#6.3, 2010 Symposium on Nuclear Data
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EXPERIMENTAL STUDIES OF LIGHT FRAGMENT PRODUCTION CROSS SECTION FOR NUCLEON INDUCED REACTION AT INTERMEDIATE ENERGIES

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Nuclear Data and applications

Nuclear Engineering → ← *High energy physics*

eV | keV | 1MeV | 10MeV | 100MeV | GeV | TeV

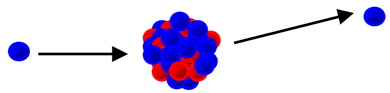
Fission Reactor | FBR | Fusion Reactor | Accelerator | Cosmic ray

← Neutron transport →

← Reaction Products →

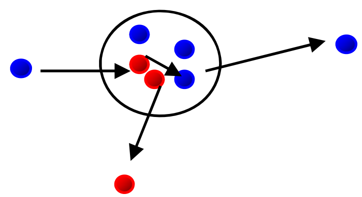
Nucleus + nucleon

Two body reactions
Scattering/ Absorption / Fission / Decay



Small reaction channel, but
Very precise data table sets

nucleon + nucleon



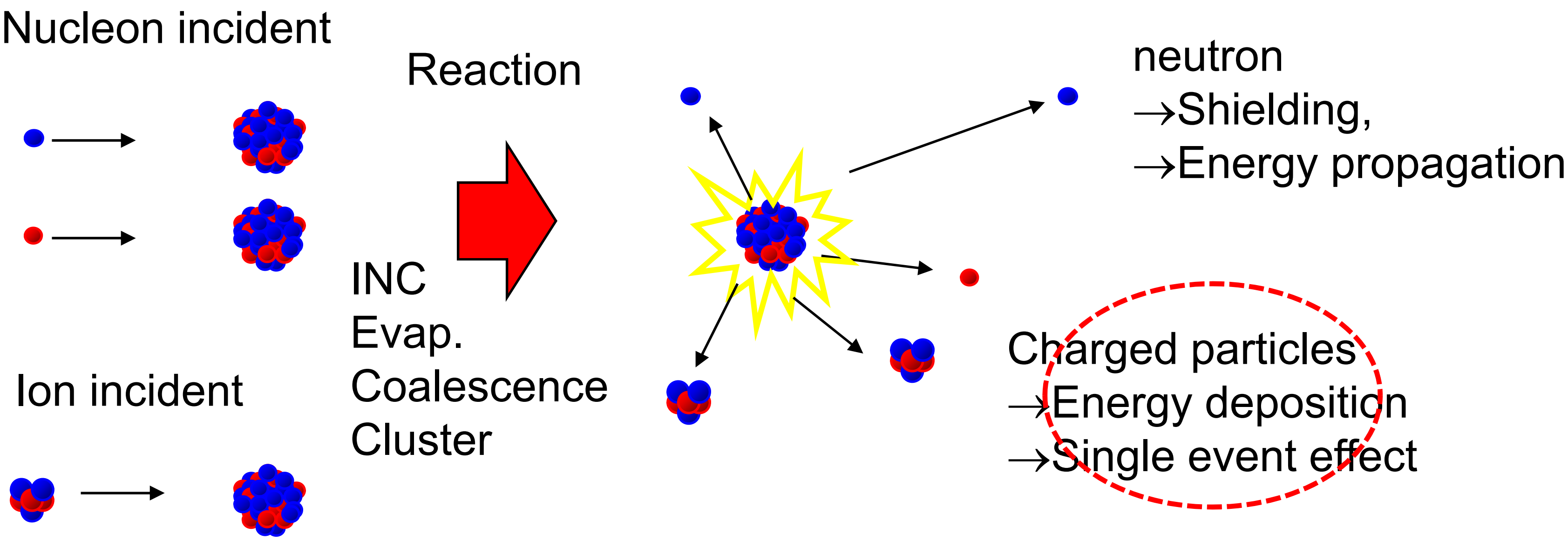
Multi body reactions,
Various reaction channels
Reaction model based on mechanism

What should come out between two hierarchies ?

Nuclear Data and applications (cont.)

<u>Reaction data on Intermediate energy</u>

Application
Tumor therapy, Single event effect, Nucleosysnthsys,
Accelerator Driven system, Radiation Safety design for accelerators



<u>Experimental data are required to show what channels and models should be considered for each application</u>

Experimental data at intermediate energies

Incident	~20 MeV	20 to 1000 MeV	Above 1000 MeV
Neutron	Done **p,d,t,α** Data available **Li,Be,B,,,,** No production	Done **p,d,t,α** Data available **Li,Be,B,,** Few data	**p,d,t,α** No data **Li,B** No
Proton	**p,d,t,α** Data available **Li,Be,B,,,,** No production	**p,d,t,α** Data available **Li,Be,B,,,,** Few data	**p,d,t,α** Few data **Li,Be,B,,,,** Few data

Uppsala, Leuven
Tohoku, Kyushu
…

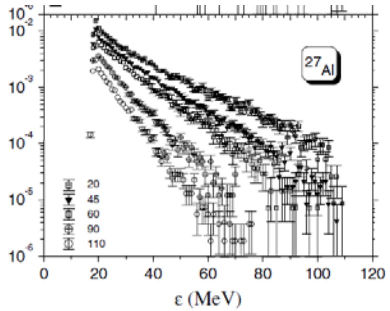
Beam should be provided by

Tohoku AVF
NIRS AVF
TIARA AVF

RCNP Ring
RIKEN

Experimental data at intermediate energies

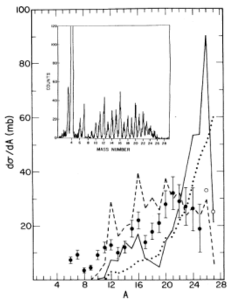
R.Green et al, Phys.Rev.C22 1594 (1980)
p+Ag 210,300,480 MeV DDX, de-E SSDs
S.J.Yennello et al., Phys Rev.C41, 79 (1990)
p+Ag 161MeV DDX, gas dE- SSD E
H.Machner et al, Phys Rev C73, 044606 (2006)
p+Al,Co,Au 200MeV DDX, SSD dE- SSD E



High energy tails are not reproduced by the calculation

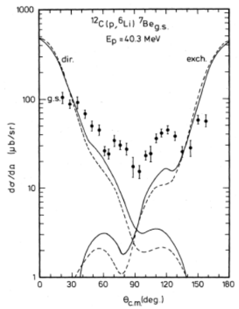
K.Katitkowski et al, PRL vol50, 1648 (1983)
p+Al 180 MeV DDX, MCP+SSDs

Limited data for light target nuclei



Model underestimate light fragment, overestimate heavy fragment

G.D'Erasmo et al, Phys Rev. C31 656 (1985)
p+C 40MeV Li ADX, MCP-MCP-SSD
S.Kato et al, Phys Let 62B 153, (1976)
p+C 51.9MeV Li ADX



Cluster structure of 12-C nuclei

Scope of this study

Systematic data for fragment production DDX on proton induced reaction

Li, Be, B,C, N, O energy spectrum
at 30, 60, 90 and 120 degree,
for 50,70,140,200,300 MeV proton incident energy
on C, N, O, Al, Ti Cu targets

The DDX of fragment production will provide….

→Information on fragment production mechanism

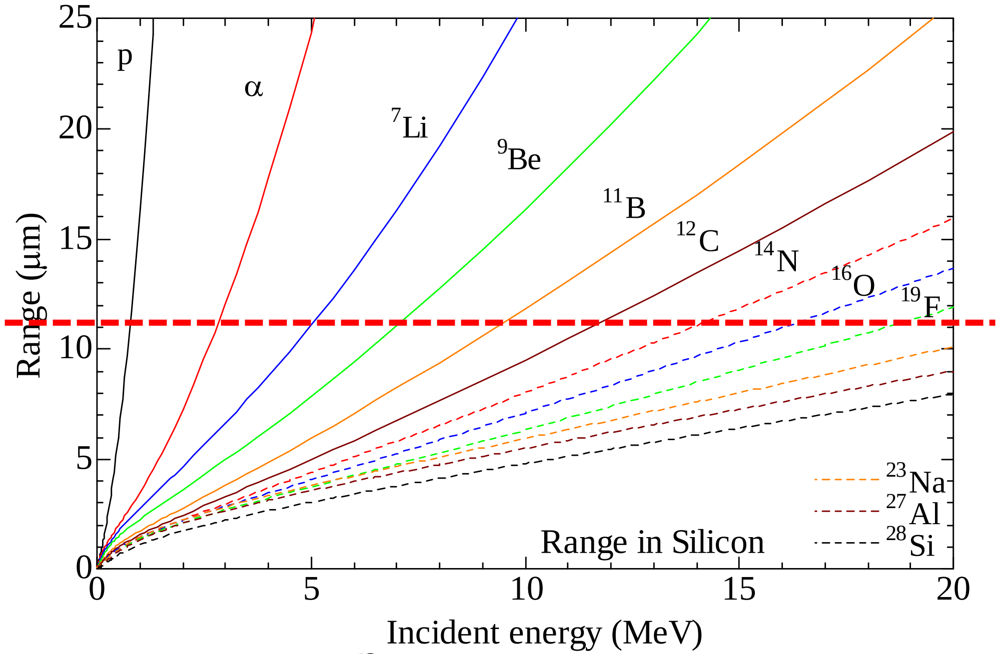
→Amount of fragment production should be taken into account for energy deposition

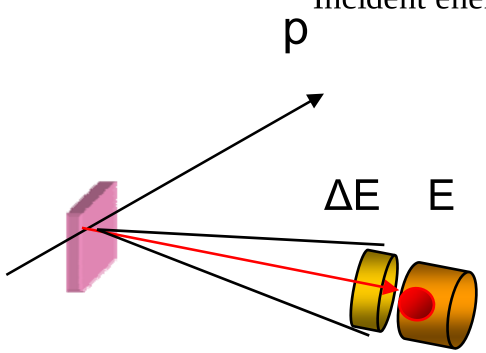
→Comparison with another experimental data and theoretical calculation results

→Applicability and limit of present models

Experimental

<u>How to measure fragments</u>



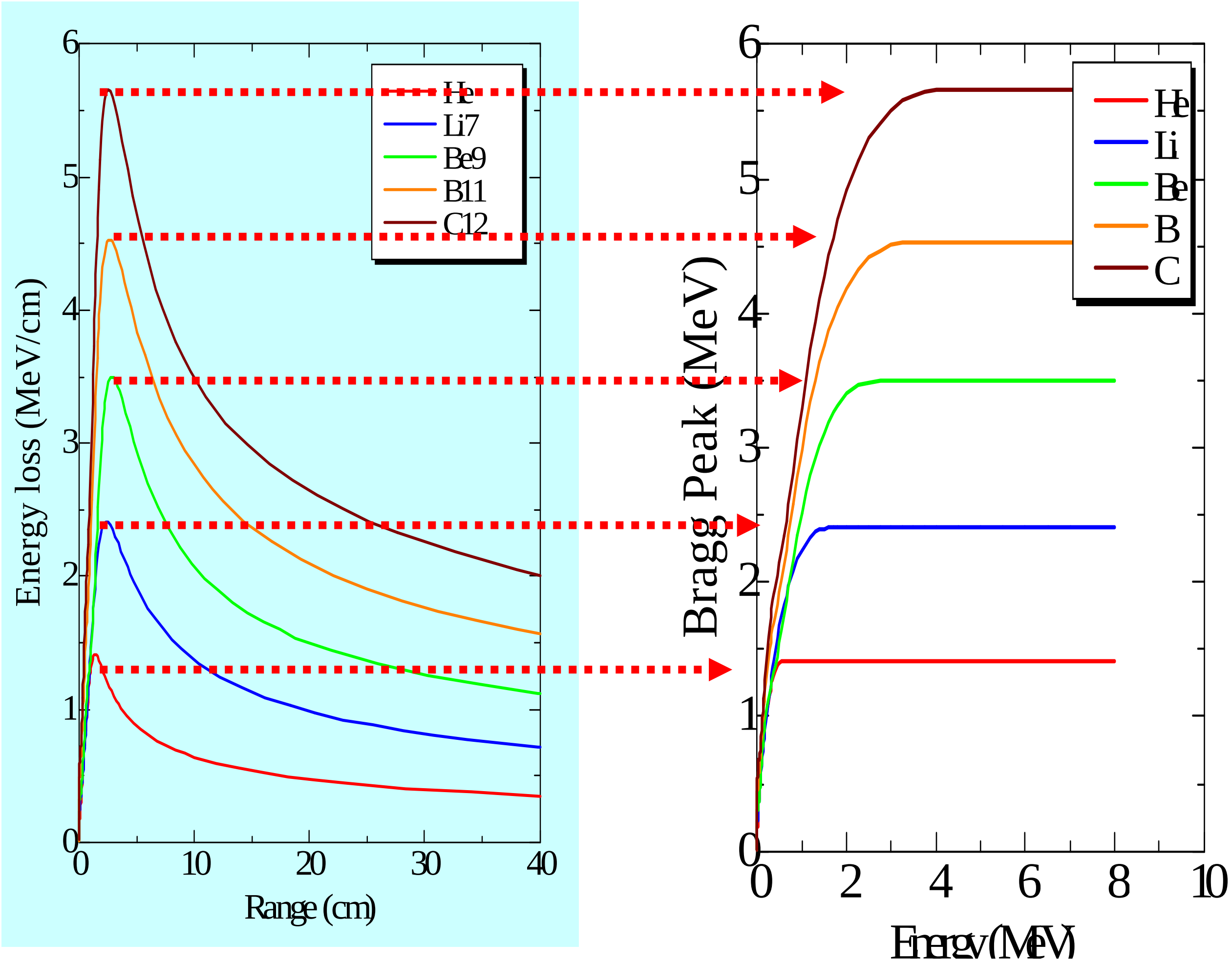


Large energy loss
→ Thin
Low production rate
→ Large area
Overlap light charged particle
→ Thin
→ Particle Identification

Thin large area SSD is not available
→ Develop detector

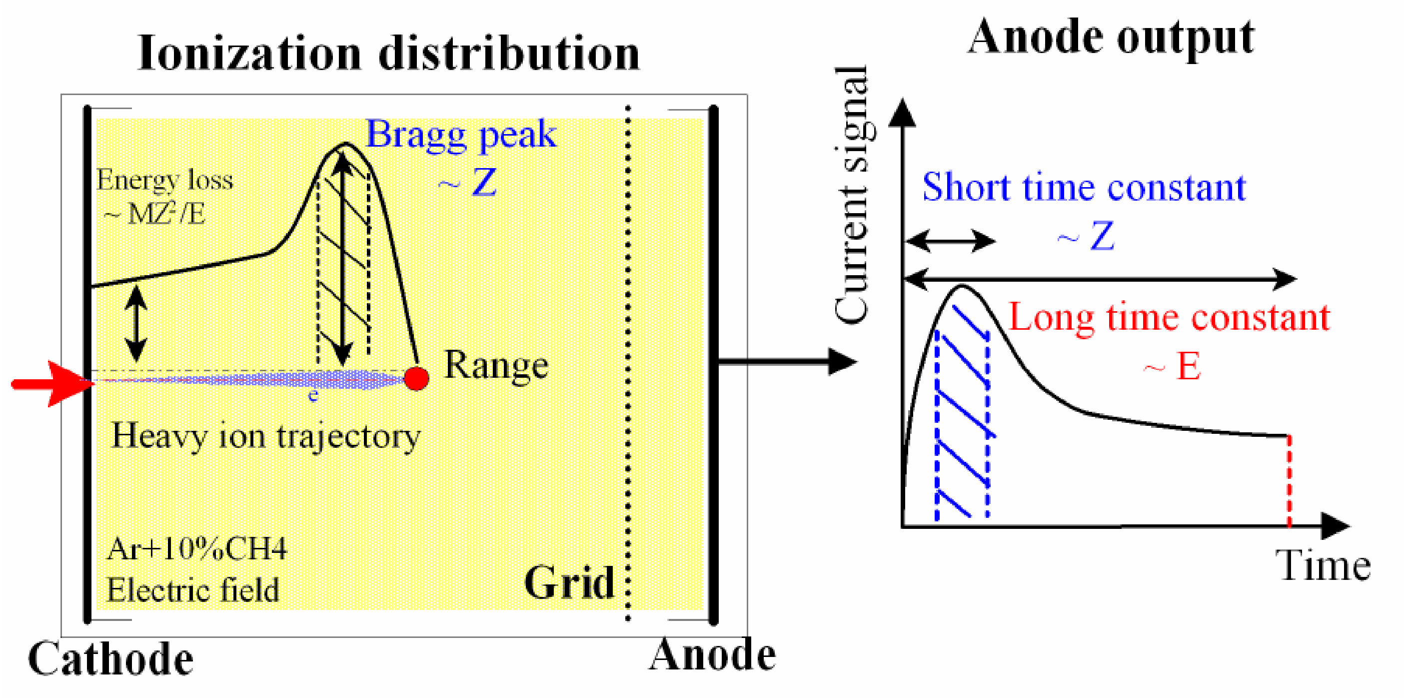
<u>Bragg Curve Counter</u>

Experimental



Different Bragg peak height → Distinguish Z number

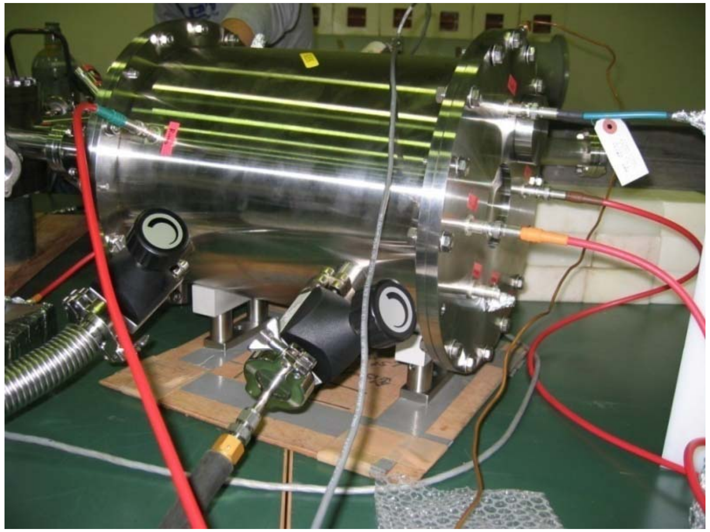
Bragg curve counter –How it works



The electric field strength between the grid and the anode is more than four times of that between the cathode and the grid to lead all electrons to the anode electrode.

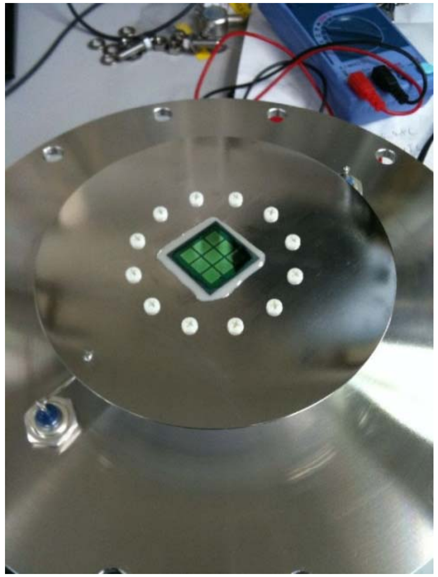
Under this condition, information on <u>energy and Bragg peak height are derived from the anode signal</u> with long and short shaping time.

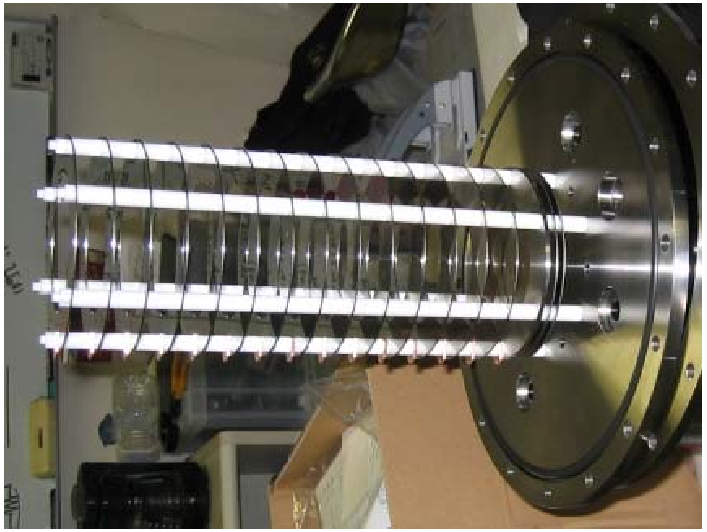
Bragg curve counter



The BCC is a cylindrical chamber having a thin entrance window, cathode, grid and anode electrodes.

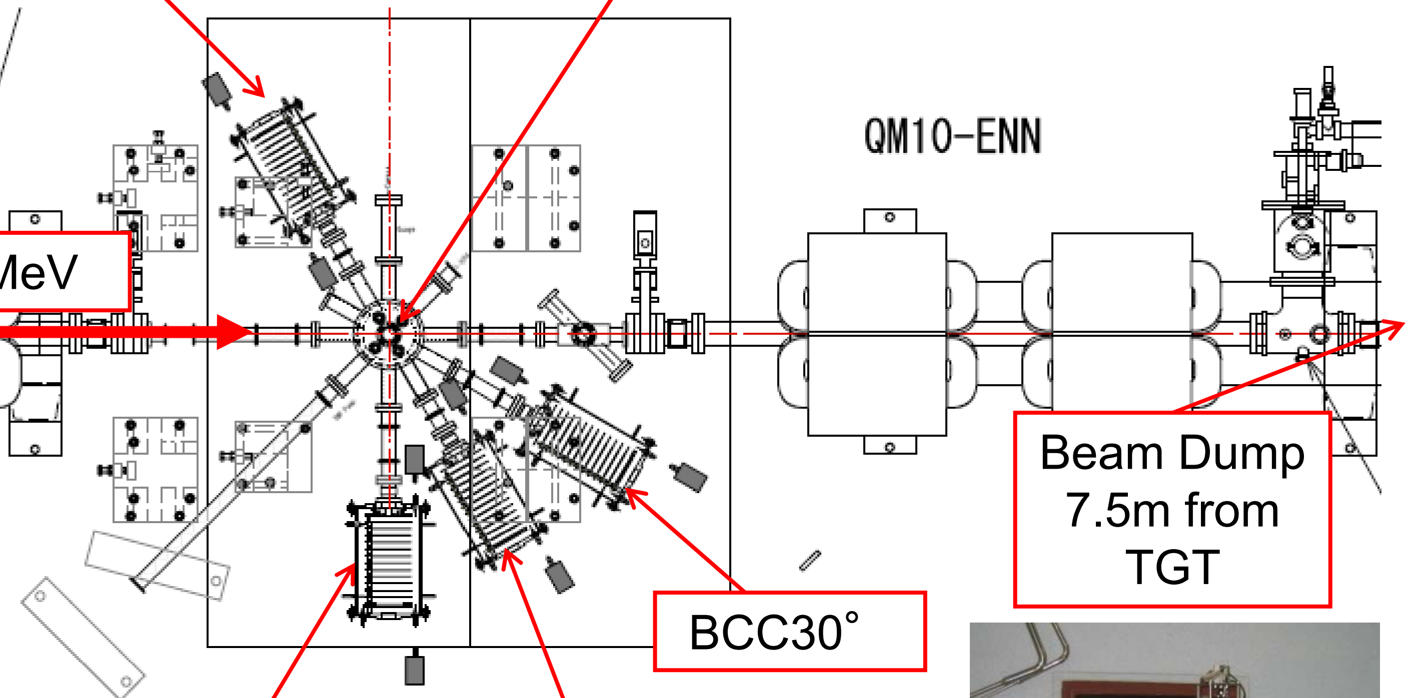
Entrance window Is a membrane of 0.5 μm - 2cm diam. SiN supported by 0.5 mm^2 Si window frame.

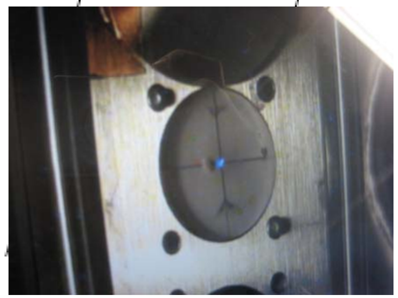




Field shaping rings are inserted between the cathode and the grid to maintain electric field.

Experimental setup



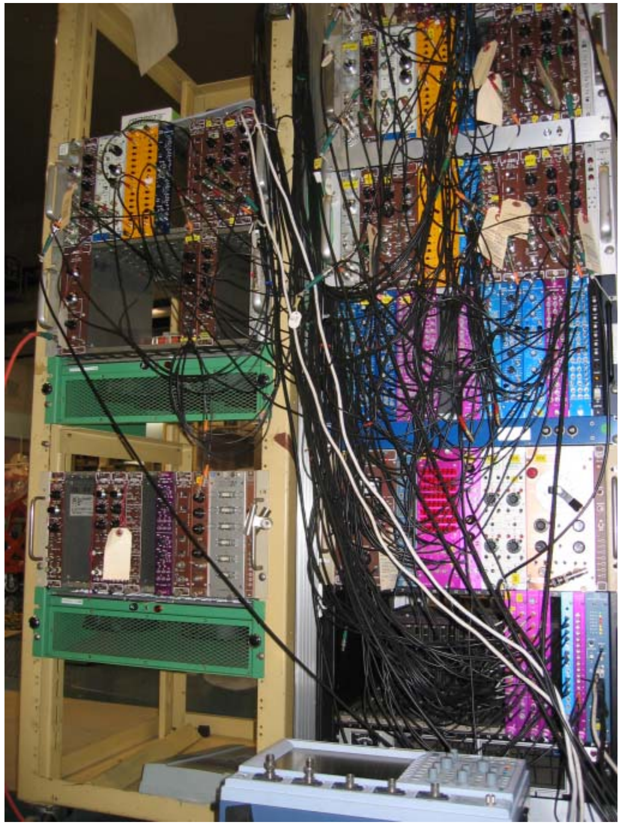


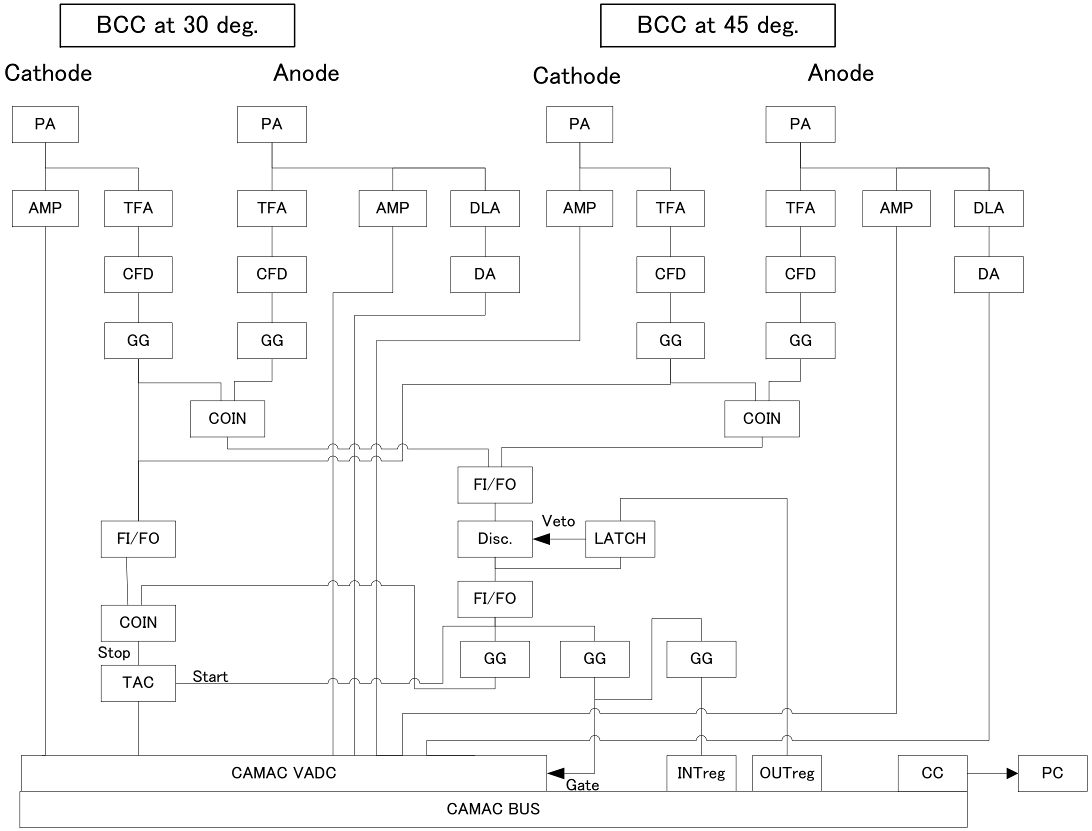
Targets – for data of C,N,O, Ti, Cu

	Thickness	Style
Graphite	206 μg/cm^2	Self support
Al	0.8 μm	Self support
Al_2O_3	1.05 μm	Sputtering on Ta 10 μm
AlN	0.91 μm	Sputtering on Ta 10 μm
Ta	10 μm	Self support
Ti	1 μm	Self support
Cu	1 μm	Self support

Data for nitrogen and oxygen were obtained from AlN and Al_2O_3 data by subtracting aluminium and tantalum data taken separately.

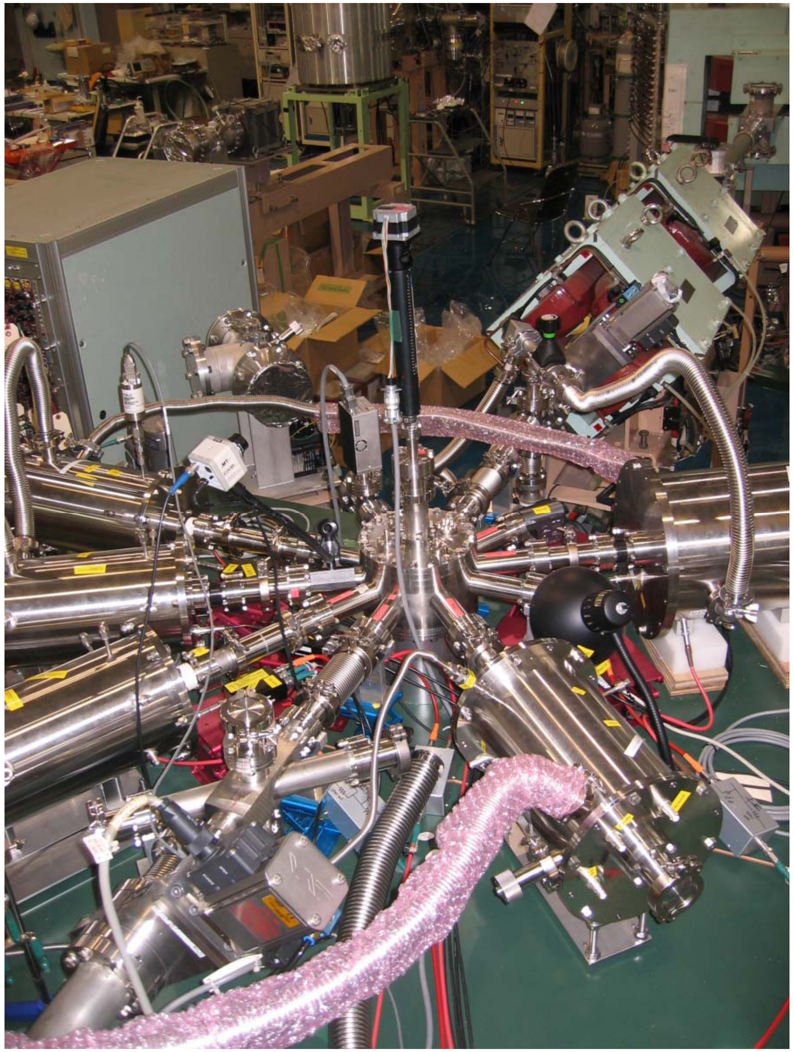
Readout electronics





Standard NIM/CAMAC modules connected to CCNET controlled by TamiDAQ (A.Tamii @ RCNP)

Data taking and analysis



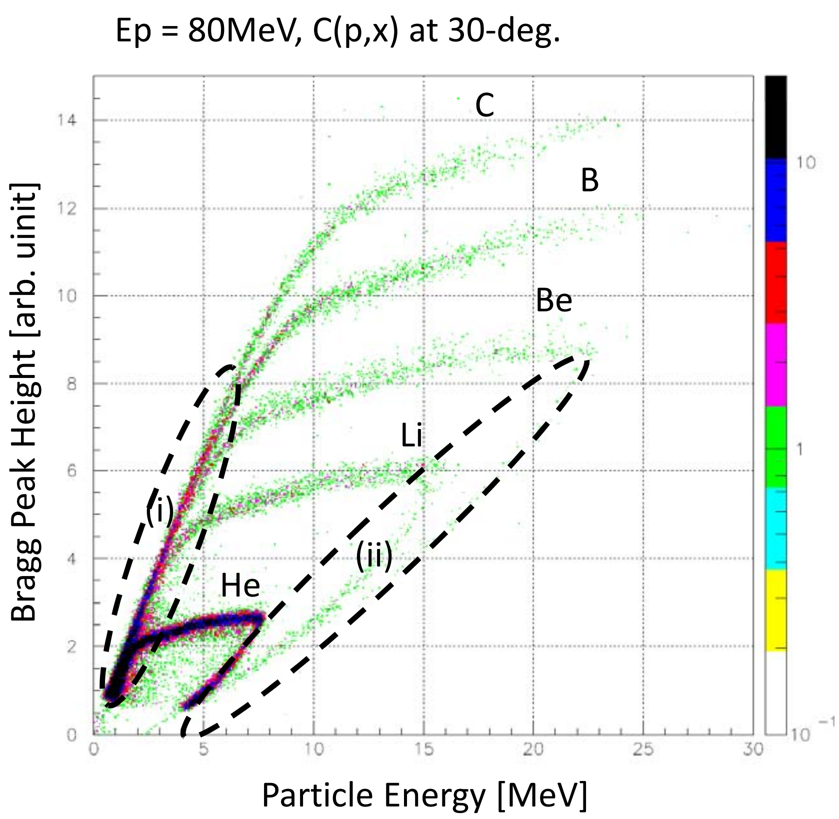
Data taking

Cyclotron facility, National institute of radiological sciences(NIRS), Japan, for 40, 50, 70 and 80 MeV protons.

Ring cyclotron facility, Research Center for Nuclear Physics(RCNP), Osaka University, Japan, for 140,200,300 MeV.

One hour run for each sample was performed with up to 10-50 nA proton beam.

Particle identification – Scheme



Fragments from carbon are clearly separated except for the events in dotted circle (i).
→ PI by Range vs Energy plot

The events in dotted circle (ii) deposit part of their energy due to punch through the BCC.
→ The missed energy of the event is estimated by off-line analysis.

→ Energy range becomes wider than conventional BCC

Detail →

M. Hagiwara, T. Sanami, T. Oishi, M. Baba, and M. Takada, *Nucl. Instrm. Meth*. A Vol 592 pp 73-79 (2008)
T.Sanami, M.Hagiwara, T.Oishi, M.Baba, and M.Takada, *Nucl. Instrm. Meth*. A Vol 589/2 pp 193-201 (2008)

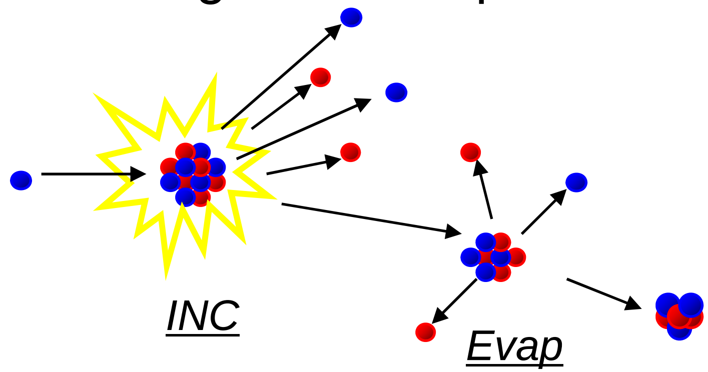
Calculation

Theoretical calculation is performed using PHITS code (v2.23).

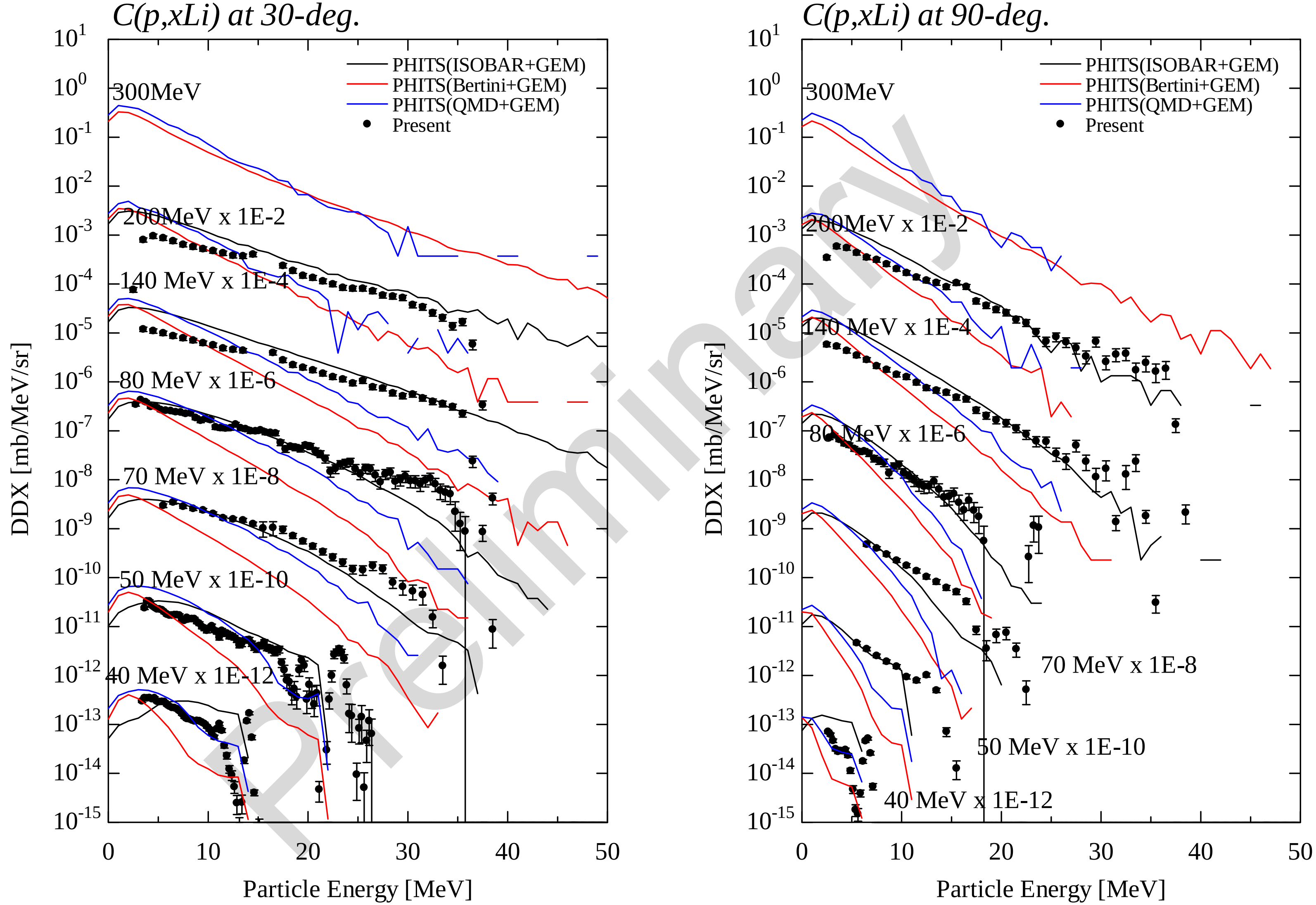
Fragment production is calculated in a 1 μm diameter sphere sample with forced collision option, and then scored at ring detectors placed at 100 cm from the sample, covering ±2.5 degree around each detector angle.

Three intra-nuclear cascade (INC) codes implemented in PHITS, ISOBAR, Bertini and QMD, are tested with general evaporation model (GEM).

PHITS
Particle and Heavy Ion Transport code System

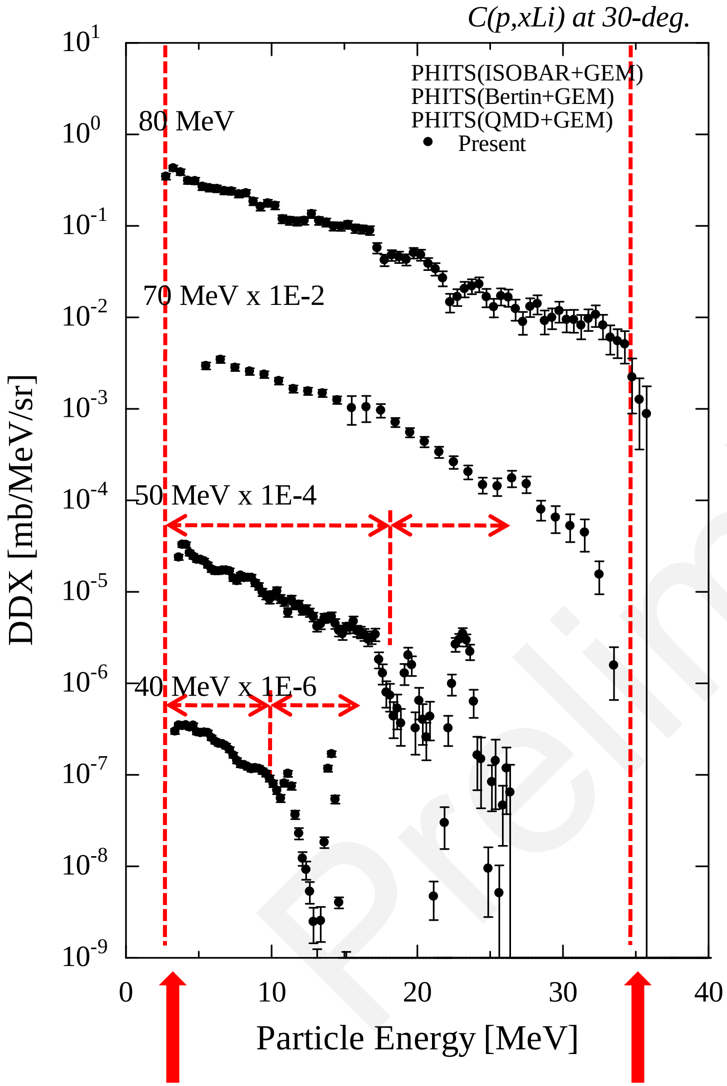


Results



C(p,xLi) at 30-deg.
C(p,xLi) at 90-deg.
PHITS(ISOBAR+GEM)
PHITS(Bertini+GEM)
PHITS(QMD+GEM)
Present
300MeV
200MeV x 1E-2
140 MeV x 1E-4
80 MeV x 1E-6
70 MeV x 1E-8
50 MeV x 1E-10
40 MeV x 1E-12
DDX [mb/MeV/sr]
Particle Energy [MeV]
Preliminary

Result – Experimental data



Cover energy of experimental data

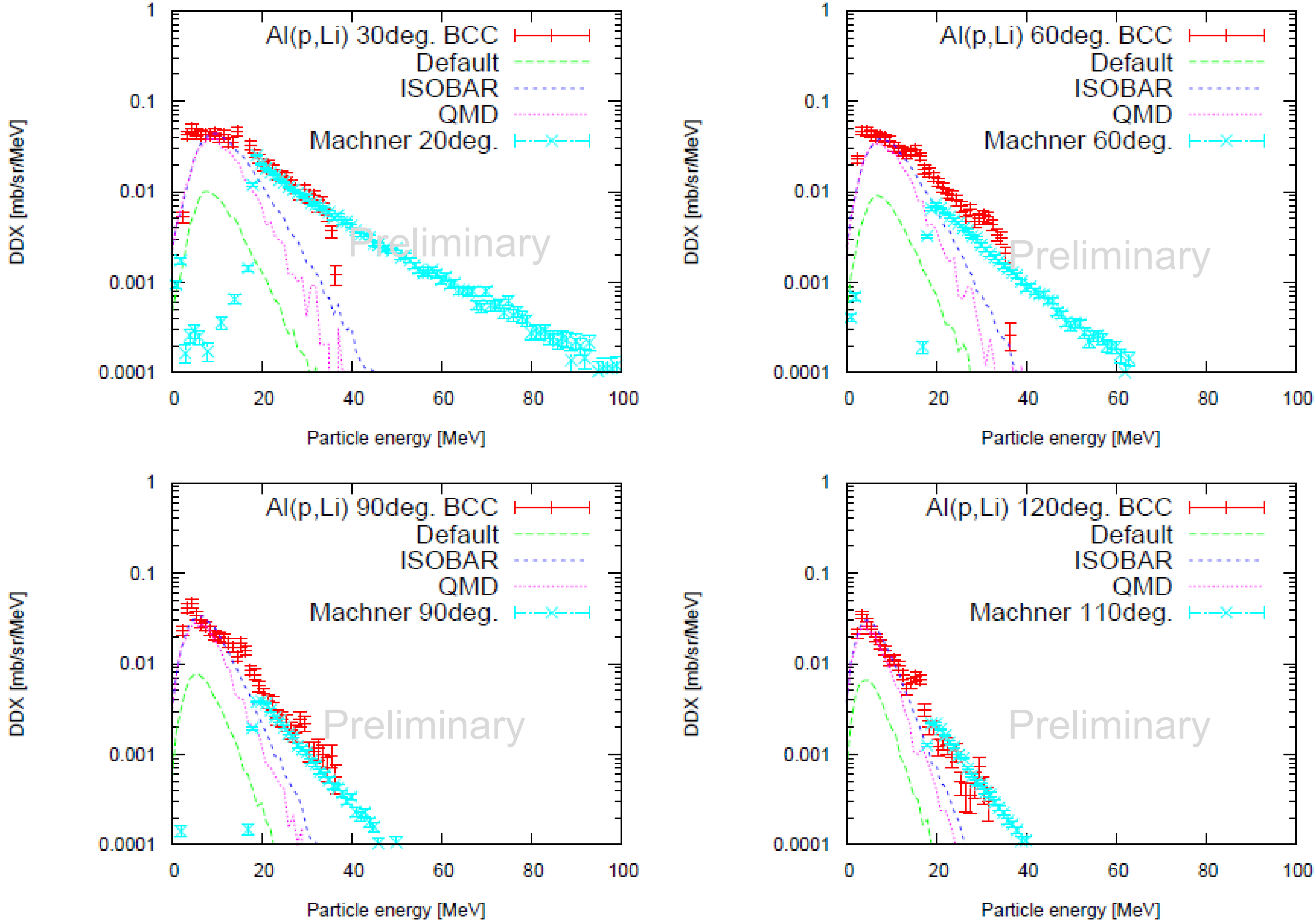
- <u>Energy compensation analysis for punch through fragments</u>
- <u>Particle identification by range-energy</u>
- <u>Thin entrance window</u>

Li : 4-40 MeV, Be : 5-45 MeV
B : 5-60 MeV, C : 6-60 MeV

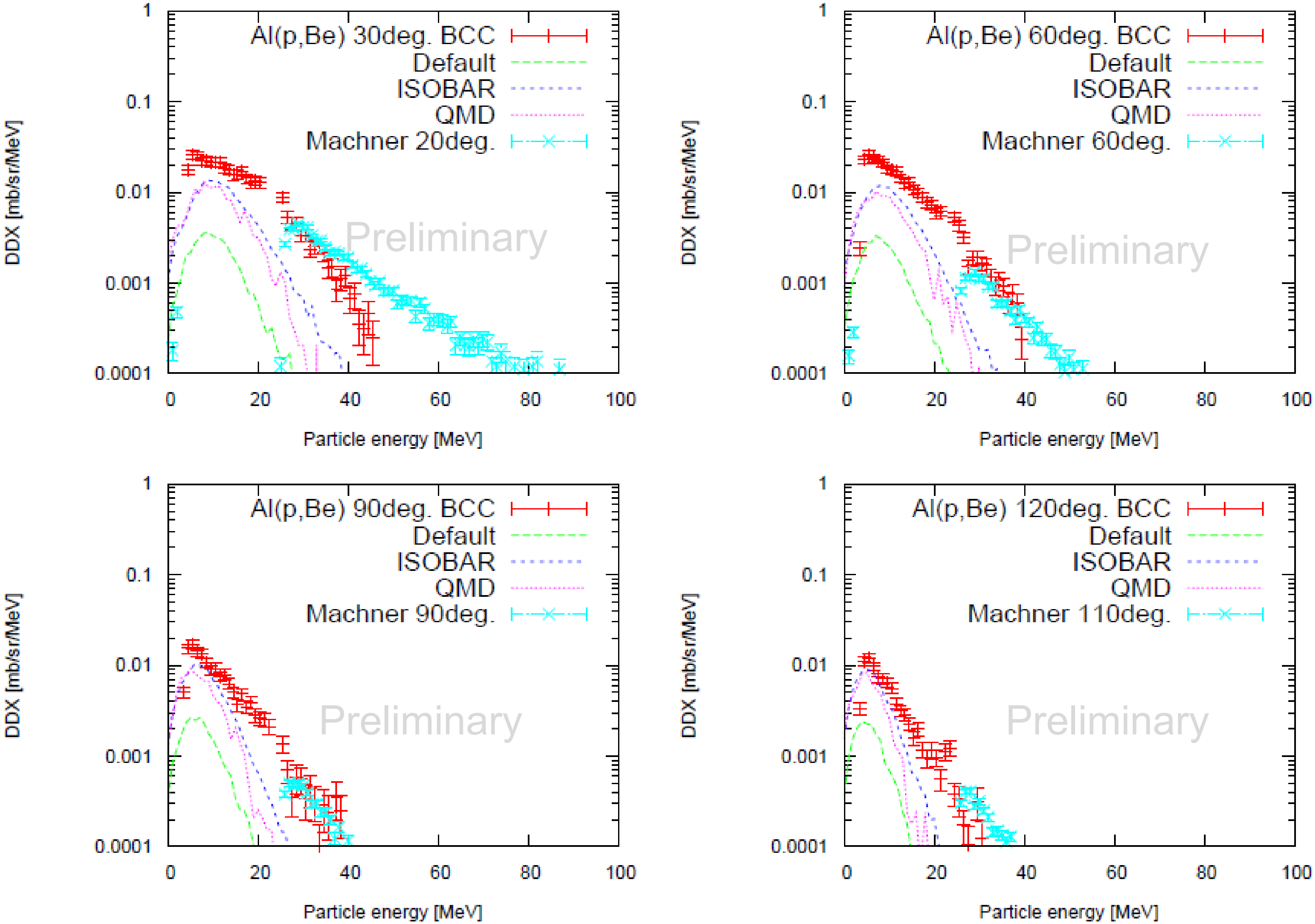
The experimental data consist of two parts,

- <u>high energy peak structure</u>, and
- <u>low energy continuous part</u>.

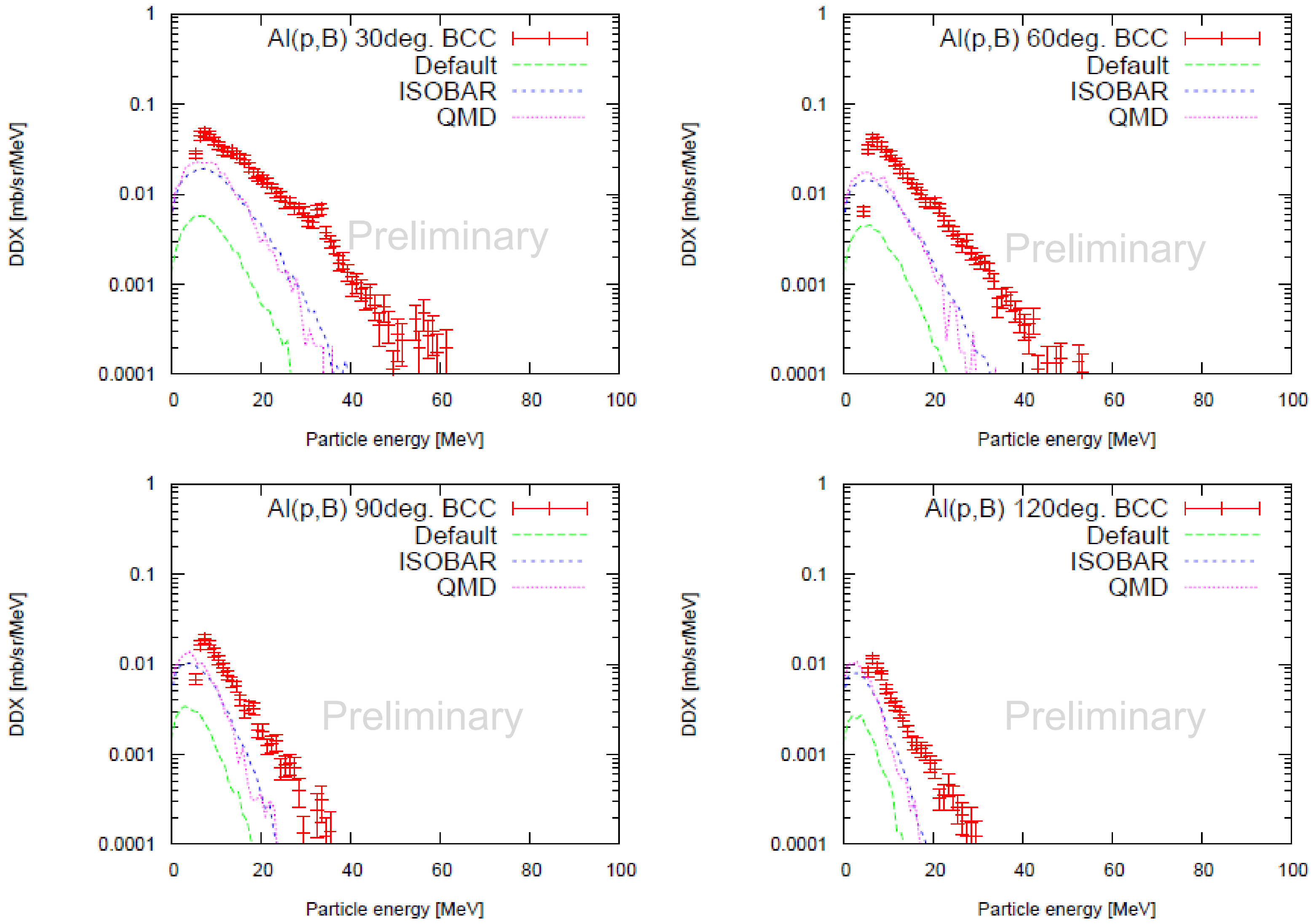
Result – Experimental data Al(p,Li) Ep=200MeV



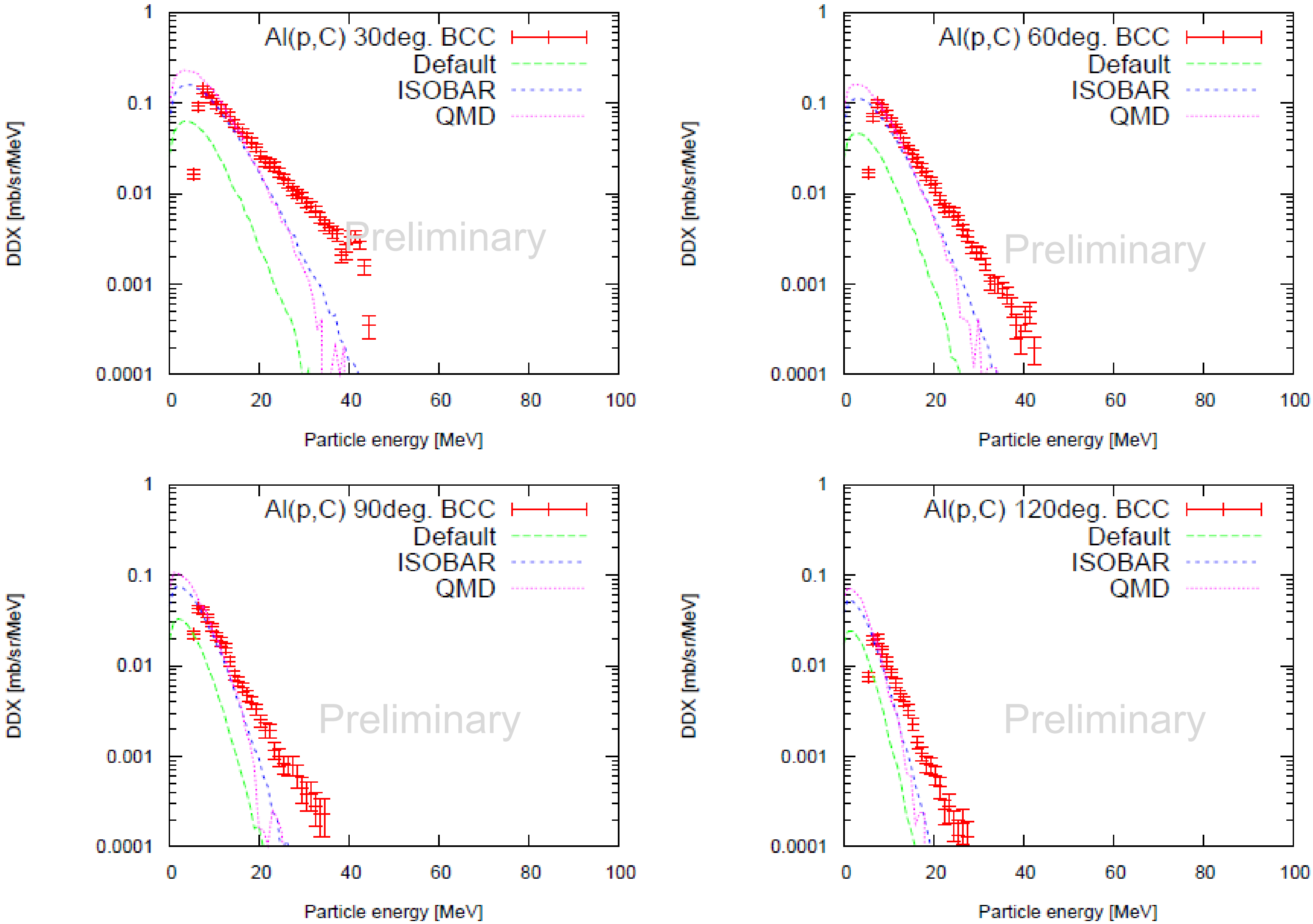
Result – Experimental data Al(p,Be) Ep=200MeV



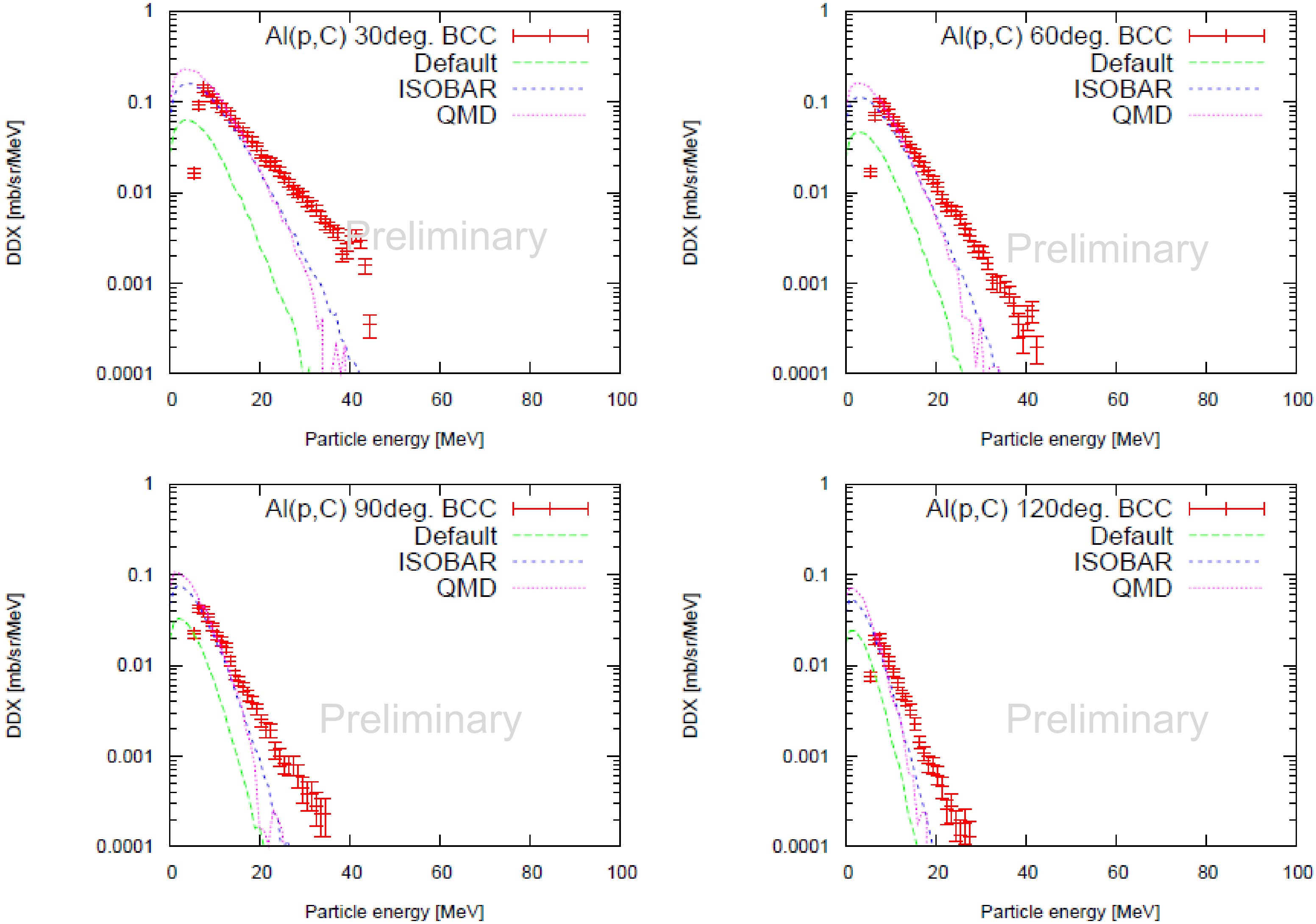
Result – Experimental data Al(p,B) Ep=200MeV



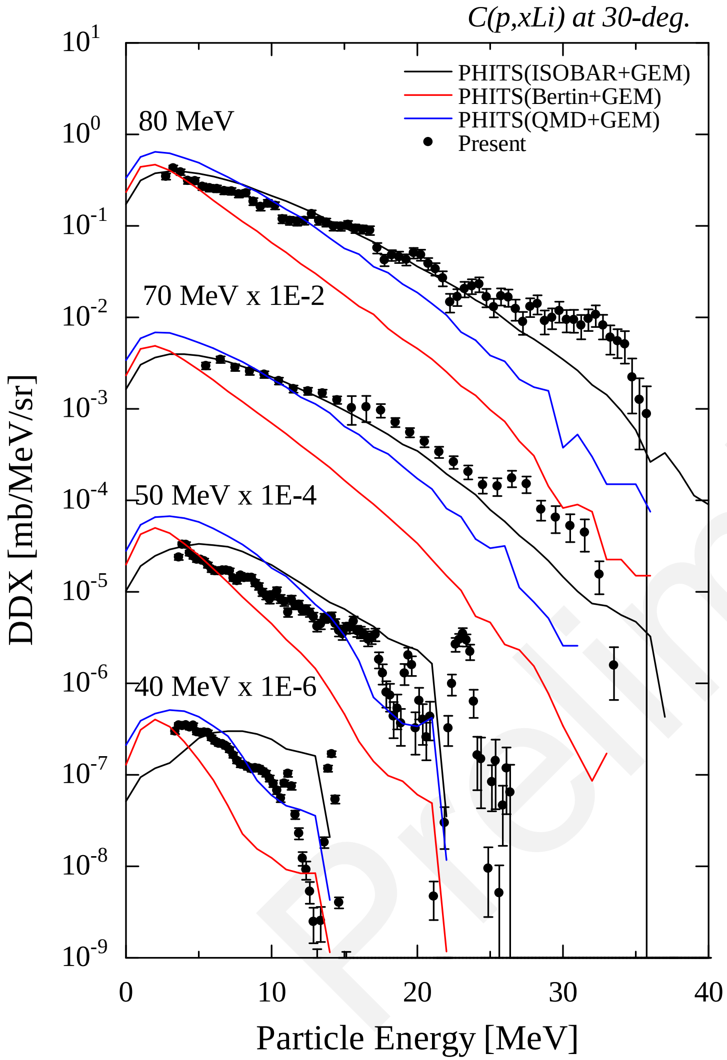
Result – Experimental data Al(p,C) Ep=200MeV



Result – Experimental data Al(p,C) Ep=200MeV



Which INC model is best at this moment?



Among the three INC models, ISOBAR+GEM model reproduces experimental data well up to 80 MeV.

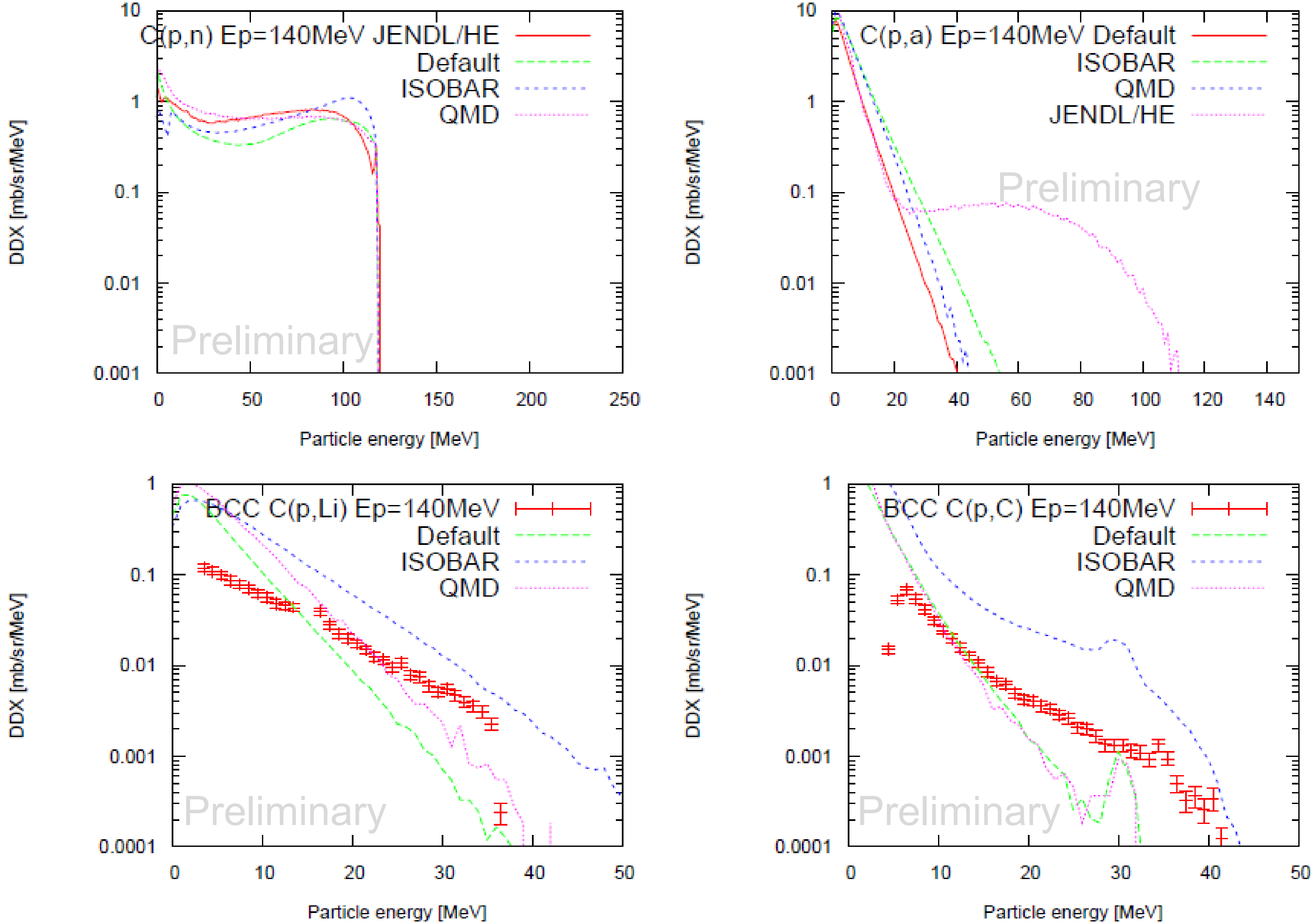
QMD+GEM model generally reproduces experimental data, too.

Bertini+GEM shows underestimation at all the energy.

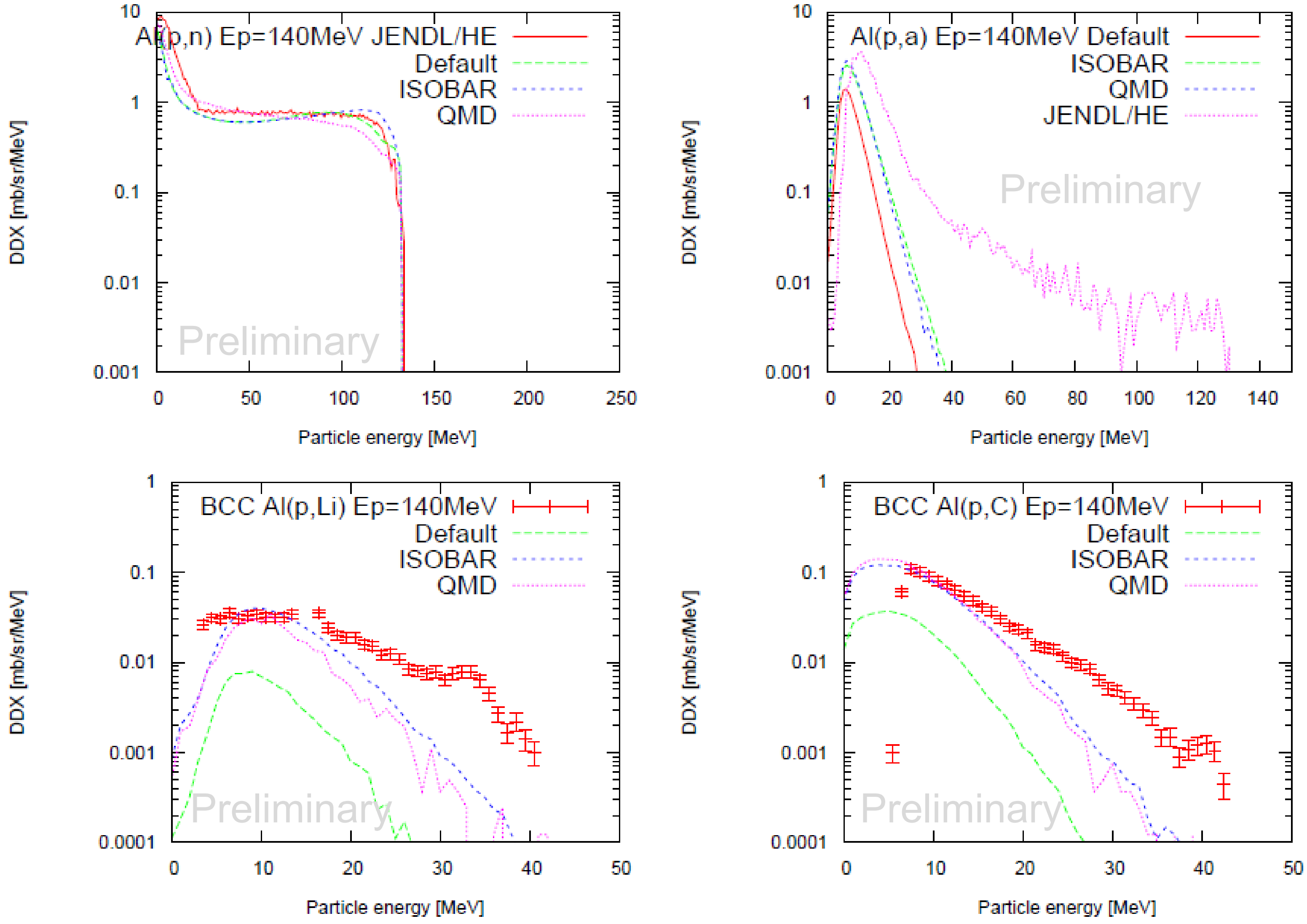
All the results underestimate high energy part of the experimental data.

The impact on the other particle emission should be confirmed for changing INC model.

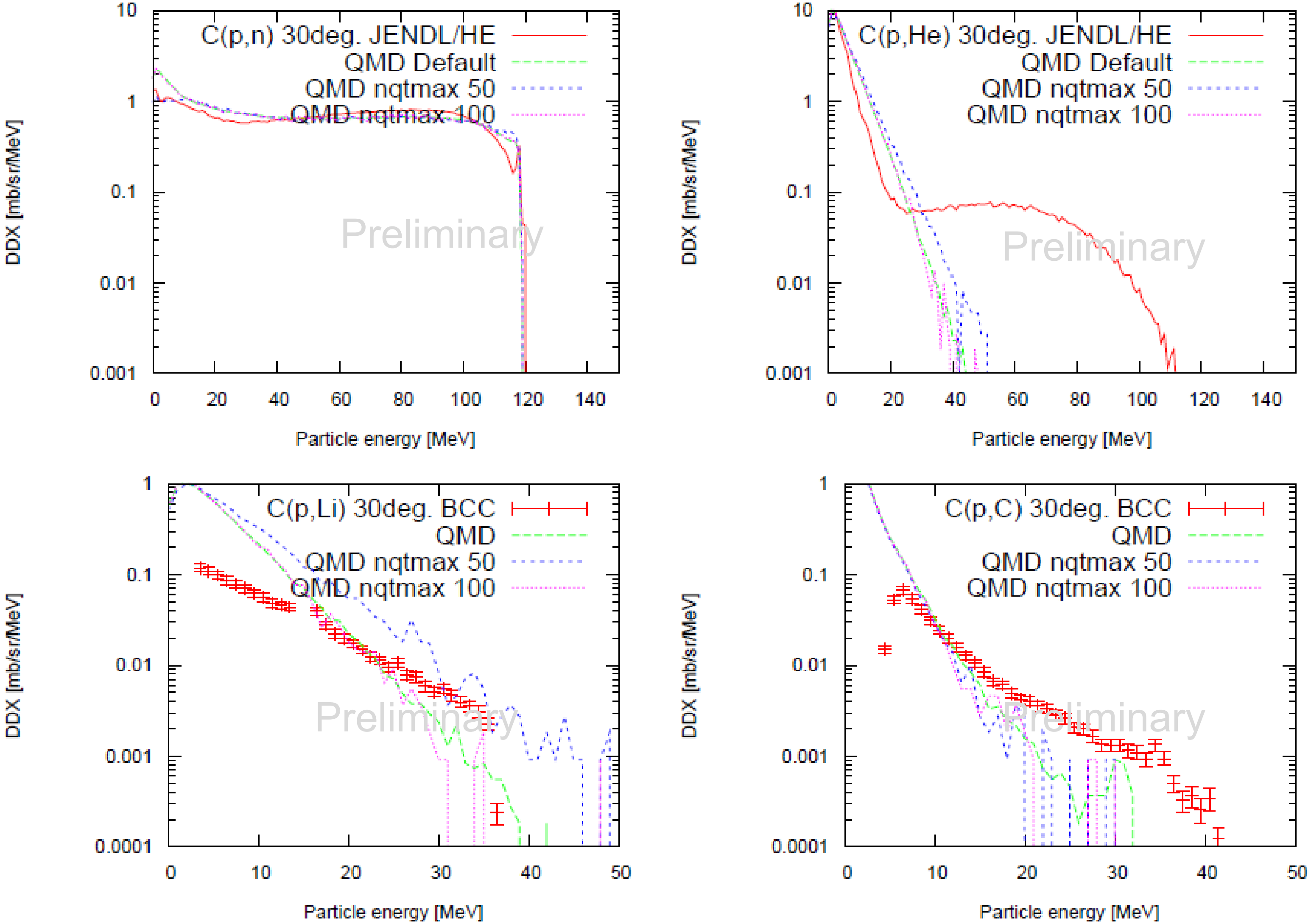
Which INC model is best at this moment?



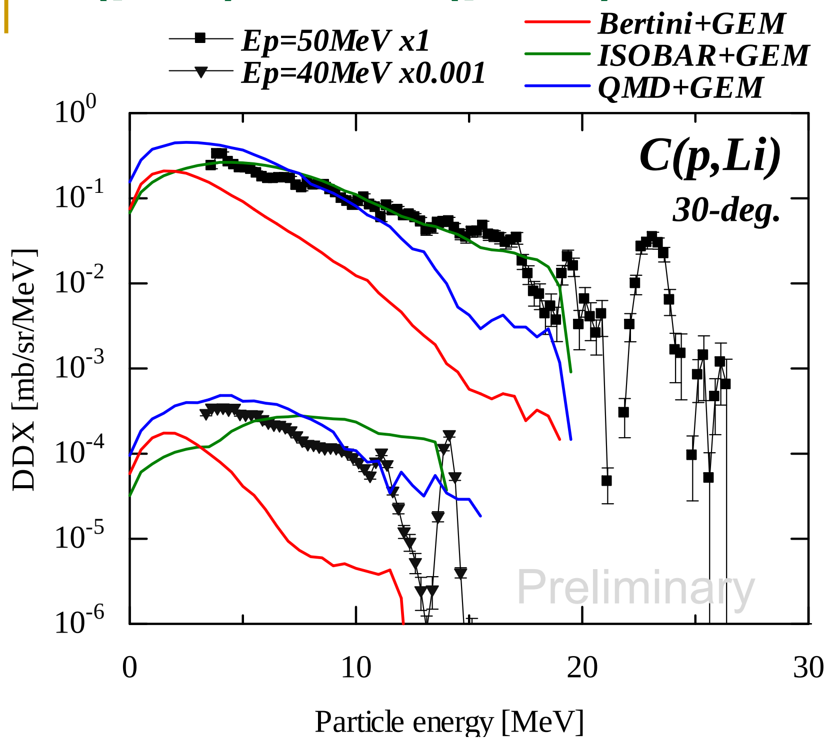
Which INC model is best at this moment?

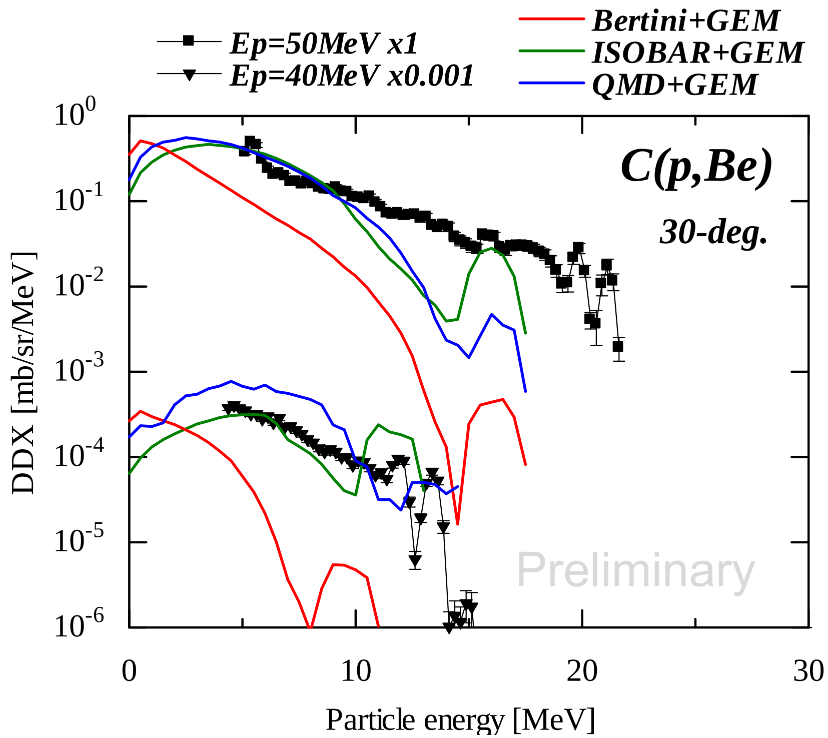


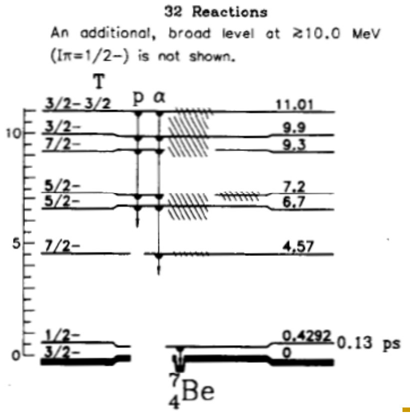
Result –C(p,C) Ep=140MeV, nqtmax

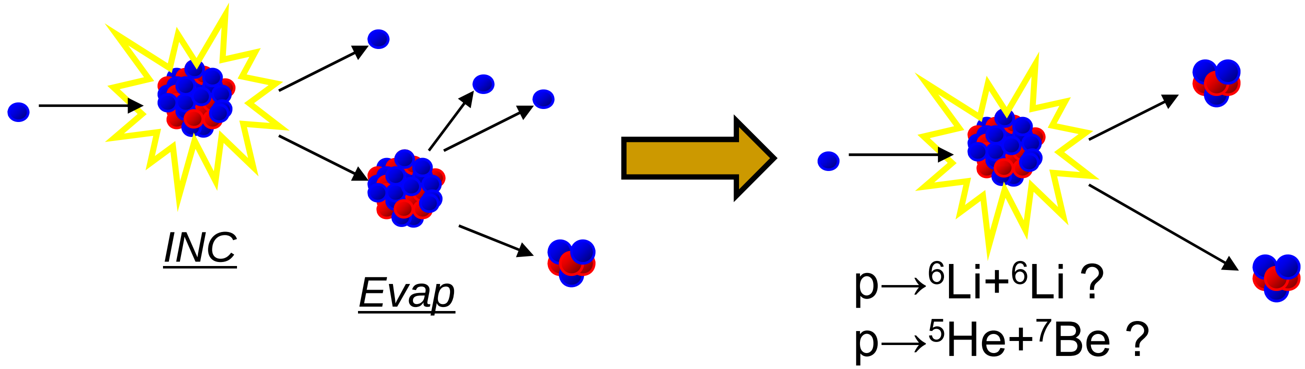


C(p,Li) and C(p,Be)

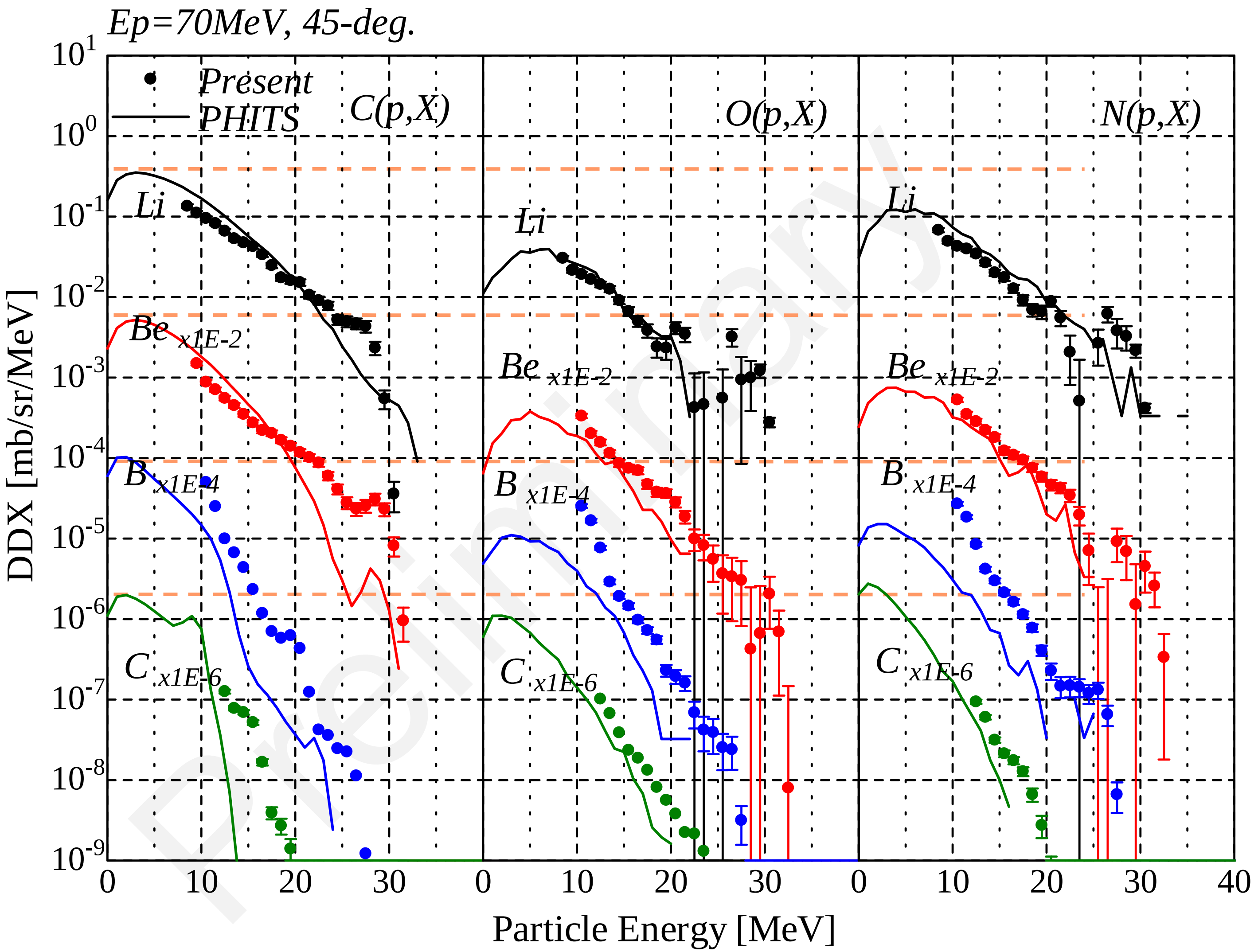








Result – Nitrogen and Oxygen



Conclusion

•Experimental results by Bragg Curve Counter:

Ep=40,50,70,80, 140,200,300 MeV , C,N,O,Al,Si, Ti Cu

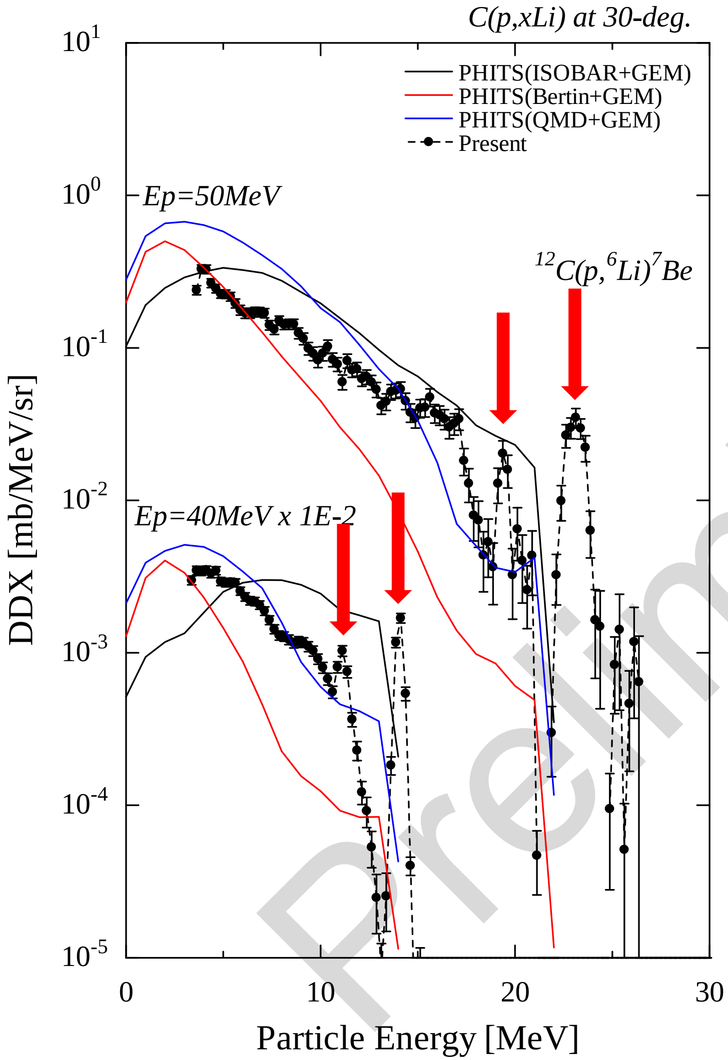
at 30,45,60,90,120,135 deg.

- Data with low threshold energy are available
- BCC data are consistent with SSD results
- The calculation models
  generally reproduce experimental results
  except for two body reaction and high energy component.
- The comparison indicates importance of
  a new model for intermediate energy region

Thank you for attention!

This program is supported by members from universities and institutes

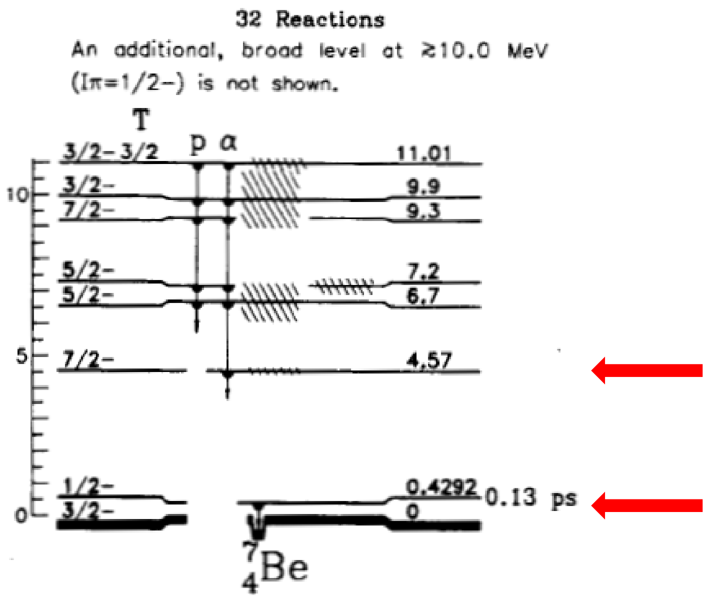
Result – Peaks of two body reaction



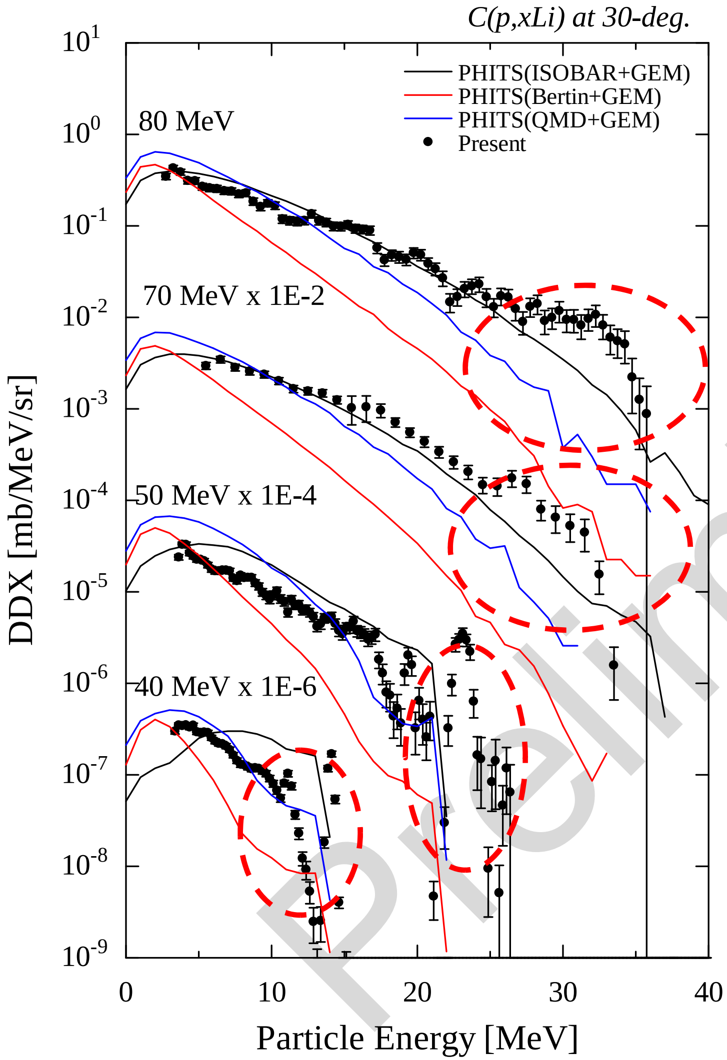
Fragments from two body reaction can be observed for 40 and 50 MeV.

→ difficult to reproduce using simple INC model.

→ consider cluster structure of ^{12}C



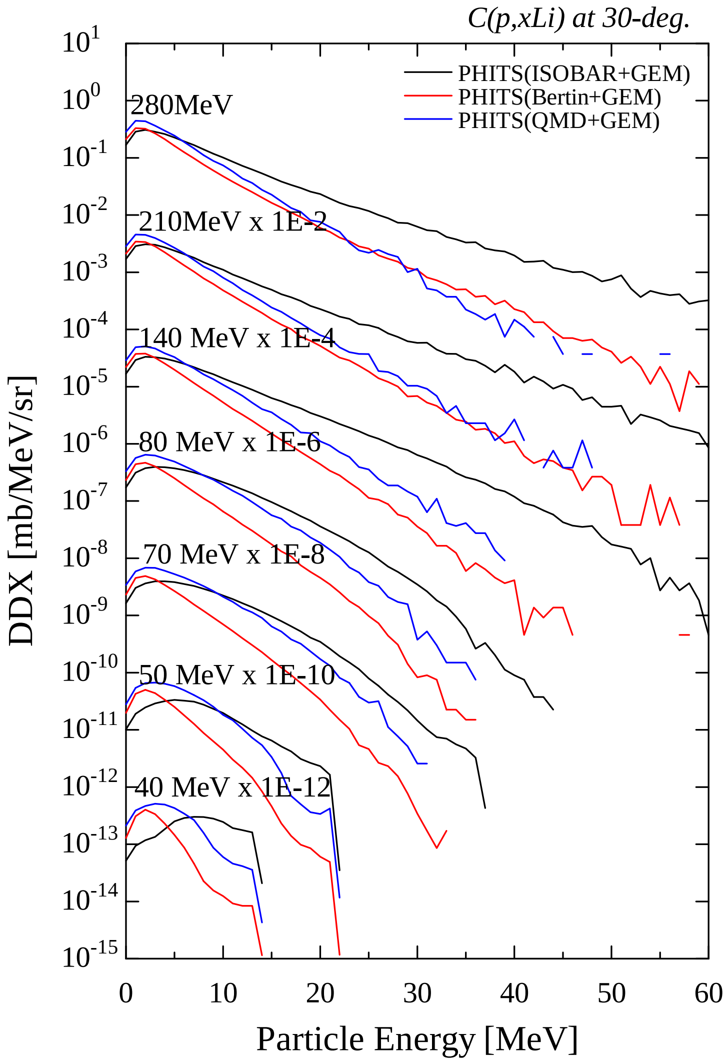
Result– Energy dependence



The difference between experimental data and calculation results for high energy part tends to increase with increasing incident proton energy and decreasing emission angle.

The data indicate importance of experimental data above 100 MeV incident energy to depict an appropriate model of fragment emission.

Result – Calculation results



The results of calculation depend on INC model, <u>however INC dose not generate Li</u>.

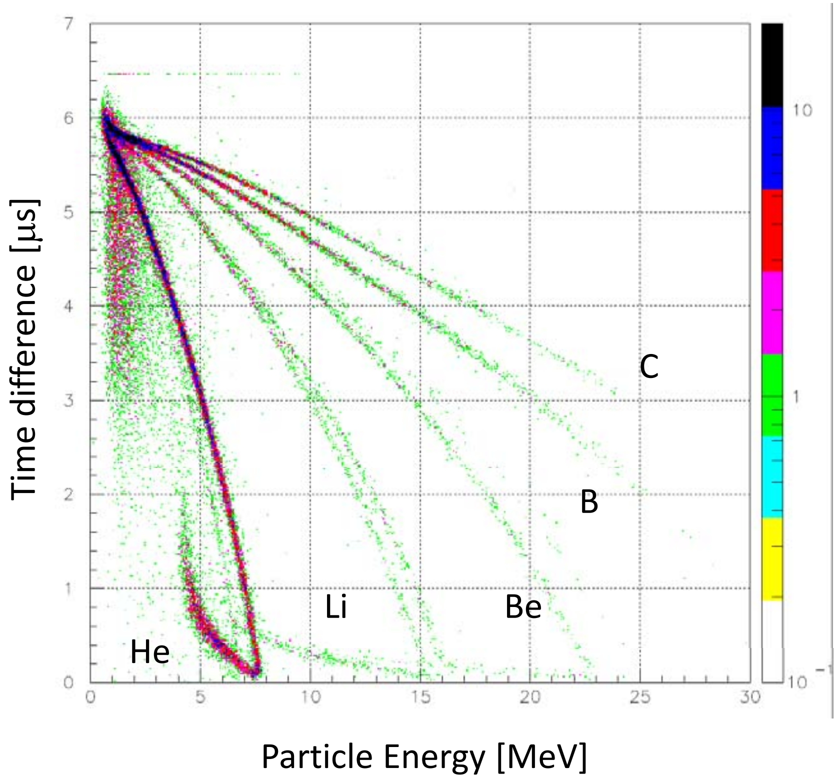
The fact could be explained that <u>available energy for evaporation stage depends on the energy waste in INC stage.</u>

When the INC wastes too much energy, <u>evaporation stage has shortage of excitation energy and nucleons</u> to produce fragment.

It becomes important for low incident energy.

Time difference vs Energy

Ep = 80MeV, C(p,x) at 30-deg.



Low energy unseparated events have energy lower than the energy of Bragg peak.

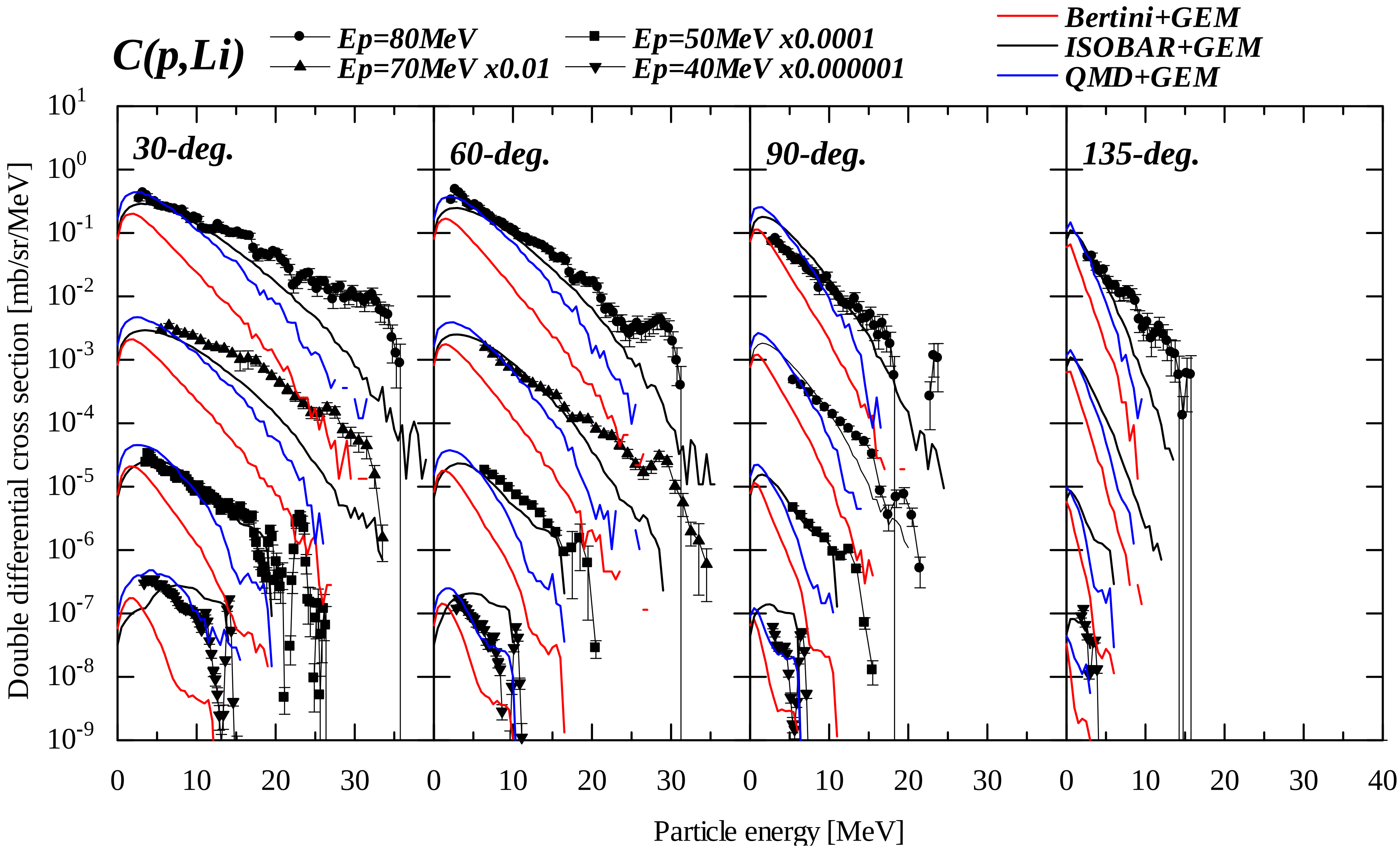
The time difference, which is obtained from timings of cathode and anode signal, correlates well with fragment range.

The events can be identified using the plot for time difference vs energy.

Detail →
T.Sanami, M.Hagiwara, T.Oishi, M.Baba, and M.Takada, *Nucl. Instrm. Meth*. A Vol 589/2 pp 193-201 (2008)

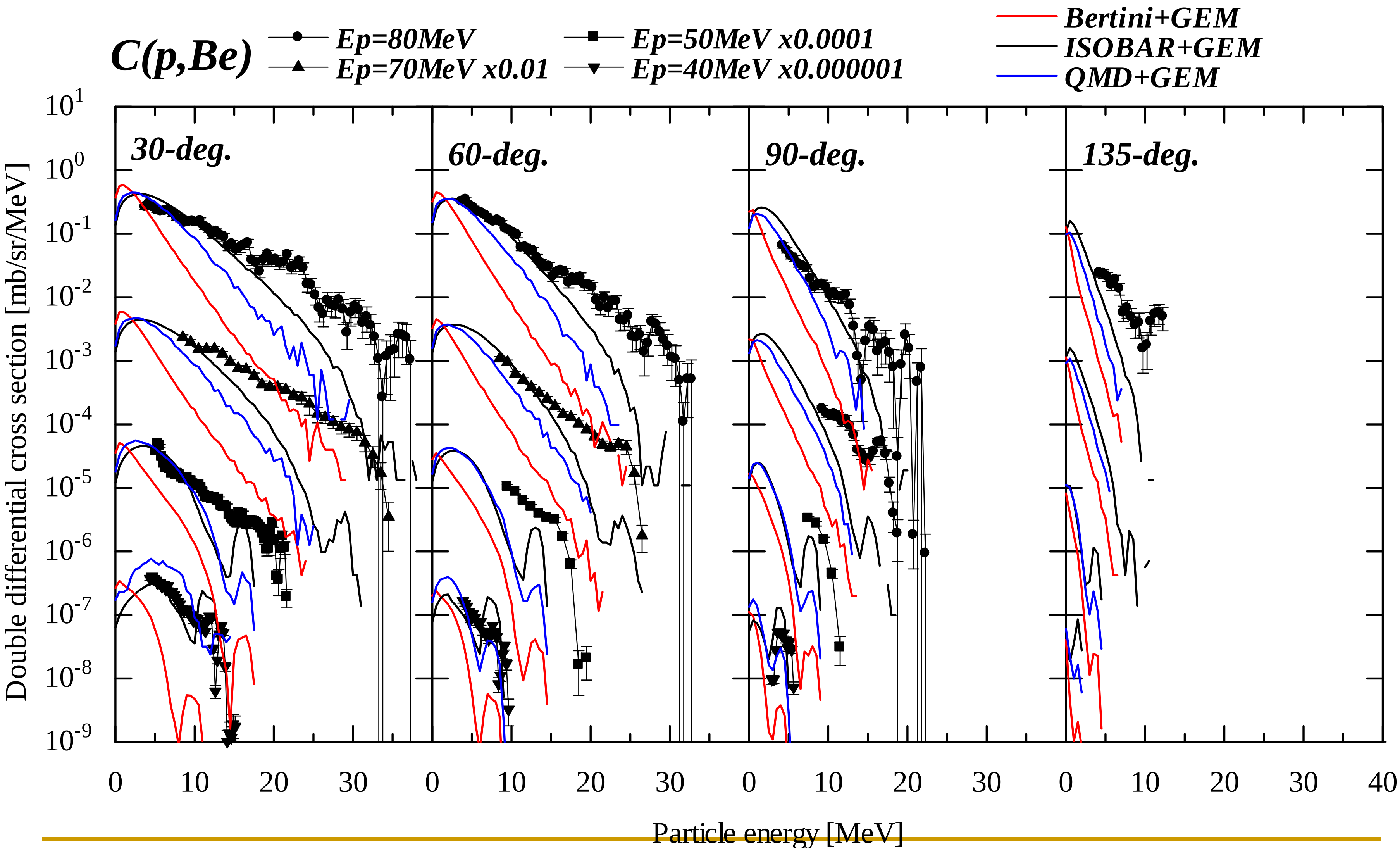
Energy spectra are normalized by number of sample atoms, number of incident protons, and, solid angle to deduce DDXs.

C(p,xLi)



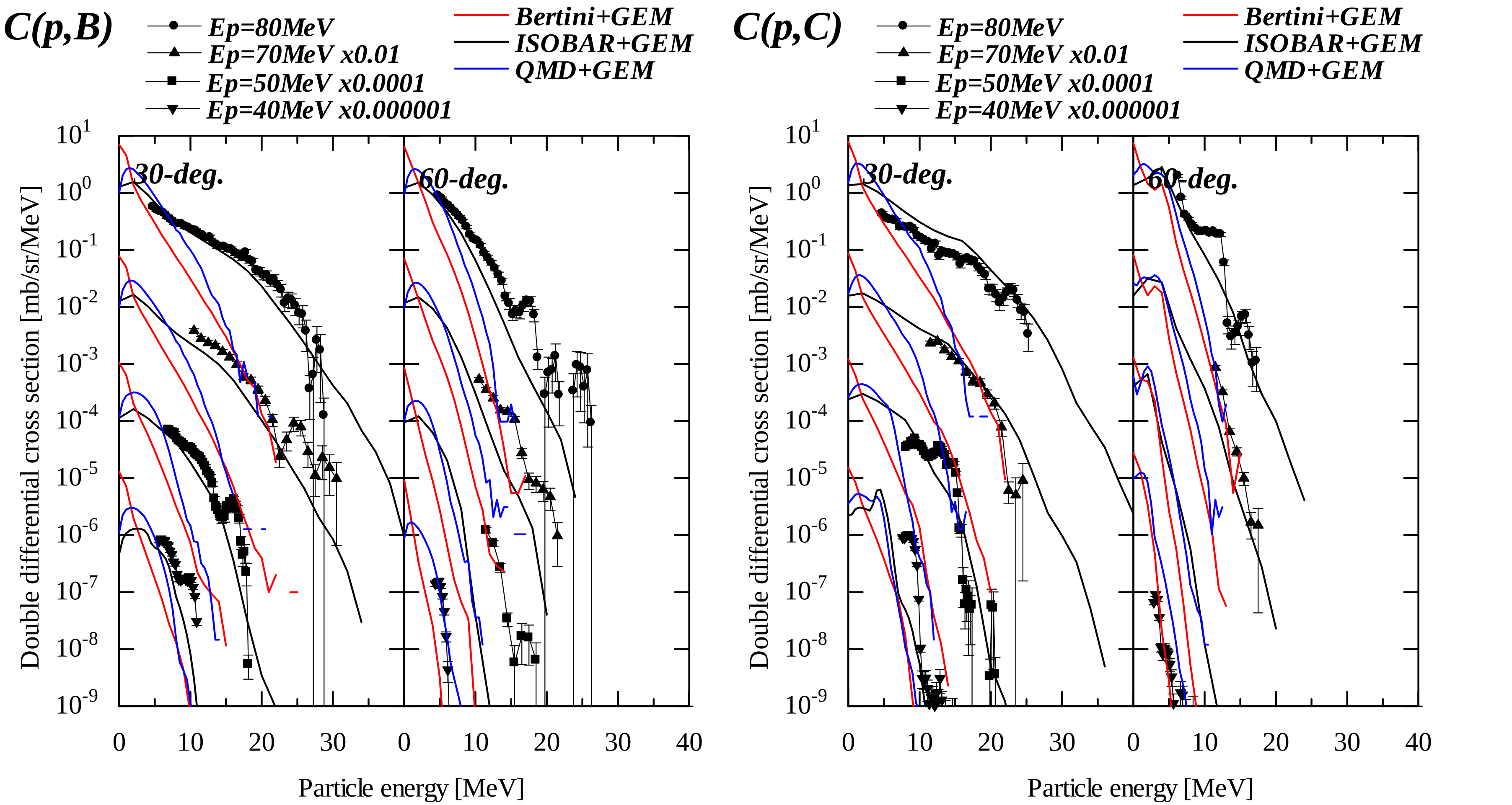
C(p,Li)
Ep=80MeV
Ep=70MeV x0.01
Ep=50MeV x0.0001
Ep=40MeV x0.000001
Bertini+GEM
ISOBAR+GEM
QMD+GEM
30-deg.
60-deg.
90-deg.
135-deg.
Double differential cross section [mb/sr/MeV]
Particle energy [MeV]

C(p,xBe)

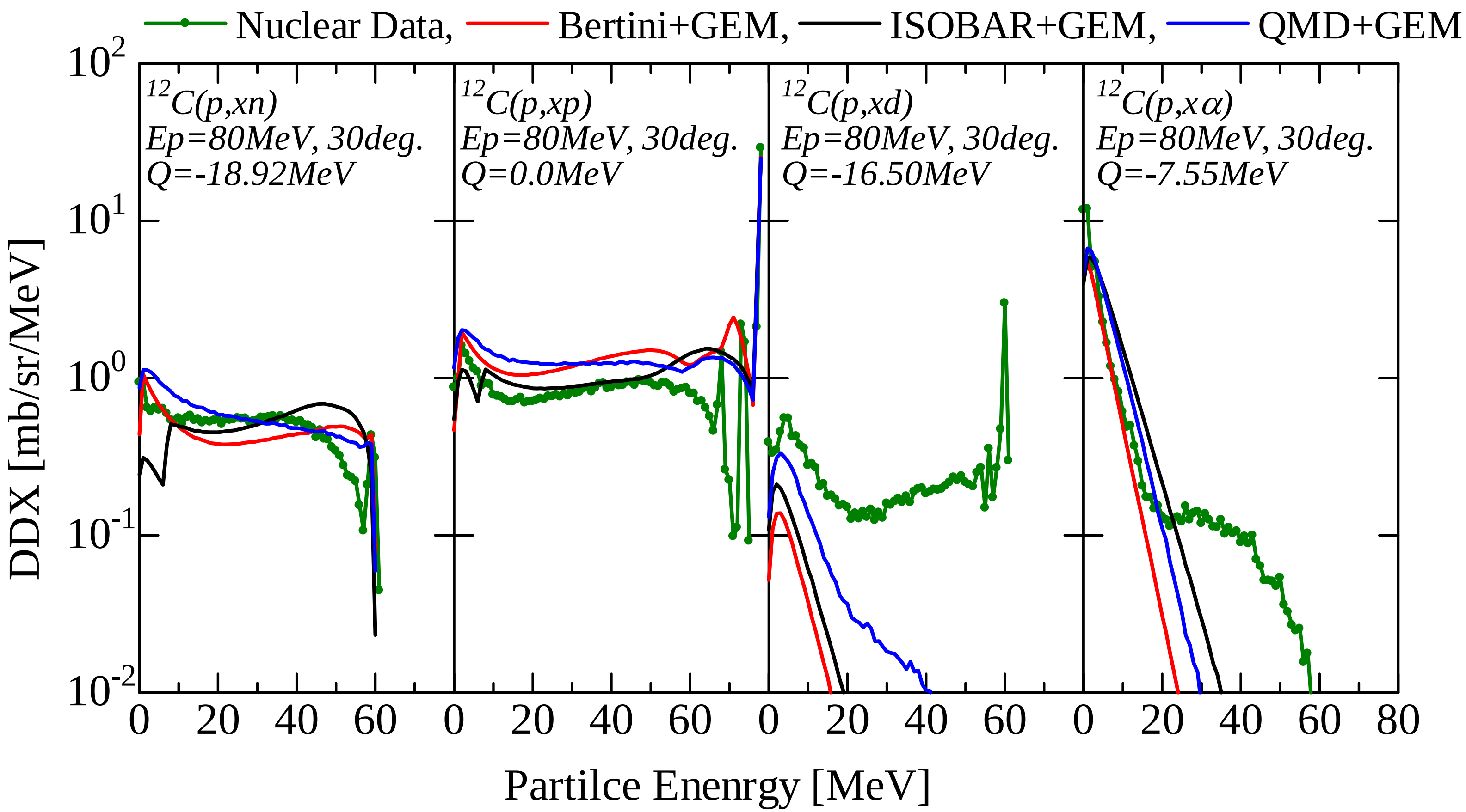


C(p,Be)
Ep=80MeV
Ep=70MeV x0.01
Ep=50MeV x0.0001
Ep=40MeV x0.000001
Bertini+GEM
ISOBAR+GEM
QMD+GEM
30-deg.
60-deg.
90-deg.
135-deg.
Double differential cross section [mb/sr/MeV]
Particle energy [MeV]

C(p,xB), C(p,xC)

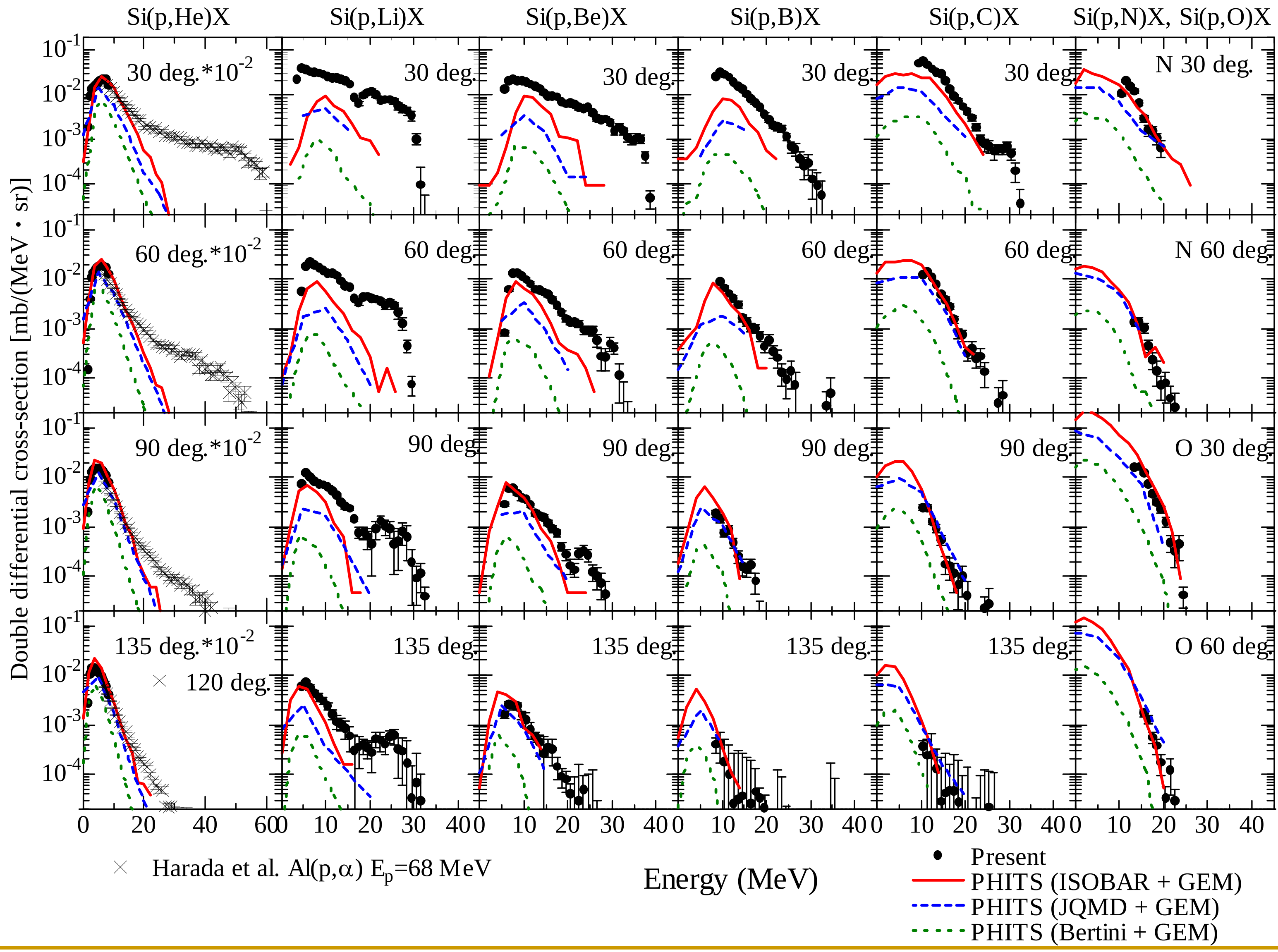

C(p,B)
Ep=80MeV
Ep=70MeV x0.01
Ep=50MeV x0.0001
Ep=40MeV x0.000001
Bertini+GEM
ISOBAR+GEM
QMD+GEM
30-deg.
60-deg.
Double differential cross section [mb/sr/MeV]
Particle energy [MeV]
C(p,C)
Ep=80MeV
Ep=70MeV x0.01
Ep=50MeV x0.0001
Ep=40MeV x0.000001
Bertini+GEM
ISOBAR+GEM
QMD+GEM
30-deg.
60-deg.
Double differential cross section [mb/sr/MeV]
Particle energy [MeV]

How much impact on the other particle emission?



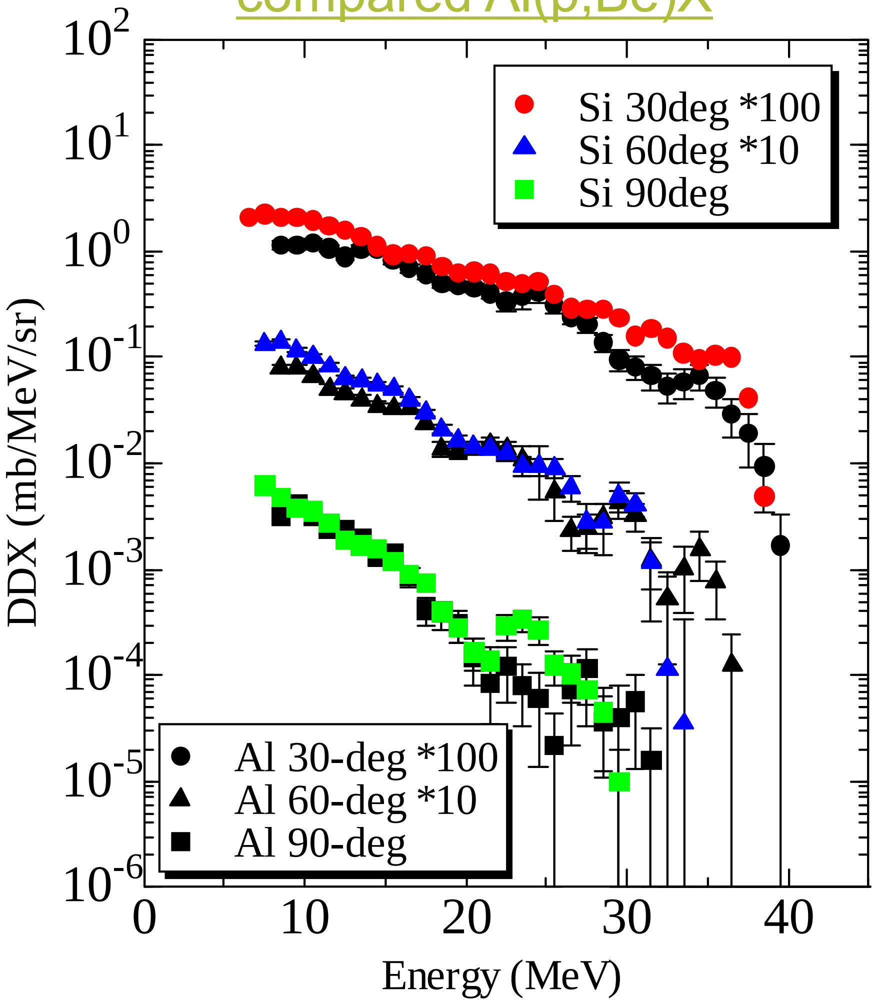
Impact on light nucleon emission is small in comparison with difference between nuclear data and calculation.

Si(p,x)

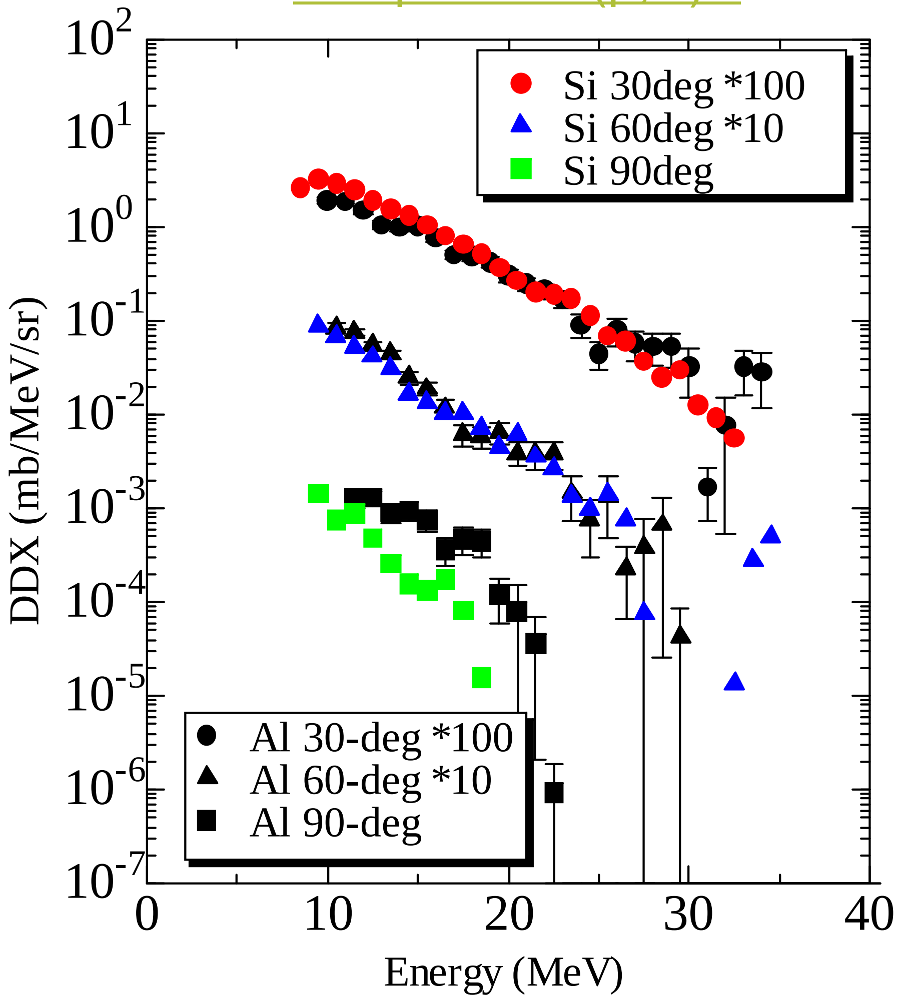

Si(p,He)X
Si(p,Li)X
Si(p,Be)X
Si(p,B)X
Si(p,C)X
Si(p,N)X, Si(p,O)X
30 deg.*10^-2
60 deg.*10^-2
90 deg.*10^-2
135 deg.*10^-2
120 deg.
30 deg.
60 deg.
90 deg.
135 deg.
N 30 deg.
N 60 deg.
O 30 deg.
O 60 deg.
Double differential cross-section [mb/(MeV · sr)]
Energy (MeV)
Harada et al. Al(p,α) Ep=68 MeV
Present
PHITS (ISOBAR + GEM)
PHITS (JQMD + GEM)
PHITS (Bertini + GEM)

Si(p,x) vs Al(p,x)

Si(p,Be)X reaction compared Al(p,Be)X

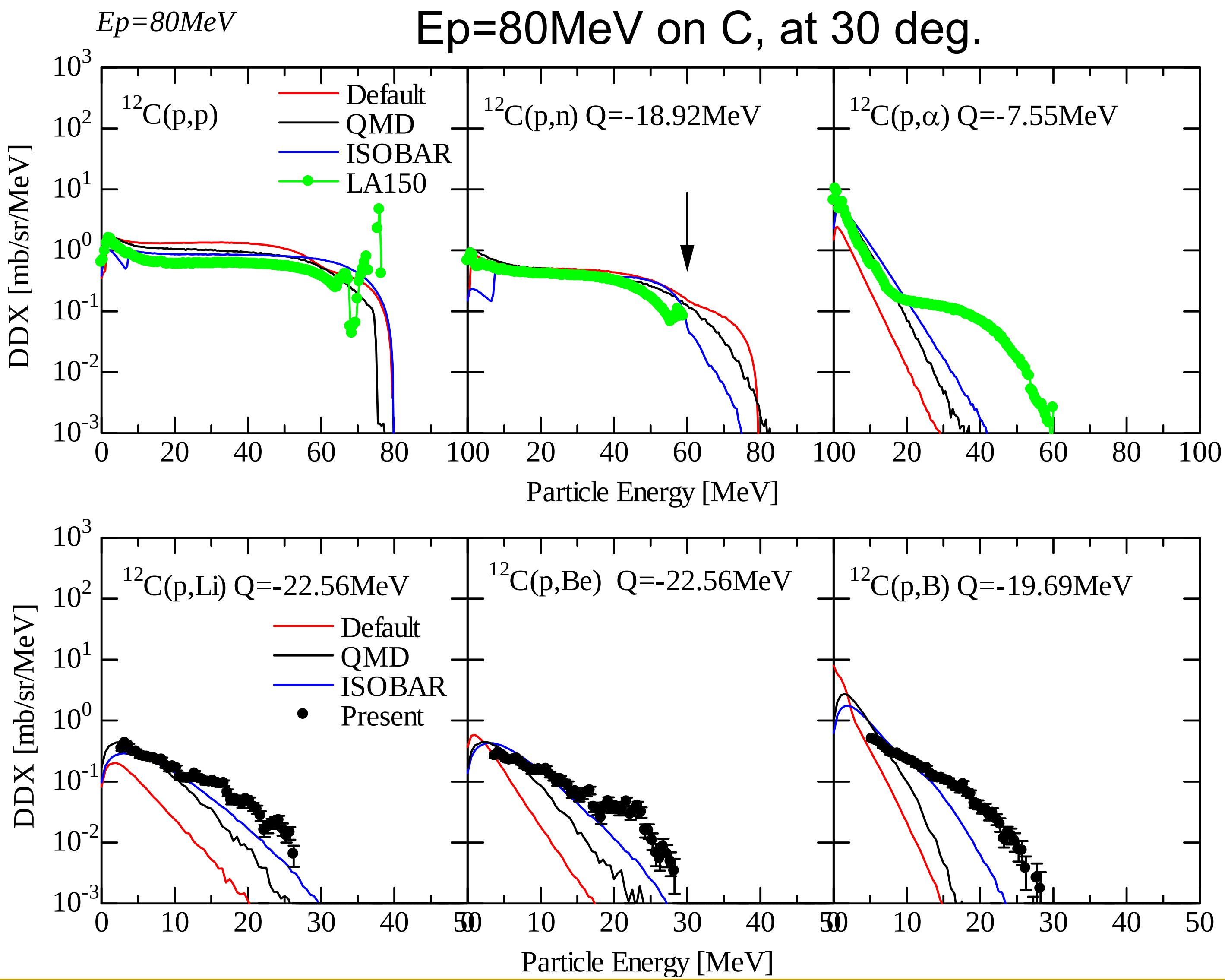


Si(p,B)X reaction compared Al(p,B)X

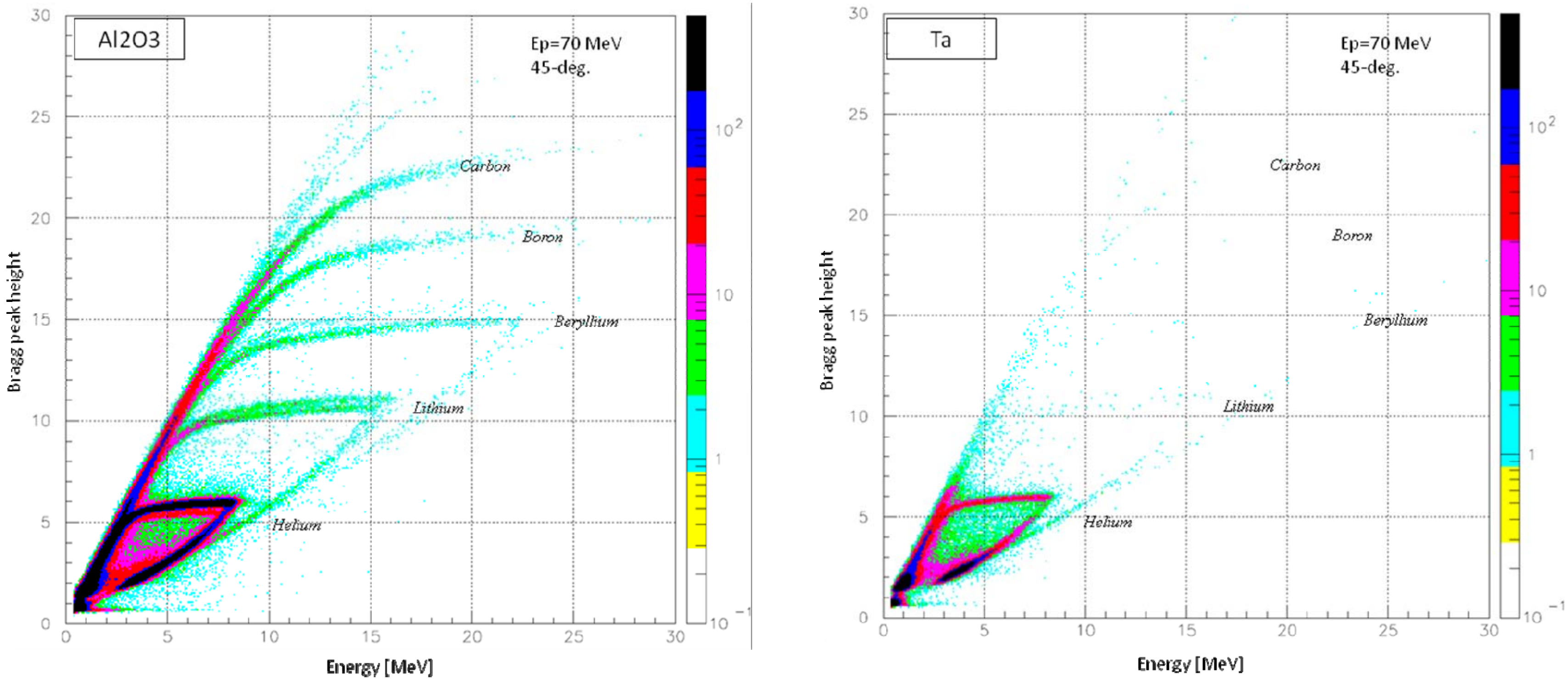


How much impact on nucleon emission?

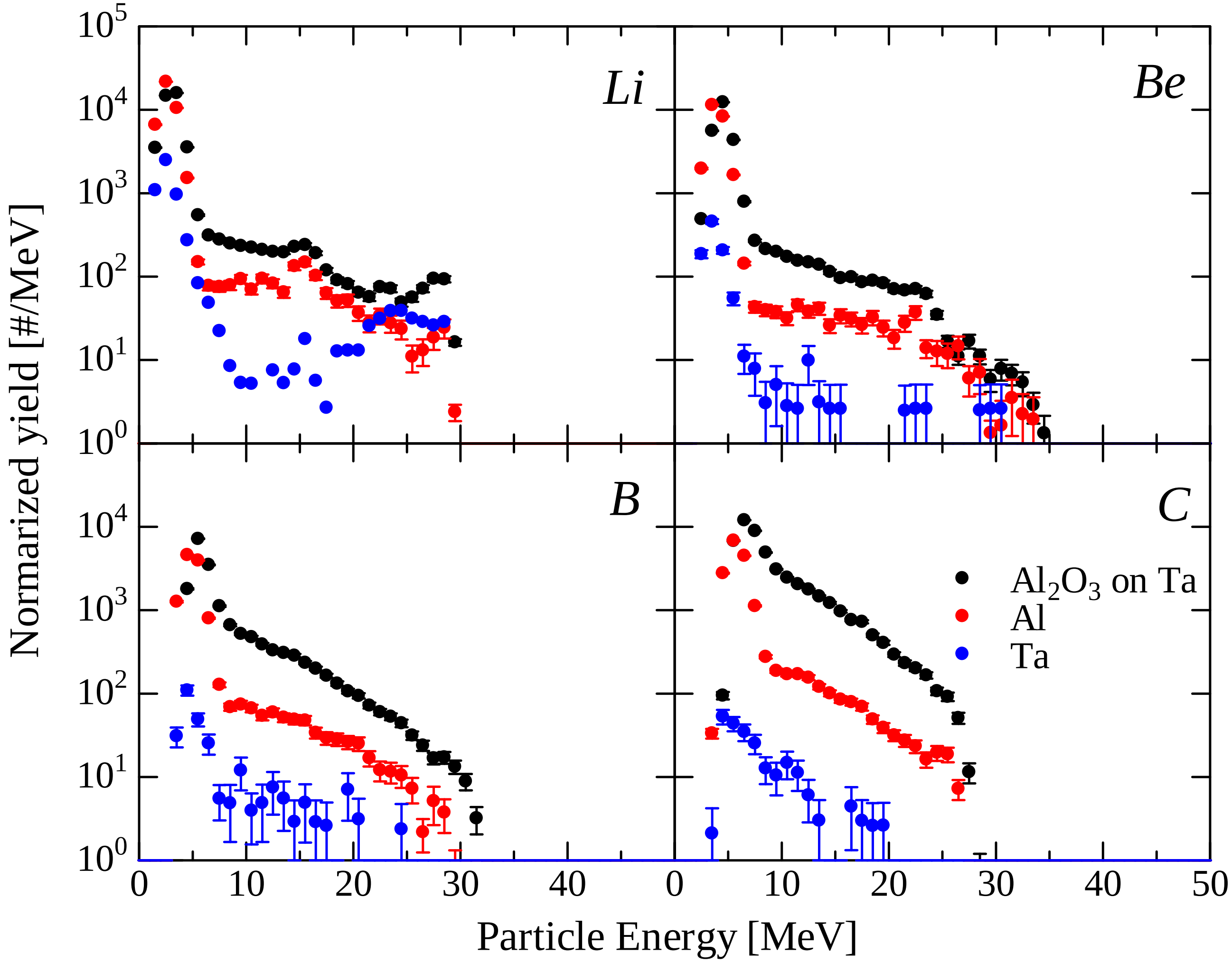
Ep=80MeV on C, at 30 deg.



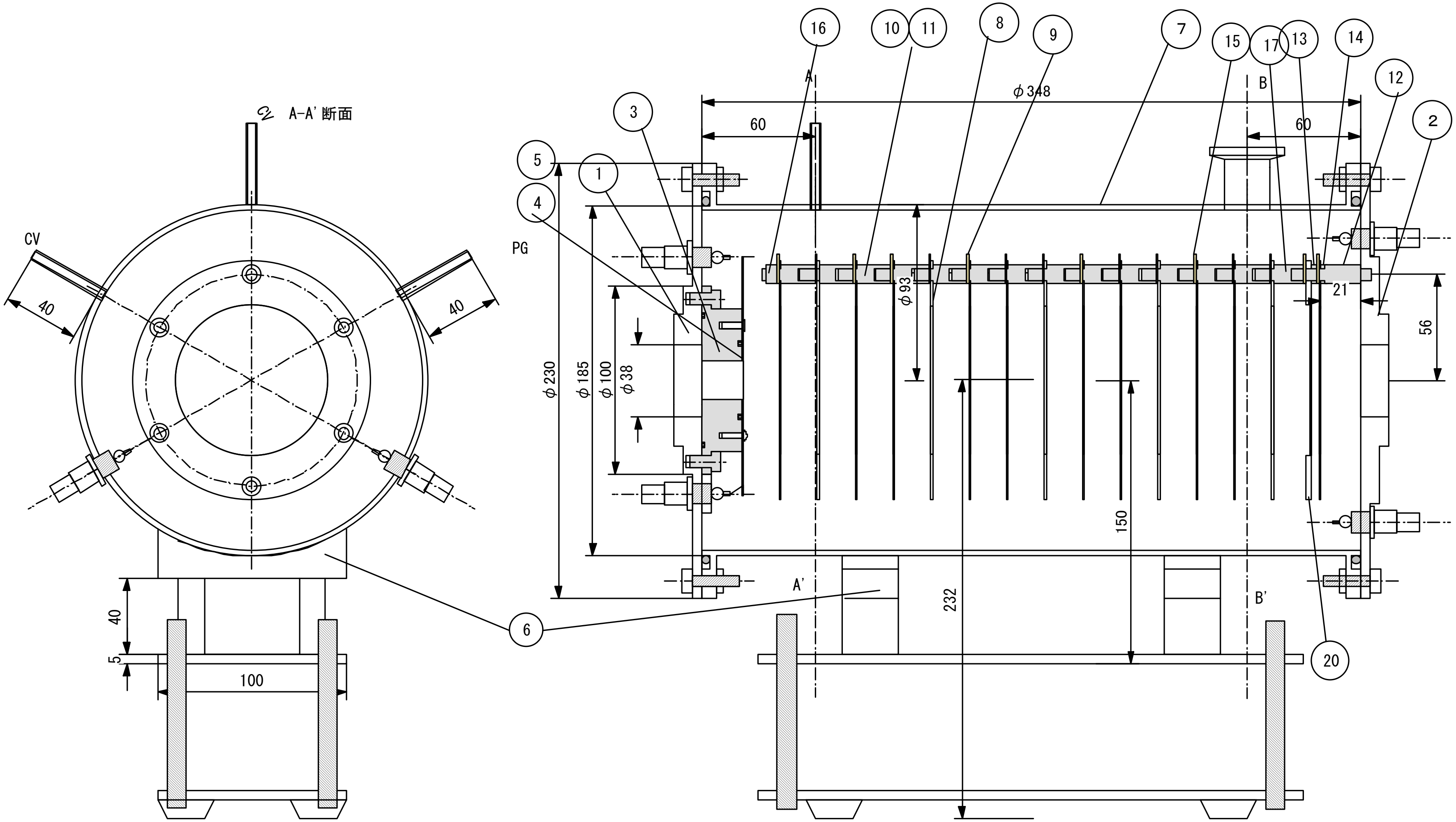
Subtraction of Al and Ta contribution



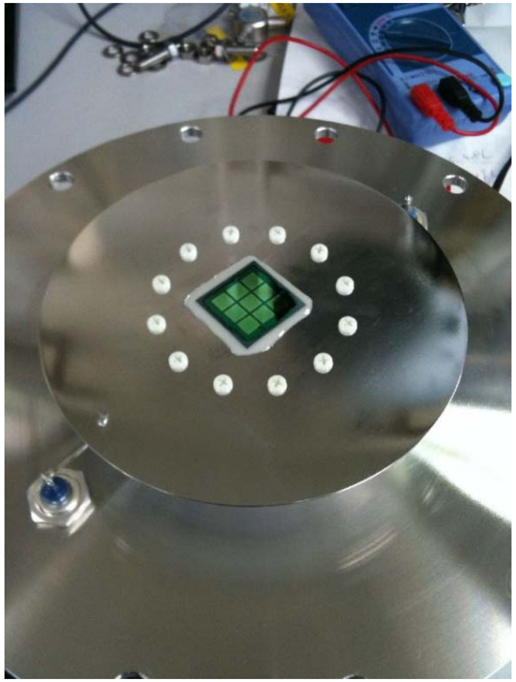
Subtraction of Al and Ta contribution

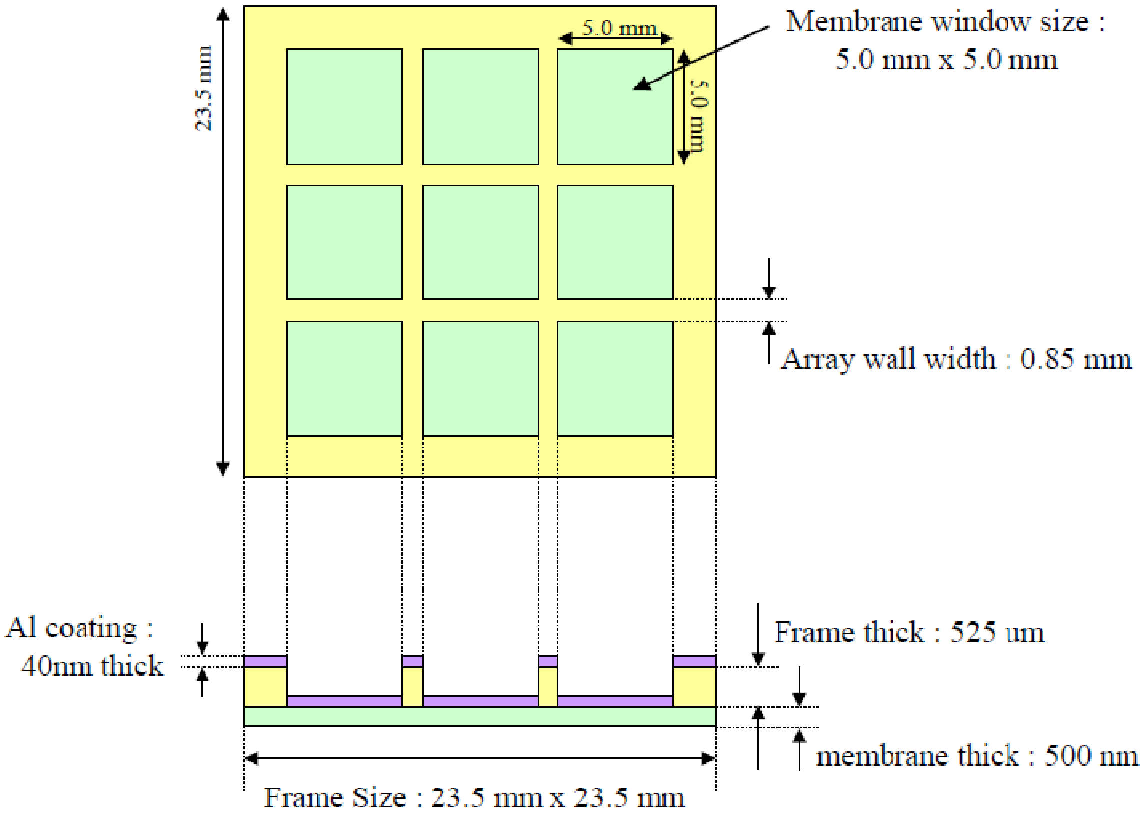


BCC structure



Entrance window





Range correlates time difference