# Analysis of hypernuclei and strange particles in the BM@N experiment

Ramin Barak

**on behalf of the BM@N Collaboration**

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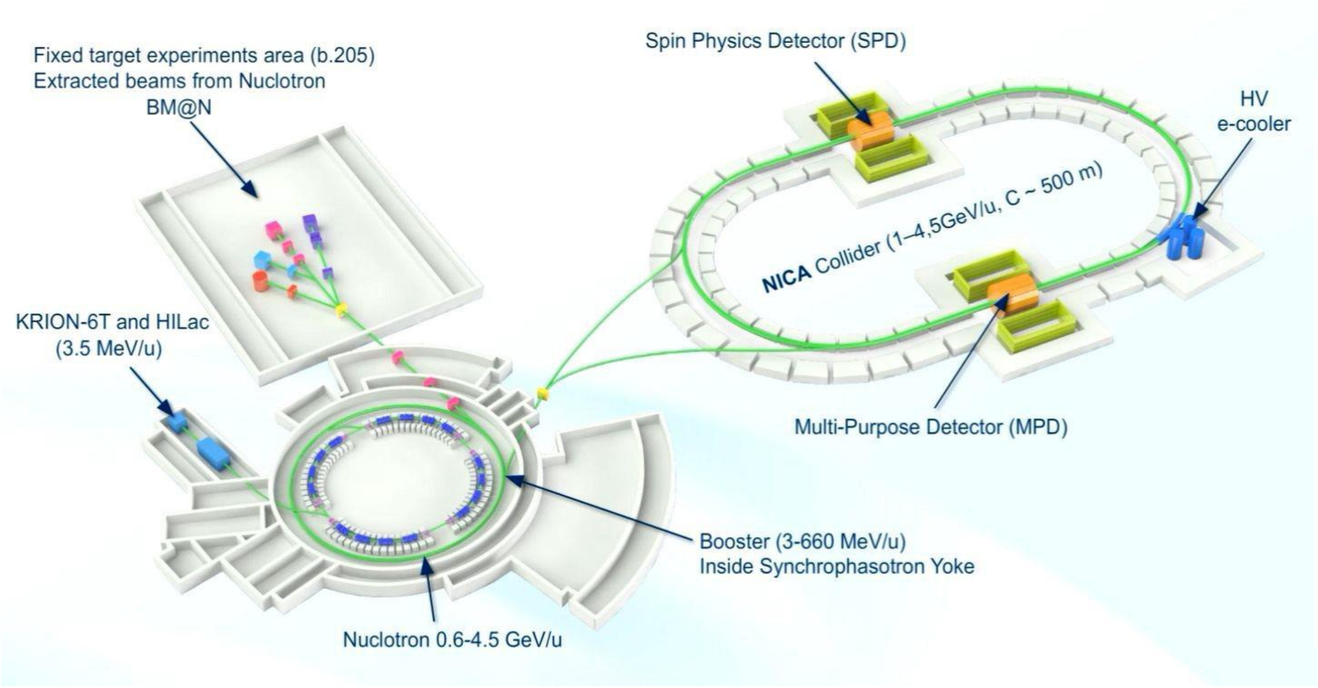
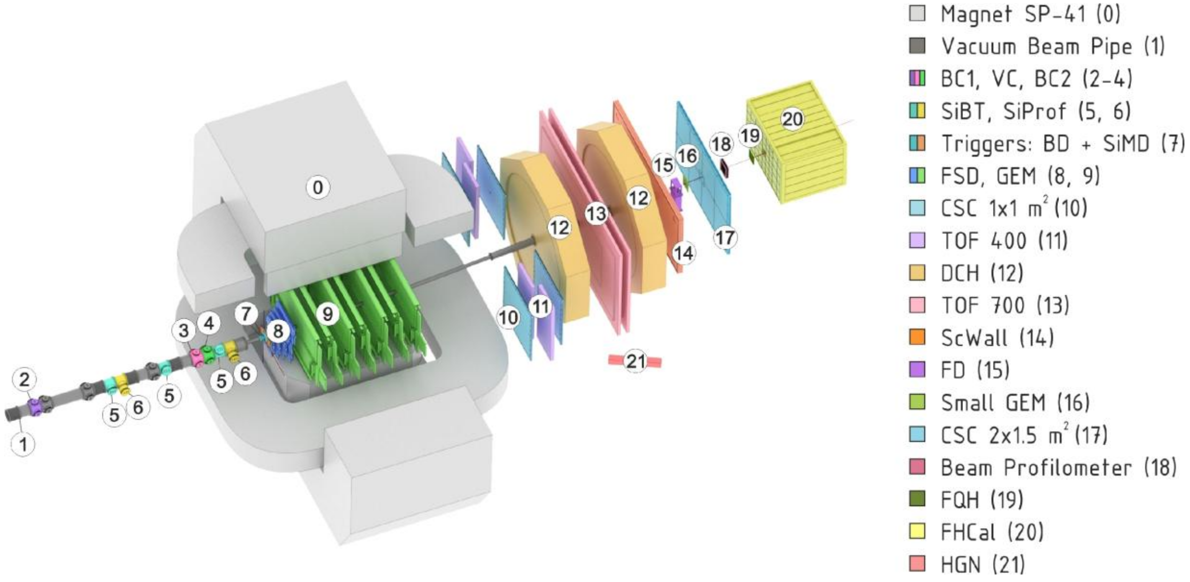
# BM@N experiment at the NICA complex

- Collisions of elementary particles and ions with a stationary target at energies up to 4 GeV per nucleon.

- Studying the properties of dense baryonic matter, the formation of hypermatter, the equation of state of symmetric and asymmetric nuclear matter, collective phenomena...




NICA accelerator complex

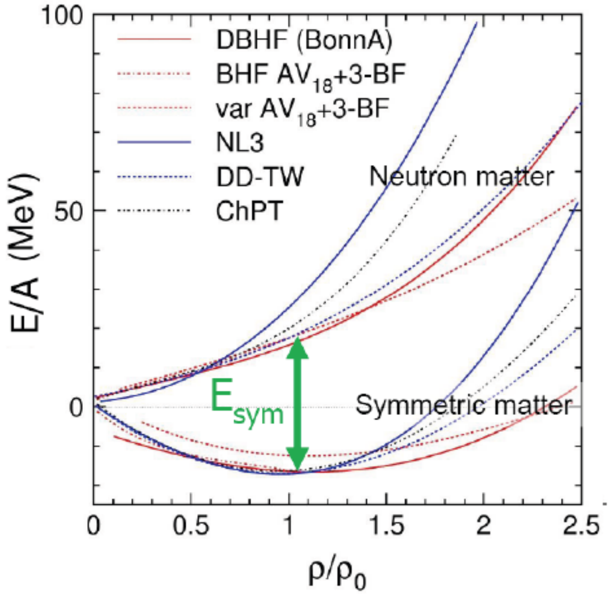


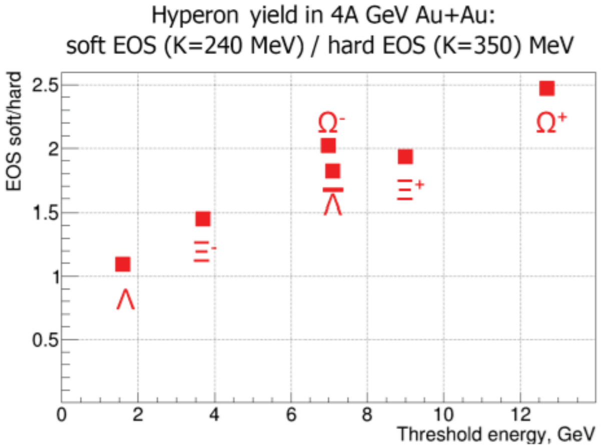

Experimental setup of BM@N

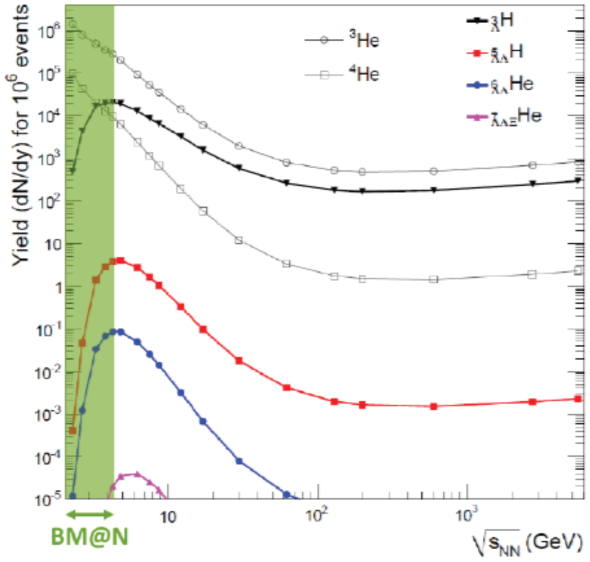
# Introduction

## Why are strange particles and hypernuclei interesting to study?

φ(1020) is expected to have a small cross-section for interactions with other non-strange particles, and its life time is relatively long (∼41 fm/c), it may keep information of the early stage of the system's evolution [1].




Study of symmetric matter EOS at $\frac{\rho}{\rho_0}$ = 3 – 5, $\rho_0$ = 0.16 $\mathrm{fm}^{-1}$:

- Elliptic flow of protons, mesons and hyperons.
- Sub-threshold production of strange mesons and hyperons.


[1] J. Phys. G: Nucl. Part. Phys. 32, S373-S380 (2006) DOI: 10.1088/0954-3899/32/12/S46.


EoS: relation between density, pressure, temperature, energy and isospin asymmetry EA(*ρ*, *δ*) = EA(*ρ*, 0) + Esym(*ρ*) ・ *δ*2, where *δ* = (*ρ*n − *ρ*p)/*ρ*.

# Goal

- Observation of strange particle (lambda hyperon, $K_S^0$, $\Xi^-$ and $\varphi(1020)$) and hypernuclei signals in the experimental data.

# Data

- Experimental data obtained in the physical session at the beginning of 2023 with a beam energy of 3.8 AGeV, a CsI target and Xe beam.
- Lambda hyperons and $K_S^0$: about 2 million experimental events were analyzed.
- $\varphi(1020)$: about 450 million experimental events were analyzed.
- $\Xi^-$: about 10 million events were analyzed.
- Hypernuclei: two cases were considered, about 500 million and 225 million events respectively.

# Data processing procedure ($\Lambda$ and $K_S^0$)

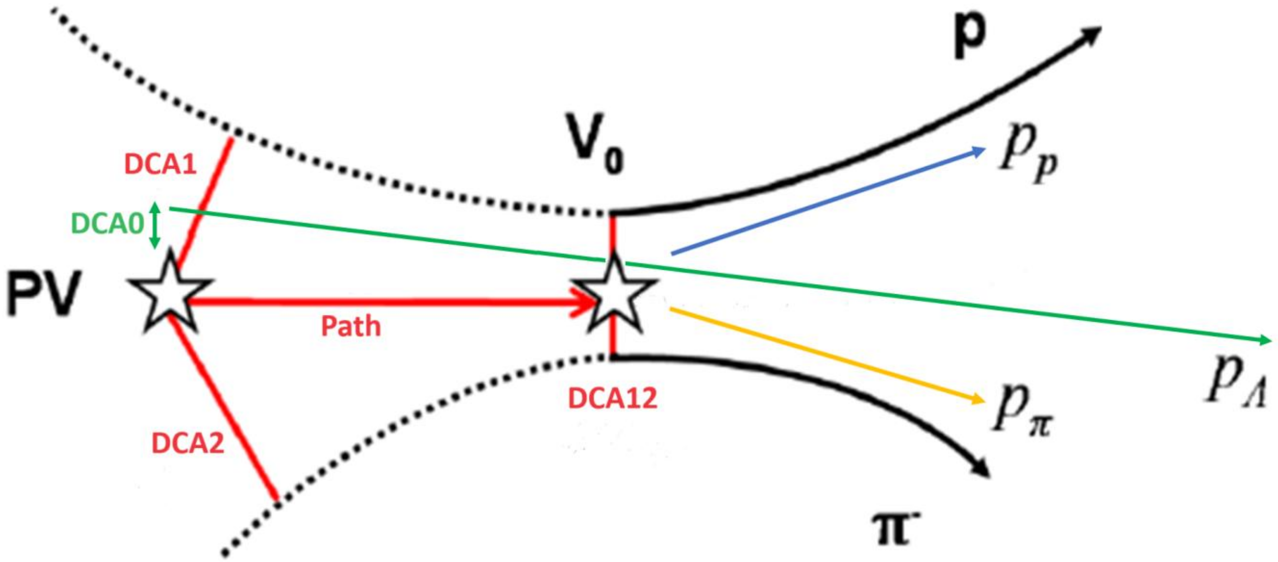
- Reconstruction of particle tracks was carried out.
- Mathematical algorithms were developed and implemented to search for the $\Lambda \rightarrow p + \pi^-$ and $K_S^0 \rightarrow \pi^+ + \pi^-$ decays:
  - shuffling pairs of particles with different signs
  - calculation of invariant mass
  - imposing a number of geometric restrictions on the parameters of each pair

PV – primary vertex.
Path – the distance traveled by Λ from the primary vertex to the point of its decay.
DCA0 – the distance between the primary vertex and the projection of momentum of Λ.

DCA1 – the shortest distance from the proton to the vertex.

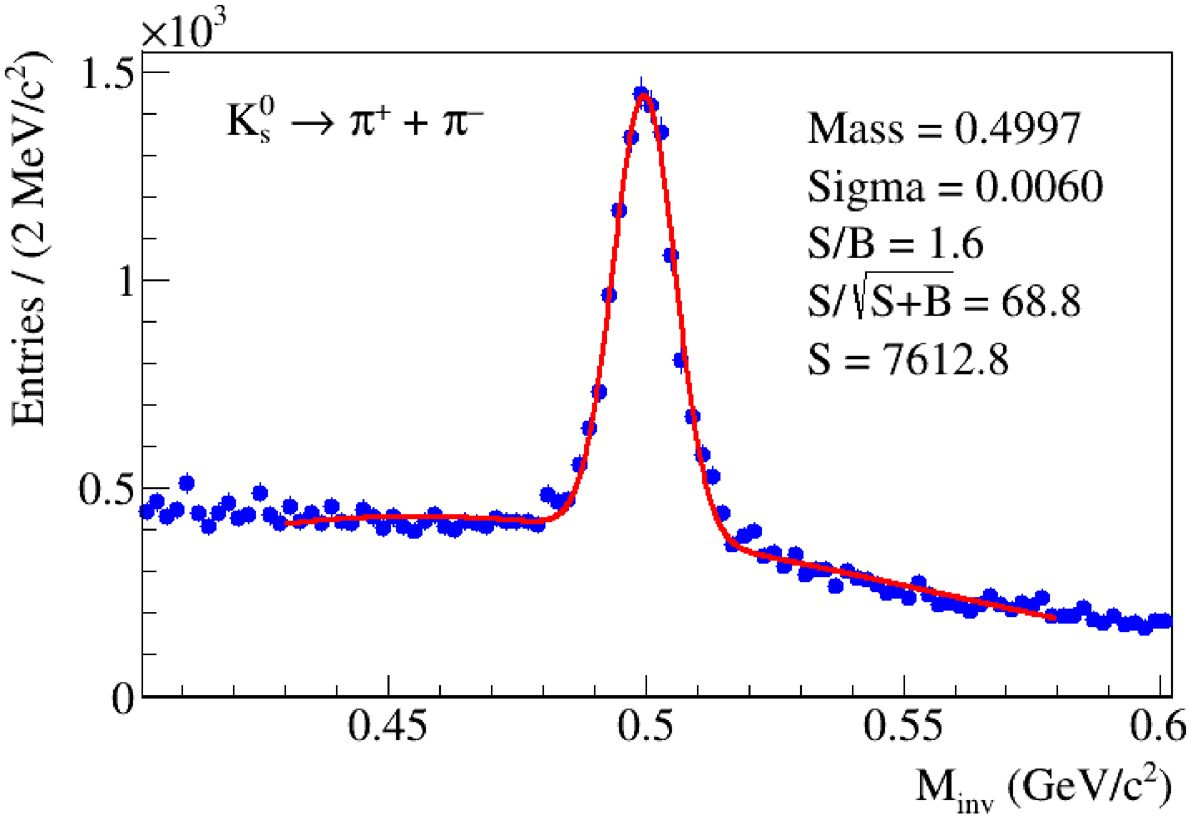
DCA2 – the shortest distance from the negative π-meson to the vertex.

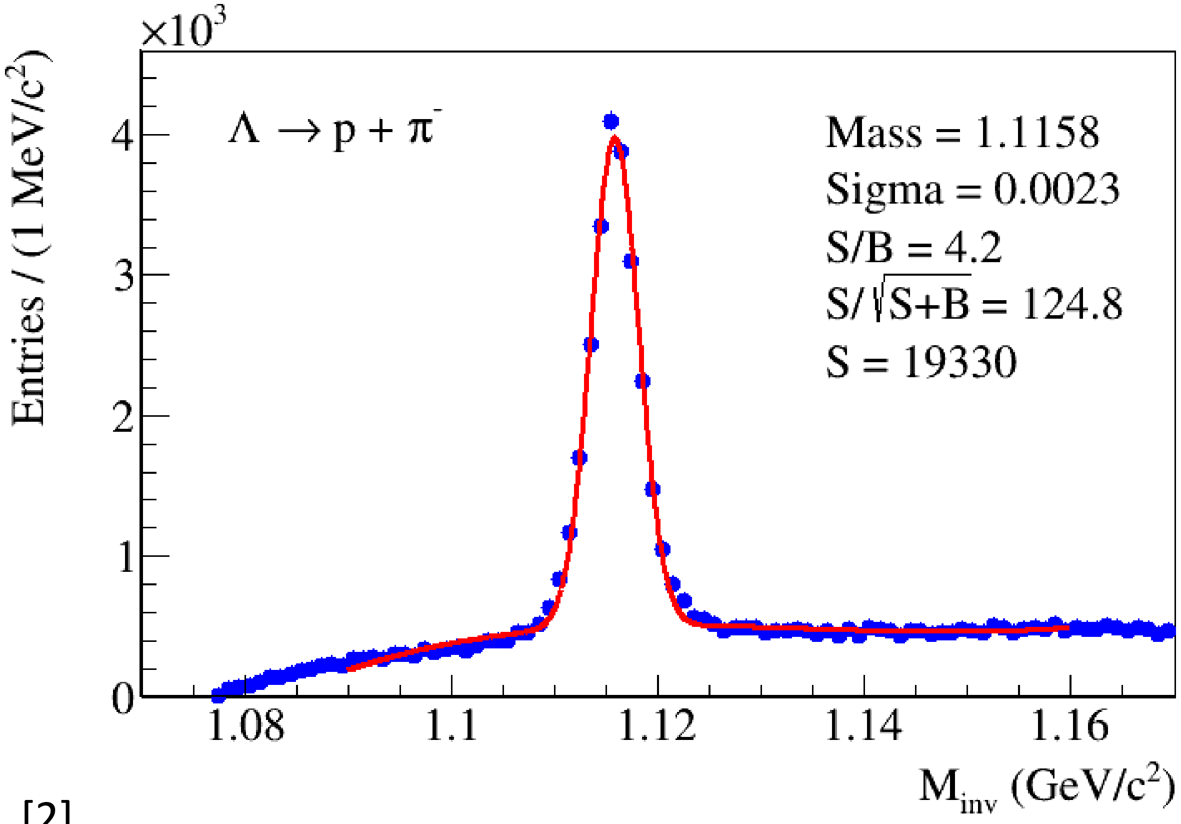
DCA12 – the distance between the proton and the negative π-meson at the decay point of Λ.




Event topology

# Results (lambda hyperons and $K_S^0$)




[2].

- path > 2.3 cm
- dca1 > 5.8
- dca2 > 5.8
- $dca12_{K_S^0} < 5.0$
- $P_{T_{\pi^+}} > 0.1\ \frac{GeV}{c}$
- $P_{T_{\pi^-}} > 0.1\ \frac{GeV}{c}$

- path > 5.2 cm
- dca1 > 3.3
- dca2 > 6.0
- $dca12_{\Lambda} < 4.3$
- $P_{T_p} > 0.1\ \frac{GeV}{c}$
- $P_{T_\pi} > 0.05\ \frac{GeV}{c}$

[2] A. Zinchenko (JINR), BM@N collaboration.

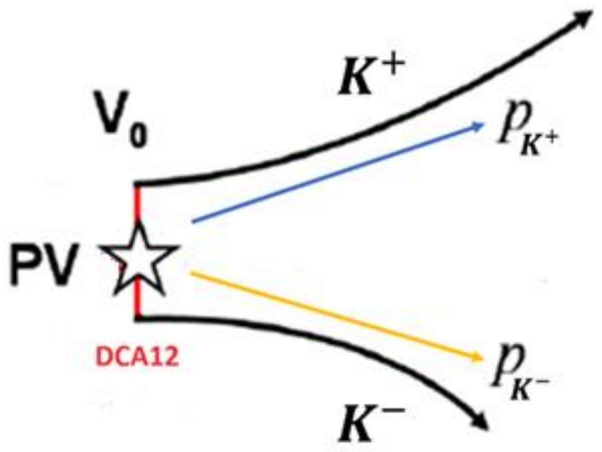
# Data processing procedure (φ(1020))

- Reconstruction of particle tracks was carried out.
- Mathematical algorithms were developed and implemented to search for the φ(1020) $\rightarrow K^+ + K^-$ decay:
  - shuffling pairs of particles with different signs
  - calculation of invariant mass
  - imposing a number of geometric restrictions on the parameters of each pair

DCA12 – the distance between $K^+$ and $K^-$ at the decay point of φ(1020).

Other restrictions employed:

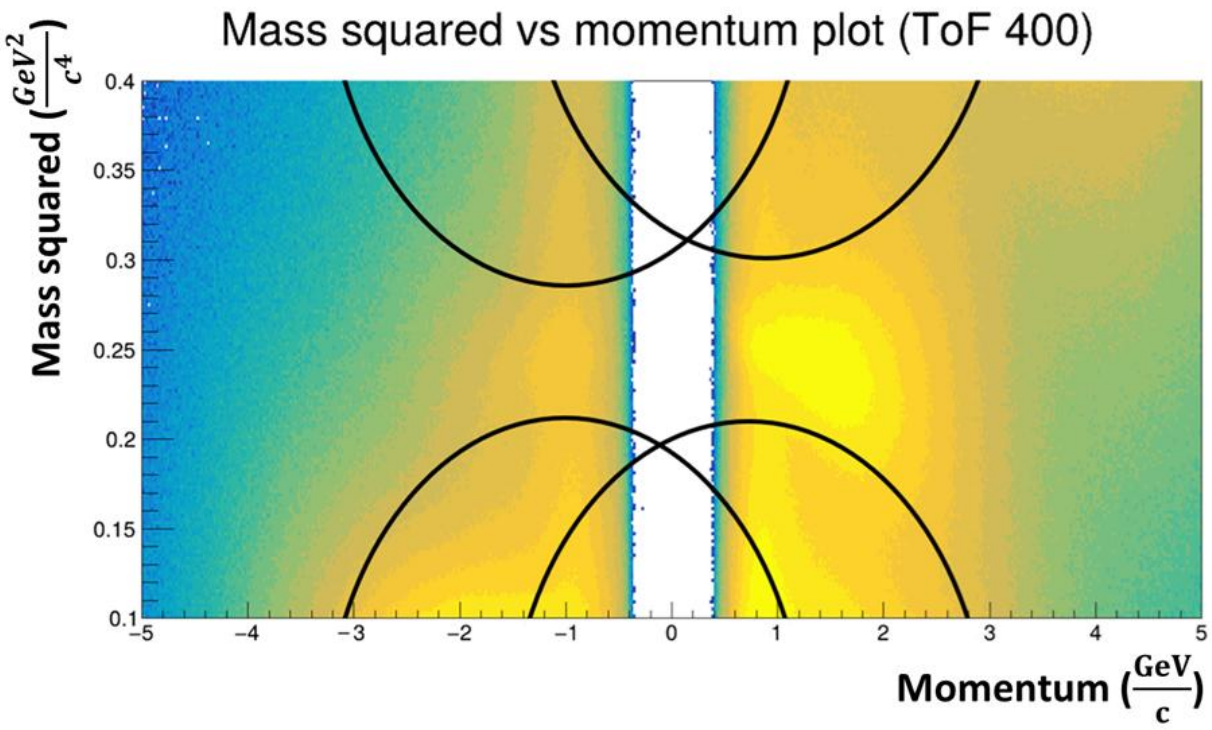
Constraints on the squared masses of the two products of decay ($K^+$ and $K^-$ ).

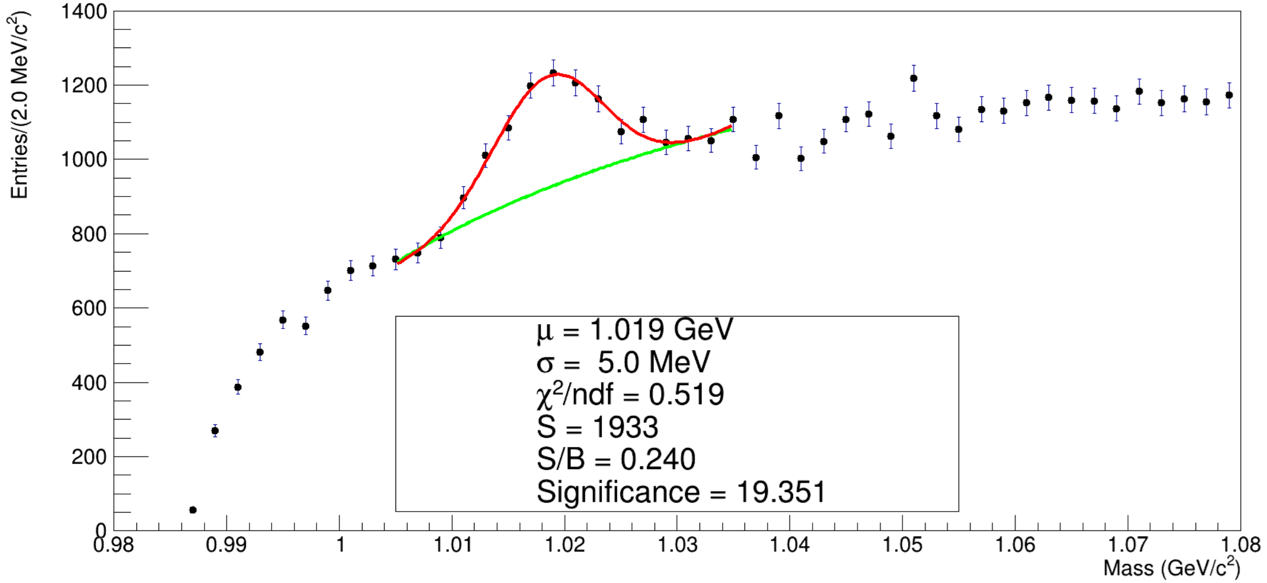



Event topology φ(1020)

# Results (φ(1020))

Following situation with regards to constraints on the squared mass was considered:

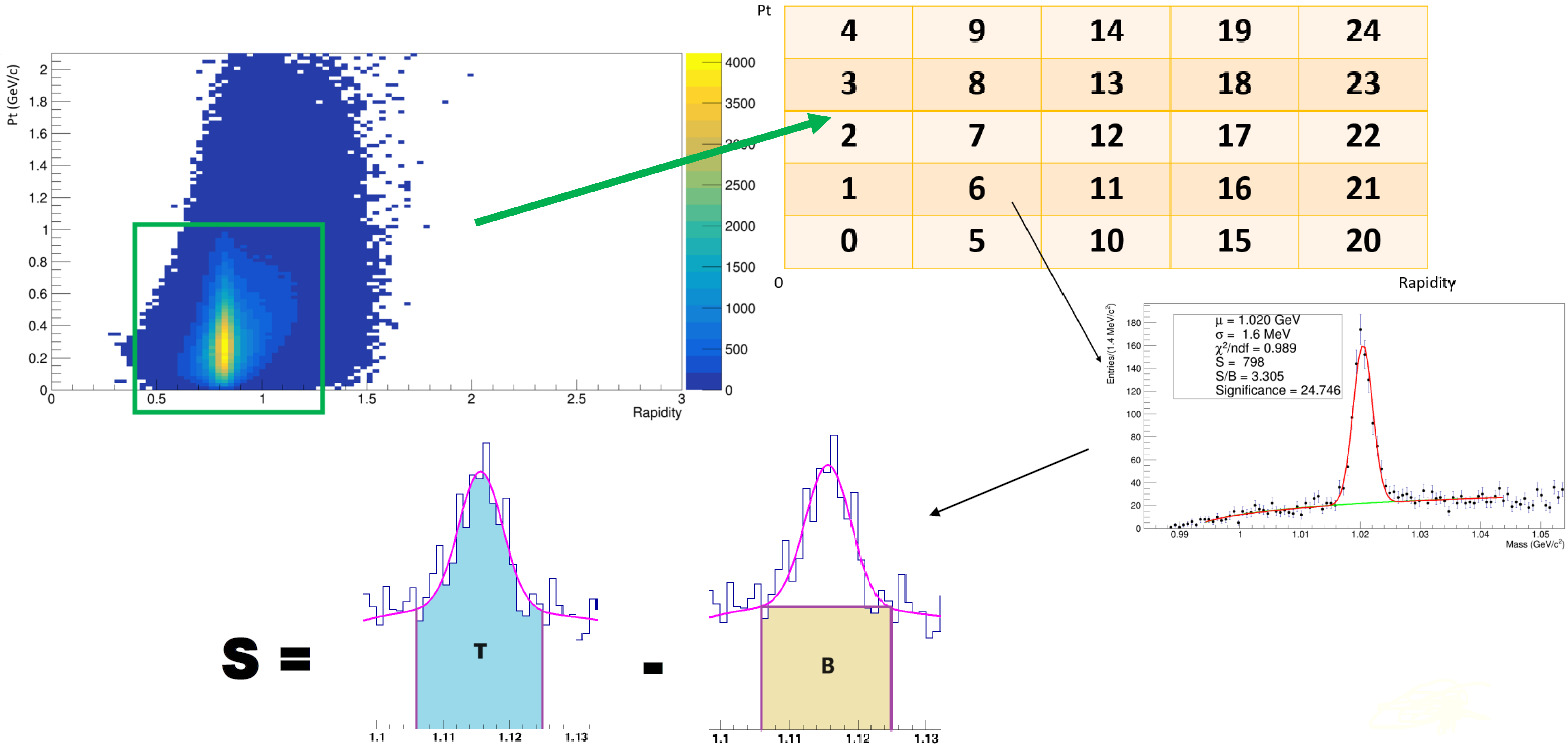



Additional constraint used :
0.0 cm <= dca12 <= 1.0 cm

# Results (φ(1020))

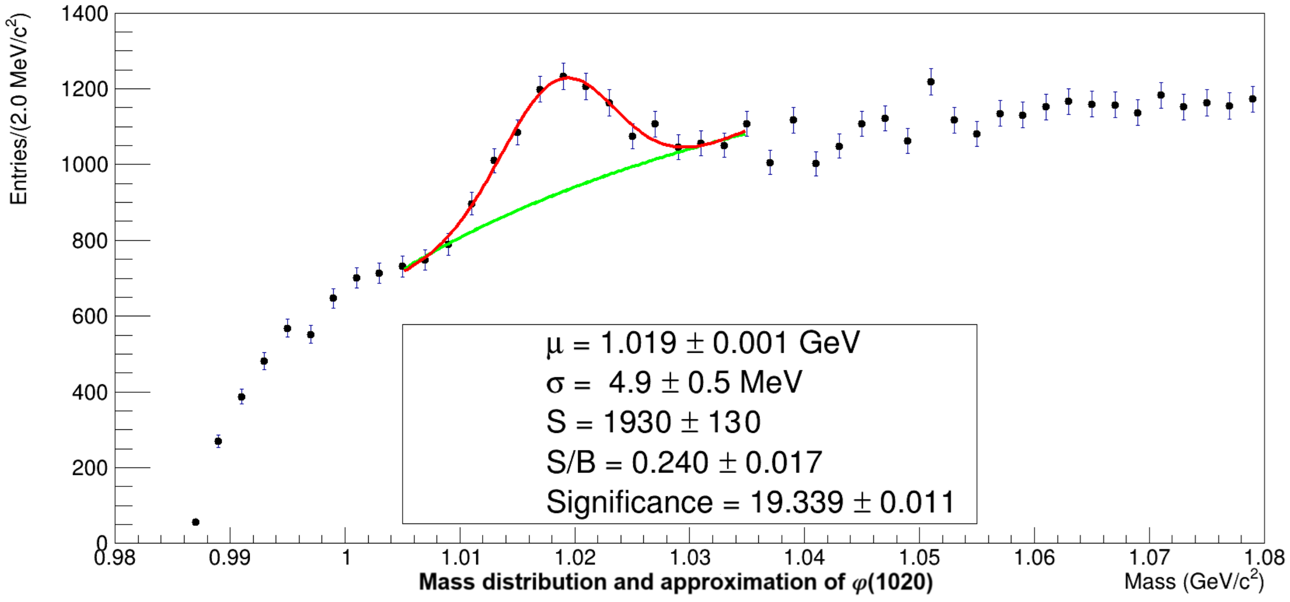
## Preliminary phase space analysis



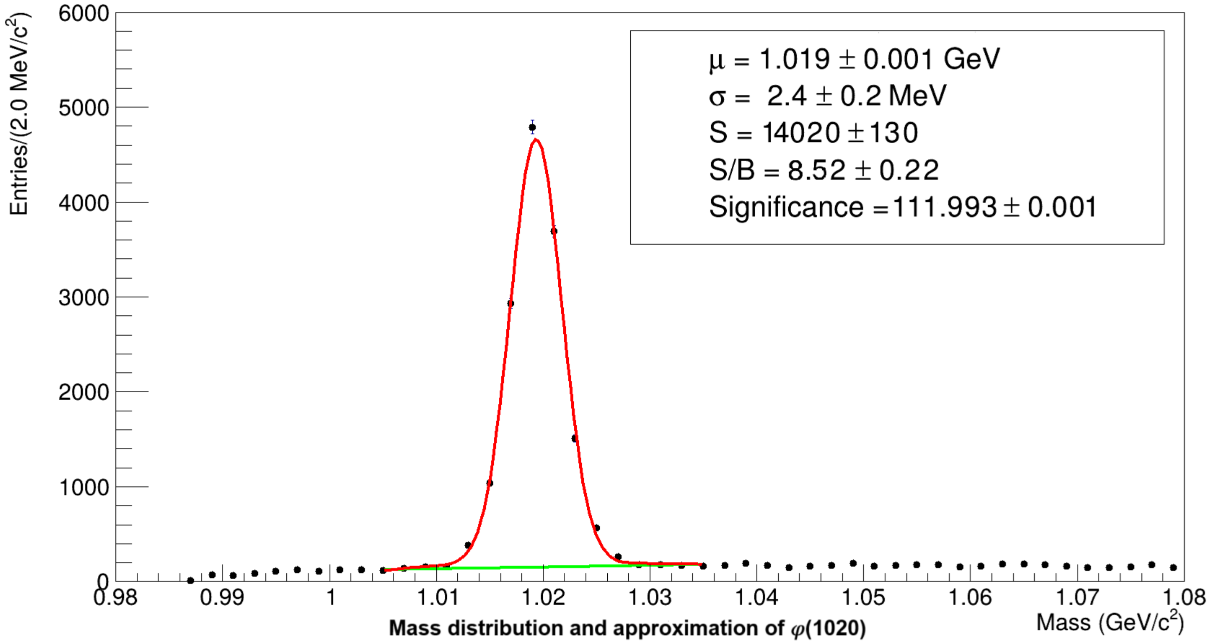
# Results (φ(1020))

## Preliminary phase space analysis

Experimental case




MC case (DCM-SMM [3].)

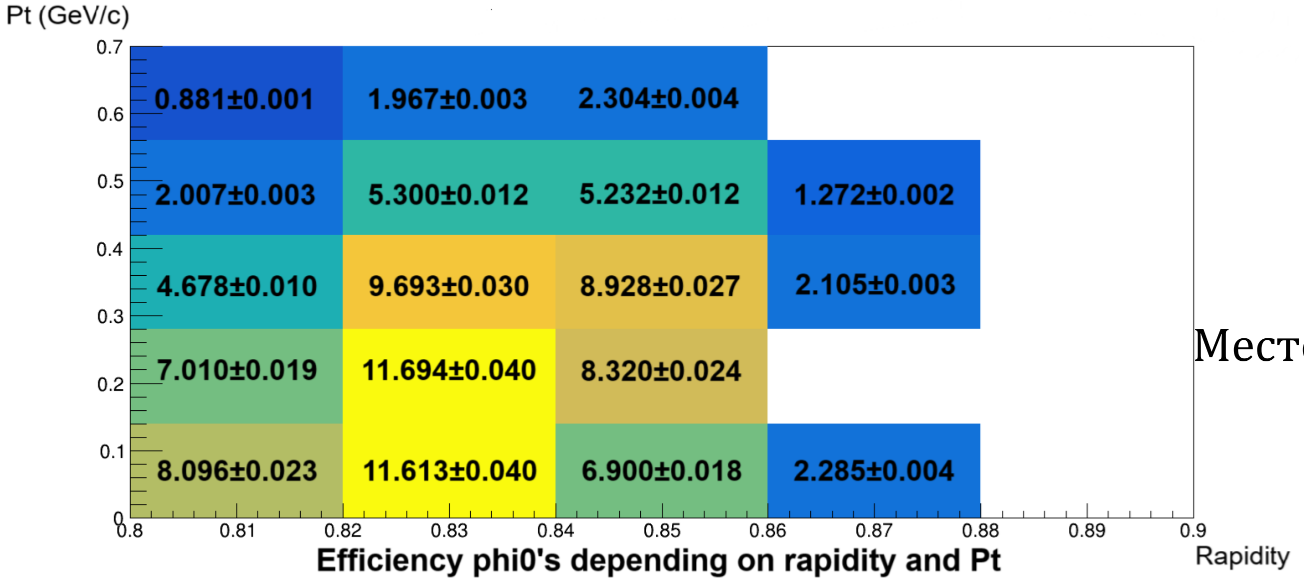


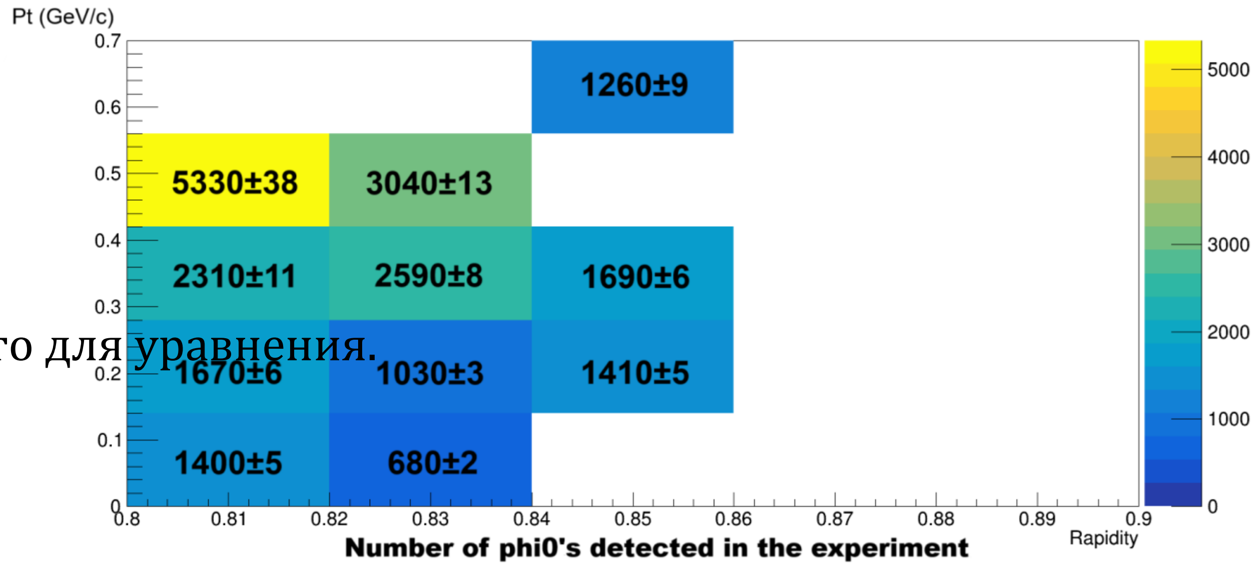

So far φ(1020) were added to each event in an artificial manner.


[3] Baznat M., Botvina A., Musulmanbekov G., Toneev V., Zhezher V. Monte-Carlo Generator of Heavy Ion Collisions DCM-SMM, Physics of Particles and Nuclei Letters 17, 3, 303-324 (2020)

# Results (φ(1020))

## Preliminary phase space analysis



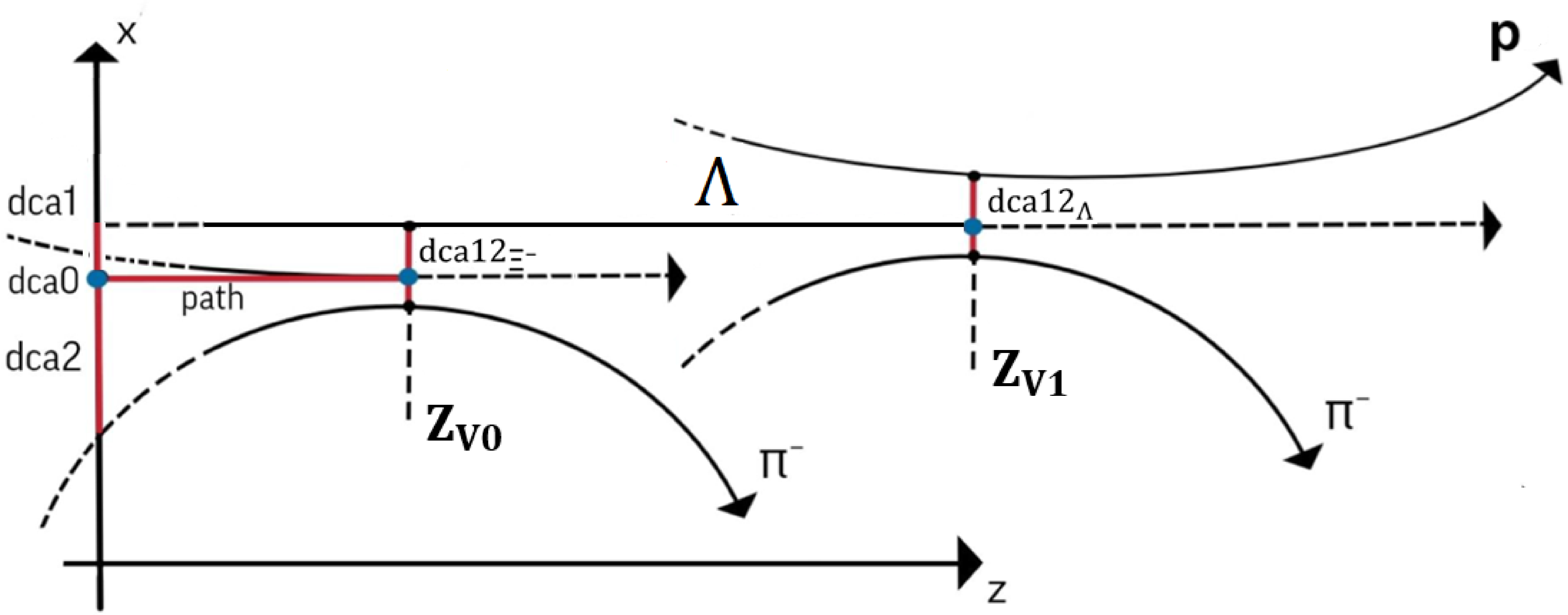




Место для уравнения.

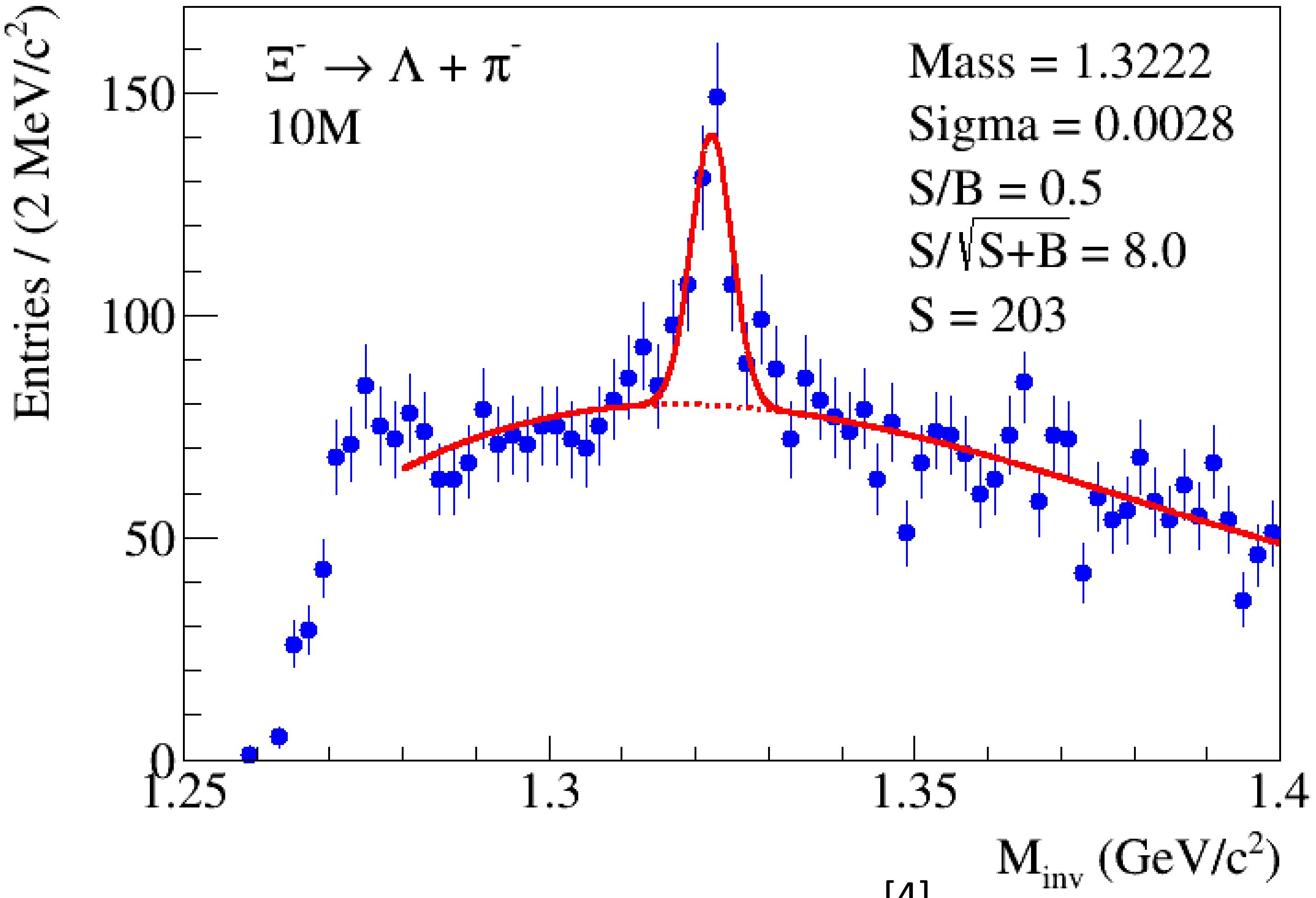
$$Efficiency = \frac{N_{reconstructed}}{N_{generated}} * 100\ \%$$

$$N_{exp} = S_{exp} * efficiency$$

# Data processing procedure ($\Xi^-$)



# Results ($\Xi^-$)



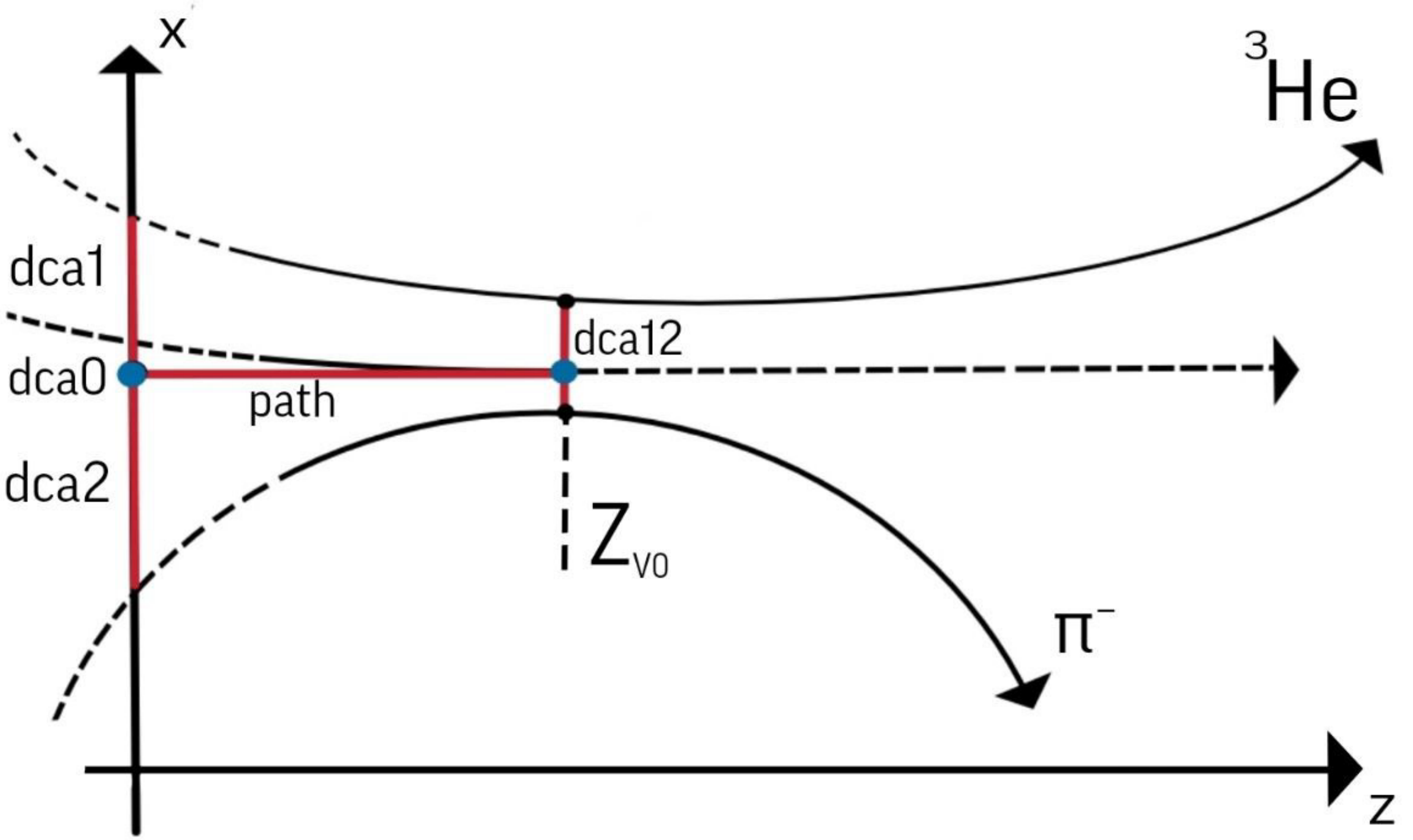

[4].

Constraints applied:

- dca1 > 4.0
- dca2 > 14.0
- dca12$_\Lambda$ < 0.4
- dca12$_{\Xi^-}$ < 0.5
- dca$_{\Xi^-}$ < 6.0
- angle < 0.03
- (abs(xi.massL-1.1157)<0.00625)
- Certain constraints regarding fake hits and reflection (mentioned on the back-up slides)

[4]. V. Vasendina, A. Zinchenko (JINR), BM@N collaboration.

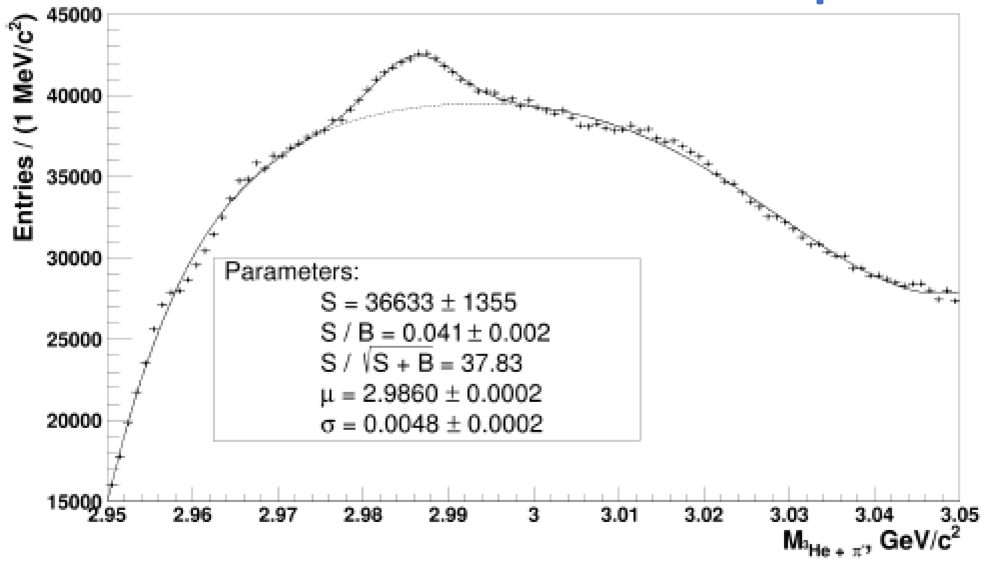
# Data processing procedure ($^{3}_{\Lambda}\mathrm{H}$)

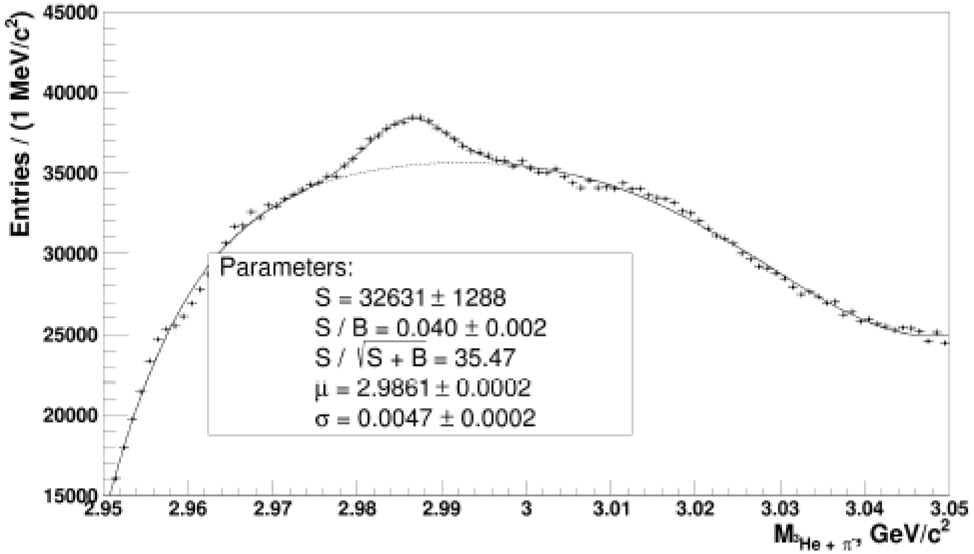



[5].


[5] S. Merts (JINR), E. Konstantinova (JINR), (2025, May 15), *Status of hypernuclei signal reconstruction in Xe+CsI Collisions in the BM@N experiment, https://indico.jinr.ru/event/5284/contributions/31168/attachments/22219/39231/merts.pdf*

# Results ($^3_\Lambda H$)
## Experimental data




[5].

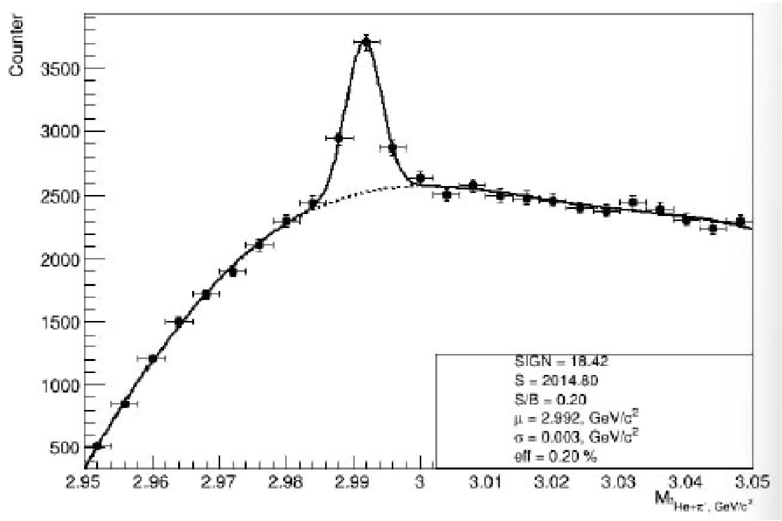
Two cases were considered:

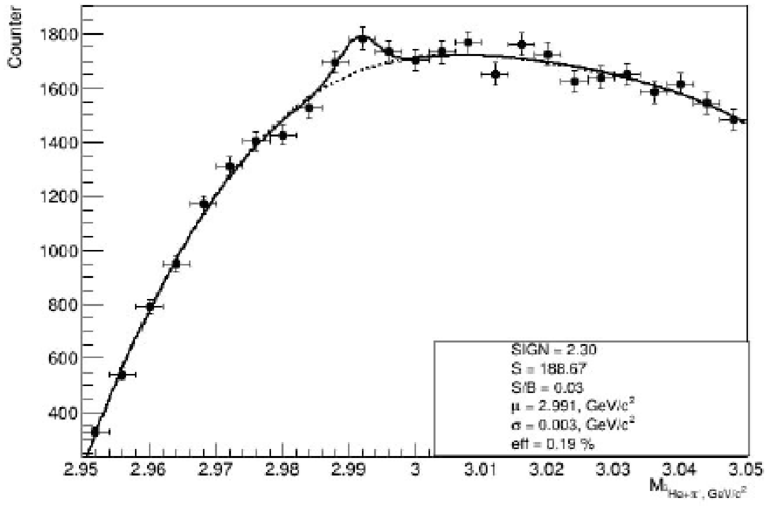
- All available experimental events.
- Events starting from a certain run.

Constraints applied:

- 4.0 cm <= path <= 14.0 cm
- 2.0 <= dca2 <= 20.0
- 0.0 <= dca12 <= 20.0
- 0.0 <= dca0 <= 10.0
- $0.0\,\frac{GeV}{c} <= P_{He} <= 20.0\,\frac{GeV}{c}$
- $0.2\,\frac{GeV}{c} <= P_{\pi} <= 20.0\,\frac{GeV}{c}$
- $14.0 <= \frac{P_{He}}{P_{\pi}} <= 20.0$

# Results ($^{3}_{\Lambda}\mathrm{H}$)
## MC data




[5].

Two data sets were generated by means of DCM-SMM model:

- 1e6 events, each one containing a $^{3}_{\Lambda}\mathrm{H}$
- 1e6 events, each tenth event containing a $^{3}_{\Lambda}\mathrm{H}$

Constraints applied:

- 0.5 cm <= path <= 50.0 cm
- 0.01 <= dca2 <= 100.0
- 0.0 <= dca12 <= 8.0
- 0.0 <= dca0 <= 1.8
- $2.0\,\frac{\mathrm{GeV}}{c} <= P_{\mathrm{He}} <= 10.0\,\frac{\mathrm{GeV}}{c}$
- $0.2\,\frac{\mathrm{GeV}}{c} <= P_{\pi} <= 1.6\,\frac{\mathrm{GeV}}{c}$
- $4.0 <= \frac{P_{\mathrm{He}}}{P_{\pi}} <= 21.0$

# Conclusion and future work

- Lambda hyperon, $K_S^0$, $\varphi(1020)$,$\Xi^-$ and ${}^3_\Lambda H$ signals were optimized by assuming relevant constraints.
- Phase space analysis was initiated in case of $\varphi(1020)$.

- Applying necessary changes to MC data in order to achieve a closer approximation to experimental data for all the four particles presented .
- Continuation of the phase space analysis.
- Estimation of the number of each of the four particles by combining the results from the experimental case and MC case (reconstruction efficiency), derivation of the cross-section.

Thank you very much for your attention!

# Back-up

Additional constraints $\Xi^-$ :

- tmvas[0]>0&&tmvas[1]>0&&tmvas[2]>-0.1 (to deal with fake hits from the three final products of decay)
- (abs(xi.mass3-1.1157)>abs(xi.massL-1.1157)) (to deal with the reflection)