Low threshold scintillation detector development for dark matter and neutrino

Zhimin Wang @ Beijing
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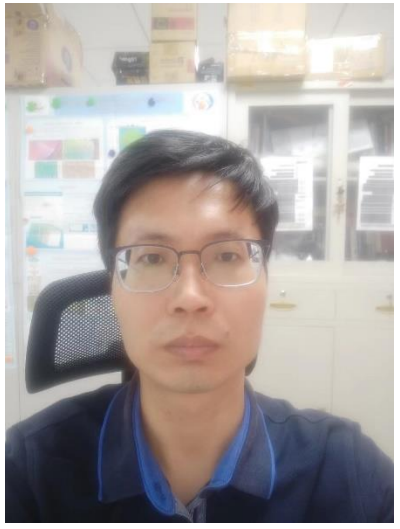
IHEP,CAS
2022-9-28



中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

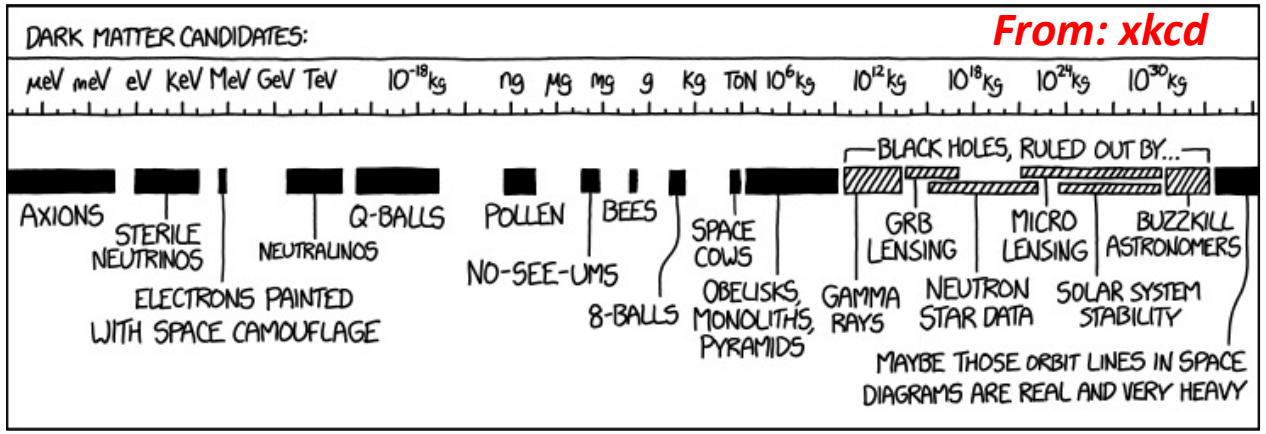
International Conference on Neutrinos and Dark Matter (NuDM-2022)
25-28 September 2022
Sharm El-Sheikh, Egypt- Online

Low threshold detector for dark matter and neutrino

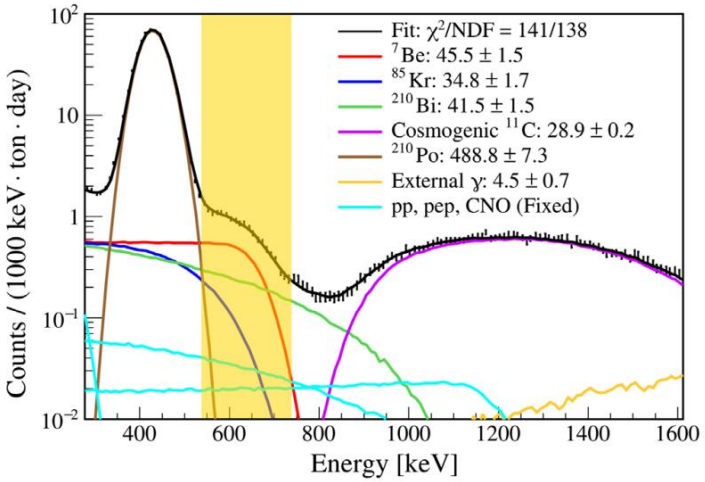
Disclaimer: Mainly focusing on the developments at IHEP, CAS

- For reactor, solar neutrinos
  - Sub-MeV
- Dark matter of WIMPs
  - Sub-keV

https://explainxkcd.com/wiki/index.php/2035:_Dark_Matter_Candidates#:~:text=In%20theoretical%20physics%2C%20a%20Q-ball%20is%20a%20stable,explainxkcd%20uses%20for%20the%20most%20common%20xkcd%20character.%29

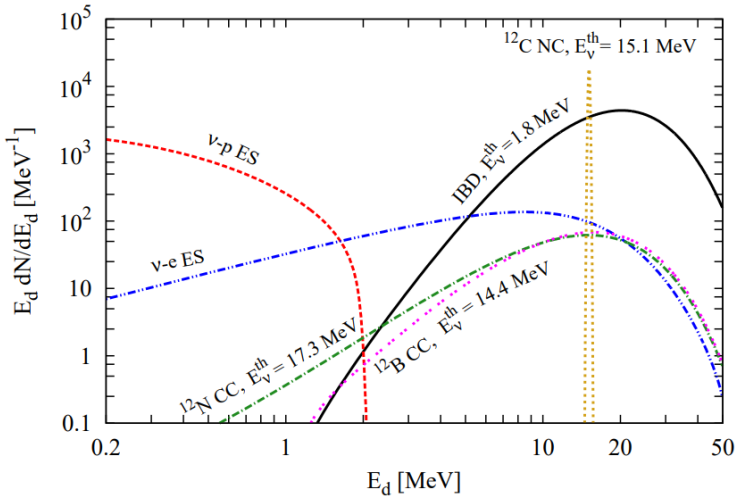


Borexino

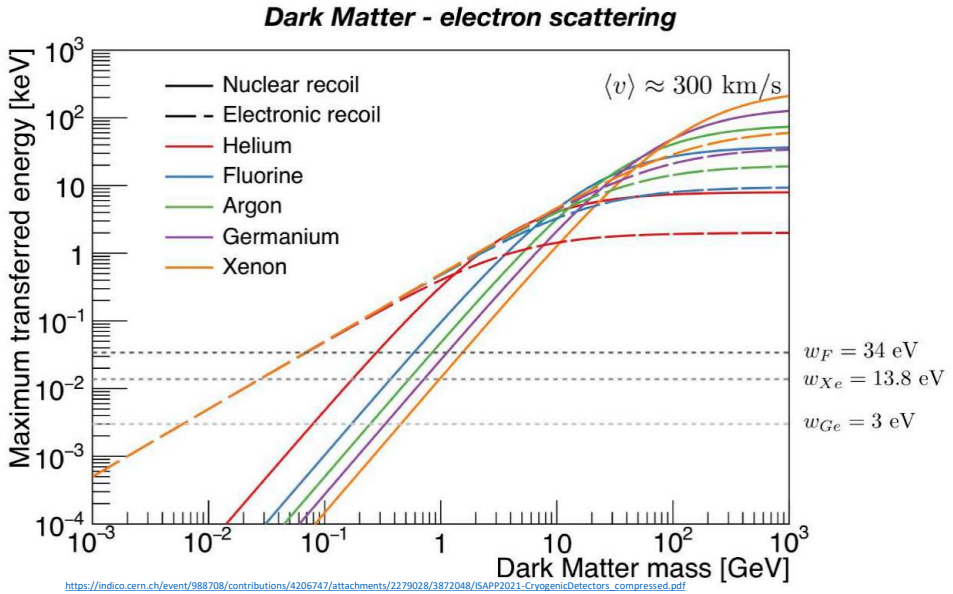


PHYSICAL REVIEW LETTERS 128, 091803 (2022)

JUNO



https://arxiv.org/pdf/1507.05613.pdf



https://indico.cern.ch/event/988708/contributions/4206747/attachments/2279028/3872048/ISAPP2021-CryogenicDetectors_compressed.pdf

Detection technologies

By Laura Manenti
https://www.researchgate.net/publication/310487182_Liquid_Argon_Time_Projection_Chambers_for_Dark_Matter_and_Neutrino_Experiments
By J. Gascon
https://indico.cern.ch/event/988708/contributions/4206747/attachments/2279028/3872048/ISAPP2021-CryogenicDetectors_compressed.pdf

- Threshold/resolution
  - Scintillation
    - 10~100 eV to produce 1~10 eV photons
  - Ionization
    - ~10 eV (gas)
    - ~1 eV (semicond.)
  - Phonon/Heat
    - ~meV (depends on heat capacitance)
- Particle discrimination

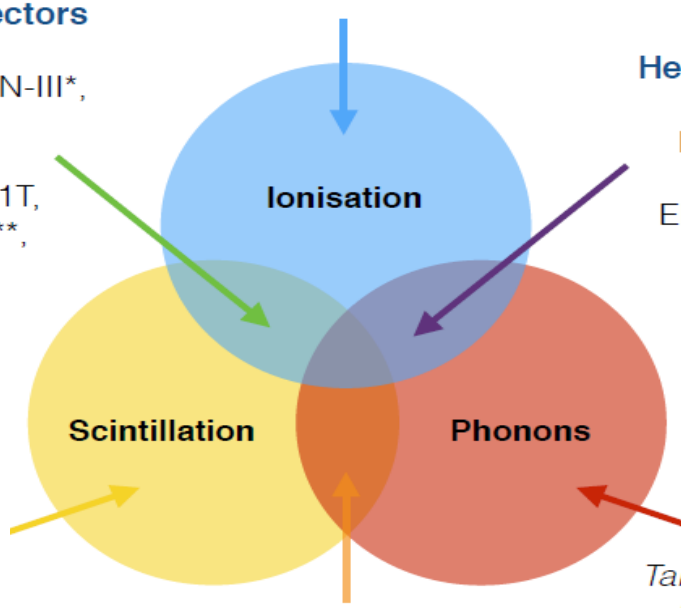
Scintillation detectors: large/huge volume

2016

Ionisation detectors
Targets: Ge, Si, CS_2, CdTe
GENIUS*, HDMS*, IGEX NEWAGE*, CoGeNT*

Light and ionisation detectors
Targets: Xe, Ar, CS_2
WARP*, ZEPLIN-II*, ZEPLIN-III*, Panda-X*, LUX**, DRIFT-I*, DRIFT-II**, XENON100***, XENON1T, DarkSide50**, ARDM***, LZ***, Darwin****
Cold (~LN_2)

Heat and Ionisation bolometers
Targets: Ge, Si
EDELWEISS-I*,-II*, CDMS**, SuperCDMS***, EDELWEISS-III***.EURECA****
Cryogenic (<50mK)



Scintillators
Targets: NaI, Xe,Ar, LS,...
ZEPLIN-I*,KIMS*,NAIAD*, ANAIS**, XMASS**,DAMA/LIBRA***,DEAP-3600***, CLEAN***,JUNO****

Bolometers
Targets: Ge, Si, AL_2O_3, TeO_2
CRESST-I*, CUORE-0**

Light and Heat Bolometers
Targets: $CaWO_4$, BGO, AL_2O_3
RESEBUD*, CRESST**
Cryogenic (<50mK)

Bubbles and Droplets
Tragets: CF_3Br, CF_3I, C_3F_8, C_4F_{10}
COUPP*, PICASSO*, SIMPLE**, PICO-2L**, PICO-60**, PICO-250****

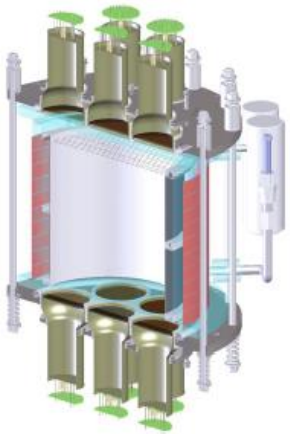
* not operating anymore
** functioning
*** under construction/upgrading
**** planned/proposed

DarkSide program

LAr

http://www.phy.sdsmt.edu/CoSSURF/talks/CoSSURF2019%20ALTON%20DarkSide.pdf
https://lpsc-indico.in2p3.fr/event/1425/contributions/1008/attachments/852/1087/Darkside-Grenoble_GDR_Jun_6_2016.pdf
https://indico.in2p3.fr/event/17777/attachments/49504/62965/C.Galbiati_slides_conf_Quest_Dark_Matter_2018_APC.pdf

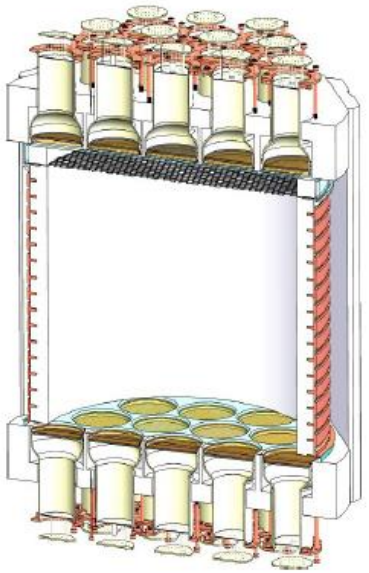
2012



DarkSide-10

- First prototype
- LY > 9PE/keV

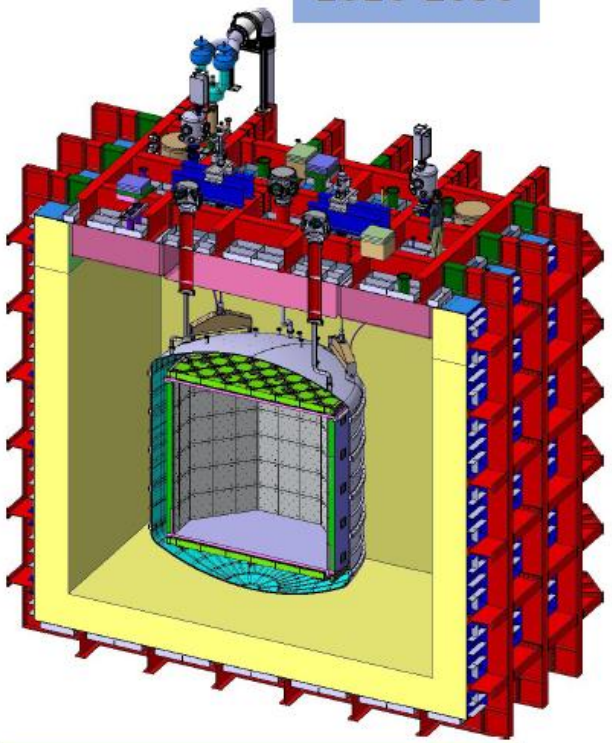
2013-2018



DarkSide-50

- Science detector
- First background-free results with UAr
- Best limits for low mass WIMP search

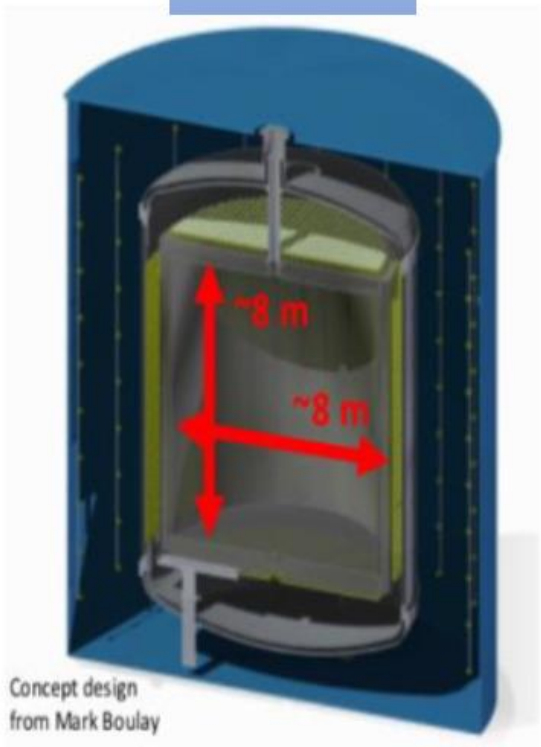
2026-2036



DarkSide-20k @LNGS

- Novel photosensor technologies
- Large scale use of UAr
- Nominal exposure: 200 t y

2030s-...



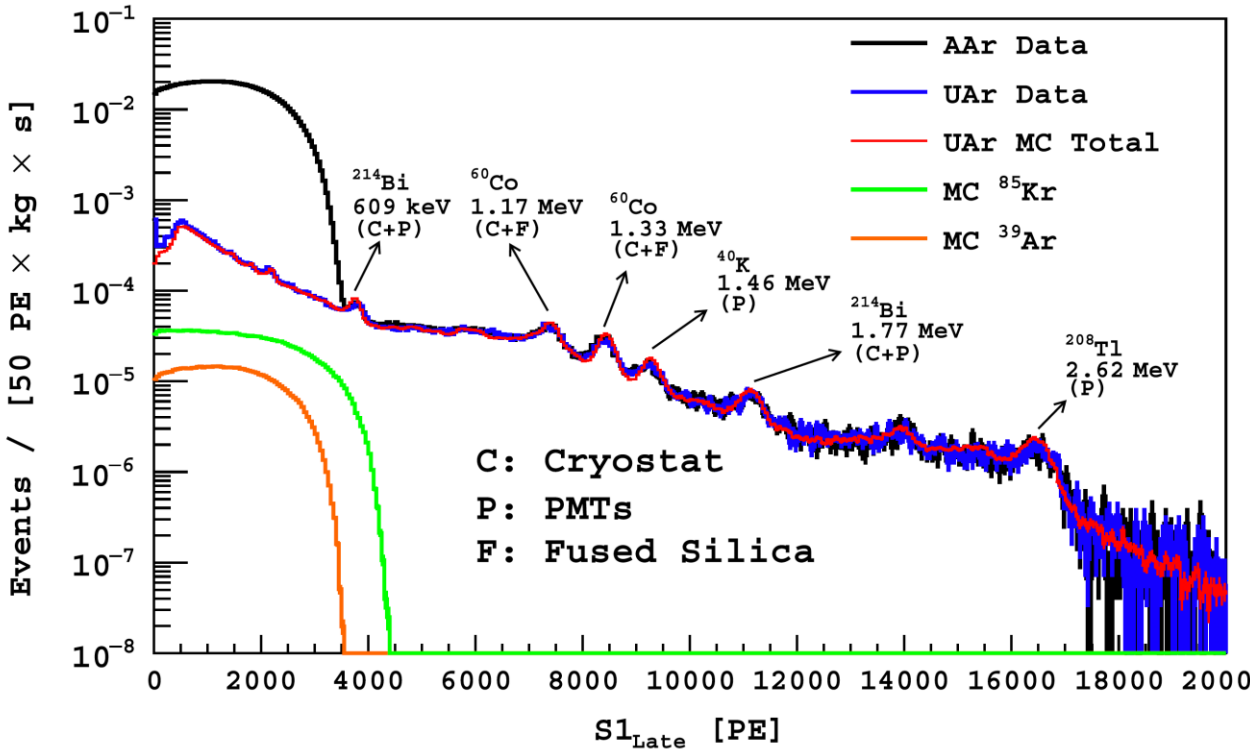
Argo@SNOLAB

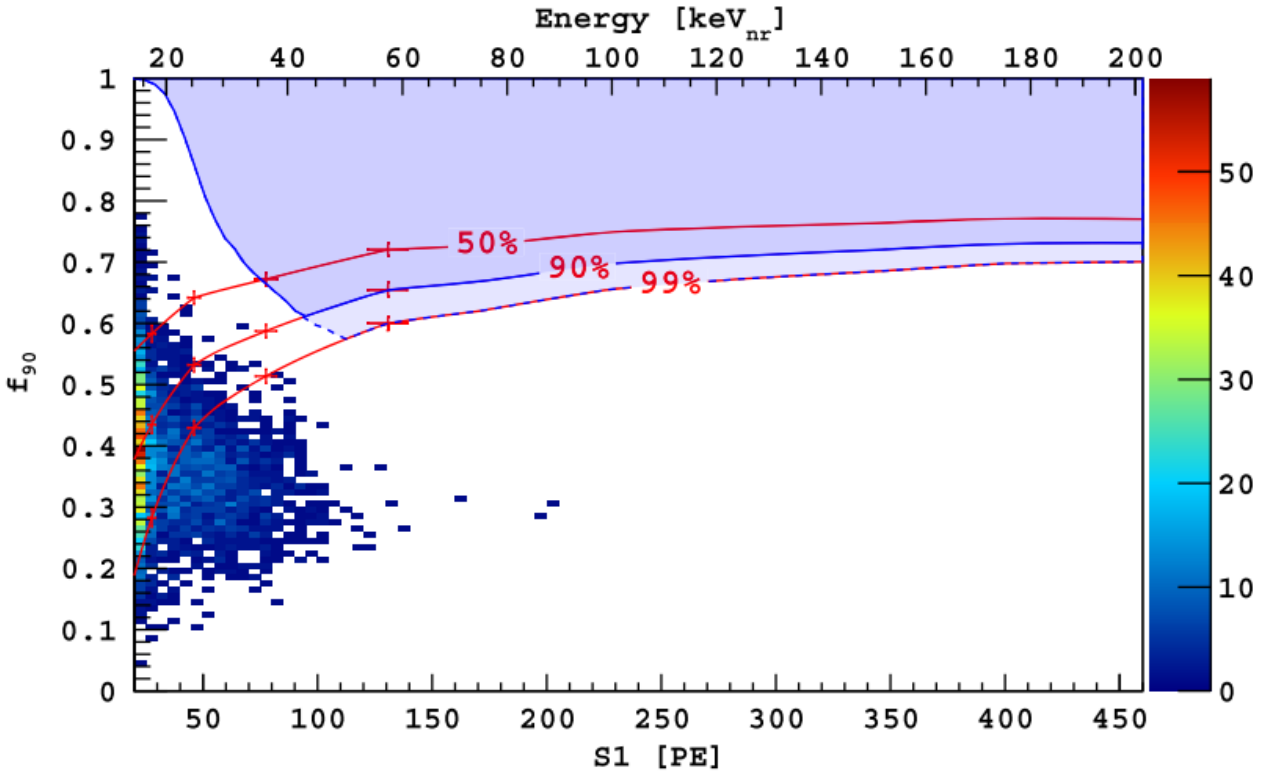
- Ultimate LAr DM detector
- Nominal exposure: 3000 t y

Phys. Rev. D 93, 081101 (2016)

Results from the first use of low radioactivity argon in a dark matter search

- Achieved with underground argon
  - 15~20 keVnr
  - 3~5 keVee





https://doi.org/10.1007/s41605-021-00243-y

CEvNS@Taishan, China (LAr proposal)

- CEvNS measurement with reactor neutrino and better confidence level
- Update measurement of the parameters of the standard model
- Electron yield and quenching factor measurement in sub-keV of LAr-TPC (reactor neutrino, nuclear recoil in ~keVnr)

☐ **Expected energy scale**

✓ 0.1-1 keV_{ee} ➔ **0.4-4 keV_{nr}** ➔ **4-20 e^-**

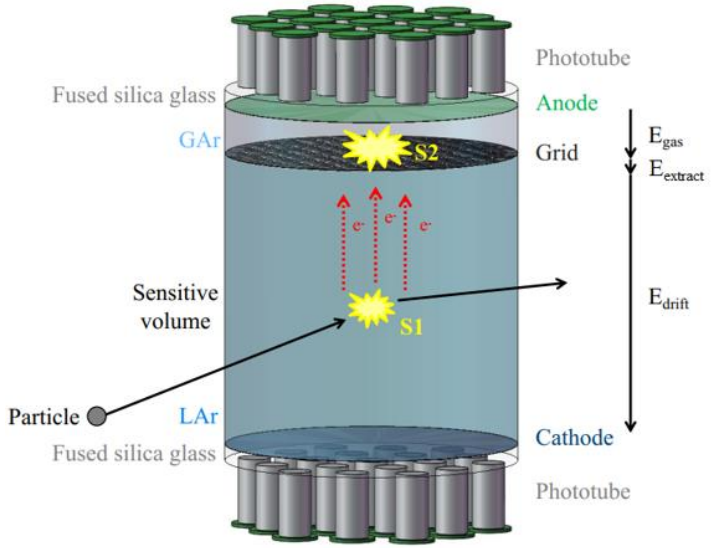
☐ **Sub-keV_{nr}:**

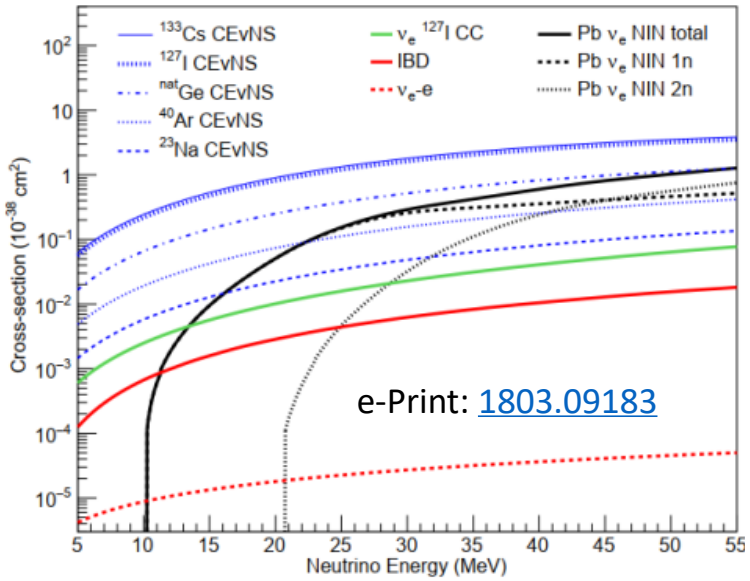
✓ Identification of single electron

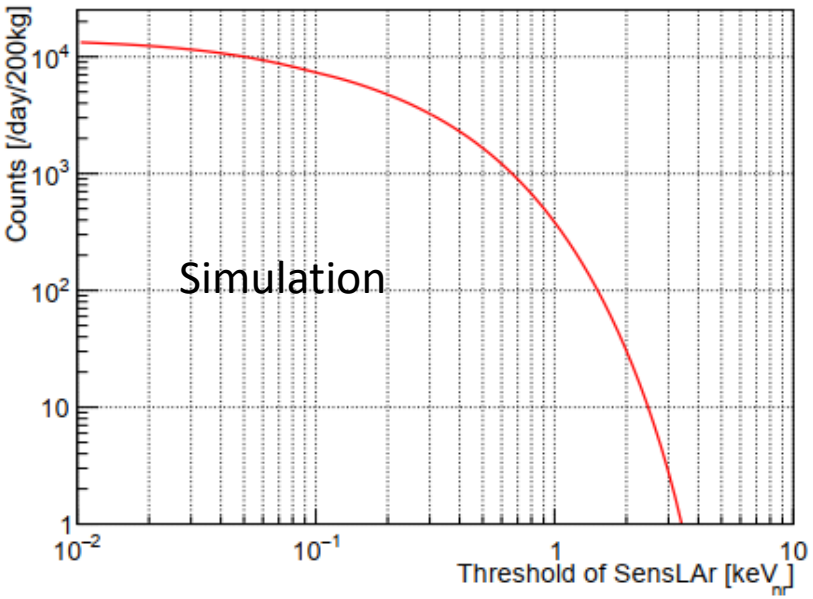
✓ Secondary amplification of electron in gas layer

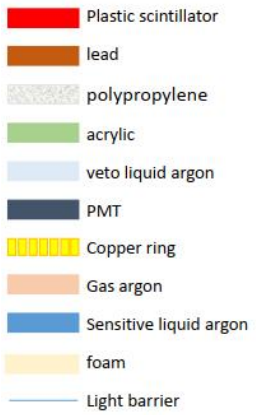
Light yield in literature: 20-30PE/e^-

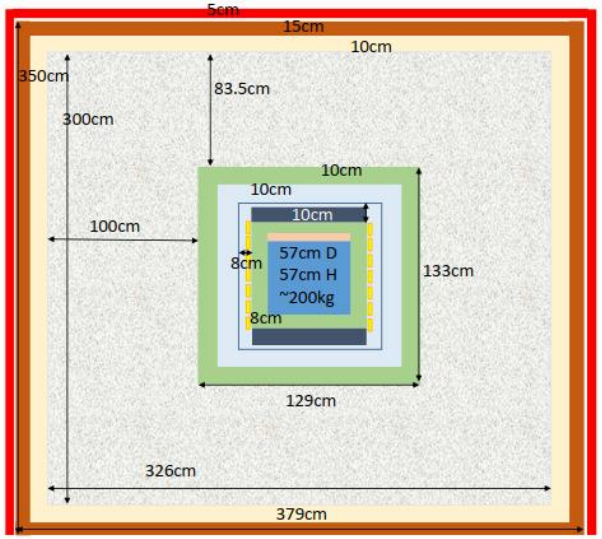
DOI: 10.1016/j.physletb.2008.08.030



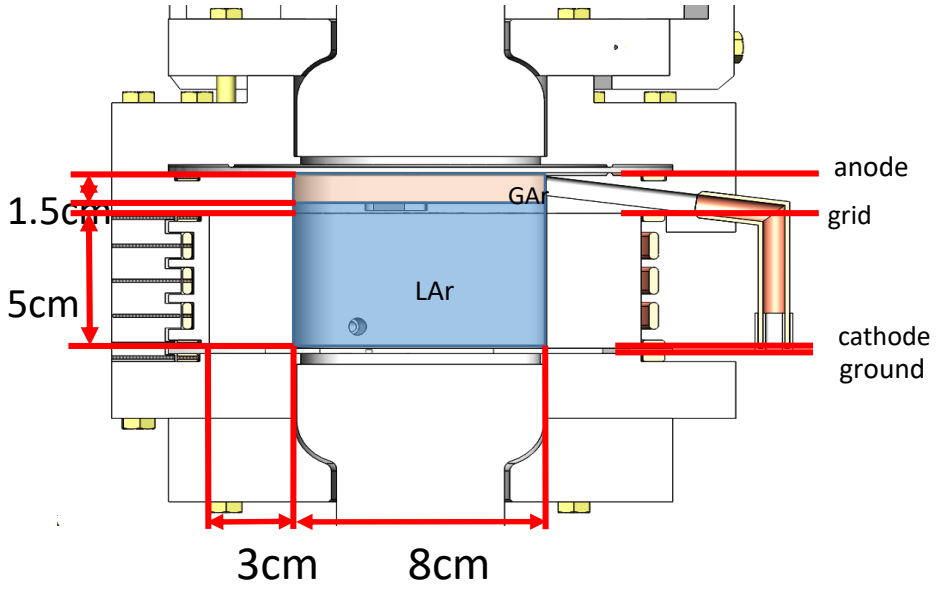








Prototype of double-phase LAr detector

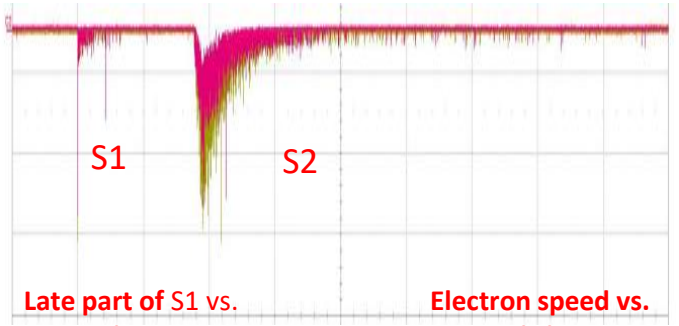


Sensitive weight: 0.35kg
LAr dimension: 5cm(H) 8cm(D)
Thickness of gas: 1.5cm
Photon sensor: two 3inch R11065PMT (top+bottom)

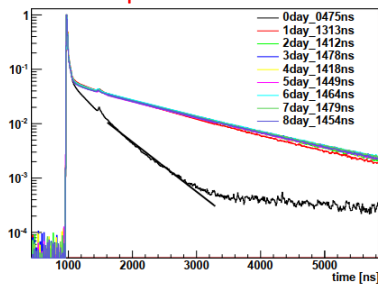
LAr-TPC

cryogenic and purification system

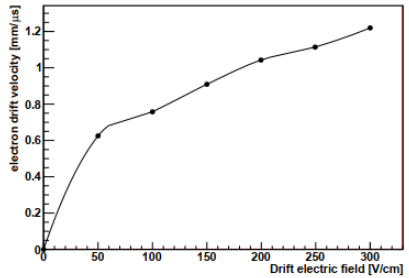
Yellow: top PMT, Red: bottom PMT



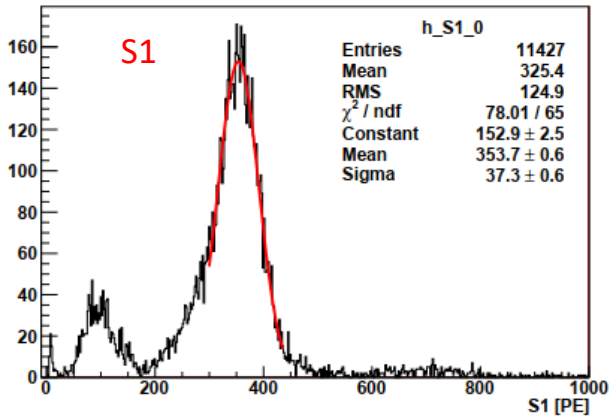
Late part of S1 vs. purification

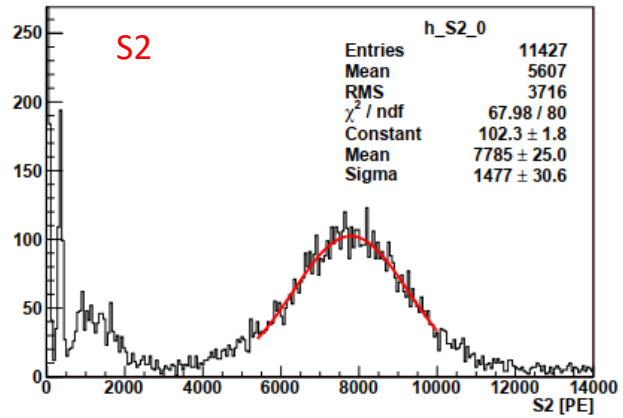


Electron speed vs. drift field

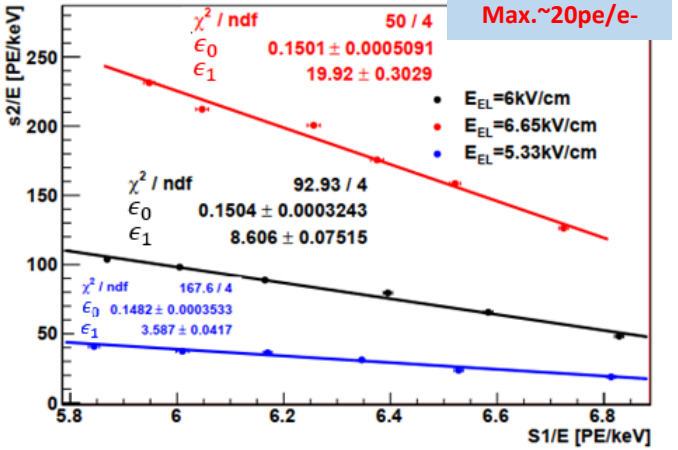


^{241}Am





Max.~20pe/e-



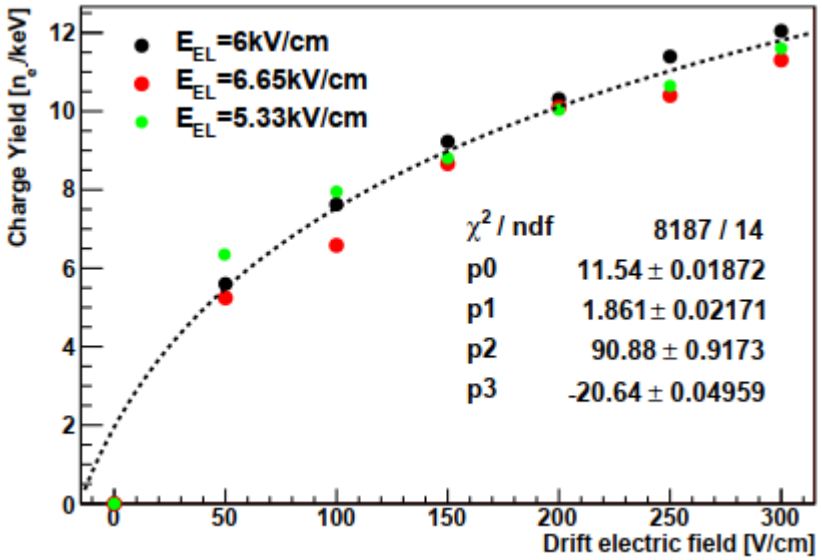
Light yield and electron yield vs. drift field

$$L_y = [0] * \log_{10}(\frac{E_{drift} + [1]}{[2]}) + [3]$$

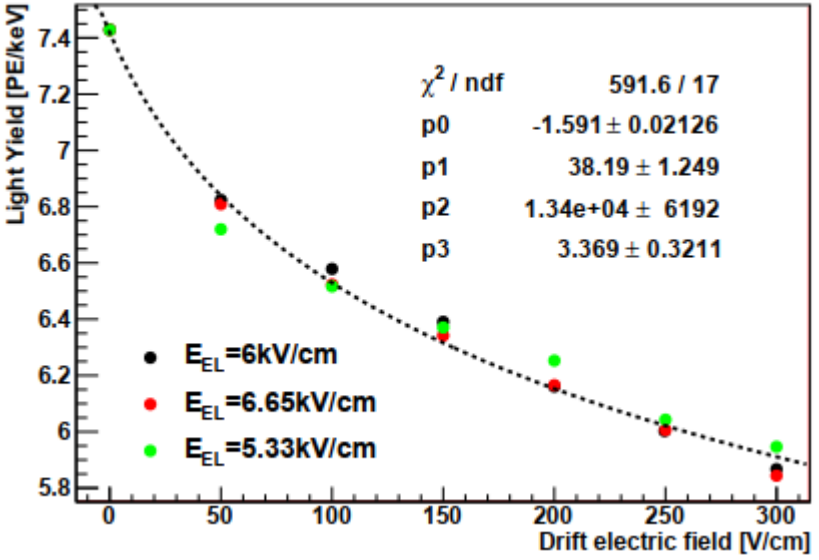
$$Q_y = [0] * \log_{10}([1] * E_{drift} + [2]) + [3]$$

$$n_{ph} = S1/\epsilon_0\,;\; n_{e^-} = S2_{corr}/\epsilon_1$$

Max.~11.5e-/keV

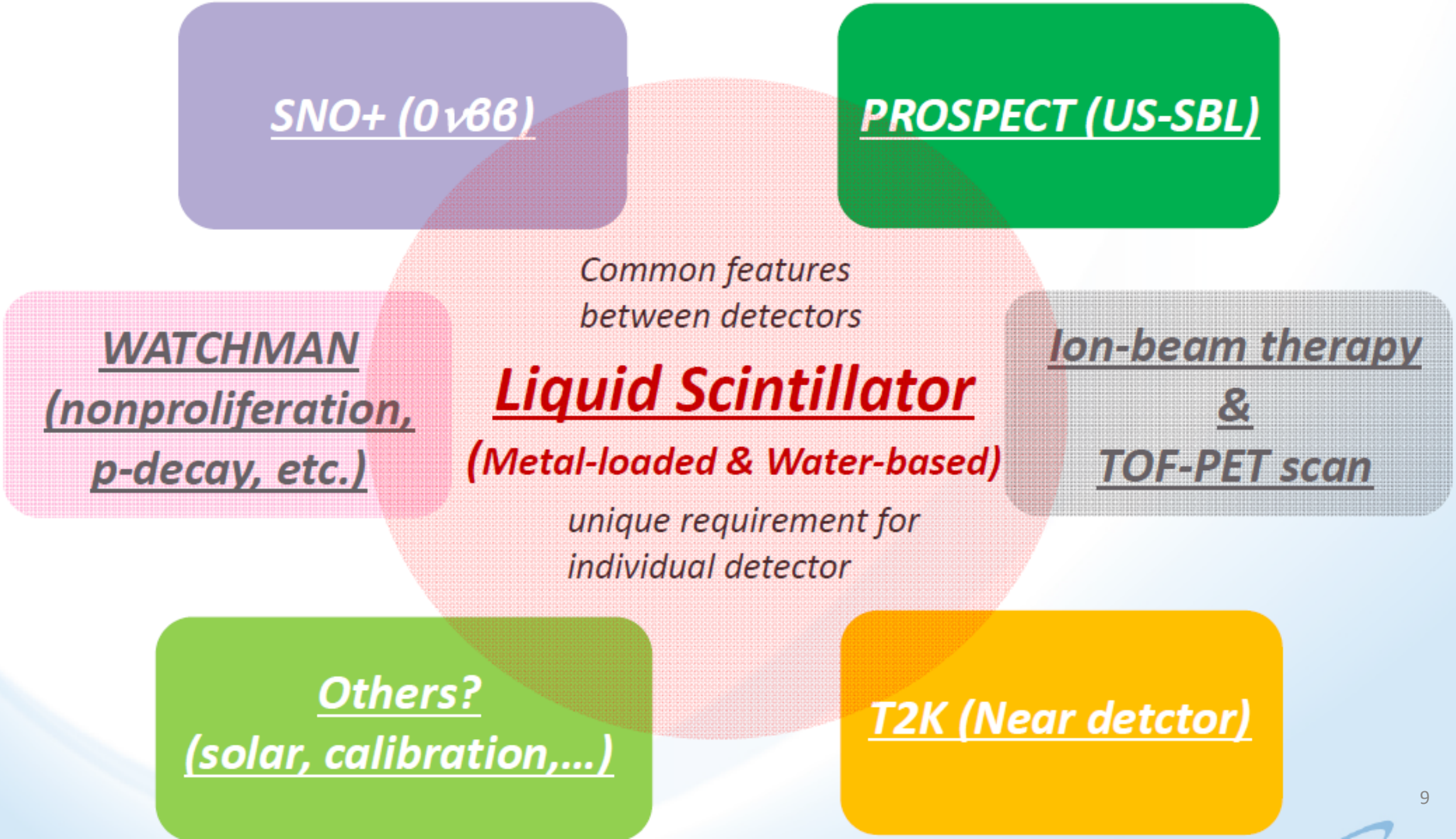


Electron yield

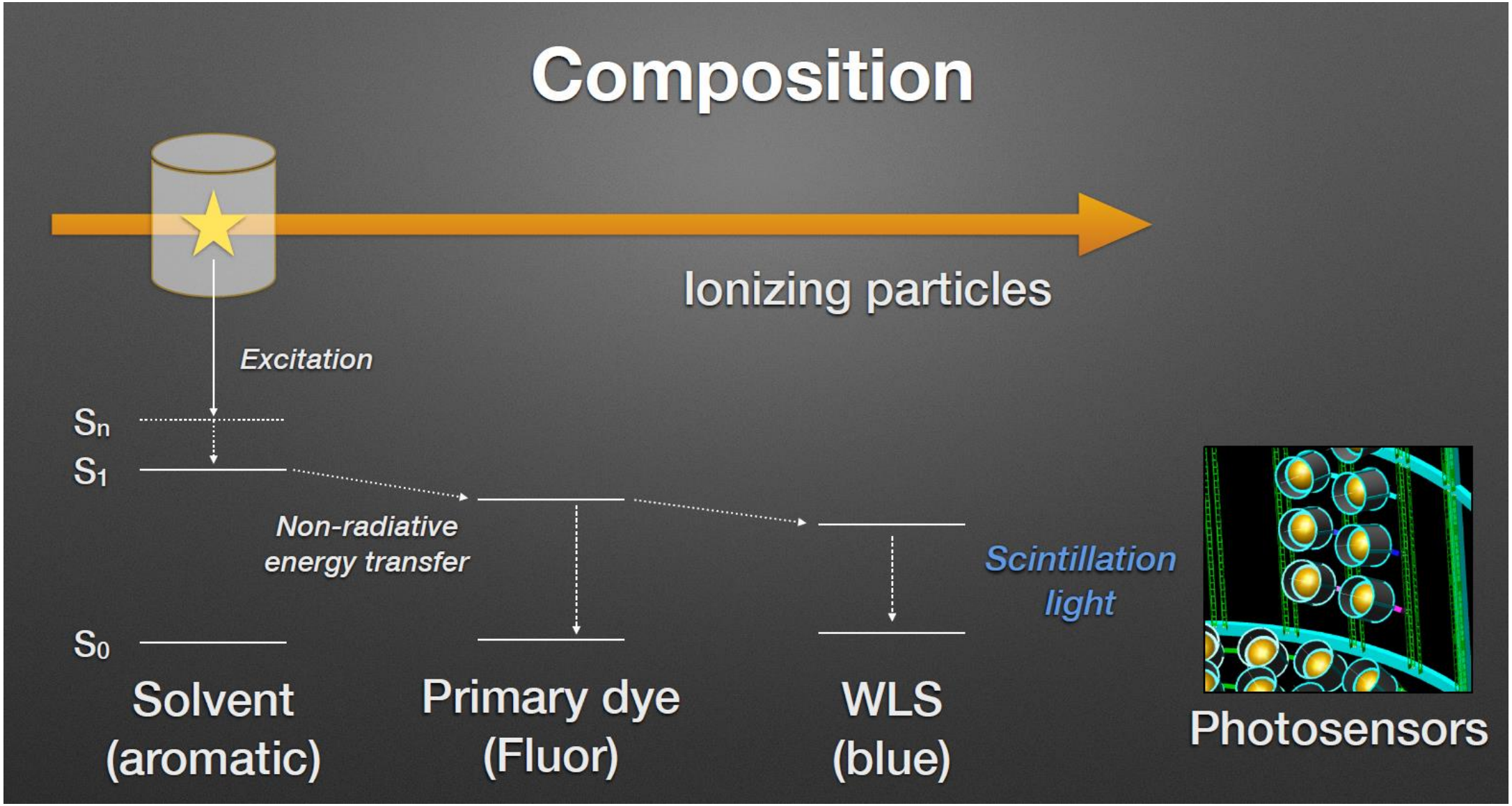


S1, Light yield

Journal of Physics G Nuclear and Particle Physics • September 2016
DOI: 10.1088/0954-3899/43/9/093001



Christian Buck (MPIK Heidelberg)
https://indico.kps.or.kr/event/30/contributions/904/



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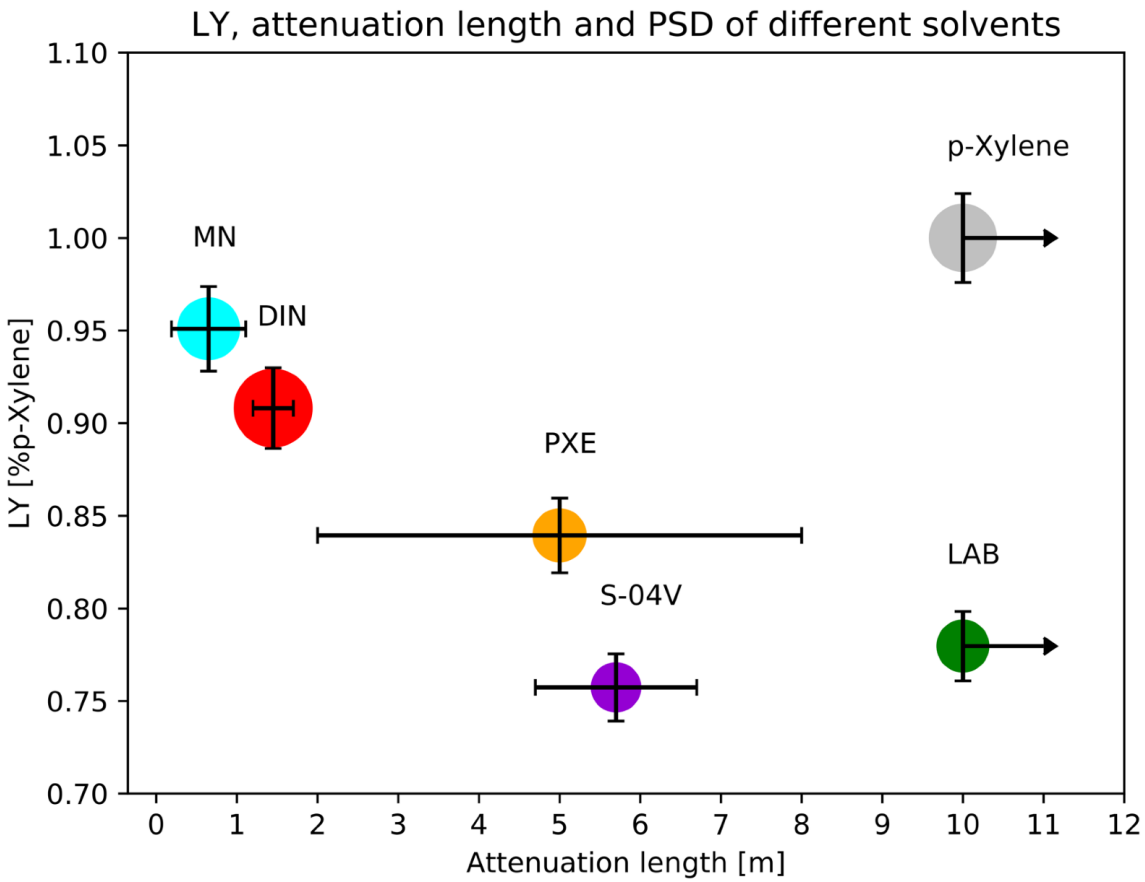
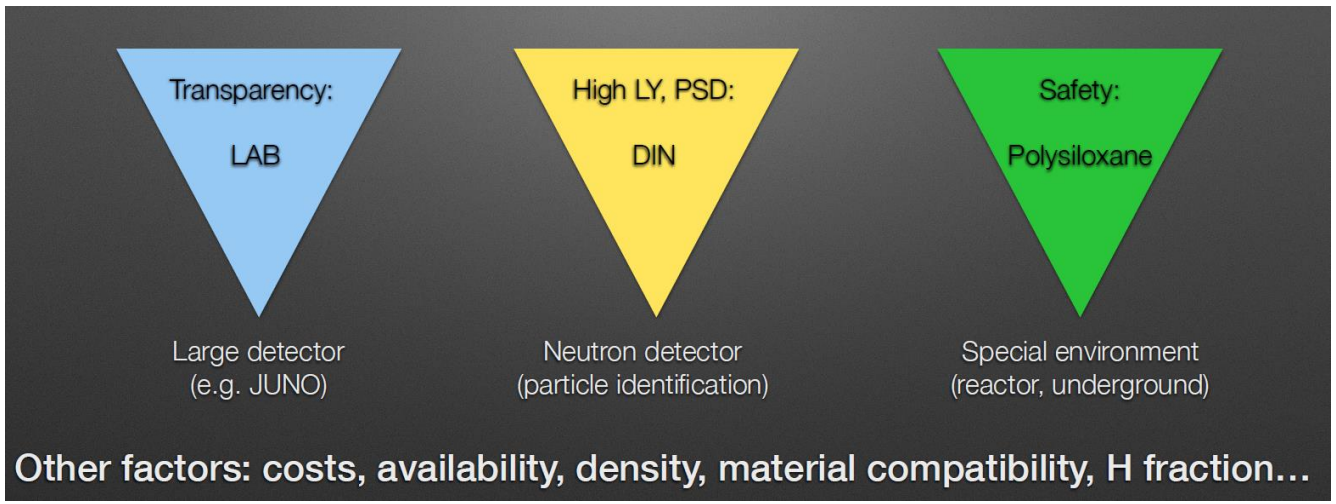
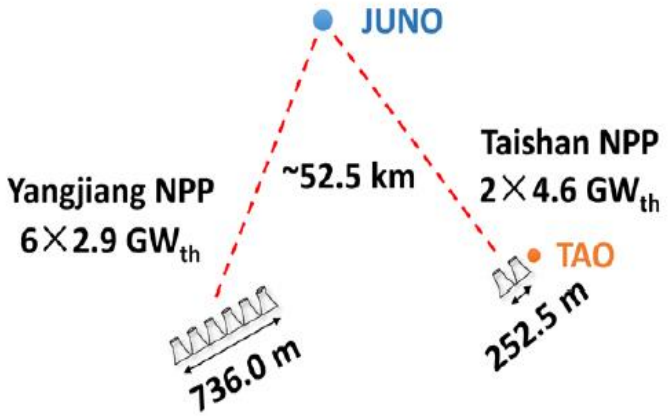


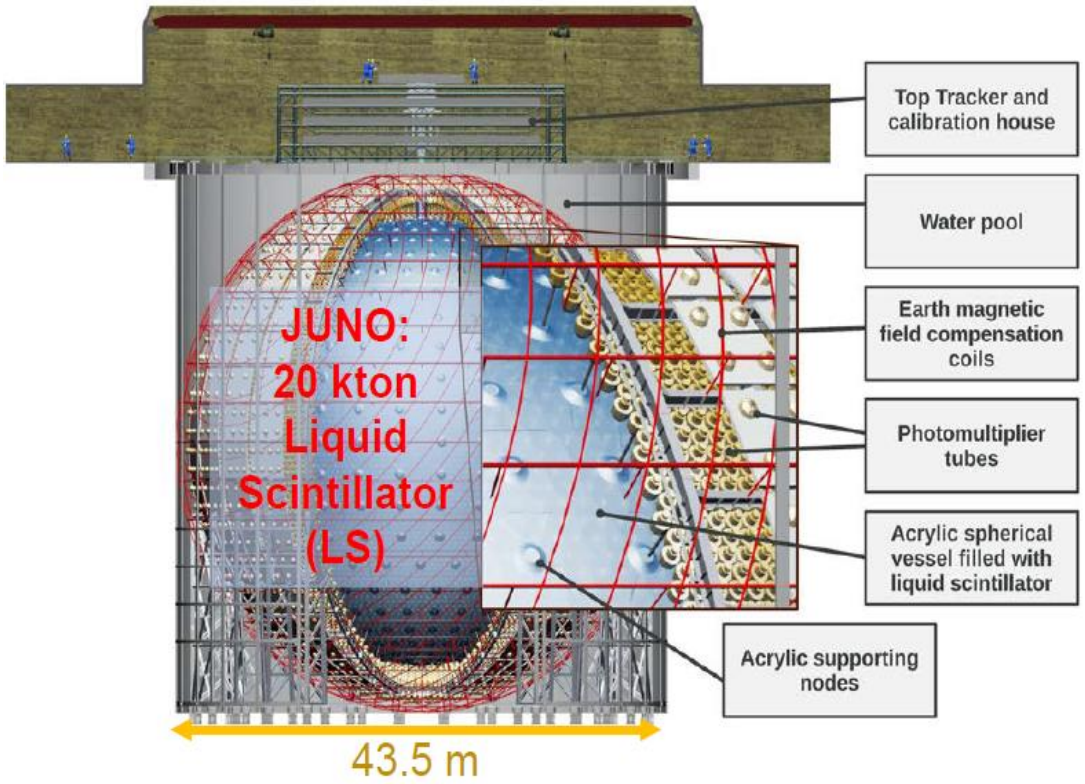


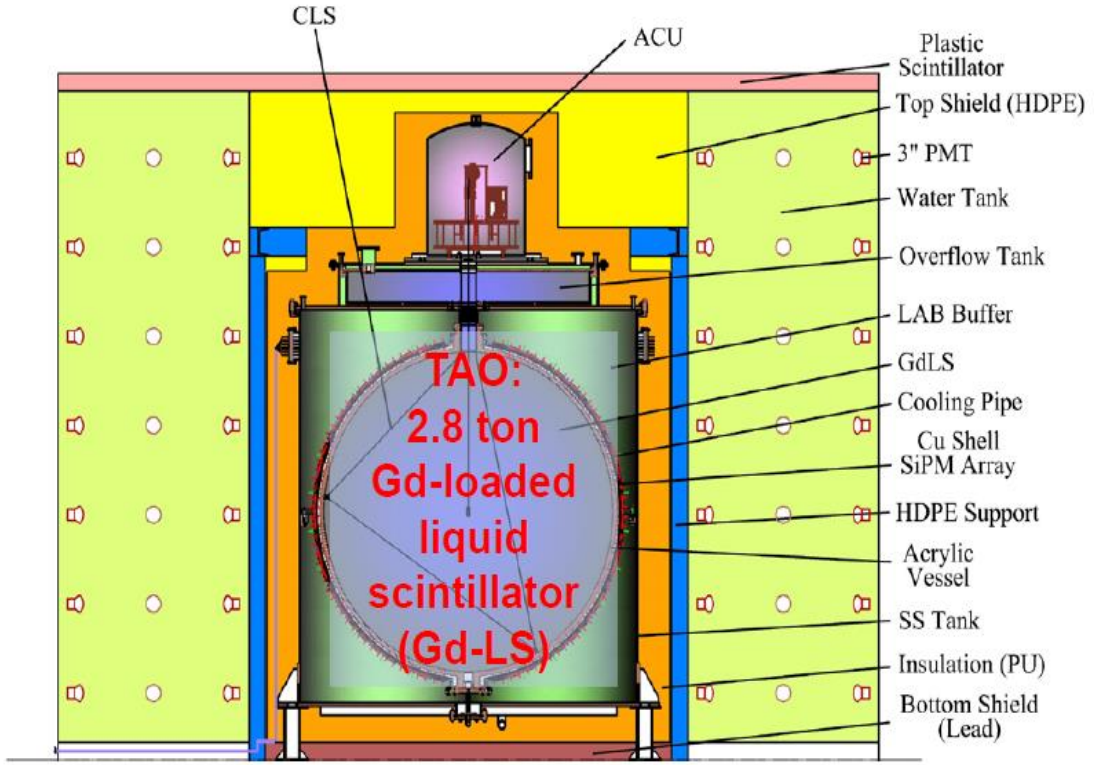
https://indico.ihep.ac.cn/event/16065/contributions/43484/attachments/62178/71736/JUNO-NMO-Sensitivity-Jinnan-Aug2022-v2.pdf

JUNO & JUNO-TAO

- A 20 kton multipurpose liquid scintillator (LS) detector
  - < 3% resolution @1 MeV
  - Optimized of neutrino mass ordering (NMO) determination
- A 2.8 ton Gd-loaded LS satellite detector
  - < 2% resolution @1 MeV

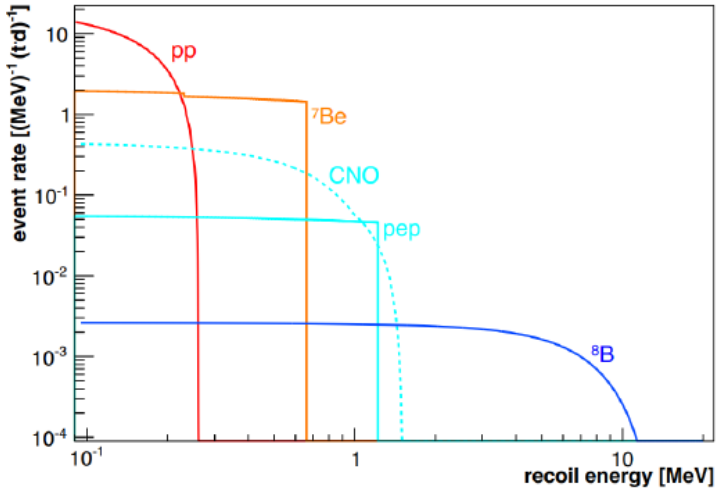


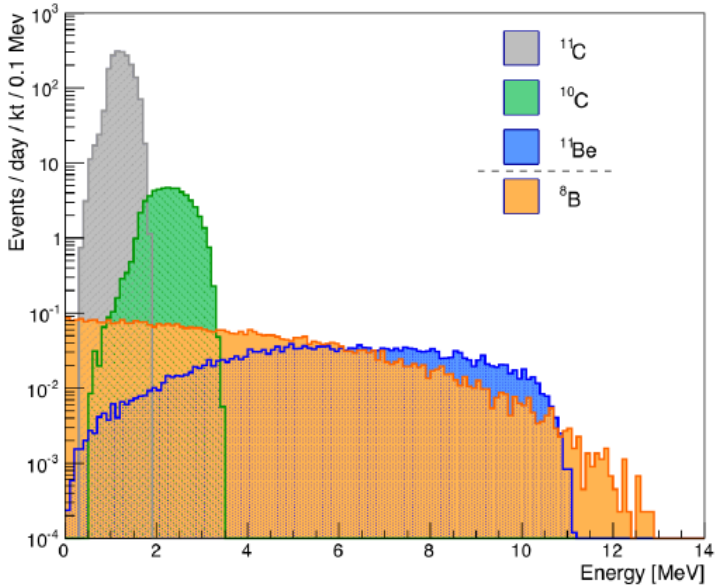


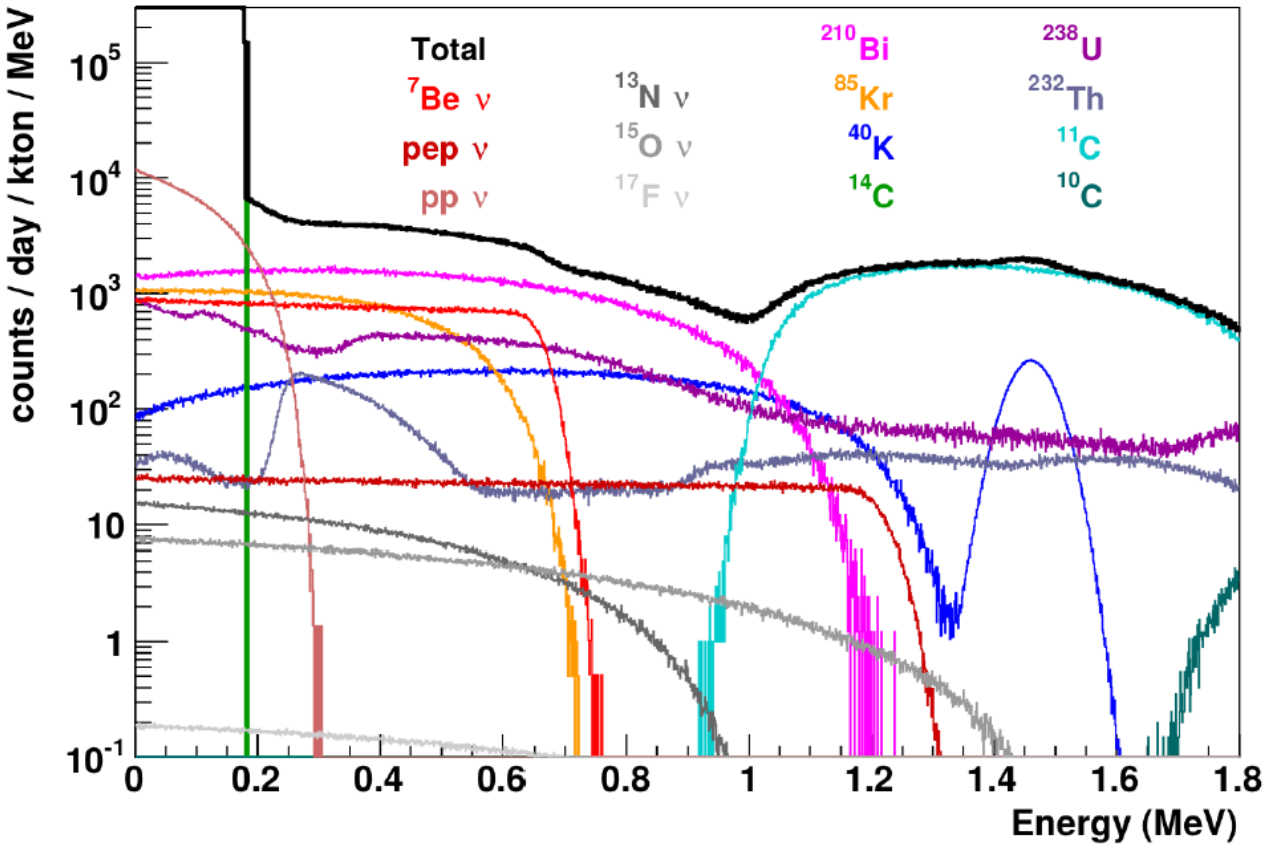


http://collaborations.fz-juelich.de/ikp/neutrino/group_mem/documents/Rikhav_Master_Thesis.pdf

JUNO: reaching sub-MeV ~0.2MeV







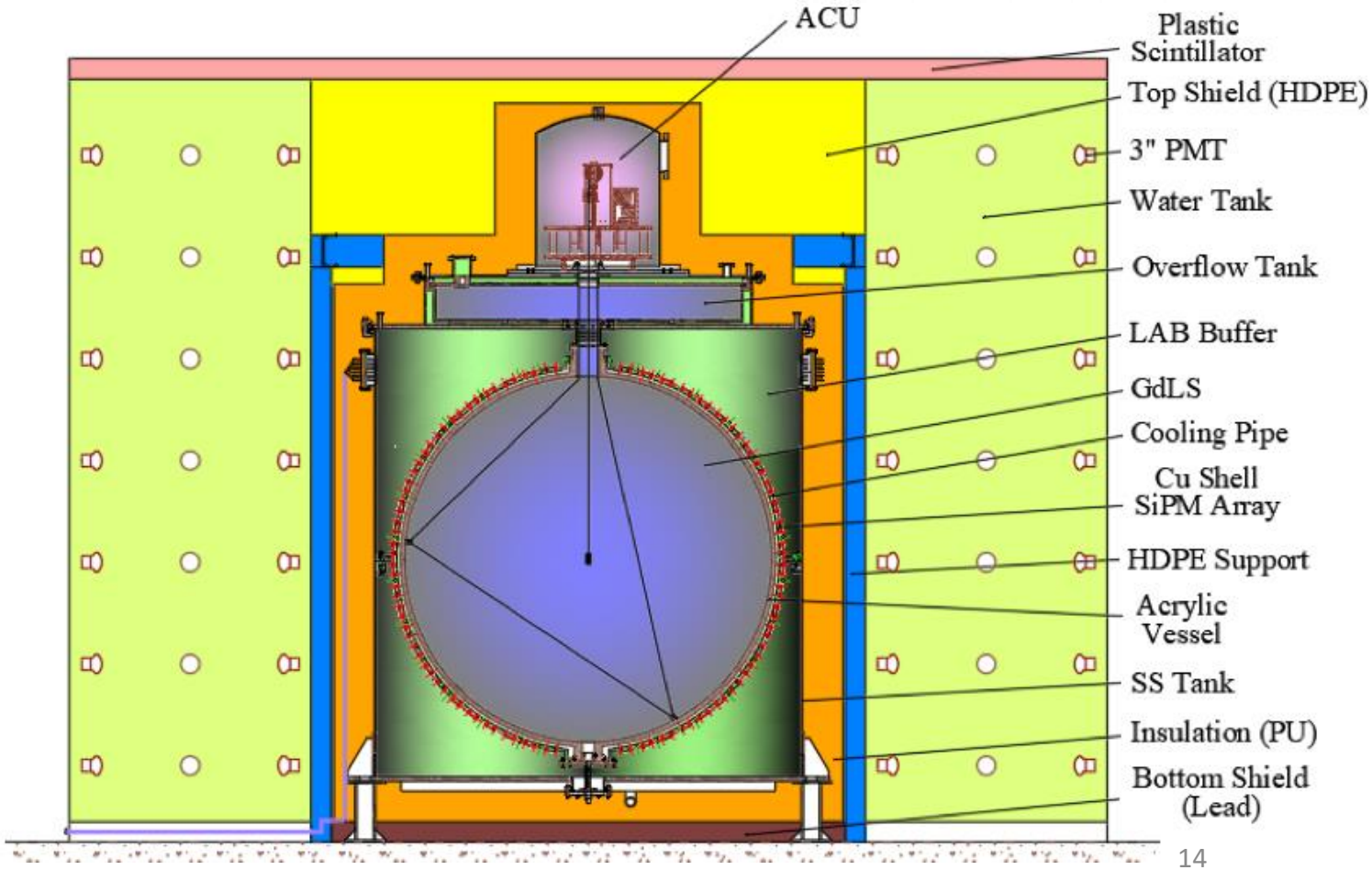
TAO Detector

Inner → **Outside**

Gd-LS ⇨ acrylic vessel ⇨ SiPM & support ⇨ LAB buffer ⇨ cryogenic vessel ⇨ water & HDPE shield ⇨ muon veto

- 1.8 m diameter, 2.8 ton GdLS (1 ton for fiducial volume cut)
- Operate at -50° C
- ~ 10 m^2 SiPM coverage (95%)
- -9.6 m underground

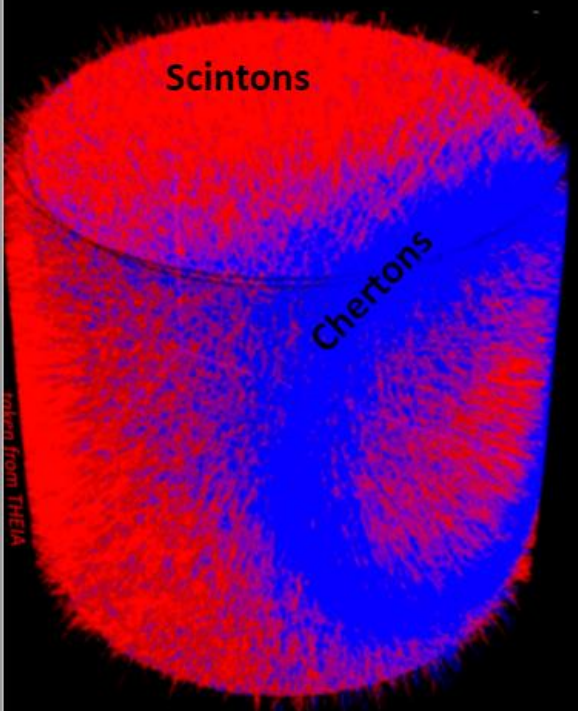
- 4000 IBD/day (2000 w/ FV)

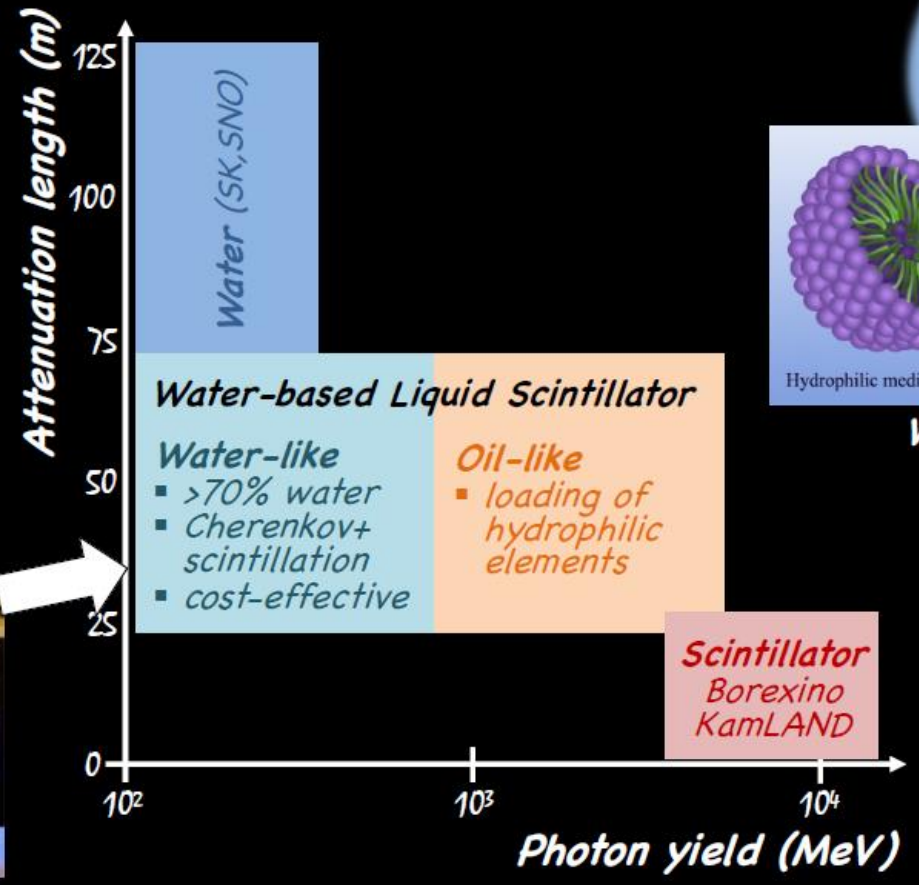


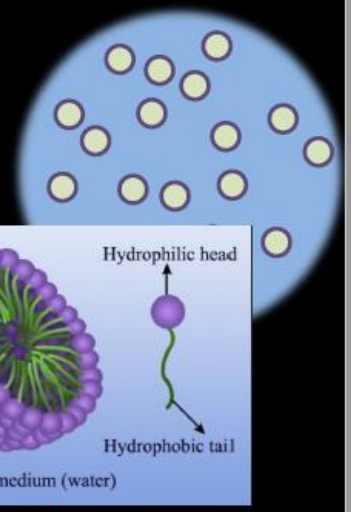
Michael Wurm (JGU Mainz)
https://indico.kps.or.kr/event/30/contributions/903/

Water-based liquid scintillators (WbLS)

→ WbLS: water + tensid + solvent (LAB) + fluor (PPO)
→ low organic fraction → high transparency



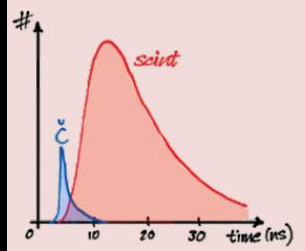




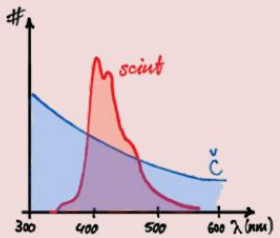
WbLS mycels

Minfang Yeh, BNL

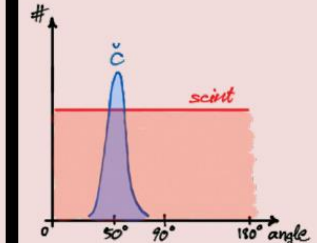
Timing
"instantaneous chertons" vs. delayed "scintons"
→ ns resolution or better



Spectrum
UV/blue scintillation vs. blue/green Cherenkov
→ wavelength-sensitivity



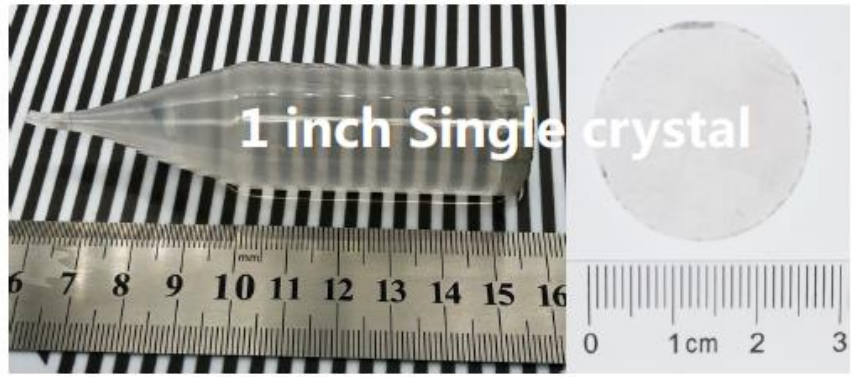
Angular distribution
increased PMT hit density under Cherenkov angle
→ sufficient granularity

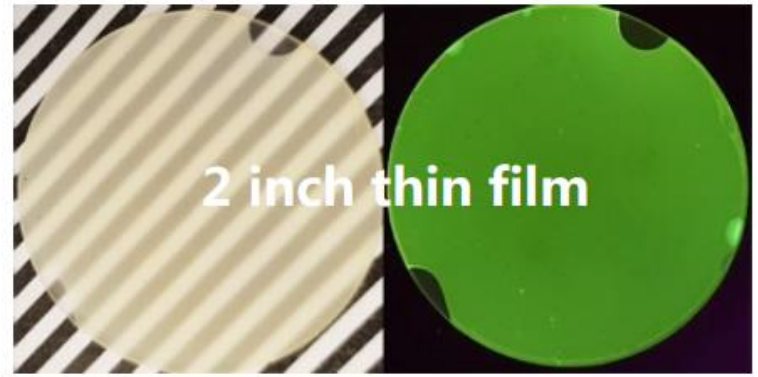


→ properties of target medium can be adjusted to physics goal
→ water content offers additional options for metal loading

➢ Summary

Composition	Hygroscopicity	Density (g/cm^3)	Light yield (ph/MeV)	Energy resolution 662 keV(%)	Scintillation decay (ns)	Afterglow 10 ms (%)	X-ray detection limit (nGy/s)
$Cs_3Cu_2I_5$	No	4.51	29,000	3.4	51 (4%) 967 (96%)	0.015	103.6
$Cs_3Cu_2I_5$:In	No	4.51	53,000	6-7	556 3746	1	96.2
$Cs_3Cu_2I_5$:Tl	**No**	**4.51**	**87,000**	**3.4**	**690 (88%) 1669 (12%)**	**0.17**	**66.3**
$CeBr_3$	Strong	5.22	68,000	3.7-4.3	17	-	-
NaI:Tl	Strong	3.67	45,000	7.1	230	-	-





专利：PCT/CN2021/099440、202210177453.6 、202210079484.8 、202110446361.9、202010573954.7

Summary

- Low threshold technology development of scintillation detector
- LAr double-phase for CEvNS
- LS for neutrinos
- New possibilities
  - Directional LS
  - Crystal with higher light yield

Thanks for your attention!!!

谢谢

arXiV: 2209.08215