FRIB

Decay of quasi-free neutrons as possible window to observe a dark decay branch

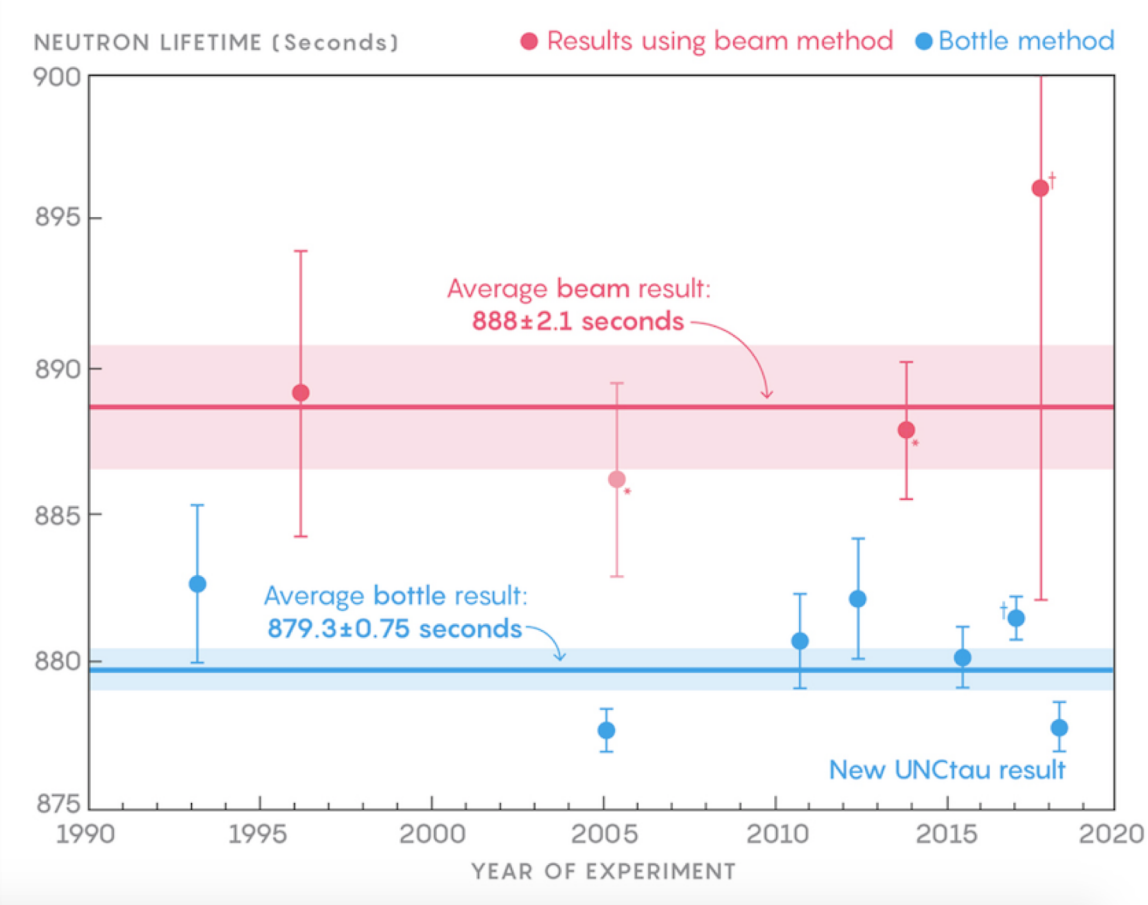
and more…

W.Mittig

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

The neutron lifetime puzzle



W. Pattie Jr. et al, Science *Science* 11 May 2018 vol. 360 no. 6389 627-632
https://arxiv.org/pdf/1802.06277.pdf, A.P.Serebrov et al.,

The neutron live-time puzzle

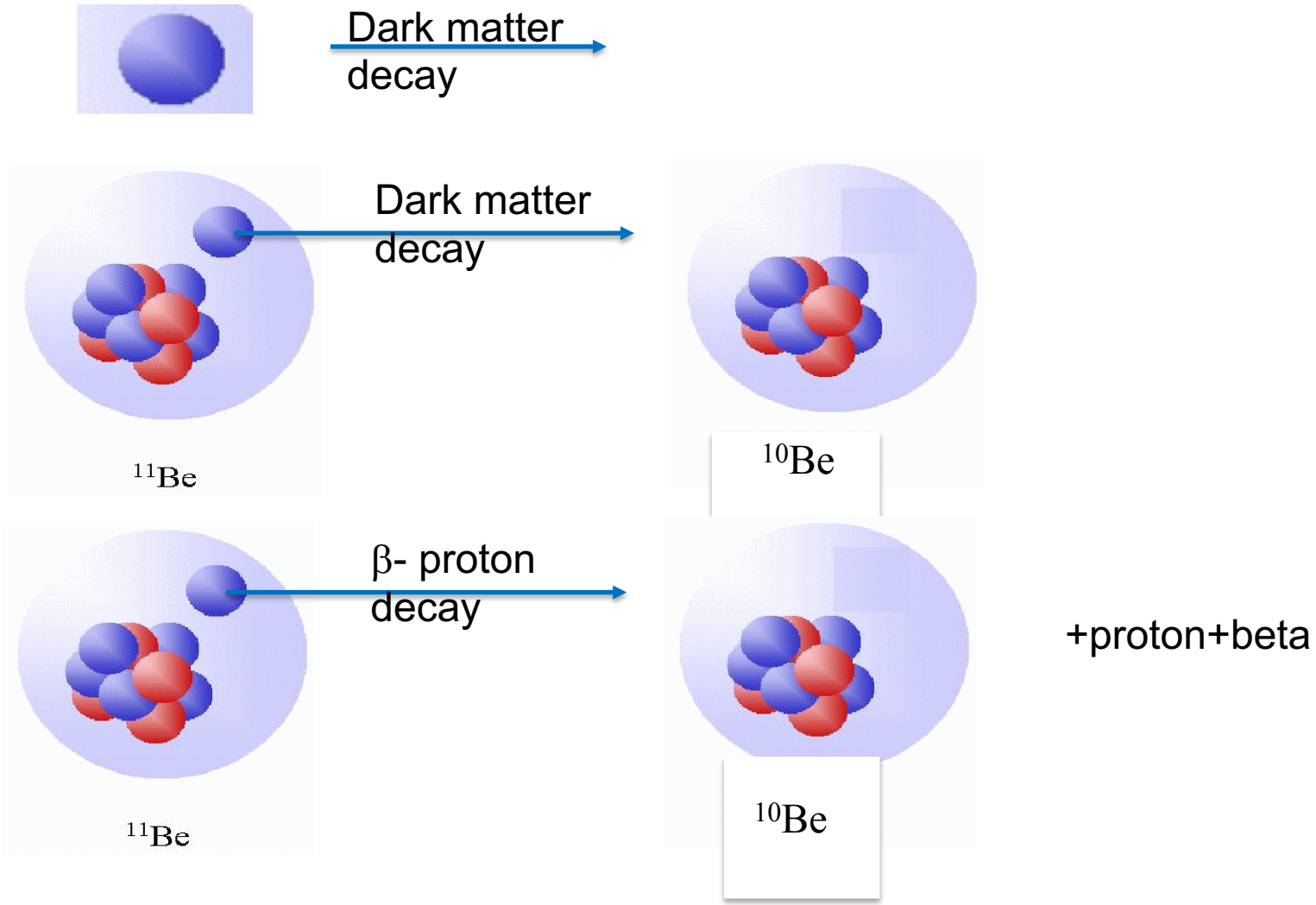
t_{bottle} = 879.6 +- 0.6 s counting remaining neutrons

t_{beam} = 888.0 +- 2.0 s counting emitted protons
Difference 4s !!
Dark Matter Interpretation of the Neutron Decay Anomaly

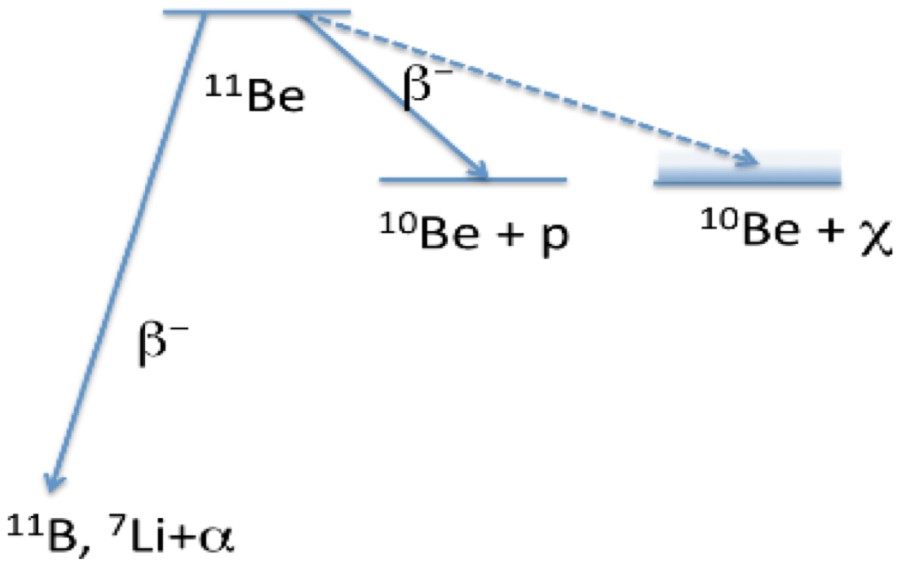
Bartosz Fornal and Benjamín Grinstein
PRL120(2018)191801

1% branch ~~n → invisible + visible~~; n → invisible

Neutron decay to invisible matter: quasifree neutron decay versus β- p decay



The quasi-free neutron dark decay: detectable reaction product



When the decaying neutron is bound in the nucleus, the dark decay may occur only if m_X value happens to be in the reduced energy range:

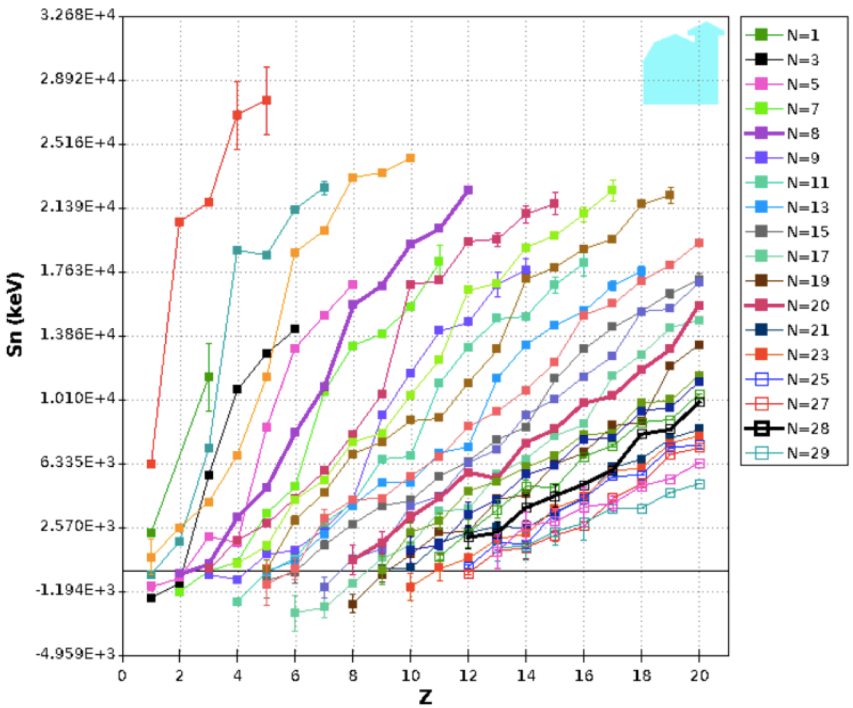
$$937.993\text{MeV} < m_X < m_n - S_n$$

with $S_n < 1.572$ MeV
In ^{11}Be S_n=501keV

Rough estimation of dark decay of the quasifree neutron of ^{11}Be by M. Pfützner and K. Riisager
$T_{½\ neutron}$=880s
Life time anomaly ~8s~1%→
partial lifetime= 880s*100=88000s
Lifetime of ^{11}Be:13.8s →
$B\chi$~13/88000~1.5*10^{-4}

M. Pfützner and K. Riisager
PHYSICAL REVIEW C **97**, 042501(R) (2018)

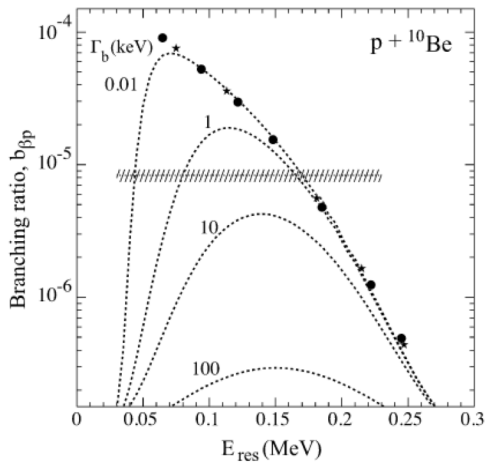
Neutron dark decay in (halo) nuclei



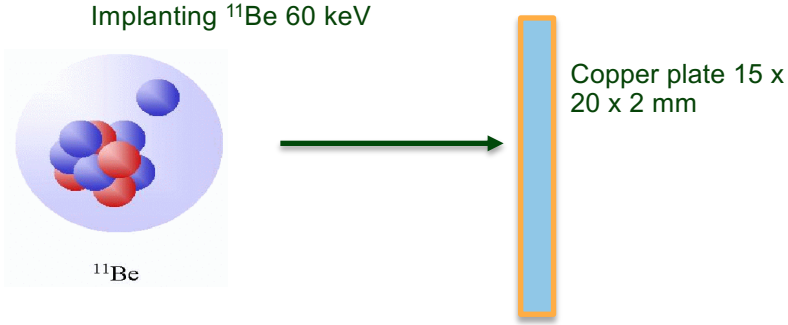
- If the neutron separation energy of a nuclei is S_n<1.572 MeV, the dark neutron decay could happen.

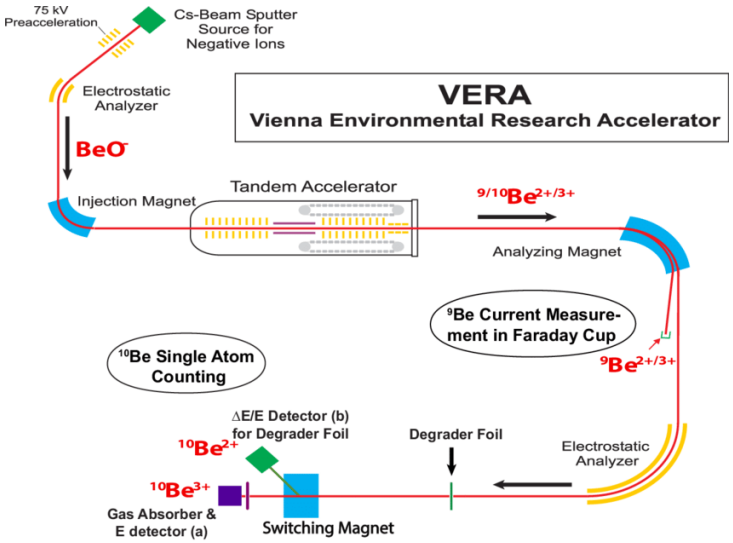
^{11}Be β$^-$-delayed proton emission

- Riisager et al. implanted ^{11}Be in a catcher and let it decay
- Then analyzed the ratio of ^{10}Be/ ^{11}B in the catcher with the accelerator mass spectrometry technique
- Deduced that the ^{11}Be -> ^{10}Be branching ratio was $8.3(9)\cdot 10^{-6}$
- This value is orders of magnitude higher than theoretical predictions
- The neutron β–decays to a proton in a resonance in ^{11}B, and it is emitted, or it directly decays into the continuum
- An unobserved resonance in ^{11}B could explain it.



Implanting ^{11}Be 60 keV

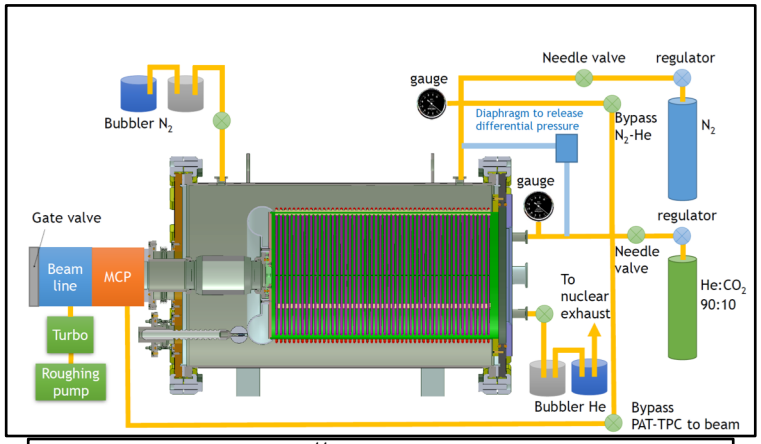


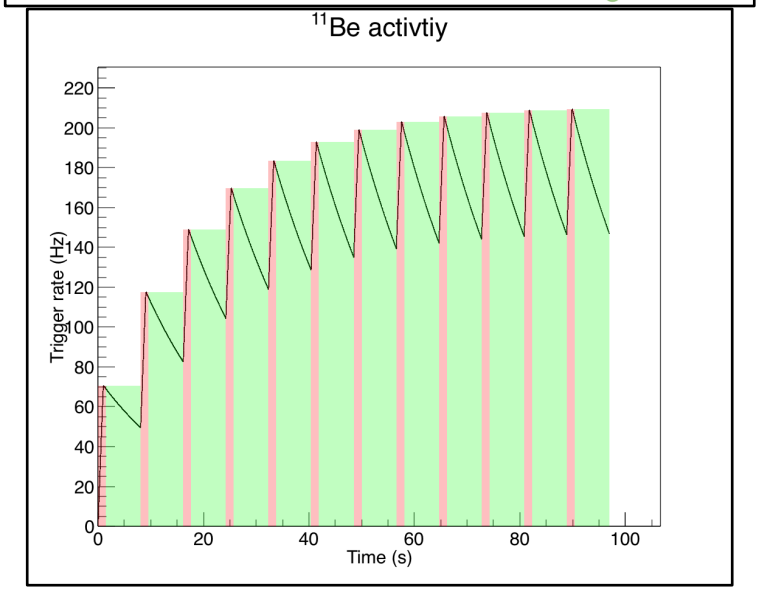


Riisager, PLB **732** 305 (2014)
Riisager, Phys. Scr. **T152,** 014001 (2013)

Experimental method: Experiment at ISAC (TRIUMF)

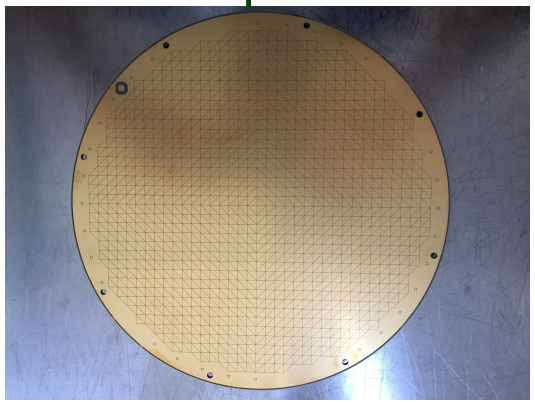
- Implant-decay on the pAT-TPC: High detection efficiency (80%) and resolution (σ(E)~5%, (σ(θ)=1 deg)
- Full reconstruction and identification of p+ and α.
- He(+10% CO_2) as thin tracking medium: low straggling and β-blind.
- The pAT-TPC was filled with 60 torr of He(+10% CO_2)
- Beam energy of 390 keV/u deposited 11Be at the center
- ^{11}Be ions drifted to the cathode
- Protons of ~180 keV stopped in 10 cm tracks
- Normalization ^{11}Be -> ^{7}Li + α, 3.47(1)%
- Experiment run in pulsed mode 1 sec implantation, 0.5 sec relaxation, 6.88 sec decay
- It was optimized for a peak activity of 200 α pps, to minimize dead time
- We run for 4.33 days or 13 8-hour shift

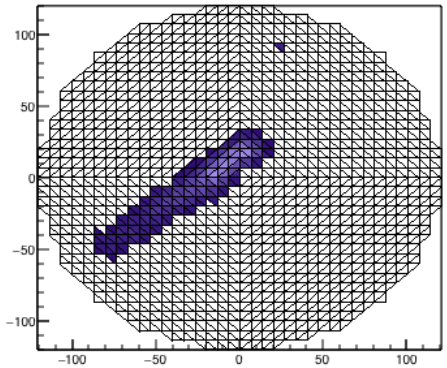




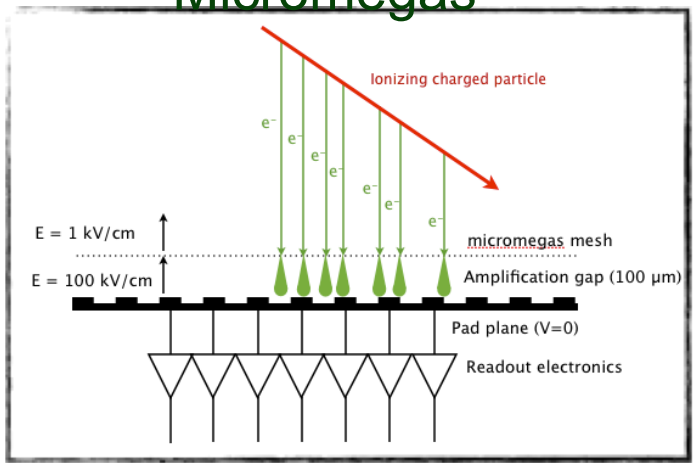
prototype Active Target Time Projection Chamber (pAT-TPC)

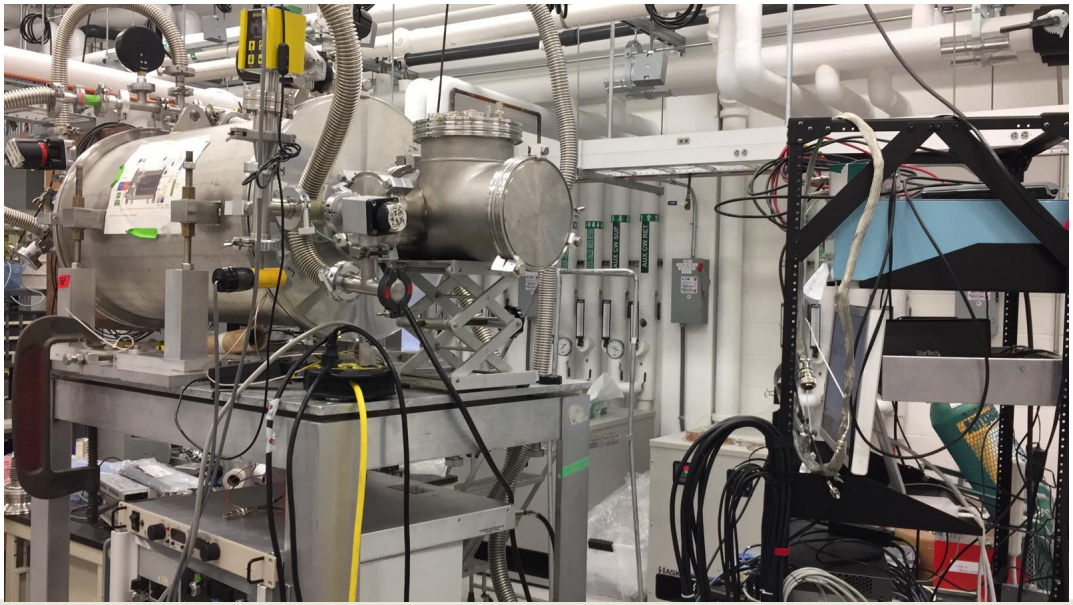
2000 pads



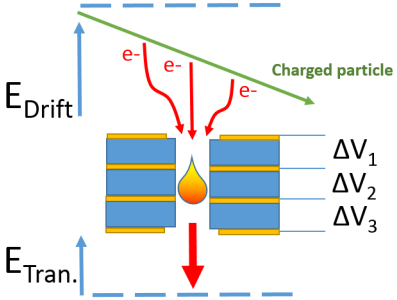


Micromegas

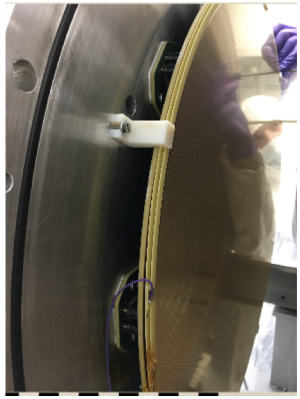




Multi Layer Thick Gas Electron Multiplier

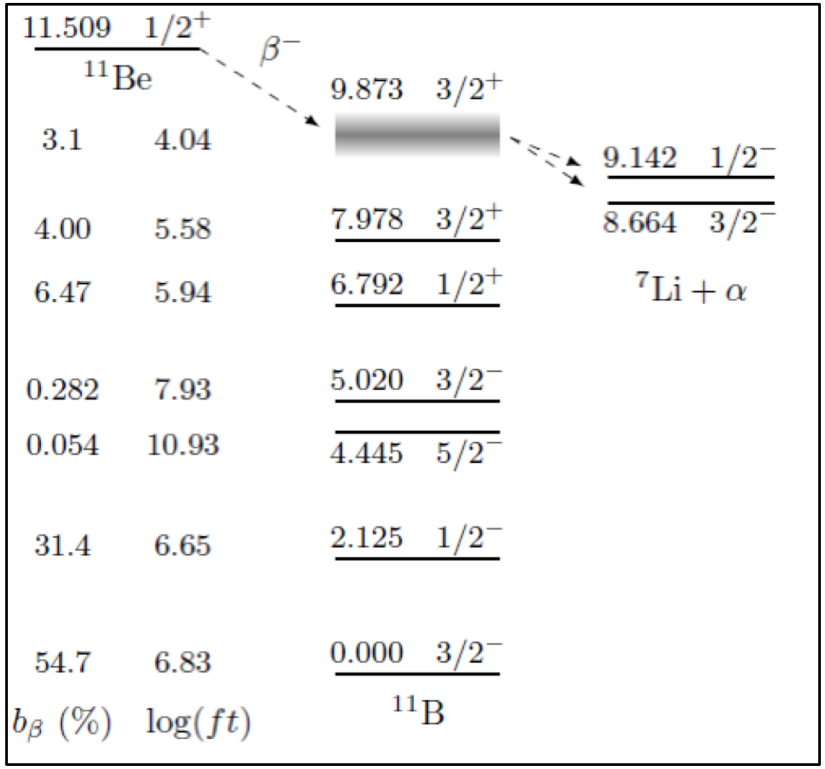


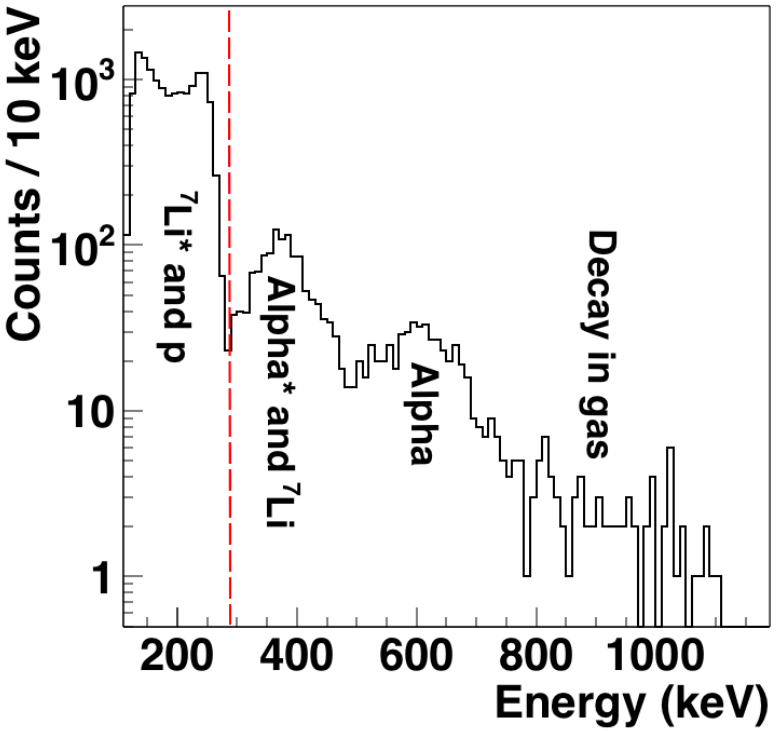
3-layer THGEM



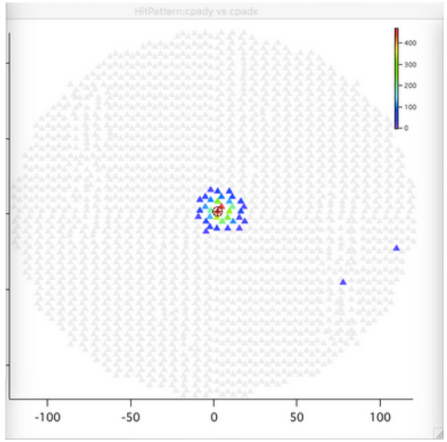
Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)

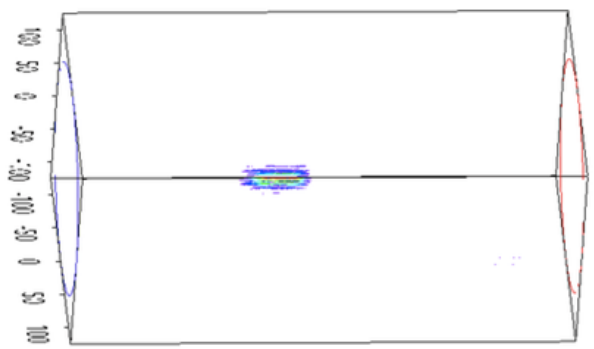
Experimental method: Calorimetry

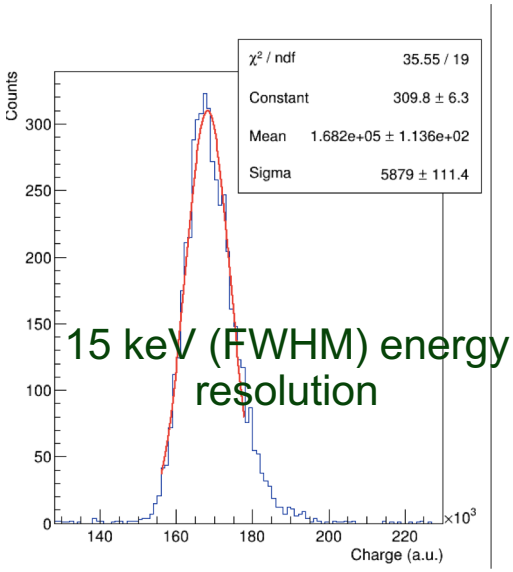


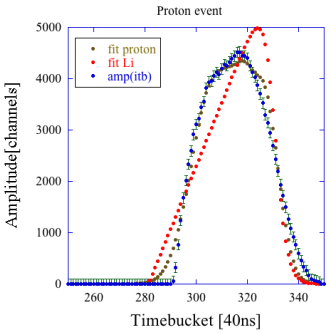


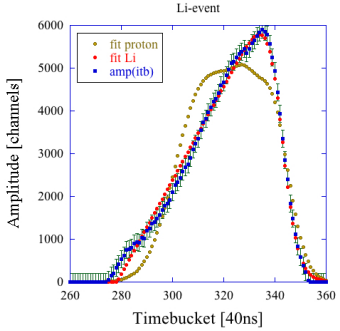
Proton beam ~180keV calibration

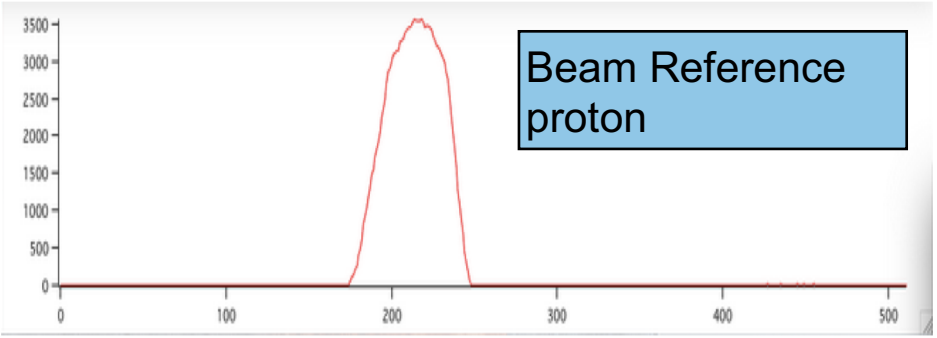




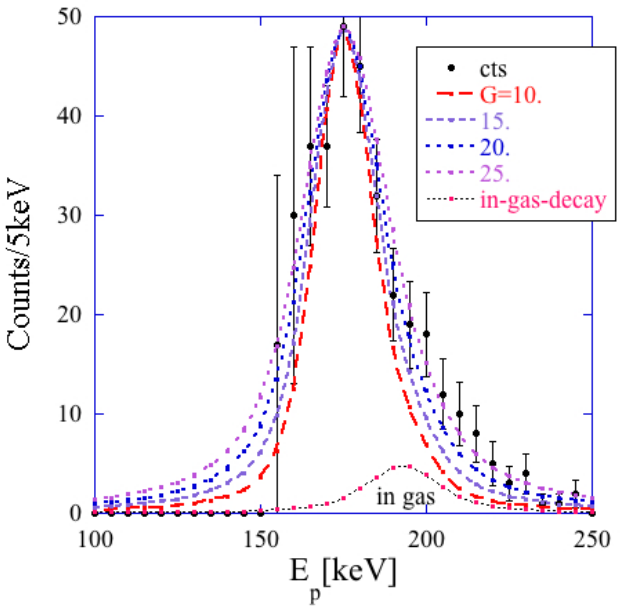








The quasi-free neutron dark decay



1) How much ^{10}Be is produced ?
Produced in the ^{11}Be decay (AMS)

AMS at Cern Isolde: $B_{10Be} = 8.3(9)*10^{-6}$

K. Riisager *et al.*, Phys. Lett. B **732**, 305 (2014).

2) How much ^{10}Be is produced
by proton decay?:
Measure the proton decay branch:

Triumf pAT-TPC
(Y.Ayyad and B. Olaizola spokespersons)

$\Gamma_{BW} = 15(^{-5}_{+10})$ keV

$E_{p\ res}$=180(+-20)keV

B_p=1.3(3)*10^{-5}

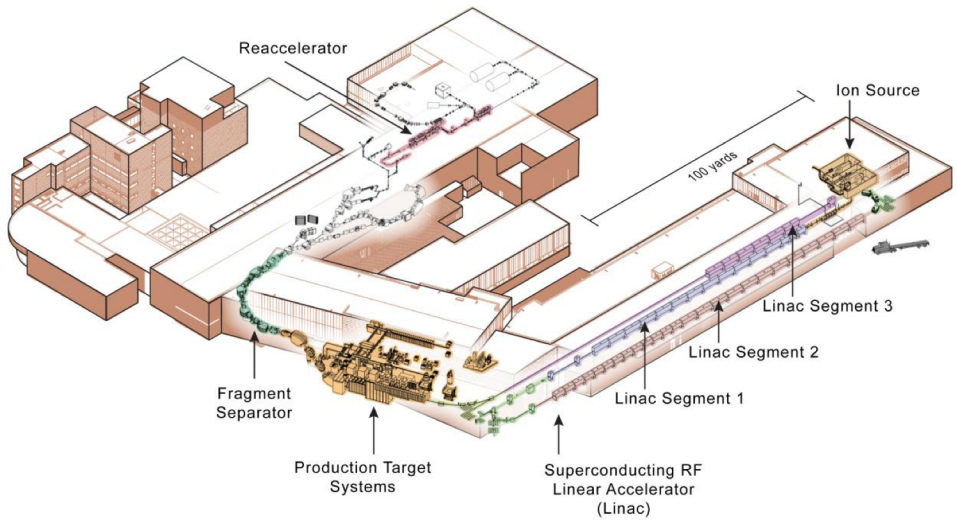
Y.Ayyad et al P R L 123, 082501 (2019)

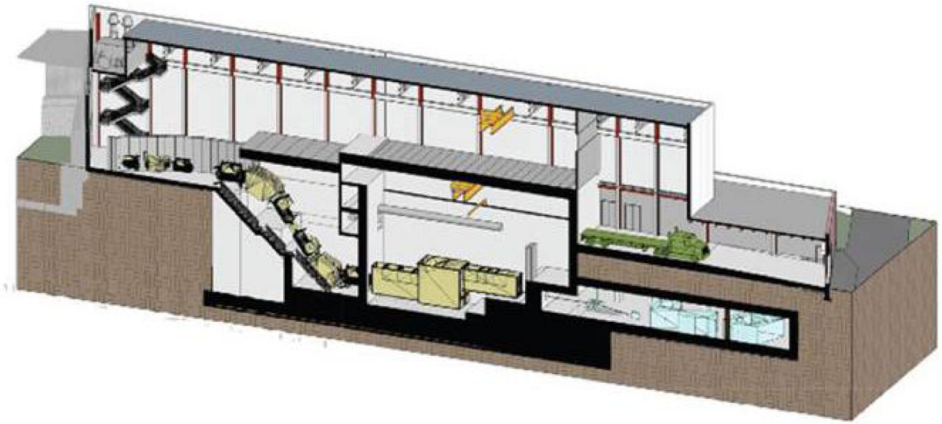
The quasi-free neutron dark decay

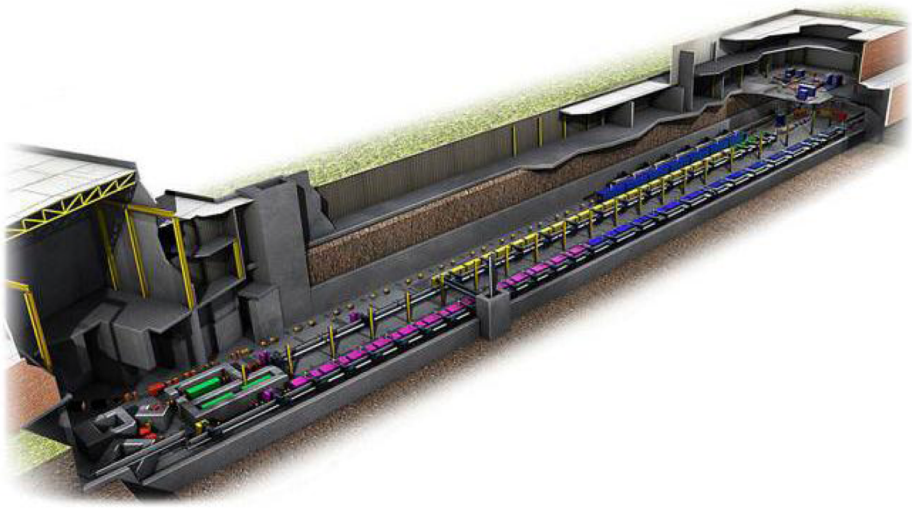
- If a dark decay is responsible for the 1% neutron life time problem, a simple estimate for a dark decay of the quasifree neutron in ^{11}Be gave ~10^{-4}
- Our measurement of 1.3(3)*10^{-5}, compared to the AMS yield of 0.83(9)*10^{-5}, sets an upper limit of ~10^{-6} for a dark decay, 2 orders of magnitude smaller than the estimation.
- We consider 2 strategies to improve the exclusion of a dark decay to better than corresponding to 1% for the free neutron: Decrease errors on B_p from presently ~30% to ~5%

- ^{6}He → ^{4}He+n+χ H.Savajols@Ganil : $B\chi$ *estimated* 1.2*10^{-5}

FRIB p to U 200MeV/n 400kW 2022







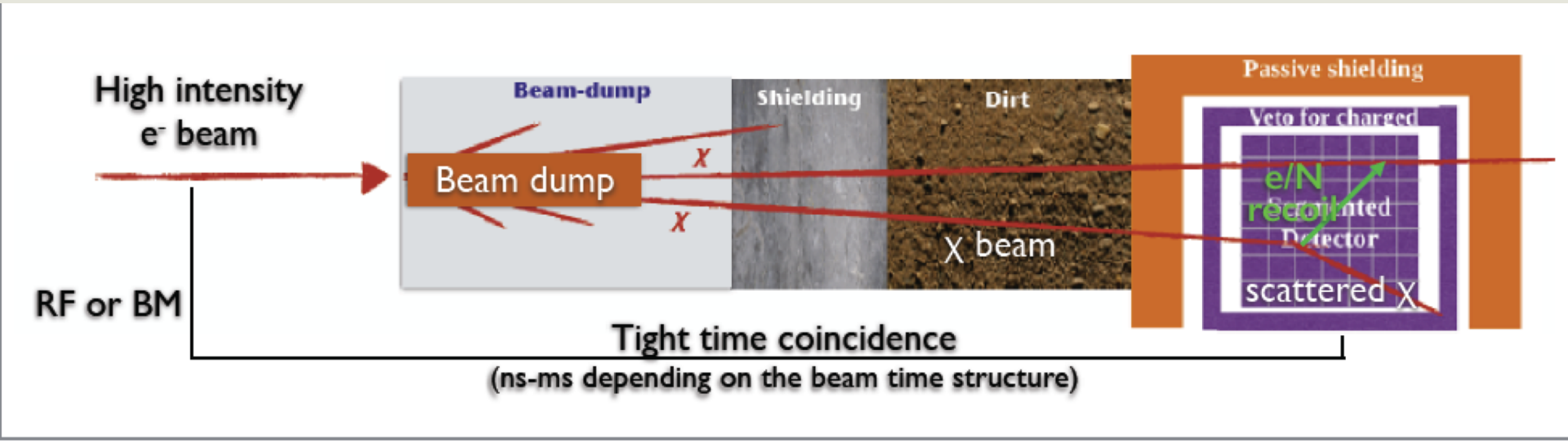
Other (im)possibilites

Accelerator based creation and detection of dark matter:
FRIB will be the highest intensity HI 200-400MeV/n 400kW accelerator in the world:
What about Beam dump experiments ?

battaglieri@ge.infn.it:

On the other hand, if the DM is hadro-phillic, no way to produce it and detect it with an electron beam. At this stage, since no experimental evidences prefer one or the other hypothesis (actually we do not have any evidences at all that the DM has a particle nature!) I think we should try different options using all possible probe/techniques.
I do not see any problems in trying with ion beams...

Beam dump experiments: very schematic



Example: BDX at Jefferson Lab

- Creation of χ
- Shielding from /determination of background
- Detection of χ

Could we use the periodic time structure of the HI (or other) beam: MHz-GHz resonances

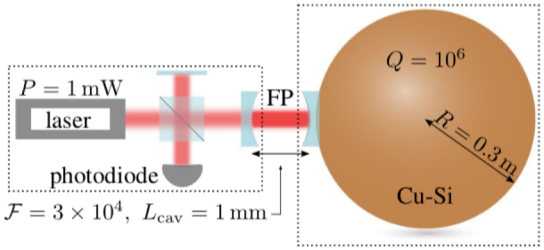
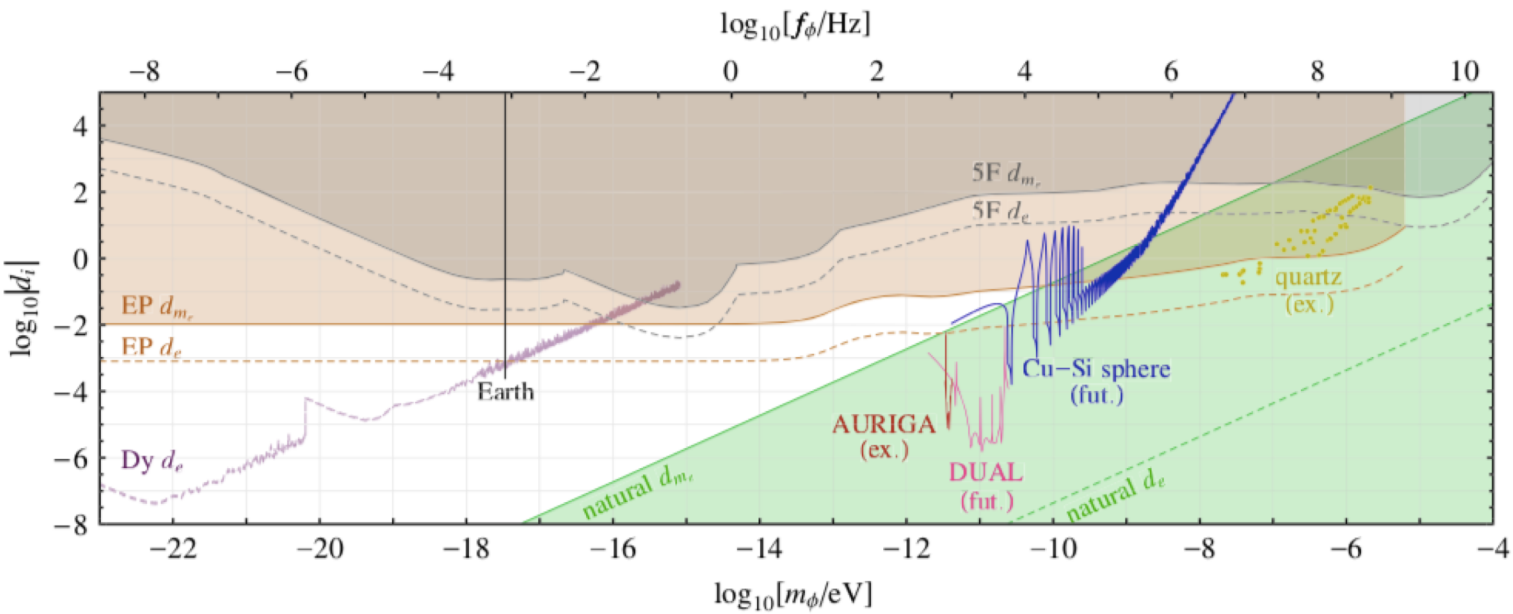


FIG. 2. Schematic of the proposed setup: a Cu-Si sphere whose surface displacement is monitored by a Fabry-Pérot (FP) interferometer. Elements encircled by the dotted lines are independently suspended and isolated from vibrations.

PRL 116, 031102 (2016) PHYSICAL REVIEW LETTERS week ending 22 JANUARY 2016

Sound of Dark Matter: Searching for Light Scalars with Resonant-Mass Detectors

Asimina Arvanitaki,[1,*] Savas Dimopoulos,[2,†] and Ken Van Tilburg[2,‡]



Could we use the periodic time structure of the HI (or other) beam: MHz-GHz resonances

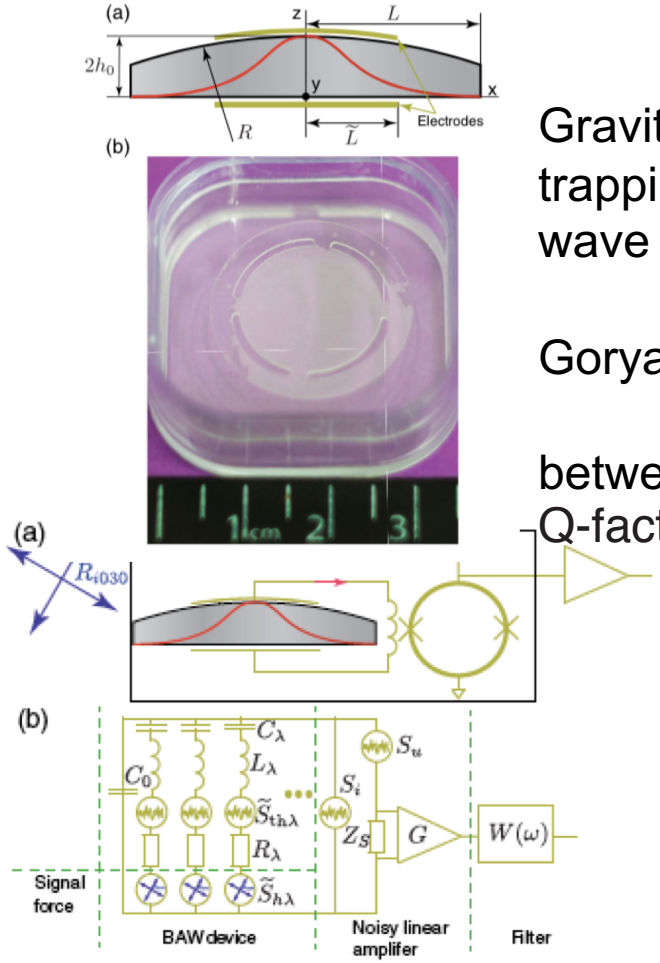
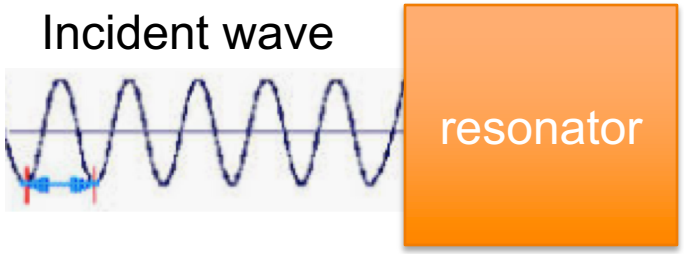


FIG. 6 (color online). (a) Experimental setup. (b) Equivalent electrical model.

Gravitational wave detection with high frequency phonon trapping acoustic cavities:piezoelectric quartz bulk acoustic wave (BAW) resonators

Goryachev et al.,PHYSICAL REVIEW D 90, 102005 (2014)

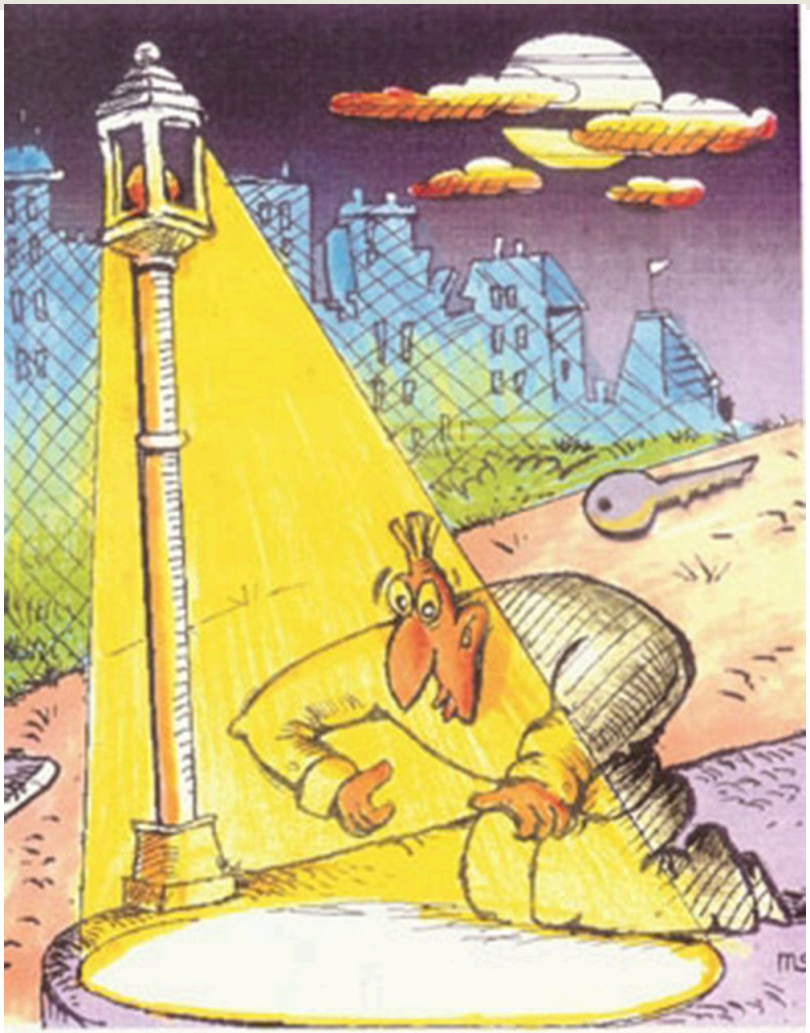
between 1 MHz and nearly 1 GHz
Q-factors of 10^9 and approaching 10^{10}



Things to do:

- Estimate the production mechanism/rate with HI
- what will be the time-structure at the detector? Will it conserve the frequency of the beam?
- What will be the periodic interaction with the detector tuned to beam frequency
- What would be the best frequency
- What would be the best distance
- ….

The street light effect



The ^{11}Be decay team:

PHYSICAL REVIEW LETTERS **123,** 082501 (2019)

Editors' Suggestion

Direct Observation of Proton Emission in ^{11}Be

Y. Ayyad,[1,2,*] B. Olaizola,[3] W. Mittig,[2,4] G. Potel,[1] V. Zelevinsky,[1,2,4] M. Horoi,[5] S. Beceiro-Novo,[4] M. Alcorta,[3] C. Andreoiu,[6] T. Ahn,[7] M. Anholm,[3,8] L. Atar,[9] A. Babu,[3] D. Bazin,[2,4] N. Bernier,[3,10] S. S. Bhattacharjee,[3] M. Bowry,[3] R. Caballero-Folch,[3] M. Cortesi,[2] C. Dalitz,[11] E. Dunling,[3,12] A. B. Garnsworthy,[3] M. Holl,[3,13] B. Kootte,[3,8] K. G. Leach,[14] J. S. Randhawa,[2] Y. Saito,[3,10] C. Santamaria,[15] P. Šiurytė,[3,16] C. E. Svensson,[9] R. Umashankar,[3] N. Watwood,[2] and D. Yates[3,10]

[1]*Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA*
[2]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[3]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*
[4]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[5]*Department of Physics, Central Michigan University, Mount Pleasant, Michigan 48859, USA*
[6]*Department of Chemistry, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada*
[7]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[8]*Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada*
[9]*Department of Physics, University of Guelph, Guelph, Ontario N1G 2W1, Canada*
[10]*Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada*
[11]*Niederrhein University of Applied Sciences, Institute for Pattern Recognition Reinarzstrasse 49, 47805 Krefeld, Germany*
[12]*Department of Physics, University of York, Heslington, York YO10 5DD, United Kingdom*
[13]*Department of Astronomy and Physics, Saint Marys University, Halifax, Nova Scotia B3H 3C3, Canada*
[14]*Department of Physics, Colorado School of Mines, Golden, Colorado 80401, USA*
[15]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[16]*Department of Physics, University of Surrey, Guildford, Surrey, GU2 7XH, United Kingdom*