Discussion on Backgrounds for the VD Drift Design

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SOUTH DAKOTA MINES

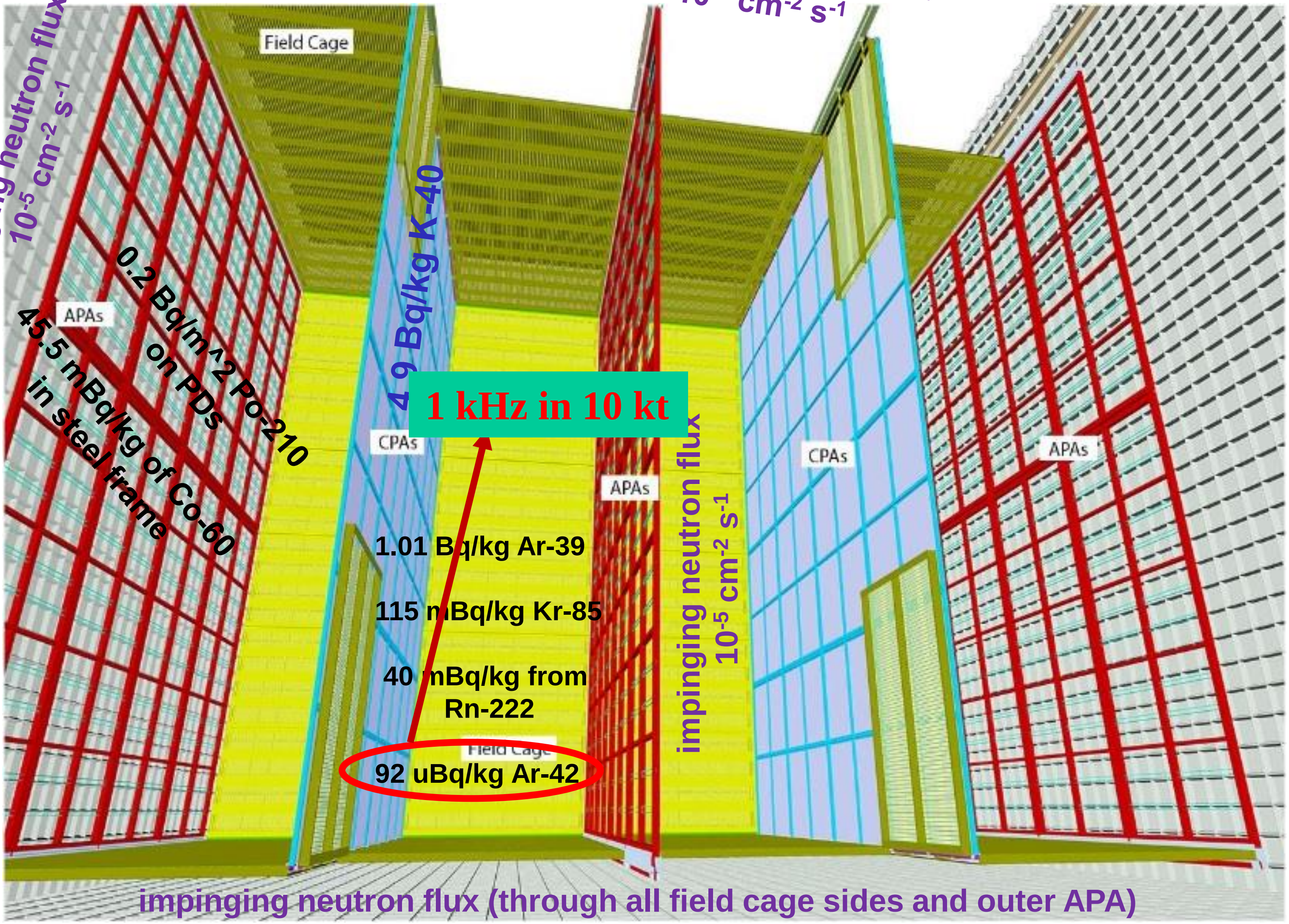
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Backgrounds Task Force Meeting

Apr 7, 2021

Synopsis of Single-Phase Backgrounds 1.0 (MCC11 & TDR)

Ar-42:



impinging neutron flux 10^{-5} cm^{-2} s^{-1}

impinging neutron flux 10^{-5} cm^{-2} s^{-1}

0.2 Bq/m^2 Po-210 on PDs

45.5 mBq/kg of Co-60 in steel frame

4.9 Bq/kg K-40

1 kHz in 10 kt

impinging neutron flux 10^{-5} cm^{-2} s^{-1}

1.01 Bq/kg Ar-39

115 mBq/kg Kr-85

40 mBq/kg from Rn-222

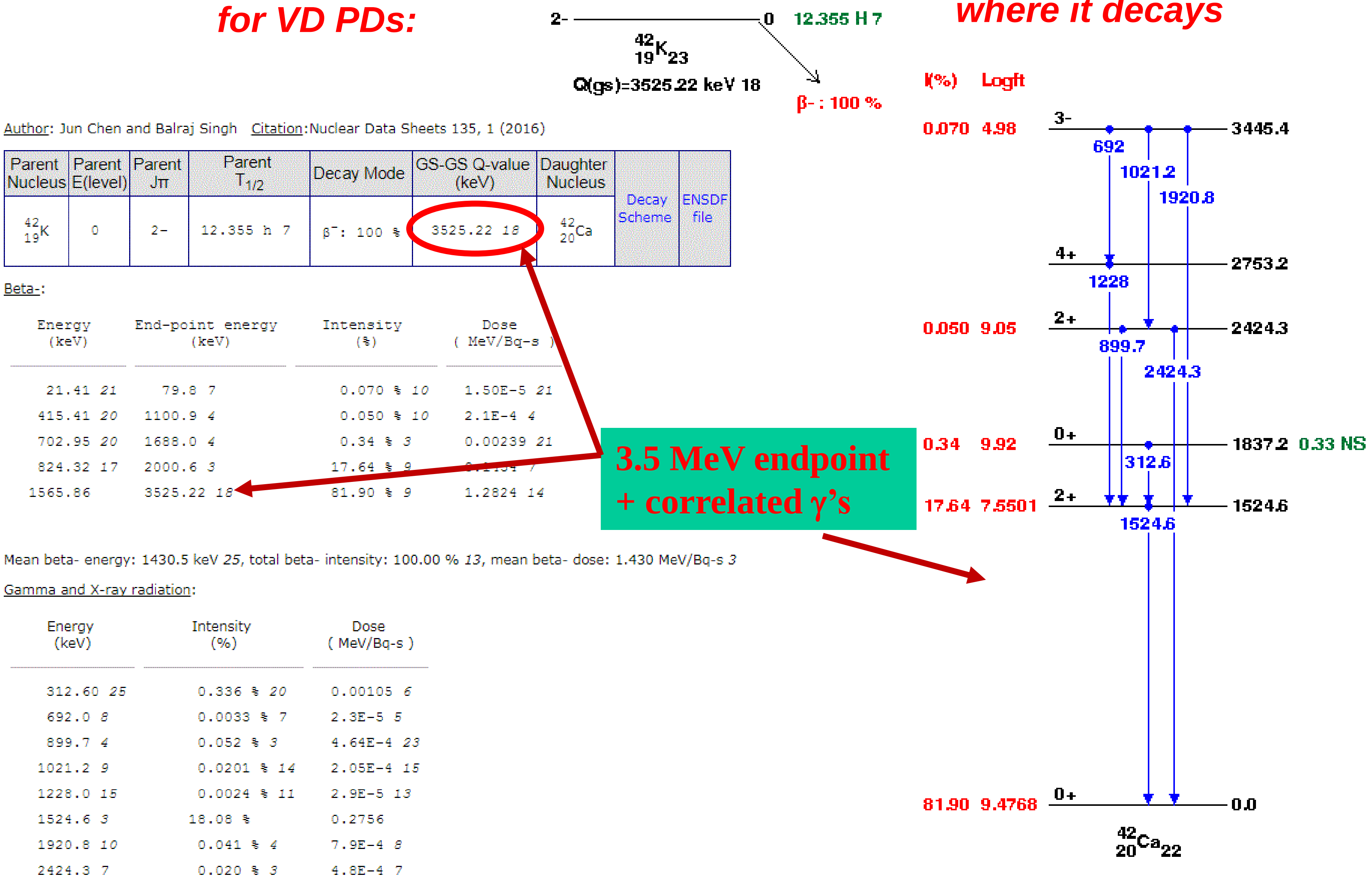
92 uBq/kg Ar-42

impinging neutron flux (through all field cage sides and outer APA)
10^{-5} cm^{-2} s^{-1}

Ar-42 (33 years long half-life) -> K-42 Background

Ar-42 is Potentially a Big Problem for VD PDs:

-> K-42 drifts to cathode where it decays



Author: Jun Chen and Balraj Singh Citation: Nuclear Data Sheets 135, 1 (2016)

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)	Daughter Nucleus	Decay Scheme	ENSDF file
$^{42}_{19}K$	0	2-	12.355 h 7	β^-: 100 %	3525.22 *18*	$^{42}_{20}Ca$		

Beta-:

Energy (keV)	End-point energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
21.41 *21*	79.8 7	0.070 % *10*	1.50E-5 *21*
415.41 *20*	1100.9 *4*	0.050 % *10*	2.1E-4 *4*
702.95 *20*	1688.0 *4*	0.34 % *3*	0.00239 *21*
824.32 *17*	2000.6 *3*	17.64 % *9*	[illegible]
1565.86	3525.22 *18*	81.90 % *9*	1.2824 *14*

3.5 MeV endpoint + correlated γ's

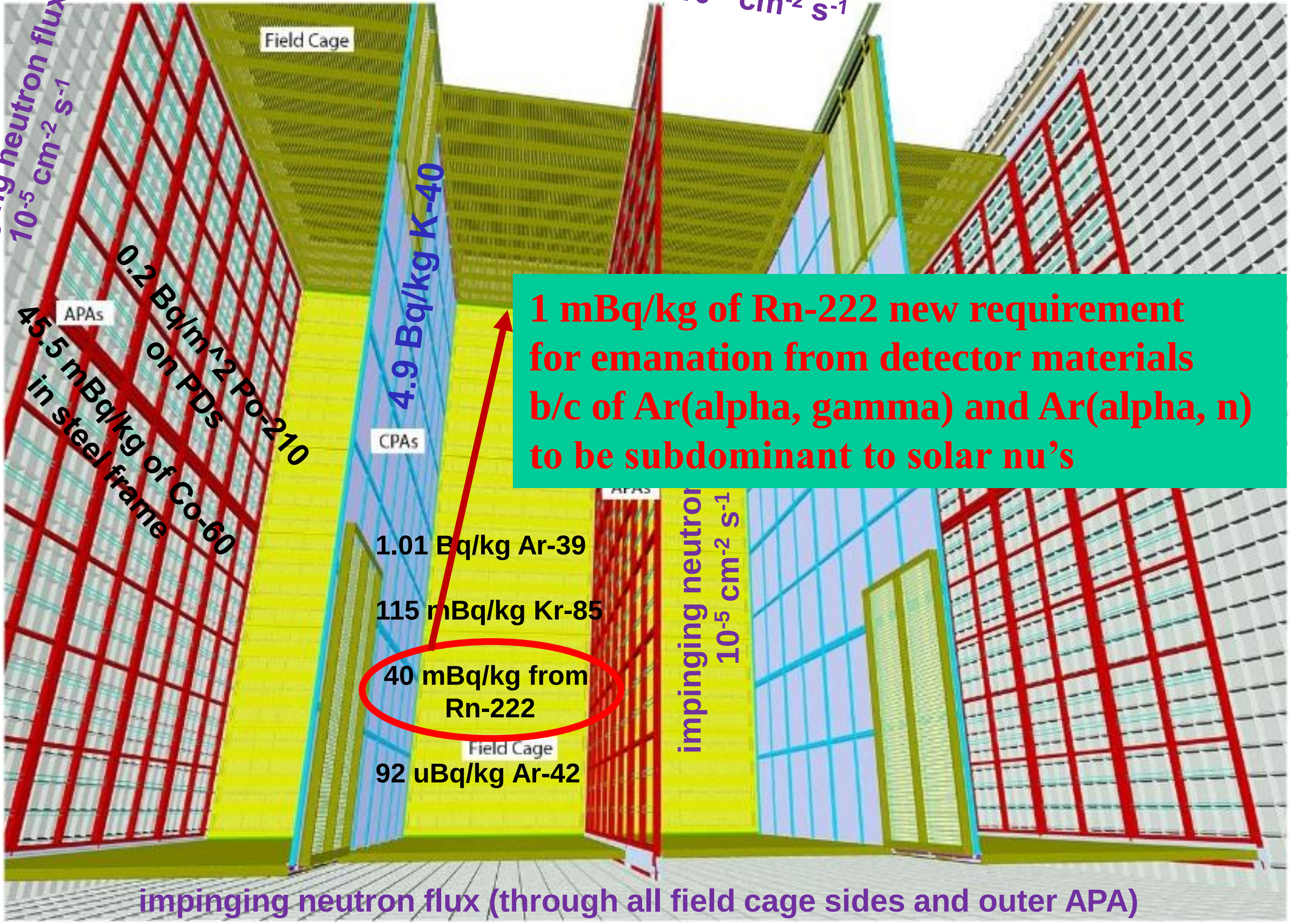
Mean beta- energy: 1430.5 keV *25*, total beta- intensity: 100.00 % *13*, mean beta- dose: 1.430 MeV/Bq-s *3*

Gamma and X-ray radiation:

Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
312.60 *25*	0.336 % *20*	0.00105 *6*
692.0 *8*	0.0033 % 7	2.3E-5 *5*
899.7 *4*	0.052 % *3*	4.64E-4 *23*
1021.2 *9*	0.0201 % *14*	2.05E-4 *15*
1228.0 *15*	0.0024 % *11*	2.9E-5 *13*
1524.6 *3*	18.08 %	0.2756
1920.8 *10*	0.041 % *4*	7.9E-4 *8*
2424.3 7	0.020 % *3*	4.8E-4 7

Synopsis of Single-Phase Backgrounds 1.0 (MCC11 & TDR)

Rn-222:



impinging neutron flux
10^{-5} cm^{-2} s^{-1}

impinging neutron flux
10^{-5} cm^{-2} s^{-1}

0.2 Bq/m^2 Po-210
on PDs

45.5 mBq/kg of Co-60
in steel frame

4.9 Bq/kg K-40

1 mBq/kg of Rn-222 new requirement
for emanation from detector materials
b/c of Ar(alpha, gamma) and Ar(alpha, n)
to be subdominant to solar nu's

impinging neutro
10^{-5} cm^{-2} s^{-1}

1.01 Bq/kg Ar-39

115 mBq/kg Kr-85

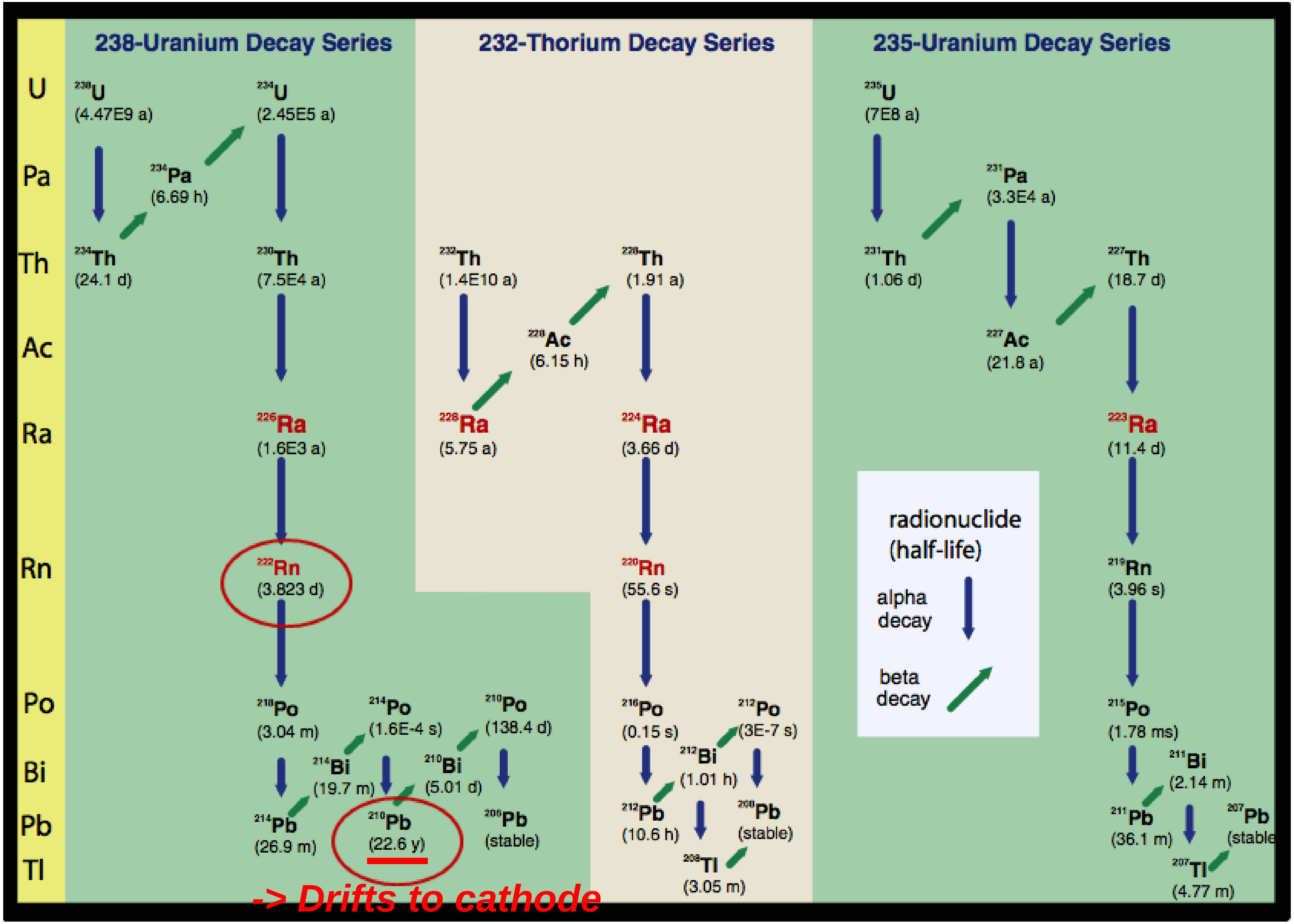
40 mBq/kg from
Rn-222

92 uBq/kg Ar-42

impinging neutron flux (through all field cage sides and outer APA)
10^{-5} cm^{-2} s^{-1}

Radon Emanating into LAr from Materials & Pb-210 from Plate-Out

Rn-222 from dominant U-238 chain
(& long-lived Pb-210 from subsequent decays)



-> Drifts to cathode where it decays

Migration Modeling: Ion drift in the DUNE LArTPC

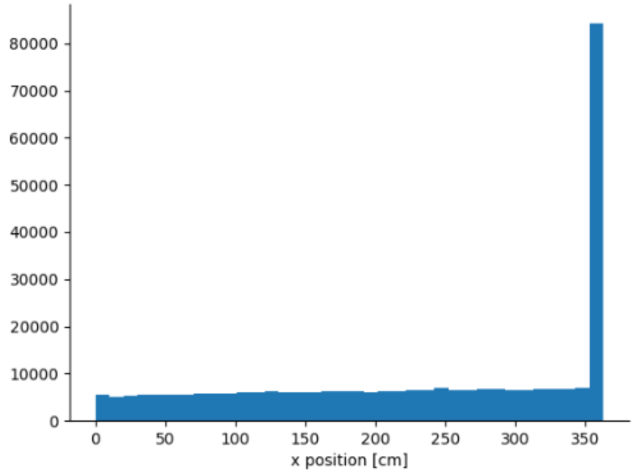
Anyssa,
Andrzej et al
at Manchester

Realistic scenario

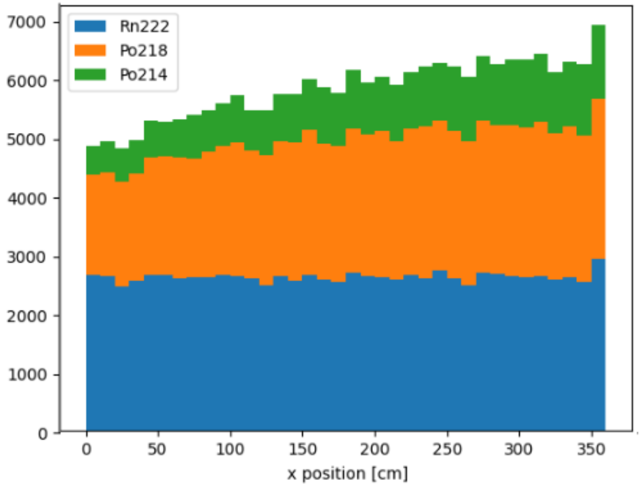
Values extrapolated from literature

Isotope	Drift velocity [cm/s]	Ion fraction
Po218	0.43	0.37
Pb214	0.4	0.37
Bi214	0.4	0.56

Distance to the cathode	Fraction of alpha decays [%]
< 30cm	34.72
< 20cm	32.5
< 10cm	30.31



Cut off last bin



Radon is Potentially a Big Problem

- **α's have high light yield in LAr (barely quenched)**

- **$^{40}Ar(\alpha, \gamma)$ -> 15 MeV γ's that look like ν's**

- **$^{40}Ar(\alpha,n)$ -> neutron captures in LAr that look like ν's**

- **α surface contamination from:**
  Construction and installation period:
  - radon daughter plate-out in air (^{210}Pb, $T_{1/2}$=22 y)
  Detector operation period:
  - radon daughter migration in LArTPC (-> cathod)

- **^{222}Rn continuously emanating into LAr from materials**

Neutrons ARE a Big Problem

- **neutron captures can look like ν's for DAQ**
  (-> rate issue, SNB trigger efficiency, solar ν's)

- **neutrons are difficult to shield**
  (-> simulate large geometry w/ detailed chemical composition)

- **external radiological neutron flux is important (rock, shotcrete)**

- **^{238}U content of materials for SF**

- **α emitter content of materials + chemical composition -> (α,n)**

- **customized (α,n) production yield calculations important!**
  (need cross section measurements where uncertainties large)

-> need for entire detector geometry & surrounding environment:
extensive radiological assays + chemical composition assays

DUNE FD Paradigms

"Quantity is better than quality" for radiological assays (γ- and α-spectroscopy, emanation) of materials in DUNE to avoid stupid mistake in building the detector (need extensive assay program)!

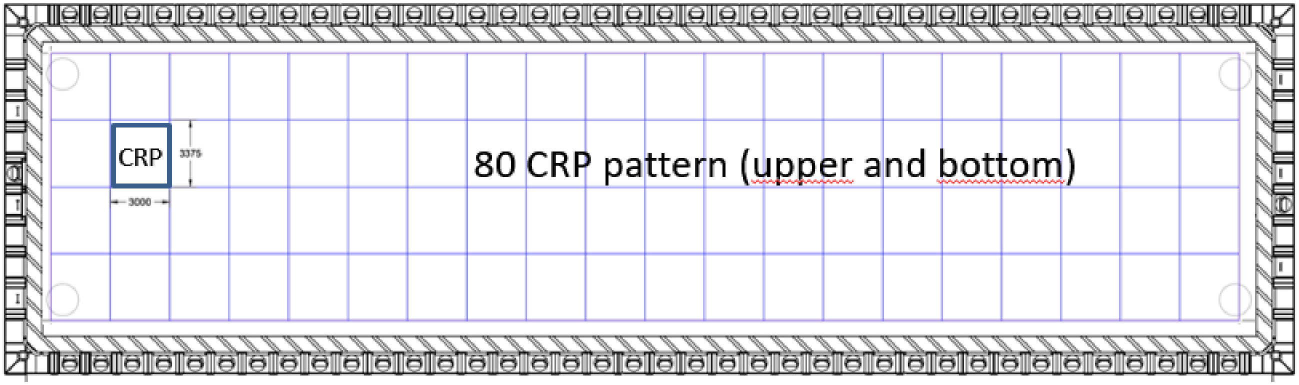
Chemical composition of detector materials very important too (different chemical assay methods like XRD, XRF, ICP-MS, FT-IR, CHN etc. needed for each different type of material!):
- insulating foam defines neutron attenuation, but also neutron capture time, even in a 10 kt LAr volume ~half of neutrons will escape!
- aluminium content drives (α, n) production rates
- cryostat is ~10% of mass of detector

Fast turn-around of assays & simulations to be able to react in time

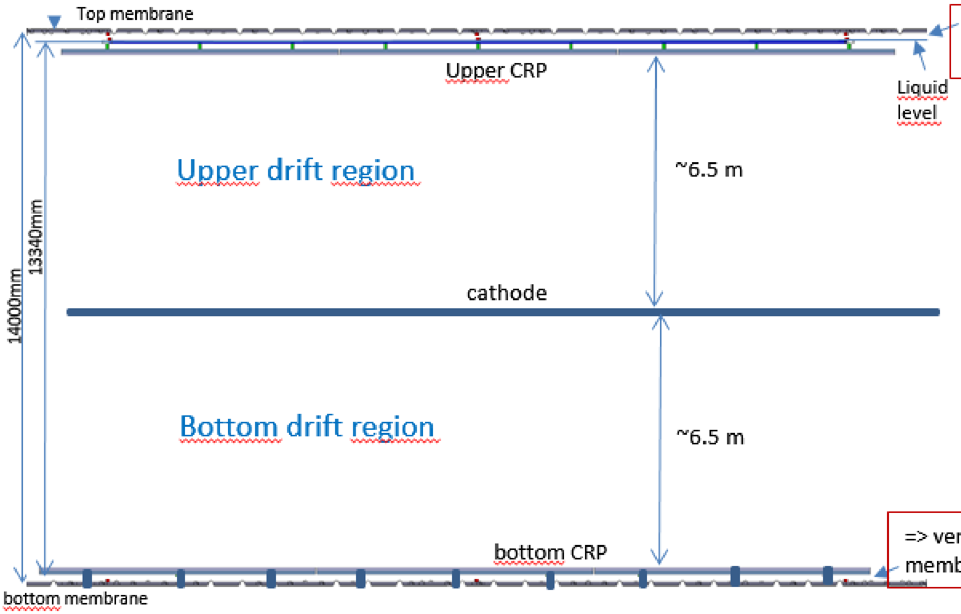
Basic VD Design Concept

General CRP geometry arrangement

Top view:



Side view :



Ullage space: 4% of total volume = **560mm**

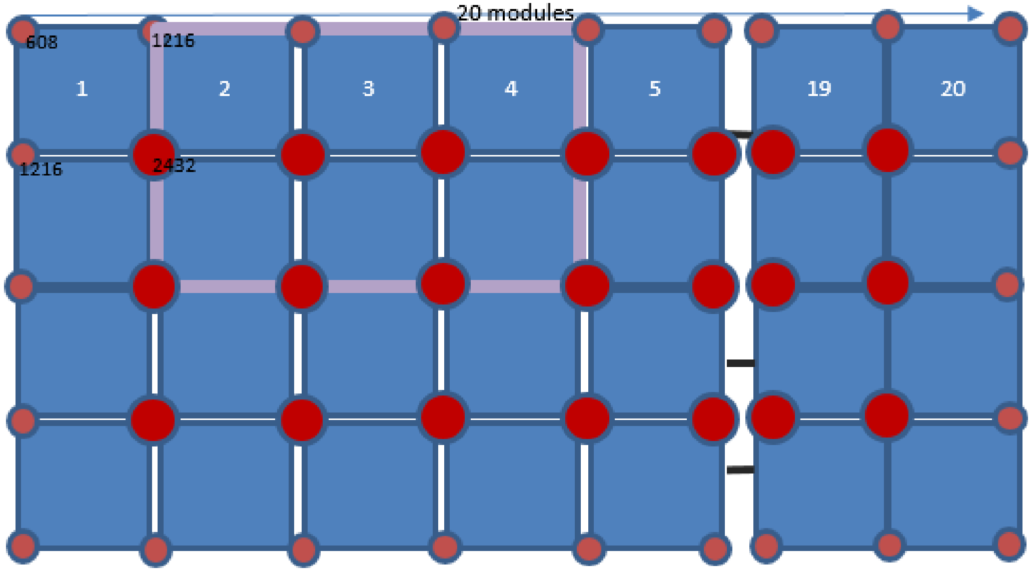
=> vertical space CRP structure to membrane = **100mm**

More Holes for External Neutrons…

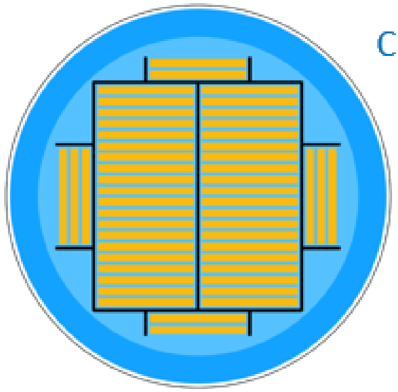
CRP electronic feedthroughs

Upper Electronic Feedthroughs

Top chimney topology: connexion at each CRP corner



Total 105 feedthroughs
The peripherical ones can be of smaller radius

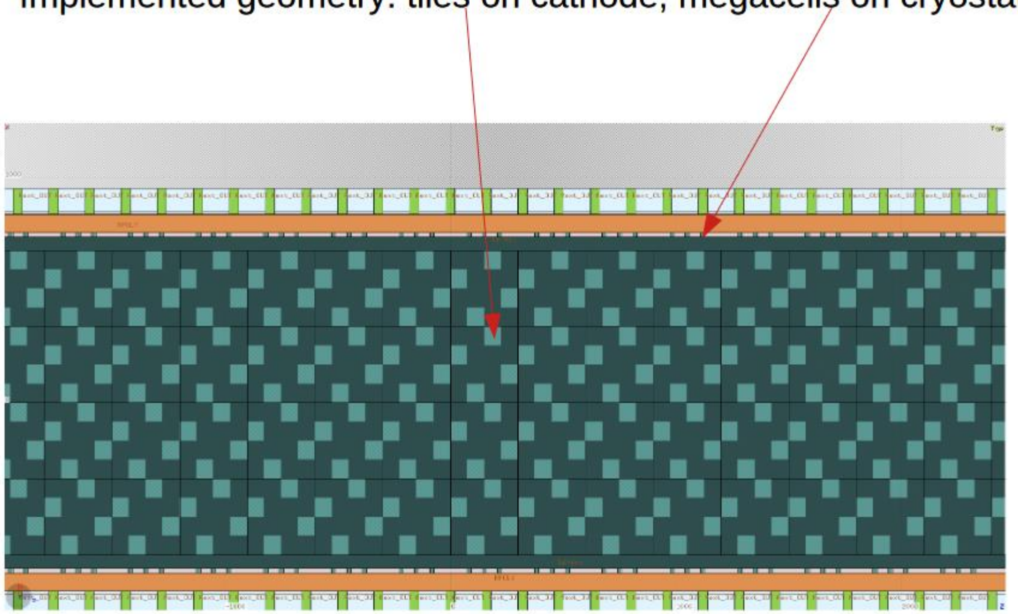


Connexion similar to DP CRP

Pipe internal diameter : 48 cm

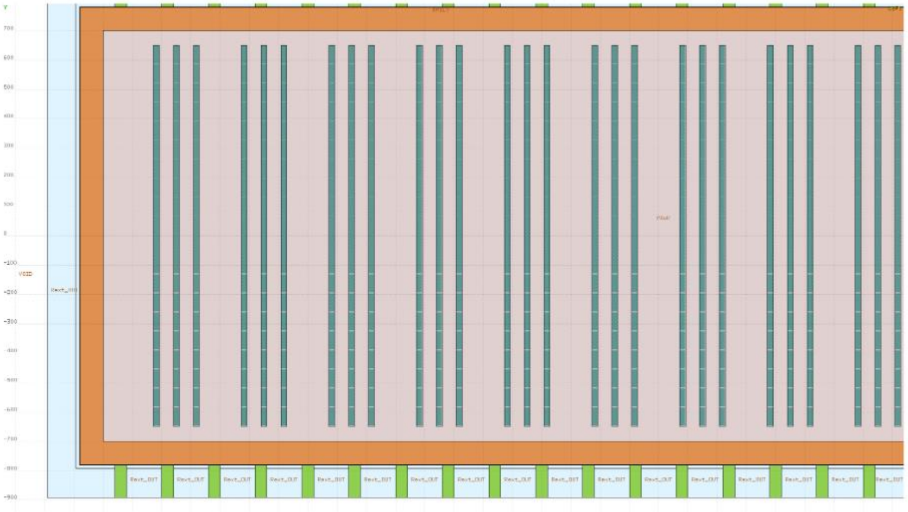
Latest Basic VD PDs Design Concept

Implemented geometry: tiles on cathode, megacells on cryostat



Tiles: 60x60 cm
4 of them
Every
~3x3 m

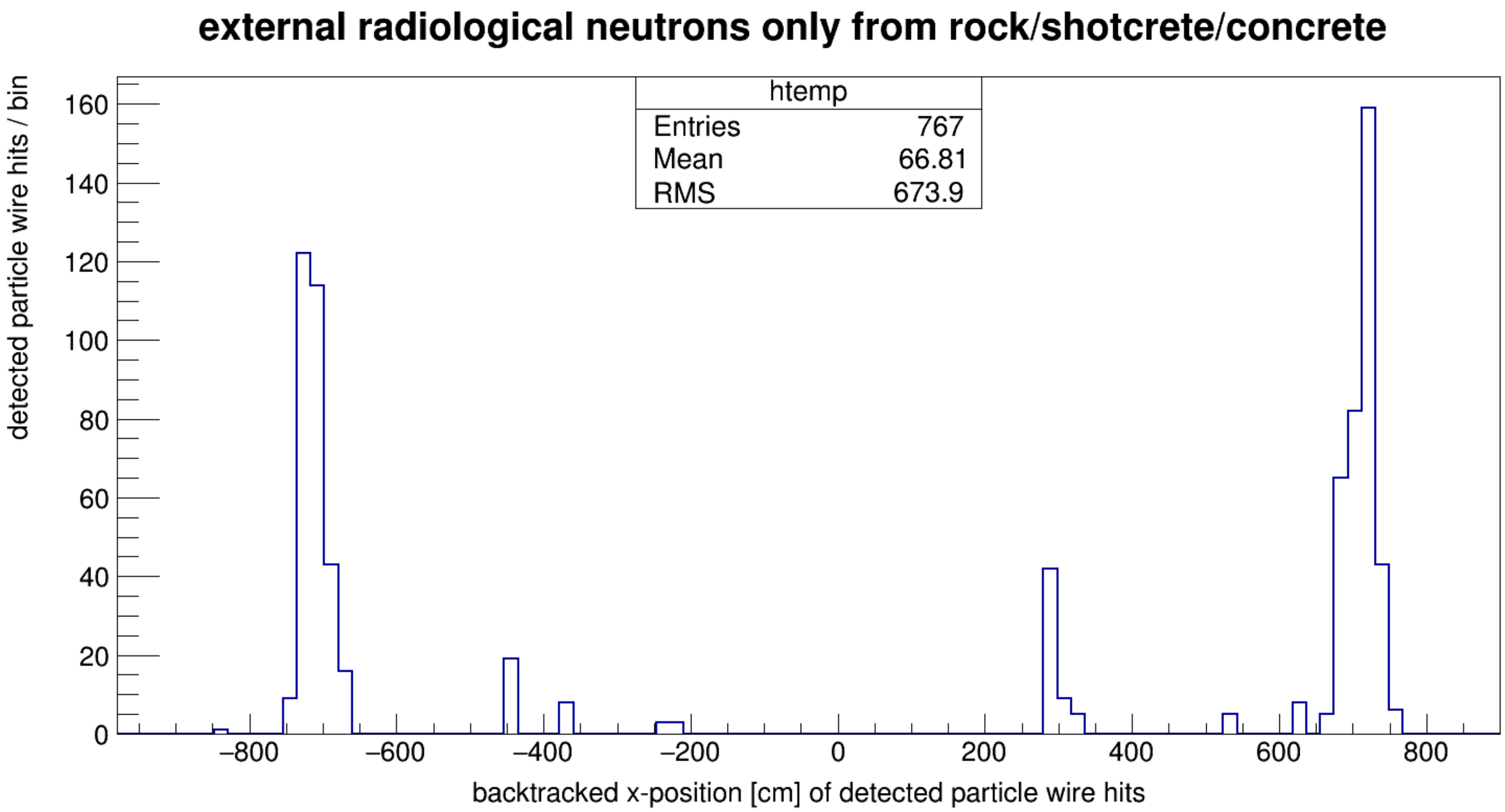
Implemented geometry: Megacells on the Cryo inner surface: side view



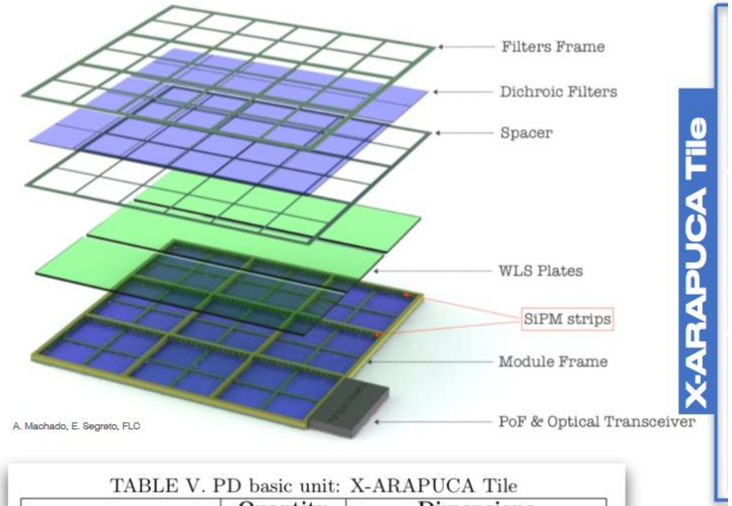
Megacells:
20x60 cm
20 Megacells in a Column
60 columns each cryo side

1 tile == 3 megacells (vertically, can study other groupings)

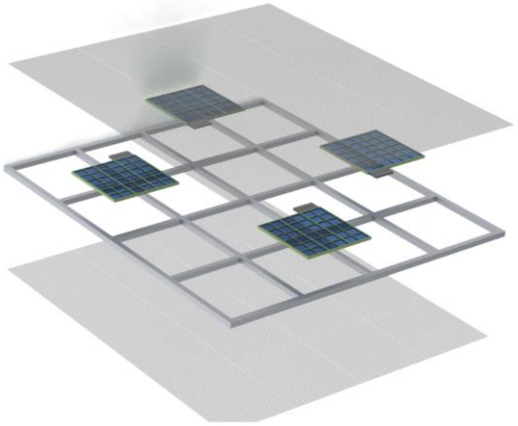
Less Passive LAr Shielding for External Neutrons



Latest Basic VD PDs Design Concept (X-ARAPUCA Tiles and MegaCells)

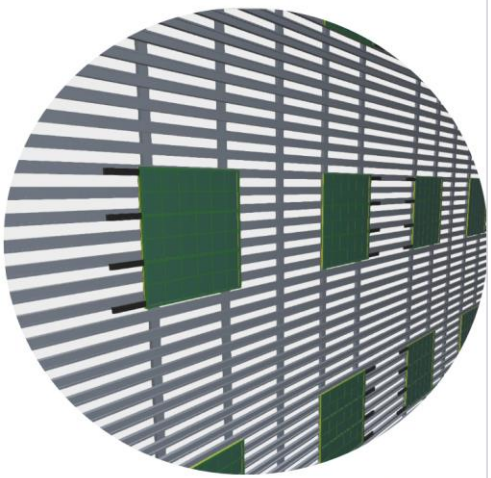


A. Machado, E. Segreto, FLC



Photon Detector into the Cathode frame under conductor mesh (exploded view)

Heriques Frandini - UNICAMP, Campinas, Br



Photon Detectors hanging on Field Cage Walls

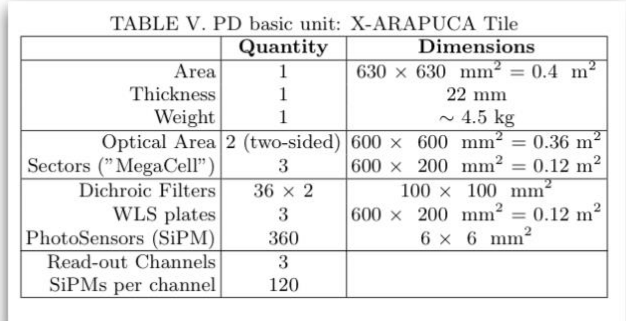
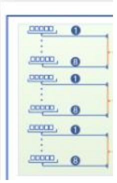


TABLE V. PD basic unit: X-ARAPUCA Tile

	Quantity	Dimensions
Area	1	630 × 630 mm^2 = 0.4 m^2
Thickness	1	22 mm
Weight	1	∼ 4.5 kg
Optical Area	2 (two-sided)	600 × 600 mm^2 = 0.36 m^2
Sectors ("MegaCell")	3	600 × 200 mm^2 = 0.12 m^2
Dichroic Filters	36 × 2	100 × 100 mm^2
WLS plates	3	600 × 200 mm^2 = 0.12 m^2
PhotoSensors (SiPM)	360	6 × 6 mm^2
Read-out Channels	3	
SiPMs per channel	120	

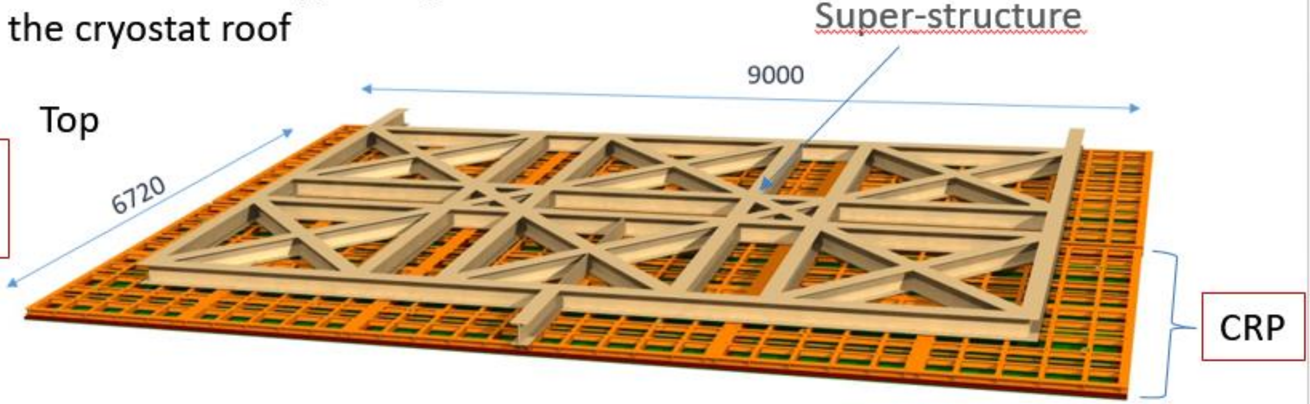


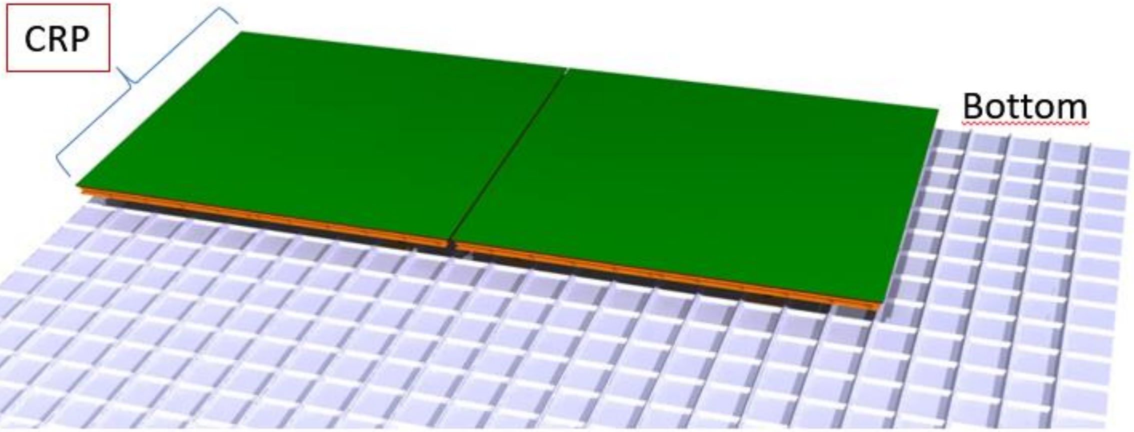
Latest Basic VD Anode Design Concept

Structure mechanical design

CRP are grouped on a common supporting structure suspended from the cryostat roof

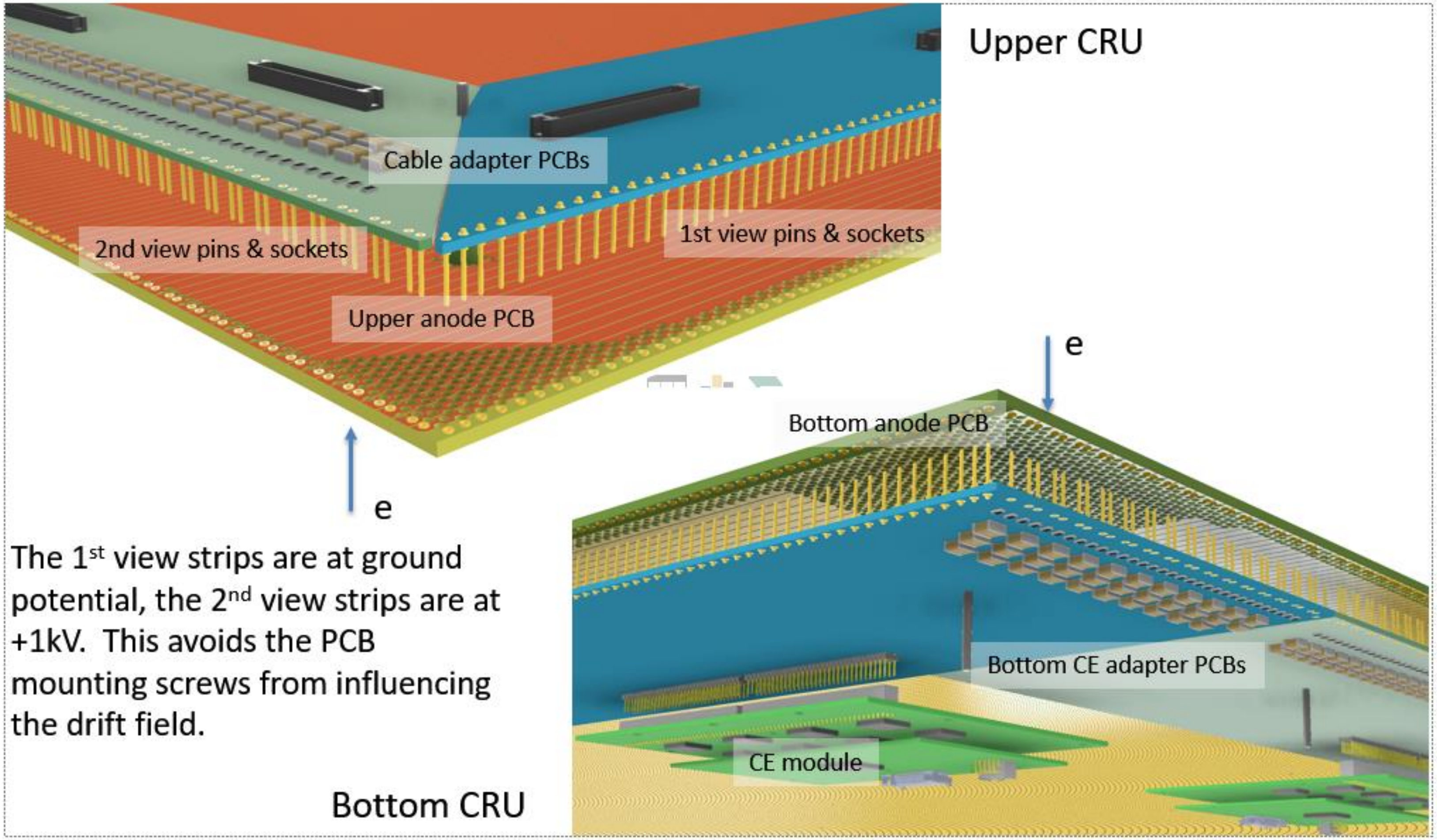
- 24 groups of 6
- 4 groups of 2





Latest Basic VD 2-View Anode Design Concept

2-View Design: CRU Assembly Details



The 1st view strips are at ground potential, the 2nd view strips are at +1kV. This avoids the PCB mounting screws from influencing the drift field.

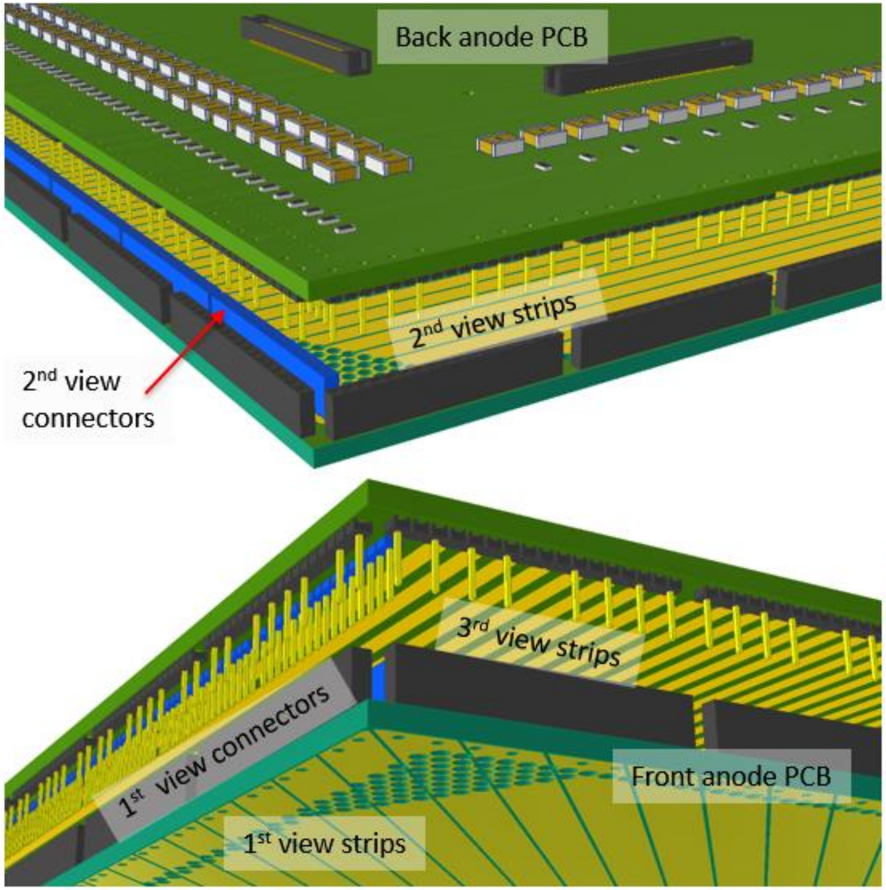
Latest Basic VD 3-View Anode Design Concept

3-View Design: CRU Assembly Details

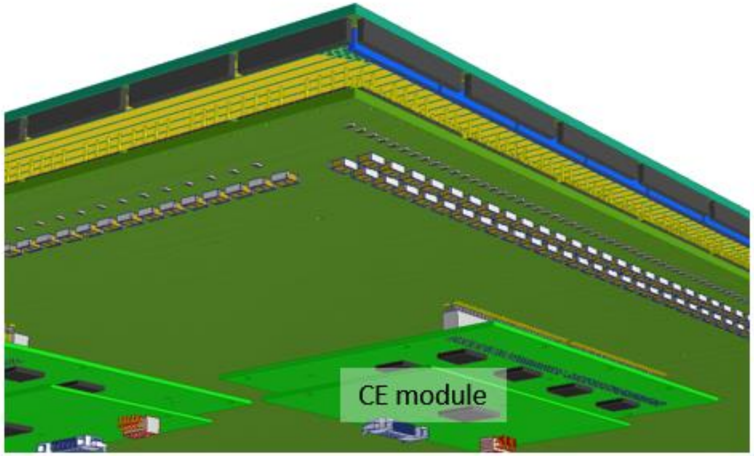
The 1st view is at ground potential, the bias voltage on the 2nd view is +800V, and on the 3rd view is +1400V.

The back PCB will be perforated to allow LAr flow. Porosity will be determined by CFD analysis.

A small version of this construction (bottom) will be tested at CERN early next year to evaluate its performance.



Upper CRU assembly details



Bottom CRU assembly details