Joint Institute for Nuclear Research
SCIENCE BRINGING NATIONS TOGETHER

# Summary of the simulation / reconstruction / analysis meeting

A.Zinchenko
*VBLHEP, JINR, Dubna, Russia*

BM@N collaboration meeting
*14-15 October 2019*

# Outline

| | | | | |
|---|---|---|---|---|
| 09:00 | New Monte-Carlo generator DCM-SMM | Dr. Genis MUSULMANBEKOV | Room 347, Building 215, VBLHEP | 09:00 - 09:10 |
| | Determination of participants in heavy ion collisions | Dr. Genis MUSULMANBEKOV | Room 347, Building 215, VBLHEP | 09:10 - 09:25 |
| | DCH reconstruction / efficiency | Mr. Nikolay VOYTISHIN | Room 347, Building 215, VBLHEP | 09:25 - 09:40 |
| | ToF-700 efficiency / calibration | Mr. Lalyo KOVACHEV | Room 347, Building 215, VBLHEP | 09:40 - 09:55 |
| 10:00 | ToF-400 efficiency / calibration | Mr. Mikhail RUMYANTSEV | Room 347, Building 215, VBLHEP | 09:55 - 10:10 |
| | Track reconstruction in Silicon / MWPC detectors in SRC run | Vasilisa LENIVENKO | Room 347, Building 215, VBLHEP | 10:10 - 10:25 |
| | Status of ECAL reconstruction / simulation | ECAL GROUP | Room 347, Building 215, VBLHEP | 10:25 - 10:45 |
| 11:00 | | | | |
| | Progress in simulation of the BM@N detectors | Dr. Dmitry BARANOV | Room 347, Building 215, VBLHEP | 11:15 - 11:35 |
| | Track reconstruction in SRC run | Mr. Sergei MERTS | Room 347, Building 215, VBLHEP | 11:35 - 11:55 |
| 12:00 | Data Quality Analysis | Mr. Pavel BATYUK | Room 347, Building 215, VBLHEP | 11:55 - 12:15 |
| | Online Monitoring System for BM@N and Raw Data Converter | Mr. Ilnur GABDRAKHMANOV | Room 347, Building 215, VBLHEP | 12:15 - 12:35 |
| | STS+GEM hybrid tracker performance studies in simulation | Dr. Alexander ZINCHENKO | Room 347, Building 215, VBLHEP | 12:35 - 12:55 |

12 talks

# New Monte-Carlo generator DCM-SMM

## Dr. Genis Musulmanbekov

### DCM-QGSM

**DCM-QGSM** – Dubna Cascade Quark-Gluon-String-Model

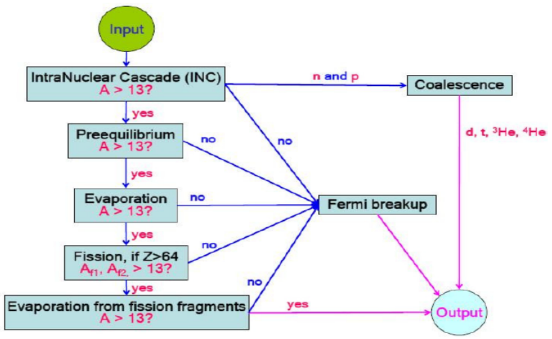
- DCM
  - + coalescence
  - + prequilibrium
  - + Fermi break-up
  - + GEM (Generalized evaporation + fission)
  - + Light hyperfragments production at coalescence stage
- QGSM ($E_{Lab}$ > 4.5AGeV)

### DCM-SMM

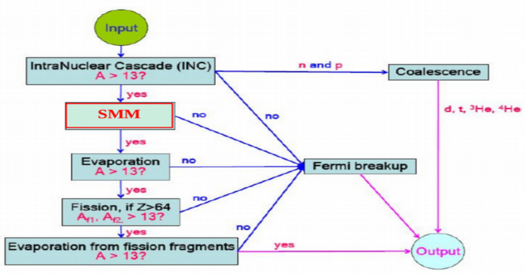
**DCM-QGSM** – Dubna Cascade Quark-Gluon-String-Model

- DCM
  - + coalescence
  - ~~prequilibrium~~
  - + Fermi break-up
  - + SMM
  - + GEM (Generalized evaporation + fission)
  - + Light hyperfragments production at coalescence stage
- QGSM ($E_{Lab}$ > 4.5AGeV)

Scheme of DCM calculations




Scheme of DCM-SMM



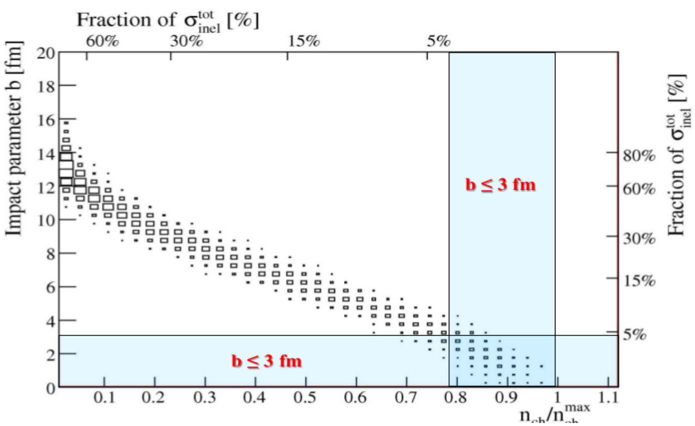

### Plan for future

- Correction of formation time concept
- Generalized Multifragmentation Model
- Implementation of the mechanism of enhancement of strangeness
- Implementation of the mechanism of enhancement of dilepton yield
- Further development

# Determination of participants in heavy ion collisions

Dr. Genis Musulmanbekov

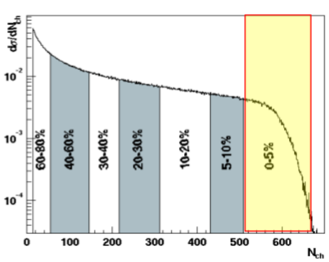
### Centrality – impact parameter – charged multiplicity



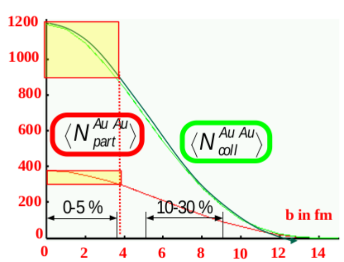

Multiplicity as a Centrality Measure → $N(b)_{coll}$ and $N(b)_{part}$

The connection between event **multiplicity** and $N(b)_{coll}$ and $N(b)_{part}$ via **centrality**

Multiplicity distribution

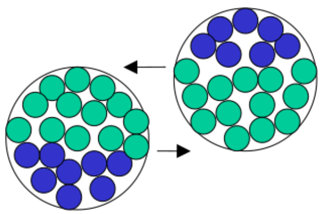



$N(b)_{coll}$, $N(b)_{part}$ vs impact parameter

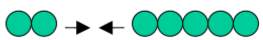



### Calculation the number of collisions and participants

**Assumption:**
Inelastic collisions of two nuclei (A-B) can be described by incoherent superposition of the collision of "an equivalent number of nucleon-nucleon collisions".




To calculate $N_{part}$ or $N_{coll}$, take

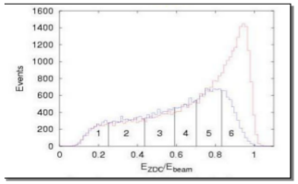


$N_{part} = 7$

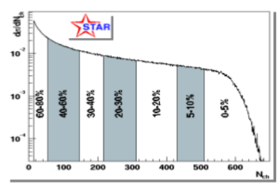
$N_{coll} = 10$

### Measurement of participants in experiments

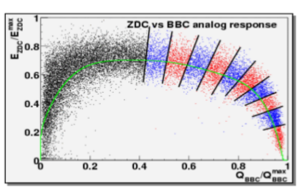
NA49




STAR




PHENIX




$E_{ZDC} = (A - N_{part}/2) / \sqrt{s}/2$

$N_{part}/2 \approx \langle N_{ch} \rangle_{AB} / \langle n_{ch} \rangle_{pp}$

$Q_{BBC} = (N_{part}/2) / \sqrt{s}/2$

$E_{ZDC} = (A - N_{part}/2) / \sqrt{s}/2$

| | |
|---|---|
| NA49 | ZDC Only - spectators |
| STAR | TPC only - participants |
| PHENIX | BBC & ZDC – participants + spectators |

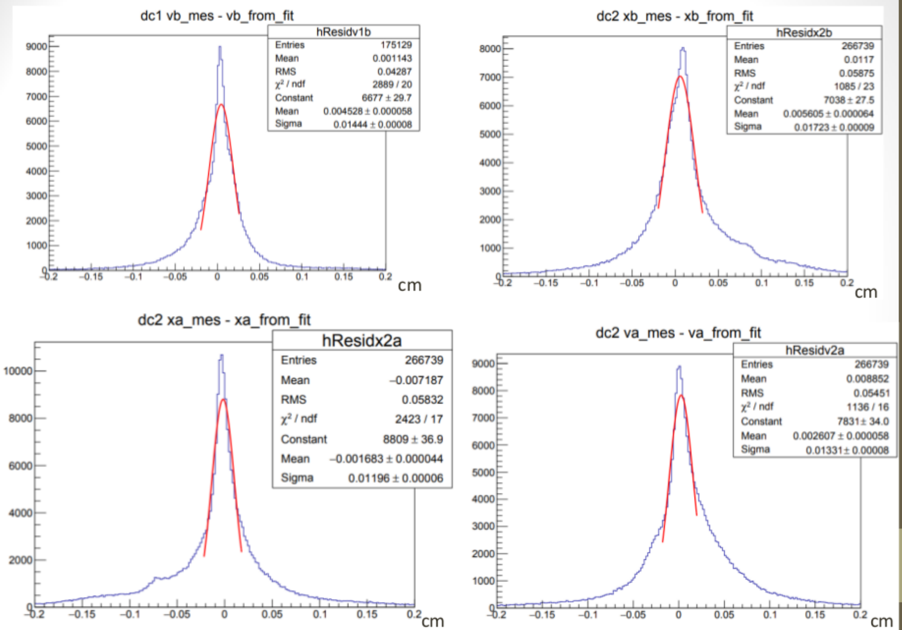
U.A.Wiedemann

A.G.Litvinenko

# DCH reconstruction and efficiency with SRC data

## Dr. Vladimir Palichik

### Some selected residuals [Measurement – segmentFit]



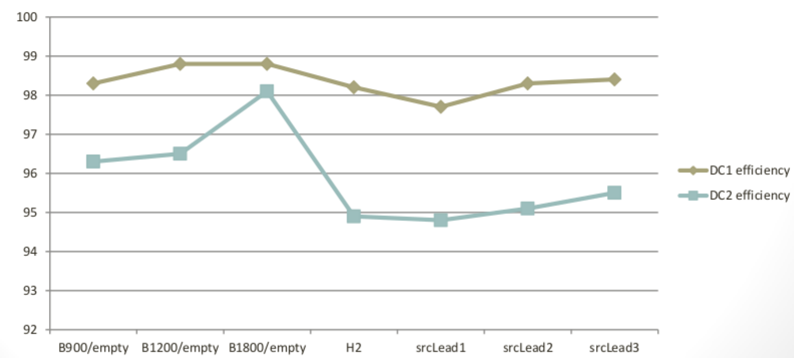

**Resolution < ~200µm**

### DCH Segment Efficiency vs. GEM track + adjacent DCH

$$DC1\_Efficiency = \frac{DC1_{segment}}{GEM_{track} + DC2_{segment}} * 100\%$$

$$DC2\_Efficiency = \frac{DC2_{segment}}{GEM_{track} + DC1_{segment}} * 100\%$$

| conditions | DC1 efficiency | DC2 efficiency |
|---|---|---|
| B900/empty | 98.3 | 96.3 |
| B1200/empty | 98.8 | 96.5 |
| B1800/empty | 98.8 | 98.1 |
| H2 | 98.2 | 94.9 |
| srcLead1(9mm) | 97.7 | 94.8 |
| srcLead2(2x9mm) | 98.3 | 95.1 |
| srcLead3(3x9mm) | 98.4 | 95.5 |

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## Conclusions

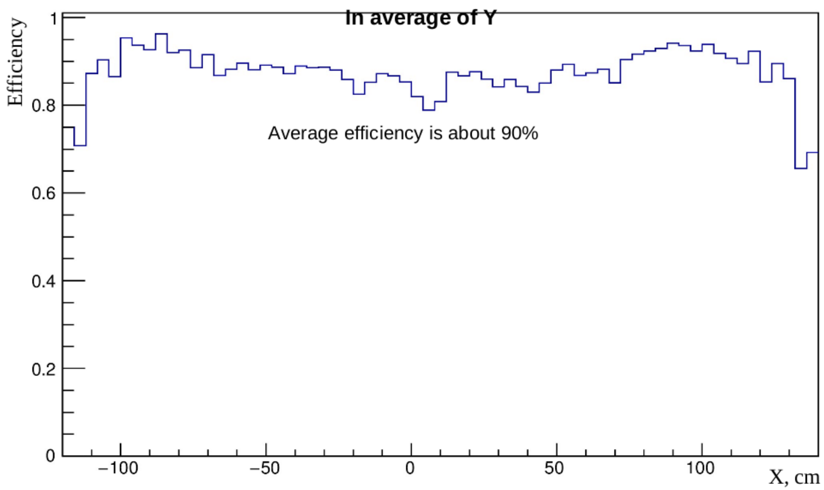
- Full reconstruction chain for DCH was developed and implemented into bmnroot;
- DCH spatial resolution is about 200 µm;
- The segment reconstruction efficiency for

DCH1 vs. GEM+DCH2 is ~98% and for
DCH2 vs. GEM+DCH1 is ~95-96%.

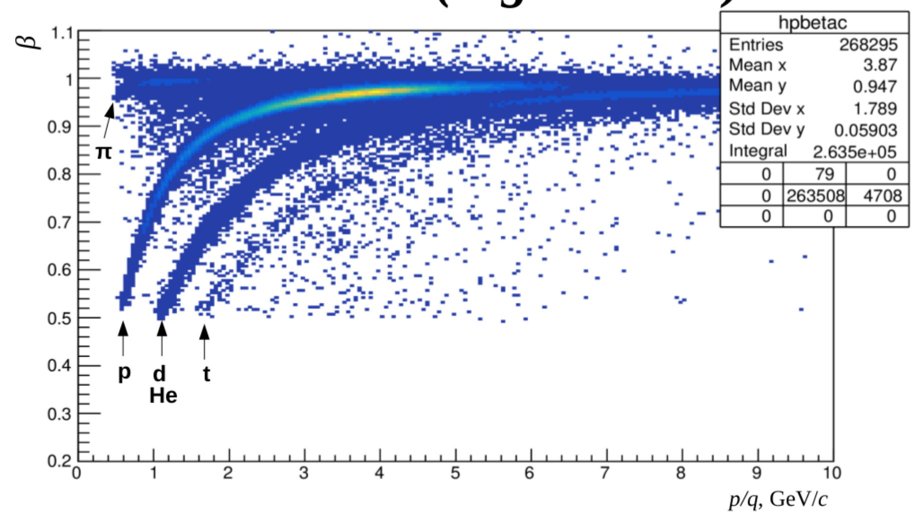
# ToF-700 efficiency / calibration. Ar data run 7.

## Mr. Lalyo Kovachev

### *TOF700 Efficiency*




### *Beta vs momentum after proton hits corrections (argon run 7)*

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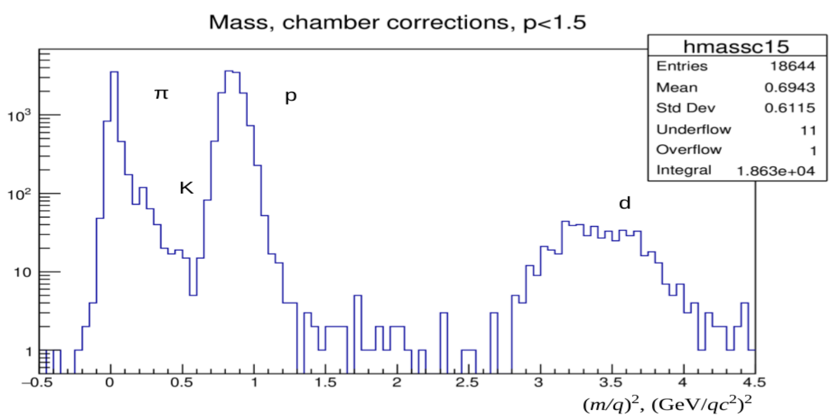



### *Conclusion*

The analysis of TOF700 efficiency was performed.
It showed sufficient efficiency for both the detector and matching procedures.
Using matched tracks for both DCH chambers showed higher efficiency.

Preliminary per-chamber calibration was done.
Even the preliminary results allow for the use of identification.

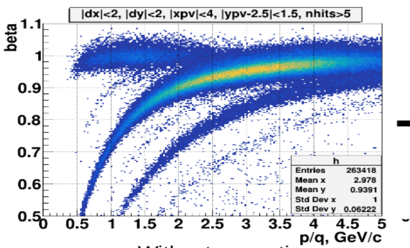
PID procedure alows for separation of pions, protons, and deutrons in the area of up to 2 GeV/*c*.
Separation of higher momentum regions requires a decrease in the time of flight error.

Further analysis and calibration should improve identification and results.

# ToF-400 performance / efficiency

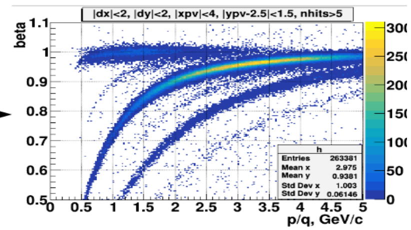
## Mr. Mikhail Rumyantsev

### ToF400 time resolution




Without correction.
Time resolution ~350 ps.

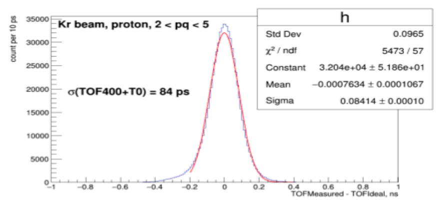
Digits to Hits



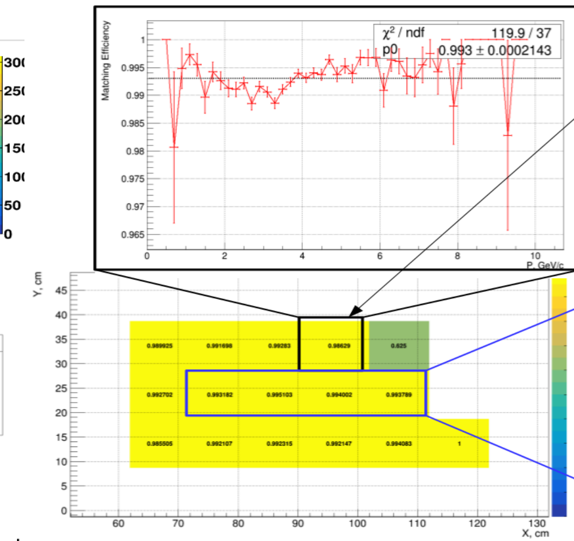

With correction.
Time resolution ~ 100 ps

Step of correction

- INL correction of readout electronics
- Time-Amplitud (Slewing) correction FEE
- Correction of the Left-Right time dependency for right Y coordinate calculation
- Time tuning on proton mass in each strip



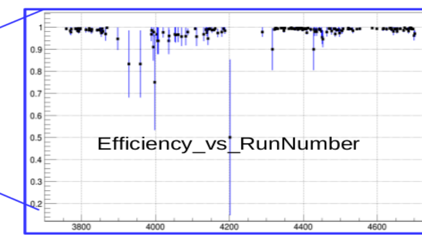

### Matching Efficiency of Gem+Csc+Dch track to ToF400



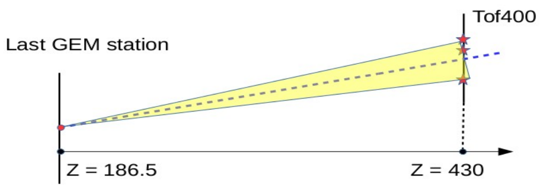

$\varepsilon\, Match = \varepsilon_{Tof} * \varepsilon_{algorithm}$

$\varepsilon_{algorithm} = f(p) \approx 1$

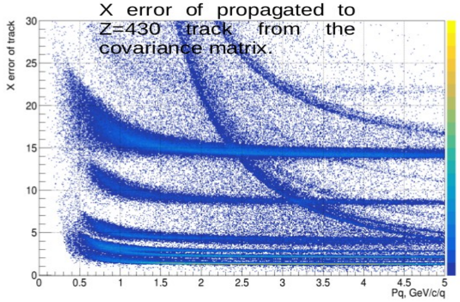
$\varepsilon_{ToF} = f(HV) > 0.99 (HV = 11.5 kV)$

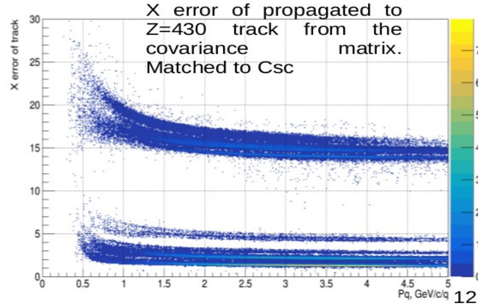



### Matching Efficiency of track to ToF400




Different bands may be different particle (for commonly used Proton pdg) or various combination of GEM station used in a track. The tracking and matching algorithms should be improved.

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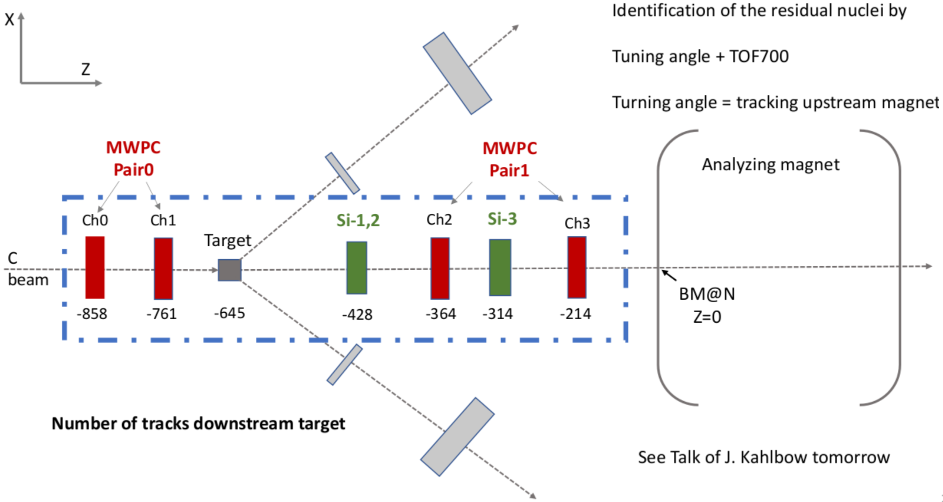
### Conclusion

- The 90% of TOF400 area are working. The broken channels/detectors of TOF400 should be fixed.
- System performance as expected (time resolution <80 ps, efficiency > 98% declared in ToF400 TDR).
- Matching algorithm should be improved. Add hypothesis about different types of particles during propagation.
- Tracking algorithm should be improved.

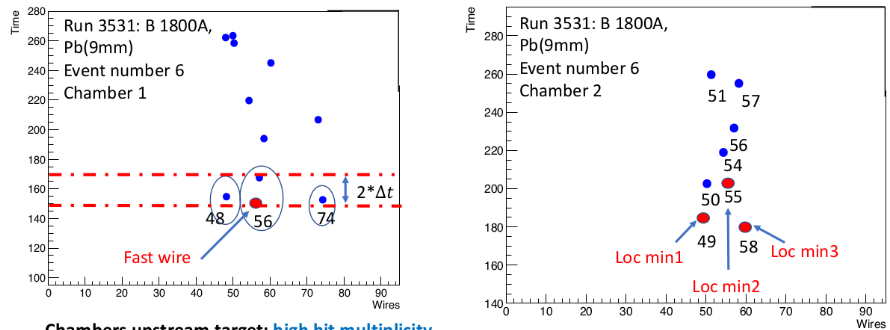
Thank you for attention.

# Track reconstruction in Silicon / MWPC detectors in SRC run  Ms. Vasilisa Lenivenko

## Tracking Upstream the Analyzing Magnet




## Improved MWPC-clustering




**Chambers upstream target: high hit multiplicity**

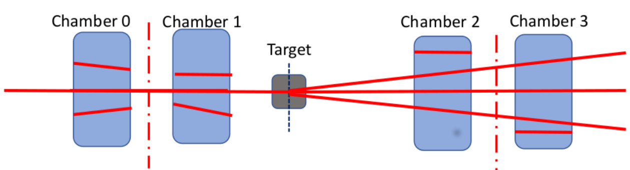
The goal reconstructing one track

1. Fast wire per plane – hit coordinate
2. Accept wires within $2*\Delta t$ ($\Delta t$ = time pitch = 8 ns)
3. Combine neighboring wires in one cluster

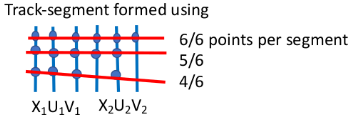
**Chambers downstream target**

The coordinate of the cluster with a time local minimum

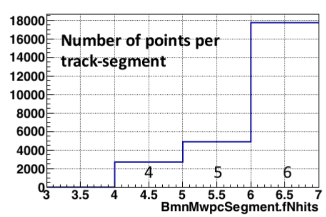
## Improved Track Reconstruction in MWPCs



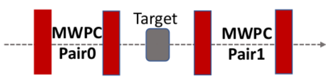

1. Track-segment = reconstructed straight track in one chamber
2. Track-segment formed using




3. Reconstruct & fit track-segment in each chamber
4. Extrapolate segments to $Z_{0,1}$= (Z1+Z2)/2 & select best pairs by $\chi^2$ criteria, **angles are not taken into account**
5. MWPC track in Pair0 and Pair1



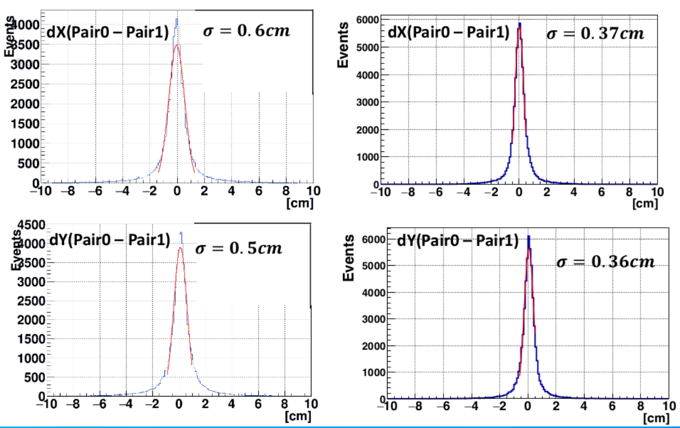

## Better Matching in Z Target with Improved Reconstruction




Old clustering and matching → Improved clustering and matching

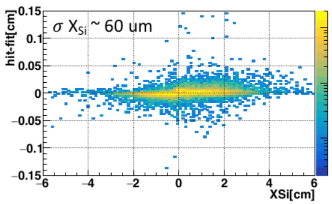
Run 2677 empty target

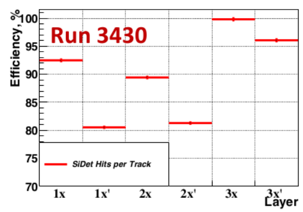
Run 3430 empty target



# Track reconstruction in Silicon / MWPC detectors in SRC run Ms. Vasilisa Lenivenko

## Resolution & Layer Hit Efficiency per Track

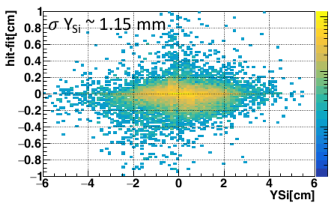


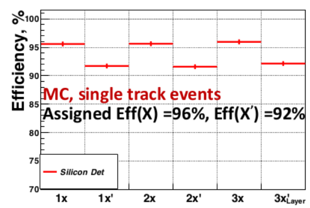




The best efficiency in 3d st with SRC data (by construction)

Some problems with Y-alignment --> to be solved

$$\text{Hit } Eff\ per\ track = \frac{\sum_i^{Num\ tracks}(1, if\ Track_{hit} on\ layer)}{Number\ of\ tracks}$$




MC data:
Algorithm returns the assigned efficiency → reconstruction works correctly

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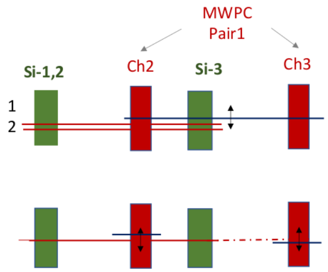
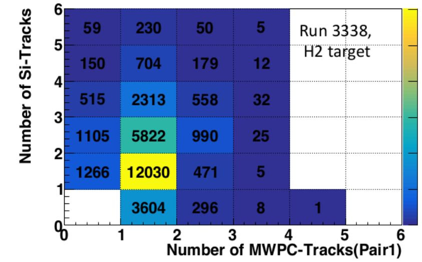
## Two Stages of MWPC-Si Matching

Si find more tracks than MWPCs

1. Si Tracks – MWPC Tracks (Pair1) matching with minimal distance

2. Matching of rest Si Tracks with MWPC Segments (Chamber 2 or Chamber 3)

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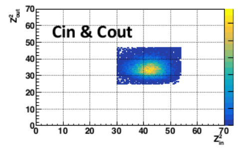
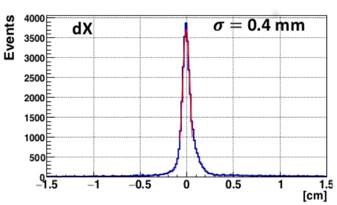
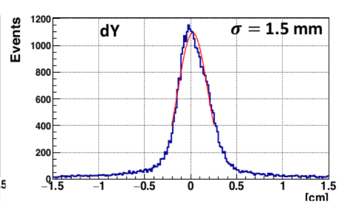
## Si – MWPC Matching at $Z_{Pair1}$

Run 3430, empty target



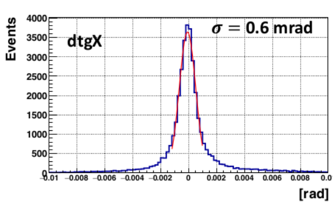



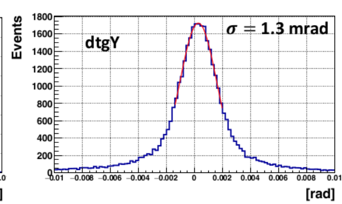




Precise coordinate in Si
→ extrapolation to MWPC

σ $X_{Si}$ ~ 50 um ; σ $Y_{Si}$ ~ 1 mm

σ $X_{MWPC}$ = $2.5/\sqrt{12}$ [mm]
σ $Y_{MWPC}$ = σ $X_{MWPC}$ * $\sqrt{2}$

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## Summary

✓New MWPC clustering motivated by multiple tracks after target
✓Si-track reconstruction – added to the repository
✓MWPC-Si matching - tested

## Outlook

- Fit of the global track MWPC-Si
- Match Si-MWPC system to the Global track (GEM & DCH)

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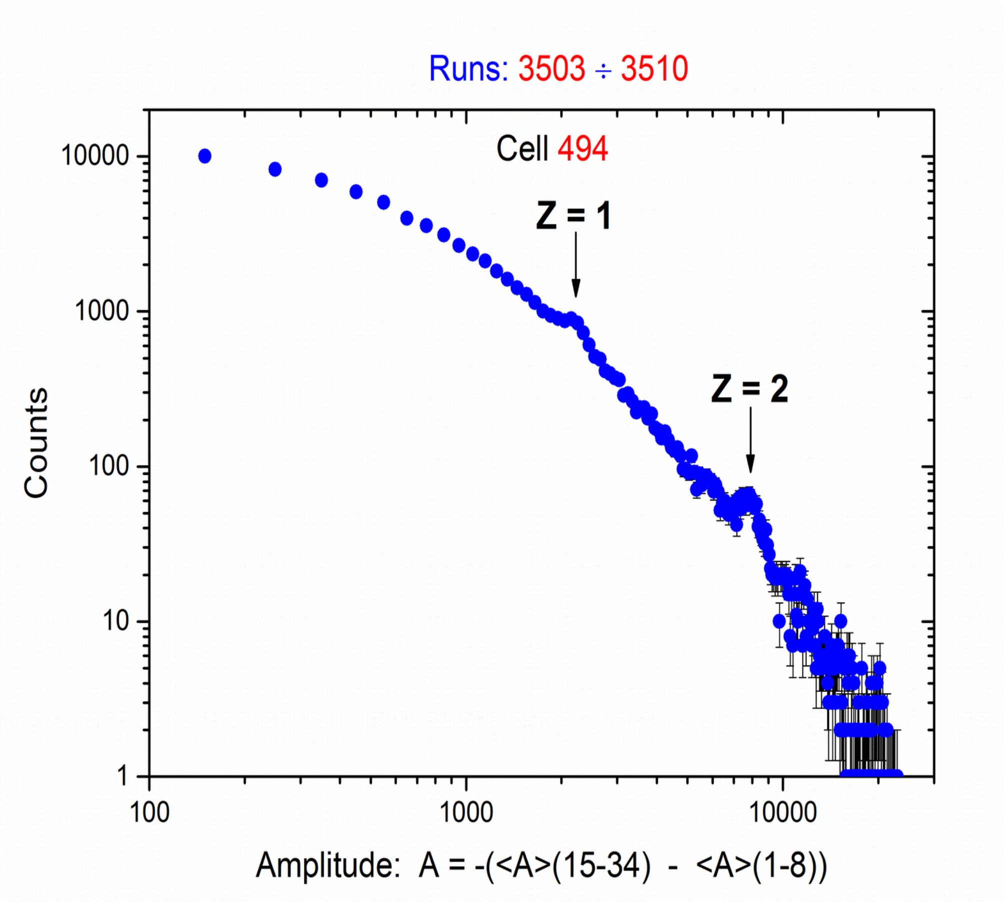
# Status of ECAL reconstruction / simulation

## Dr. Khachik Abraamyan

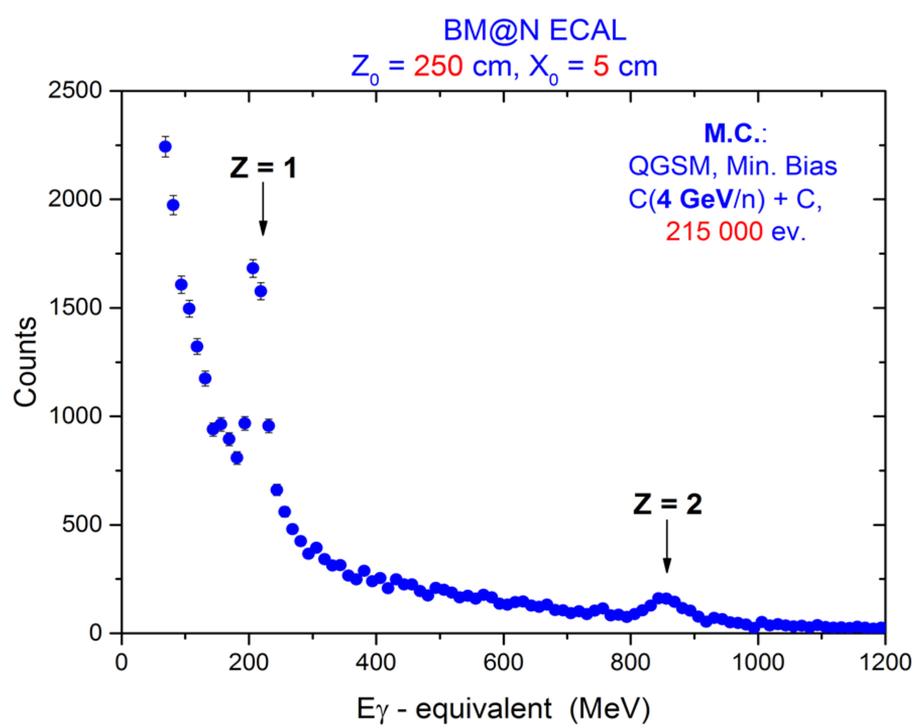
**Amplitude spectrum in one of the cells of the calorimeter in the experiment on a carbon beam, using a lead target, in the 55th run of the Nuclotron (March-April 2018)**



# Status of ECAL reconstruction / simulation

## Dr. Khachik Abraamyan

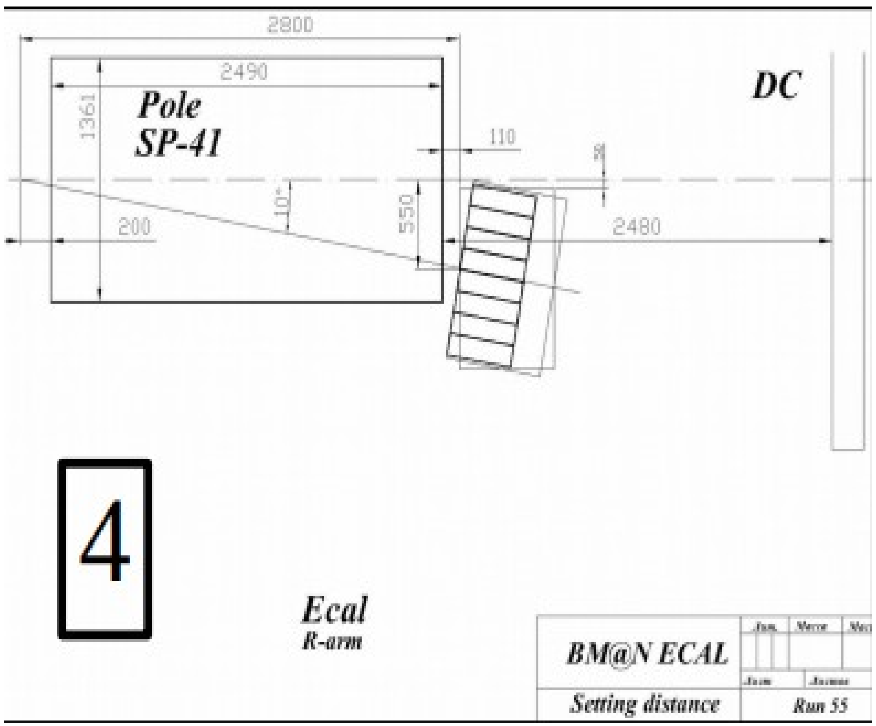
**Amplitude spectrum in a separate cell of the calorimeter (in photon energy equivalents) in the reaction C(4 GeV/nucleon)+C: Model QGSM, Min. bias.**



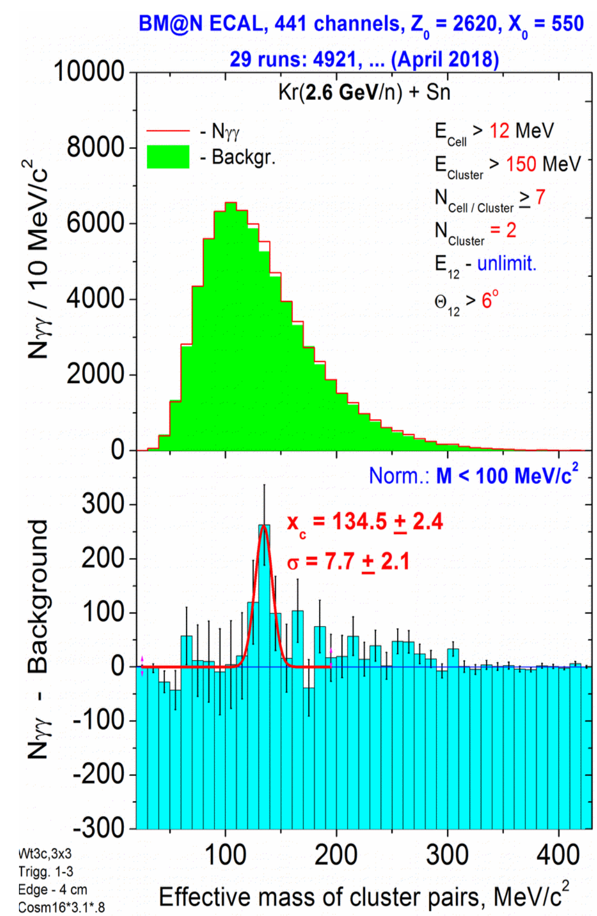
# Status of ECAL reconstruction / simulation

## Dr. Khachik Abraamyan

**Effective mass distributions of photon pairs (pairs of clusters) in the reaction**
**Kr (2.6 GeV / nucleon) + Sn**




Location of the ECAL in the 55th run of the Nuclotron, on a beam of Kr nuclei with an energy of 2.6 GeV per nucleon, using a tin target.



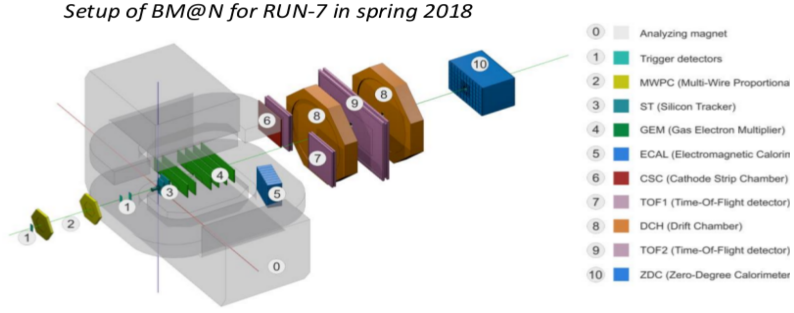
# Outlook

1. Further analysis of the data using the results of time analysis of the clusters;
2. Data simulation and estimation of efficiency of detection of $\pi^0$ and other particles;
3. To engage all 504 channels of the Right arm of the Calorimeter;
4. For further investigations of two-photon spectra in a wide range of masses up to the mass of η meson, it is necessary to collect and install the second – the Left arm of the Calorimeter.

# Progress in simulation of the BM@N detectors
Dr. Dmitry Baranov

## Tracking system of the BM@N experiment

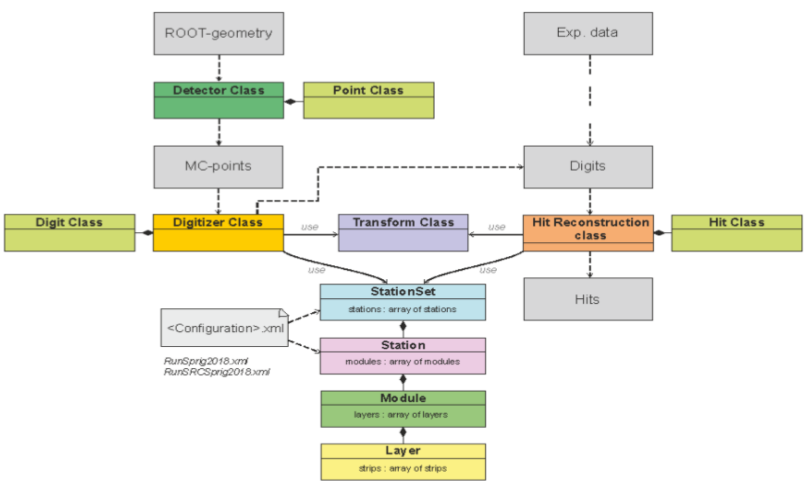
*Setup of BM@N for RUN-7 in spring 2018*




**Detectors of the tracking system in BM@N:**

- **GEM** (Gas Electron Multiplier)
- **SILICON** (Semi-conductor detector)
- **CSC** (Cathode Strip Chamber)
- **DCH** (Drift Chamber)

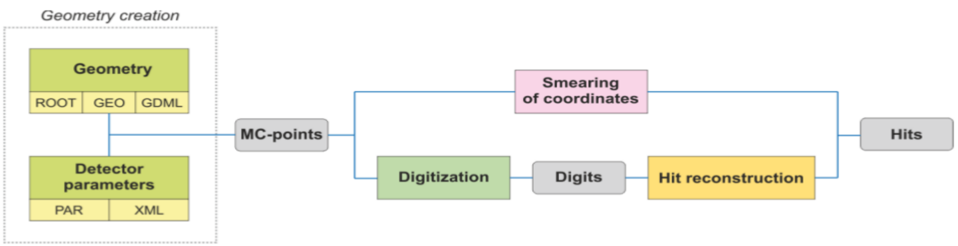
## Program implementation of processing procedures




*Scheme of program implementation for simulation and reconstruction procedures. Such program structure allows us to make some changes in any part with minimal modifications in other parts.*

## Simulation of BM@N detectors

**Detector simulation stages:**




*Scheme of the main stages of the simulation*

## Conclusion

**Brief overview:** features of data processing for simulated detectors

| | GEM | SILICON | CSC | DCH |
|---|---|---|---|---|
| **Detector type** | gaseous | semi-conductor | gaseous | gaseous |
| **Readout type** | micro-strips | micro-strips | micro-strips | multi-wires |
| **Geometry format** | ROOT | ROOT | ROOT | ROOT |
| **Parameters description** | XML file | XML file | XML file | constants embedded in code |
| **Simulation** | realistic based on Garfield+ | simplified based on Gaussian smearing | simplified based on Gaussian smearing | simplified based on Gaussian smearing with distance dependence |
| **Hit reconstruction** | strip intersections | strip intersections | strip intersections | track segments |

# Track reconstruction in SRC run
## Mr. Sergei Merts

BM@N

### Event reconstruction in SRC

General goal:
Reconstruct global tracks from target to DCH + tracks in arms + PID

Particular tasks:

1. Track reconstruction inside magnet
2. Matching tracks in downstream direction
3. Matching tracks in upstream direction
4. Track reconstruction in arms
5. Particle identification by ToF, common charge and momentum

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BM@N

### Inside magnet

Unified approach to reconstruct tracks both for the BM@N setup and for the SRC setup:

1. reconstruct 3D points of detector response (hits)
2. create cells (two connected hits on a different planes)
3. select cells by their slope
4. create track-candidates (cells connection w.r.t slope difference)
5. select candidates by number of hits (minimal limit is 4 hits)
6. fit candidates by Circle approximation
7. refit candidates by Kalman Filter in forward and backward directions
8. select candidates by shared hits (no common hits)

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BM@N

### Alignment

For special runs without magnetic field:

- Reconstruct straight tracks
- Fit track over its hits by straight line
- Calculate residuals from track to hits for each station (ResX)
- Move all hits on station to ResX/2
- Do again

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BM@N

### Lorentz shifts estimation

Iterative algorithm:

- Reconstruct track-candidates
- Set rigidity to 8 GeV/(qc)
- Fit track over its hits by Kalman Filter with fixed rigidity
- Calculate residuals from track to hits for each station (ResX)
- Move all hits on station to ResX/2
- Do again

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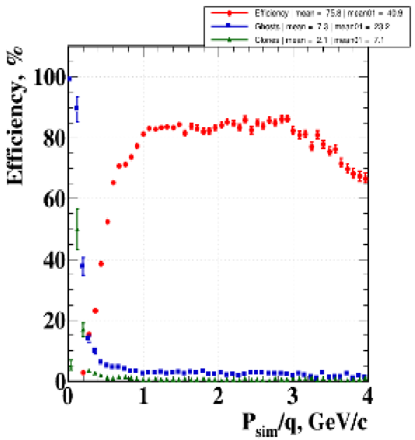
# Track reconstruction in SRC run
## Mr. Sergei Merts

BM@N

### Efficiency on ArPb (Simulated data)




- Reconstructable tracks ($N_{MC}$): MC-track with more then 3 points
- Reconstructed tracks ($N_{rec}$): All reconstructed tracks
- Well tracks ($N_{well}$): Reconstructed tracks more then 60% of hits corresponded to same MC-track
- Wrong tracks ($N_{wrong}$): Reconstructed tracks less then 60% of hits corresponded to same MC-track
- Split tracks ($N_{split}$): Reconstructed tracks corresponded to same MC-track
- Efficiency: $\frac{N_{well} - N_{split}}{N_{MC}} \cdot 100\%$
- Percent of ghosts: $\frac{N_{wrong}}{N_{rec}} \cdot 100\%$
- Percent of clones: $\frac{N_{split}}{N_{rec}} \cdot 100\%$

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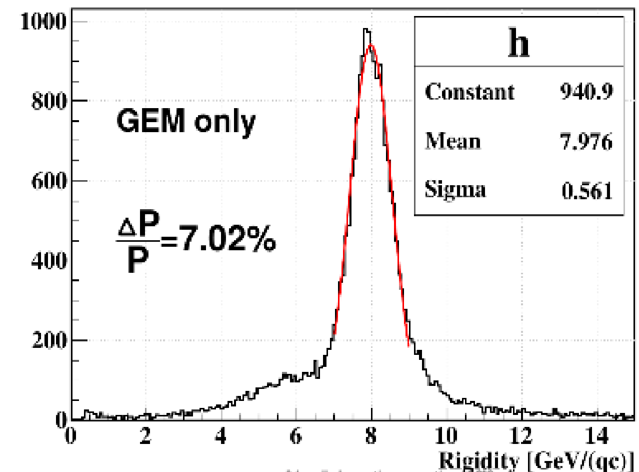
BM@N

### Momentum resolution

Special run without target

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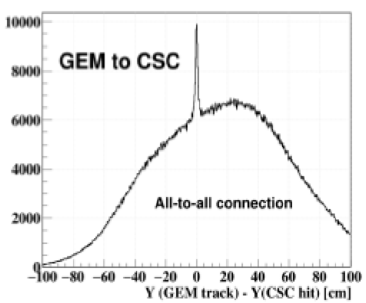
BM@N

### Common algorithm of matching

Step 1. Alignment:

- Propagate each track to plane with hits
- Create track-to-hit (all-to-all) connections
- Calculate and fit residuals → $\mu_x, \mu_y, \sigma_x, \sigma_y$
- Shift all hits by $\mu_x, \mu_y$

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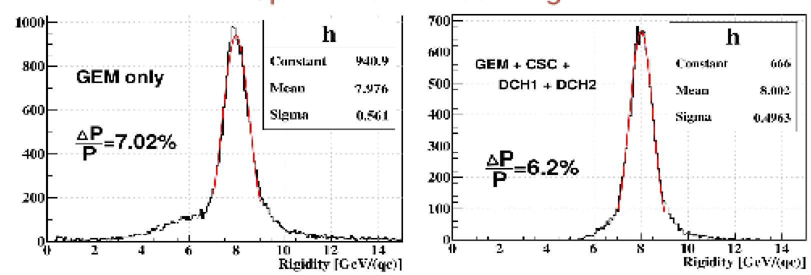
BM@N

### Momentum Resolution

Special run without target

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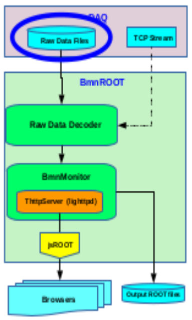
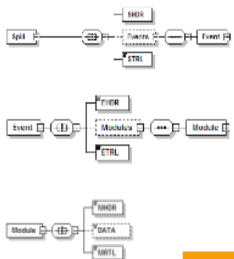
# Online Monitoring System for BM@N and Raw Data Converter Mr. Ilnur Gabdrakhmanov

## Monitoring workflow

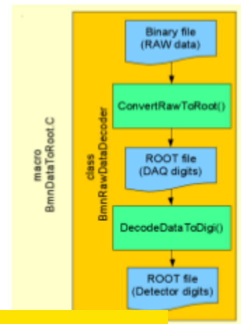



Raw Data Format





## Decoding scheme




First step (Data Converter):

- Read a binary data file with RAW-data.
- Parse the data blocks: run/spill/event/module.
- Create «DAQ-digits» (ADC, TDC, TQDC, HRB, SYNC, etc.) accordingly DAQ-data-format and write them into a tree.

Second step (Data Decoder):

- Read detector mappings (channel-to-strip) from the Unified Database
- Calculate pedestals and common modes of channels
- Clear noisy channels
- Decode DAQ-digits into detector-digits (BmnGemDigit, BmnTofDigit, etc.)
- Write the tree with detector-digits to a ROOT-file



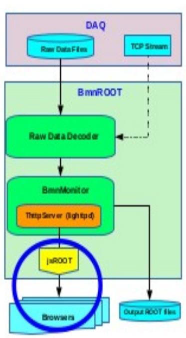
## Current status

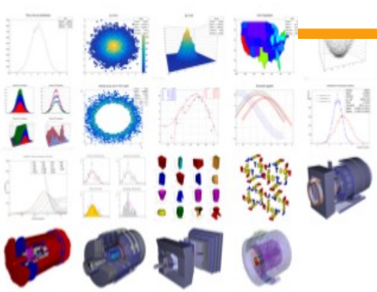
Future Development Roadmap

- Parallelization of Raw Data Decoding
- Further QA Automation
- Embedding of The Full Event Reconstruction Chain and Tracks Visualization into Online.



## jsROOT

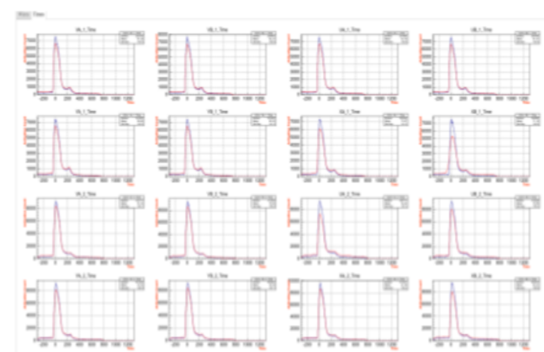


jsROOT website
https://root.cern.ch/js/



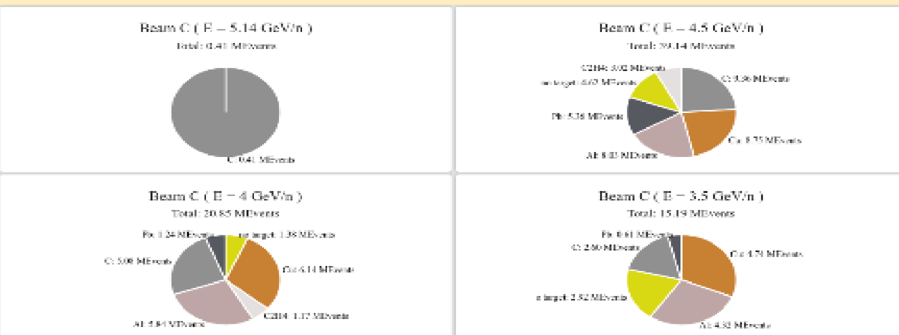
## ...erview. Drift Chambers



# Data Quality Analysis
# Mr. Pavel Batyuk

## BM@N RUN6: existing experimental data

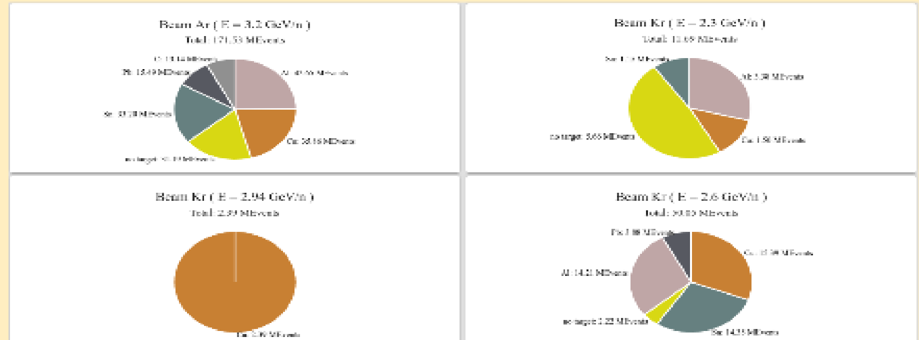
### Carbon run




Total amount is about of 75 MEvents

## BM@N RUN7: existing experimental data

### Argon and Krypton run




Total amount is about of 237 MEvents
(increased by factor of 3 if comparing with RUN6)

## BM@N offline QA-system

### What does it do right now?

- Different histograms are drawn for different detectors (meant those ones I called earlier as "basic distributions").
  - Triggers: Distributions of amplitudes, times, channels.
  - Coordinate detectors (GEM, SILICON, CSC): Distributions of fired strips per each station, module and layer.
  - Time detectors (TOF, MWPC, DCH): Distributions of amplitudes, planes, times and strips
  - Calorimeter detectors (ECAL, ZDC): Distributions of amplitudes and channels
- Basic hit and track distributions got from the tracking developed by our group (S. Merts et. al.).
- All mentioned above can be visualized either for a run we analize (current) or couple of them (current and reference)

## BM@N offline QA-system

Partially filled with data produced by the BmnRoot software release (19.10.0)

### RUN6, BM@N

- No high-level data put (hits, tracks ...), just "raw" information from detectors
- Processed of about of 0.5 kFiles.

### RUN7, BM@N

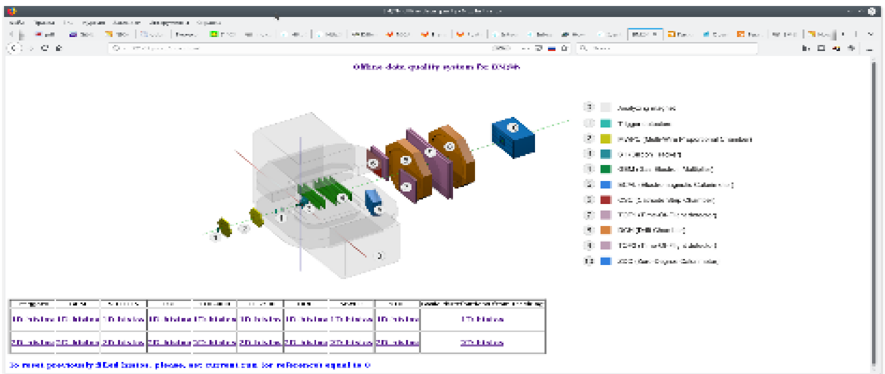
- Processed of about of 0.6 kFiles, mainly corresponding to argon part of the run
- Shown high-level information is obtained with the current release of software

### RUN7, SRC

- Processed of about of 1 kFiles.
- Shown high-level information is obtained with the current release of software

# Data Quality Analysis
# Mr. Pavel Batyuk

## Structure of the BM@N offline QA-system




## BM@N offline QA-system, conclusion

It is hosted on vm221-75.jinr.ru (LIT JINR, cloud infrastructure), probably, to be changed in future to bmn-qa.jinr.ru

### Already done:

- Extended to all possible configurations of BM@N existed
- Adopted clicking menu to choose release, period, setup ...
- Added an useful info canvas with meta-information on runs being analyzed

### To be done:

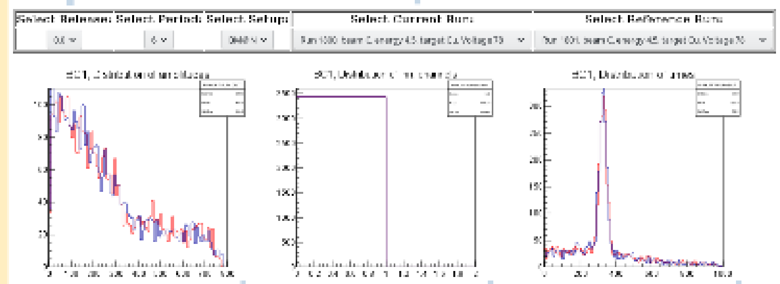
- Prepare a stable release of the system
- Add multi-user access
- Extend set of existing histograms and eliminate those ones not representative
- Establish correct binning and histogram ranges for some detectors
- Produce list of shown histograms with their brief explanations
- Improve visibility and usability of the system



## BM@N offline QA-system

### Distributions of basic trigger parameters (amplitude, channels, time ...)

| Current Run: 1800 | Ref. Run: 1801 |
|---|---|
| Energy: 4.50 | Energy: 4.50 |
| Beam: C | Beam: C |
| Target: Cu | Target: Cu |



# STS+GEM hybrid tracker performance studies in simulation

Dr. Alexander Zinchenko

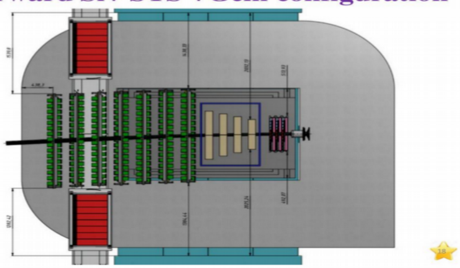
1. Tracker performance for different magnetic field settings.
2. Development of the fast digitizer for GEMs.



## Geometry

A.Zinchenko

**Forward Si+ STS +Gem configuration**





## Field settings

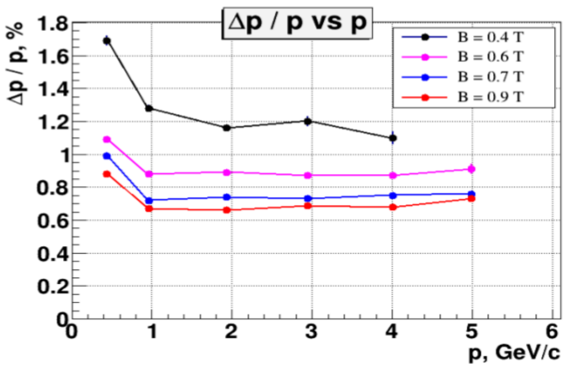
A.Zinchenko

Choose magnetic field to be proportional to the Au beam magnetic rigidity p/Z

| To, AGeV | Rigidity, GeV/c | Max. field, kG |
|---|---|---|
| 1.5 | 5.612 | 3.776 |
| 2.5 | 8.249 | 5.550 |
| 3.5 | 10.818 | 7.284 |
| 4.5 | 13.358 | 8.993 |

## Momentum resolution

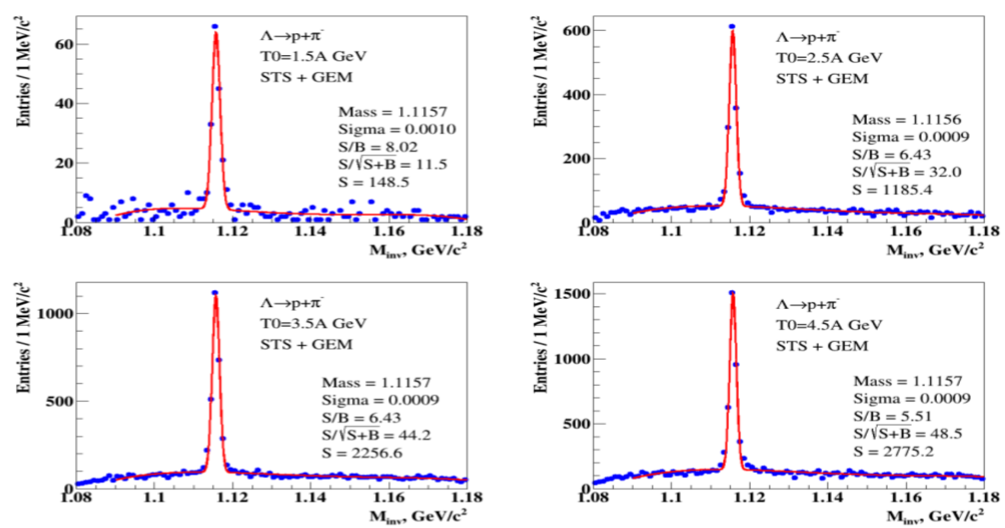
A.Zinchenko






## Λ peak for different energies

A.Zinchenko



# STS+GEM hybrid tracker performance studies in simulation

Dr. Alexander Zinchenko



## Fast digitizer based on cluster shape library



**Cluster shape library:**

10k single track events with p = 1.6 GeV/c (median track momentum in Au+Au @ 4 GeV) at fixed position in station 5 (first GEM station)
- clusters from two readout planes.

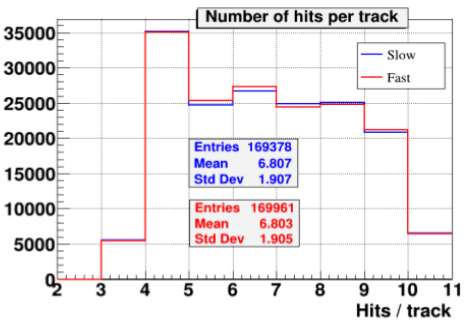
2-D grid of angles in bending plane (from -60 to +60 deg with a step of 10 deg) and non-bending plane (from -20 to +20 deg with a step of 10 deg).

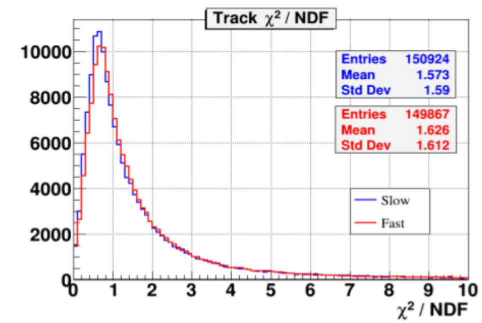
For each angle 2-D correlation plot of COGx' vs COGx.



## Track reconstruction



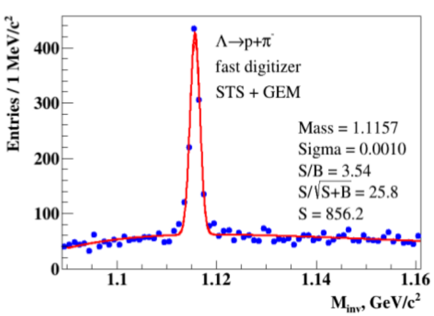


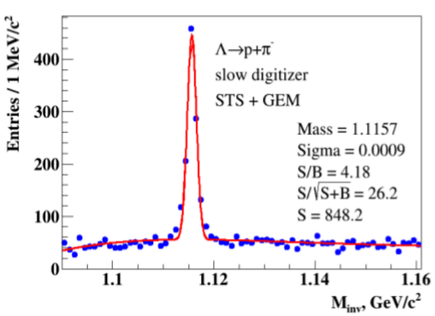






## Lambda reconstruction








## Summary



Lowering the magnetic field value does not significantly affect the track reconstruction performance.

Fast digitizer accelerates the processing by a factor of ~3.5.

# Conclusions

1. There is a progress in data analysis (including simulation, reconstruction, data quality control, analysis methods).
2. Teams involved are gaining experience.
3. Still quite long road ahead.