MEG実験LXeガンマ線検出器のアップグレードの為の研究

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他 MEGコラボレーション

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MEG and upgrade

- MEG will reach the goal statistics soon. Goal sensitivity = 5×10^{-13}.
- Upgrade
  - **Aiming a sensitivity improvement by factor 10**.
  - Several ideas for each sub-detectors
  - R&D and MC studies have been started
  - Proposal in the next year

MEG upgrade

μ rate : $3\times10^{7} \rightarrow$ **1×10^{8}**, already possible at the πE5 beam line

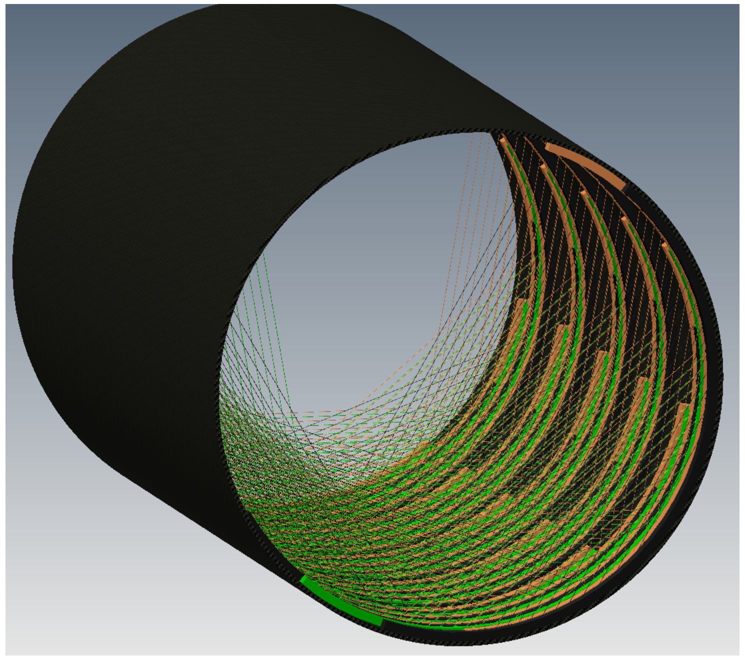
γ : Smaller photo-sensors, presented in this talk

e^{+}

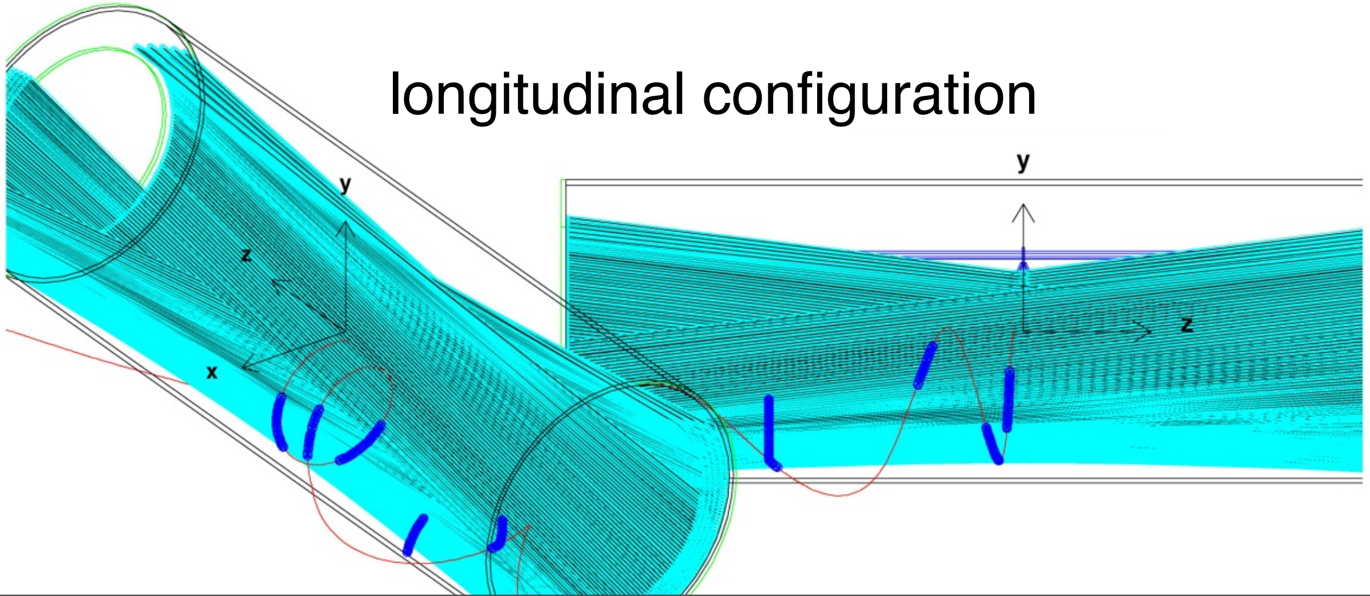
Single volume drift chamber,

- Stereo wire configuration
- Transverse or longitudinal configurations
- Smaller cell size
- More number of hits
- Less material than the present chambers
- Higher transmutation efficiency to TOF counter

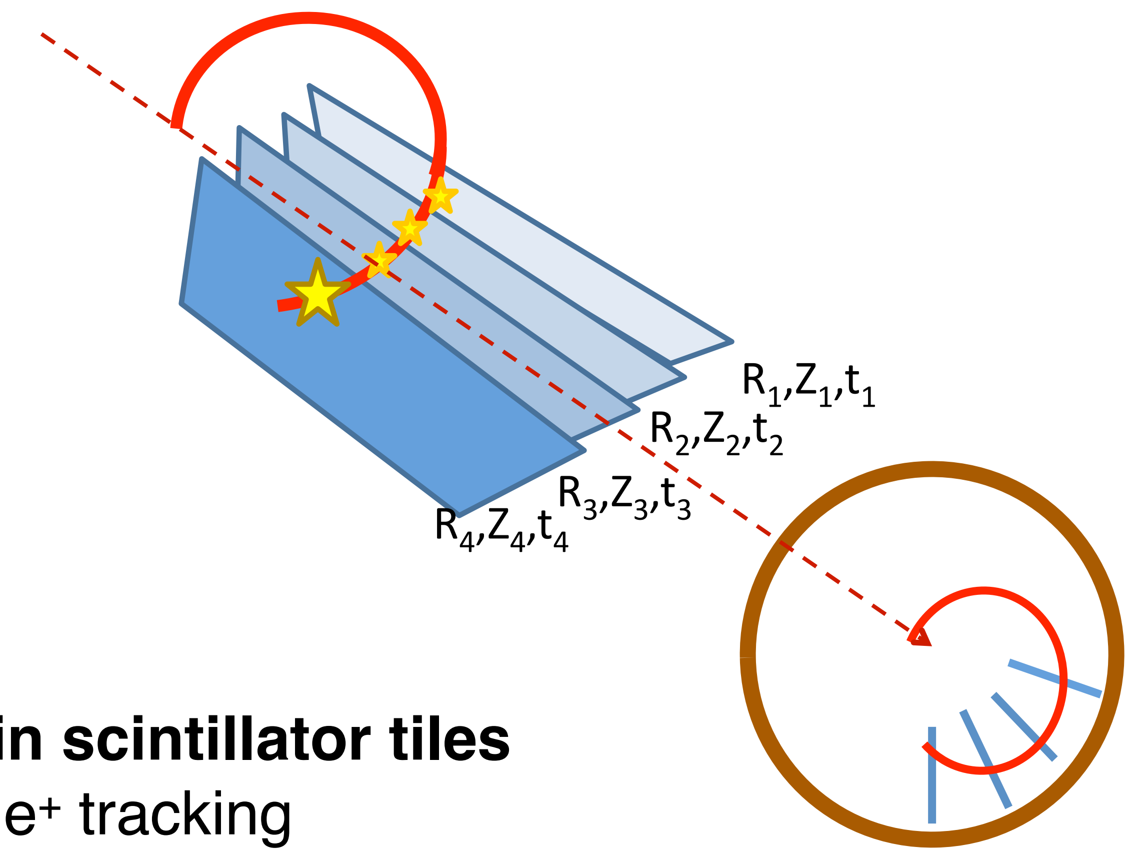
transverse configuration



	Present	Goal
Efficiency	41%	80%
$\sigma(p)$	350 keV	150 keV
$\sigma(\theta)$	10 mrad	5 mrad
$\sigma(\phi)$	11 mrad	5 mrad

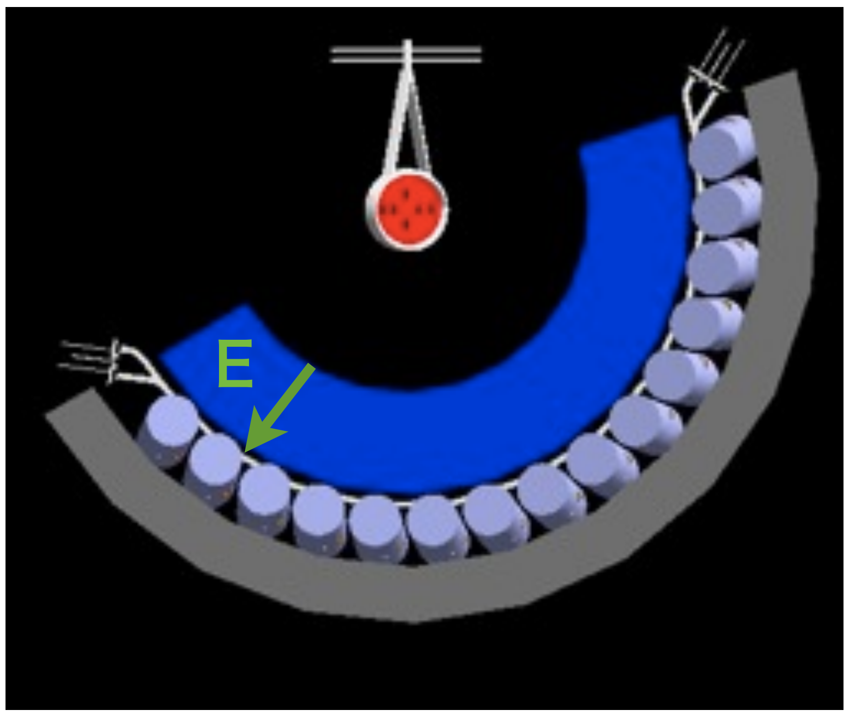


Other ideas

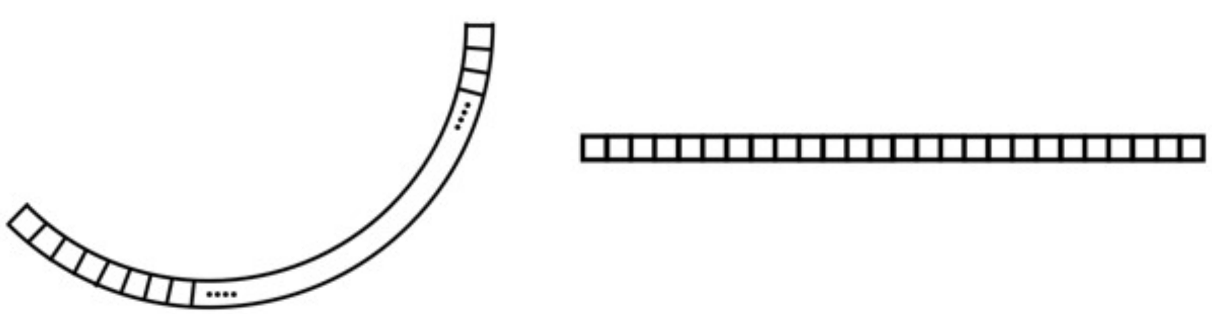


Thin scintillator tiles
for e^+ tracking

TPC for e^+



→ 藤井祐樹 (25aFB13)

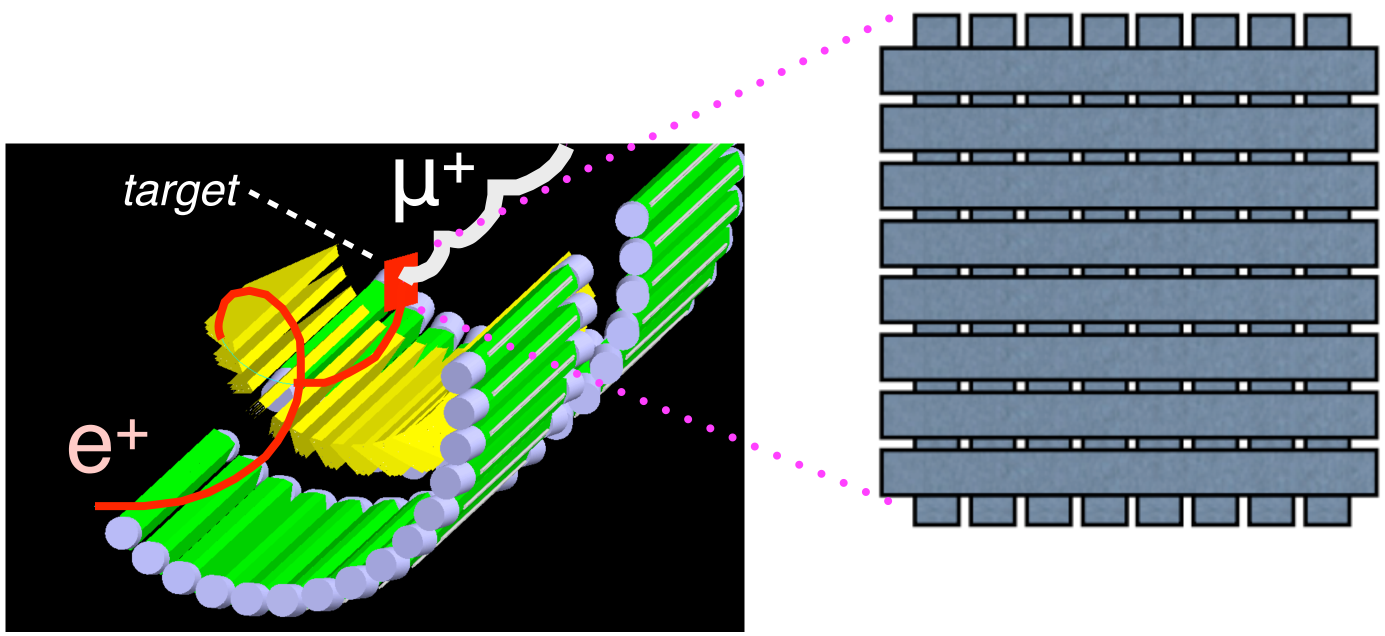


Segmented e^+ timing counter
($3\times3\times3$ cm^3)

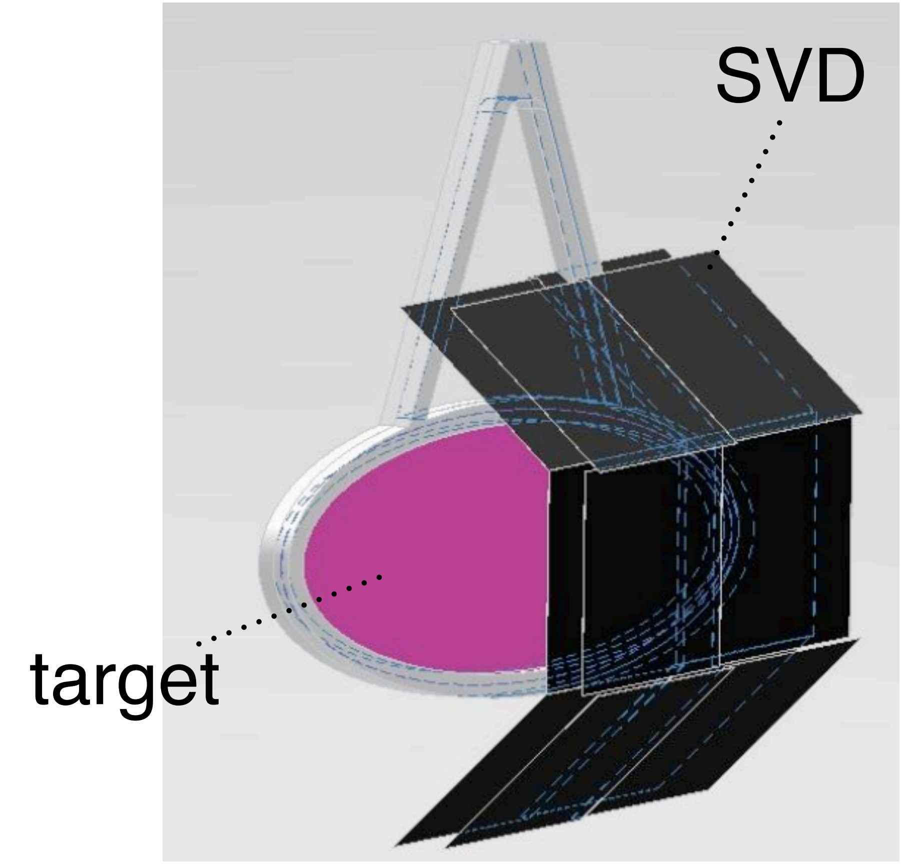
- Readout using PPD
- No need to protect from He gas
- Works in B-field
- More optimum arrangement
- Less pileup

Other ideas

“Active” target
Target made of scintillators



Silicon vertex detector

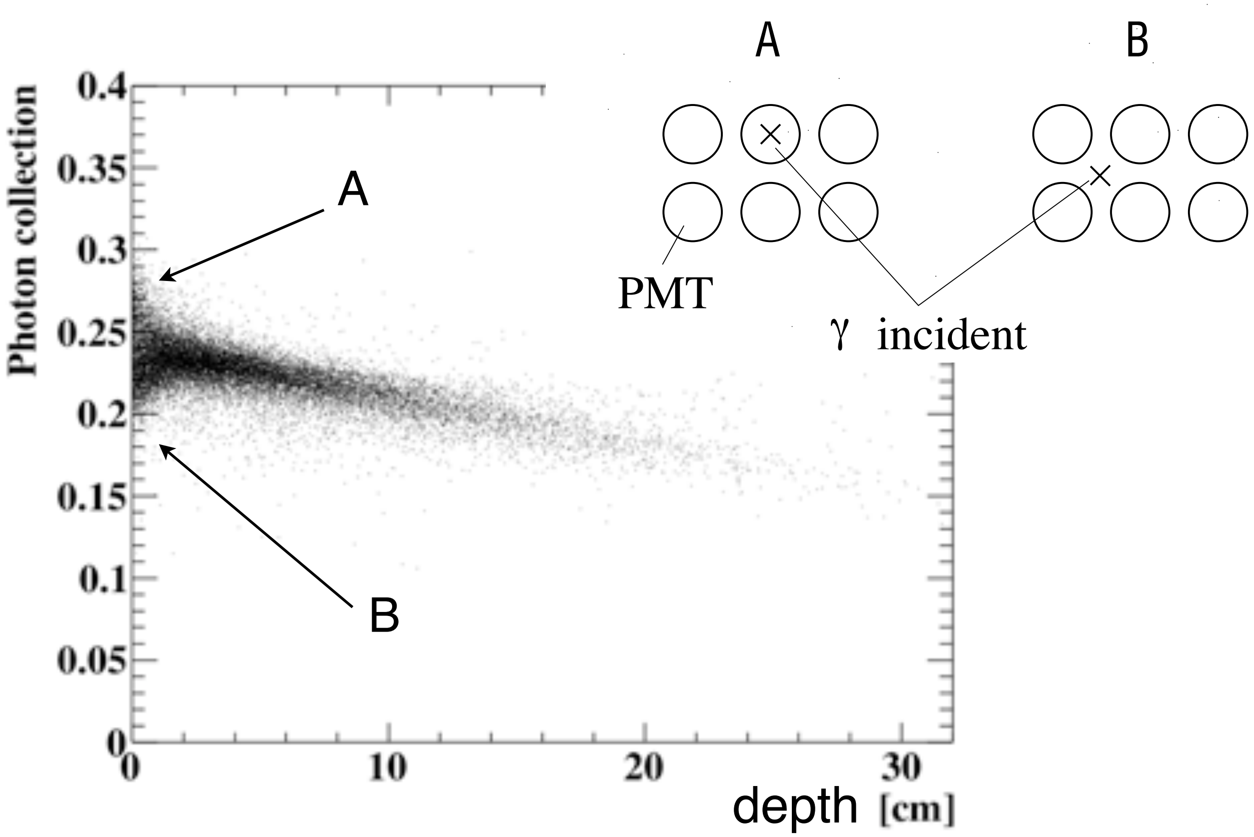


γ detector upgrade

What is limiting the resolutions ?

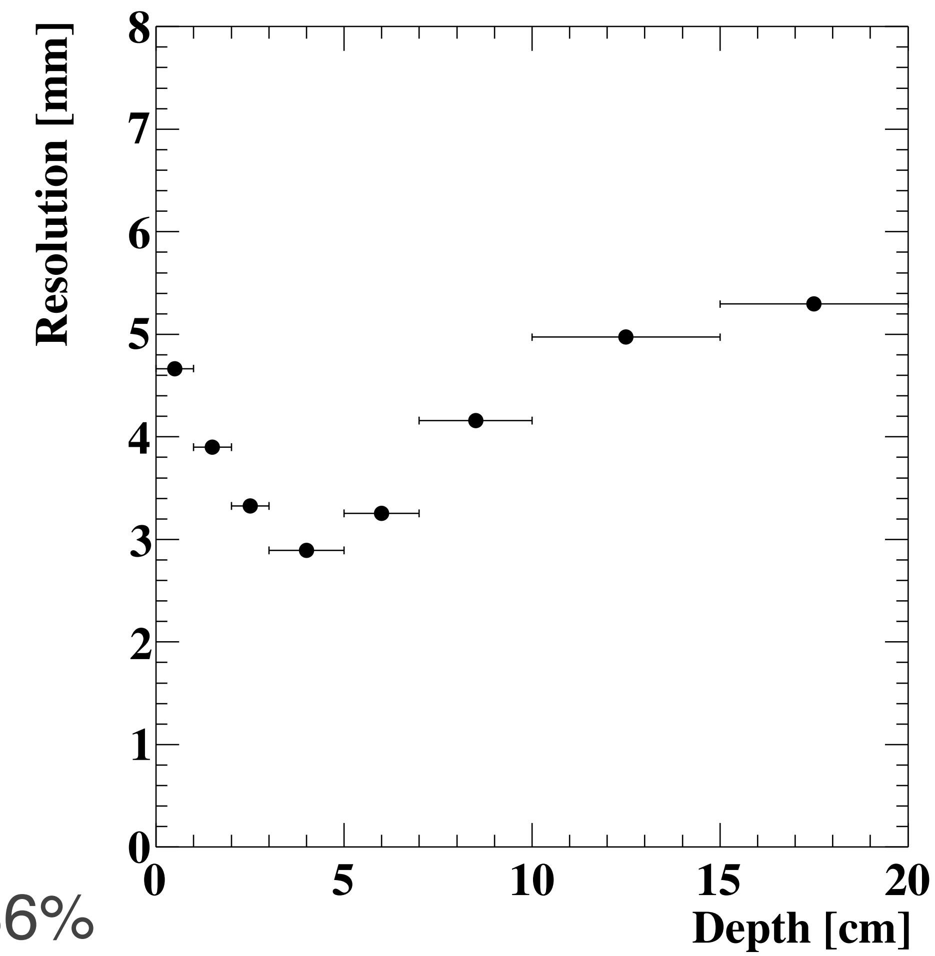
We correct energy or position using the 1st conversion position, but...

- The size of PMT (2 inch) → makes position dependence for shallow events
- Fluctuation of shower shape → limits capability of the correction using the 1st conversion position



# of events
depth < 2cm : 36%
depth < 3cm : 47%

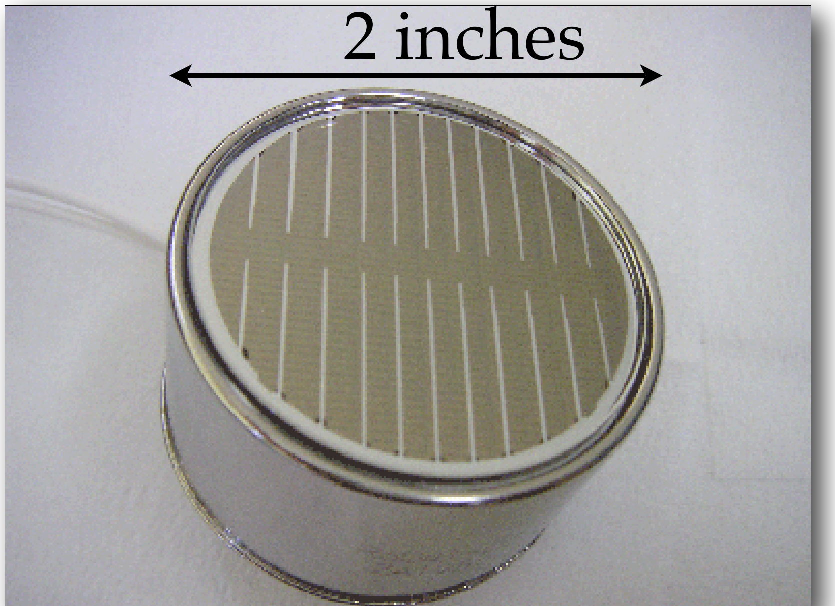
position resolution

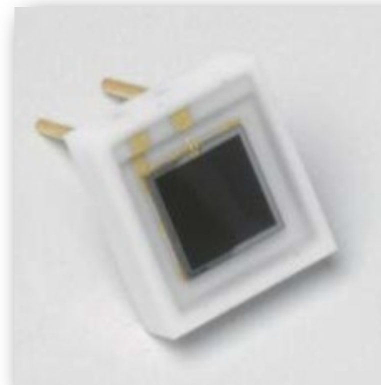


Upgrade concept

Present

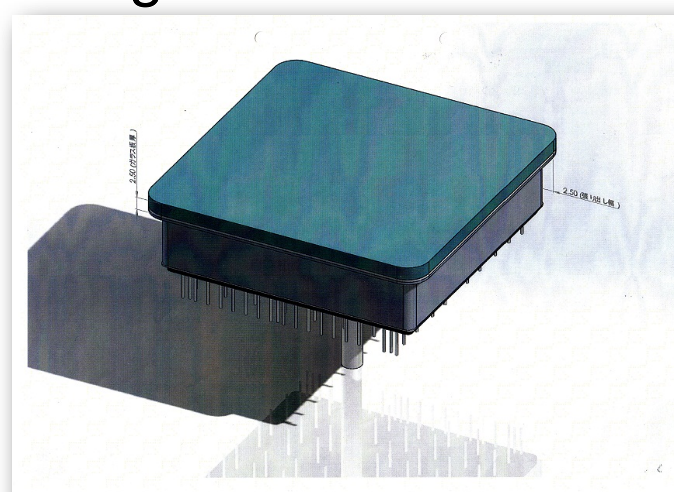
PMT





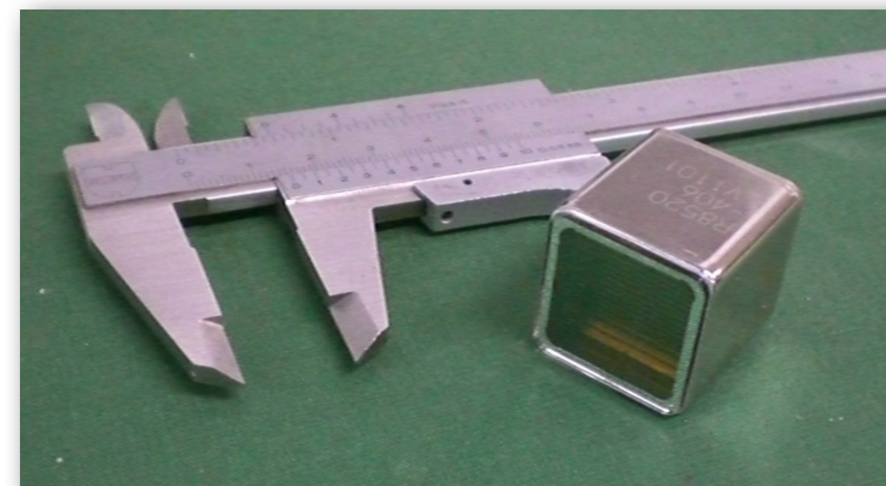
PPD (MPPC, SiPM...)

Multi-anode flat panel PMT
testing in KEK



Smaller PMT
testing in Pisa

1 inch

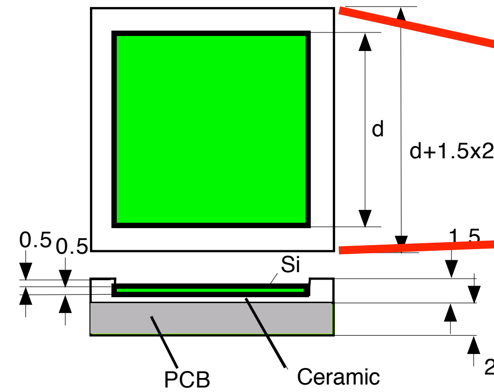


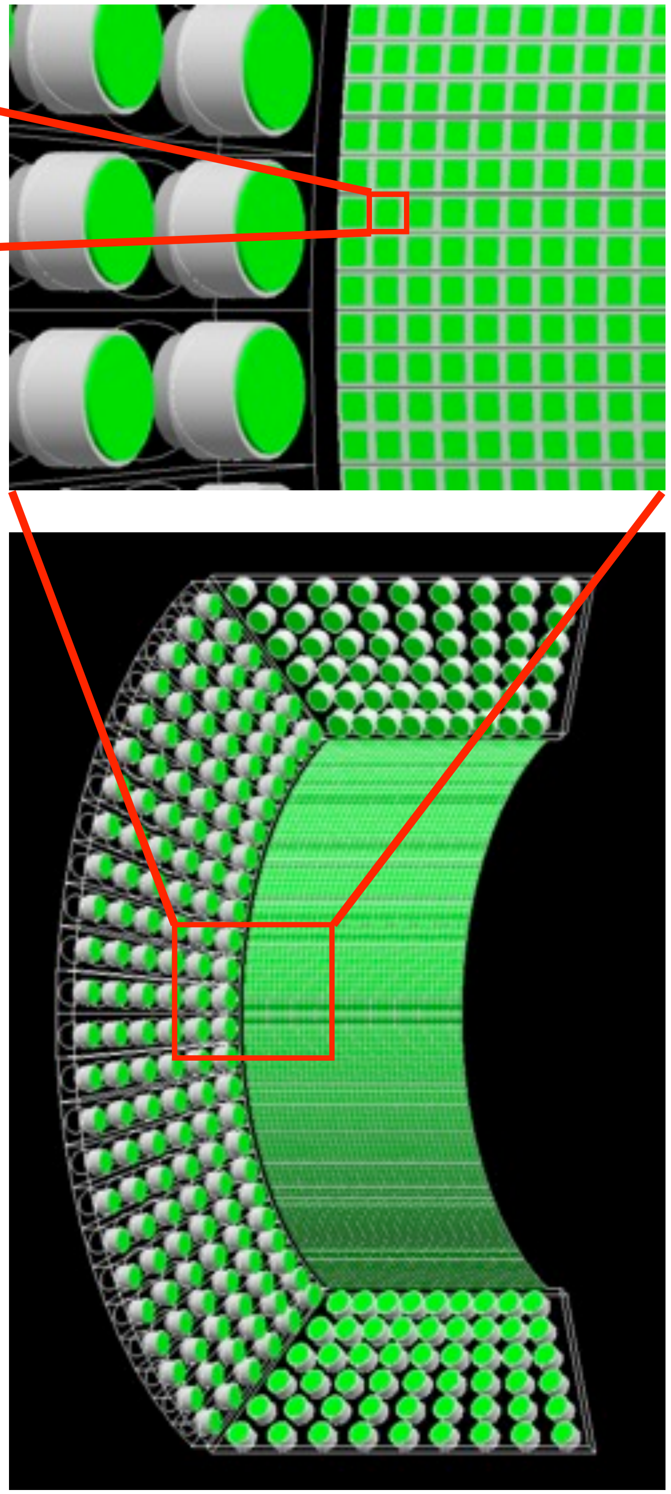
- Replace PMTs on the inner face with smaller photo-sensors (PMT or PPD)
  - Square shape → More uniform response
  - Smaller size → Better position resolution

Studies on PPD → 岩本敏幸 (25pFA8)

Possible configuration in final detector

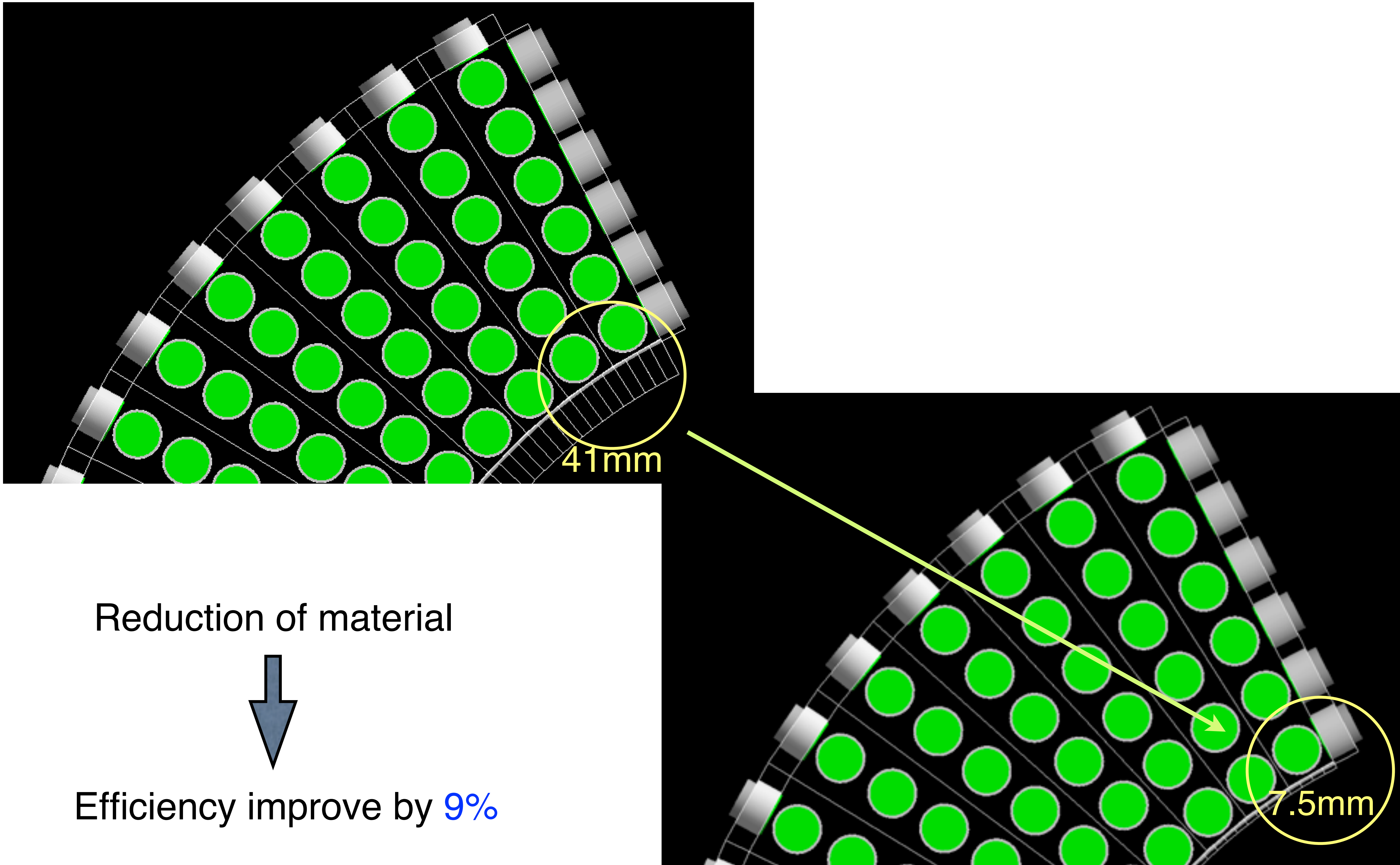
- Large PPD
  - Sensor size: 12×12mm^2
  - Ceramic base + PCB





- Each inner PMT is replaced by 4x4=16 PPDs
  - Number of sensors on inner face: up to 3456
- Material thickness <a few % of X_0
  - Si($5\times10^{-3}X_0$), Ceramic base($7\times10^{-3}X_0$), PCB($10^{-2}X_0$)
- Heat load (each PPD requires one cable)
  - Sensor power consumption (~80mW in total)
  - Heat inflow from cable (~40W in total)
  - Only 20W increase compared to present heat load for inner PMTs (10W(PMT), 13W(cables))

Detection efficiency (MC)

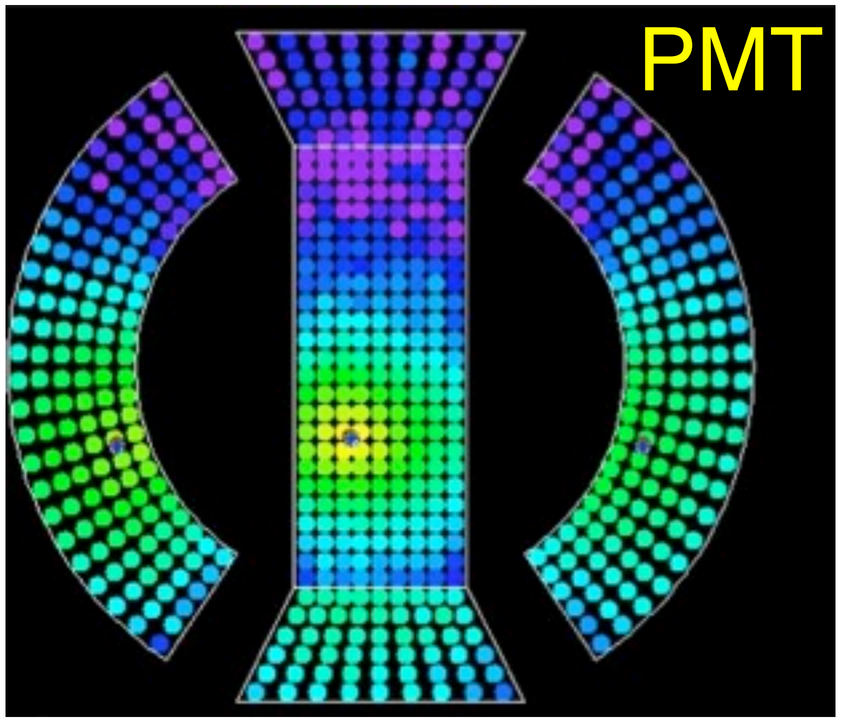


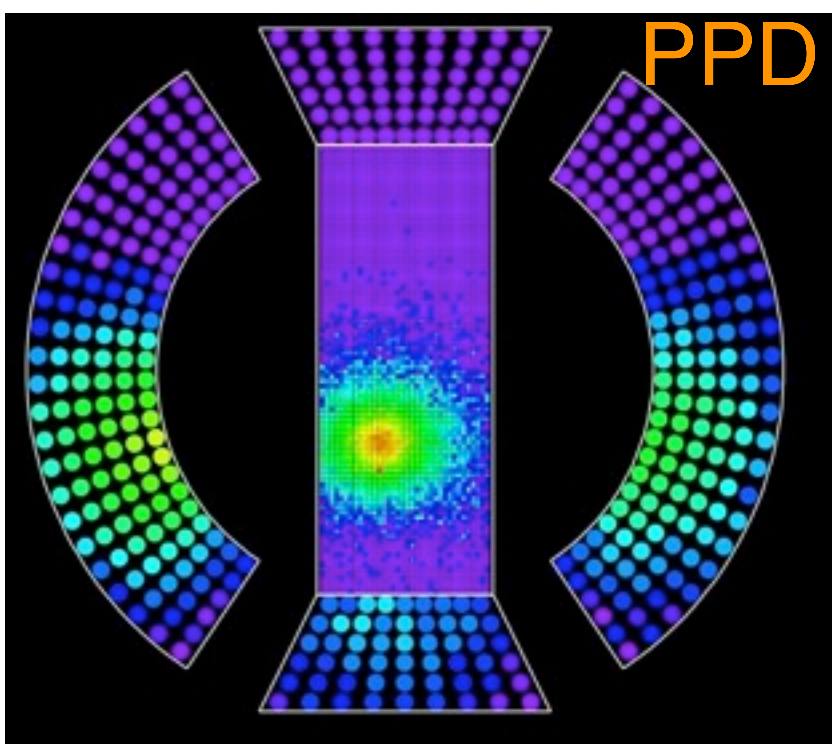
Reduction of material

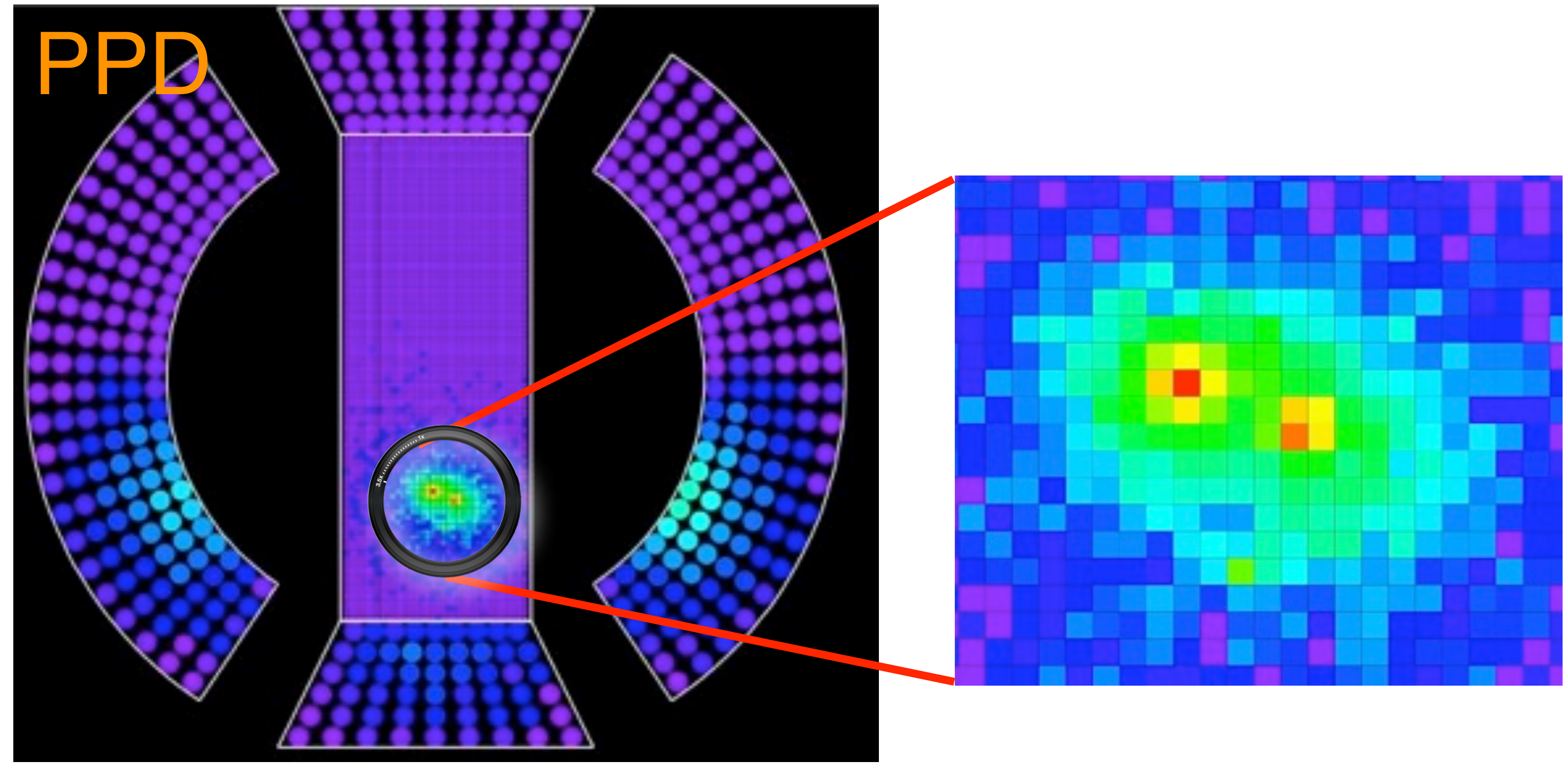
↓

Efficiency improve by 9%

Imaging calorimeter







9×24 → 36x93

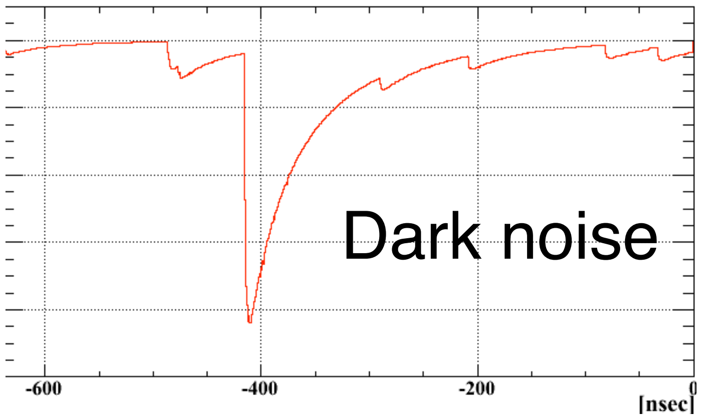
~16 times the # of "pixels"

Performance of LXe detector with PPDs is being studied in MC

Preliminary results are shown in the following slides.
The results are already better than PMT MC using the same reconstruction algorithm.
We are going try to develop new reconstruction algorithms to take the advantage of the smaller size.

MC simulation

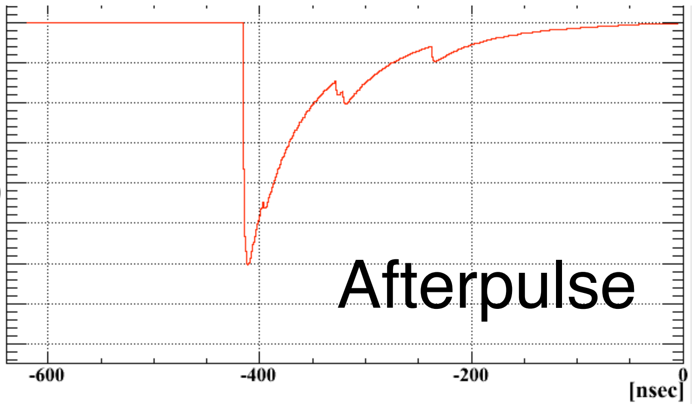
- MEG MC code is modified to simulate PPD configuration.
- Optical simulation
  - Reflection on Si
  - Record the pixel# for each photoelectrons. Used for WF simulation
- PPD waveform simulation
  - Single photoelectron response. The rise and decay constants are adjustable.
  - Dark count
  - Crosstalk
  - After-pulsing
  - Saturation and recovering



(Actual noise rate is much lower.)

Higher noise rate for these plots
just for a demonstration.

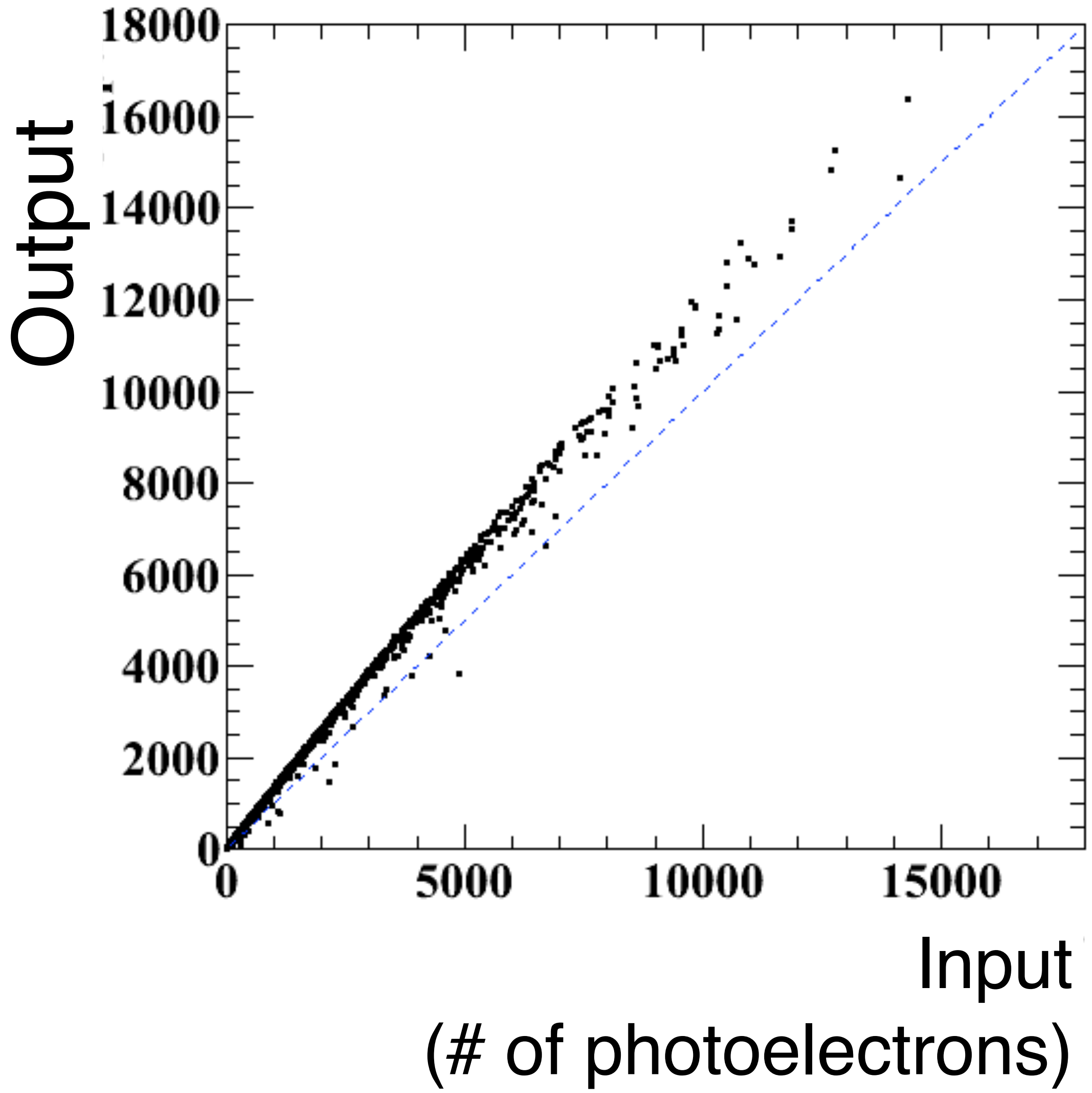
simulated waveforms

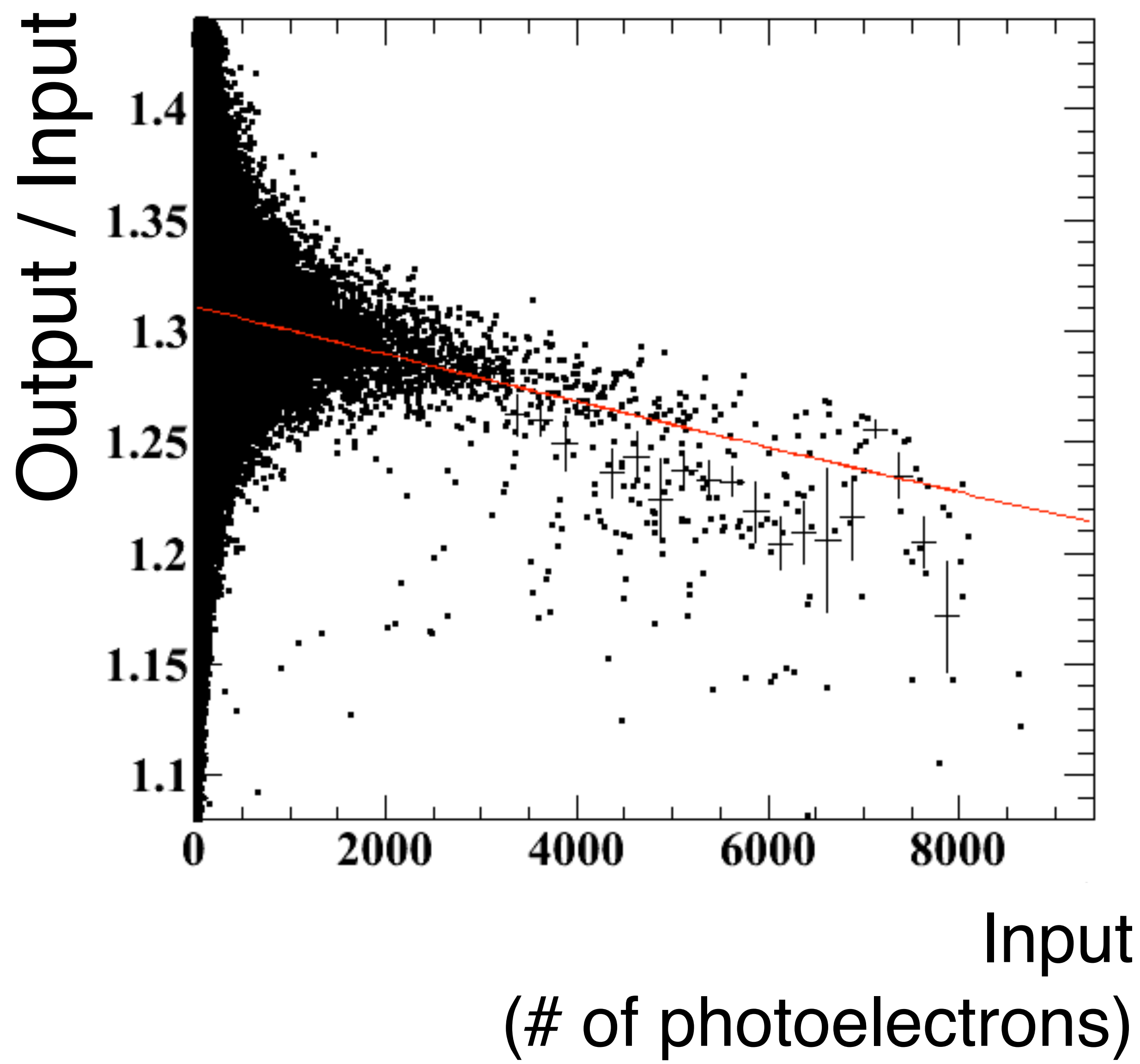


Response curve

Total N_{pixel} = 57600

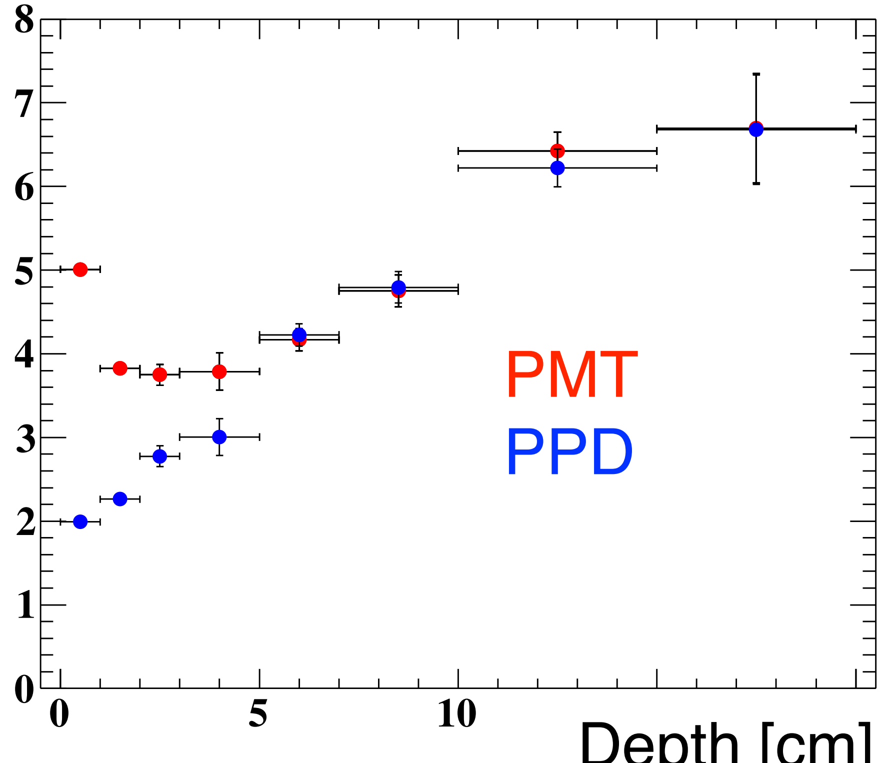
# of photoelectrons of each MPPC



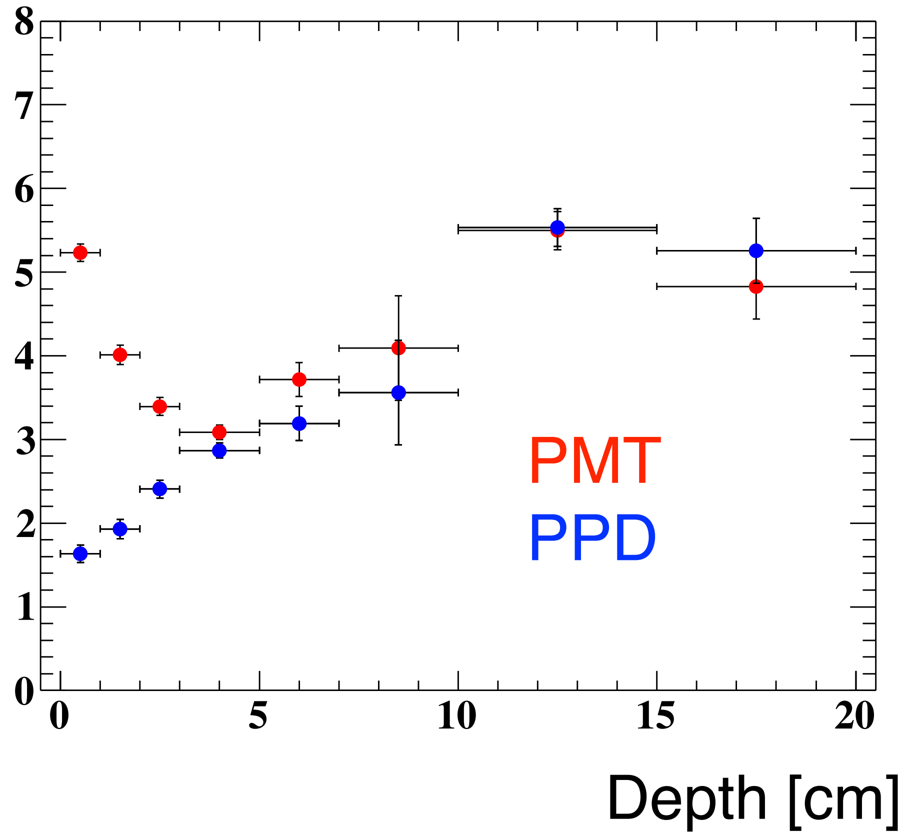


Position resolution (MC)

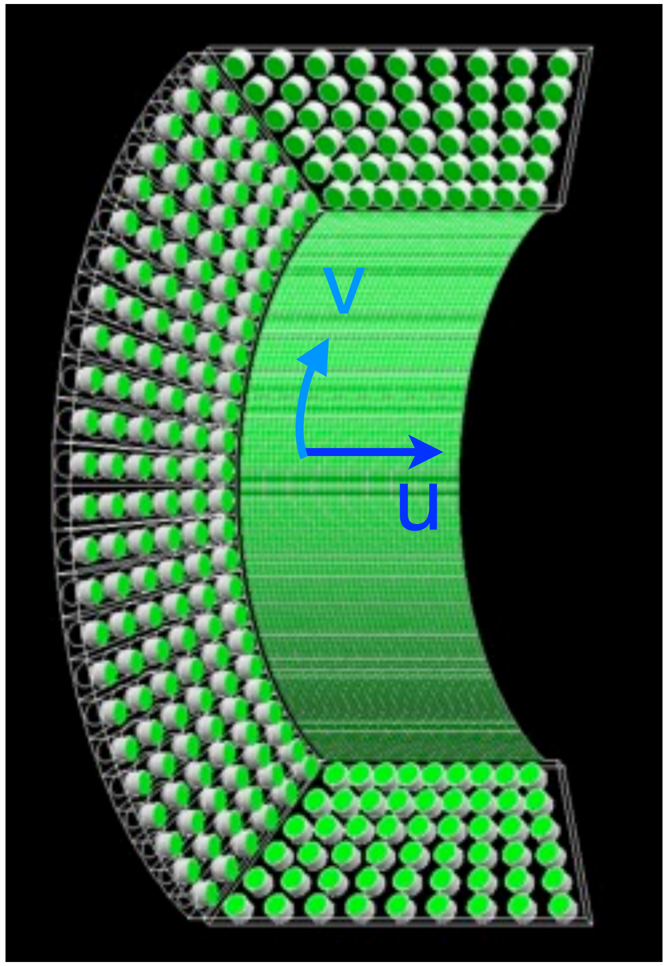
U resolution



V resolution



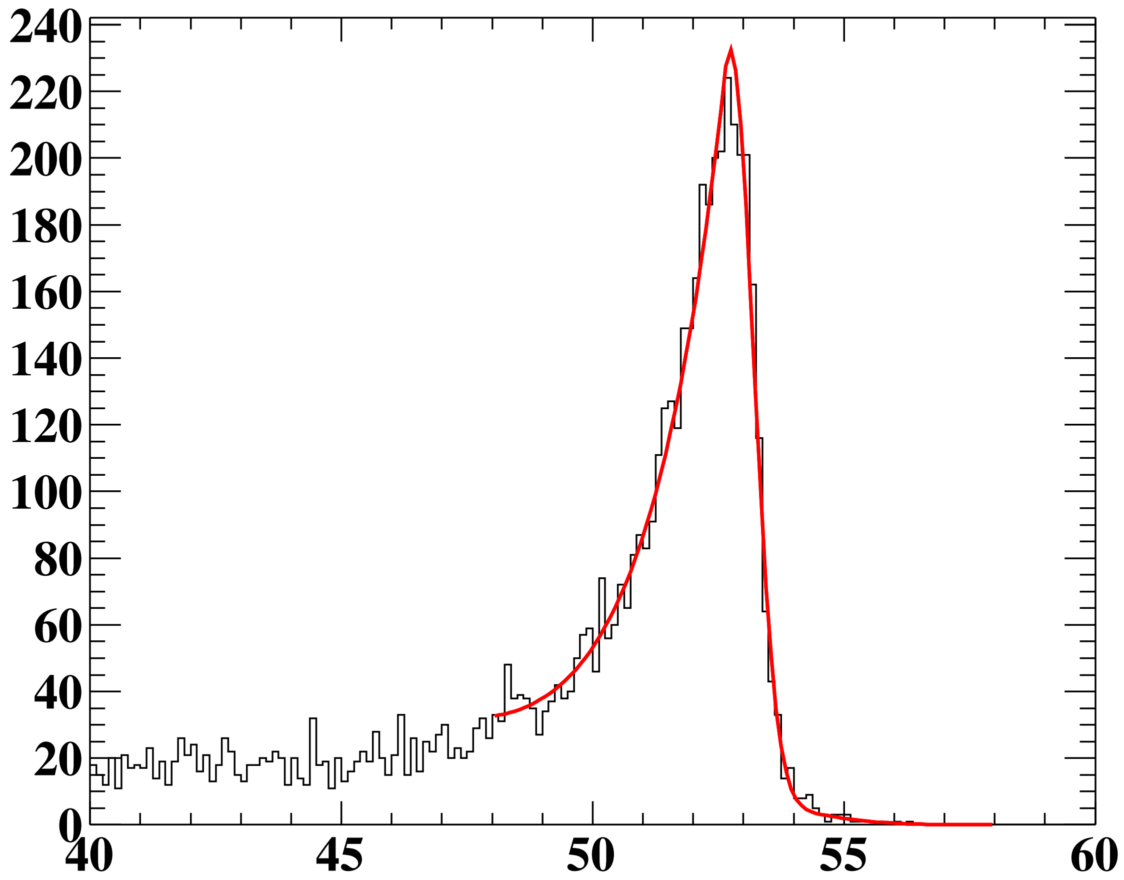
depth < 3cm : PPD is better
depth > 3cm : Almost same resolution



Electronics noise is not added in this study to investigate the intrinsic performance

Energy resolution (MC)

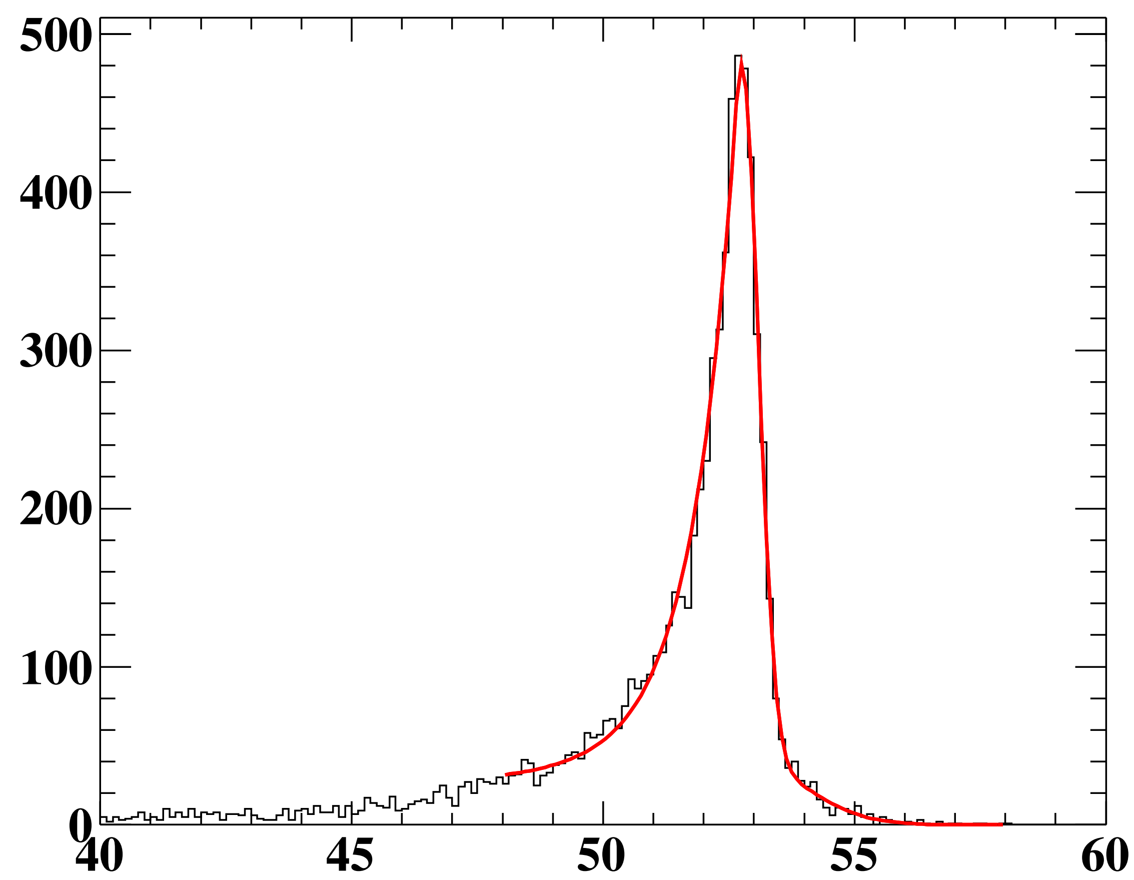
Depth < 2cm



$\sigma = 0.9$ %

c.f. PMT MC : 2.1%

Depth > 2cm



$\sigma = 0.7$ %

c.f. PMT MC : 1.0%

Electronics noise is not added in this study to investigate the intrinsic performance

Summary

- MEG will reach the goal statistics soon. Goal sensitivity = 5×10^{-13}.
- Upgrade
  - **Aiming a sensitivity improvement by factor 10**.
  - Proposal in the next year
  - Several ideas for every part.
    - R&D and MC studies have been already started
  - LXe γ detector
    - Smaller photo-sensors. (PPD, multi-anode PMT, smaller PMT)
    - Simulation studies taking into account cross-talk, after-pulsing etc.
      - Efficiency improvement by 9%.
      - Position and energy resolutions will be improved.
        - About a factor 2 improvement of each variable in the shallow part.
    - More realistic MC including electronics noise to be done.

Back up

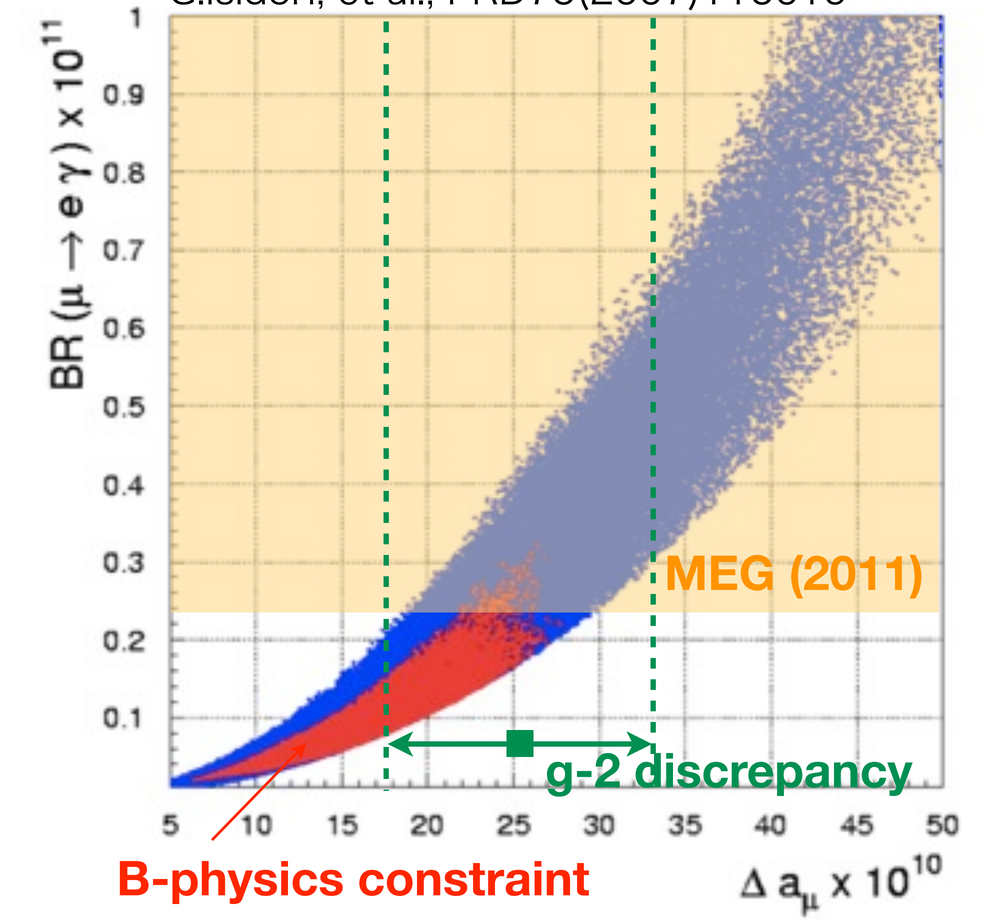
Typical parameters used for MC

- QE (reflection not included in this number) : 30 %
- Pixel size. 50 µm
  - N_{pixel} 57600 µm

Leading edge	10 ns
Trailing edge	50 ns
Dead time	1 ns
Recovery time	50 ns
After pulse	50 ns(10%), 200 ns(5%)
Crosstalk	15%
Random noise	500 Hz
gain	2e6
DRS attenuation	1/3

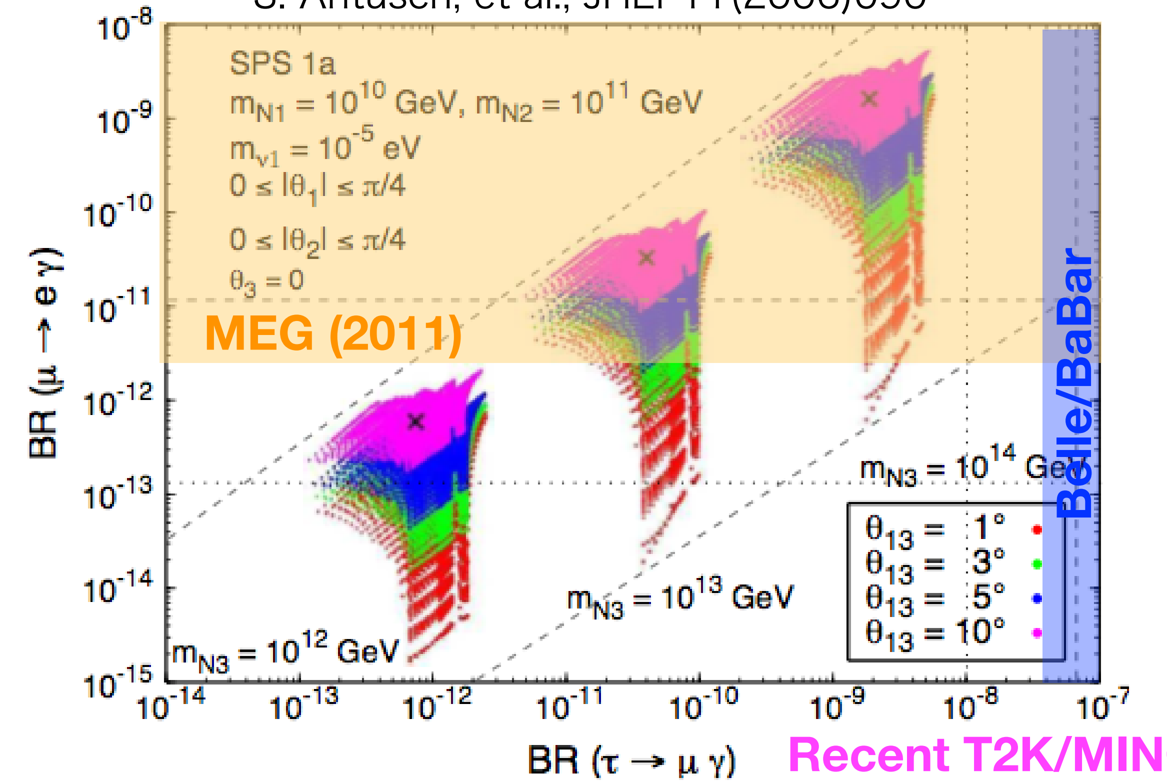
SUSY-GUT

G.Isidori, et al., PRD75(2007)115019



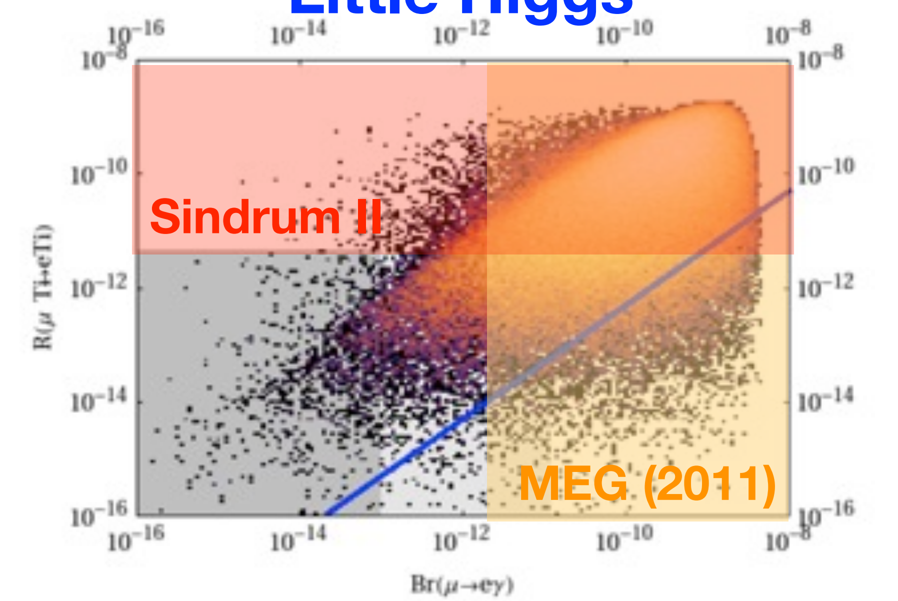
SUSY-Seesaw

S. Antusch, et al., JHEP11(2006)090



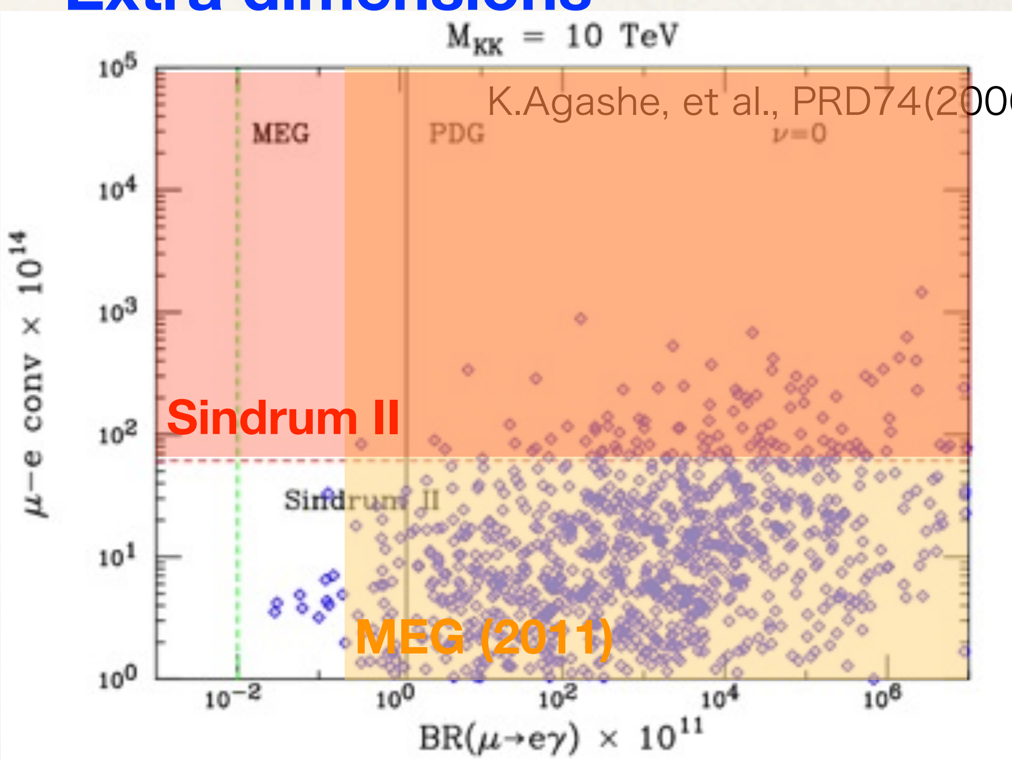
Recent T2K/MINOS/ Double Chooz results favors large θ_{13}!

Little Higgs



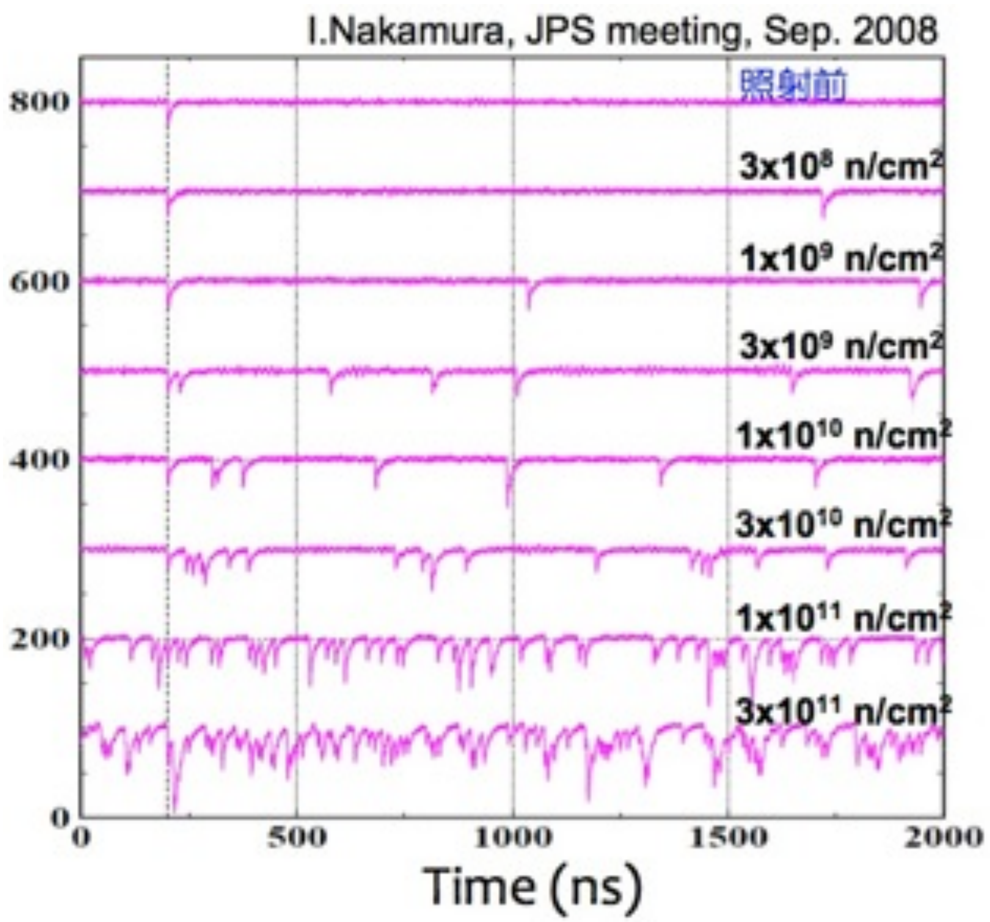
M.Blanke et al., Acta Phys.Polon.B41(2010)657

Extra dimensions



Radiation hardness

- Radiation produces defect in silicon bulk or Si/SiO2 interface which may deteriorate PPD performance.
  - Dark count rate, leakage current, PDE,...



- **Fast neutron**
  - $>10^8$ n/cm^2 : Increase of dark count rate
  - $>10^{10}$ n/cm^2 : Loss of single p.e. detection capability

Expected Neutron flux for 5 years of MEG run

- $<1.6\times10^8$ n/cm^2

- **γ-ray**
  - >200 Gy : Increase of leak current

MC : 0.58Gy with $10^8\mu$/s for 5-years

Possible advantage of PPD in MEG LXe detector

- Higher photon detection efficiency (yet to be proved)
- High granularity and better uniformity with smaller sensor size and better coverage.
- Operation in magnetic field
- Reduction of material on the inner face
- Easier calibration using single photoelectron signals
- Very low power consumption

Possible issues of PPD in MEG LXe detector

- Photon detection efficiency (PDE) for VUV light
- Dark count
- Optical crosstalk
- After-pulsing
- Radiation hardness
- Dynamic range
- Reflection on sensor surface
- Sensor size

Dark count, crosstalk and after-pulsing

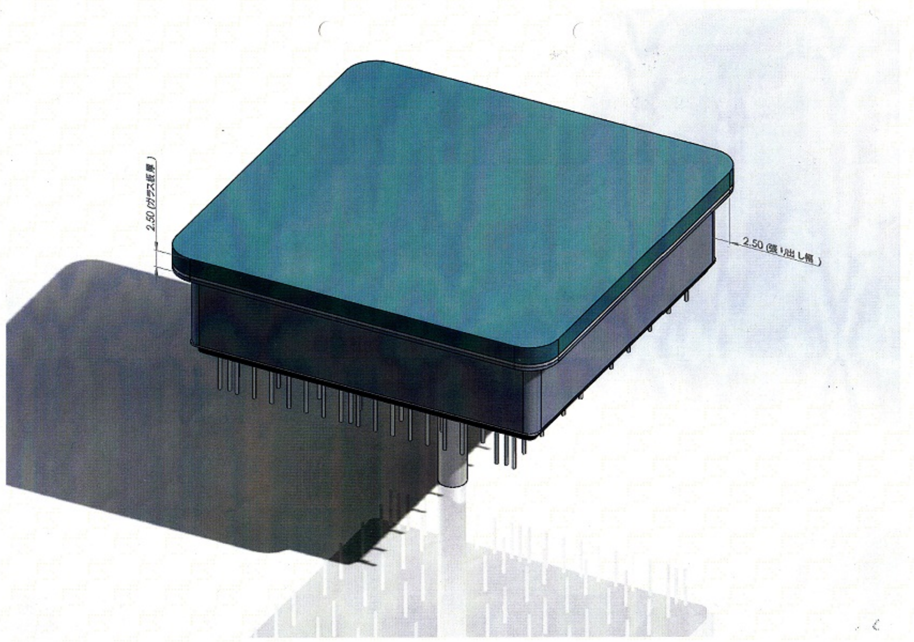
- **Dark count**
  - Thermally generated free carriers produce dark counts
  - 100k-10MHz per mm^2 at room temperature.
  - Can be reduced at low temperature (10^5 reduction expected at LXe temperature)
    - Dark rate below 100 Hz (3×3 mm^2) is confirmed at LXe temperature.
- **Crosstalk**
  - Hot carrier luminescence generate signal in adjacent pixels
  - Crosstalk probability : 10-20 %
- **After-pulsing**
  - Carriers trapped during primary avalanche and released during a several 100ns triggering secondary avalanche(s).
  - Pileup effects in case of MEG LXe detector.

Current performance of the MEG LXe detector

- **Energy resolution : 1.7%** (depth > 2 cm)
  - Worse than MC(=1%). Some reasons are possible, not yet conclusive (e.g. Errors in knowledge of optical properties, PMT instability...)
- **Position resolution : 5 mm**
  - Consistent with MC
- **Time resolution : 67 psec**
  - Reasonable.
- **Detection efficiency : 65.5±1.5 %**
  - Consistent with MC

Other possibilities : New PMT tests

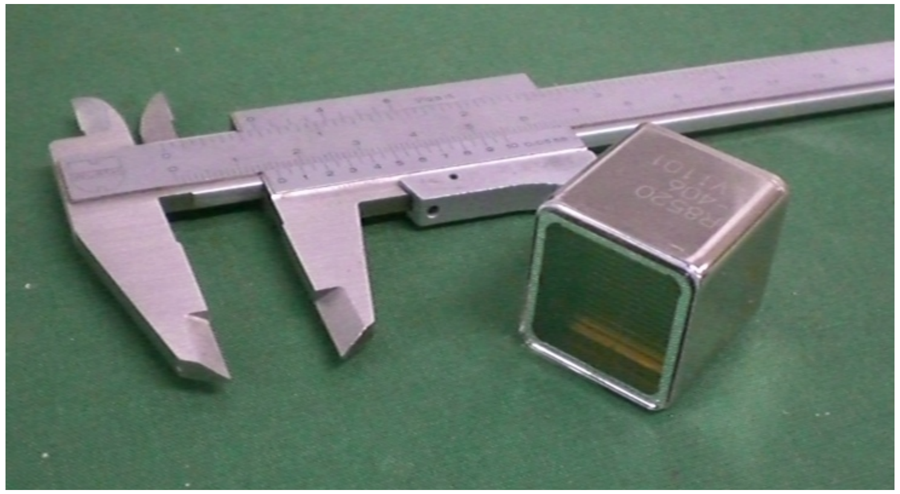
Flat panel PMT for LXe



- **Square shape**
  Smaller dead space, and more uniform response
- **Multi-anode**
  Readout each pixel (6x6 mm^2)
  Can be used for the small detector concept.

Base-model, Hamamatsu H8500 series
- Metal channel dynode
- Dimension : 52 × 52 × 27.4 mm
- Multi anode (8 x 8 pixels)
  → development of readout electronics is needed
- Gain : 1.5 × 10^6
- QE : 24% @ 420nm, room temperature
  → Photocathode modification for LXe use

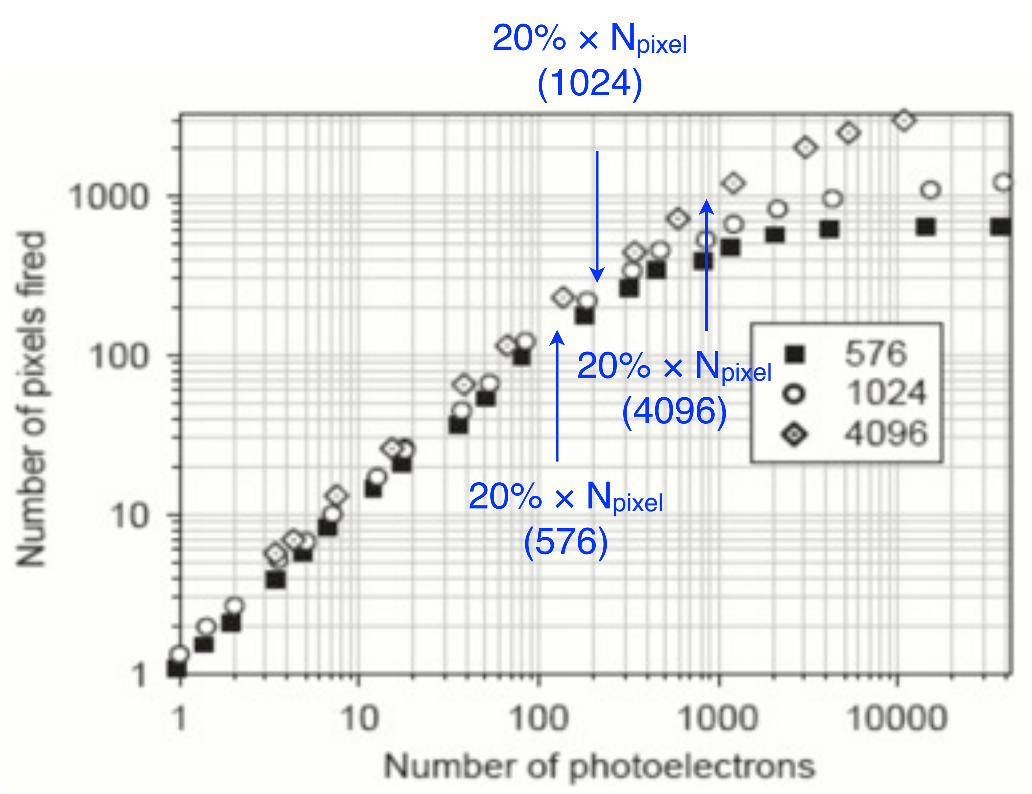
1" PMT for LXe

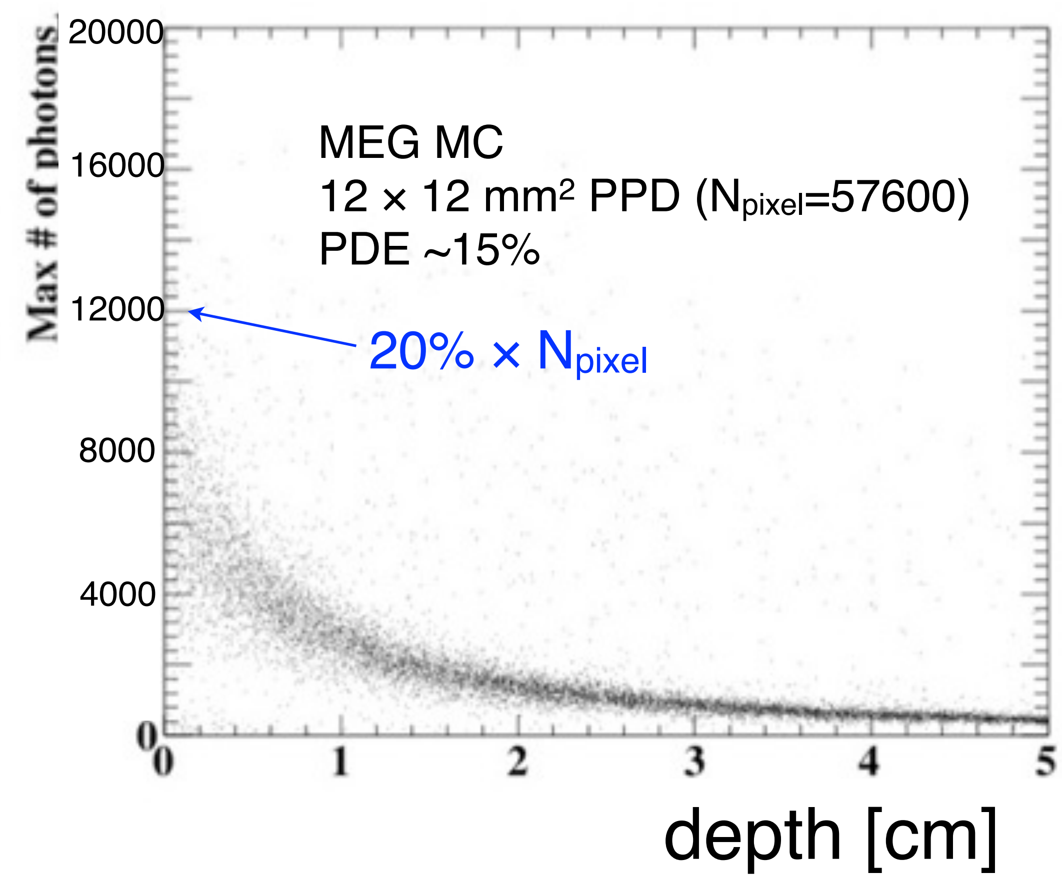


- Test of a 1″ square PMT
  - Hamamatsu R8520-406
    - smaller version of our present PMTs
    - gain ~ 10^6
    - QE ~ 20% in the VUV

Dynamic range

- PPD response shows a non-linearity if number of detected photon is large relative to total number of pixels
- Optimal condition $N_{p.e.} < N_{pixel}$
- Might be an issue for very shallow event for MEG LXe detector. At least we would need a careful calibration.



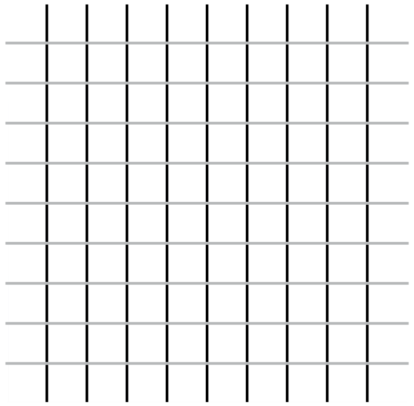


Software implementation

Each carrier knows its
- time
- cell #

Carrier queue

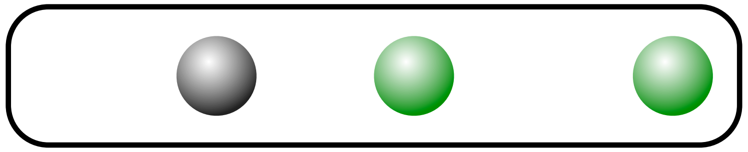
sorted in time



Cell status map

Each carrier knows its
- time
- cell #

Carrier queue



sorted in time

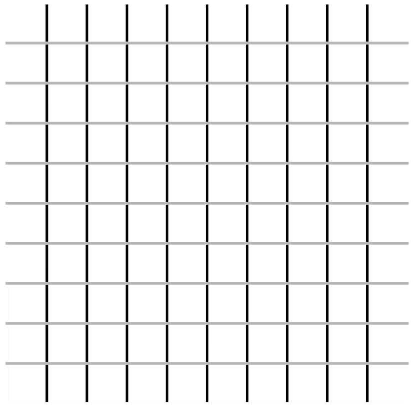


Photo-electrons

Dark noise

Cell status map

Each carrier knows its
- time
- cell #

Carrier queue

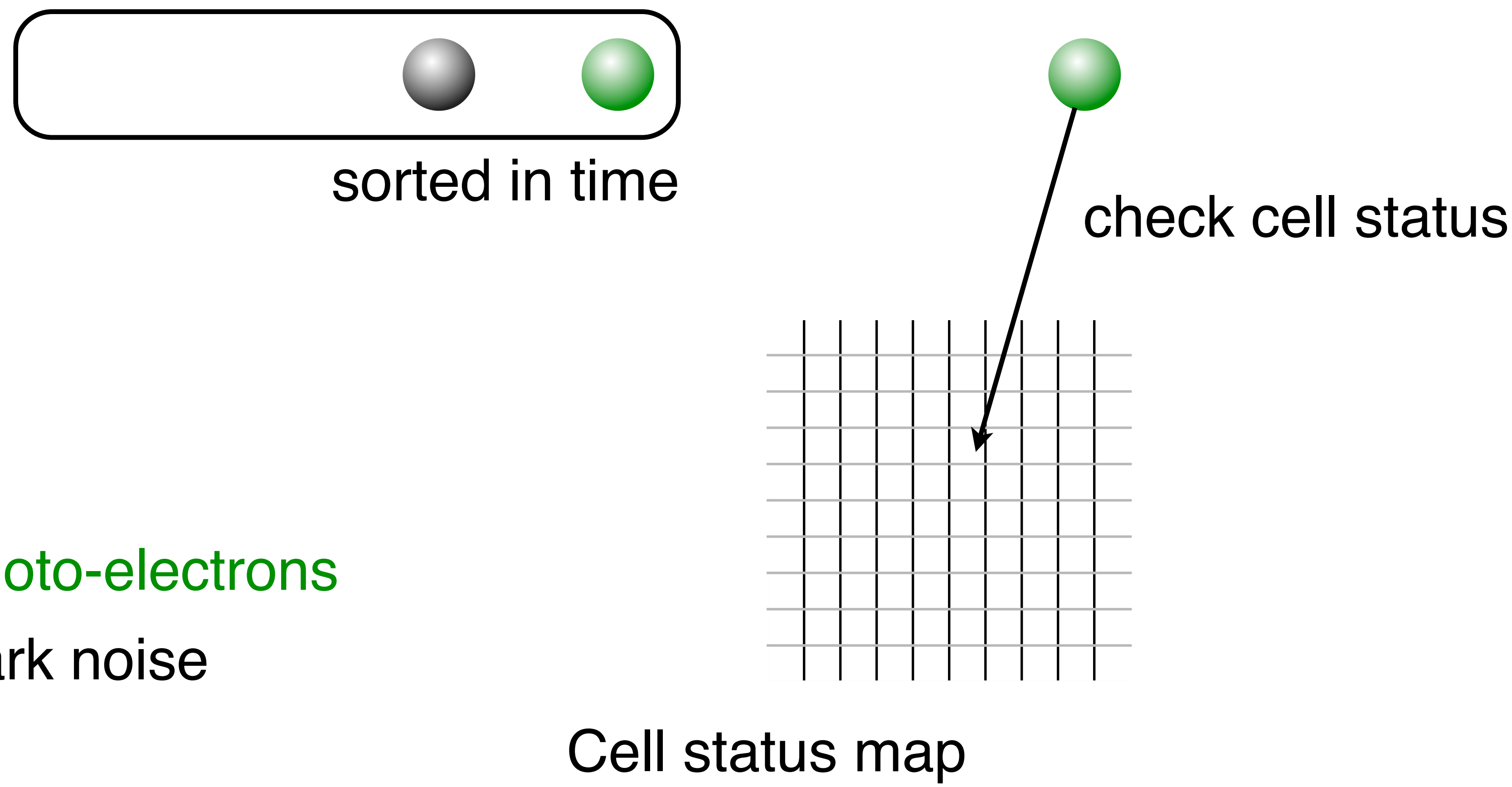


Photo-electrons

Dark noise

Each carrier knows its
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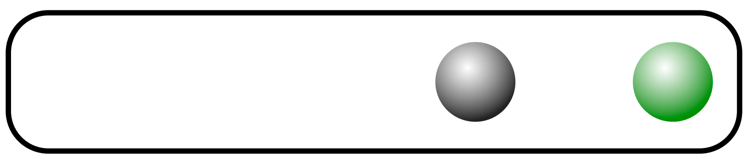
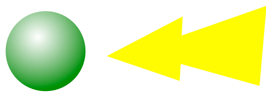
Carrier queue



sorted in time

avalanche



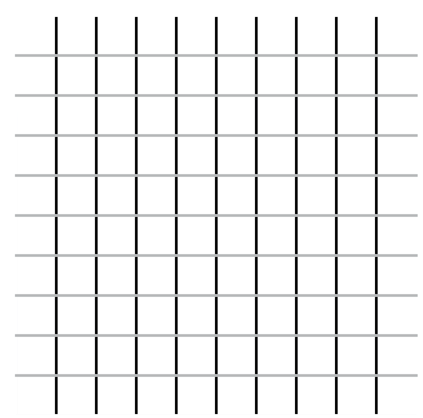


Photo-electrons

Dark noise

Cell status map

Each carrier knows its
- time
- cell #

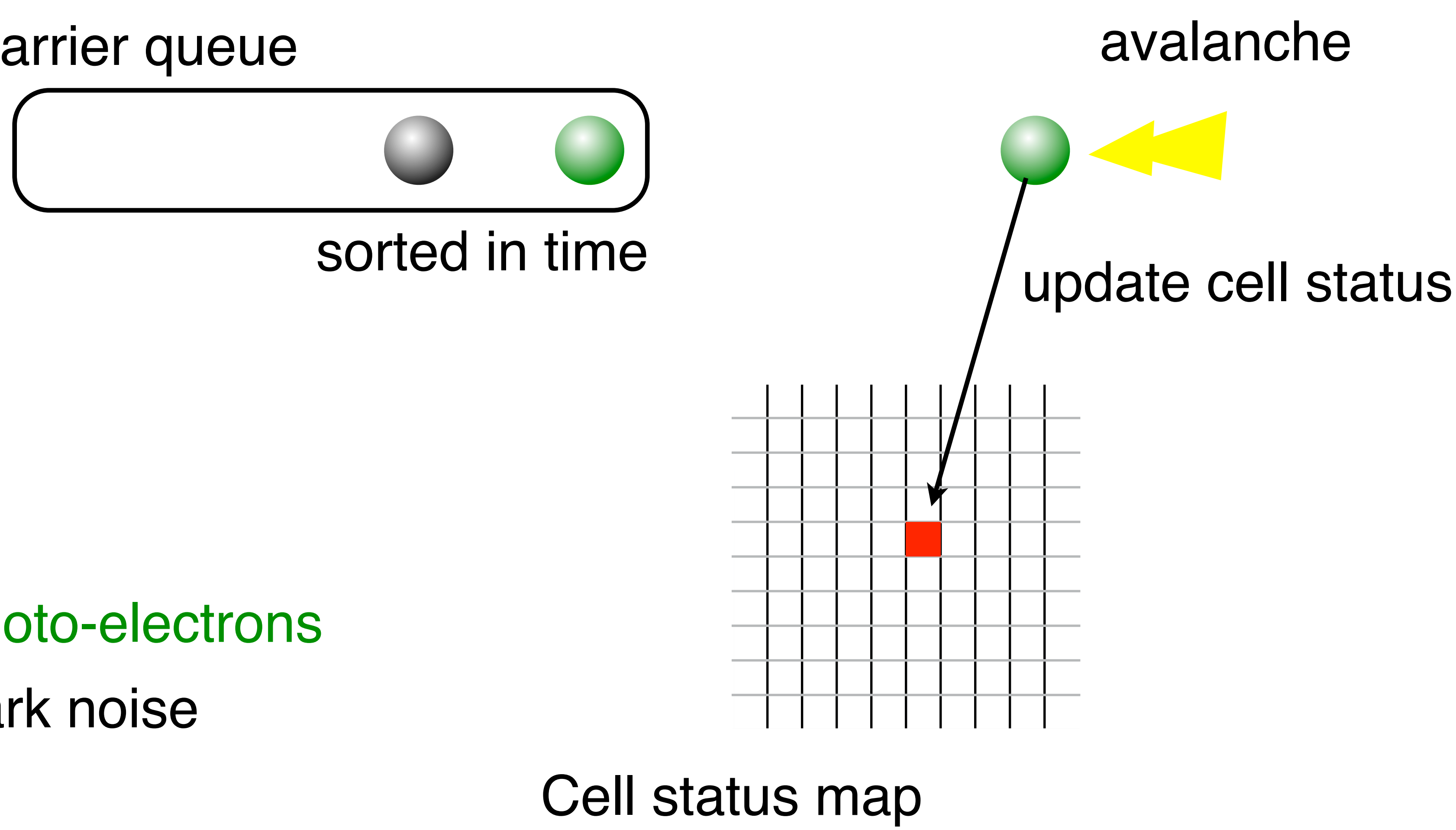


Photo-electrons

Dark noise

Each carrier knows its
- time
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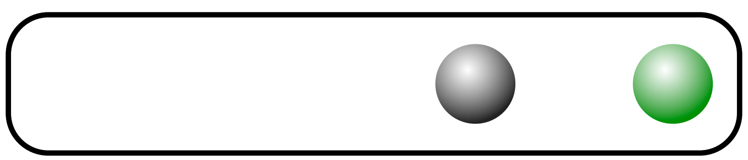
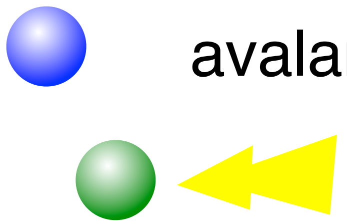
Carrier queue



sorted in time



avalanche

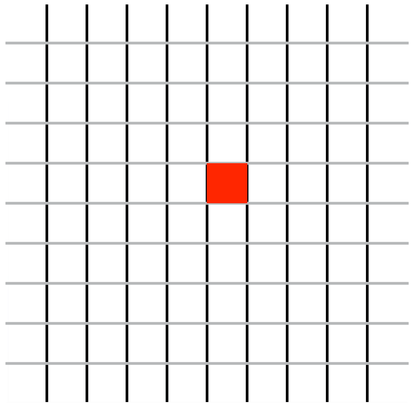


Photo-electrons

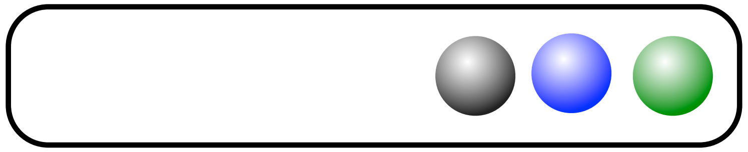
Dark noise

After-pulse

Cell status map

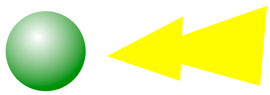
Each carrier knows its
- time
- cell #

Carrier queue



sorted in time

avalanche



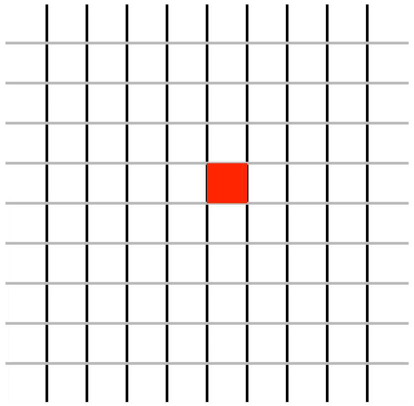


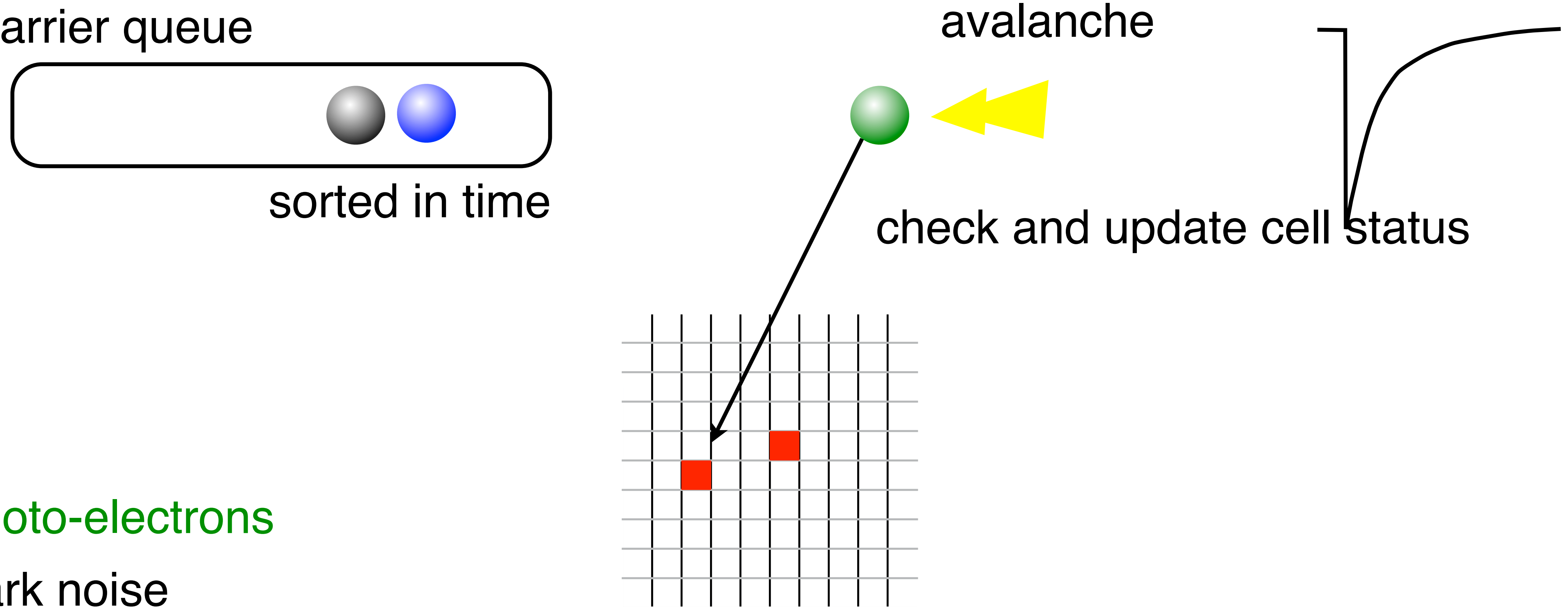
Photo-electrons

Dark noise

After-pulse

Cell status map

Each carrier knows its
- time
- cell #



Each carrier knows its
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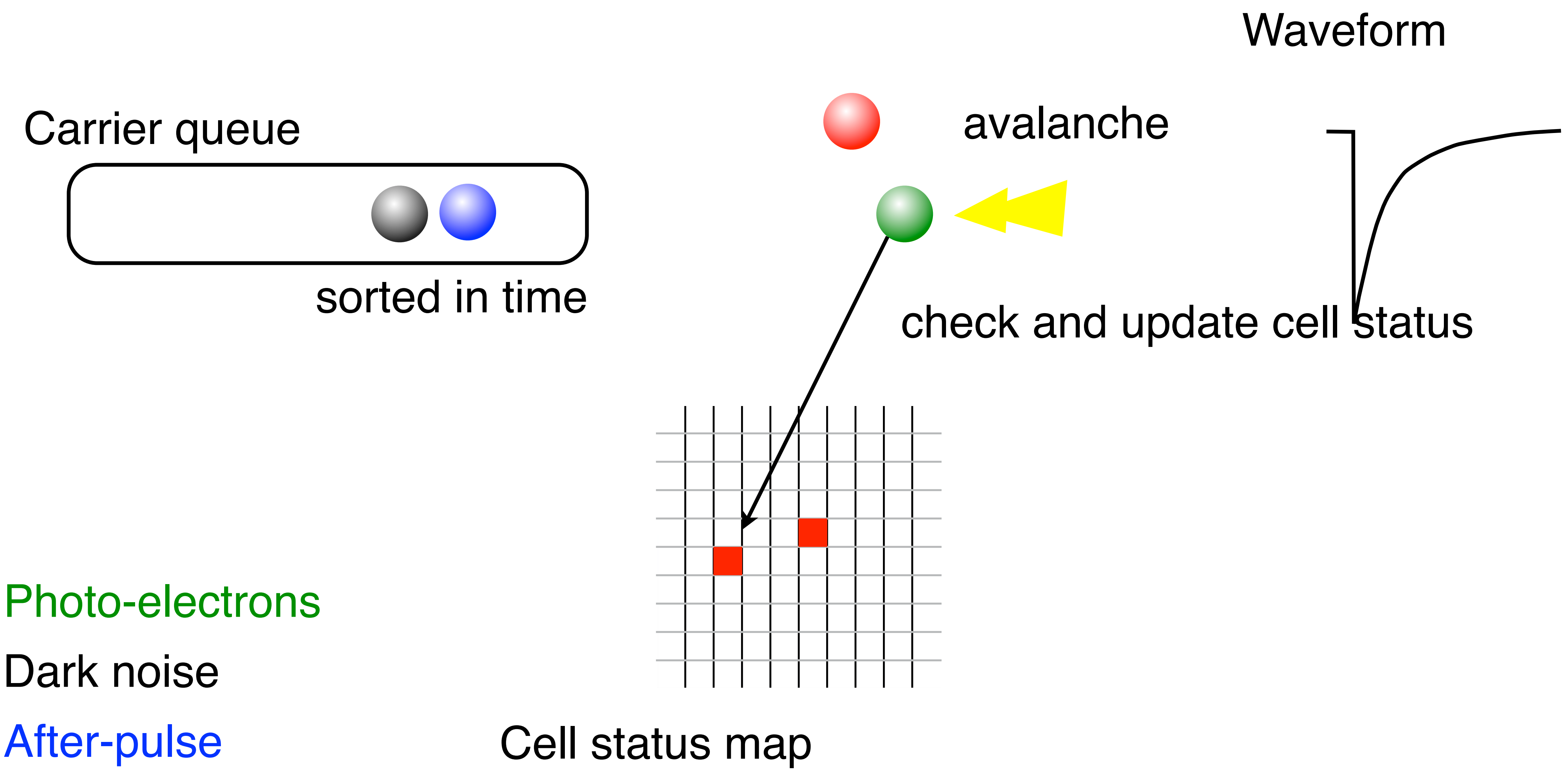

Photo-electrons

Dark noise

After-pulse

Crosstalk

Software implementation

Each carrier knows its
- time
- cell #

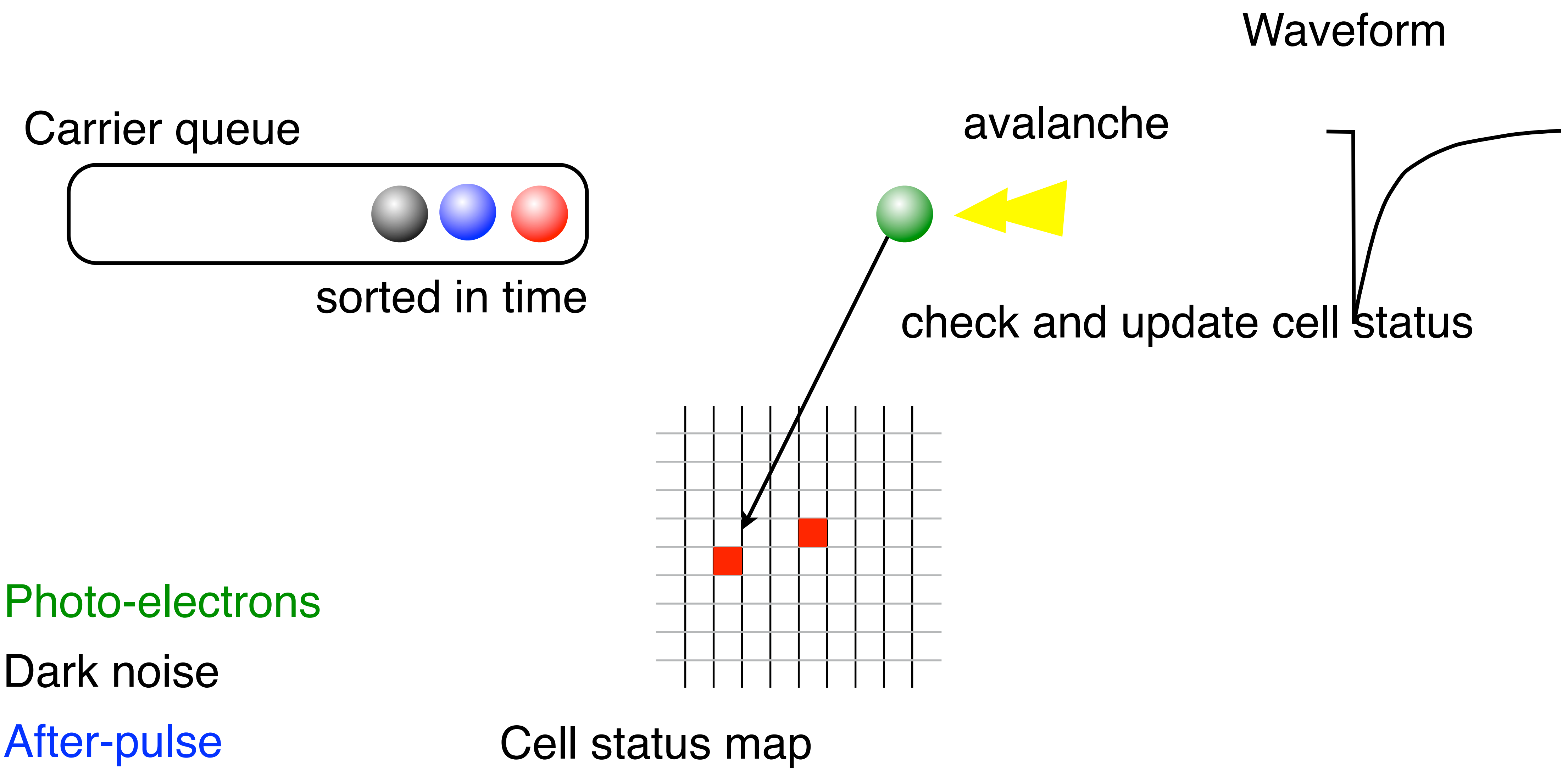

Photo-electrons

Dark noise

After-pulse

Crosstalk

Software implementation

Each carrier knows its
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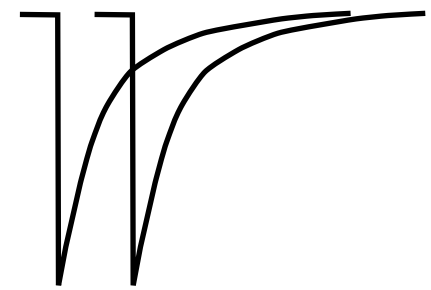
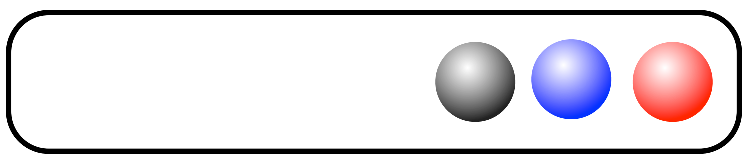
- cell #

Waveform



Carrier queue



sorted in time

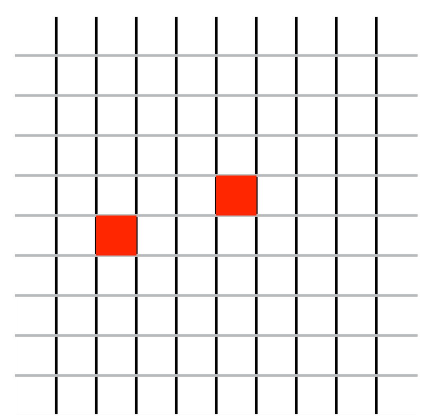


Photo-electrons

Dark noise

After-pulse

Crosstalk

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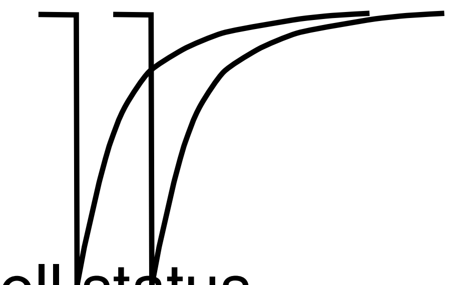
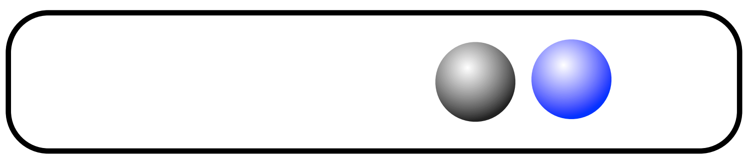
Waveform

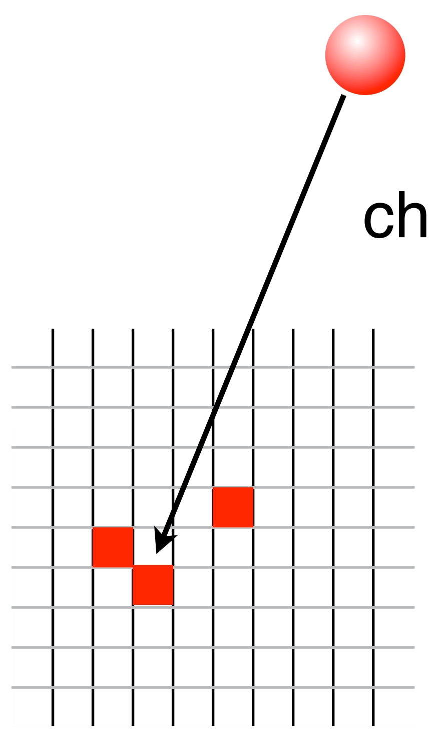


Carrier queue



sorted in time

check and update cell status



Cell status map

Photo-electrons

Dark noise

After-pulse

Crosstalk

Software implementation

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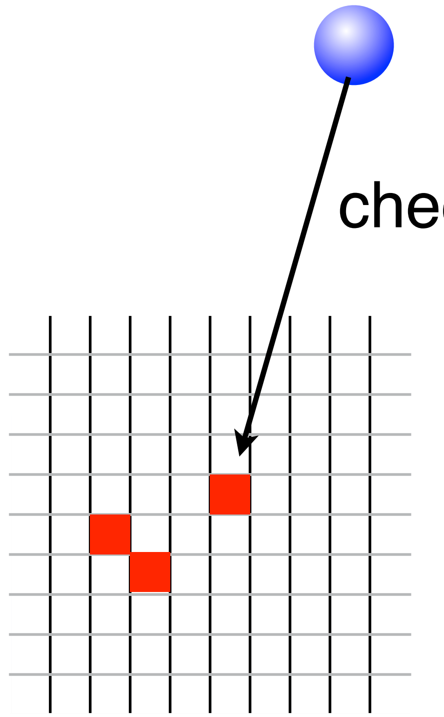
- cell #

Carrier queue

sorted in time



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Cell status map

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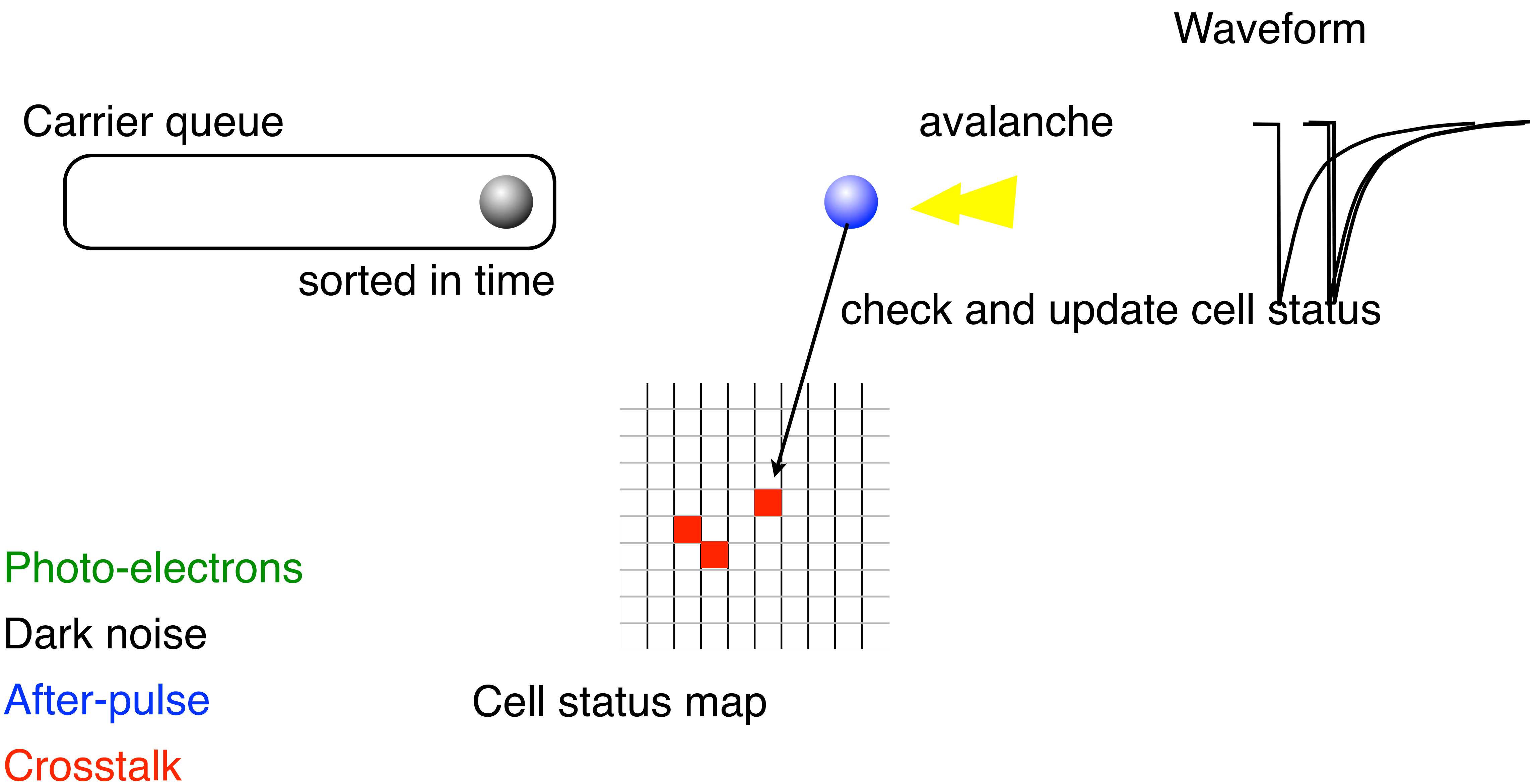

Software implementation

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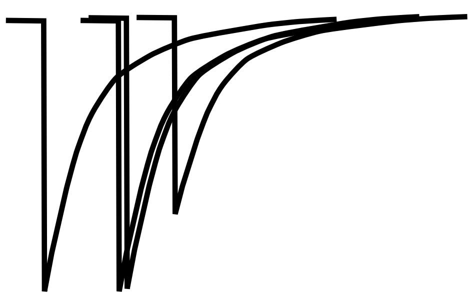
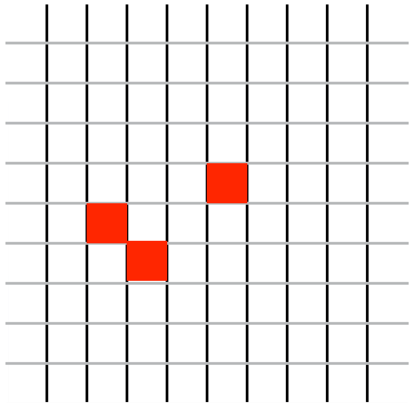


Carrier queue

sorted in time



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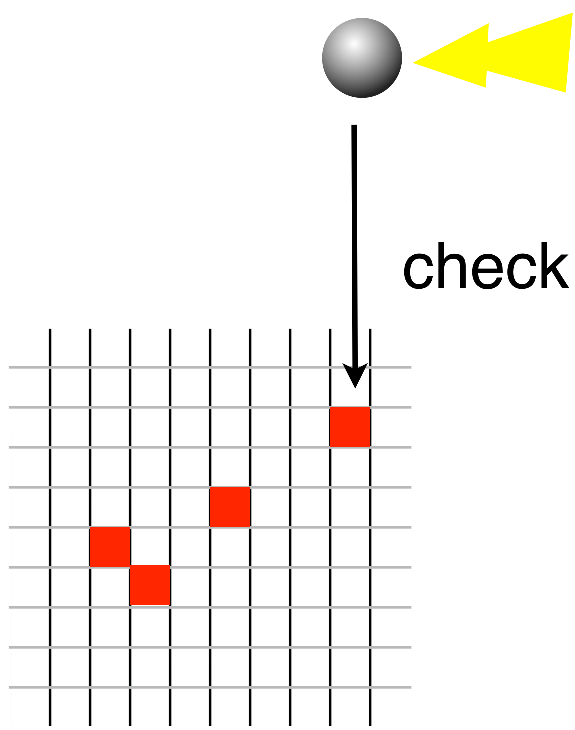
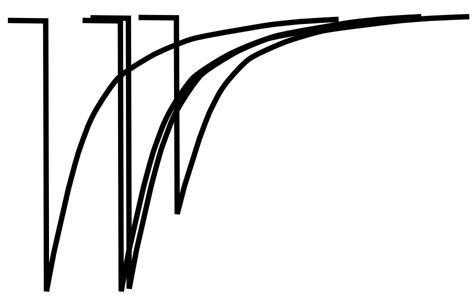
avalanche





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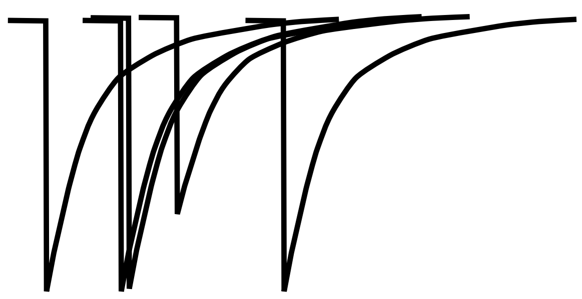
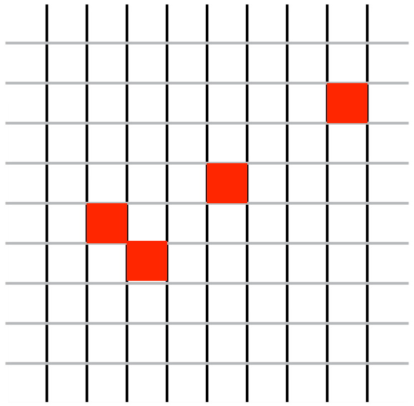


Carrier queue

sorted in time



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