TRIUMF TRIUMF e-linac production of tiny-coupled MeV-mass particles

Disturbing neither ARIEL isotope production nor cyclotron:

- **TRIUMF's e-linac Constraints**
- **Backgrounds and their suppression**
- **Detector, shielding requirements**
- **Competitiveness to A' only**

Luca showed scenarios with the A' boson decaying to other particles.
I will show for simplicity just bosons A' with no other particles

Comparative advantages:
Possibility of 0 beam-produced neutrons
(Detector length)/(Detector distance) can be large
Harness brilliant duty cycle for TOF measurements of A' mass
talk is also @ http://daqshare.triumf.ca/~trinat/ariel_workshop_behr.pdf

A collaboration slide would normally go here

I thank for info:

theory: David Mo., Dave Mc. (Maxim P., Adam R.)

detectors: Chris, Annika, Doug B., Stan, Akira

shielding: Anne

elinac info without disturbing ARIEL: Shane, Doug S., Victor, Oliver

Luca

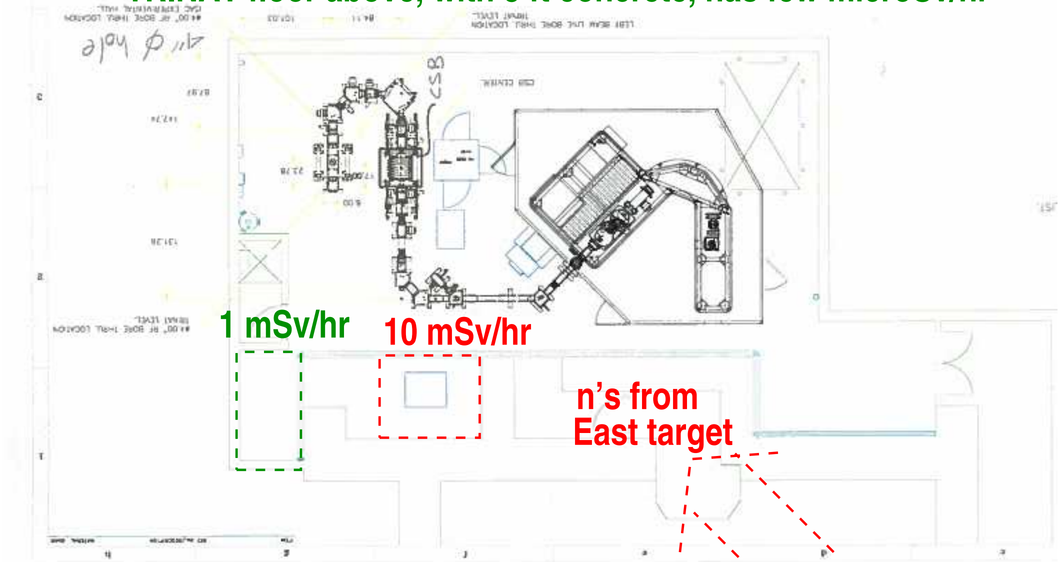
- **all of you for working for 17 minutes more–**

To invent better methods, do the two homework problems before the end of the BBQ

TRIUMF

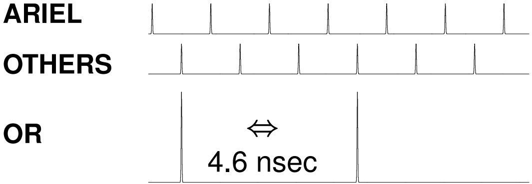
Rad-hard environment in ISAC mass-separator room

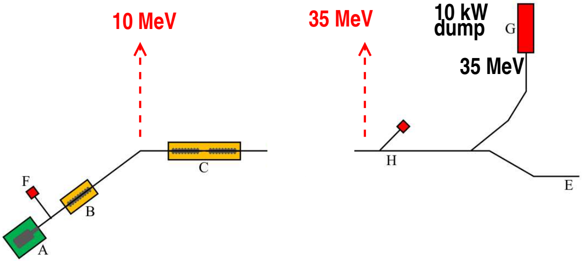
TRINAT floor above, with 3 ft concrete, has few microSv/hr



TRIUMF

Half the 1.3 GHz e-linac pulses are for non-ARIEL use





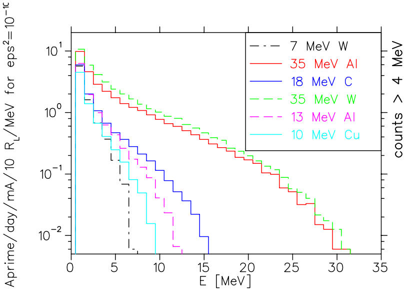
- **Every other bucket to ARIEL:**
  Other buckets free at same time
  with 650 MHz chopper Storey PhD
  (Present e-gun makes 100 ps pulses:
  pulsed laser(s) for 10 ps pulses)
- **Space charge limit 100 pC/bunch**
  Total power 300 kW of RF
- **So 100 kW to ARIEL with 200 kW**
  elsewhere, 4.6 ns spacing,
  20 mA at 10 MeV or 6 mA at 35 MeV

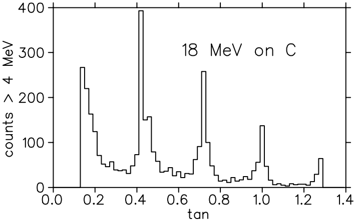
Beam dumps are non-trivial for
power. 10 MeV much easier to shield

20 MeV possible with a 2nd electron gun
(THz Stage 3 Verzilov: TUG talk)
Any energy OK 1 week/month during ARIEL
e-target changes.

- **Burrow west under offices to suppress**
  spallation n's from cosmic-ray μ
  by one order

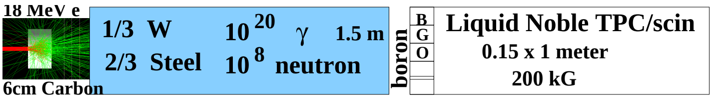
Production. ‘photons through wall’ technique





- **Production is like bremsstrahlung, reduced by ϵ^2**

For light A' masses, I use GEANT4 and ignore mass.



Want to be below (γ,n) in target and shield
or known $\sigma(\gamma, n)$ $\Rightarrow$ $n/\gamma \sim 10^{-4}$ in W
Need rejection of fast n's with $\sim 10^{-8}$ fidelity
One fix 2 slides below Luca has another

- **Detection by two processes**

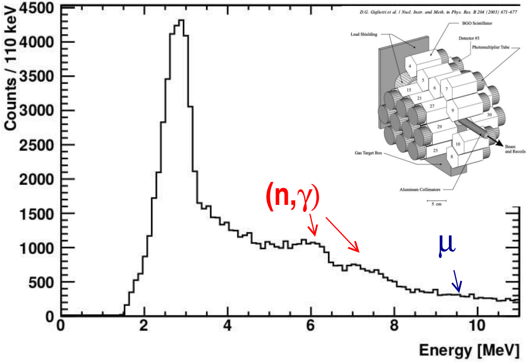
A' interacts in detector: $\propto \epsilon^2$

A' decays in detector: also $\propto \epsilon^2$

TRIUMF Backgrounds, detector energy thresholds

- $E_{e-} < \pi$ **threshold**
- $E_{e-} < (\gamma, n)$ **threshold**

  and/or detector threshold 10 MeV to avoid (thermal n, γ)



Natural γ 2.6 MeV; $\mu \to n \sim 100$ MeV

	(γ,n) MeV	isotopic impurities	
W	7 MeV		
^{48}Ti	11.6	^{49}Ti 8.1 5%	
^{63}Cu	10.9	^{65}Cu 9.9 16%	clean
^{56}Fe	11.2	^{57}Fe 7.6 2%	
^{55}V	11.1		clean
^{27}Al	13.1		clean
^{16}O	15.7	^{18}O 8.0 0.2%	decent
^{28}Si	17.2	^{29}Si 8.5 4%	isotope
^{12}C	18.7	^{13}C 4.9 1%	isotope

Some thermal (n,γ) proceeds to states with large E1 and/or M1 to low-lying states. This is only distinguishable from $A' \to e^+e^-$ by directionality, i.e. it's not 'zero background'.

TRIUMF

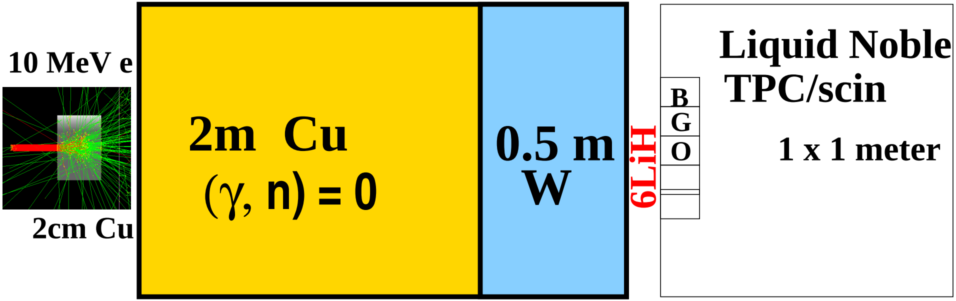
Detector, shielding requirements

Discriminate against fast neutrons (cosmic ray μ spallation)

$<$100 psec timing to take advantage of duty cycle

TOF to determine $m_{A'}$ directly

At linac E_{e-}=10 MeV + Cu there are 0 neutrons produced IF:



n shielding: Singh Badiger Ind Jour Pure Appl Phys 54 443 (2016)

Zero-Background sensitivity to A' $m\sim$ few MeV

ϵ^2 to detect 10 A''s

20mA, 10 MeV (6mA, 35 MeV)
1 year (EOT 4x10^{24})
Detector: 10 pair production lengths long, 1 meter diameter
(DRAGON BGO: $\div$ rates by 10)

$A'Z \rightarrow e^+e^-$ Z sensitivity:

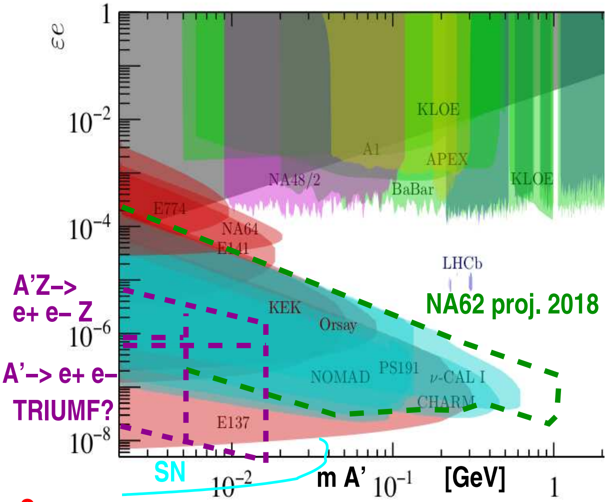
$E_{A'}$ Thresh:	4 MeV	10 MeV
10MeV+Cu	$7\text{x}10^{-12}$	none
18MeV+C	$5\text{x}10^{-12}$	$14\text{x}10^{-12}$
35MeV+W/Al	$2.6\text{x}10^{-12}$	$3.4\text{x}10^{-12}$

$A' \rightarrow e^+e^-$

$$\gamma c\tau_{A'} = \frac{E_{A'}}{m_{A'}} \frac{3\epsilon^2}{\alpha m_{A'}} \hbar c$$

$$N_{A'} = N_\gamma \epsilon^2 \frac{L}{\gamma c\tau_{A'}} e^{-\frac{d}{\gamma c\tau_{A'}}}$$

Ilten Soreq Williams Xue 1801.04847



Homework: DRAGON BGO better in a line?

TRIUMF $m_{A'} \leq 1 MeV$: A' is long-lived

$A'Z \rightarrow e^+e^-Z$ with TRIUMF eLinac comfortably beats LSND, and stellar evolution above 0.25 MeV

But $A' \rightarrow \gamma\gamma\gamma$ has τ that alters BBN
and CMB (Fradette 1407.0993)

Can avoid making too many if

Treheat $< 3 GeV \frac{10^{-12}}{\epsilon^2}$ (Dave Mc., Mon)

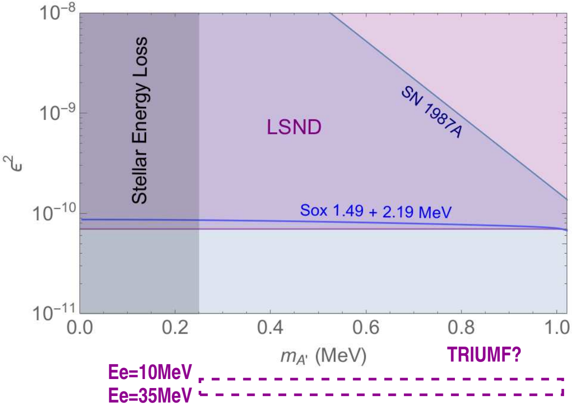
BBN works at Treheat $\geq$ 5 MeV,

though you don't get electroweak scale baryogenesis (1206.2942)

unless ϵ^2 is two orders smaller,

though there are other ways (like 1508.05392, and Dine-Affleck 0303065)

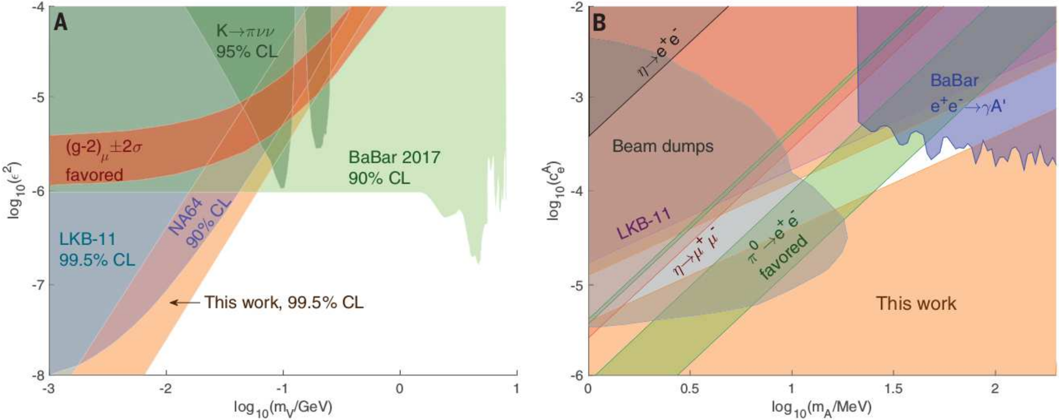
Pospelov Tsai 1706.00424



TRIUMF $m_{A'} \sim 10 MeV, \epsilon \sim 10^{-4}$ decay before beam dumps

New motivation for "Mont's gap": Parker et al. Science 360 191 (2018)

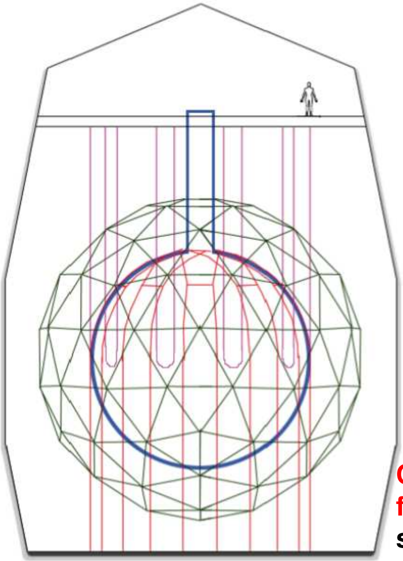
α from $\bar{h}/M$ atom interferometry underpredicts (g-2)$_e$ by 2.4σ



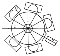
NA64 'beam into active target' works even if $A' \rightarrow$ invisible before detector.

Homework: design hermetic target/calorimeter for 10^4/s 35 MeV e^-'s

TRIUMF 10 MeV Rhodotron near a large underground detector



Jongen et al. 1993,
IBA Industrial
10 MeV 20 mA Rhodotron
diameter 2.9 m, 49% efficiency,
108 MHz, few M$



Tiny natural backgrounds are nice, and possibly essential

Better (detector size/distance) for $A' \to e^+e^-$

Higher Z would be nice, but still many interaction lengths in water or liquid scintillator for $A' \to \chi\chi'$ and $A'Z \to e^+e^-Z$ scenarios

Could be scheduled after WIMP experiments beat the ν floor (i.e. ν's from sun halt) HALO's 70 n/sec ^{252}Cf source notifies all when in use

TRIUMF elinac for tiny couplings: summary

Disturbing neither ARIEL isotope production nor cyclotron:

- **TRIUMF's e-linac Constraints** Brilliant duty cycle if detector has brilliant timing
- **Backgrounds and their suppression**
  elinac energy E_e=10 MeV+Cu eliminates beam-produced neutrons;
  10 MeV threshold to eliminate (thermal n,γ) events might work for E_e=35 MeV
  Natural backgrounds at surface are likely to be a limitation
- **Detector requirements:** $<$ 100 ps timing, discrimination against fast n's from cosmics, relatively high Z
- **Competitiveness** Detector size/distance is useful for $A' \rightarrow e^+e^-$ in detector, though SN1987A constraints are robust and daunting.
  TRIUMF eLinac could improve experimental limits for $\mathbf{0.2MeV} \leq m_{A'} \leq \mathbf{1MeV}$ by 15-30x, though such A' could have major impact on cosmology
  Luca showed $A' \rightarrow \chi\chi'$, which offers more compelling sensitivity
- **Comparative advantages: Possibility of 0 beam-produced neutrons**
  (Detector length)/(Detector distance) can be large
  Harness brilliant duty cycle for TOF measurements of A' mass

No ν's is bad news: ν's go into 4π

1806.02784 PROSPECT 1-month data disfavors the 1 eV $\bar{\nu}$ (and mentions as straw man their 'best' place, a 78%-ish 5 eV $\bar{\nu}$ admixture). They and others should keep counting :).

If that reverses itself, can one look for a ν sterile admixture, twin to the reactor $\bar{\nu}$ sterile?

For $\bar{\nu}$ from ^{13}C(γ,p)^{12}B and ν from ^{14}N(γ,2n)^{12}N

you MUST make neutrons, so must shield well.

dΩ shown here $\sim$ few %, detect perhaps 1000 $\bar{\nu}$/yr and only 100's of ν.

You need $\sim$50,000 ν, so you must cover 2π with

1.5 m of steel/tungsten, followed by meter-thick high-Z detector

(to use larger ν cross-section vs. $\bar{\nu}$)

and you still don't quite get there.

Also needs a macroscopic duty cycle $\sim \tau$, 20 msec.