Alikhanov Institute for Theoretical and Experimental Physics
Russian Federation State scientific center

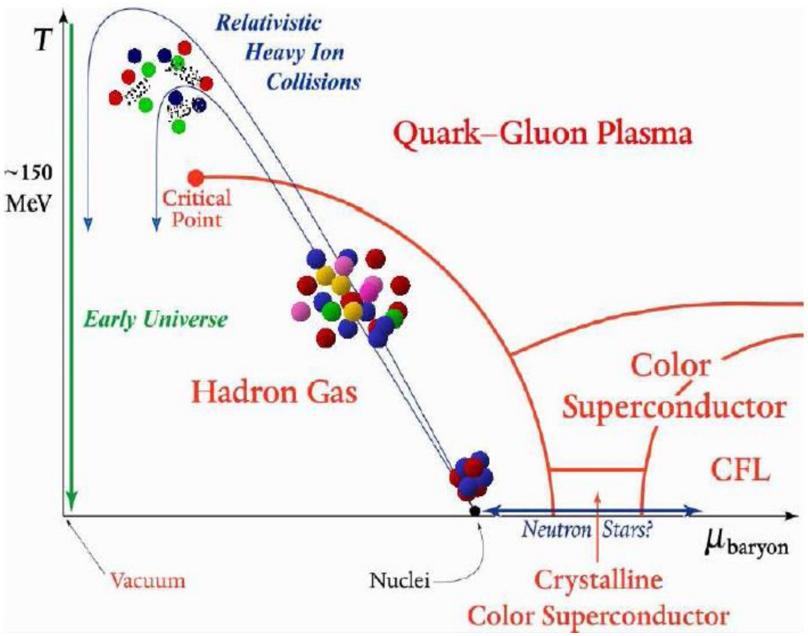
# Dense cold matter with special trigger at TWA, Nuclotron, NICA, and FAIR

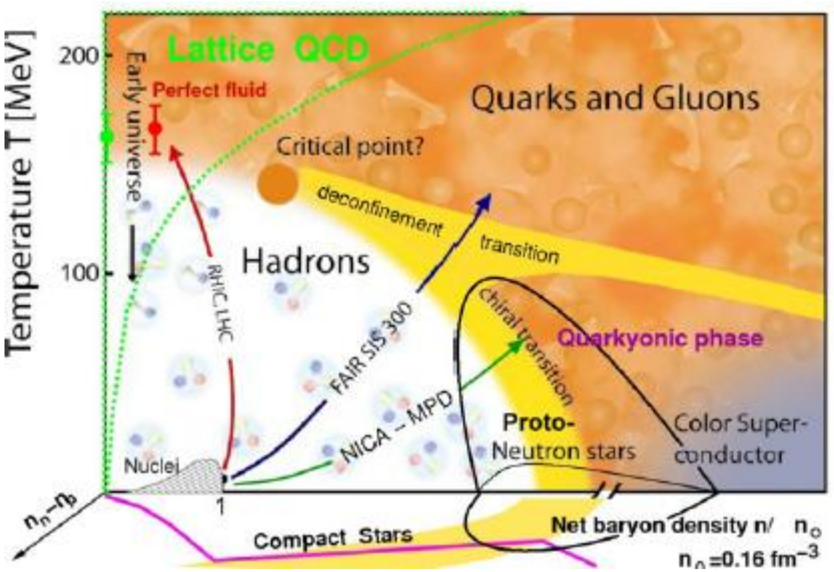
**A.Stavinsky**

**for FLINT collaboration @ IBS-XX**

**Dubna, 8 october 2010**

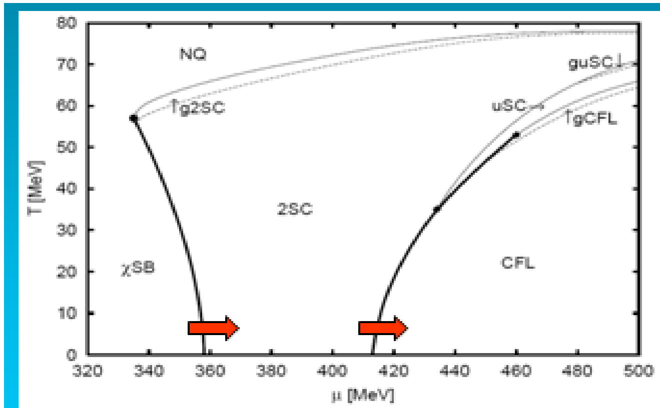
# Phase diagram of nuclear matter

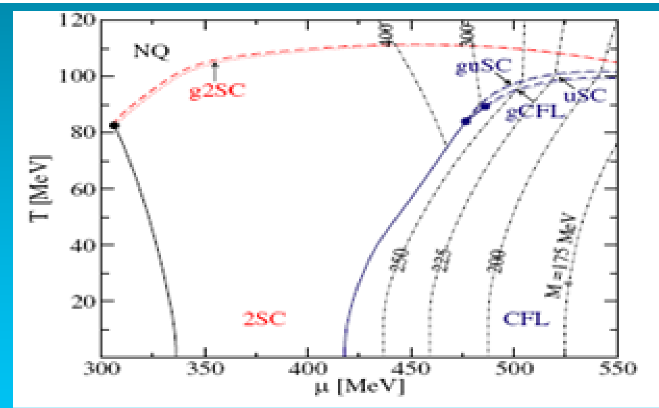



*ρ/ρ$_0$»1, T/T$_0$«1(DenseColdMatter): rich structure of the QCD phase diagram - new phenomena are expected!

**Diagram study not finished-additional new phenomena can be found



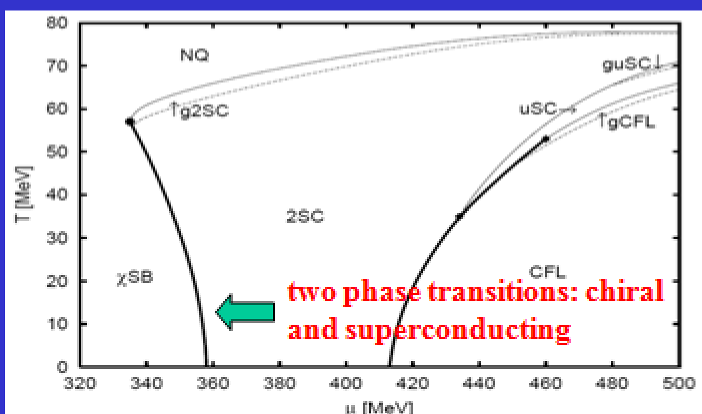

Rüster et al Phys.Rev.D 2005

Blaschke et al Phys.Rev.D 2005

Two first order phase transitions:

Hadronic matter → 2SC → CFL

Ref.: Pagliara



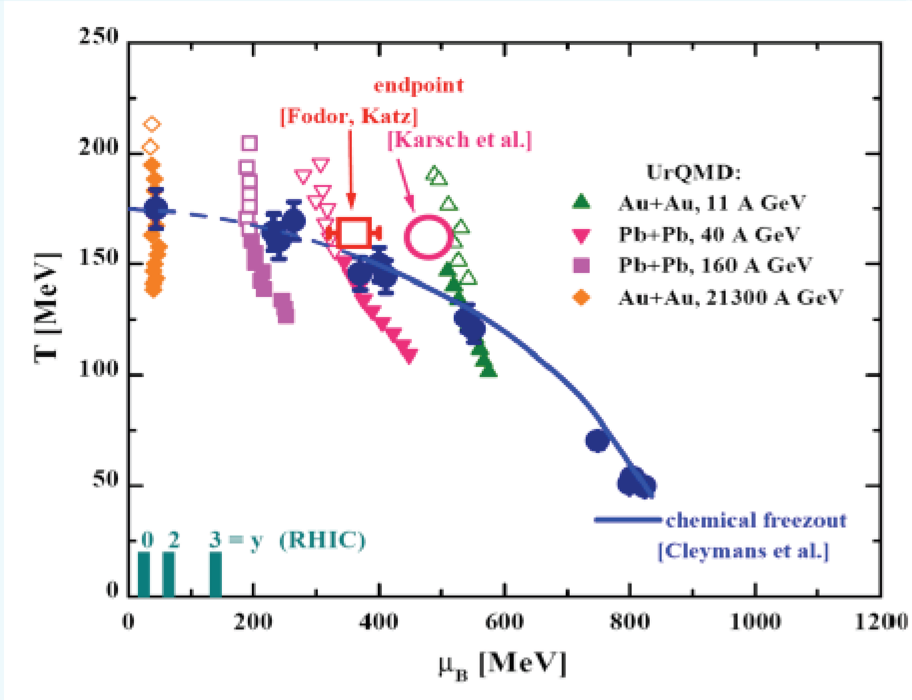

**assumption that "deconfinement" and chiral symmetry restoration coincide (see also Bender et al. Phys.Lett.B 1998)**

Is the diquark condensate a good order parameter for deconfinement at finite density ??

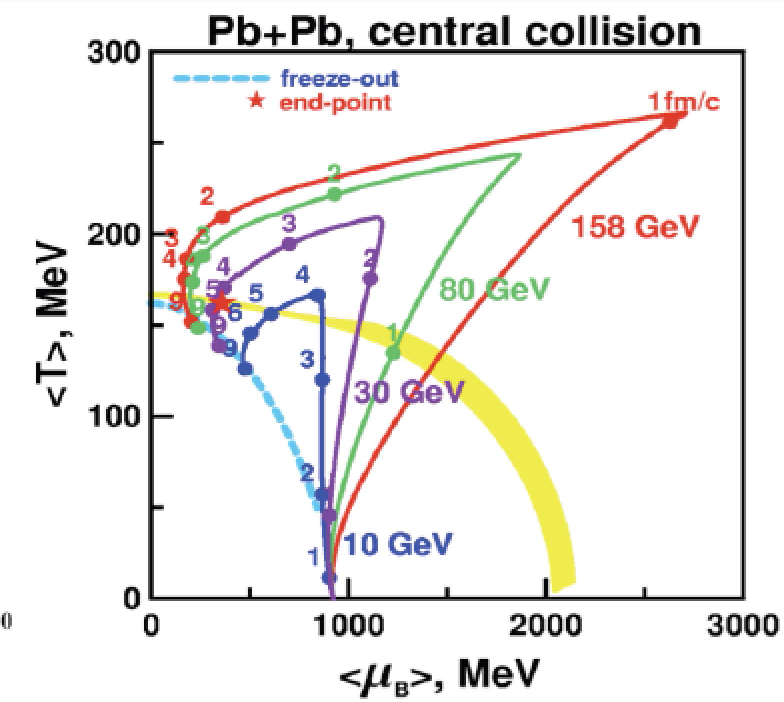
(see also Bentz et al Nucl.Phys.A 2002)

*Correlations between signatures could be a signal of the two phase transitions as the density increases and the temperature decreases

L.V. Bravina et al., Phys. Rev. C60 (1999) 044905




Y. Ivanov, V. Russkikh, V. Toneev, Phys. Rev. C73 (2006) 044904



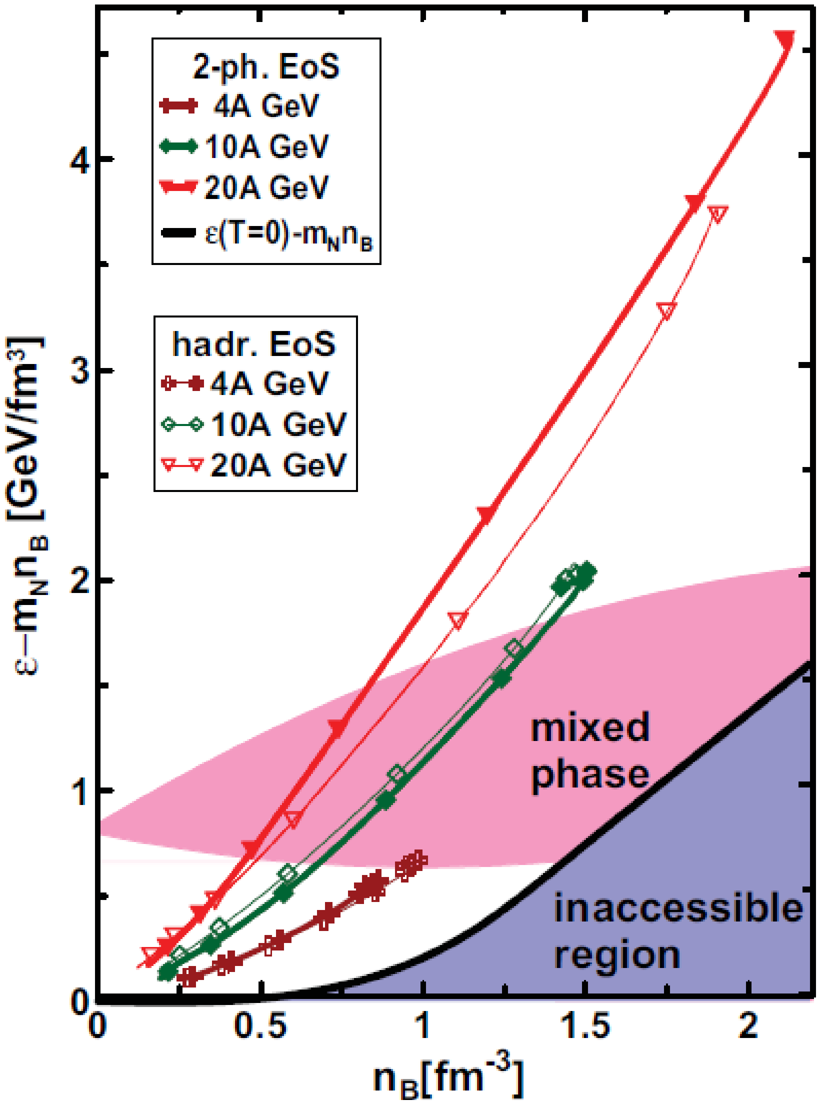

Nuclear collisions from 10 to 40 AGeV are the tools to look for the onset of deconfinement (and the critical point?)

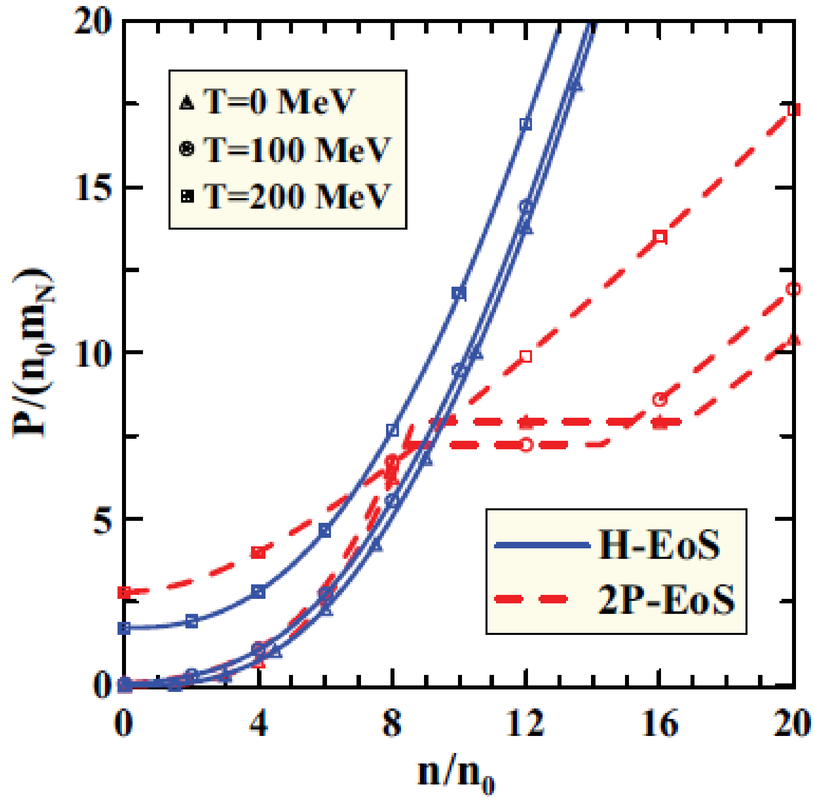


***Region $\rho/\rho_0 \gg 1$, $T/T_0 \ll 1$ (DenseColdMatter) hardly accessible experimentally by standard way

# Equation-of-state with and without phase transition

Y. Ivanov, CPOD2010

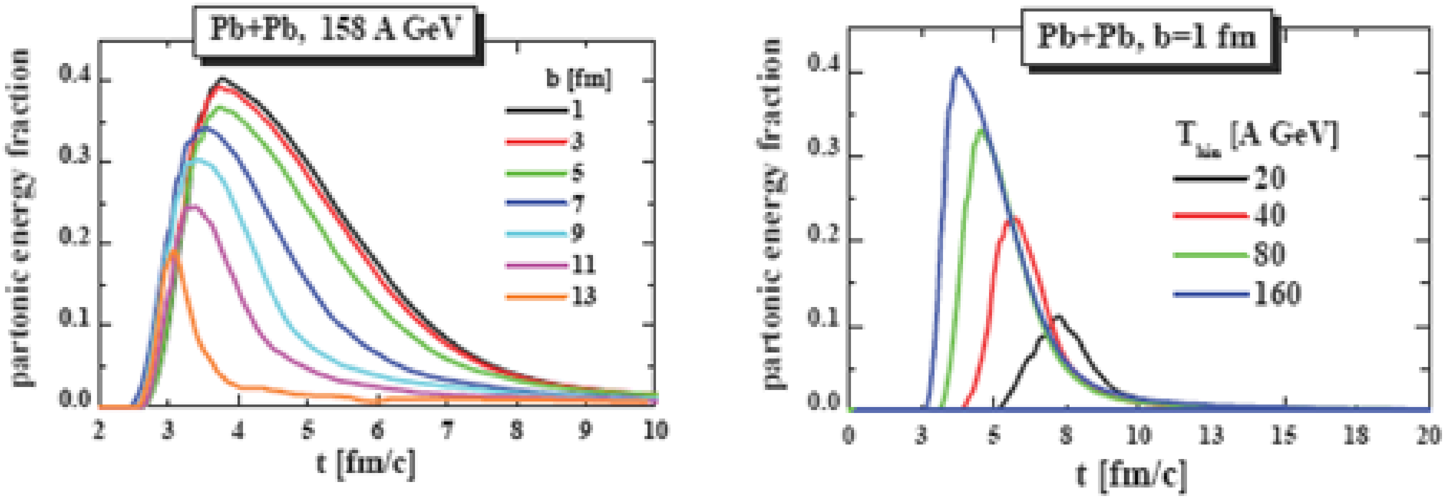


# Cassing – Bratkovskaya: Parton-Hadron-String-Dynamics

## Perspectives at FAIR/NICA energies

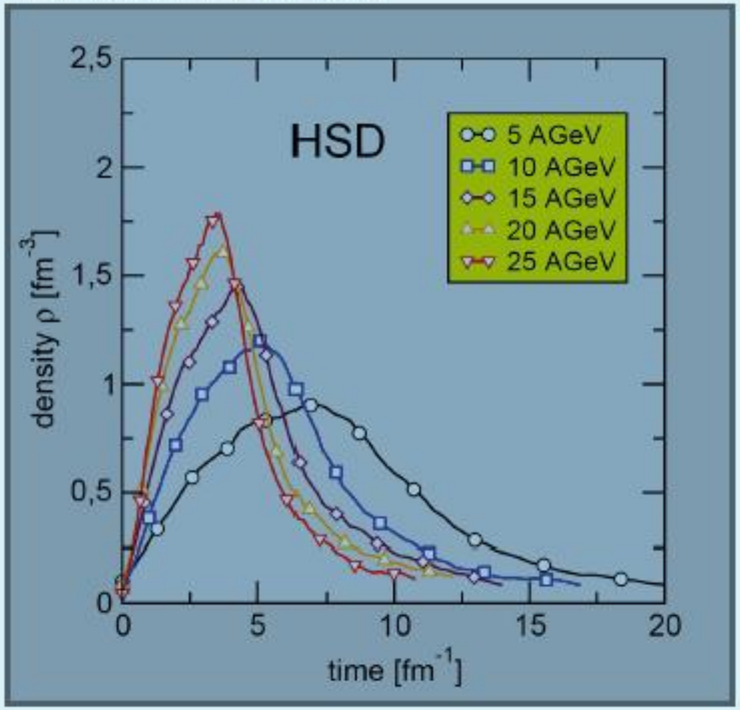
### partonic energy fraction vs centrality and energy



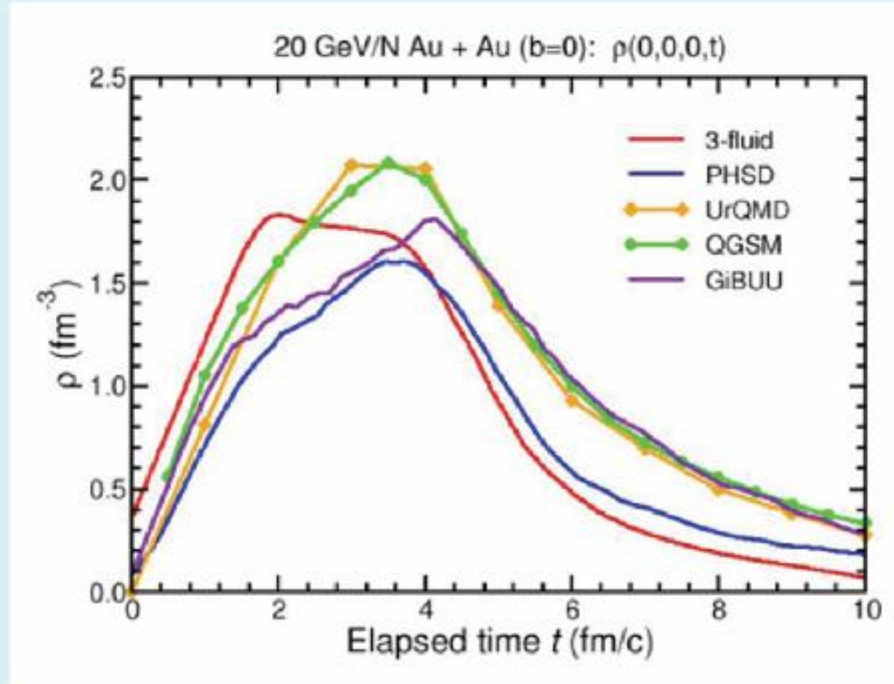

→Dramatic decrease of partonic phase with decreasing energy and centrality !

****New phase expected to be a small effect – trigger (selection criteria)

E. Bratkovskaya, W. Cassing




from CBM Physics Book




Transport models predict high densities for moderate collisions energies

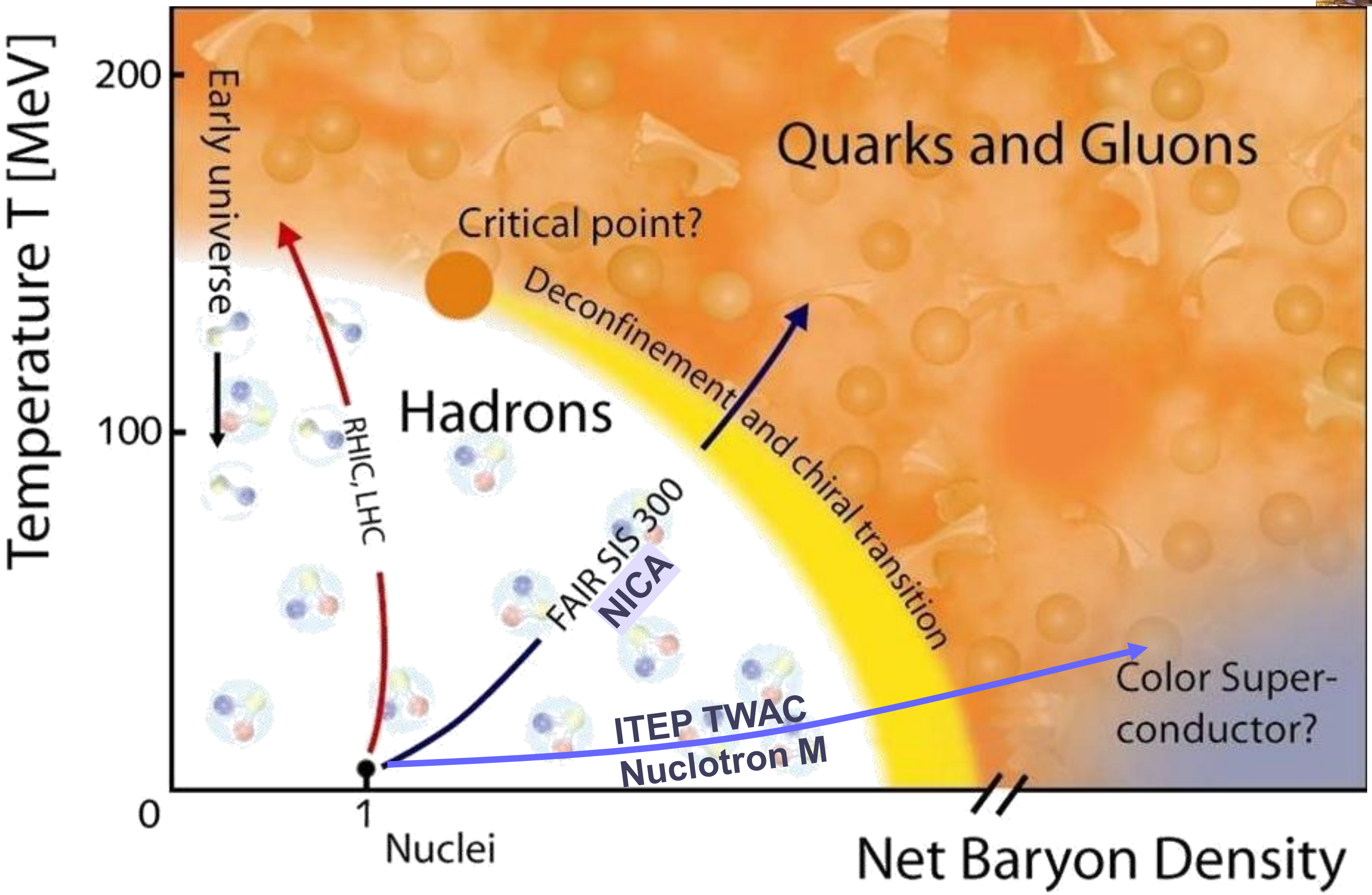
Different models agree qualitatively

CPOD 2010, Dubna, 27 August 2010 3 Volker Friese

*****New phase hardly to be expected as long lived one even for Au+Au collisions

# Possible solution for the study of the region $\rho/\rho_0 \gg 1$, $T/T_0 \ll 1$ (DenseColdMatter) :

## high $p_t$ flucton-flucton interaction




Main idea: to select events with dense matter droplet in the final state with rare cumulative trigger

# Cumulative effect

1966 G.A. Leksin: pC →p(137°)X @ 1.0, 6.0 GeV

no peaks from pd-, pt-,pHe-… reactions in inclusive spectra.

the protons spectra beyond *NN* kinematical limits

1970 A.M. Baldin, V.S.Stavinskiy :

a) Particle production in AA → superposition of N+N, N+2N, 2N+N…

b) iN+jN subprocess follow the scaling (the same x-dependence as for N+N int.)

1) X>>1

2) $b_{ik}$>>1

3) r~$r_h$

A lot of data have been accumulated at JINR , see for example
A.M.Baldin et. al.,Sov.J.Part.Nucl.,8(1977)175;
JINR comm.E1-8054,Nucl.Phys.A434(1985)695.
V.S.Stavinsky, Sov.J.Part.Nucl.,10(1979)949;

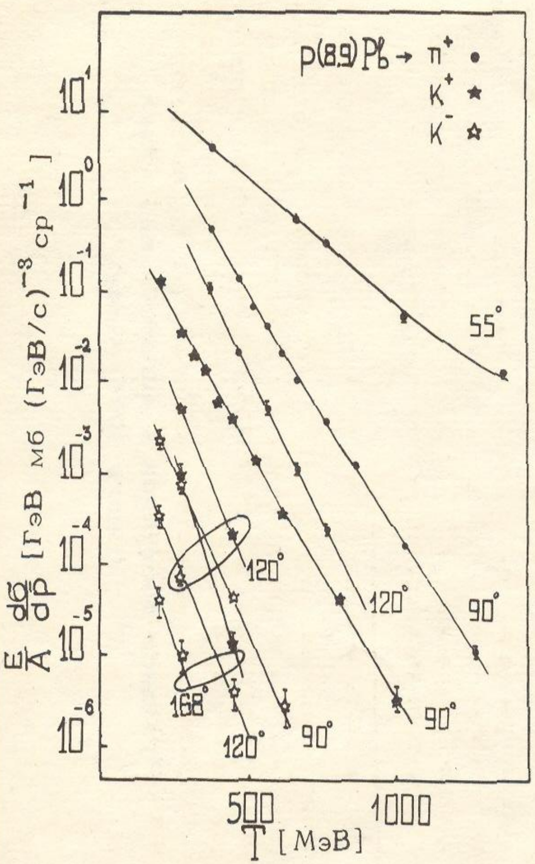



Рис.1. Инклюзивные сечения рождения положительных и отрицательных каонов и (для сравнения) положительных пионов. Линии соединяют экспериментальные точки.

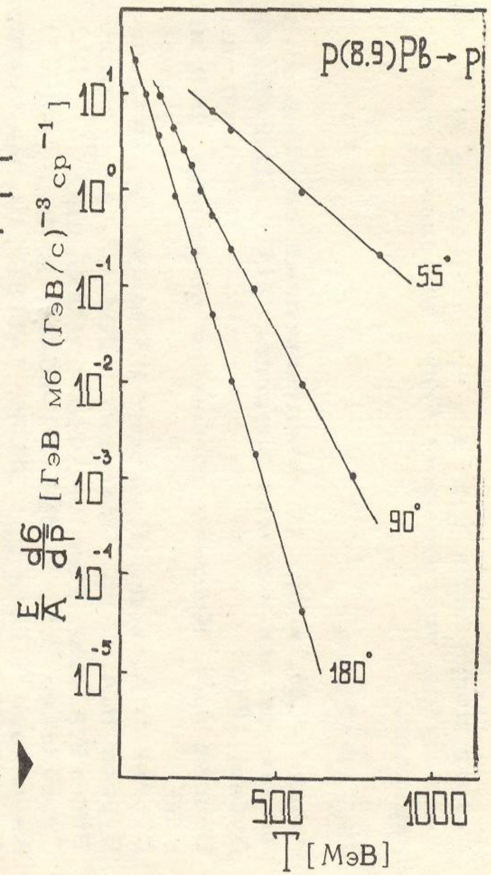
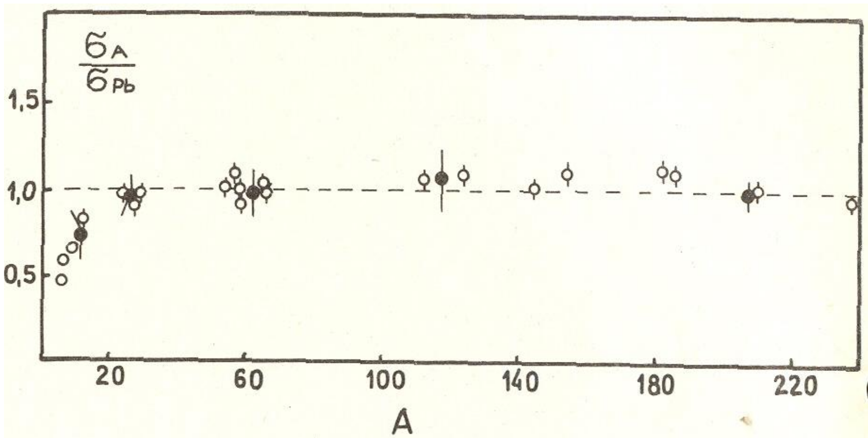
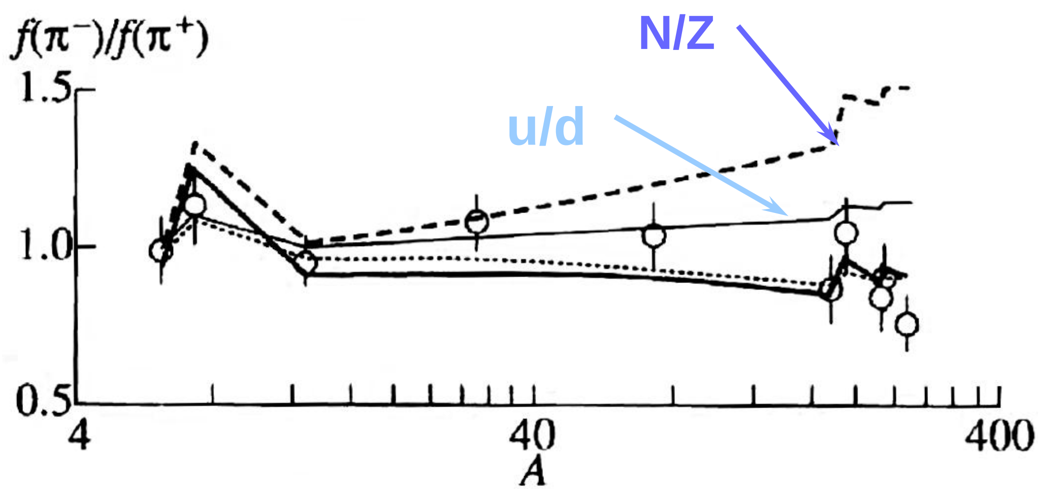



Рис.2. Инклюзивные сечения рождения протонов. Линии соединяют экспериментальные точки.



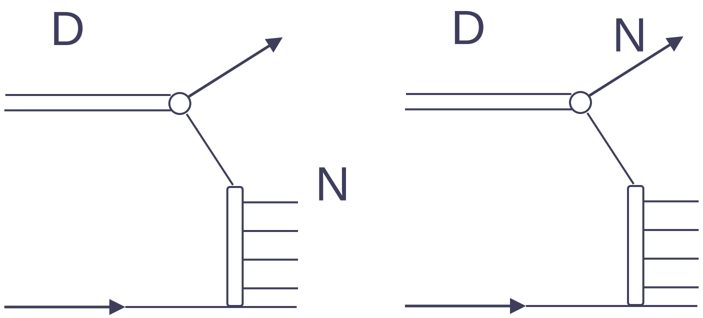

Some important JINR results:

- A-dependence
- Isotopic effect
- Spin effects

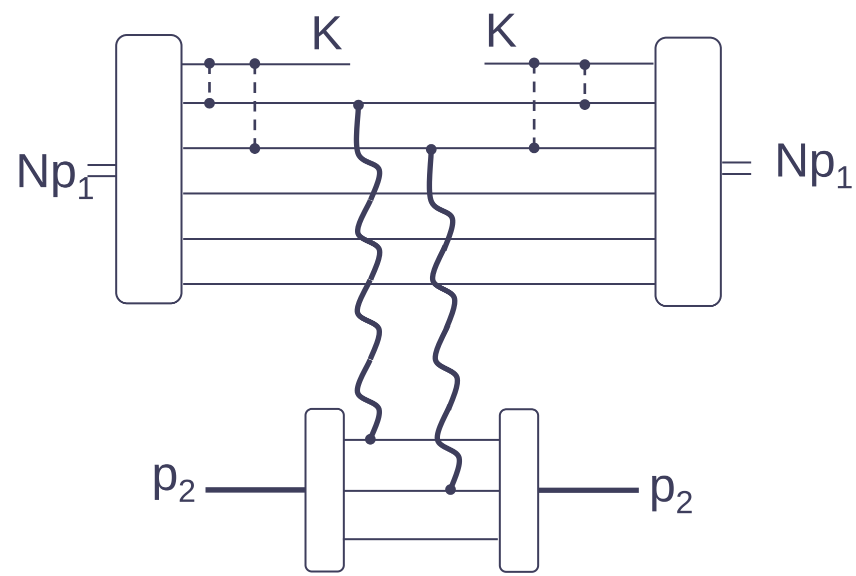



For isotopic effects see, also Yad.Fiz. 59 4 694 (1996)

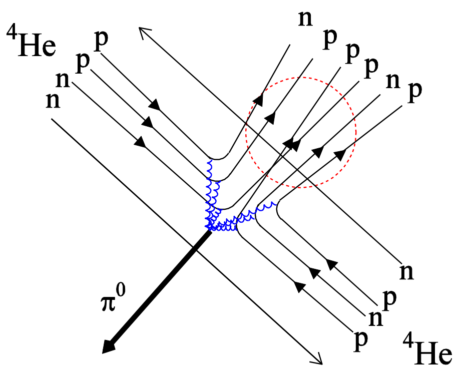
# Cumulative particle production

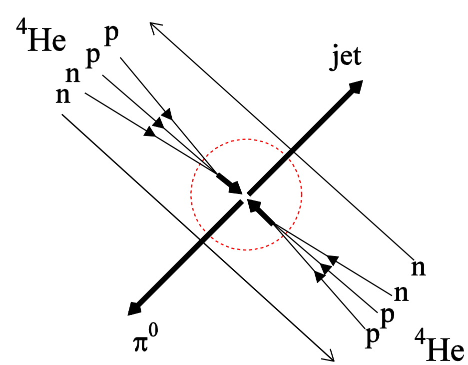


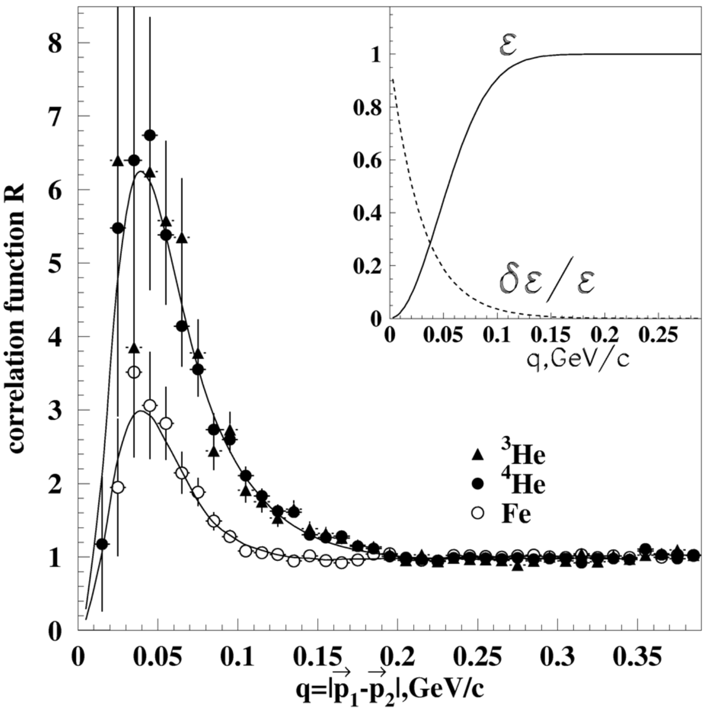

L. Frankfurt and Strikman
Phys. Let. 76B,3 (1978)




M. Braun and V. Vechernin,
Nucl. Phys. B **427**, 614 (1994)



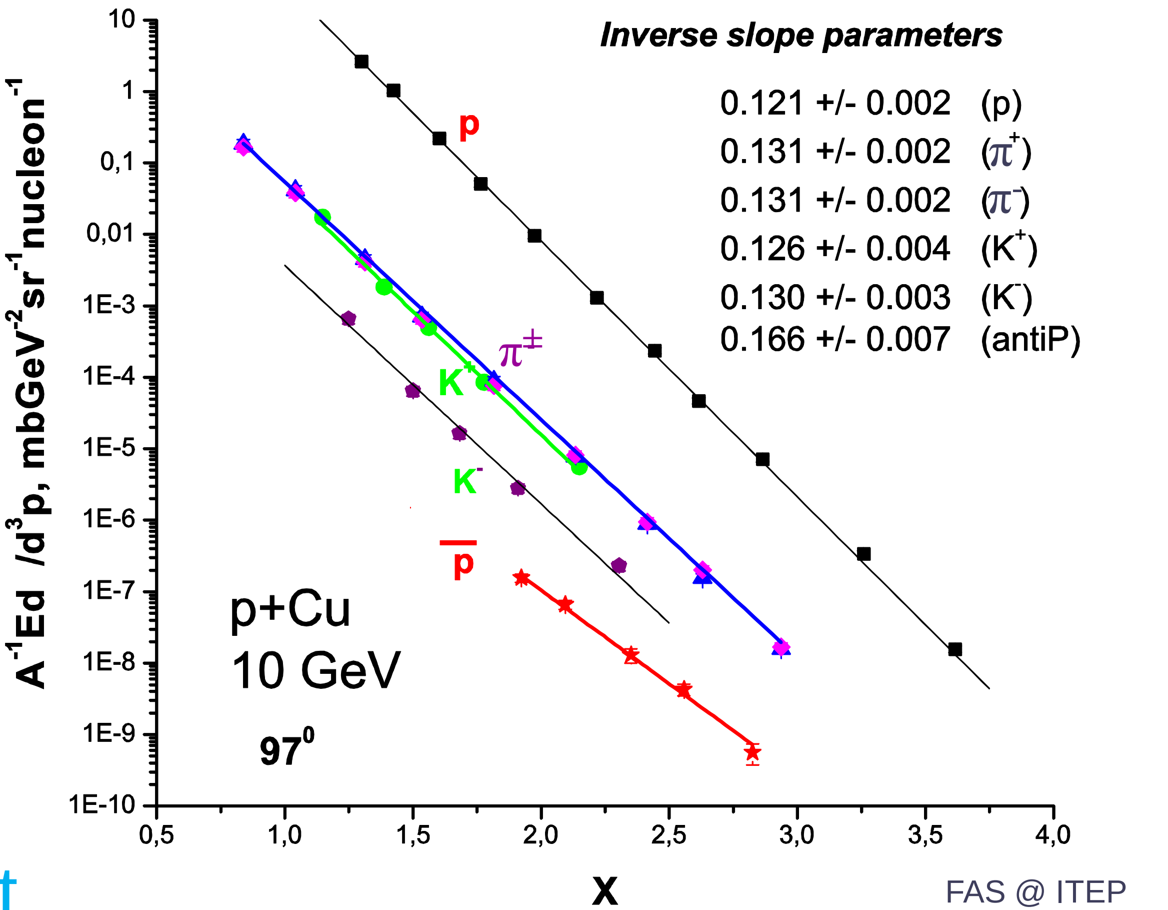






$r_f$~1-1.5fm

A.S.et al., Phys.Rev.Lett. 93,192301 (2004)

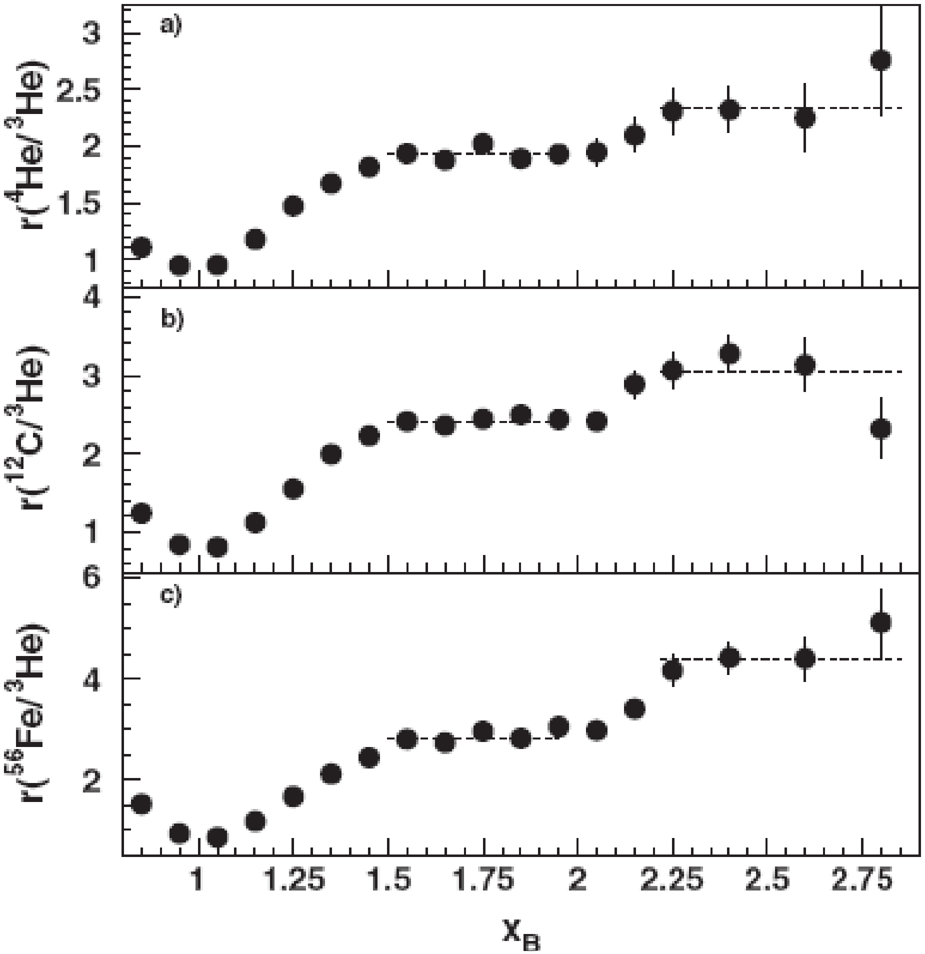
- Multinucleon effect
- Locality




X – minimal target mass [ $m_N$ ]
needed to produce particle

FAS @ ITEP
(Boyarinov et.al
Yad.Fiz 57
(1994) 1452)

# CLAS $e^-A \rightarrow e^-X$ @~4 AGeV




K.S. Egiyan et al. Phys. Rev. Lett. 96, 082501 (2006)

•No rescattering

| | $a_{2N}$, % | $a_{3N}$, % | $(a_{2N})^2$, % |
|---|---|---|---|
| $^3He$ | 8.0±1.6 | 0.18±0.06 | 0.64 |
| $^4He$ | 15.4±3.3 | 0.42±0.14 | 2.4 |
| $^{12}C$ | 19.3±4.1 | 0.55±0.17 | 3.7 |

dramatic decreasing of the cross sections with N-max N~4

$\boldsymbol{x}_B = Q^2/2m_N \boldsymbol{U}$

aA(flucton) $N_{max}$ ~ 4

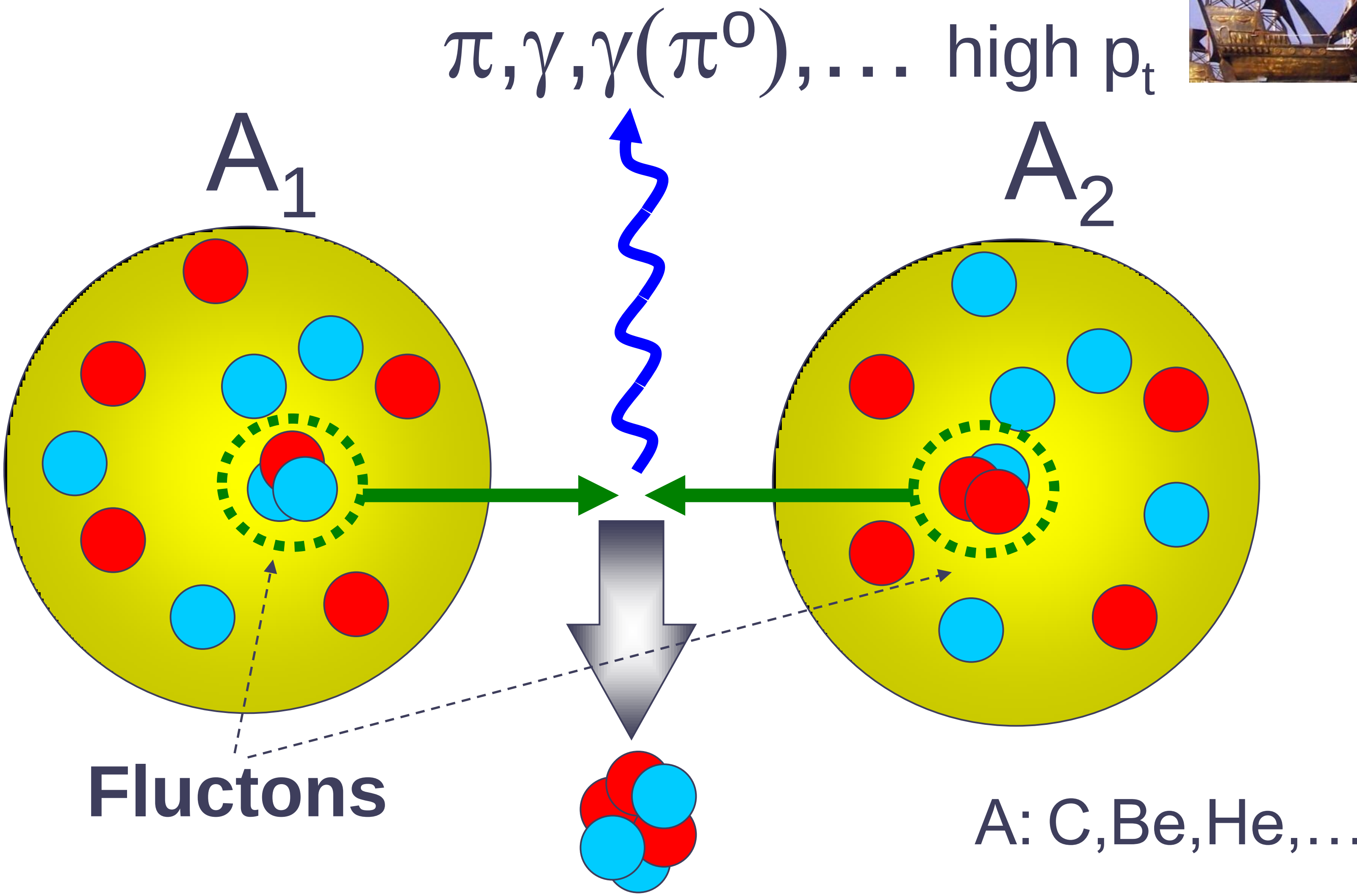
Possible solutions :

~~Fragments~~

~~Lower initial  energy~~

not only formally large cumulative number, but also $b_{ik}$»1(A.M.Baldin)

AA(flucton+flucton): $N_{max}$~7-8




**Dense baryon system**

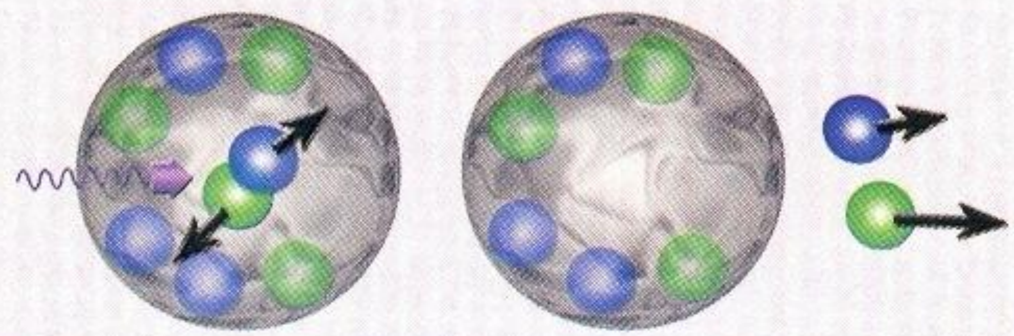


Fig. 1. Scattering of a virtual photon off a two-nucleon correlation, $x > 1.5$, before (left) and after (right) absorption of the photon.

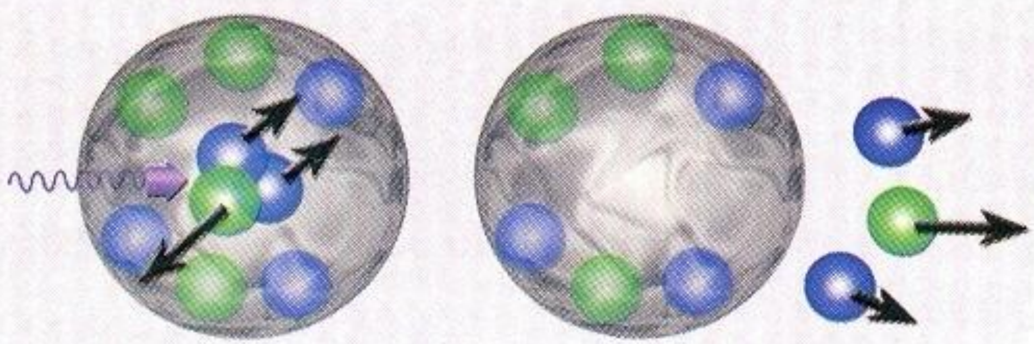
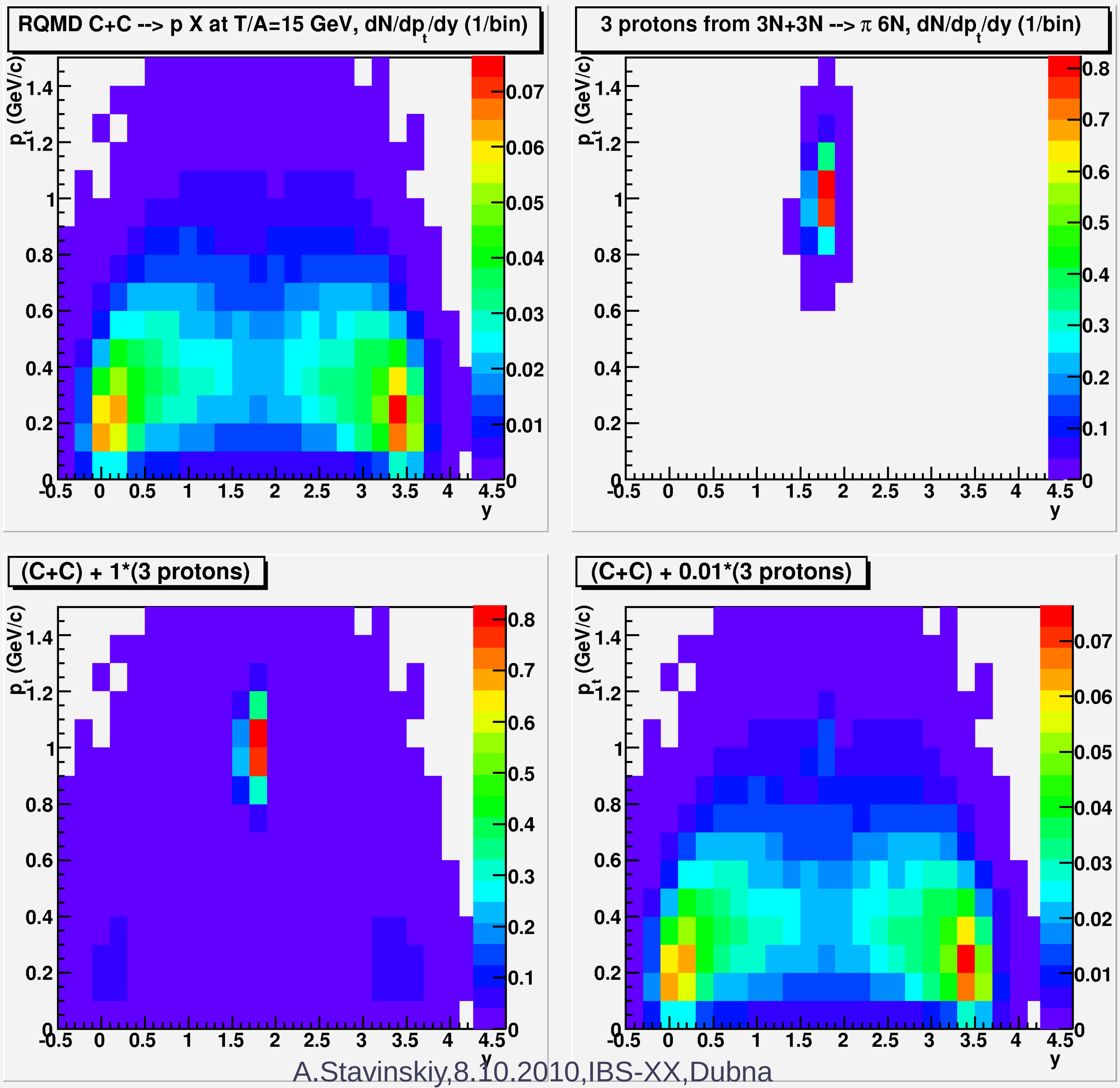


Fig. 2. Scattering of a virtual photon off a three-nucleon correlation, $x > 2$, before (left) and after (right) absorption of the photon.

Fig.ref.:CERN Courier



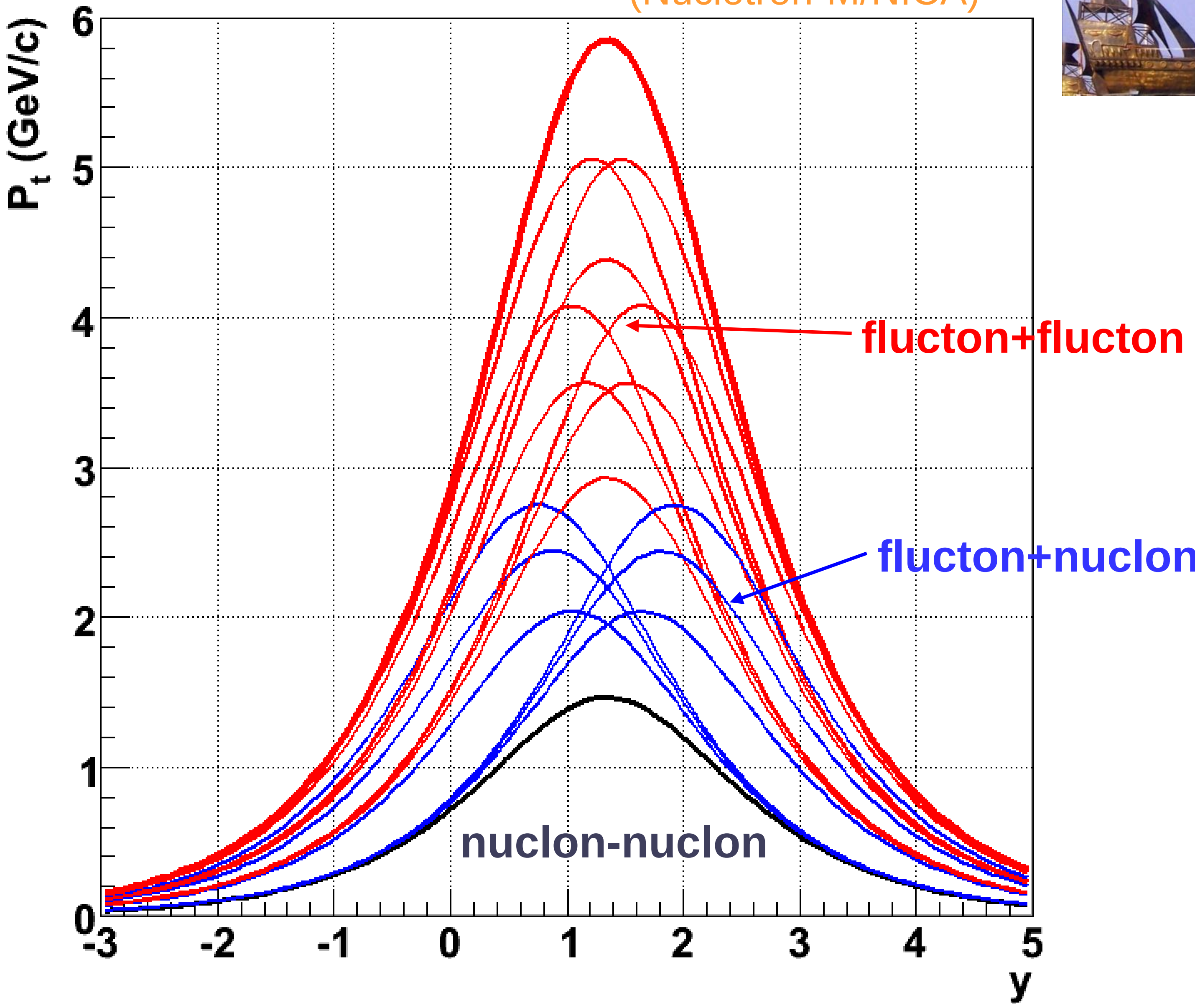
RQMD C+C --> p X at T/A=15 GeV, dN/dp_t/dy (1/bin)
3 protons from 3N+3N --> π 6N, dN/dp_t/dy (1/bin)
(C+C) + 1*(3 protons)
(C+C) + 0.01*(3 protons)
p_t (GeV/c)
y

# Criterium: r»l

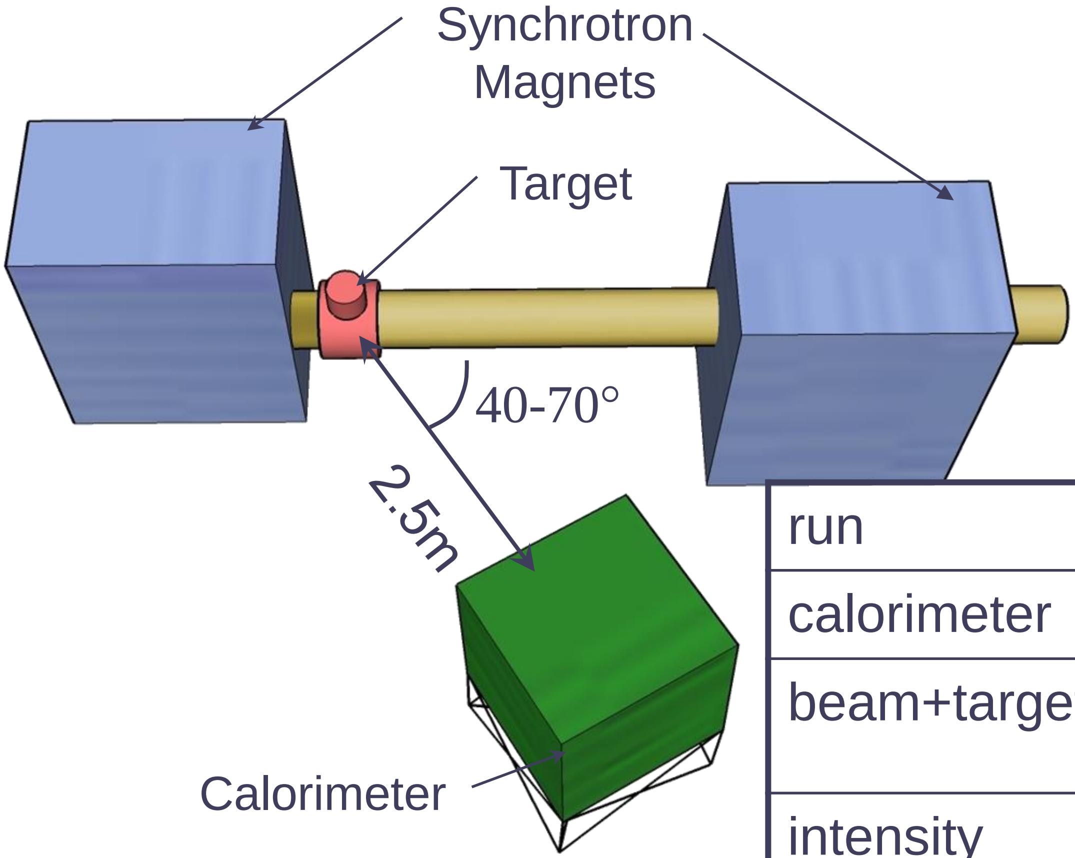
| | number of particles | Size(r), fm | free path, (l)fm |
|---|---|---|---|
| Heavy Ions: | 1000 | 10 | 1 |
| flucton-flucton | 10 | 1 | 0.1 |

# He+He @ 6 AGeV

(Nuclotron-M/NICA)

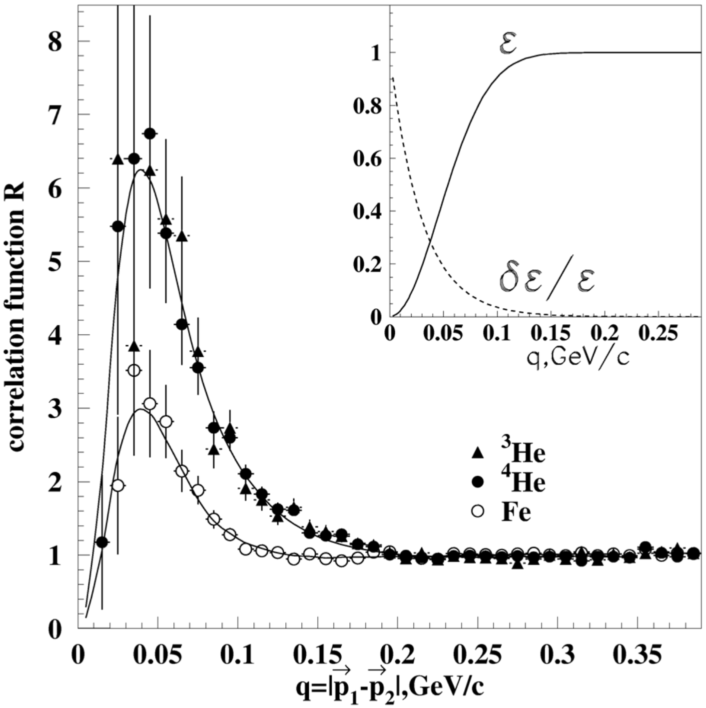



# FLINT@ITEP: $^{12}C + Be \rightarrow \gamma + X$



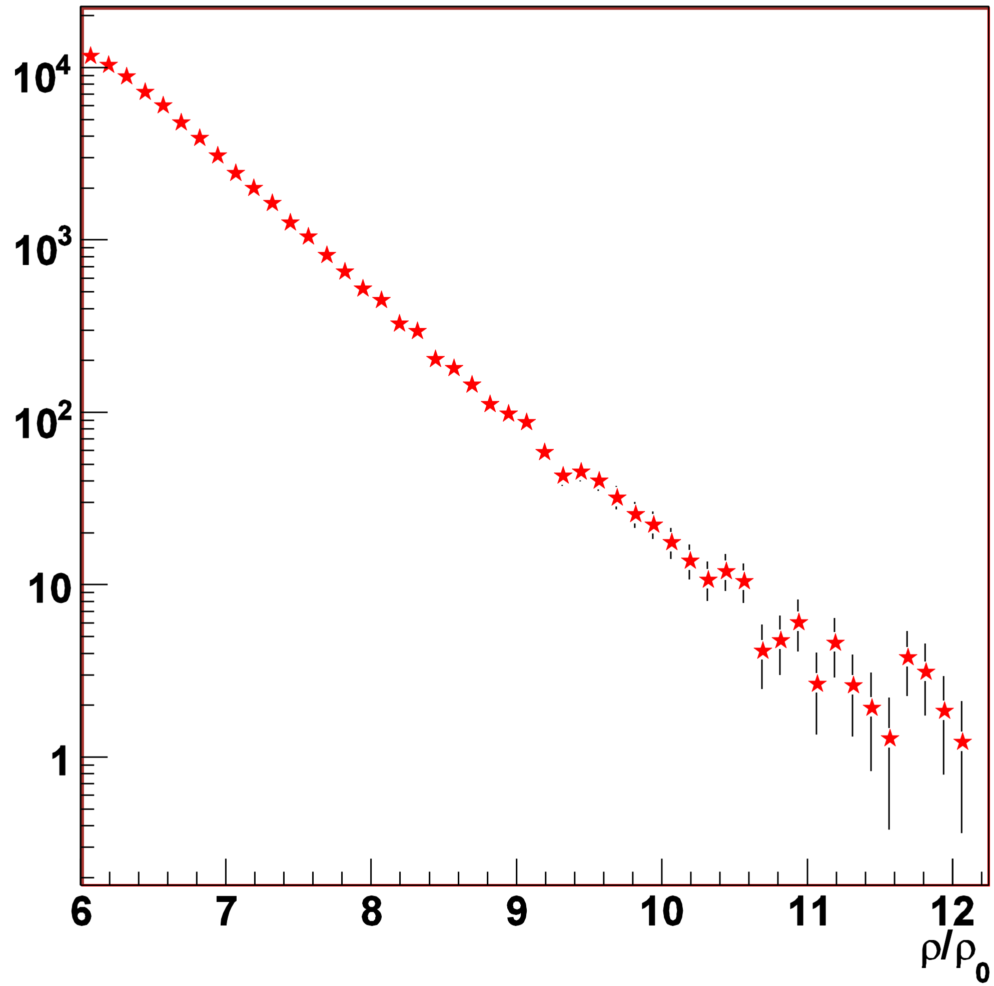

| run | 2007 | 2010 |
|---|---|---|
| calorimeter | ~50 modules | ~125 modules |
| beam+target | Be+C $E_K$=3.2 AGeV | Be+C 2,0, 3.2, 4.0 AGeV |
| intensity | ~$10^7$N/spill | ~$2*10^8$N/spill |
| trigger | E>1GeV in any glass block | Different triggers |
| exposition | 1day | 20days |
| Data | ~750K events | ~10M events |

# An estimate of baryon density




$r_f$~1-1.5fm

A.Stavinsky.et al., Phys.Rev.Lett. 93,192301 (2004)



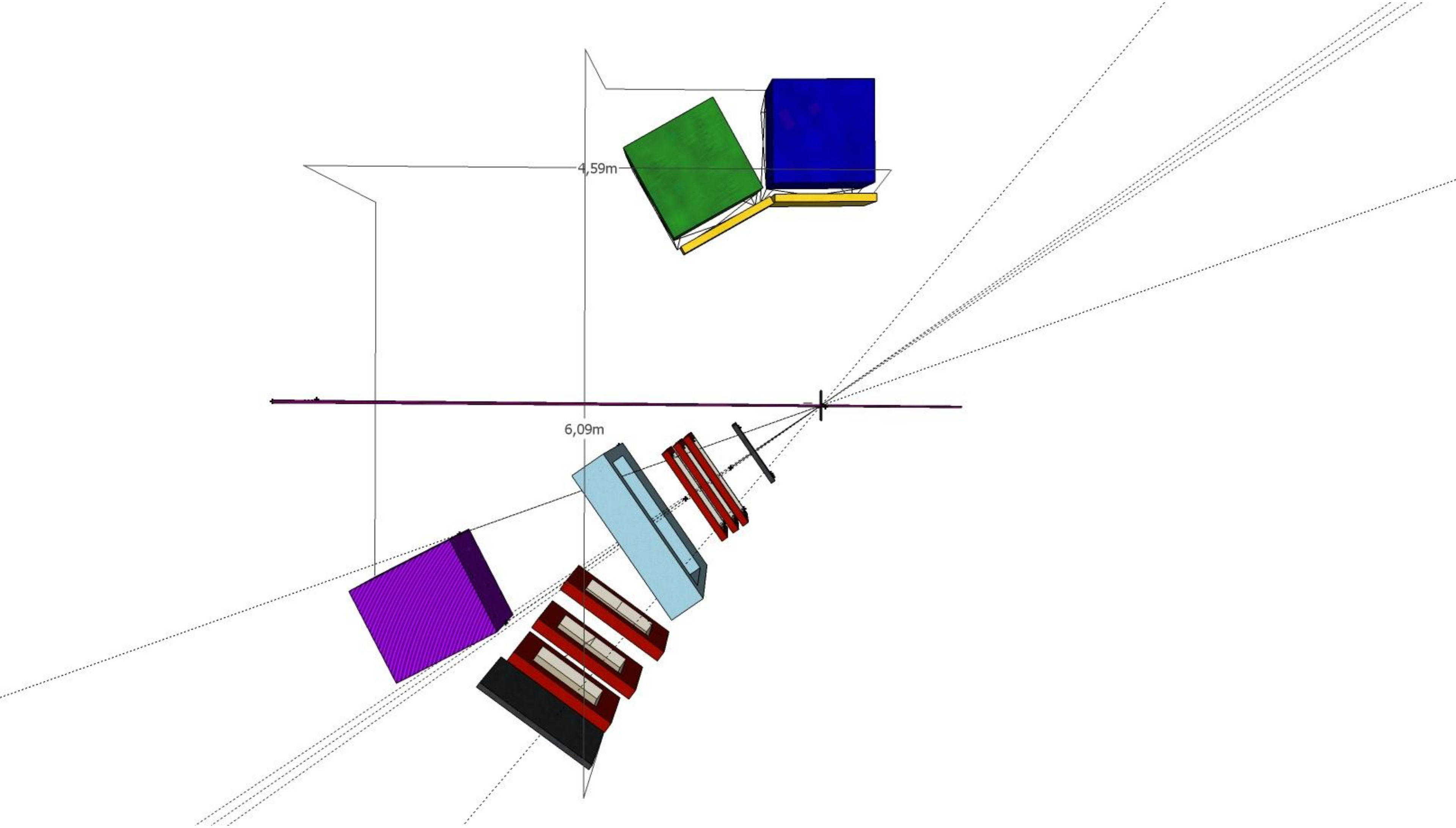
# FLINT II

**Clusterization (close in momentum space)**
**Femtoscopy (close in coordinate space )**

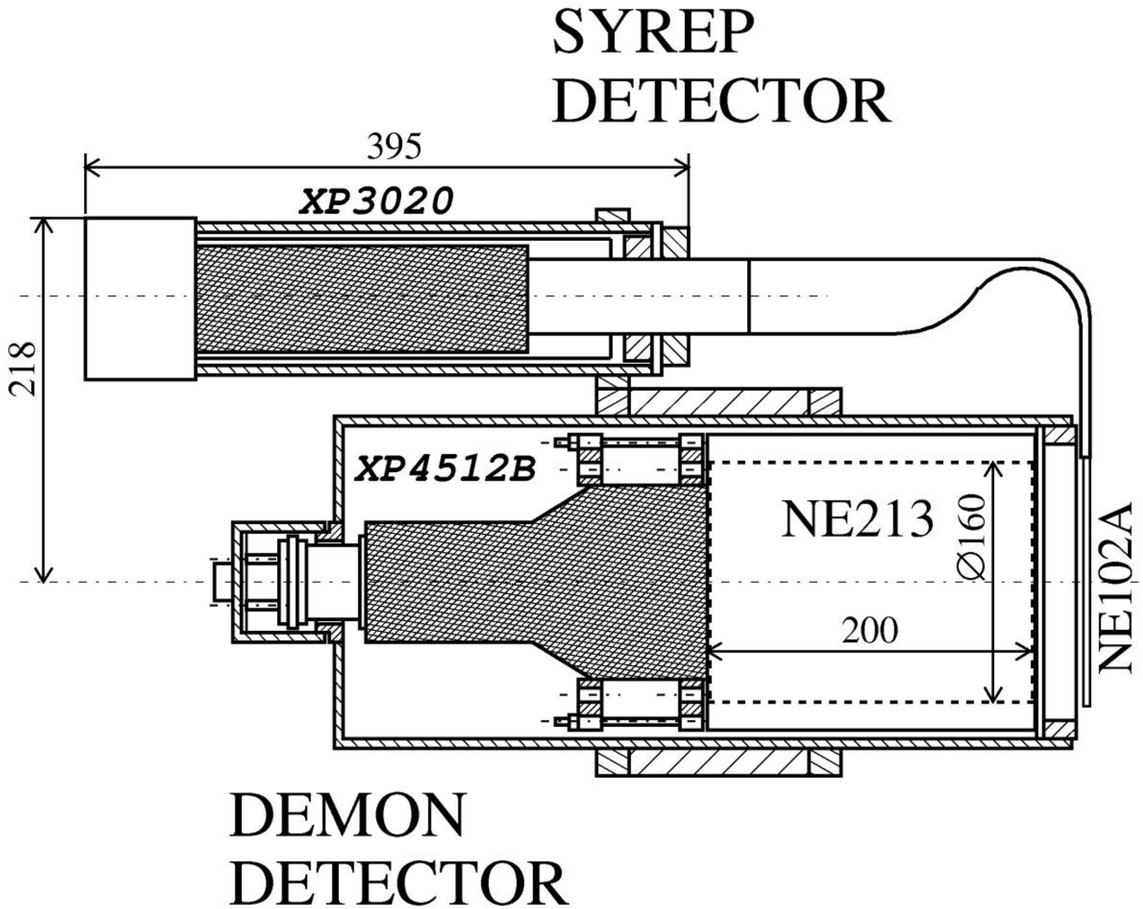
Trigger

| | |
|---|---|
| **Isosymmetrisation** | **(p/n, $\pi^+/\pi^-$ c.s. ratios)** |
| **Strangeness** | **(SU(3) symmetry restoration)** |
| **Vector mesons** | **(vector/scalar meson ratio increase)** |
| **Exotic** | **(Pauli principle →(qqqqs), (qqqqqqs))** |
| **…** | |

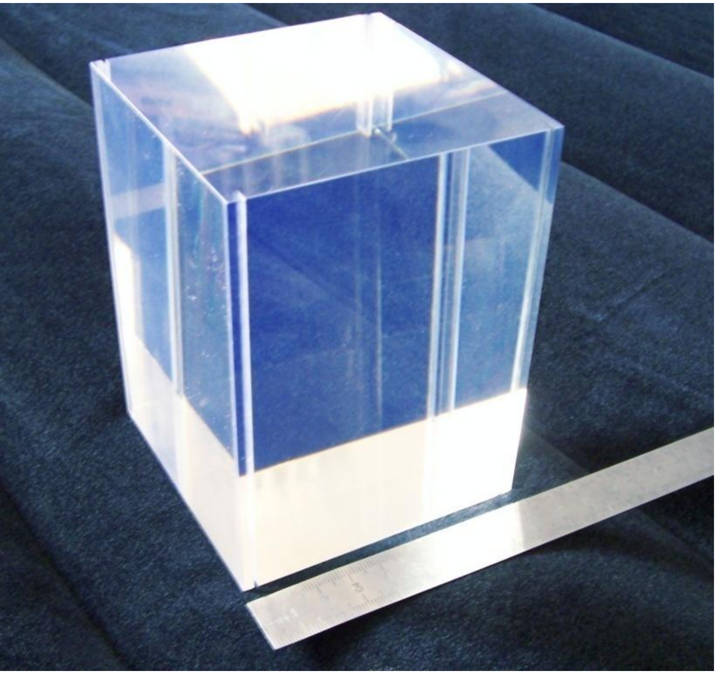
# FLINT II set up(project) for TWA and Nuclotron M

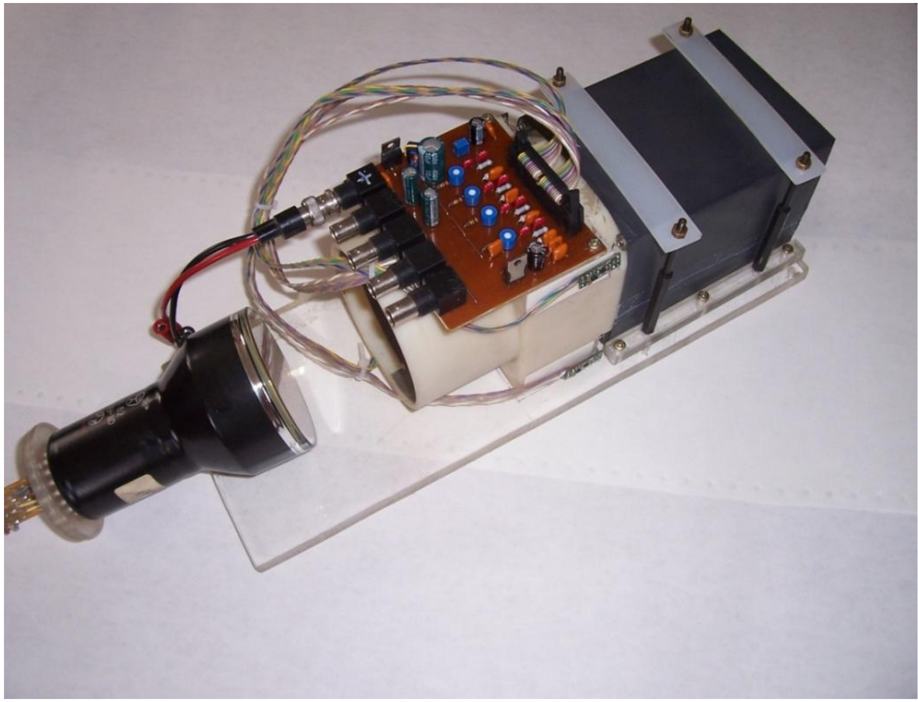


Time resolution 0.15ns
Neutron efficiency ~ 20%



# Neutron detector for FLINT





First prototype:

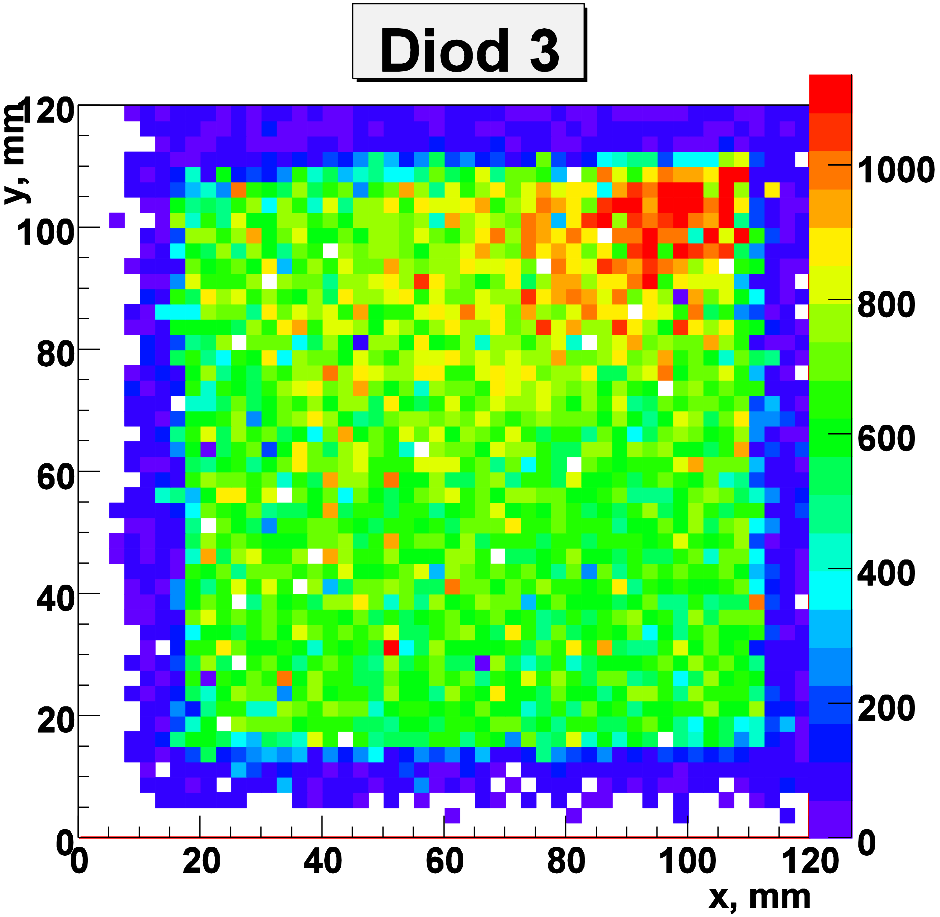
Plastic Scintillator  96 * 96 * 128 $mm^3$

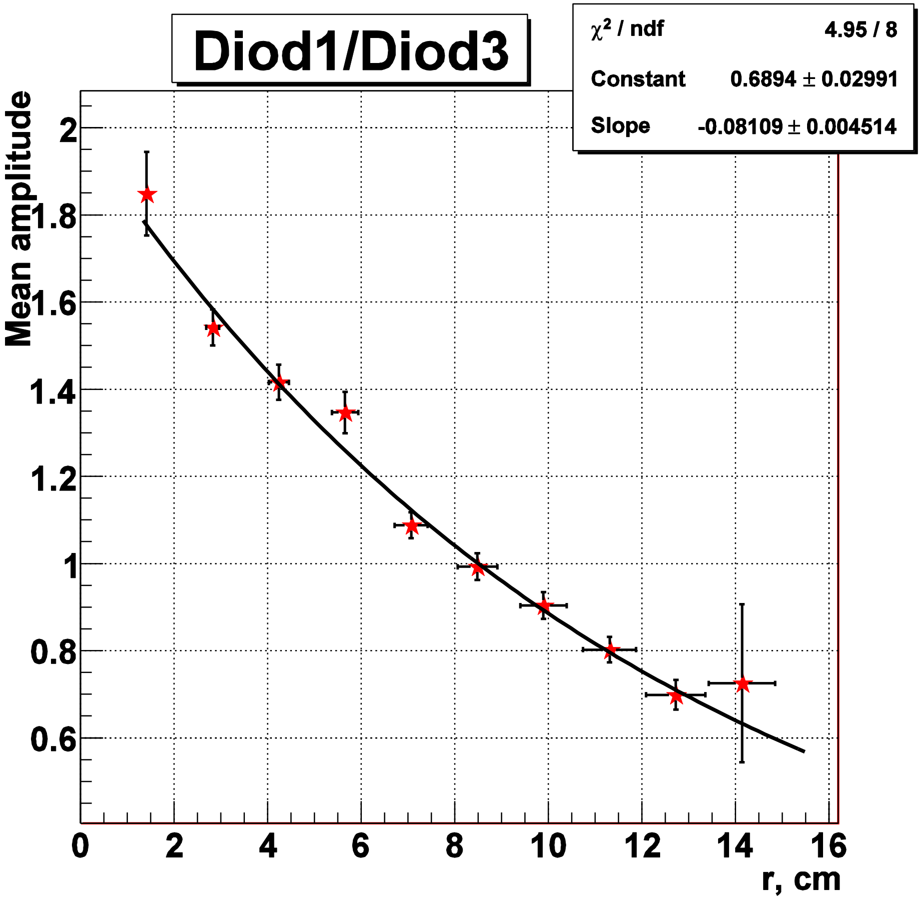
Fiber: KYRARAY,Y-11,d =1mm,

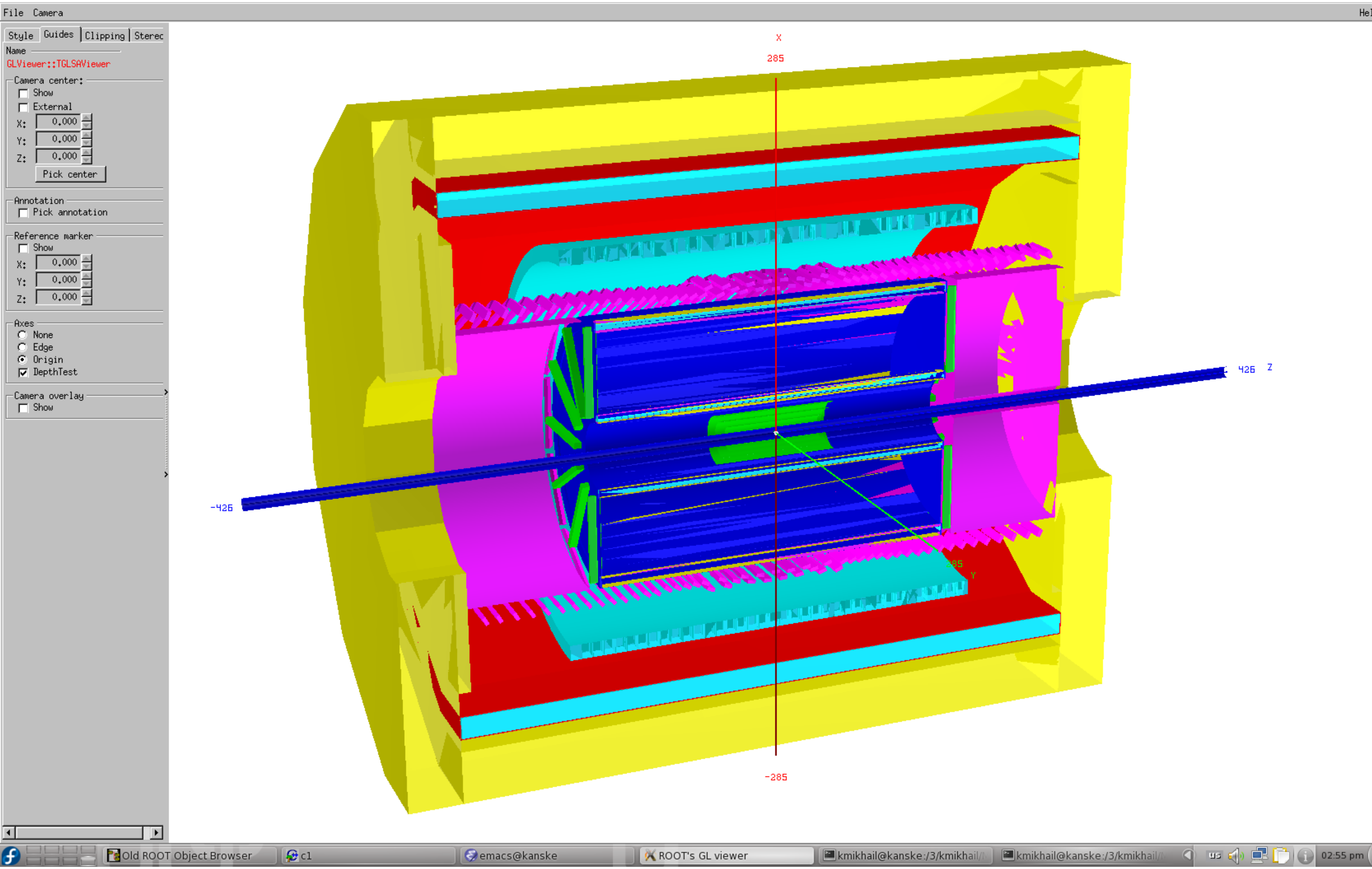
4 MRS APD & Amplifier - CPTA(Golovin)

Matrix for FLINT 6x6=36
Matrix for NICA ~3000

# Neutron detector for FLINT(beam test June 2009,preliminary results)




File Camera
Help
Style
Guides
Clipping
Stereo
Name
GLViewer::TGLSAViewer
Camera center:
Show
External
X: 0.000
Y: 0.000
Z: 0.000
Pick center
Annotation
Pick annotation
Reference marker
Show
X: 0.000
Y: 0.000
Z: 0.000
Axes
None
Edge
Origin
DepthTest
Camera overlay
Show
X
285
-285
426
Z
-426
Y
Old ROOT Object Browser
c1
emacs@kanske
ROOT's GL viewer
02:55 pm

# Rate estimate (preliminary)

Estimated possible data sample (based on ITEP experimental data):

ITEP: $10^6$sec*$10^7$int/sec*0.2ster ~5*$10^3$events (CC) for Q1+Q2~5.5

current experiment (see next report by G.Sharkov for FLINT collaboration)

Nuclotron-M: $10^6$sec*$10^8$int/sec*0.3ster ~$10^4$ events (CC) for Q1+Q2~6

dedicated experimental set-up, large beam intensity and close to optimal initial energy(upper limit of Nuclotron M)

NICA: $10^6$sec*$10^5$int/sec*10ster ~3*$10^3$ events(CC) for Q1+Q2~5.5

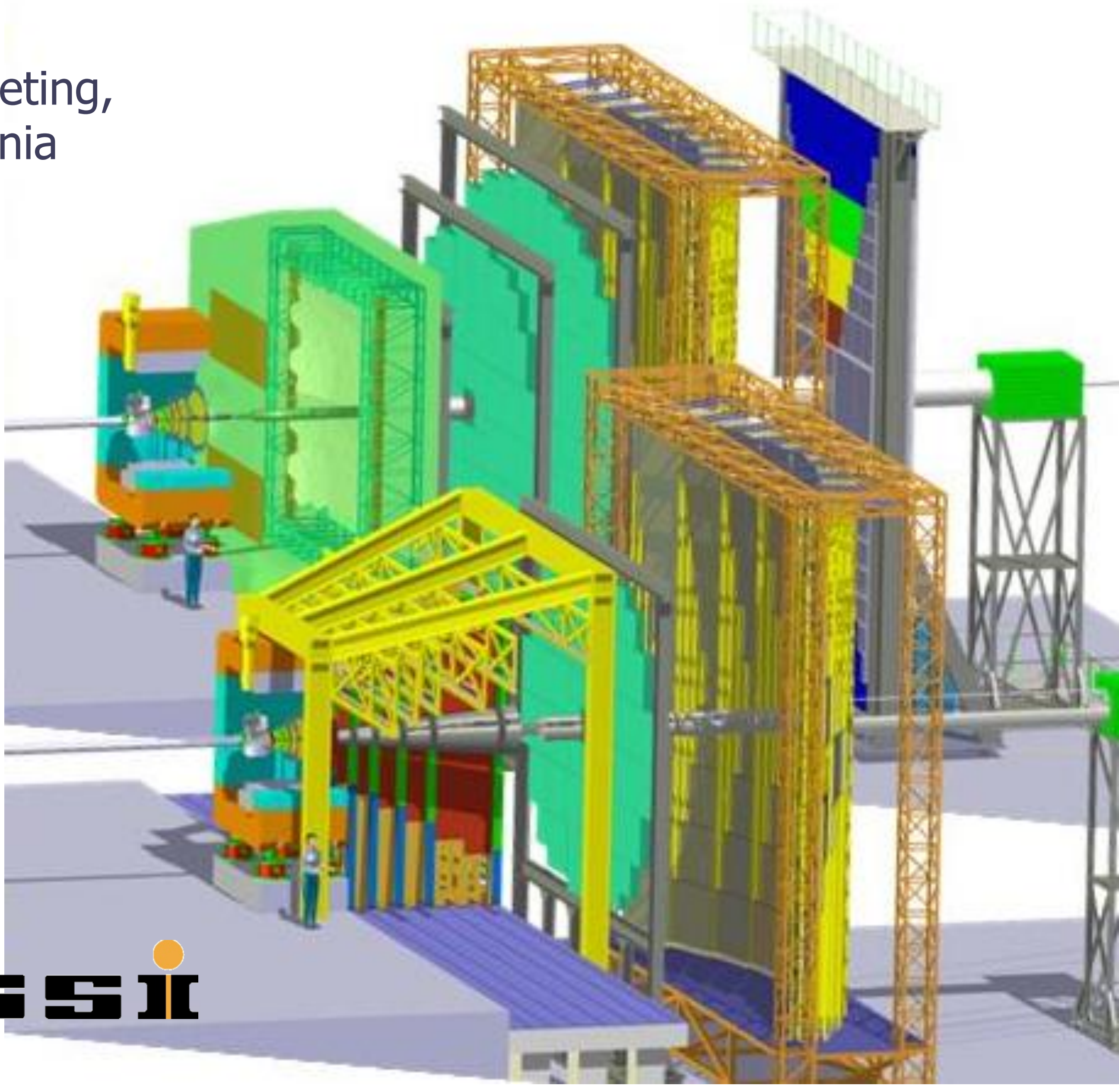
~4π detector (correlations), close to optimal initial energy(lower limit of NICA)

CBM@SIS100: $10^6$sec*$10^8$int/sec*10ster ~$10^4$ events(CC) for Q1+Q2~6.5

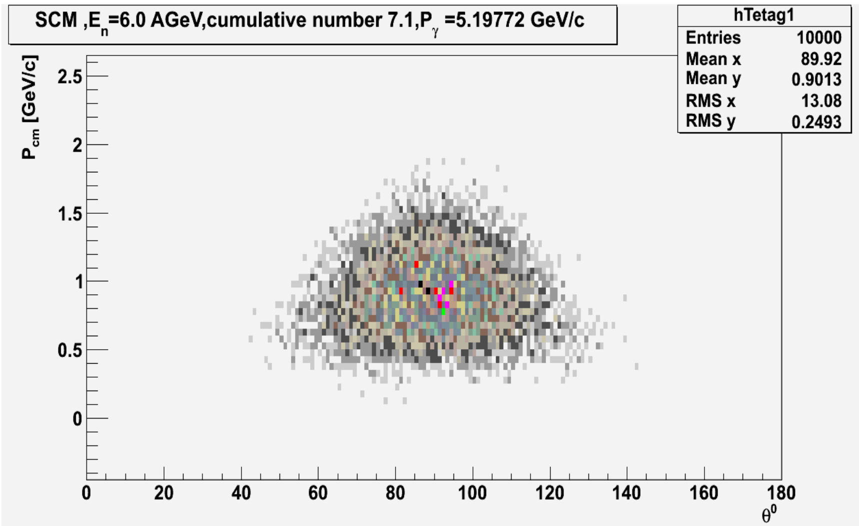
large universal detector +beam intensity

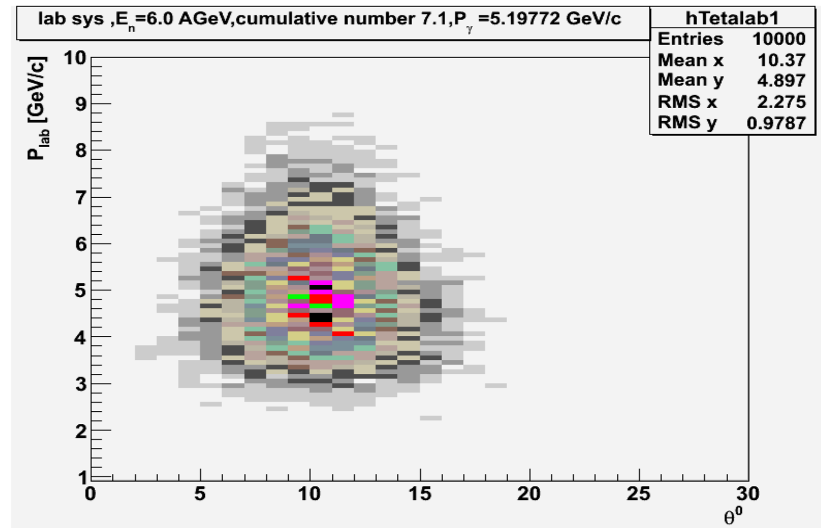
# The Status of CBM at FAIR

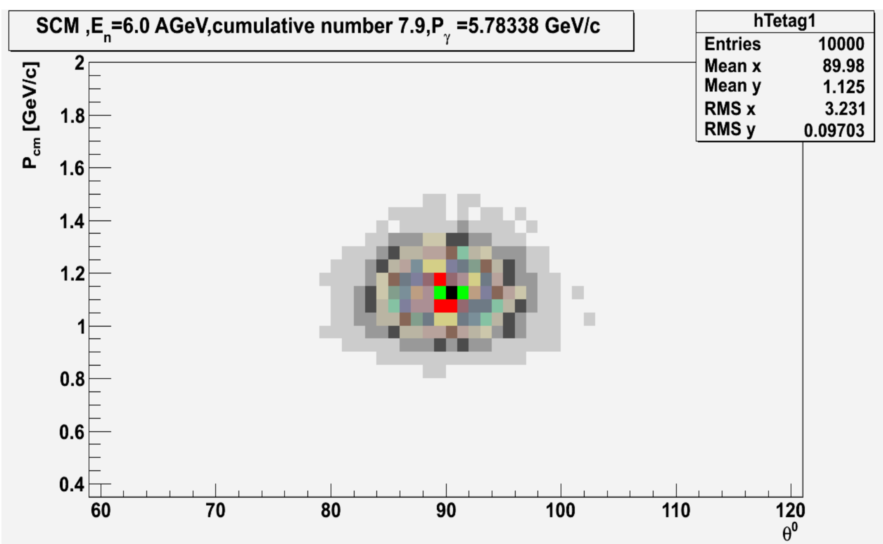
Peter Senger, GSI,
16CBM-collaboration meeting,
27.9-1.10.2010,Romania

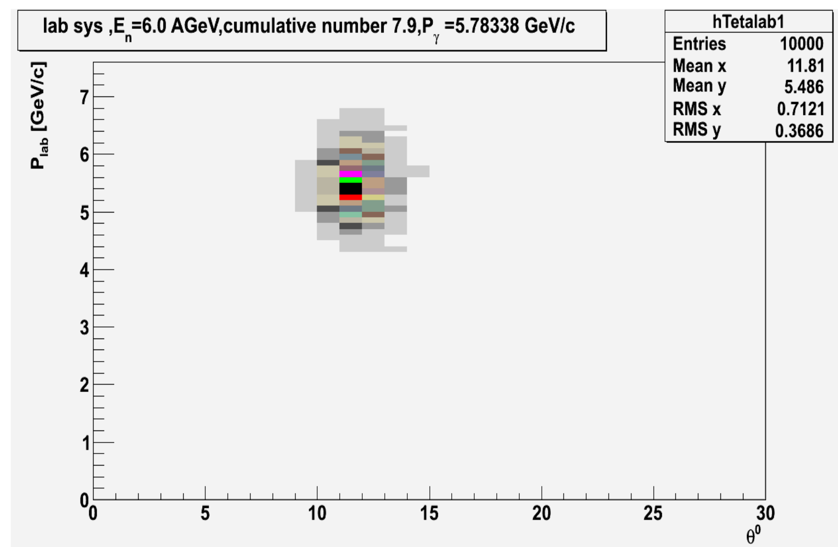


# Dense baryon system region for T/A =6.0 GeV



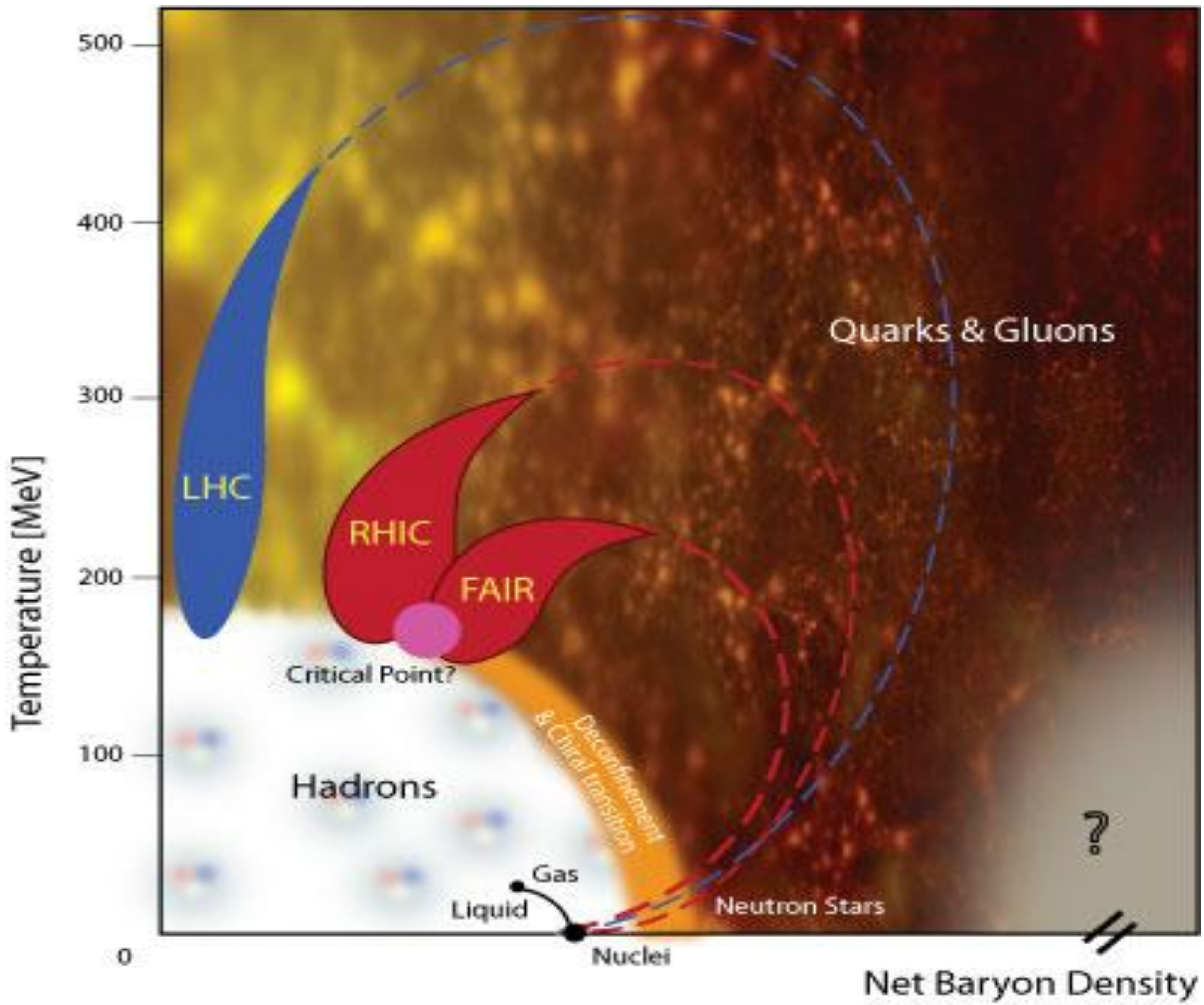
# DCM @ NICA

| Detector \ Task | ECAL (trigger) | Neutron detector | TOF | Magnet | Vertex detector | Tracking detector |
|---|---|---|---|---|---|---|
| Trigger | 🔴 | | | | | |
| Cluster | 🔴 | 🔴 | 🔴 | 🔴 | | 🔴 |
| Femtoscopy | 🔴 | 🔴 | 🔴 | 🔴 | | 🔴 |
| Isosymmetri-sation | 🔴 | 🔴 | 🔴 | 🔴 | 🟡 | 🔴 |
| Strangeness | 🔴 | 🟡 | 🔴 | 🔴 | 🔴 | 🔴 |
| Vector mesons | 🔴 | | 🔴 | 🔴 | 🟡 | 🔴 |
| Exotics | 🔴 | 🟡 | 🔴 | 🔴 | 🟡 | 🔴 |
| Multi-bosons/ fermions | 🔴 | 🟡 | 🔴 | 🔴 | 🟡 | 🔴 |

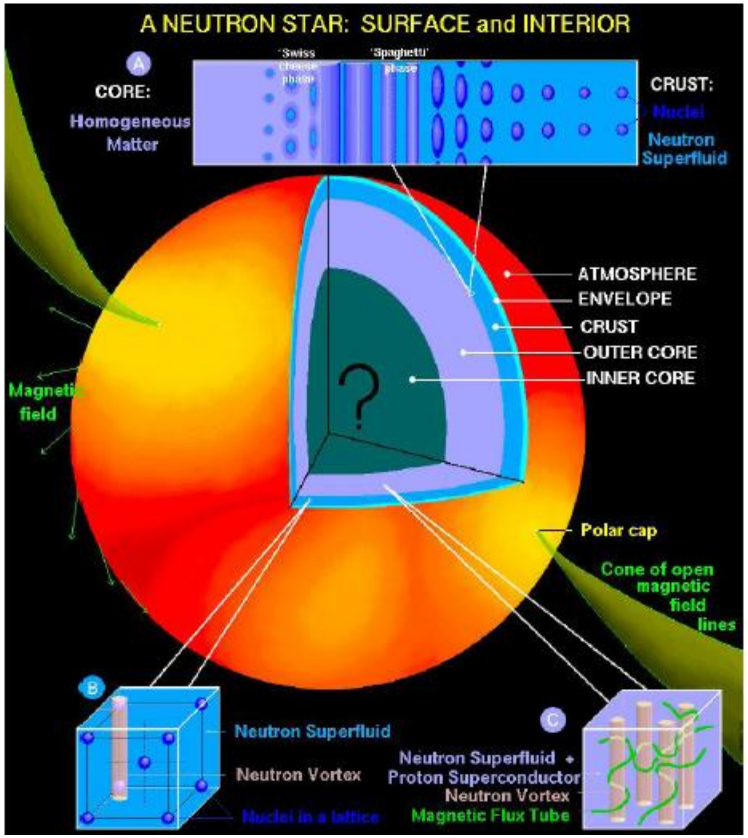
# Conclusion

1. New phase diagram sector proposed for the study. It potentially create new wide experimental program.
2. Possible trigger is proposed; its efficiency is under experimental test
3. A lot of work must to be done-cooperation are welcome.

# Extra slides



Quarks & Gluons
LHC
RHIC
FAIR
Critical Point?
Deconfinement & Chiral transition
Hadrons
Gas
Liquid
Nuclei
Neutron Stars
?
Temperature [MeV]
500
400
300
200
100
0
Net Baryon Density




A rendition of the structure and phases of a neutron star (courtesy of Dany Page)

nucl-th/0901.4475

The discovery of neutron stars in the form of pulsars
has been a major stimulus to dense matter studies

Observables:

- gravitational red shift
- central density of the star
- moments of inertia
- pulsar timing

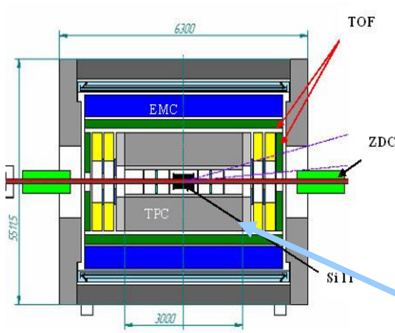
These informations can be inferred from the photons, randing from the radio waves to X-rays, and also those involving neutrinos and gravity waves

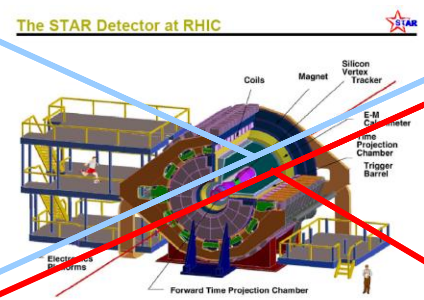
[T.K.Jha,nucl-th/0902.0262]

# Outlook

- **Physical motivation**
- **Program status @ FLINT**
- **Future with FAIR-CBM, NICA-MPD**
- **Conclusions**

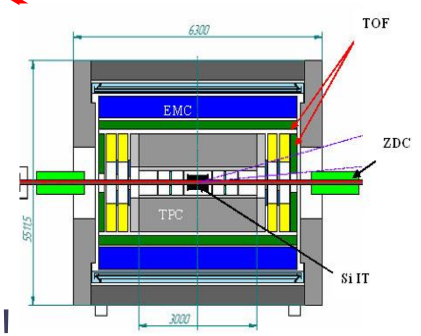
# Where is MPD NICA ?

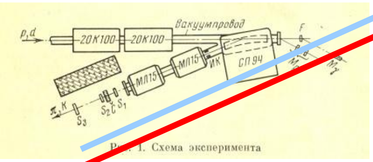



Methodic level, theory

Energy range




New energy range for present day detectors & theory!

1970

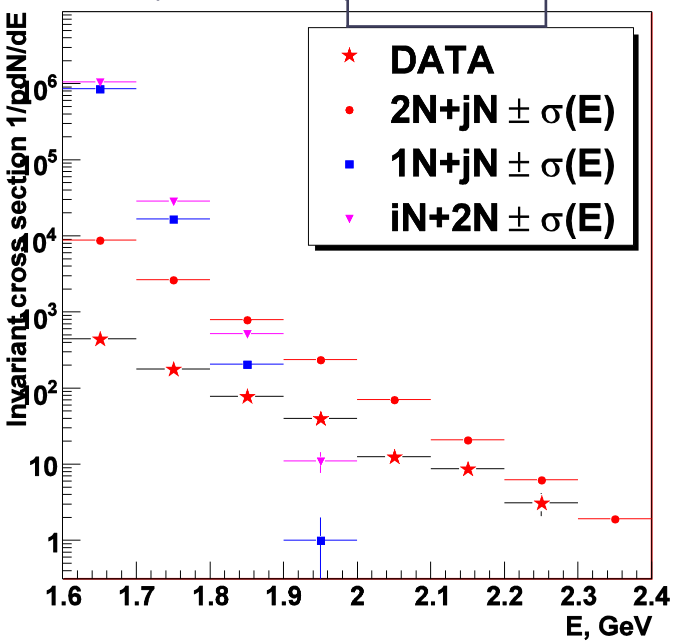
2000

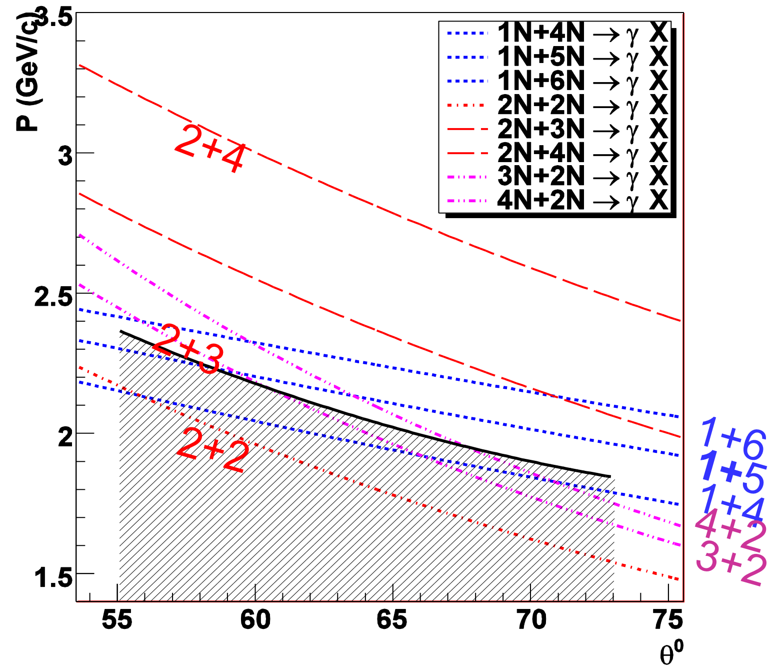
2015

# Arguments for FF: slope parameter(see figure) (also min (Ni+Nj)&angular dependence)

| | Δp(X+1 ), MeV | $T_0$, MeV | $T_0 \pm \sigma(E)$, MeV |
|---|---|---|---|
| 1N+jN | 140±20 | 20±3 | ~ 34±4 |
| iN+2N | 160±80 | 23±11 | ~ 36±15 |
| 2N+jN | 570±70 | 81±10 | ~ 85±11 |

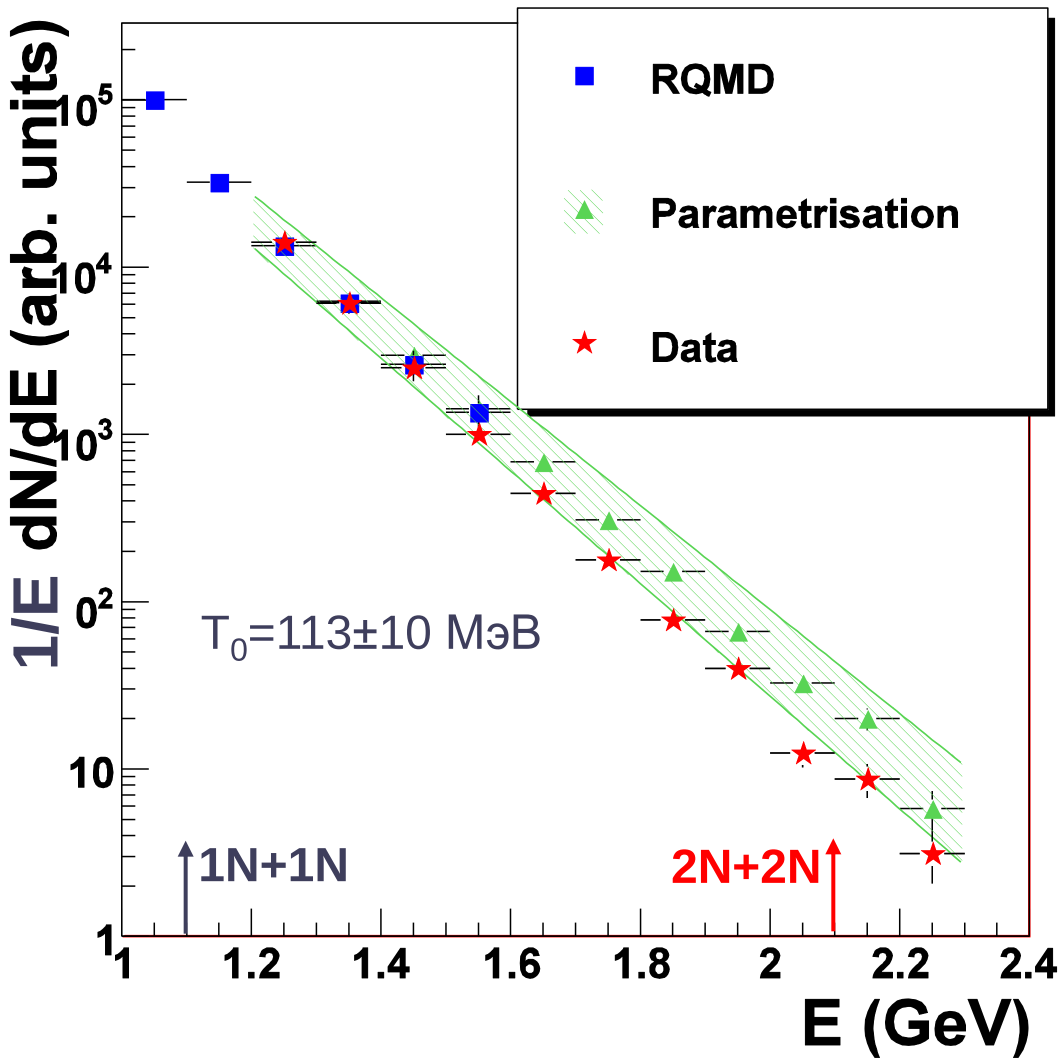
• $T_{0exp}$=113±10 МэВ



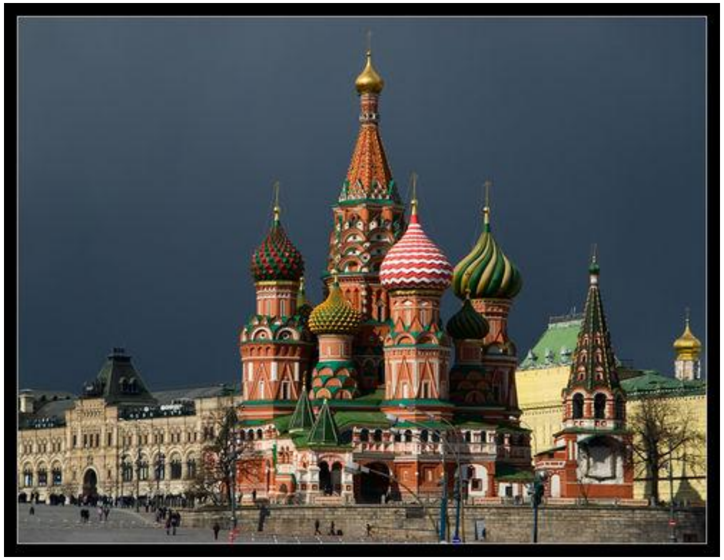



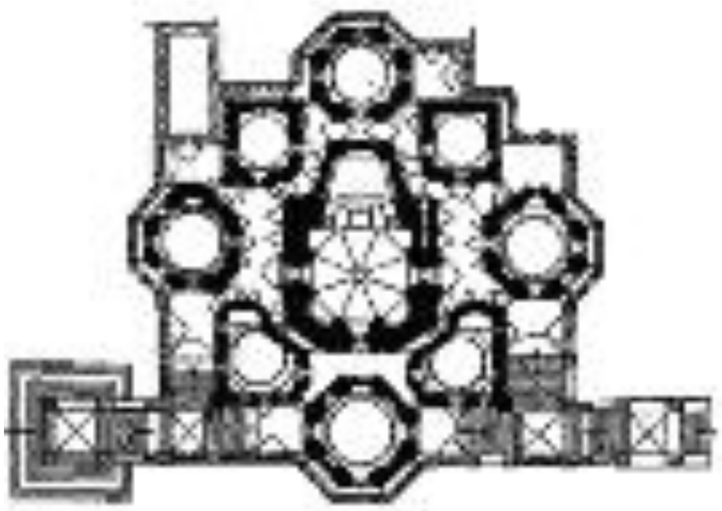

• 2+3 !

# Results(2008)

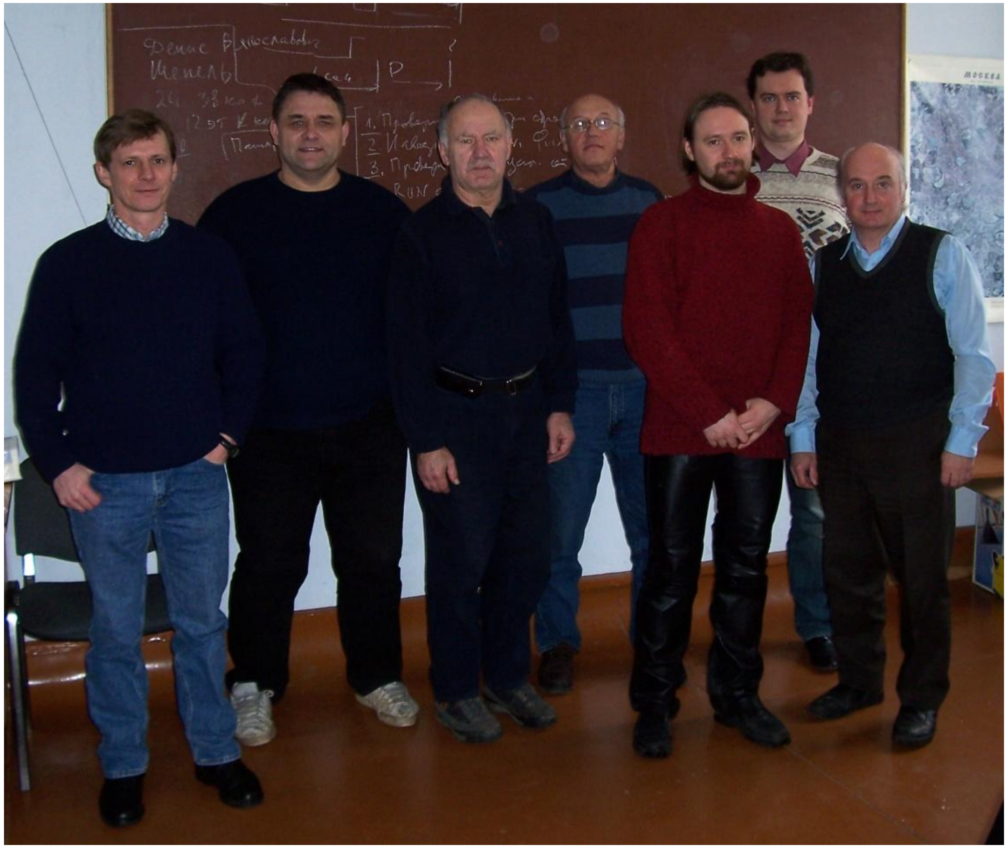


# How many constituents needed to say about matter?

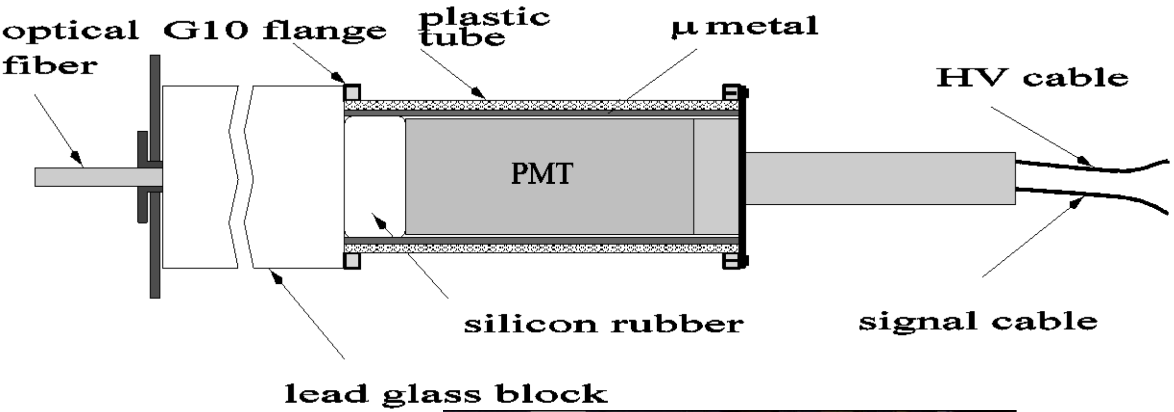




**1000-100-10?**
**It depends on density!**



# FLINT subsystems




matrix 8x8

100x100x380 mm³

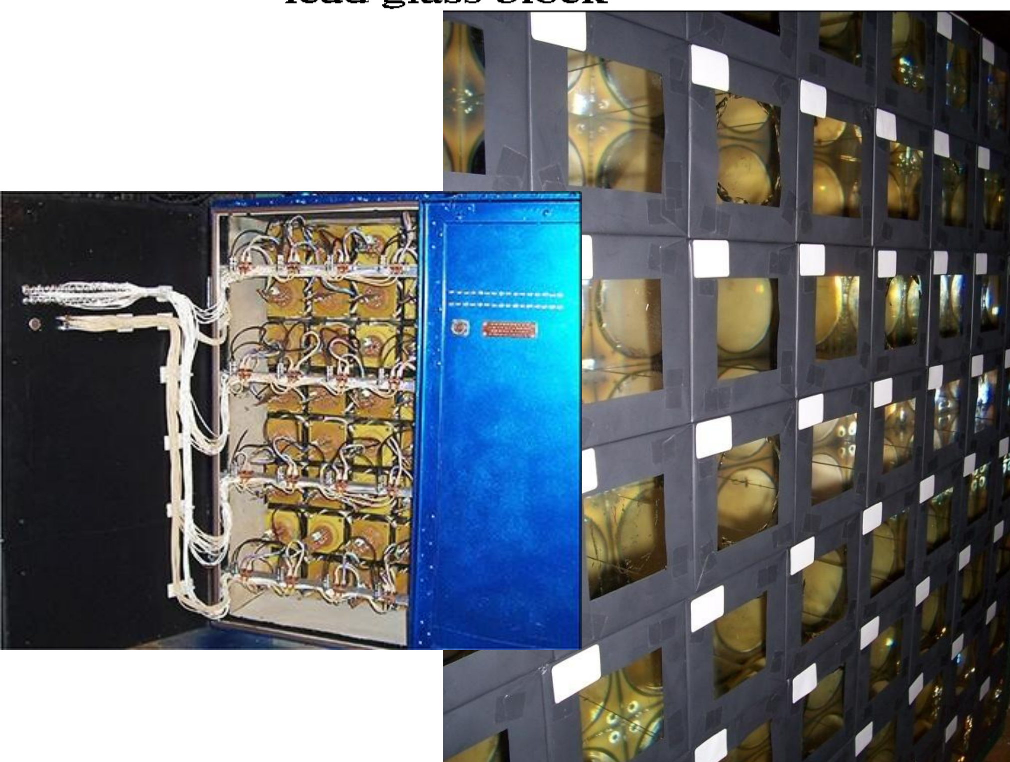
Lead glass F8

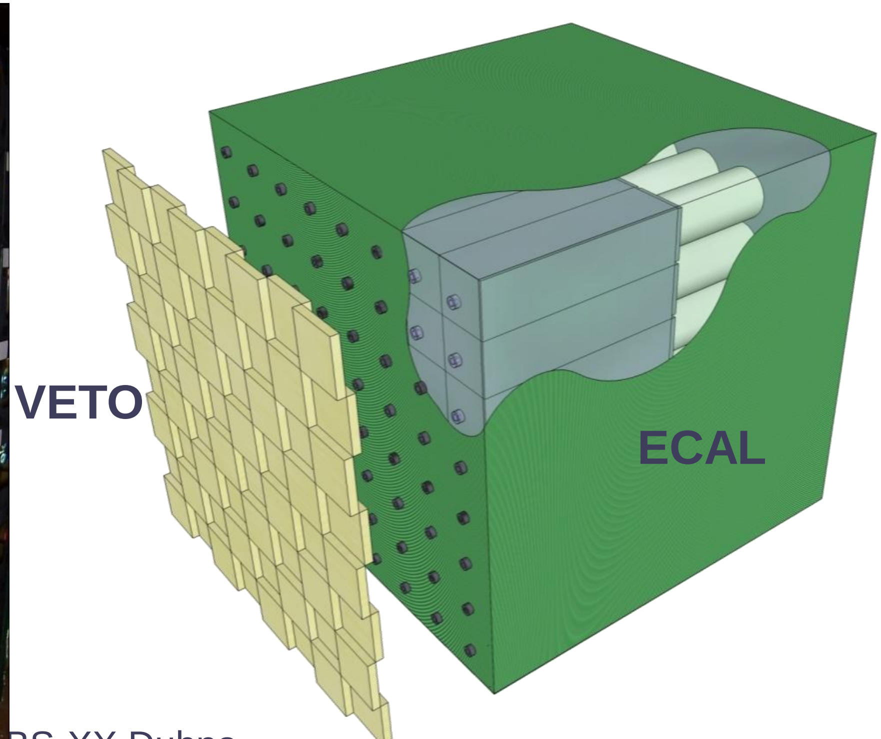
$\rho$=3.6g/cm³

$X_{rad}$=3.1cm

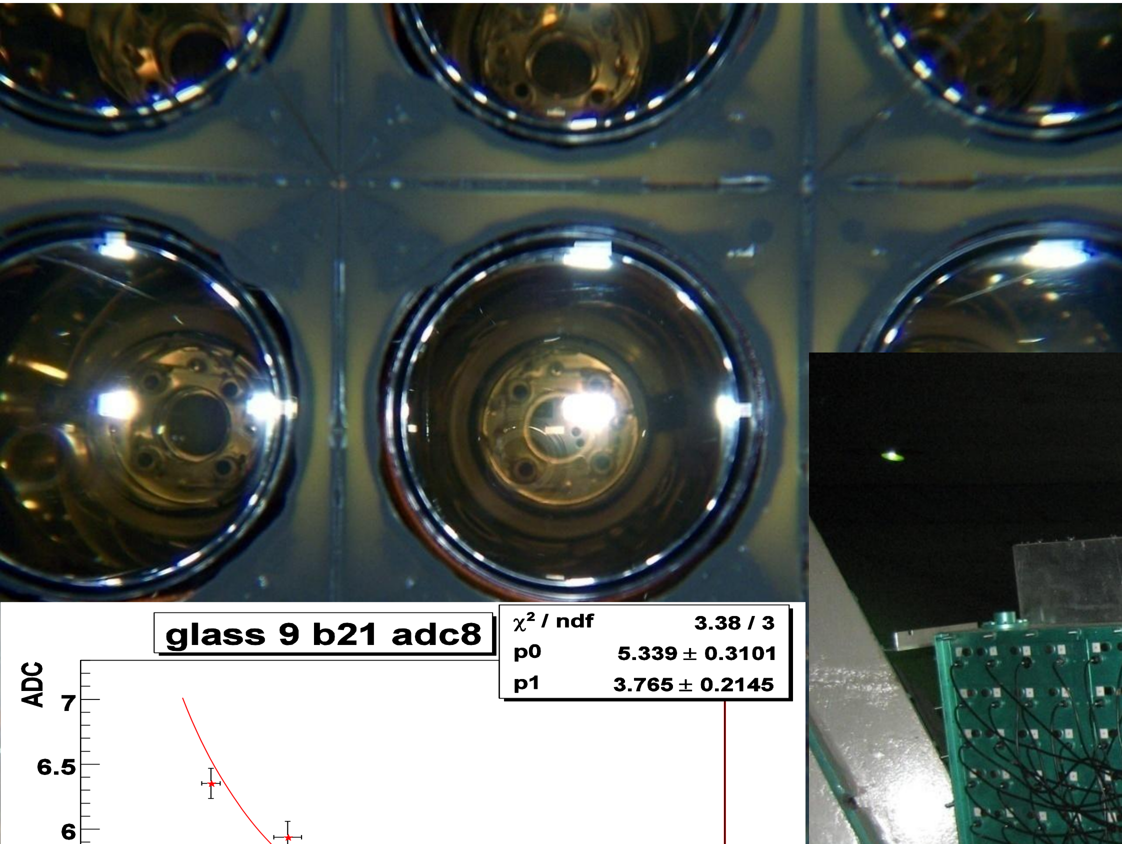
$R_M$=3.6cm

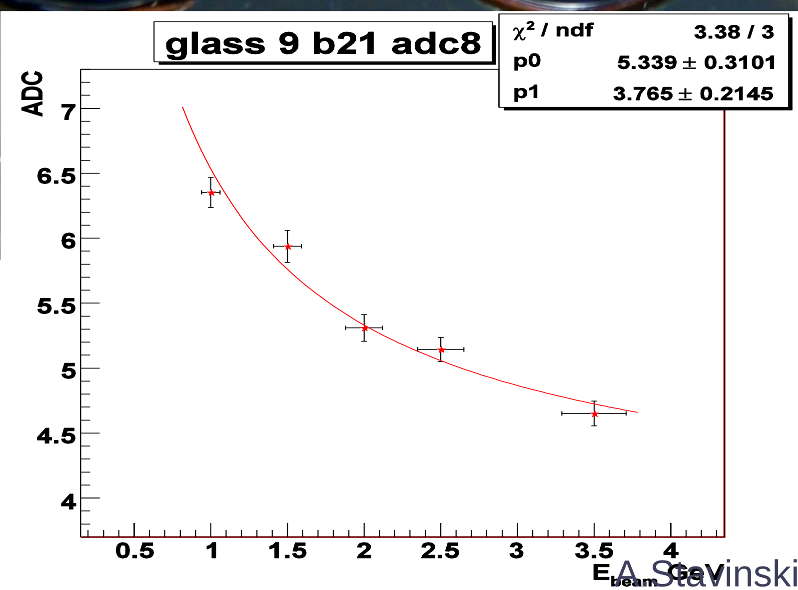
Mass~1.5 Tonn





# Celorimeters & LED-monitoring system



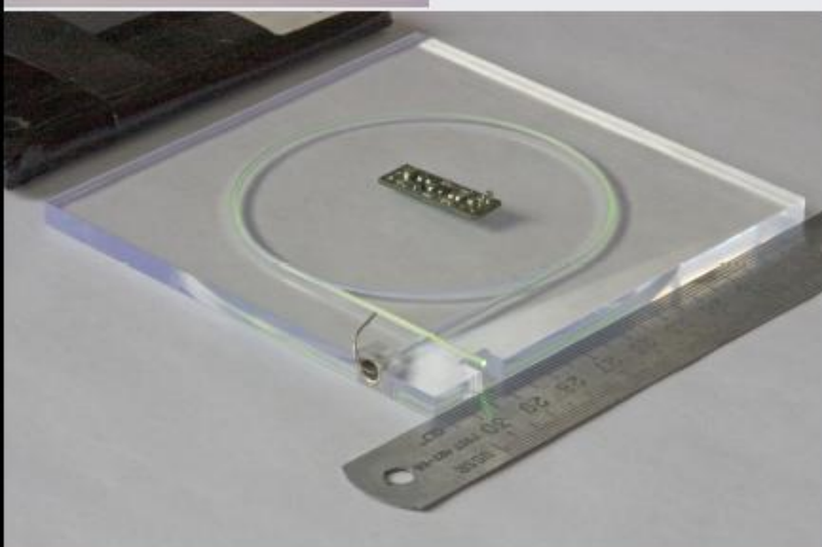


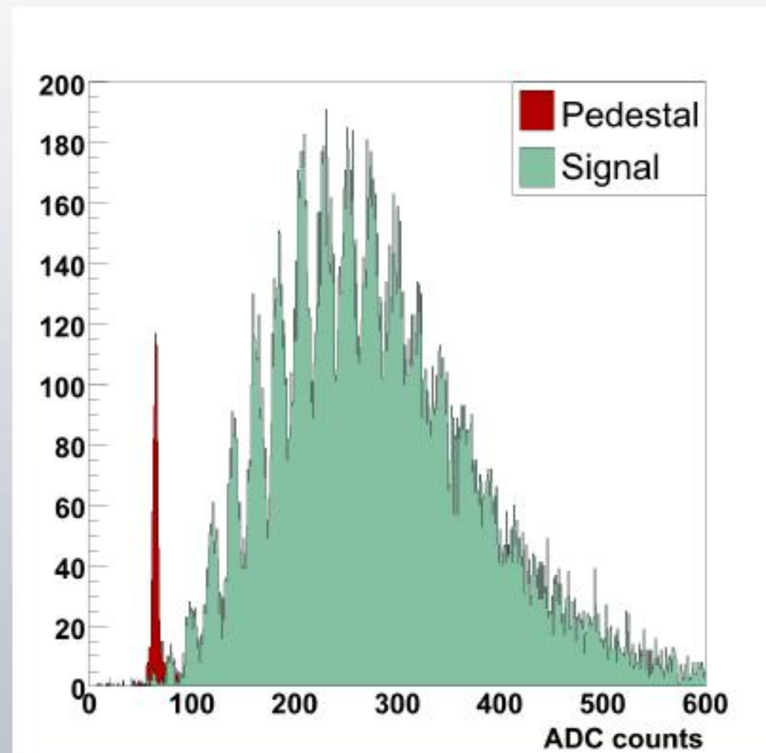

# VETO-system for FLINT


Plastic Scintillator 105 * 105 * 5 mm^3

Fiber: KYRARAY,Y-11,d =1mm, wavelength shift

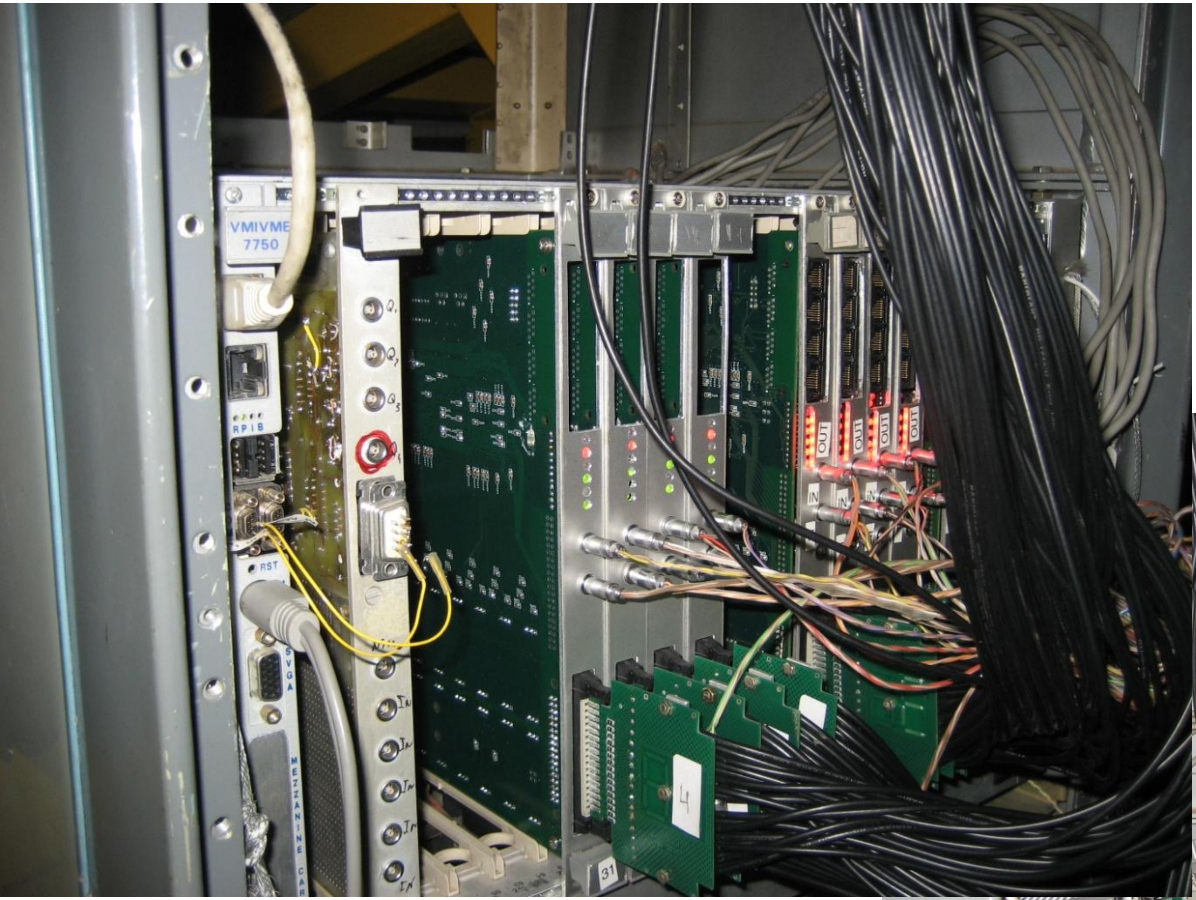
MRS APD & Amplifier - CPTA(Golovin)





# VETO system supermodule

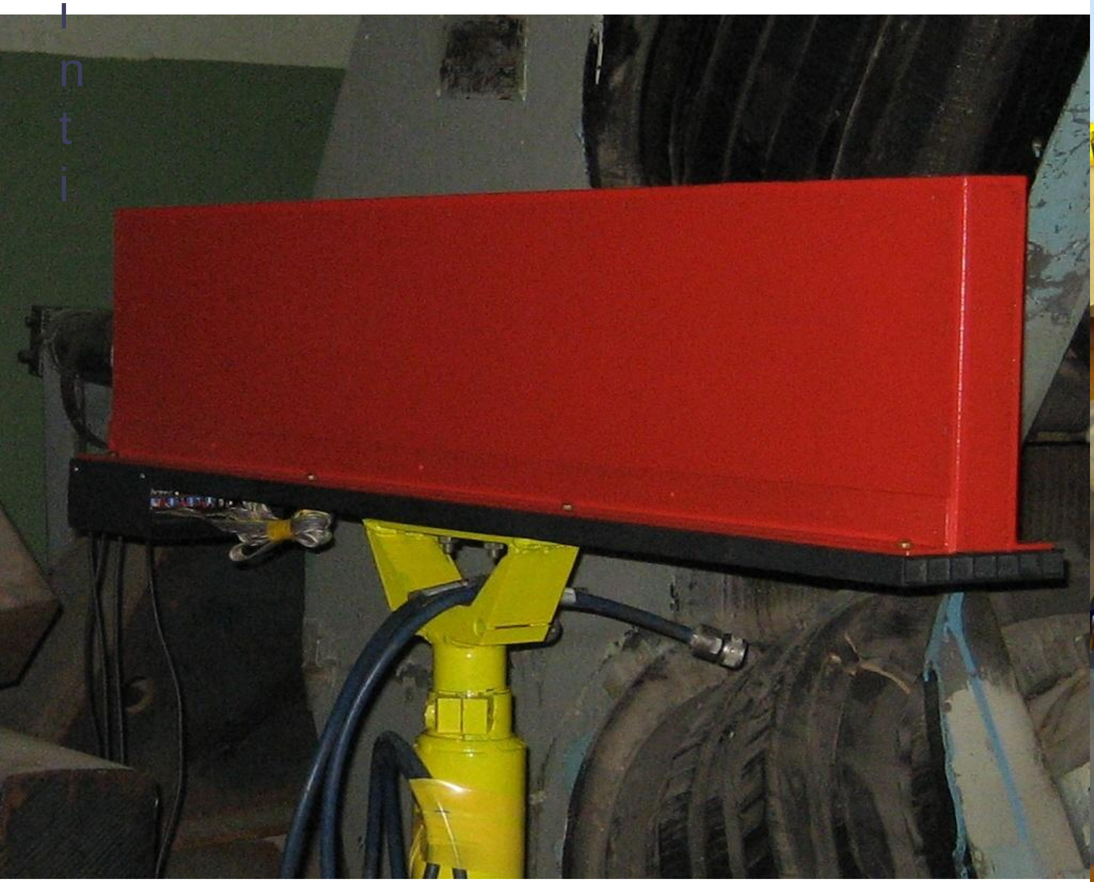
# Electonics(VME)

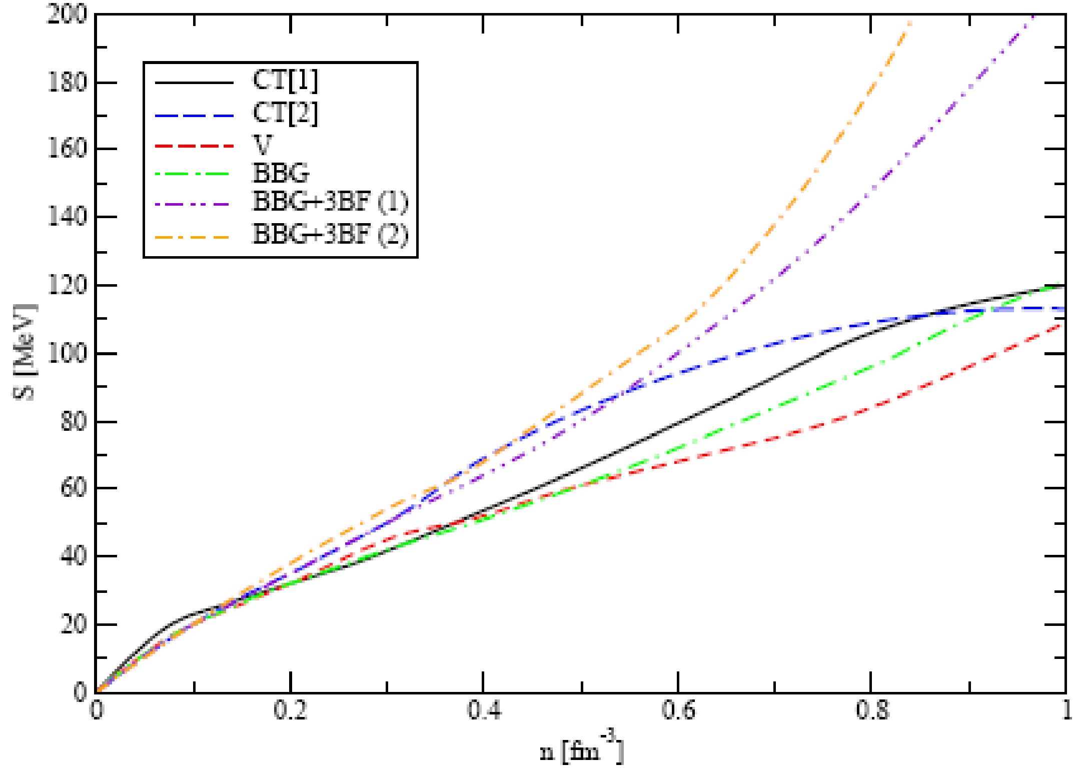



# Beam monitoring system

(scintillator+wevelength shifter(Y11)+ MRS APD)

Scinti



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Phys.58(2007)158
nucl-th/0601086

Figure 14: Dependence of symmetry energy of nuclear matter on density. CT[1] and CT[2] refer to the results of refs. [112] and [113] obtained within the covariant $T$-matrix theory. V refers to the variational result of ref. [114] which includes a three-body force; BBG refers to the results based on the BBG theory with two-body forces [115]; BBG(1) includes in addition a microscopically derived three-body force [116, 117, 118]; BBG(2) is the same as BBG(1) but with a phenomenological three-body force [119, 120].

The physics of dense hadronic matter and compact stars

Armen Sedrakian


[112] H. Müther, M. Prakash, and T. L. Ainsworth, Phys. Lett. B **199** (1987) 469.

[113] C.-H. Lee, T. T. S. Kuo, G. Q. Li, and G. E. Brown, Phys. Rev. C **57** (1998) 3488.

[114] A. Akmal, V. R. Pandharipande, and D. G. Ravenhall, Phys. Rev. C **58** 1804 (1998).

[115] X. R. Zhou, G. F. Burgio, U. Lombardo, H.-J. Schulze, and W. Zuo, Phys. Rev. C **69** (2004) 018801.

[116] S. A. Coon et al., Nucl. Phys. A **317** (1979) 242.

[117] P. Grangé, A. Lejeune, M. Martzolff, and J.-F. Mathiot, Phys. Rev. C **40** (1989) 1040.

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[119] B. S. Pudliner, V. R. Pandharipande, J. Carlson, and R. B. Wiringa, Phys. Rev. Lett. **74** (1995) 4396.

[120] B. S. Pudliner, V. R. Pandharipande, J. Carlson, S. C. Pieper, and R. B. Wiringa, Phys. Rev. Lett. [illegible]

Prog.Part.Nucl.
Phys.58(2007)158
nucl-th/0601086

At densities around the saturation density the only baryonic degrees of freedom are protons and neutrons, which form an iso-duplet whose approximate free-space $SU(2)$ symmetry is largely broken in matter. At larger densities the number of stable baryons increases. These include the isospin 3/2 nucleon resonances $\Delta^{\pm}$, $\Delta^0$ and the strangeness carrying baryons (hyperons). The hyperonic states can be

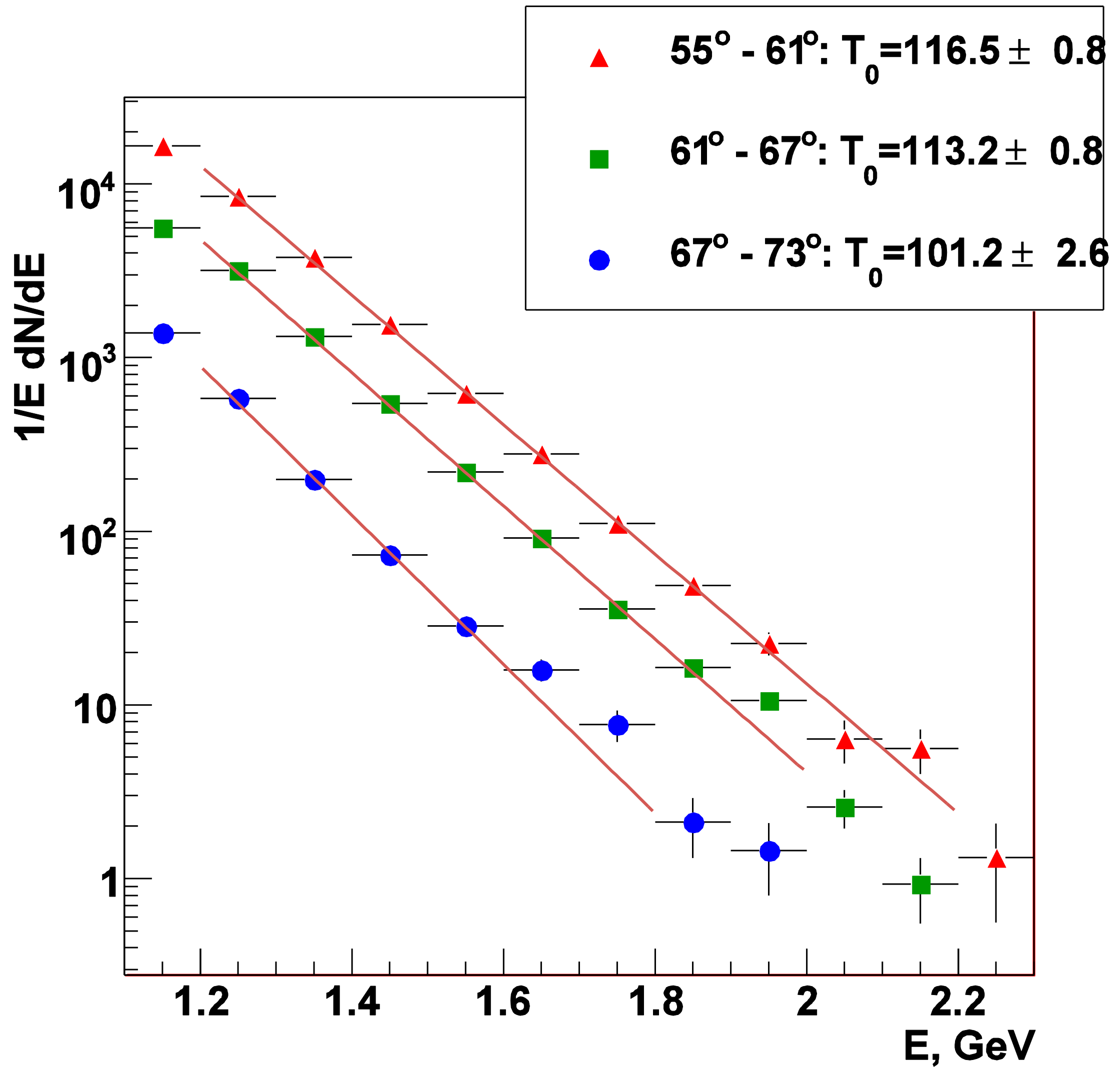
perons and nucleons, the threshold for hyperons to become stable is determined by comparison of the hyperon mass to the largest available energy scale - the neutron Fermi energy [121]. The $\Sigma^-$ hyperons can appear in matter through the weak hyperonic (inverse) beta-decay reactions $e^- + n \to \Sigma^- + \nu_e$ and hadronic weak decay $n + \pi^- \to \Sigma^-$. The energy balance in the first reaction implies $2\mu_n \simeq M_{\Sigma^-} = 1197$ MeV, where $\mu_n$ is the chemical potentials of neutrons (we used the fact that the chemical potential of neutrons and electrons are almost equal in matter under $\beta$ equilibrium, see subsection 2.7). The r. h. side of the second reaction is $O(\mu_n)$, therefore it is negligible compared to the first reaction. Similar arguments apply to other hyperons which are stabilized either through the hyperonic $\beta$ decays or hadronic weak decays. For example for the lightest hyperon $\Lambda^0$ one finds

$$\left.\begin{array}{cc} p + e^- \to \Lambda^0 + \nu_e, \quad p + \pi^- \to \Lambda^0, & O(\mu_p) \\ n + \pi^0 \to \Lambda^0 & O(\mu_n) \end{array}\right\} = M_\Lambda = 1116 \text{ MeV} \tag{124}$$

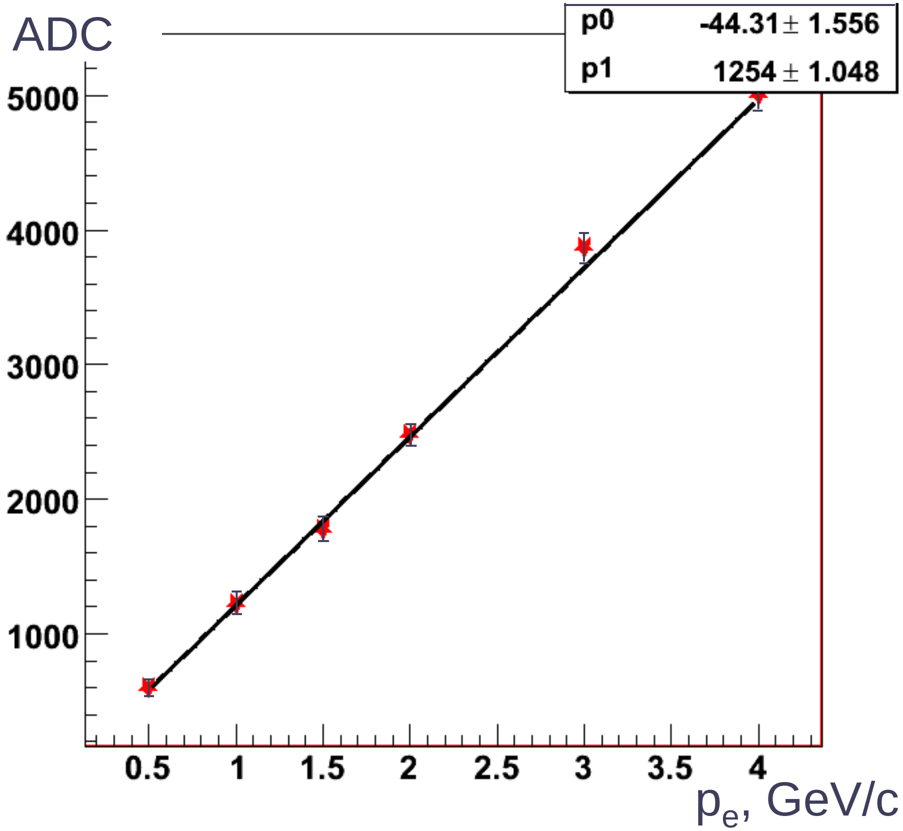
The reactions in the first line being $O(\mu_p)$, where $\mu_p \ll \mu_n$ is the proton chemical potential, can be neglected and $\Lambda^0$ appear primarily through the weak hadronic process in the second line. Since the r. h. side of this reaction is $O(\mu_n)$ and the mass difference $M_{\Sigma^-} - M_\Lambda < \mu_n$ at relevant densities, $\Sigma^-$ hyperons appear first.

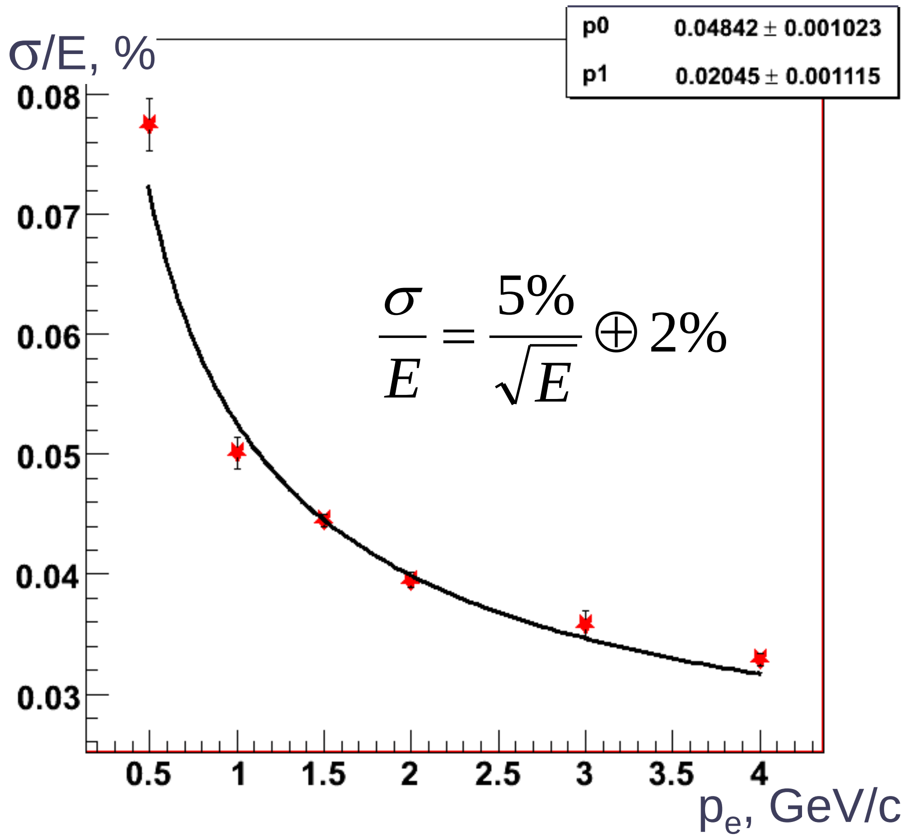
## n»1: N → ΛK ?

# Angular dependence

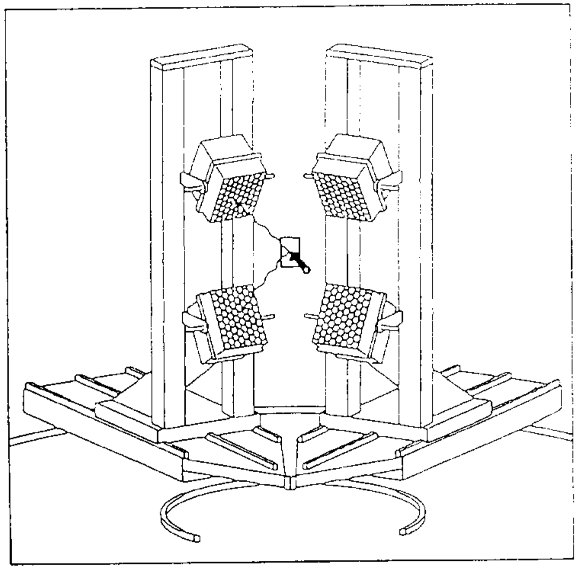


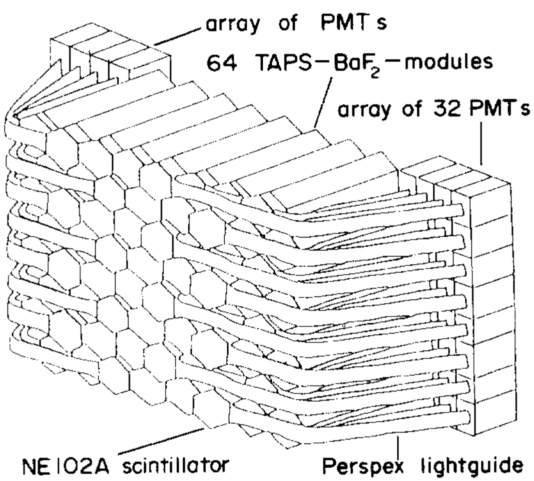

# linearity & energy resolution

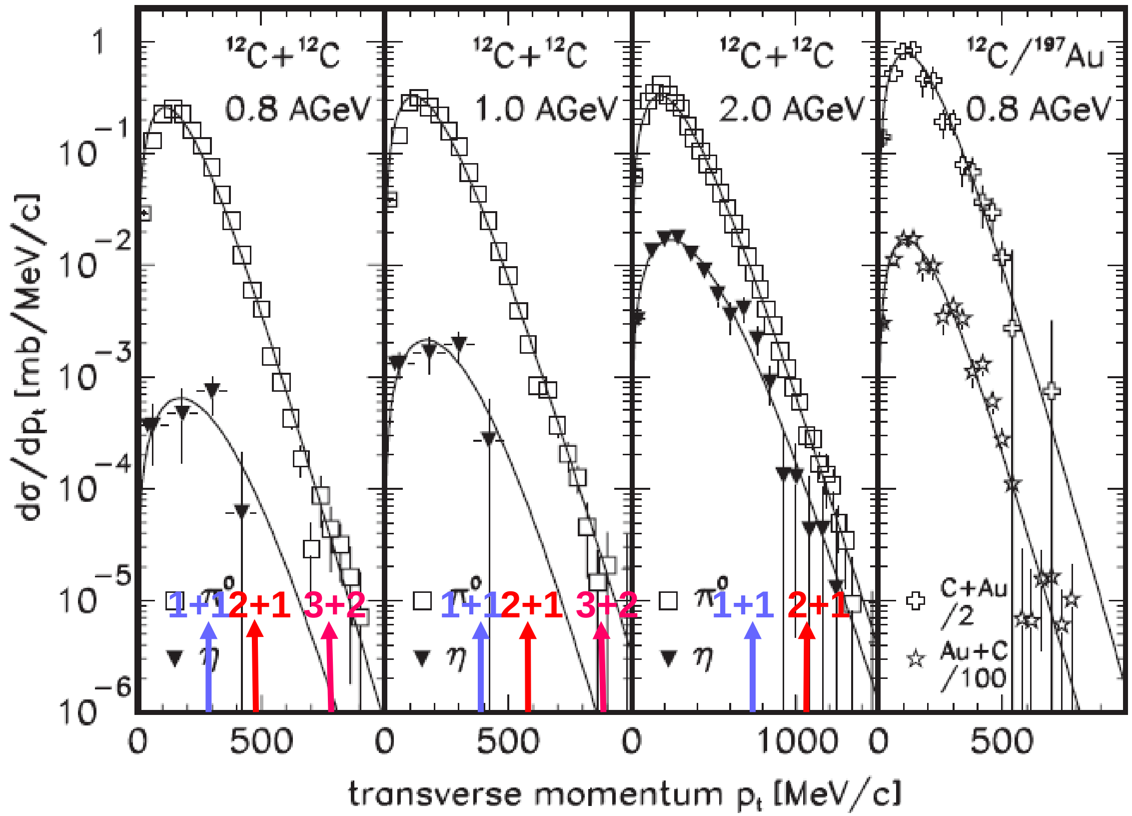


# TAPS $^{12}C+^{12}C \rightarrow \pi^0(\eta)X$ @ 0.8, 1.0 & 2.0 AGeV



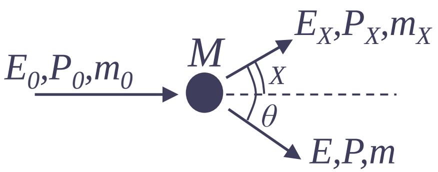



Z. Phys. A 359, 65–73 (1997)

- Постановка задачи реалистична
- Необходимы бóльшие iN+jN при бóльших $E_0$

# Кумулятивное число

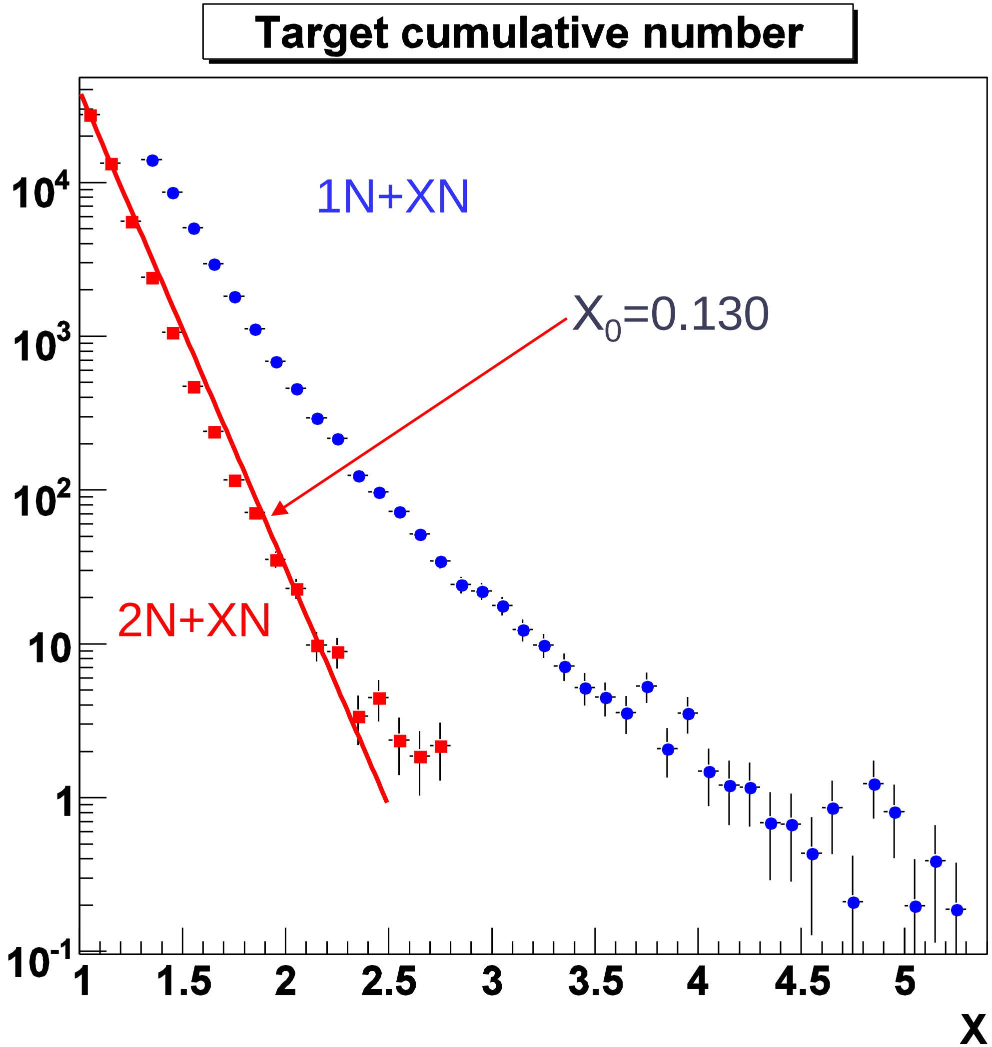



$$\begin{cases} E_0 + M = E + E_X \\ p_0 = p \cdot \cos\theta + p_X \cdot \cos X \\ 0 = p \cdot \sin\theta + p_X \cdot \sin X \\ m_X^2 = (m_0 + M)^2 \end{cases} \Rightarrow \begin{cases} E_X^2 = E_0^2 + M^2 + E^2 + 2E_0M - 2EM - 2E_0E \\ p_X^2 = p_0^2 + p^2 - 2p_0 p\cos\theta \\ m_X^2 = (m_0 + M)^2 \end{cases}$$

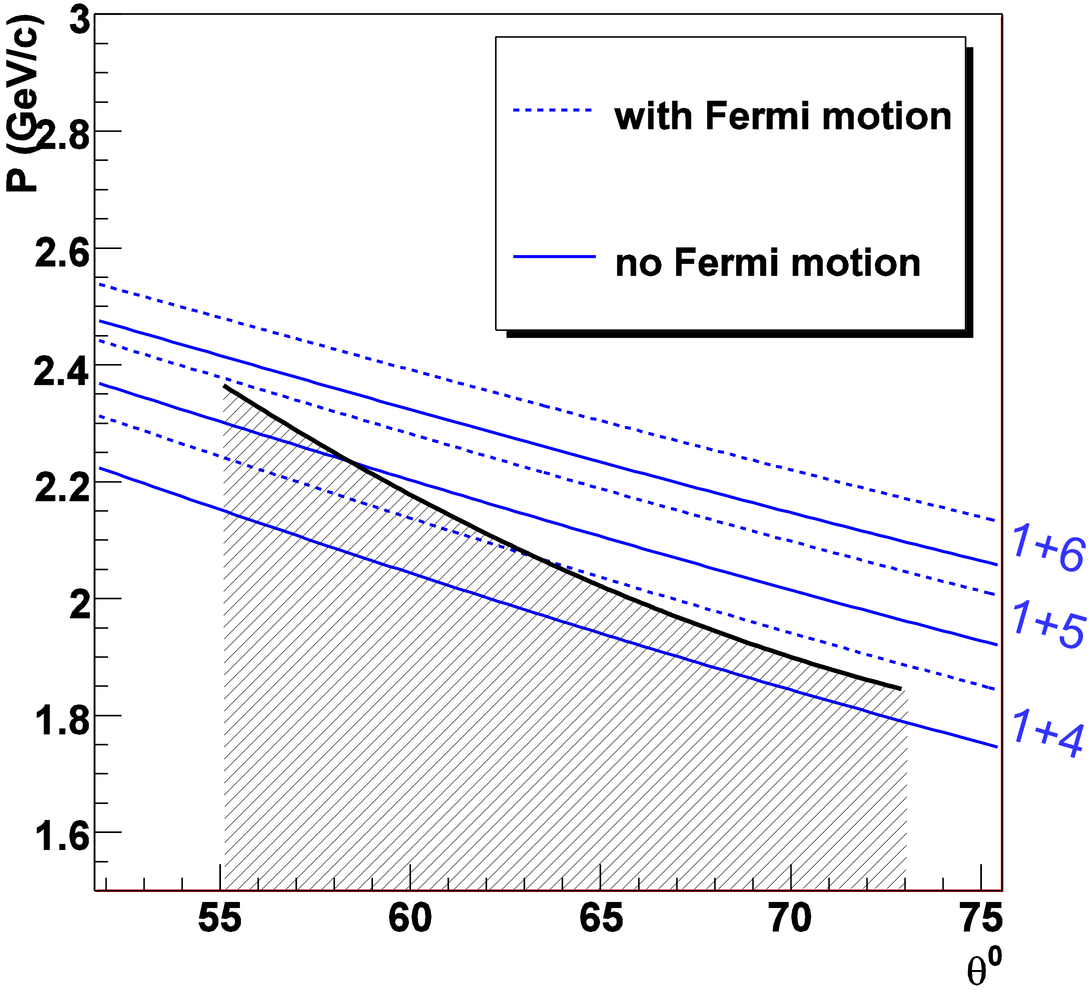
$$X \cdot m_N = M = \frac{E_0E - p_0 p\cos\theta - m^2/2}{T_0 - E}$$

| | | | |
|---|---|---|---|
| 1+N | 4,0 | 1+(N+1) | 5,0 |
| 2+N | 1,9 | 2+(N+2) | 3,9 |
| 3+N | 1,6 | 3+(N+3) | 4,6 |

# спектр в гипотезе флуктон-флуктонного взаимодействия



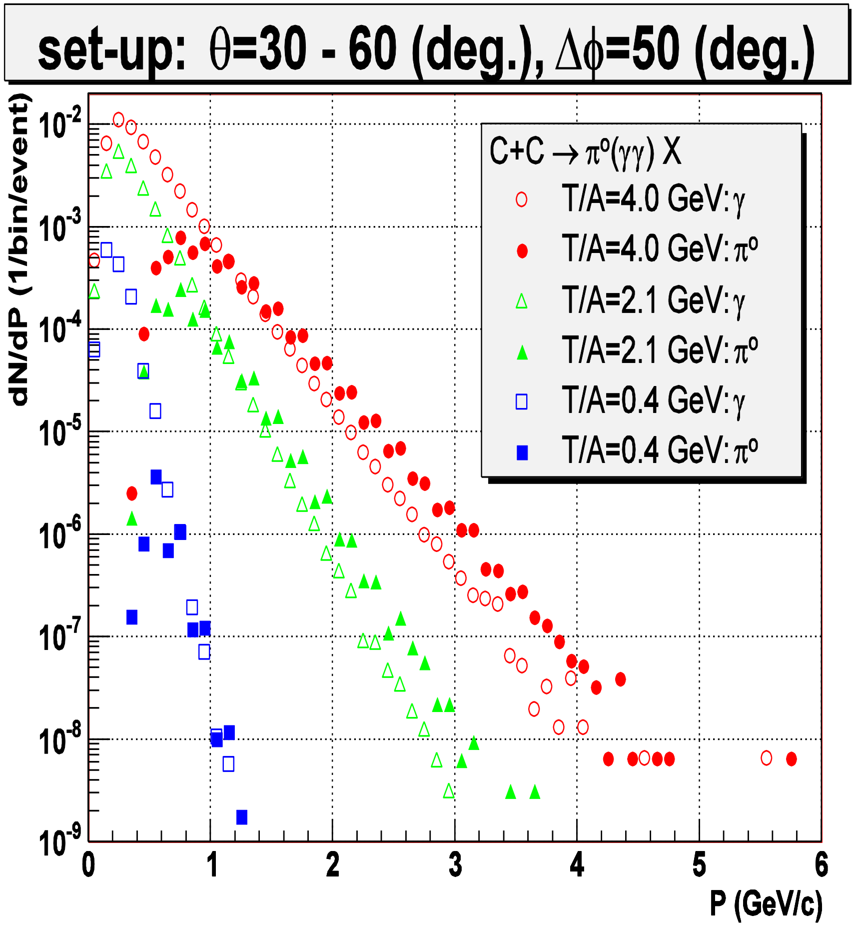
# Fermi motion



•разыгрываются $\pi°$, в направлении аксептанса

•$\pi° \rightarrow \gamma\gamma$

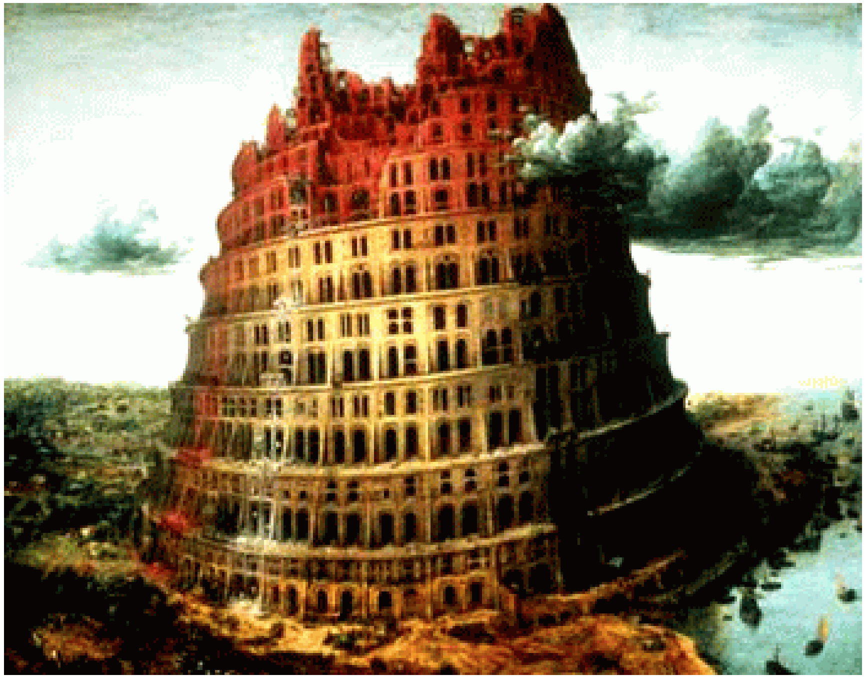
•в жёсткой части наклон $\gamma$ уменьшается → ассиметричные распады $\pi°$



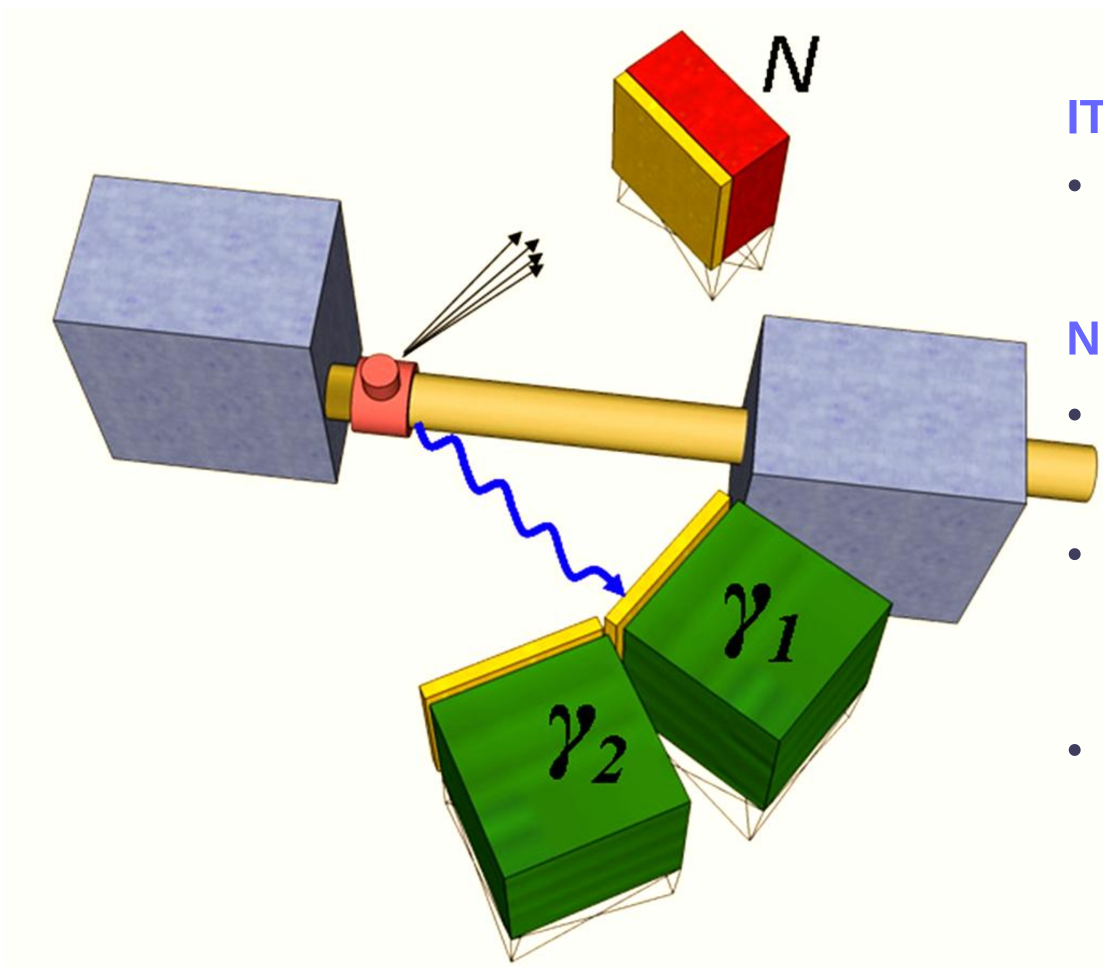
# Is it possible to create dense cold matter in lab?

At large scale - probably not (left figure)

Al relatively small scale – probably yes (right one)



# Next steps




**ITEP**

- Neutron detector beam test
  - Time resolution

**Nuclotron M, MPD-NICA**

- Neutron detector beam test
  - Efficiency study
- AA→ γ + X
  - as high $Q_1+Q_2$ as possible with FLINT@Nuclotron-M
- AA→ γ + B + X
  - dense baryon matter study @ MPD-NICA

# Phase diagram of nuclear matter