Performance studies of femtoscopy at CBM

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Abstract

The study of nucleon-nucleon (N-N), nucleon-hyperon (N-Y), and hyperon-hyperon (Y-Y) interactions are fundamental to understanding the physics of relativistic heavy-ion collisions, neutron stars and the existence of various exotic hadrons. Geometry and dynamics of a particle-emitting source in heavy-ion collisions can be inferred via a femtoscopy method. Two-particle correlations at small relative momentum exploit Quantum Statistics (QS) and the Final State Interactions (FSI), which allow one to study the space-time characteristics of the source of the order of 10^{-15} m and 10^{-23} s. Femtoscopy also enables the investigation of FSI between hadrons, as searches for possible bound states in neutron stars. The CBM experiment will cover a significant part of the QCD Phase Diagram using collisions of heavy nuclei for several beam energies, which baryon-rich region will be studied via femtoscopy. Baryon measurements together with meson ones provide complementary information about source characteristics. In this poster, performance studies of femtoscopic measurements of various particle combinations at different collision energies and centralities will be shown.

Femtoscopy - technique to determine the size of the source emitting correlated particles . Konin-Prat equation [1,2] :

$$C(q) = \int \rho(r)|\psi(q,r)|^2 dr$$

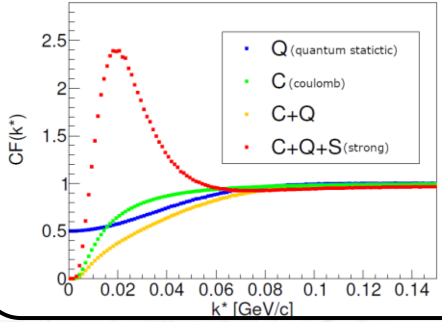
$\rho(r)$ - spatio-temporal structure of the source

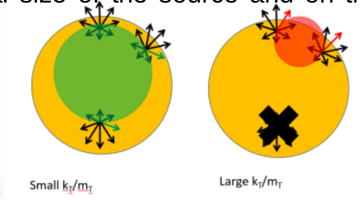
$|\psi|(q,r)|^2$ - correlations between particles: quantum statistic (for pairs of identical particles) and interactions (Coulomb and strong)

$C(q) = \frac{N(q)}{D(q)}$ - correlation function [3]

q - momentum difference
N(q) - distribution of correlated pairs
D(q) - distribution of uncorrelated pairs

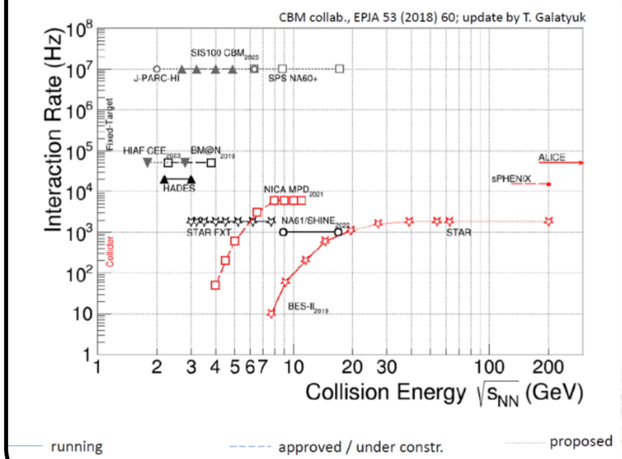
Femtoscopy is sensitive to the dynamics of the collision. The range of the correlations depends on the geometrical size of the source and on the dynamics of collision.





Interactions between particles
CBM will operate at energies where there is a transition from meson- to baryon-dominated matter

CBM (Compressed Baryonic Matter) is a future experiment at FAIR (Facility for Antiproton and Ion Research).
CBM will be fixed-target experiment, there will be no fixed geometry. There different detectors will be used to optimize the measurements of hadrons, electrons and muons. One of the main advantages of the CBM is extremely high interaction rate [3]



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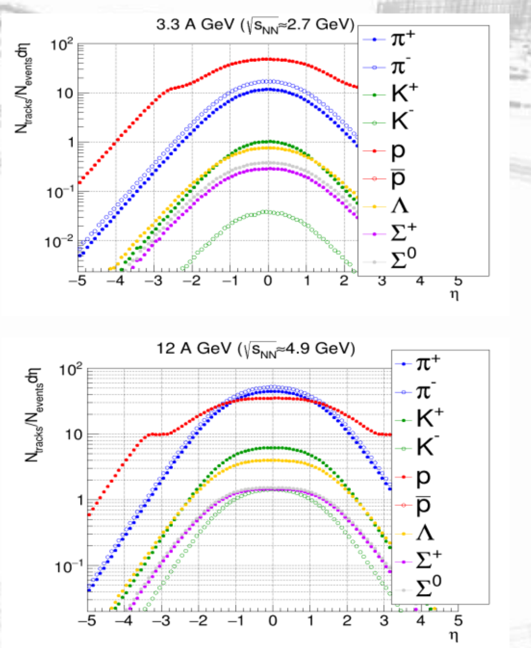
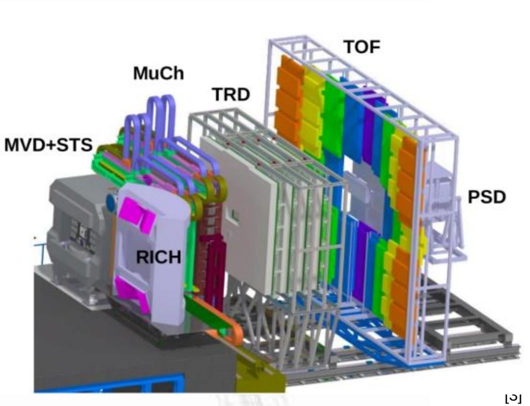
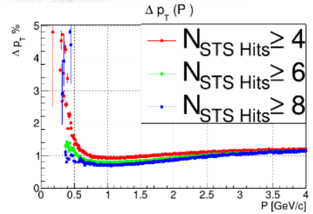


UrQMD 3.4

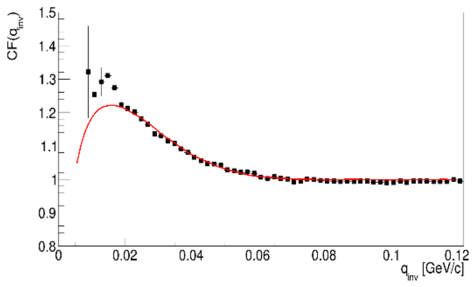
CBM detector [4]

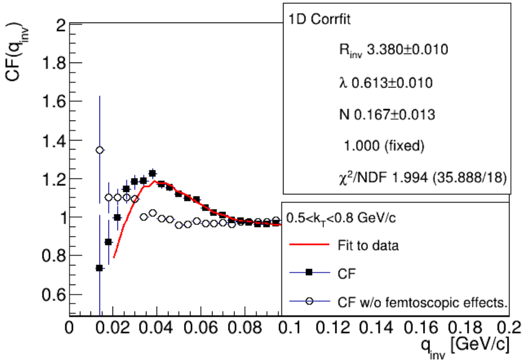


CBM will be able to precisely measure the momentum

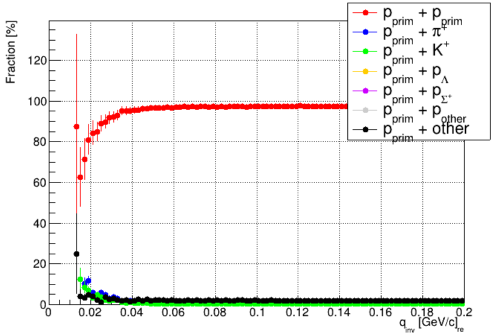


Pion-pion (left) and proton-proton (right) correlation function [5,6]





Pair's fractions



The composition of proton-proton correlation function after applying experimental cuts. Simulation done with UrQMD model.
Criteria of data selection:

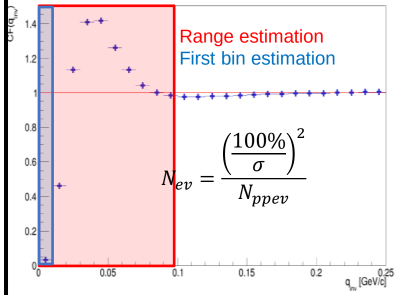
- DCA for rejecting secondary tracks
- ToF m2 for PID
- Number of STS hits for quality of tracks
- Two-particle cuts based on shape of the particle trajectories.

Track/pair selection criteria

	Proton-proton		Pion-pion	
	min	max	min	max
DCA_{xy} [cm]	0	0.5	0	0.1
p_T [GeV/c]	0.2	20	0.2	2
η	1	3.5		
NhitsSTS	5	12	6	8
charge	1	1	-1	-1
m^2_{TOF} [GeV^2/c^4]	0.75	1.15	0	0.05
STS exit sep. [cm]	1	500	0.5	500
k_T [GeV/c]	0.2	10	0.2	0.6
$\lvert\Delta X_{max}\rvert$ [cm] **$\lvert\Delta\eta^*\rvert$ [rad]**	0.05	-0.05	**0.02**	**-0.02**
$\lvert\Delta Y_{max}\rvert$ **$\lvert\Delta\varphi^*\rvert$[rad]**	0.05	-0.05	**0.05**	**-0.05**

Statistic estimation

Femtoscopic analysis requires sufficient statistic. The number of needed events can be estimated from simulations [7,8]



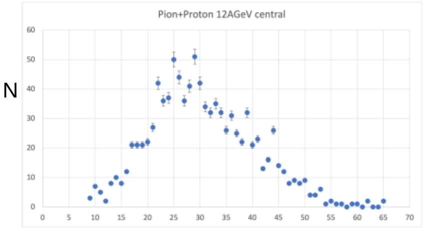
$$N_{ev} = \frac{\left(\frac{100\%}{\sigma}\right)^2}{N_{ppev}}$$

RANGE ESTIMATION

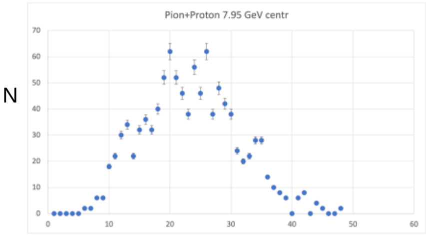
1. Estimate the range of the correlation effect (10 points)
2. Estimate the mean number of pairs per 1 bin per event (N_{ppev}):
3. Determine the number of needed events (N_{ev}) for given statistic uncertainty σ

FIRST BIN ESTIMATION:

1. Calculate the correlation function for a given number of events
2. Estimate the statistical error bar of the first bin (σ): (value of the correlation function)/(size of the error bars)* 100%
3. Properly scale the CF to get desired error
4. Estimate the number of desired events



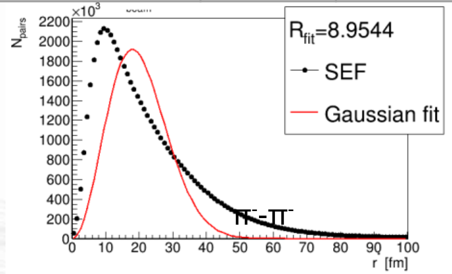
Pairs per event in first 10 bins bin of the CF

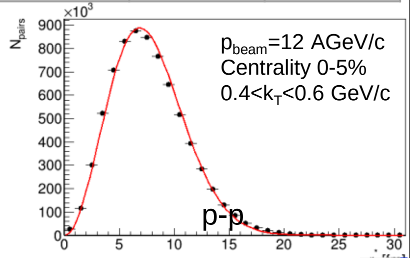


Pairs per event in first 10 bins bin of the CF

Needed statistic for central collisions (0-5%), statistic estimated by number of pairs in first bin of the CF [7,8].

Stat. uncert. (first bin of CF)	p-p	Λ-Λ	K^+-p	π^+-K^+	π^+-p
pBeam 3.3 A GeV/c					
10%	1.5 M	657 M	664 k	164 k	1.2 M
5%	6.2M	2 629 M	1.8 M	656 k	4.8 M
2% (1%)	38.6M	16. 43 G	66.4 M	16.4 M	120 M
pBeam 12 A GeV/c					
10%	3.9 M	17 M	1.2 M	920 k	2.6 M
5%	15.5 M	68 M	4.7 M	3.7 M	10.4 M
2% (1%)	96.9 M	428 M	117.6 M	92 M	260 M





Source emission function plots– direct access to the shape of the measured source from MC

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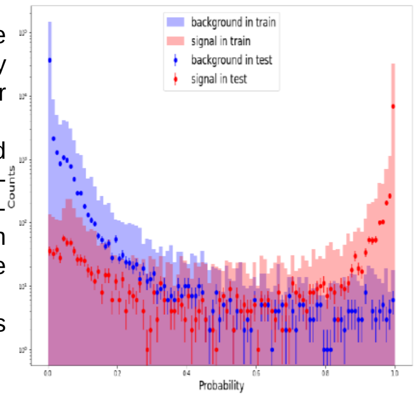
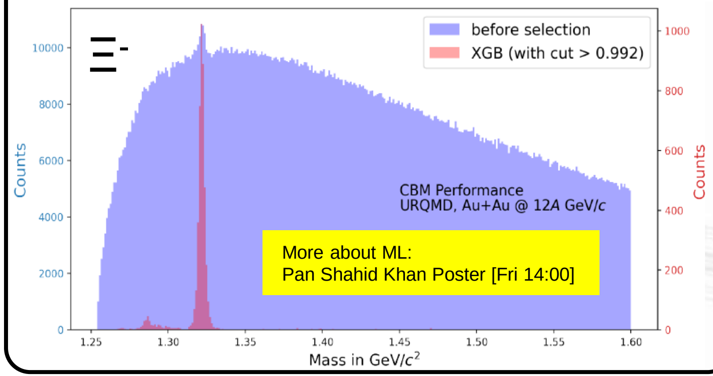
Multistrange particles

Xi particles are reconstructed by products of decay. For reconstruction KFPackage will be used (KFPackage is Kalman-filter based V0/Xi-Finder used also in other experiments like STAR, ALICE). Optimization of cuts is done by ML [9].





More about ML:
Pan Shahid Khan Poster [Fri 14:00]

Summary:

CBM will be a very good detector for measurements of proton-proton and pion-pion correlations. The influence of residual correlations on proton-proton measurements will be very small, which simplifies the measurements.

Plans:

- Feasibility studies of measurements at SIS-18 energies (Energy up to 2A GeV)
- Feasibility studies of measurements of exotic baryon correlations
- Feasibility studies of measurements the proton-proton correlations in 3D
- Development of software for 3D Femtoscopy of protons

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