

粒子物理前沿卓越 创新中心答辩

中微子平台

孟月

上海交通大学

2020/12/5

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2. 2020年度个人工作总结
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1. 个人介绍

教育经历

2004.08 - 2008.07 哈尔滨工业大学，学士学位

2008.08 - 2014.08 美国弗吉尼亚理工大学，博士

导师: Jonathan Link

毕业论文: The Daya Bay Reactor Neutrino Experiment

工作经历

2014.09 – 2018.10 美国阿拉巴马，博士后

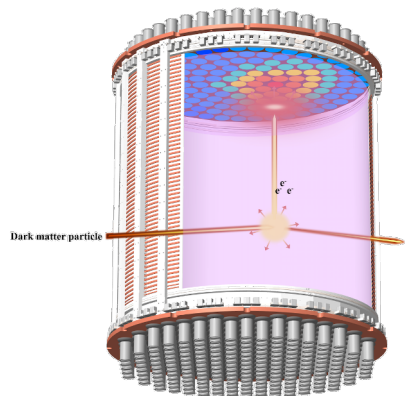
LUX-ZEPLIN(LZ)暗物质实验

导师: Jerry Busenitz and Andreas Piepke

2018.11 – 至今 上海交通大学，助理教授

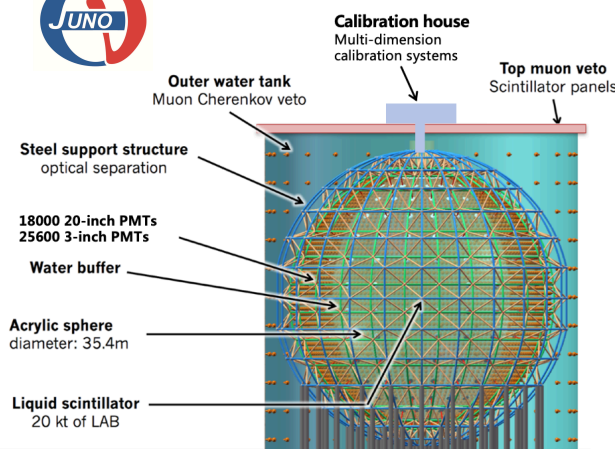
研究方向

暗物质直接探测(PandaX-4T)



气液两相型氙探测器

中微子性质测量(JUNO)



液体闪烁体探测器

极低放射性测量技术

- 高纯锗探测器
- 氦气测量系统
- 氦测量系统
- ICPMS
- Alpha探测器
- 水氦测量系统
- 中子活化分析

.....

2. 2020年度个人工作总结 -- PandaX-4T暗物质实验 PANDA X

建设四川锦屏二期(B2厅)低本底实验空间和配套设施

氦气含量:
 $0.09 \pm 0.19 \text{ Bq/m}^3$
($<0.4 \text{ Bq/m}^3$ at 90% C.L.)
实验大厅中的氦的含量大约
为 110 Bq/m^3



空气除氦系统



千级洁净间

水放射性测量:

	Th-232 [ppt]	U-238 [ppt]
原水	0.279 ± 0.036	142.1 ± 0.6
高纯水	0.064 ± 0.016	0.030 ± 0.001
水屏蔽体水	0.137 ± 0.025	0.351 ± 0.014



超纯水系统



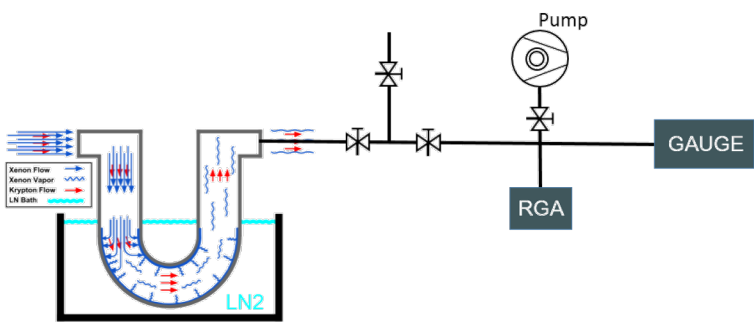
万级洁净间

2. 2020年度个人工作总结 -- PandaX-4T暗物质实验

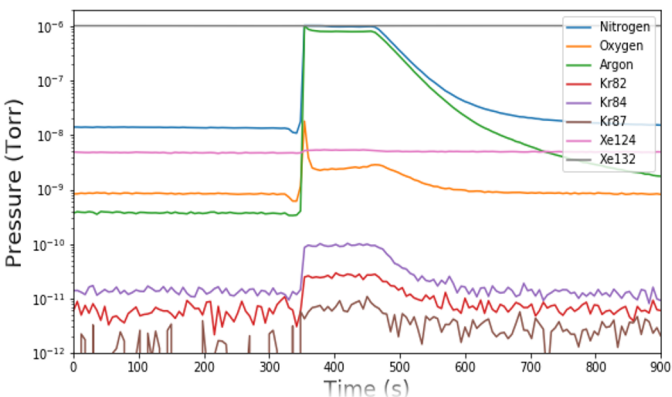
氦测量系统



氦测量系统

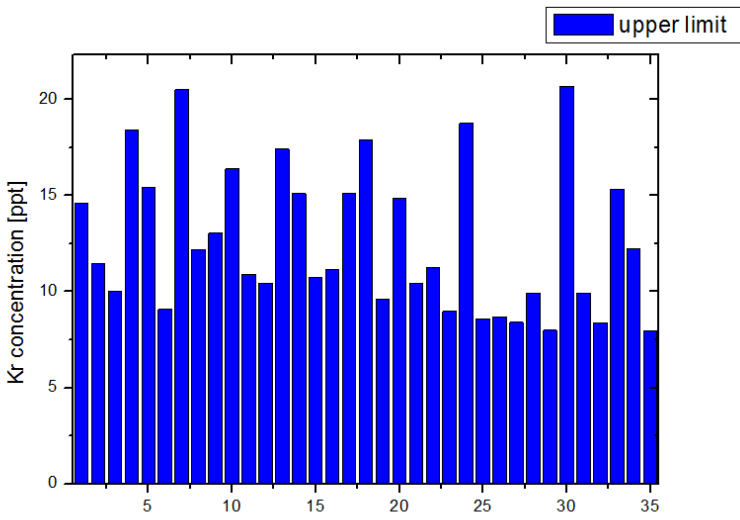


氦测量系统结构图



气体组分分压测量图

	Original xenon	71 h
Final Result	1952.75 +- 129.65 ppt	<7.96 ppt@90%C.L.



35批纯化Xe测量结果

系统作用

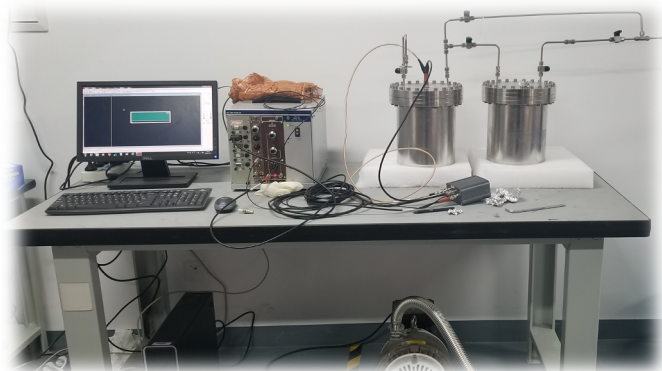
测量氦气中的杂质氦气的浓度，给PandaX-4T实验5.7吨氦气纯度提供保证。系统目前放置在锦屏地下实验室。

系统介绍

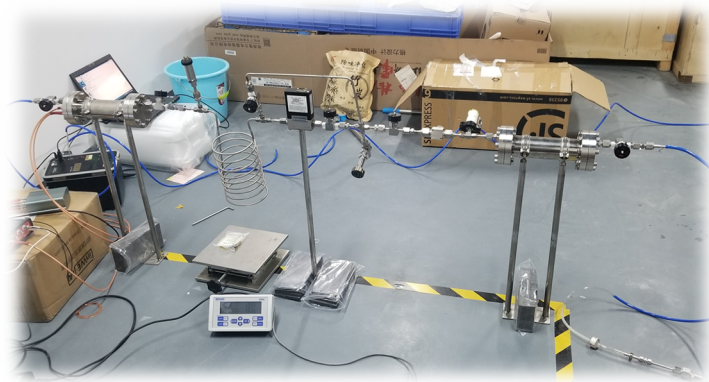
氦测量系统利用冷阱富集技术和质谱仪(Residual Gas Analyzer)来监测超痕量的氦杂质，测量灵敏度可达7.99 ppt (@90% C.L.)。同时也可以监控氮气、氧气和氩气等杂质的相对浓度。

2. 2020年度个人工作总结--PandaX-4T暗物质实验

氦测量系统



7.4L 氦探测器



冷阱富集系统

系统作用

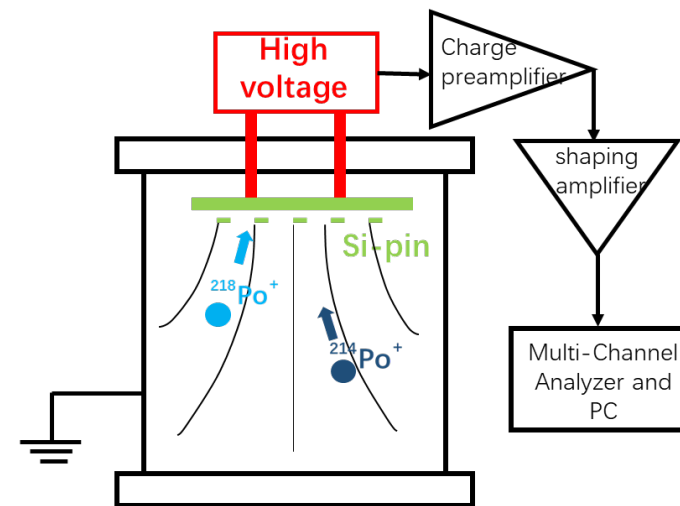
测量材料本身氦射气发散率，为探测器建设甄选低氦析出率的材料，降低ER本底，目前放置在上海交通大学

系统介绍

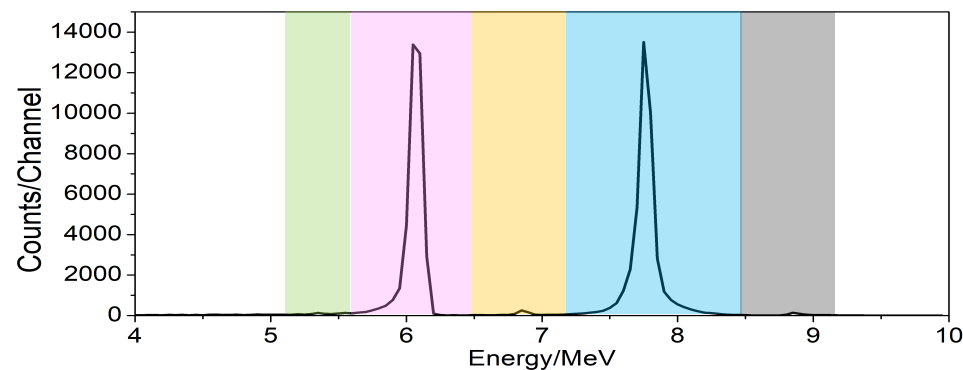
氦气可以衰变成带正电的Po-218和Po-214，其阿尔法的能量分别为6.1MeV和7.8MeV，可以通过利用Si-PIN光电二极管和静电收集氦子体方法来测量氦子体衰变率，进而反推材料中的氦气活度。

7.4L氦气探测系统灵敏度达到 1.26 ± 0.16 mBq

冷阱富集测量系统最小探测活性可达到 0.05 ± 0.03 mBq (< 0.10 mBq@90% C.L.)



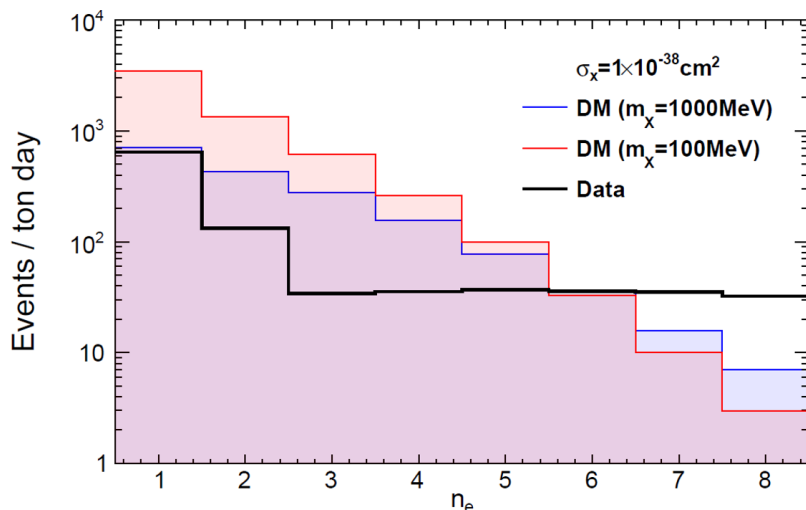
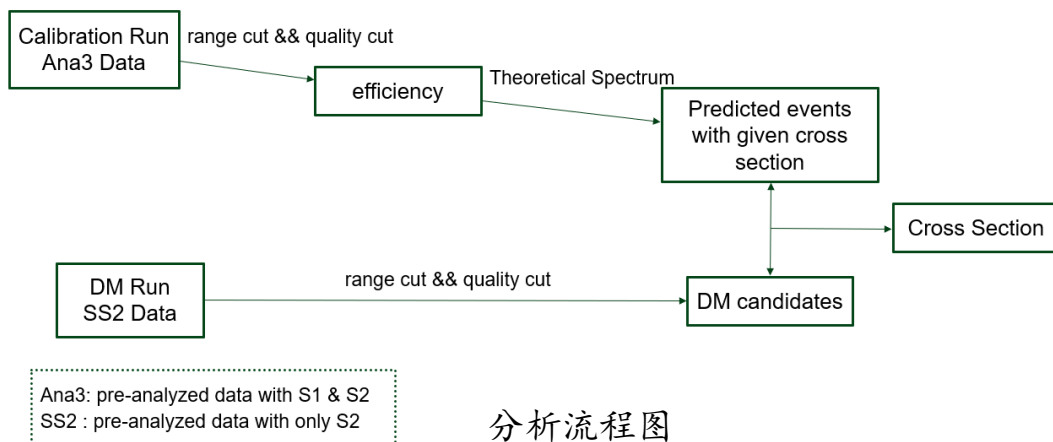
探测器原理图



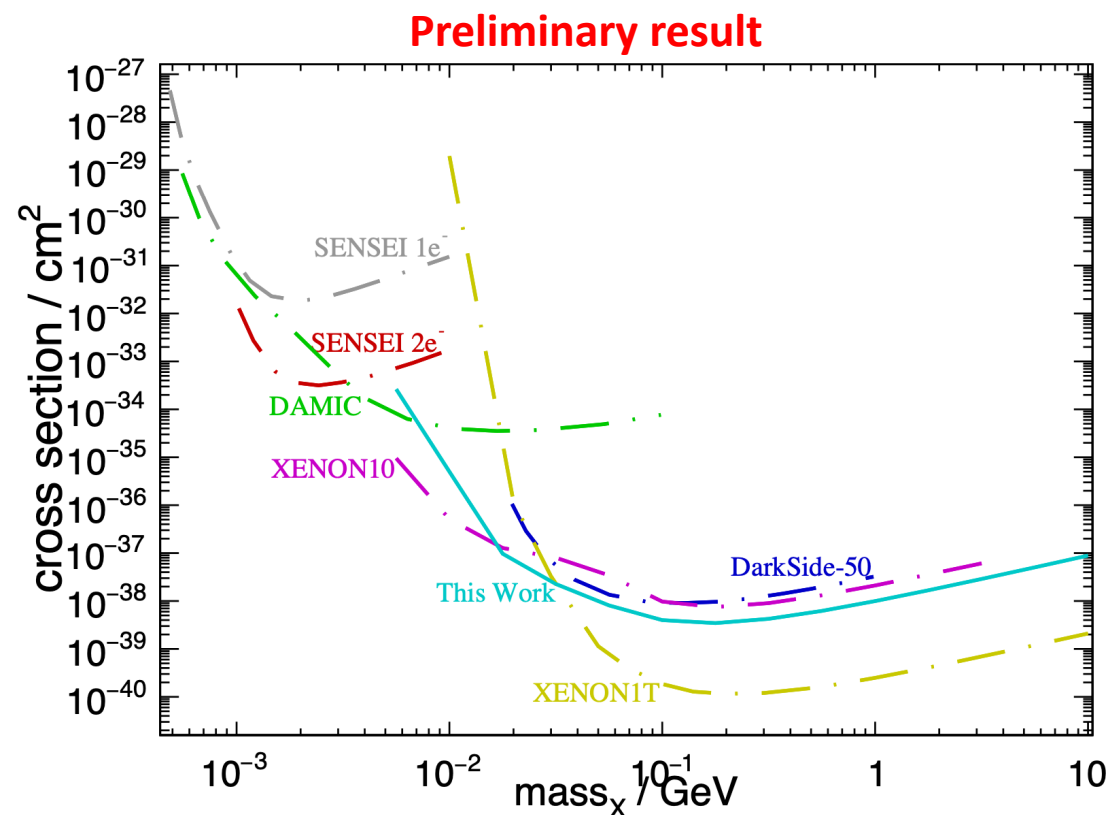
2. 2020年度个人工作总结--PandaX-4T暗物质实验

PandaX-II 电子-WIMP 相互作用分析

- Sub-GeV light dark matter interaction search (S2 only analysis)



理论和数据能谱



Electron and WIMP interaction exclusion limit

2. 2020年度个人工作总结 -- JUNO中微子实验

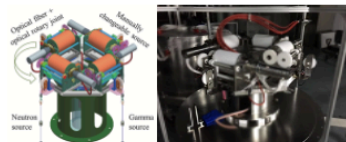


JUNO刻度系统

推进刻度子系统R&D:

Automatic Calibration Unit (ACU)

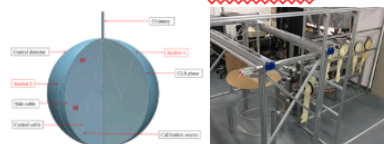
- 1D central axis scan with gamma sources, neutron sources and laser automatically



ACU prototype

Cable Loop System (CLS)

- 2D plane source scan with cable loops assembled on both hemisphere sides

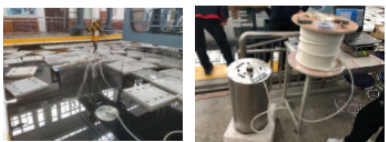


CLS layout

CLS motor prototype

Remotely Operated Vehicle (ROV)

- 3D source scan with a self-driven vehicle unit

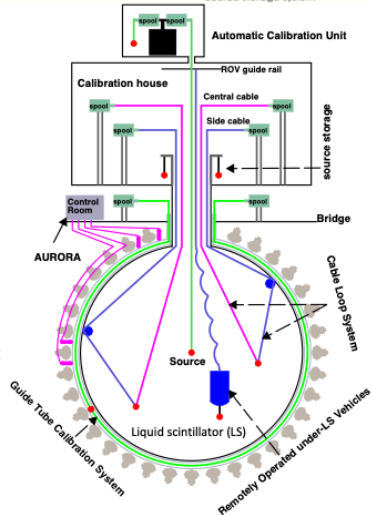
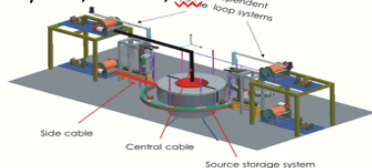


ROV water test

ROV

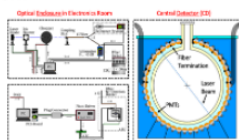
Calibration house

- Source storage, motors to control CLS system, ROV rail, etc



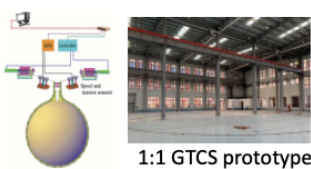
AURORA (A Unit for Researching Online the LSc tRAnsparency)

- Monitor and determine LS attenuation length, scattering length and absorption length with laser system



Guide Tube Calibration System (GTCS)

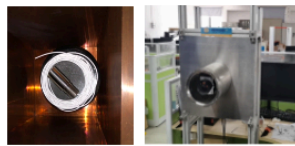
- Calibrate boundary area and provide boundary condition for the CD



1:1 GTCS prototype

Ultrasonic sensor system (USS) and CCD

- positioning ROV and CLS

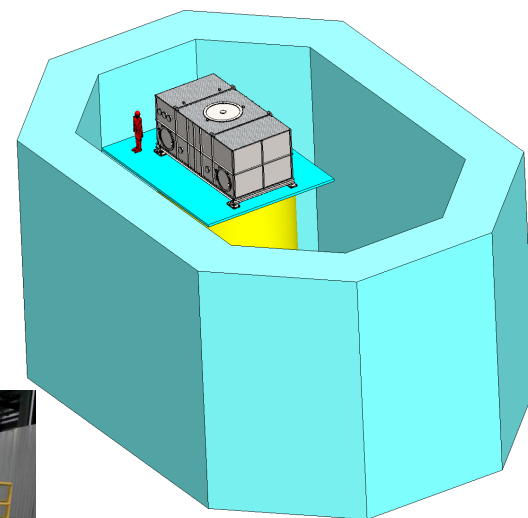


USS prototype

CCD prototype

JUNO刻度系统整合测试+dayabay探测器

- 放射源物理性质验证
- 子系统机械运动测试
- 多系统联调
- 辅助系统优化



Layout of Daya Bay EH2 AD3 and JUNO calibration house

2. 2020年度个人工作总结 -- JUNO中微子实验



放射性控制

如何洗？

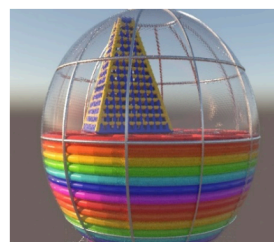
Acrylic clean strategy



Acrylic sphere cleaning

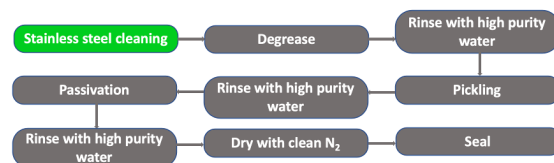


Water spray

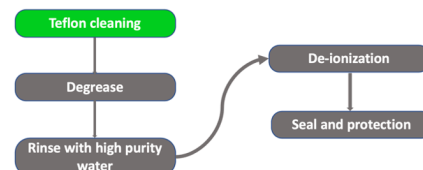


Wipe with air cushions

Stainless steel cleaning



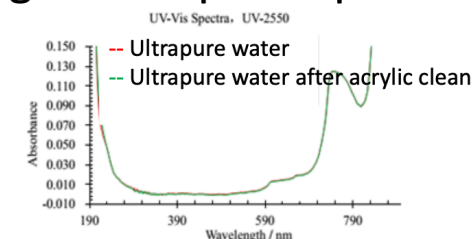
Teflon cleaning



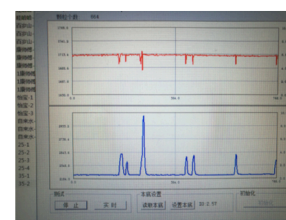
如何验证洗干净了？

1. Conductivity monitoring
Measured resistivity of rinsing water before and after cleaning is less than $4\text{M}\Omega\cdot\text{cm}$

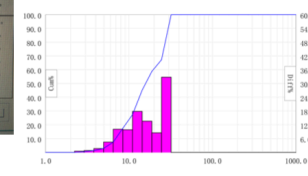
2. Light absorption spectra



3. Particulate counting, better than JUNO level 50



Rinsing water measurement



Surface measurement

4. ICP-MS measurement, the rinsing water before and after acrylic cleaning

Conc. [ppt]	Before	After
^{238}U	<0.17 @90% C.L.	0.13 ± 0.01
^{232}Th	<0.01 (MDA)	<0.18 @90% C.L.

2. 2020年度个人工作总结 - 低本底测量技术研发

放射性测量技术研发

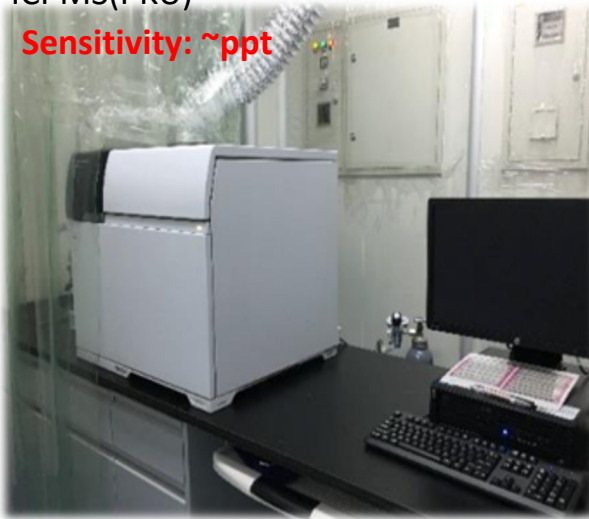
HPGe(CJPL-I)

Sensitivity: $\sim \text{mBq/kg}$



ICPMS(PKU)

Sensitivity: $\sim \text{ppt}$



Radon emanation measurement system(SJTU)

Sensitivity: $\sim 2 \text{ mBq}$



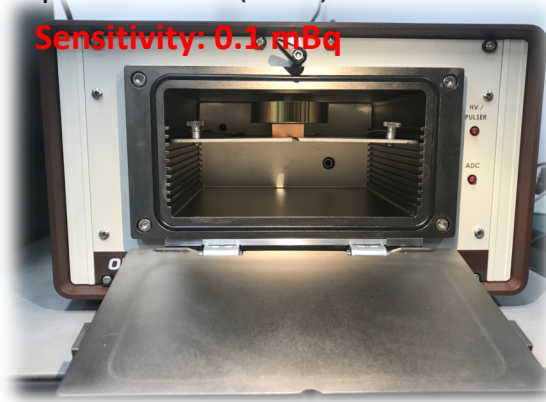
Kr counting station(CJPL-II)

Sensitivity: $\sim 10 \text{ ppt}$



Alpha detector(SJTU)

Sensitivity: 0.1 mBq



Cold trap radon emanation system(SJTU)

Sensitivity: $\sim 0.05 \text{ mBq}$



2. 2020年度个人工作总结 -- 低本底测量技术研发



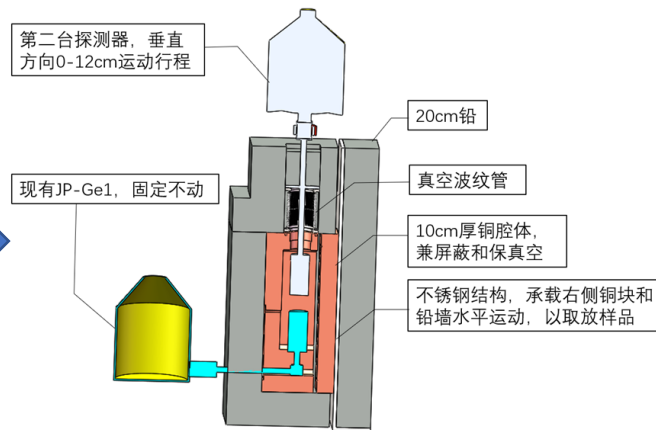
放射性测量技术升级

HPGe Ge1 → double Ge detectors



Sensitivity: ~mBq/kg

升级



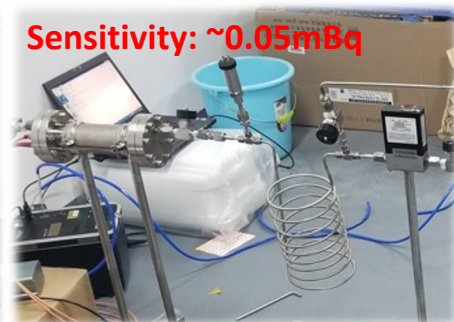
D=10cm, H=1cm的Teflon样品模拟

核素	JP-Ge1 MDA(mBq)	双探头MDA(mBq)	双探头/JP1-Ge1
Co60	0.404	0.426	105.43%
Cs137	0.354	0.275	77.58%
K40	8.103	5.672	70.00%
Th232_Ac228	1.512	1.303	86.17%
Th232_Th228	0.985	0.798	81.06%
U235	1.348	0.959	71.19%
U238_Ra226	12.875	9.056	70.33%
U238_Rn222	0.907	0.759	83.74%
Pb210	15.274	8.319	54.47%
Am241	0.953	0.747	78.41%

Radon emanation measurement system



Sensitivity: ~2mBq



Sensitivity: ~0.05mBq

升级



1. Low background copper counting chamber

	Th-232(10^{-12} g/g)	U-238(10^{-12} g/g)
Cu1	<5.22	9.25±1.54
Cu2		1.07±0.21

2. Optimized cold trap
3. Optimized electric field
4. Upgraded pre-amp

3. 论文

- A New Method for Evaluating the Effectiveness of Plastic Packaging Against Radon Penetration, **Yue Meng**, Jerry Busenitz and Andreas Piepke, Applied Radiation and Isotopes 156 (2020) 108963, 2020.3

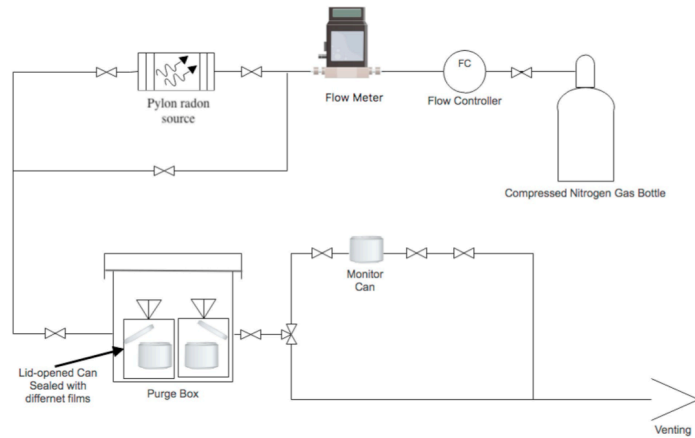


Fig. 1. The radon purge system.

Properly corrected measured ratios of radon concentrations inside and outside of bags made from the materials listed here.

Bag material	R'	Film thickness [μm]
Polypropylene	0.856 ± 0.004	101.6
Transparent Mylar	0.0005 ± 0.0002	76.2
Metallized Mylar-Type 1	0.0004 ± 0.0001	63.5
Metallized Mylar-Type 2	0.0009 ± 0.0002	101.6
Metallized Mylar-Type 3	0.0017 ± 0.0002	109.2
PFA	0.99 ± 0.01	50.8
FEP	0.097 ± 0.001	127.0
Nylon	0.0077 ± 0.002	50.8

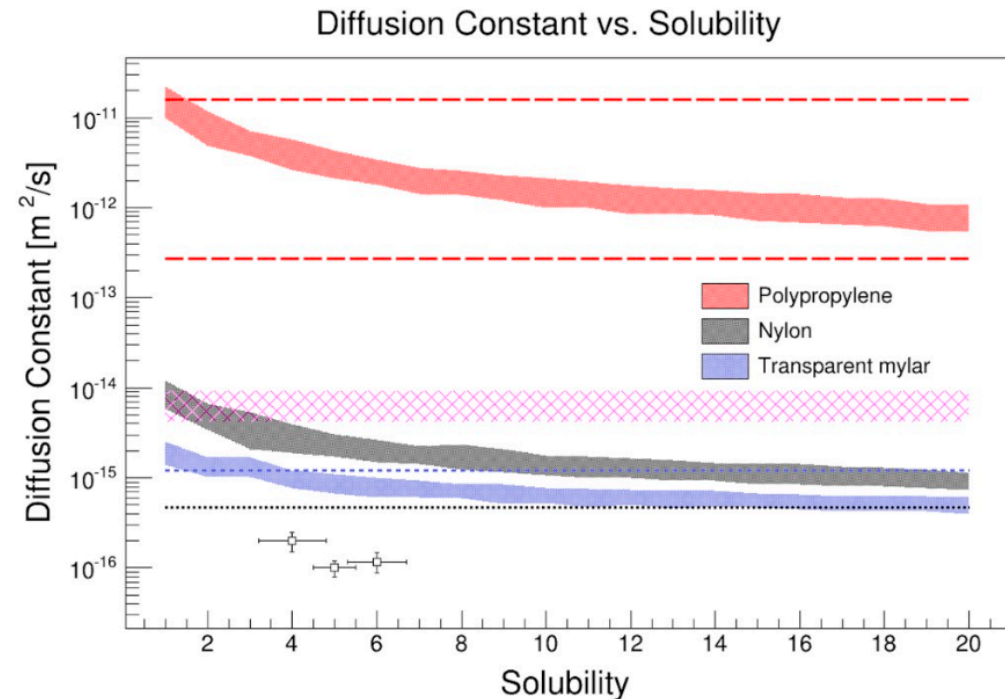
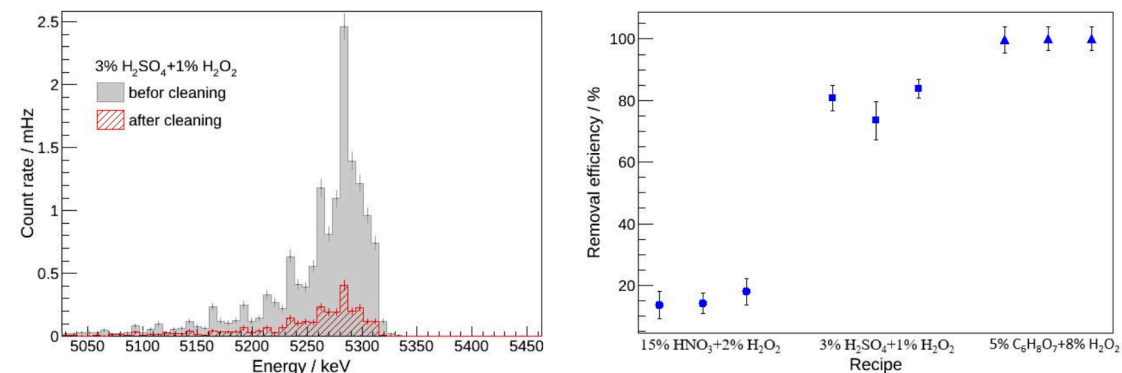


Fig. 5. Diffusion constants versus solubility of polypropylene (red band), Nylon (black band) and transparent Mylar (blue band), estimated from the data presented in this paper. Also shown (by points, lines, and hatched bands) are results from previous measurements.

3. 论文

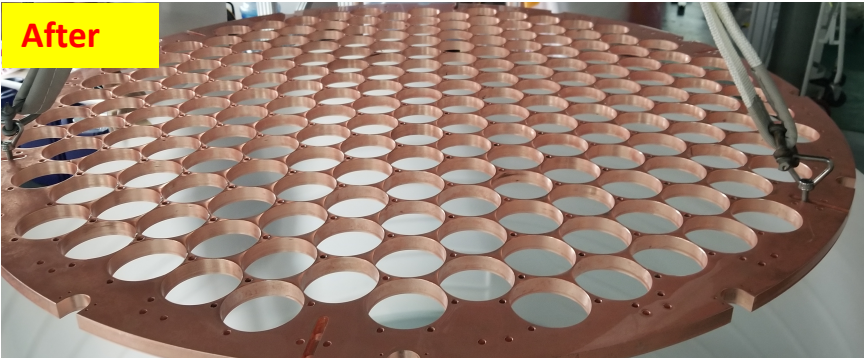
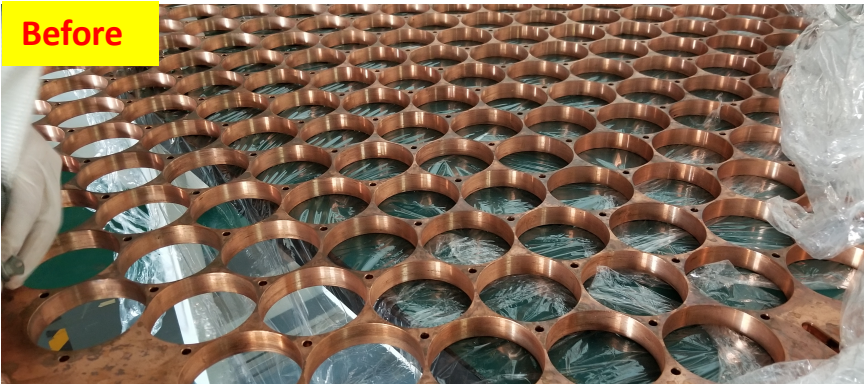
- Investigation of Radioactive Radon Daughters Removal Methods from Copper Surface FU Mengting, WANG Siguang, CHENG Chen, **MENG Yue (corresponding author)**, QIAN Zhicheng, NING Xuyang, SI Lin, WU Mengmeng, YAO Yukun, submitted to Nuclear Techniques, 2020



氦子体去除测量和比较

铜样品 Copper sample	序号 Number	²³² Th 含量	²³² Th 检出限	²³⁸ U 含量	²³⁸ U 检出限
		²³² Th conc. / pg·g ⁻¹	²³² Th detection limit / pg·g ⁻¹	²³⁸ U conc. / pg·g ⁻¹	²³⁸ U detection limit / pg·g ⁻¹
内部 Bulk	1	182.80±18.07	18.23	246.80±32.13	3.51
	2	68.80±26.48	10.96	455.20±20.42	2.11
	3	97.52±24.01	8.93	230.35±14.69	1.72
	4	96.01±6.44	7.65	40.28±5.00	1.47
	5	52.41±14.26	8.80	47.07±4.37	1.70
表面 Surface	1	68.39±12.54	9.26	58.18±4.45	1.78
	2	106.57±22.39	5.16	34.54±4.84	0.99
	3	42.93±13.58	3.60	283.06±12.84	0.69
	4	9.17±7.29	6.40	23.42±6.49	1.23
	5	47.18±8.60	4.96	38.08±6.38	0.90

铜内部和处理铜表面的 ²³²Th 和 ²³⁸U 的含量



3. 论文

- The LUX-ZEPLIN (LZ) radioactivity and cleanliness control programs, LZ collaboration, arXiv:2006.02506, Accepted by JINST (2020) (Meng contributed radon emanation measurement, Ge assay, NAA and ICPMS measurement.)

HPGe

Detector	FWHM 1332 keV [keV]	Integral (60 - 2700) keV [kg ⁻¹ .day ⁻¹]	Tl-208 2614.5 keV [kg ⁻¹ .day ⁻¹]	Bi-214 609.3 keV [kg ⁻¹ .day ⁻¹]	Co-60 1332.5 keV [kg ⁻¹ .day ⁻¹]	K-40 1460.8 keV [kg ⁻¹ .day ⁻¹]	Pb-210 46.5 keV [kg ⁻¹ .day ⁻¹]
Belmont	1.92	135.0	0.3	1.4	1.6	1.0	-
Merrybent	1.87	167.4	0.4	1.8	0.6	1.9	-
Lunehead	1.86	582.4	2.0	4.7	1.5	9.2	-
Roseberry	1.58	181.1	<0.4	<0.4	0.6	0.7	0.3
Chaloner	1.56	1053.0	1.7	9.5	1.2	8.3	1.7
Lumpsey	1.66	4256.8	12.2	60.3	1.6	7.0	13.7
MERLIN	3.59	68868.3	9.7	7.5	-	20.0	80.2
MAEVE	3.19	956.1	1.8	1.4	0.5	3.5	49.6
MORGAN	2.68	1338.8	3.2	8.8	3.8	4.8	4.6
MORDRED	2.44	2103.2	2.1	3.9	1.6	7.4	29.0
SOLO	5.52	786.9	-	3.3	-	-	-
Ge-II	3.6	9600	<1.4	3.6	10.3	2.3	-
Ge-III	2.71	8600	<0.5	9.6	1.7	2.5	1.6

Radon emanation

Detector	Type	Chamber Volumes [L]	Chamber Blank Rates [mBq]	Transfer Efficiency [%]	Detector Efficiency [%]	Cross-Calibration [Measured/EXO-activity]
SDSM&T	PIN-diode	13	0.2	94	25	0.89±0.15
		300	0.2	80		1.11±0.28
Maryland	PIN-diode	4.7	0.2	96	24	1.13 ± 0.19
UCL	PIN-diode	2.6	0.2	97	30	1.49±0.15
		2.6	0.4	97		
Alabama	Liquid Scint.	2.6	<0.4	34	36	0.83±0.17
		2.6				

ICPMS

Sample	Supplier	Detector	Units	²³⁸ U	²³² Th
Polystyrene Foam	Styrodure	UCL	mBq/kg	3.3(10)	0.57(21)
Forward Field Region Titanium Weld Sample	Timet	UCL	mBq/kg	2.1(2)	0.14(4)
Forward Field Region Titanium Weld Sample	Timet	UCL	mBq/kg	2.4(3)	4.3(2)
Ti weld sample from CHAMP; Material Adjacent To Weld	Timet	UCL	mBq/kg	2.3(4)	0.59(13)
Ti weld sample from CHAMP; Weld Material	Timet	UCL	mBq/kg	2.9(3)	15(1)
Multi-Layer Insulation	RUAG (Vienna)	University of Alabama	mBq/kg	14(2)	31(6)
Polyethylene Foam	Foam Factory	University of Alabama	mBq/kg	20(3)	2.6(4)
Titanium Plate 4 x 6 0.125	Timet	PNNL	mBq/kg	9.8(2)	0.09(1)
Misc					
SNO Acrylic	RPT	University of Alabama	mBq/kg	0.30(12)	0.36(7)
JUNO Acrylic	Juno Experiment	University of Alabama	mBq/kg	0.27(5)	0.03(1)
JUNO Acrylic	Juno Experiment	University of Alabama	mBq/kg	0.66(11)	0.15(2)
Outer Detector					
Outer Detector Tank Acrylic	Reynolds (from Thailand)	UCL	mBq/kg	0.04(4)	0.02(3)
Outer Detector Tank Acrylic	Reynolds	UCL	mBq/kg	0.11(11)	0.03(3)
Acrylic Sheet	Reynolds	University of Alabama	mBq/kg	0.13(3)	0.26(8)
Cast Acrylic Slab	Reynolds	University of Alabama	mBq/kg	0.31(5)	0.20(7)
Adhesive	Reynolds	University of Alabama	mBq/kg	-0.03(8)	0.06(4)

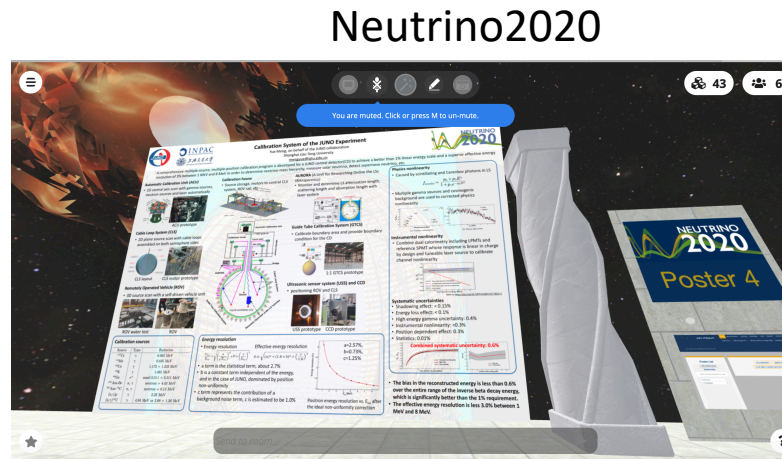
NAA

Sample	Supplier	Detector	Mass [g]	Units	²³⁸ U _e	²³² Th _e	⁴⁰ K
PMT Cabling							
Raw FEP Pellets	Axon	University of Alabama	3.1	mBq/kg	<0.017	0.036(4)	0.17(2)
Raw FEP Pellets	Axon	University of Alabama	3.1	mBq/kg	<0.052	0.037(5)	0.18(2)
FEP Inner Cable Jacket	Axon	University of Alabama	2.5	mBq/kg	<0.060	0.083(12)	5.1(5)
FEP Outer Cable Jacket	Axon	University of Alabama	2.6	mBq/kg	<0.024	0.096(12)	11(1)
TPC							
PTFE 8764 For Skin Region	Boedeker Plastics	University of Alabama	8.3	mBq/kg	0.018(5)	0.029(3)	0.018(4)
PTFE FLON008	Flontech	University of Alabama	2.8	mBq/kg	<0.027	0.051(6)	0.33(2)
Teflon NXT85	DuPont	University of Alabama	2.9	mBq/kg	<0.021	0.028(4)	0.122(1)
Teflon 807NX	DuPont	University of Alabama	2.8	mBq/kg	0.038(10)	0.029(4)	0.096(5)
PTFE 8764	Boedeker Plastics	University of Alabama	2.8	mBq/kg	<0.043	0.013(3)	0.066(4)

4. 会议报告+科普



JUNO status (invited talk)



Calibration System of the JUNO Experiment



Radioactive Cleanliness Control for the JUNO Experiment

暑期学校



探测宇宙中的变色龙: 中微子

Detecting the Chameleon of our Universe: Neutrinos

孟月

粒子物理与宇宙学重点实验室
物理与天文学院

2020李政道研究所暑期夏令营

中微子的来源

中微子的历史

中微子的探测方法

中微子震荡现象

中微子震荡参数测量

如何设计中微子实验

未来中微子方向

关于中微子的脑洞

科普

第71期若水畅坛(水工实验专场)



宇宙的“幽灵” --- 暗物质

孟月

PandaX暗物质实验组
上海交通大学物理与天文学院

2020/9/25



5. 基金申请

暗物质和中微子实验氦本底的测量与控制

浦江人才计划

上海市科学技术委员会

2019/10/1 – 2021/9/30

目标:

现今世界范围内对氦的测量和控制还没有达到预计的目标，测量手段的改进，新材料的应用，新的表面处理方法的研发将会从根本上改进发散氦和氦子体沉积诱发的本底。此项目的研发结果可直接用于PandaX-4T暗物质实验和江门中微子实验(JUNO)，进一步可以拓展到其他国内的低本底实验中，为下一代吨级以及吨级以上探测器氦本底的控制提供参考和知识及硬件的储备。

硬件研发，样品测量

PandaX-4T暗物质实验本底的测量和分析

青年科学基金项目

国家自然科学基金委员会

2021/1-2023/12

目标:

- 结合材料放射性和模拟结果，直接计算探测器放射性本底
- 利用数据，实时分析惰性气体本底的贡献
- 利用新分析方法，实时采用高能伽马事例推出中子本底
- 研究wall事例的来源，建立概率密度函数，计算本底在信号区的泄露概率
- 总结PandaX-4T暗物质实验的各项本底贡献，并通过探测器信号模型建立本底事件的多维分布

数据分析

6. 团队组建+学生培养

博士



司琳(交大)



程晨(中山)

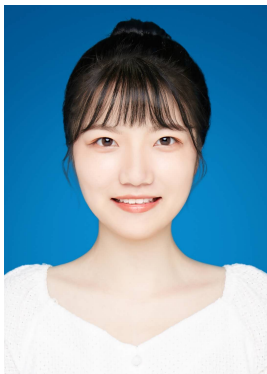


武蒙蒙(中山)



钱志成(交大)

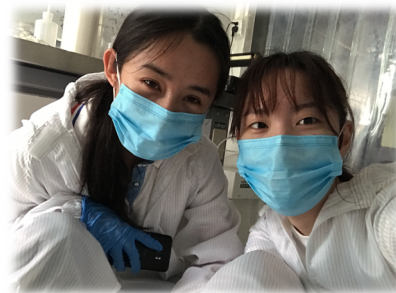
硕士



付孟婷(北大)



姚玉坤(交大)



7. 计划

- PandaX-4T暗物质本底数据分析
- JUNO刻度系统Daya Bay现场安装调试
- JUNO安装过程的放射性控制
- Daya Bay退役拆除系统
- 低本底技术的升级改造
 - 升级：HPGe，氦气测量系统，氦气测量系统
 - 研发：水氦探测器研发

感谢各位老师