Electron & Ion Detection Solutions

You can detect the difference

Sub-nanosecond Detection of Charged Particles with Fast Scintillator and Photon Sensor

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Outline

- Background and motivation
  - Applications of charged-particle detection with ns time resolution
  - Limitations of current technologies
- El-Mul detection solutions
  - Detector concept and architecture
  - Detector specifications
- Experimental results with various light sensors
  - PMT
  - HPD
- Summary and Outlook

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Background

- Applications for fast particle detectors (0.5-5 ns time resolution) in numerous fields :
  - Medical Devices
  - Particle Physics
  - Electron Microscopy
  - Time-of Flight Mass Spectrometry (TOF-MS)

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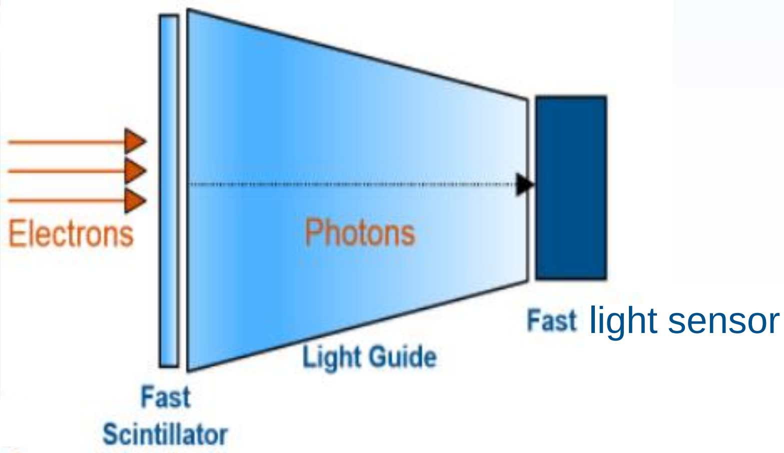
- Applications for fast particle detectors (0.5-5 ns time resolution) in numerous fields :
  - Medical Devices
  - Particle Physics
  - **Electron Microscopy**
  - **Time-of Flight Mass Spectrometry (TOF-MS)**
- Need for fast detector in SEM to increase throughput (semi-conductor) and reduce charging (semi and analytical tools)
- Need for sub-ns detector in TOF-MS to improve mass resolution for large molecules ($\Delta t/t \propto \Delta m/m$)

Existing Detectors and their Limitations

Detector	Limitation
Microchannel Plate (MCP)	• Low fill factor • Short lifetime • HV electronics
Electron Multiplier (discrete dynodes)	• HV electronics • Contamination
Plastic scintillator & light sensor	• Short lifetime

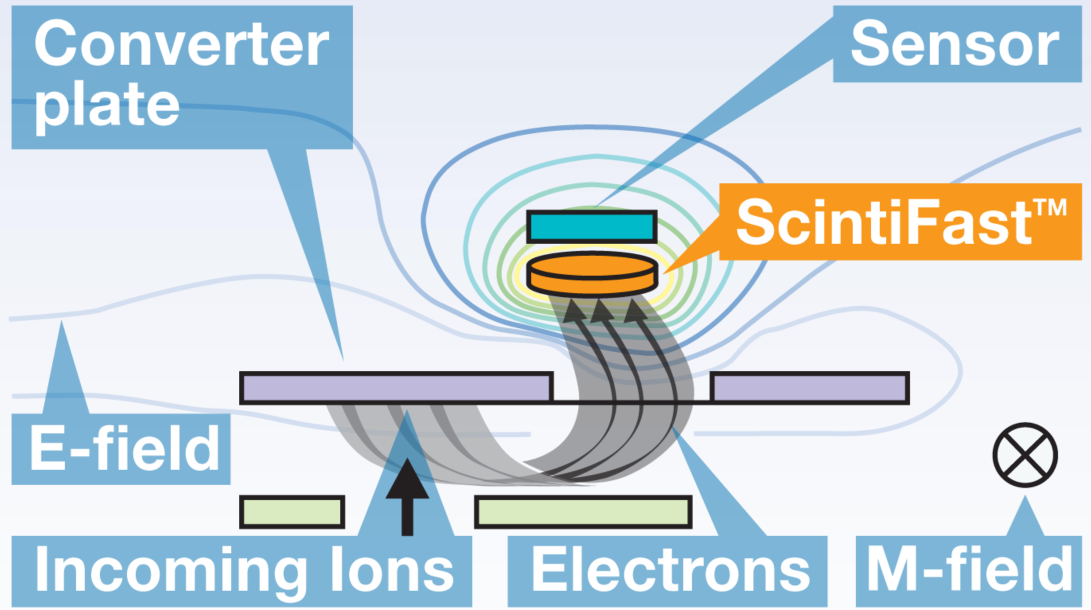
El-Mul Solution:

fast inorganic scintillator SCINTIFAST™ + light sensor



El-Mul TOF Detector Configurations

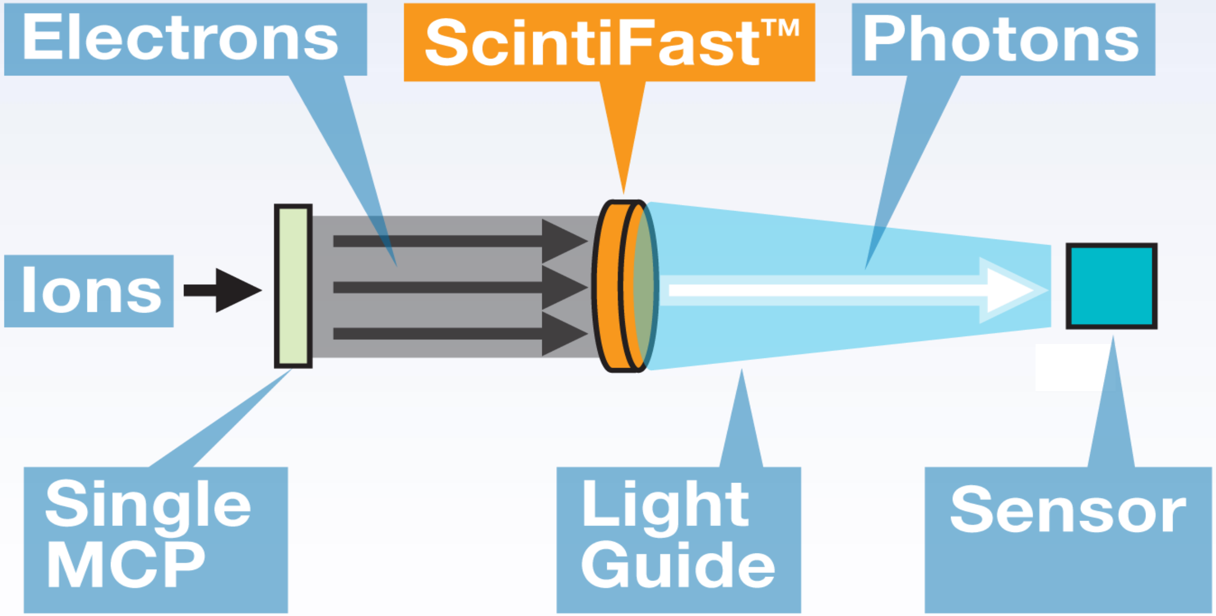
- MTOF™



- Electrons directed to scintillator by ExB field
- Near 100% detection efficiency (depends on convertor efficiency)
- Switchable polarity
- Cost-effective, high lifetime (no MCP)

El-Mul TOF Detector Configurations

- Optimax™



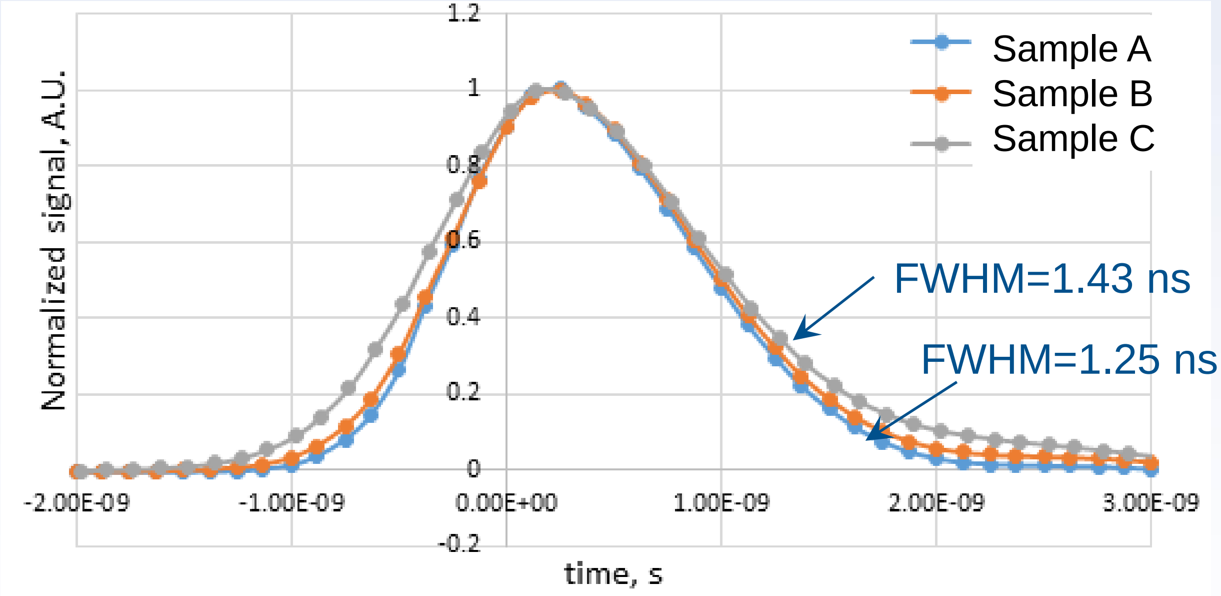
- High Gain
- Switchable polarity

Detector Main Specifications

Parameter	Ideal	Compromise	Comments
Temporal resolution (Pulse FWHM)	<0.5 ns	<1.0 ns	for TOF detector; <5 ns for fast SEM detectors
Gain	>500,000	>50,000	ideally detector can read single ion signal without MCP nor additional electronics
Dynamic range (pulse mode)	single ion to 1,000	single ion to few 100's	
Average output current	>100 μA	>50 μA	
Sensor photocathode output for single ion input	>5 ph-e	>4 ph-e	to discriminate real signal from spontaneous emission

Scintillator response with PMT

- Scintillator measured with Hamamatsu's PMT9880



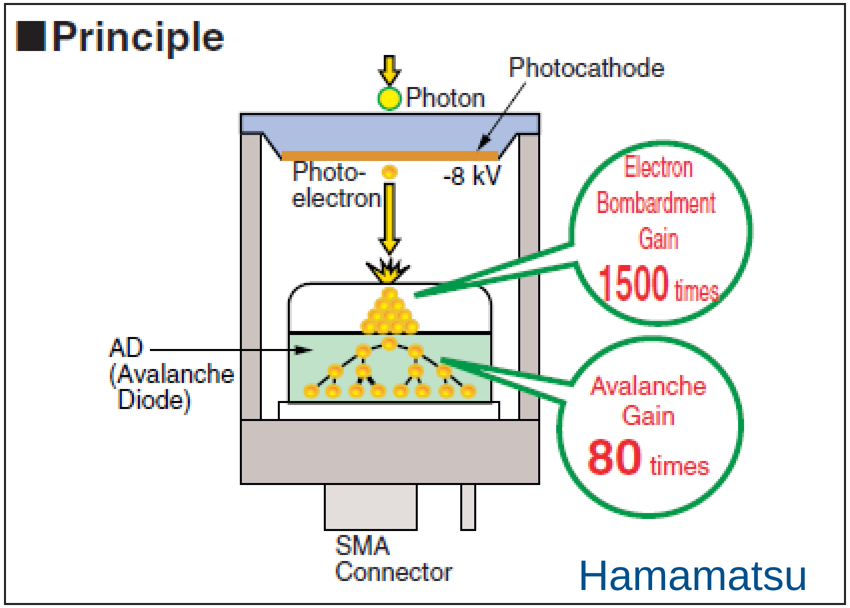
- PMT9880 FWHM: 1.2 ns → Time resolution limited by PMT response

Need for faster light sensor

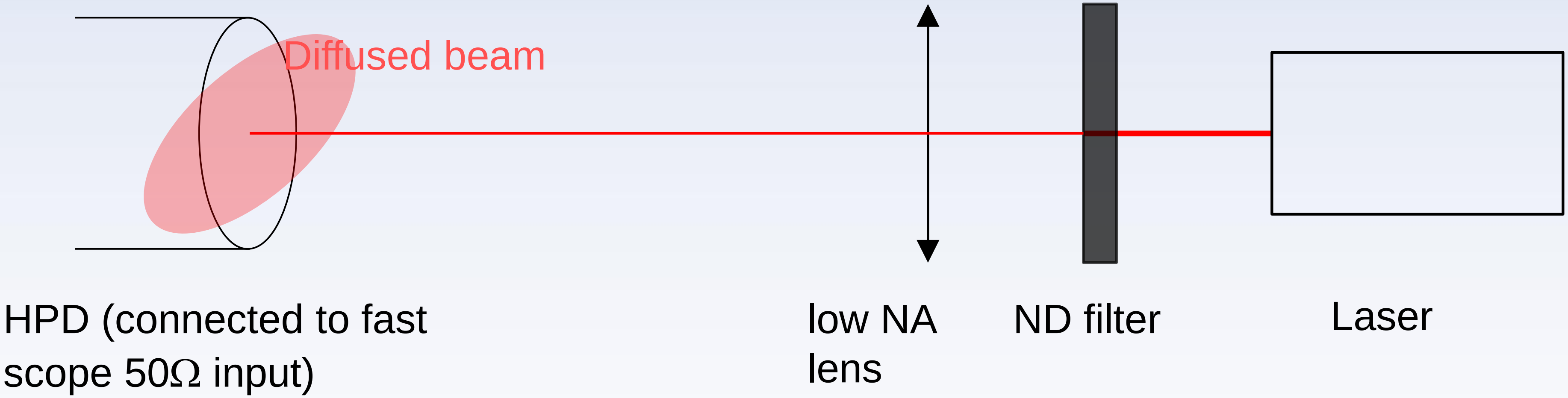
HPD characteristics

R106467U-06 (Hamamatsu)

- Nominal FWHM: 650 ps
- Maximum gain 120,000
  - 6 mV output on 50 Ω for single ion input (assuming 4 ph-e per ion)
- Low gain fluctuations
- Dynamic range: see below
- Effective area smaller than PMT9880

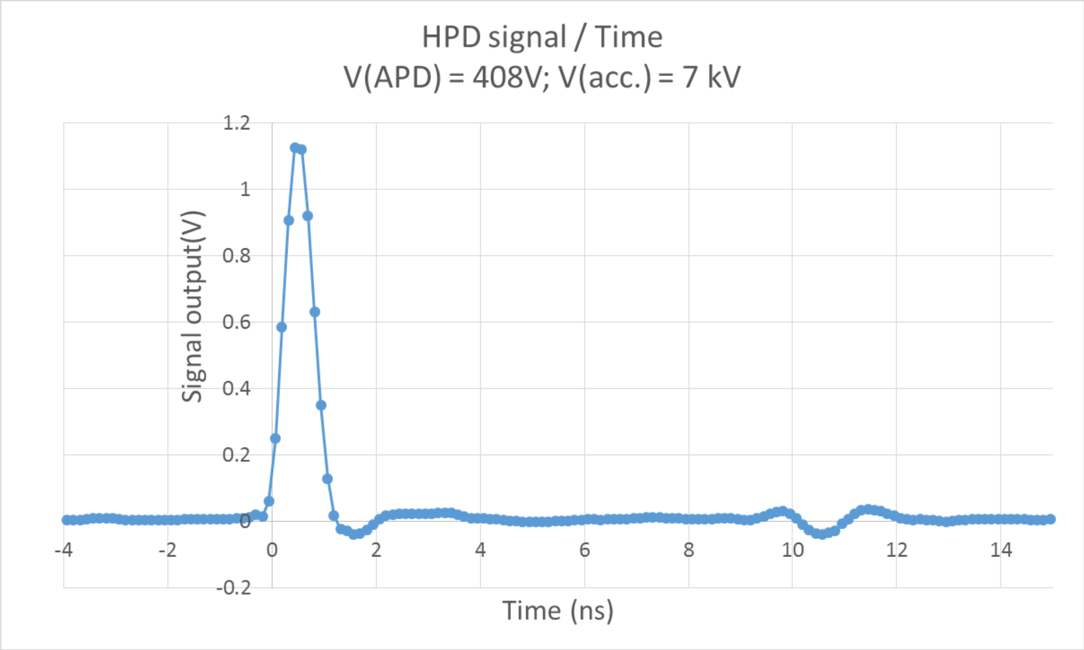


HPD evaluation with ps laser



- Laser wavelength: 635 nm → QE ~0.5% for HPD
- Pulse width: 80 ps typical, 100 ps max. **<< HPD pulse width**
- Tunable repetition rate – 20 kHz to 20 MHz

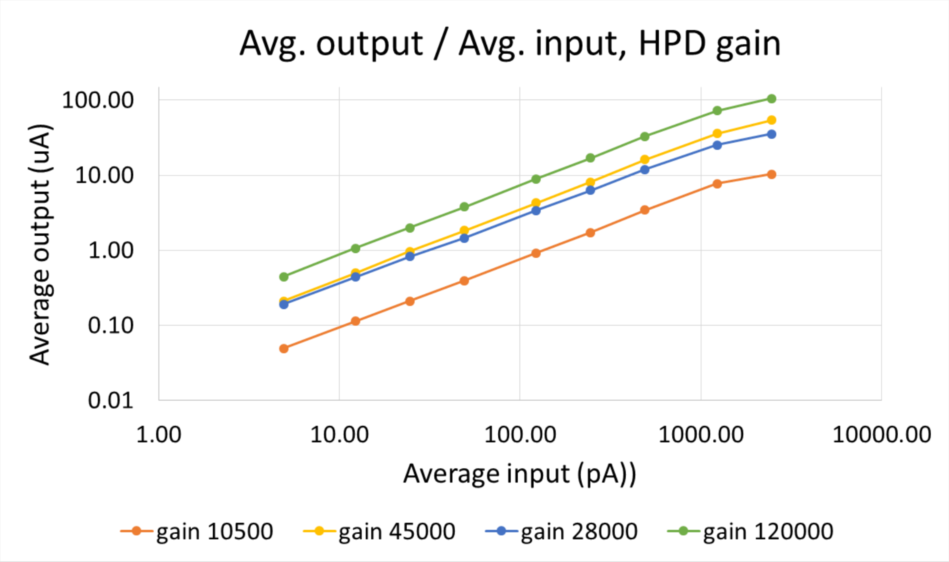
HPD pulse shape

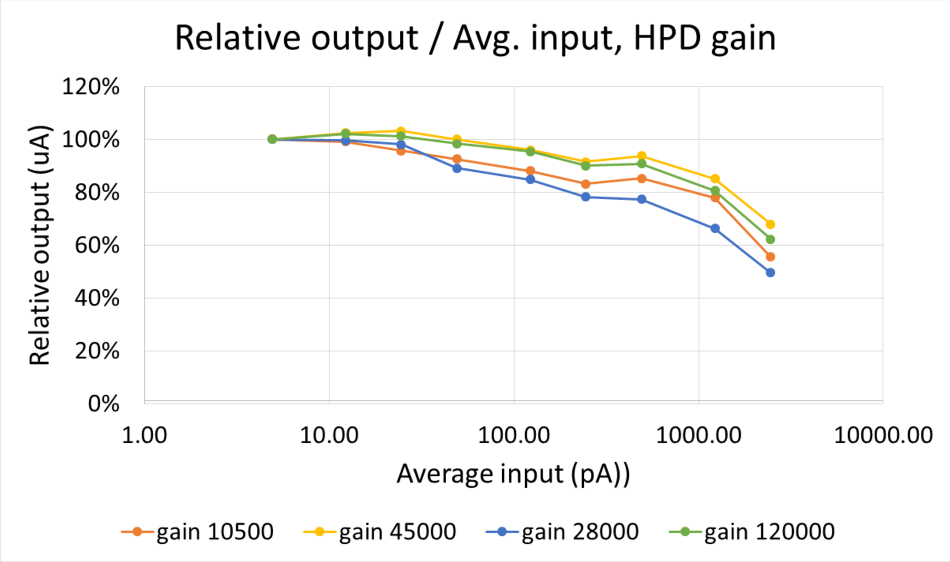


- FWHM = 640 ps
- Reproducible pulse shape; ripple at 10 ns probably from cable
- Post-peak undershoot ~ 4% (maybe from cable)

HPD Dynamic range (average output)

- Repetition period varied from 100 ns to 50 μs

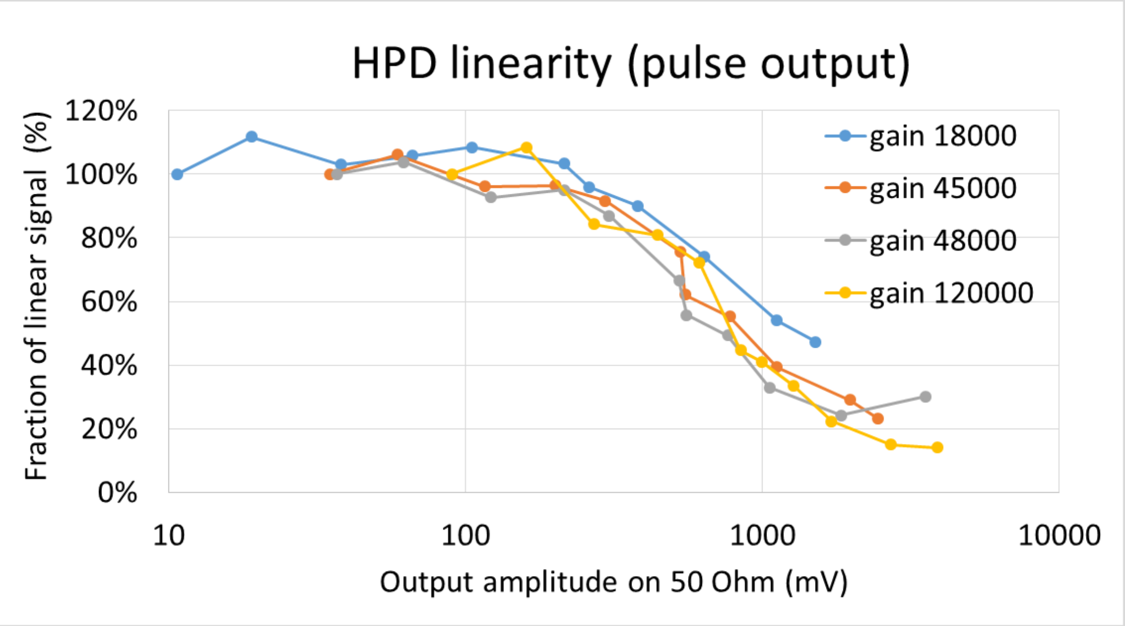




- Linearity of **average output current is input-limited** (not related to gain)
- Linear response up to ~0.4 nA input (i.e. up to ~50 μA output at maximum gain).
- No degradation of timing

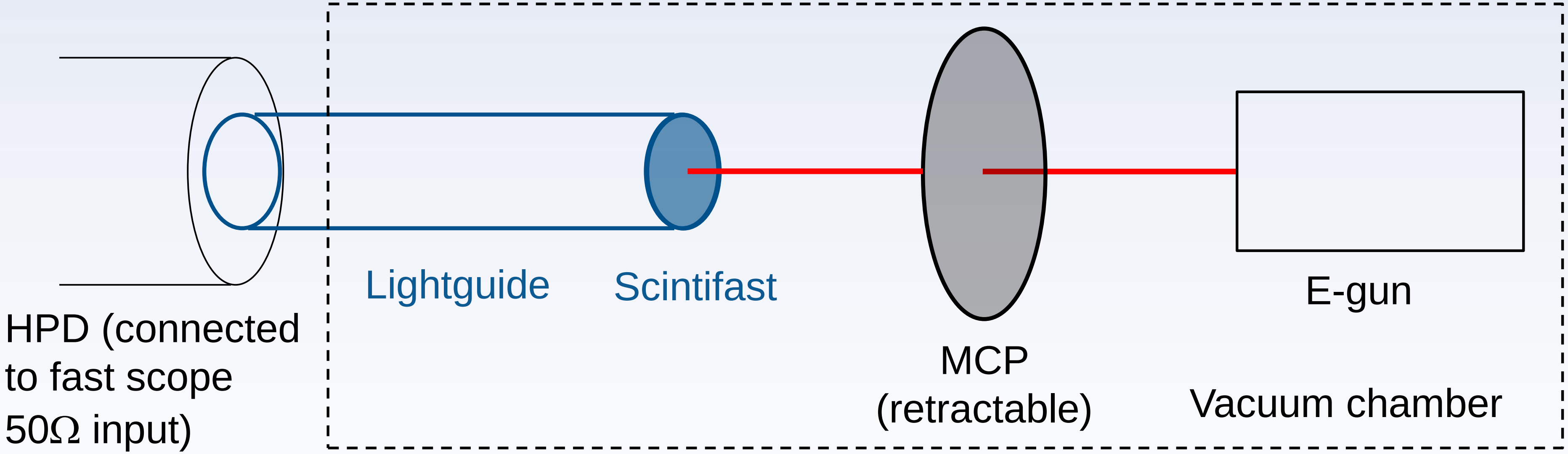
HPD Dynamic Range (pulse output)

- Input intensity changed with set of filters
  - Calibration using PMT R9880 as reference



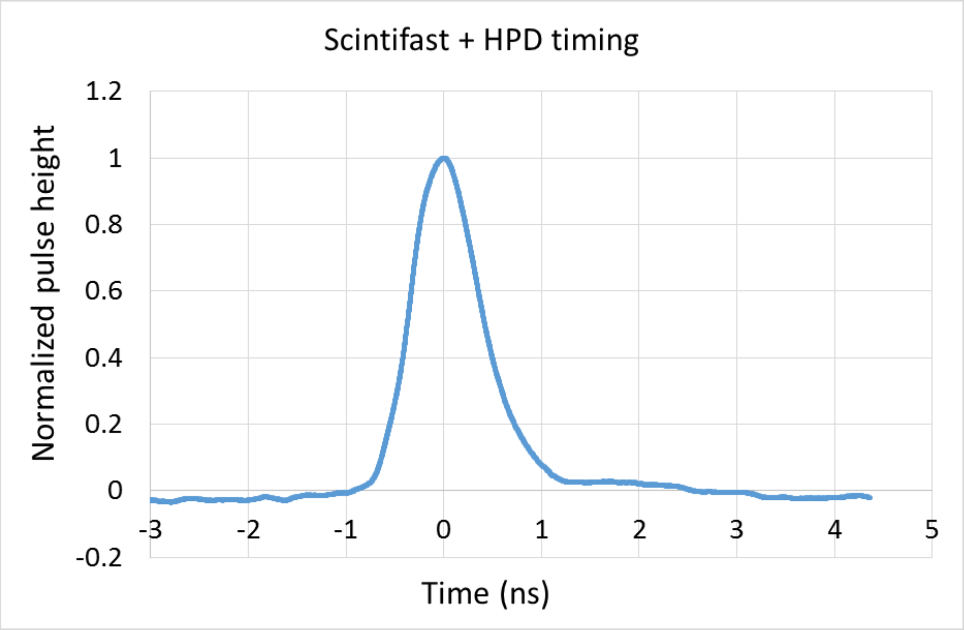
- Linearity of **pulse output current is output-limited** (depends on gain)
  - At gain 18,000: linearity up to ~ 3 orders of magnitude
  - At gain 120,000: linearity up to ~ 2 orders of magnitude
  - No degradation of timing

Scintifast + HPD – experimental setup



- E-gun energy up to 10 kV
- E-gun current < 1 pA (for single event detection)
- MCP can be removed from beam path at will

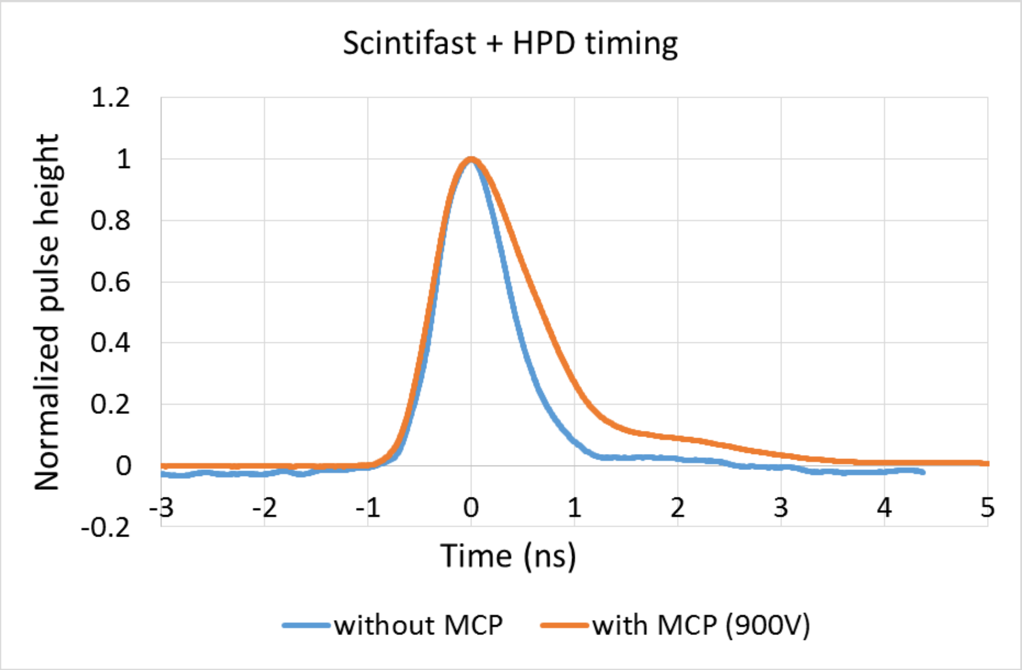
Scintifast + HPD timing – without MCP



- E-gun energy: 10 keV
- Scintifast voltage: +3 kV
- HPD gain: ~120,000
- ~2.5 ph-e per electron (estimate)
- Average of 1024 traces
- **FWHM = 0.79 ns**

Sub-ns time resolution reached with Scintifast™ and HPD

Scintifast + HPD timing – with MCP



- E-gun energy: -10 kV
- Scintifast voltage: +5 kV
- Average of 1024 traces
- FWHM = 1.1 ns

- Pulse broadened by MCP

Summary and Outlook

- Detector concept with inorganic fast scintillator and fast photo-sensor was presented
- Sub-ns electron detection with Scintifast™ and HPD was experimentally proven
- Time resolution is still mainly limited by light sensor
- Next steps:
  - Improve photon yield (scintillator, light collection)
  - HPD + external amplifier (to improve dynamic range)
  - MCP-PMT + external amplifier
  - APD for direct electron detection
  - Si-PM – can it be used for sub-ns?

Electron & Ion
Detection Solutions

You can detect the difference

Thank You!

Questions and Discussion