Electromagnetic interaction of leptons with heavy nuclei in ultra-peripheral ultra-relativistic collisions

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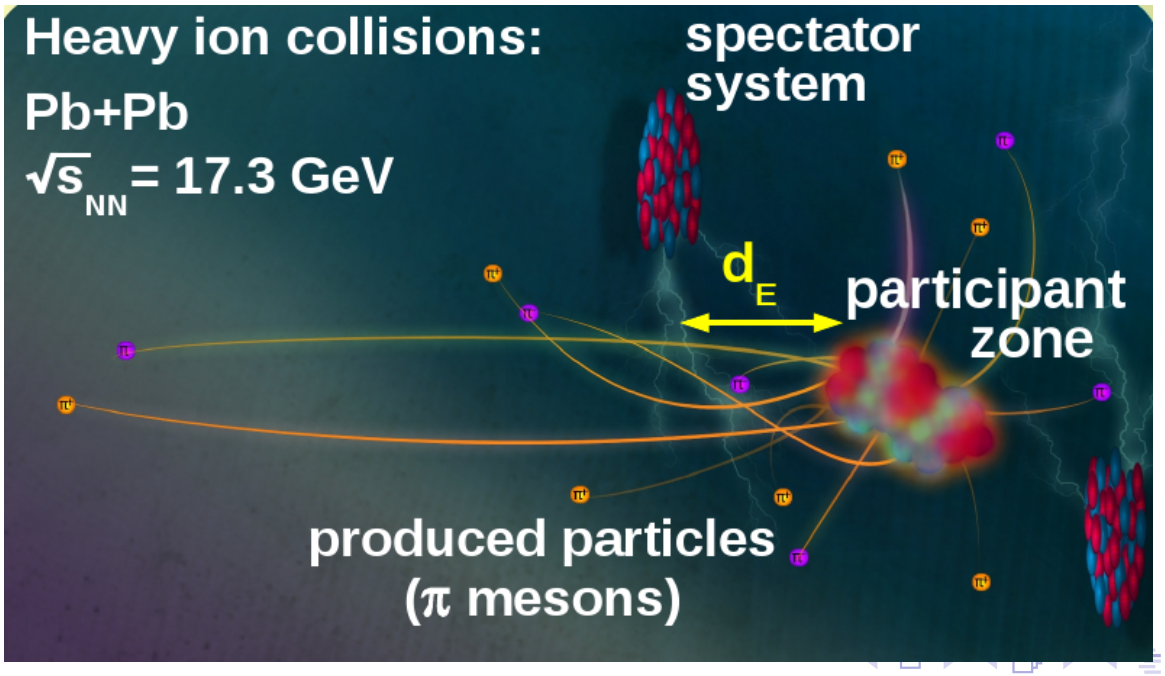
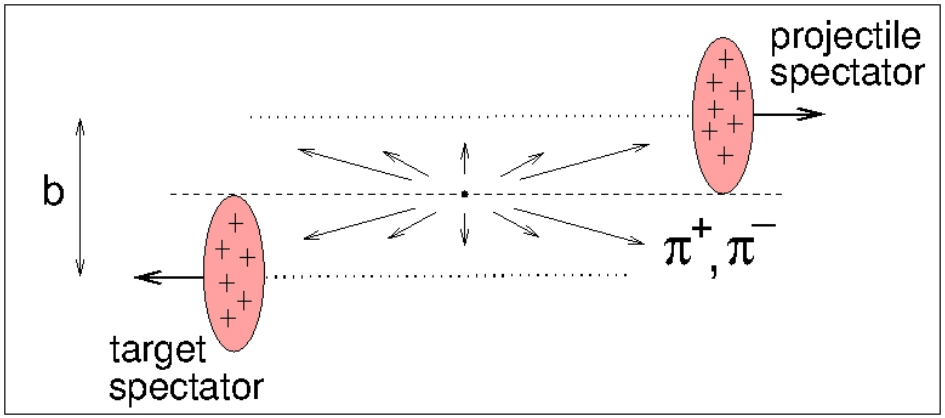
Heavy - Ion Collisions

Pb + Pb Collision - (Thanks to A. Szczurek)

- Noncentral collisions unambiguously lead to azimuthal asymmetries and presence of spectators.
- Azimuthal correlations between particles and the reaction plane – one of the main subjects of heavy ion collisions provide information about collective effects.
- The presence of charged fast moving spectators generate strong electromagnetic fields. A. Rybicki and A. Szczurek, PR**C75** (2007) 054903;PR**C87** (2013) 054909.

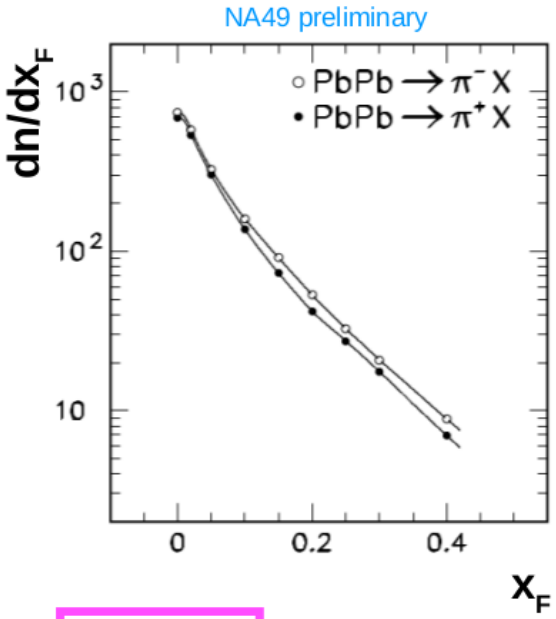


Modeling a Peripheral Heavy - Ion Collisions



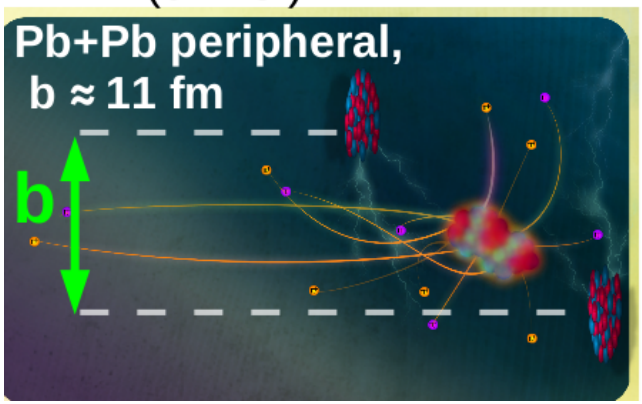
- The collision takes place at a given impact parameter b.
- The two charged spectator systems follow their initial path.
- The participating system evolves until pions are produced.
- Charged pion trajectories are modified by EM interaction.
- **The spectator systems undergo a complicated nuclear deexcitation/fragmentation process (not fully understood)**.
- The pion emission – single point in space. The emission time t_E is a free parameter. We assume that the initial (x_F, p_T) distribution of the emitted pion is that for underlying N+N collisions (rescaled).
- **The fragmentation of the spectator systems was neglected**, the influence of participant charge, strong Final State Interaction were not considered.

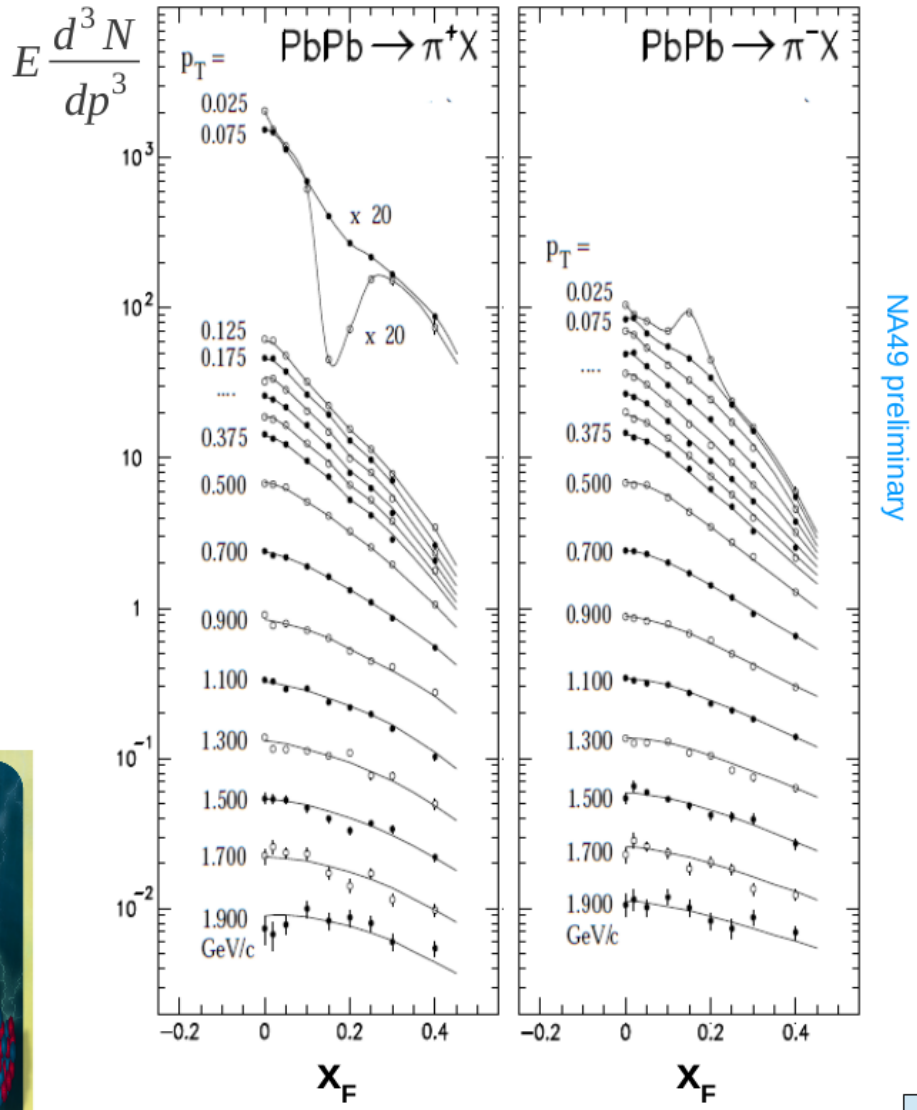
Modeling a Peripheral Heavy - Ion Collisions



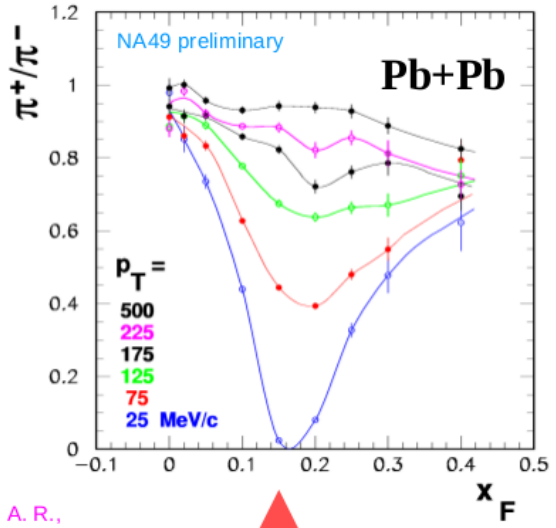
$$x_F = \frac{p_L}{p_L^{beam}}$$

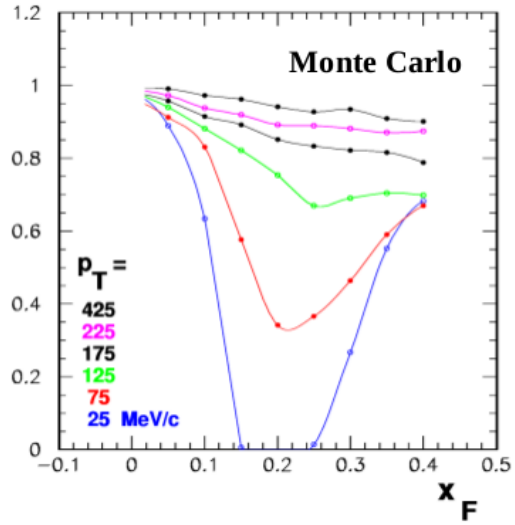
(c.m.s.)





Modeling a Peripheral Heavy - Ion Collisions



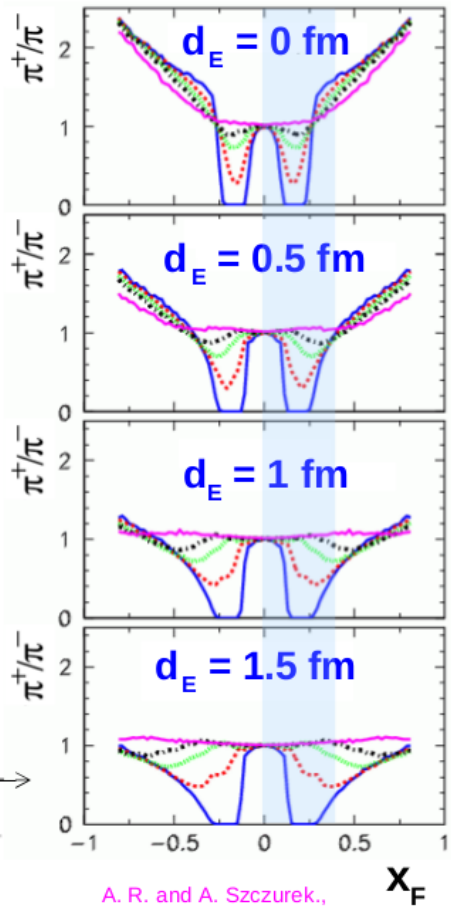


A. R.,
Acta Phys. Polon.
B42 (2011) 867

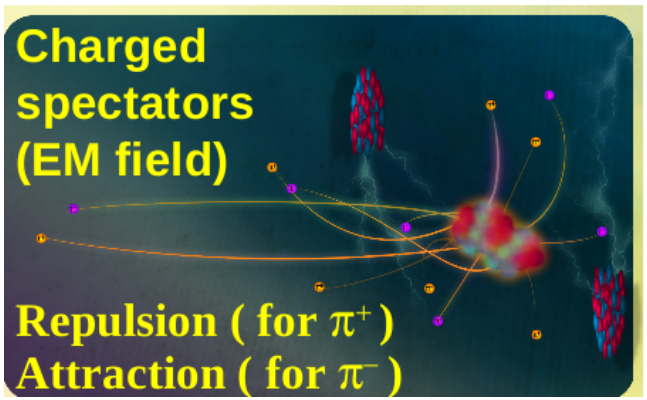
spectator velocity:
$x_F = 0.15 = m_\pi/m_N$

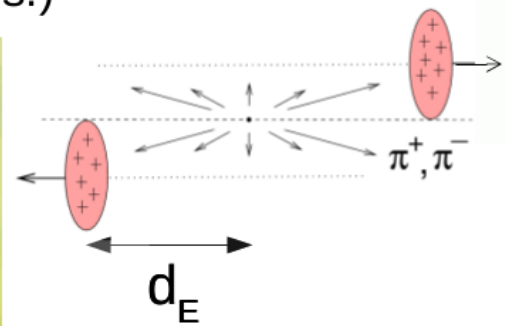
$$x_F = \frac{p_L}{p_L^{beam}}$$ (c.m.s.)

$d_E \approx 0.75$ fm !



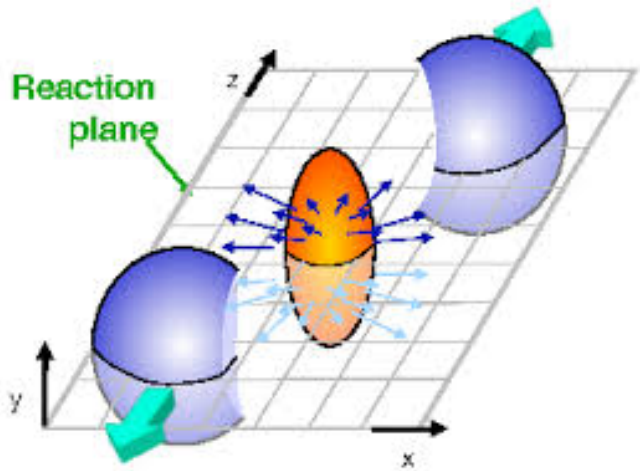
A. R. and A. Szczurek.,
Phys. Rev. **C75** (2007)
054903

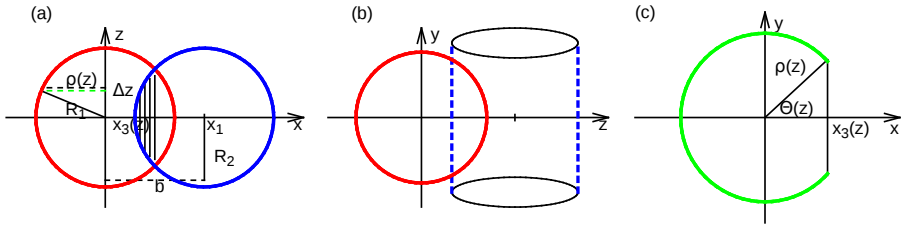


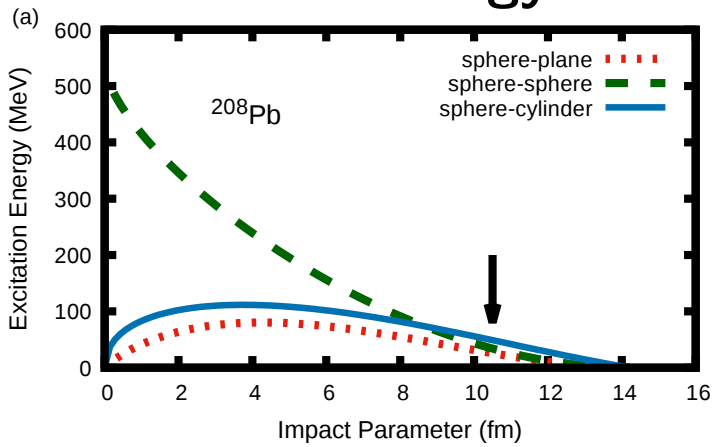


Pb + Pb Collision - Geometrical Scenarios

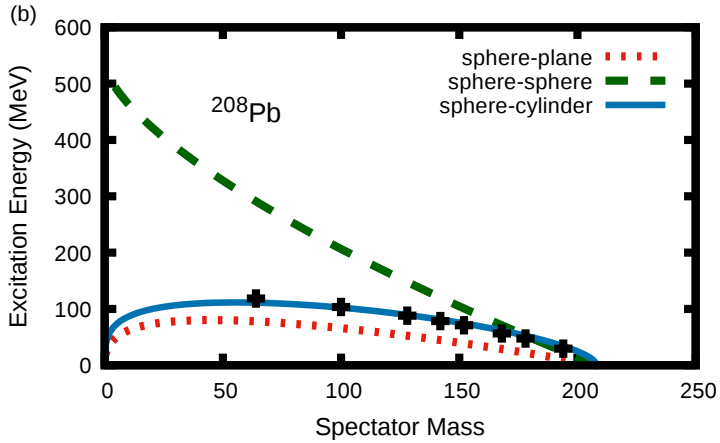
After collision - very deformed shapes of the spectator -
the deformation energy translated to excitation energy of the spectator







$$E_{def} = E_{surf}(def) - E_{surf}(0)$$



K. M., A. Szczurek, P.N. Nadtochy, APPB Proc. Suppl., 10 (2017) 113, arXiv:1708.03716

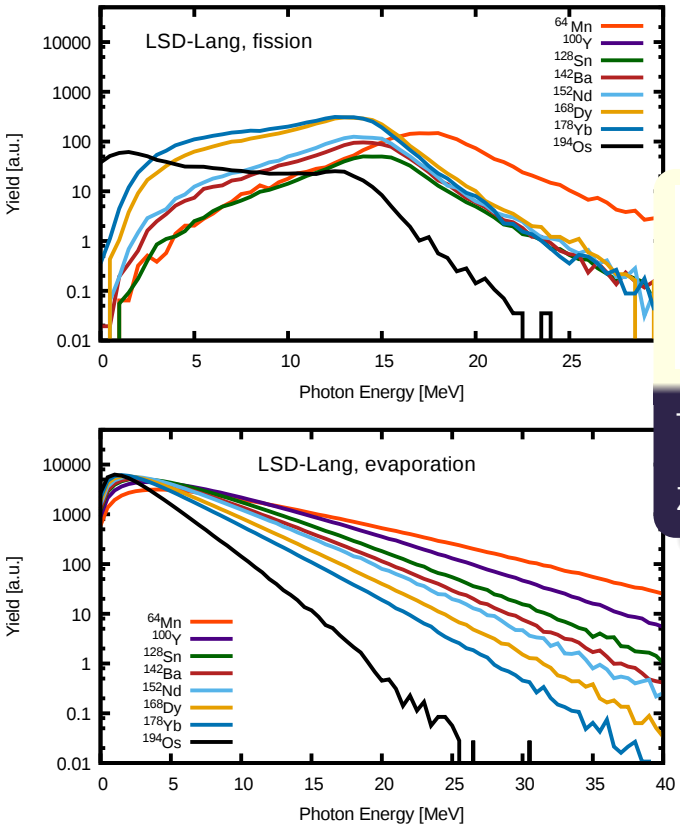
^{208}Pb + ^{208}Pb at 158 GeV/A SPS CERN

Pb + Pb Collision - Photon Emission

Statistical emission of particles and γ-rays with emission widths of A.S. Iljinov et al,Yad.Fiz.33(1981)997,

Nucl.Phys.A543(1992)517

LSD+Langevin

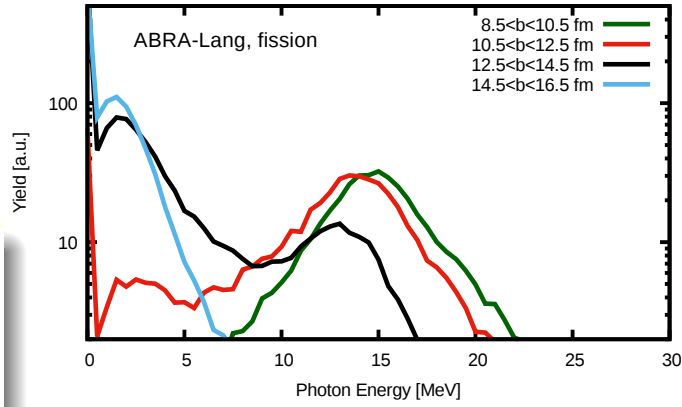


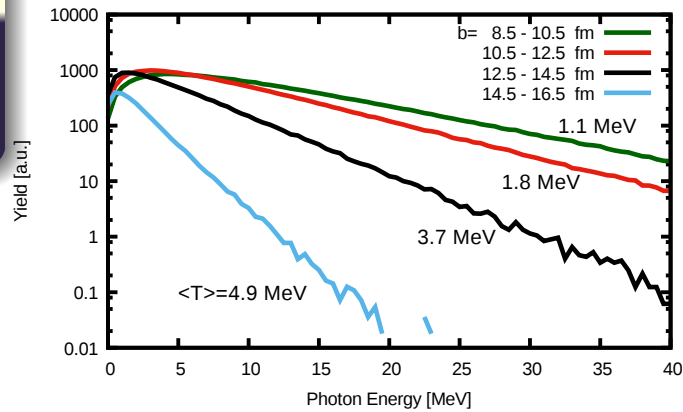
duction is possible. A rapid rupture of the neck during the fission process together with strong Coulomb forces involved (causing a displacement of neutrons against protons) may create giant resonances formed upon the fission fragments. One of possible decay channels of giant resonances is the light particle emis-

T.Srokowski, A.Szczurek, A.Budzanowski,

Z.Phys.A 333(1989)83

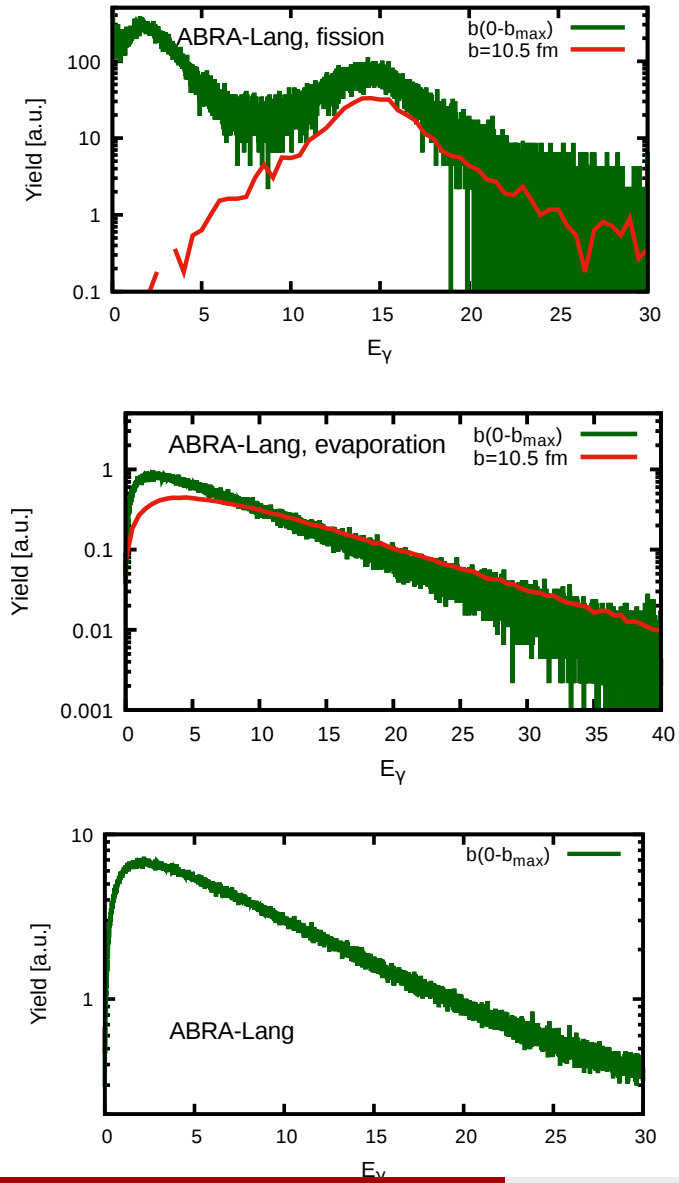
ABRA+Langevin



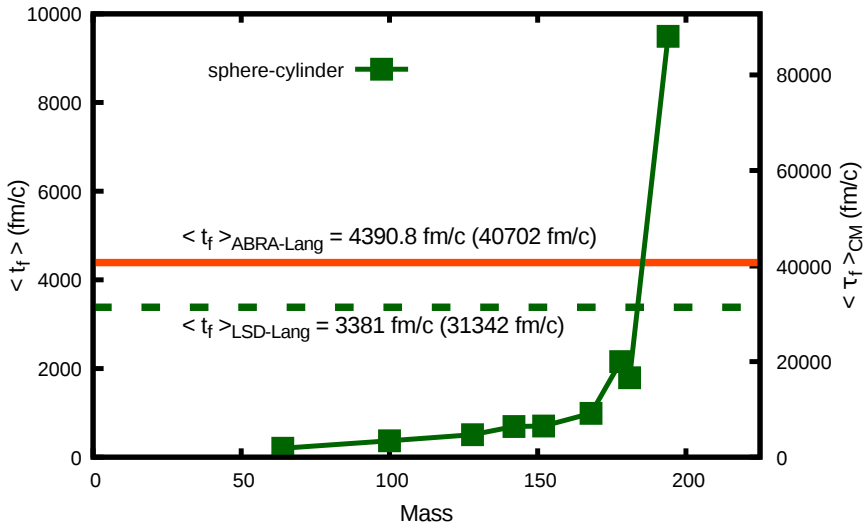


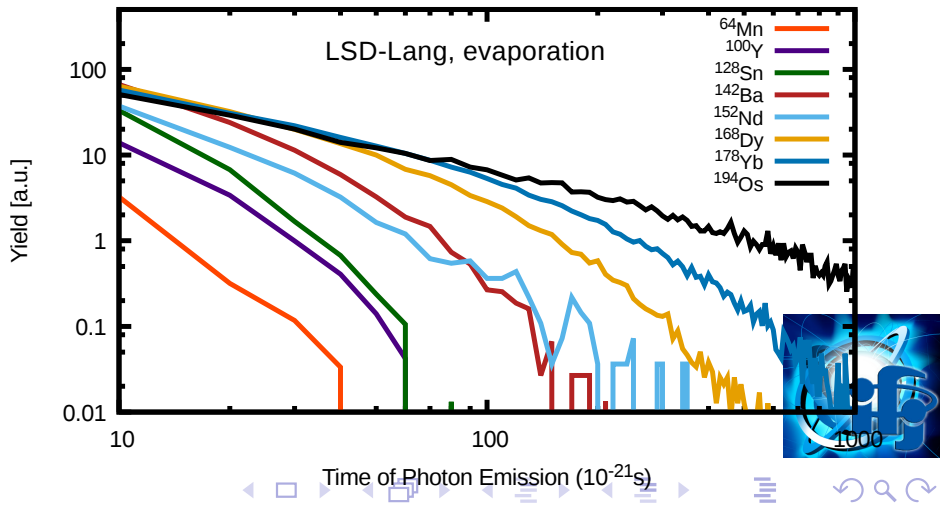
Pb + Pb Collision - Time

Photon energy spectra



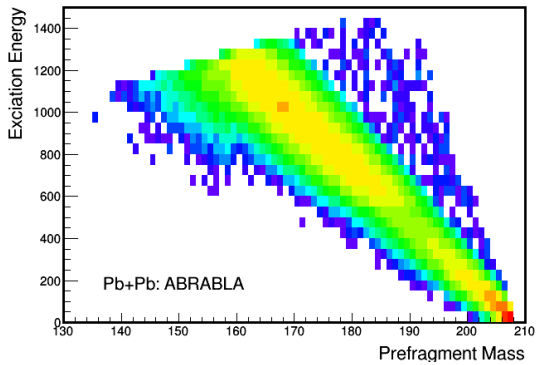
Fission/Photon emission time

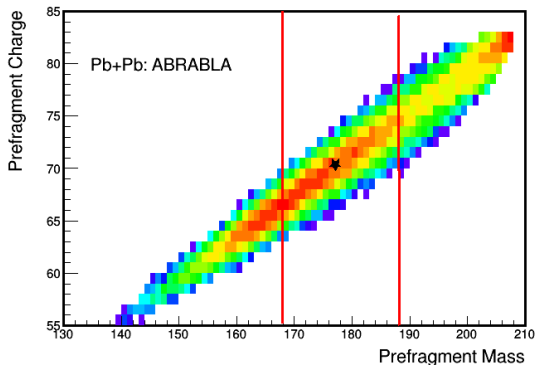


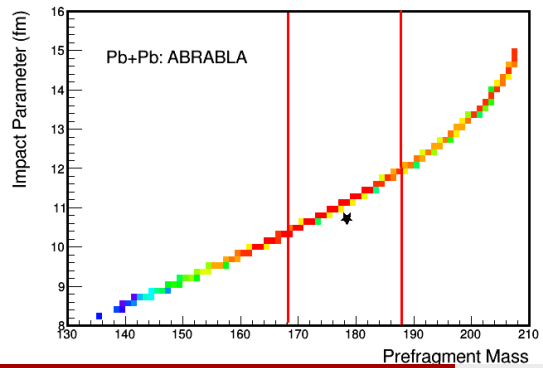


Pb + Pb Collision - Fluctuation

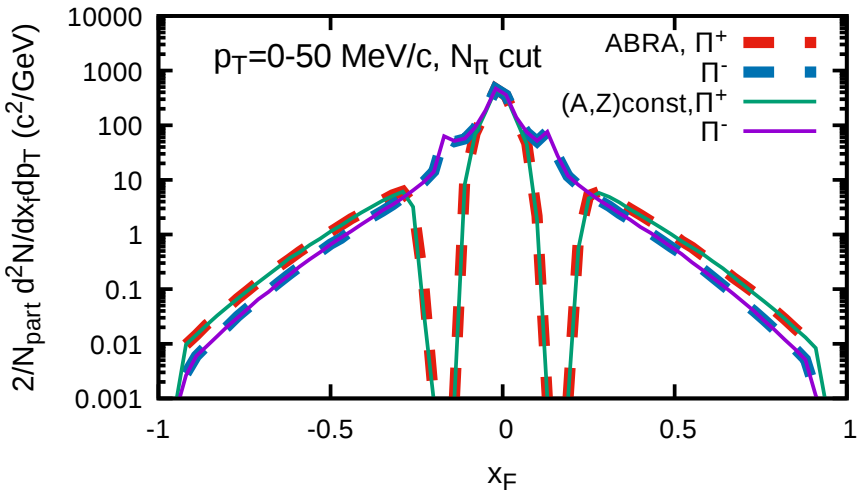
Mass/charge of the spectator

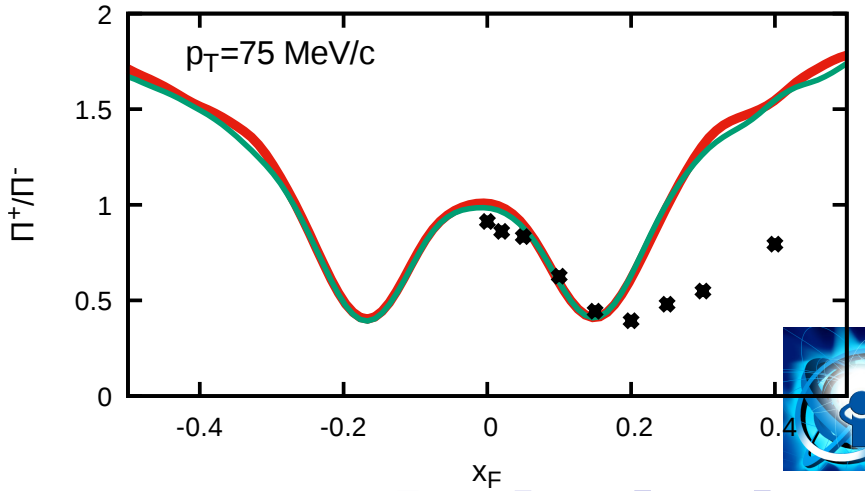




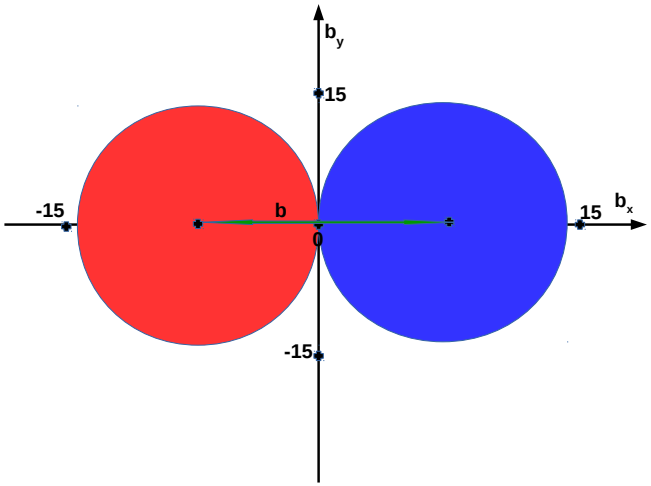


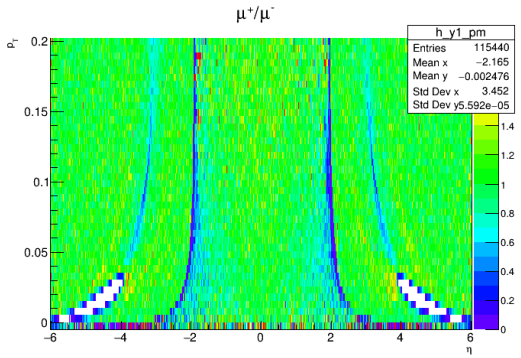
A/Z/B fluctuation in pion ratio

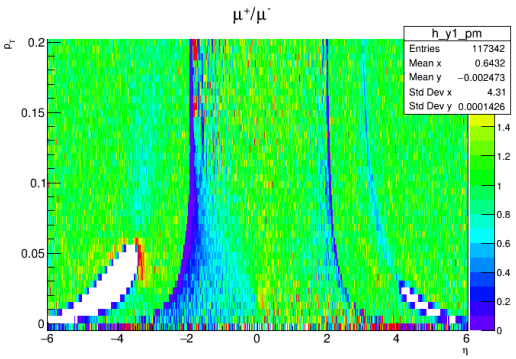


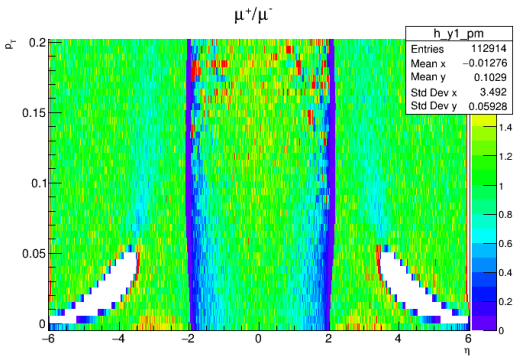


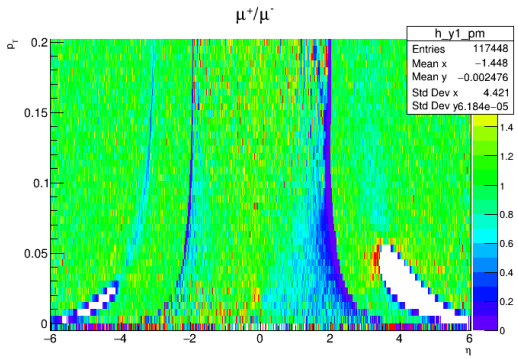
Pb + Pb Collision - Muon - spectator interaction

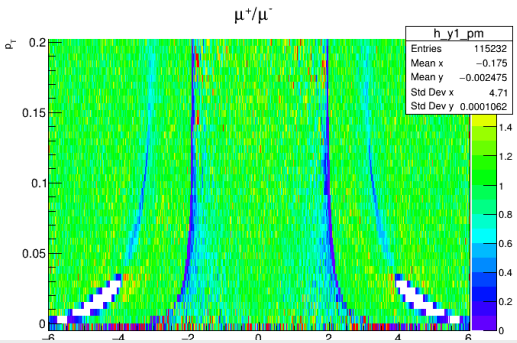






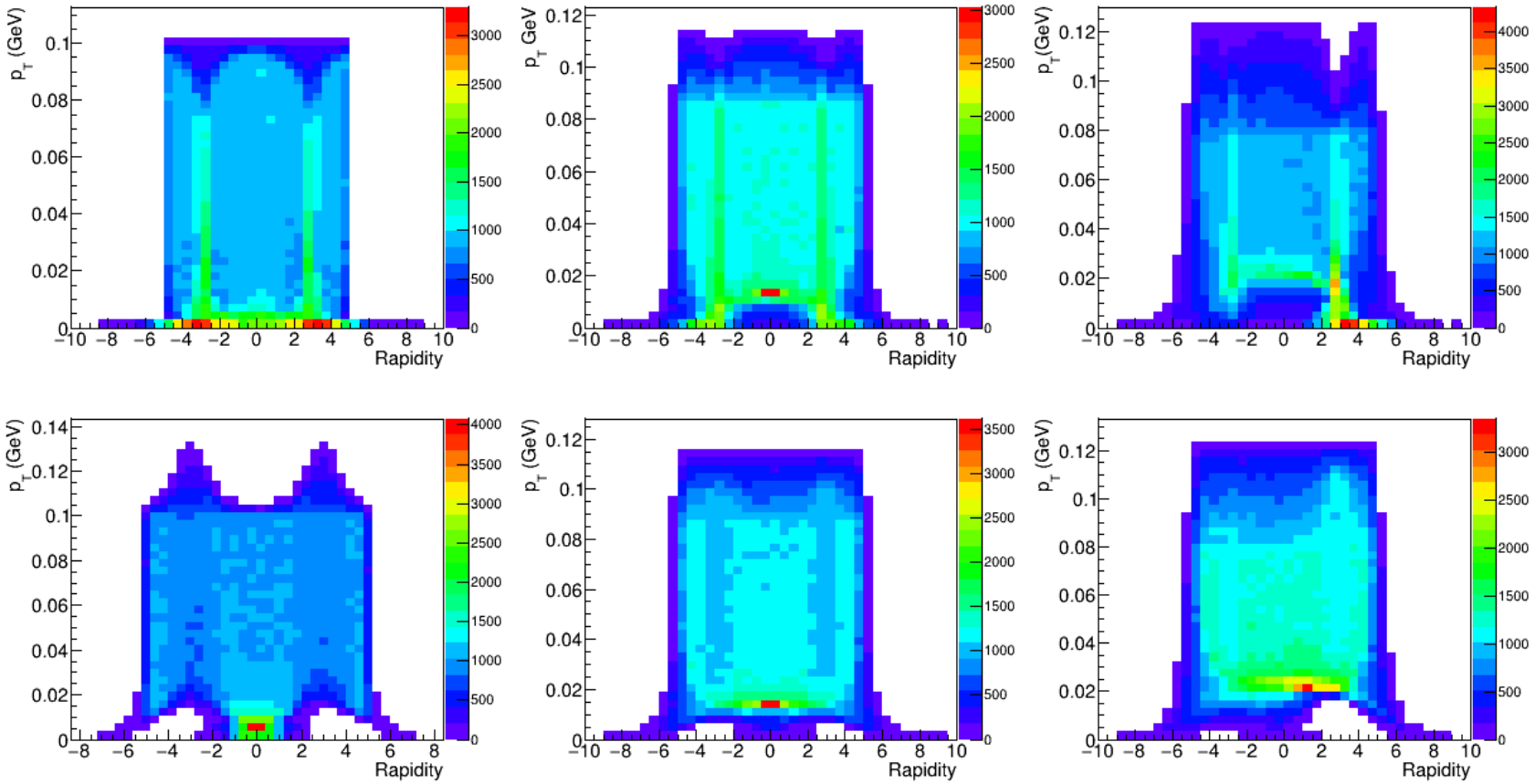






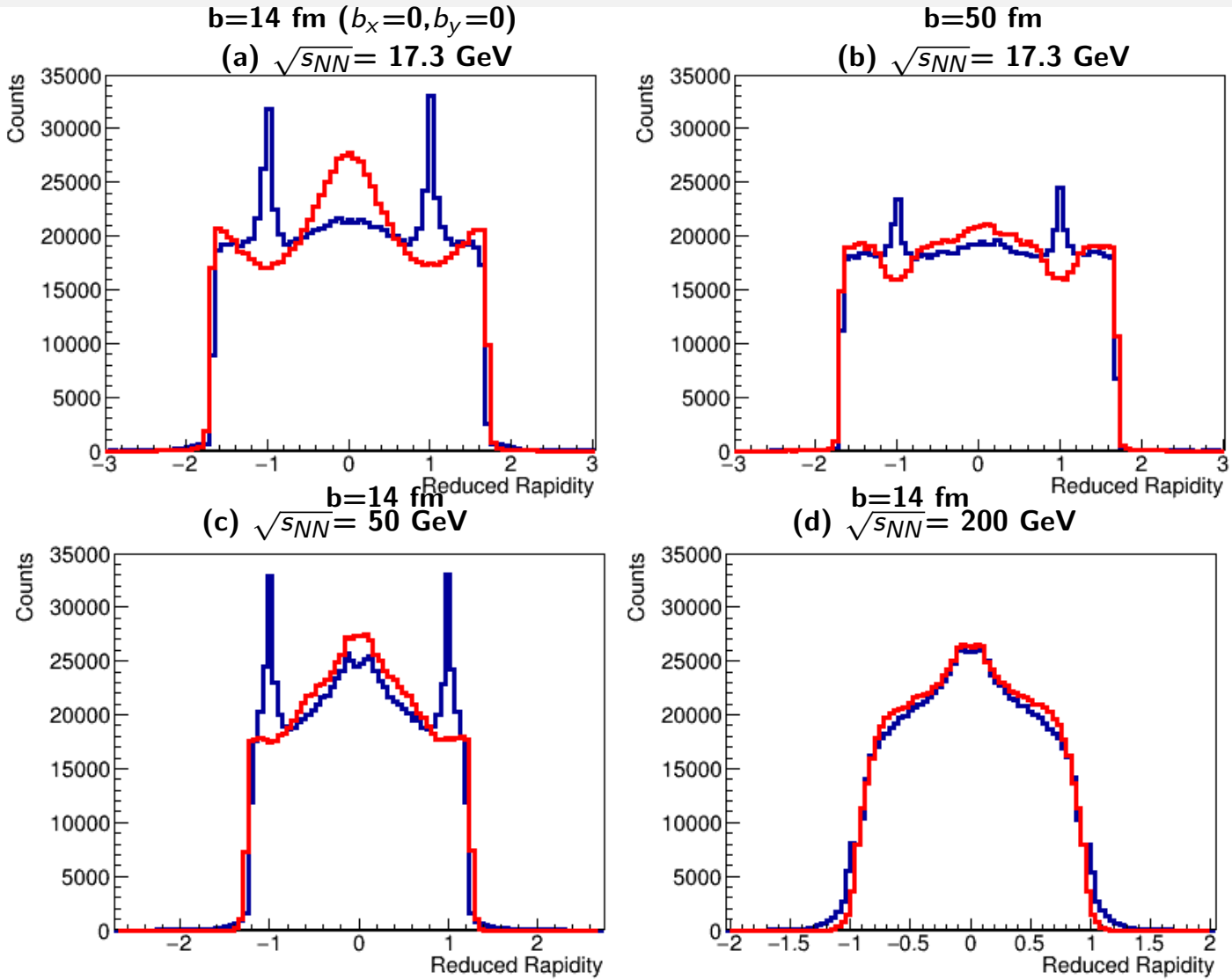
Pb + Pb Collision - electron and positron - spectator interaction

(a) (b_x=0, b_y=0) **(b) (b_x=0, b_y=15 fm)** **(c) (b_x=15 fm, b_y=0)**



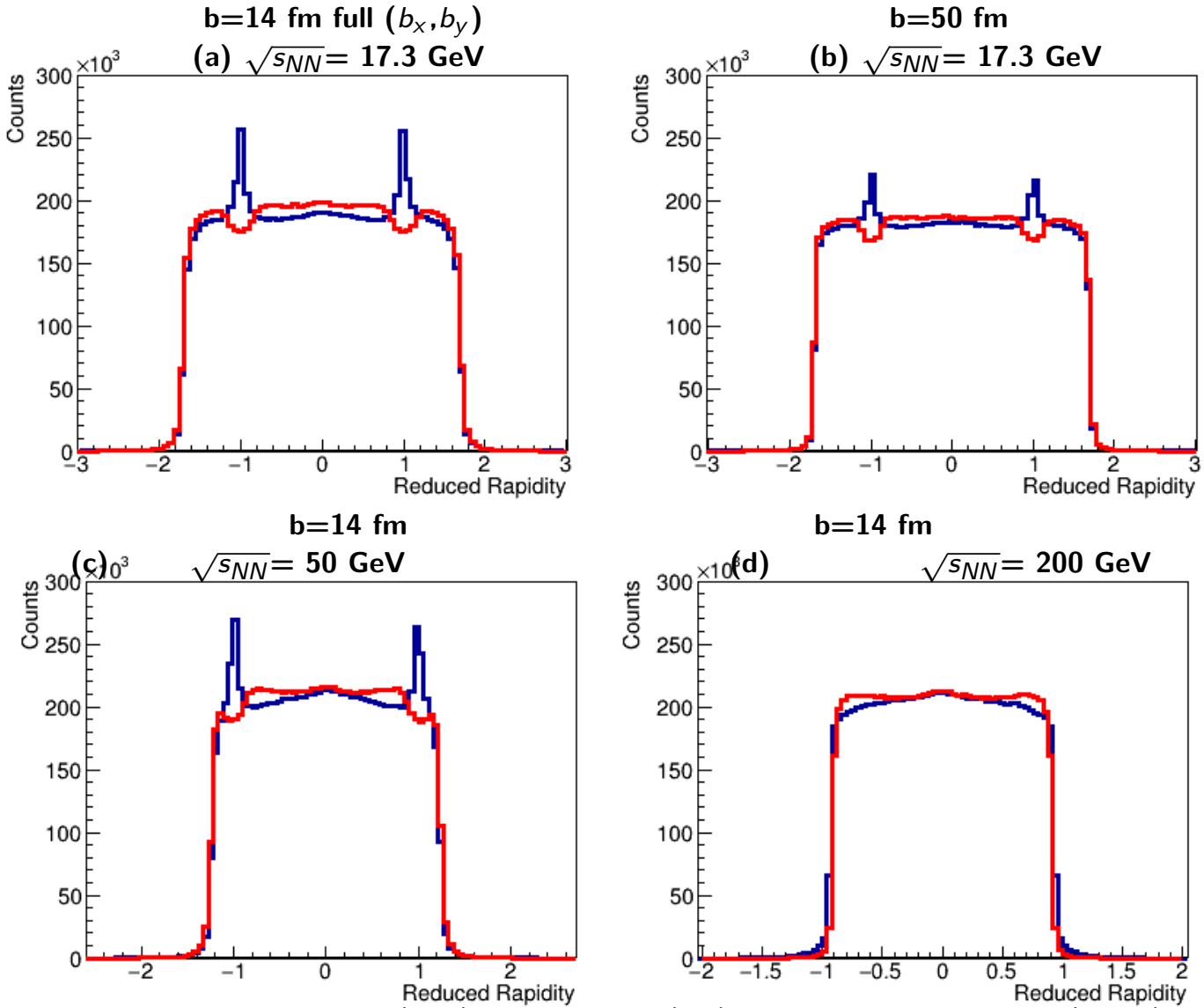
K. M., M. Kłusek-Gawenda, J. Józefiak, and A. Szczurek, arXiv:2107.13239v1, submitted to PRC

Pb + Pb Collision - electron and positron - spectator interaction



Reduced rapidity distributions for final electrons (blue) and positrons (red) for fixed b and (b_x=0,b_y=0) plane of emission points at three collision energies: $\sqrt{s_{NN}}$=17.3, 50 and 200 GeV.

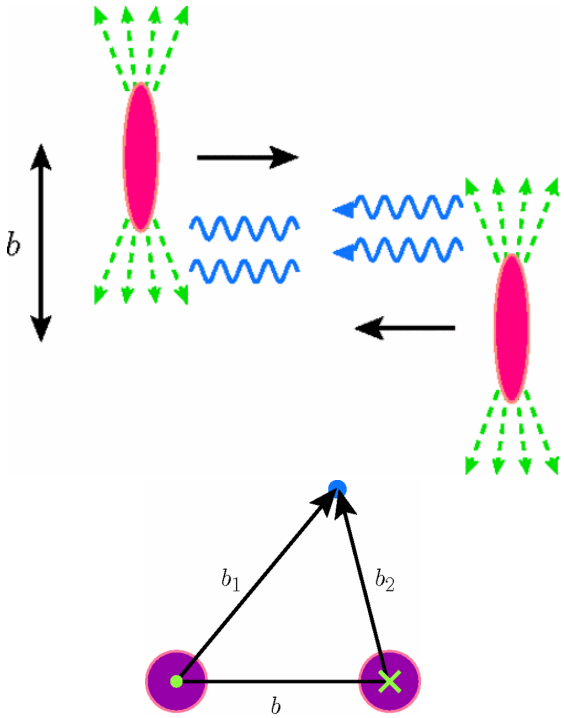
Pb + Pb Collision - electron and positron - spectator interaction



Reduced rapidity distributions for final electrons (blue) and positrons (red) for fixed b and intgrated (b_x,b_y) plane of emission points at three collision energies: $\sqrt{s_{NN}}$=17.3, 50 and 200 GeV.

Electron and positron production - EPA model

The equivalent photon approximation (EPA) is standard semiclassical alternative to the Feynman rules for calculating the cross section of EM interaction.Due to coherent action of all the protons in the nucleus , the EM field surrounding the ions is very strong. Produce the 'equivalent' or 'quassireal' photons.



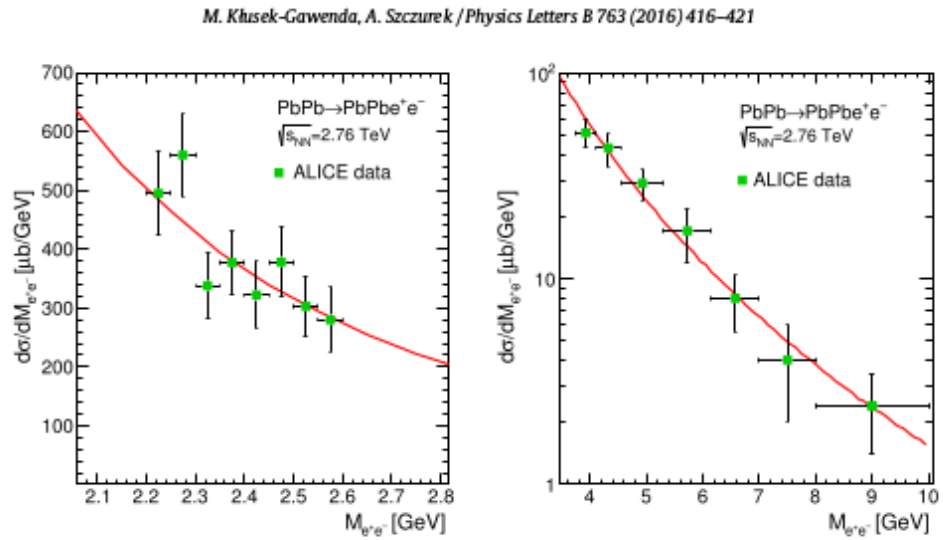


Fig. 2. Invariant mass distributions of dielectrons in UPC of heavy ions calculated within our approach [10] together with the recent ALICE data [22].

M. Kłusek-Gawenda, PRC82,014904

Charged lepton production - EPA model

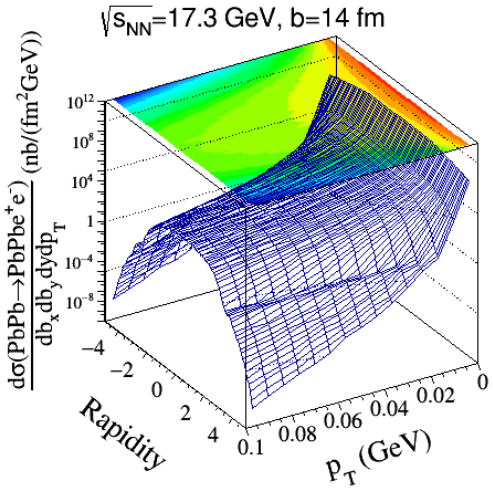
Double scattering production of l^+l^- pairs using the b-space equivalent photon approximation (EPA) model (G. Baur, L. Filho, NPA 518(4), 786 (1990); M. Kłusek-Gawenda, PLB 790, 339 (2019)).

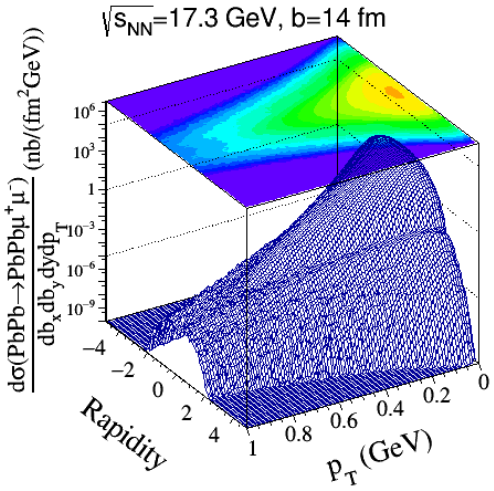
$$\sigma_{A_1A_2\to A_1A_2l^+l^-}(\sqrt{s_{A_1A_2}}) =$$

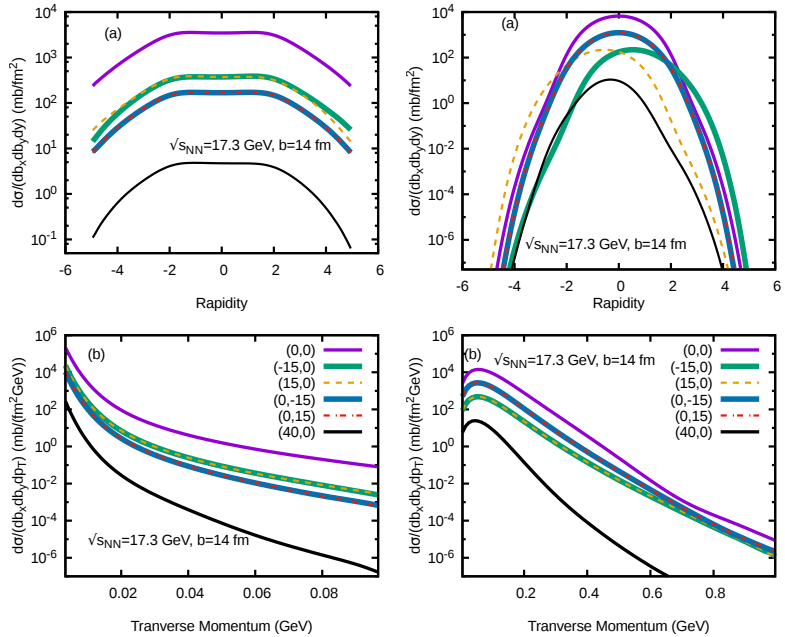
$$= \int \frac{d\sigma_{\gamma\gamma\to l^+l^-}(W_{\gamma\gamma})}{d\cos\theta} N(\omega_1, b_1)N(\omega_2, b_2)S^2_{abs}(b)$$

$$\times \quad 2\pi b db d\bar{b_x} d\bar{b_y} \frac{W_{\gamma\gamma}}{2} dW_{\gamma\gamma} dY_{l^+l^-} \; d\cos\theta,$$

where $N(\omega_i, b_i)$ are photon fluxes, $W_{\gamma\gamma} = M_{l^+l^-}$ is invariant mass and $Y_{l^+l^-} = (y_{l^+} + y_{l^-})/2$ is rapidity of the outgoing system and θ is the scattering angle in the $\gamma\gamma \to l^+l^-$ center-of mass system. The gap survival factor S^2_{abs} assures that only ultra-peripheral reactions are considered.

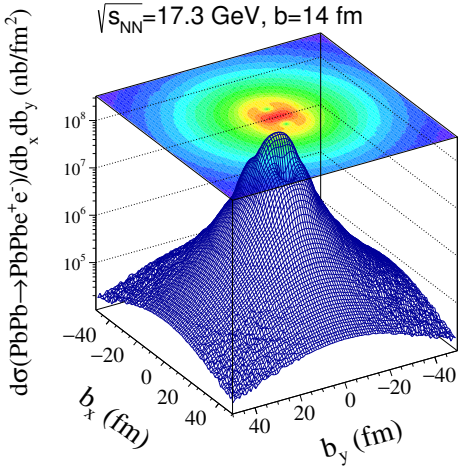


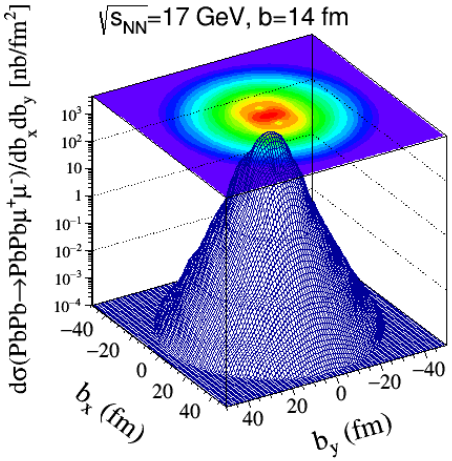


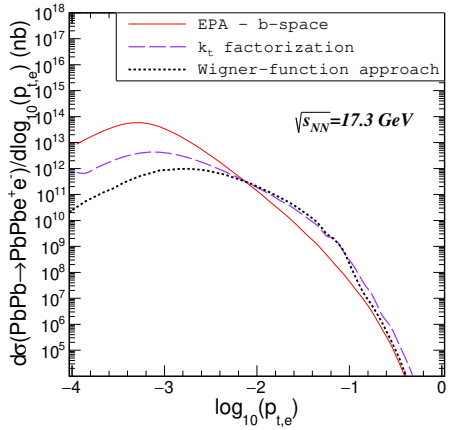


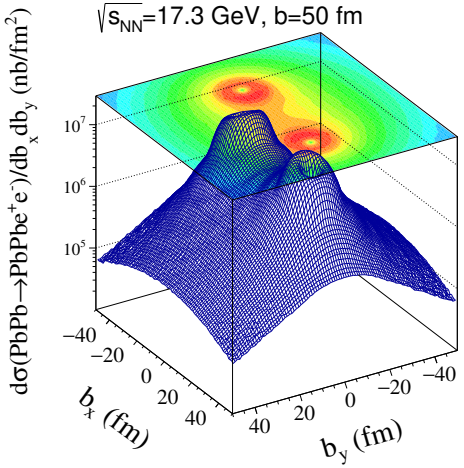
The differential cross section for various emission points of leptons (electrons (left) and muons (right)) produced in the ^{208}Pb+^{208}Pb reaction at 158 GeV/nucleon energy ($\sqrt{s_{NN}} = 17.3$ GeV) at impact parameter 14±0.05 fm.

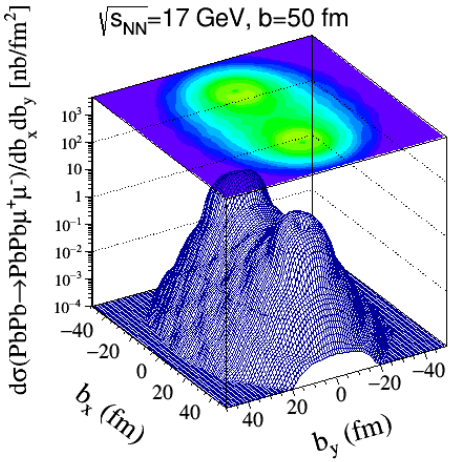
Charged lepton production - EPA model

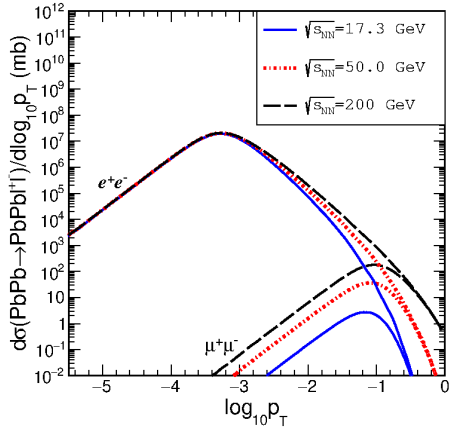










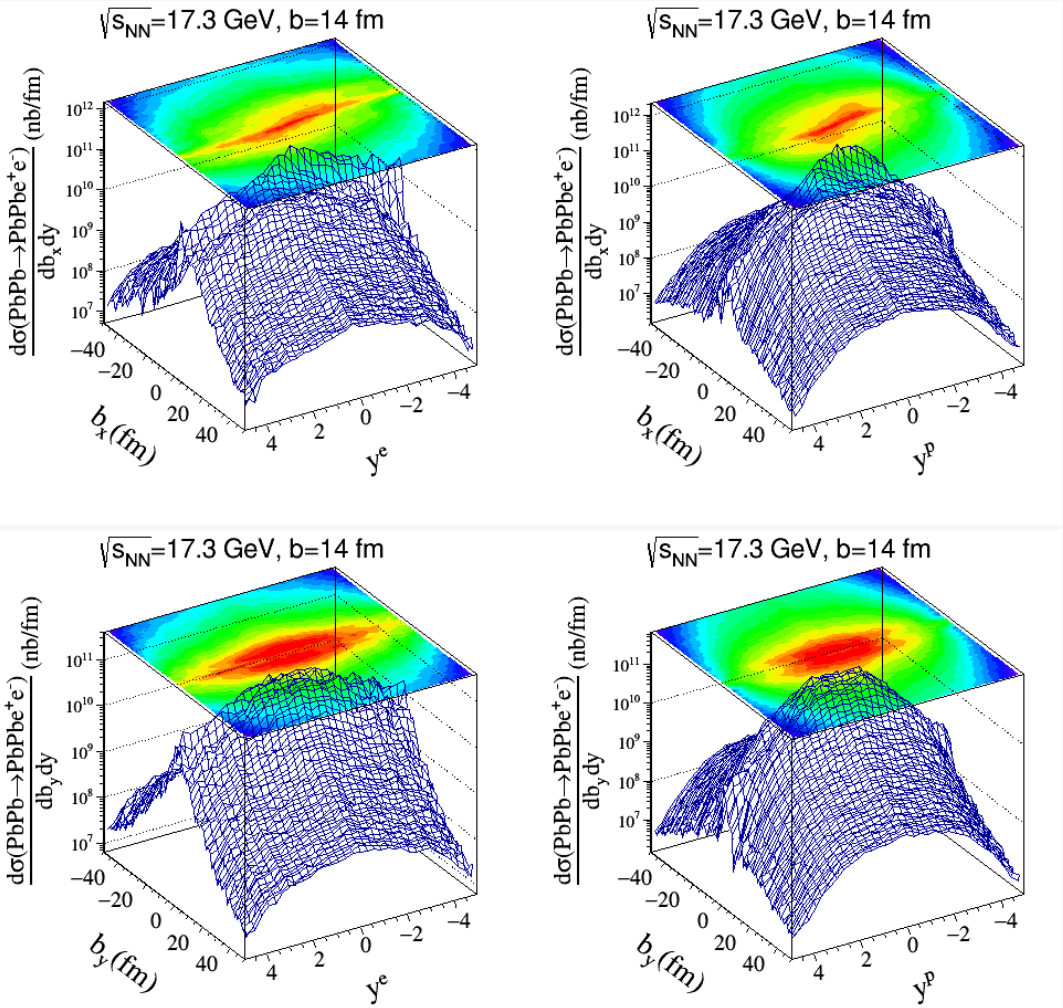


Two-dimensional cross section as a function of b_x and b_y for two values of impact parameter: (a) b=14±0.05 fm and (b) b=50±0.05 fm.

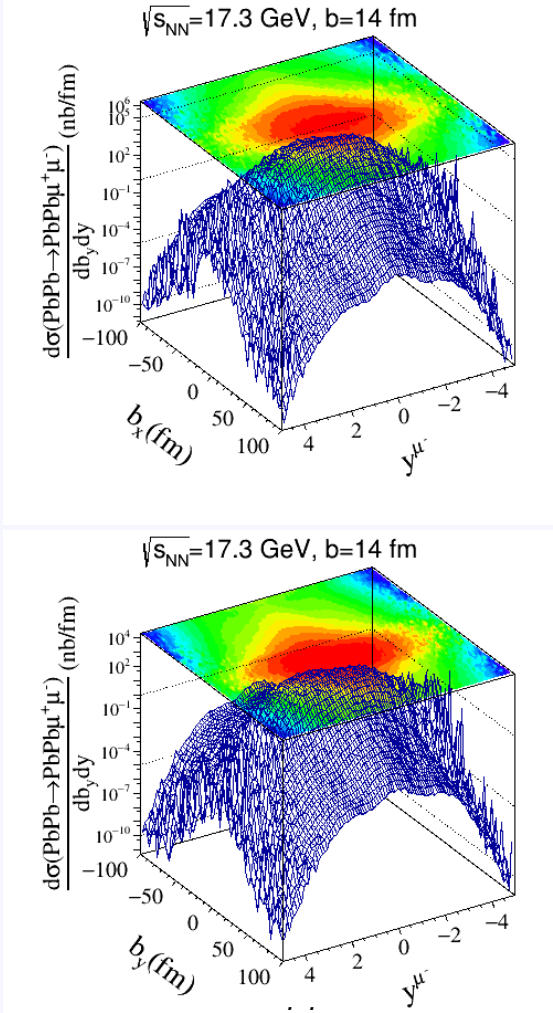
Differential cross section for PbPb→PbPbl^+l^- as a function of $\log_{10}(p_{t,e})$. The b-space EPA with its counterpart for the Wigner-function approach

Pb + Pb Collision -charged lepton - spectator interaction

Electrons – Positrons



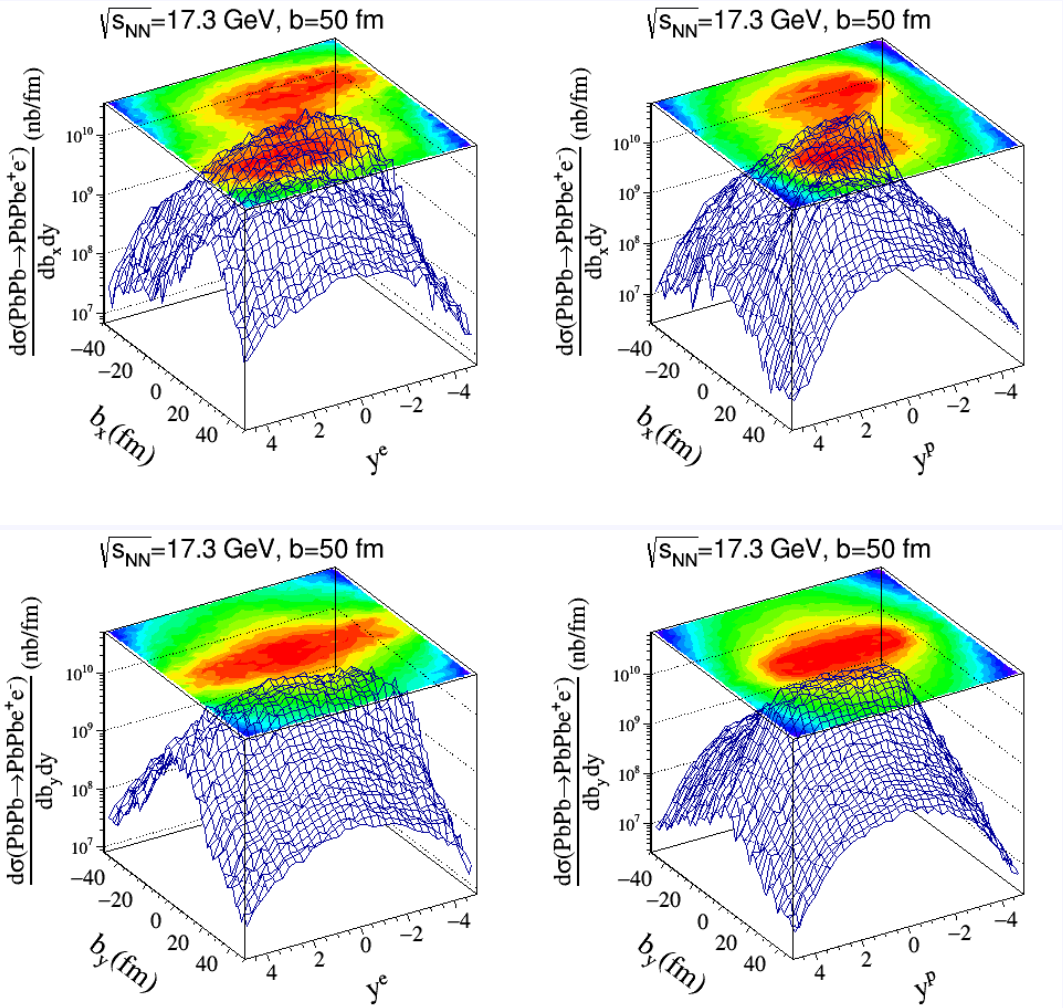
Muons



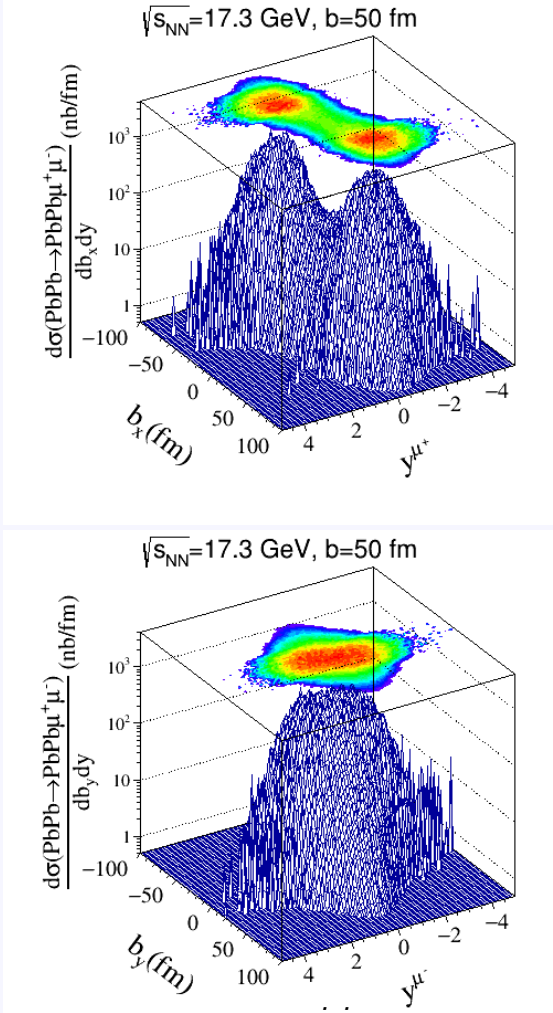
Distribution of leptons for $\sqrt{s_{NN}}$= 17.3 GeV at b=14 fm integrated over (b_x, b_y)=(-50 fm, 50 fm), p_T^{ini}=(0, 0.1 GeV)

Pb + Pb Collision - charged lepton - spectator interaction

Electrons – Positrons



Muons

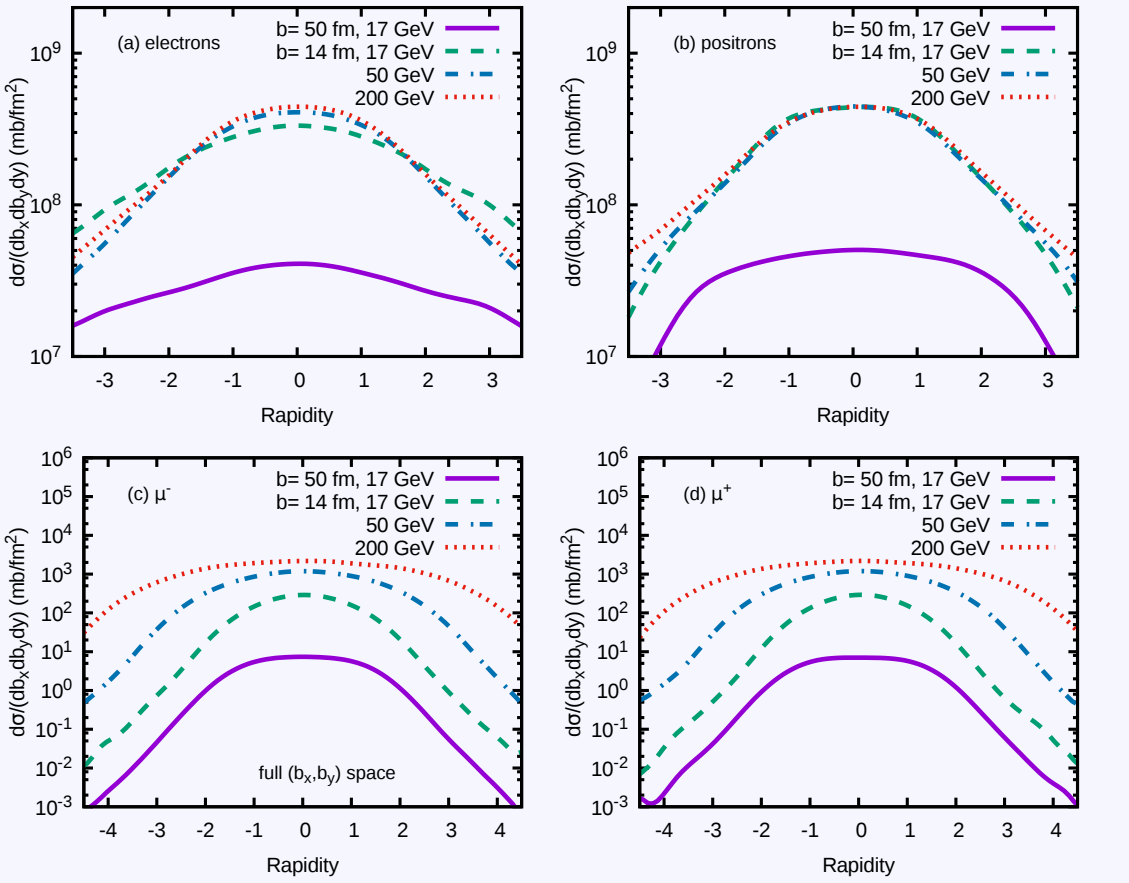


Distribution of leptons for $\sqrt{s_{NN}}$= 17.3 GeV at b=50 fm integrated over (b_x, b_y)=(-100 fm, 100 fm), p_T^{ini}=(0, 0.1 GeV).

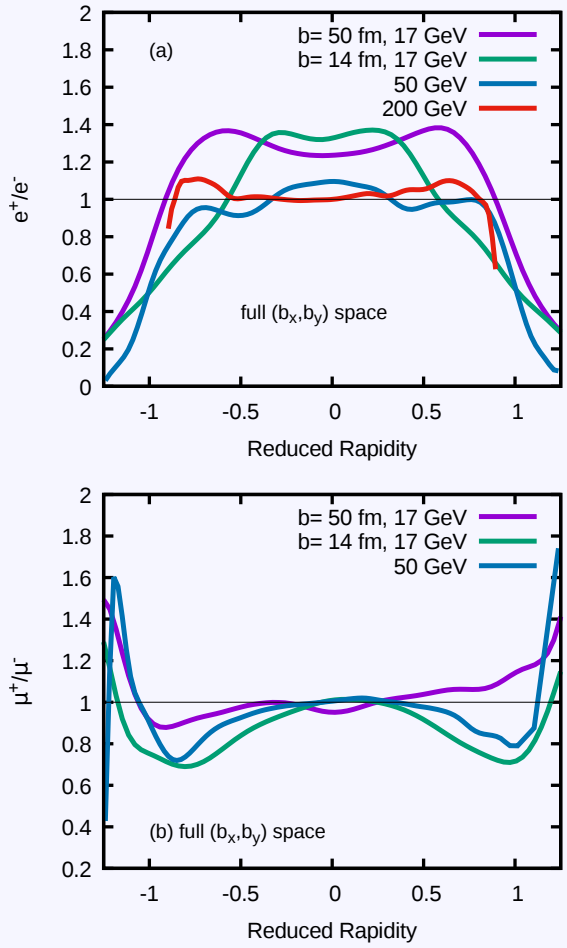
Pb + Pb Collision - charged lepton - spectator interaction

Rapidity distribution of leptons for $\sqrt{s_{NN}}$= 17.3 GeV (b=14 fm, 50 fm) and 50 GeV and 200 GeV with b=14±0.05 fm (only) integrated over (b_x, b_y)=(-50 fm, 50 fm), p_T^{ini}=(0, 0.1 GeV).

Rapidity Distribution



Ratio of rapidities



Summary

- The moddeling of the heavy-ion collisions suffered of the lack of knowledge about time evolution of the spectators and deexcitation channels.
- Our calculation estimated the excitation energy of the spectators.
- The dynamic evolution of various spectators produced in peripheral collisions Pb+Pb at 158 GeV/nucleon energies has been investigated.
- The photon energy spectra and emission time are estimated.
- Spectator-induced EM effects in charged pion production give insight to space-time properties of the system of hot and dense matter created in heavy ion collisions.
- They suggest a picture of the longitudinal evolution of the system at the initial stage at CERN SPS energies largely governed by the energy-momentum conservation.
- The cross section of electrons/positrons produced via photon-photon fusion in heavy ion UPC can be rather reliably calculated and turned out to be large, especially for low transverse momentum electrons/positrons.
- The impact parameter equivalent photon approximation is well suitable for investigating the electromagnetic effects.
- On the experimental side only rather large transverse momentum electrons/positrons could be measured so far at RHIC and the LHC, typically larger than 0.5 GeV.
- However, the integration over full (b_x, b_y) plane washes out this effect to large extent.
- We have found that only at small transverse momenta of electrons/positrons one can observe sizeable EM effects.