Nuclear Physics at Project-x

R. K. Choudhury

Nuclear Physics Division

Bhabha Atomic Physics Division

Mumbai 40085

Plan of talk

1. Present studies

- Reaction studies involving weakly bound stable projectiles
- Weak interaction study by n+p→d+gamma measurement

2. Intent for Project-x

- Nuclear structure and reaction studies involving RIBs
- Electric Dipole Measurement

Weakly bound projectiles are interesting, why?

Low breakup threshold

Stable ions

$^{6}Li \rightarrow \alpha + d$, $S_{\alpha d} = 1.48$ MeV,

$^{7}Li \rightarrow \alpha + t$, $S_{\alpha t} = 2.45$ MeV,

$^{9}Be \rightarrow \alpha + \alpha + n$, $S_{\alpha n} = 1.57$ MeV,

- Study simulates reactions involving RIBs
- Formation probability of SHE
- Extrapolation to low energy capture cross section → Astrophysical interest

Advantage → Stable and large intensity

Unstable ions

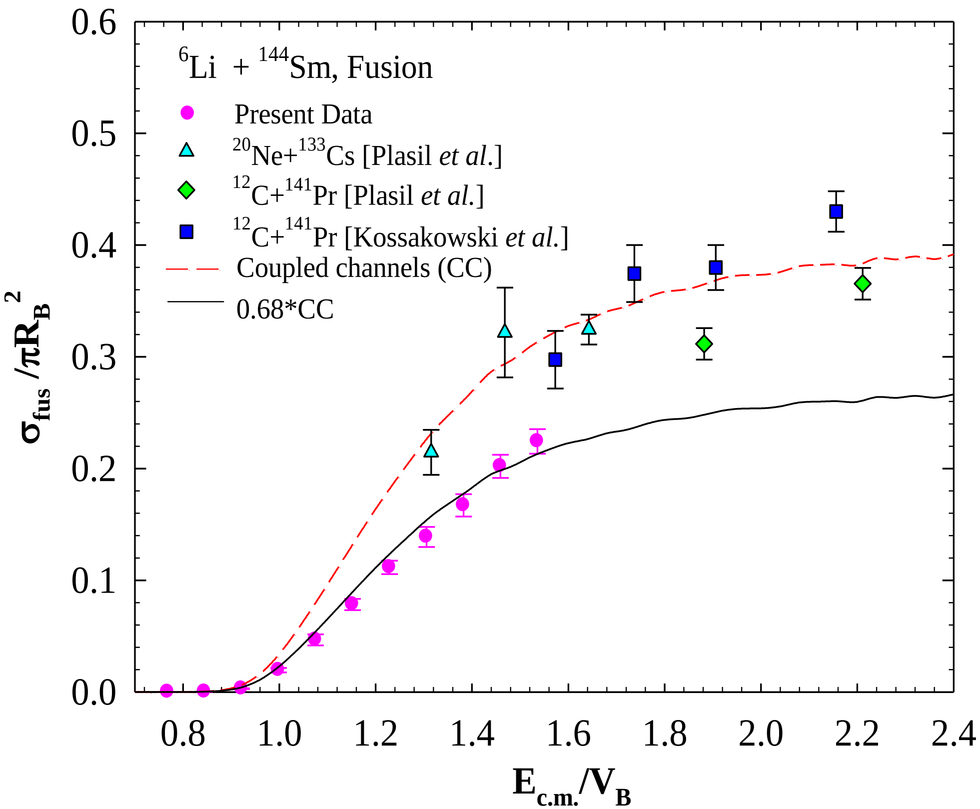
$^{6}He \rightarrow \alpha + 2n$, $S_{\alpha 2n} = 0.97$ MeV,

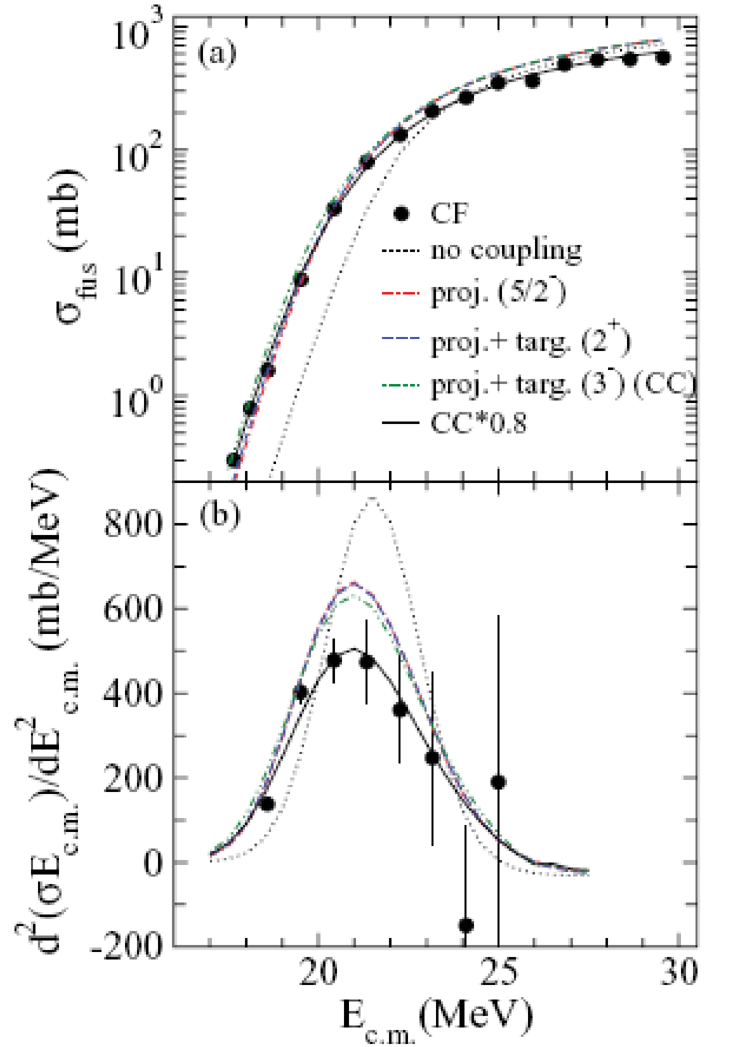
Fusion involving weakly bound projectiles

Fusion in presence of breakup channel

→enhance fusion due to coupling /

→suppress fusion due to loss of flux ???





P.K. Rath, S. Santra et al., PRC 79, 051601(R) (2009)

C. S. Palshetkar, S. Santra et al., PRC 82, 044608 (2010)

Systematics of fusion suppression

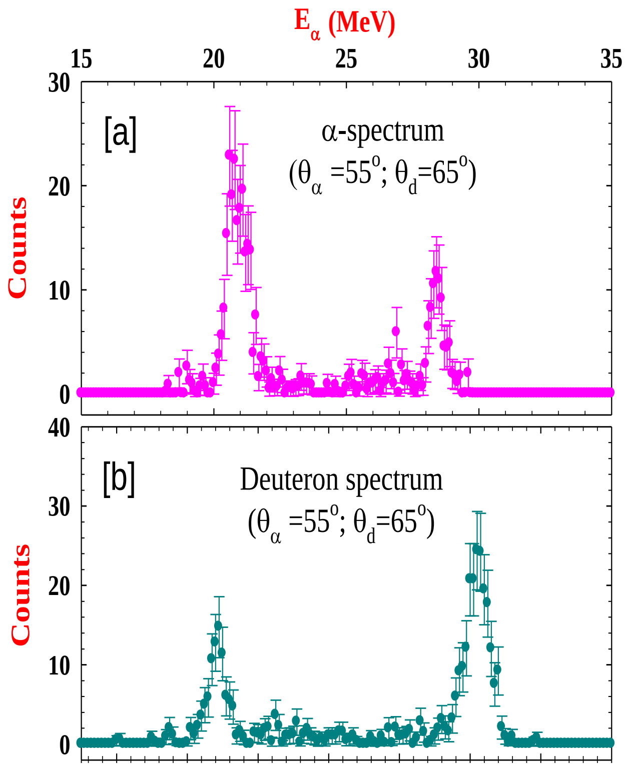
→Complete fusion at energies above the Coulomb barrier gets suppressed

Projectile	Breakup threshold	Target	Supp. factor	Reference
^{6}Li	$S_{\alpha d}$=1.48	^{209}Bi	36%	PRC 70, 024606 (2004).
^{6}Li		^{208}Pb	34%	PRC 68, 044605 (2003).
^{6}Li		^{144}Sm	32%	PRC 79, 051601(2009)
^{9}Be	$S_{\alpha\alpha n}$=1.57	^{208}Pb	32%	PRC 89, 272701 (2002)
^{9}Be		^{144}Sm	10%	PRC 73, 064606 (2006)
^{9}Be		^{124}Sn	28%	PRC 82, 054601 (2010)
^{9}Be		^{89}Y	20%	PRC 82, 044608 (2010)
^{7}Li	$S_{\alpha t}$=2.45	^{209}Bi	26%	PRC 70, 024606 (2004).
^{7}Li		^{165}Ho	18%	PRC 79, 051601(2009)
^{7}Li		^{165}Tb	26%	PLB 636, 91 (2006).

→Complete fusion suppression increases with target atomic number

→ It decreases with the increase of projectile breakup threshold

Resonant breakup in $^{6}Li+^{209}Bi$: Forward-backward asymmetry



S. Santra et al.,
PLB 677, 139 (2009)

T_α is forward to T_d:

→Distinct forward-backward asymmetry in the yields of sequential peaks

→Low energy α-peak is enhanced

Anisotropy

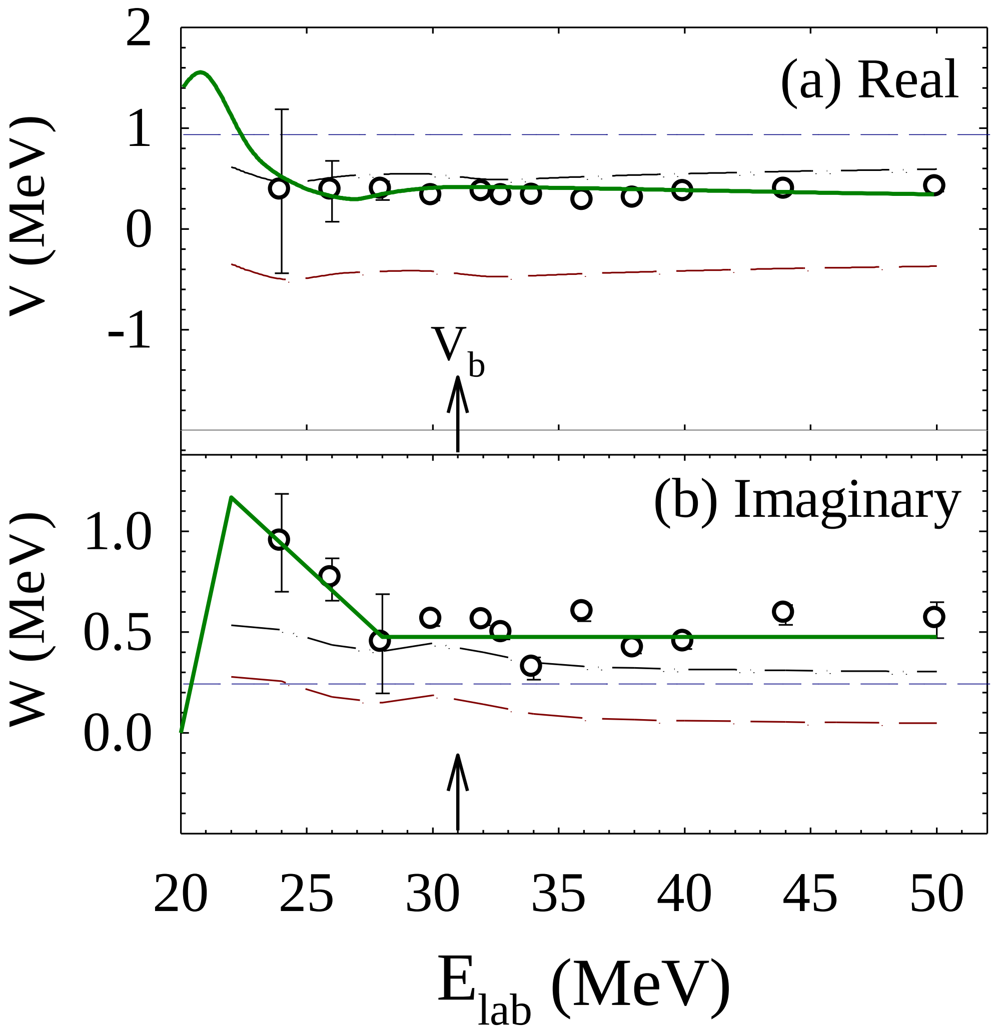
→Anisotropic distribution of breakup fragments in rest frame of ^{6}Li

(1) could arise from strong polarization of clustered ^{6}Li in the field of ^{209}Bi

(2) reorientation effect due to static quadrupole moment of 3^{+} state

→3^{+} state corresponds to *l*=2 state →emission of α and *d* in the rest frame of ^{6}Li would not be isotropic

Energy dependence of OM and polarization potential



→**Effective (dash-dot) i.e., bare (short dashed) + polarization (long dashed) potential is close to OM potential (hollow circles)**

→**ΔWp becomes more attractive at sub-barrier energies**

S. Santra et al.,
PRC 83, 034616 (2011)

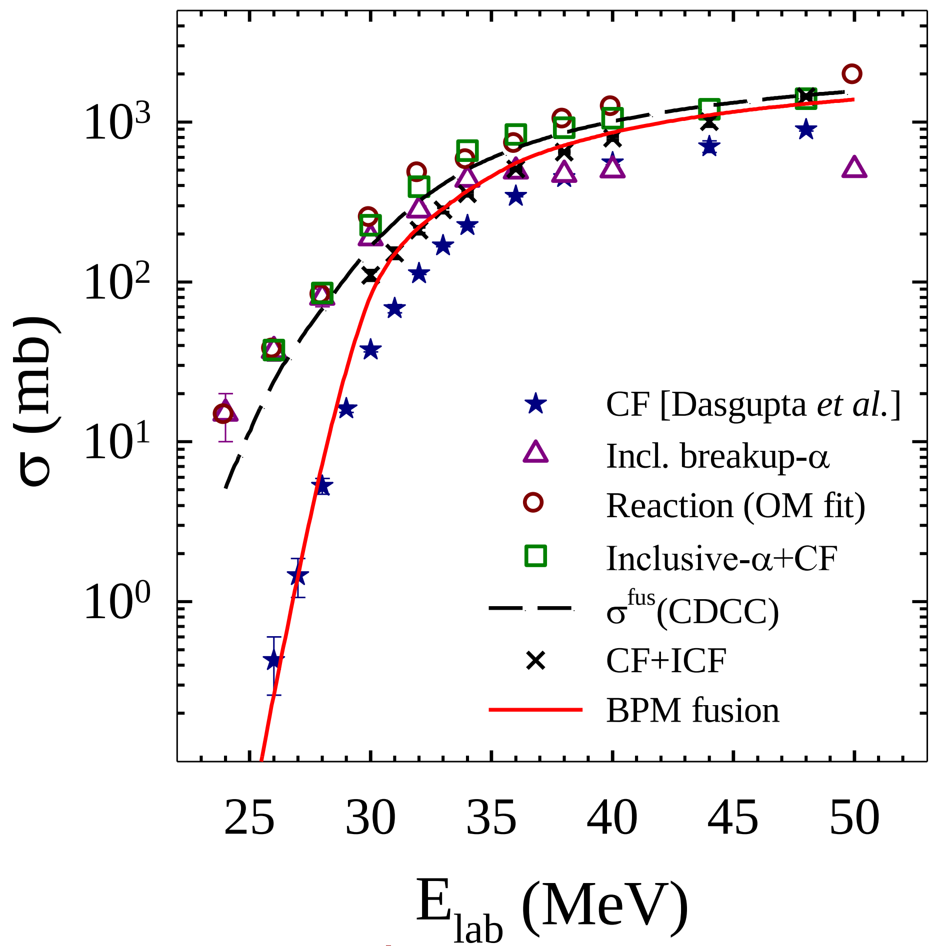
α-particle production

1. Measurements involving the projectiles ($^{6,7}Li$, ^{6}He, ^{9}Be) with α+x cluster structure show significantly large cross sections for α-particle production

→ a part of it from breakup (direct or sequential)
→ In addition to transfer of x to the target and others

2. Exclusive measurements of α-particles are essential to delineate different processes leading to such a large inclusive cross section

Inclusive breakup, fusion and reaction cross sections



S. Santra et al.,
PRC 83, 034616 (2011)

→Inclusive breakup very large ~ $\sigma_{Rreaction}$ @ low energies

→ σ(Incl. alpha+CF) ~ $\sigma_{Rreaction}$

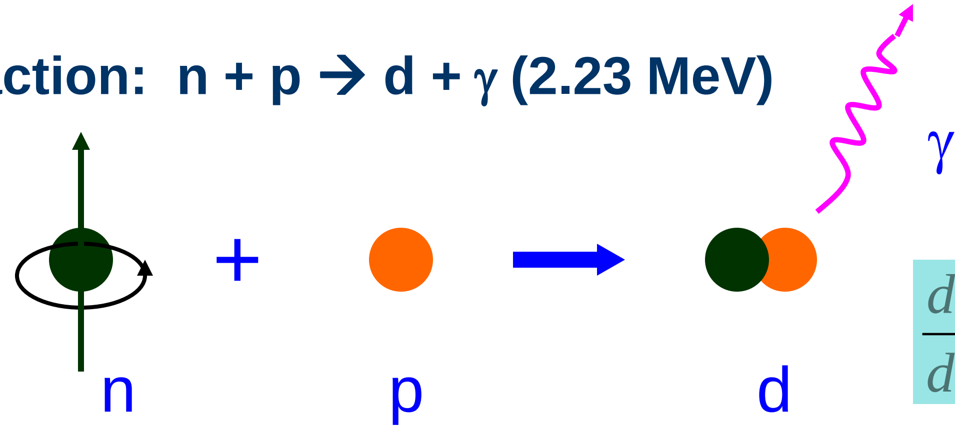
→At high energies, CF data is suppressed by ~30-40% compared to BPM fusion

→Delineation of exclusive contributions to large alpha is necessary

Measurement of parity violating γ-asymmetry in the capture of cold neutron by para-hydrogen

Measurement of parity violating γ-asymmetry in the capture of cold neutron by para-hydrogen

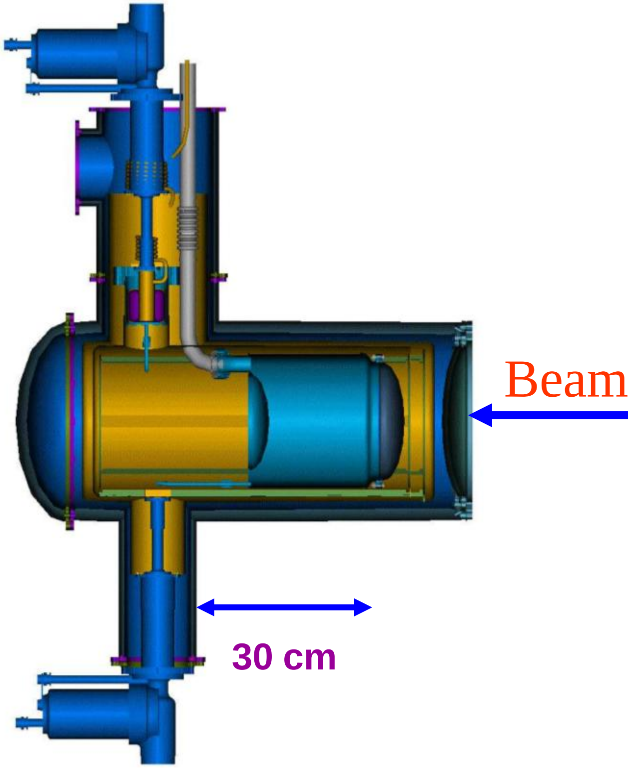
The reaction: n + p → d + γ (2.23 MeV)

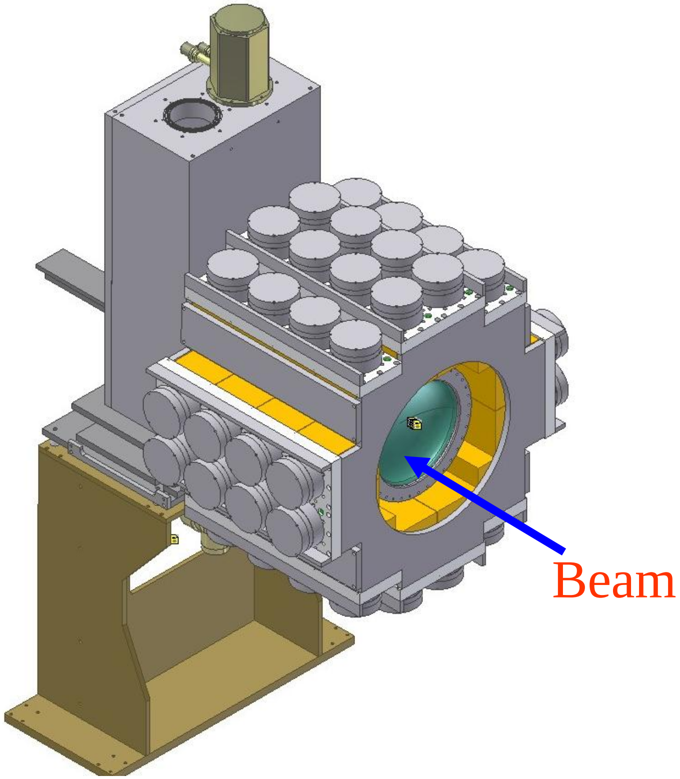


$$\frac{d\sigma}{d\Omega} = \frac{1}{4\pi}[1 + A_\gamma \cos(\theta_{S_n.K_\gamma})]$$

- **We will measure A_γ, the parity-violating asymmetry in the distribution ($d\sigma/d\Omega$) of emitted γ's.**
- **Expected asymmetry ≈ -5.0×10^{-8}**
- **Goal experimental error ~ 0.5×10^{-8}**
- **The asymmetry depends mainly on the $\Delta I=1$ weak pion coupling H_π^{1}, → $A_\gamma \approx -0.045 H_\pi^{1}$ (for n-p system)**
- **Being 2-body system, no structural uncertainty**
  ⇒ An unambiguous measurement of H_π^{1}.

Liquid Para-Hydrogen Target : - the heart of the experiment





Target vessel, cryogens and the main vacuum chamber

Assembly of the Target, And CsI Detectors

S. Santra et al.,
NIM 620, 421 (2011)

Present Status and future plans

n+p→d+γ

- Experiment at LANSCE is completed with limited statictics (measured asymmetry at LANSCE of $(1.27\pm2.1(\text{stat.}))10^{-7}$)

- ➢ Experiment is moved to Spallation Neutron Source (SNS), ORNL → 1st experiment in FnPB of SNS
- ➢ SNS, with 1.4 MW power, is the brightest in the world
- ➢ Neutron flux is ~12 times more than LANSCE
- ➢ SM bender polarizer instead of 3He spin filter provides a gain of 4 to polarized neutrons
- ➢ The sensitivity, $\Delta A_\gamma/A_\gamma$, of $5\text{x}10^{-9}$ is expected to be achieved by 2011-2012.

n+d→t+γ at SNS

- ➢ Proposal is made. Provides another hadronic weak coupling constant

Scope in Project-x

1. **Electric Dipole Moment Measurement using 225Ra, 223Rn, 221Fr, etc**

2. **Nuclear structure and dynamics study using radioactive ion beams**

EDM measurement on ^{225}Ra and ^{223}Rn

1. EDM measurement of ^{225}Ra is going on at Argonne National Laboratory

2. Michigan university is planning to measure the EDM of ^{223}Rn using TRIUMF facility

Project X: Target Spallation Production

Protons on thorium target: 1 mA x 1000 MeV = 1 MW

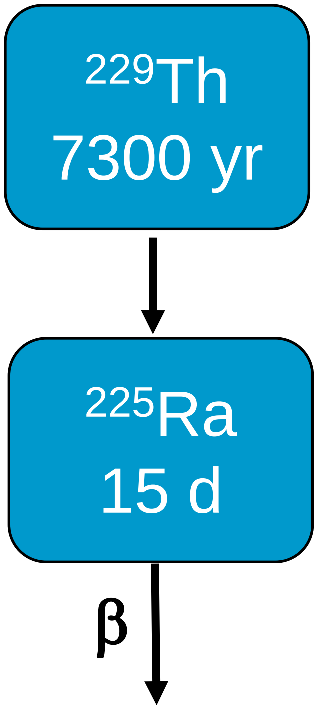
Predicted yields of some important isotopes (~10^2-10^4 x present):

Radon:	^{219}Rn >10^{14}	^{223}Rn ~10^{11} /s	
Francium:	^{211}Fr ~10^{13}	^{221}Fr >10^{14}	^{223}Fr >10^{12} /s
Radium:	^{223}Ra >10^{14}	^{225}Ra >10^{13} /s	
Actinium:	$^{225\text{-}229}$Ac >10^{14} /s		

Yields simulated by I.C. Gomes using MCNPX, Project X workshop, October 2009

Project X will enable a new generation of fundamental symmetry-test experiments, and bring exciting opportunities for discovering physics beyond the Standard Model.

Search for ^{225}Ra EDM at Project -X



Present scheme

1 mCi ^{229}Th source → 4 x 10^{7} s^{-1} ^{225}Ra

- Upgrade path to 10 mCi
- Projected EDM sensitivity: 10^{-26} – 10^{-27} e-cm
- Equivalent to 10^{-28} – 10^{-30} e-cm for ^{199}Hg
- Current limit on ^{199}Hg: 2 x 10^{-28} e-cm

Search for ^{225}Ra EDM at Project X

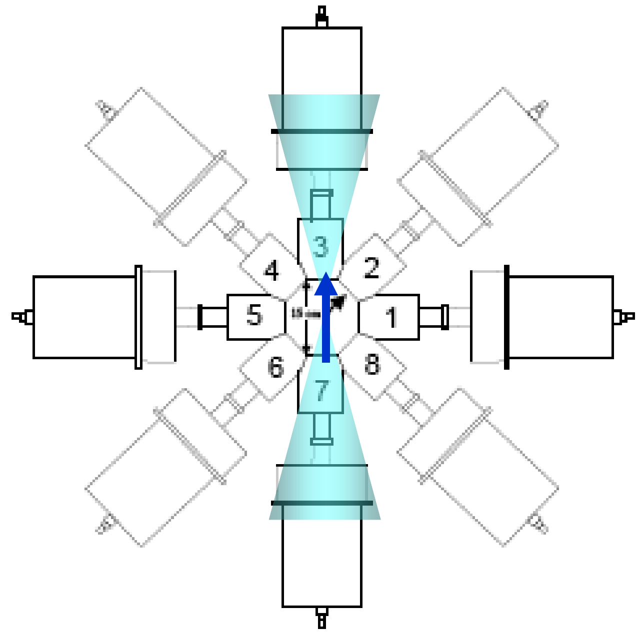
Project X yield: 1 x 10^{13} s^{-1} ^{225}Ra

- Projected EDM sensitivity: 10^{-28} e-cm
- Equivalent to 10^{-30} – 10^{-31} e-cm for ^{199}Hg
- Study systematics at 10^{-29} e-cm for ^{225}Ra

Radon-EDM Experiment

TRIUMF E929 Spokesperson

T. Chupp (Univ of Michigan)
C. Svensson (Guelph)



Funding: NSF, DOE, NRC (TRIUMF), NSERC

Produce rare ion radon beam

- **Collect in cell with co-magnetometer**
- **Measure free precession**

  (γ anisotropy or β asymmetry)

^{223}Rn (23 min) EDM projected sensitivity

Facility	^{223}Rn Yield	S_d (100 d)
ISAC	$10^7 – 10^8$ s^{-1}	10^{-26} - 10^{-27} e-cm
Project X	10^{11} s^{-1}	10^{-28} e-cm

~ 10^{-30} e-cm for ^{199}Hg

Proposal - 1

- **First, we want to participate in the ongoing measurements on EDM at ANL and TRIUMF**

- **Parallely, we plan to prepare for the EDM measurements at project-x**

Proposal - 2

Study of nuclear structure and dynamics using RIB

- **Radioactive isotopes produced in the spallation by high intensity proton beam can be accelerated and then used as secondary beam for above studies**

- **Reaction studies using RIBs have implications in the field of (i) Super Heavy Elements formation, (ii) Reactions of astrophysical interest, etc.**

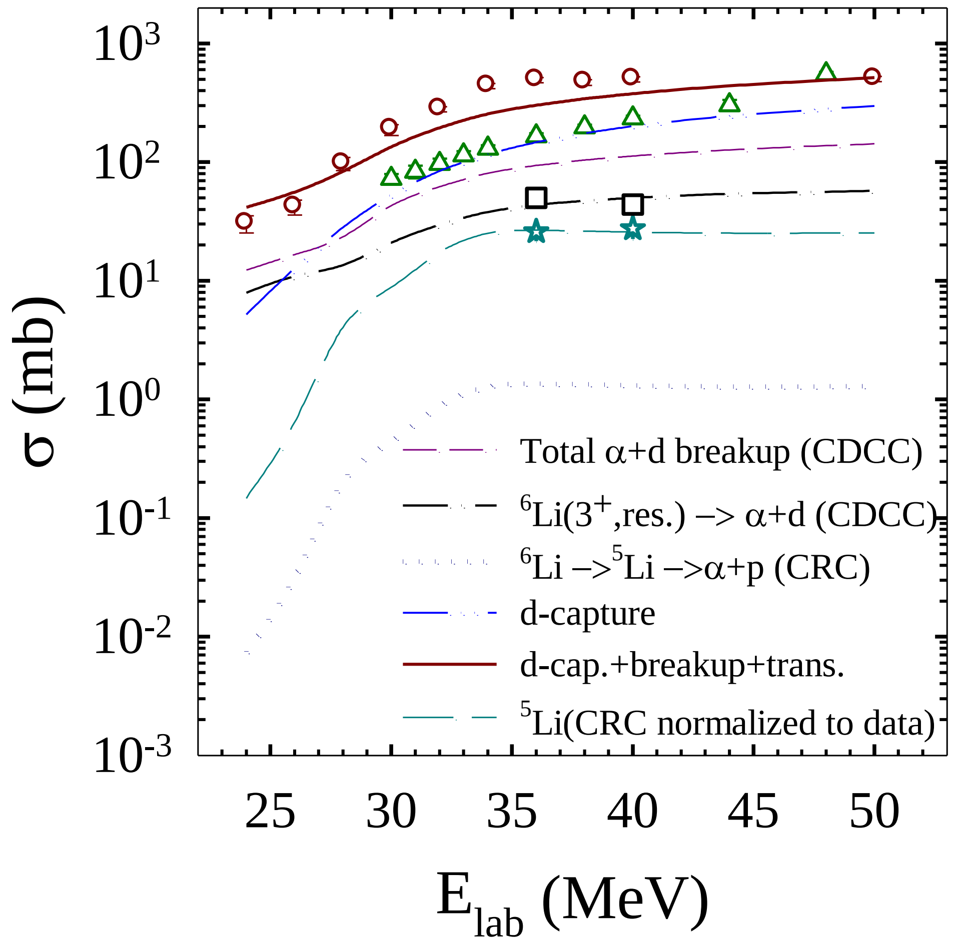
- **The study of structure of the nuclei near the neutron and proton drip lines is a very interesting field**

- **We propose for a beam line involving post-acceleration of the radioactive isotopes produced in the spallation**

- **Plan for experiments using secondary beams for the study of nuclear structure and dynamics**

Thank You

Inclusive and exclusive α-production



→Total $\sigma_{\alpha d}$ (theory) << σ_{α} (incl)

→$\sigma_{\alpha p}$(exp) + $\sigma_{\alpha d}$(th) < σ_{α}(incl)

→Other possible sources :

(1) (^{6}Li,α)

(2) (^{6}Li,^{5}He→n+α)

(3) (^{6}Li,^{7}Li→α+t)

(4) partial fusion (d-cap)

→ICF (d-cap) contribution is maximum

→ICF+(α-d) breakup gives most alphas

→Understood the origin of large inclusive alpha

S. Santra et al.,
To be submitted to PRC