136th session of the Scientific Council

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

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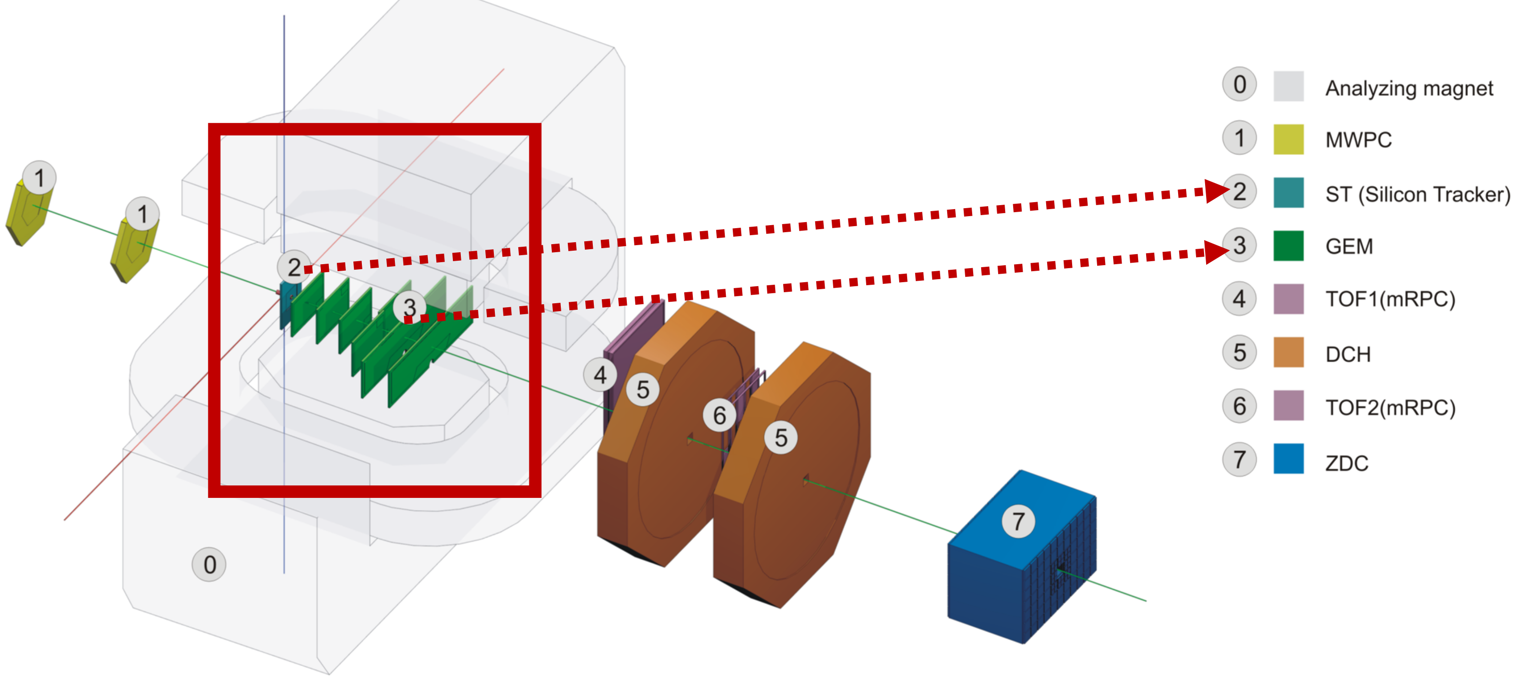
Setup scheme

$C + A \rightarrow X$, A : C, Al, Cu, Pb

Energy beam = 4.0 AGeV, 4.5 AGeV



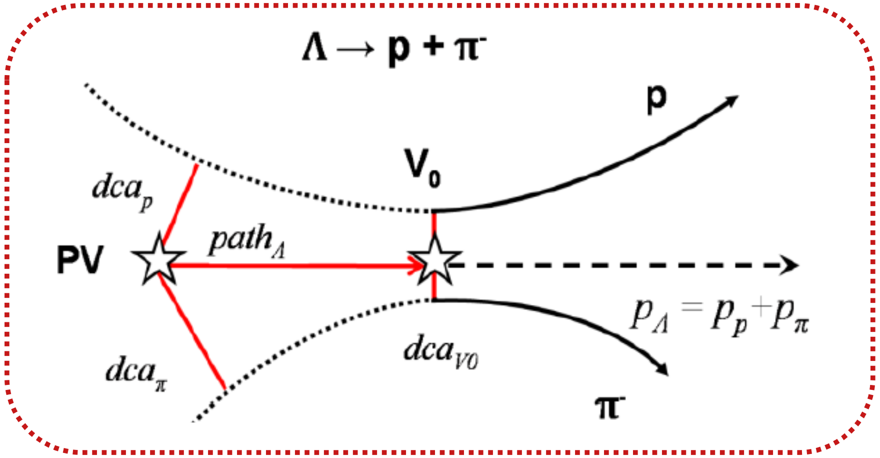
Central tracker:
- One plane of a forward Si detector;
- 6 GEM stations:
  - 5 GEM detectors (66x41 cm^2);
  - 2 GEM detectors (163x45 cm^2);

Triggers: BD, BC_1, BC_2, T_0, VETO;

Gas Electron Multiplier (GEM) system:
To measure momenta of a charged particle;

Event reconstruction in GEM in C+A interaction;

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

Criteria for the selection of Λ - hyperons :

1 Each track has at least 4 of the 6 hits in (Si+GEM);

2 $p_{pos} < 3.9(4.4)$ GeV/c for a beam energy of 4 (4.5) AGeV;

3 $p_{neg} > 0.3$ GeV/c;

4 dca < 1 cm;

5 Distance between the decay vertex V_0 and the primary vertex: path > 2.5 cm;

K. A. Alishina, Yu. Yu. Stepanenko, "Study of Λ–hyperon production in collisions of heavy ions with solid targets in the BM@N experiment" volume 21,part 4, 2024

Trigger efficiency

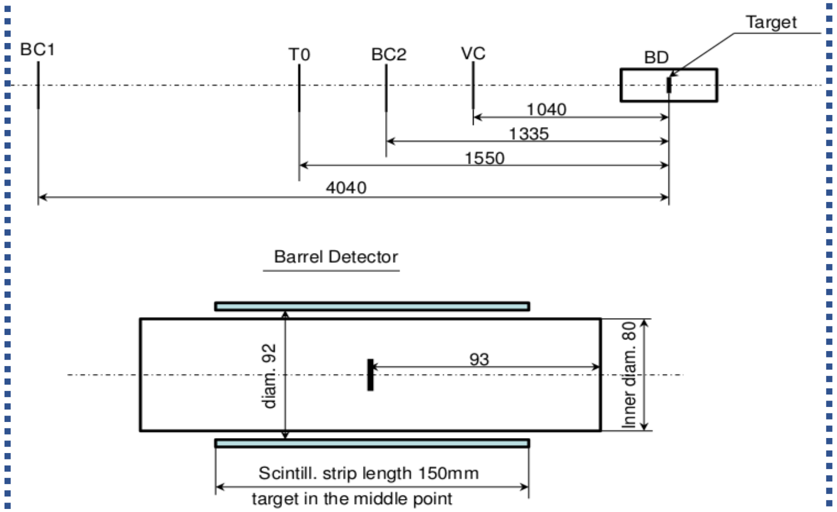
The trigger efficiency was evaluated by a convolution of the GEANT simulation of the trigger BD detector response to DCM-QGSM events with reconstructed Λ hyperons and the GEANT simulation of delta electrons.

$$\varepsilon_{trig} = N_{sim_{\Lambda}}(BD \geq n)/N_{sim_{all\Lambda}}$$

Table 1. Trigger efficiency ε_{trig}

4 AGeV	C	Al	Cu	Pb
ε_{trig}(BD≥2)	0.80±0.02	-	-	-
ε_{trig}(BD≥3)	-	0.87±0.02	0.92±0.02	0.95±0.02

4.5 AGeV	C	Al	Cu	Pb
ε_{trig}(BD≥2)	0.80±0.02	-	-	-
ε_{trig}(BD≥3)	-	0.83±0.02	0.91±0.02	0.94±0.02



Schematic view and positions of the beam counters, barrel detector and target

ε_{trig} is used for evaluation of production cross section;

Physical analysis steps

1 The experiment accumulated data, but the statistics from the reconstructed selected lambda candidates are not very rich. (N_{data}~5.9×10^5).

2 The high statistic MC data set was generated: (N_{MC} ~3.8×10^7). MC were tuned to data and acceptance was evaluated in (y-p_T) cells with high pression.

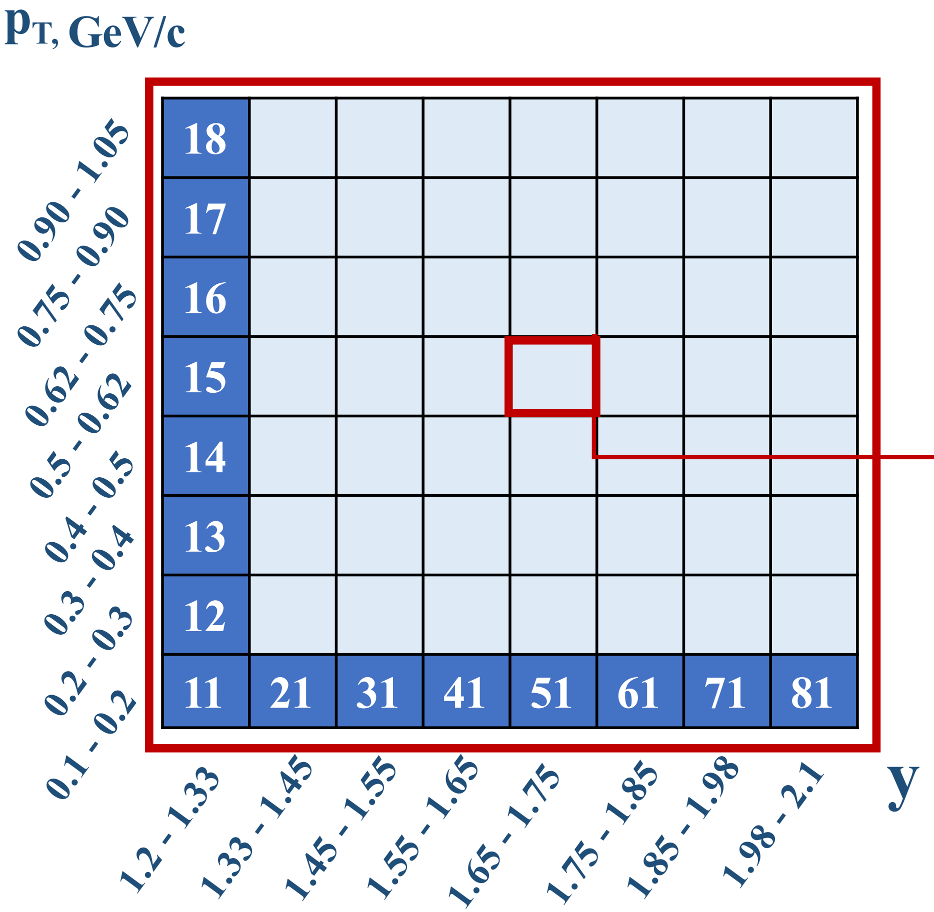
3 Each event was weighted with the acceptance for each cell.

4 1D distributions in y or p_T were evaluated as the projections of 2D distributions to the corresponding kinematic variable.

Acceptance evaluation procedure (QGSM)

Kinematic measuring range (4, 4.5 AGeV):

$0.1 < p_T < 1.05$ GeV/c
$1.2 < y_{lab} < 2.1$



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

2 To get the number of events generated by the MC

3 In each cells the invariant mass distribution fit with

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

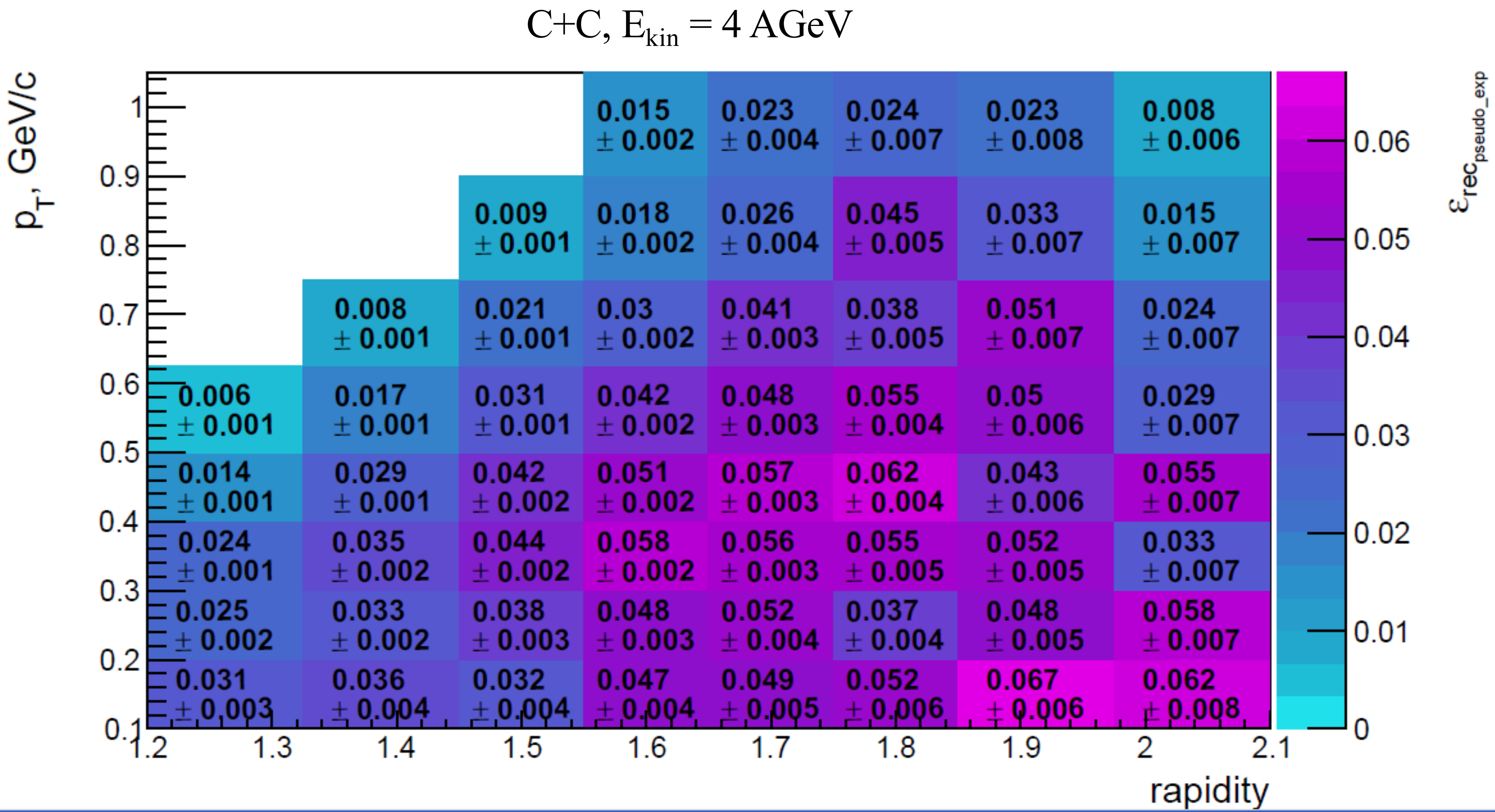
N, A, B are free parameters,
$M_0 = 1.078$ ГэВ/c^2 is the threshold limit, m is the mass value.

4 Each event is weighted with $\varepsilon_i = MC_{rec\_i}/MC_{gen\_i}$,
MC_{rec_i} is evaluated number of Λ,
MC_{gen_i} is the number of Λ generated;

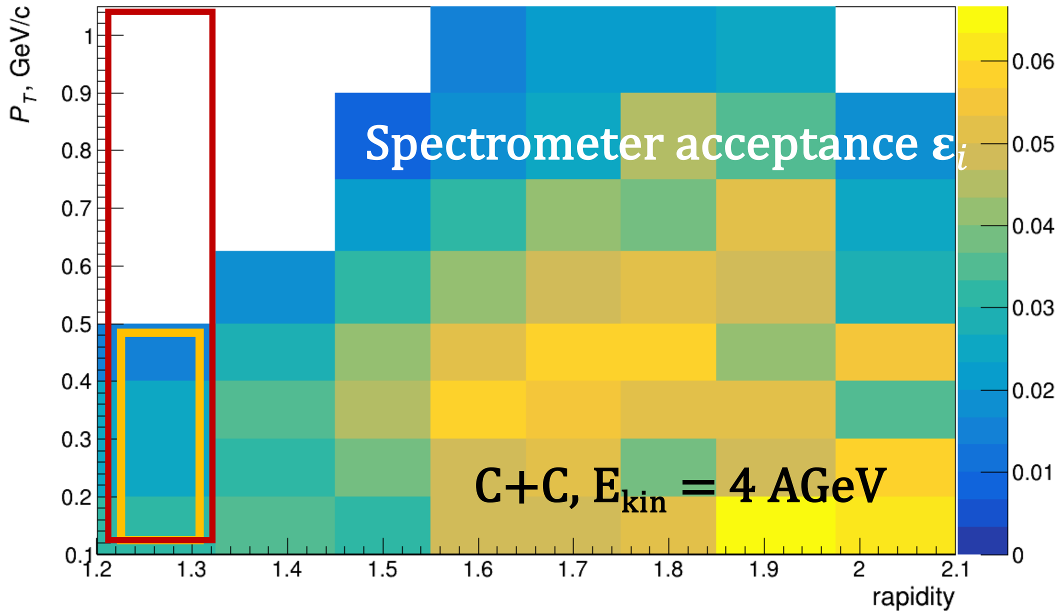
Evaluation of the precision of the acceptance

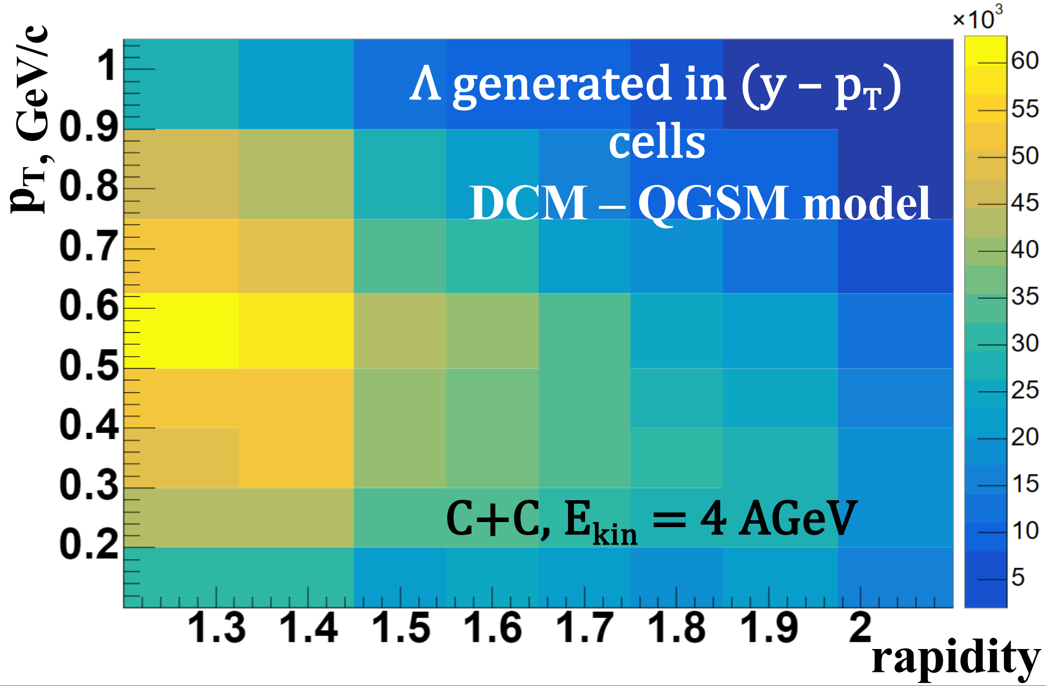
Pseudo-experiment

In each bin the bin content was modified by gaussian distribution with the widths equal to the bin error.
The "new" histogram was fit an the new signal was evaluated.
Procedure was repeated 1000 times and the signal values are presented in a bottom histogram.



Extrapolation to low acceptance (y-pT) cells





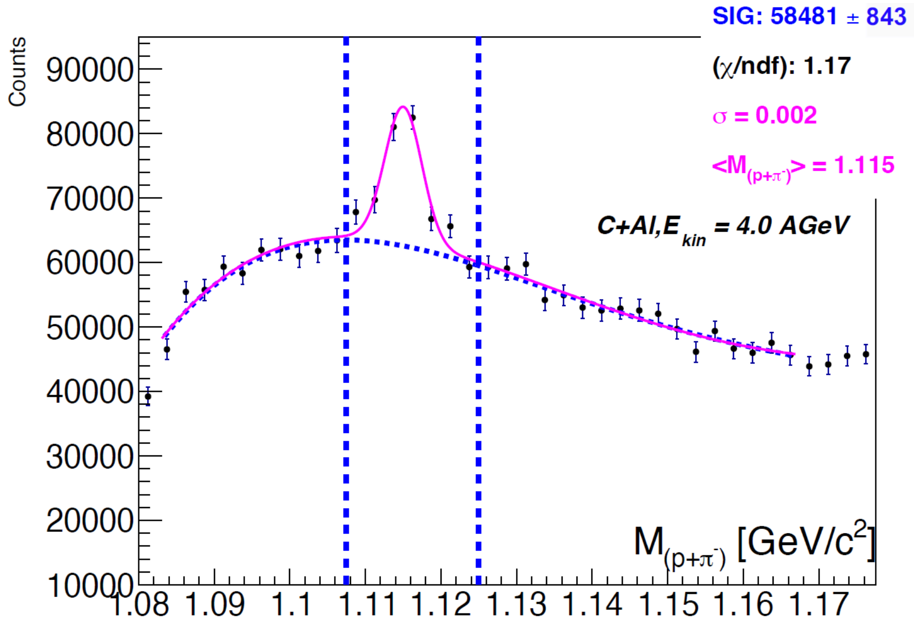
Extrapolation steps:

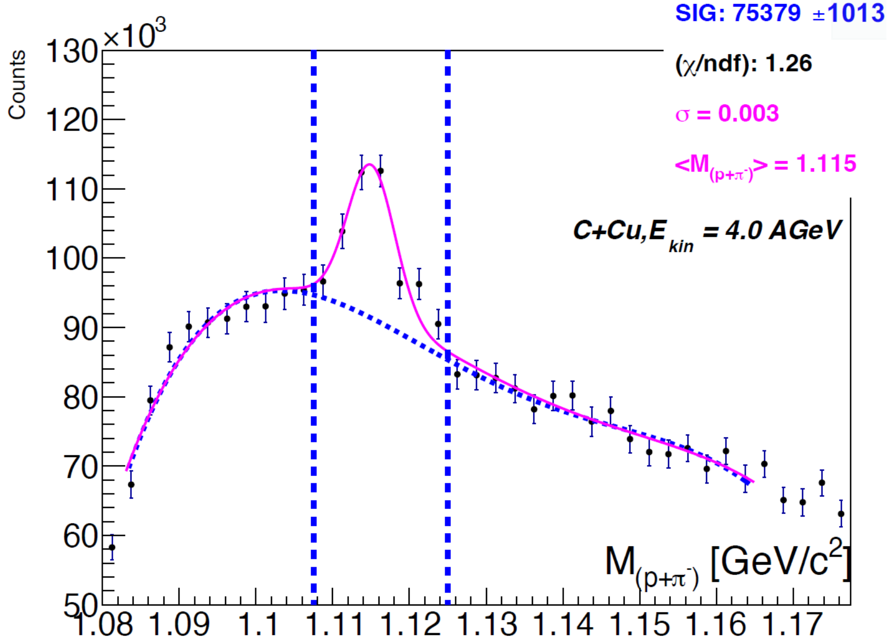
1) Extrapolation based on the DCM – QGSM model.

2) Extrapolation factor is calculated $f_{extr} = N_{all}/N_{con}$, N_{all} – sum of all generated events; N_{con} – sum of generated events in cells with high acceptance;

3) f_{extr} - is used for evaluation of production cross section in full kinematic range;

Mass distribution of the Λ (DATA)





Procedure in DATA C+A → X

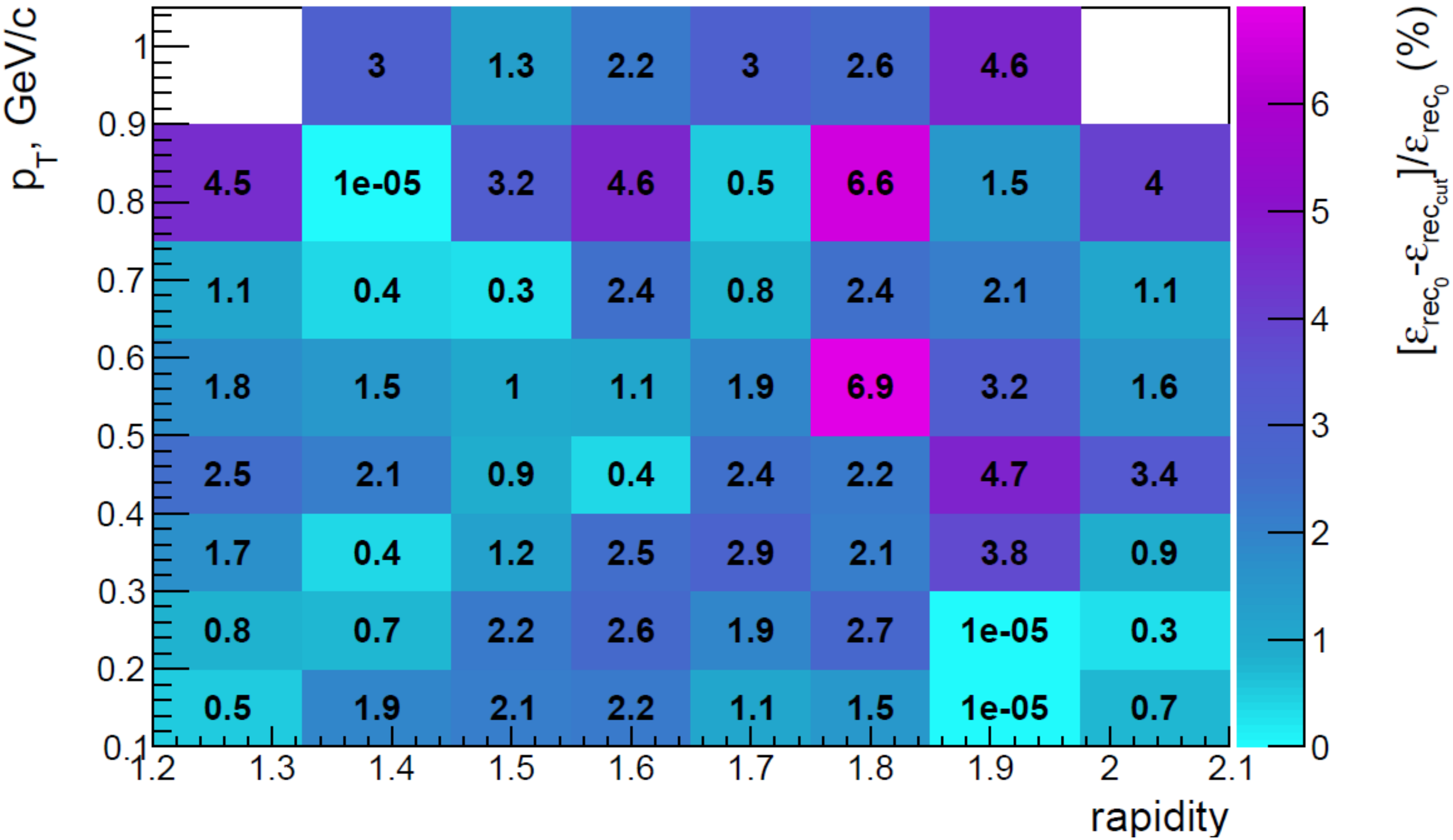
1) Split (y, pT) area in small cells for MC/DATA (8x8);
2) To each event assigned the weight ε_i;
3) Sum the cells by $\sum_{ij} y_{ij}$ and by $\sum_{ij} pT_{ij}$

0.1 < pT <1.05
and
1.2 < ylab < 2.1

- Λ signal width ~ 2.0 - 4 MeV;
- **Signal** = hist – Background in **1107.5 - 1125** MeV/c^2;

Data yields stability check

C+Cu, E_{kin} = 4.5 AGeV



ε_{rec_0} - efficiency of hyperon lambda reconstruction at lambda selection criteria:
path > 2.5 cm, dca < 1 cm;

$\varepsilon_{rec_{cut}}$ - efficiency of hyperon lambda reconstruction at variation of lambda selection parameters:

path > 2.25 cm, path > 2.75 cm, **fixed:** dca < 1 cm;

dca < 0.9 cm, dca < 1.1 cm, **fixed:** path > 2.5 cm;

Cross sections $\sigma_\Lambda(y/p_T)$ of the Λ

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

weighted signal

$$\sigma_\Lambda(p_T) = [\sum_y N^\Lambda_{rec}(y,p_T)/\varepsilon_{rec}(y,p_T)]/[\varepsilon_{trig}\cdot\varepsilon_{pileup}\cdot L]$$
$$\sigma_\Lambda(y) = [\sum_{p_T} N^\Lambda_{rec}(y,p_T)/\varepsilon_{rec}(y,p_T)]/[\varepsilon_{trig}\cdot\varepsilon_{pileup}\cdot L]$$

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.

Table 2. Integrated **luminosities** collected in interactions of the carbon beam of 4.0 and 4.5AGeV with different targets.

Interactions, target thickness		Integrated luminosity/ 10^{30} cm^{-2}		Integrated luminosity/ 10^{30} cm-2
C+C (9 mm)	4 AGeV	6.06	4.5 AGeV	4.69
C+Al (12 mm)		2.39		3.60
C+Cu (5 mm)		2.00		3.06
C+Pb (10 mm)		0.22		0.84

Yields of the Λ

The **Y_Λ** of Λ hyperon in C+A interactions are calculated in bins of (y - p_T) cells according to the formula:

$$Y_\Lambda(y - p_T) = \sigma_\Lambda(y - p_T)/\sigma_{inel}$$

$\boldsymbol{\sigma_{inel}}$ is the cross section for minimum bias inelastic C+A interactions(model).

The cross sections for inelastic C+Al, C+Cu, C+Pb interactions calculated by the formula (DCM-QGSM): $\sigma_{inel} = \pi R_0^2 (A_P^{1/3} + A_T^{1/3})^2$

R_0 = 1.2 fm is an effective nucleon radius, A_P and A_T are atomic numbers of the beam and target nucleus [1]. The **uncertainties** for C+Al, C+Cu, C+Pb inelastic cross sections are estimated by formula: $\sigma_{inel} = \pi R_0^2 (A_P^{1/3} + A_T^{1/3} - b)^2$ with R_0 = 1.46 fm and b = 1.21 [2].

Table 6. Inelastic cross sections $\boldsymbol{\sigma_{inel}}$ for carbon-nucleus interactions

Interaction	C+C	C+Al	C+Cu	C+Pb
Inelastic cross section, mb	830±50	1260±50	1790±50	3075±50

[1] Kalliopi Kanaki "Study of Λ hyperon production in C+C collisions at 2 AGeV beam energy with the HADES spectrometer".
[2] H.Angelov et al., P1-80-473, JINR, Dubna.

Integrated yields (Preliminary) of the Λ

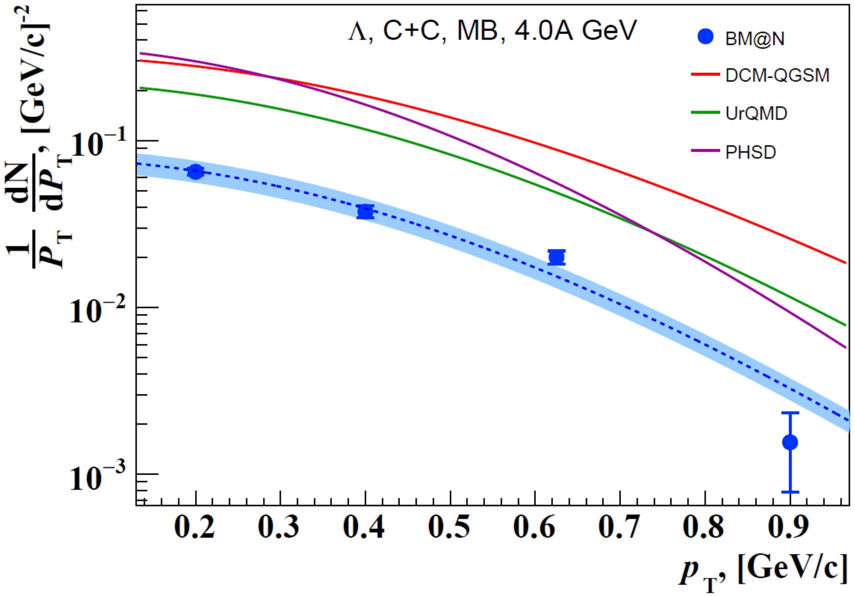
Full data statistics

The data were collected by periods(I and II)

Target	Full (yields ± stat ± sys)	I period (yields ± stat ±sys)	II period (yields ± stat ±sys)
		Yields total, 4.0 AGeV	
C + C	**0,011±0,003±0,002**	0,011±0,004±0,002	0,011±0,003±0,002
C + Al	**0,026±0,007±0,004**	0,028±0,008±0,004	0,029±0,011±0,004
C + Cu	**0,030±0,006±0,005**	0,035±0,009±0,005	0,027±0,009±0,004
C + Pb	**0,039±0,015±0,006**	0,039±0,015±0,006	-
		Yields total, 4.5 AGeV	
C + C	**0,013±0,004± 0,002**	0,012±0,006±0,002	0,012±0,005±0,002
C + Al	**0,023±0,006±0,004**	0,022±0,008±0,003	0,023±0,007±0,004
C + Cu	**0,037±0,007±0,006**	0,035±0,011±0,005	0,035±0,009±0,005
C + Pb		**low statistic**	

$0.1 < p_T < 1.05$ and $1.2 < y_{lab} < 2.1$

Invariant p_T spectra of Λ hyperons vs predictions of the models



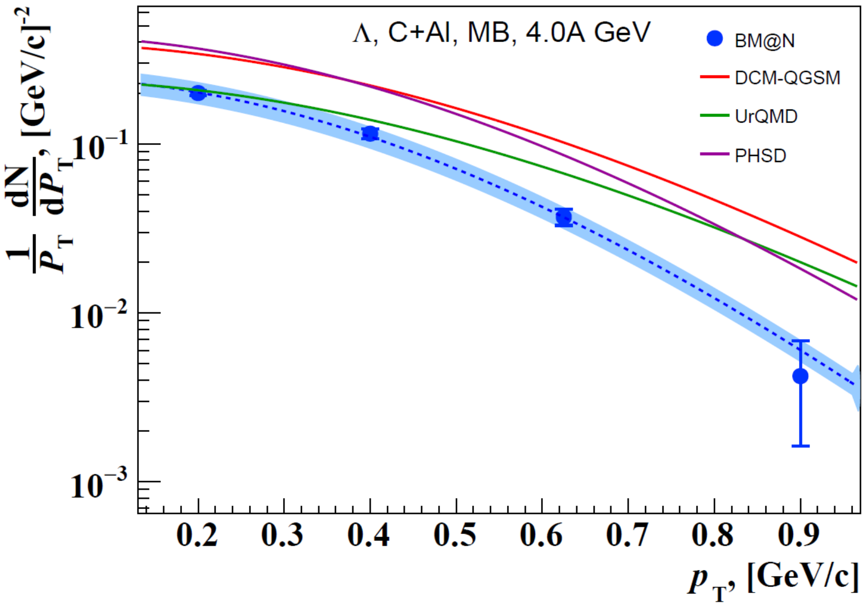
The measured spectra of the Λ yields in pT are parameterized by the formula:

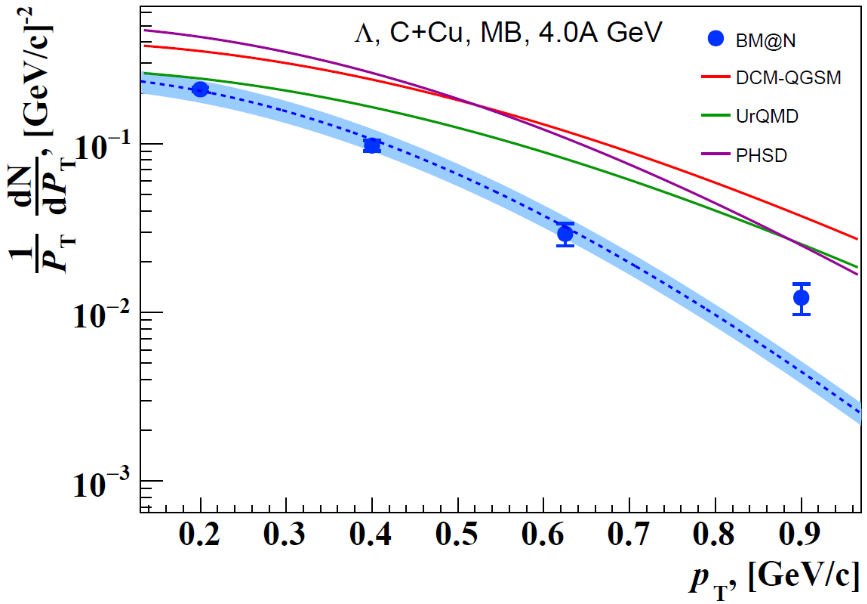
$$1/p_T\, d^2N/dp_T dy = N \cdot \exp(-(m_T - m_\Lambda)/T)$$

The transverse mass $m_T = \sqrt{m_\Lambda^2 + p_T^2}$,

The **N** normalization,

The inverse slope parameter **T** are free parameters of the fit;





SLOPE RESULTS (Preliminary)

4.0 AGeV	T_0, MeV, C+C	T_0, MeV, C+Al	T_0 MeV, C+Cu	T_0 MeV, C+Pb
BM@N	114±19±17	108±16±16	96±14±14	83±8±12
DCM - QGSM	126	120	133	130
UrQMD	107	128	133	136
PHSD	87	100	105	98

4.5 AGeV	T_0, MeV, C+C	T_0, MeV, C+Al	T_0, MeV, C+Cu	T_0, MeV, C+Pb
BM@N	116±24±17	115±7±17	101±3±15	Due to low statistics
DCM - QGSM	132	133	135	142
UrQMD	122	128	130	134
PHSD	101	106	109	108

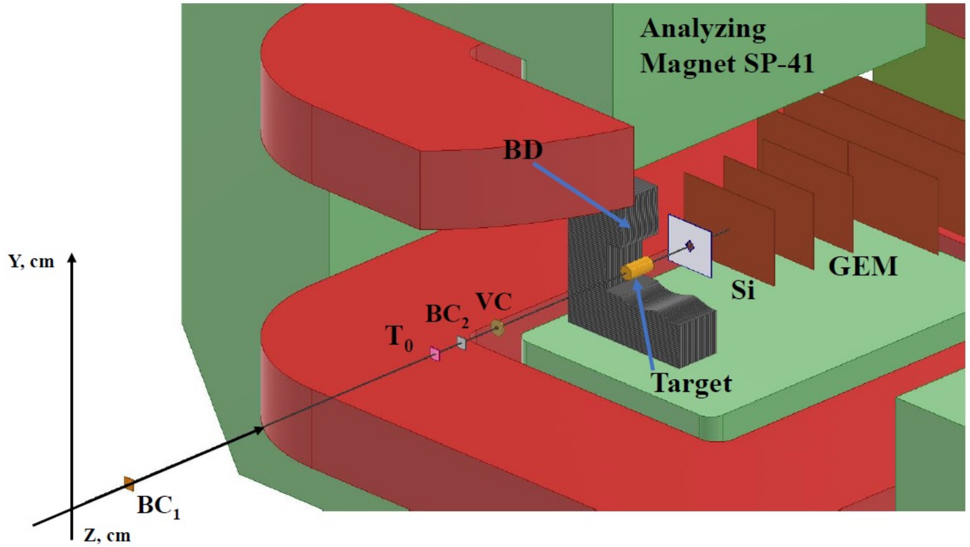
Summary

1. Preliminary results of yields and cross sections

2. Preliminary the slopes from the p_T spectra

Back up

Event selection criteria



1 Number of tracks in selected events:
positive>=1, negative>=1;

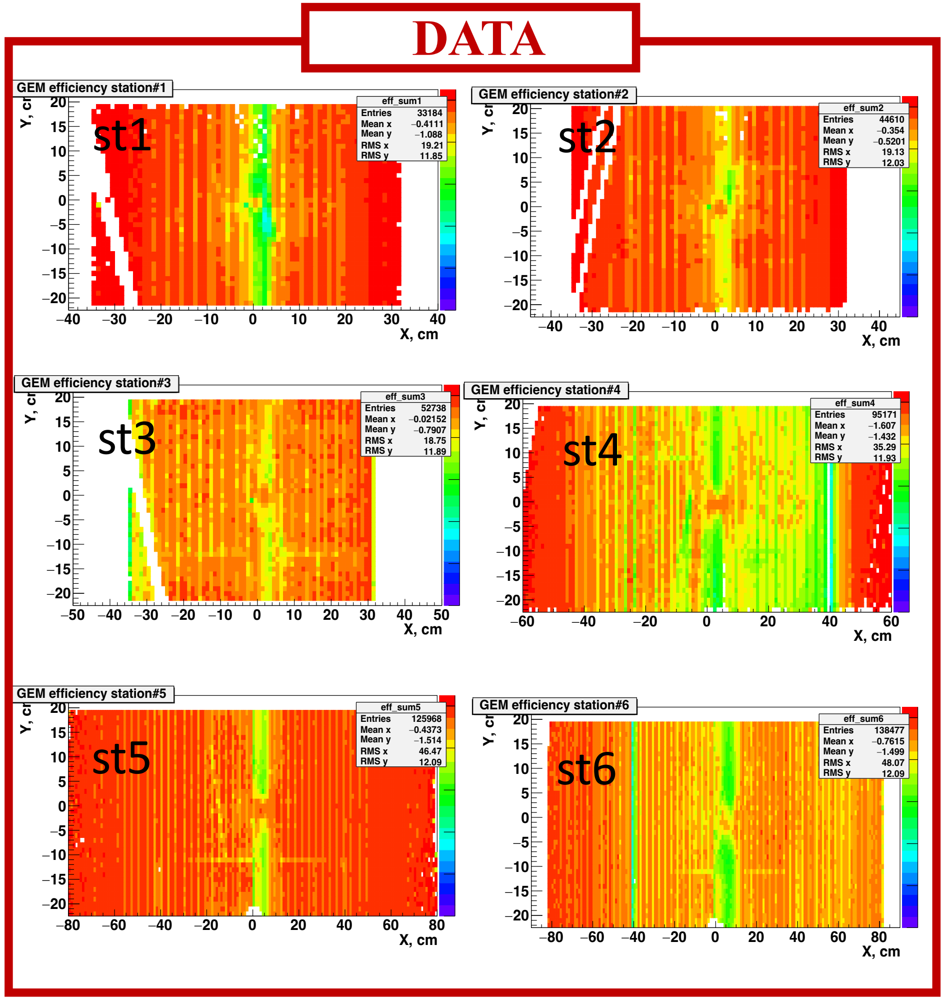
2 Number of signals in the start detector: T_0=1,

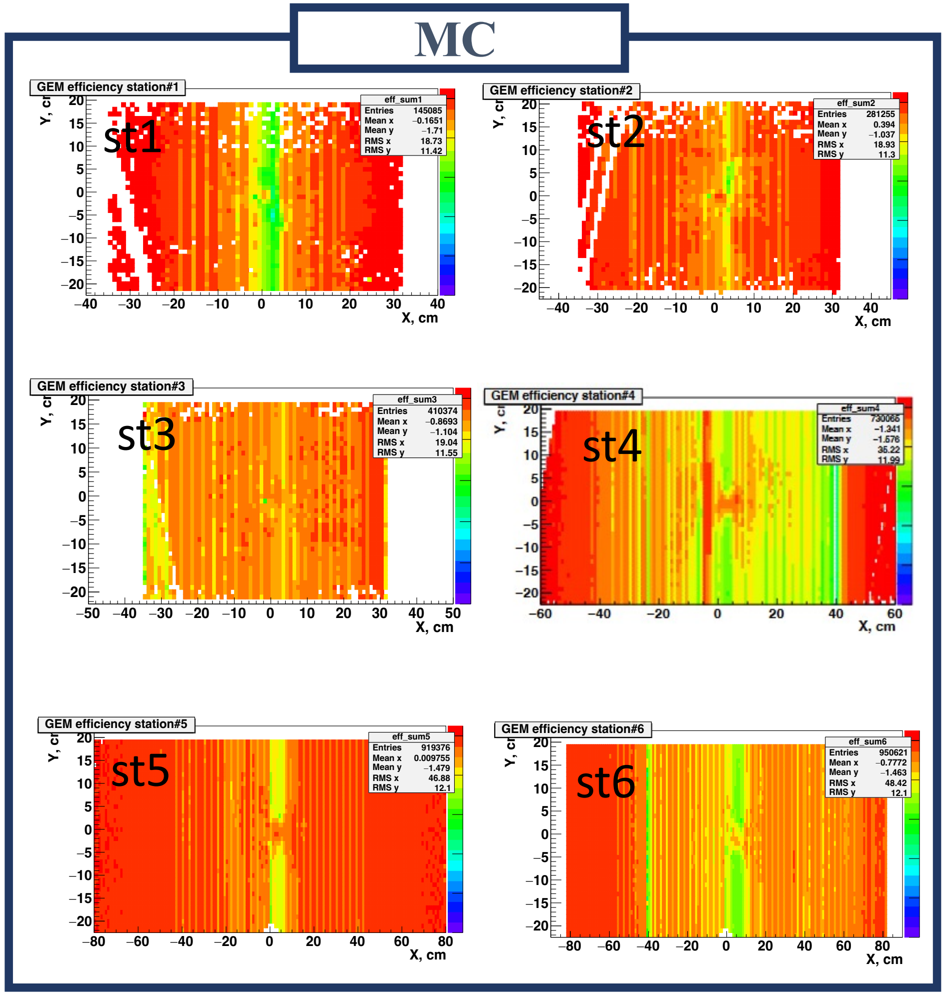
3 Number of signals in the beam counter:
BC_2=1,

4 Number of signals in the veto counter around the beam: Veto=0;

5 Trigger condition in the barrel detector: number of signals BD>=2 or BD>=3 (run dependent);

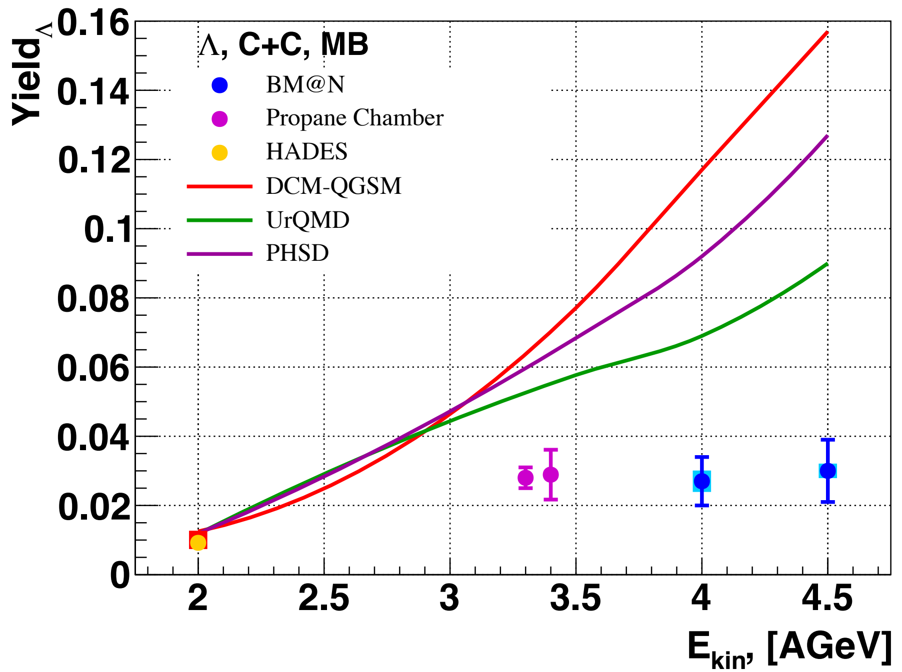
GEM efficiencies comparison Data/MC (4.0GeV C+C) after applying effs to MC





For each GEM station they were estimated using the following approach:

1. Select good quality tracks with the number of hits per track (excluding the station under study) not less than N;
2. Check that track crosses the detector area, if yes, add one track to the denominator;
3. If there is a hit in the detector, which belongs to the track, add one track to the numerator;
4. **GEM** efficiency = sum of tracks in numerator / sum of tracks in denominator.



The error bars represent the statistical errors;

The blue bands show the systematic errors;

The predictions of the **DCM-QGSM**, **UrQMD** and **PHSD** models are shown as colored lines.

BM@N result is compared with data taken from another experiments:

[1] Kalliopi Kanaki, PhD "Study of Λ hyperon production in *C+C* collisions at 2A GeV beam energy with the HADES spectrometer", 2007

[2] D. Armutlijsky et al., Report No, P1-85-220, JINR, Dubna

[3] S.Arakelian et al., Report No, P1-83-354, JINR, Dubna