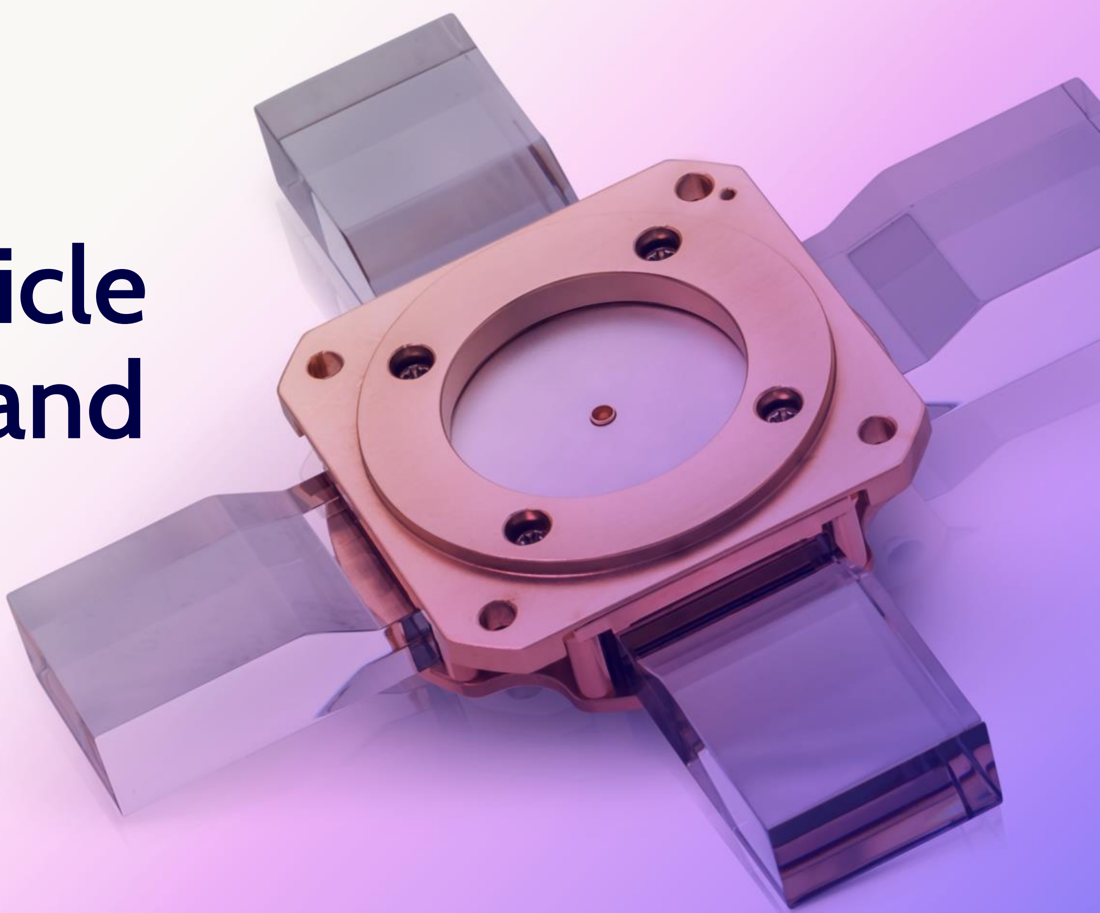
Sub-nanosecond Charged Particle Detector with Fast Scintillator and Hybrid Photodetector



TREDI 2020: 15th “Trento” Workshop on Advanced Silicon Radiation Detectors

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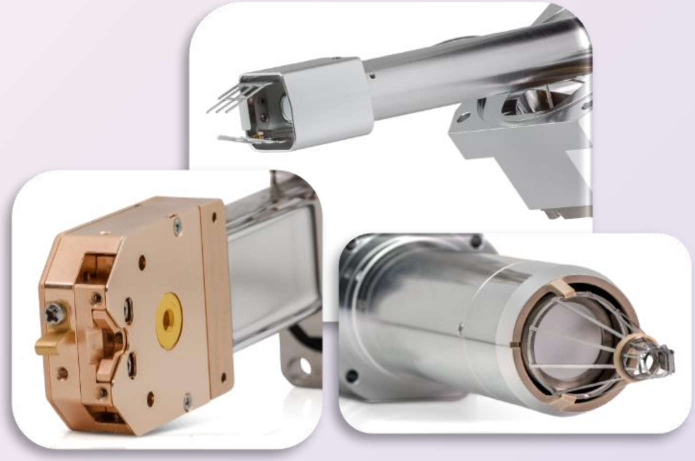
El-Mul Technologies, Ltd.

About El-Mul Technologies

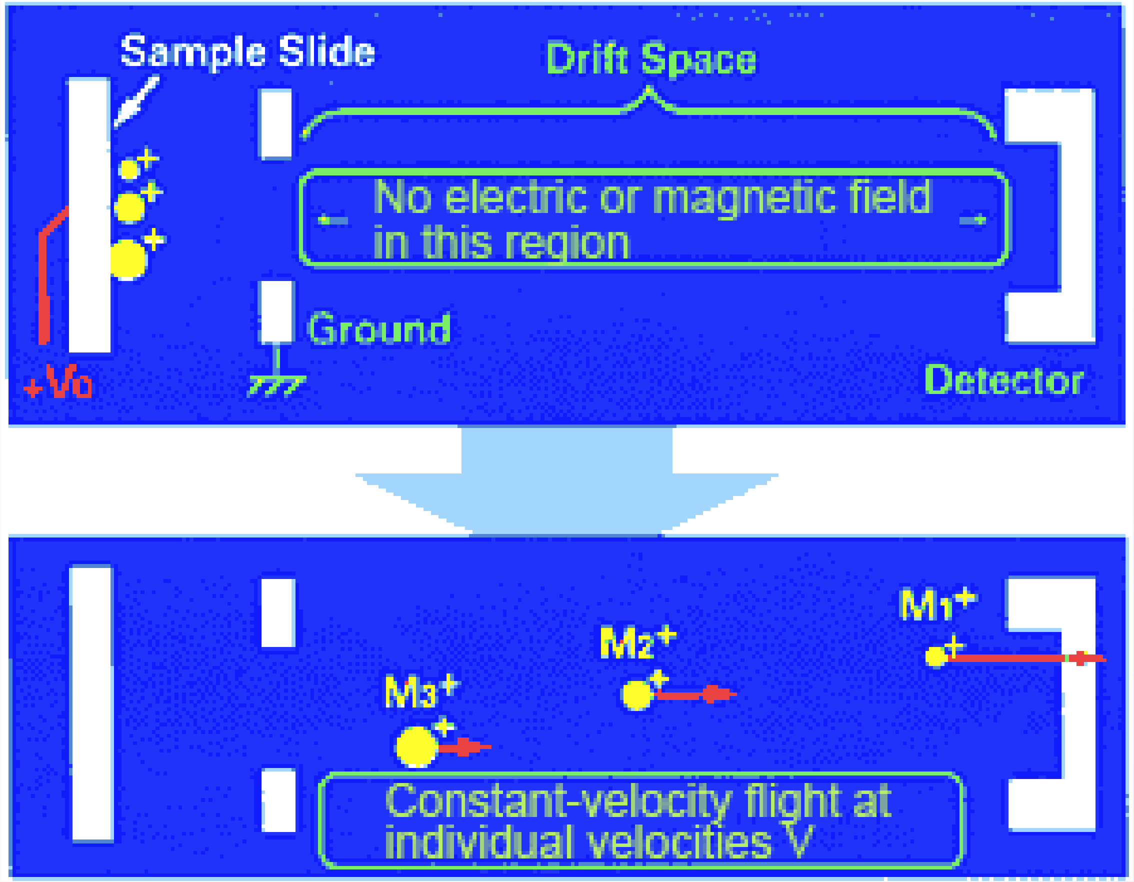
- Located in Rehovot, Israel
- Established in 1992, private ownership
- 37 employees (15 in R&D), clean room production
- Supplier of customized charged particles detectors for various markets and technologies:
  - Electron and Ion microscopy
    - Analytical instrument industries (SEM, FIB, Litho)
    - Semiconductor tools (inspection, metrology)
  - Mass spectrometry
    - High resolution Time of Flight (TOF) detectors



Motivation for sub-ns Detectors

- Applications for sub-ns particle detectors in numerous fields:
  - Medical Devices (e.g. PET)
  - 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 isotopic resolution and mass resolution for large molecules

TOF Detector Requirements



$M_3 > M_2 > M_1$

Desirable TOF detector characteristics:

- **fast**: faster detector = better resolution ($\Delta m/m \propto \Delta t/t$)
- **quantitative**
  - pulse front detection not enough
  - **wide dynamic range** required (e.g. for isotopic separation)
- **high gain** (ideally no need for additional amplifier)
- **long lifetime**

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Detector Main Specifications

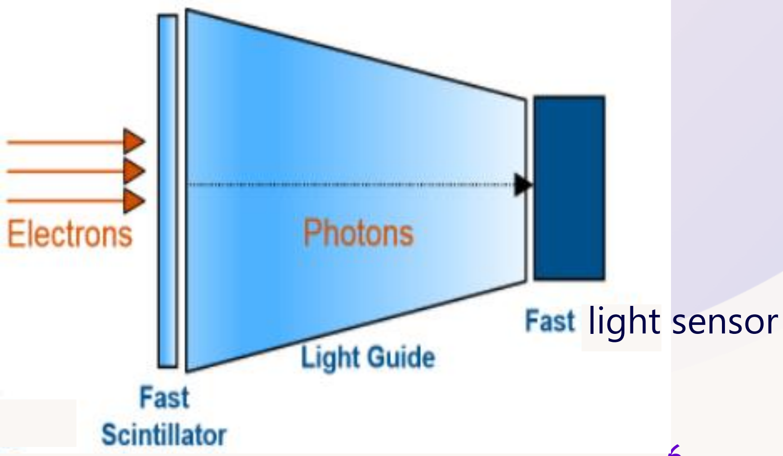
Parameter	Ideal	Min. requirements	Comments
Time resolution (Pulse FWHM)	<0.5 ns	<1.0 ns	
Gain	>500,000	>50,000	ideally detector can read single ion signal without MCP nor additional electronics
Dynamic range (pulse mode)	1-1000	1-100	Number of ions / pulse
Average output current	>50 µA	>10 µA	
Lifetime	100 C	50 C	Accumulated output charge

Existing Detectors and Limitations

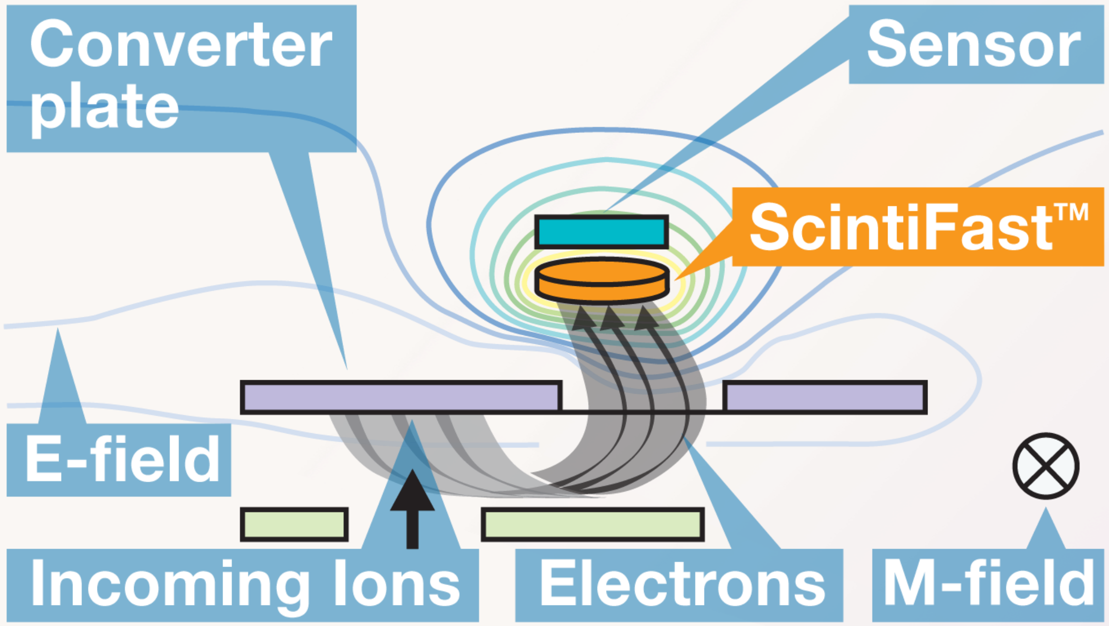
Detector	Limitation
Microchannel Plate (MCP)	• Low fill factor • Non-planar → ion jitter • Short lifetime • HV electronics
Electron Multiplier (discrete dynodes)	• HV electronics • Contamination • Short lifetime
Plastic scintillator & light sensor	• Short lifetime

El-Mul Solution:

fast inorganic scintillator SCINTIFAST™ + light sensor



MTOF^{TM} Concept



- Electrons directed to scintillator by ExB field
- Near 100% detection efficiency (depends on convertor efficiency)
- Switchable polarity
- Cost-effective, high lifetime (no MCP)
- E and B chosen such that the ion and secondary electron jitter remains <0.3 ns

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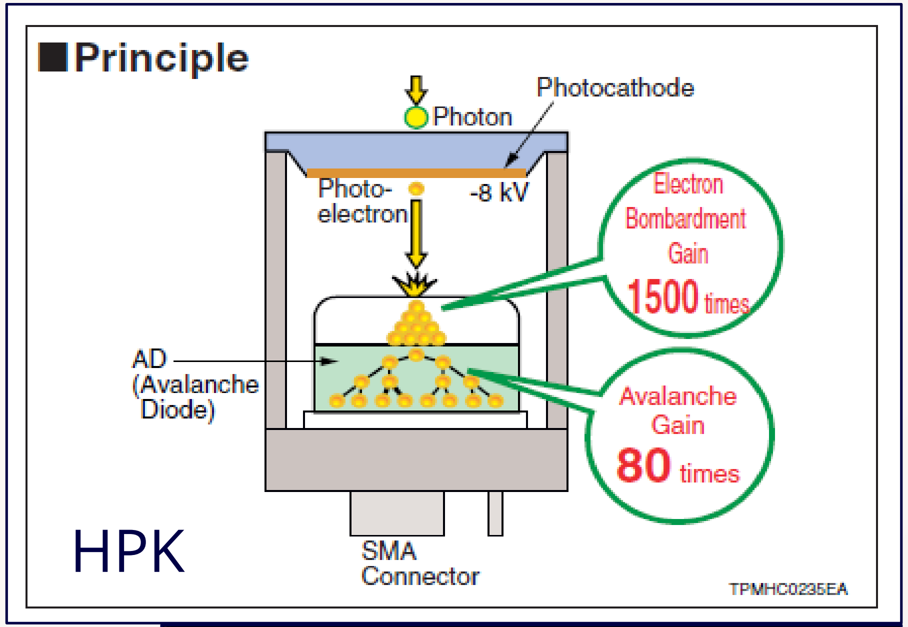
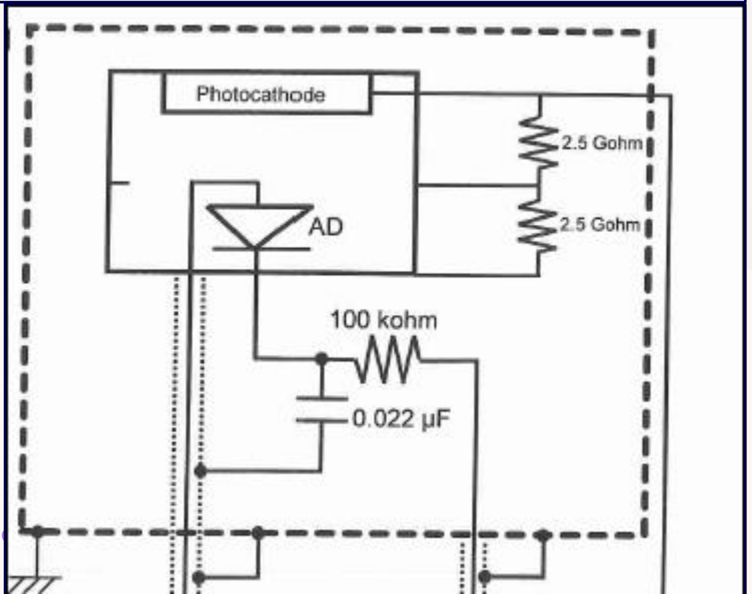
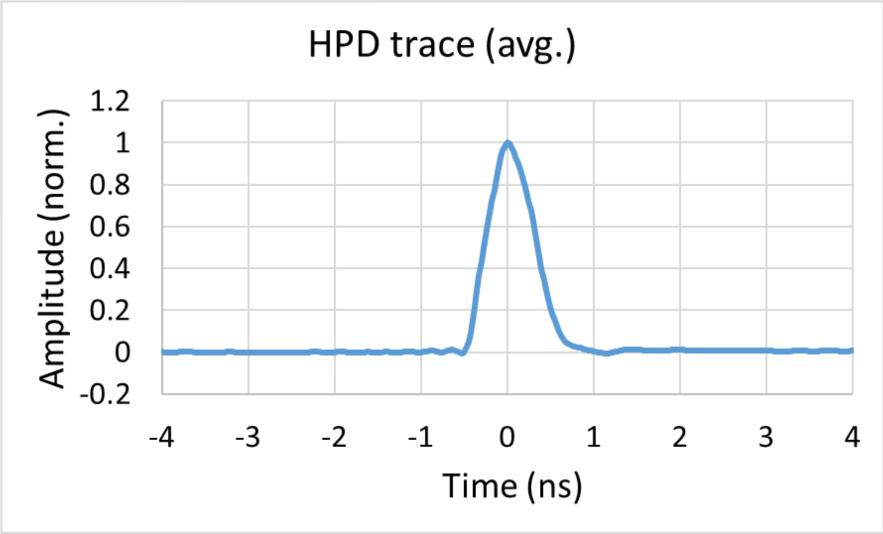
HPD Characteristics



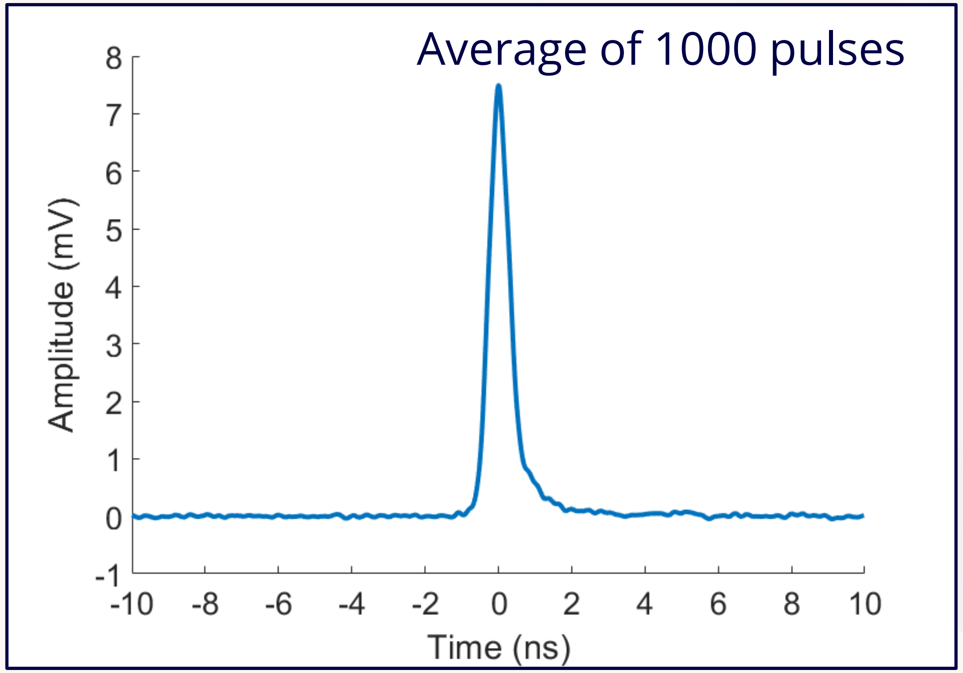


- R10467U Hybrid photodetector (HPK)
- HPD is fast and relatively compact
- Nominal FWHM: 600 ps
- Maximum HPD gain 160,000
  - Recommended 130,000
- Sealed tube → no contamination
- Custom-made electronics

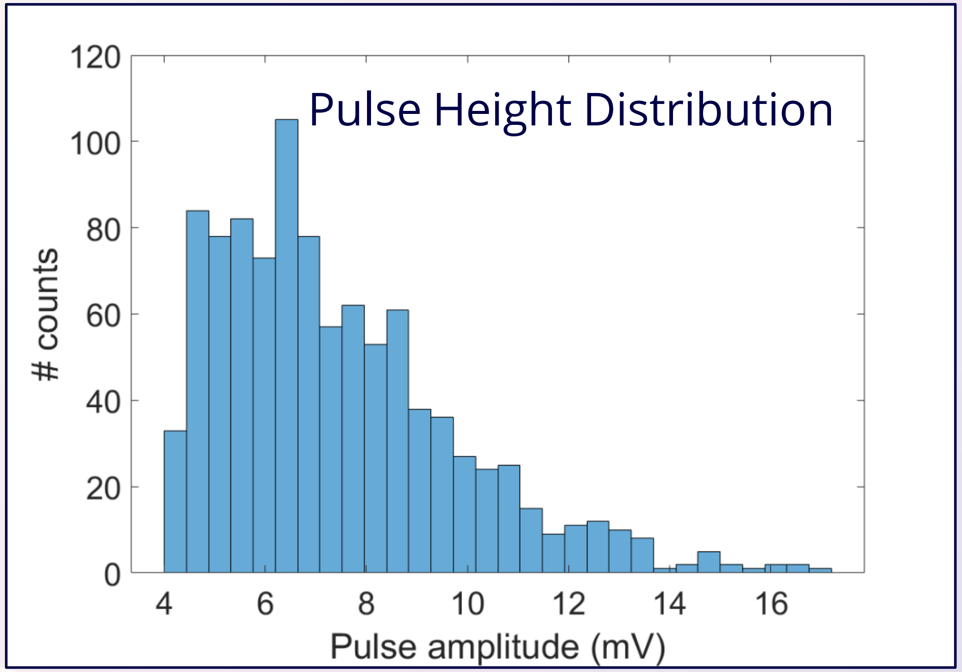


Single Electron Response

- Subassembly: ScintiFast + Light-guide + HPD, irradiated with 10 kV electron gun
  - E-gun current < 0.1 pA → Single electron response measured
- HPD gain ~120,000



FWHM = 0.65 ns, no ringing

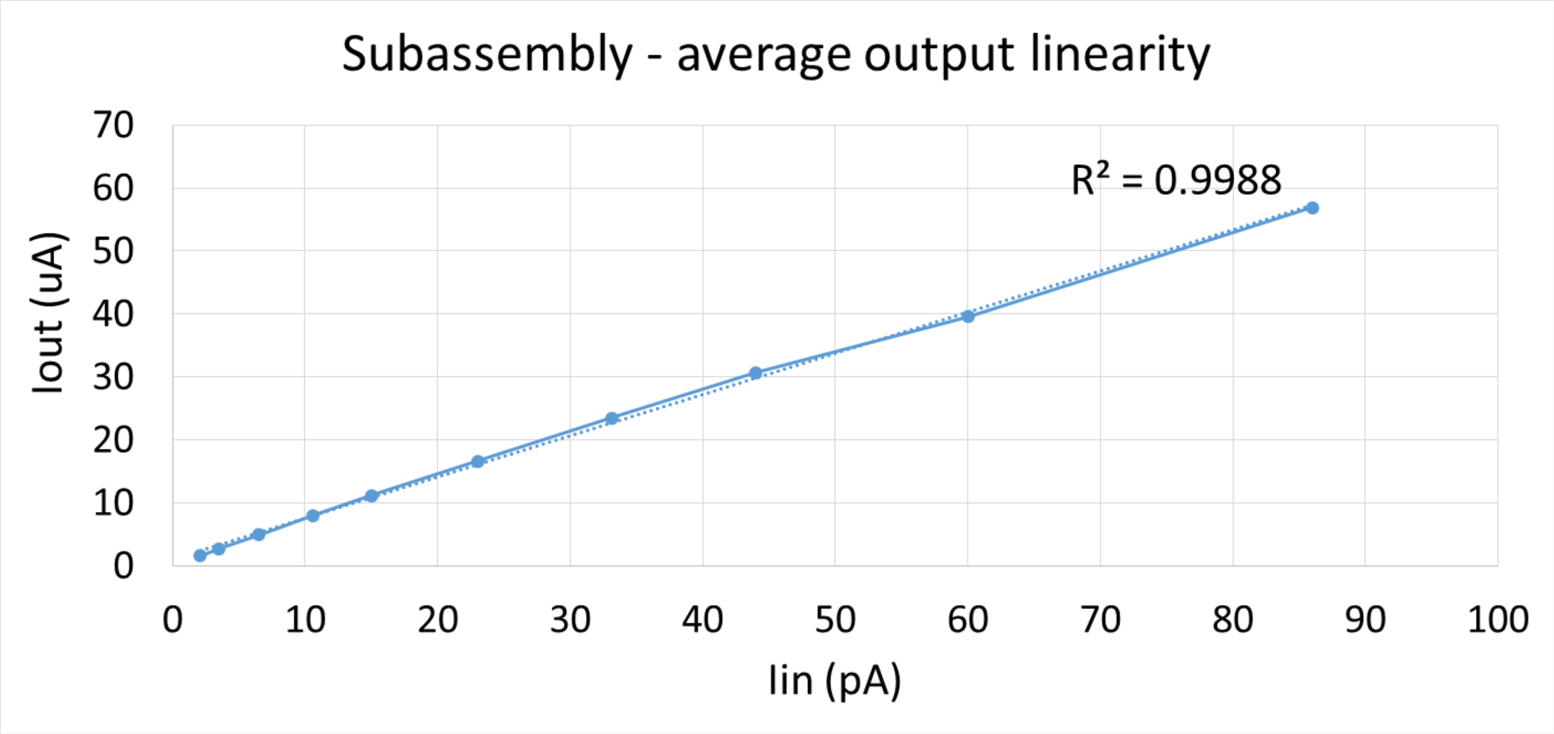


Pulse height = 7.5 ± 2.4 mV

5.8 ph-e / e → real / false event discrimination

Linearity and Dynamic Range

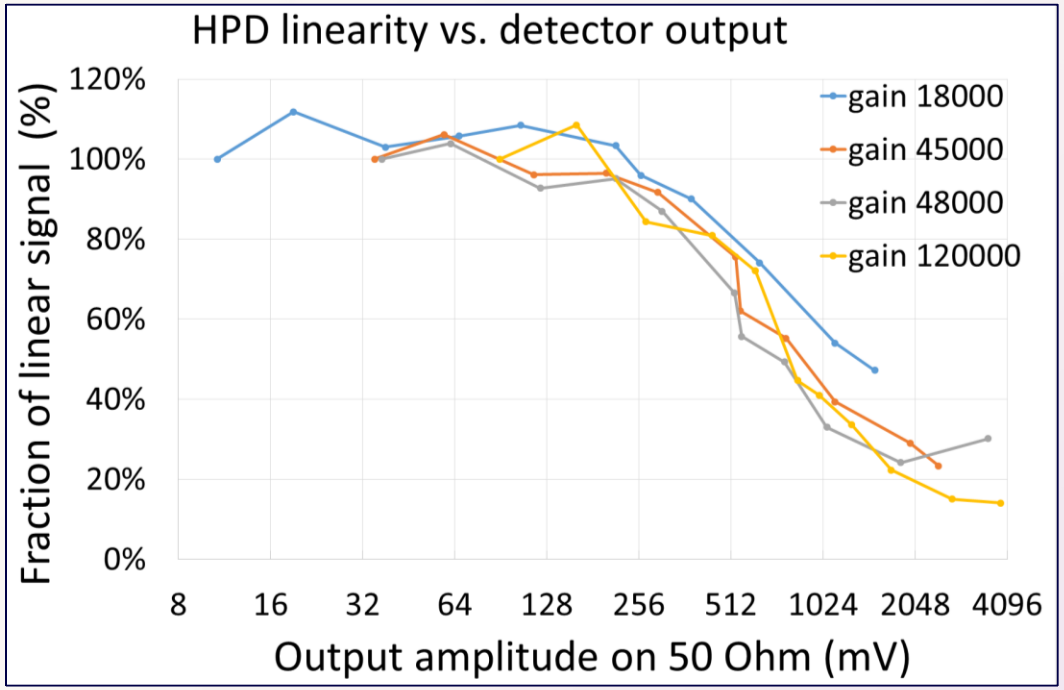
- Average output linearity, measured in vacuum with electron gun



- Average output is linear up to about 50 μA

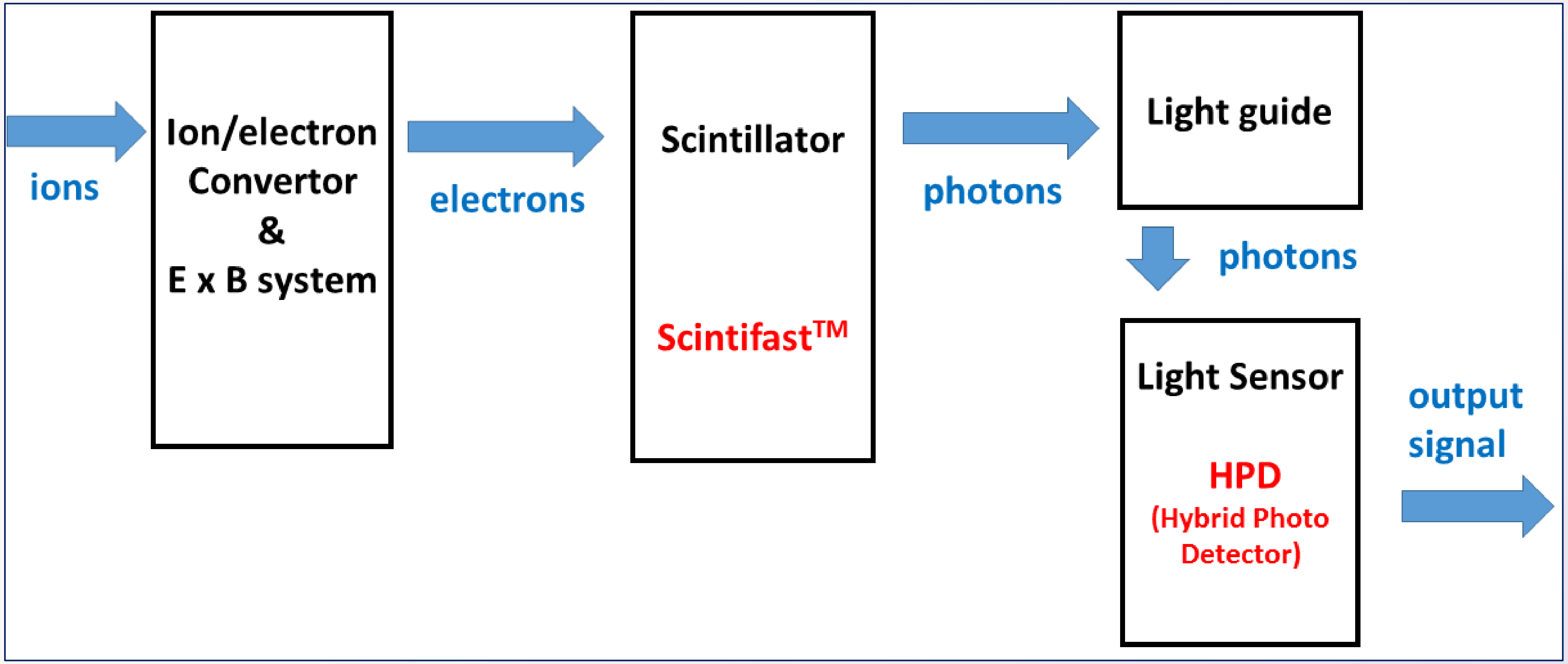
Linearity and Dynamic Range

- Measurement performed on HPD using pulsed ps laser



- Linearity is output-limited
- Pulse output linear up to ~250 mV output, then monotonic sublinear without pulse distortion up to at least 4 V (80 μA on 50 Ω scope)
- Overall dynamic range of several orders of magnitude with non-linearity corrections

TOF Detector Prototypes

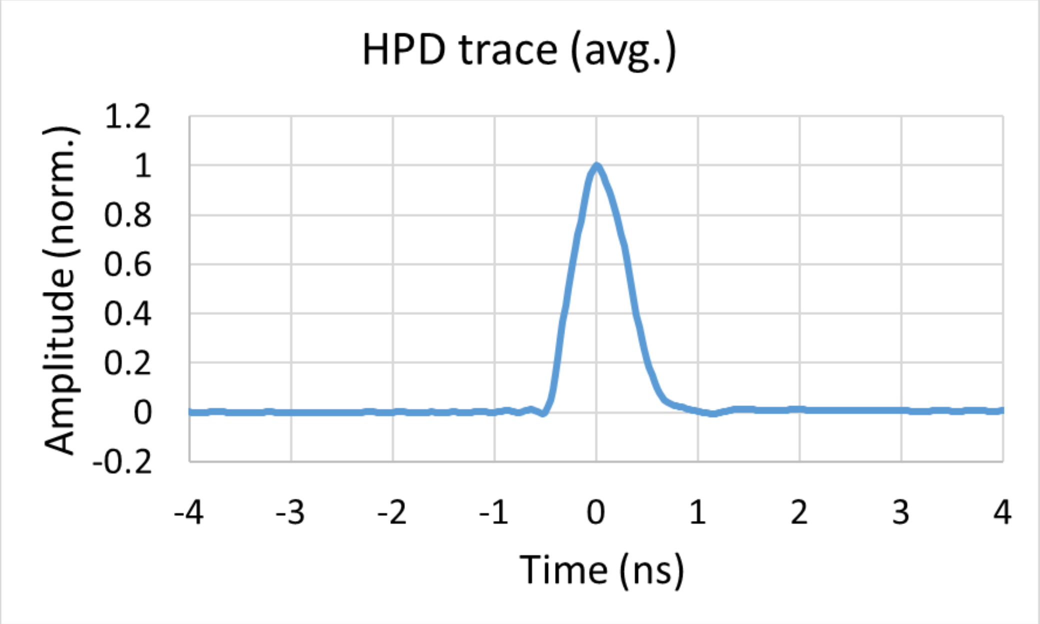


- Several prototypes already designed and built for mass spectrometry companies
- Several detector have already been tested on real mass spectrometry instruments
  - All tested detector showed outstanding mass resolution, stability and lifetime

Improving Detector Resolution

- Detector timing currently limited by the HPD
  - The HPD pulse width is a combination of:
    - physical transit time of charge carriers inside the Si AD
    - τ = RC: discharge time of the AD capacitor C into the 50Ω load resistor R

→ Decreasing AD diameter → lower C → faster HPD?



- Apply analog and / or digital signal processing to improve resolution past FWHM
  - Not only front detection – quantitative information and pulse separation also required
  - Low number of photons → stochastic variability

Summary and Outlook

- We presented the concept and results of a charged particle detector based on a novel inorganic scintillator coupled to a hybrid photodetector (HPD)
- The detector exhibits
  - Single electron pulse width of ≤ 0.7 ns
  - Dynamic range of several orders of magnitude
  - Stability and lifetime far better than competing technologies
- Next steps
  - Further improve detector time resolution
    - Faster light sensor (e.g. HPD with smaller AD – but other options also considered)
    - Analog and/or digital signal processing
  - Application of the detector concept to other fields (e.g. nuclear physics, PET)
    - Possibly with another light sensor e.g. SiPM

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Detect the Difference

Thank You!