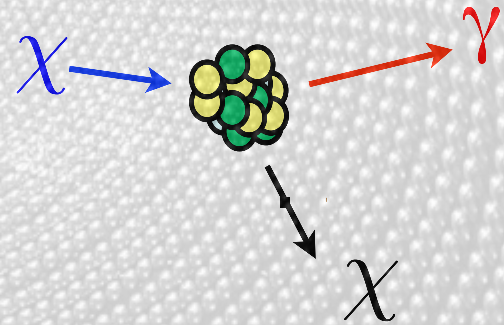
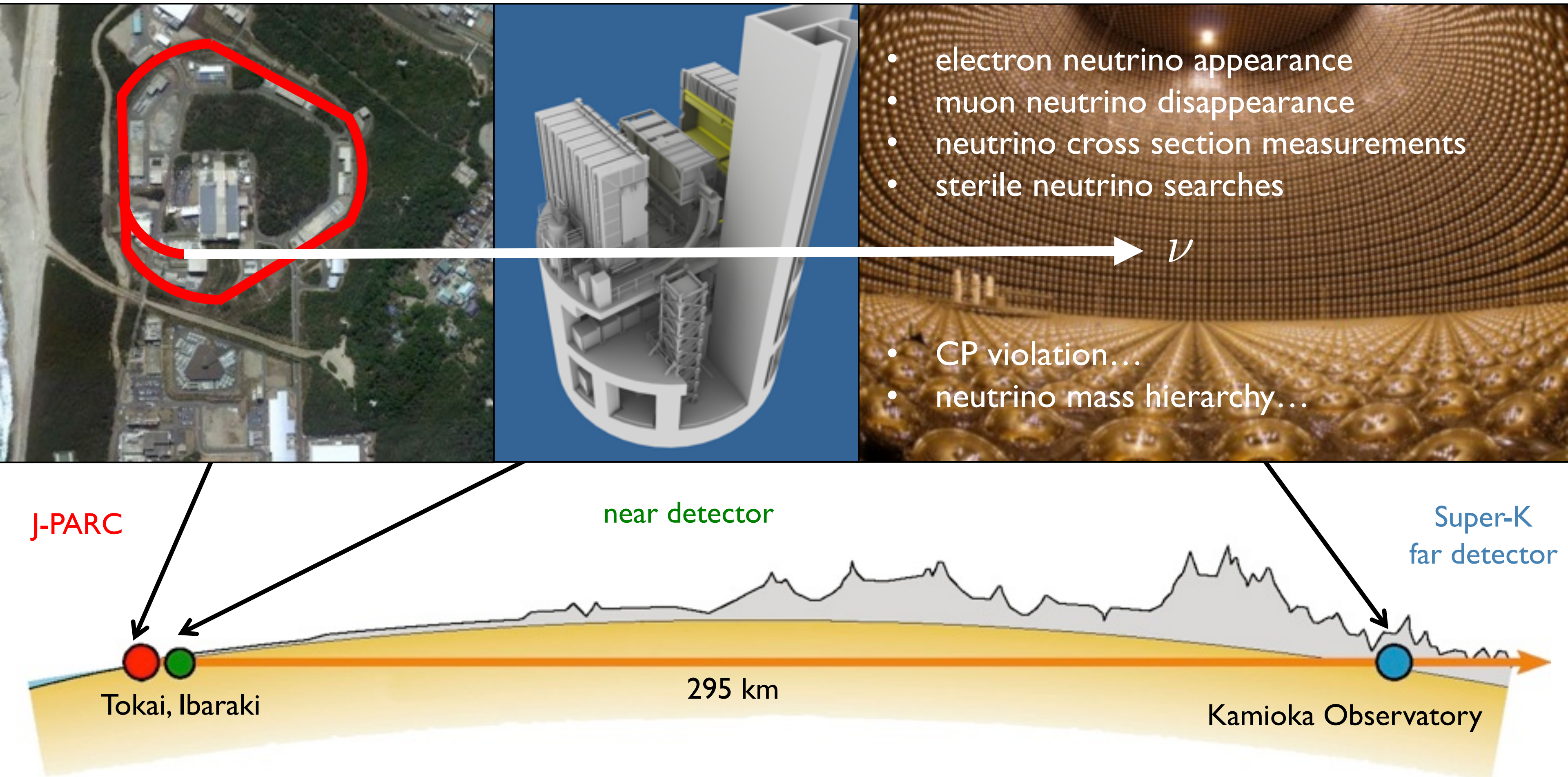
Corina Nantais
Local meeting
04 May 2017

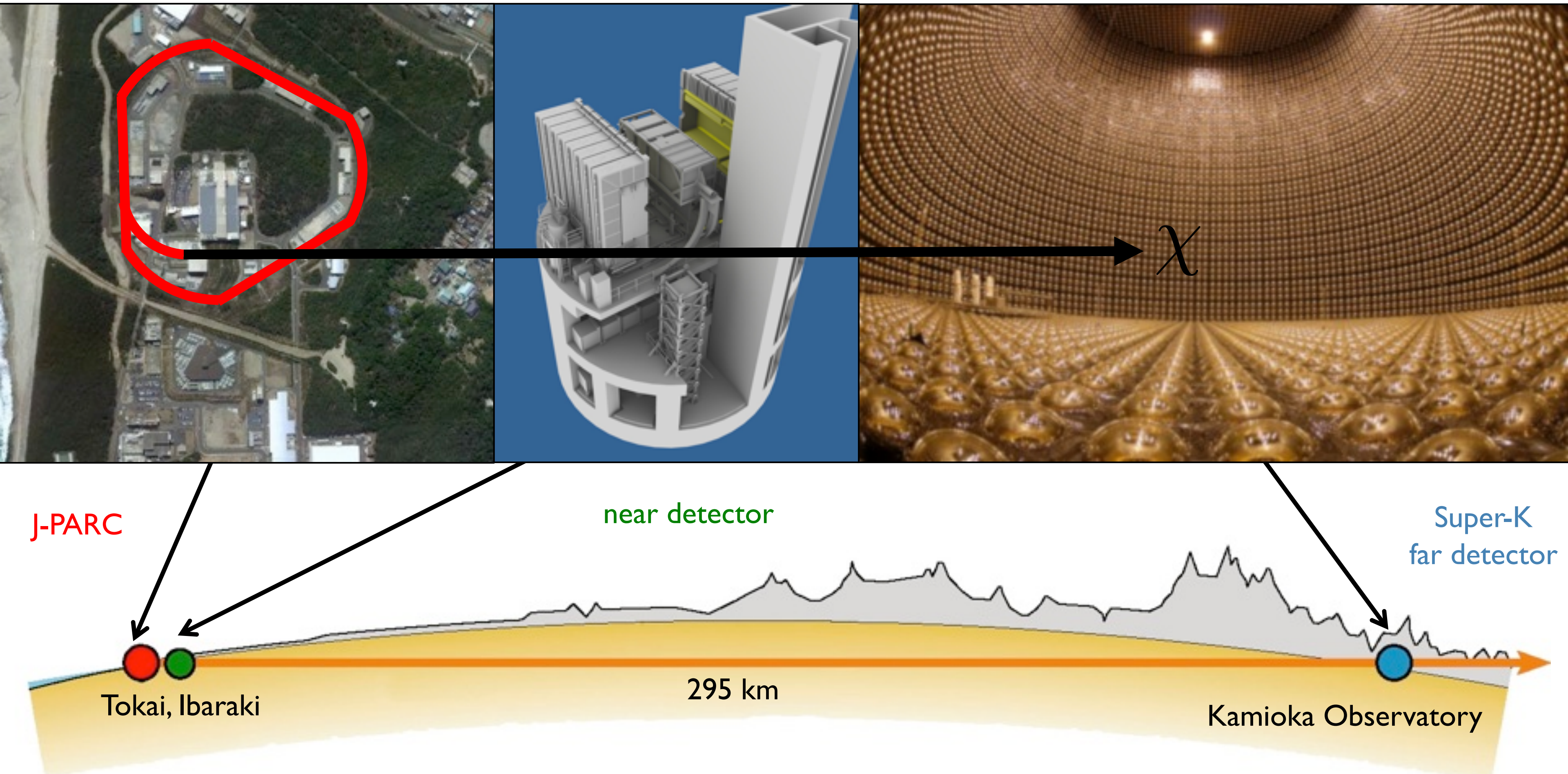


Search at Super-Kamiokande for neutral current de-excitation gamma rays induced by light dark matter in the T2K neutrino beam

T2K is a long baseline neutrino oscillation experiment



T2K ... can be used to produce and then detect DM



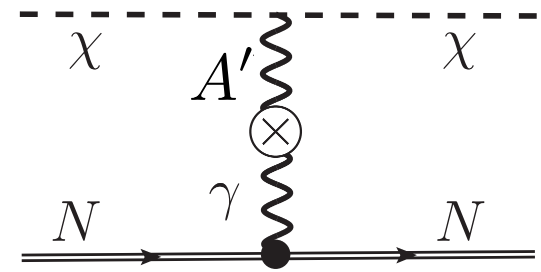
Propose to detect accelerator-produced sub-GeV (light) dark matter in Super-K

Dark sector connected to Standard Model through vector portal

Kinetic mixing between Standard Model γ and vector mediator A'

$$m_{A'} > 2\, m_{\chi}$$

$$A' \rightarrow \chi + \bar{\chi}$$

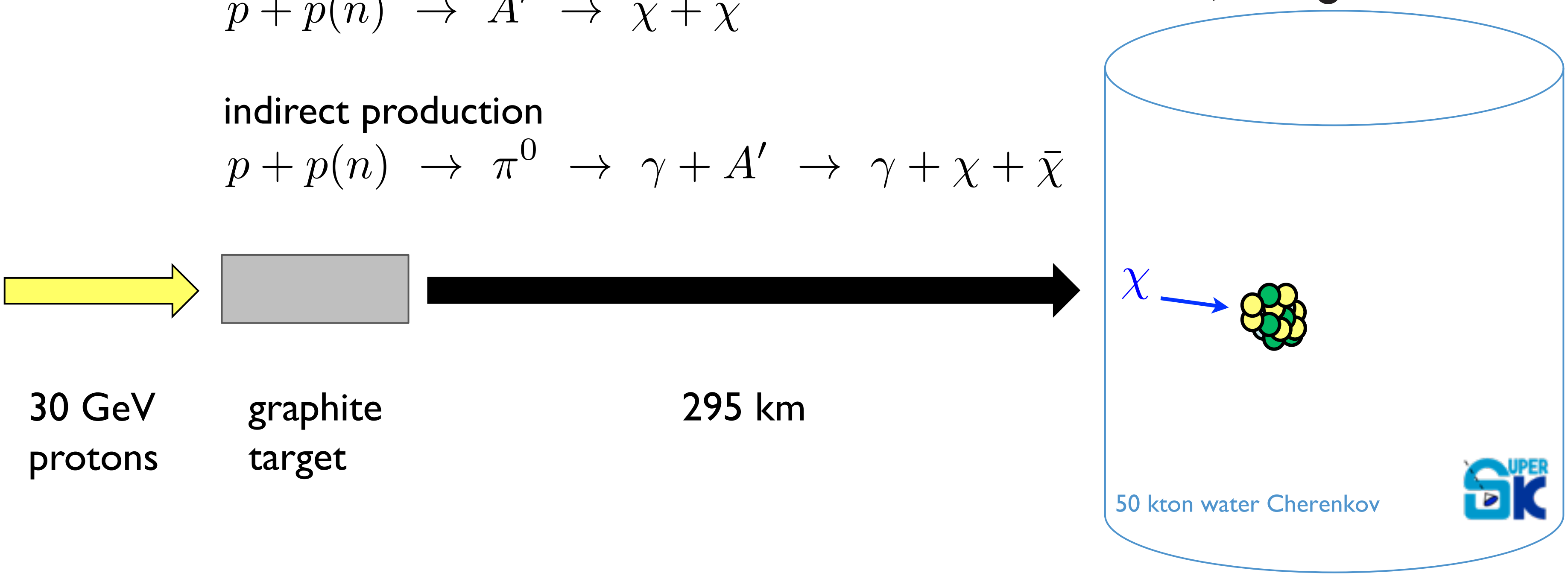


direct production

$$p + p(n) \rightarrow A' \rightarrow \chi + \bar{\chi}$$

indirect production

$$p + p(n) \rightarrow \pi^0 \rightarrow \gamma + A' \rightarrow \gamma + \chi + \bar{\chi}$$

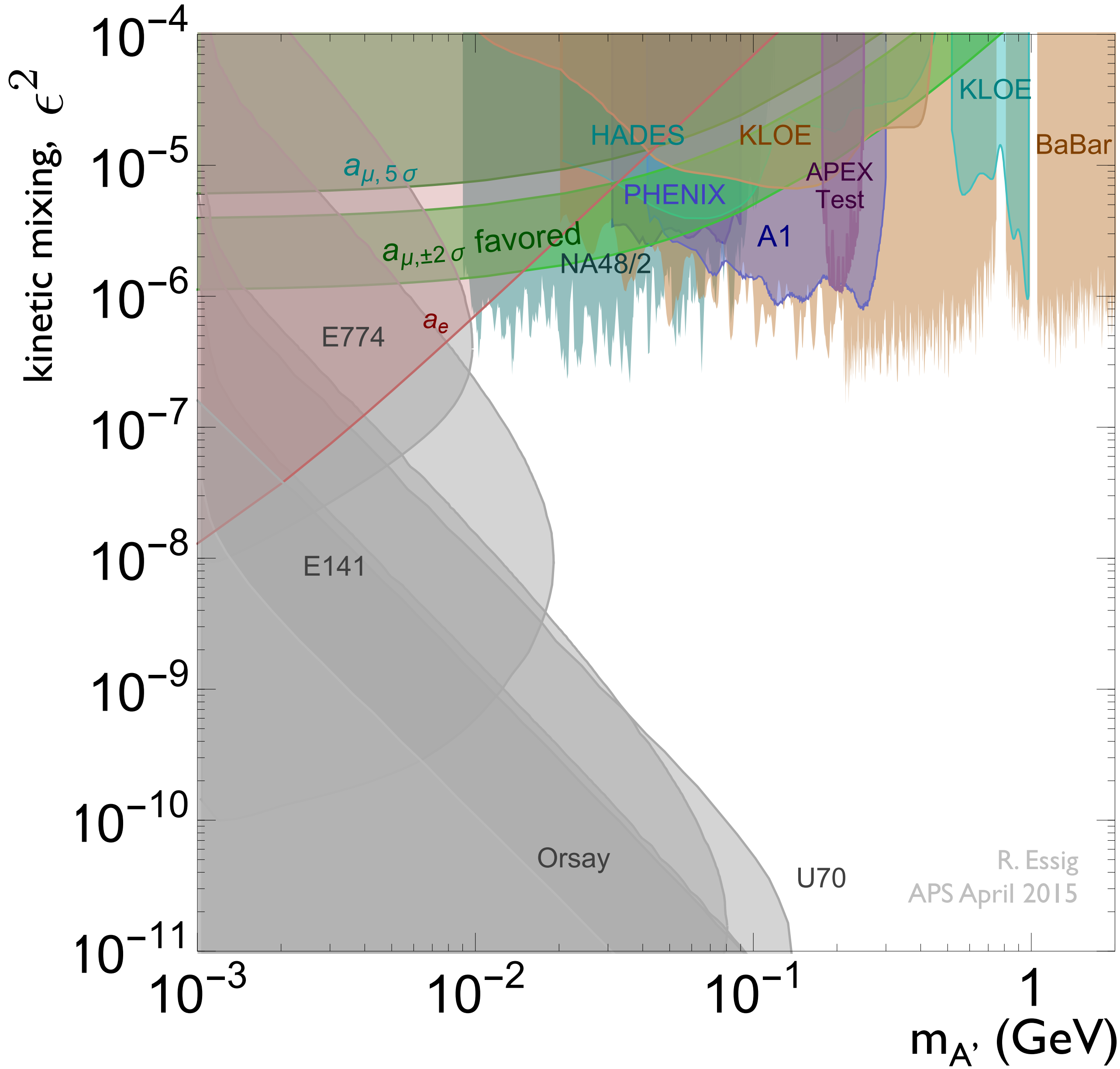


30 GeV protons

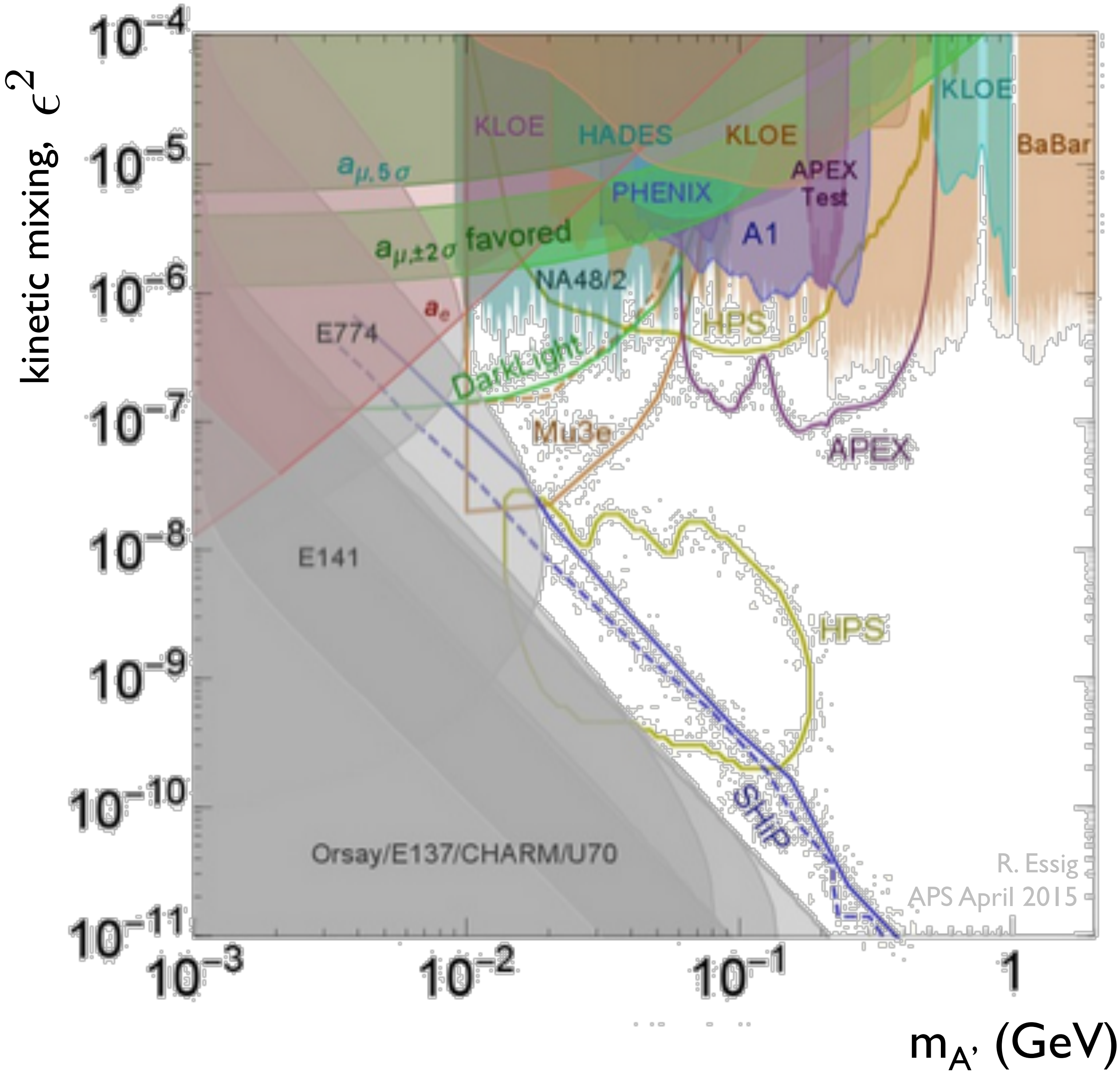
graphite target

295 km

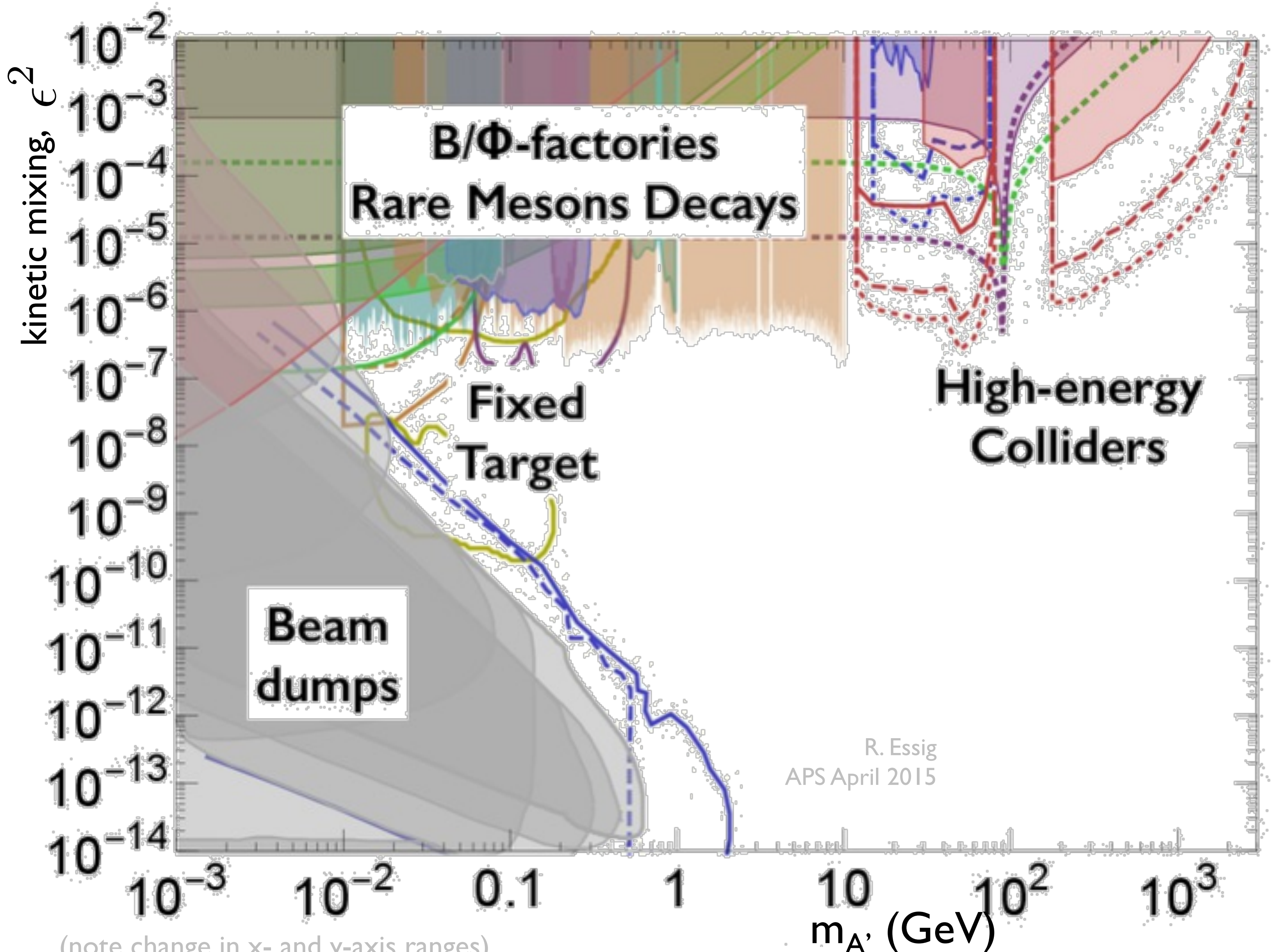
Some current constraints



Some future projections

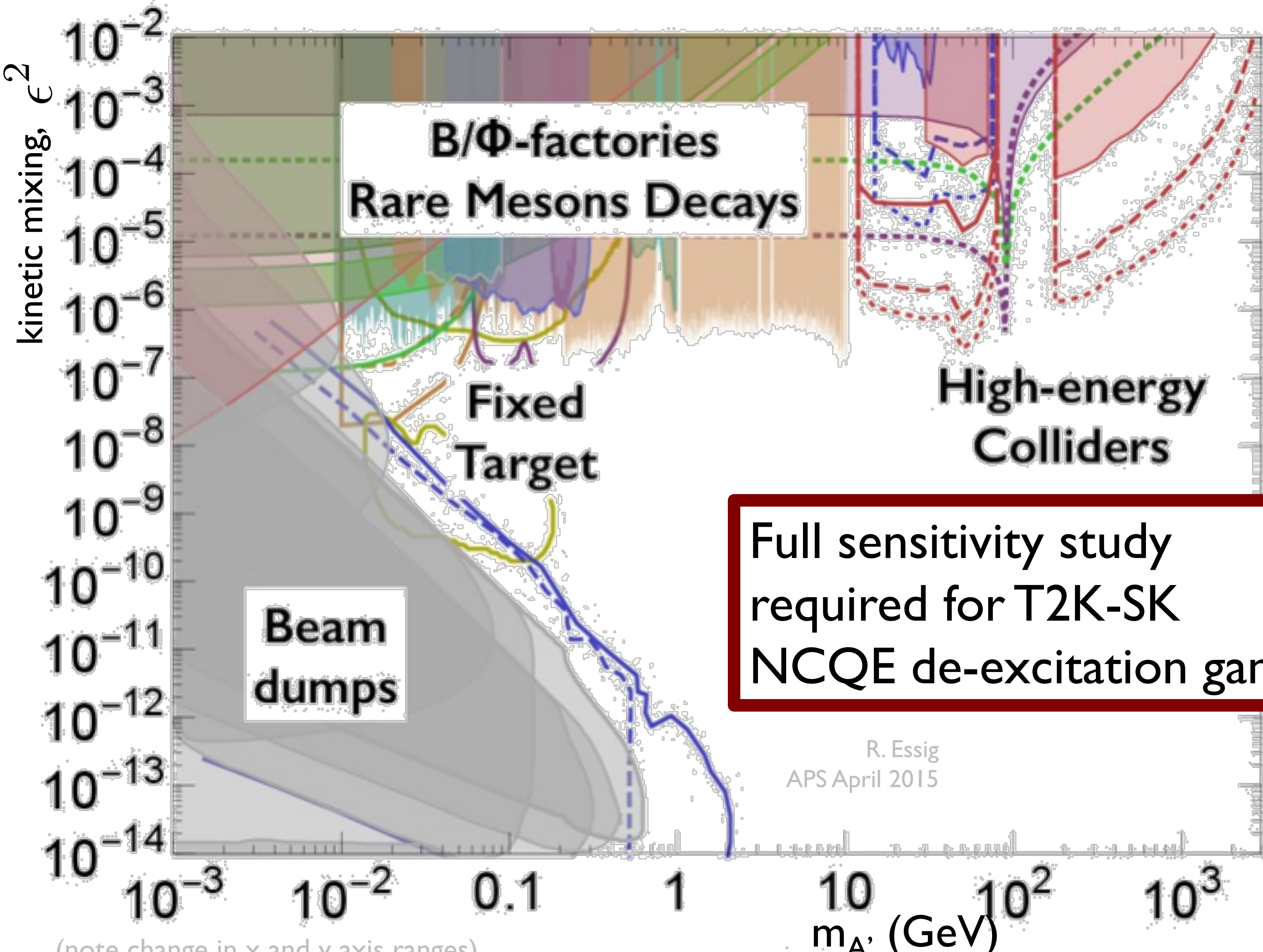


Types of experiments



(note change in x- and y-axis ranges)

Types of experiments

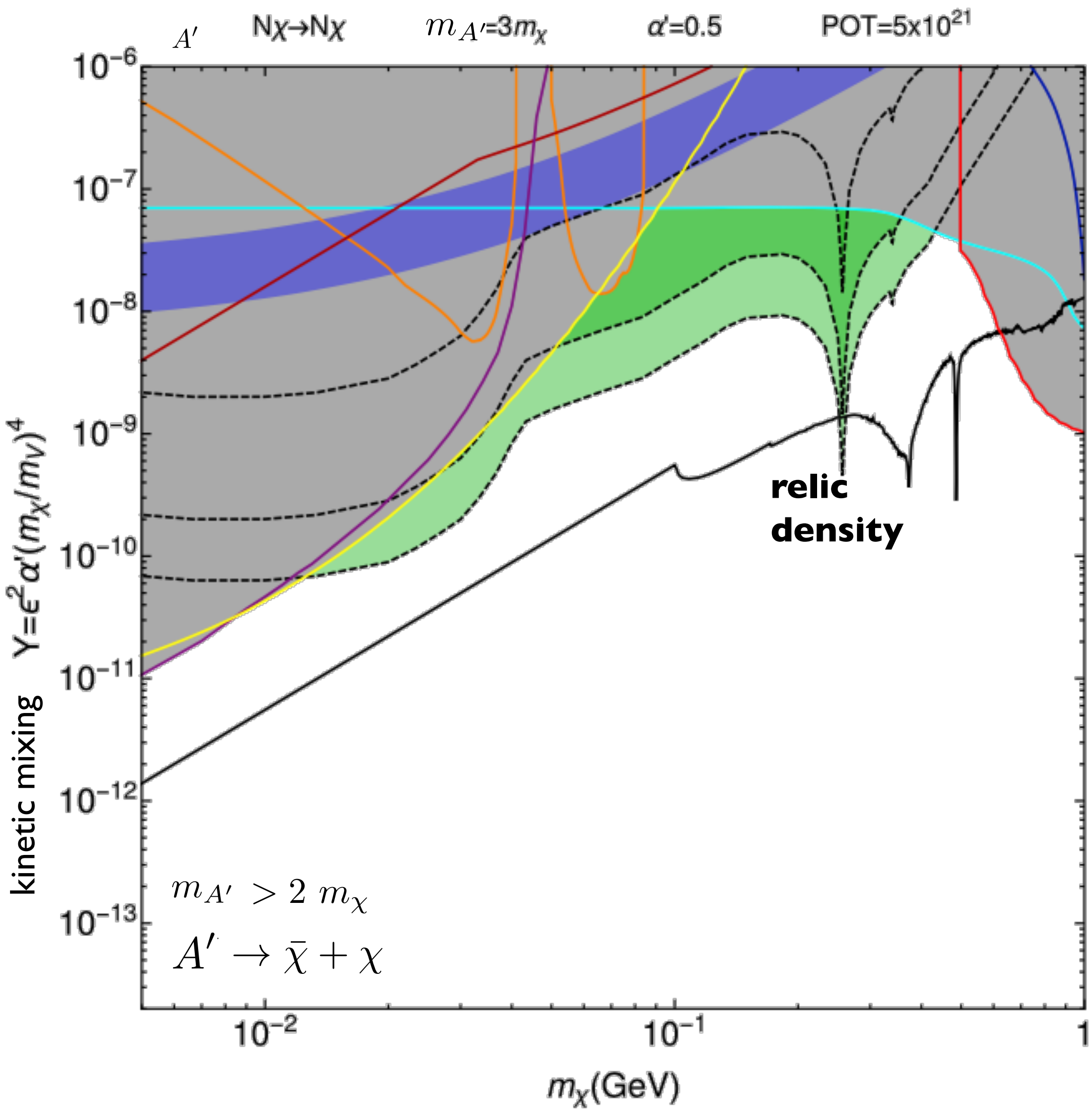


Full sensitivity study required for T2K-SK NCQE de-excitation gammas

(note change in x and y axis ranges)

Theorist estimate of T2K Super-K sensitivity

P. de Niverville, C.-Y. Chen, M. Pospelov, and A. Ritz, PRD **95**, 035006 (2017)



Some model-dependent constraints:

LSND

E137

BaBar

$K^+ \to \pi^+$ + invisible

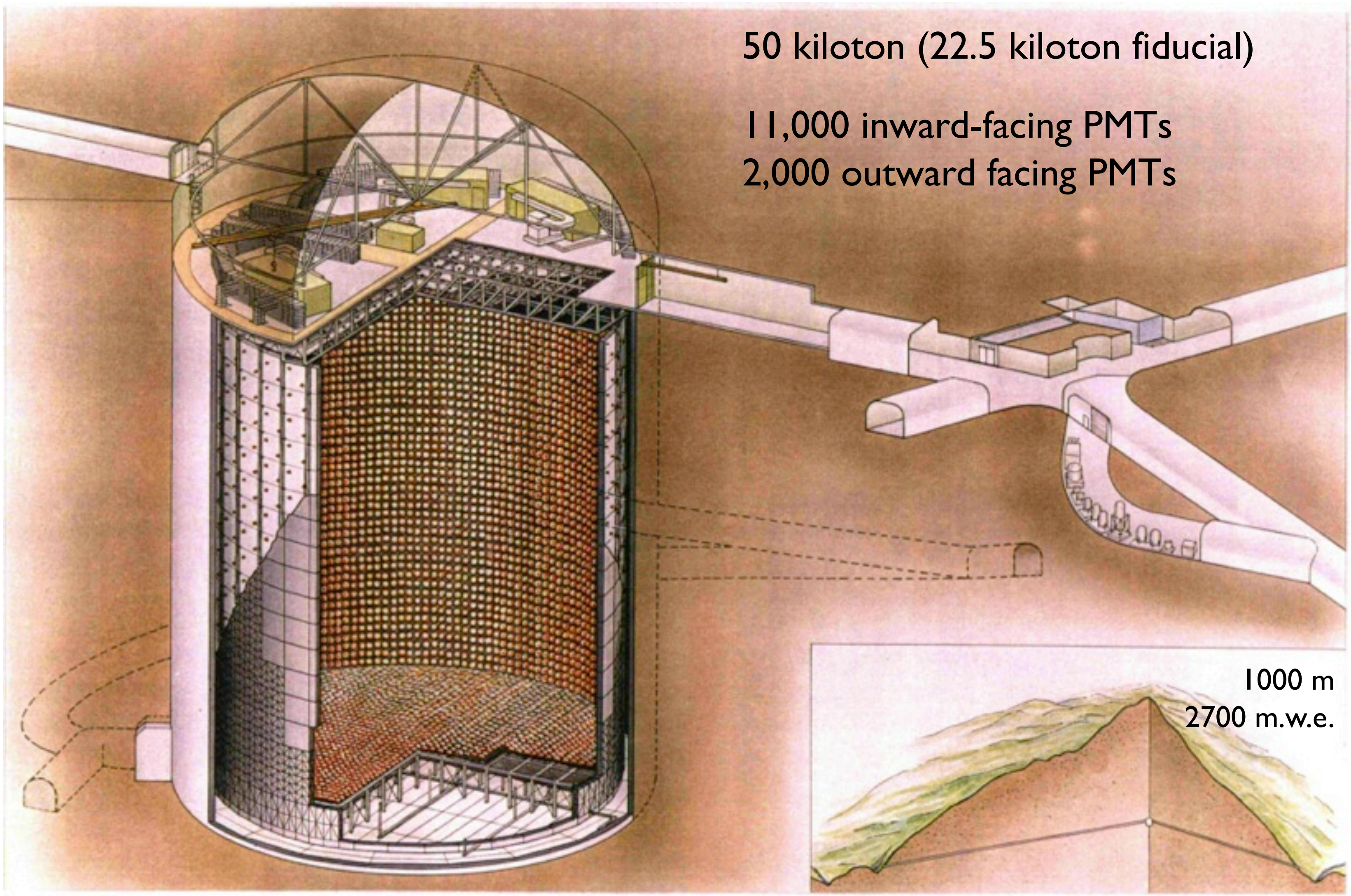
electron/muon g-2

$J/\psi \to$ invisible

direct detection

T2K Super-K
projected sensitivity
>1 events
>10 events
(>1000 events)

Super-K water Cherenkov detector is well understood



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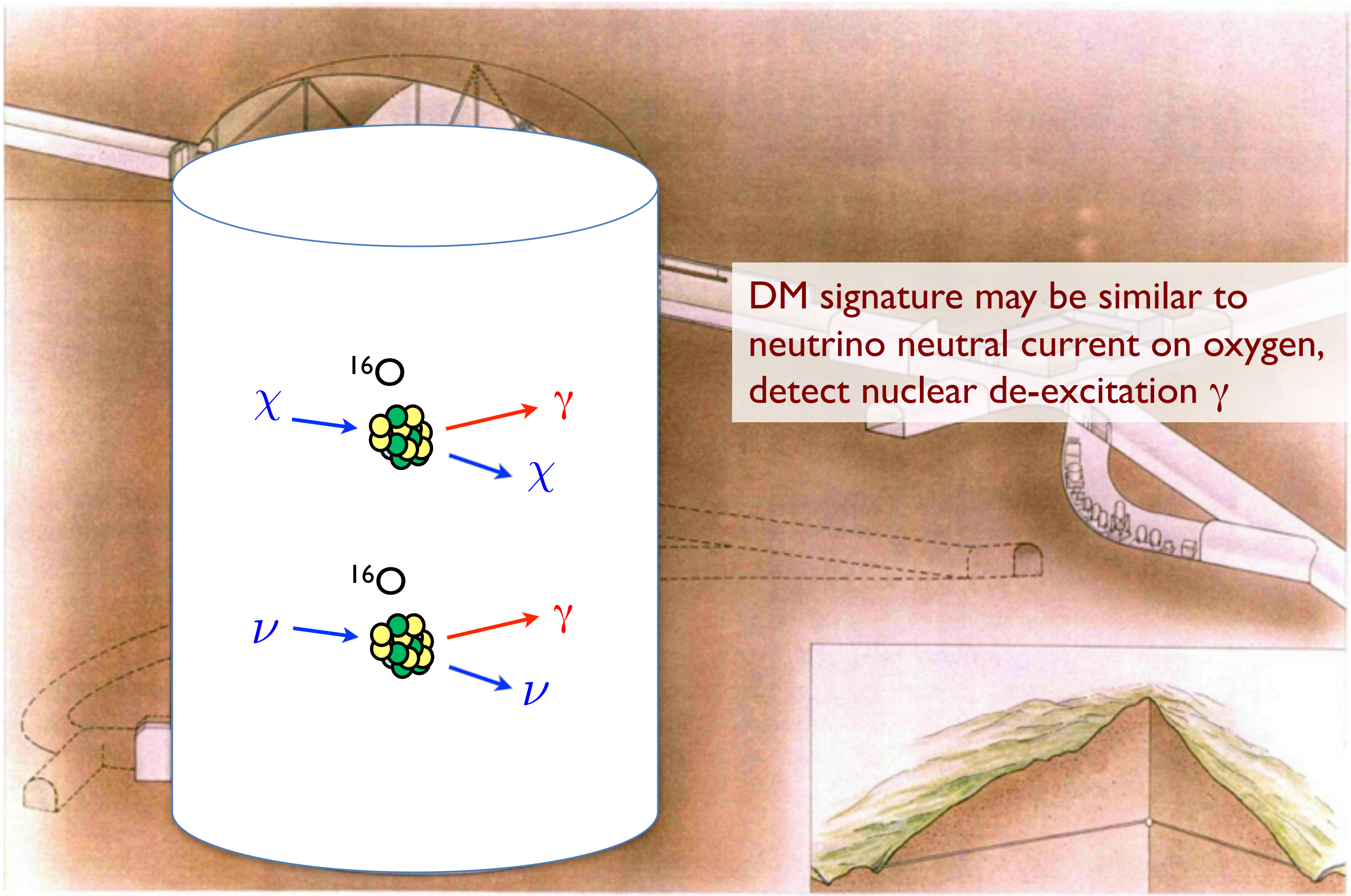
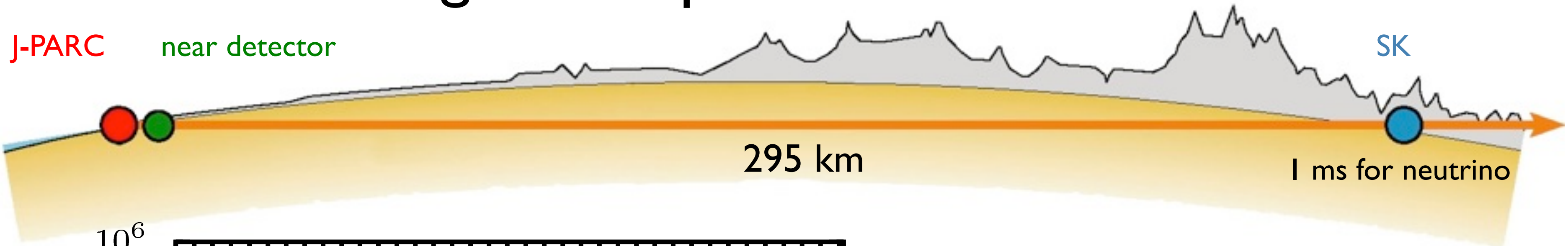
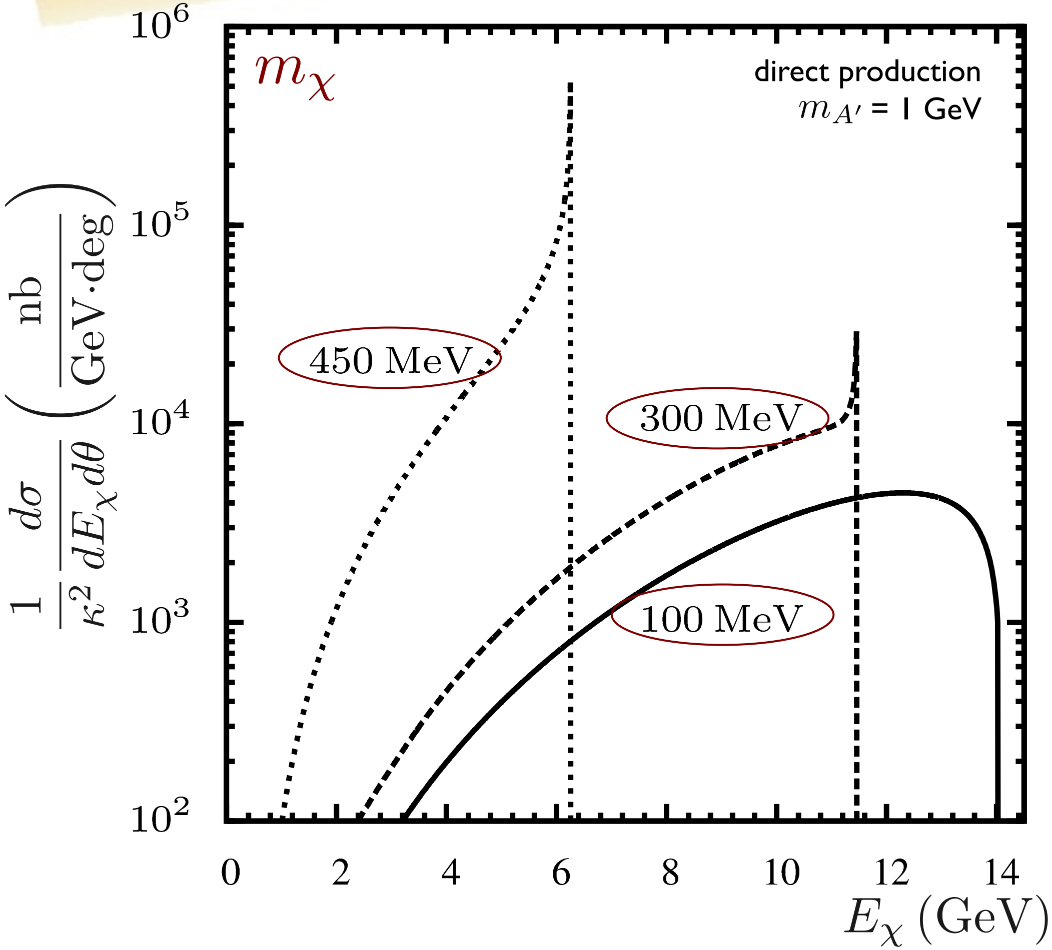


Time of flight to separate DM from neutrino

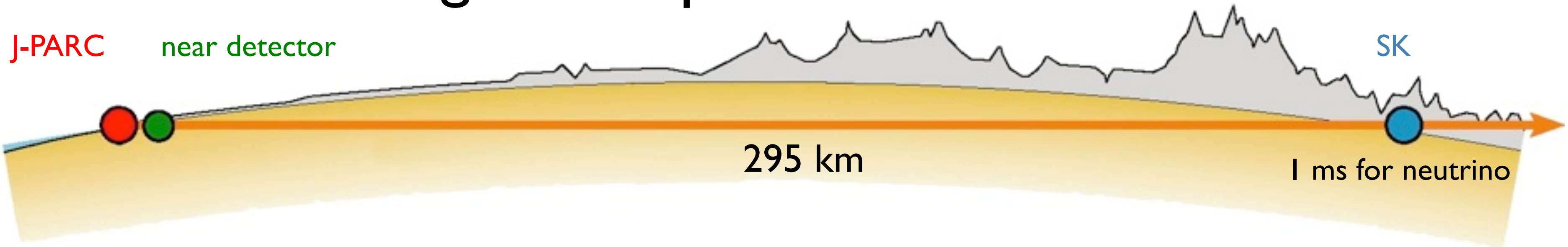


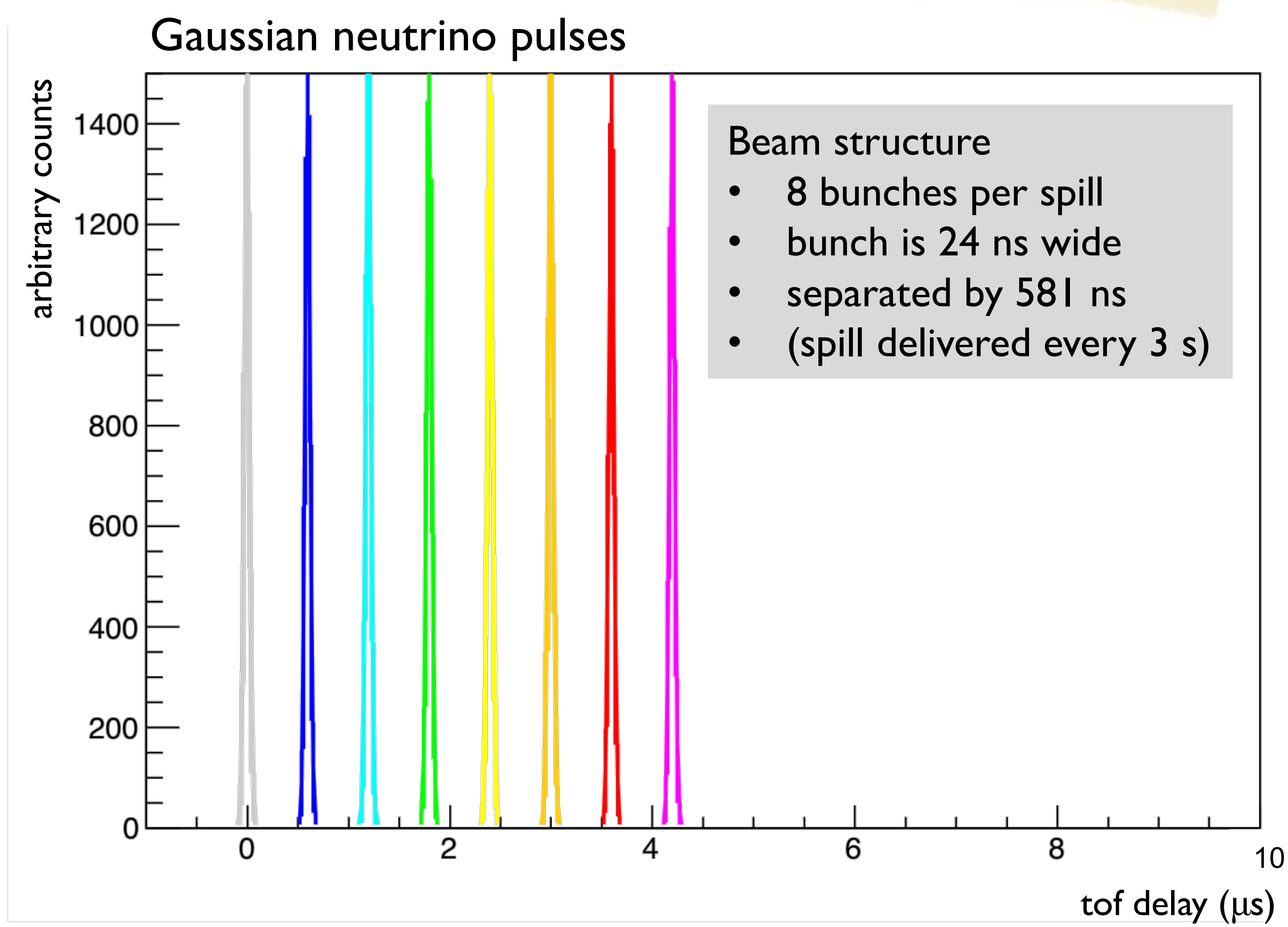


m_χ	TOF delay
450 MeV	3 μs
300 MeV	400 ns
100 MeV	30 ns

PRD **86** 035022 (2012), data from author

Time of flight to separate DM from neutrino





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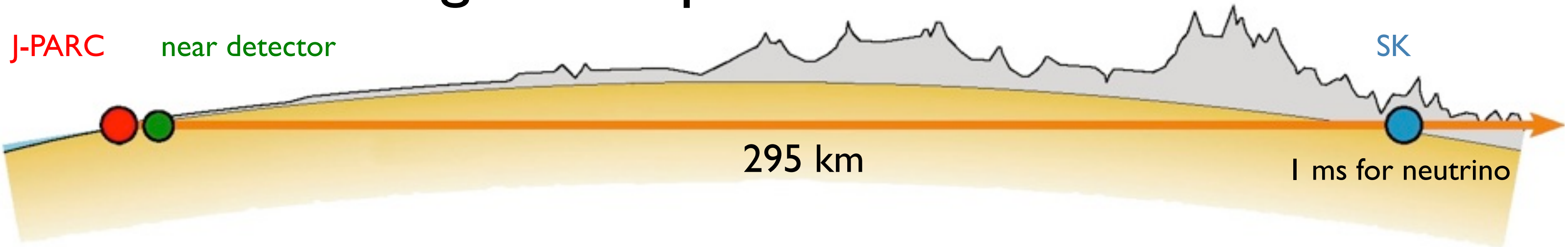
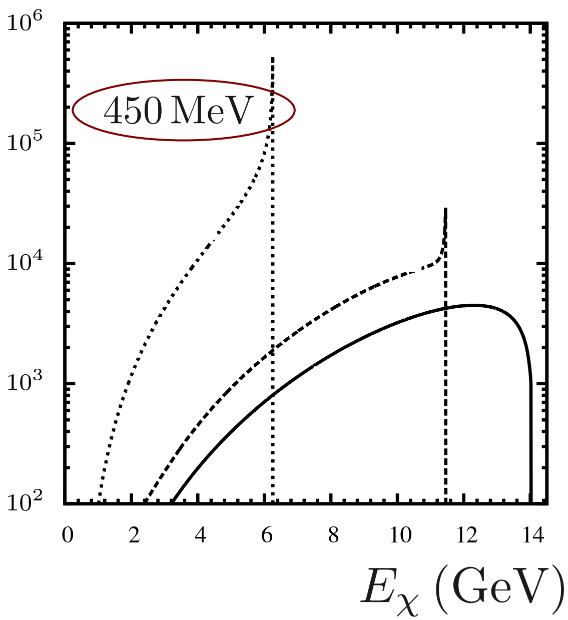
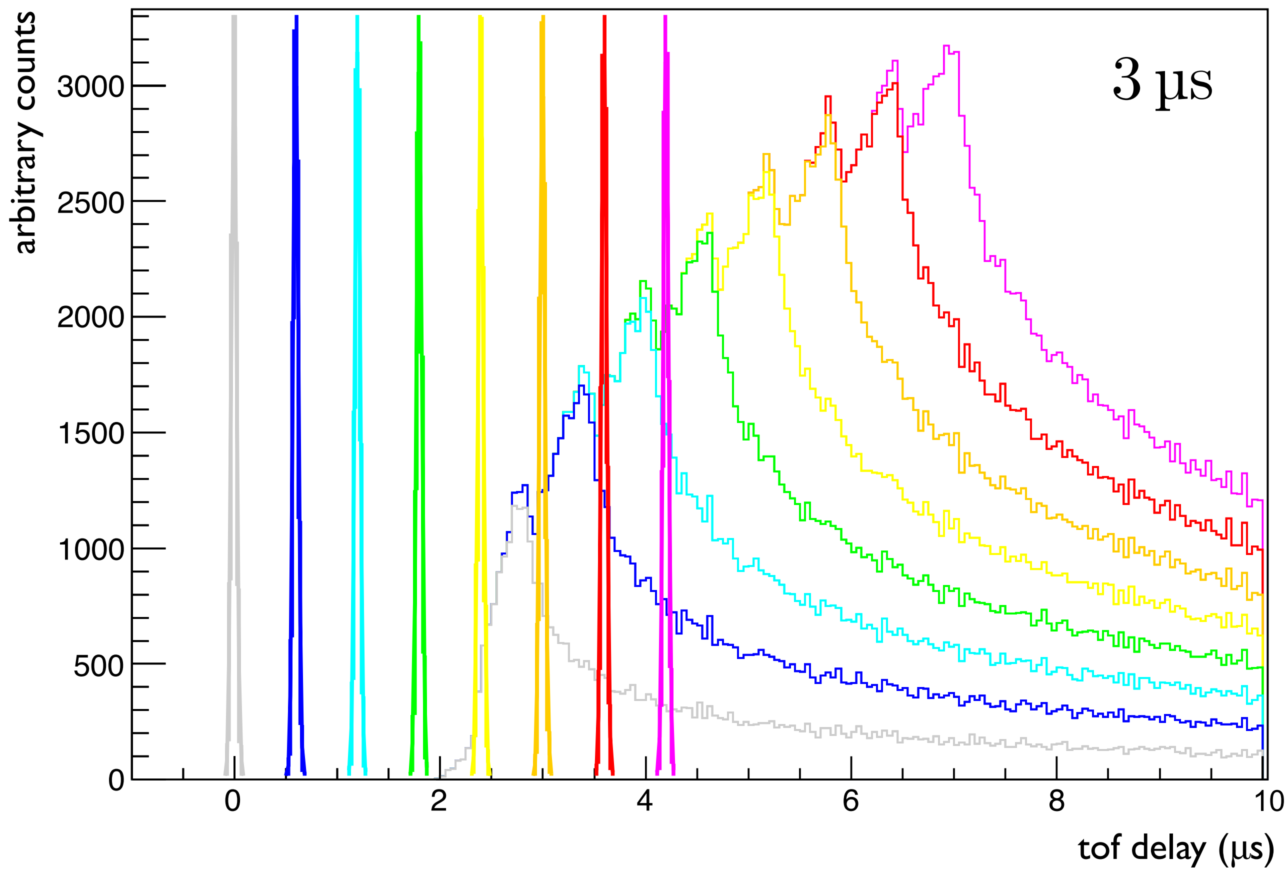
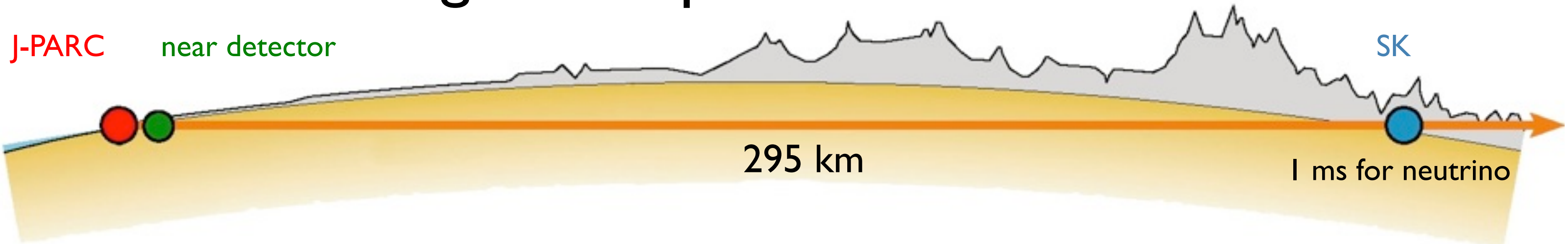


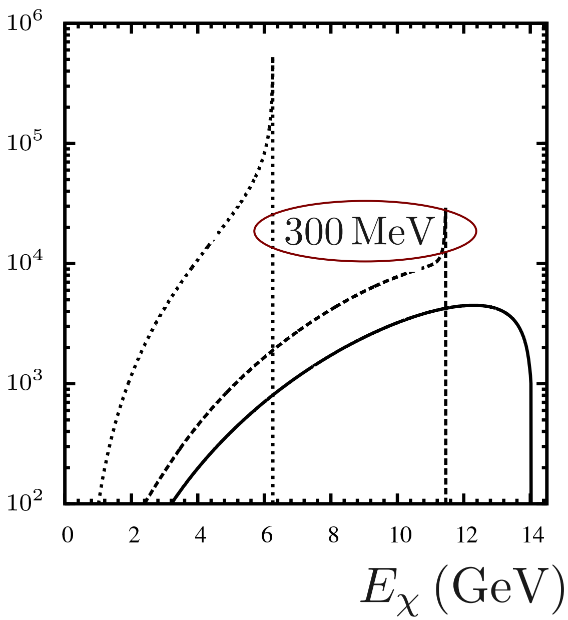


Gaussian neutrino pulses, followed by DM distributions

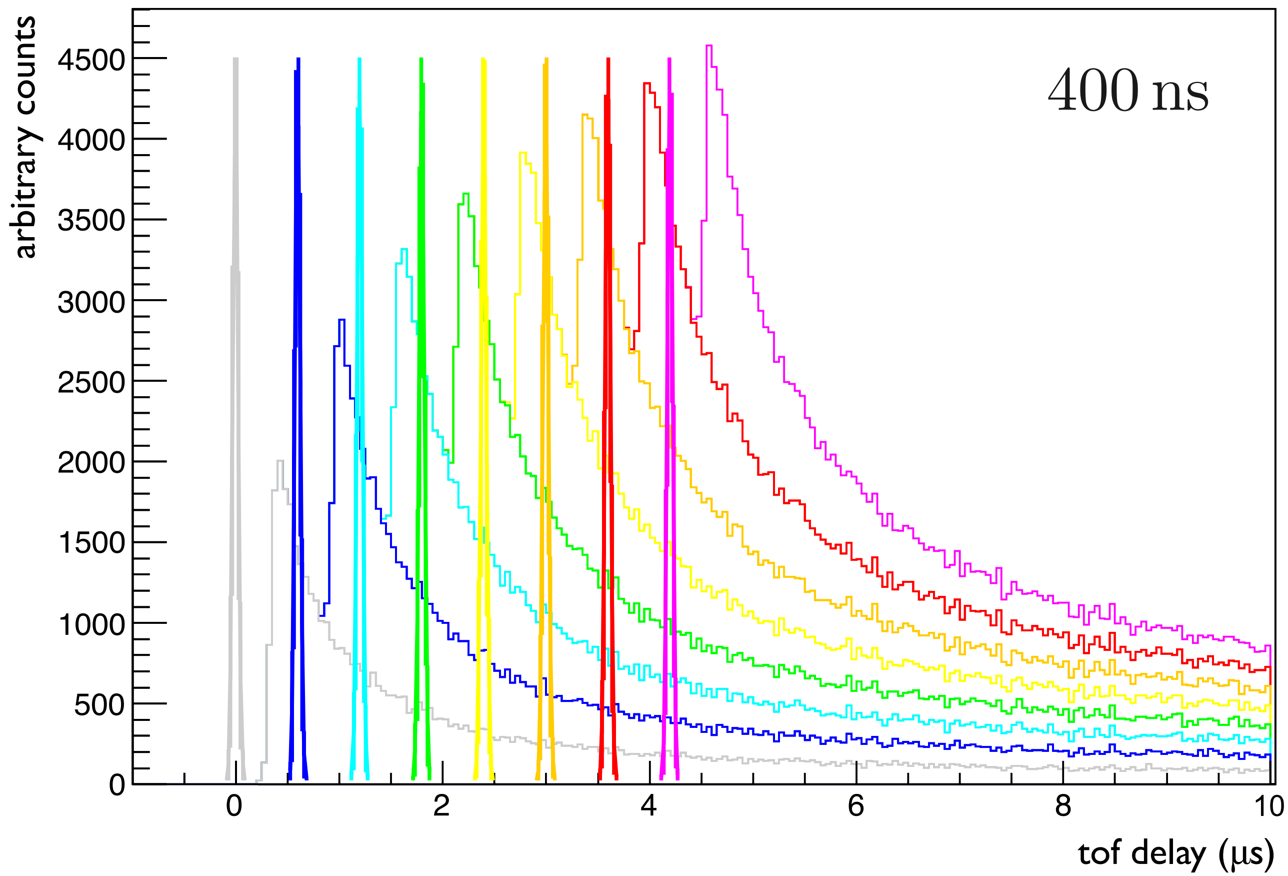


Time of flight to separate DM from neutrino

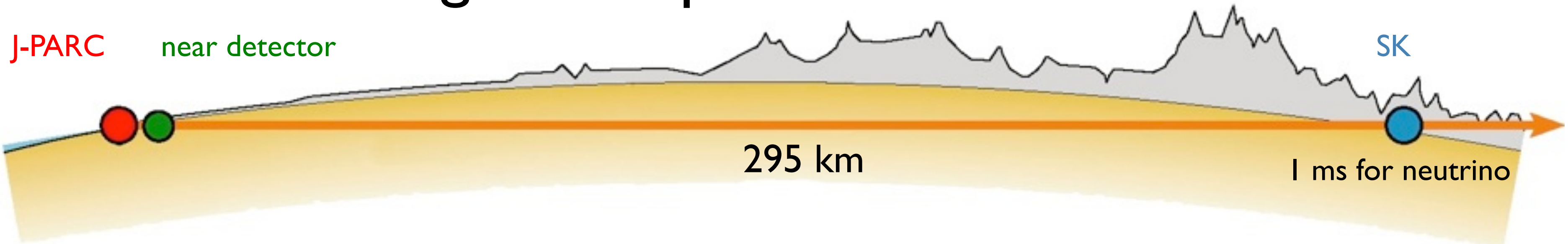


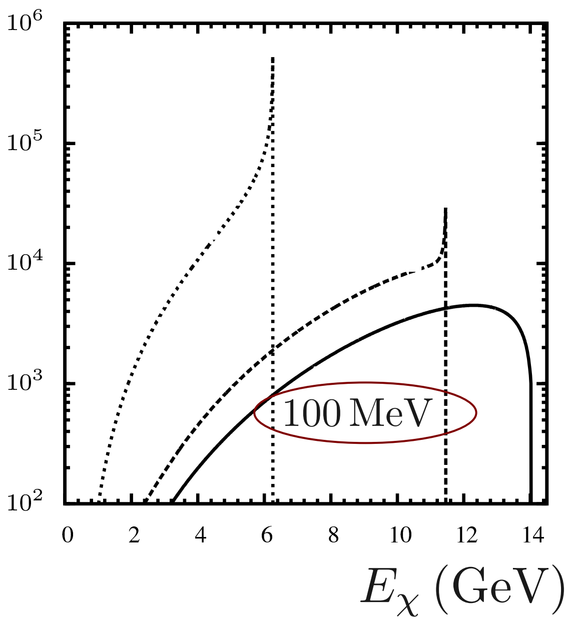


Gaussian neutrino pulses, followed by DM distributions

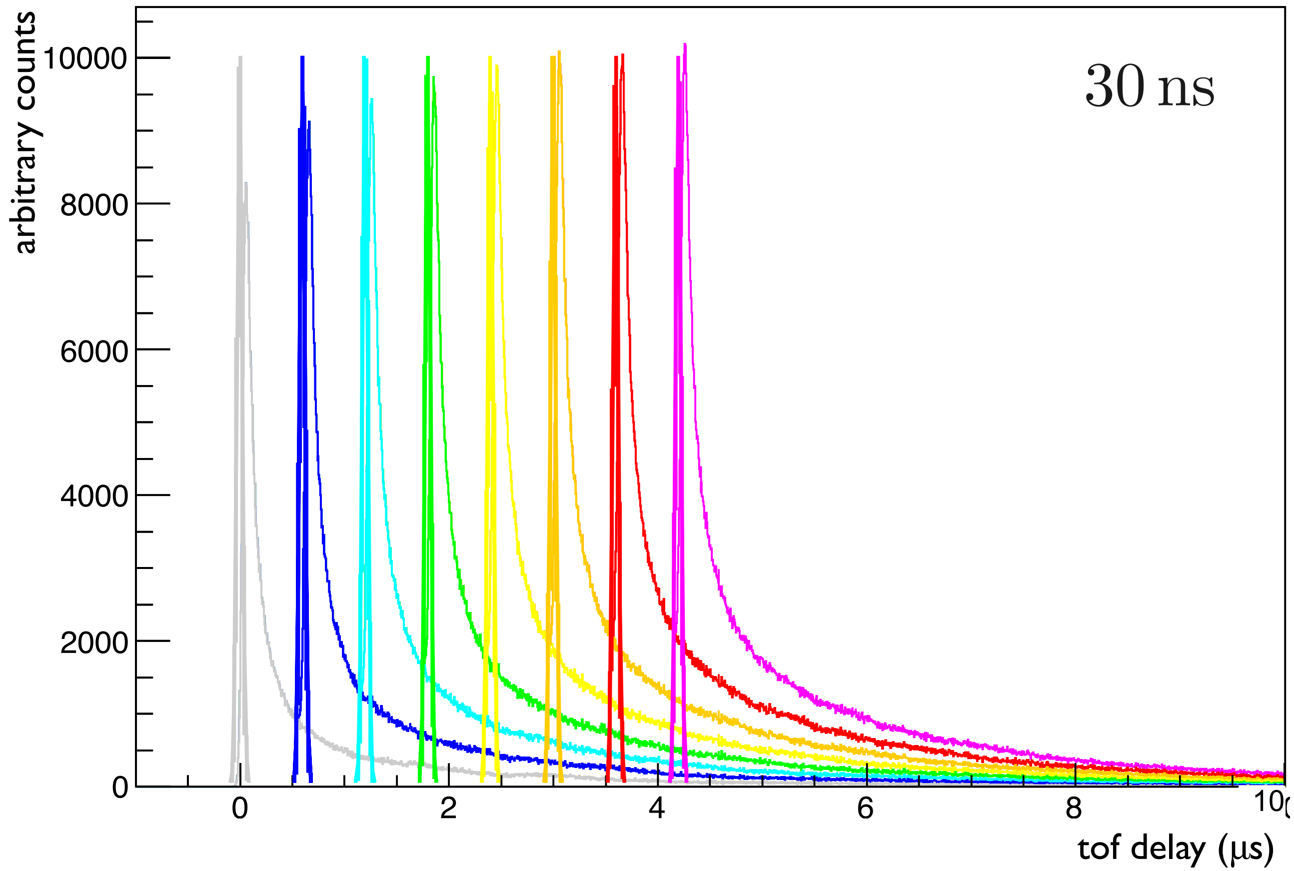


Time of flight to separate DM from neutrino

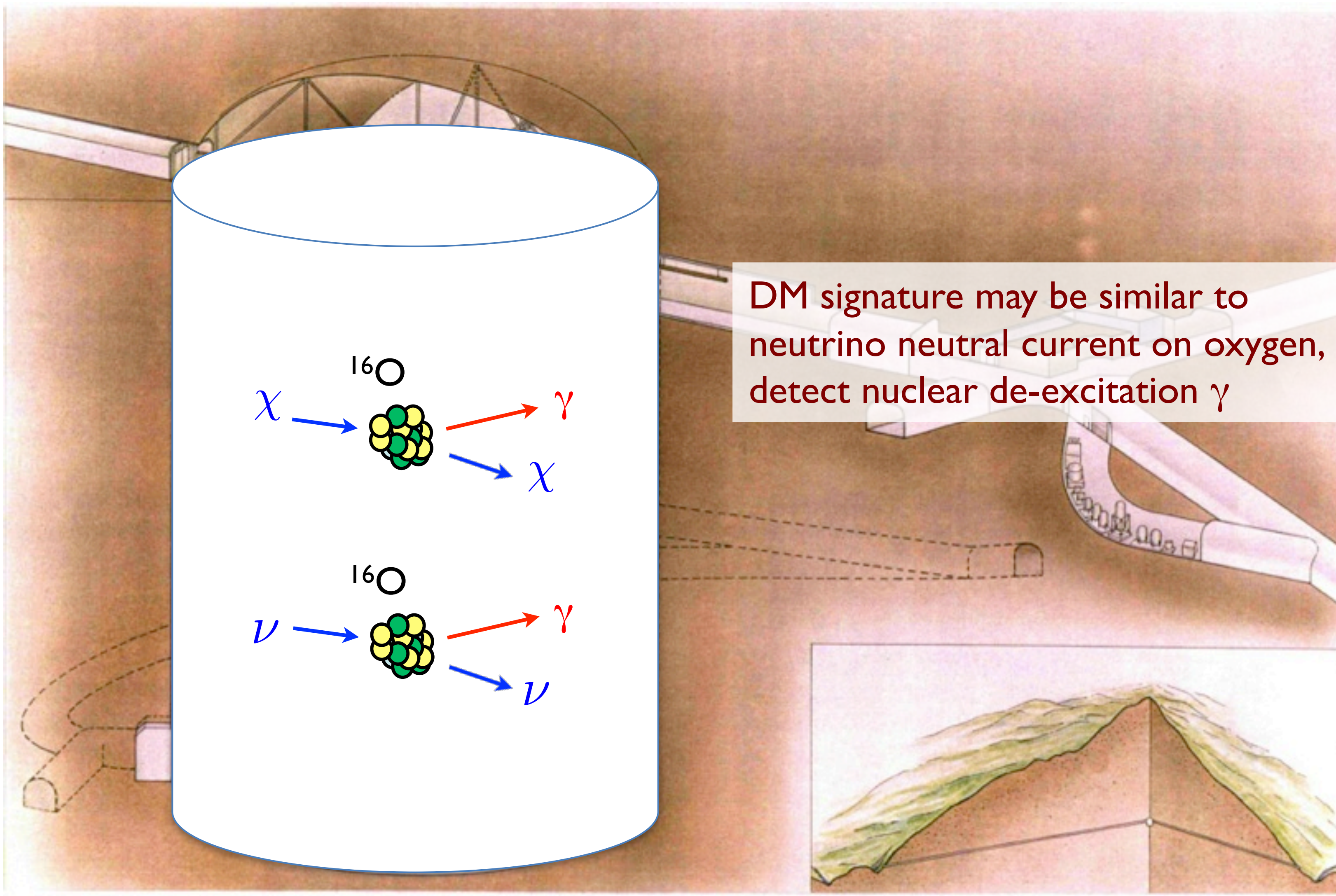




Gaussian neutrino pulses, followed by DM distributions

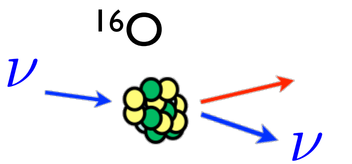


Study NCQE for neutrino first, then apply to DM



DM signature may be similar to neutrino neutral current on oxygen, detect nuclear de-excitation γ

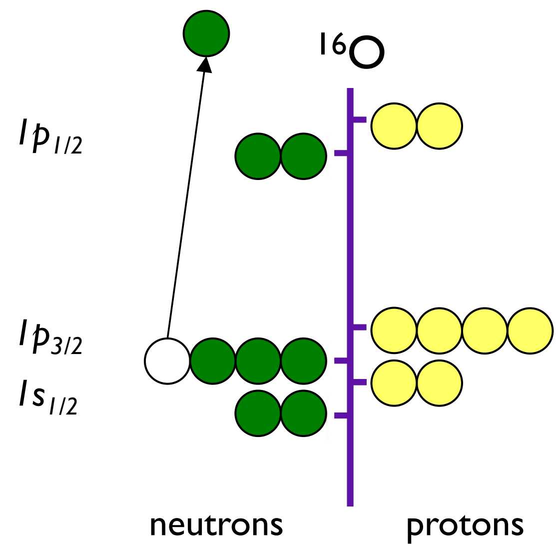
Nuclear de-excitation gammas after the neutrino-oxygen neutral current quasi-elastic (NCQE) interaction



The incident particle excites the ^{16}O nucleus,
and Super-K detects the gammas from the nucleus de-exciting

600 MeV neutrino beam → single nucleon emission is dominant

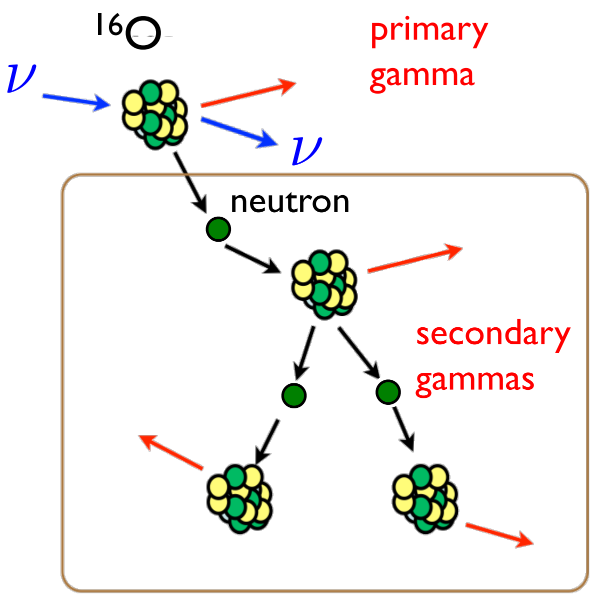
contribution of $1p_{3/2}$ is overwhelming:
6.32 MeV from $(1p_{3/2})_p$
6.18 MeV from $(1p_{3/2})_n$



PRL **108** 052505 (2012)

T2K made first observation at this energy T2K, PRD **90** 072012 (2014)

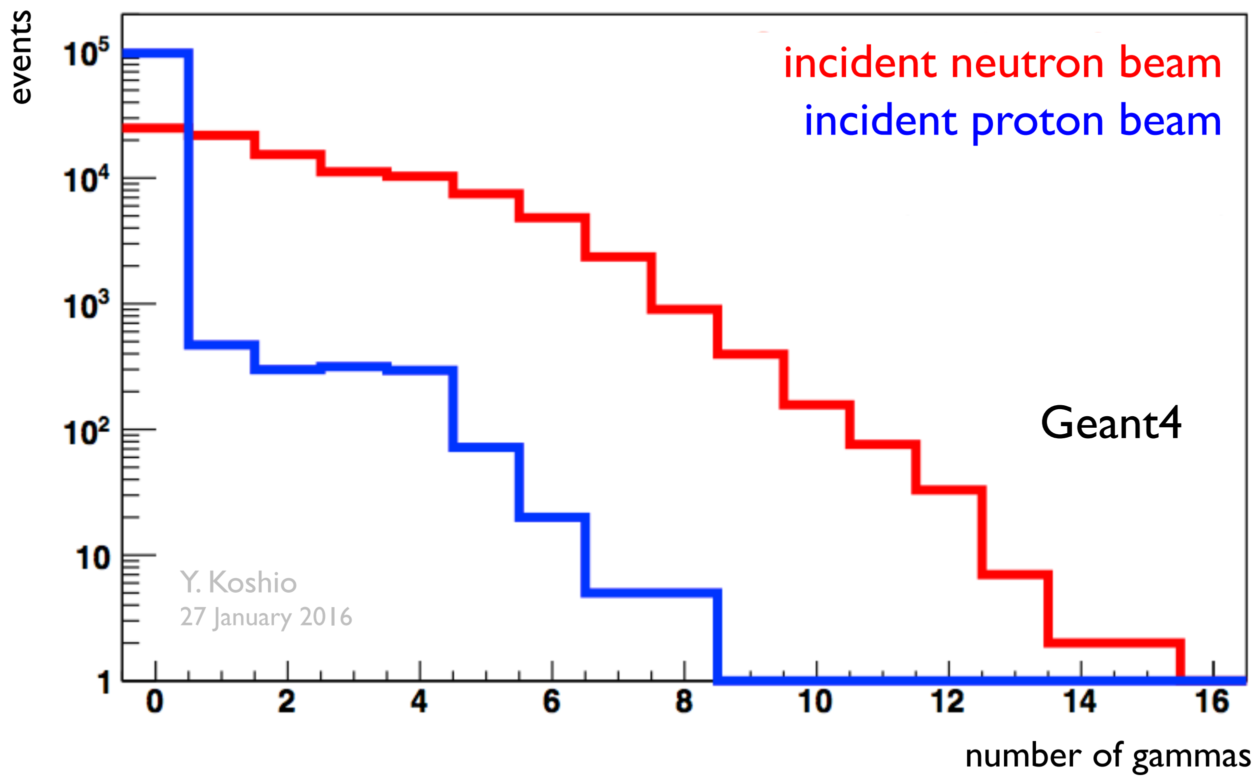
Need to understand secondary gamma production



An emitted neutron can excite another ^{16}O nucleus, producing secondary gammas

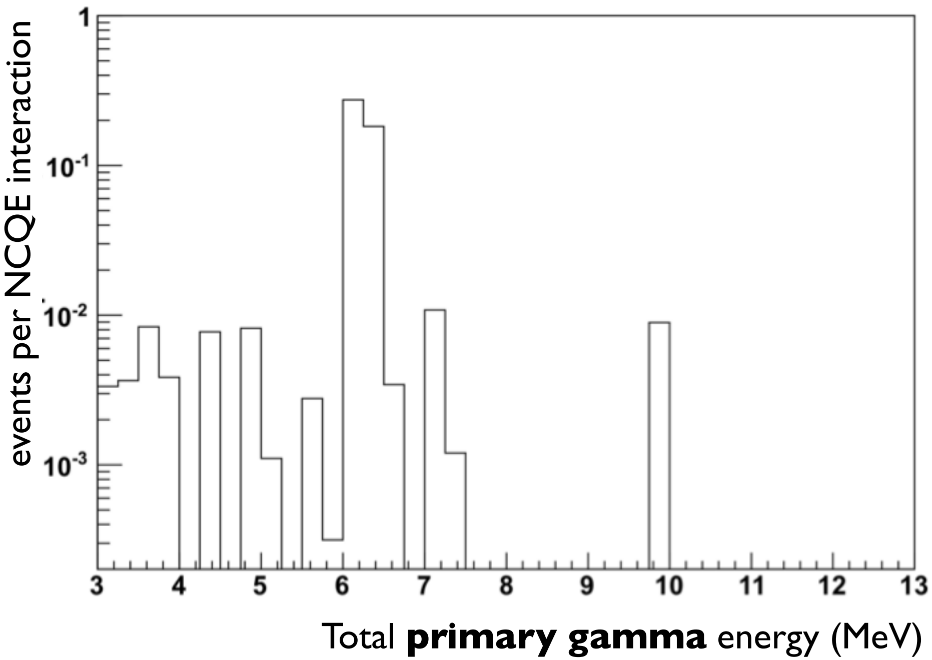
Cannot be easily separated by energy or timing

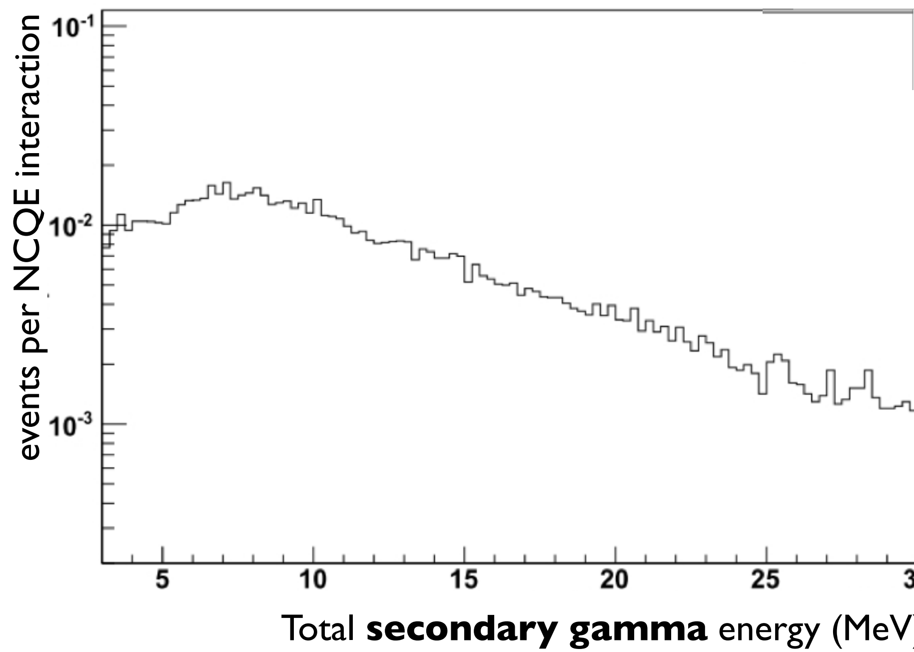
Neutrons, not protons, generate most secondary gammas



K. Huang
PhD thesis

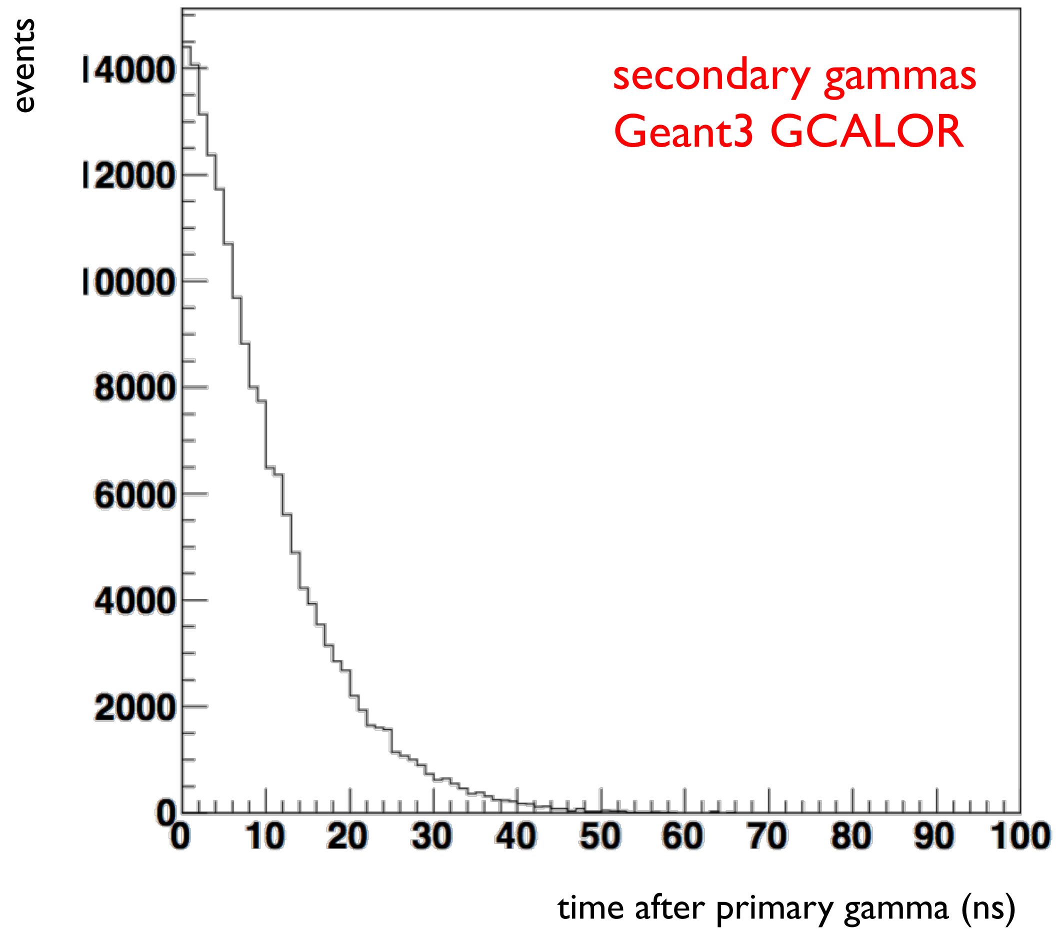
Can’t separate secondary gammas using energy



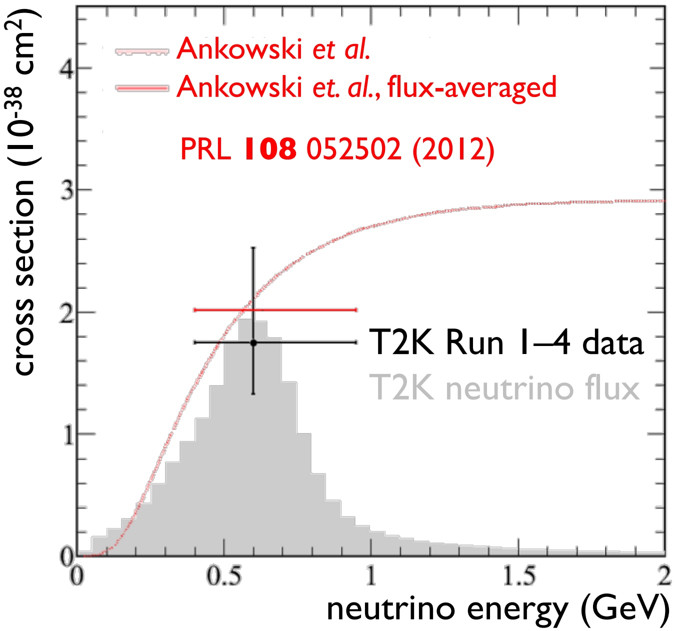


(note different x-axis ranges)

Can’t separate secondary gammas using timing



Reduce systematic uncertainty due to secondary gammas



	Signal	Background		
interactions	NCQE	NCother	CC	beam-unrelated
fraction of sample	68.6%	25.5%	4%	2%
Flux	11%	10%	12%	–
Cross-section	–	18%	24%	–
Primary γ production	10%	3%	6%	–
Secondary γ production	13%	13%	7.6%	–
Detector response	2.1%	2.1%	2.1%	–
Oscillation parameters	–	–	10%	–
Total systematic error	20%	25%	30%	0.8%

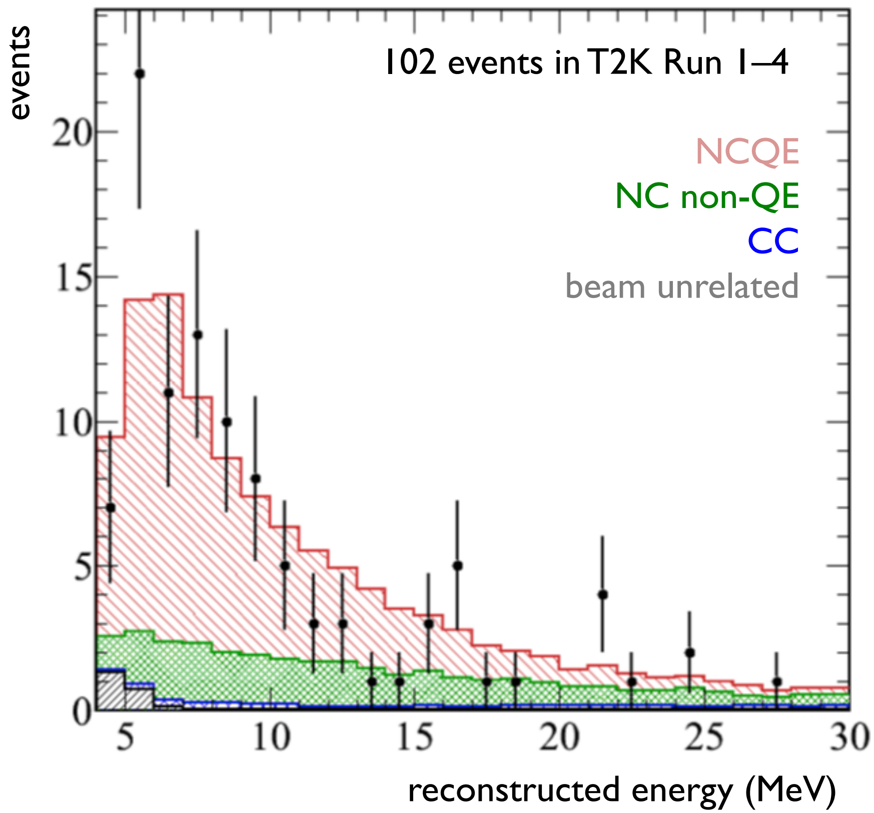
TN-244

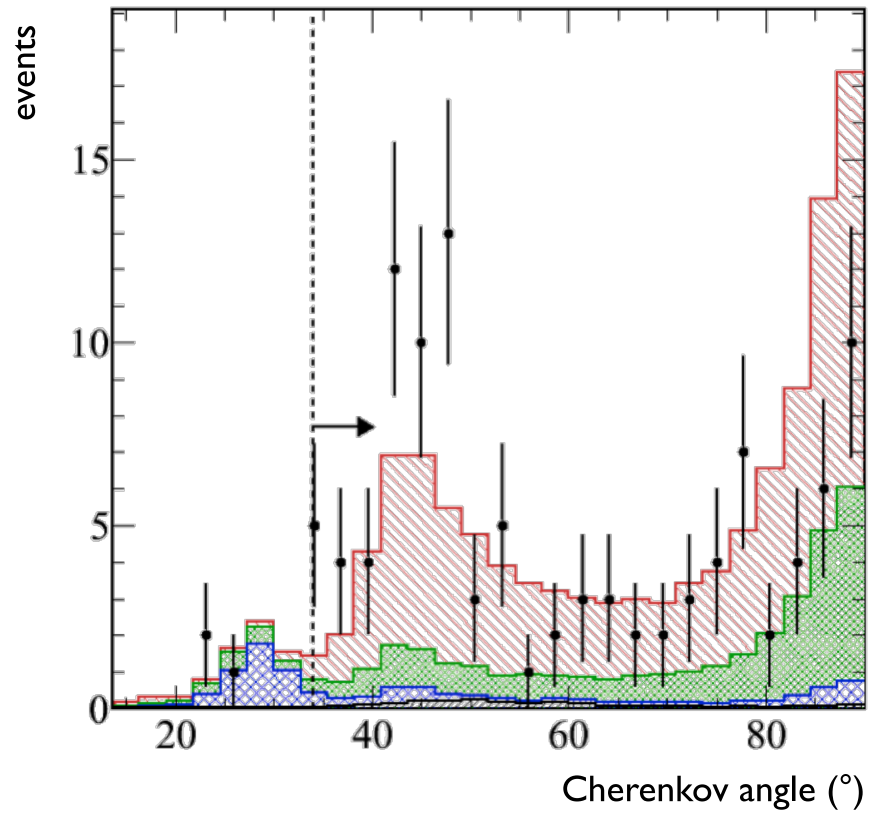
neutrino-oxygen NCQE cross section

$$< \sigma^{\mathrm{obs}}_{\nu,\ \mathrm{NCQE}} >= \left(1.75 \ \pm\ 0.27\ (stat.)\ ^{+0.70}_{-0.36}\ (sys.)\right) \times 10^{-38}\ \mathrm{cm}^2$$

Need to understand secondary gamma production

Analysis of neutrino-oxygen NCQE events in T2K-SK

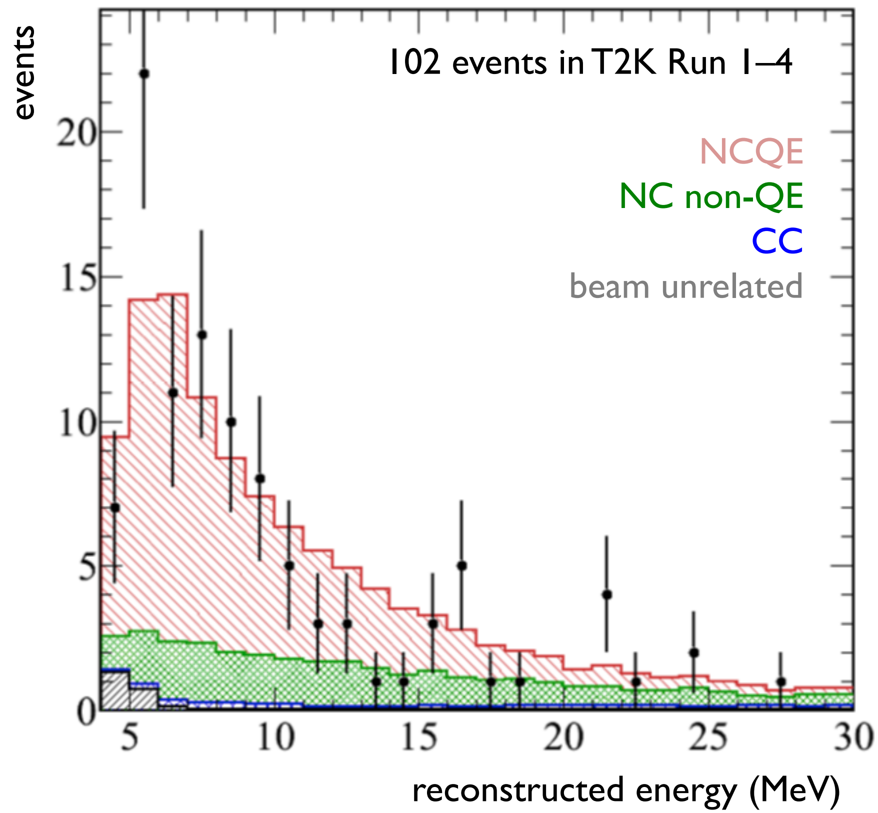


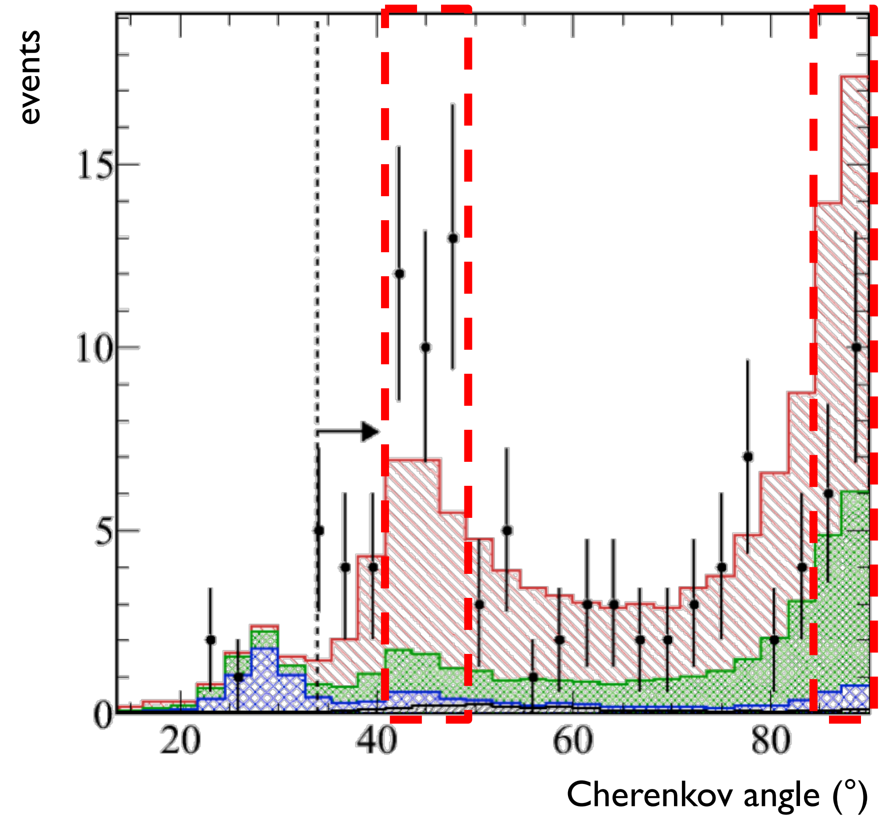


Selection cuts

- 4–30 MeV reconstructed energy
- > 34° Cherenkov angle to remove muons
- ±100 ns of beam timing
- fiducial volume
- reconstruction quality cuts

Analysis of neutrino-oxygen NCQE events in T2K-SK





Selection cuts

- 4–30 MeV reconstructed energy
- > 34° Cherenkov angle to remove muons
- ±100 ns of beam timing
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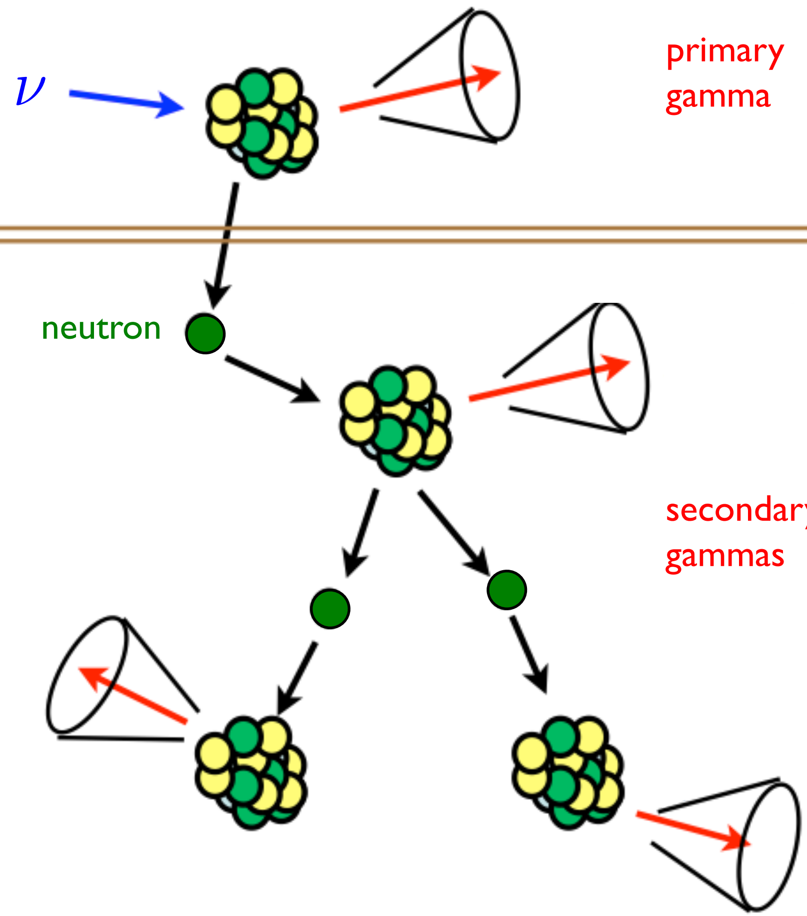
suspect discrepancy is due to poor model of secondary gammas

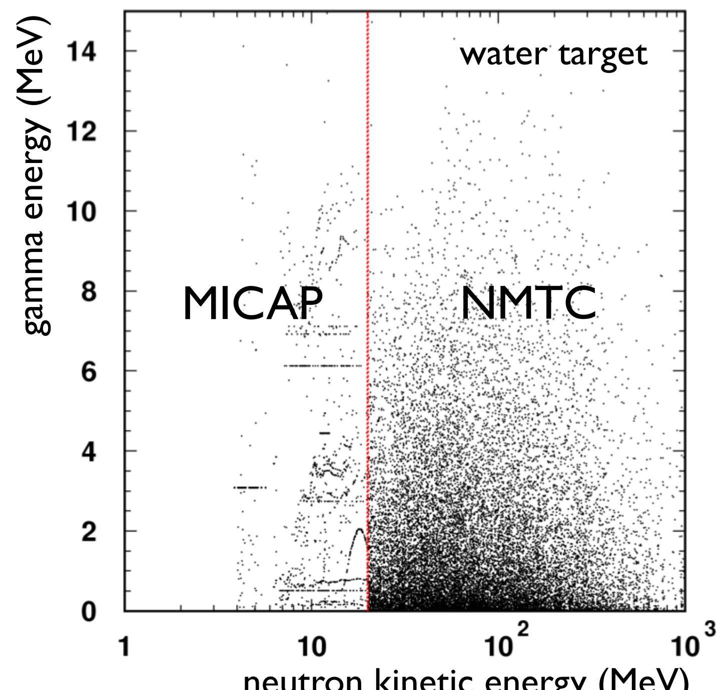
Current MC is NEUT and GCALOR

NEUT for neutrino-nucleus interactions



Super-K detector simulation
SKDETSIM (Geant3-based GCALOR)

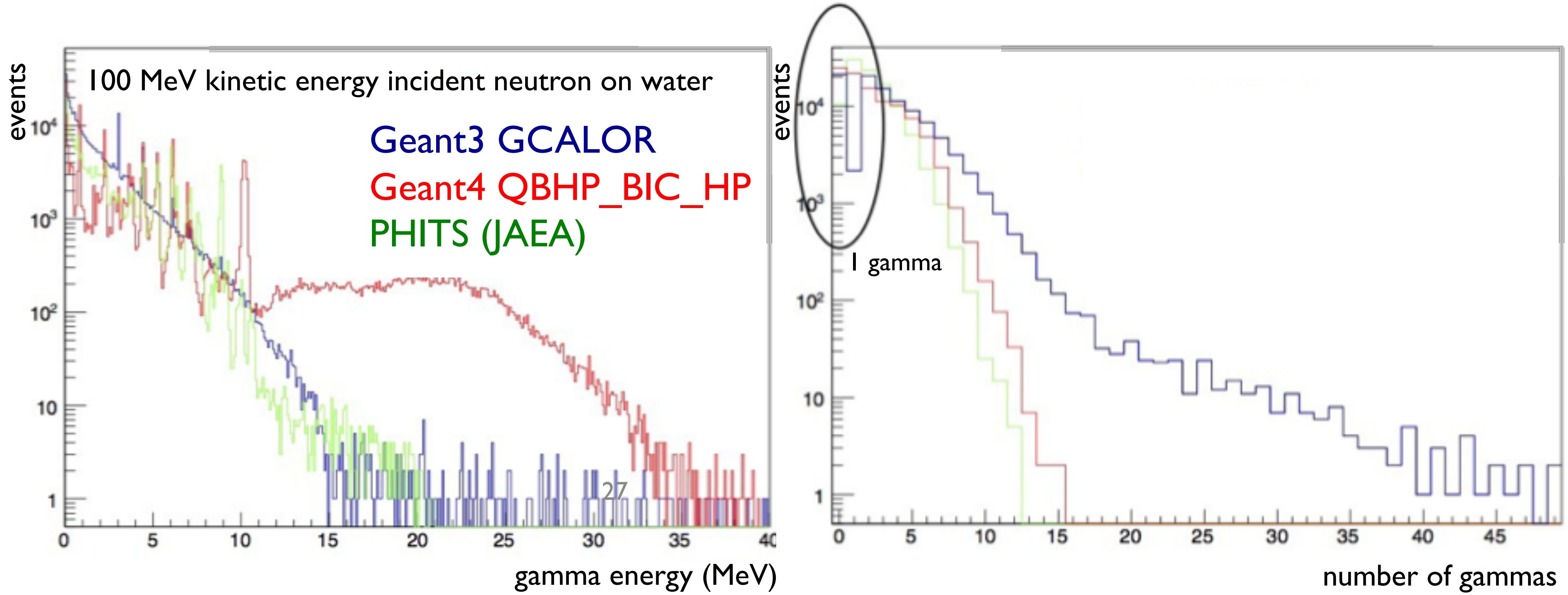
GCALOR models don't match at 20 MeV



K. Ueno
PhD thesis

MC simulations do not agree

Simulations based on various theoretical nuclear models, not data

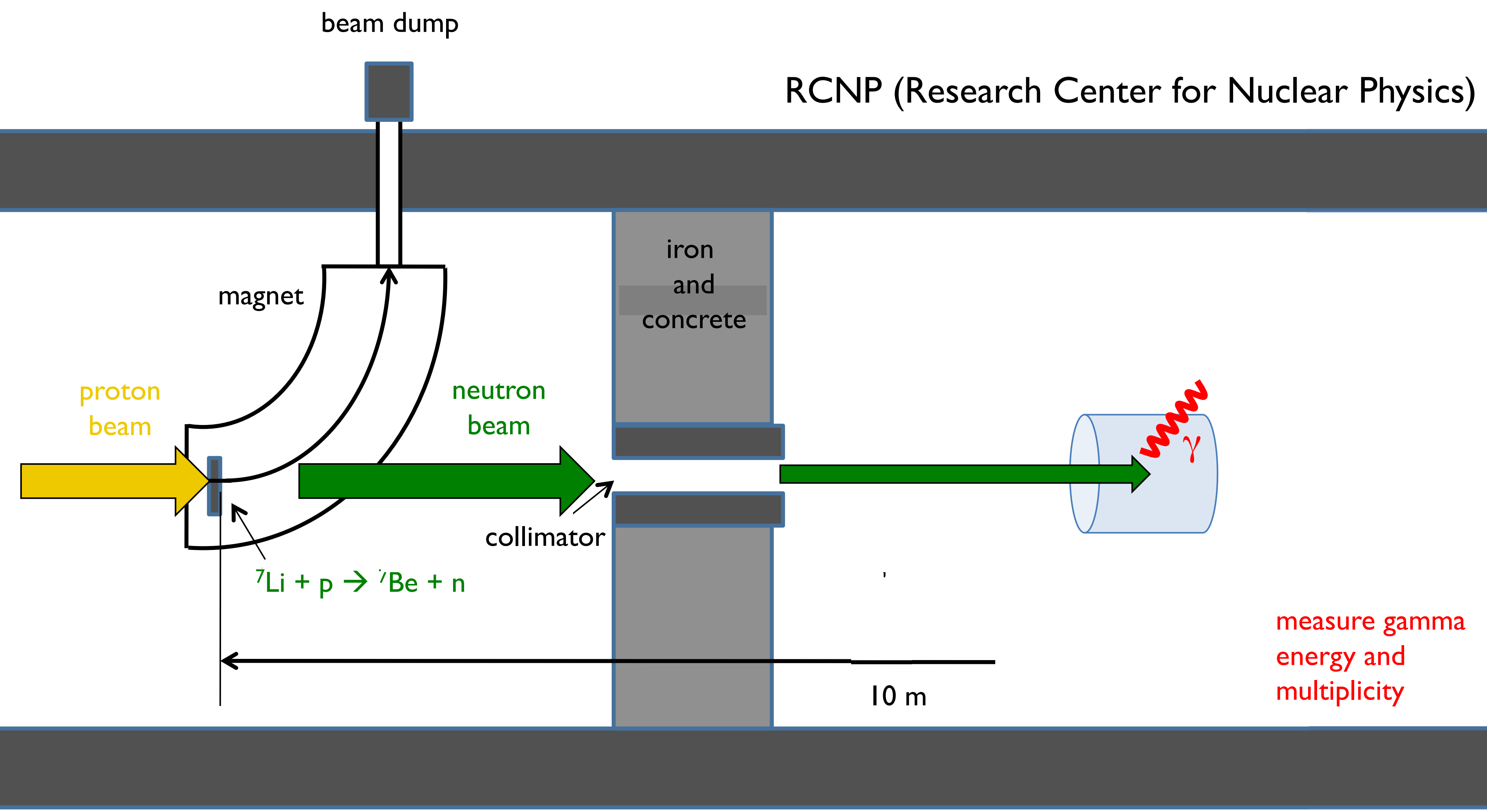


(FLUKA not shown)

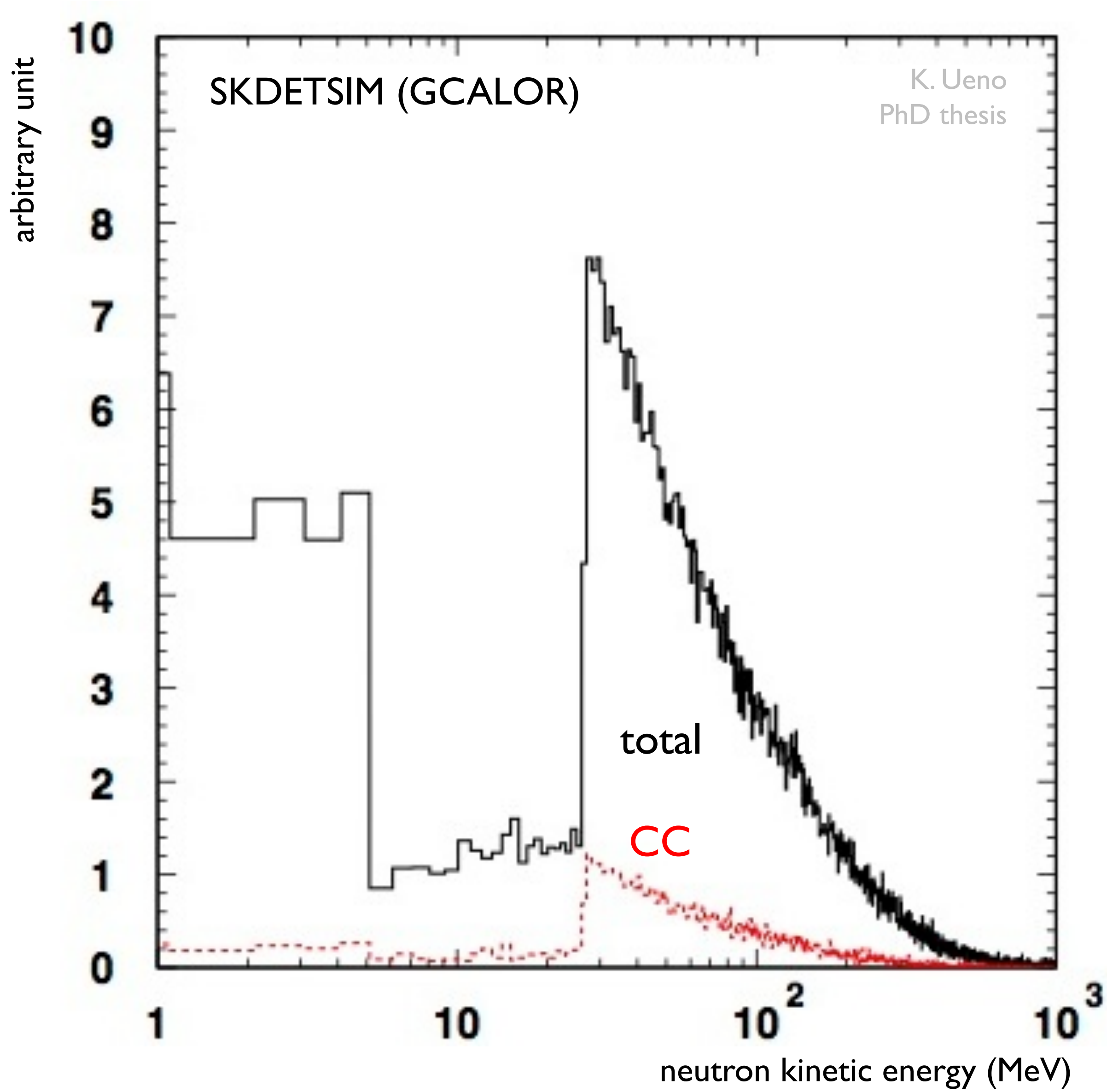
Need data to establish reliable simulations

PHITS (**P**article and **H**eavy **I**on **T**ransport code **S**ystem)
JAEA (**J**apan **A**tomic **E**nergy **A**gency)

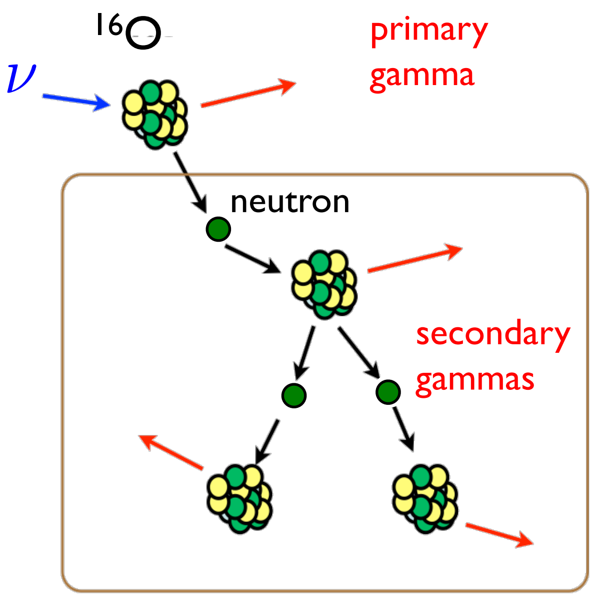
Measure gamma production from neutron beam on water



30–300 MeV neutrons escape the nucleus

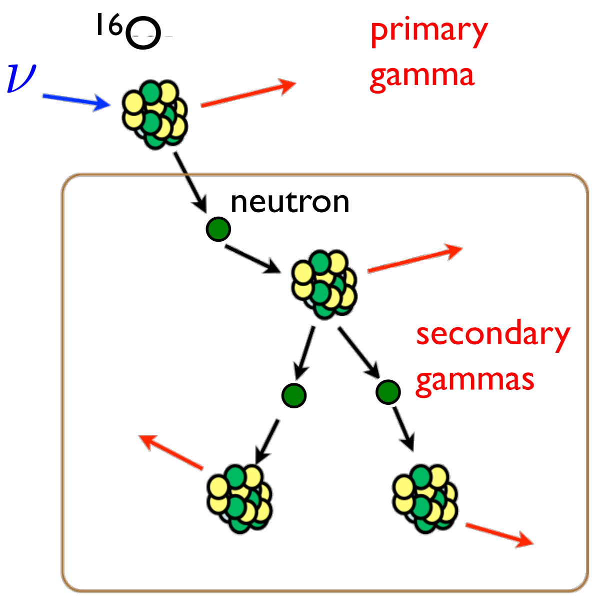


A series of experiments at RCNP



- parasite experiment #1: with E361
- parasite experiment #2: with E400
- pilot experiment #1: E465
- pilot experiment #2: E487
- final experiment

A series of experiments at RCNP



- parasite experiment #1: with E361
- parasite experiment #2: with E400
- pilot experiment #1: E465
- pilot experiment #2: E487
- final experiment

Pilot experiment #1: E465

24 h beamtime in June 2016

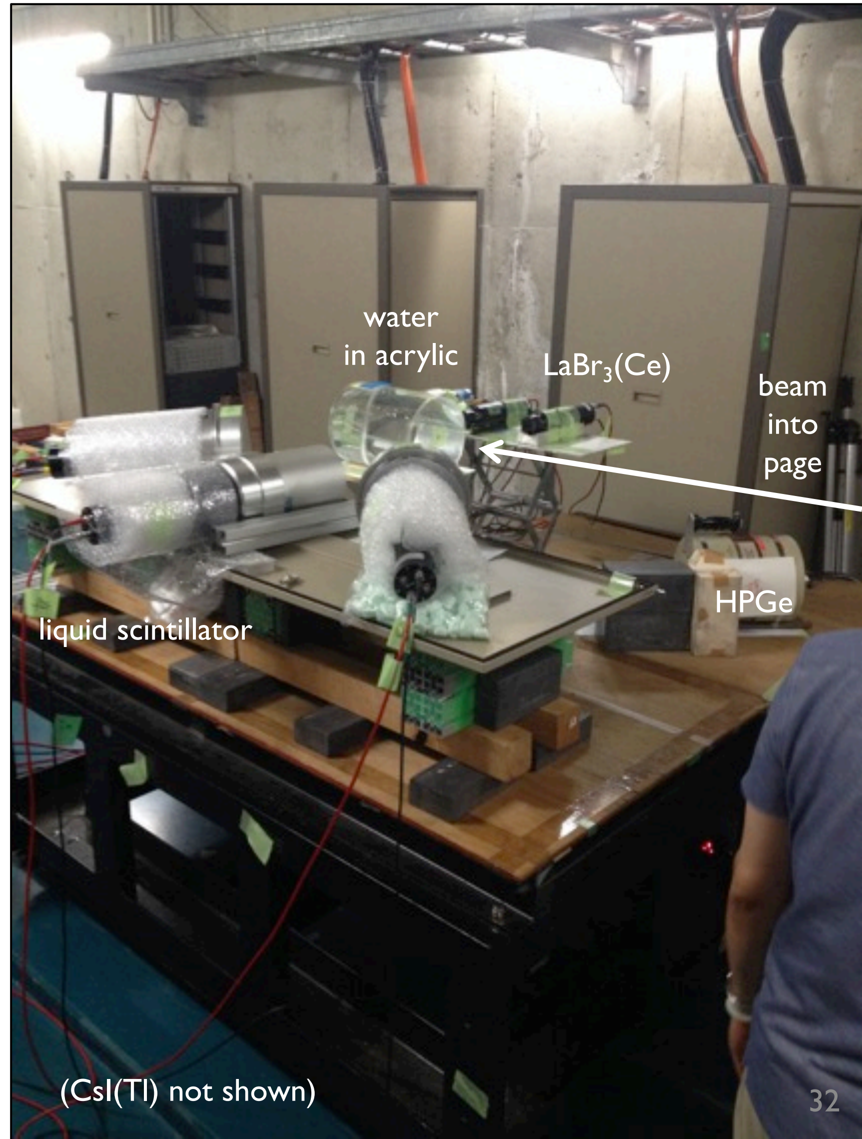
80 MeV neutron energy

water-filled acrylic container

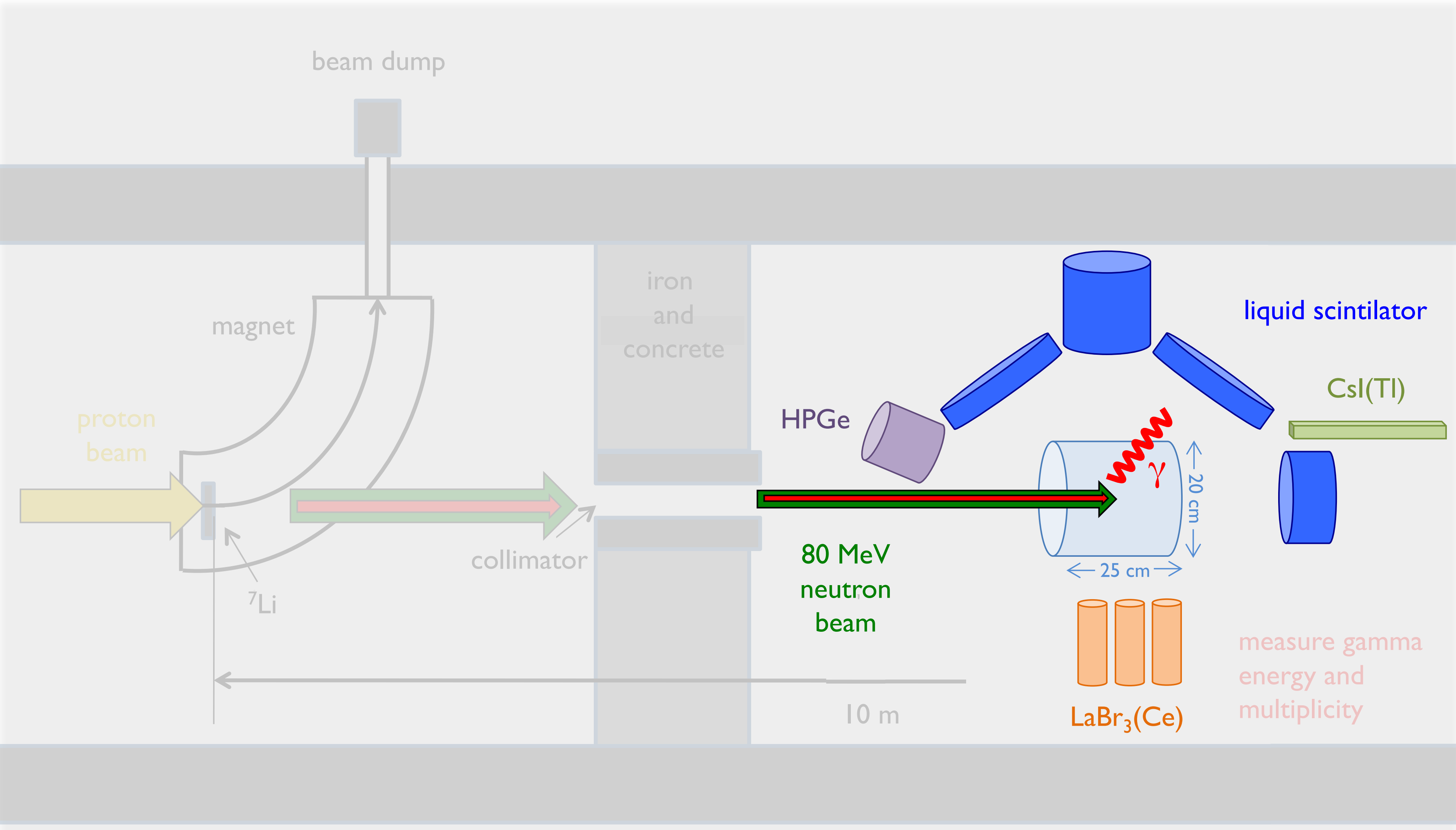
Configurations:

1) beam on with water (signal)
2) beam on without water (beam-related background)
3) beam off (beam-unrelated background)

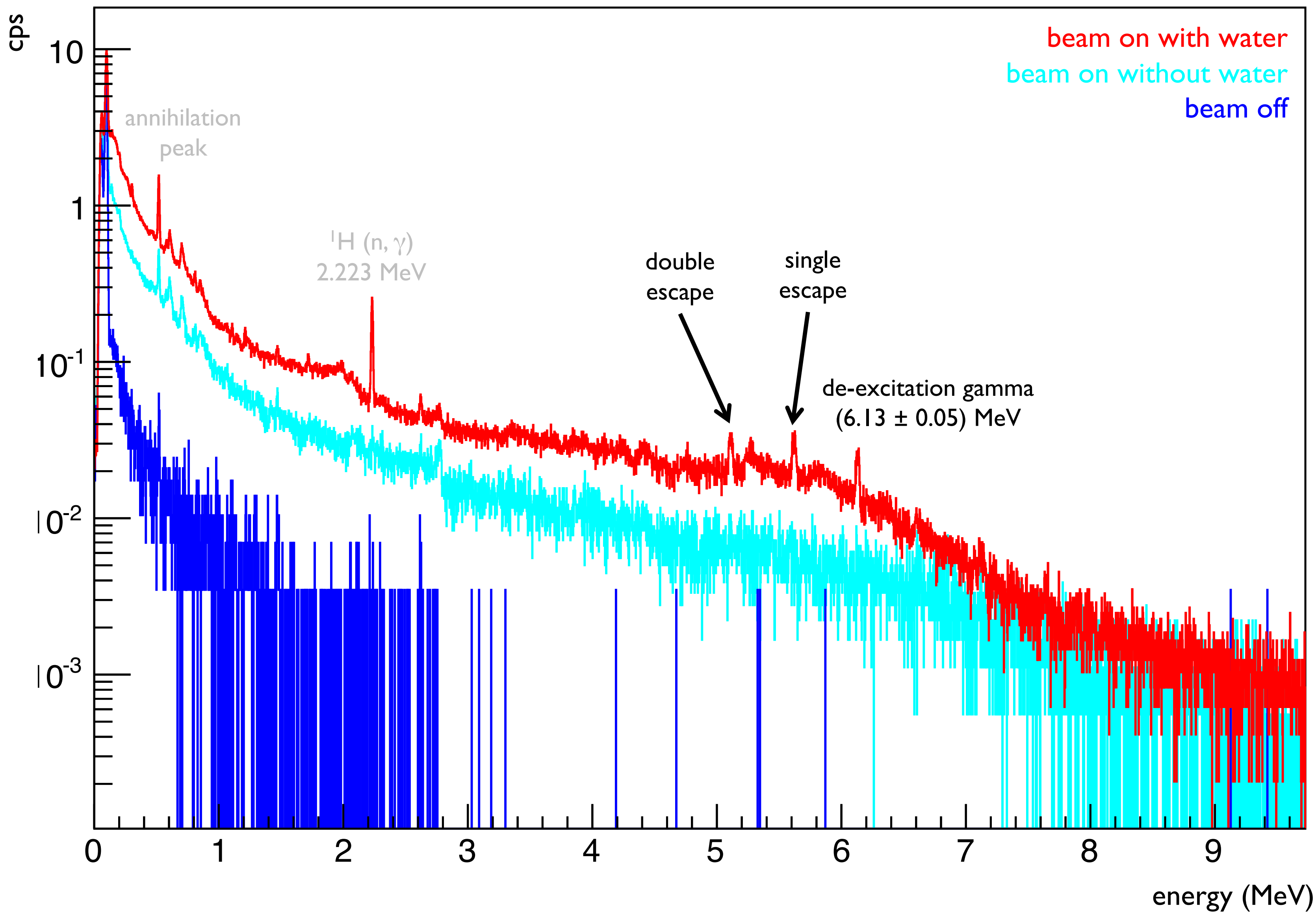
AmBe, ^{60}Co calibration



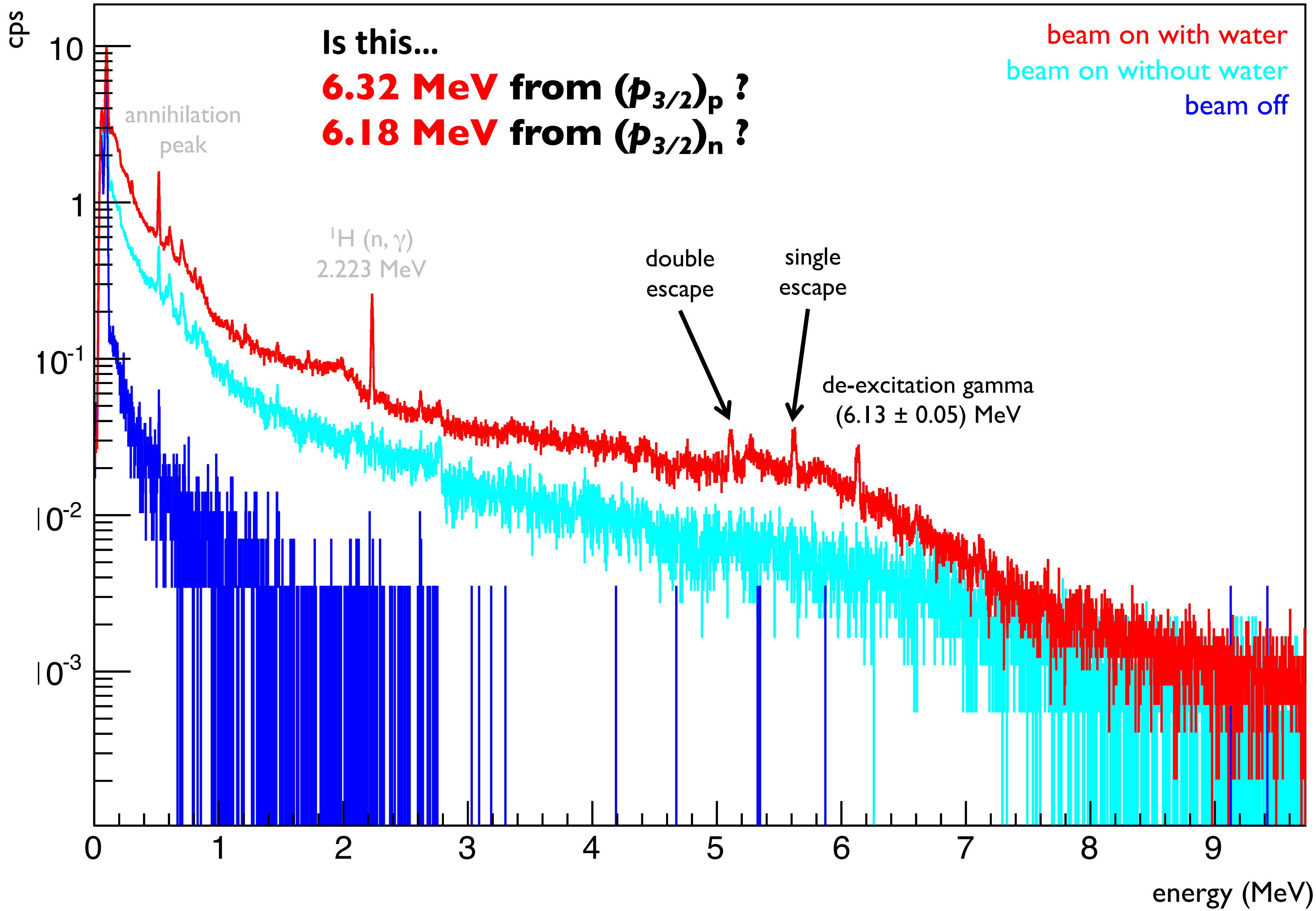
Testing several detectors



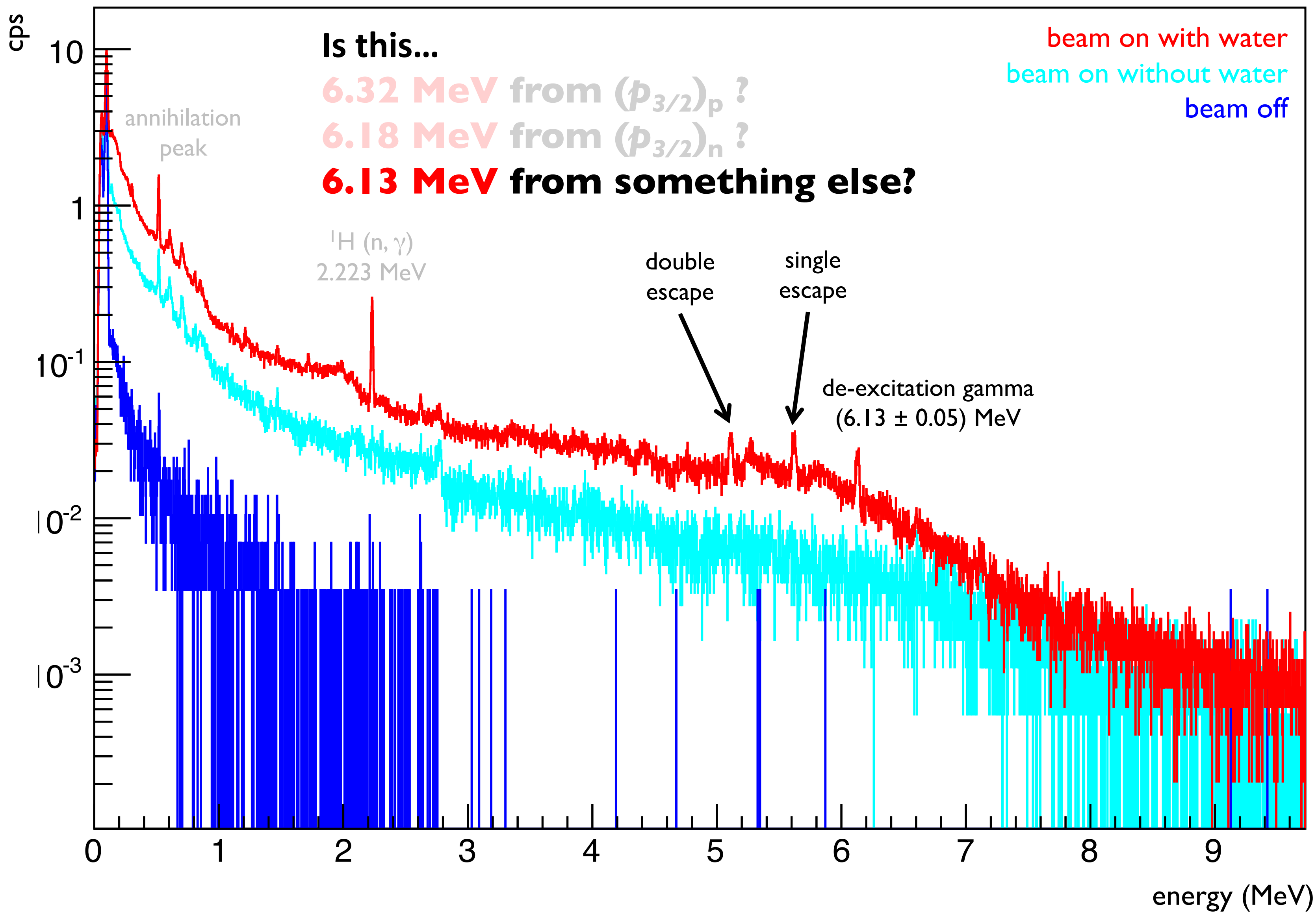
neutron-induced ^{16}O de-excitation gammas in HPGe



neutron-induced ^{16}O de-excitation gammas in HPGe



neutron-induced ^{16}O de-excitation gammas in HPGe



Summary

Search at SK for NCQE de-excitation gammas induced by DM in T2K neutrino beam

- understand detection of gammas in SK after neutrino-oxygen NCQE
- measure secondary gamma production using neutron beam on water, reduce systematic
- improve neutrino analysis, then apply to DM
- DM-neutrino discrimination using time of flight
- compare ratio of neutrino and DM for model independent cross section
- compare neutrino and antineutrino mode data, DM rate won’t change
- present results of this complimentary search

Future work

neutrino analysis

- update T2K Runs 1–4 with T2K Runs 5–8, develop analysis for antineutrino events
- update to newest version of MC, NEUT and SKDETSIM
- update neutrino oscillation parameters
- update to improved reweighting for neutrino flux and neutrino cross section

sensitivity study

production:

- indirect production, π^0 from T2K FLUKA proton beam on graphite target
- direct production, estimate from number of protons on target

detection:

- energy and direction of dark matter into usual MC (NEUT and SKDETSIM)

timing selection

- resolution and uncertainty

secondary gamma production

- depending on results, tune SKDETSIM (Geant3) or select another MC simulation