Liquid Detectors

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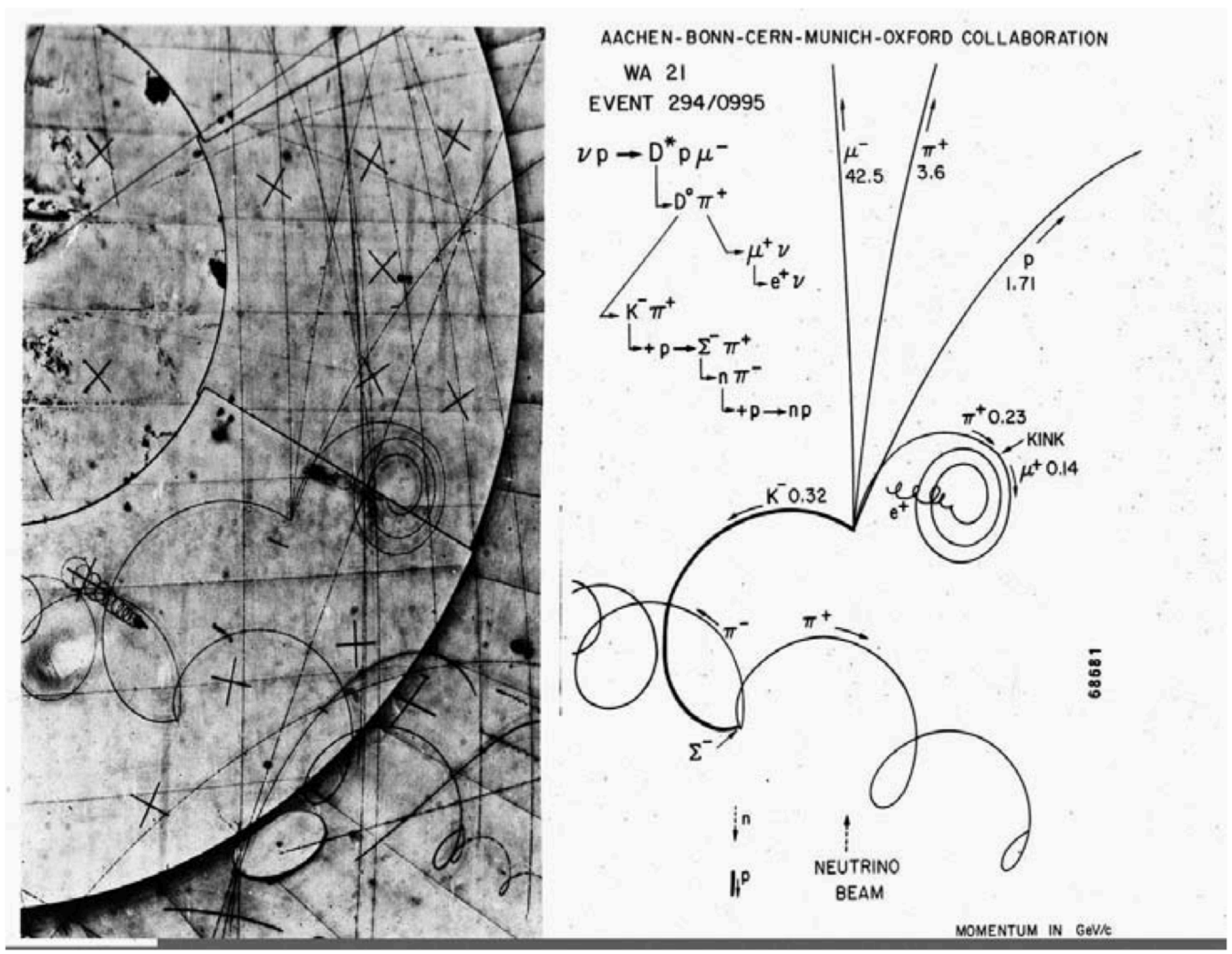
TF2: Liquid detectors

- primarily focus on detector technology using noble liquids, but will also include any other technologies that use liquid media such as water Cherenkov or liquid scintillators
- Accelerator based: neutrino physics
- Astroparticle physics: neutrino physics, dark mater, …
- Collider physics: calorimetry
- Speakers: 6 (ν-DM), 1 (collider), 1 (EDM)

Bubble chamber

- No reason why a liquid cannot be used as the active medium for detection



- One of the earliest and extremely successful imaging detectors
- Built for tracking particles in high energy particle collisions
- Made of a sealed container filled with a liquefied gas
- When particles pass through this fluid, they produce dense tracks of localized electron ion pairs
- The energy delivered to the liquid during this process produces tiny bubbles along the particle's track

Properties of liquids (1/2)

- The principle mechanism of a liquid filled detector is the same as gas filled detector
- A charge pair is created by the incident particle and the resulting change in current or voltage across the electrodes is measured
- Unfortunately, unlike gases, in liquids the energy needed to create a charge pair does depend on the type of liquid

Properties of liquids (2/2)

Liquid	W (eV)	G
Liquid Argon	23.7	4.2
Liquid Krypton	20.5	4.9
Liquid Xenon	16.4	6.1
Tetramethylsilane (TMS)	33.3	3.0
Tetramethylgermanium (TMG)	33.3	3.0
Tetramethyltin (TMT)	25.6	3.9
Hexamethyldisilane (HMDS)	50	2.0

W: energy needed to create an electron ion pair
G: yield of electrons for an energy of 100 eV

- Pros:
  - The energy needed to produce a charge pair in the liquefied noble gases are lower than the usual 30 eV for gases
  - Higher molecular density, because of which the total deposited energy per unit path length traversed by the radiation is also higher
- Cons:
  - The higher density implies spatial proximity of molecules → increase the recombination probability of charges → introduce some uncertainty in the proportionality of measured pulse height with the deposited energy.

Commonly used liquid detection media

Properties of liquefied noble gas

Property	Argon	Krypton	Xenon
Z	18	36	58
A	40	84	131
Radiation Length (cm)	14.2	4.7	2.8
Critical Energy (MeV)	41.7	21.5	14.5
Fano Factor	0.107	0.057	0.041
Normal Boiling Point (K)	87.27	119.8	164.9
Liquid Density at Boiling Point (gcm^{-3})	1.4	2.4	3.0
Dielectric Constant	1.51	1.66	1.95
Scintillation Light Wavelength (nm)	130	150	175

- Liquefied argon (used as ionizing detectors) is the most commonly used detection medium in large area detectors, such as liquid calorimeters for high energy physics experiments
- Liquid xenon is generally used as a scintillation medium for neutrino experiments and DM searches
  - light wavelength, refractive index and Fano factor
  - biggest disadvantage is its cost! $2/kg vs $1500/kg

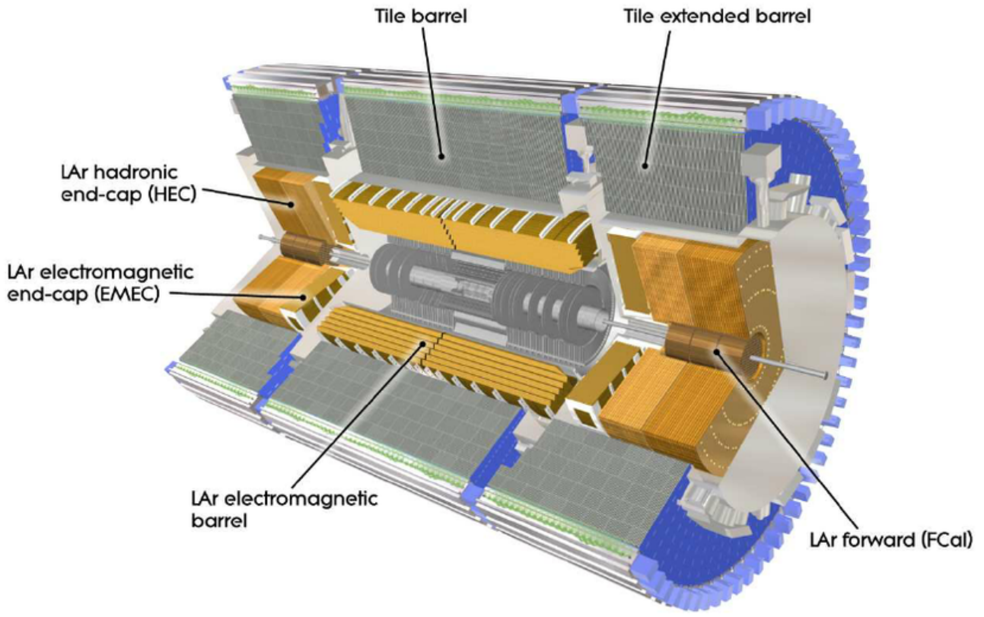
Why liquefied noble gases ?

- They are dielectrics → suitable for free charge transport
- The large drift lengths of electrons make them suitable for building large area detectors
  - the larger drift length is a consequence of lower recombination probability in liquefied noble gases as compared to molecular liquids

Current noble liquid calorimeters

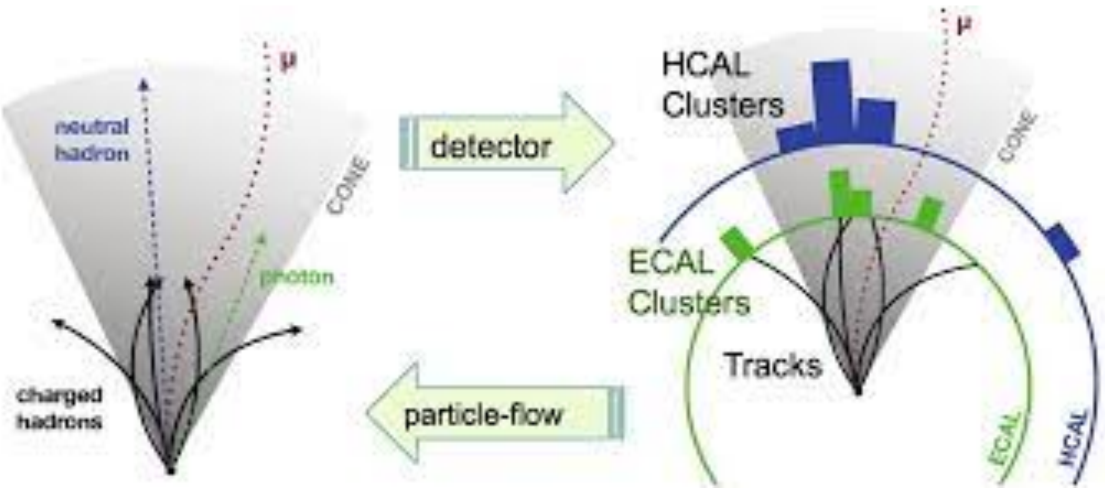
- Well understood concept with good experience from HERA, D0, NA31, ATLAS
- Advantages
  - Very good energy resolution
  - Excellent linearity and stability of response
  - Radiation hardness
  - Very good timing and position resolution
  - PID capability
  - Cost effective solution
- Current design of the noble liquid calorimeters has limited granularity
- Alternative to silicon calorimeters

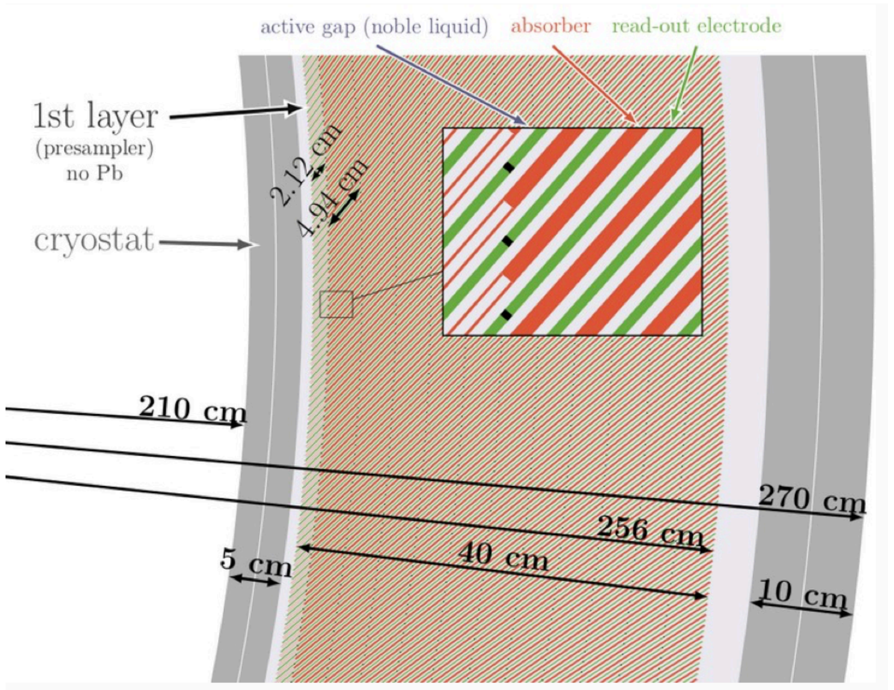
ATLAS LAr calorimeter



Future noble liquid calorimeter

- Future calorimeters has be optimized for advanced reconstruction techniques such as particle flow algorithm or machine learning
  - Energy resolution
  - Particle identification
- "Smooth" connection between the tracker and calorimeter → high granularity is the key ingredient
- High granularity possible with usage of multi-layer PCBs
  - Good performance achieved using MC simulations
  - Considered as a benchmark for FCC-hh detector and an option for FCC-ee detector





R&D projects on noble liquid calorimeters

1/ Carbon composite cryostat (CERN)
-- Low material budget in front of the calorimeter crucial for e.g. energy resolution

2/ High density feed through design (CERN)

– 10 x # channels compared to ATLAS, up to 50 cables/cm^2

3/ Read-out electrode design and performance optimisation (CERN, CNRS-IJCLab)

– Important e.g. for keeping the electronic noise low

4/ Software development (CERN, Charles Uni)

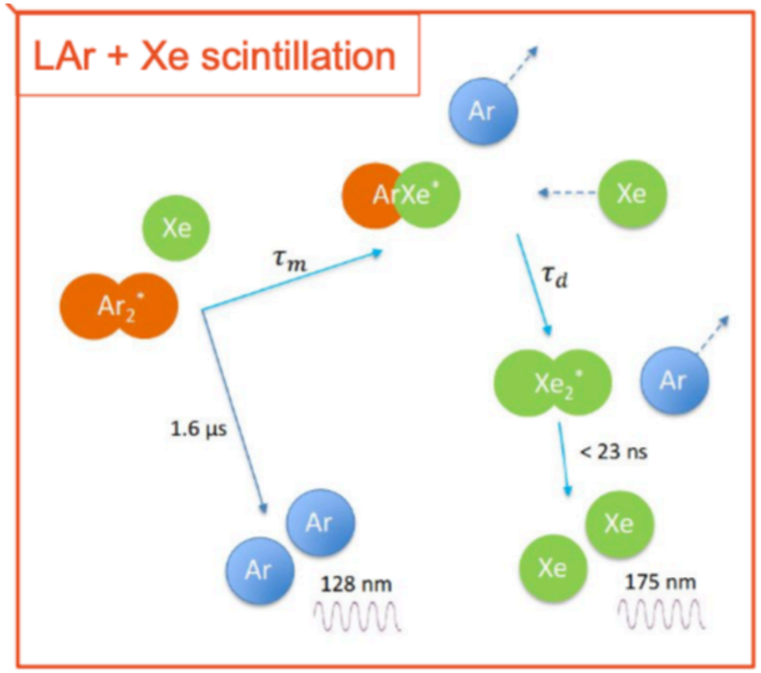
R&D projects supported by: CERN EP R&D, H2020 (AIDAinnova)

More details about the project will be shown at ECFA TF6 Calorimeters session by B. Francois (https://indico.cern.ch/event/999820/)

R&D on noble properties

- Basic properties
- Spike Ar with Xe
- Near IR instead of UV
  - LAr NIR light could potentially provide an alternative to the challenges faced by VUV
- Superradiance
- Radiopurity
- HV

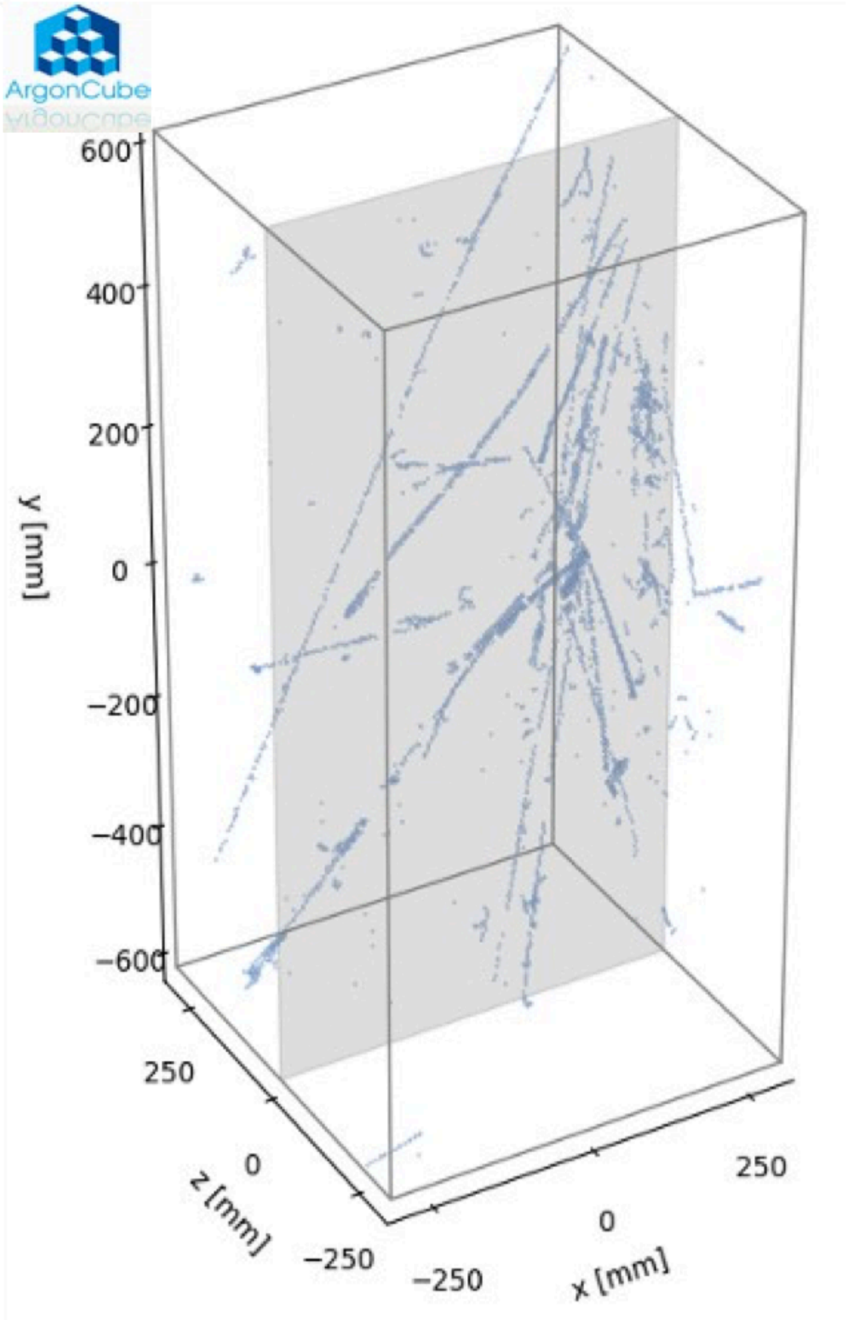
WLS is convenient but it has some issues:
- Low geometrical efficiency
- Sensitivity to mechanical stress
- Scattering and re-absorption of the re-emitted light inside the WLS layer
- Dependence of the WLS efficiency on the coating method



Xenon doping：shift 128 nm wavelength to 175 nm
more uniform light distribution
increase light yield and detection efficiency
possible mitigation for N_2 contamination

R&D on nobel charge collection

- Charge amplification in liquid – stability
- Hybrid readouts (charge→ electroluminescence → high-granularity optical imagers) – scalability, cost, performance
- Charge collection in noble liquids from wires to pixels as happened in HEP tracking
  - R&D on pixel charge processing ASICs
- Cryogenic charge amplifiers – low power and more channels



R&D on noble cold and pure

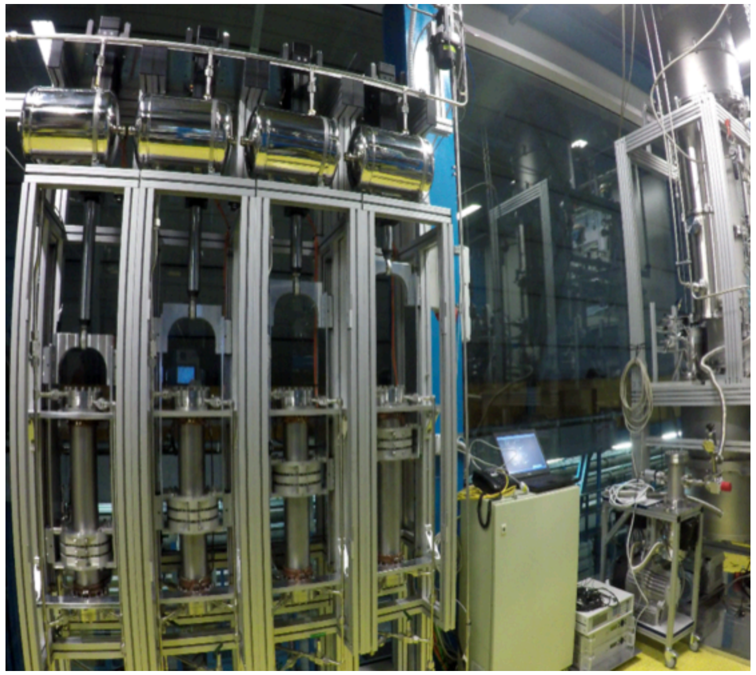
- Bigger and bigger experiments that need to be cold and pure → more and more complex cryogenics and Ar/Xe handling

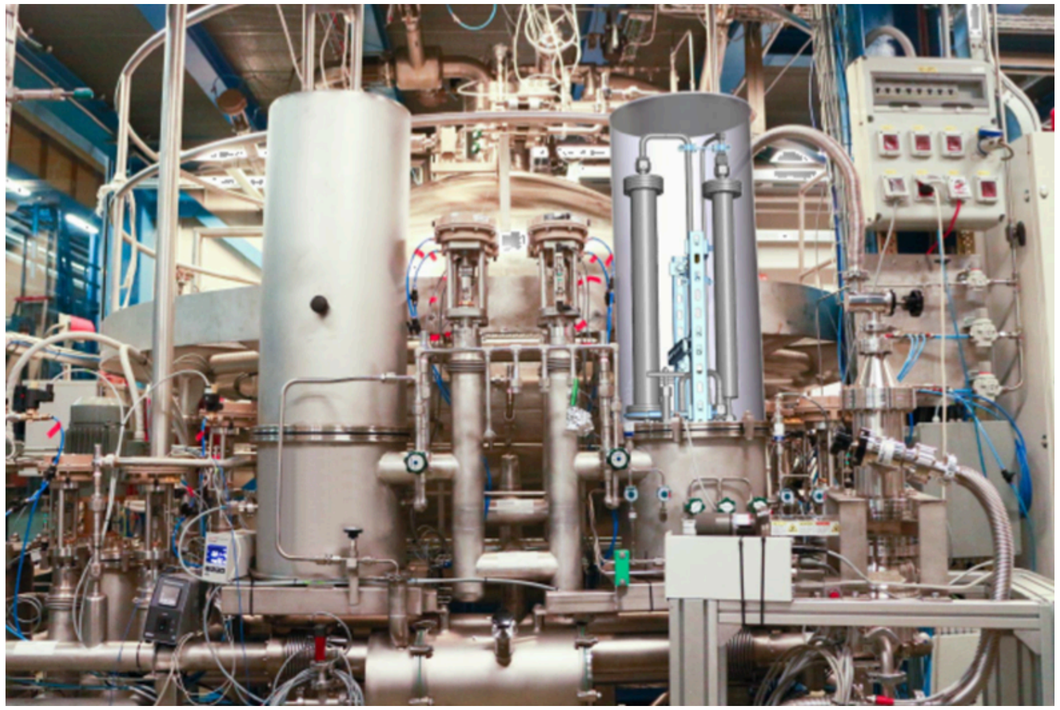
- Scaling

- Purification in liquid phase

- Key supporting technologies

    - clean pumps, clean heat-exchangers, clean & failure-safe storage

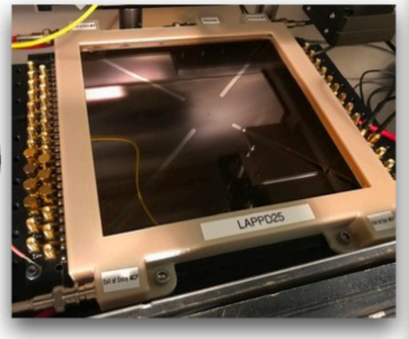
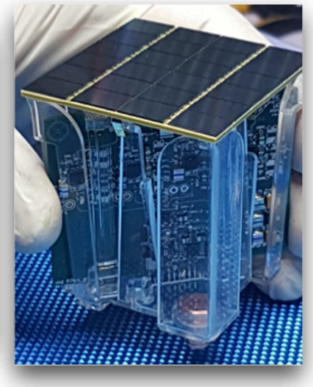




R&D on noble light

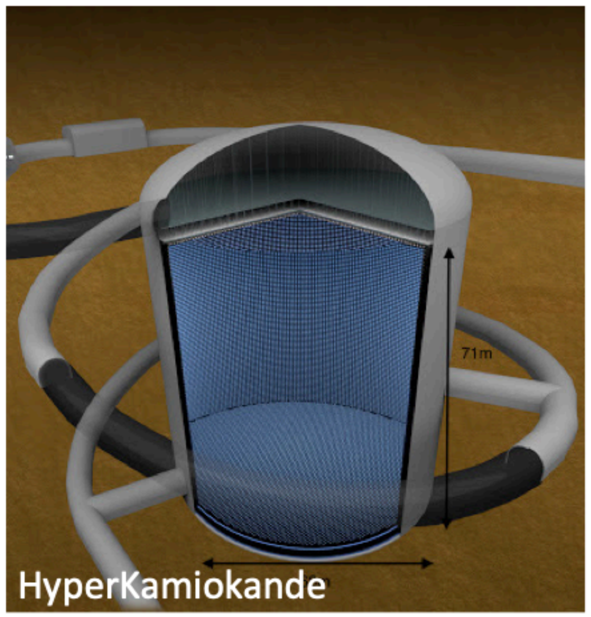
- Maximizing light collection & spectral sensitivity
- Sensor properties → SiPM
- Integration of light/charge readout

Experiment	Type	Photodetector	Area (m^2)
nEXO	LXe	FBK, Hamamatsu, 3DdSiPM	5
DARWIN	LXe	SiPM is one option	8
TAO	LSci	FBK	10
DarkSide-20k	LAr	FBK NUV-HD triple dopant	30
ARGO	LAr	SiPM is baseline option	200
DUNE	LAr	Light guide or trap + SiPM	10-1000

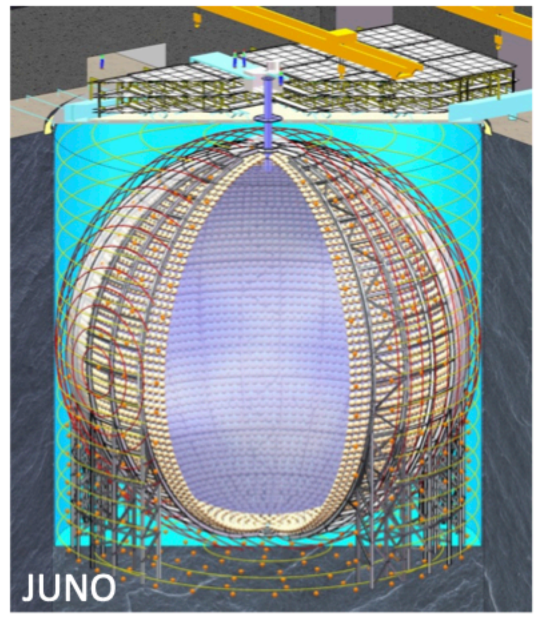




R&D on liquid scintillator and water detectors

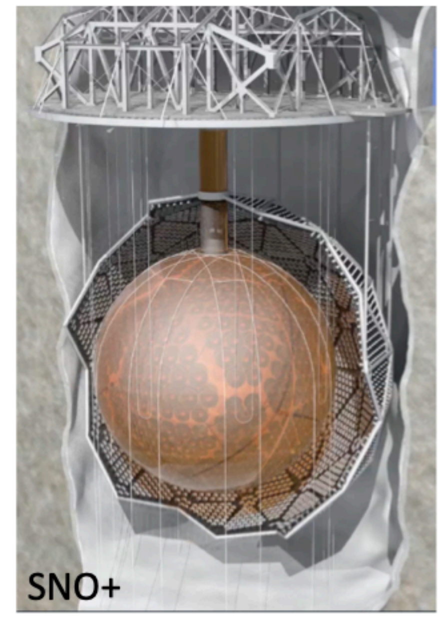
large-volume water(+Gd) detector



ultrapure LS detector



metal-loaded (Te) LS detector

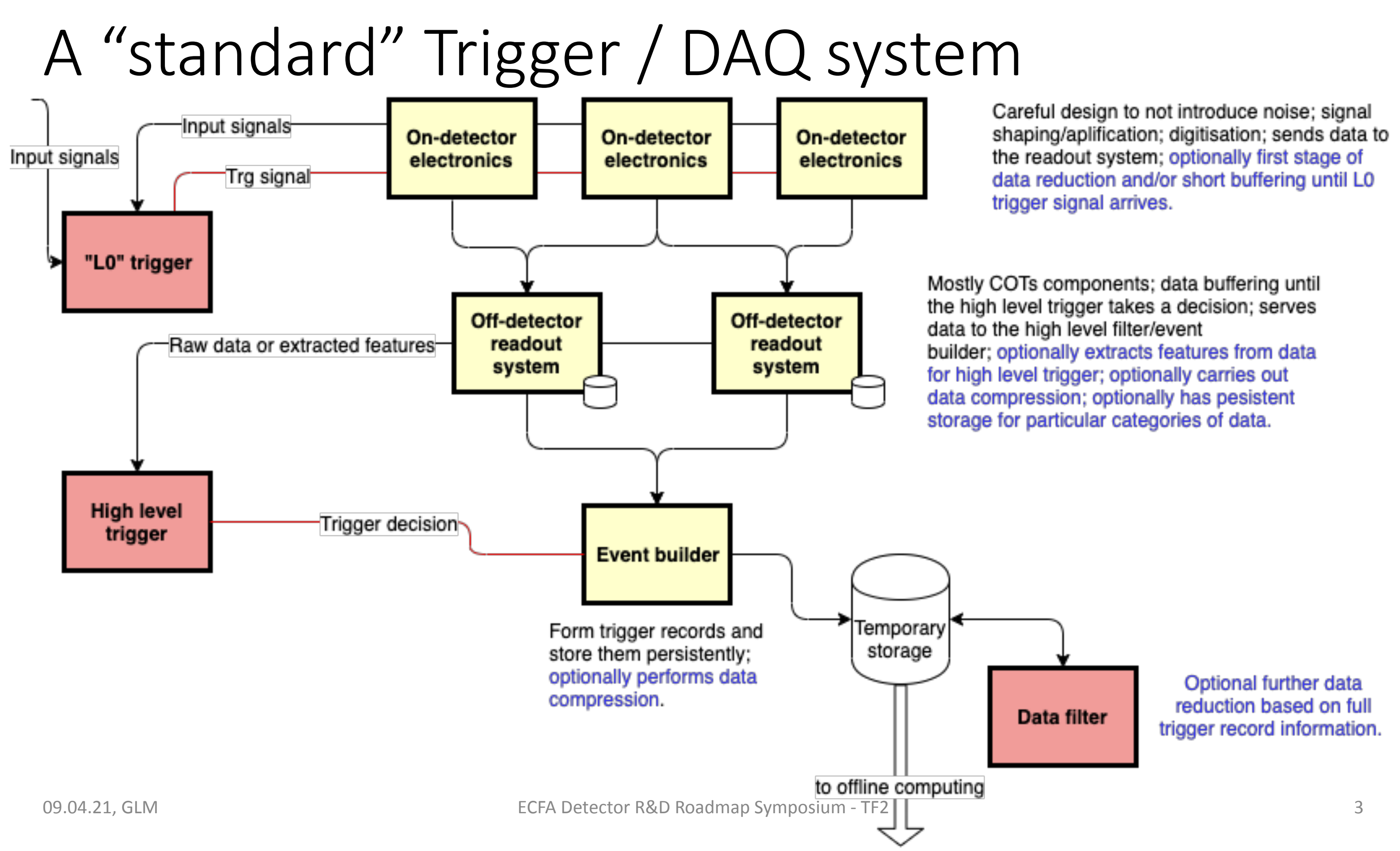


efficient veto detector (water, LS, Gd-dopted)

- Hybrid Cherenkov/scintillation
- Cold liquid scintillation
- Opaque LS with fiber readout
- LS doped with quantum-dots

R&D on readout challenges

- What needs to be done outside the liquids ?
- Many cross links with other TFs
- Large detectors → handle large amount of data (1-10 TB/s range)
- Mixture of fast (light) and slow (charge) signals
- Data-bursts for rare event triggers



Summary

- Liquid detectors have been used in high energy experiments and also neutrino/DM experiments
  - LAr is the benchmark detector for FCC
- A lot of R&D activities are on-going
- Stress by many: “Need to collaborate instead of compete”