Study on Double-side Strip Readout for ScECAL

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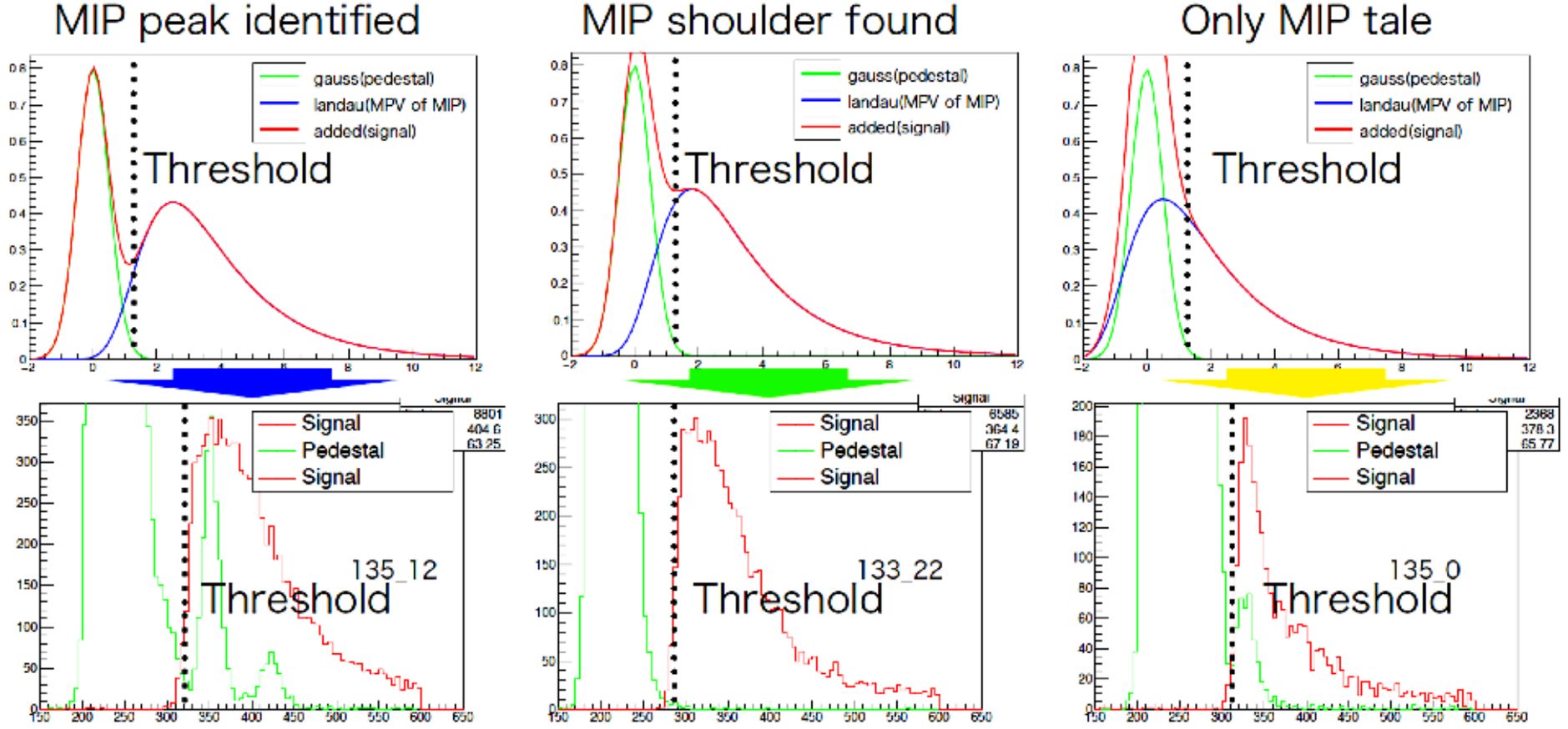
Small-Cell Photosensor for ScECAL

- **SiPM with small pixel pitch (~10μm) is required for ScECAL to improve dynamic range.**
- **Issues on SiPM with small cell**
  - Lower gain → **poor single p.e. resolution**
  - Lower PDE → **lower MIP yield**
  - S/N of EBU analog front-end is not good enough for small-cell SiPM



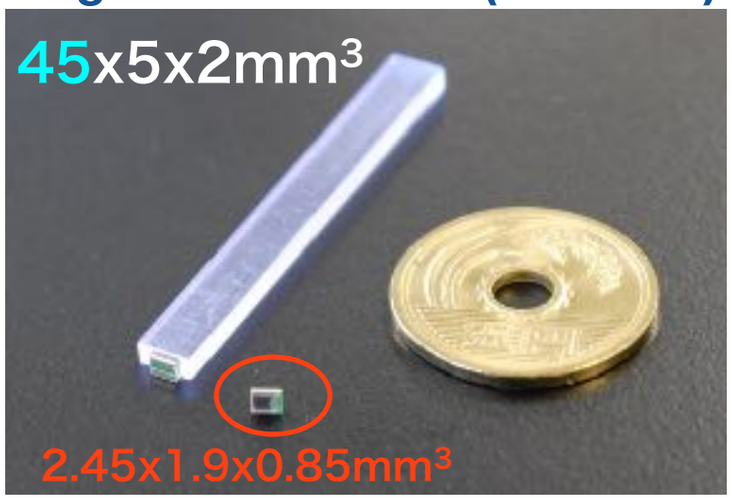
Possible Solutions

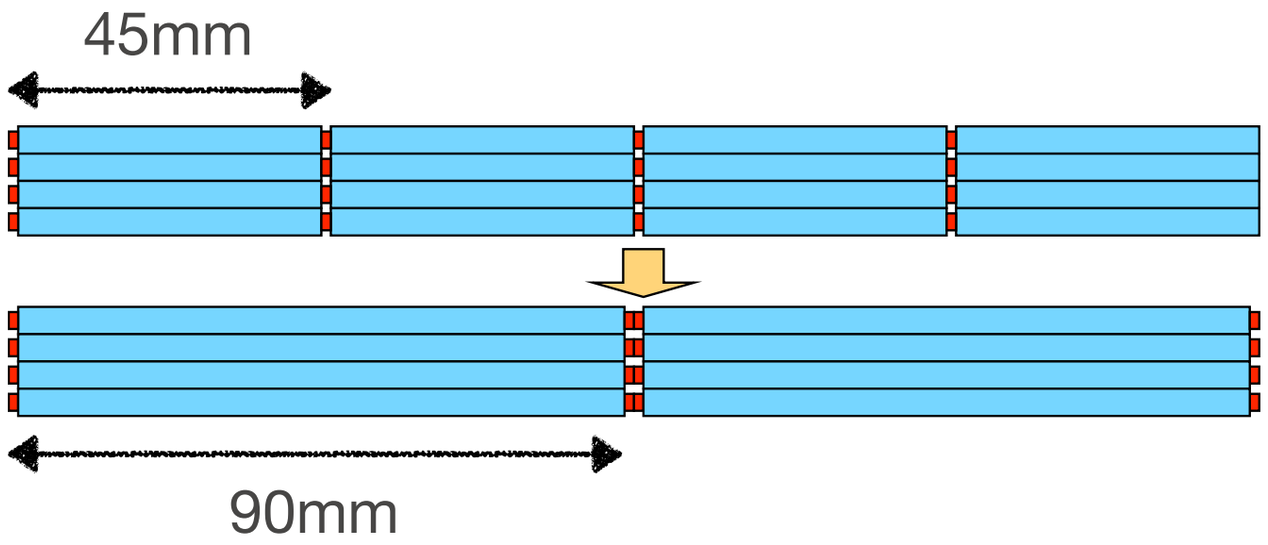
- Improve gain/PDE of SiPM
- Increase photon yield
- Increase sensor area
- Improve S/N at EBU readout
- A little larger pixel pitch (15μm?)
- Double SiPM readout

Double-sided Readout Strip

- **Double SiPM readout at strip ends**
- **Possible advantages**
  - Suppress random hit by taking coincidence → Lowering MIP threshold
  - More uniform response
  - Higher light yield
  - Scintillation photons shared by two SiPMs → Mitigation of saturation
  - Position reconstruction → Remove ghost hits
- **Issues**
  - Need longer strip to avoid increasing # of SiPMs (90mm instead of 45mm)
  - More saturation with longer strip?

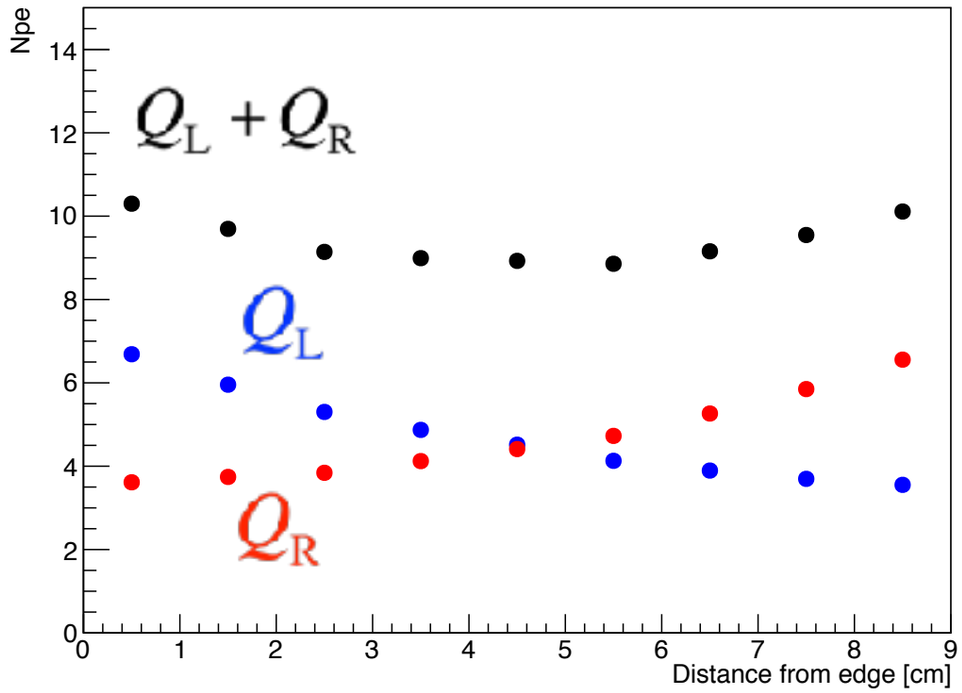
Single-side readout (L=45mm)





Updates since Last Meeting

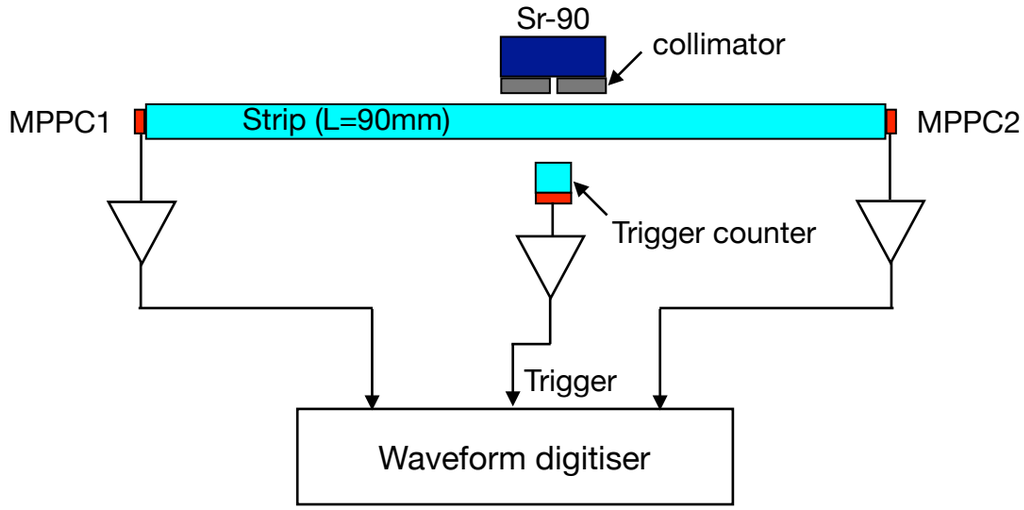
- **Good performance already demonstrated in the previous studies, but with non-optimal setup**
  - Reasonably good light yield
  - Uniform response
  - Possibility of position reconstruction discussed
- **New results are coming from improved setup**
  - Better scintillator and more realistic SiPM (10μm cell)
  - Higher light yield
  - More uniform response
  - Noise suppression test



Position dependence observed in previous test

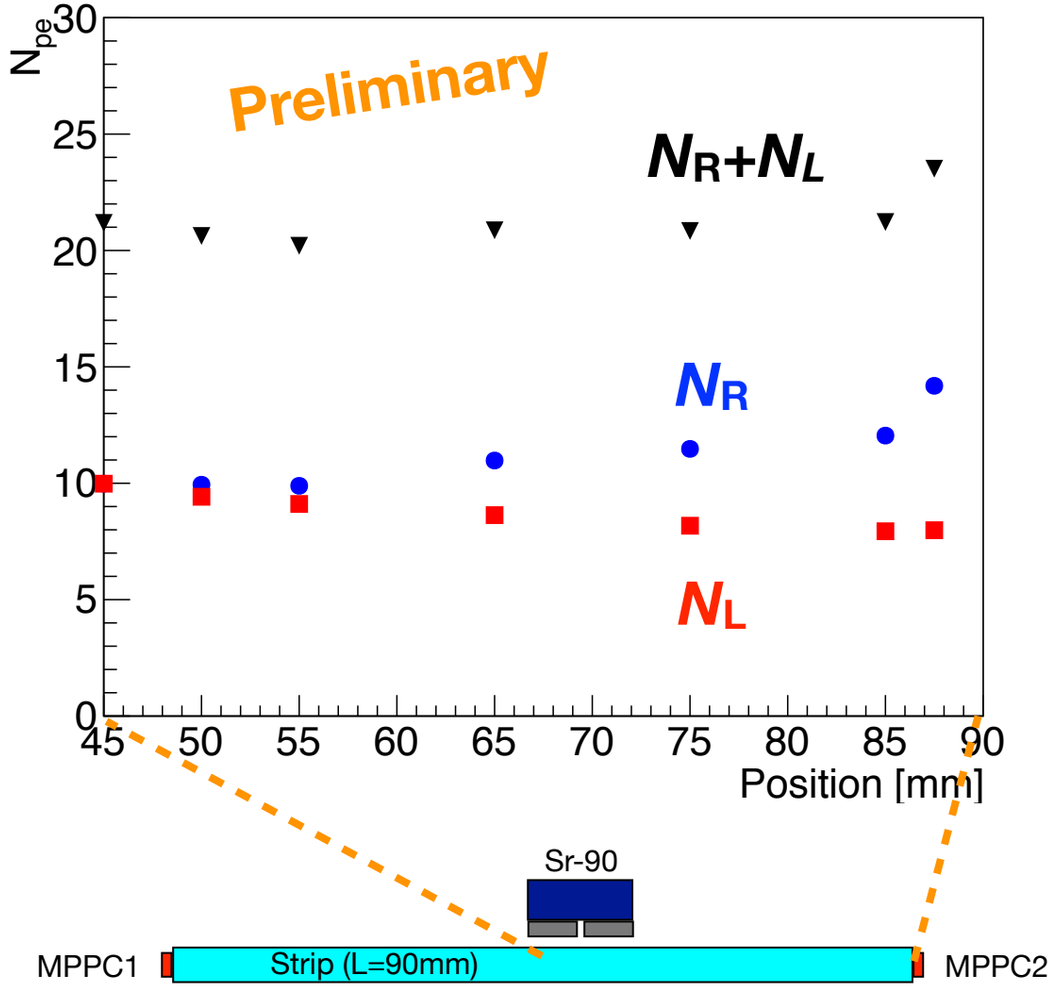
Prototype Test with Improved Setup

- **Improvement w.r.t. previous setup**
  - Scintillator
    - EJ-232 → **EJ-212 (~BC400)**
    - **EJ-212**
      - General purpose
      - Higher light yield
      - Longer attenuation length (~160cm)
      - Emission peak: 423nm → better matches SiPM response
  - SiPM
    - More realistic SiPM
      - MPPC S12571-010P (1×1mm^2 10μm-pixel) operated at over-voltage of 5.5V
      - Lower PDE



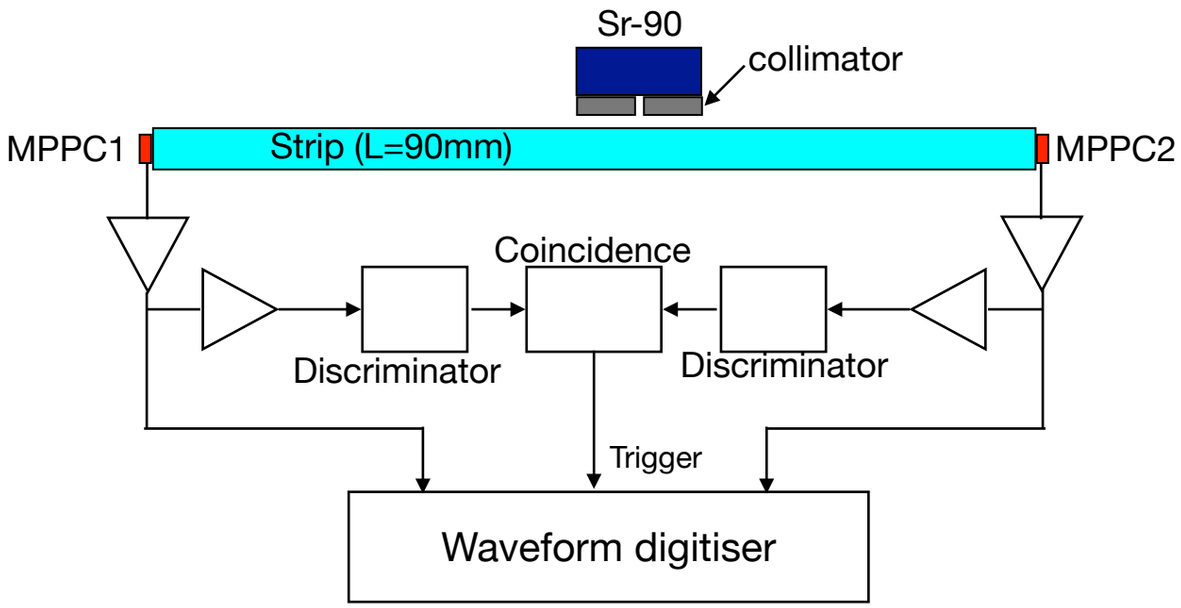
Position Dependence

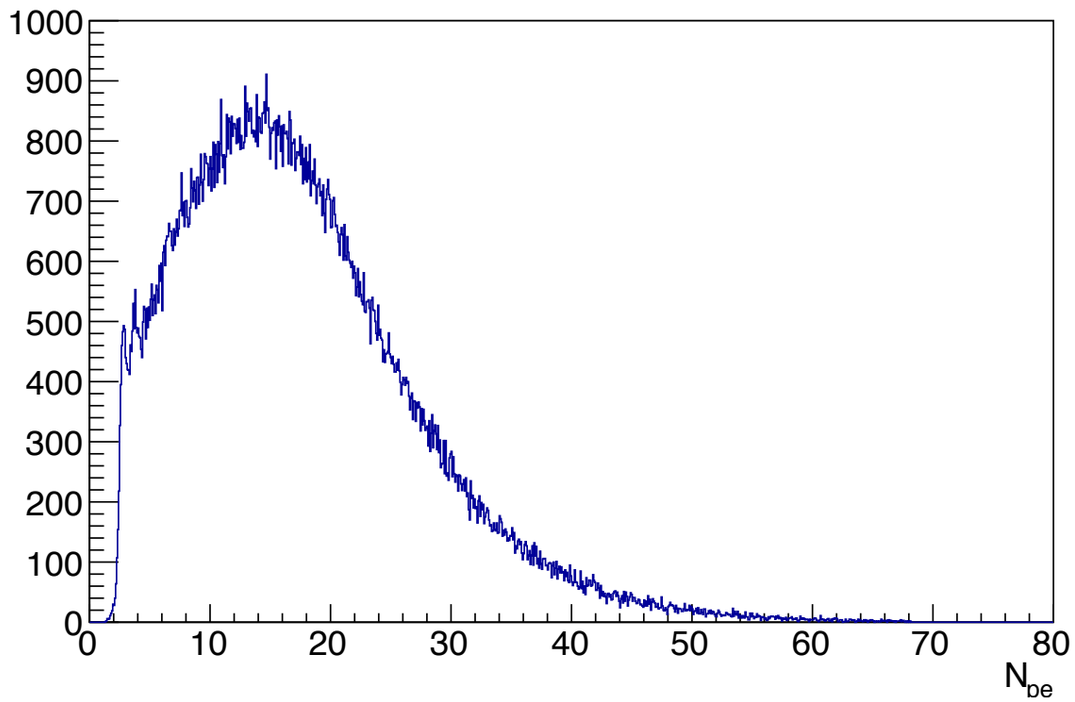
- **Improved performance w.r.t. previous setup**
  - **Overall N_{pe} ~21** (MPV) → twice higher light yield!
  - Excellent uniformity in charge sum at both ends
- **Slightly peaky response observed near strip edge**
  - Can be improved with bottom-side SiPM readout with wedge



Noise Suppression with Double-side Readout

- **Demonstrate noise suppression with double-side readout**
  - **Very low threshold (~0.5pe)** at each MPPC to simulate high noise rate
    - Dark count rate ~150kcps for each MPPC >> Sr-90 hit rate (<10kHz)
    - **N.B.** this extremely low threshold is NOT necessary (typical threshold ~0.5MIP). Just for demonstration purpose.
  - Taking coincidence at both MPPCs
  - Triggering on coincidence signal. No trigger counter.
  - Waveform analysis is still being optimised.
    - N_{pe} is estimated from waveform height instead of charge and hence is underestimated.





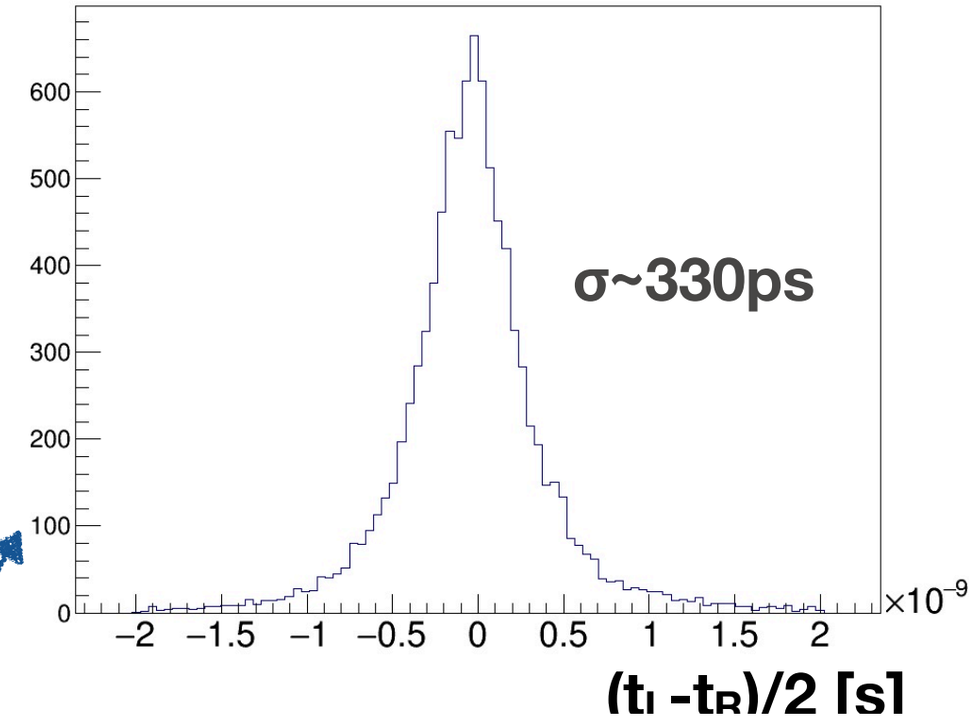
- **Dark noise hits completely suppressed!**
- Low N_{pe} events due to low energy β from Sr-90

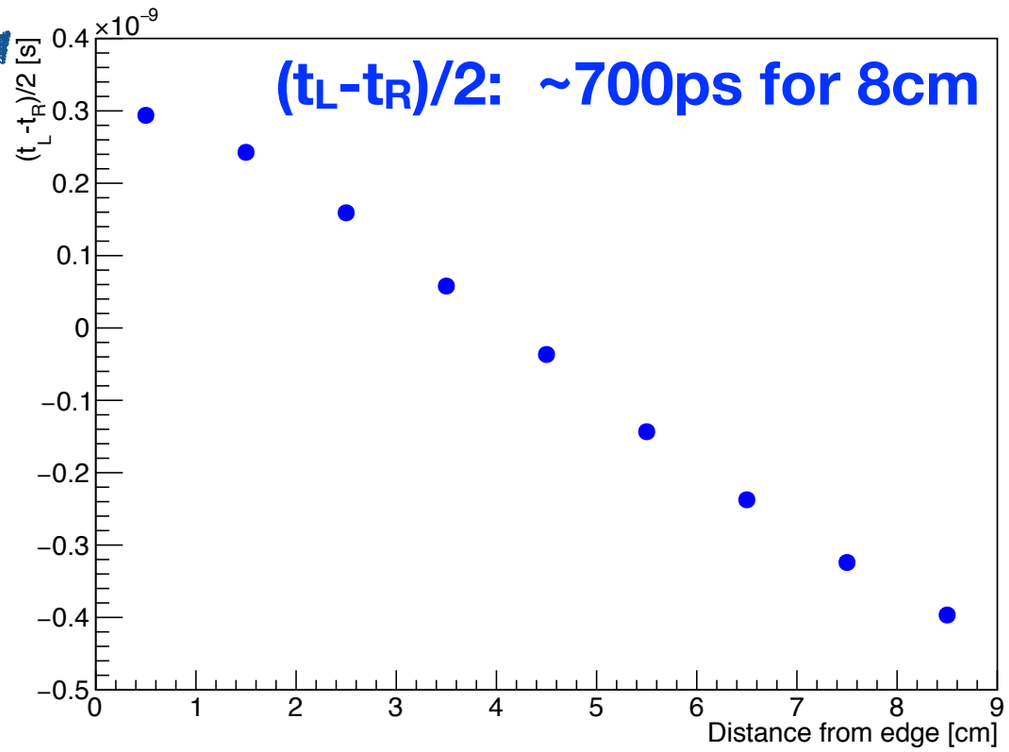
Position Reconstruction

- **Two possibilities**
  - Charge ratio
    - Difficult due to low N_{pe} statistics
  - Time difference
    - **σ~4cm** measured with preliminary setup
    - Performance improvement expected with larger N_{pe} statistics with optimal scintillator/SiPM

From previous test.

To be updated with improved setup





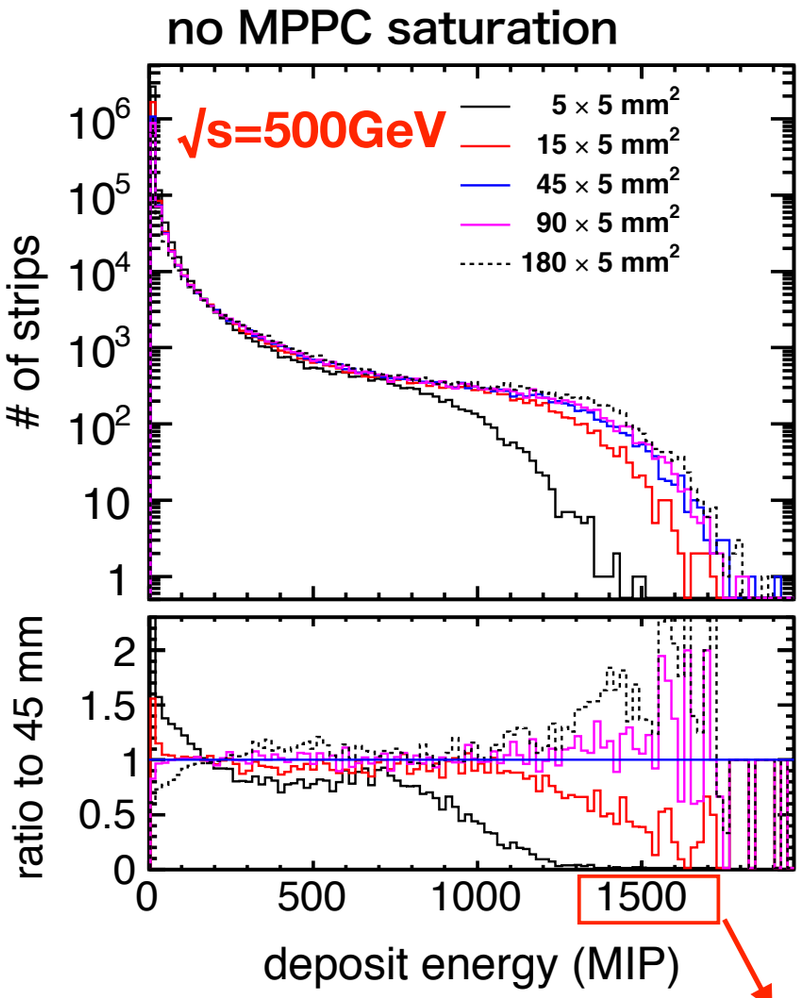
Other Issues for Longer Strip

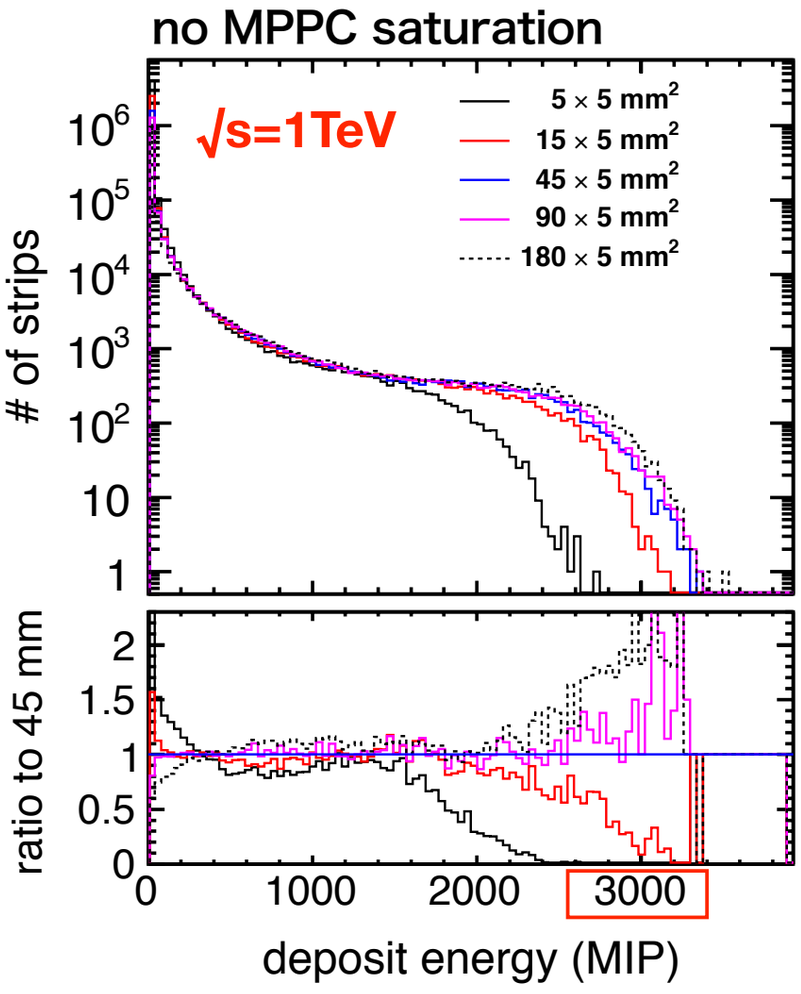
- **Possible issues**
  - Larger energy deposit per strip for Bhabha event? → more saturation
  - More ghost hits?
- **Effects of strip length studied by MC simulation**
  - Studied by Kotera-san
  - $\sqrt{s}$ = 500GeV, 1TeV
  - Bhabha events @θ~90°
  - No digitisation simulated. Compared energy deposits only.

Energy Deposit per Strip

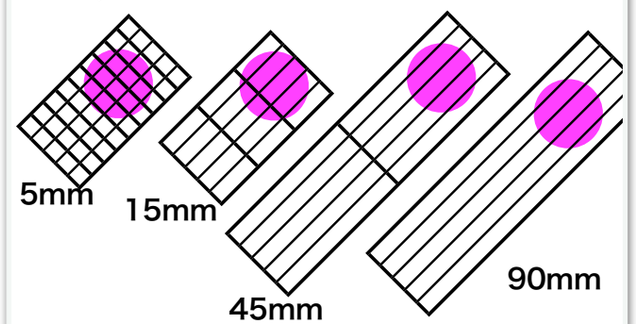
Considering Bhabha events at √s = 500 GeV, 1 TeV

K. Kotera





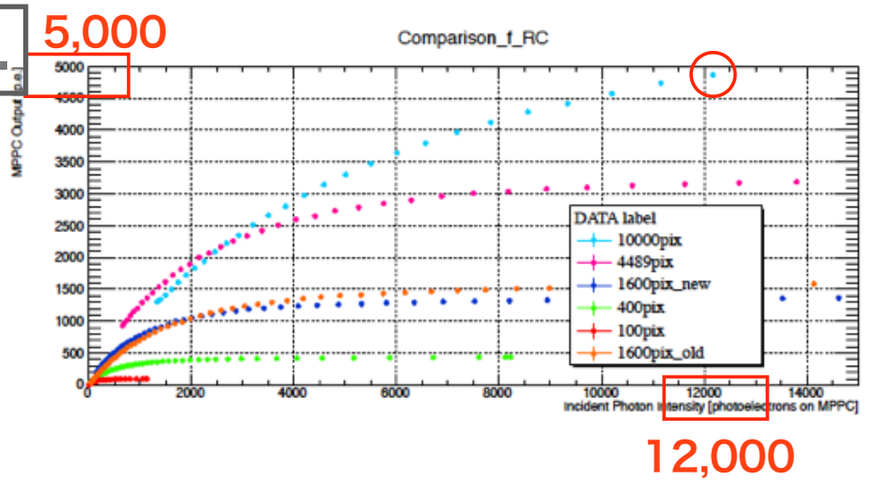
- 45, 90mm no serious difference.



- core sizes of clusters are smaller than 45mm

1500MIP → N_{pe} ~10k for nominal strip config.

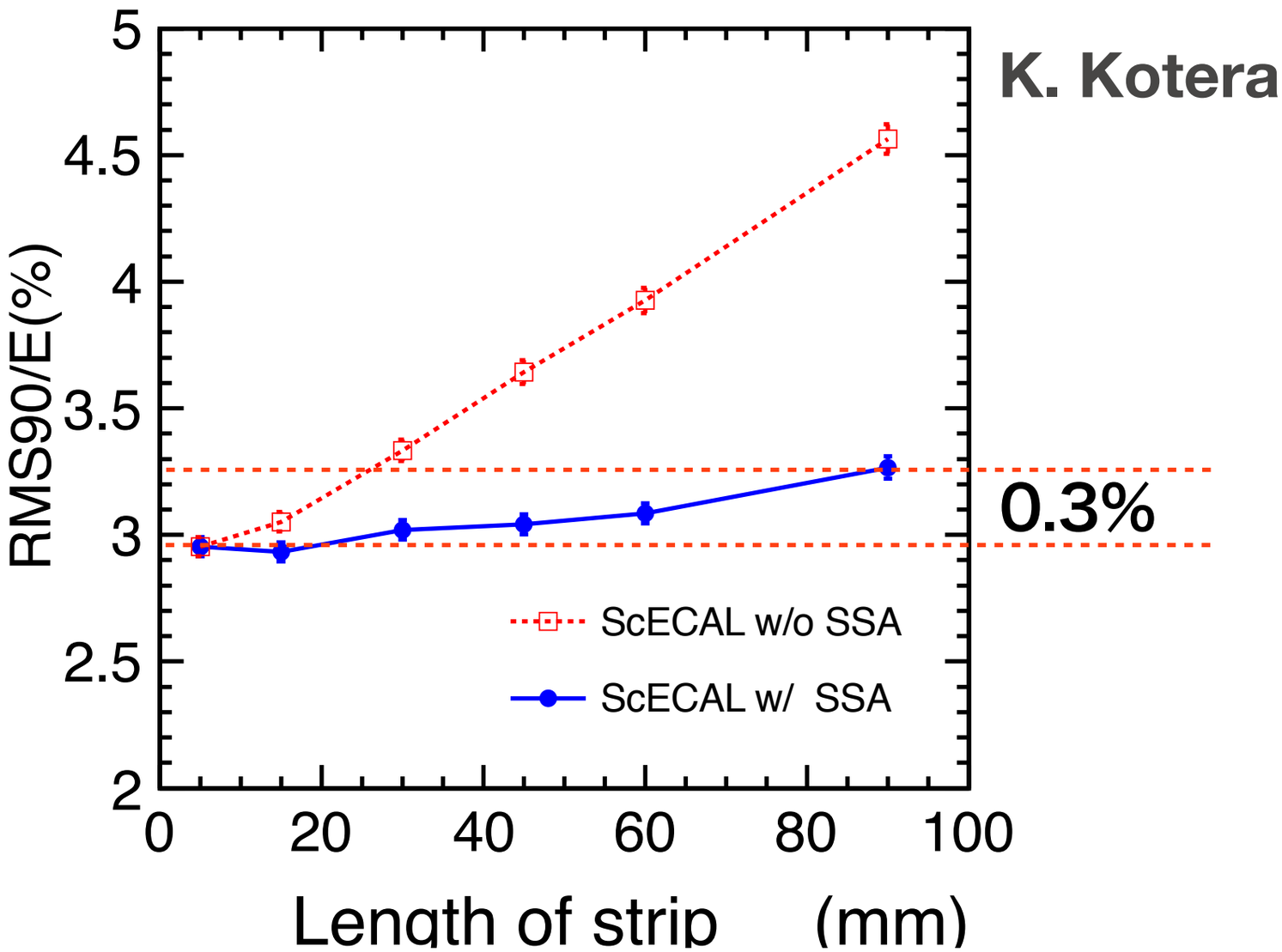
Response of 10μm-cell SiPM



- **No significant difference at longer strip**
  - Cluster size smaller than strip length
- **Saturation not worsened with longer strip**

Jet Energy Resolution

- **JER slightly worsened for longer strip due to ghost hits**
- **Can be improved by**
  - Additional tile layers
  - Position reconstruction with double-sided readout (?)



Summary and Prospects

- **Double-sided SiPM-readout under study to improve performance of strip with small-cell (10μm) SiPM**
  - Random hit can be highly suppressed by taking coincidence at SiPMs at both ends
  - Twice longer strip is necessary to avoid increasing # of SiPMs
- **Looks promising**
  - Higher light yield (N_{pe}~20)
  - Excellent uniformity
  - Noise hits suppression works as expected
  - Possibility of position reconstruction with double-sided readout
  - Found in MC simulation that calorimeter performance is not worsened with longer strip in terms of highest energy deposit and JER.
- **Next steps**
  - Further performance studies with improved setup
    - Test of position reconstruction
  - Double-sided readout together with bottom-side readout to improve peaky response at strip edge