第一届“粤港澳”核物理论坛

14 MeV下^{93}Nb(n,2n)$^{92g+m}$Nb反应截面的高精度测量

陈 建 琪

大湾区大学(筹)

chenjianqi@gbu.edu.cn

2022/7/5

学校简介

2018年谋划筹建，

2019年明确在东莞设立，

2021年大湾区大学（筹）成立

2022年列入广东省政府报告

力争2023年正式开办

- 2018年，广东省谋划在大湾区布局设立一所世界一流的高水平大学。
- 2019年，省教育厅和东莞市联合成立大湾区大学筹建工作领导小组。
- 2020年，时任省长马兴瑞提出支持东莞市加快推进大湾区大学“高起点谋划、高格局定位、高水平建设”的筹建工作；省政府常务会议审议通过《大湾区大学初步办学方案》。
- 2021年，正式成立独立事业单位“大湾区大学（筹）”作为筹建实体。
- 2022年，广东省政府工作报告明确提出推进“大湾区大学”建设。

筹建负责人简介

田刚院士

大湾区大学筹建负责人
美国哈佛大学博士，数学家，
中国科学院院士、美国艺术与科学院院士，
北京大学数学科学学院学术委员会主任、教授、博士生导师，
北京大学原副校长，中国民主同盟中央委员会副主席。

办 学 定 位

大湾区大学定位为**新型研究型大学**，以理工科为主，兼有管理学科；在本科、硕士、博士多层次上办学，立足东莞、服务广东、面向全国、放眼世界。旨在办成一所独具特色的、引领未来科技发展、产业升级和社会进步的世界一流大学。

—— 学 科 建 设 ——

■ 重点聚焦**物质科学、先进工程、生命科学、新一代信息技术、理学、金融**等六个领域，覆盖工学、理学、管理学等三个学科门类

■ 前期拟依托相关单位建立三大学院：**物质科学学院、先进工程学院、理学院**

校园展望

■ 按“一校两区”进行总体建设

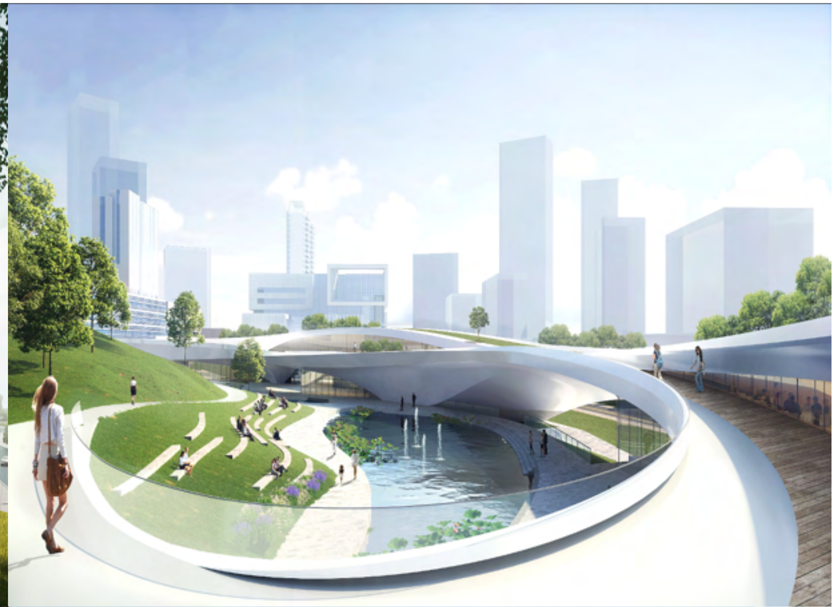
- 总投资：100亿元
- 设立松山湖校区和滨海湾校区，占地2356亩，总建筑面积100万平方米。

松山湖校区

- 选址于东莞松山湖高新区，毗邻松山湖材料实验室、中国散裂中子源、华为总部等。
- 占地约**256亩**，建筑面积约**25万平方米**。
- 预计**2023年9月**前教学区完成建设并投入使用。

- 主要建设与综合性国家科学中心有关大科学装置、新型研发机构融合办学的学科领域，设立相关领域研究院，开展部分领域高年级本科生培养

松山湖校区

滨海湾校区效果图

招聘公告

优先考虑不限于

- ❖ 新能源材料
- ❖ 功能信息材料
- ❖ 先进材料结构

重点鼓励不限于

- ❖ 中子及同步辐射
- ❖ 超快及阿秒激光技术
- ❖ 电子显微镜技术
- ❖ 物质科学计算技术

https://www.gbu.edu.cn/detail/article/118

Outline

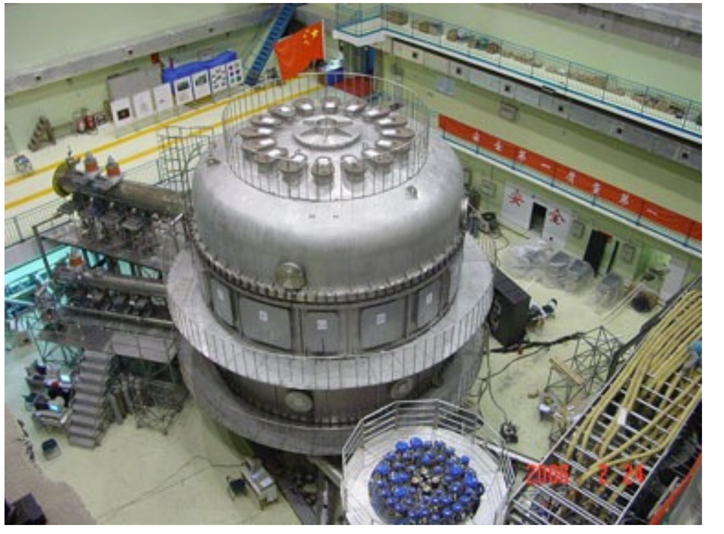
- Background
- The status of $^{93}Nb(n,2n)^{92g+m}Nb$ cross section
- Challenge and method
- The whole experiment layout
- Background and Corrections
- Results and Uncertainty
- Summary

Background

- ^{93}Nb 100% isotopic abundance, an important alloy in fusion reactor.

$E(n,2n)_{th}$ = 9 MeV

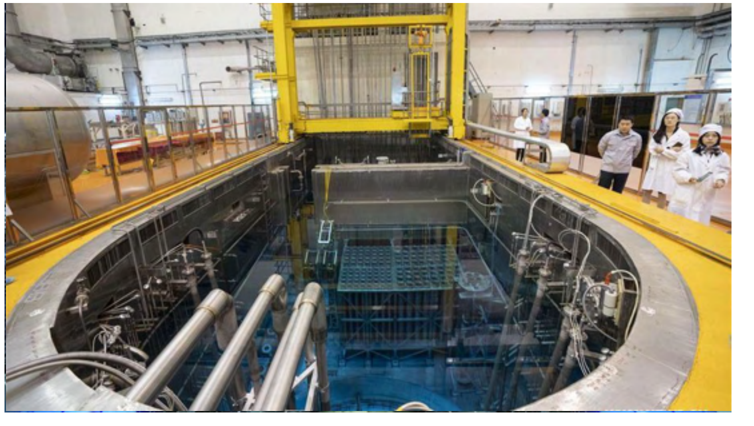
Owe to its high threshold of (n,2n) reaction, so it can be used as indicator for T-D reaction.



The experimental advanced superconducting tokamak (EAST)

- ^{93}Nb also an important alloy in the reactor.

A significant portion of the fission neutron spectrum which lies above the threshold of (n,2n) reaction for most of the reactor materials.

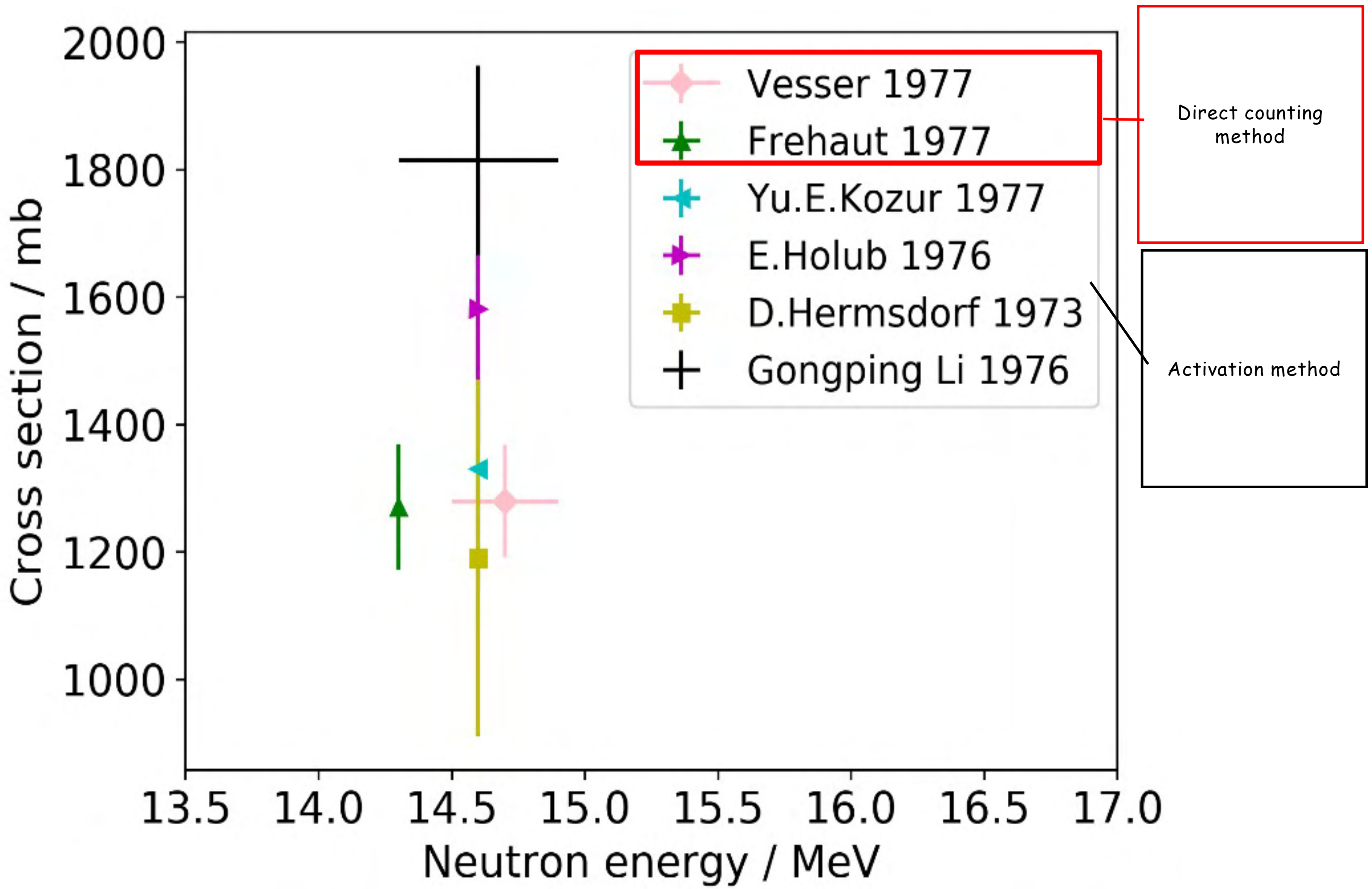


The China Advanced Research Reactor (CARR)

[Hassan Physica Scripta, 2009, 78(4):2517-2530.]

[Ichihara A . Journal of Nuclear Science and Technology, 2016, 53(12):7.]

The status of $^{93}Nb(n,2n)^{92g+m}Nb$ cross section



What are the difficulties?

- activation method

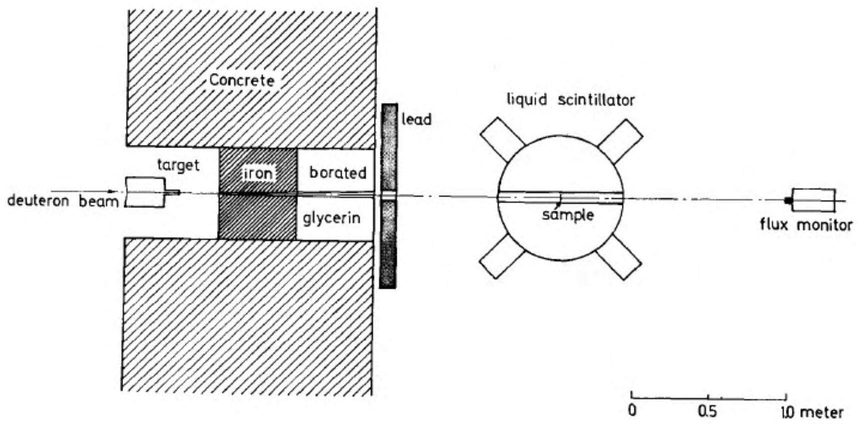
Reaction	half-life	E_γ/KeV
^{93}Nb(n,2n)^{92m}Nb	10.15 d	934.53
^{93}Nb(n,2n)^{92g}Nb	3.2×10^{7} y	934.53

$$\boldsymbol{N} = \boldsymbol{N}_0 \cdot \mathrm{e}^{-6.7\times10^{-9}\cdot \mathrm{t}}$$

The half-life of ^{92g}Nb is so long, which need long time to match statistical require.

This method is impractical for (n,2n) cross section measurement of ^{93}Nb.

- direct counting method

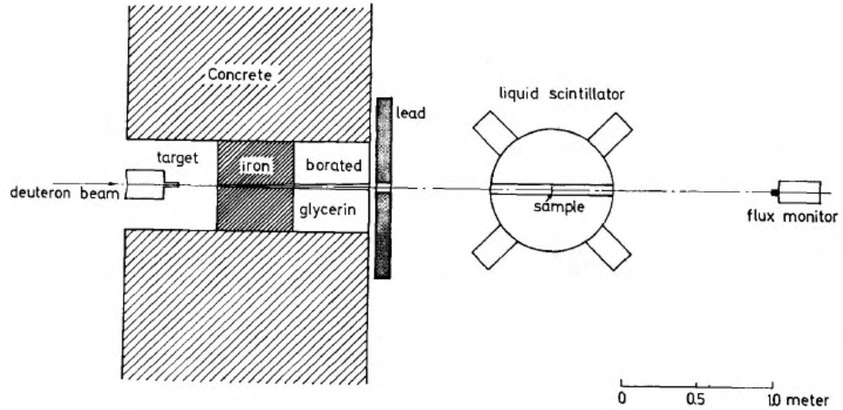


The High γ background.

The delayed γ-rays in the sample will enhance the background and are difficult to distinguish.

【Veeser, Physical Review C,1977,16(5):1792.】

Challenge and method

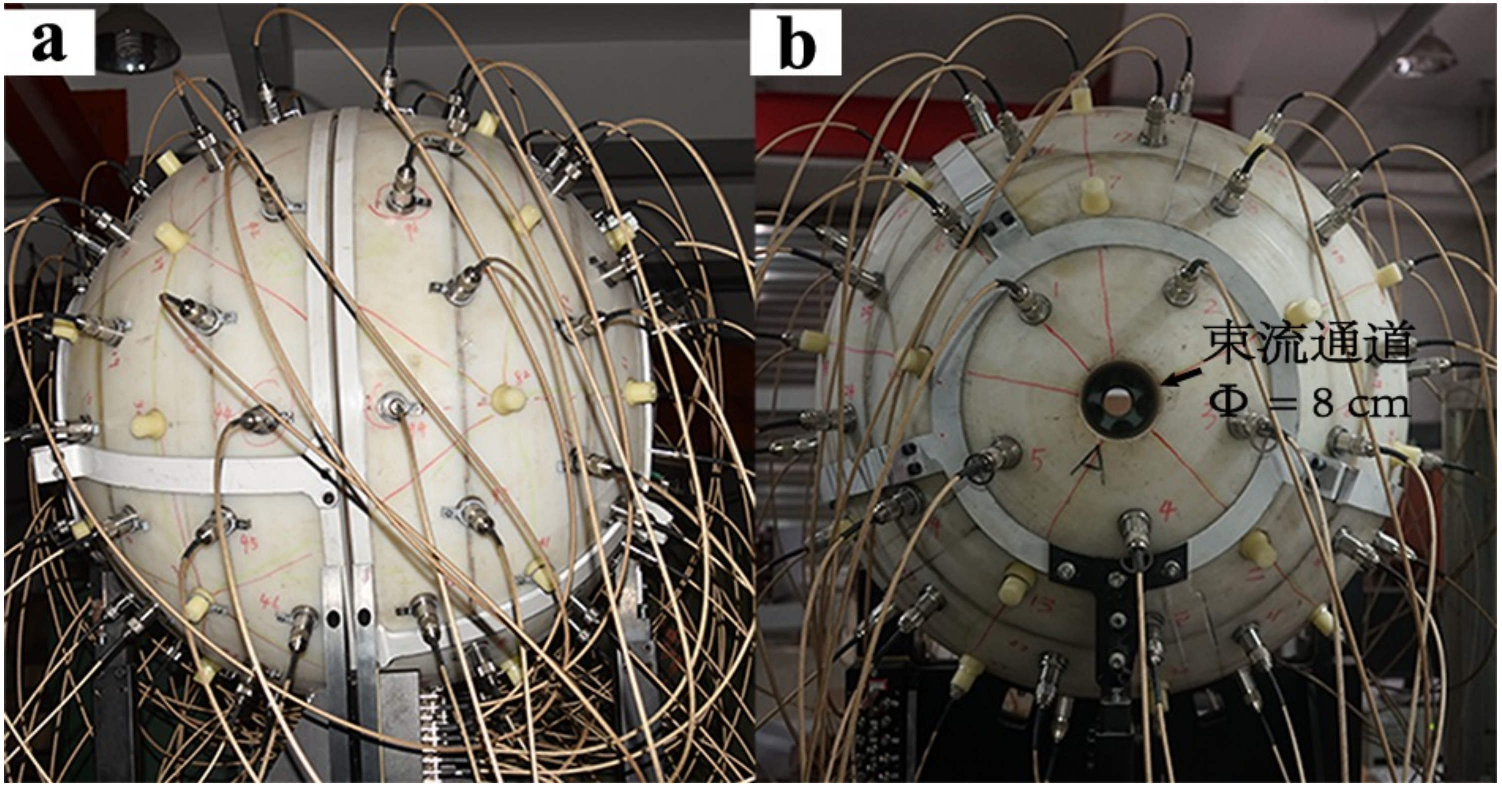


- bad n/gamma discrimination

  New detector
  better n/γ discrimination
  high detection efficiency for neutron emitted from (n,2n) channel

The geometry of the detector

- Front view panel
- Side view panel

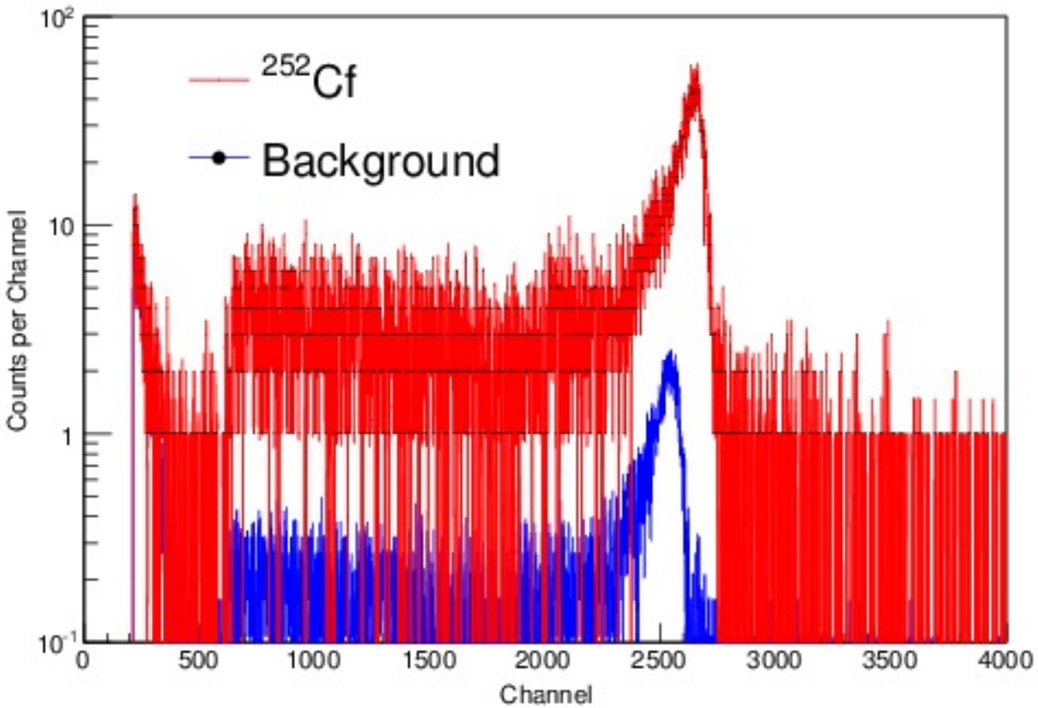


- Basic properties

110 ^{3}He tubes， polyethylene moderator ($\phi_{out} = 80$ cm, $\phi_{out} = 20$cm) , center channel ($\phi = 8$ cm),

The detection principle

$n + {}^3He \rightarrow p + {}^3H$ +765 KeV



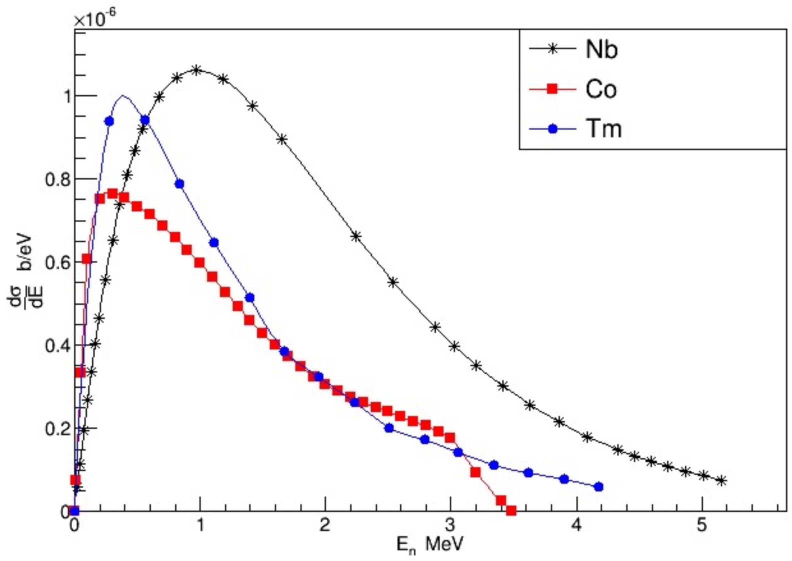
Application

- (a,n) reaction cross section measurement
- fission research
- beta-decay studies
- inelastic neutron acceleration cross section measurement

This type of detector can clearly distinguish neutron signals from γ ray signals and electric noises.

The detector performance — efficiency

- Energy spectrum for secondary neutron from (n,2n) reaction



For Nb, Tm and Co, the average neutron energies emitted through (n,2n) reaction are 1.81 MeV, 1.41 MeV and 1.22 MeV respectively.

- Detector shaped in cylindrical

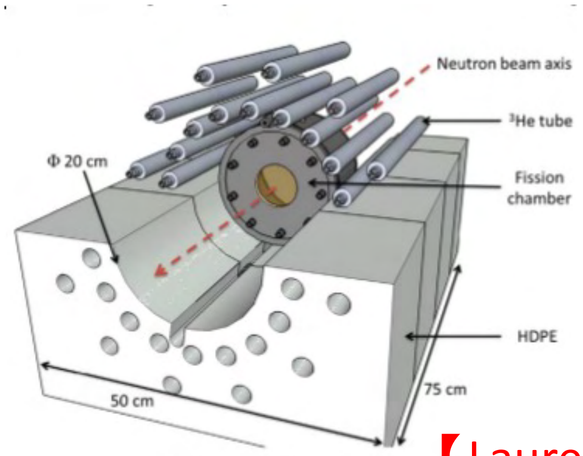
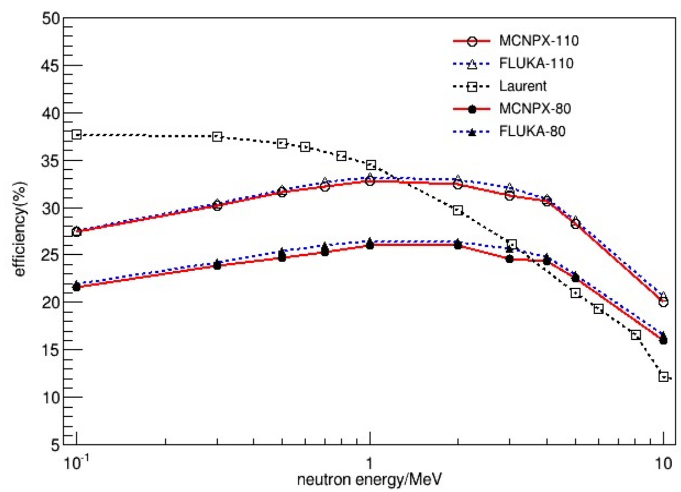


Fig. 1. Schematic view of the ³He counter setup.

【Laurent, NIMA, 745 2014:99-105】

- Detection efficiency vs energy



The detector performance — efficiency

- Detection efficiency of secondary neutron from (n,2n) reaction

Sample	MC codes	$\varepsilon_0(\%)$	$f_e(\%)$	$\varepsilon(\%)$
Nb	MCNPX	31.76	97.45	30.95
Tm	MCNPX	31.26	97.45	30.46
Co	MCNPX	31.62	97.45	30.81
Co-cendl	MCNPX	31.30	97.45	30.50
Nb	FLUKA	32.10	93.86	30.13
Tm	FLUKA	31.80	93.86	29.85
Co	FLUKA	32.30	93.86	30.32
Co-cendl	FLUKA	31.90	93.86	29.94

- ^{252}Cf fission neutron calibration

	experiment	FLUKA(fe)	MCNPX(fe)
Efficiency	29.03±0.5%	30.93±2%	29.79±1.7%

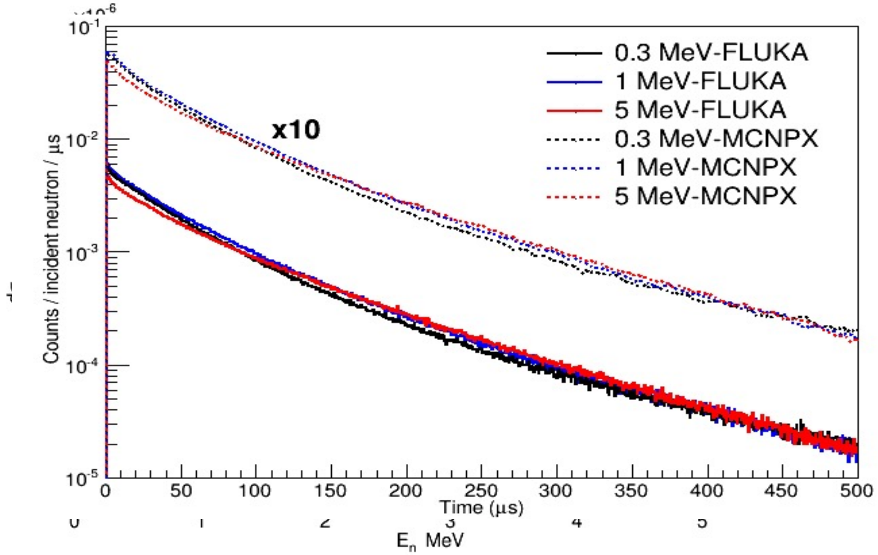
$$\boldsymbol{\varepsilon = \varepsilon_0 \cdot f_e}$$

$\boldsymbol{\varepsilon_0}$ ***Detection efficiency obtained through MC simulation***

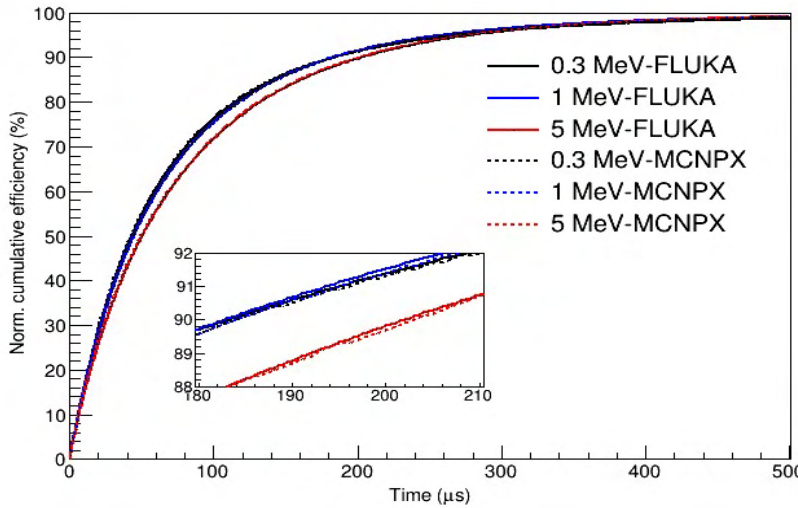
f_e $^{252}\mathrm{C}f$ effiency calibration factor

The detector performance — moderation time

- Moderation time distribution for different neutron energy



- Cumulative efficiency relative to the maximum as a function of time

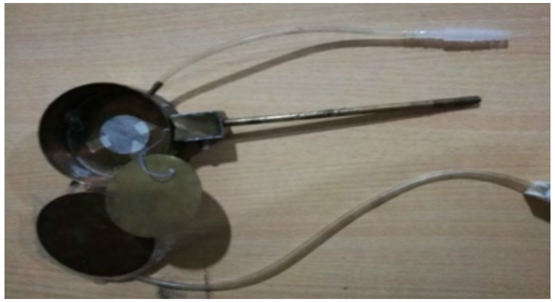


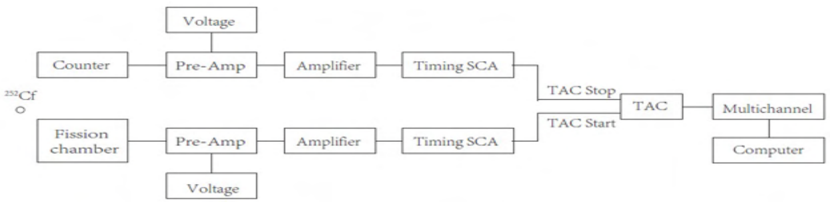
Remark

- First, about 90% of neutrons are detected within 200 μs after neutron emission.
- Second, the fraction of the neutrons detected during a given time is nearly independent of neutron energy.

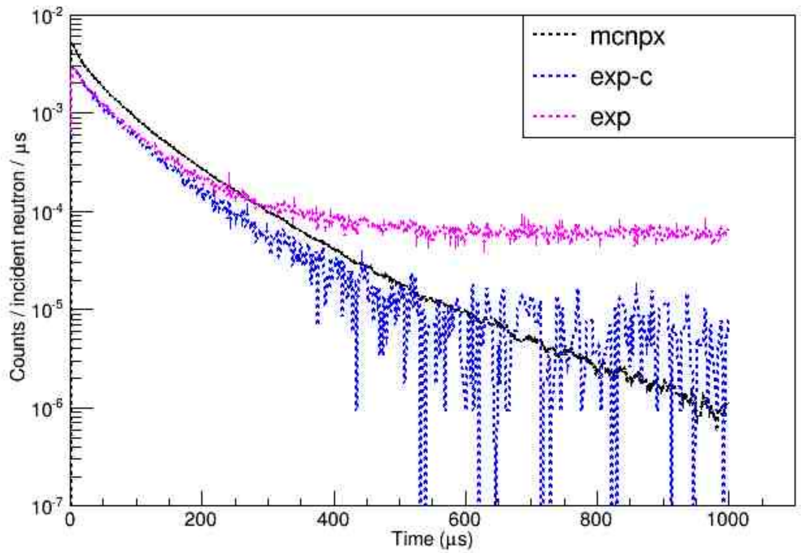
The detector performance — moderation time

- Experiment for moderation time





- Experiment result

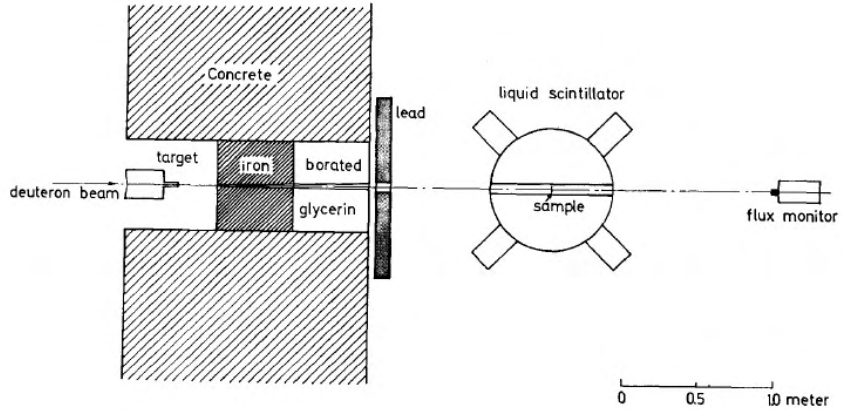


- The time needed to count 90% neutrons

	MCNPX	exp-c
Moderation time	198 µs	194 µs

- Gate time 200 µs

Challenge and method



- bad n/gamma discrimination

  A new neutron detector

  better n/γ discrimination ✓

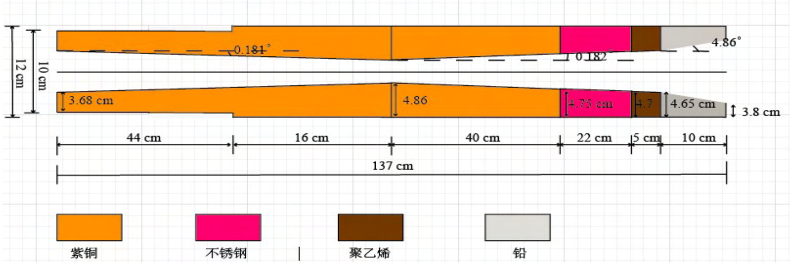
  high detection efficiency for neutron from (n,2n) channel ~30% ✓

- high neutron induced background

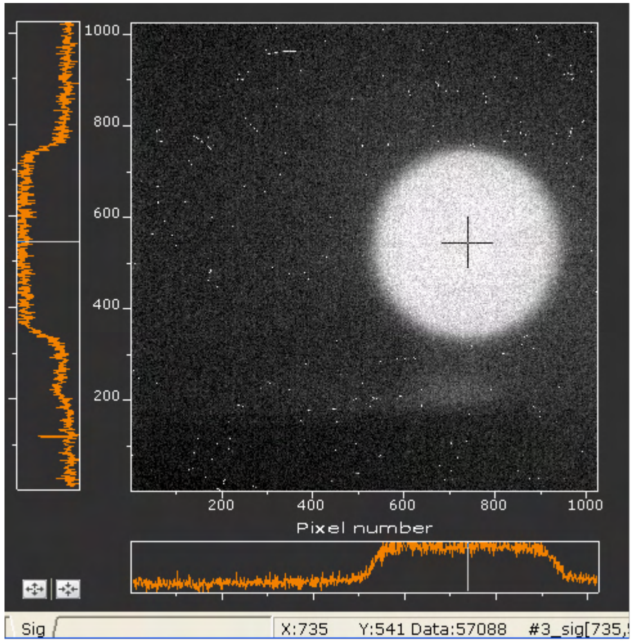
  A great neutron collimator and dump.

Collimator effectiveness

- The design and actual photo of collimator



- Checked through the neutron radiography



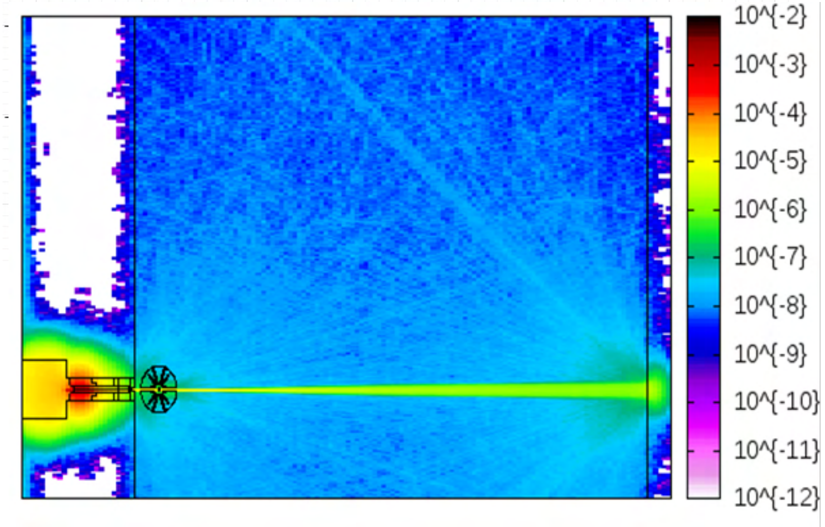
From x axial umbra diameter 3.47 cm, penumbra diameter 0.93 cm

From y axial umbra diameter 3.35 cm penumbra diameter 1.02 cm

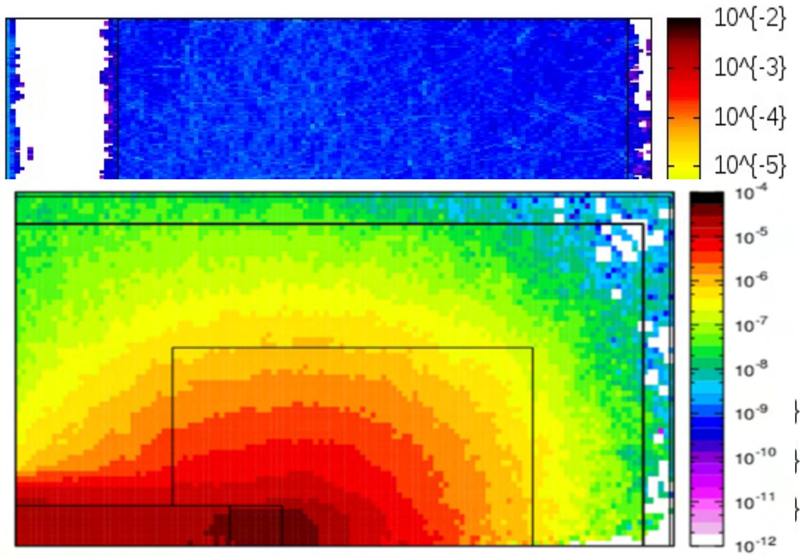
Can well cover the sample size

Influence of scattered neutrons from wall

- relative flux without capture



- relative flux with capture

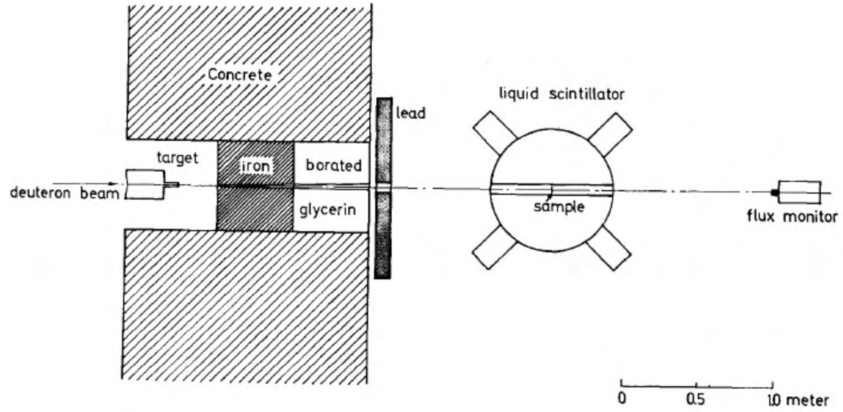


- The total neutrons captured by the detection system when 1000000 neutrons irradiated along the collimator inlet

Condition	Without capture	With capture
FLUKA	178	177
MCNPX	176.5	176.3

The function of capture is invalid.

Challenge and method



• bad n/gamma discrimination

A new neutron detector

better n/γ discrimination ✓

high detection efficiency for neutron from (n,2n) channel ~30% ✓

• high neutron induced background

A great neutron collimator and dump. 1/5000 ✓

• systematic uncertainty evaluation

Two independent relative measurements

Samples

- **Nb sample** Sample needed to be measured.
- **Tm sample** Standard sample 1. $\sigma_{Tm}(n,2n) = 1988 \pm 99\ \mathrm{mb}$

【ENDF Data.】

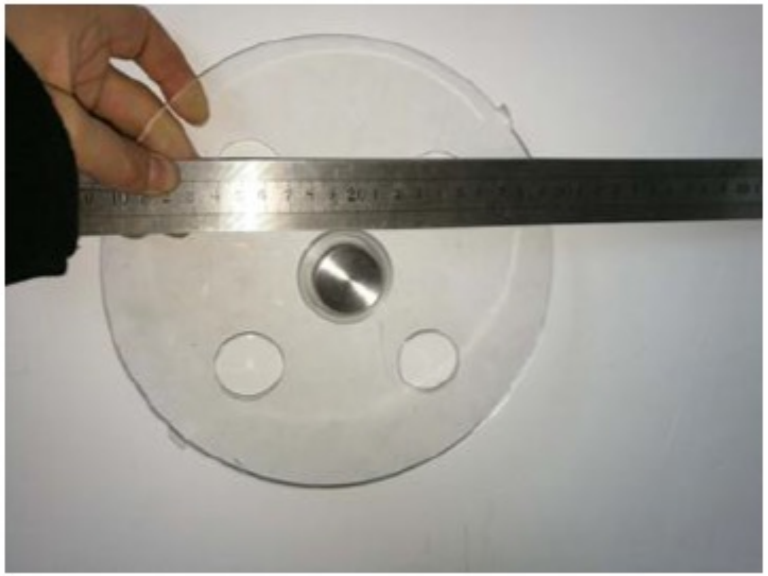
- **Co sample** Standard sample 2. $\sigma_{Co}(n,2n) = 775 \pm 7.69\ \mathrm{mb}$

【Hasan, S. J. *Journal of Physics G: Nuclear Physics, 12*(5), 397.】

- ***C* sample** Sample used to evaluated the accidental 2n events.

For *C* sample $\boldsymbol{U_{(n,2n)th} > 20\ MeV}$

- **Sample holder**

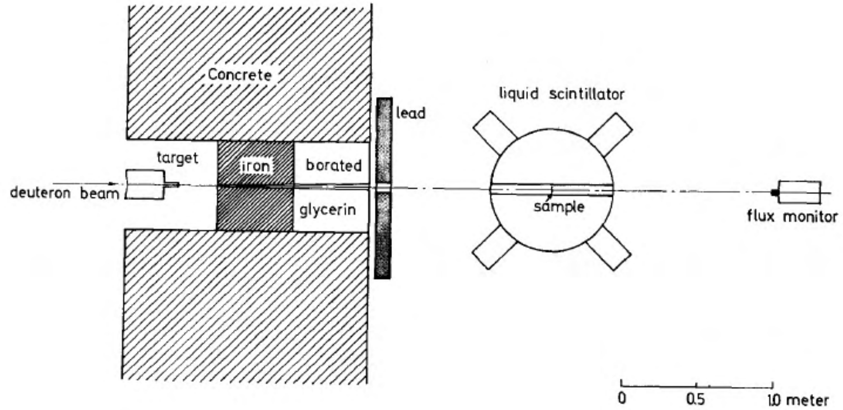


- **Basic parameters**

Same dimension: 3 cm **in diameter, 2 cm in height.**

A successive run was taken for every sample and can for a live time of 4 h each.

Challenge and method



- bad n/gamma discrimination

  A new neutron detector
  better n/γ discrimination ✓
  high detection efficiency for neutron from (n,2n) channel ~30% ✓

- high neutron induced background

  A great neutron collimator and dump. ✓

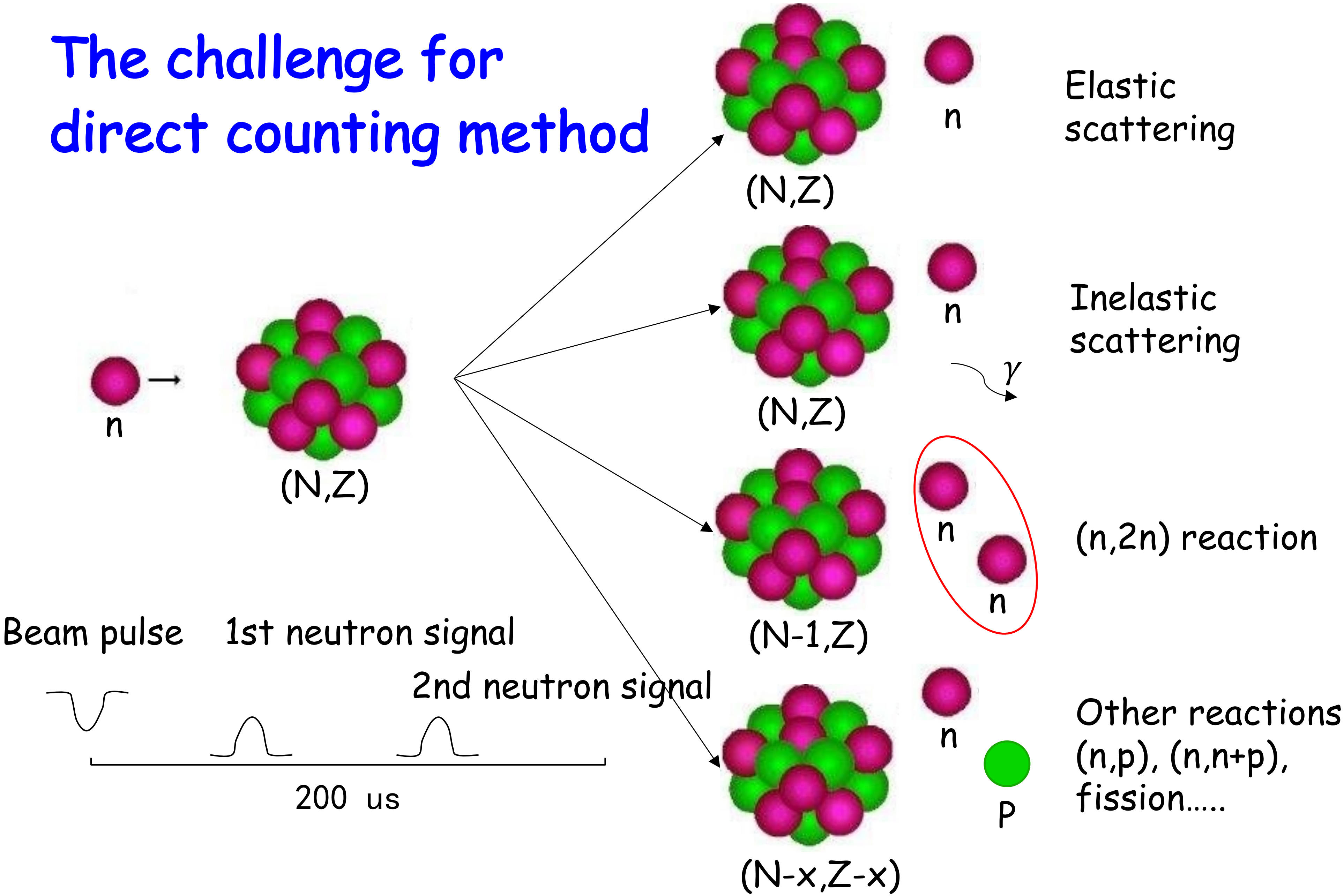
- systematic uncertainty evaluation

  Two independent relative measurements for cross-check 1/5000 ✓

- spurious 2n event

  pulse beam
  C sample used to evacuate the contribution of (n,n) and (n,n') for another samples. ($U_{(n,2n)th} > 20\ MeV$)

The challenge for direct counting method



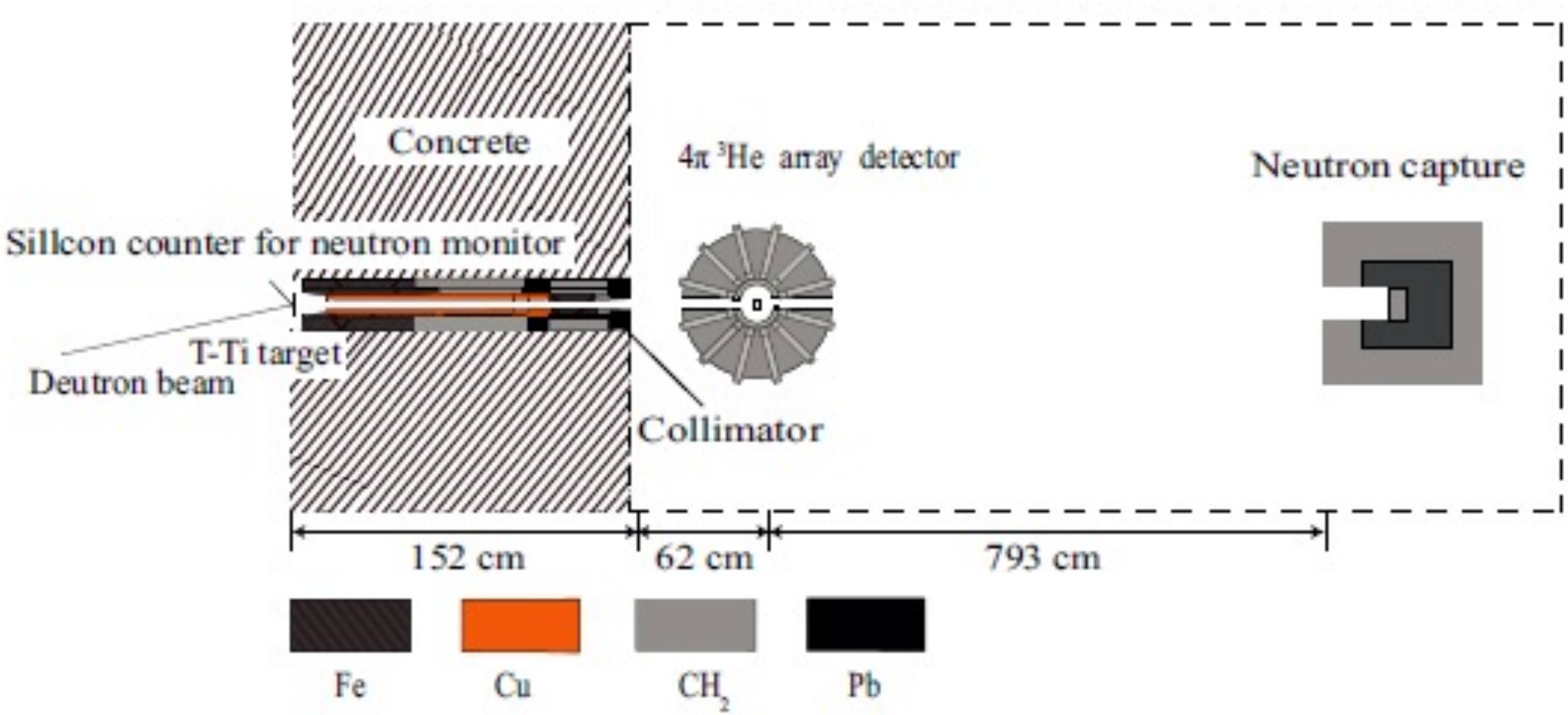
$$N_{2n} = N_b + N_{(n,2n)} = (N_{b-b} + N_{b-s} + N'_{s-s}) + N_{(n,2n)}$$

Background neutrons

The experiment layout

The experiment arrangement

- Experiment in CIAE on January 15th, 2018.



- **Neutron source** Cockroft-Walton type neutron generator

Neutron source

- Accelerator

  Cockroft-Walton type neutron generator

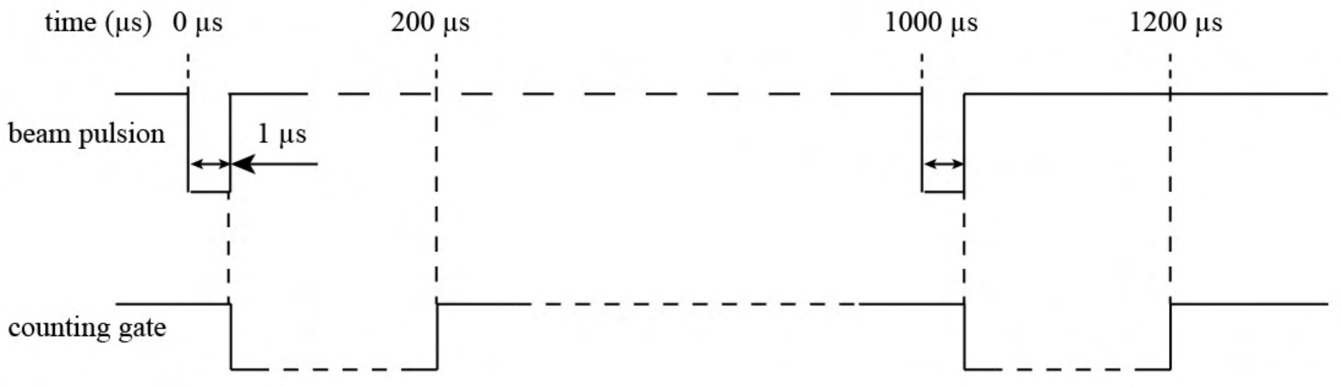
  $d+T \rightarrow n+^{4}He$ +17.59 MeV

- Neutron energy E_n=14.72±0.5 MeV Calculated through TARGET code

- Neutron flux $I_n = 1\times10^7 n/s$ in 4π solid angle at target position.

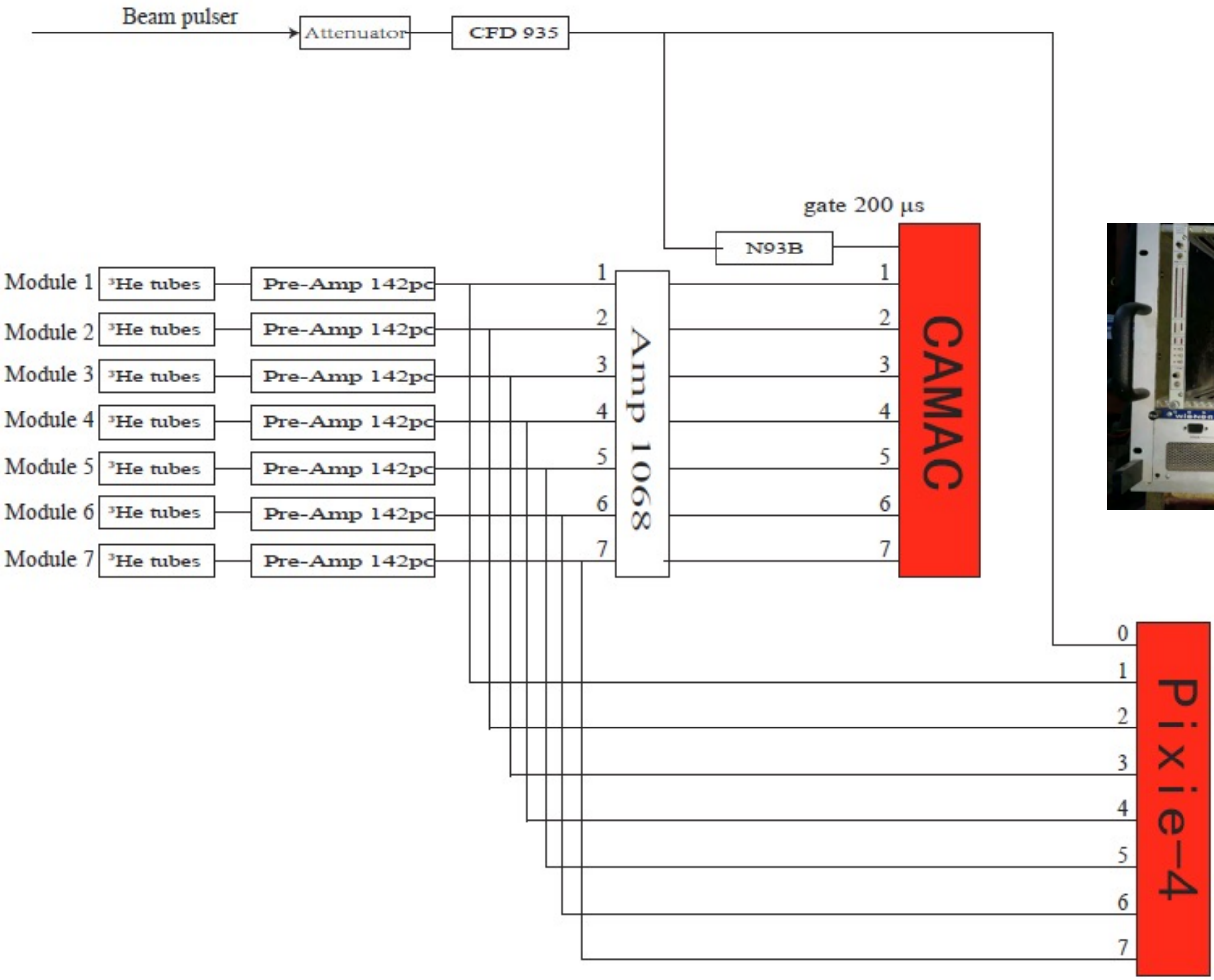
  Monitored by counting associated alpha particles.

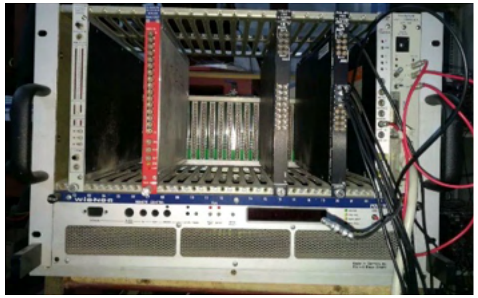
- Pulsed neutron beam



According to inverse square law, $0.12\ n/pulse$ at sample position.

Electric and DAQ system





Corrections

- **A series of corrections (considered)**

  a). A background correction

  b). A correction for dead time losses

  c). An efficient correction

  d). A multiple event correction

  e). A correction for events not included in the samples

- **A series of corrections (unconsidered)**

  a). Not considering the flux attenuation in the sample

  b). Not considering the $N_{(n,2n)}$ events in 3n and 4n events

  c). Not considering the loss of secondary neutron in the sample

Results and uncertainties

- **Results based on different samples and MC codes**

Sample	Total 2n	N_{b-b}	N_{b-s}	N'_{s-s}	N_b	$N_{(n,2n)}$	η
Nb	37638	2016	3015	3633	8664	28974	3.344
Tm	31705	1963	2592	2826	7381	24324	3.295
Co	340101	1882	3068	4377	9328	24773	2.656
C	5070	2532	1762	776	5070		

- **Calculated based on $\sigma_{Tm}(n,2n)$ and $\sigma_{Co}(n,2n)$**

$$\sigma_{Nb}(n,2n) = \frac{N_{Nb(n,2n)}}{N_{Tm}(n,2n)} \cdot \frac{S_{Tm}}{S_{Nb}} \cdot \frac{\epsilon_{Tm}}{\epsilon_{Nb}} \cdot \frac{\epsilon_{Tm}}{\epsilon_{Nb}} \cdot \sigma_{Tm}(n,2n)$$

$\sigma_{Tm}(n,2n) = 1988 \pm 99$ mb $\quad S_{Tm} = 1.09\text{E}+23\ /\text{cm}^2 \quad S_{Nb} = 6.72\text{E}+22\ /\text{cm}^2$

$$\sigma_{Nb}(n,2n) = \frac{N_{Nb(n,2n)}}{N_{Co}(n,2n)} \cdot \frac{S_{Co}}{S_{Nb}} \cdot \frac{\epsilon_{Co}}{\epsilon_{Nb}} \cdot \frac{\epsilon_{Co}}{\epsilon_{Nb}} \cdot \sigma_{Co}(n,2n)$$

$\sigma_{Co}(n,2n) = 775 \pm 7.69$ mb $\quad S_{Co} = 1.87\text{E}+23\ /\text{cm}^2$

Results and uncertainties

- **Results based on different samples and MC codes**

Based sample	MCNPX-ENDF	MCNPX-CENDL	FLUKA-ENDF	FLUKA-CENDL
Co	1513±40 mb	1490±39 mb	1502±40 mb	1471±39 mb
Tm	1418±76 mb	1418±76 mb	1426±76 mb	1426±76 mb

Results and uncertainties

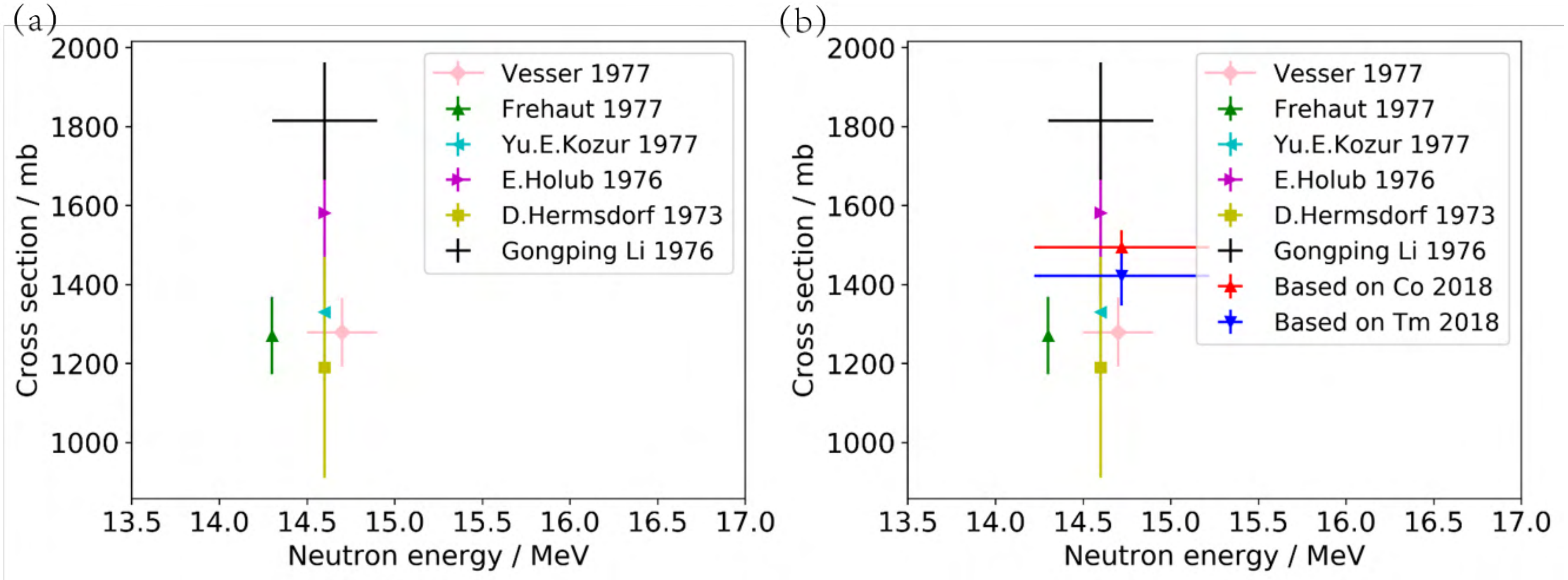
- **Based on Tm**

Uncertainty source	Uncertainty %
Efficiency calculation	0.11
The $^{169}Tm(n,2n)^{168}Tm$ cross section	5
The total 2n events for Nb	0.56
The total 2n events for Tm	0.61
The total 2n events for C	1.56
Total	5.38

- **Based on Co**

Uncertainty source	Uncertainty %
Efficiency calculation	0.11
The $^{59}Co(n,2n)^{58}Co$ cross section	0.95
The total 2n events for Nb	0.56
The total 2n events for Co	0.59
The total 2n events for C	1.56
Total	2.56

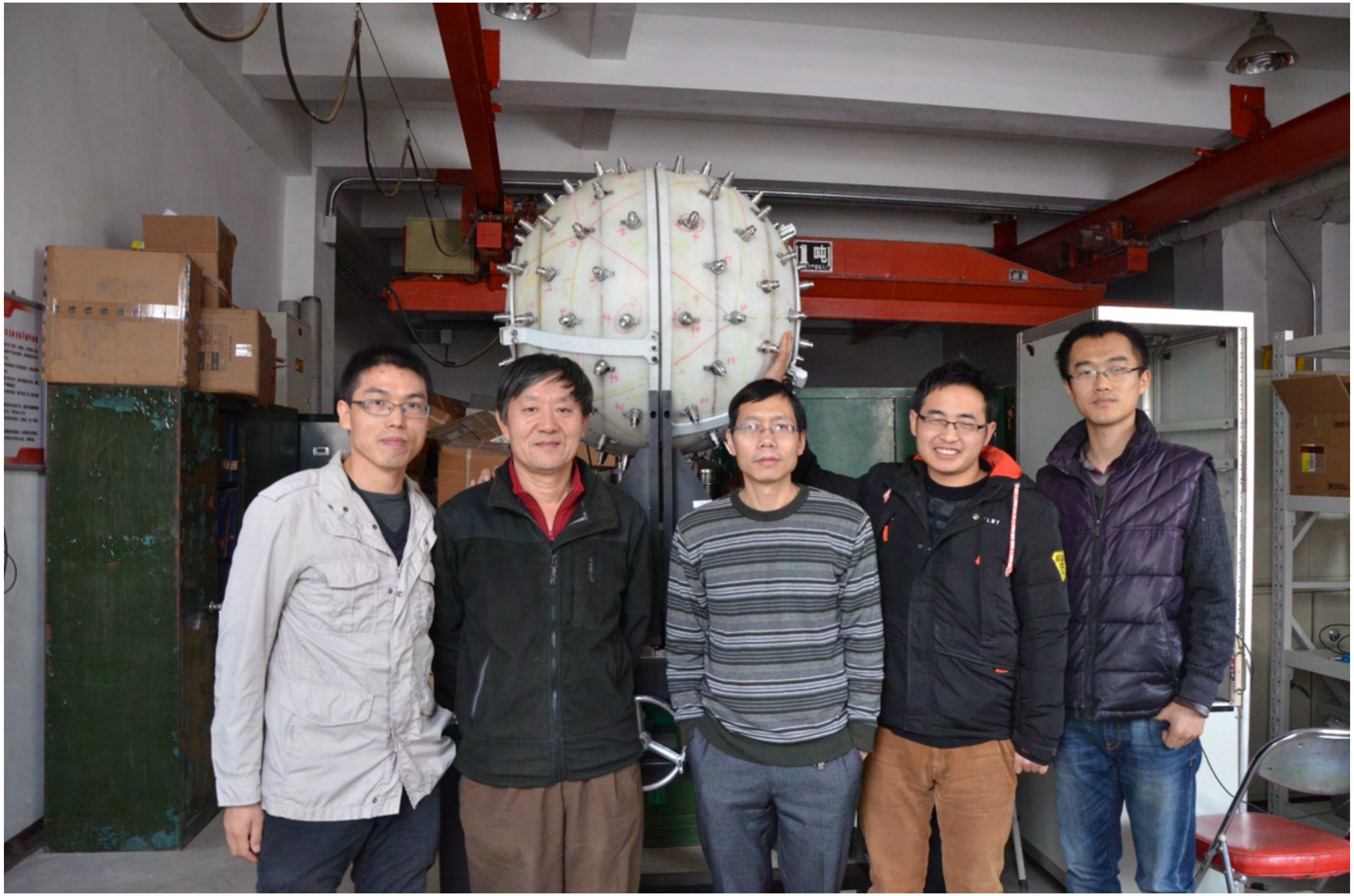
Results and uncertainties



Summary

- Develop a spherical ^{3}He tubes array detector, which has an flat efficiency in interesting energy range and find that this type of detector is suitable to use at (n,2n) reaction cross-section measurement.
- Provide the new experiment data for $^{93}Nb(n,2n)^{92g+m}Nb$ cross section with the least uncertainty.

Our research team



Colleagues taken part in this experiment

欢迎各位老师批评指正！

也欢迎大家来大湾区大学访问交流！

Backup spare

总体背景

粤港澳大湾区总面积5.6万平方公里；

目前，粤港澳三地现有高校 192所，每百万人口拥有的高校约2.64 所，低于纽约湾区 11.24 所、旧金山湾区 10.71 所、东京湾区 5.95 所，显示粤港澳大湾区高等教育资源总量不足。

东莞作为粤港澳大湾区建设的节点城市，办学层次和结构体系有待完善，高等教育综合实力有待提高———大湾区大学应运而生。