

# Fast Resonance decays in nuclear collisions

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# Motivation

- ❖ The Resonance decays is one of the important effect to relate fluid properties to the experimental measured particles
- ❖ The resonance decay is an “old” subject can be included numerically with: Terminator, Azhydro, ..
- ❖ Usually are time consuming calculations
- ❖ If one is interested in only resonance decay a more efficient way is possible

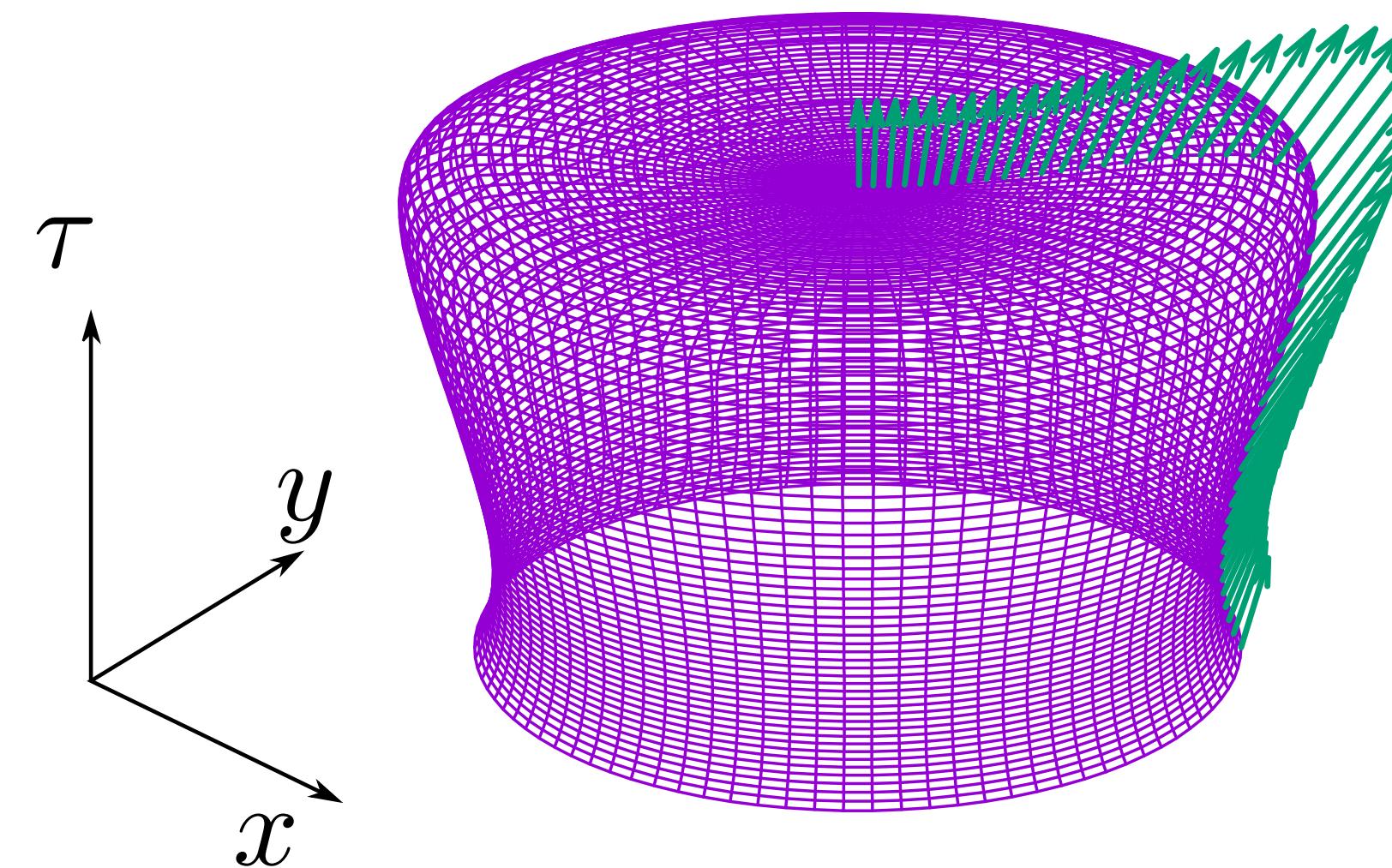
# Cooper Frye Freeze out

Primary particles are produced with the Cooper Frye formula

$$\underbrace{E_p \frac{dN_a}{d^3 p}}_{\text{primary spectrum}} = \frac{\nu_a}{(2\pi)^3} \int_{\sigma} f^a(p^\mu; \underbrace{T, u^\mu, \pi^{\mu\nu}, \dots}_{\text{fluid properties}}) p^\mu d\sigma_\mu$$

The single particle distribution function:  
local equilibrium + viscous correction

$$f(p^\mu; u^\mu, T, \dots) = \underbrace{f_{\text{eq}}(\bar{E}_p = -p_\mu u^\mu; T, \mu)}_{\text{Bose-Einstein or Fermi-Dirac}} + \underbrace{\delta f_{\text{shear}} + \delta f_{\text{bulk}} + \dots}_{\text{various ansatzes; } \eta, \zeta \text{ dependent}}$$



# Main idea

Usually first the particles are produced (many) and then decayed

$$\underbrace{E_p \frac{dN_b}{d^3 p}}_{\text{decay products}} = \underbrace{\int_{\mathbf{q}} D_{a \rightarrow b}(p, q)}_{\text{decay map}} \underbrace{\frac{\nu_a}{(2\pi)^3} \int_{\sigma} f^a(q^\mu) q^\mu d\sigma_\mu}_{\text{freeze-out}}.$$

But we can reverse the order of integration!

$$E_p \frac{dN_b}{d^3 p} = \frac{\nu_b}{(2\pi)^3} \int_{\sigma} \int_{\mathbf{q}} \underbrace{\frac{\nu_a}{\nu_b} D_{a \rightarrow b}(p, q) f^a(q^\mu) q^\mu d\sigma_\mu}_{g_b^\mu(p^\mu)}$$

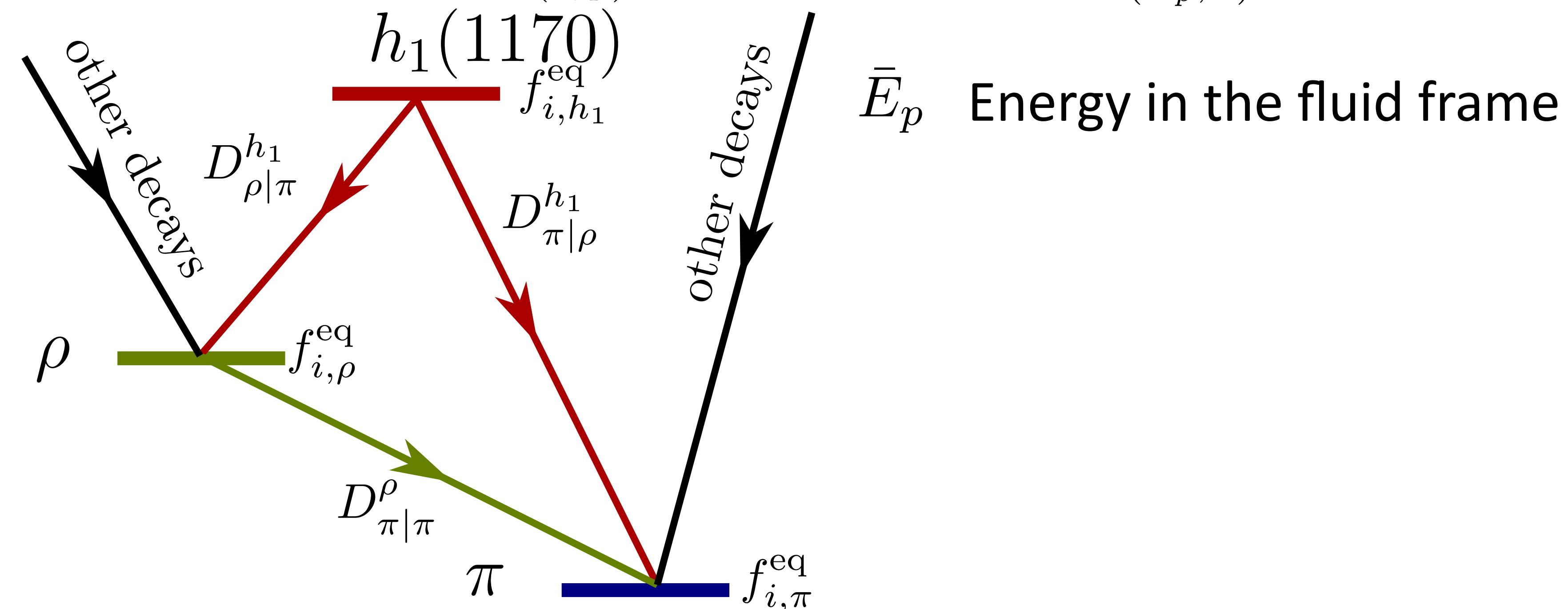
Only few integrals over the freeze out surface are needed

$\pi, p, K$

# Computing the irreducible components

Decomposition of the distribution function

$$g^\mu = f_1^{\text{eq}}(\bar{E}_p, T, \mu) \underbrace{(p^\mu - \bar{E}_p u^\mu)}_{\text{vector } (0, \vec{p})} + f_2^{\text{eq}}(\bar{E}_p, T, \mu) \underbrace{\bar{E}_p u^\mu}_{\text{scalar } (\bar{E}_p, \vec{0})}$$

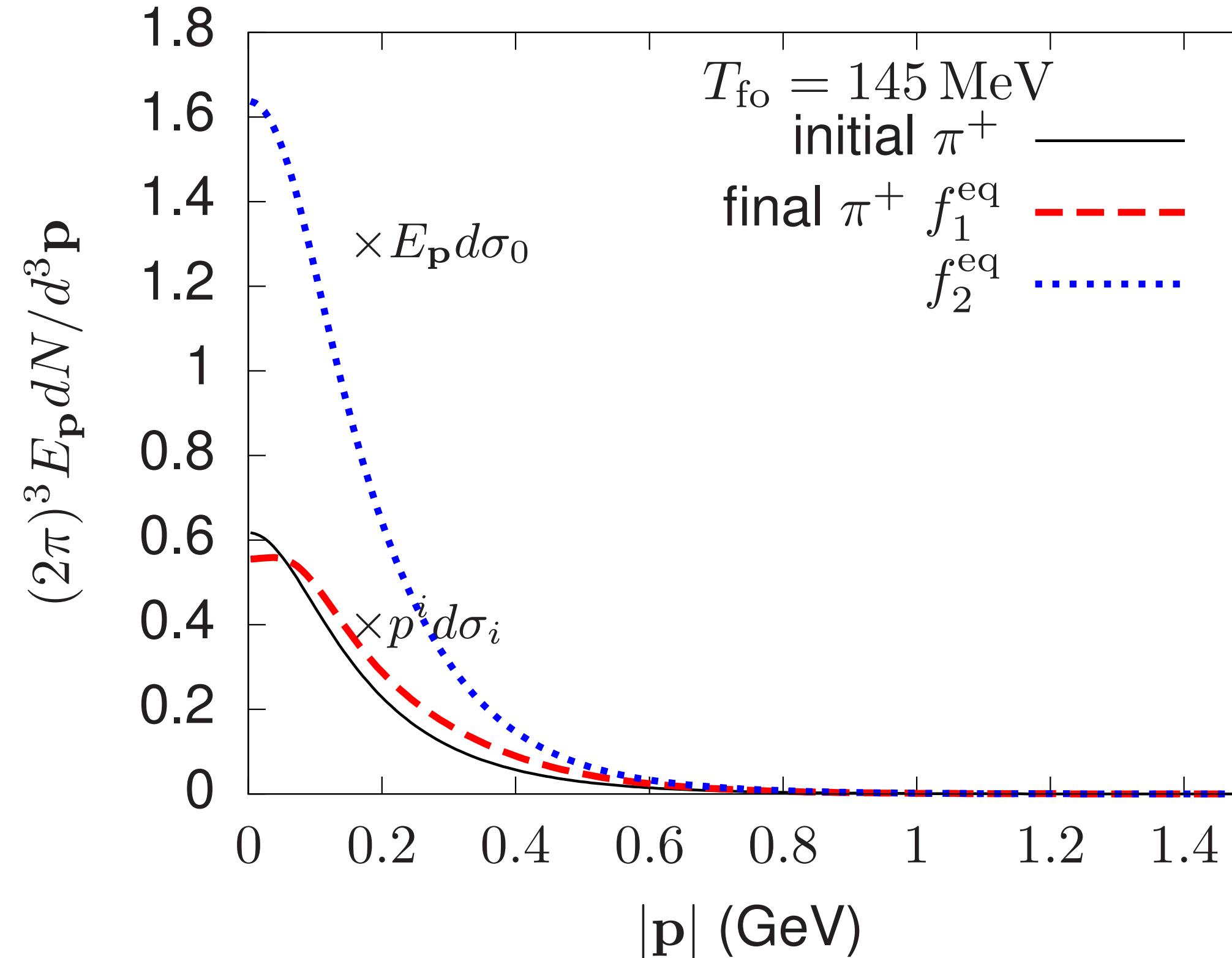


- ◆ Assuming only isotropic decays
- ◆ Initialization done with thermal distributions
- ◆ Each decay corresponds to a 1-d integral
- ◆ Different components are independent

# Final decay distribution for pion

Final pion spectrum after resonance decays in fluid rest frame

$$(2\pi)^3 E_p \frac{dN}{d^3 p} = \int_{\sigma} [f_1^{\text{eq}}(E_p, T, \mu) p^i d\sigma_i + f_2^{\text{eq}}(E_p, T, \mu) E_p d\sigma_0] \Big|_{u^\mu = (1, \vec{0})}$$



The two components are computed once and can be used in every frame

# FastReso

The new Cooper Frye formula with decay feed down included

$$E_p \frac{dN_b}{d^3p} = \frac{\nu_b}{(2\pi)^3} \int_{\sigma} d\sigma_{\mu} \left\{ F p^{\mu} + G u^{\mu} + H p^{\nu} \pi_{\nu}^{\mu} \right\},$$

with the explicit terms:

$$F = f_1^{\text{eq}} + f_1^{\text{shear}} \pi_{\rho\sigma} p^{\rho} p^{\sigma} + f_1^{\text{bulk}} \Pi,$$

$$G = f_2^{\text{eq}} - f_1^{\text{eq}} + (f_2^{\text{bulk}} - f_1^{\text{bulk}}) \Pi + (f_3^{\text{shear}} - f_1^{\text{shear}}) \pi_{\rho\sigma} p^{\rho} p^{\sigma} \bar{E}_p,$$

$$H = (f_2^{\text{shear}} - f_1^{\text{shear}}) \frac{2}{5} |\bar{\mathbf{p}}|^2.$$

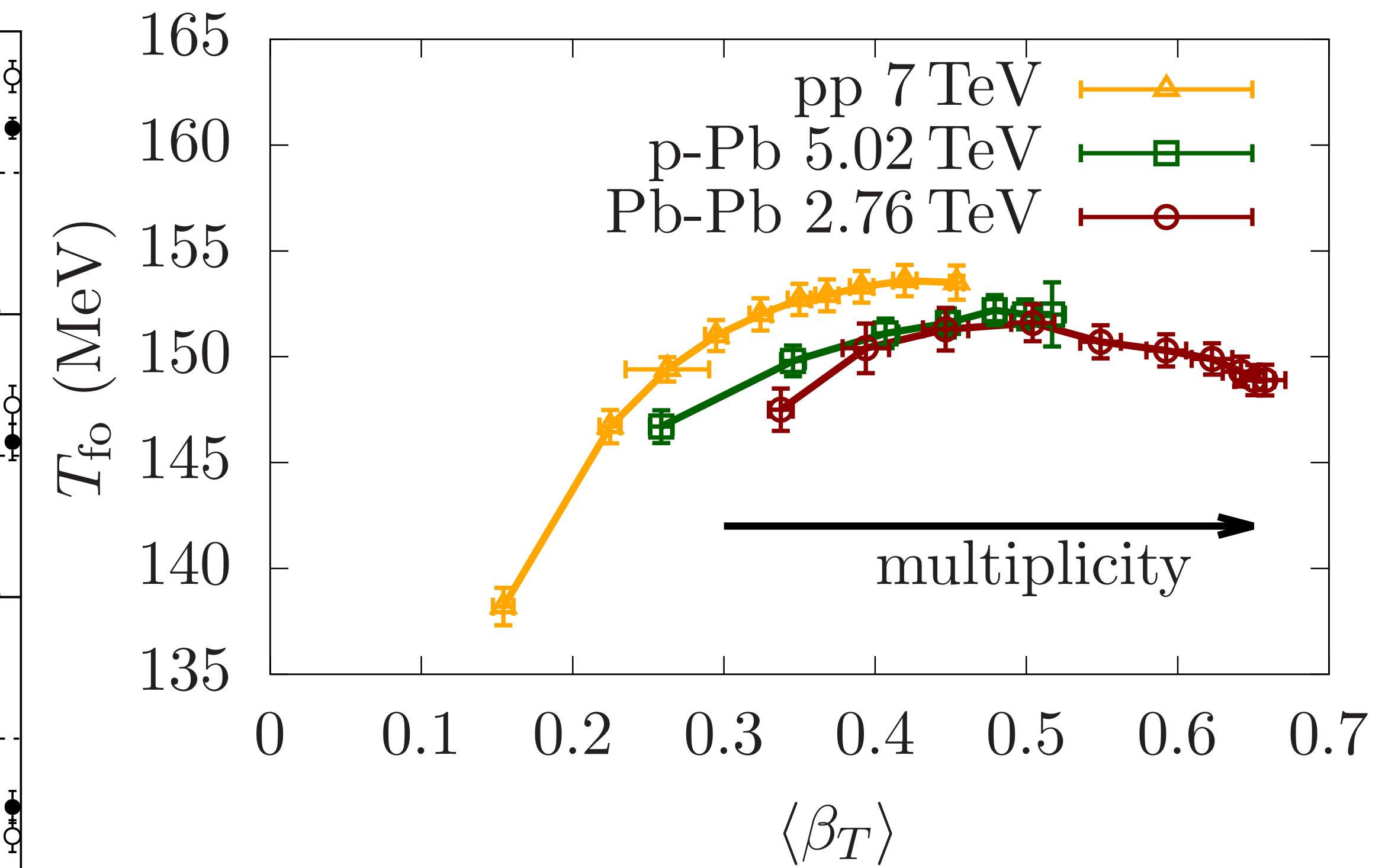
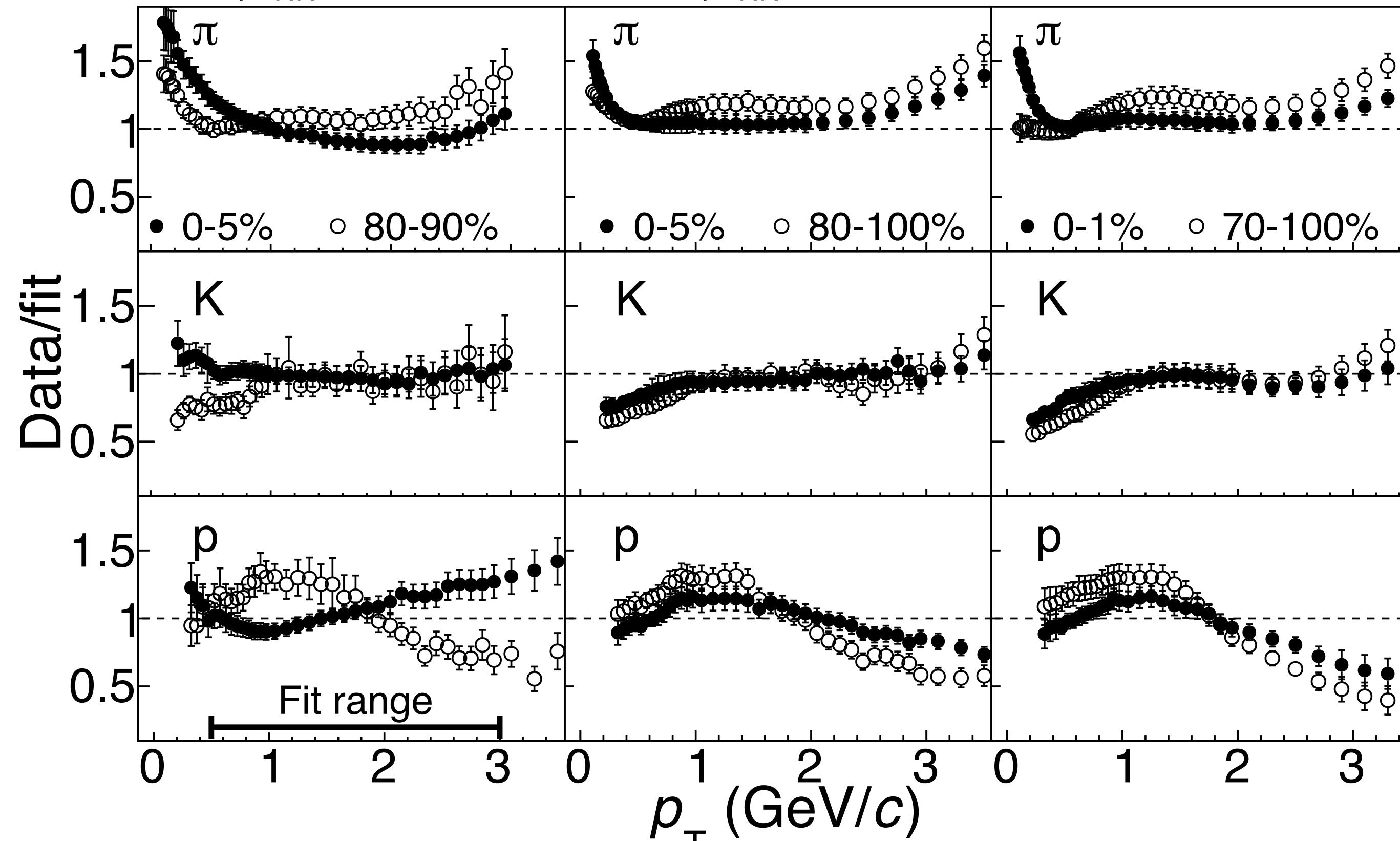
- ◆ Only 7 invariant scalar functions for each final particle species
- ◆ The irreducible components can be easily computed with:  
<https://github.com/amazeliauskas/FastReso>
- ◆ Works for generic freeze out surface

# Blast Wave fit with decay feed down

[A.Mazeliauskas, V. Vislavicius 1907.11059 ]

Due to the fast procedure it is computationally inexpensive to do the analysis.

Pb-Pb,  $\sqrt{s_{NN}} = 2.76 \text{ TeV}$    p-Pb,  $\sqrt{s_{NN}} = 5.02 \text{ TeV}$    pp,  $\sqrt{s} = 7 \text{ TeV}$



Temperature almost constant

- Overall good fits  $\chi^2/\text{Ndof} \sim 1$
- Single normalisation for all 3 particles
- No viscous corrections

# Global fluid fits to particle spectra at LHC

[D. Devetak , A. Dubla , S. Floerchinger, E. G. , S. Masciocchi, A. Mazeliauskas, I. Selyuzhenkov 1909.10485]

$$s(r) = \frac{\text{Norm}_i}{\tau_0} \langle T_R(r, \phi) \rangle .$$

- ◆ Trento initial conditions (azimuthally averaged)

[J. S. Moreland, et al., PRC (2015)]

- ◆ Viscous hydrodynamic evolution (FluiduM)

[S. Floerchinger, E.G., L. Jorrit PRC (2019)]

- ◆ FastReso freeze out with  $\sim 700$  resonances PDG 2016

[P.Parotto, private communication ]

- ◆ 4 parameters + centrality dependent normalization

	Norm <sub>i</sub>	$\tau_0$ (fm/c)	$\eta/s$	$(\zeta/s)_{\max}$	$T_{\text{fo}}$ (MeV)
	30-60	0.2-0.6	0.1-0.25	0.005-0.1	130-155

- ◆ Pions Kaons Protons,  $p_t < 3$  GeV/c, 5 centrality classes

0-5 %, 5-10 %, 10-20 %, 20-30 %, 30-40 %

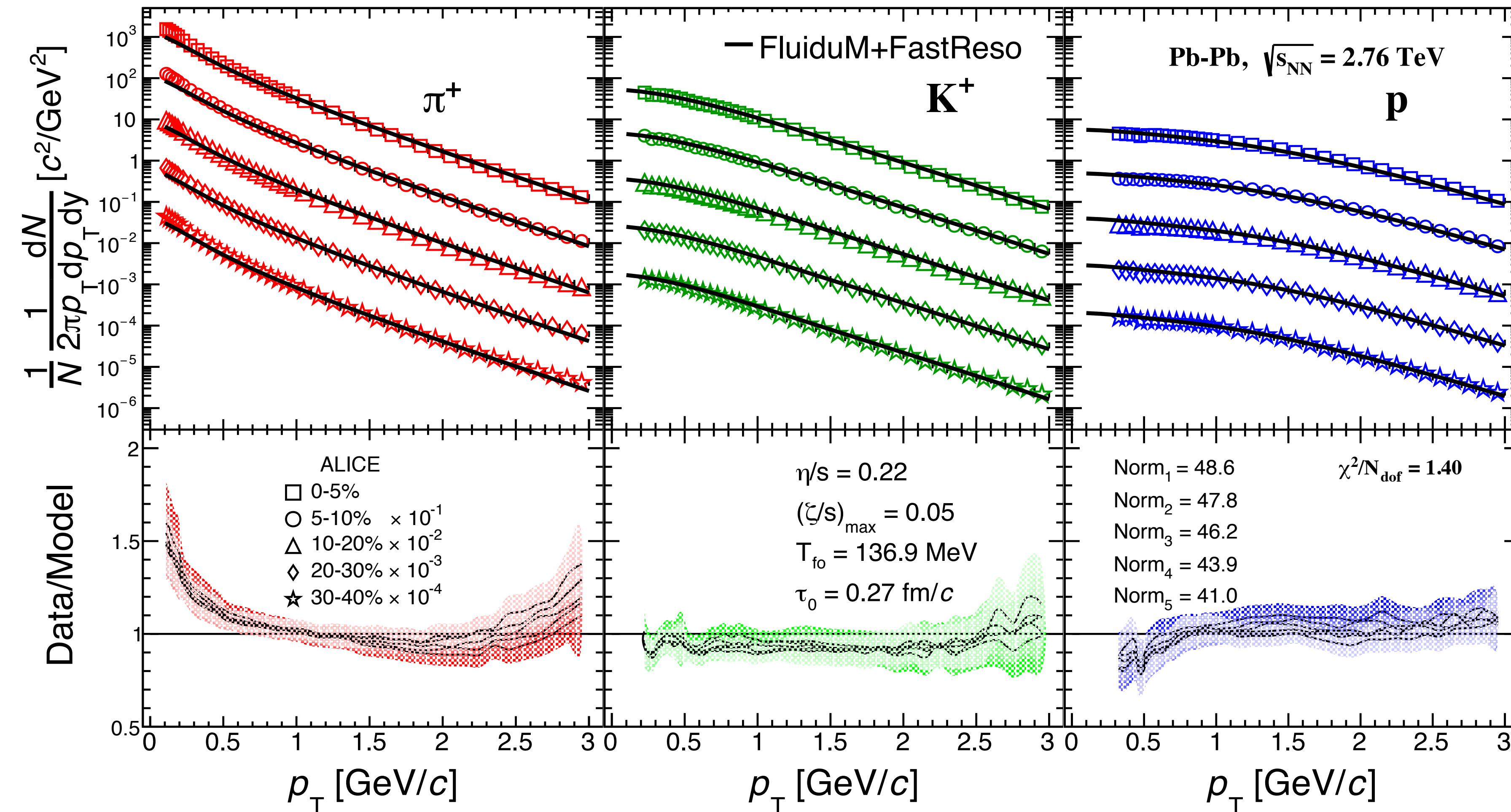
[B. Abelev et al. (ALICE), PRC88, (2013)]

- ◆  $10^5$  parameter configurations per centrality

- ◆ Minimized the  $\chi^2$  with experimental errors.

# Best Fit pt spectra

Fit the pt spectra of pions kaons and protons in the first five centralities



$$\chi^2/N_{dof} = 1.4$$

$$N_{dof} = 546$$

Model	Best fit
Norm <sub>1</sub>	48.6
Norm <sub>2</sub>	47.8
Norm <sub>3</sub>	46.2
Norm <sub>4</sub>	43.9
Norm <sub>5</sub>	41.0
$\tau_0$ [fm/c]	0.27
$\eta/s$	0.22
$(\zeta/s)_{\max}$	0.05
$T_{fo}$ [MeV]	136.9

Visually good agreement, but statistically significant deviations

The main discrepancy is for pions at low  $p_T$

# Summary

- ◆ The code is publicly available at [https://github.com/  
amazeliauskas/FastReso](https://github.com/amazeliauskas/FastReso)
- ◆ The method can handle large sets of resonances
- ◆ Initial distribution can be changed, e.g. viscous or diffusion perturbations

# Outlook

- ◆ Work in progress on inclusion of resonance widths
- ◆ Work in progress on pT-resolved vn fits
- ◆ Same idea could be generalised to HBT