MEG II実験のための背景ガンマ線同定用低運動量陽電子タイミングカウンターの実機製作と性能評価

Development status of low momentum positron timing counter to identify BG gamma ray from radiative muon decay in MEG II experiment

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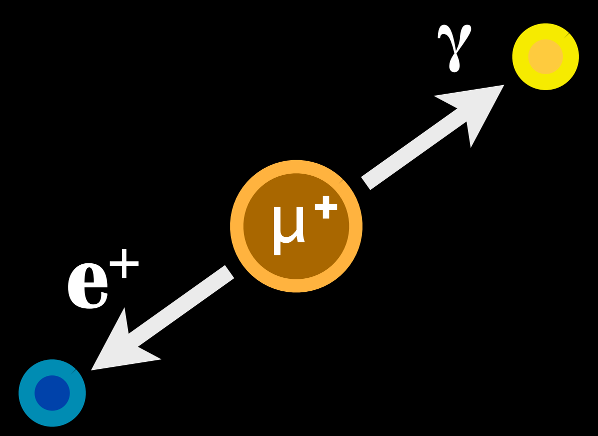
CONTENTS

◇ μ→eγ decay search

- In standard model with neutrino oscillation, the branching ratio is too small to detect the decay: ~O(**10^{-54}**)
- On the other hand, some beyond standard models predict large branching ratio: ~O(**10^{-14} - 10^{-13}**) whose level our experiment can reach!!
- **Discovery of μ→eγ = Discovery of new physics**



◇ Signal Event : 2-body decay from a muon at rest

- Both **e+** and **γ** have a **monochromatic energy** (52.8 MeV)
- They are emitted **time-coincidently**, and
- **back to back**

Basic Idea

high precision measurement of energy, timing and opening angle of e+ and γ

MEG II EXPERIMENT

◇ Upgrade of MEG Experiment

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Status:
Y.Uchiyama
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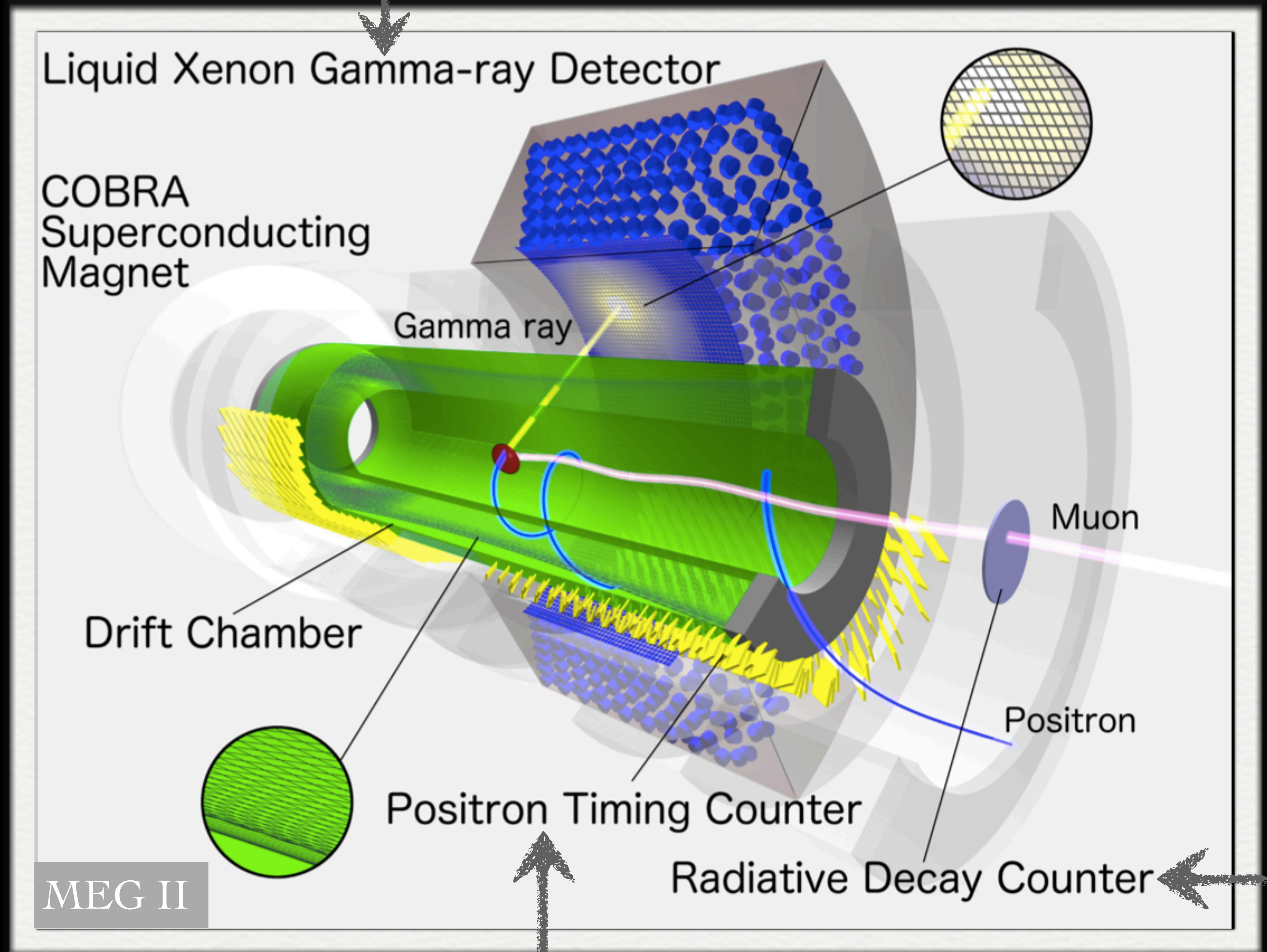

MEG I
Upper Limit:
5.7×10^{-13}
(90% C.L.)

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MEG II Sensitivity Goal: 4×10^{-14}

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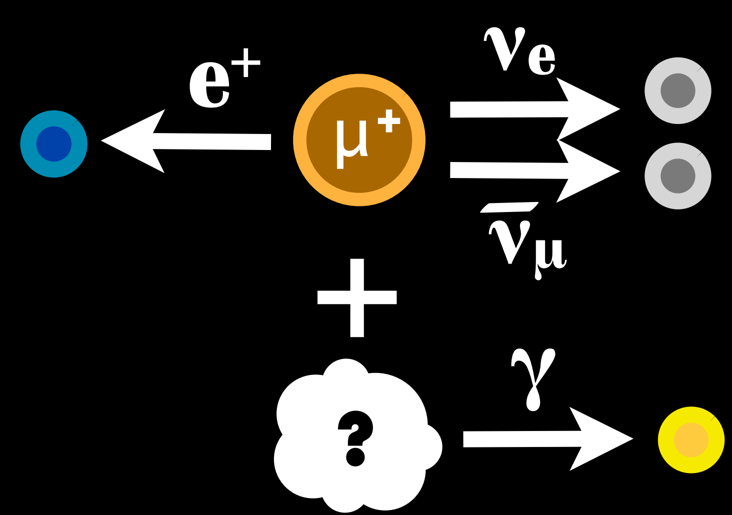
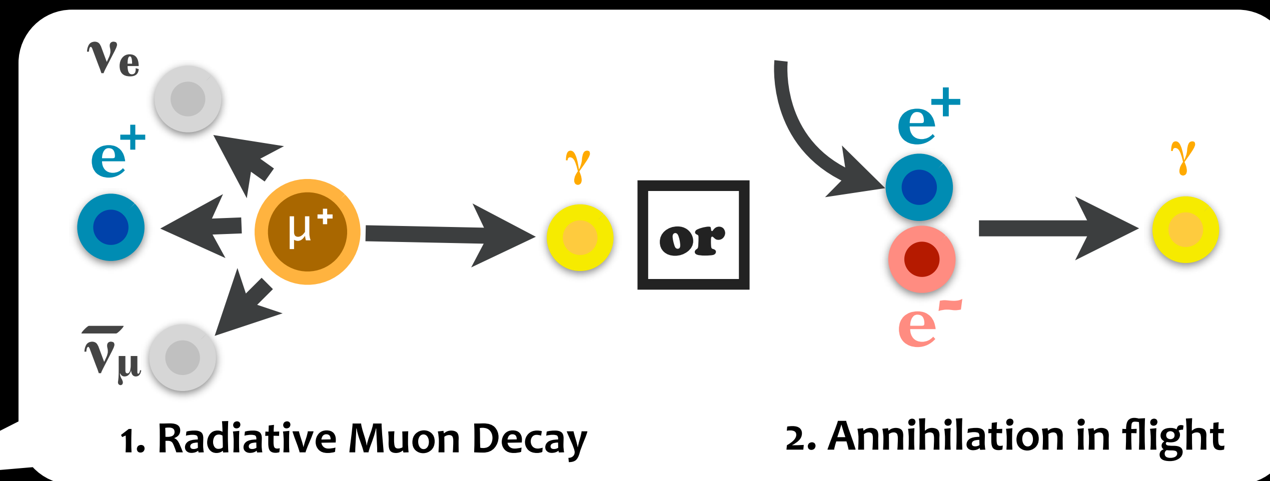
- Doubled beam rate: 7×10^{7}muons/s
- PMTs in LXe Detecter are partially replaced with MPPCs
- A low mass stereo drift chamber
- A multi-tile scintillation timing counter
- New BG tagging detector is introduced

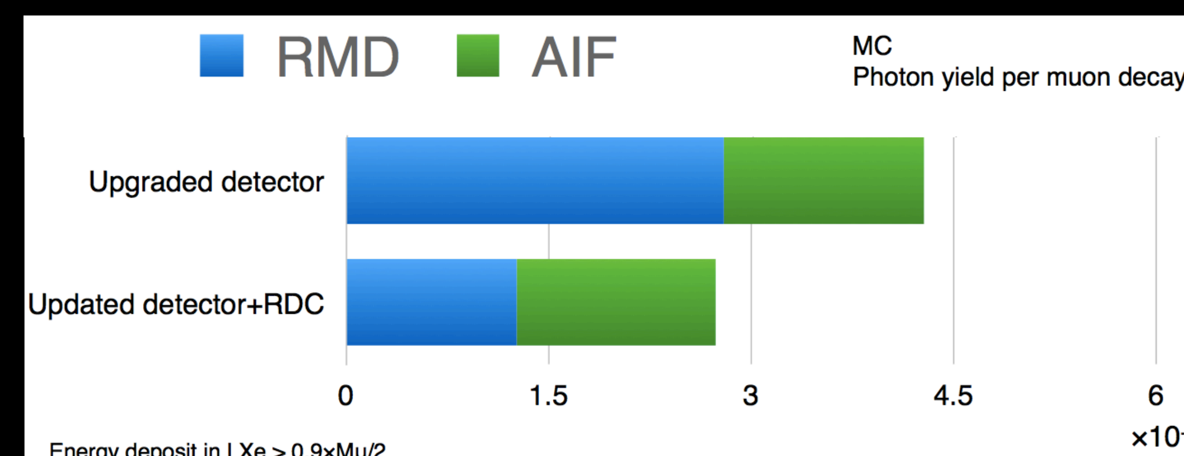
RADIATIVE DECAY COUNTER

◇ Main Background Event : accidental background





- Radiative Decay Counter (**RDC**) tags Radiative Muon Decay actively (→Next page)
- 16 ~ 28% higher sensitivity can be achieved by introducing RDC



	sensitivity
without RDC downstream	5.0×10^{-14}
with RDC downstream	4.3×10^{-14}
with full RDC	★ $3.9 \sim 4.1\times10^{-14}$

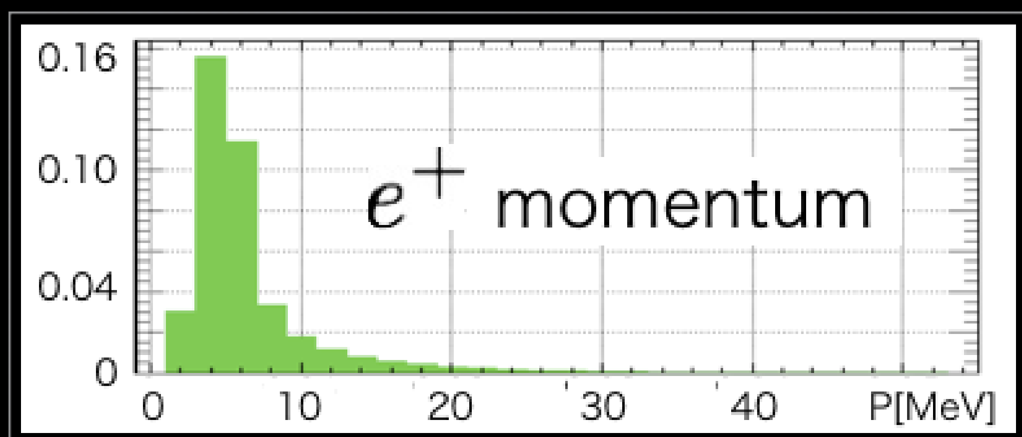
16~28%

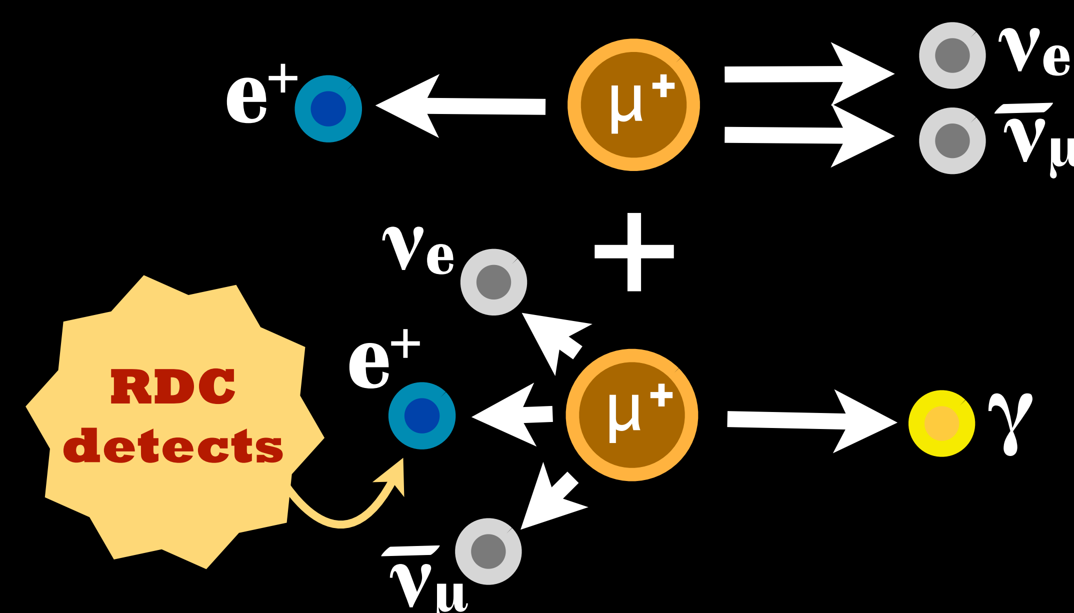
★ depending on detection efficiency (50%~80%)

RADIATIVE DECAY COUNTER

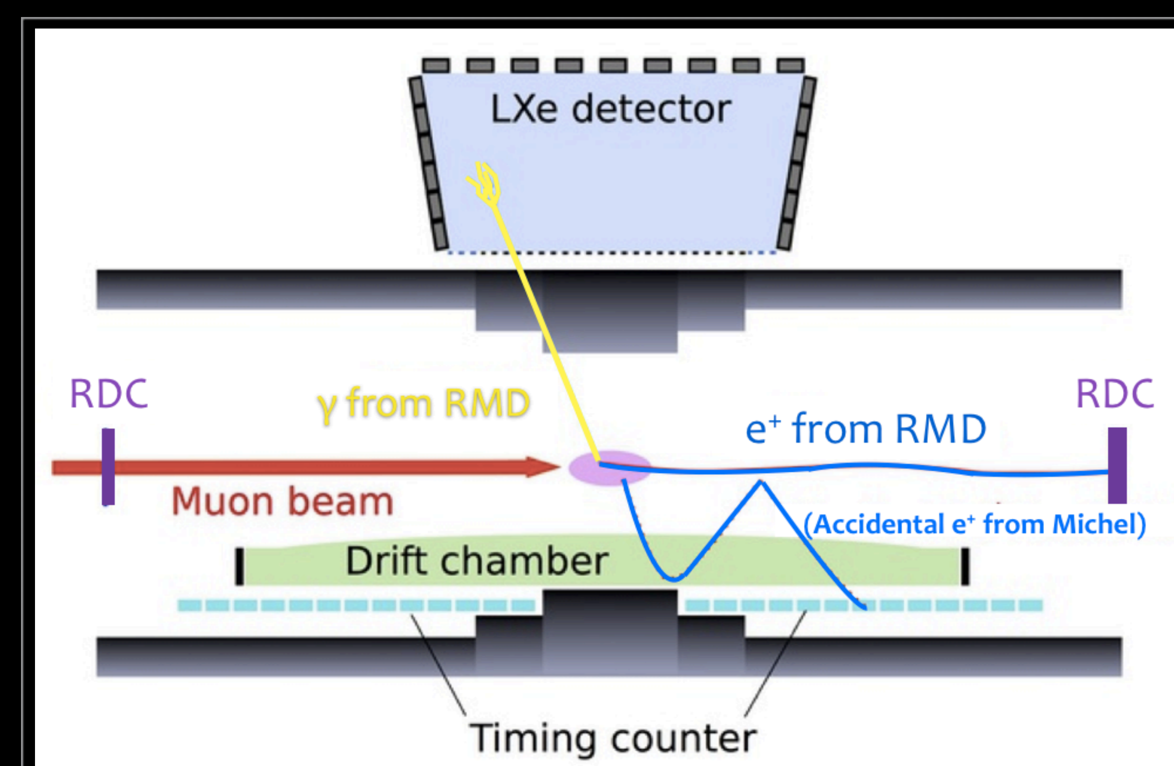
◇ Active tagging of Radiative Muon Decay

- Radiative Muon Decay with
  a high energy (> 48 MeV) gamma ray
  simultaneously emits
  a **low momentum positron (typically: ~5 MeV).**





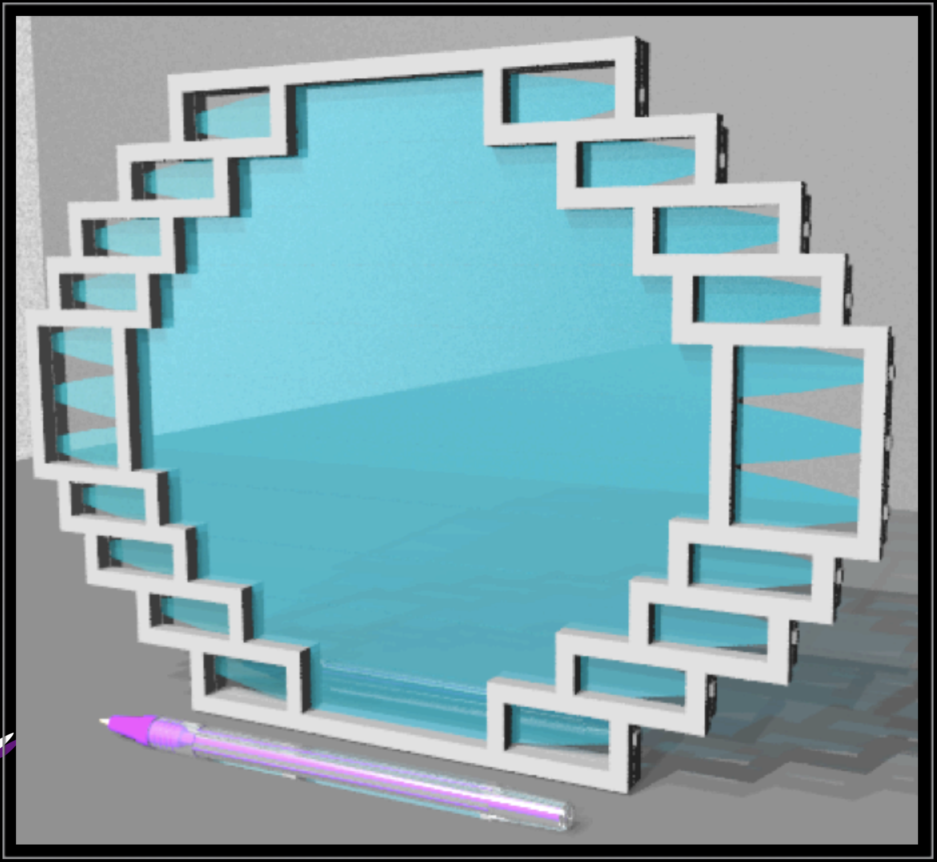
- It has small turning radius
  →Small counters are set
  on the beam axis
- measure **time coincidence**
  between γ and low momentum e^+
- measure **energy** of e^+ to distinguish
  Radiative Decay from Michel decay ←**downstream only**



RADIATIVE DECAY COUNTER

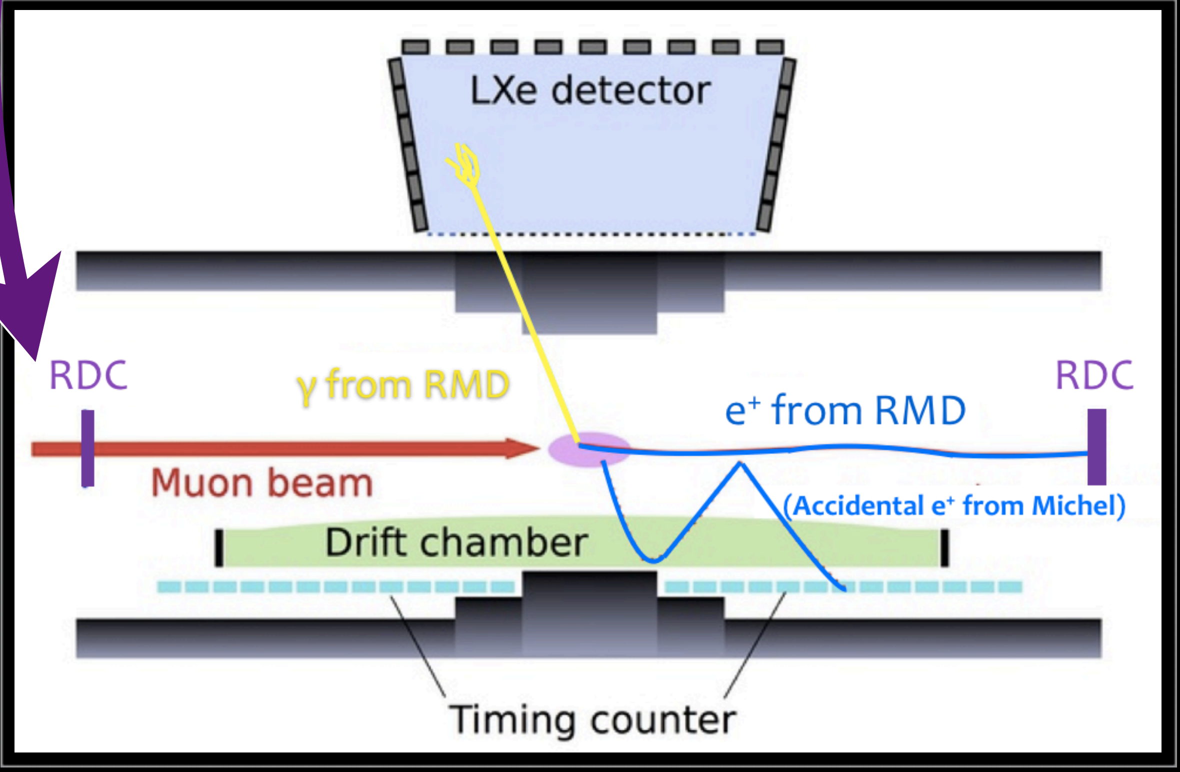
◇ Upstream RDC

- Made of 704 plastic scintillation fibers
  - thickness = 250 μm
  - small effect on μ^+ beam transportation
- Separate μ^+ from e^+ using difference of energy deposit
- Measure **time coincidence** between γ and e^+ (from radiative decay)



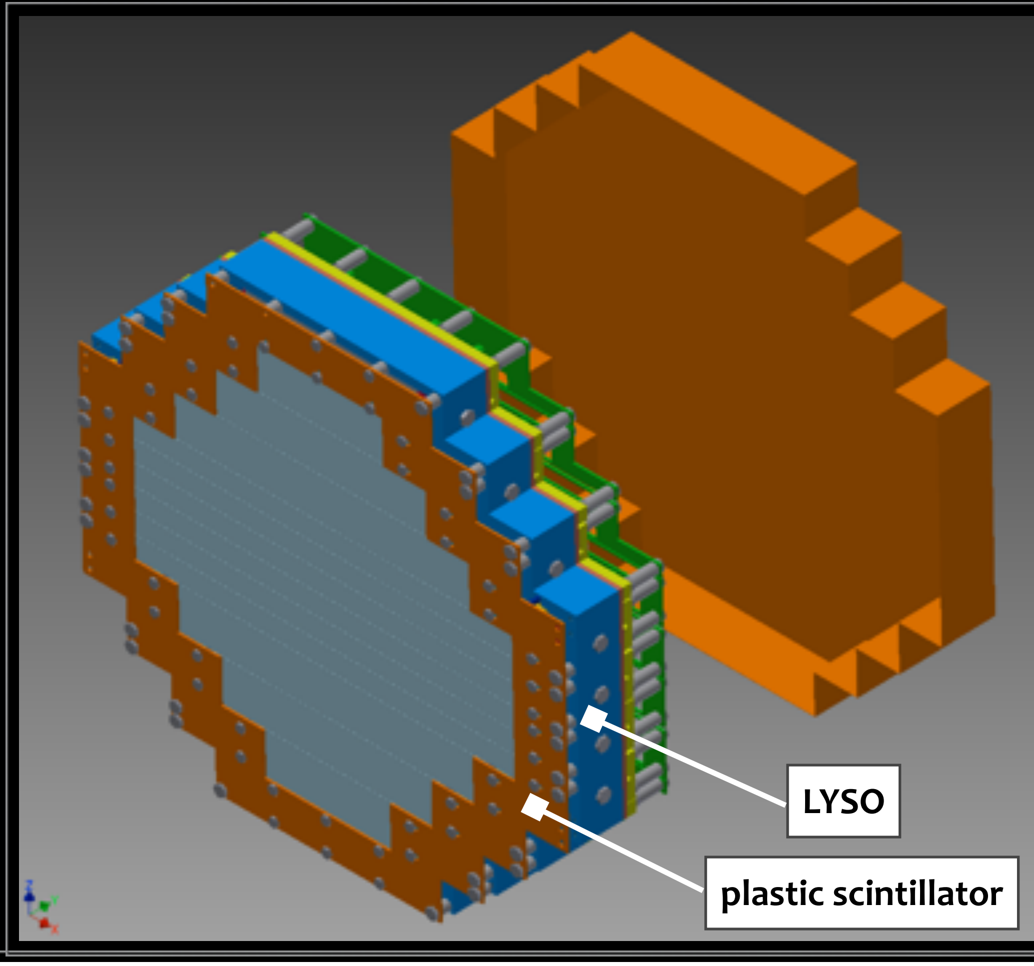
The effect on the μ^+ beam properties ?

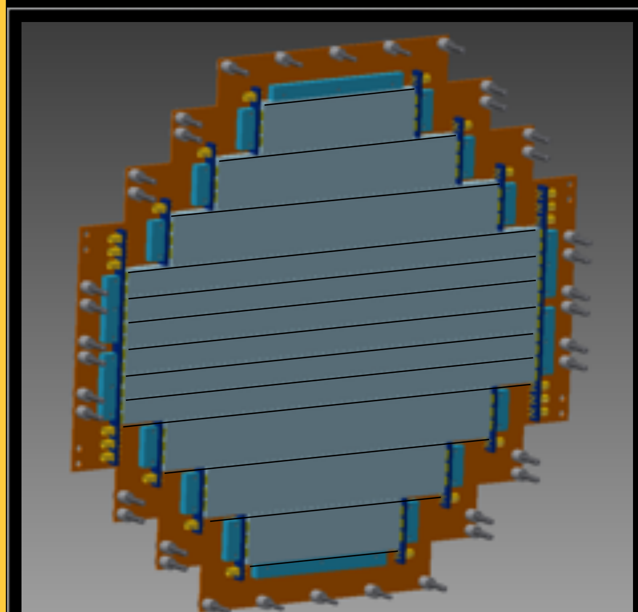
- In simulation,
  - stopping efficiency will be decreased by 3 %: 71.9% (w/o RDC)→69.8% (w/ RDC)
  - A small influence on the beam spread (6~7 %). sigma X: 1.11 cm (w/o RDC)→1.19 cm (w/ RDC) sigma Y: 1.07 cm (w/o RDC)→1.13 cm (w/ RDC)
- We plan to measure it with beam using a mock-up detector in this Autumn.



◇ Downstream RDC

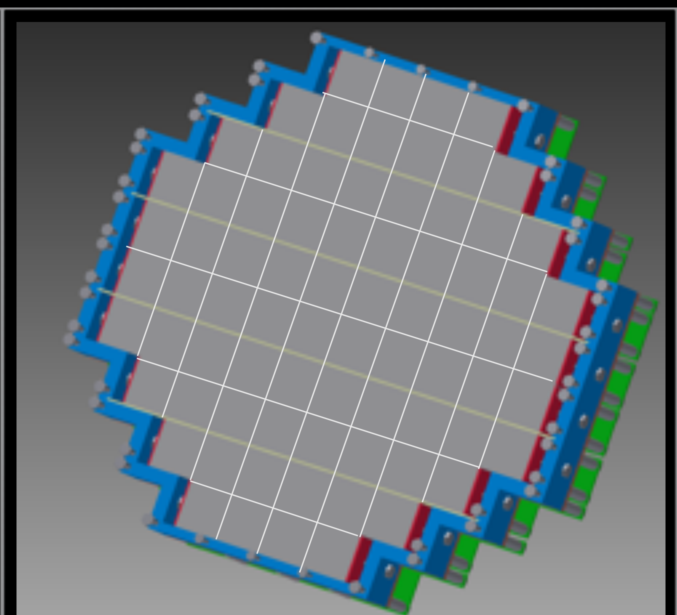
- Already approved by the collaboration
- 12 Plastic scintillation bars
  - length: 7 ~ 19 cm, width: 1 ~ 2 cm, thickness: 5 mm
  - **measure time coincidence between γ and e^+**
- 76 LYSO crystals
  - $2 \times 2 \times 2\ \mathrm{cm}^3$
  - **measure energy deposit and distinguish Radiative Decay and Michel Decay**



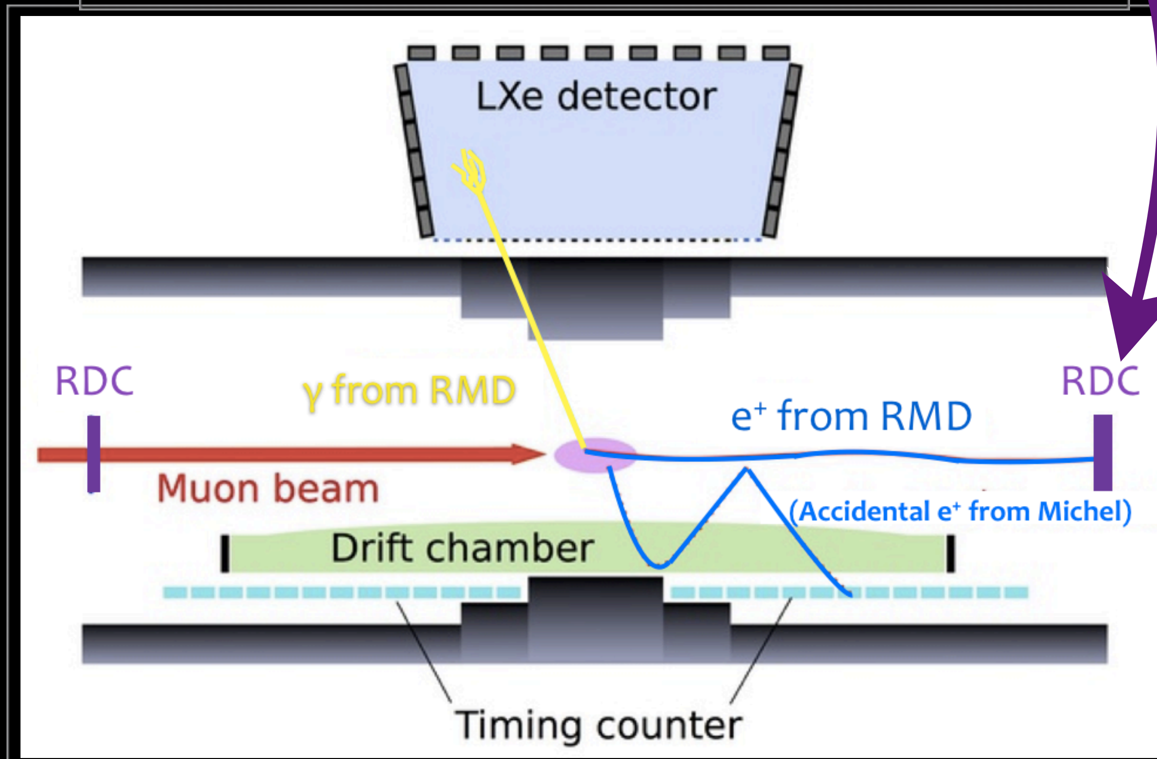


plastic scintillator

This talk



LYSO

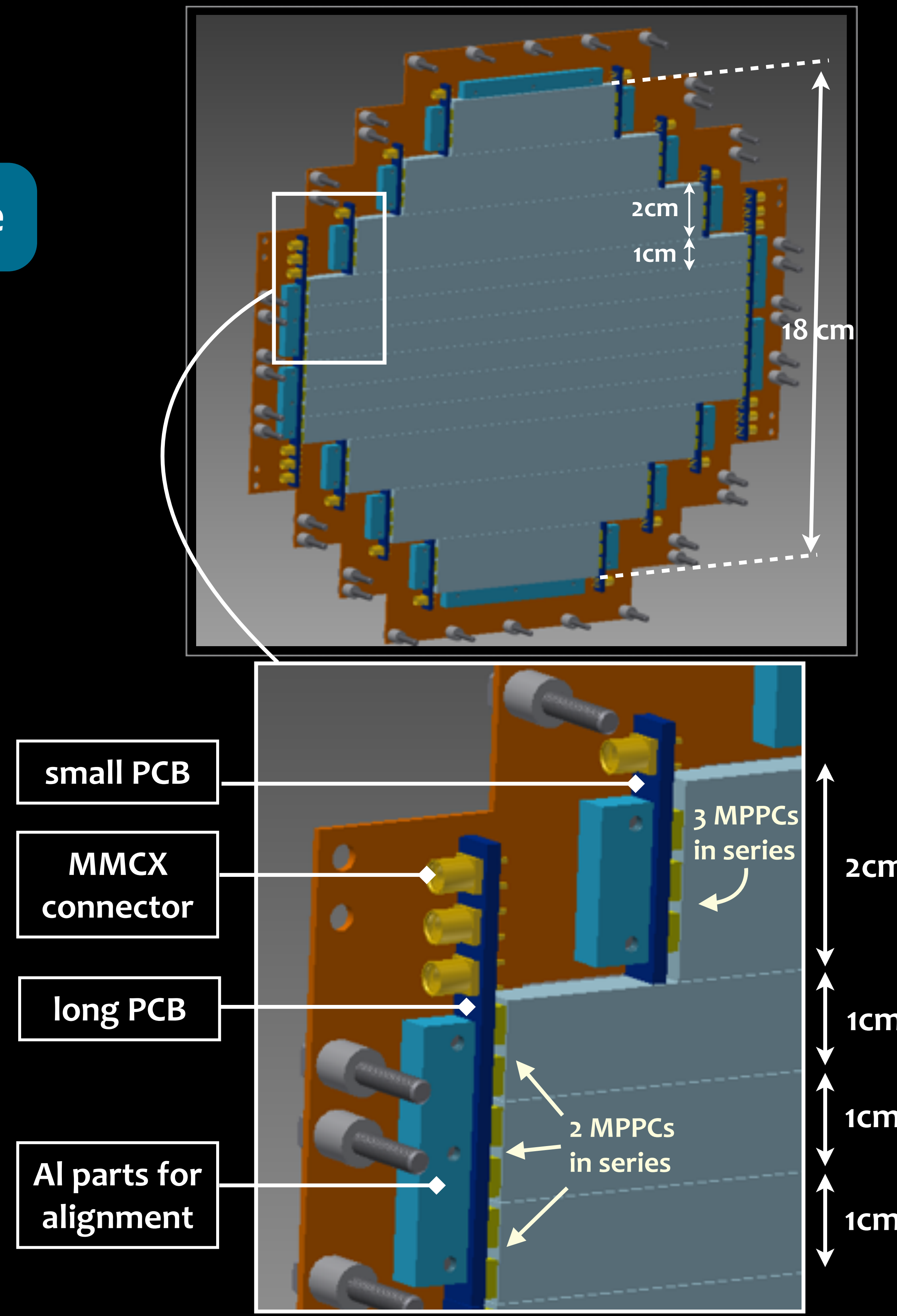


RADIATIVE DECAY COUNTER

◇ Plastic scintillator

Good performance within limited space

- BC-418 (Saint-Gobain)
  - large light yield
  - fast response (decay constant: 1.4 nsec)
- Two types of width: 1 cm & 2 cm
  - 1 cm: for reducing pileup events
- Series connected MPPCs
  - sharpen waveforms
- PCBs: compact readout circuits
  - MMCX cables are used.
  - 3 narrow bars are attached on a long PCB
- Required time resolution ~ 100 psec



STATUS&SCHEDULE

downstream RDC

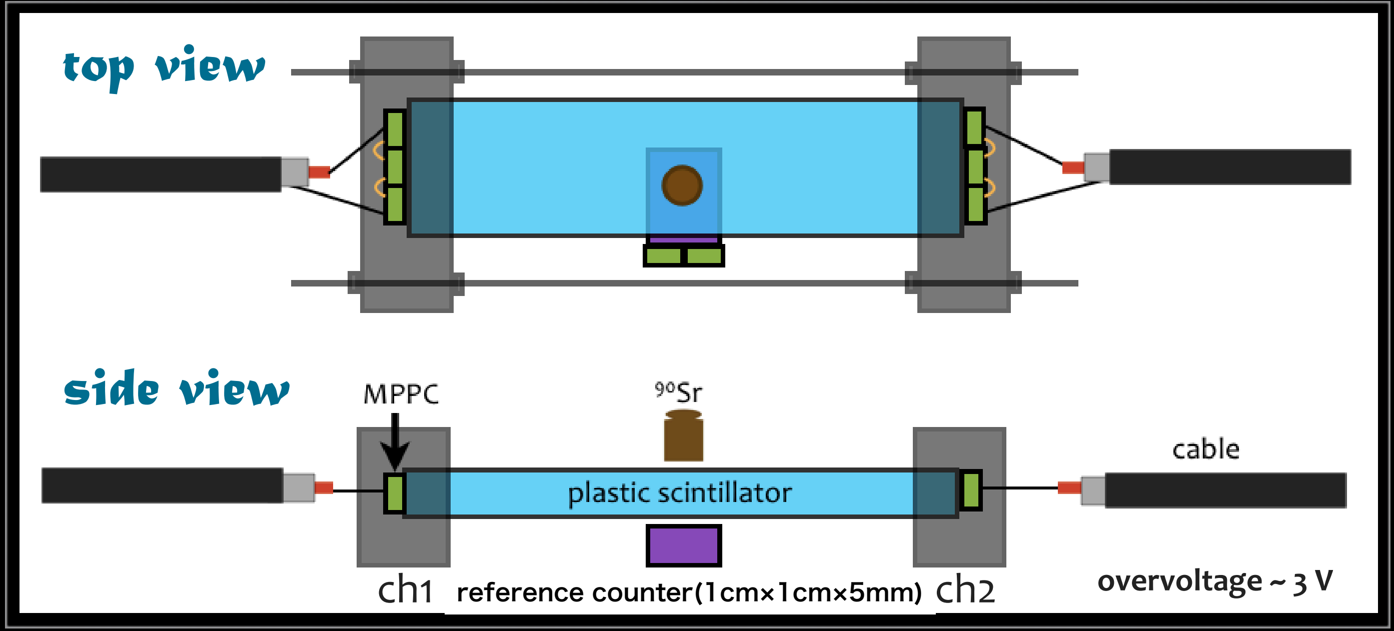
		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
R & D	RMD detection with prototype ✓									
	crystal selection ✓									
	MPPC selection ✓									
	crystal shape optimization ✓									
	optical coupling optimization									
	afterglow study									
Production	MPPC test									
	holder production									
	PCB production									
	plastic scintillator test									
	counter assembling & test									
	mover production									
	operation test									

SCINTILLATOR TEST

◇ Plastic scintillator

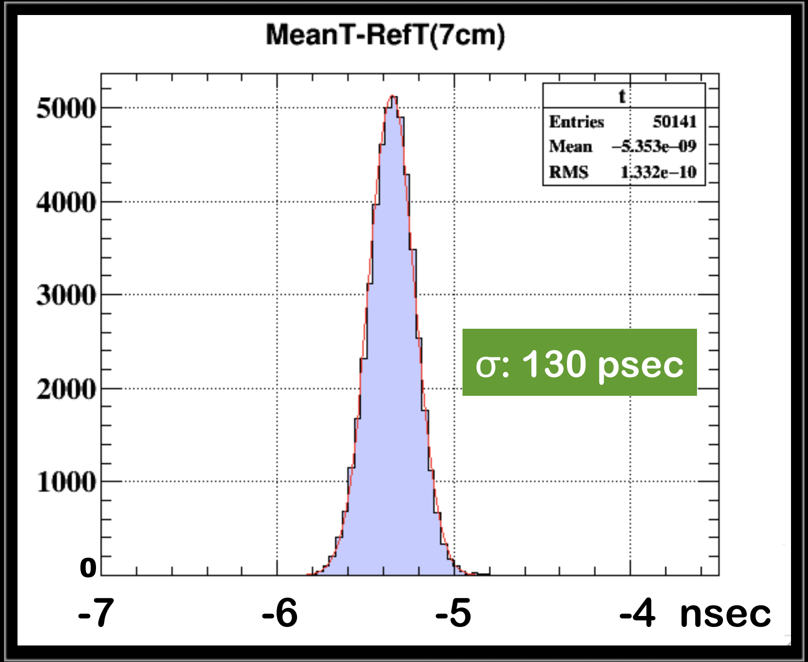
setup

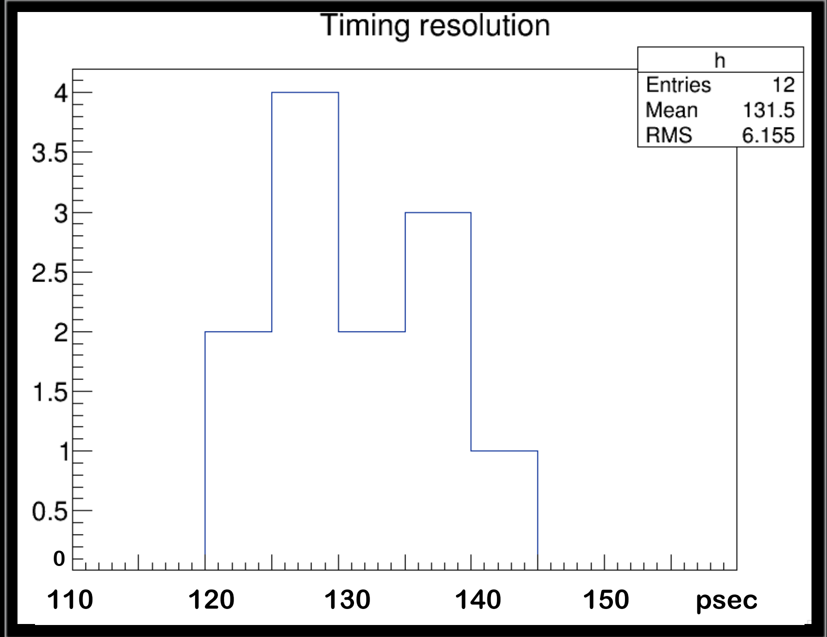
- 12 scintillation bars were tested.
- MPPCs were attached on both sides of a scintillation bar.
- 2 or 3 MPPCs were connected in series.
- optical grease was used for coupling.
- radioactive source: ^{90}Sr.
- trigger: hit in reference counter.

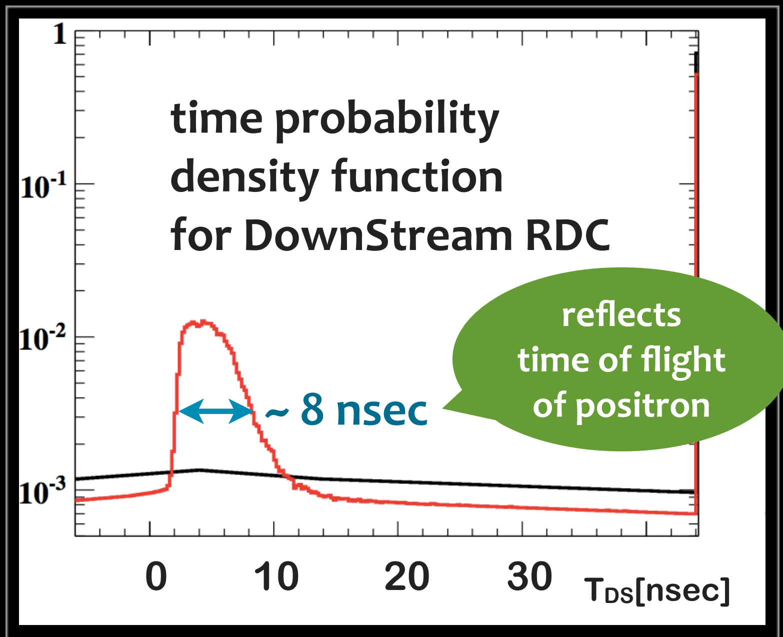


- calculate **[T(ch1)+T(ch2)]/2 - T(reference)**
  - constant fraction time
- Fit the distribution with Gaussian function and the **sigma** is defined as time resolution

- **Result: 120-145 psec**
  - This value **includes resolution of the reference counter.** (the resolution of reference counter : ~100 psec)
  - The resolution of the bars is **good enough.**



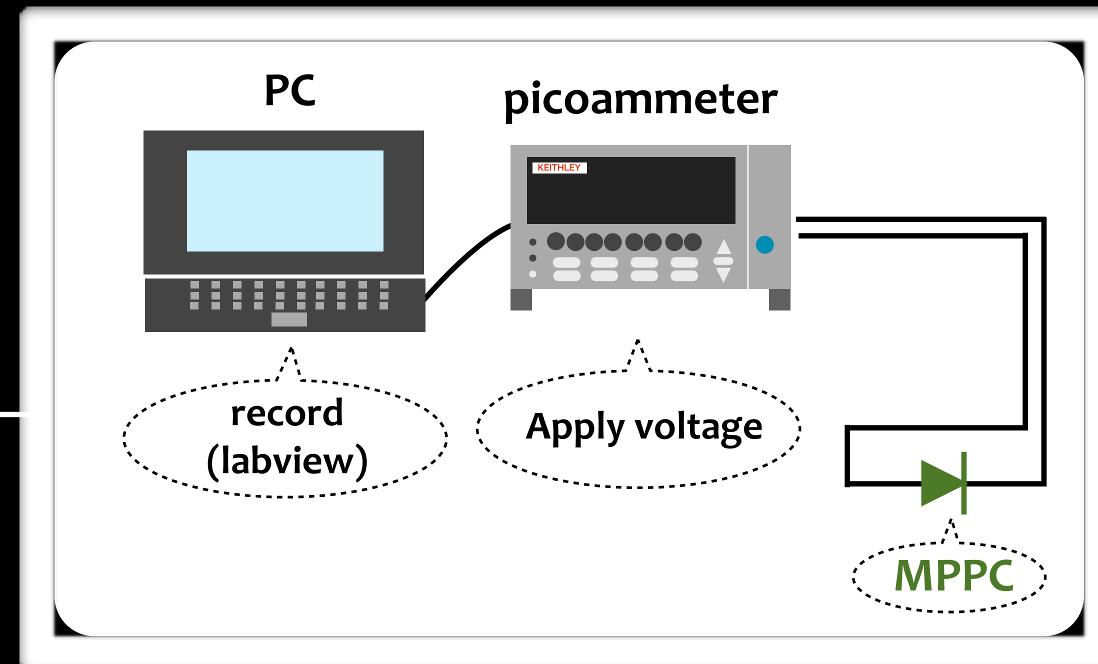


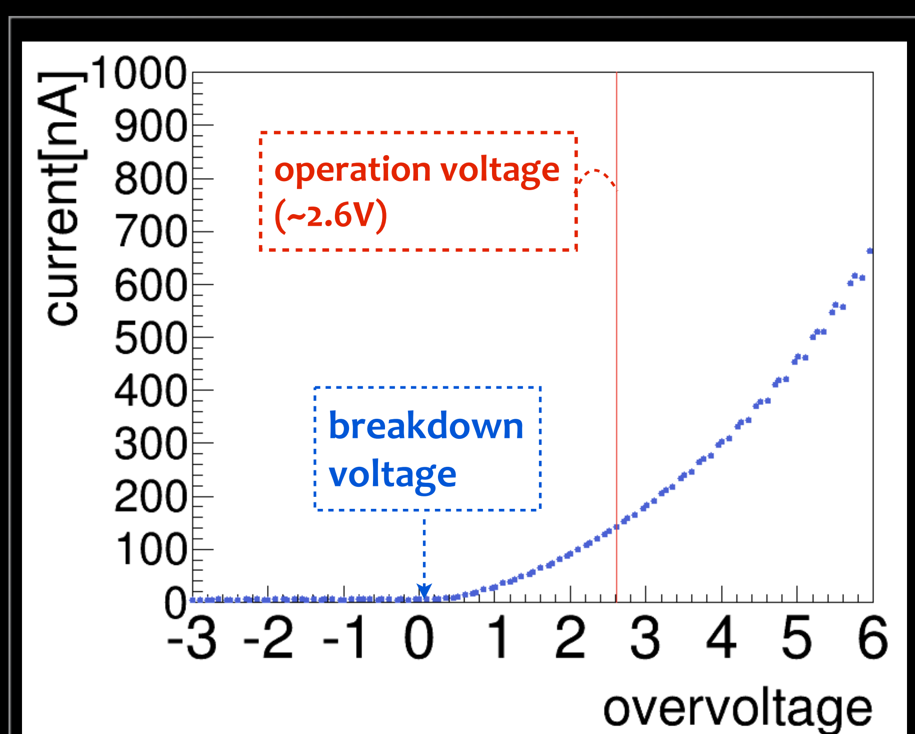


MPPC GROUPING

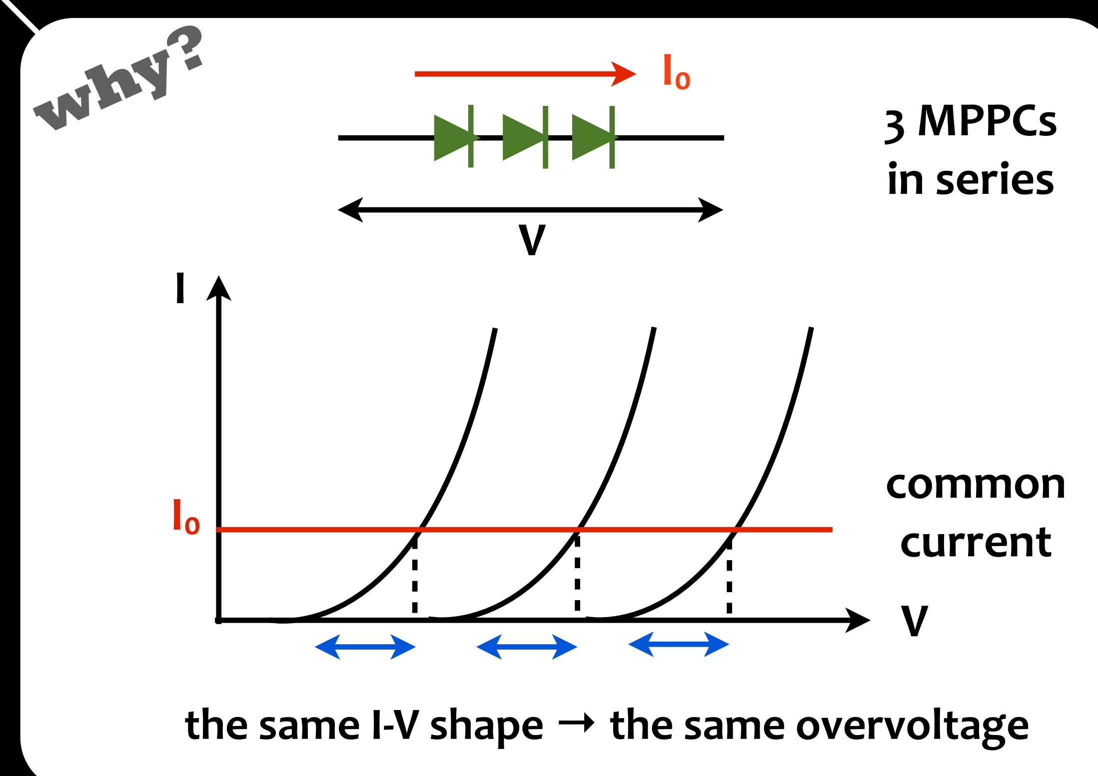
◇ MPPCs for plastic scintillator

- Grouping
  - there are 12 scintillation counters
    →MPPCs are divided into 24 groups
  - measure I-V curve for all of MPPCs
  - MPPCs which show close I-V shapes
    are put in the same group.



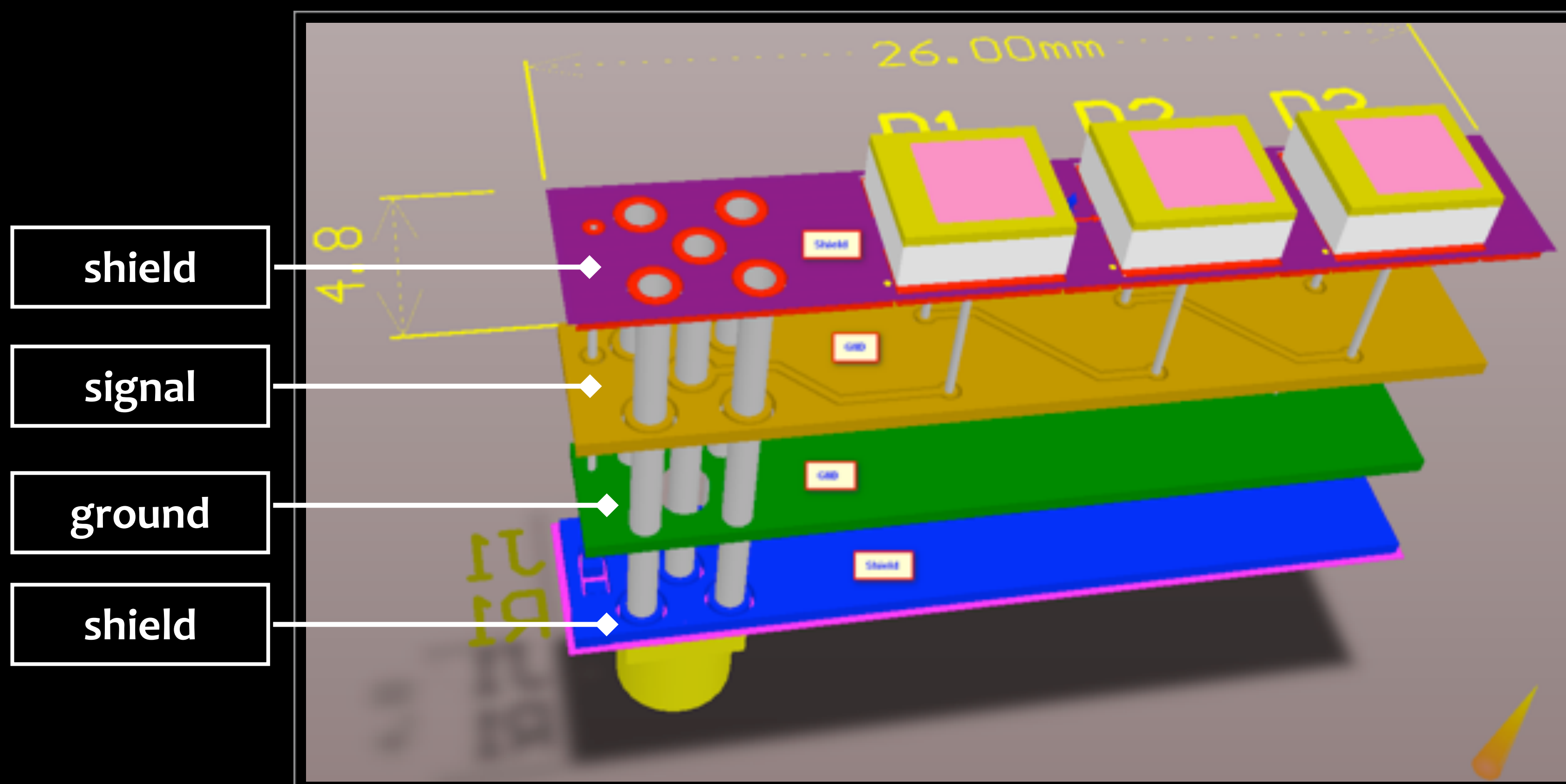


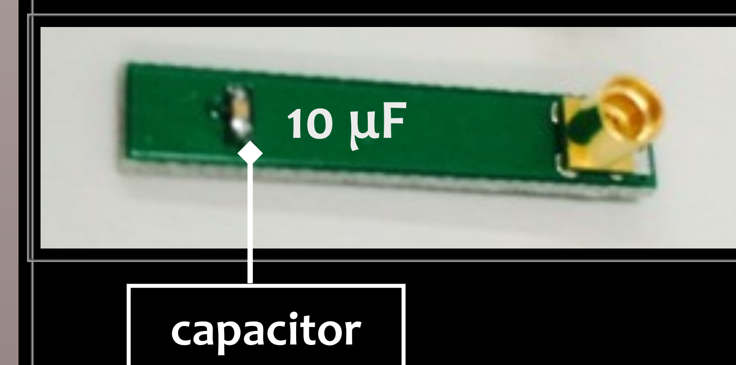
I-V curves of 3 MPPCs
in the same group

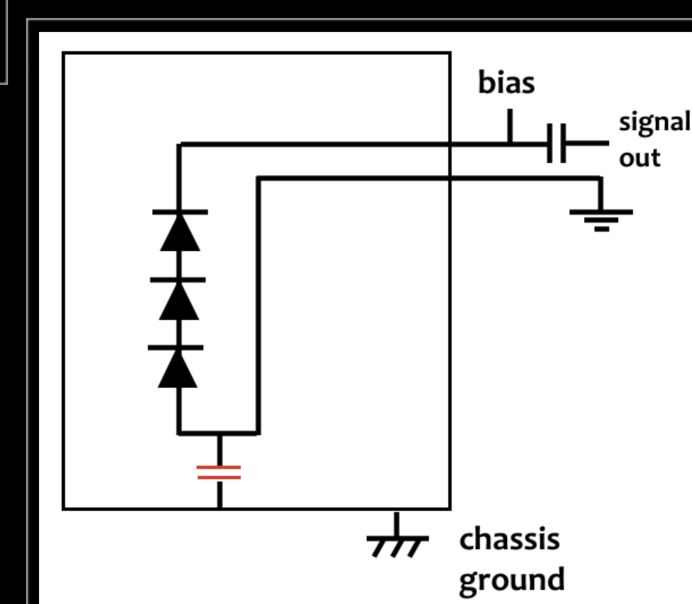


◇ PCB design

- Consists of 4 layers:
  - shield layers on both sides for noise suppression





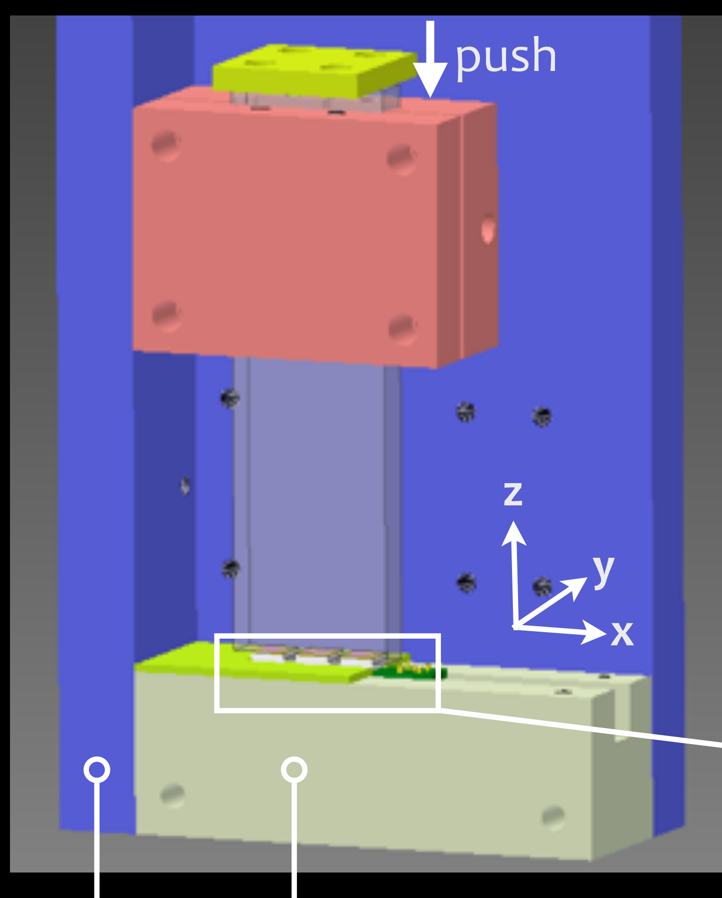


- Capacitors for noise reduction
  - connecting ground of MPPCs with chassis ground
    (this is effective on reducing noise by our experience)
  - avoid ground loop.

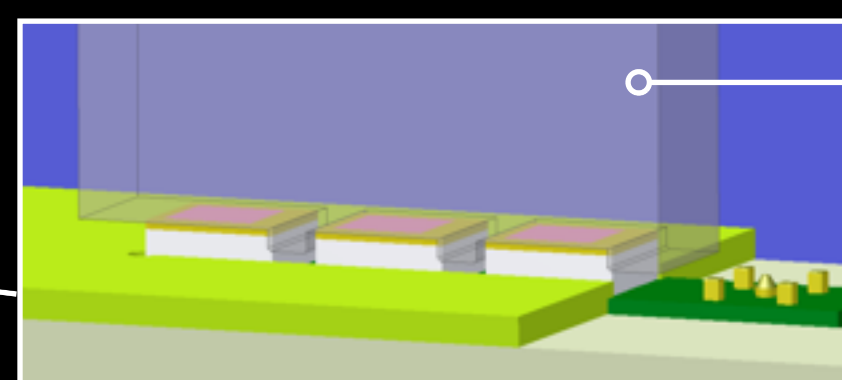
◇ Assembling

- Conductive epoxy (CW2400)
  - attach MPPCs to a PCB without heating
  - strong mechanical bonds
  - good electrical conductivity

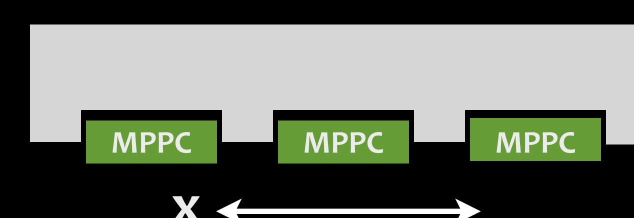
- Alignment jig



- a π - shaped acrylic part
  for y-direction alignment
- oil coated (small friction)
  → avoid glue adhering

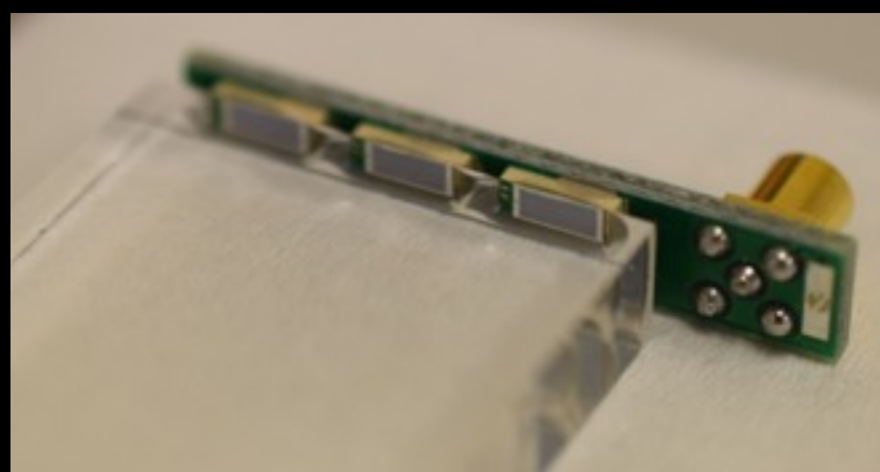


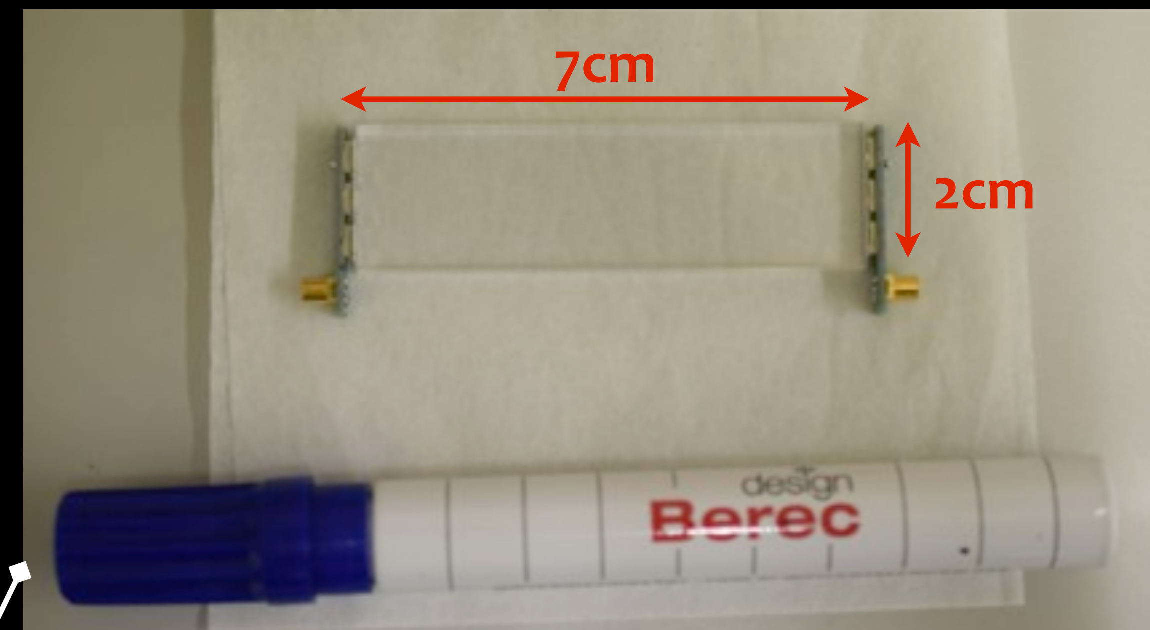
- an acrylic part
  for x & z direction alignment

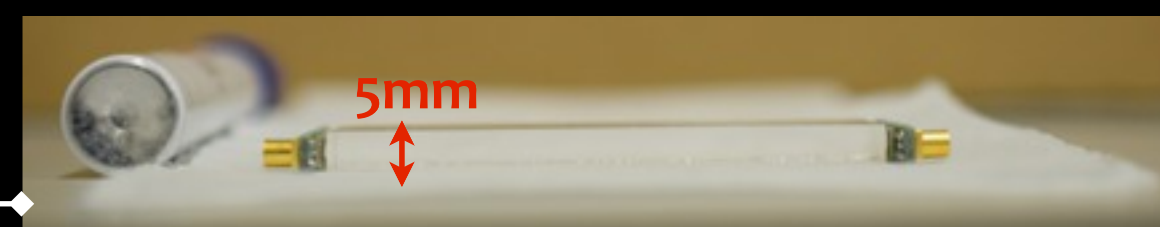


◇ Assembling

- Optical cement
  - used for coupling between PCBs and scintillation bars
    →aligned with the jig







the smallest counter

- Aluminized mylar
  - used as a reflector

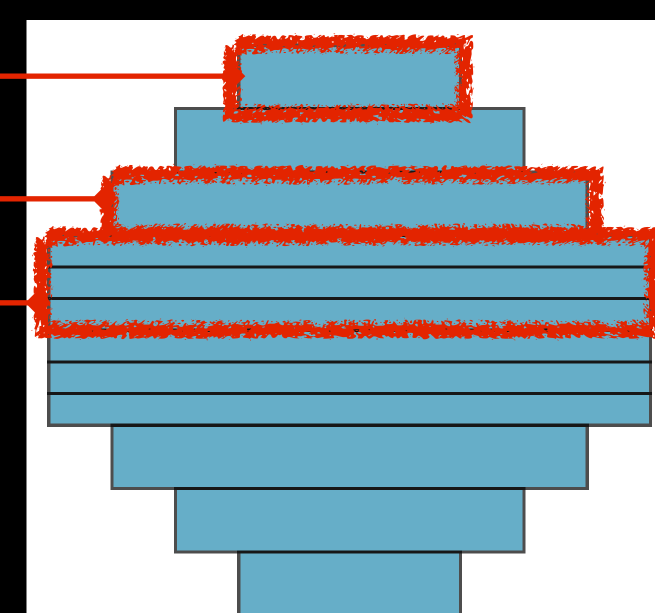
7cm

15cm

19cm

↓

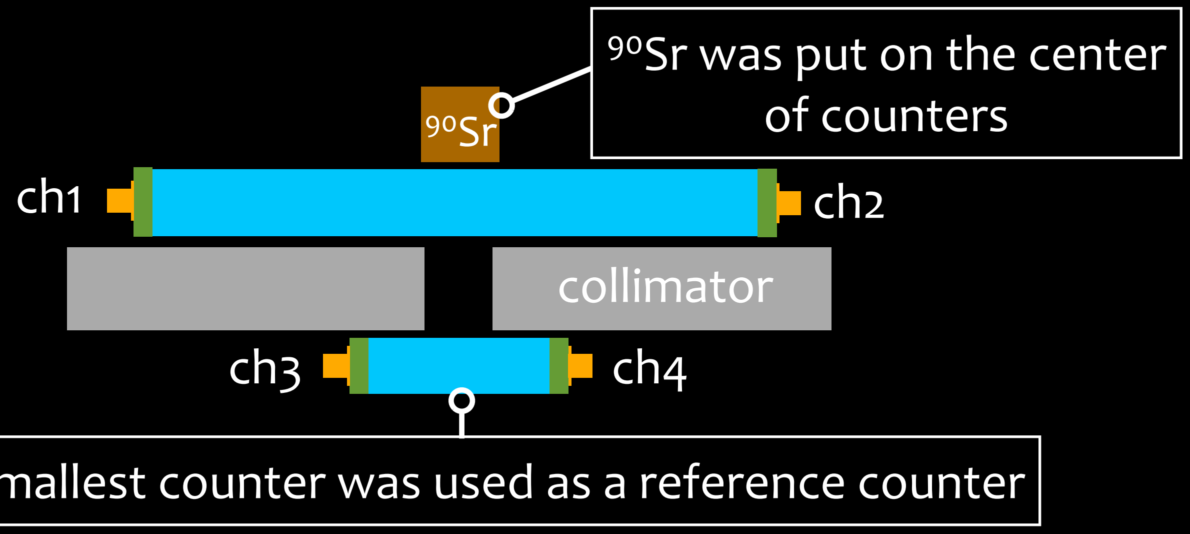
3 counters have been assembled



COUNTER PRODUCTION & TEST

◇ Counter Test

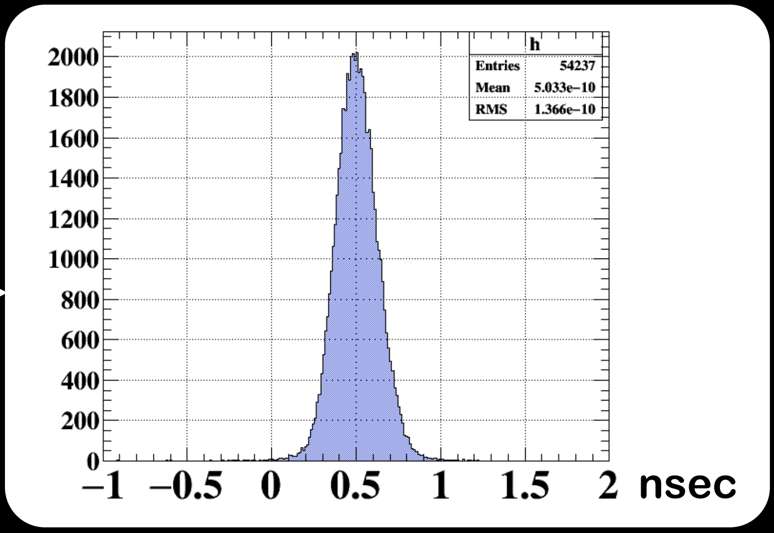
- Time resolution of assembled counters



→ σ ~ 65 psec

- $[T(ch1) + T(ch2)] / 2 =: T_{mean}$
- $[T(ch3) + T(ch4)] / 2 =: T_{ref}$

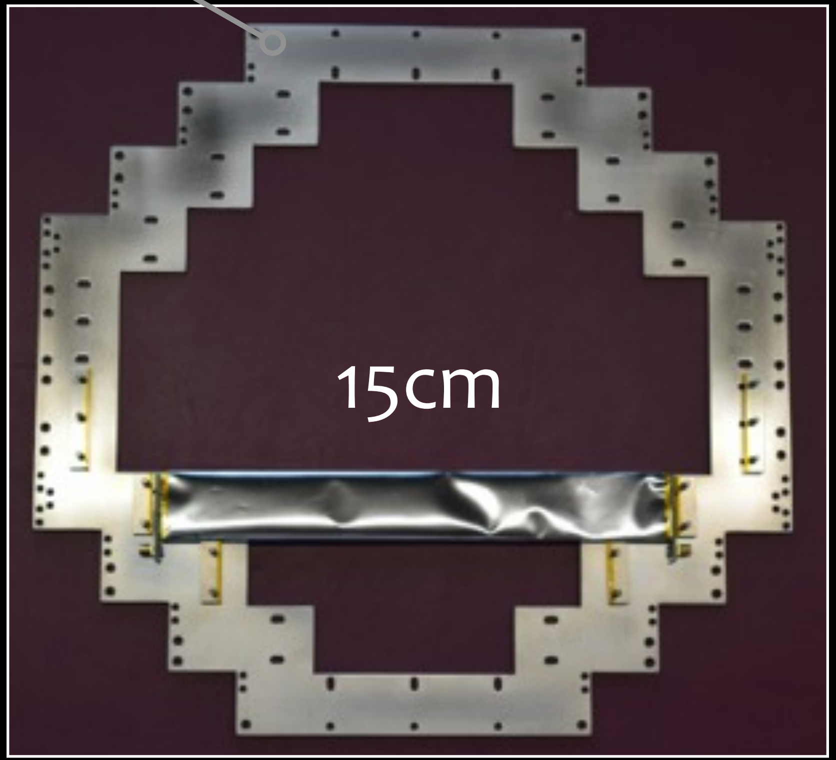
$T_{mean} - T_{ref}$ distribution

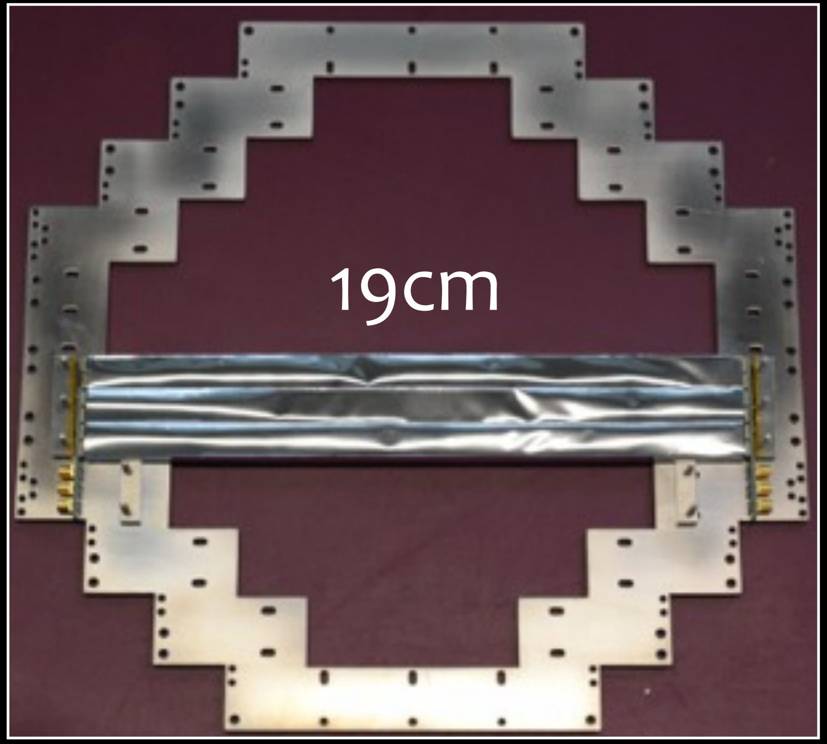


	time resolution
15 cm	71 psec
19 cm	104 psec

→ good enough for RDC

a frame for plastic scintillators





Summary & Prospect

◇ Summary

- 16 ~ 28% sensitivity improvement will be achieved by introducing RDC.
- Downstream RDC has already been approved.
- Plastic scintillator bars have arrived and showed good time resolution.
- Counter production has started.
- Assembled counters showed good performance.

◇ Prospect

- Finish counter production and their test
- Combine plastic scintillator part with LYSO part,

  and test them as overall downstream RDC.

  →Downstream RDC will be prepared by the end of this year.
- Study on Upstream RDC with beam will be started this autumn.

END

BACKUP

Radiative Decay Counter

◇ Plastic scintillator

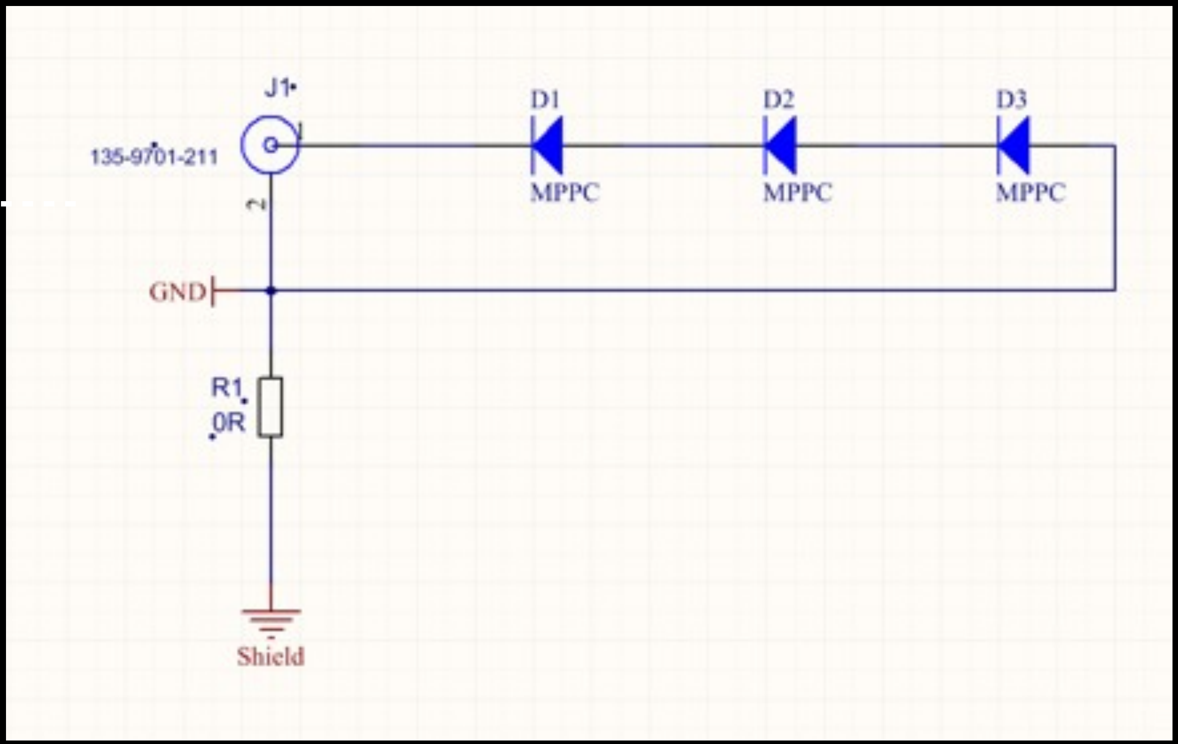
Physical Constants of SGC Plastic Scintillators

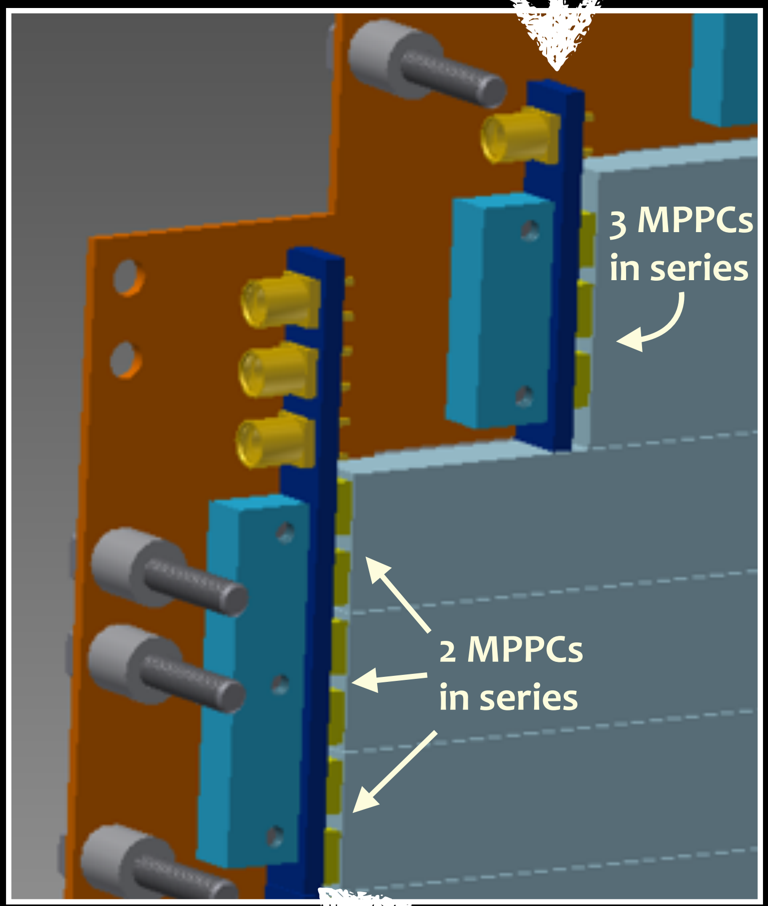
Scintillator	Light Output % Anthracene[1]	Wavelength of Maximum Emission, nm	Decay Constant, Main Component, ns	Bulk Light Attenuation Length, cm	Refractive Index	H:C Ratio	Loading Element % by weight	Density	Softening Point °C
BC-400	65	423	2.4	250	1.58	1.103		1.032	70
BC-404	68	408	1.8	160	1.58	1.107		1.032	70
BC-408	64	425	2.1	380	1.58	1.104		1.032	70
BC-412	60	434	3.3	400	1.58	1.104		1.032	70
BC-416	38	434	4.0	400	1.58	1.110		1.032	70
BC-418	67	391	1.4	100	1.58	1.100		1.032	70
BC-420	64	391	1.5	110	1.58	1.102		1.032	70
BC-422	55	370	1.6	8	1.58	1.102		1.032	70
BC-422Q	11	370	0.7	<8	1.58	1.102	Benzephenone,0.5%*	1.032	70
BC-428	36	480	12.5	150	1.58	1.103		1.032	70
BC-430	45	580	16.8	NA	1.58	1.108		1.032	70
BC-440	60	434	3.3	400	1.58	1.104		1.032	99
BC-440M	60	434	3.3	380	1.58	1.104		1.039	100
BC-444	41	428	285	180	1.58	1.109		1.032	70
BC-452	32	424	2.1	150	1.58	1.134	Lead,5%	1.080	60
BC-454	48	425	2.2	120	1.58	1.169	Boron,5%	1.026	60
BC-480	**	425	–	400	1.58	1.100		1.032	70
BC-482A	QE=.86	494	12.0	300	1.58	1.110		1.032	70
BC-490	55	425	2.3	NA	1.58	1.107		1.032	70
BC-498	65	423	2.4	NA	1.58	1.103		1.032	70

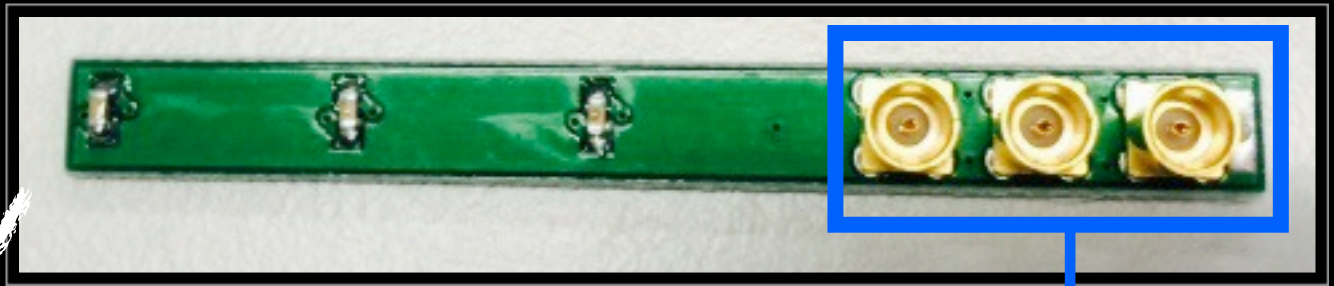
[1] Anthracene light output = 40-50% of NaI(Tl)   * 0.1 to 5 weight % also available   ** Ratio of Cerenkov light to scintillator light = 10:1

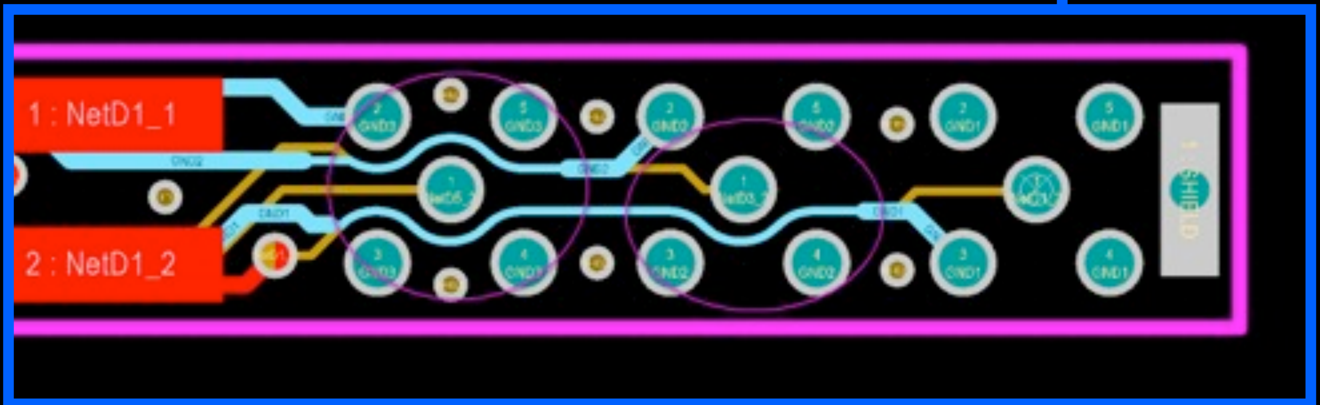
http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/SGC%20Organics%20Brochure.pdf

COUNTER PRODUCTION & TEST





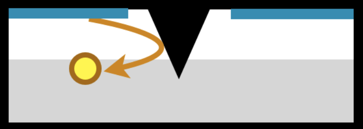




MPPC GROUPING

◇ MPPCs for plastic scintillator

- MPPC (Multi-Pixel Photon Counter)
  - S13360-3050PE
  - pixel size: 50×50 μm^2
  - crosstalk suppression
  - 2 or 3 series connection
  - 60 MPPCs are used



trenches between pixels suppress crosstalk