SiPM読み出しによる高時間分解能シンチレーションカウンターの開発

2013年9月20日
日本物理学会2013年秋季大会@高知大学

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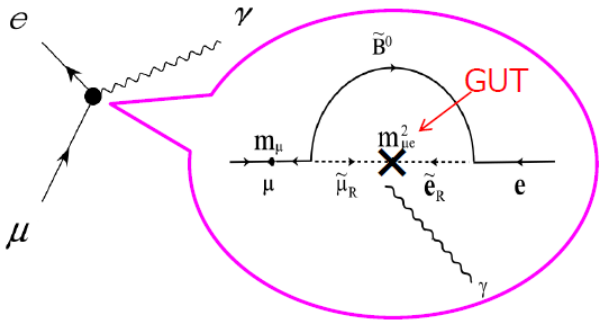
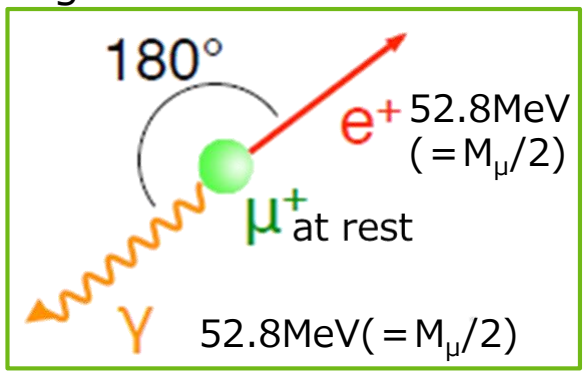
Motivation

MEG
Mu-E-Gamma Collaboration

- **Search for lepton-flavor-violating μ→eγ decay**
  - Forbidden in SM
  - But enhanced in many BSM
- **MEG experiment**
  - Searching for μ→eγ down to O(10^{-13})
  - Completed data-taking Aug.2013
  - Analysis for final result ongoing
- **Upgrade**
  - Push down to **O(10^{-14})**
  - Approved by PSI, R&D progress
  - To start DAQ in 2016



Signature

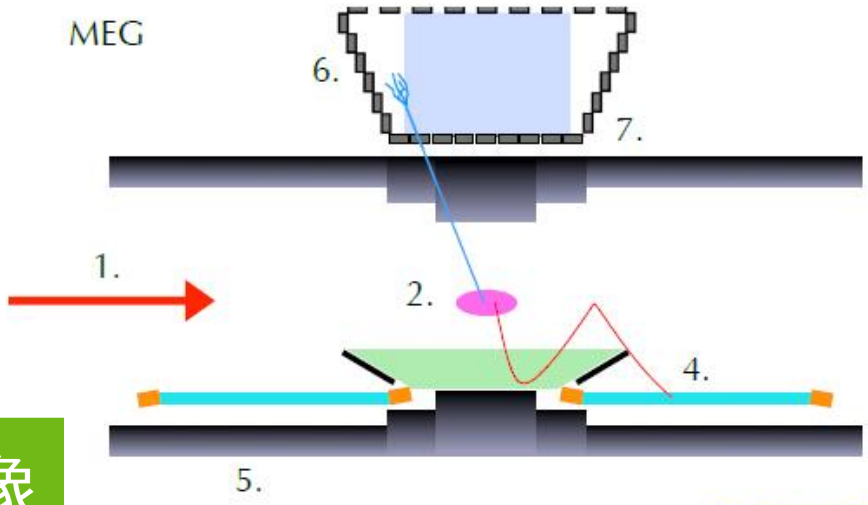


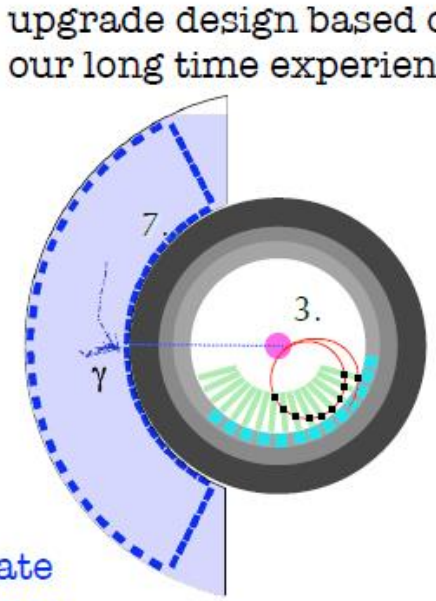
22pSE5 岩本

Required to suppress **accidental BG**

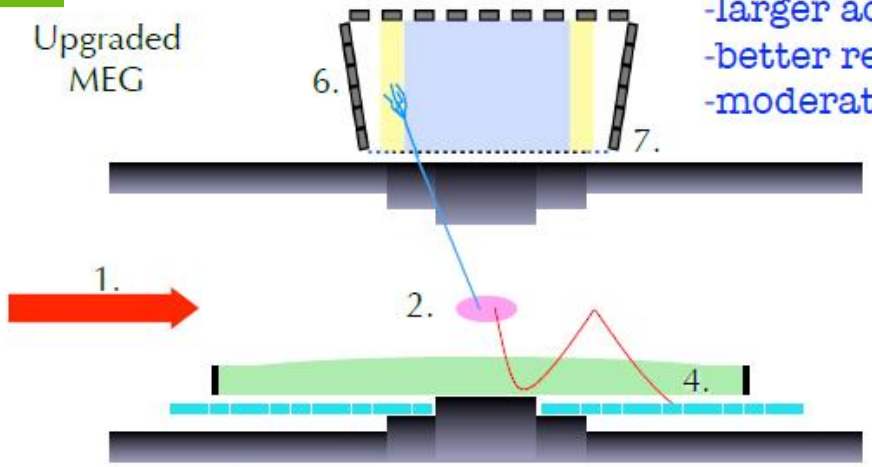
MEGアップグレード

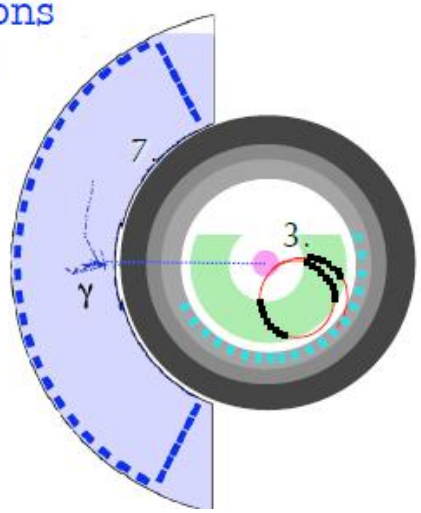
全体像





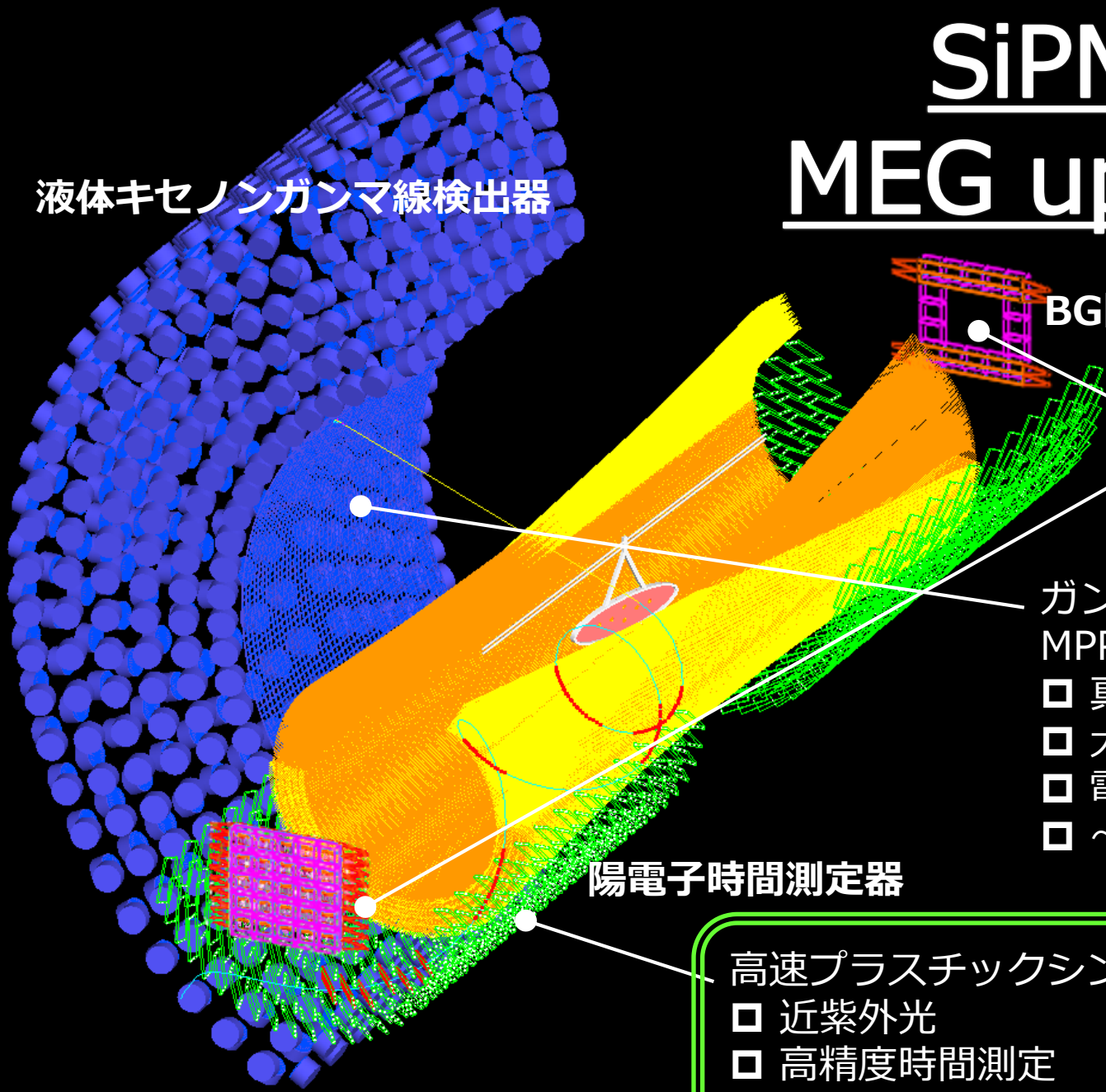
-higher beam rate
-larger acceptance
-better resolutions
-moderate cost





MEG Upgrade Proposal
(http://arxiv.org/abs/arXiv:1301.7225)

SiPM in MEG upgrade

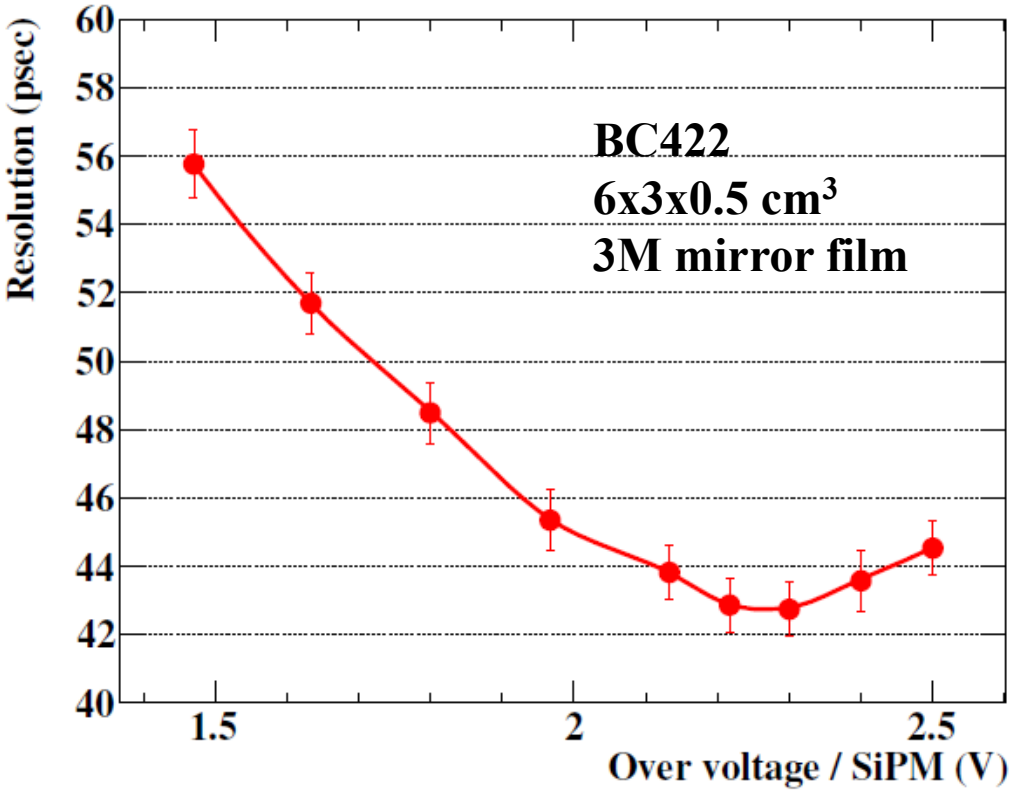


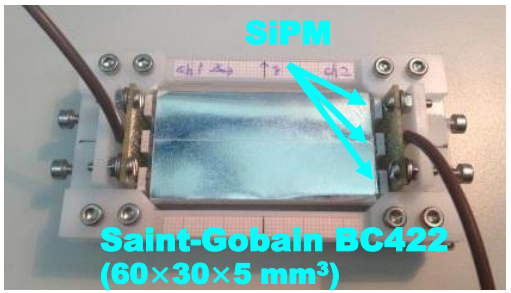
新たに導入を検討
- GSO+プラシン＋ファイバー

ガンマ線入射面をPMTからMPPCに置き換える
- 真空紫外光に有感
- 大型
- 電荷測定・時間測定
- ～4000ch

高速プラスチックシンチレータ読み出し
- 近紫外光
- 高精度時間測定
- ～500 counters × 2ch (3000 SiPMs)

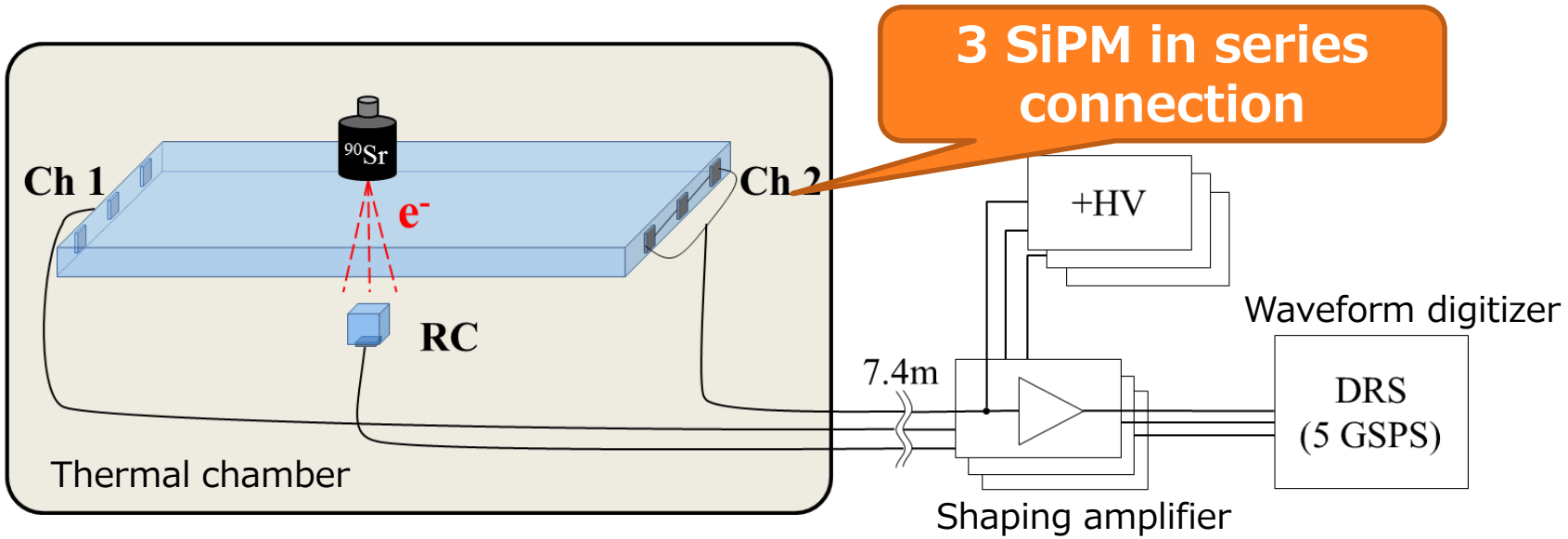
Previous results





- Achieved excellent resolution of 43 ps(σ) at relatively high over-voltage
- Observed deterioration at further over-voltage
  - Increase of dark noise, after pulsing

Test setup



- **Scintillator :** BC422, 60x30x5mm^3
- **Sensor :** 3x3mm^2, 50μm-pixel SiPMs
- **Reference counter :** BC422, 5x5x5mm^3, 1 MPPC for trigger & collimation
- **^{90}Sr β-source** (<2.28MeV)
- **Amplification & shaping** (pole-zero cancellation)
- **High speed sampling with waveform digitizer**

Topics today

- **Further study to understand the timing resolution of plastic scintillation counter from SiPM properties**
- **Detail comparison of different type of SiPMs**
  - Recently, many manufacturers produce **blue-sensitive** SiPMs with 'p-on-n' structure
  - **New MPPCs** from Hamamatsu
    - New standard MPPC
    - New trench MPPC

T.Nagano et.al, IEEE NSS/MIC 2012

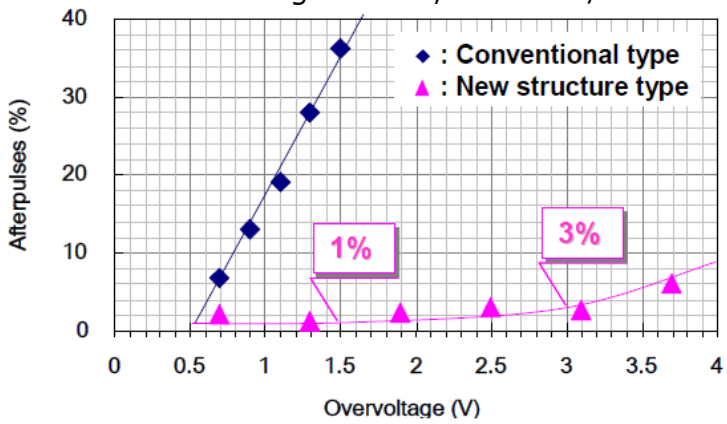


Fig.10. Afterpulse probability compared with conventional MPPC and new structure MPPC

HPK has recently developed new technologies
- After pulse suppression
- Trench for cross-talk suppression
- Metal quench resistor
- High fill factor for small pixel
- Etc.

IEEE NSS/MIC 2012, VCI 2013 Id:180

Pursue ultimate timing performance of general scintillation counter

SINGLE SENSOR PROPERTIES

Test samples

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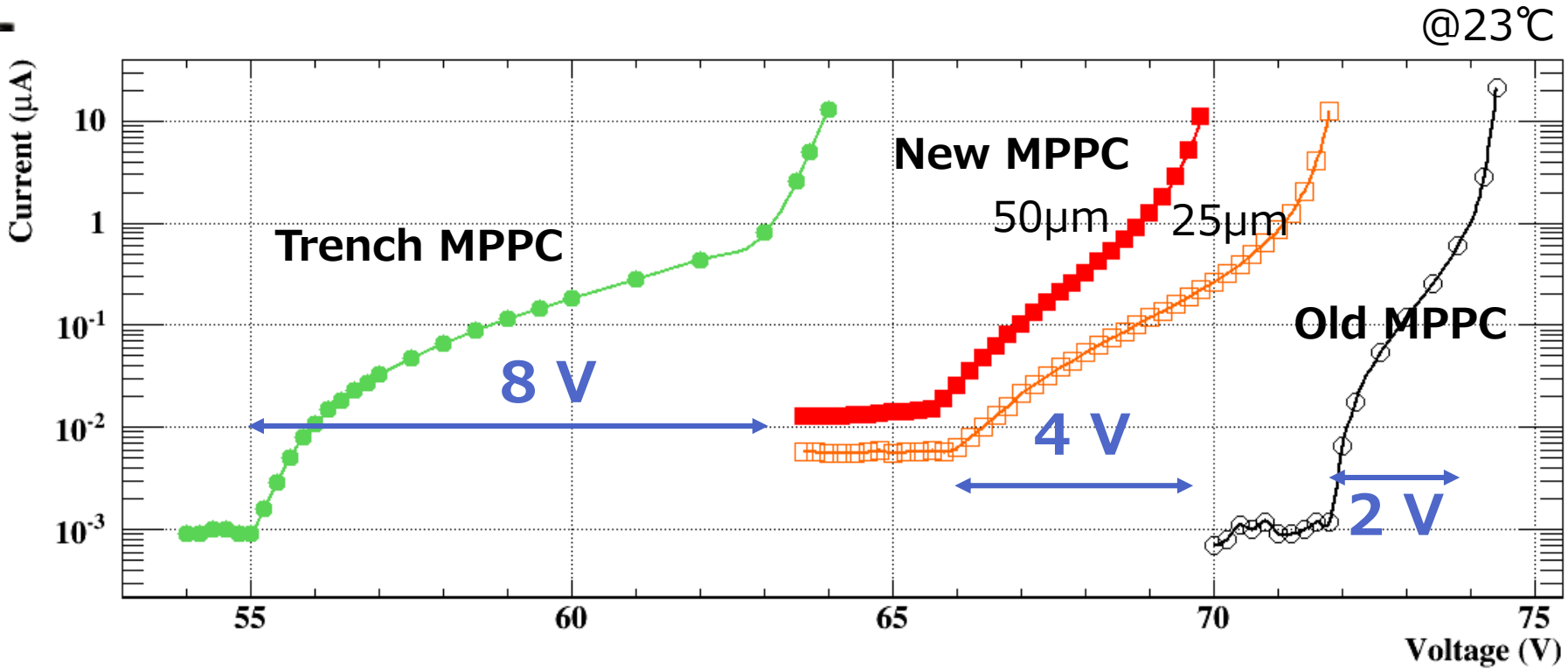
Manufacturer	Model number	Type	
HPK	S10362-33-050C	Conventional MPPC (**Old**)	Ceramic package
	S10931-050P		Surface mount
	S12572-050C(X)	**New** MPPC (Standard)	
	S12572-025C(X)		25μm pixel
	S12652-050C(X)	**Trench**-type MPPC	
	3X3MM50UMLCT-B		Improved fill factor
AdvanSiD		NUV type	
KETEK	PM3350 prototype A	Trench type	
SensL	MicroFB-30050-SMT	B-series with fast output	
	MicroFB-30035-SMT		35μm pixel

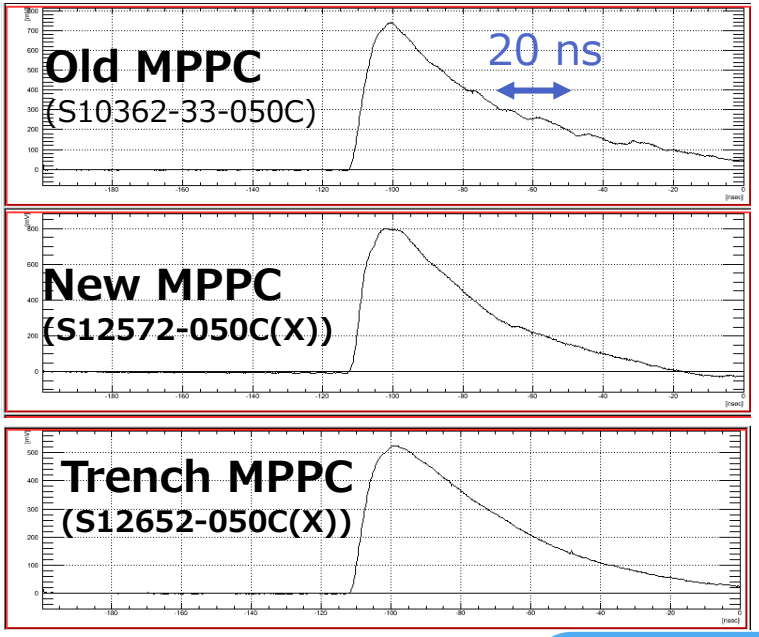
Common features:
3×3 mm^2 dimension, p-on-n structure

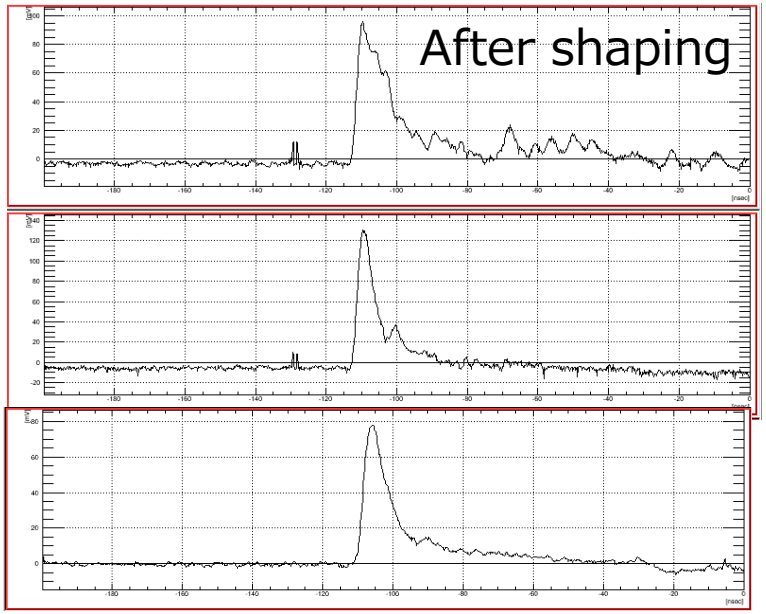
I-V characteristics



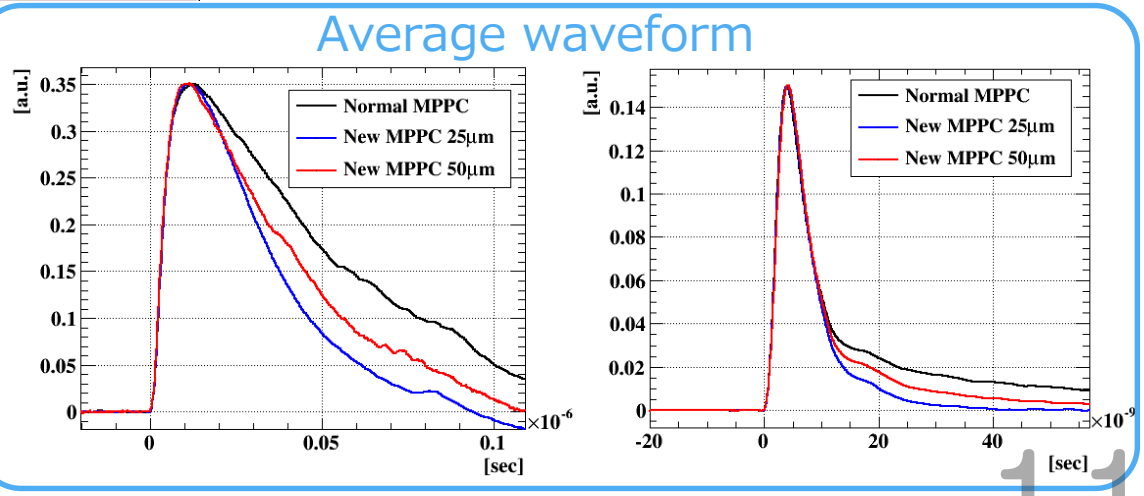
- Much wider operational range.
- Breakdown voltages are lower by 5 V (standard), 15V (trench)

Snapshot of waveform





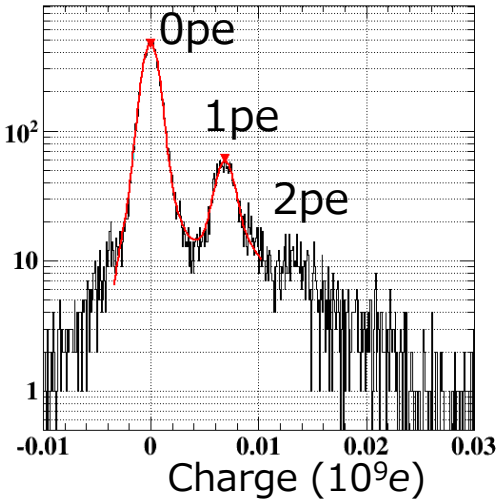
- Confirmed less after-pulsing



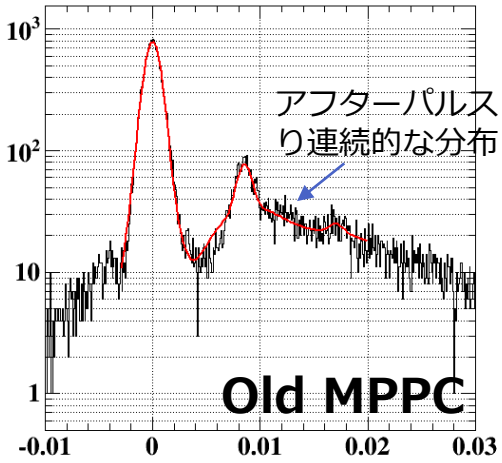
p.e. counting

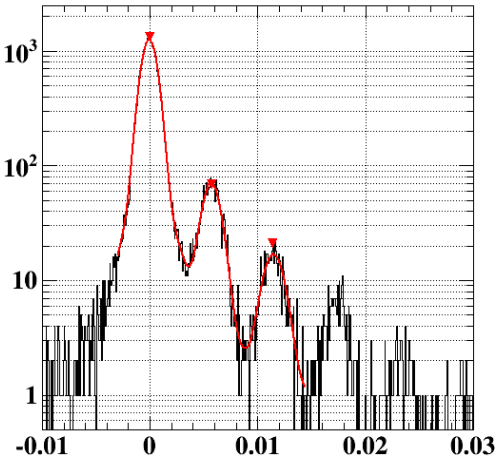
- **Dark measurement**
  - Random trigger
- **Photo-electron counting capability**
  - Large improvement in the separation

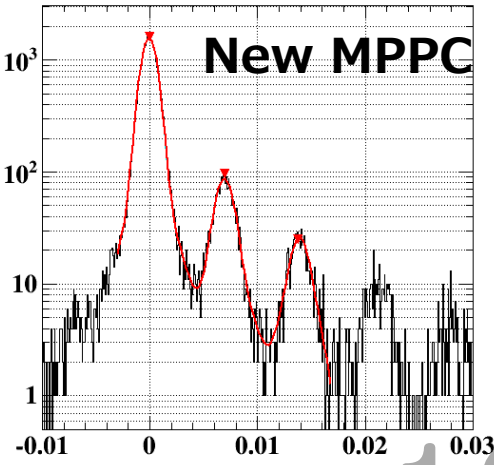
Over-voltage ~2.0 V



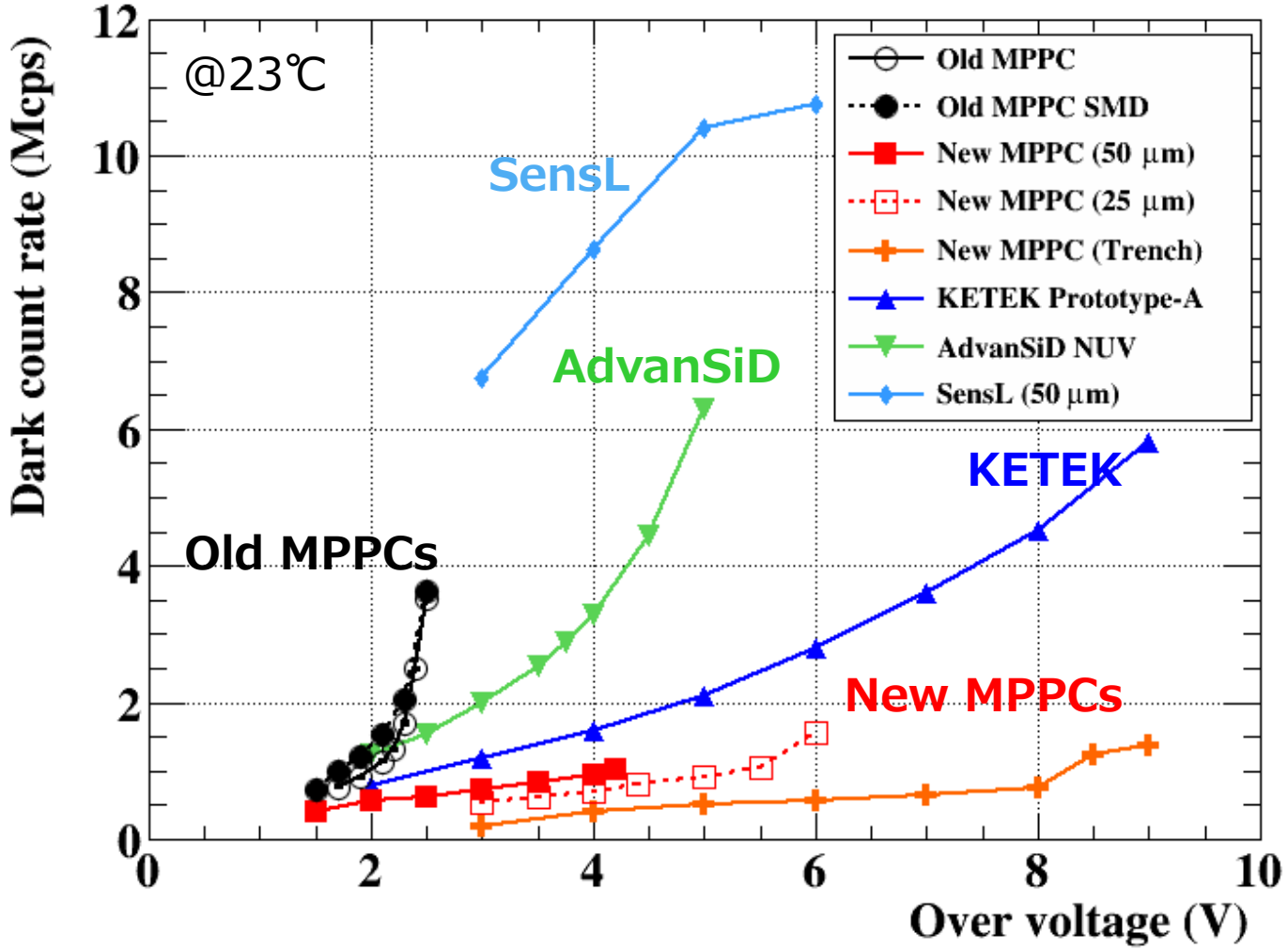
Over-voltage ~2.5 V





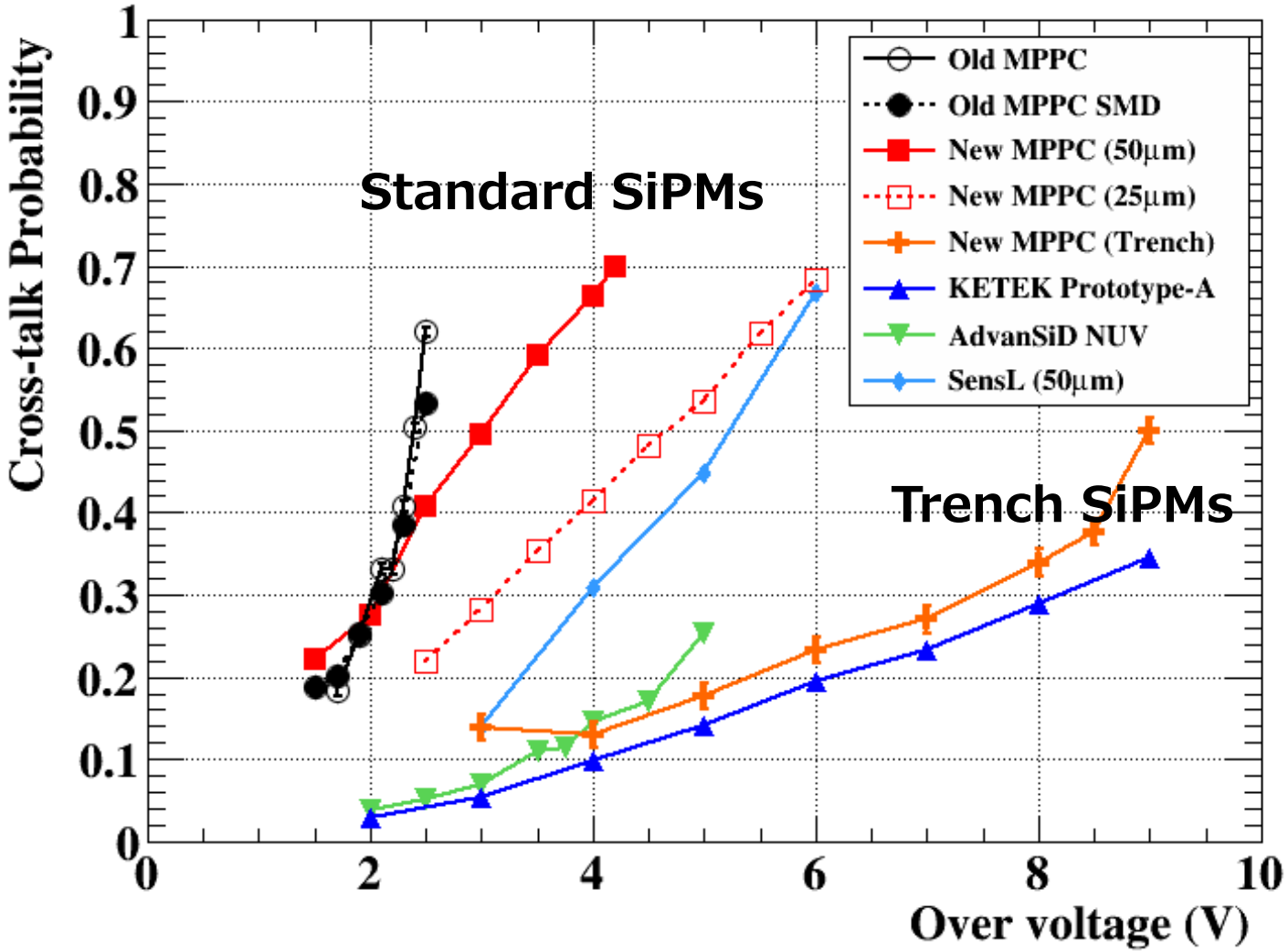


Dark count



Kept controlled up to high V_{over} due to the after-pulse suppression

Cross talk



@23℃

Cross-talk Probability $\equiv \frac{\#\geq 2pe}{\#\geq 1pe}$

Cross talk

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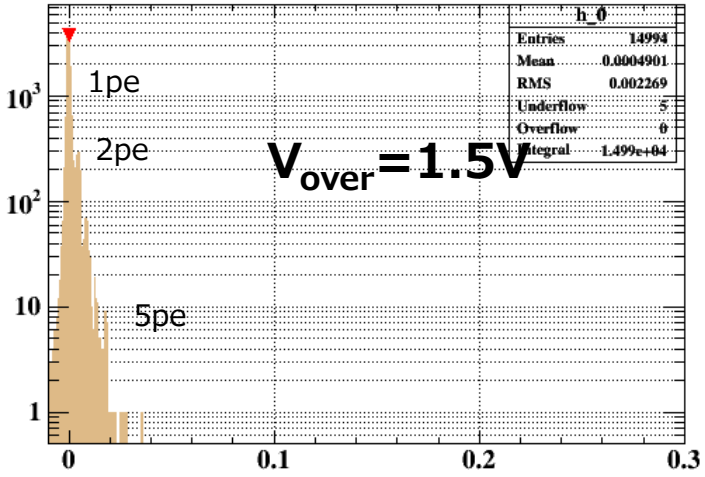
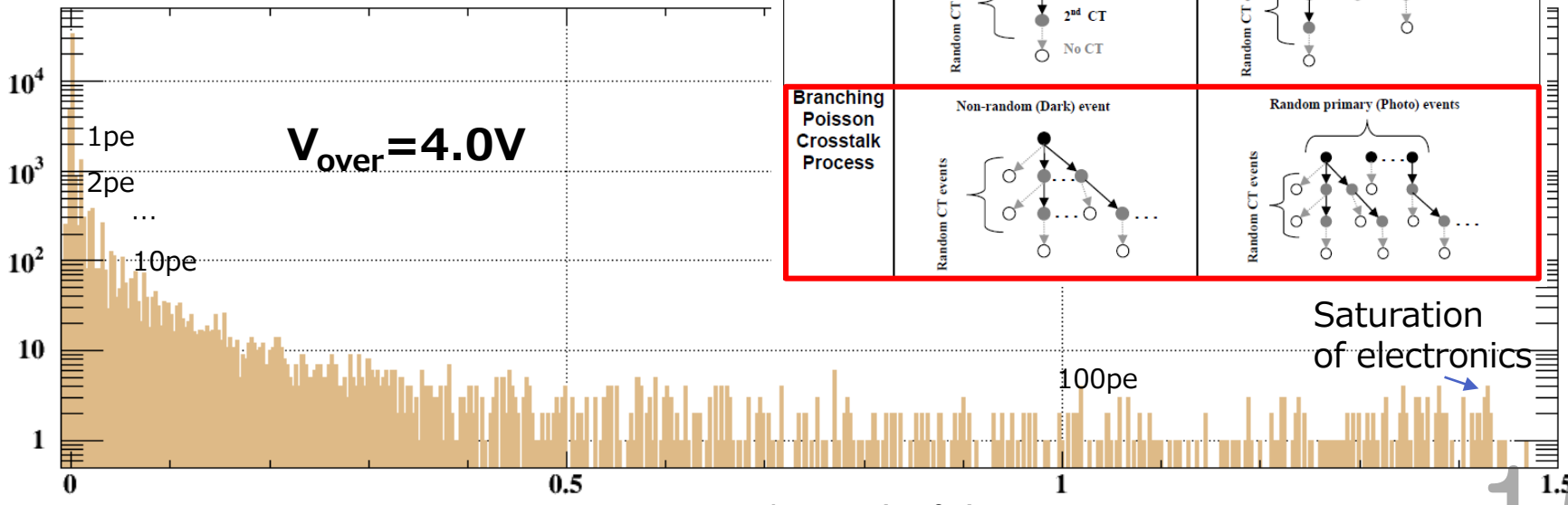
Standard NEW MPPC





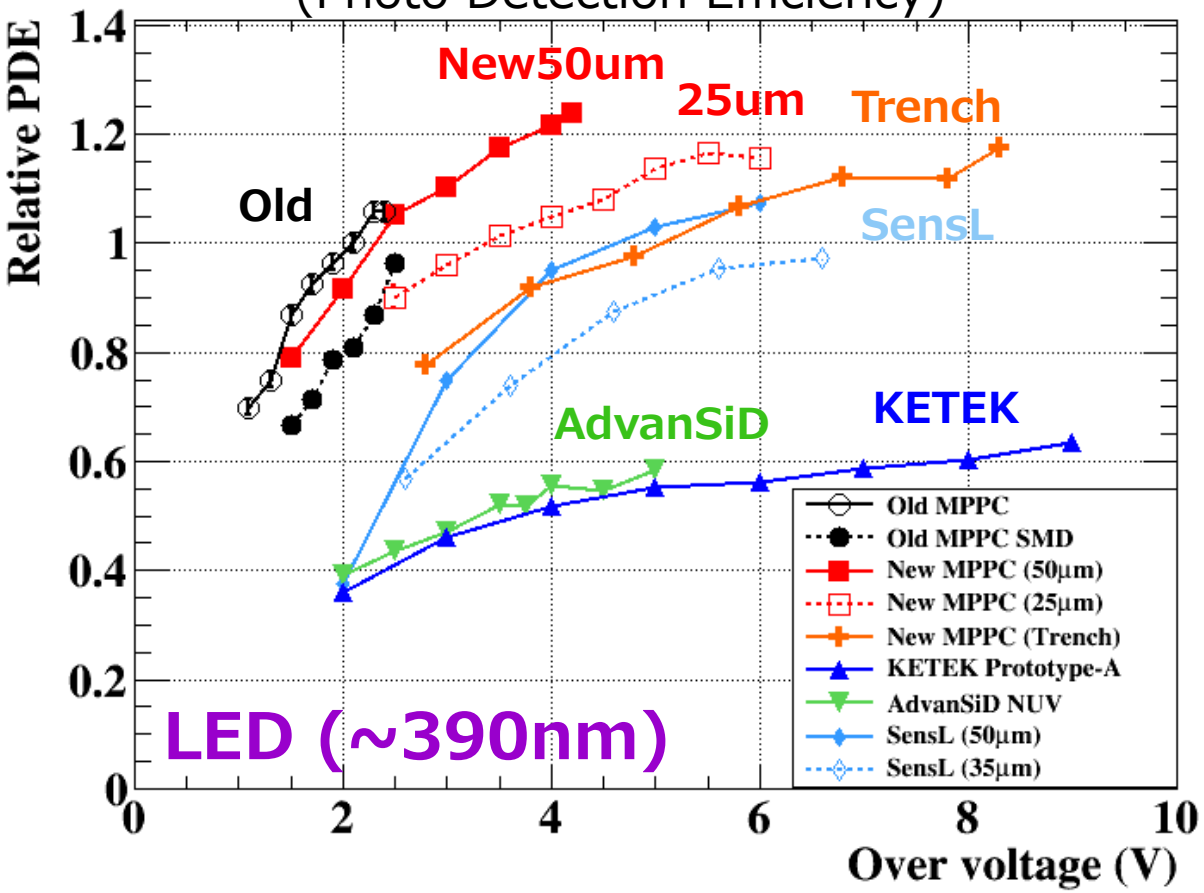
- **Cross talk increases at high bias**
  - Very long tail in charge distribution
  - Cross-talk process runaway
  - Big impact on energy measurement (excess noise factor)
  - Impact on time measurement?

arXiv:1109.2014

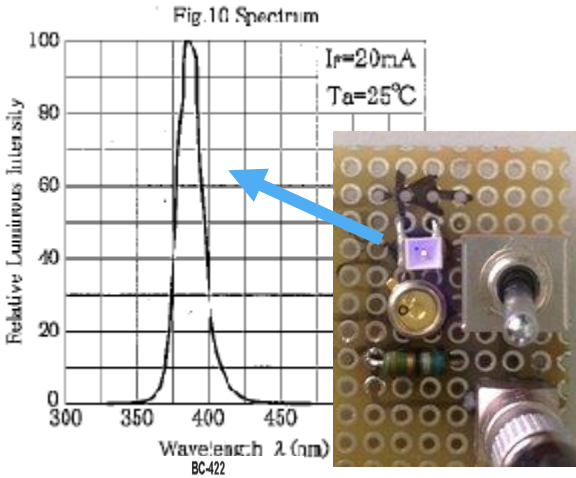
Crosstalk Models	Single primary event *N≡1* e.g. SSPM Dark Spectrum	Poisson number of primaries *<N>=μ* e.g. SSPM Photon Spectrum
Geometric Chain Crosstalk Process	Non-random (Dark) event; Random CT events; Primary; 1st CT; 2nd CT; No CT	Random primary (Photo) events; Random CT events
Branching Poisson Crosstalk Process	Non-random (Dark) event; Random CT events	Random primary (Photo) events; Random CT events

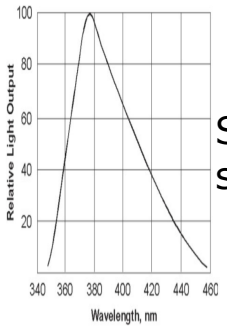
PDE with UV-LED

(Photo Detection Efficiency)



- Measure relative PDE using UV-LED (~ scinti. Light)
- Calculate PDE from 0 p.e. probability





Scintillator spectrum

- ✓ Extended PDE at higher V_{over} for new MPPCs
- ✓ Recovered fill factor for smaller pixel (25um)
- ✓ Trench-type MPPC also shows good PDE due to relatively high fill factor (55%, ~10% lower than standard type)

PDE with UV-LED

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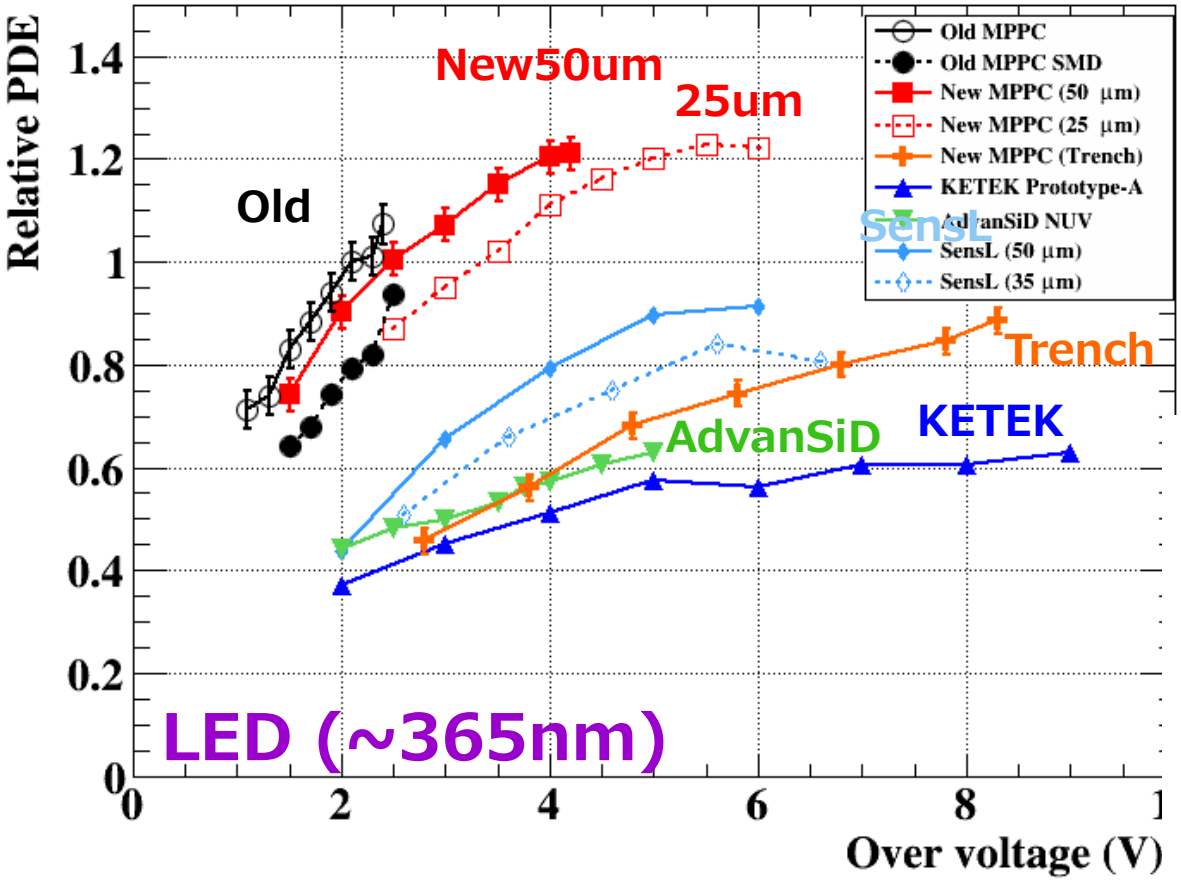

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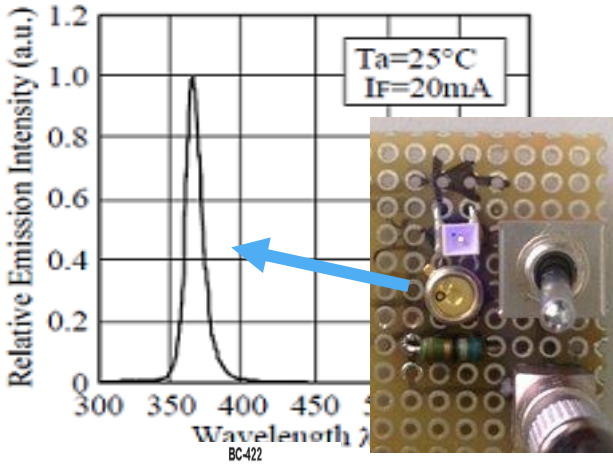

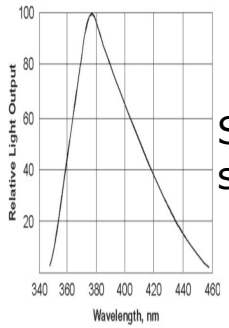

Scintillator spectrum

- ✓ Extended PDE at higher V_{over} for new MPPCs
- ✓ Recovered fill factor for smaller pixel (25um)
- ✓ Trench-type MPPC also shows lower PDE for short wavelength (?)

PDE with UV-LED

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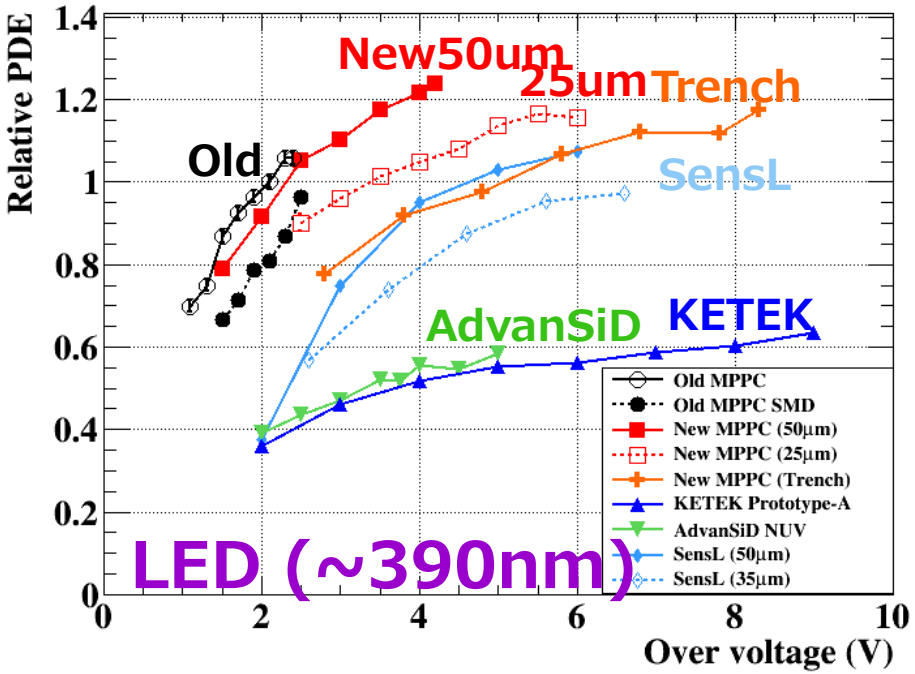

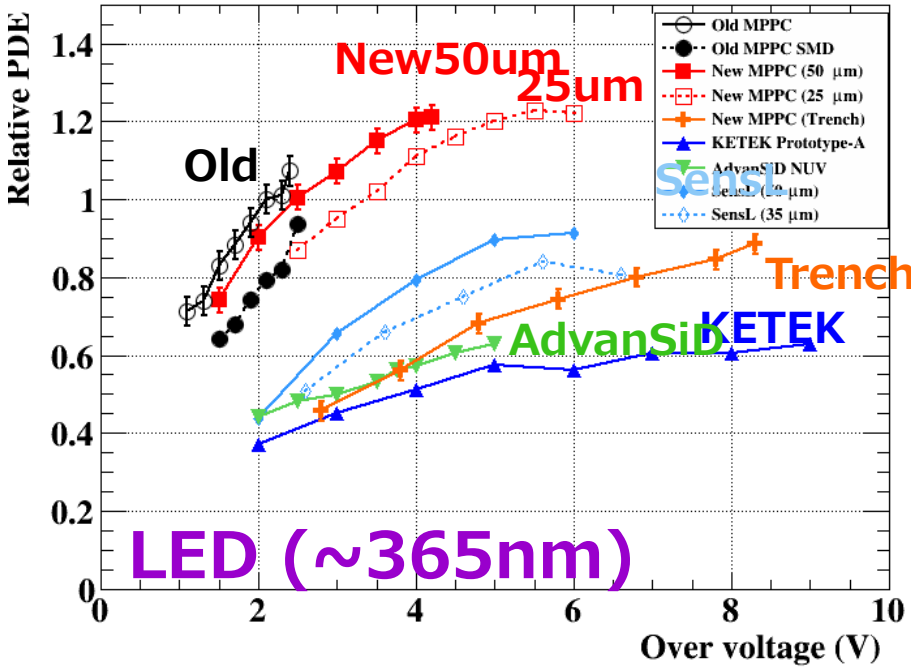

*Relative scales for the two plots are not same

HPK MPPCs show higher PDE for near-UV

- ✓ Extended PDE at higher V_{over} for new MPPCs
- ✓ Recovered fill factor for smaller pixel (25um)
- ✓ Trench-type MPPC also shows good PDE due to relatively high fill factor (55%, ~10% lower than standard type).
  But PDE is suppressed at shorter wave length (?)

SCINTILLATOR SIGNAL READOUT BY 3 MPPC SERIES CONNECTION

3 series connection

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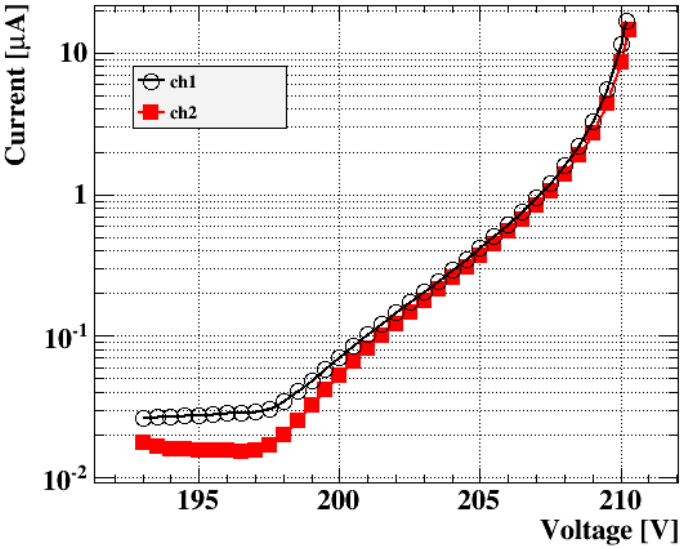
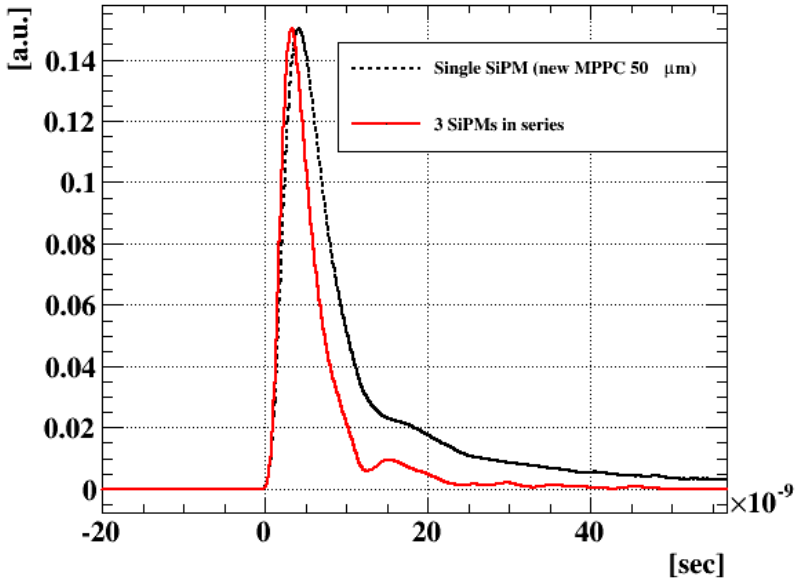
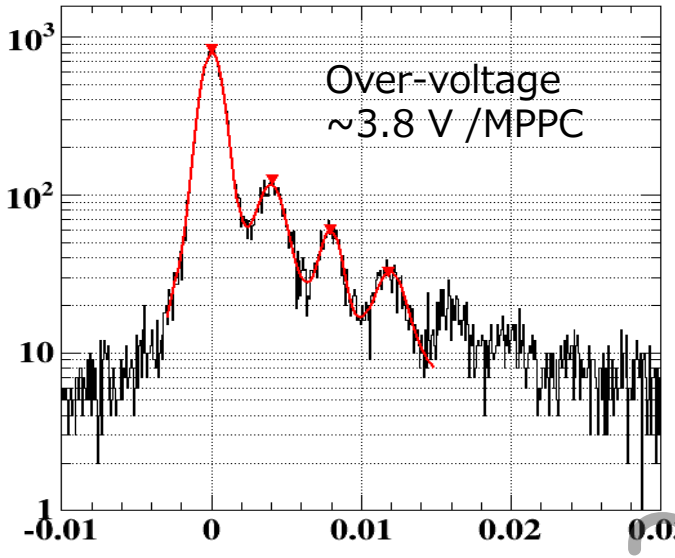
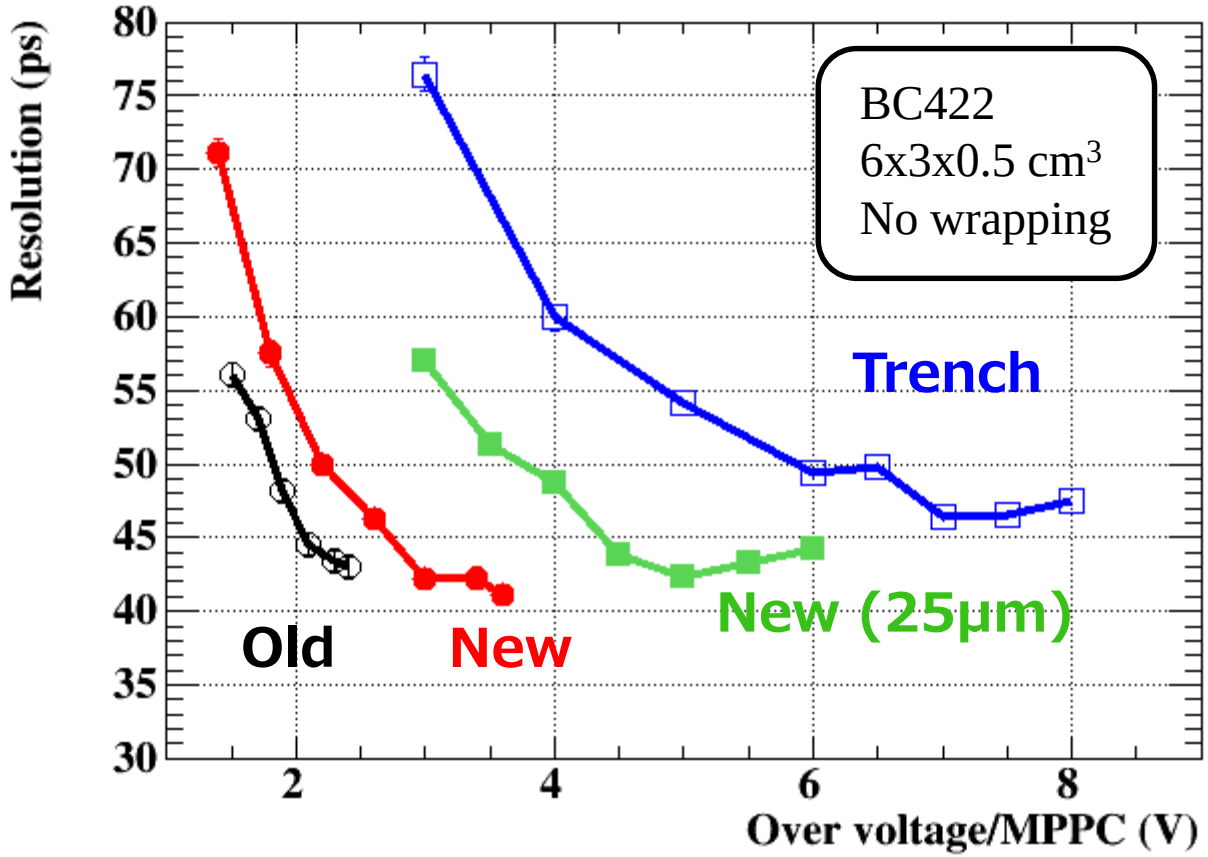
- **直列につないだ3つのセンサーを1チャンネルで読み出す**
  - 実効的に大面積化。検出光量の増加で分解能をあげる。
  - 両端に3倍のバイアス電圧を供給。
- **共通電流で個々のセンサーにかかる電圧が調整される**
  - Over-voltageが自動的に大体そろう
- **直列接続でキャパシタンス減少**
  - シャープな波形
  - ゲイン減少 (~40%)





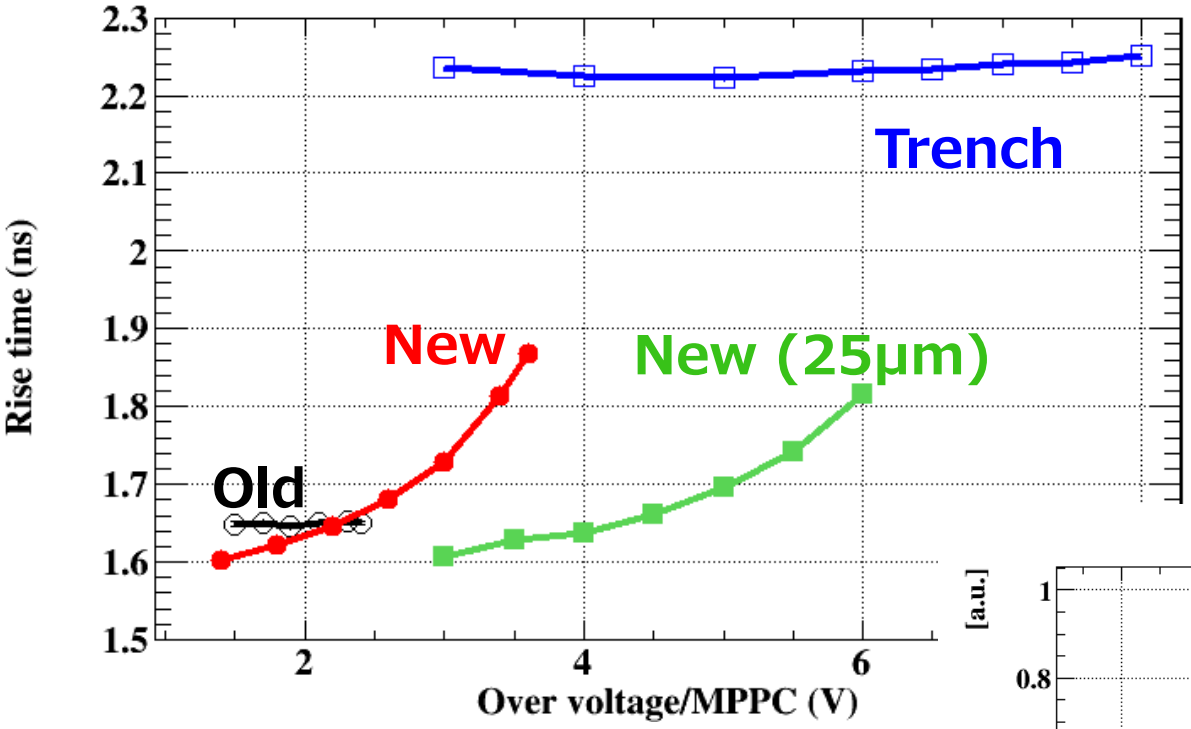


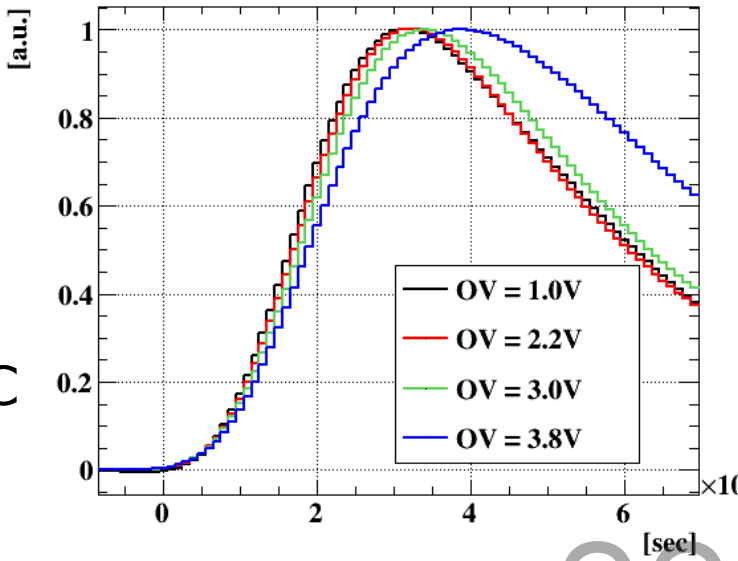
Time resolution



- Almost same resolution attained at each optimal bias. (No major improvement)
- Trench-type shows slightly poorer resolution

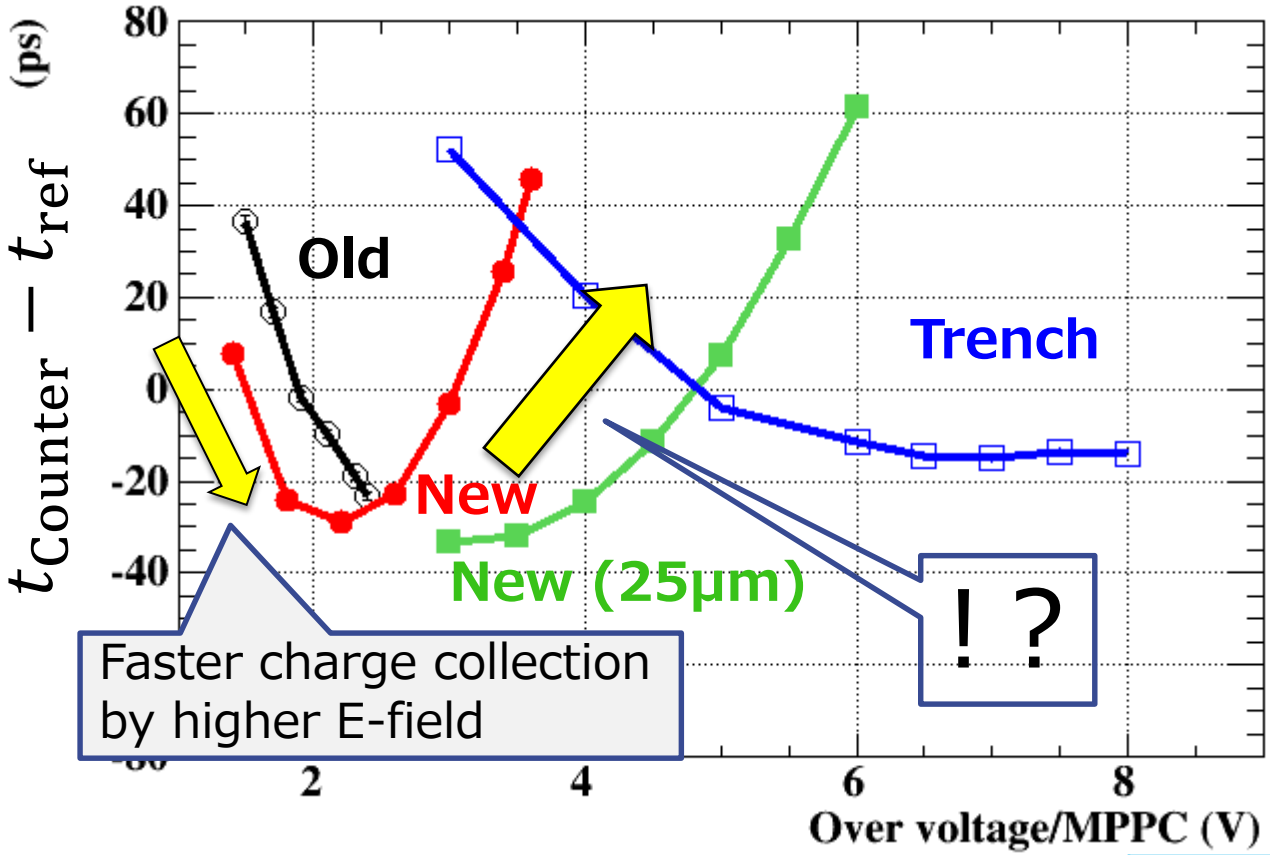
Rise time





- Observe **softening** of waveform as V_{over} for standard new MPPC
- **Slower** pulse shape for Trench MPPC
  - ✓ This sample is not the final version.
  - ✓ HPK is trying to improve this

Pulse timing

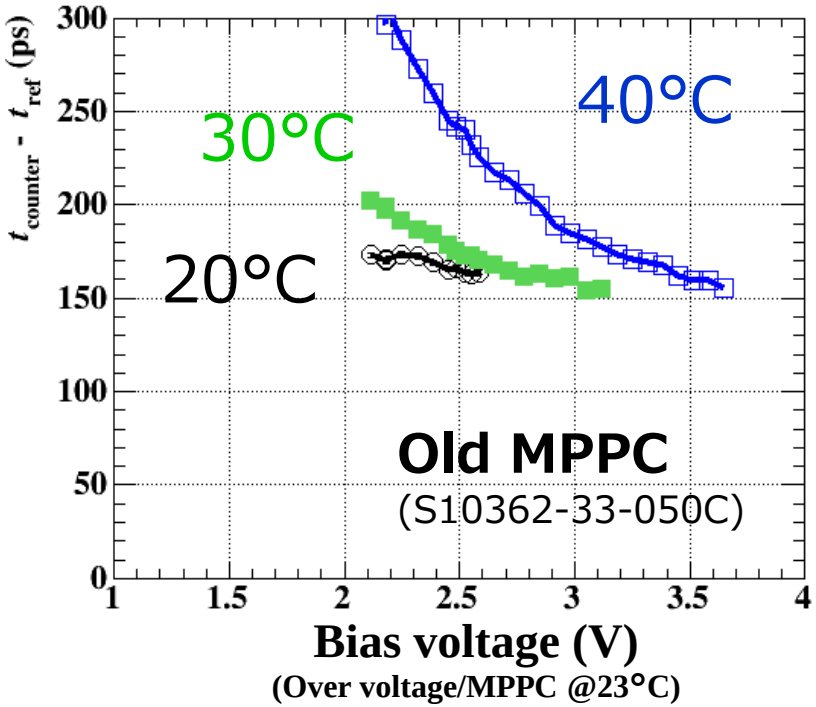


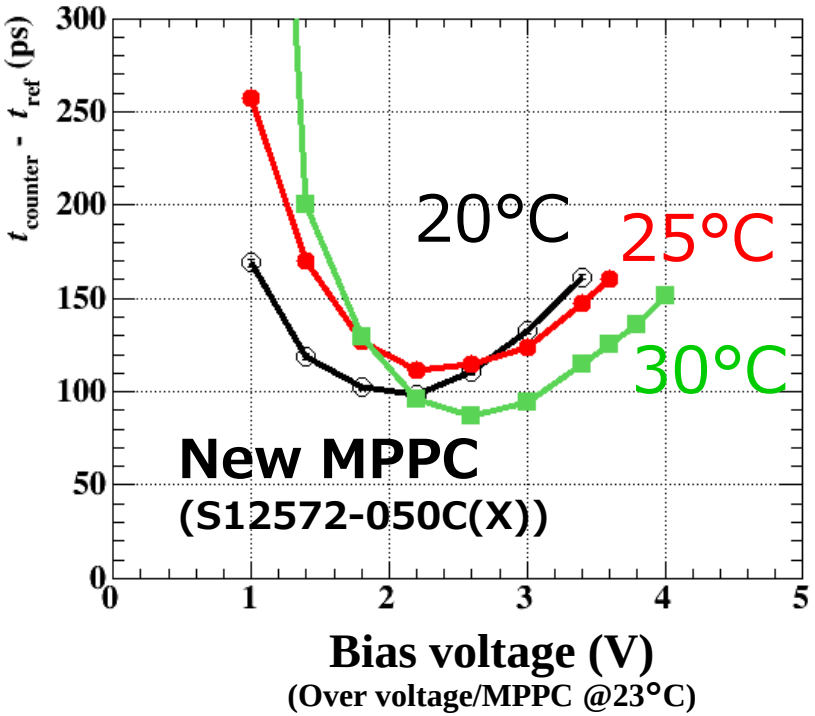
Pulse time by Constant-Fraction method

- As a consequence of softened pulse shape, **time measurement drifts** for applied bias
- → Larger **temperature dependence** of time measurement

Old	2.5 ps/℃
New	5.5 ps/℃
New 25um	2.8 ps/℃
Trench	**0.1 ps/℃**

Temp vs Timing





- **バイアス一定の場合の時間測定(mean)の温度依存性**
- **高バイアス下での時間のドリフト(波形のなまり)により新型では温度依存性が大きくなってしまった。(5度の変化で~30ps)**

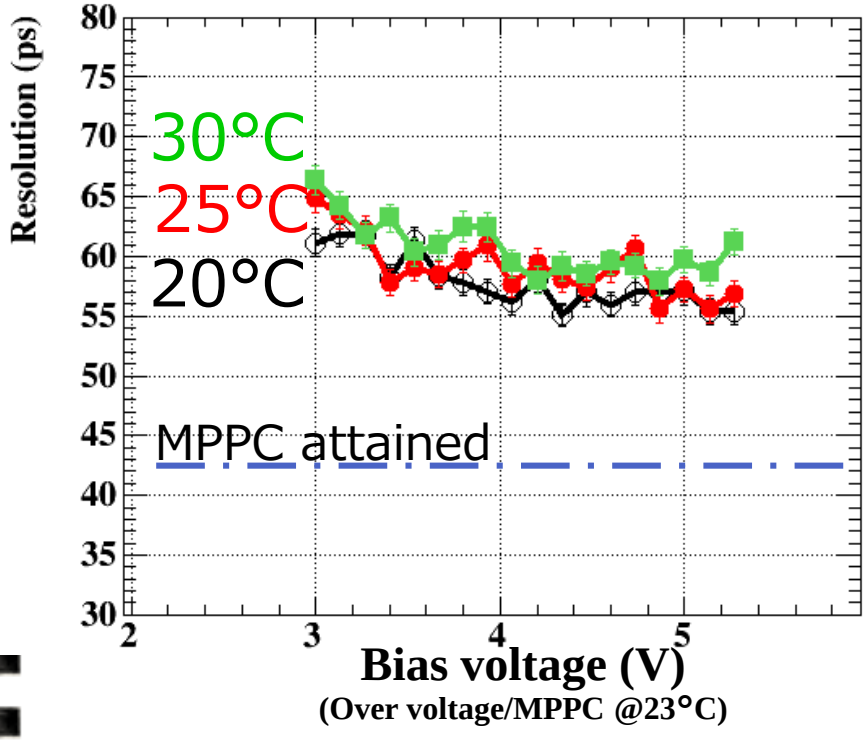
温度変化の寄与(一様分布仮定)

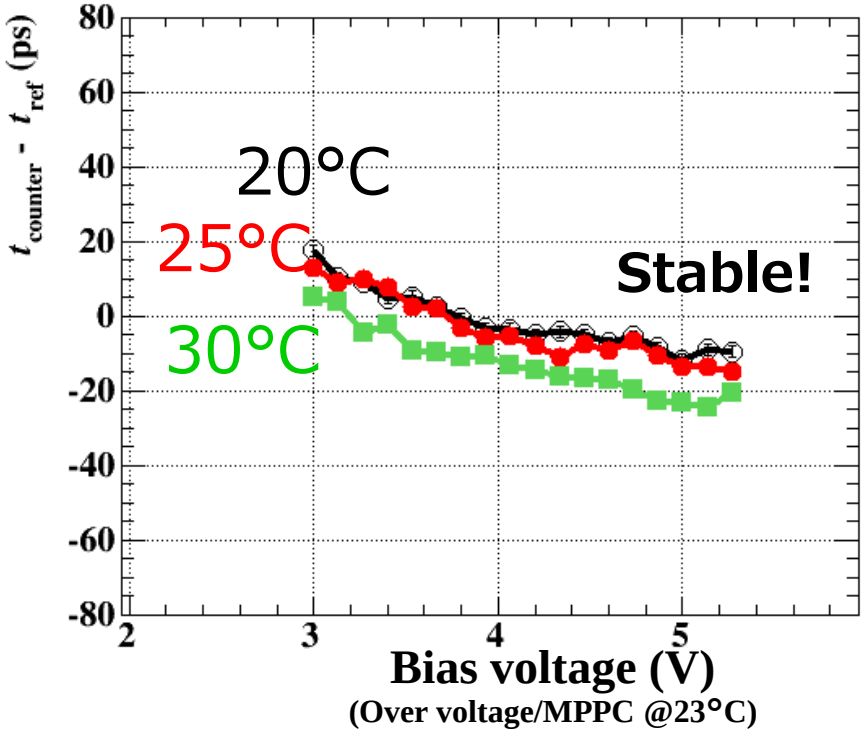
$30 \oplus 30/\sqrt{12} = 31.2$ ps

検出器の分解能(最終目標値)

問題となるレベルではない

AdvanSiD





- 10–15 ps poorer resolution
- Good stability for wide bias range
  - ✓ No more care for temperature

Breakdown coefficient
AdvanSiD: **24** mV/℃
KETEK : **16** mV/℃

MPPC Old: **49** mV/℃
MPPC New:**59** mV/℃

まとめ

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- **New MPPC**
  - after pulseの大幅削減, 動作領域の拡大
    - ✓ パルス後の安定性向上。高計数率下測定で有効。
  - Trench-type, 加えてcross talk抑制
  - Small pixelでもfill factor改善で同等のPDE
- **時間測定の温度依存性**
  - New MPPCで悪化
  - Trench-typeではKETEK, AdvanSiD同様安定
- **シンチレータ時間分解能**
  - p.e. statisticsがドミナント → PDEが重要
    - ✓ 近紫外光で高いPDEを有する浜松MPPCで高分解能
  - New MPPCでは到達分解能に大幅な改善は見られない。

	After pulse, noise	Cross talk	PDE	Bias, Temp. stability	Time resolution
Old MPPC	△	▼	○	△	◎
New MPPC (Standard)	◎	▼	◎	▼	◎
New MPPC (25um)	◎	▼	◎	△	◎
New Trench MPPC	◎	◎	○	◎	○
AdvanSiD NUV	▼	○	▼	◎	△
KETEK	▼	◎	▼	◎	▼

◎ ○ △ ▼
Good ←

時間分解能追求ならStandard MPPC (50 or 25 μm pixel)
総合性能ならTrench MPPC

Scintillator

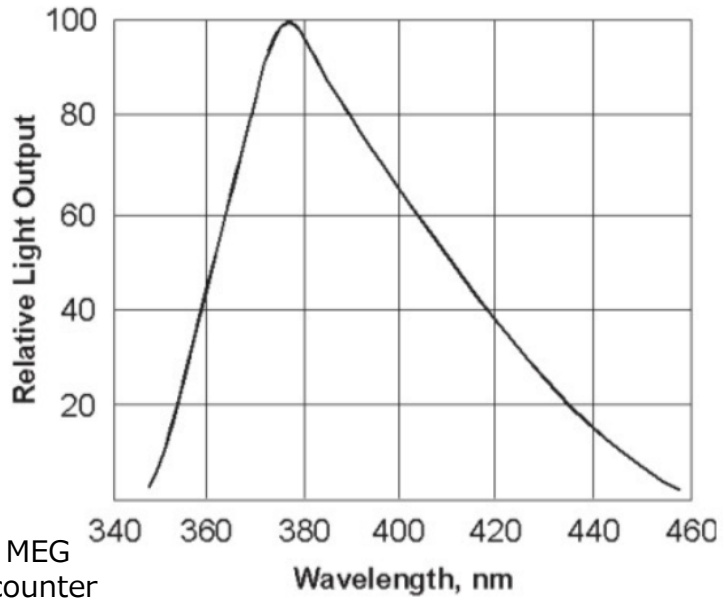
Fast scintillators from Saint-Gobain

properties	BC418	BC420	BC422	BC404
Light Output [% Anthracene]	67	64	55	68
Rise Time [ns]	0.5	0.5	**0.35**	0.7
Decay Time [ns]	1.4	1.5	1.6	1.8
Wavelength [nm]	391	391	370	408
Attenuation Length [cm]	**100**	110	8	140

Used in the beam test

Used in this study (Best)

Present MEG timing counter



- **Faster scintillator gives higher time resolution**
  - P.e. at the earliest part are only effective
  - Scintillation with fast response given in near-UV light

1 pe signal

MEG
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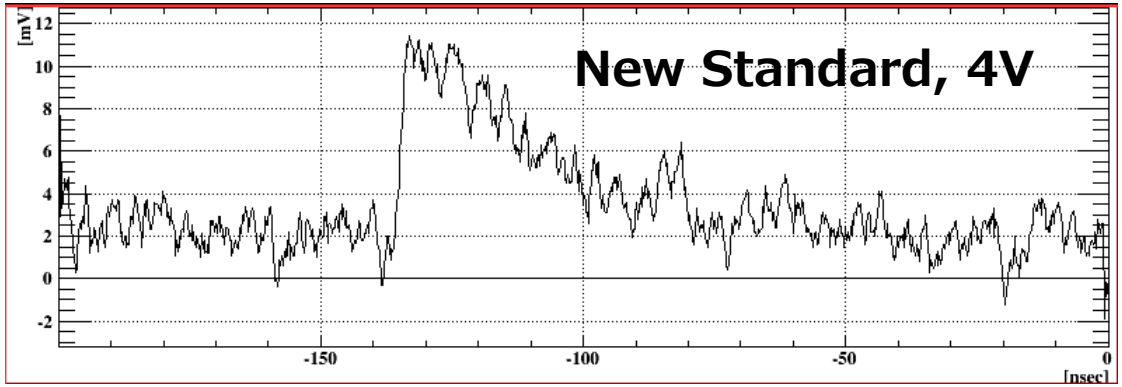
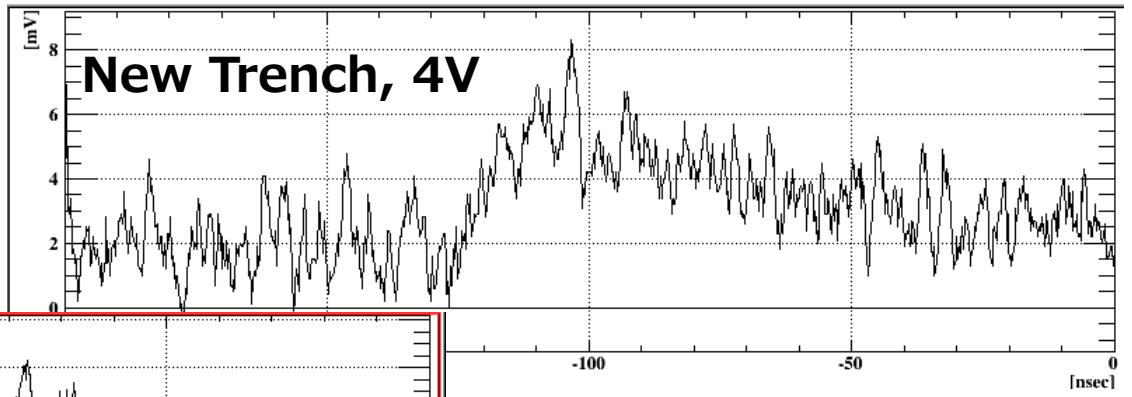
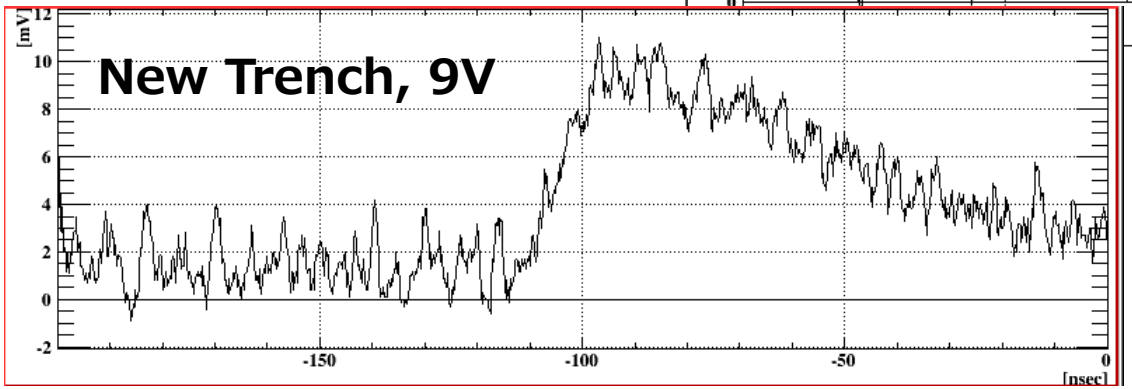
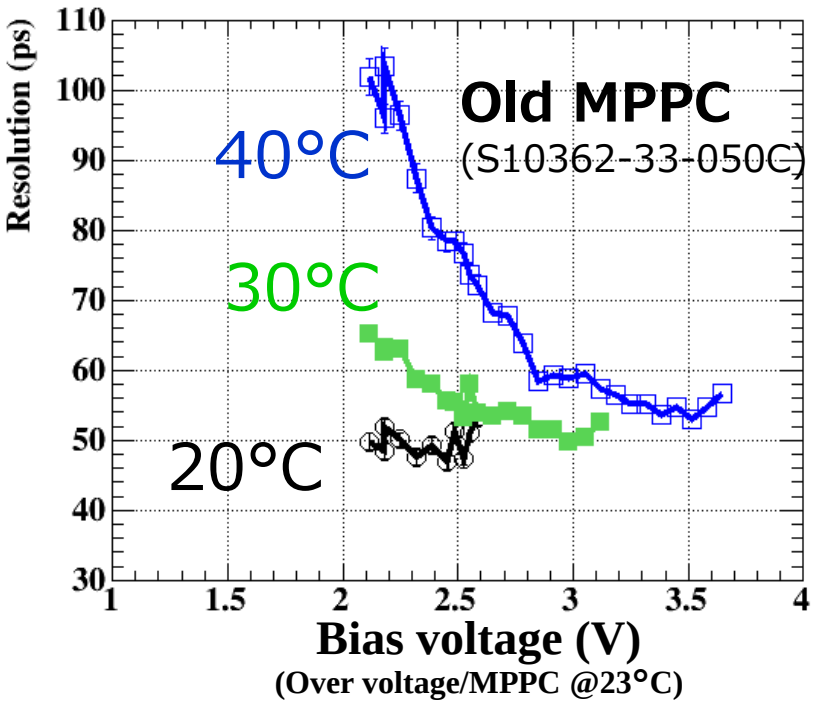


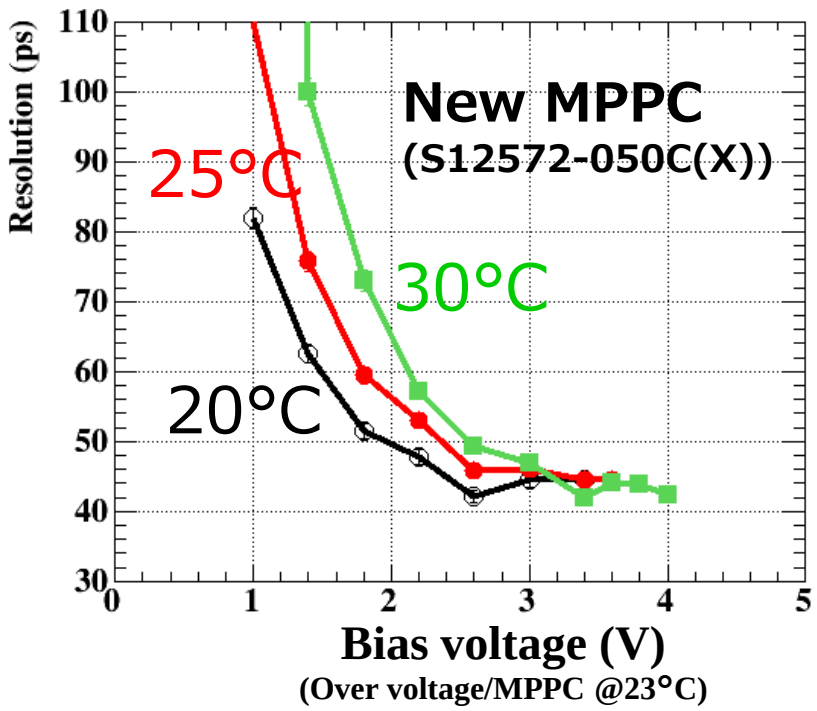




Trench型で大幅な波形のなまりを観測。

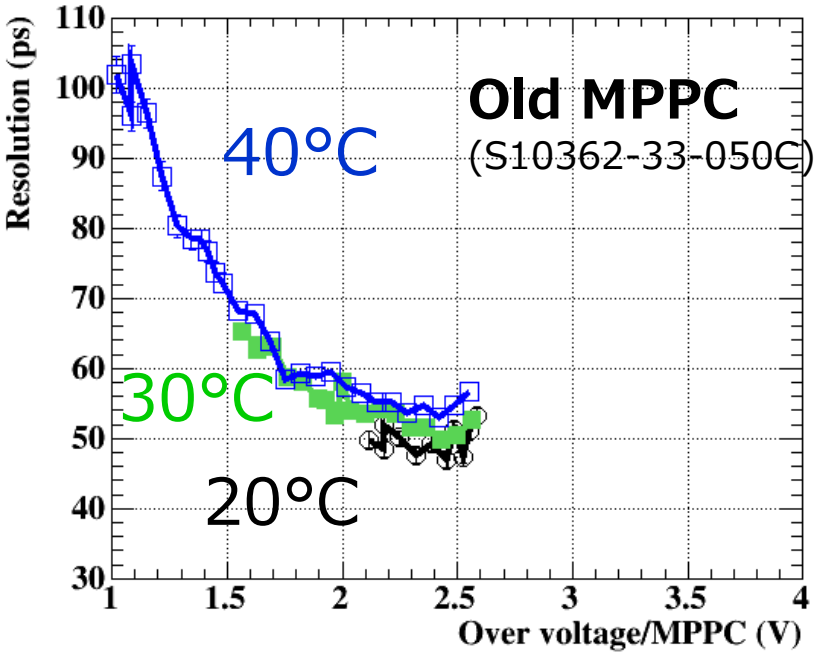
Temp. vs Resolution

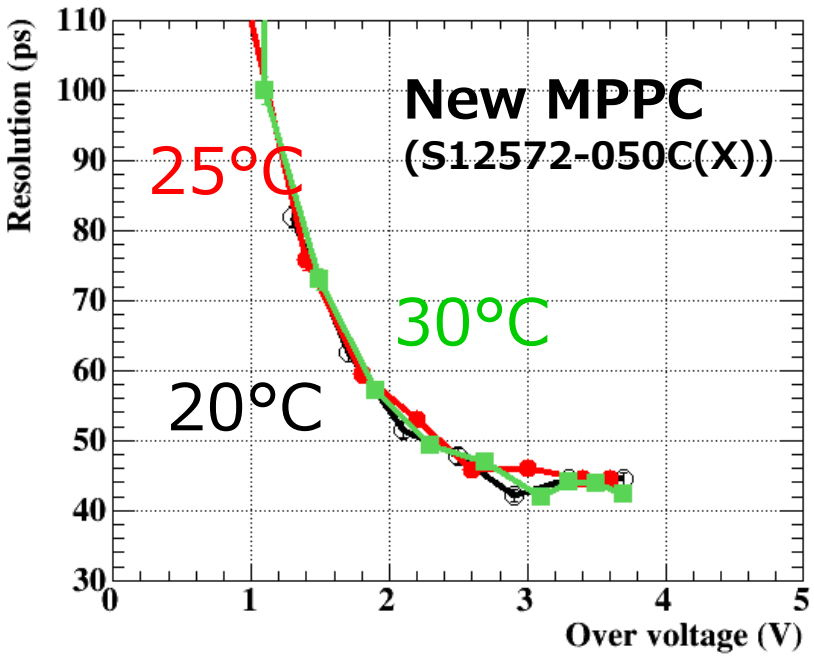




- **バイアス一定の場合の分解能の温度依存性**
  - ✓ レファレンスカウンタは各温度でOver-voltageをそろえてある
- **新型では高バイアスをかけることで、到達分解能は安定に得られる。**

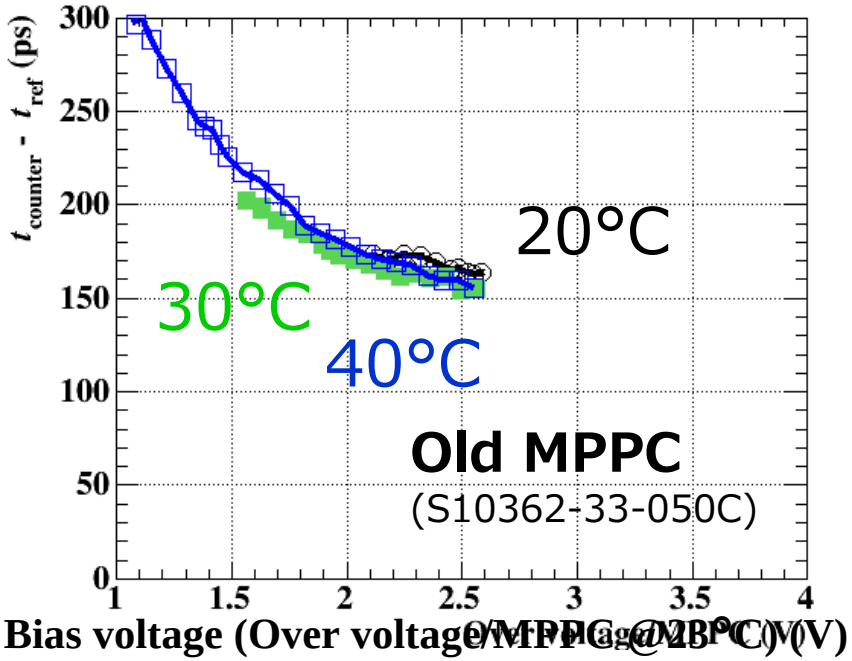
Temp. vs Resolution

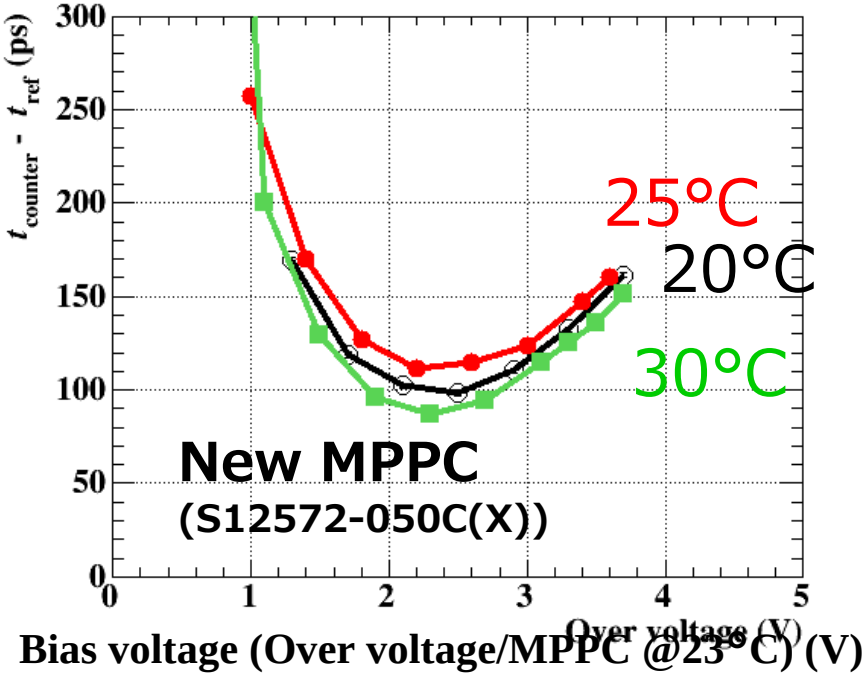




- **Over voltage一定での分解能温度依存性。**
  - ✓ 新型(旧型)60mV/°C(55mV/°C)の温度係数を仮定して補正。

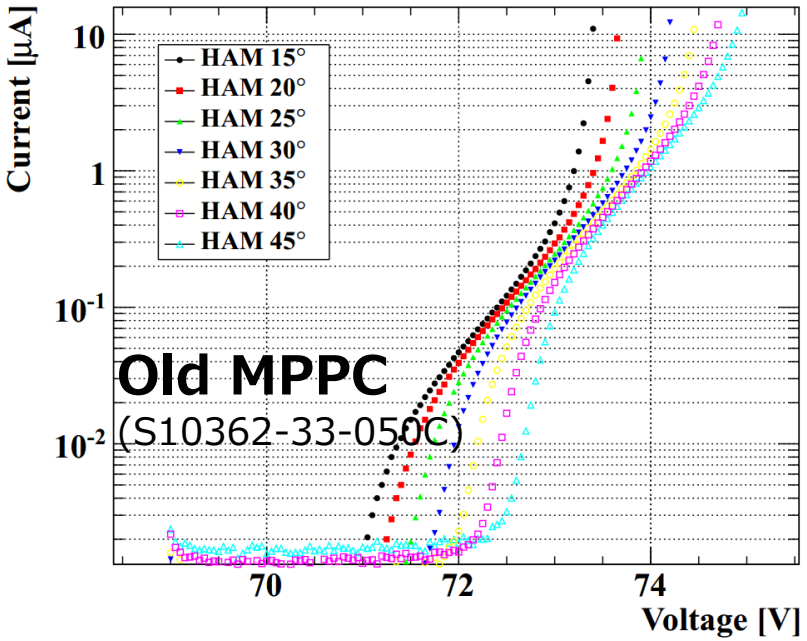
温度依存性・時間測定

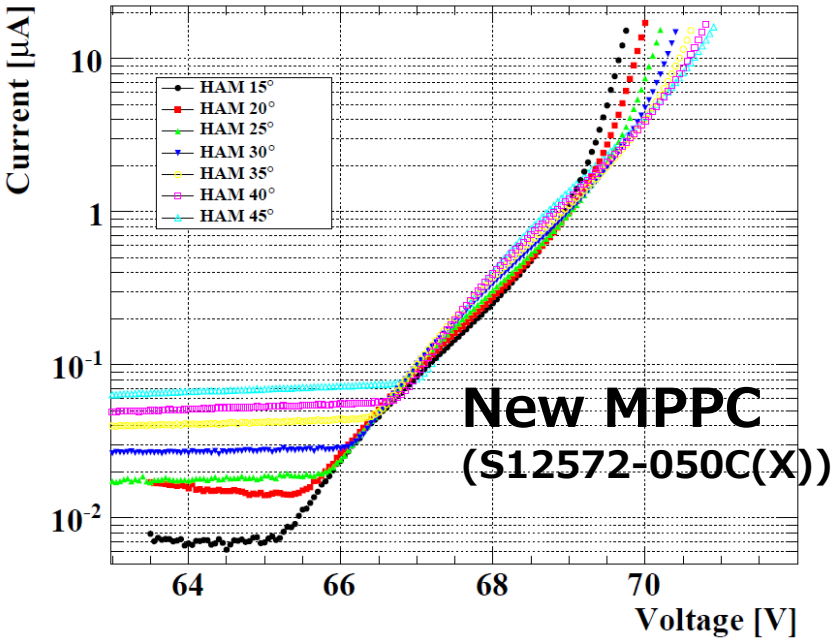




- **Over voltage一定での時間測定温度依存性。**
  - ✓ 新型(旧型)60mV/°C(55mV/°C)の温度係数を仮定して補正。
- **もし温度変化をバイアスコントロールでアクティブに補正できれば影響を最小限にできる。**

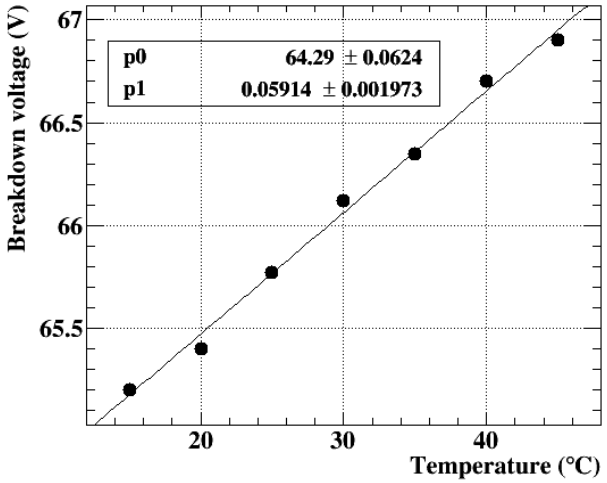
温度依存性



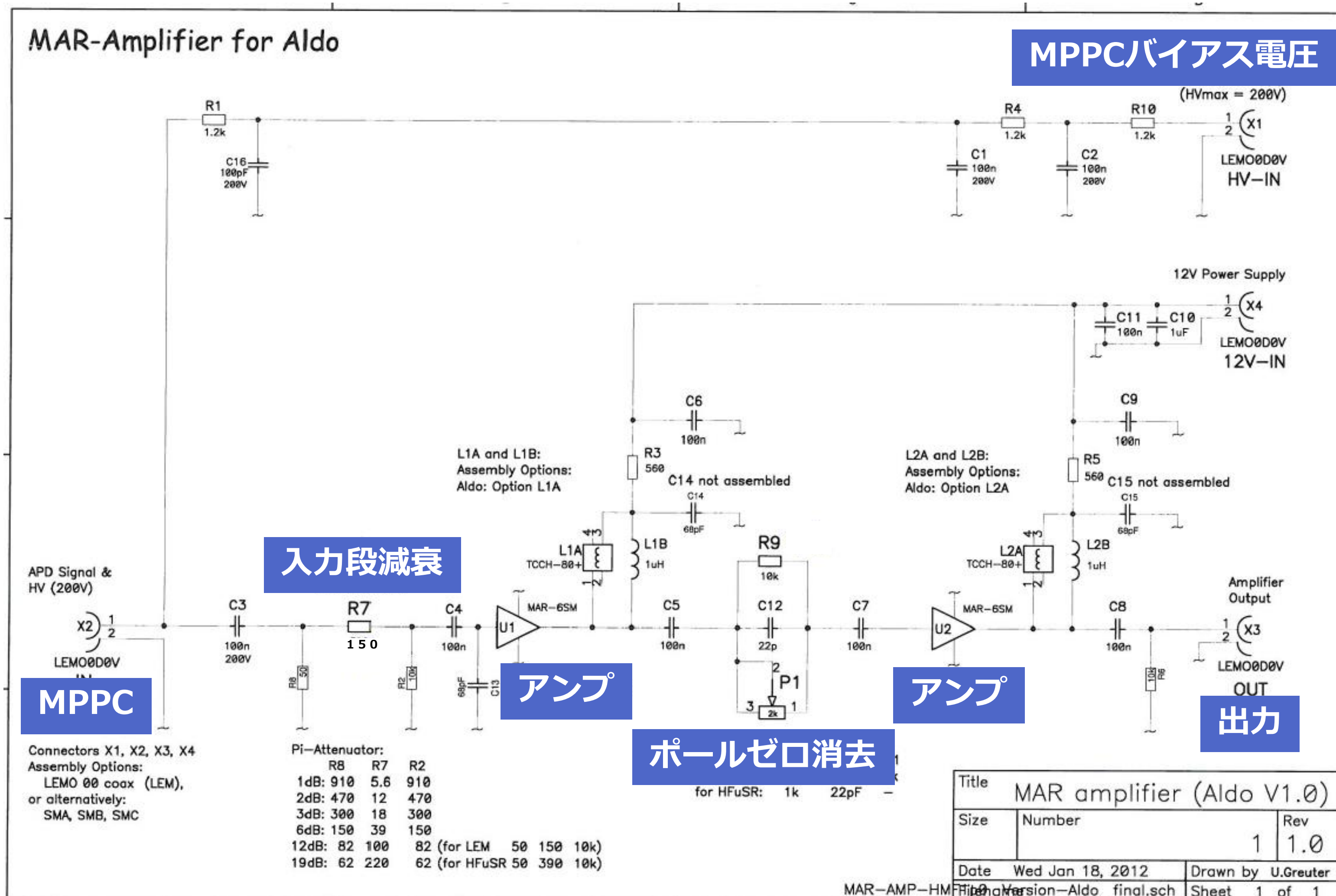


- **降伏電圧の温度依存性**
  - Old:49 mV/℃
  - New:59 mV/℃

参考:
AdvanSiDセンサー:24 mV/℃
KETEKセンサー：16 mV/℃
(どちらもp-on-n, blue sensitive type)

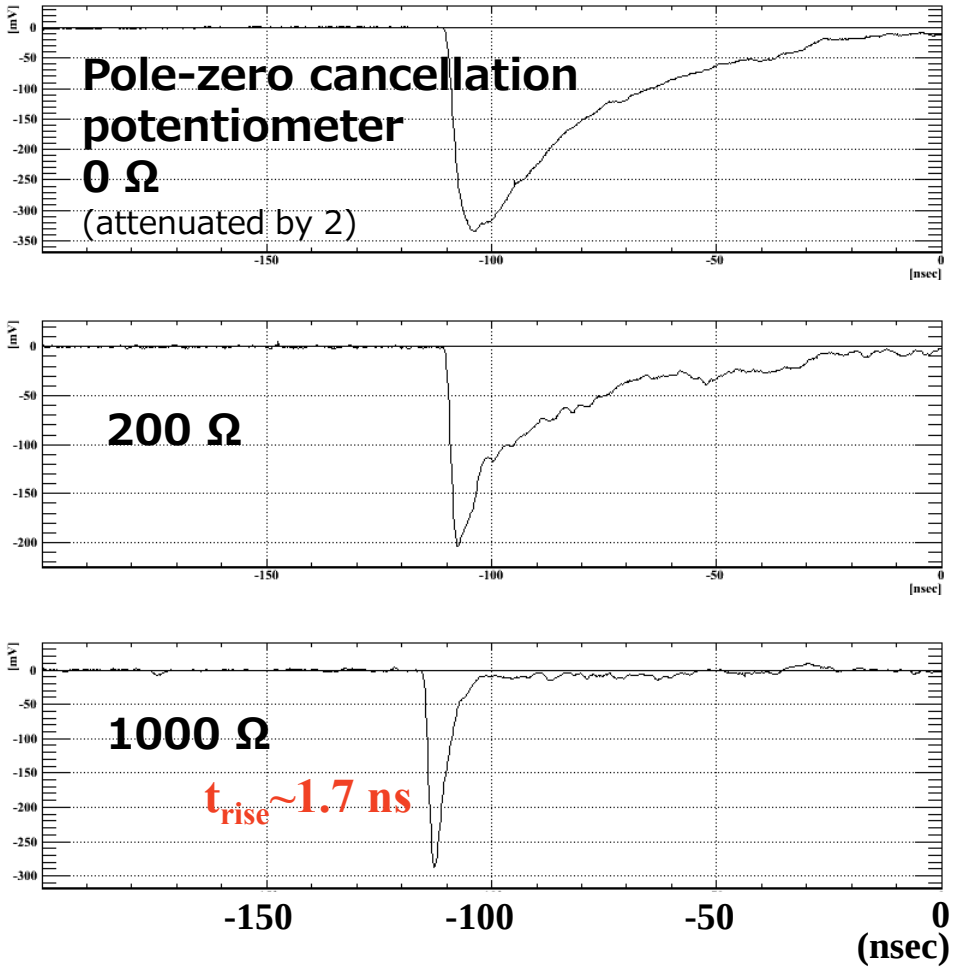


整形・増幅器



MAR-Amplifier for Aldo
MPPCバイアス電圧
(HVmax = 200V)
R1
1.2k
C16
100pF
200V
R4
1.2k
R10
1.2k
C1
100n
200V
C2
100n
200V
X1
LEMO0D0V
HV−IN
12V Power Supply
X4
C11
100n
C10
1uF
LEMO0D0V
12V−IN
C6
100n
C9
100n
R3
560
R5
560
L1A and L1B:
Assembly Options:
Aldo: Option L1A
C14 not assembled
C14
68pF
L2A and L2B:
Assembly Options:
Aldo: Option L2A
C15 not assembled
C15
68pF
L1A
TCCH−80+
L1B
1uH
R9
10k
L2A
TCCH−80+
L2B
1uH
入力段減衰
APD Signal &
HV (200V)
X2
LEMO0D0V
C3
100n
200V
R7
150
C4
100n
MAR−6SM
U1
C5
100n
C12
22p
C7
100n
MAR−6SM
U2
C8
100n
Amplifier
Output
X3
LEMO0D0V
OUT
P1
2k
MPPC
アンプ
アンプ
出力
ポールゼロ消去
Connectors X1, X2, X3, X4
Assembly Options:
LEMO 00 coax (LEM),
or alternatively:
SMA, SMB, SMC
Pi−Attenuator:
R8 R7 R2
1dB: 910 5.6 910
2dB: 470 12 470
3dB: 300 18 300
6dB: 150 39 150
12dB: 82 100 82 (for LEM 50 150 10k)
19dB: 62 220 62 (for HFuSR 50 390 10k)
for HFuSR: 1k 22pF
Title
MAR amplifier (Aldo V1.0)
Size
Number
1
Rev
1.0
Date Wed Jan 18, 2012
Drawn by U.Greuter
Sheet 1 of 1
MAR−AMP−HMF_final−Version−Aldo_final.sch

Shaping



Signal from scintillator
(3 MPPC in series connection)

- **For precise time measurement**
  - Restore baseline by pole-zero cancellation, and
  - Extract fast rise-part

Excess noise factor

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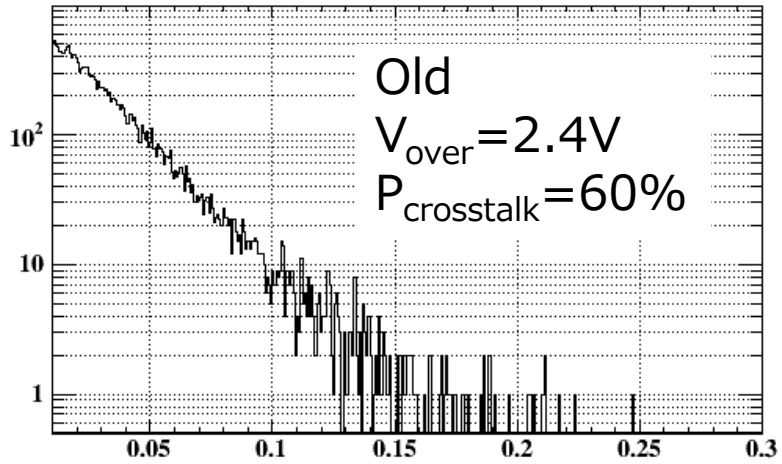
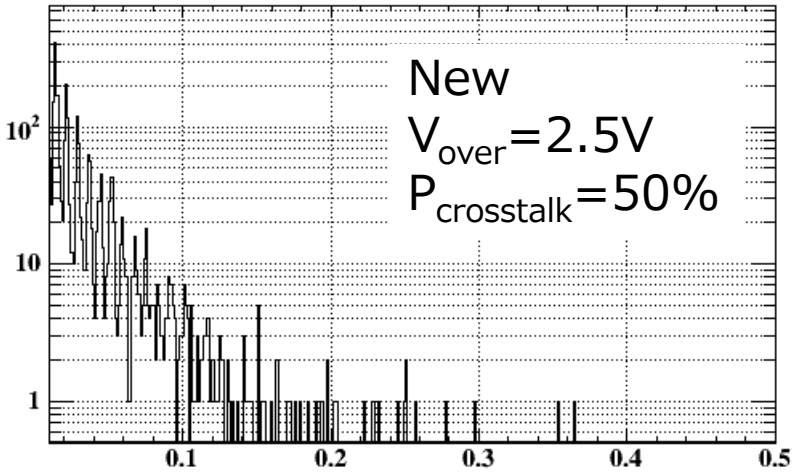
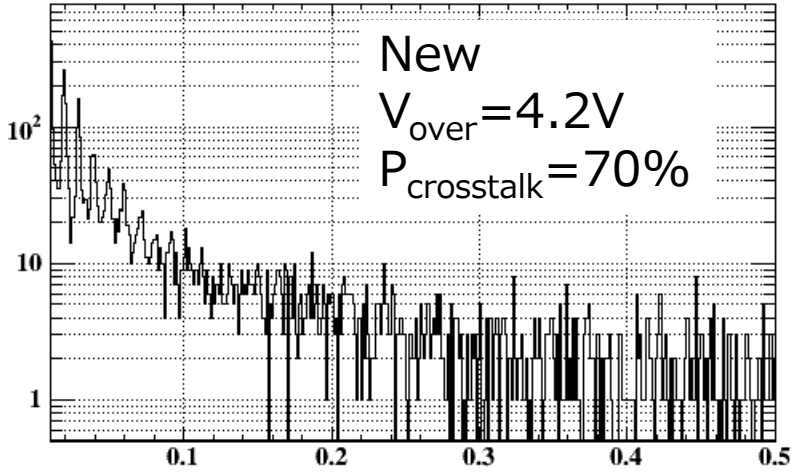
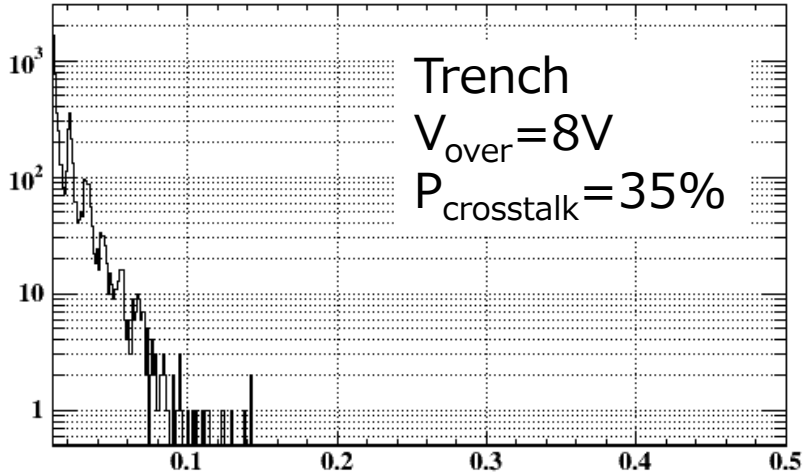


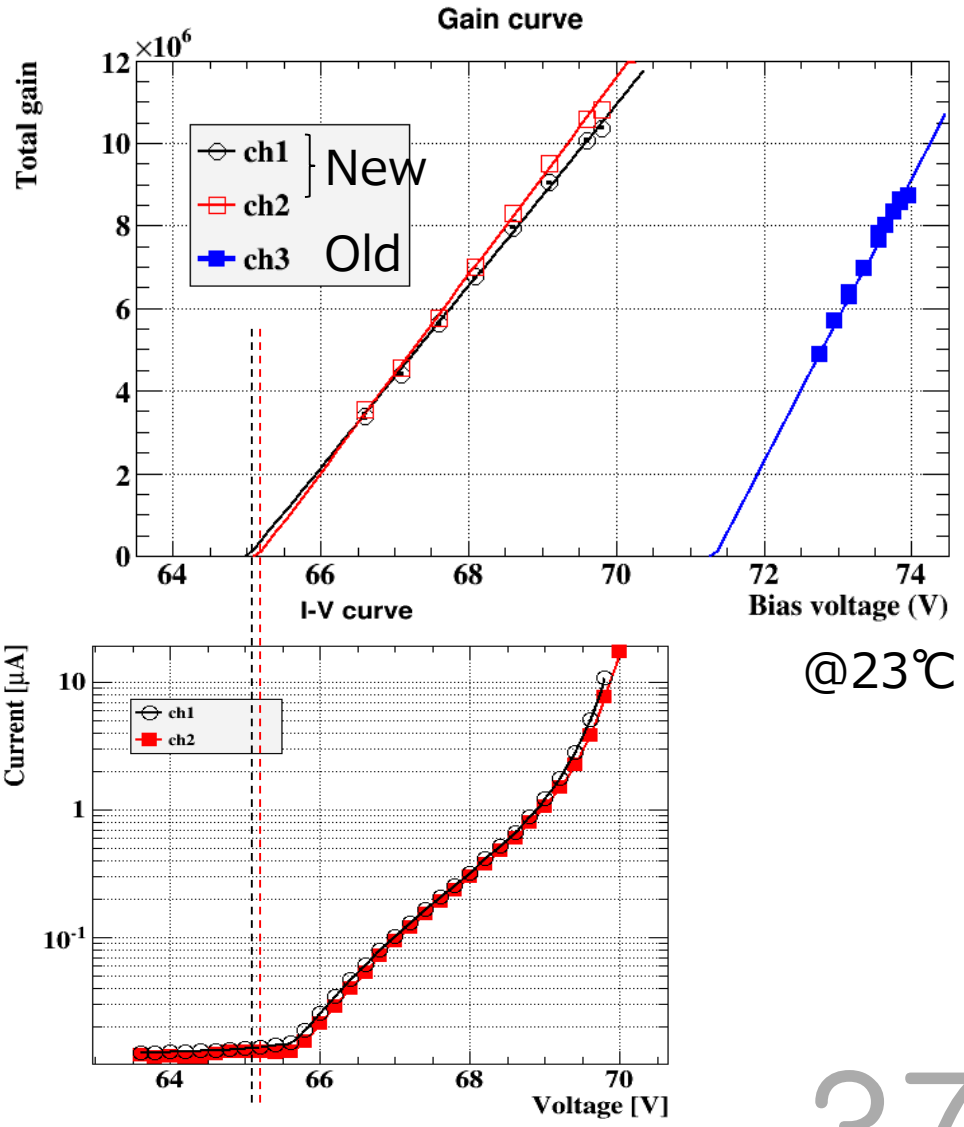






Gain

- 数光子ピークからゲインの見積もり
  - バイアス依存性
    - 線形性はかねがねよい。
    - 高バイアスでずれ？
  - 同じover-voltageではゲインは従来型より低い。



@23℃

Total gain includes amp, splitter, offline shaping.