MC numbers and data benchmark for absolute efficiency

Wenqiang Gu (SJTU)

All efficiencies in one table (MC)

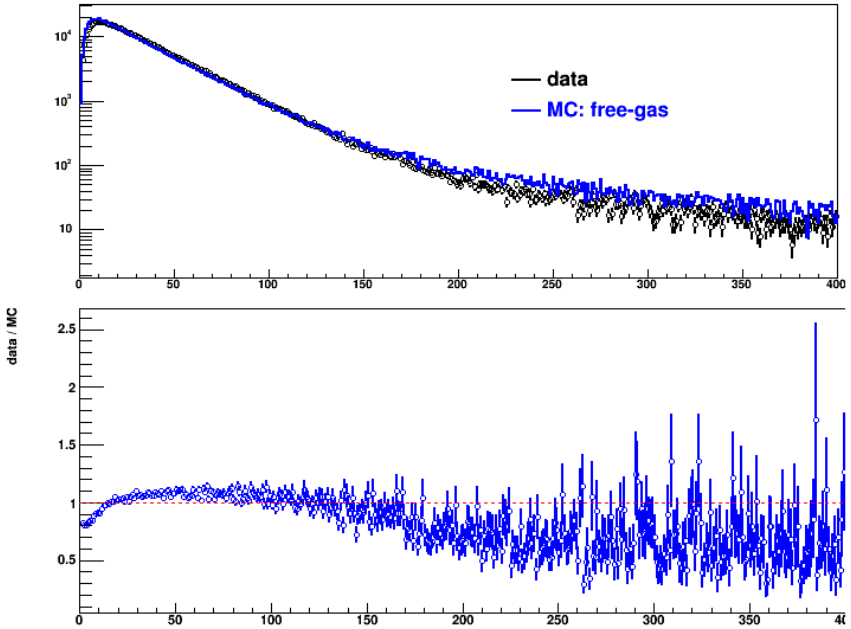
	M14A (Guofu doc-9844, %)	**M14A (Wenqiang, %)**	**M13B (Wenqiang, %)**	**M14A^{+}(Wenqiang,%)**	**Free-gas (Wenqiang, %)**	**Suggested**
Capture time cut	98.7 (0.12)	**98.9**	98.8	98.5	98.3	**98.7 (0.2)**
Prompt energy cut	99.81 (0.10)	99.87	99.89	99.87	99.85	99.87 (0.10)
Gd capture fraction	**84.17 (0.95)**	84.2	**83.8**	84.1	85.9	**83.8 (0.95)**
Delayed energy cut	92.7 (0.97)	92.4	90.3	92.2	92.2	92.7 (0.97)
Spill-in	**104.9 (1.00)**	104.9	**105.1**	**106.1**	**107.1**	**106.1 (1.0)**
Combined	**80.6 (1.76)**	80.6	78.5	80.9(1)	83.2(2)	**81.2 (1.7)**

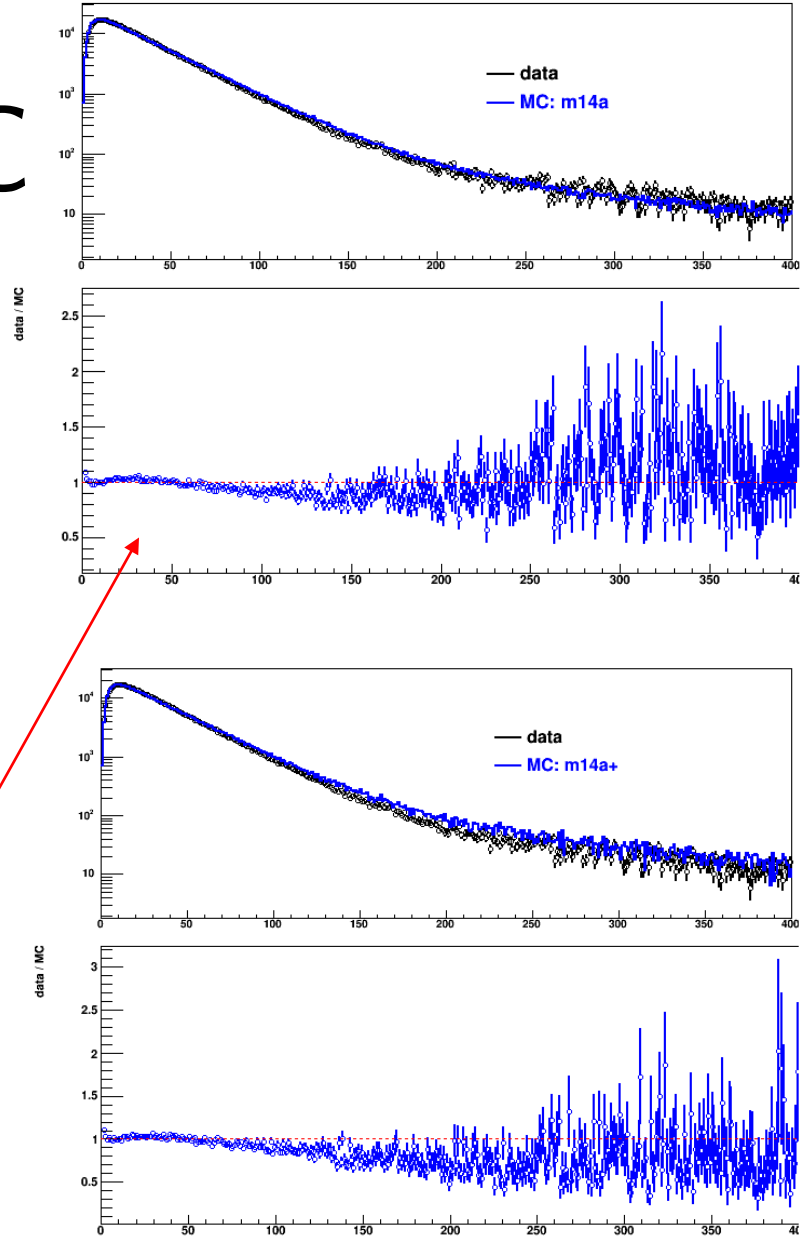
- M14A^{+} : IBD simulation with M14A script and the neutron transportation bug fixed
- Uncertainties are in the parentheses

Problems

- Efficiency of **capture time** changes among MC samples, but the uncertainty is only 0.1%, is it sufficient? How about the central value?
- **Gd capture fraction** changes from m13b (83.8%) to m14a (84.2%), what makes the difference?
- **Spill-in** changes one sigma with the bug in neutron transportation fixed.
- Guofu's efficiency extracted from m14a differ from Wenqiang's in some components although the final number is identical.
- Shall we change the number in the coming reactor long paper?

(I) Capture time: Data vs. MC

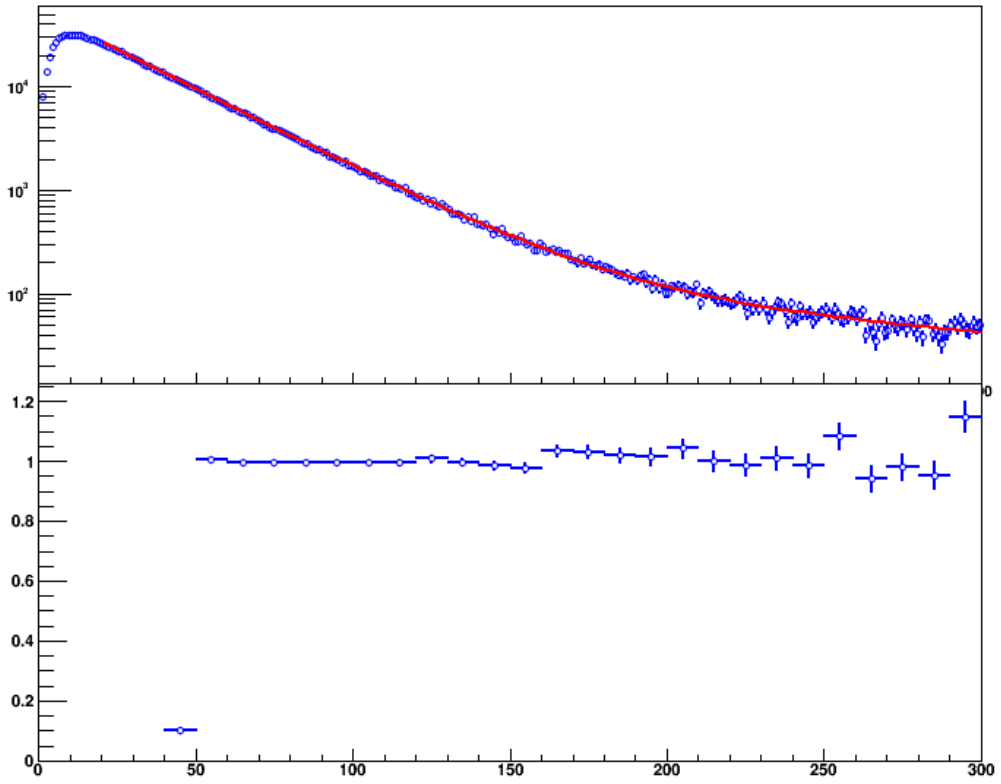




- Capture time tail (>100us) changes the efficiency significantly among MC samples
  - Free-gas: 98.3 %
  - M14a: 98.9 %
  - M14a+: 98.5 %

By looking at the agreement with data, M14A should be the best one.

(I) Capture time: data-driven efficiency



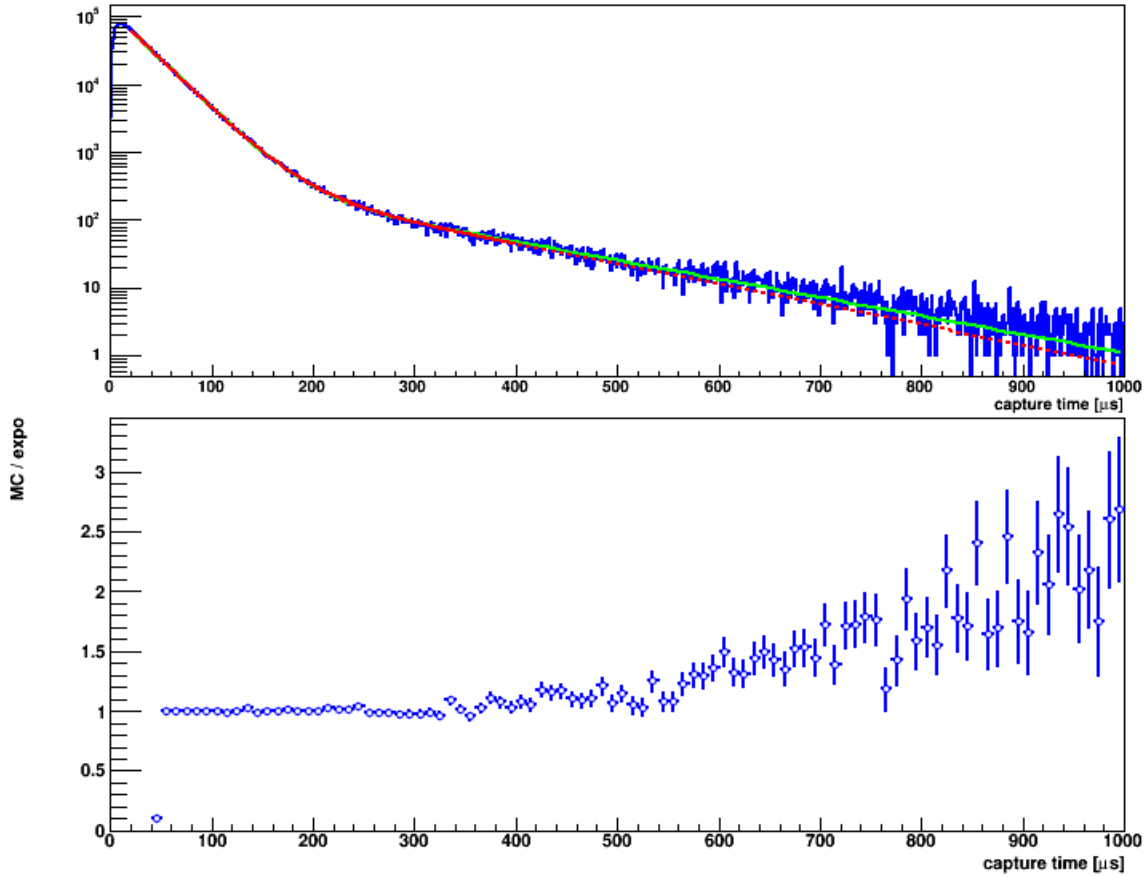
- One can predict the efficiency with a best tuned MC, or extract it from data itself.

- Select IBD events with (1,400)us
  - Ep>3MeV to remove accidental background
- Fit to time range (20,400)us with two exponential function, which indicates efficiency below 200us is 99.02%
- By taking in account 0.1% loss below 1us, the efficiency for (1,200)us is 98.9%

MC validation (with m14a, m13b)

- However, MC shows that if one only fit capture time up to 400us (red line), it brings ~0.1% overestimation

- The efficiency from this data driven method is 98.8%, close to M14A prediction (98.9%)



Supplementary

- IBD events $<$ 1us

  M14a: 0.10%

  Free-gas: 0.13%

(II) Gd capture fraction

TABLE VI: Source results

		AmC	AmBe	PuC PR	PuC nC*	PuC O*
$\epsilon_{Gd-combined}$	Data	$84.45\% \pm 0.10\%$	$84.63\% \pm 0.04\%$	$84.68\% \pm 0.01\%$	$84.62\% \pm 0.02\%$	$84.14\% \pm 0.02\%$
	MC	$84.51\% \pm 0.12\%$	$84.47\% \pm 0.11\%$	$84.44\% \pm 0.03\%$	$84.21\% \pm 0.09\%$	$84.02\% \pm 0.08\%$

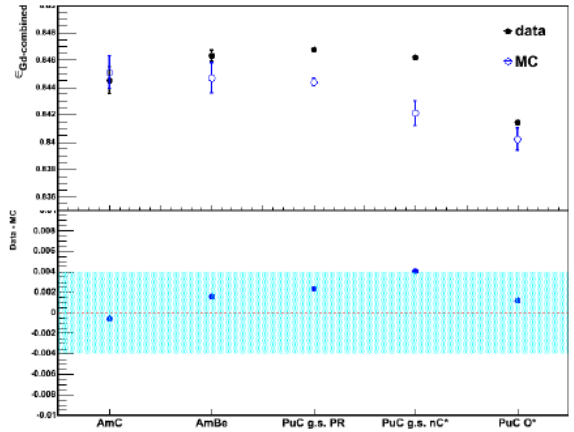


FIG. 5: All source results data vs MC. A 0.4% uncertainty band can cover the biggest difference between data and MC.

- In the tech note, the neutron source validation is done at AD center with NuWa-3.9.2 (the version for m13b)
- However, it changes from m13b (3.9.2) to m14a (3.11.0)

Data vs. MC

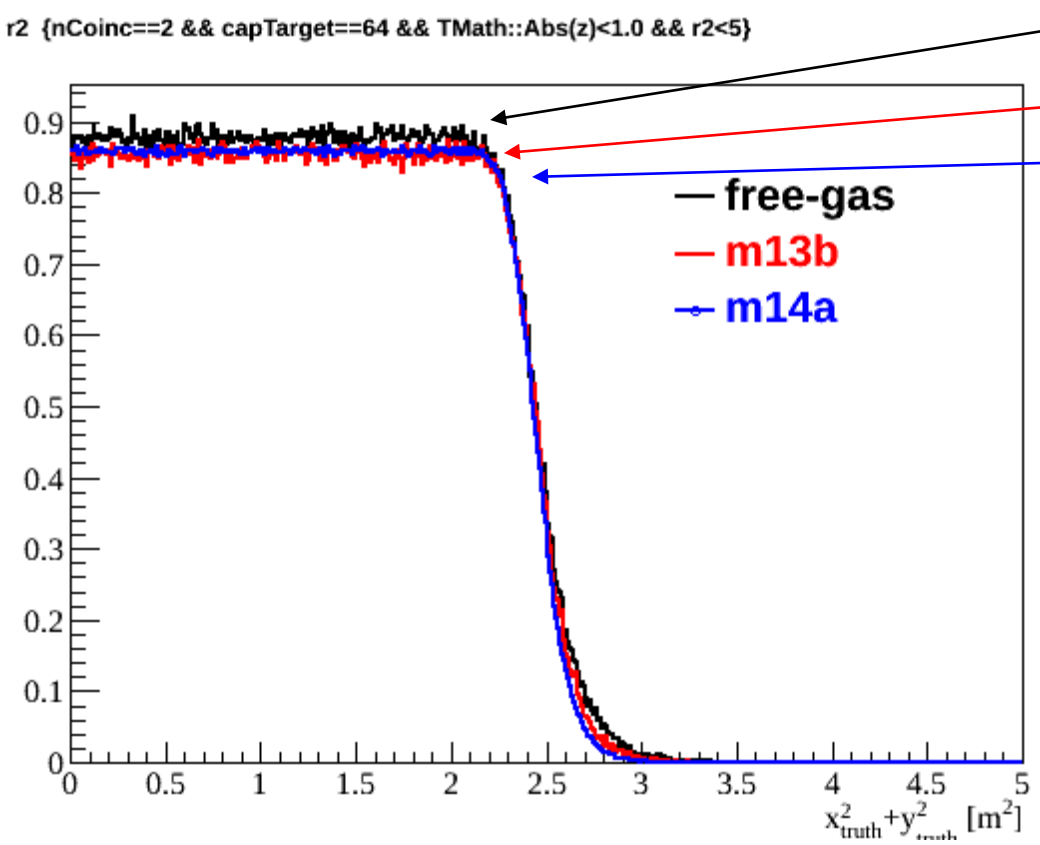
- Take the event fraction in delayed spectrum: (6,12)MeV / (1.8,12)MeV

	Data (ligs)	MC (3.9.2)	MC(3.9.2^{+})	MC(3.9.2^{++})	MC (3.11.0)
AmC	**84.45(10) %**	**84.5(1)**	**84.8(1)**	**85.1(1)**	**85.2(1)**
AmBe	**84.63(04)**	84.7(1)			85.4(1)

3.9.2^{+}: NuWa-3.9.2 with ticket# 1393 (the order of cross section data)
3.9.2^{++}: NuWa-3.9.2 with 1) ticket# 1393; 2) G4 nCapture γ spectrum

- Although NuWa-3.11.0 has a better agreement on capture time (benefit from ticket #1393), NuWa-3.9.2 agrees better for AD center Gd capture fraction.

Gd capture fraction for IBD(MC truth)



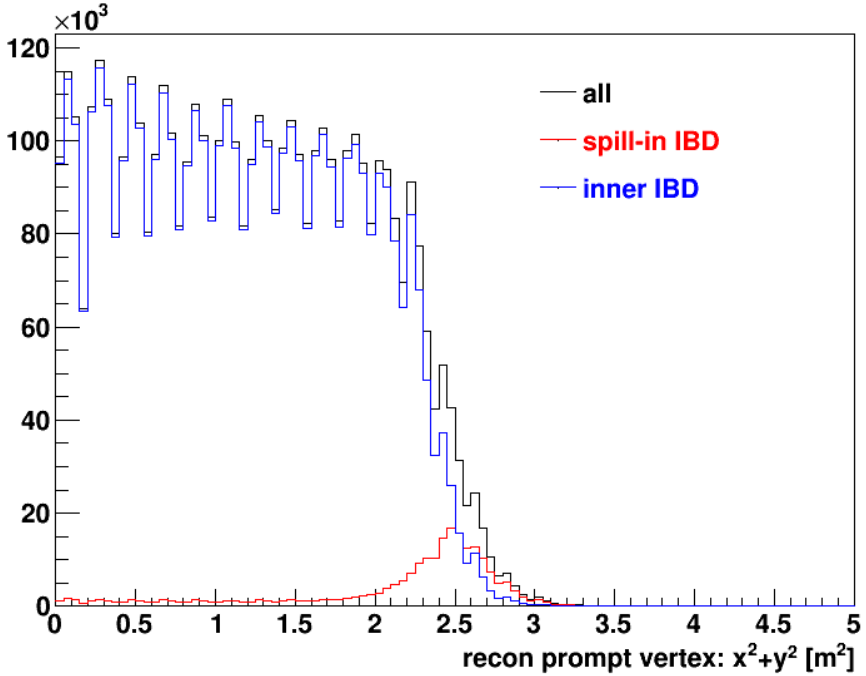
- Gd fraction at **AD center**
  - Free-gas: 87.8(2) % (stats.)
  - M13b: 85.4(2) %
  - M14a: 85.8(1) %
- Gd fraction in **full volume**
  - Free-gas: 85.9 %
  - M13b: 83.8 %
  - M14a: 84.2 %
- If **normalized with m13b** at AD center, Gd fraction in full volume is
  - Free-gas: **83.6 %**
  - M13b: 83.8 %
  - M14a: **83.8%**

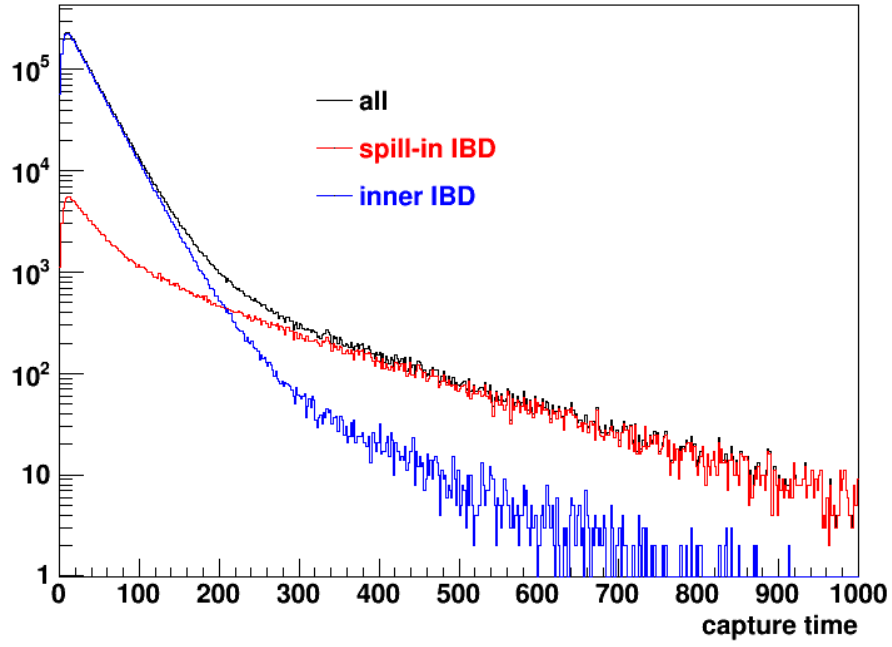
→ Very small difference due to neutron scattering modeling once the Gd fraction is settled at AD center

(III) Spill-in

- The MC prediction on spill-in
  M14A: 4.9%
  M14A^{+}: 6.1%
  Free-gas: 7.1%
- It seems that 6.1% with 1% uncertainty is enough.
- However, M14A^{+} doesn't agree data better for the capture time (as shown in the previous slides).
  - Not a better modeling?
  - Although we do see some indications that there should be more spill-in events from top and bottom boundary (see next slides)

High purity spill-in sample

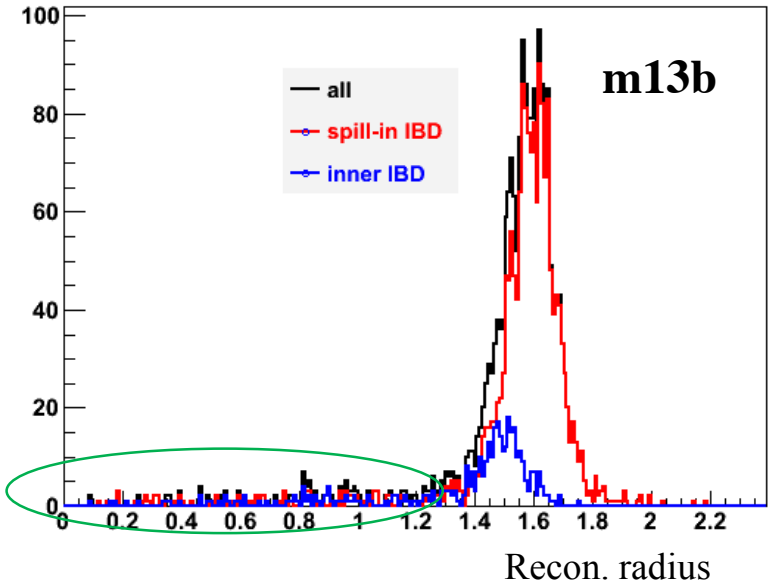


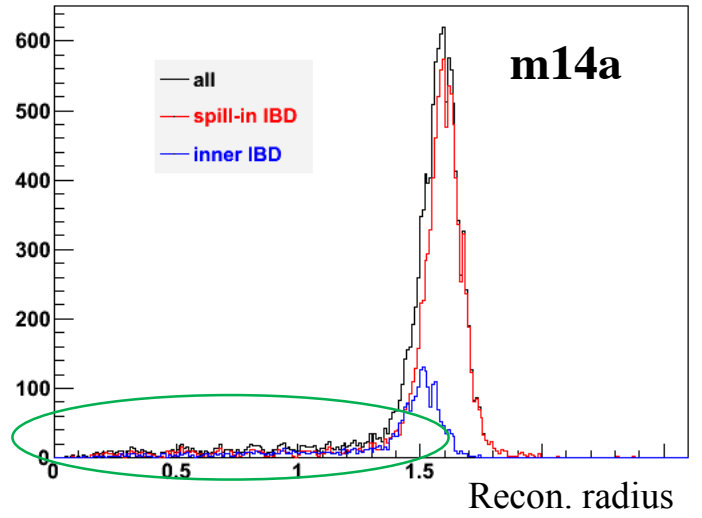


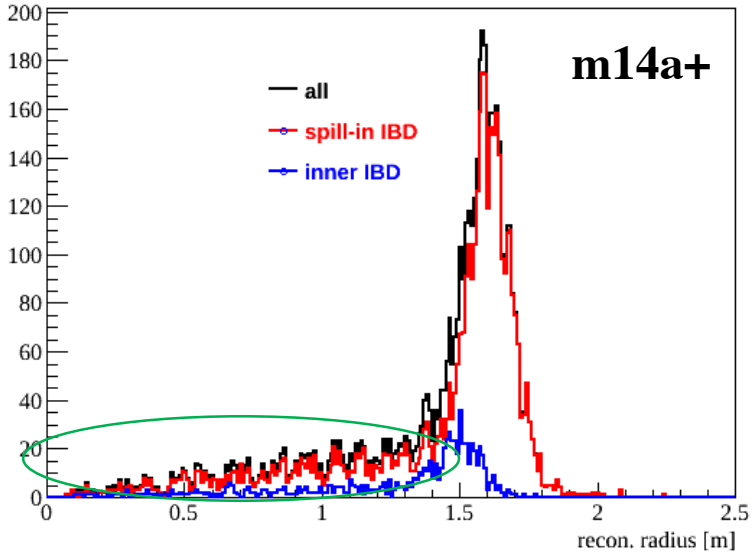
- According to M14A, with a capture time cut (250us, 400)us and recon. vertex cut Rp>1.4m, we can have a set of IBD events with very high purity **(>70%)** of spill-in events, although the efficiency is only **4%**

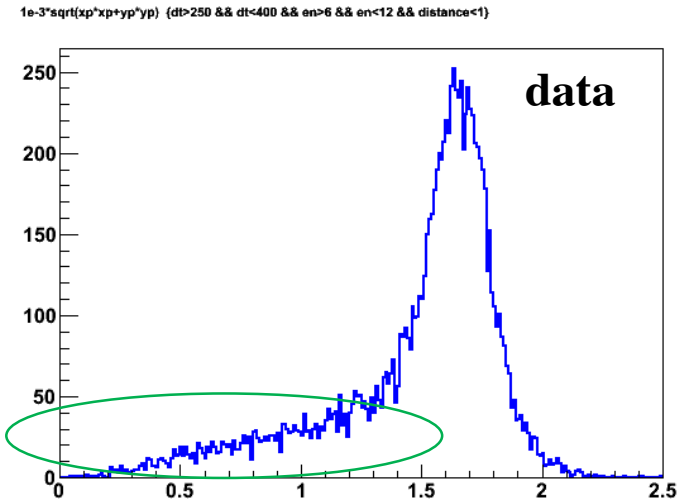
MC vs data

- It looks like we do have more spill-in events from top and bottom once we fix the z-bug (m14a → m14a$^+$)
- M14a$^+$ is closer to data









One more word about the neutron transportation bug in z (ticket# 1443)

- The culprit **G4UHadronElasticProcess** is no longer available in the later version of geant4 (current version in NuWa: G4.9.2)
- Answer from geant4 group: now they don't provide technical support for versions $< 4.9.6$
- Liang suggests to upgrade the NuWa-geant4 to the latest version 4.10.2
  - To be clear, it's not an attempt to have a precise modeling on neutron scattering, but to avoid some problems (if any) in the old version of geant4.

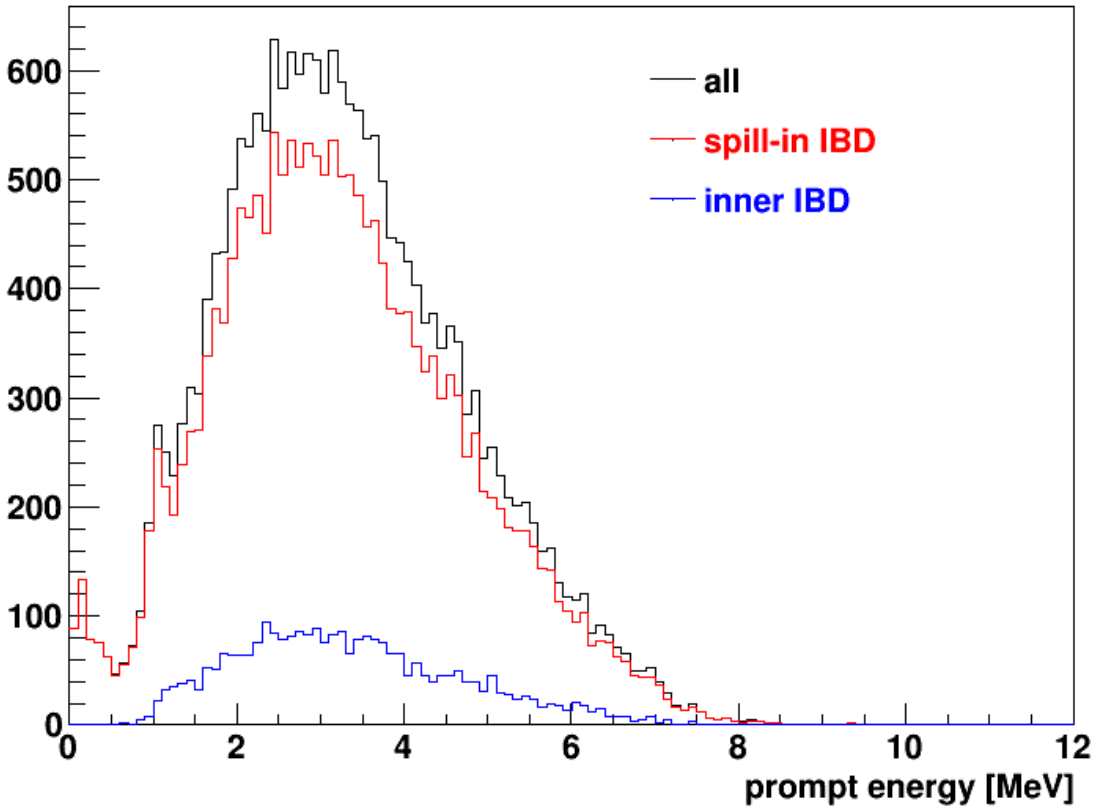
Summary and questions

- Capture time efficiency doesn't change too much from M14A with a data-driven estimation, but the uncertainty (0.12%) seems to be a little underestimated
- Gd capture fraction seems to be overestimated in M14A sample. M13B agrees neutron source better at AD center
- Spill-in has shifted 1 sigma from M14A with the neutron transportation fixed.
- Wenqiang's absolute efficiency from M14A is identical with Guofu's number, however, some components are not identical (capture time and delayed energy cut), why? Due to different definition?
- The final change on M14A is about 0.6% by following the slides above, which is still covered by the uncertainty (**1.76%**). After a discussion with Bryce and Jianglai, we all prefer to keep the current value.

The next thing to do

- The next update on absolute efficiency will come after the new special calibration hopefully this year.
- Meanwhile, the study of the combined efficiency with all neutron calibrations (including MCS) is ongoing.

Backup (improved spill-in selection)



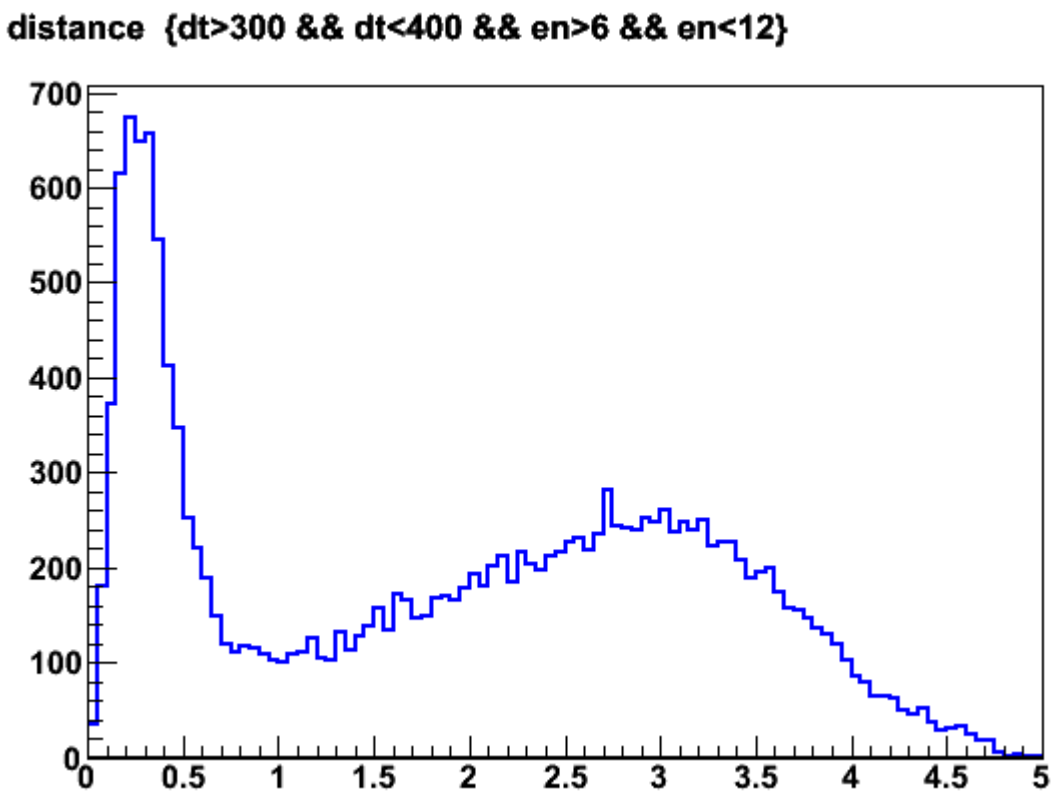
A high-purity spill-in sample ?

May be hopeless to measure spill-in absolute rate

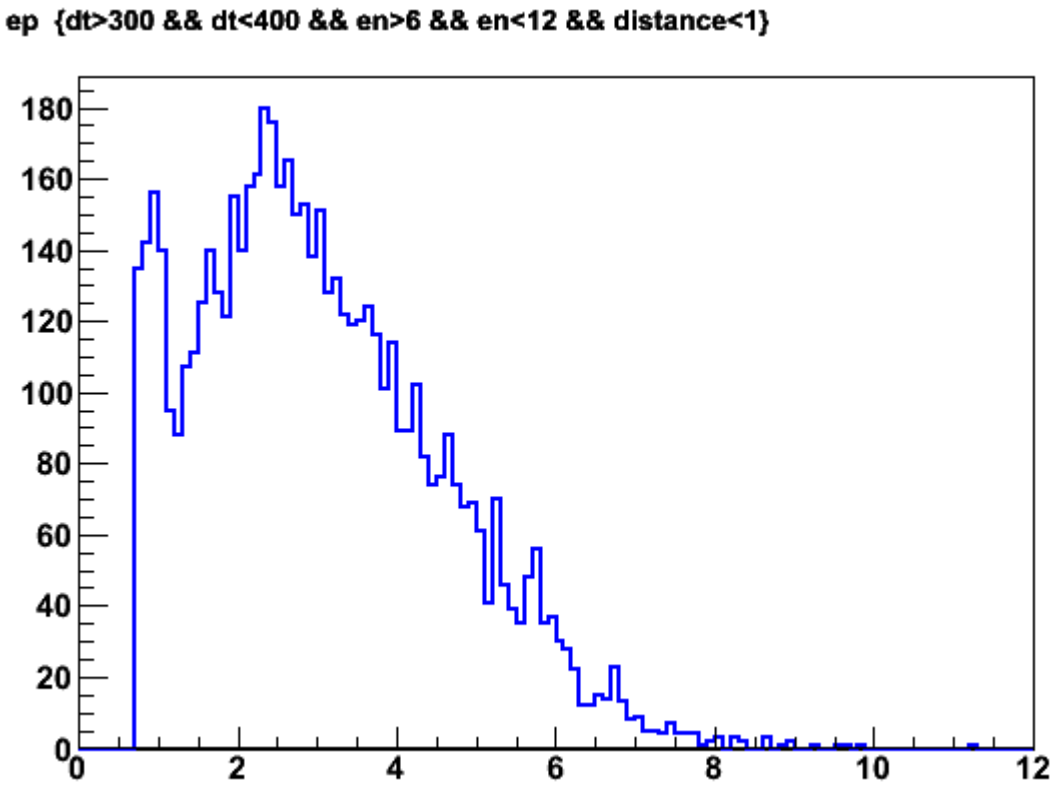
1) 5% spill-in → 3.2% (after delayed energy cut)
2) 3.2% → **0.4%** (250us < dt < 1000us), or
   3.2% → **0.2%** (250us < dt < 400us)

- According to M14A, only **capture time** and **reconstructed vertex** is sensitive to spill-in events
- Practice with M14A , select IBD events with
  - Edelayed > 6MeV (has to use it to avoid LS IBD)
  - dt > 300us
  - Rp^2 >2 (Actually this cut doesn't improve the selection too much since we use dt>300, most of them are already near boundary.)

What does the data say? With IBD time window (1,400us)

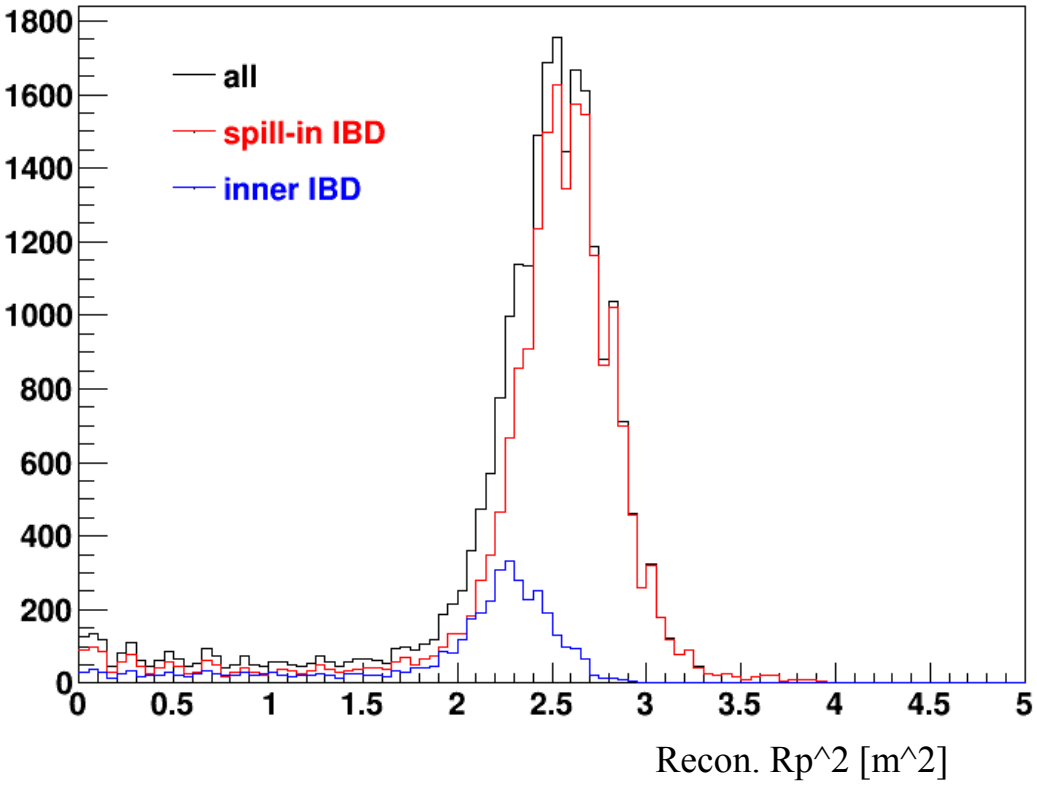


- By looking at the prompt-delayed distance, a lot of accidentals

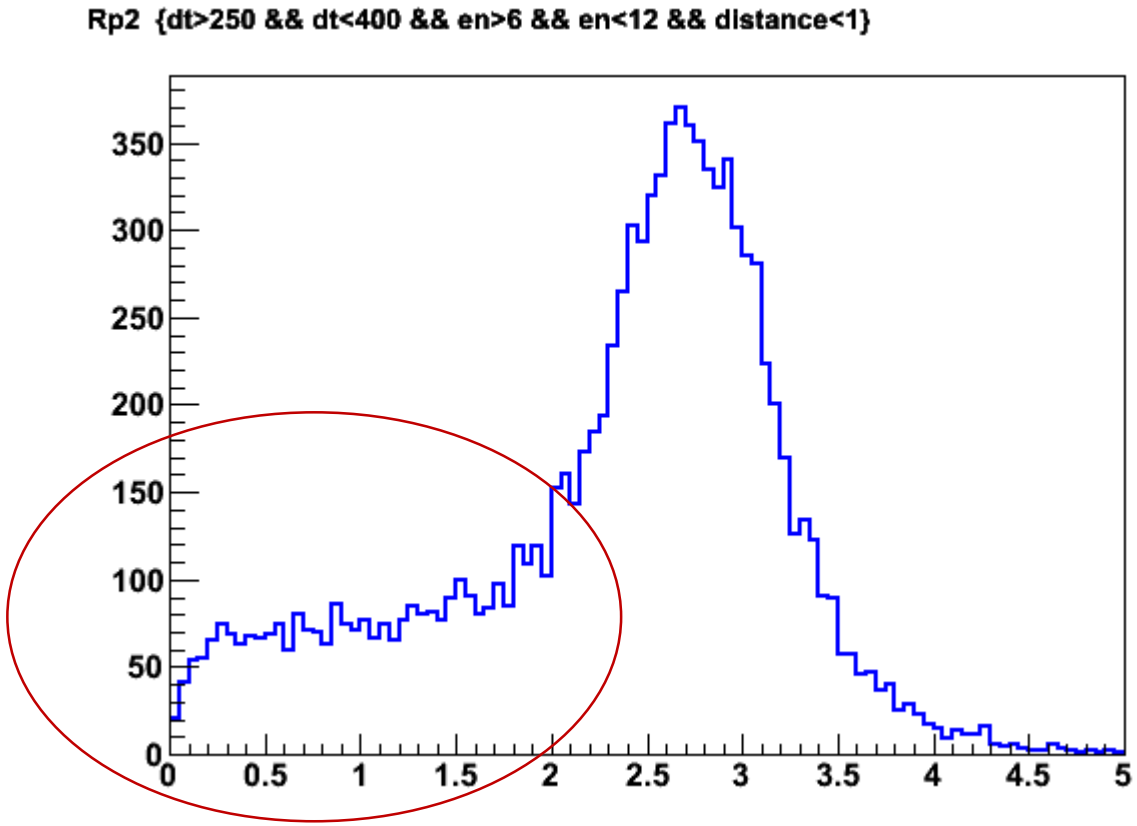


- Prompt energy, accidentals removed by cutting distance < 1m
- By comparing with M14A, seems more 1MeV gamma, more IAV? Or residual accidental?

MC vs. data: Rp^2



- MC peaks at 2.55



- Data peaks at 2.65
- Indicates more spill-in from top and bottom