TRIUMF at the precision frontier

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TRIUMF Science Week

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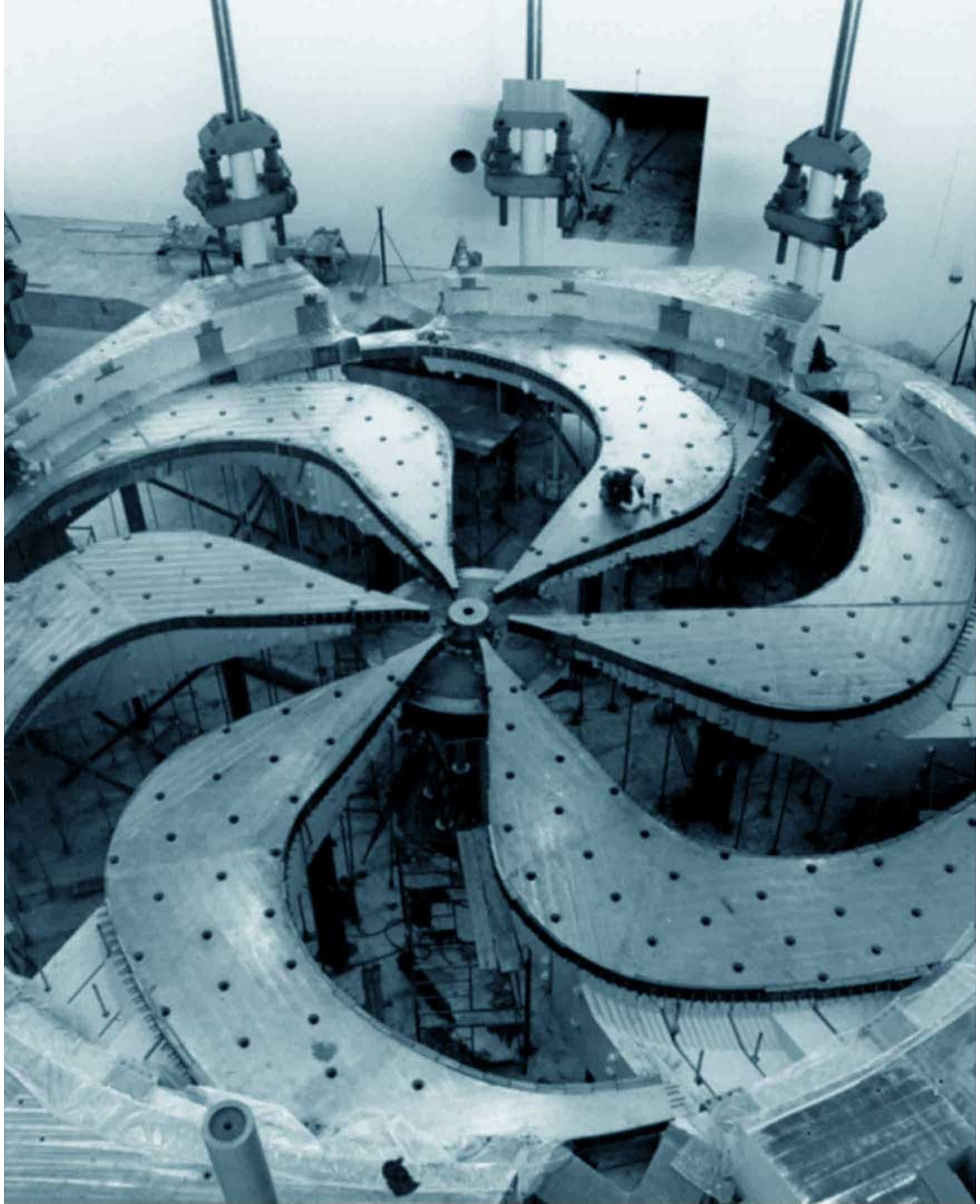


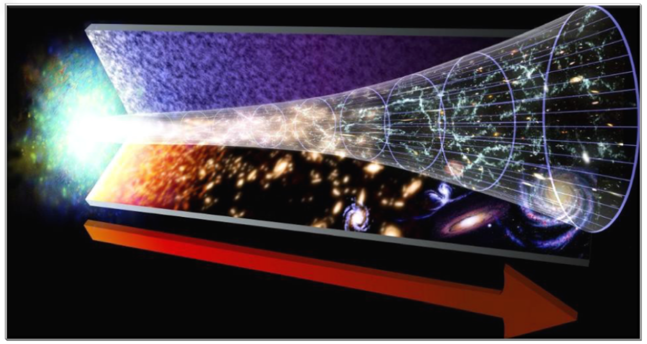
Discovery, accelerated

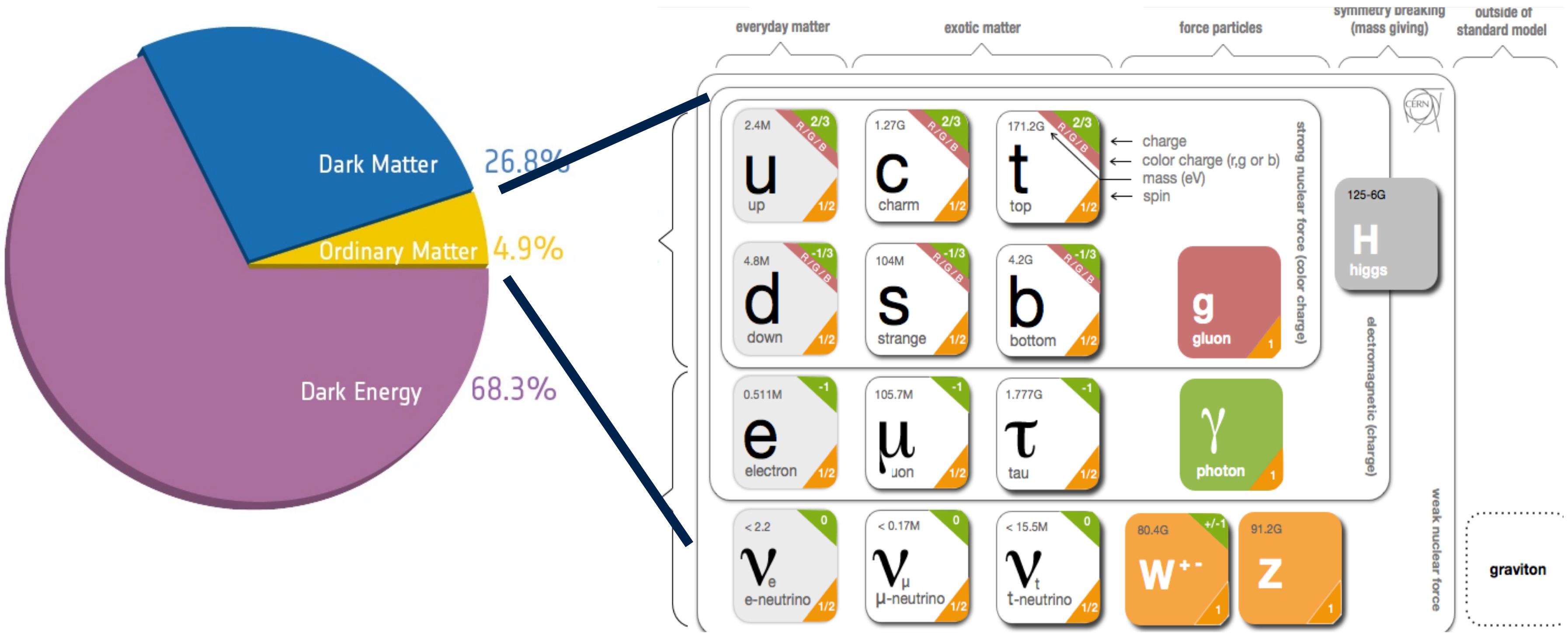

Outer Space
Inner Space
Cosmology & Dark Matter
Nuclear Astrophysics
Particle Physics
Accelerators, Detectors, and Data Sciences
Electronics & Radiation Testing
Nuclear Physics
Nuclear Medicine
Molecular & Materials Science
TRIUMF

TRIUMF

There is still a lot that we don't understand:

Image credit: NASA / GSFC





- What is the origin of neutrino masses?
- Why is there so much more matter than antimatter?
- What is dark matter?
- How to solve the hierarchy problem?
- Why does time have a direction?

Image credit: O. Shmahalo, Quanta Magazine

Discovery, accelerated

Outline

Particle Physics at TRIUMF participates in the following research topics:

- High Energy Frontier
- Neutrinos and Dark Matter
- Precision Tests of Fundamental Interactions

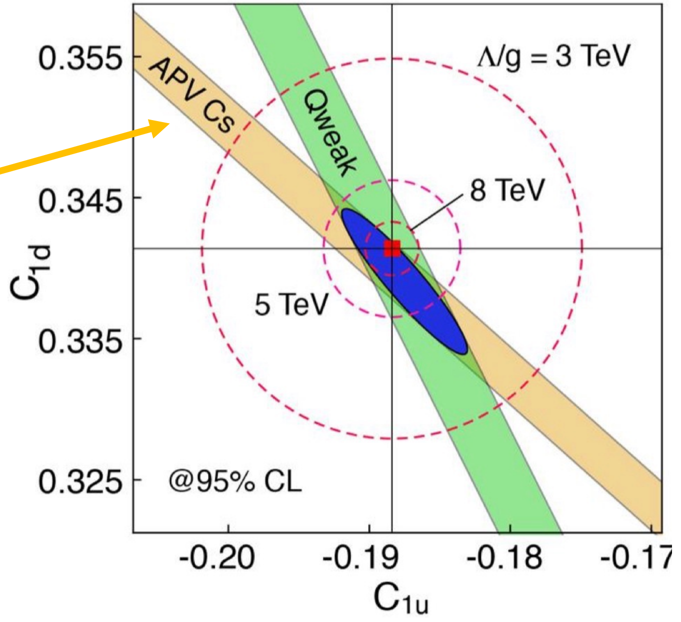
- Overlap with Nuclear Physics at the Fundamental Symmetries front

Status update of our activities during current 5YP

- This talk will cover the Precision Frontier, while the talks in the next session will cover projects in astro-particle physics, as well as accelerator based particle physics

FrPNC

from: Carlini (Qweak presentation), PANIC 2017



Atomic parity violation (APV) test with laser trapped francium

- Z-boson exchange between atomic e^- and quarks
- Previously measured in Cs, effect in Fr 18 x larger
- ^{211}Fr isotopes from TRIUMF's ISAC, 3min half-life
- Sensitive to beyond standard model physics such as: leptoquarks; extra heavy bosons (eg. Z'); light, dark bosons

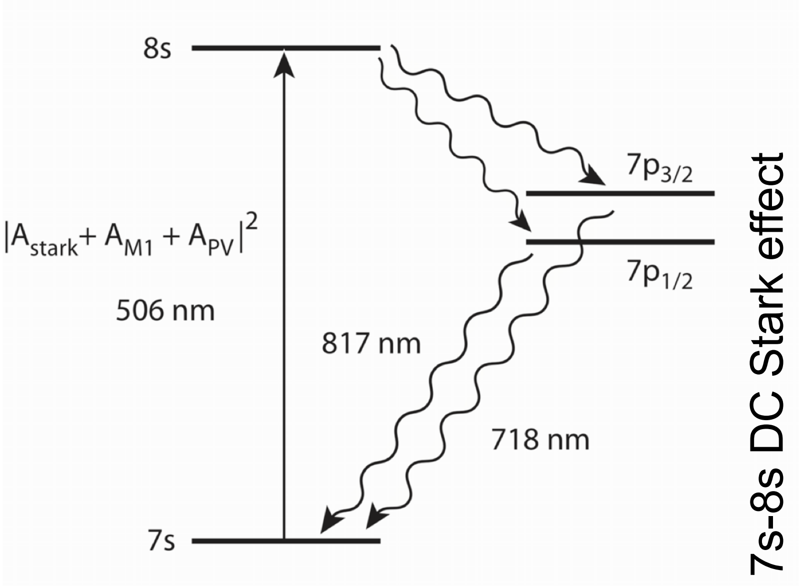
Parity violating (PV) e^- – quark coupling constants $C1_u$ and $C1_d$
Important parameter of weak interaction (Weinberg angle θ_W)
Strongly improved constraint on C1 parameter space!

q_{up}: $2\,C_{1u} = +1 - 8/3 \sin^2\theta_W$
q_{dn}: $-2\,C_{1d} = -1 + 4/3 \sin^2\theta_W$

Material courtesy of G. Gwinner

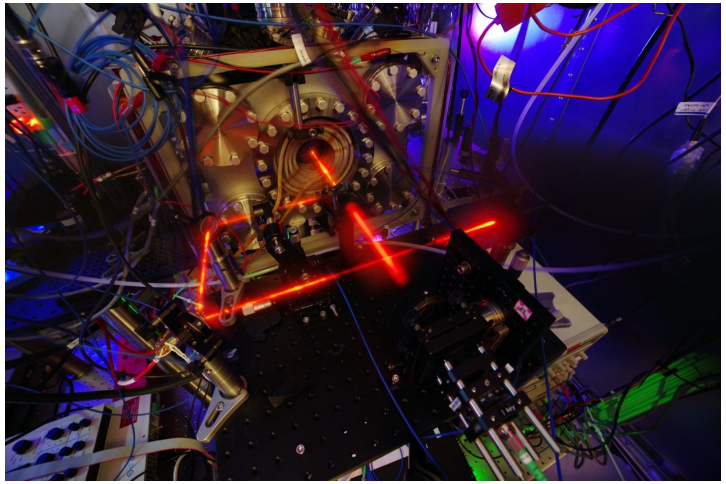
FrPNC

Atomic parity violation (APV) test with laser trapped francium



7s-8s DC Stark effect

- $<n's'|\, H_{PV}\, |np> \;\propto Z^3$ (Bouchiat, 74)
- PV (parity-violating) interaction mixes electronic s & p states
- Previous work (Wieman @ NIST Boulder) relies on Cs atomic beam; high flux needed (10^{13} s^{-1} cm^{-2}), each atom used once
- Re-using atoms in trap:
  APV is possible with $10^6 - 10^7$ atoms → 10^6 fewer atoms
- Signature: drive strictly forbidden s → s E1 transition
- Laser trapping in a MOT, trap lifetime ~ 20 s



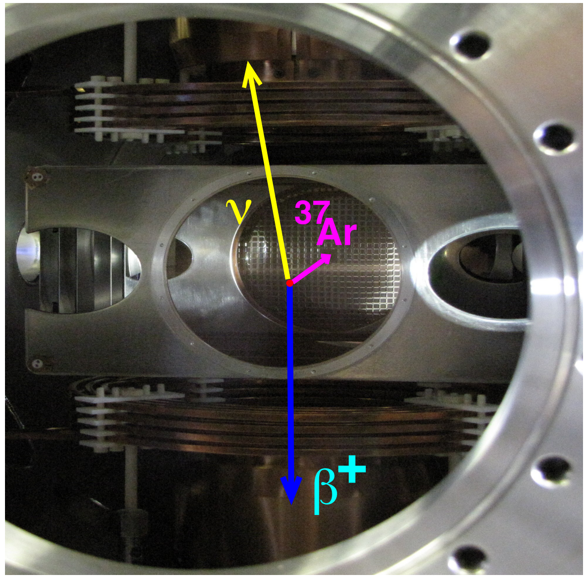
Francium trap facility

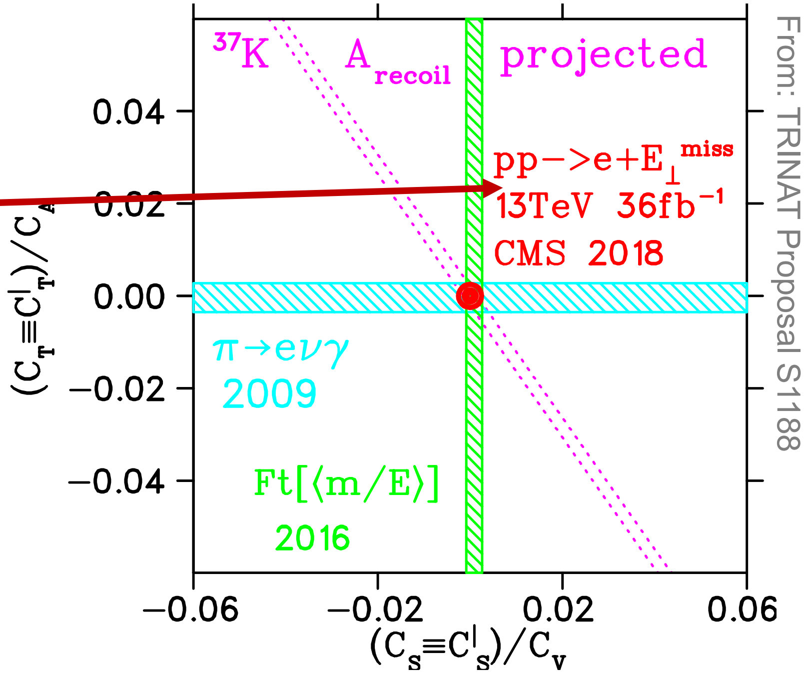
TRINAT

Neutral atom trap for measuring β-decay and recoil asymmetries

Highlights:
- Most accurate nuclear β asymmetry using polarized ^{37}K (Fenker PRL 120 062503)
- Constraints on interactions making right-handed ν's (complementary to eg. muon decay and W' searches)

Next:
- Asymmetry of nuclear recoils from ^{37}K
- Similar sensitivity to 4-fermion contact interpretation as LHC $p+p \to e^- + E_\perp^{\text{miss}}$
- Relative scalar and tensor couplings C_T and C_S will shift away from zero for beyond standard model interactions



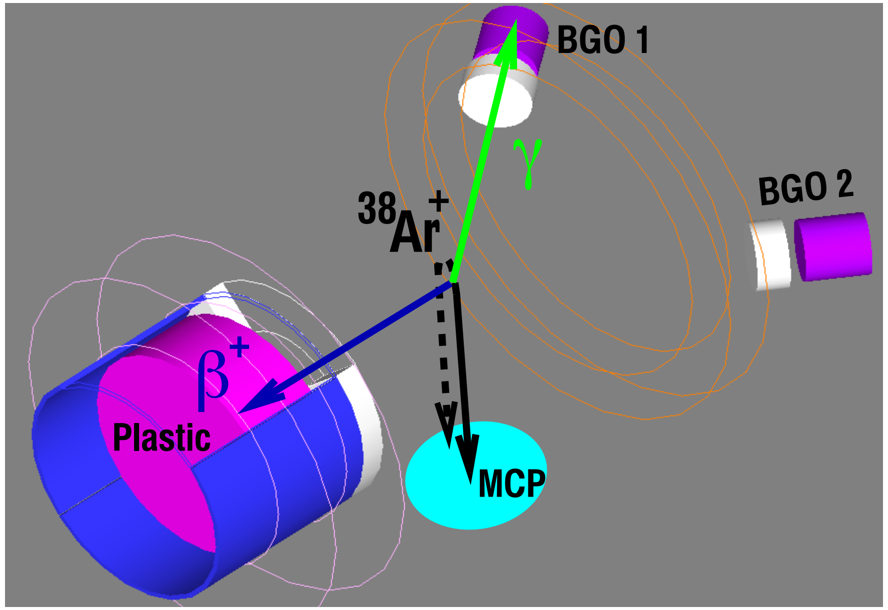


Material courtesy of J. Behr

TRINAT

Neutral atom trap for measuring β-decay and recoil asymmetries

- Test T-reversal $^{38\mathrm{m}}\mathrm{K} \rightarrow {}^{38}\mathrm{Ar}+\beta\nu\gamma$
- $\vec{p}_\nu \cdot \vec{p}_\beta \times \vec{p}_\gamma \xrightarrow{t\rightarrow -t} -\vec{p}_\nu \cdot \vec{p}_\beta \times \vec{p}_\gamma$
- Unique possibility for this process (involving first generation)



- Potential future opportunity
- We consider $D\hat{J} \cdot \frac{\vec{p}_\beta}{E_\beta} \times \frac{\vec{p}_\nu}{E_\beta}$ in ^{45}K

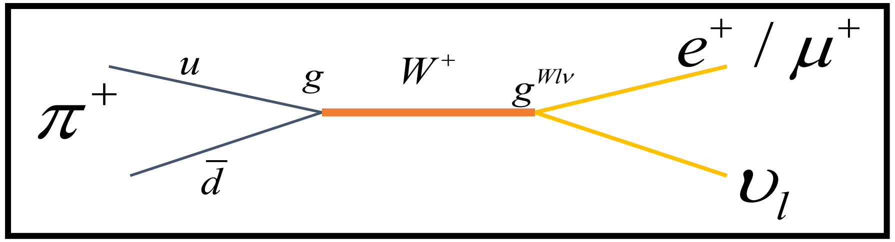
  'isospin-forbidden mirror' decay:
- T-reversal violation enhanced by a factor 4…100
  (must measure first the ratio strength TRV over Coulomb interaction)
  → complementary to neutron EDM

Material courtesy of J. Behr

PIENU

Measurement of the pion decay branching ratio

- Most Accurate Test of Charged Current Lepton Flavor Universality (Current best result on electron/muon universality)
- Theoretical expectation $^{theo}R_{e/\mu} = 1.2353(02)\ 10^{-4}$
- Initial PIENU result $^{exp\ \pi}R_{e/\mu} = 1.2344(30)\ 10^{-4}$
- Results in $g_e / g_\mu = 0.9996 \pm 0.0012$



- Full data set $10^7\ \pi^+ \rightarrow e^+ \nu$ events
- Precision goal $\pm 0.1\ \%$

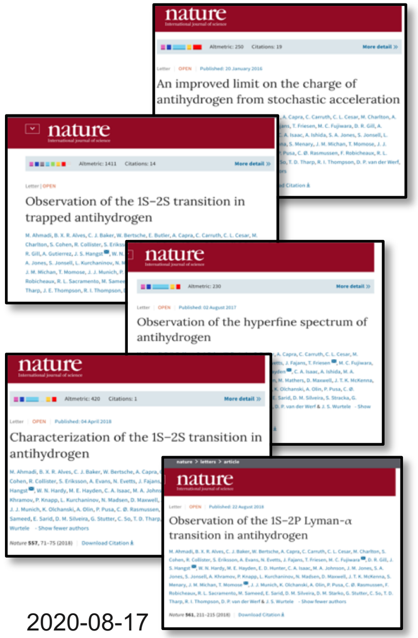
$$\frac{\pi^+ \rightarrow e^+\nu(\gamma)}{\pi^+ \rightarrow \mu^+\nu(\gamma)}$$

- New results on rare and exotic decays – improvements by one order of magnitude:
  - Massive sterile neutrinos $\pi^+ \rightarrow e^+/\mu^+\ \nu_4$
  - Exotic muon decay $\mu \rightarrow e\ X$
  - Dark sector decays $\pi^+ \rightarrow e^+/\mu^+ \nu\ X$

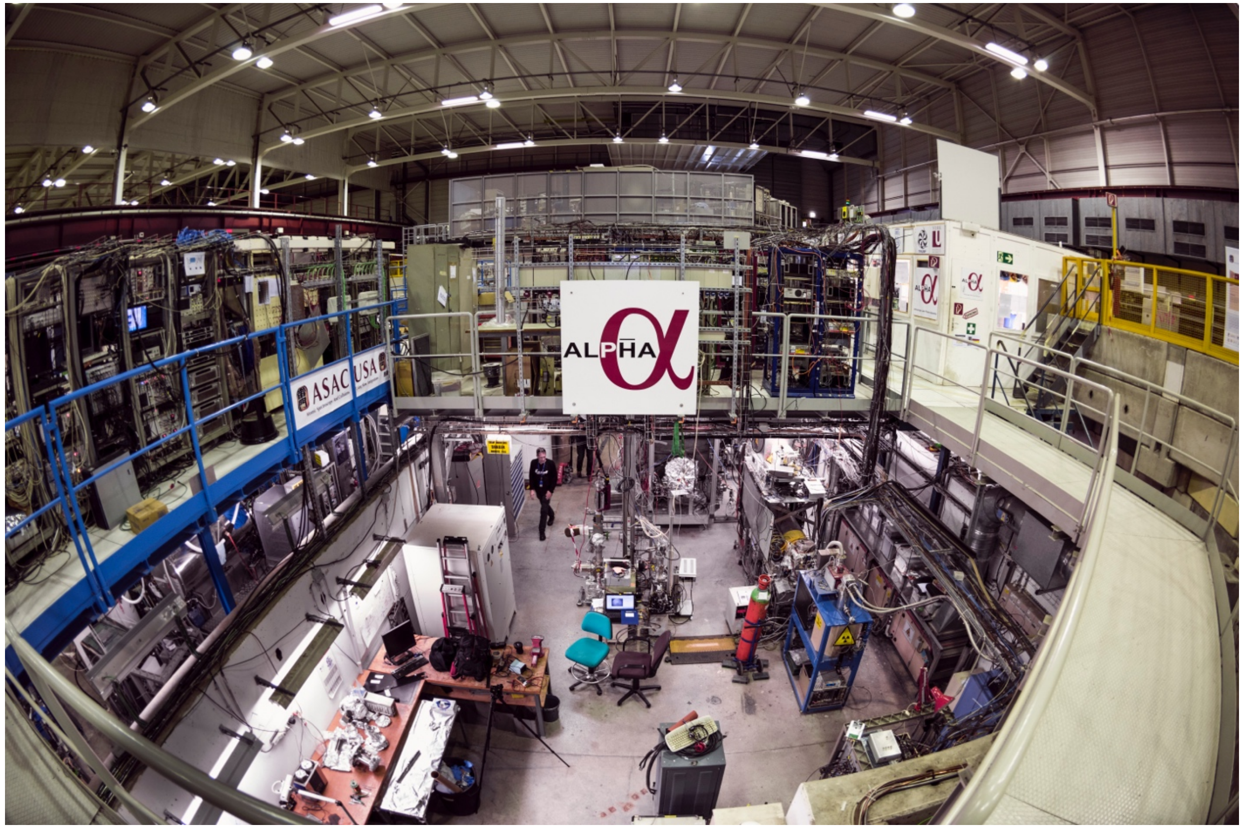
Material courtesy of D. Bryman

ALPHA

- Apparatus to synthesize antimatter and study it
- Located at CERN's antiproton decelerator (AD)
- Combine atomic physics and particle physics techniques to perform tests of fundamental symmetries with antihydrogen



2013 NSERC Polanyi Award



Material courtesy of M. Fujiwara

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ALPHA

Testing symmetry between matter & antimatter

- Ground-breaking technology developments to synthesize, confine, manipulate and characterize antihydrogen atoms
- Spectroscopic test of CPT symmetry in antihydrogen
  - 2×10^{-12} precision in 1s-2s laser spectroscopy (most precise measurement on antimatter to date)
  - Lyman-alpha, Lamb shift, and hyperfine spectroscopy of antihydrogen
  - Laser cooling of antihydrogen
  - Microwave spectroscopy of antihydrogen
- Gravitational free fall of antimatter
  - First measurements were taken before CERN shutdown
  - Top priority when beam comes back in 2021

ALPHA-g detector and TRUIMF people

Material courtesy of M. Fujiwara

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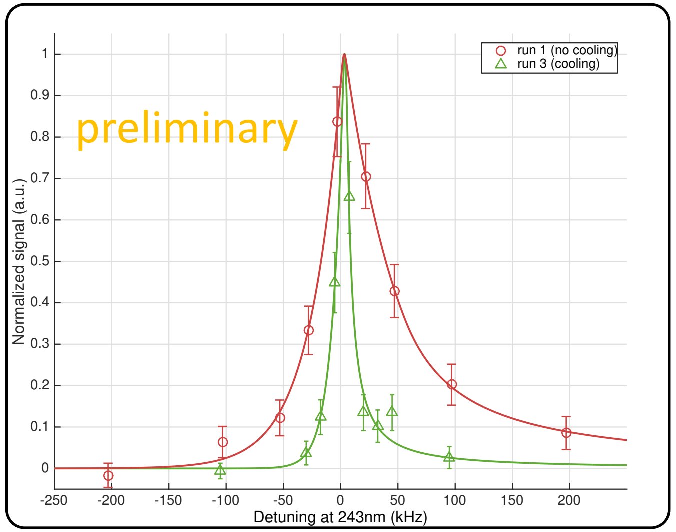
ALPHA

Laser cooling of antihydrogen: a major breakthrough and game changer

- Laser at 121 nm (VUV) is extremely challenging
- Two further papers submitted to Nature:
  - Demonstration of cooling
  - First application



Radial-drift TPC built at TRIUMF

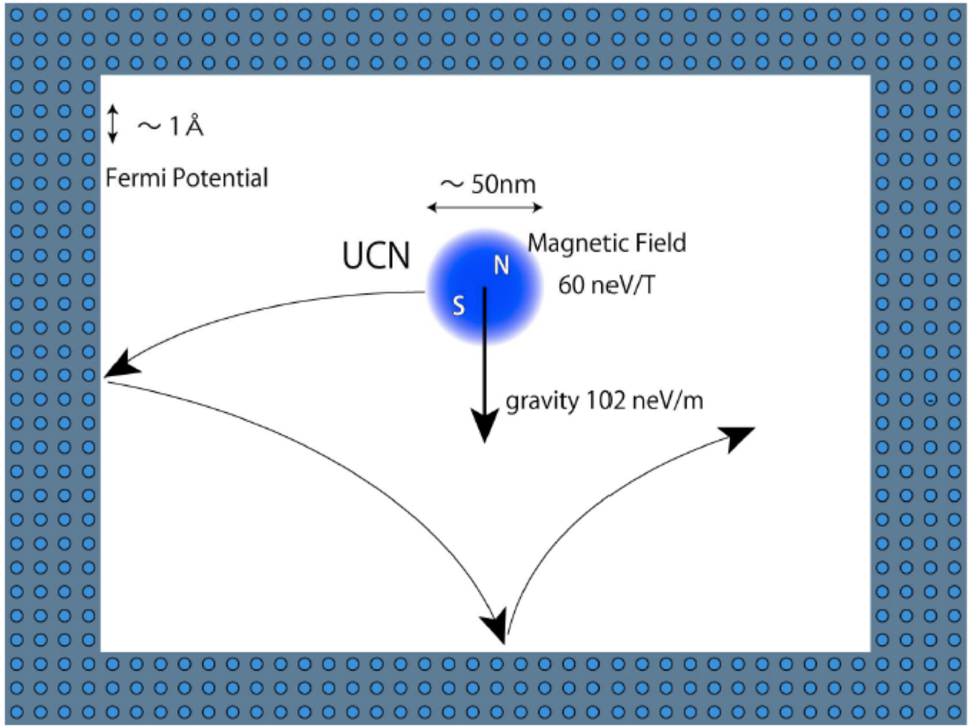
CERN

Future ideas in ALPHA: quantum sensing

Material courtesy of M. Fujiwara

TUCAN

- Ultracold neutrons (UCN): very low energy neutrons, behave like a gas, can be stored and allow long observation times
- Advantageous over neutron beam experiments due to reduced systematics
- UCN enable high precision measurements of neutron properties and interactions
- Currently, most flagship UCN experiments are statistics limited!



UCN confined in a material box

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TUCAN

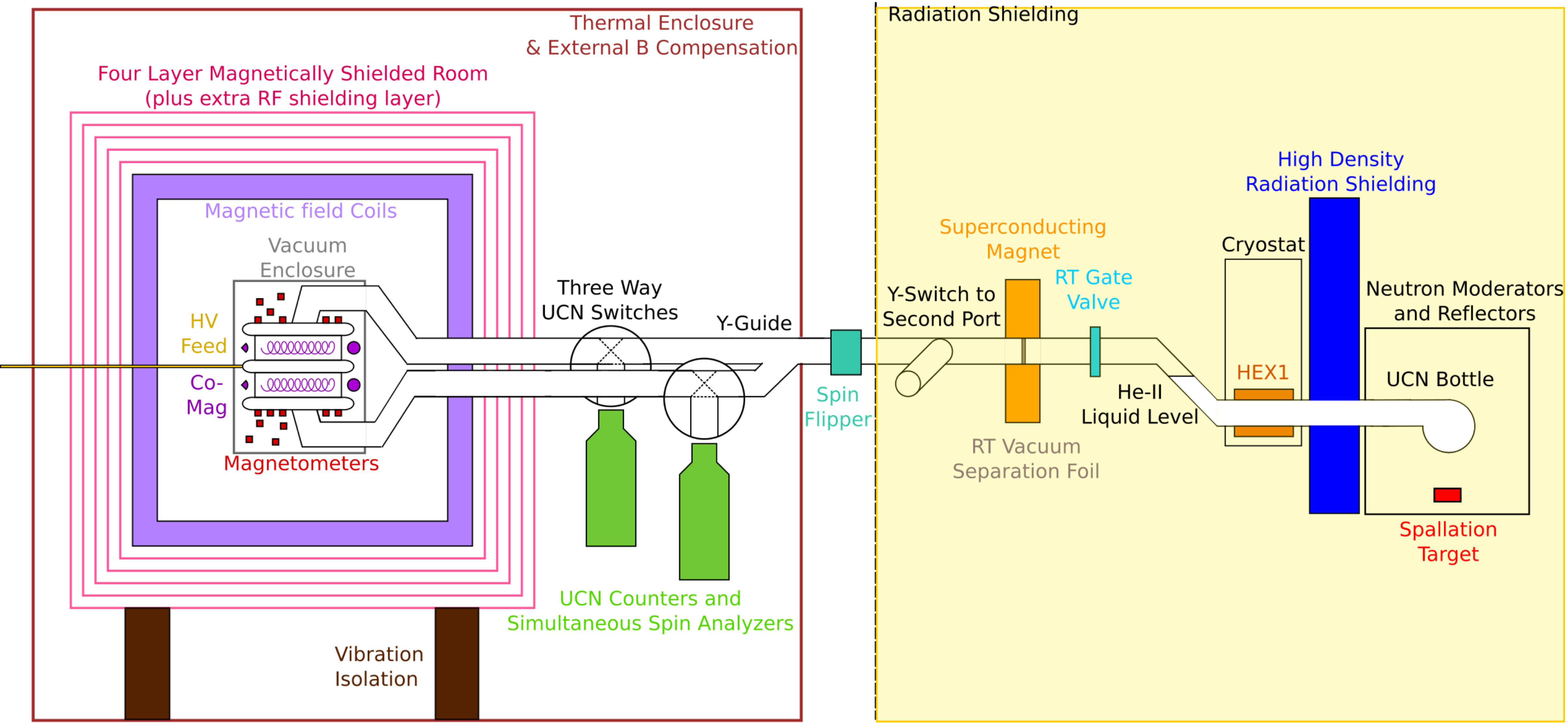
Creating Ultracold Neutrons (UCN) for

the Neutron electric dipole moment search (nEDM) & future UCN user facility

- Spallation neutron source & superfluid Helium converter
- New proton beamline BL1U built 2013 – 2017, branching off of BL1A
- UCN beamtimes at TRIUMF with Japanese prototype source cryostat in 2017, 2018, and 2019
- Next generation world class UCN source, currently at technical design stage aiming at competitive densities
- Developing next generation nEDM spectrometer, currently at conceptual stage

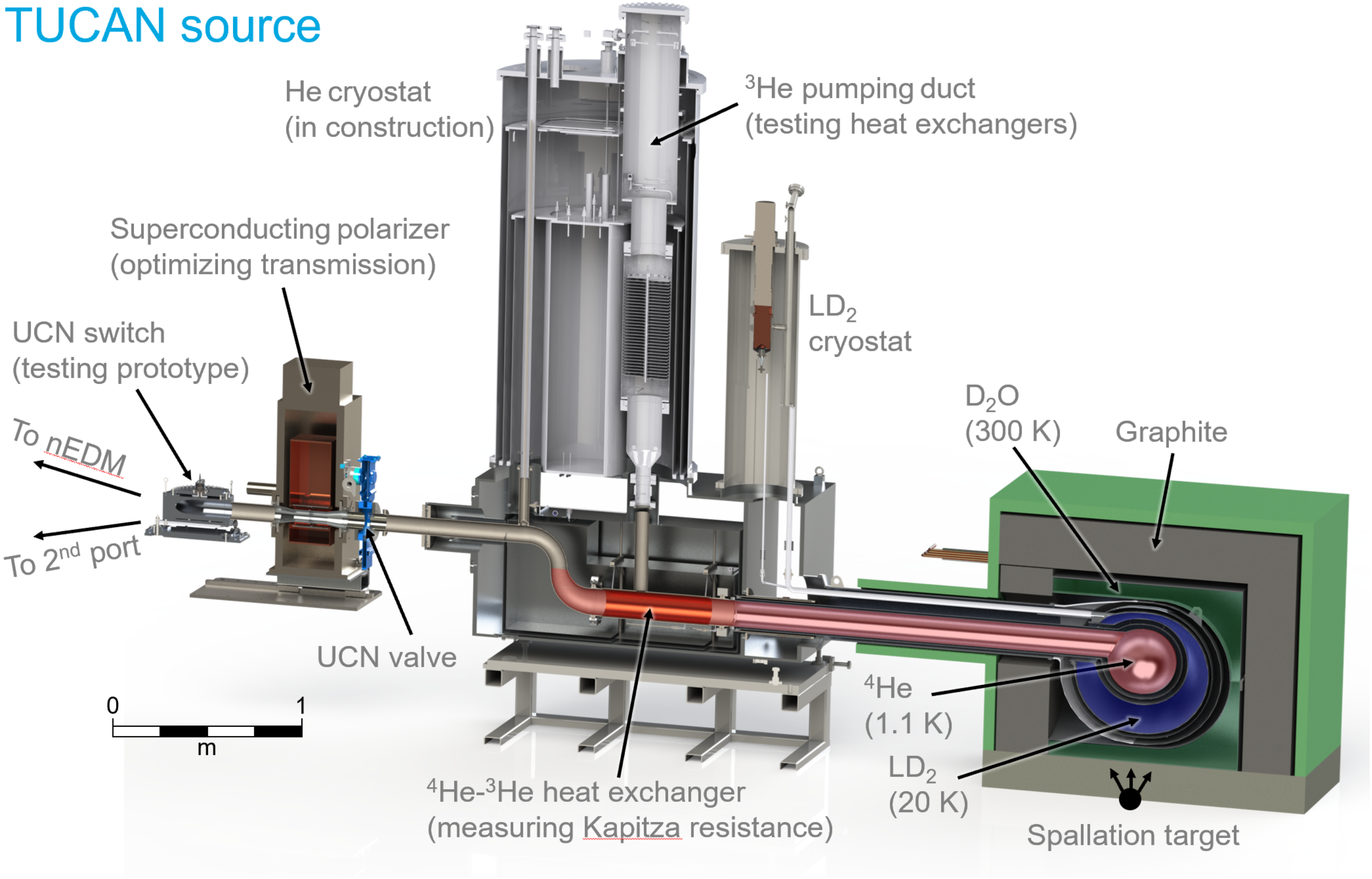
UCN beamline and counter

The TUCAN facility – a sketch:

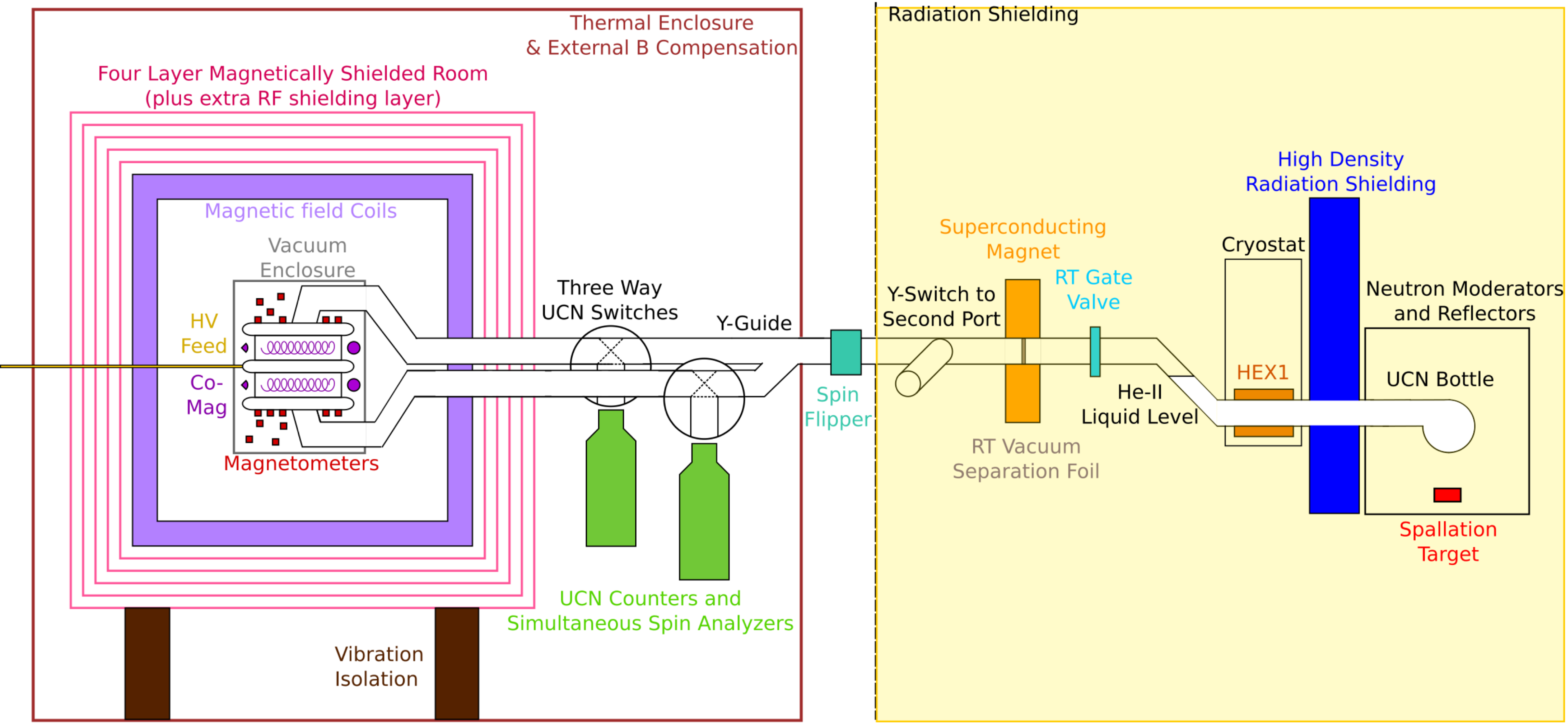


The new cryostat for UCN at TRIUMF

TUCAN source



The TUCAN facility – a sketch:



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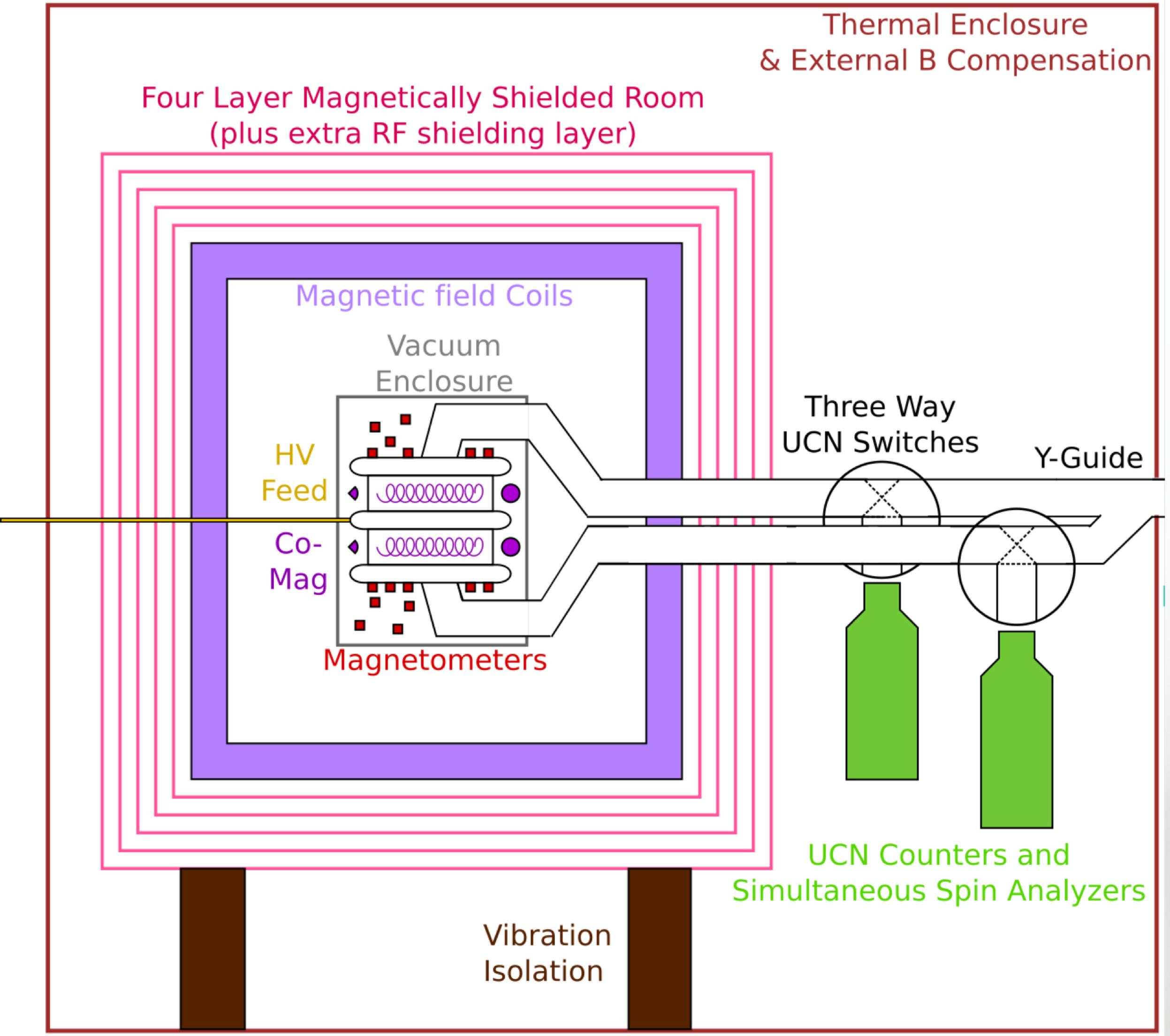

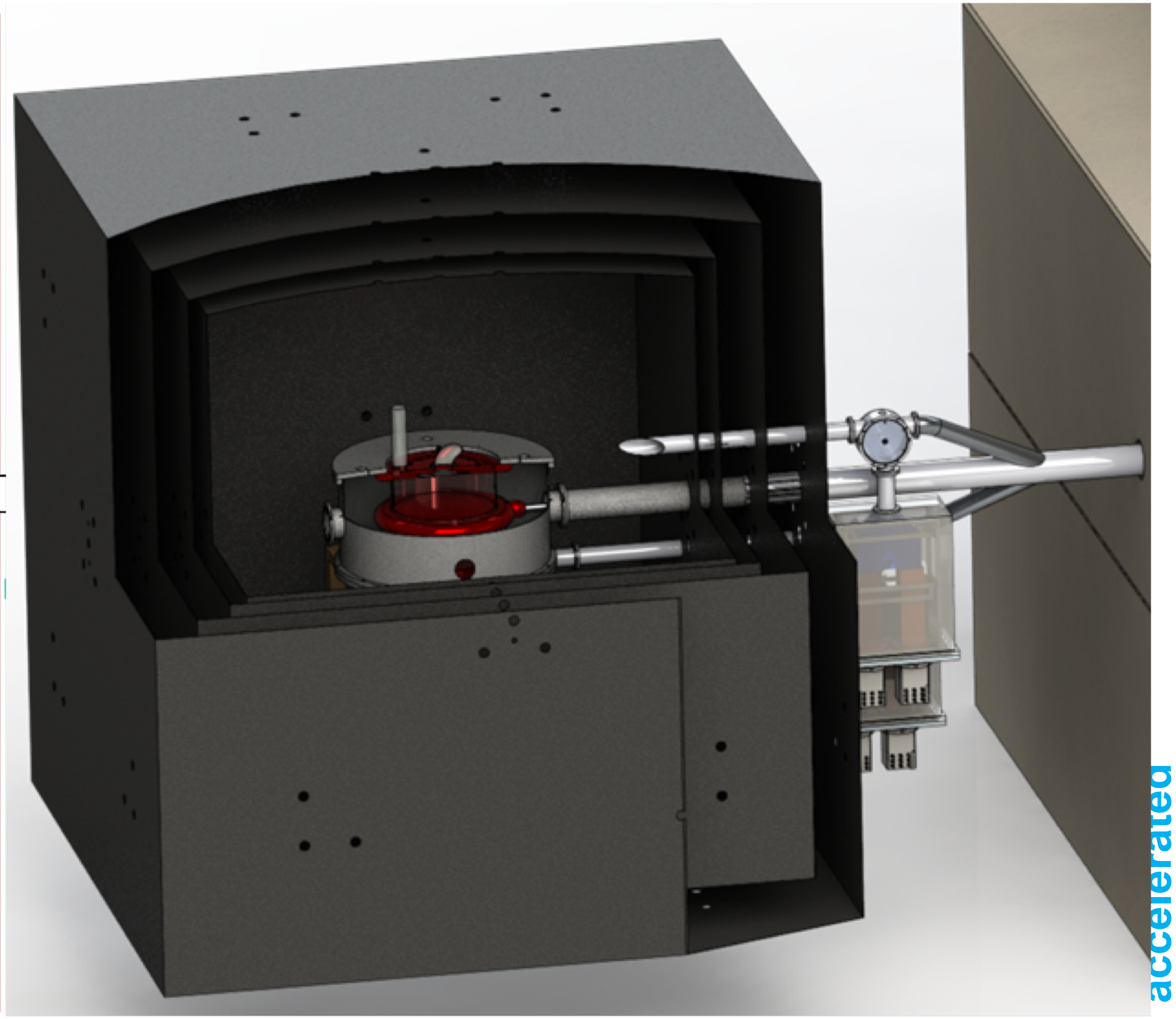

accelerated

Summary

- TRIUMF’s current 5YP (2020 – 2025) ensures the continued relevance and success of Canadian and TRIUMF’s particle (and nuclear) physics at the fundamental symmetries front
- Exciting times ahead, based on our current activities & future plans
- Stay tuned for astro-particle physics and accelerator based particle physics

Enjoy Science Week and be inspired!

Thank you

Merci

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