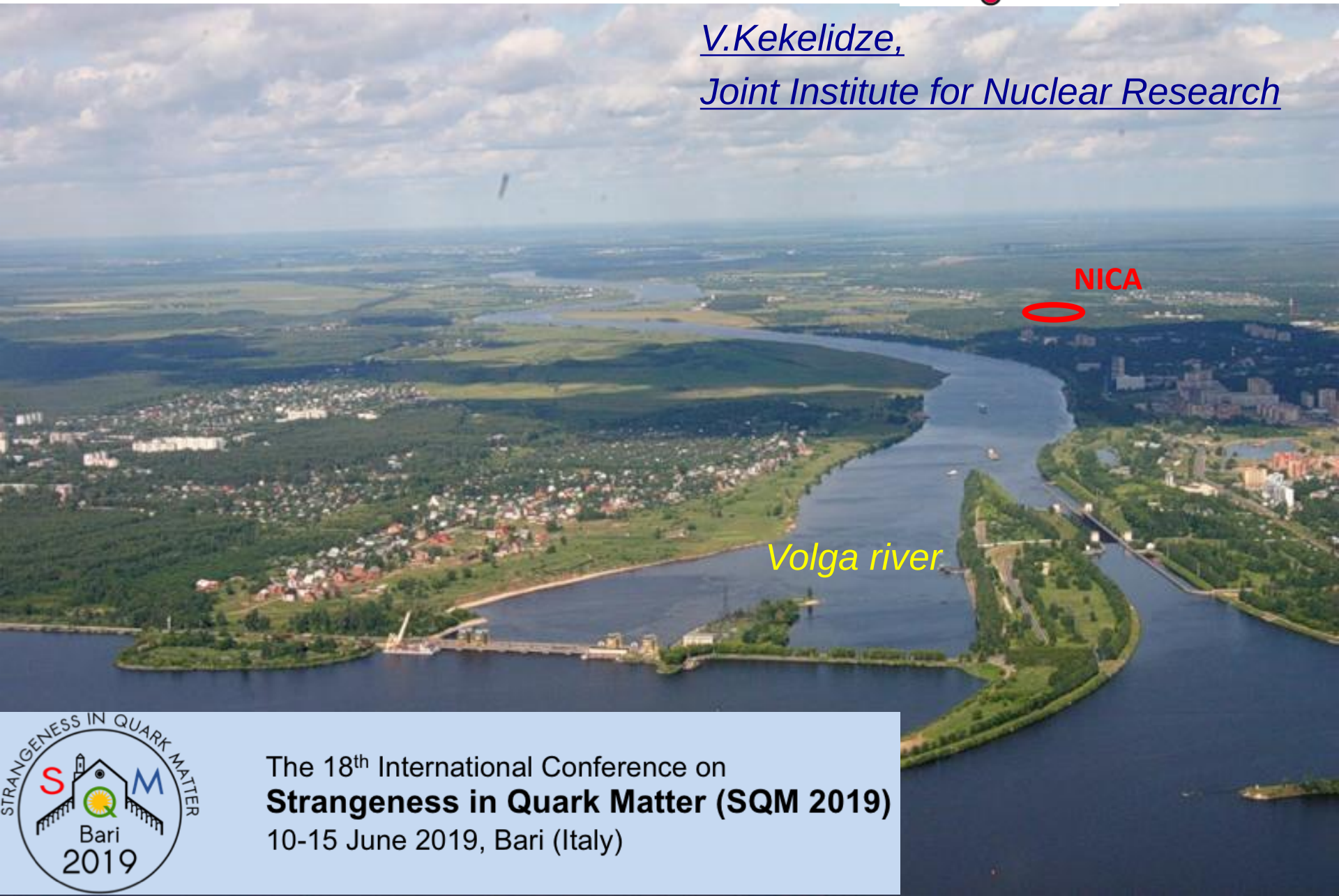
Status and Prospects at NICA

V.Kekelidze,

Joint Institute for Nuclear Research



The 18th International Conference on
Strangeness in Quark Matter (SQM 2019)
10-15 June 2019, Bari (Italy)

NICA (Nuclotron based Ion Collider fAcility)

Goals: ***to obtain comprehensive information on***

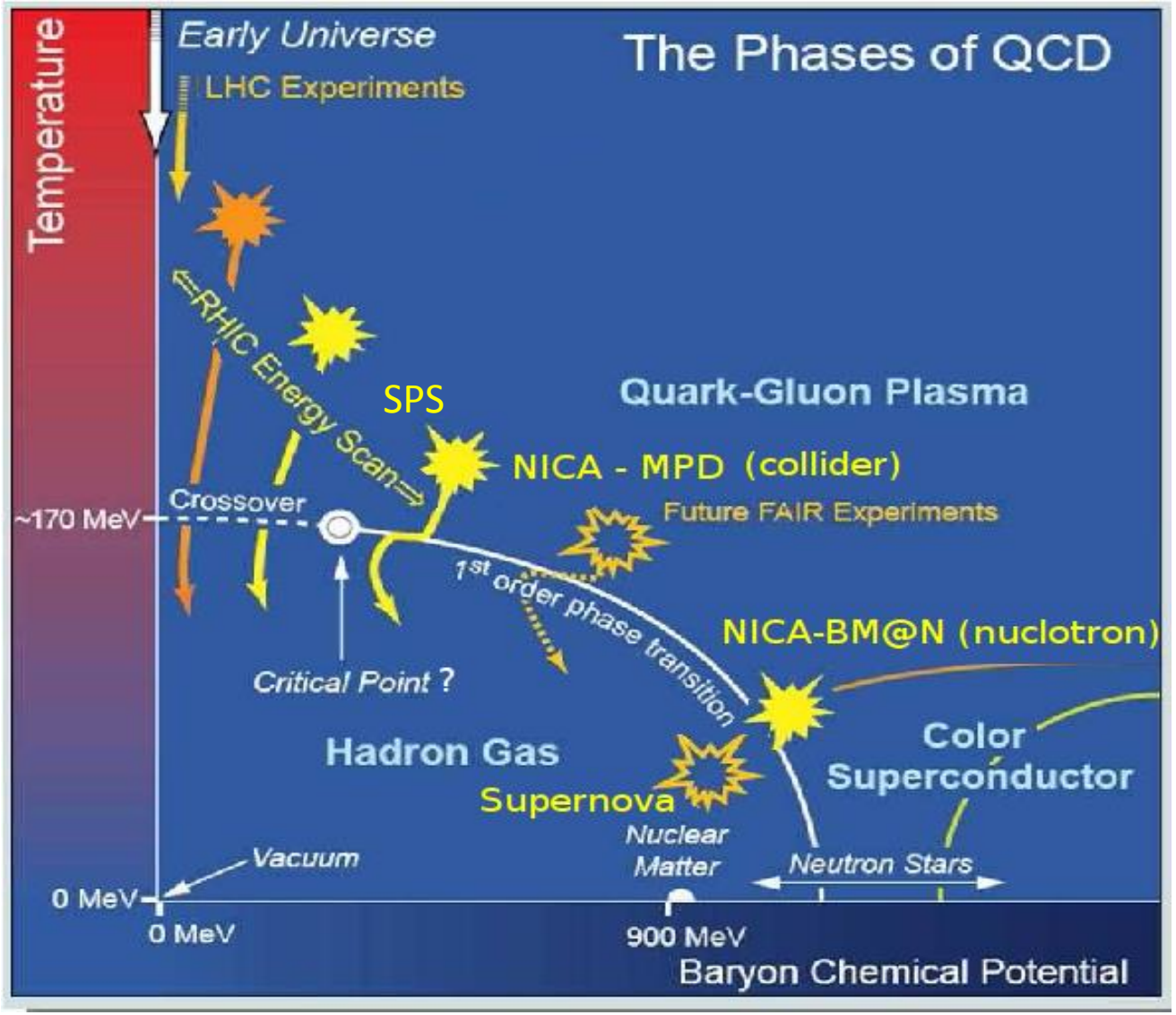
- hot and dense baryonic matter:
  - *whether there is a phase transition ?*
  - *is it a first-order phase transition ?*
  - *whether there is a critical end-point?*
- nucleon spin structure:
  - *how the spin of proton / neutron is composed?*

- *Essential upgrade of existing accelerator complex*
- *Construction of **Collider** to provide collisions of*
  - *ion species from **p** to **Au** at energy range $\sqrt{S_{NN}}$= **4** - **11** GeV*
  - *polarized **p** u **d** up to energy $\sqrt{S}$ =**27** GeV (p)*
- *Construction of **3** detectors: **Baryonic Matter @ Nuclotron (BM@N)**,*

  Multi Purpose Detector (MPD)** and **Spin Physics Detector (SPD)

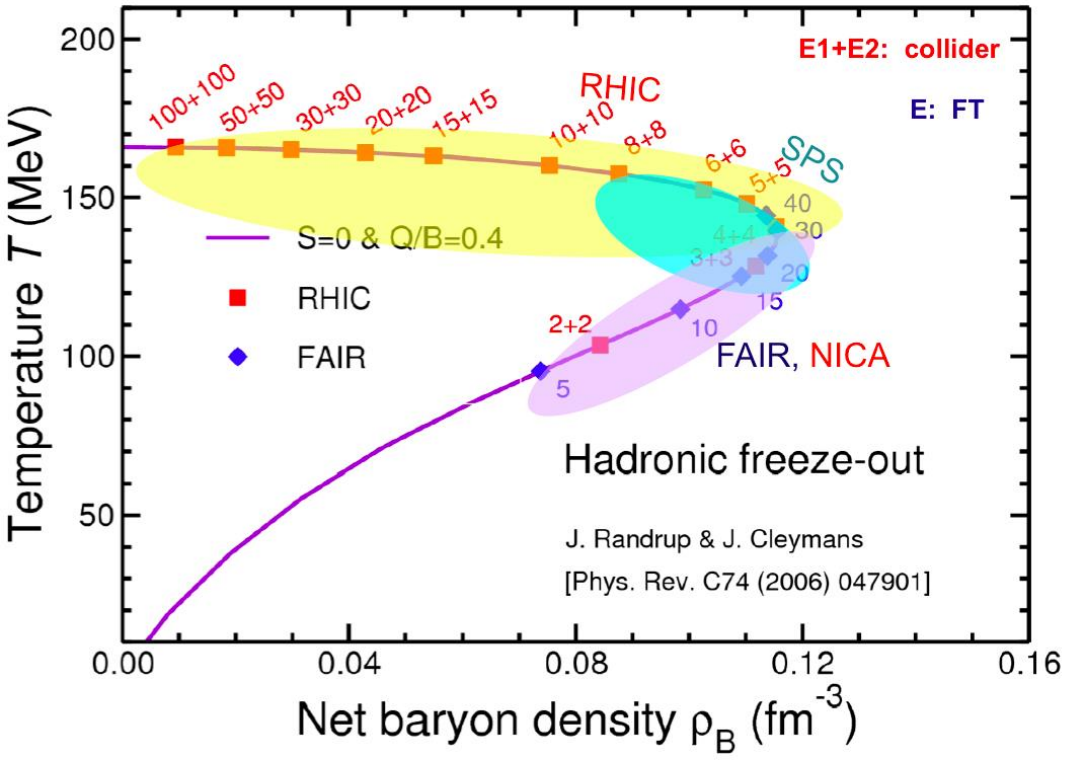
Exploration of the QCD Phase Diagram

Exploring high-density baryonic matter: maximum freeze-out density



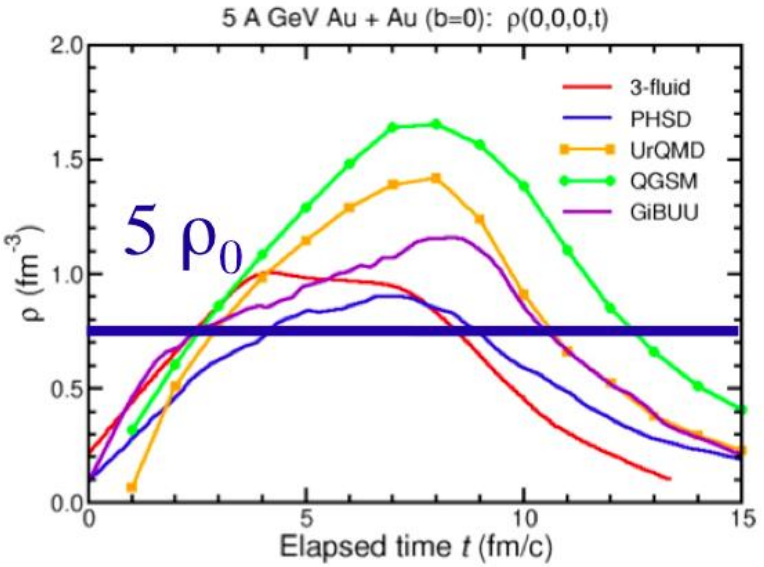
Net Baryonic density to be reached in Au + Au collisions

freeze-out conditions

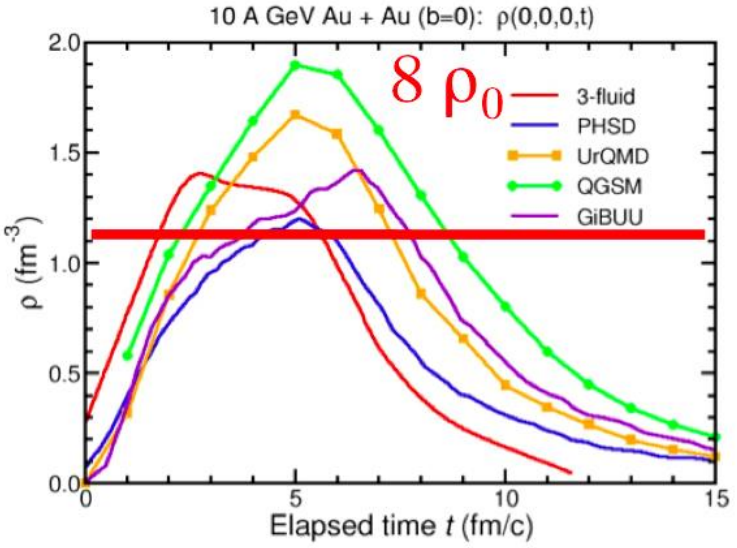


I.C. Arsene at al.,
Phys. Rev. C75 (2007) 24902.

5 A GeV

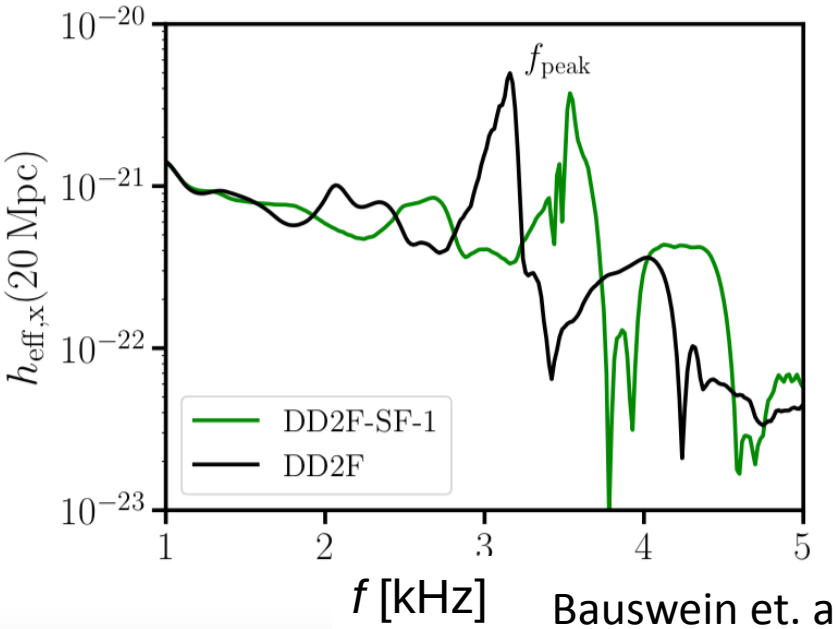


10 A GeV



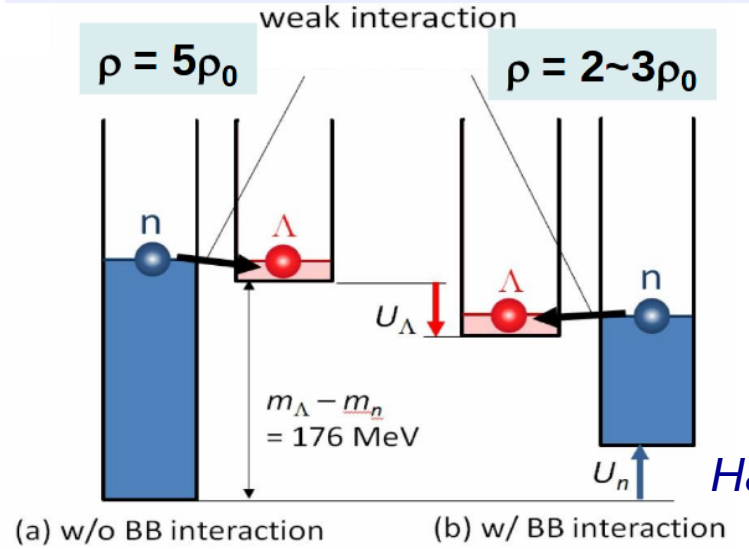
Similarity of Stellar Objects & Heavy Ion Collisions

1st OPT: grav waves from mergers

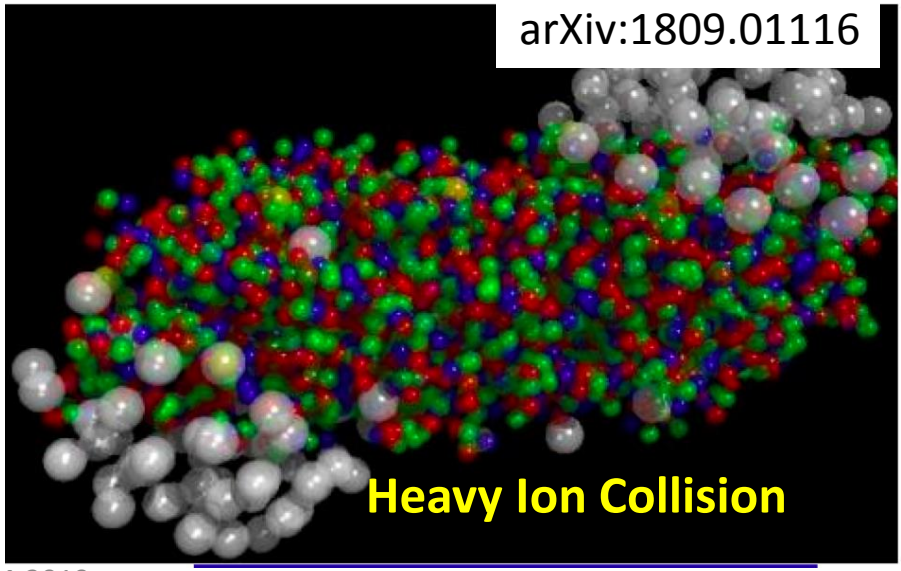


Bauswein et. al., arXiv:1809.01116

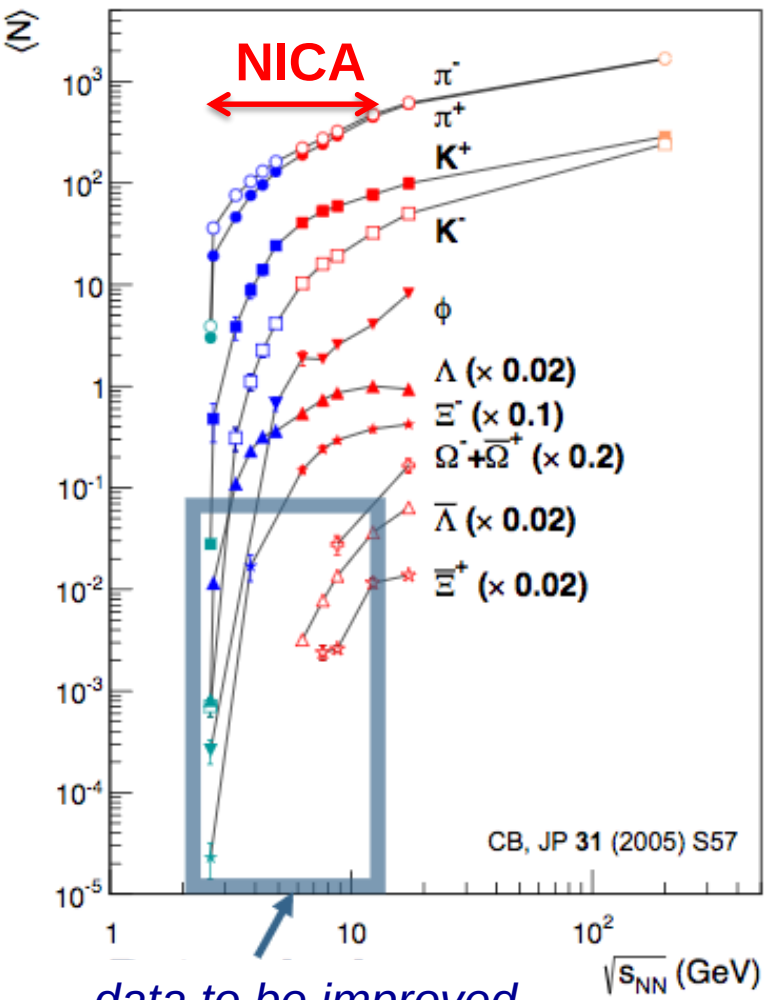
appearance of strangeness changes EOS, depends on strangeness-nucleon interaction



H. Tamura, Hadron 2017

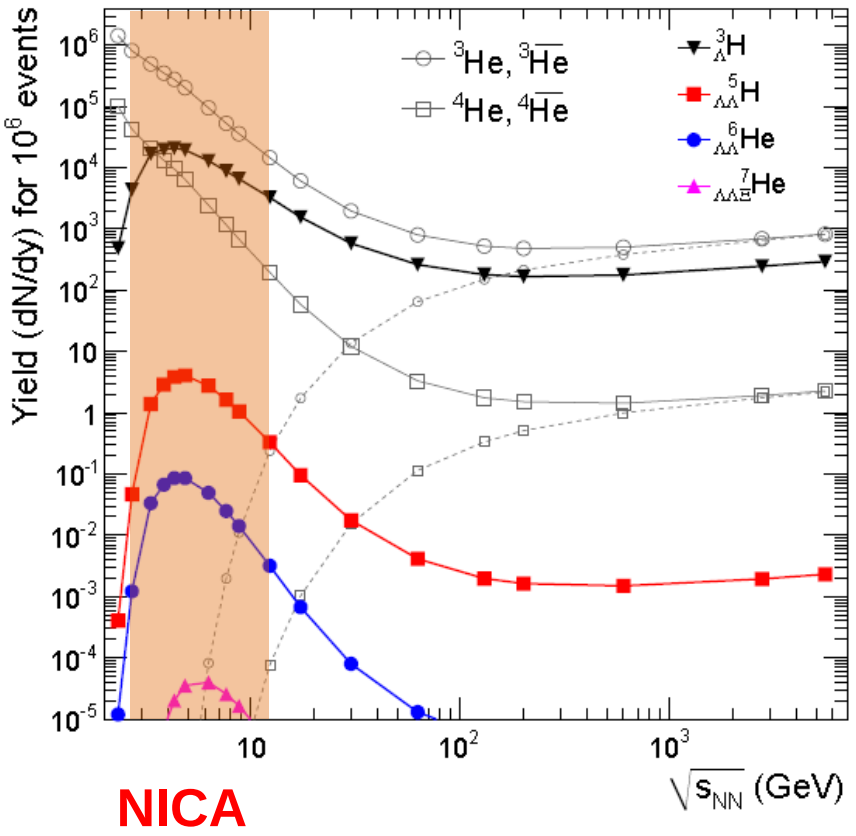


Energy Dependence of Total Yields



data to be improved
C. Blume, SQM-2017

*Hypernuclei production enhanced at high baryon densities (**NICA**)*



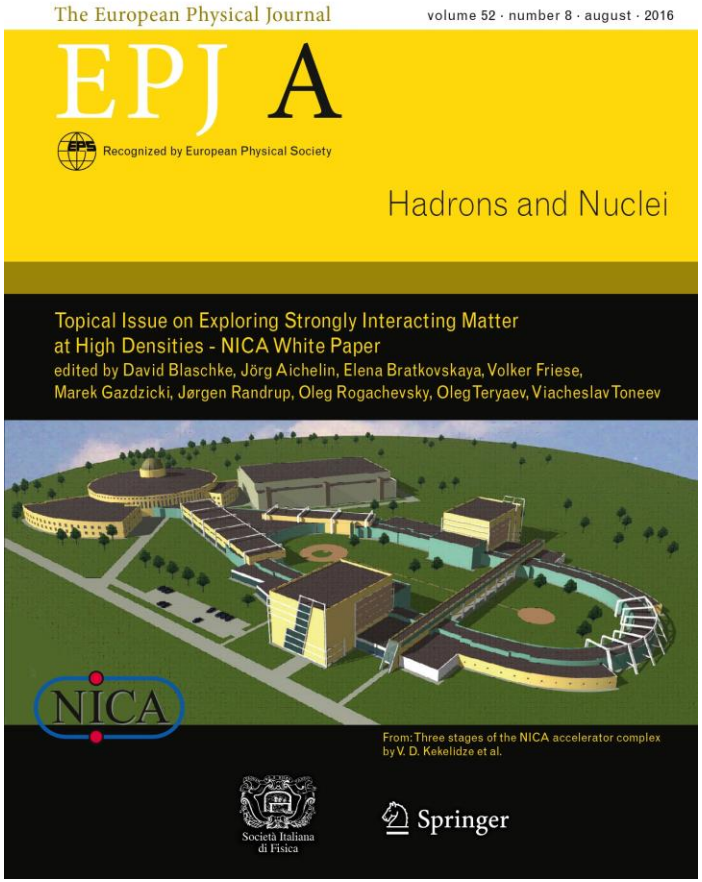
A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stoecker

QCD matter at the NICA energies:

- *high net baryon density – **density frontier**;*
- *maximum in K^+/π^+ ratio;*
- *maximum in Λ/π ratio;*
- *transition from a Baryon dominated system to a Meson dominated one;*
- *maximum of the Λ polarization;*
- *1-st order transition & mixed phase creation;*
- *Critical Endpoint ?*

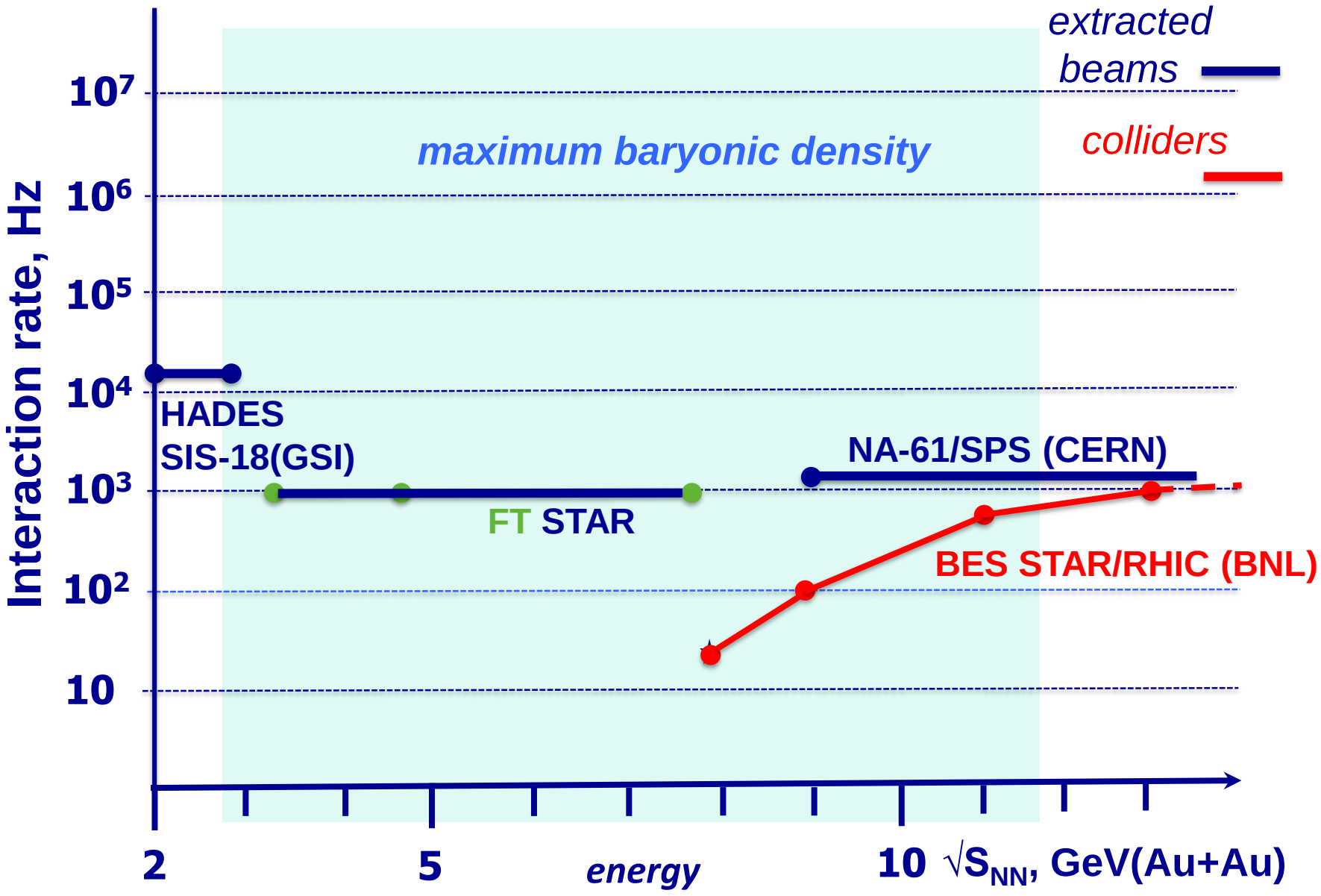
NICA Whte Paper

*Physics targets for the exploration of first order phase transitions in the region of the QCD phase diagram accessible to NICA & FAIR and possible observable effects of a "mixed phase indicated in the release of the "NICA White Paper" as a Topical Issue of the **EPJ A** (July 2016).*

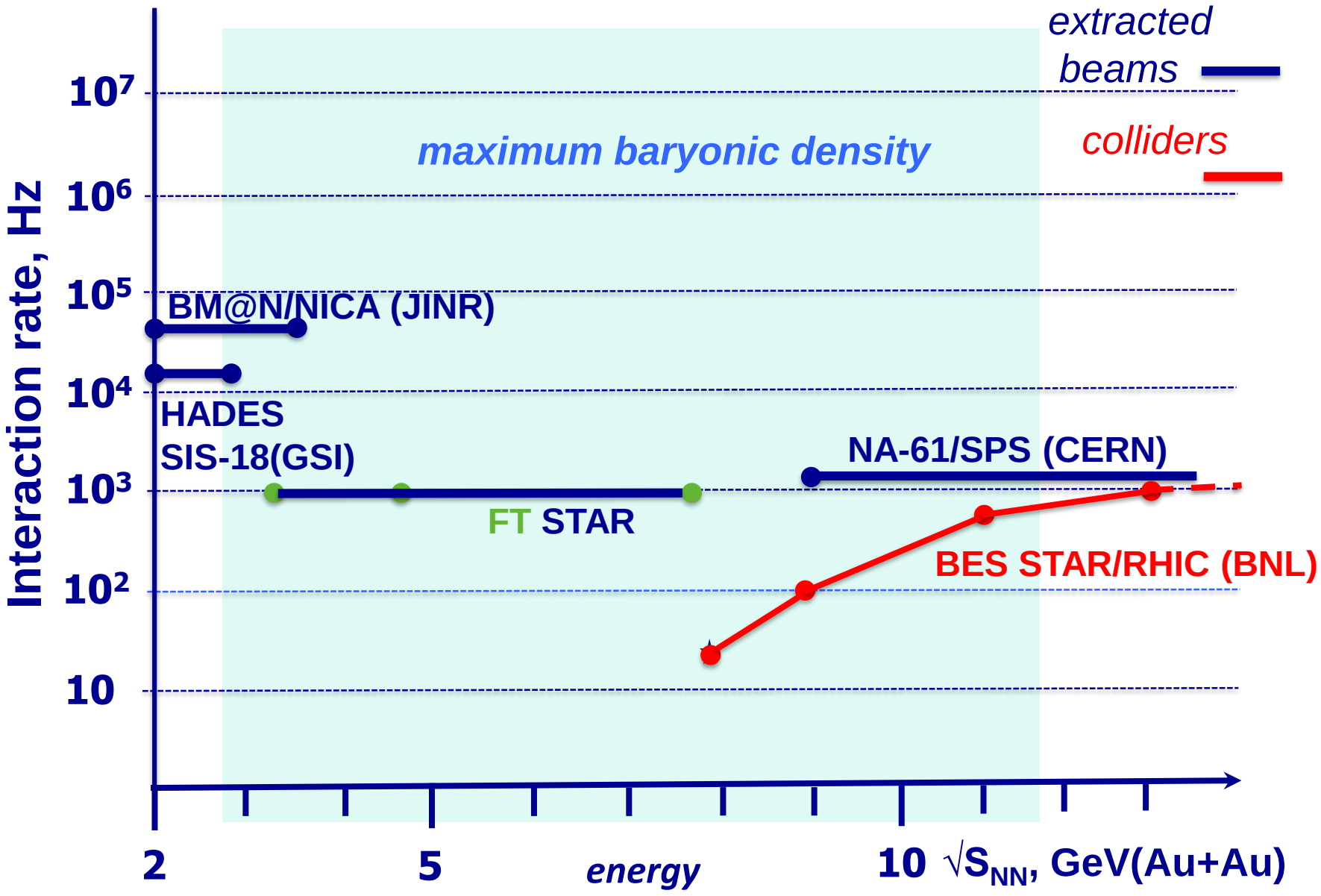


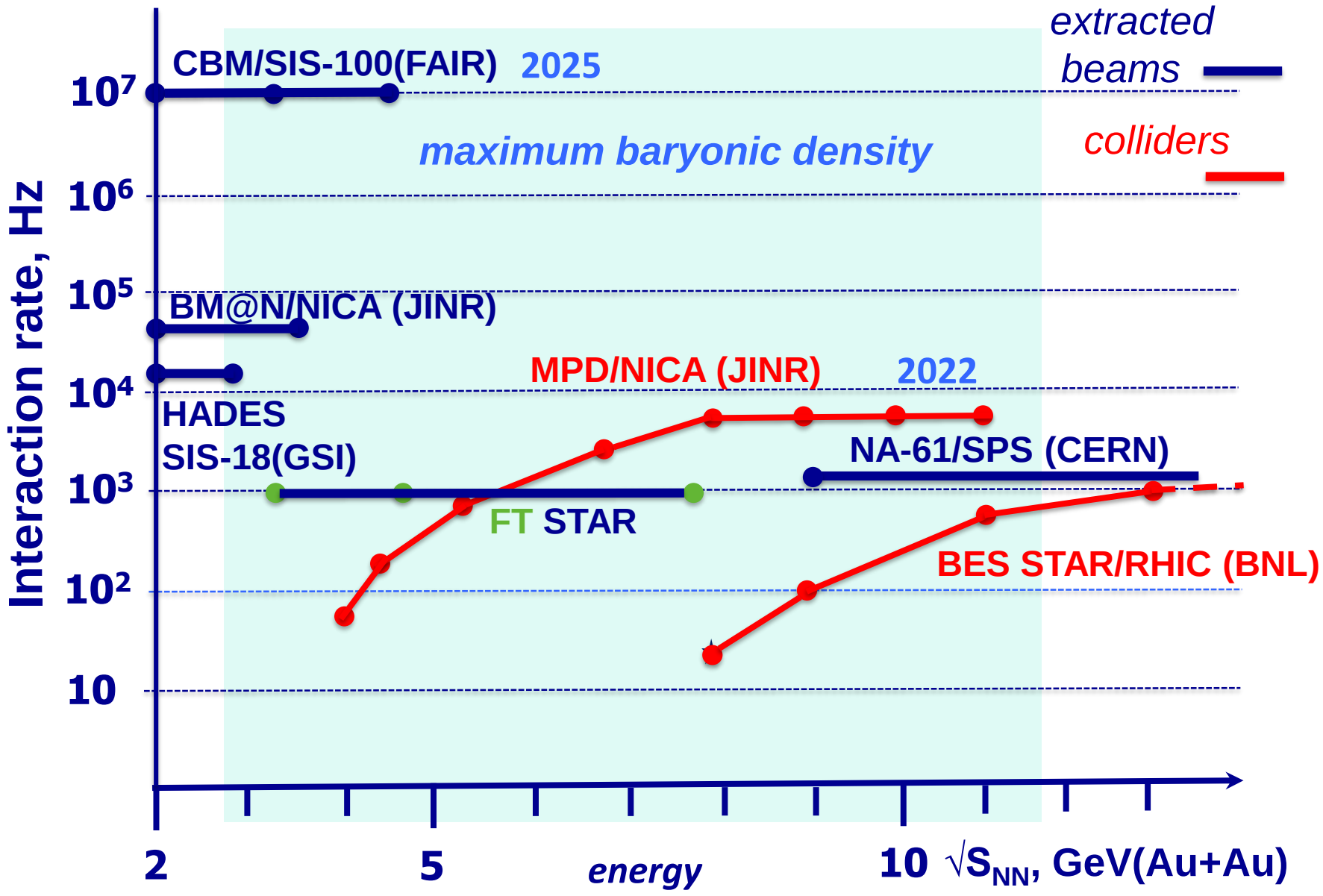
111 *contributions,*
188 *authors*
from **24** *countries*

Set-ups: *in operation*

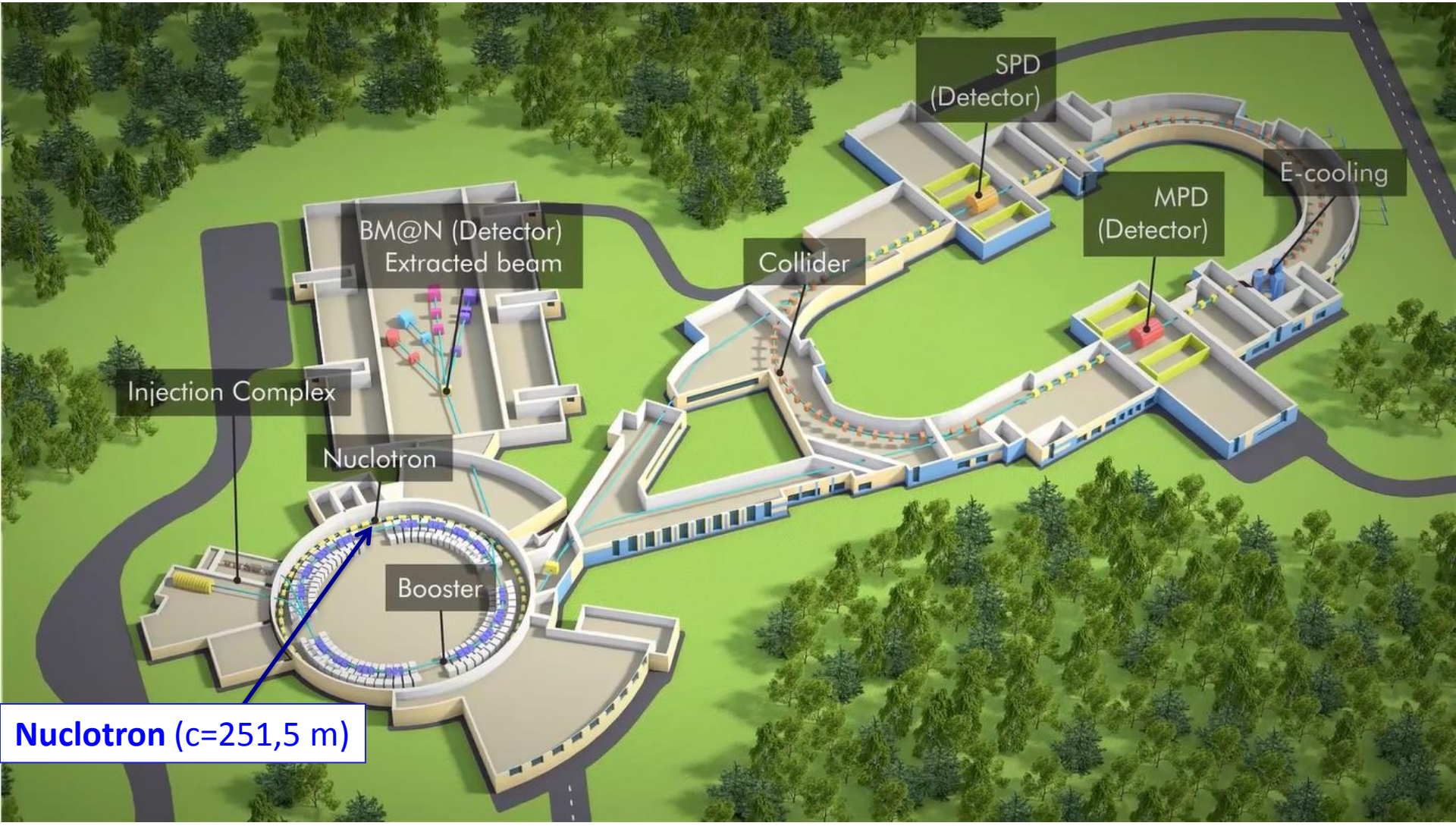


Set-ups: *in operation*

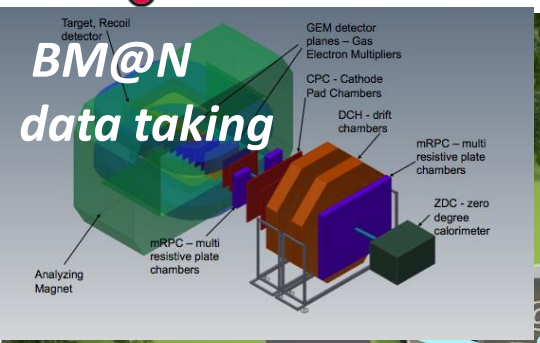



Set-ups: in operation
In construction
extracted beams
colliders
CBM/SIS-100(FAIR) 2025
maximum baryonic density
BM@N/NICA (JINR)
MPD/NICA (JINR) 2022
HADES
SIS-18(GSI)
NA-61/SPS (CERN)
FT STAR
BES STAR/RHIC (BNL)
Interaction rate, Hz
10⁷
10⁶
10⁵
10⁴
10³
10²
10
2
5
energy
10 √S_NN, GeV(Au+Au)

Complex objects



Complex objects



SPD (Detector)

MPD (Detector)

E-cooling

@N (Detector)

acted beam

Collider

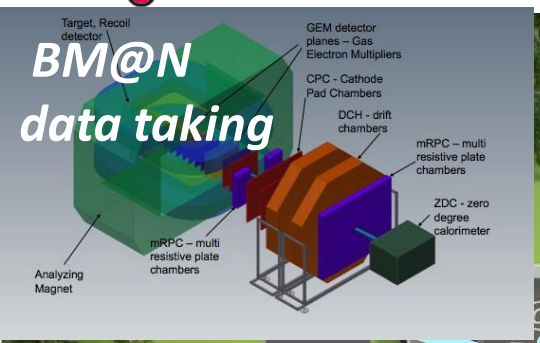
Injection Complex

Nuclotron

Booster

Nuclotron (c=251,5 m)

Complex objects



SPD (Detector)

E-cooling

MPD (Detector)

@N (Detector)

acted beam

Collider

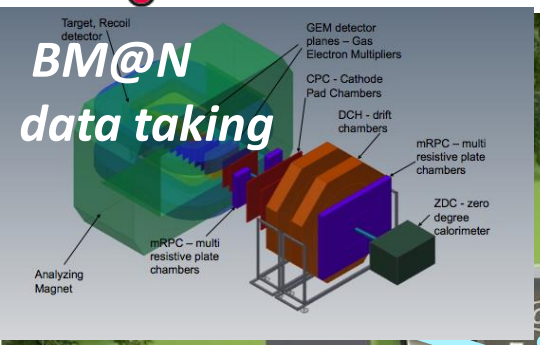
Injection Complex

Nuclotron

Booster- 2019

Nuclotron (c=251,5 m)

Complex objects



BM@N data taking

SPD (Detector)

E-cooling

MPD (Detector)

@N (Detector)

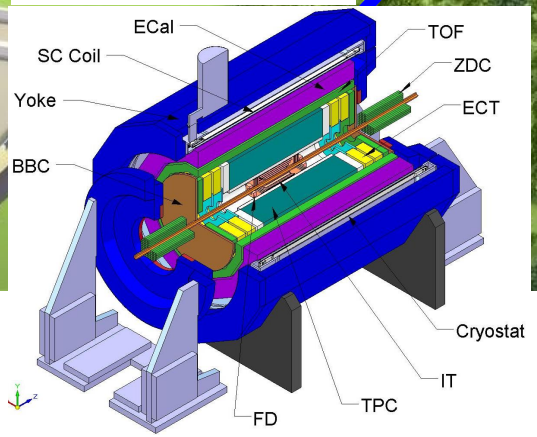
Collider

Injection Complex

Nuclotron

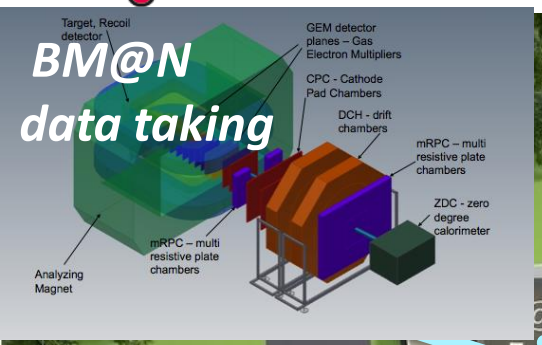
Booster- 2019

MPD - 2020



Nuclotron (c=251,5 m)

Complex objects



BM@N data taking

SPD (Detector)

MPD (Detector)

E-cooling

@N (Detector)

cted beam

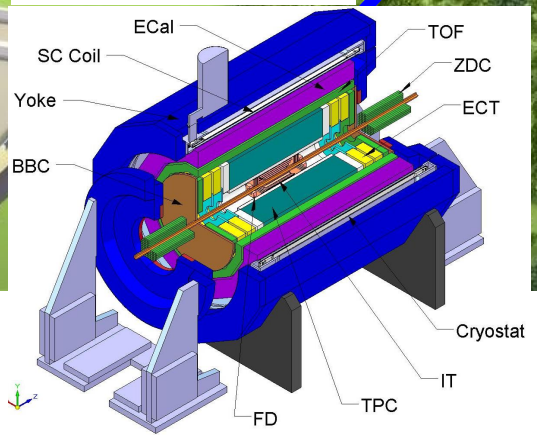
Collider - 2022

Injection Complex

Nuclotron

Booster- 2019

MPD - 2020



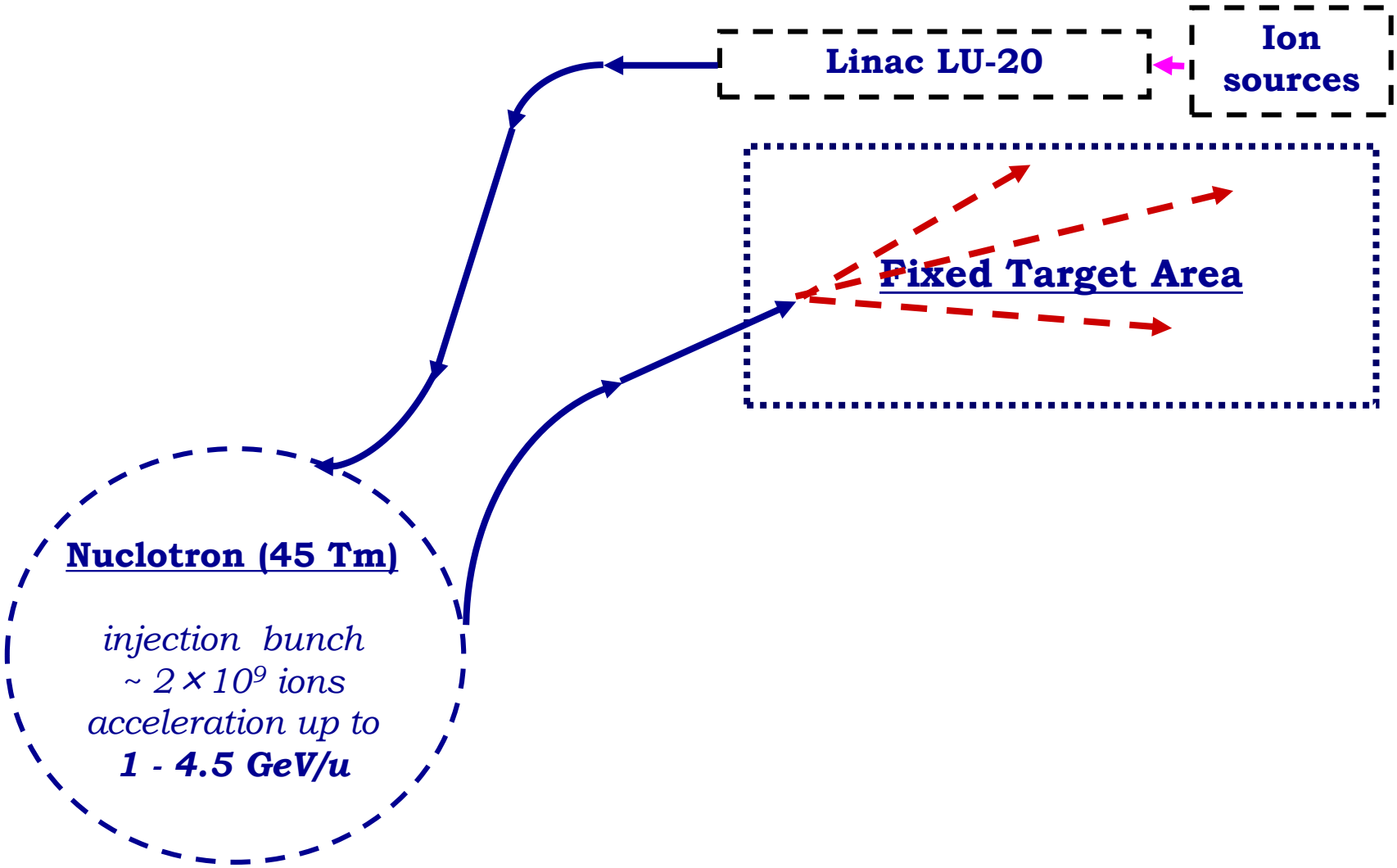
Nuclotron (c=251,5 m)

NUCLOTRON *in operation since **1993***

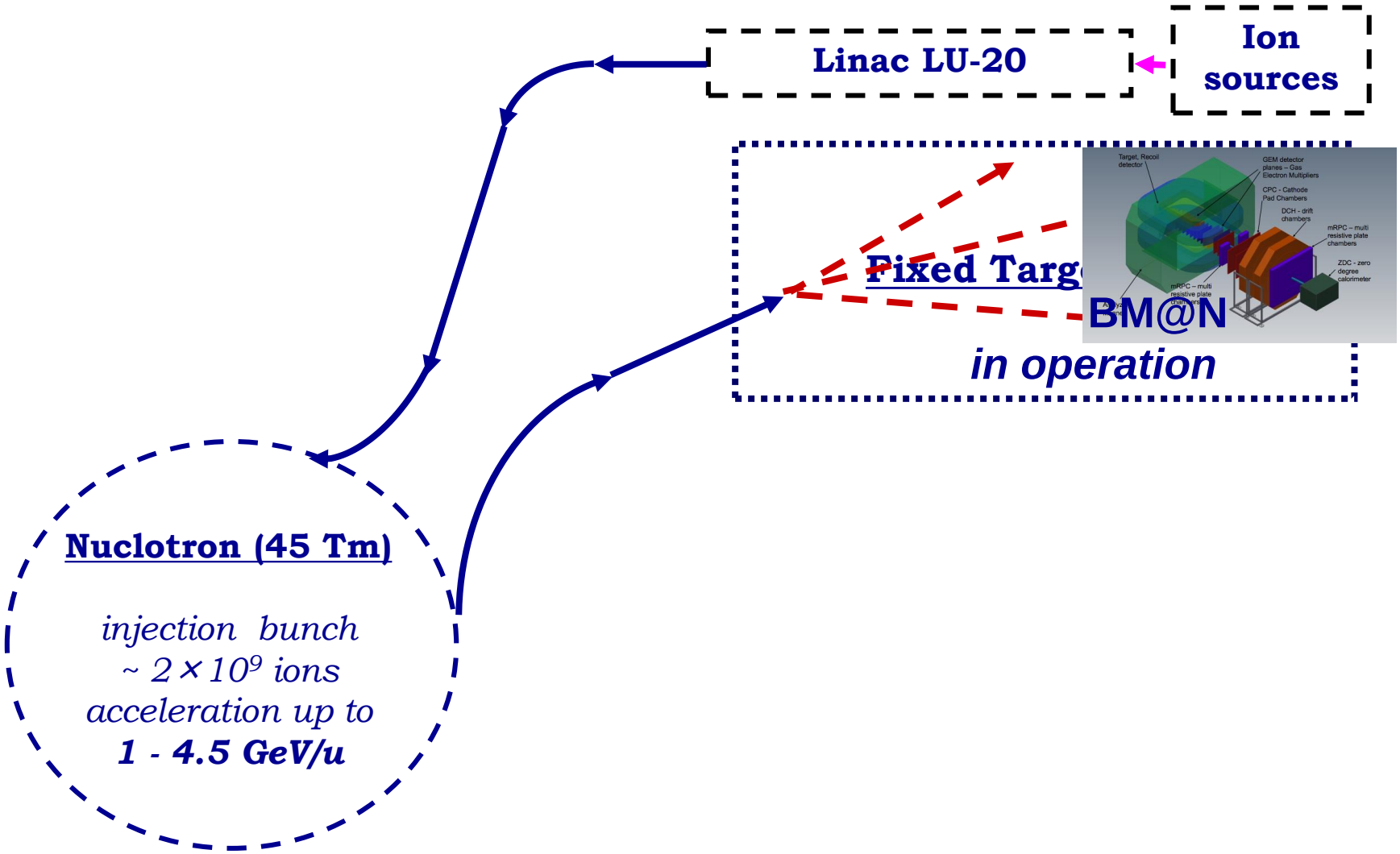
*modernized in **2010-2015***

Parameters	
type	SC synchrotron
particles	↑p,↑d, nuclei
max. kin. energy, GeV/u	12.07 (↑p); 5.62 (↑d) 4.38 (Au)
injection energy, MeV/u	5 (↑p,↑d) 570-685 (Au)
magnetic rigidity, T m	25 – 43.25
circumference, m	251.52
vacuum, Torr	10^{-9}
*intensity, **Au** /pulse*	$1\ 10^{9}$

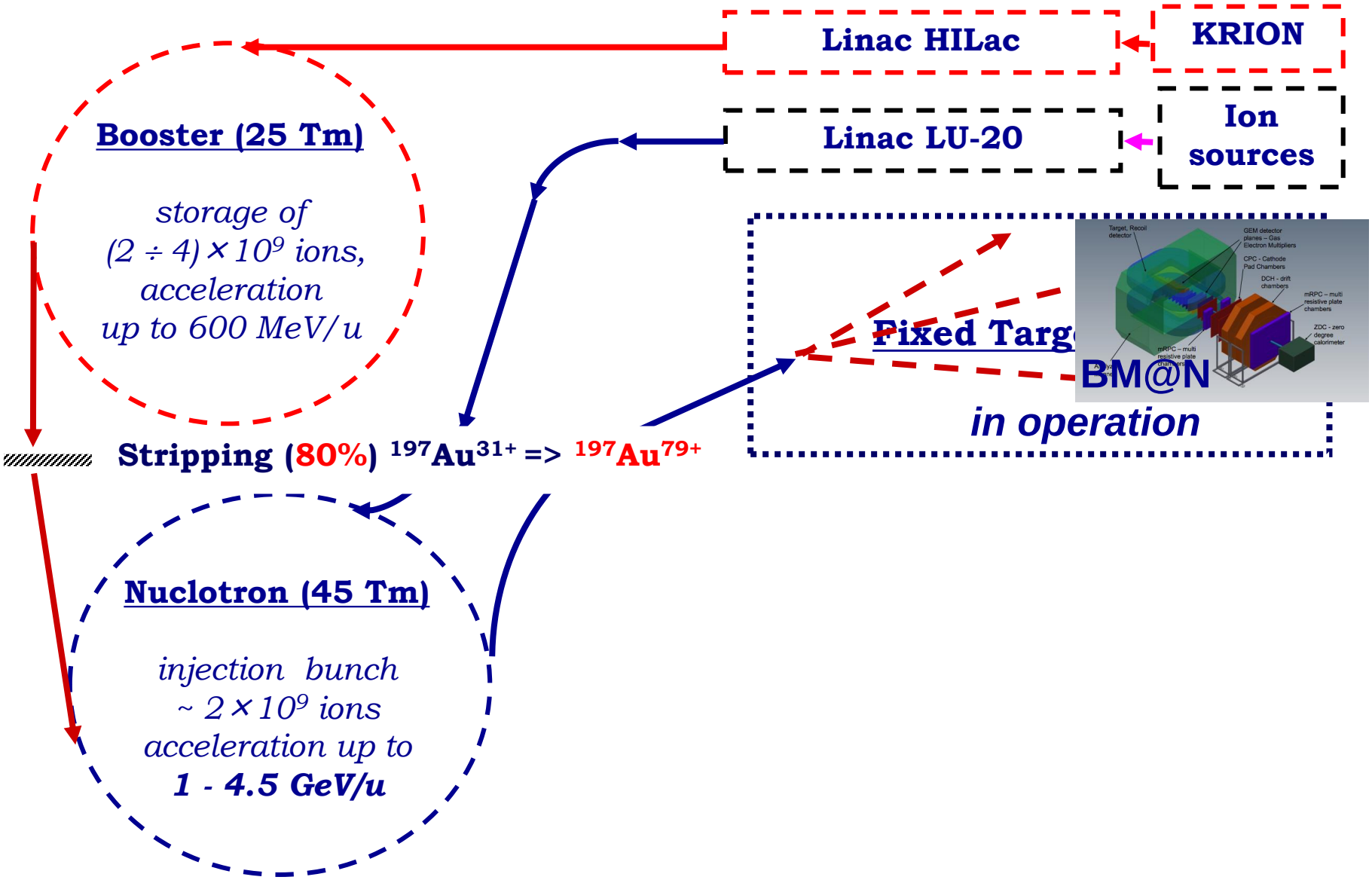
Structure and Operation Regimes



Structure and Operation Regimes



Structure and Operation Regimes



Structure and Operation Regimes

Linac HILac

KRION

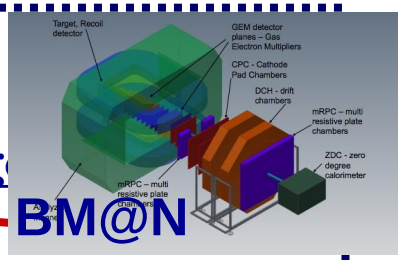
Linac LU-20

Ion sources

Booster (25 Tm)

storage of
$(2 \div 4) \times 10^9$ ions,
acceleration
up to 600 MeV/u

Fixed Targ



BM@N

in operation

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$

Nuclotron (45 Tm)

injection bunch
~ 2×10^9 ions
acceleration up to
1 - 4.5 GeV/u

IP-2

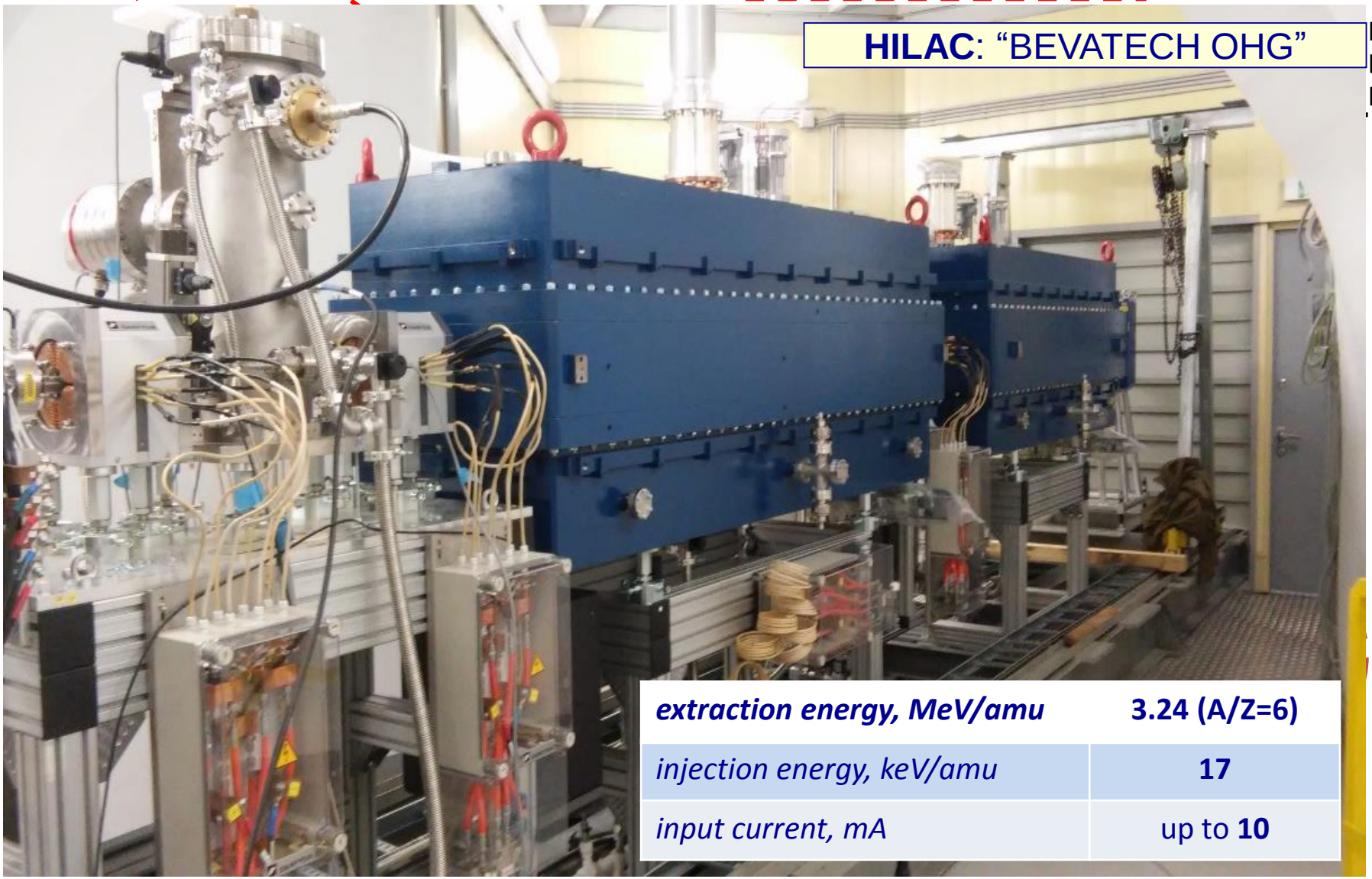
Two SC collider rings

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

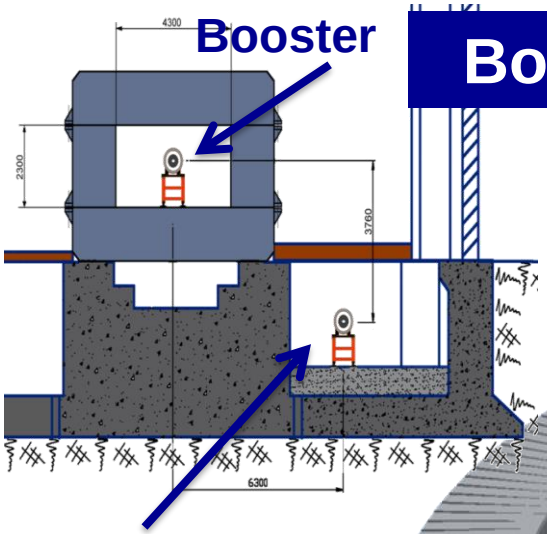
Structure and Operation Regimes

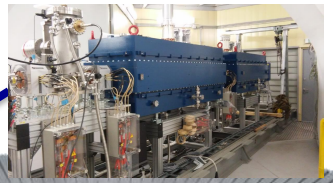
Linac HILac ← **KRION**

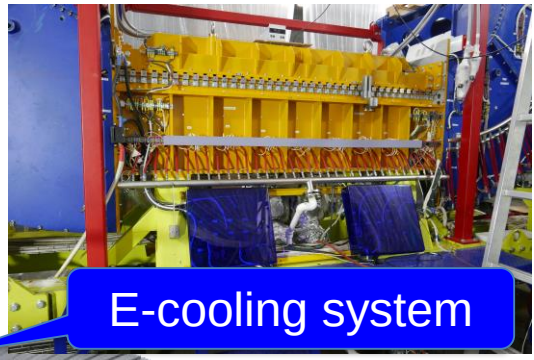


extraction energy, MeV/amu	**3.24 (A/Z=6)**
injection energy, keV/amu	**17**
input current, mA	up to **10**

Booster: *assembly since 2018*







injection

Feed box

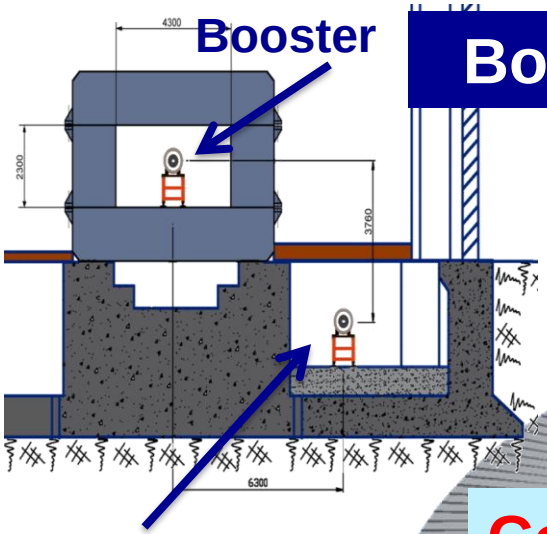
Power supply

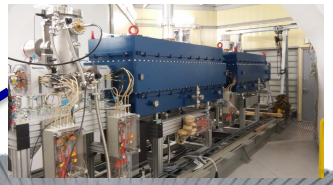
extraction

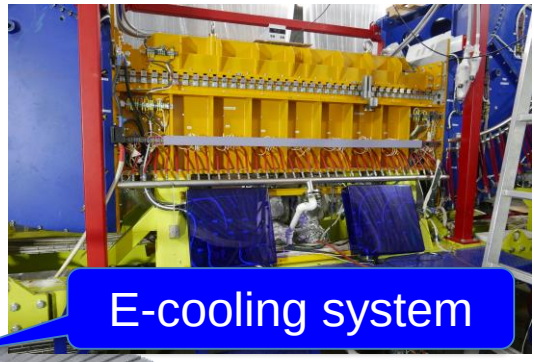
Accelerating station

Nuclotron

Booster: *assembly since 2018*







injection

Commissioning – December 2019

Feed box

ower
upply

extraction

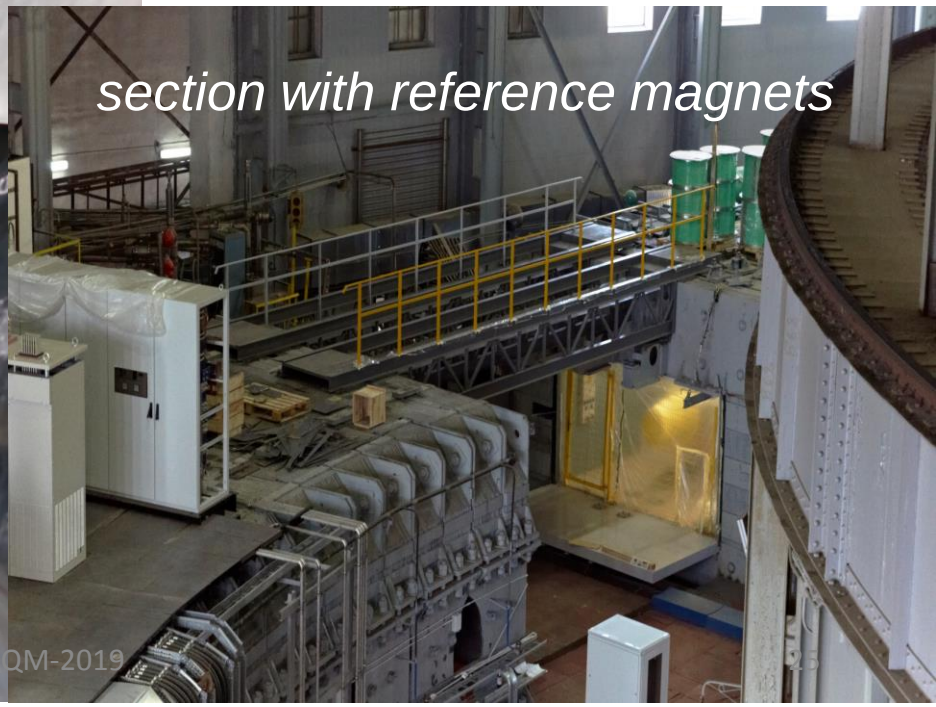
	value
ion species	A/Z ≤ 3
max. energy, MeV/u	**600**
injection energy, MeV/u	3.2
magnetic rigidity, T m	1.6 – 25.0
circumference, m	210.96
vacuum, Tor	10^{-11}
*intensity, **Au** /p*	$1.5\ 10^{9}$
RF region,MHz	0.5 -2.53

Nuclotron


Injection channel


power supply system

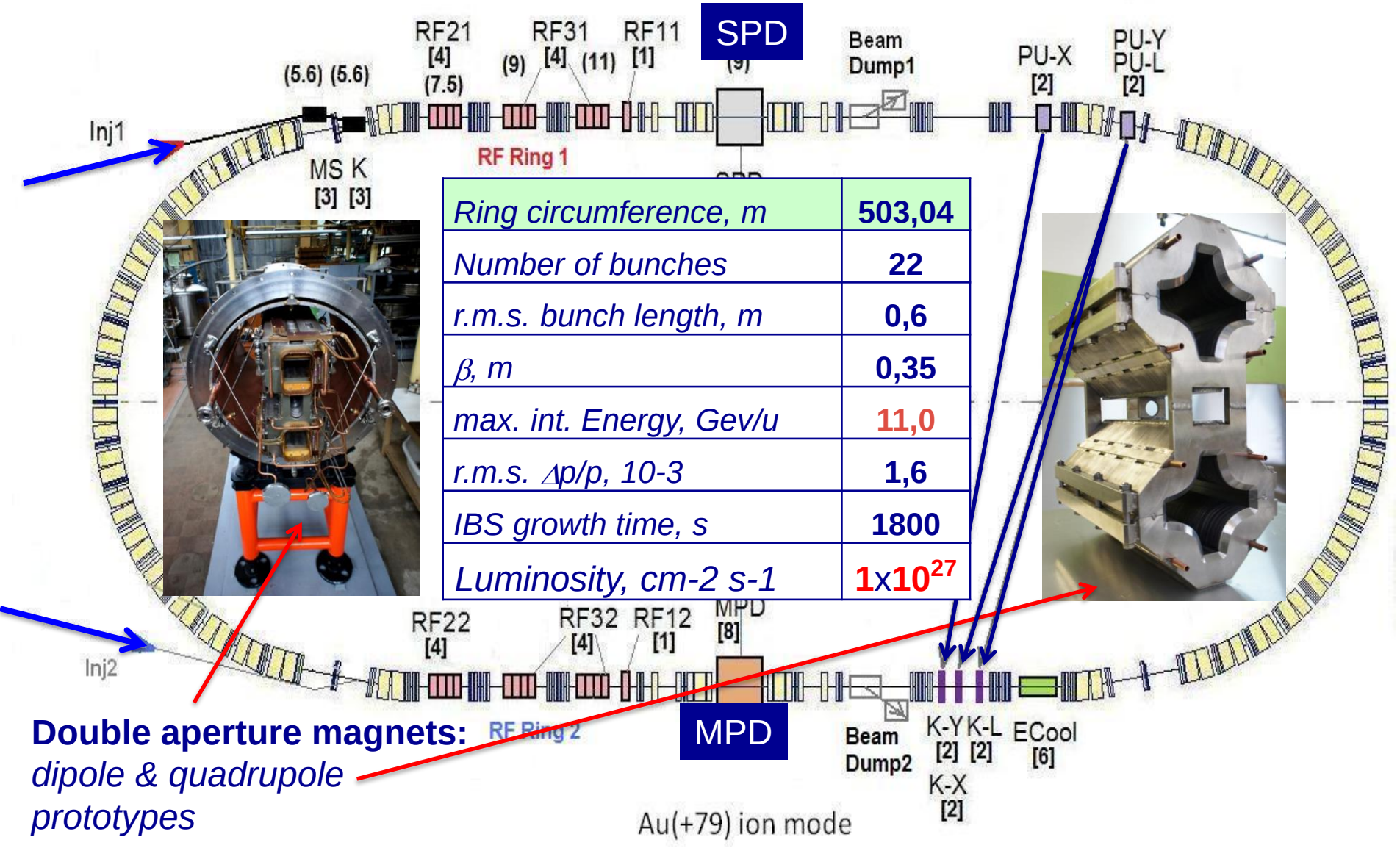

dipoles in the tunnel


section with reference magnets

The Collider

Commissioning – 2022

45 T*m, *4.5 GeV/u for* Au^{79+}



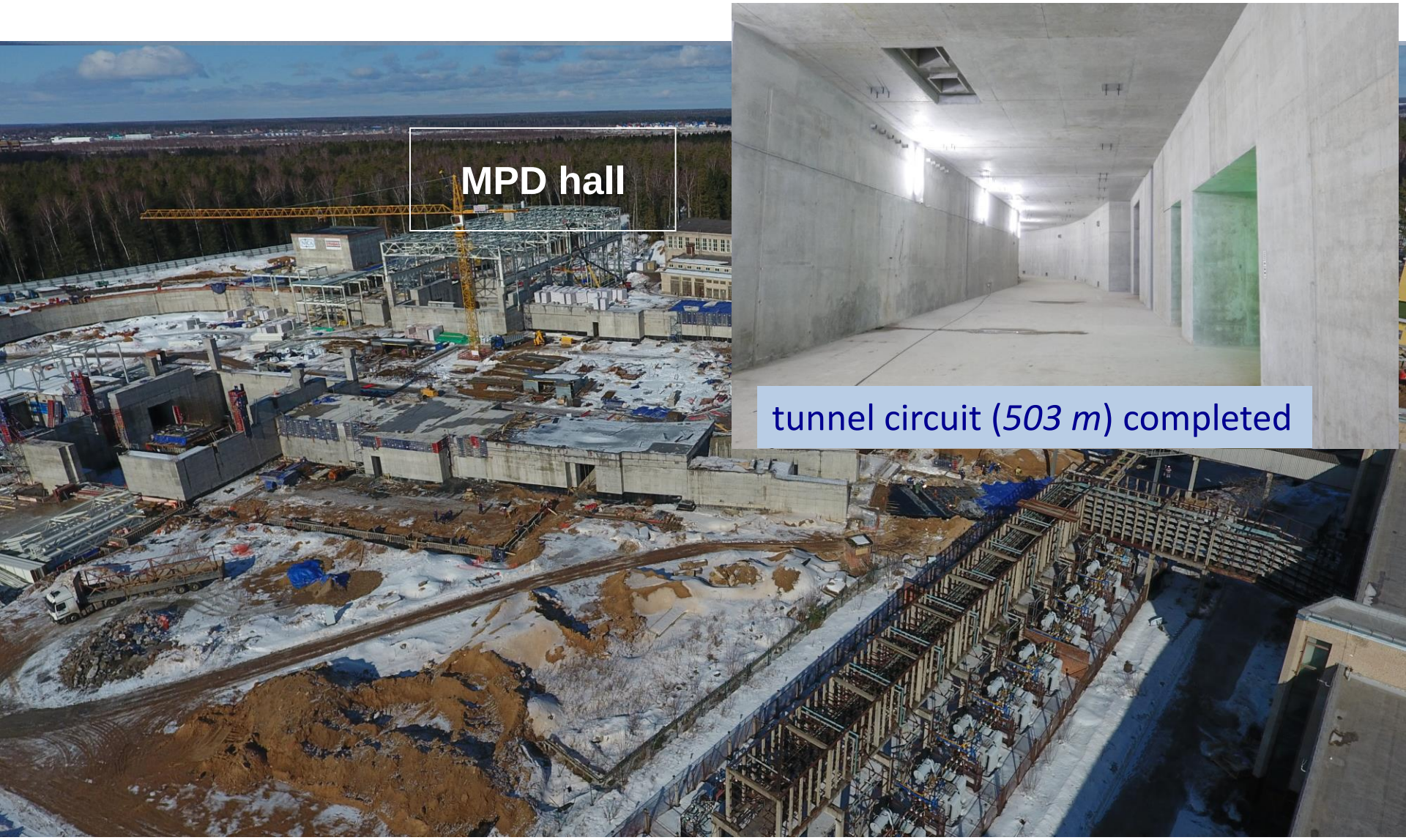
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
IBS growth time, s	**1800**
Luminosity, cm-2 s-1	**1x10^{27}**

Double aperture magnets:
dipole & quadrupole prototypes

Civil Construction 2017

Civil Construction 2019

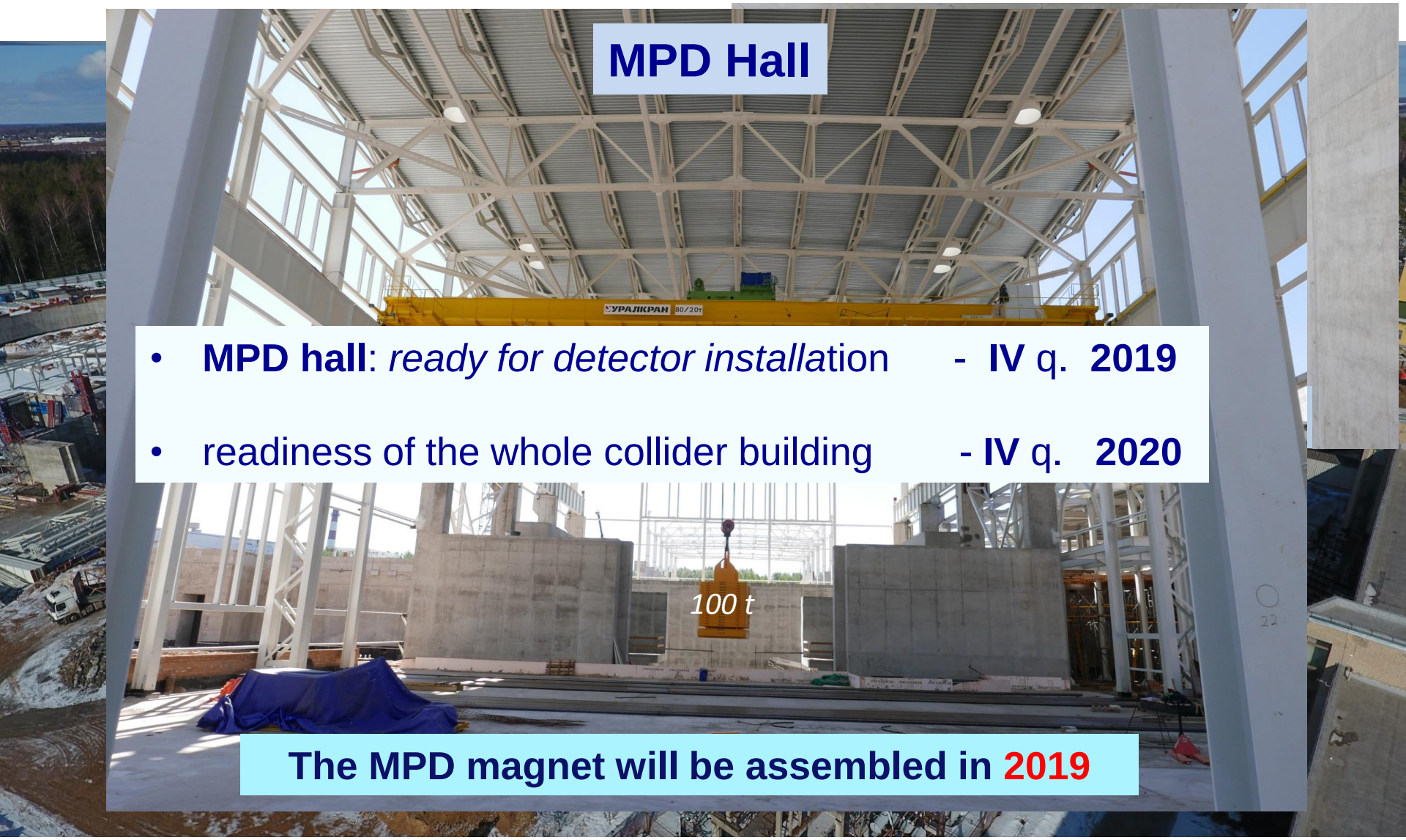
Civil Construction 2019



tunnel circuit (*503 m*) completed

Civil Construction 2019

Civil Construction 2019



- **MPD hall**: *ready for detector installation* - **IV** q. **2019**
- readiness of the whole collider building - **IV** q. **2020**

The MPD magnet will be assembled in 2019

kick-off meeting on formation of the MPD and BM@N Collaborations

carried out in Dubna on 11-13 April, 2018

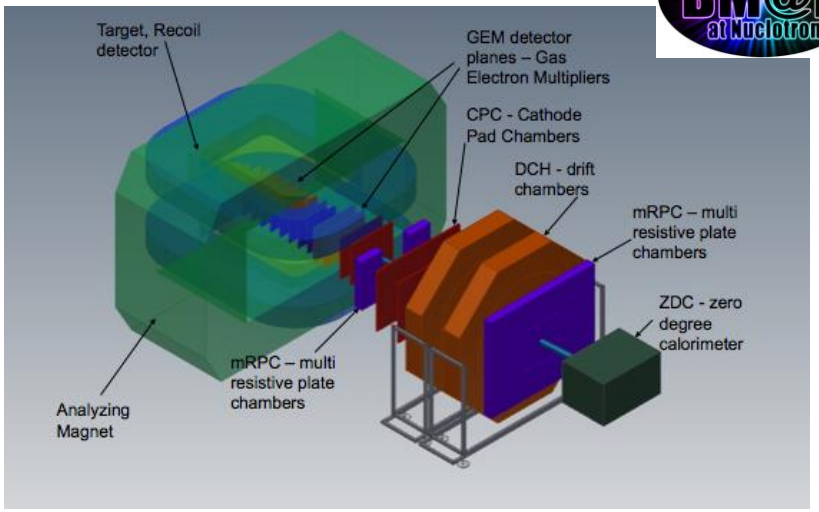
https://indico.jinr.ru/conferenceDisplay.py?ovw=True&confId=385

The II and III meetings took place in October 2018 and April 2019

Baryonic Matter at Nuclotron (BM@N) Collaboration:

11 *Countries,* ***21*** *Institutions,*
230 *paricipants*

spokesperson – ***M. Kapishin, JINR***



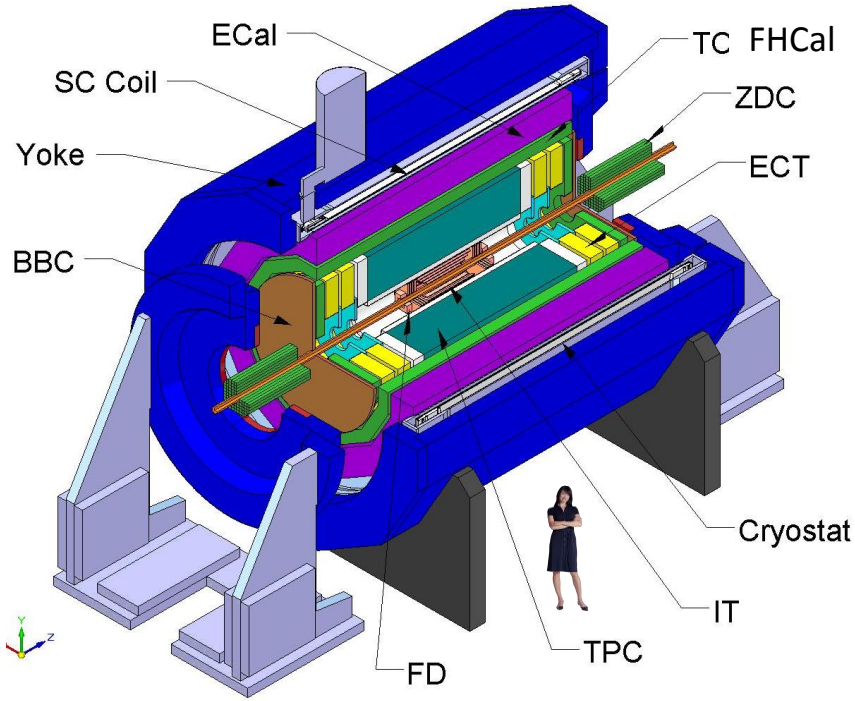
University of Plovdiv, ***Bulgaria;***
Institute of High Energy Physics, ***China;***
Shanghai Institute of Nuclear and Applied Physics, CFS, ***China;***
Tsinghua University, Beijing, ***China;***
Nuclear Physics Institute CAS, ***Czech Republic;***
Tubingen University, ***Germany;***
Tel Aviv University, ***Israel;***
Joint Institute for Nuclear Research;
Almaty Institute of Physics & Technology, ***Kazakhstan;***
Institute of Applied Physics, Chisinev, ***Moldova;***
Warsaw University of Technology, ***Poland;***
University of Wroclaw, Wroclaw, ***Poland;***
Institute of Nuclear Research RAS, Moscow, ***Russia;***
Institute of Theoretical & Experimental Physics, NRC KI, Moscow, ***Russia;***
NRC Kurchatov Institute, Moscow, ***Russia;***
Moscow Engineer and Physics Institute, ***Russia;***
Skobeltsin Institute of Nuclear Physics, MSU, ***Russia;***
Massachusetts Institute of Technology, Cambridge, ***USA.***

MPD Collaboration:

*spokesperson – **A. Kiesel WUT, Poland***

NICA

***10** Countries, **32** Institutes, **465** participants*

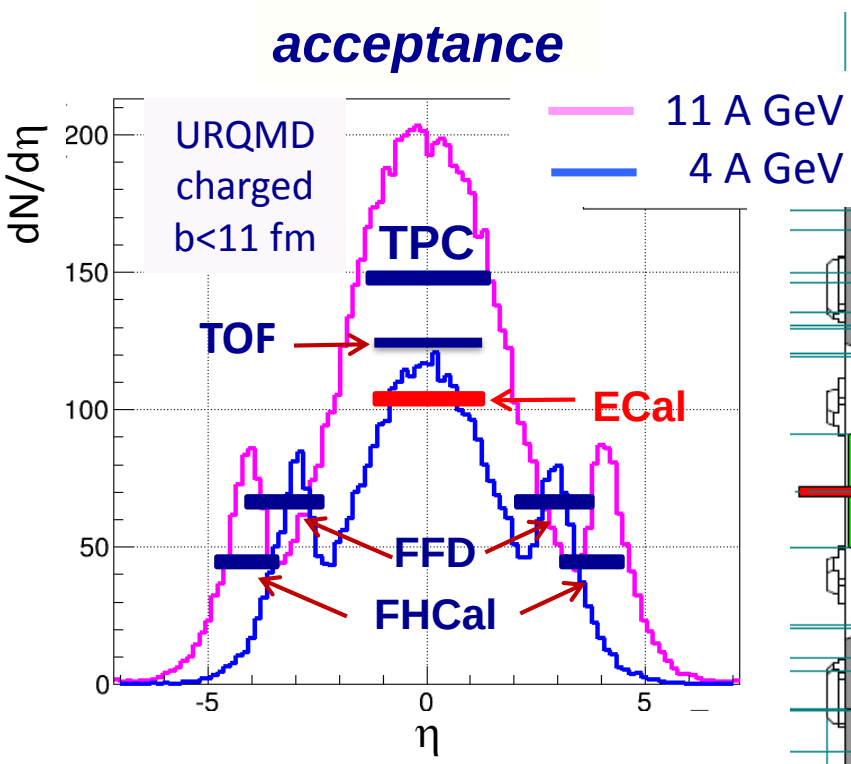


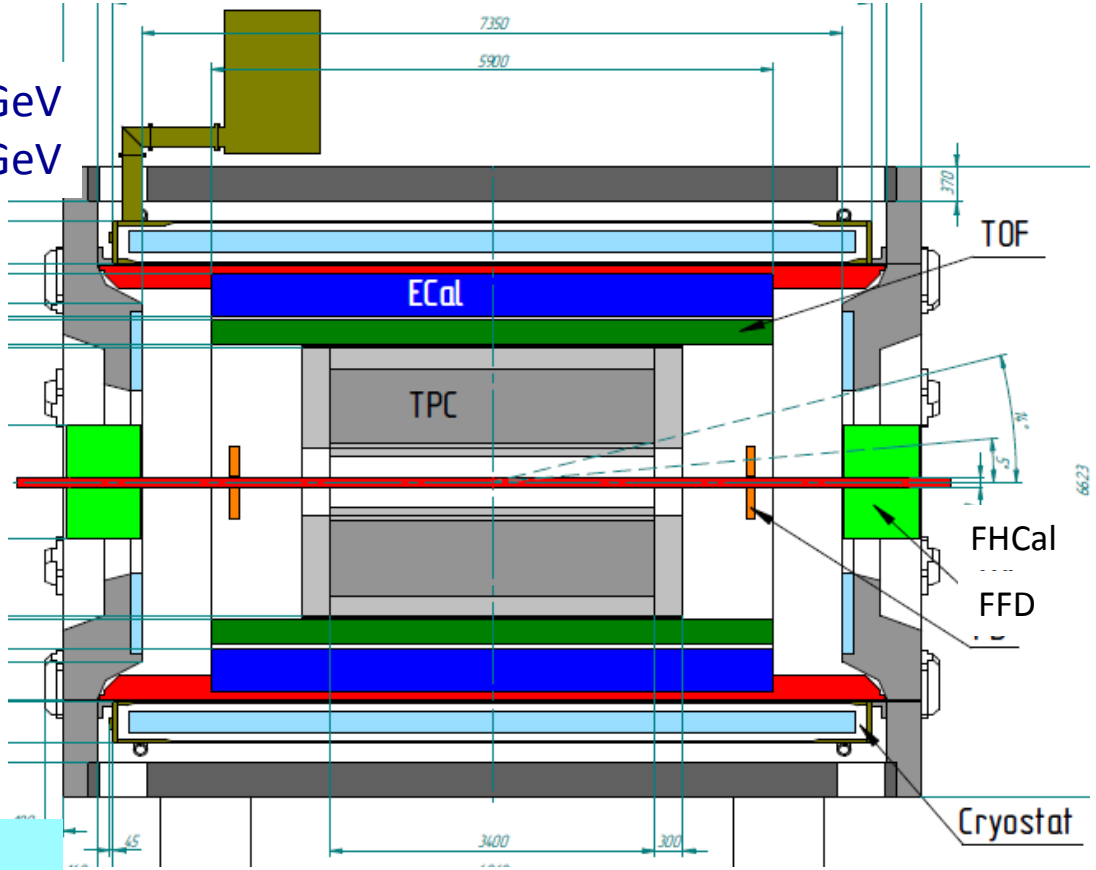
*Baku State University, NNRC, **Azerbaijan**;*
*University of Plovdiv, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chili**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huizhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*

*IHEP, Beijing, **China**;*
*University of South China, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Tubingen University, Tubingen, **Germany**;*
*Tel Aviv University, Tel Aviv, **Israel**;*
Joint Institute for Nuclear Research;
*IPT, Almaty, **Kazakhstan**;*
*UNAM, Mexico City, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*WUT, Warsaw, **Poland**;*
*NCN, Otwock – Swierk, **Poland**;*
*UW, Wroclaw, **Poland**;*
*Jan Kochanowski University, Kielce, **Poland**;*
*INR RAS, Moscow, **Russia**;*
*MEPhI, Moscow, **Russia**;*
*PNPI, Gatchina, **Russia**;*
*INP MSU, Moscow, **Russia;***
*KI NRS, Moscow, **Russia**;*
*SPSU - Dept. of NP, **Russia;***
*St. Petersburg, **Russia**;*
*SPSU – Dept. of HEP, St. Petersburg, **Russia**;*
*North Ossetia State University, Vladikavkaz, **Russia**;*

Multi-Purpose Detector (MPD)

stage I: TPC, TOF, ECAL, FHCal, FFD





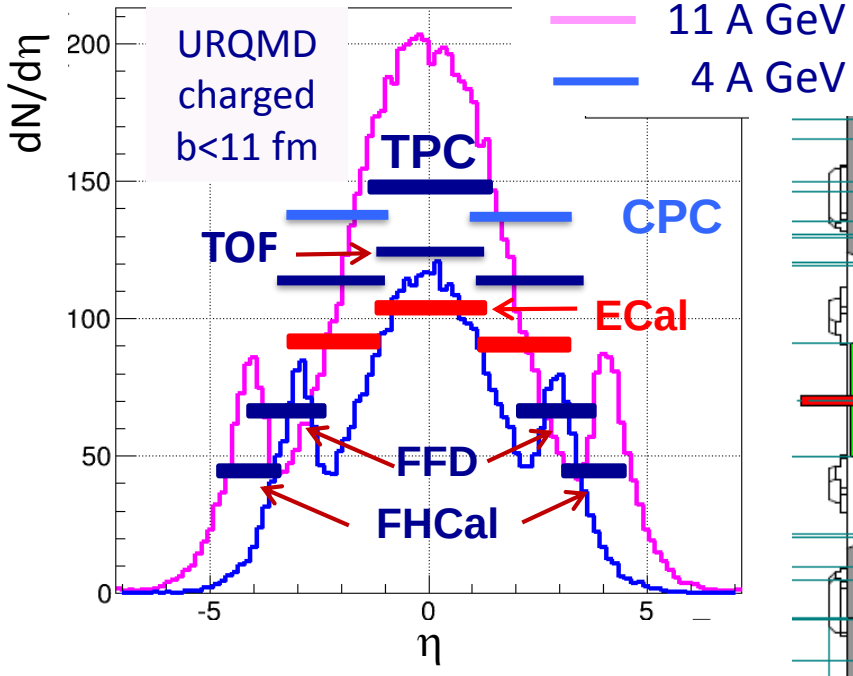
stage I: *put in operation in* ***2022***

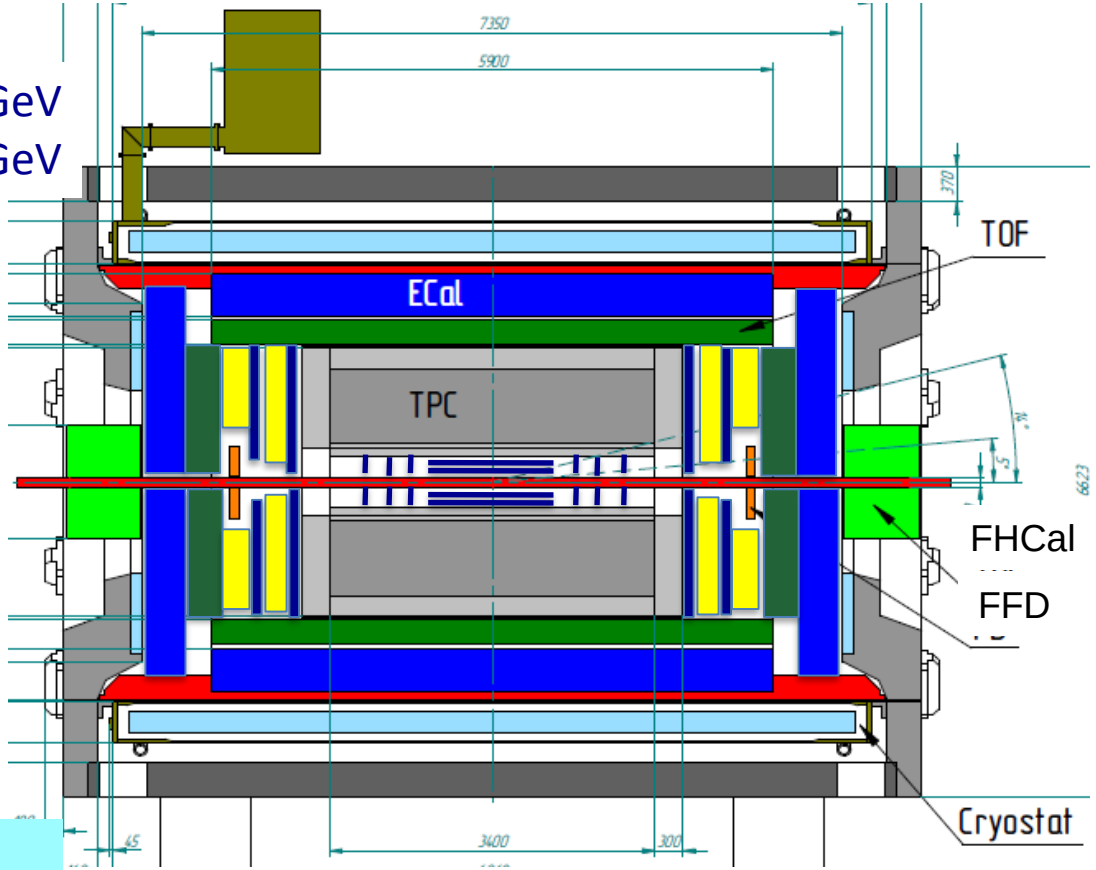
Multi-Purpose Detector (MPD)

stage I: TPC, TOF, ECAL, FHCal, FFD

stage II (2023): + ITS + EndCap (CPC, Straw, TOF, ECAL)

stage II *acceptance*



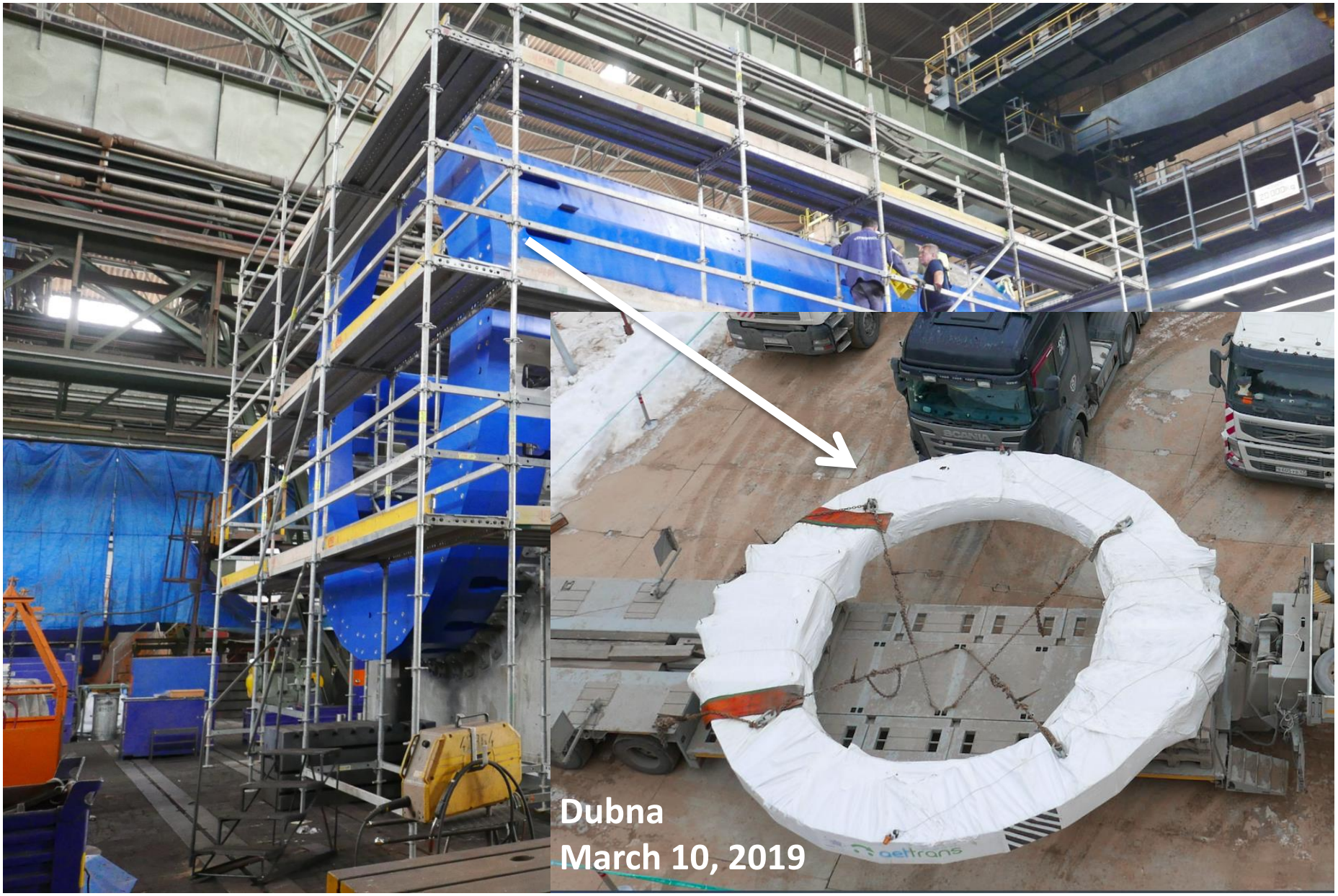


stage I: *put in operation in* ***2022***

The yoke

Control assembly at HM Vitkovice:
tolerances ~ 0,5 mm

The yoke



The SC Coil and cold mass

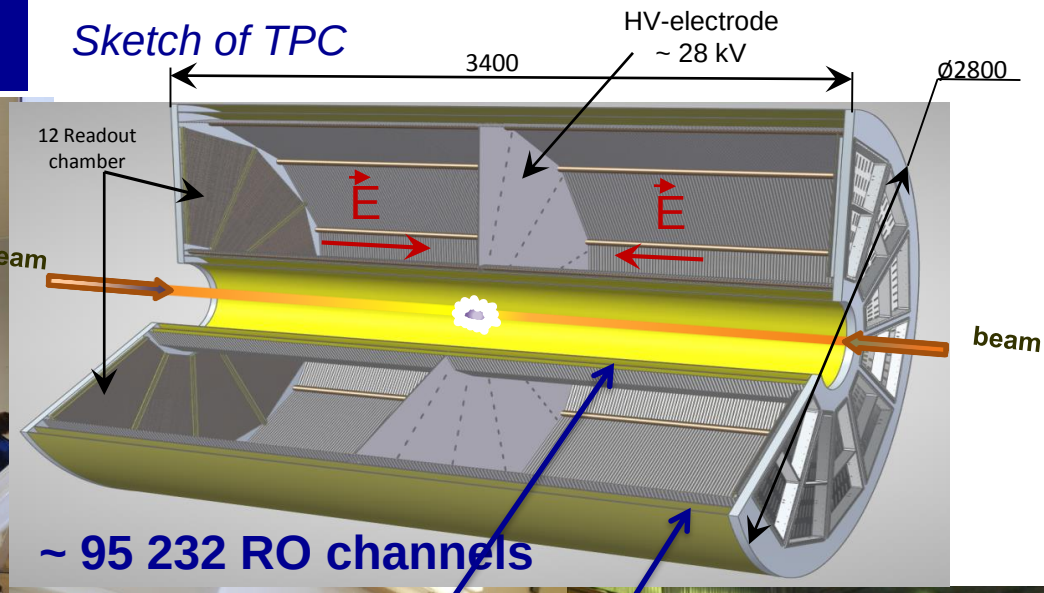
The SC Coil and cold mass

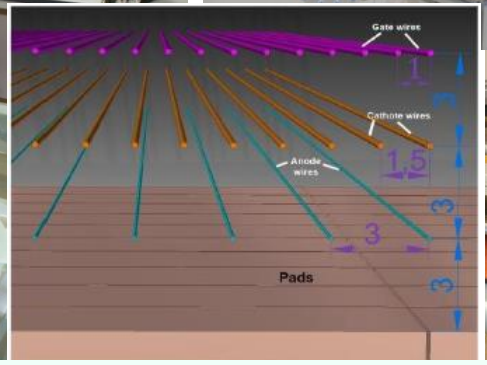
module assembly

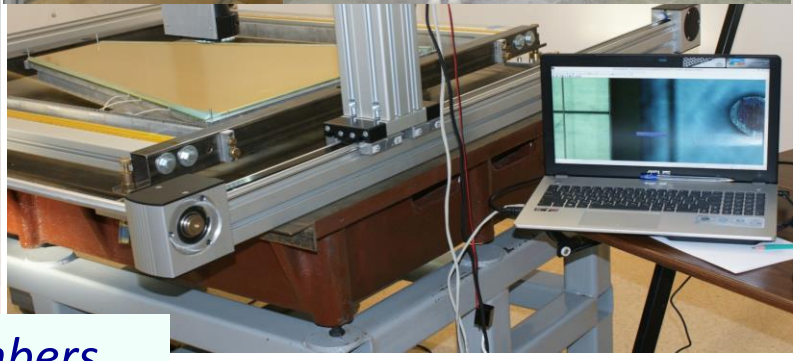
TPC: *assembly stage*

assembly workshop (clean room) & tooling

Sketch of TPC

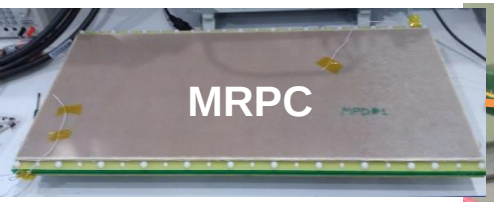






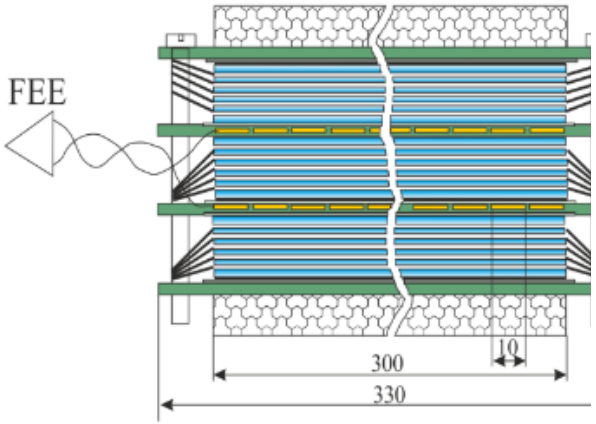
production of RO Chambers

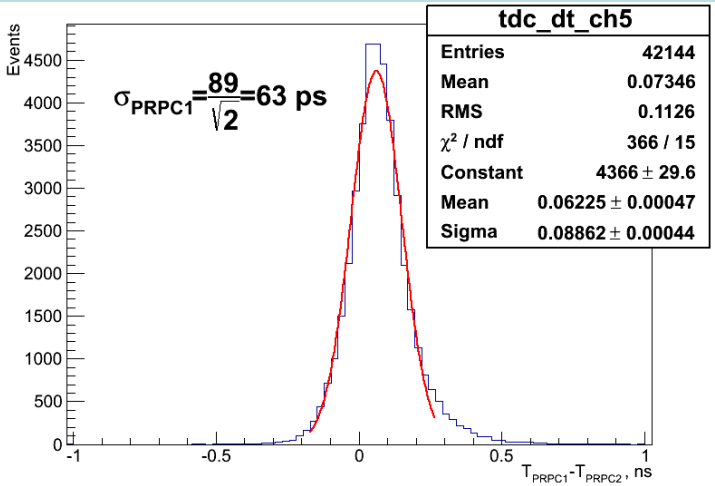
TOF Barrel: MRPC ready for mass production



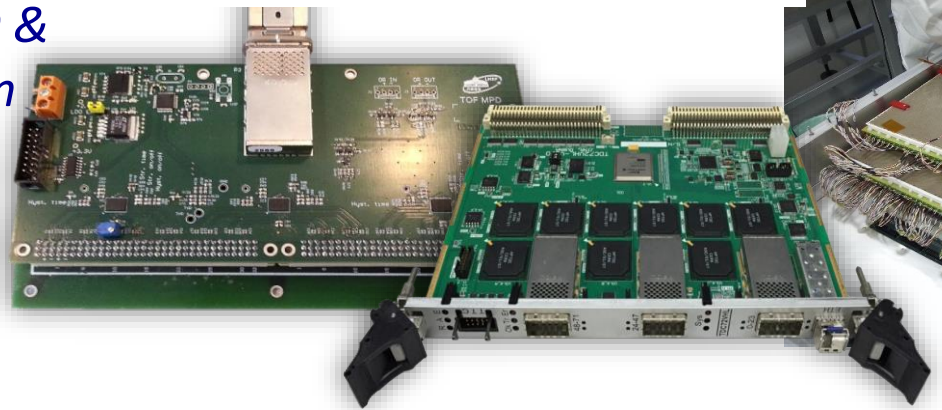
28 modules
280 MPRC's
13 440 channels

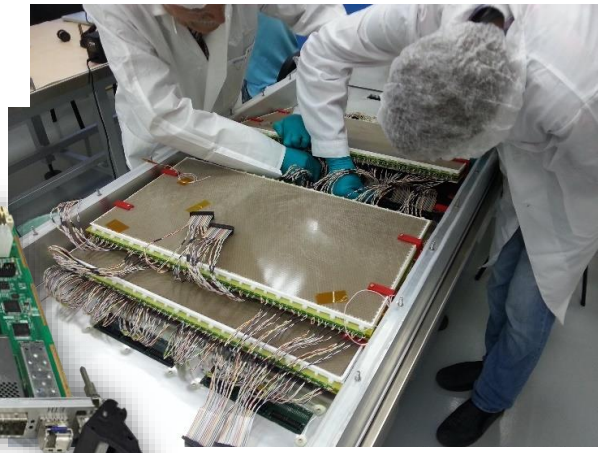
workshop for the MRPC mass-production





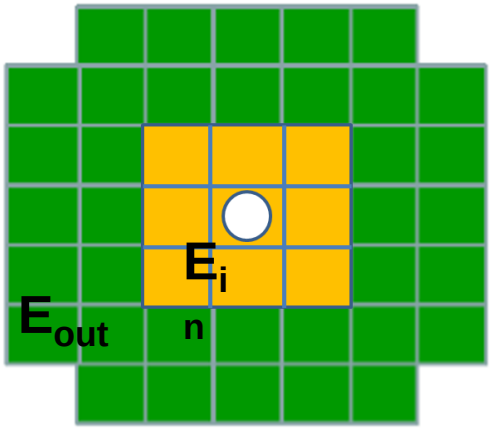
basic elements - NINO & HPTDC chips have been Purchased to produce read-out electronics for the TOF + reserve





FHCAL: for determination of reaction plane and centrality

*responsibility of **INR RAS***

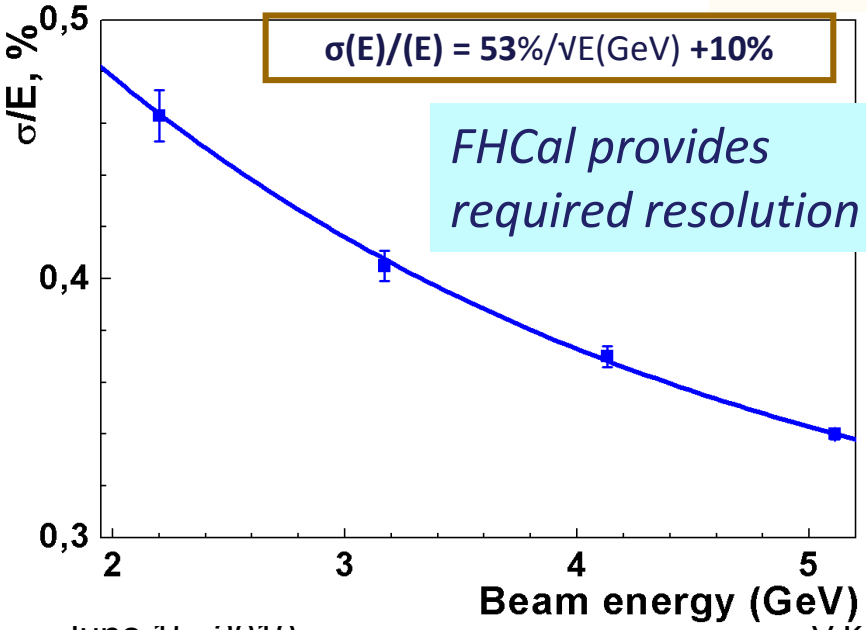


- 2-arm (left/right) calorimeter (at ~3.2 m from the IP)
- arm consists of 45 modules - 15x15 cm^2 each
- module - 42 lead/scintillator layers

FHCal coverage: $2.2<|\eta|<4.8$

Transverse granularity allows to measure:

- *the reaction plane with the accuracy* **~ 20^0-30^0**
- *the centrality with accuracy below* **10%.**

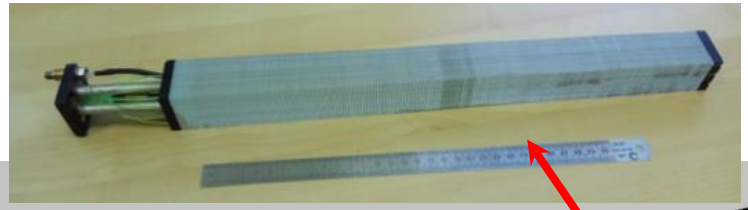


FHCal provides required resolution

modules production – in progress

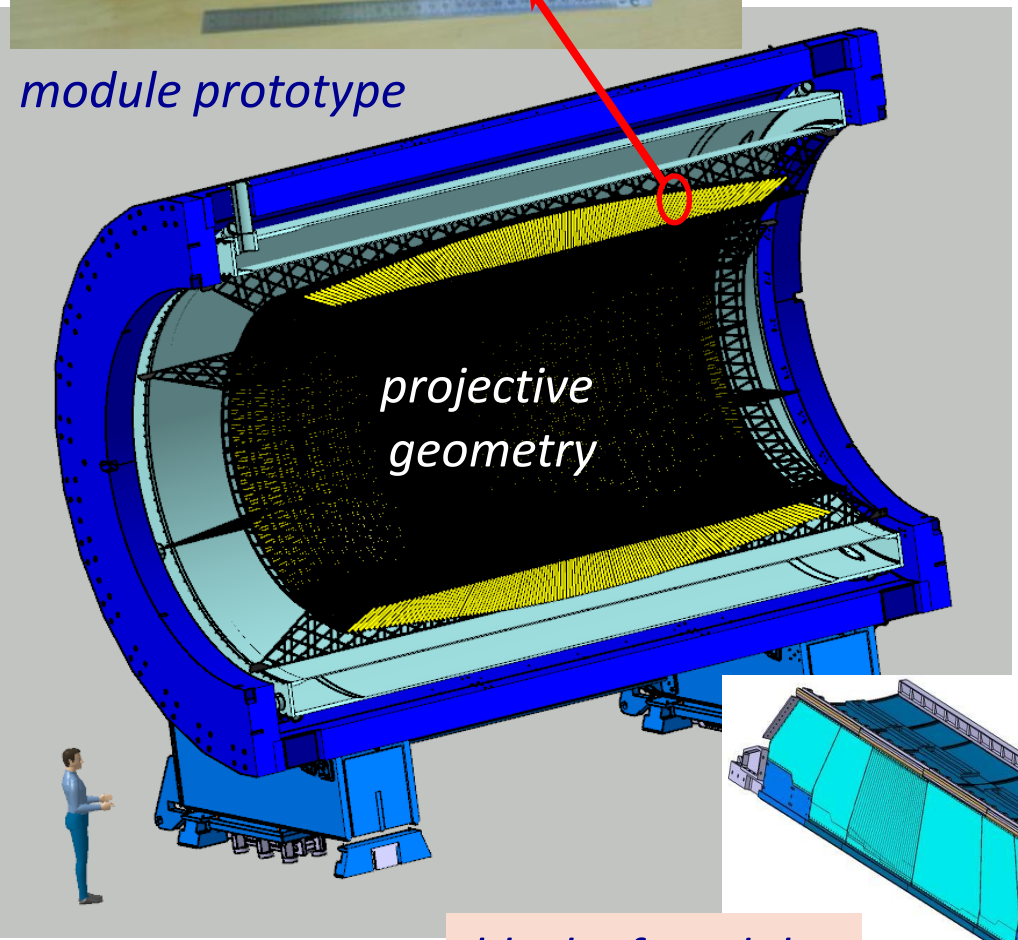
ECAL: *common project with* ***Tsinghua University,*** *China*

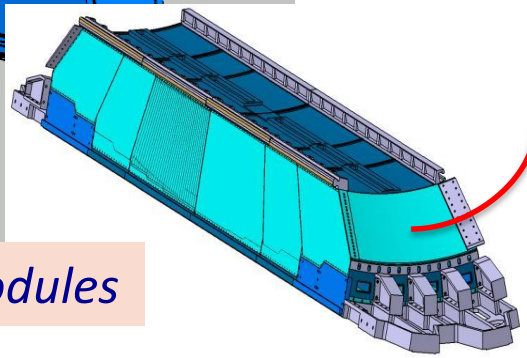
ECAL ~ **43 000** modules of various shapes



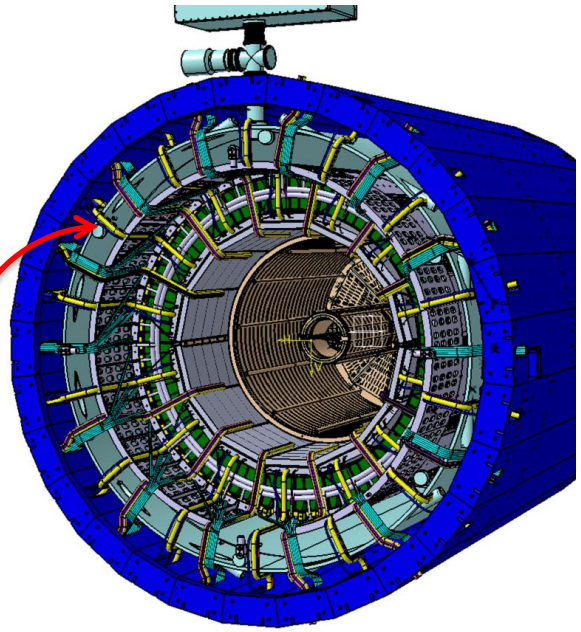
module prototype

- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2),*
- *σ(E) better than 5% @ 1 GeV;*
- *time resolution ~500 ps*





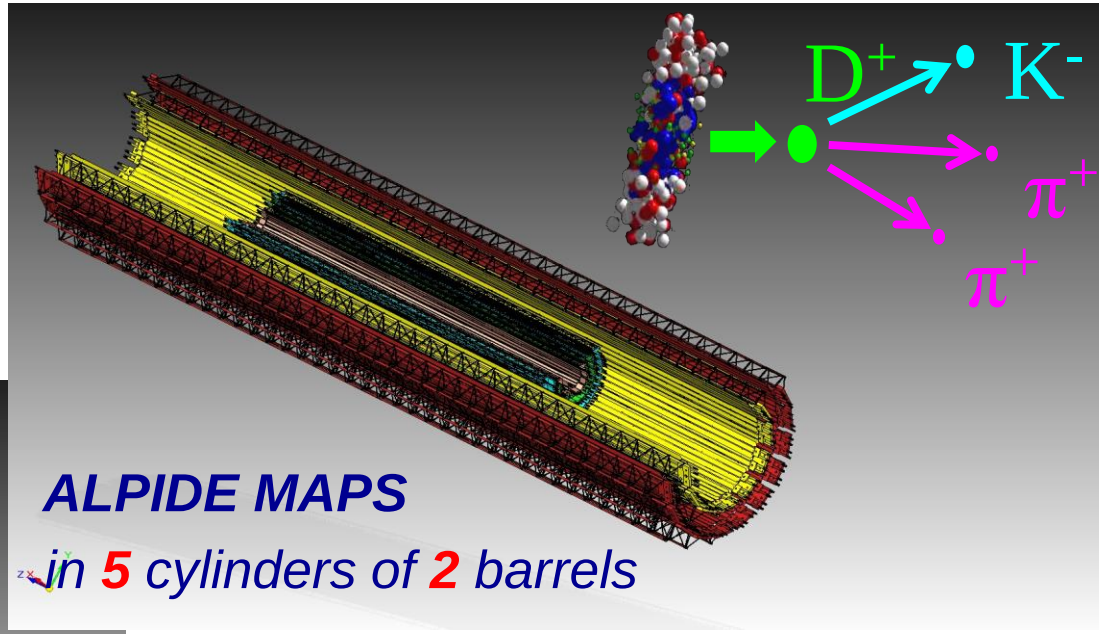
block of modules



Inner Tracker System

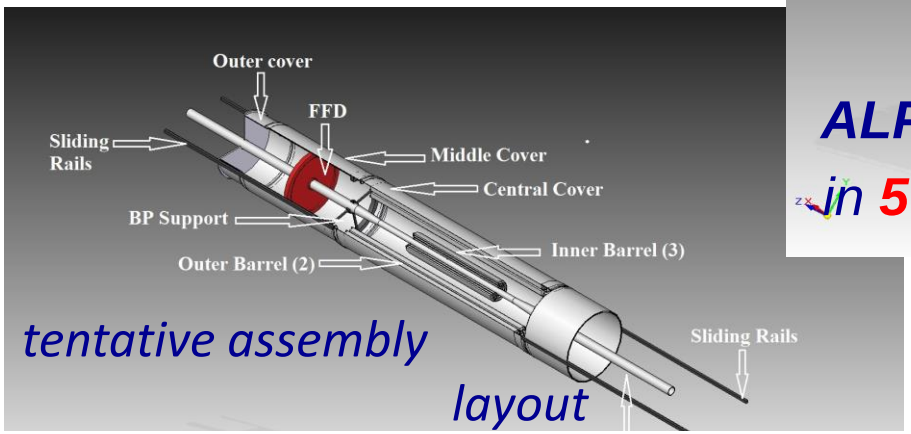
*technology from **ALICE / CERN***

- ***MAPS** of new **ALICE ITS***
- *carbon fiber space frames;*



ALPIDE MAPS

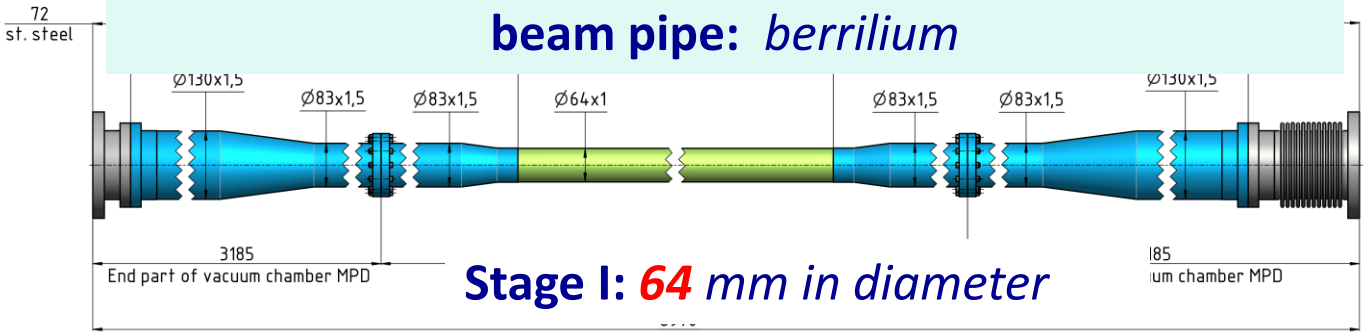
*in **5** cylinders of **2** barrels*



tentative assembly layout

***4,9 ·10⁹** pixels, active area **3,9 m²**.*

beam pipe: *berrilium*



Stage I: ***64** mm in diameter*

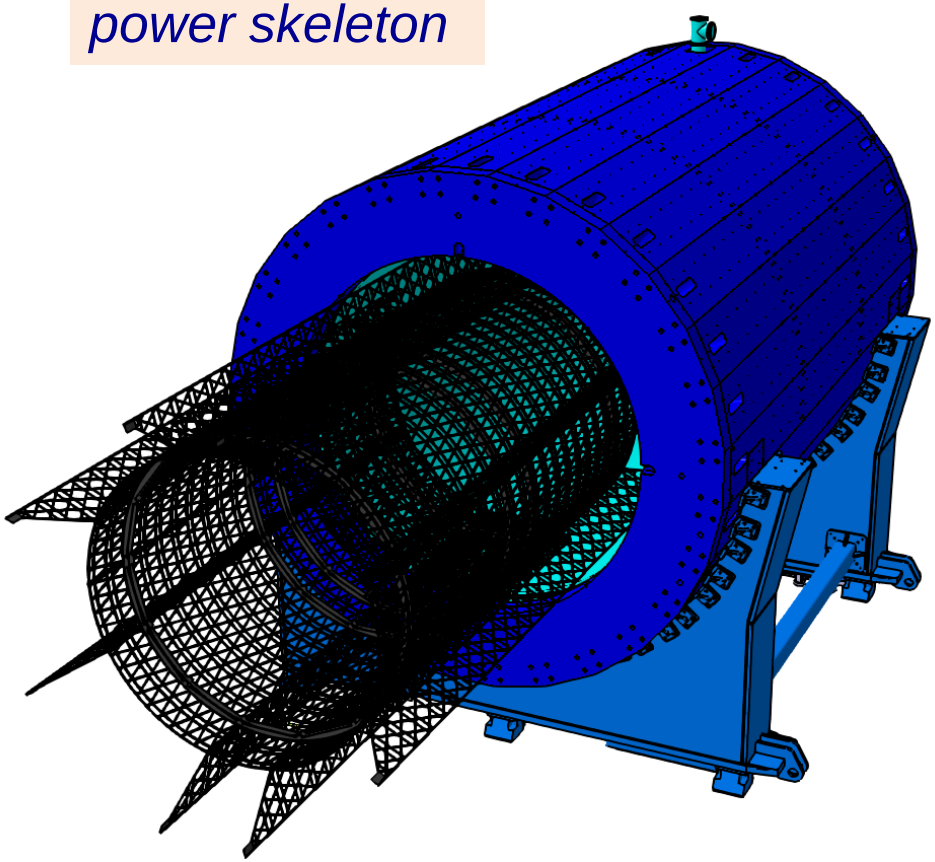
Stage II:

***38** mm in diameter*

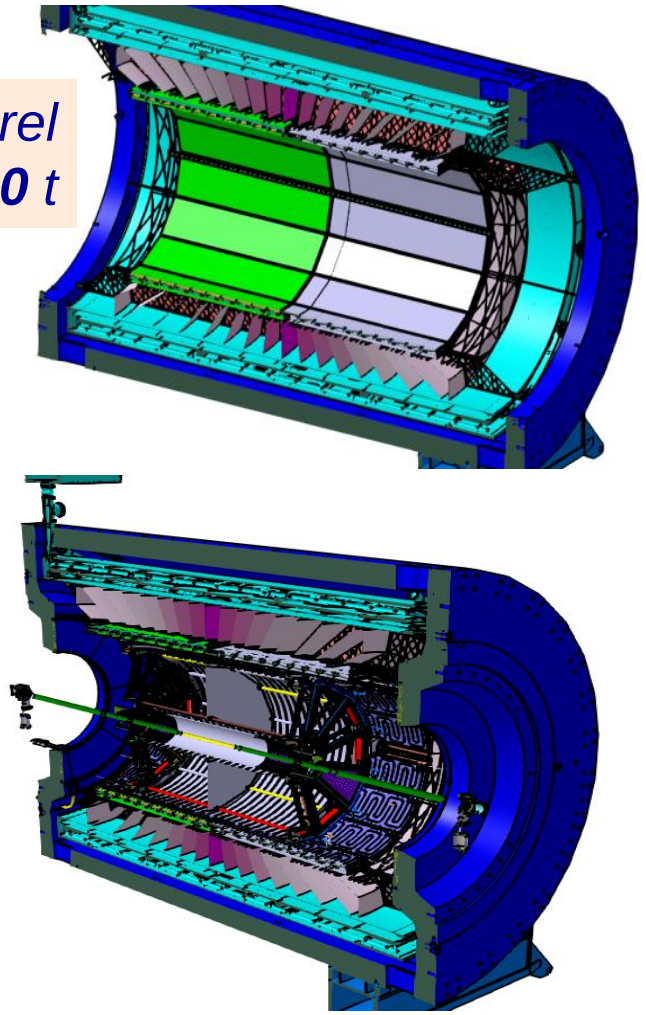
Integration

support structure of carbon fiber

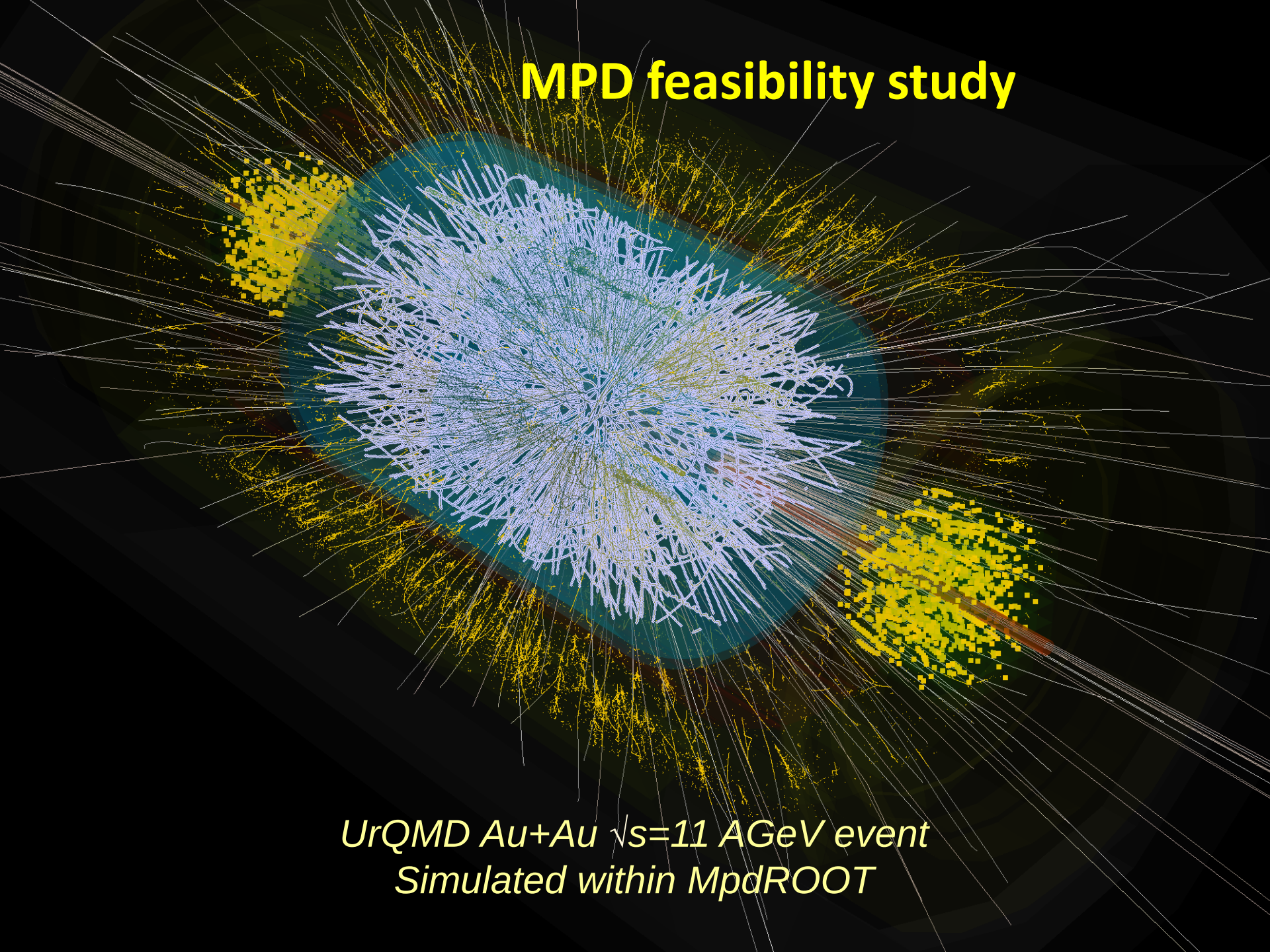
power skeleton



***ECal** barrel*
*~ **100** t*



MPD feasibility study



UrQMD Au+Au √s=11 AGeV event
Simulated within MpdROOT

MPD Physiscs Working Groups

PWG1
Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Vertex determination
- Event plane measurement at all rapidities
- Spectator measurement

PWG2
Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase diagram

PWG3
Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

PWG4
Electromagnetic probes

- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra and search for in-medium modification of resonances and intermediate mass region

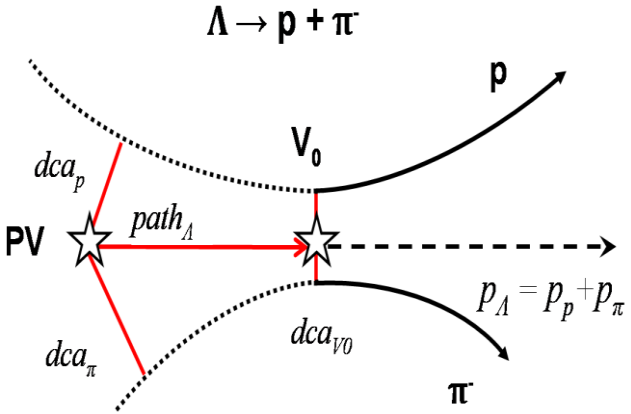
PWG5
Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Study of hyperons

V. Vasendina, A. Zinchenko, V. Kolesnikov

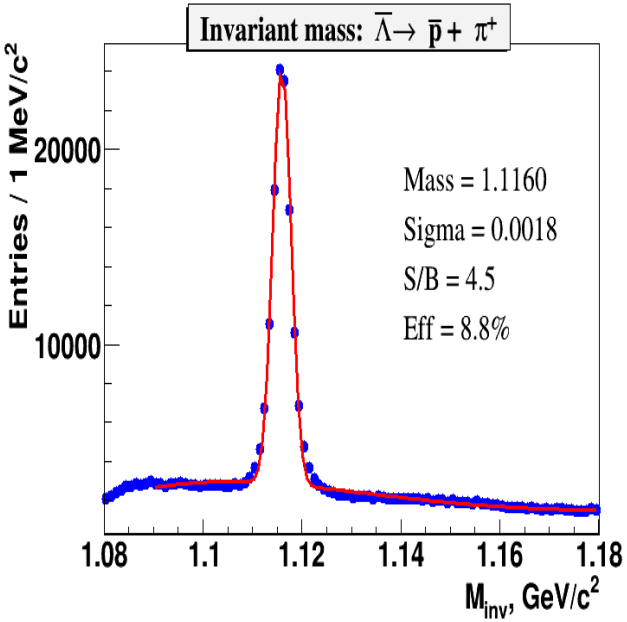
- ***8****M minbias Au+Au @ 11 GeV (PHSD model)*
- *TPC & TOF, $|\eta|< 1.3$*
- *track reconstruction and PID (dE/dx+TOF)*
- *secondary vertex finding technique*

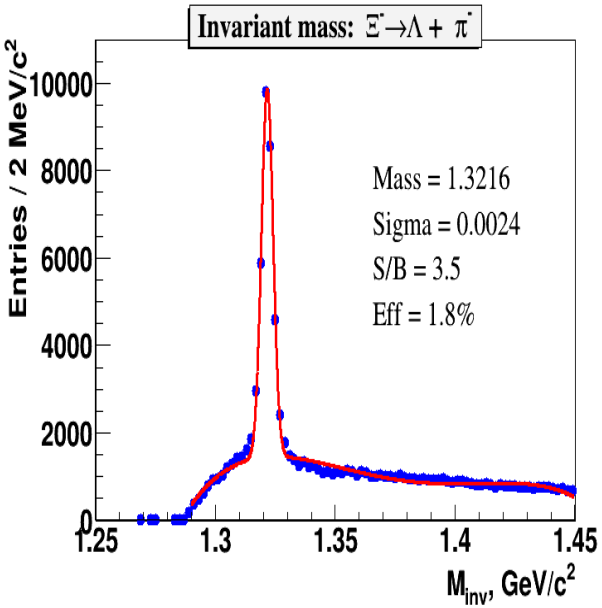


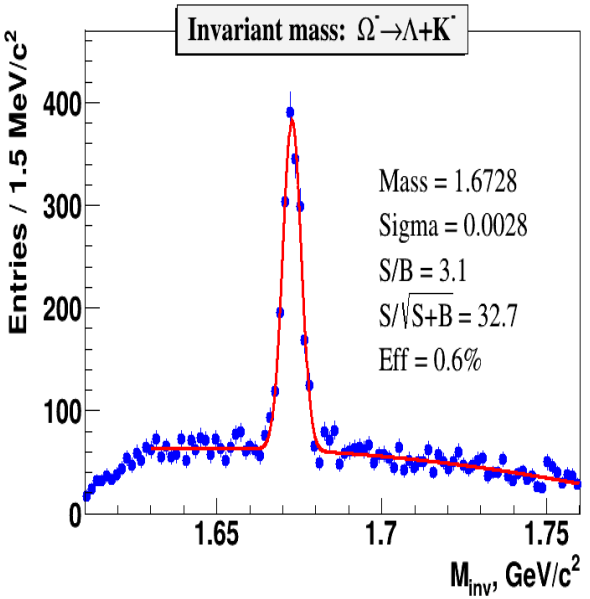
PV *- primary vertex;*
V0 *- vertex of decay;*
dca- *distance of closest approach;*
path *– decay length*

Yields for 10 weeks of running

Λ	Λ	Ξ^-	Ξ^+	Ω^-	Ω^+
$6\ 10^9$	$7.3\ 10^7$	$3\ 10^7$	$1\ 10^6$	$1\ 10^6$	$3\ 10^5$

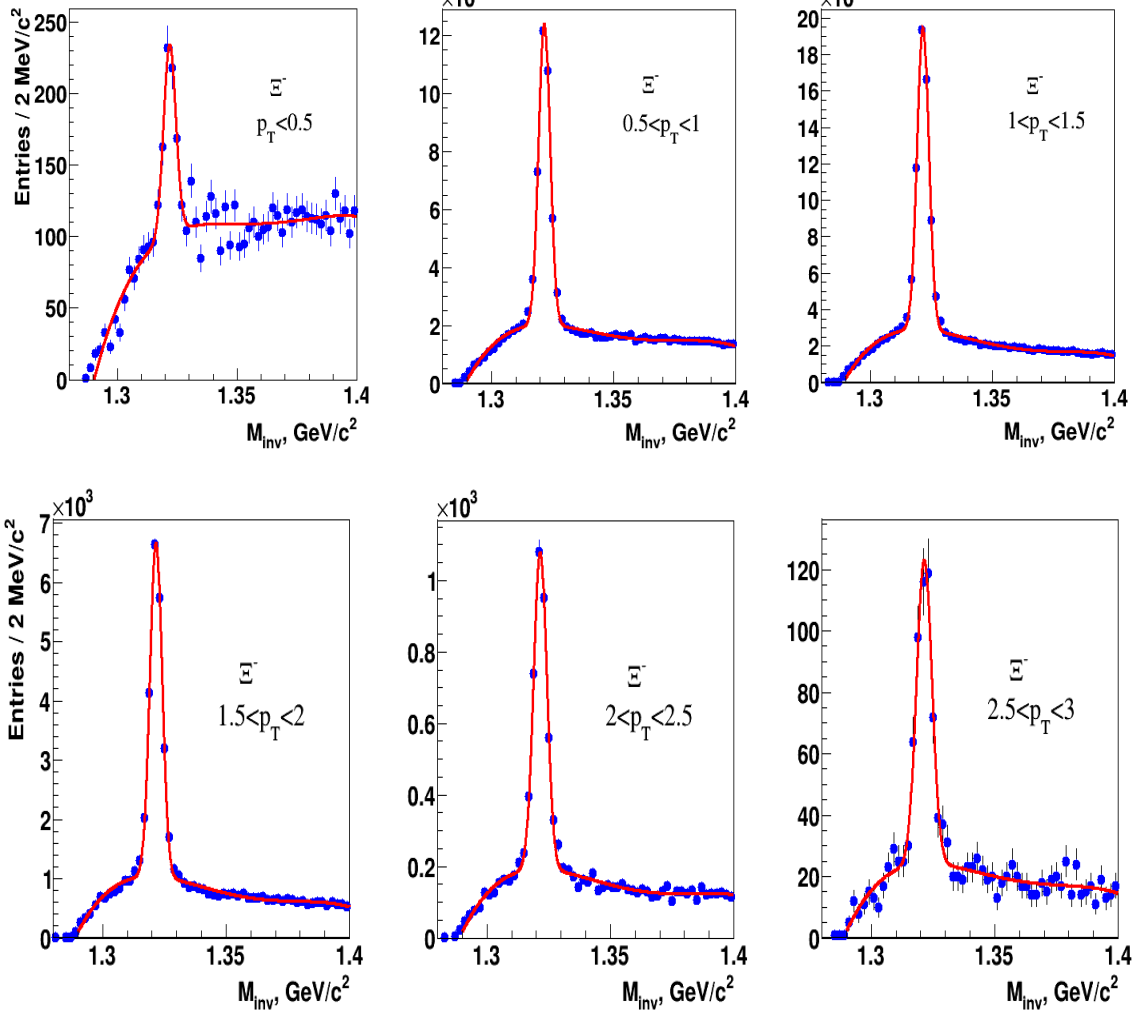


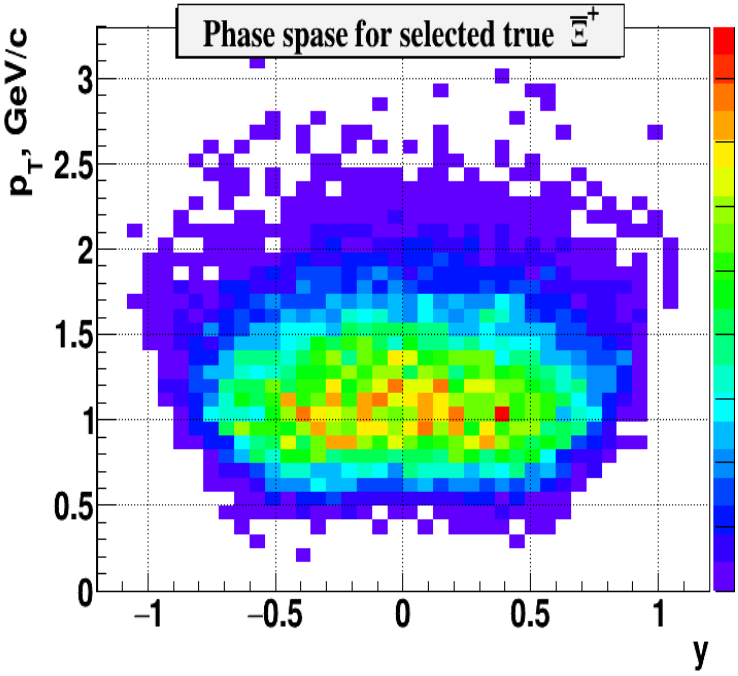


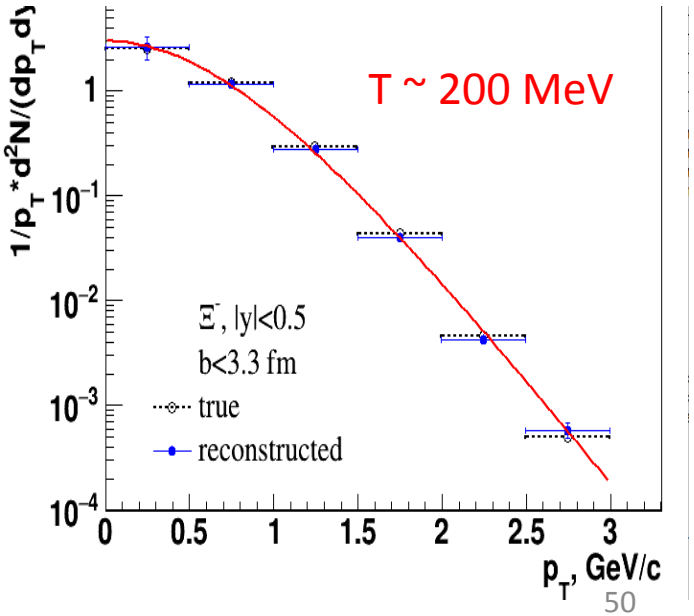


Ξ^- reconstruction, phase space, invariant spectra

- *reconstruction of hyperons in pT intervals*
- *invariant pT-spectra in centrality bins*





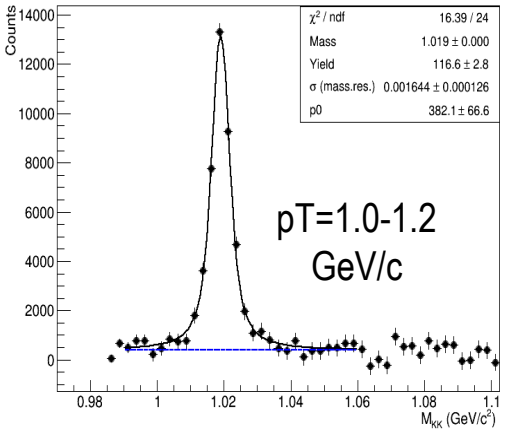


Resonances

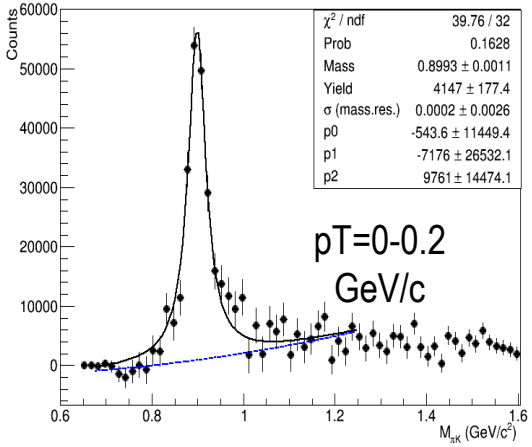
D. Ivanishchev, D. Kotov, M. Malaev, V. Riabov, Yu. Ryabov

- *Minbias Au+Au@11 (UrQMD modle)*
- *Full event reconstruction and realistic PID*
- *Topoly cuts and secondary vertex finding for hyperons*
- *Event mixing for background estimation*

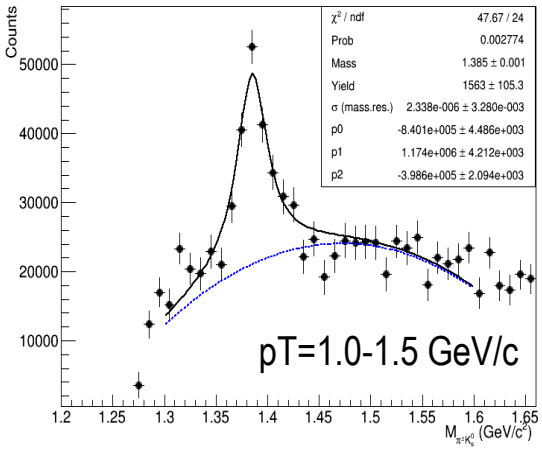
$\phi(1020) \rightarrow K^+K^-$,



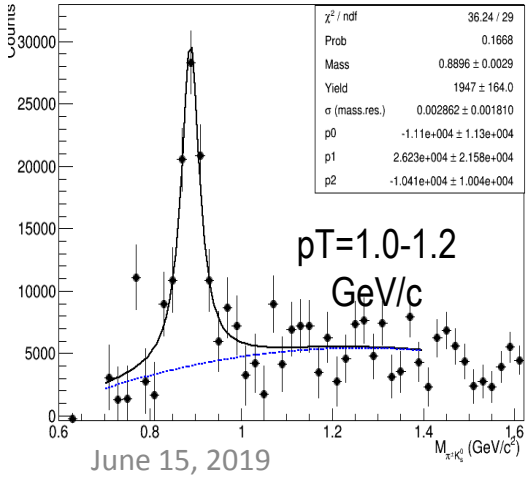
$K^*(892)^0 \rightarrow K^{\pm}\pi^{\pm}$



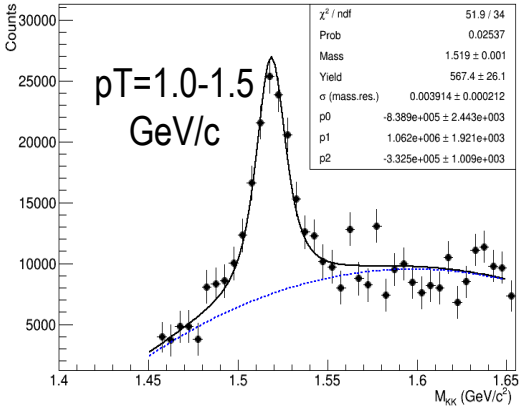
$\Sigma(1385)^{\pm} \rightarrow \pi^{\pm}\Lambda$ ($\Lambda \rightarrow p\pi$)



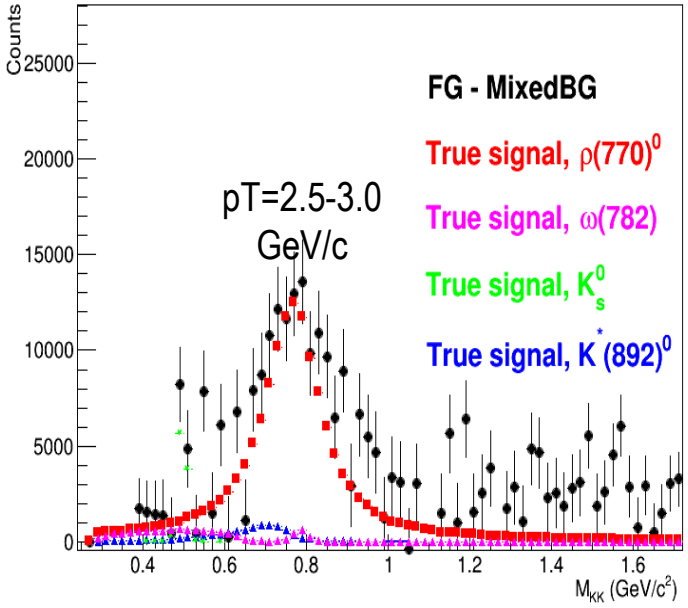
$K^*(892)^{\pm} \rightarrow \pi^{\pm}K_s$ ($K_s \rightarrow \pi^+\pi^+$)



$\Lambda(1520) \rightarrow pK^-$



$\rho(770)^0 \rightarrow \pi^{\pm}\pi^{\pm}$,

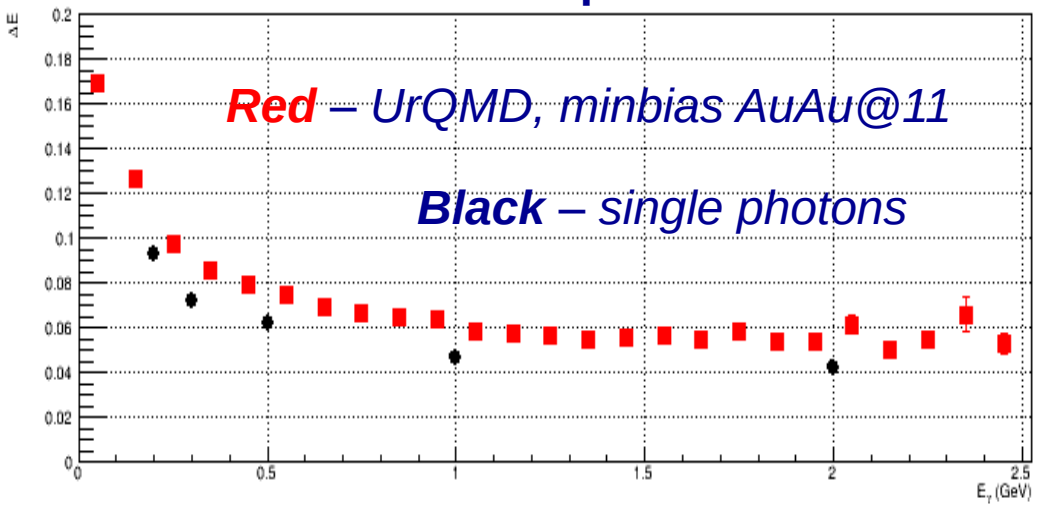


ECAL simulation

V. Riabov, A. Zinchenko, M. Martemyanov, V. Kulikov

*Realistic ECAL reconstruction & analysis – large acceptance **ECAL** of good energy resolution is an ideal tool for measurement of neutral mesons in a wide momentum range*

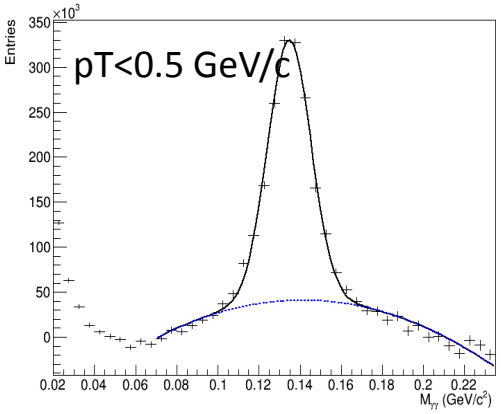
ECAL resolution for photons

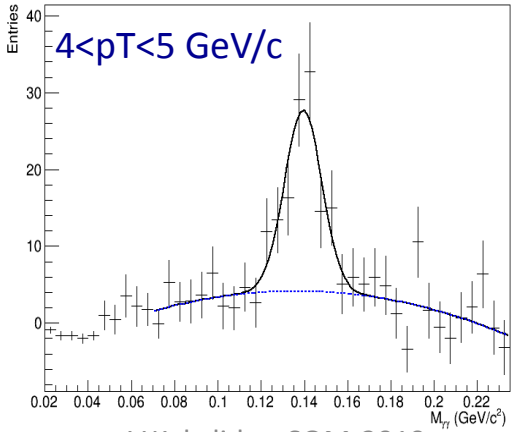


***Red** – UrQMD, minbias AuAu@11*

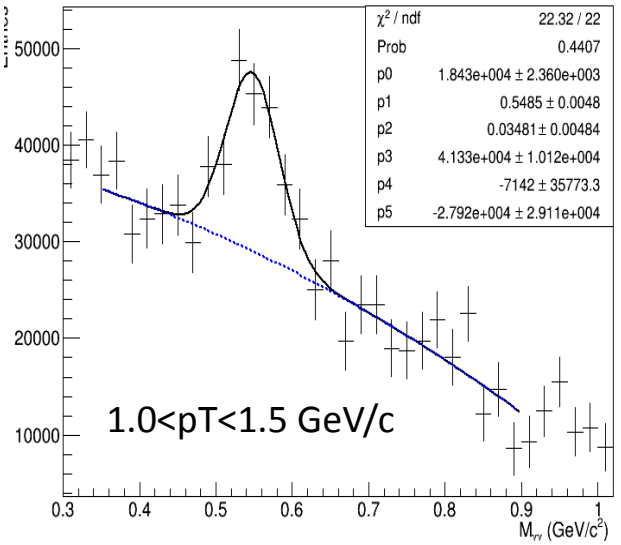
***Black** – single photons*

π^0-meson in central Au+Au





η-meson in minbias Au+Au

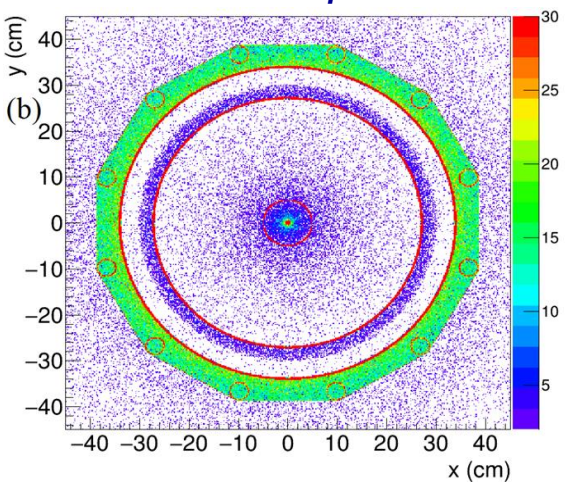


π^0 (η) reconstruction with ECAL – feasible!

π^0 and η reconstruction via conversion

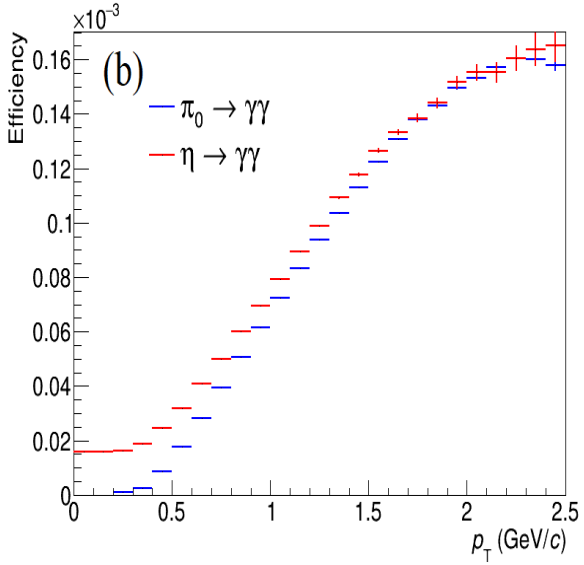
D. Ivanishchev, D. Kotov, E. Kryshen, M. Malaev, V. Riabov, Yu. Ryabov

conversion points

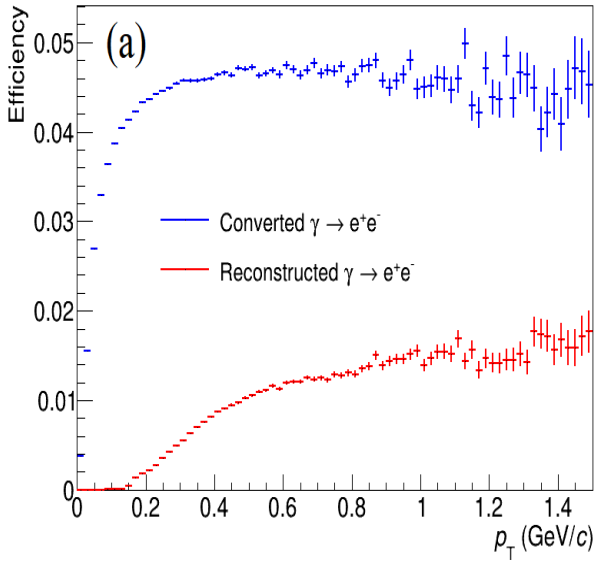


- *Photon reconstruction, complimentary to ECAL*
- *Direct photons, neutral mesons, geometry scan etc.*
- *Minbias AuAu@11, UrQMD - conversion on the beam pipe and inner layers of the TPC*

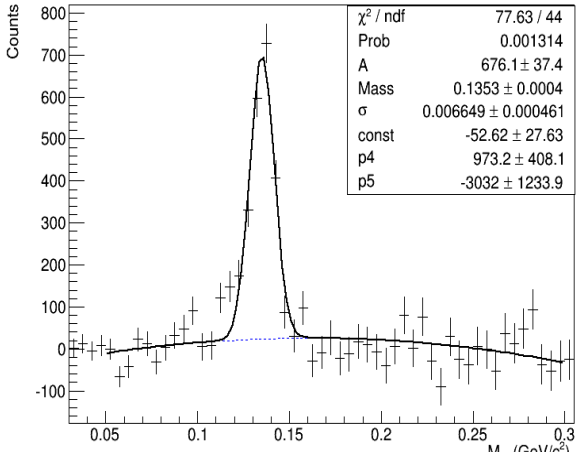
π^0 & η reconstruction efficiency vs pT



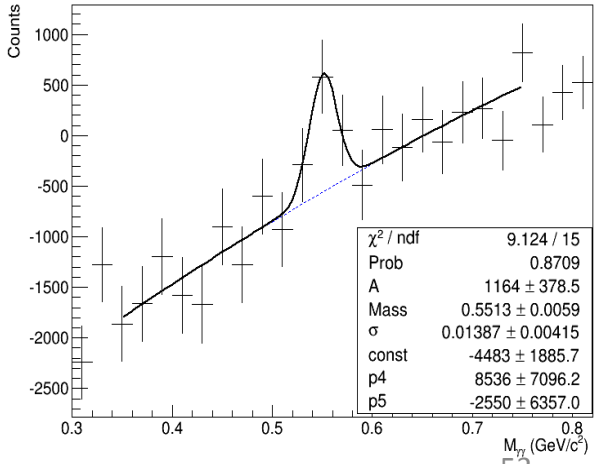
γ-conversion efficiency in the beam pipe & TPC vs pT



$\pi^0 \to \gamma\gamma \to (e^+e^-)(e^+e^-)$



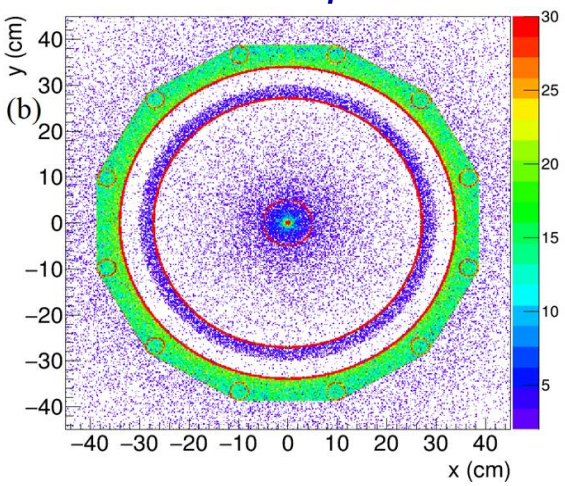
$\eta \to \gamma\gamma \to (e^+e^-)(e^+e^-)$



π^0 and η reconstruction via conversion

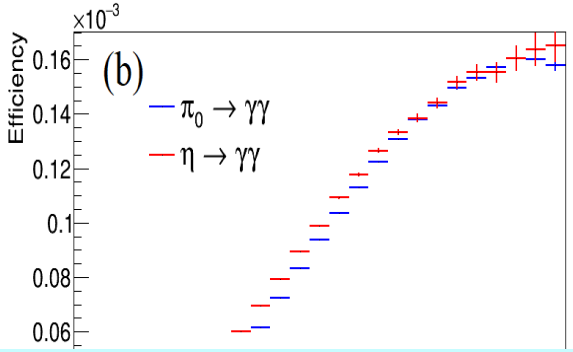
D. Ivanishchev, D. Kotov, E. Kryshen, M. Malaev, V. Riabov, Yu. Ryabov

conversion points

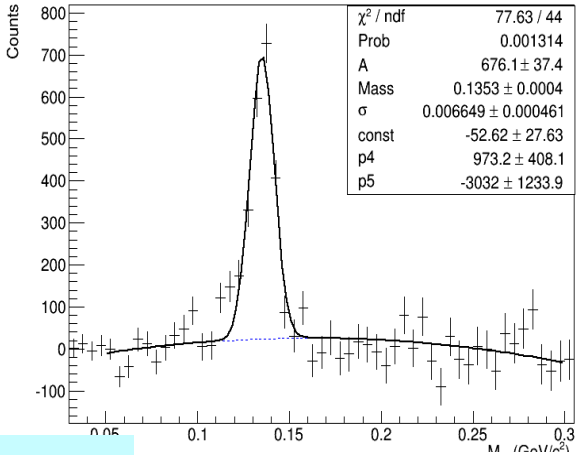


- *Photon reconstruction, complimentary to ECAL*
- *Direct photons, neutral mesons, geometry scan etc.*
- *Minbias AuAu@11, UrQMD - conversion on the beam pipe and inner layers of the TPC*

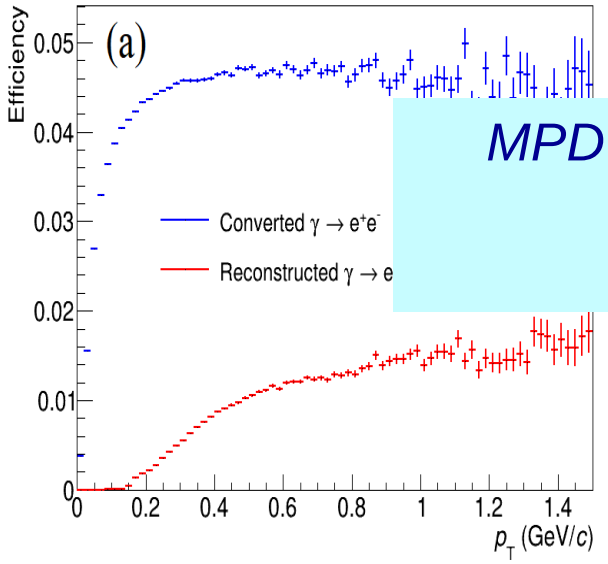
π^0 & η reconstruction efficiency vs pT



$\pi^0 \to \gamma\gamma \to (e^+e^-)(e^+e^-)$

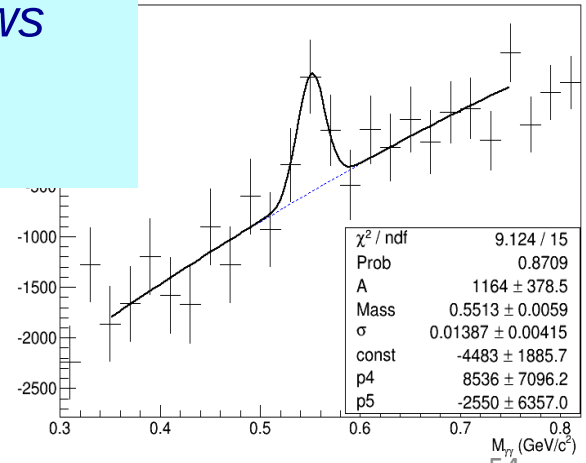


γ-conversion efficiency in the beam pipe & TPC vs pT



MPD standard configuration allows to reconstruct π^0 and η via conversion pairs

$\eta \to \gamma\gamma \to (e^+e^-)(e^+e^-)$



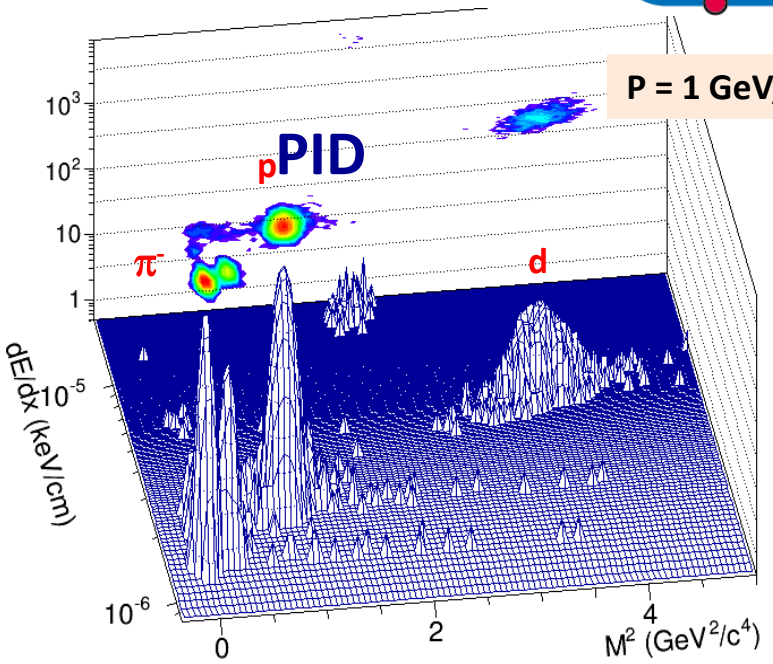
Hypernuclei @ MPD

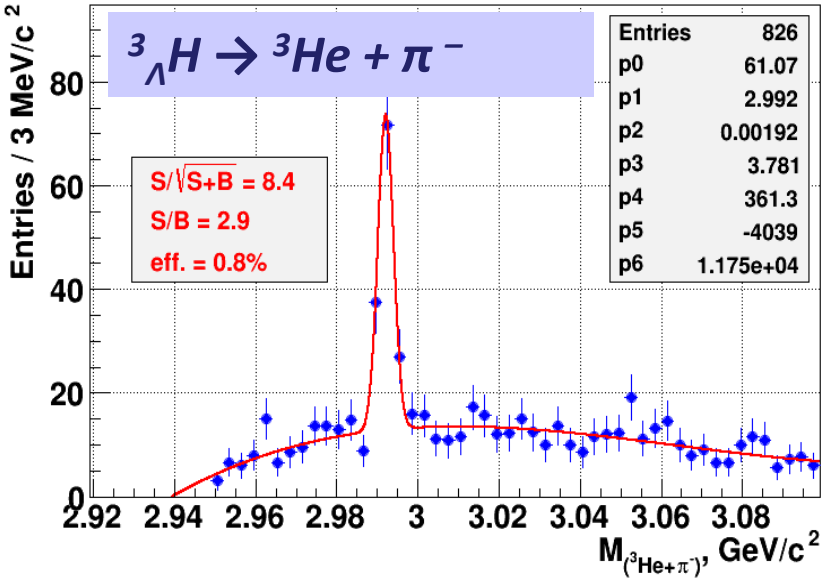
Hypertritons

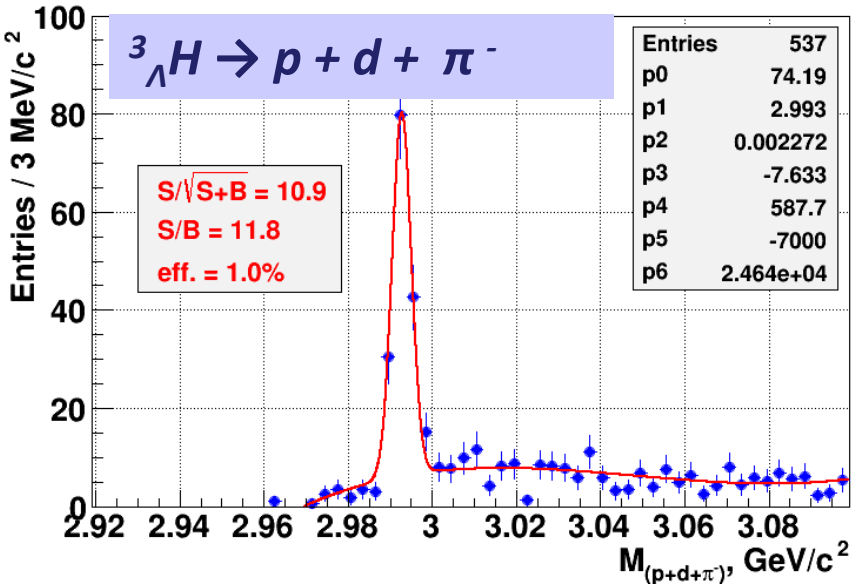
central Au+Au @ 5A GeV

(DCM-QGSM)

~ 10^6 $^3_\Lambda H$ *are expected in 10 weeks*







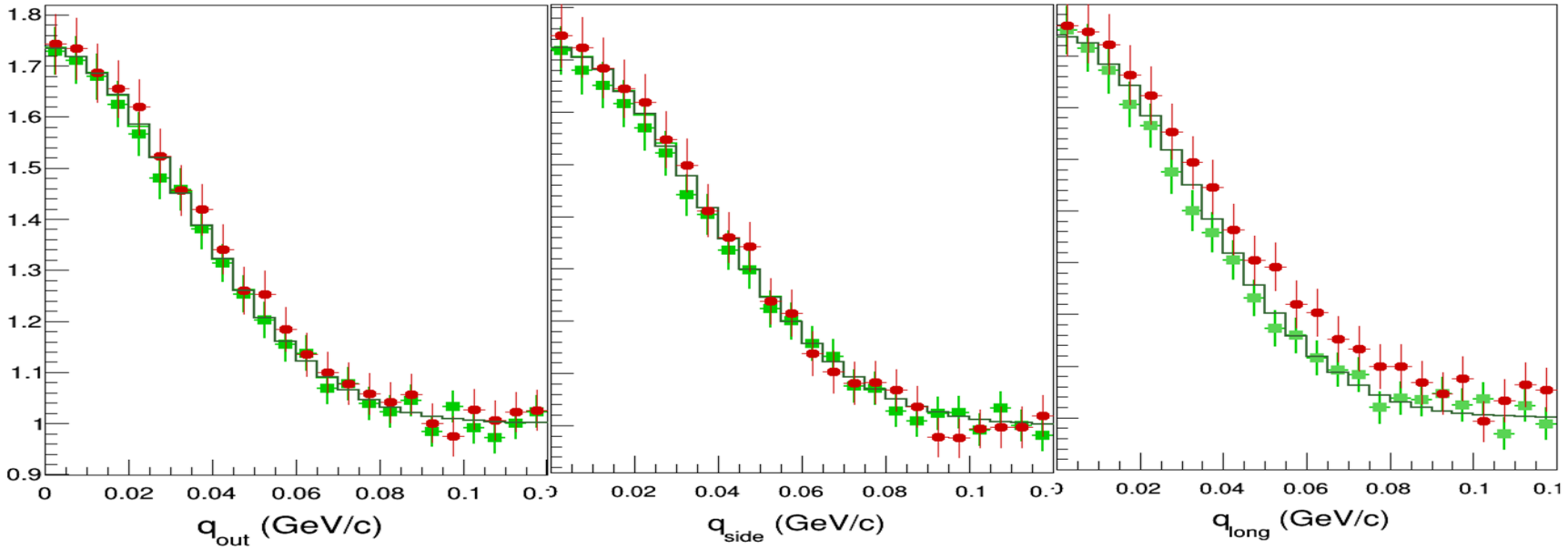
Femtoscopy correlations

P. Batyuk, L. Malinina, K. Mikhaylov, G. Nigmatkulov

Study of collective effects, space-time characteristics of the emitting source at kinetic freeze-out, collision dynamics and quark-hadron phase transitions via femtoscopic correlations of hadrons

- *MC input: vHLLE+UrQMD model implements hydro stage with different EoS, tuned to reproduce experimental data*
- *Data set : Au+Au collisions at 11 GeV, MPD full reconstruction chain*
- *Kaon particle ID and Correlation Function (CF) reconstruction*

Projections of 3D kaon CF on the Out-Side-Long directions
***Green** – first order phase transition (1PT), **Red** – crossover (XPT)*



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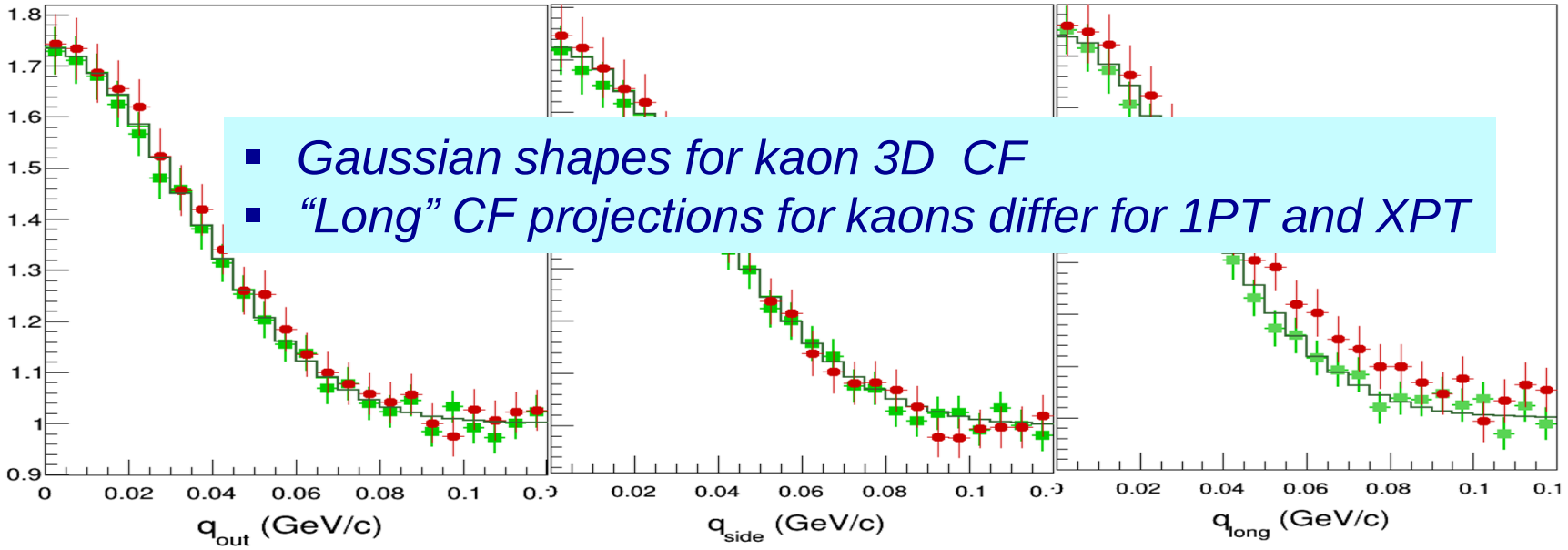

- *Gaussian shapes for kaon 3D CF*
- *"Long" CF projections for kaons differ for 1PT and XPT*

Concluding remarks

- **Density frontier is less explored area and its study**
  could lead to new interesting results
- **NICA complex has a potential for competitive research**
  in the field of baryon rich matter
- **The BM@N experiment has already started data taking**
- **The construction of both NICA Collider and detector (MPD)**
  are going close to the schedule
- **New participants are welcome to join NICA**

Thank you