Multi Pixel Photon Counter

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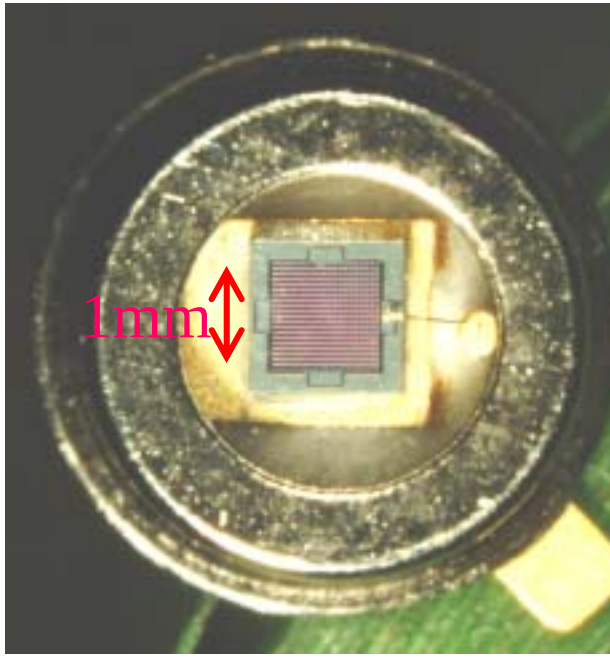
KEK

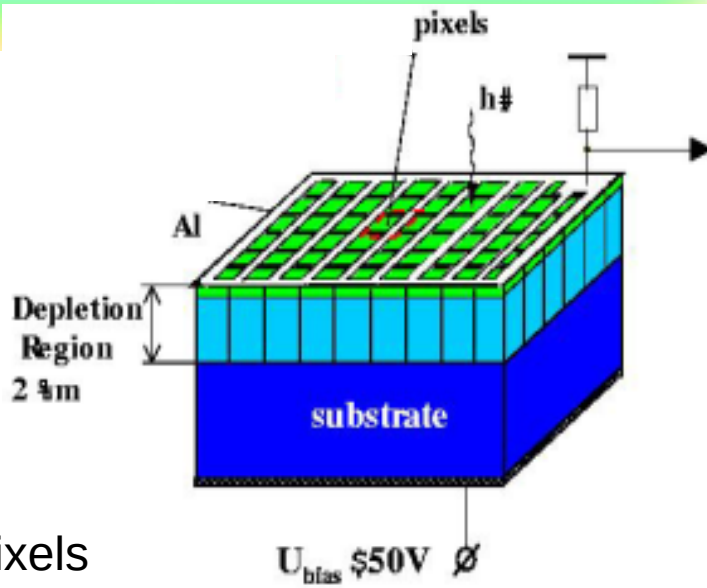
Introduction

- MPPC is new semiconductor photon sensor
  - Technology is very similar to SiPM.
  - Under development by Hamamatsu Photonics (HPK)
    - MPPC have not been listed in their products yet.
    - HPK delivered many kinds of test samples to T2K and ILC-CAL.
- R&D groups in JP-HEP.
  - ILC Calorimeter (Kobe U, Niigata U, Sinsyu U, Tsukuba U)
  - T2K Near detector (Kyoto U)
  - KEK Detector Technology Development group

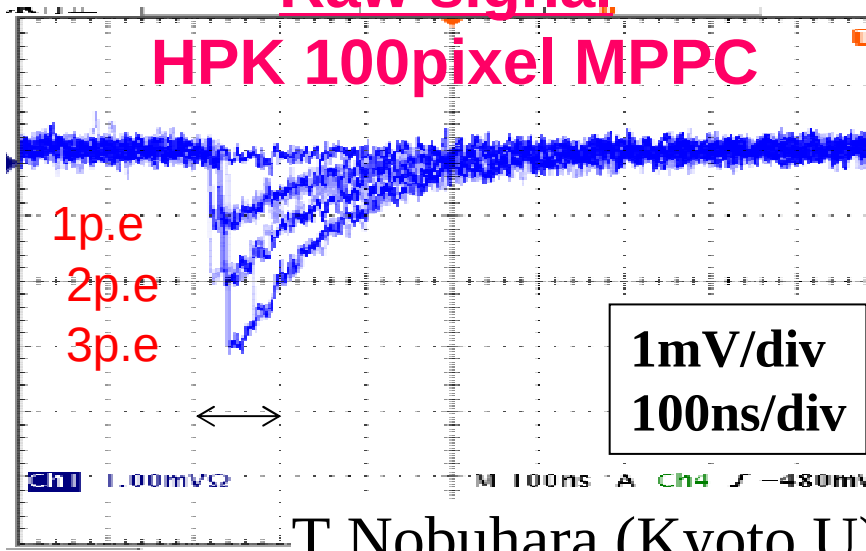


Principal of MPPC

- Micro APD pixel array
  - # of pixels … 100, 400, 1600
  - Each pixel is operated in Geiger-mode.
    - Bias voltage = 40 ~ 70V
      … Only one operation parameter
  - Outputs from all pixels are directory connected (“Wired-OR”)
    - # of read out = 1 channel / device
    - Pulse height of output signal ←→ # of hit pixels
  - # of hit pixels ←→ # of photons
- Gain = ~10^6
  - No amplifier is needed
- Compact size
  - Suitable for optical fiber readout.
- Works in the Magnetic field.
- High QE is expected.
- Expected cost is ~ $10 / device.



Raw signal



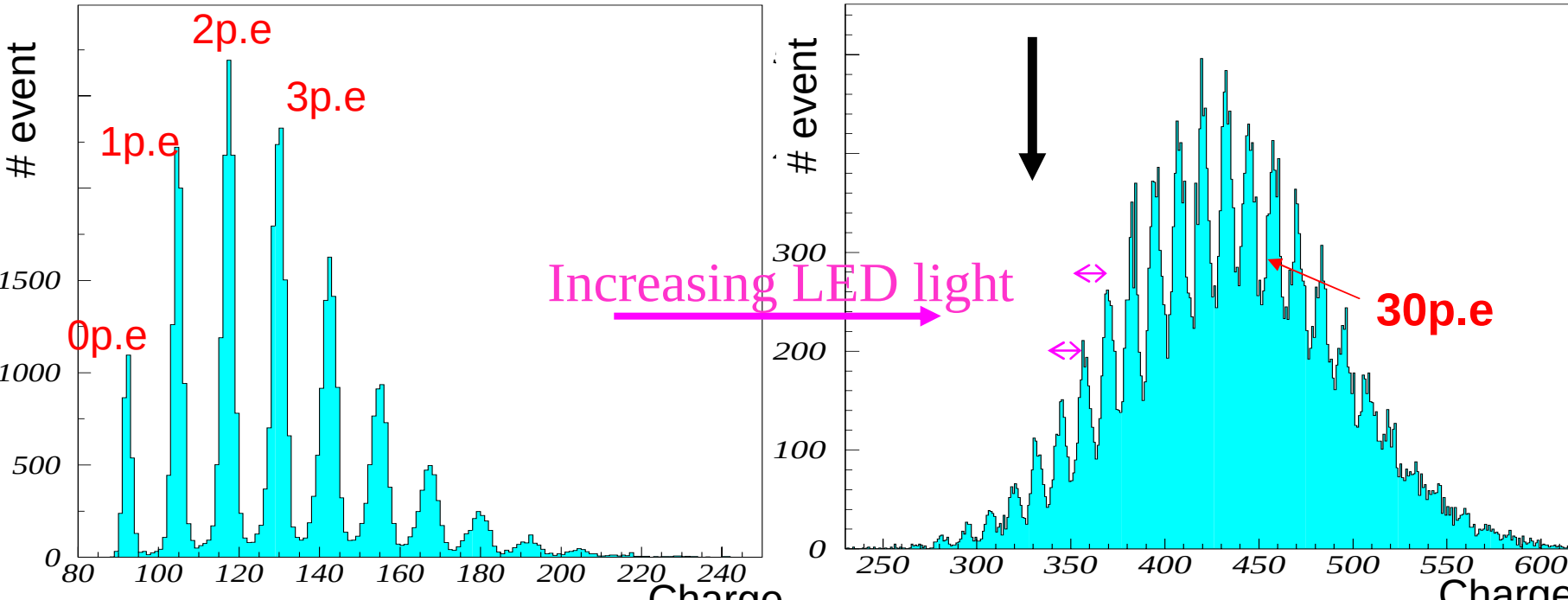
R&D Items

- Measurement of basic performance w/ LED
  - Gain, Noise rate, Cross talk, Photon Detection Efficiency (PDE), linearity
    ← These parameters strongly depends on the bias voltage.
- Pixel by Pixel uniformity
  - Inject photon to pixel by pixel using well focused laser beam
    - 532nm Laser system @ Niigata University
    - 825nm Laser system @ KEK
- Beam test @ KEK 12GeV PS test beam line
  - Detect the particle using Plastic-scintillator + WLS optical fiber + MPPC
  - Beam data is taken in Nov, 2005
  - Analysis is in progress.

Photon counting by MPPC

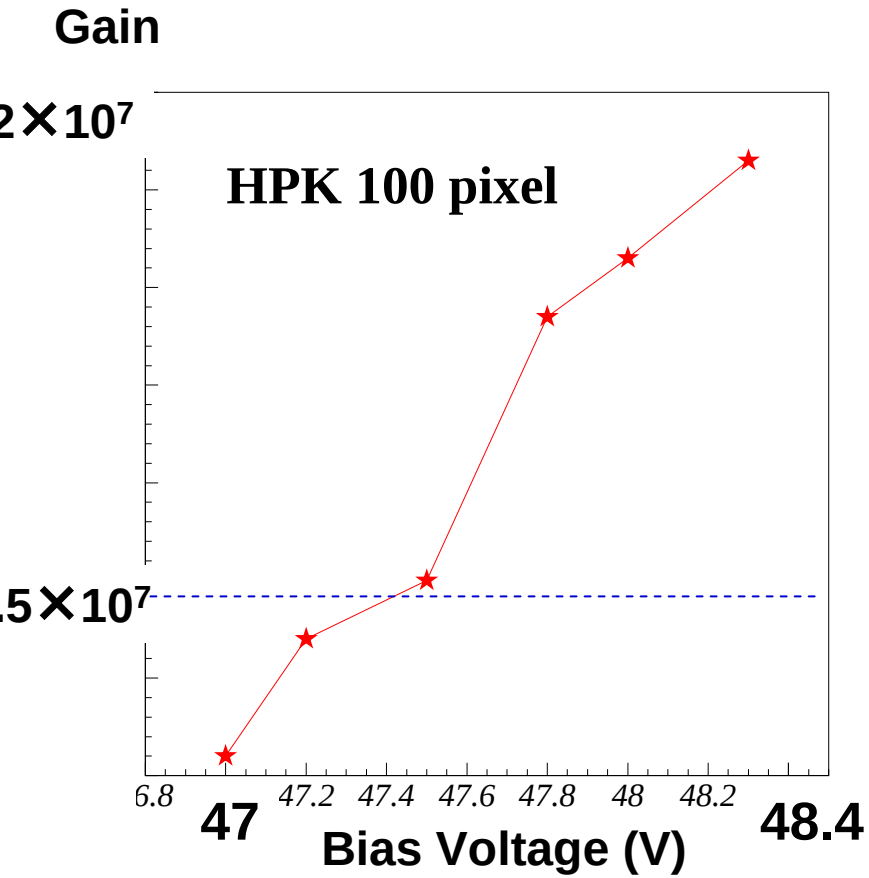
- Charge distribution
  - LED light (HPK 100 pixel)
  - We can distinguish up to 45 p.e. peak.
  - Variation of Intervals between peaks is in 2%.

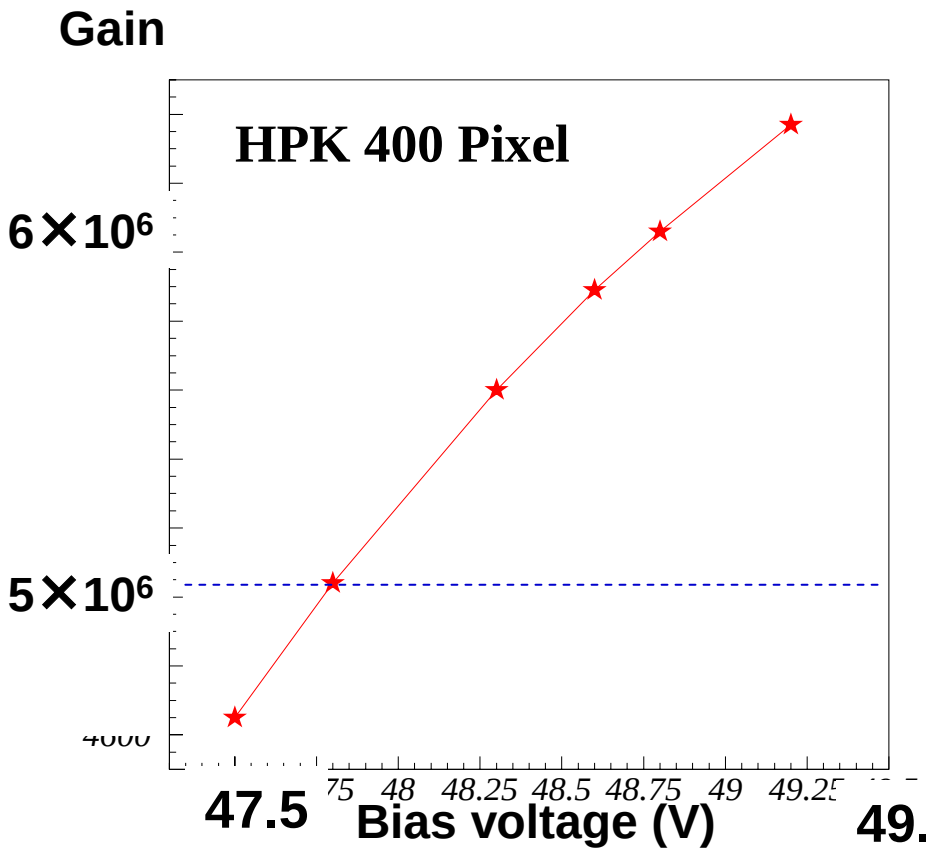
  → Gains for each pixels are uniform.



MPPC Gain

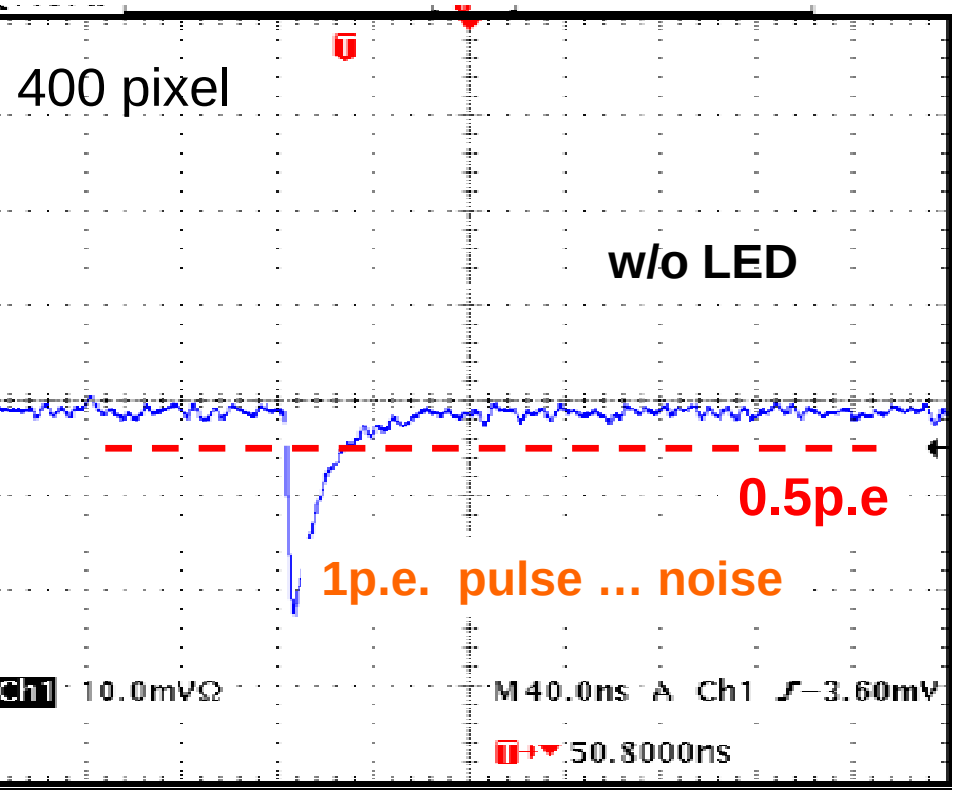
- Gain = 8×10^5 ~ 2×10^7



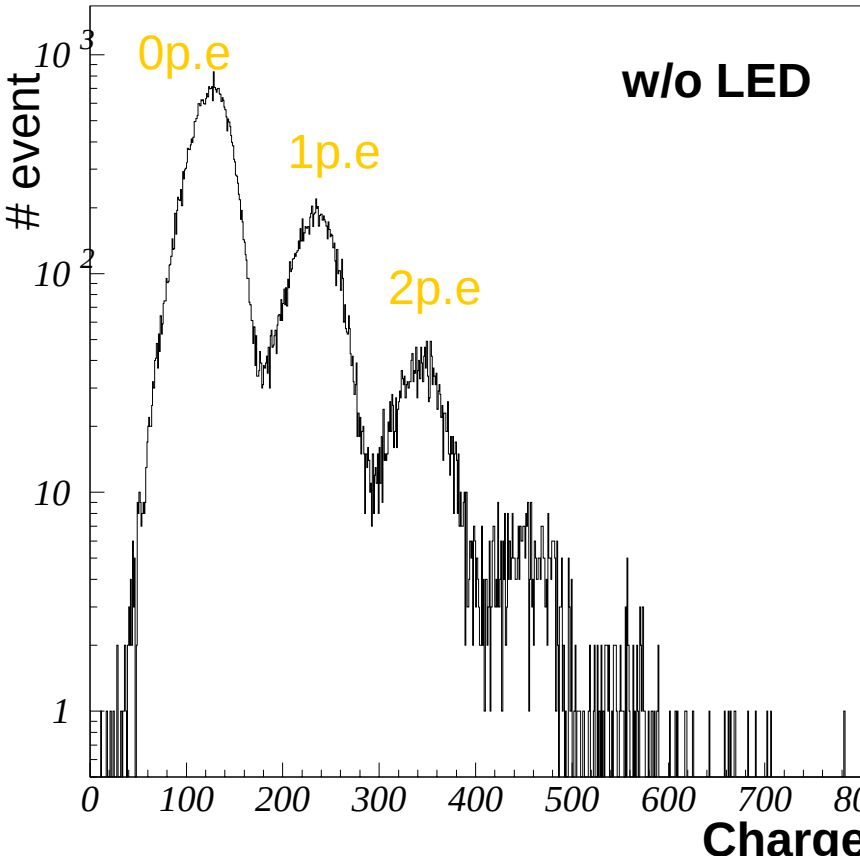


Noise Rate

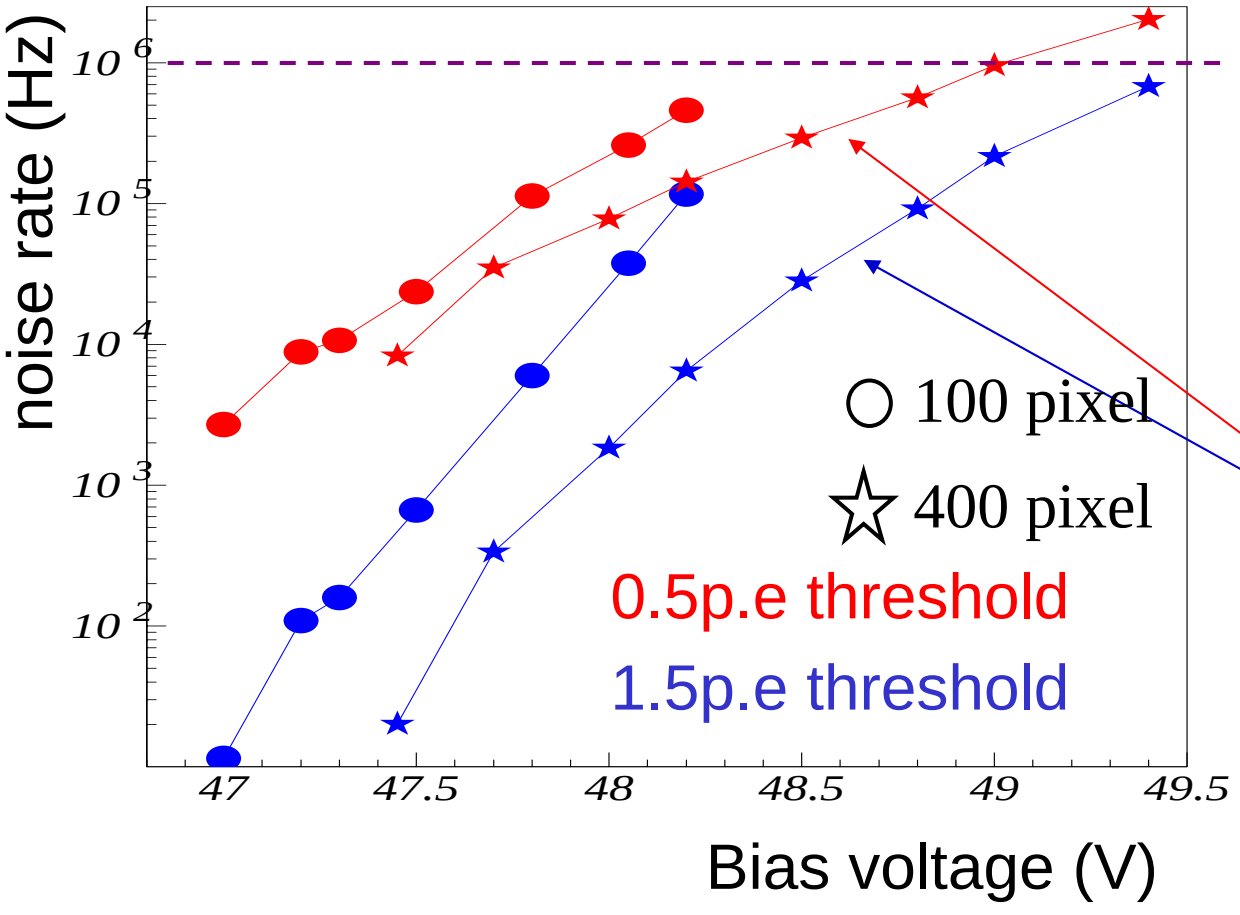
- Measure the signal rate w/o LED light.



Charge distribution for Noise



Noise Rate v.s. Bias voltage (20°C)

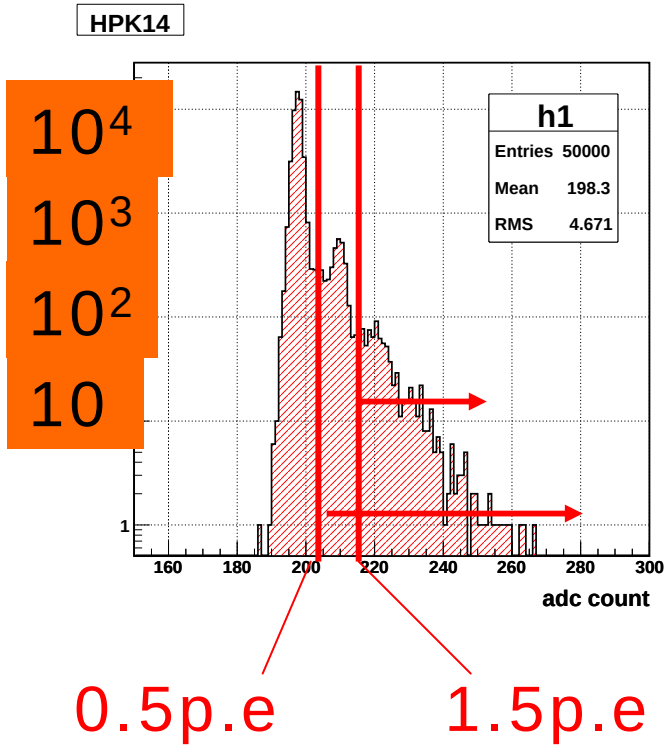


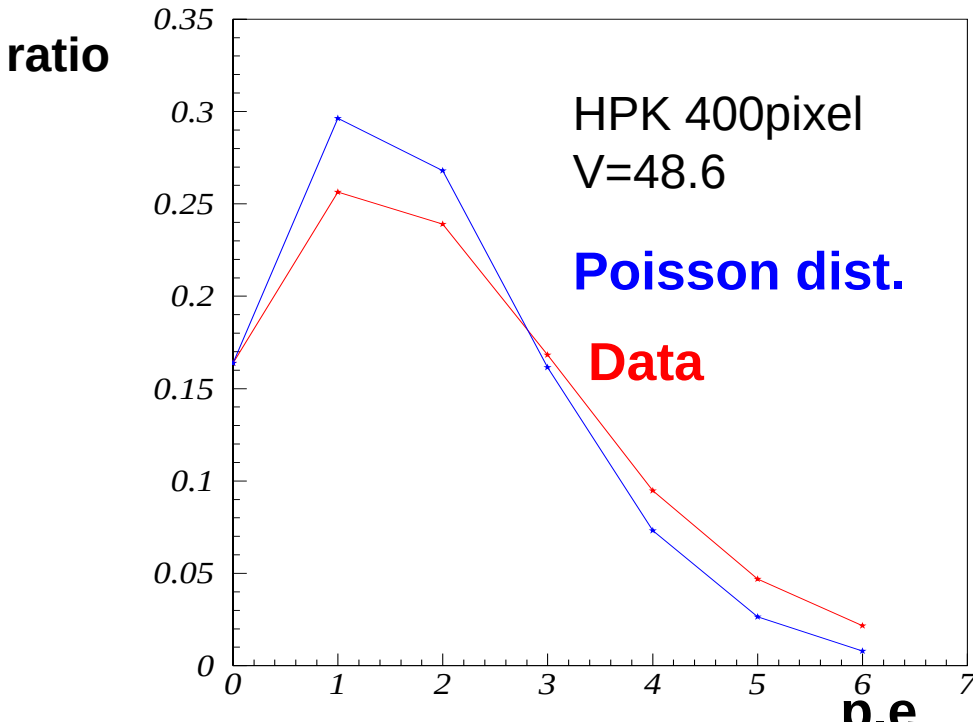
1MHz

Noise > 1p.e. is less than 10 %

Cross talk among the pixels

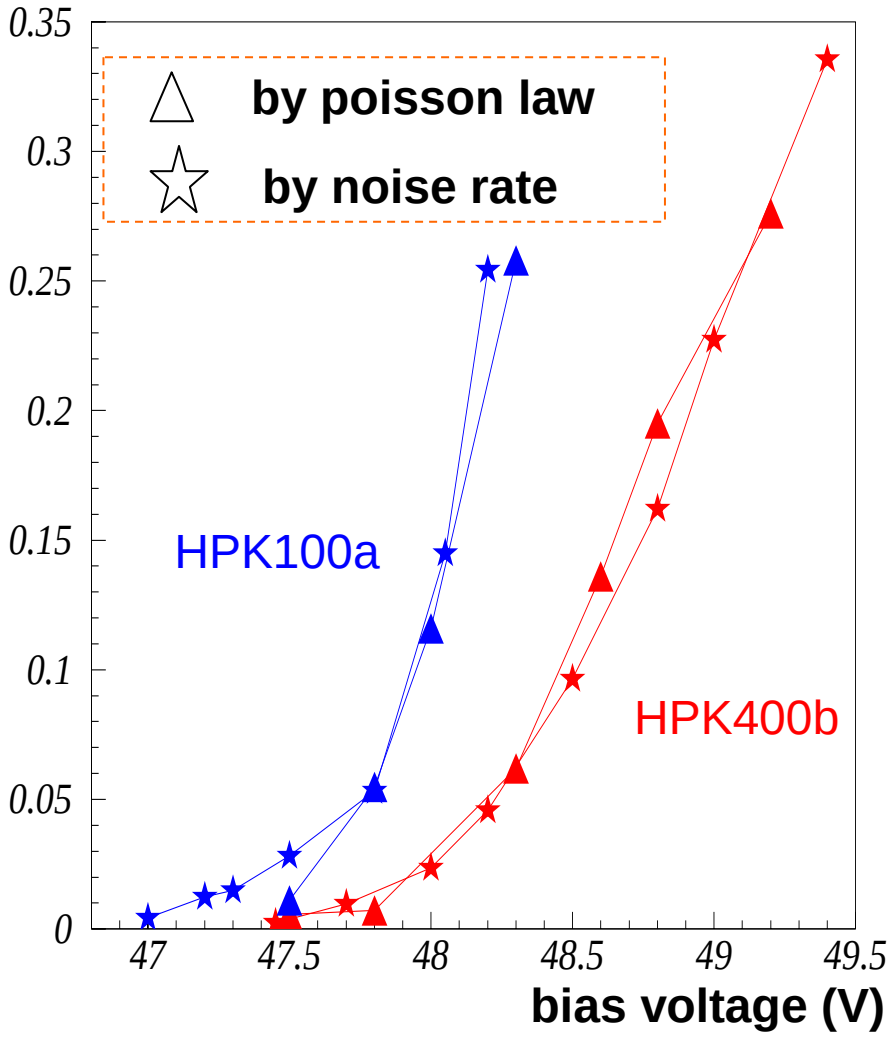
- Cross talk is measures in 2 methods.
  - Noise rate … (Noise > 1.5 p.e) / (Noise > 0.5 p.e)
  - Discrepancy of charge distribution from Poisson distribution.





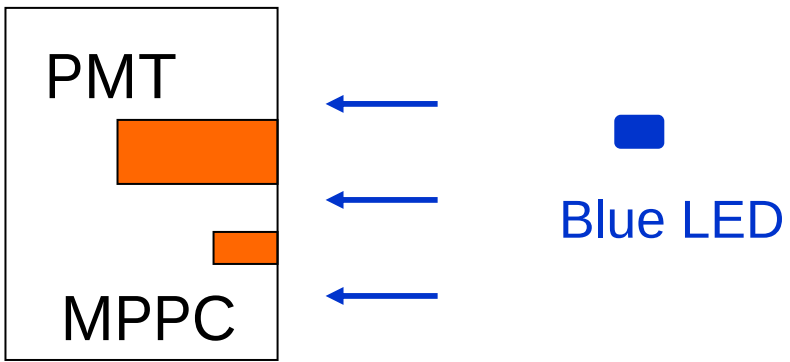
X-talk v.s. bias V (20℃)

X- talk Rate



Linearity measurement

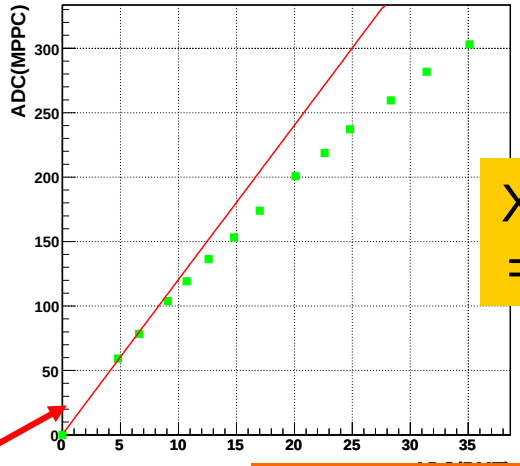
- If the light intensity became large, several photons injected in a pixel.
  → Counted as single photon because of the Geiger-mode operation.
- Linearity measurement is important to determine the number of pixels.
- Linearity is also affected by cross talk.
  - Linearity is measured by changing the bias voltage to check the x-talk effect.
- We use the PMT as a reference of light intensity.



Linearity (HPK 100 pixel)

M.Taguchi (Kyoto U)

MPPC ADC count

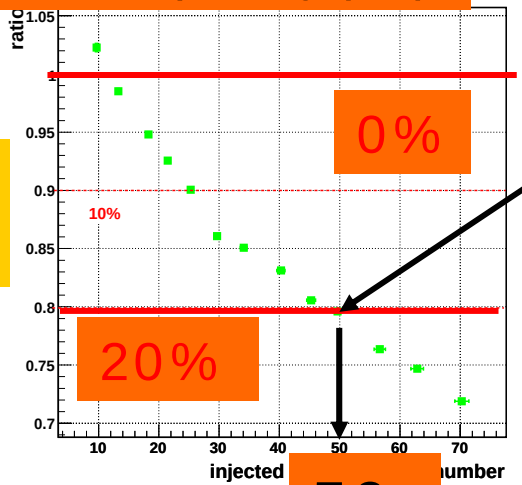


X-talk rate =0.03

Fit with line

PMT ADC count

Discrepancy(%)

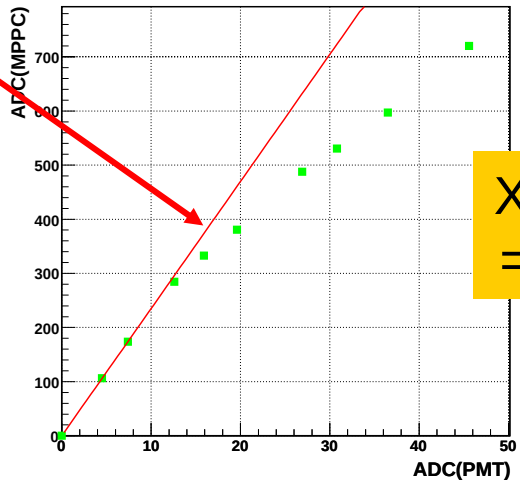


20%@50p.e

50

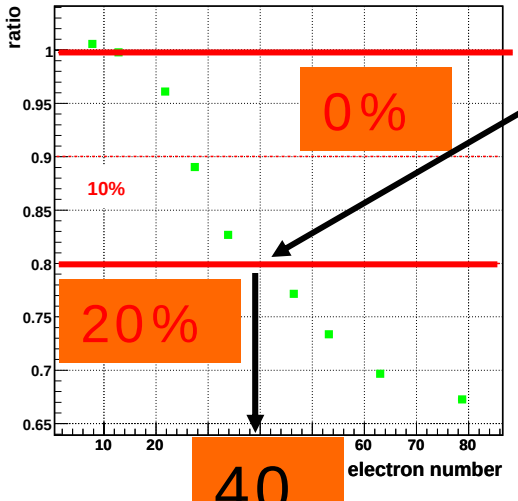
# of photon

HPK14 linearity



X-talk rate =0.2

HPK14 linearity



20%@40p.e

40

# of photon

PDE (photon detection efficiency)

- # of photo electron in signal/ # of injected photon

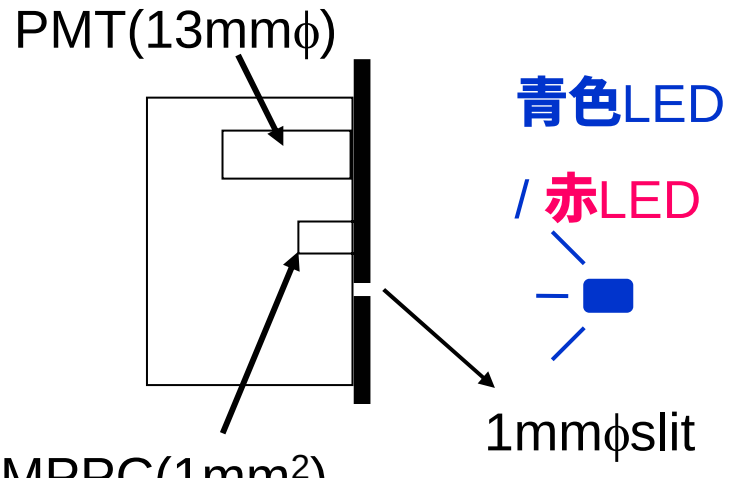
$$PDE = \varepsilon_{pixel} \times Q.E. \times \varepsilon_{Geiger}$$

Geometrical Eff. (30~50%)
Depends on MPPC type

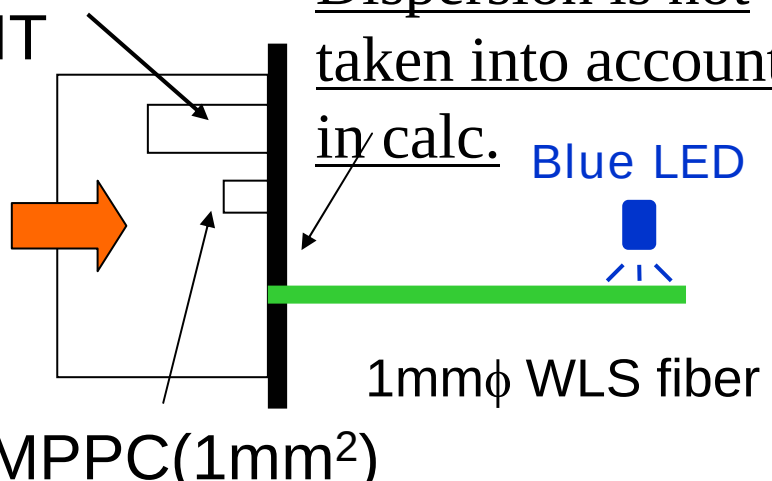
Quantum Eff. (60~80%)
Depends on wave length

Probability for p.e. to invoke Geiger discharge (60~80%)
Depends on bias voltage

PDE relative to PMT is measured.



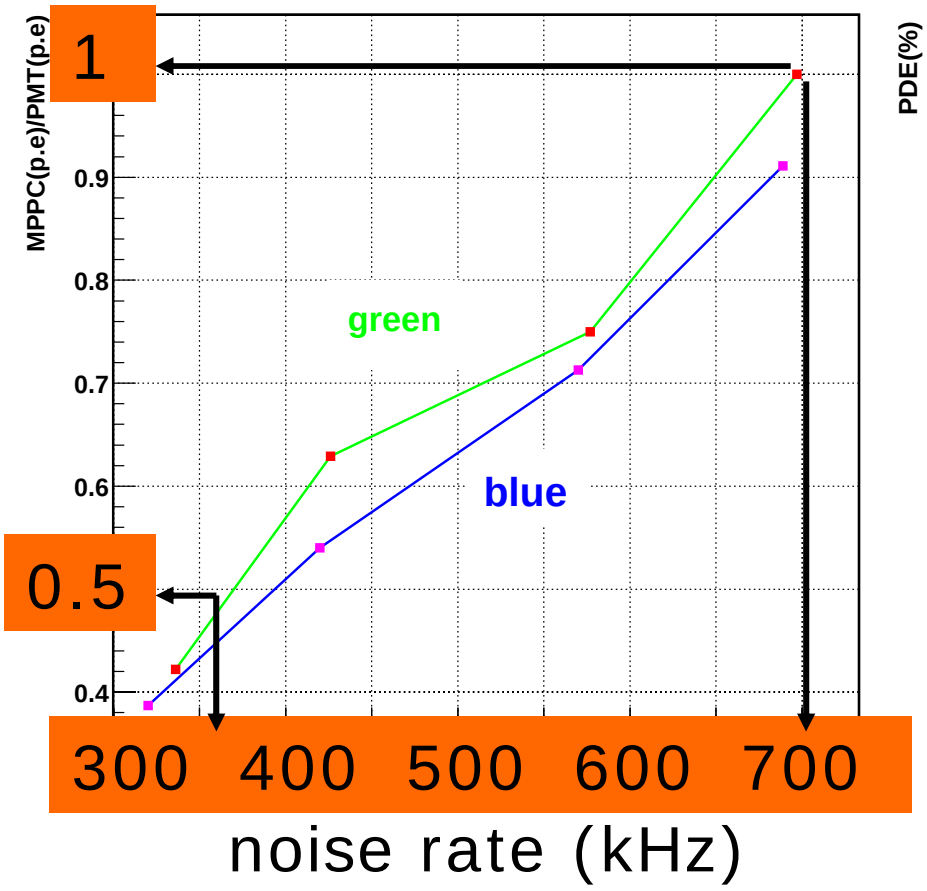
Dispersion is not taken into account in calc.



Measured PDE

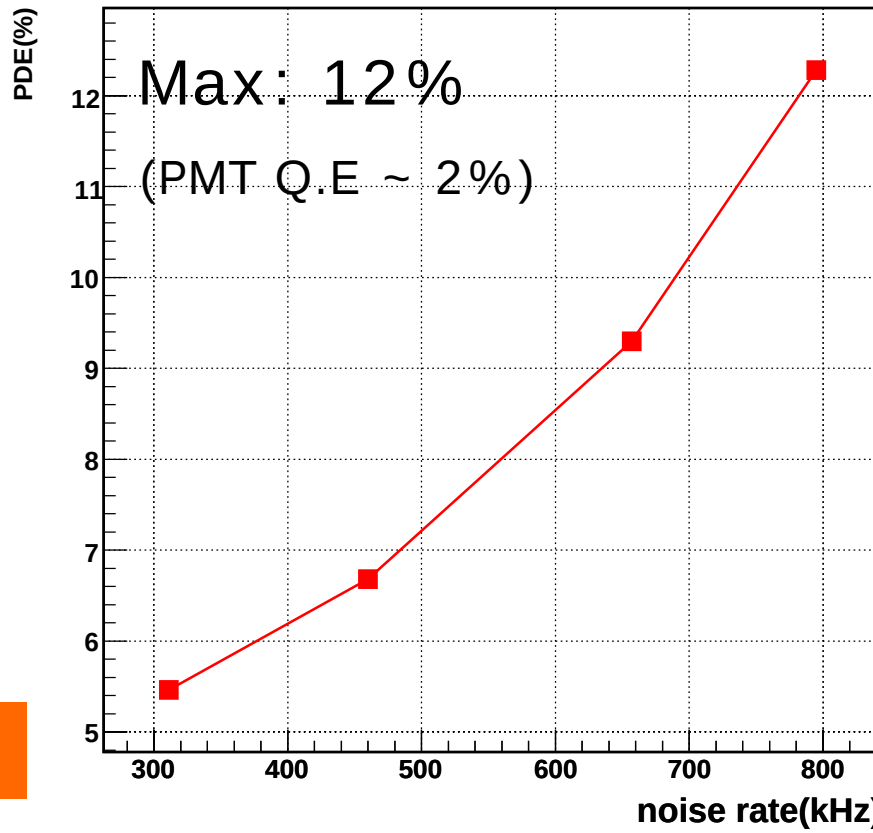
PDE(MPPC)/PDE(PMT)

Blue/ green



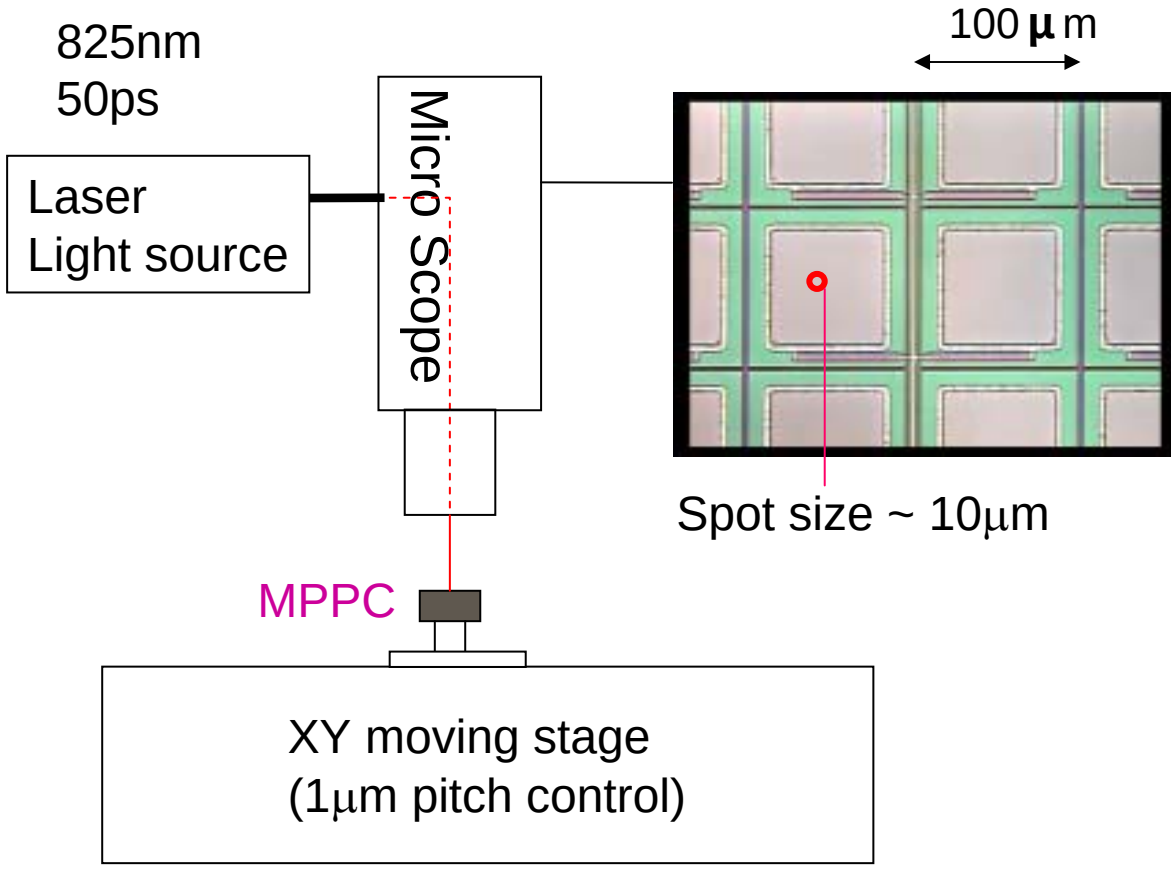
PDE(MPPC) Red

assuming PDE(PMT=2%)



Performance test w/ Laser

- Test MPPC pixel by pixel (HPK 100 pixel)



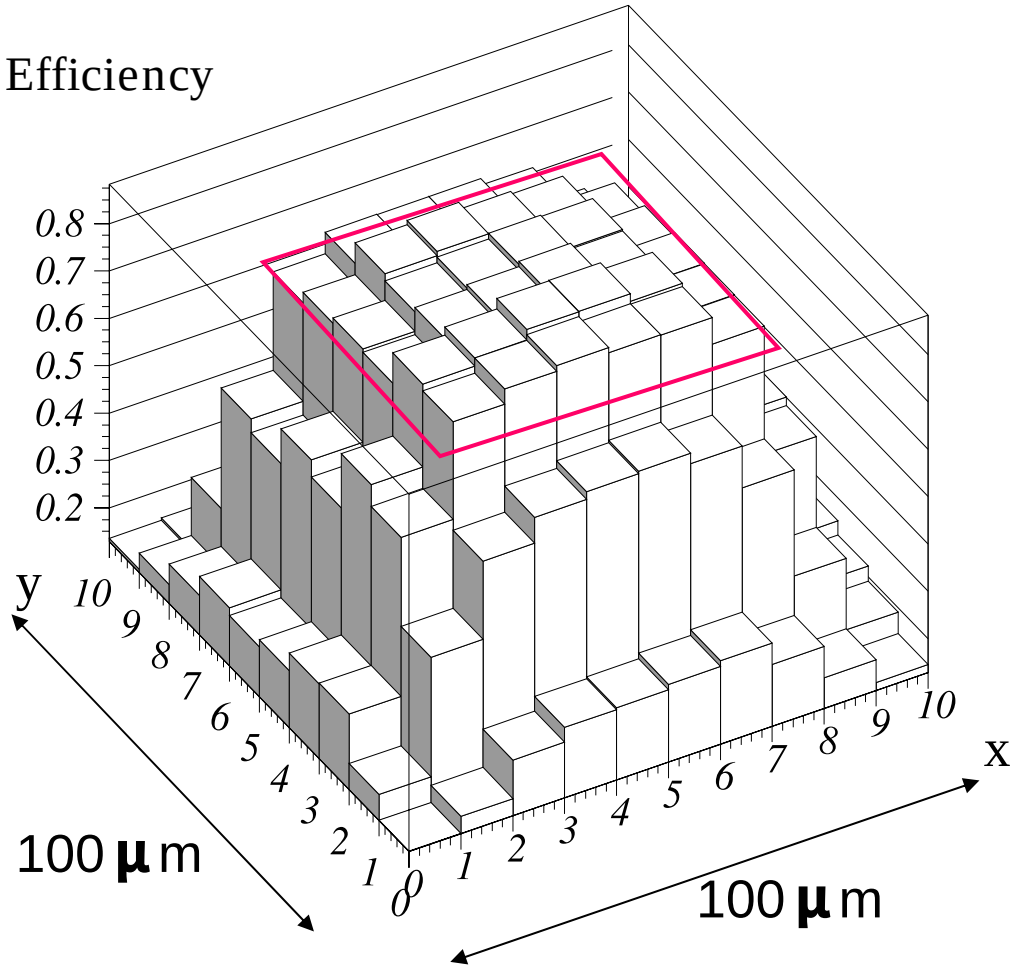
• Check the uniformity of efficiency in single pixel
•Pixel by Pixel deviation of gain and efficiency

の測定を行った

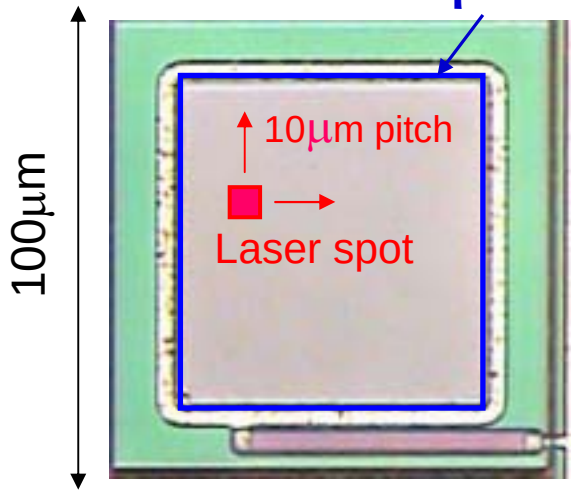
Uniformity: Single pixel

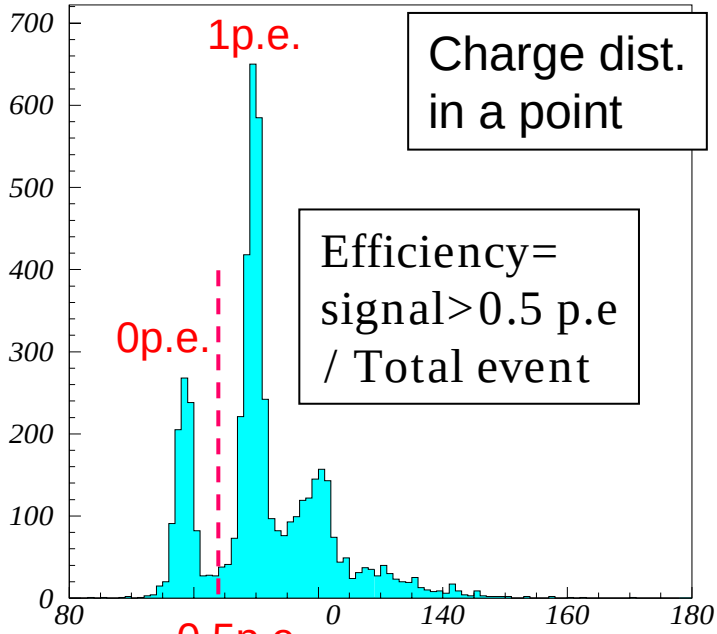
Flat area: 60x60 μm²

HPK 100pixel



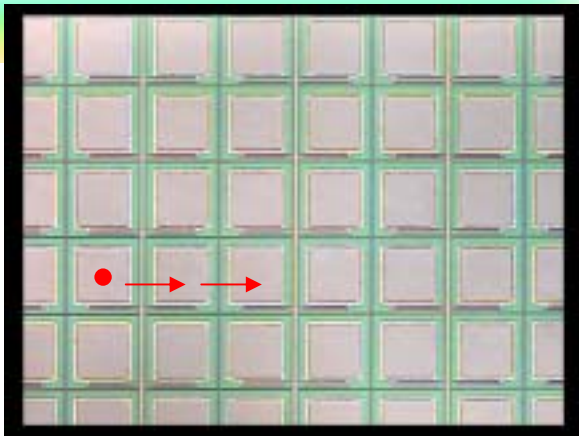
Sensitive region
70x70 μm





Uniformity: Pixel by Pixel

Set laser spot @ center of each pixel

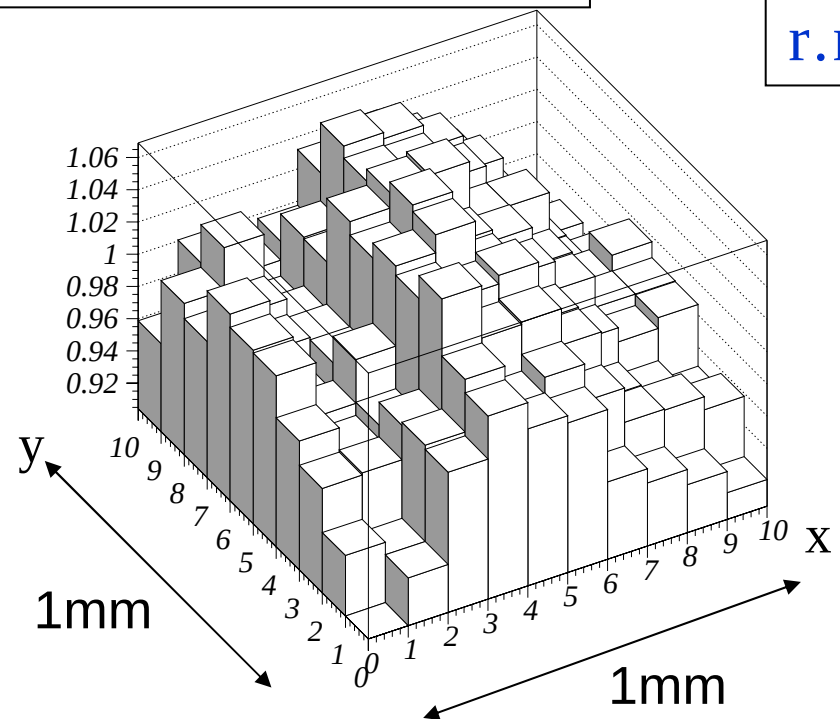


HPK 100 pixel

Very good uniformity

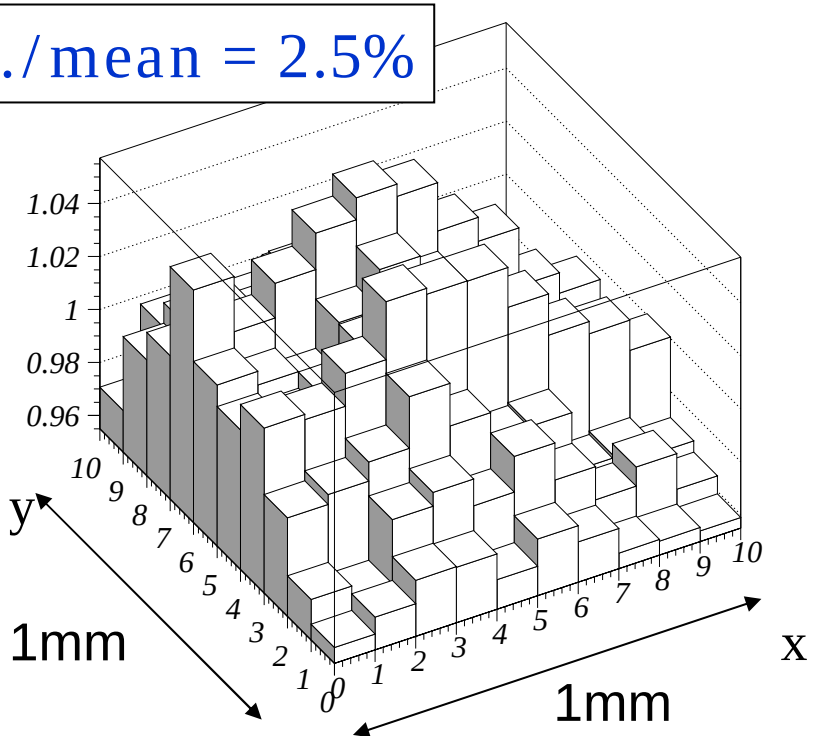
Relative Gain

r.m.s./mean = 3.6%



Relative Efficiency

r.m.s./mean = 2.5%



Summary& Prospect

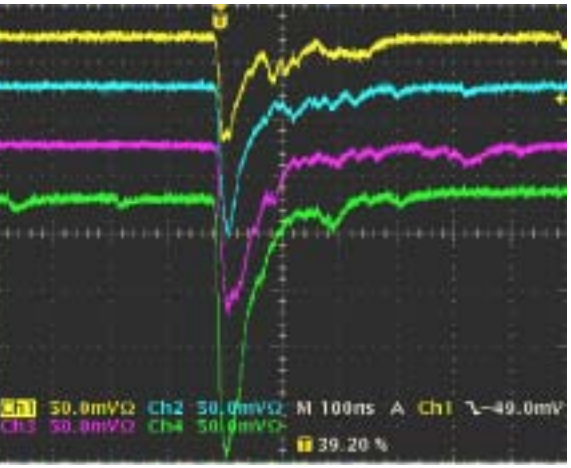
- MPPC is promising device for photon counting.
  - Gain ~ 10^6-10^7
  - Noise rate: O(1MHz) for >0.5 p.e., O(10~100kHz) for >1.5 p.e.
  - X-talk rate: < ~0.2
  - Photon Detection Efficiency: comparable to PMT
  - linearity: Discrepancy within 20% up to 40% of # of pixels
  - Efficiency in single pixel is uniform
  - Pixel by Pixel deviation of gain and efficiency is very small
- HPK delivered new samples to T2K and ILC-CAL group.
  - Sample test in progress.

ビームによるシンチ＋ファイバー読み出しのテスト

動機 T2K **前置検出器と同じ読み出し条件で、**
MPPC**によって**T2K**の要請を満たす光量が得られるか。**
さらに、pとπ**の識別が可能か**

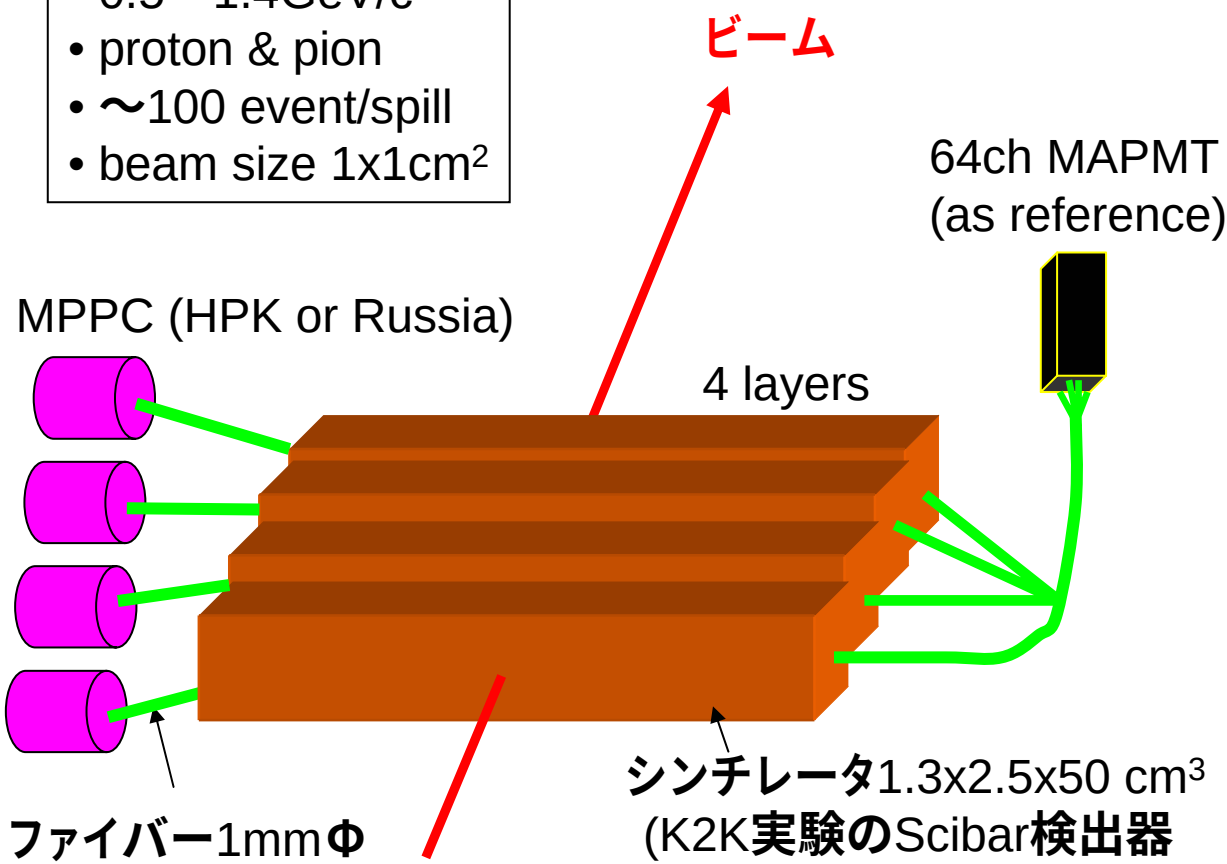
MIP**に対して**5p.e.**以上**

4ch**全ての**
ビームによるMPPC
シグナルを見ることが
できた



setup

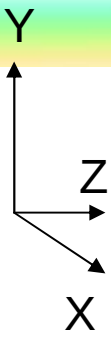
- 0.5〜1.4GeV/c
- proton & pion
- 〜100 event/spill
- beam size 1x1cm^2

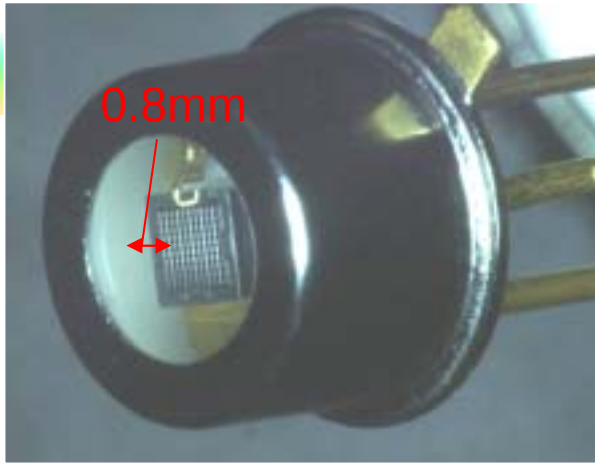


HPK製MPPCにおけるファイバーのalignment

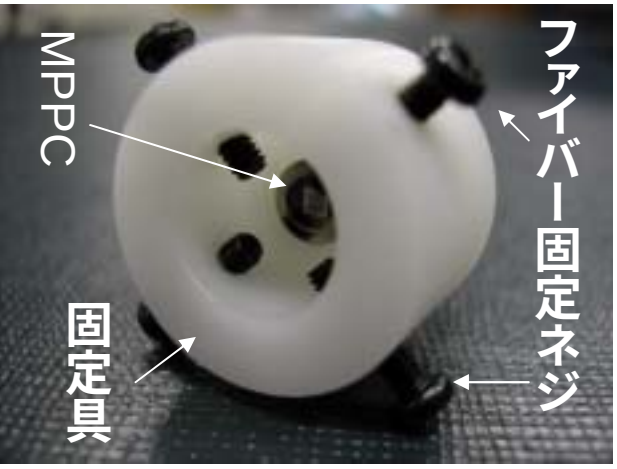
HPK製MPPCの受光面とパッケージの位置関係

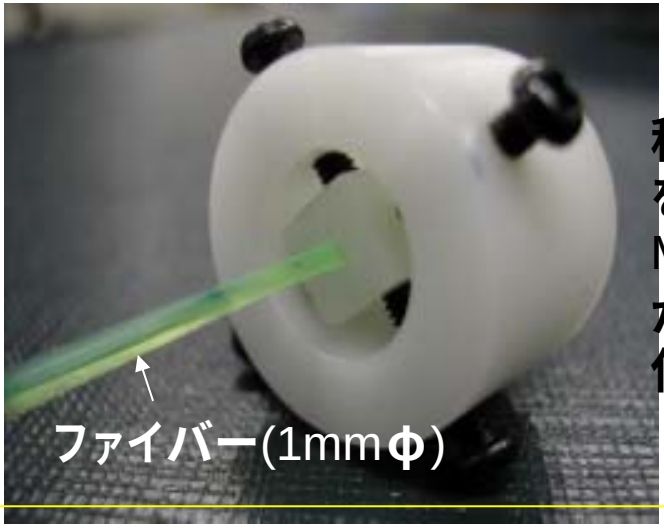
- Z方向： 透明カバーと受光面に隙間が存在
  → 受光面-ファイバー間距離は0.8mmとなる
- X,Y方向 ：サンプルごとにばらつきがある
  → サンプルごとにファイバーの位置合わせを行った





X、Y方向位置合わせ





移動ステージでファイバーをスキャンし、MPPCシグナルが最大の点でファイバーの位置を固定した

X,Y方向の位置のずれにより最大20%,Z方向の隙間により約60%の光量のロスが存在

ファイバーから40°で一様に光が広がっているとした場合の値

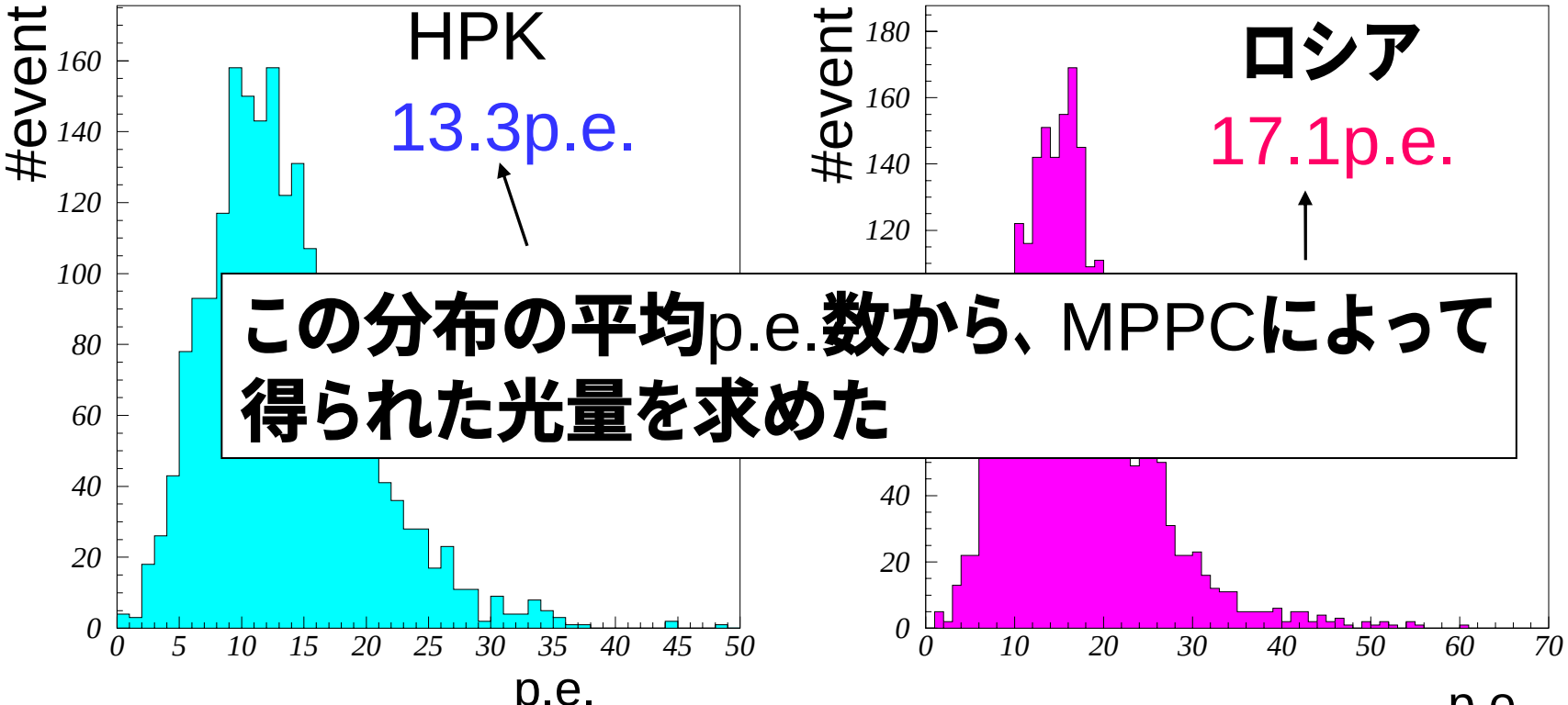
現段階のパッケージ構造によるもので、デバイスの性能からくるものではない

MIPによる光量（p.e.）1

Photon Detection Efficiency (PDE) =MPPCの受光面(1mm^2)にフォトンが入射したときに、それを検出する確率
（バイアス電圧に依存する）

PMTと比較したPDEを、HPK製は70%, ロシア製は100%となるようにバイアス電圧を設定した

MIPによるパルスの電荷量分布においてピークをみることができた



この分布の平均p.e.数から、MPPCによって得られた光量を求めた

MIPによる光量 (p.e.) II

MIPにより、MAPMTで得られた光量は18.2p.e.だった

HPK

PDEがPMTの70%のときの光量(p.e.)

Serial#	光量(p.e.)	PMTとの比(%)
#13		
#14		
#16	13.3	73
#17	7.2	39

PDEはZ方向のロスを含めた値

ロシア

PDEがPMTの100%のときの光量(p.e

Serial#	光量(p.e.)	PMTとの比(%)
		126
		94

ロシアの方はファイバーと受光面間での光のロスは十分小さい
(パッケージ構造上)

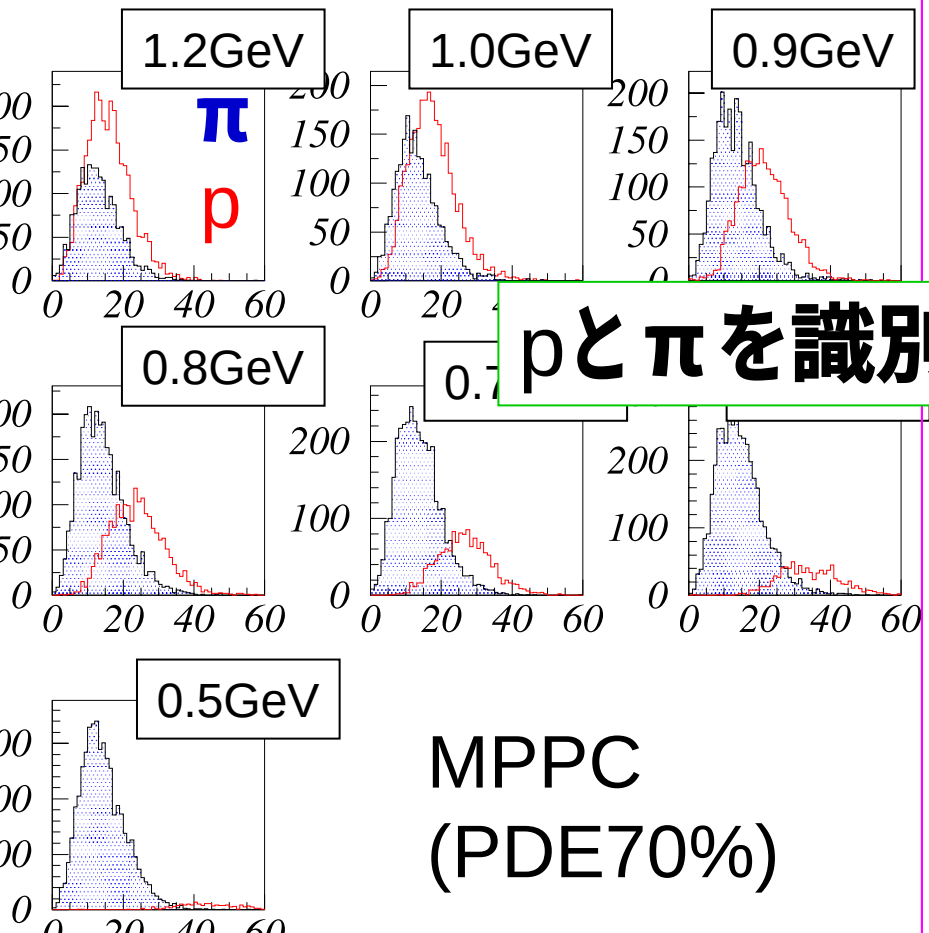
MPPCにおいて、T2Kからの要請をみたす光量が得られた

期待される光量からのずれの原因としては、
ともにPDEの測定誤差があり、
さらにHPK製において、
ファイバーのX,Y方向の位置のずれによる光のロスが挙げられる

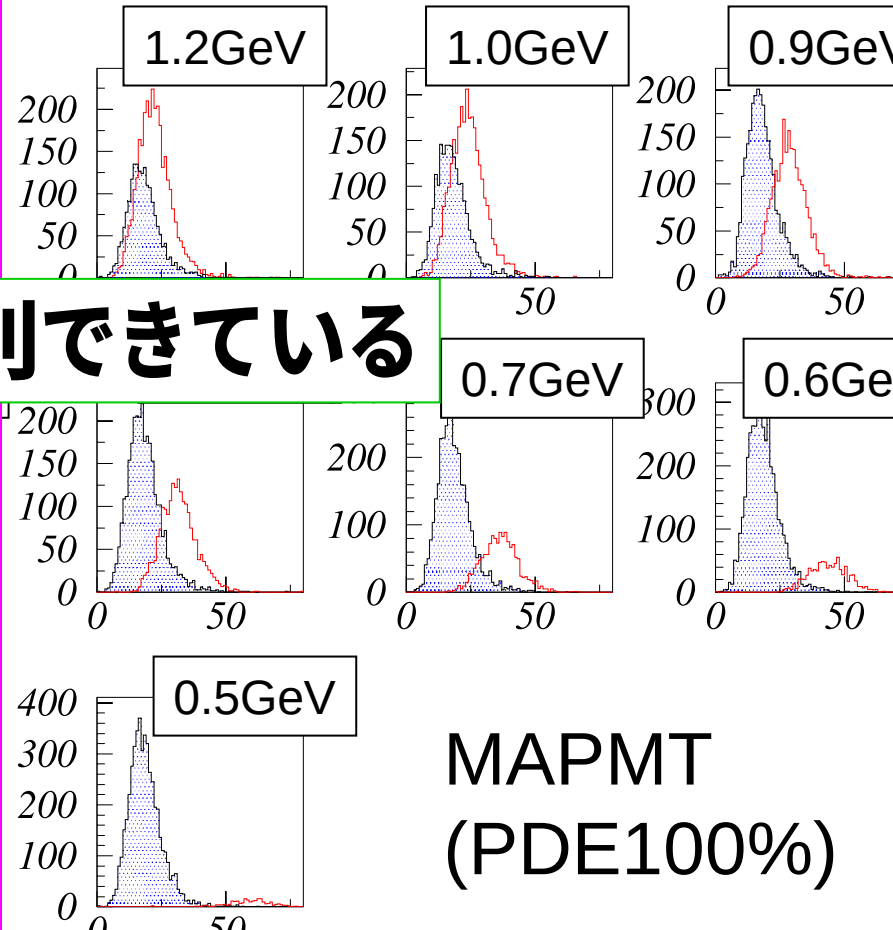
p/π Separation

MIPによるシグナルのMean,r.m.s. ⟶

	Mean	r.m.s.
MPPC	13.3p.e.	6.2p.e.
MAPMT	18.0p.e.	6.6p.e



pとπを識別できている



MPPC
(PDE70%)

MAPMT
(PDE100%)