北京航空航天大學
BEIHANG UNIVERSITY

Charge-changing reaction study via the cross section measurements of ^{18}O on carbon and lead at around 370 MeV/nucleon

Reporter: Jin-Rong Liu

Supervisor: Bao-Hua Sun   Jian-Wei Zhao

The 29th International Nuclear Physics Conference

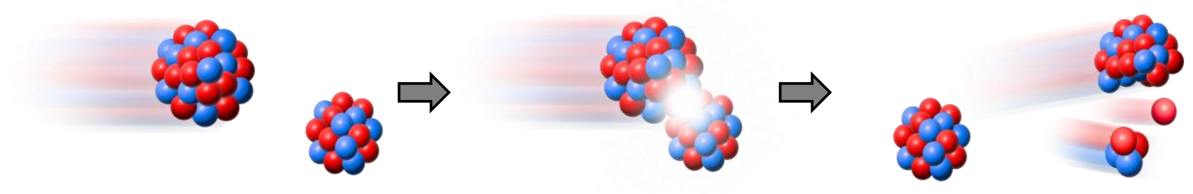
May26, 2025 DCC, Daejeon, Korea

北京航空航天大学
BEIHANG UNIVERSITY

contents

德才兼备 知行合一

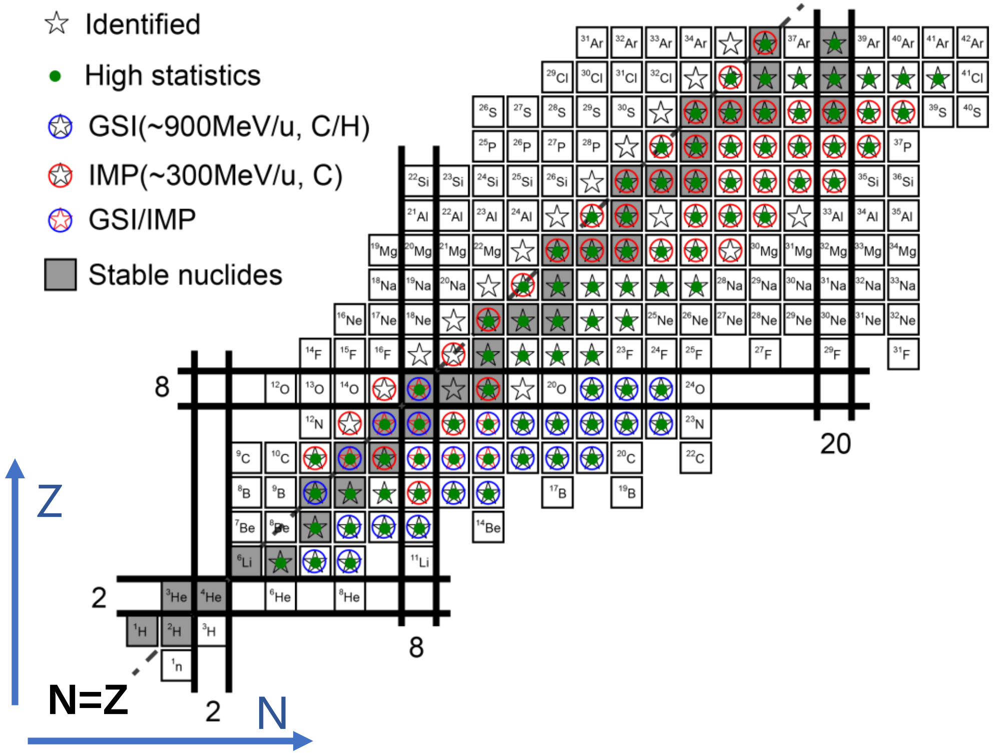
Charge changing cross section



- **Charge changing cross section (CCCS) :**

The total probability of removing at least one proton from the projectile nucleus in the collision with the target nucleus.

- **To extract charge radii**
- **Studying nuclear reaction mechanism**
- **Studying mirror nuclei/nuclear matter**

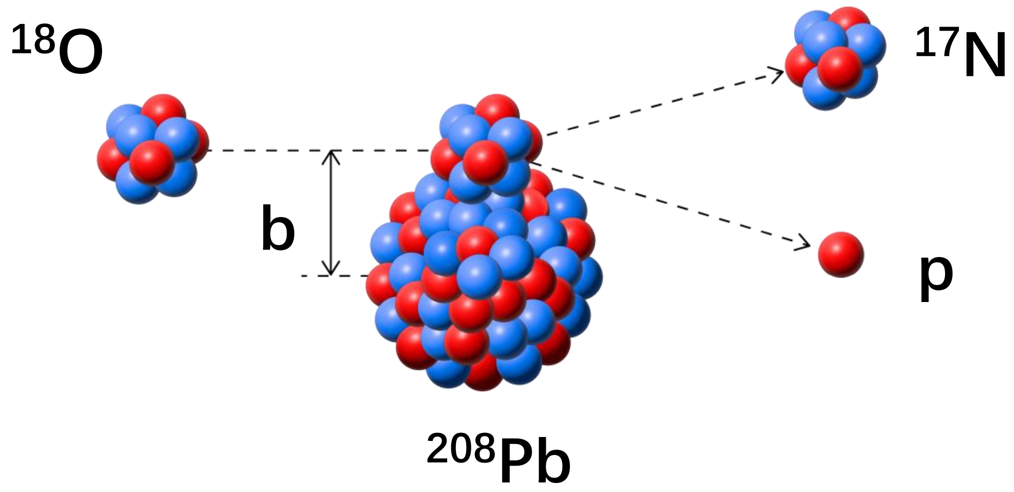


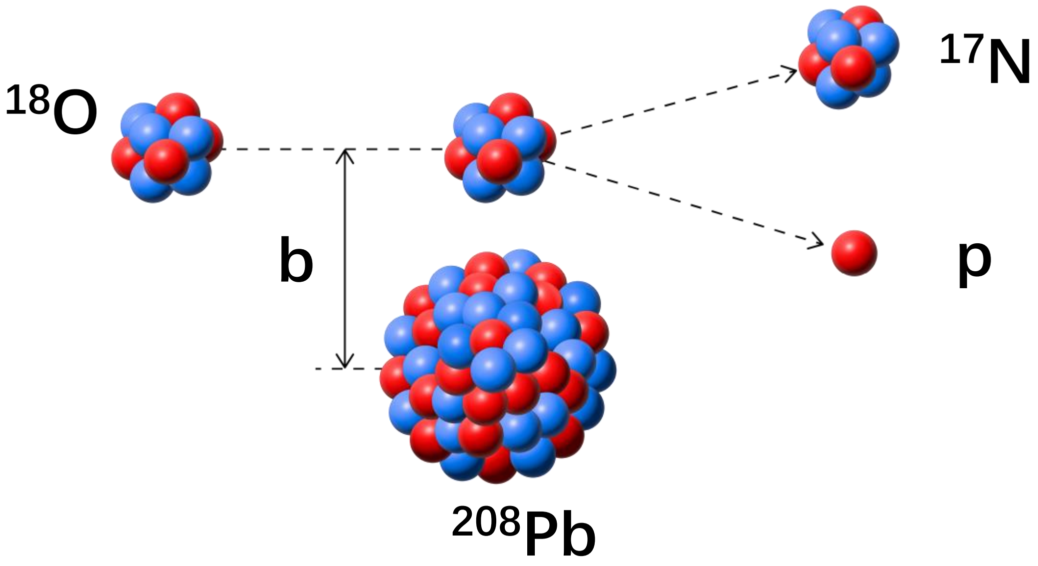
High precision CCCS measurements

- **Facilities: HIRFL/GSI/RIKEN/RCNP**
- **Nuclear region: p and sd shell**
- **Target: H/C target**
- **Energy: <1GeV/nucleon**

Nuclear and EM dissociation in CCCS

北京航空航天大學 BEIHANG UNIVERSITY





Nuclear dissociation

- ☐ Direct charged removal
- ☐ Charged particle evaporation (CPE)

on C target : 5-20%

on H target : 20-50%

J.W. Zhao, B.H.Sun and I. Tanihata *et al.*, PLB 847 (2023) 138269.

J. C. Zhang, B.H.Sun and I. Tanihata, *et al.*, .Sci. Bull. 69 (2024) 1647-1652.

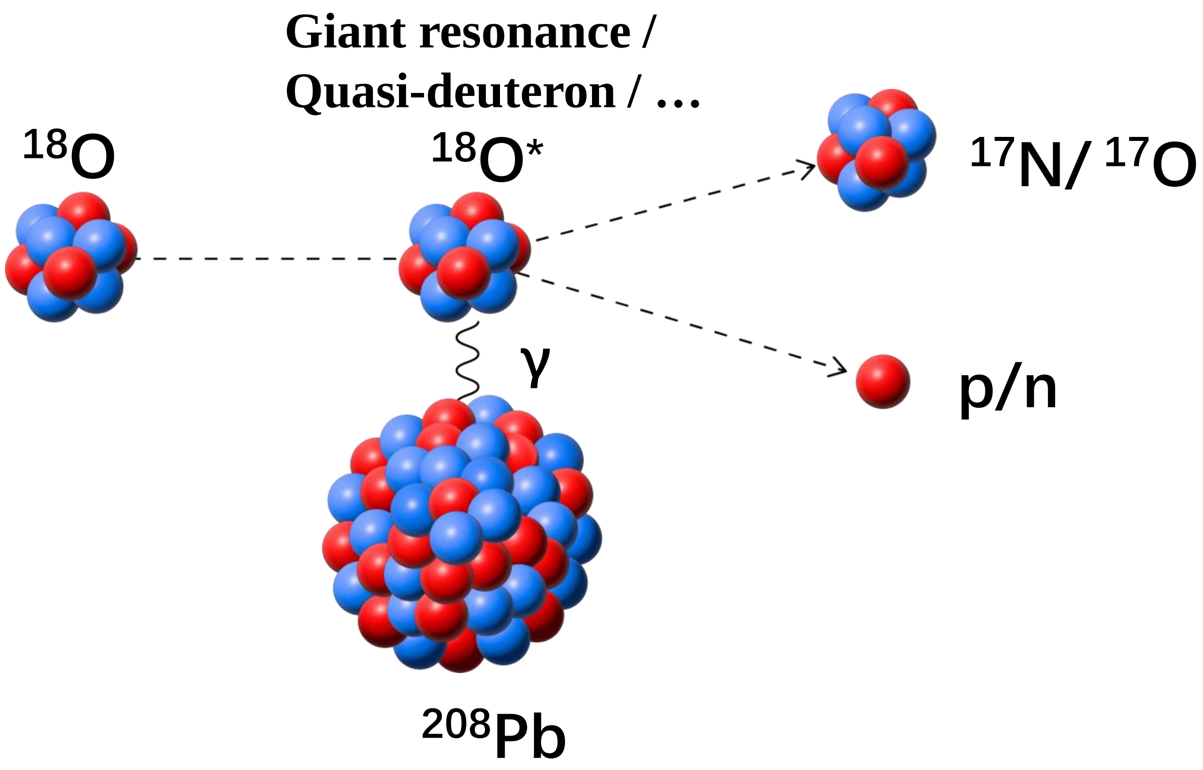
M. Tanaka, M. Takechi and A. Homma et al., Phys. Rev. C 106 (2022) 014617.

Electromagnetic dissociation

On heavy target : considered or not?

Electromagnetic dissociation (EMD) process

Weizsacker-William (WW) approximation



- **Virtual photons of target：**

$$N_{\pi l}(\omega) = Z_1^2 \alpha \frac{l[(2l+1)!!]^2}{(2\pi)^3 (l+1)} \sum_m |G_{\pi l m}(\frac{c}{v})|^2 g_m(\xi), \xi = \frac{\omega R}{\gamma v}$$

$$N_{E1}(\omega) = \frac{2}{\pi} Z_1^2 \alpha (\frac{c}{v})^2 [\xi K_0 K_1 - \frac{v^2 \xi^2}{2c^2}(K_1^2 - K_0^2), \omega = \frac{E_\gamma}{\hbar}$$

$$N_{M1}(\omega) = \frac{2}{\pi} Z_1^2 \alpha [\xi K_0 K_1 - \frac{\xi^2}{2}(K_1^2 - K_0^2)] \ldots$$

- **Photonuclear cross section of projectile:**

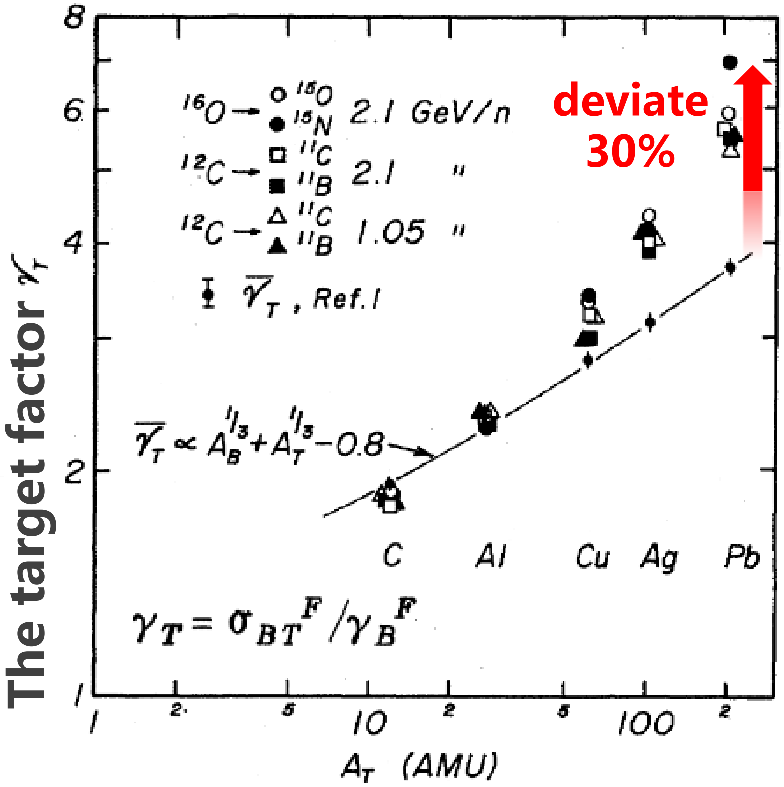
(γ, p)/(γ, n)/(γ, abs)…

- **EMD cross section of projectile:**

$$\boldsymbol{\sigma}_{\mathbf{cc}}^{\mathbf{EM}} = \int N(\mathrm{E}_\gamma)\, \sigma_\gamma(\mathrm{E}_\gamma)\, dE_\gamma$$

E. Fermi, Z. Phys. 29 (1924) 315.
C.F. Weizsacker, Z. Phys. 88 (1934) 612.
J.D. Jackson, Classical Electrodynamics (Wiley, New York, 1975).
C. A. Bertulani and G. Baur, Phys. Rep. 163 (1988) 299-408.

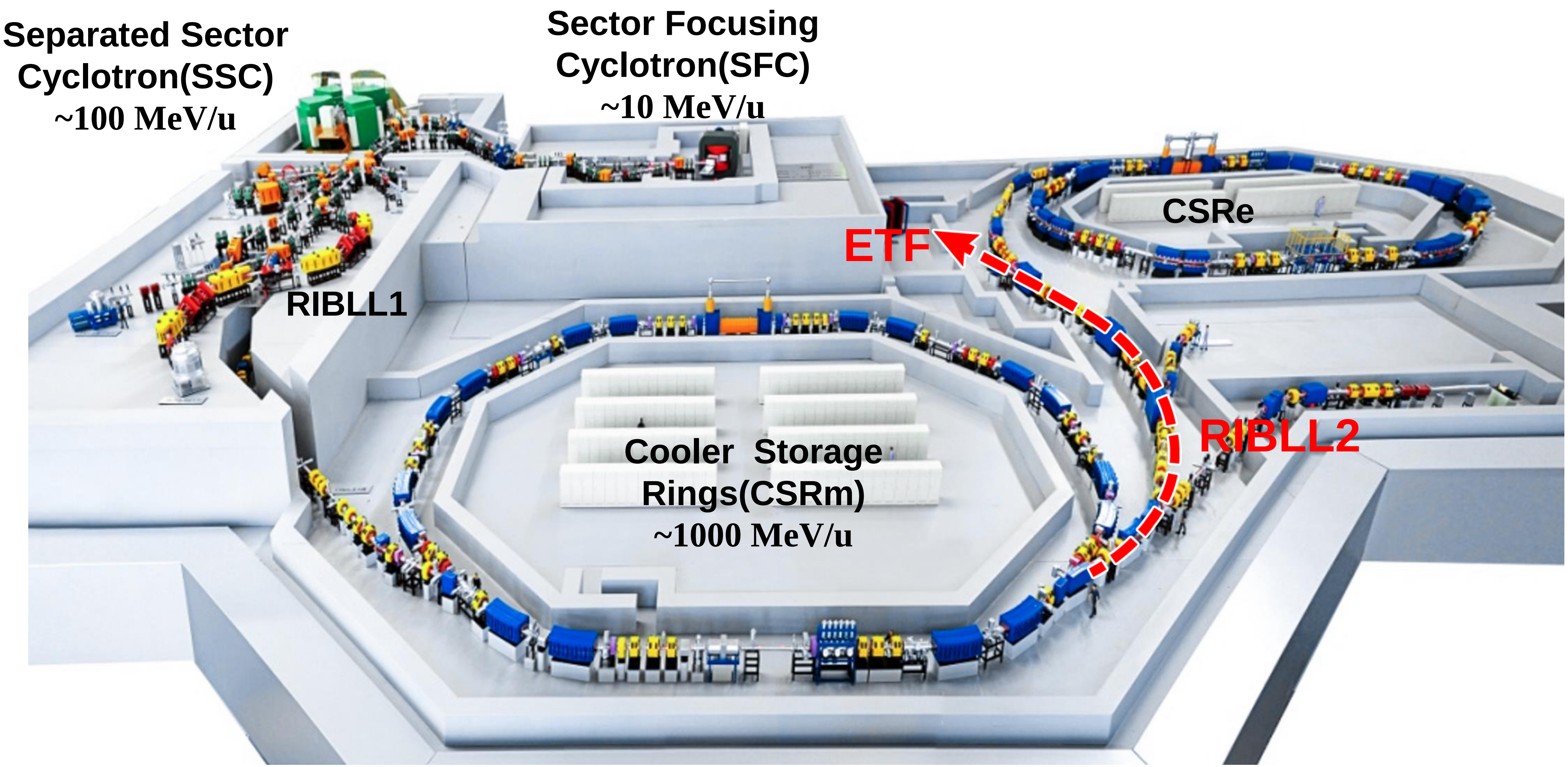
The development of EMD experiments



H. H. Heckman *et al.*, Phys. Rev. Lett. 37 (1976) 56-59.

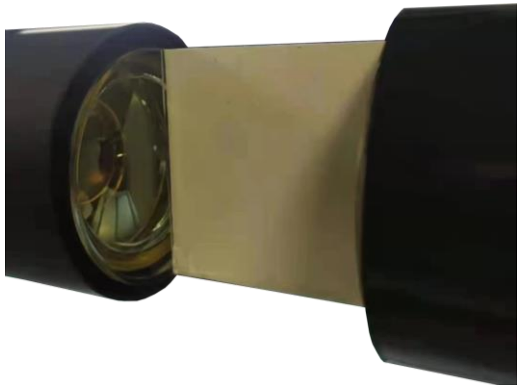
- As the **projectile/target mass number and incident energy increase**, EMD **becomes larger**.
- Significant deviations of γ_T from $\overline{\gamma_T}$, up to 30% on Pb target.
- These researches are above 1GeV/nucleon, while the EMD account for CCCSs **below 1GeV/nucleon** is **uncertain**!

Heavy Ion Research Facility at Lanzhou (HIRFL)



- ✓ Ions range: from hydrogen to uranium
- ✓ Beam energy: 2.8 GeV for protons, 1GeV/nucleon for heavy ions

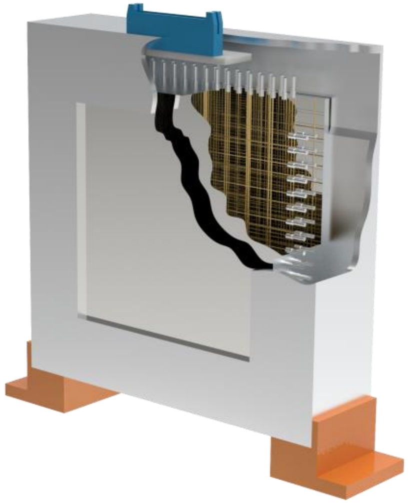
The RIBLL2 and the External Target Facility (ETF)



Plastic Scintillator

Silicon

Multi-Sample Ionization Chambers



Multi-Wire Drift Chamber

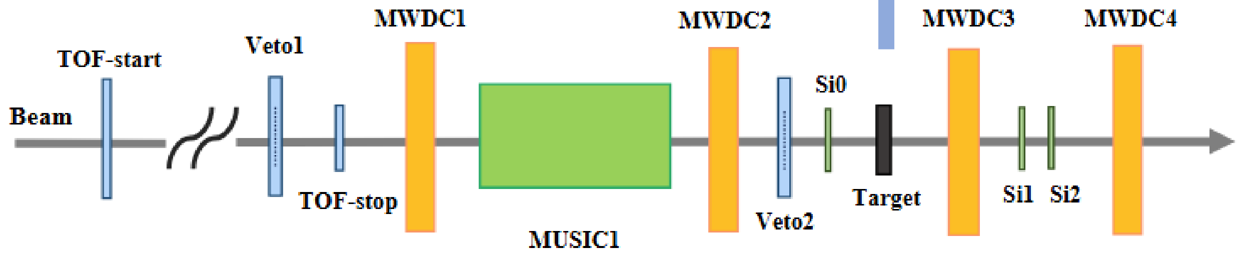
Experiment and Data analysis

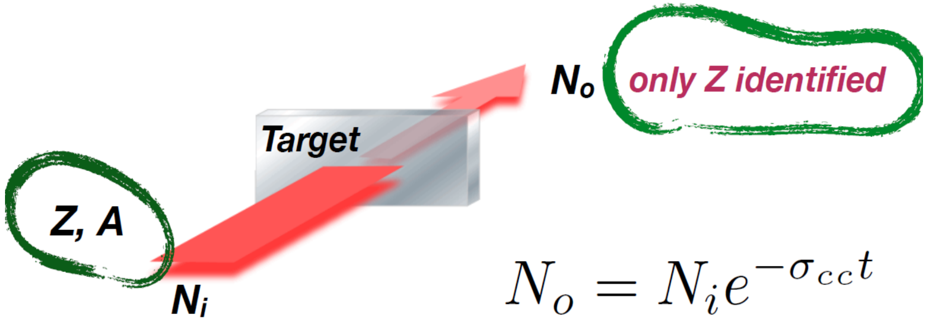
北京航空航天大學
BEIHANG UNIVERSITY

370 MeV/nucleon

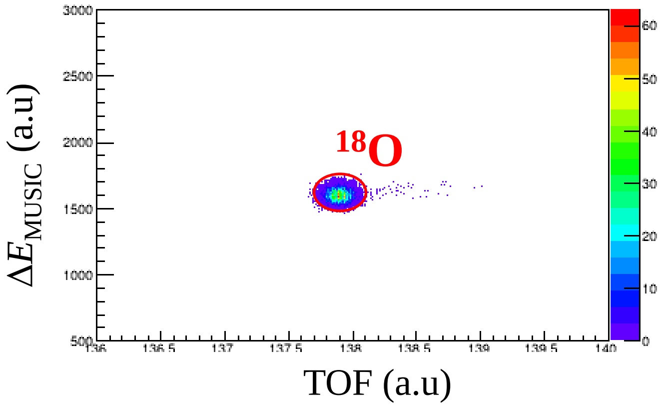
^{18}O primary beam

- 2.767 (2) g/cm^2 C target
- 3.797 (3) g/cm^2 Pb target

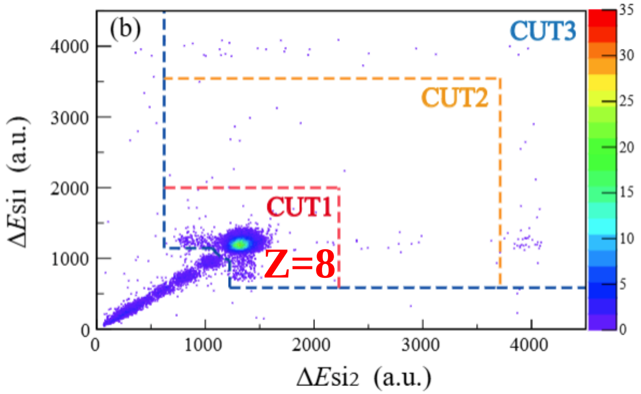




$$N_o = N_i e^{-\sigma_{cc} t}$$



Clear PID before target



Z identification after target

- **Incident particle :** $B\rho - TOF - \Delta E$
- **Outgoing particle :** ΔE

$$B\rho = \frac{\mathrm{mv}}{\mathrm{q}} \propto \frac{A}{Z}\beta \ , \quad \beta = \frac{L}{TOF \cdot c} \ , \quad \Delta E \propto \frac{Z^2}{\beta^2}$$

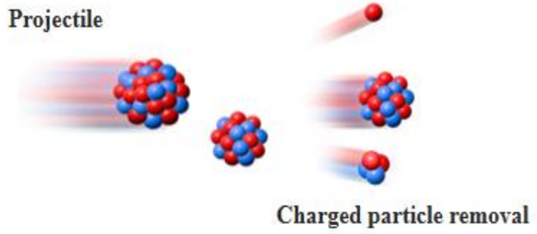
- **Transmission method:**

$$\sigma_{\mathrm{cc}}^{\mathrm{exp}} = \frac{1}{t}\ln\left(\frac{\gamma^0}{\gamma}\right) = \frac{1}{t}\ln\left(\frac{N_{out}^0/N_{in}^0}{N_{out}/N_{in}}\right)$$

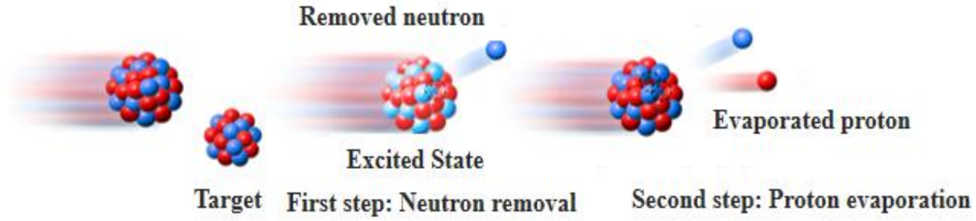
NN estimation

$$\sigma_{cc}^{exp} \approx \sigma_{cc}^{direct} + \sigma_{cc}^{evap} + \sigma_{cc}^{EM}$$

- Direct (σ_{cc}^{direct})



- Evaporation (σ_{cc}^{evap})



Glauber model (Zero-range)

$$\sigma_{cc}^{direct} = 2\pi\int b[1 - T^P(b)]db$$

$$T^P(b) = \exp[-(\sigma_{pp}(E)\rho_p^T\rho_p^P + \sigma_{np}(E)\rho_n^T\rho_p^P)]$$

$$\sigma_{cc}^{evap} = \sum_i \sigma_{-in} \cdot P_i^{evap}$$

$$\sum_i \sigma_{-in} = \sigma_R - \sigma_{cc}$$ → normalized by Glauber model

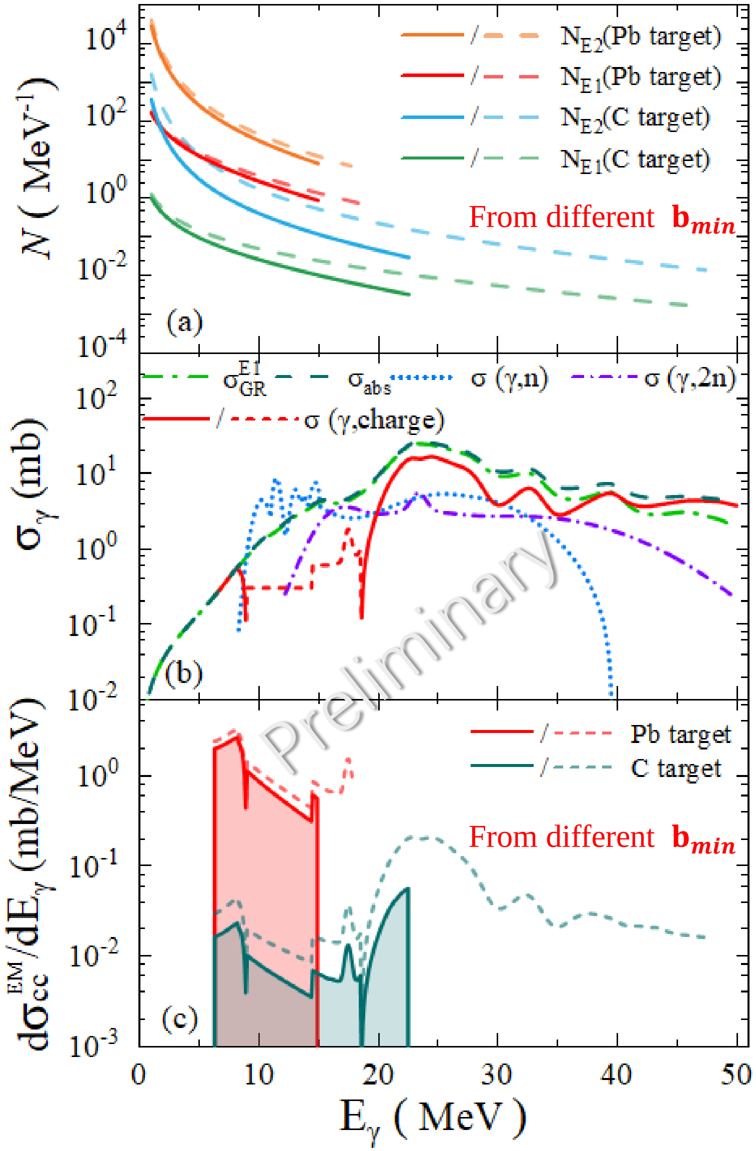
$$P_i^{evap} = \int_{S+V_b}^{\infty} \rho(E) \cdot \omega_e(E)dE$$

Gaimard-Schmidt (GS) Gemini++

J.W. Zhao, B.H.Sun and I. Tanihata *et al.*, Phys.Lett. B 847 (2023) 138269.

EM estimation

北京航空航天大學 BEIHANG UNIVERSITY



$$\sigma_{cc}^{exp} \approx \sigma_{cc}^{direct} + \sigma_{cc}^{evap} + \sigma_{cc}^{EM}$$

$$\sigma_{cc}^{EM} = \int_{S_{charge}}^{E_\gamma^{max}} N(E_\gamma)\, \sigma(\gamma, \text{charge})\, dE_\gamma, \quad E_\gamma^{max} = \frac{\gamma\beta\hbar c}{b_{min}}$$

$\sigma(\gamma,\text{charge}) \approx \sigma_{abs} - \sigma(\gamma,1n) - \sigma(\gamma,2n)$ $\quad$ $\sigma(\gamma,1n)$ $\sigma(\gamma,2n)$: experimental data

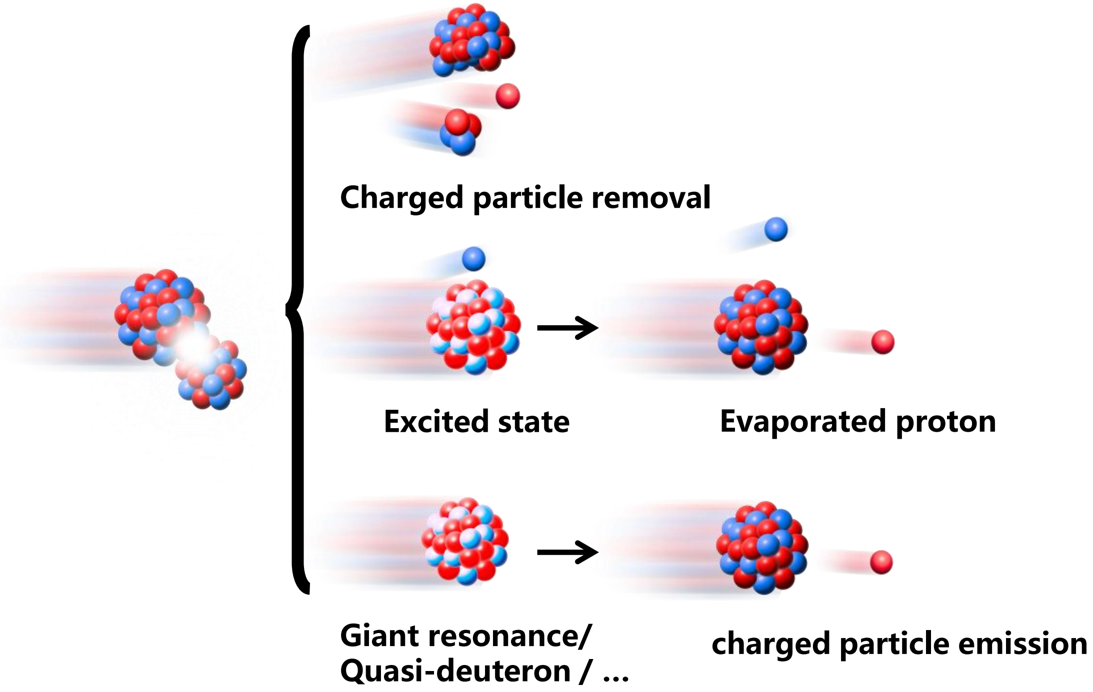
$\sigma_{abs} = \sigma_{GR}^{E1} + \sigma_{GR}^{E2} + \sigma_{QD}$ $\quad$ $\sigma_{GR}^{E1(E2)}$: giant resonance with E1(E2) $\quad$ σ_{QD}: quasi-deuteron

Quasiparticle random-phase approximation (QRPA) → Chadwick's model

- **The dominant transitions in the EM process are E1 and E2.**
- **On the same target, $N_{E2}(E_\gamma) \approx 10^2 * N_{E1}(E_\gamma)$.**
- **The $N_{E1(E2)}^{Pb}(E_\gamma)$ on Pb target ≈ 10^2* $N_{E1(E2)}^{C}(E_\gamma)$ on C target.**
- **The σ_{GR}^{E1} represents the major fraction of σ_{abs}.**
- **Throughout the process, E1 transition is dominant.**
- **The shadowed areas represent total σ_{cc}^{EM} on C and Pb.**

Result & Disscussion

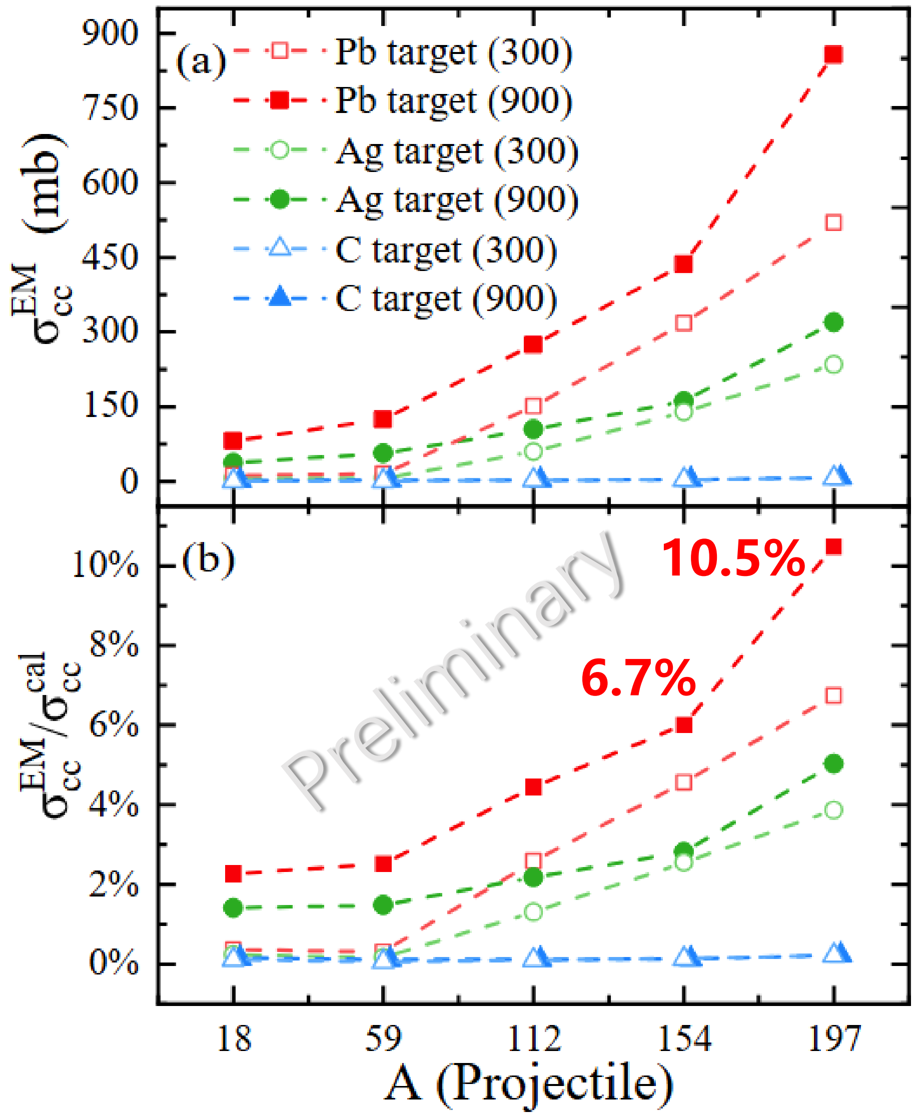
P+T	E(MeV/nucleon)	σ_{cc}^{direct}(mb)	σ_{cc}^{evap}(mb)	σ_{cc}^{EM} (mb)	σ_{cc}^{cal} (mb)	σ_{cc}^{exp}(mb)
$^{18}O + ^{nat}C$	372	764	106	0.2(19)	870.2	863(21)
$^{18}O + ^{nat}Pb$	378	3169	169	9.2(49)	3347.2	3386(137)



- Considering these three components, the experimental data is **reproduced**.
- The CPE contributes **12.3%** and **5%** to CCCS of ^{18}O on C and Pb target, respectively.
- The proportion of EMD in CCCS is less than **1%**.
- These imply that **Pb target** may be more suitable to **extract charge radii**.

EMD estimation of heavier nuclei

北京航空航天大學 BEIHANG UNIVERSITY



- The EMD cross section grows larger with increasing energy and projectile/target mass number.
- For **various projectiles** on **C** target, the EMD remains **below 1%.**
- In the case of ^{197}**Au** of CCCS on **Pb** target at 300 and 900 MeV/nucleon, the EMD is **6.7%** and **10.5%**, respectively.

Summary & Outlook

北京航空航天大學
BEIHANG UNIVERSITY

◆ Summary

- CPE contributes **12.3%** (C target) and **5%** (Pb target) to CCCS of ^{18}O at around 370 MeV/nucleon.
- EM proportion is **less than 1%** in CCCS of different projectiles on C targets **at 1 GeV/nucleon**.
- In the case of ^{197}**Au** of CCCS on **Pb** target at 300 and 900 MeV/nucleon, the EMD is **6.7%** and **10.5%**, respectively.

◆ Outlook

- Improve experimental precision to further refine model.
- Attempt to measure CPE or EMD to verify the correctness of the conjecture.

北京航空航天大學
BEIHANG UNIVERSITY

Thanks！

Reporter： Jin-Rong Liu

Supervisor：Bao-Hua Sun Jian-Wei Zhao