Studies of Critical Fluctuations and Electromagnetic Effects in NA61/SHINE Beyond 2020

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1) New measurements on electromagnetic effects;

2) New measurements on critical fluctuations.

work in collaboration with
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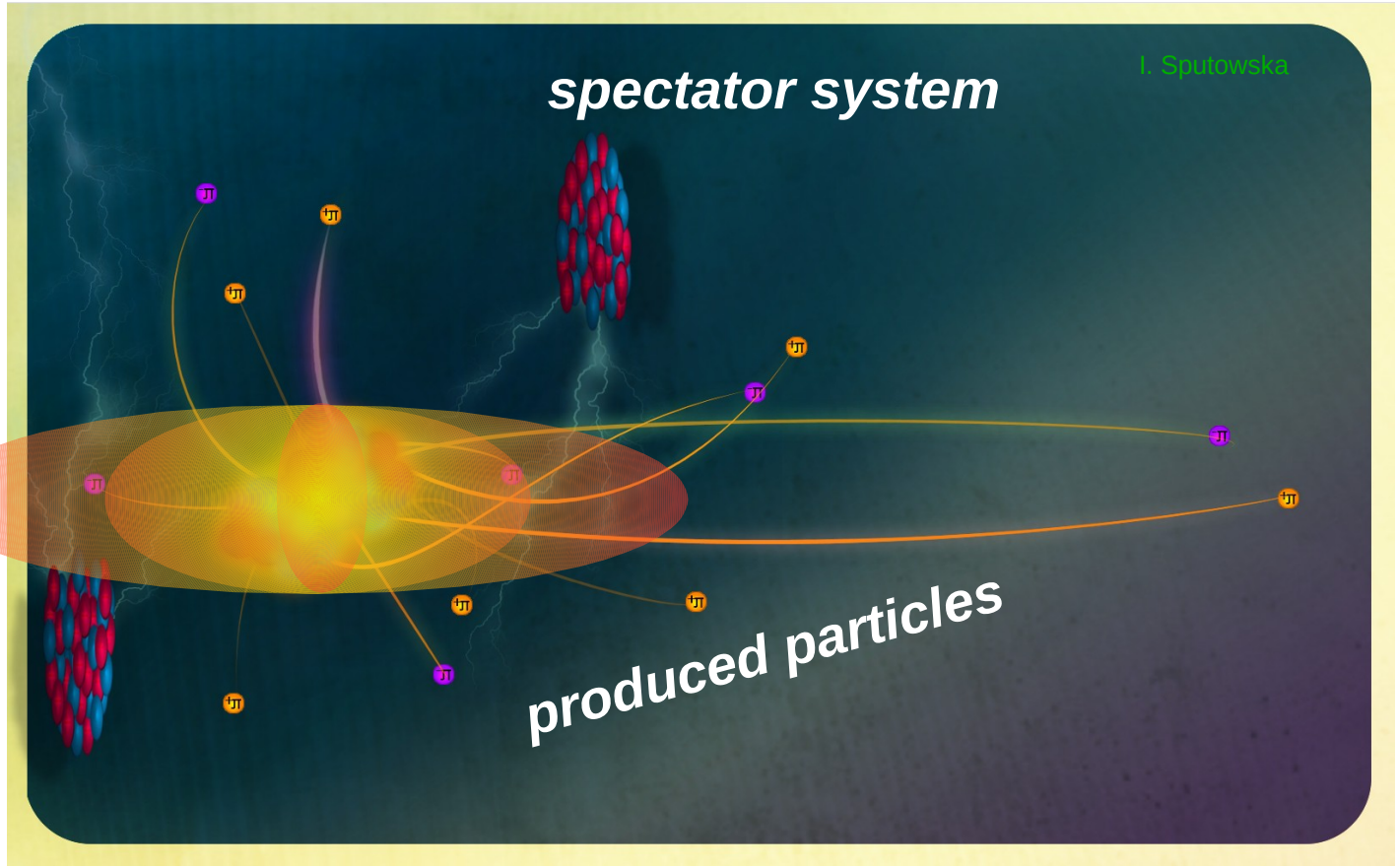
Nikos Antoniou, Fotis Diakonos,
Antoni Marcinek, Vitalii Ozvenchuk, Mirek Kiełbowicz,
Sneha Bhosale, Łukasz Rozpłochowski

On the advantages of studying strong electromagnetic fields with an upgraded NA61/SHINE Beyond 2020 Detector

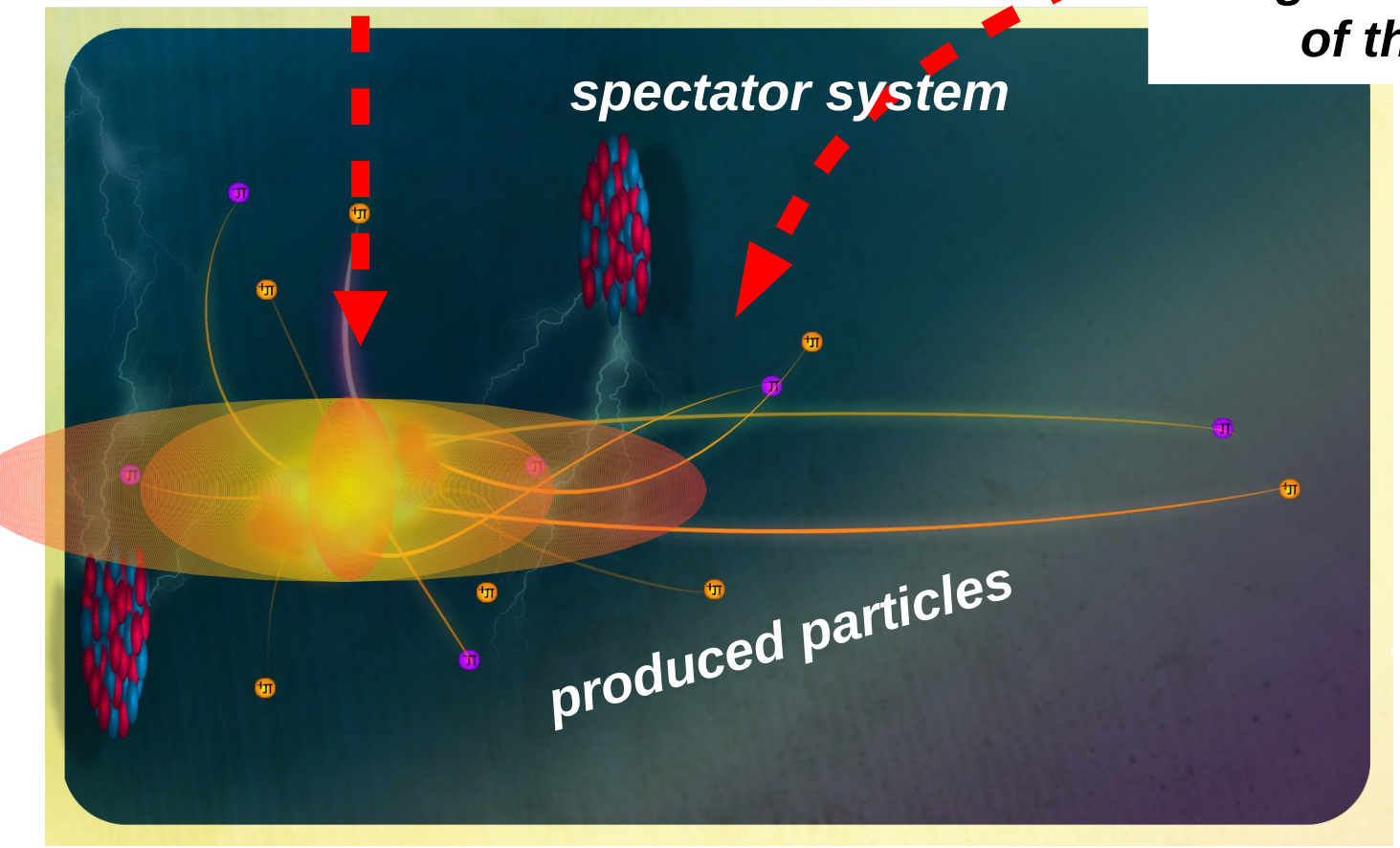


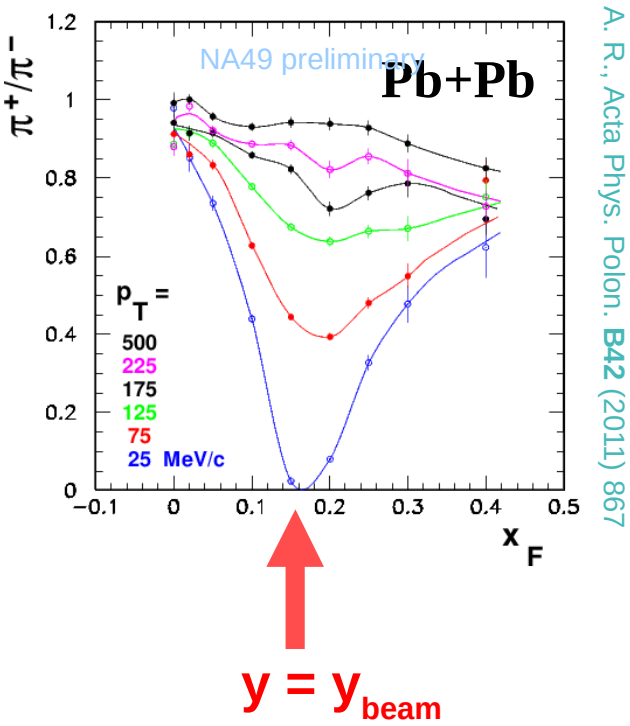
D. E. Kharzeev, L. D. McLerran, H. J. Warringa, Nucl. Phys. **A 803** (2008) 227
Y. Burnier, D. E. Kharzeev, J. Liao and H. -U. Yee, Phys. Rev. Lett. **107** (2011) 052303
(and further, very rich literature)

NA61/SHINE, SPSC-P-330-ADD-8
See also: A. R. and A. Szczurek,
Phys. Rev. **C75** (2007), Phys. Rev. **C87** (2013)
A. Szczurek, M. Kiełbowicz, A.R.,
Phys.Rev. **C95** (2017)

Mid-rapidity:
magnetic field
Chiral Magnetic Effect
Chiral Magnetic Wave
...

Large region of
forward (or backward) rapidity:
electric and magnetic fields;
space-time evolution
of the collision,
longitudinal evolution
of the system.





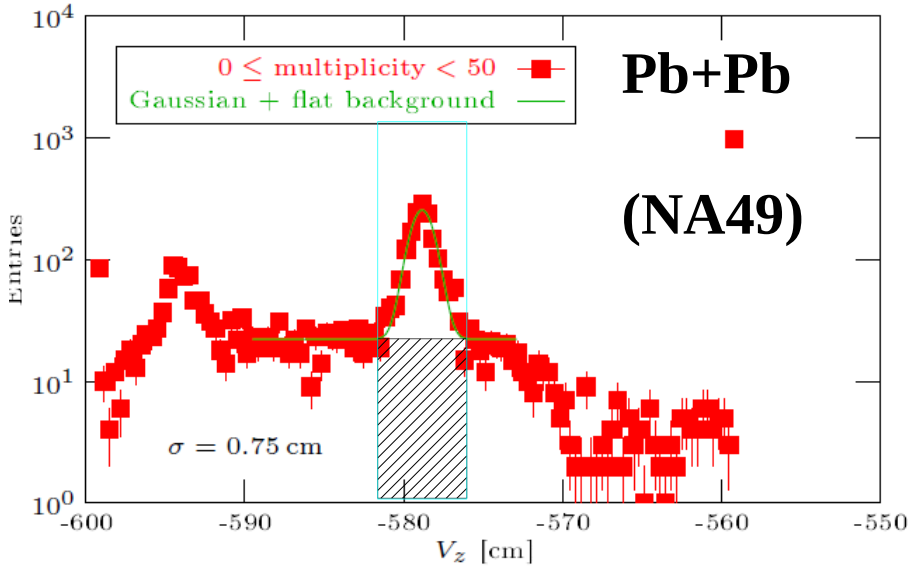
A. R., Acta Phys. Polon. **B42** (2011) 867

High statistics measurements of Pb+Pb collisions with a new vertex detector can bring measurements of EM distortions to a new level. An example will be given below.

A well-defined collision vertex

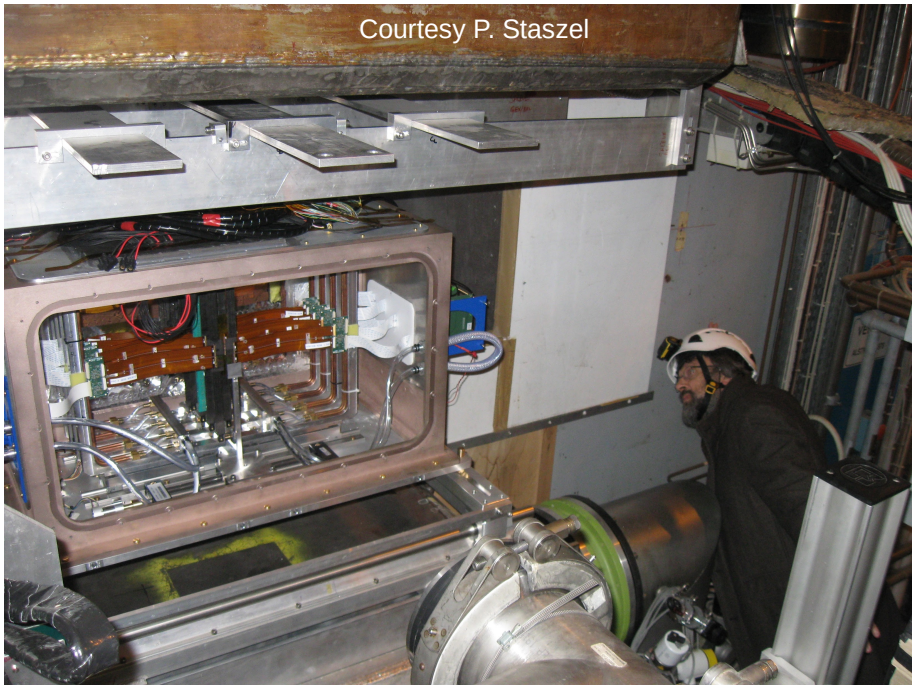
can decrease the beam-gas background contribution for low multiplicity Pb+Pb events.

- Better access to **more peripheral collisions** → together with presence of **PSD** → **better control** on **initial conditions** of the **spectator charge**.



A. Laszlo, PhD Thesis, KFKI Budapest, 2007

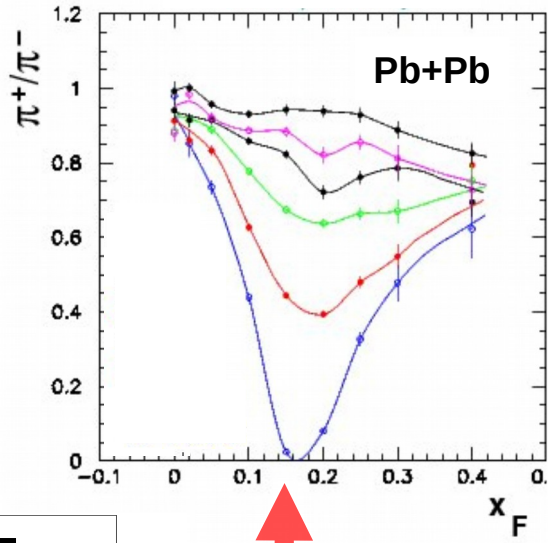
Actually... why should we care about the spectator system?

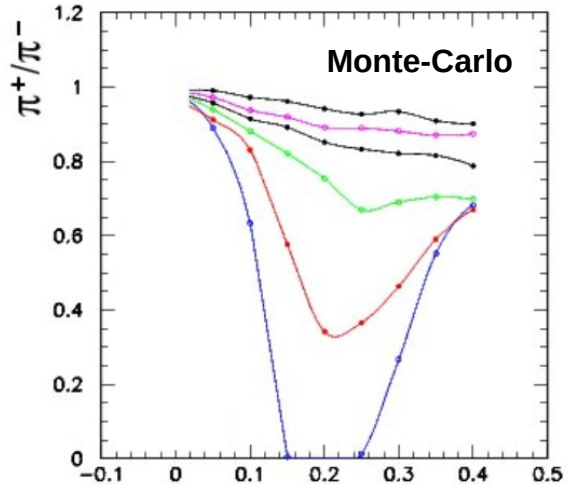


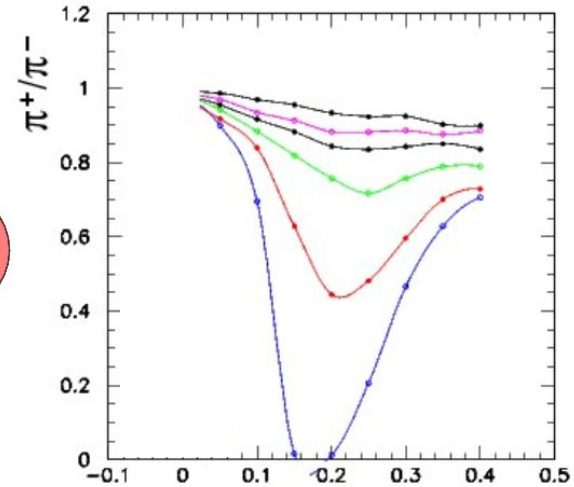
We know since some time that the shape of the EM distortion is sensitive to the space-time scale of spectator fragmentation.

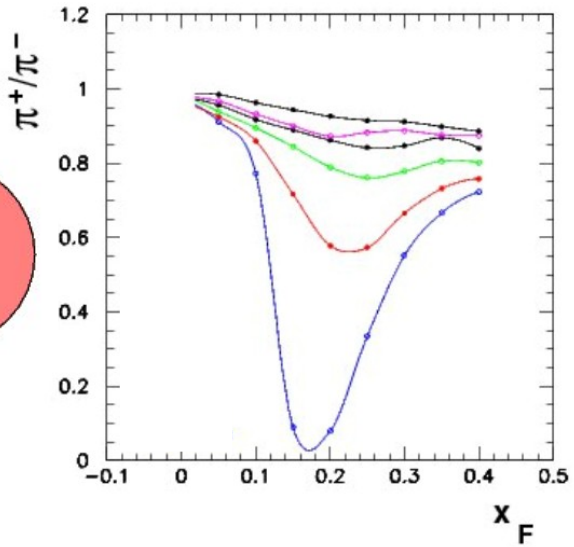
What do we know about the space-time evolution of spectator break-up?

NA49 preliminary, A.R., Acta Phys. Pol. B42, 2011









p_T =
325
175
125
75
25 MeV/c

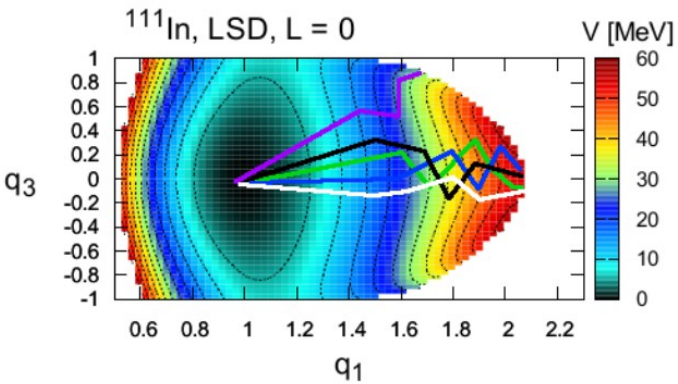
$y = y_{beam}$

A.R., Acta Phys. Pol. B42, 2011

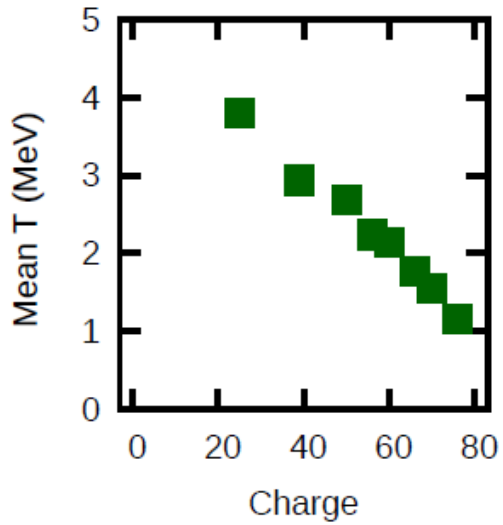
The spectator is a highly excited, unstable nuclear system.

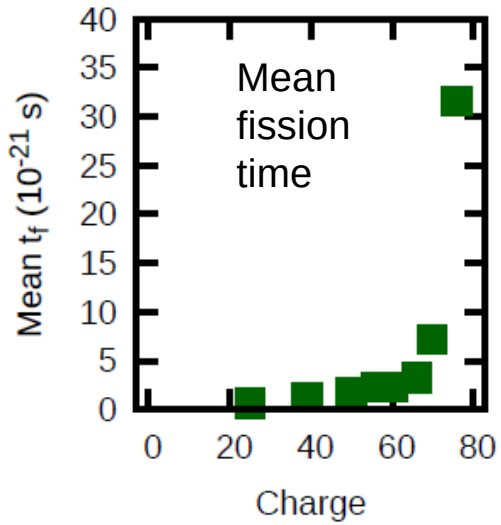
How does it come to fragmentation? In what time scales?

E.g.: a theoretical work has been recently performed for our (Pb+Pb) case using 4D Langevin Equations within the stochastic approach.

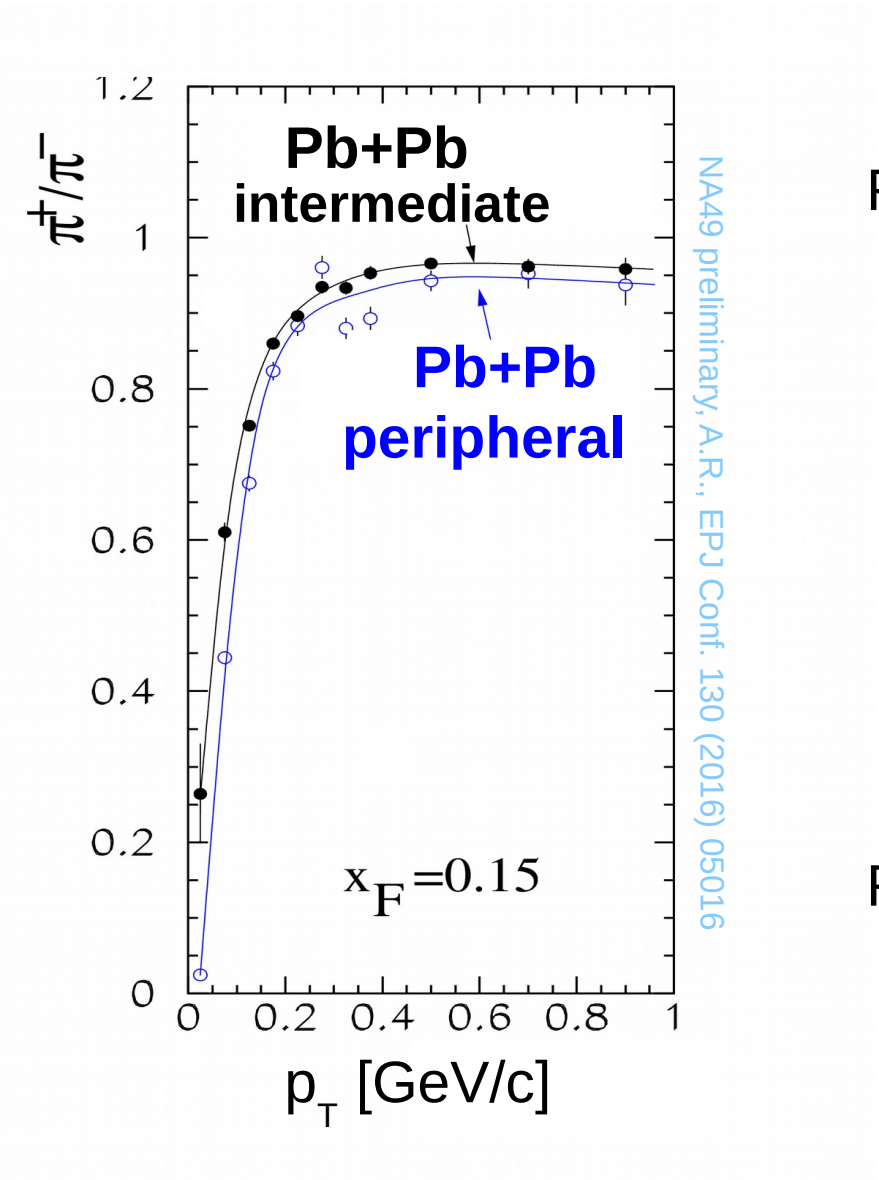


K. Mazurek, A. Szczurek, P. N. Nadtochy, **arxiv:1612.05397**

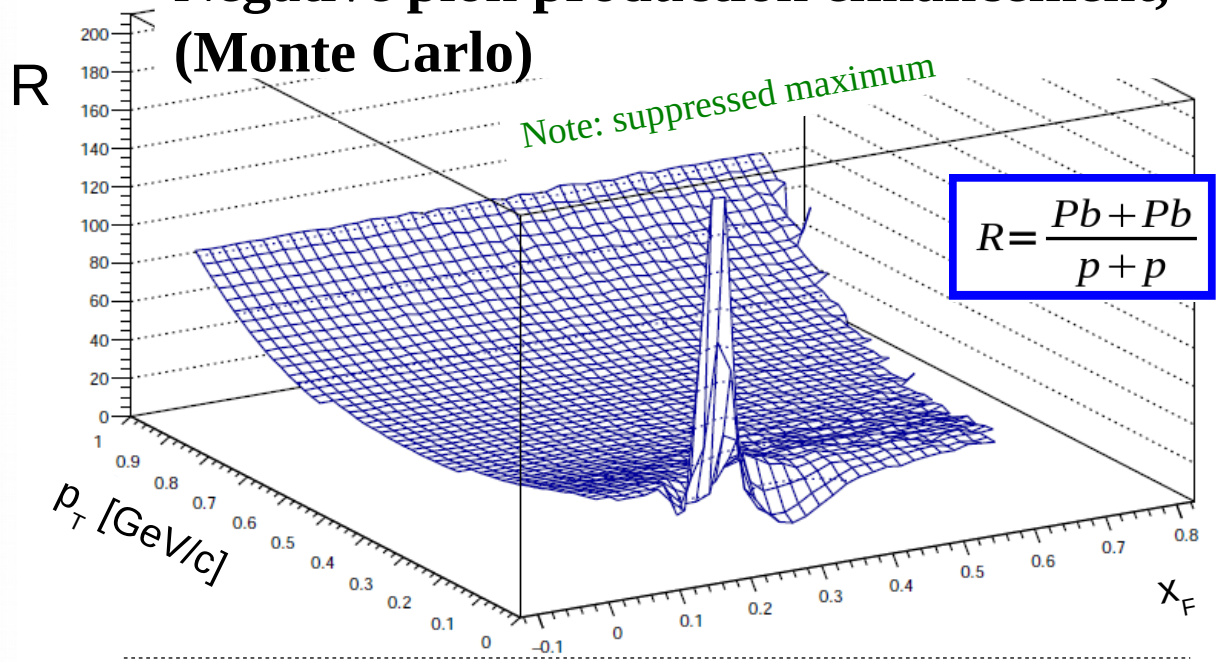


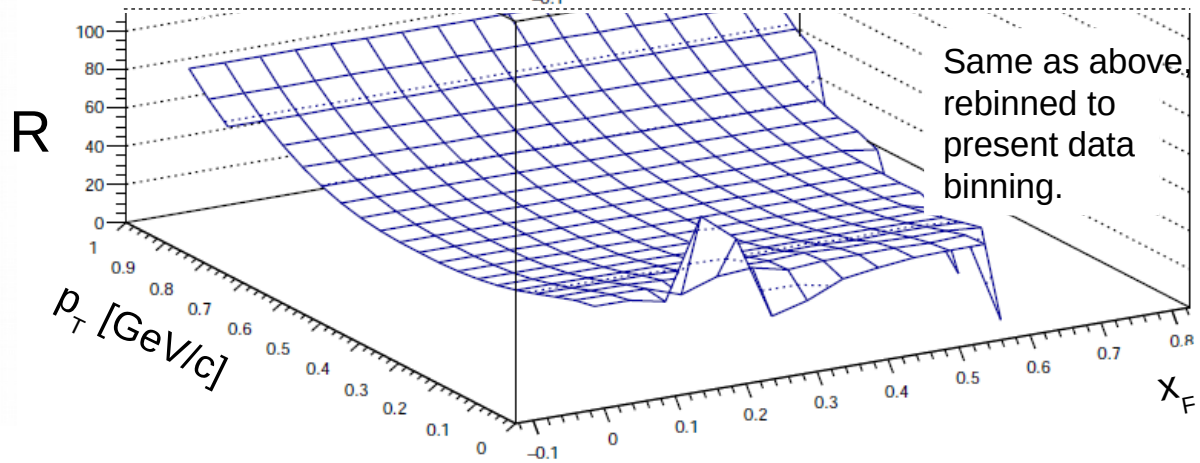


How to test such a space-time calculation? Using what kind of data?
NA61/SHINE (Beyond 2020) could provide such data,
if only there is high statistics ...



Negative pion production enhancement, (Monte Carlo)





The spectator-sensitive region is characterized by steep local changes of π^+/π^-, $d^2n/dydp_T$, etc.

A high statistics measurement can uncover this sensitivity.

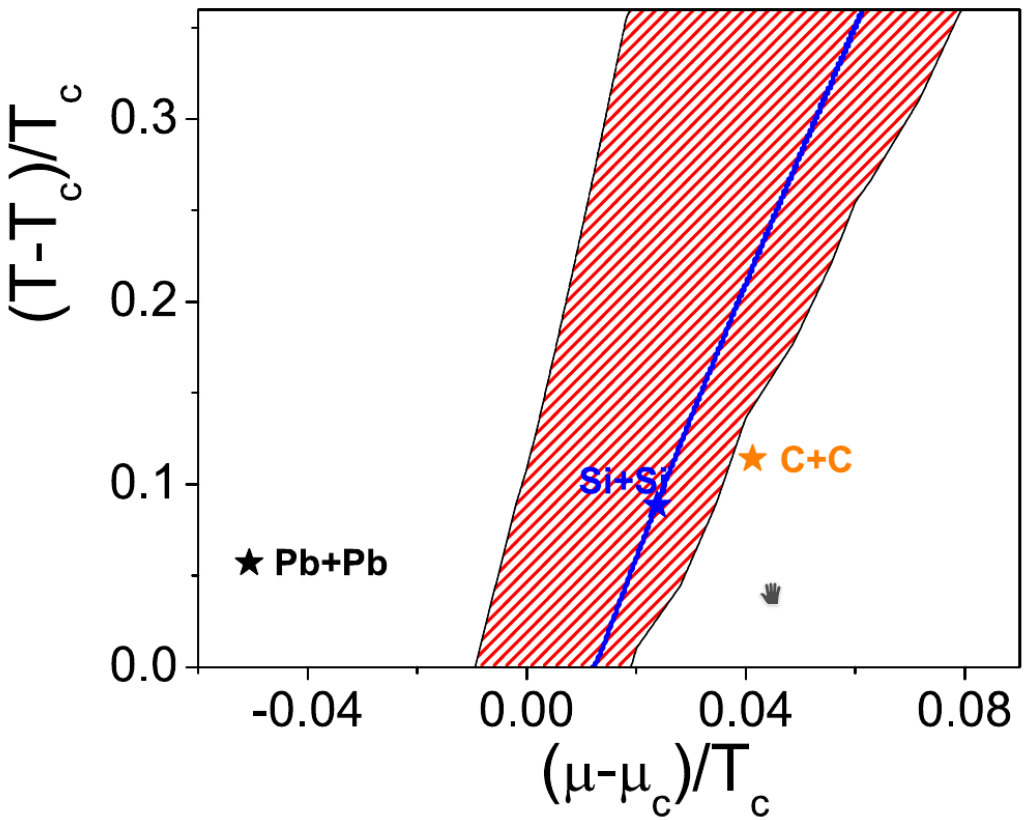
Summary – E/M

- High statistics measurements of Pb+Pb collisions with a new vertex detector can bring measurements of EM effects to a new level, providing independent information on the space-time evolution of nuclear fragmentation using highly energetic pions (in addition to information on the space time evolution of the participant system).

- Thus, NA61/SHINE Beyond 2020 would cover the whole region of physical phenomena from classical nuclear physics up to the QGP scale.

- Such measurements would necessitate no extra data taking effort w.r.t. any possible studies of centrality dependence of hadron production already possible in NA61/SHINE.

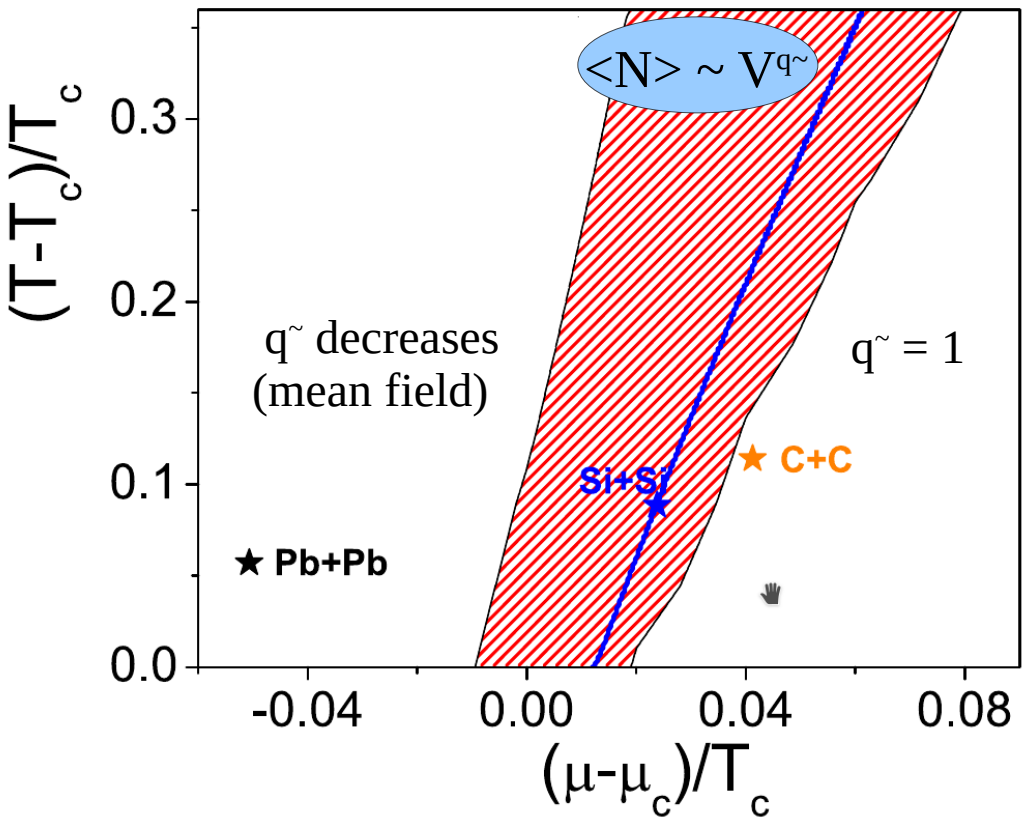
Probing the critical region through baryon number density scaling in NA61



N.G.Antoniou, F.K.Diakonos, X.N.Maintas, C.E.Tsagkarakis, arXiv:1705.09124 [hep-ph]

- Non-conventional baryon density fluctuations detected by intermittency analysis: NA49 Si+Si collisions at maximum SPS energy;
- Indicates a freeze-out near the critical end point;
- We are looking for the most promising NA61 candidates, in system size & collision energy, to probe the critical region.
- Theoretical study performed to estimate the size of the critical region (μ,T) where power-law scaling of baryon-number multiplicity moments can be observed;

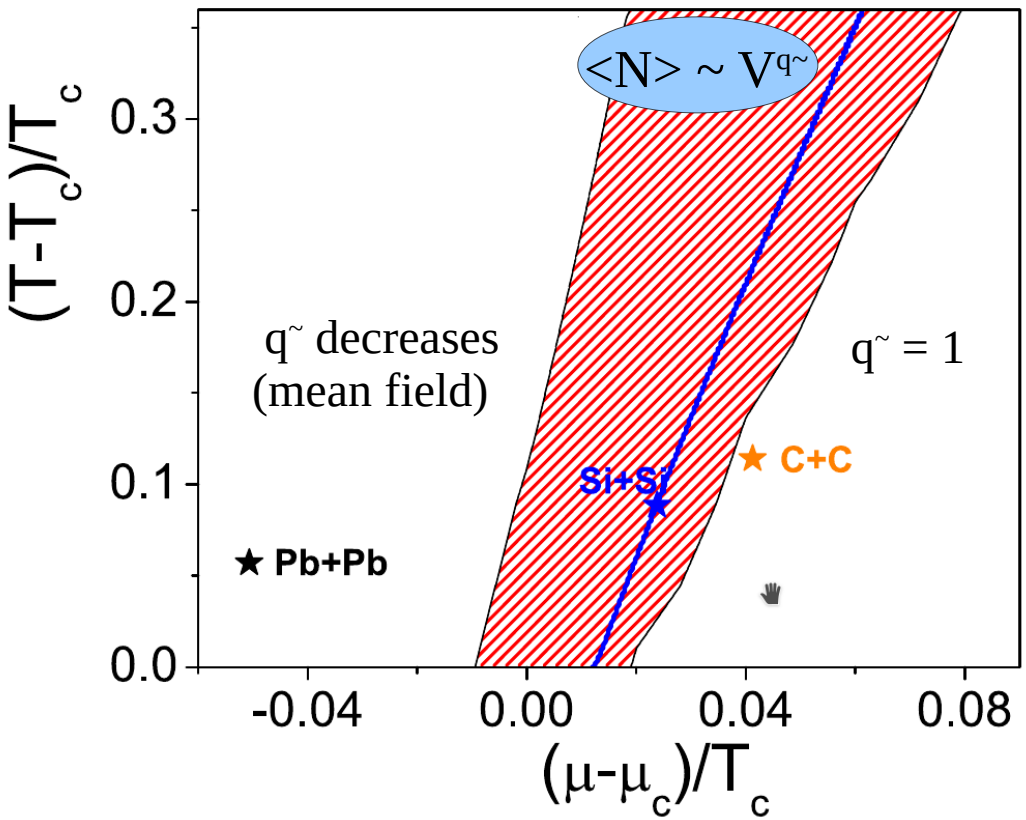
Probing the critical region through baryon number density scaling in NA61



N.G.Antoniou, F.K.Diakonos, X.N.Maintas, C.E.Tsagkarakis, arXiv:1705.09124 [hep-ph]

- φ^6 effective action belonging to the 3D-Ising Universality Class;
- Field $\varphi \rightarrow$ Baryon number density n_b;
- We can determine the region around (T_c,μ_c) where mean multiplicity $\langle N \rangle$ scales with system volume V with a non-trivial exponent $\tilde{q}$, $\langle N \rangle \sim V^{\tilde{q}}$;
- Broad in T_c, narrow in μ_c;
- Based on measured intermittency index & estimated freeze-out location, NA49 Si+Si freeze-out falls into critical scaling region;
- The other 2 NA49 systems examined (Pb+Pb and C+C at maximum SPS energy) fall outside the critical region.

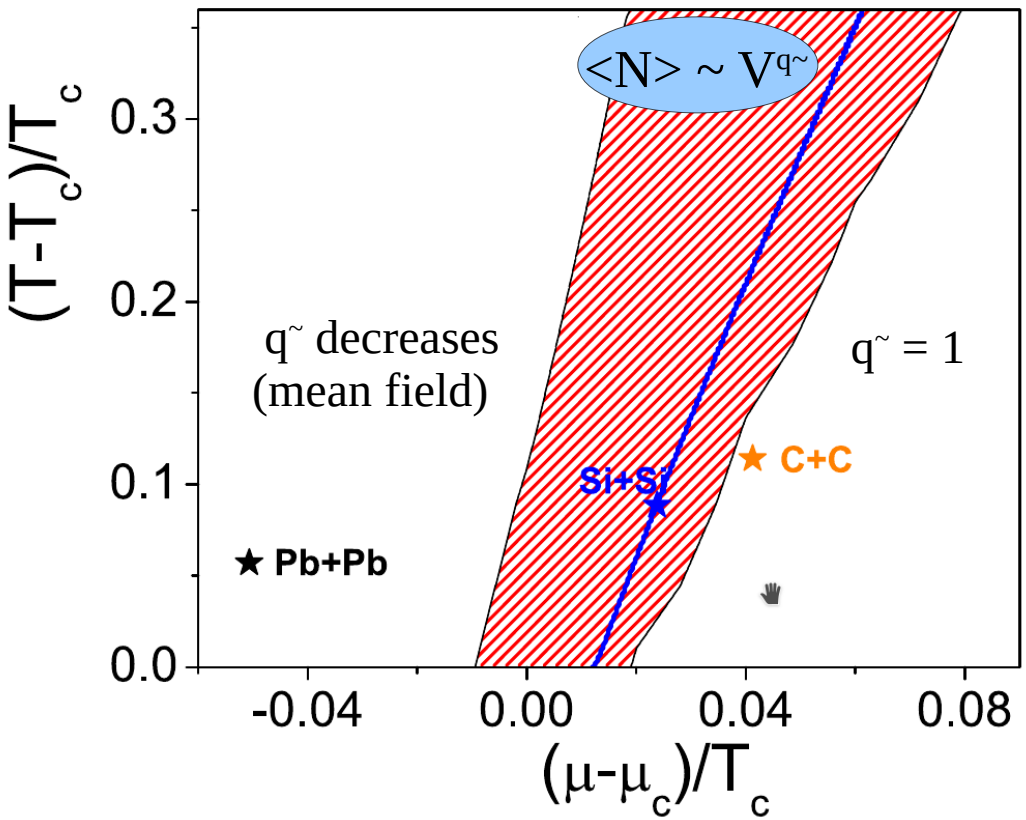
Probing the critical region through baryon number density scaling in NA61



N.G.Antoniou, F.K.Diakonos, X.N.Maintas, C.E.Tsagkarakis, arXiv:1705.09124 [hep-ph]

- Candidates for probing the critical region in NA61 beyond 2020:
  - Pb+Pb for a variety of different energies:
  - Theoretical analysis indicates 110 → 150 AGeV with a 10 GeV step.
  - Experimentally, a probe within 80 → 158 AGeV, would be an excellent approximation if achievable.

Probing the critical region through baryon number density scaling in NA61



N.G.Antoniou, F.K.Diakonos, X.N.Maintas, C.E.Tsagkarakis, arXiv:1705.09124 [hep-ph]

- Candidates for probing the critical region in NA61 beyond 2020:
  - Si+Si @ 158 A GeV

    (max. SPS energy)
  - Very high statistics needed! (> 1M events would be preferable)
  - Good particle ID (via dE/dx and/or TOF)
  - proton purity of 80% used in NA49, 90% would be preferable if possible in NA61.

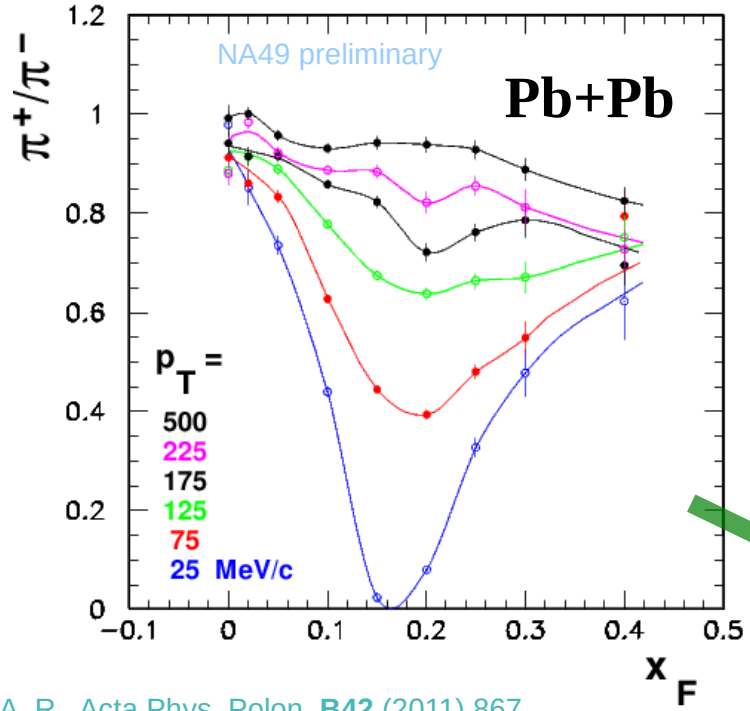
Summary – Critical Fluctuations

• Previous analysis of baryon number density scaling in NA49 Si+Si indicates that the region of the critical point can be probed by intermittency analysis of baryon density in transverse momentum space, provided that the system freeze-out is within a small distance from the critical end-point.
• We estimate the size of the critical region to be narrow along the baryochemical potential and considerably wider along the temperature direction.
• High statistics and good quality proton identification is required if an intermittency analysis is to be successful.
• The most promising candidate systems for detecting critical fluctuations of baryon density are: a higher-statistics than NA49 Si+Si system at maximum SPS energy, as well as a Pb+Pb energy scan in the range 80 → 158 AGeV.

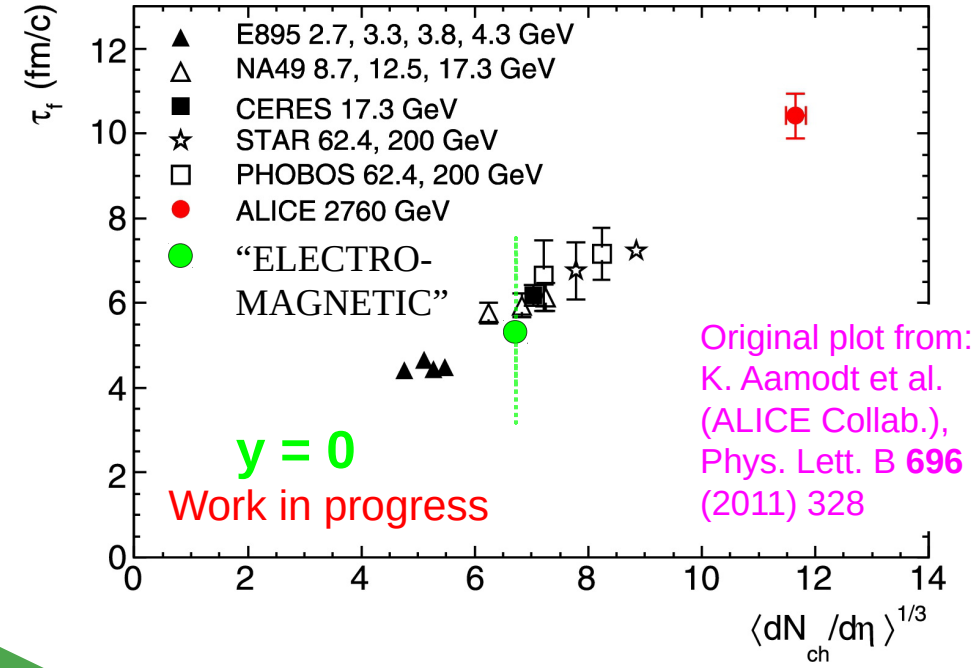
Acknowledgments.

This work was supported by the National Science Centre, Poland (grant no. 2014/14/E/ST2/00018).

Extra Slides.



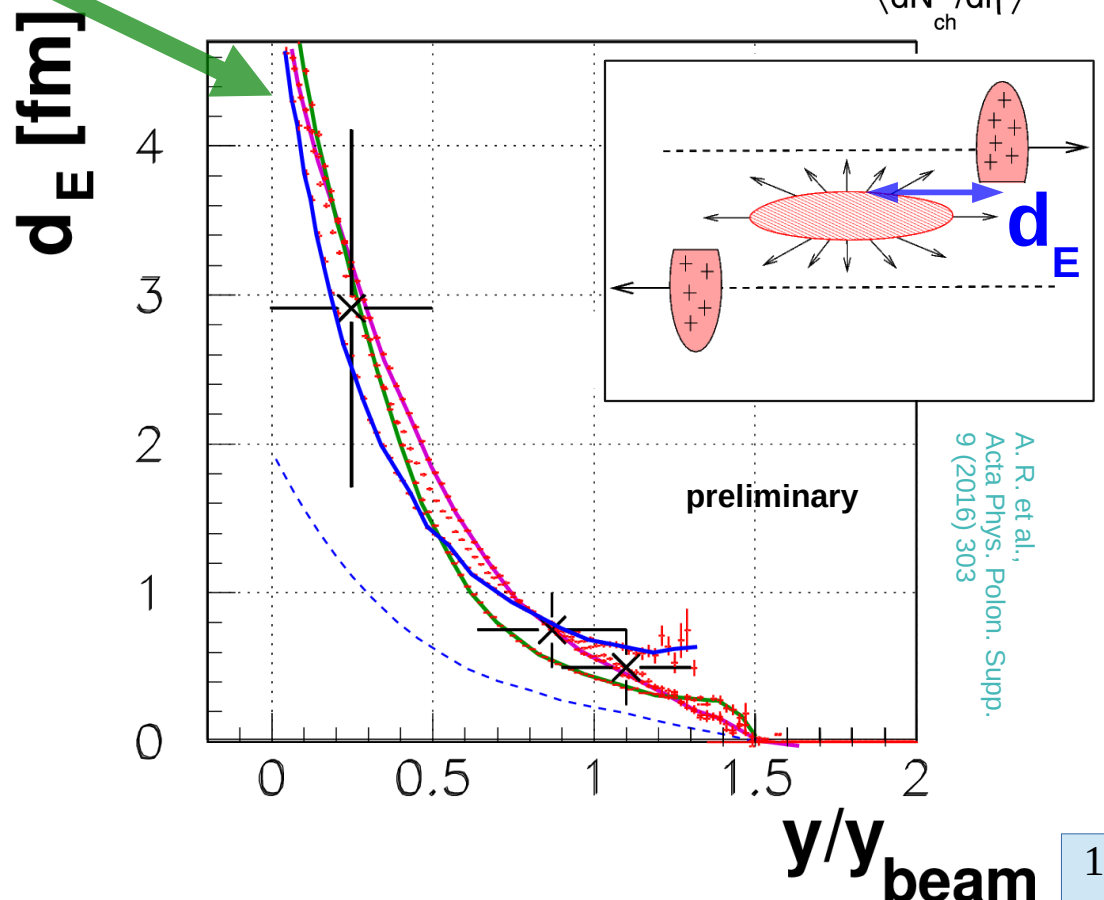
A. R., Acta Phys. Polon. **B42** (2011) 867



Original plot from: K. Aamodt et al. (ALICE Collab.), Phys. Lett. B **696** (2011) 328

Space-time evolution of the system

- The EM distortion brings information on the particle's emission distance from the spectator system, $\mathbf{d_E}$;
- Space-time evolution of the system can be unfolded by simulations.



A. R. et al., Acta Phys. Polon. Supp. 9 (2016) 303