# Rapidity dependent particle production at FAIR energies

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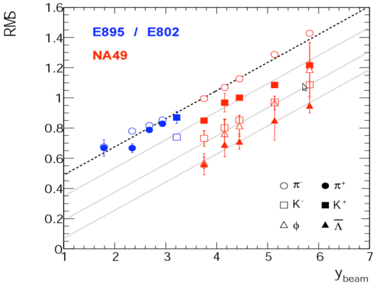
# Introduction

- Rapidity and pseudo-rapidity distributions are quite informative of particle production mechanism.
- Net-baryon density and beam energy plays a vital role in the production and distribution of baryons in the phase space.
- Thus, the net-baryon density is expected to influence the width of the rapidity distribution of baryons.
- The state of art large acceptance detectors of CBM experiment will give it access to almost the entire forward rapidity hemisphere. Thus evolution of width of the rapidity distribution with beam energy and centrality will be experimentally addressed.

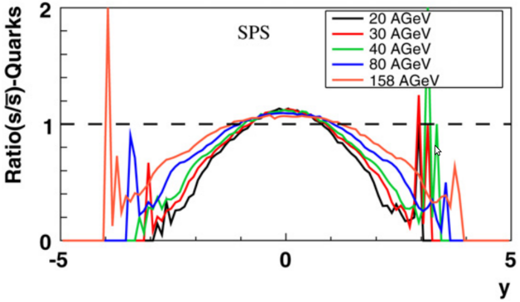
- There exist experimental results on the evolution of width of rapidity distribution on beam rapidity for a number of hadrons (including $\bar{\Lambda}$) [Friese et al. Pos(CPOD 2009)005.]

  But, no result has been reported inclusive of $\Lambda$ baryon whose mass is in close proximity with $\phi$ meson.

  One has to remember that-
  $\Lambda(uds)$ : created from leading baryons.
  $\bar{\Lambda}(\bar{u}\bar{d}\bar{s})$ : created from newly produced quarks.



- Further, strangeness enhancement is considered to be one of the traditional signatures of QGP [Rafelski, Muller Phys. Rev. Lett. 48 (1982) 1066].
- Any study on strangeness considered local as well as global strangeness conservation. But strangeness may not conserved locally [Steinheimer et al. Phys. Lett. B 676 (2009)].



- Differential strangeness enhancement results are not available from any experiment yet.

  Thus, it would be desirable to cross-check these findings using UrQMD with experimental results, which will be possible when CBM Experiment comes into operation.

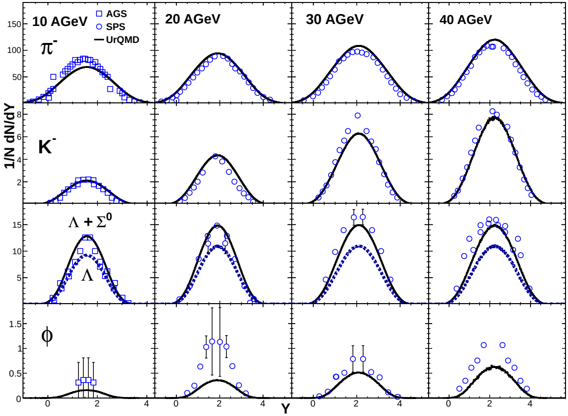
# Results

Events are generated using UrQMD-3.3p1 for Au+Au collision @ FAIR energies.

**Event statistics :**

| Energy (AGeV) | Events (Million) | $\pi^-$ $\times 10^8$ | $K^-$ $\times 10^7$ | $\Lambda$ $\times 10^7$ | $\phi$ $\times 10^5$ | $\Xi^-$ $\times 10^5$ | $\Omega^-$ $\times 10^4$ |
|---|---|---|---|---|---|---|---|
| 10 | 4.6 | 7.37 | 1.74 | 6.70 | 9.76 | 7.68 | 2.73 |
| 20 | 3.1 | 7.66 | 2.72 | 6.40 | 17.81 | 11.80 | 6.30 |
| 30 | 4.9 | 14.28 | 6.55 | 15.15 | 42.36 | 24.20 | 20.07 |
| 40 | 1.1 | 3.47 | 1.82 | 3.51 | 11.02 | 6.31 | 6.12 |

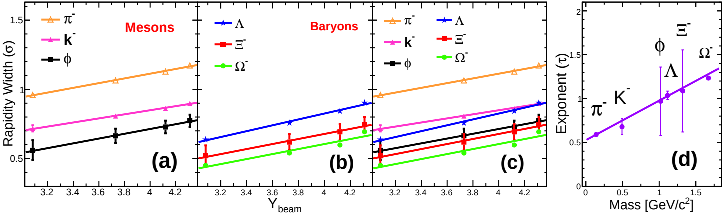
# Rapidity spectra at FAIR energies



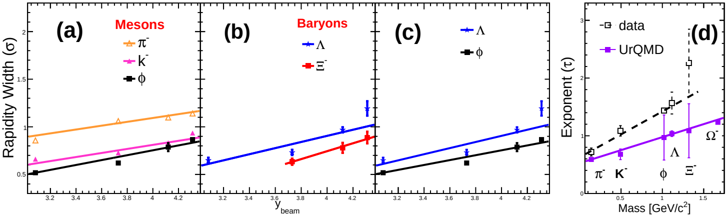

- For lighter particles like pion and kaons UrQMD explains the data fairly well.
- While for heavier mesons like $\phi$ as the energy increases there is a considerable disagreement between the UrQMD and eperimental data.

# Rapidity width as a function of beam rapidity

## UrQMD



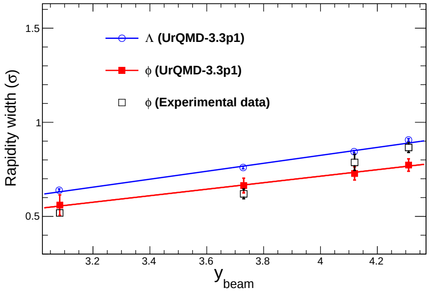

## Experimental data



# Observation

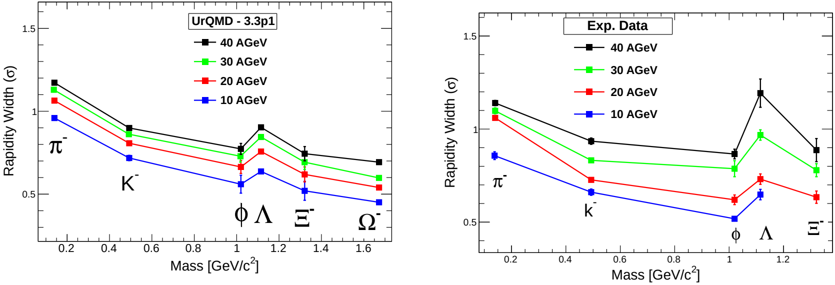
- Scaling behaviour of the type $\sigma \propto y_b^{\tau}$ is observed for both UrQMD and experimental data.
- NA49 have reported similar results [Pos(CPOD 2009)005.]
- Mass dependent nature of the exponent.
- Mass ordering is violated if studied hadrons are taken together - contradicts NA49 findings. NA49 results is with lambda bar.
- Mesons and baryons separately follow mass ordering.

# Is underestimation of $\phi$ in UrQMD affecting the mass ordering ?




The mass ordering is found to be unaffected.

# A better picture of mass ordering violation




Here again the same picture is repeated

The observed violation of mass ordering can be understood from the point of view that baryon production is sensitive to the net baryon density, while mesons are not or only slightly.

1. The rapidity distribution of a particle, whose production is sensitive to net-baryon density, will tend to follow the distribution of the net-baryon density.
2. Net-baryon number is connected to the production of light quarks (up and down).
3. Since the $\Lambda$ contains two light quarks, it can be expected to couple stronger to the net-baryon number than the $\Xi^-$, which has only one light valence quark, or the $\Omega^-$, which has none.

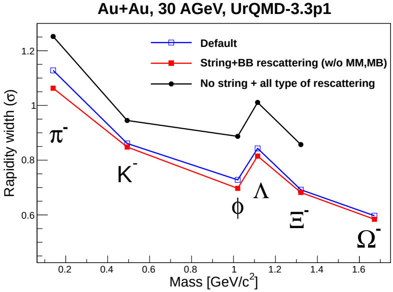
- The coupling to net-baryon density influences the kinematical behavior (mass dependence).

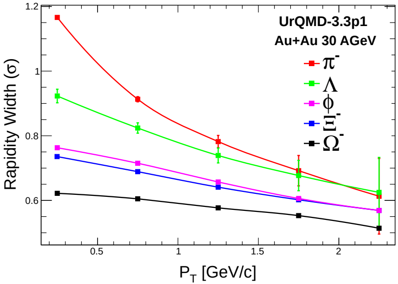
  i.e baryon width $\rightarrow$ kinematics + net-baryon density
  
  meson width $\rightarrow$ only kinematics.

- That's the reason for species dependent mass ordering.

To trace the origin of the mass ordering effect, we considered the following three scenarios using UrQMD-3.3p1

1. String + BB rescattering (w/o MM, MB scattering)
2. All type of rescattering excluding String excitation and fragmentation
3. Default UrQMD



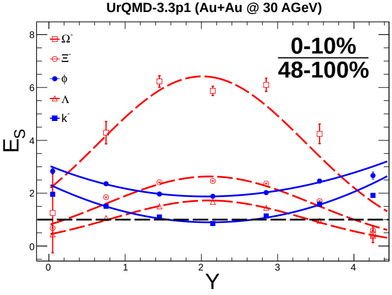

1. The width of the rapidity distribution of each species is increased due to multiple MM and MB scattering. This is also evident from the rapidity width vs $P_T$ plot.
2. A similar kind of mass ordering behavior could be observed for all the three scenarios considered.

# Rapidity dependence of strangeness enhancement

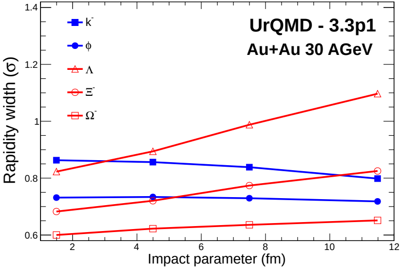
$$E_S = \left[\frac{(Yield)_{AA}}{< N_{\pi^-} >}\right]_{central} / \left[\frac{(Yield)_{AA}}{< N_{\pi^-} >}\right]_{peripheral}$$

S. Soff et al. Phys. Lett. B 471 (1999)

- $E_S > 1$ at almost all rapidities.
- $E_S$ is strongly dependent on rapidity.
- For baryons, enhancement factor is seen to be maximum at mid-rapidity.
- For mesons, the same is found to be maximum at beam and target rapidity.
- Moreover, in a hadronic model like UrQMD, the enhancement is due to hadronic rescattering.



# Rapidity width as a function of centrality




- For the studied baryons, the rapidity width decreases for central collisions as a result of nuclear stopping.
- At FAIR energies, due to baryon stopping the $\mu_B$ is expected to be high at mid-rapidity and depending on $\mu_B$ there is a preference for baryon production over meson production, resulting in more strange baryons at mid-rapidity.
- At forward rapidity the strangeness ends up in more production of mesons like kaons and $\phi$.

# Summary

- For both UrQMD and experimental data,
  - The mass ordering is observed to be violated if the studied hadrons are taken together.
  - However, the width of the rapidity distribution follows mass ordering separately for the studied mesons and baryons.
- For strange baryons the enhancement is found to be maximum at mid rapidity while for strange mesons maximum enhancement is found to be at beam and target rapidities.
- Thus, the variation $E_S$ as a function of rapidity for the studied mesons and baryons are found to be completely different.
- Studied observables are quark content dependent.

# Future plan

- Realistic analysis using CBM detector acceptance cut and identify particle by invariant mass analysis.
- At other energies where the net-baryon density distribution is expected to be different.
- Remaining mesons and baryons will also taken into consideration.
- UrQMD+hydro.

# Acknowledgments

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# THANK YOU