RAON-6: Nuclear Data Production System

중이온가속기 활용 국제공동연구기획사업
연차 워크샵

NDPS Group

2021. 11. 18

RAON-6 (NDPS)

■ **연구개발목표**

해외 중성자 활용 시설을 이용해 핵자료 측정 실험을 수행하여 RAON의 NDPS 시설을 활용할 수 있는 **전문가 육성**

■ **성과목표**

중성자 이용을 통한 핵자료 측정과 관련 기술 개발, NDPS 활용 분야 국제 경쟁력 확보 방안

■ **연구내용**

- 해외 중성자 시설들을 이용하여 (n, xn), (n, f), (n, γ) 등 **중성자 유발 핵반응 측정 실험** 수행
  - 해외가속기 연구소와의 교류협력 방안 수립
  - **국제공동연구 과제 발굴** 및 수립
- 해외 중성자 활용 시설에 **대학원생, 박사후 연구원을 파견**
  - 중성자 유발 핵반응 측정 실험 및 분석을 통해, 다양한 중성자 발생 및 측정 방법을 익힘으로써 **신진 연구 인력**을 양성
- NDPS 활용 관련 미래 **연구 주제** 발굴

■ **연구성과물:**

- 국제공동연구 과제계획서
- 연수결과보고서
- 출판논문
- 연구의향서

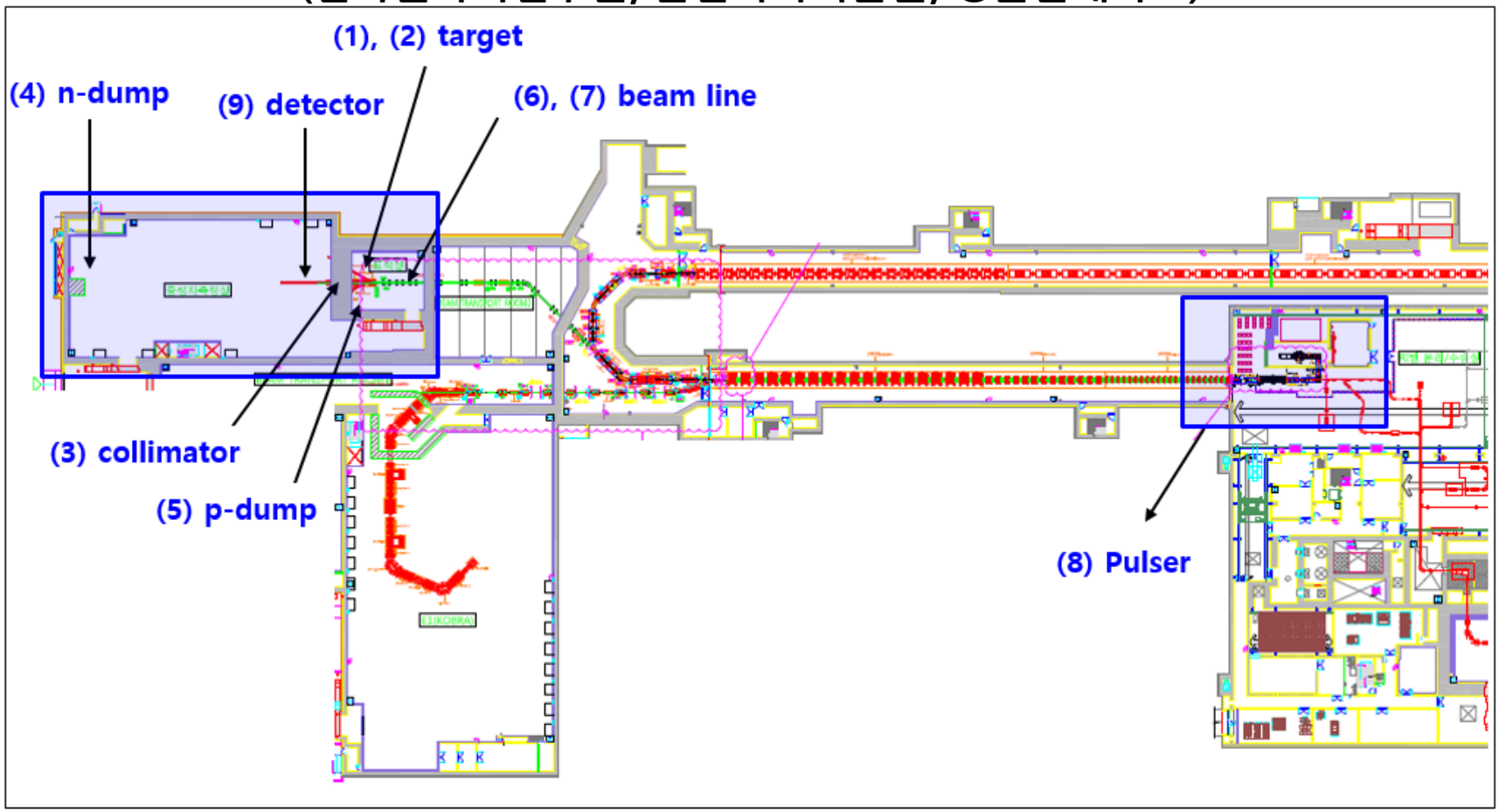
NDPS 국제공동연구그룹

- 중이온가속기사업단 : 이상진
- 성균관대학교 : 홍승우, Vivek CHAVAN
- 경북대학교 : 김귀년
- 울산과기원 : 정모세
- 한국원자력연구원 : 송태영, 양성철, 양승대, 이영욱, 이승현, 이창희, 허민구
- Kyushu University : Nobuhiro SHIGYO, Yukinobu WATANABE
- GELINA, JRC : Peter SCHILLEBEECKX
- Kyoto University : Hiroshi YASHIMA
- Tokyo Institute of Technology : Satoshi CHIBA
- JAEA : Katsuhisa NISHIO

nDPS
Nuclear Data Production System

주요 연구 성과: NDPS 장치 구축

(한국원자력연구원, 울산과학기술원, 성균관대학교)



1) Thick 중성자 표적시스템 (C 표적)

2) Thin 중성자 표적시스템 (Li 표적)

3) 중성자 콜리메이터 (양질 중성자 빔, Fe+PE)

4) 중성자 빔 덤프 (고속중성자 저감, 콘크리트)

5) 양성자 빔 덤프 (양성자 빔 정지, Cu)

6) 이온 수송용 빔 라인 (사중극, 이중극전자석, 빔 라인)

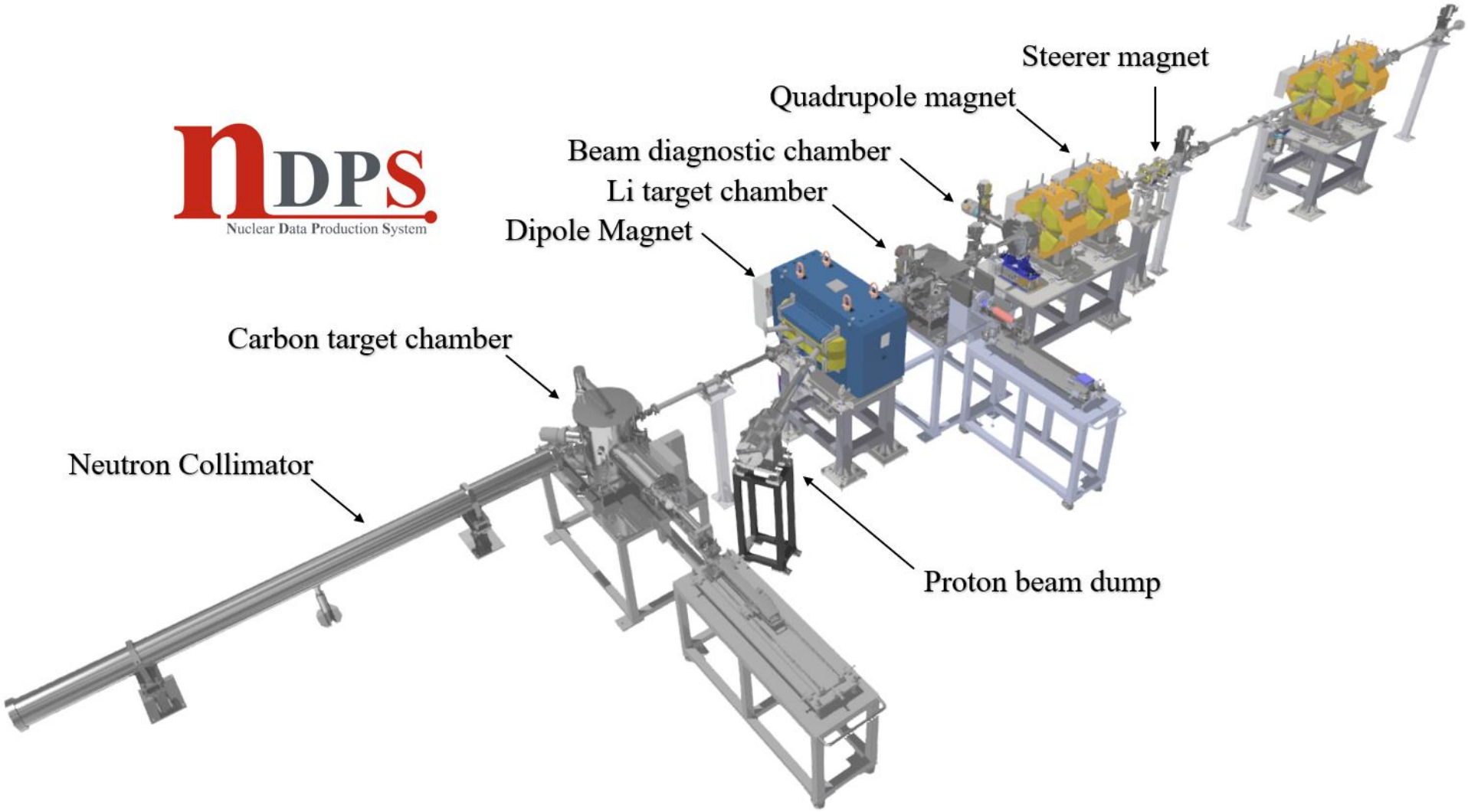
7) 진공시스템 (진공상태 유지)

8) 입사기 구간 펄스 빔 제공장치 (펄스 빔 제공)

9) 검출기시스템 (빔 모니터링, 실험용 검출시스템)

주요 연구 성과: NDPS Beam line 구축

- Monoenergy neutron beam : proton beam on Li target
- White neutron beam : deuteron beam on C target

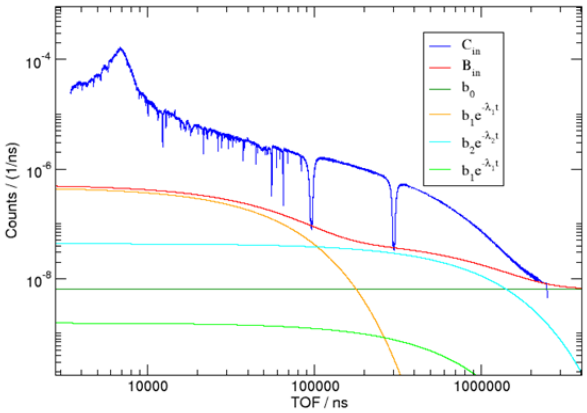


RAON-6 (NDPS) 4차년도 연구계획

연구참여자 **홍승우(성균관대), 김귀년(경북대), 정모세(울산과기원), V. N. Bhorasker(성균관대), 차반비벡(성균관대) 외 대학원생 5명**

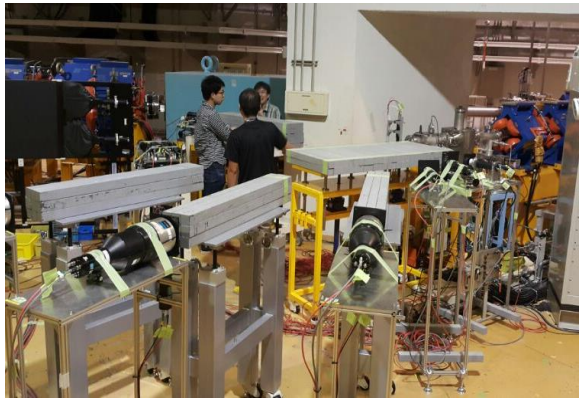
연구목표 (4차년도)

- GELINA 시설 이용 ^{142}Ce neutron capture 실험 데이터 분석, 대학원생 및 박사후 연구원 등을 파견
- HIMAC Xe/Kr 중이온 빔을 이용한 충돌 실험연구
- RAON에 최적화된 SBS의 상세설계와 이를 위한 인력 양성 및 GANIL과의 협력



▪ GELINA TOF 시설

- ^{142}Ce neutron capture 실험 데이터 분석
- 대학원생 및 연구원 등 파견



▪ HIMAC 시설

- Xe 또는 Kr 중이온 빔과 Cu 타겟을 이용한 핵반응으로부터 생성되는 이차중성자의 이차미분단면적 측정 및 분석

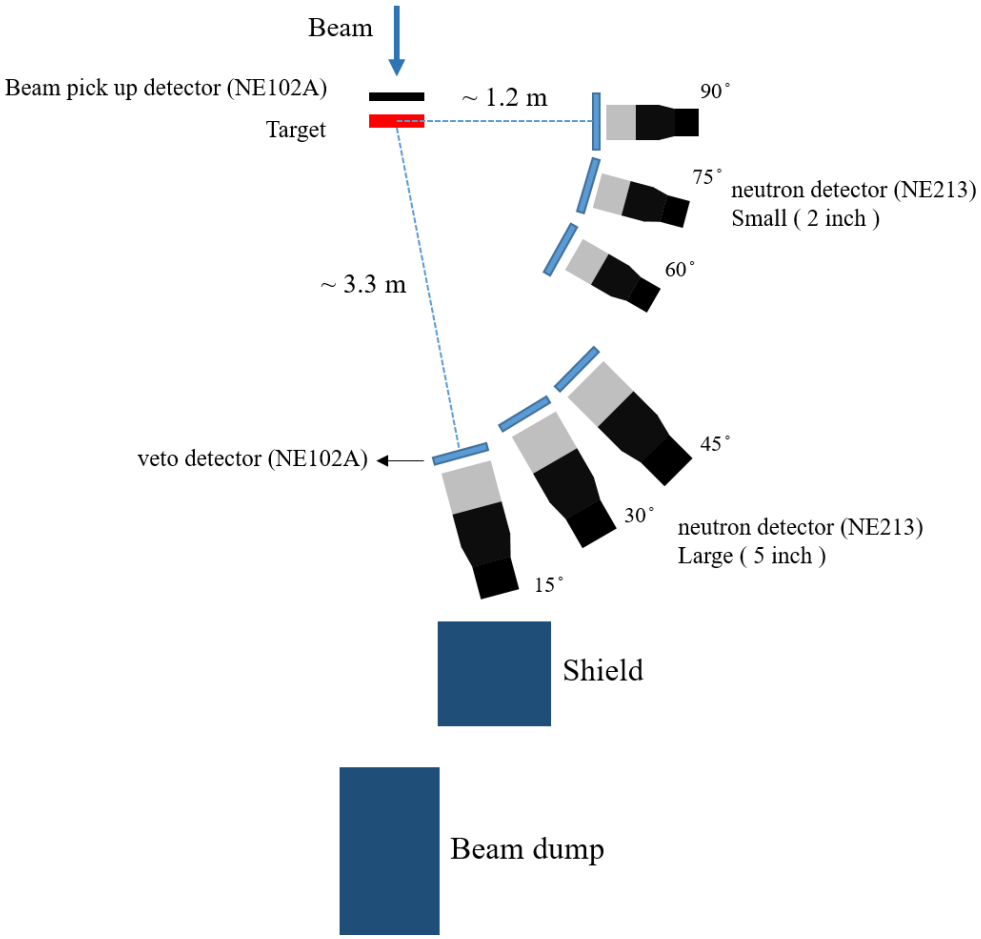
▪ GANIL/SBS 시설

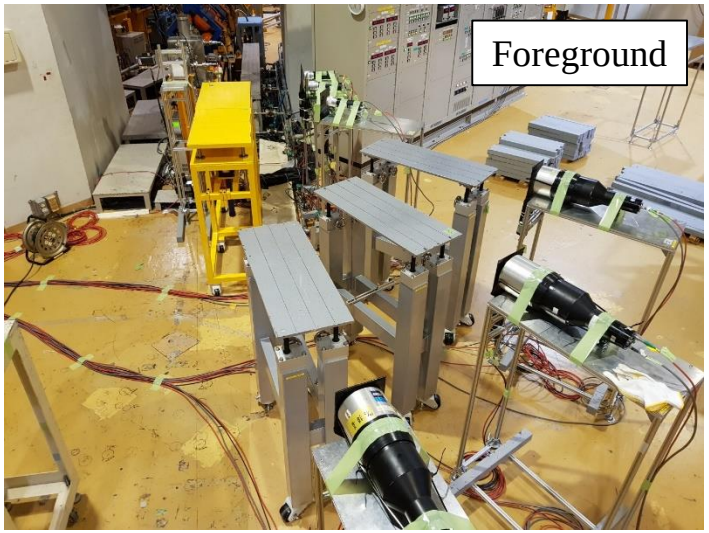
- GANIL SBS 시운전 정보 및 개발 경험 획득
- 주요 컴포넌트별 설계변수 및 사양을 최종 확정하여, 향후 예산이 확보되는 경우 바로 제작에 들어갈 수 있도록 준비
- 향후, SBS 개발에 참여할 수 있는 인력 양성

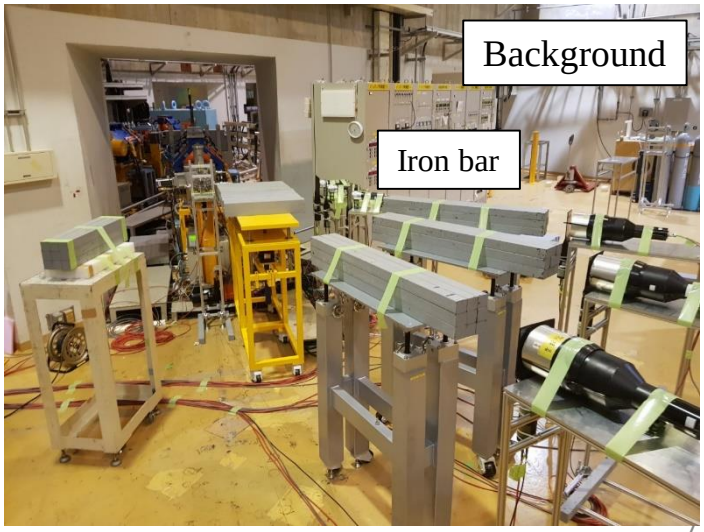
주요 연구 성과

■ ^{136}Xe + ^{nat}C, ^{93}Nb, ^{209}Bi 충돌 이차중성자 발생 실험 데이터 분석 (HIMAC)

Experimental set up



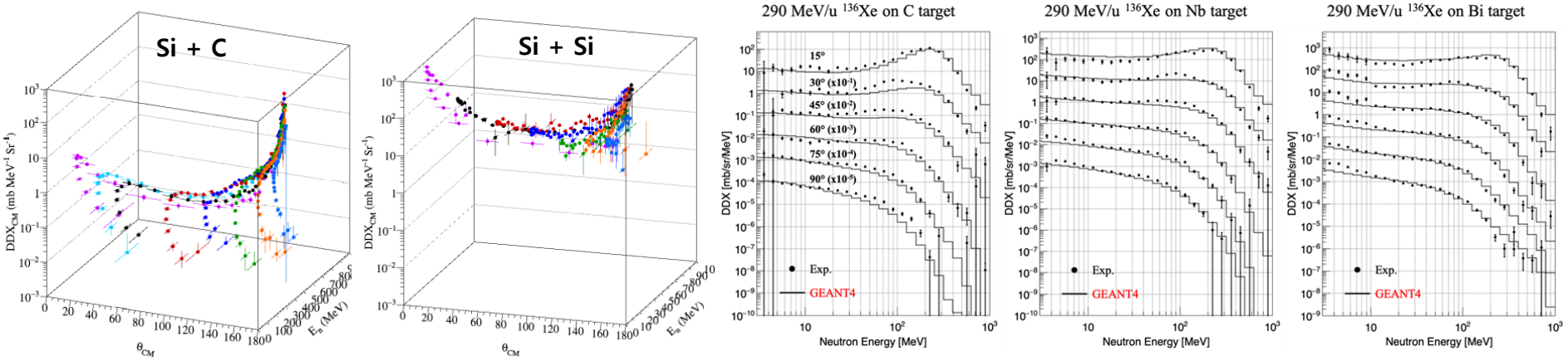




주요 연구 성과

- **HIMAC 이온 빔을 이용한 이차 중성자 측정 실험**

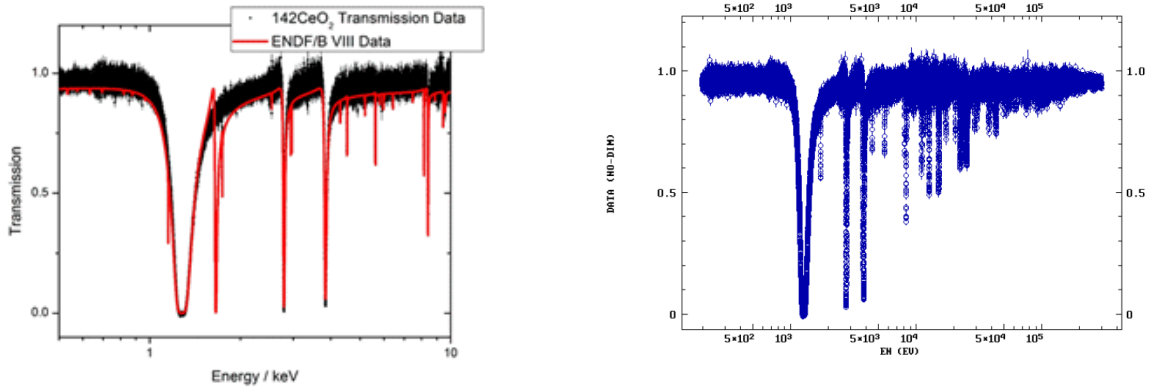
- HIMAC 시설 Si빔, Xe빔 이용 실험데이터 분석완료 및 논문 작성 중



Double differential cross section in the COM frame of ^{28}Si + C, Si (왼쪽), Differential cross section of ^{136}Xe + C, Nb, Bi(오른쪽).
실험 데이터는 몬테카를로 시뮬레이션 프로그램의 결과와 비교분석 하였으며, 논문 작성 중에 있다.

- **GELINA 실험 (n,tot) cross section 분석 및 EXFOR 등재**

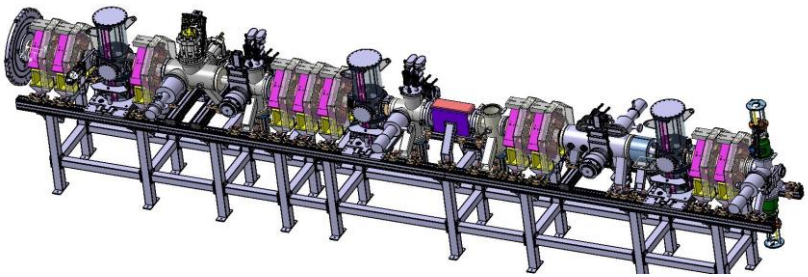
- ^{142}Ce transmission cross section 분석 - 최종 분석 데이터 EXFOR 등재

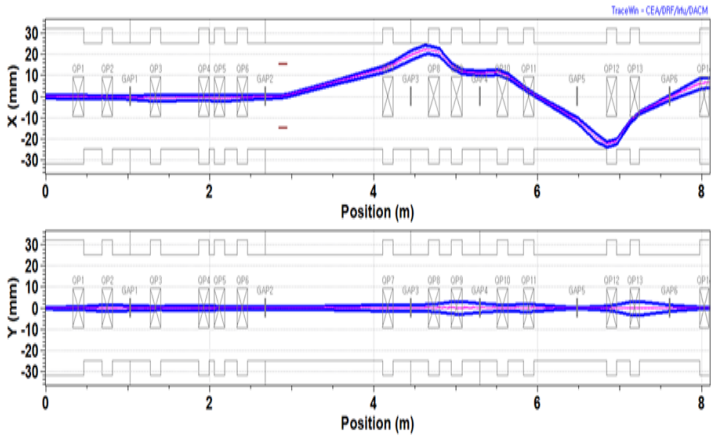


^{142}Ce의 neutron transmission 데이터와 ENDF/B VIII data library(왼쪽) EXFOR에 등재된 ^{142}Ce의 neutron transmission 데이터 (오른쪽)

주요 연구 성과

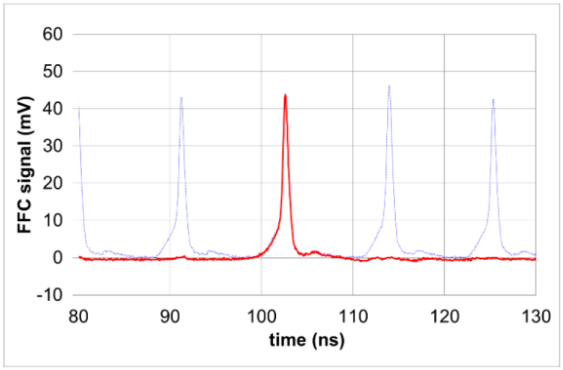
■ Single Bunch Selector 상세 설계



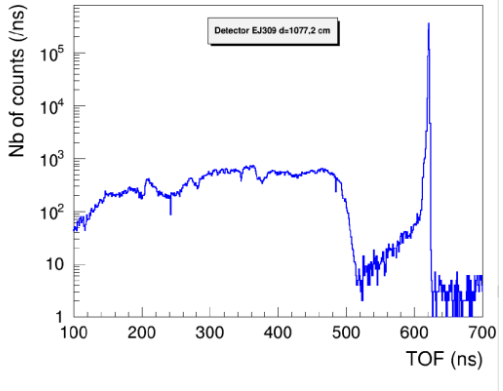


▪ GANIL/SBS 시설
- RAON MEBT 에 설치 가능한 GANIL 형태 SBS의 상세 설계
- GANIL SBS 시운전 정보, 개발 경험 획득
- 향후, SBS 개발에 참여할 수 있는 인력 양성

▪ **Single Bunch Selector 시뮬레이션 결과**
- GANIL 연구진과 온라인으로 정보교환
- RAON MEBT 시뮬레이션 진행
- SBS 펄서 관련 독일 업체 FID technology와 정보교환



a)



GANIL 연구진으로 부터 제공받은 SBS 시운전 데이터
좌: Fast Faraday cup 으로 확인한 단일 번치 선택 과정 / 우: Gamma detector 에서 얻어진 단일 픽크 신호

주요 성과

• **논문 발표 성과 (4편)**

- **International Journal of Modern Physics E, 30, 2150009 (2021)**; E. J. In et al
  제목: Neutron drip line in the deformed relativistic Hartree-Bogoliubov theory in continuum: Oxygen to Calcium
- **Nuclear Inst. and Methods in Physics Research, A, 1023, 165647 (2021)**: Y. Cheon et al
  제목: Mitigation of space-charge-driven resonance and instability in high-intensityl inear accelerators via beam spinning
- **Radiation Physics and Chemistry, 191, 109832 (2022)**; Vivek Chavan et al
  제목: The effects of alpha irradiation on the optical reflectivity of composite polymers
- **Nuclear Physics A, Submitted** ; Vivek Chavan et al
  제목: Monoenergetic neutrons from 9Be (p,n) 9B reaction induced by 35, 40 and 45 MeV protons

• **학회 발표 (5회)**

- **2021년 봄 한국물리학회(4월) 논문 발표:**
  - 2021.04.22. 성균관대학교(홍승우)
    발표제목: Status of construction of NDPS facility
- **RAON Users Workshop-2021**
  - 2021.07.22, 성균관대학교 (홍승우)
    발표 제목: Fission experiments at NDPS
- **2021년 가을 한국물리학회(10월) 구두 발표:**
  - 2021.10.20. 성균관대학교(문달호)
    발표제목: Neutron detection system status of Nuclear Data Production System
  - 2021.10 21. 성균관대학교(홍승우)
    발표제목: Fission experiments at the NDPS
  - 2021. 10. 21. 울산과학기술원(곽동현)
    발표제목: 고해상도 TOF(Time of Flight) 중성자 실험을 위한 단일 번치 빔 생성 시스템 제작 연구

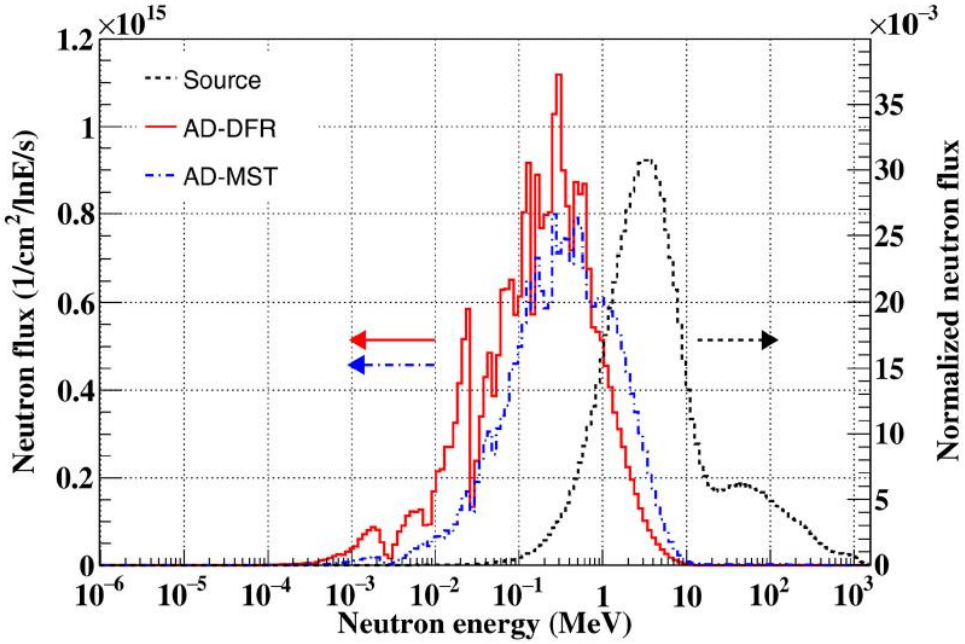
Possible experiments at NDPS (LOI)

- Measurements of (n, xn) reactions with quasi mono-energy neutrons by activation technique
  - ^{59}Co(n,xn), ^{93}Nb(n,xn), ^{197}Au(n,xn), ^{209}Bi(n,xn)

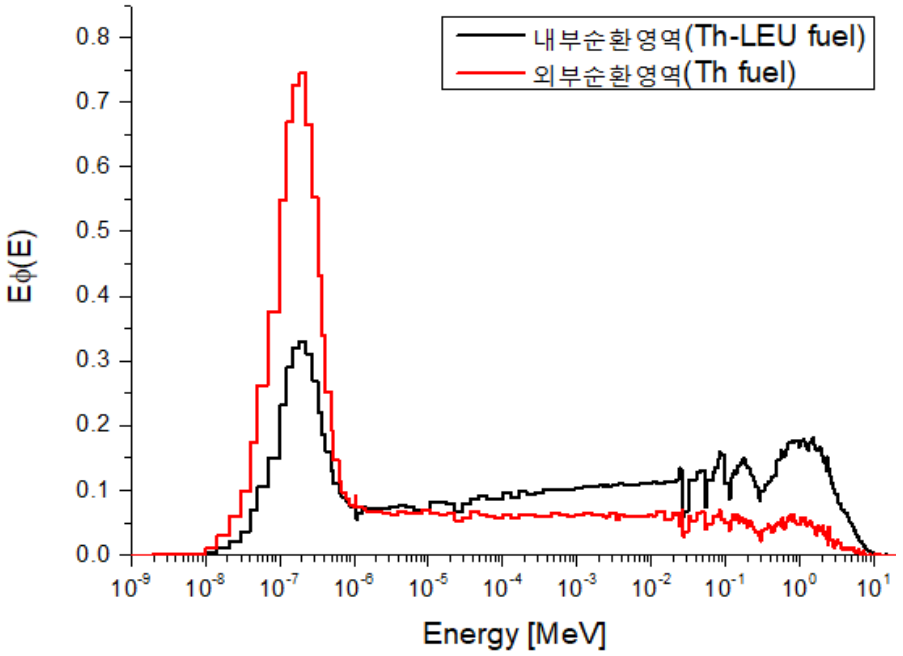
- Fission cross section measurements for heavy elements (Pb, Bi, Th, etc.) or actinides (Np, Am, Cm, etc)

Motivation: Neutron spectra for **fast** reactors

Neutron spectra in the
Accelerator Driven Subcritical Reactor



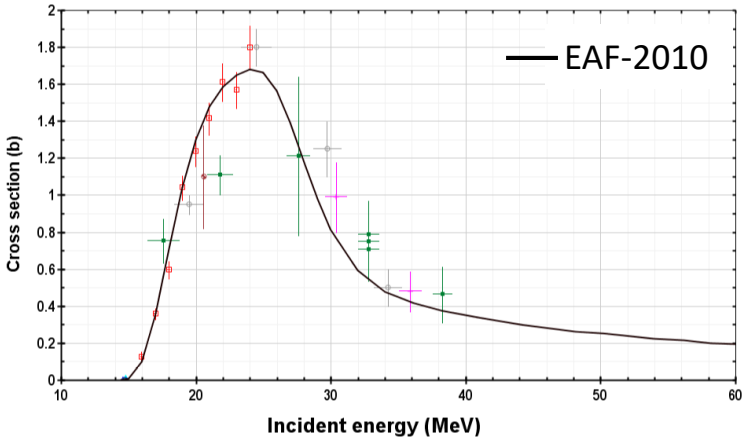
Neutron spectra in a usual
(Thermal) Critical Reactor



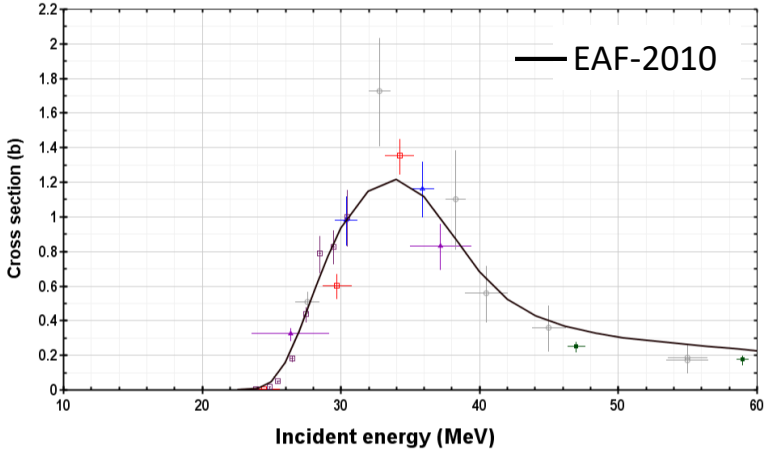
S. I. Bak et al, Eur. Phys. J. Plus (2019) **134**: 603

Motivation : **Lack of (accurate) nuclear data**

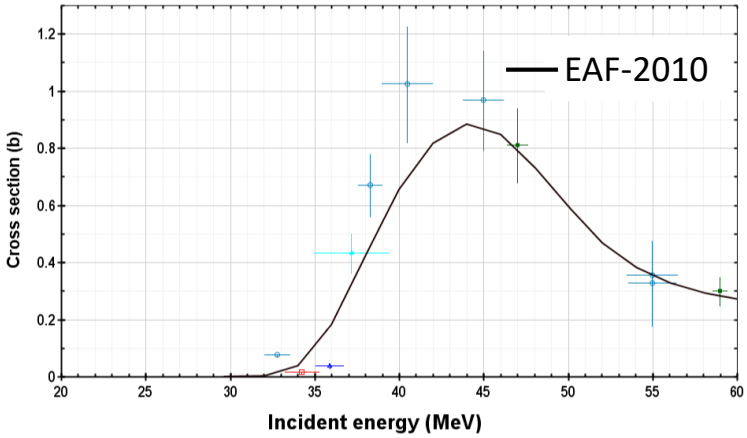
- **^{209}Bi(n,xn) cross sections**
  - ^{209}Bi(n,3n) ^{207}Bi



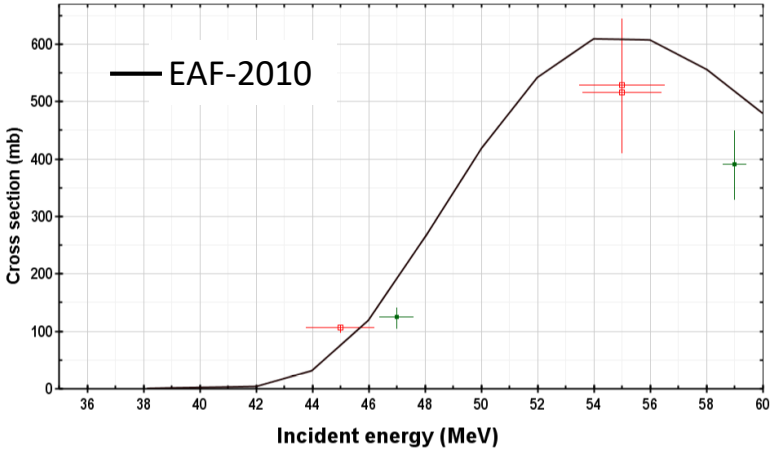
  - ^{209}Bi(n,4n) ^{206}Bi



  - ^{209}Bi(n,5n) ^{205}Bi



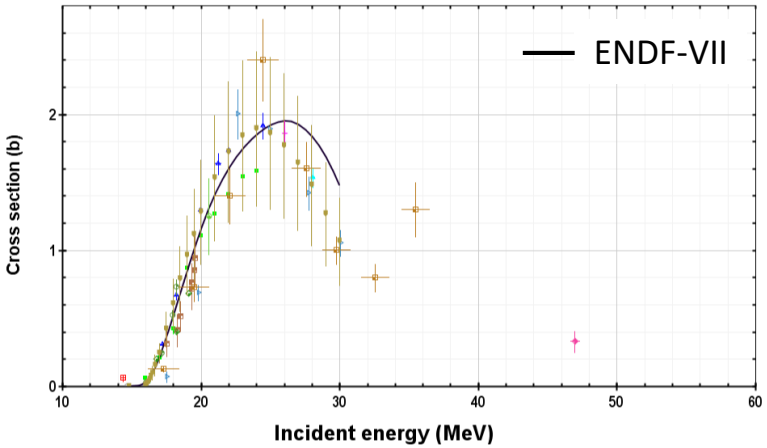
  - ^{209}Bi(n,6n) ^{204}Bi



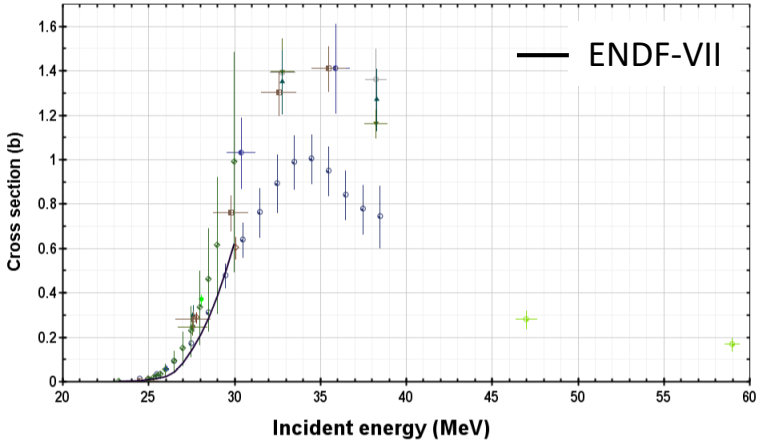
Accurate data are needed for monitoring neutron flux

Motivation : **Lack of (accurate) nuclear data**

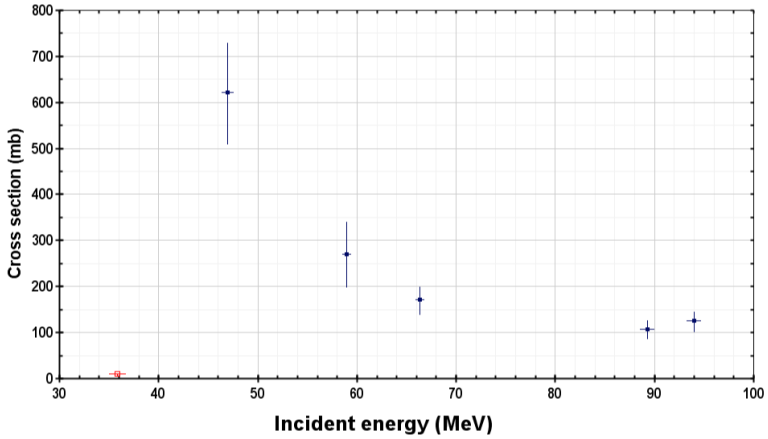
- **^{197}Au(n,xn) cross sections**
  - ^{197}Au(n,3n) ^{195}Au



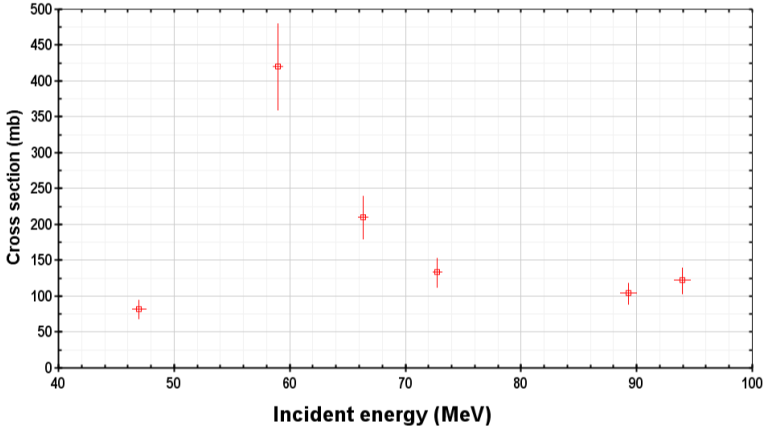
  - ^{197}Au(n,4n) ^{194}Au



  - ^{197}Au(n,5n) ^{193}Au



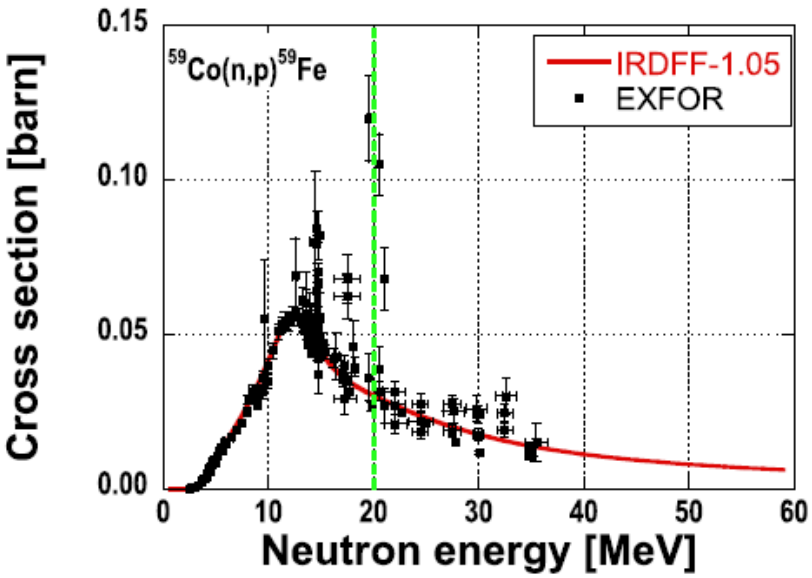
  - ^{197}Au(n,6n) ^{192}Au

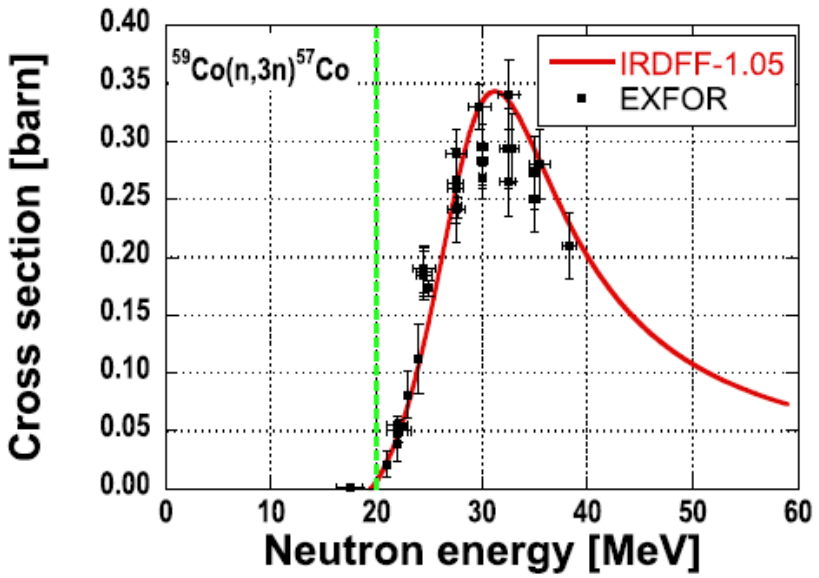


Accurate data are needed for monitoring neutron flux

Motivation : **Lack of (accurate) nuclear data**

- **^{59}Co(n,xn) cross sections**



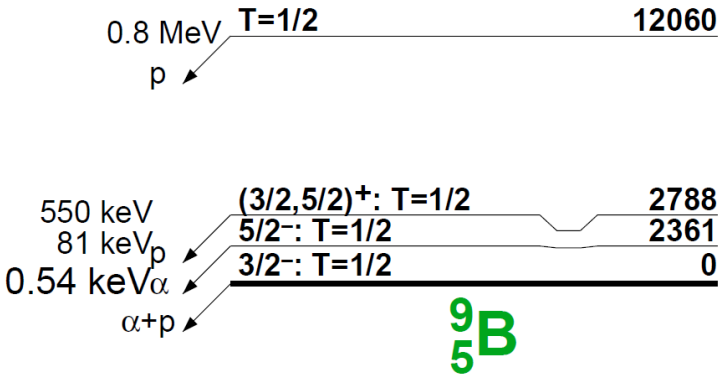


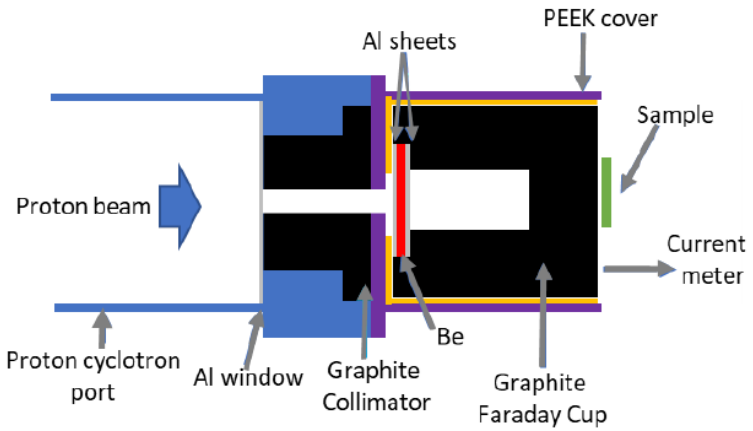
Accurate data are needed for monitoring neutron flux

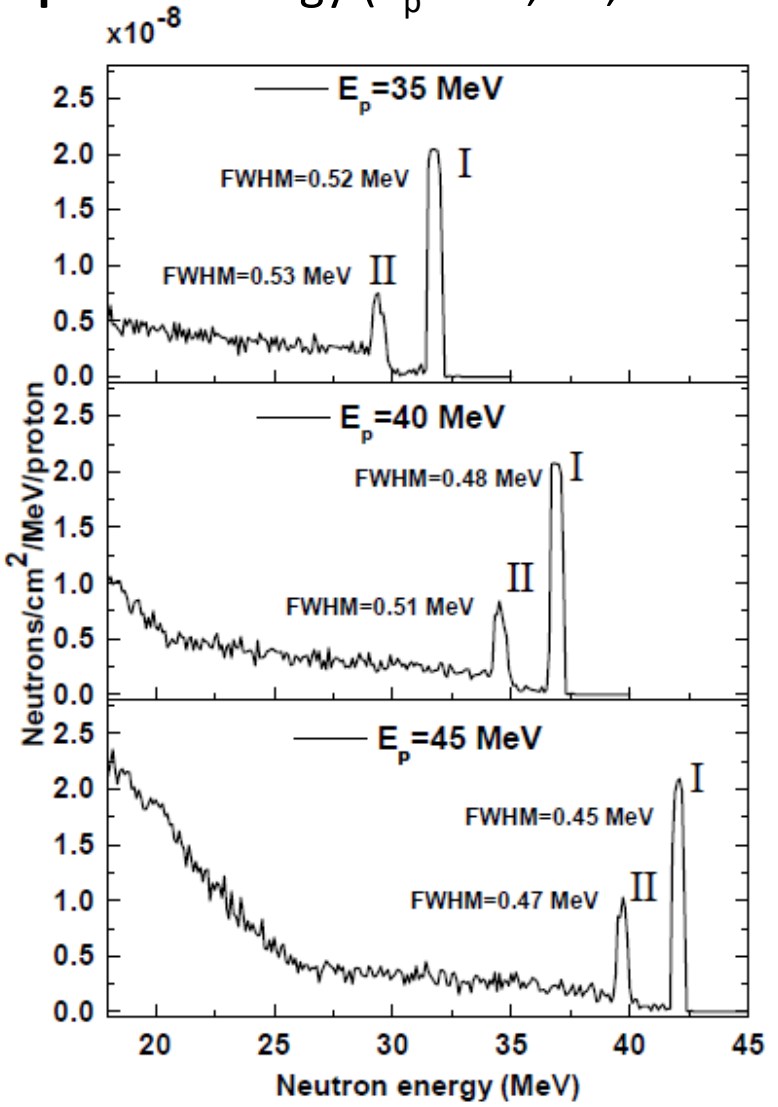
[1] S. Kwon, et al., Nuclear Materials and Energy 16 (2018) 207-211

Monoenergy neutron beams at KIRAMS via ^{9}**Be (p, n)** ^{9}**B**

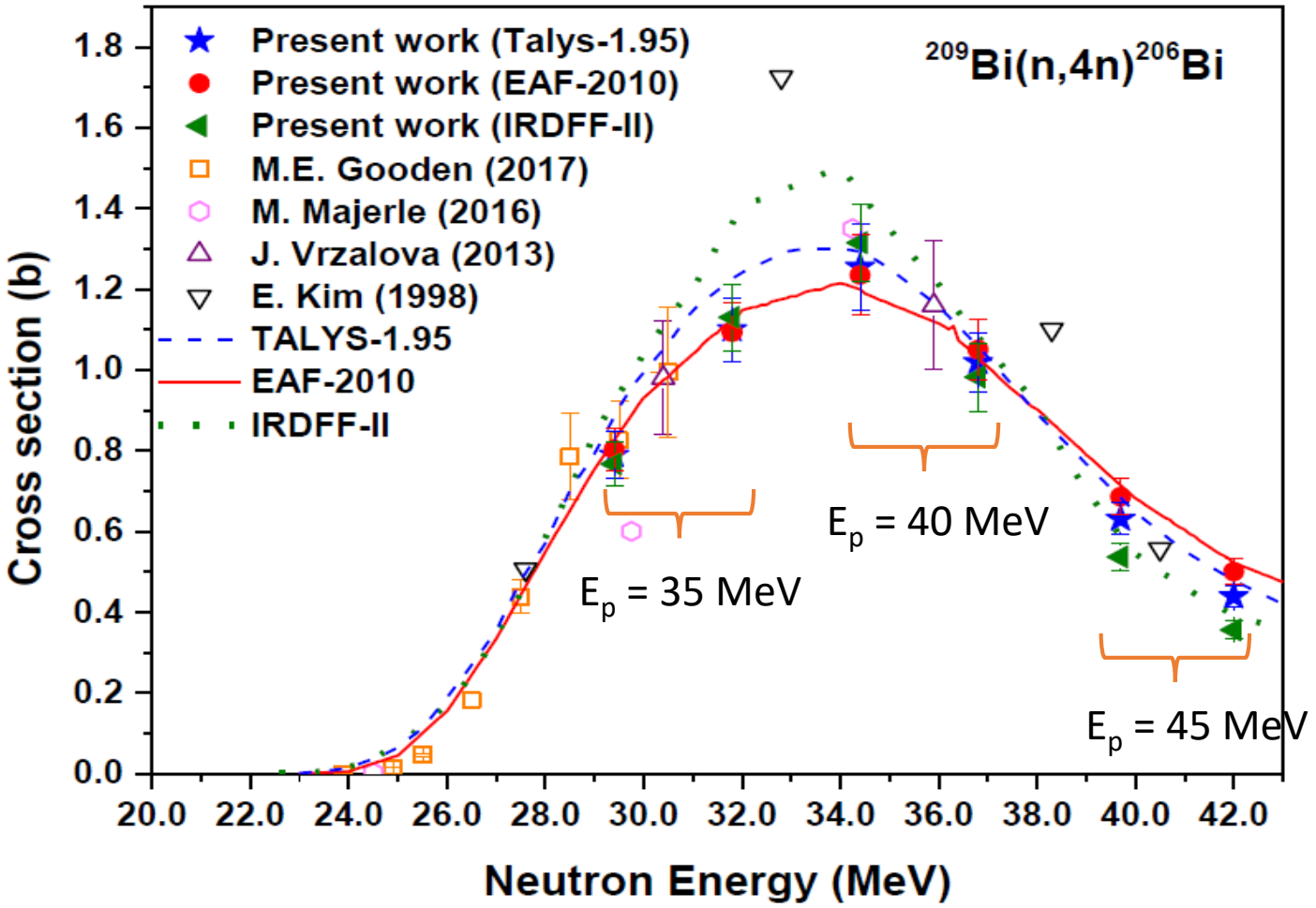
- Initially, **proton beams** will provided at NDPS. (Deuteron beams later.)
- At KIRMAS, two neutron energies with one **proton** energy (E_p = 35, 40, 45 MeV)







Cross sections for ^{209}Bi (n, 4n) ^{206}Bi



V. Chavan et al. “Monoenergetic neutrons from 9Be(p,n)9B reaction induced by 35, 40 and 45 MeV” Nuclear Physics A

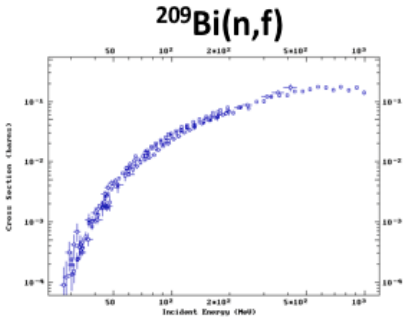
Plan for measuring (n, xn) cross sections

- Cross-section measurements by activation techniques
- Monoenergetic neutrons from $^{9}Be(p,n)^{9}B$ reaction
- Samples : Au, Bi, Co foils
- Proton energy: ~80 MeV
- Reactions
  - $^{209}Bi(n,3\text{-}6n)\,^{207\text{-}204}Bi$
  - $^{197}Au(n,2\text{-}7n)\,^{196\text{-}193}Au$
  - $^{59}Co(n,p)\,^{59}Fe$, $^{59}Co(n,2\text{-}4n)\,^{58\text{-}6}Co$
- Detector for gamma-rays measurement : HPGe detector

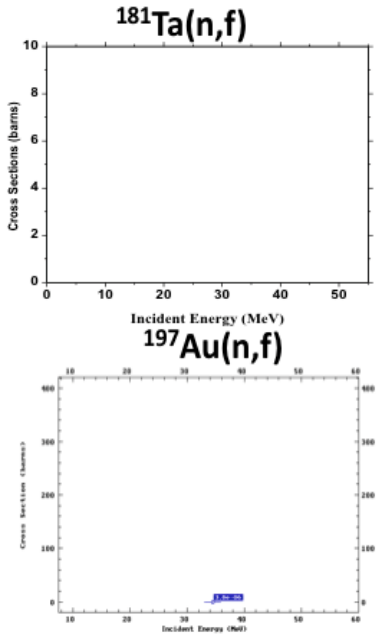
Motivation : **Neutron-induced fission**

■ High energy neutron induced (n,f) cross sections

- Measurement of Cross section and fission fragment yield for ^{209}Bi 및 ^{nat}Pb used in the Lead Bismuth eutectic (LBE) for GEN IV reactor
- Toxic ^{210}Po is produced by ^{209}Bi via (n,ɣ), but data are not sufficient.
- Data for new fuel (^{232}Th) and structure materials (such as ^{181}Ta)



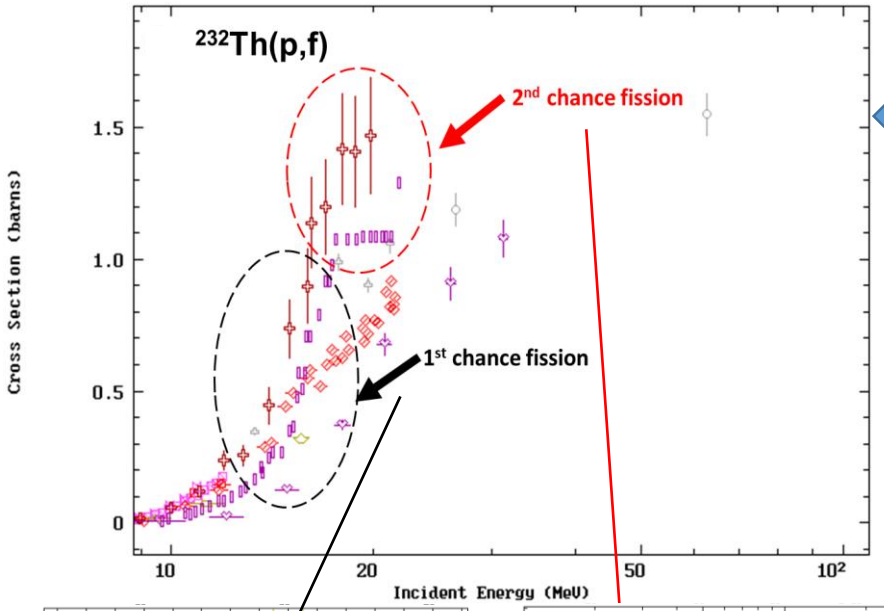
Fission Cross section EXIST
Angular distribution of fission fragment No DATA



Fission Cross section No DATA
Angular distribution of fission fragment No DATA

Motivation : **Neutron-induced fission**

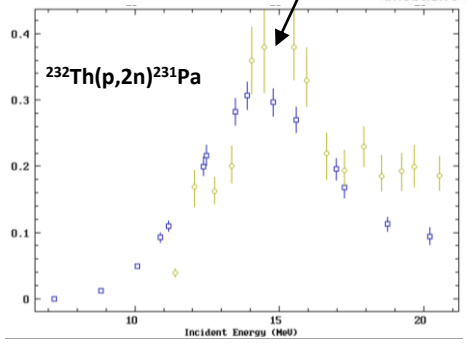
■ High energy neutron induced reaction: Th-232 (n,f)

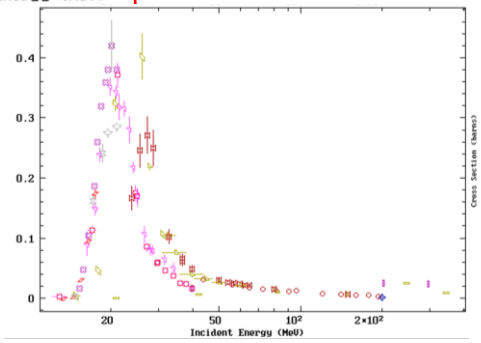


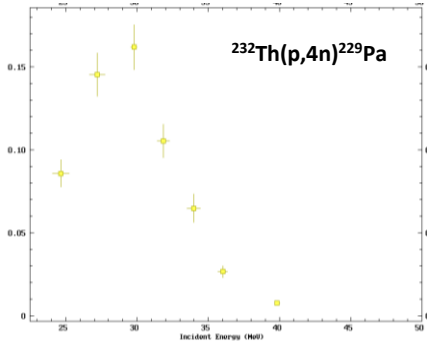
- Lack of sufficient data for fission cross section above 20 MeV
- Discrepancy among the cross sections

Probe to understand multichance fission →
Symmetric to asymmetric ratio →

1. Step in fission cross section
2. Measurement of fission yield
3. Measurement of (p,xn) reaction cross section

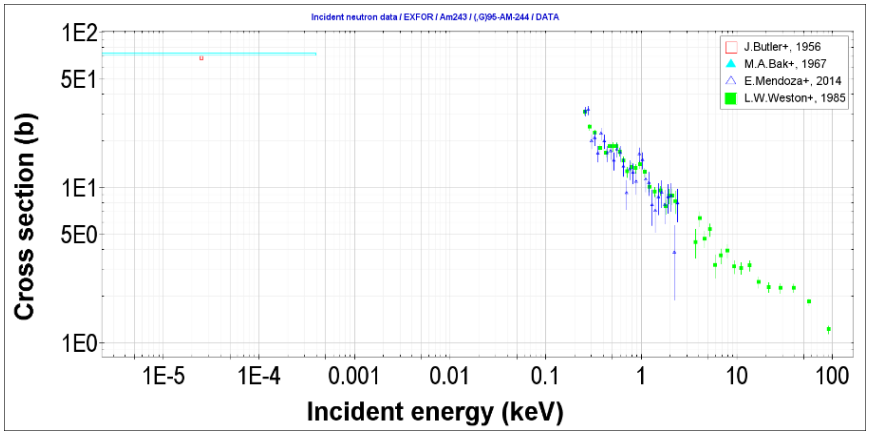




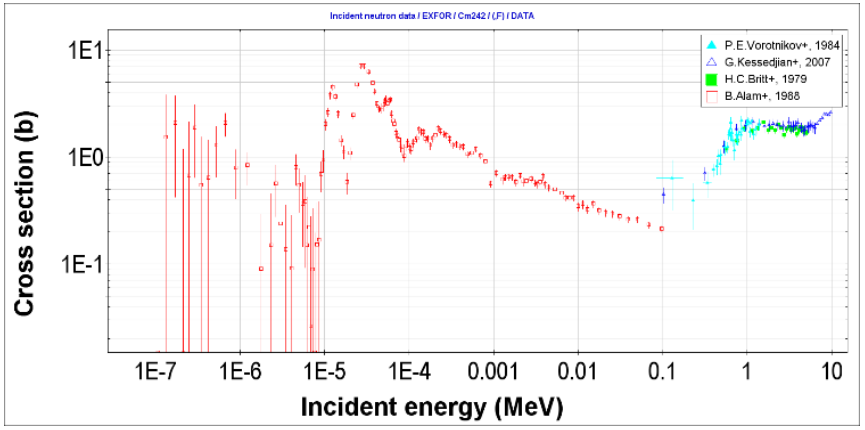


Lack of nuclear data for high energy neutrons

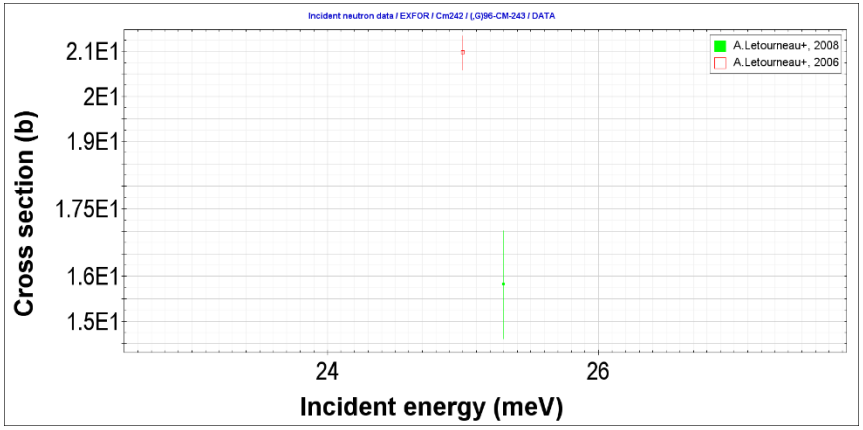
243Am (n, ɣ)



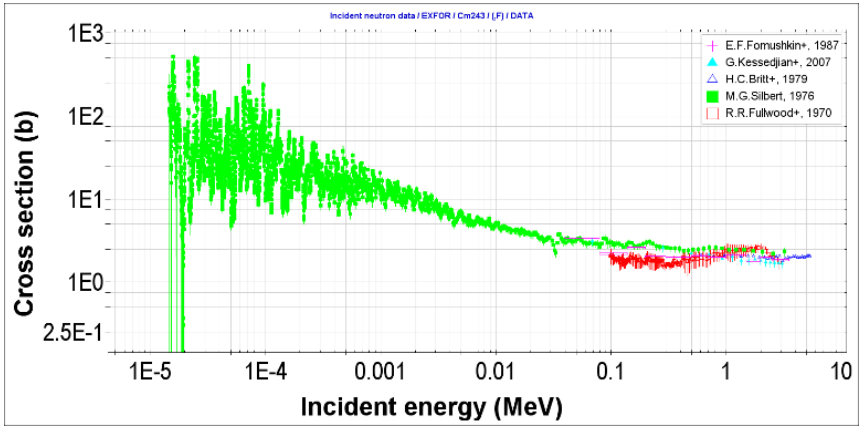
242Cm (n, f)



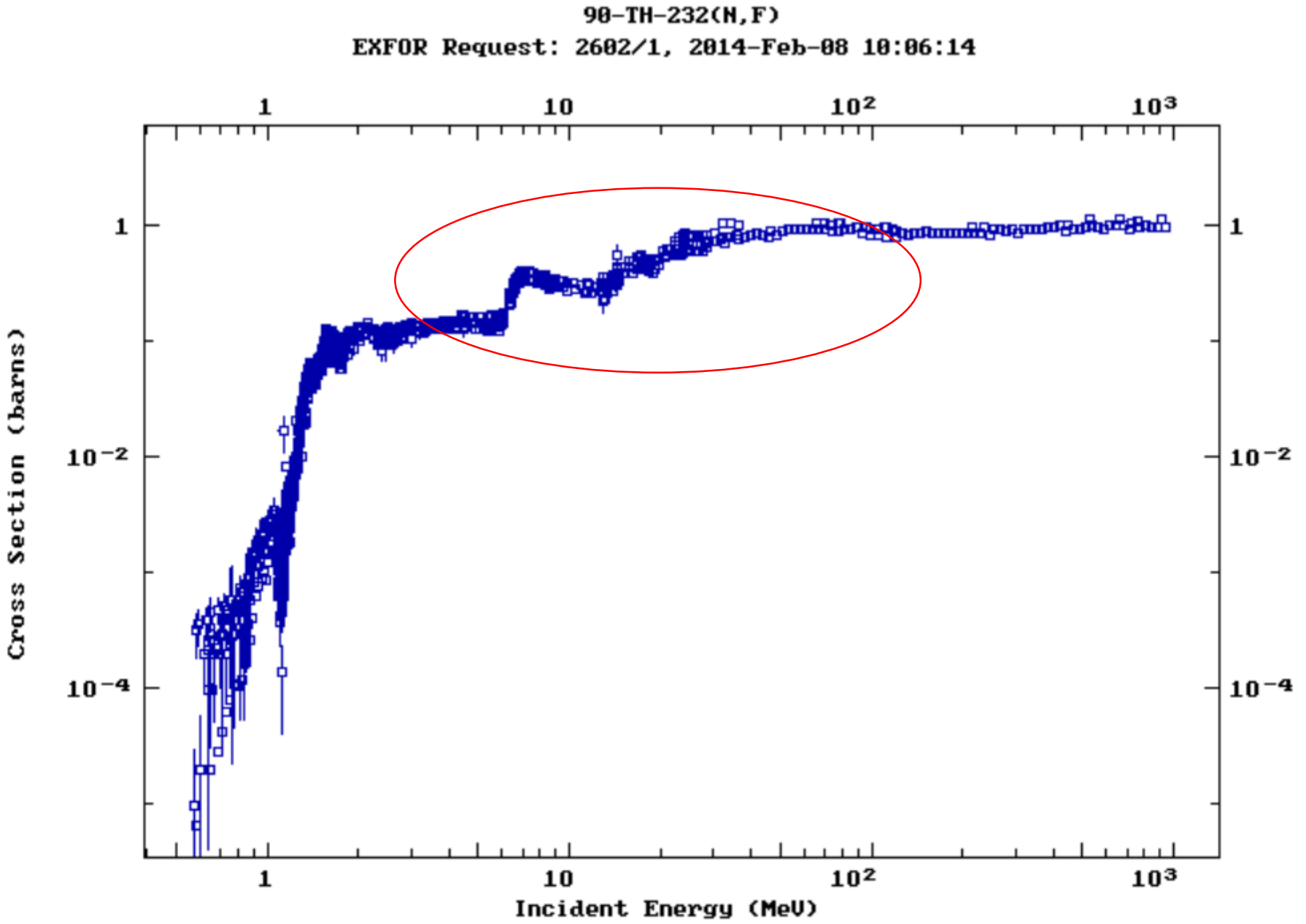
242Cm (n, ɣ)



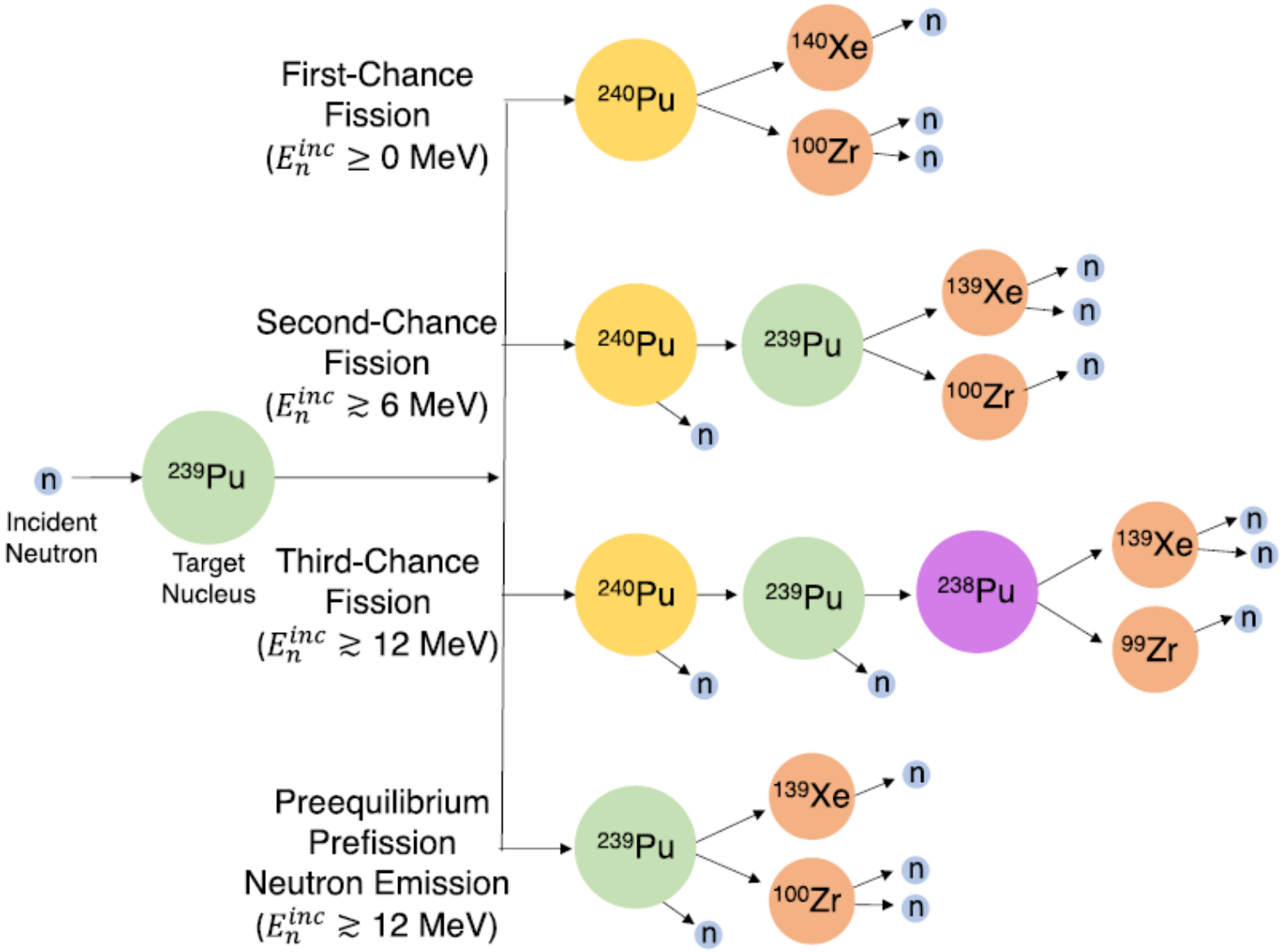
243Cm (n, f)



232Th (n, fission)

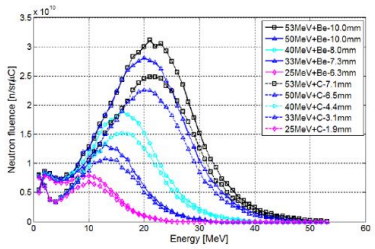


Multichance Fission

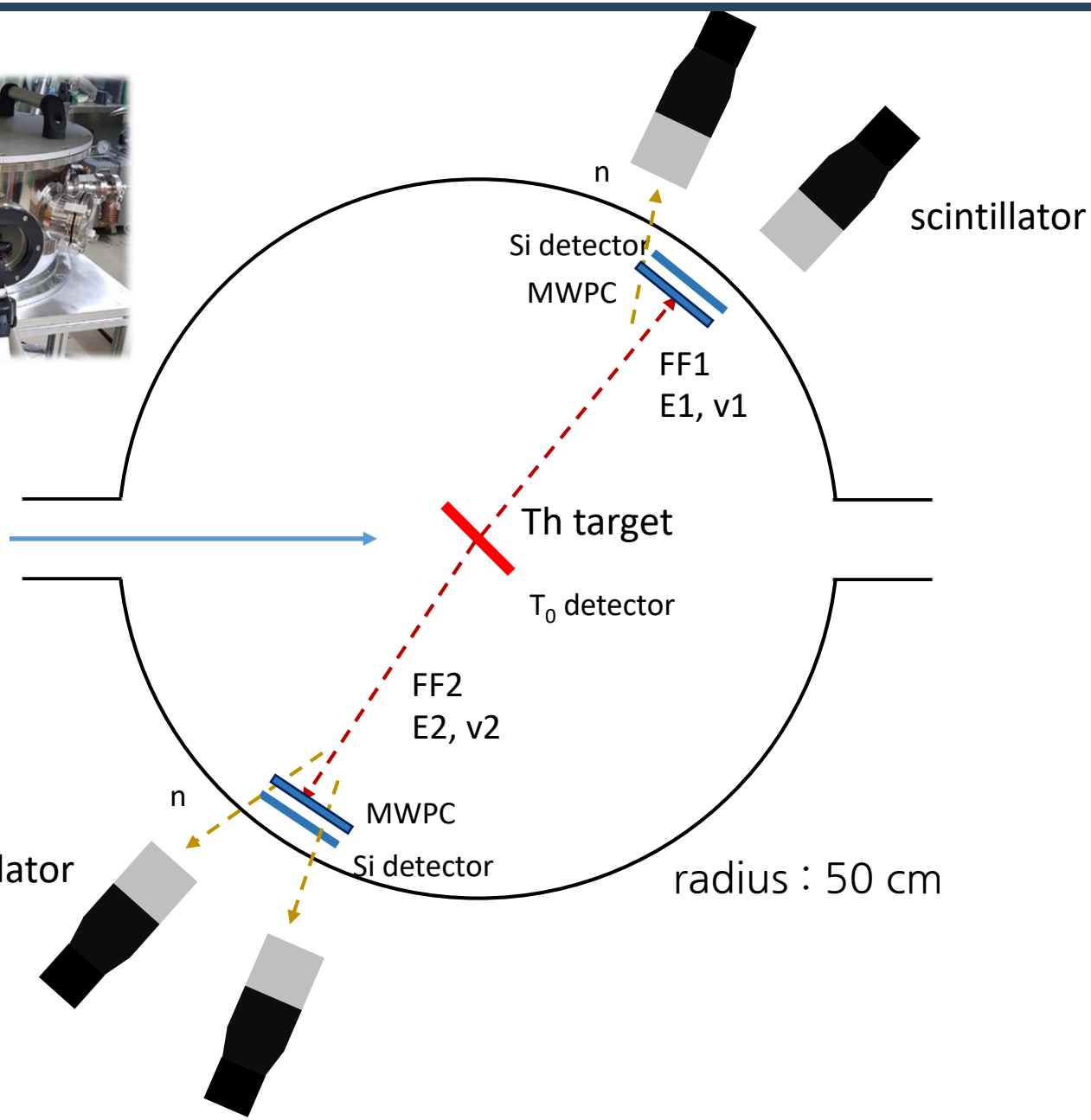


K.J. Kelly, et al., Phys. Rev. Lett., 122, 072503 (2019)

Experimental setup

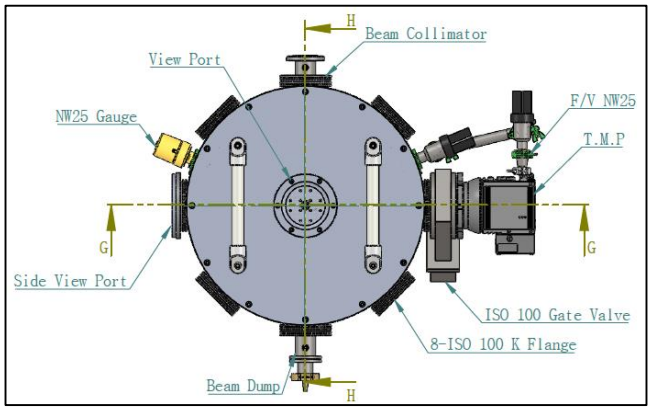


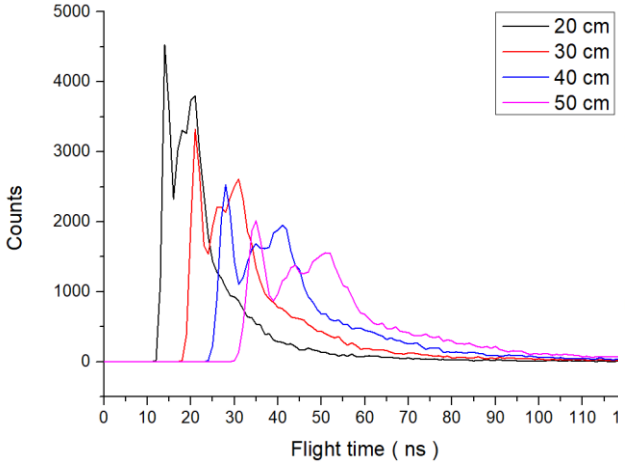
neutron

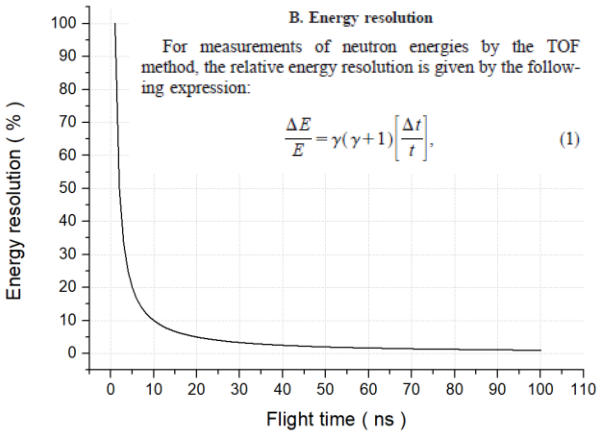


Experimental setup

Fission chamber

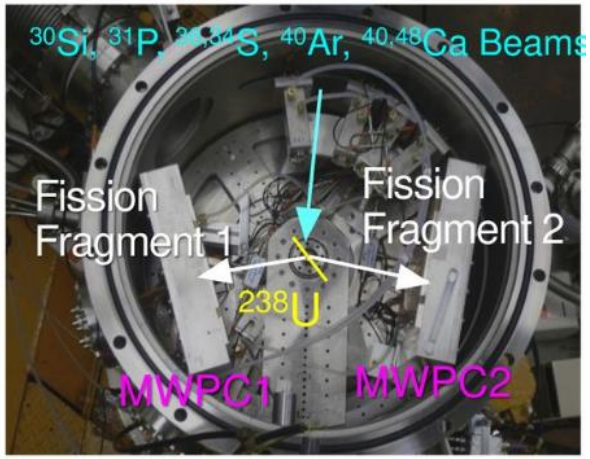




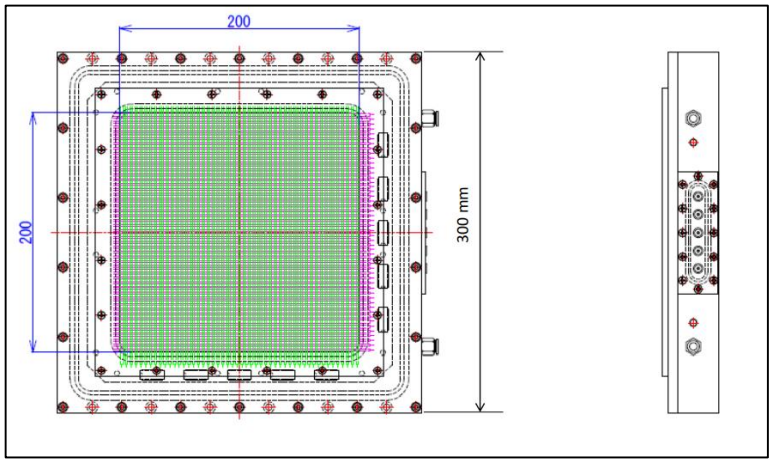


-> 지름 : 1000 mm / 높이 : 400 mm

K. Nishio (JAEA)



MWPC detector



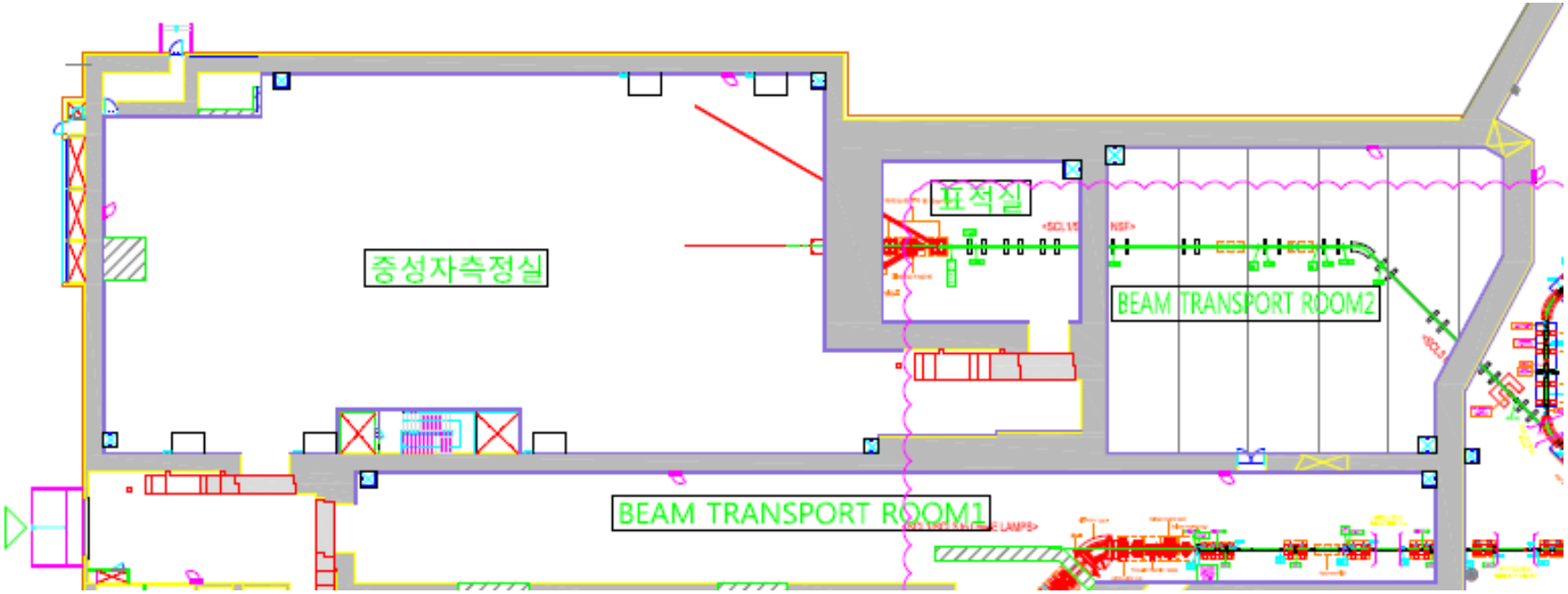
Active area of MWPC

1. 140mm x 140mm
2. 200mm x 200mm
3. 400mm x 200mm

T0 detector : MCP

Plan (2021-2023)

	2021	2022	2023
가속기 장치	P2DT → NDPS 구간 구축 준비	P2DT → NDPS 구간 구축완료	
실험 장치	NDPS 내부 - Beam line (KAERI) - Pulse beam (UNIST) - 검출기 (SKKU) 구축 완료	KIRAMS - mono-energy neutron beam - Th(n,f) ▪ Cross section ▪ Fission fragment distribution	NDPS - White neutron beam - TOF 실험 - Th(n,f)



Summary

- 핵자료 생산은 과학, 공학, 응용(의료) 분야의 기초 자료로서 매우 중요함.
- NDPS 국제공동연구그룹을 구성하여 국제공동연구를 추진함.
- (n, xn) 실험 및 핵분열 실험 주제 발굴
- 2023년 NDPS에 양성자 빔이 공급될 예정으로 초기 실험 계획 수립.
- 추가적인 이용자 확보 및 검출기 구축 필요.