n} m_i$

Suitable for MC provided W is known

Sampling hadron configurations $K = \{h_1, \ldots, h_n; \vec{p}_1, ...\vec{p}_n\}$ via Markov chains

We construct sequences of random configurations

$$K_1\,,\ K_2\,,\ K_3, ...K_t\,, ...$$

such that $f_t(K_t)$ converges towards $f(K)$ for $t \to \infty$

with f = microcanonical probability distribution

The law changes step by step ($f_t \rightarrow f_{t+1}$) :

$$f_{t+1}(K) = \sum_{K'} f_t(K')\, p(K' \rightarrow K)$$

with $p(K \rightarrow K')$ of the form

$$w(K \rightarrow K') \times \min\left(1,\, \frac{f(K')}{f(K)}\, \frac{w(K' \rightarrow K)}{w(K \rightarrow K')}\right)$$

2.2 Grand canonical limit

For very large M we should recover the "grand canonical limit" for single particle spectra:

$$f_k = \frac{g_k V}{(2\pi\hbar)^3} \exp\left(-\frac{E_k}{T}\right),$$

The average energy is

$$\bar{E} = \frac{g_k V}{(2\pi\hbar)^3} \sum_k \int_0^\infty E_k \exp\left(-\frac{E_k}{T}\right) 4\pi p^2 dp$$

Changing variables via $E_k dE_k = pdp$, and using $K_1(z) = z\int_1^\infty \exp(-zx)\sqrt{x^2-1}dx$, and $3\,K_2(z) = z^2 \int_1^\infty \exp(-zx)\sqrt{x^2-1}^3 dx$

=>

$$\bar{E} = \frac{4\pi g_k V}{(2\pi\hbar)^3} m^2 T \left(3TK_2(\frac{m}{T}) + mK_1(\frac{m}{T})\right).$$

The microcanonical decay of an object of mass M and volume V should converge (for $M \to \infty$) to the GC single particle spectra

with T obtained from $M = \bar{E}$.

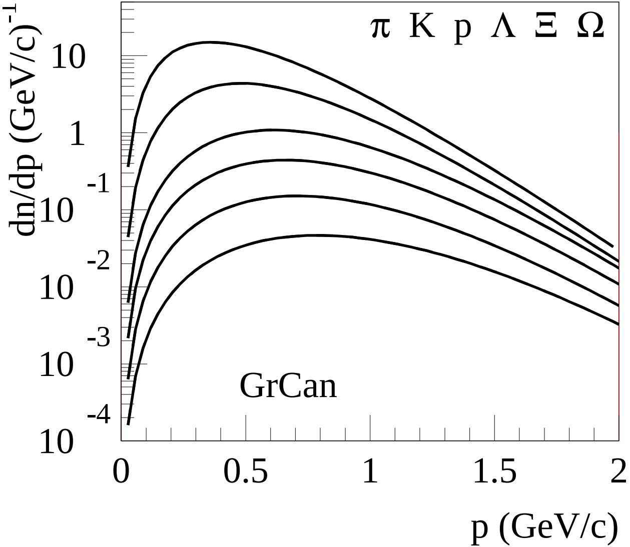
2.3 Comparing GC et MiC decay

We consider a complete (?) set of hadrons ($\approx$ 400, PDG list)

We check the effect of

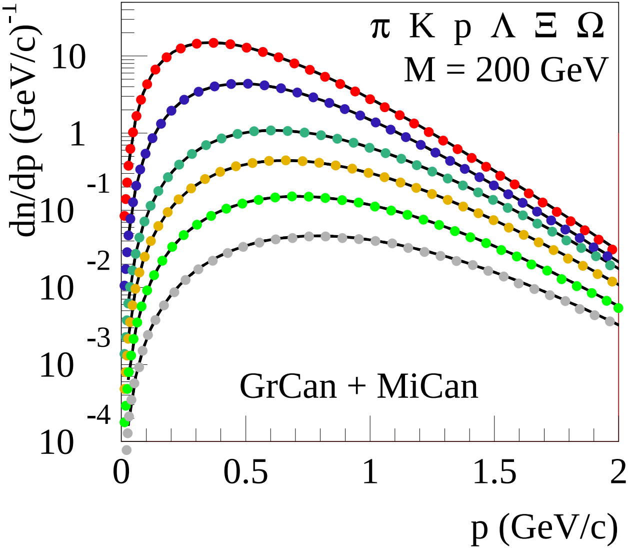
- **energy conservation**
- **flavor conservation**

GC decay, E/V= 0.333 GeV/fm^3 T=164 MeV



V=150 fm^3

GC+MiC decay, E/V= 0.333 GeV/fm^3 M=200 GeV

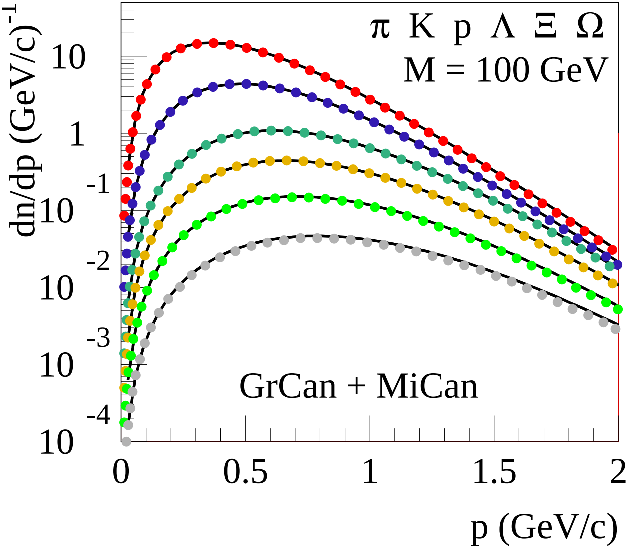


V=600 fm^3

$\times \frac{1}{4}$

good test for
Metropolis proposal

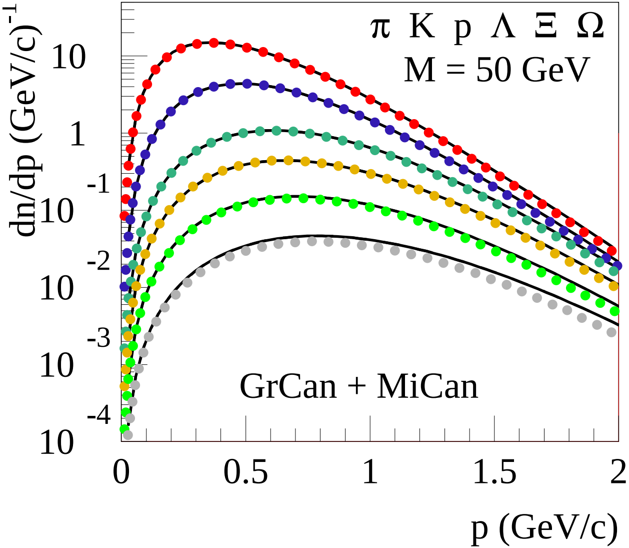
GC+MiC decay, E/V= 0.333 GeV/fm^3 M=100 GeV



V=300 fm^3

$\times \frac{1}{2}$

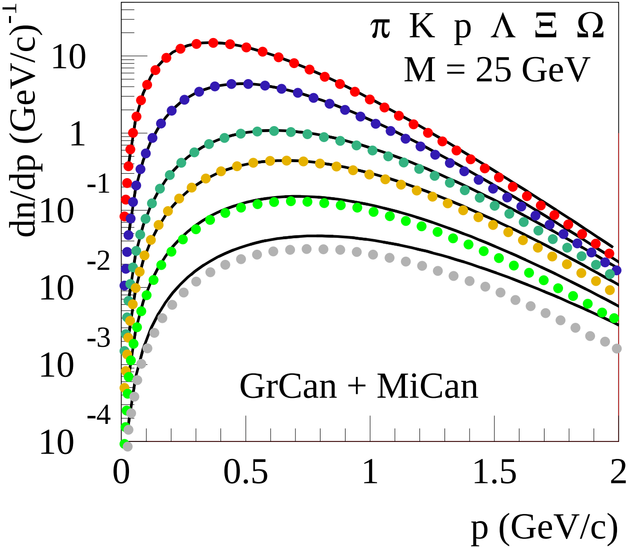
GC+MiC decay, E/V= 0.333 GeV/fm^3 M=50 GeV



V=150 fm^3

×1

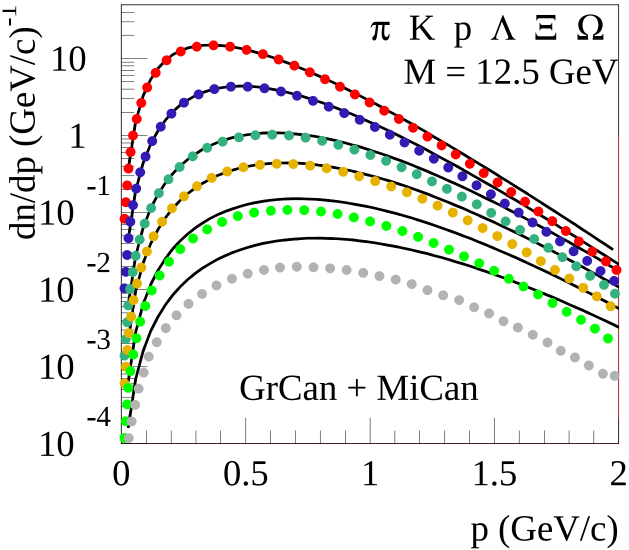
GC+MiC decay, E/V= 0.333 GeV/fm^3 M=25 GeV



V=75 fm^3

×2

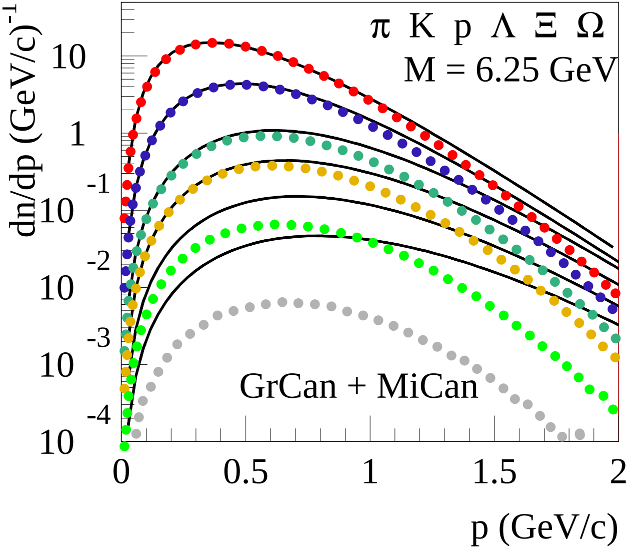
GC+MiC decay, E/V= 0.333 GeV/fm^3 M=12.5 GeV



V=37.5 fm^3

×4

GC+MiC decay, E/V= 0.333 GeV/fm^3 M=6.25 GeV



V=18.75 fm^3

$\times 8$

3 Summary

- New microcanonical hadronization procedure:
  - Very efficient, possible for the first time to simulate "big" systems
  - Works for "complete" hadron set (PDG)
  - Coincides with GC results for big systems
  - Unique procedure, for big and small systems
- Todo: Incorporate flow