# Investigation of initial states and development of methods for their analysis in proton and nuclear collisions at energies of the NICA collider.

***G. Feofilov*, I. Altsybeev, E. Andronov, D. Prokhorova, V. Sandul, A. Seryakov, F. Valiev, A. Zarochentsev**
V.Fock Institute for Physics, Laboratory of Ultra-High Energy Physics, Saint-Petersburg State University

***V. Abramovsky***
Novgorod State University

***A. Baldin***
Joint Institute for Nuclear Research

**The Conference "RFBR Grants for NICA"**
***https://indico.jinr.ru/event/1469/timetable/#all.detailed***
***Wednesday, 21.10.2020, 11:00-11:35***

***Supported by RFBR grant №18-02-40097***

# Layout

- Introduction. Initial states in A+A collisions

PART 1

- Methods of analysis of initial states in p+p and A+A collisions

PART 2

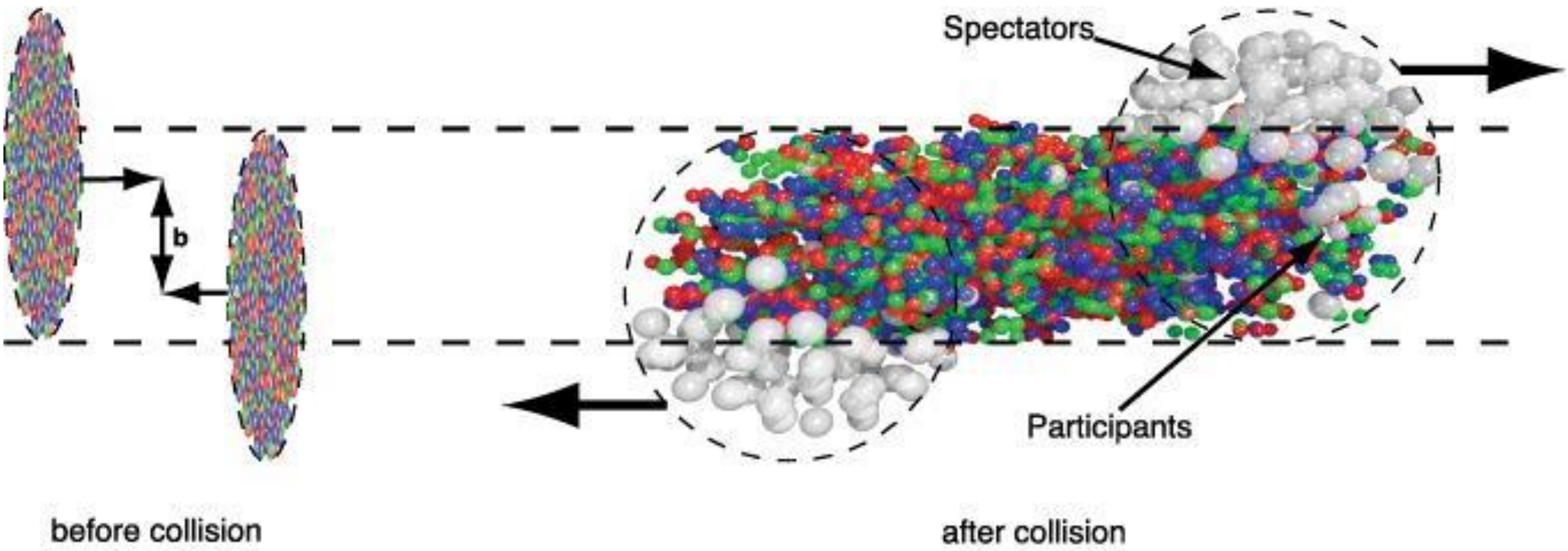
- Results of model simulations

PART 3

- Fast Beam-Beam Collisions counters (FBBC) for NICA

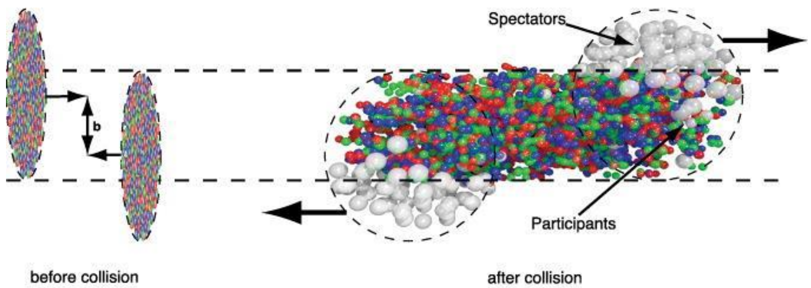
- Conclusions and plans

# Some terminology and definitions




- Impact parameter – b
- Nucleon-participants (*Npart*) – nucleons collided at least once
- Nucleon-spectators ($Nspec = 2A - Npart$) nucleons which didn't interact
- Number of nucleon-nucleon collisions (*Ncoll*)
- Multiplicity of charged particles (*N*ch)

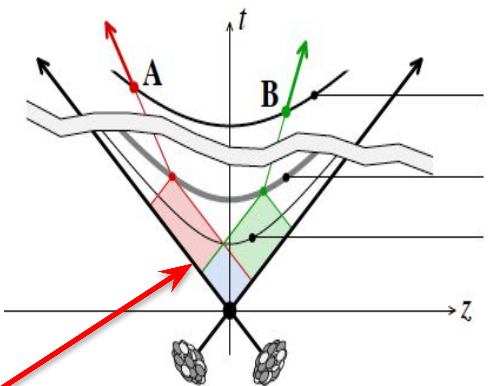
# Some terminology and definitions




*Centrality of collision and Initial conditions used in selection of classes of events*

➢ Proxies for the impact parameter *b:*
- Multiplicity of charged particles
- Nucleon-participants (*Npart*)
- Transverse energy ($E_T$)

***Stages of AA collision***




A.Dumitru et al., arXiv: 0804.3858

*The initial state of collision is defined by the collision centrality and dynamics*

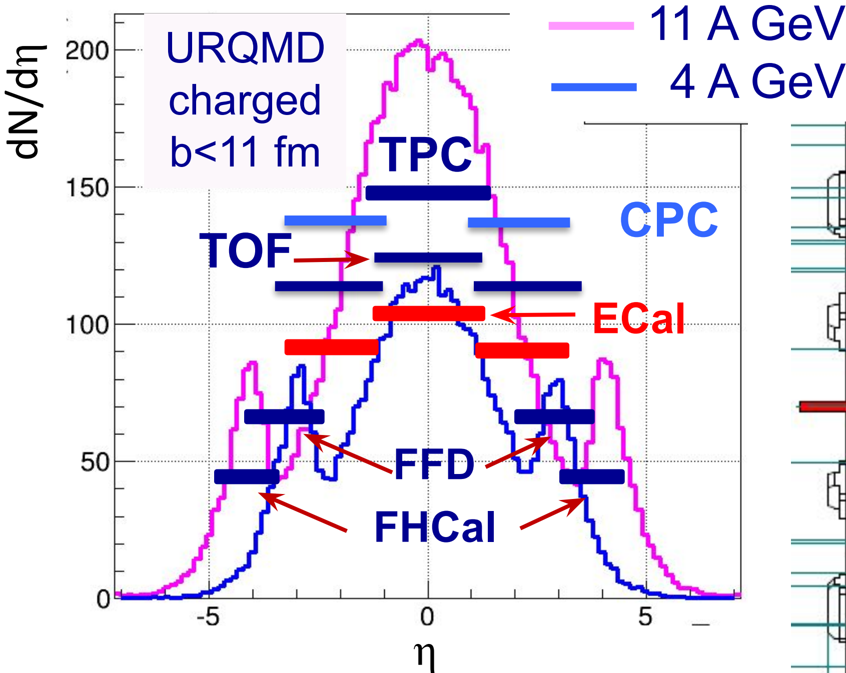
➢ *Fluctuations and Long-range correlations*

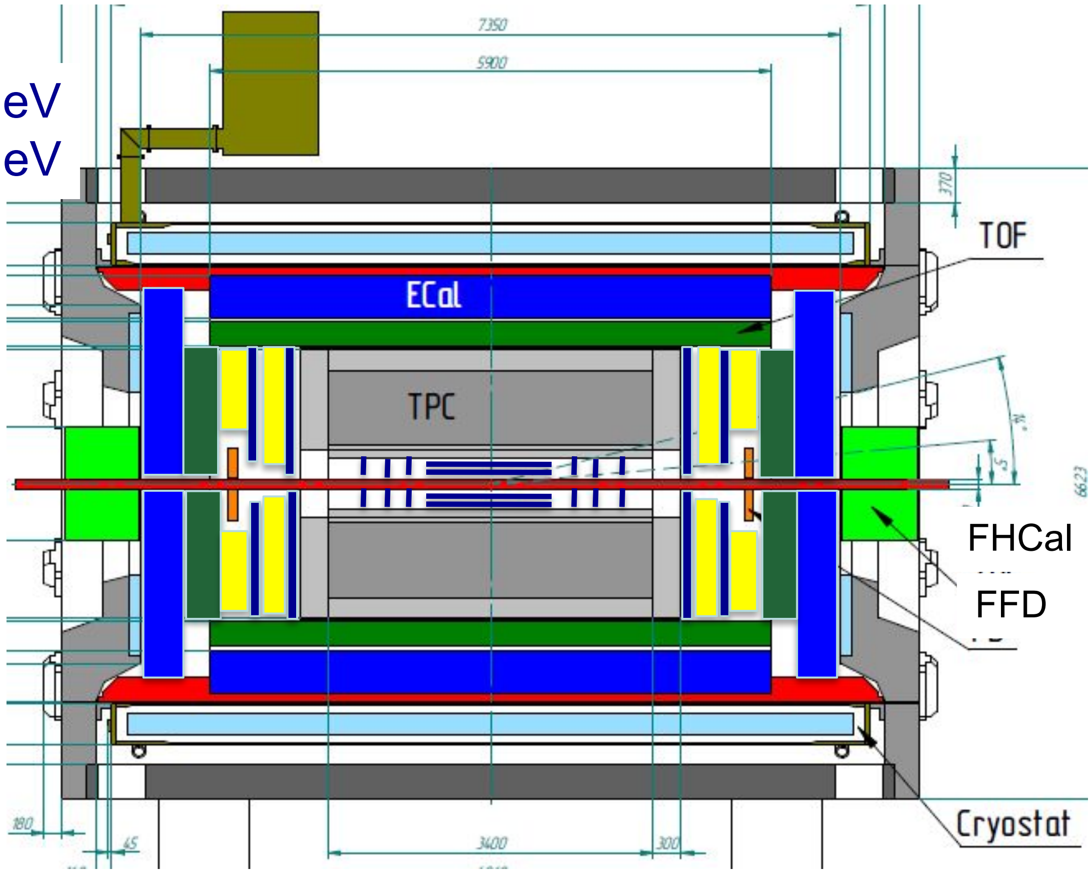
# Multi-Purpose Detector (MPD)

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

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

**stage II** ***acceptance***



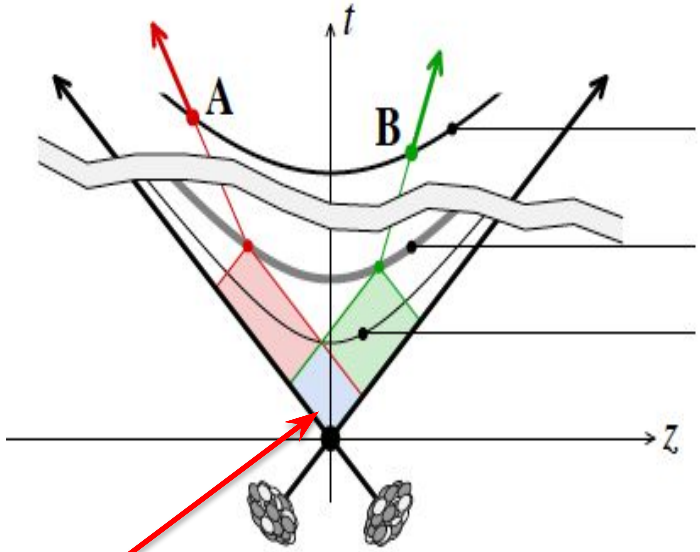

***Selection of classes of events:***
***FFD, FHCal, Ecal…***
***+Beam-Beam collisions counters***

# Initial conditions of multiparticle production

***Task 1)***

***To measure, event-by-event, in p+p and A+A collisions, under well defined initial conditions, the following:***

- Event charge particle multiplicity
- Event mean transverse momentum ($p_T$)
- Event transverse energy ($E_T$)
- Particle types and ratios
- Event net charge
- Number of nucleon-participants ($N_{part}$)
- Event-plane and flow harmonics, etc.




A.Dumitru et al., arXiv: 0804.3858

- ***initial state of collision is defined by the collision centrality and dynamics***

# Initial conditions of multiparticle production

***Task 2)***
***To get at the next step of analysis***
***the mean values of observables for carefully selected classes of events (i.e. for classes of well defined initial conditions):***

- Mean charged particles density at midrapidity ($<dN_{ch}/d\eta_{|\eta=0}>$) for a given class of selected events
- Pseudorapidity distribution ($dN_{ch}/d\eta$),
- Total mean multiplicity ($N_{ch}$)
- Mean transverse momentum ($<p_T>$) and
- Mean event transverse energy ($<E_T>$)
- Mean values of particle ratios

# Initial conditions of multiparticle production

***Task 3)***
***To define criteria for selection of classes of events (classes of well defined initial conditions).***

- **Different estimators of centrality** of A+A collision could be considered **as a proxy** for the impact parameter ***b*:**
  -- Spectator nucleons ($N_s$) and number of nucleons-participants ($N_{part}$);
  -- Event transverse energy ($E_T$);
  -- Multiplicity.
- **Selection of classes of events** is very important for further studies of fluctuations and various correlations of observables, for studies of flow harmonics, light and heavy flavor yields, event shape engineering etc.
- Nevertheless, the trivial fluctuations of the initial conditions could be large.
- These **"volume" fluctuations** should be eliminated or taken into account in the event selection procedure

# In the given report:

We consider three main directions of study:

1) Theoretical analysis of pp and AA collisions at NICA energies

-- modified Glauber approach to estimates of $N_{coll}$ in A+A collisions

2) Model simulations using available event-generators and analysis of impact parameter distributions, classes of events and fluctuations of observables in A+A collisions at NICA energies

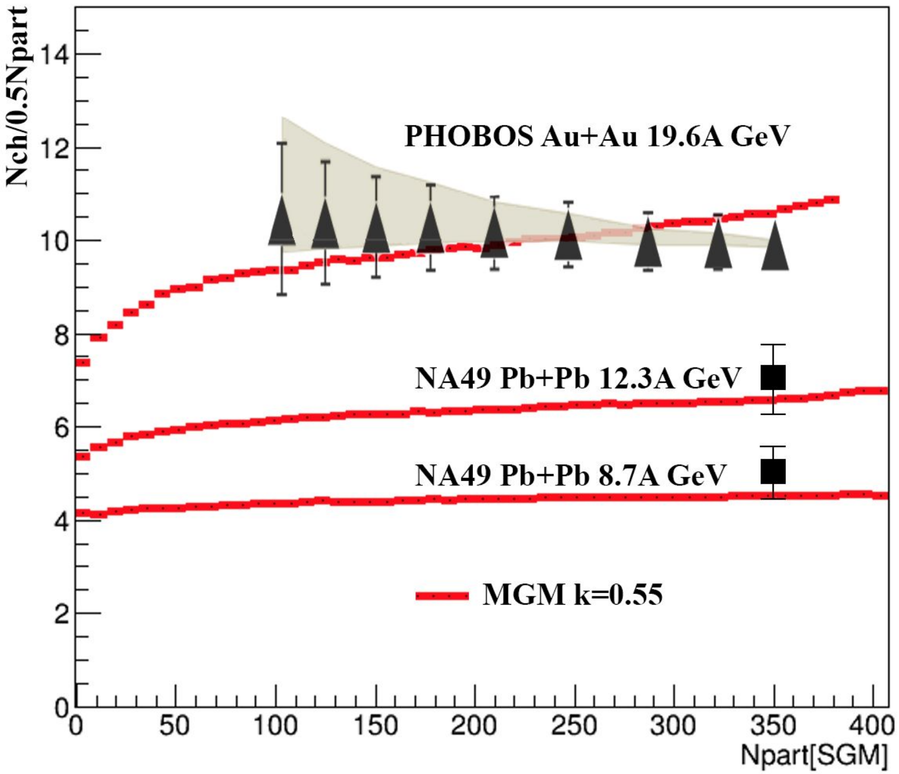
-- test of strongly intensive observables

-- application of Identity method in separation of tracks of different particles

3) Development of a new concept of event-selection and beam-beam collisions monitoring

# PART 1

# Modified Glauber Model [1] for NICA/SPS/RHIC energies



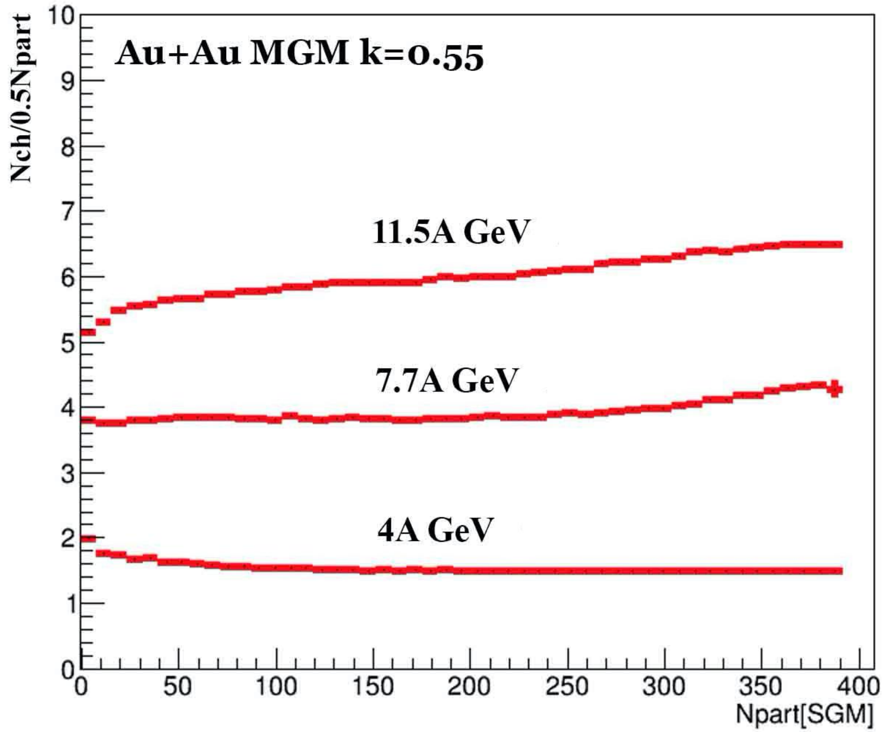

- The fixed portion (1-k) of momentum in the center of mass system[1] is lost by nucleon in each inelastic collision
- Losses are due to the production of charged and neutral particles
- Parameter k is defined by fitting the available experimental data on charged-particle multiplicity yields in A+A collisions

Modified Glauber Model (MGM) calculations for A+A collisions (red lines – new results [A.Seryakov, G.Feofilov]) in comparison to experimental data from SPS and RHIC



[1] G. Feofilov, A. Ivanov, Journal of Physics G CS, 5, (2005) 230-237.

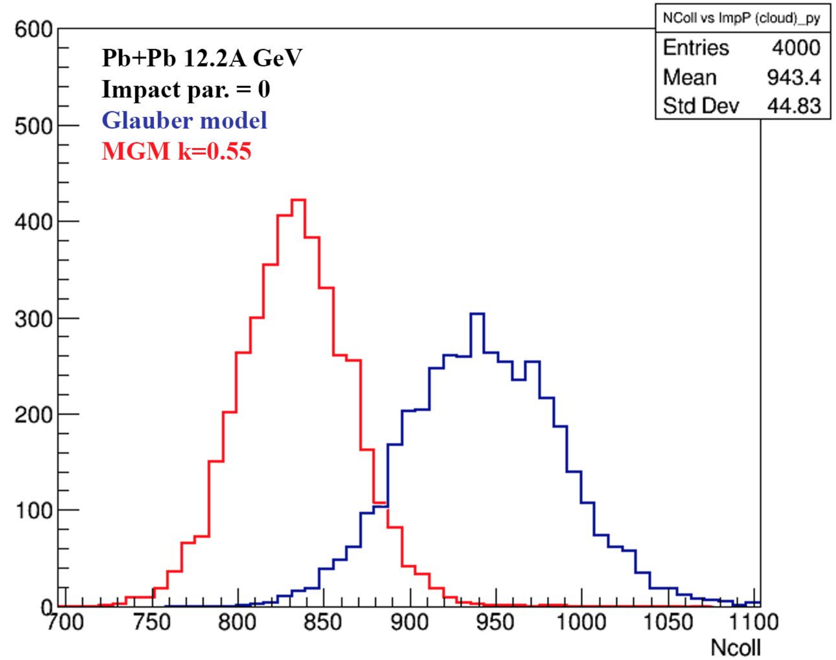
# Modified Glauber approach for Au+Au collisions at NICA energies

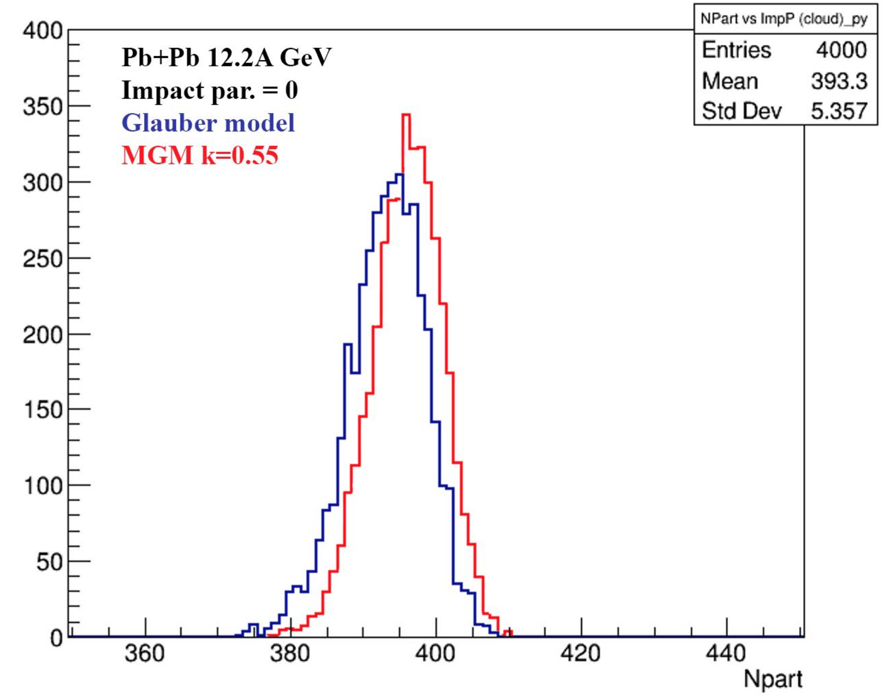



Total multiplicity of charged particles, normalized by the $N_{part}$ vs. $N_{part}$

- our predictions for Au+Au collisions for NICA energies calculations using the MGM with a momentum loss coefficient **k = 0.55.**

# MGM and GM for Pb+Pb collisions: $N_{coll}$ and $N_{part}$ fluctuations




Glauber model and MGM calculations of $N_{coll}$ (left) and $N_{part}$ (right) for $b$=0 Pb+Pb collisions (red lines – new results [A.Seryakov,G.Feofilov])

- **Account of energy-momentum conservation in multiparticle production process decreases considerably values of $N_{coll}$**

# Conclusions: Part 1

- Predictions of the modified Glauber model with the account of momentum and energy conservation in multiparticle production show considerable difference in such quantity as number of binary nucleon-nucleon collisions $N_{coll}$ widely used in data analysis. This fact is under investigations and will be accounted for the MPD data event classes applications.

# PART 2

# Strongly intensive observables

It is desirable to exclude trivial fluctuations in searches for critical effects and studies of initial stages. Special families of observables called strongly intensive were introduced [1]:

$$\Delta[A, B] = \frac{1}{C_\Delta}\Big[\langle B\rangle\omega[A] - \langle A\rangle\omega[B]\Big]$$

$$\Sigma[A, B] = \frac{1}{C_\Sigma}\Big[\langle B\rangle\omega[A] + \langle A\rangle\omega[B] - 2\big(\langle AB\rangle - \langle A\rangle\langle B\rangle\big)\Big].$$

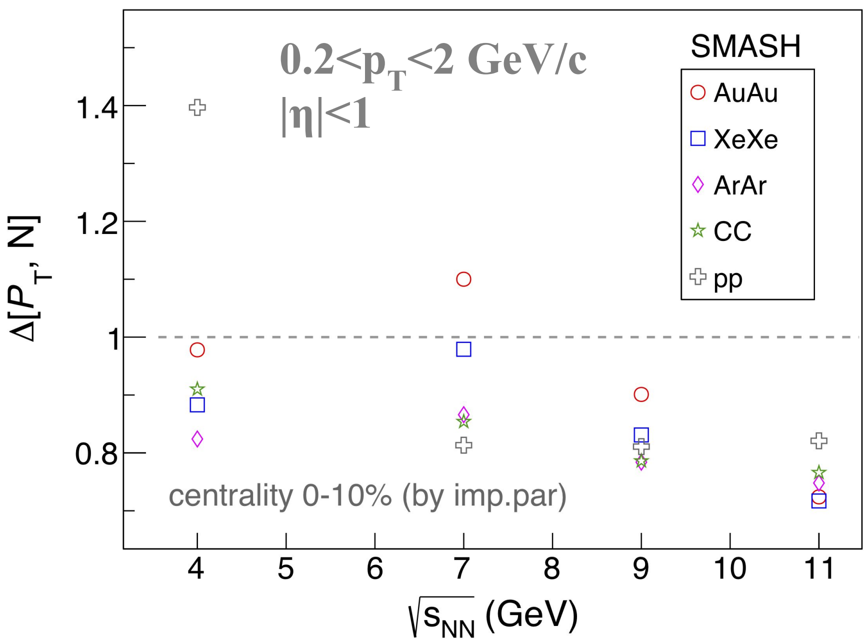
- ➢ constructed for pairs of extensive observables
  - ○ multiplicity-total transverse momentum correlations ($N$-$P_T$)
  - ○ forward-backward multiplicity correlations ($N_F$-$N_B$)
- ➢ suppress dependence on volume and volume fluctuations in model of independent sources
- ➢ sensitive to the presence of the critical point of strongly interacting matter [2]

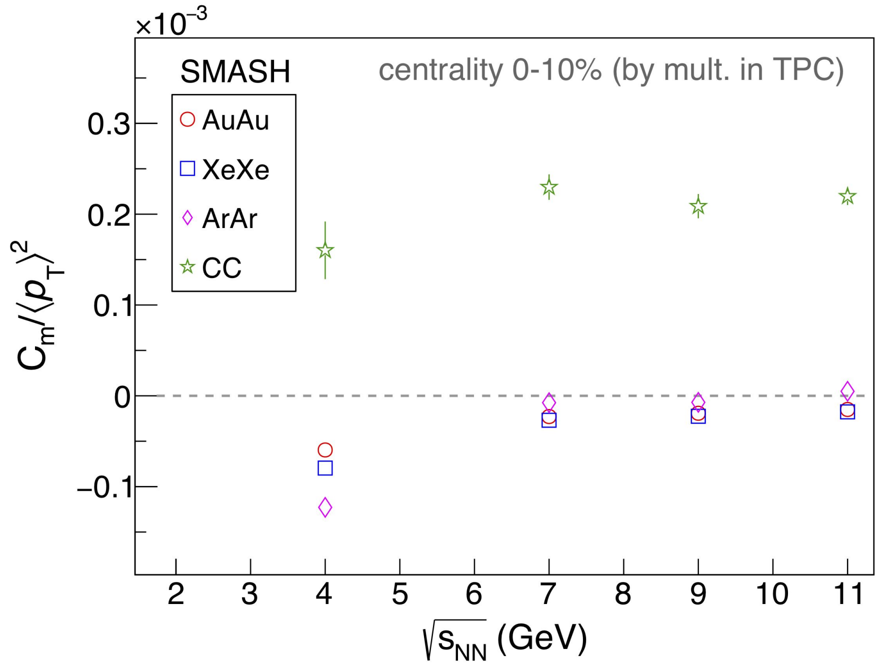
For $P_T$-N fluctuations these observables are closely connected with the two-particle $p_T$ correlator $C_m = \langle \Delta p_{\mathrm{T},i}, \Delta p_{\mathrm{T},j}\rangle$ [3].


[1] M. Gorenstein, M. Gazdzicki, Phys.Rev.C84, 014904 (2011)
[2] V. Vovchenko et al., J.Phys.A49, 015003 (2015)
[3] ALICE Coll., Eur.Phys.J.C74, 3077 (2014)

# Strongly intensive observables - $P_T$ vs N

MPD MC production (request #8) - pure SMASH simulations

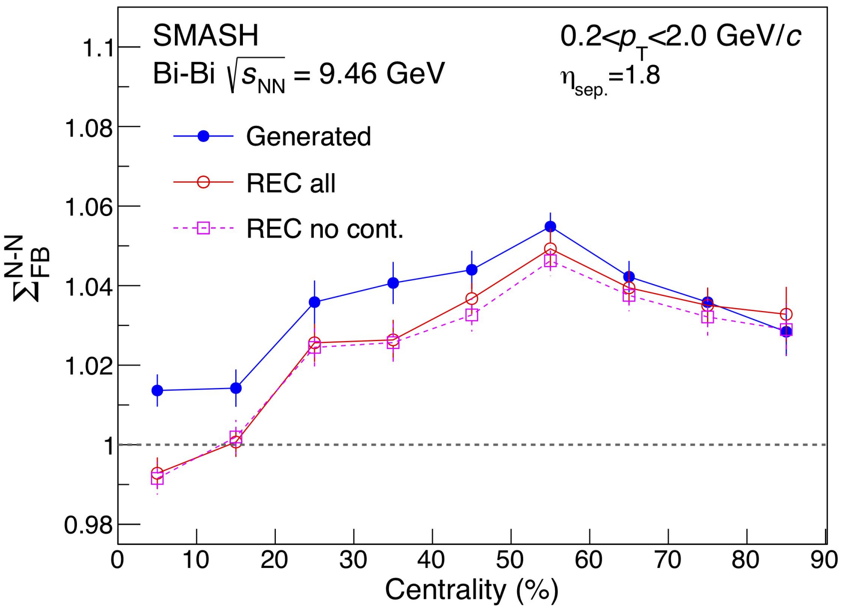


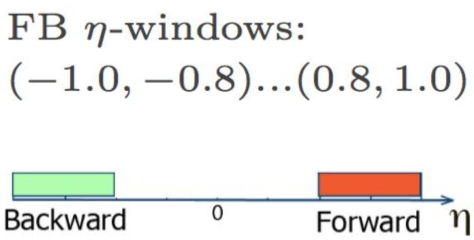




- Energy vs. system scan - probing diagram of strongly interacting matter at different T and $\mu_B$
- Non-trivial 'background' (no critical phenomena in SMASH) for critical behaviour search - rapid transition in region (4-7) GeV visible in $\Delta$
- Transition from positive to negative values of the two-particle transverse momentum correlator with increase of colliding nuclei atomic number

# Strongly intensive observables: Forward-backward correlations $N_F$ vs. $N_B$

MPD MC production (request #6) - SMASH+GEANT+reco



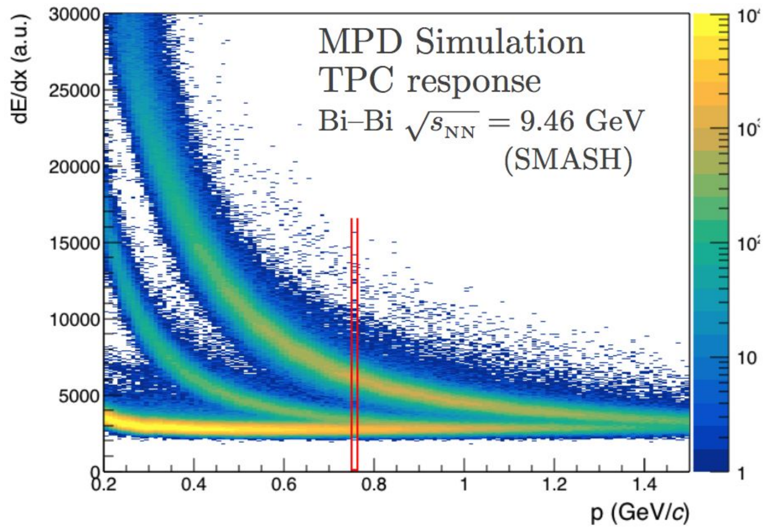



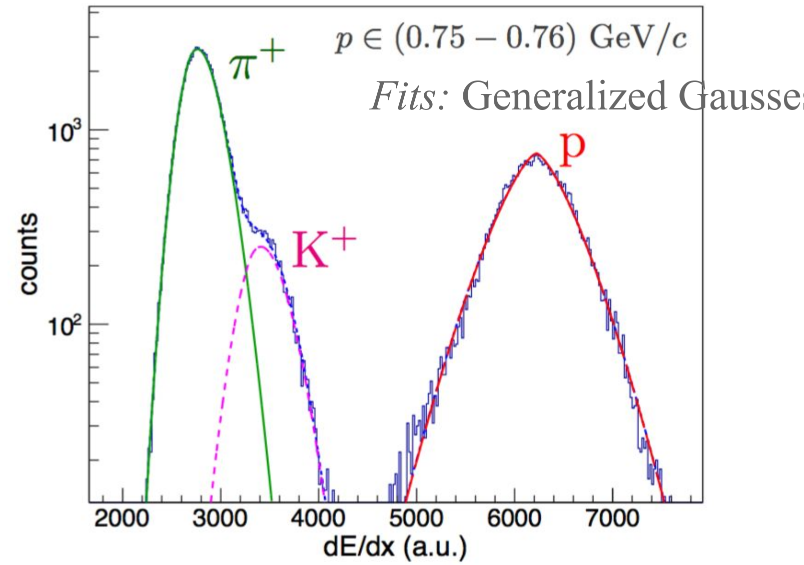

- ➢ Moderate dependence on centrality -> deviation from strong intensity
- ➢ Small detector effect for peripheral collisions, up to 5% difference for central
- ➢ Small influence of contamination (from weak decays, detector material)
- ➢ Unfolding procedure was also successfully tested

# Identity method - fluctuations with PID

*The idea:* **Identity Method eliminates the effect of particle mis-identification** using these probabilities, and allows for the calculation of pure and mixed moments of multiplicity distributions. M.Gazdzicki et al.,Phys.Rec.C83, 054907 (2011)

*Example: momentum slice* 0.75-0.76 GeV/c:




$$\omega_j(x_i) = \frac{\rho_j(x_i)}{\rho(x_i)} \in [0,1], \quad \rho(x_i) = \sum_j \rho_j(x_i),\ W_j \equiv \sum_{i=1}^{N} \omega_j(x_i).$$

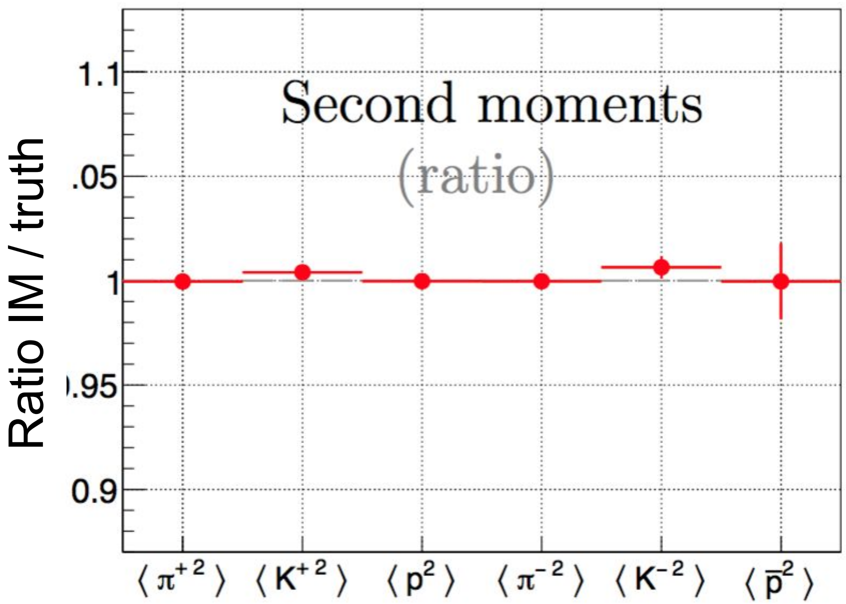
$$\boxed{\langle N_j^n \rangle = A^{-1} \langle W_j^n \rangle}$$

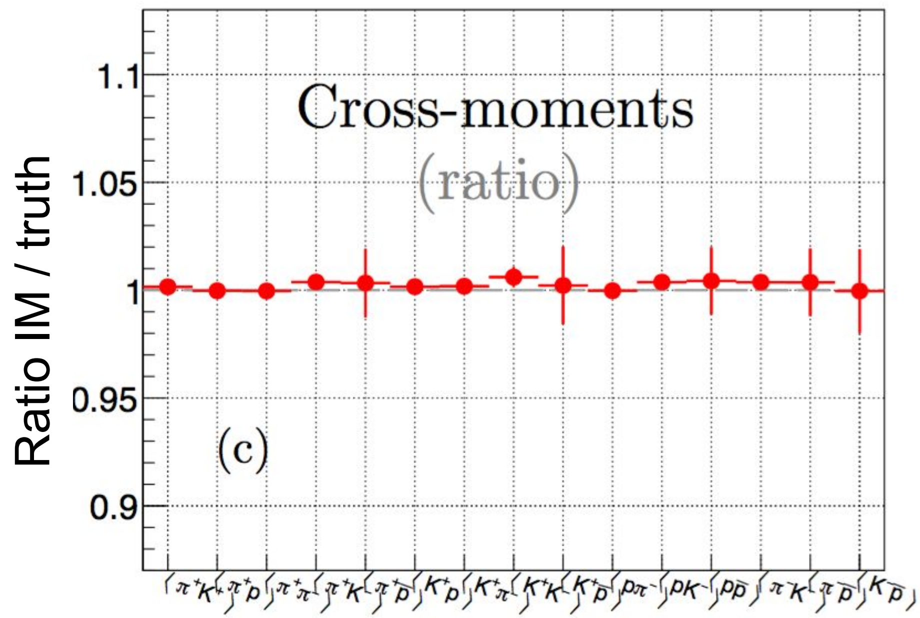
*Moments corrected with the IM can be used for:*

- Fluctuations of particle yields in full acceptance (e.g. net-proton)
- Forward-Backward correlations of identified particles

# Identity method: ratio to the *true* moments

MPD MC production (request #6) - SMASH+GEANT+reco, BiBi @ 9.46 GeV
centrality 0-20% (by mult. in TPC)
$|\eta|<1$, p in **0.3–1.2** GeV/$c$




- Reasonable quality is achieved in these first tests
- Room for improvement:
  - dE/dx fits
  - Increased statistics

# Conclusions: Part 2

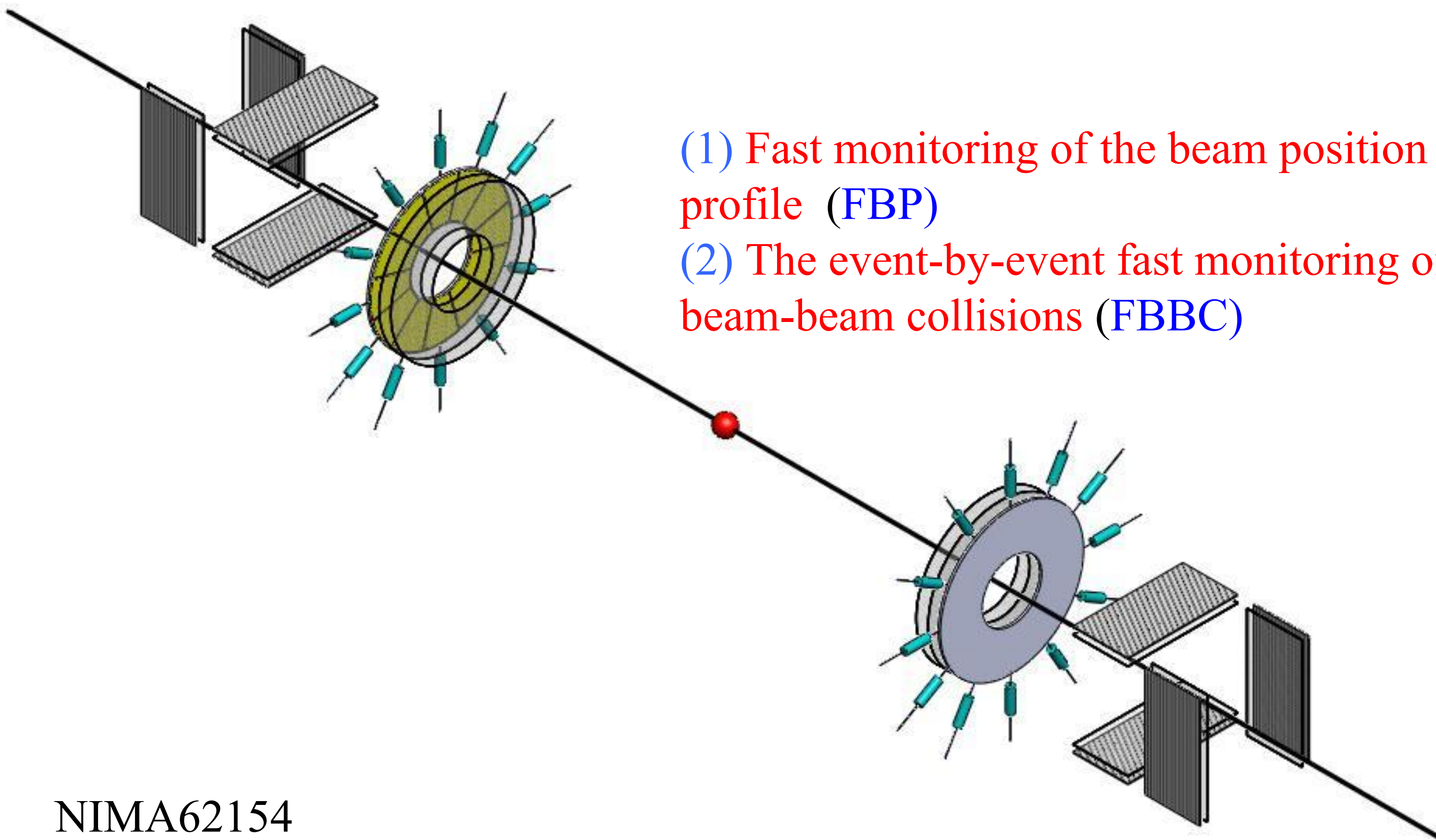
- The example of the system-energy scan of the phase diagram of strongly interacting matter was performed in the SMASH generated data in terms of the strongly intensive quantity $\Delta[P_T,N]$ and two-particle $p_T$ correlator $C_m$.

- The detector bias influence on the strongly intensive quantity $\Sigma[N_F,N_B]$ for different centrality classes and for different pseudorapidity acceptance of the Forward and Backward intervals was estimated.

- The application of Identity methods is checked at NICA energies using MC event-generators data. It is  shown to be useful in particle identification in A+A collisions at MPD/NICA.

# PART 3

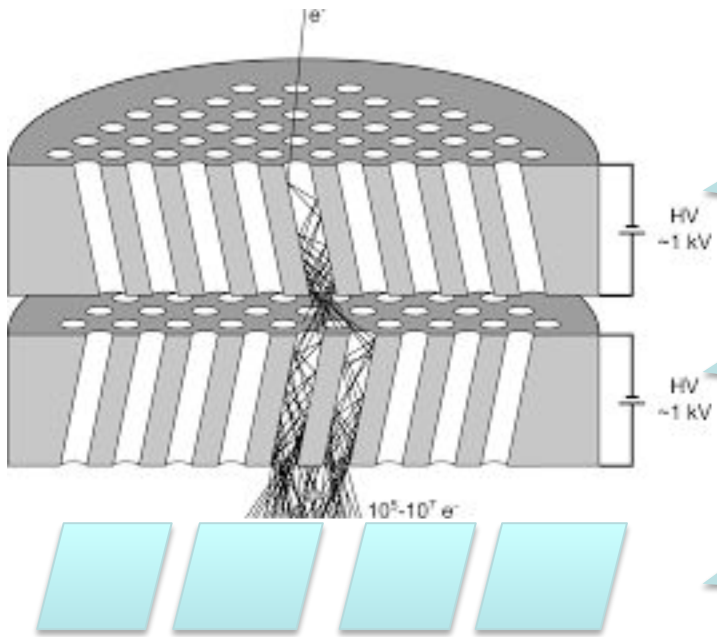
# MCP-based solutions for Beam Position Monitor (BPM) and Fast Beam-Beam Collisions counters (FBBC) for NICA



(1) Fast monitoring of the beam position and profile (FBP)
(2) The event-by-event fast monitoring of beam-beam collisions (FBBC)

NIMA62154
DOI: 10.1016/j.nima.2019.04.108

# Micro Channel Plates (MCPs) as a MIP detector [1,2]

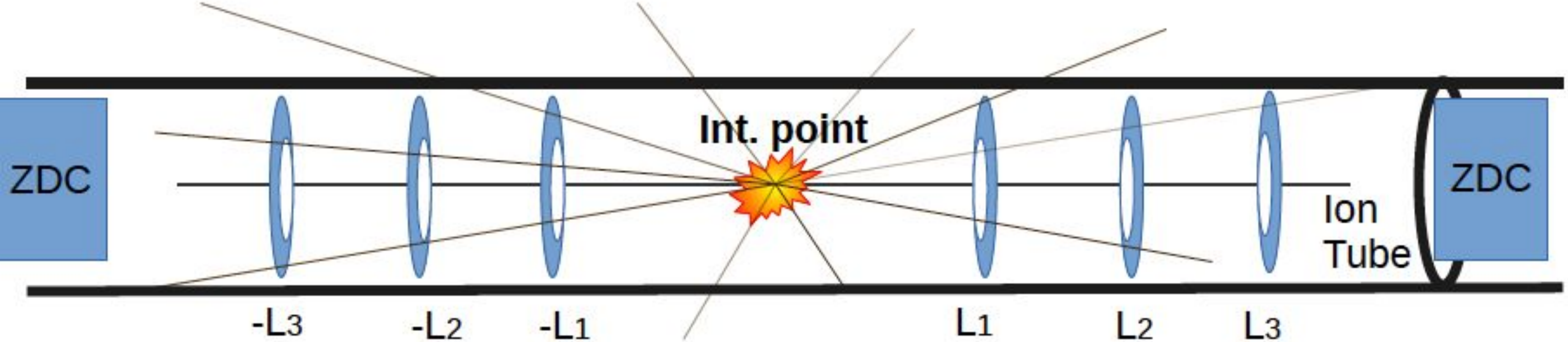



Active target-converter

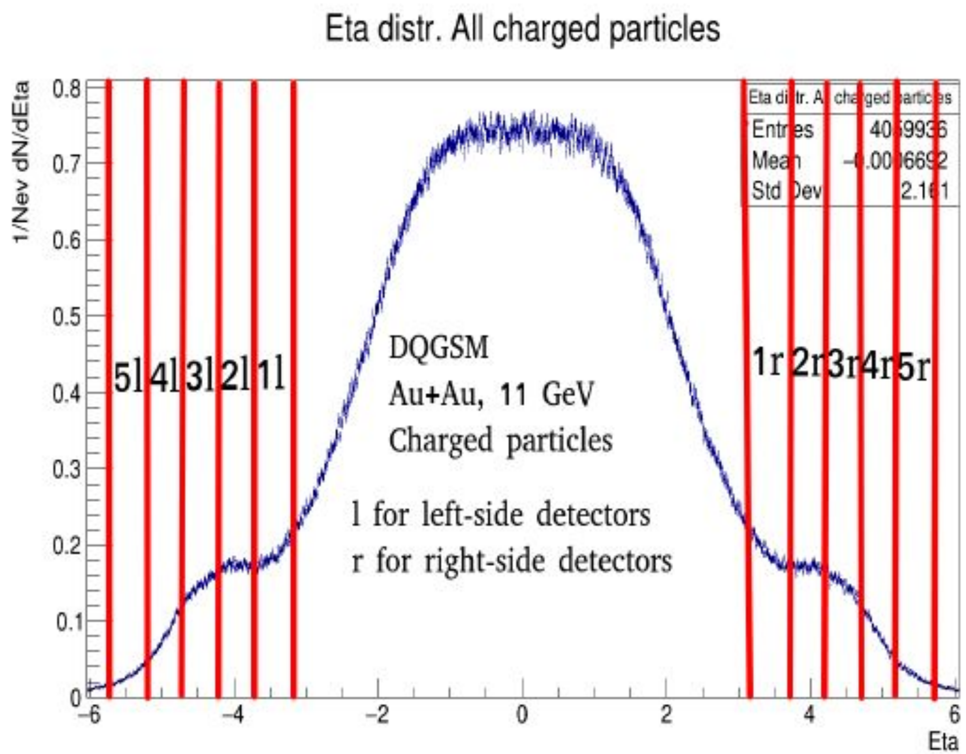
MCP-Amplifier

Readout anodes

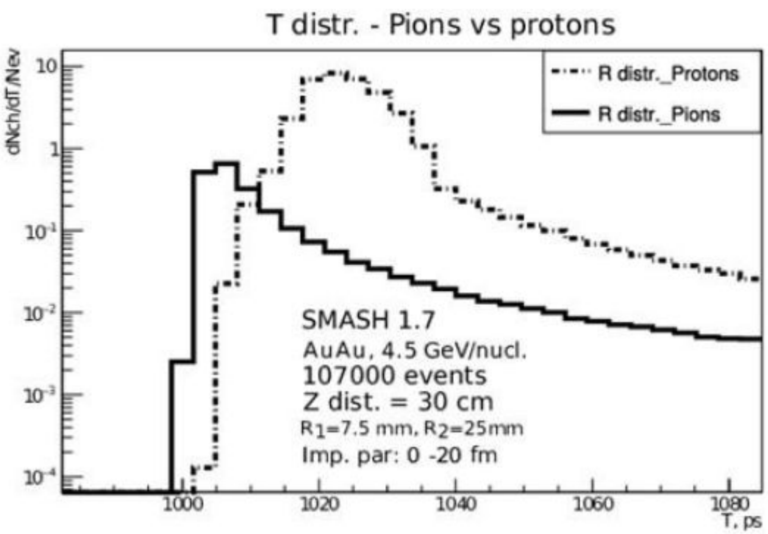

[1]A.Baldin,G.Feofilov,F.F.Valiev et al.
Microchannel plates as a detector for 800 MeV/c charged pions and protons. // JINR Rapid Communications. 1991. No 4/50/-91. p.27-36.
[2] A.A.Baldin, G.Feofilov,Yu.Gavrilov, A.Tsvinev,F.Valiev,
Proposals for a new type of microchannel-plate-based vertex detector// NIM A323. 1992. p. 439-444.

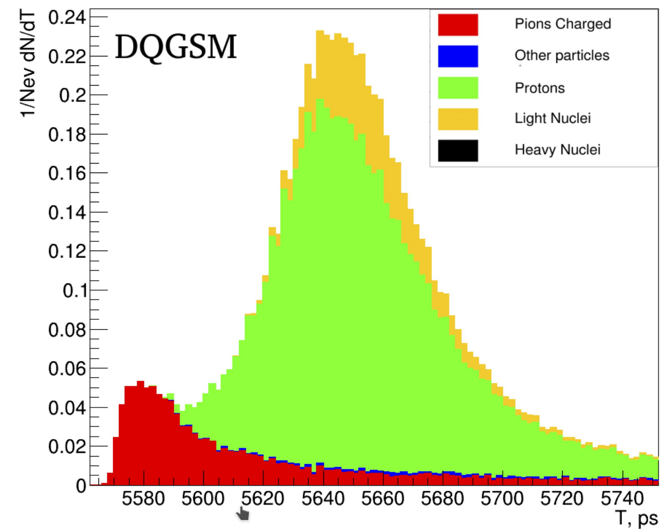



- **Used MC generators:** UrQMD, SMASH, DQGSM (without GEANT)
- **Collisions:** Au+Au, √s = 11 GeV per NN pair, impact parameter = 0 – 14 fm, 10000 events
- **Number of plates:** 5 right + 5 left;
- **L1,… , L5** = [30 / 50 / 80.3 / 138.9 / 231.5] cm
- **Covered pseudorapidity region:** $3.18 < |\eta| < 5.73$
- **Charged particles** only

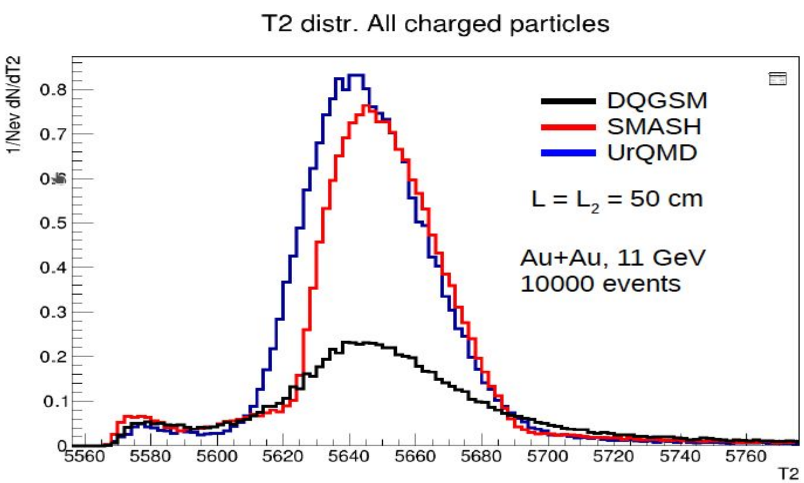


# ToF particle distributions for Au+Au collisions




## Time distributions: generators comparison




This figure illustrates why we cannot clearly compare results of different MC generators since we did not create algorithm of nuclei fragments recognizing for SMASH and UrQMD outputs.

# Conclusions: Part 3

- Compact beam-beam collisions (BBC) monitor is proposed for NICA beams at the MPD and future SPD installations.
- The high timing resolution allows, for each event of collision, the event-selection in the Interaction Region, beam-gas collision suppression, fast precise trigger signal.
- The work on new centrality selection criteria base on the TOF separation of pions and protons with this BBC is in progress

# Conclusions and plans

- The comparison of the Modified Glauber Model predictions with the Standard Glauber calculations showed the considerable difference in mean values and fluctuations in case of $N_{coll}$ (and some shift of in case of $N_{part}$). This can be due the absence of the energy-momentum conservation account in the processes of inelastic binary collisions in the Standard Glauber approach, and therefore gives the overestimated values of $N_{coll}$.

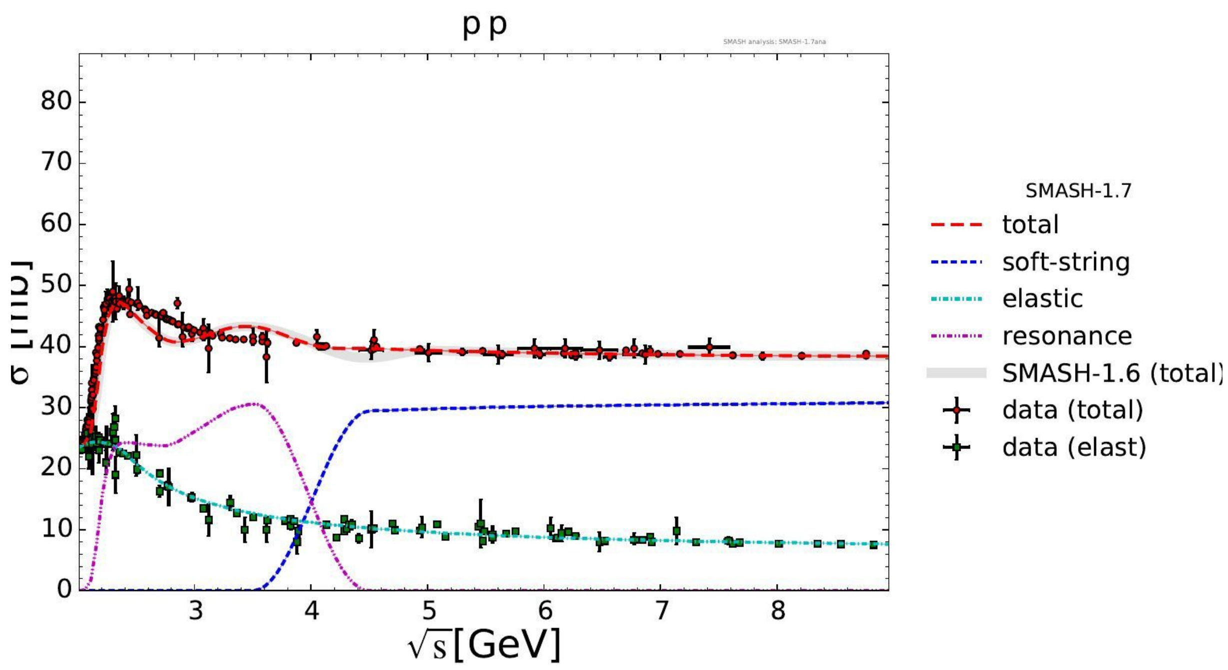
- The example of the system-energy scan of the phase diagram of strongly interacting matter was performed in the SMASH generated data in terms of the strongly intensive quantities. The detector bias influence was estimated, tests of Identity method and unfolding were performed. It is planned to repeat the calculations with the UrQMD model.

- Feasibility study of the proposed MCP-based fast beam-beam collisions compact monitor was performed basing on the MC simulations. Resulting time-of-flight distributions obtained with the DQGSM model showed that the position of the event IP in the beam-line direction can be measured with a high precision. High timing capabilities of the proposed monitor are to be investigated further in view of indications to discriminate by TOF spectra analysis different types of particles produced at very forward rapidities.

Thank you for your attention!

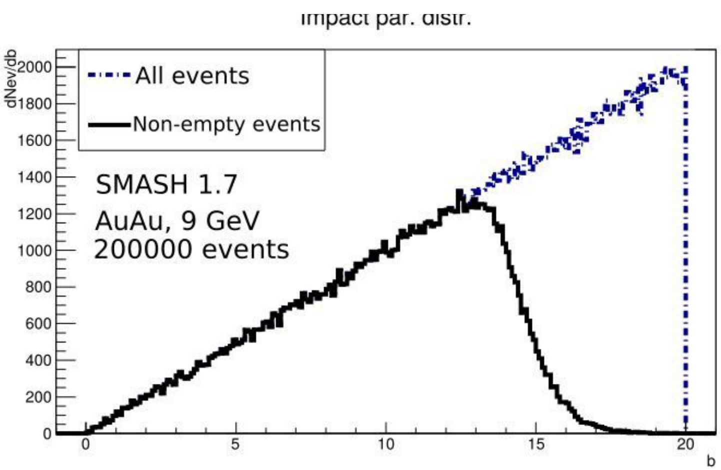
# BACK-UP SLIDES

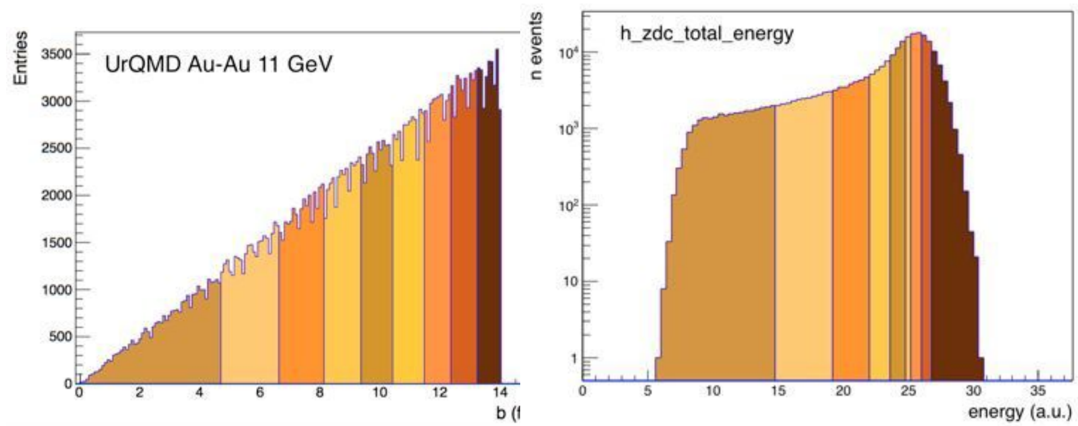
# Energy dependence of different processes in pp collisions




Dependence of the total scattering cross section for proton-proton collisions and the contribution of individual processes to it.
Data vs. SMASH

# MC (SMASH and UrQMD) simulations of impact parameter distributions in Au+Au

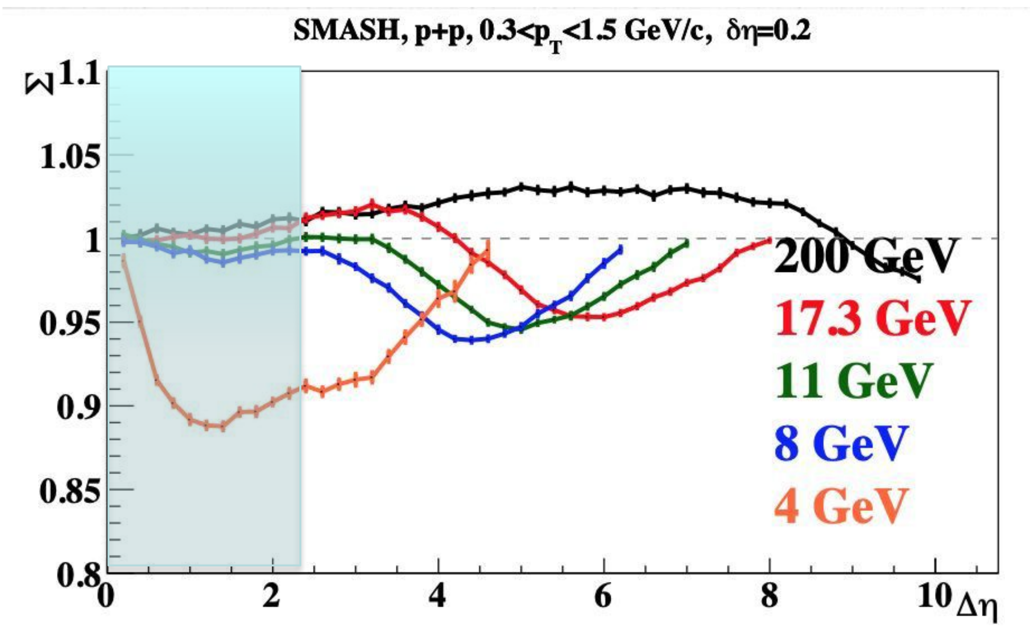



Distribution of events generated in SMASH by impact parameter b: solid line - min. bias events, broken line - all generated events.

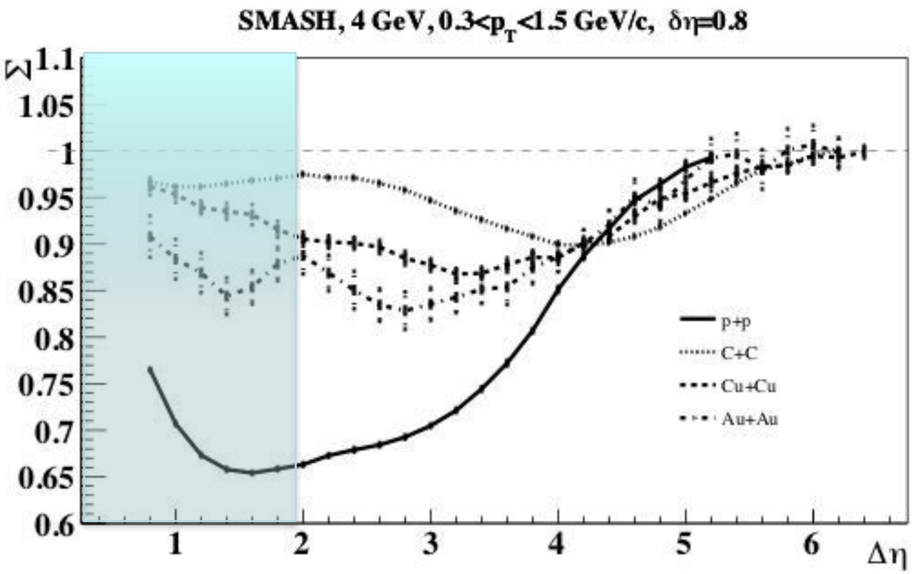
Event classes (10% wide) in the range 0-90%, received by dividing the distribution of UrQMD events into 9 classes by the impact parameter (left) and energy distribution in the FHCal calorimeter (right).

# Strongly intensive observables in SMASH



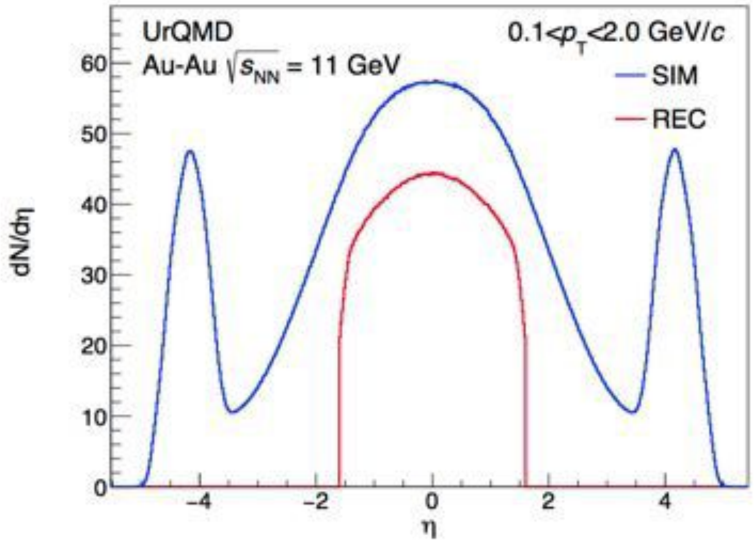

Σ [nF, nB] as a function of the distance between the pseudo-rapidity windows Δη, calculated for inelastic p + p interactions in the SMASH v.1.6 event generator for five energies: 4, 8, 11, 17.3 and 200 GeV. The width of the pseudo-rapidity windows is δη = 0.2. For each energy a million events were generated. Statistical error calculated by the subsample method.

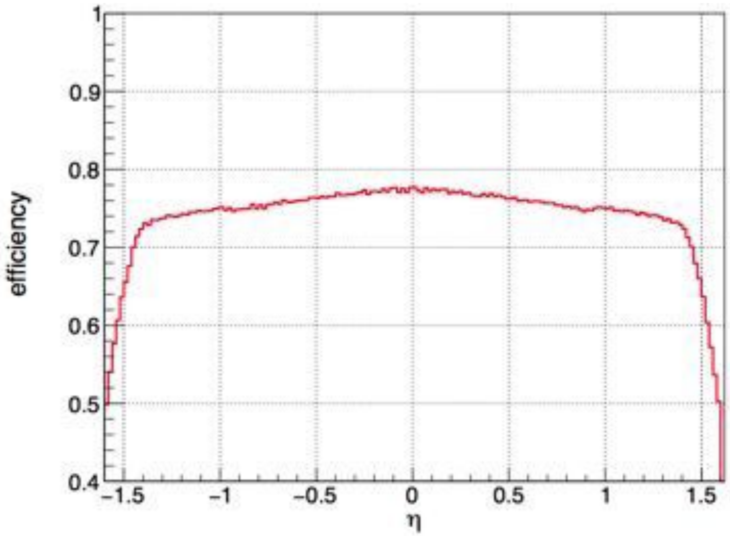
# Strongly intensive observables in SMASH




Σ [nF, nB] as a function of the distance between the pseudo-rapidity windows Δη, calculated for inelastic p + p interactions (1M events), central (b = 0 fm) C + C (300k events), Cu + Cu (30k events) and Au + Au (5k events) collisions in event generator SMASH v.1.6 for an energy of 4 GeV per nucleon pair.
Width pseudo-rapidity windows δη = 0.8 For each energy 1mln events. The statistical error is calculated using the subsample method.

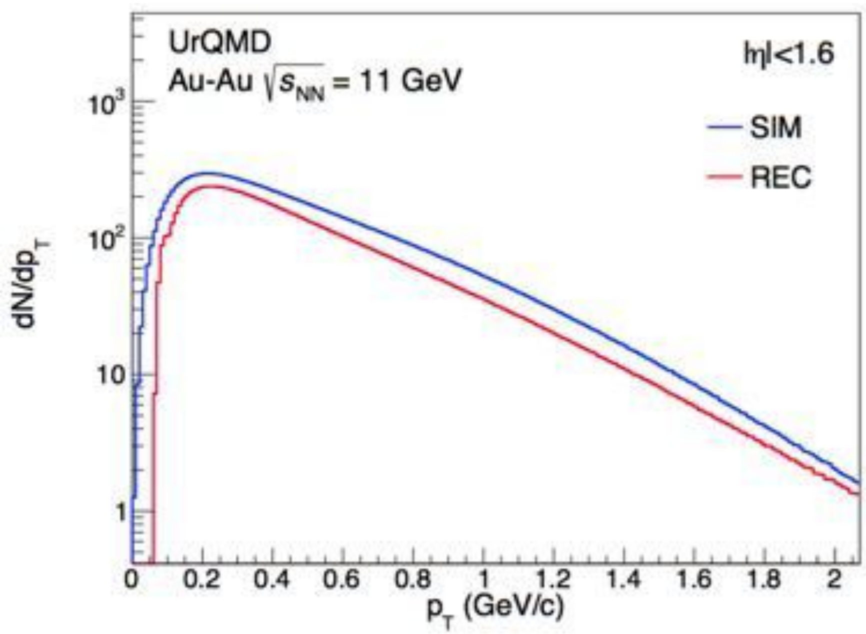
# UrQMD simulations and reconstruction

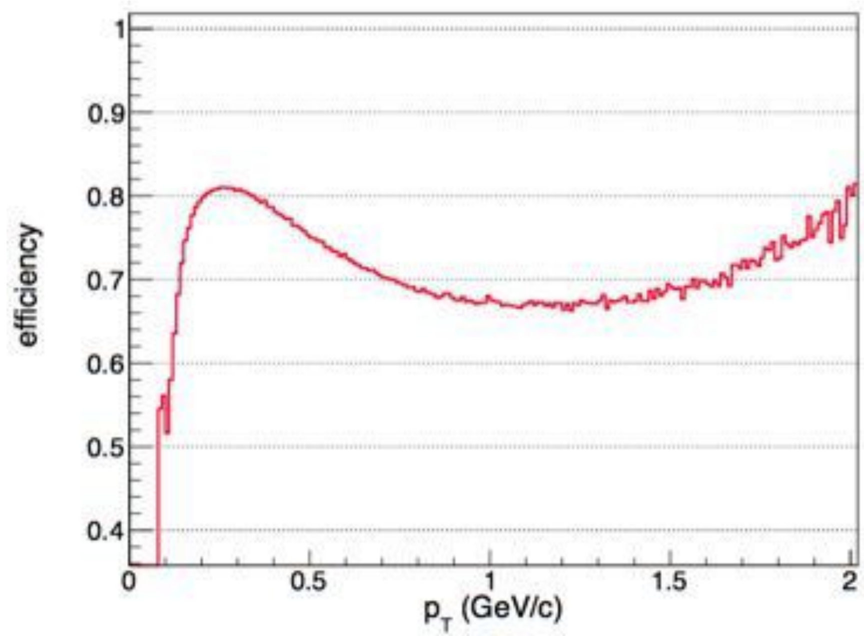



Left: distribution of particles (sim) and reconstructed tracks (rec) over pseudo-rapidity in UrQMD simulations (left).
Right: registration efficiency tracks as a function of pseudorapidity, for the pT range (0.1, 2.0 GeV / s).
Preliminary estimates based on simulated MPD datasets, located in the zfs storage.

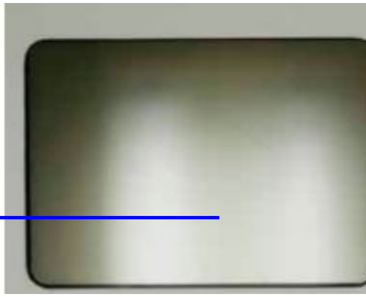
# UrQMD simulations and reconstruction



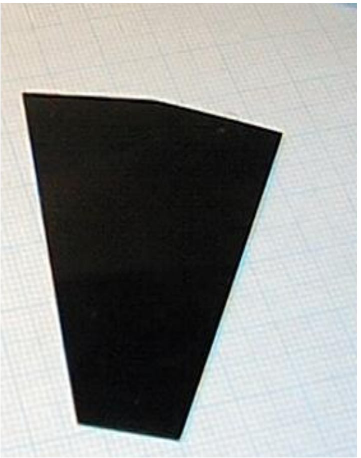

Left: distribution of particles (sim) and reconstructed tracks (rec) over transverse momentum (pT) in UrQMD simulations (left).
Right: efficiency registration of tracks as a function of pT (in the range | η | <1.6).

# Micro Channel Plates



**OPTIONS:**

1) High resolution rectangular 43x63 mm$^2$ MCPs with 6-15 µm - channel diameter -- could be used for the **BPM**



2) Sector type MCPs with the multipad isochronous readout of the MCP array--could be used for the **FBBC**

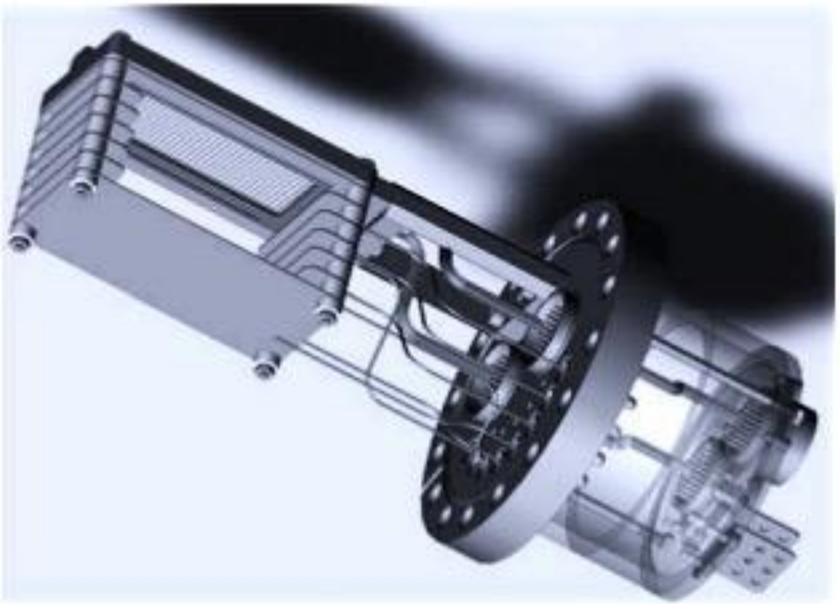
3) MCP 56-15ch 12-15 with 15 µm - channel diameter --could be considered for **a very compact FBBC** placed inside the vacuum beam pipe (Dimensions: 24 mm center hole and the outer diameteris 60 mm)

**OPTIONS:**

VTC "BASPIK" detectors with a gap clearance between MCPs (with separated power supply). **https://baspik.com/eng/news/456/**

This unique feature helps to get amplification gain factor above $1\times10^7$

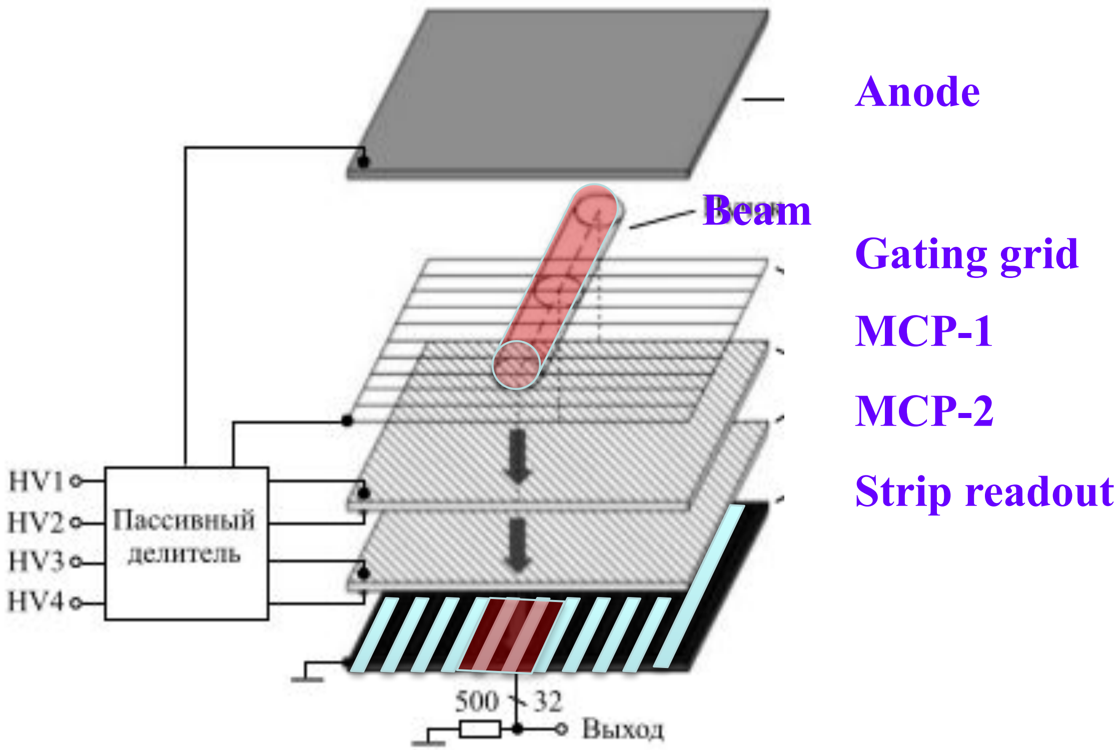
# First test results of the beam profile Monitoring



MCP-based device for fast monitoring of the beam profile (FBP) at the NUCLOTRON [1]

[1] A.Baldin, A.Berlev, I.Kudashkin, A.Fedorov, Space-time characteristics of the circulating beams, Letters to ECHAIA, 2014, vol.11, №2 (186), p.209-218

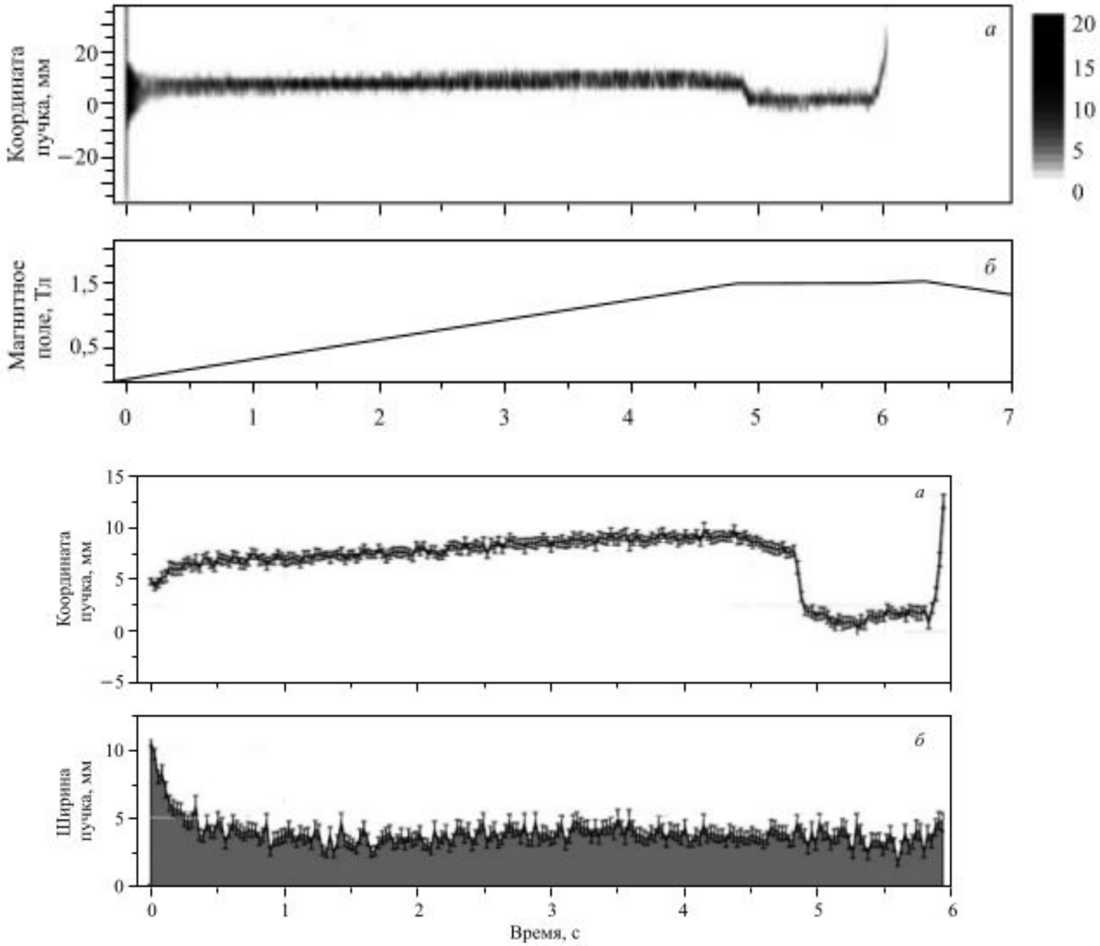
# Beam Position Monitor (BPM) [1]





[1] A.Baldin, A.Berlev, I.Kudashkin,
A.Fedorov, Letters to ECHAIA, 2014, vol.11,
№2 (186), p.209-218

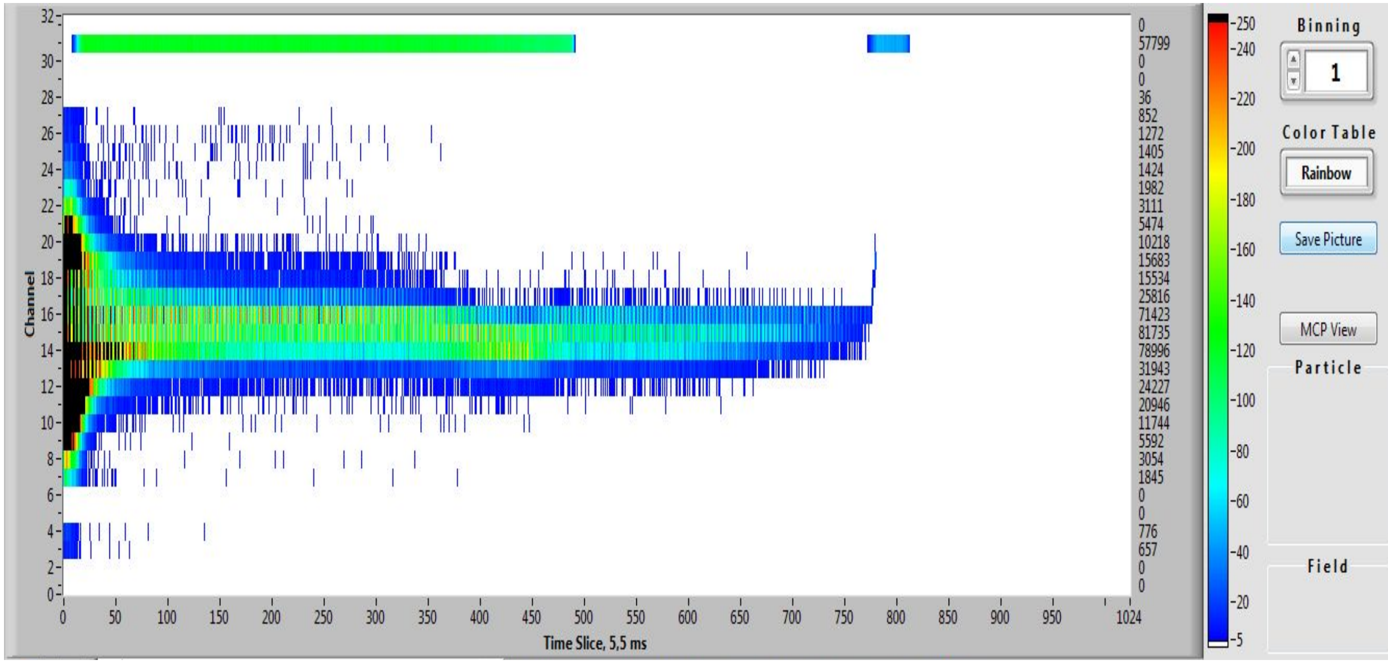
# Space-time characteristics of the circulating beams: tests at Nuclotron, JINR




Example of the deutron beam position measurements
by using the residual gas interaction MCP-based detector at the NUCLOTRON.
The energy of deutron beams was= 4GeV, beam intensity -$10^8$, Vacuum $10^{-8}$ Torrr.[1]

[1] A.Baldin, A.Berlev, I.Kudashkin, A.Fedorov, Letters to ECHAIA, 2014, vol.11, №2 (186), p.209-218

# Space-time characteristics of the circulating beams: tests at Nuclotron, JINR in February-April 2018

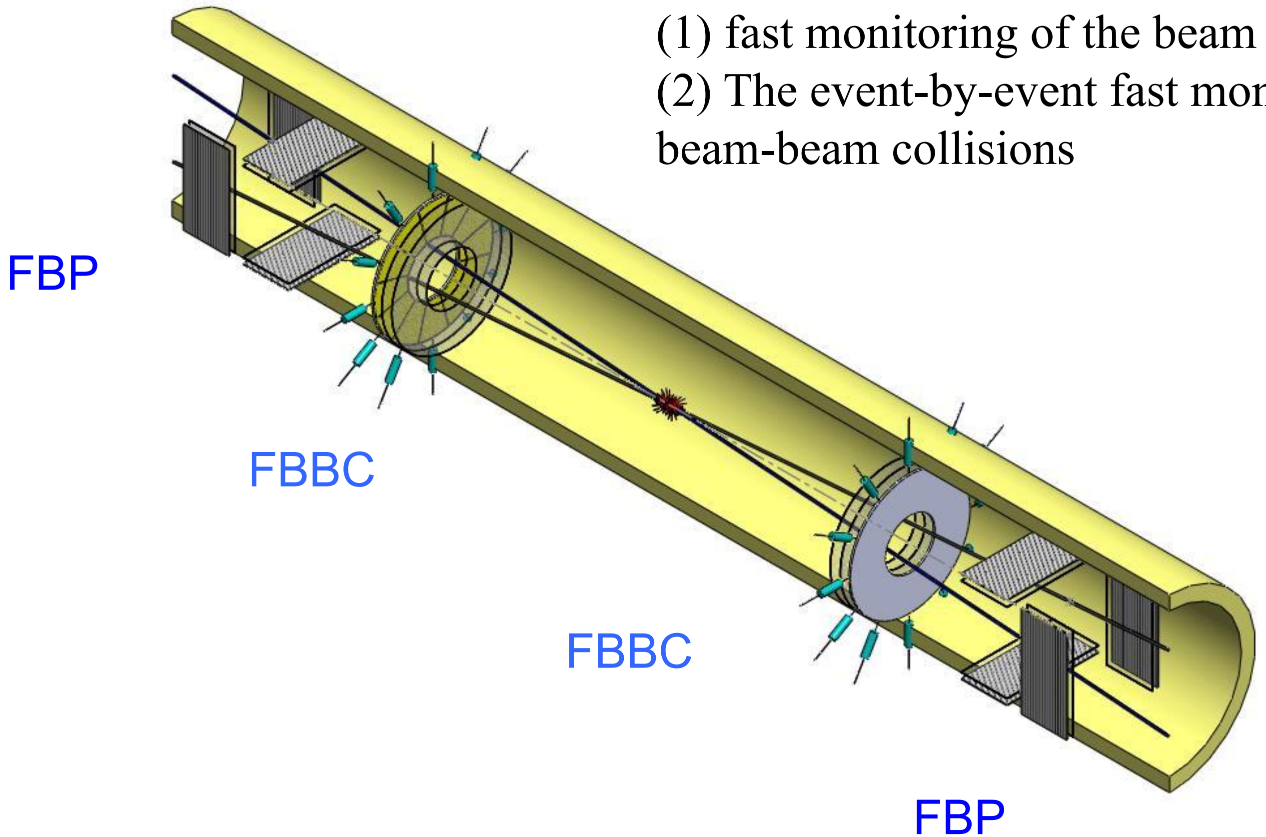



Dynamic profile of an accelerated krypton beam inside the NUCLOTRON accelerator ring (Vertical readings of the upper pattern in mm).

Example of the Kr beam position measurements at the NUCLOTRON. The energy of beams was 3.5GeV , beam intensity --$10^6$, vacuum { $10^{-8}$ Torrr. Time Slice = 5,5 ms. Y scale has 3 mm channel bin width.

# Fast Beam-Beam Collisions Monitoring (FBBC)

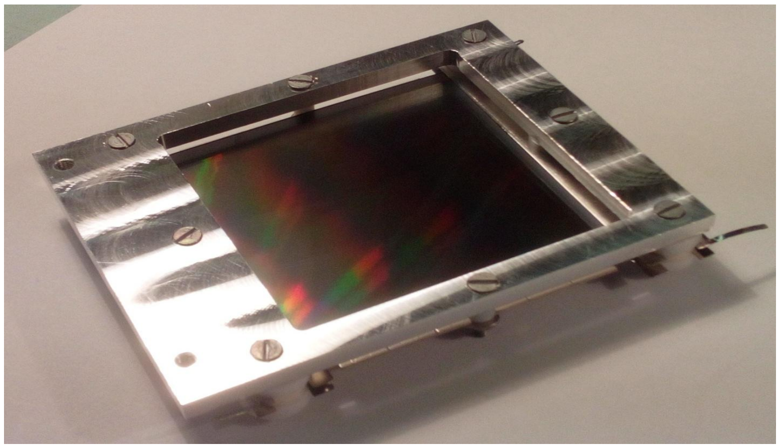
(1) fast monitoring of the beam profile (FBP)
(2) The event-by-event fast monitoring of beam-beam collisions



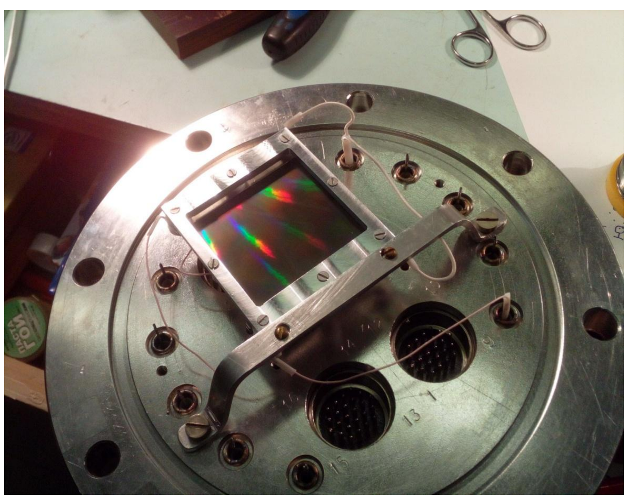

NIMA62154
DOI: 10.1016/j.nima.2019.04.108

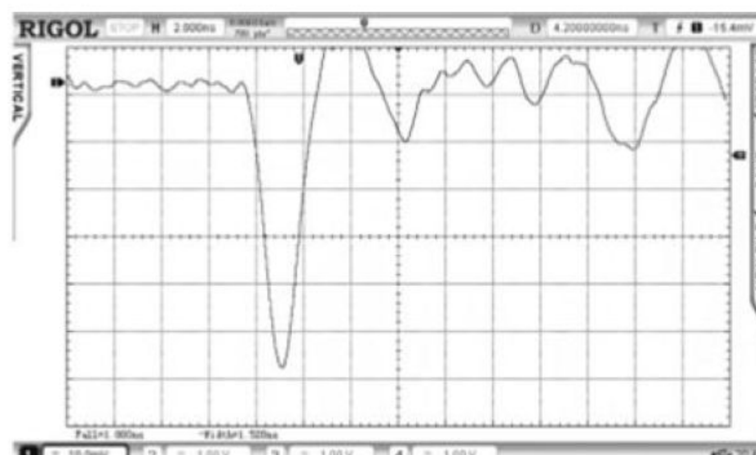
# For Test set-ups at JINR and SPbSU for Micro Channel Plates

MCPs: 43x63, 6mkm channel
https://baspik.com/eng/products/mkp/

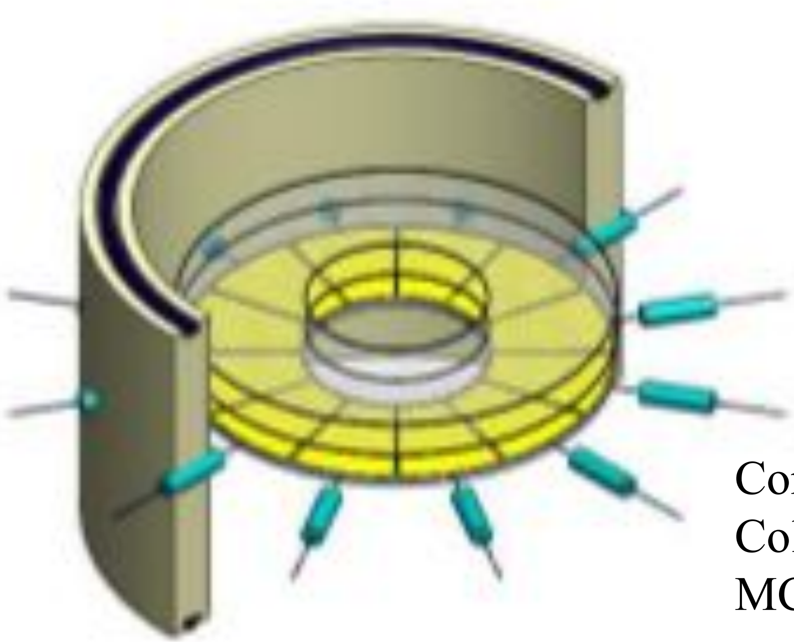



The ultra-high vacuum (UHV) compatibility and low-mass compact design.





# Fast Beam-Beam Collisions Monitoring (FBBC) conceptual design



Compact module of the Fast Beam-Beam Collision Monitor (FBBC) based on the circular MCP chevron setup.

Sector cathode readout pads and two MCP set-ups are embedded
into a vacuum flange with hermetic 50 Ohm signal and HV feedthroughs.

# Micro Channel Plates as a MIP detector

[1]A.Baldin,G.Feofilov,F.F.Valiev et al. ,"Microchannel plates as a detector for 800 MeV/c charged pions and protons." // JINR Rapid Communications. **1991.** No 4/50/-91. p.27-36.

[2] A.A.Baldin, G.Feofilov,Yu.Gavrilov, A.Tsvinev,F.Valiev, "Proposals for a new type of microchannel-plate-based vertex detector", // NIM A323. **1992**. p. 439-444.

[3]V.Bondila, L.Efimov D.Hatzifotiadou, G.Feofilov, V.Kondratiev, V.Lyapin, J.Nysten, P.Otiougova, T.A.Tulina, W.H.Trzaska, F.Tsimbal, L.Vinogradov, C.Williams, Results of in-beam tests of an MCP-based vacuum sector prototype of the T0/centrality detector for ALICE, NIM A, Volume 478, Issues 1–2, 1 February 2002, Pages 220-224.

[4] G. Feofilov, V. Kondratev, O. Stolyarov, T. Tulina, F. Valiev, and L. Vinogradov, Development and Tests of MCP Based Timing and Multiplicity Detector for MIPs, ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2017, Vol. 14, No. 1, pp. 150–159. © Pleiades Publishing, Ltd., **2017**.

# Strongly intensive quantities Unfolding