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Freeze-out state from analysis of transverse momentum spectra in Pb Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

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Motivation

P_T spectra fits typically do not include resonance decays

See e.g. ALICE Collaboration ArXiv:1303.0737[hep-ex]
Centrality dependence of pi,K,p production in Pb-Pb at 2.76 TeV

By including resonances we go in the direction of talk by W. Florkowski on Tuesday: their chemical nonequilibrium with single temperature + Krakow model + THERMINATOR explains hadron abundances + spectra

This talk: hadron abundances not yet, just spectra

Two (three) temperature scenario $T_{critical} \geq T_{chemical} \geq T_{kinetic}$

Blast wave model kinetic freeze-out implemented in DRAGON

DRAGON

B. Tomášik, Comp. Phys. Commun. 180 (2009) 1642- 1653.

DRAGON is MC code based on Blast Wave model
+ decays of unstable resonances, 277 hadrons included
+ possible fragmentation of fireball is included (not used here)

$$\frac{dN}{dy\, d^2 p_t} \sim \int d\Sigma_\mu(x)\, p^\mu \frac{1}{\exp(\sqrt{p^2+m_i^2}/T) \mp 1} = \int d^4 x\, S(x,p)$$

$$S(x,p)\, d^4x = \delta(\tau - \tau_{\mathrm{fo}})\, m_t \cosh(\eta_s - y)\, G(r) \exp\left(-\frac{p^\mu u_\mu}{T}\right) \tau\, d\tau\, d\eta_s\, r\, dr\, d\theta$$

Freeze-out at const proper time $\sqrt{t^2 - z^2} = \tau_0 = const$

Transverse velocity $\beta_T = \eta_f \left(\frac{r}{R}\right)^n$

R is radius of cylindrical fireball at freeze-out

$T_{ch} = 0.152\ GeV$
$\mu_B = 0.001\ GeV$
$\mu_S = 0\ GeV$

y uniform (-1,1)

T_{kin}, η_f and n are varied to find the best χ^2 fit

(T_{kin} in steps of 4 MeV, η_f in steps of 0.01 and n in steps of 0.02)

Comparison of DRAGON with ALICE ArXiv:1303.0737 [hep-ex]: Centrality dependence of pi,K,p production in Pb-Pb at 2.76 TeV

6 species: $p, \bar{p}, \pi^-, \pi^+, K^-, K^+$

$$0.3\text{ GeV} < p_T\text{ (protons)} < 3\text{ GeV}$$
$$0.5\text{ GeV} < p_T\text{ (pions)} < 1\text{ GeV}$$
$$0.2\text{ GeV} < p_T\text{ (kaons)} < 1.5\text{ GeV}$$

No resonances

(ALICE)

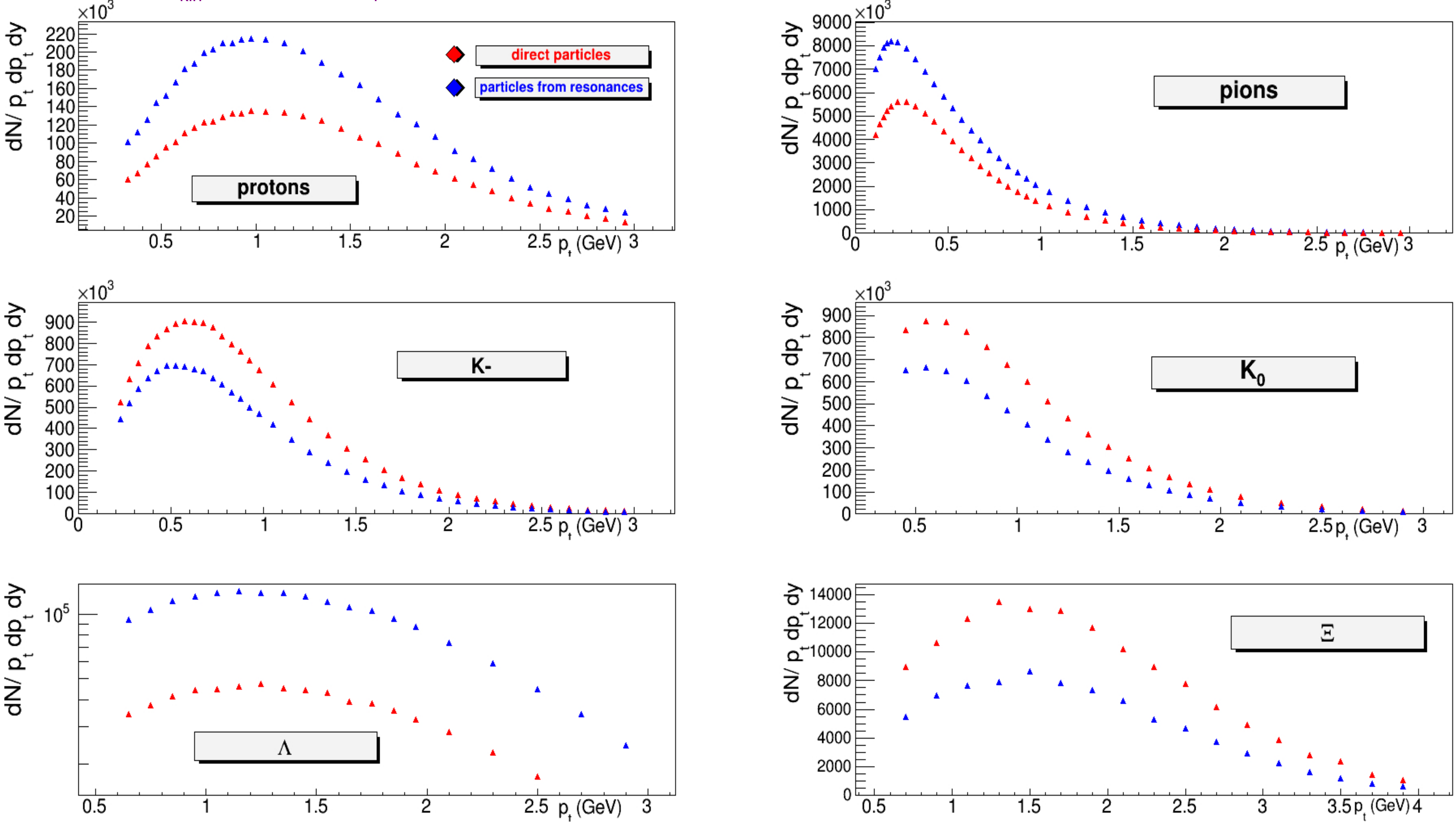
centrality [%]	T_{kin} (MeV)	η_f	n	$\langle\beta_T\rangle$	χ^2/N_{dof}
0 - 5	98 (95)	0.88	0.73 (0.71)	0.645 (0.651)	0.171
5 - 10	98 (97)	0.88	0.73 (0.72)	0.645 (0.646)	0.233
10 - 20	102 (99)	0.87	0.73 (0.74)	0.637 (0.639)	0.223
20 - 30	102 (101)	0.87	0.79 (0.78)	0.624 (0.625)	0.238
30 - 40	110 (106)	0.85	0.81 (0.84)	0.605 (0.604)	0.256
40 - 50	110 (112)	0.85	0.97 (0.94)	0.572 (0.574)	0.239
50 - 60	118 (118)	0.82	1.01 (1.10)	0.545 (0.535)	0.345

Resonances

centrality [%]	T_{kin} (MeV)	η_f	n	$\langle\beta_T\rangle$	χ^2/N_{dof}
0 - 5	82	0.89	0.69	0.662	0.143
5 - 10	94	0.88	0.69	0.654	0.181
10 - 20	90	0.88	0.71	0.649	0.175
20 - 30	98	0.87	0.75	0.633	0.181
30 - 40	102	0.86	0.79	0.616	0.186
40 - 50	118	0.84	0.89	0.581	0.188
50 - 60	126	0.82	1.01	0.545	0.254

DRAGON P_T spectra: particles produced directly vs resonance produced

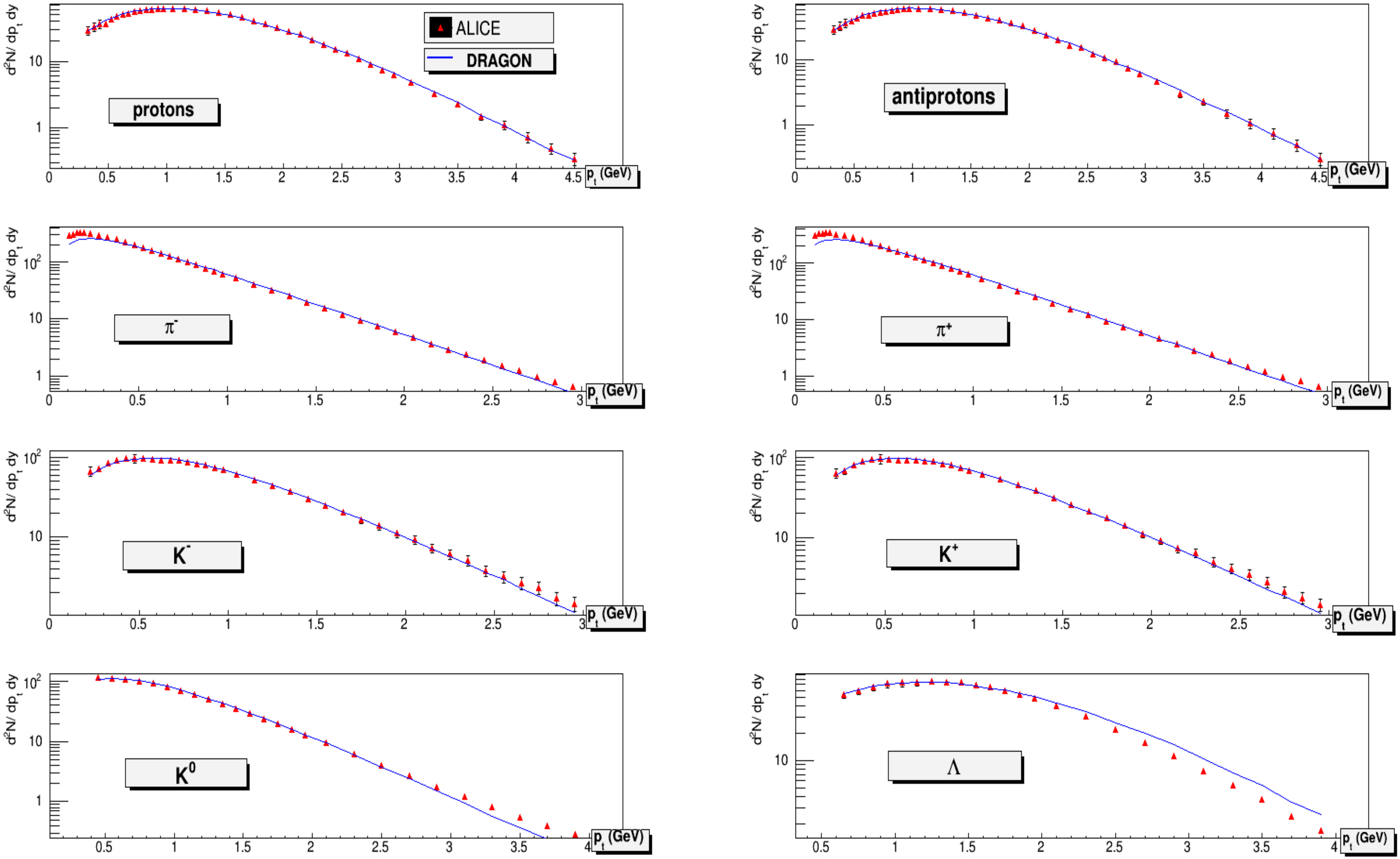
T_{kin} = 98 MeV, η_f = 0.88, n = 0.69



Transverse momentum spectra $p, \bar{p}, \pi^-, \pi^+, K^-, K^+, K^0, \Lambda$

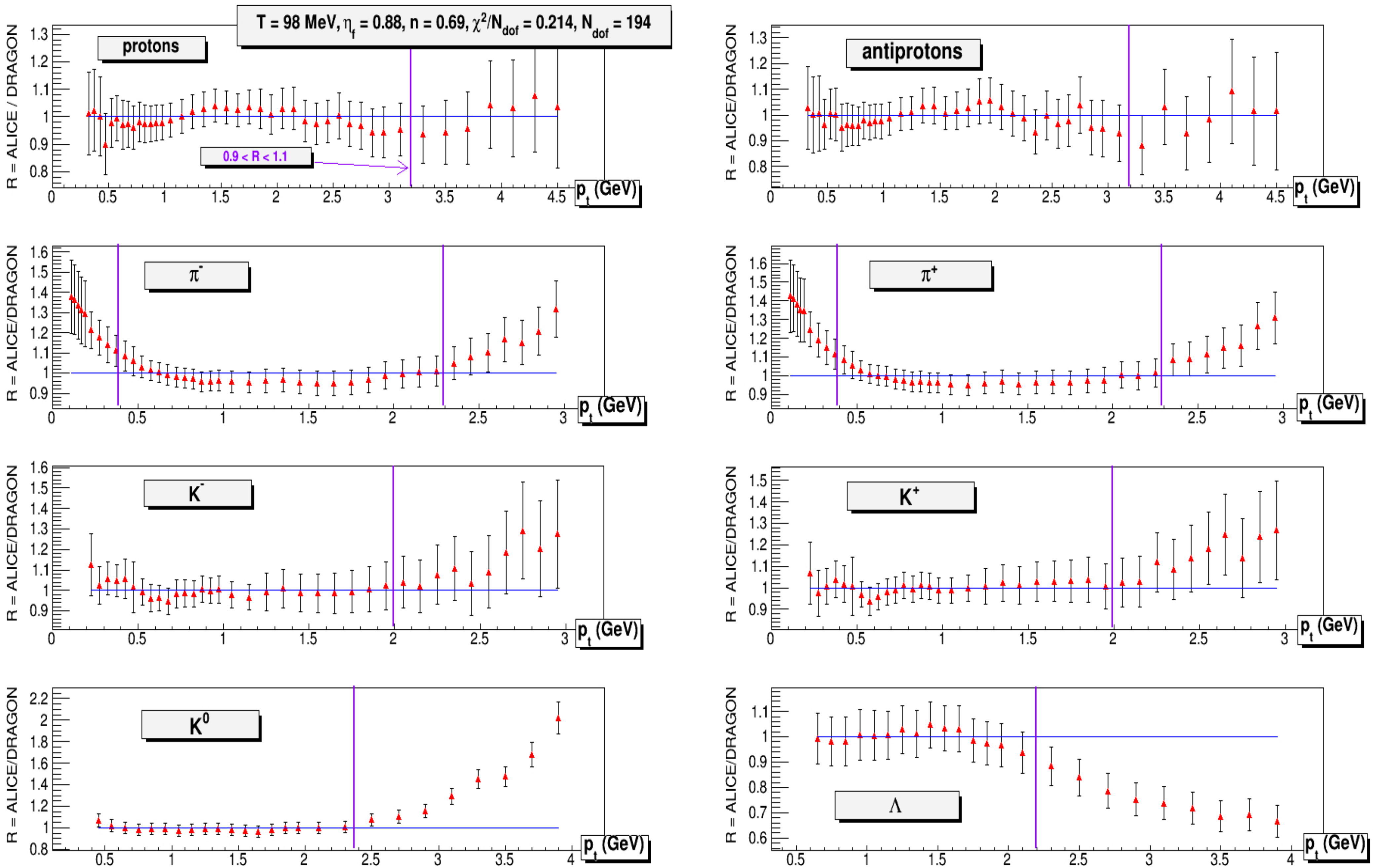
Bins included in the fit $0.9 < \quad R_i = N_i^{exp}/N_i^{MC} \quad < 1.1$

0-5% most central Pb+Pb experimental data, T = 98 MeV, n_f = 0.88, n = 0.69, χ^2/N_{dof} = 0.214

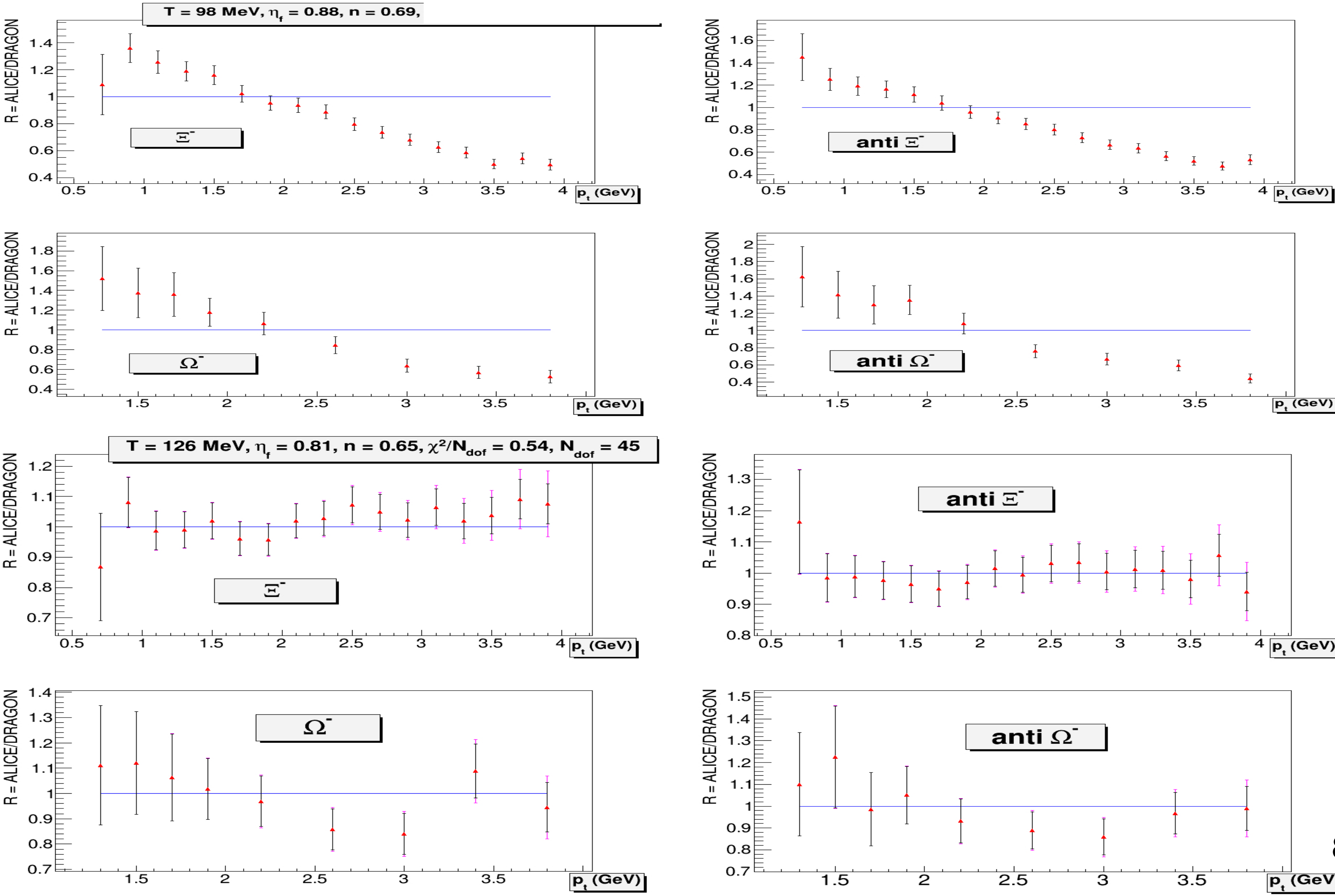


R = ALICE/DRAGON

0-5% most central Pb+Pb experimental data



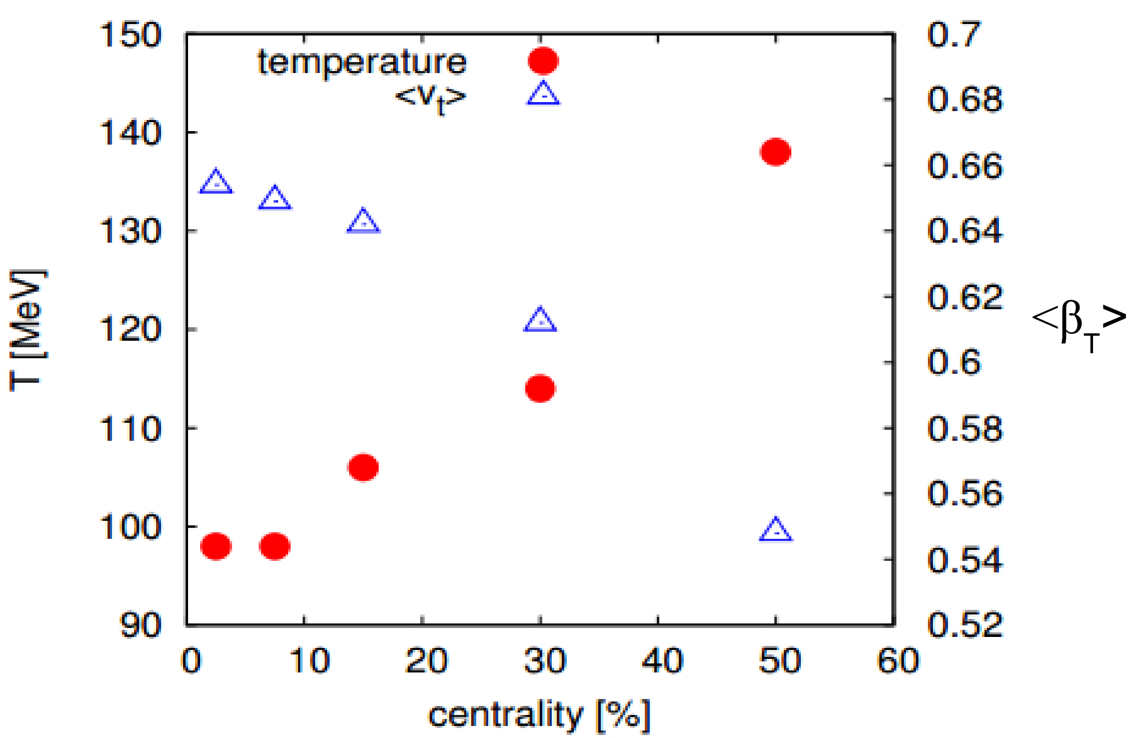
R = ALICE/DRAGON (Ξ and Ω)



Centrality dependence

8 species $p, \bar{p}, \pi^-, \pi^+, K^-, K^+, K^0, \Lambda$

centrality [%]	T_{kin} (MeV)	η_f	n	$\langle\beta_T\rangle$	χ^2/N_{dof}	N_{dof}
0 - 5	98	0.88	0.69	0.654	0.214	194
5 - 10	98	0.88	0.71	0.649	0.266	197
10 - 20	106	0.87	0.71	0.642	0.272	210
20 - 40	114	0.86	0.81	0.612	0.294	202
40 - 60	138	0.82	0.99	0.548	0.339	194



Conclusions

- *Hadrons receive important contribution from resonance decays*
- *DRAGON fits to ALICE 0-5% data yield T_{kin} = 98 MeV, $\langle\beta_T\rangle$ = 0.65*

  (for 40-60%: T_{kin} = 138 MeV, $\langle\beta_T\rangle$ = 0.55)
- *Ξ and Ω freeze out earlier T_{kin} = 126 MeV for 0-5%*
- *Low p_t pion region – pion chemical potential?*

$$\frac{dN}{dy\, d^2 p_t} \sim \int d\,\Sigma_\mu(x)\, p^\mu \frac{1}{\exp\left(\sqrt{p^2+m_i^2}/T\right) \mp 1} = \int d^4 x\, S(x, p)$$

Minimum $\chi 2$

$$\chi^2(T_{kin},\eta_f,n)=\sum_{i=1}^{8}\sum_{j_{min}}^{j_{max}}\frac{[N_{DRAGON}^{norm}(i,j,T_{kin},\eta_f,n)-N_{ALICE}^{norm}(i,j)]^2}{\sigma_{ALICE}^{norm}(i,j)^2}$$

i runs over 8 species p,anti-p, π-, π+,K-,K+,K_0 and Λ

j runs over p_T bins

Each of 8 hadron spectra is normalized independently.

N_{DRAGON} (N_{ALICE}) gives normalized numbers of hadrons of i-th species in the j-th bin

σ is combination of statistical and systematic errors.