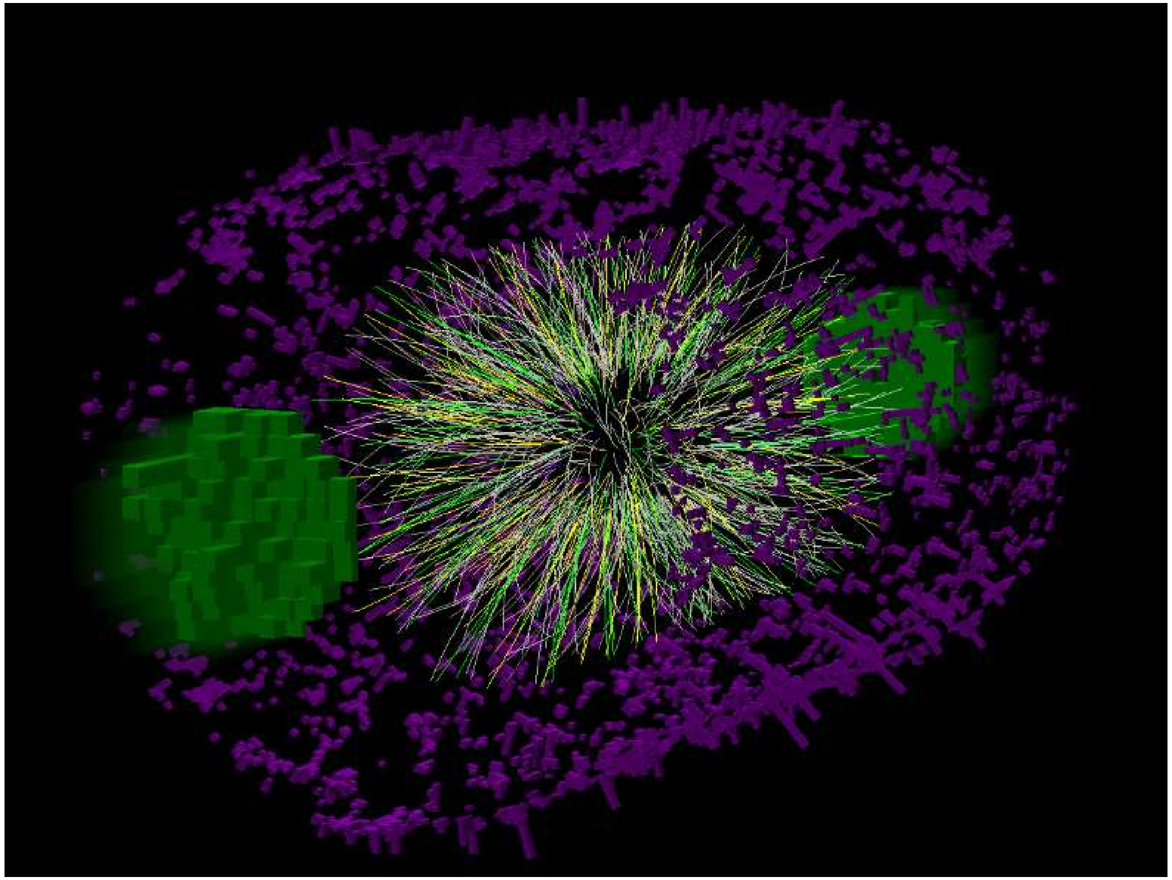
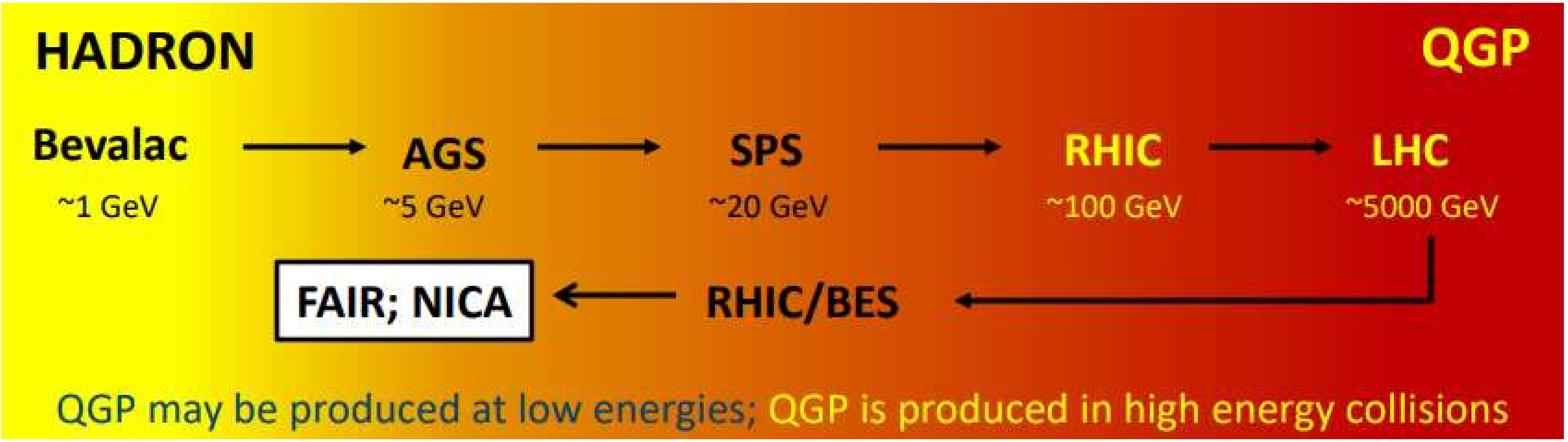
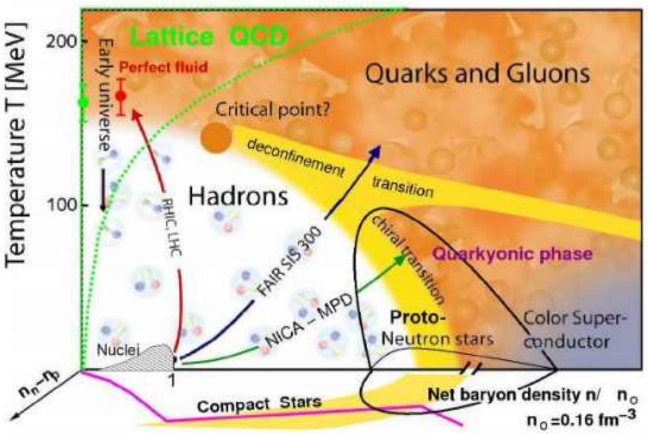
Nuclotron based **I**on **C**olider f**A**cility

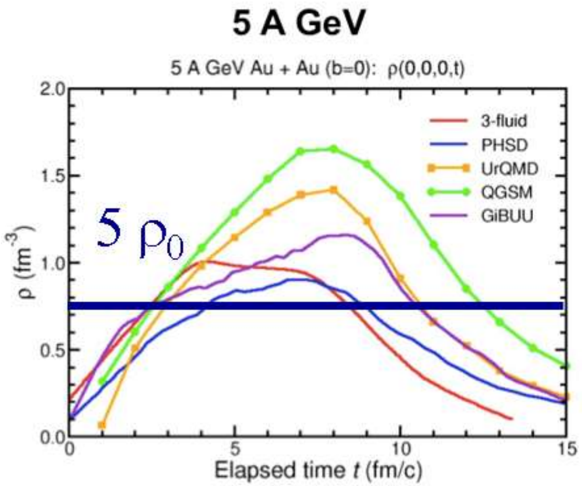
В. Рябов, ЛРЯФ ОФВЭ

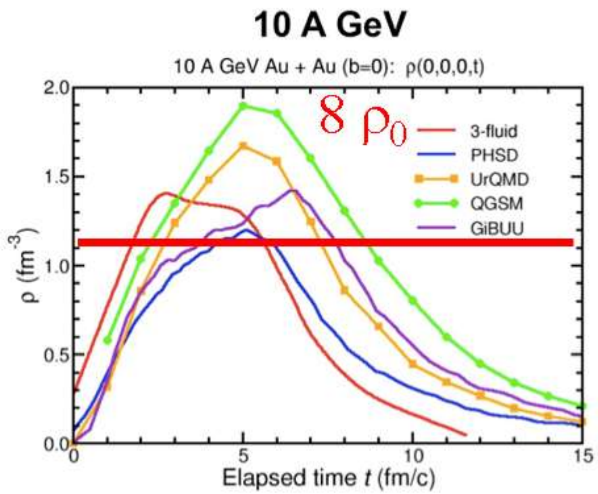


Цели проекта NICA





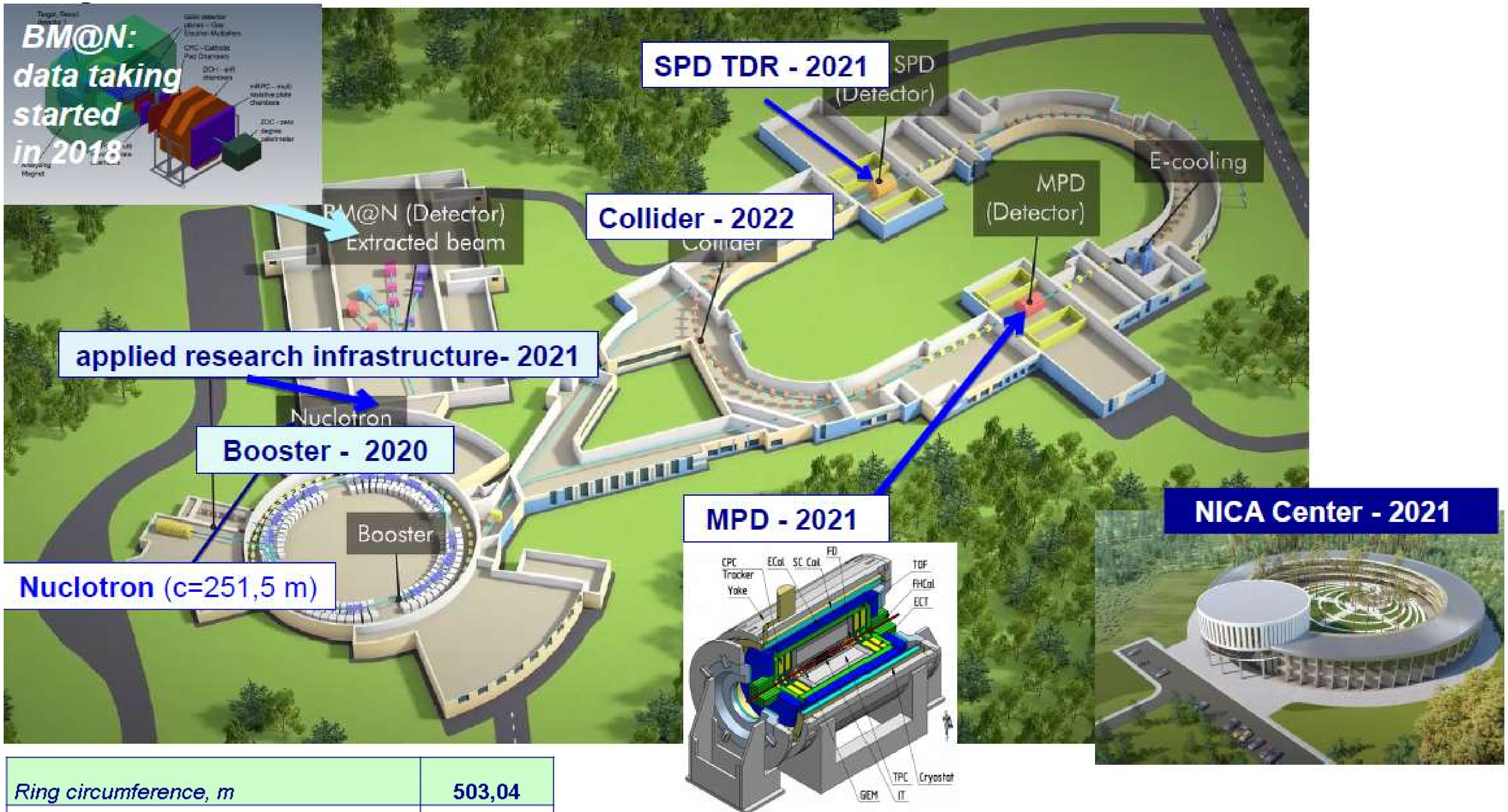




I.C. Arsene at al., Phys. Rev. C75 (2007) 24902.

- Изучение плотной и горячей ядерной материи при максимальных барионных плотностях (фазовый переход $\varepsilon_c \sim 0.5$-1 ГэВ/фм^3, $\rho_c \sim 5\rho_0$)
- Продолжение экспериментов на RHIC и LHC, 100-1000 ГэВ → 4- 11 ГэВ

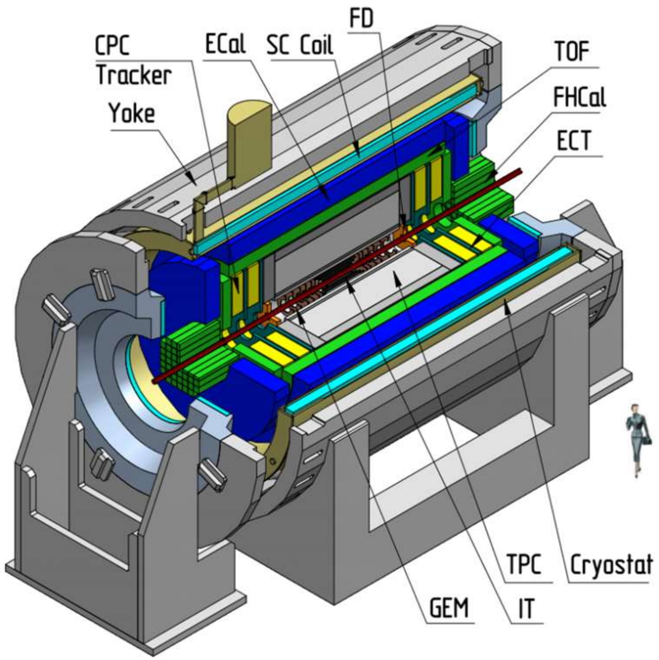
Комплекс NICA

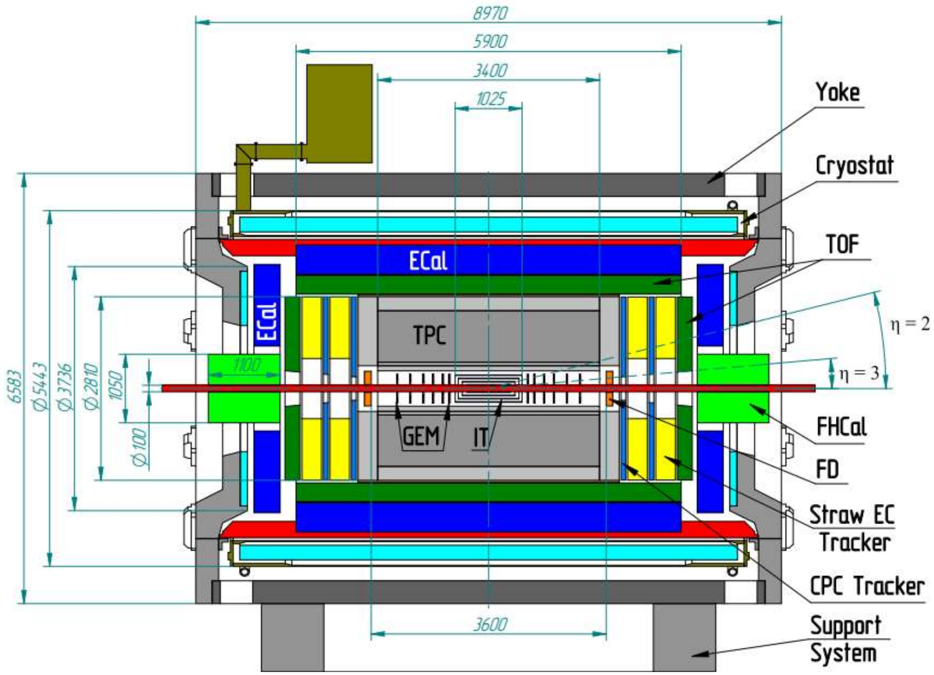


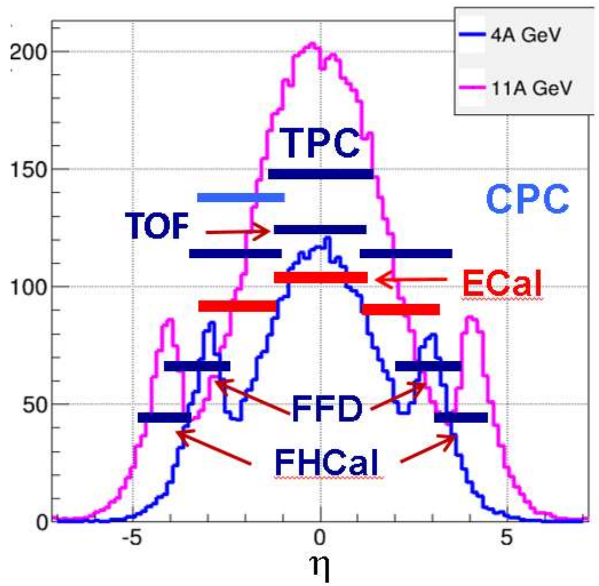
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
Luminosity, cm^{-2} s^{-1}	**$1x10^{27}$**

- Mega-science project
- Modernization of existing accelerator facility and construction of the collider complex:
  - relativistic ions from p to Au, $\sqrt{s_{NN}}$ = 4-11 GeV
  - polarized p and d, $\sqrt{s_{NN}}$ = 27 GeV (p)

Multi-Purpose Detector

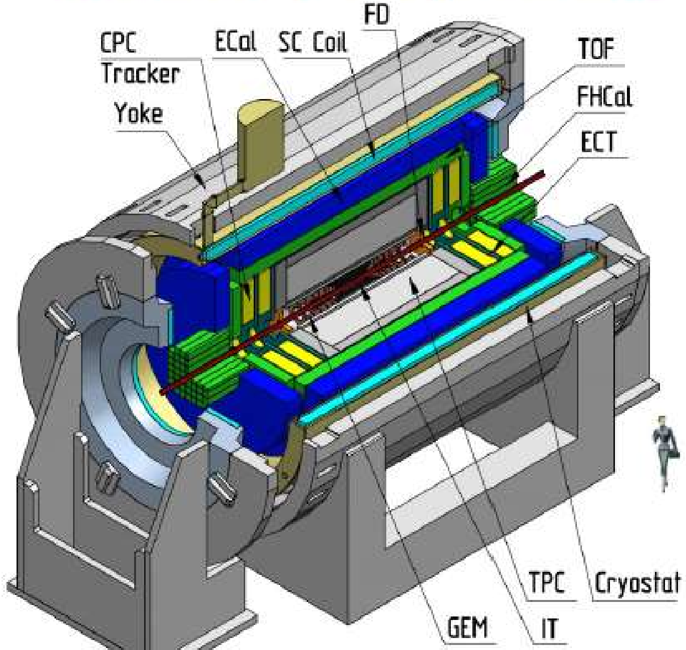






- Большой и однородный аксептанс
- Мало материалов (прозрачный)
- PID (TPC, TOF, ECAL)
- DAQ ~ 6 кГц

Multi-Purpose Detector (MPD) Collaboration



11 *Countries,* ***475*** *participants,*
33+5 *Institutes and* ***JINR***

AANL, Yerevan, ***Armenia;***
Baku State University, NNRC, ***Azerbaijan****;*
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chile****;*
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****;*

NICA

IHEP, Beijing, ***China****;*
University of South China, ***China****;*
Three Gorges University, ***China****;*
Institute of Modern Physics of CAS, Lanzhou, ***China****;*
Palacky University, Olomouc, ***Czech Republic****;*
NPI CAS, Rez, ***Czech Republic****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
Joint Institute for Nuclear Research*;*
FCFM-BUAP (Mario Rodriguez) Puebla, ***Mexico****;*
FC-UCOL (Maria Elena Tejeda), Colima, ***Mexico****;*
FCFM-UAS (Isabel Dominguez), Culiacán, ***Mexico****;*
ICN-UNAM (Alejandro Ayala), Mexico City, ***Mexico****;*
CINVESTAV (Luis Manuel Montaño), Mexico City, ***Mexico****;*
Institute of Applied Physics, Chisinev, ***Moldova****;*
WUT, Warsaw, ***Poland****;*
NCNR, Otwock – Świerk, ***Poland****;*
University of Wrocław, ***Poland****;*
University of Warsaw, ***Poland****;*
Jan Kochanowski University, Kielce, ***Poland****;*
Belgorod National Research University, ***Russia****;*
INR RAS, Moscow, ***Russia****;*
MEPhI, Moscow, ***Russia****;*
Moscow Institute of Science and Technology, ***Russia****;*
North Osetian State University, ***Russia****;*
NRC Kurchatov Institute, ITEP, ***Russia****;*
Kurchatov Institute, Moscow, ***Russia****;*
St. Petersburg State University, ***Russia;***
SINP, Moscow, ***Russia****;*
PNPI, Gatchina, ***Russia****;*

Физические задачи

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

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

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

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

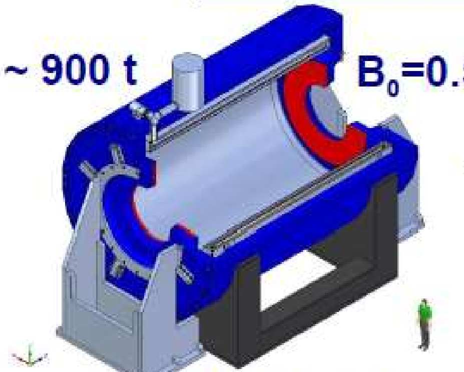
Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Строительство детектора

SC Solenoid

~ 900 t

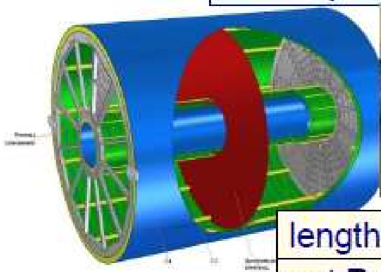
B_0=0.5 T

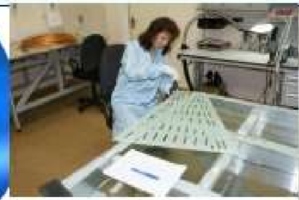


Yoke – produced & delivered

cryostat with SC coil - ready for cold tests

TPC) – basic tracker





length	*340 см*
out Radii	*140 см*
N chan.	***95 232***

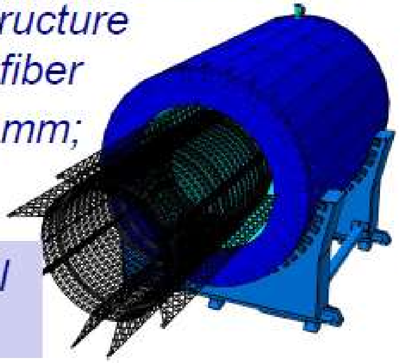
TOF system

Integration

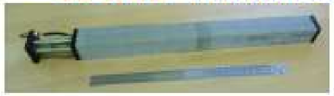
support structure of carbon fiber

*sagite ~ **5** mm; 0,13 X_0*

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



~ **43 000** modules

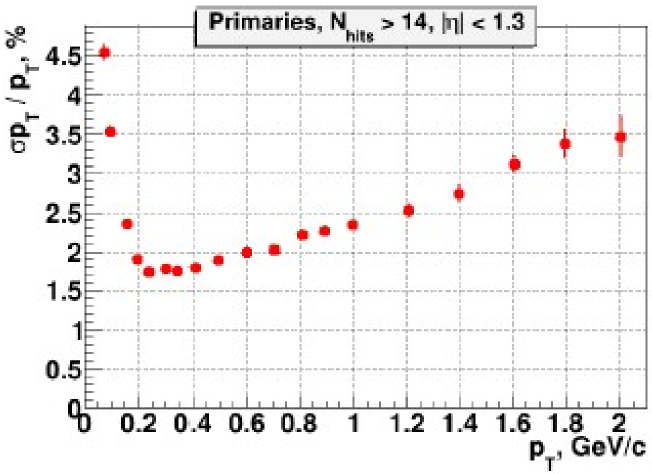


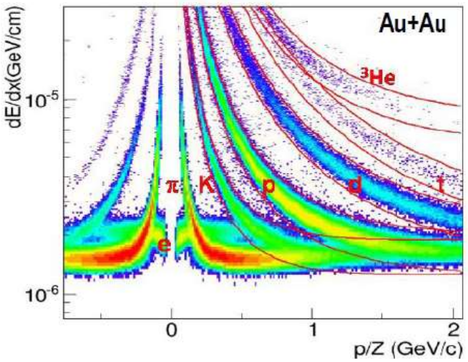
ECAL

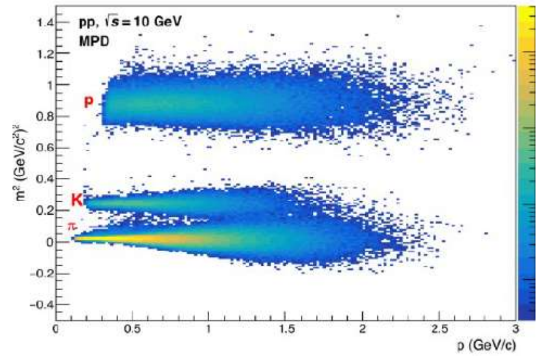
Pb+Sc "shashlyk" type Ecal

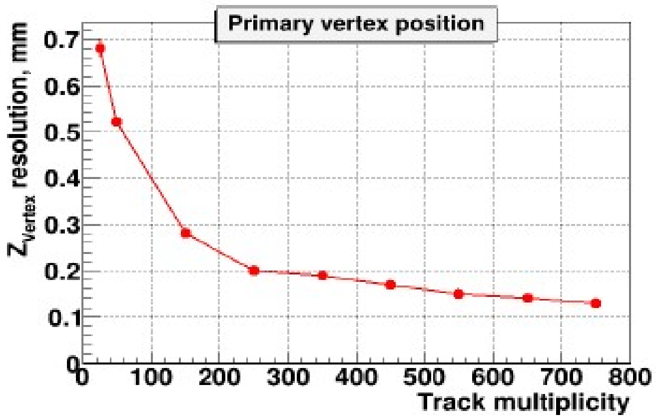
MPD global performance (stage-I)

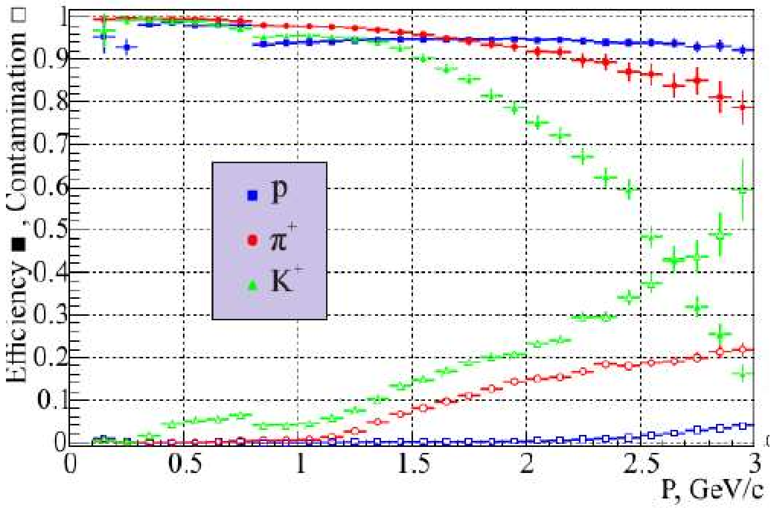
TPC 3D-tracking: $|\varphi| < 2\pi$, $|\eta| < 1.6$
PID: dE/dx (TPC) + time-of-flight (TOF) + e-ID (ECAL)
→ π/K up to 1.5 GeV/c, K/p up to 3 GeV/c
FHCAL: $2 < |\eta| < 5$
Trigger & T0: FFD
DAQ: ~ 6 kHz





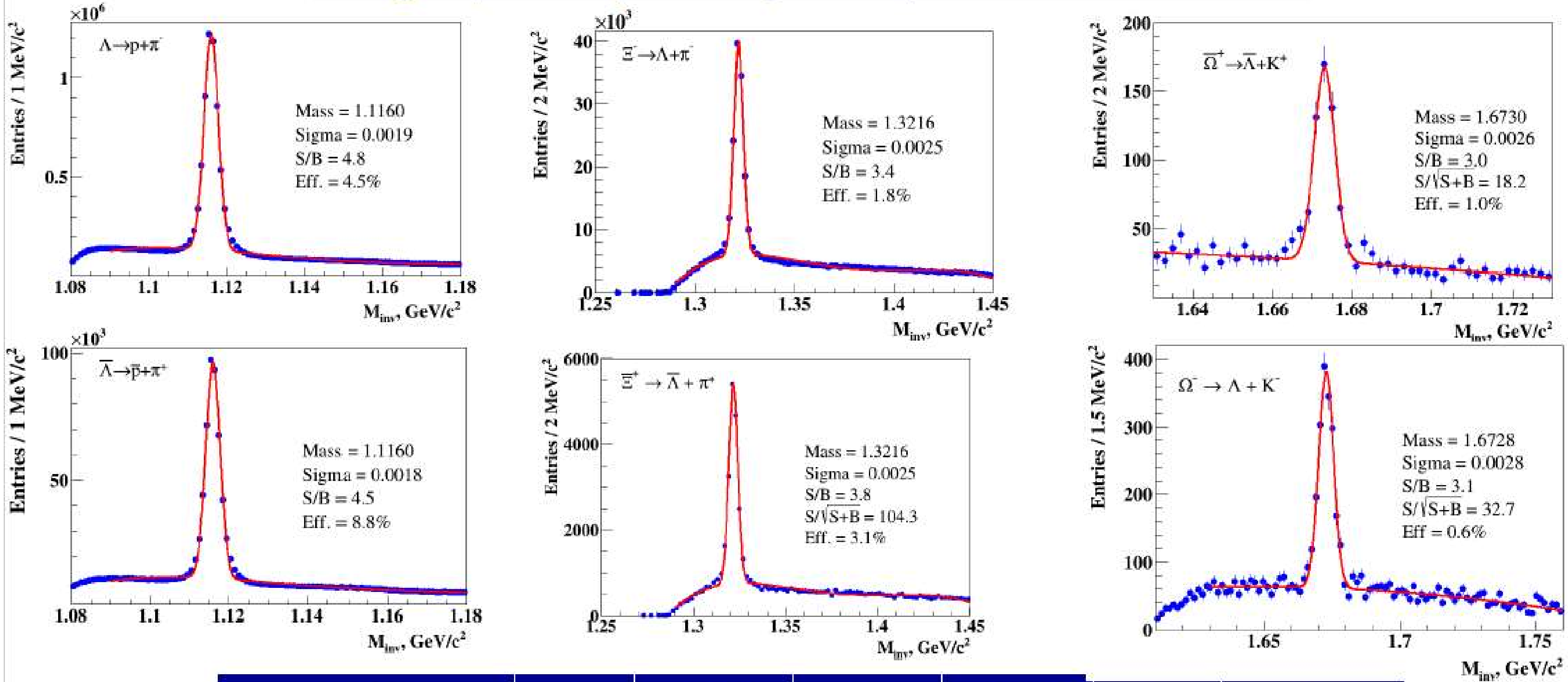






(Мульти)странные адроны

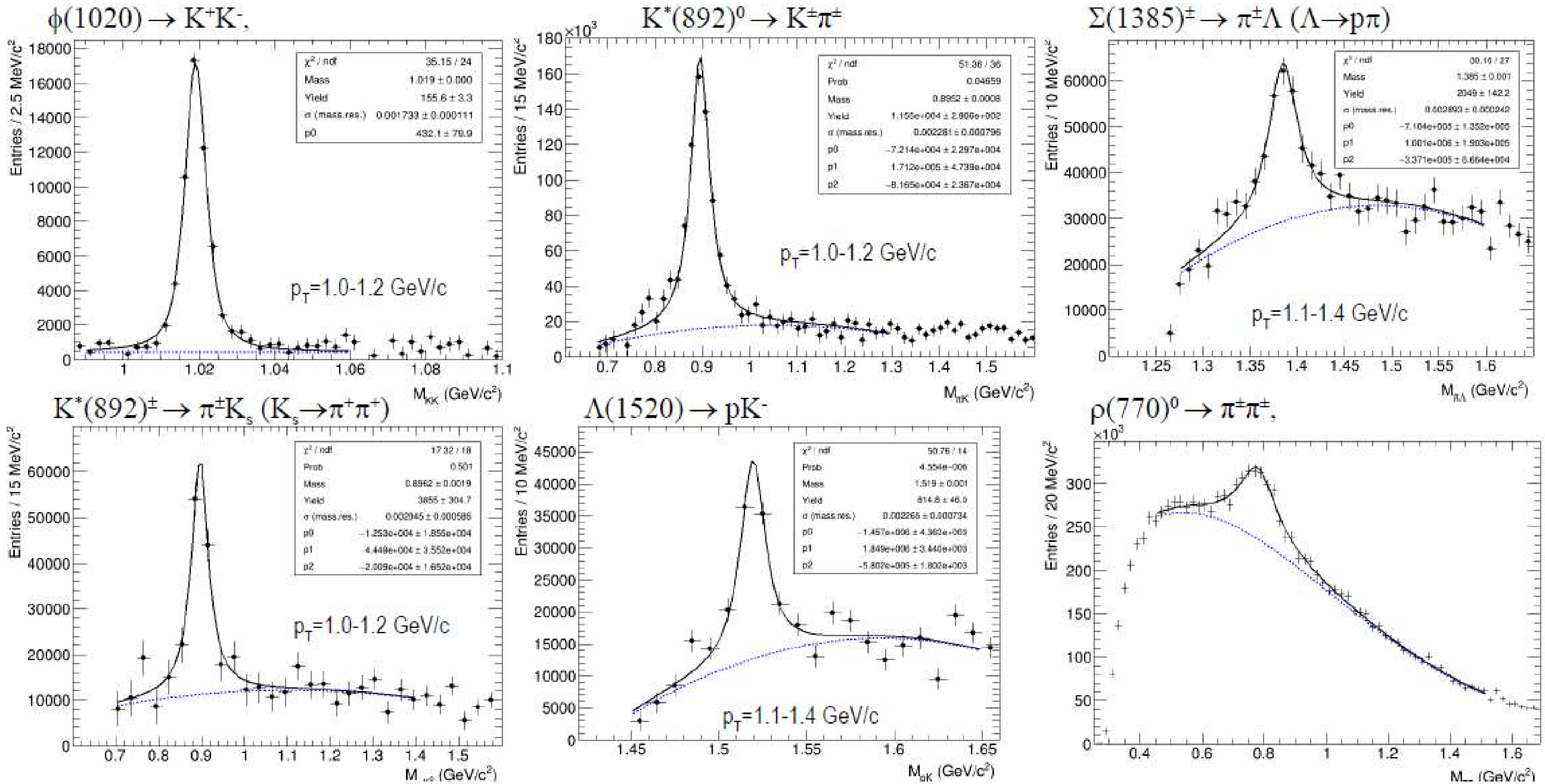
Stage'1 (TPC+TOF): Au+Au @ 11 GeV, PHSD + MPDRoot reco.



particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
yield in 10week	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

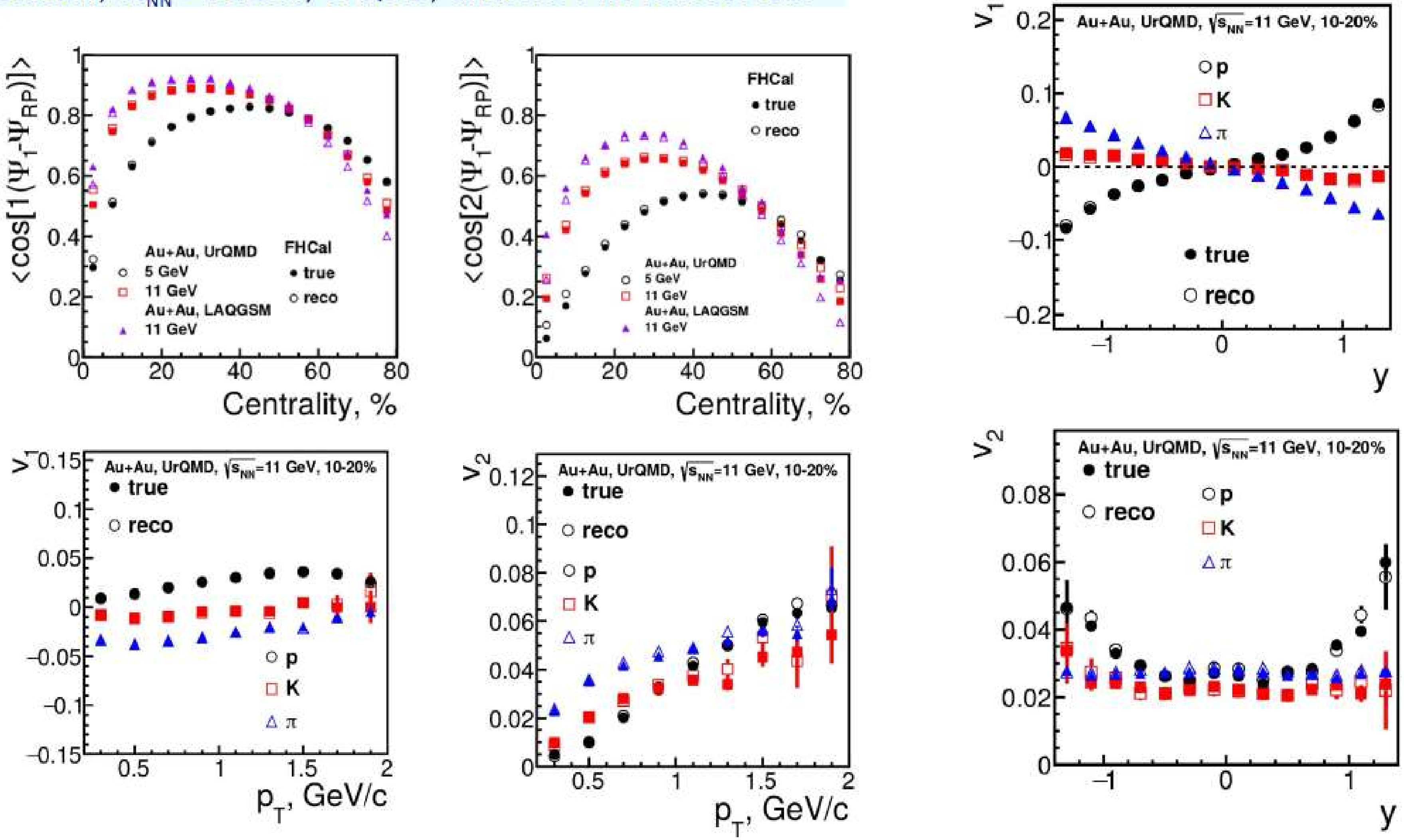
Адронные резонансы

· Minbias Au+Au@11 (UrQMD) · Full reconstruction and realistic PID · Topology cuts and secondary vertex · Event mixing for background



Коллективный поток

Au+Au, $\sqrt{s_{NN}}$ = 11 GeV, UrQMD, GEANT3 + MPDRoot reco.

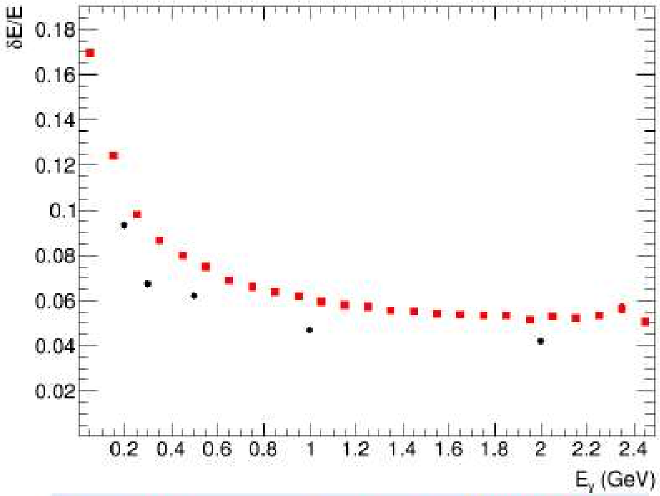


Электромагнитные сигналы

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

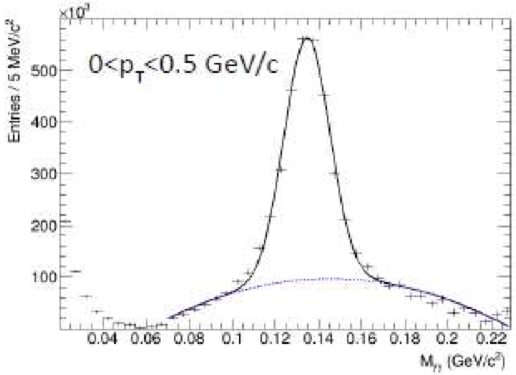
ECAL resolution for photons

Black markers – single photons
Red markers – UrQMD, minbias AuAu@11

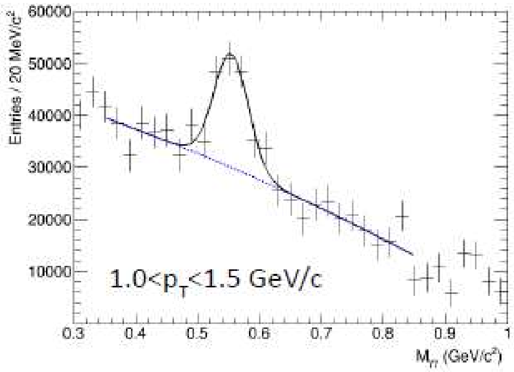


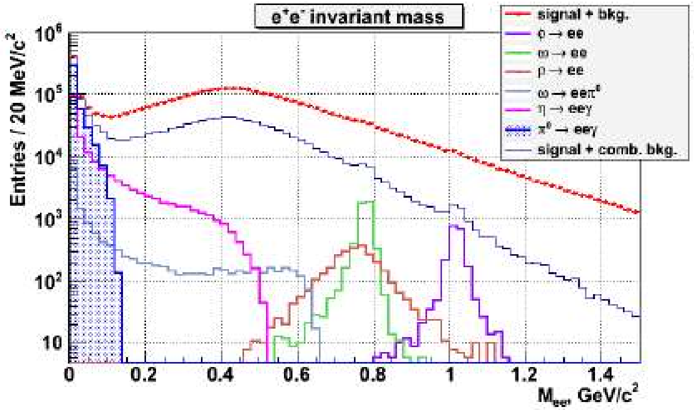
- **π^0 (η) reconstruction in MPD ECAL – feasible!**

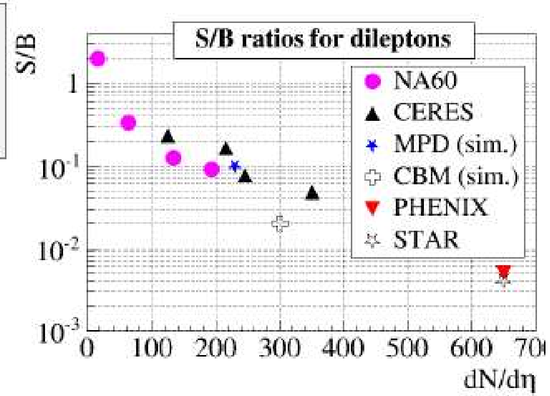
π^0-meson in central Au+Au



η-meson in minbias Au+Au

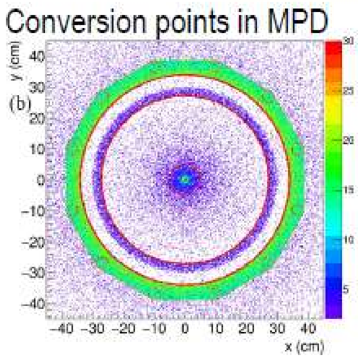


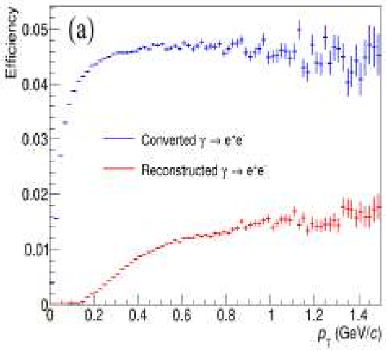


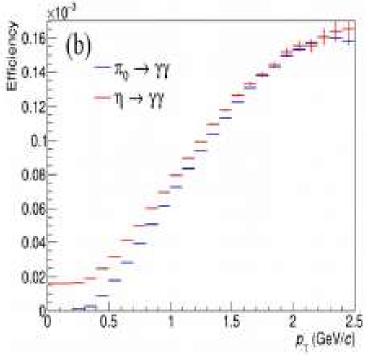


Конверсионные фотоны

- 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



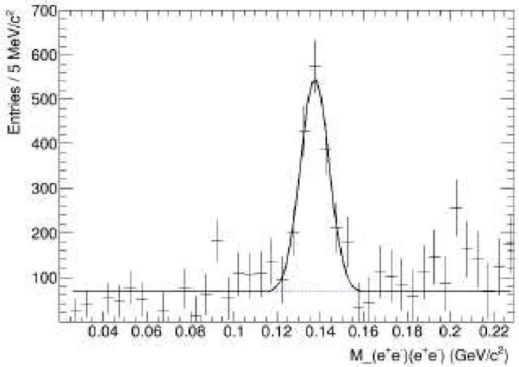




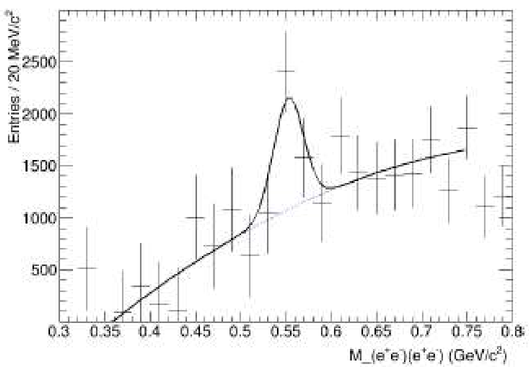
α) γ-conversion efficiency in the beam pipe & TPC vs p_T

b) MPD efficiency for π^0 and η reconstruction vs meson's p_T

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



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



- Standard MPD configuration allows to reconstruct p^0 and η via conversion pairs

ПИЯФ в MPD

- Основные вклады ПИЯФ:
  - ✓ газовая система TPC
  - ✓ программное обеспечение для реконструкции сигналов в ECAL (digitizer-clusterizer) в условиях высокой множественности
  - ✓ моделирование детектора, подготовка к измерению различных физических сигналов (адронные резонансы, диэлектронный континуум, ЛВМ, нейтральные мезоны, фотоны и др.)
  - ✓ теоретическое изучение цветовой прозрачности в pA столкновениях
  - ✓ участие в разработке и производстве трековых станций для форвардных спектрометров в рамках обновления экспериментальной установки

- 9 докладов на международных конференциях в 2019 году
- 4 публикации в реферируемых журналах

Заключение

- Проект NICA/MPD успешно реализуется
- Созданы международные коллаборации BM@N и MPD
- Детектор MPD позволяет измерять интересующие сигналы
- Участие в NICA/MPD является естественным продолжением деятельности ПИЯФ/ОФВЭ, участия в экспериментах RHIC/PHENIX и LHC/ALICE, сотрудничества с FAIR/CBM


С Новым Годом!
2020

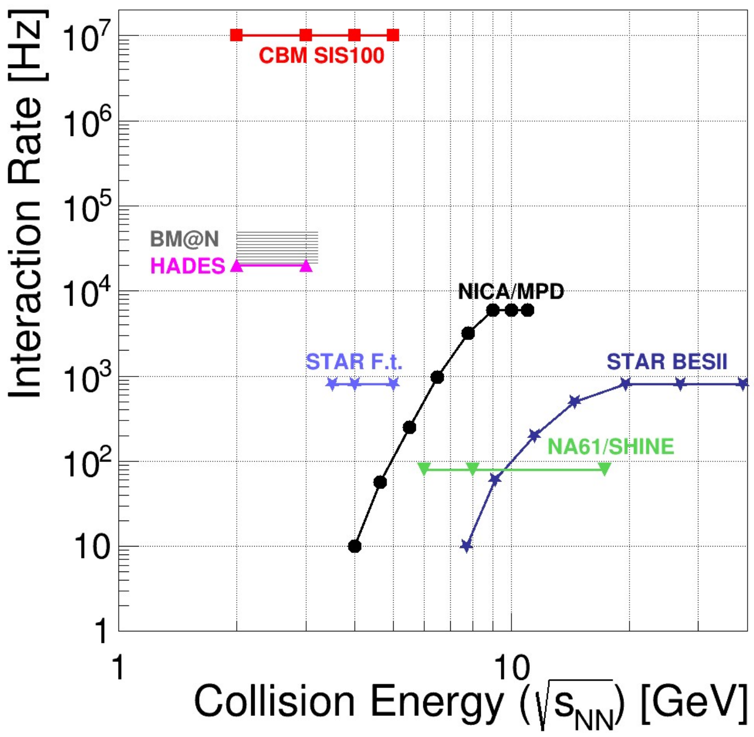
BACKUP

ПИЯФ в MPD

Country	Institute name	First name(s)	Last name
RUSSIA	PNPI, Gatchina, RUSSIA	Aleksei	Ezhilov
RUSSIA	PNPI, Gatchina, RUSSIA	Oleg	Fedin
RUSSIA	PNPI, Gatchina, RUSSIA	Vadim	Guzey
RUSSIA	PNPI, Gatchina, RUSSIA	Dmitrii	Ivanishchev
RUSSIA	PNPI, Gatchina, RUSSIA	Alexey	Khanzadeev
RUSSIA	PNPI, Gatchina, RUSSIA	Leonid	Kochenda
RUSSIA	PNPI, Gatchina, RUSSIA	Dmitrii	Kotov
RUSSIA	PNPI, Gatchina, RUSSIA	Petr	Kravchov
RUSSIA	PNPI, Gatchina, RUSSIA	Evgeny	Kryshen
RUSSIA	PNPI, Gatchina, RUSSIA	Anna	Kyrianova
RUSSIA	PNPI, Gatchina, RUSSIA	Mikhail	Malayev
RUSSIA	PNPI, Gatchina, RUSSIA	Victor	Maleev
RUSSIA	PNPI, Gatchina, RUSSIA	Yuri	Naryshkin
RUSSIA	PNPI, Gatchina, RUSSIA	Denis	Pudzha
RUSSIA	PNPI, Gatchina, RUSSIA	Yuriy	Riabov
RUSSIA	PNPI, Gatchina, RUSSIA	Vladimir	Samsonov
RUSSIA	PNPI, Gatchina, RUSSIA	Victor	Solovyev
RUSSIA	PNPI, Gatchina, RUSSIA	Alexander	Vasilyev
RUSSIA	PNPI, Gatchina, RUSSIA	Marat	Vznuzdaev
RUSSIA	PNPI, Gatchina, RUSSIA	Mikhail	Zhalov
RUSSIA	PNPI, Gatchina, RUSSIA / MEPhI	Victor	Riabov

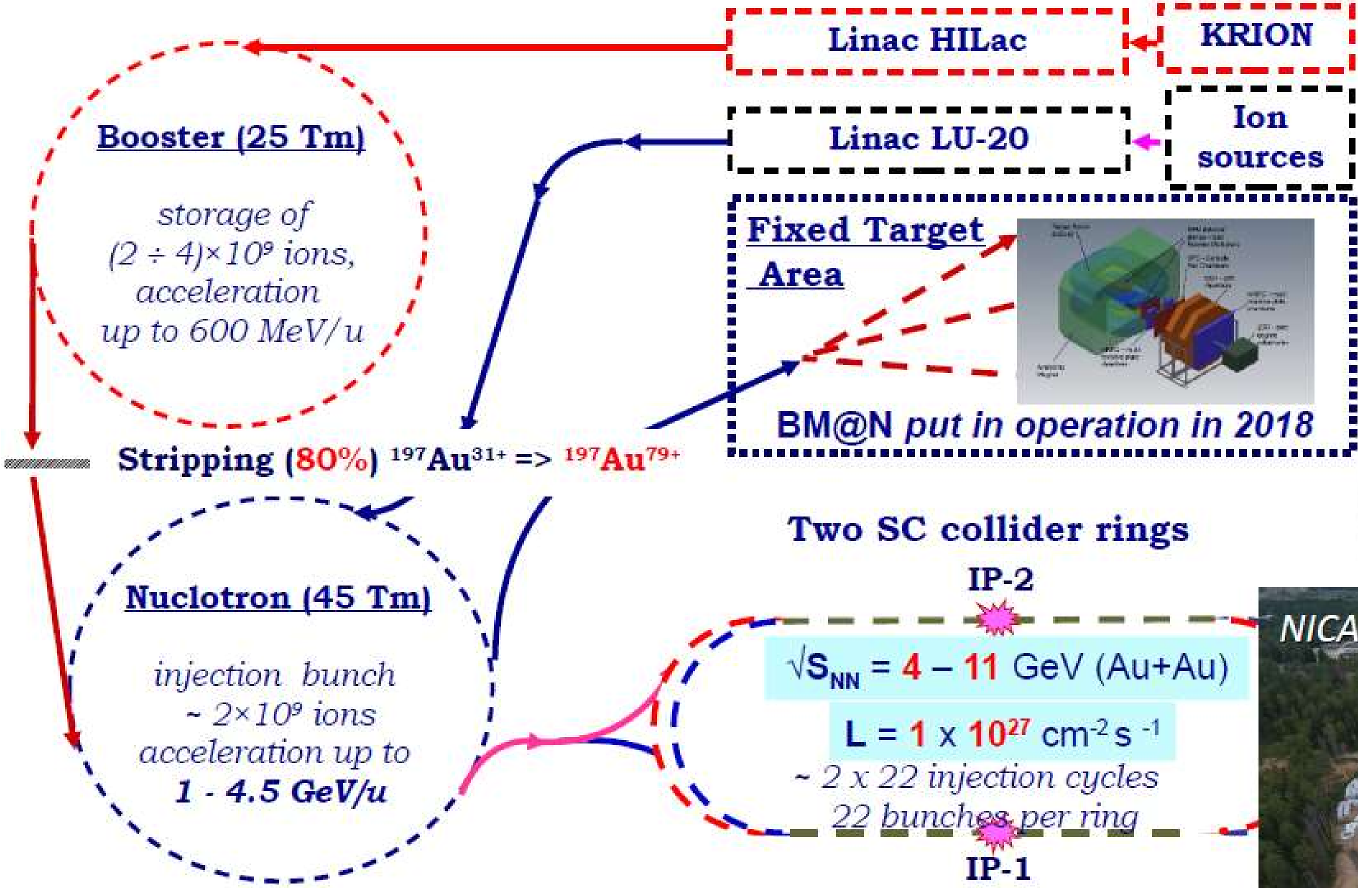
Showing 1 to 21 of 21 entries (filtered from 468 total entries)   Previous Next

NICA vs. HADES/BES-II/NA61/CBM

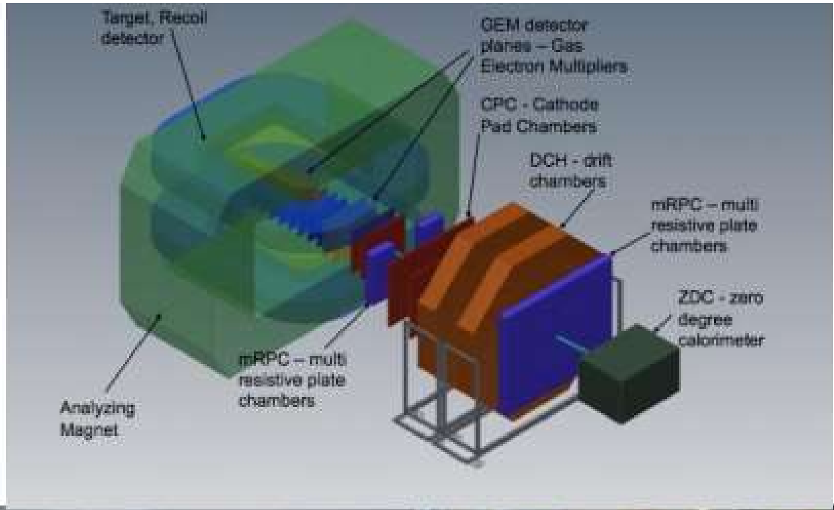


- Все эксперименты перекрывают друг друга по энергии взаимодействия
- Специализированные установки (FAIR/CBM, NICA/MPD) позволяют изучать редкие сигналы за счет более высокого темпа набора статистики
- NICA/MPD – коллайдерная установка, одновременно обладающая большим и симметричным аксептансом и позволяющая измерять редкие сигналы при отсутствии паразитических эффектов, присутствующих в экспериментах с фиксированной мишенью

Ускорительный комплекс



Эксперимент BM@N (fixed target)
Baryonic Matter @ Nuclotron

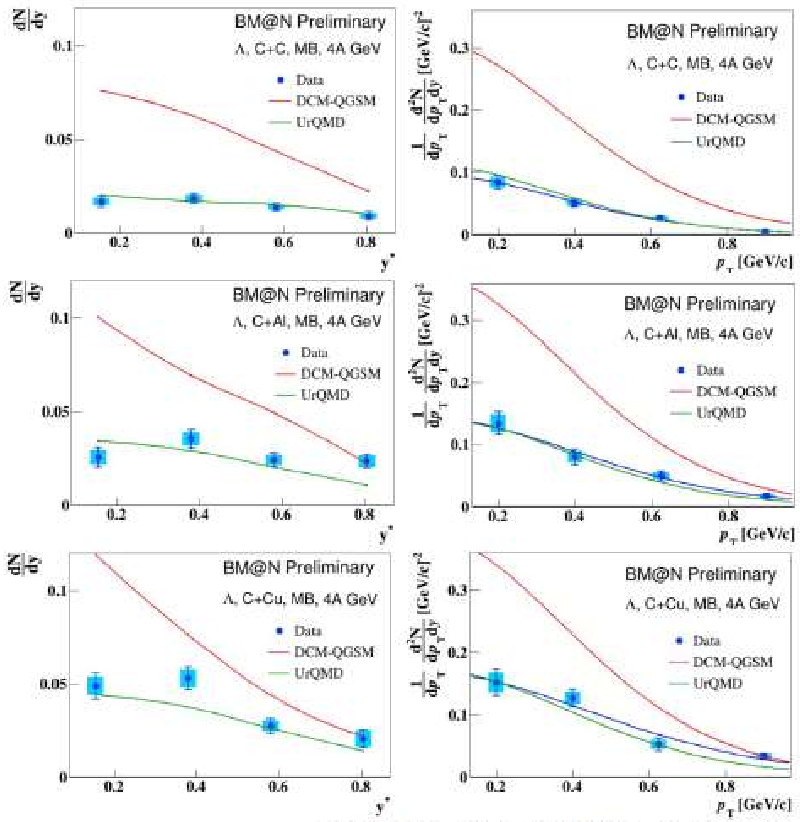


the first run: ***March 22 – April 3, 2018***:
targets: ***C, Al, Cu, Sn, Pb;***

beams			*statistics*
$^{12}C^{6+}$	***4,0 -4,5 AGeV***		***20 M events***
$^{40}Ar^{16+}$	***3,2***	***AGeV***	***130 M events***
$^{84}Kr^{26+}$	***2,3***	***AGeV***	***50 M events***

BM@N experiment: Λ hyperon yield in 4 AGeV Carbon-nucleus interactions

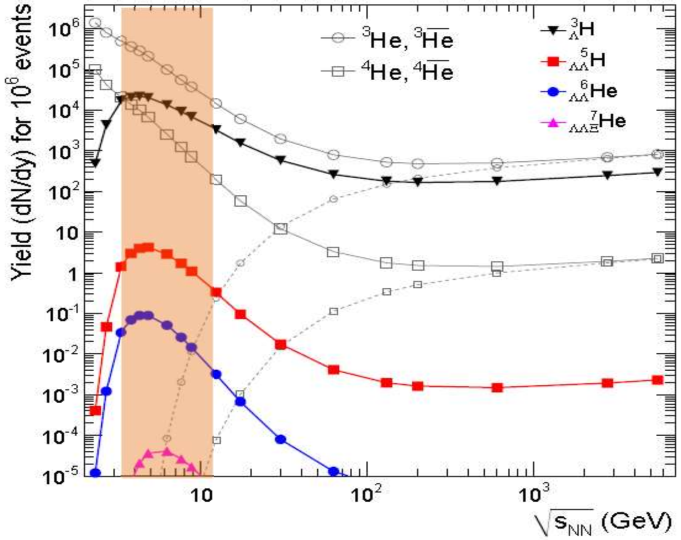
Λ yield as a function of rapidity in c.m.s. Λ yield as a function of transverse momentum



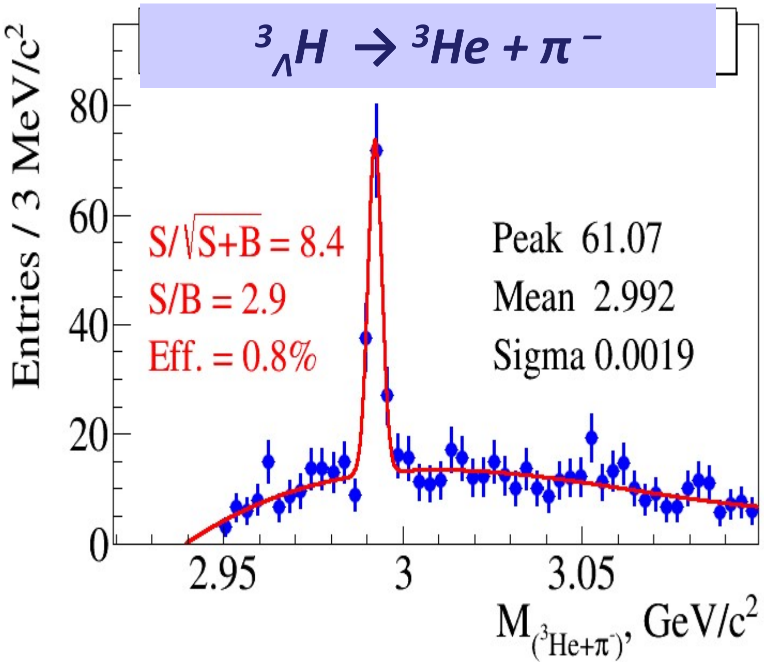
courtesy of the BM@N experiment

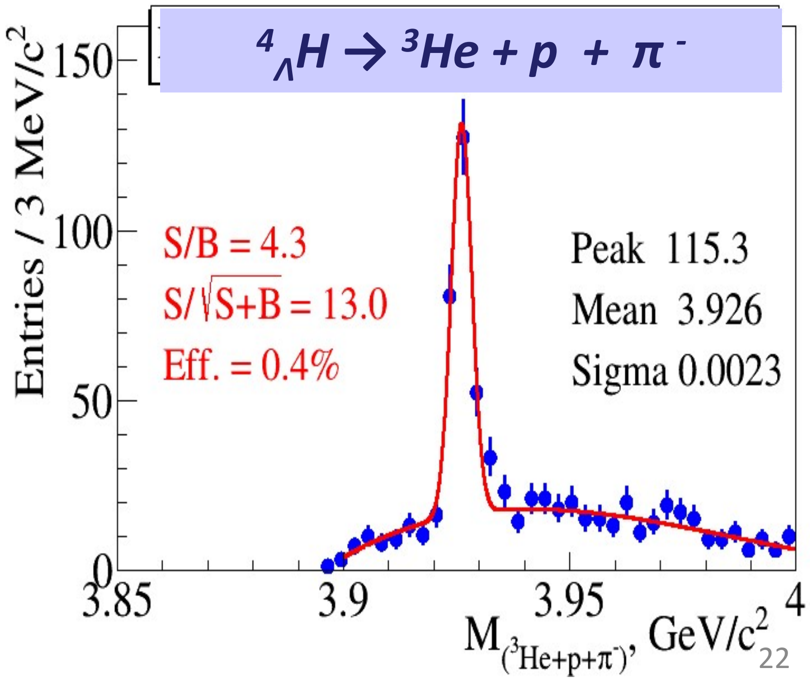
Гиперядра

*central **Au+Au @ 5** AGeV; DCM-QGSM*

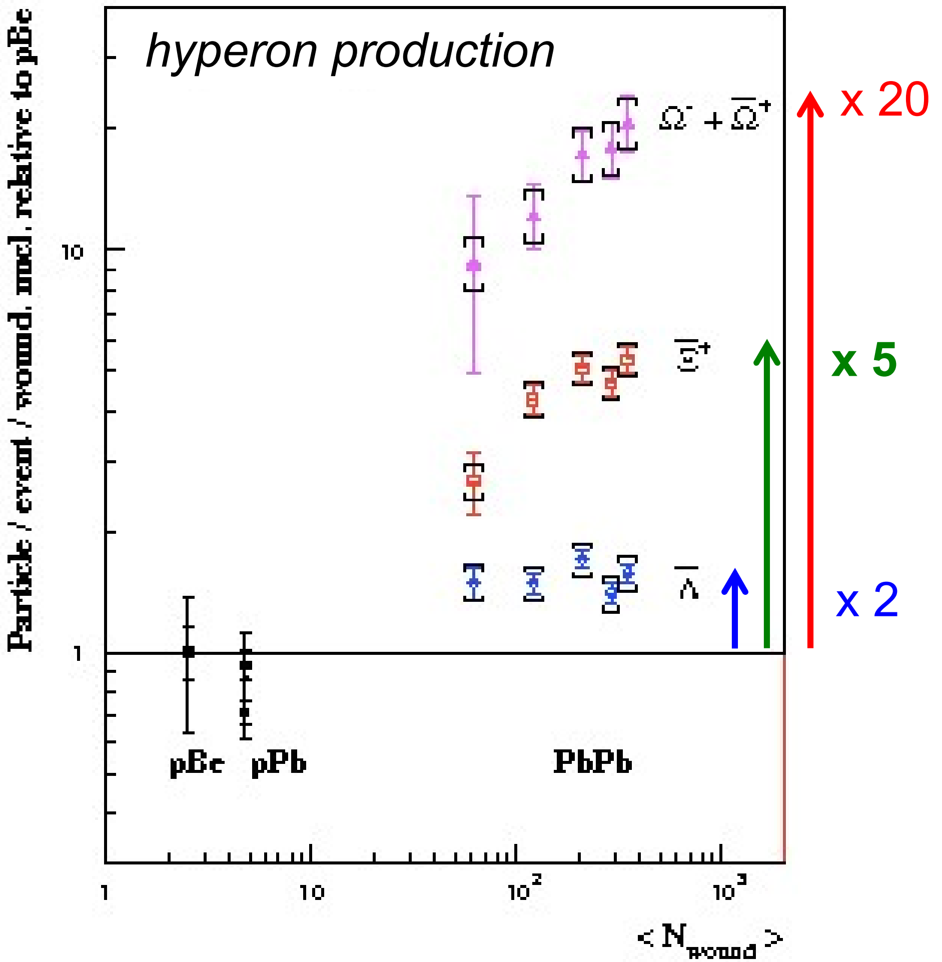


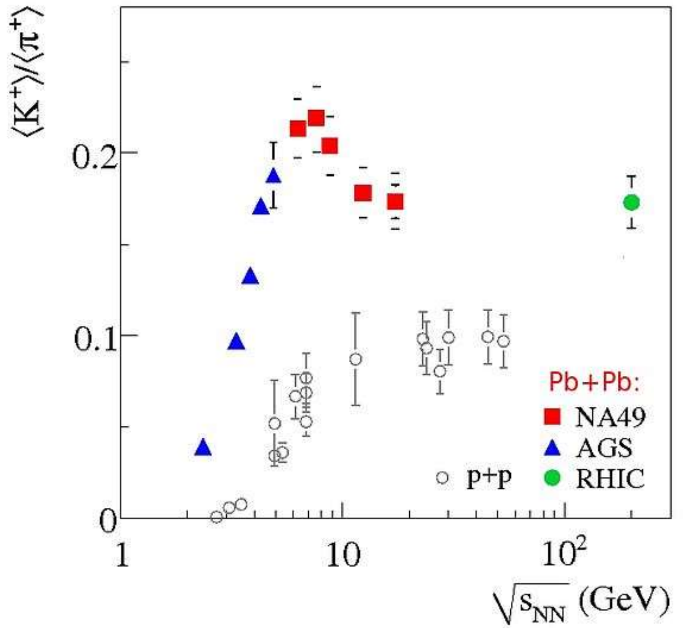
hyper nucleus	yield in 10 weeks
$^3_\Lambda$He	$9 \cdot 10^5$
$^4_\Lambda$He	$1 \cdot 10^5$

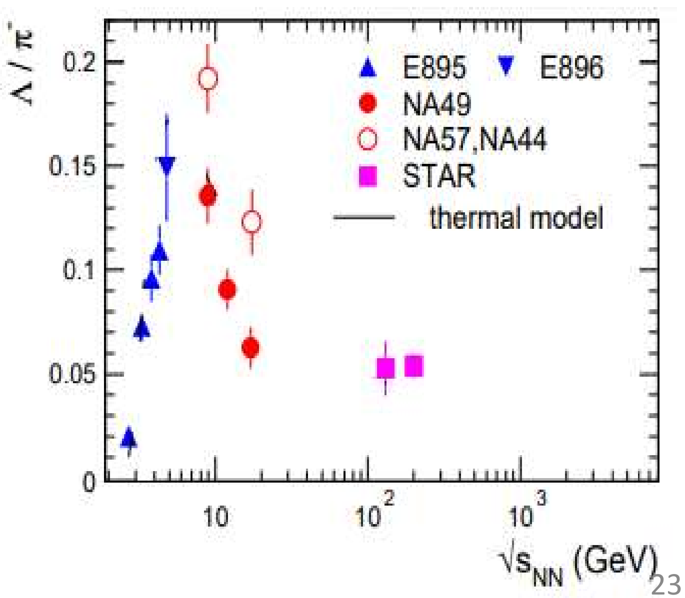




Strangeness enhancement: SPS, RHIC, LHC



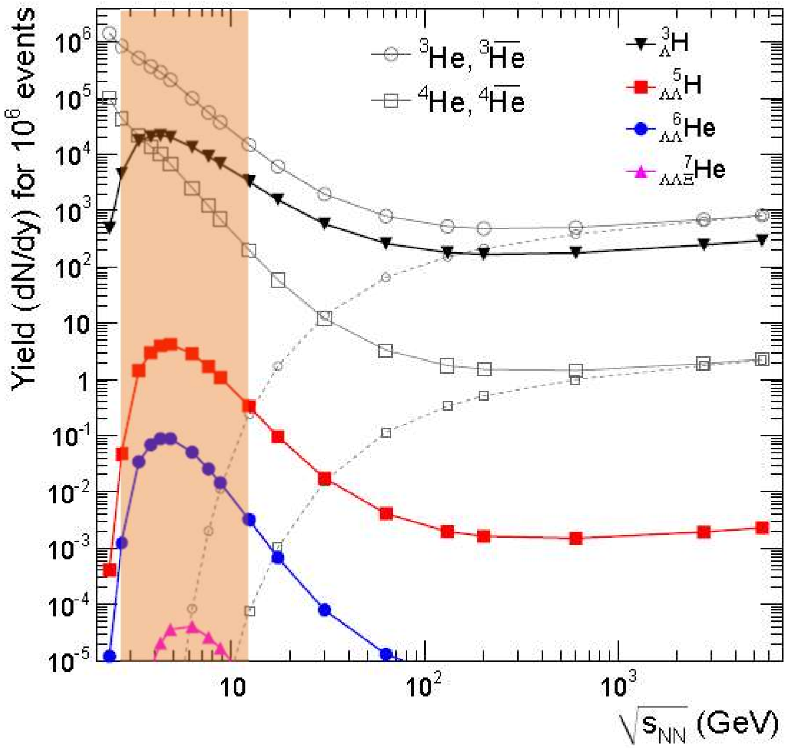




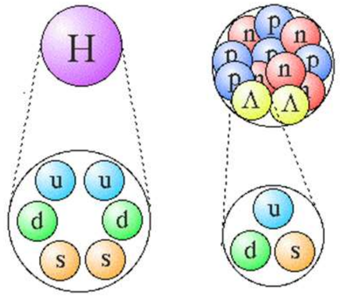
- In some models "horns" in particle ratios indicate onset of chiral symmetry restoration and deconfinement
- Requires mode detailed and precise data

Hypernuclei

- At relatively low beam energies, where the baryochemical potential and, hence, the baryon density is maximum (NICA/FAIR energy regime) objects with a large number of baryons and moderate strangeness are abundantly produced



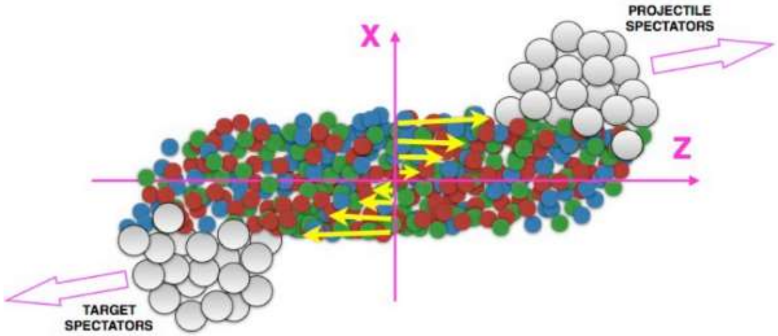
A. Andronic et al., Phys. Lett. B697 (2011) 203



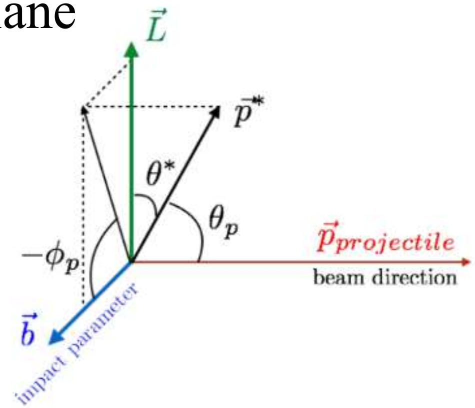
- Hypernuclei provides unique opportunity to study the strange particle-nucleus interaction in a many-body environment
- Astrophysical researches indicate an appearance of hyperons in the dense core of a neutron star

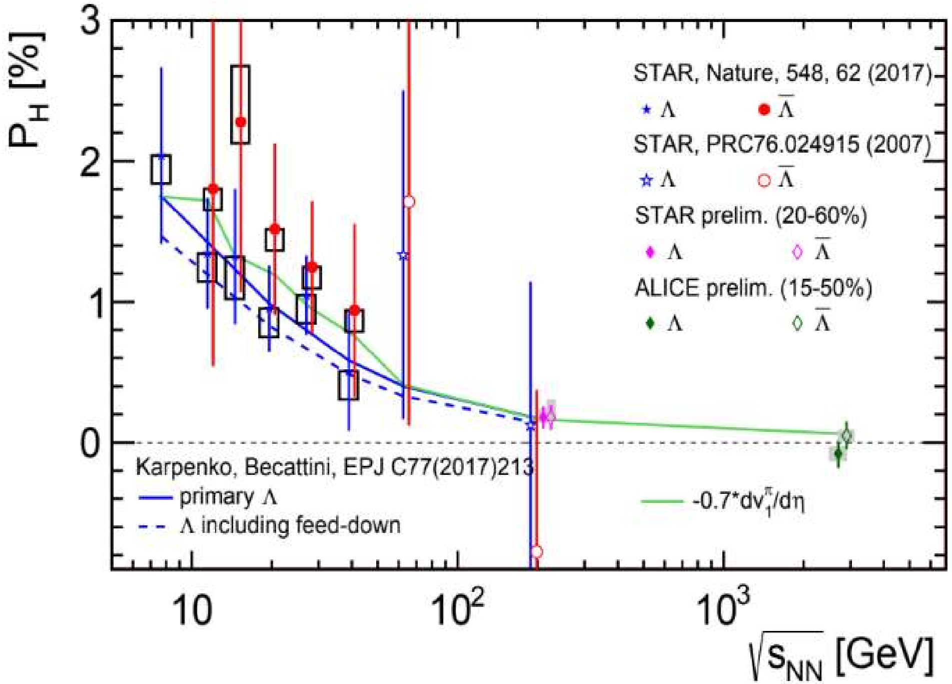
Global polarization

- Global polarization along one preferential direction – the system orbital momentum || magnetic field



- Need to know the direction of the angular momentum → first harmonic event plane



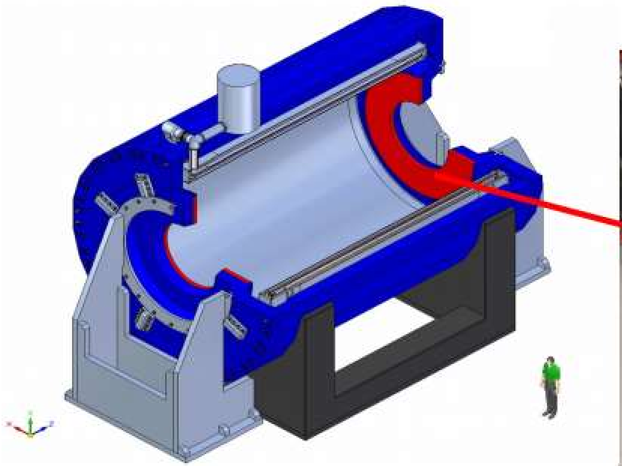


$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_H P_H \cos\theta^*$$

$$\Lambda \to p + \pi^-$$

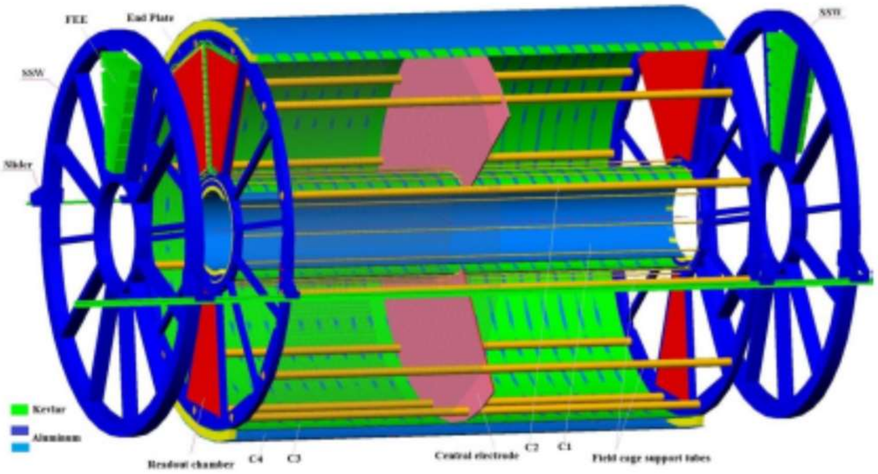
$$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} \approx 0.624$$

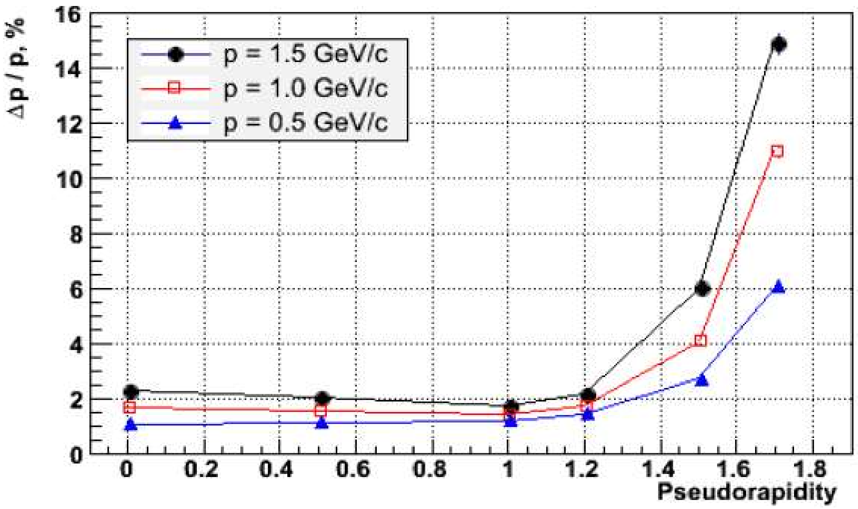
Magnet fabrication: ASG (Genova) & Vitktovice HM



End of 2018 – SC coils are ready
March 2019 – Solenoid is ready
May 2019 – Transportation to Dubna
Oct 2019 – Assembling of Magnet Yoke and Solenoid at JINR
Nov 2019 – Magnetic field measurements

TPC – Time Projection Chamber





Item	Dimension
Length of the TPC	340cm
Outer radius of vessel	140cm
Inner radius of vessel	27 cm
Outer radius of the drift volume	133cm
Inner radius of the drift volume	34cm
Length of the drift volume	170cm (of each half)
HV electrode	Membrane at the center of the TPC
Electric field strength	~140V/cm;
Drift gas	90% Ar+10% Methane, Atmospheric pres. + 2 mbar
Gas amplification factor	~ 10^4
Drift velocity	5.45 cm/µs;
Drift time	< 30µs;
Temperature stability	< 0.5°C
Number of readout chambers	24 (12 per each end-plate)
Segmentation in φ	30°
Pad size	5x12mm^2 and 5x18mm^2
Number of pads	95232
Pad raw numbers	53
Maximal event rate	< 7 kHz (Lum. 10^{27})
Electronics shaping time	~180 ns (FWHM)
Signal-to-noise ratio	30:1
Signal dynamical range	10 bits
Sampling rate	10 MHz
Sampling depth	310 time buckets

TPC – Time Projection Chamber

C1

- Length: 3.4 m
- Diameter: 0.54 m

C2

- Length: 3.4 m
- Diameter: 0.676 m

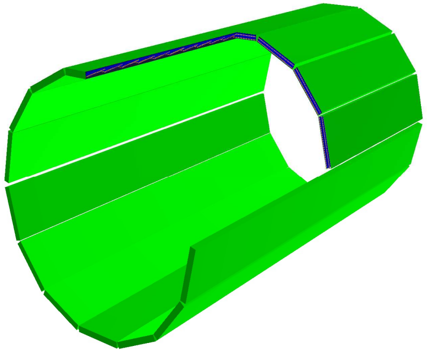
C3

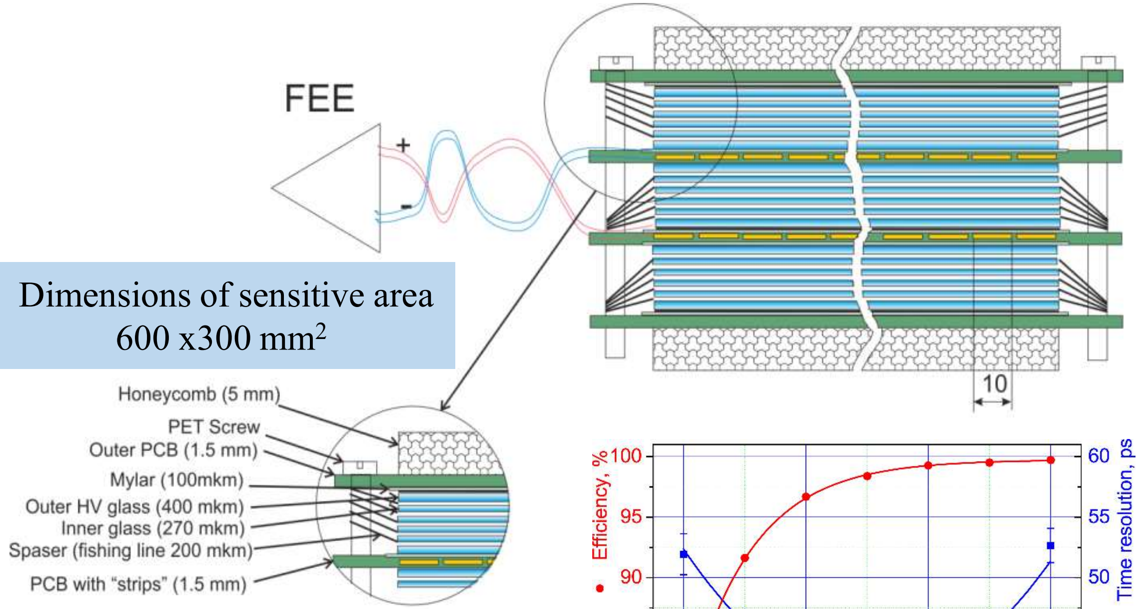
- Length: 3.4 m
- Diameter: 2.66 m

C4

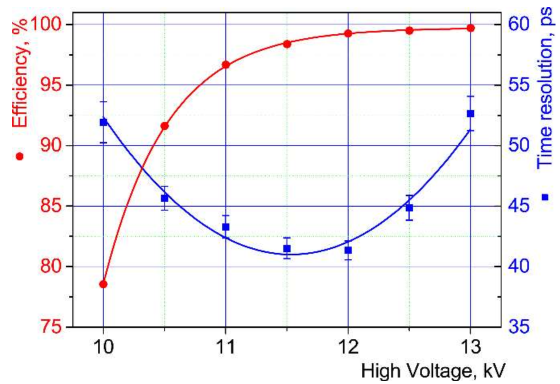
- Length: 3.4 m
- Diameter: 2.814 m

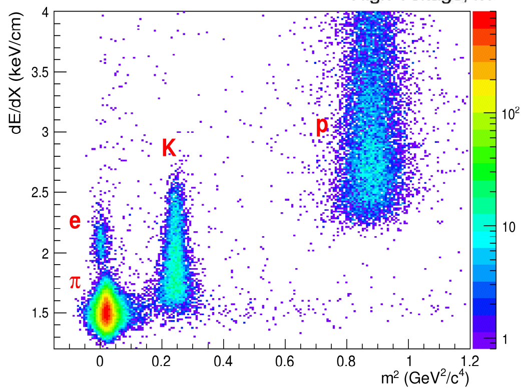
TOF – Time Of Flight





Dimensions of sensitive area
600 x300 mm^2



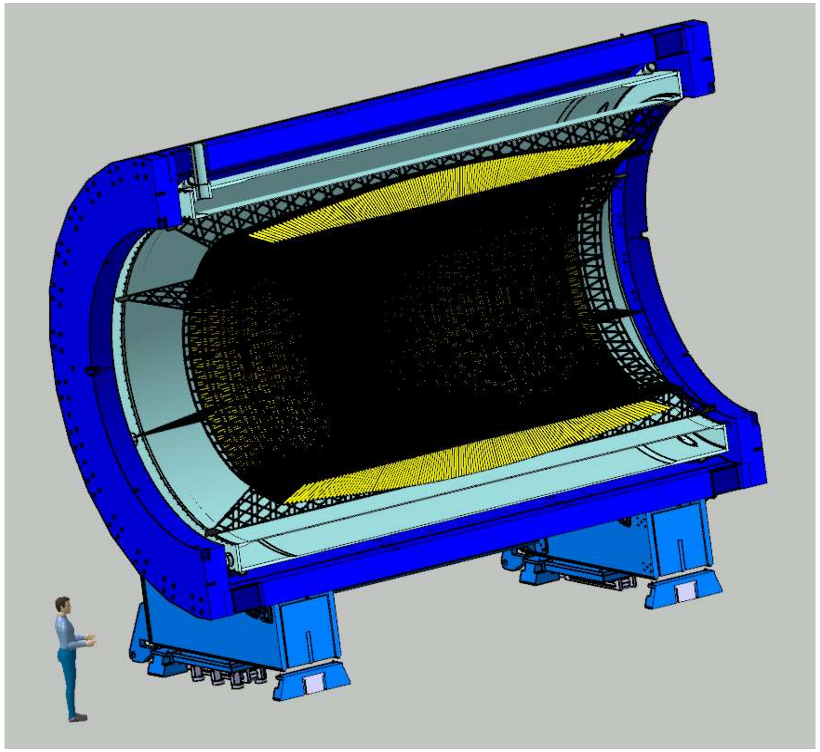


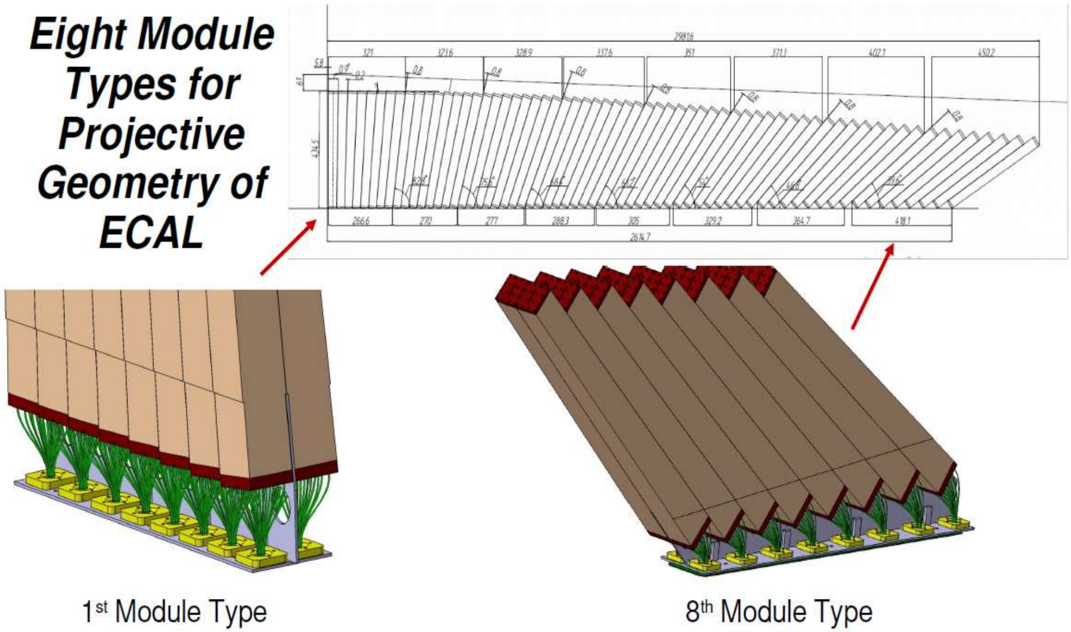
Main parameters of the TOF system.

	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	13440 (1680 chips)

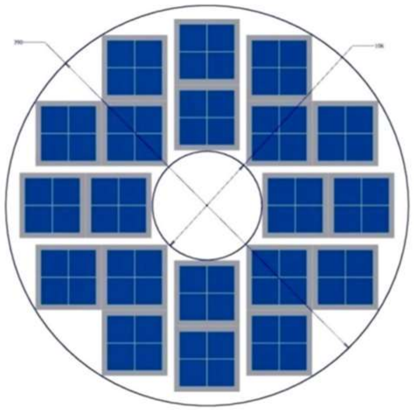
ECAL – Electromagnetic CALorimeter

- Pb+Sc “Shashlyk”, 43,000 towers
- read-out: WLS fibers + MAPD
- L ~ 35 cm (~ 14 X_0)
- Segmentation (4x4 cm2),
- $\sigma(E)$ better than 5% @ 1 GeV;
- time resolution ~500 ps

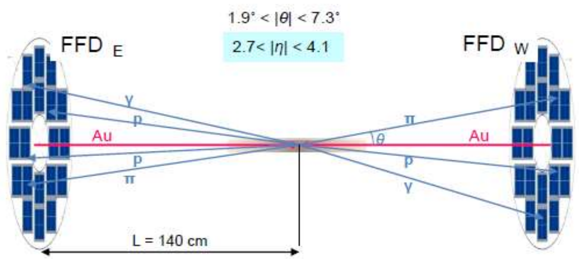




FFT – Fast Forward Detector



The FFD sub-detector consists of 20 modules based on Planacon MCP-PMTs



FFD provides information on
- fast triggering of Au-Au collision
- start signal for TOF
- bunch crossing region position

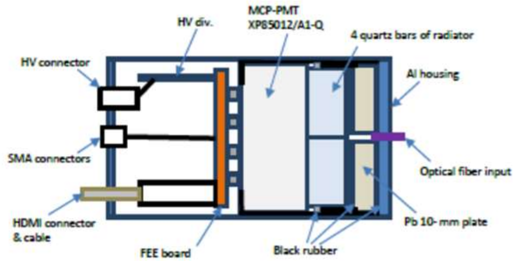
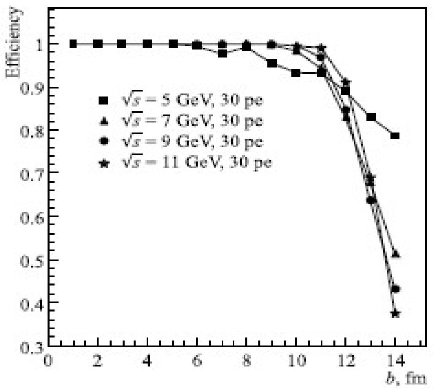
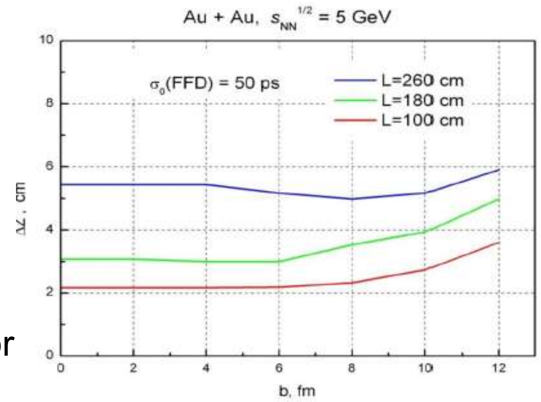


Fig. 4-1. A scheme of the FFD module.

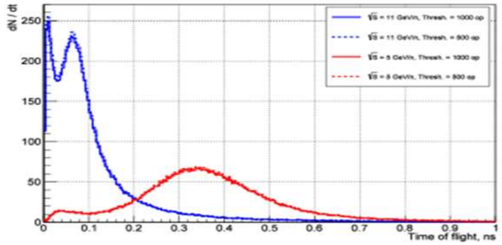
15 mm quartz radiator
10 mm Lead converter



FFD efficiency for peripheral collisions

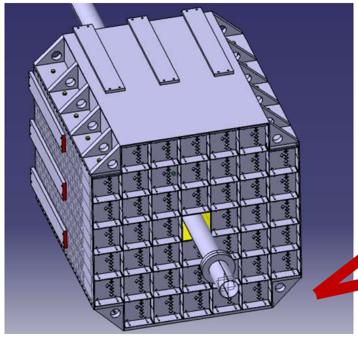


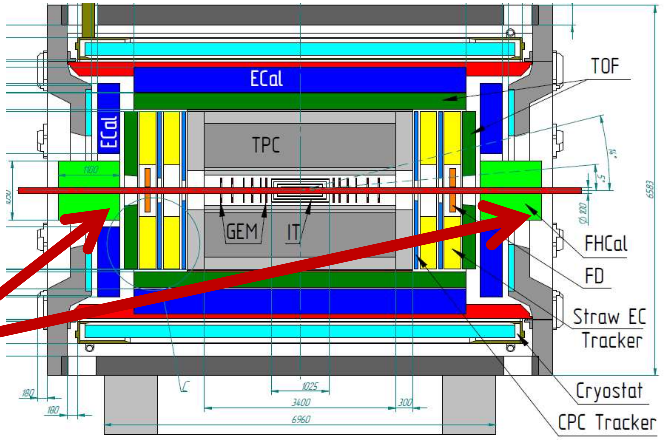
The vertex resolution for Au-Au collisions at √s=5GeV/n for three distances from interaction point



The delay of charged particle arrival in FFD modules in comparison with arrival time of photons for Au + Au collisions at $\sqrt{s_{NN}}$ = 5 (red) and 11 (blue) GeV and FFD position of 140 cm.

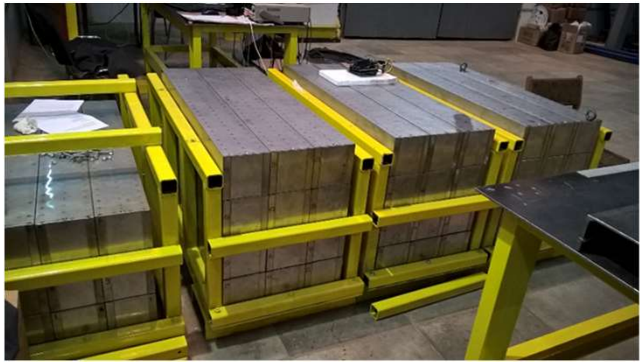
FHCAL – Forward Hadron CALorimeter

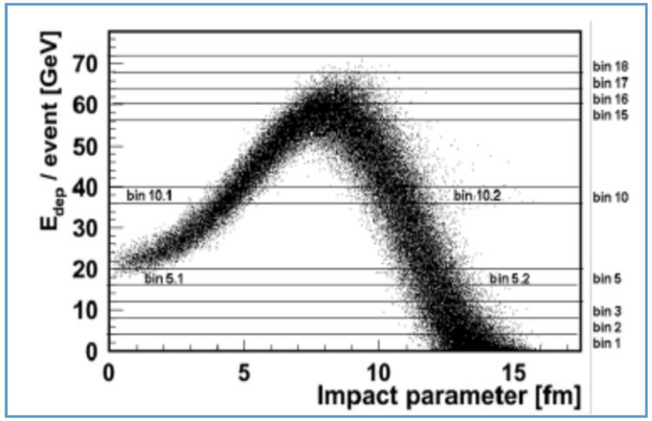


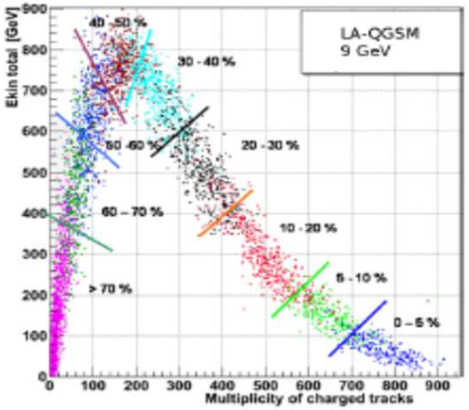


- Two-arms at ~3.2 m from the interaction point
- Each arm consists of 45 individual modules.
- Module size 150x150x1100cm^3 (55 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module
- reaction plane resolution ~ 20-30^0
- centrality resolution ~ 10%

σ(E)/(E) = 56.1%/√E(GeV) +2.1%







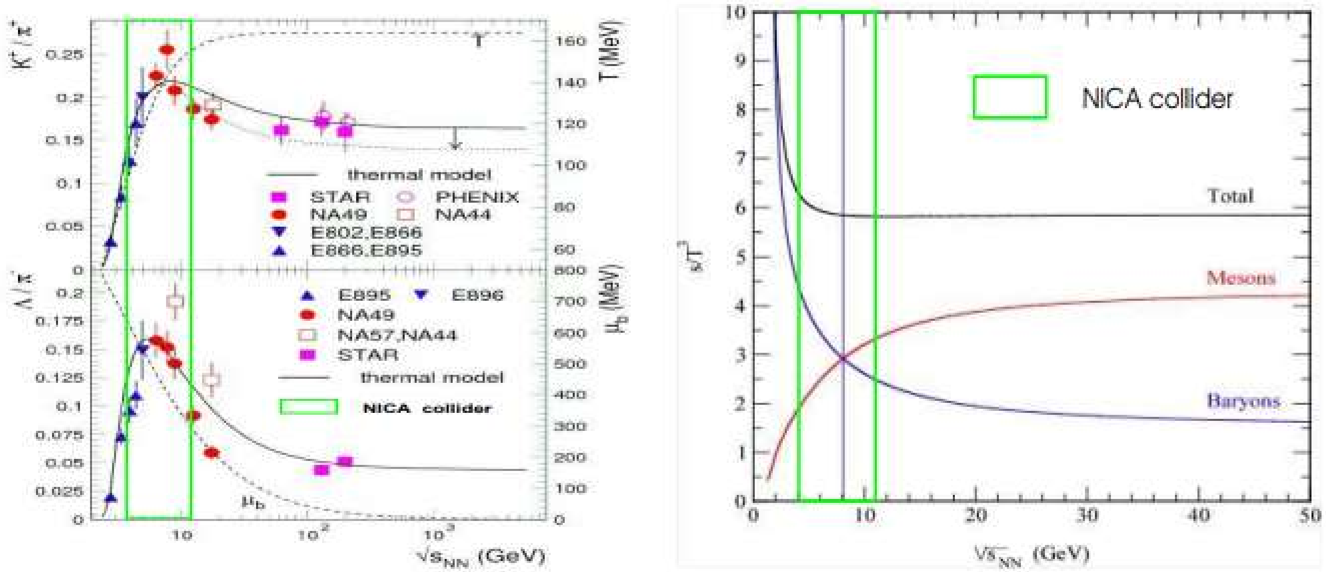


Figure 3.13: Left panel: Energy dependence of hadron yields relative to pions. Right panel: Baryonic and mesonic contributions to the entropy density as a function of the center of mass energy of heavy-ion collisions. When increasing the energy above that where the horn in the K^+/π^+ and Λ/π^+ ratios is observed, $\sqrt{s} \sim 10$ GeV, the system changes its character from baryon- to meson-dominated.

We introduce various moments definitions of the event-by-event multiplicity distributions: Mean, $M = < N >$, Variance, $\sigma^2 = < (\Delta N)^2 >$, Skewness, $S = < (\Delta N)^3 > / \sigma^3$, and Kurtosis, $\kappa = < (\Delta N)^4 > / \sigma^4 - 3$, where $\Delta N = N - < N >$. Skewness and Kurtosis are equal to zero for gaussian distributions. Thus, they are ideal probes to demonstrate the non-Gaussian fluctuations feature near the critical point, in particularly a sign change of the skewness or kurtosis may be a hint of that the system is evolving in the vicinity of the critical point [3, 78]. We have calculated the various moments of net-proton ($\Delta p = N_{\rm p} - N_{\bar{\rm p}}$) distributions from transport models. The kinetic coverage of protons and anti-protons used in our analysis is $0.4 < p_{\rm T} < 0.8$ GeV/c and $|y| < 0.5$. Fig. 3.14 (left panel) shows the number of participant ($N_{\rm part}$) dependence of moment

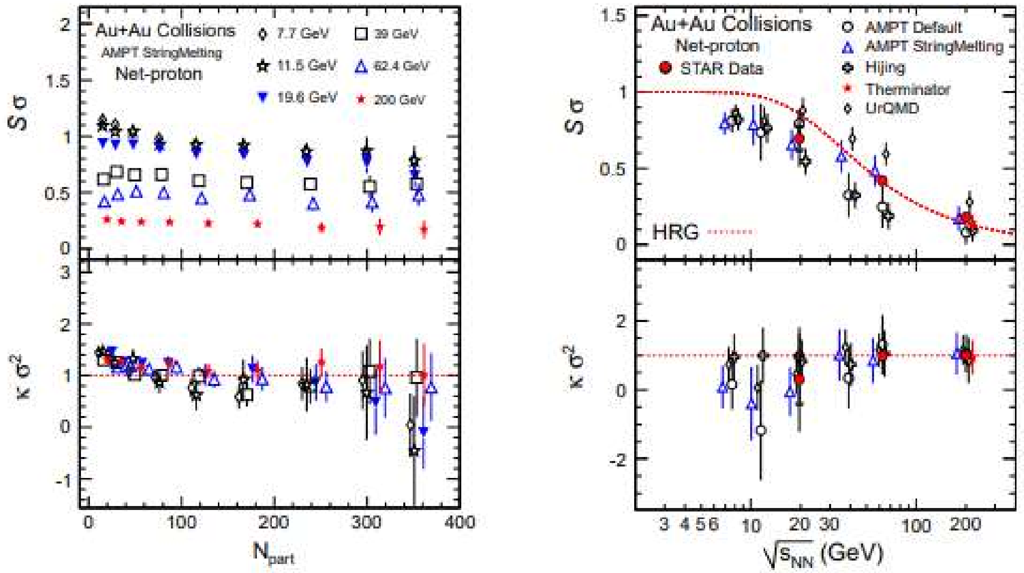


Figure 3.14: **Left panel:** Centrality dependence of moment products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions for Au + Au collisions of various energies from AMPT String Melting model calculation. **Right panel:** Energy dependence of moment products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions for Au + Au collisions of various models and STAR data.

products $S\sigma$, $\kappa\sigma^2$ of net-proton distributions from the AMPT string melting model for various energies. In Fig. 3.14 (right panel), the energy dependence of moment products $S\sigma$, $\kappa\sigma^2$ for most central net-proton distributions from STAR data [79] are compared with the results from various models. We see the data are in good agreement with the HRG model ($\kappa_{\rm B}\sigma_{\rm B}^2 = 1$, $S_B\sigma_{\rm B} = tanh(\mu_{\rm B}/T)$) [80] and the thermal model (Therminator) results. A large deviation from constant as a function of $N_{\rm part}$ and collision energy for $\kappa\sigma^2$ may indicate new physics, such as critical fluctuations [3]. Recent lattice QCD calculations from [81] have shown that $\kappa\sigma^2$ non-monotonically depends on colliding energy in the neighbourhood of the critical point.