Gadolinium study for a water Cherenkov detector

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for Super-Kamiokande Collaboration

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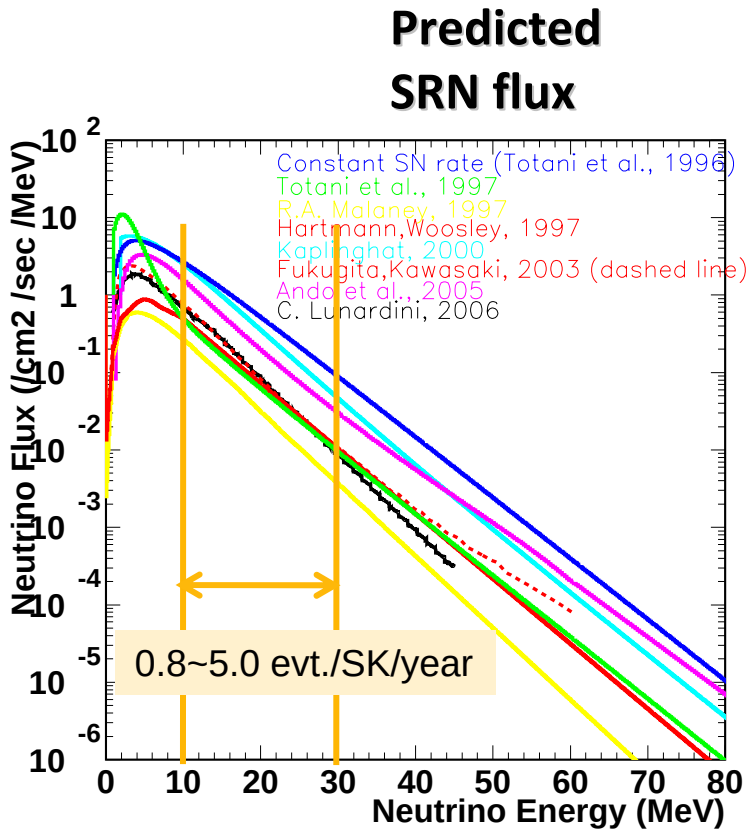
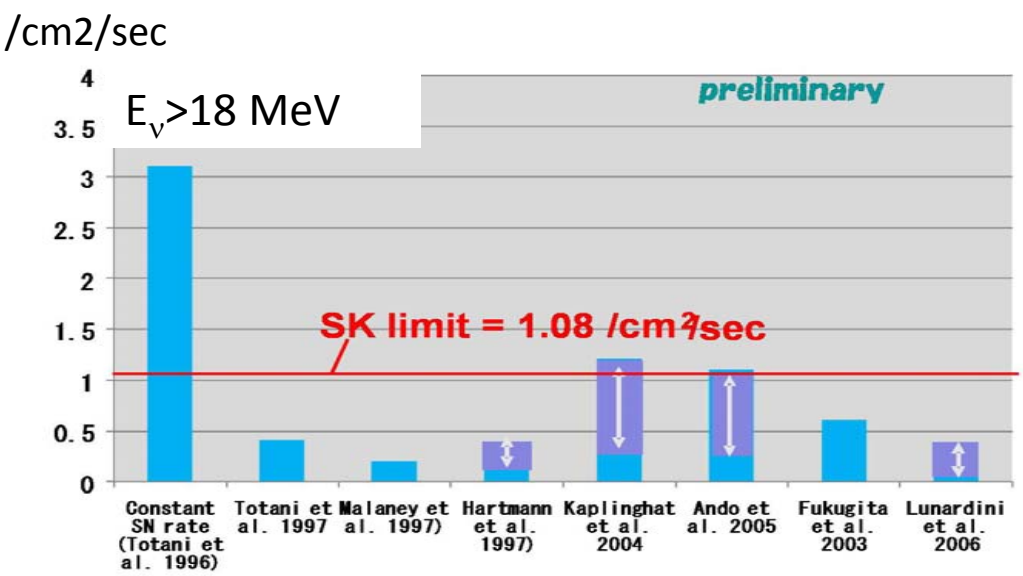
Introduction

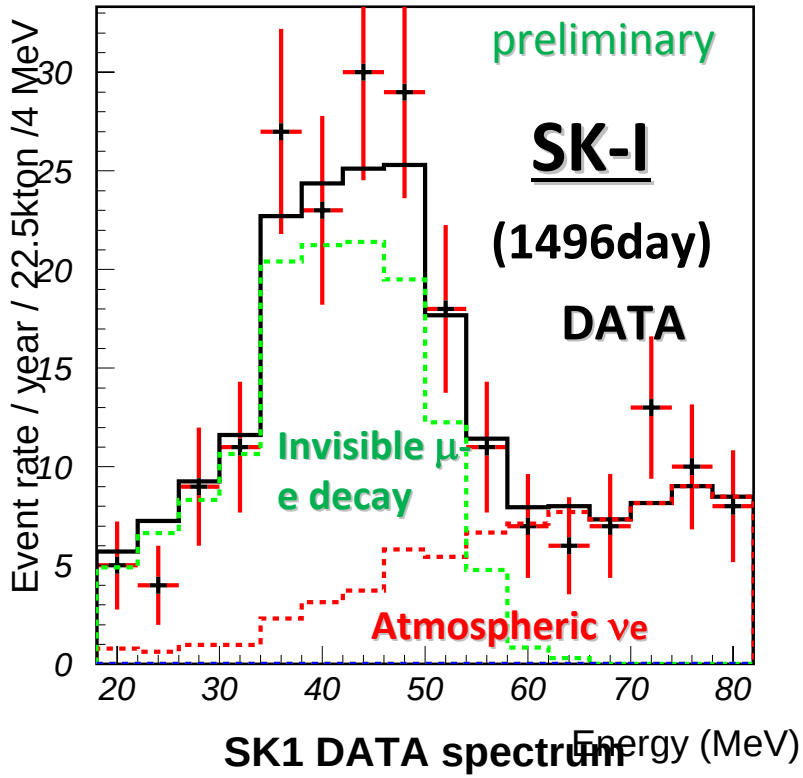
- Supernovae emit huge numbers of neutrinos.
- In the Universe, there exist diffuse neutrino background emitted from the past supernovae.
  - Supernova Relic Neutrino (SRN)
- Detection of SRN can give us knowledge of
  - Galaxy evolution
  - History of star formation
  - Neutrino properties
  - …



SRN Detection
at Super-Kamiokande (SK)

- SK is the best SRN detector so far
  - Latest limit 1.08/cm^2/s @90%C.L. (T.Iida, TAUP09)
  - M. Malek *et al*., PRL 90, 061101 (2003)
- Main backgrounds
  - atmospheric neutrinos
  - invisible muons



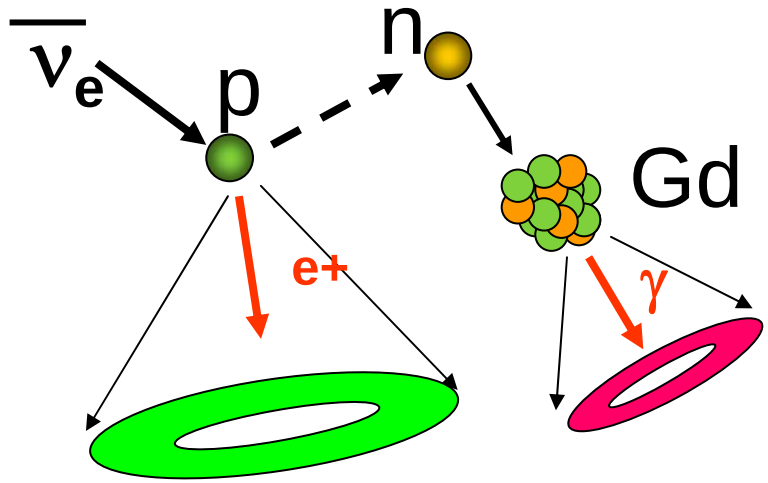


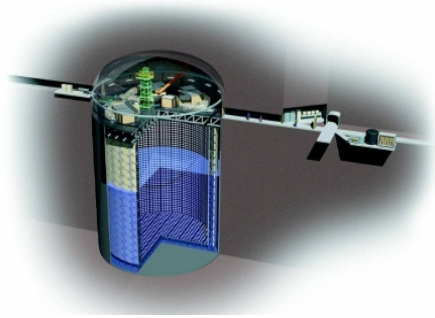
- the current limit is 3 times larger than predictions
- need 3 times sensitivity

GADZOOKS!
Gadolinium in SK

John F. Beacom and Mark R. Vagins, Phys.Rev.Lett. 93 (2004) 171101

- Large cross section of Gd for neutron capture
  - ~49,000 barns (0.3 barns on free proton)
  - neutron captured Gd emits 3-4 gammas in total energy 8MeV
- Coincident signal detection to suppress background
- Tagging neutron with Gd will lower threshold!
  - Down to 10 MeV
    - Spallation event suppression
  - Invisible muon reduced by a factor of 5

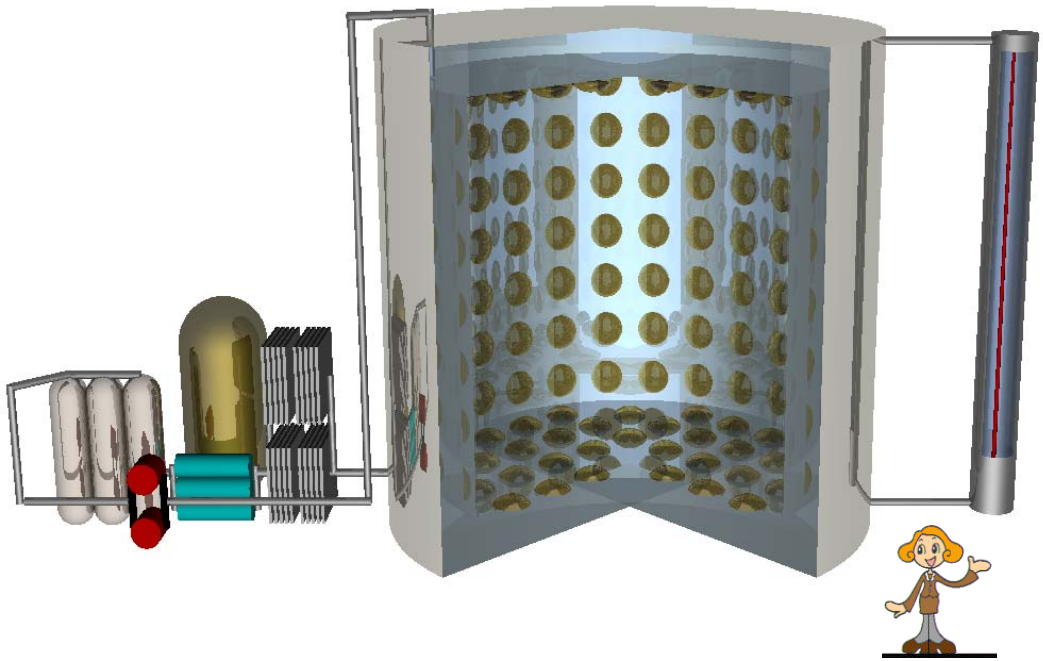




Prototype Detector
before introducing Gd into SK

- Effect on SK material?
- Water transparency?
- How to purify Gd water?
- How to introduce/remove Gd?
- Effect on solar neutrino trigger rate?

EGADS
Evaluating Gadolinium's Action on Detector Systems



- A test facility consisting of
  - 200-ton water detector,
  - water purification system,
  - attenuation length measurement system.
- Full budget for EGADS has been approved!

Gd Candidates
search for the best compound

Gd compound	corrosion	light attenuation
$GdCl_3$	X(*)	O
$Gd(NO_3)_3$	O	X(**)
$Gd_2(SO_4)_3$	O	O

- Corrosion tests mainly on stainless steel
- Gd sulfate is the best candidate found so far
- Material soak test is being carried out
  - All samples from SK components: rubber, plastic, acryl, FRP, tyvek, cable tie, cables…

(*) for example, arXiv:0805.1499v2 [physics.ins-det]

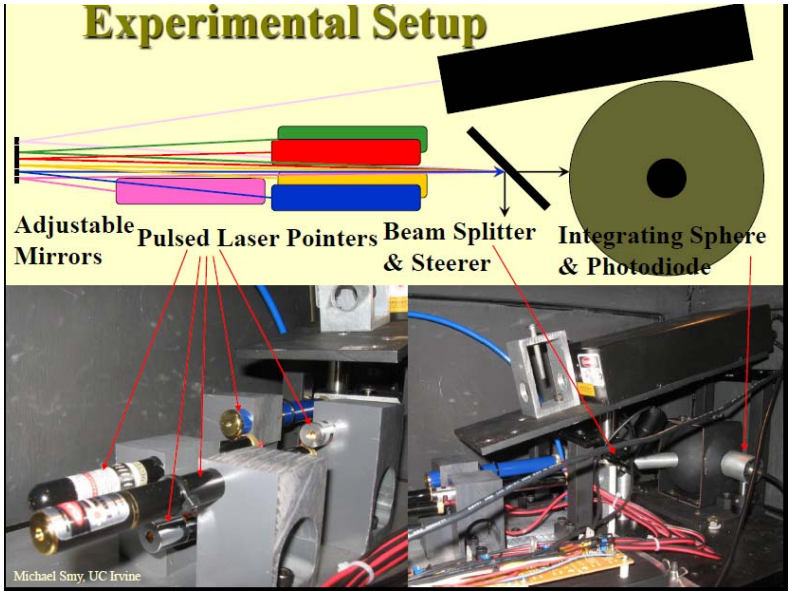
(**) strong absorption by Nitrate below 350nm, study done at UCI with UV/VIS spectrometer

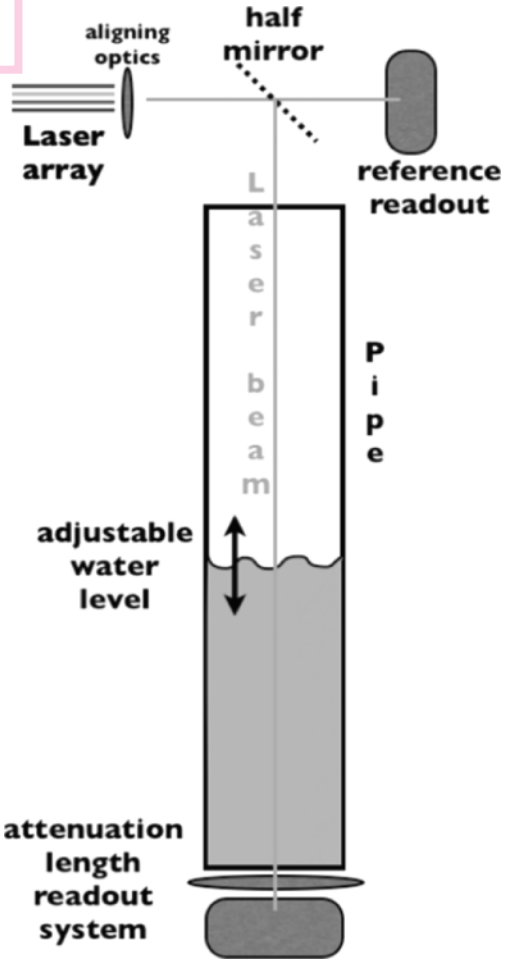
Transparency Measurement at UCI

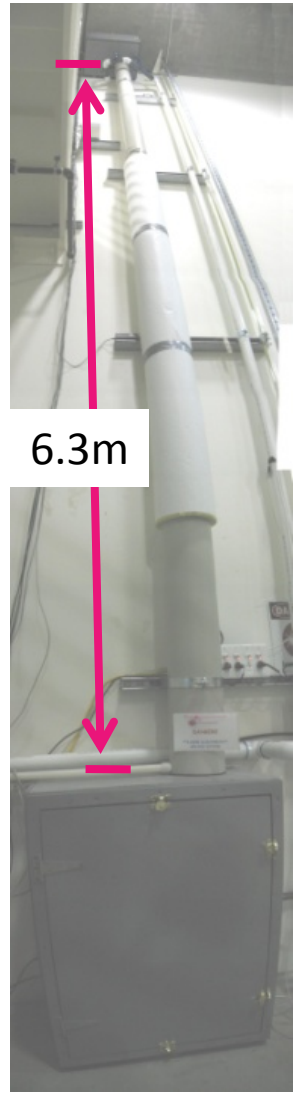
M. Smy

IDEAL

Irvine Device Evaluating Attenuation Length





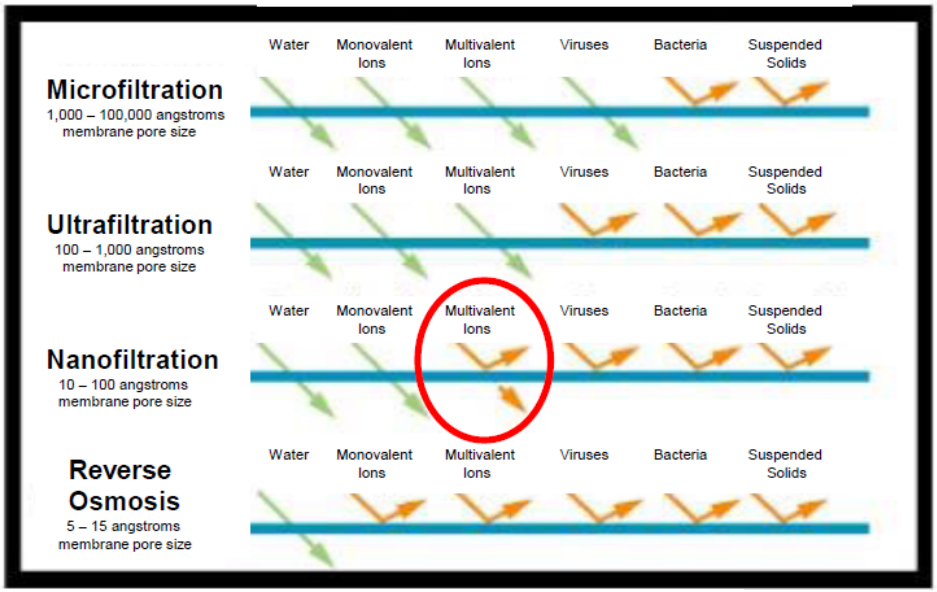


- Measure attenuation length for several wavelengths
  - λ :337~650nm
- Light attenuation measured by varying the height of water.

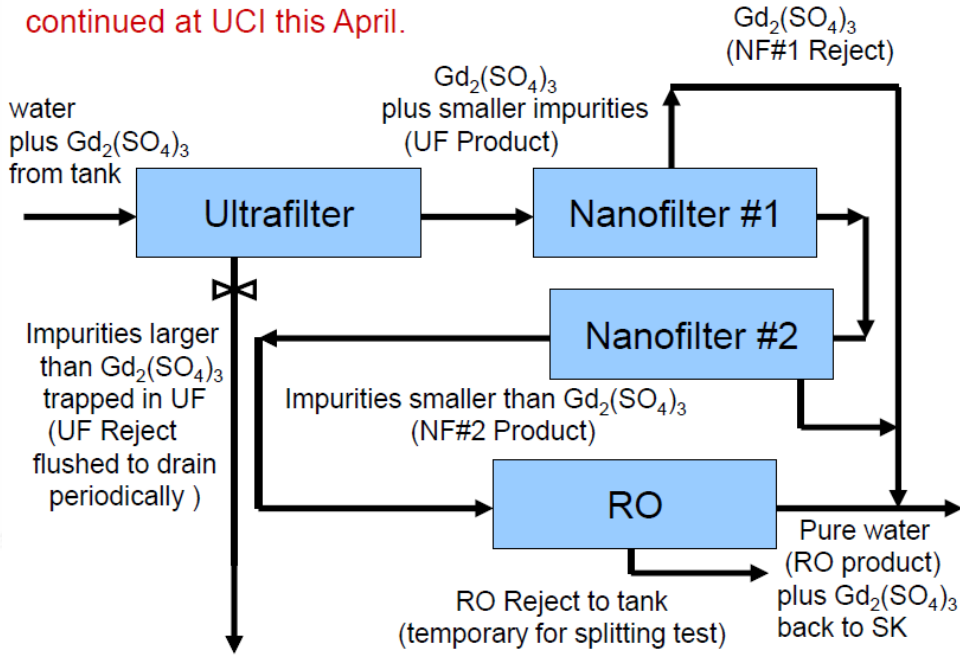
Selective Filtration at UCI

M.R. Vagins

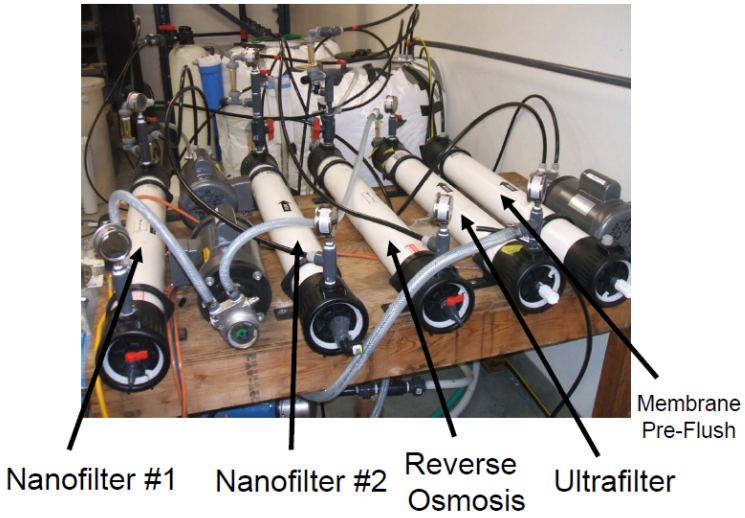
$Gd_2(SO_4)_3 \rightarrow 2\ Gd^{3+} + 3\ (SO_4)^{2-}$



Selective filtration studies using a double NF stage (in series) continued at UCI this April.



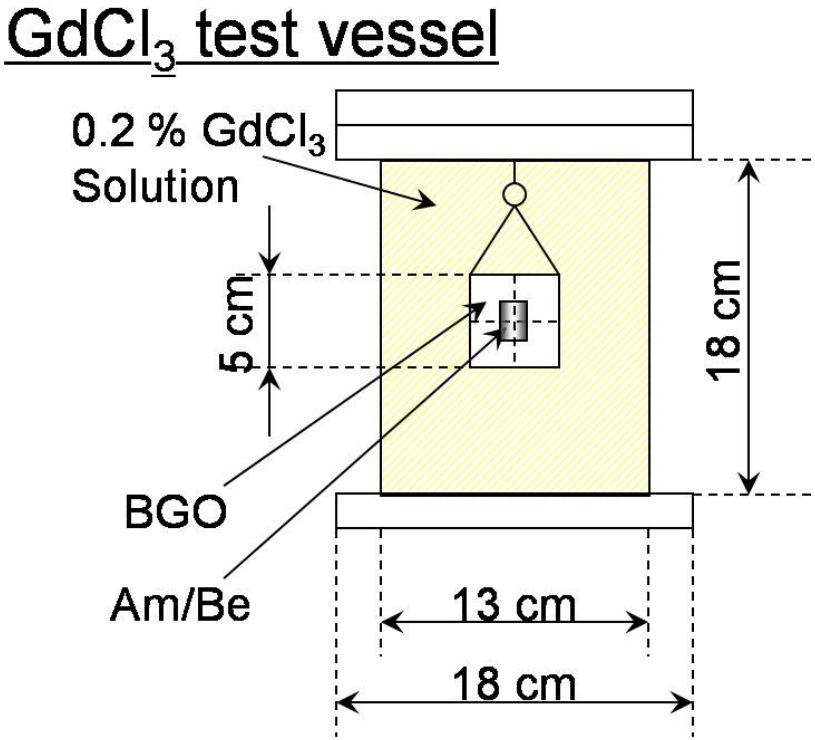
Current Selective Filtration Setup @ UCI



- A prototype system is being constructed at UCI.
- Demonstrates Gd sulfate is removed with 99.99% efficiency, and <0.05ppm for RO output.

Neutron Tagging Eff. Measurement at SK

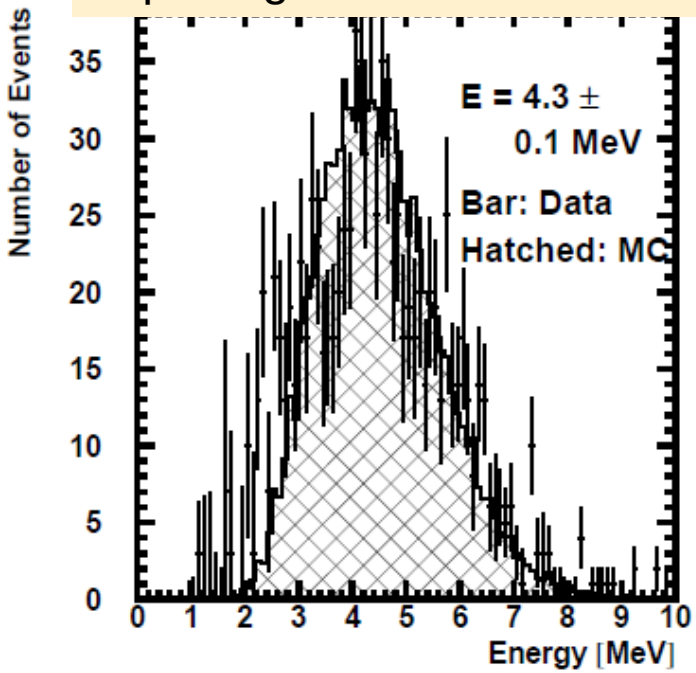
H. Watanabe et al., Astropart., Phys. 31, 320 (2009)



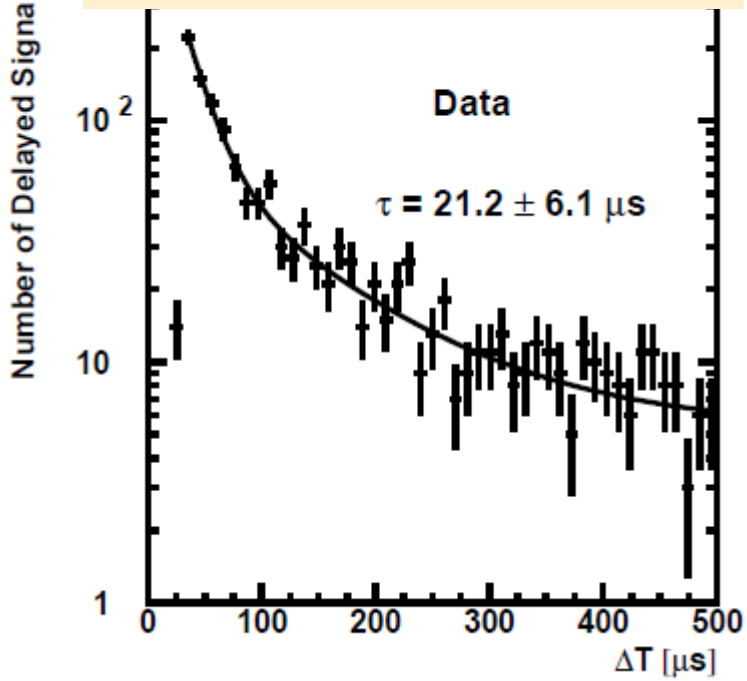
- Am/Be source emits 4.43MeV gamma and neutron simultaneously
  - the prompt gamma detected by BGO simulates the positron from inverse beta reaction.
- The vessel is deployed in SK.

Neutron Tagging Eff. Measurement at SK (cont'd)

energy of gammas from Gd capturing neutrons



time diff. btw. prompt gamma and Gd capturing neutrons

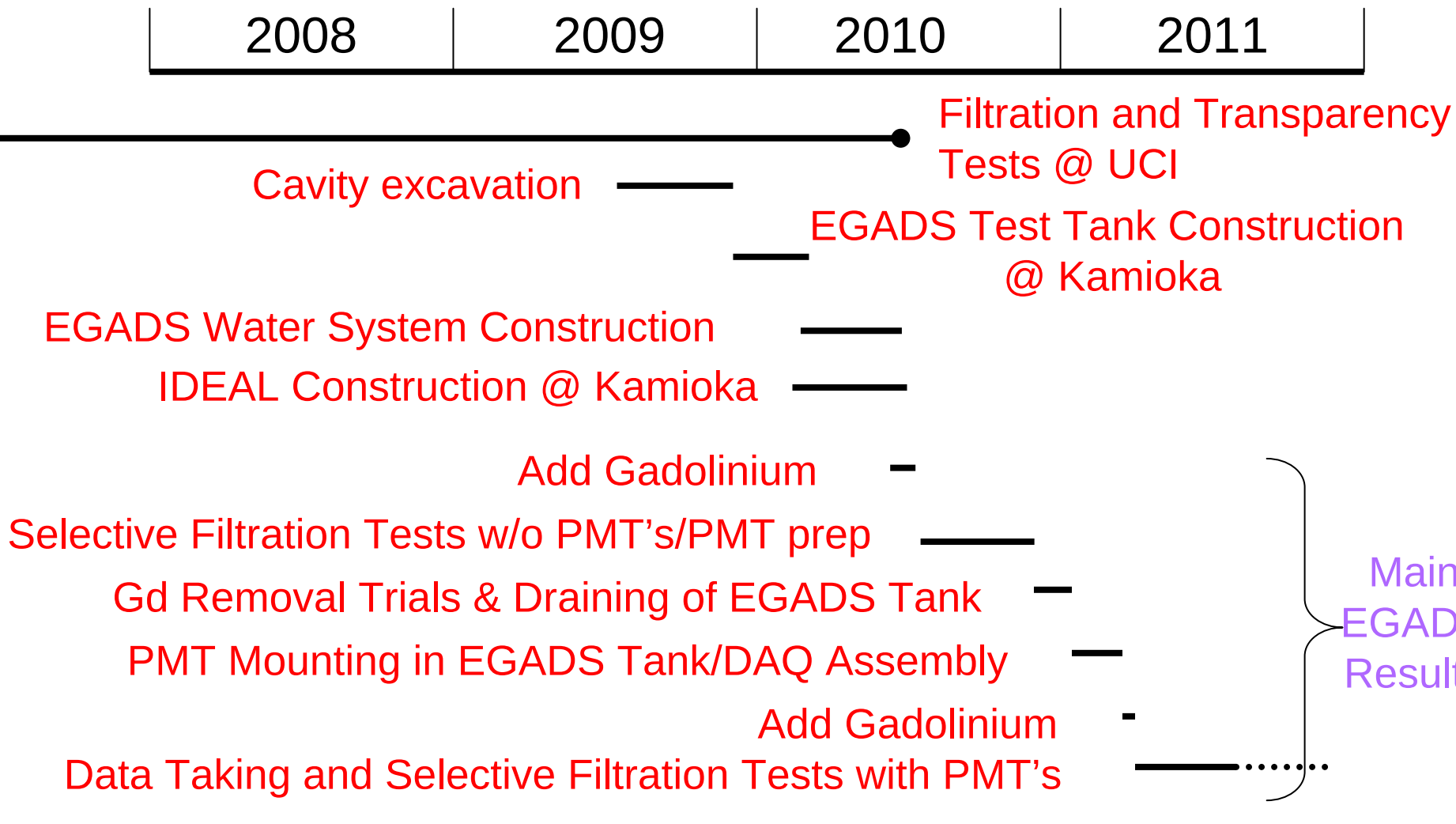


- The energy and time distributions are within expectations.
- The tagging efficiency is measured to be 66.7%.
  - accidental BG is < 2 x10^{-4} with E>10MeV

Summary

- A large Gadolinium dissolved water Cherenkov detector is considered for SRN detection.
  - GADZOOKS! at Super-Kamiokande
- A small scale prototype detector (EGADS) will be built, as R&D for GADZOOKS!
- EGADS construction in the Kamioka mine will start at the end of this year.
- Ongoing tests
  - Filtration and transparency systems
  - Material corrosion tests
- Results from EGADS in 2011!

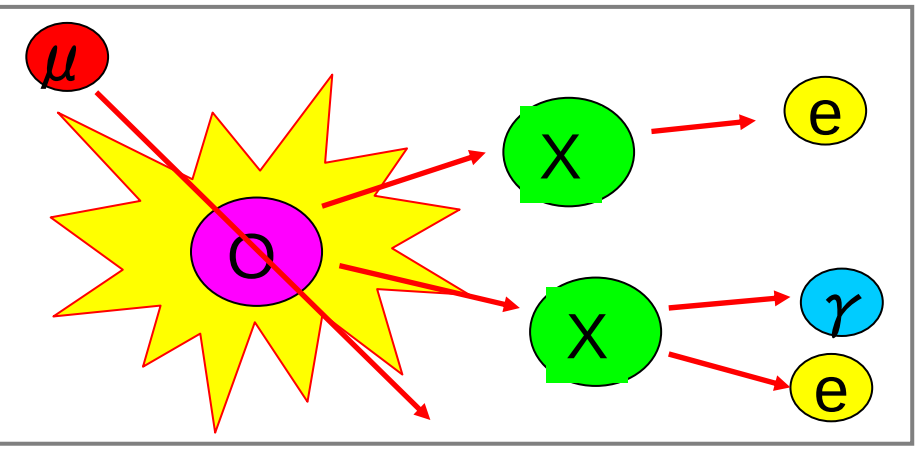
Schedule of GADZOOKS! R&D

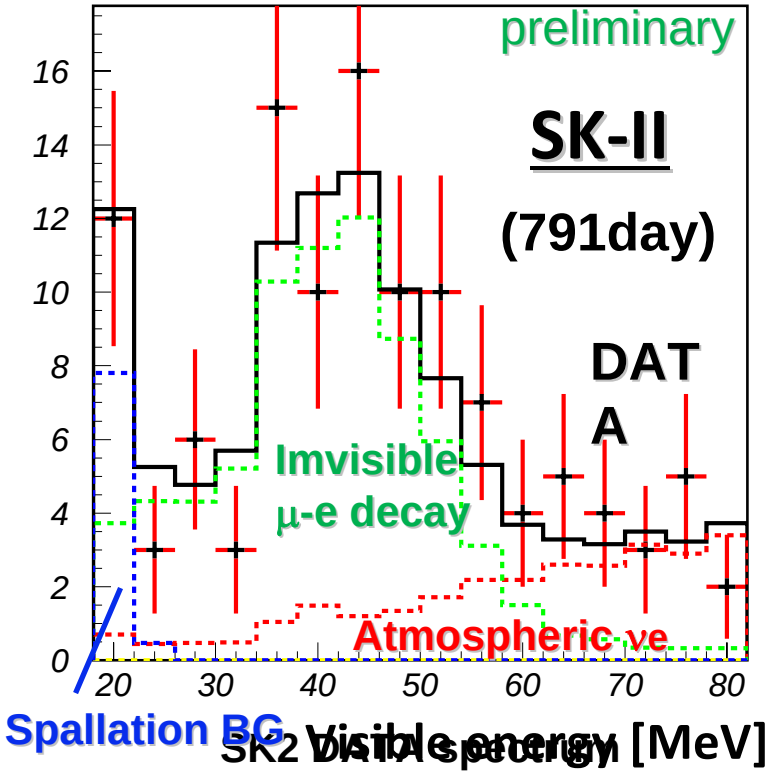


backup slides

Spallation

Spallation product is made by cosmic ray muon. Some of spallation products can be a BG for SRN search.





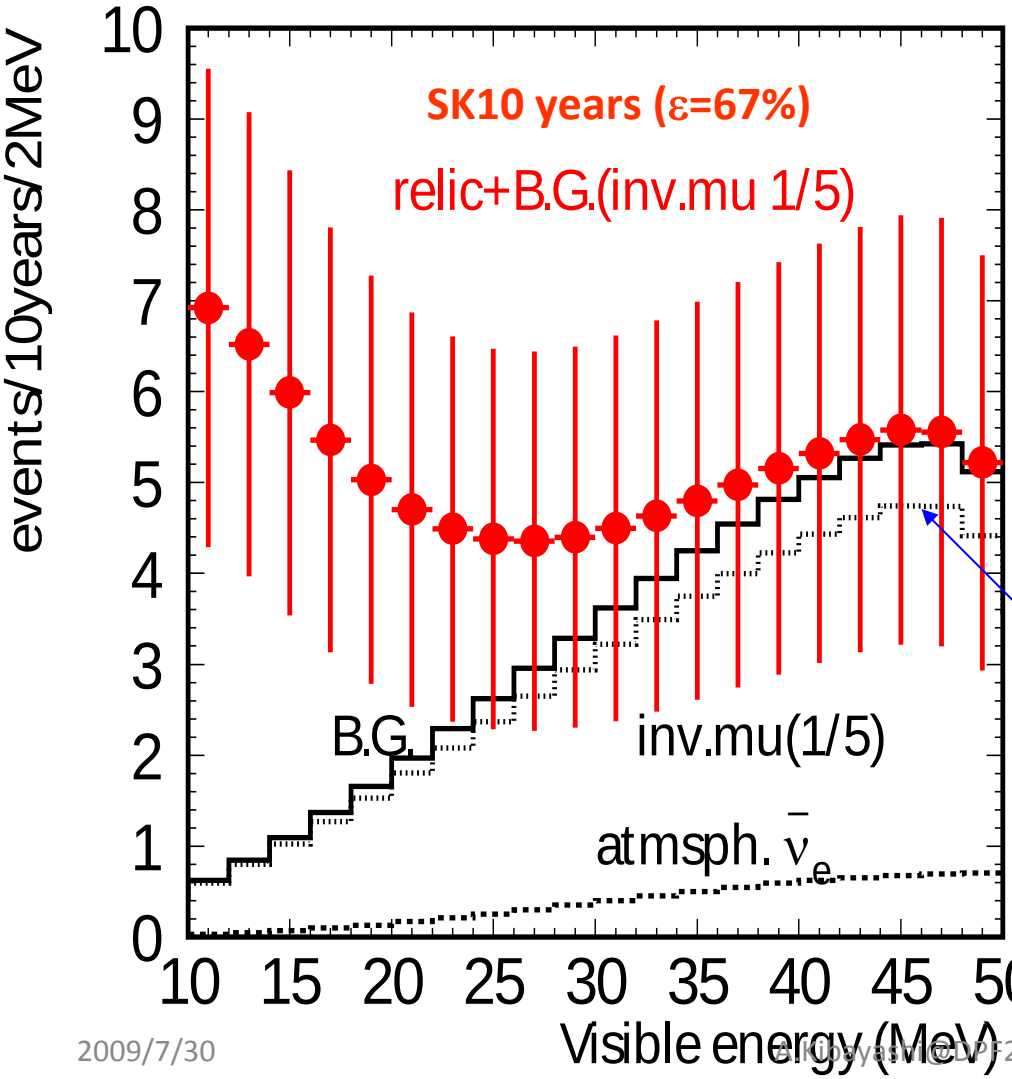
SK2 DATA spectrum

Analysis lower energy threshold is limited by spallation BG. Try to make good spallation event cut for lower energy threshold and better efficiency.

Possibility of SRN detection

Relic model: S.Ando, K.Sato, and T.Totani, Astropart.Phys.18, 307(2003) with NNN05 flux revision

If invisible muon background can be reduced by neutron tagging



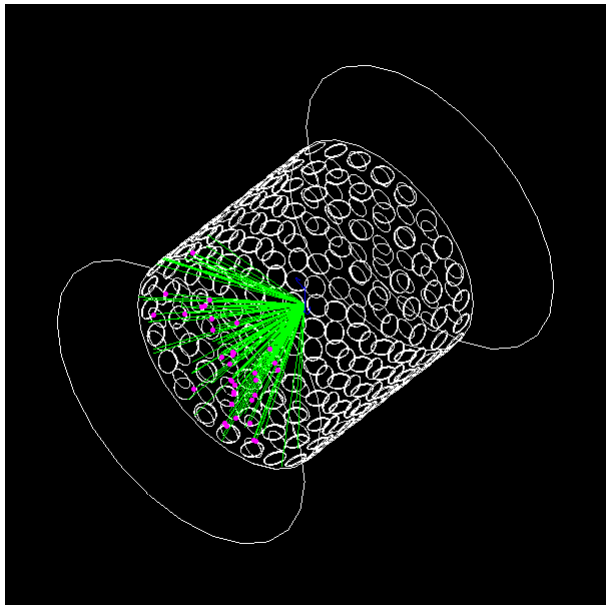
Assuming 67% detection efficiency.

With 10 yrs SK data,
Signal: 33, B.G. 27
(E_{vis} =10-30 MeV)

Assuming invisible muon B.G. can be reduced by a factor of 5 by neutron tagging.

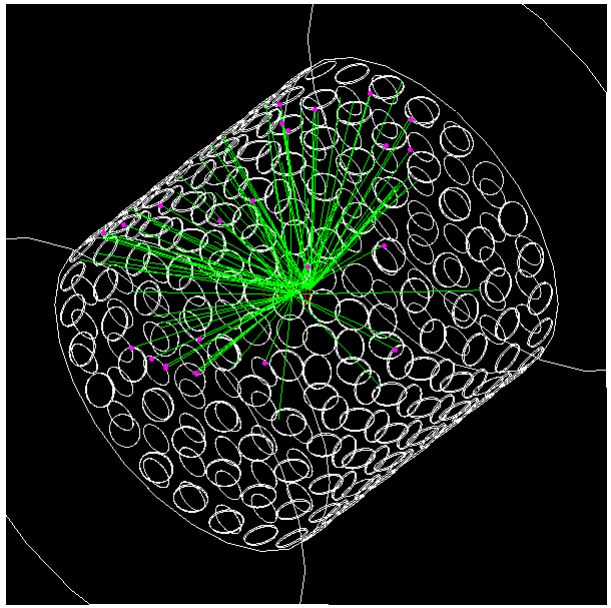
EGADS MC

positron



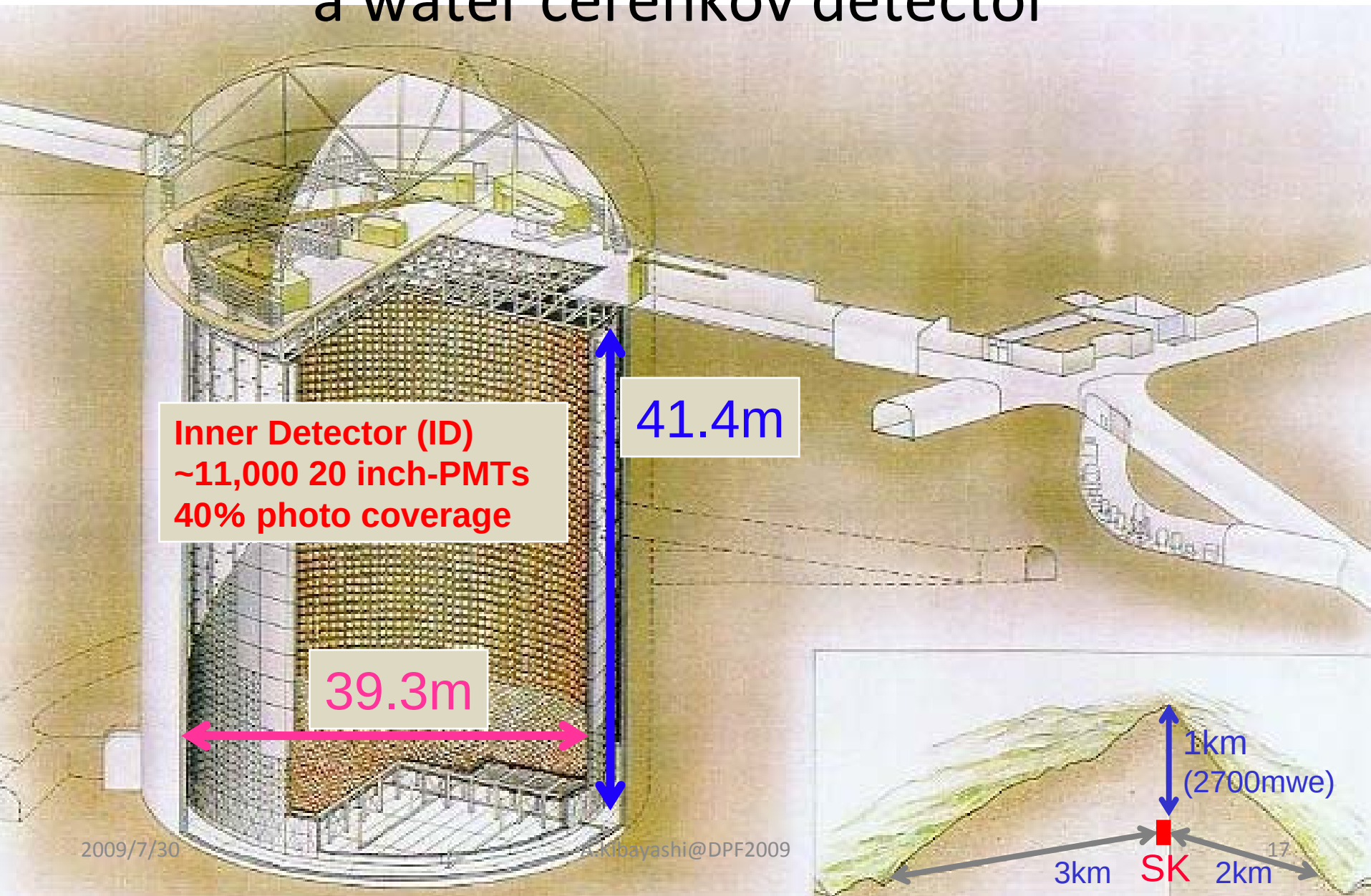
Vertex resolution
120~200 cm depending on cut

Gd capture 157

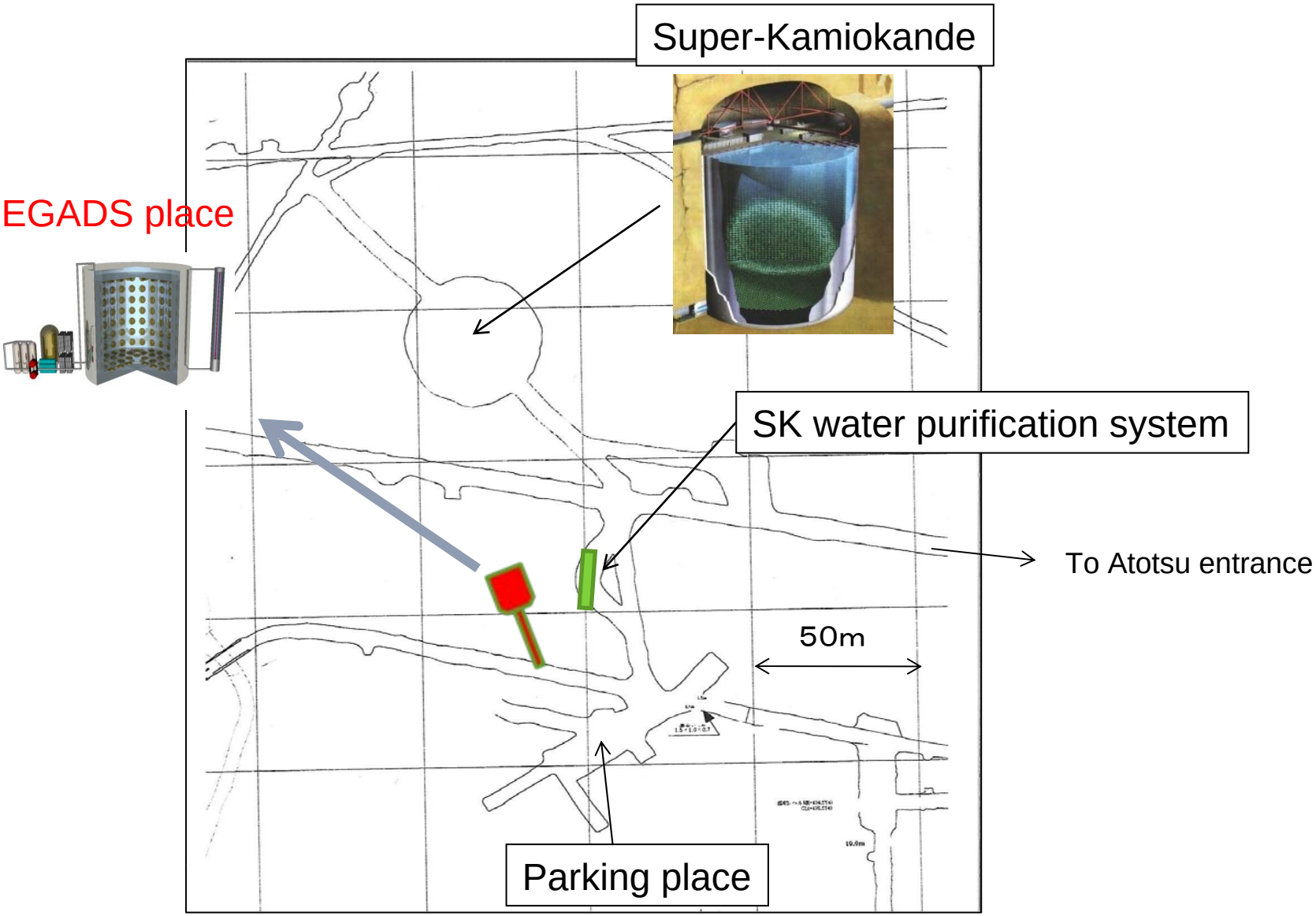


Vertex resolution
120~160cm depending on cut

Super Kamiokande (SK)
a water cerenkov detector

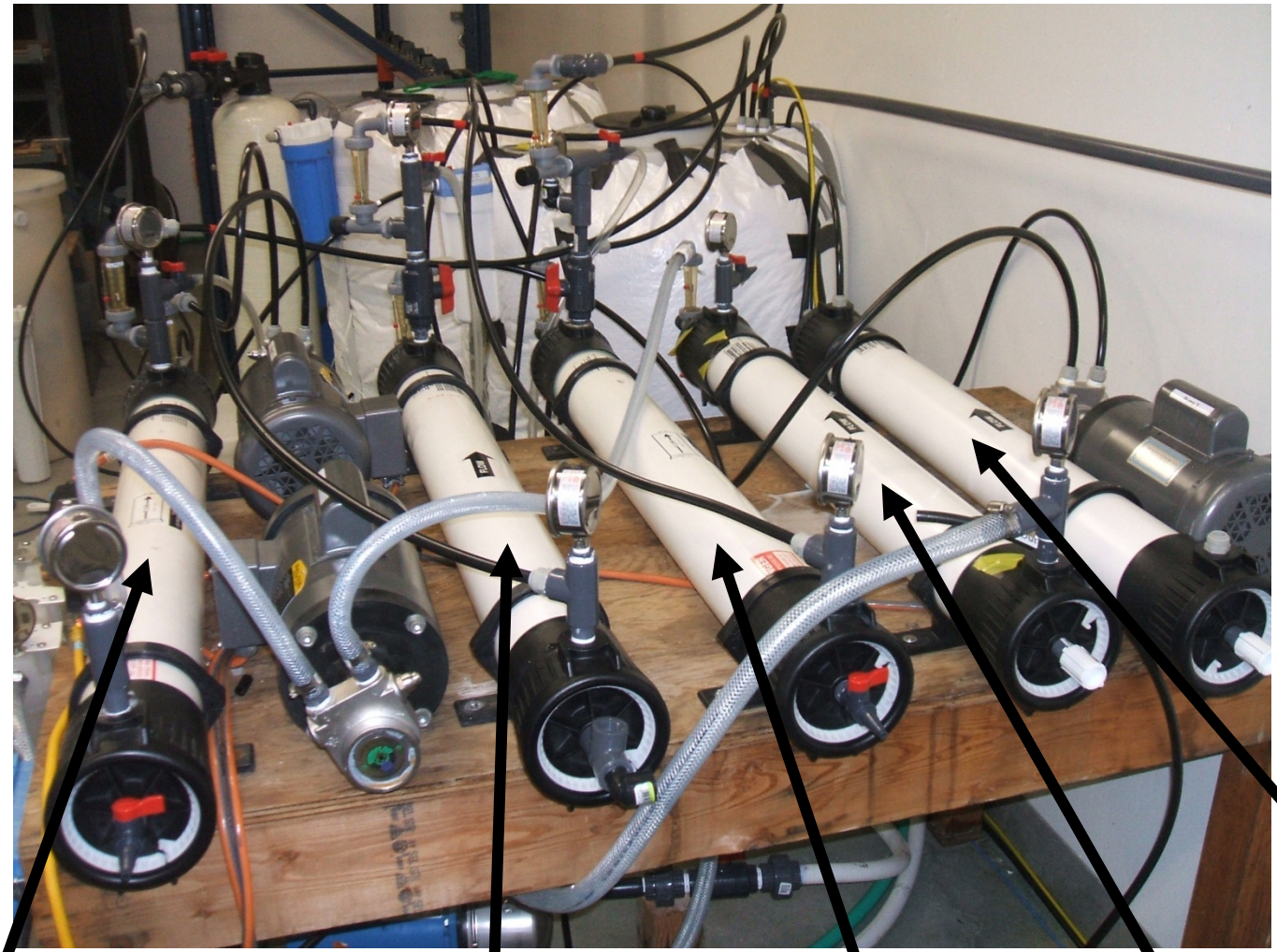


Possible location of the New Cavity



神岡地下坑道図

Current Selective Filtration Setup @ UCI



Membrane Pre-Flush

Nanofilter #1

Nanofilter #2

Reverse Osmosis

Ultrafilter

Membrane Type	Gd Remaining in Product Stream vs. Original Tank Concentration	SO_4 Remaining in Product Stream vs. Original Tank Concentration	Gd in Reject Streams	SO_4 in Reject Streams
NF Stage 1 (Nitto)	0.15%	<0.11%	99.85% (returned to “SK” by NF1)	>99.89% (returned to “SK” by NF1)
NF Stage 2 (Nitto)	<0.006%	<<0.11%	>99.994% (returned to “SK” by NF1+NF2)	>>99.89% (returned to “SK” by NF1+NF2)
RO (Koch)	<<0.006%	<<0.11%	<<0.006%	<<0.11%

Ran continuously for six weeks – no filter or membrane clogging

- Expected rates at SK (Beacom & Vagins, 2004)
  - /22.5 kton
  - SRN neutrino 5 /year
  - Reactor neutrino 5000 /year
- Reactor neutrino at EGADS
  - Photosensitive Vol. ~114 ton: 25 /year
  - 2m from wall fiducial vol. ~1.5 ton: 1 /3years