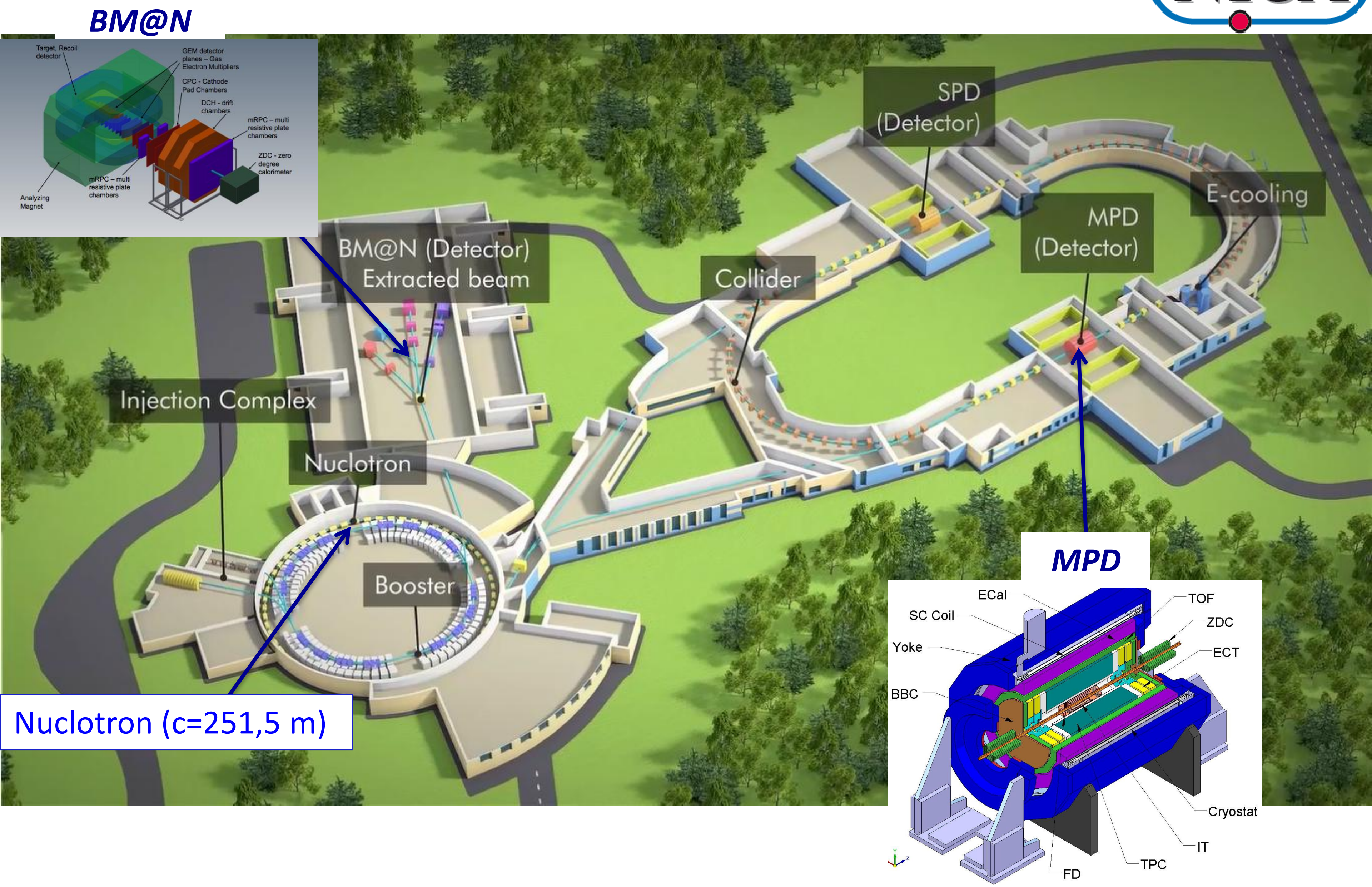
Joint Institute for Nuclear Research
International Intergovernmental Organization

Baryon rich matter research at NICA

V. Kekelidze, A. Kovalenko, R. Lednicky, V. Matveev,
I. Meshkov, A. Sorin, G. Trubnikov
(for the NICA collaboration)

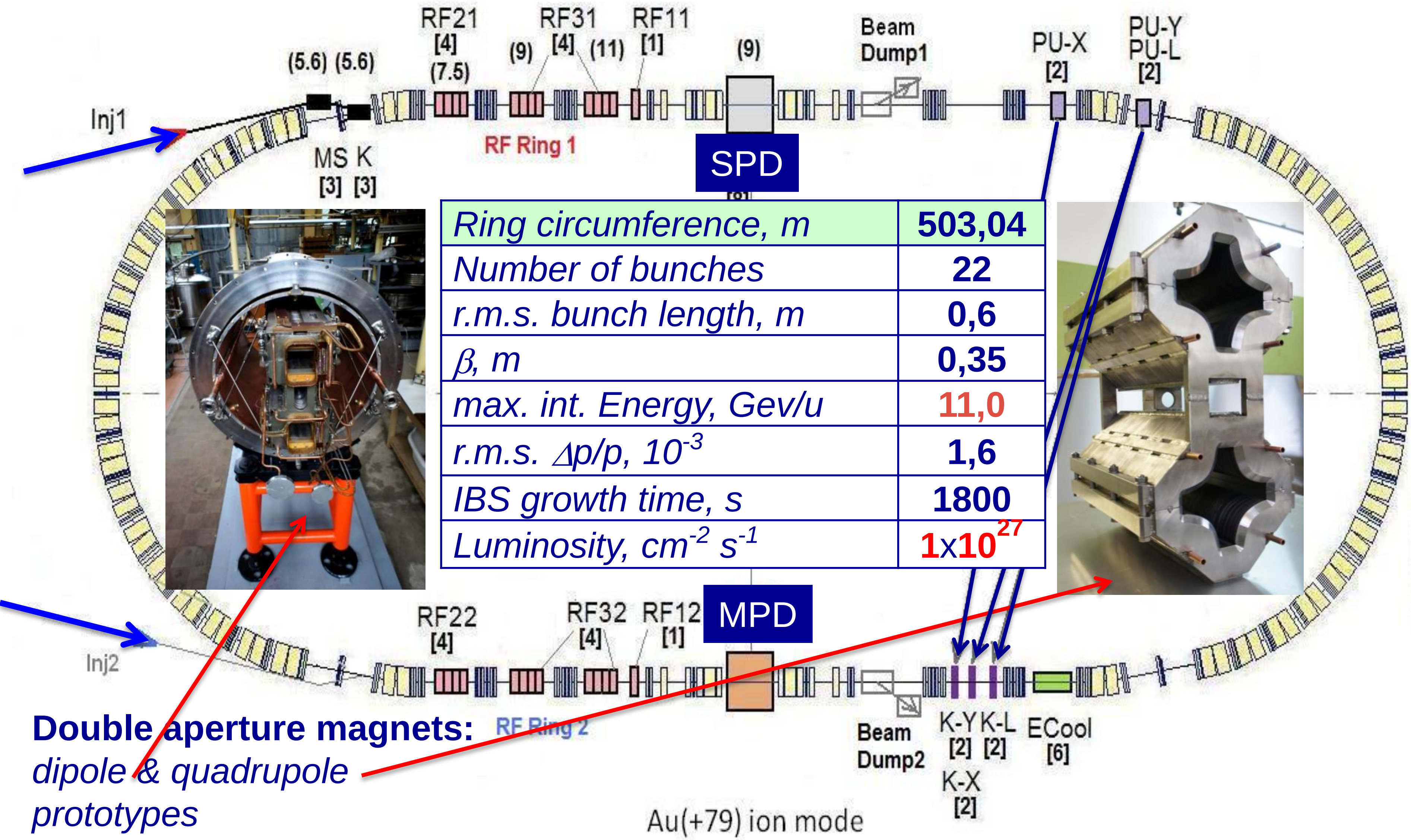
Critical Point and Onset of Deconfinement
Stony Brook University, USA, 11 August 2017


NICA


BM@N
Target, Recoil detector
GEM detector planes – Gas Electron Multipliers
CPC - Cathode Pad Chambers
DCH - drift chambers
mRPC – multi resistive plate chambers
ZDC - zero degree calorimeter
mRPC – multi resistive plate chambers
Analyzing Magnet
SPD (Detector)
E-cooling
MPD (Detector)
BM@N (Detector) Extracted beam
Collider
Injection Complex
Nuclotron
Booster
Nuclotron (c=251,5 m)
MPD
ECal
TOF
SC Coil
ZDC
Yoke
ECT
BBC
Cryostat
IT
TPC
FD

The Collider

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



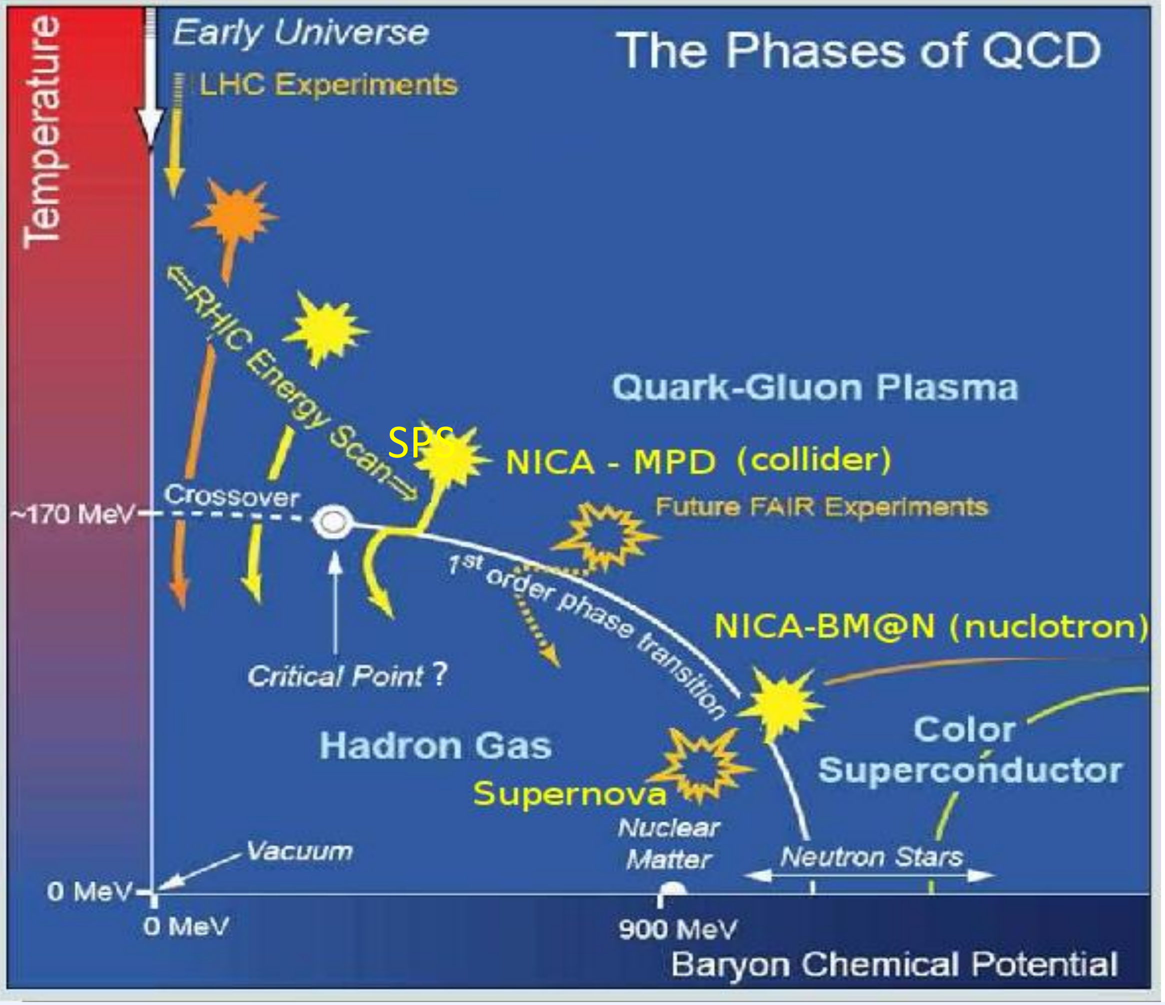
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. $\Delta p/p$, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, $cm^{-2}\ s^{-1}$	**1×10^{27}**

Double aperture magnets:
dipole & quadrupole prototypes

Civil Construction

Exploration of the QCD Phase Diagram

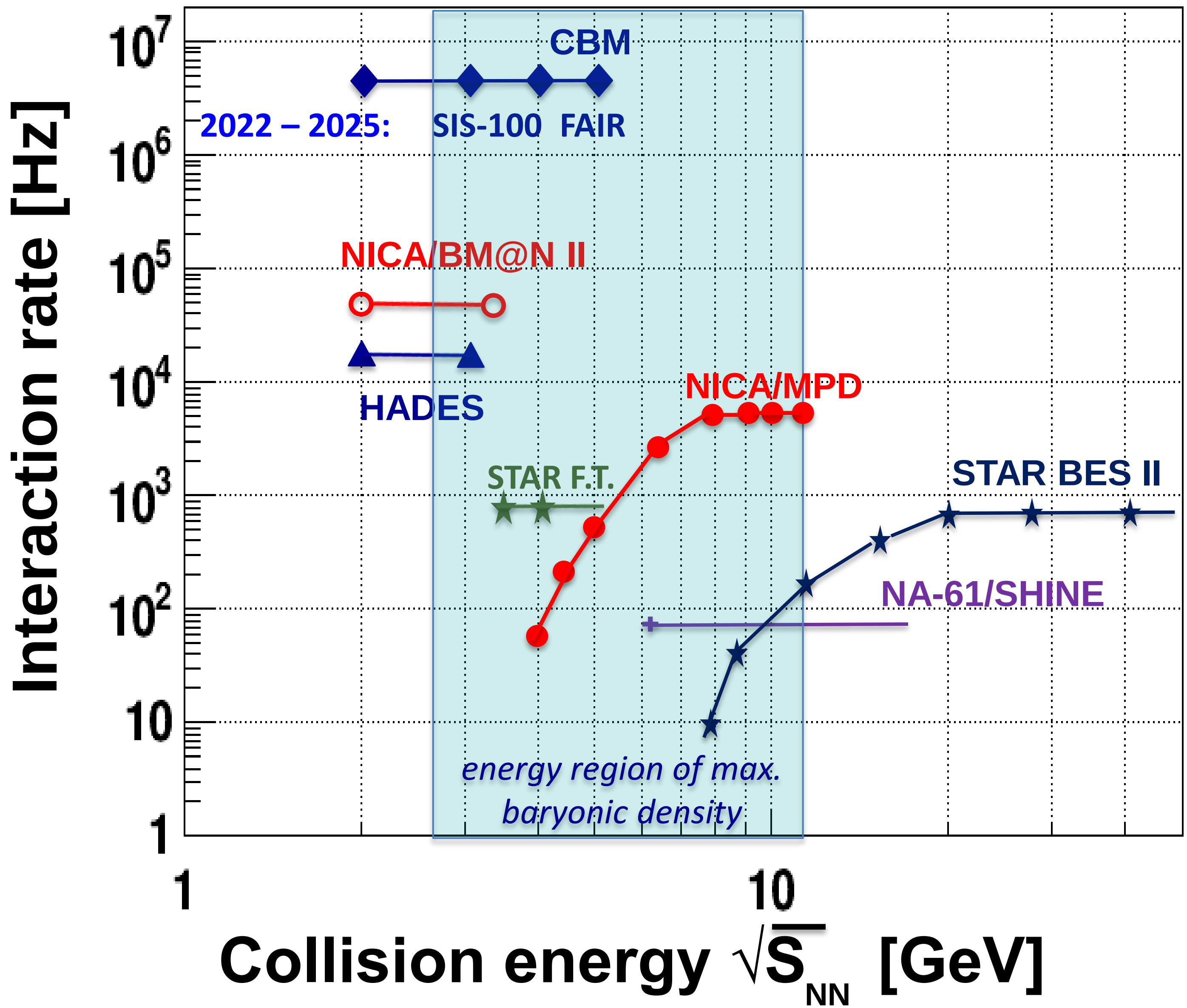
Exploring baryon rich matter: maximum freeze-out density



NICA is well suited for exploring the transition between hadronic and QG phases at high net baryon density

This is a top priority of the NICA program

Present and future HI experiments

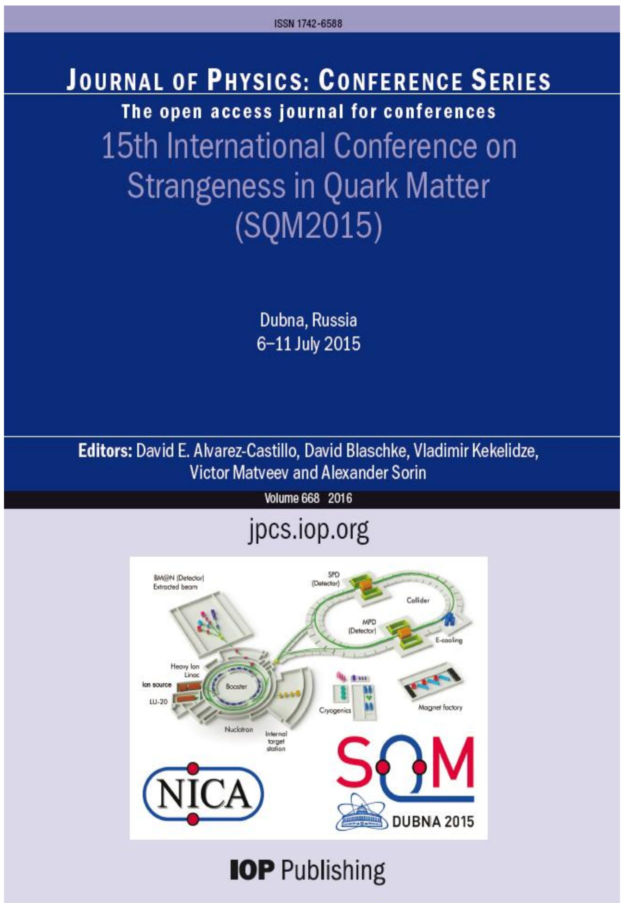


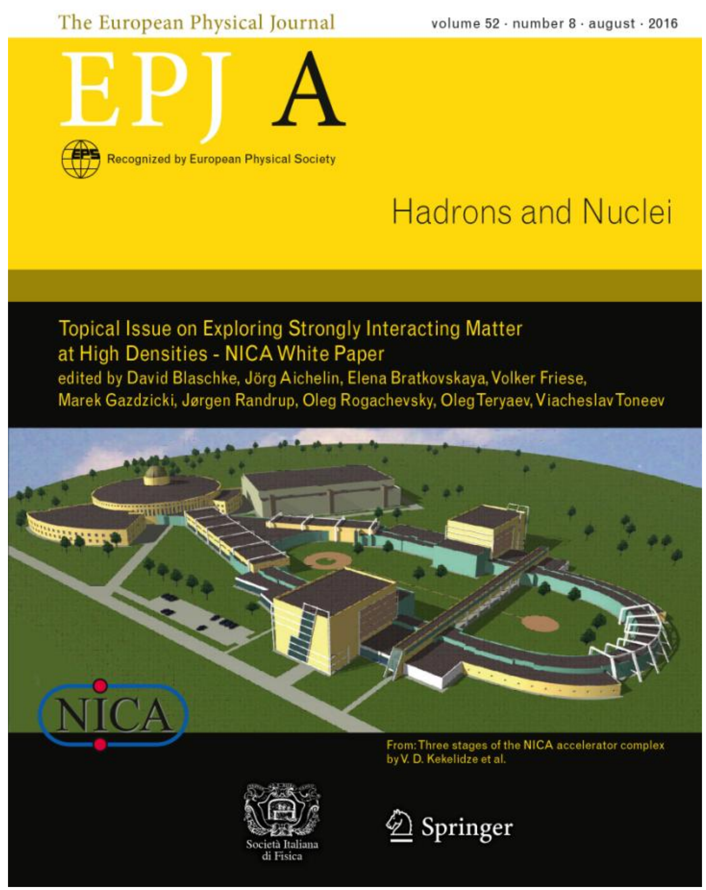
Physics objectives

- ***Bulk properties, EOS***
  - particle yields & spectra, ratios, femtoscopy, flow
- ***In-Medium modification of hadron properties***
  - onset of low-mass dilepton enhancement
- ***Deconfinement (chiral) phase transition at high ρ_B***
  - enhanced strangeness production
- ***QCD Critical Point***
  - event-by-event fluctuations & correlations
- ***Chiral Magnetic (Vortical) effect, Λ polarization***
- ***Y-N interactions in dense nuclear matter***
  - hypernuclei

New issues: NICA White Paper, SQM proceedings

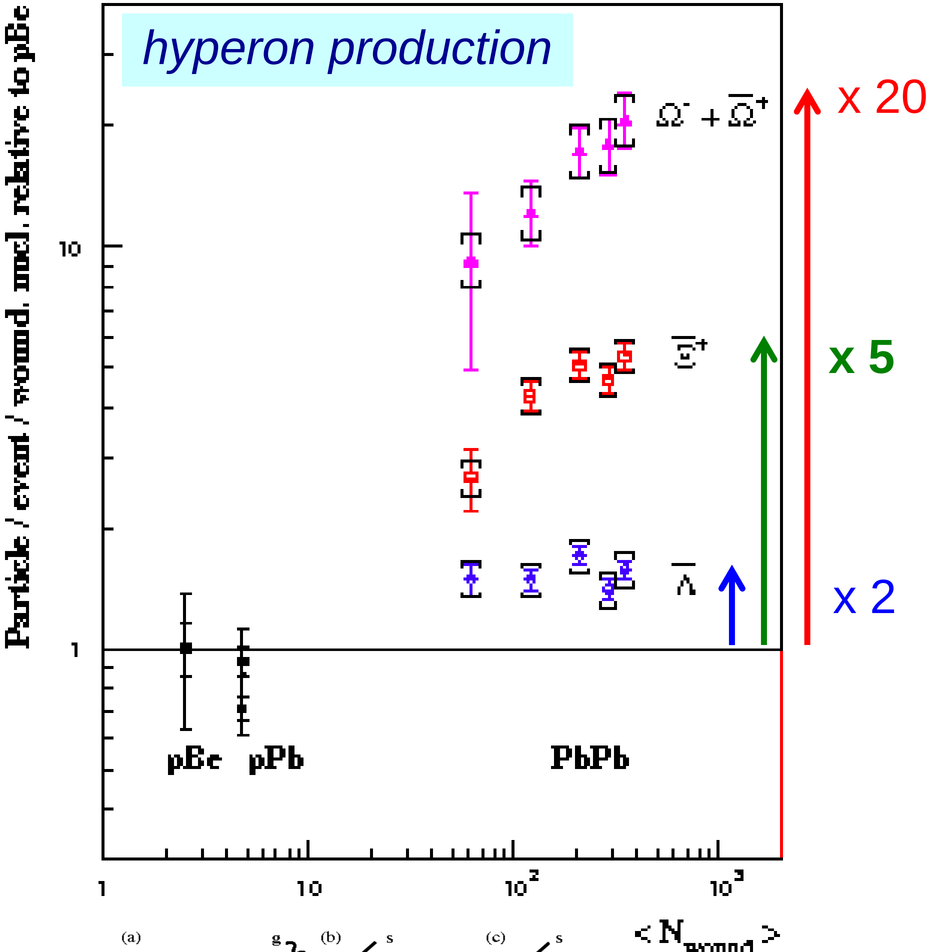
*Physics targets for the exploration of first order phase transitions in the region of the QCD phase diagram accessible to NICA & FAIR and possible observable effects of a "mixed phase indicated in the release of the "NICA White Paper" as a Topical Issue of the **EPJ A** (July 2016).*

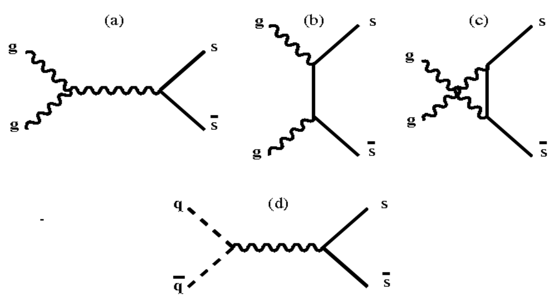




111 *contributions,*
188 *authors*
from **24** *countries*

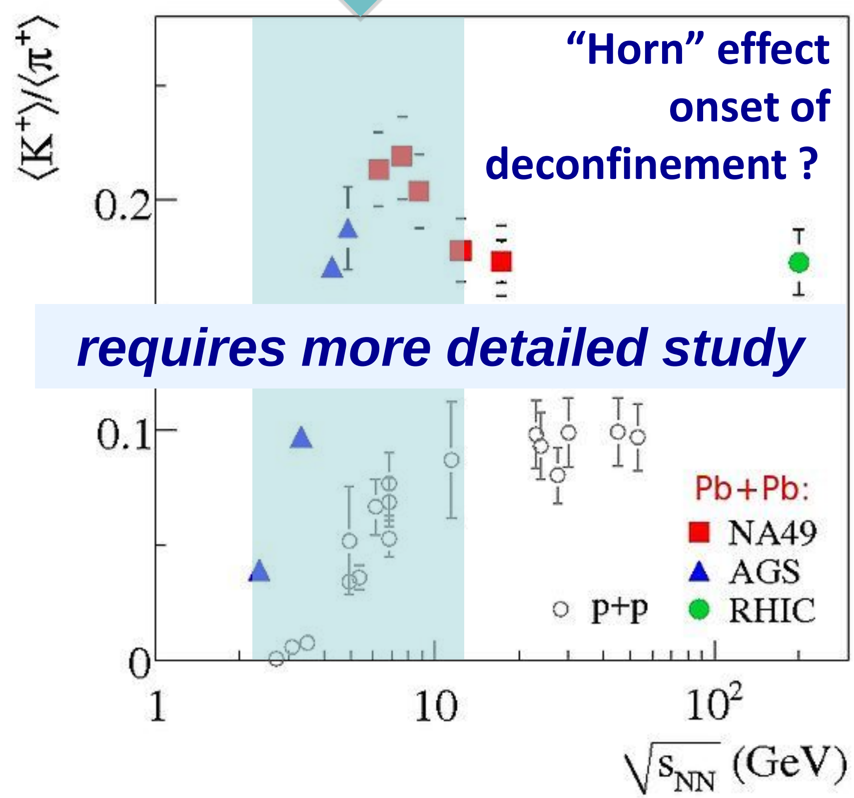
Strangeness Enhancement: SPS CERN, RHIC





Indication to chiral symmetry restoration

energy region of **NICA**

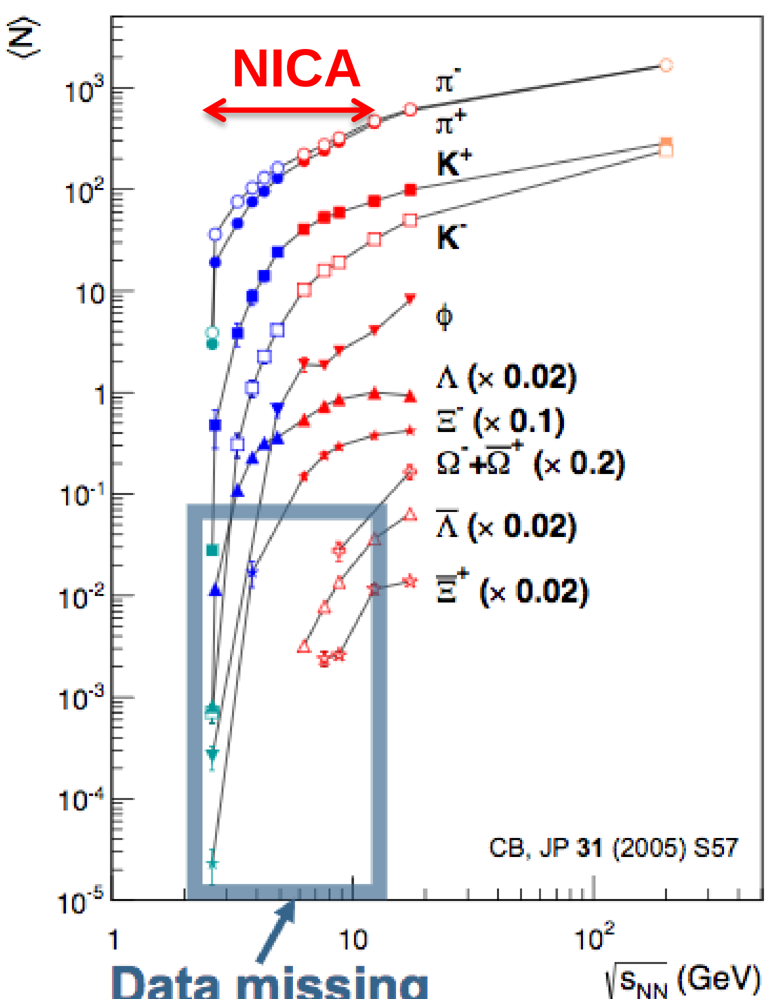


requires more detailed study

NA49 : *Phys. Rev. C 77, (2008)*

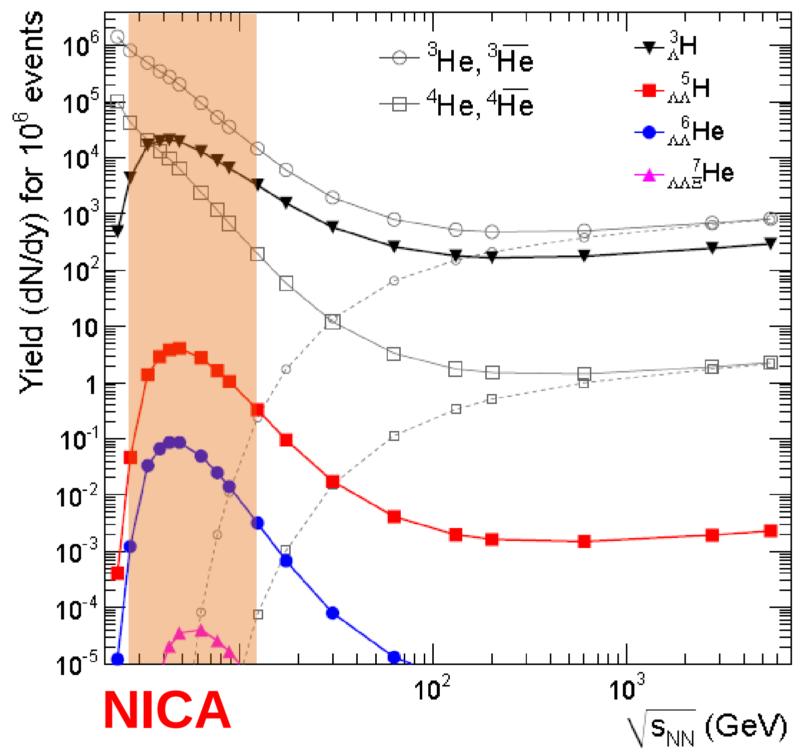
STAR : *QM2011 proceedings*

Energy Dependence of Total Yields



Data missing
or to be improved!

Hypernuclei production enhanced
at high baryon densities (NICA)

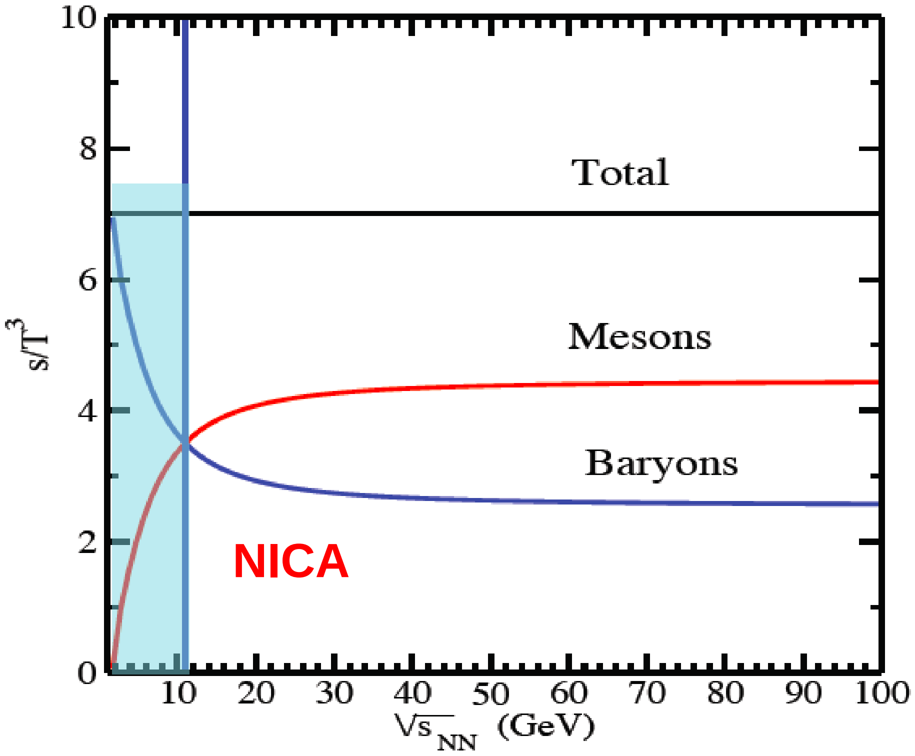


A. Andronic et al., Phys. Lett. B697 (2011) 203

C. Blume, SQM-2017

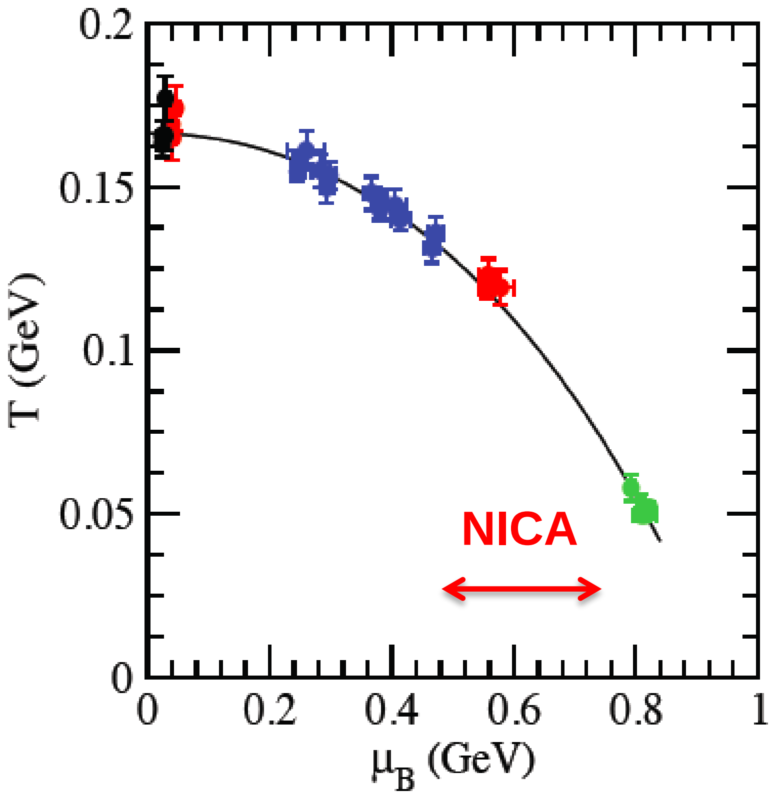
more issues

a transition from a baryon-dominated to a meson-dominated media



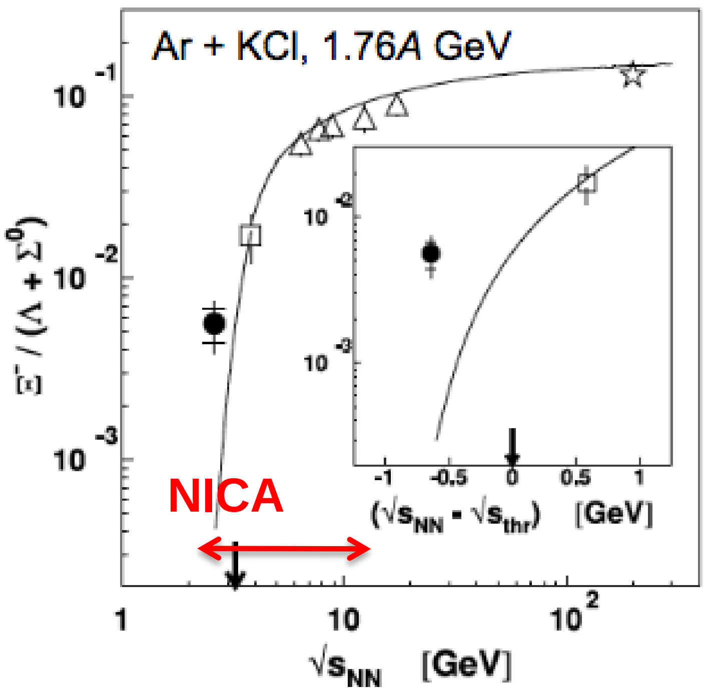
H. Oeschler et al.
Physics Letters B615 (2005) 50-54.

less studied region

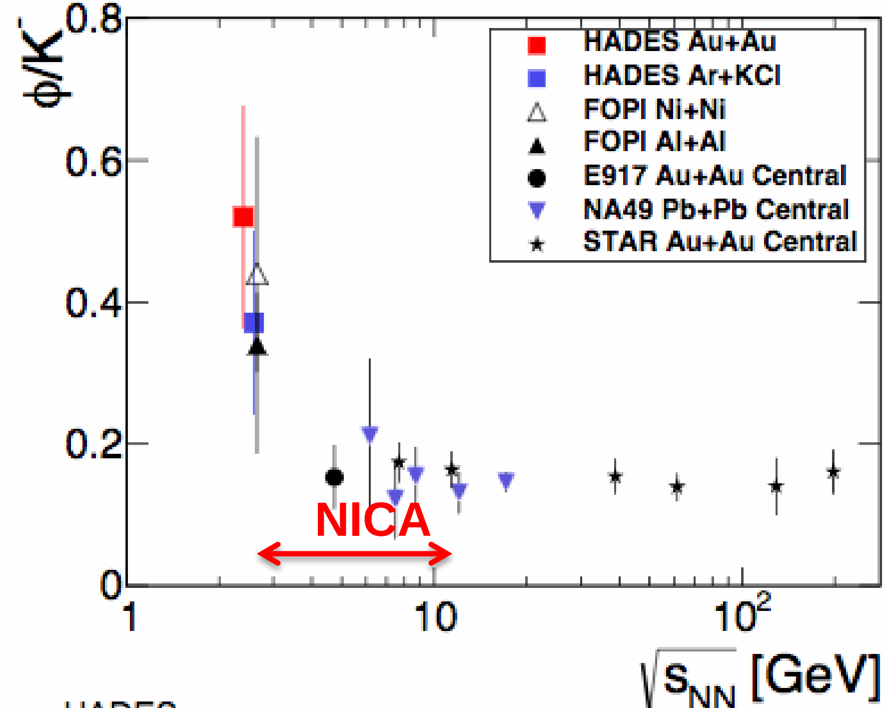


J. Cleymans, SQM-2017.

Production ratios:
hadrons with extra s-quark over others with just one
NICA energies- *sub threshold and above*



HADES
PRL **103** (2009) 132301



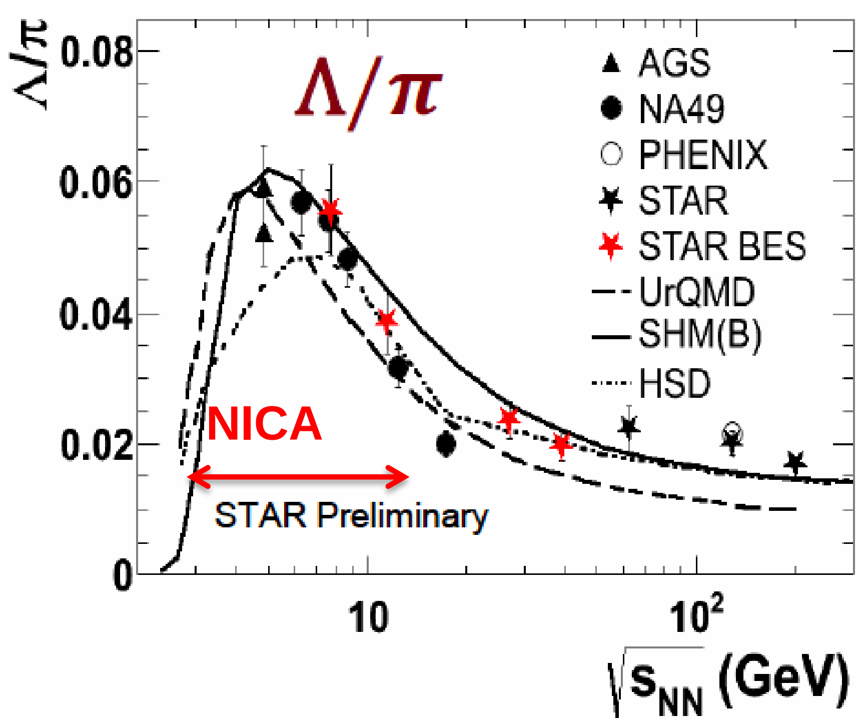
HADES
arXiv:1703.08418

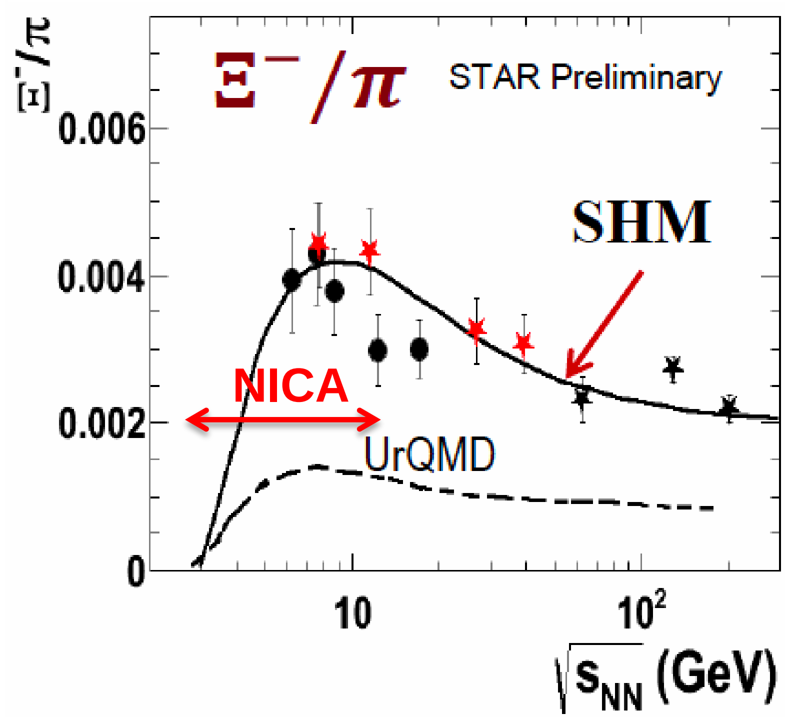
Non-trivial energy dependence at very low energies:

- *Surprisingly high **Ξ−** yield, data clearly above model expectation*
- *Dramatic rise of **ϕ**/K**−** ratio towards low energies*

C. Blume, SQM-2017

Strange baryon to pion ratios





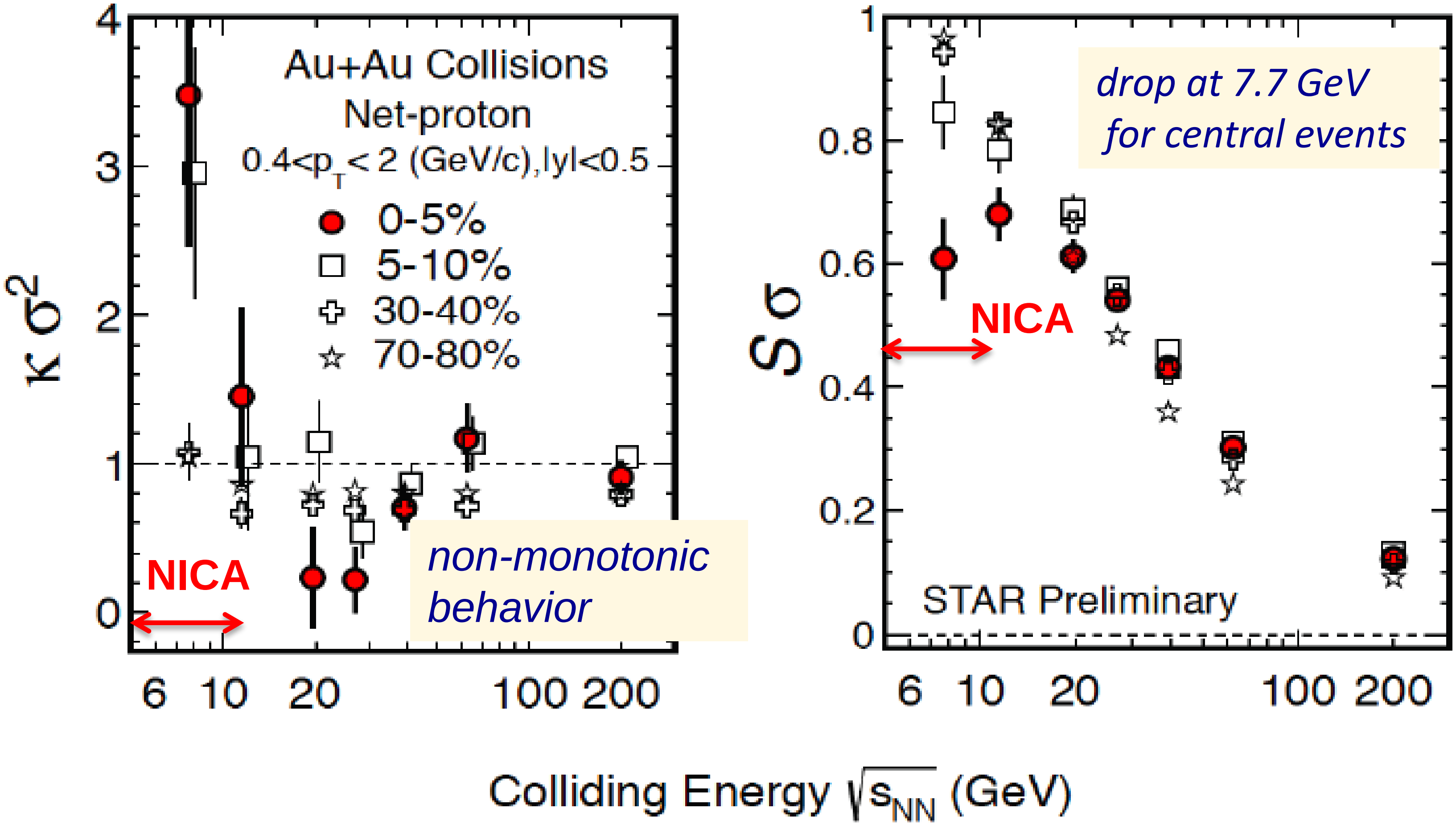
D. Tlusty, SQM-2017

maximum net baryon density of GCE~ 8 GeV

Randrup, Cleymans, PRC 74, 047901, 2006.

Event-by-event fluctuations

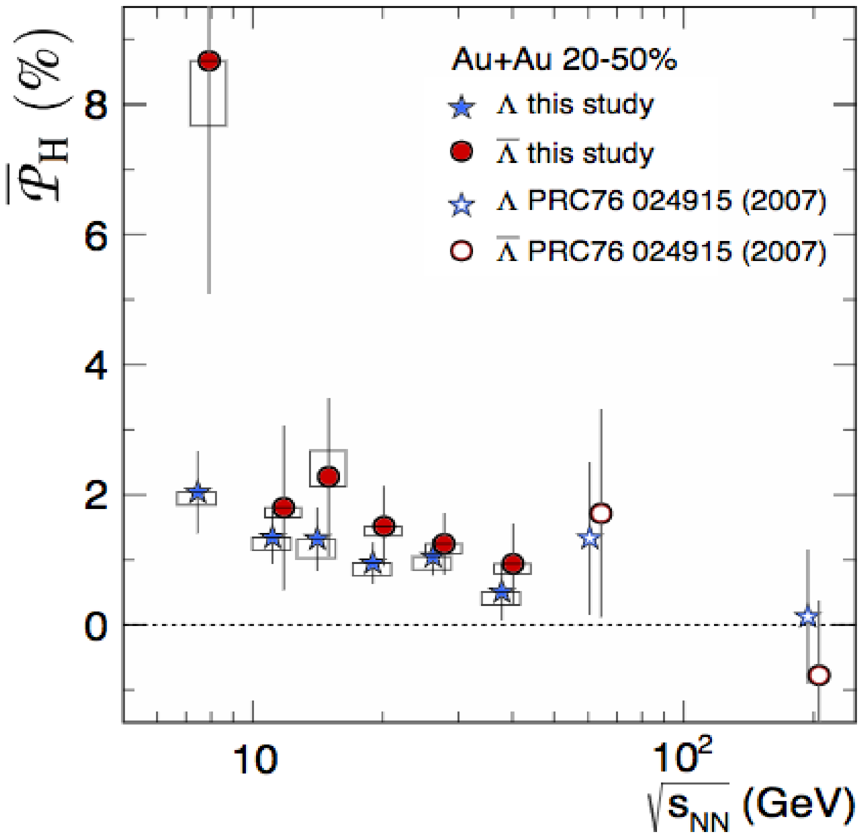
STAR data: *X. Luo, PoS CPOD2014, 019 (2015); STAR: PRL 112, 032302 (2014)*

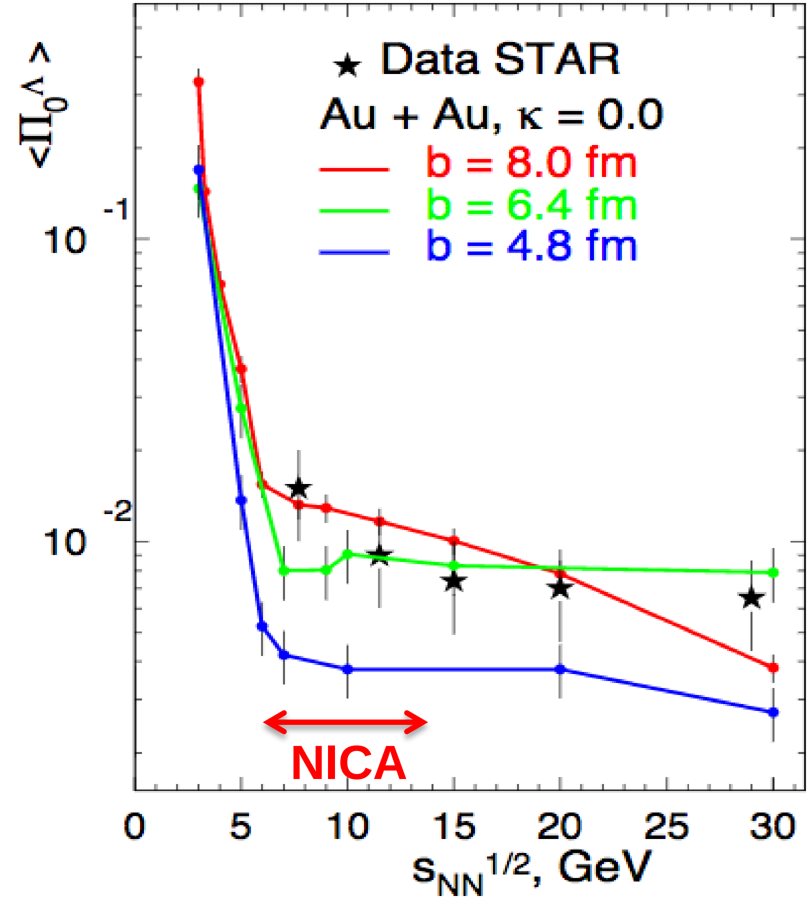


more statistics & precise control of systematics are needed to explore this region

A. Rustamov, SQM-2017

Vorticity & Λ Polarization





O. Rogachevsky, A. Sorin, O. Teryaev, Phys. Rev. C 82, 054910, 2010;

M.Baznat, K.Gudima A.Sorin, O.Teryaev arXiv:1701.00923

STAR Coll.,arXiv:1701.06657

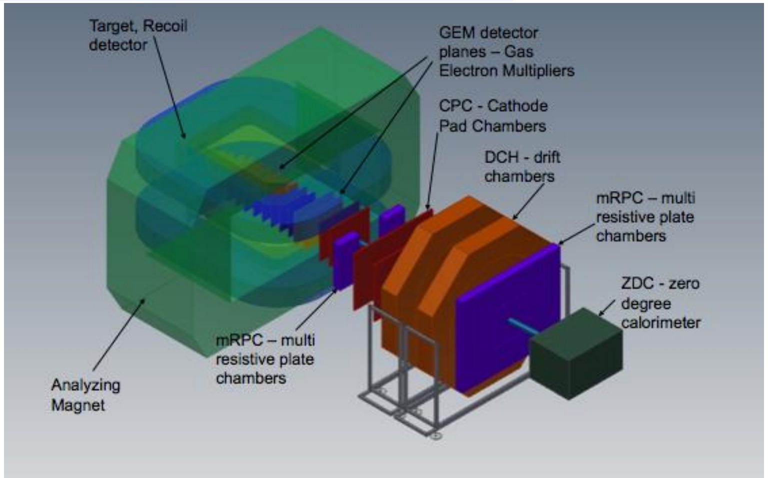
QCD matter at the NICA energies:

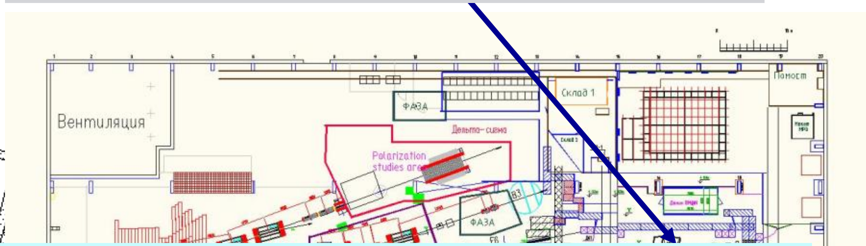
- ***high net baryon density – density frontier;***
- ***maximum in K^+/π^+ ratio;***
- ***maximum in Λ/π ratio;***
- ***transition from a Baryon dominated system to a Meson dominated one;***
- ***maximum of the Λ polarization;***
- ***1-st order transition & mixed phase creation;***
- ***Critical Endpoint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

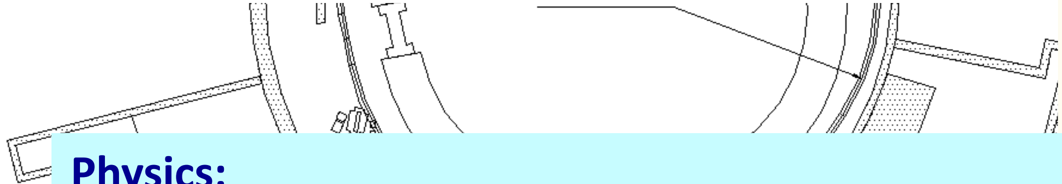
Baryonic Matter at Nuclotron (BM@N)

experiment at Nuclotron extracted beams

BM@N Collaboration:
Russia: *INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Institut*
Bulgaria: *Plovdiv University;*
China: *Tsinghua University, Beijin;*
Poland: *Warsaw Tech.University*
Israel: *Tel Aviv University*
Germany: *Frankfurt University; GSI*
USA: *MIT*
France: CEA





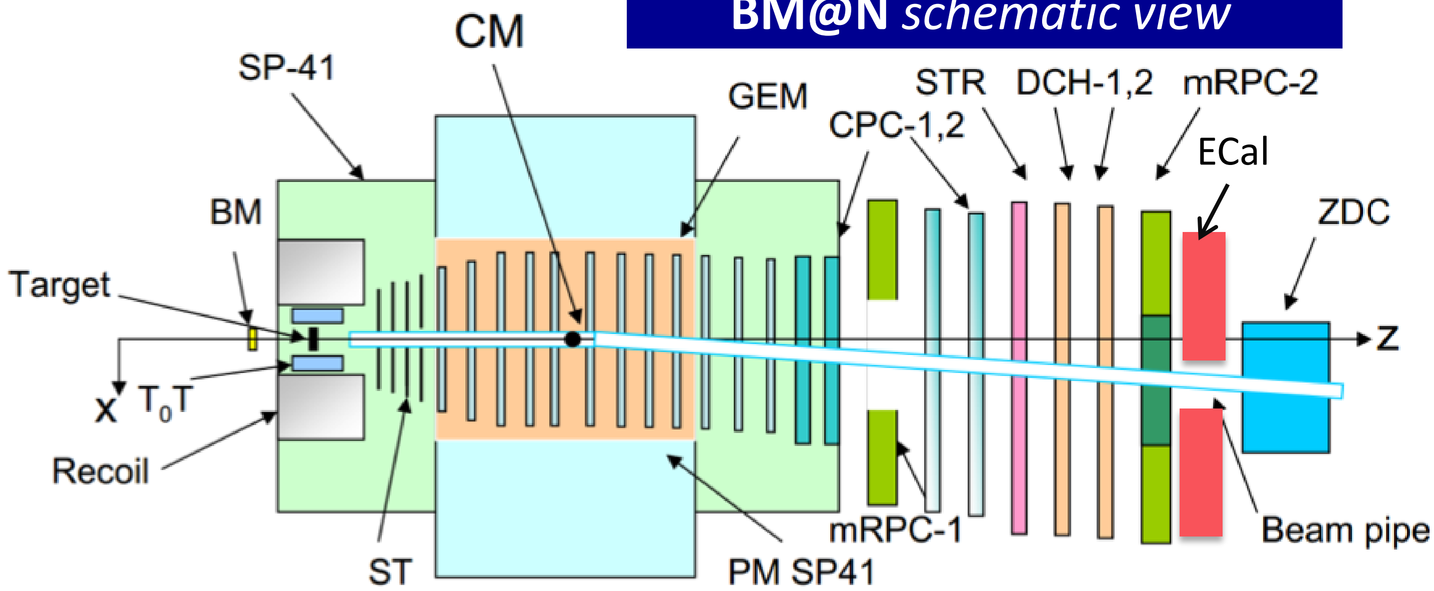


Physics:

- ✓ *strange / multi-strange hyperon and hypernuclei production at the threshold*
- ✓ *hadron femtoscopy*
- ✓ *short range correlations*
- ✓ *event-by event fluctuations*
- ✓ *in-medium modifications of strange & vector mesons in dense nuclear matter*
- ✓ *electromagnetic probes, states decaying into γ, e (with ECAL)*

BM@N status and milestones

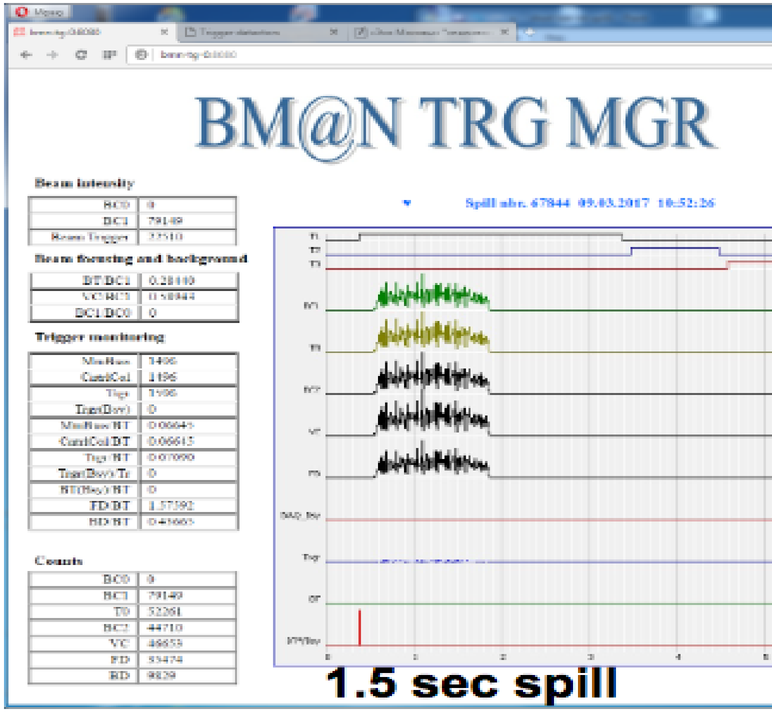
BM@N *schematic view*



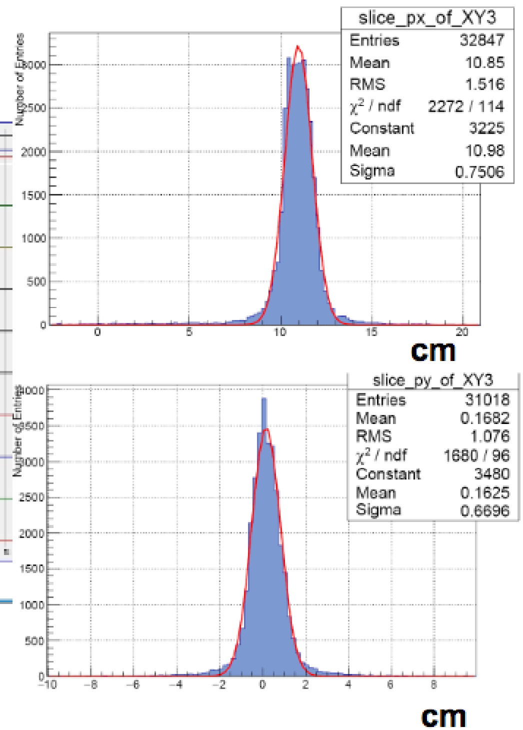
BM@N configuration

	DAQ	GEM *(CERN)*	ST	TOF	Outer tracker
• **2016, IV**:	*basic config.*	*6 half planes*	*1 small plane*	*half config.*	*DCH*
• **2017, III:**	complete	*10 h/pl.*	*2 s/pl.*	*basic*	*DCH*
• **2019, I:**	**-"-**	*8-10 full pl.*	*2 s.,2 large pl.*	*complete*	*Straw+DCH*

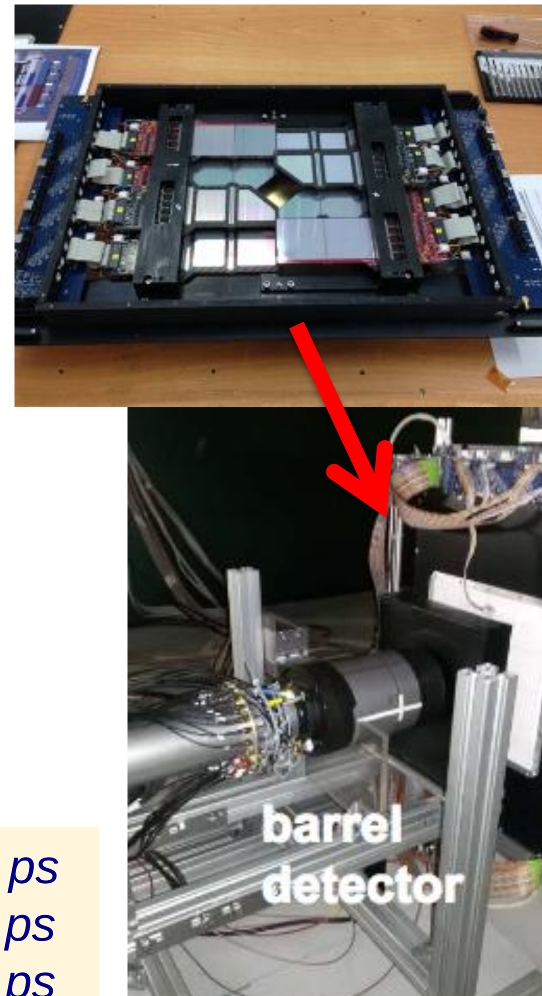
Deuteron / Carbon beam at BM@N



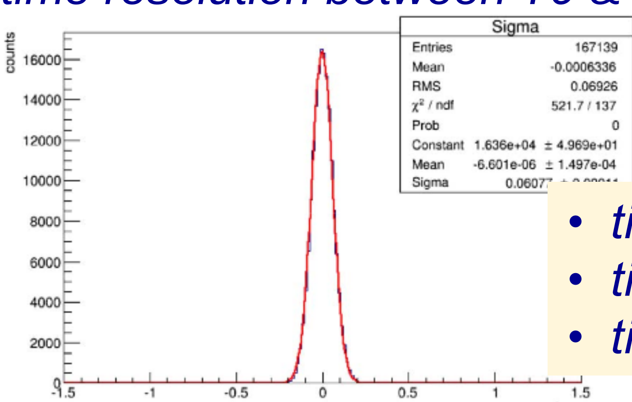
X, Y profiles of deuteron beam in 1st GEM



Si detector



time resolution between T0 & BC2

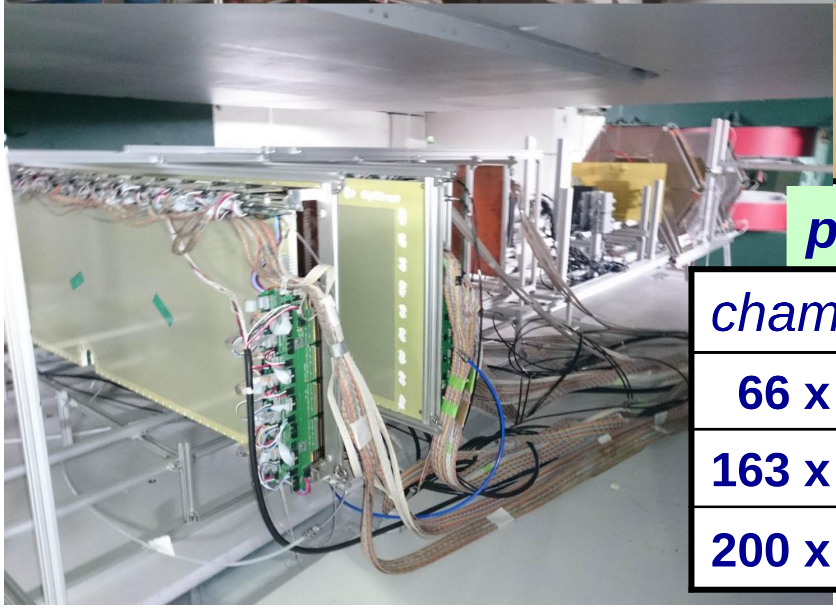


- *time resolution of T0 ~43 ps*
- *time resolution of ToF-700 ~65 ps*
- *time resolution of ToF-400 ~53 ps*

GEM detectors for BM@N central tracker

GEM production at CERN PH-DT MRT workshop for BM@N

GEM's installed in BM@N magnet



plan of production of triple GEM's

chamber size	**2015-16**	**2017**	**2018**	**2019**
66 x 41 cm^2	**5**			
163 x 45 cm^2	**2**	**6**	**6**	
200 x 45 cm^2			***design***	**6**

BM@N plans

year	2016	2017 Feb.-Mar.	2017 Nov.-Dec.	2019	2020 + ..
beam	d (↑)	C, Ar	Kr	Au	Au, p
maximum intensity, Hz	1M	1M	1M	1M	10M
trig. rate, Hz	10k	10k	20k	20k	50k
central tracker	6 GEM half pl.	8 GEM half pl.	10 GEM half pl.	8 GEM full pl.	12 GEM or 8+2Si
expiment status	techn. run	techn. run	physics run	physics stage 1	physics stage 2

beam: E_{kin} = 3.5, 4.0, 4.4 AGeV

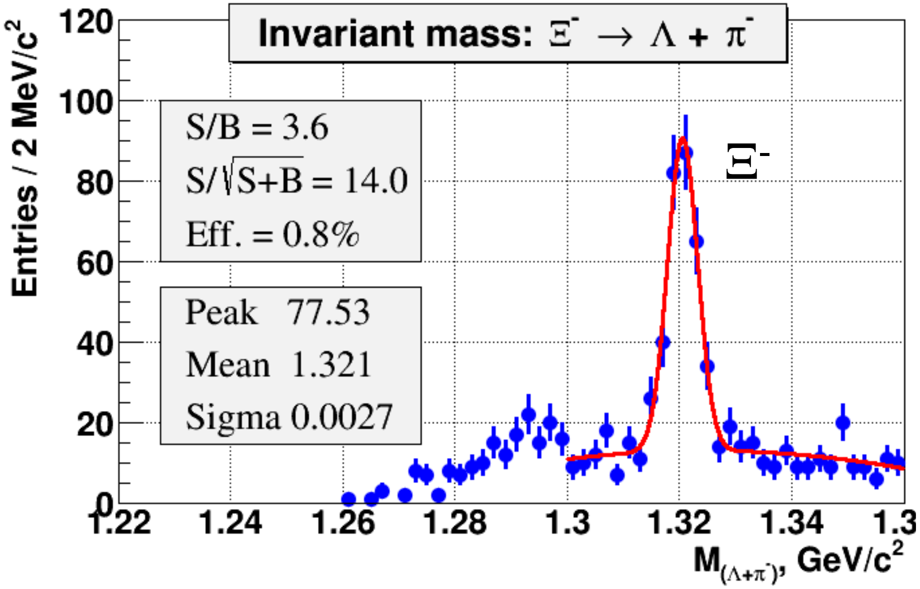
BM@N *feasibility study*

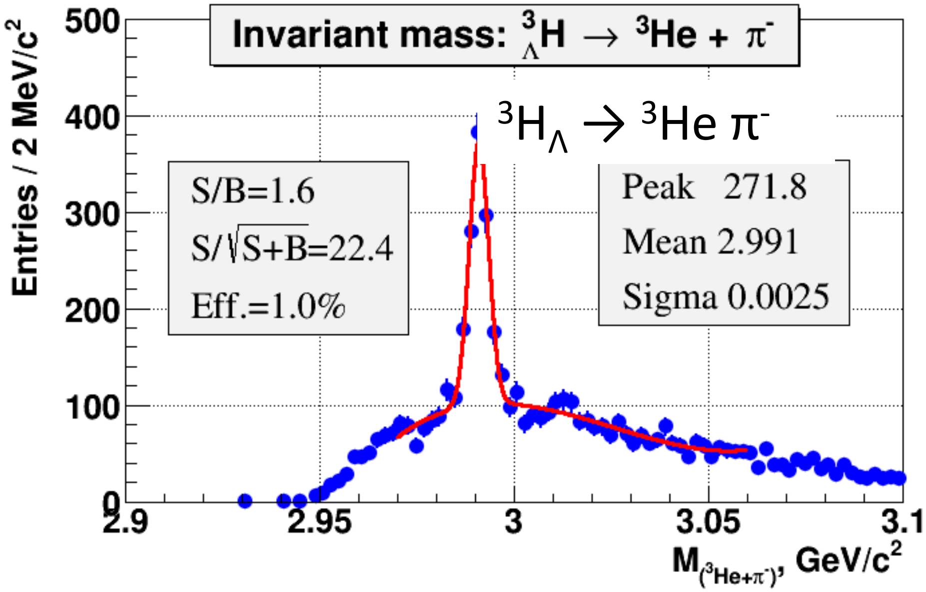
A.Zinchenko, V.Vasendina

Simulation: *UrQMD & DCM-QGSM, Au+Au 4,5 AGeV*

900 k central events
7,5M Ξ^- in 1 m, 20 kHz trigger

2,6M central events
8,5M $^3H_\Lambda$ in 1 m, 20 kHz trigger

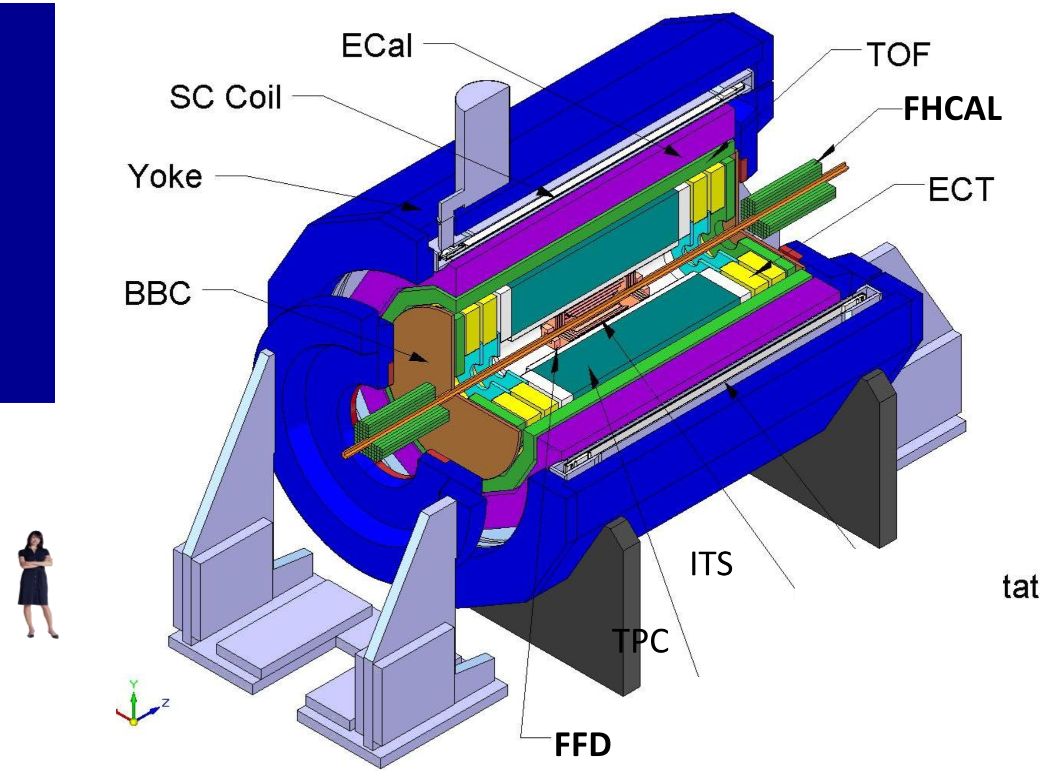




MultiPurpose Detector (MPD)

Main target:

- *study of hot and dense baryonic matter at the energy range of max net baryonic density*



MPD Collaboration:

- *JINR, Dubna;*
- *PI Az.AS, Baku, Azerbaijan;*
- *PPC BSU, Minsk, Belarus;*
- *WUT, Warsaw, Poland;*
- *INR, RAS, Russia;*
- *MEPhI, Moscow, Russia;*
- *ITEP, NC KI, Moscow, Russia;*
- *PNPI NC KI, Saint Petersburg, Russia;*
- *CPPT USTC, Hefei, China;*
- *Tsinghua University, Beijing, China;*
- *SS, HU, Huzhou, Republic of South Africa;*
- *DF, US, Mexico;*
- *ICN UNA; Mexico;*
- *DF, CIEA del I.P.N, Mexico;*
- *FCF-M UAS, Sinaloa, Mexico;*
- *FCF-MB UAP, Puebla, Mexico;*
- *CCTVal, Univ. Téch. Federico Santa María, Chile.*

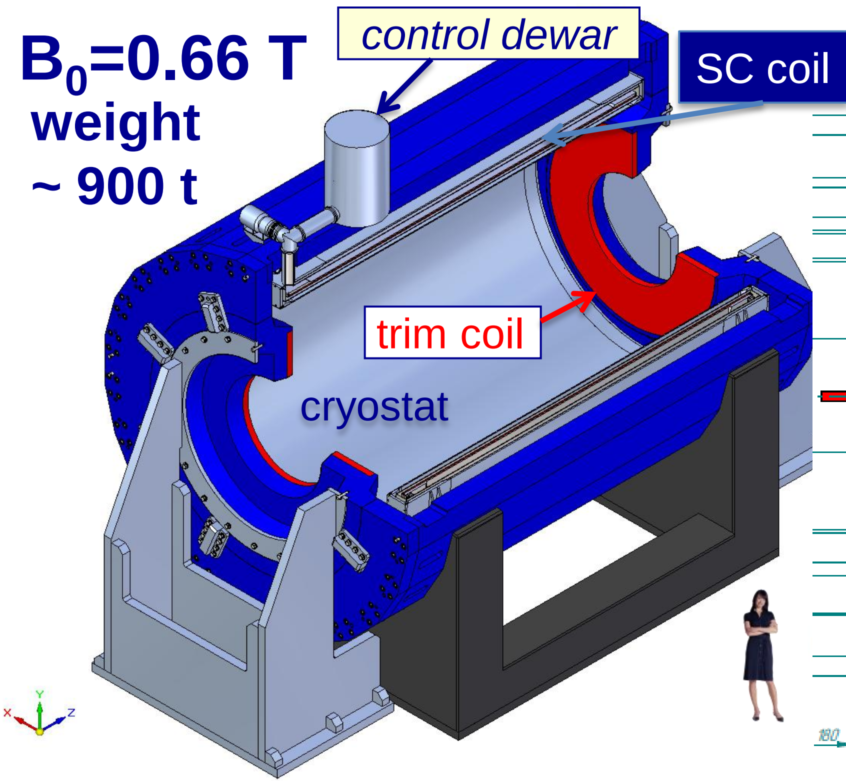
MPD detector for Heavy-Ion Collisions @ NICA

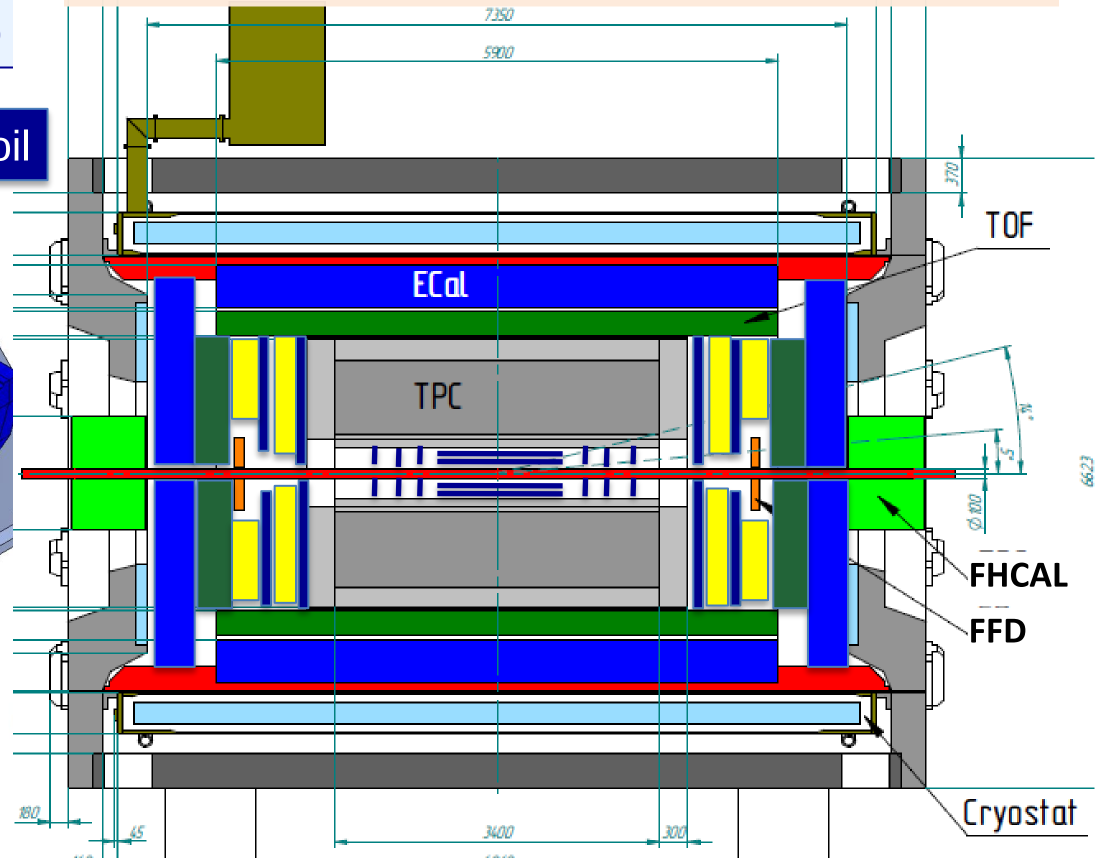
Tracking: up to |η|<1.8 (TPC)
PID: hadrons, e, γ (TOF, TPC, ECAL)
Event characterization:
centrality & event plane (FHCAL)

Stage 1: **TPC, TOF, ECAL, FHCAL, FFD**

Stage 2: **ITs + Endcaps (tracker, TOF, ECAL)**

B_0=0.66 T
weight
~ 900 t

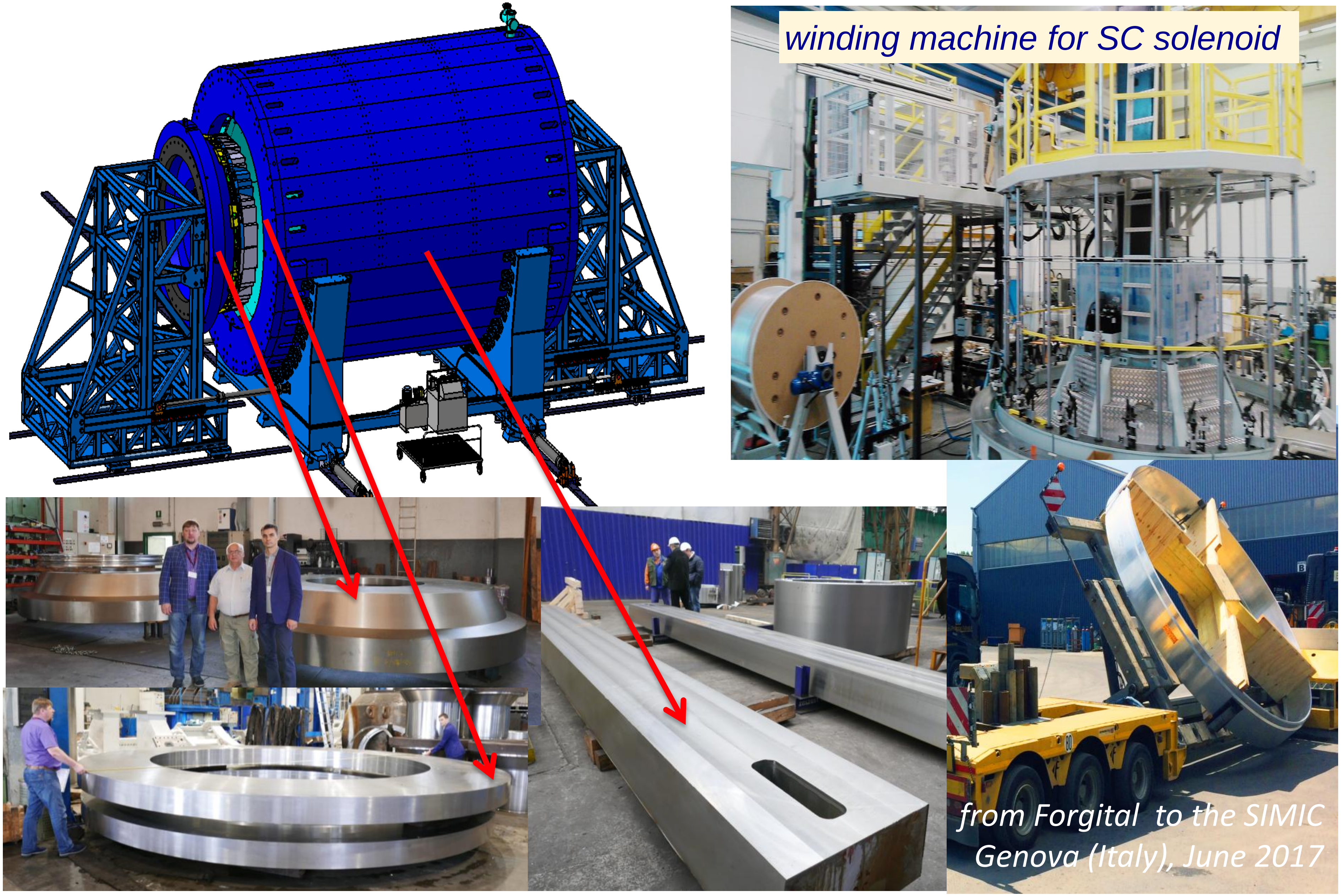




General contractor:
ASG Superconductors,
Genova, Italy

Status: *technical design – completed / close to completion; preparation for the mass production*

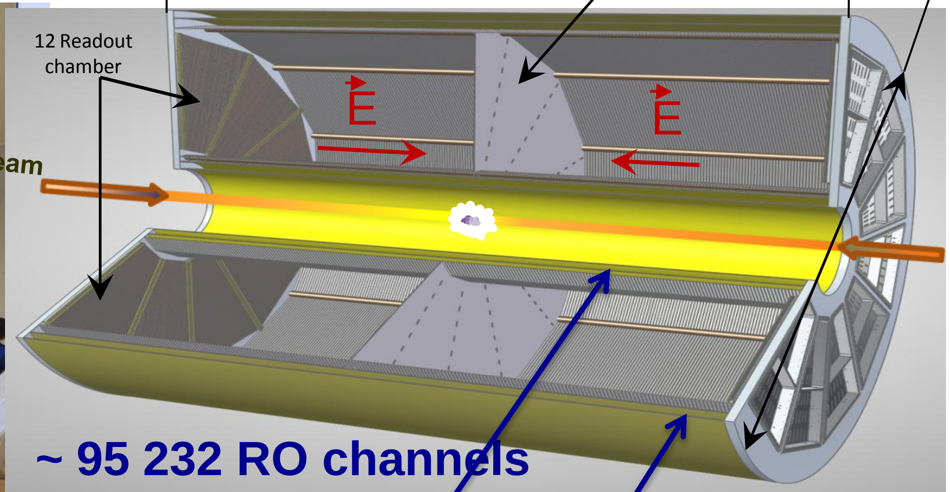
Magnet production: *at ASG (Genova) & Vitkovice HM*

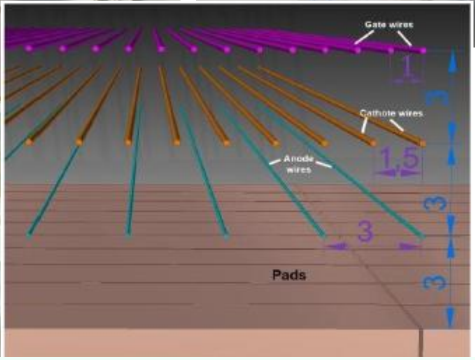


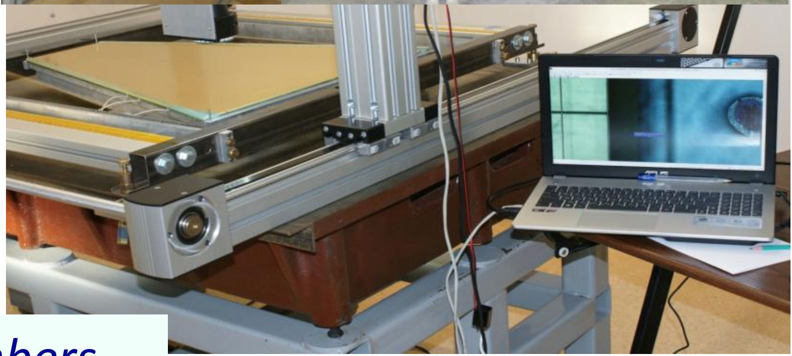
TPC: *assembly stage*

assembly workshop (clean room) & tooling

Sketch of TPC

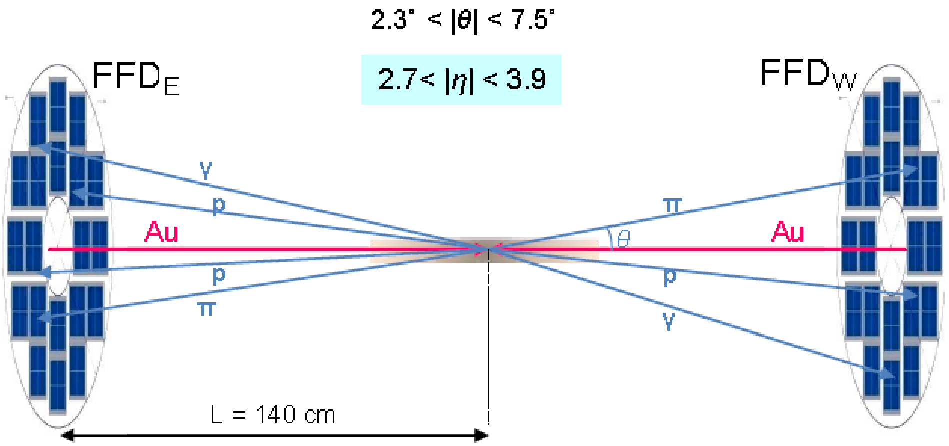




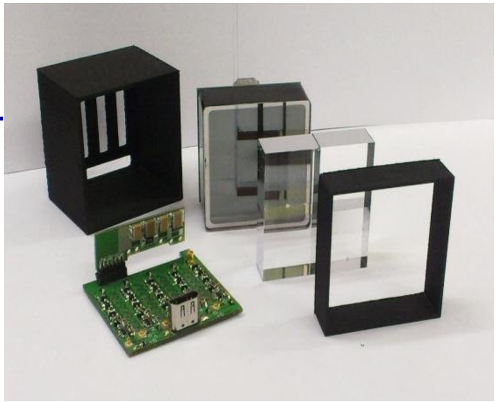


production of RO Chambers

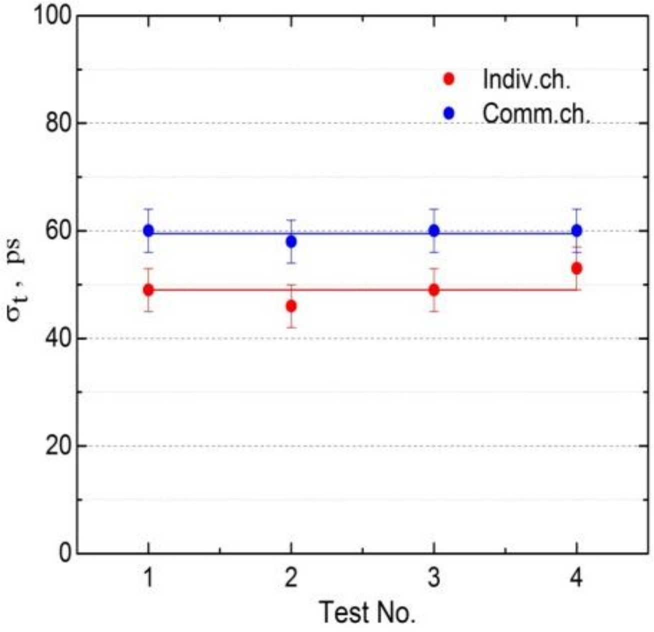
Fast Forward Detector - FFD *(Cherenkov)*



***80 channels**:*
lead converter + quartz radiator

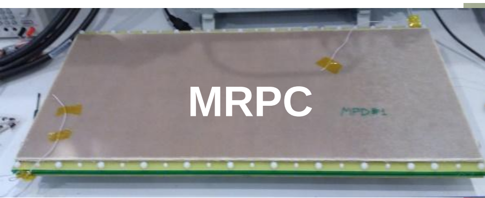


time resolution < 50 ps



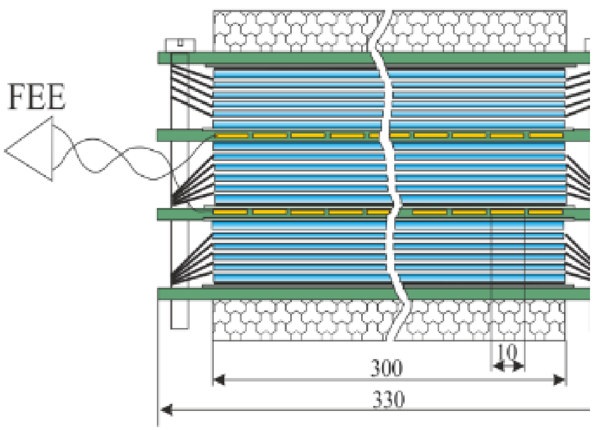
- *TDR – OK!*
- *production close to completion*
- *tests of the trigger electronics & software at BM@N*

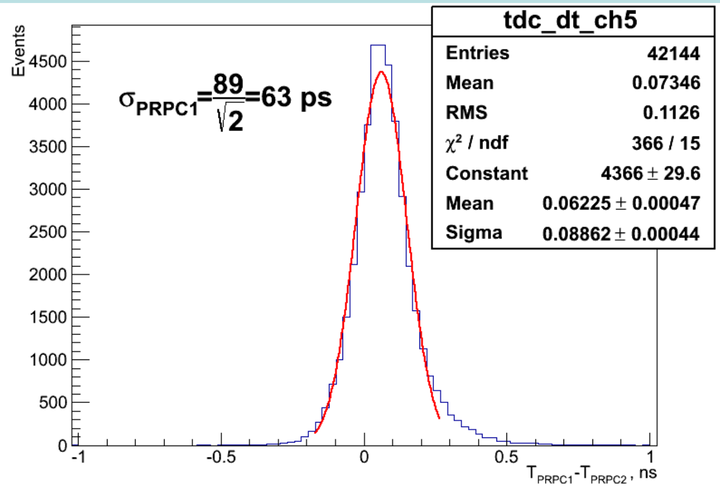
TOF Barrel: MRPC ready for mass production

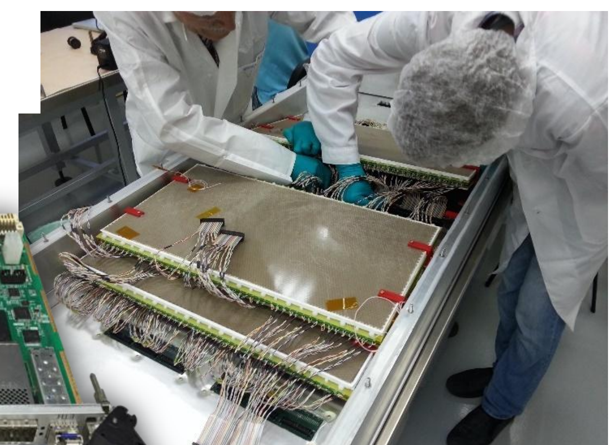


28 modules
280 MPRC's
13 440 channels

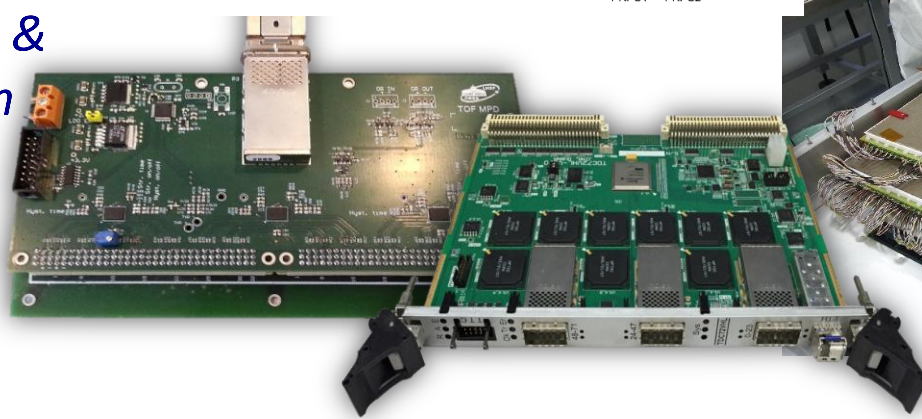
workshop for the MRPC mass-production





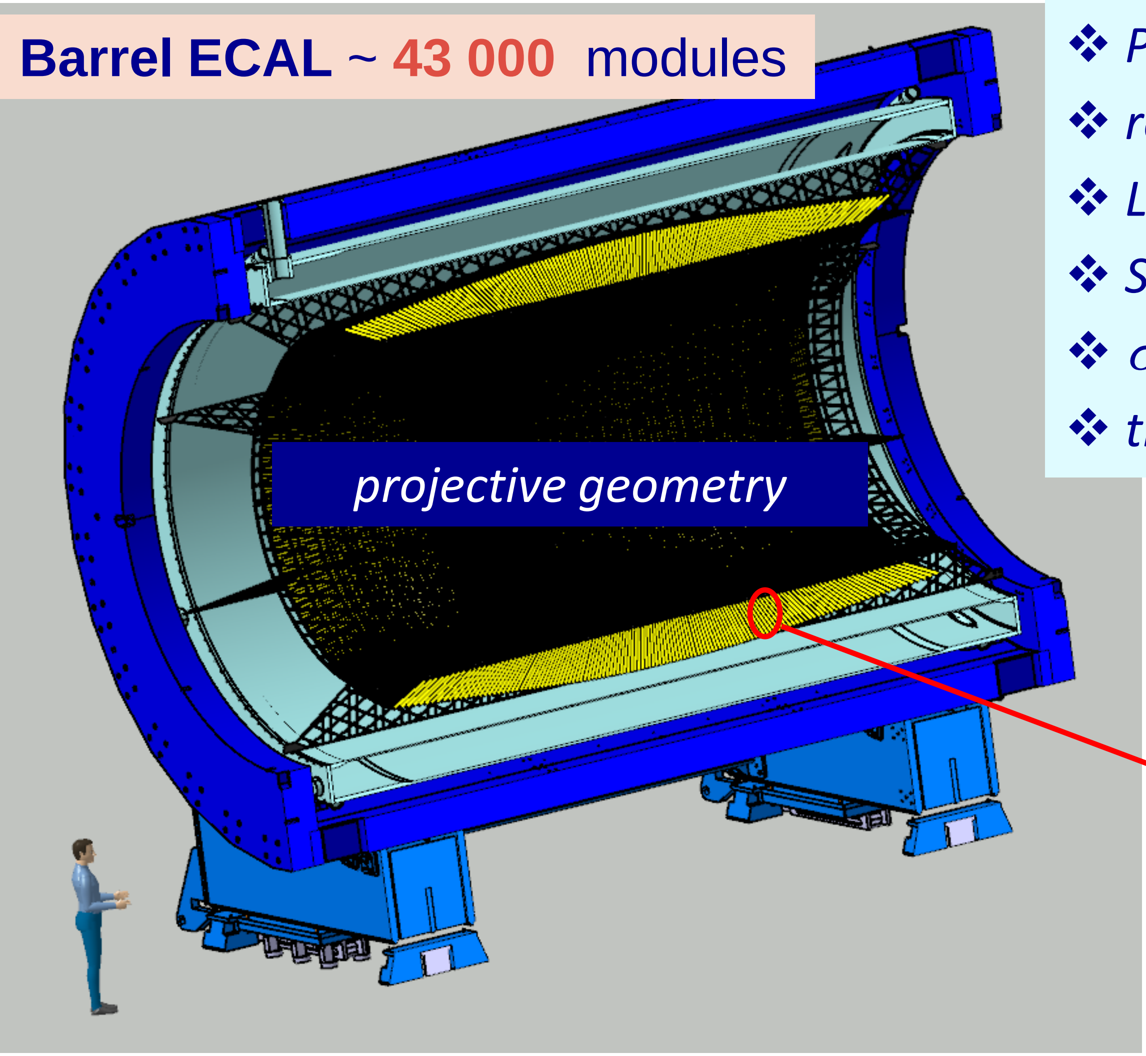


basic elements - NINO & HPTDC chips have been Purchased to produce read-out electronics for the TOF + reserve

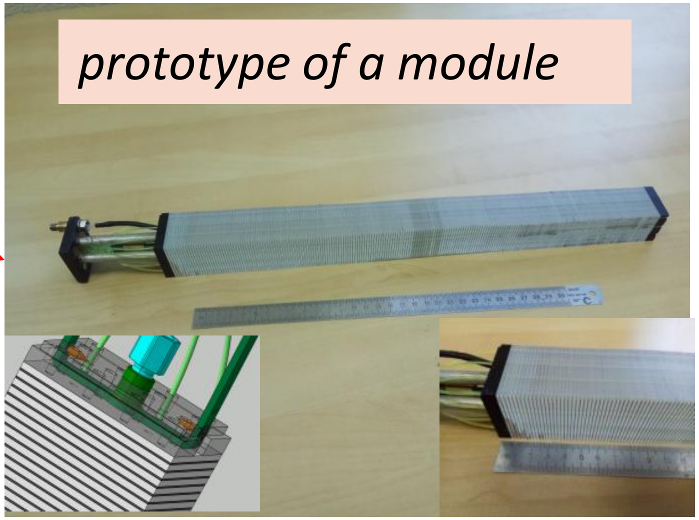


Electromagnetic calorimeter: ECAL

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



- *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*



Inner Tracking System

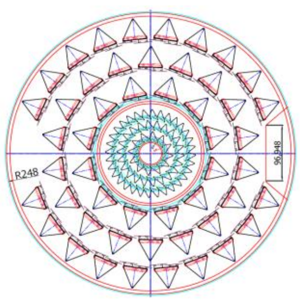
ALICE/CERN & JINR – joint efforts for:

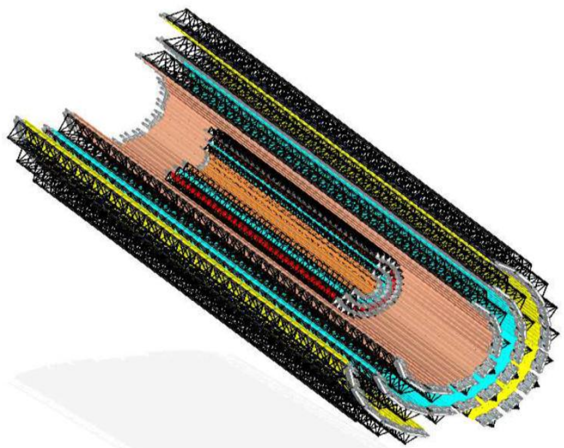
- *manufacturing the **ITS** carbon fiber space frames for **NICA** (BM@N & MPD)& **FAIR;***
- *construction of **MAPS based ALICE type ITS***

workshop for detector assembly & test was put in operation in 2015

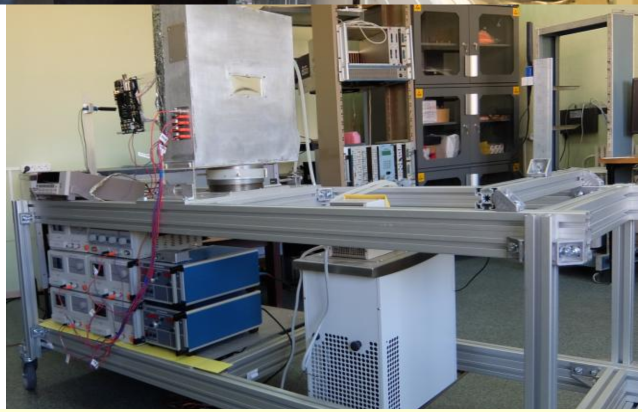
at the workshop

***ITS MPD** layout*





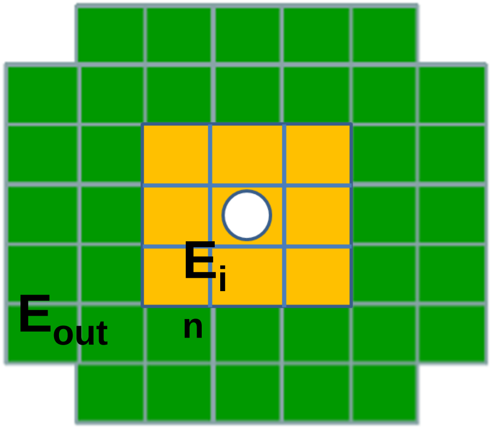
# layer	R0 mm	Active l, mm	N of staves	N of chips / layer	active area, cm2	number of pixel cells
1	24,4	542,4	12	216	889,9	113 246 208
2	42,0	542,4	22	264	1 087,7	138 412 032
3	60,0	542,4	32	384	1 582,1	201 326 592
4	107,	1477,5	12	1176	4 845,1	616 562 688
5	156,5	1477,5	18	1764	7 267,7	924 844 032
6	206,5	1477,5	24	2352	9 690,2	1 233 125 376
Total:				6156	25 362,7	3 227 516 928



*stand for beam tests of boards with sensors – **in operation***

FHCAL: for determination of reaction plane and centrality

*responsibility of **INR RAS***

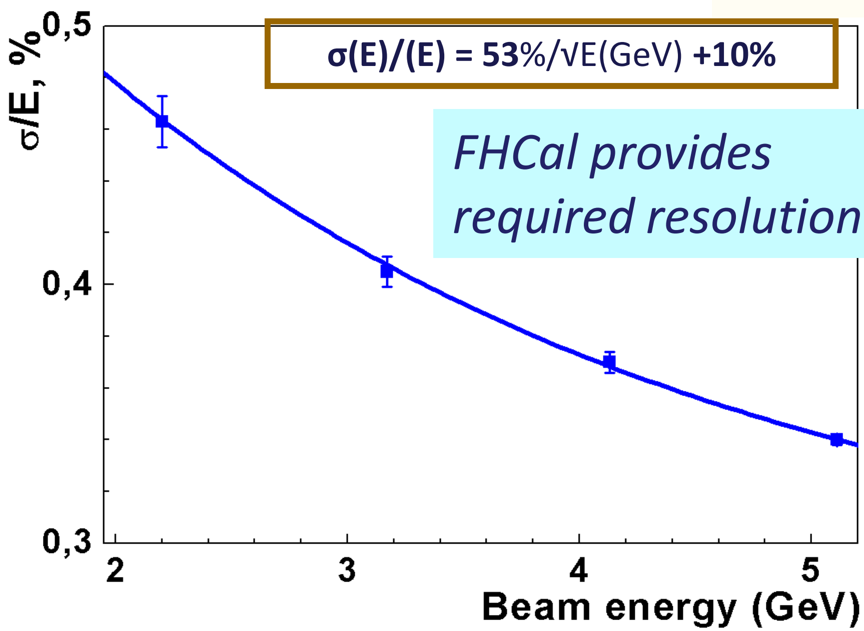


- 2-arm (left/right) calorimeter (at ~3.2 m from the IP)
- arm consists of 45 modules - 15x15 cm^2 each
- module - 42 lead/scintillator layers

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%.**



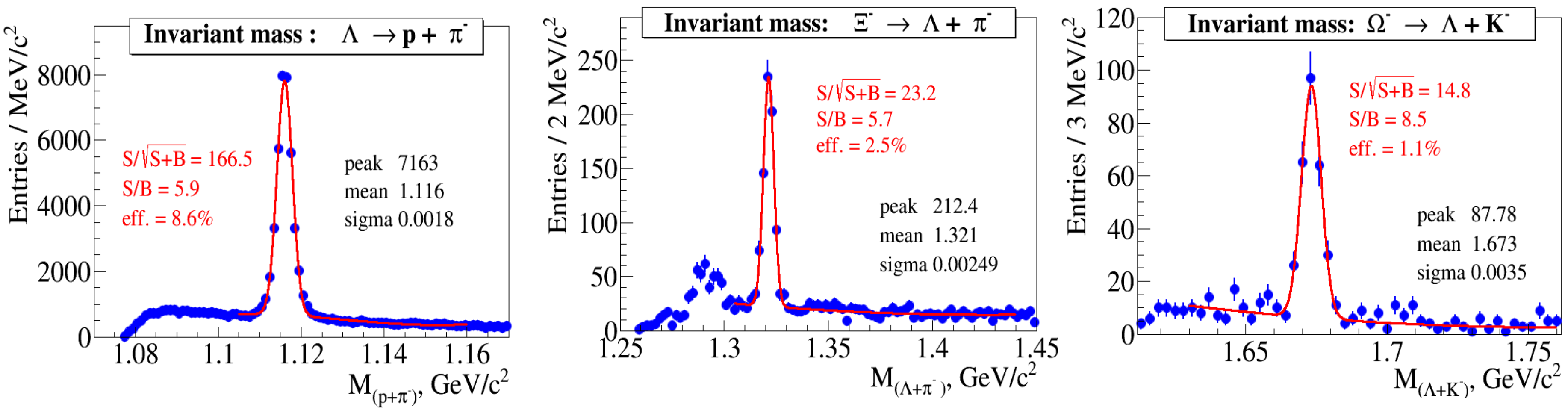
FHCal provides required resolution

modules production – in progress

MPD performance: hyperons

production of multi-strange hyperons to study the properties of the strongly interacting system and signal for QGP

- *Central Au+Au @ 9A GeV (UrQMD) , TPC+TOF barrel*
- *Realistic tracking and PID, secondary vertex reconstruction*



Yields for 10 weeks of running

hyperon	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-	$\bar{\Omega}^+$
statistics	$6\ 10^9$	$7.3\ 10^7$	$3\ 10^7$	$1.6\ 10^6$	$1.4\ 10^6$	$3\ 10^5$

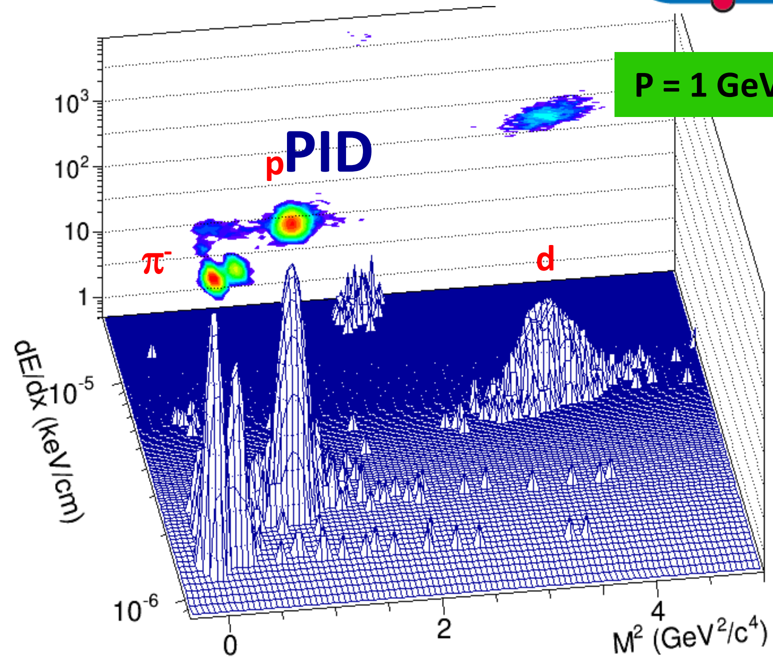
Hypernuclei @ MPD

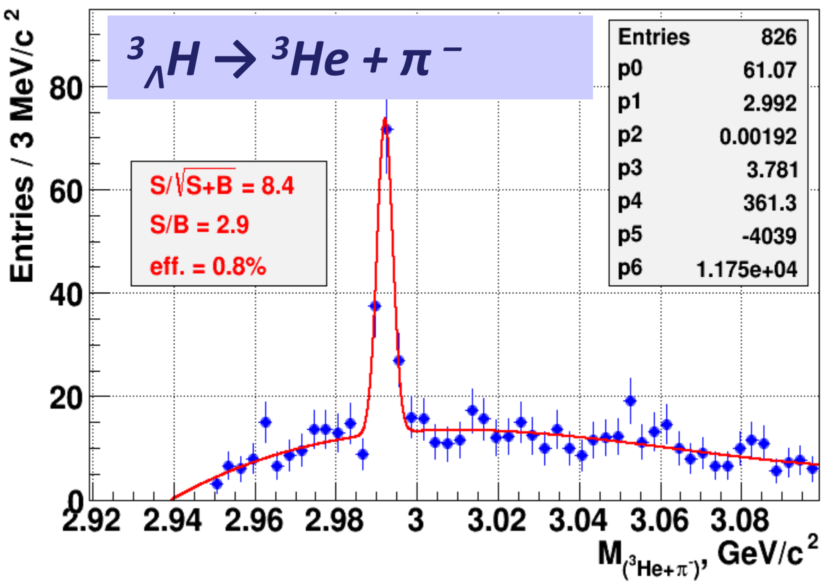
Hypertritons

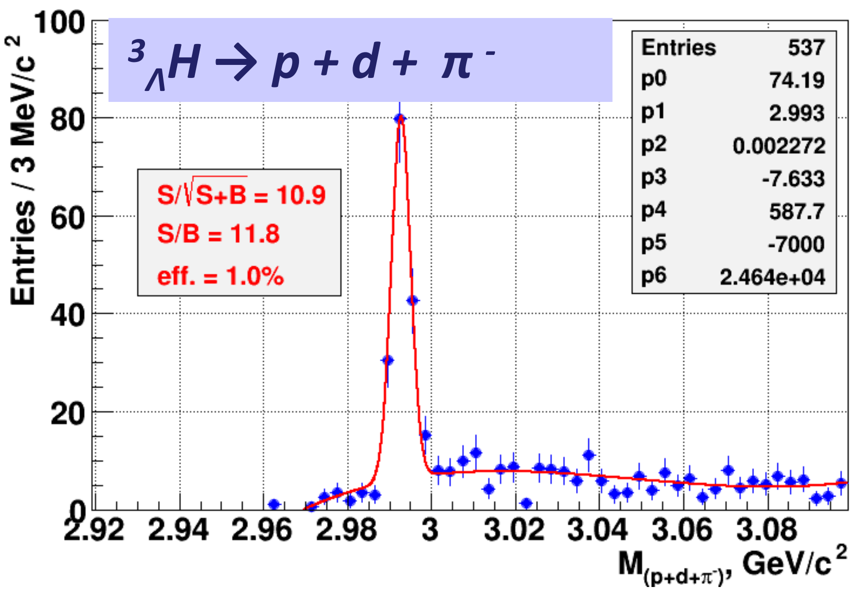
central Au+Au @ 5A GeV

(DCM-QGSM

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

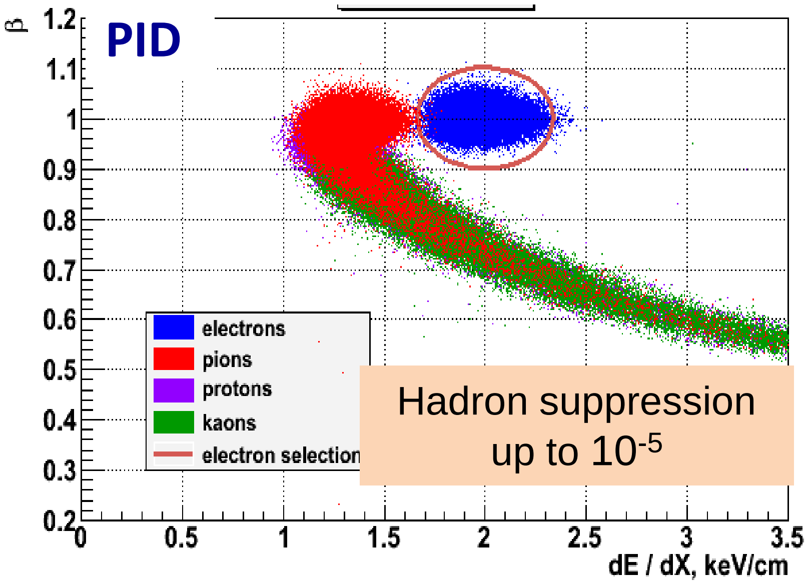




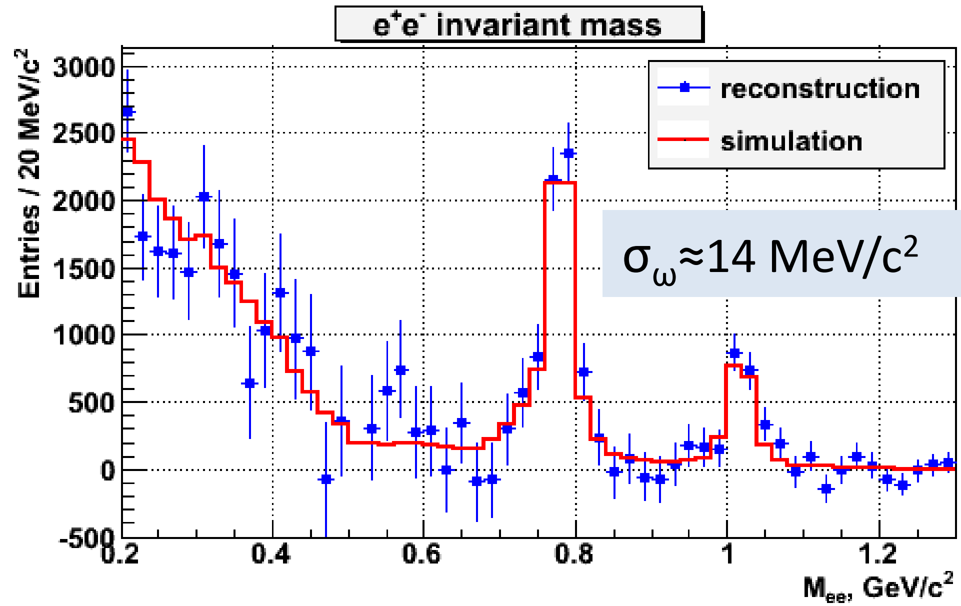


MPD performance for dileptons

Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density



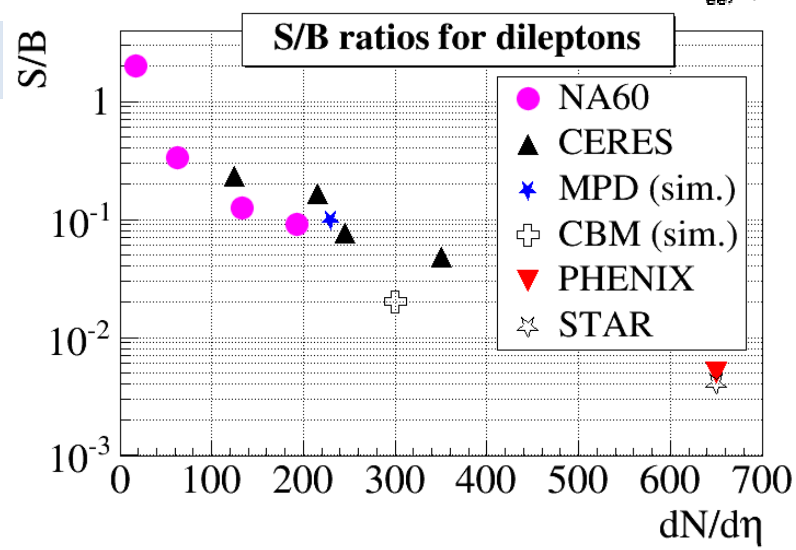
Hadron suppression up to 10^{-5}



$\sigma_\omega \approx 14$ MeV/c^2

Yields, central Au+Au st $\sqrt{s_{NN}}$ = 8.8 GeV/u

meson	Yields		Yield/1 w
	4π	y=0	
ρ	31	17	$7 \cdot 10^4$
ω	20	11	$7 \cdot 10^4$
φ	2.6	1.2	$1.7 \cdot 10^4$



ECAL tasks

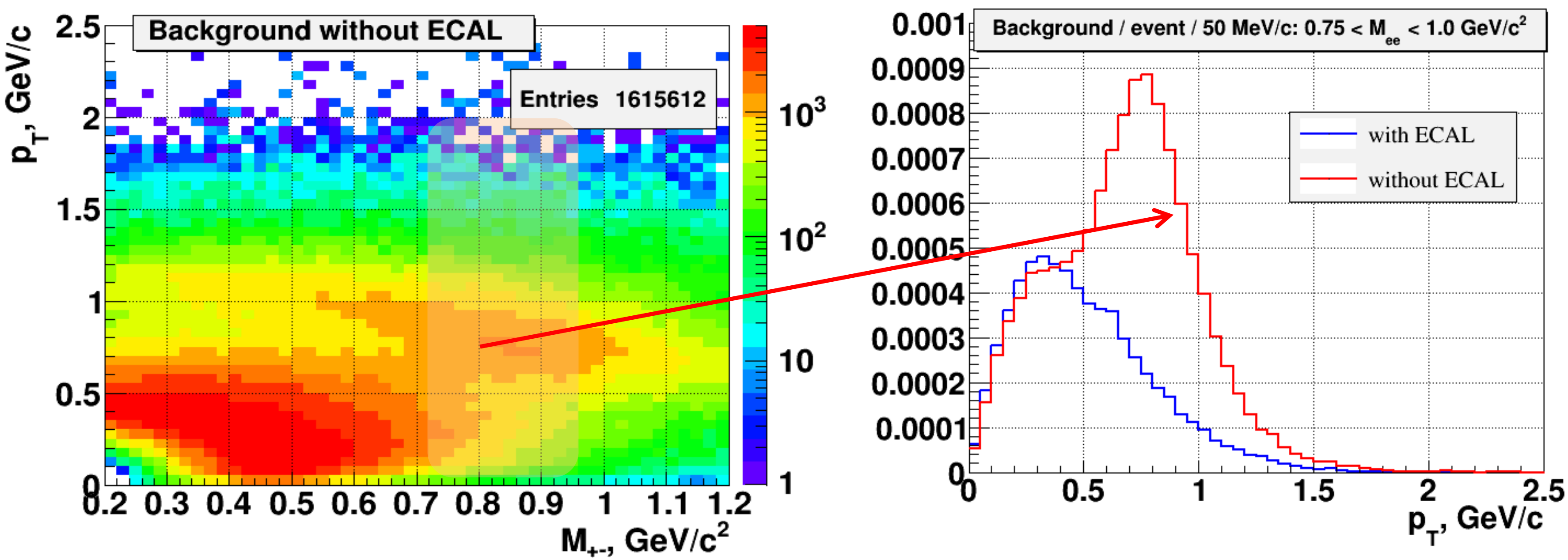
high acceptance & purity e/γ identification

- *in-medium modifications in dilepton spectra*
- *thermal radiation from QGP*
- *bulk properties via study of spectra, flow & correlations of photons*

Challenge for electron measurements in Au+Au at NICA:

suppression of hadron background in the region:

M(e+e-) > 0,7 GeV/c^2; pT >0.5 GeV/c **complementary to TOF**



- Study dileptons under highest baryon density
- Unveil onset of excess?
- Critical point? First order phase transition?

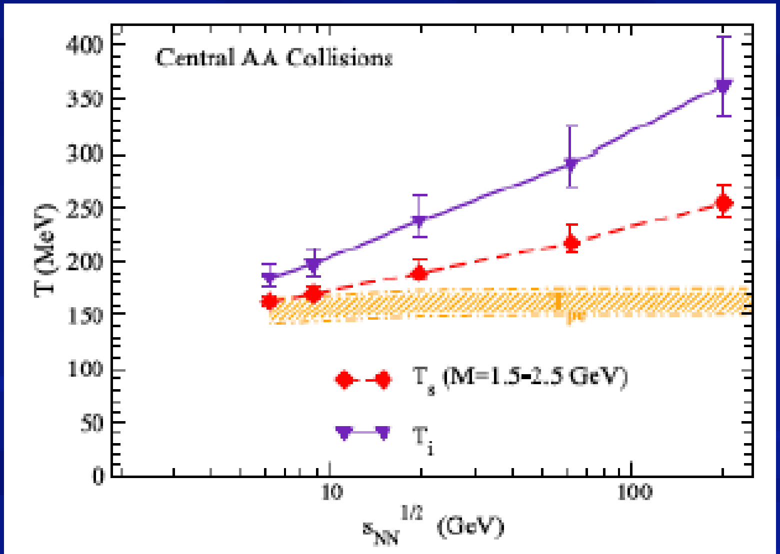
IMR as thermometer

and LMR as chronometer

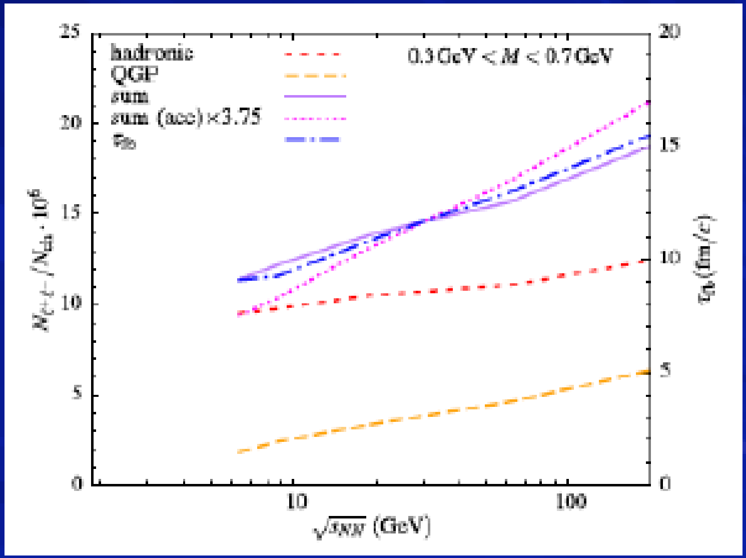
Rapp and Hees, PLB 753, 586 (2016)

m = 1 – 3 GeV/c^2

T given by inverse slope of the acceptance corrected mass spectrum in the IMR.

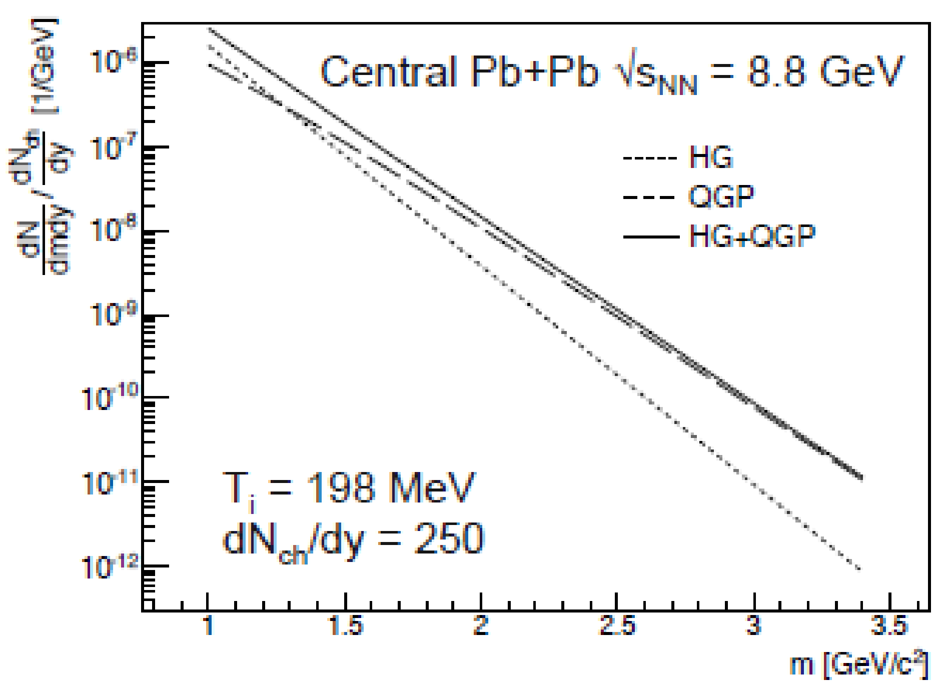


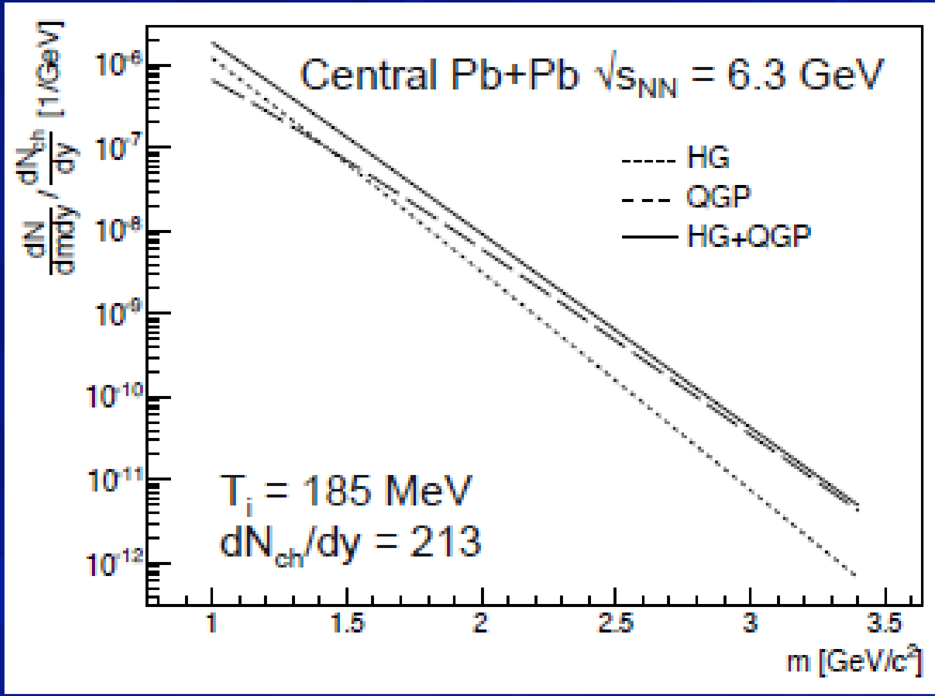
The thermal radiation integrated in the LMR m = 0.3 – 0.7 GeV/c^2 tracks the fireball lifetime quite well



Thermal yields at low energies

R. Rapp – private communication



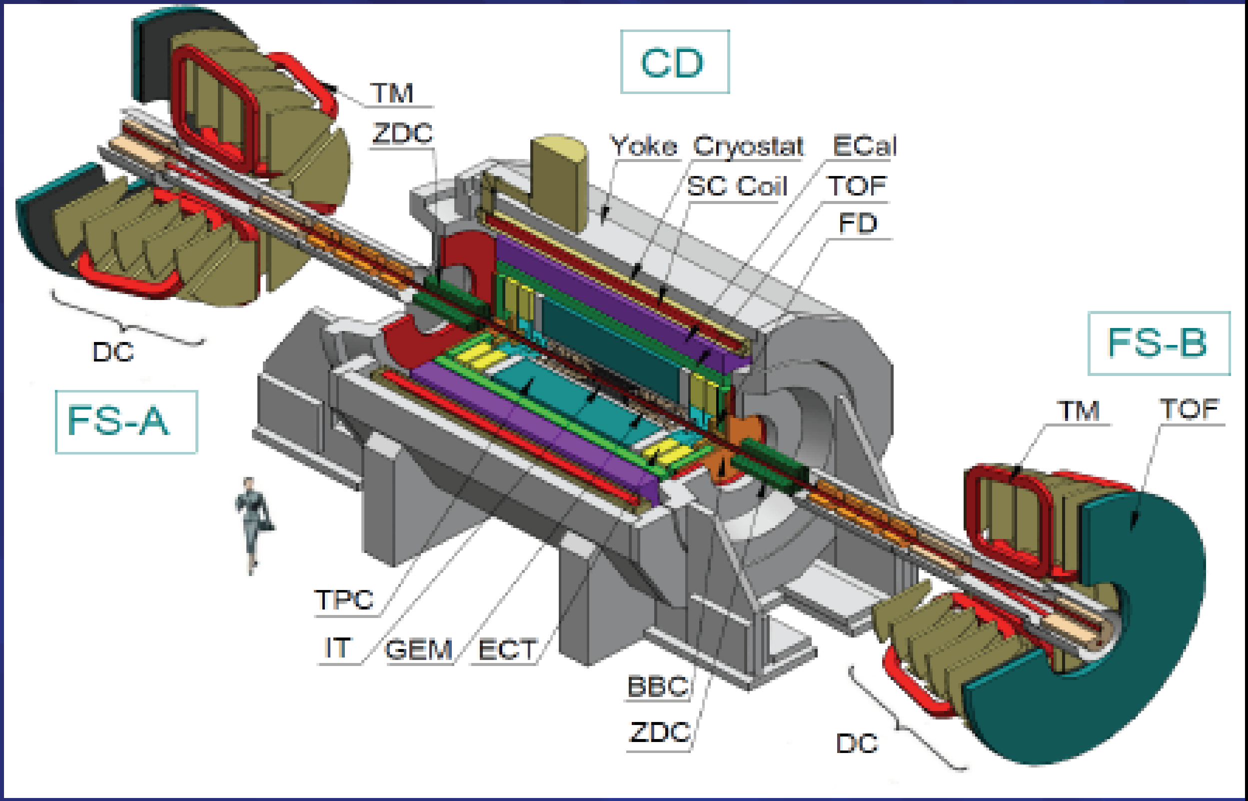


- Cross sections decrease by almost two orders of magnitude between central Au+Au at 200 GeV and central Pb+Pb at 6.3 GeV at m=2 GeV/c^2
- Challenging measurements

Cross sections down by ~3 orders of magnitude between RHIC and NICA energies.

MPD detector at NICA

- 9 m long 6 m diameter
- Low material budget
- Tracking (TPC):
  up to $|\eta|<2$, 2π in azimuth
- PID (TOF, TPC, ECAL):
  hadrons, e, γ



Estimate of dilepton yield in central Au+Au at $m = 2 - 2.5\ GeV/c^2$

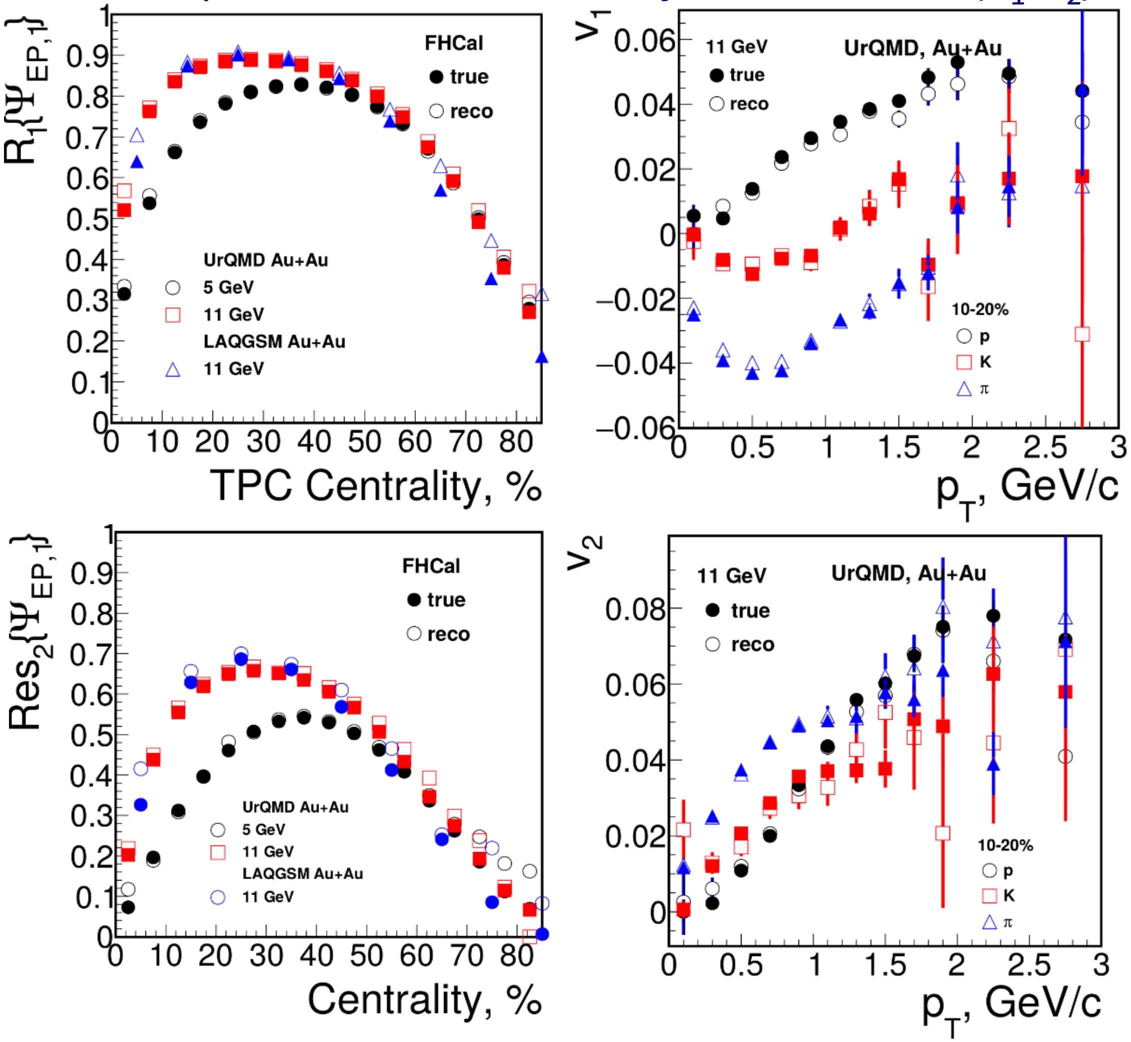
$\sqrt{s_{NN}} = 8$ GeV	410 pairs/10 d
$\sqrt{s_{NN}} = 6.3$ GeV	54 pairs/10 d

Summary

- All systems at all energies studied show an enhancement of dileptons.
- A single model consistently reproduces the observed enhancement.
- ! The thermal radiation from the QGP dominates the dilepton excess in the IMR. Provides a measurement of the average temperature of the medium in the QGP phase.
- ! The thermal radiation from the HG dominates the dilepton excess in the LMR. Seems to track the medium lifetime.
- Emerging picture for the realization of CSR: the ρ meson broadens in the medium, the a_1 mass drops and becomes degenerate with the ρ.
- Missing:
  - precise measurements of IMR at RHIC energies.
  - v_2 measurements of the excess dileptons.
- ! Clear predictions and strong experimental program to study dileptons at low energies.

Flow performance: *v_n of charged hadrons (FHCal event plane)*

event plane resolution *flow harmonics (v_1/v_2)*



MEPhI/GSI:
P. Parfenov, I. Svintsov
I. Selyuzhenkov, A. Taranenko

Azimuthal flow coefficients:
$v_n = \langle \cos[n(\varphi - \Psi_{EP,1})] \rangle / R_n\{\Psi_{EP,1}\}$

- $R_n\{\Psi_{EP,1}\}$ - resolution correction factor
- φ – azimuthal angle of the produced particles
- $\Psi_{EP,1}$ - event plane angle

Centrality with TPC estimator

Good event plane resolution with FHCal
Simulated v_n (true) and reconstructed v_n (reco) are in a good agreement

strategy in 2021-2023

energy and system size scan from 4 to 11 GeV in steps of 1-2 GeV

limitation by the accelerator:

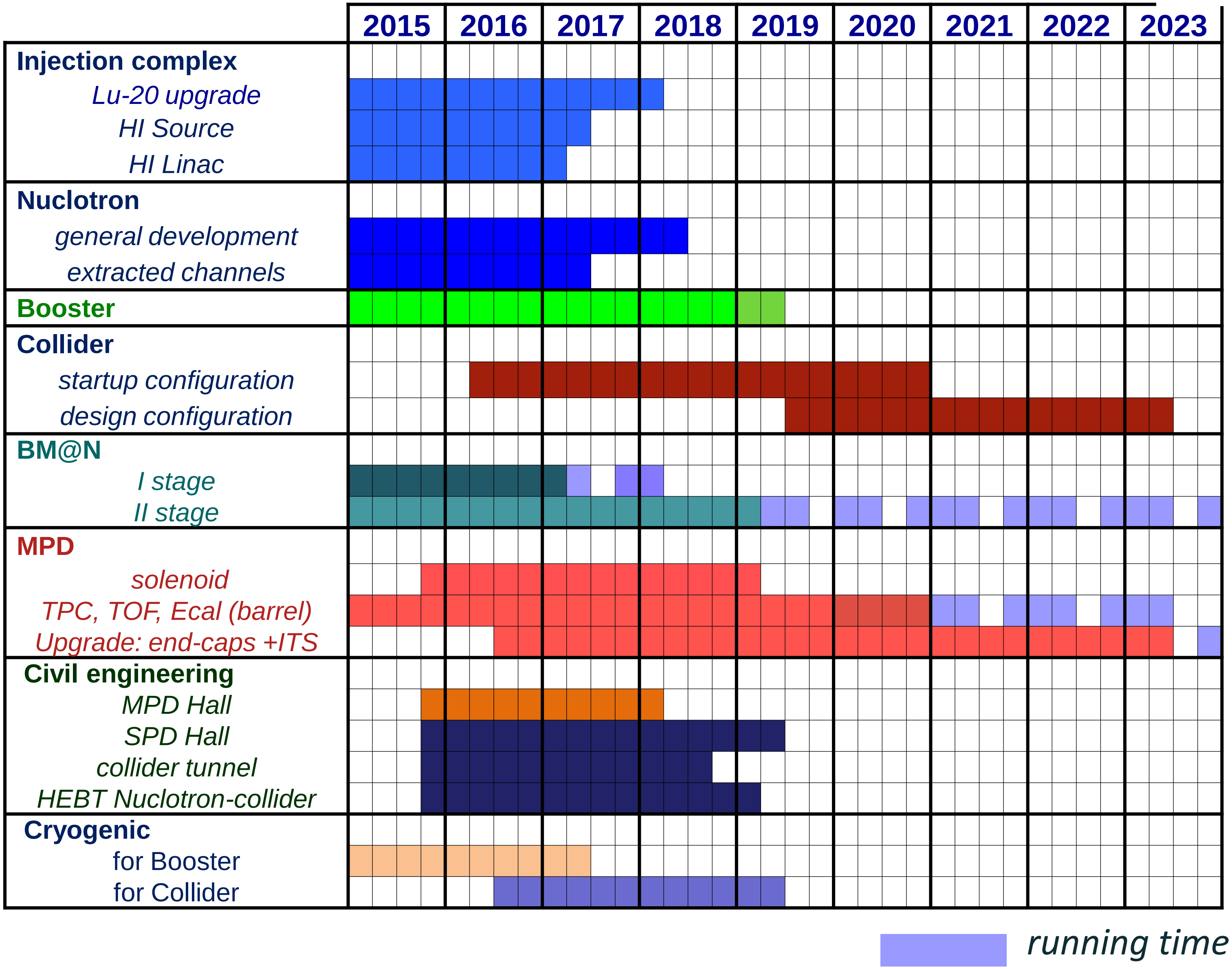
- *lower luminosity*
- *extra reduction by 40% because of a larger beam diamond*

Detector limitation

- ***TPC*** *tracking: $|\eta|<1.8$ (N points>10)*
- ***TOF*** *coverage: $|\eta|<1.2$*
- ***PID****: combined $|\eta|<1.2$, $0.1<pT<4$ GeV/c,*

  limited in $1.2 < |\eta| < 1.8$ (only dE/dx)
- ***ECAL*** *coverage : $|\eta|<1.2$*
- ***FHCAL*** *coverage: $2.2<|\eta|<4.8$*
- ***FFD*** *inside the TPC inner pipe*

NICA schedule



Concluding remarks

- Density frontier is less explored area and its study *will lead to new interesting results*
- NICA complex has a potential for competitive research *in the field of baryon rich matter*
- The construction of both detectors BM@N & MPD *is going close to the schedule*
- NICA is open for new participants

Welcome to join NICA!

Thank you for attention!