

Overview of the analysis activity

A.Zinchenko

for the BM@N collaboration
VBLHEP, JINR, Dubna, Russia



- ✓ Run 6
- ✓ SRC
- ✓ Run 7
- ✓ Run8+
- ✓ Development of models for heavy-ion interactions
- ✓ Physics program extension
- ✓ Summary

On luminosity measurement in carbon run – I

Mikhail Zavertyaev



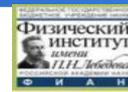
Goal & Solution.



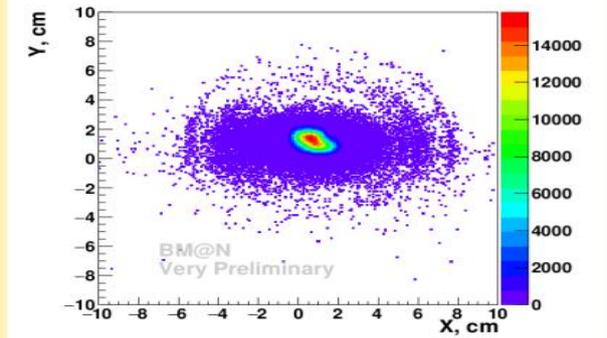
For the production cross section the luminosity evaluation is the crucial point.

In Run-6 data there is no information about beam particle parameters : X/Y position on the target.

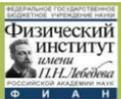
The proposed solution based on X/Y position of the reconstructed vertices on the target.



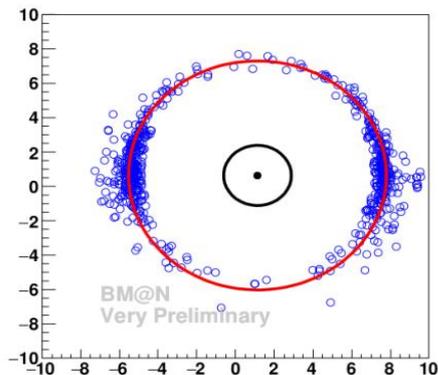
Target Region, as it is .



At least 3 tracks in Primary vertex.
Maximum 10 tracks per event.



Tube Trace, fit .

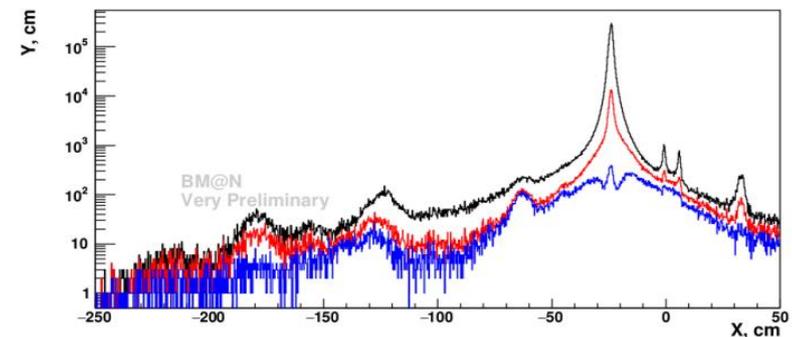


At least 3 tracks in Primary vertex. Maximum 10 tracks per event.

1	Mean	6.56164e+00 +/- 1.19551e-02
2	Sigma	2.19681e-01 +/- 1.24890e-02



Z of Vertices, >3 tracks .



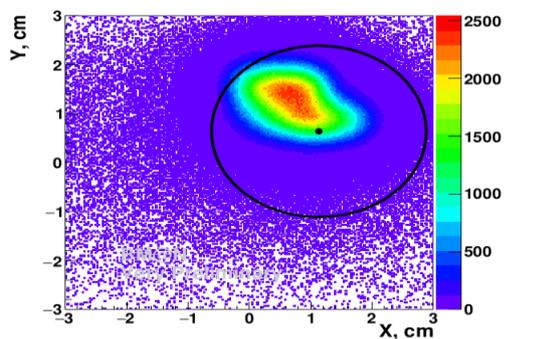
At least 4 tracks in Primary vertex. Maximum 10 tracks per event.
Black - all Vertices, Red - $\rho > 1.0\text{cm}$, Blue $\rho > 1.75\text{cm}$,

- $z(TG) = -23.850$
- $z(VC) = -127.850$
- $z(BC2) = -157.350$
- $z(T0) = -178.850$

On luminosity measurement in carbon run – II

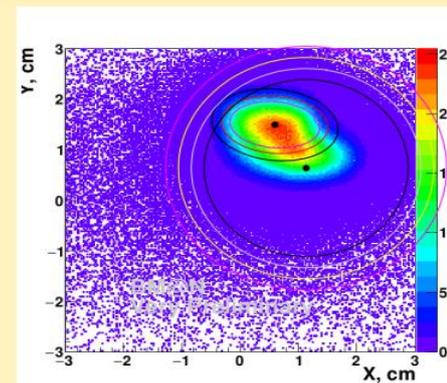
Mikhail Zavertyaev

X/Y of Vertices, no shift.



At least 3 tracks in Primary vertex. Maximum 10 tracks per event.
The beam spot touches the target edge.

X/Y of Vertices and geometry.



Ellipses : Black - 90%, Red - 80%, Blue - 70% of Vertices inside the ellipse
Target : Gray - $+1\sigma$, Yellow - $+2\sigma$, Magenta- $+3\sigma$

How to use.

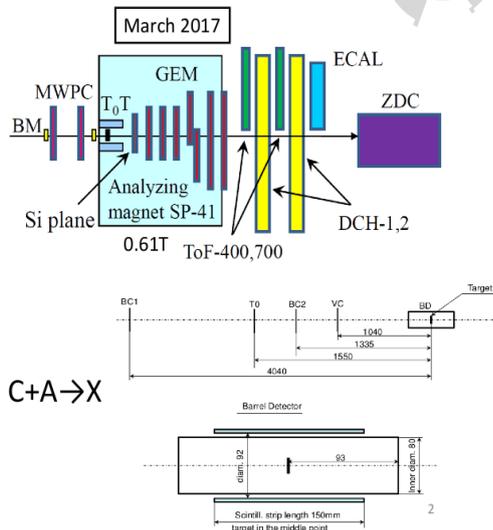
1. Choose the BEAM ELLIPSE. Accept the only events with X/Y of the primary vertex inside the ellipse area.
It gives proper Λ statistic.
2. Watch the ELLIPSE size and Target areas,
do the correction to the Lumi values.

Status of the Λ hyperon analysis in the carbon beam – I

Yury Stepanenko

BM@N configuration in Run6

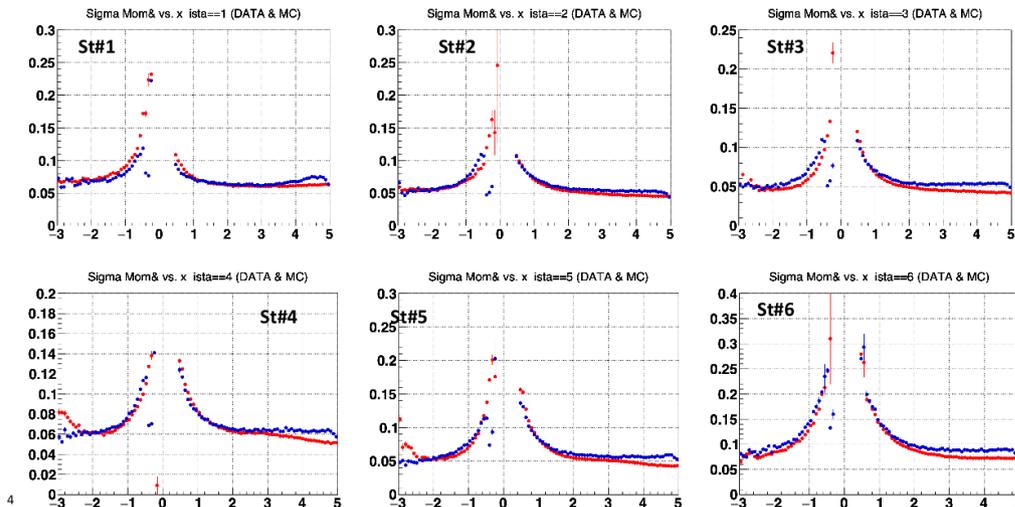
- Central tracker
 - One plane of a forward Si detector
 - 6 GEM stations
 - 5 GEM detectors (66x41 cm²)
 - 2 GEM detectors (163x45 cm²)
- Triggers: BD, BC1, BC2, T0, VETO
- Beam Ekin=4.0 and 4.5 GeV
 - Intensity 10⁵ per spill
 - Spill duration 2-2.5 sec.
- Physics: measure inelastic reactions C+A→X
 - Targets: C, Al, Cu, Pb



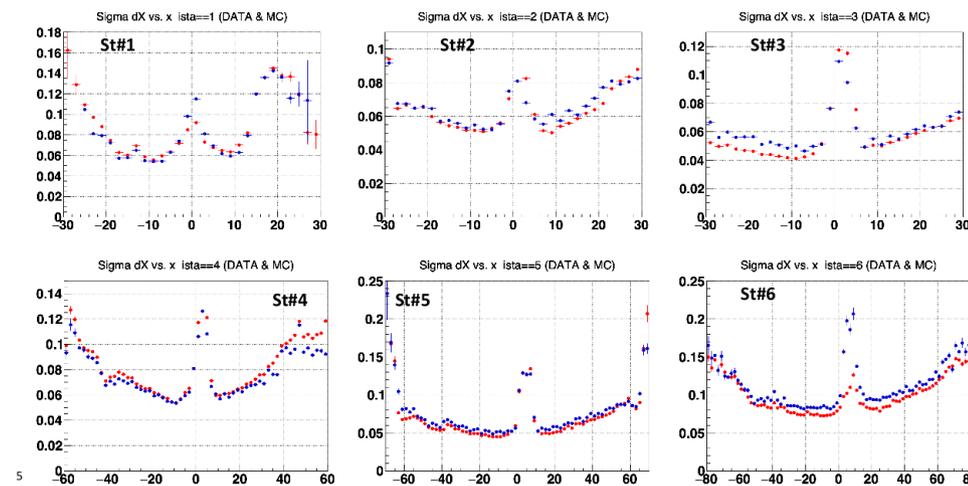
Analysis current status

- Main goal of current analysis** – cross-check with previous analysis (was performed by Gleb Pokatashkin)
- From previous analysis status:**
 - Check residuals for MC & Data ✓
 - Make corrections for residuals in Data & MC ✓
 - Momentum smearing procedure for MC simulation ✓
 - Check GEM efficiencies for MC & Data ✓
 - Apply efficiencies for MC simulation ✓
- Analysis:** compare distributions MC/Data for pt/momentum/etc. ⚠
 - X/Y residuals smearing ✓
 - MC Pools tuning (in progress) ⚠
 - Control plots (very preliminary) ⚠
- Measure cross-sections of the Λ^0 's hyperon

Mean Dx vs Momentum (DATA & MC 4.0GeV C+Cu)



Sigma Dx vs x (DATA & MC 4.0GeV C+Cu)

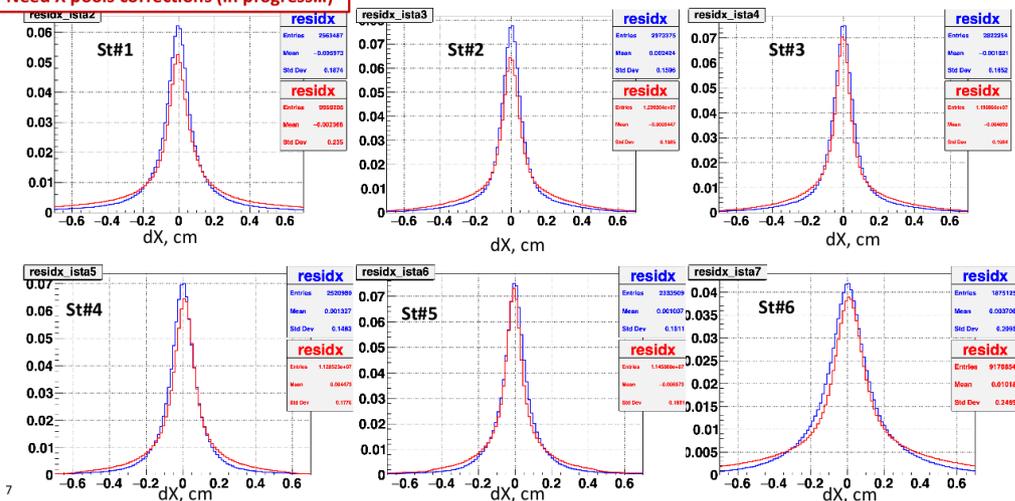


Status of the Λ hyperon analysis in the carbon beam – II

Yury Stepanenko

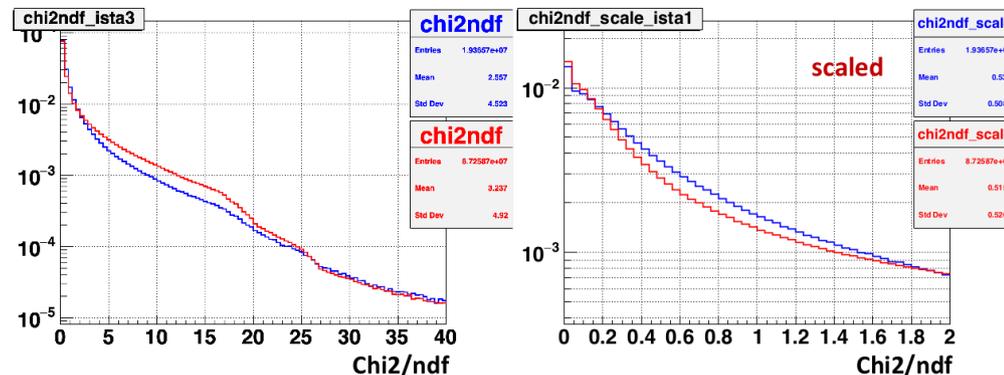
Sigma Dx vs x (DATA & MC 4.0GeV C+Cu)

Need X pools corrections (in progress...)



Blue: MC
Red: DATA

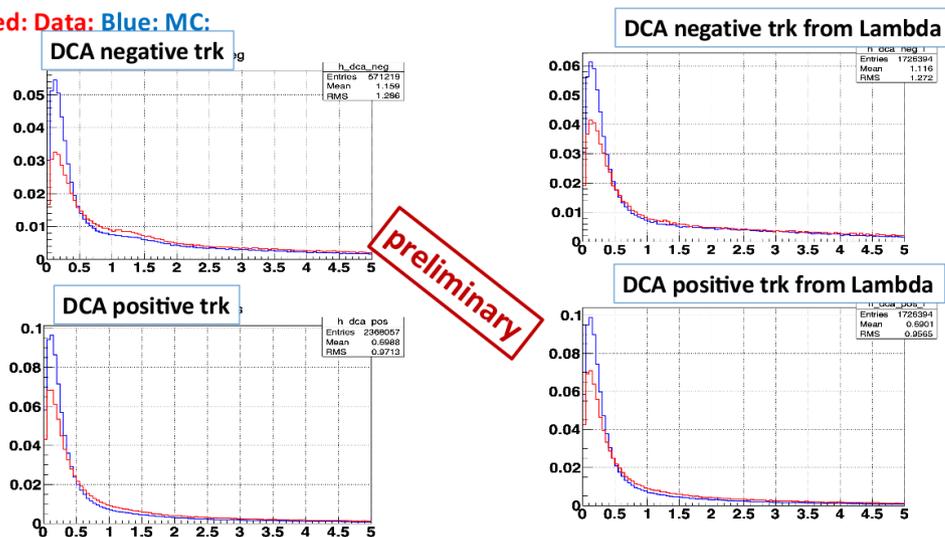
Chi2/ndf of tracks



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C+Cu (4.0 GeV) Control plots (DCA tracks to PrimVtx)

Red: Data; Blue: MC;

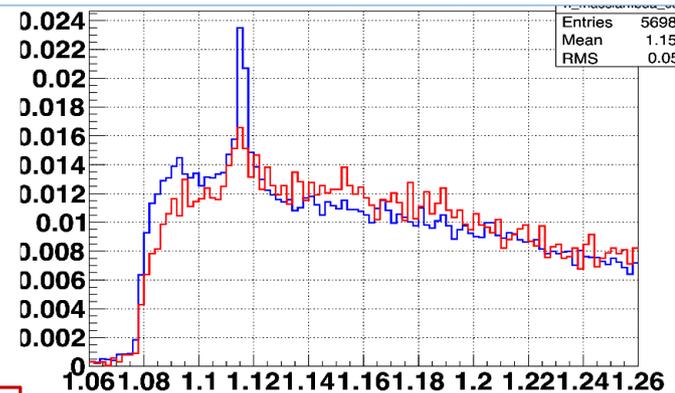


C+Cu (4.0 GeV)

Red: Data; Blue: MC;

Control plots (Mass L0)

Mass Lambda after more tight cuts (dca, path, momentum)



On light fragments in SRC data

Andrei Driuk

Goals of the current analysis

1. Analysis of yields of different fragments in C+p reaction
2. Comparison with the different physical models
3. Comparison with results of other experiments

2

Outline

1. Background (Results of the previous collaboration meeting)
2. Pt – balance
3. Empty target accounting
4. Comparison with MC simulation
5. Summary

3

Pt balance

Considered:

1. One global track
2. The events with one track in the left or right arm were selected.
3. P_x^{left} – momentum of fragments with the track in the left arm ($x > 0$),
 P_x^{right} – momentum of fragments with the track in the right arm ($x < 0$)
 Study $P_x^{\text{left}}/P_x^{\text{right}}$.

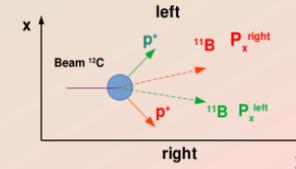


Fig. 5 P_x - balance

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Pt balance

The visible slope is not so essential to define protons or pions

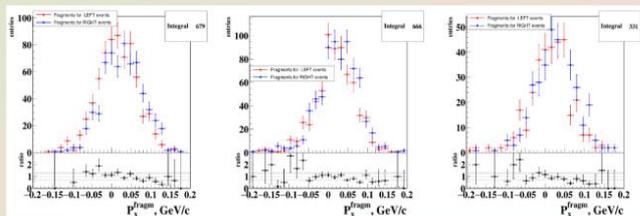


Fig. 8 P_x for boron isotopes and their relations in the experiment

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Fragment spots

Analysis of spots distributions:

1. Different number of tracks in the events
2. Low momentum (< 1.5 GeV/c/q) in the events
3. Negative particles in the events

Results:

1. Dependence on number of global tracks in the events
2. See no significant difference in events with additional low momentum positive or negative particles

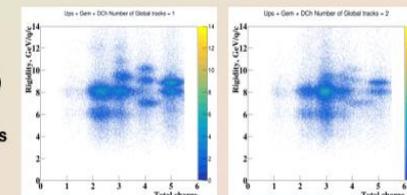


Fig. 9 The influence of different cuts in events on fragment spots (1 global tracks in the left figure and 2 tracks in the right)

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Comparison with MC Data

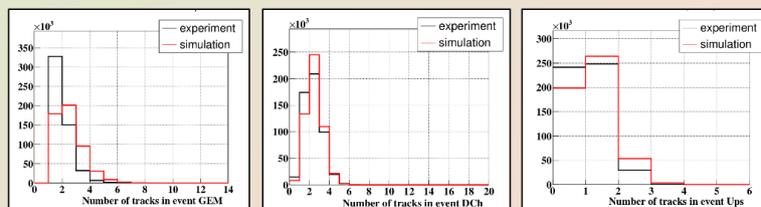


Fig.16 Number of tracks in events a) GEM , b) DCh, c) Upstream

20

Summary

1. No visible changes in the P_x balance for the left and right arms in the experiment.
2. Events with empty target were taken into account. The coefficient for spill normalization were calculated.
3. Response of the GEM detectors in MC was adopted to the experimental data. However, number of GEM tracks in events requires the corrections.
4. The matching efficiency of different detector subsystems was estimated in the experiment and MC. The mean values are close enough.

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Plans

1. The goal of the analysis is to evaluate yields of fragments in C+p reactions
2. Analysis of correlated fragments for two and more tracks.

23

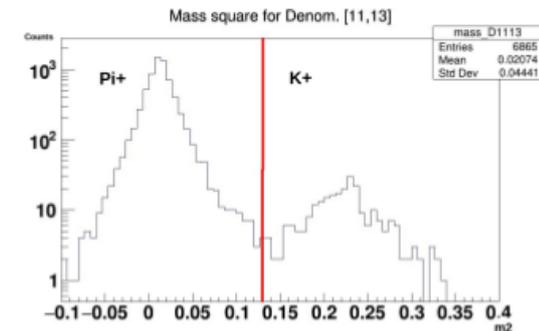
On TOF-400 K^+ and π^+ analysis in Ar run – I

Anastasia Khukhaeva

Issues

- 1 Estimation of trigger efficiency for different trigger conditions: (BD>1, BD>2, BD>3, FD>2, FD>3) on ToF-400 in Ar run.
BD - barrel detector, FD - silicon detector, 1-3 - number of counts.
- 2 Identification of K^+ and π^+ on ToF-400 in Ar run at momentum: ($0.5 < p < 2.3 \text{ GeV}/c$)

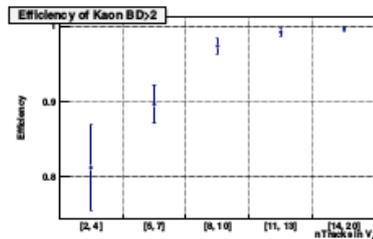
Mass square histogram FD>3 for [11,13]



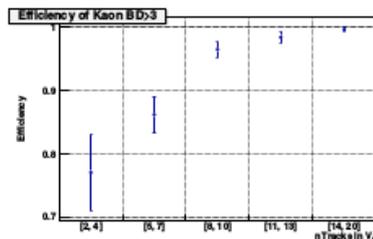
if ($m^2 > -0.1$) and ($m^2 < 0.13$) - π^+
if ($m^2 > 0.13$) and ($m^2 < 0.34$) - K^+

- The Centrality bins is taken according to number of tracks participated in V_p .

Trigger efficiency for Kaon BD>2, BD>3



- BD>2
 - [2,4]-81±5%
 - [5,7]-90±3%
 - [8,10]-97±1%
 - [11,13]-99,2±0.6%
 - [14,20]-99,6±0.4%



- BD>3
 - [2,4]-77±6%
 - [5,7]-86± 2%
 - [8,10]-98±0.8%
 - [11,13]-96±1 %
 - [14,20]-99.6± 0.3%

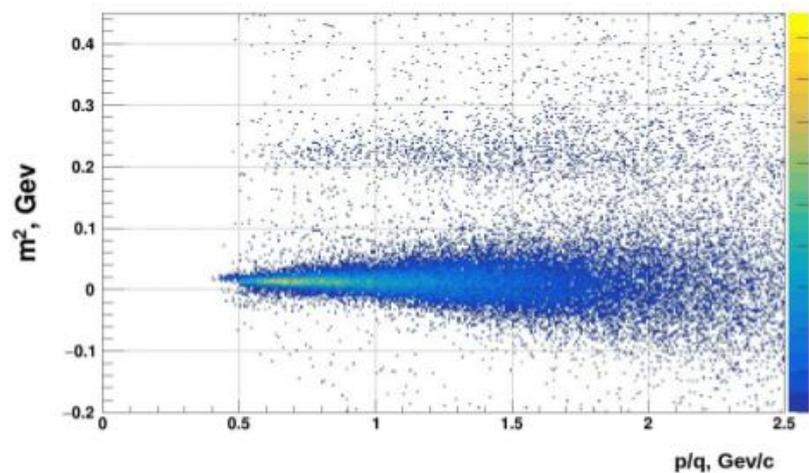
Efficiency table ($0.5 < p < 1.5$)

		FD>2	FD>3	BD>3	BD>2	BD>1
K+	[2,4]	24%	13%	77%	81%	85%
	[5,7]	35%	25%	86%	90%	94%
	[8,10]	44%	31%	98%	97%	99.1%
	[11,13]	58%	44%	96%	99.2%	99.6%
	[14,20]	76%	47%	99.6%	100%	100%
Pi+	[2,4]	19%	12%	62%	70%	81%
	[5,7]	27%	17%	85%	89%	93%
	[8,10]	35%	23%	94%	96%	98%
	[11,13]	44%	30%	98%	98%	99.4%
	[14,20]	56%	41%	99%	99%	99.7%

On TOF-400 K^+ and π^+ analysis in Ar run – II

Anastasia Khukhaeva

2-dimensional Mass square histogram



Slices Y for various momentum

Signals are fitted with Gaussian distribution

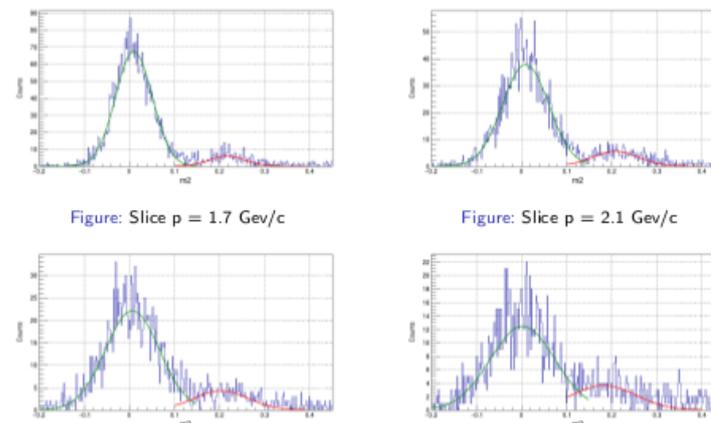


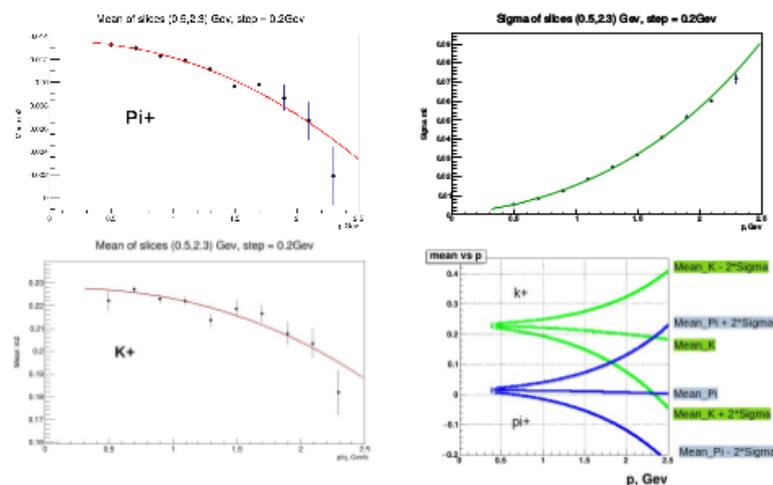
Figure: Slice $p = 1.7$ GeV/c

Figure: Slice $p = 2.1$ GeV/c

Figure: Slice $p = 1.9$ GeV/c

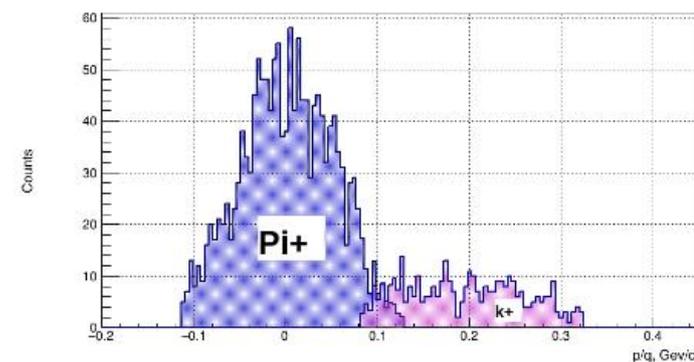
Figure: Slice $p = 2.3$ GeV/c

Obtained parameters vs momentum



Mass square histogram for K^+ and π^+

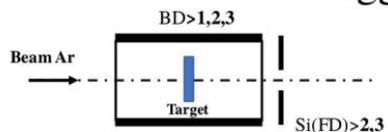
$P = 2.1$ GeV/c



On TOF-400 fragment analysis in Ar run – I

Ksenia Alishina

Trigger efficiency



Selection criteria for the square of the mass:

- p: $0.3 < m^2 < 1.4$ (GeV)²
- d: $2.6 < m^2 < 5.5$
- He³: $1.4 < m^2 < 2.6$
- t: $5.5 < m^2 < 9.5$

Selection criteria p/q:

- p: $p/q < 2$, GeV/c
- He³: $p/q < 3$
- d: $p/q < 4$
- t: $p/q < 5$

Procedure estimate trigger efficiency:

1. Filter by Ar data : select those files that do not contain the trigger condition being investigated.
2. Set the criteria by $(m/q)^2$ and p/q for fragments.
3. Set a condition on the number of tracks at the vertex (2...20).

$$4. \text{ Using formula } \epsilon_{Trig_n} = \frac{N(m/q^2)(BD>n;FD>m)}{N(m/q^2)(FD>n)}, n=1,2,3; m=2,3;$$

Primary Vertex Criteria :

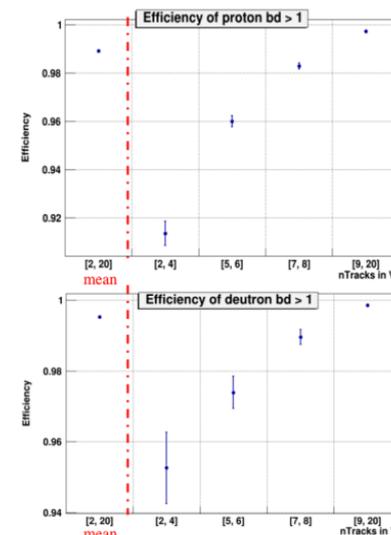
- 5 < Z_v < 5 cm,
- 2.0 < X_v < 2.6 cm,
- 0.135 < Y_v < 4.88 cm
- Number of hits per track > 5

Trigger condition BD>1

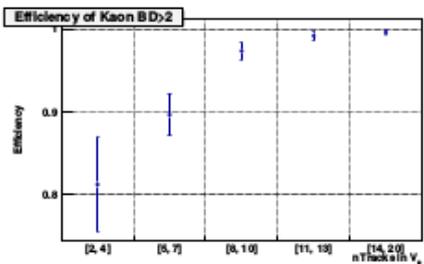
$$\epsilon_{BD1} = \frac{N(m/q^2)(BD>1,2,3;FD>2,3)}{N(m/q^2)(FD>1)}$$

	nTrack in Vp	Num/Denom	Efficiency	Error
p	(2,4)	2893/3167	0.913483	0.0049955
	(5,6)	6837/7122	0.959983	0.0023225
	(7,8)	10496/10678	0.982956	0.0012527
	(9,20)	109782/110061	0.997465	0.0001516
	(2,20)	155625/157322	0.989213	0.0002604
d	(2,4)	422/443	0.952596	0.0100963
	(5,6)	1195/1227	0.97392	0.0045498
	(7,8)	2190/2213	0.989607	0.0021568
	(9,20)	25719/25754	0.989607	0.0002296
	(2,20)	34498/34662	0.995269	0.0003687

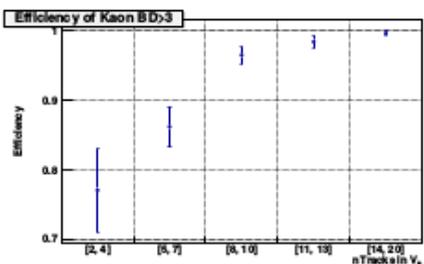
*nTracks in Vp - Number Tracks in primary vertex



Trigger efficiency for Kaon BD>2, BD>3



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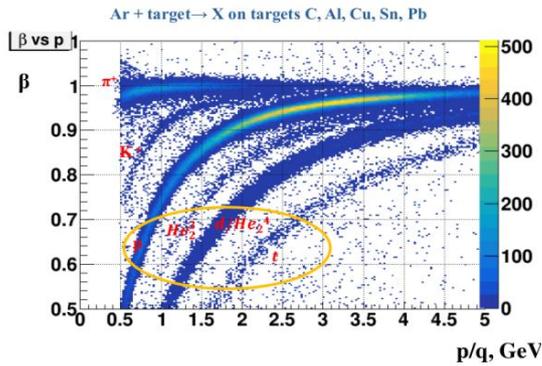
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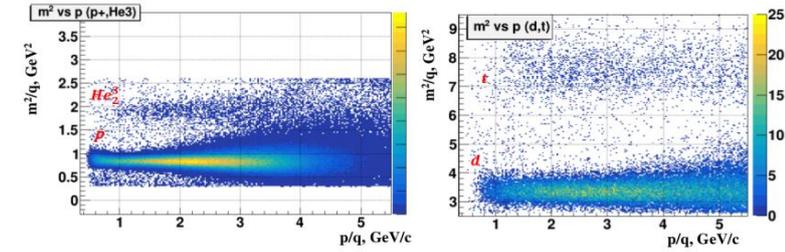
On TOF-400 fragment analysis in Ar run – II

Ksenia Alishina

β vs p/q plot bands for π^+ , K^+ , p , He^3 , d/He^4 , t (TOF 400).

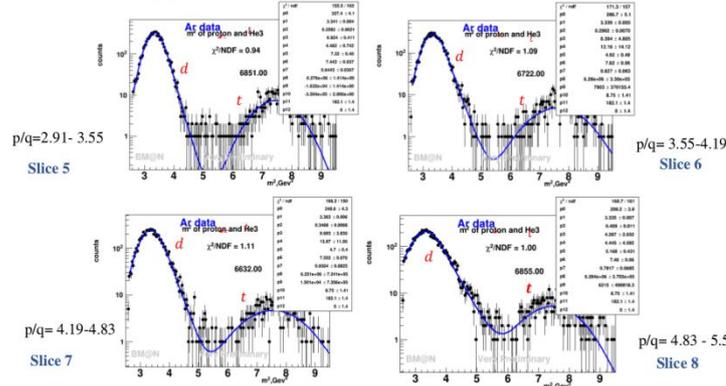


Distribution of the m^2 of the p/q for nuclear fragments



- Get slices along m^2 vs p/q for nuclear fragments
- Fit each slice using ModGauss(1st peak) + ModGauss(2nd peak) + expo(background) function
- Get Mean & Sigma from the fit
- Make plots: dependencies Mean (m^2) vs p/q , $\sigma(m^2)$ vs p/q , Mean (m^2) $\pm 2\sigma(m^2)$
- Get information about identification fragments

Slice (m^2 vs p/q) fit ModGauss(1st peak) + ModGauss(2nd peak) + expo(background)



Distribution mean (m^2) vs p/q , mean (m^2) $\pm 2\sigma$

Summary

The result :

- The efficiency of the triggers for the proton and deuteron has been evaluated
- Fit m^2 vs p/q function (ModGauss(1st peak) + ModGauss(2nd peak) + expo(background))
- Preliminary: $\sigma(m^2)$ and mean (m^2) were obtained in the range of momenta 0.35-5 GeV/c for (p, He^3, d, t)
- Preliminary: bounds mean(m^2) $\pm 2\sigma(m^2)$ were obtained in the range of momenta 0.35-5 GeV/c for (p, He^3, d, t)

The plans:

- Pt spectra of fragments (p, He^3, d, t) for Data and MC
- P and Y spectra of fragments (p, He^3, d, t) for Data and MC

On π^+ , π^- identification in Ar run – I

Konstantin Mashitsin

BM@N The main goal of the analysis

- Identifying π^\pm, K^\pm
- Estimation of the π, K mesons production cross section

K. Mashitsin 8th Collaboration Meeting 2/27

BM@N Outline

- Particle identification in the BM@N experiment
- Filtering experimental data
- Comparison of Monte Carlo data and experiment
- Adding realistic effects to event simulation
- Summary

K. Mashitsin 8th Collaboration Meeting

BM@N Before/After

K. Mashitsin 8th Collaboration Meeting 14/27

BM@N Comparison of Exp and MC

Monte Carlo's behavior repeats the experiment

Monte Carlo

- Generator: DCMSMM
- System: Ar + Cu
- Energy: 3.2 AGeV
- Smearing Vertex
- Lorentz Shifts
- Dead strips, hits

Exp data

- System: Ar + Cu
- Energy: 3.2 AGeV

K. Mashitsin 8th Collaboration Meeting 24/27

BM@N Summary

- Calibration of the detector by coordinates and time
- Algorithms for filtering experimental data have been implemented
- Realistic effects have been added to the modeling process
 - Smearing Vertex
 - Lorentz Shifts
 - Dead strips, hits
- Parameters of MC tracks inside the magnet repeat the experimental data.

K. Mashitsin 8th Collaboration Meeting 25/27

BM@N Future plans

- Estimate efficiency of matching
- Identify π, K mesons in experimental data
- Evaluate the efficiency of detectors through simulation
- Normalize the number of identified particles to the efficiency of the detectors and tracking
- Evaluate yields of identified π^\pm, K^\pm

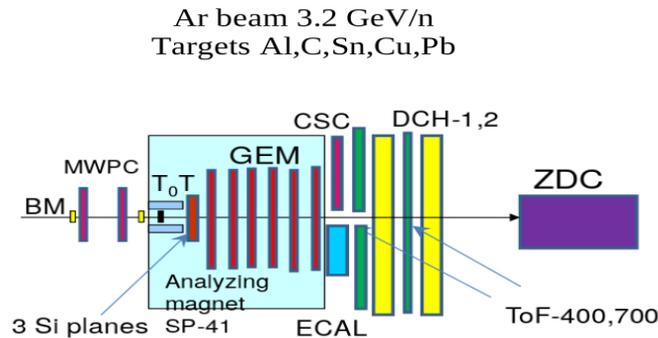
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Current Progress in TOF700 Fragment

Analysis in Argon data run 7 - I

Lalyo Kovachev

Argon data run 7



Schematic drawing of the location of the TOF700 on the BM@N setup

TOF700 Particle Identification chain

For **Data** and **MC** we use the **same** Identification chain

For **MC** we use **DCM QGSM** Generator

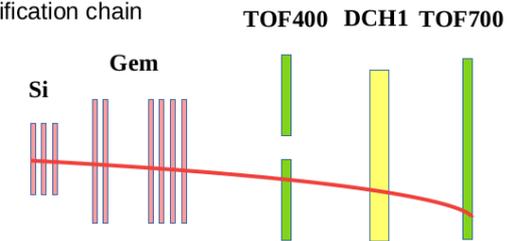
Si-GEM(data) tracks from **V. Plotnikov**

DCH tracks from **DCH** group

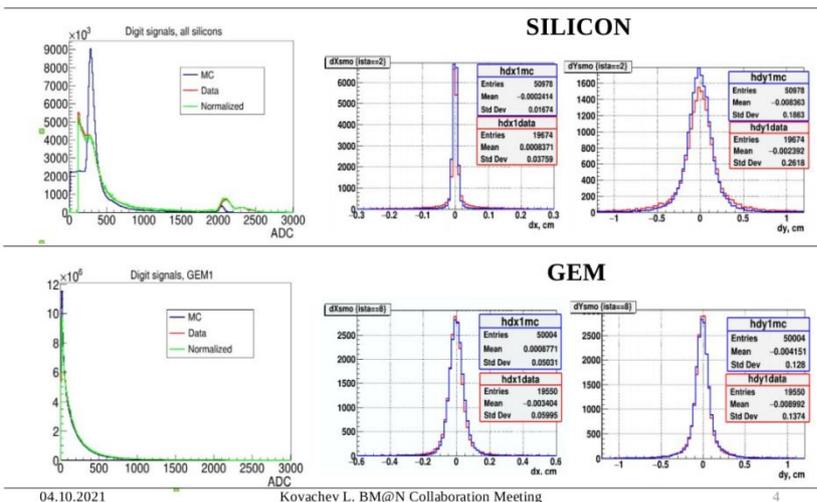
TOF700 hits from **Y. Petukhov**

Si-GEM tracks are extrapolated to the **DCH1** z-position and matched against the **DCH1** tracks

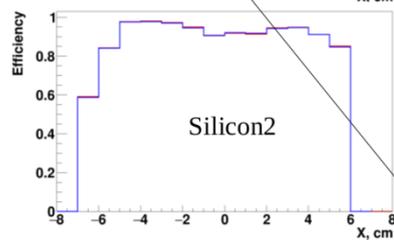
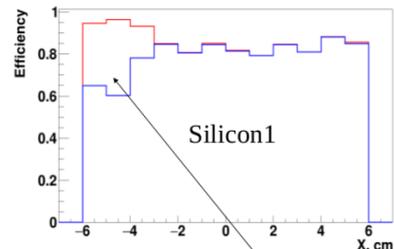
Successfully matched tracks are extrapolated to the **TOF400** and **TOF700** planes and matched against the **TOF400** and **TOF700** hits



Signal Normalization and Residual Smearing (V. Plotnikov)

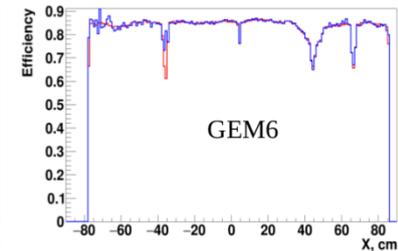
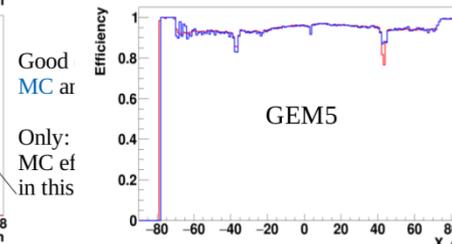
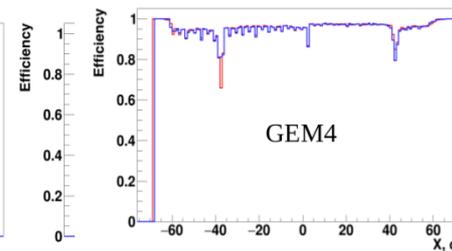


Silicon Effic



Good MC at
Only: MC ef in this

GEM Efficiency



Data - Red
MC - Blue

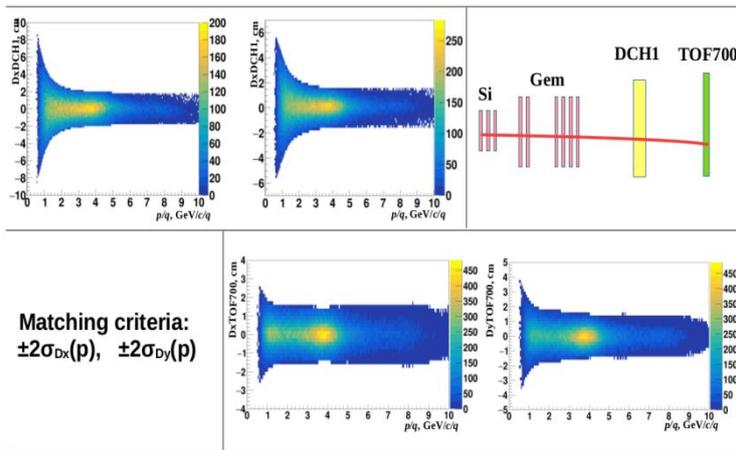
We see good efficiency for the data, and about the same efficiency for MC.

Current Progress in TOF700 Fragment

Analysis in Argon data run 7 - II

Lalyo Kovachev

Momentum dependence of matching criteria

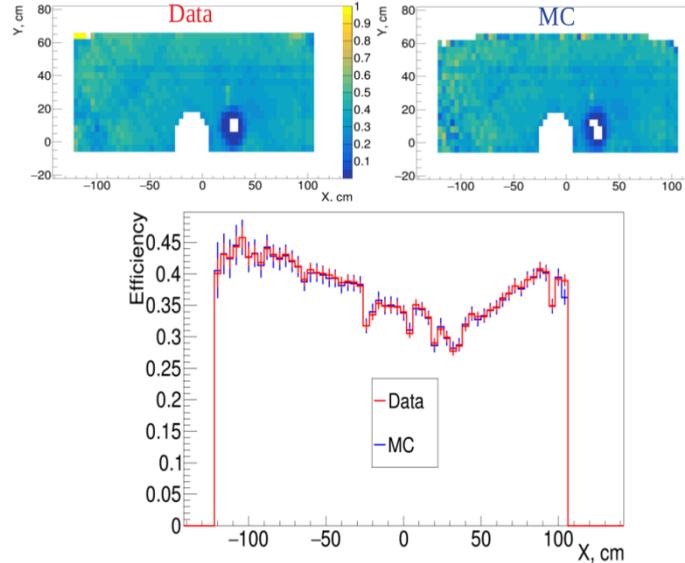


04.10.2021

Kovachev L. BM@N Collaboration Meeting

9

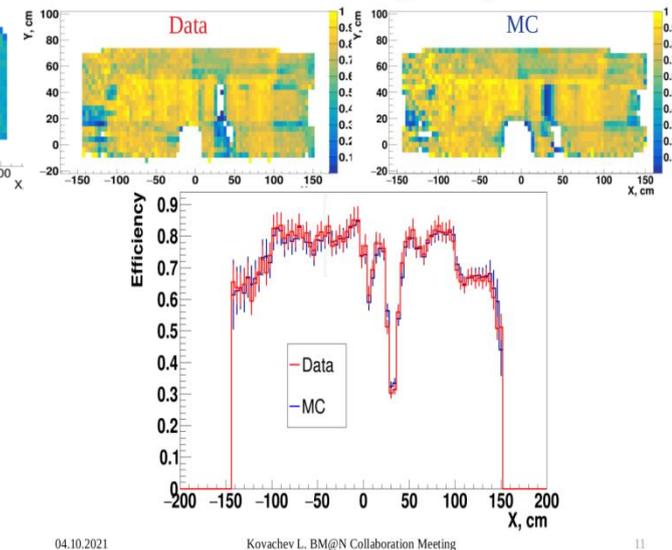
DCH1 Efficiency



04.10.2021

Kovachev L. BM@N Collaboration Meeting

TOF700 Efficiency

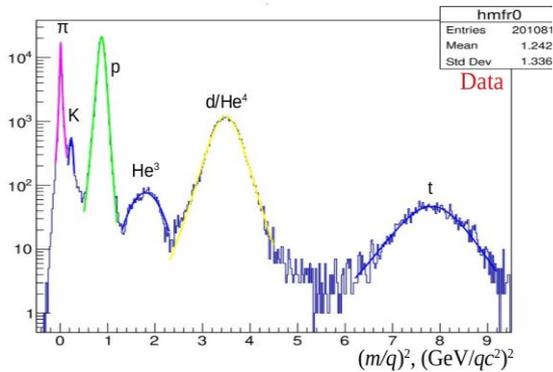


04.10.2021

Kovachev L. BM@N Collaboration Meeting

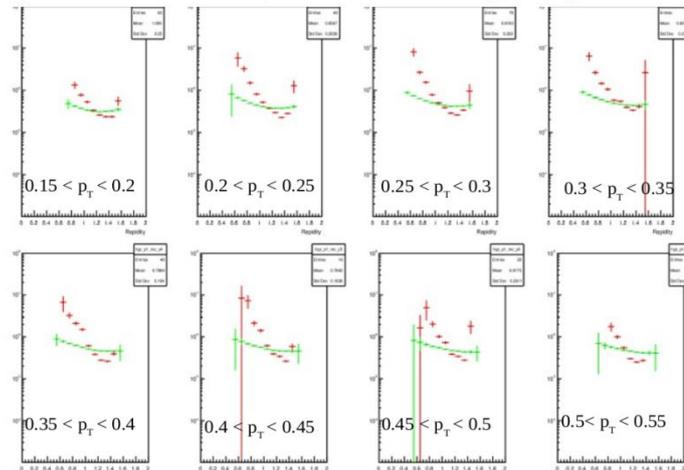
11

Reconstructed M^2 distribution



Note: different momentum ranges for different fragment

Rapidity distributions for protons in different intervals on P_t for MC model and efficiency corrected

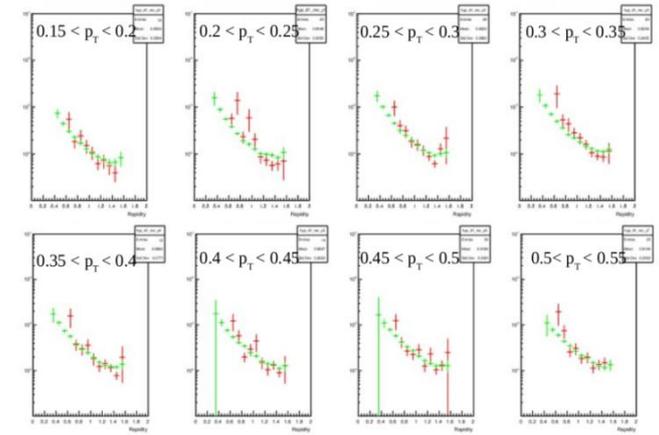


Significant differences between behavior on MC and Data.

04.10.2021

Kovachev L. BM@N Collaboration Meeting

Rapidity distributions for deuterons in different intervals on p_t for MC model and efficiency corrected Data



Here we have a much more better agreement in distributions

04.10.2021

Kovachev L. BM@N Collaboration Meeting

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TOF400 π^+ , K^+ analysis in Argon run - I

Vasily Plotnikov

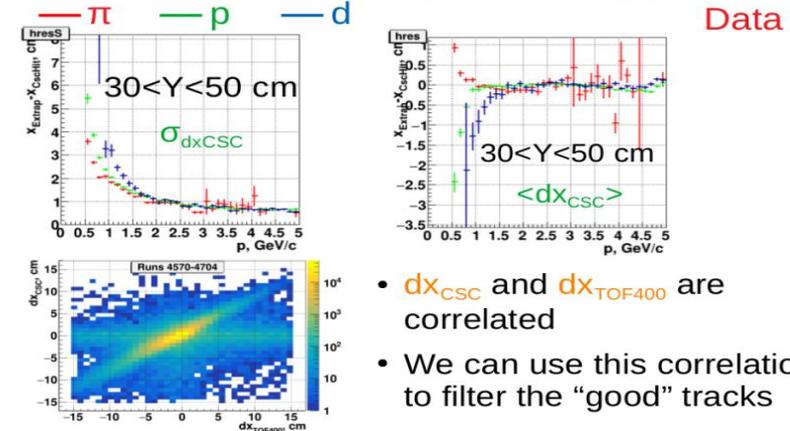
Outcomes of the 7th CM

- A strong dependence of CSC/TOF400 residuals on P
- There are two main reasons: scattering on the material and the difference between the field map and the real magnetic field
- Detailed GEM geometry has been applied
- We start to take into account the dependence on p when matching tracks with CSC and TOF400 hits
- We begin to recalculate the efficiencies of GEM, CSC and TOF400, taking into account the smearing of residuals depending on P

Vasilii Plotnikov, 04.10.2021

5

P-dependence of CSC/TOF400 residuals on particle type

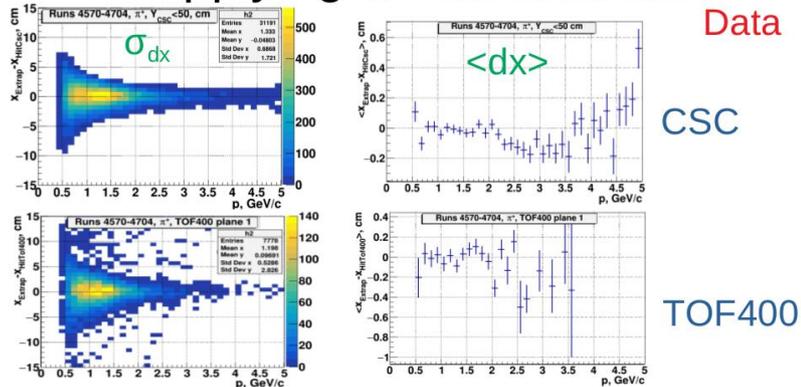


- dx_{CSC} and dx_{TOF400} are correlated
- We can use this correlation to filter the “good” tracks

Vasilii Plotnikov, 04.10.2021

8

CSC/TOF400 residuals after applying π^+ -corrections

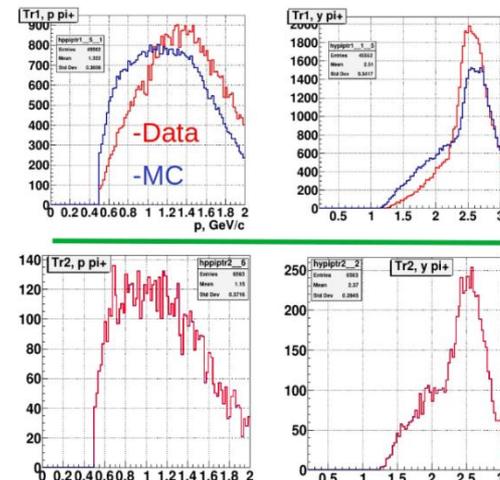


- $\langle dx \rangle(p)$ close to 0 at $p < 2.5$ GeV/c

Vasilii Plotnikov, 04.10.2021

9

P/Y spectra after applying π^+ -corrections



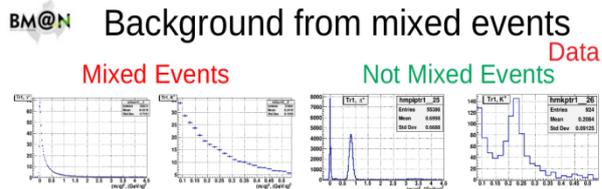
- From 6th Collaboration Meeting
- Without dynamic windows
- New result
- With dynamic windows
- P and Y spectra for π^+ become softer

Vasilii Plotnikov, 04.10.2021

10

TOF400 pi+, K+ analysis in Argon run - II

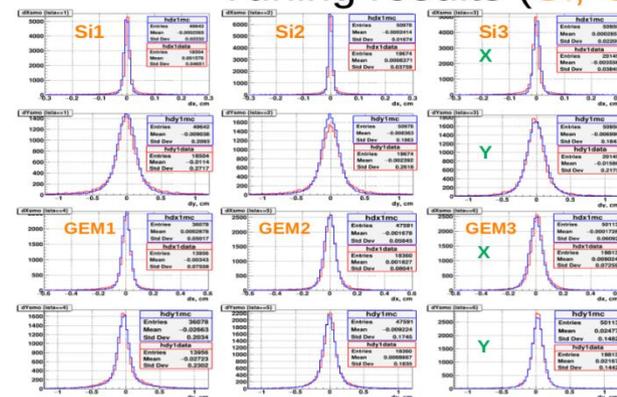
Vasily Plotnikov



Analyzes using this version of tracking

- Lambda analysis in Ar run (Pavel Batyuk)
- ToF-700 fragment analysis in Ar run (Lalyo Kovachev)
- ToF-400 fragment analysis in Ar run (Ksenia Alishina)
- ToF-700 π^+ , K^+ analysis in Ar run (Anastasia Huhaeva)

Identified track residuals. Tuning results (Si, GEM)



- Data
- MC
- Residuals for Data and MC are close to each other

- The background from mixed events has a Landau shape with a maximum in the pion mass
- Background level at $0.34 < (m/q)^2 < 0.54$ around 10 on each plot. So we can assume the same nature of it
- $bkg/sig_{K^+} \leq 22\%$, $bkg/sig_{\pi^+} \leq 3\%$

Vasilii Plotnikov, 04.10.2021

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Vasilii Plotnikov, 04.10.2021

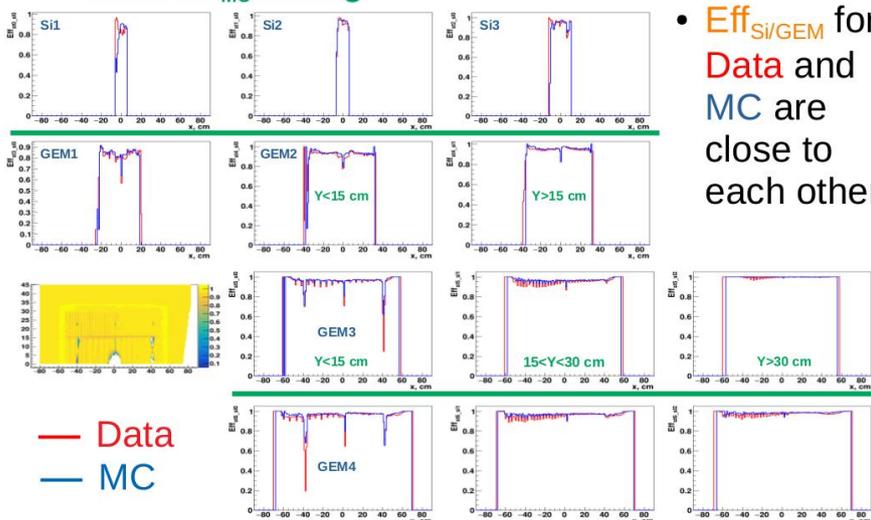
21

Vasilii Plotnikov, 04.10.2021

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Si/GEM efficiency (Data vs MC)

After Eff_{MC} tuning



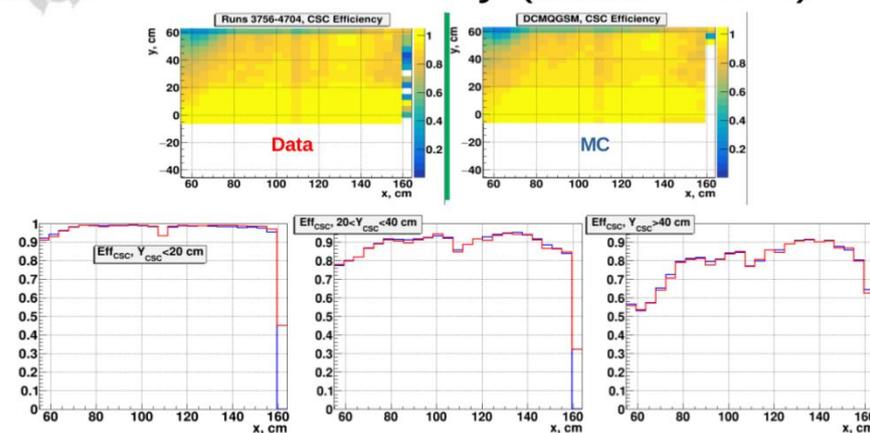
- Eff_{Si/GEM} for Data and MC are close to each other

— Data
— MC

Vasilii Plotnikov, 04.10.2021

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CSC efficiency (Data vs MC)



- Efficiencies for Data and MC are close to each other

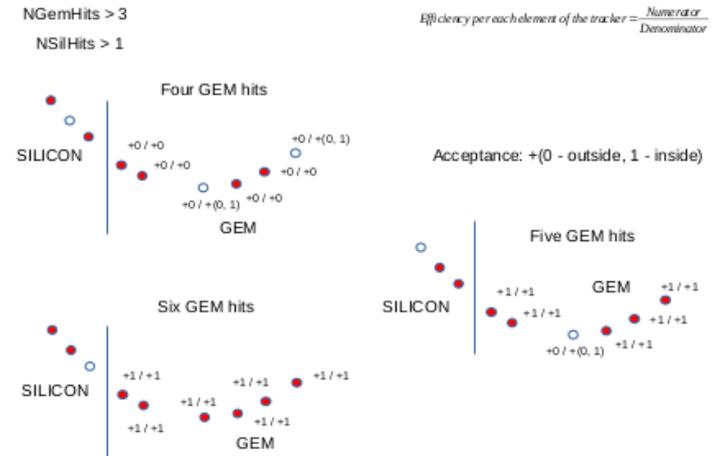
Vasilii Plotnikov, 04.10.2021

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Outline:

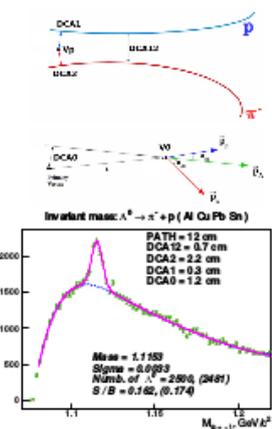
- Towards realistic Monte Carlo simulation of BM@N Central Tracker
- Efficiencies of tracking procedure calculated for silicon and GEM part of BM@N Central tracker
- Preparations to get Λ^0 yields ...

Calculation scheme:

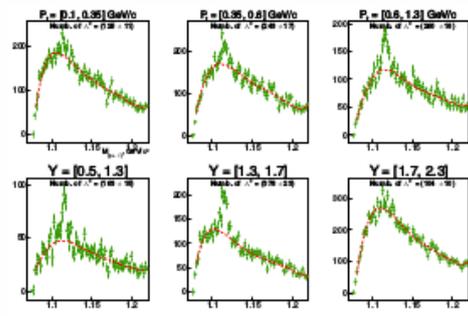


Looking at reconstructed Λ^0 in data and Monte Carlo

- Done for all targets
- Three chosen P_T bins: (0.1, 0.35), (0.35, 0.6) and (0.6, 1.3) GeV/c
- Three chosen Y bins: (0.5, 1.3), (1.3, 1.7) and (1.7, 2.3)
- Lower value of first bin and upper value of last bin were chosen not to suppress signal significantly (done when analyzing all targets)
- For each chosen bin ($S \pm \Delta S$) is estimated

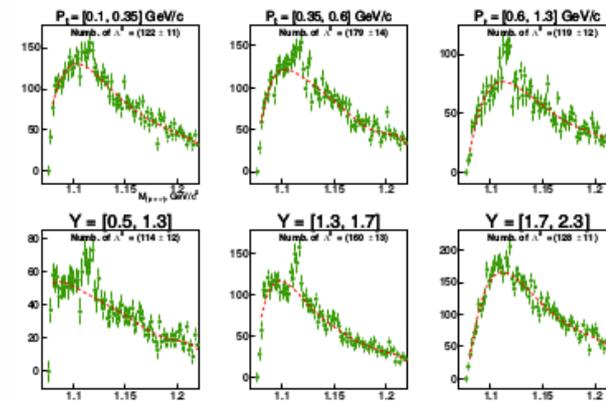


Target: Cu

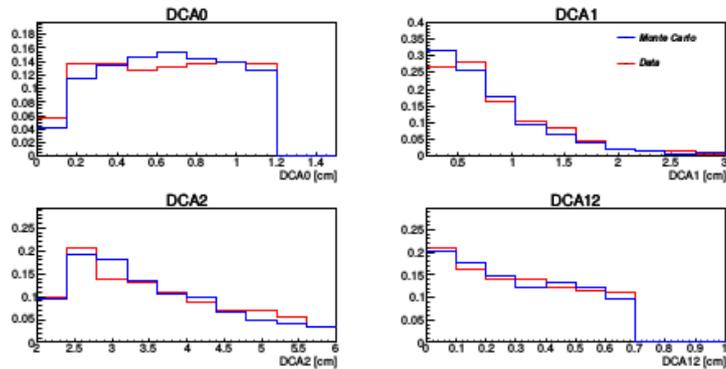


Reconstruction of Λ^0 with realistic (improved) Monte Carlo (Target - Cu)

Can we use this version of MC to get yields?



Geometrical cuts in data and Monte Carlo



- Achieved relatively good agreement between Monte Carlo and data by making use of the same set of geometrical cuts

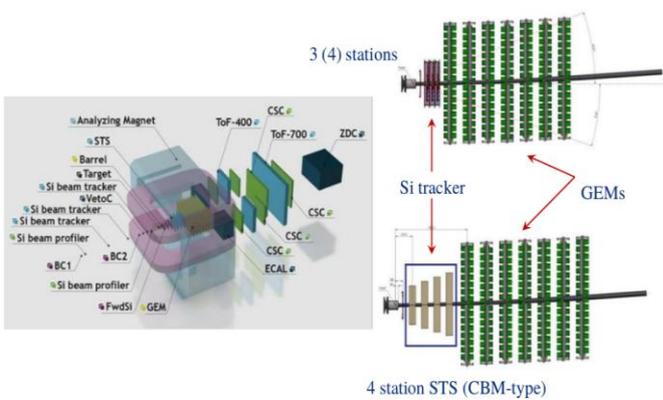
Conclusion:

- Improved Monte Carlo of the BM@N Central Tracker seems to be almost "matured": some small fixes for silicon part of the tracker required
- Suppression of Λ^0 signal looks reasonable in Monte Carlo if compared with experimental data
- Next step of the work consists of getting Λ^0 yields for all targets

Monte Carlo feasibility studies for heavy-ion interactions - I

Alexander Zinchenko

Detector geometry in future runs



05.10.2021

A. Zinchenko

5

Data set in Run 8

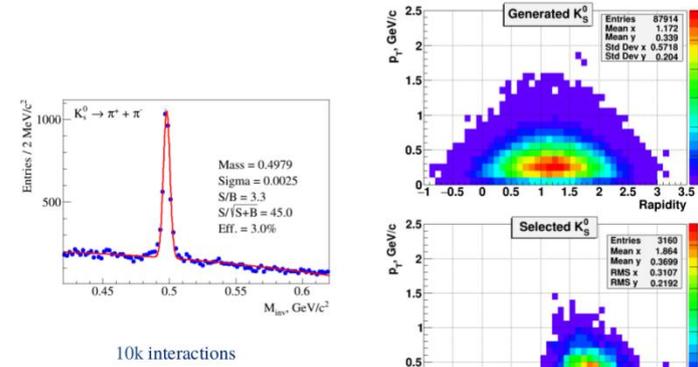
Detectors: Si (3 stations) + GEMs (7 stations)
Generator: DCM-SMM, Xe+Sn at $T_0 = 3.9A$ GeV ($\sqrt{s_{NN}} = 3.296$ GeV), 10k-5M min. Bias events
PID: TOF (if needed)
Statistics: K_s^0 - 8818 within 50 cm of primary vertex (in 10k events)
 Λ - 10225 within 50 cm of primary vertex (in 10k events)
 Ξ - 111 in 10k (54175 in 5M)
 Ω^- - 95 in 5M
 ΛH^3 - 6309 in 5M \rightarrow enriched ΛH^3 sample (randomly add 1 ΛH^3 per 30 events according to y - p_T distribution) \rightarrow scale factor 27.4

05.10.2021

A. Zinchenko

8

K_s^0 reconstruction in Run 8

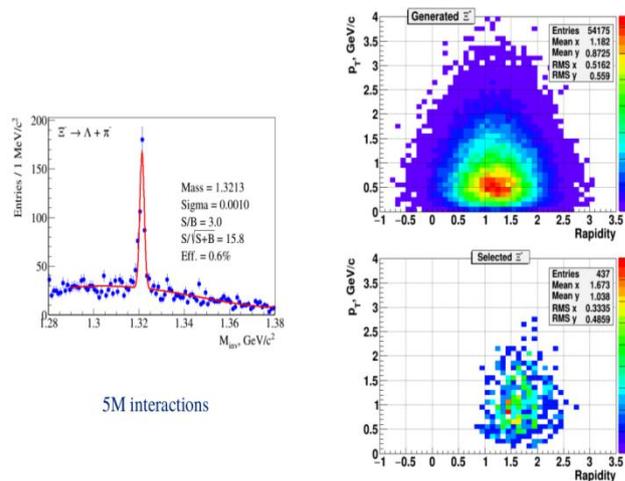


05.10.2021

A. Zinchenko

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Ξ^- reconstruction in Run 8



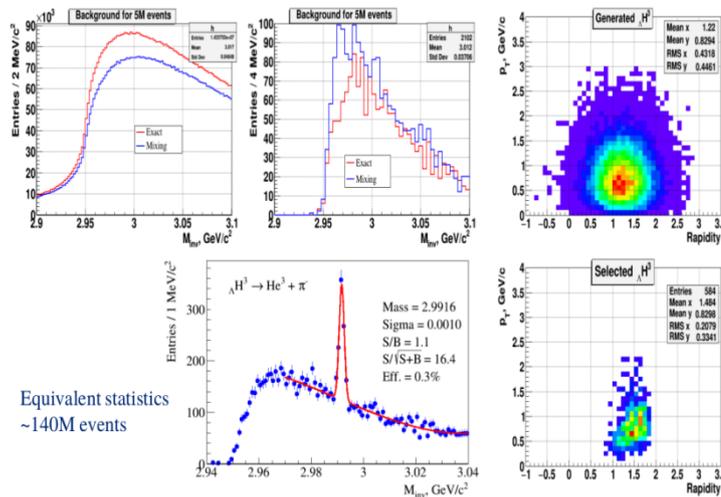
5M interactions

05.10.2021

A. Zinchenko

11

ΛH^3 reconstruction in Run 8



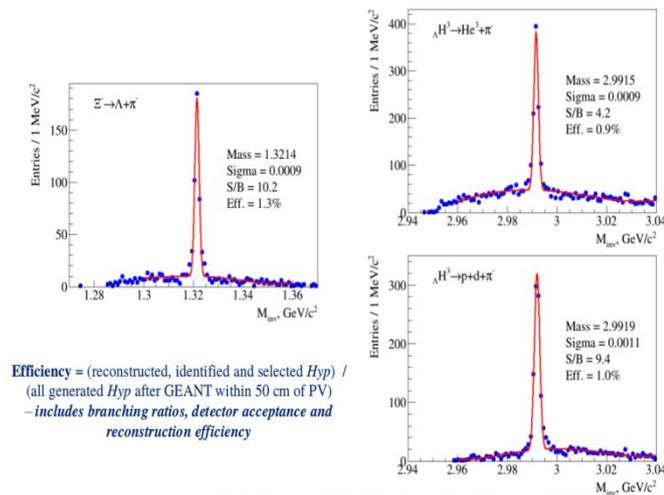
Equivalent statistics
 $\sim 140M$ events

05.10.2021

A. Zinchenko

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Ξ^- and ΛH^3 reconstruction



Efficiency = (reconstructed, identified and selected Hyp) / (all generated Hyp after GEANT within 50 cm of PV)
 - includes branching ratios, detector acceptance and reconstruction efficiency

05.10.2021

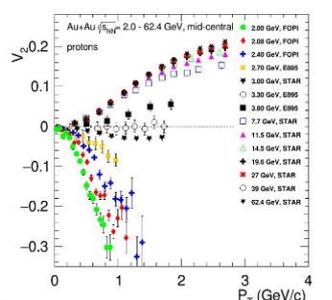
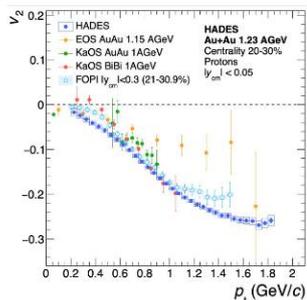
A. Zinchenko

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Performance studies for future flow measurements in heavy-ion collisions - I

Petr Parfenov

Why do we need new flow measurements with BM@N?

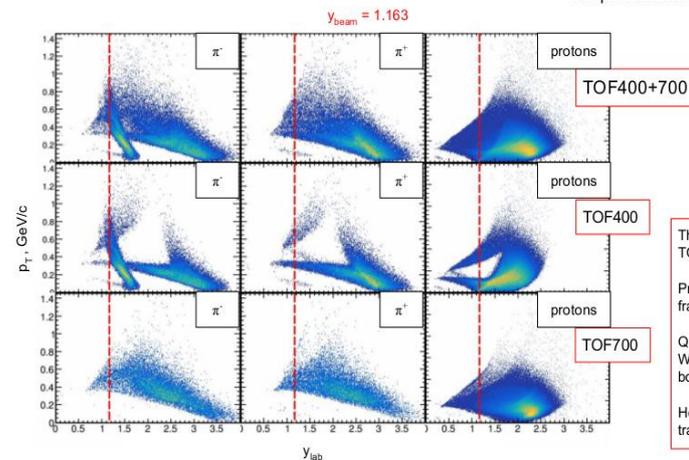


- Lack of differential flow measurements at $\sqrt{s_{NN}}=2.3-3.3$ GeV
- Difference between results from different experiments (e.g. FOPi vs. HADES) is the main source of existing systematic errors in v_n measurements
- Future BM@N data for $\sqrt{s_{NN}}=2.3-3.3$ GeV will provide detailed and robust v_n measurements

3

Acceptance: tracking + TOF PID

Momentum extrapolated to $z=0$ using PDG; Require matched TOF hit



There are no pions at midrapidity in TOF acceptance

Proton acceptance is very fragmented

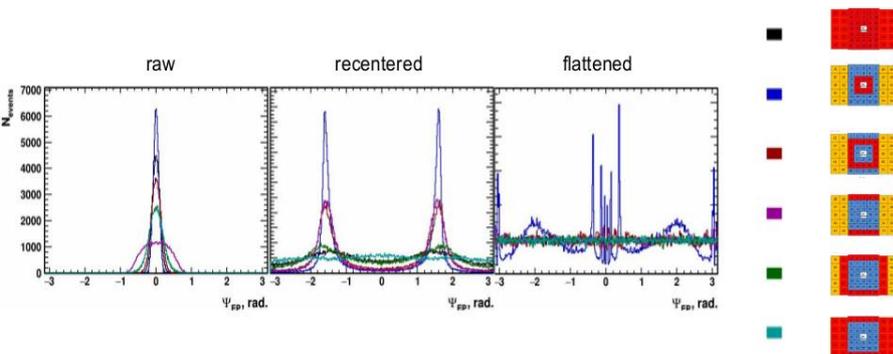
Q: Will there be track matching with both TOF400 and TOF700 hits?

How TOF hit is associated for the tracks that have hits in both TOFs?

11

Event plane distributions for mid-central collisions ($b = 5-6$ fm)

$$\Psi_{FP} = \tan^{-1} \left(\frac{Q_{1y}}{Q_{1x}} \right)$$



Further investigation of acceptance corrections is needed

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Summary

Anisotropic flow at BM@N energy range:

- Cascade models fail to reproduce v_n and the models with incorporated mean-field theory with different EoS are required
- There's a difference between $v_2(p_T)$ of protons and neutrons

Xe+Sn data with BM@N GEANT4 simulation and CA-tracking reconstruction:

- Asymmetry in reconstructed vertex position and DCA of pions
- Currently, there's a mismatching for protons where the proton track is associated with the pion hit in TOF400 / TOF700
- TOF400 acceptance should be optimized to improve acceptance of pions and protons, especially near mid-rapidity region
- Event plane determination using FHCAl is implemented, corrections for the non-uniform acceptance should be further investigated

20

MC generators DCM-QGSM and DCM-SMM

Genis Musulmanbekov

DCM-QGSM and DCM-SMM

Contents

- Motivation
- LAQGSM
- DCM-QGSM
- DCM-SMM
- Comparison:
 - Similarity and difference
 - Spectators yield
- Determination of numbers of participants and spectators
- Conclusions
- Plans for Future

LAQGSM and DCM-QGSM

Participant/overlap region

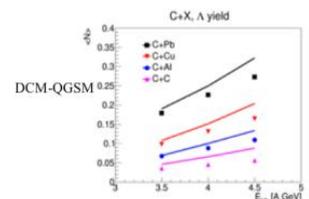
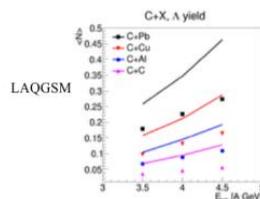
- ✓ Production of species (mesons, nucleons, resonances, hyperons, ...) in binary collisions;

LAQGSM **overestimates** meson production for

- larger colliding nuclei (kaons even at production threshold)
- higher energies
- more centralities

DCM-QGSM is **modified** LAQGSM

- Meson production is suppressed artificially (by formation time) for better agreement with experimental data.
- Corrections of different channels with hyperon production



Spectator region - nuclear spallation

DCM-QGSM,

- ✓ Preequilibrium emission
- ✓ Fermi break-up
- ✓ Sequential Evaporation
- ✓ Fission

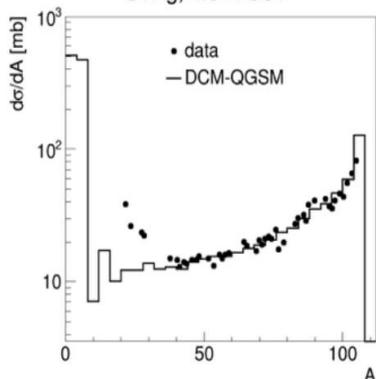
DCM-SMM

- ✓ Fermi break-up
- ✓ Multifragmentation
- ✓ Evaporation
- ✓ Fission

Models: DCM-QGSM vs DCM-SMM

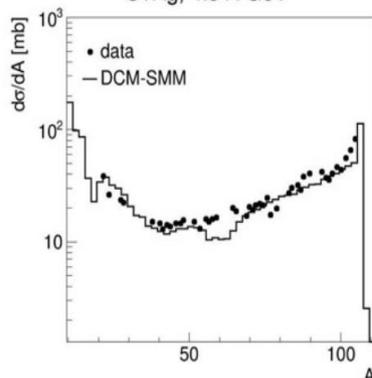
DCM-QGSM

Preequilibrium emission
Sequential evaporation
C+Ag, 4.5 A GeV



DCM-SMM

Statistical Multifragmentation
Evaporation
C+Ag, 4.5 A GeV



Conclusions

- DCM-SMM is more reliable for description of the residual nucleus spallation
- DCM-QGSM with sequential evaporation of the residual nucleus more or less agrees with DCM-SMM for peripheral events
- Plans: to combine both into the generator DCM-QGSM-SMM

DCM-QGSM-SMM: Plans for Future

Any transport model with characteristics of binary collisions taken from exp. data overestimates particle production for heavy ion collisions

1. Modification of nucleon properties in heavy ion collisions
2. Inclusion of heavy resonances in binary collisions
3. Development of the mechanism of strangeness enhancement
4. Development of the mechanism of enhancement of mass spectra dileptons

Clusters in transport approaches

Victor Kireyeu

Basic models for heavy-ion collisions



The origin of clusters



Phase-space Minimum Spanning Tree (psMST)



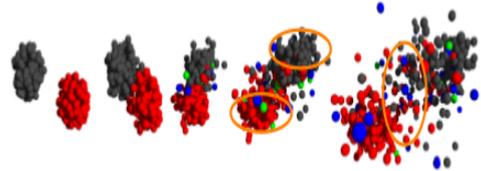
In order to understand the microscopic origin of clusters formation one needs:

- a realistic model for the dynamical time evolution of the HIC
- dynamical modeling of cluster formation based on interactions

Cluster formation is sensitive to nucleon dynamics → one needs to keep initial and final nucleon correlations by realistic nucleon-nucleon interactions in transport models:

- Quantum-Molecular Dynamics (QMD) – allows to keep correlations.
- Mean-field (MF) based models – correlations are smeared out.

Projectile/target spectators: heavy cluster formation
Midrapidity: light clusters



IQMD: Ch. Hartnack

(Anti-)hypernuclei production:

- at mid-rapidity by Λ coalescence during expansion
- at projectile/target rapidity by re-scattering/absorption of Λ by spectators

"Cluster dynamics studied with the phase-space Minimum Spanning Tree approach",
V. Kireyeu, Phys. Rev. C 103, 054905 (2021), arXiv:2103.10542

- Open source C++ library licensed under the terms of the GNU GPLv3.
- Based on the idea of the MST algorithm (proximity criteria).
- Momentum criteria: psMST can be used to study the influence of the momentum correlations of nucleons and hyperons for the formation of (hyper)nuclei.
- Can be applied to all transport models which propagate hadrons.

Previously "Naive Clusterization", "Kinetic Clusterization".

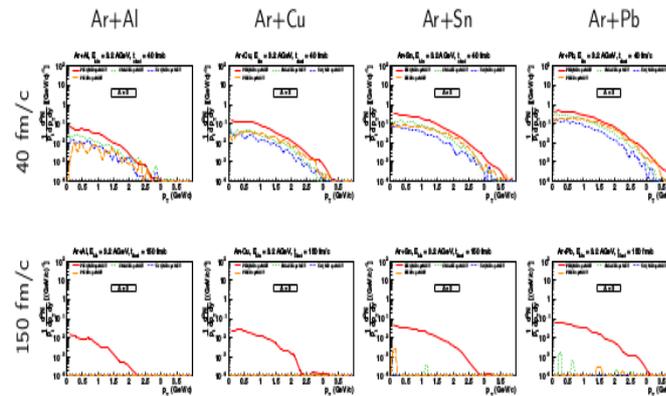
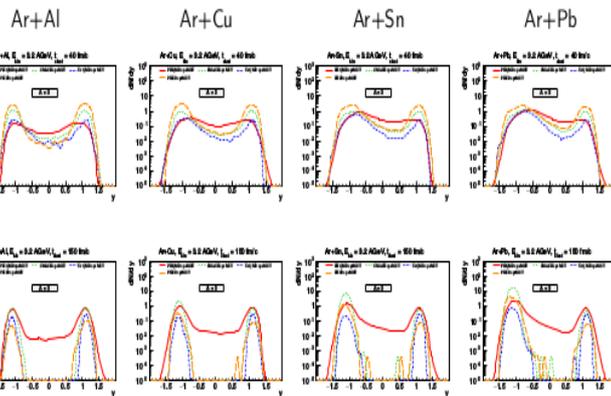
A = 3



A = 3



Conclusions



- The psMST algorithm has been applied to QMD-based PHQMD-2.0 (density dependent 2-body potential), mean field based PHSD-4.0 (mean-field potential for baryons) and two models SMASH-2.0 and UrQMD-3.4, both in the cascade mode without potentials.
- The PHQMD with psMST predicts more clusters in the mid-rapidity region than the other models → the n-body quantum molecular dynamics allows to keep the potential induced spacial correlations of baryons.
- The psMST library is an open source tool which can be used in the stand-alone mode or can be integrated into experimental software frameworks for the simulations of the clusters production.

Clusters at low energies are sensitive to the potential interactions.

Spin Physics Detector: concept and program - I

Vladimir Ladygin



SPD collaboration



Requirements to polarized beam facility



SPD and World polarized pp-facilities

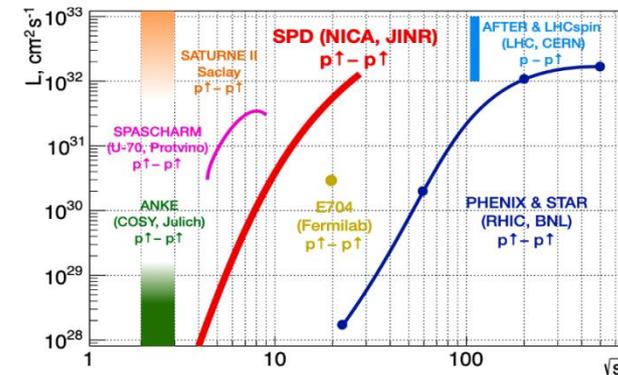


Armenia
Belarus
Chile
China
Cuba
Czechia
Egypt
France
Italy
Poland
Russia
Serbia
South Africa
Ukraine

33 laboratories and individual contributors from 14 countries
~ 300 participants

- polarized and nonpolarized pp-, dd-collisions
- $p\uparrow p(\downarrow)$ at $\sqrt{s}_{pp} = 12 + 27$ GeV (5 + 12.6 GeV kinetic energy)
- $d\uparrow d(\downarrow)$ at $\sqrt{s}_{nn} = 4 + 13$ GeV (2 + 5.5 GeV/u kinetic energy)
- $L_{av} \approx 1 \cdot 10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}$ (at $\sqrt{s}_{pp} \geq 27$ GeV)
- sufficient lifetime and polarization degree (few hours, 70%)
- longitudinal and transverse polarization in MPD and SPD
- pd- collision mode should be available

The facility operation in pp - mode at $\sqrt{s}_{pp} = 27$ GeV reaching average luminosity of $1.0 \cdot 10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}$ remains the first priority task for coming years.



Polarized dd-collisions are only at SPD!

4

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Scientific mission of SPD



SPD first stage physics



Layout of SPD



-Contribute to the world effort in understanding the strong interaction using unpolarized and polarized pp, pd and dd collisions at $\sqrt{s}_{pp} = 27$ GeV.

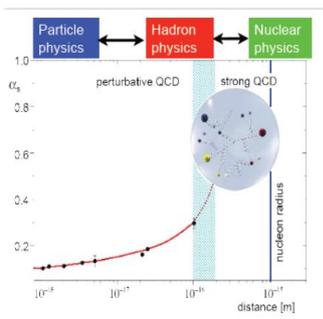
-Origin of the hadron mass: the Higgs mechanism accounts for some percent of the hadron mass: gluon dynamics

-Multiquark states

-Structure of the nucleon (charge, magnetic, spin distributions) and of light nuclei

-Open questions in light nuclei structure - spin observables

-Observables in ion-ion collisions (up to Ca-Ca system)



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Spin amplitudes of NN elastic scattering

Di-quarks dynamics

Vector meson production (strange, charm...):

spin-isospin effects, backward emission...

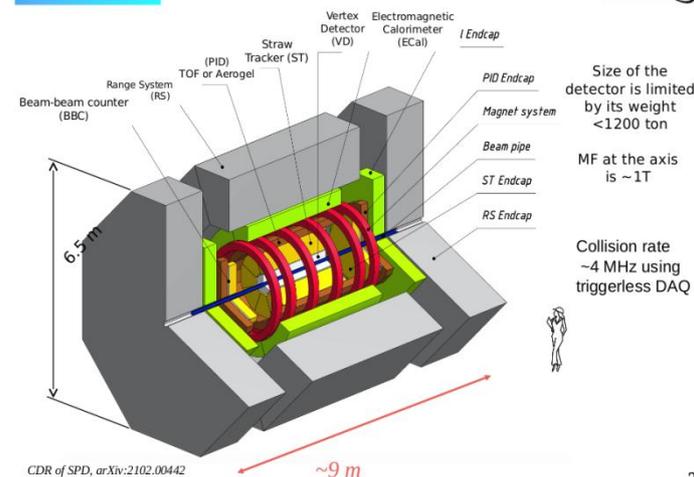
Deuteron short range spin structure

Scaling properties of spin observables

Diffractive and hard scattering

Heavy ion collisions

.....



CDR of SPD, arXiv:2102.00442

22

Spin Physics Detector: concept and program - II

Vladimir Ladygin



Synergy with BM@N

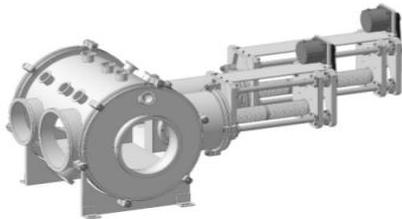


- Complimentarity of the physics programs for symmetric collisions (energy scan): *pp-, dd-, CC- CaCa-*
- Possibility to study spin effects and polarization phenomena in the fixed target mode in *pp-, dp-, dd-, dA-* collisions;
- Joint efforts in R&D for novel detectors: *gaseous (GEM-straw), MAPS, SiPM readout etc.* using SPD test facilities.

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Beam test area of SPD at Nuclotron



2 target stations,
2 spectrometers with PID
gas, DAQ, DCS (TANGO, WinCC)



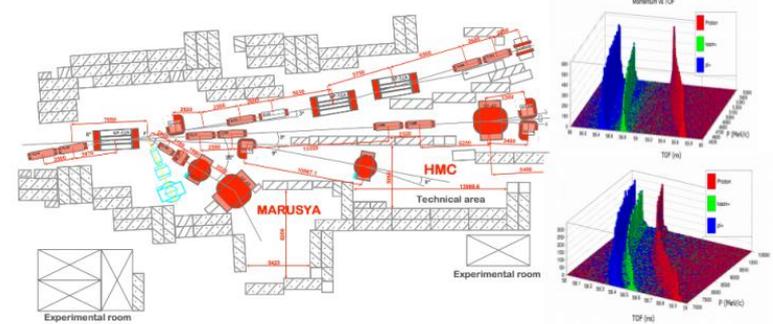
Invite BM@N with their
needs and contribution

P, MeV/c	d	p,n	π^\pm	K^+	K^-	μ^\pm	e^\pm
400	10^3	10^5	10^5	10^3	10^2	10^3	10^3
800	10^3	10^4	10^4	10^3	10^2	10^3	10^3
1500	10^2	10^4	10^4	10^3	10^2	10^2	10^2
2000	10^4	10^5	10^4	10^3	10^2	10^2	10^2
7000	10^4	10^6	10^3	10^3	10^2	10^2	10^2

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Beam test area of SPD at Nuclotron



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Conclusions



SPD (Spin Physics Detector) at the JINR-NICA collider - a multipurpose 4π detector for QCD studies with polarized proton and deuteron beams at \sqrt{s} up to 27 GeV.

SPD - a facility for comprehensive study of gluon content in proton and deuteron at large x

SPD – unique facility for polarized deuteron collisions

A strong tradition for polarized beams and targets exists at JINR-DUBNA, where unique polarized proton, neutron and deuteron beams are available in the GeV range.

SPD is open for new ideas and collaborators.

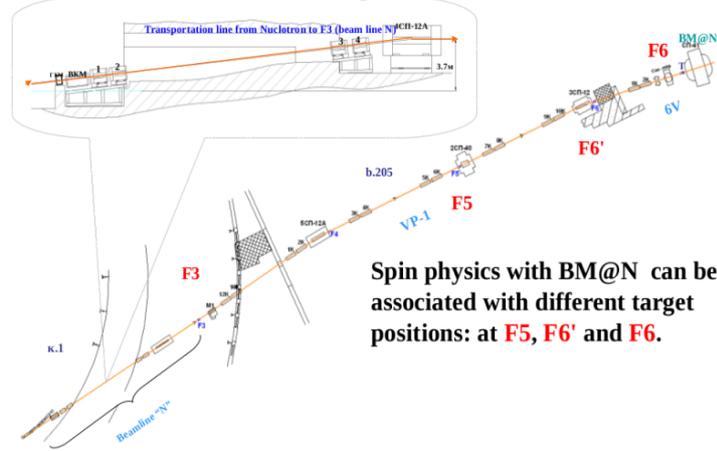
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Polarization studies at Nuclotron and BM@N

Vladimir Ladygin



Transportation line of the Nuclotron extracted beam to the BM@N spectrometer



Spin physics with BM@N can be associated with different target positions: at F5, F6' and F6.

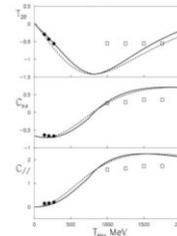
6

Polarization observables for polarized deuteron induced reactions

Target position is in F5



$^3\text{He}(d,p)^4\text{He}$

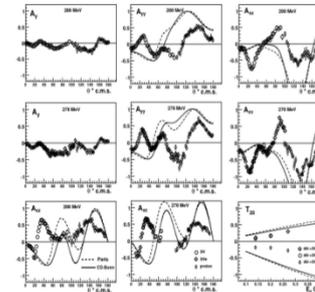


- The measurements of the tensor analyzing power T_{20} and spin correlation C_{xx} in the $^3\text{He}(d,p)^4\text{He}$ reaction in the kinetic energy range between 1.0 and 1.75 GeV can be performed at the BM@N area.
- The polarization observables for the $p(d,p)d$, $d(d,p)t$ and $d(A,p(0^\circ))X$ at intermediate and high energies also can be studied.
- Non-nucleonic degrees of freedom and baryonic resonances properties can be studied in the $d(A,d(0^\circ))X$ and $d(A,\pi(0^\circ))X$ reactions at different energies.
- The tensor analyzing power T_{20} can be studied for the meson production in the $d(A,3\text{He}(0^\circ))X$ reactions.

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Polarization observables for polarized deuteron induced reactions

Target position is near F6

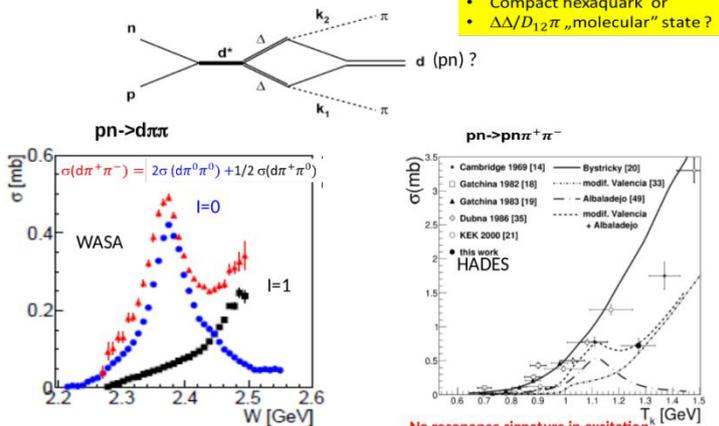


The tensor A_{yy} and vector A_{yx} analyzing powers in $dd \rightarrow ^3\text{He}(^4\text{He})$ reaction at forward angles to study unexplained structure in tensor observables sensitive to the 3-body spin structure.

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Hot topic: $d^*(2380) - 0(3^+)$ resonance

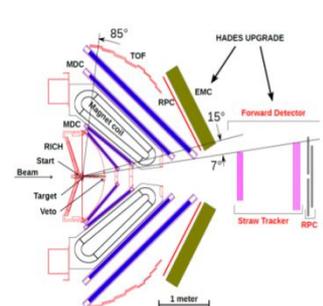
$d^*(2380): I=0, J=3^+, \Gamma=70 \text{ MeV}$



No resonance signature in excitation function of $pn \rightarrow \text{new HADES measurement!}$

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HADES plans



BM@N advantages:
-magnetic analysis in forward direction
-polarized beam!

Investigation of the vector analyzing power A_y in neutron induced reactions (with the proton spectator detection) like $np \rightarrow pn$, $np \rightarrow pp\pi$, $np \rightarrow pn\pi\pi$, $np \rightarrow d\pi\pi$ etc. reactions at the energies 1.0-2.0 GeV.

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Conclusion

BM@N setup is well suited for the physics with polarized deuterons using new SPI.

Such measurements can provide new insight to spin structure of SRC, mechanisms of baryonic resonances and d^* production.

However, such program requires the advanced extracted deuteron beam polarimetry.

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Possible exclusive d+p reactions to study at BM@N

Yury Uzikov



Analysis activity in several directions: Run6, Run7 PID, Run7 V0s, SRC, preparations for future runs, ideas for the physics program extension.