Neutron Generators For Calibration

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4th Hyper-K Open Meeting

Introduction - Neutrons are handy

- Detector calibration with neutrons is useful
  - Low energy calibration point
  - Neutron tagging efficiency calibration (H, Gd)

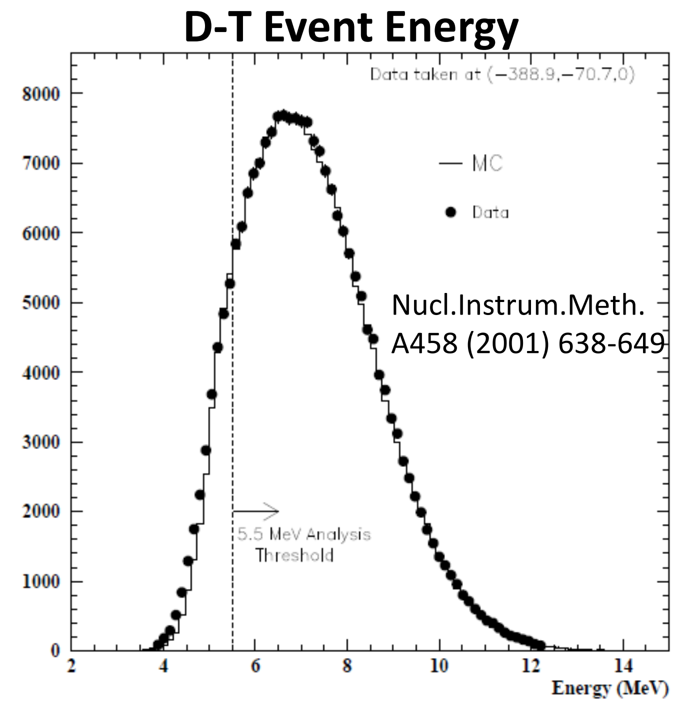
- Neutron tagging using the 2.2 MeV gamma tagging has been demonstrated in SK
  - Applications to proton decay background reduction
  - Antineutrino tagging for beam and atmospheric ν

- Similar electronics planned for Hyper-K and Hyper-K prototype,
- Running detectors can help test neutron calibration technologies (and benefit from them)
  - EGADS and Super-K
  - Worth exploring neutron generators
- There are commercially available neutron generators based on ^3H + ^2H fusion, which have successfully been used at Super-K and SNO ("D-T" generator)

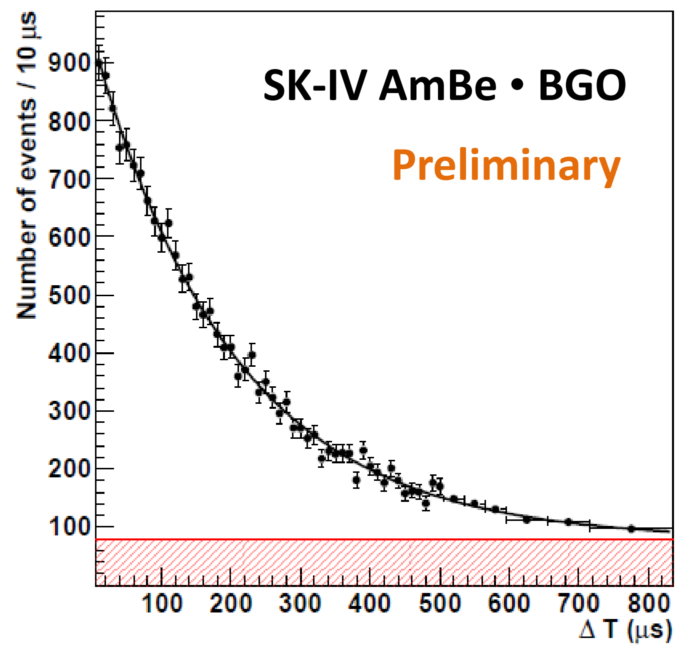
- Currently exploring ideas for compact, pulsed neutron generation
  - Highlight one of theme here

Neutrons for Calibrations

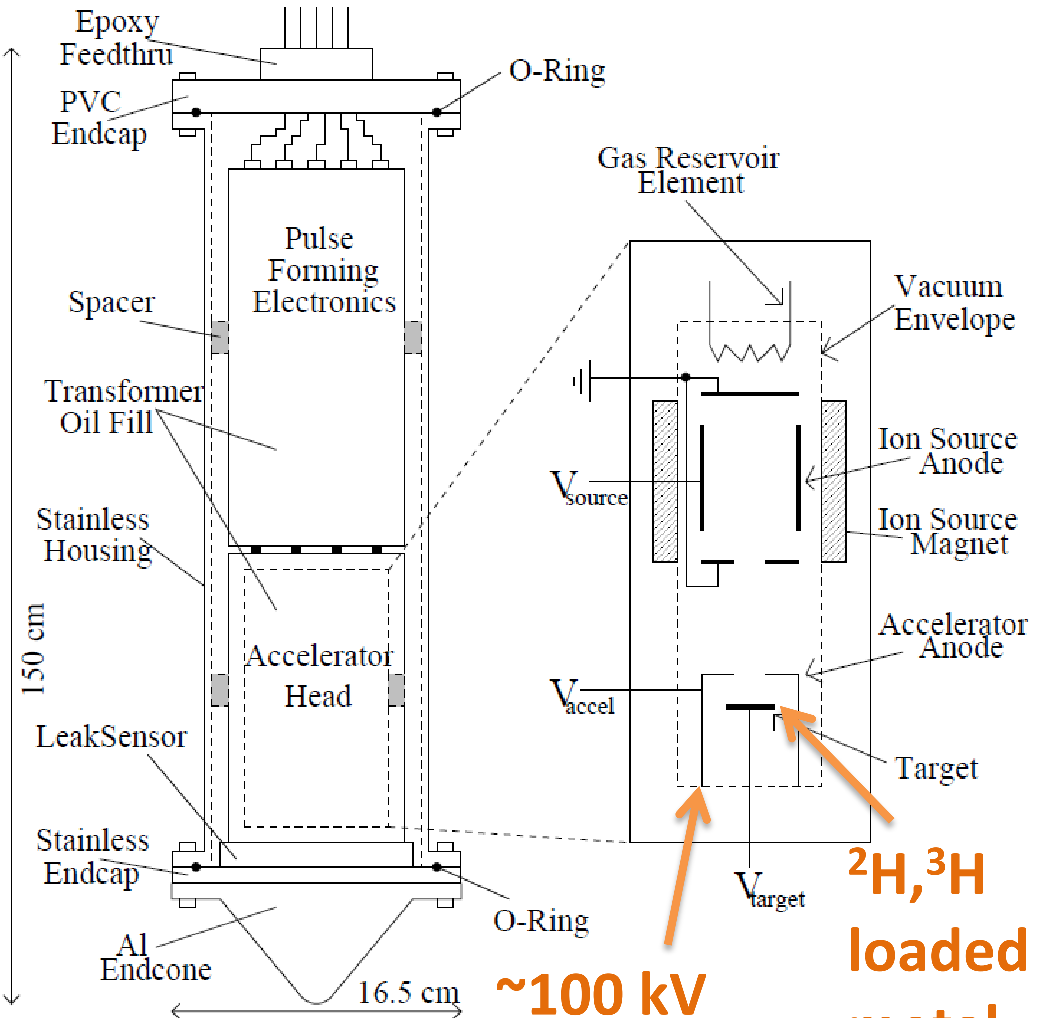
- Low energy calibration source
  - $^{16}O + n \rightarrow {}^{16}N$ (decay 4.3 MeV e^- + 6.1 MeV γ)
  - 7.3s half-life
  - Calibration of absolute energy scale and its position dependence
  - However, process is only ~1% efficient so high intensities are needed



- Calibrate neutron tagging efficiency
  - with 2.2 MeV γ from H(n,γ)d
  - with Gd : n+Gd $\rightarrow$ 8 MeV with a few γ
  - Generally lower intensities desired to prevent pile up



The Super-K D-T generator



$$^{3}\mathrm{H} + {}^{2}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + n.$$

14.2 MeV

- Penning Ion source that induces deuterium-tritium fusion to create neutrons
- Max pulse rate 100 Hz
- 10^6 neutrons per pulse
- O(100) kV accelerating potential to bring plasma to the target
- Accelerator electronics are mounted with the source so the entire apparatus is large : 150 cm x 16.5 cm ϕ

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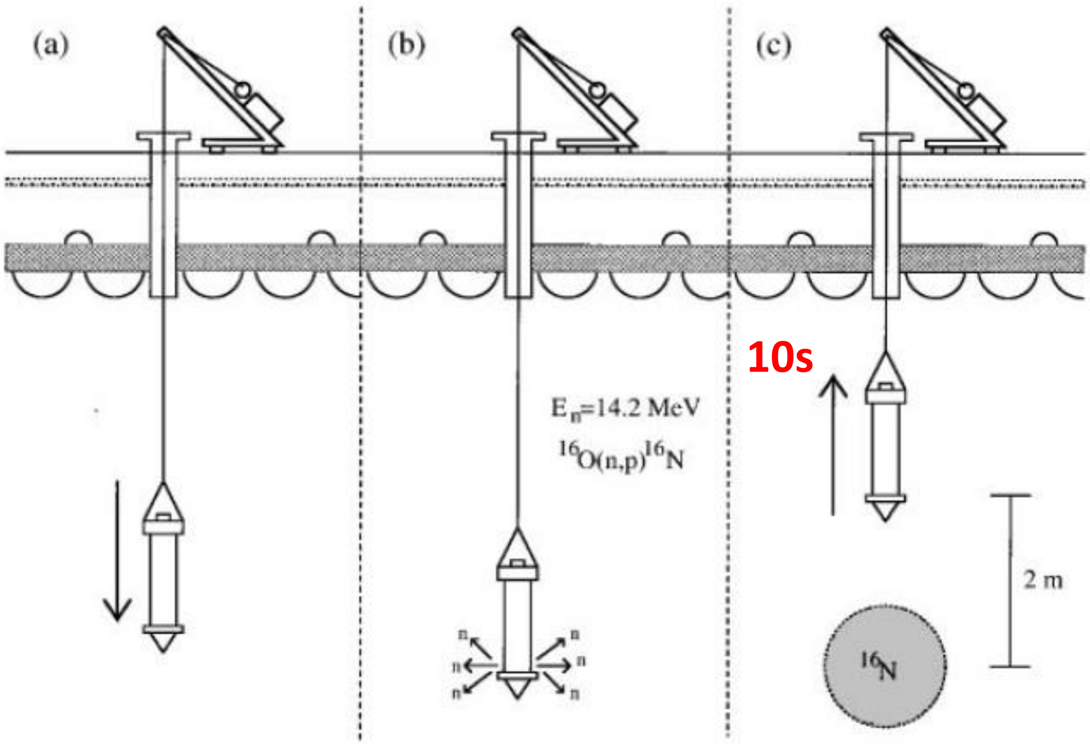
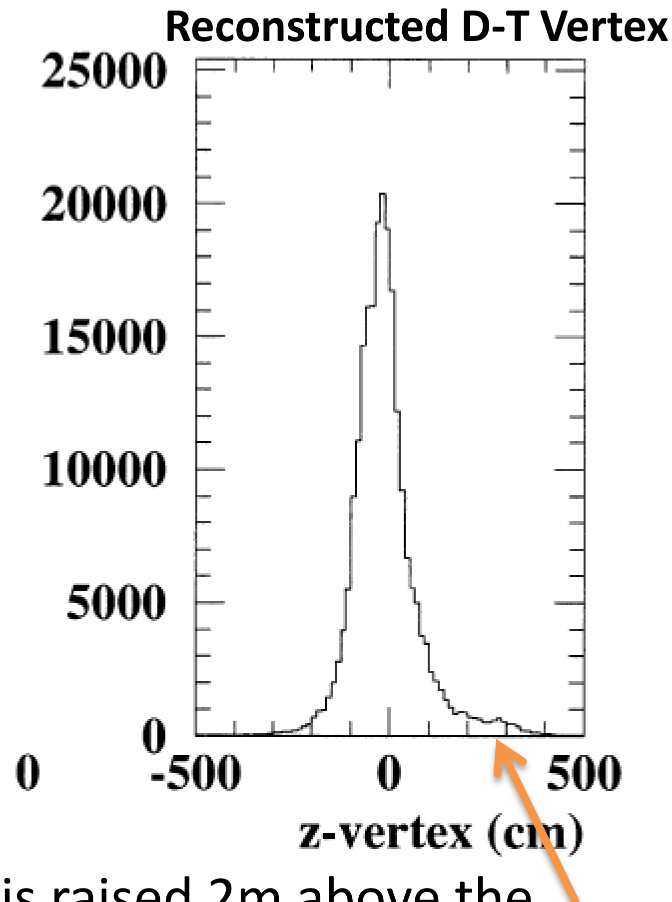
The Super-K D-T generator : In action





- During the calibration process the DT generator is raised 2m above the original fire position to reduce shadowing/interaction with the device
  - Basically unavoidable
- Causes diffusion of events along axis of this motion as water is displaced
- Range of utility in the vertical direction is limited
- Device is not so mobile

Neutron Generator Wish List

- Compact
  - Deployment at multiple positions
  - Useable in smaller detectors EGADS, **HK Prototype**
  - Minimal water displacement

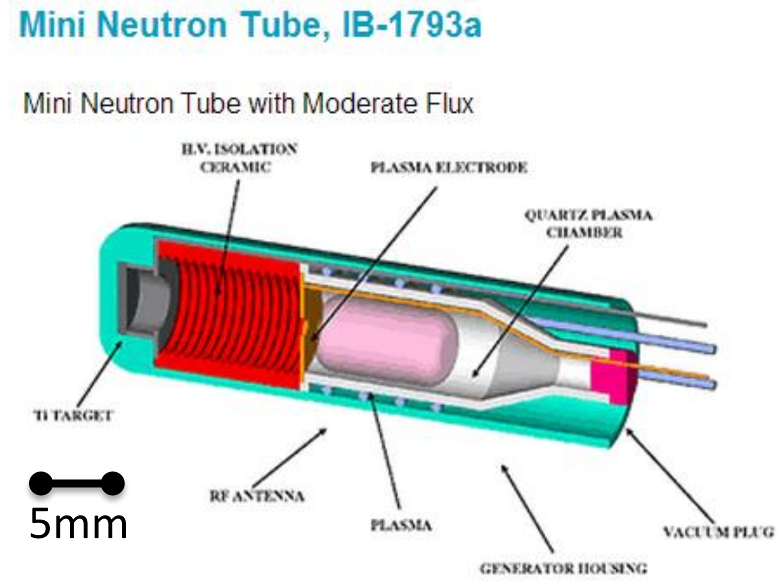
- Pulsed/Triggered (ie timing information)
  - Reduce reliance on coincident techniques (AmBe • BGO matrix)
  - Particularly useful for neutron tagging studies

- “Tunable” intensity
  - High intensity (SK Style) ^{16}N calibrations
  - Low intensity - tagging efficiency

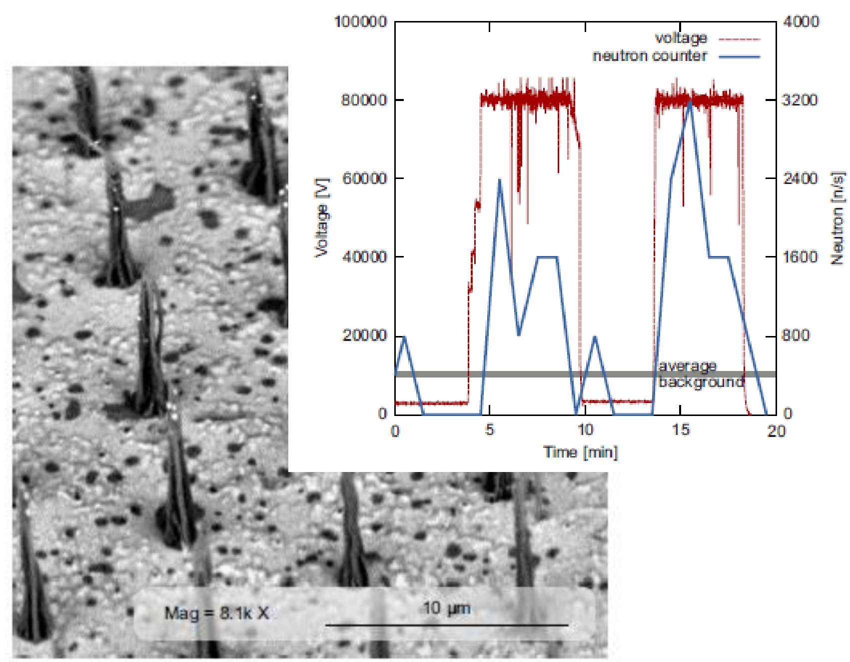
- Rechargeable after gas reservoir depletion
  - Ability to resupply ion source (without going to manufacturer)
  - Construction in house?
- Automated
- Mobile (or distributable)

Neutron Generators in General

- Typical neutron generators are based on the D-D (2.4 MeV n) or D-T (14.2 MeV n) fusion
- There are a variety of schemes for making compact neutron generators
  - Several active groups/Labs (Japan/US)
- Target applications need higher neutron fluxes than would be useful for tagging calibrations
  - Landmine detection
  - Luggage scanning
  - Oil logging
- Various technologies involve RF-driven plasmas, or subsystems (vacuum pumping, cooling, etc.) which may not be ideal for our purposes
- Talk about a potential alternative today



http://www.lbl.gov/ttd/techs/lbnl1764.html



Novel Surface Mounted Neutron Generator (Neutristor)

- J. Elizondo-Decanini at Sandia National Laboratories in the U.S. has been developing a compact neutron source based on surface deposition and lithography
- Original development motivation is for cancer therapy
  - Introduce ^{10}B into cancer cell
  - $n + {}^{10}B \rightarrow {}^{4}He + {}^{7}Li + \gamma$
    - α and ^{7}Li cause local cell damage
- To prevent damage to healthy cells put the source as close as possible to target
- Goals:
  - Small
  - Inexepensive

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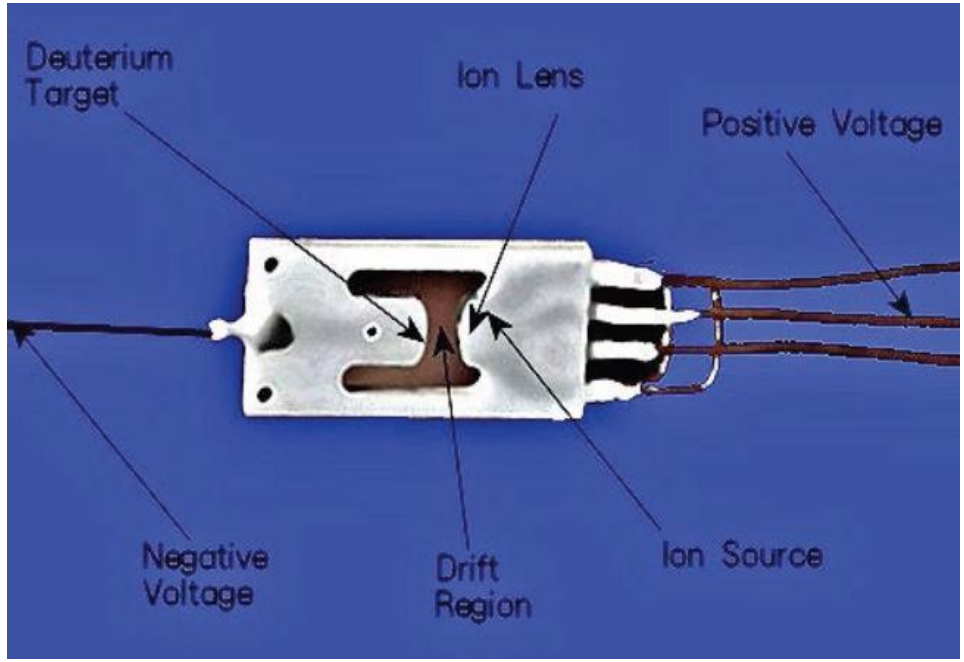
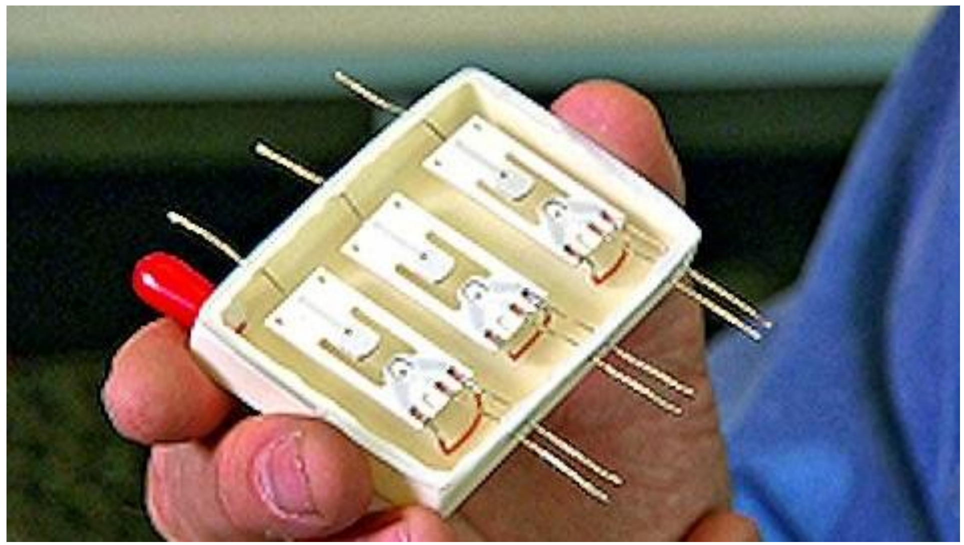
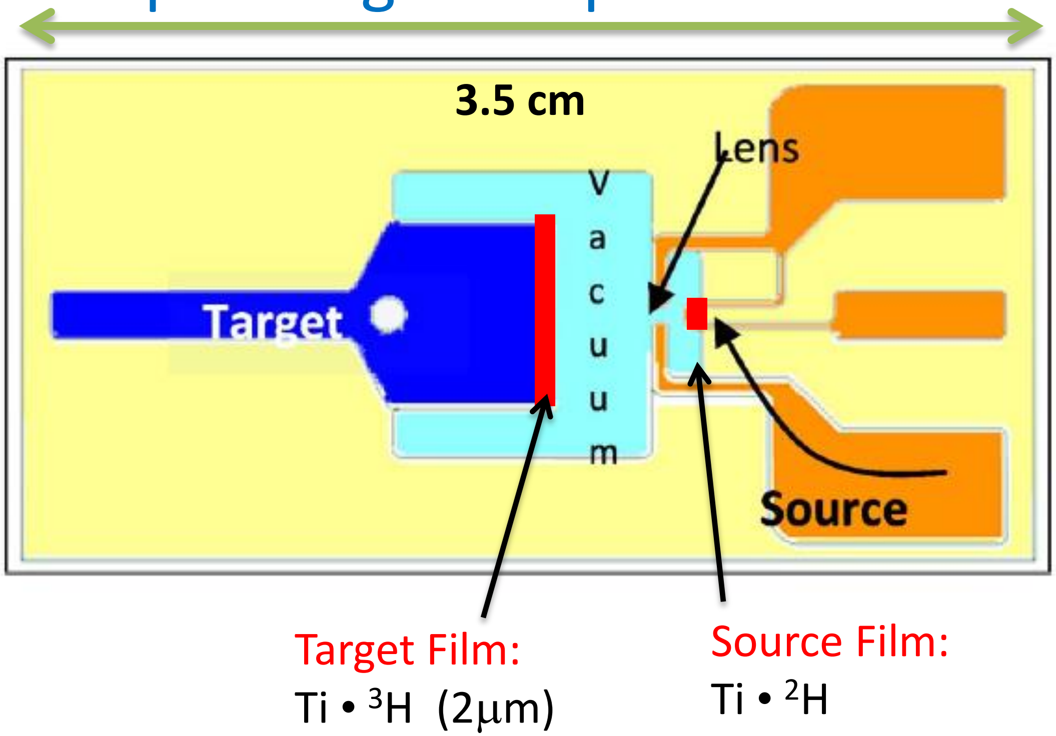


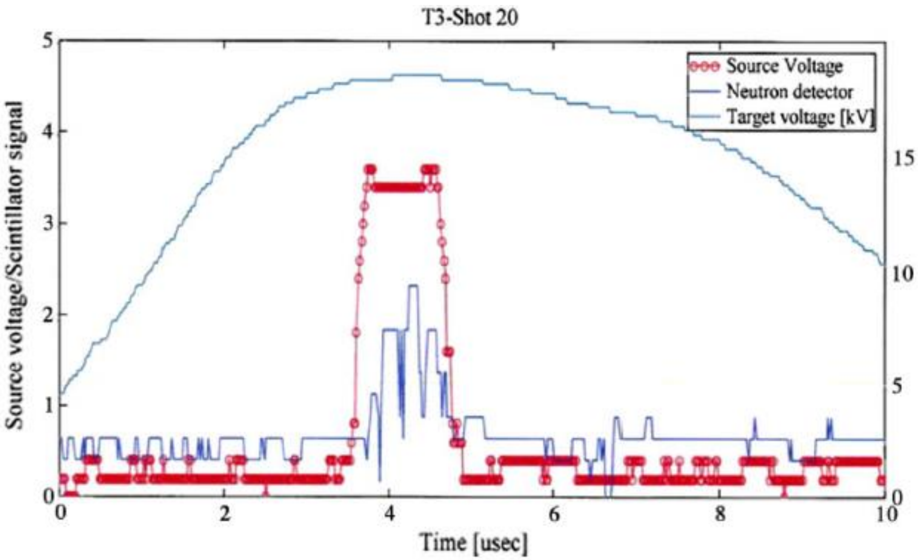


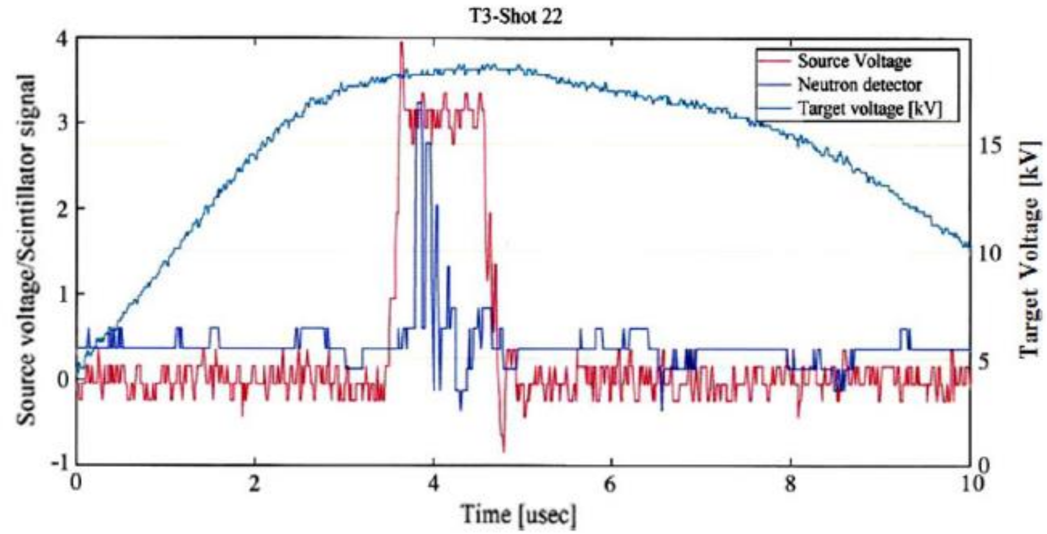
Neutristor : The Operating Principal



- Deuterium and Tritium thin films are deposited onto to the ion source and target elements
- Applying O(300)V at the source gap causes breakdown and the formation of an arc. The arc heats the source film releasing deuterium into the vacuum and ionizing it at the same time
- An accelerating voltage O(15)kV across the target is used to accelerate $^{2}H^{+}$ (etc.) ions onto the target film to induce D-T fusion
- An electrostatic lens is used to focus the ion flow to the target

Neutristor : Performance





- Several prototype devices have been built and operated successfully

- Source voltage 600 V (>150 kV/cm at ion source gap)
- Target (accelerating voltage) 20 kV trapezoid, 10μs in duration

- Produces ~2000 n per pulse (10^9 n/s)
- Long rep time O(60) s to allow the device to cool

- Principal of operation is proven

The Story

- The Neutristor seems promising so have made contact with the developer
- Possible to build a low profile device with little weight for calibrations
  - Better for HK Prototype than standard DT
- Lower target voltage than standard DT generator means it may be possible to supply HV ex-situ and make a minimally invasive source
  - Near the boundary of most reasonably priced feed-throughs
  - Potential Safety issues
- Anticipated cost is somewhat cheap : O(3000) $US per neutristor
  - Hopefully cheaper if proven useful for medical applications
- A vendor is currently working to market the device for commercial applications
  - The time scale is somewhat uncertain: Currently securing investment capital
  - Most likely available on the timescale of the HK prototype, maybe sooner

The Down-sides

- Currently only low intensity devices have been tested, so calibration using $^{16}O(n,p)^{16}N$, which is only about 1% efficient will be hard to impossible
  - Shot rate is currently too low for this application

- Inventor works for a national lab…
  - Cannot directly sell to outside groups so no prototype to "play" with yet
  - Some arrangements can potentially be made through Universities with connections to the laboratory (?)

- However, fabrication of the device seems relatively straight-forward
  - Possible to fabricate using a Deuterium target and avoid issues related to Tritium exportation
  - Additionally other, slightly larger D-D based sources can be built with more traditional means (Now under study)

Neutristor : The Device

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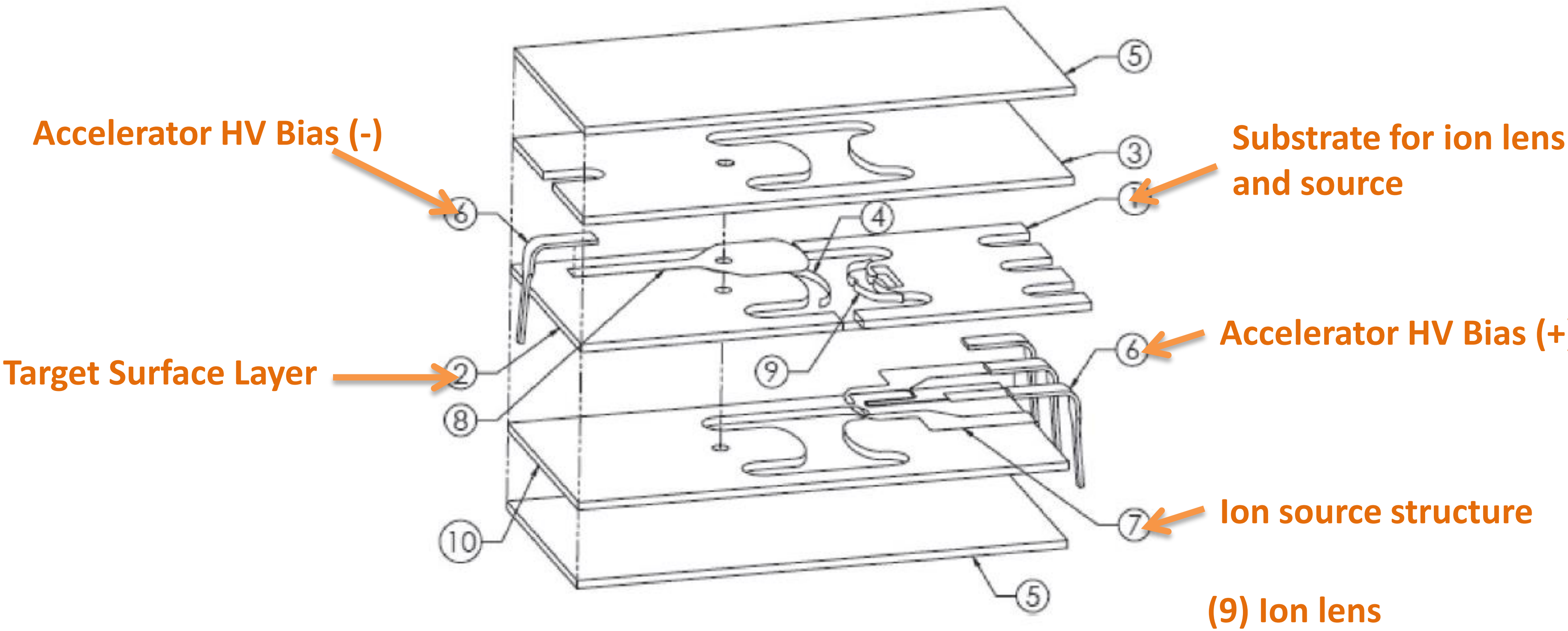


- Relatively detailed information on the device’s construction is available in the literature
  - Device dimensions as well as film deposition techniques are documented
  - Fabrication techniques are “standard”

Summary

- Considerations for neutron based calibrations are now underway
- Potential application and testing
  - EGADS, Super-Kamiokande
  - Hyper-K Prototype detector
  - Hyper-Kamiokande

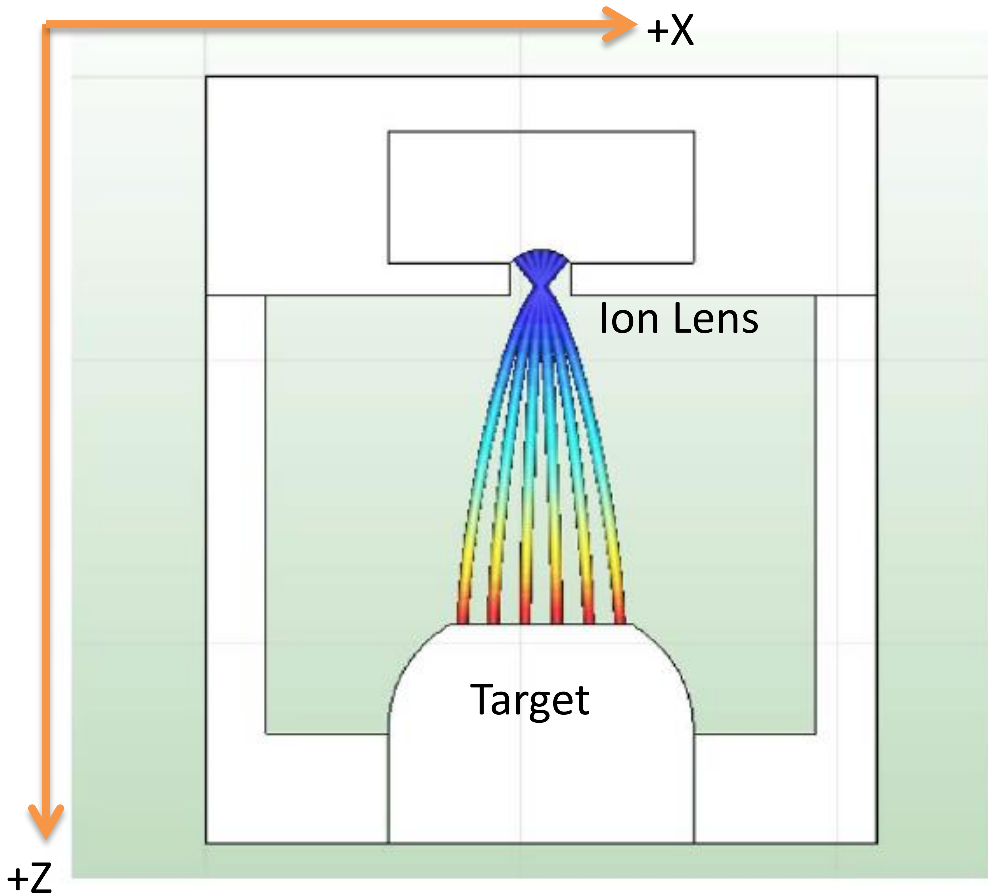
- The Neutristor seems promising – particularly as it is likely to be simple to operates and cheap
  - Access to a prototype for testing is needed to really flesh out the idea

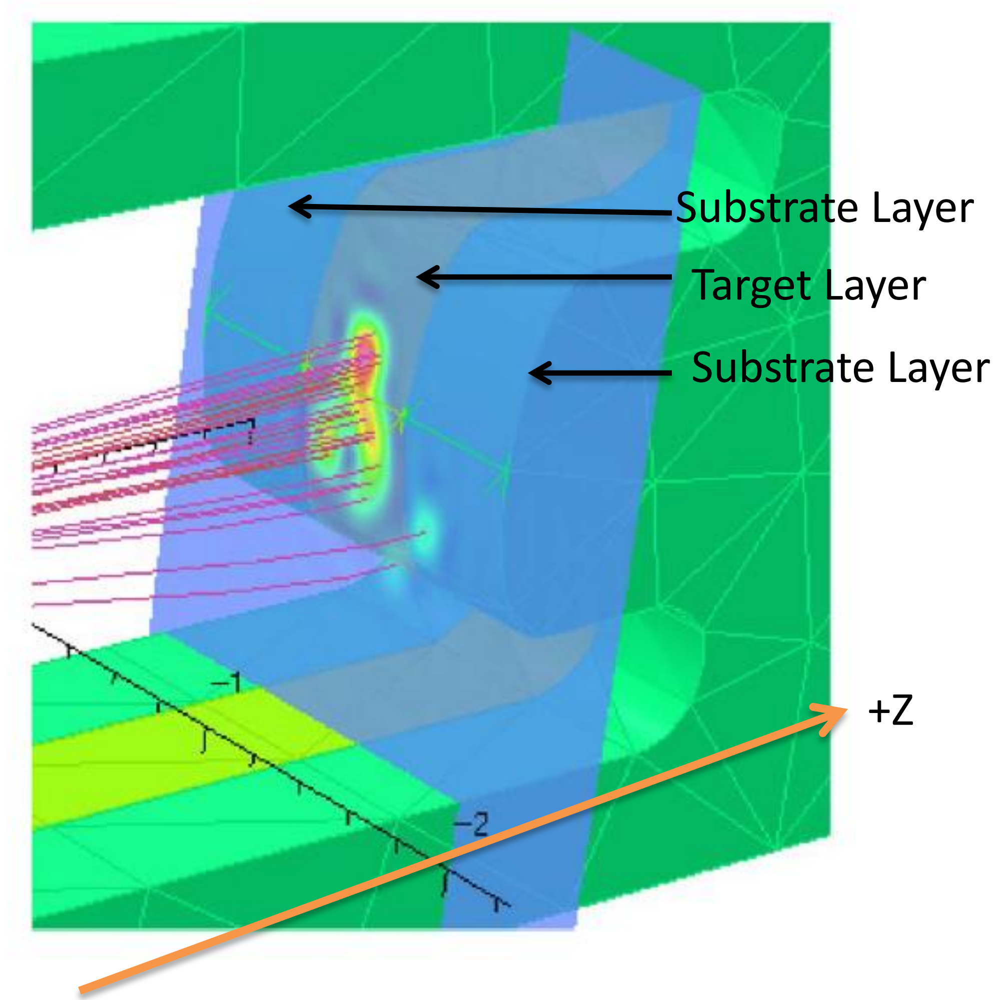
- An application for funding to pursue ideas for neutron generators has been submitted (decision by 2014.4)
  - Other techniques (D-D generator, Nano-tip acceleration, etc.) are being considered

- Of course your thoughts and ideas are appreciated

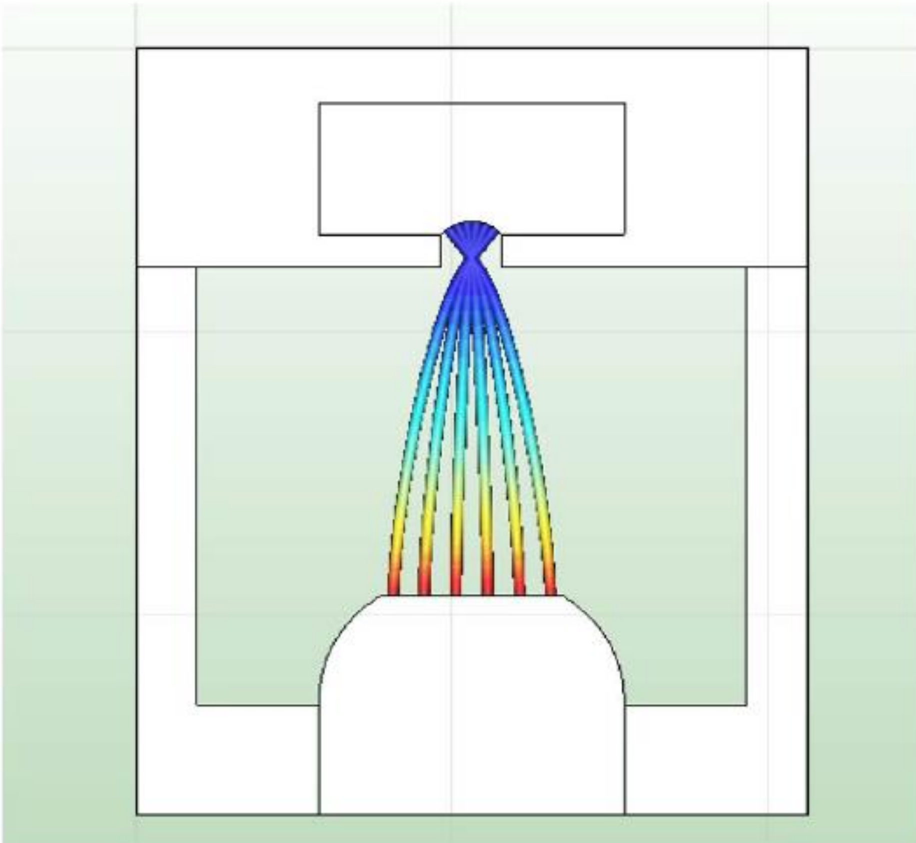
Supplements

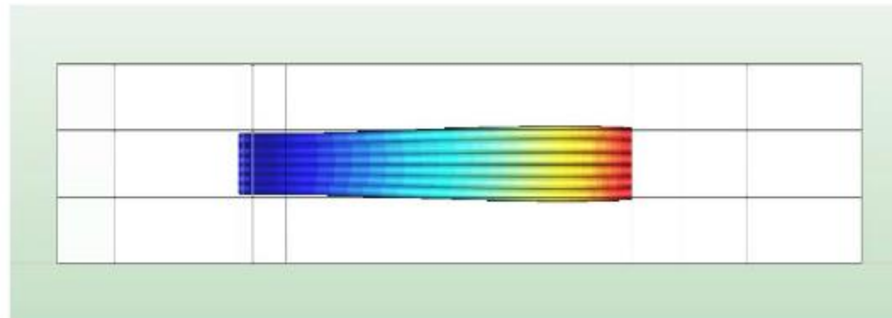
Neutristor : Simulations

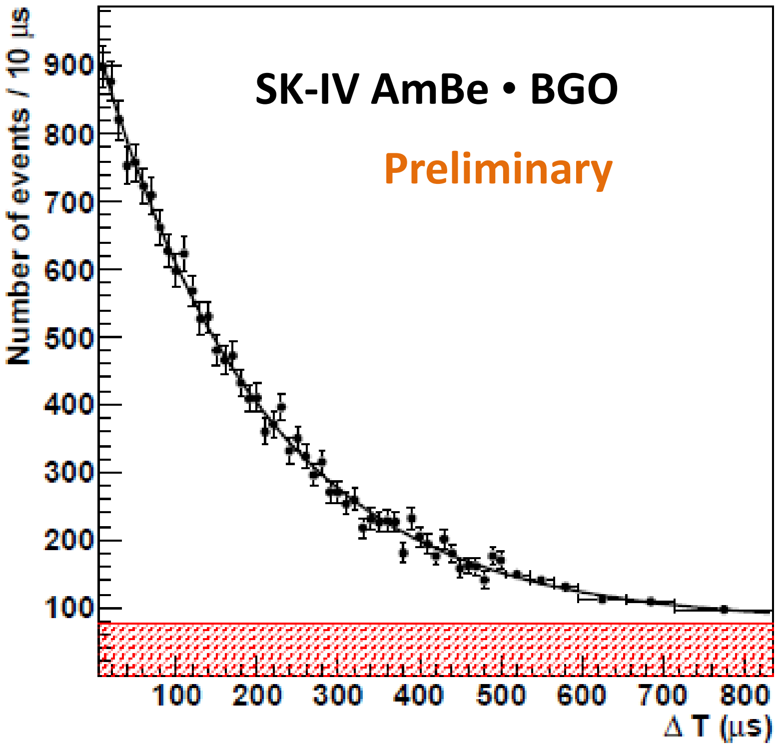




- Simulations guide the production process
- Size dominated by electric field shape : higher target voltage (more n) means larger device
  - Possible in principal






SK-IV AmBe • BGO
Preliminary
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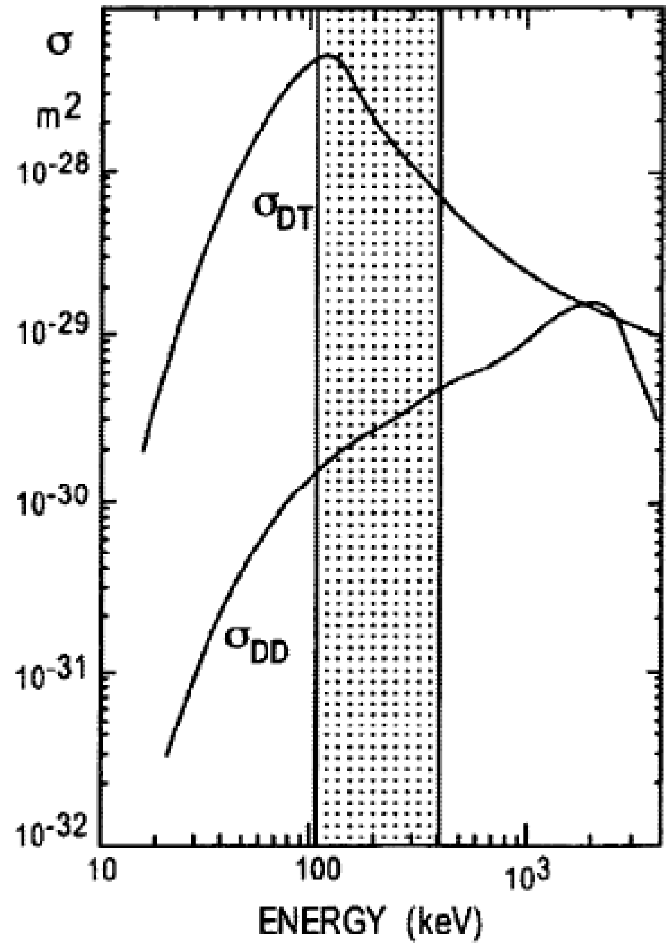
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