# Electromagnetic splitting of directed flow in heavy ion collisions

Andrzej Rybicki
H. Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

1) Motivation
2) Methodology
3) Splitting of directed flow
   - predictions for $\pi^+$ and $\pi^-$
   - comparisons to existing data
4) Conclusions

work in collaboration with
**Antoni Szczurek**

# 1)
# Motivation

- Non-central collisions lead to:
  1) azimuthal anisotropies;
  2) presence of spectators.

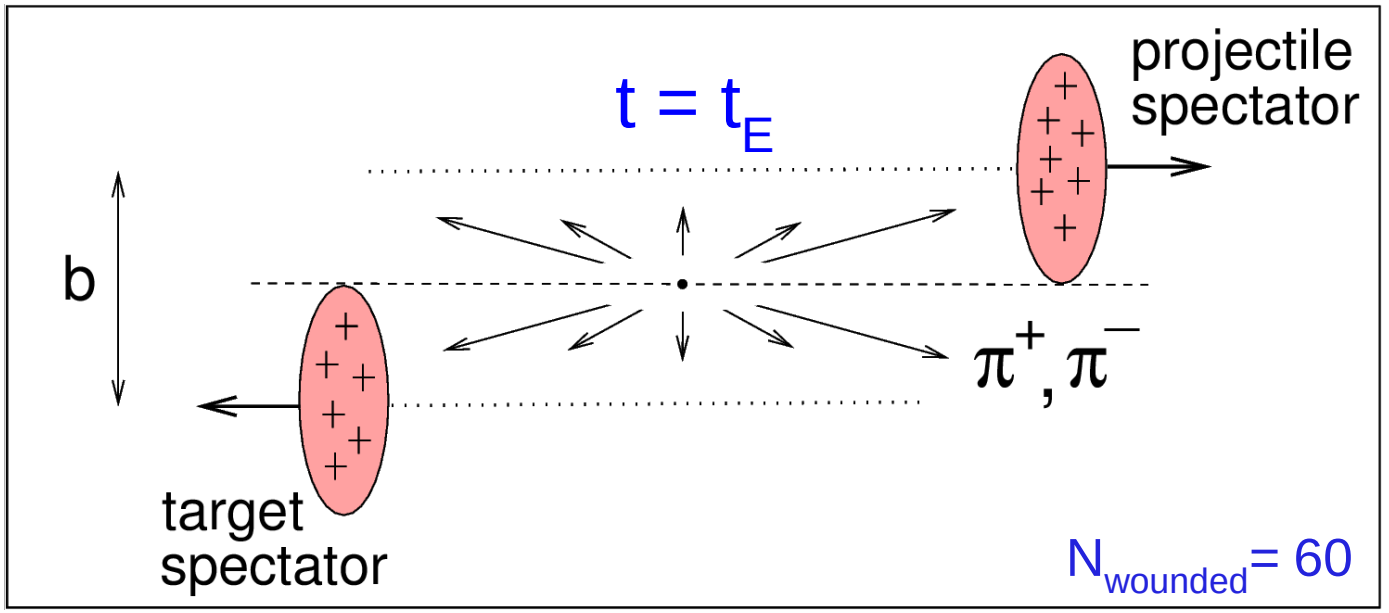
- The presence of charged, rapidly moving spectators generates strong electromagnetic fields.

- The electromagnetic effects modify single particle spectra.
  A.R., A. Szczurek, Phys. Rev. **C75** (2007) 054903,
  A.R., Acta Phys. Polon. **B42** (2011) 867

- Do the electromagnetic effects influence the azimuthal correlations? ( YES )

- Can we gain new information on the dynamical evolution of the participant system? ( YES )

# *2) Methodology*




Pb+Pb peripheral,

$\sqrt{s_{NN}}$=17.3 GeV

See also:
A. R. and A. Szczurek, Phys. Rev. **C87** (2013) 054909.

- the collision takes place at a given impact parameter b.
- the spectator systems = uniform spheres (in their rest frames).
- the pion emission - single point in space. The emission time $t_E$ is a free parameter.
- the initial distribution of the emitted pions is assumed similar to N+N collisions (scaled). Full azimuthal symmetry is assumed.
- charged pions are traced in the spectator EM field.

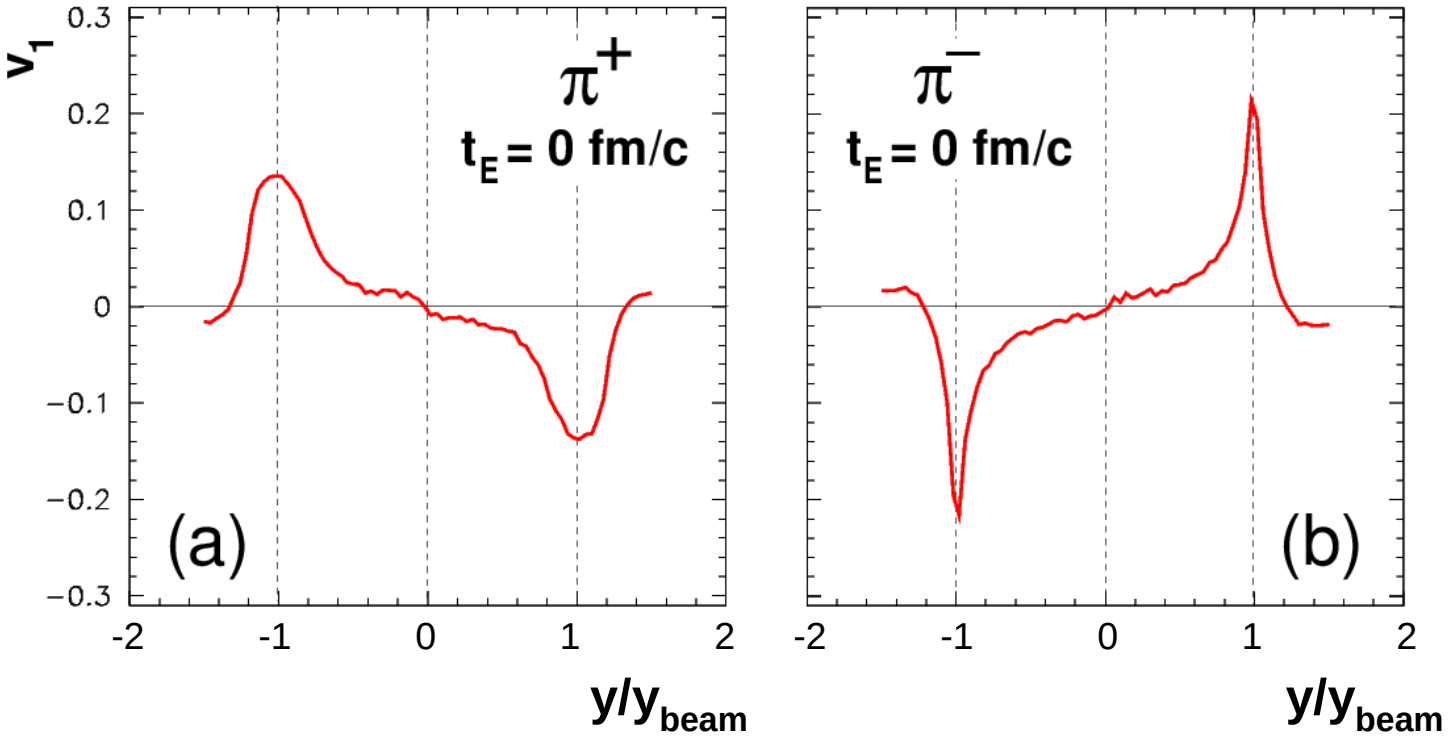
# *3)*
# *Results*

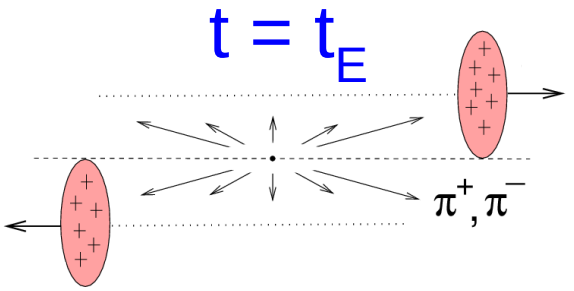
- Directed flow: $v_1 \equiv \langle \cos( \phi - \Psi_r ) \rangle$
- Reflects sidewards collective motion.
- Pure electromagnetic effect below.

Pb+Pb peripheral,

$\sqrt{s_{NN}}$=17.3 GeV

$0 < p_T < 1$ GeV/c



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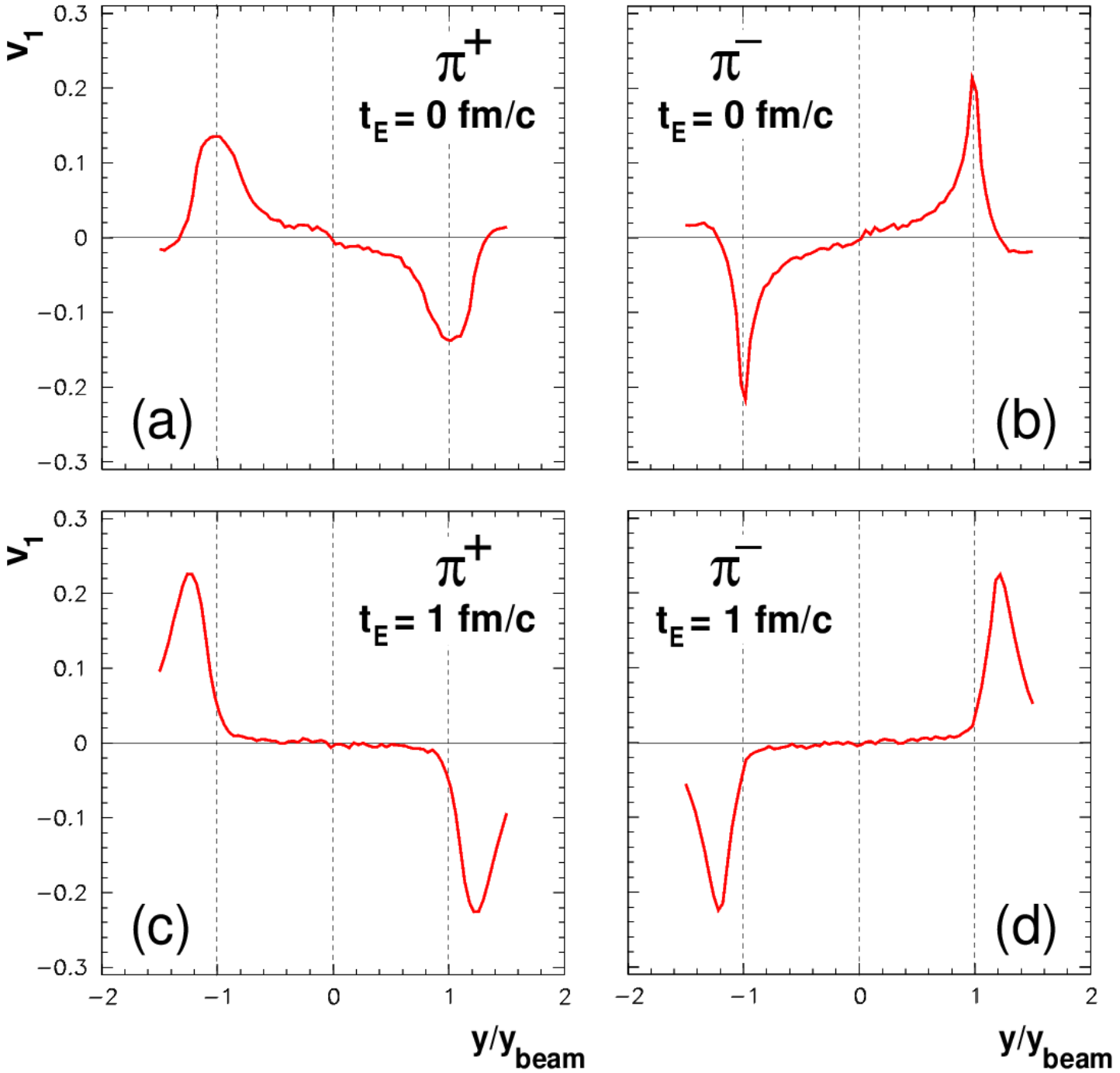
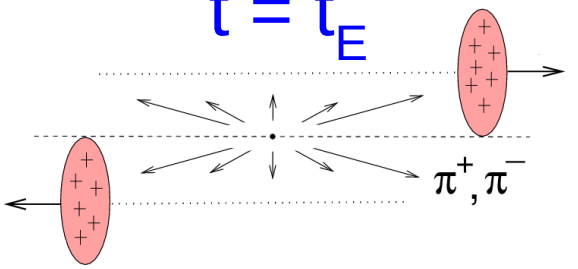
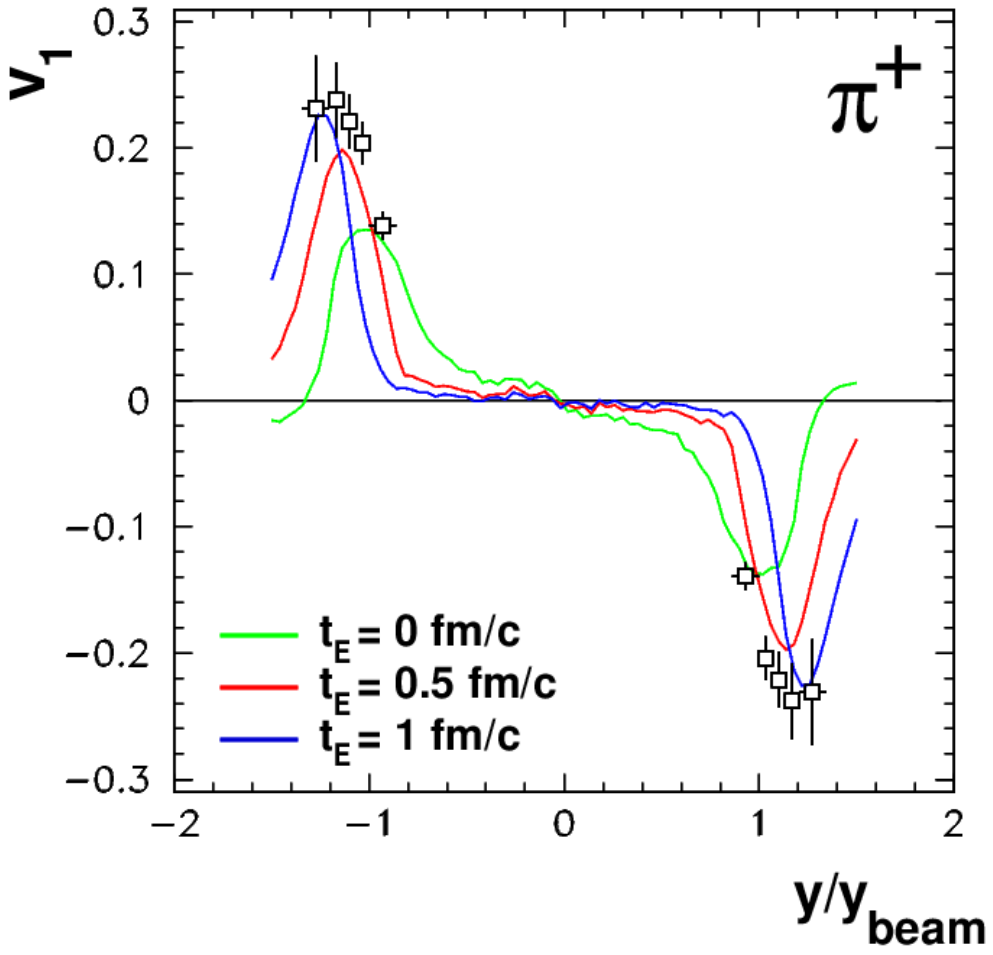


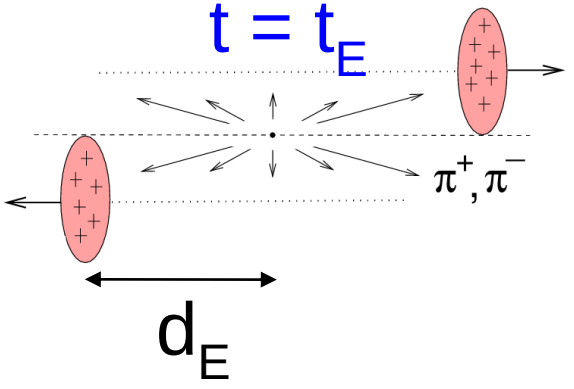




Dependence on initial conditions.

# Comparison to WA98 data

Pb+Pb peripheral,
$\sqrt{s_{NN}}$ = 17.3 GeV




Note in our model:

$d_E = ( \beta_{spect} t_E ) \approx t_E$

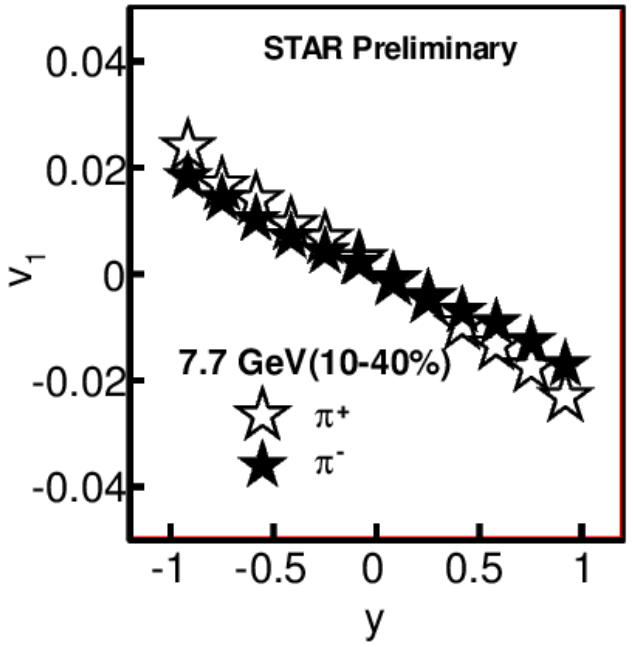
$d_E < 1$ fm

data points from:
H. Schlagheck (WA98 Collaboration),
Nucl. Phys. A **663**, 725 (2000).

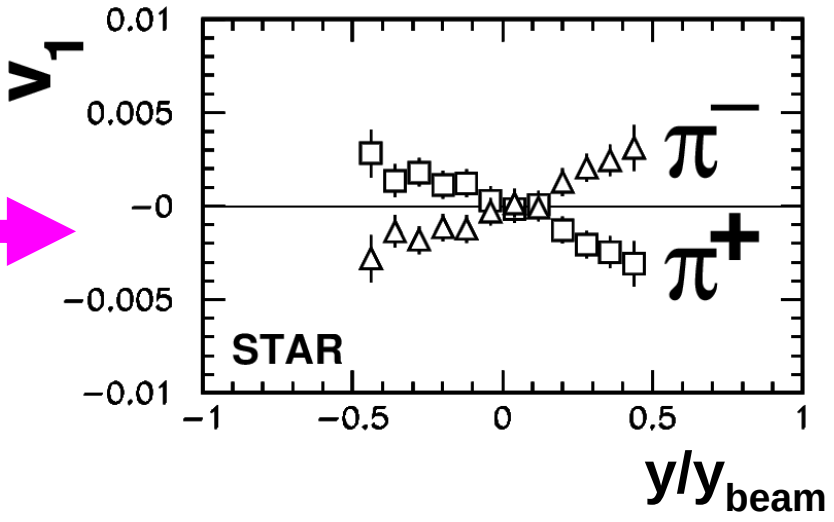
# *Results:*
# *Part II - Beam Energy Scan at RHIC*

See also: A. Szczurek, A.R.,
*Proc. EPS Conf., 2013*, arXiv:1310.4076.

Y. Pandit (STAR Collaboration),
Acta Phys.Pol. Suppl 5, 439 (2012)



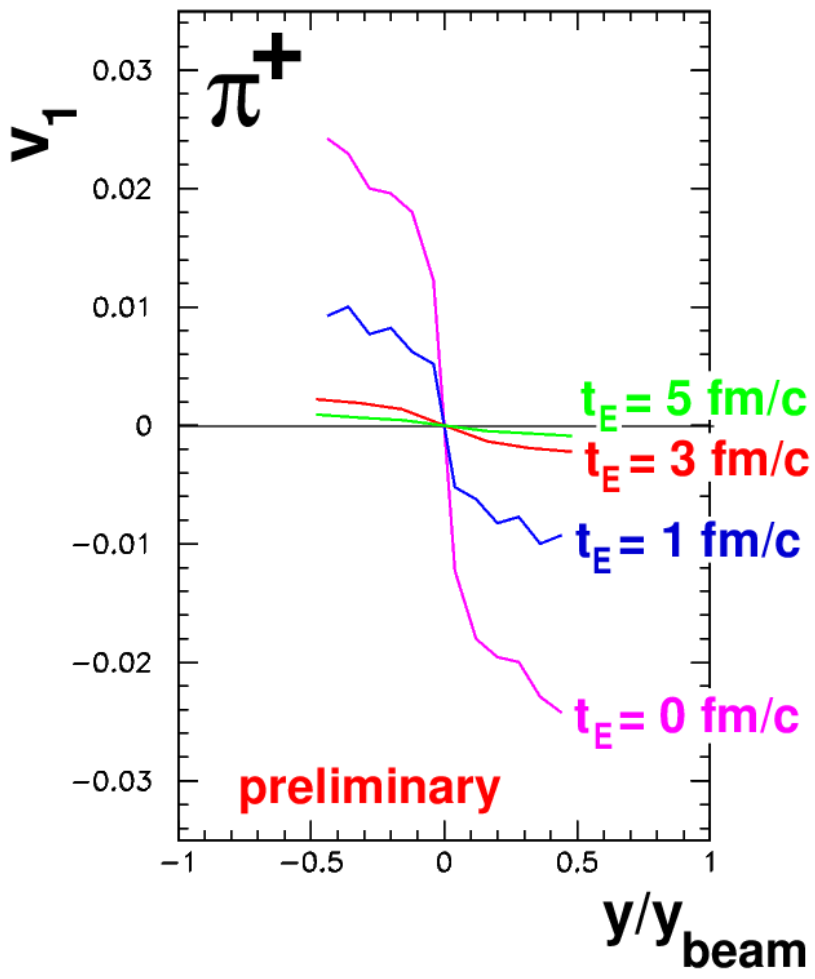

- positive and negative pions
- Au+Au, $\sqrt{s_{NN}}$ = 7.7, 11.5, 39 GeV
- centrality: 10% - 40%
- $0.2 < p_T < 1.6$ GeV/c

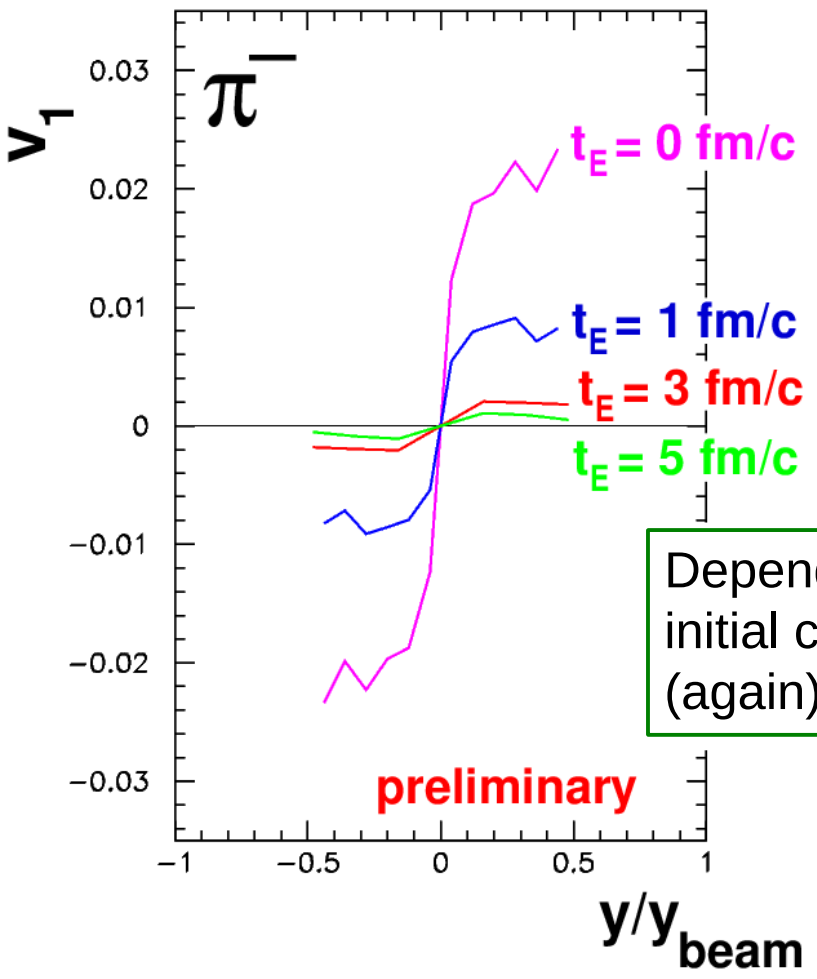



We assume:
- $v_1^{\pi^+} \approx v_1^{flow} + v_1^{\pi^+,EM}$
- $v_1^{\pi^-} \approx v_1^{flow} + v_1^{\pi^-,EM}$

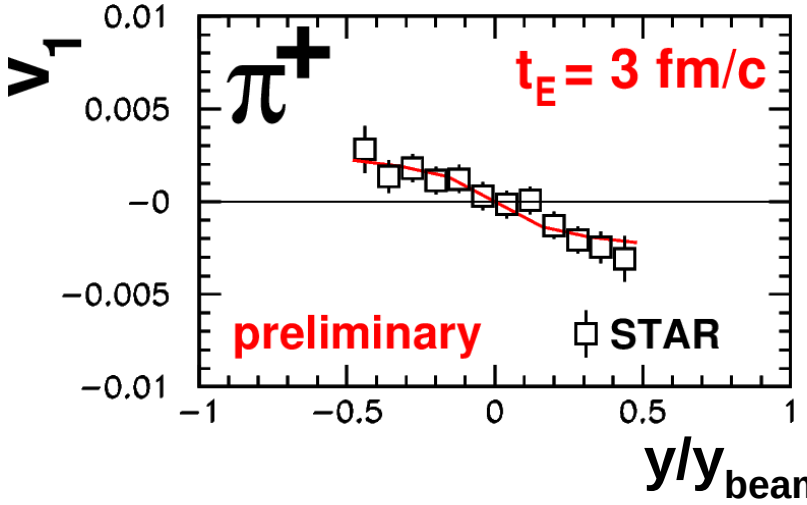
We know:
- $v_1^{\pi^+,EM} \approx -v_1^{\pi^-,EM}$

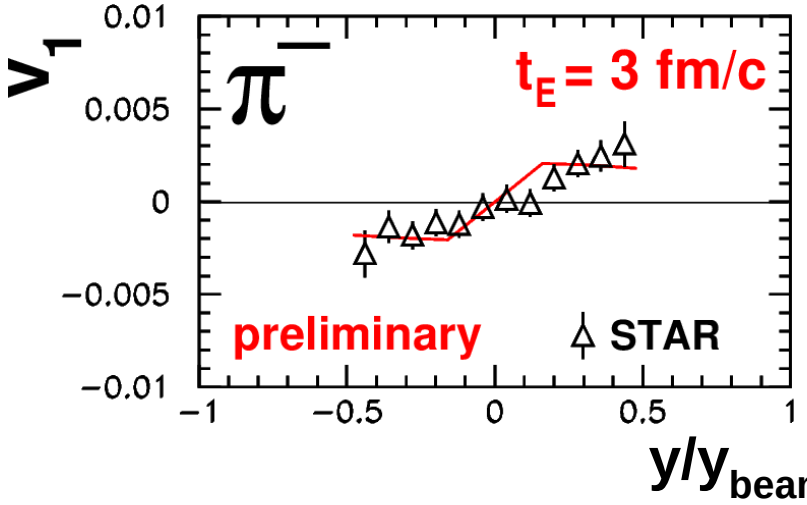
This gives:
- $v_1^{\pi^+,EM} \approx (v_1^{\pi^+} - v_1^{\pi^-})/2$
- $v_1^{\pi^-,EM} \approx -(v_1^{\pi^+} - v_1^{\pi^-})/2$




Dependence on initial conditions (again).

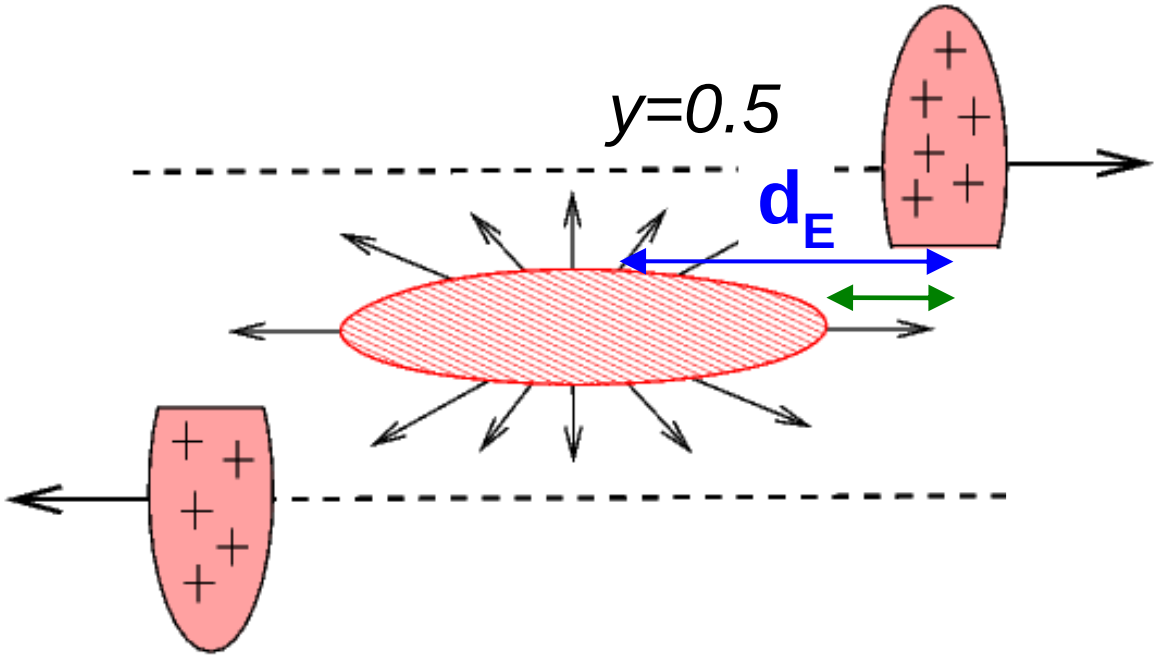


# Where are we?

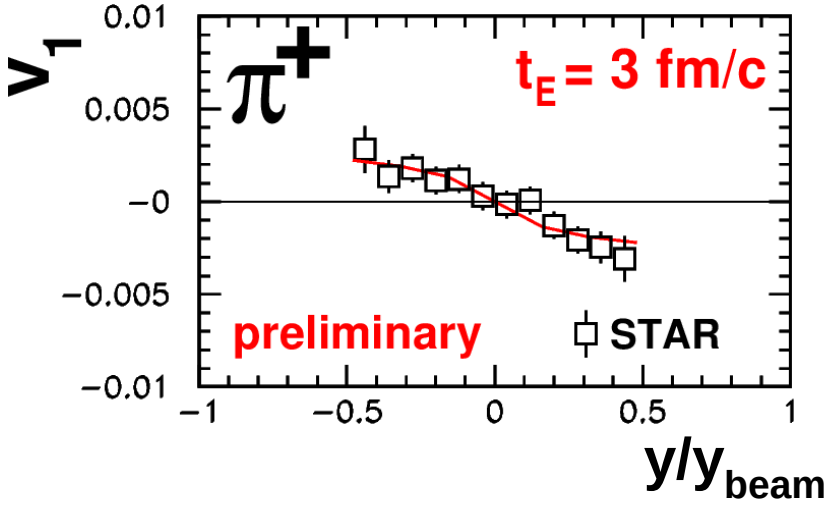
In our model:

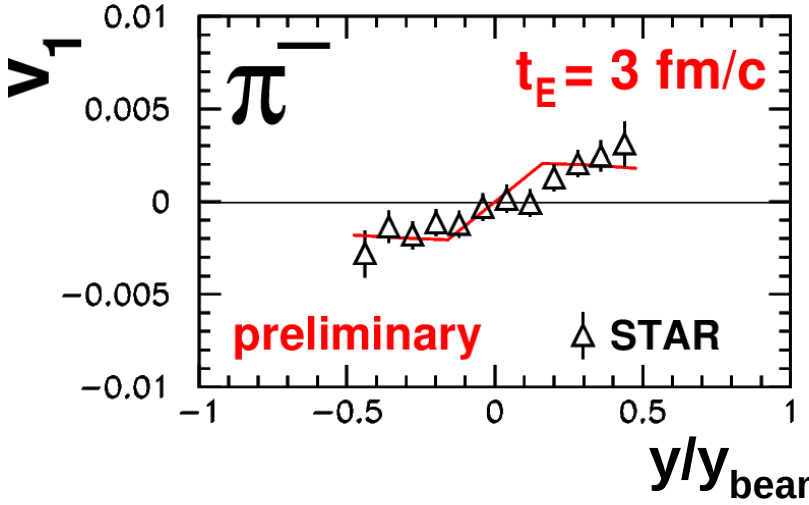
$d_E \approx t_E$




**$d_E \approx 3$ fm**

**$d_E < 1$ fm (WA98)**



# 4) Conclusions

- Electromagnetic fields generated by charged, rapidly moving spectators lead to azimuthal distortions which can modify directed flow.

- The effect on positive and negative pions is opposite and leads to a splitting of $v_1$. This splitting is superimposed on other effects (like hydrodynamics).

- This effect seems to be confirmed by STAR data.

- The electromagnetic splitting strongly depends on the emission time of pions and can therefore be used to extract information on the space-time evolution of the system.

*Thank you!*

# Acknowledgments.

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