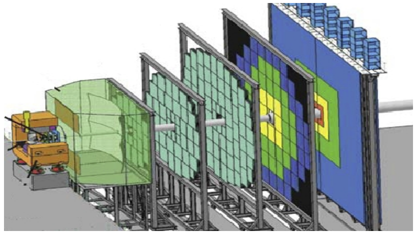
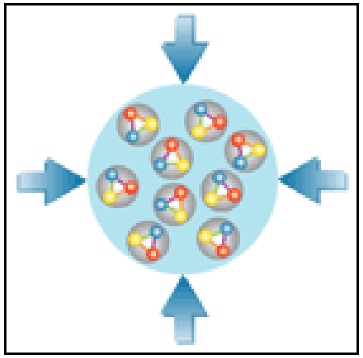




Compressed Baryonic Matter Studies at GSI Accelerator Complex

02-1-1106-2011/2022

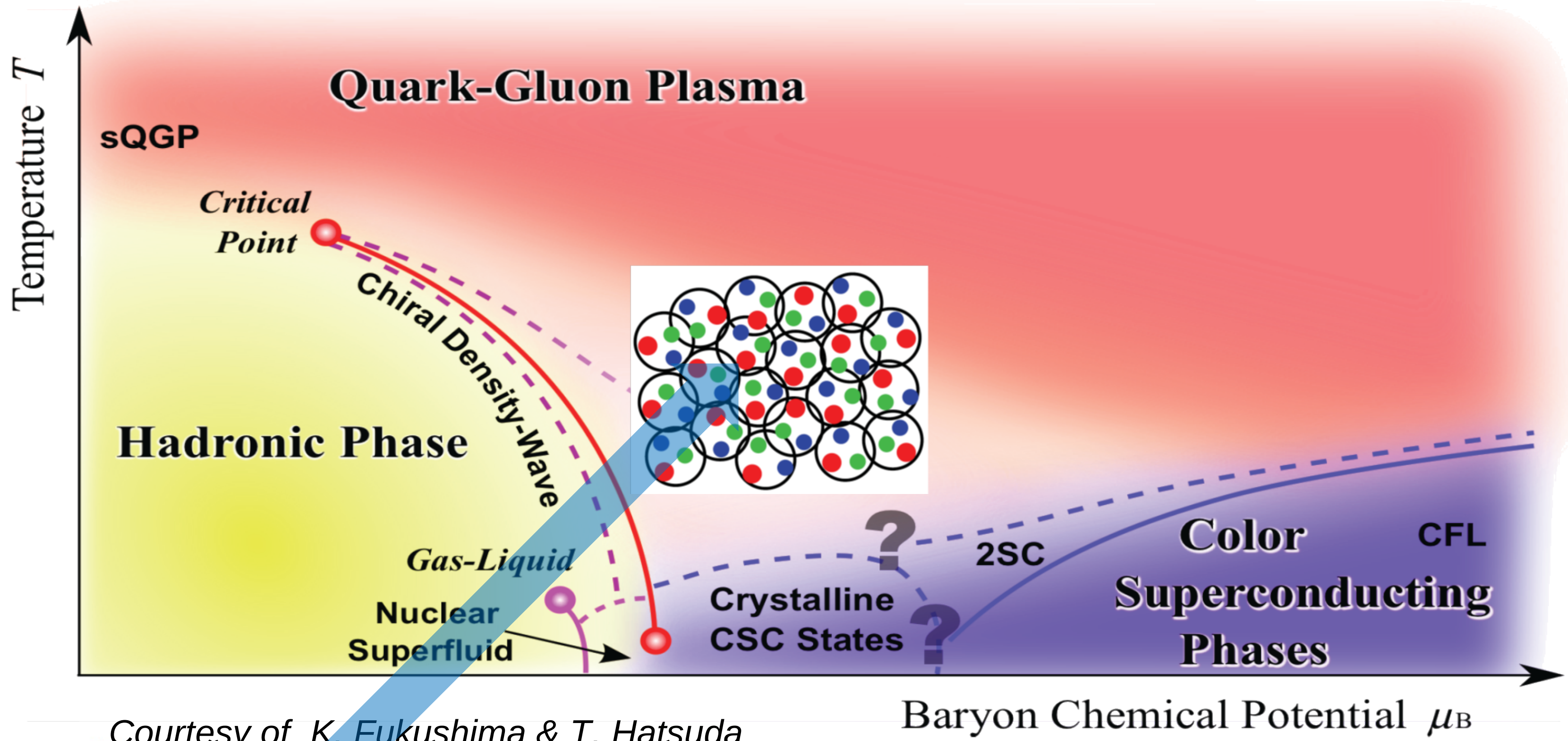
Leaders: V.V.Ivanov, V.P.Ladygin
Deputy : O.Derenovskaya

V.P.Ladygin for JINR team at CBM

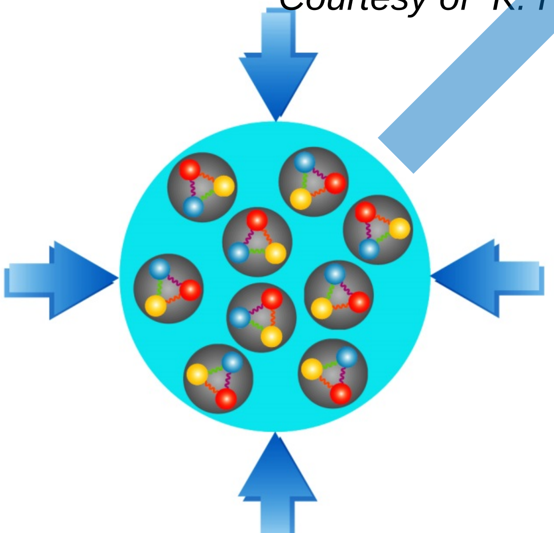
LHEP JINR

January 18, 2021

Exploring the QCD phase diagram



Courtesy of K. Fukushima & T. Hatsuda



At high baryon density:

N of particles > N of antiparticles

Densities like in neutron star cores

L-QCD not (yet) applicable

- **Models predict first order phase transition with mixed or exotic phases**
- **Experiments: BES at RHIC, NA61 at CERN SPS, CBM/HADES at FAIR, NICA at JINR**

CBM Collaboration

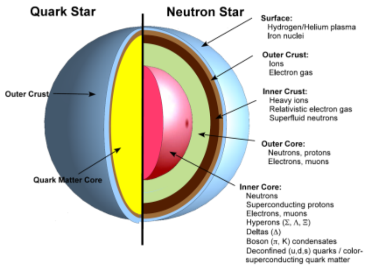
2 CM in 2020 were virtual

About 500 participants from 44+2(55) Institutes and Universities

CBM physics case and observables at SIS100

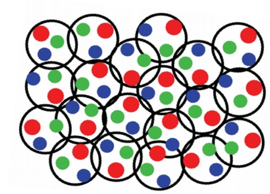
The equation-of-state at neutron star core densities

- collective flow of hadrons
- particle production at threshold energies (multi-strange hyperons)



Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$)



New /mixed phase of strongly-interacting matter

- excitation function and flow of lepton pairs
- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω)

Charm production and propagation at threshold energies

- excitation function in p+A collisions (J/ψ, ψ', D^0, $D^\pm$)
- charmonium suppression in cold nuclear matter

Strange matter

- (double-) lambda hypernuclei
- strange meta-stable objects

T.Ablyazimov et al., Eur.Phys.J. A53 (2017) 60

Experimental requirements

10^5 - 10^7 Au+Au reactions/sec

determination of displaced vertices ($\sigma \approx 50\ \mu$m)

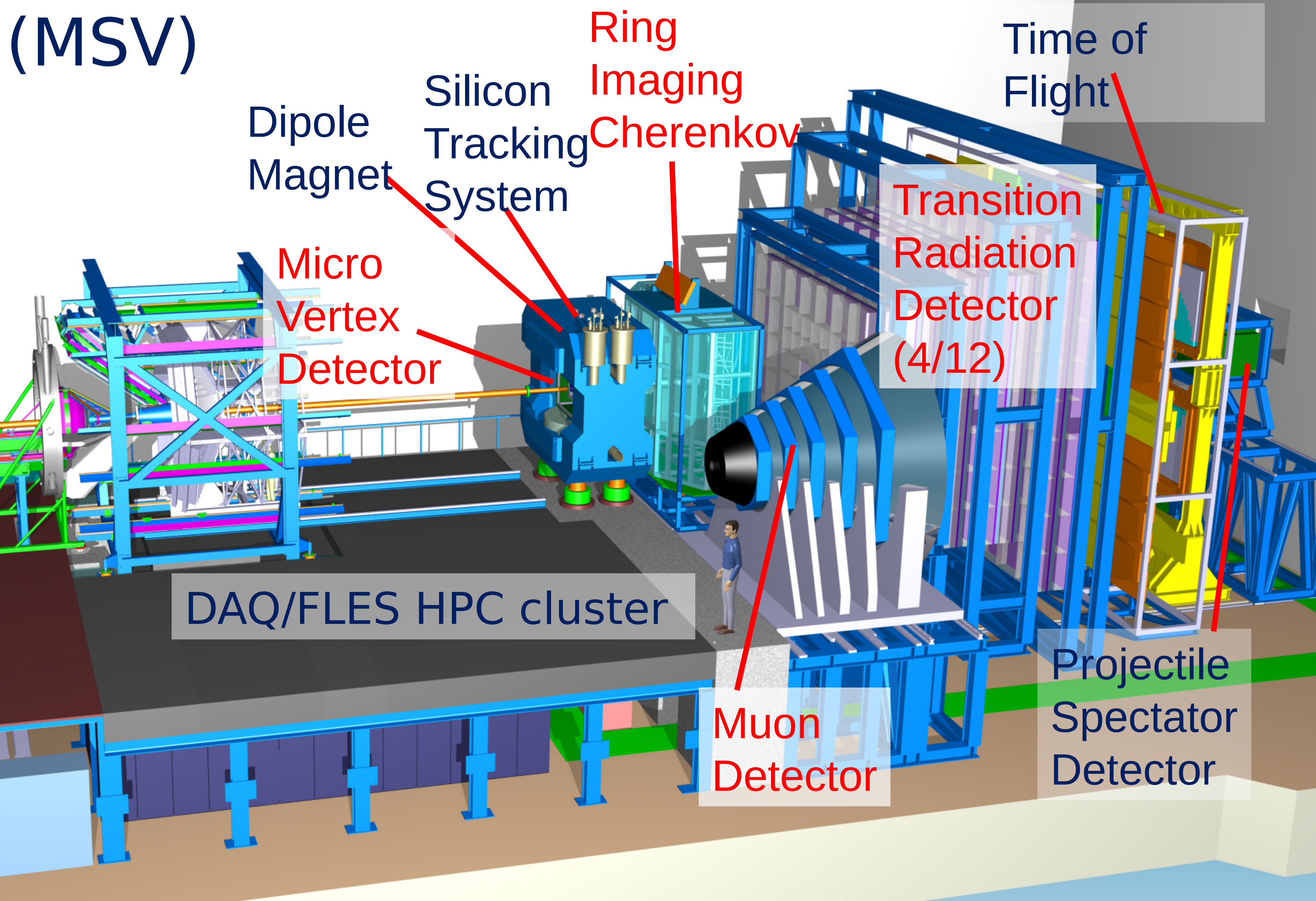
identification of leptons and hadrons

fast and radiation hard detectors

free-streaming readout electronics

high speed data acquisition and high performance computer farm for online event selection
4-D event reconstruction

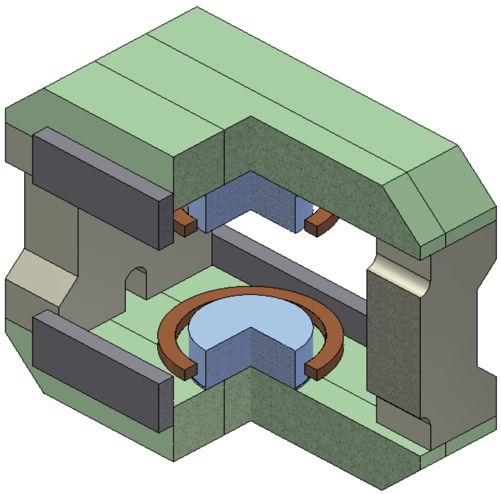
CBM detector (MSV)

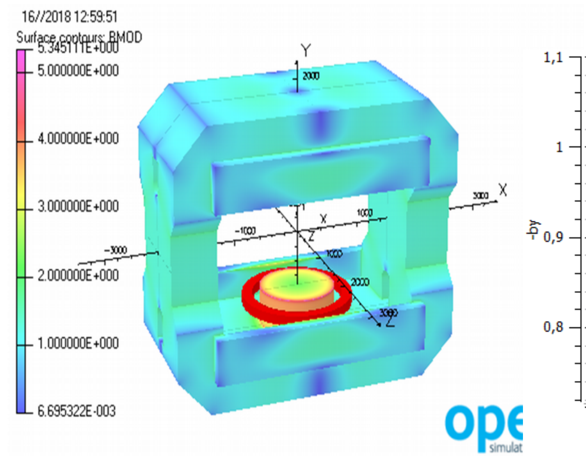


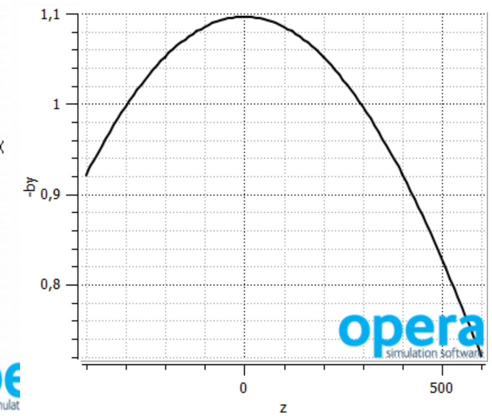
JINR participation in CBM

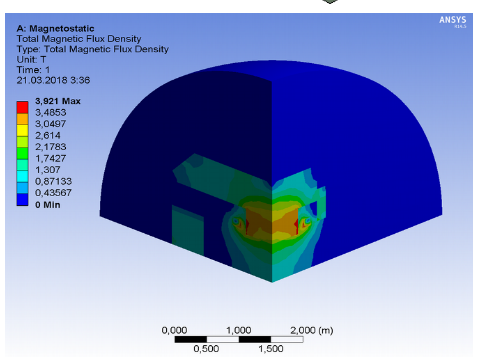
- **Expertize of the SC dipole magnet**
- **Development of methods and algorithms for global tracking (LIT)**
- **Study of multi-particle dynamics in heavy ion collisions at CBM**
- **BM@N2, mCBM (join activity FAIR/NICA)**
- **R&D of a straw tube tracker and scintillation detectors prototypes, beam tests (join activity FAIR/NICA)**

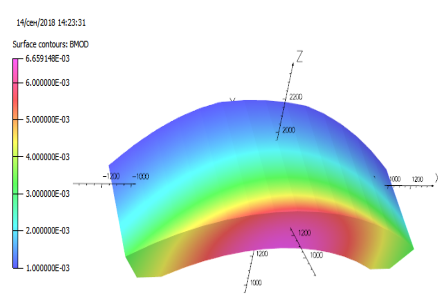
Expertize of the CBM SC Dipole Magnet











Expertize:
Electromagnetic and stress calculations for new CBM magnet

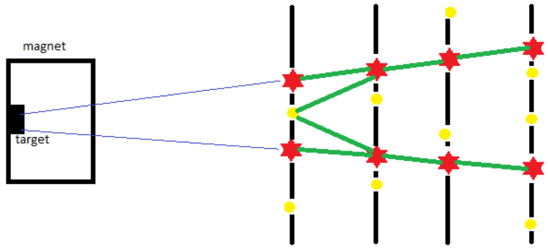
Opera

RICH photodetectors Box optimization.

Magnetic field calculations.

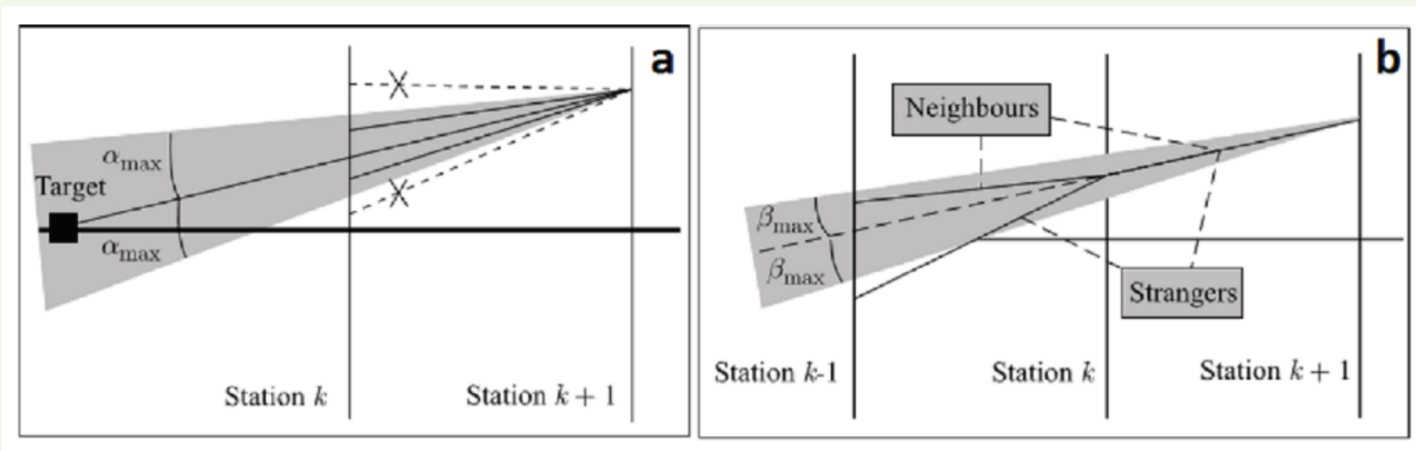
Preliminary Design Review – in 2019
Final Design Review - in 2021 (postponed)
FAT and commissioning participation

Binned track reconstruction algorithm in TRD and MUCH



Motivation: For J/ψ reconstruction in real time experiment track reconstruction algorithm independent of information from other detectors is required. Currently, the track following technique is applied to solve this task (A. Lebedev). It needs tracks, reconstructed in STS detector as seeds.

<u>Track reconstruction algorithm includes the following stages:</u>



(a) Segment set formation and (b) segments binding procedure

Comparison of the methods in TRD example

<u>1. Efficiency</u>

Following technique	Binned algorithm
97%	98%

<u>2. Runtime</u>

Following technique	Binned algorithm
5.8 ms/track 0.043 s/event	0.125 ms/track 0.925 ms/event

T.O. Ablyazimov and V.V. Ivanov

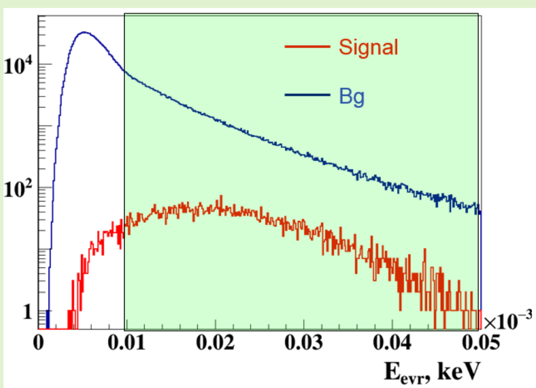
Towards to the J/ψ → e⁺e⁻ triggering with TRD

Motivation: The study of the charmonium production is one of the key objectives of the CBM experiment. To register them via the dielectron decay channel, one needs a reliable electron–positron identification in the condition of intense fluxes (up to 107 collisions per second), a high multiplicity of secondary particles (from 100 to 1000 particles per nucleus–nucleus collision) and a dominant hadronic background, primarily from pions. The TRD is the most suitable for solving the above-mentioned task.

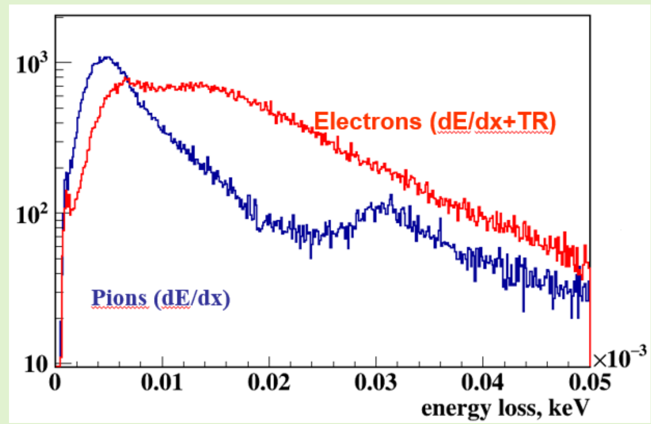
1. The track reconstruction in the TRD based on binned algorithm

2. Average energy losses (a.e.l.)

$$E_{avr} = \frac{E_1 + E_2 + E_3 + E_4}{4} > 10^{-5}$$



3. Electron identification



<u>Methods:</u>

- artificial neural network;
- w^k_n criterion
- likelihood method

Suppression factor corresponding to 10% of electron losses

ω_4^2	π+/-	All bg
	1.9	3.2
ANN	2	3.6
LFR	2.1	4.5

Common suppression factor after two cuts (a.e.l. + el.id.)

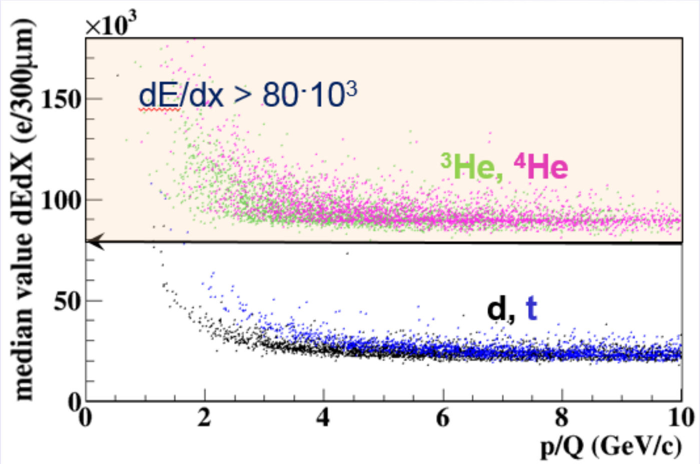
		all background
1.	a.e.l. +	8.2
2.	a.e.l. + ANN	8.7

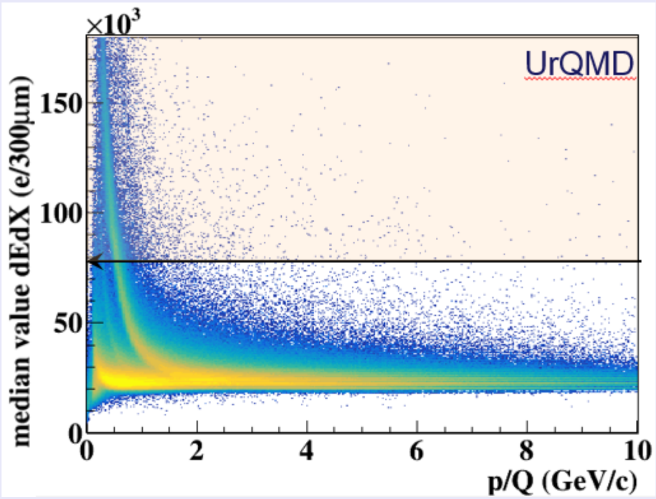
O. ... anov

Heavy fragments (^{3}He and ^{4}He) identification using energy loss method in the STS detector

Motivation: in order to accurately measure the yields of hypernuclei and their lifetime, it need to identify their decay products including ^{3}He and ^{4}He with maximum significance. The possibility of using the CBM-STS detector for particle identification in addition to the dedicated PID detectors was studied.

Median value of dE/dx

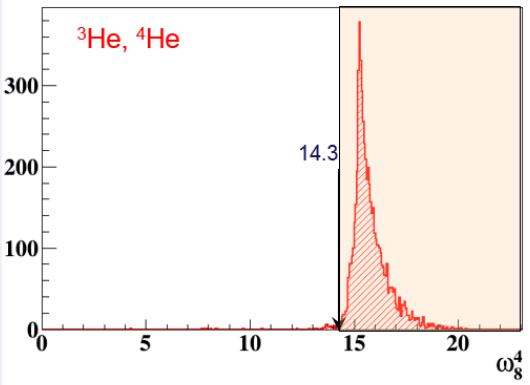




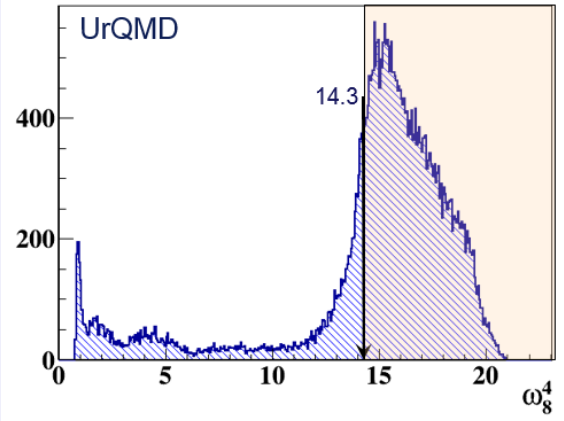
Particle identification in STS

ω_n^k criterion

$$\omega_n^k = -\frac{n^{\frac{k}{2}}}{k+1} \sum_{j=1}^{n} \left\{ \left[\frac{j-1}{n} - \phi(\lambda_j) \right]^{k+1} - \left[\frac{j}{n} - \phi(\lambda_j) \right]^{k+1} \right\},$$

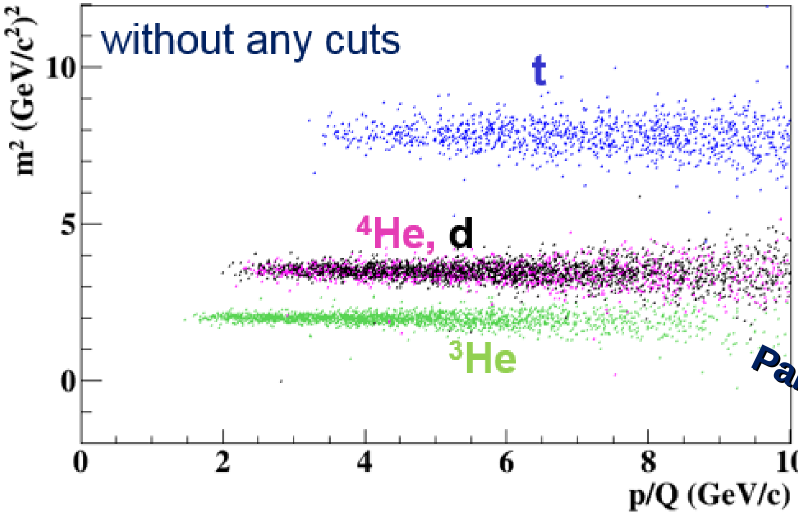


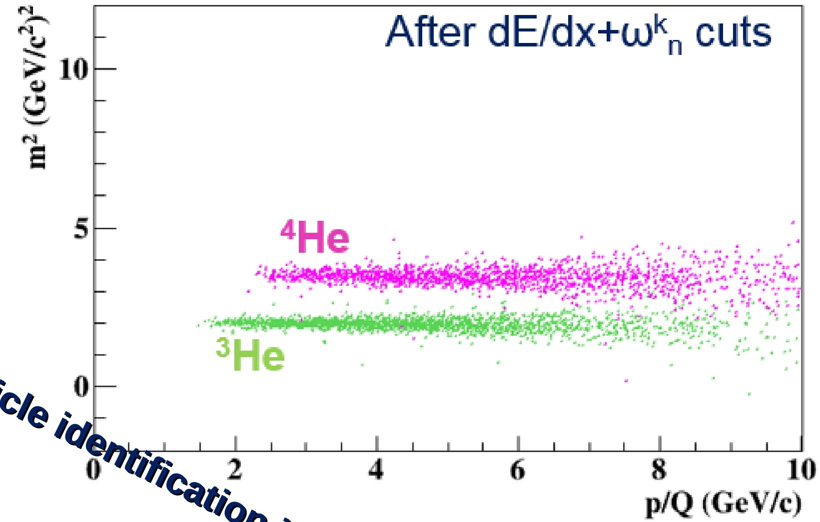
~90% Protons



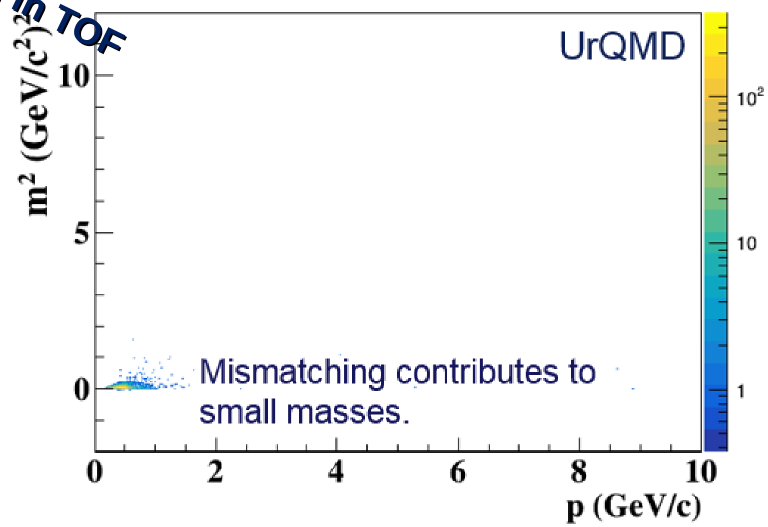
O.Yu. Derenovskaya, V.V. Ivanov, I.O. Vassiliev

Heavy fragments (^3He and ^4He) identification using energy loss method in the STS detector





Particle identification in TOF



Conclusions

The ω^k_n criterion was successfully adapted for the STS detector. It allows to separate doubly charged particles from the single one.

The combination of dE/dx cut and ω^k_n criterion has shown high level of the background suppression. The ω^k_n gives the additional background suppression 1.3.

The combination of TOF + STS allows to separate ^3He and ^4He from the deuteron background.

Geometry database for the CBM experiment

The Geometry database (DB) supports the geometry which describes the setup of the CBM experiment at the detailed level required for simulation of the transport of particles through the setup using GEANT3.

The main purpose of the Geometry DB is to provide convenient tools for:

1)managing the geometry modules (MVD, STS, RICH, TRD, RPC, ECAL, PSD, Magnet, Beam Pipe);

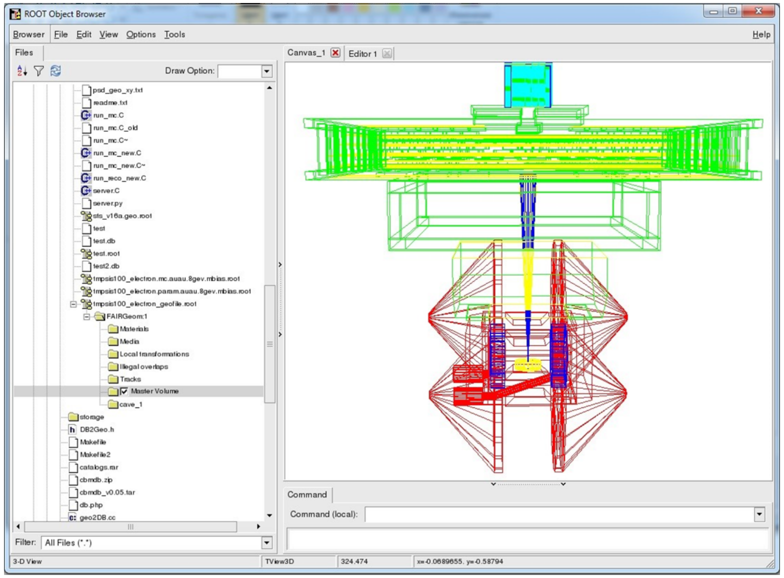
2)assembling various versions of the CBM setup as a combination of geometry modules and additional files (Field, Materials);

3)providing support of various versions of the CBM setup. The members of the CBM collaboration may use both Graphical User Interface (GUI) and Application Programming Interface (API) tools to work with the Geometry DB.

```
[aleksand@cbmdb geomdb]$ root -b -q getSetupList.C
   ------------------------------------------------------------
  | Welcome to ROOT 6.11/01                http://root.cern.ch |
  |                               (c) 1995-2017, The ROOT Team |
  | Built for linuxx8664gcc                                    |
  | From heads/master@f5d2f9a, May 22 2017, 22:58:00           |
  | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q' |
   ------------------------------------------------------------


Processing getSetupList.C...
sqlite://test2.db
Setup list:
Tag                 Date           Author               Description
sis100 electron     23.06.2016     evgeny               desc sis100 electron
```

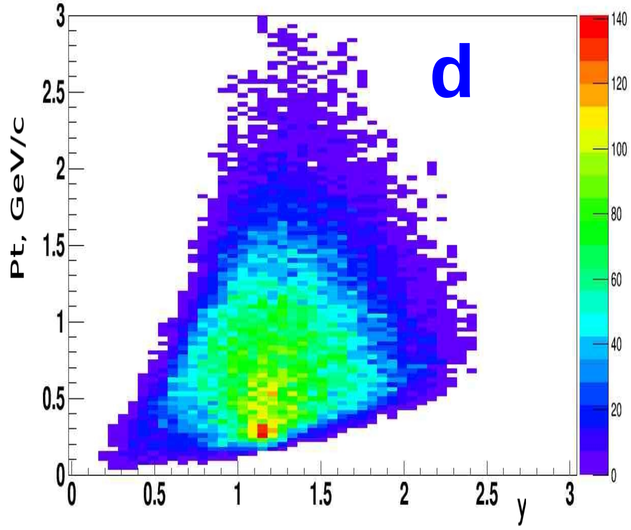
The Application Programming Interface (API) is implemented as set of macros of the ROOT framework.

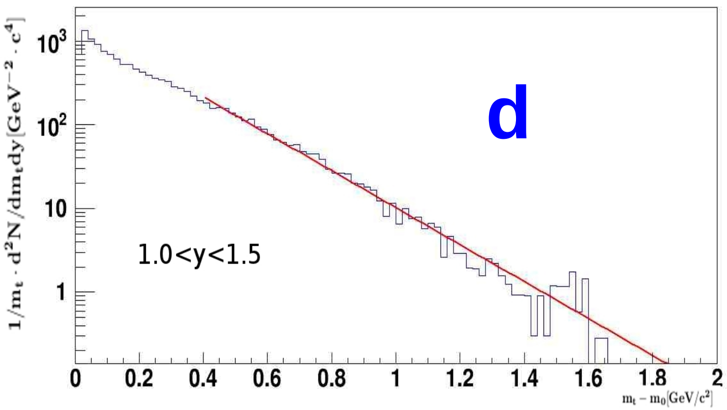


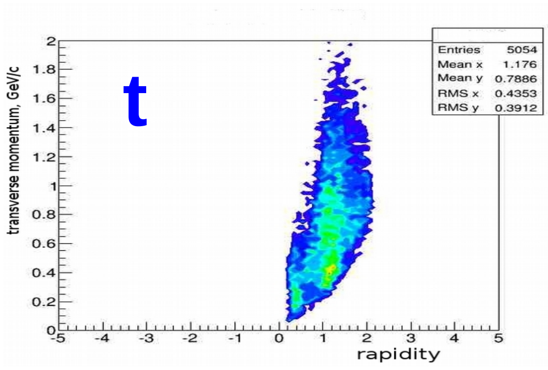
GUI was implemented as a standard web-interface.

E.P. Akishina, E.I. Alexandrov, I.N. Alexandrov, I.A. Filozova, V. Friese and V.V. Ivanov

Study of multiparticle dynamics at CBM at SIS100







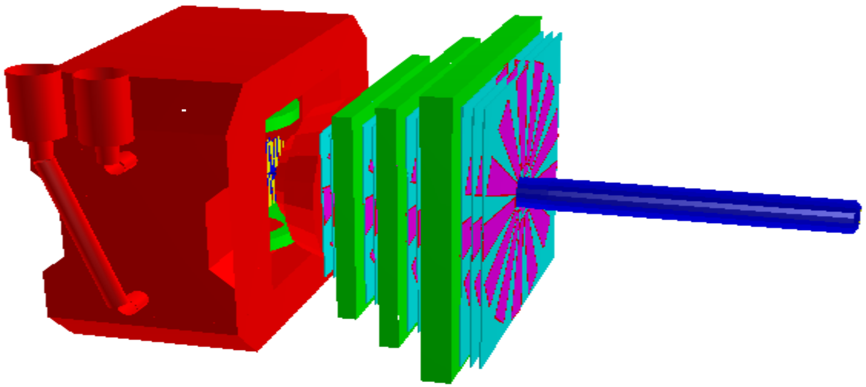
Nuclear fragments:

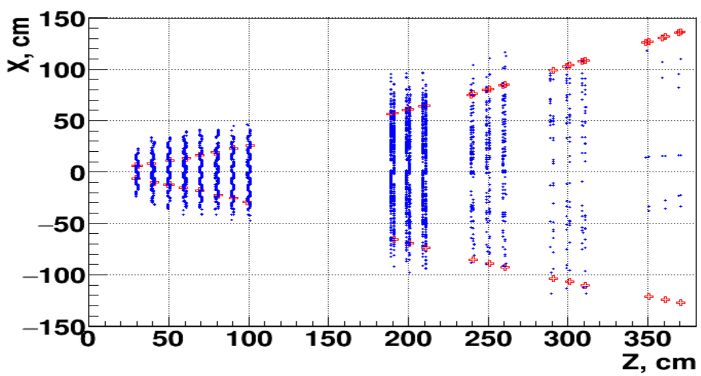
Coalescence parameters for d, t, ^{3}He, ^{4}He

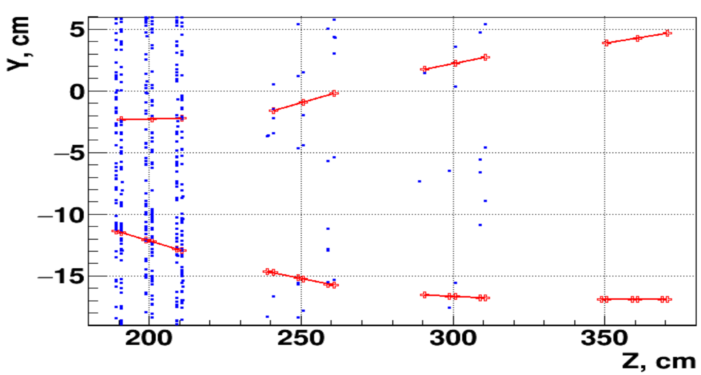
Correlations

Hypernuclei

A vector finding approach to track reconstruction in CBM-MUCH





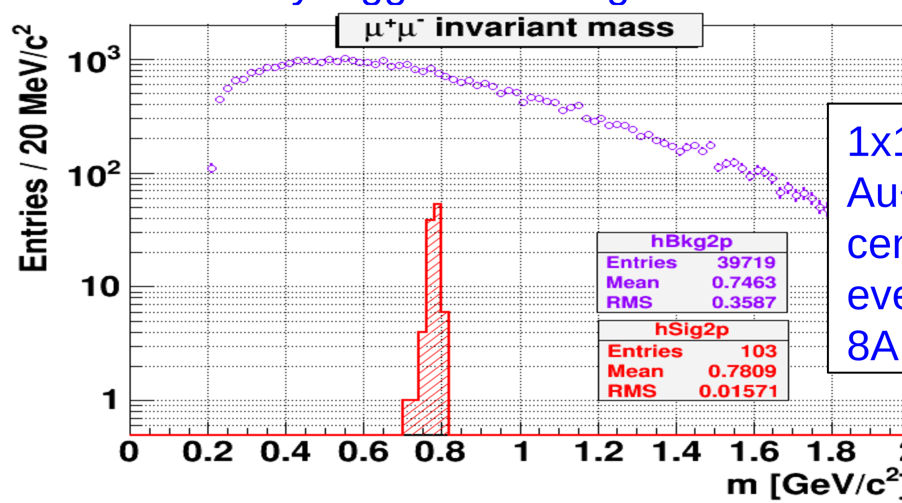


Low-mass vector meson decays: □□□□□

- very low yield of signal di-muon pairs
- background: false (ghost) tracks + hadron decays

Build vectors for each station to:

- better handle different MUCH detectors (GEMs and Straws)
- facilitate parallel processing
- unify trigger / tracking tasks

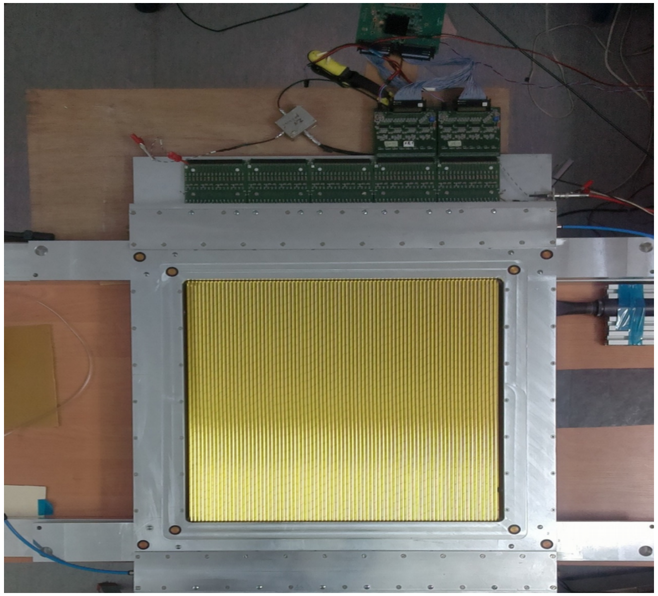


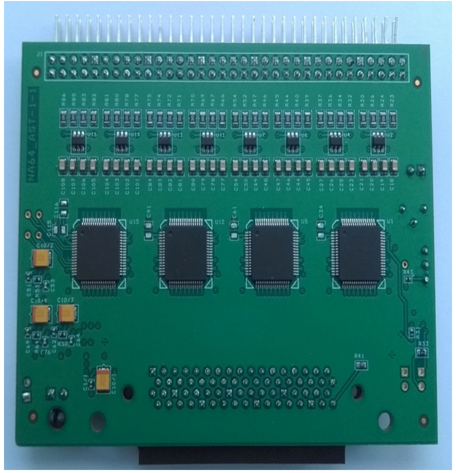
1×10^7 Au+Au central events @ 8A GeV

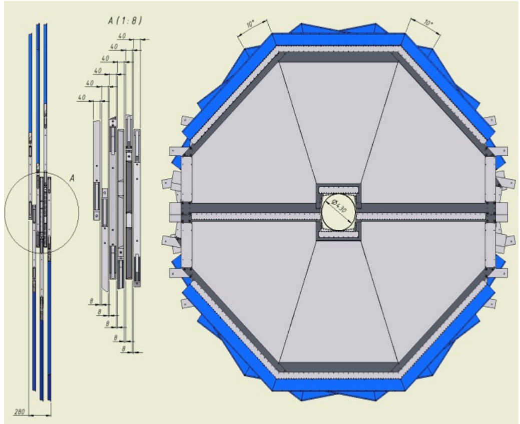
Future developments:

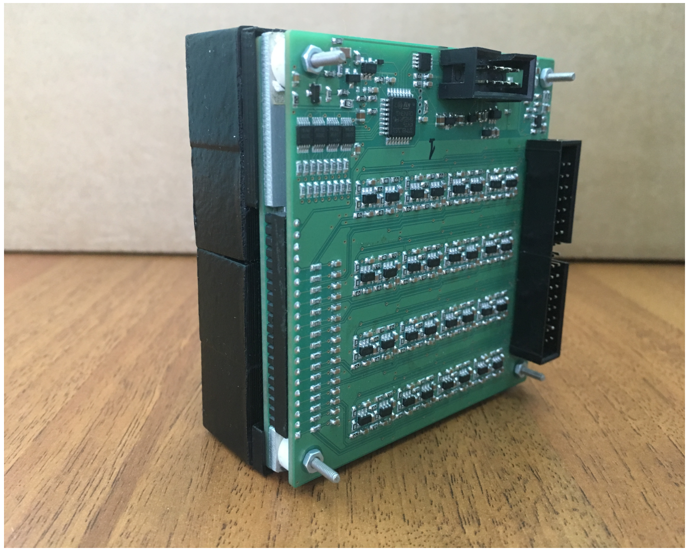
- RPCs as last stations
- use TOF information to suppress hadron contribution
- FLES

R&D: straw detectors for MUCH, calorimetry





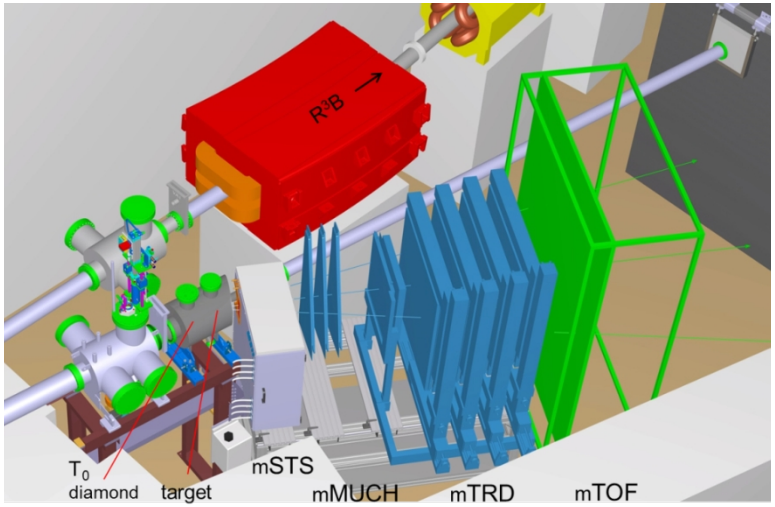




Rectangular straw prototype with FEE has been produced and tested. 16-channels Hamamatsu SiPM read out board has been developed.

Applications: SPD test zone, BMN2, SPD

FAIR phase0: mCBM and BM@N2



mSTS

First data taking - March 2019
Spring 2020 -without foreigners

Impact for BM@N2:
STS, T0, free-streaming DAQ

Publications, talks etc.

- **Total number of publications in 2016-2020 is ~75:**

-9 Regular journals

-46 CBM Progress Reports

-20 Proceedings

- **About 40 talks at CBM collaboration meetings**

V.P.Ladygin is the Deputy of CBM Spokeperson

Plans for 2021-2025

1. Signing of the CBM Construction MoU.
2. Participation in the construction and commissionning of the CBM detector:
-SC Magnet expertize,
-algorithms and databases development,
-physics simulation,
-FAIR Phase0 participation,
-R&D for FAIR/NICA.

Synergy between CBM/HADES and MPD/BM@N increases thanks to signed Germany-Russia road map.

Resources for 2021-2025

Form No. 29

Estimated expenditures for the Project CBM:JINR participation

Expenditure items	Full cost	2021 y.	2022 y.	2023 y.	2024 y.	2025 y.
Direct expenses for the Project						
1. Accelerator (Nuclotron)	400	-	100	100	100	100
2. Computers	-	-	-	-		
3. Computer connection	-	-	-	-		
4. Design bureau	800	200	200	200	100	100
5. Experimental Workshop	-	-	-	-		
6. Materials	41	13	7	7	7	7
7. Equipment	40	8	8	8	8	8
8. Common fund	205	25	45	45	45	45
9. Payments for agreement-based research						
10. Travel allowance, including:	85	15	15	15	20	20
a) non-rouble zone countries	85	15	15	15	20	20
b) rouble zone countries	-	-	-	-		
c) protocol-based						
Total direct expenses	371	61	75	75	80	80

* - BMBF-JINR grant (500k$ = 100k$/year) is expected in addition

PROJECT LEADER

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER-ECONOMIST

BMBF grant is delivered for CBM/HADES in 2021

CBM: JINR participants

Leaders:
V.V.Ivanov, V.P.Ladygin
Deputy:
O.Derenovskaya

LHEP: FTE=4.0
S.Avdeev, M.Baznat, A.Bychkov, O.Fateev, Yu.Gusakov, A.Ierusalimov, V.Ladygin, N.Ladygina, A.Malakhov, S.Reznikov, A.Shabunov, A.Zinchenko, G.Kekelidze, S.Parzhitsky, A.Savenkov, V.Pavlov, N.Veselova, I.Zhukov, I.Boguslavsky, V.Lysan, I.Lapshina, T.Andreeva, D.Dementiev, V.Elsha, A.Kolozhvari, V.Komarov, Yu.Murin, A.Rybakov, T.Semchukova, A.Sheremetiev, V.Shitenkov, E.Streletskaya, A.Voronin, N.Zamiatin, N.Sukhov

LIT: FTE=3.9
P.Akishin, E.Akishina, E.Alexandov, I.Alexandrov, S.Belogurov, D.Belyakov, O.Derenovskaya, I.Filozova, V.Ivanov(jnr.), V.Ivanov, A.Kryanev, S.Lebedev, A.Raportirenko, P.Zrelov, Yu.Russov

SWOT Analysis

Strengths:
CBM physics program focuses on the high-statistics studies of the rare probes like dileptops, charm and cascade hyperons which provide the information on the early stage of the strong interaction unachievable in others ongoing experiments in the energy range of SIS100 (2-11 AGeV).

Weaknesses:
CBM experiment will start in 2027. Therefore, there will be strong competition with the results obtained by STAR BES-II, NA61 and MPD/BM@N.

Opportunities:
Synergy between NICA and FAIR/GSI experiments. Germany-Russia Road map and CREMLIN-2. DAAD and BMBF-JINR grants for young researchers.

Threats:
Delay of the FAIR beam commissionning due resources lack and pandemy impact. High competition for the available SIS18 beam for mCBM. Delays with the CBM Construstion MoU signing (infrastructure of the CBM cave). COVID-19 pandemy impact.

Conclusions

1. CBM physics program is complimentary to the studies at LHC and RHIC at high temperatures and low densities, as well as to the studies performed or planned at SPS, RHIC and NICA at high baryonic densities and moderate temperatures. CBM will focuse on the studies of the rare probes like dileptops, charm and cascade hyperons which provide the information on the early stage of the strong interaction.

2. JINR contribution into CBM is important, the feedback with NICA projects is very large due to synergy of the studies at FAIR/GSI and NICA.

3. CBM/HADES project is included in the current 7-years JINR perspective plan and in the perspective plan until 2030.

4. JINR participation in CBM at FAIR is an good example of the "pragmatic" collaboration:

-BMBF grant for silicon trackers,

-Germany-Russia road map,

-DAAD and BMBF-JINR programs for youth exchanges,

etc.

Request for the recommendation

Prolongate the project with the 1-st priority for 2021-2025 for the CBM detector construction phase.

Thank you for the attention!

Participants

Participants from JINR (FTE)

Laboratory	№№	Name, Surname	FTE	№№	Name, Surname	FTE
LHEP	1	Avdeyev S.P.	0.1	2	Fateev O.V.	0.1
4.0 FTE	3	Bychkov A.V.	0.1	4	Gusakov Yu.V.	0.1
	5	Ladygin V.P.	0.2	6	Ladygina N.B.	0.1
	7	Malakhov A.I.	0.1	8	Reznikov S.G.	0.1
	9	Shabunov A.V.	0.1	10	Baznat M.	0.1
	11	Zinchenko A.I.	0.1	12	Kekelidze G.D.	0.1
	13	Parzhitsky S.S.	0.2	14	Savenkov A.A.	0.2
	15	Pavlov V.V,	0.1	16	Veselova N.I.	0.1
	17	Zhukov I.A.	0.1	18	Boguslavsky I.V.	0.2
	19	Lysan V.M.	0.2	20	Lapshina I.V.	0.2
	21	Andreeva T.V.	0.1	22	Dementiev D.V.	0.1
	23	Elsha V.V.	0.1	24	Kolozhvari A.A.	0.1
	25	Komarov V.G.	0.1	26	Murin Yu.A.	0.1
	27	Rybakov A.A.	0.1	28	Semchukova T.V.	0.1
	29	Sheremetiev A.D.	0.1	30	Shitenkov M.O.	0.1
	31	Strelezkaya E.A.	0.1	32	Voronin A.L	0.1
	33	Zamiatin N.I.	0.1	34	Sukhov N.V.	0.1
LIT	35	Akishin P.G.	0.5	36	Akishina E.P.	0.5
3.9 FTE	37	Alexandrov E.I.	0.3	38	Alexandrov I.N.	0.3
	39	Belogurov S.G.	0.1	40	Belyakov D.V.	0.2
	41	Derenovskaya O.Yu.	0.5	42	Filozova I.A.	0.2
	43	Ivanov V.V. (jr)	0.2	44	Ivanov V.V.	0.5
	45	Kryanev A.V.	0.2	46	Lebedev S.A.	0.1
	47	Raportirenko A.M.	0.2	48	Zrelov P.V.	0.1

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CBM project:JINR participation

Project CBM - 1-st priority 2011-2020 (last term 2016-2020)

CBM (and HADES) are within one scientific pilar of FAIR
HQM (Hadron-Quark Matter)