Summary WG4 (Experimental techniques)

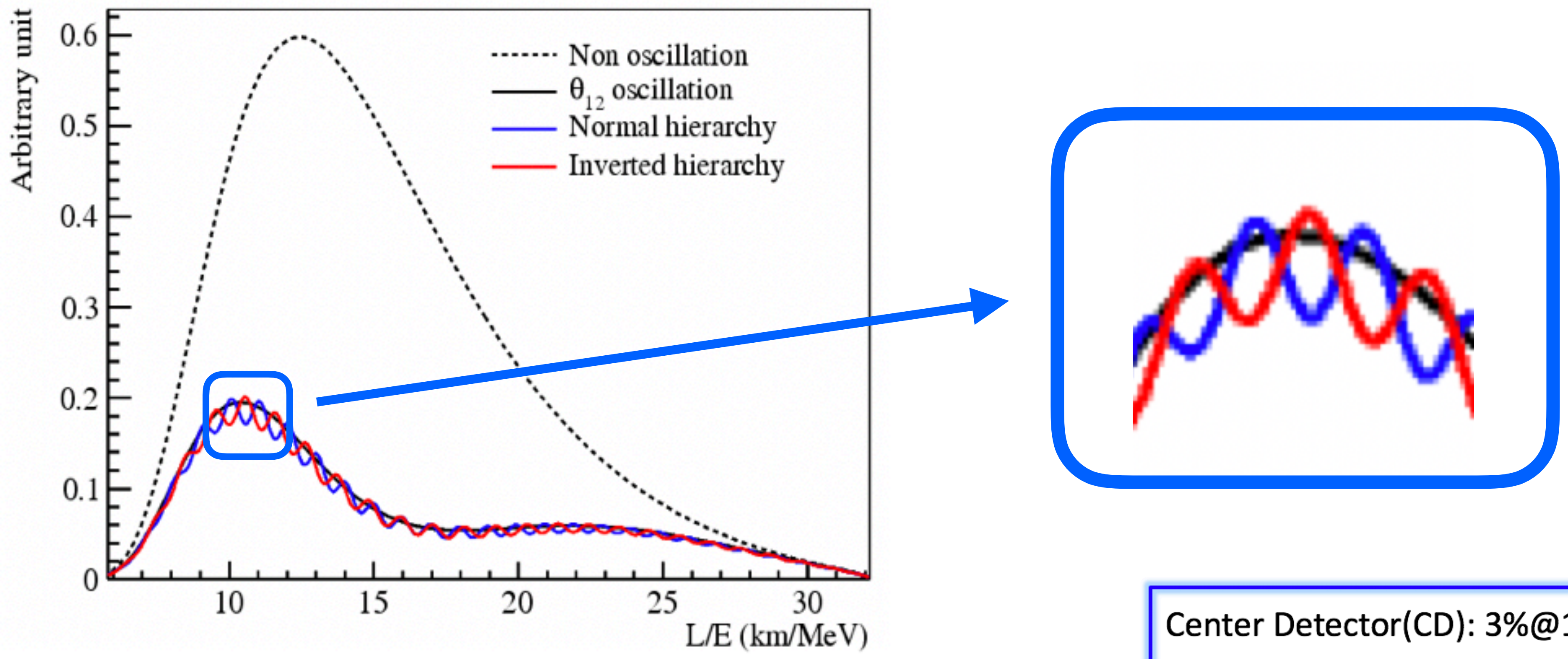
Davide Sgalaberna (CERN)

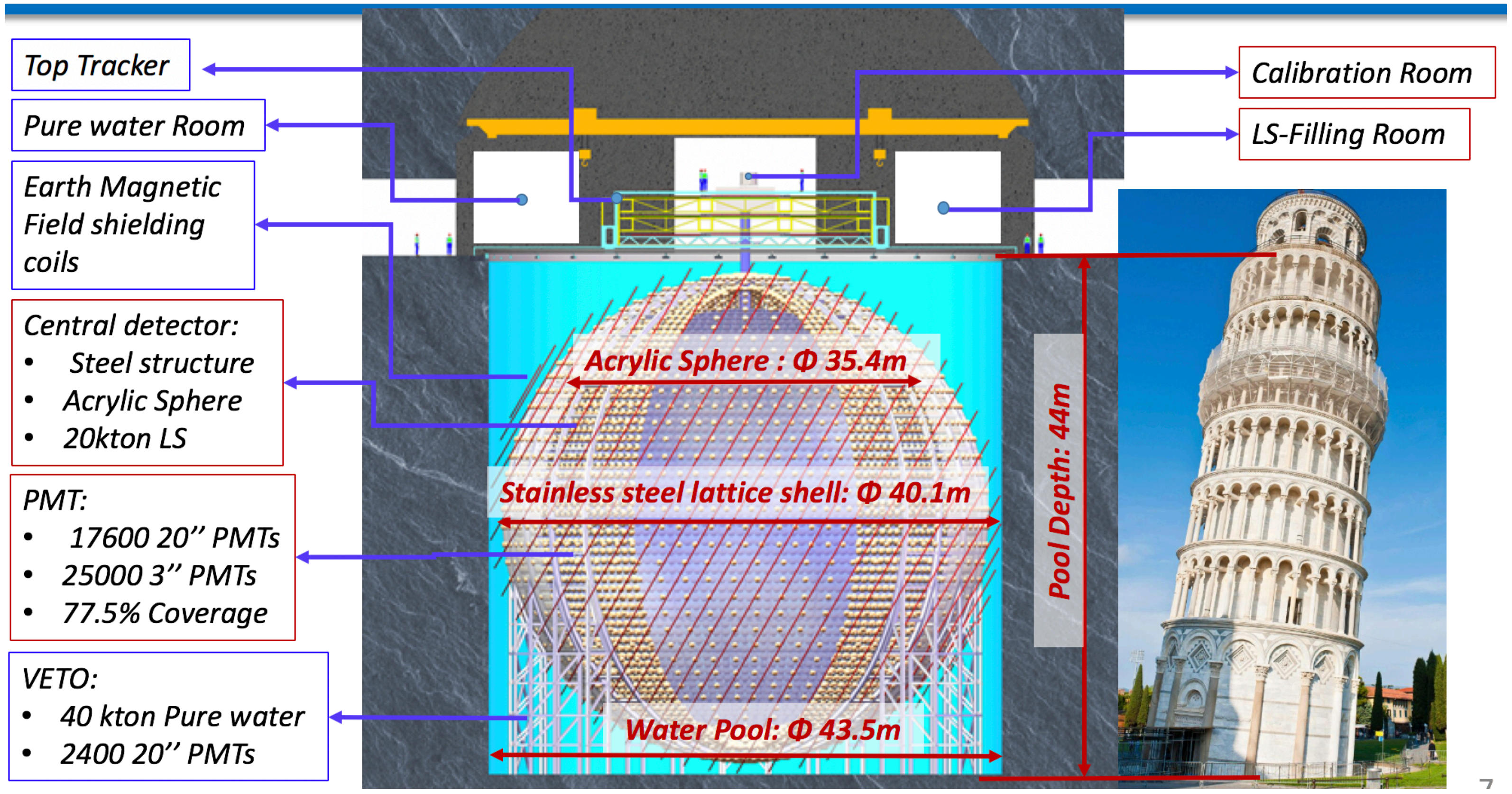
XVth Rencontres du Vietnam

9th August 2019

Cong Guo (IHEP)

JUNO





Top Tracker

Pure water Room

Earth Magnetic Field shielding coils

Central detector:
- Steel structure
- Acrylic Sphere
- 20kton LS

PMT:
- 17600 20'' PMTs
- 25000 3'' PMTs
- 77.5% Coverage

VETO:
- 40 kton Pure water
- 2400 20'' PMTs

Calibration Room

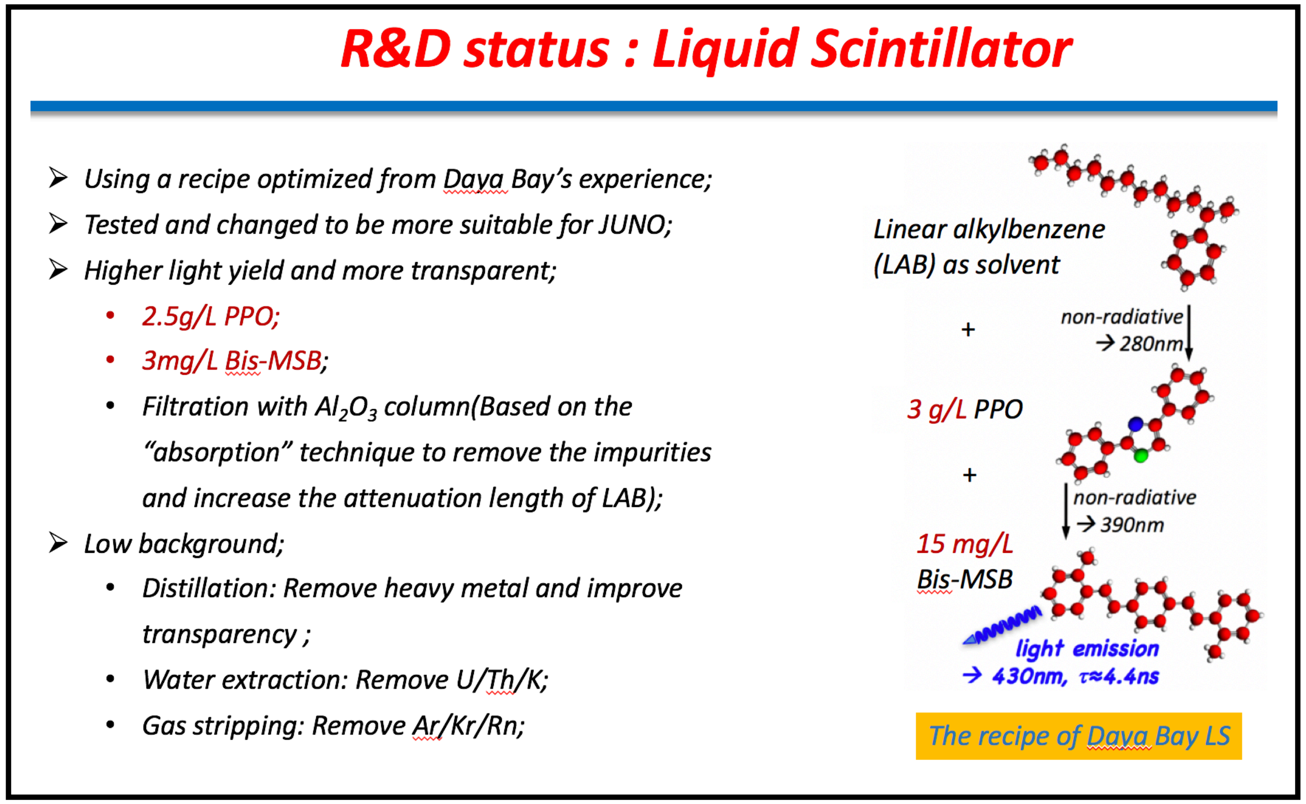
LS-Filling Room

Center Detector(CD): 3%@1MeV

- Liquid Scintillator
  - Light yield >1100P.E./MeV;
  - Attenuation length > 22m@430mn;
- PMT
  - Full coverage;
  - High quantum & collection efficiency;
- Acrylic sphere
  - High Transparency ;
  - Good mechanical strength for >20 years;
- Low radioactivity
  - $^{238}\mathrm{U}, ^{232}\mathrm{Th} \leq 10^{-15}$g/g, $^{40}\mathrm{K} < 10^{-16}$g/g for LS in reactor neutrino measurement ;
  - $^{238}\mathrm{U}, ^{232}\mathrm{Th}, ^{40}\mathrm{K} \leq$ 1ppt for acrylic;

Cong Guo (IHEP)

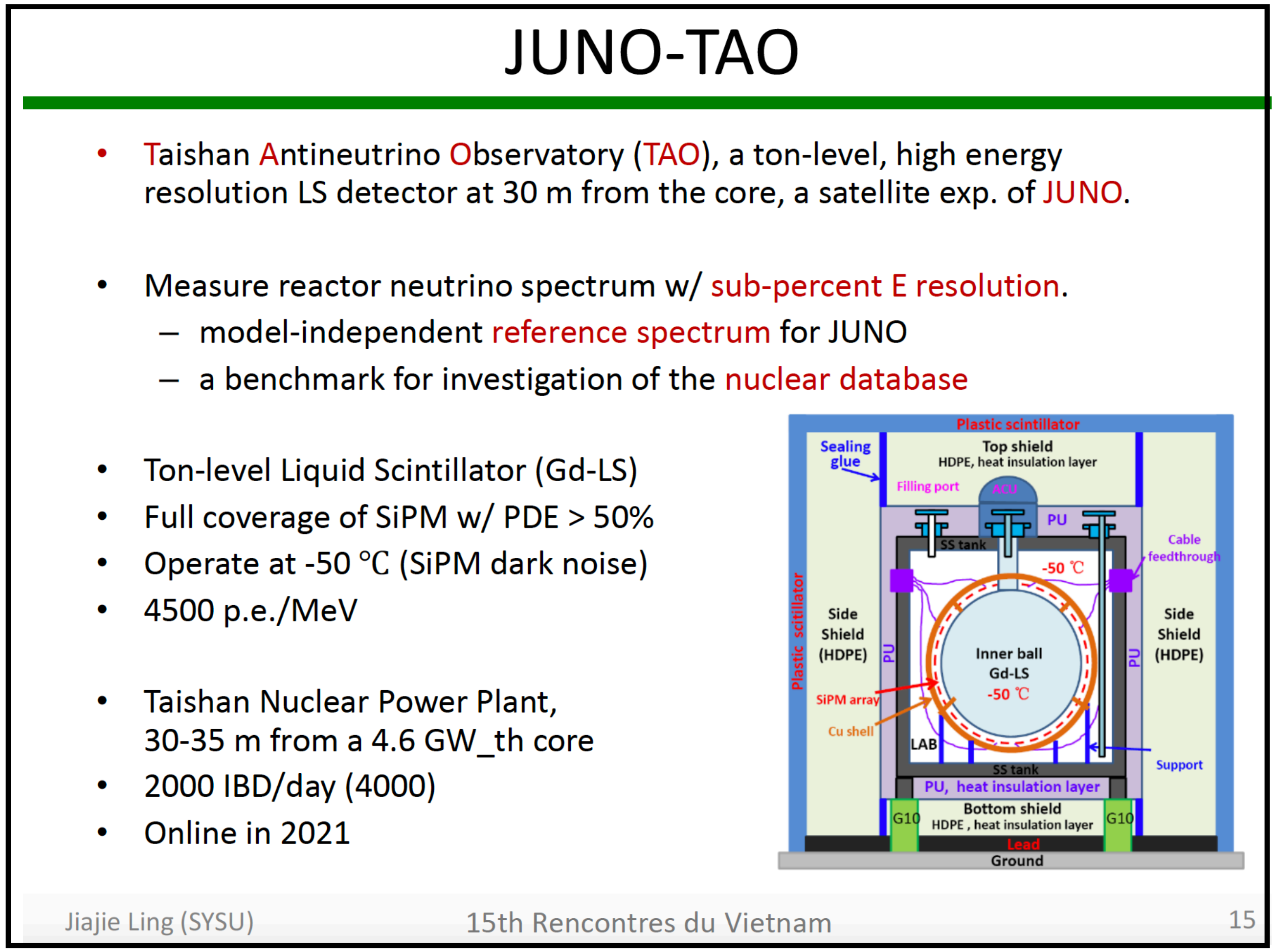
JUNO



R&D status : Liquid Scintillator

- ➢ *Using a recipe optimized from Daya Bay's experience;*
- ➢ *Tested and changed to be more suitable for JUNO;*
- ➢ *Higher light yield and more transparent;*
  - *2.5g/L PPO;*
  - *3mg/L Bis-MSB;*
  - *Filtration with Al_2O_3 column(Based on the "absorption" technique to remove the impurities and increase the attenuation length of LAB);*
- ➢ *Low background;*
  - *Distillation: Remove heavy metal and improve transparency ;*
  - *Water extraction: Remove U/Th/K;*
  - *Gas stripping: Remove Ar/Kr/Rn;*

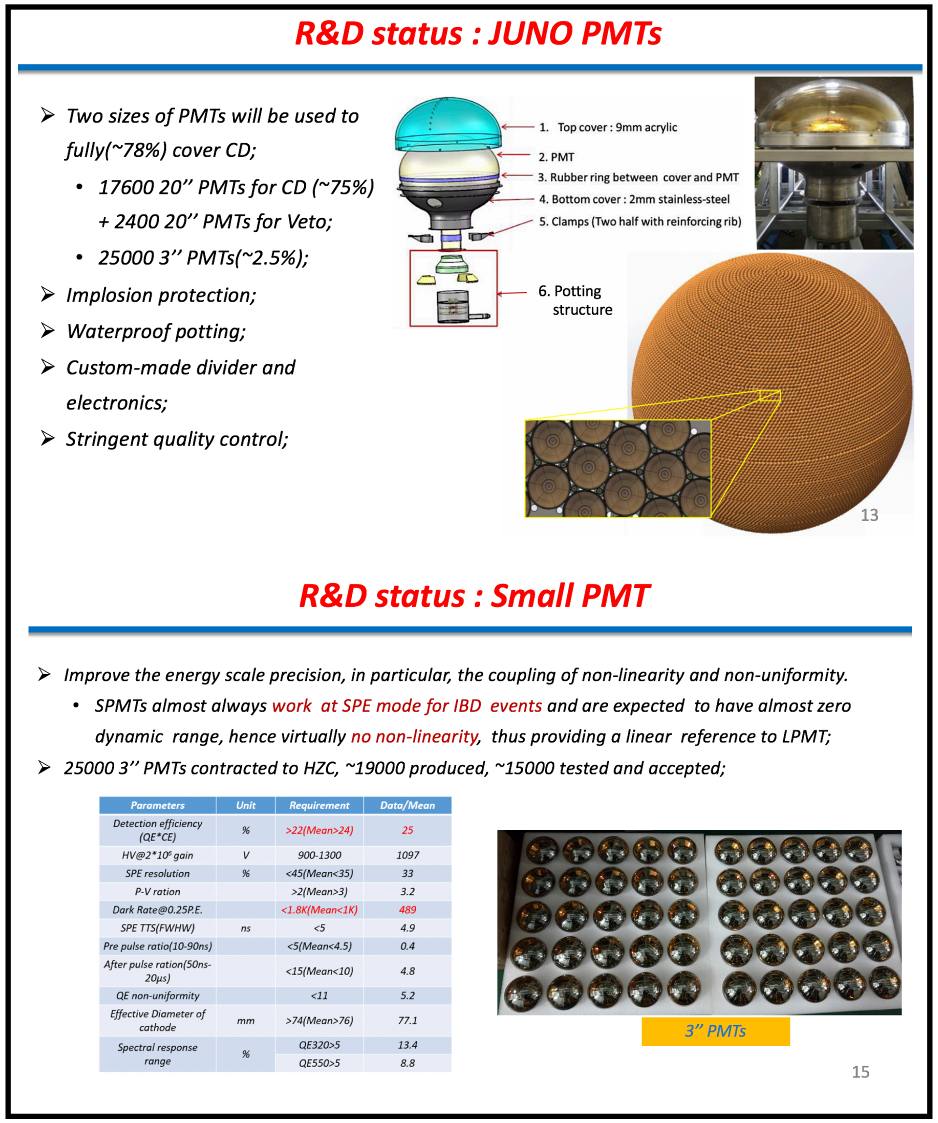
The recipe of Daya Bay LS



JUNO-TAO

- Taishan Antineutrino Observatory (TAO), a ton-level, high energy resolution LS detector at 30 m from the core, a satellite exp. of JUNO.
- Measure reactor neutrino spectrum w/ sub-percent E resolution.
  - – model-independent reference spectrum for JUNO
  - – a benchmark for investigation of the nuclear database
- Ton-level Liquid Scintillator (Gd-LS)
- Full coverage of SiPM w/ PDE > 50%
- Operate at -50 ℃ (SiPM dark noise)
- 4500 p.e./MeV
- Taishan Nuclear Power Plant, 30-35 m from a 4.6 GW_th core
- 2000 IBD/day (4000)
- Online in 2021

Jiajie Ling (SYSU) 15th Rencontres du Vietnam 15



R&D status : JUNO PMTs

- ➢ *Two sizes of PMTs will be used to fully(~78%) cover CD;*
  - *17600 20'' PMTs for CD (~75%) + 2400 20'' PMTs for Veto;*
  - *25000 3'' PMTs(~2.5%);*
- ➢ *Implosion protection;*
- ➢ *Waterproof potting;*
- ➢ *Custom-made divider and electronics;*
- ➢ *Stringent quality control;*

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R&D status : Small PMT

- ➢ *Improve the energy scale precision, in particular, the coupling of non-linearity and non-uniformity.*
  - *SPMTs almost always work at SPE mode for IBD events and are expected to have almost zero dynamic range, hence virtually no non-linearity, thus providing a linear reference to LPMT;*
- ➢ *25000 3'' PMTs contracted to HZC, ~19000 produced, ~15000 tested and accepted;*

Parameters	*Unit*	*Requirement*	*Data/Mean*
*Detection efficiency (QE*CE)*	*%*	*>22(Mean>24)*	*25*
*HV@2*10⁶ gain*	*V*	*900-1300*	*1097*
SPE resolution	*%*	*<45(Mean<35)*	*33*
P-V ration		*>2(Mean>3)*	*3.2*
Dark Rate@0.25P.E.		*<1.8K(Mean<1K)*	*489*
SPE TTS(FWHW)	*ns*	*<5*	*4.9*
Pre pulse ratio(10-90ns)		*<5(Mean<4.5)*	*0.4*
After pulse ration(50ns-20μs)		*<15(Mean<10)*	*4.8*
QE non-uniformity		*<11*	*5.2*
Effective Diameter of cathode	*mm*	*>74(Mean>76)*	*77.1*
Spectral response range	*%*	*QE320>5*	*13.4*
		QE550>5	*8.8*

3'' PMTs

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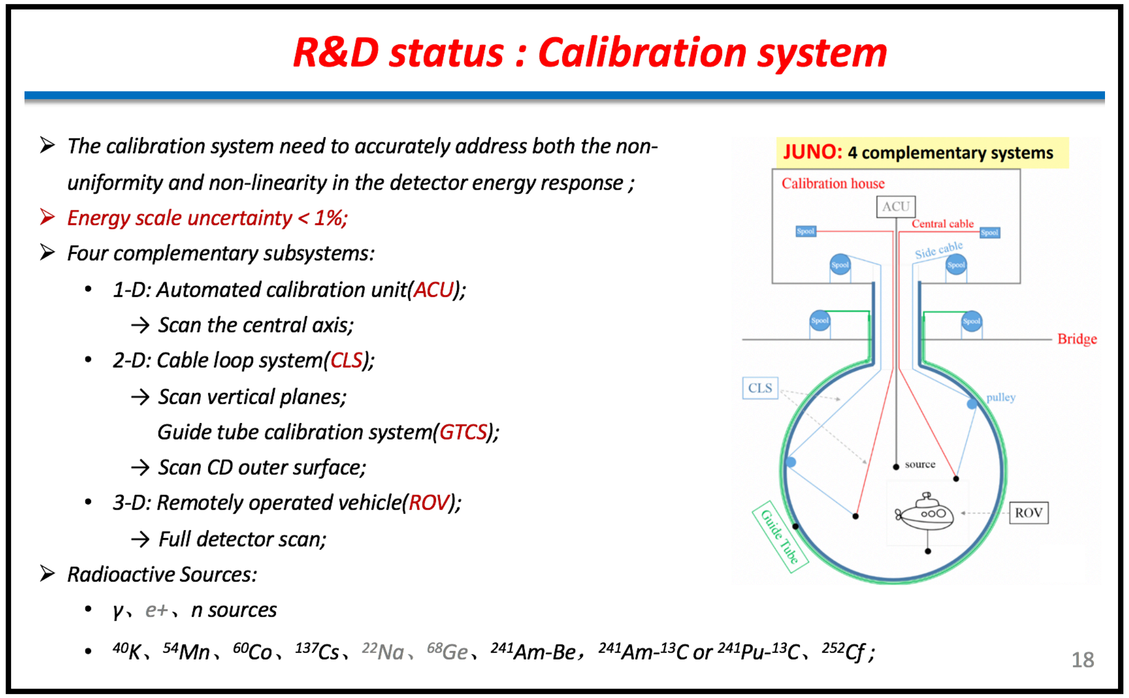

R&D status : Calibration system

- ➢ *The calibration system need to accurately address both the non-uniformity and non-linearity in the detector energy response ;*
- ➢ *Energy scale uncertainty < 1%;*
- ➢ *Four complementary subsystems:*
  - *1-D: Automated calibration unit(ACU);*
    - *→ Scan the central axis;*
  - *2-D: Cable loop system(CLS);*
    - *→ Scan vertical planes;*
    - *Guide tube calibration system(GTCS);*
    - *→ Scan CD outer surface;*
  - *3-D: Remotely operated vehicle(ROV);*
    - *→ Full detector scan;*
- ➢ *Radioactive Sources:*
  - *γ、e+、n sources*
  - *^{40}K、^{54}Mn、^{60}Co、^{137}Cs、^{22}Na、^{68}Ge、^{241}Am-Be，^{241}Am-^{13}C or ^{241}Pu-^{13}C、^{252}Cf ;*

JUNO: 4 complementary systems

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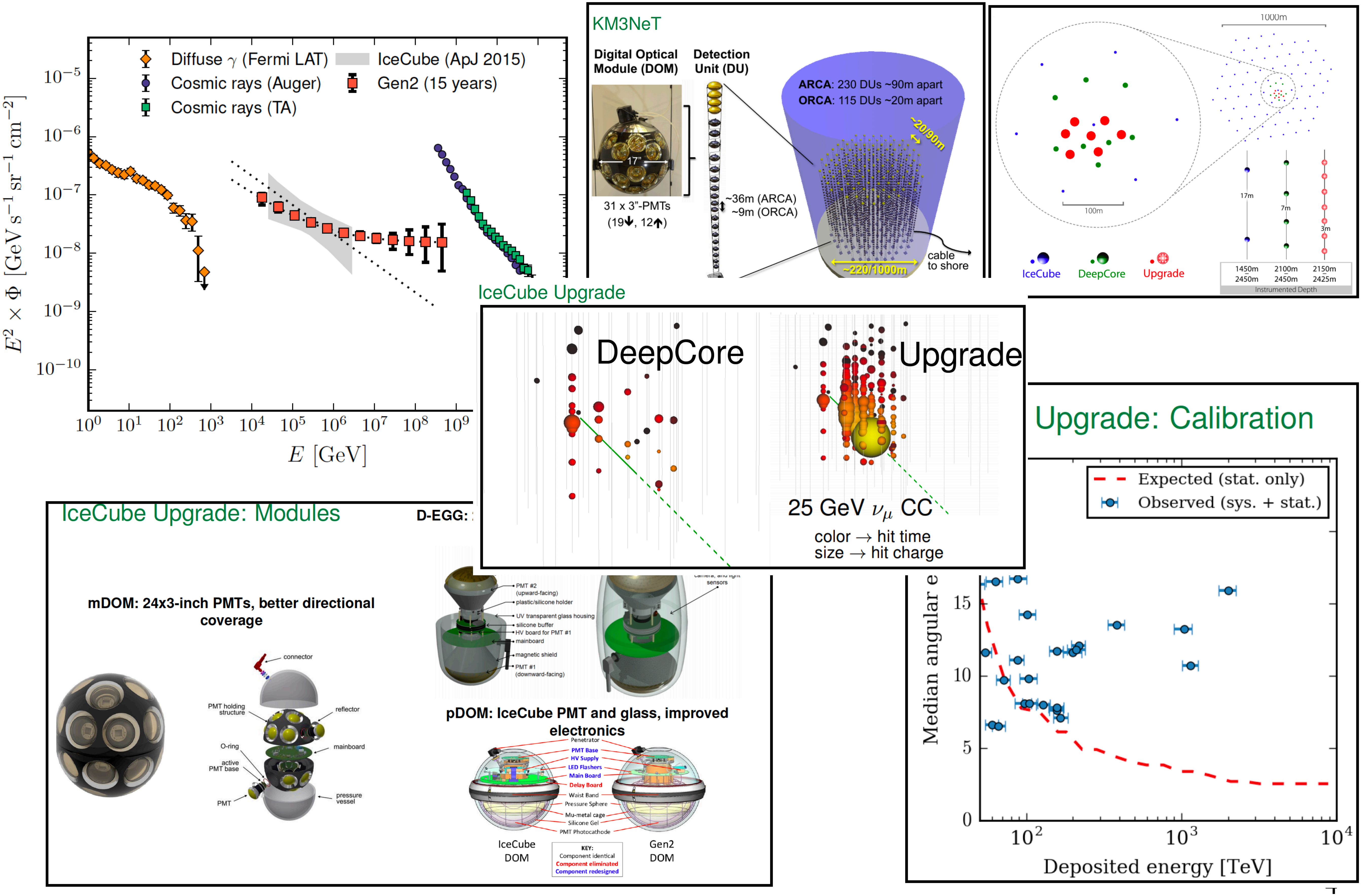
IceCube upgrade & Km3Net

J.Highnight (U.Alberta)



KM3NeT

Digital Optical Module (DOM) **Detection Unit (DU)**

31 x 3"-PMTs (19↓, 12↑)

ARCA: 230 DUs ~90m apart
ORCA: 115 DUs ~20m apart

IceCube Upgrade

25 GeV ν_μ CC

color → hit time
size → hit charge

IceCube Upgrade: Modules

mDOM: 24x3-inch PMTs, better directional coverage

pDOM: IceCube PMT and glass, improved electronics

Upgrade: Calibration

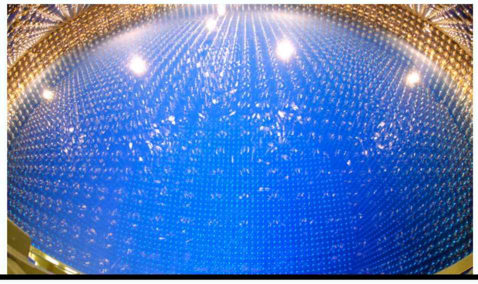
SuperK towards Gadolinium

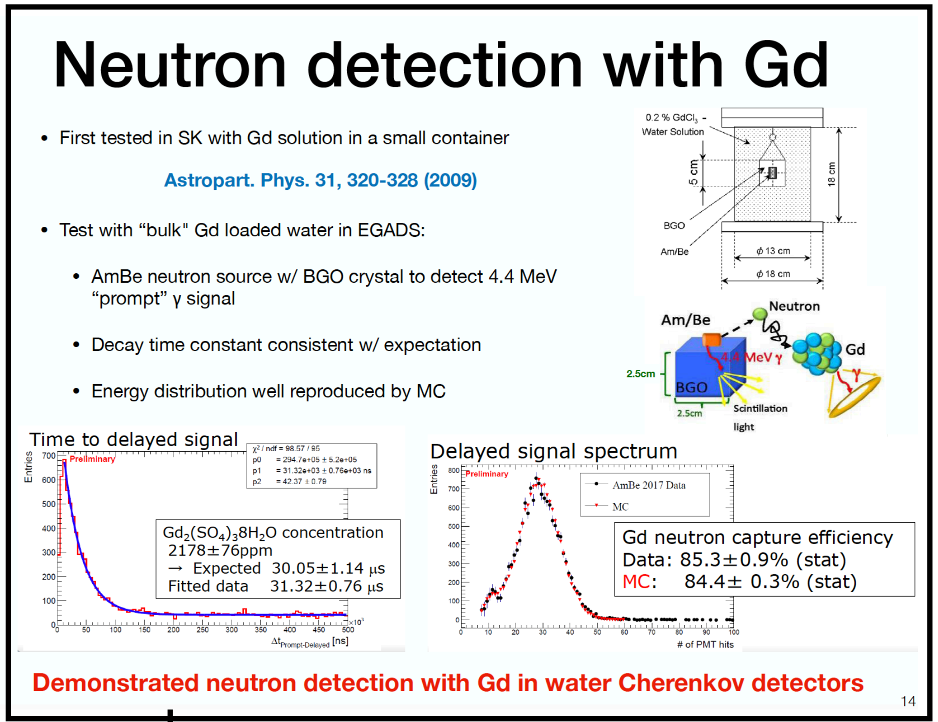
Nakajima-san (ICRR, U.Tokyo)

Advantage of Gd:

- Large n-capture cross section:
  - 90% of Gd capture efficiency at 0.2% loading of $Gd_2(SO_4)_3$ (corresponds to 100 ton/SK)
- Large released energy of ~8MeV
  - Well above most of natural radioactivity and the SK trigger threshold

Strongly tag electron antineutrinos by prompt (e^+) and delayed (n-Gd) coincidences





Neutron detection with Gd

- First tested in SK with Gd solution in a small container

  Astropart. Phys. 31, 320-328 (2009)

- Test with “bulk" Gd loaded water in EGADS:
  - AmBe neutron source w/ BGO crystal to detect 4.4 MeV “prompt” γ signal
  - Decay time constant consistent w/ expectation
  - Energy distribution well reproduced by MC

$Gd_2(SO_4)_3 8H_2O$ concentration
2178±76ppm
→ Expected 30.05±1.14 μs
Fitted data 31.32±0.76 μs

Gd neutron capture efficiency
Data: 85.3±0.9% (stat)
MC: 84.4± 0.3% (stat)

Demonstrated neutron detection with Gd in water Cherenkov detectors

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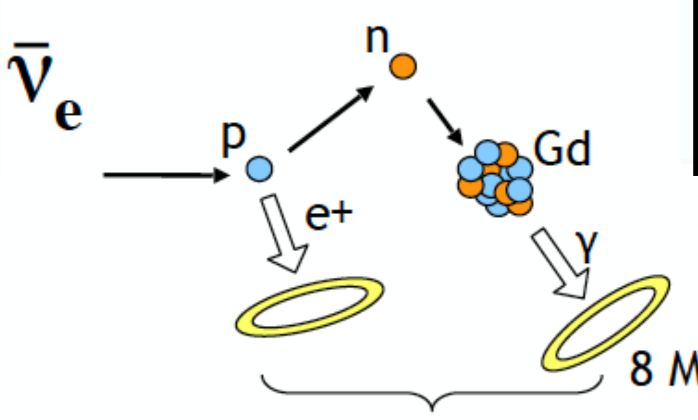
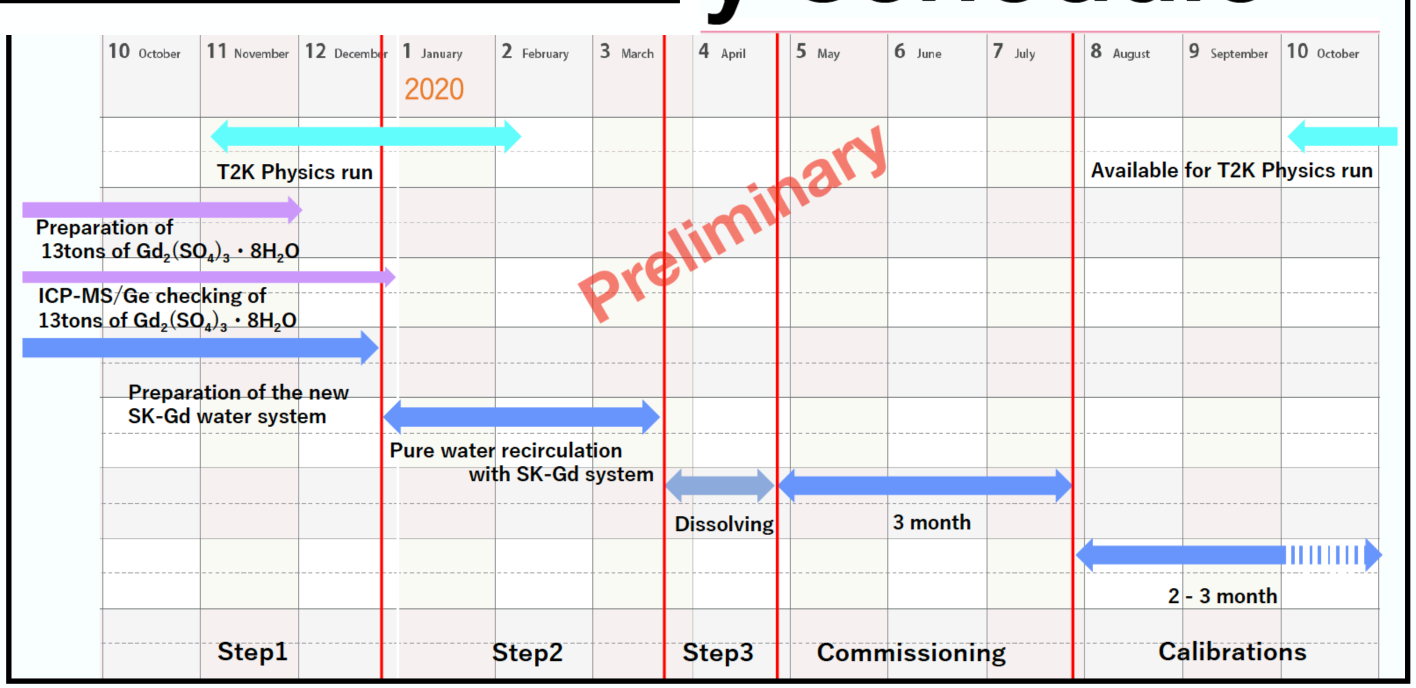


ΔT~30μs, Vertices within 50cm

Goals of SK-Gd

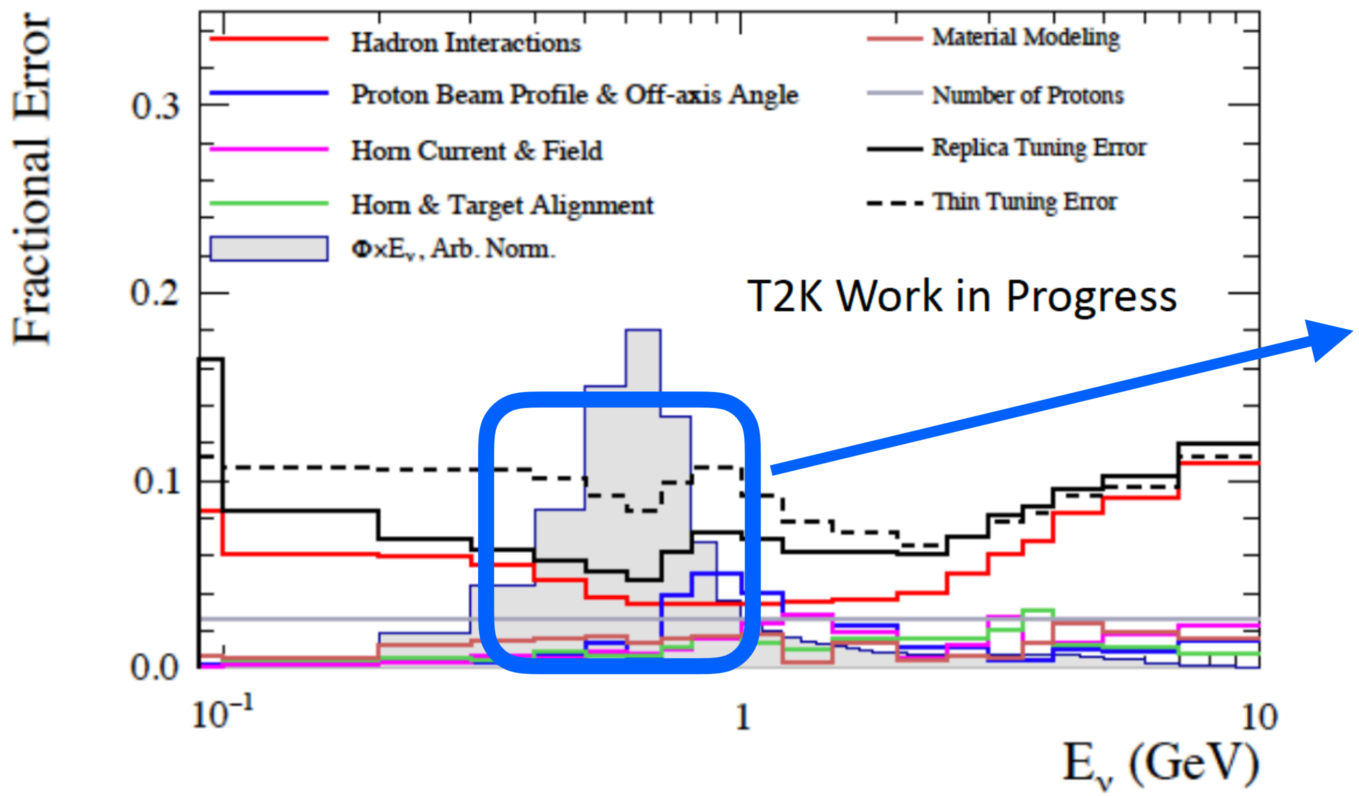
- **First observation of Supernova Relic Neutrinos**
- Improve pointing accuracy for galactic supernova
- Precursor of nearby supernova by Si-burning neutrinos
- Reduce proton decay background
- Neutrino/anti-neutrino discrimination (Long-baseline and atmospheric neutrinos)
- Reactor neutrinos

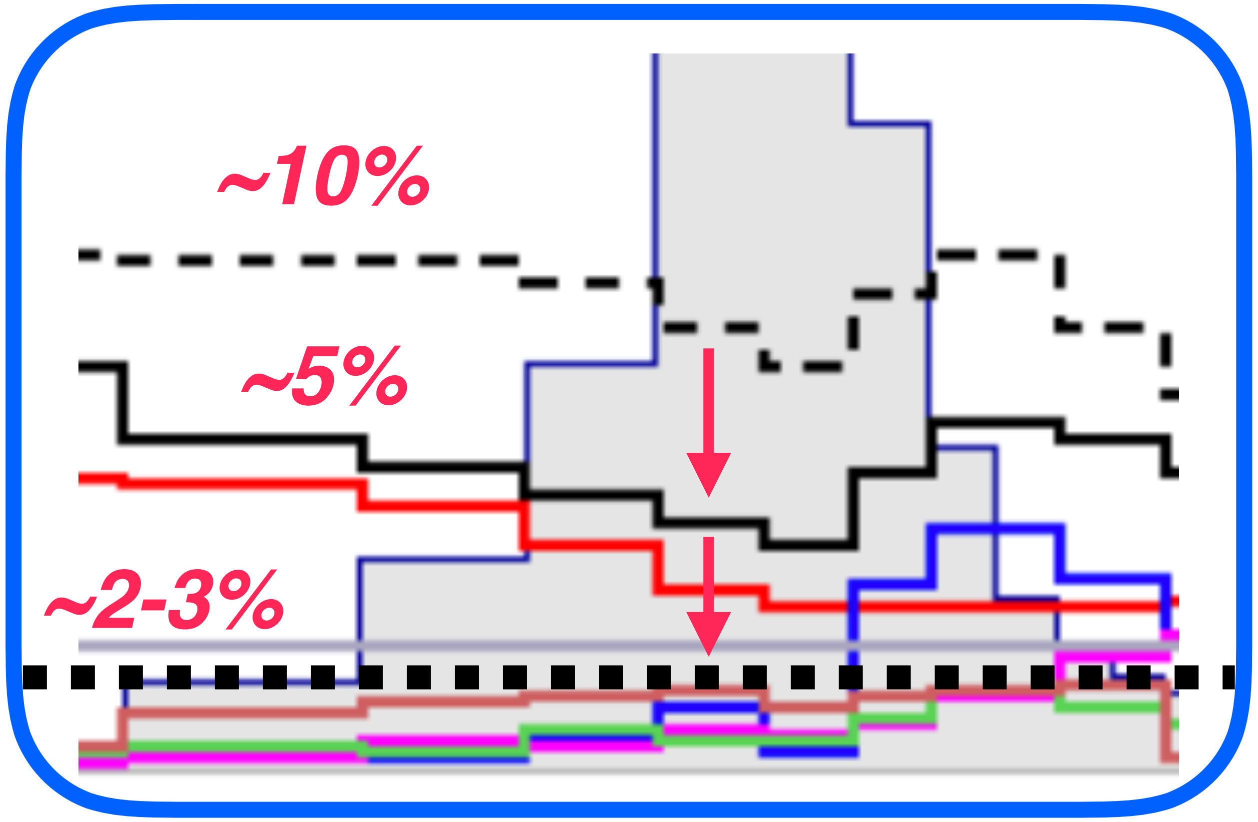
y schedule

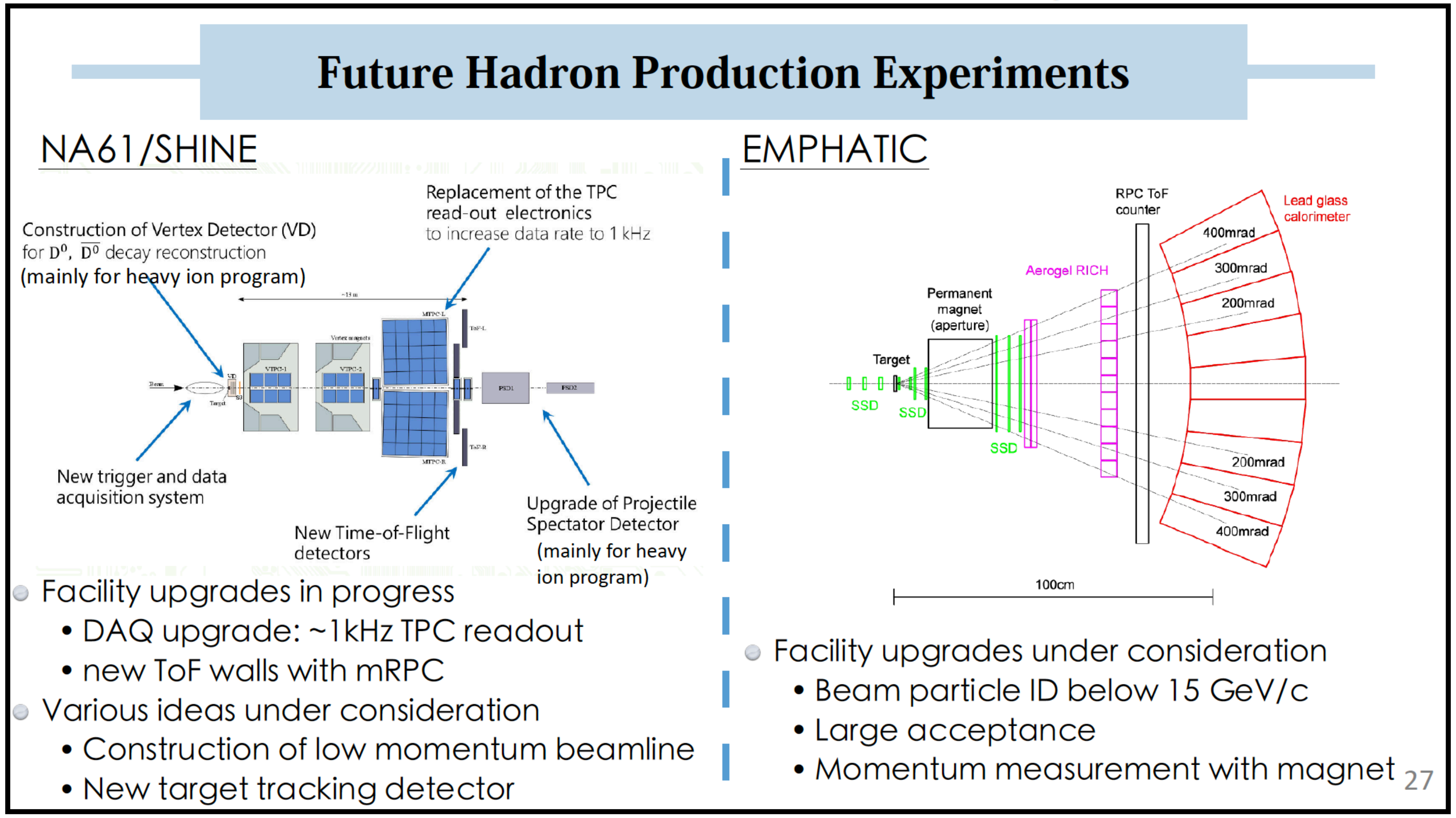


Neutrino flux measurement: Hadron production

Nagai-san (U.Colorado Boulder)







Future Hadron Production Experiments

NA61/SHINE

Construction of Vertex Detector (VD) for D^0, $\overline{D^0}$ decay reconstruction (mainly for heavy ion program)

Replacement of the TPC read-out electronics to increase data rate to 1 kHz

New trigger and data acquisition system

New Time-of-Flight detectors

Upgrade of Projectile Spectator Detector (mainly for heavy ion program)

- Facility upgrades in progress
  - DAQ upgrade: ~1kHz TPC readout
  - new ToF walls with mRPC
- Various ideas under consideration
  - Construction of low momentum beamline
  - New target tracking detector

EMPHATIC

- Facility upgrades under consideration
  - Beam particle ID below 15 GeV/c
  - Large acceptance
  - Momentum measurement with magnet

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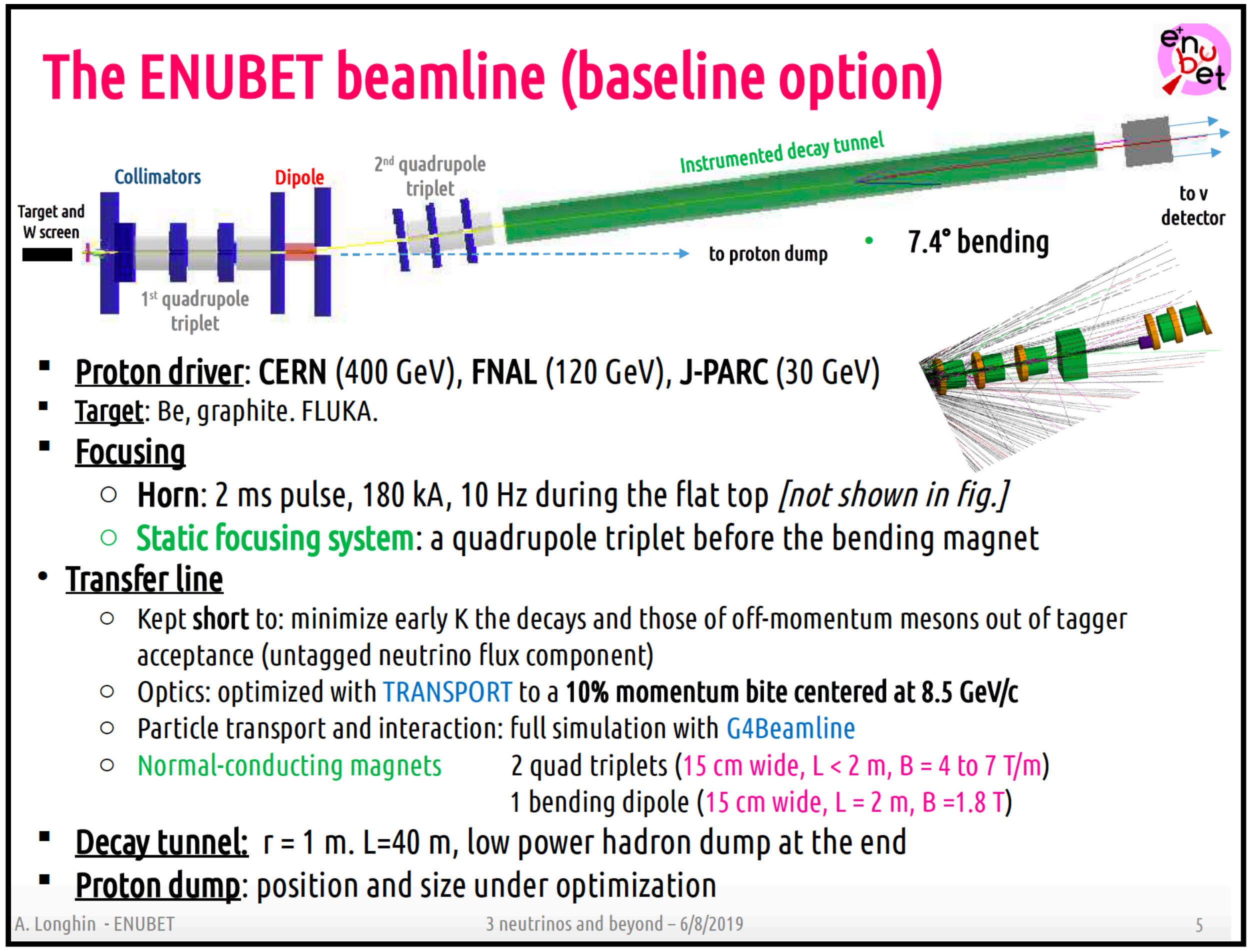
- Independent methods nu+e scattering, low-nu, momentum imbalance+neutrons, etc.) will be a good cross check
- Joint analysis of p-C/Ca/Be/… helfpul to better constrain the models ?

ENUBET

A.Longhin (U.Padova)

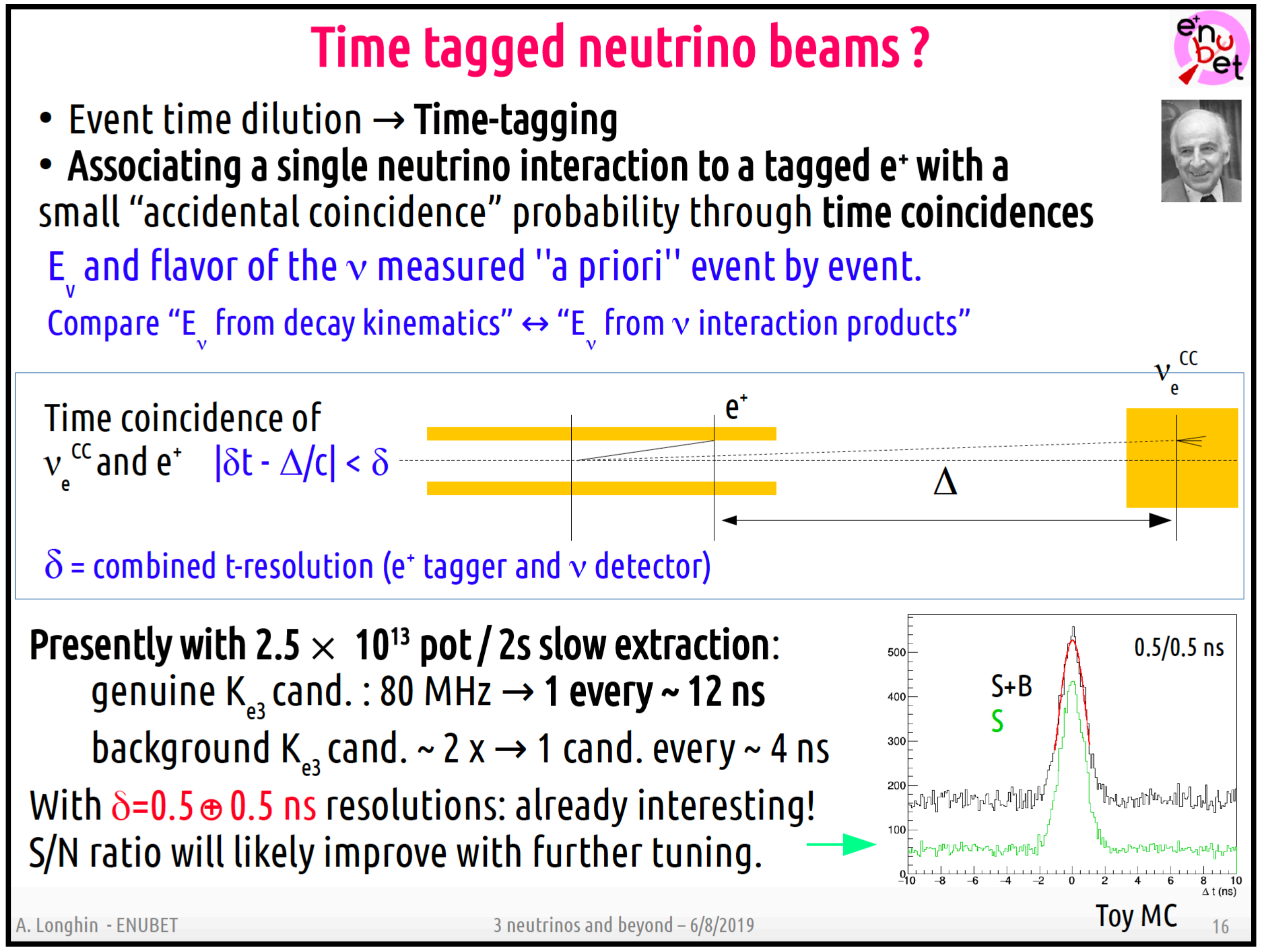


The ENUBET beamline (baseline option)

- 7.4° bending

- **Proton driver**: **CERN** (400 GeV), **FNAL** (120 GeV), **J-PARC** (30 GeV)
- **Target**: Be, graphite. FLUKA.
- **Focusing**
  - **Horn**: 2 ms pulse, 180 kA, 10 Hz during the flat top *[not shown in fig.]*
  - **Static focusing system**: a quadrupole triplet before the bending magnet
- **Transfer line**
  - Kept **short** to: minimize early K the decays and those of off-momentum mesons out of tagger acceptance (untagged neutrino flux component)
  - Optics: optimized with TRANSPORT to a **10% momentum bite centered at 8.5 GeV/c**
  - Particle transport and interaction: full simulation with G4Beamline
  - Normal-conducting magnets 2 quad triplets (15 cm wide, L < 2 m, B = 4 to 7 T/m)
    1 bending dipole (15 cm wide, L = 2 m, B =1.8 T)
- **Decay tunnel:** r = 1 m. L=40 m, low power hadron dump at the end
- **Proton dump**: position and size under optimization

A. Longhin - ENUBET 3 neutrinos and beyond – 6/8/2019 5



Time tagged neutrino beams ?

- Event time dilution → **Time-tagging**
- **Associating a single neutrino interaction to a tagged e⁺ with a** small "accidental coincidence" probability through **time coincidences**

E_ν and flavor of the ν measured "a priori" event by event.

Compare "E_ν from decay kinematics" ↔ "E_ν from ν interaction products"

Time coincidence of ν_e^{CC} and e^+ $|\delta t - \Delta/c| < \delta$

δ = combined t-resolution (e^+ tagger and ν detector)

Presently with 2.5×10^{13} pot / 2s slow extraction:
genuine K_{e3} cand. : 80 MHz → **1 every ~ 12 ns**
background K_{e3} cand. ~ 2 x → 1 cand. every ~ 4 ns
With $\delta = 0.5 \oplus 0.5$ ns resolutions: already interesting!
S/N ratio will likely improve with further tuning.

Toy MC

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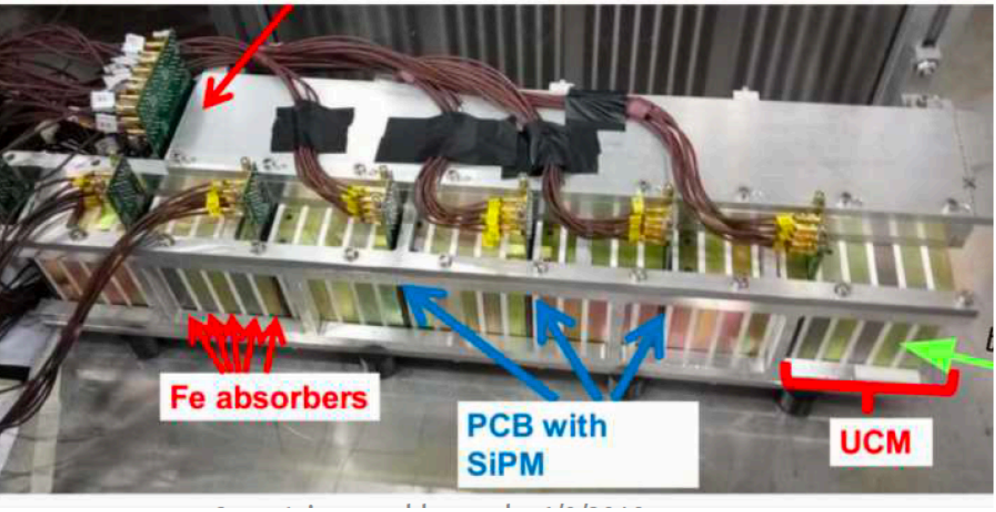
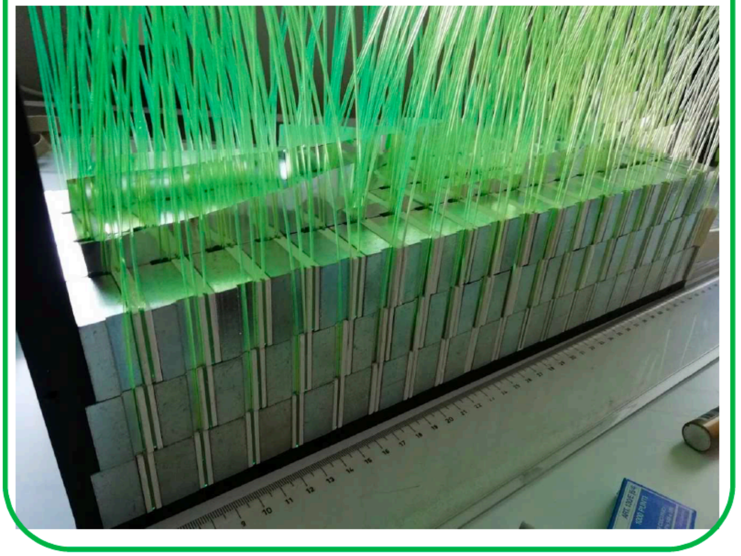
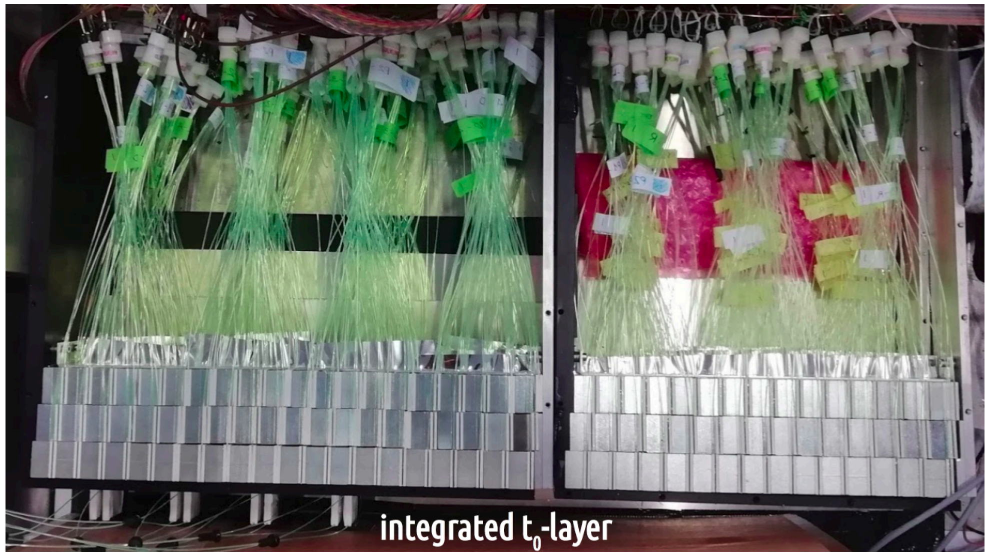
CERN PS test beam Nov 2016



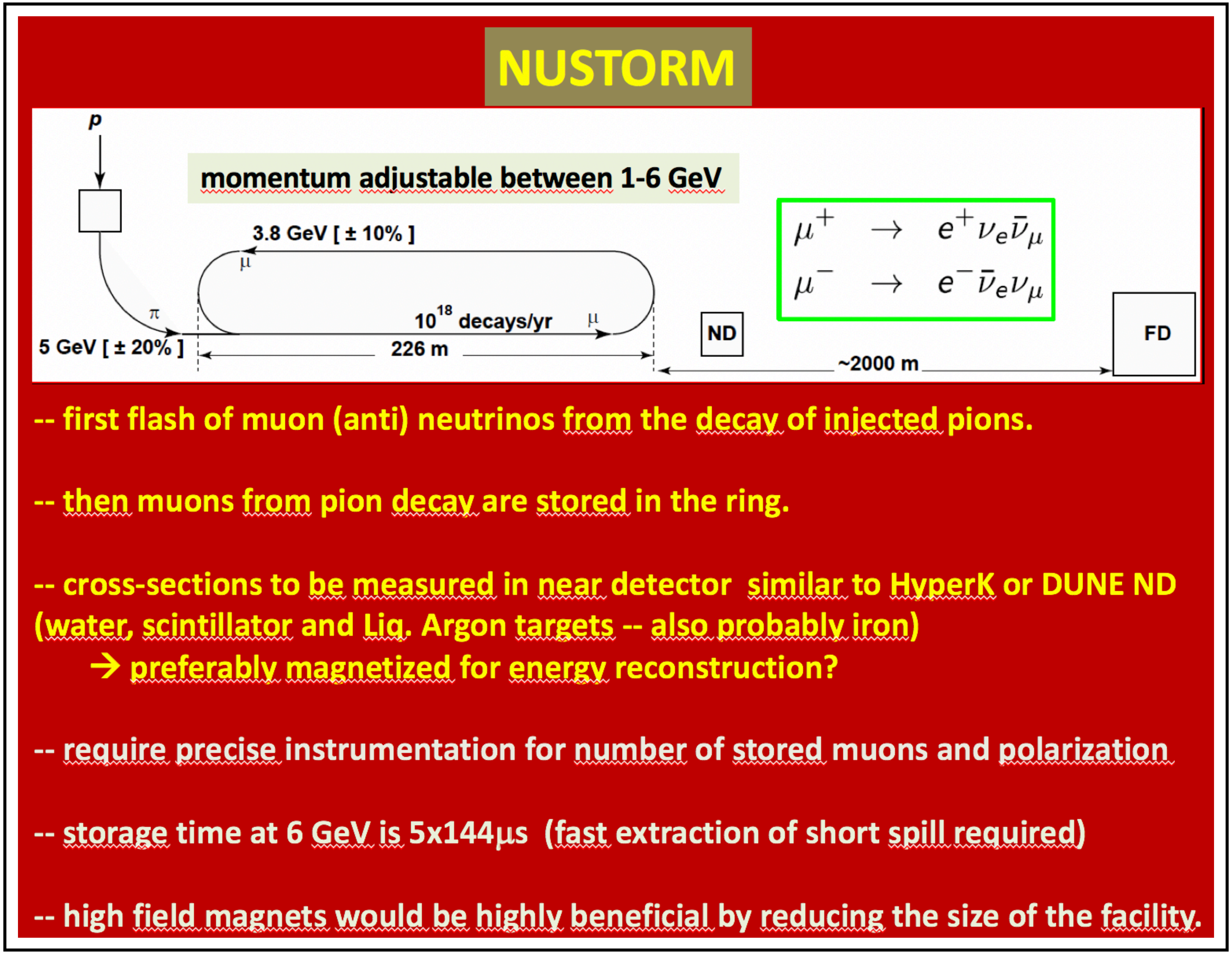
Sampling calorimeter with lateral WLS light collection





NuStorm

A.Blondel (LPNHE)



NUSTORM

$$\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$$
$$\mu^- \rightarrow e^-\bar{\nu}_e\nu_\mu$$

-- first flash of muon (anti) neutrinos from the decay of injected pions.

-- then muons from pion decay are stored in the ring.

-- cross-sections to be measured in near detector similar to HyperK or DUNE ND (water, scintillator and Liq. Argon targets -- also probably iron)

→ preferably magnetized for energy reconstruction?

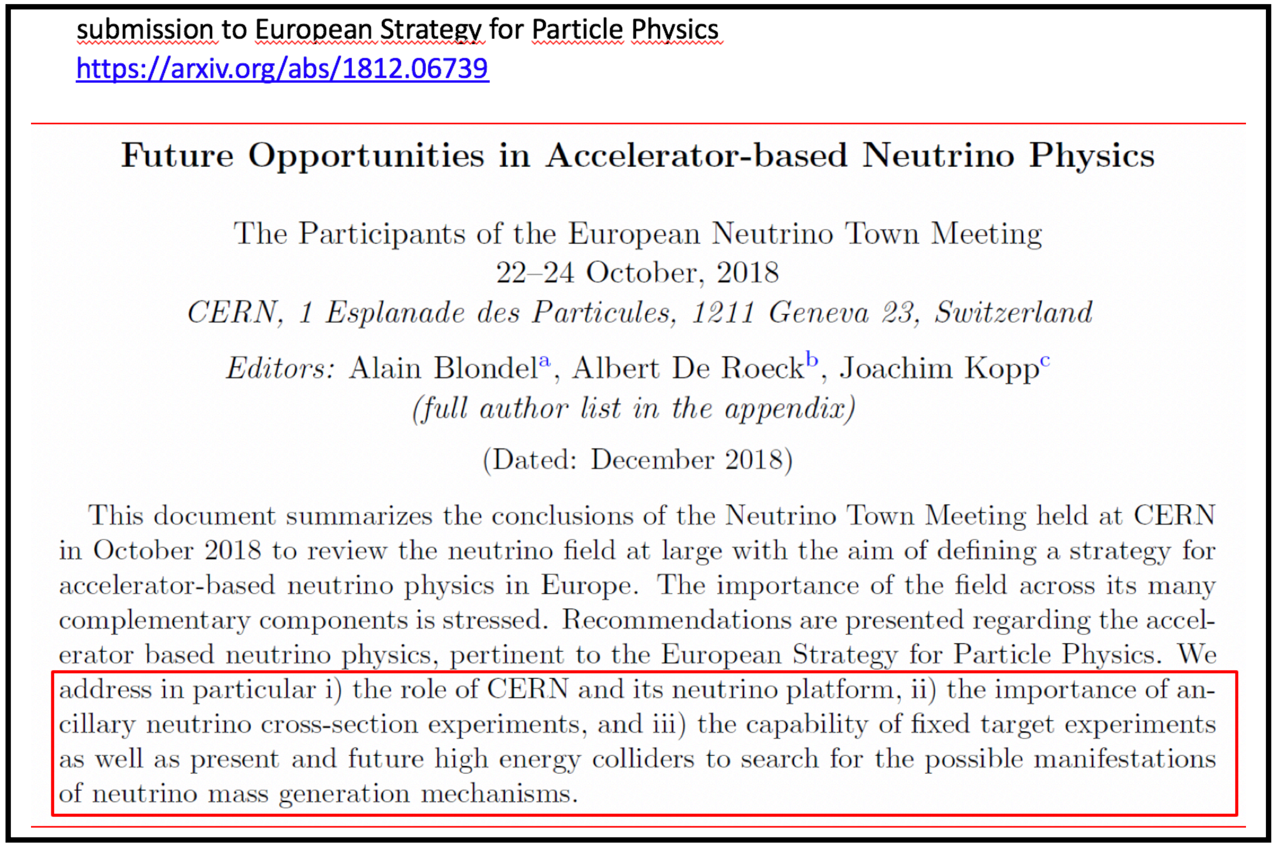
-- require precise instrumentation for number of stored muons and polarization

-- storage time at 6 GeV is 5x144μs (fast extraction of short spill required)

-- high field magnets would be highly beneficial by reducing the size of the facility.

Recommandations

A.Blondel (LPNHE)



submission to European Strategy for Particle Physics
https://arxiv.org/abs/1812.06739

Future Opportunities in Accelerator-based Neutrino Physics

The Participants of the European Neutrino Town Meeting
22–24 October, 2018
CERN, 1 Esplanade des Particules, 1211 Geneva 23, Switzerland

Editors: Alain Blondel[a], Albert De Roeck[b], Joachim Kopp[c]
(full author list in the appendix)

(Dated: December 2018)

This document summarizes the conclusions of the Neutrino Town Meeting held at CERN in October 2018 to review the neutrino field at large with the aim of defining a strategy for accelerator-based neutrino physics in Europe. The importance of the field across its many complementary components is stressed. Recommendations are presented regarding the accelerator based neutrino physics, pertinent to the European Strategy for Particle Physics. We address in particular i) the role of CERN and its neutrino platform, ii) the importance of ancillary neutrino cross-section experiments, and iii) the capability of fixed target experiments as well as present and future high energy colliders to search for the possible manifestations of neutrino mass generation mechanisms.

RECOMMANDATION:

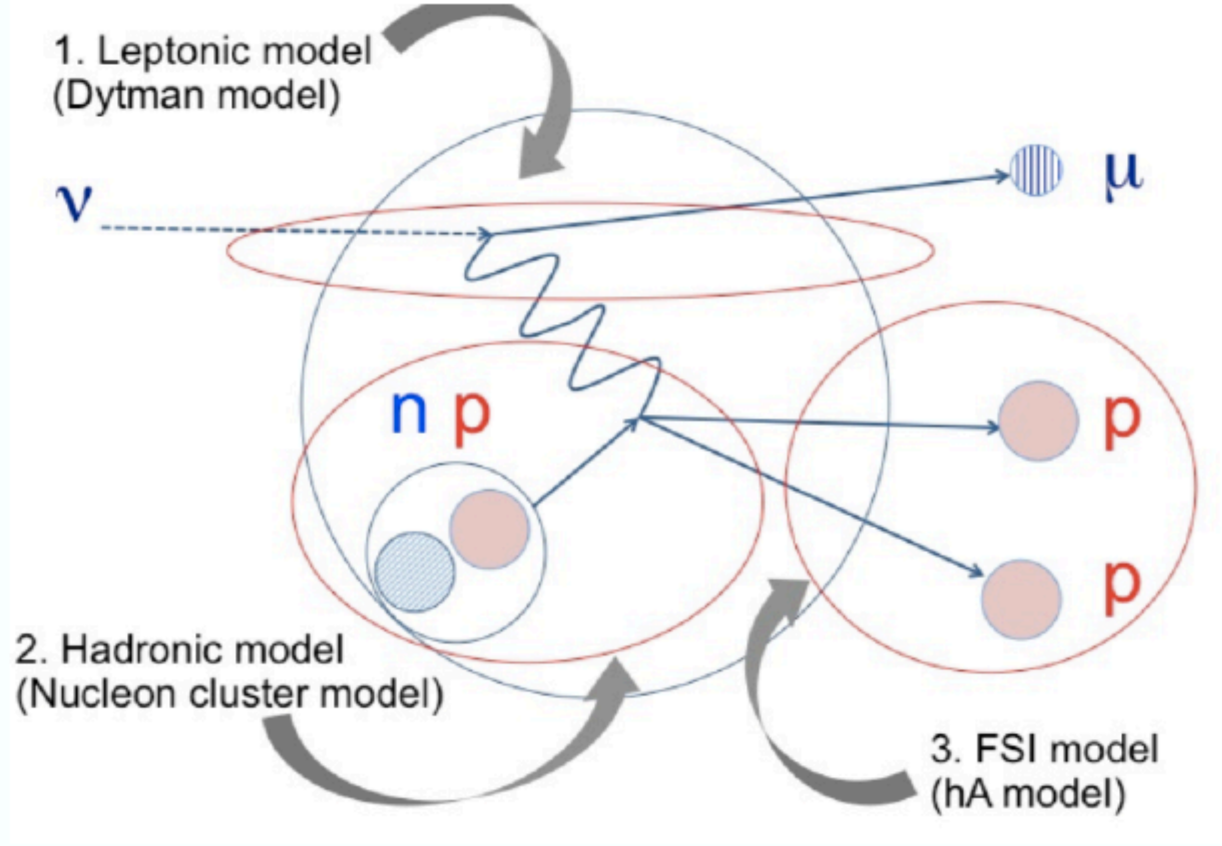
Extracting the most physics out of DUNE and HyperK will require ancillary experiments:

1) CERN should continue improving NA61/SHINE towards percent level flux determinations;

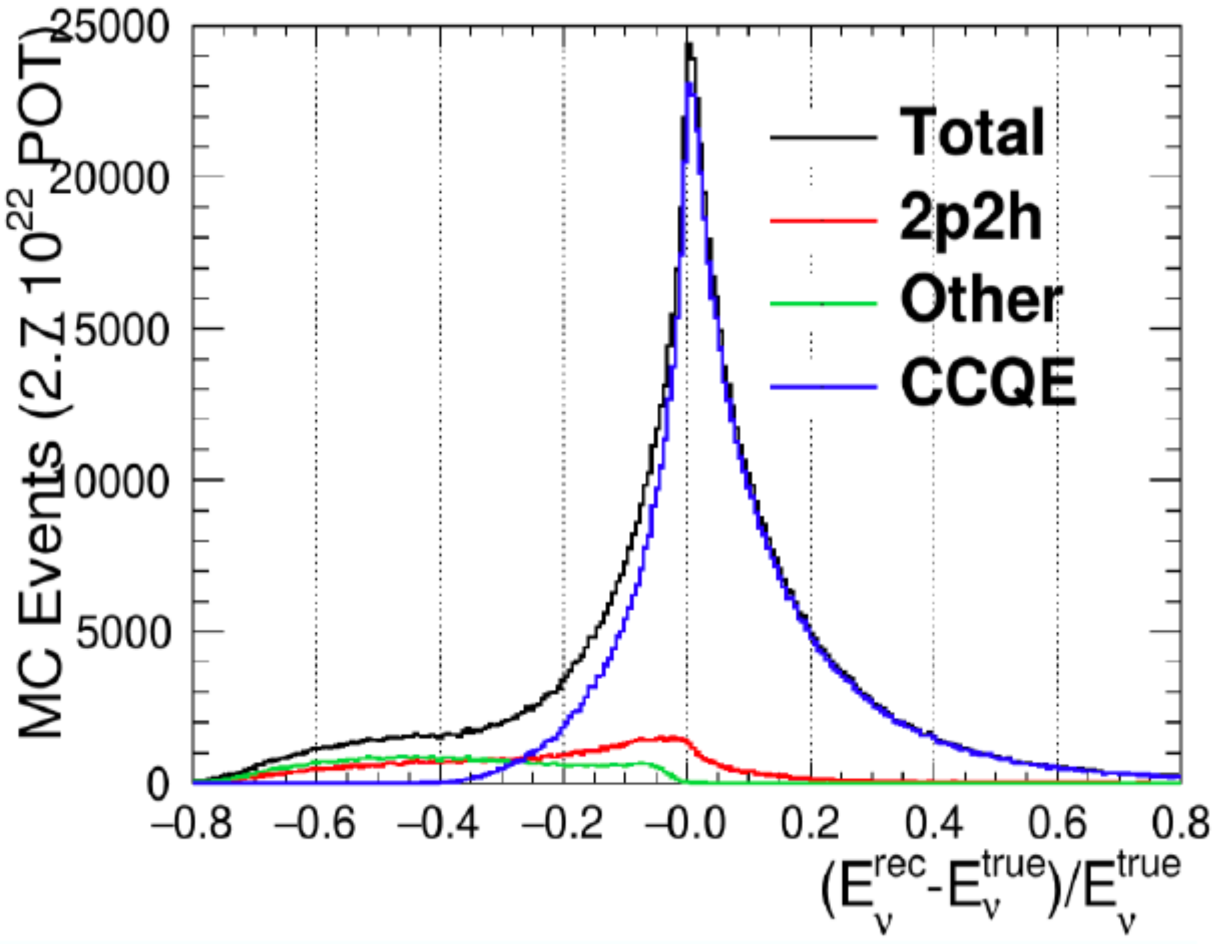
2) a study should be set-up to evaluate the possible implementation, performance and impact of a percent-level electron and muon neutrino cross-section measurement facility (based one.g. ENUBET or NuSTORM) with conclusion in a few years;

Complementarity between different techniques is very important

Precise detection of neutrino interactions

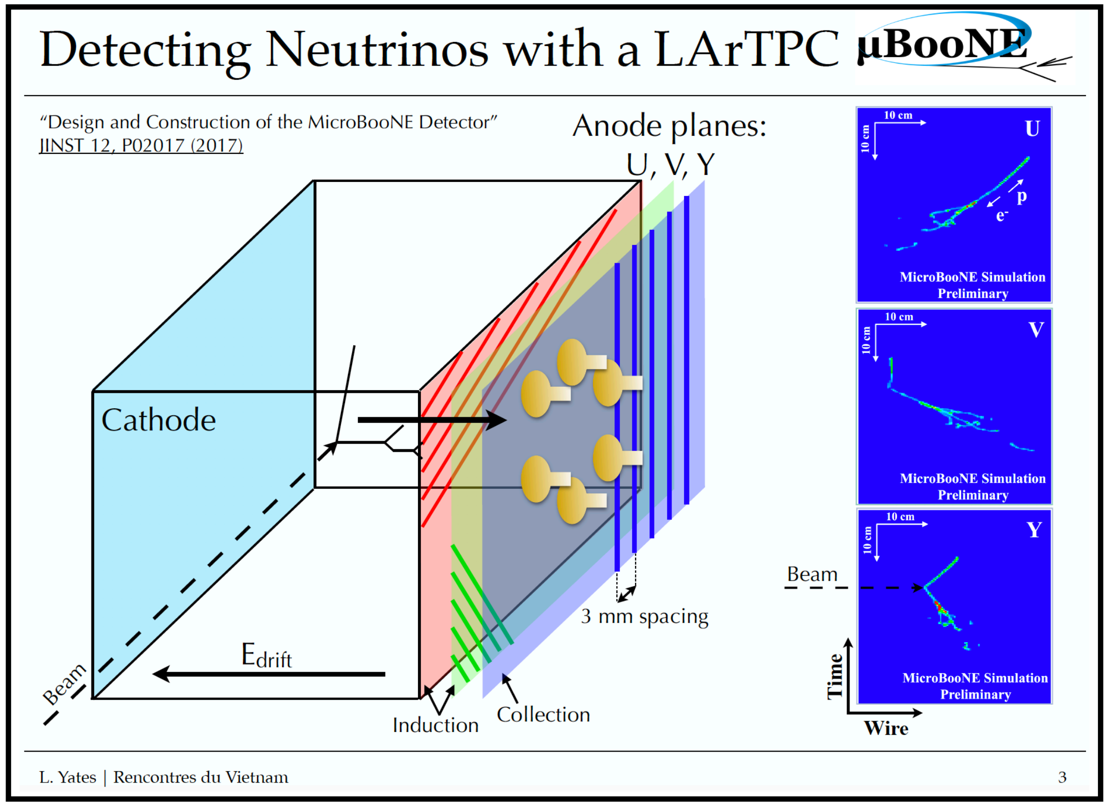


Nieves et al. PRC 83 045501 (2011)
Martini et al. Phys.Rev. D87 (2013) 013009



This is very tough!
That's why we need more precise (but big) detectors

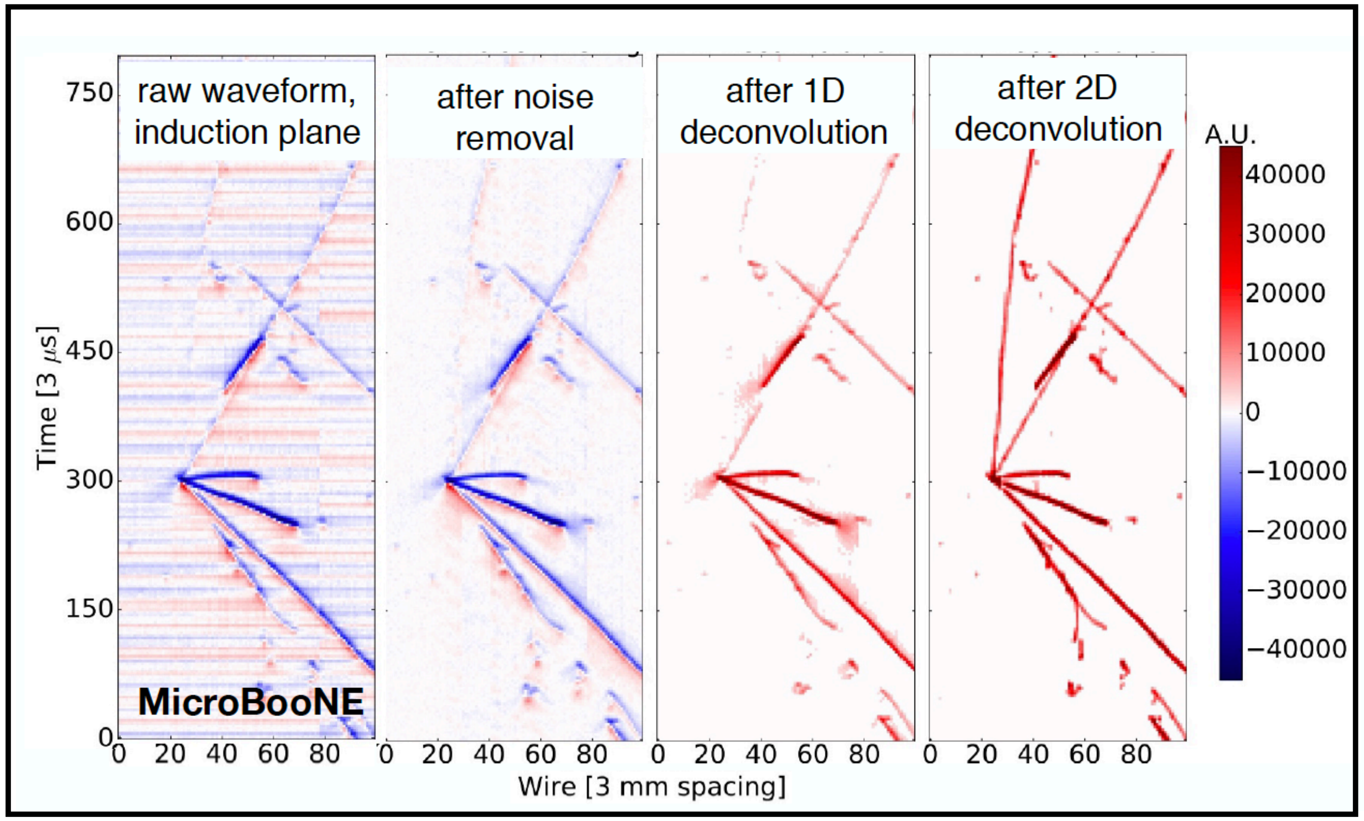
L.Yates (MIT) LAr detectors @SBN / MicroBooNE

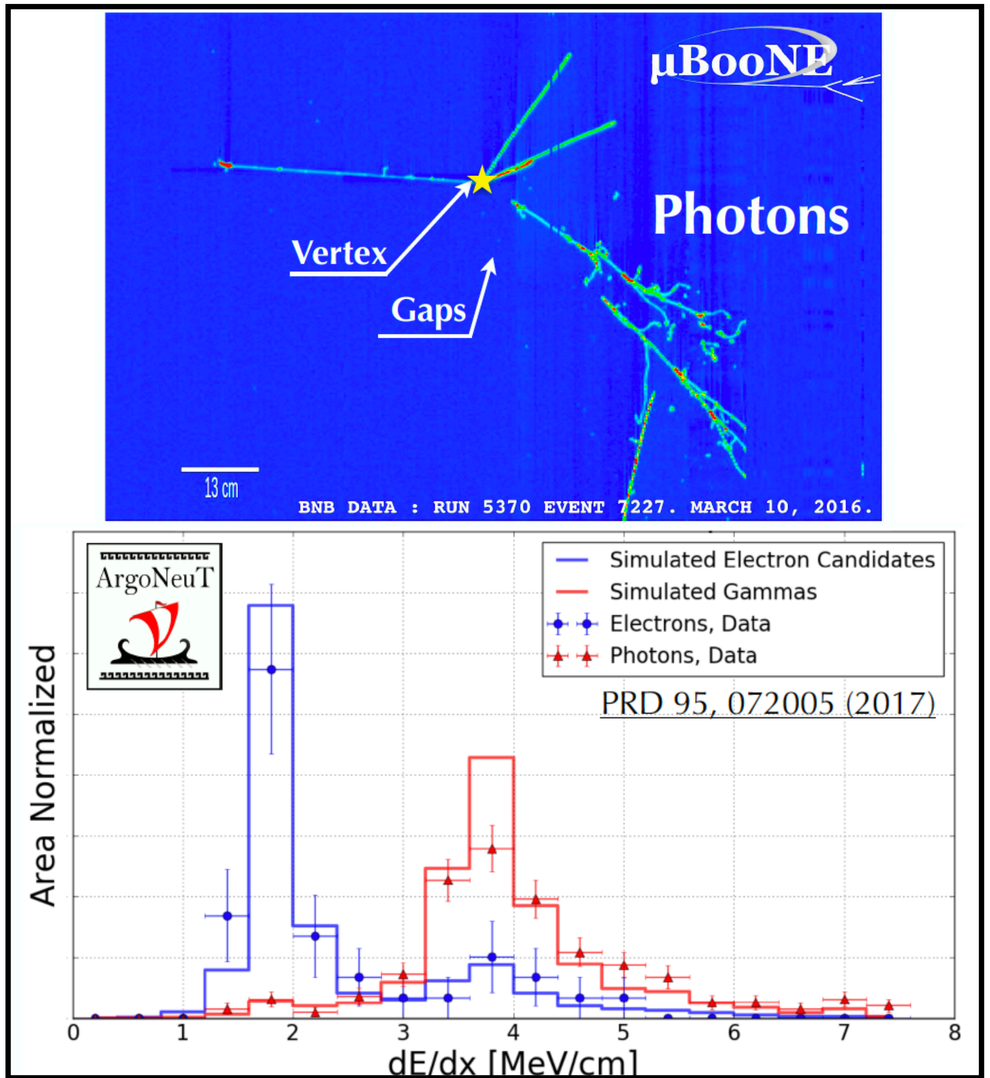


Detecting Neutrinos with a LArTPC

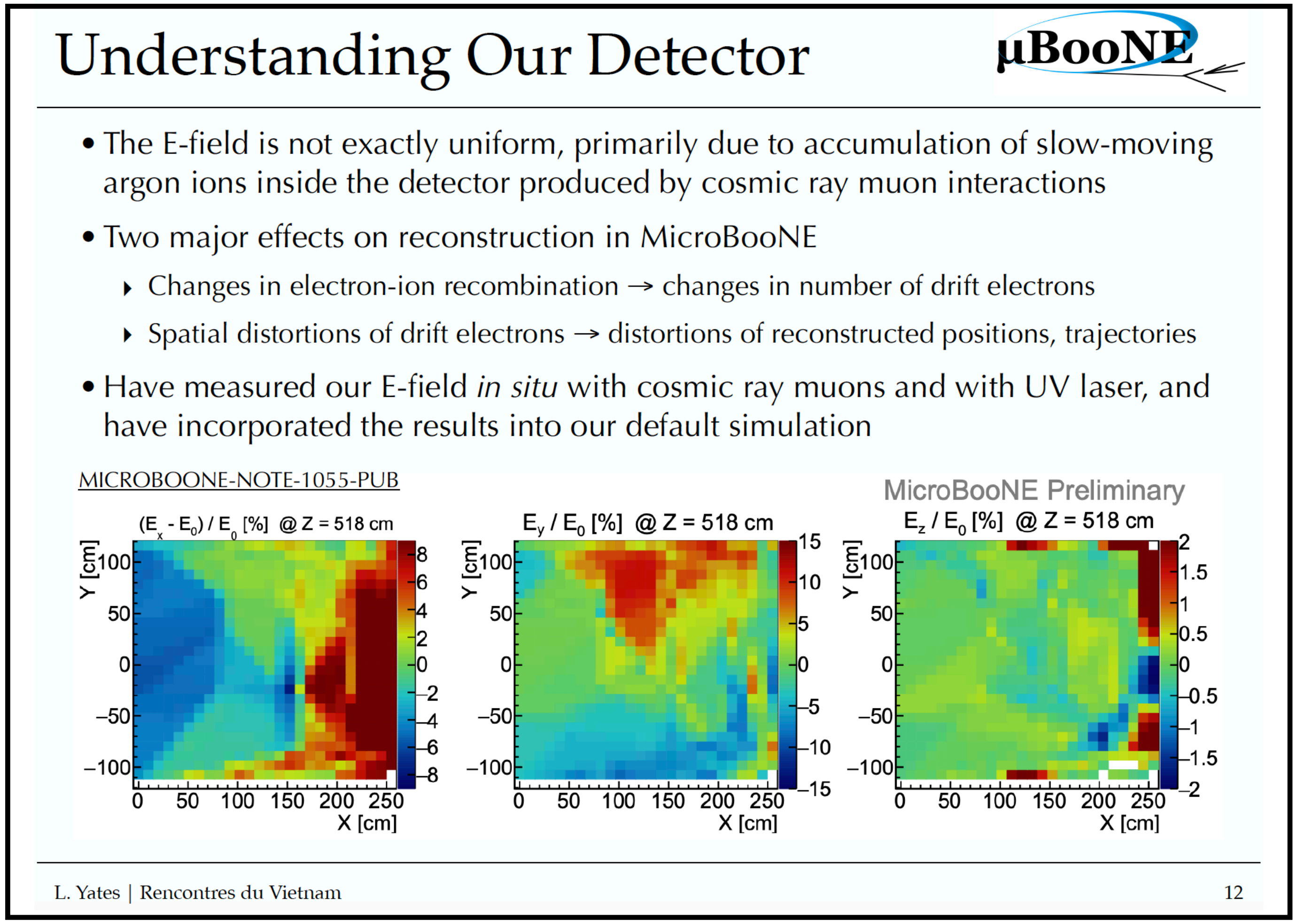
“Design and Construction of the MicroBooNE Detector”
JINST 12, P02017 (2017)

L. Yates | Rencontres du Vietnam 3





PRD 95, 072005 (2017)



Understanding Our Detector

- The E-field is not exactly uniform, primarily due to accumulation of slow-moving argon ions inside the detector produced by cosmic ray muon interactions
- Two major effects on reconstruction in MicroBooNE
  - Changes in electron-ion recombination → changes in number of drift electrons
  - Spatial distortions of drift electrons → distortions of reconstructed positions, trajectories
- Have measured our E-field *in situ* with cosmic ray muons and with UV laser, and have incorporated the results into our default simulation

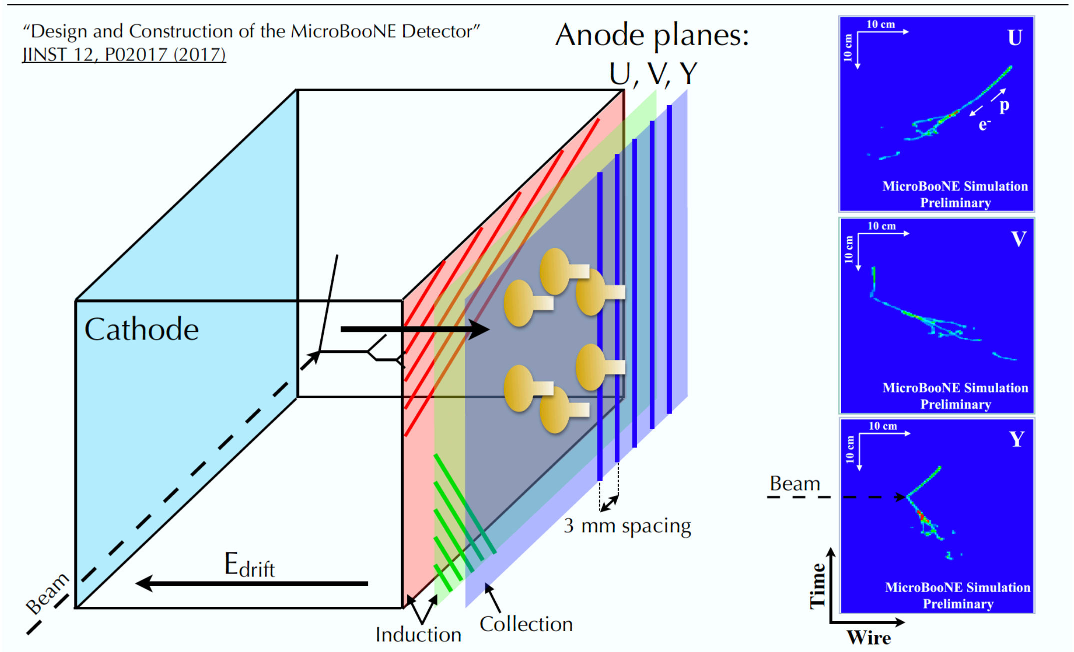
MICROBOONE-NOTE-1055-PUB

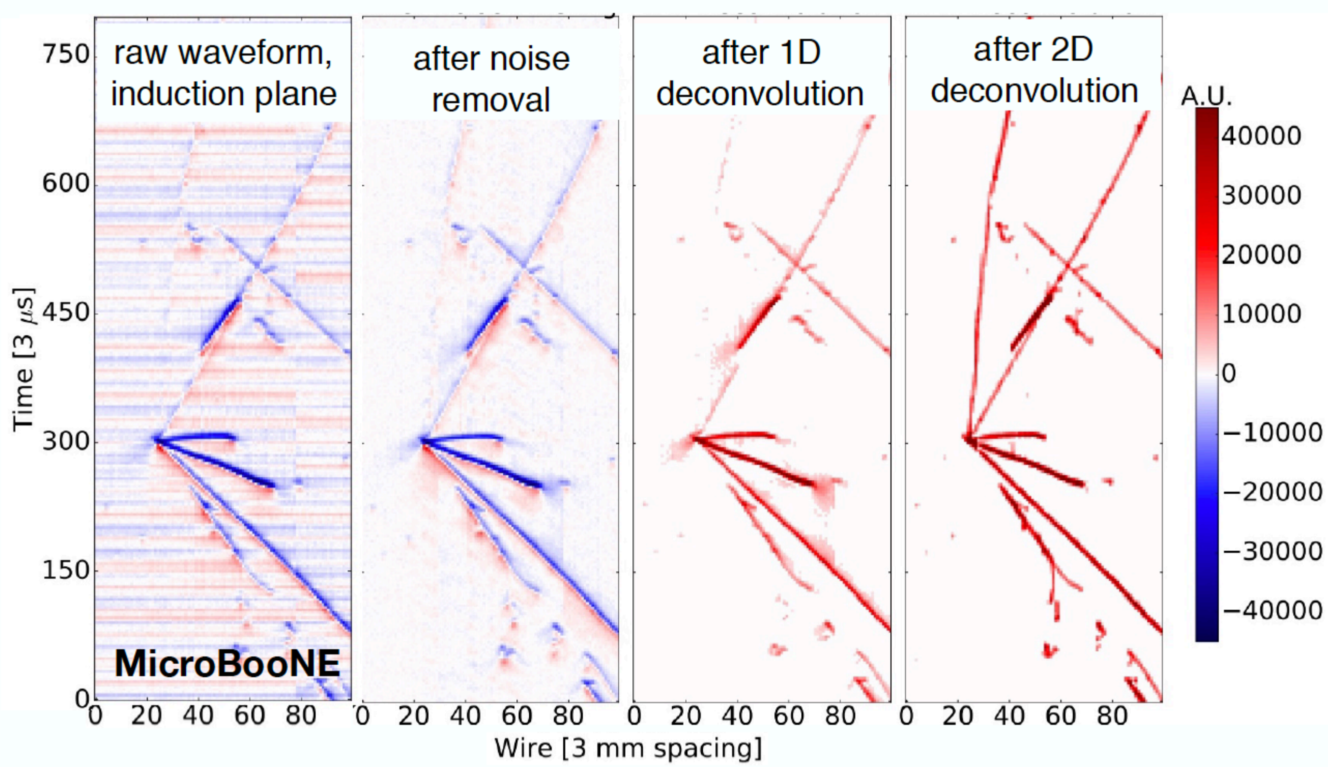
L. Yates | Rencontres du Vietnam 12

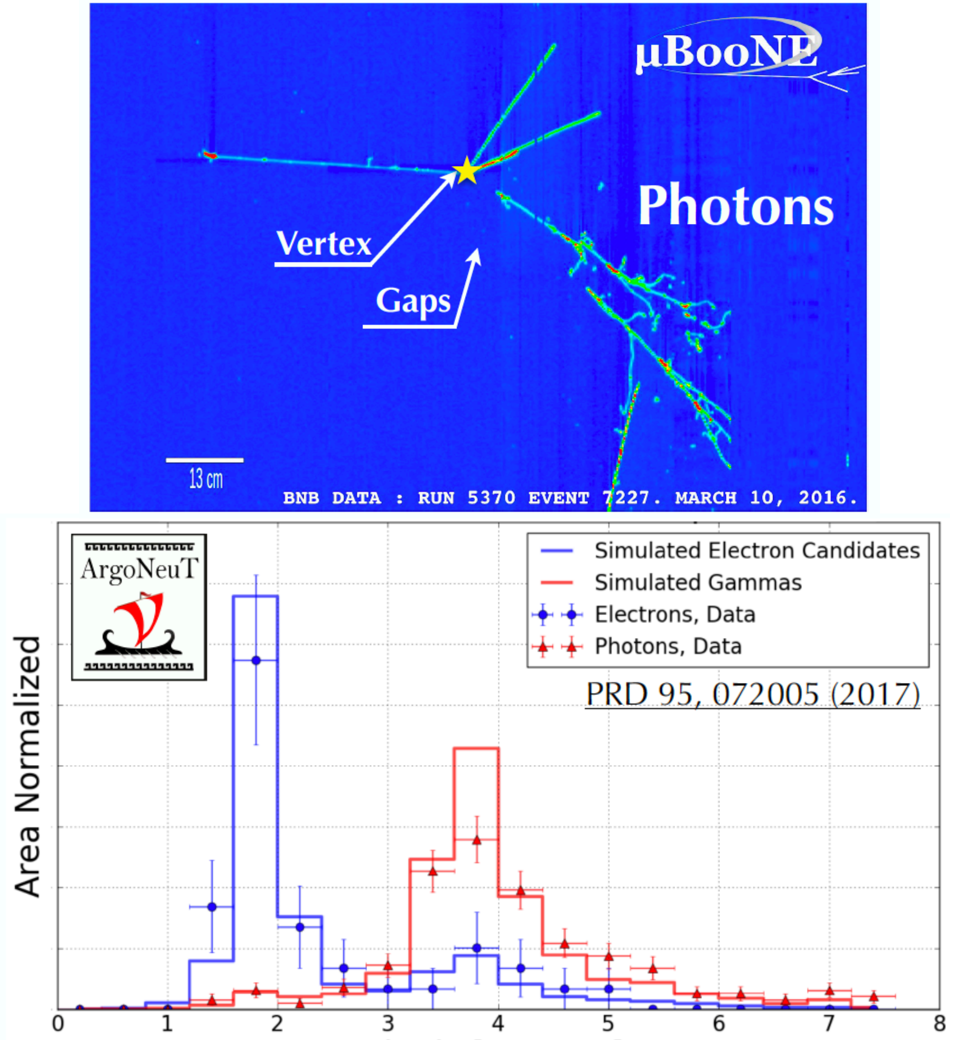
L.Yates (MIT) LAr detectors @SBN / MicroBooNE

Detecting Neutrinos with a LArTPC

"Design and Construction of the MicroBooNE Detector"
JINST 12, P02017 (2017)

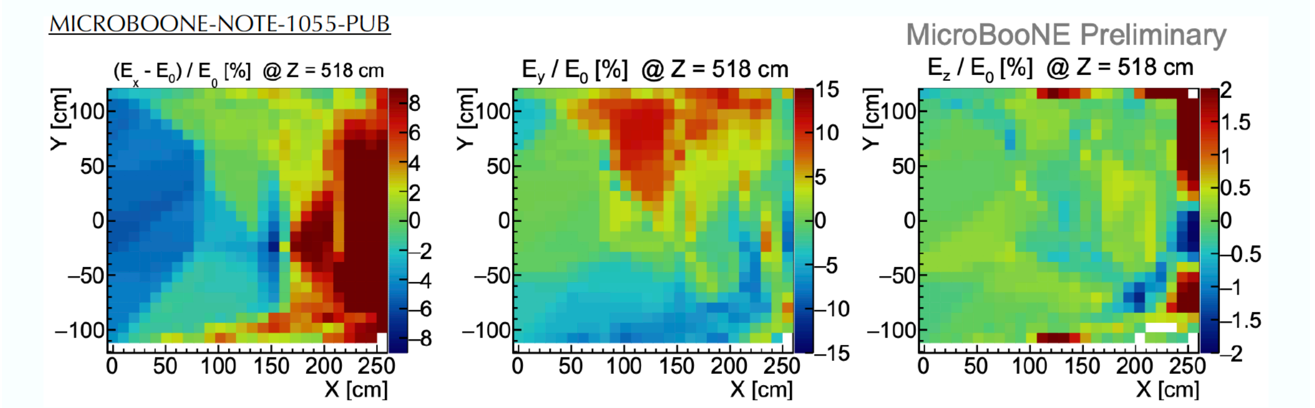






Understanding future detectors

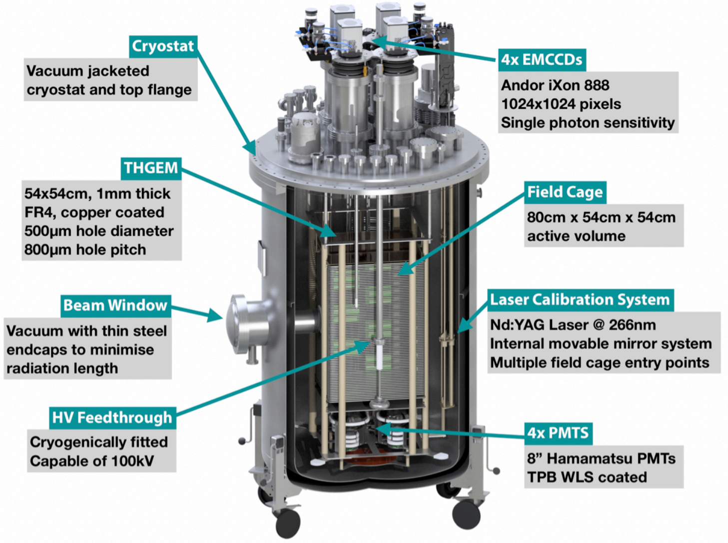
Issues understood in current and near-future LAr detectors will be useful for farther-future ones too. Development of reconstruction tools, understanding of common detector response issues, etc.



B.Philippou (U.Liverpool)

ARIADNE

- **Dual-phase LArTPC.**
- **1500L** vacuum jacketed cryostat.
- Scroll + turbo pump evacuates the cryostat to **10^{-5} mbar** before filling.
- Nominal drift field **0.5kV/cm.**
- **50MΩ x 79 rings** resistor chain.
- **Internal** positive displacement pump **filtration and purification system.**
- **300W** cryorefrigerator.


Cryostat
Vacuum jacketed cryostat and top flange

4x EMCCDs
Andor iXon 888
1024x1024 pixels
Single photon sensitivity

THGEM
54x54cm, 1mm thick
FR4, copper coated
500µm hole diameter
800µm hole pitch

Field Cage
80cm x 54cm x 54cm
active volume

Beam Window
Vacuum with thin steel endcaps to minimise radiation length

Laser Calibration System
Nd:YAG Laser @ 266nm
Internal movable mirror system
Multiple field cage entry points

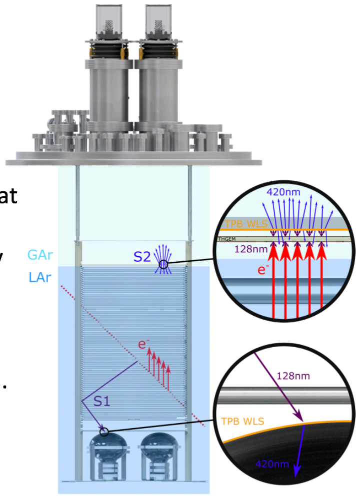
HV Feedthrough
Cryogenically fitted
Capable of 100kV

4x PMTS
8” Hamamatsu PMTs
TPB WLS coated

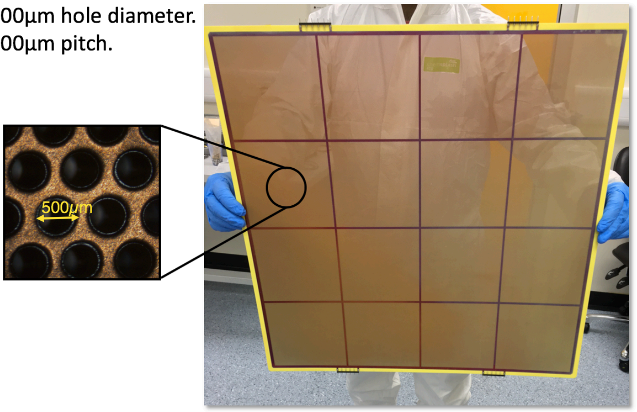
Benefits

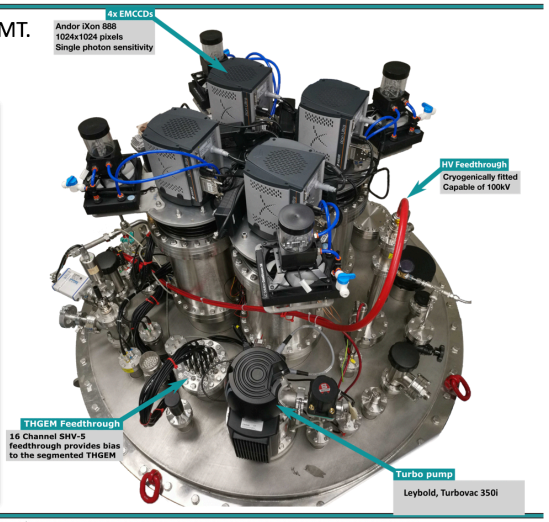
ARIADNE – innovative optical readout over tradition charge readout.

- **Superior signal** – more light than charge (~100s of photons per accelerated e^-).
- **Good calorimetry** – 16bit dynamic range EMCCD sensors.
- **High spatial resolution** – 4x EMCCD sensors with 1024x1024 pixel area, aimed at a THGEM area of 53cm² (therefore running in 4x4 binning mode ~1mm/pixel).
- **Low energy threshold** – gain generated in THGEM and single photon sensitivity EMCCDs (~100keV).
- **Very low noise** – Cameras decoupled from TPC electronic noise.
- **Access/upgrades** – cameras are externally mounted, decoupled from cryogenics, therefore no venting of the LAr is required for upgrades and repairs.
- **Cost efficient** – no need for thousands of individual channels as is necessary in charge readout.



- **16 Pad** segmented THGEM – complimentary timing information to PMT.
- Manufactured by CERN PCB workshop.
- 1mm thickness.
- 500µm hole diameter.
- 800µm pitch.

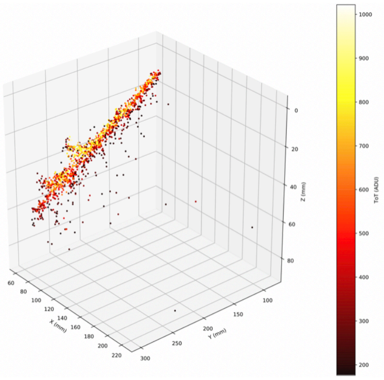



4x EMCCDs
Andor iXon 888
1024x1024 pixels
Single photon sensitivity

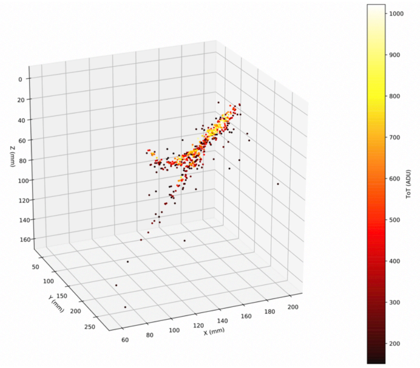
HV Feedthrough
Cryogenically fitted
Capable of 100kV

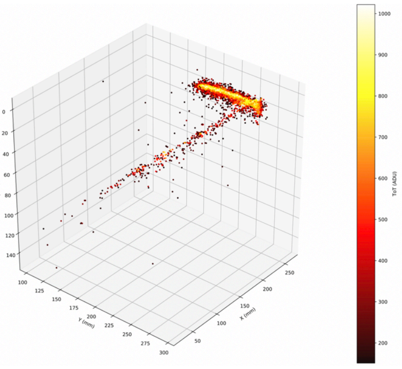
THGEM Feedthrough
16 Channel SHV-5 feedthrough provides bias to the segmented THGEM

Turbo pump
Leybold, Turbovac 350i

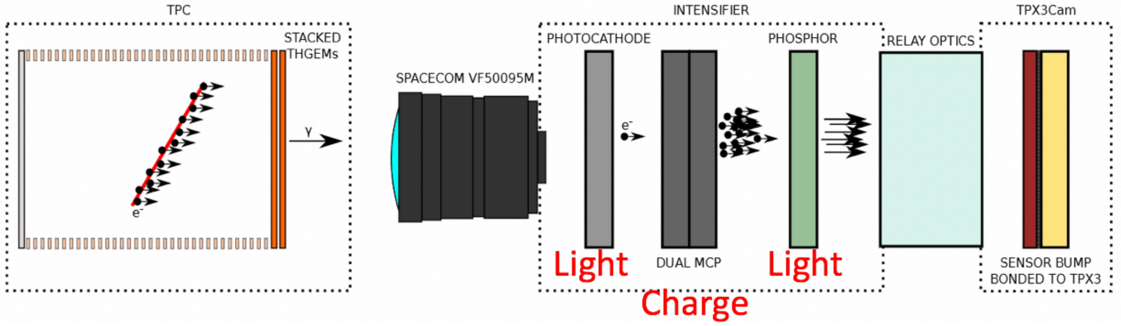


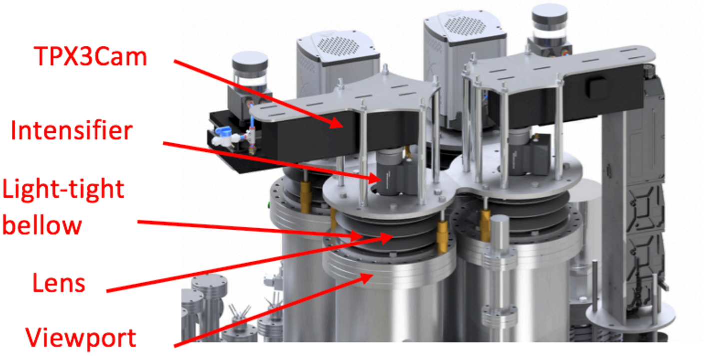
- 100µsec drift window.
- 20cm tracks.



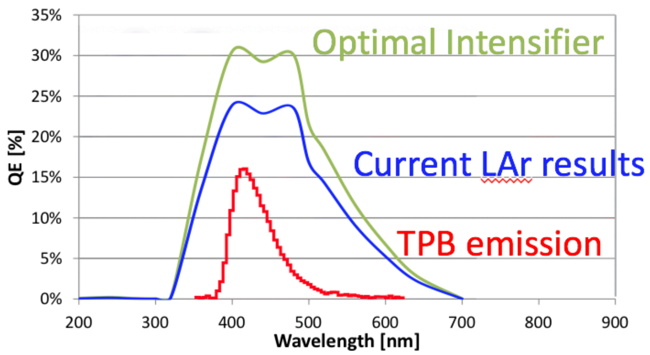


TPX3 requires pairing to an intensifier.





Current intensifier output brightness : 0.5 cd/m²
Final output brightness (typ) : 3.0 cd/m²



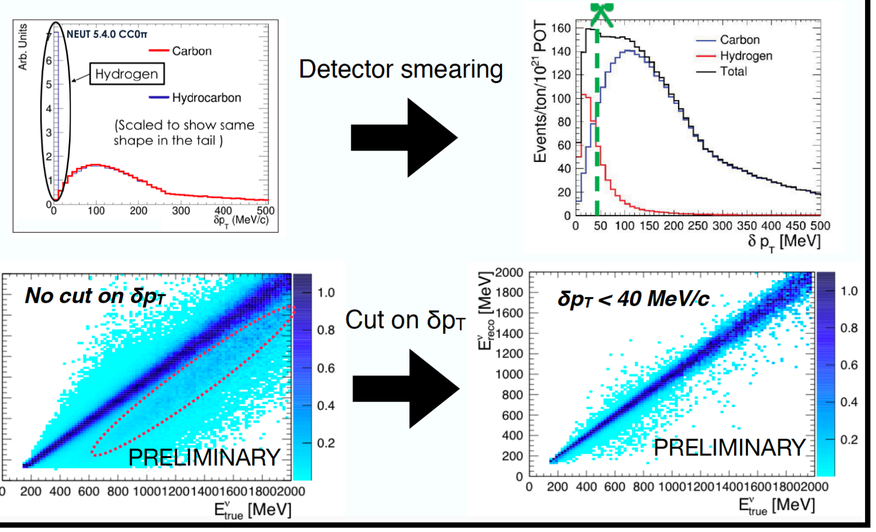
A completely new concept for LAr readout, that could simplify a lot the detector configuration

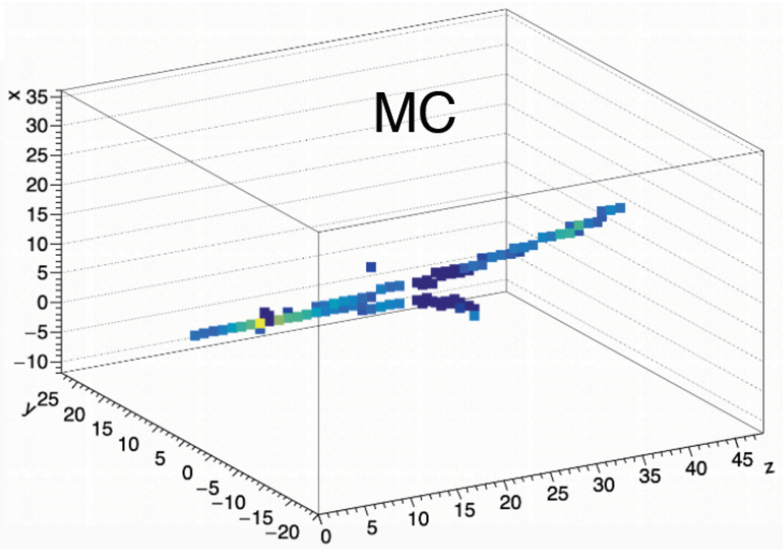
SuperFGD for T2K/HK and DUNE

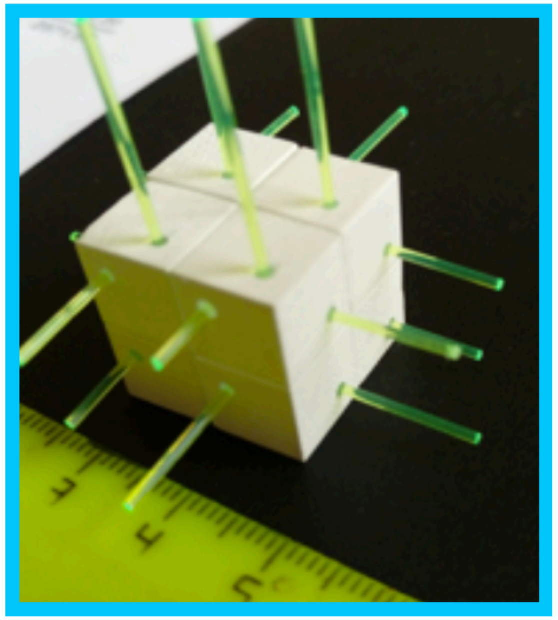
D.Sgalaberna (CERN)

New method to infer $\bar{\nu}_\mu$ flux

- Isolate NuBar-hydrogen and NuBar-carbon interactions with low nuclear effects
- Use neutron kinematics to precisely compute the event transverse momentum



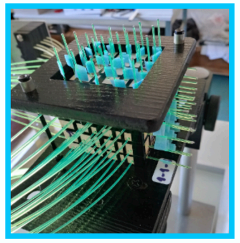


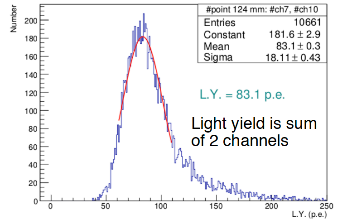


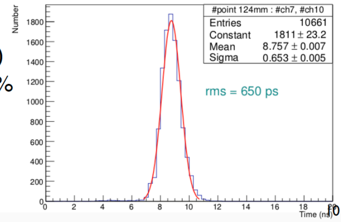
Characterization of the SuperFGD concept

- Prototype 5x5x5 cm³, 1.3 m WLS fibers (Al-based paint at fiber end)
- Exposure to a 6 GeV π test beam at CERN
- Multi Pixel Photon Counter (MPPC)based readout

NIM A923 (2019) 134-138



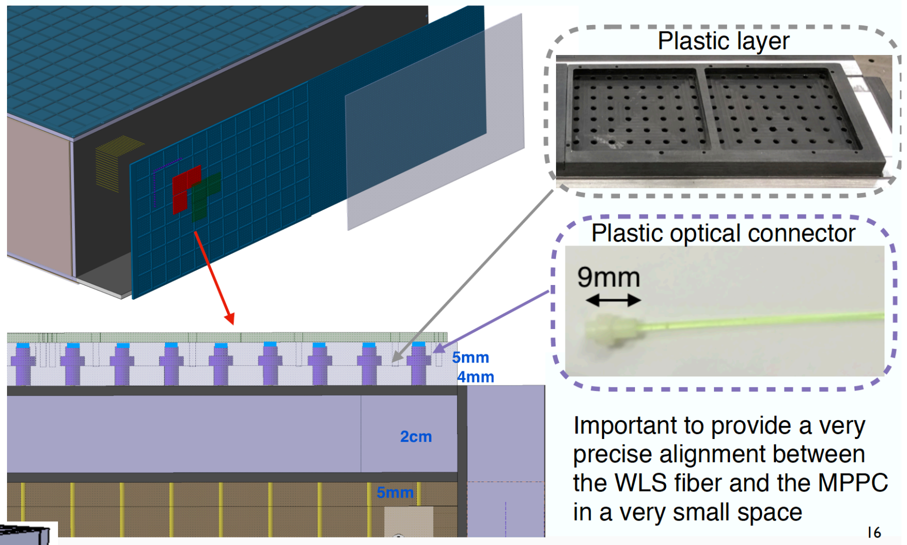




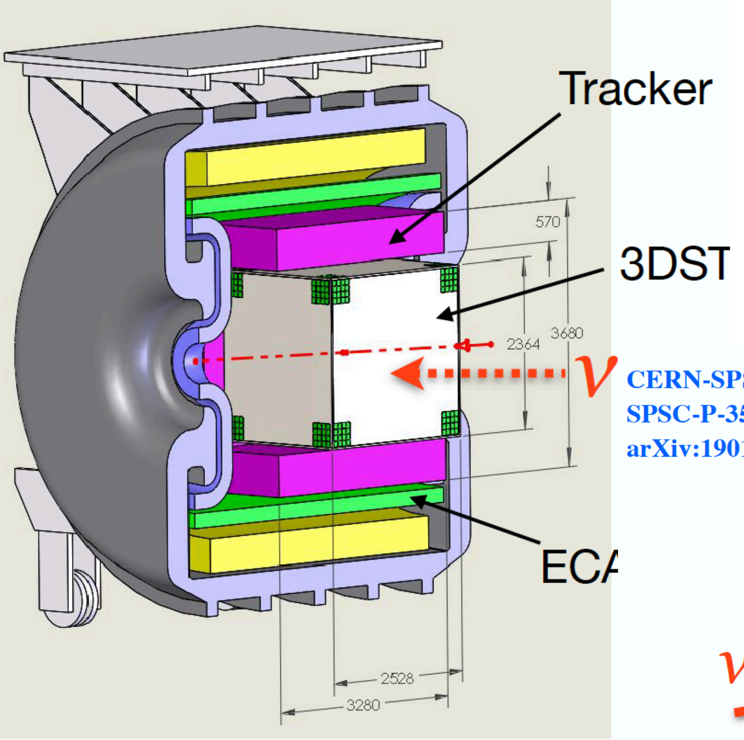
- Average light yield ~ 41 p.e. / fiber / cube (MIP)
- Light cross-talk between adjacent cubes ~ 3.7%
- Very good intrinsic time resolution (measured with a 5 GHz waveform digitizer)
  - $\sigma_t \sim 0.95$ ns (1 channel, 1 cube)
  - $\sigma_t \sim 0.65$ ns (2 channels, 1 cube)

The SuperFGD detector

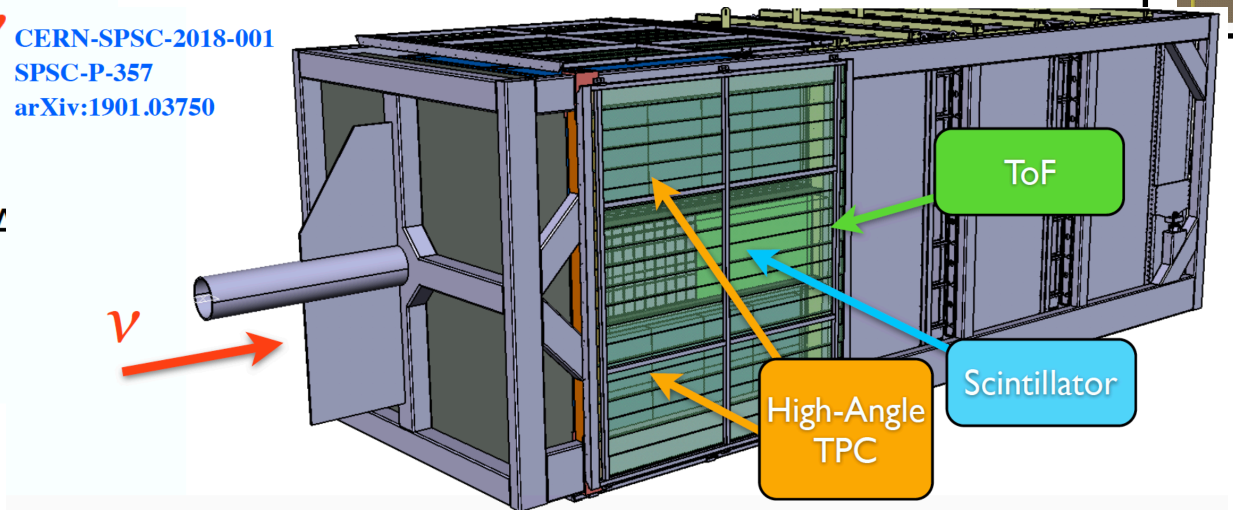
Very compact design increases HA-TPC acceptance to low-momentum particles



Important to provide a very precise alignment between the WLS fiber and the MPPC in a very small space



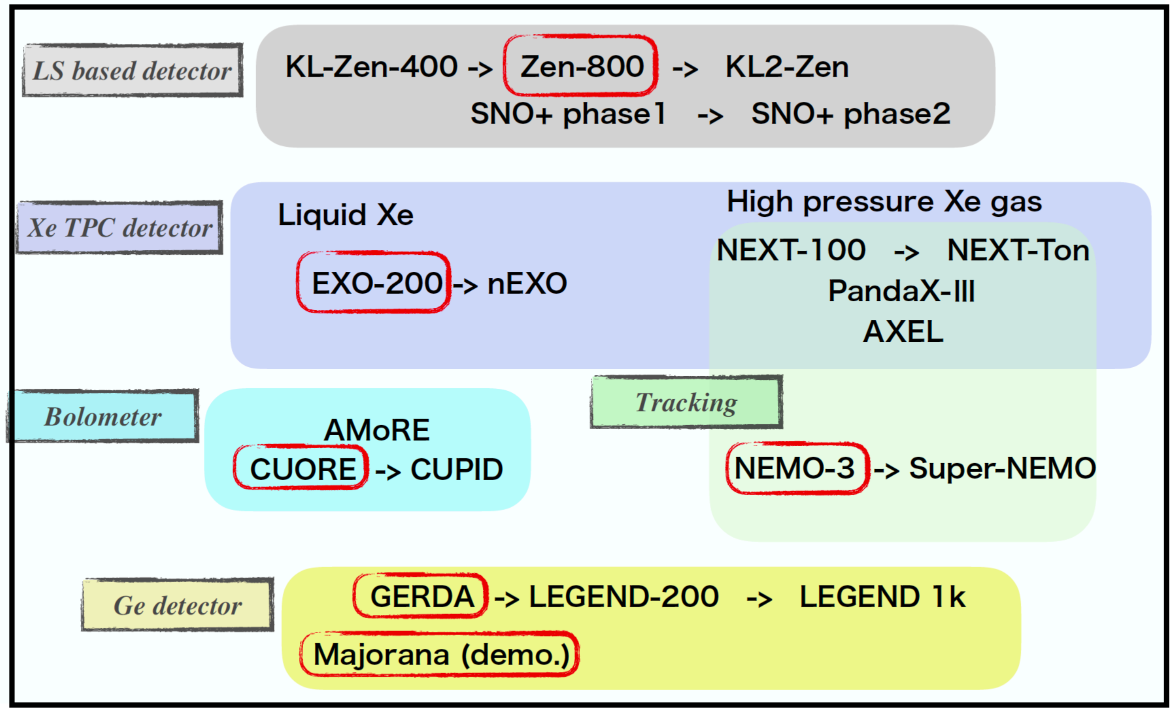
CERN-SPSC-2018-001
SPSC-P-357
arXiv:1901.03750



Neutron detection with kinematics measurement is a new paradigm to be demonstrated with data!

Nu-less ββ decay searches

Ueshima-san (U.Tohoku)



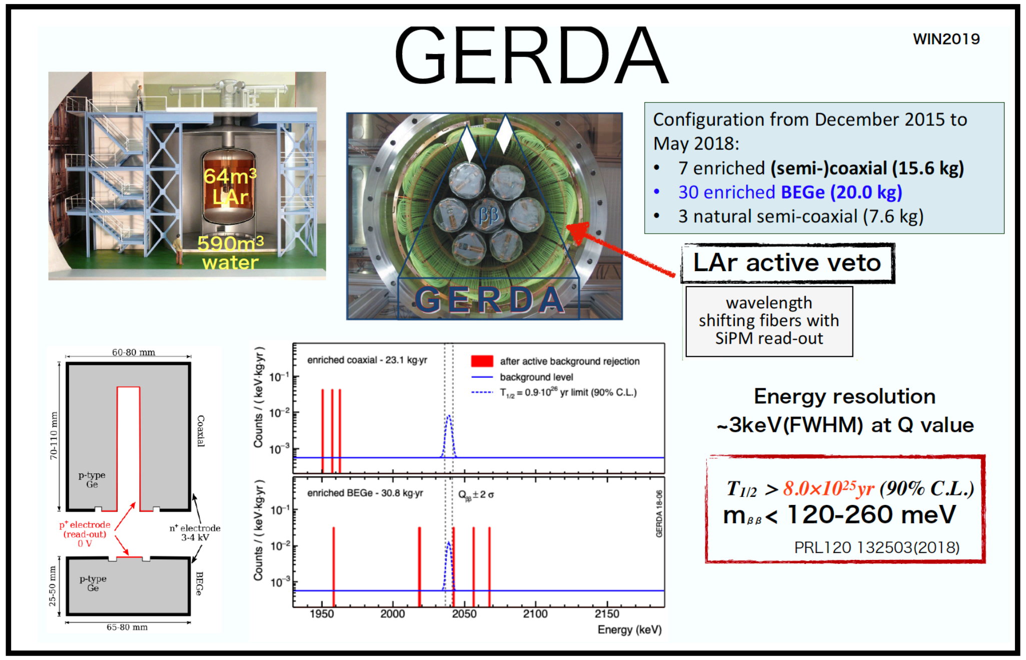
LS based detector
KL-Zen-400 -> **Zen-800** -> KL2-Zen
SNO+ phase1 -> SNO+ phase2

Xe TPC detector
Liquid Xe
EXO-200 -> nEXO
High pressure Xe gas
NEXT-100 -> NEXT-Ton
PandaX-III
AXEL

Bolometer
AMoRE
CUORE -> CUPID

Tracking
NEMO-3 -> Super-NEMO

Ge detector
GERDA -> LEGEND-200 -> LEGEND 1k
Majorana (demo.)



GERDA

WIN2019

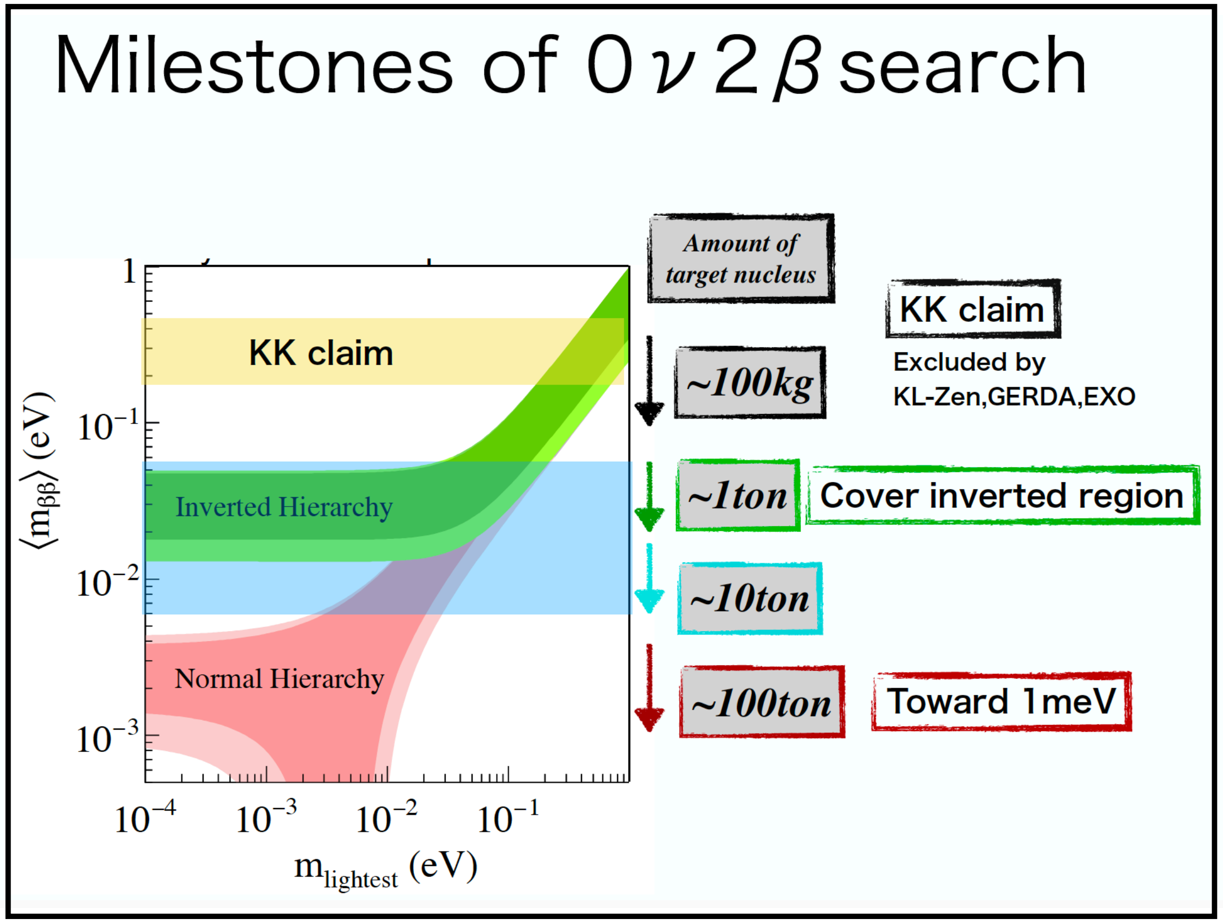
Configuration from December 2015 to May 2018:
- 7 enriched **(semi-)coaxial (15.6 kg)**
- 30 enriched **BEGe (20.0 kg)**
- 3 natural semi-coaxial (7.6 kg)

LAr active veto

wavelength shifting fibers with SiPM read-out

Energy resolution ~3keV(FWHM) at Q value

$T_{1/2} > 8.0\times10^{25}$yr (90% C.L.)
$m_{\beta\beta} <$ 120-260 meV
PRL120 132503(2018)



Milestones of 0ν2β search

Amount of target nucleus

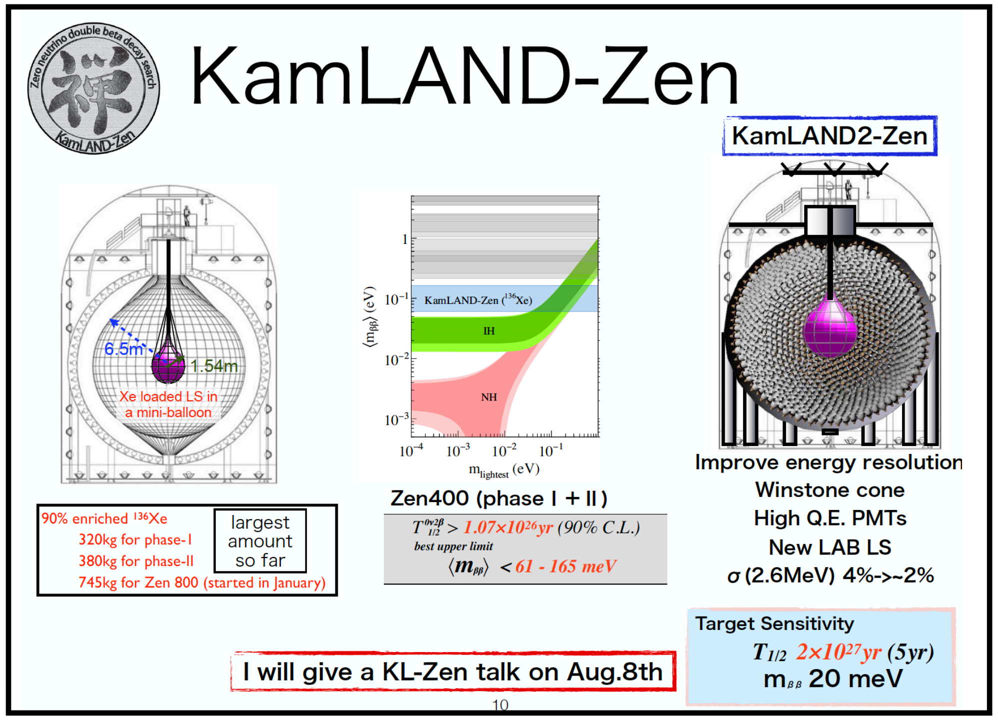
~100kg — KK claim
Excluded by KL-Zen,GERDA,EXO

~1ton — Cover inverted region

~10ton

~100ton — Toward 1meV

SuperNEMO
AMoRE
NEXT
PandaX-III
SNO+
KL2-Zen
LEGEND
CUPID
nEXO



KamLAND-Zen

90% enriched ^{136}Xe
320kg for phase-I
380kg for phase-II
745kg for Zen 800 (started in January)

largest amount so far

Zen400 (phase I + II)
$T^{0\nu2\beta}_{1/2} > 1.07\times10^{26}$yr (90% C.L.)
best upper limit
$\langle m_{\beta\beta}\rangle <$ 61 - 165 meV

KamLAND2-Zen
Improve energy resolution
Winstone cone
High Q.E. PMTs
New LAB LS
σ (2.6MeV) 4%->~2%

Target Sensitivity
$T_{1/2}$ 2×10²⁷yr (5yr)
$m_{\beta\beta}$ 20 meV

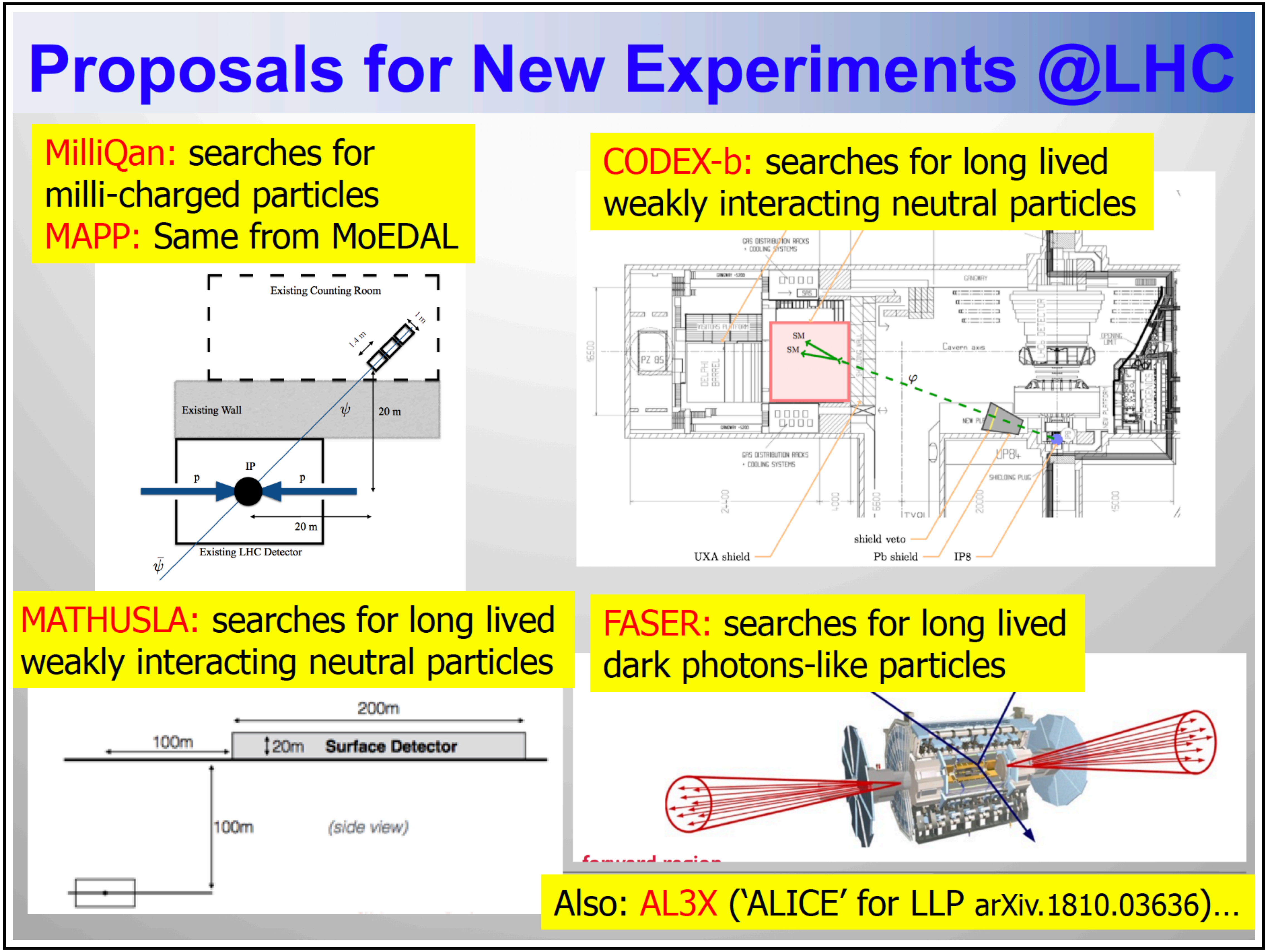
I will give a KL-Zen talk on Aug.8th

10

> "How much could a ~100ton detector" cost?"
>
> "Maybe like DUNE / HyperK"

FASER & Mathusla

A. de Roeck (CERN)



Proposals for New Experiments @LHC

MilliQan: searches for milli-charged particles
MAPP: Same from MoEDAL

CODEX-b: searches for long lived weakly interacting neutral particles

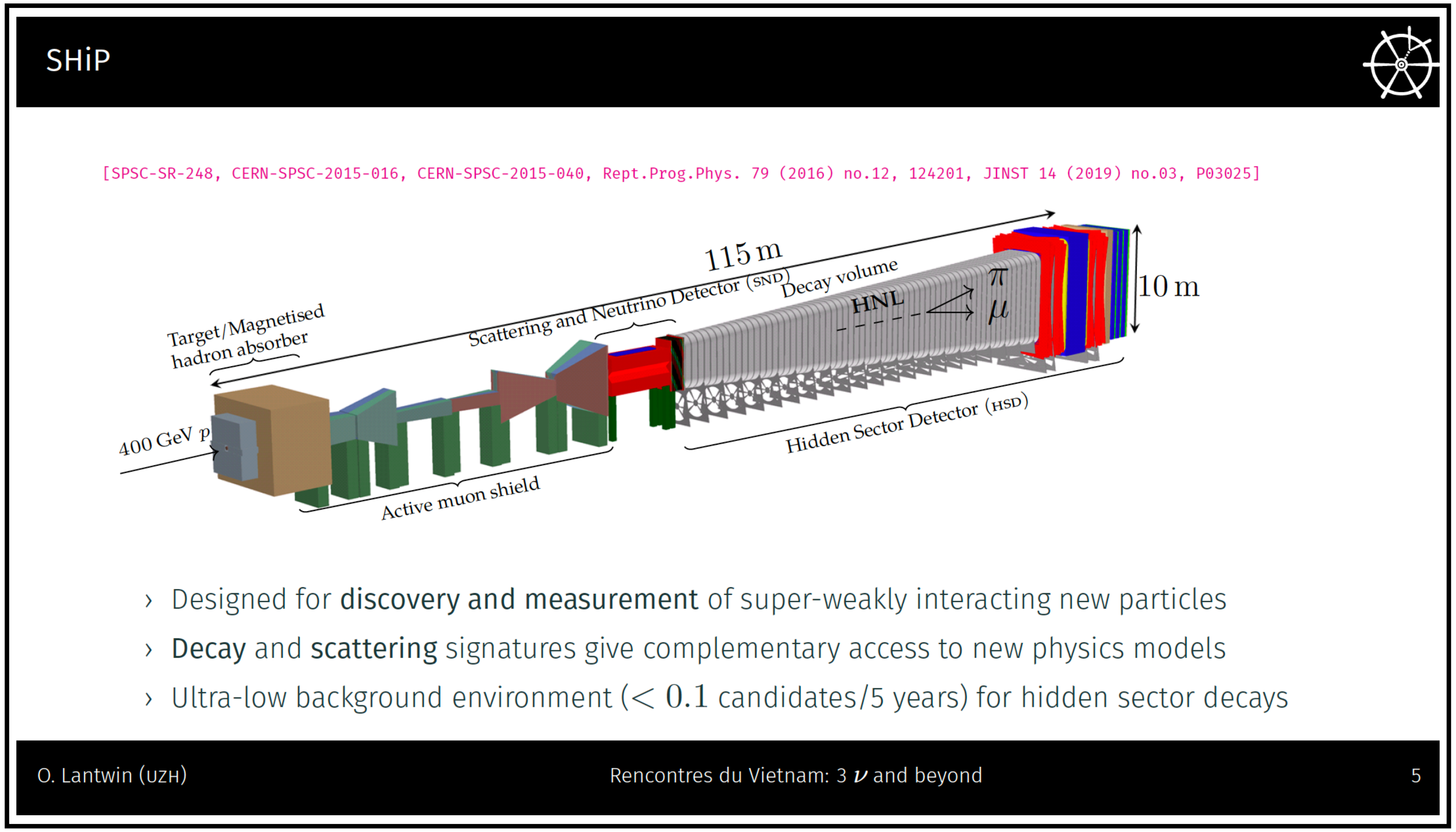
MATHUSLA: searches for long lived weakly interacting neutral particles

FASER: searches for long lived dark photons-like particles

Also: AL3X ('ALICE' for LLP arXiv.1810.03636)…

HNL @SHiP

O. Lantwin (U.Zurich)

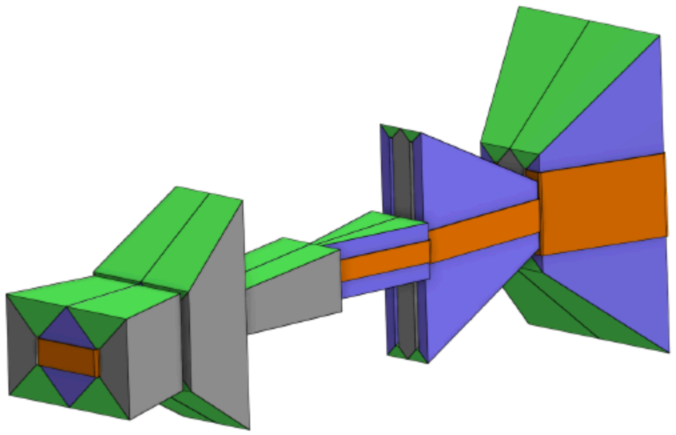


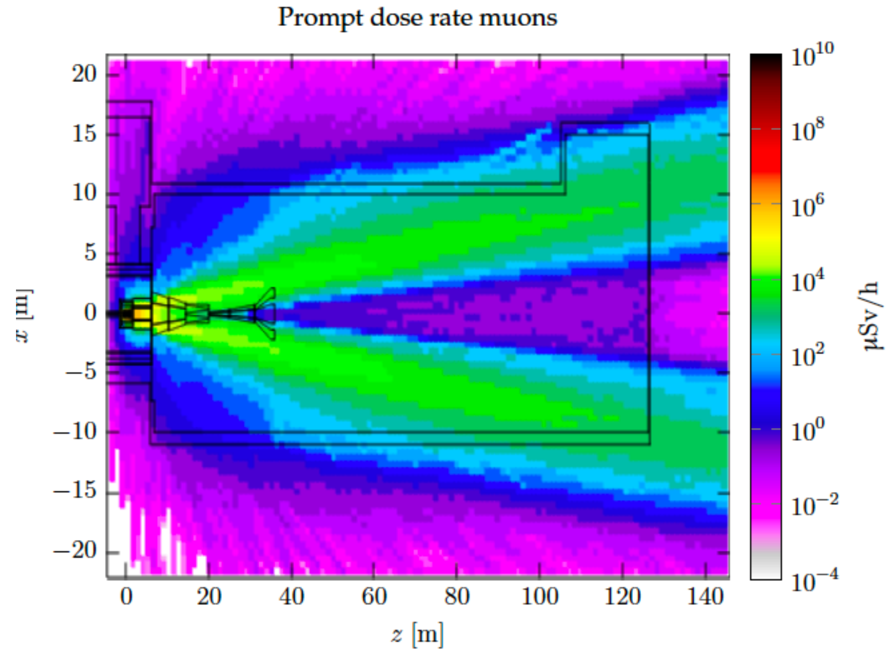
SHiP

[SPSC-SR-248, CERN-SPSC-2015-016, CERN-SPSC-2015-040, Rept.Prog.Phys. 79 (2016) no.12, 124201, JINST 14 (2019) no.03, P03025]

- Designed for **discovery and measurement** of super-weakly interacting new particles
- **Decay** and **scattering** signatures give complementary access to new physics models
- Ultra-low background environment (< 0.1 candidates/5 years) for hidden sector decays

O. Lantwin (UZH) Rencontres du Vietnam: 3 ν and beyond 5



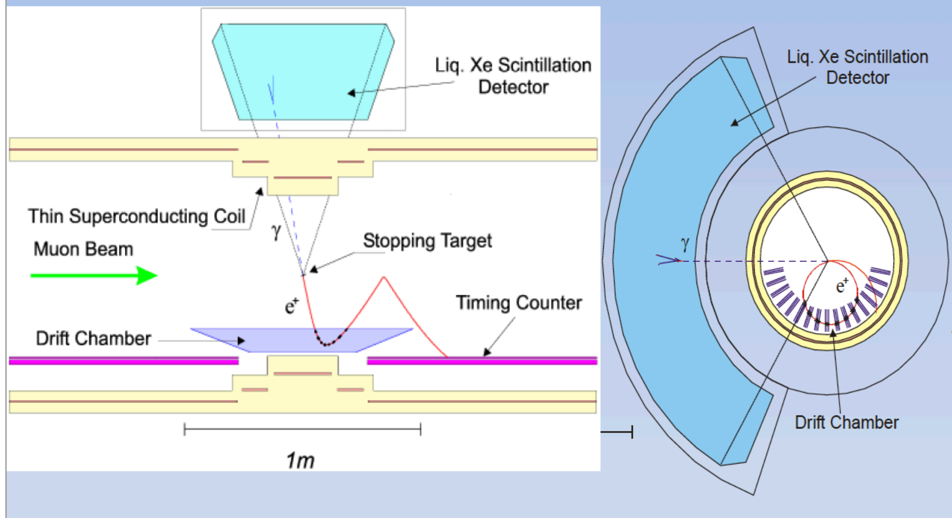


Prompt dose rate muons

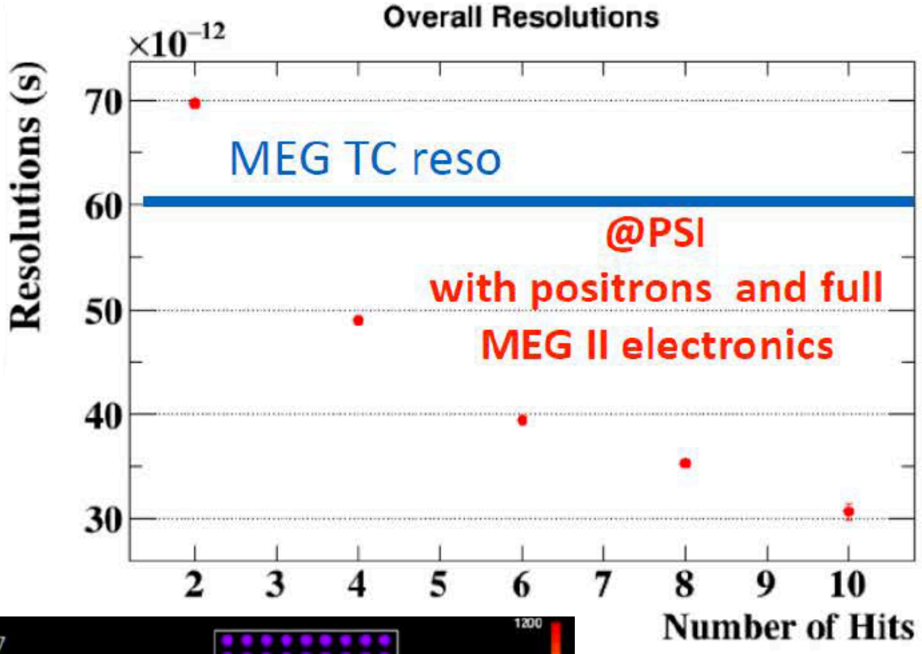
- < 0.1 background events expected → 3 candidates sufficient for discovery
- Can measure decay vertex, invariant mass, impact parameter of signal candidate
  - mass, charge and flavour of new particles measurable
  - redundant background rejection (+background tagger, timing,...)

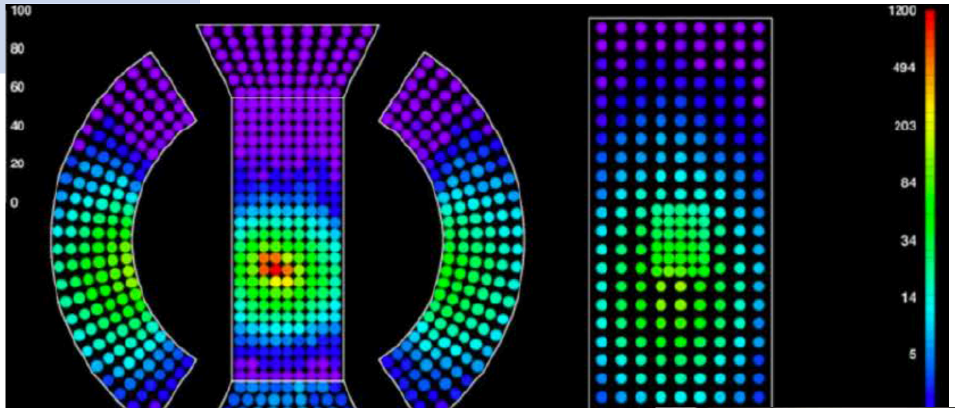
A.Baldini (INFN Pisa)

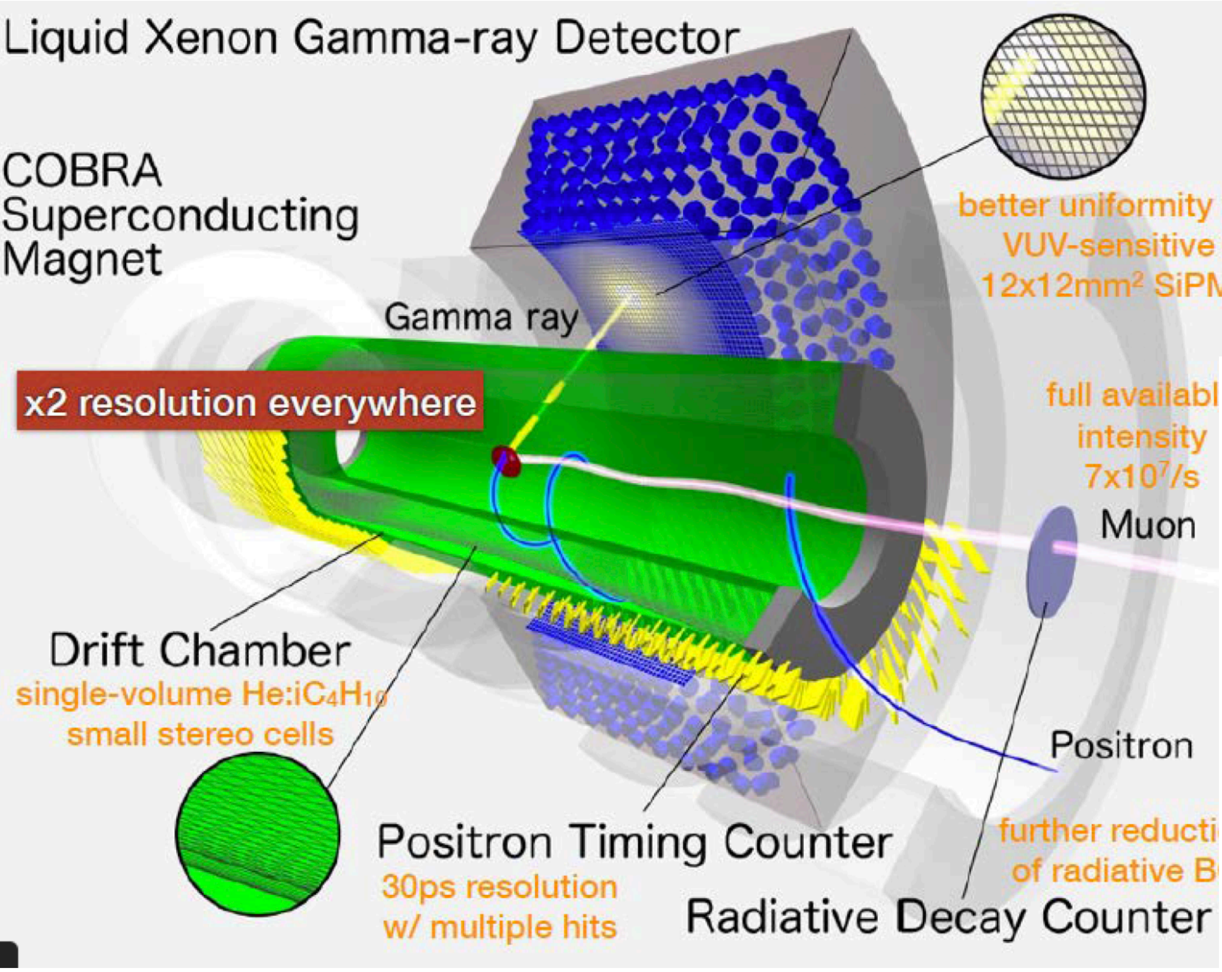
$\mu \to e\gamma$ @MEG

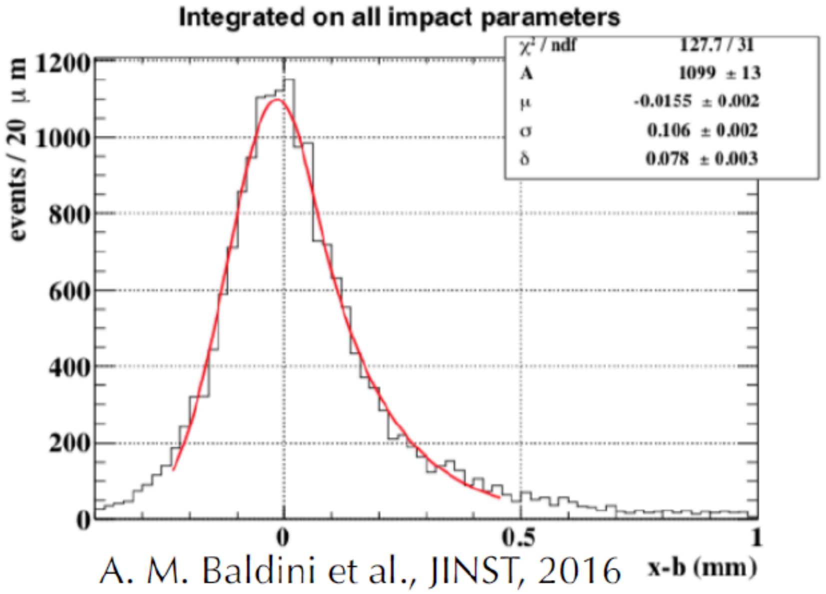


1. Stopped beam of 3 10^7 μ /sec in a 150 μm target
2. Solenoid spectrometer & drift chambers for e^+ momentum
3. Scintillation counters for e^+ timing
4. Liquid Xenon calorimeter for γ detection (scintillation)









A. M. Baldini et al., JINST, 2016

L. Galli et al., TNS, 2015