Using MPPCs for T2K Fine Grain Detector

Fabrice Retière (TRIUMF)
for the FGD group
University of British Columbia, Kyoto University,
University of Regina,TRIUMF and University of Victoria

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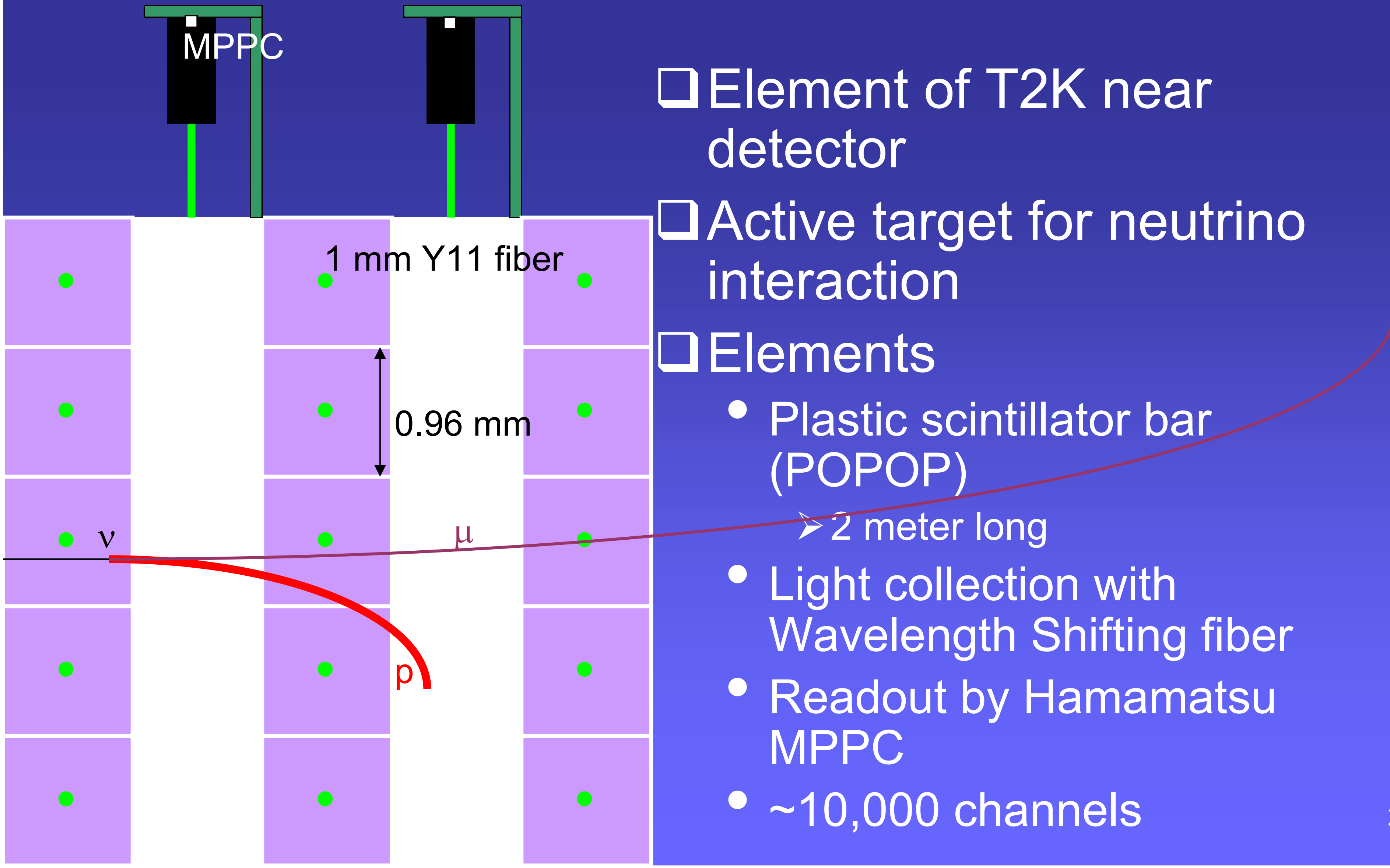
T2K Fine Grain Detector



- Element of T2K near detector
- Active target for neutrino interaction
- Elements
  - Plastic scintillator bar (POPOP)
    - 2 meter long
  - Light collection with Wavelength Shifting fiber
  - Readout by Hamamatsu MPPC
  - ~10,000 channels

FGD physics requirements

- 100% efficiency for MIP crossing a bar
- Particle identification
  - By dE/dx for particle crossing the FGD
  - By range, especially for stopping protons
    - Large energy released (10 MIPs)
  - By detecting Michel positrons for stopping π^+
- Position resolution
  - Bar width & no information along the bar
- Timing resolution
  - ~ 3ns per neutrino interaction for matching with photons in calorimeter

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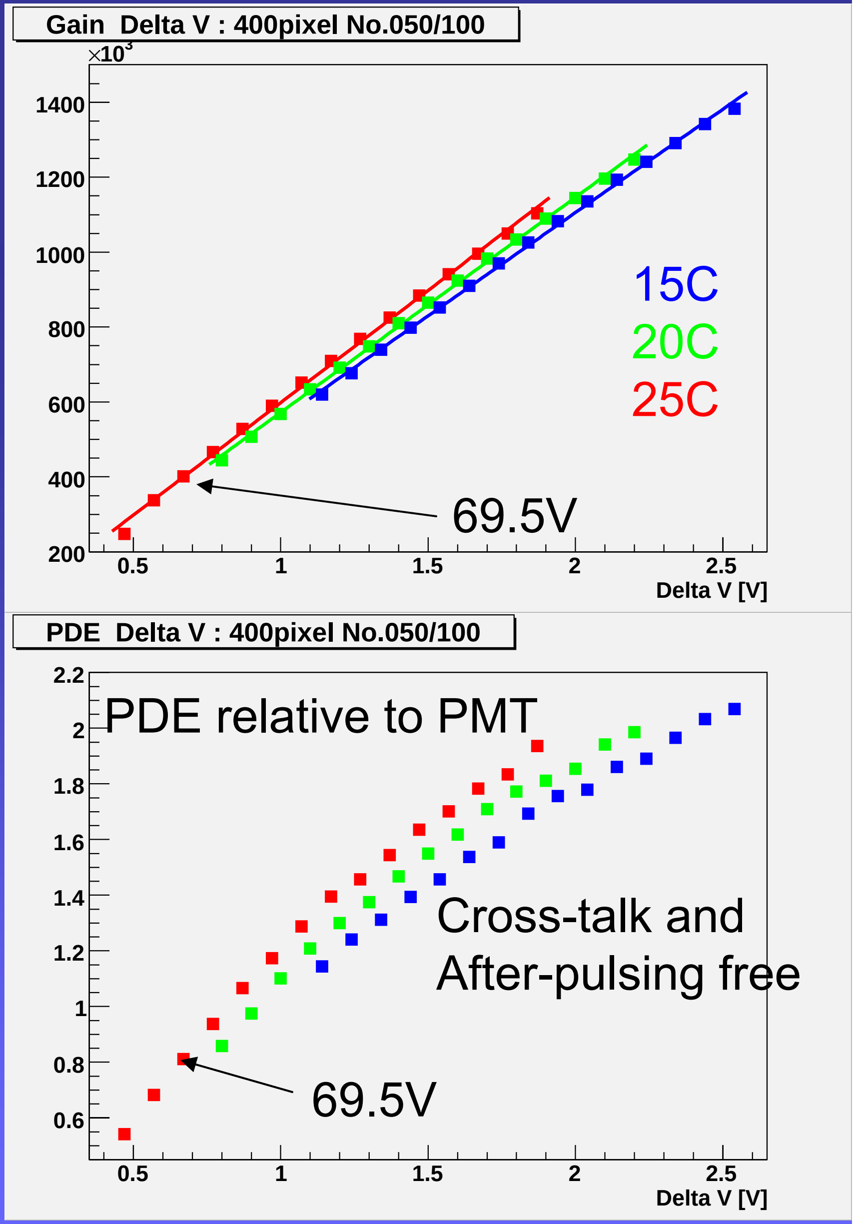
MPPC basic parameters

- ❑ Gain > 2 10^5
  - i.e. 1PE = 2 10^5 e-
    - ➢ Way above typical electronics noise
- ❑ Photo-detection efficiency
  - Comparable or better than PMT
    - ➢ But need to measure PDE for proper wavelength



S. Gomi et al. (Kyoto University)

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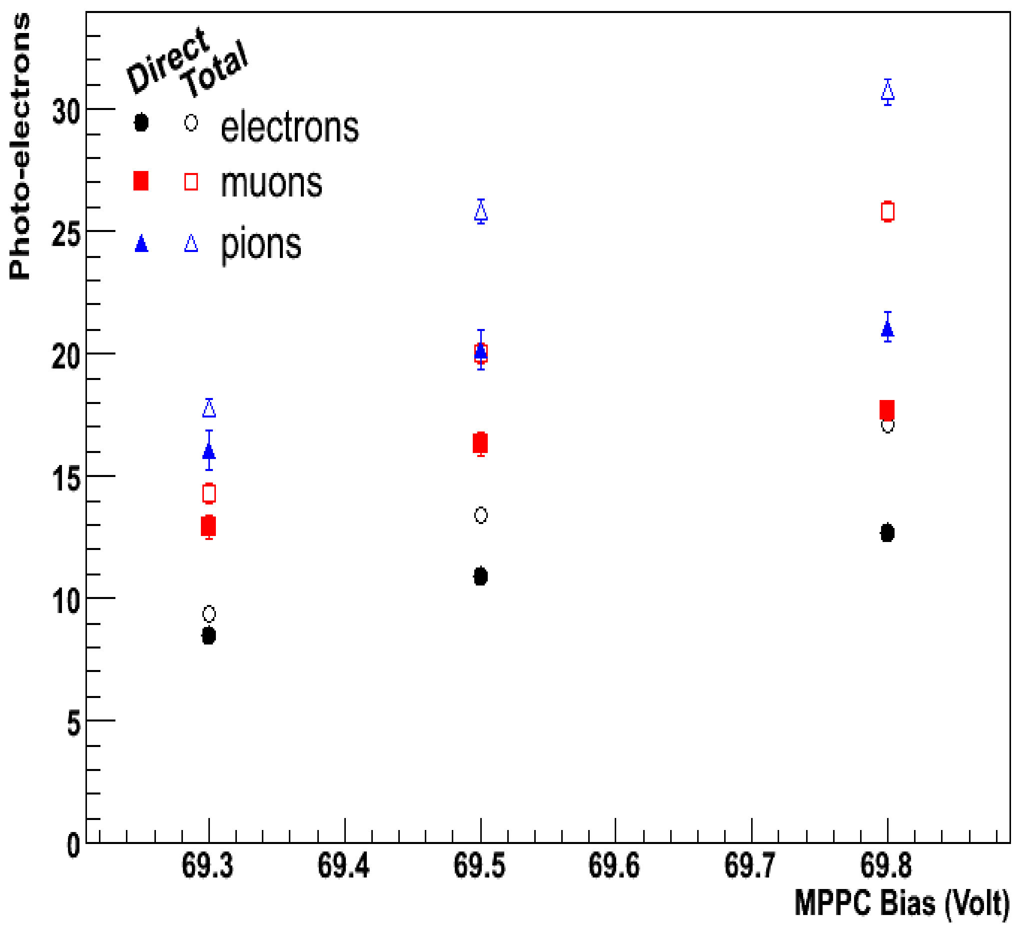
Photo-electron per MIP
MPPC fulfill requirements



- Beam test at TRIUMF
  - 120 MeV/c particles
- Electrons are minimum ionizing
- Worst case scenario
  - No fiber mirroring
  - End of the bar
- More than 10 direct PE even at 69.5V
  - No need to run at higher voltage
- Issue of Fiber-MPPC coupling still being addressed
  - New coupler
  - 1.2x1.2 mm^2 MPPC

MPPC fulfilling requirements

- Quantum efficiency
  - For 100% efficiency need more than 10 PE per MIP
    - Go for at least 15 PEs per MIP
- Energy resolution. Not directly a MPPC issue
  - Driven by photon statistics (~25% for 15 PE)
    - Increase quantum efficiency would help
- Timing resolution.
  - Not a MPPC issue in principle (fast)
- Dynamic range
  - 400 pixels provide more than 50 MIPs dynamic range due to saturation
- Nuisances: Dark noise, cross-talk, after-pulsing

Reading out MPPCs

- Compromise between timing resolution and integration time
  - Desirable to measure all pulses continuously during beam spill (5 μs) and about 2 muon decay constant (2.2 μs) after spill
  - Chose a waveform digitization solution
    - Use the Switch Capacitor Array designed for Time Projection Chamber (AFTER ASIC)
    - Fairly slow shaper (100 ns rise time)
    - 50 MHz sampling frequency
    - 512 time bin ~ 10 μs total integration time

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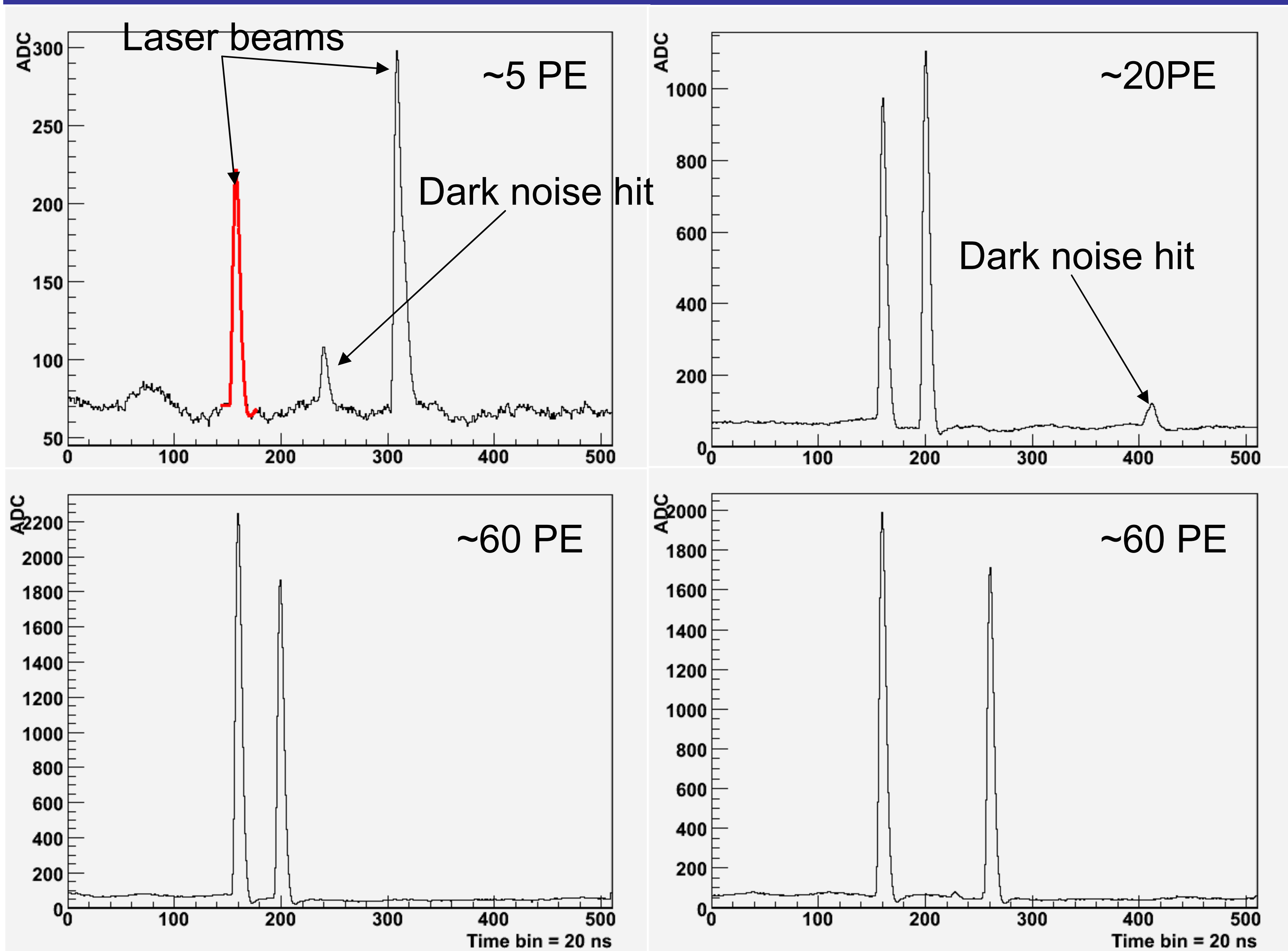
Waveforms from MPPC coupled to AFTER ASIC



Fulfilling the dynamic range and energy resolution requirements

- For calibration need to identify 1 PE peak
  - Noise set to 0.2 PE
- Maximum dynamic range = 400 PE
  - After-pulsing may increase beyond 400 pixel

- ASIC noise ~ 2,000 e-
  - MPPC gain ~ 5 10^5
  - 0.2 PE noise $\Rightarrow$ attenuate by ~50
- ASIC dynamic range = 600 fC
  - Dynamic range 0.2 PE to ~200 PE
  - Need another channel with higher attenuation

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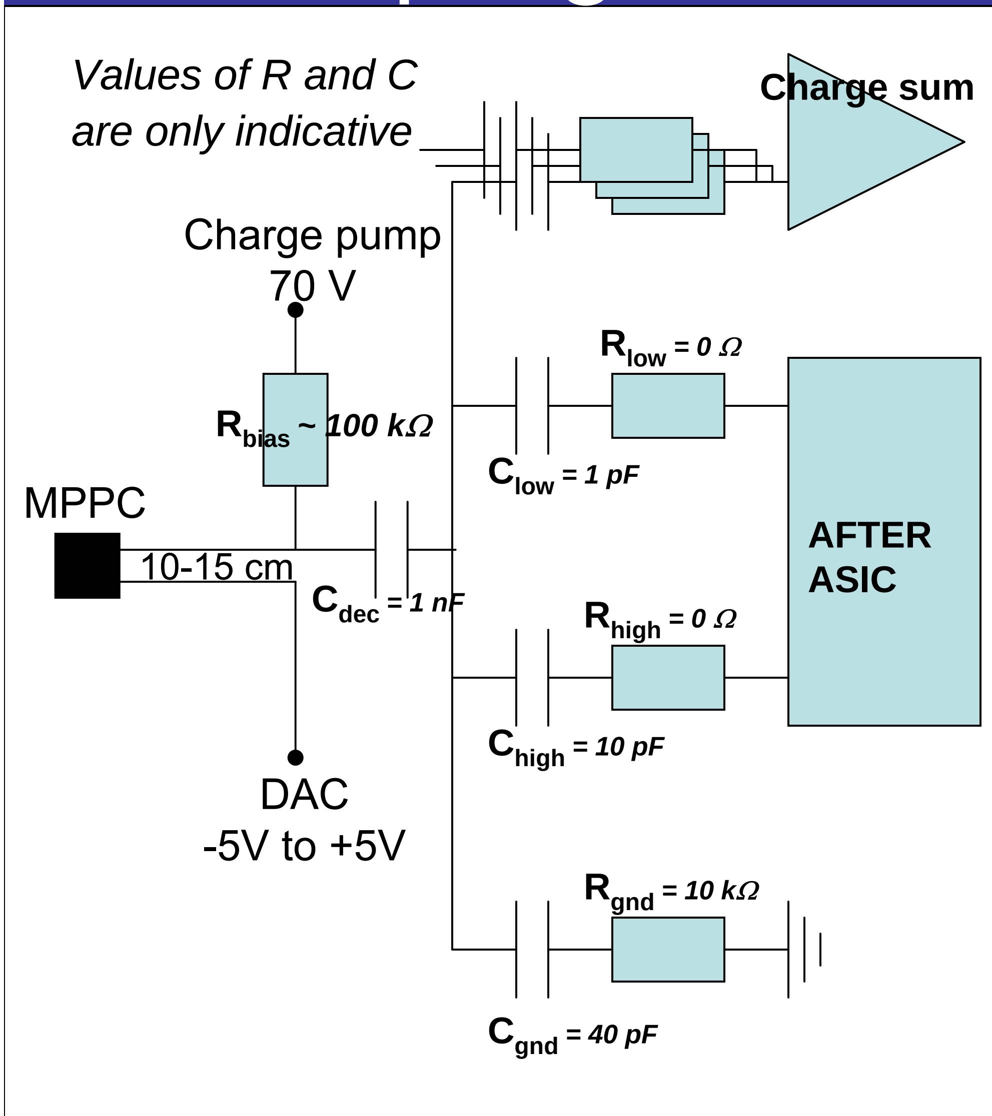
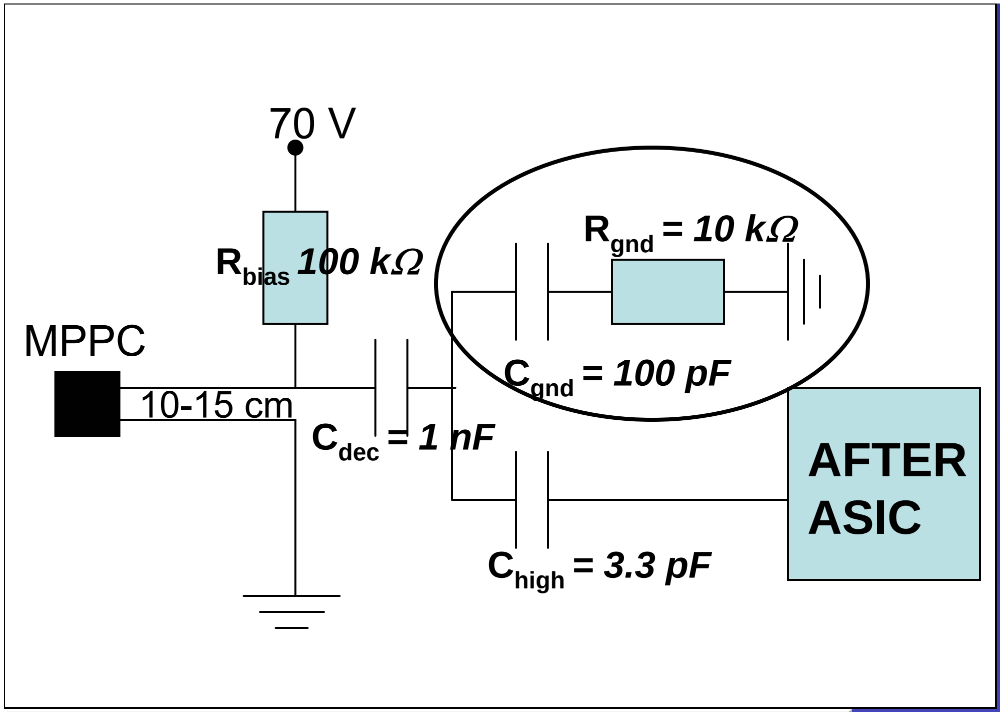
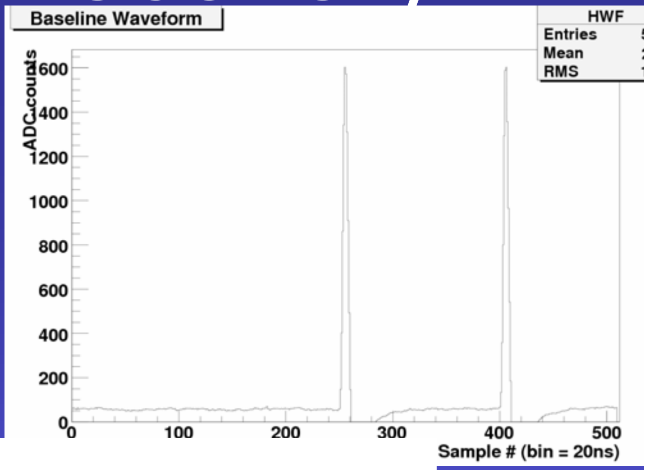
Coupling AFTER ASIC to MPPC

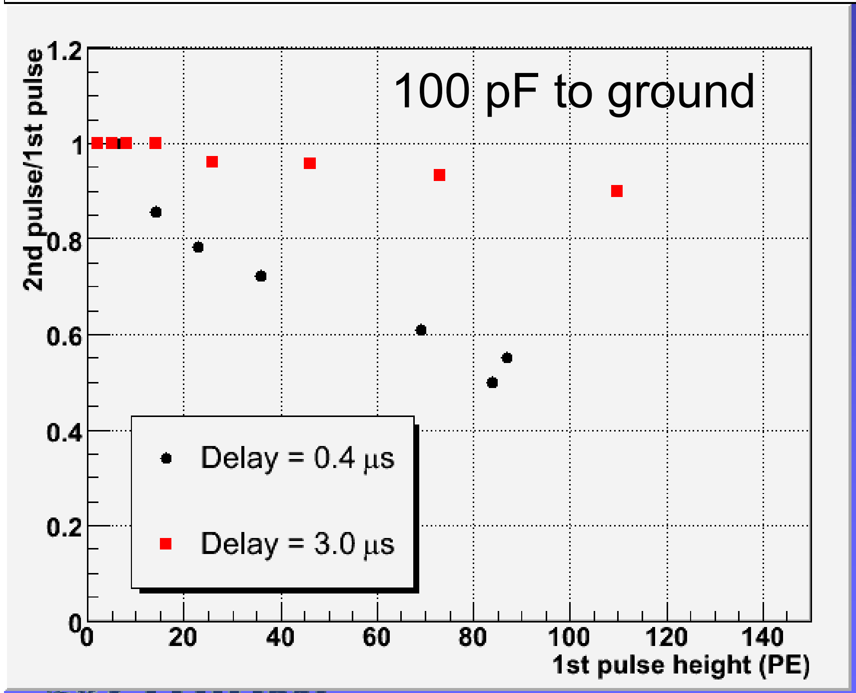


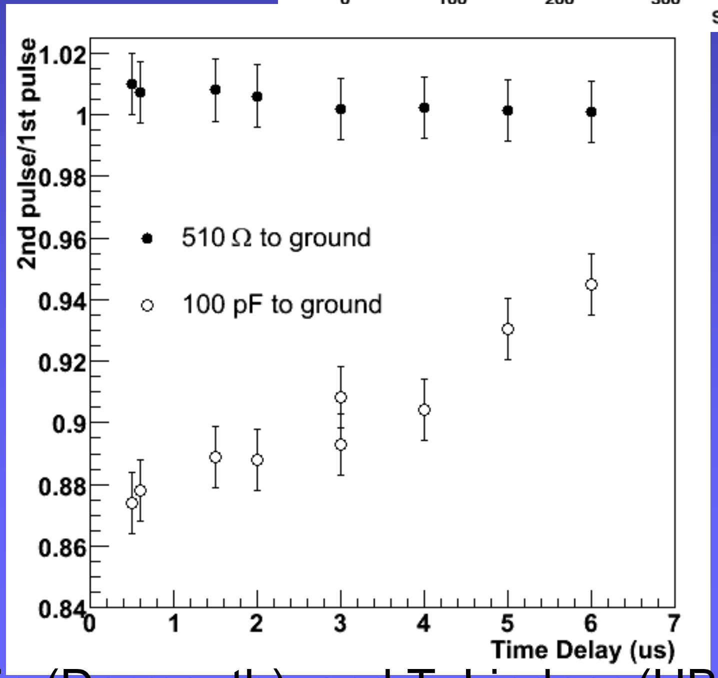
- Issues
  - Attenuation
    - High/low input to ASIC
  - Low input capacitance
    - Low electronic noise
  - Noise from resistors
  - MPPC recovery
    - Require small R_{bias} with purely capacitive termination
  - Minimize reflections (50 Ω line)
  - Pulse shape
- Solution
  - Not clear yet. Some answer from Spice simulations
  - Building a specific 8 channel prototype

Pulse shape and recovery









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N. Jain (Darmouth), and T. Lindner (UBC)

Timing resolution

- Obtained by fitting waveforms
  - Fit rising edge only
- Source of fluctuations
  - Photon arrival time
    - Fiber and scintillator decay constants
- Waveform distortion
  - Dark noise
  - After-pulsing
    - Need to measure after-pulsing to evaluate effect

Configuration	Resolution for MIP (20 PE)
Simulations + waveform fit	3 ns
Data + full waveform fit	5 ns
Data + rising edge fit	4±1 ns

Beyond the gross features
Estimating the MPPC Nuisances

- Dark noise
  - Add pulses. Increase data size
    - But useful for gain calibration
  - At <500 kHz, does not affect timing and energy resolution
- Cross-talk
  - Marginal worsening of energy resolution (if <20%)
  - Increase number of PE
    - May skew timing resolution
- After-pulsing
  - Worsen timing resolution when fitting full waveform

Measuring Dark noise, cross-talk and after-pulsing

- Fast recovery biasing scheme: no resistance in series
- Trigger on Dark noise hits (~0.3 PE threshold)
- Use fast amplifier (CAEN N978)
- Use 1 GHz digitizer (CAEN V1789)
- Search for pulses
  - Extract MPPC*Amplifier response function
  - Search for pulses based on rise time + fall time + amplitude criteria
  - Fit by a superposition of response functions
    - Add more pulses if poor fit (partial pulse overlap)
  - <u>Pulse finding is the main source of systematic errors</u>

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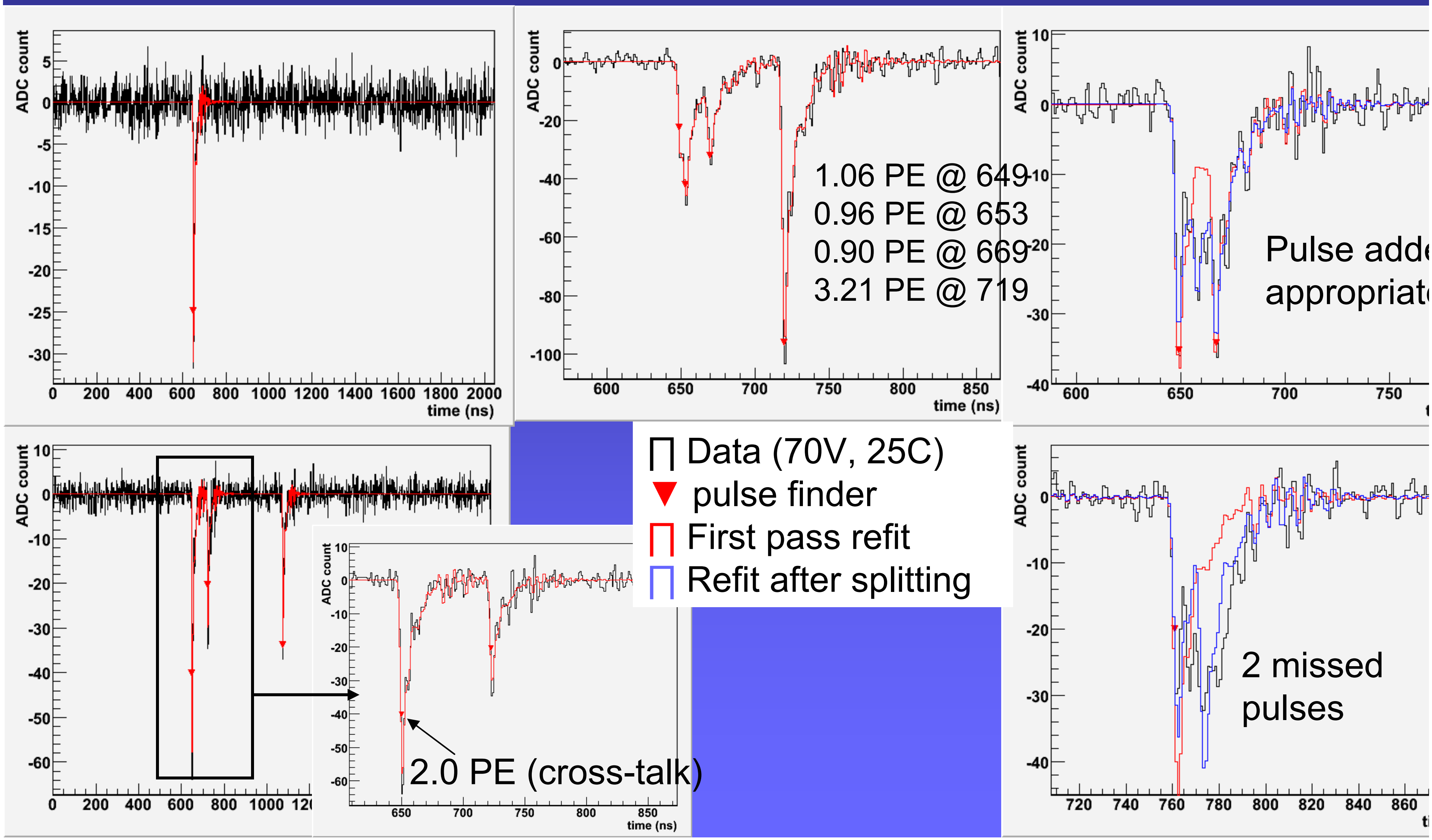
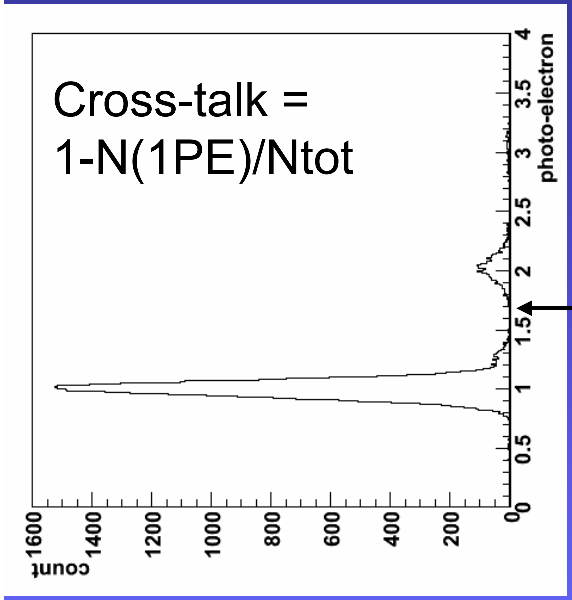
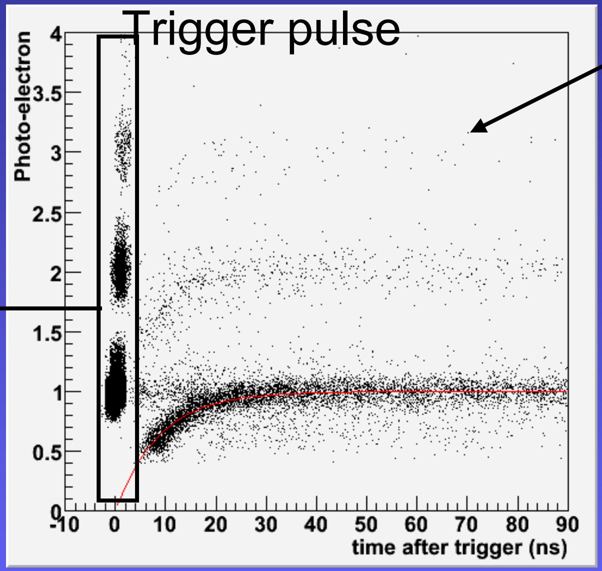
Typical waveforms with after-pulsing test setup

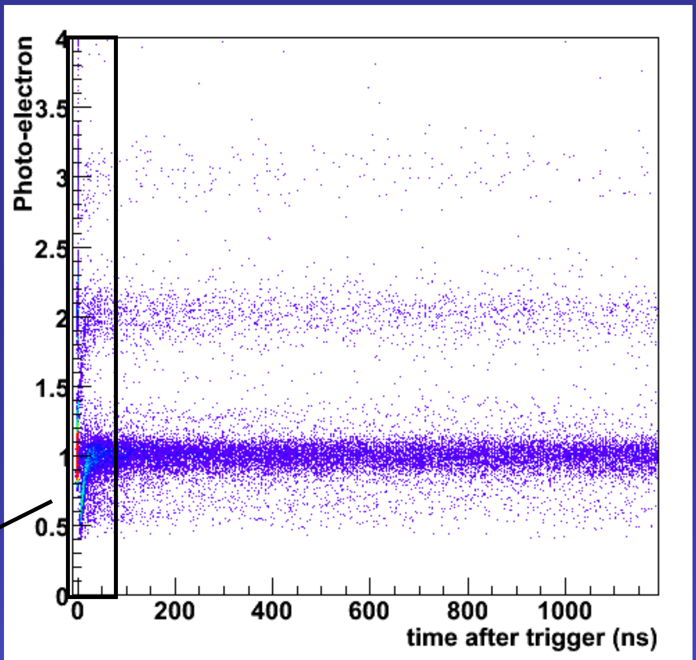


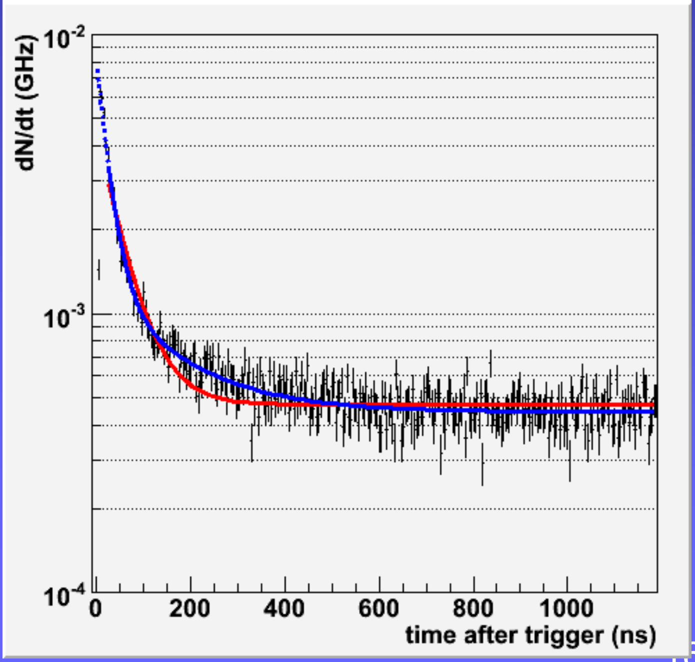
Amplitude vs time for all pulses

70 V, 25C

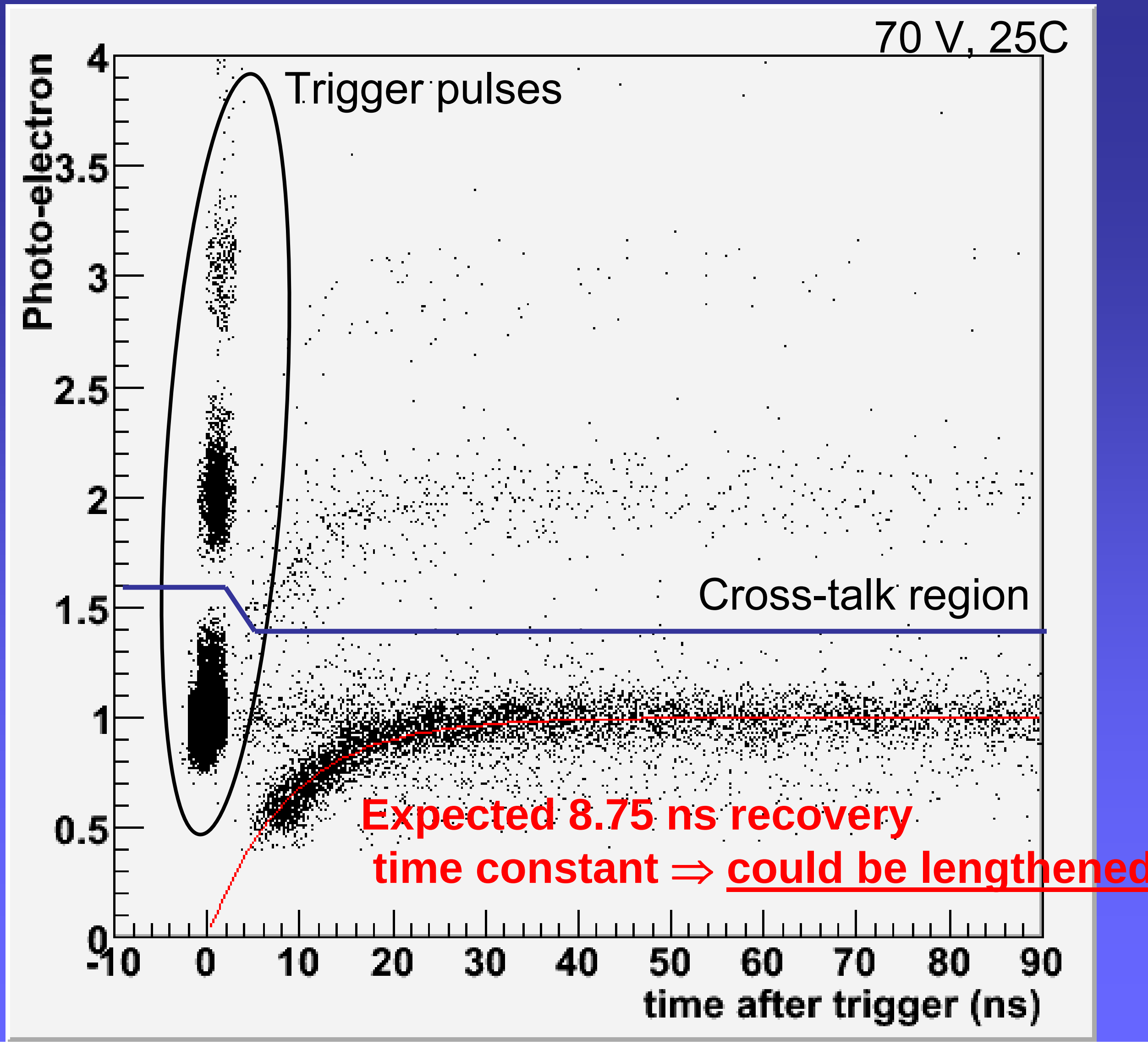








Hit amplitude vs time



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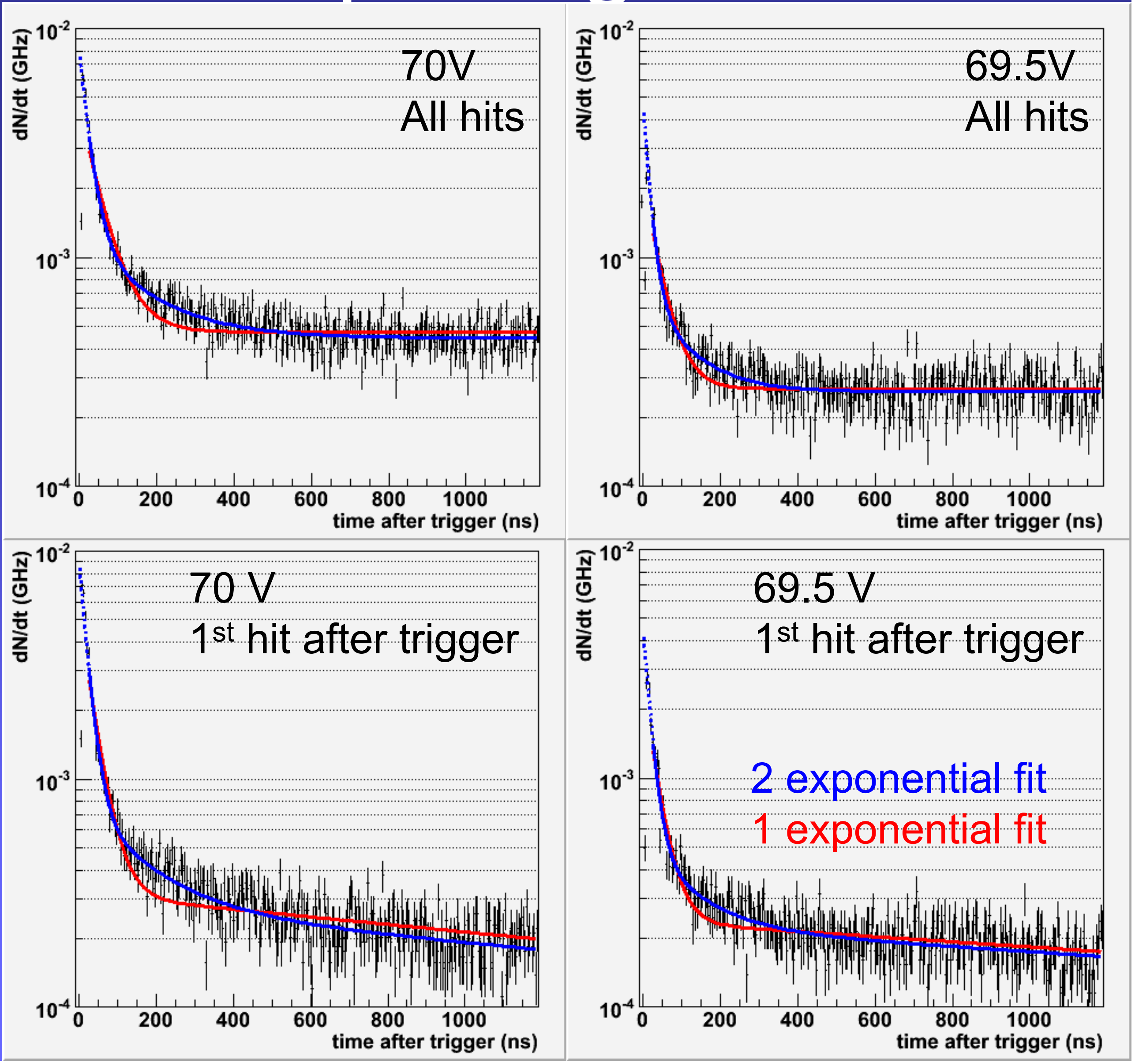
Reducing after-pulsing by playing with recovery time

- It is possible to reduce after-pulsing by increasing the recovery time
  - Resistance in series with bias
  - Introduce dead time after the pulse
    - Is there an acceptable compromise?
  - For the FGD, readout issue may force us to run with a long recovery time
    - After-pulsing is then automatically reduced
- FGD approach
  - Run a low bias voltage: after-pulsing ~ 10%

Separating Dark Noise and after-pulsing

- Count all hits
  - No cross-talk
  - Sensitive to multiple after-pulse
- Histogram the time of the 1st hit after trigger
  - No cross-talk
  - No multiples
    - But more complicated fit



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After-pulsing fit results

- Fit is impaired by low statistics
  - 69.5V and 70V have more statistics
  - Long time constant hard to pin down
    - Increase of constant in all hits expected
  - Short time constant 20-30 ns
    - Dominate the after-pulsing

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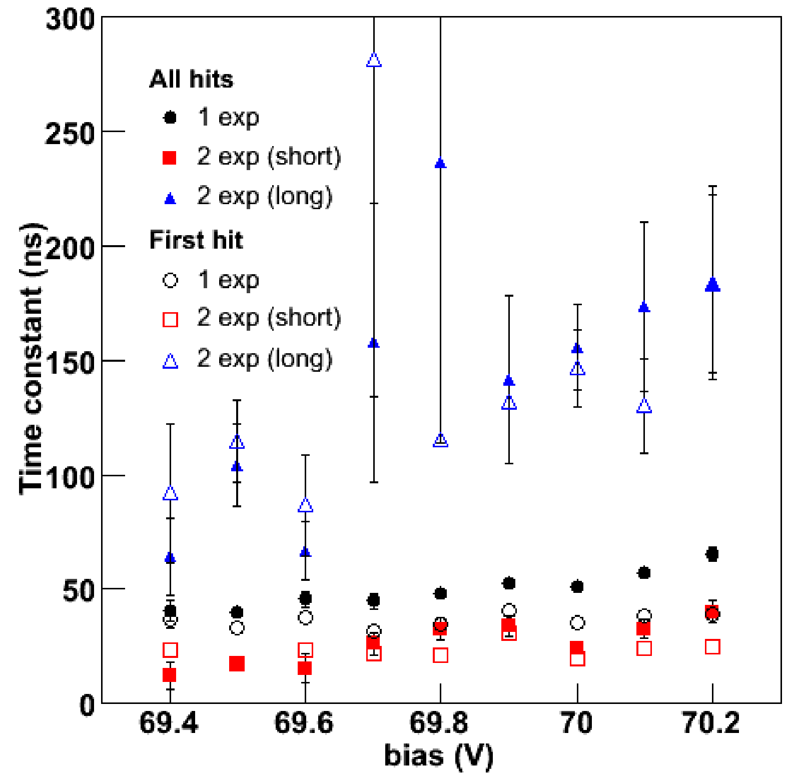
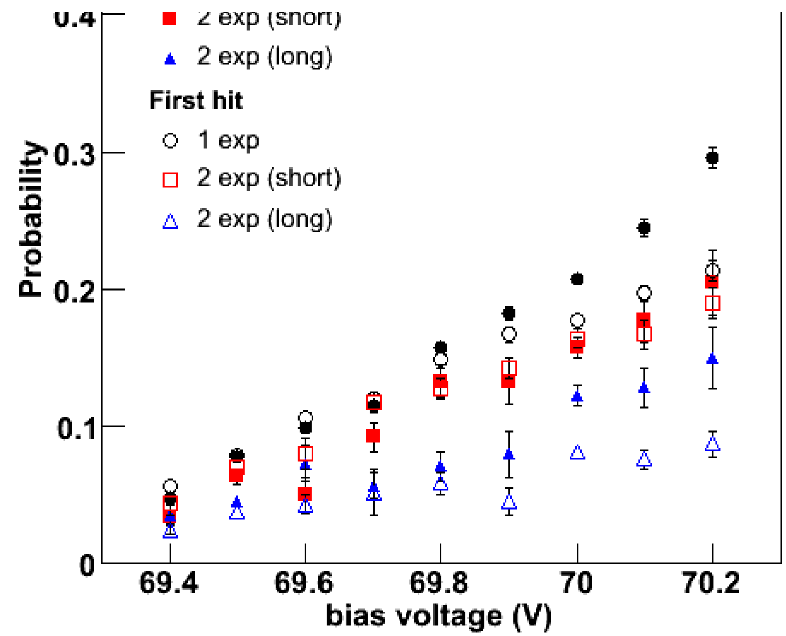
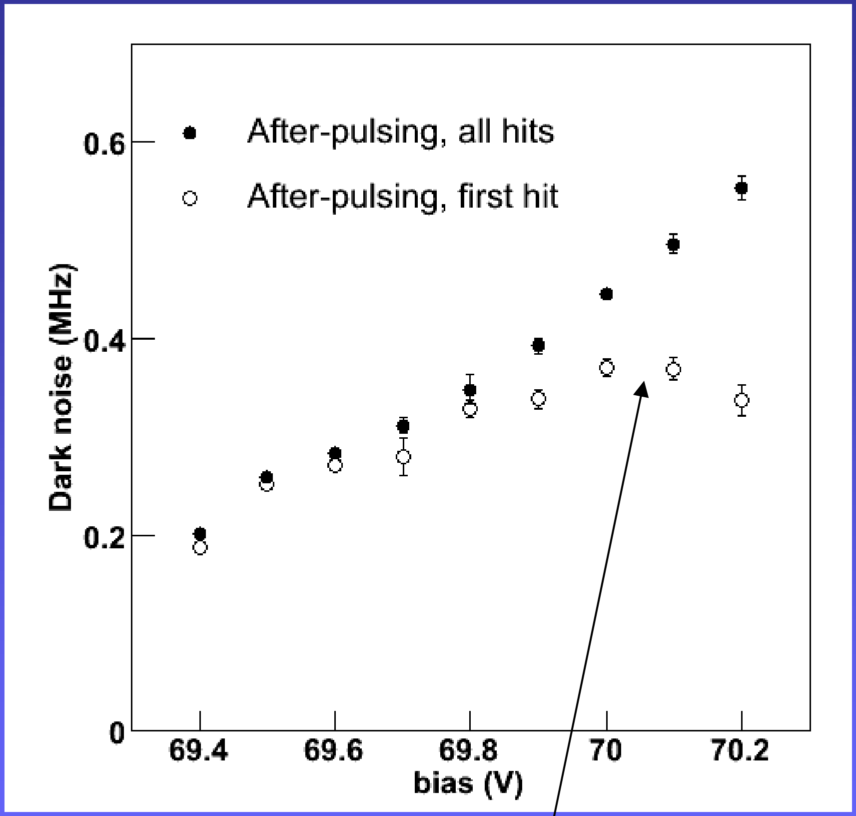
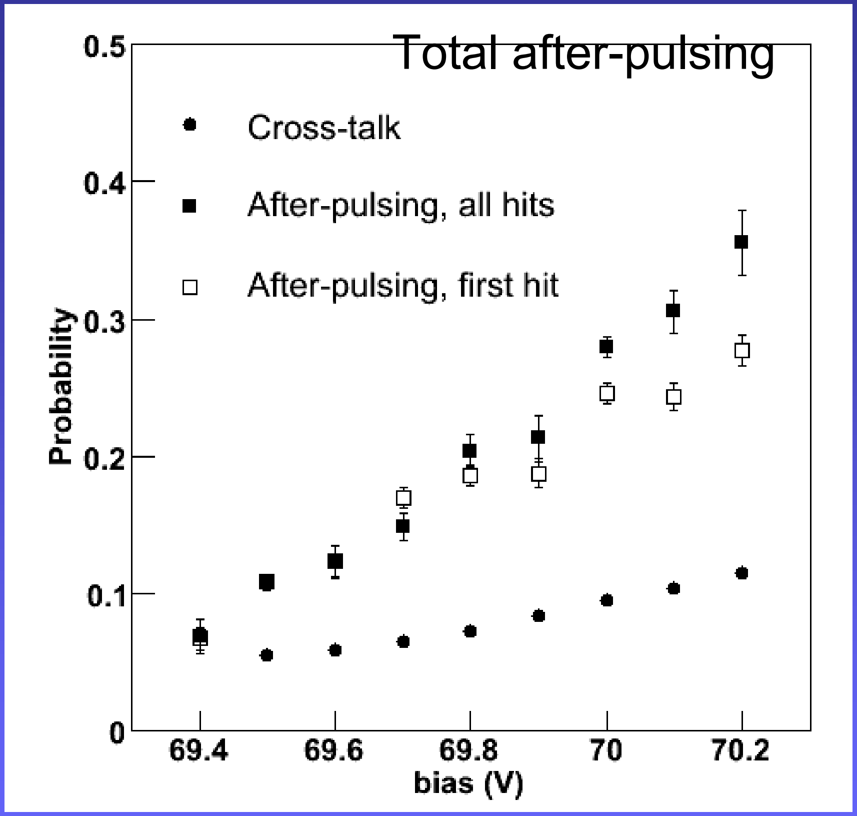




Competing contributions





Is dark noise really saturating and
the visible increase due to after-pulsing?

Conclusions

- MPPC + AFTER combination fulfill FGD requirements
- MPPC nuisances are under control for the FGD application
  - After-pulsing is dominant
    - Run MPPC at low bias to avoid significant after-pulsing
    - Not a problem. Quantum efficiency is large enough
- Investigating interplay between recovery, pulse shape, and after-pulsing
  - Is there an optimum design?

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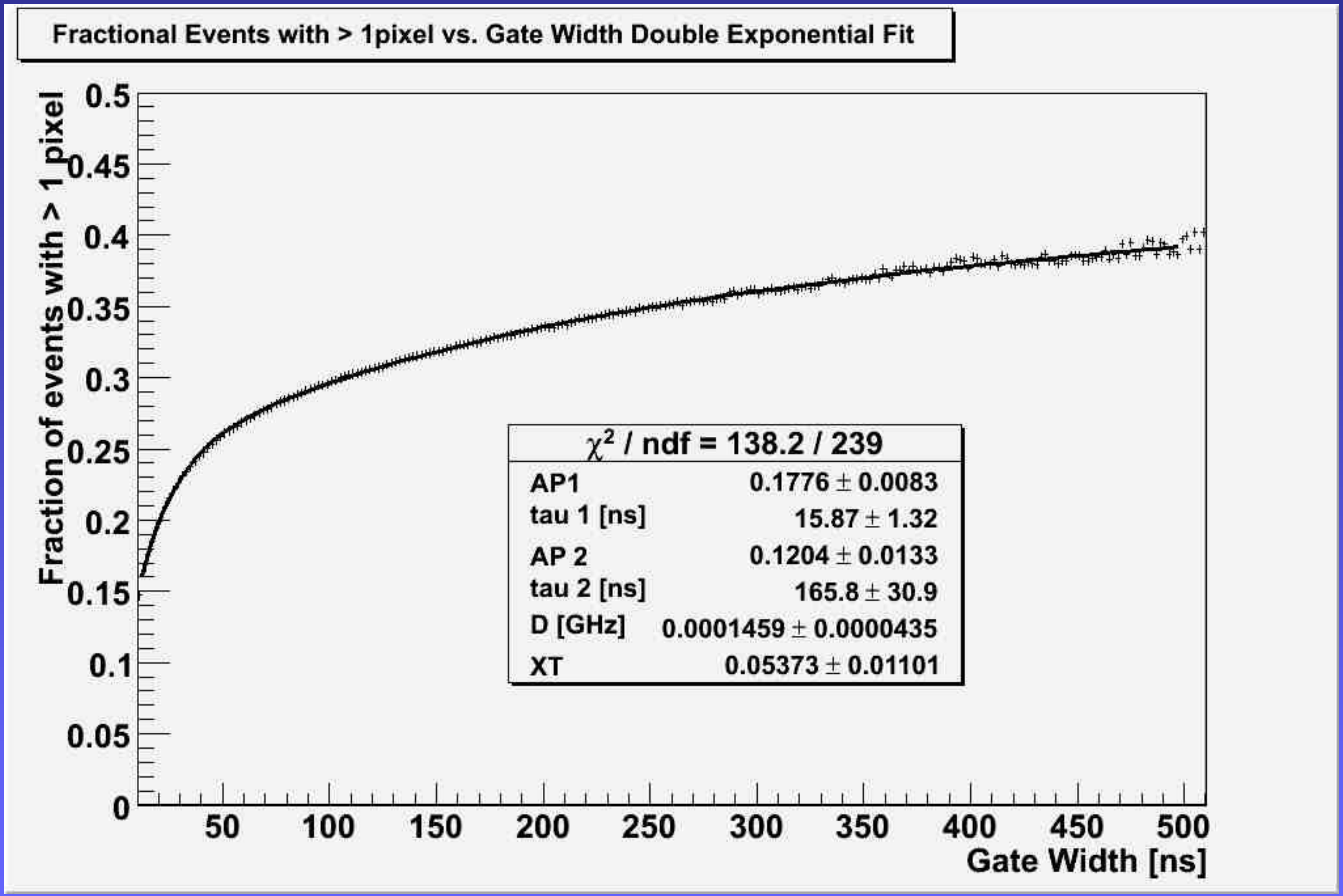
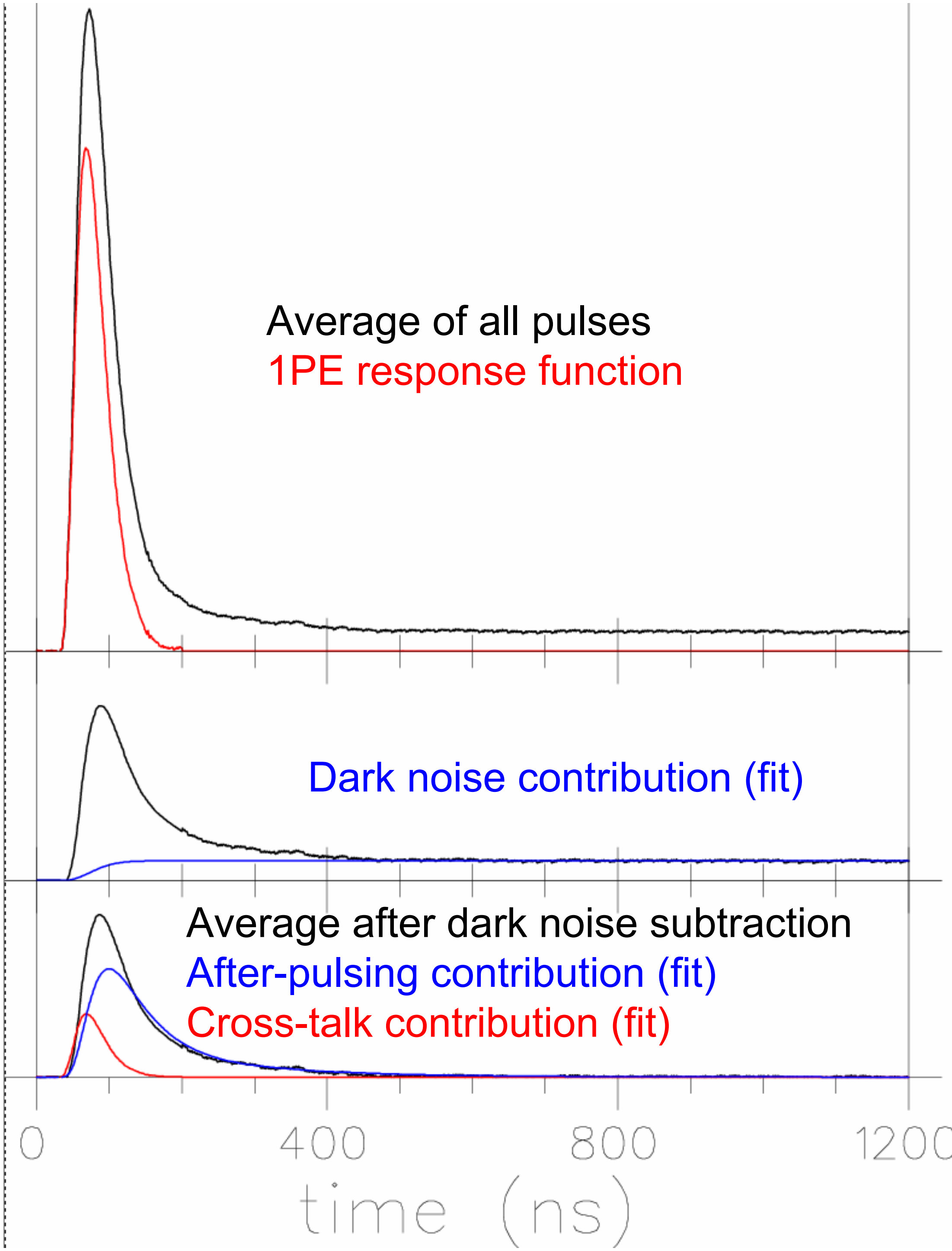
Back-up

Measuring after-pulsing with gate technique



Measuring after-pulsing with average technique



R. Tacik (U. Regina)

1st hit timing distribution fit function

$$dN/dt = e^{-DN\cdot t} * \left[(1 - Ap - Ap \cdot e^{\frac{-t}{\tau}}) DN \right] + \frac{Ap}{\tau} e^{\frac{-t}{\tau}} e^{-DN\cdot t}$$

DN = dark noise rate
Ap = After-pulsing probability
τ = After-pulsing time constant

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