$^{12}C + {}^{12}C$ fusion at low energies

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Introduction

- Reactions occuring in star influences the nucleosynthesis as well as evolution of stars
- Cloud of gas - garvitational colapse – Temprature increase – fusion of nuclei
- Light ion fusion (^{1}H and ^{4}He) & heavy ion fusion
- Accurate determination of cross-sections and reaction rates of these reactions is primary goal of nuclear astrophysics
- In stars reaction occurs in Gamow window energy region
- Cross-section in this region is very less (pb or even less)
- Theoretiacl calculation is used for describing phenomenon

Motivation

- For $^{12}C+^{12}C$ lots of measurement in high energy region but less in low energy region with higher uncertainty
- Presence of resonances at each 400 keV energy step
- Simple extrapolation to Gamow window not possible
- Gamow window has not been reached in direct measurement
- Indirect measurements still controversial
- Small cross-section ➡ Low counting rate ➡ Measurement difficult

$$\sigma = Y/\varepsilon N_B N_T$$

σ= cross-section, Y= No. Of counts, ε= Detector efficiency,

N_B= No. Of beam particle, N_T= no. of target nuclei/area

Reaction rate

- Reaction rate

$$r=N_xN_y<\sigma v>/(1+\delta_{xy})$$

r= reacton rate, N_x and N_y is available nuclei

$<\sigma v>$ is product of MB stastics and cross-section, $(1+\delta_{xy})$ is delta function

→ Stars follow MB statistics

$$\psi(v) = 4\pi v^2 \left(\frac{m}{2\pi kT}\right)^{3/2} exp\left(-\frac{mv^2}{2kT}\right)$$

→ Product of MB statistics and cross section

$$\langle \sigma v \rangle = \frac{8}{(\pi\mu)^{1/2}} \frac{1}{(kT)^{3/2}} \int_0^\infty S(E) exp\left(-\frac{E}{kT} - \frac{b}{E^{1/2}}\right) dE$$

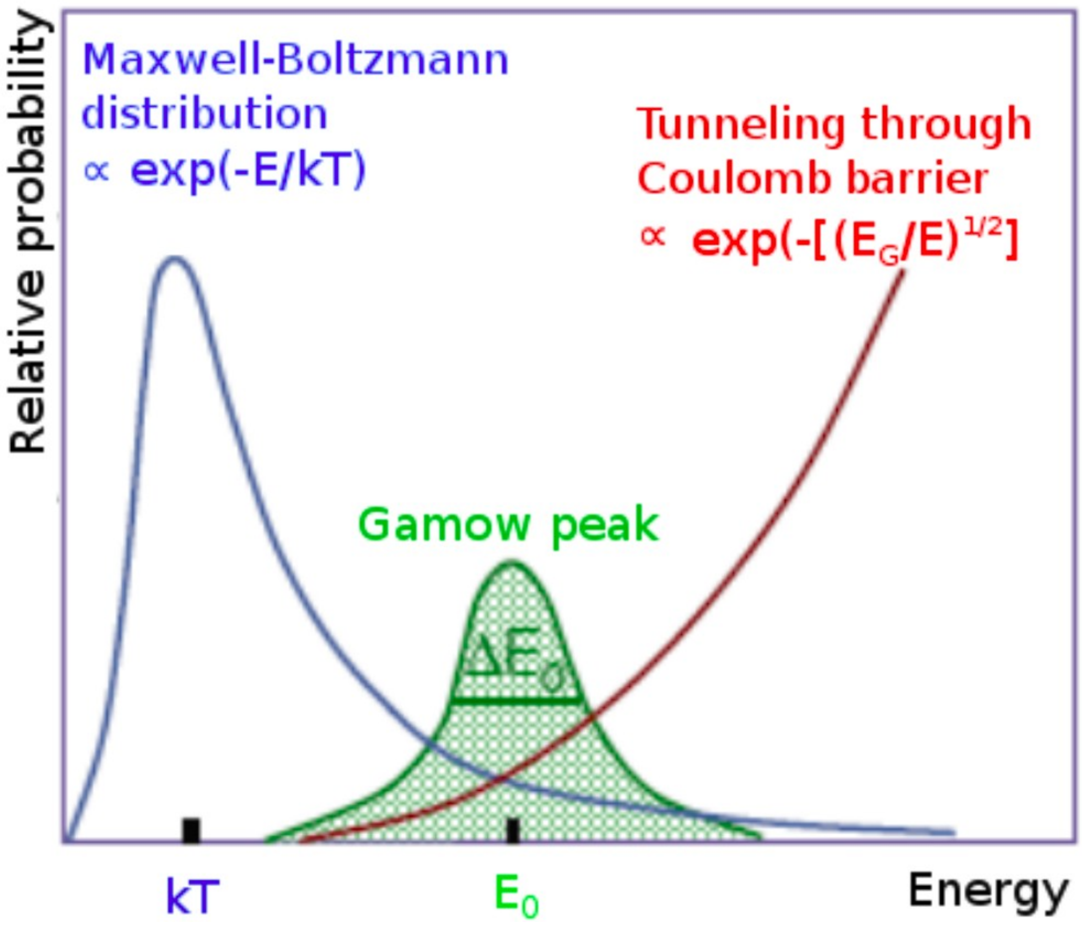
Gamow window

- Product leads towards a peak E_0

  $E_0=(bkT/2)^{2/3}$

  The Gamow peak

- ΔE_0 is range in which stellar reactions occurs promentoly



Carbon burning

- Gatway to heavy ion fusion
- Mass of star 8-10$M_\odot$
- Temperature 0.5-1 GK
- Gamow window 1-2 MeV
- Leads to the synthesis of heavier element A>20
- $^{12}C+^{16}O$, $^{16}O+^{16}O$ reactions are also possible
- At low energies majority of cross-sections comes from ground and first excited state
- At low energies alpha and proton channels are important

$$^{12}C + \ ^{12}C \rightarrow \ ^{23}Mg + n \ (Q \ = \ -2.62MeV)$$

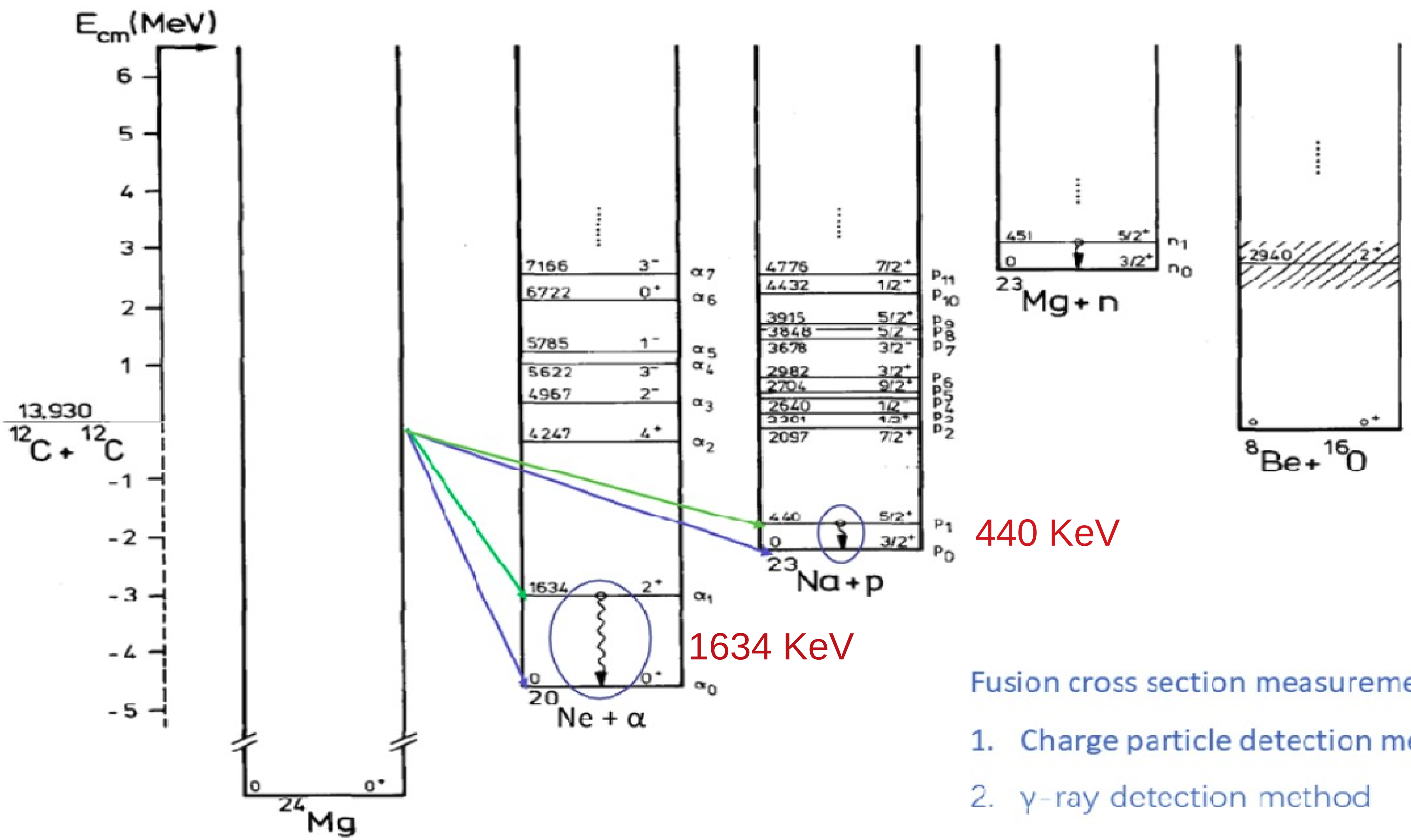
$$^{12}C + \ ^{12}C \rightarrow \ ^{23}Na + p \ (Q \ = \ 2.24MeV)$$

$$^{12}C + \ ^{12}C \rightarrow \ ^{20}Ne + \alpha \ (Q \ = \ 4.62MeV)$$

$$^{12}C + \ ^{12}C \rightarrow \ ^{16}O + 2\alpha \ (Q \ = \ -0.12MeV)$$

$$^{12}C + \ ^{12}C \rightarrow \ ^{16}O +^{8} Be \ (Q \ = \ -0.21MeV)$$

$^{12}C + {}^{12}C$ Level Scheme

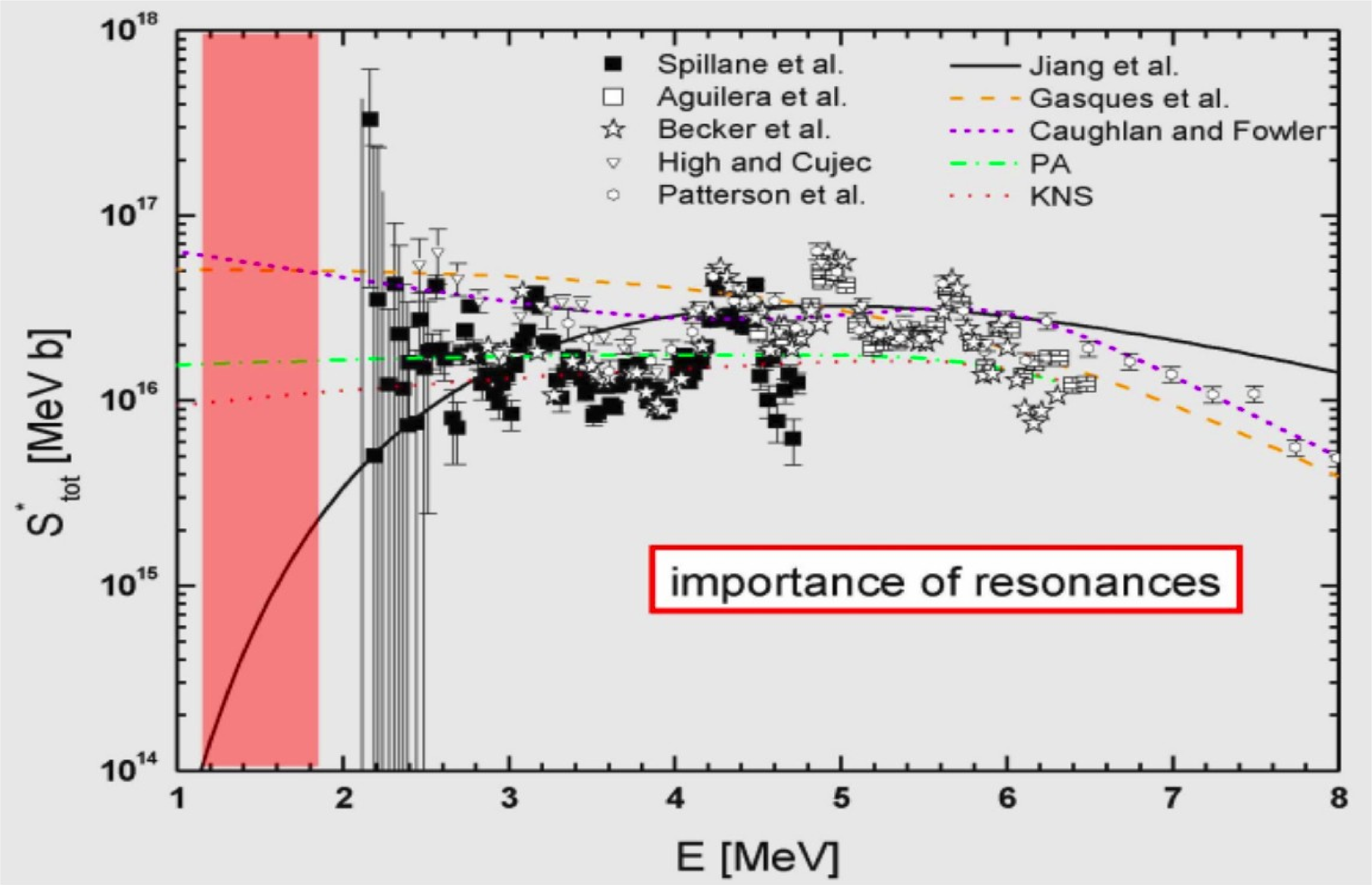


Fusion cross section measurements

1. Charge particle detection method
2. γ-ray detection method

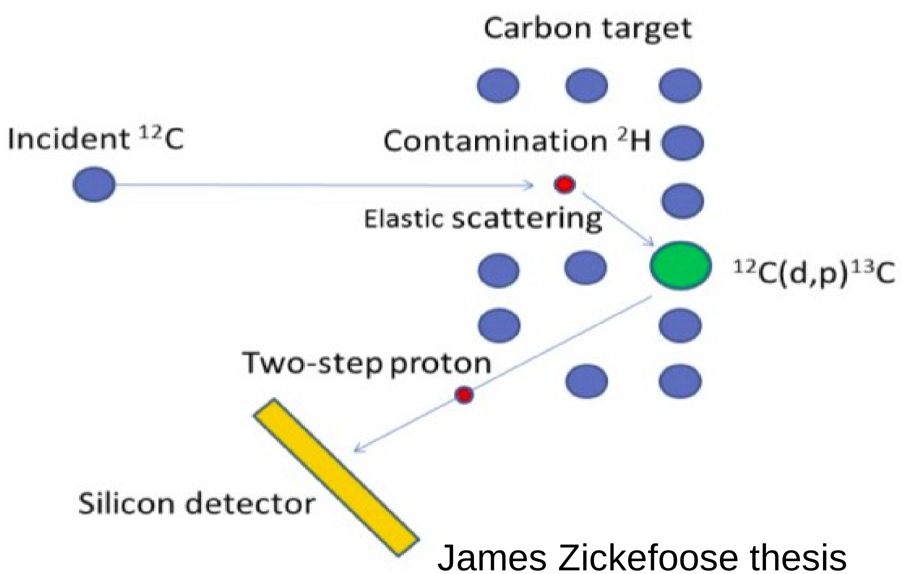
* Charge particle and γ-ray coincidence method

Different measurements of $^{12}C+^{12}C$



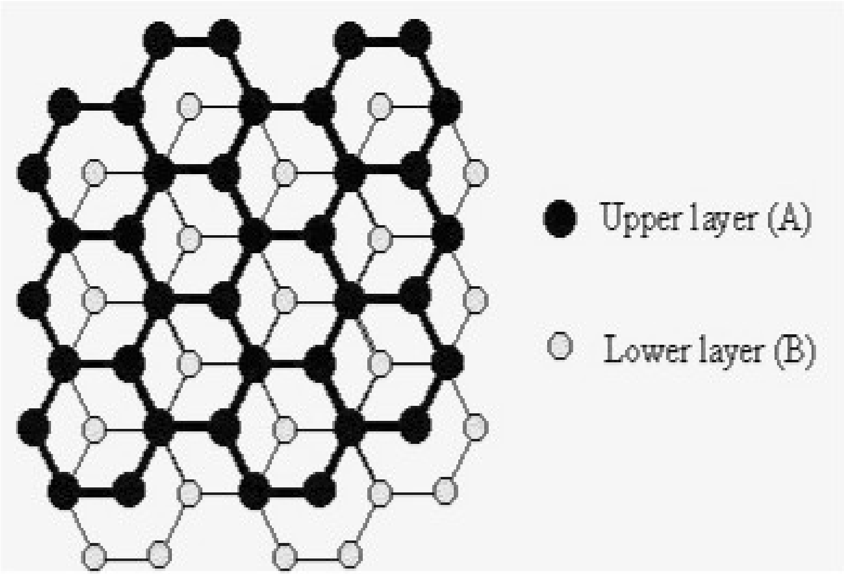
Target

- Impurity
  - Hydrogen and Deuterium
  - Deuterium produces proton through d(12C,p)13C
- Reduction of impurity
  - Perordic analysis of deuterium concentration
  - Highly odered pyrolytic graphite (HOPG)



James Zickefoose thesis

Two step process



HOPG structure

Background problem in γ- ray method

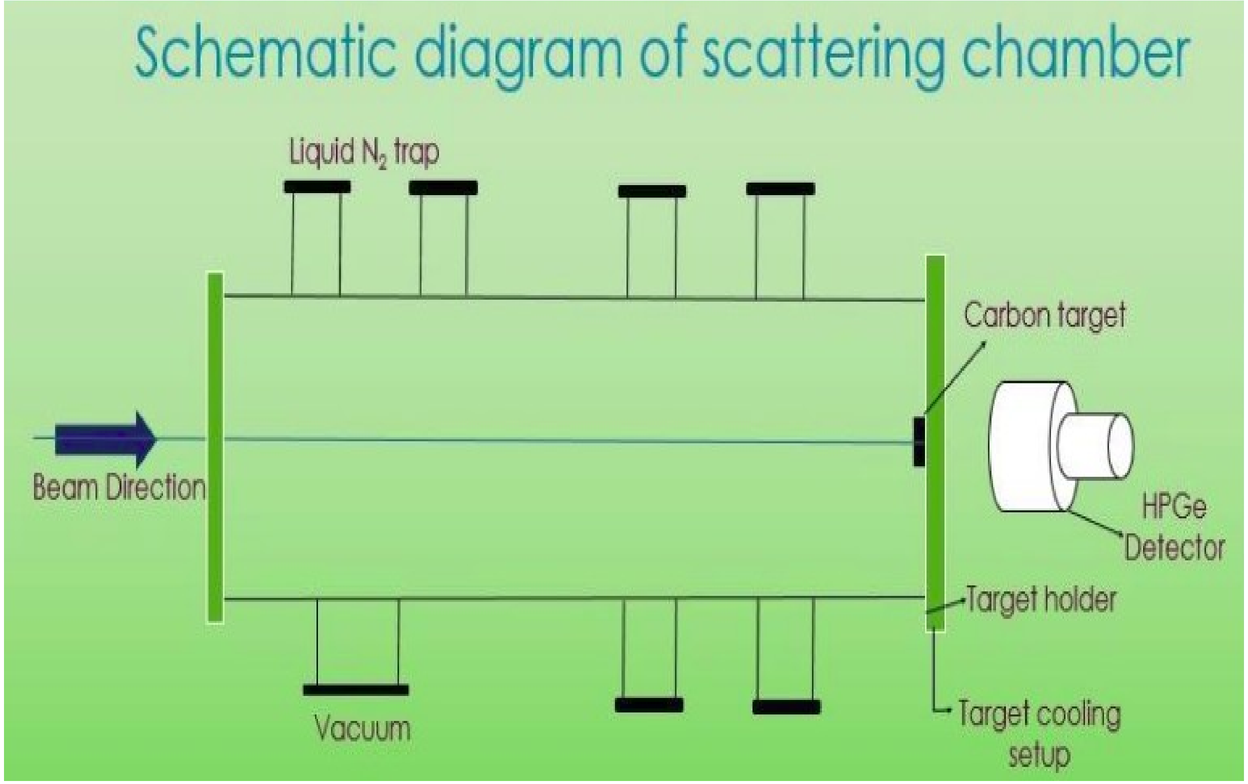
- Natural back ground
- Beam induced background (target impurity)
- $^{1}H(^{12}C,\gamma)^{13}N$ with energy E_{γ} = 2.36 MeV
- $^{2}H(^{12}C,p\gamma)^{13}C$ with energy E_{γ} = 3.09 MeV
- γ-ray peaks from $^{12}C+^{12}C$ reaction are at 440 & 1634 KeV
- Compton background of contaminant's peak interfere with the resolution of carbon fusion peak.

Detector and digitizer

- CANBERA HPGe clover detector
- CAEN digitizer (DT5725S)
- Digitizer parameter are such fine tuned that it gives resolution less than 2keV for ^{60}Co (each peak)
- Digitizer gives addback here (CoMPASS program)
- Output can be obatined in root format so easy to analysie

Scattering chamber

- Target cooling with water
- Copper tube as subpressor
- LN_2 cooling (cold trap)
- Place to hold a camera
- Quadrupole mass specrometer (monitoer rest gas of vaccum)
- Utra high vaccum
- Collimator
- Vacuum gauges



Summary

- Target impurity (^{1}H, ^{2}H, other than ^{12}C elements)
- Natural background and beam induced background
- Charge particle mesurement gives the ground state contribution
- γ-ray mesurement does not account for ground state transition
- Charge-particle and γ-ray coincidence measurement
- High beam current: More nuclei to take part in reactions
- High detector efficiency: Detect more events (close geometry)
- Increased target thickness

Near future plan

- Scattering chamber
- Close geometry mesurement (Summing correction)
- Once we get beam time from FRENA facility at SINP than we shall perform
  - $^{27}Al(p,\gamma)^{28}Si$ reaction for machine calibration
  - low energy measurements for $^{12}C+ {}^{12}C$ fusion reaction.

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