The XXVII International Scientific Conference of Young Scientists and Specialists (AYSS-2023)

“Study of Λ - hyperon production in collisions of heavy ions with solid targets in the BM@N experiment”

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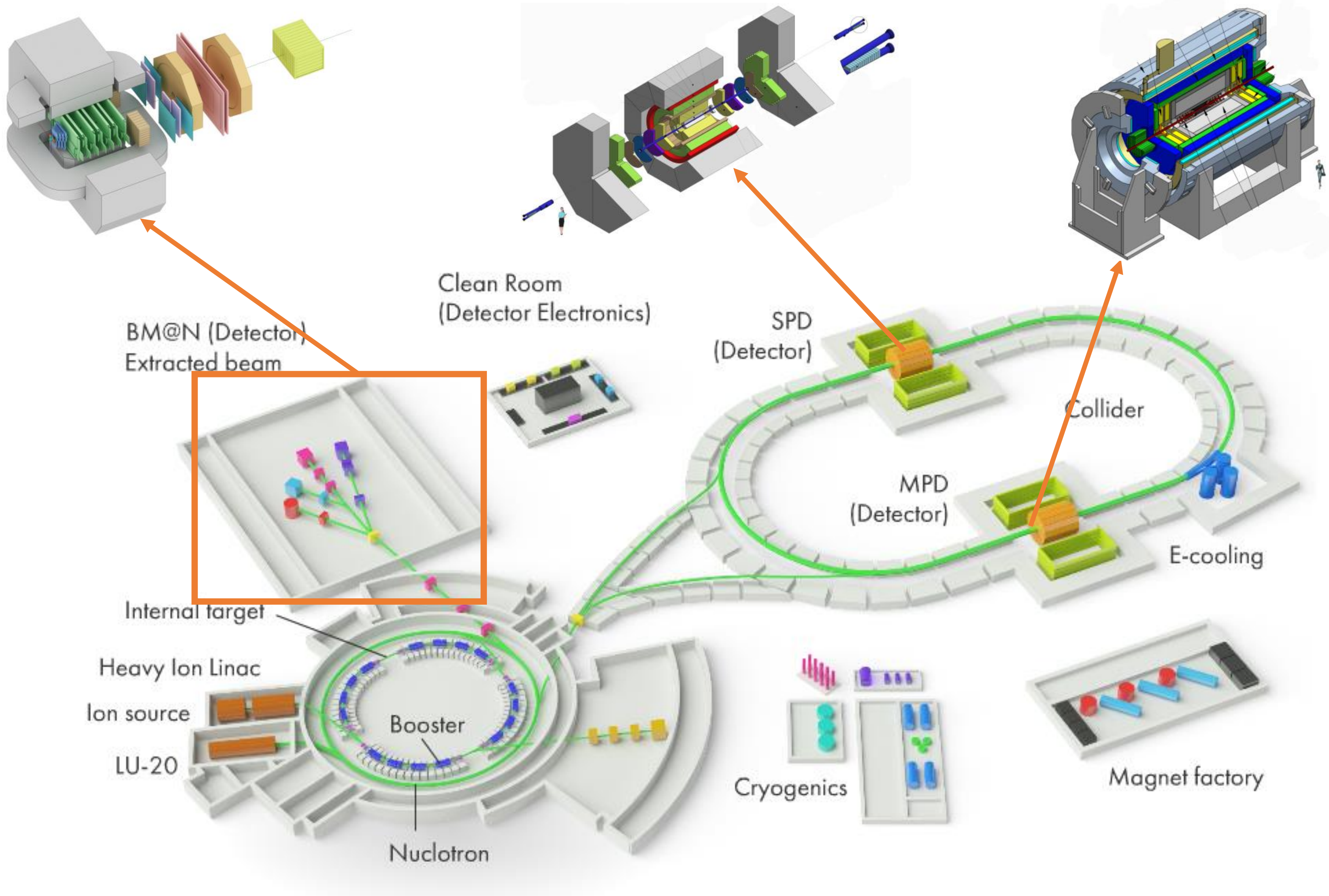
JINR, Dubna, Russia

BM@N at NICA Complex



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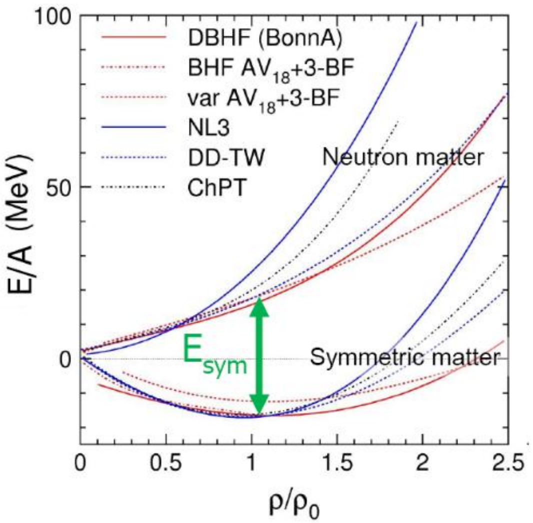

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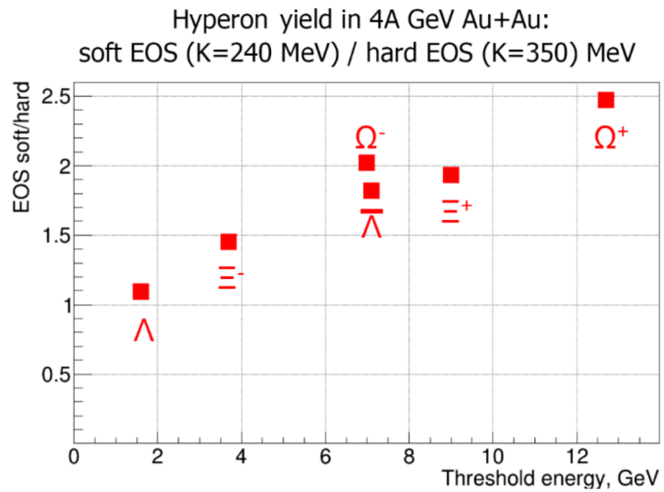

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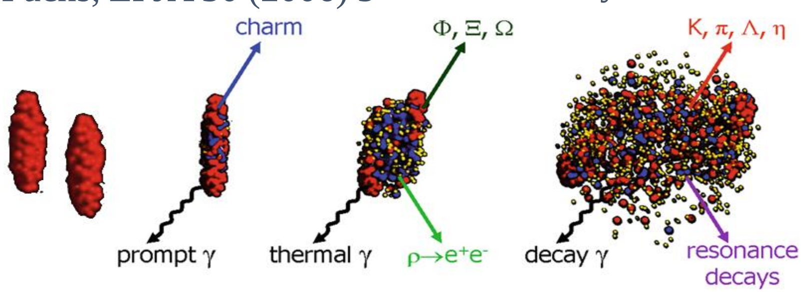
EoS study for symmetric matter at $\rho/\rho_0 = 3 - 5$, $\rho_0 = 0.16 fm^{-1}$:

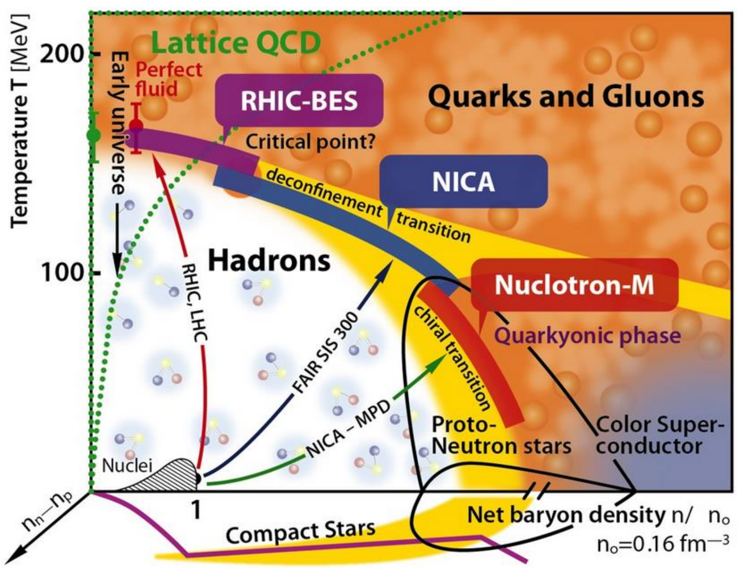
- Elliptical flow of protons, mesons and hyperons;
- Sub-threshold production of strange mesons and hyperons extract nuclear;
- Incompressibility (K_{mn}) from the modeled data;



EoS: The relation between density, pressure, temperature, energy and isospin asymmetry.

$$E_A(\rho,\delta) = E_A(\rho,0) + E_A(\rho)\,\delta^2$$
$$\delta = (\rho_n - \rho_\rho)/\rho$$

Incompressibility of the nucleus: $K_{mn} = 9\rho^2 \frac{\partial^2}{\partial \rho^2}(E/A)|_{\rho=\rho_0}$



Goal and tasks of the job

Goal of the job:

To develop an effective procedure for Λ^0 signal extraction, which will allow us to estimate the production cross section in the $\Lambda^0 \rightarrow p + \pi^-$ decay channel and the Λ^0 yields formed in the interaction of heavy ions with the nuclei of solid targets.

Tasks:

- To get the efficiency of signal reconstruction in the MC.
- To plot the mass distribution $\Lambda^0 \rightarrow p + \pi^-$ with efficiency ω_i over the kinematic range (p_T y).
- To Define kinematic areas with low reconstruction efficiency ω_i .
- Perform measurement of areas of low efficiency using the GQSM model.
- To estimate the number of extracted signal by the fitting method.
- To obtain the cross sections and yields in C+A (4, 4.5AGeV) reactions.

Study of the Λ hyperon in the BM@N experiment

- BM@N can only register charged particle signals in the run6 configuration.
- The main focus is on the decay Λ ⟶ pπ- with a decay probability of 64%.

Mass	$m_\Lambda = 1115.683 \pm 0.006$ MeV
Mean life	$\tau = (2.632 \pm 0.020) \times 10^{-10}$c
Decay length	$c\tau = 7.89\ cm$
Baryon charge	$\mathrm{B} = +1$
strangeness	$\mathrm{S} = -1$
Coulomb charge	$\mathrm{Q} = 0$
$\Lambda \rightarrow p\pi^-$	$BR = (63.9 \pm 0.5)\%$
$\Lambda \rightarrow p\pi^0$	$BR = (35.8 \pm 0.5)\%$

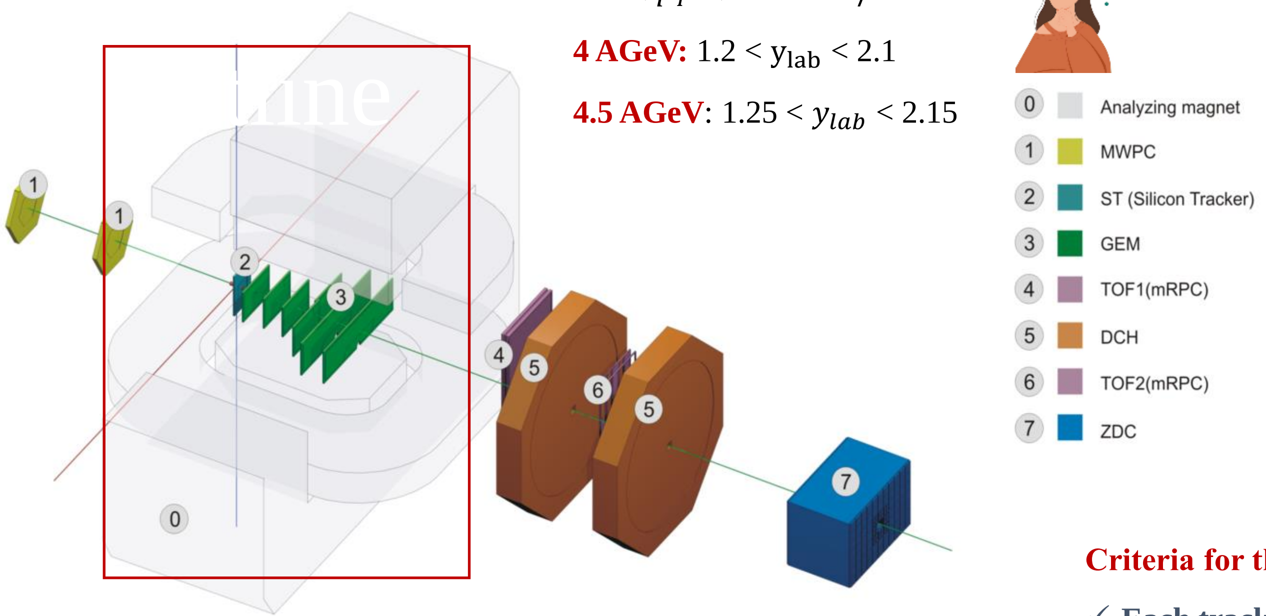
- The Λ-decay is reconstructed by its invariant mass: $m_{inv} = \sqrt{(E_p + E_{\pi^-})^2 - (\overrightarrow{p_p} + \overrightarrow{p_{\pi^-}})^2}$;
- The equation includes the moments of the decay products p and π- and the opening angle of their direction vectors at the decay vertex;

The parameters set the limits of the analysis:

- Detector acceptance, momentum, and angular resolution (defines mass resolution);
- Primary and secondary vertex reconstruction, providing tools for background separation;

Analysis scheme C+A→X (run-6)

Setup scheme (spring 2017)



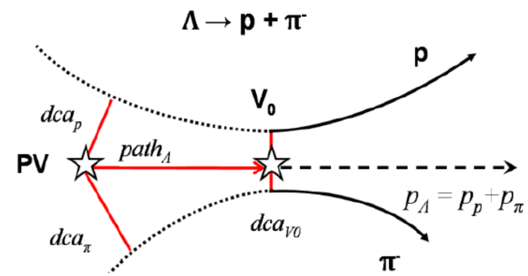
Kinematic measuring range:

$0.1 < p_T < 1.05\ GeV/c$

4 AGeV: $1.2 < y_{lab} < 2.1$

4.5 AGeV: $1.25 < y_{lab} < 2.15$

Selection of events with Λ hyperon



Event topology:
PV – primary vertex
V0 – vertex of hyperon decay
dca – distance of the closest approach
path – decay length

Λ decay reconstruction in Central tracker(Si+GEM) in C+A interaction
C + A → X , A : C, Al, Cu, Sn, Pb

Gas Electron Multiplier (GEM) system:
To measure momenta of a charged particle and reconstruct the interaction point

Criteria for the selection of Λ-hyperons :

- ✓ Each track has at least 4 of the 6 hits in (GEM);
- ✓ p_{pos} < 3.9(4.4) GeV/c for a beam energy of 4 (4.5) AGeV;
- ✓ p_{neg} > 0.3 GeV/c;
- ✓ dca < 1 cm;
- ✓ Distance between the decay vertex V_0 and the primary vertex: path > 2.0 - 2.5 cm (target dependent).

*K. A. Alishina, Yu. Yu. Stepanenko, A.Y Khukhaeva" Gem residuals corrections in monte-carlo simulation for the run 6 at the BM@N experiment", PEPAN letters – volume 19,part 5, 2022

Procedure in MC modelling(QGSM)

1. Divide the kinematic measuring range by y, p_T into (8x8) cells in the MC simulation;

Kinematic measuring range:

$0.1 < p_T < 1.05\ GeV/c$

4 AGeV: $1.2 < y_{lab} < 2.1$

4.5 AGeV: $1.25 < y_{lab} < 2.15$

h18	h28	h38	h48	h58	h68	h78	h88
h17	h27	h37	h47	h57	h67	h77	h87
h16	h26	h36	h46	h56	h66	h76	h86
h15	h25	h35	h45	h55	h65	h75	h85
h14	h24	h34	h44	h54	h64	h74	h84
h13	h23	h33	h34	h53	h63	h73	h83
h12	h22	h32	h42	h52	h62	h72	h82
h11	h21	h31	h41	h51	h61	h71	h81

$\boldsymbol{C + A \ \rightarrow X, 4.0(4.5)AGeV}$

2. To get the number of events generated by the MC;
3. Fit with function (*) the 8x8 matrix cells of the MC for the reconstructed events with Λ.

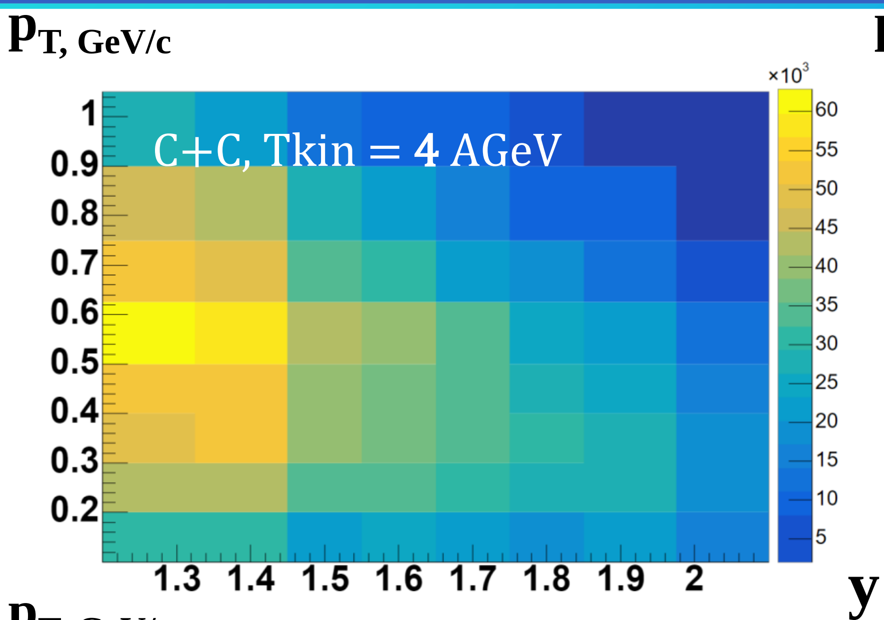
Function for background estimation:

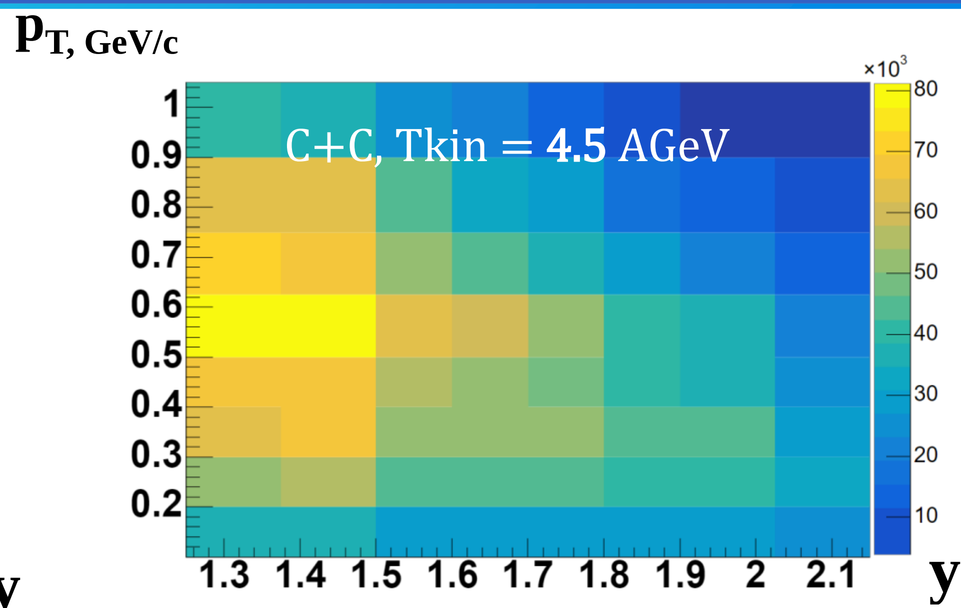
$$f_{bg} = N \cdot (x - M_0)^A \cdot e^{-B\cdot(x-M_0)} \qquad (*)$$

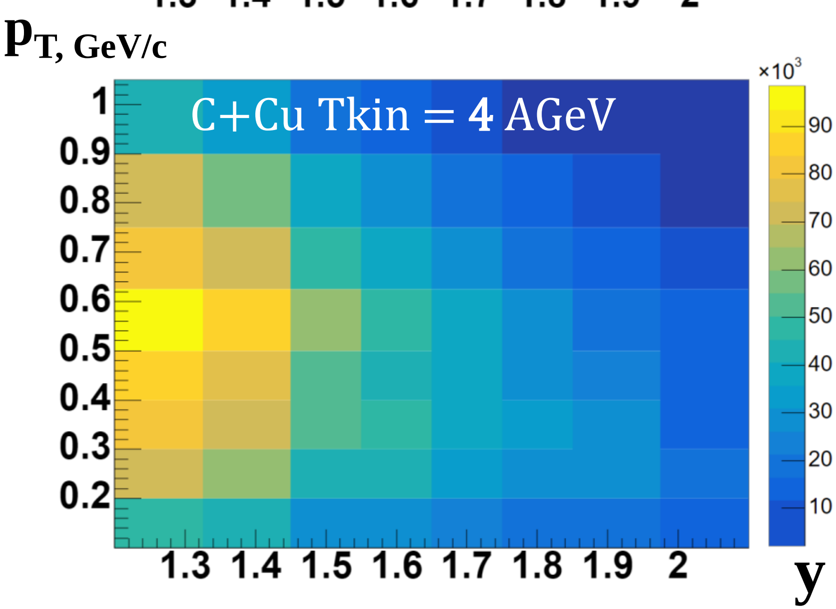
Where N, A, B are free parameters of the fitting function, $M_0 = 1.078$ ГэВ/c^2, x is the mass value.

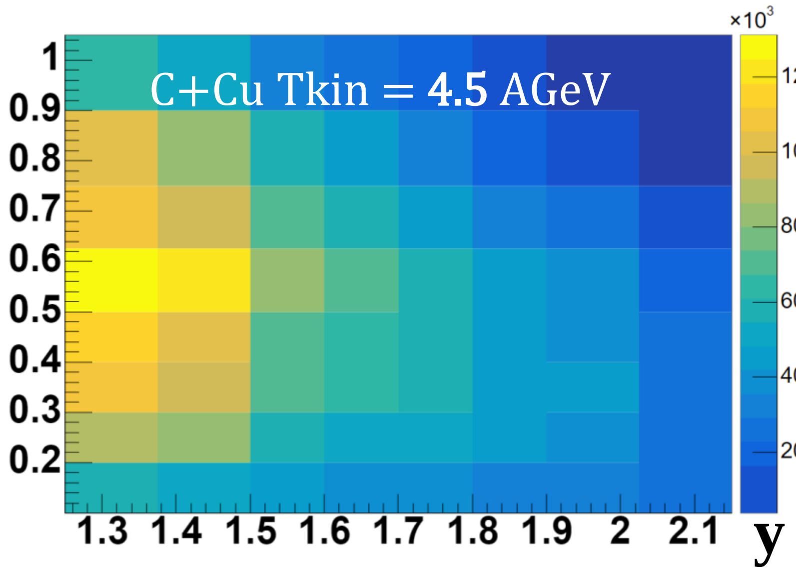
4. To get the weight of each cell: $\omega_i = MC_{rec\_i}/MC_{gen\_i}$, where MC_{rec_i} is the number of extracted MC signal (step 3), MC_{gen_i} is the number of events generated by the MC;

QGSM generated Λ's for P_T

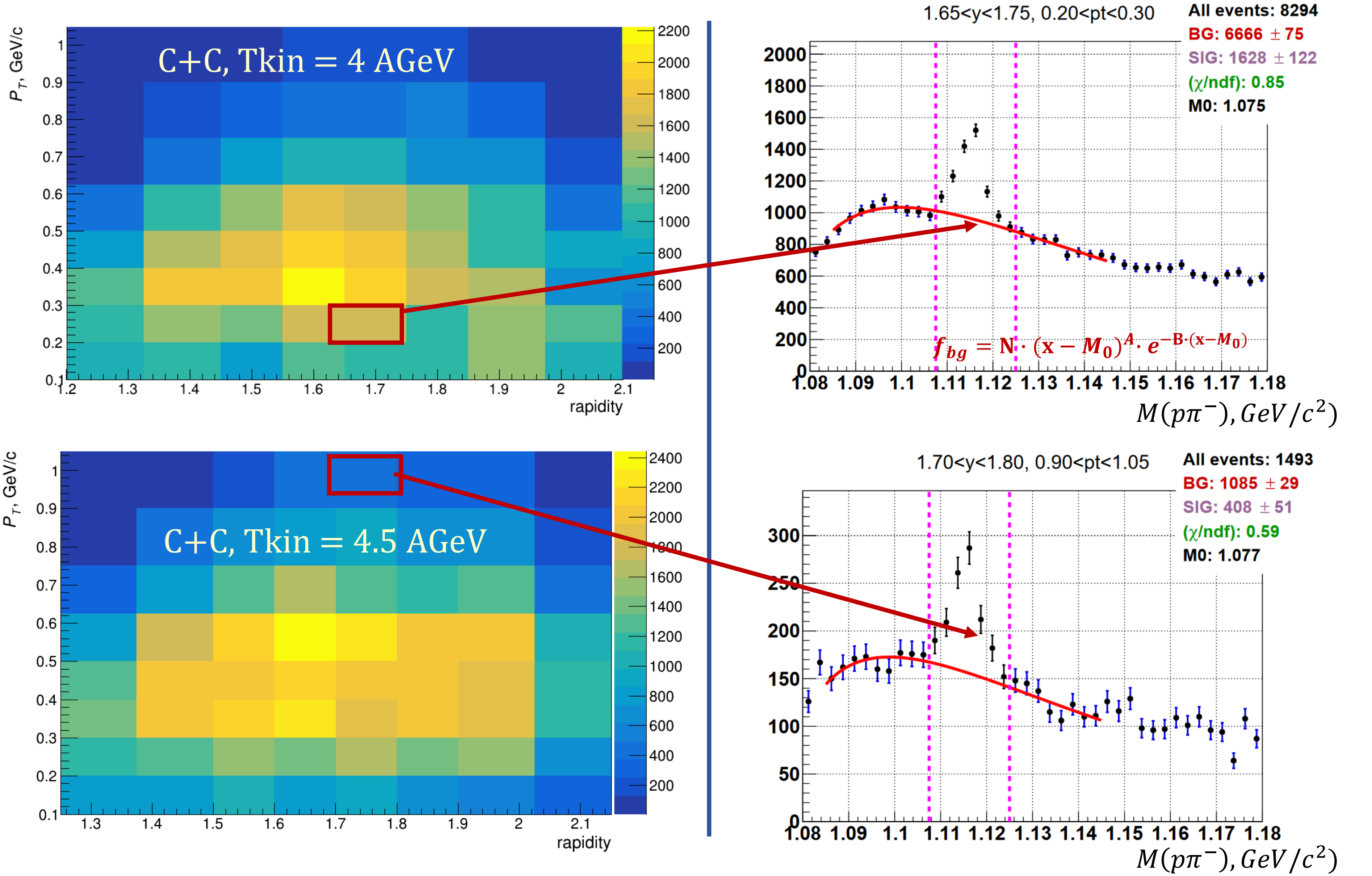




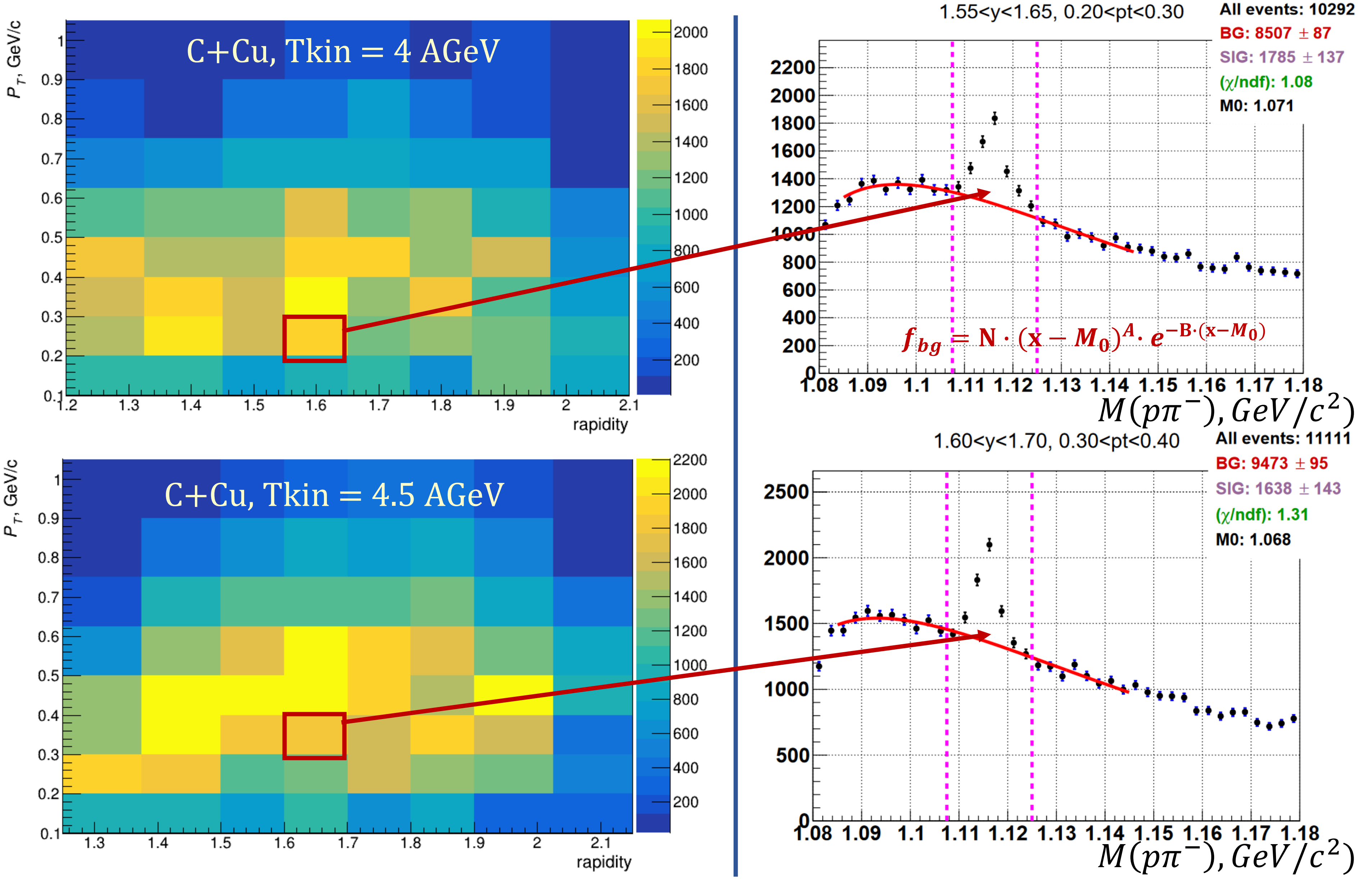




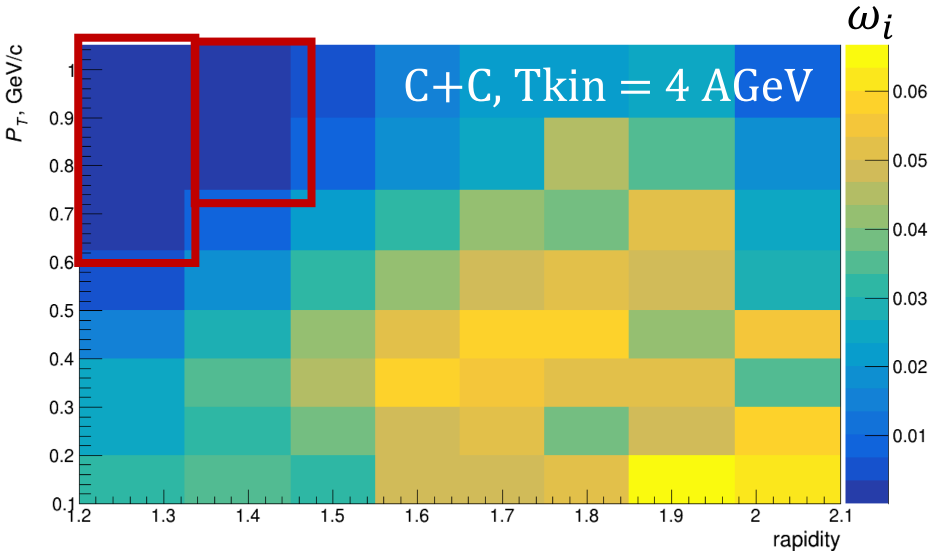
Distribution of the reconstructed signal in the MC

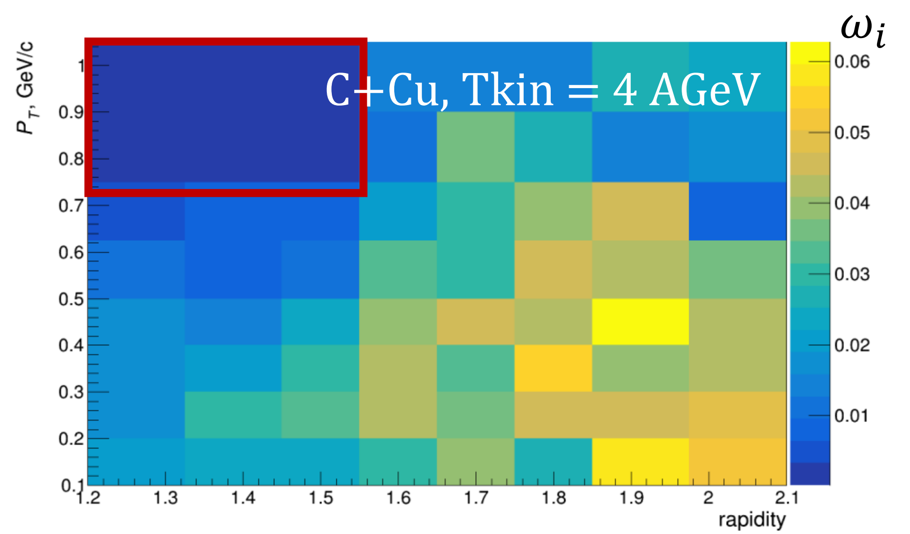


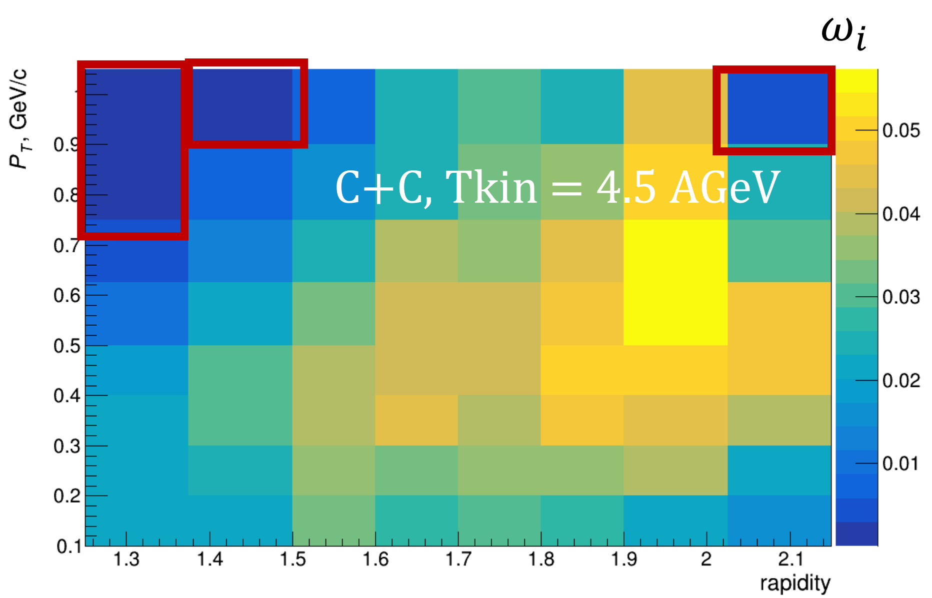
Distribution of the reconstructed signal in the MC

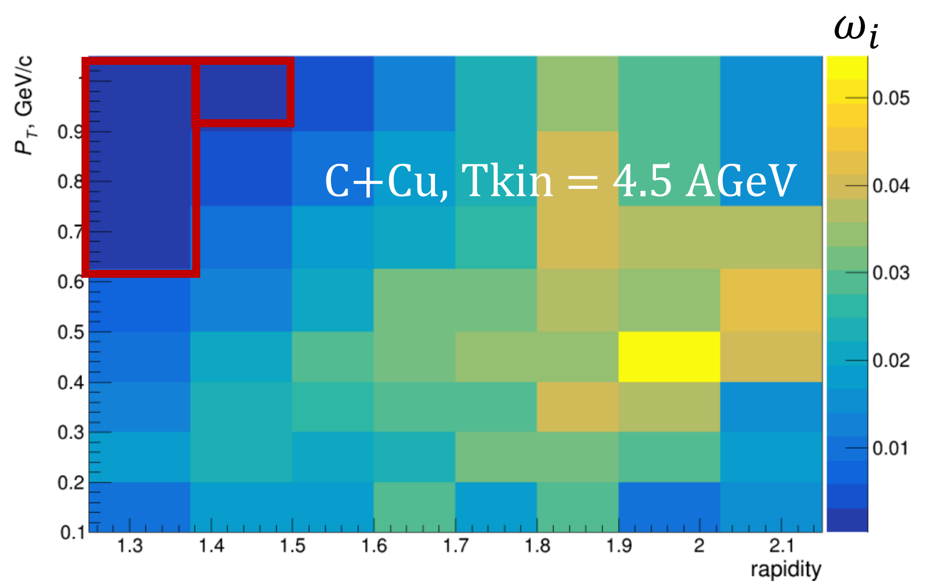


Reconstruction efficiency Λ's for $P_T(y)$









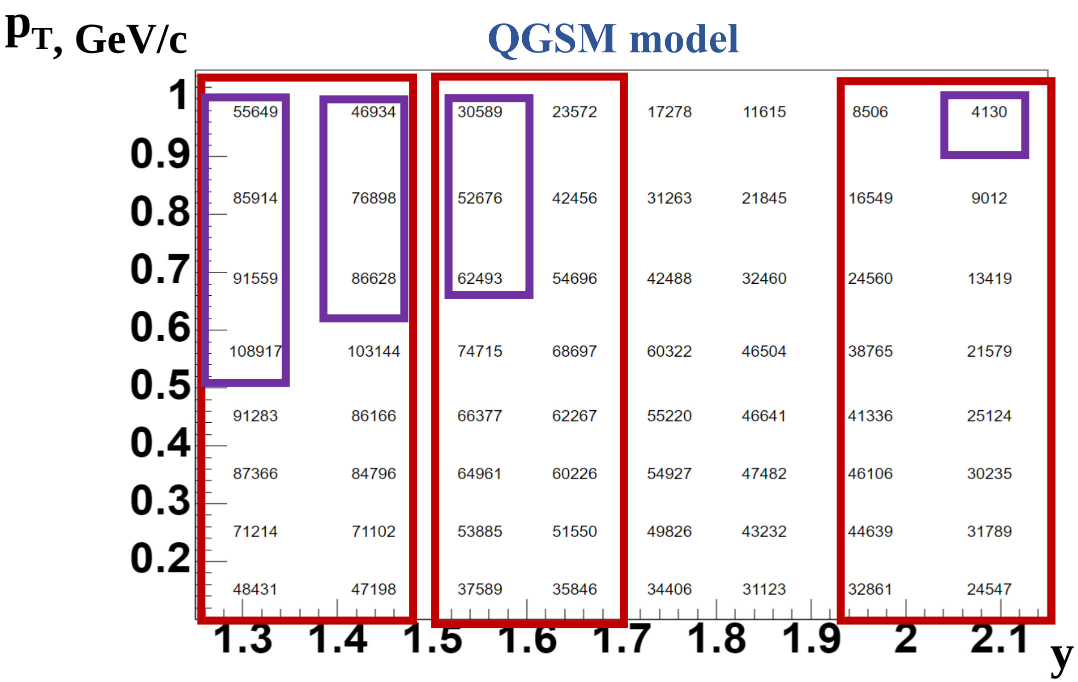
Set the boundary $\boldsymbol{\omega_i \geq 0.01}$ - cells below this boundary are discarded.

- Let's highlight the areas where cells have been discarded from consideration (**Purple rectangles**);
- Sum all the cells in two neighboring columns by the rapidity y;
- Sum the cells in which the efficiency $\boldsymbol{\omega_i \geq 0.01}$;
- To obtain extrapolation factors by the formula : $f_{extrcon} = {}^{N_{all(a+b)}}/_{N_{con(a+b)}}$;

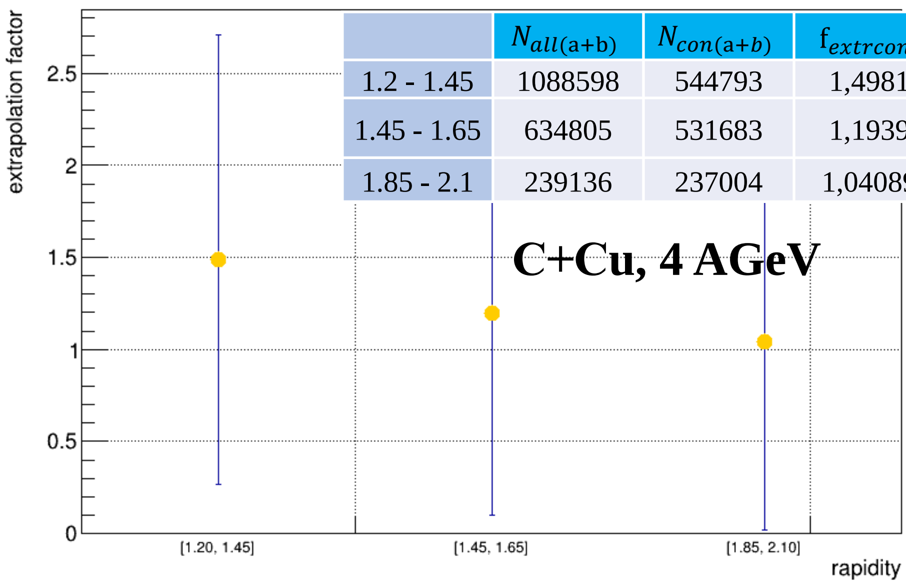
$N_{all(a+b)}$ – sum of all generated events in paired columns(a,b) by y; $N_{con(a+b)}$ – sum of all considered in paired columns (a,b) by y;

- Multiply $f_{extrcon}$ by the content of the histogram $M_{inv}(\Lambda \rightarrow p\pi^-)$ in the data for the kinematic respective region;

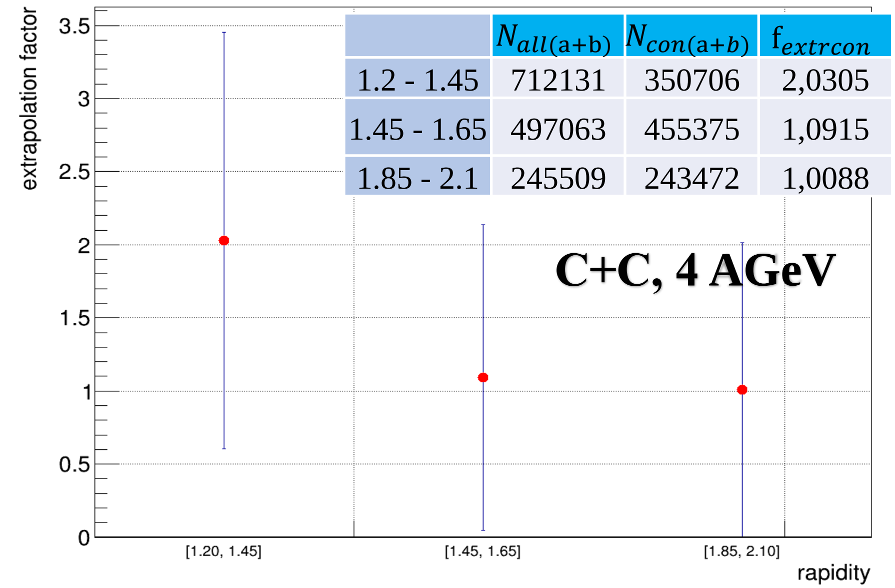
- To obtain distributions $M_{inv}(\Lambda \rightarrow p\pi^-)$ to estimate the number of reconstructed Λ - hyperons;



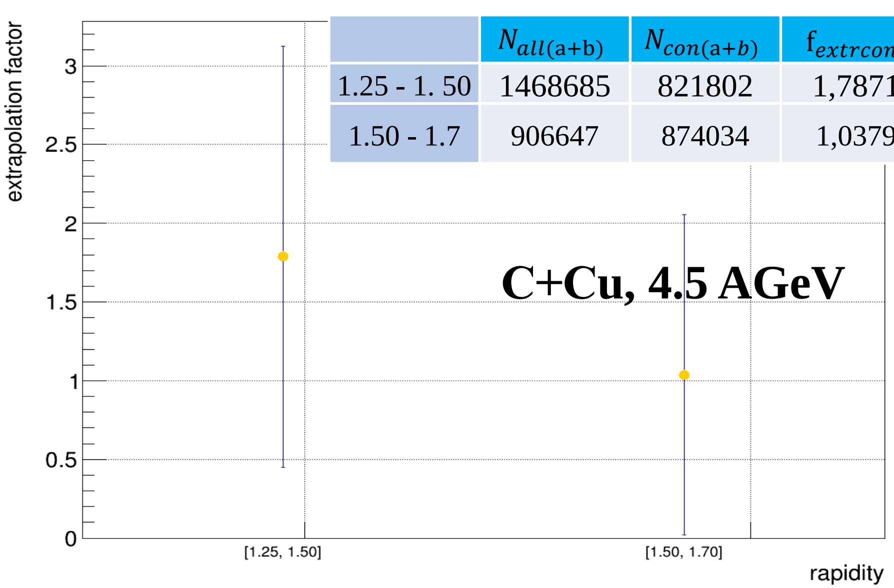
Extrapolation from the QGSM model



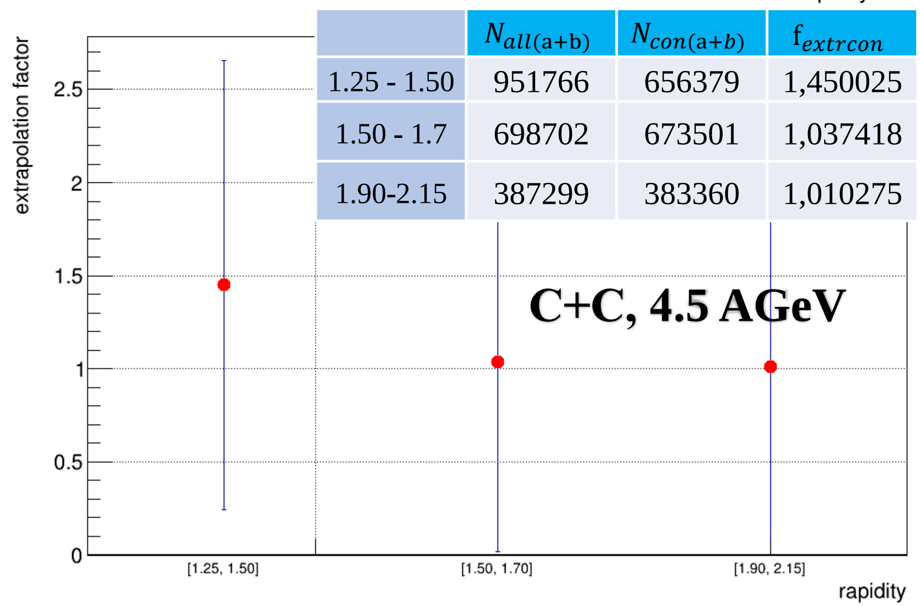
	$N_{all(a+b)}$	$N_{con(a+b)}$	$f_{extrcon}$
1.2 - 1.45	1088598	544793	1,4981
1.45 - 1.65	634805	531683	1,1939
1.85 - 2.1	239136	237004	1,04089



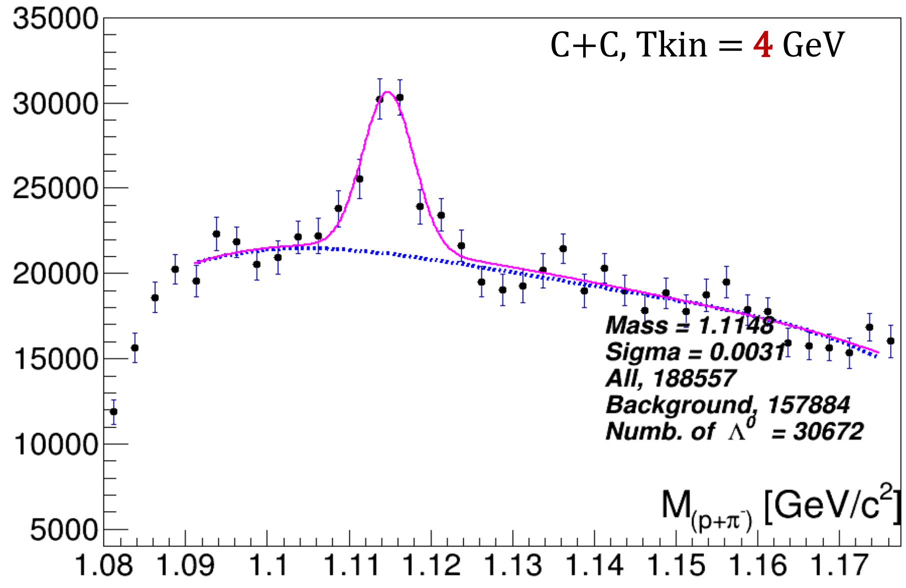
	$N_{all(a+b)}$	$N_{con(a+b)}$	$f_{extrcon}$
1.2 - 1.45	712131	350706	2,0305
1.45 - 1.65	497063	455375	1,0915
1.85 - 2.1	245509	243472	1,0088

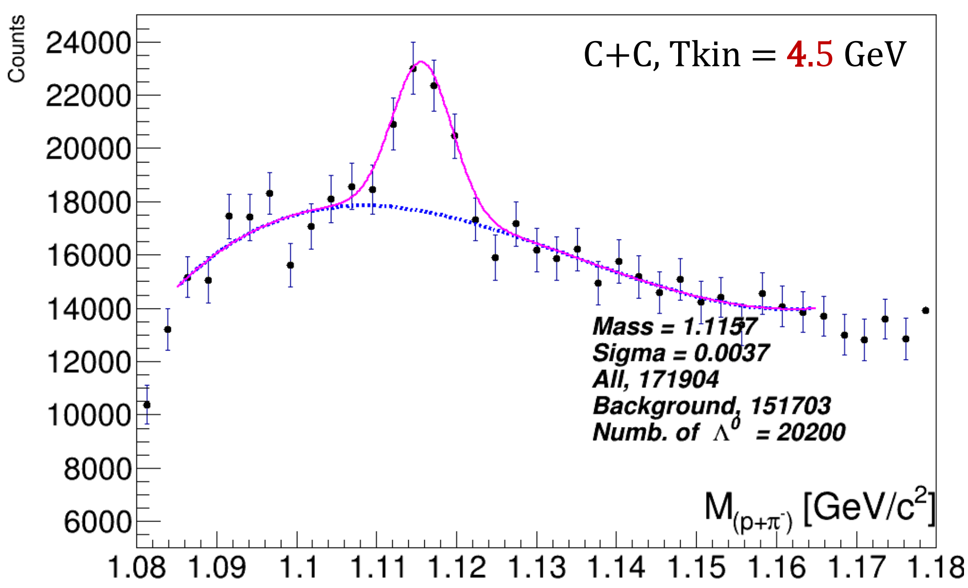


	$N_{all(a+b)}$	$N_{con(a+b)}$	$f_{extrcon}$
1.25 - 1. 50	1468685	821802	1,7871
1.50 - 1.7	906647	874034	1,0379



	$N_{all(a+b)}$	$N_{con(a+b)}$	$f_{extrcon}$
1.25 - 1.50	951766	656379	1,450025
1.50 - 1.7	698702	673501	1,037418
1.90-2.15	387299	383360	1,010275





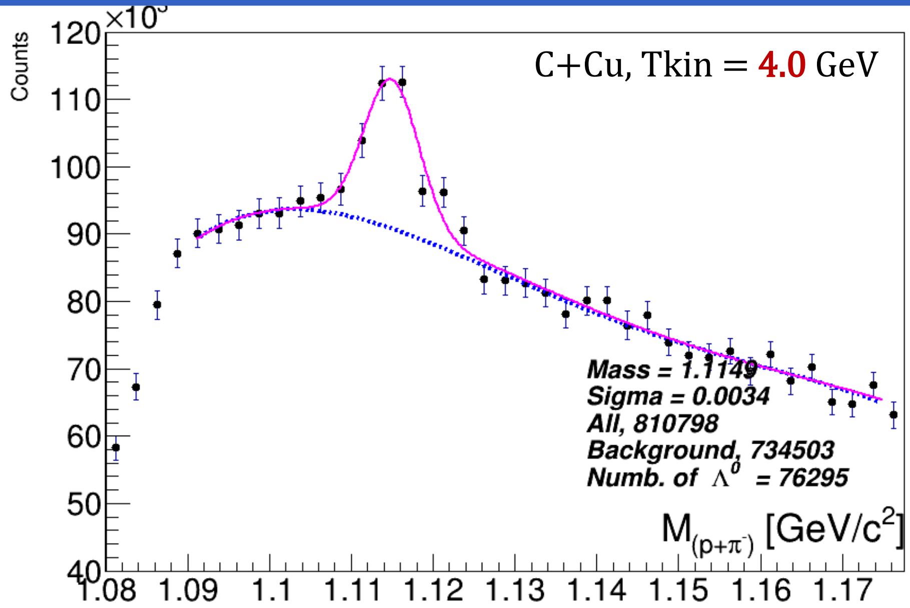
Procedure in DATA C+A → X

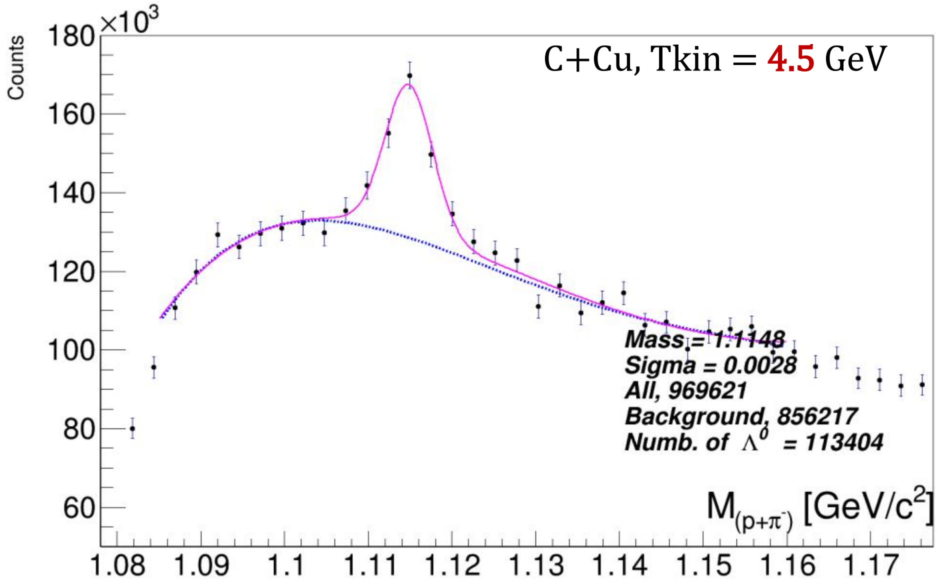
1) Split the area by y, p_T into smaller cells in DATA (8x8);
2) Apply cuts on the efficiency $\boldsymbol{\omega_i} \geq \mathbf{0.01}$;
3) Plot mass histogram with weight of $1/\omega_i$;
4) Applying extrapolation;
5) Sum the cells by $\sum_{ij} y_{ij}$ and by $\sum_{ij} pT_{ij}$

Reaction C+C	signal $N^{\Lambda}_{rec}(p_T/y)$
4.0 AGeV	30672
4.5 AGeV	20200

- Λ signal width ~ 2.0 - 4 MeV(due to low statistics);
- Signal = hist – Background(bg) **in 1107.5-1125** MeV/c²;
- Background → 4th polynomial(**Blue dashed**);
- $err(stat) = \sqrt{\sum w_i}$;

One-dimensional mass distribution of the $\Lambda^0 \rightarrow p\pi^-$(DATA)





Procedure in DATA C+A → X

1) Split the area by y, p_T into smaller cells in DATA (8x8);
2) Apply cuts on the efficiency $\boldsymbol{\omega_i} \geq \mathbf{0.01}$;
3) Plot mass histogram with weight of $1/\omega_i$;
4) Applying extrapolation;
5) Sum the cells by $\sum_{ij} y_{ij}$ and by $\sum_{ij} pT_{ij}$

Reaction C+Cu	signal $N^{\Lambda}_{rec}(p_T/y)$
4.0 AGeV	76295
4.5 AGeV	113404

- Λ signal width ~ 2.0 - 4 MeV(due to low statistics)
- Signal = hist – Background(bg) **in 1107.5-1125** MeV/c²
- Background → 4th polynomial(**Blue dashed**)
- $err(stat) = \sqrt{\sum w_i}$

Cross sections and yields of the $\Lambda \to p\pi^-$

The inclusive cross section σ_Λ and Y_Λ of Λ hyperon in C+A interactions are calculated in bins of y (pT) according to the formulae:

$$\sigma_\Lambda(y) = \sum y[N^{\Lambda}_{rec}(y, p_T)/\varepsilon_{rec}(y, p_T) \cdot \varepsilon_{trig} \cdot \varepsilon_{pileup} \cdot L] \quad (**)$$

$$\sigma_\Lambda(p_T) = \sum p_T[N^{\Lambda}_{rec}(y, p_T)/\varepsilon_{rec}(y, p_T) \cdot \varepsilon_{trig} \cdot \varepsilon_{pileup} \cdot L] \quad (**)$$

$$Y_\Lambda(y) = \sigma_\Lambda(y)/\sigma_{inel} \quad (***)$$

$$Y_\Lambda(p_T) = \sigma_\Lambda(p_T)/\sigma_{inel} \quad (***)$$

where L is the luminosity, N^{Λ}_{rec} is the number of recontacted Λ-hyperons, ε_{rec} is the combined efficiency of the Λ - hyperon reconstruction, ε_{trig} is the trigger efficiency, ε_{pileup} is the suppression factors of reconstructed events, σ_{inel} - is the cross section for minimum bias inelastic C+A interactions.

Beam kinetic energy 4.0 GeV		
Target	**C + C**	**C + Cu**
Yields total(preliminarily)	0,0112±0,0011(stat)	0,0302±0,0023(stat)

Beam kinetic energy 4.5 GeV		
Target	**C + C**	**C + Cu**
Yields total(preliminarily)	0,012±0,0015(stat)	0,0366±0,0028(stat)

Summary and plans

Done:

- ✓ The Λ^0 reconstruction efficiency was determined in each of the 64 cells for C+A reaction separately in MC.
- ✓ Cells with $\omega_i < 0.01$ were identified and excluded from the analysis.
- ✓ An extrapolation procedure was developed and applied to measure regions with $\omega_i < 0.01$.
- ✓ Mass distributions Λ^0 were obtained with weight ω_i for each cell out of 64 in the MC and physical data.
- ✓ Preliminary results on the computation of yields and cross sections were obtained. C+C, C+Cu (4, 4.5) results are reported.

Plans:

Obtain final results taking into account systematic error.

To apply the skills obtained in the analysis of Xe + GsI.

Thank you for your attention!