JUNO

(SPMT⊕ABC intro)

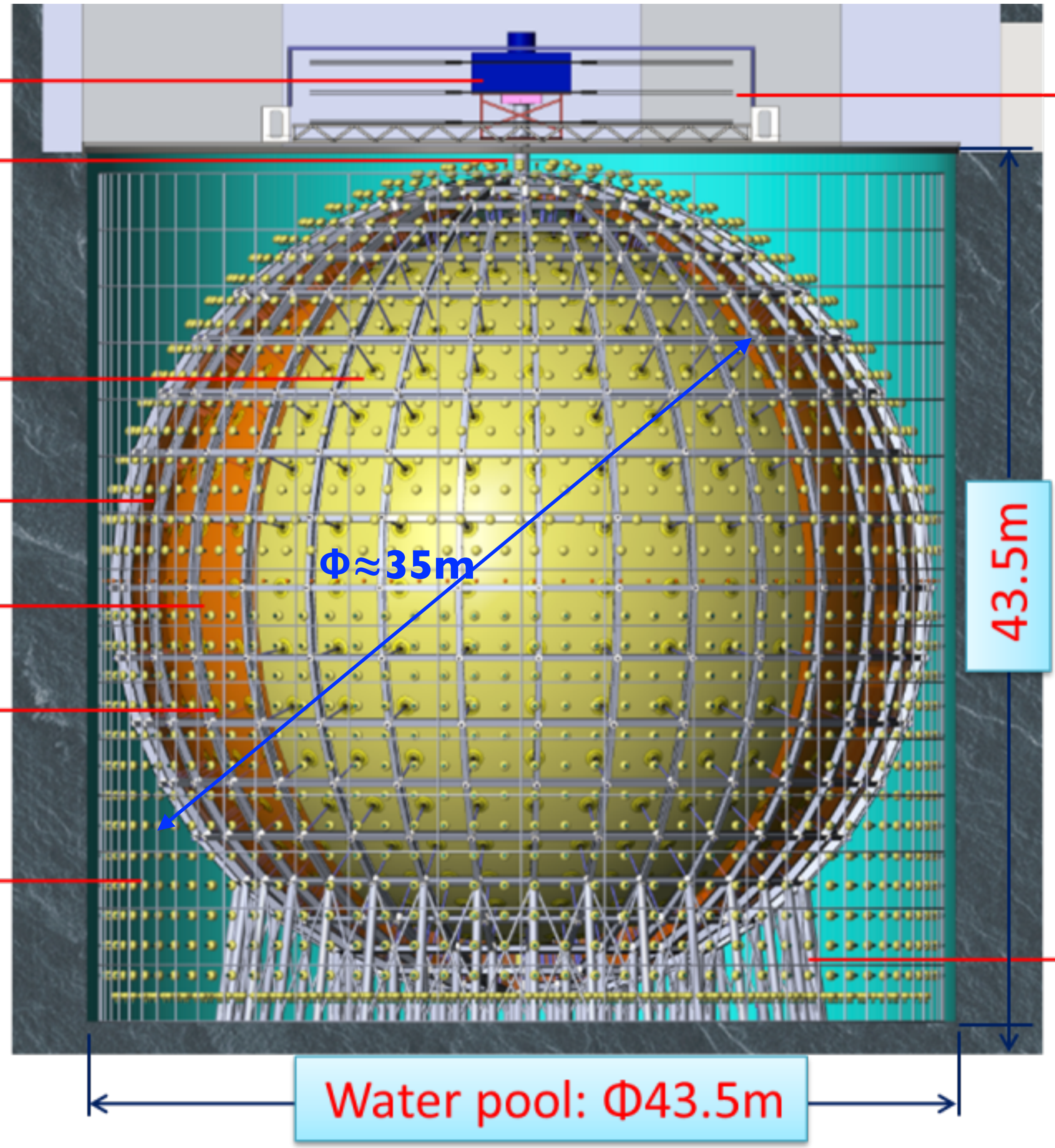
JUNO-ABC evaluation
CENBG (Bordeaux)

Anatael Cabrera
on behalf of the SPMT group
CNRS / IN2P3 @ APC (Paris) — LNCA (Chooz)

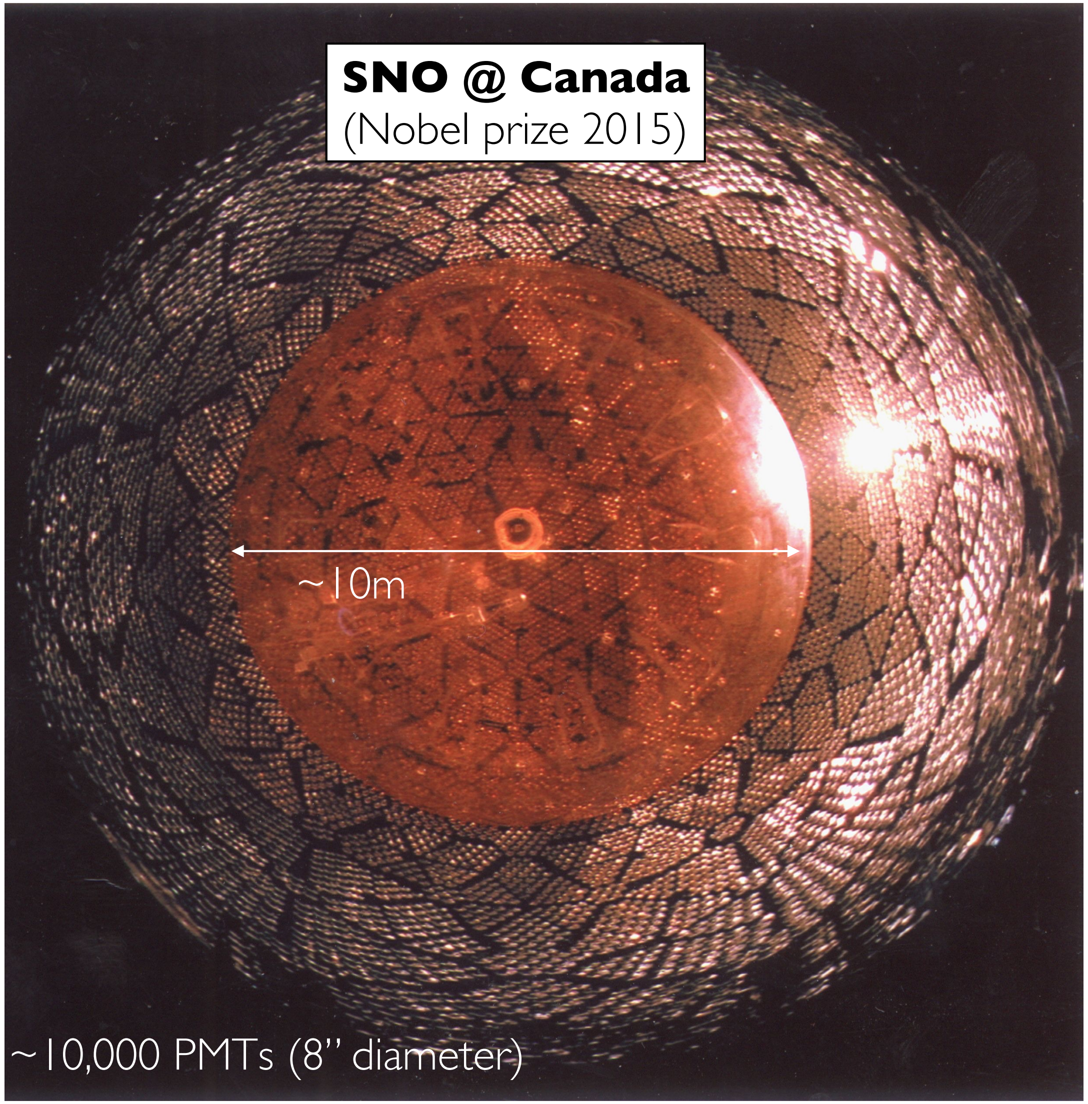
what/why the SPMT?…

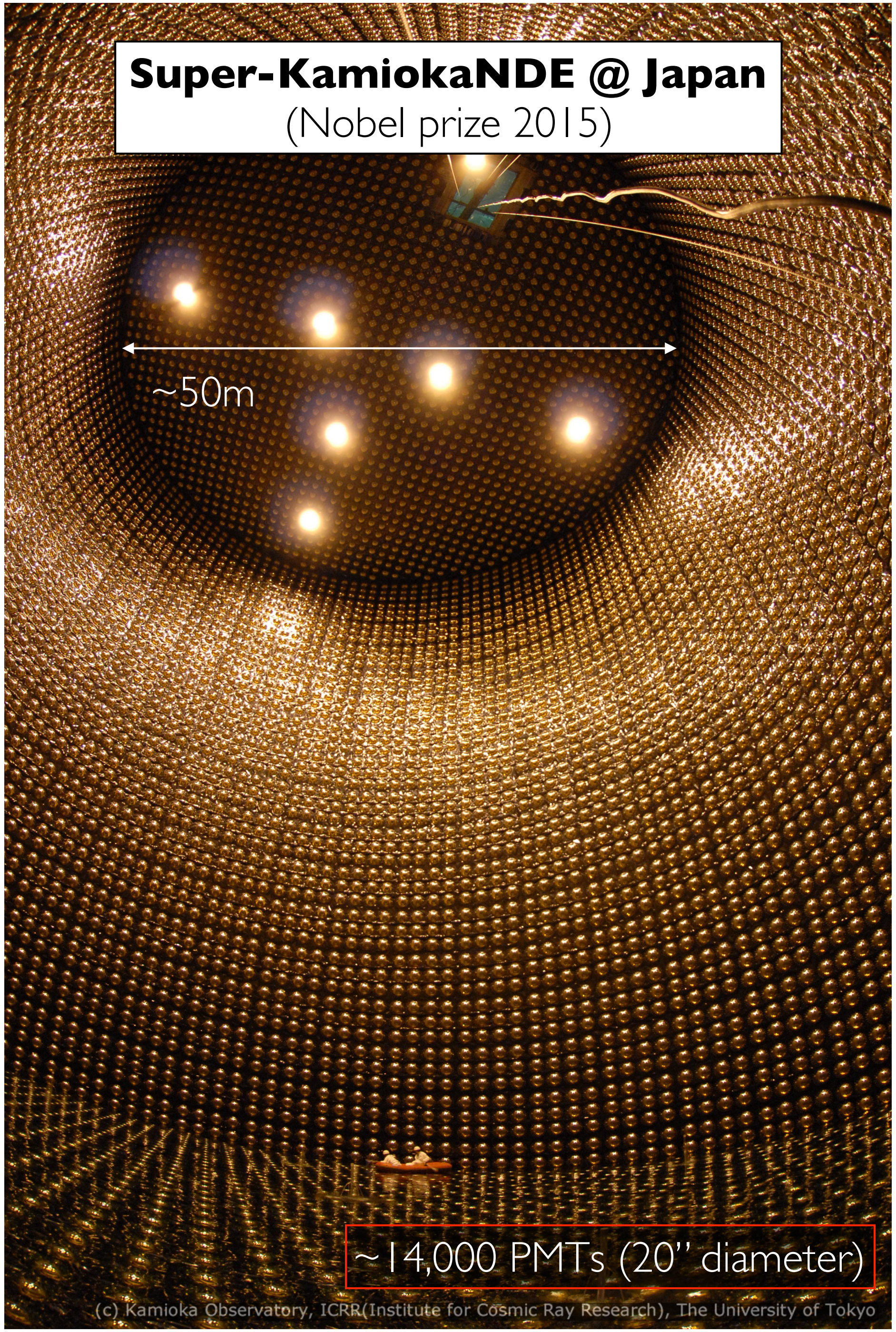
(fast physics recap)

the JUNO detector…

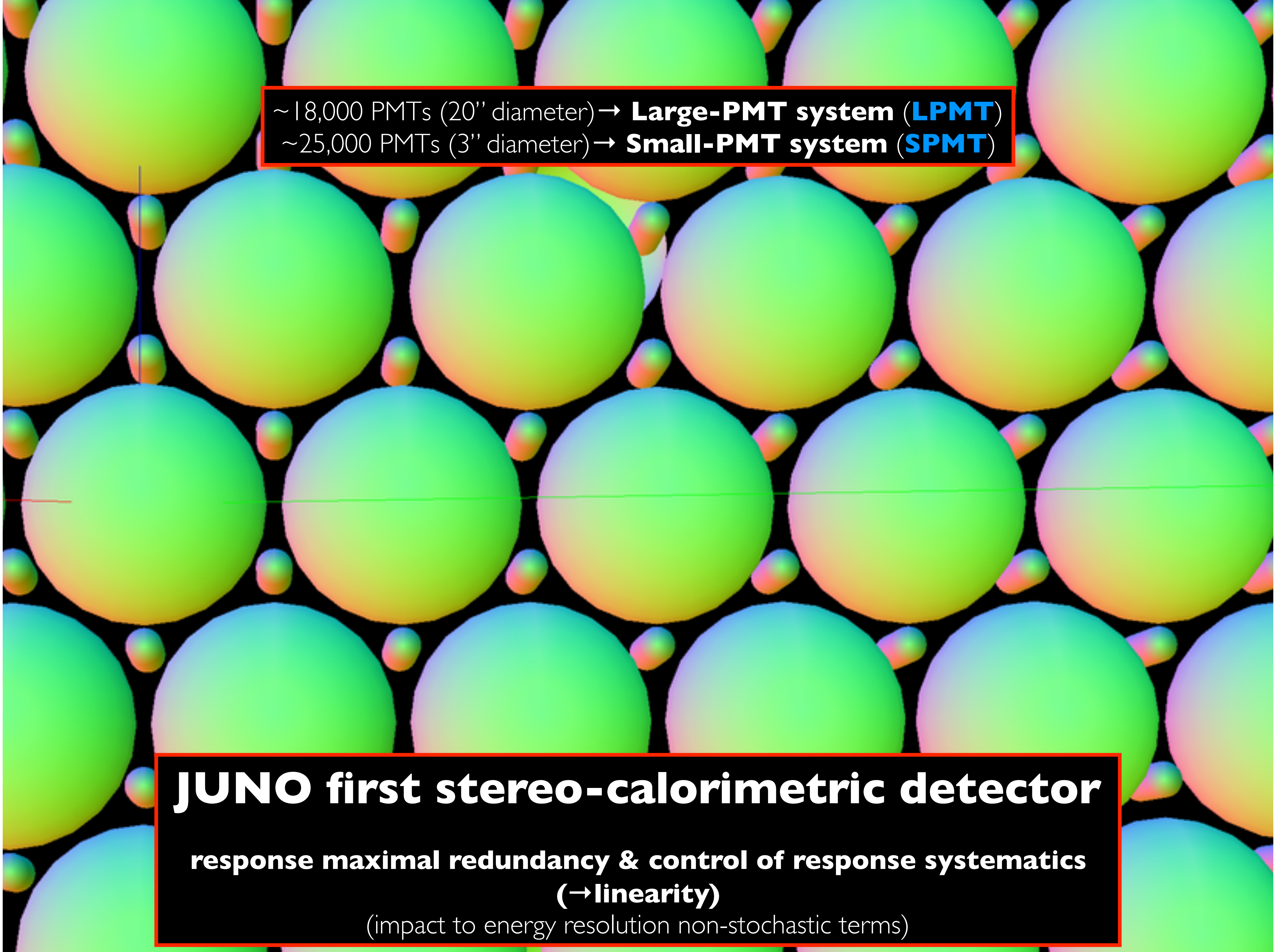


the JUNO detector (predecessors)…





JUNO can be regarded as a hybrid of both…
(filled with liquid-scintillator→ **~100x more light**)



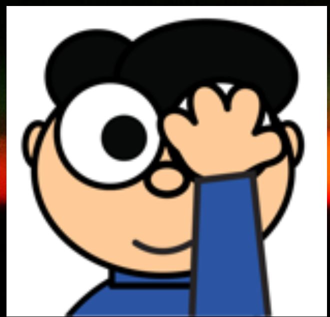
~18,000 PMTs (20" diameter)→ **Large-PMT system** (**LPMT**)
~25,000 PMTs (3" diameter)→ **Small-PMT system** (**SPMT**)

JUNO first stereo-calorimetric detector

response maximal redundancy & control of response systematics
(→linearity)
(impact to energy resolution non-stochastic terms)

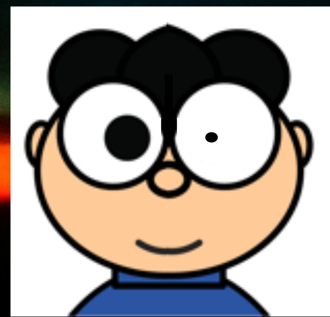
JUNO upgrade…

JUNO
(before)

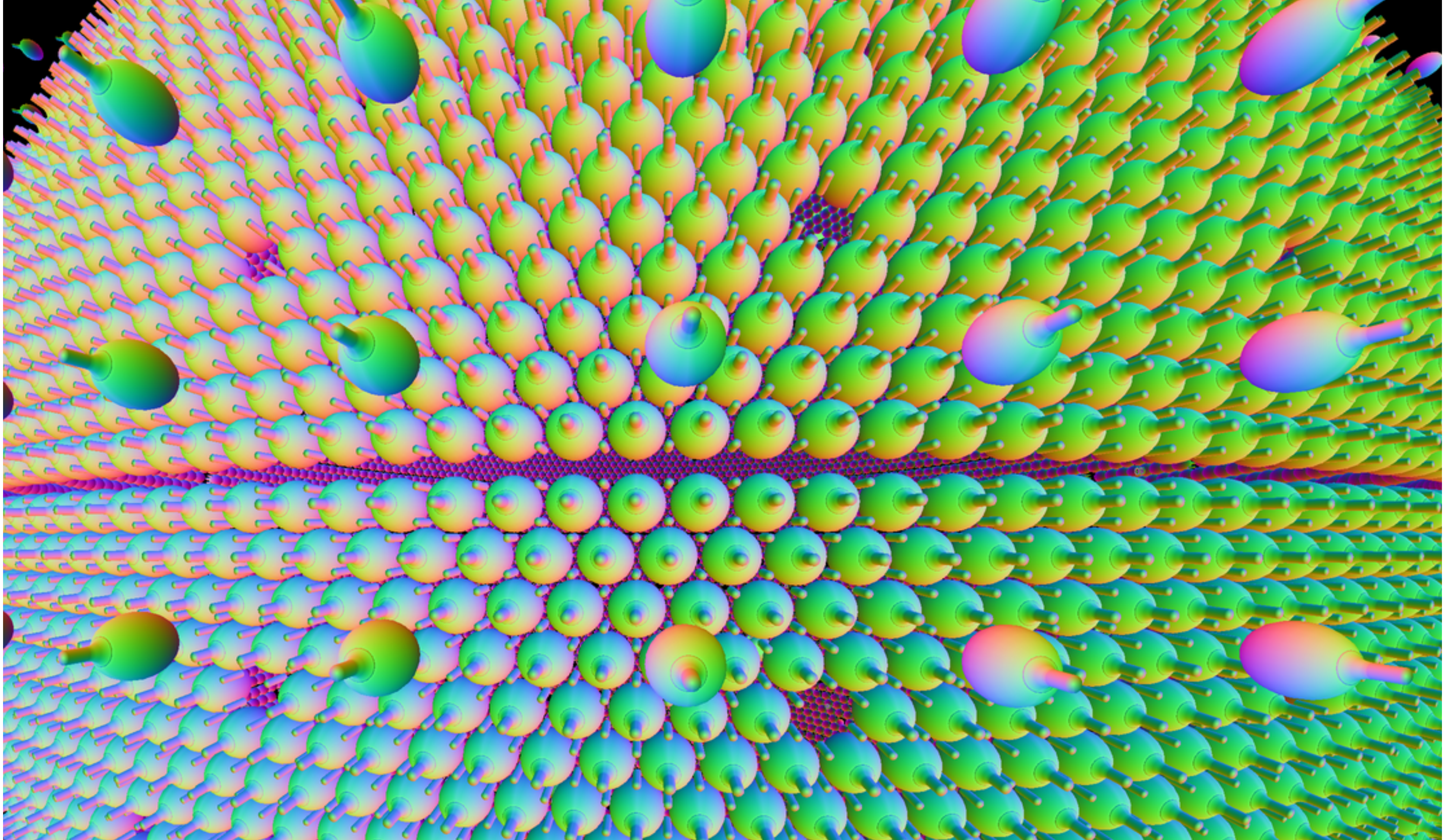


single-calorimetric

JUNO
(now)



stereo-calorimetric



JUNO: a photo-cathode colloso

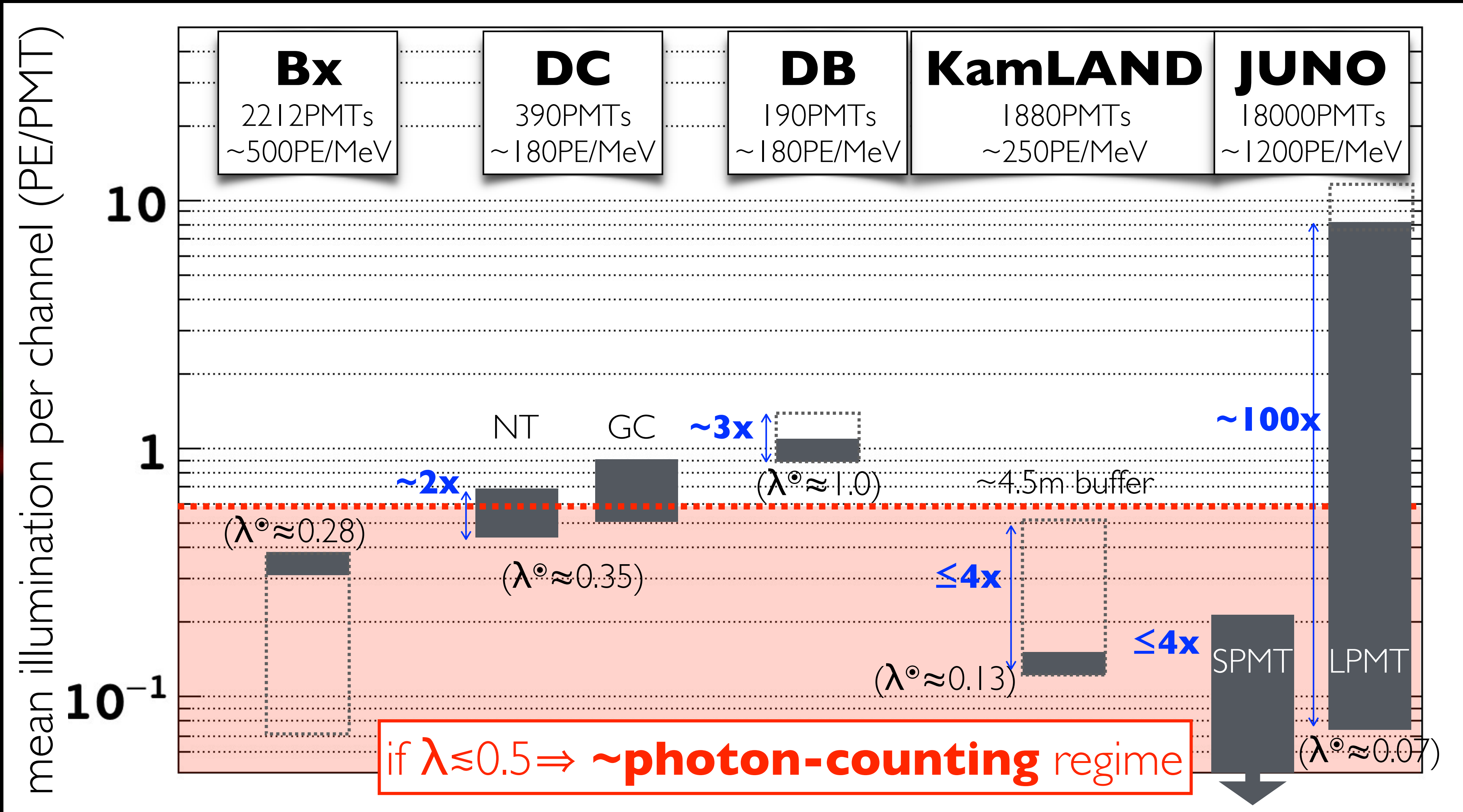
highest light level ever made (≥1000 PE/MeV)

highest “calorimetry” control of systematics

the JUNO challenge…

@1MeV

$\lambda^{\odot}$ = mean illumination per channel @ center



HIGHEST precision calorimetry (≲3% @ 1MeV)

⊕

LARGEST dynamic range in calorimetry (channel-wise) [⇒ **uniformity⊕linearity⊕stability**]

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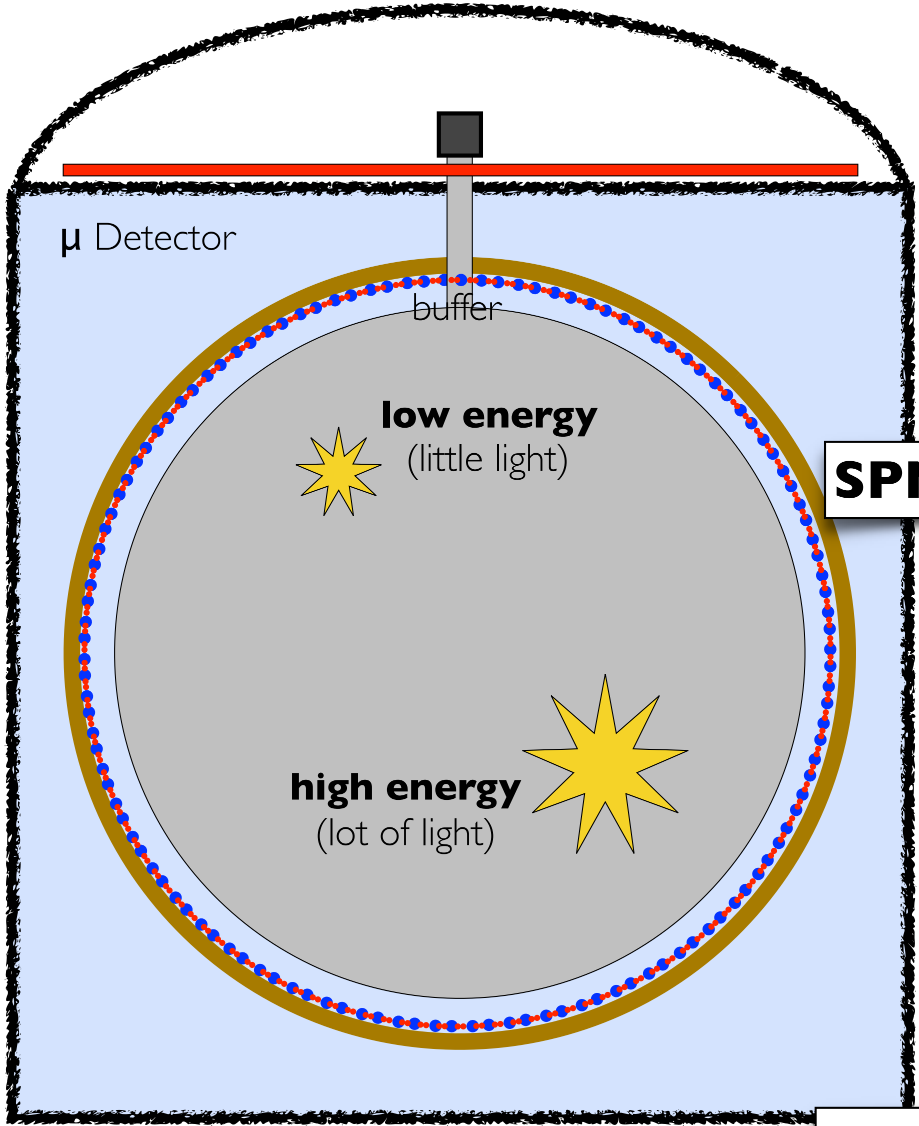
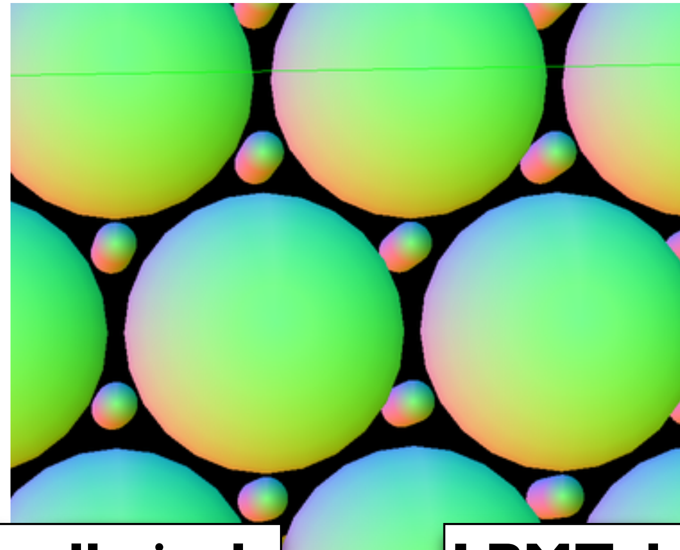
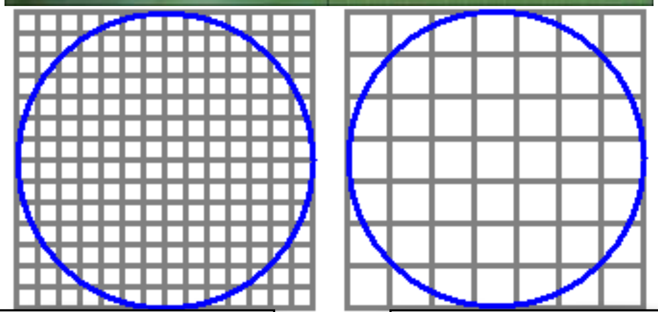
the competition SPMT vs LPMT…





SPMT: small pixels

LPMT: large pixels



unit of area

one photon per pixel
$\Longrightarrow$ "0" dynamic range
[no non-linearity]

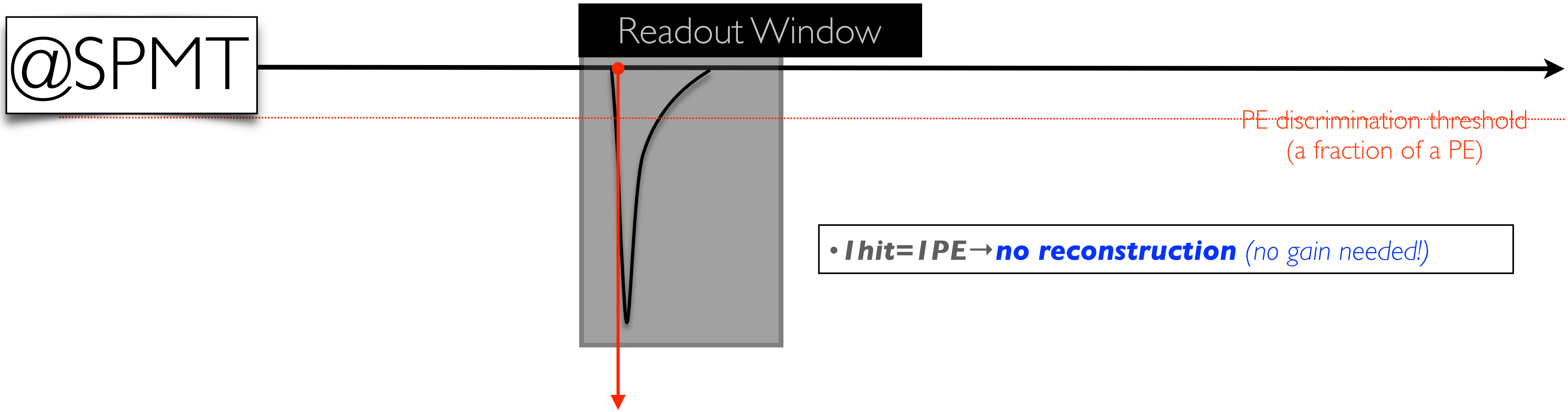
many photons per pixel
$\Longrightarrow$ large dynamic range!
[non-linearity control]

SPMT regime…

Photon Counting
(Photon-Statistics)

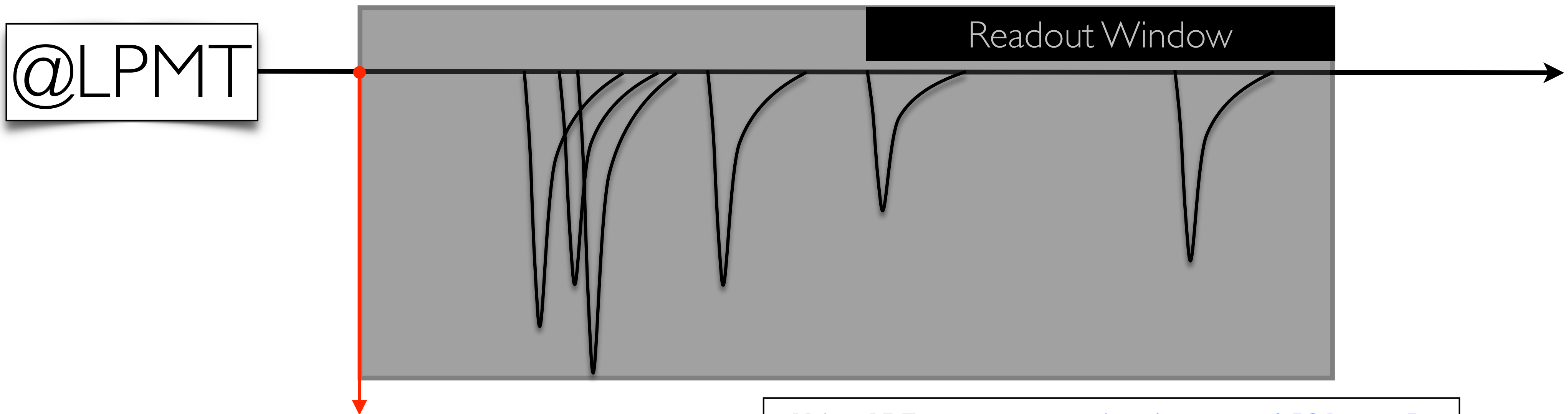
1hit = 1PE

Photon-Counting vs Charge-Integration…



time-stamp (self-trigger)
(pulse @ threshold→ discriminator)

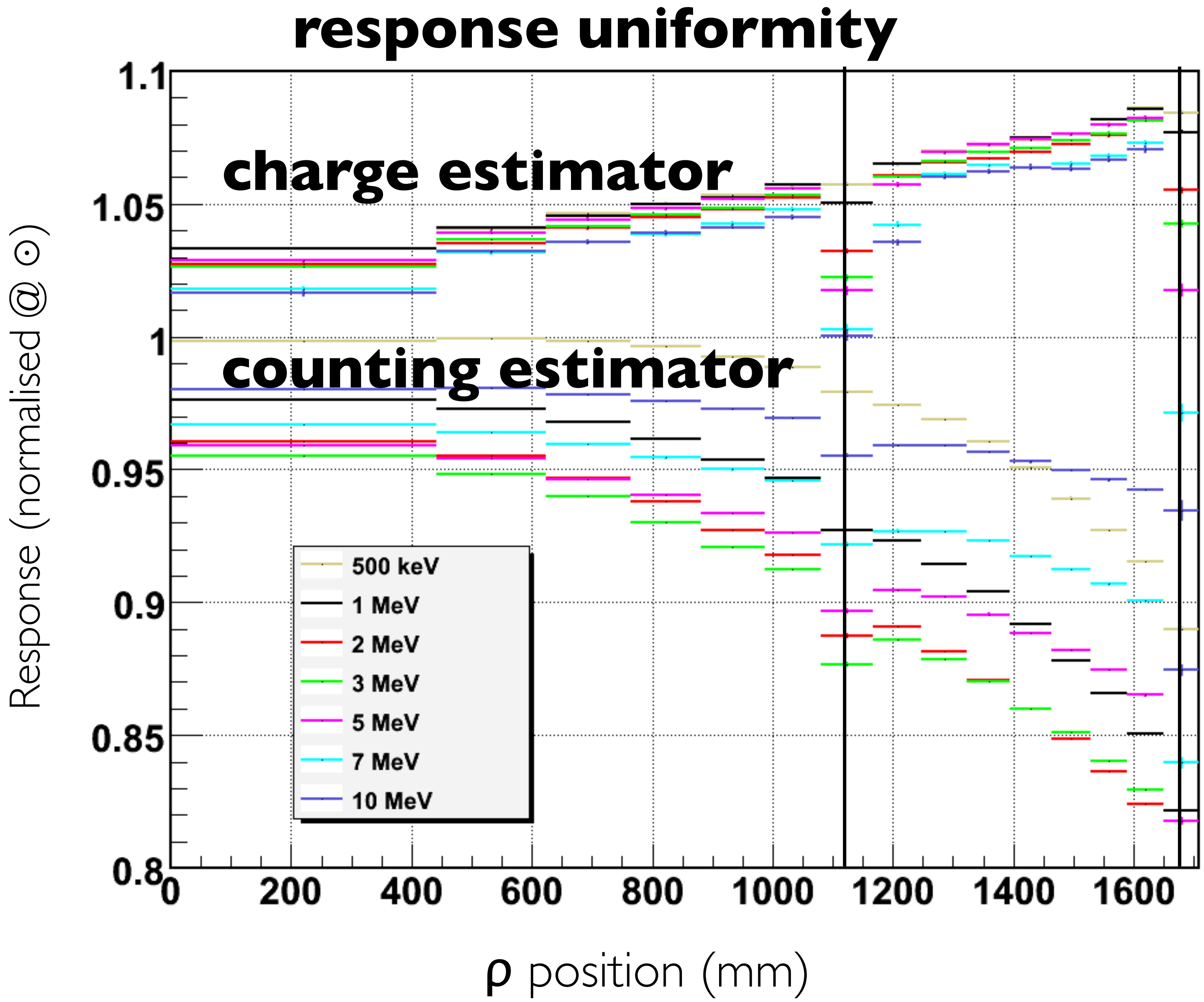
- *1hit=1PE→**no reconstruction** (no gain needed!)*



time-stamp (global trigger)
(readout-window sampled, example @ start)

- *1hit≠1PE→**reconstruction is a must! [QI-reco]***

Photon Counting vs Charge Integration in action…



charge & **counting** both useful→ **highly complementary**!!

the cooperation SPMT⊕LPMT…

SPMT

one photon per pixel
$\Longrightarrow$ "0" dynamic range
[no non-linearity]

LPMT

many photons per pixel
$\Longrightarrow$ large dynamic range!
[large non-linearity]

(key point)

BOTH (SPMT and LPMT) see the SAME events

BOTH see the SAME ENERGY but estimated differently!
(if one was non-linear, the other will see it in relative)

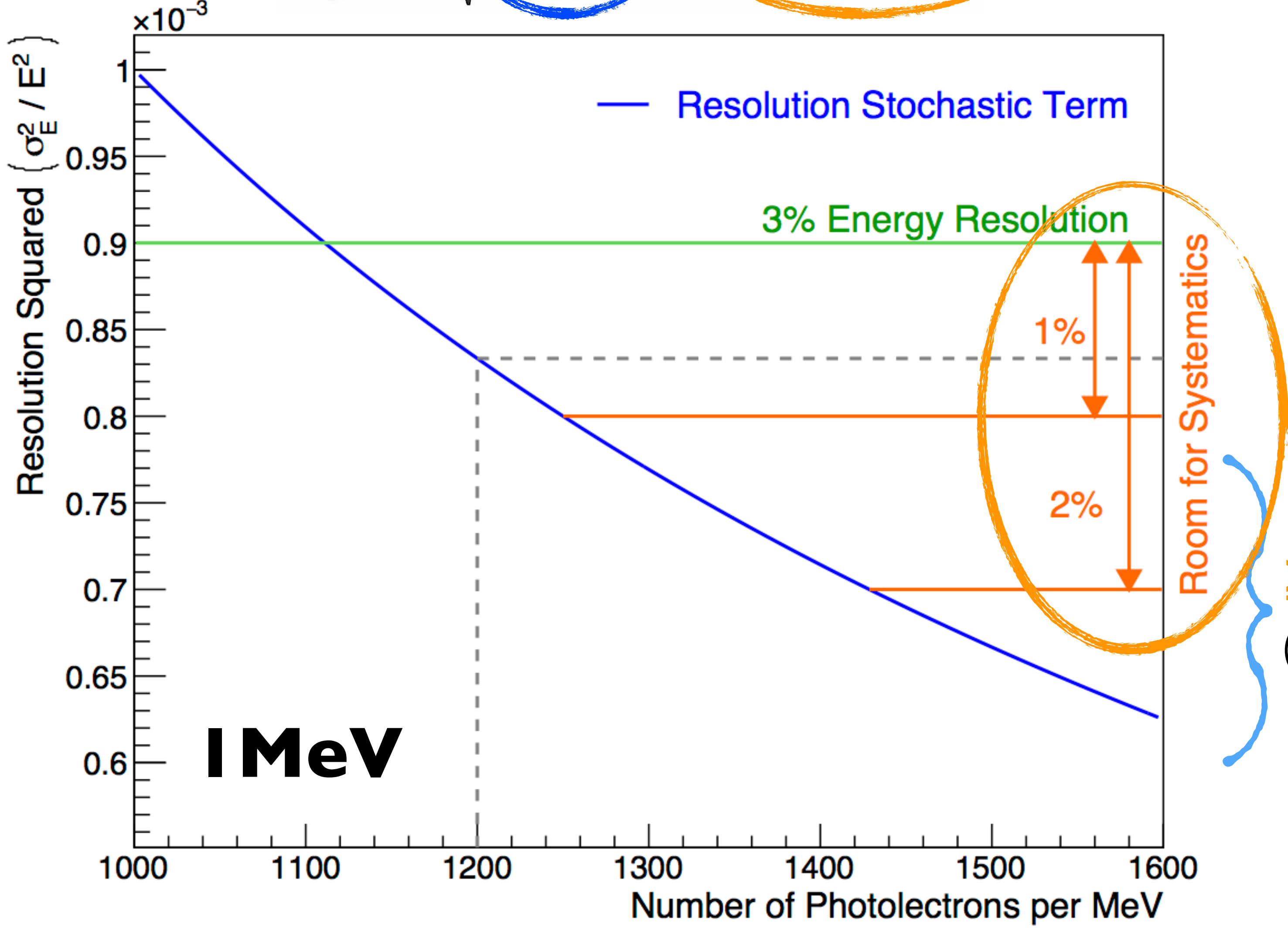
SPMT⊕LPMT (together) = **precision!**

JUNO calorimetry condition…

lot of light is a necessary but not sufficient condition

$$\frac{\sigma(E)}{E} = \sqrt{\frac{\sigma^2_{STOCH}}{E} + \sigma^2_{NON-STOCH}(E)}$$

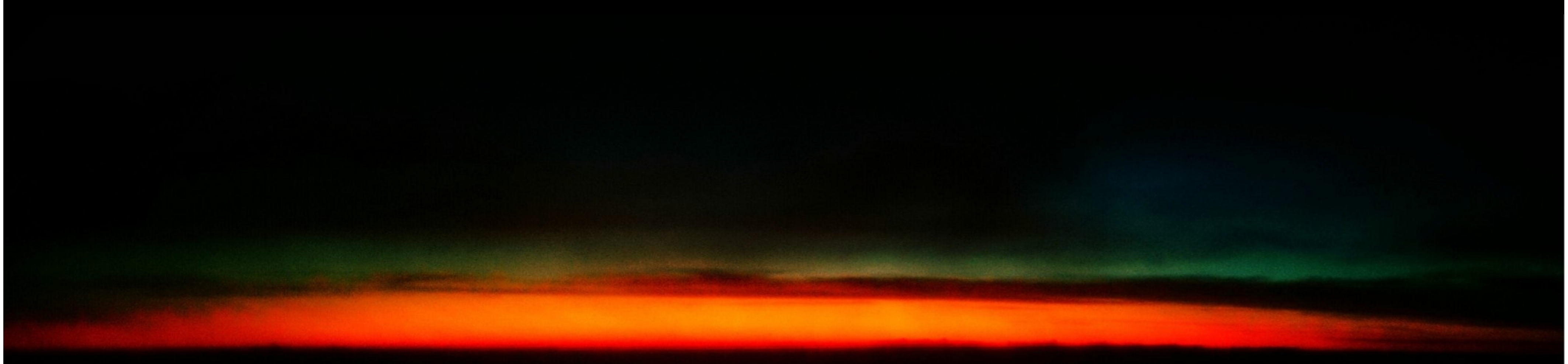
≤3% @ 1MeV



≥2%
(previous experiments)

challenging calorimetry systematics control

LPMT⊕SPMT complementarity…



LPMT
- linear (sensitive to tiny deviations)
- uniform (increase away from centre)
- stability (sensitive to both gain & zeroes)

SPMT
- non-linear (robust due to Poisson)
- uniform (decrease away from centre)
- stability (sensitive to gain (less) but zeroes)

LPMT⊕SPMT: differences use to aide LPMT response control

(correct systematics beyond stability⊕linearity⊕uniformity)

LPMT's view…

lot of them but hard to control!

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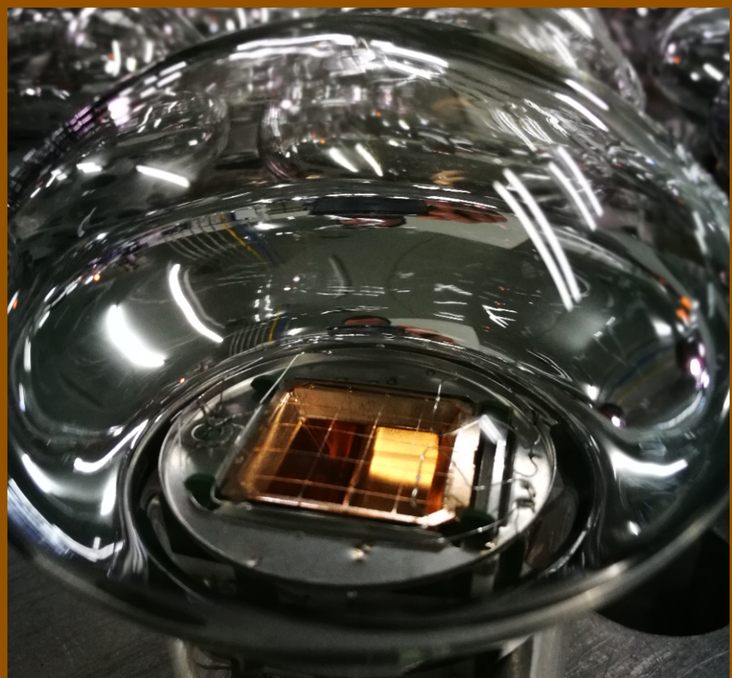
LPMT⊕SPMT's view…

now precision physics!

WANTED

~~DEAD~~ OR ALIVE

(don't break them!)



REWARD much neutrino physics ⊕ calorimetry!!

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rich physics…

- **high precision stereo calorimetry (LPMT⊕SPMT)**
- **high precision neutrino oscillation physics, etc**
- **high rate supernova detection (acceptance ≥90% Galaxy)**
- **4π μ-tracking & after muon spallation products (n-activation)**

and more… (skip here)

physics → detector requirements…

- **high precision stereo calorimetry (LPMT⊕SPMT)**

constraint: [1,10]MeV (photon-statistics), low rate, charge resolution

- **high precision neutrino oscillation physics, etc**

constraint: same as stereo-calorimetry (byproduct)

- **high rate supernova detection (acceptance ≥90% Galaxy)**

constraint: [1,30]MeV, hugh rate(!!!), charge resolution

- **4π μ-tracking & after muon spallation products (n-activation)**

constraint: ~[5,40]PE, time resolution (new PMT), linearity, high rate

trigger rate driven by dark-noise (~1k/s) & muons (~1k/s)

why the SPMT design?

(JUNO⊕physics constraints)

SPMT into JUNO…

“‘pertubative’” JUNO re-design

⊕

low cost

⊕

up to 36 000 channels (25 000 now)

⊕

tight schedule

[details in Cedric’s & Cayetano’s talk]

SPMT into JUNO…

"pertubative" JUNO re-design

⊕

(**very**) low cost

⊕

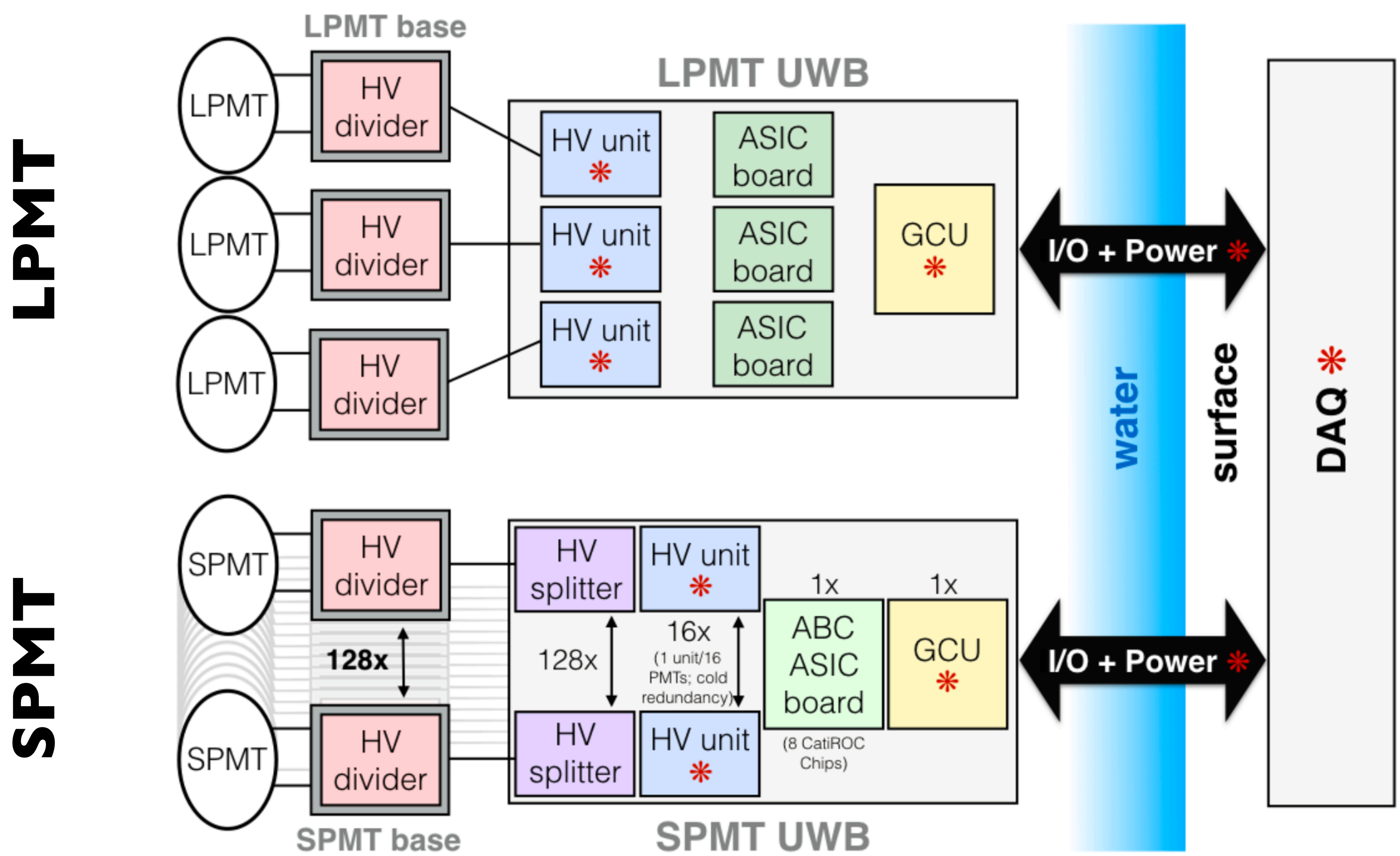
up to 36 000 channels (25 000 now)

⊕

(**very**) tight schedule

[details in Cedric's & Cayetano's talk]

LPMT & SPMT commonalities…



* = Items common to both LPMT & SPMT systems

LPMT & SPMT design very similar→ influence each other strongly

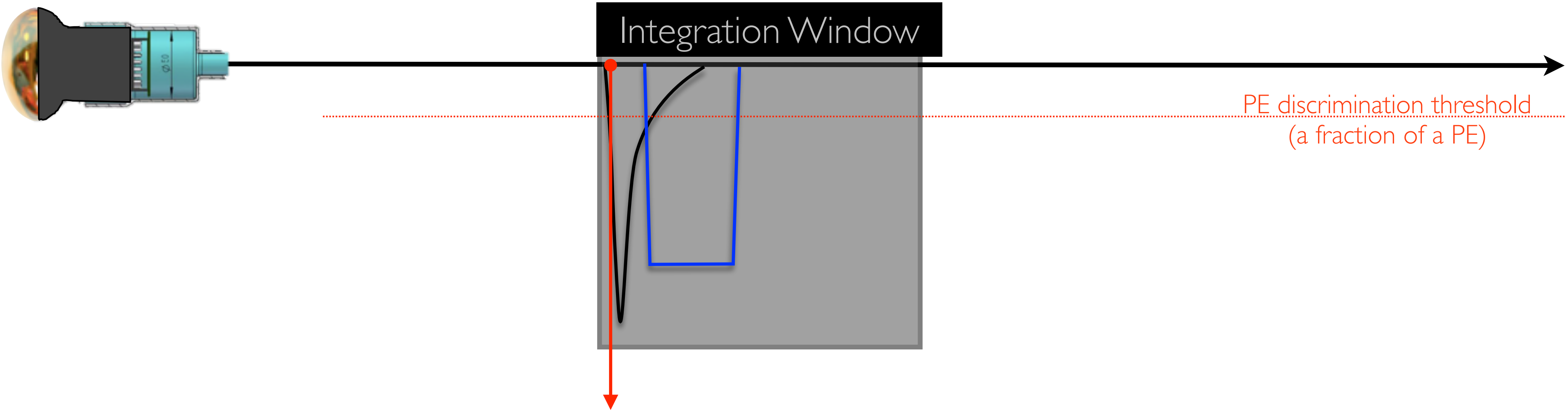
(maximise common elements→ **reduce cost & smooth integration**)

Anatael Cabrera (CNRS-IN2P3 & APC)

(most important) JUNO-SPMT specifications…

		goal	critical	comment
3" PMT	**physical diameter**	≤80mm	yes	light level (photon-counting tuning)
	SPE width	≤40%	yes	SPE discrimination efficiency
	dark count (@1/4 PE)	≤1.5k/s	yes	DAQ/readout rate (dominant)
	TTS (sigma)	≤1.5ns	yes	position reconstruction
	HV nominal (g=10^6)	[0.8,1.3]kV	no	signal size (discrimination for noise)
	QE@420nm (average)	≥25%	yes	light level (photon-counting tuning)
	non-linearity [0,5]PE	≤1%	yes	linearity in physics regime (redundancy)
	non-linearity [5,100]PE	≤10%	no	linearity above main physics
	current	≤10μA	yes	many PMTs on 1HV channel
CatiROC	**time resolution**	≤0.5ns	yes	negligible wrt PMT
	charge resolution	>1/10 PE	yes	negligible wrt PMT & SPE discrimination
	pre-amp gain	[2,10]	ok	compensate (channel-wise) PMT gain
	(non supernova) max rate	10kHz	yes	non-supernova physics rate capability
	deadtime	≤10μs	ok	limits ADC maximal rate
	supernova max rate	10MHz	yes	supernova physics rate capability

Photon-Counting detection…



Light Detection via Photon-Statistics…

- **1hit = 1PE (multi-PE not possible)**
  →**no reconstruction** *(extreme: no gain needed!)*
- *multi-PE contamination constraint by low-light level (i.e. λ(Poisson)≤0.1)*
- ***time-stamp*** *(example: discriminator on rising edge)*
- ***charge info*** *(no need→ but do something funky!)*
- ***deadtime-less***

→ ***"DIGITAL" READOUT LIMIT***

Light Detection via Charge Measurement…

- **1hit ≥ 1PE (multi-PE possible)**
  →***calibration gain needed***
- *multi-PE contamination constraint by low-light level (i.e. λ(Poisson)≤0.1)*
- ***time-stamp*** *(TDC-like)*
- ***charge info*** *(ADC)*
- ***deadtime-ful***

→ ***"ANALOGUE" READOUT LIMIT***

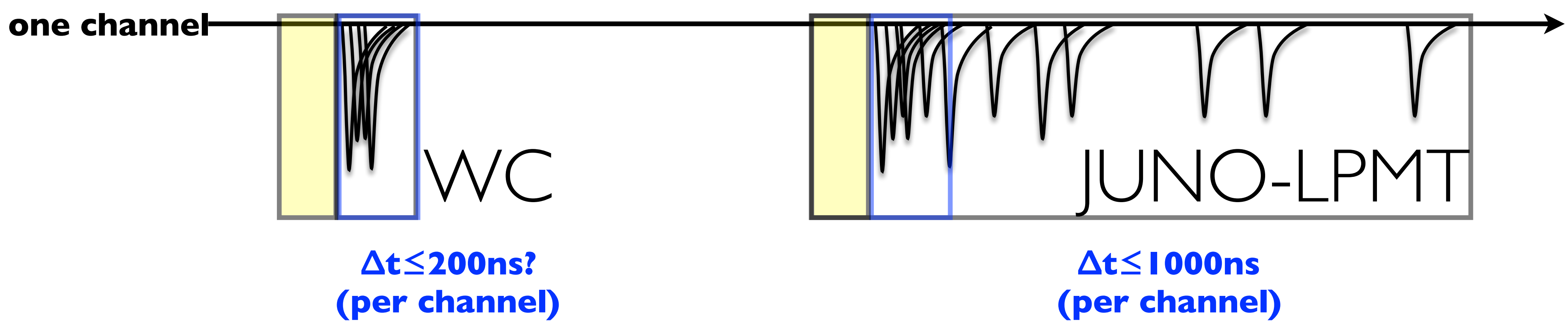
CatiROC⊕ABC can do both

the challenge…

CatiROC not good for JUNO

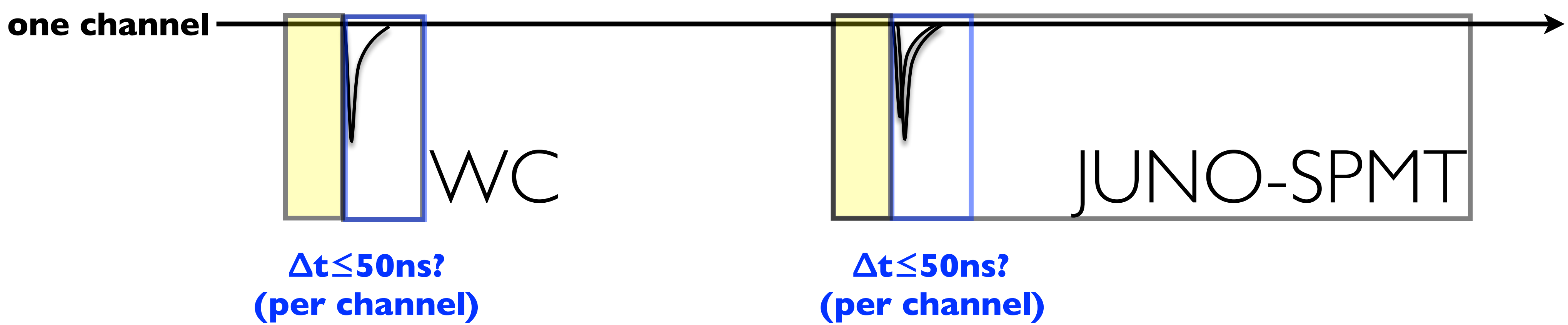
$\Delta t(ToF) \leq 200ns$ (per channel)

designed for Water-Cherenkov…



CatiROC acceptance window ≤200ns (per channel) → truncate some scintillation light

SPMT works in Photon-Statistics (low light level: 1PE per trigger)



WC ≈ SPMT-JUNO

good news…

SPMT-JUNO (low light)

$\oplus$

PE self-trigger

CatiROC→JUNO!

(non-trivial)

but not enough…

“‘non-deterministic’’ deadtime

&

maximal rate $\lesssim$100k/s(?)

→**success only via ABC**

(even less trivial)


today's evaluation…
what to expect?

we think… but do you agree?

system CatiROC⊕ABC
powerful SPMT readout

constraints:
tight schedule ⊕ underwater

[**no room for (big) mistakes**]

ABC card strategy…

ABC-v0: first prototype

(goal: basic multi-ASIC readout)

this evaluation here!

(i.e. v0→v1)

ABC-v1: final card

(goal: v0 ⊕ extra functionalities)

bad news (sorry)...

ABC-v0: available only since JAN-2018
(production delays)

✓ single-ASIC demonstration
⁇ multi-ASIC demonstration
(FW development still ongoing)

IMPORTANT: any HW defaults?

your attention (please)…

demonstration-0: CatiROC work in JUNO?
(we think so→**do you disagree?**)

demonstration-1: ABC work in JUNO?
(ongoing effort→**feedback please**)

demonstration-2: SPMT readiness for JUNO?
(complete strategy→**feedback please**)

milestones 2018…

(3x) **ABCv0→ PMT testing system (China)**
[25,000 PMTs to be tested]

(3x) **ABCv1 ready for production & validation**

(220x) **ABCv1 production**
(~2000) **CatiROCs production**
[early 2019: **prepare within 2018**]

final validation & full integration
[late 2019 — some details here]

ready for detector installation
[2020 — no details here]

SPMT system approved…

mid-2016

(most work 2017)

the SPMT team…

20 laboratories (9 countries) so far...

our (international) team...

Armenia
- Yerevan Physics Institute (Yerevan)

Brasil
- FABC (Sao Paulo)
- PUC (Rio de Janeiro)

Belgium
- UBL (Brussels)

Chile
- PUC (Santiago) **(project/physics coordination)**

China
- IHEP (Beijing) **(project/physics coordination)**
- SYSU (Guangzhou)

France
- APC (Paris) **(project/physics coordination)**
- CENBG (Bordeaux) **(technical coordination)**
- CPPM (Marseille)
- LLR (Paris)
- OMEGA (Paris)
- SUBATECH (Nantes)

Italy
- Padova-INFN (Padova)

Russia
- Moscow State University (Moscow)
- Institute of Nuclear Research & Russian Academy of Science (Moscow)

Taiwan
- National Taiwan University NTU (Taipei)
- National Chiao Tung University NCTU (Hsinchu)
- National United University NUU (Miaoli)

ABC-electronics related team (CNRS/IN2P3)…

coordination:

- Anatael CABRERA (APC, France) [**electronics**]
- Miao HE (IHEP, China) [**PMT**]
- Pedro OCHOA (PUC-Santiago, Chile) [**HV+under-water boxes**]

project manager:

- Cedric CERNIA (CENBG, France) [**all⊕interfaces + connectivity**]

engineers:

- Selma CONFORTI (OMEGA, France) [**CatiROC**]
- Frederic DRUILLOILE (CENBG, France) [**ABC testing**]
- Amelie FOURNIER (CENBG, France) [**under-water-box**]
- Cedric HUSS (CENBG, France) [**ABC routing**]
- Alexis NOURI (APC, France) [**ABC design** — left]
- Abdel RABII (CENBG, France) [**ABC FW**]
- Cayetano SANTOS (APC, France) [**ABC FW**]
  →(collaboration) Andrea TRIOSSI (CERN, Switzerland)
- Guillaume VANROYEN (SUBATECH, France) [**ABC DAQ**]

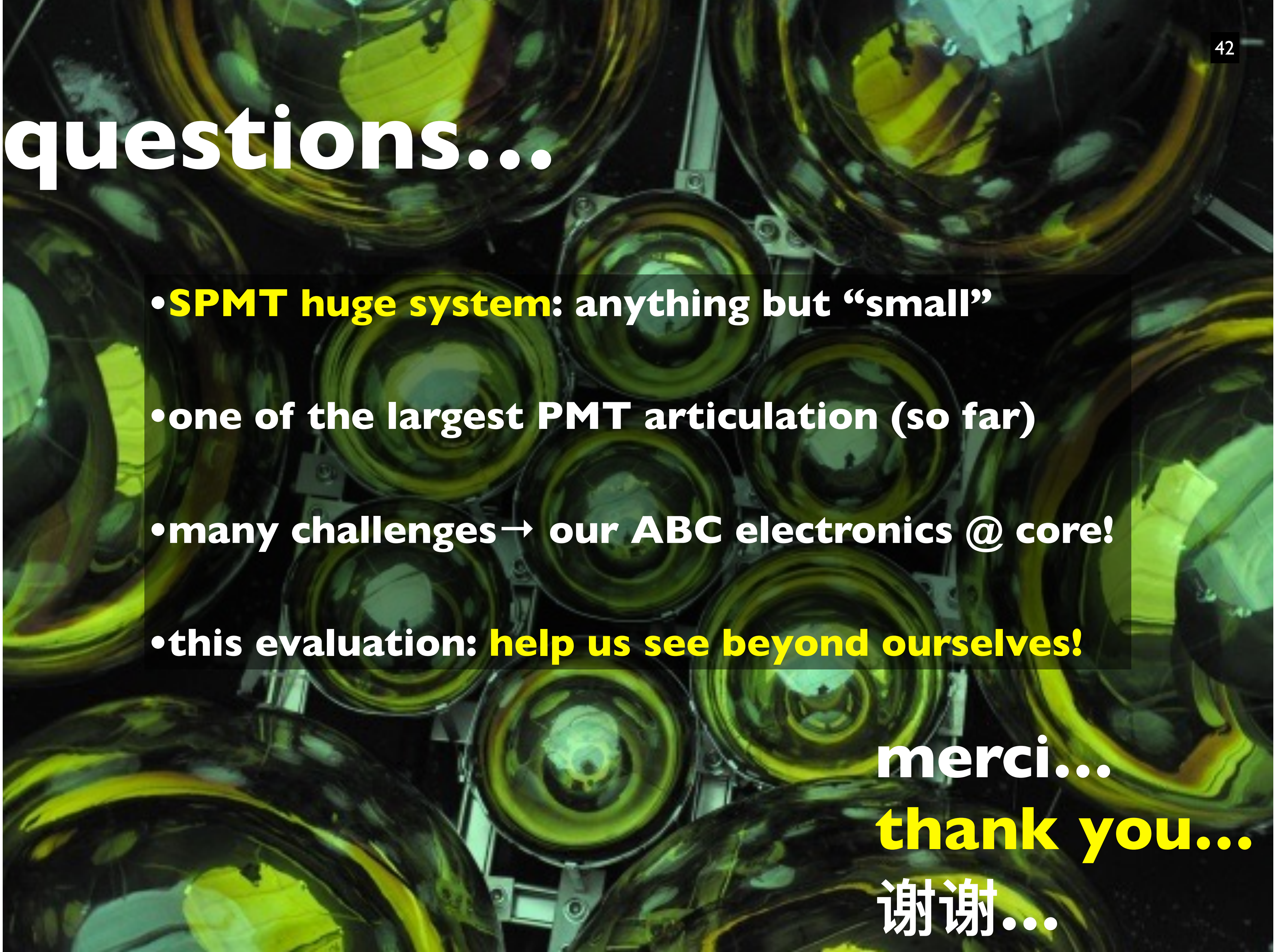
physicists @ SPMT-CNRS/IN2P3 (support):

- Clement BORDEREAU (CENBG, France) [**PhD**]
- Jose BUSTO (CPPM, France)
- Yang HAN (APC, France) [**PhD**]
- Cecile JOLLET (CENBG, France)
- Frederic PERROT (CENBG, France) [**simulation**]
- Mariangela SETTIMO (SUBATECH, France) [**DAQ**]
- Christophe de la TAILLE (OMEGA, France) [**CatiROC**]
- Frederic YERMIA (SUBATECH, France)

strong international collaboration behind [previous page]

5 laboratories working together

[APC⊕CENBG⊕CPPM⊕Ω⊕SUBATECH]



questions…

- **SPMT huge system**: anything but "small"
- one of the largest PMT articulation (so far)
- many challenges→ our ABC electronics @ core!
- this evaluation: **help us see beyond ourselves!**

merci…

thank you…

谢谢…