# Hydrodynamic predictions for LHC heavy-ion beams at 2.76 TeV [1]

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[1] Piotr Bożek, M.Ch., Wojciech Florkowski, Boris Tomasik, arXiv:1007.2294 [nucl-th]

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## LHC heavy-ion run at 2.76 TeV

- Gathered data by ALICE and CMS Collaborations from *pp* collisions at $\sqrt{s} = 2.36$ TeV.

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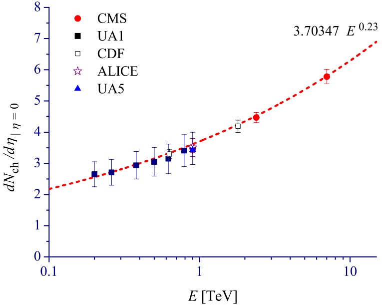
- Gathered data by ALICE and CMS Collaborations from *pp* collisions at $\sqrt{s} = 2.36$ TeV.
- Multiplicity as a function of beam energy




L. McLerran, M. Praszalowicz, Acta Phys. Polon. **B41** (2010) 1917

# Multiplicity

## prediction for Pb-Pb collision at 2.76 TeV

- multiplicity parametrization from p-p collisions

$$\left.\frac{dN^{pp}(E)}{d\eta}\right|_{\eta=0} = 3.70347\left(\frac{E}{1\,\mathrm{TeV}}\right)^{0.23}, \qquad (1)$$

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- multiplicity for Pb-Pb at 2.67 TeV

$$\left.\frac{dN^{PbPb}(\mathbf{b})}{d\eta}\right|_{\eta=0} = \left.\frac{dN^{pp}}{d\eta}\right|_{\eta=0} N_{src}(\mathbf{b}) = 4.82\, N_{src}(\mathbf{b}).$$

# Number of sources

optical Glauber approximation

- combination of wounded nucleons ($N_{WN}$) and binary collision ($N_{BC}$)

$$N_{src} = \frac{1-\alpha}{2} N_{WN} + \alpha N_{BC}$$

- parameter $\alpha$ takes into account the contribution of minijets to the fireball density (for LHC at 2.76 TeV $\alpha = 0.16$)

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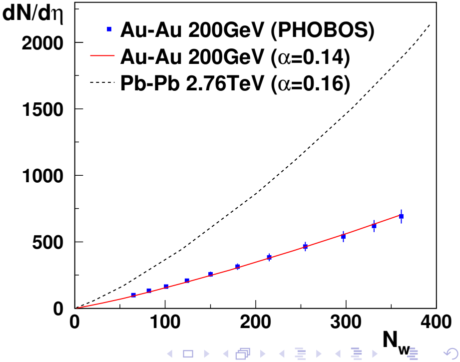
- centrality dependence [$N_{src}(\mathbf{b})$] calculated with GLISSANDO[a] with $\sigma_{NN} = 63$ mb
- nuclear density profile $\rho_{src}(\tilde{\mathbf{b}}, \mathbf{x}_\perp)$ from optical Glauber approximation reproduces the number of sources — modified impact parameter



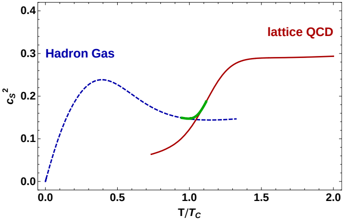

[a] W. Broniowski, M. Rybczynski, P. Bozek, Comput. Phys. Commun. **180** (2009) 69

# Hydrodynamic evolution

with statistical hadronization

LHYQUID

- relativistic hydrodynamics of perfect fluid,
- boost-invariant equations, with $\mu_B = 0$,
- equation of state with cross-over phase transition,
- freeze-out at $T = const$,



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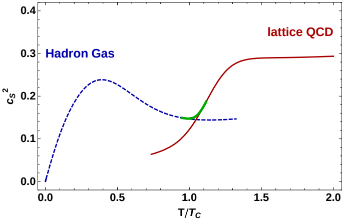
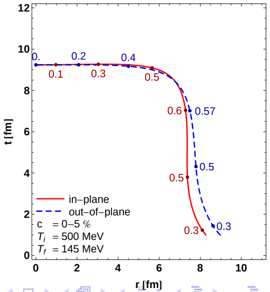



`THERMINATOR`[a]

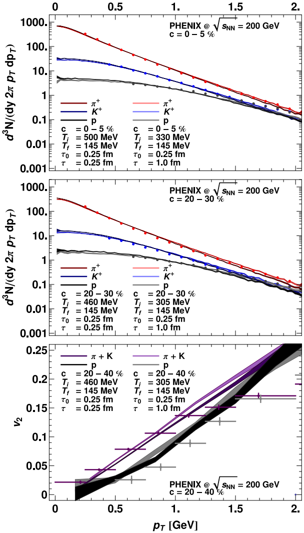
- freeze-out hypersurface with velocity profile,
- Monte-Carlo integration of Cooper-Frye formula
- decay of resonances `SHARE` database

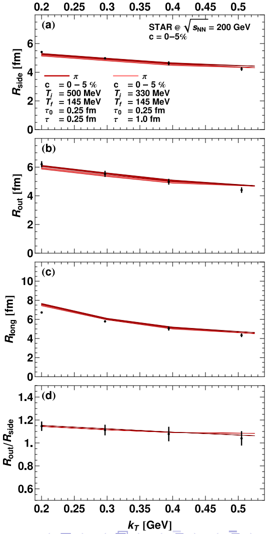



[a] A. Kisiel, T. Taluc, W. Broniowski, W. Florkowski, Comput. Phys. Commun. **174** (2006) 669

# Description of RHIC soft physics

## $p_T$-spectra, $v_2$, HBT



# Hydrodynamic evolution of matter at LHC

## Initial entropy density

- Relation between nuclear density profile and the initial entropy density

$$s(\mathbf{b}, \mathbf{x}_\perp, \tau = \tau_i) = s(T_i) \frac{\rho_{src}(\mathbf{b}, \mathbf{x}_\perp)}{\rho_{src}(0,0)}$$

where $\tau_i$ - initial time, $T_i$ - temperature at the center of the fireball, with $\mathbf{b} = 0$.

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- Scaling of the total initial entropy: RHIC $\rightarrow$ LHC

$$\frac{S^{PbPb}(\mathbf{b}, 2.76)}{S^{AuAu}(\mathbf{b}, 0.200)} = \frac{s_i^{PbPb} N_{src}^{PbPb}(\mathbf{b}) \rho_{src}^{AuAu}(0,0)}{s_i^{AuAu} N_{src}^{AuAu}(\mathbf{b}) \rho_{src}^{PbPb}(0,0)} = \frac{\left.\frac{dN^{PbPb}(\mathbf{b},2.76)}{d\eta}\right|_{\eta=0}}{\left.\frac{dN^{AuAu}(\mathbf{b},0.200)}{d\eta}\right|_{\eta=0}}$$

Anzatz: ratios of total initial entropy (at midrapidity) are equal to the ratios of the multiplicities.

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$$\frac{s_i^{PbPb}}{s_i^{AuAu}} = \frac{\rho_{src}^{PbPb}(0,0)}{\rho_{src}^{AuAu}(0,0)} \frac{4.82\, N_{src}^{AuAu}(\mathbf{b})}{\left.\frac{dN^{AuAu}(\mathbf{b},0.200)}{d\eta}\right|_{\eta=0}} \approx 3.2$$

with centrality 0-5% for Au+Au at $\sqrt{s_{NN}} = 200$ GeV the number of sources is 308, and multiplicity density 667 (PHENIX), and $\rho_{src}^{PbPb}(0,0) = 6.76\,\mathrm{fm}^{-2}$, $\rho_{src}^{AuAu}(0,0) = 4.71\,\mathrm{fm}^{-2}$

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- initial central temperature

$$s_i = s(T_i) - \text{relation through the EoS}$$

RHIC multiplicity is reproduced with $T_i$ = 520 MeV at $\tau_i$ = 0.25 fm.
Initial central temperature for LHC @ $\sqrt{s_{NN}}$ = 2.76 TeV is
$T_i = 735$ MeV at $\tau_i = 0.25$ fm, or $T_i = 480$ MeV at $\tau_i = 1.0$ fm.

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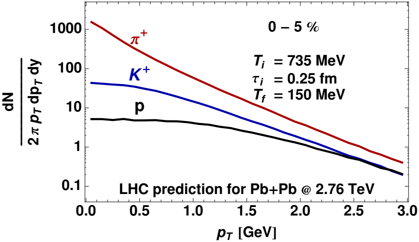
- freeze-out temperature [chemical and kinetic]
  $T_f = 150\,\text{MeV}$

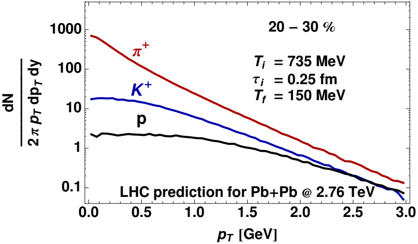
- all chemical potentials equal to zero ($\mu_B, \mu_{I_3}, \mu_S$)

# Results

## Particle spectra

- $p_T$-spectra



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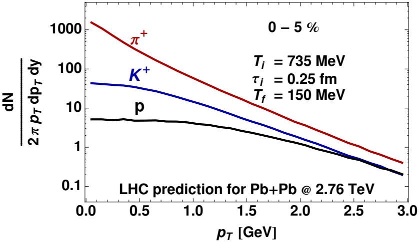
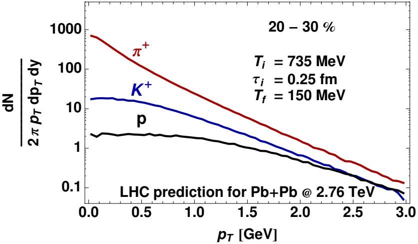
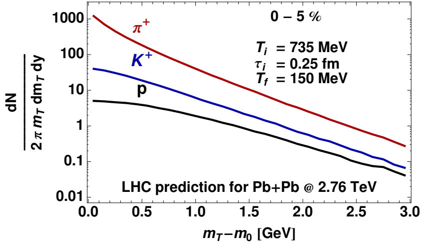



- $m_T$-spectra



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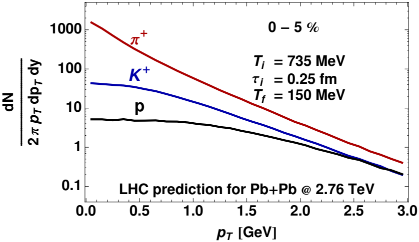


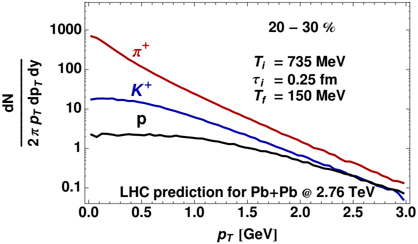


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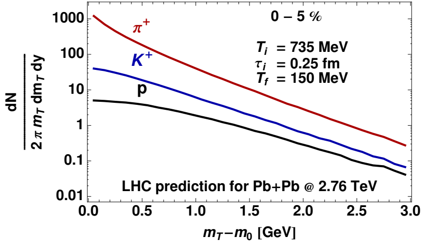
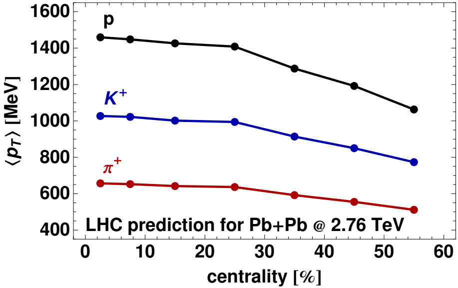



- Multiplicity density of charged particles at midrapidity

| centrality | $\frac{dN}{d\eta}$ | $\frac{dN}{dy}$ |
|---|---|---|
| 0 - 5 % | 2161 | 2457 |
| 20 - 30 % | 905 | 1036 |

# Results

## Average transverse momentum

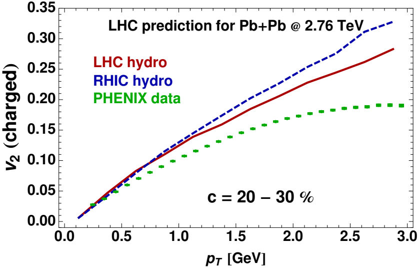



- Increase form the RHIC top energies by 35 to 40 %,
- e.g. average $p_T$ for pions at RHIC is 473 MeV and at the LHC 636 MeV

# Results

## Elliptic flow coefficient

- similar to RHIC's slope at low $p_T$
- lower values for higher $p_T$
- $\langle v_2^{LHC} \rangle = 0.088$, $\langle v_2^{RHIC} \rangle = 0.065$
- viscous effects decrease $v_2$ even more – to match the data



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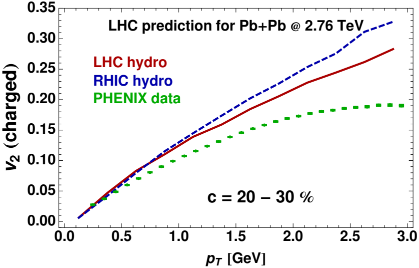
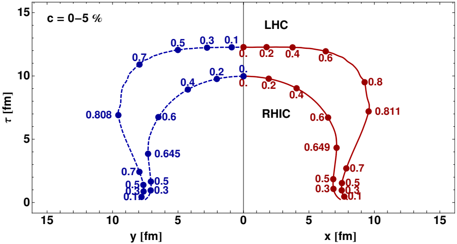
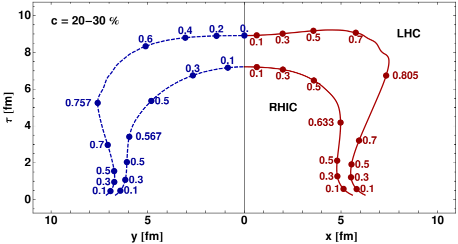


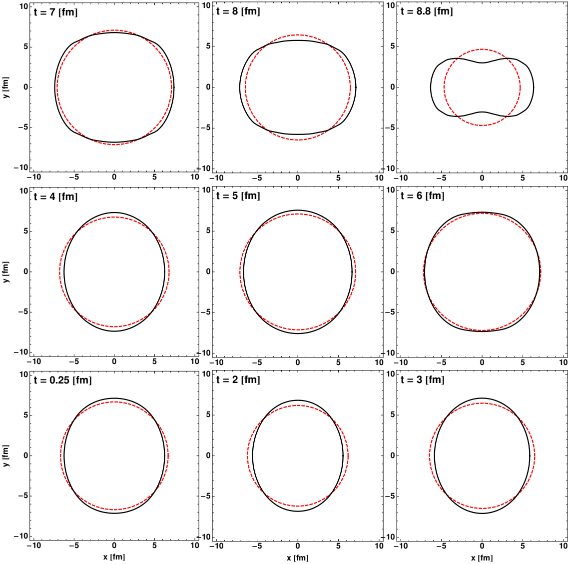

- Freeze-out hypersurfaces



# Results

## Why is $v_2(p_T)$ smaller at LHC?

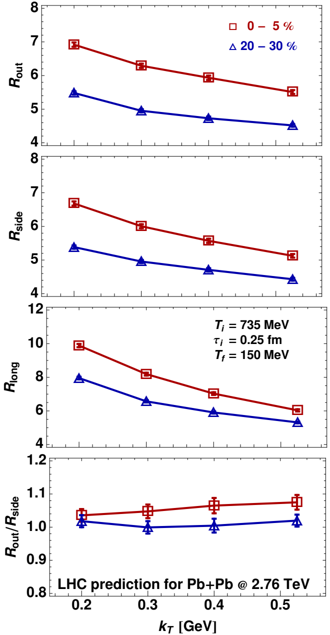



- The system changes shape over time, form almond-shape to pumpkin-like.
- Largest velocity on the hypersurface is when the shape changes — surface production of particles with largest $p_T$.
- Volume production form x-elongated source.

# Results

## femtoscopy - HBT radii

- $R_{\mathrm{out}}$ and $R_{\mathrm{side}}$ increase by approx. 1 fm when compared with RHIC top energy results,
- $R_{\mathrm{long}}$ rises by about 2 - 2.5 fm,
- steeper $k_T$ dependence - result of stronger hydrodynamic flow,
- $R_{\mathrm{out}}/R_{\mathrm{side}}$ close to unity, gently raising with $k_T$.



# Conclusions

- Prediction for the future heavy-ion beam at $\sqrt{s_{NN}} = 2.76$ TeV was made, based on the LHC proton-proton run at $\sqrt{s} = 2.36$ TeV,
- Compared with RHIC top energy results we observe:
  - harder $p_T$ spectra,
  - 35 - 40% increase of the $\langle p_T \rangle$ and $\langle v_2 \rangle$,
  - high multiplicity ($> 2000$ charged particles for central collisions),
  - saturation of $v_2(p_T)$ due to source shape change,
  - moderate rise of HBT radii and stronger $k_T$ dependence.
- Opened questions:
  - Is the perfect fluid approximation valid? How important are the viscosity corrections at those energies.
  - Is there going to be a plateau at midrapidity distribution that will justify the usage of boost-invariant models for central region?