Status of the NICA project

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Joint Institute for Nuclear Rsearch, Dubna

NICA days 2015 in Warsaw,
November 3 – 7, Warsaw, Poland

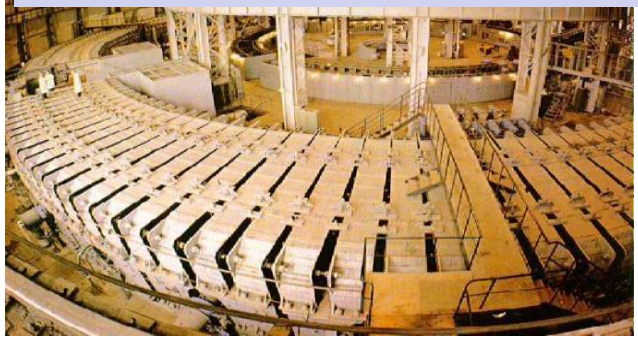
from the Synchrophasotron to the Collider NICA

1957 Synchrophasotron

10 GeV proton synchrotron – the world leader in energy

the start up of high energy era

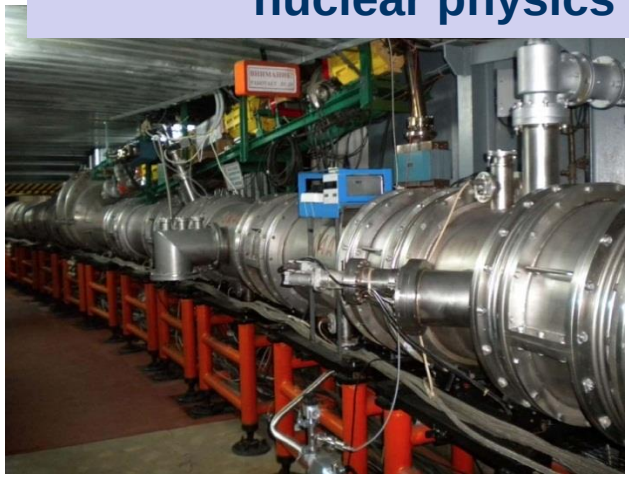
V.I.Veksler –the discovery of *Phase Stability Principle (1944)*



1993 Nuclotron

the first superconducting accelerator of heavy ions based on Dubna type SC magnets

A.V.Baldin the pioneer of relativistic nuclear physics



2019 NICA

The superconducting Collider of heavy ions

Study of nuclear matter at extreme conditions and spin physics

NICA (Nuclotron based Ion Colider fAcility) – the flagship project in HEP of Joint Institute for Nuclear Research (JINR)

Main targets of the NICA project:

- ***study of hot and dense baryonic matter***
- ***investigation of nucleon spin structure, polarization phenomena***

- *development of accelerator facility for HEP @ JINR providing intensive beams of relativistic ions from p to Au polarized protons and deuterons with max energy up to* $\sqrt{S_{NN}}$ *= 11 GeV (Au^{79+}) and =27 GeV (p)*

The NICA Complex

existing facility

to be constructed one

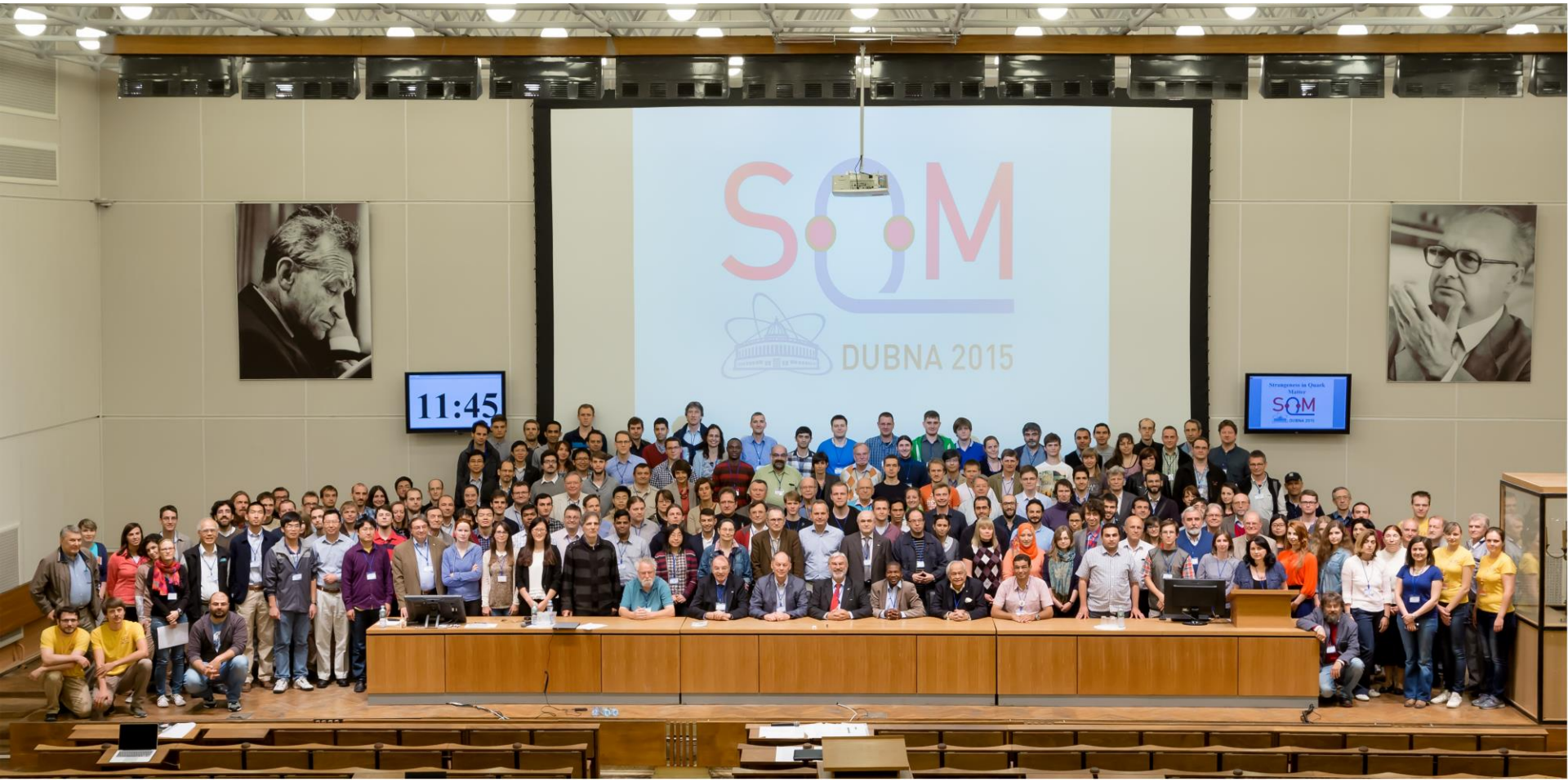
*the contract for civil construction has been signed with general contractor **STRABAG***
*(**Bodostal-3** & **PCJ** are in the list of sub-contactors);*
the works have started

NICA collider major parameters

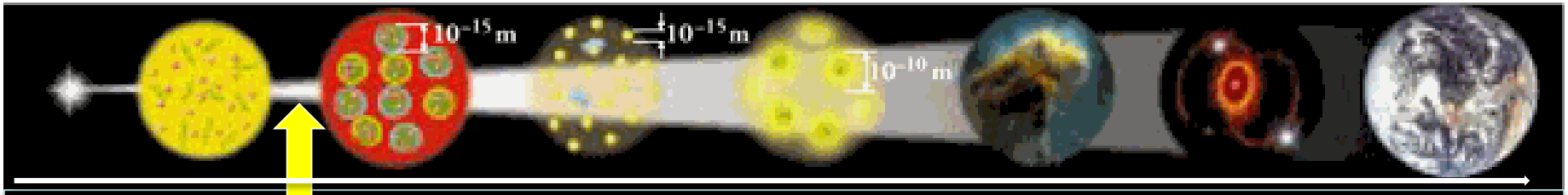
Ring circumference, m	**503.04**
heavy ions	
β, m	**0.35**
*energy range for **Au**$^{79+}$: $\sqrt{S_{NN}}$, GeV*	**4 - 11**
r.m.s. $\Delta p/p$, 10^{-3}	**1.6**
*Luminosity for **Au**$^{79+}$, cm^{-2} s^{-1}*	**1x10^{27}**
polarized particles	
*max. energy for polarized **p**, Gev*	**27**
*Luminosity for **p**, cm^{-2} s^{-1}*	**1x10^{32}**

Physics objectives

Heavy ion collisions



mini "Big Bang" in the laboratory

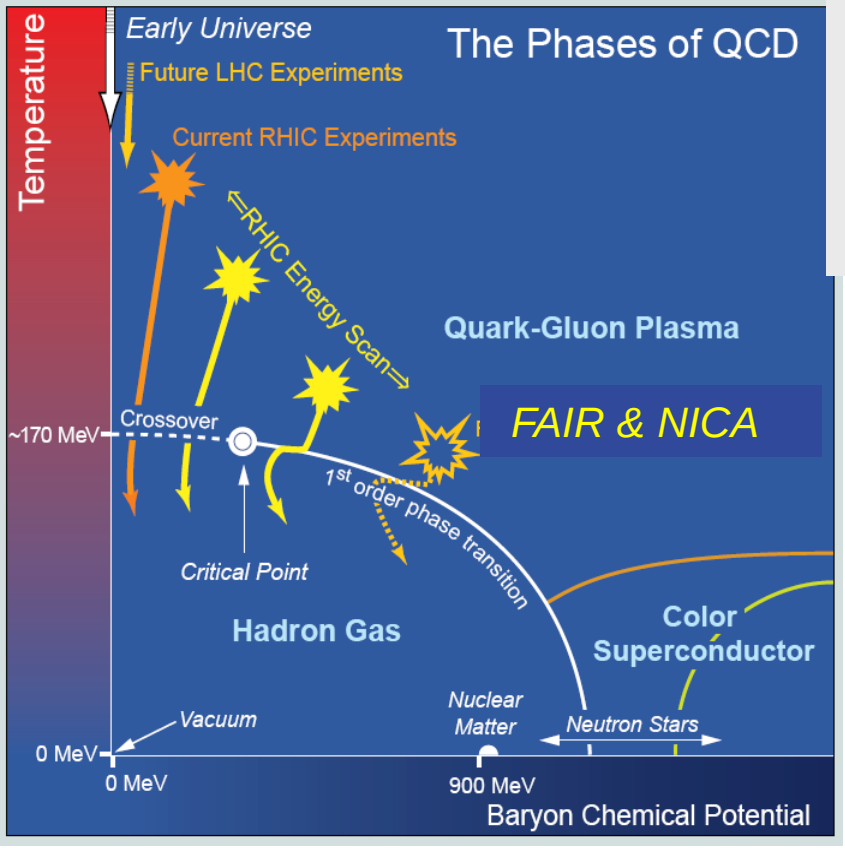


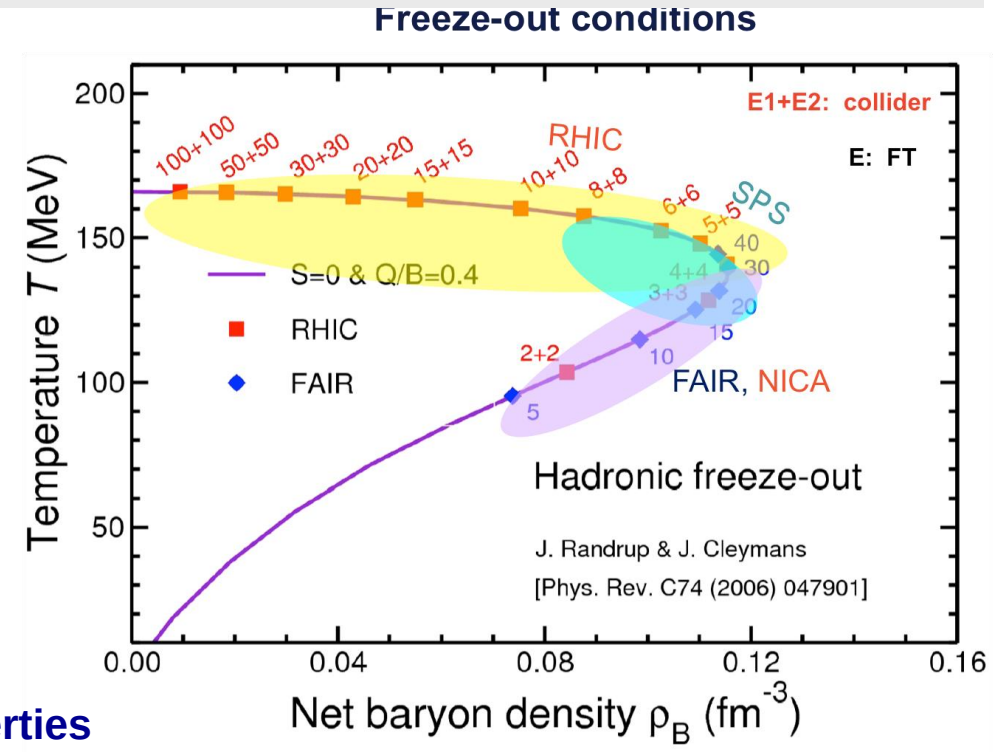
Big Bang	Q-G plasma	p & n formation	low mass nuclei formation	neutral atom formation	star formation	dispersion of massive elements	Today
T	$>10^{12}$ K	10^{12} K	10^{9} K	4000 K	20 - 3 K	< 20 K	3 K
time	10^{-6} s	10^{-4} s	3 min	400 k yr	10^{9} yr	$> 10^{9}$ yr	15 10^{9} yr

Physics

QCD matter at NICA :

- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*





- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** - *enhanced strangeness production*
- **QCD Critical Point** - *event-by-event fluctuations & correlations*
- **Strangeness in nuclear matter** - *hypernuclei*

charged particle collisions :

electrons, protons (hydrogen nucleus), heavy ions (nuclei)

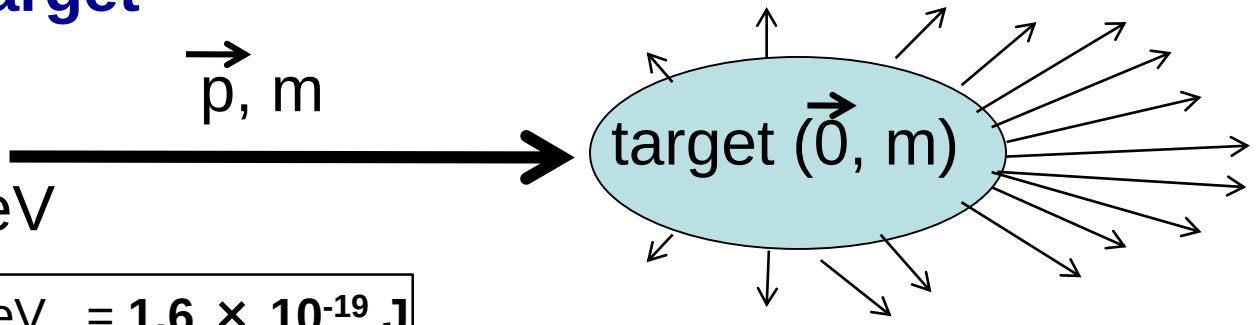
Expriments:

$$S_{NN} = (E_1+m)^2 - (\vec{p} + \vec{0})^2 \approx 2pm + 2m^2$$

✓ **with fixed target**

p = **10** GeV

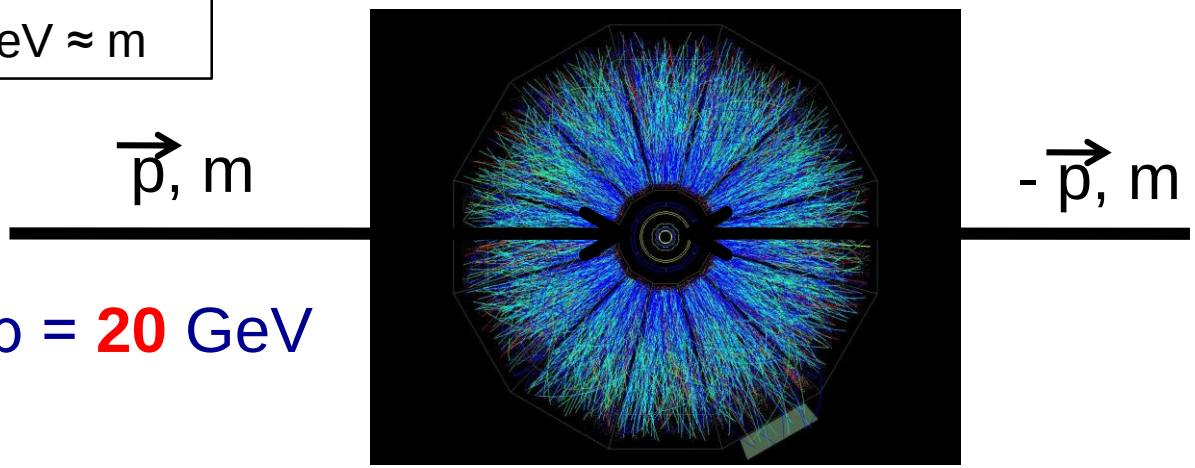
$\sqrt{S_{NN}} \approx$ **4,5** GeV



1eV = **1.6 × 10^{-19} J**

1GeV=10^9 eV ≈ m

✓ **at collider**



$\sqrt{S_{NN}} \approx 2p =$ **20** GeV

Experimental modes

collider **fixed target**

advantages:

- ***coverage of max. phase space***
- *minimum biased acceptance*
- *free of target parasitic effects*
- *….*

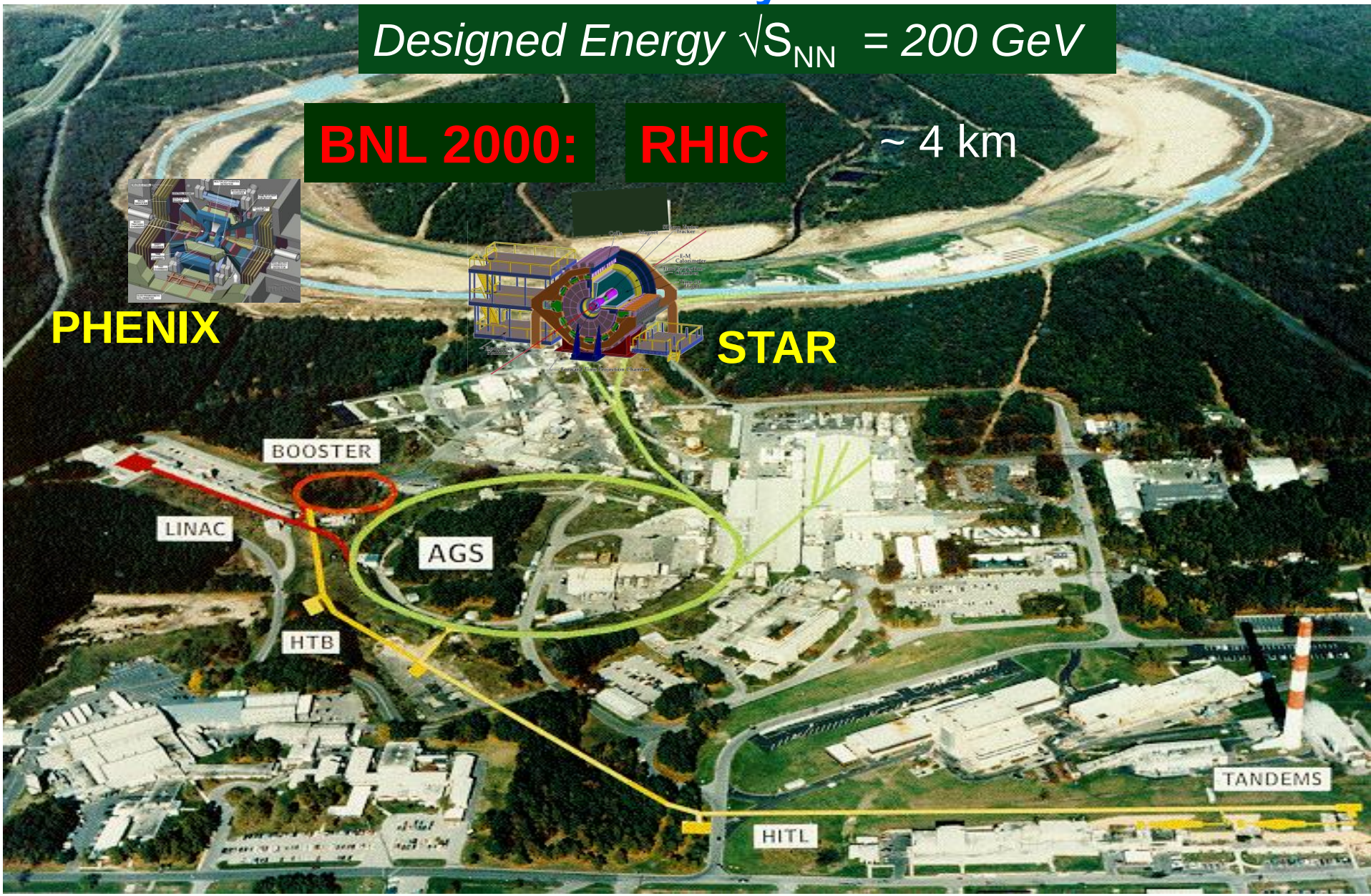
- *rate is limited just by detector capability*
- *easy upgradable*
- *….*

disadvantages:

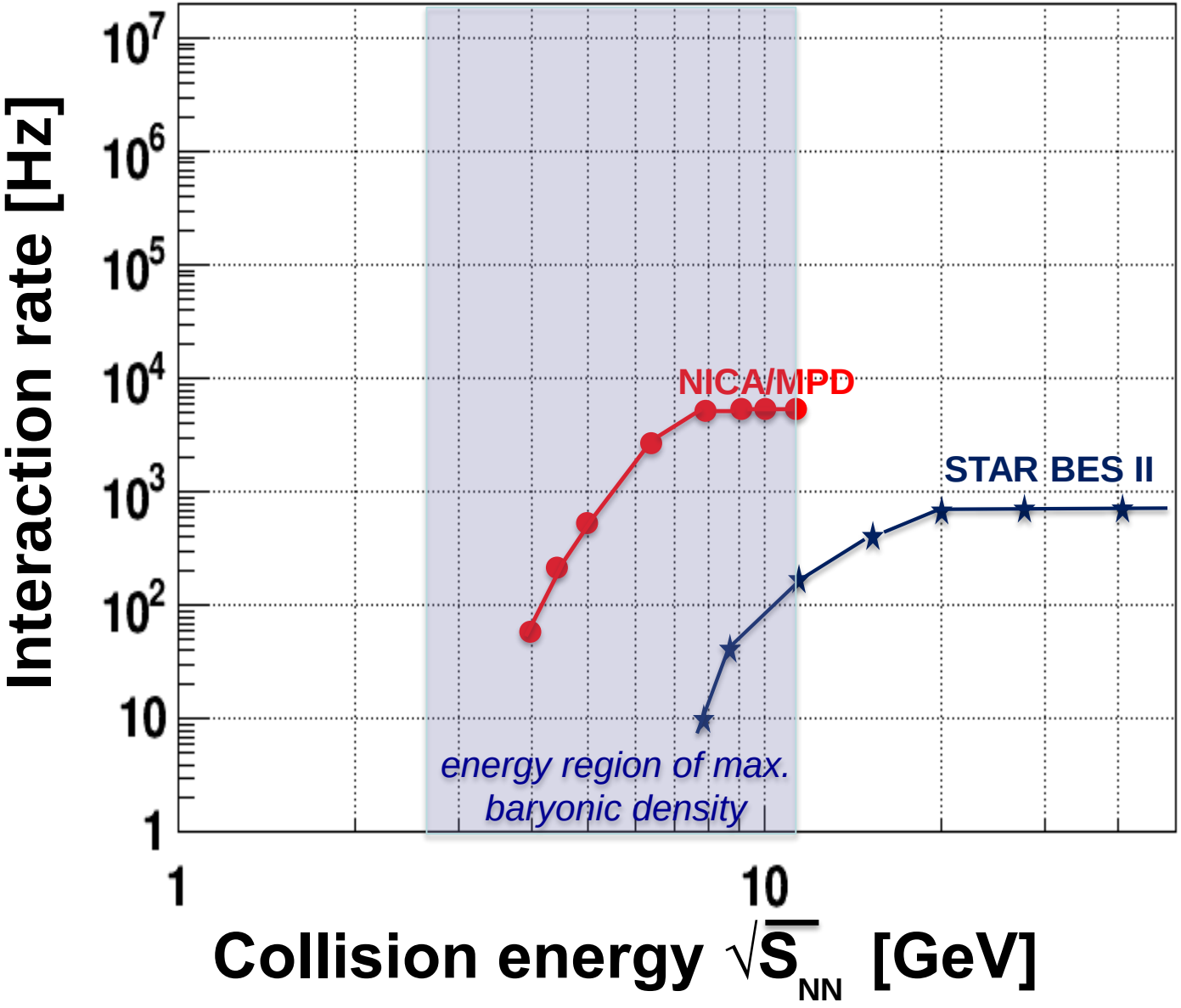
- *rate is limited by luminosity*
- *limited combinations "beam"/"target"*
- *…..*

- *a limited phase space*
- *momentum dependent corrections*
- *target influenced corrections*

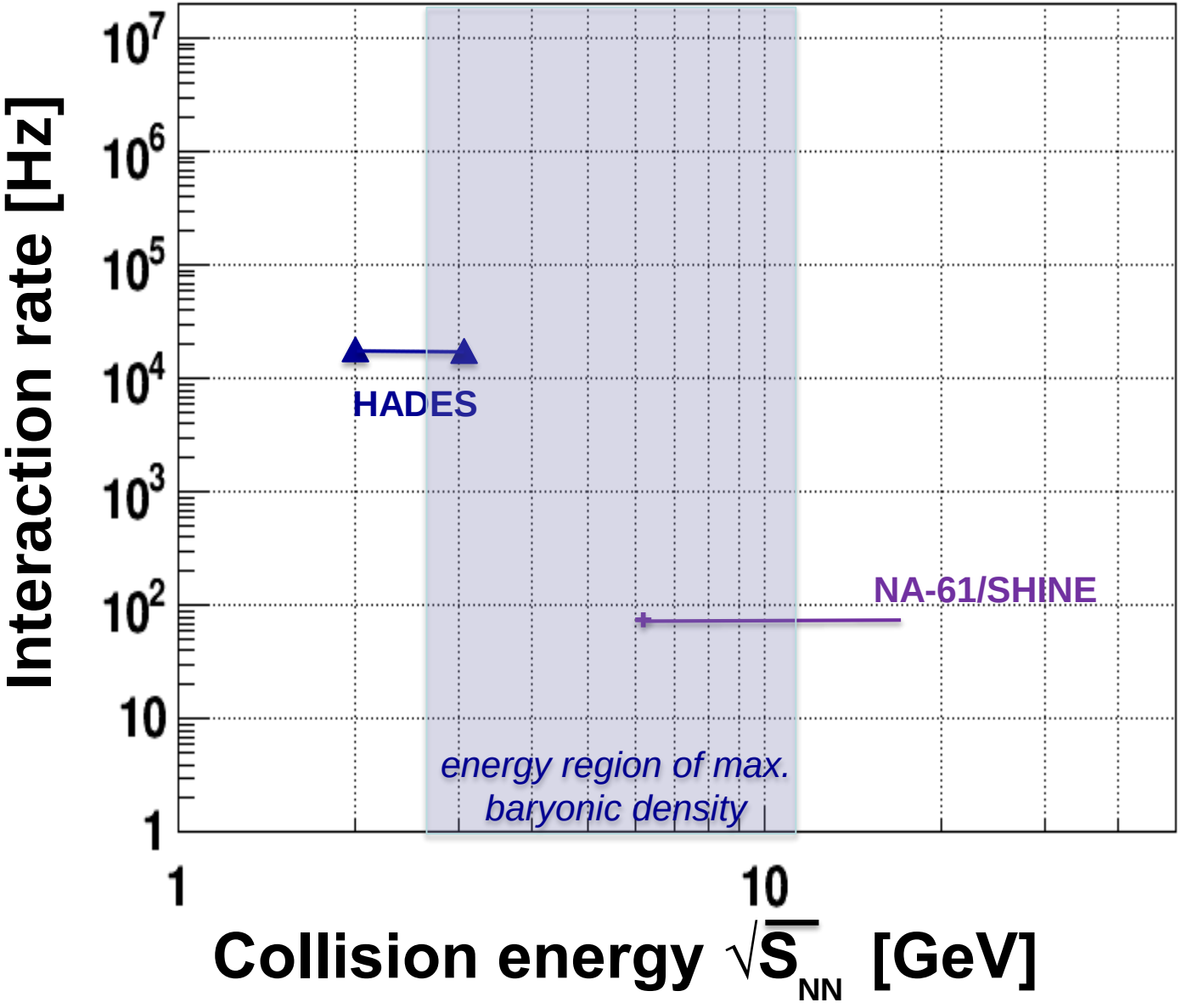
Relativistic Heavy Ion Collider



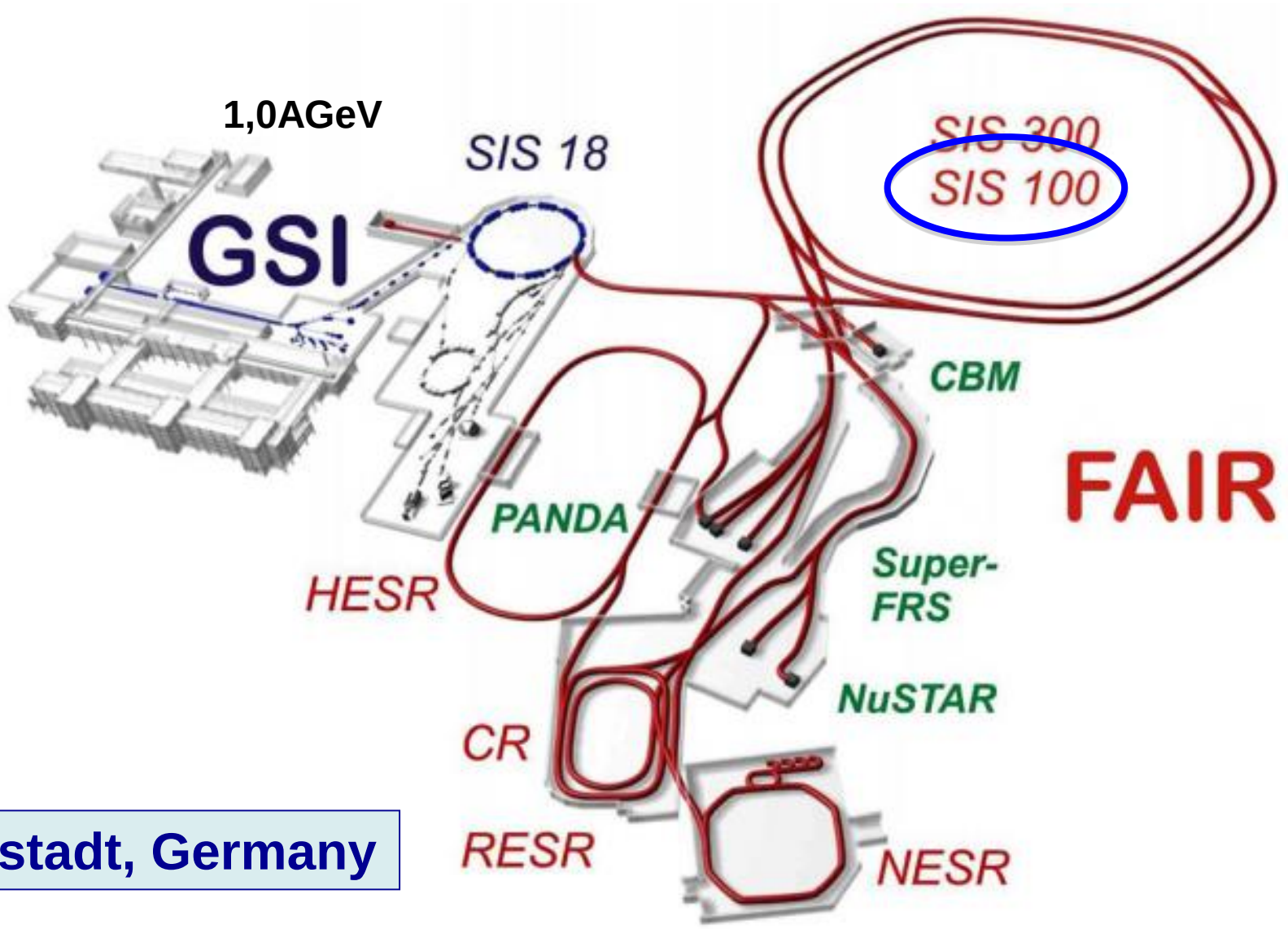
Present and future HI collider experiments



Present HI F.T. experiments

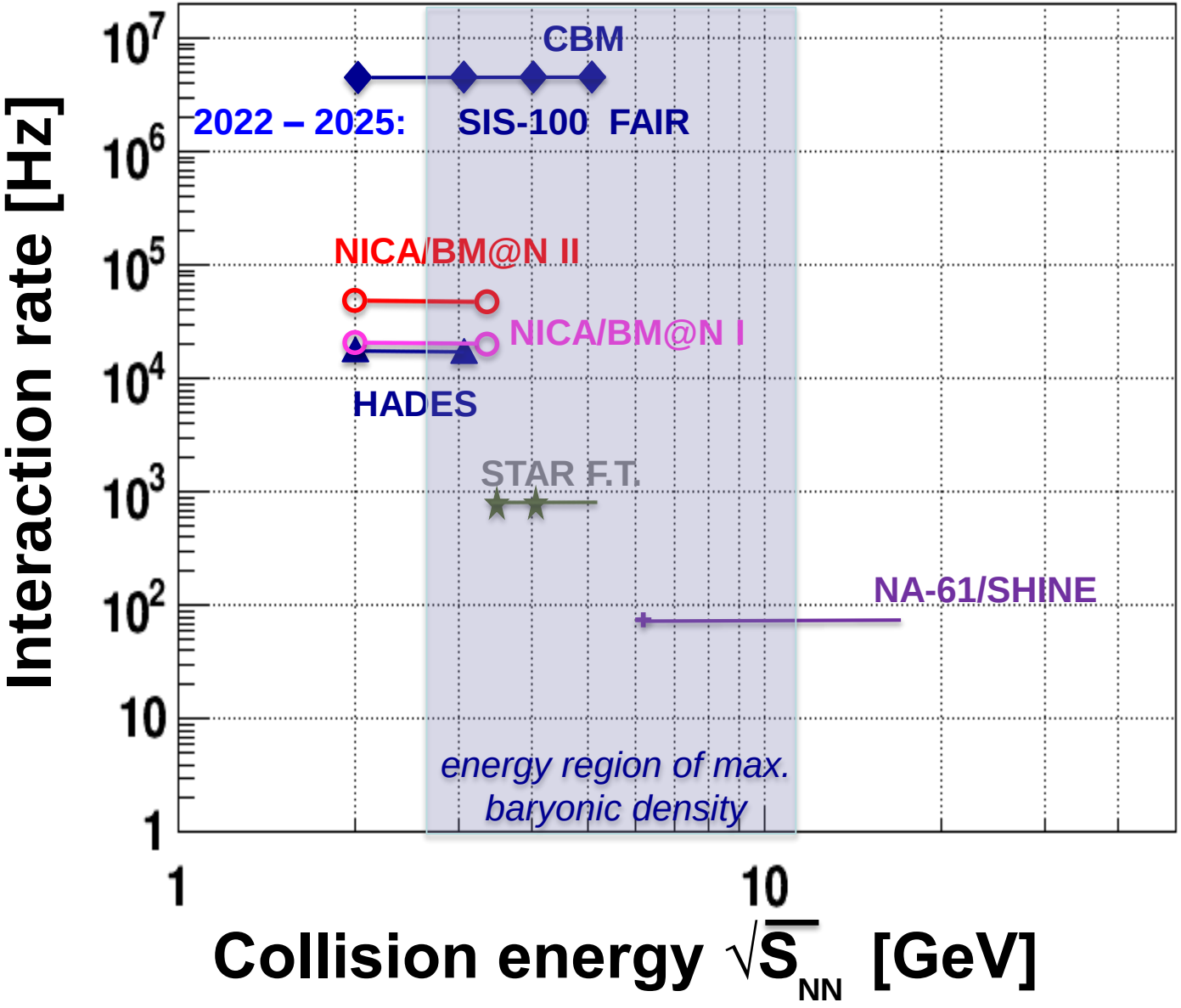


*Complex **FAIR:** experiments with fixed target*

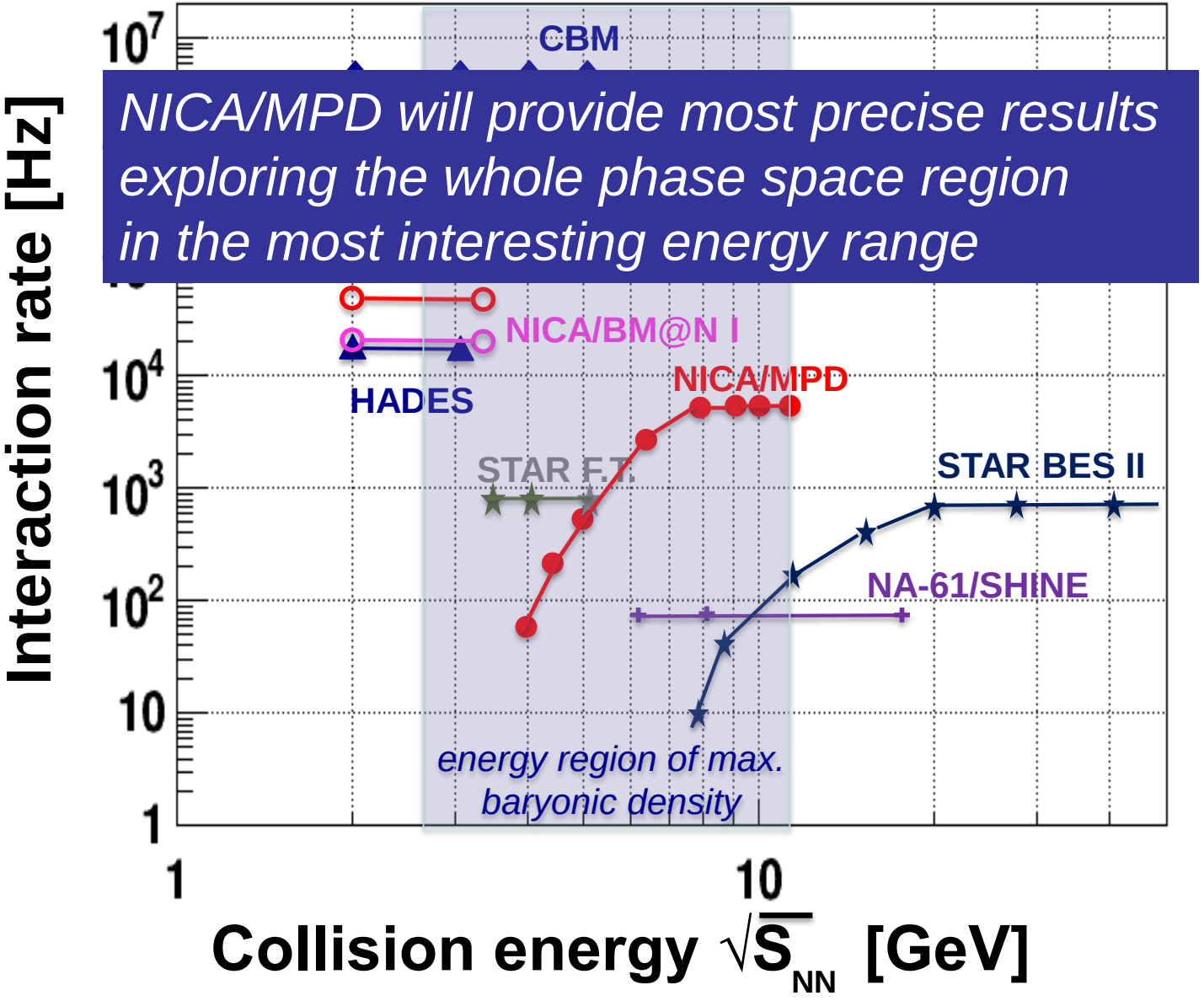


Darmstadt, Germany

Present and future HI F.T. experiments



Present and future HI experiments



Both, collider and fixed target approaches,
are complementary and necessary
for approval of potential discovery

In this view the **NICA** and **FAIR** projects are complementary and their joined efforts have aimed to discovering and to studying new forms of baryonic matter

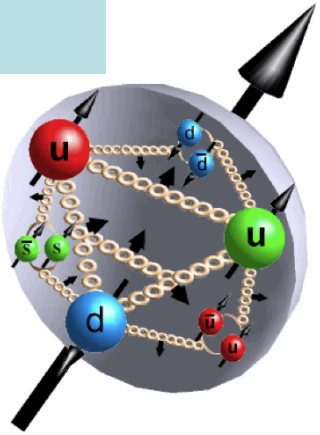
SPD (Spin Physics Detector) *at the Collider*

Collider provides both:
transversally & longitudinally polarized ***p*** & ***d***
with energy up to $\sqrt{S}$ = ***27 GeV***

Collaboration is forming;
project is under preparation

Nucleon spin structure

Sum rule: $$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g.$$

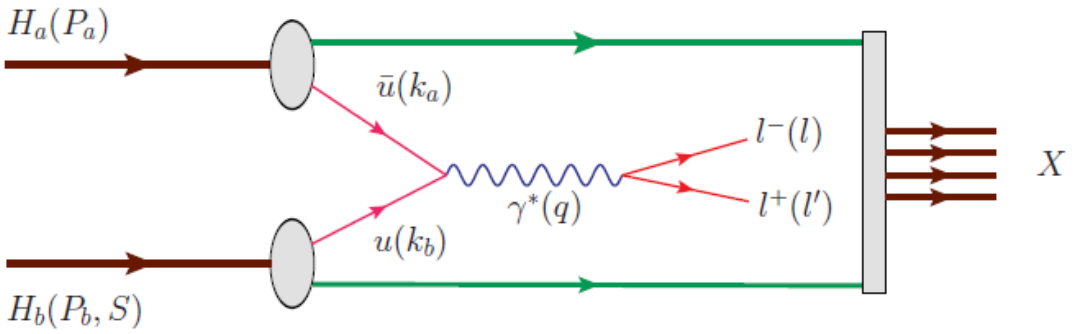


Nucleon spin structure study using

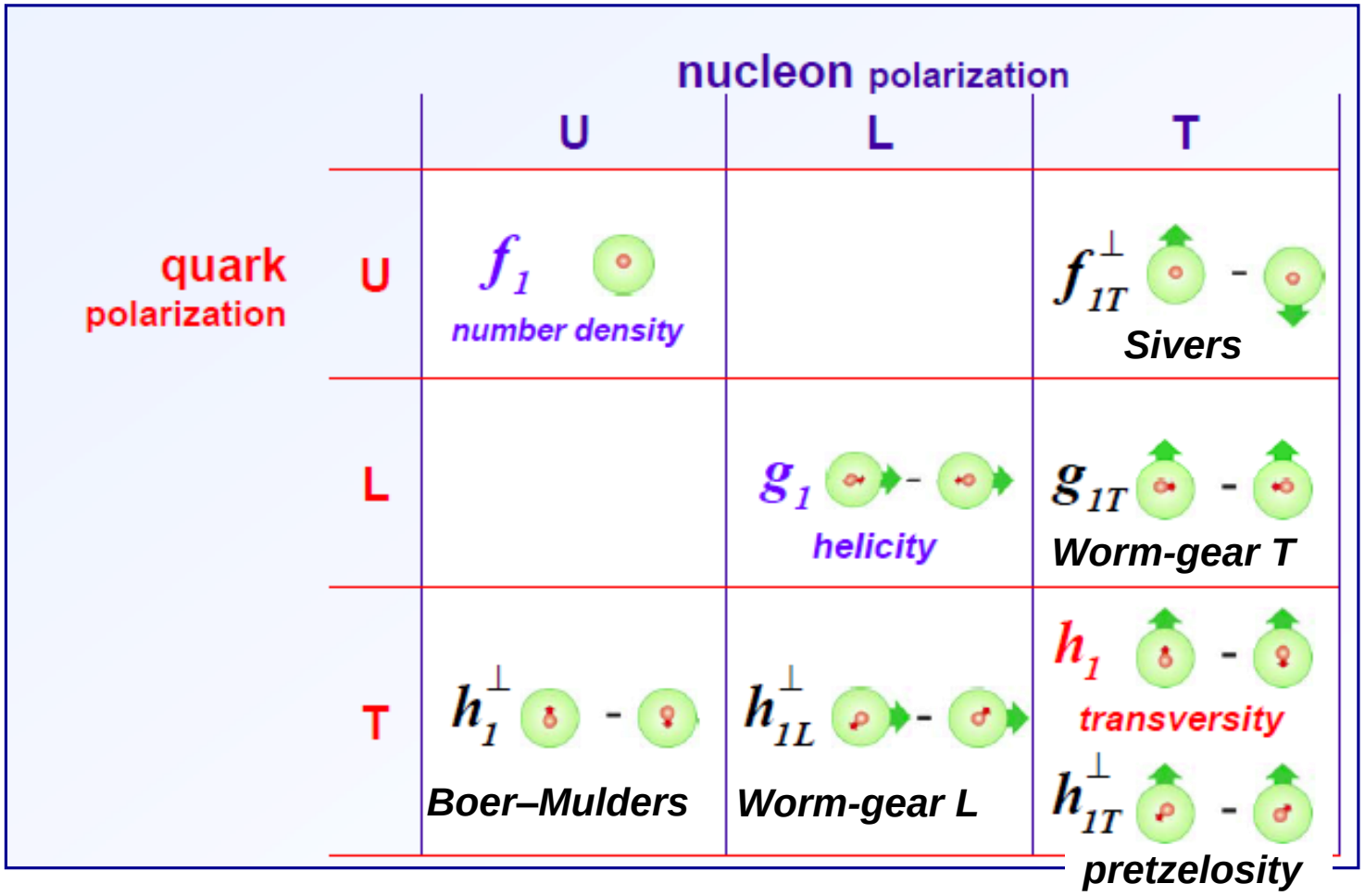
the Matveev-Muradyan-Tavkhelidze-Drell-Yan mechanism, DVCS & SIDIS processes (*new PDFs*):

- *8 intrinsic-transverse-momentum dependent PDFs at leading twist*
- *azimuthal asymmetries with different angular modulations in the hadron and spin azimuthal angles, Φ_h and Φ_s*

Direct photons production (*gluon polarization*)



nucleon vs quark polarizations



Experiments studying nucleon spin structure

experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	F.T.	F.T.	F.T.	collider	collider	collider
Beam/target	π- , p	anti-p, p	π- , p	pp	pp	pp, pd,dd
Polarization:b/t	0; 0.8	0; 0	0; 0	0.5	0.5	0.7
Luminosity	$2{\cdot}10^{33}$	$2{\cdot}10^{32}$	$3.5{\cdot}10^{35}$	$5{\cdot}10^{32}$	$5{\cdot}10^{32}$	10^{32}
$\sqrt{s}$, *GeV*	14	6	16	200, 500	200, 500	10 - 26
$x_{1(beam)}$ *range*	0.1-0.9	0.1-0.6	0.1-0.5	0.03-1.0	0.03-1.0	0.1-0.8
q_T, *GeV*	0.5 -4.0	0.5 -1.5	0.5 -3.0	1.0 -10.0	1.0 -10.0	0.5 -6.0
Lepton pairs,	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+, e+e-
Data taking	2015	>2025	2013	>2016	>2016	>2020
Transversity	NO	NO	NO	YES	YES	YES
Boer-Mulders	YES	YES	YES	YES	YES	YES
Sivers	YES	YES	YES	YES	YES	YES
Pretzelosity	NO	NO	NO	NO	YES	YES
Worm Gear	NO	NO	NO	NO	NO	YES
Direct γ	NO	NO	NO	YES	YES	YES

SPD/NICA will provide unique opportunity

*not available at other facilit*ies

to study all of the PDF in one experiment

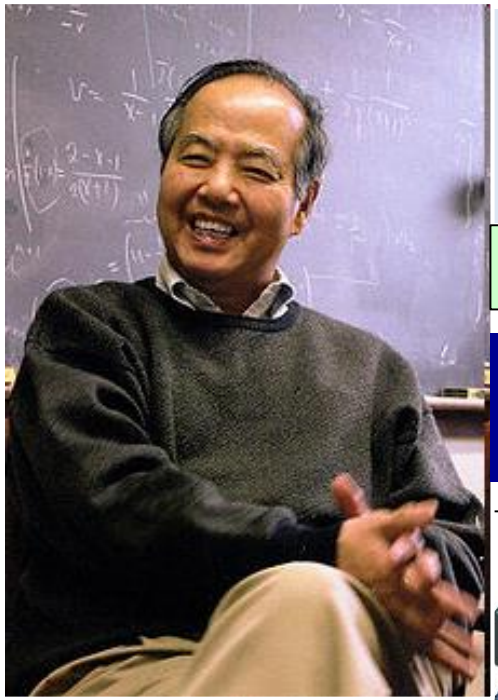
and obtain the comprehensive information

on the nucleon spin structure

at high statistical level

with min. systematic uncertainties

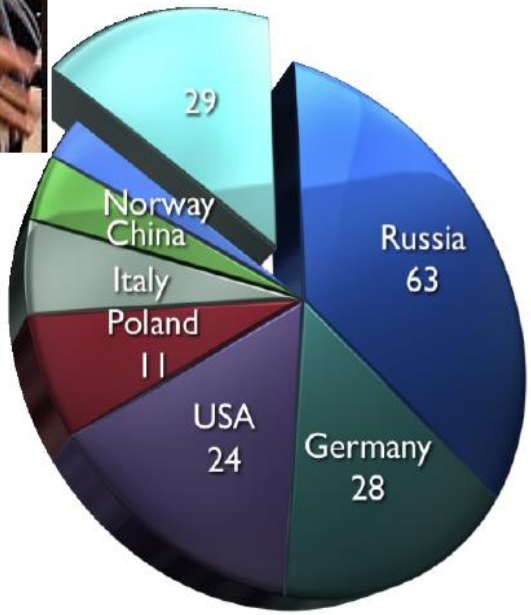
NICA White Paper – International Effort

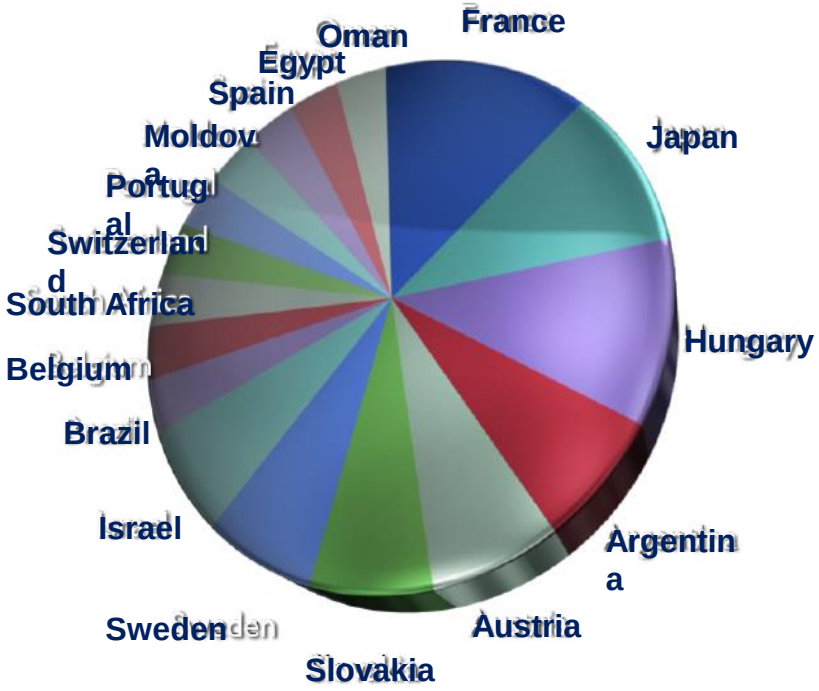


T.D.Li: *"The NICA heavy ion collider will be a very major step towards the formation*

Statistics of White Paper Contributions:

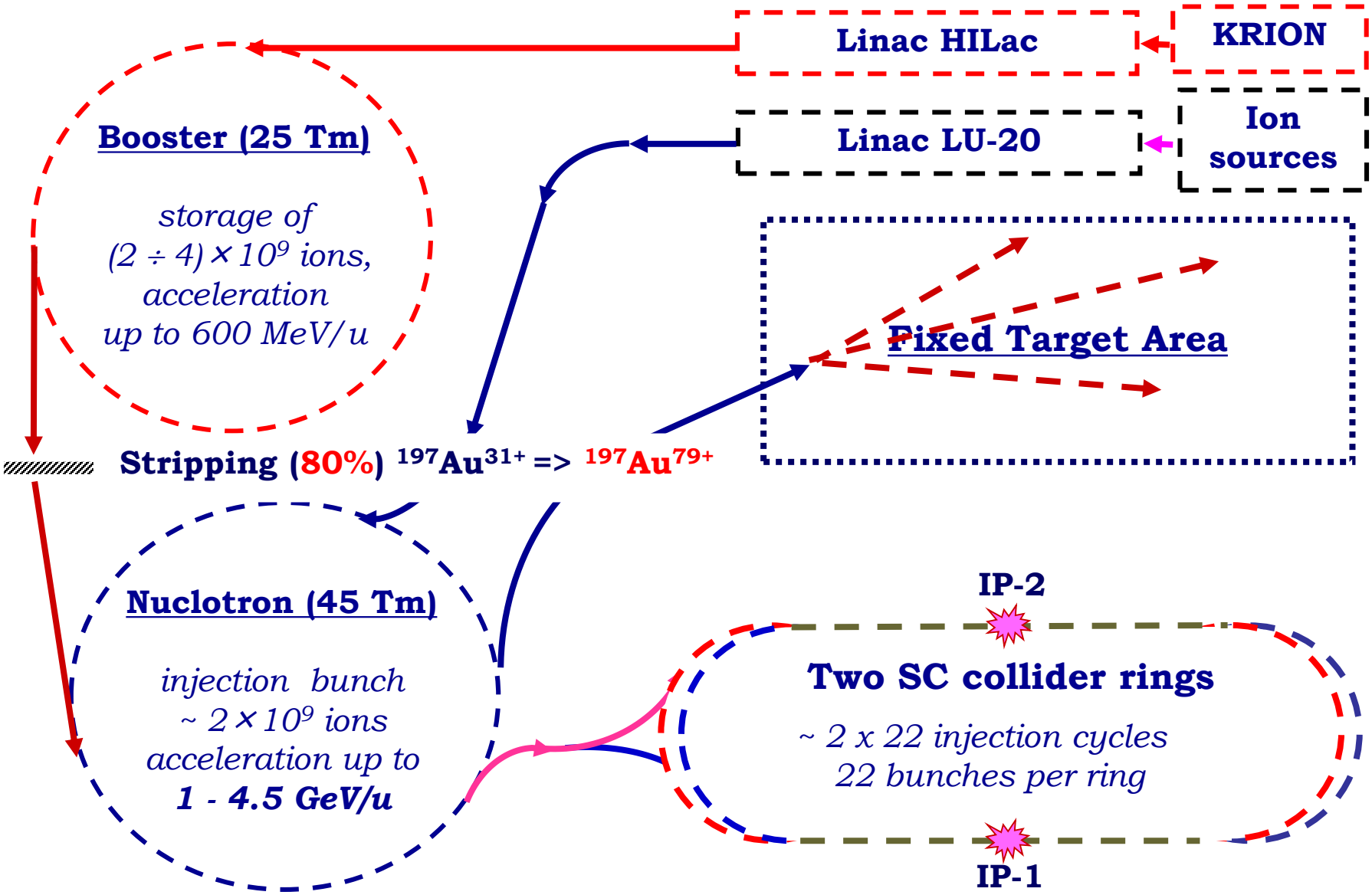
111 *contributions,*
188 *authors from* **70** *centers in* **24** *countries*





Status of the accelerator complex

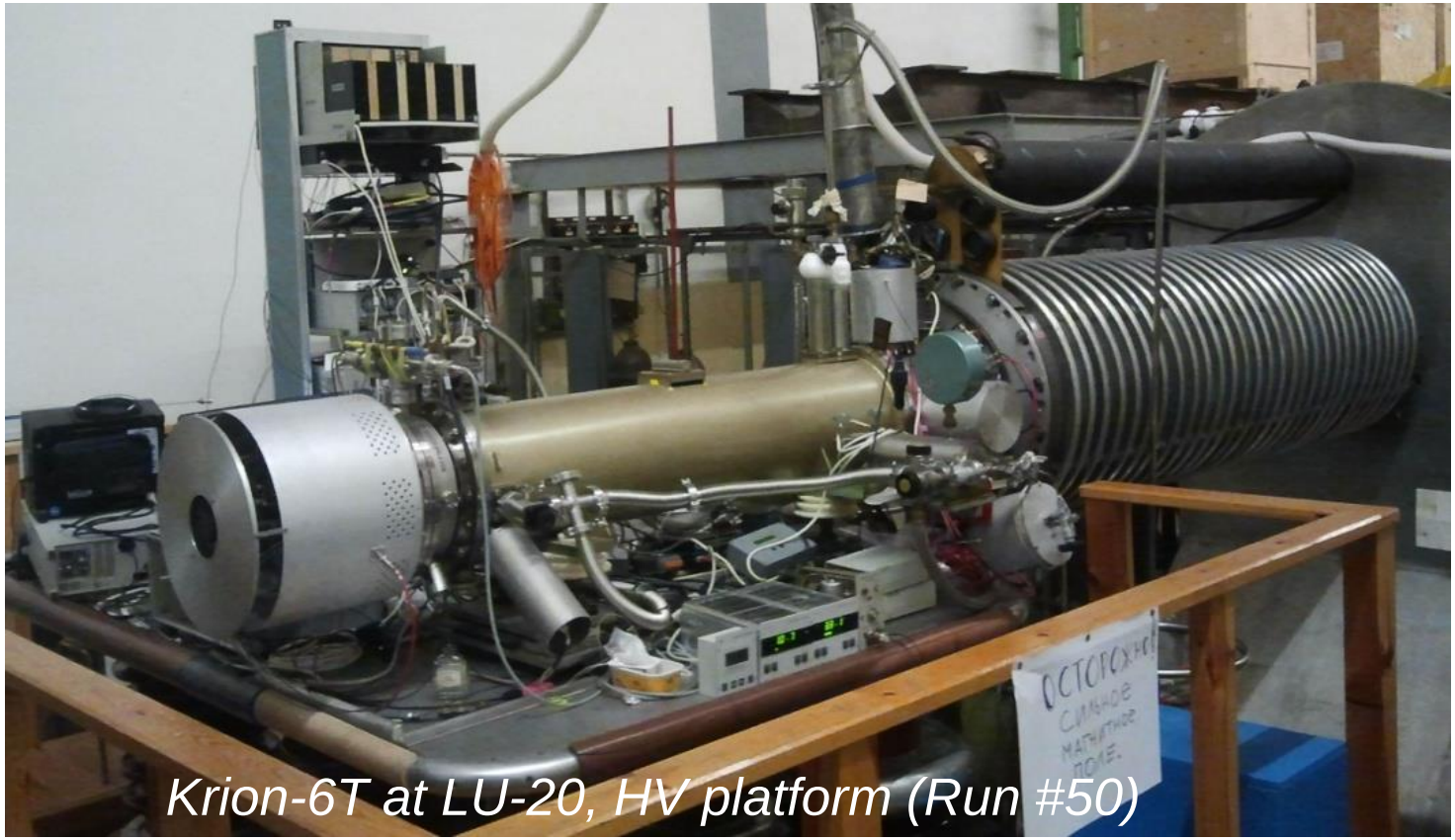
Structure and Operation Regimes



Krion-6T (*Electron String Ion Source*)

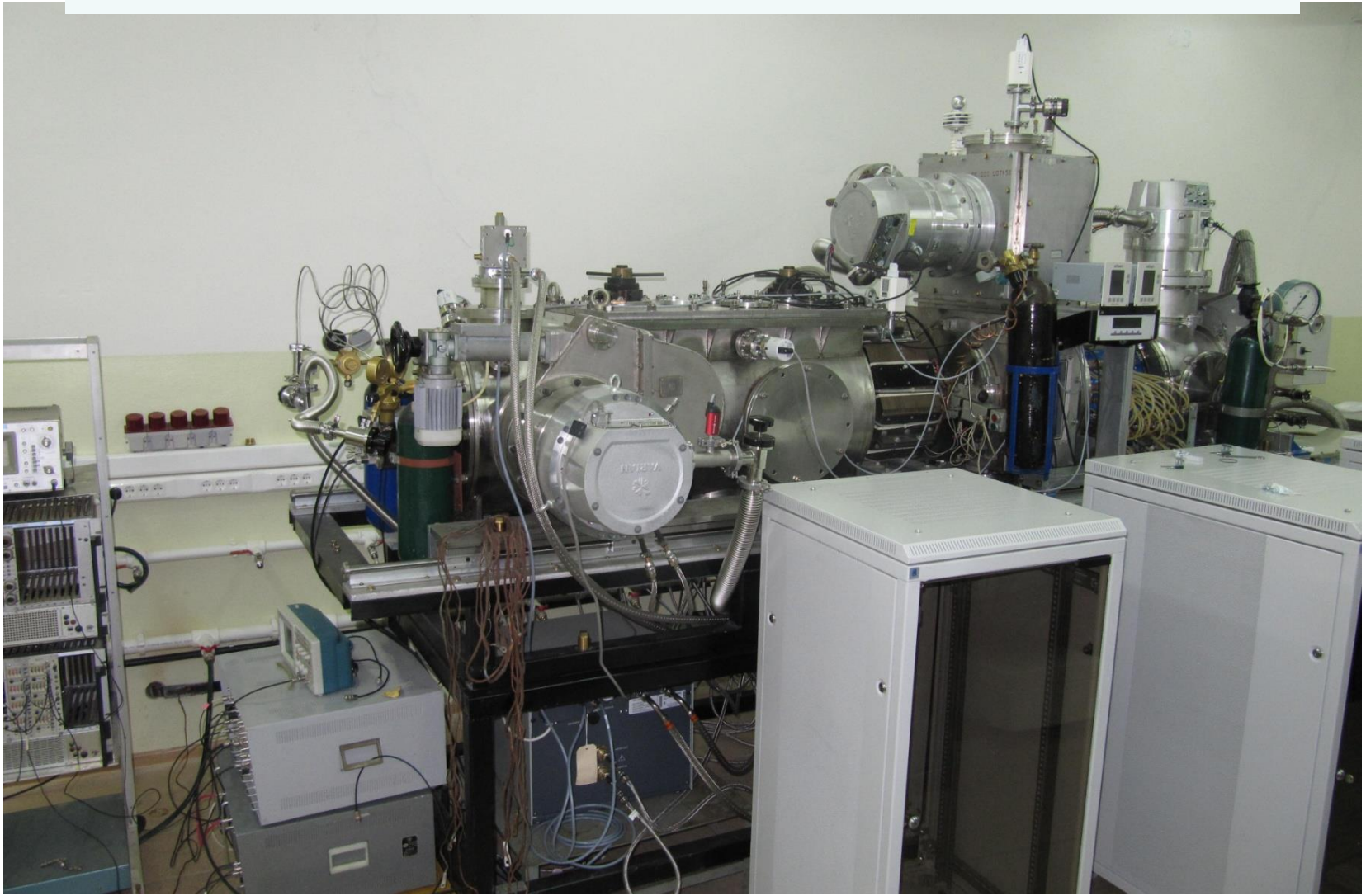
Project parameters: *magnetic filed up to 6.0 T, electron energy up to 15 keV*

- *B= 5.4 T reached in a robust regime;*
- *produced beams*: $Au^{30+} \div Au^{32+}$, $6 \cdot 10^8$ ppp, repetition rate 50 Hz



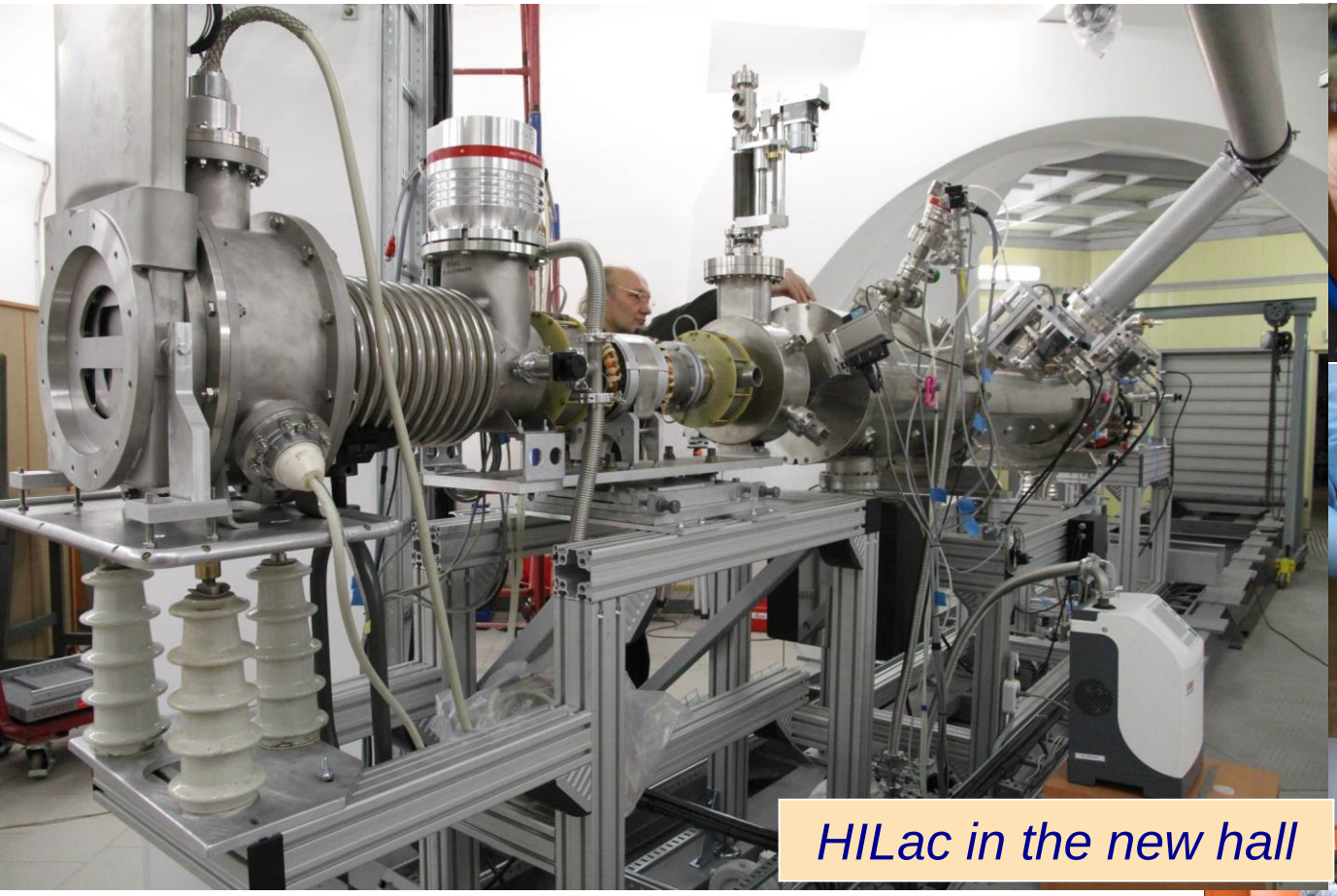
Krion-6T at LU-20, HV platform (Run #50)

Source for polarized particles (SPP)



Source has been assembled; now it is commissioned to achieve
10^{10} *polarized deuterons pp; the first beam run is foreseen in beg of 2016*

NICA Heavy ion injector (HILAC)



HILac in the new hall

Design & fabrication by "BEVATECH OHG", Germany

Commissioning in 2015

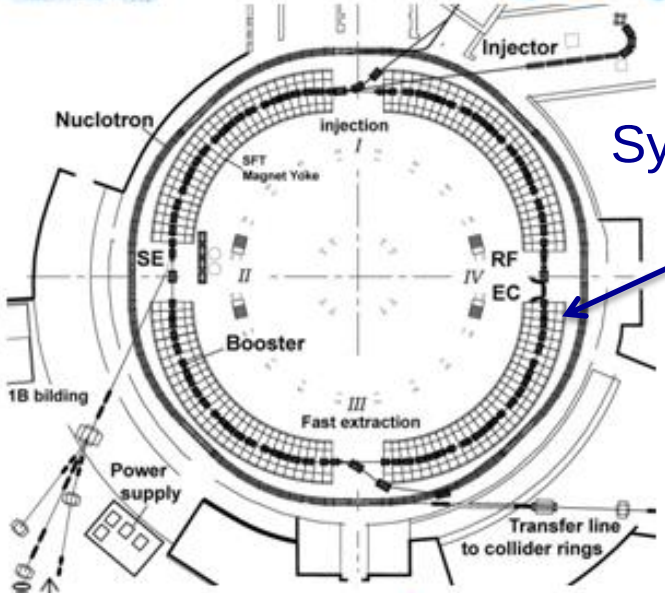
RF system assembled in new hall (world unique)

The Booster

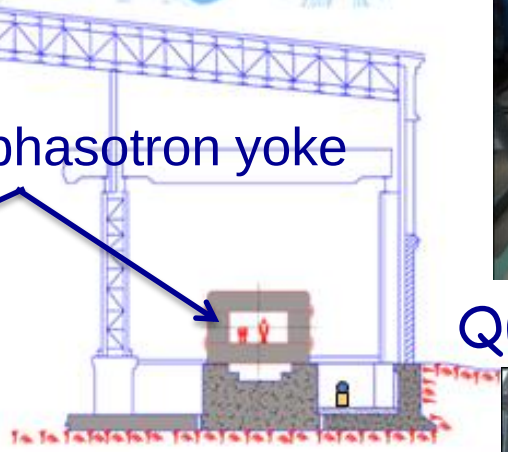
Booster synchrotron: *C = 211m,*
*25 T*m, 600 MeV/u for Au^{31+}*
ultra high vacuum, electron cooling

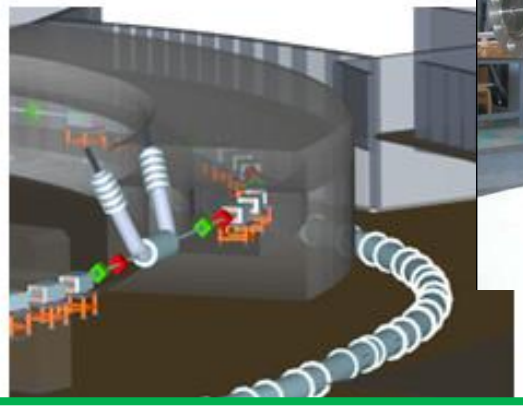
Dipole SC magnet

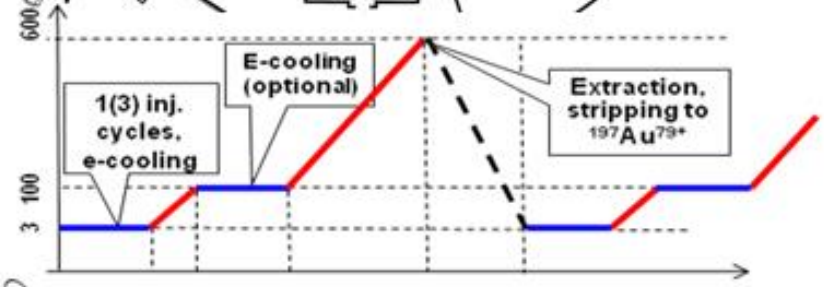
Quadrupole SC magnet



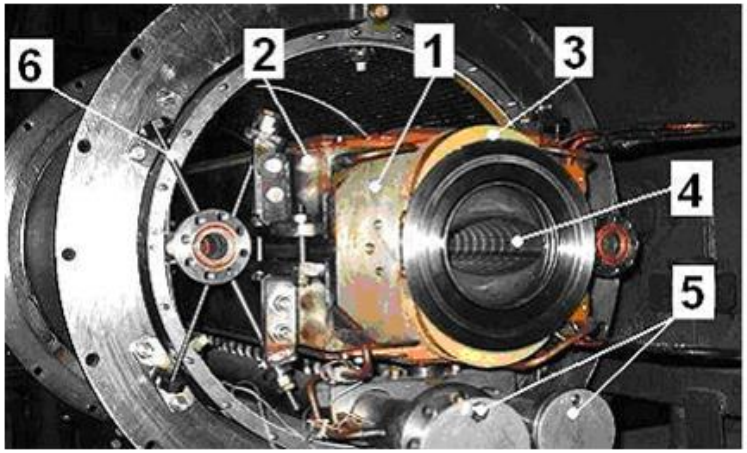
Synchrophasotron yoke

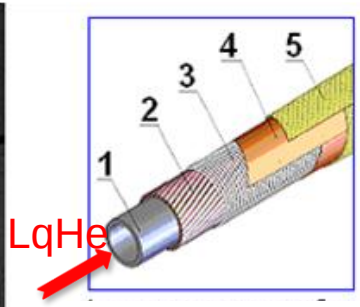




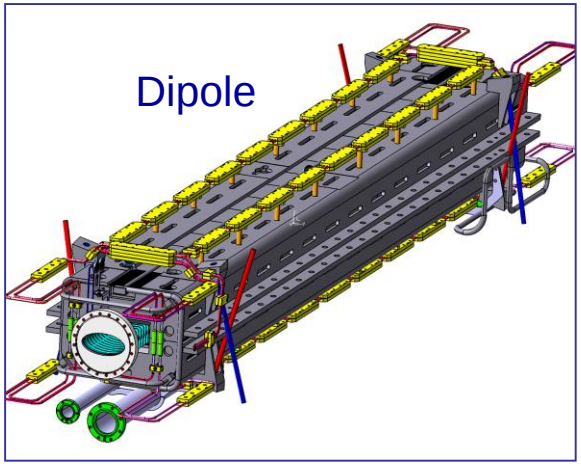


“Dubna type” fast cycling SC magnet technology

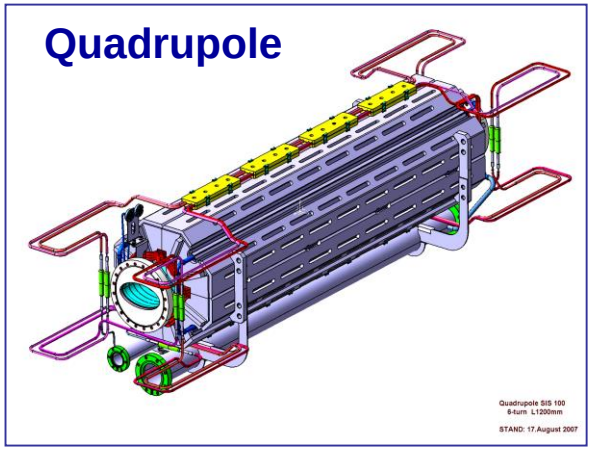




1 - Melchior pipe
2 - Niobium-titanium composite wire
3 - nichrome wire
4,5 - isolation



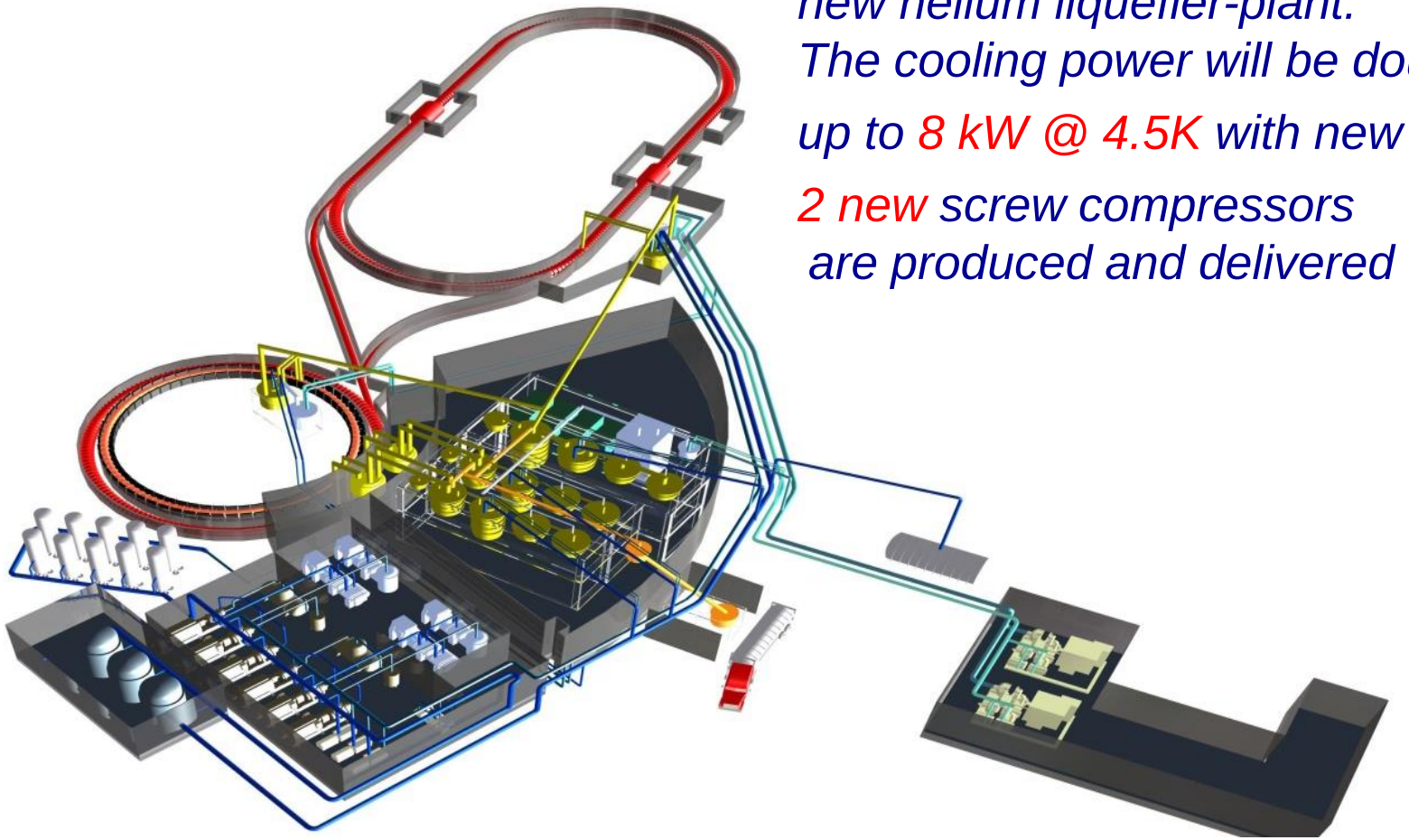
Magnet for SIS 100 (FAIR, Germany)



SC Magnets for Booster, Collider & SIS-100/FAIR workshop at VBLHEP JINR *(bld. 217)*

JINR cryogenic complex

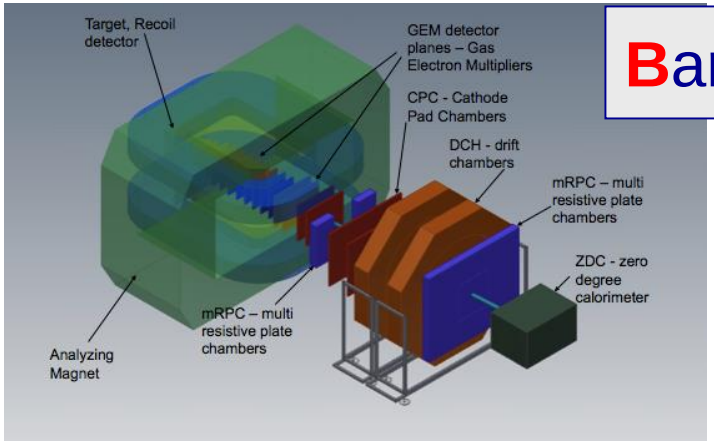
Technical design project is in the final stage:
new helium liquefier-plant.
The cooling power will be doubled
up to 8 kW @ 4.5K with new plant;
2 new screw compressors
are produced and delivered to Dubna



New building will be constructed
to accommodate the new Cryo Complex

Experiments at NICA

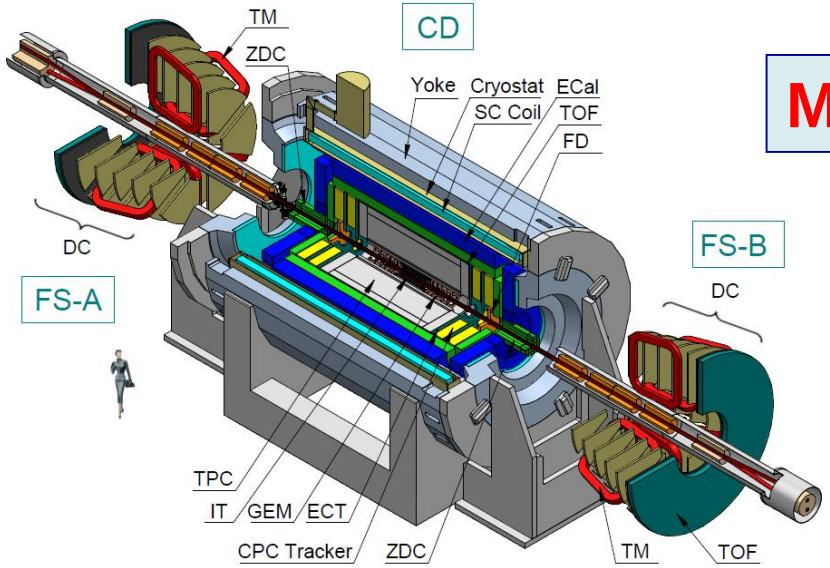
3 detectors



Baryonic **M**atter at **N**uclotron (**BM@N**)

the fixed target experiment at the Nuclotron

Stage I 2017



MultiPurpose Detector (MPD)

at the Collider

Stage I 2019

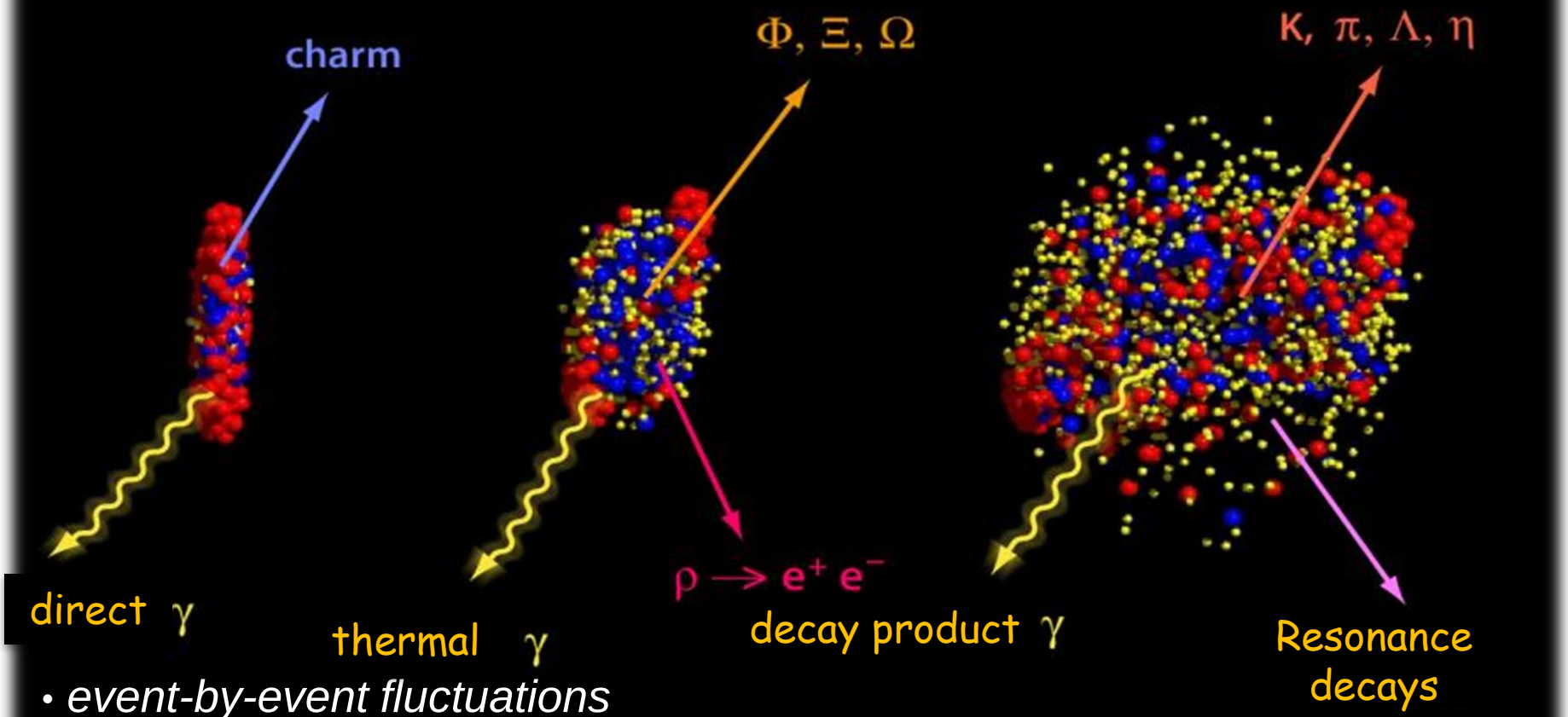
SPD (Spin Physics Detector) *at the Collider*

project is under preparation

MultiPurpose Detector (MPD)

the observables in AA, pA and pp collisions:

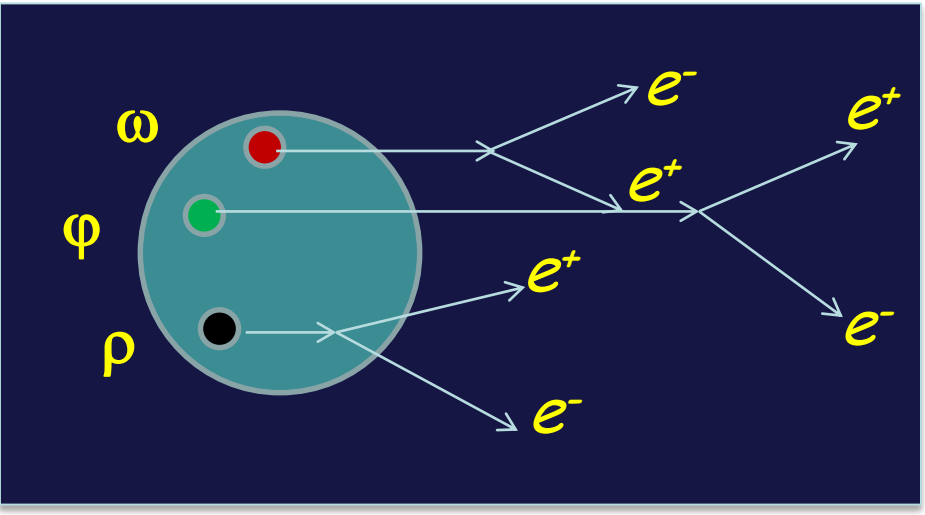
- *multiplicity of produced hadrons (π, K, p, Λ, Ξ, Ω)*
- *electromagnetic probes: electrons, gammas, vector meson decays,*



- *event-by-event fluctuations*
- *femtoscopy of π, K, p, Λ*
- *…..*

Lepton pair production

- *In-medium modification of vector meson properties may signal on partial chiral symmetry restoration in heavy ion collisions*
- *dileptons as penetrating probes of the fireball interior – no FSI*



ω : cτ = **23 fm** M=783 MeV, Γ=8 MeV
φ : cτ = **44 fm** M=1019 MeV, Γ=4 MeV
ρ : cτ = **1.3 fm** M=768 MeV Γ=149 MeV

required mass resolution ~ 10 MeV

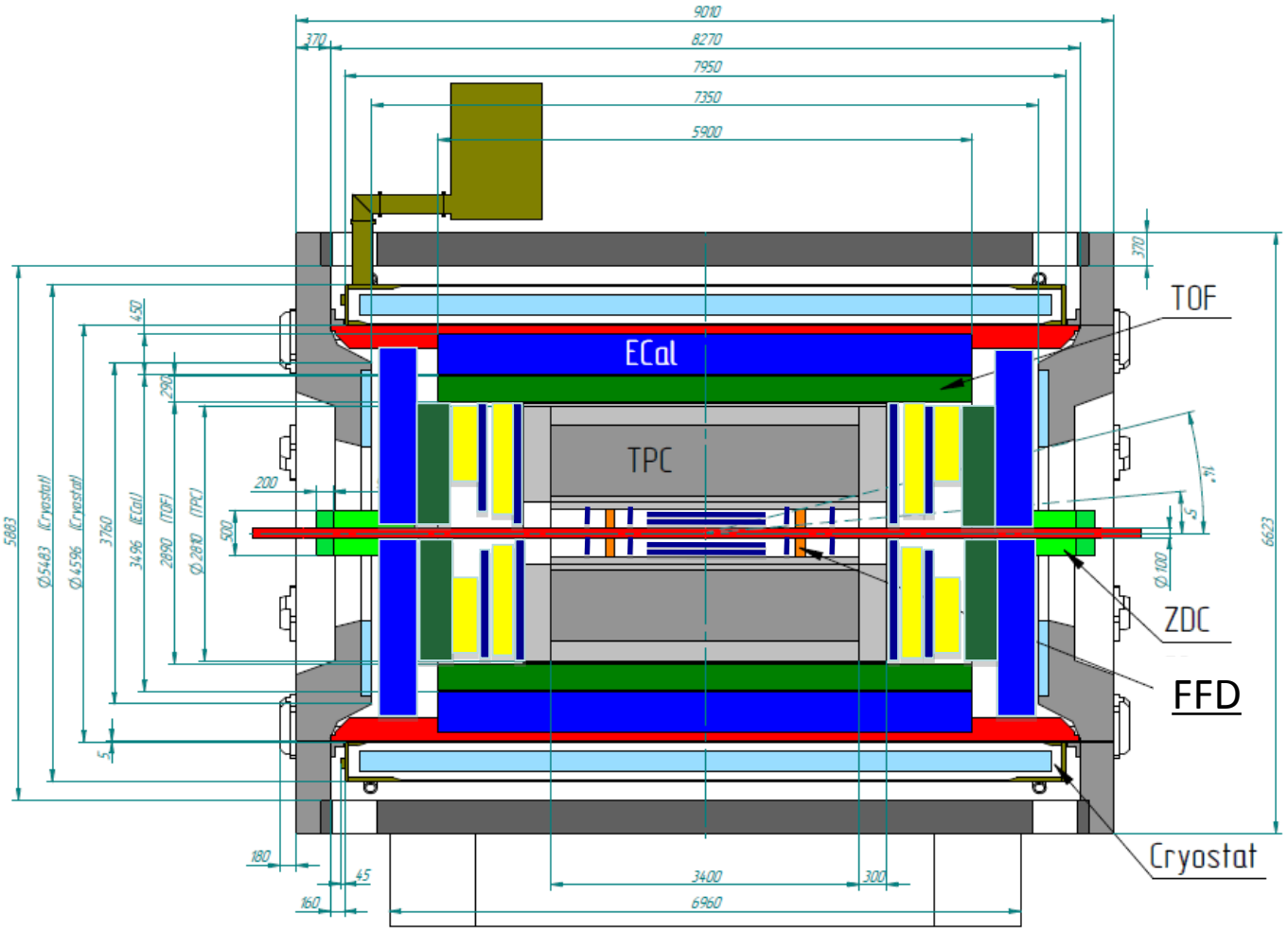
the detector relevant features:

- **low material budget;**
- **electron reliable ID & hadron extra suppression by ECAL;**
- **high event rate allowing study of dielectron continuum at high p_T.**

MPD detector

Stage 1: TPC, TOF, ECAL, ZDC, FD

Stage 2: IT + Endcaps (tracker, TOF, ECAL)



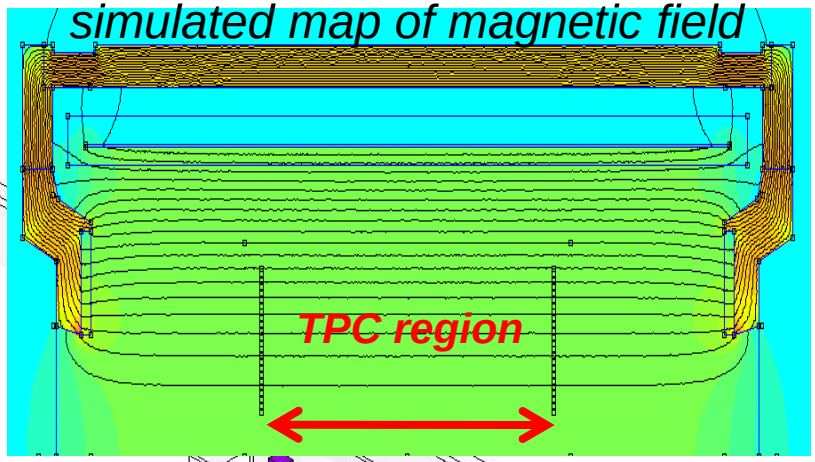
MPD magnet

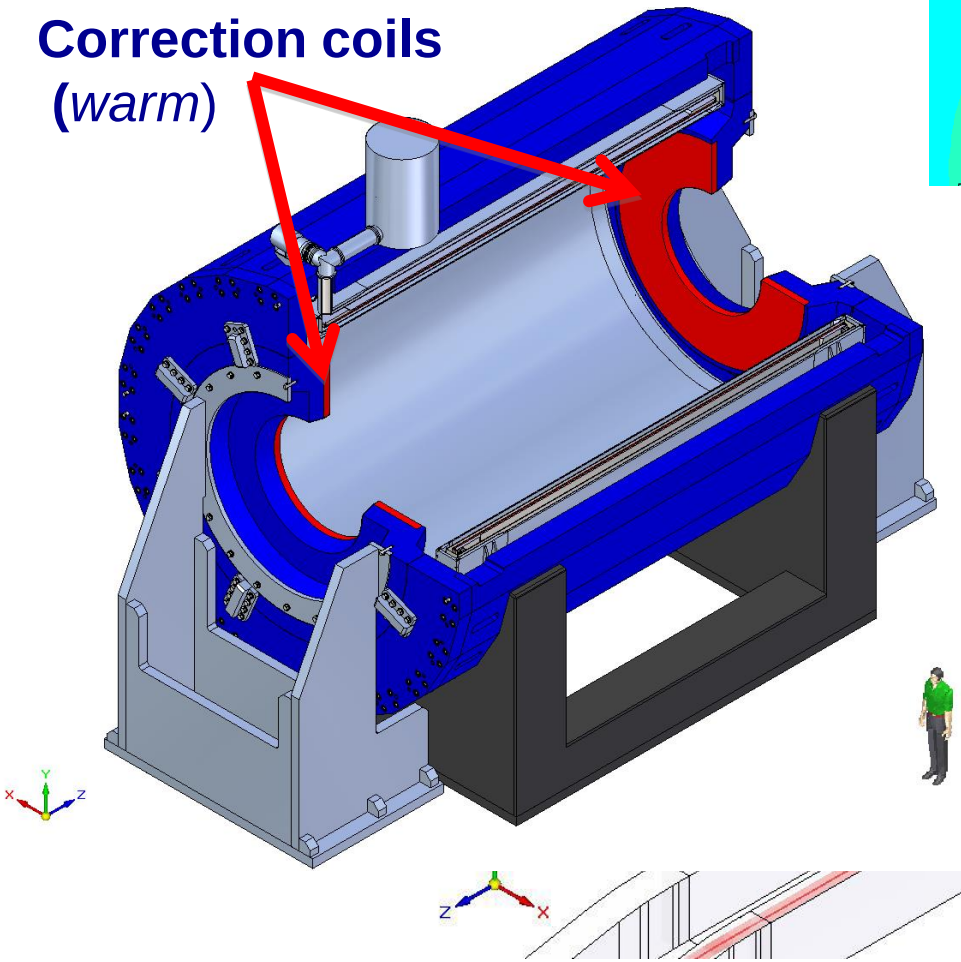
Superconducting solenoid:

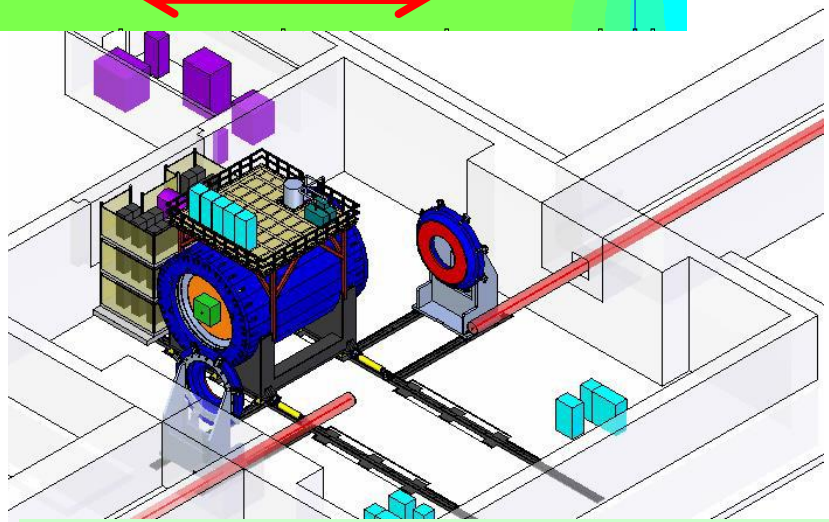
B_0=0.66 T; ~ 900 t

high level (~ 3x10^{-4}) of magnetic field homogeneity

Correction coils (*warm***)**







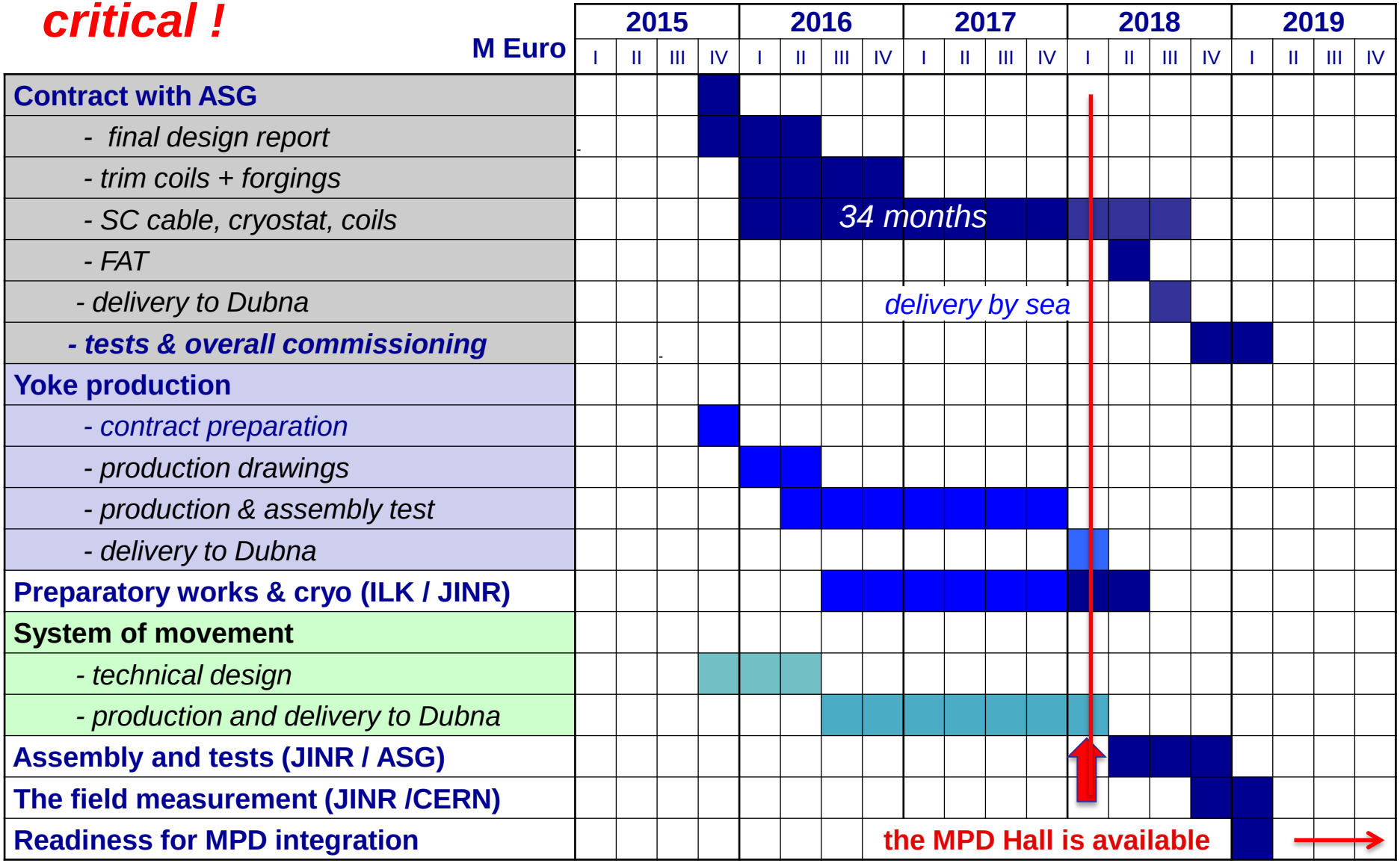
Magnet status:

technical design – completed;

contracts with the producers- in preparation

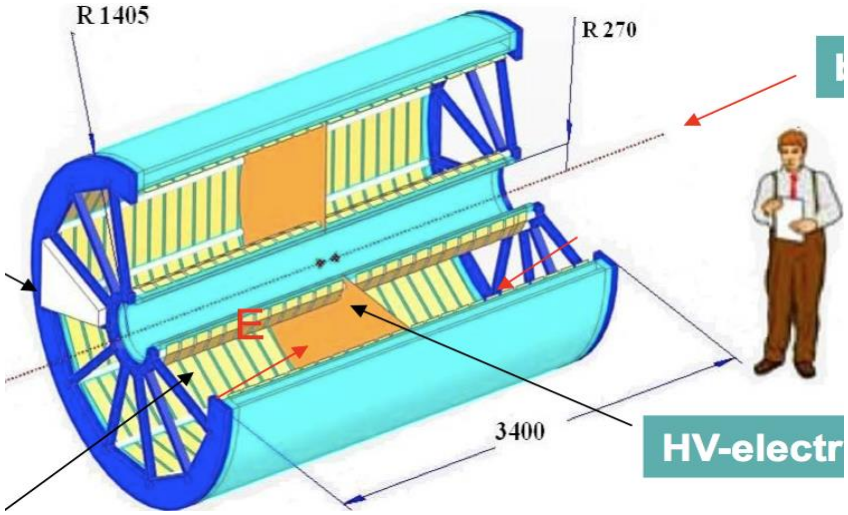
Schedule for MPD Magnet fabrication & commissioning

critical !



TPC- *technical project, preparation for fabrication*

Dia. =3000 mm, L = 3400 mm, FEE = 120 000 ch, δp/p < 2%



FEC-64 prototype (ALTERA FPGA, ALTRO, PASA chips)

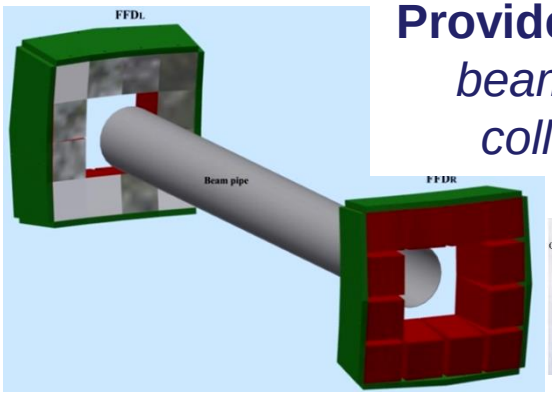
Cylinder C2, preparation for vacuum tests

Cylinder C3 manufactured in Dec. 2013

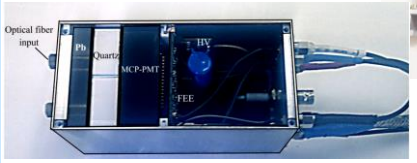
Time of Flight system (TOF)

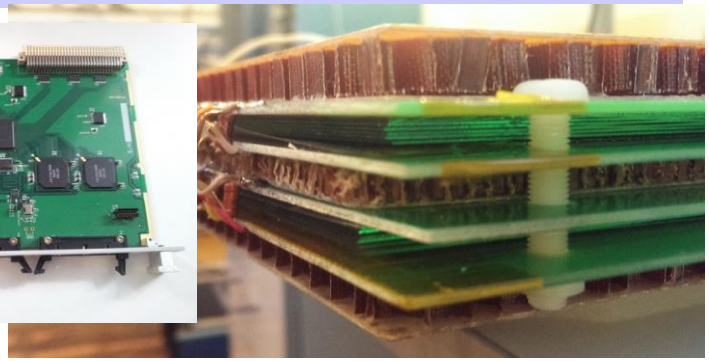
Fast Forward Detector (FFD): *production stage*

mRPC – TDR has been prepared, *ready for mass production*



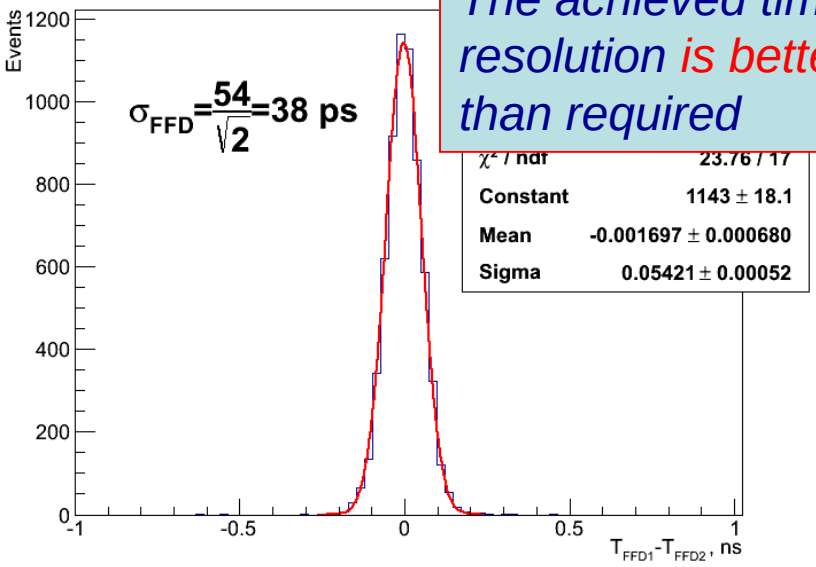
Provides: *T0 for TOF, beam adjustment & collision L0-trigger*

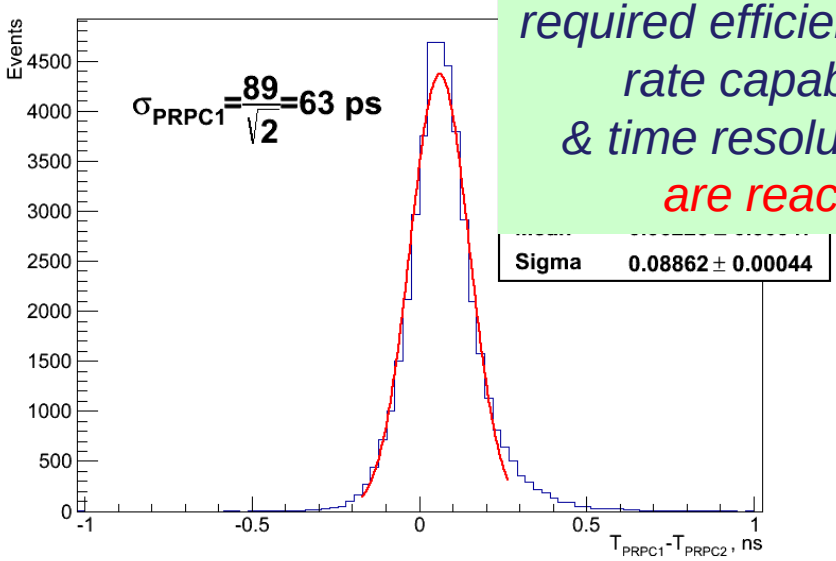




Zhu Weipinga, Wang Yi, Feng Shengqin, Wang Jingbo, Huang Xinjie, Shi Li, V. Babkin, V. Golovatyuk, M. Rumiantcev, G. Eppley, T. Nussbaum, ***NIM A 735, 277–282, 2014***

The achieved time resolution is better than required





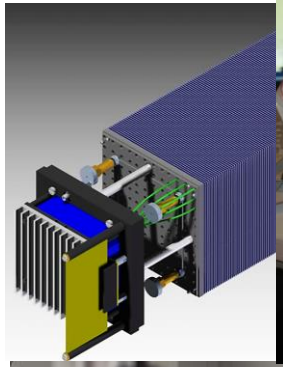
required efficiency, rate capability & time resolution are reached

Calorimetry

ECAL – *TDR - in preparation*

L ~35 cm (~ 14 X_0), Pb+Scint. (4x4 cm^2)
read-out: WLS fibers + MAPD

Energy resolution **2.5% / √E**

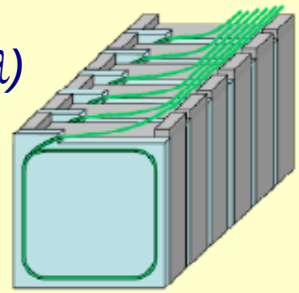


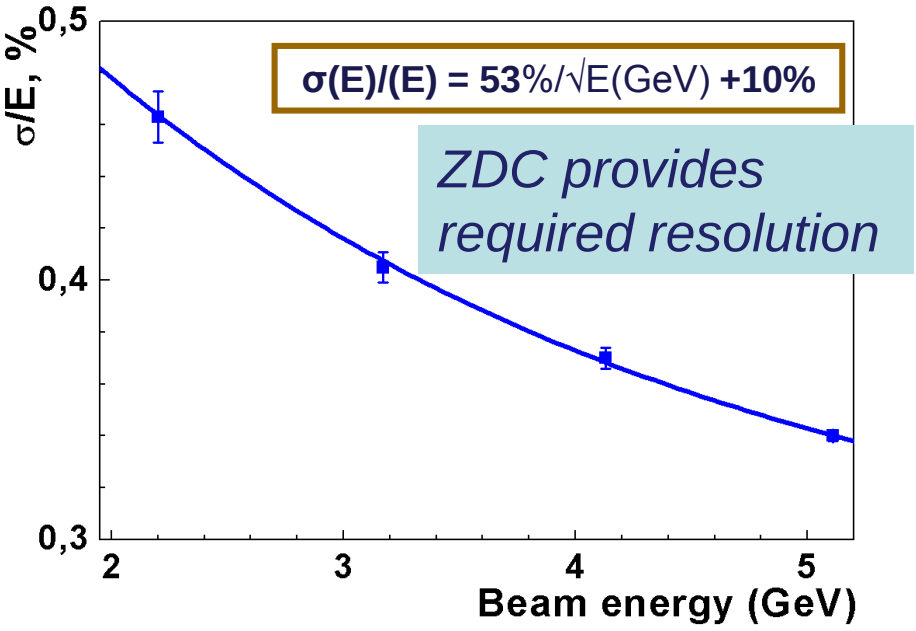
Preparation for tests with electron beams at DESY (December'13)

Zero Degree Calorimeter (ZDC): TDR stage

ZDC coverage: 3.2<|η|< 4.8

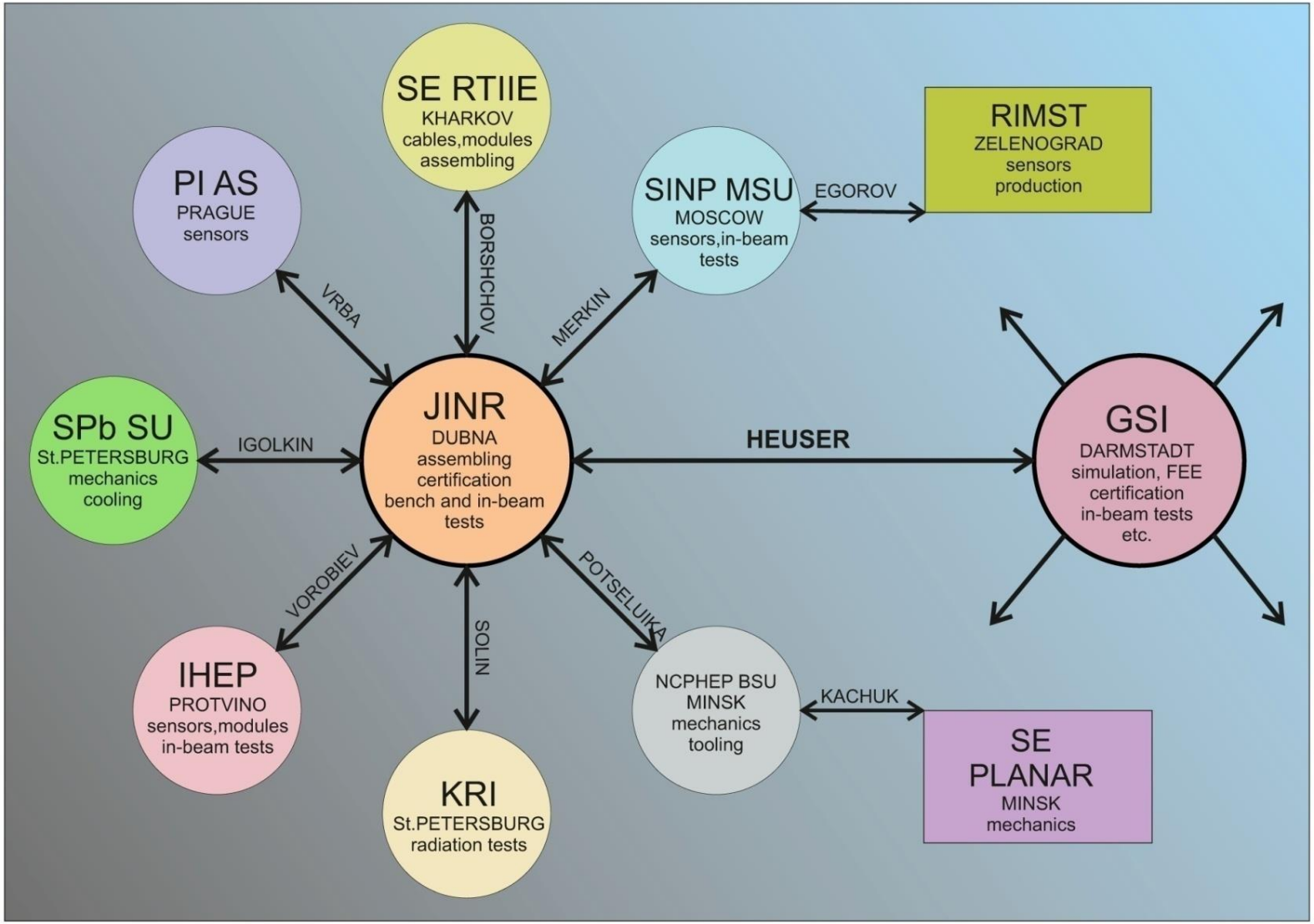
Pb-scintillator sampling (5λ)
Read-out: fibers + AvalanchePD





ZDC provides required resolution

CBM-MPD consortium structure
*for R&D and production of IT modules (since **2008**)*

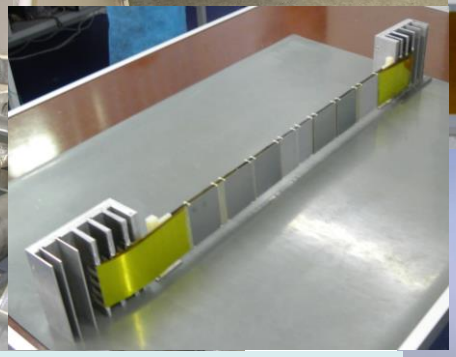


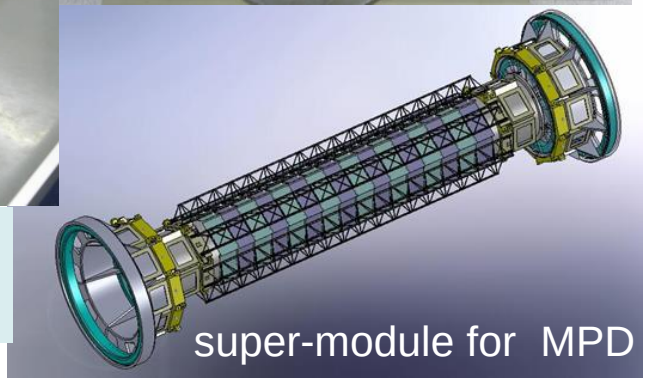
Workshop for microstrip detector assembly & test

the clean workshop has started operation in 2015.

***CERN** & **JINR** have signed **MoU** for manufacturing the STS carbon fiber space frames for **NICA** (BM@N & MPD) and **FAIR** (CBM)*

CBM-MPD Consortium





project is supported by the **CREMLIN** grant *(in the framework of HORIZON-2020)*

MPD *(I-stage)* detector status

1. **Magnet** – *contracts in preparation*
2. **Integration** – *project in preparation*
3. **ECAL** – *TDR in preparation*
4. **ZDC** – *TDR close to completion*
5. **TOF** – *TDR close to completion*
6. **FFD** – *TDR close to completion*
7. **TPC** – *TDR close to completion:*
   - *assembly area preparation*
   - *fabrication of basic elements*
   - *readout chambers – production + R&D (alternative)*
   - *ALTRO-based Front-End card prototype*

- preproduction stage

MPD I stage

feasibility study

Simulation & analysis framework

- ✓ *Software repositories*
- ✓ *Software tests*
- ✓ *Forum*
- ✓ *Information, etc.*

Event generators

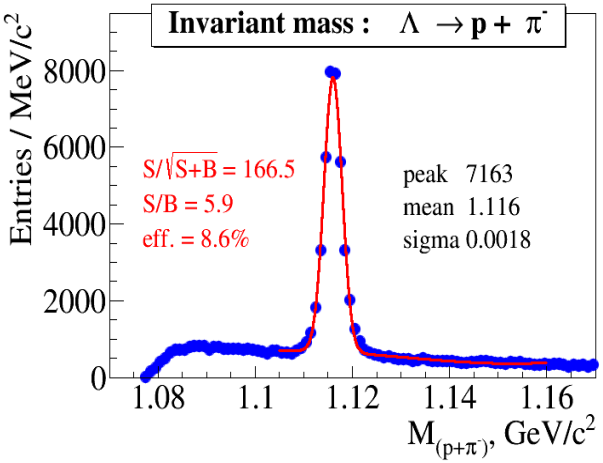
UrQMD 2.3; LA QGSM; SHIELD on fly
pHSD; UrQMD 3.4; 3FD + particlization

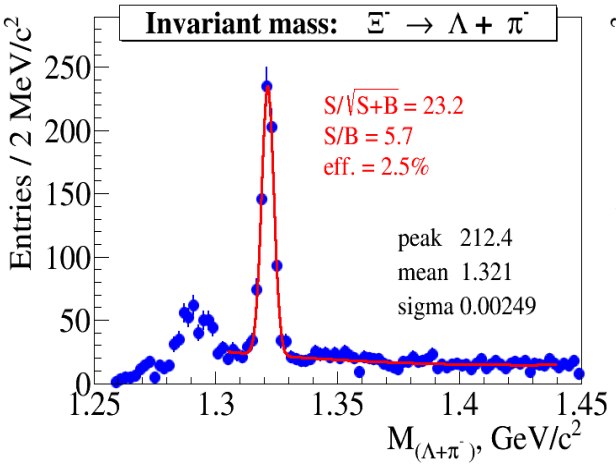
- *inherits basic properties from FairRoot, C++ classes;*
- *extended set of event generators for heavy ion collisions;*
- *detector composition & geometry;*
  particle propagation by GEANT3/4;
- *advanced detector response functions,*
  realistic tracking and PID included.

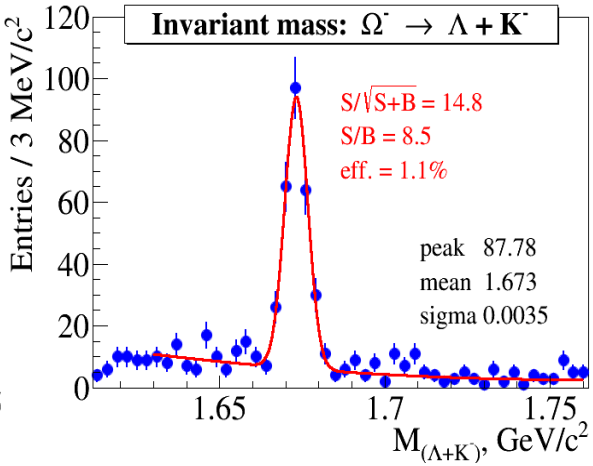
MPD performance: hyperons

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

Particle	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-	$\bar{\Omega}^+$
Expected yield	$5.8{\cdot}10^9$	$7.3{\cdot}10^7$	$2.9{\cdot}10^7$	$1.6{\cdot}10^6$	$1.4{\cdot}10^6$	$2.9{\cdot}10^5$

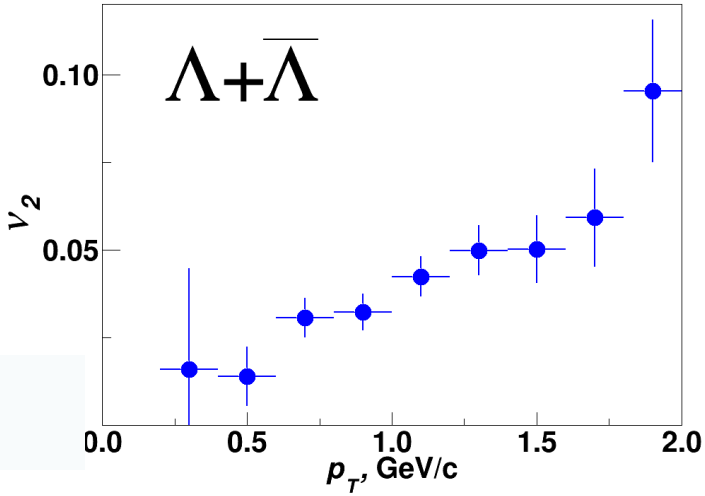
A. Zinchenko, at "SQM 2015"

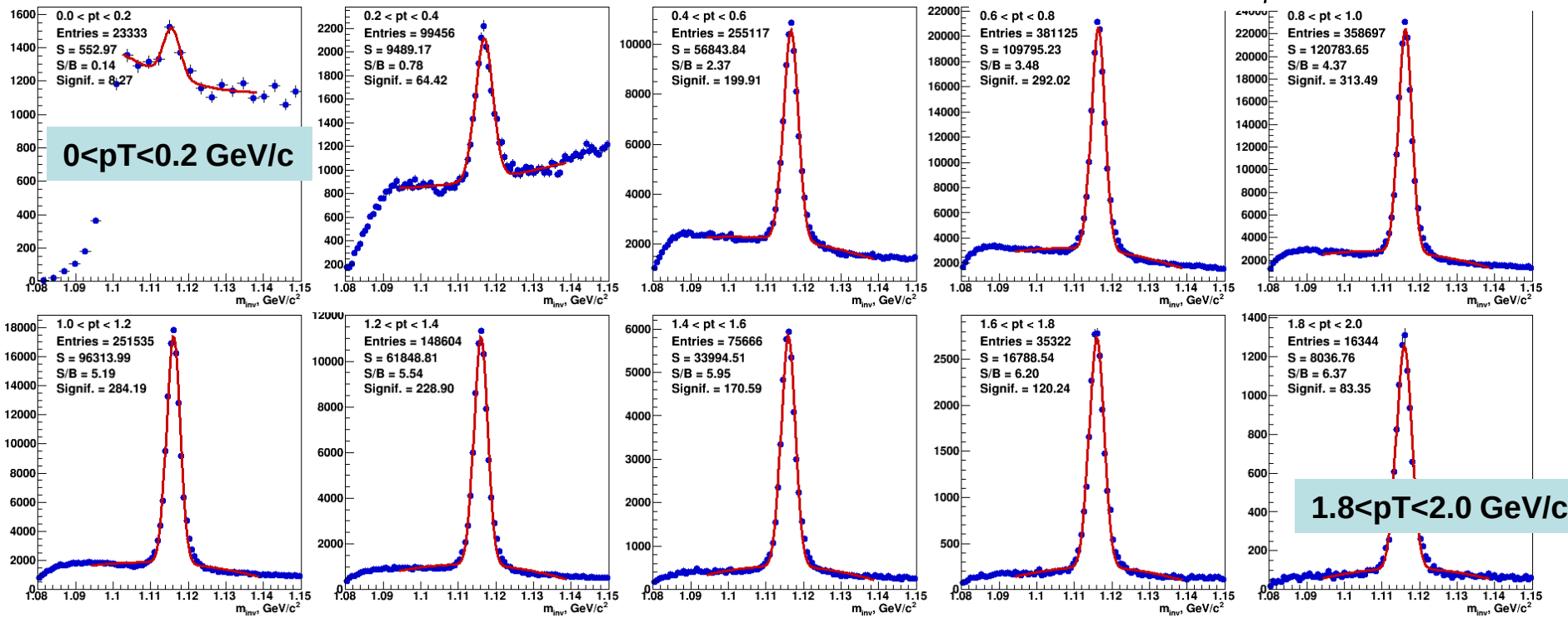
MPD performance: hyperon flow

Momentum anisotropy (elliptic flow) originates from initial spatial anisotropy. V2 depends on matter properties and EOS

- Min. bias Au+Au @ 11A GeV (UrQMD) , TPC+TOF barrel
- Realistic tracking & PID, secondary vertex reconstruction
- Event plane from TPC tracks

N. Geraksiev, at "SQM 2015"





MPD performance : ϕ (1020)

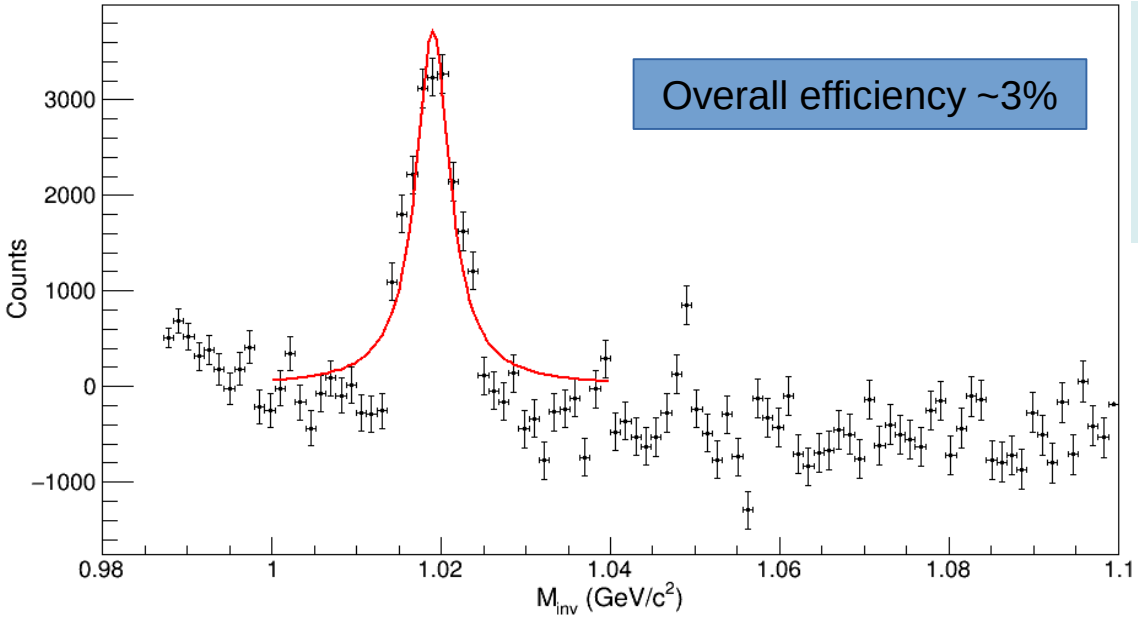
Motivation:

** The lightest bound state of hidden strangeness*

** Low cross-section in nuclear matter and early freeze-out*

Data set and analysis

- *Central Au+Au collisions, at $\sqrt{s_{NN}}$ = 11 GeV (UrQMD)*
- *Channel of decay: $\phi \rightarrow K^+K^-$, realistic tracking and PID (TOF + dE/dx)*



Measured values:

Width = 4.96 ± 0.25 (MeV/c^2)

M_{inv} = 1019.03 ± 0.12 (MeV/c^2)

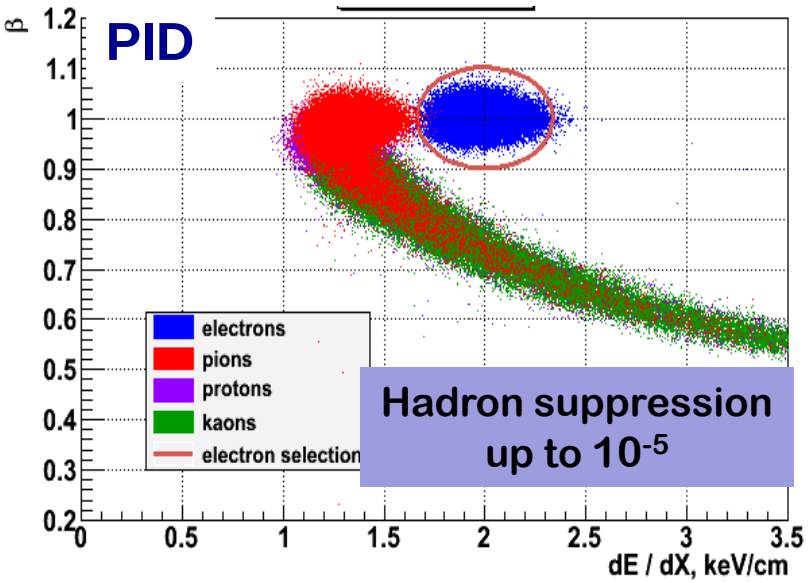
close to ones generated (PDG)

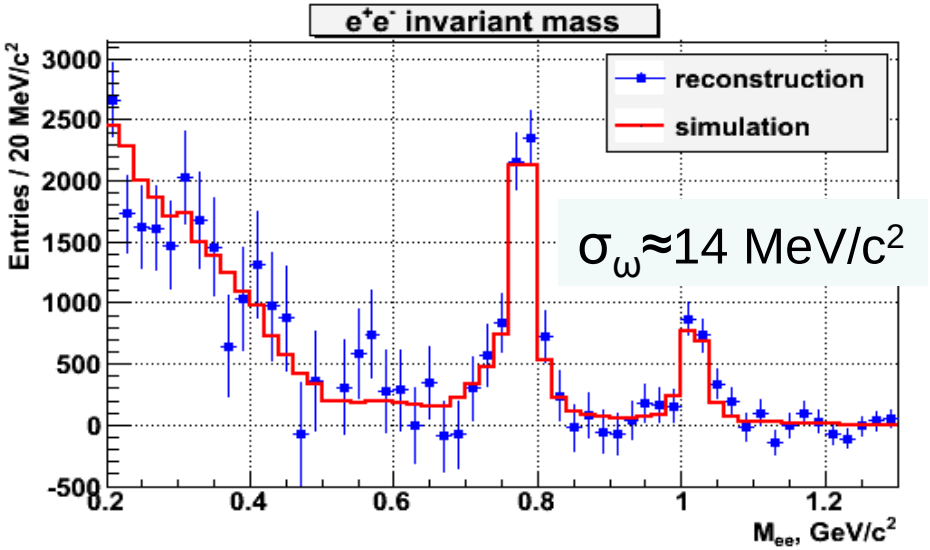
***L. Yordanova**, at "SQM 2015"*

MPD performance for dileptons

A. Zinchenko, at SQM-2015

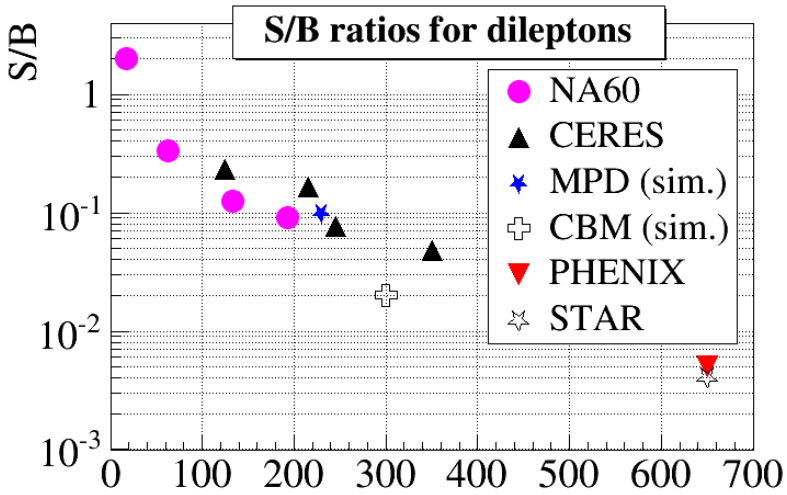
Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density





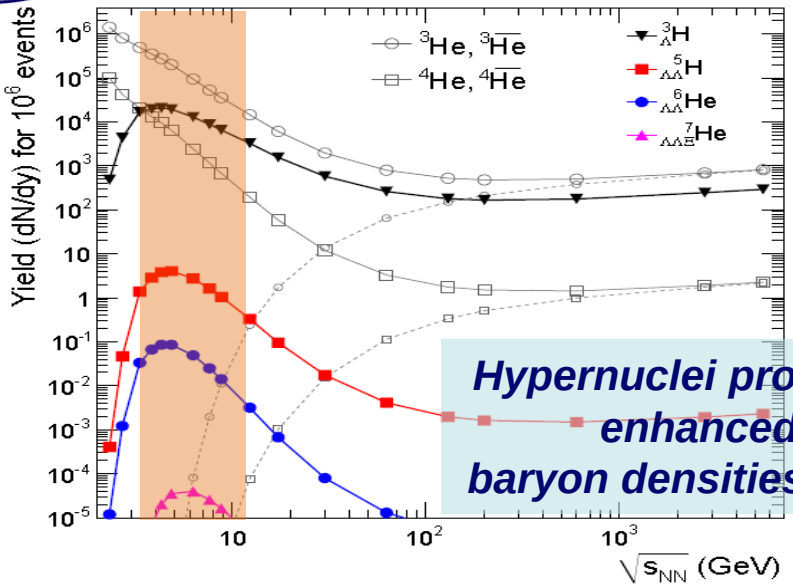
Yields, central Au+Au st $\sqrt{s_{NN}}$ = 8.8 GeV/u

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	$1.7 \cdot 10^4$

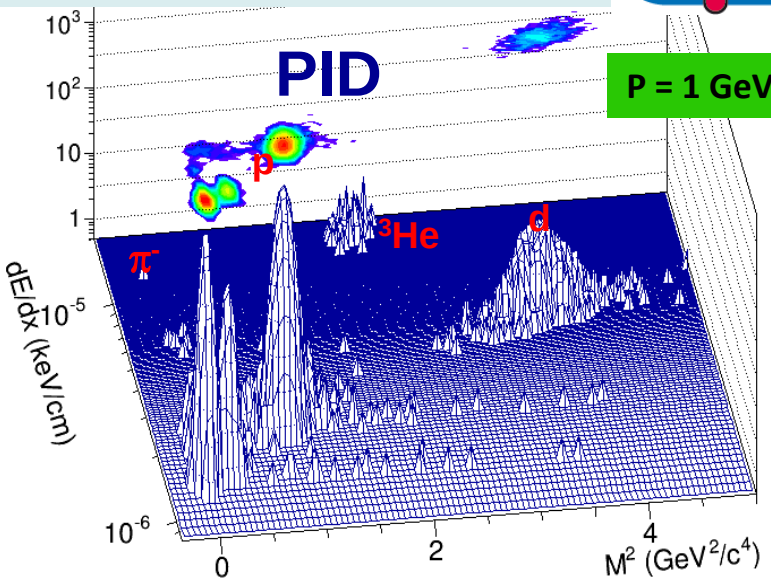


Hypernuclei @ MPD

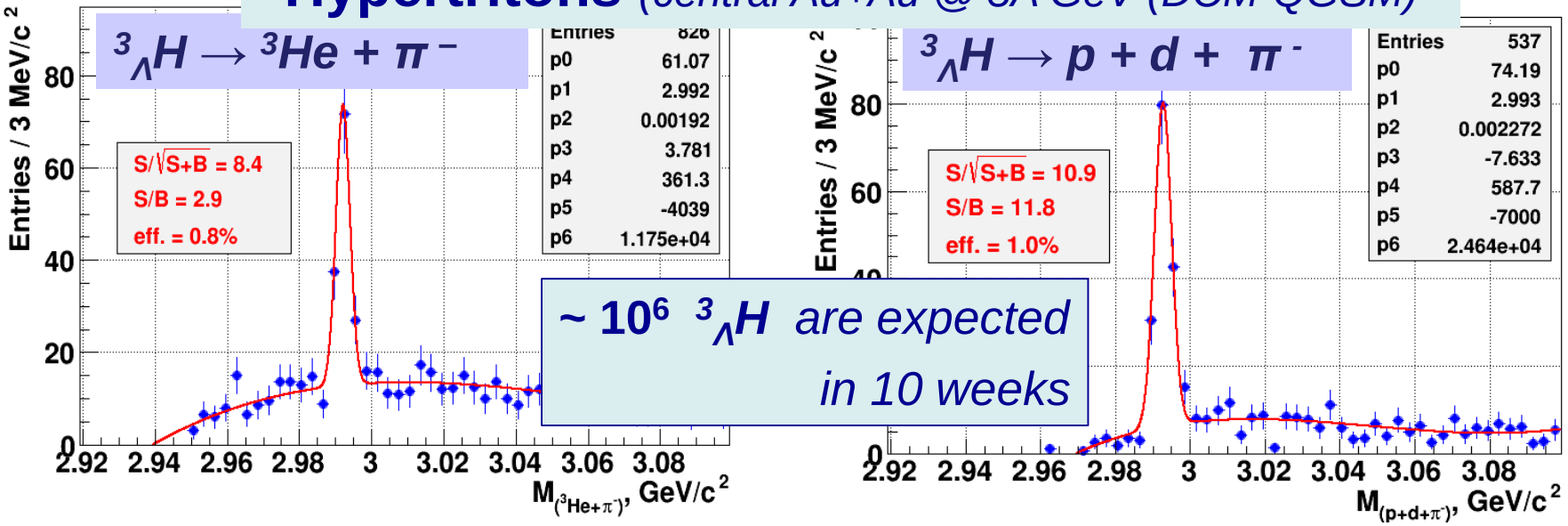
M. Ilieva, at "SQM-2015"



Hypernuclei production enhanced at high baryon densities (NICA)

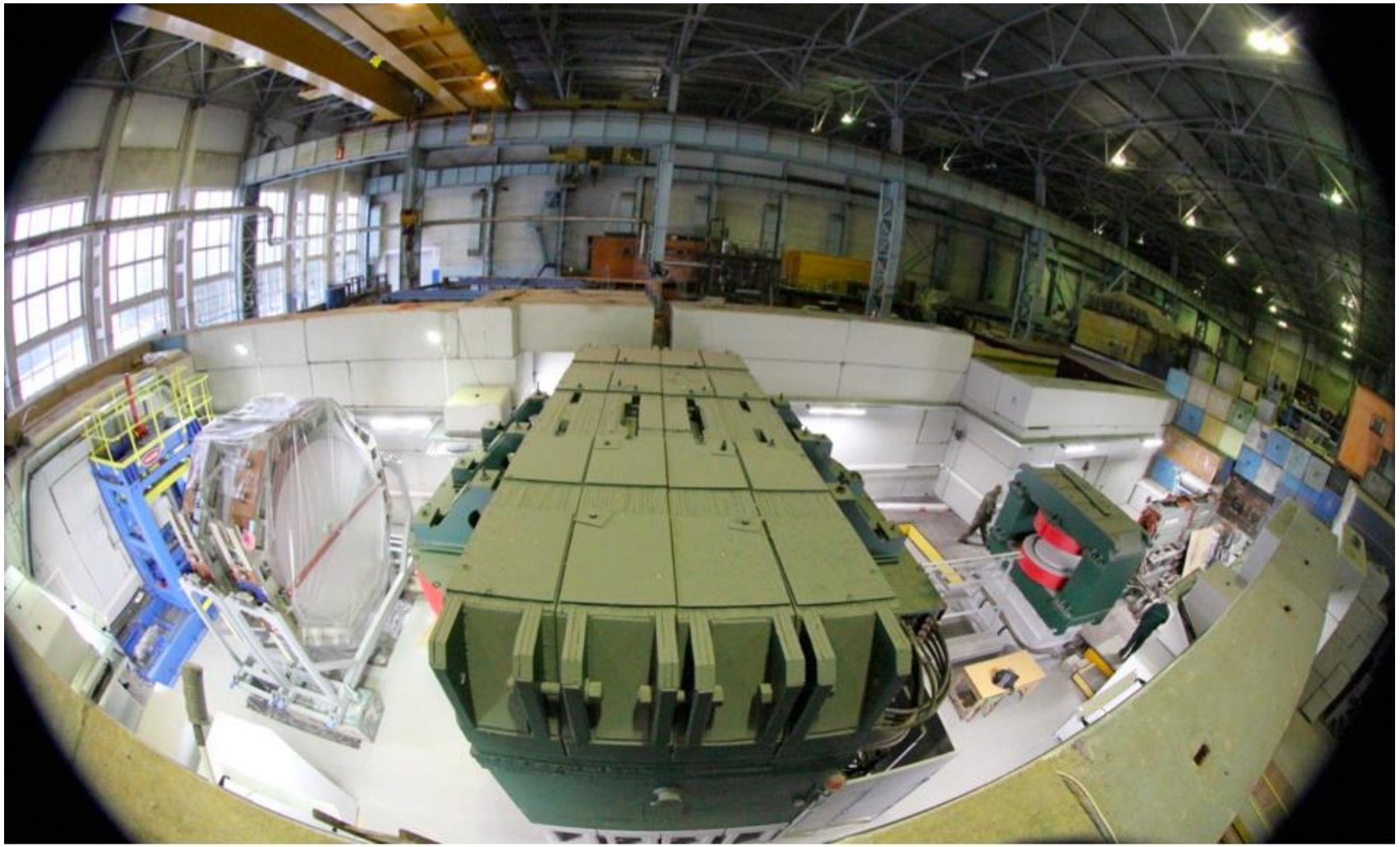


Hypertritons *(central Au+Au @ 5A GeV (DCM-QGSM)*



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

Experiments at NICA:
Baryonic Matter at Nuclotron (BM@N)
at the Nuclotron extracted beams



Nuclotron Beams

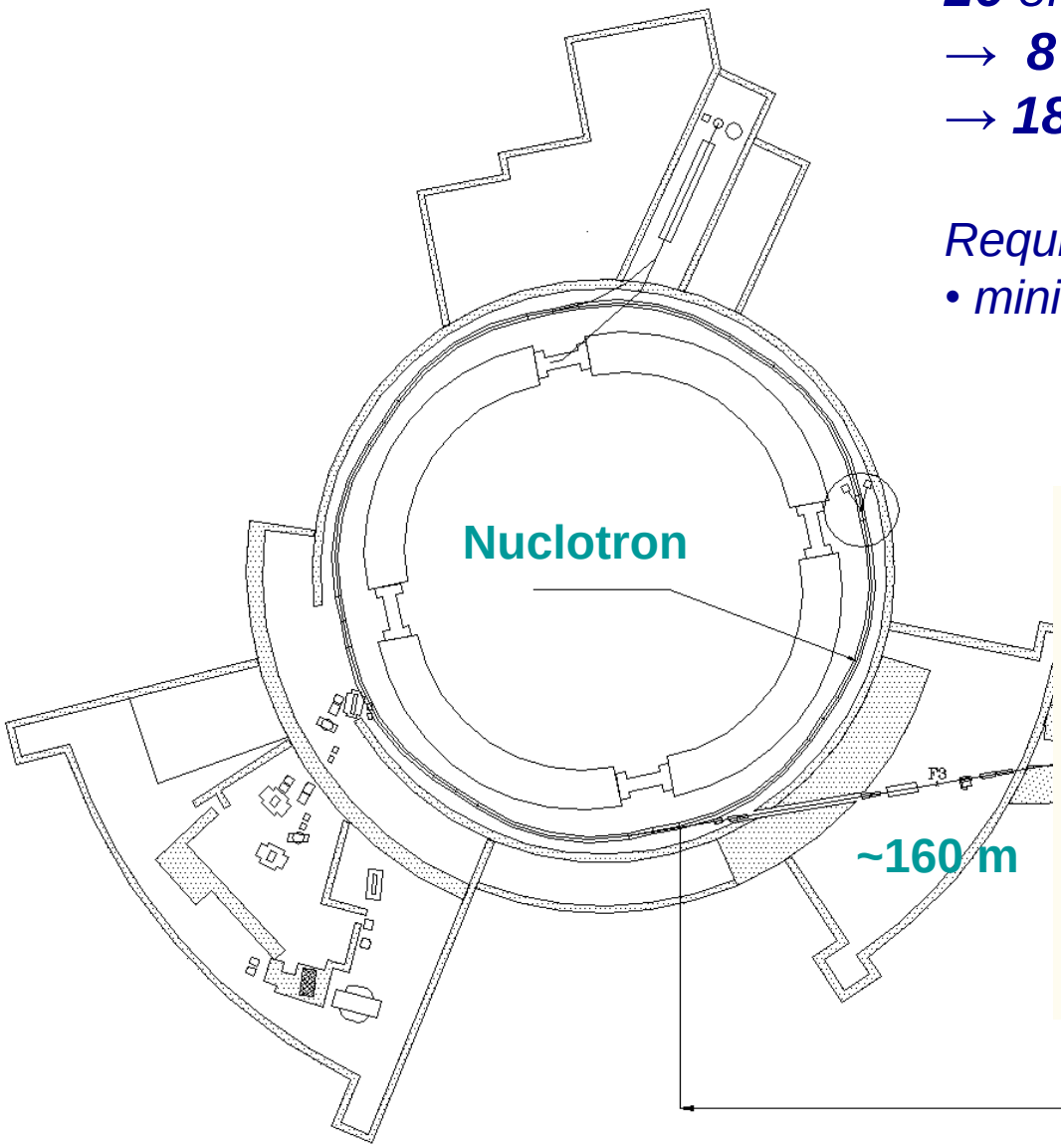
Parameter	*Project (2017)*	
Magnetic field, T	2.0 (Bρ = 42.8 T·m)	
Field ramp, T/s	1.0	
Repetition period, s	5.0	
	Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	7.0	$5 \cdot 10^{10}$
Heavy ions	*With KRION-6T & Booster*	
$^{40}Ar^{18+}$	5.9	$2 \cdot 10^{10}$
$^{56}Fe^{26+}$	6.4	$1 \cdot 10^{10}$
$^{124}Xe^{48/42+}$	5.0	$2 \cdot 10^{9}$
$^{197}Au^{79+}$	5.5	$2 \cdot 10^{9}$
Polarized beams	*With SPI*	
p↑	12.9	$1 \cdot 10^{10}$ *)
d↑	6.6	$1 \cdot 10^{10}$

*) *With the Siberian snake*

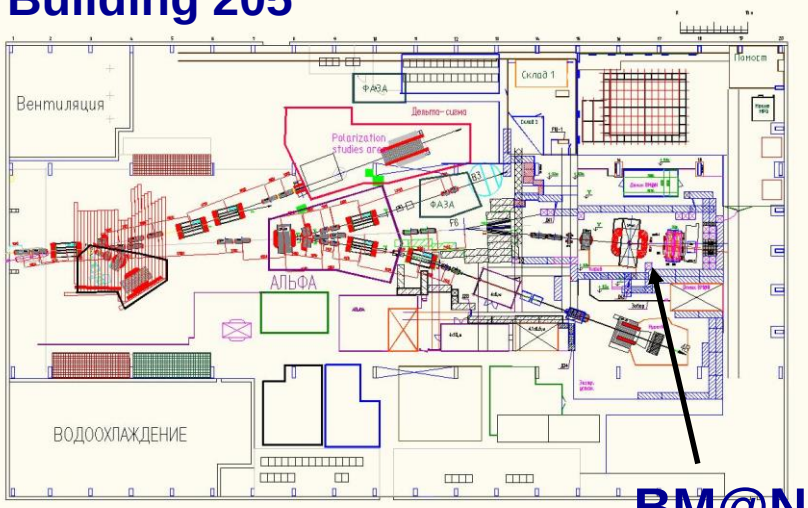
Nuclotron to BM@N beam line

26 elements of magnetic optics:
→ 8 dipole magnets
→ 18 quadruple lenses

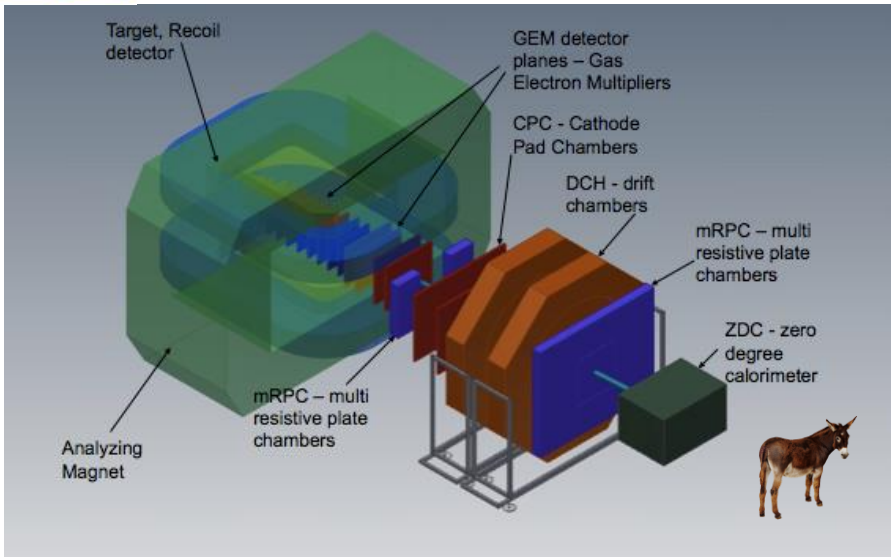
Requirements for Au beam:
• minimum dead material
→ need to replace air intervals /foils with vacuum



Building 205



BM@N (Baryonic Matter at Nuclotron): *the 1st stage*



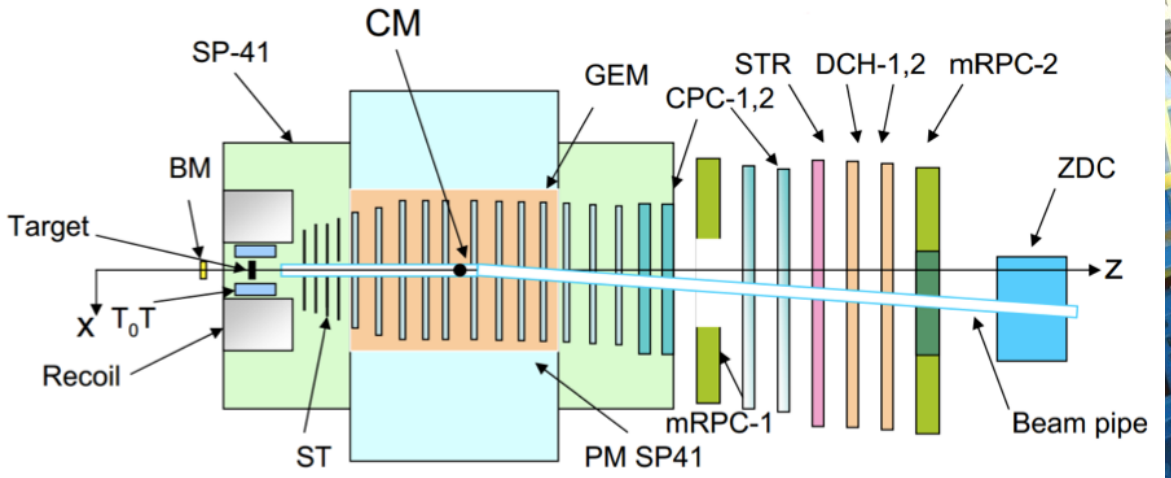
Expression of interest from scientists:

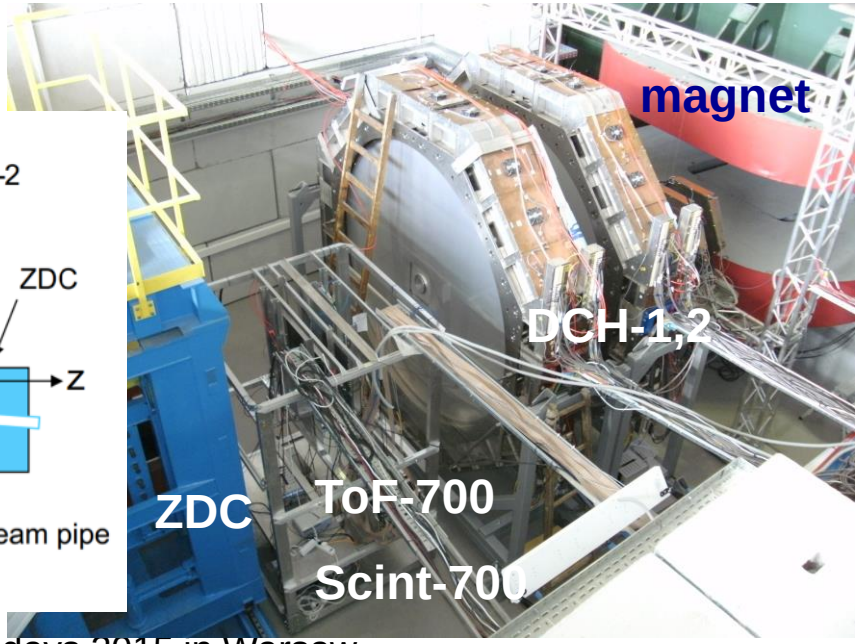
IN, SINP MSU, IHEP + S-Ptr Univ. (RF);
GSI, Frankfurt U., Gissen U. (Germany):
+ CBM-MPD IT-Consortium,

Physics:

- ✓ *hyperon production*
- ✓ *hadron femtoscopy*
- ✓ *in-medium effects for strange & vector mesons*
- ✓ *electromagnetic probes (optional)*

BM@N *schematic view*



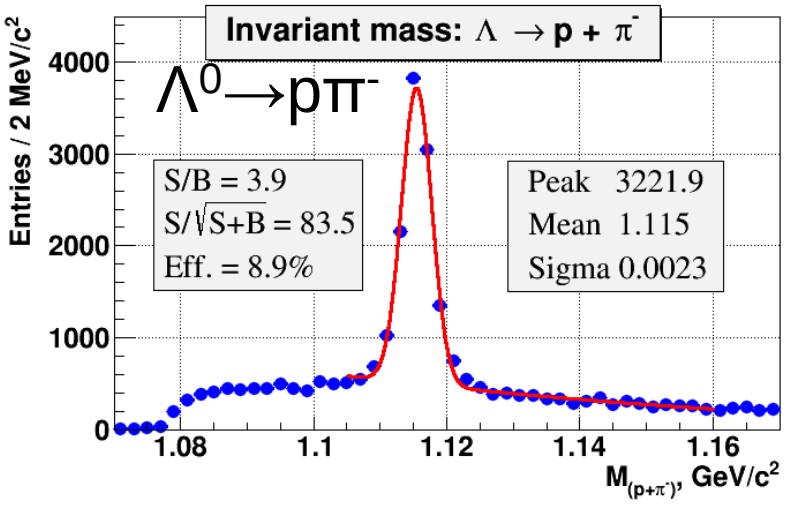


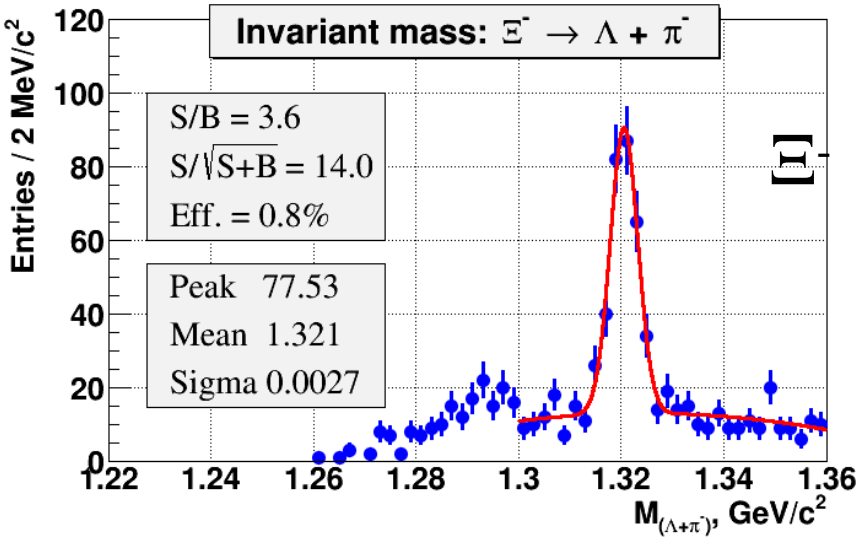
GEM tracker: Λ^0, Ξ^-, $^3H_\Lambda$ reconstruction

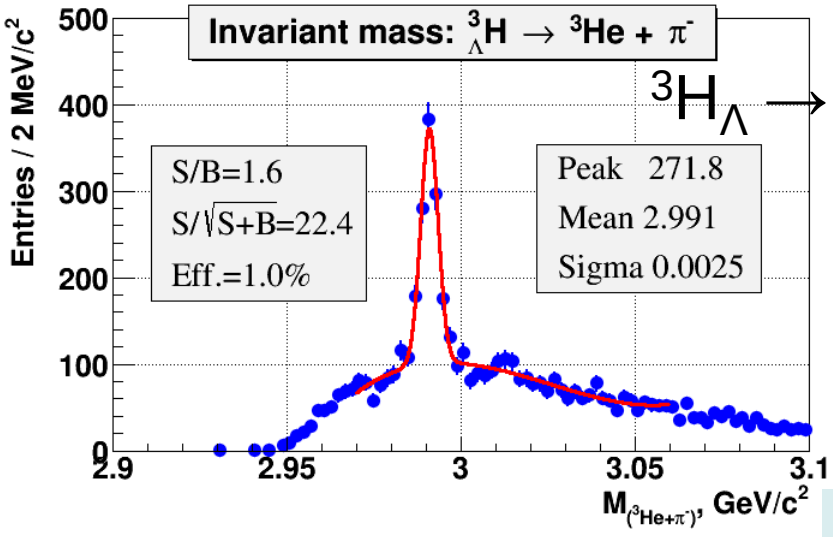
A.Zinchenko, V.Vasendina

12 planes of GEM tracker

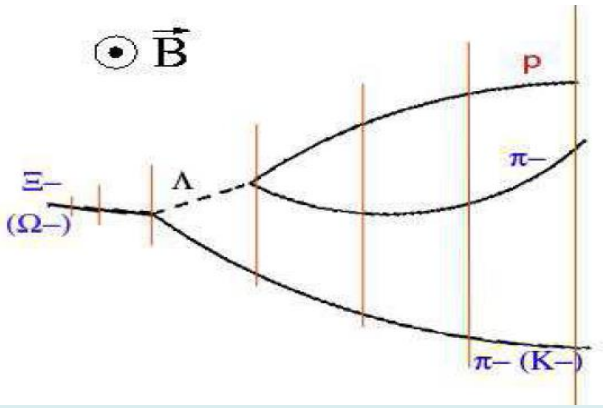
UrQMD & DCM-QGSM, Au+Au, $E_{kin.}$ = 4.5A GeV, 2 ×10^6 events;





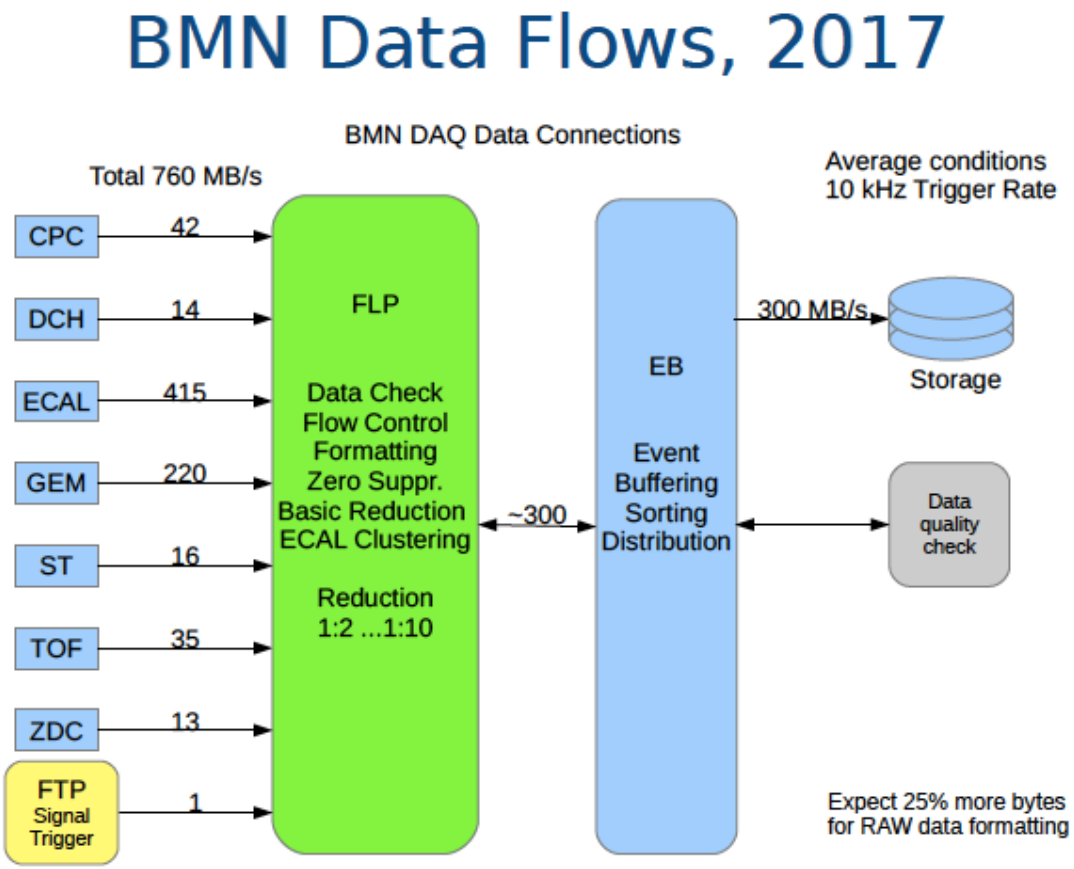


$\Xi^- \rightarrow \pi^- + \Lambda^0 \rightarrow p\pi^-$



For more details: D. Suvarieva, at SQM-2015

NICA computing request



80 kB/event
20 - kHz trigger rate
60% beam on time
20% DAQ standby time
950 MB/s readout rate
(4800 MB/s peak)
25 TB RAW data per day

Up to 5 PB RAW data / year

Together with MPD (2020)
> 10 PB RAW data / year

Needs:

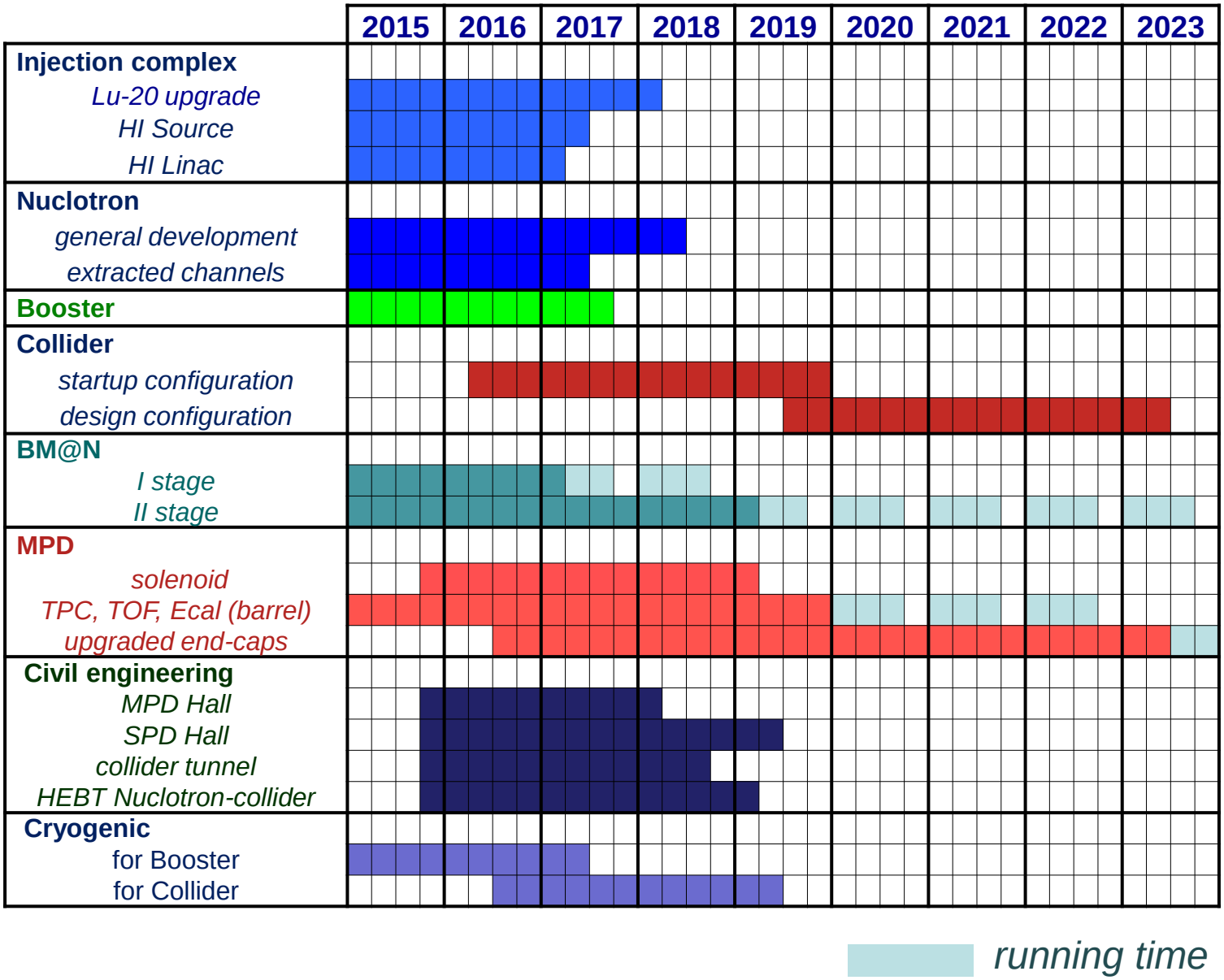
- Comp. CPU – 5 000 GHz
- Cpmp. CPU cores – 1600
- Comp. RAM – 10 000 GB
- Disc storage – 2 200 TB
- Mass storage – 20 PB/year

BM@N milestones

- **ZDC** *complete configuration* — **2016**
- **DAQ** *complete config.* — *end* **2017**
- **GEM** *8 planes* — *end* **2017**
- **TOF** *complete config.* — *end* **2017**
- **GEM** *12 planes* — *end* **2018**
- **ST** *4 planes* — **2019**

- *technical runs with* ***d, C, Li*** — **2015 - 2017**
- *physics run* **BM@N** *(I stage) with* ***p, Xe*** — *Nov* **2017**
- *physics run* **BM@N** *(II stage) with* ***Au*** — *Feb* **2019**

NICA schedule



International cooperation

Armenia
Australia
Azerbaijan
Belarus
Bulgaria
Brazil
CERN
China
Cuba
Czech Rep.
DPRK
France
Georgia
Germany
Greece
India
Italy
Japan
Kazakhstan
Moldova
Mongolia
Poland
Romania
RSA
Russia
Serbia
Slovakia
Ukraine
USA
Uzbekistan
Vietnam

Conclusive remarks

*In the medium-term prospect the NICA complex will be the only facility in Europe providing unique high intensity ion beams (from **p** to **Au**, **p**↑ and **d**↑) **in the energy range** from **2 – 27 GeV** (c.m.s.), which could be used for both fundamental and applied researches.*

Researches at the NICA complex will contribute to

- *discovery and study of new forms of nuclear matter;*
- *comprehensive study of nucleon spin structure;*
- *applied researches, like irradiation of biological objects by heavy ion beams (space mission program) etc.*

NICA *is supported through relevant European partnership and intergovernmental research organizations.*

NICA *is a lighthouse project on the* ***JINR-Roadmap****, established and approved through all of the* ***JINR member*** *states including* ***5*** *from the* ***EU****.*

It is one of the Mega-Science project adopted through Russia, however constructed and operated as ***pan-European RI*** *at the* ***International Intergovernmental organization JINR*** *in Dubna.*

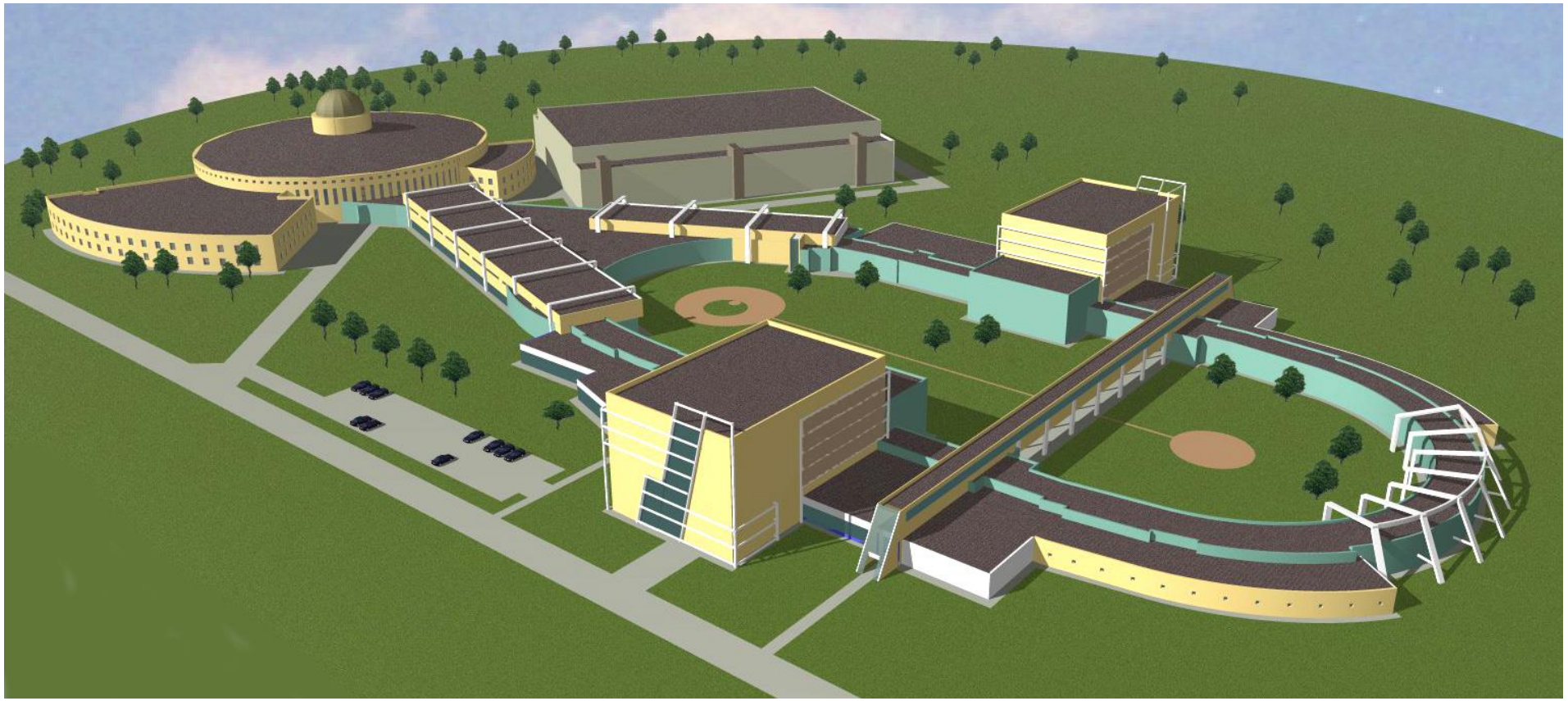
NICA project has been proposed for inclusion in the **ESFRI Roadmap**

NICA will complement the new **Research Infrastructure map** according to the long term needs of the **European research communities**

The presence of **NICA** in the **ESFRI Roadmap** will ensure:

- *larger European participation to meet the challenges of the complex experiments to be performed in the next decades*
- *strategic long-term research planning*

You are welcome to join the NICA project




NICA
Thank you