U.S. DEPARTMENT OF ENERGY

Office of Science

Tommaso Isidori

Fast detectors for polarimetry at the EIC

Forward QCD: open questions and future directions, KU - May 24, 2022

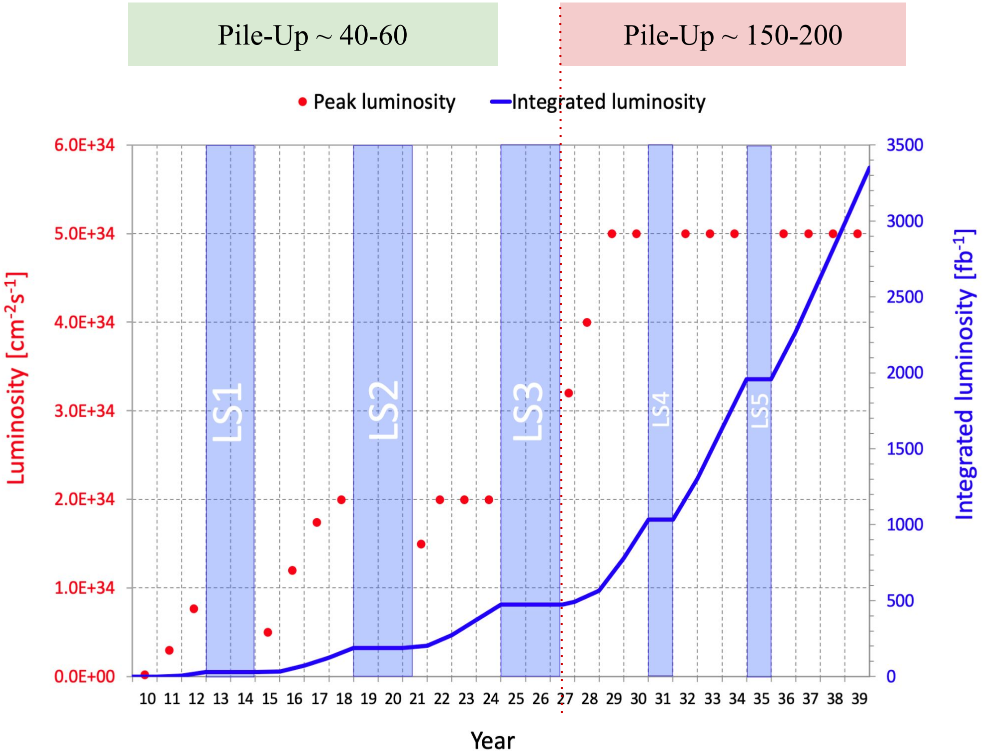
THE UNIVERSITY OF KANSAS

Introduction to particle detectors

Timing

The **discrimination of background events** in High Energy Physics (HEP) experiments **is becoming more challenging**

For example, at the LHC:



[Detector upgrade at Run3 and HL-LHC]

Fast detectors for polarimetry at the EIC

Timing

$$\mathcal{L}(t) = \frac{1}{\sigma}\frac{dN}{dt}$$

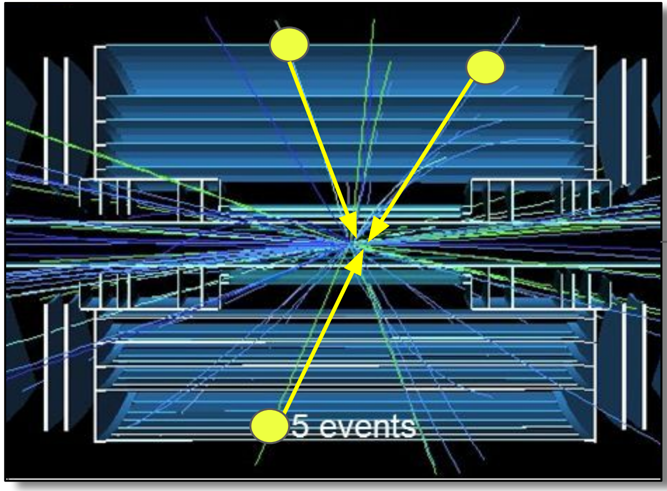
Luminosity

Measures how efficiently the collider can produce collision events

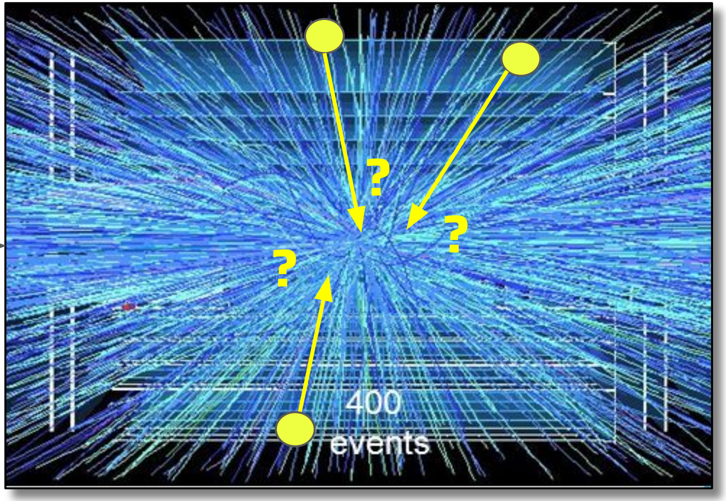
Pile-UP

unwanted extra **collisions**, overlapping in the detectors

$$\mu(t) = \frac{\sigma \mathcal{L}(t)}{f n_b}$$



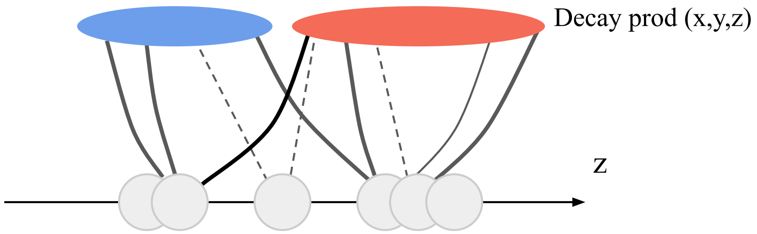
Luminosity increases



Introduction to particle detectors

Timing

Using Tracking:

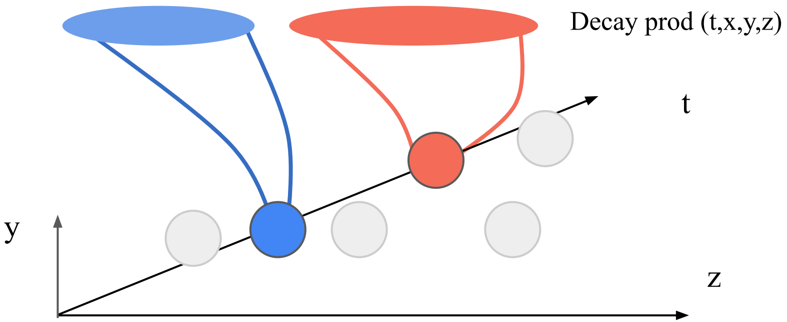


Minimization of the relative distance of closest approach:

$|\Delta z(\text{track,PV})| <$ average line density of events

Tracking + Timing:

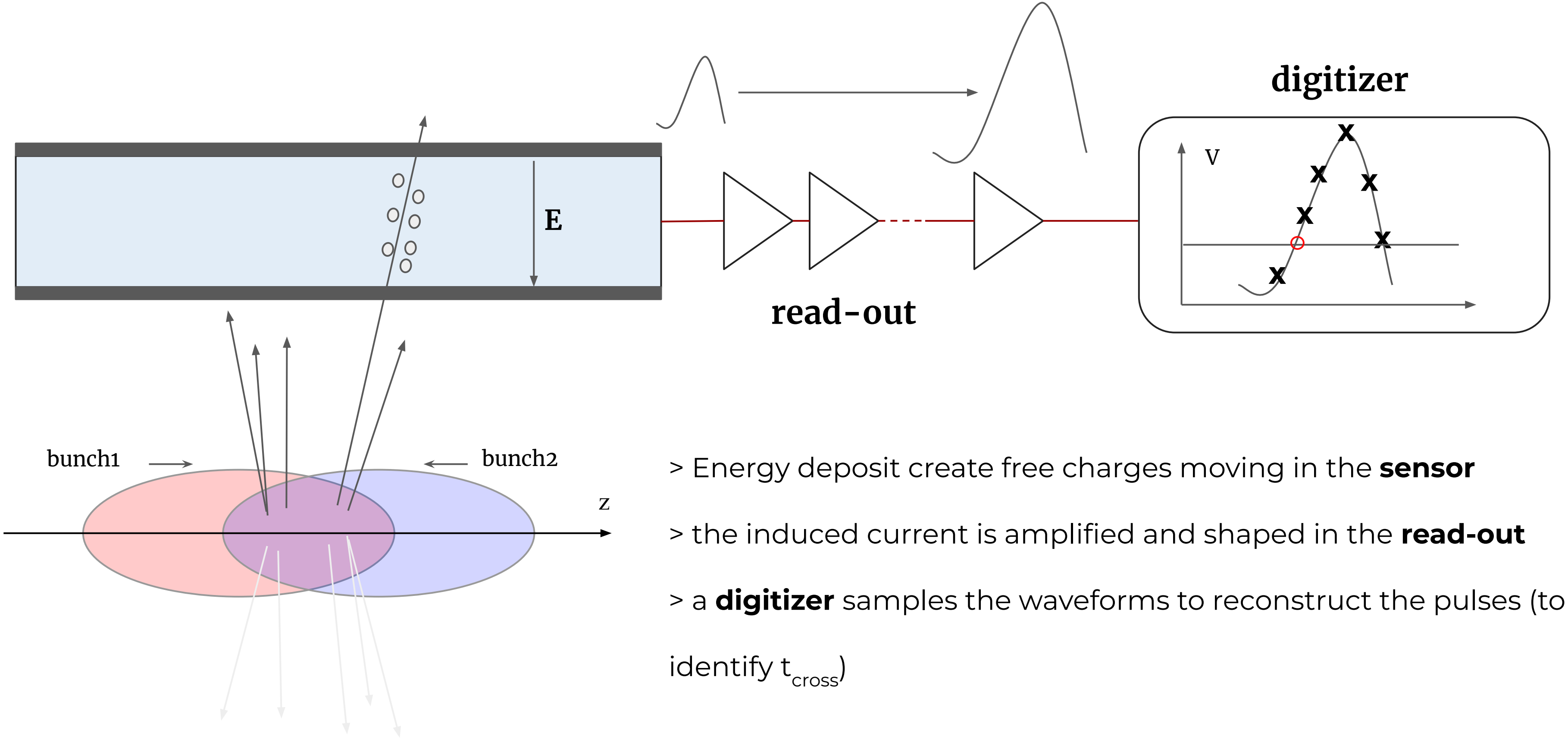
→ $|\Delta t(\text{track,PV})| < N \times \sigma_t$



$$\begin{cases} \sigma_t \sim O(\text{tens ps}). \\ \sigma_L = 1\backslash N^{1/2} (\sigma_t + \sigma_t + \dots)^{1/2} c \sim \text{mm} \end{cases}$$

Fast detectors for polarimetry at the EIC

Timing



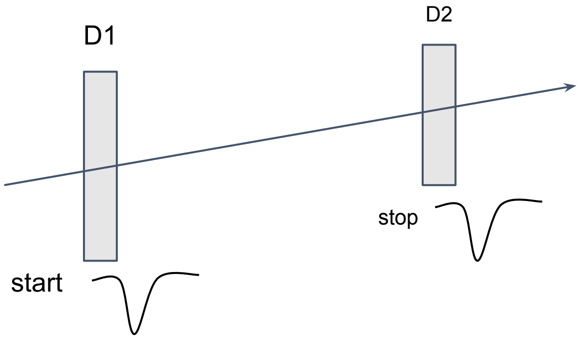
> Energy deposit create free charges moving in the **sensor**

> the induced current is amplified and shaped in the **read-out**

> a **digitizer** samples the waveforms to reconstruct the pulses (to identify t_{cross})

Fast detectors for polarimetry at the EIC

Timing



$$L \approx |t_{start} - t_{stop}|\, v$$

$$\sigma_z = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2} \cdot c$$

$$\sigma_{tot} = \frac{1}{N} \cdot \sqrt{\sigma_{det1}^2 + \sigma_{det2}^2 + ..} \approx \frac{1}{\sqrt{N}} \cdot \sigma_{det}$$

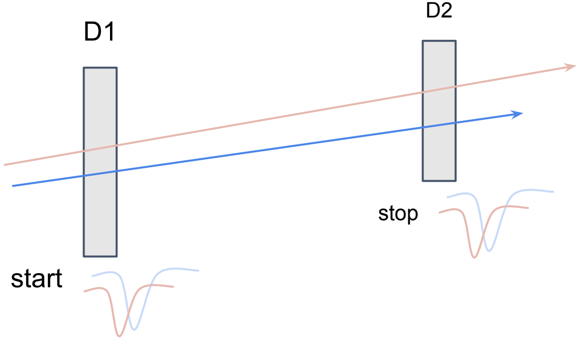
Uncertainty

The TOF can be used for particle ID

$$\Delta t = t_2 - t_1 = L\left(\frac{1}{v_1} - \frac{1}{v_2}\right) \approx \frac{Lc}{2p^2}(m_1^2 - m_2^2)$$

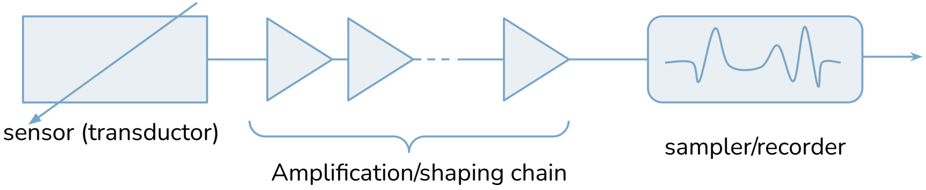
Precise Detector

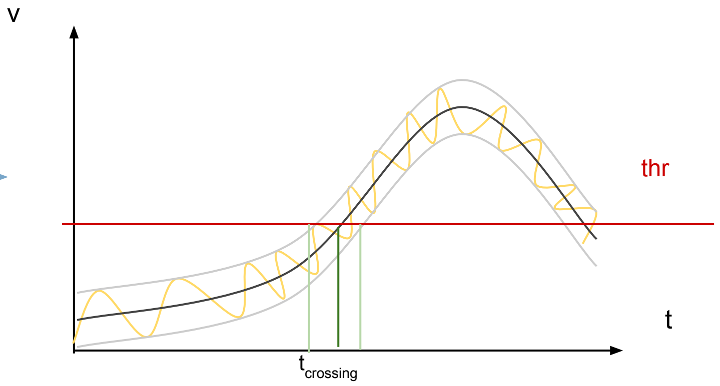
- Timestamp of particle's passage with small uncertainties.
- Suited for **TOF**, **difference of time of arrival**, **time reference for HEP detectors**...
- Uncertainty can go as low as **σ ~ 10ps.**
- Timing measurement affect the spatial reconstruction accuracy $\sigma_L \propto \sigma_t$



Fast detectors for polarimetry at the EIC

Fast Detectors





The precision of the timing measurement comes from a combination of factors…

$$\sigma_t^2 = \underline{\sigma^2_{jitter}} + \sigma^2_{Time\ Walk} + \underline{\sigma^2_{Local\ ionization}} + \underline{\sigma^2_{TDC}} + \underline{\sigma^2_{Distortion}}$$

Contributions are mitigated with the choice of a performing sensor

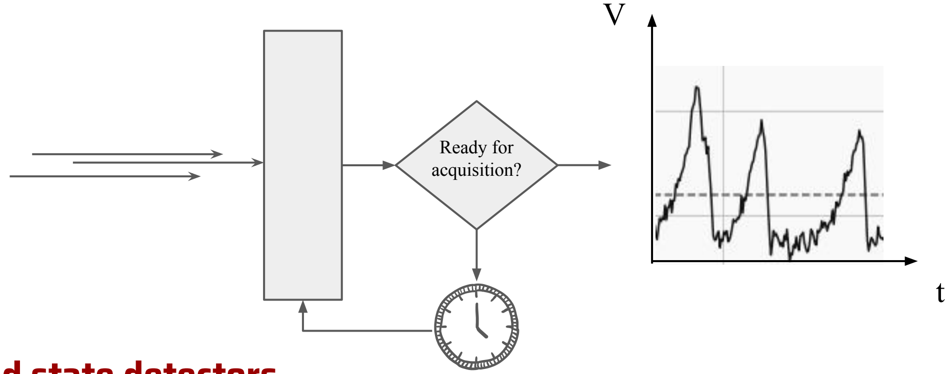
Contributions are mitigated with the choice of a read-out electronics

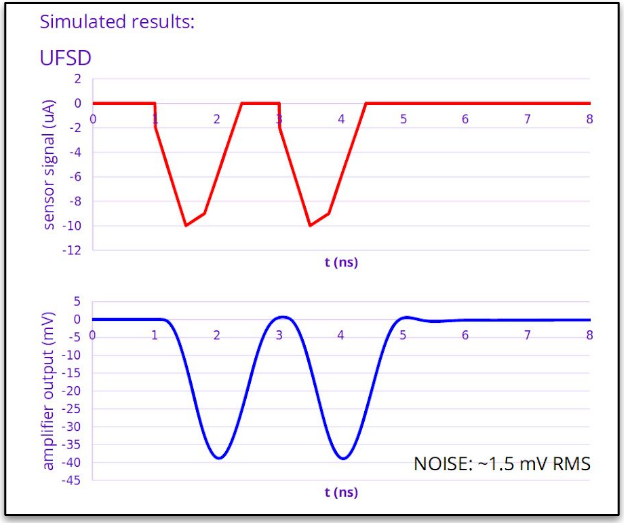
Fast detectors for polarimetry at the EIC

Fast Detectors

Fast detector

- Output a narrow pulse in response to the passage of a particle.
- Modern electronic components can be combined to develop circuit that outputs pulses as narrow as **~ few ns.**
- A fast integration of the signal reduces the dead time of the detector: **single particle resolution can be achieved up to high rates**





Solid state detectors

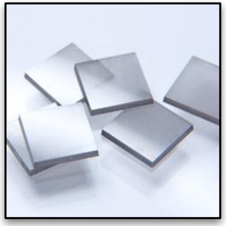
> excellent spatial resolution

> short time integration

> no energy calibration needed (for particle counting)

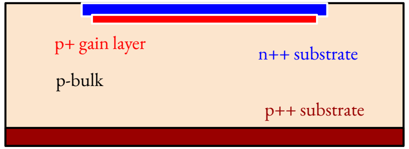
Fast detectors for polarimetry at the EIC

Fast Detectors



Chemical Vapor Deposition (sCVD) diamond

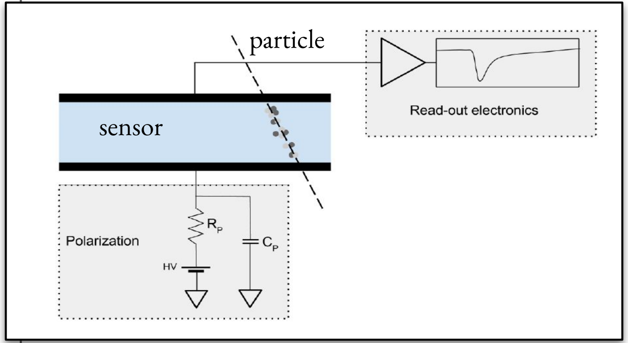
- > low dielectric constant (low capacitance)
- > high carriers mobility
- > incredibly low dark currents
- > The complicated production process limits the size to few mm^3
- > intrinsically radiation hard

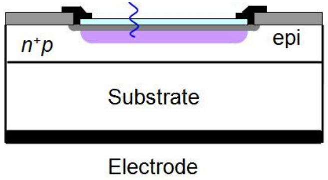


Low Gain Avalanche Diode (LGAD)

- > low gain(compared to APDs) → necessity to add an additional gain layer
- > fast rise time (dark currents' electron don't cause avalanche processes)
- > low dark currents
- > the thickness is substantially reduced (> 50 μm)
- > Can be produced with Carbon insertion to reduce the radiation damages

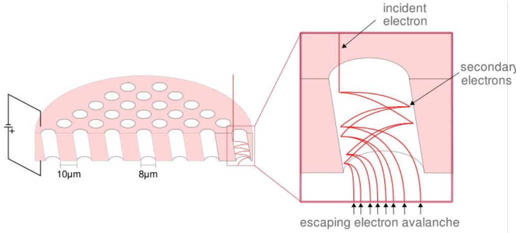
Standard operation





Silicon PhotoMultiplier (SiPM)

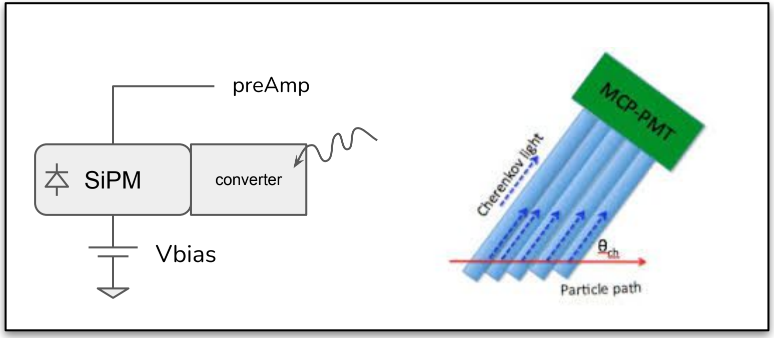
- > Photo detection efficiency (PDE) ranges from 20 to 50%
- > Gain ~ 10^6
- > Low timing jitter
- > not sensitive to external magnetic fields
- > Small dimensions and low voltages required for bias



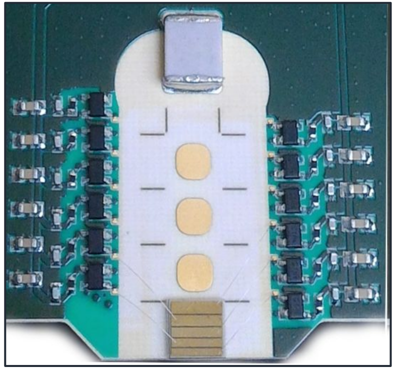
Multi Channel Plate (MCP)

- > avalanche transit time ~100 ps range
- > Gain ~ 10^4 - 10^8
- > fast rise time
- > exceptionally low dark current < 0.5pA/cm2
- > 0.4-3.0 mm thick plates
- > up to ~1M channels/cm^2 of 5-15 m m diameter

Standard operation



CVD (Diamond) detectors



TOTEM - PPS diamond detectors

- ✓ Low Dielectric constant ($C = \epsilon_0 \epsilon_d \frac{S}{d} = \frac{Q}{V}$)
- ✓ High saturation velocity for electron and holes
- ✓ High Resistivity
  - × Really expensive: high purity required
  - × Smaller signal with respect to Silicons

	Diamond	**Silicon**
band gap [eV]	**5.48**	**1.12**
intrinsic resistivity [Ω/cm]	**> 10^{15}**	**2.3×10^{5}**
electron mobility [cm^2/V s]	**< 4600**	**1350**
hole mobility [cm^2/V s]	**< 3400**	**480**
hole lifetime [s]	**10^{-10} - 10^{-6}**	**10^{-3}**
saturation velocity [cm/s]	**1.6- 2.6 $\times 10^{7}$**	**10^{7}**
density [g/cm^3]	**3.52**	**2.33**
dielectric constant	**5.7**	**11.9**
energy to create e-h [eV]	**13.1**	**3.63**
energy loss for MIPs [MeV/cm]	**4.69**	**3.21**
average pairs created / 1 µm	**36**	**88.9**
displacement energy [eV]	**37.5 - 47.6**	**36**

Fast detectors for polarimetry at the EIC

Fast Detectors

The use of thin Silicon sensors provided of gain layer is becoming more common.

Why Thin?

> **Shorter drifting times** > Shorter integration time

> Planar Geometry with **side >> width** reduce the $\sigma^2_{Distortion}$

BUT

→ **Landau fluctuations enhanced in thinner sensors** $\sigma^2_{Local\ ionization}$

Also, **smaller drifting region → Smaller signals**

$$\sigma_{jitter} \simeq 1.25\frac{t_{rise}}{SNR}\downarrow$$

Fast detectors for polarimetry at the EIC

Fast Detectors

Why (low) Gain?

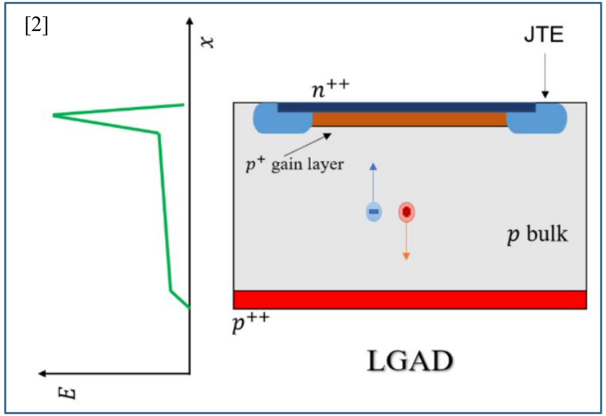
Adding a gain layer $N(l) = N_0 e^{a(E)l}$

> recovers the loss in amplitude

> the current $\frac{di_{gain}}{dt} \propto q\, vs\, \frac{G}{d}$

BUT

Multiplication processes too big slow the signal collection



Low Gain Avalanche Detectors (LGAD)

> low gain(compared to APDs), G = 5 - 20

> fast rise time (dark currents' electron don't cause avalanche processes)

> low dark currents

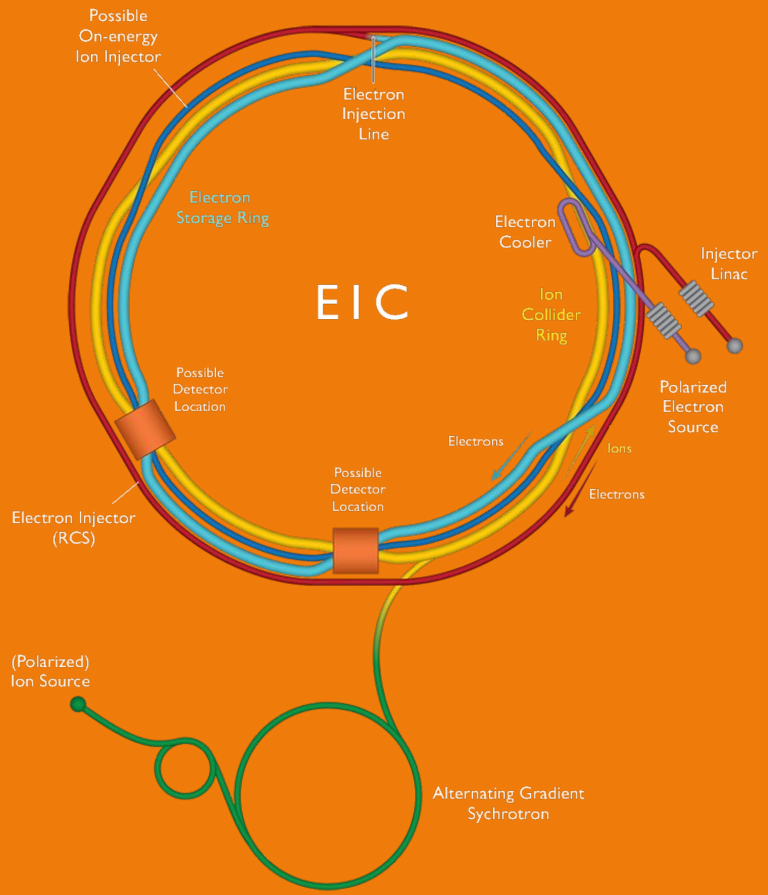
> typical thickness ~ 50 μm

> excellent radiation resistance

Study of Ionization charge Density-induced gain suppression in lgads

Fast detectors for polarimetry at the EIC

The beamline



Lower luminosity

560 MHz RF

330 bunches

→ 33 ns between bunches

Electron current up to 1.2A

Ion current up to 0.46 A

High luminosity

560 MHz RF

1320 bunches

10 ns between bunches

Electron current up to 2.4 A

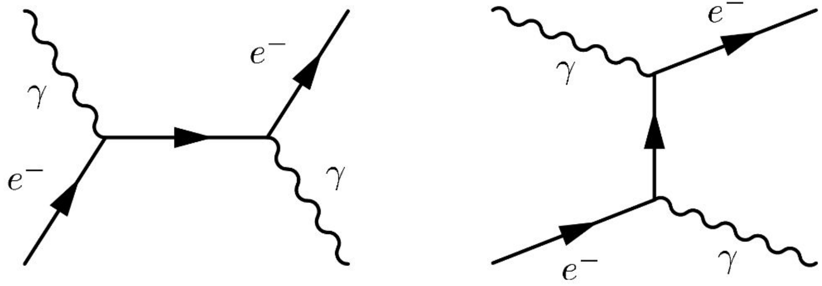
Ion current up to 0.92 A

Fast detectors for polarimetry at the EIC

Compton Electron Polarimetry

After every interaction @ the EIC, the level of polarization is verified using on-beam detectors.

Compton polarimeters represent one of the best option for measuring the polarization asymmetry of high energy particle beams.



Total Compton cross section (unpolarized + polarized)

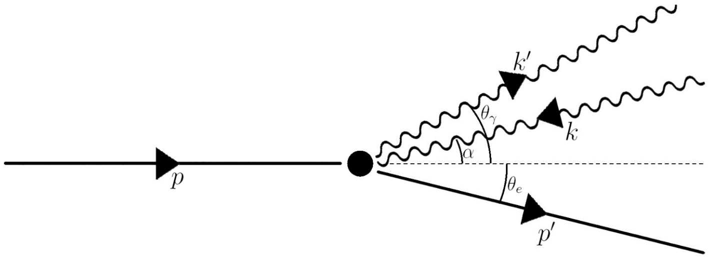
$$\frac{d\sigma^{\pm}}{d\rho} = \frac{d\sigma}{d\rho} \pm \frac{d\sigma}{d\rho}_p$$

.. it displays an asymmetry with the helicity state

$$\sigma(\vec{e} + \gamma \;\rightarrow\; e' + \gamma') \neq \sigma(\overleftarrow{e} + \gamma \;\rightarrow\; e' + \gamma')$$

Theoretical longitudinal asymmetry

$$\begin{cases} A_{QED}(\rho) = \dfrac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \\ \rho = k'/k \cong \dfrac{4\gamma^2}{1 + \frac{4k\gamma}{m_e} + \theta_\gamma^2\gamma^2} \end{cases}$$



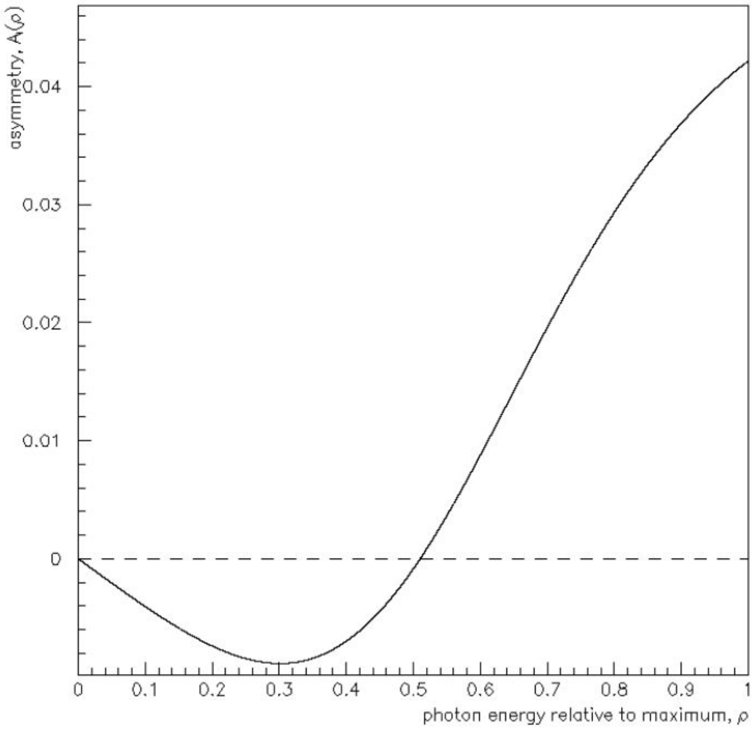
Fast detectors for polarimetry at the EIC

Compton Electron Polarimetry

Observable for average polarization of the beam:

Longitudinal analyzing power

$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-} = \boldsymbol{P_e} * P_\gamma * A_{QED}(E_e, k_\gamma, k_{\gamma'})$$

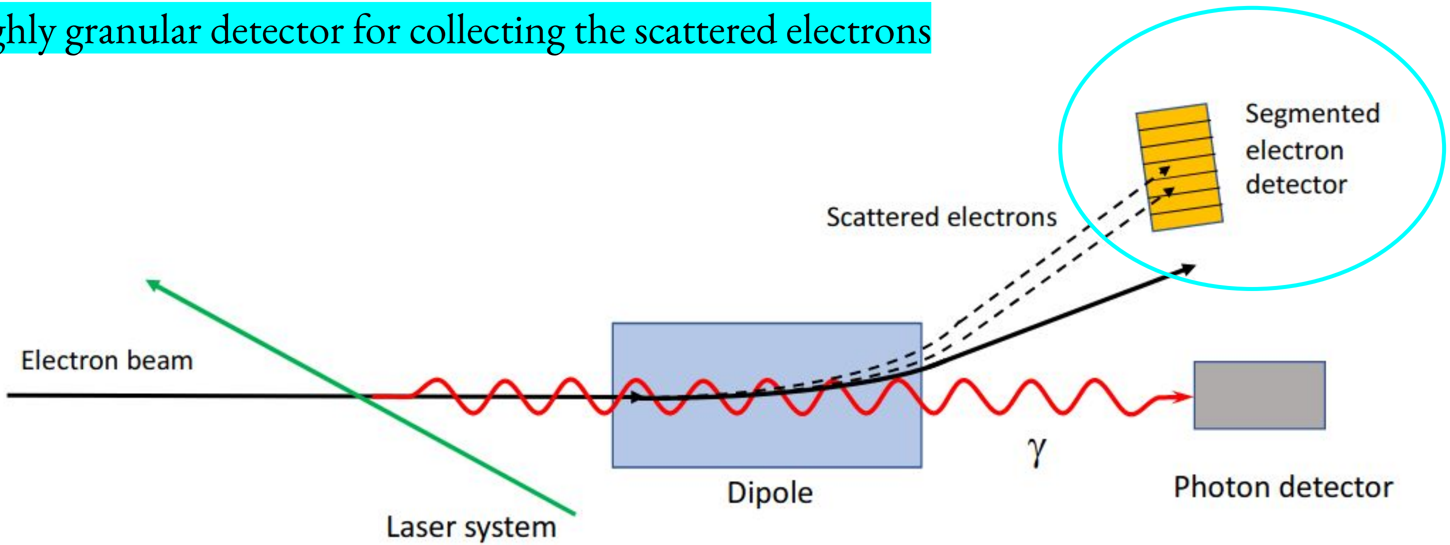


Fast detectors for polarimetry at the EIC

Compton Electron Polarimetry

- A powerful light source for producing the Fabri-Perot Cavity
- Magnetic apparatus to guide the electron beam to the cavity
- EM calorimeter for measuring the back-scattered photons energy
- A highly granular detector for collecting the scattered electrons

$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-}$$

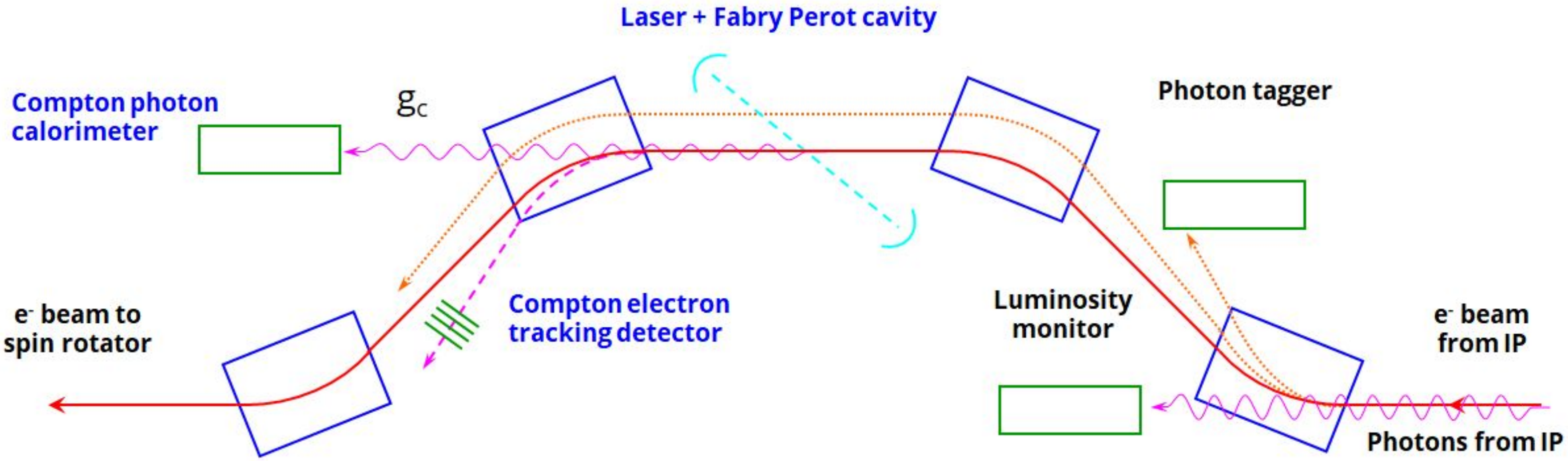


Dave Gaskell- Overview of Polarimetry at EIC, May 6, 2020

Fast detectors for polarimetry at the EIC

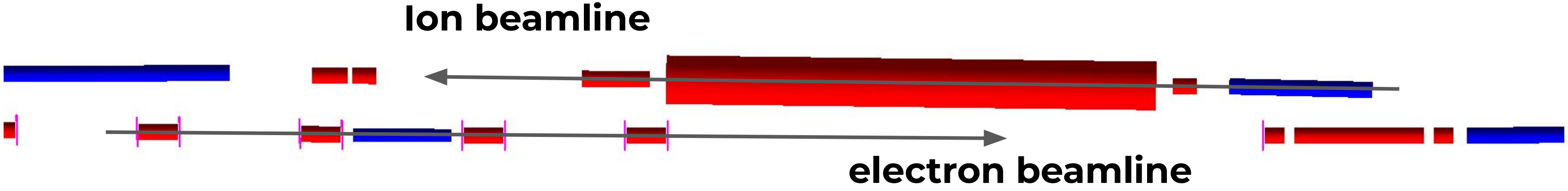
Compton Electron Polarimetry

When inserted in the electron beamline:

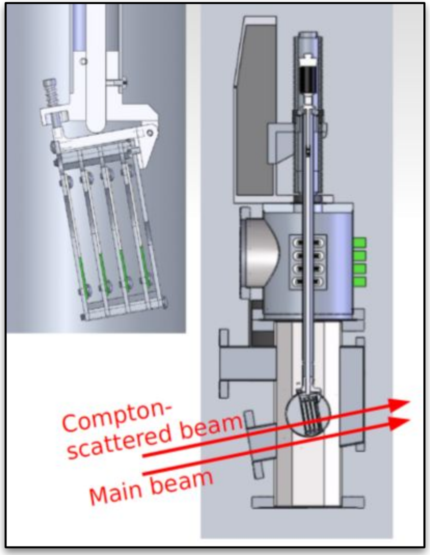


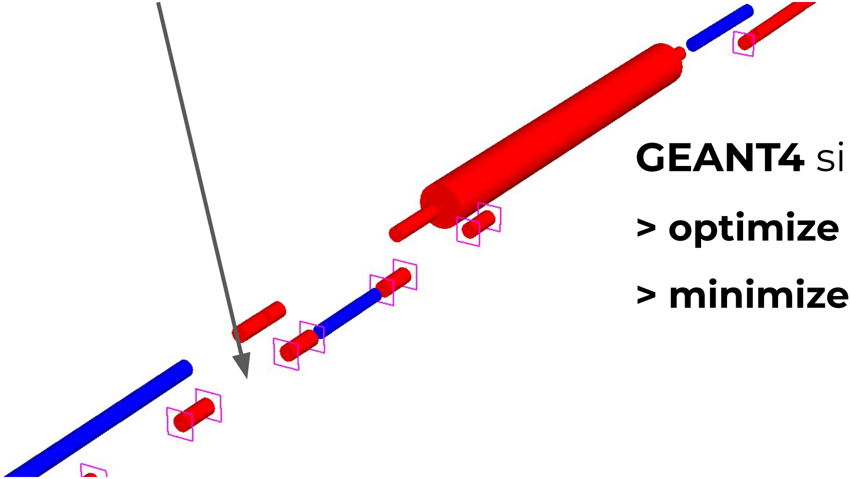
Fast detectors for polarimetry at the EIC

Compton Electron Polarimetry



Roman pots: detectors (kept in a secondary vacuum) moved to approach the beam to really close distance





GEANT4 simulation:

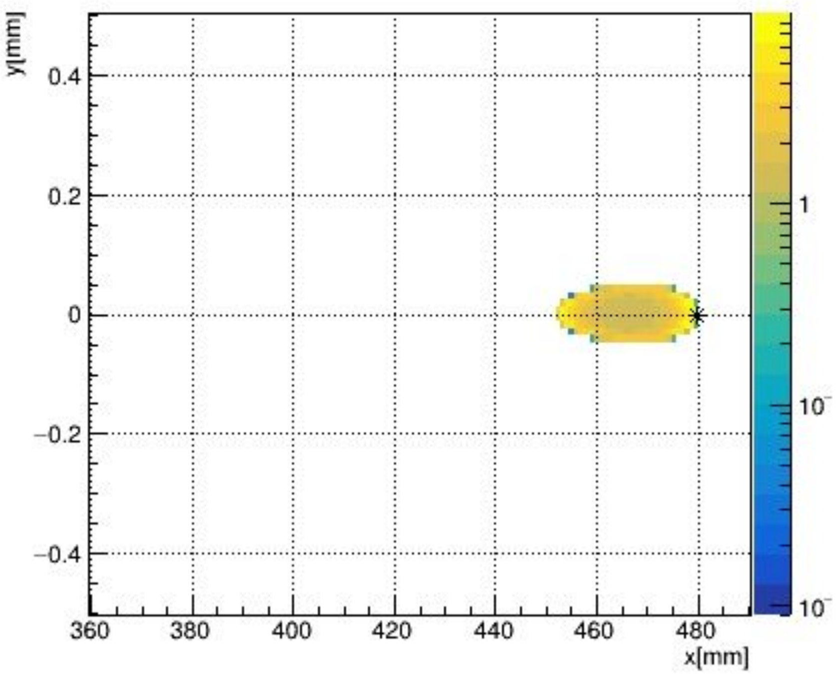
> optimize the hit occupancy

> minimize the impact on the optics

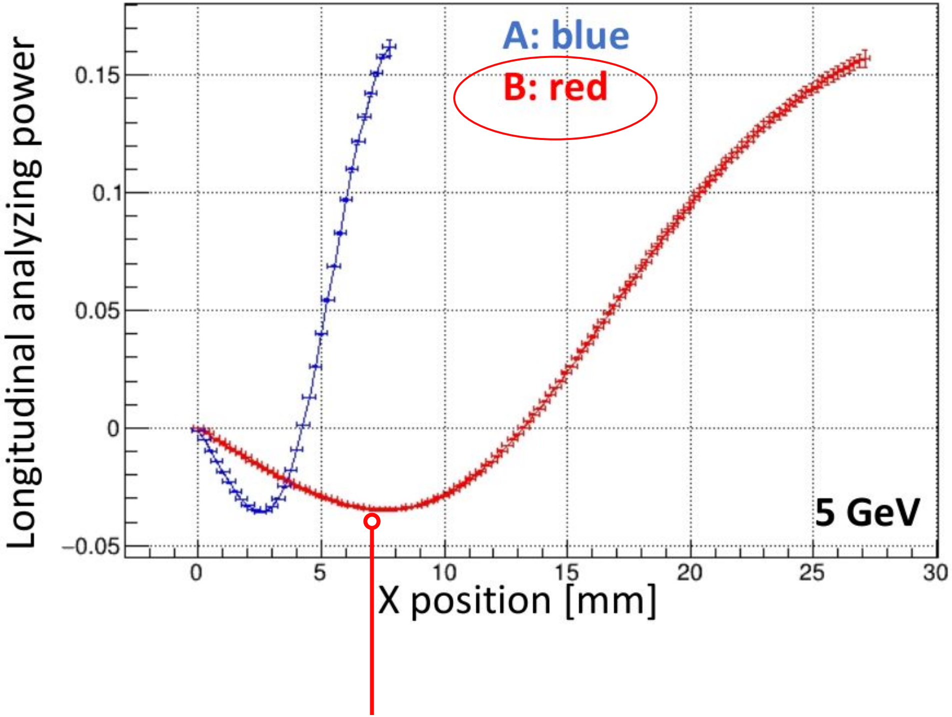
Fast detectors for polarimetry at the EIC

Compton Electron Polarimetry

Hit distribution @ 5 GeV



Analyzing power vs position @ 5 GeV



closest approach of the detector is defined by the 5 GeV configuration (~7mm)

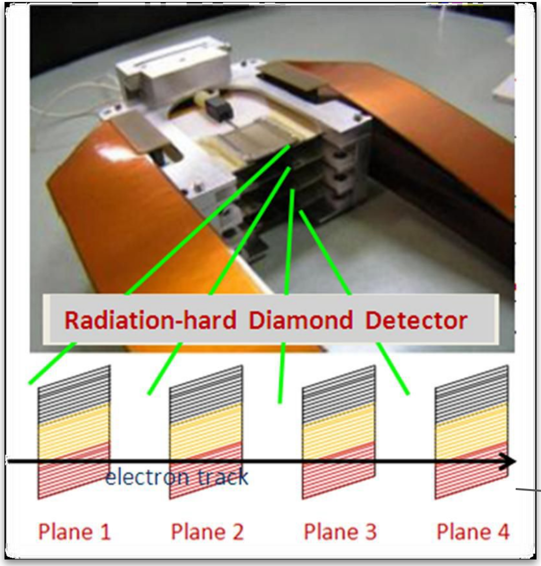
Fast detectors for polarimetry at the EIC

Current technology

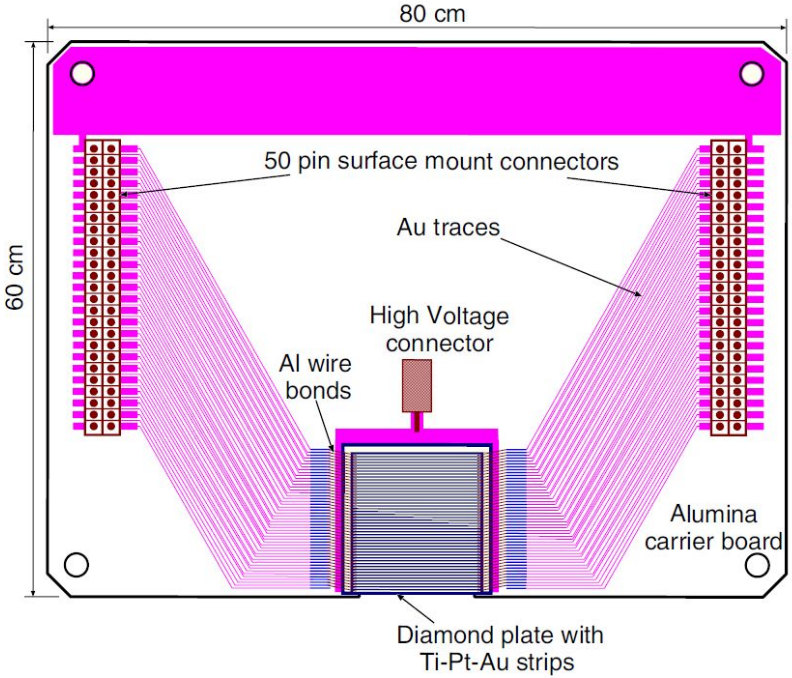
The electron detector

> set of four diamond planes each with 96 “microstrips” of metal alloy etched on the Surface.

> Each strip is 0.180 mm wide separated by 0.02 mm.



[2]



The stack of multiple detectors offers 4 independent measurements and trigger options

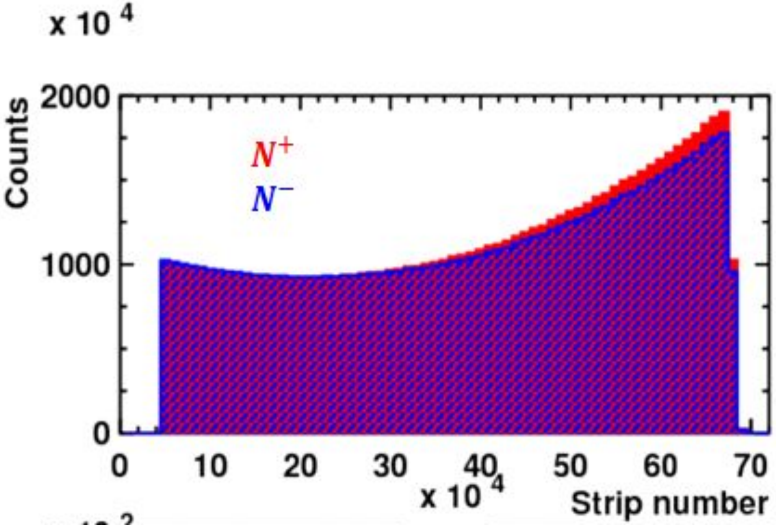
A. Narayan et al. - Precision Electron-Beam Polarimetry at 1 GeV Using Diamond Microstrip Detectors

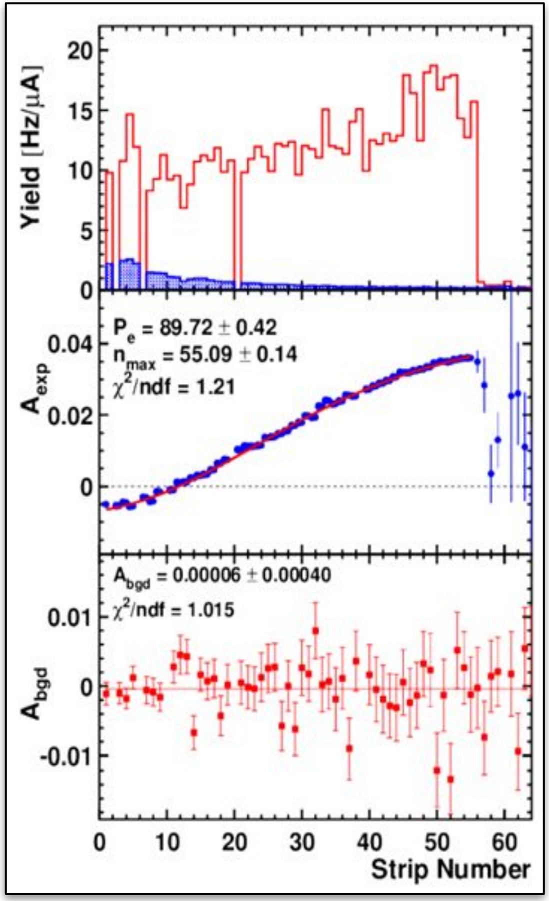
Fast detectors for polarimetry at the EIC

Current technology

$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-} = \boldsymbol{P_e} * P_\gamma * A_{QED}(E_e, k_\gamma, k_{\gamma'})$$

$$A^n_{EXP} = P_\gamma * P_e * A^n_{QED}(\rho)$$





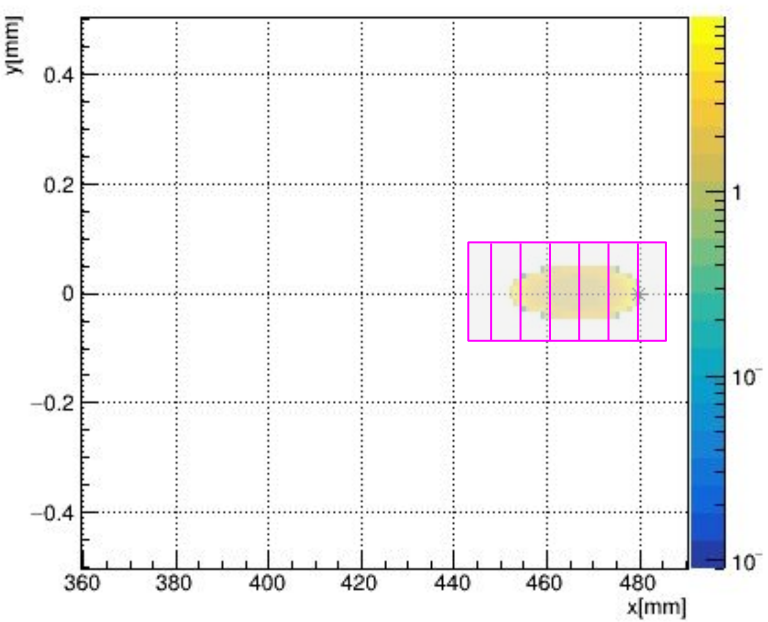
A. Narayan et al. - Precision Electron-Beam Polarimetry at 1 GeV Using Diamond Microstrip Detectors

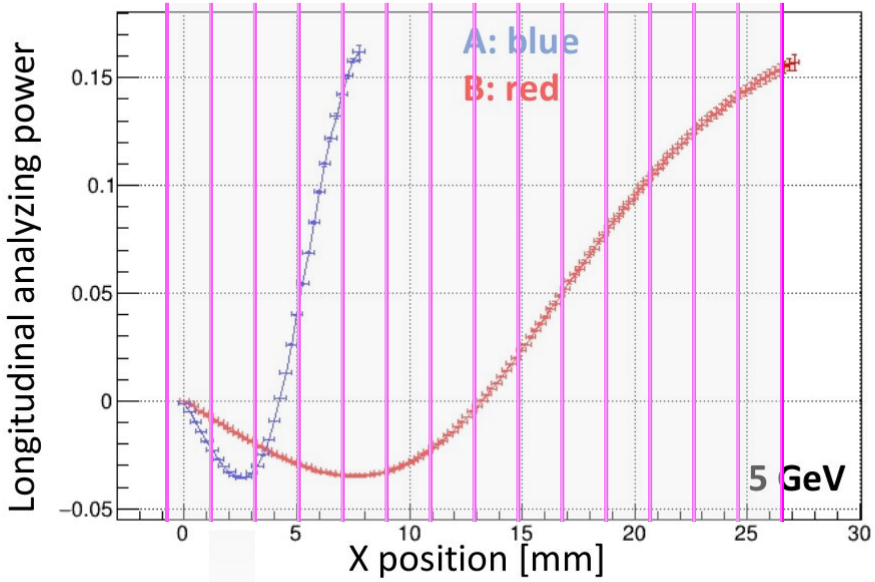
Fast detectors for polarimetry at the EIC

Current technology

$$A^n_{EXP} = P_\gamma * P_e * A^n_{QED}(\rho)$$

$$\rho = \frac{E_\gamma}{E_\gamma^{\max}} \approx \frac{E_e^{\text{beam}} - E_e}{E_e^{\text{beam}} - E_e^{\min}}$$

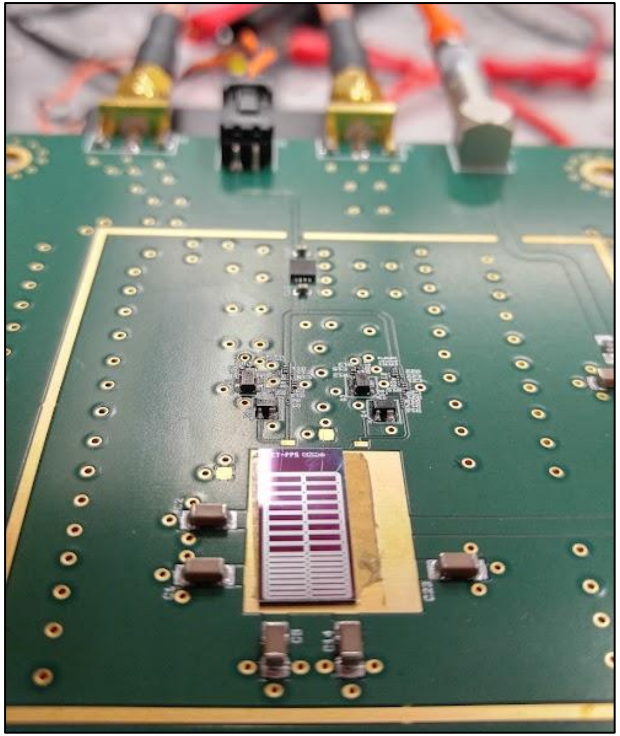




Strip size optimized for **best occupancy** and **hit rate** AND reconstruction of the **analyzing power**

Fast detectors for polarimetry at the EIC

The technology proposed



Detector request:

Fast Response

> Single particle counting for every bunch crossing per channel

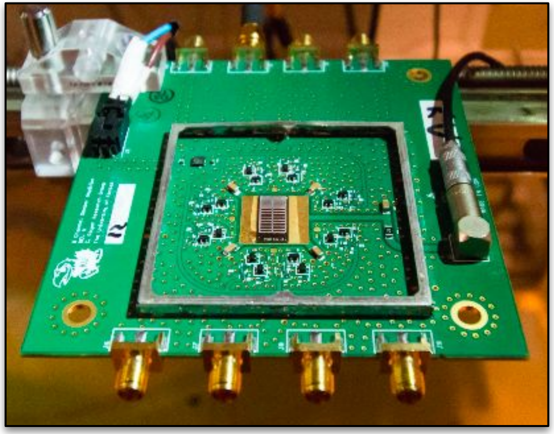
> expected rate ~ 1 photons/bunch crossing → 1/10ns ~ 100MHz

> Sensor, amplifier, digitizer, DAQ to be designed

Aiming for 1% or better electron polarization accuracy (and 0.5 % for parity violation program)

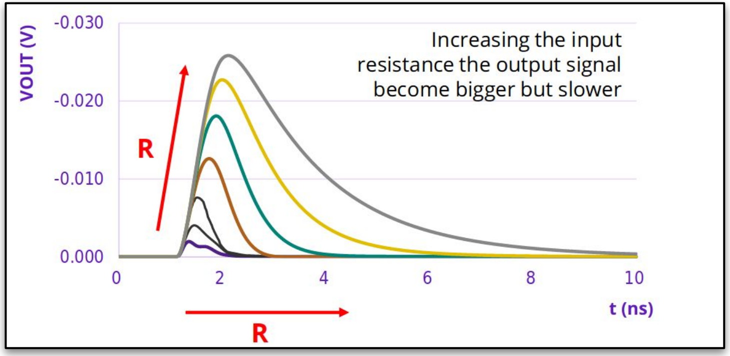
Fast detectors for polarimetry at the EIC

The technology proposed

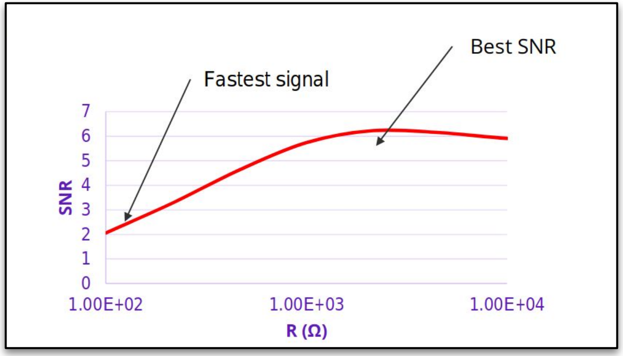


KU read-out board

- discrete components
- 8 identical two-stages transimpedance* amplifiers w/ adjustable gain
- adjustable input RC to adapt it to different solid state sensors
- control over integration time and time resolution
- 20mm^2 x 20mm^2 HV pad with stable bias up to ~ 500V



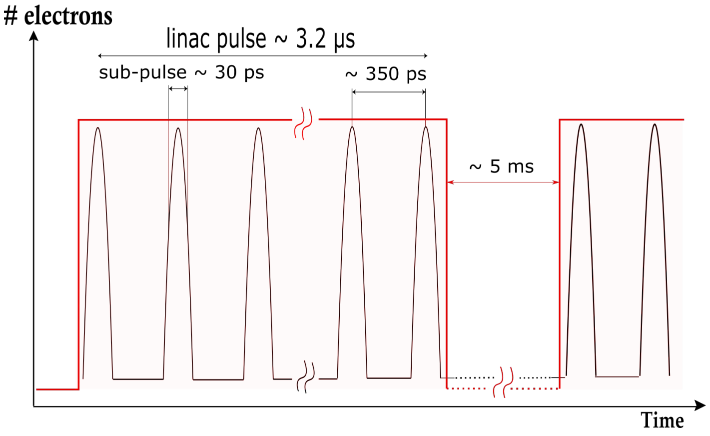
Increasing the input resistance the output signal become bigger but slower



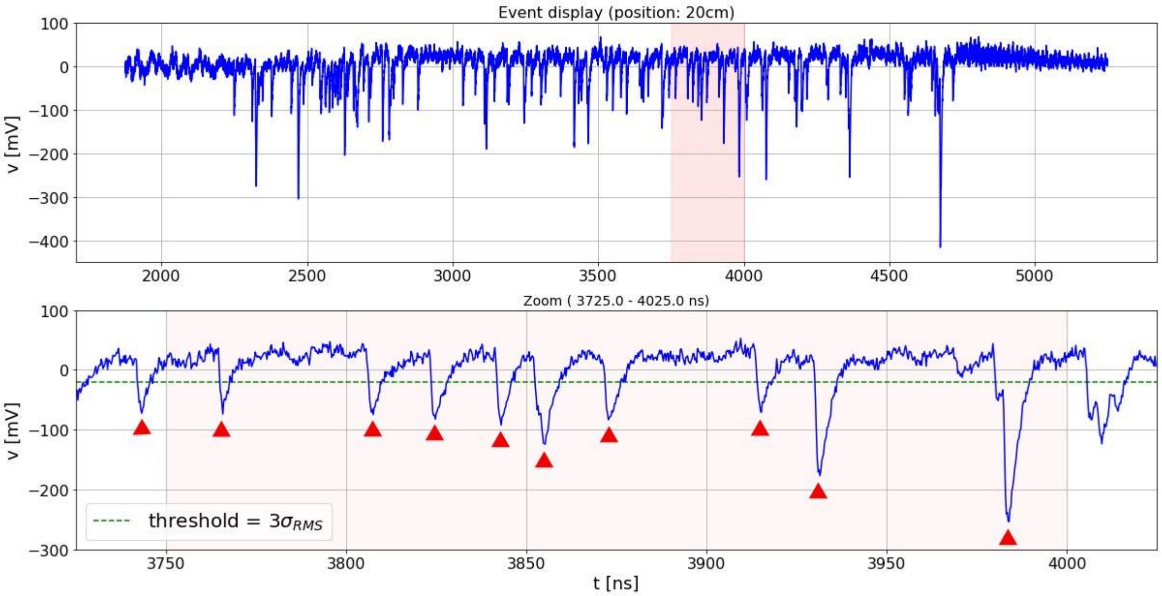
Increasing the input impedance, the signal becomes bigger but slower

Fast detectors for polarimetry at the EIC

Previous tests - single particle ID



The detectors was used to monitor an high-rate medical electron beam



> Fast digitizer to collect the waveforms

> Dedicated algorithm to reconstruct the individual crossing particles

Fast detectors for polarimetry at the EIC

Previous tests - single particle ID

LGAD operating as a single-quantum detector.

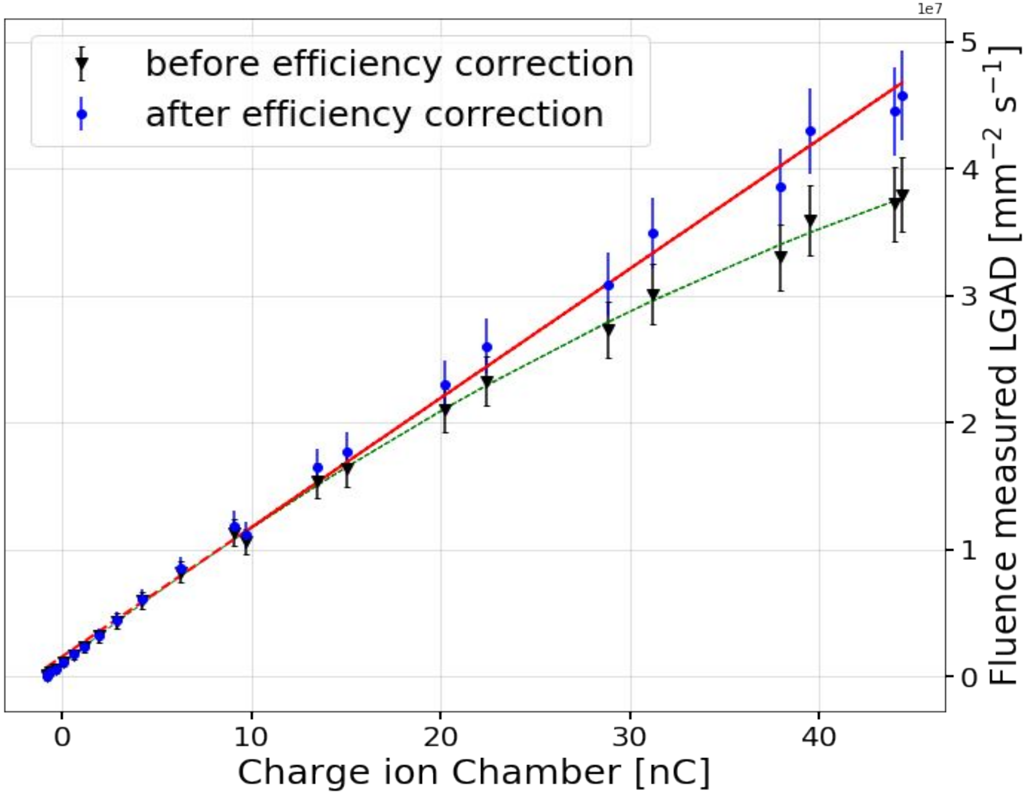
Typical pulse duration ~ 10 ns

if the **rate of incident particles** **< 200 MHz**:

resolves single electrons with a time resolution of ~50 ps

On average, the algorithm fails when two particles pass through the detector within **6.5 ns** of each other

Probability of happening = exp(-6.5 μ)
μ = incident particle rate [GHz]



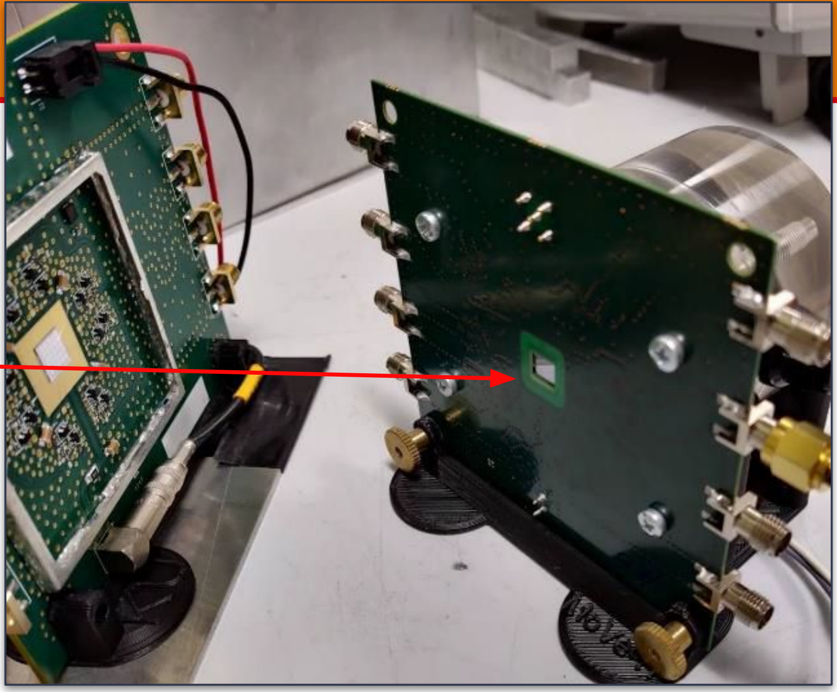
Fast detectors for polarimetry at the EIC

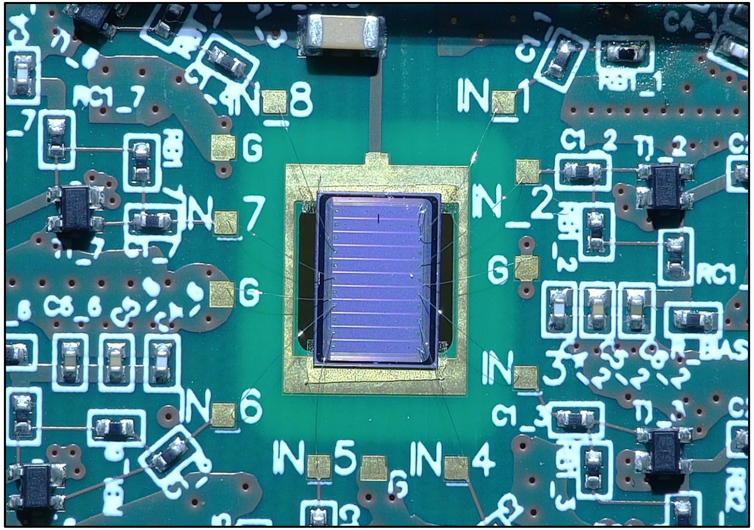
New prototypes

We can do better!

> Optimization of the read-out for single particle ID

> Reduction of the material budget behind the sensor's active area (for radiation transparency)





Use of thinner LGADS for MIPs:

> Thickness ~150 um (tot)

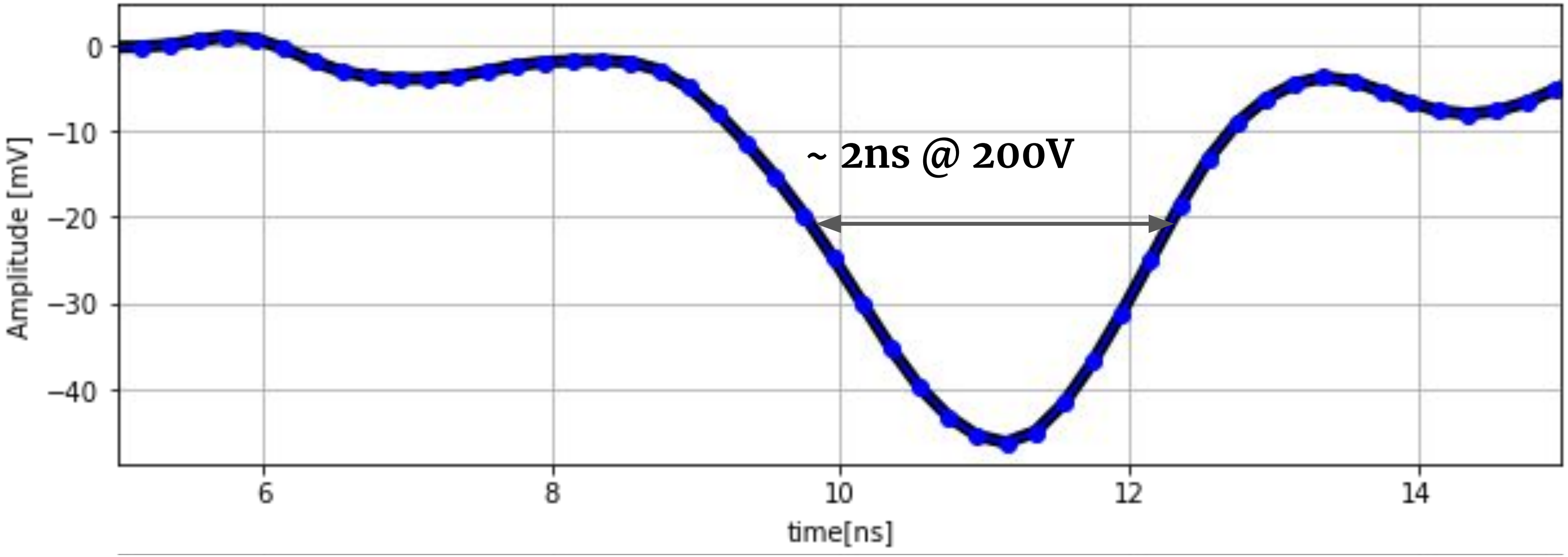
> linearity up to 10 MIPs, for high rates (>200MHz)

> optimized for single particle ID

Fast detectors for polarimetry at the EIC

New prototypes

Using ^{90}Sr electrons

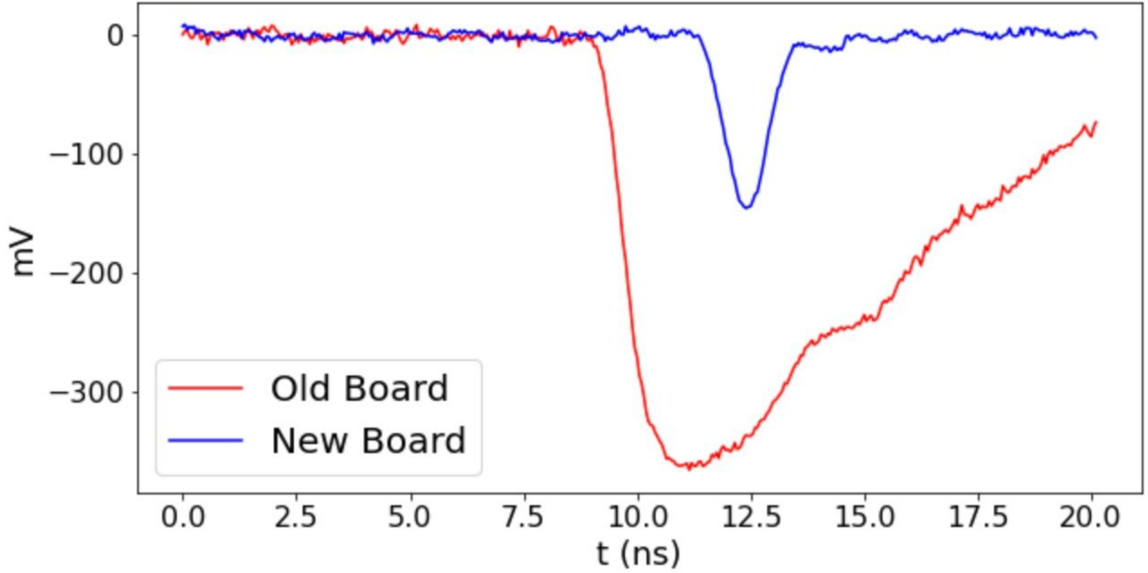


Fast detectors for polarimetry at the EIC

New prototypes

Using ^{90}Sr electrons

Average pulse duration ~ 1/5 of the previous prototypes



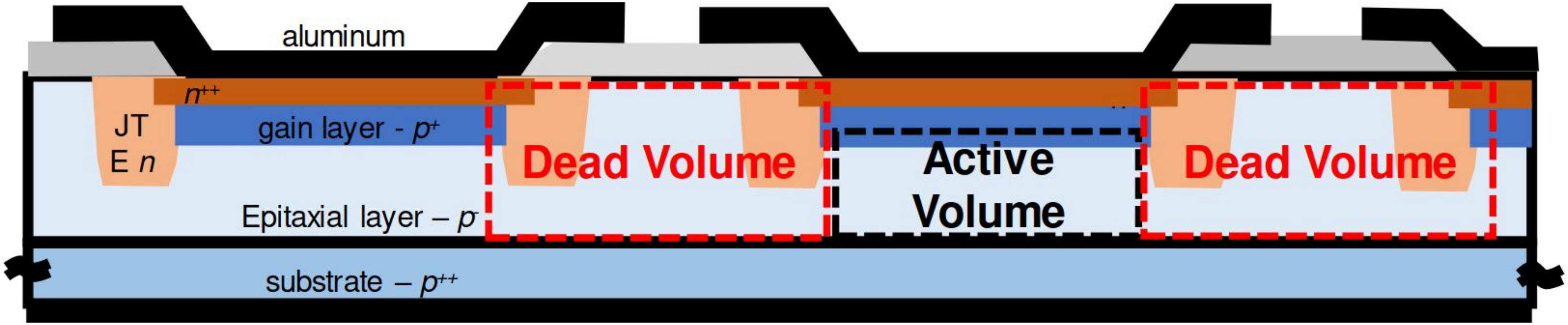
Sacrificing some of the SNR the duration can be further reduced

Pulses 10 times shorter would improve by an order of magnitude the single-particle res. capabilities

Fast detectors for polarimetry at the EIC

New prototypes

The high electric field needed for the gain layer (3kV/cm), limits the minimum distance between pads:



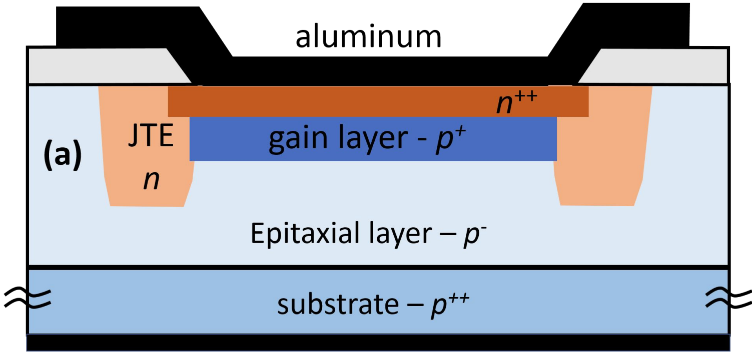
Remember: the lateral dimensions of have to be much larger than thickness of substrate for a uniform multiplication field → Large pads are preferred

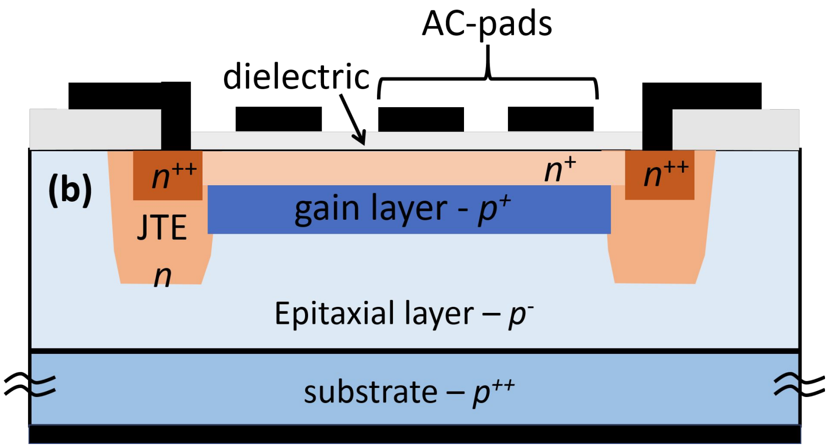
Fill factor (active area/total area) << 100 %

G. Giacomini - From LGADs to AC-coupled LGADs for fast timing applications

Fast detectors for polarimetry at the EIC

New prototypes

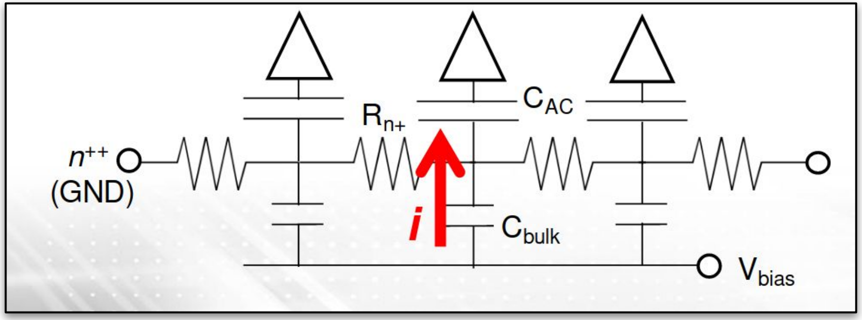




AC–LGAD technology

> High-doped low-r n_{++} → large low-doped high-r n_{+}

> thin insulator over n_{+}, with fine-pitch electrodes



G. Giacomini - From LGADs to AC-coupled LGADs for fast timing applications

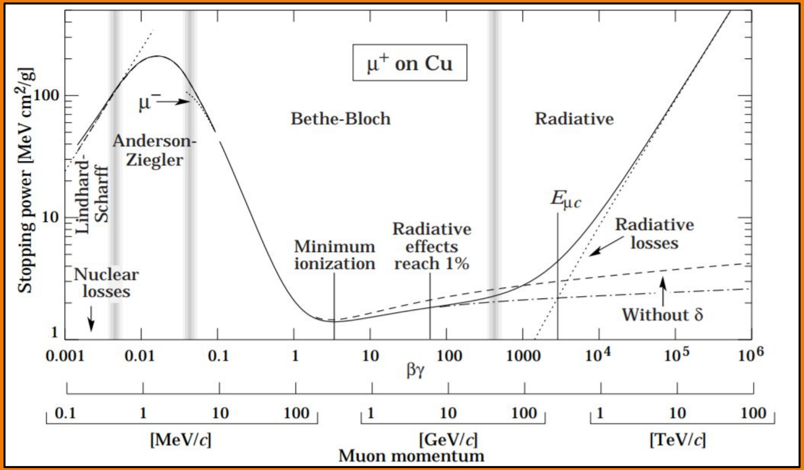
Conclusions

- New prototypes will need the design of optimized read-out for faster integration
  - Pulses 10 times shorter would improve by an order of magnitude the single-particle res. capabilities
- Thinner LGADs with optimized granularity provide better space and time resolution (AC-LGADs ?)
- For covering larger areas requires the development of dedicated ASICs
- This technology is of great appeal for polarimetry at the EIC, where, at the High lumi conditions, the polarization of the bunches have to be monitored every few ns.
- The promising radiation hardness of these sensors grants stable operation up to high absorbed fluences

Introduction to particle detectors

principles of detection

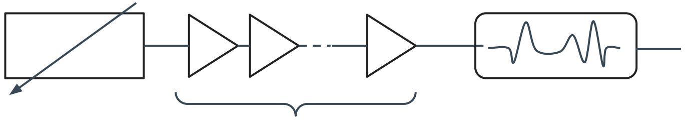
A particle detector works as a transductor, converting in useful information the energy lost by a charged particle passing through its active volume...



$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2}\cdot\frac{nz^2}{\beta^2}\cdot\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\cdot\left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right)-\beta^2\right]$$

The shape, the duration and the amplitude of the generated pulse give info about the incident particles

Generic particle detector principle of operation (solid state)



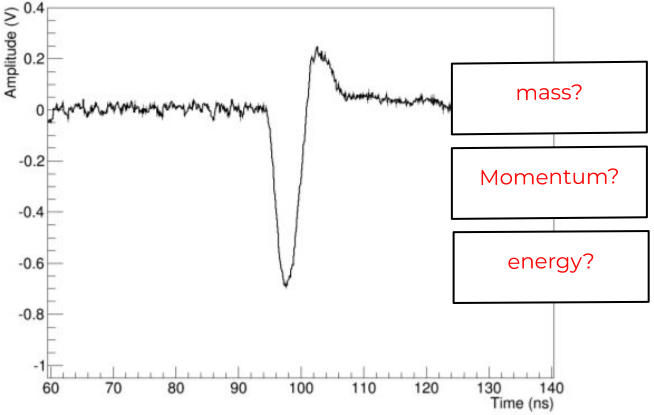
sensor
(transductor)

Amplification/shaping chain

sampler/recorder

data

1. The energy lost by incident particles generates free charges moving through the sensor's active volume.
2. The read-out electronics shapes and amplifies the signals.
3. A fast, high-bandwidth sampler records and store the waveforms.



mass?

Momentum?

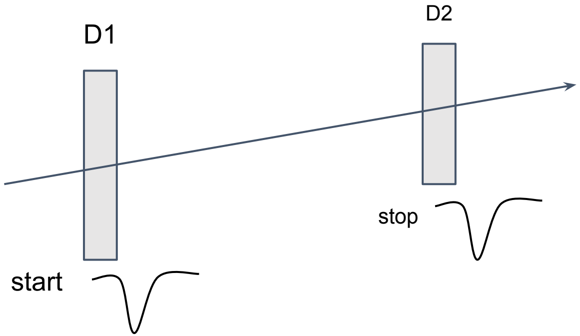
energy?

Introduction to particle detectors

timing

When we talk about “Timing detectors” we usually refer to detecting devices optimized to accurately reconstruct particles times of arrival when collected from the sensor.

In the example of two devices (D1,D2) detecting the passage of a particle...



$$L \approx |t_{start} - t_{stop}|\, v$$

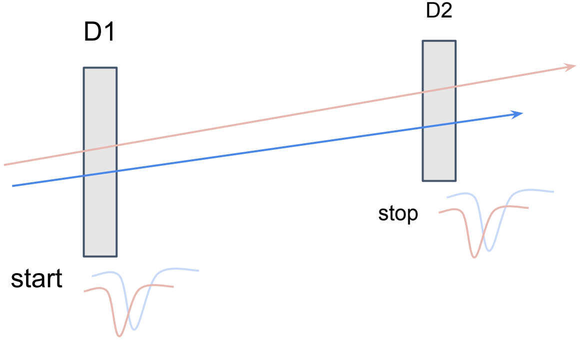
$$\sigma_z = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2} \cdot c$$

$$\sigma_{tot} = \frac{1}{N} \cdot \sqrt{\sigma_{det1}^2 + \sigma_{det2}^2 + ..} \approx \frac{1}{\sqrt{N}} \cdot \sigma_{det}$$

Uncertainty

...When two particles cross the detector the TOF can be used for particle ID

$$\Delta t = t_2 - t_1 = L\left(\frac{1}{v_1} - \frac{1}{v_2}\right) \approx \frac{Lc}{2p^2} \boxed{(m_1^2 - m_2^2)}$$



Precise Detector

- Output the timestamp of a particle’s passage in the active volume with a small uncertainty.
- Suited for **TOF**, **difference of time of arrival**, **time reference for HEP detectors**...
- In new generation detectors, the time uncertainty can go as low as **σ ~ 10ps.**
- The accuracy of the timing measurement affect the spatial reconstruction accuracy $\sigma_L \propto \sigma_t$

Introduction to particle detectors

sensors and properties

First step: choosing the sensor

$$\sigma^2_t \sim \overset{*}{\sigma}^2_{jitter} + \overset{*}{\sigma}^2_{Landau} + \sigma^2_{TimeWalk} + \sigma^2_{Distorsion}$$

* **Sensor's contributions:**

Jitter = Variation in time caused by the noise of the system.

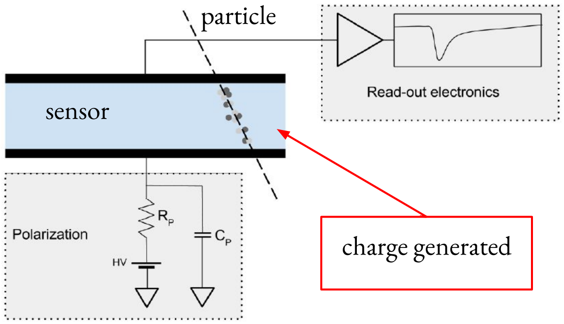
Landau = local stochastic fluctuations of the energy loss spatial distribution

The quality of the sensor, the production process, the material used … Decide the performance of the detector, drastically influencing properties such as:

- Charge Collection Efficiency (CCE)
- radiation tolerance
- gain due to multiplication processes
- …

Solid state detectors are the most commonly used for timing

The polarization circuit connected to one of the electrodes, **provides the E-field** needed **to drift the** free **charges** inside the bulk, hence **generating the current collected by the read-out**



Solid state sensors

- **μ > 1000 (cm2/V)s** High **mobility** of the carriers

- **v_s > 10^7 cm/s** - High **saturation velocity**

- **$C_{sensor} \propto \varepsilon_0\varepsilon_d$ (S/d)** the sensor capacitance is proportional to the dielectric constant (low capacitance means shorter integration time)

- The **Displacement energy** in sensors of new generation drastically improved (lifespan up to **10^{15} n_{eq}**)

- **Low thickness** and **material budget.** Sensor size down to ~**50μm**

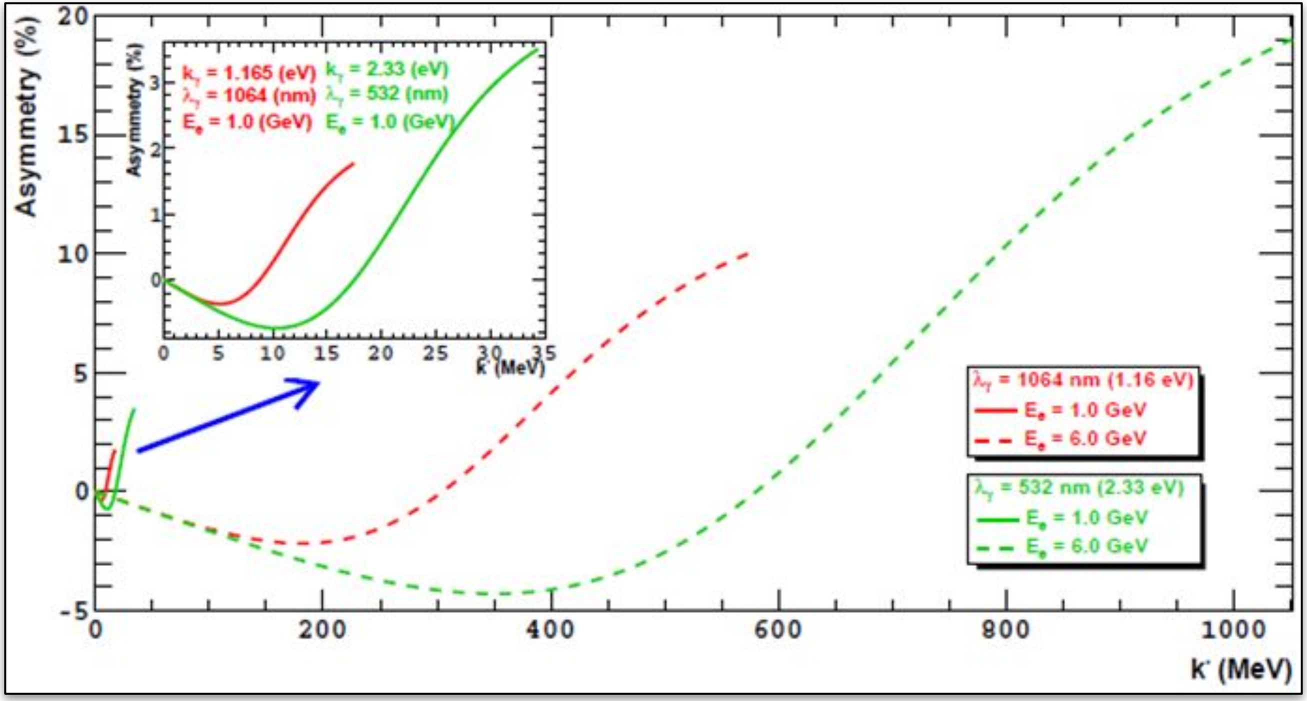
- **High granularity** on the active area

Fast detectors for polarimetry at the EIC

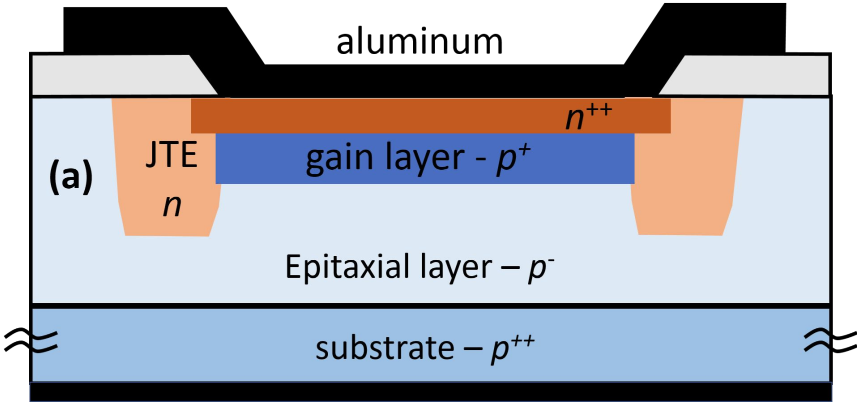
Compton Electron Polarimetry

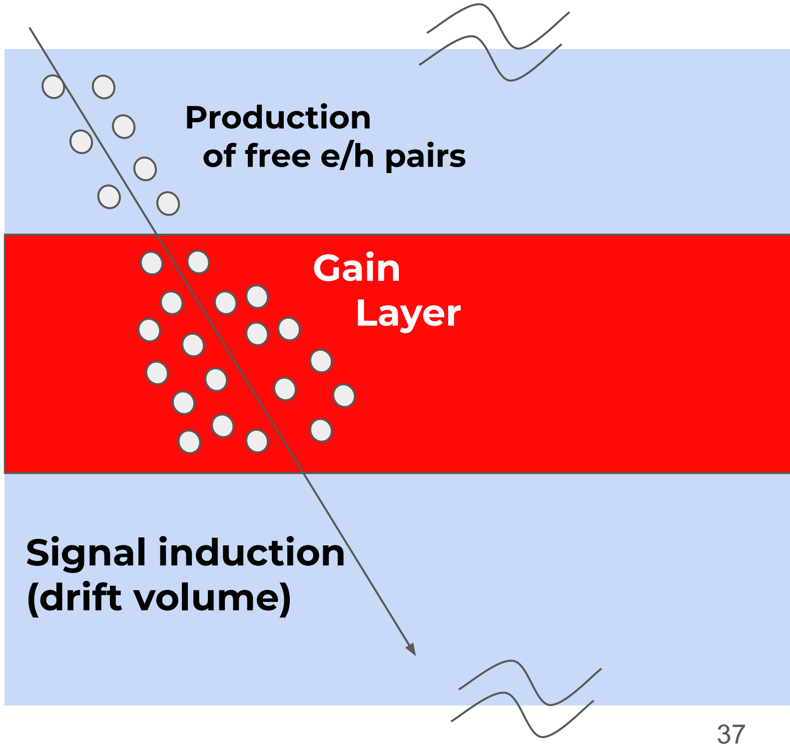
$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-} = \boldsymbol{P_e} * P_\gamma * A_{QED}(E_e, k_\gamma, k_{\gamma'})$$

> Compton edge and zero needed to fit $\mathbf{P_e}$ to $\mathbf{A_{measured} = P_e A_{theory}}$



Low Gain Avalanche Detectors (LGAD)





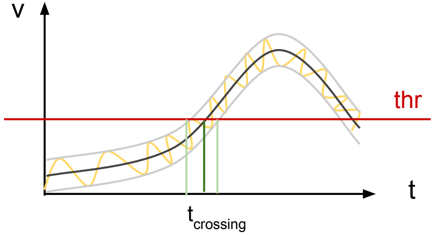
Introduction to particle detectors

Front End and post-processing

$$\sigma^2_t \sim \overset{*}{\sigma^2}_{jitter} + \sigma^2_{Landau} + \overset{*}{\sigma^2}_{TimeWalk} + \sigma^2_{Distorsion}$$

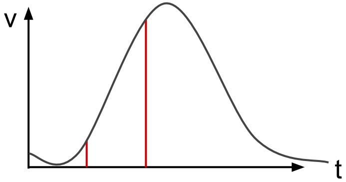
* contribution of the FE

* post-processing corrections



read-out

The predominant contribution introduced by the shaping and amplifying chain comes from the **noise fluctuations** that, in turn affect the Signal to Noise Ratio (SNR)



front-end

The choice of a performing sampler directly influence the timing precision of the instrument as the jitter depends on the slope of the signal's rising edge. The bottleneck of the rising time for fast detectors comes from the **sampler's bandwidth.**

$$\boxed{\sigma_{jitter} \simeq \frac{noise}{dV/dt} = 1.25\frac{\tau_{0.1} - \tau_{0.9}}{SNR} = 1.25\frac{t_{rise}}{SNR}}$$

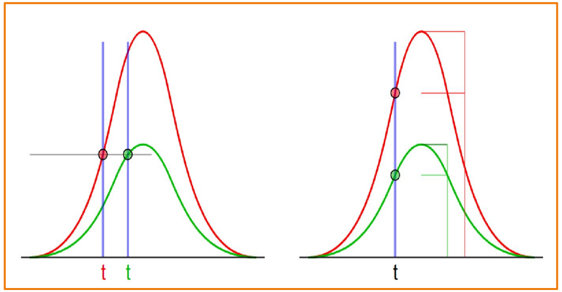
With

$$\boxed{t_{rise} = \frac{0.35}{Bandwidth}}$$

Note (post-processing data):

Some of the contributions come from effects that are intrinsic to the nature of the measurement and can only be corrected during the analysis procedure.

The **Time Walk** is the mis-reconstruction of the timestamp of simultaneous pulses with **different amplitudes**.



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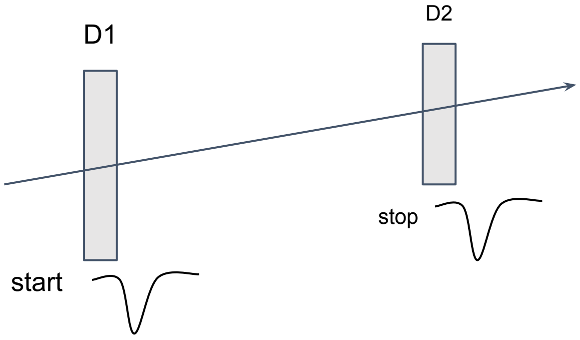

$$L \approx |t_{start} - t_{stop}|\, v$$

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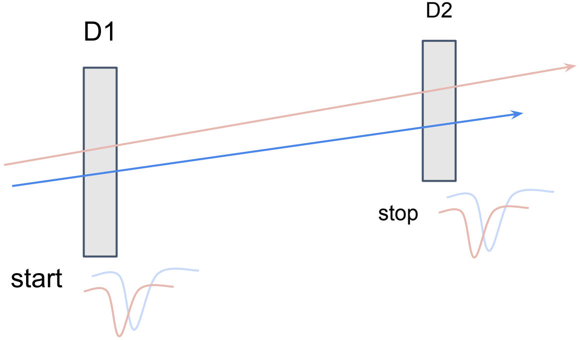

Precise Detector

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- In new generation detectors, the time uncertainty can go as low as **σ ~ 10ps.**
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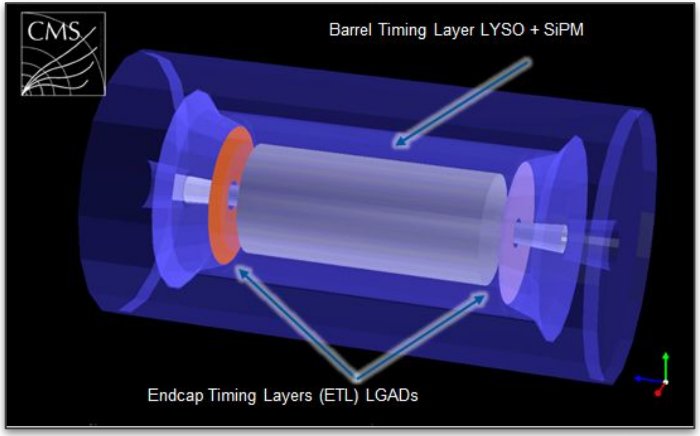
Precise detectors TOF and particle ID

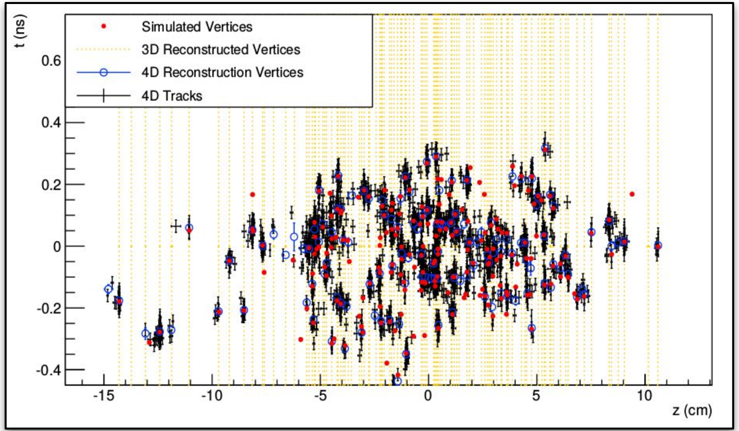
The CMS Mip Timing Layer

The CMS MTD - ETL & BTL



	Barrel LYSO+SiPM	Endcap LGAD
Coverage	$\lvert\eta\rvert < 1.5$	$1.5 < \lvert\eta\rvert < 3.0$
Surface Area	$\sim 40\ \mathrm{m}^2$	$\sim 12\ \mathrm{m}^2$
Power Budget	$\sim 0.5\ \mathrm{kW/m}^2$	$\sim 1.8\ \mathrm{kW/m}^2$
Radiation Dose	$\leq$ 2e14 neq/cm^2	$\leq$ 2e15 neq/cm^2
Installation Date	2022	2024

[1] Precision timing at CMS for HL-LHC - Artur Apresyan | TREDI 2017
[2] Test Platform for Automated Scan of Multiple Sensors - N.Minafra
[3] Timing detectors in the CMS experiment - T.Isidori



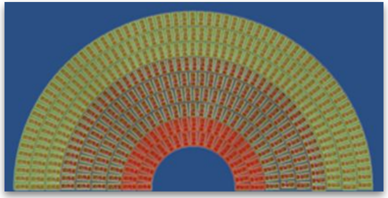
MIP Timing Layer with 40 ps of time precision is required

impact on the physics program:

> improved track and vertex reconstruction abilities
> lepton reconstruction efficiency
> diphoton vertex location
> missing transverse momentum resolution
> reduction of the pile up jet rate

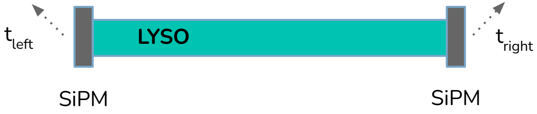
selected technologies

ETL - LGAD



- Pad size: 1.3 x 1.3 mm^2
- High fill factor (>85% per layer)
- 16624 sensors of 2x4 cm^2

BTL - LYSO + SiPM



- Lutetium-yttrium orthosilicate crystals activated with cerium
- active volume (per strip) = 3 × 3 × 57 mm^3
- SiPM active area = 9 mm^2,
- SiPM light collection efficiency (LCE) ~ 15%

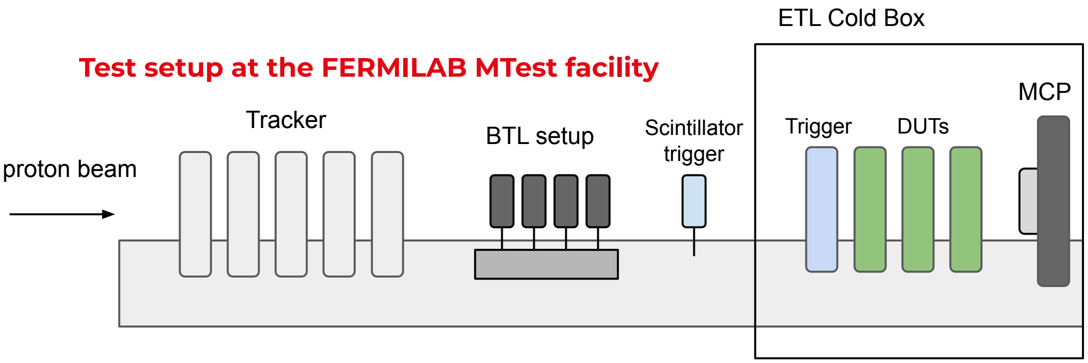
Precise detectors TOF and particle ID

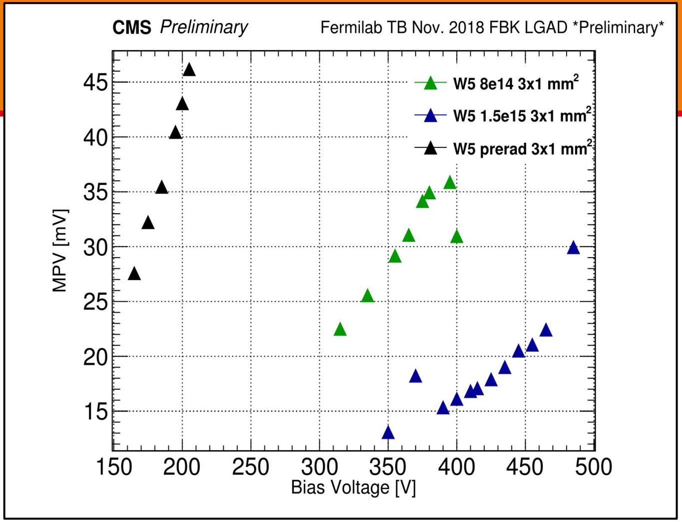
The CMS Mip Timing Layer

The CMS MTD

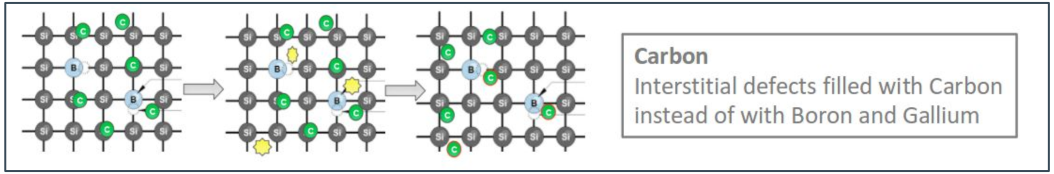
Since 2017 US-CMS has been heavily involved in the design, test and characterization of the new generation timing detectors for the MTD project. In particular, the KU group collaborates with the R&D on the LGAD wafers needed for the End-Cap Timing Layer.

Test setup at the FERMILAB MTest facility

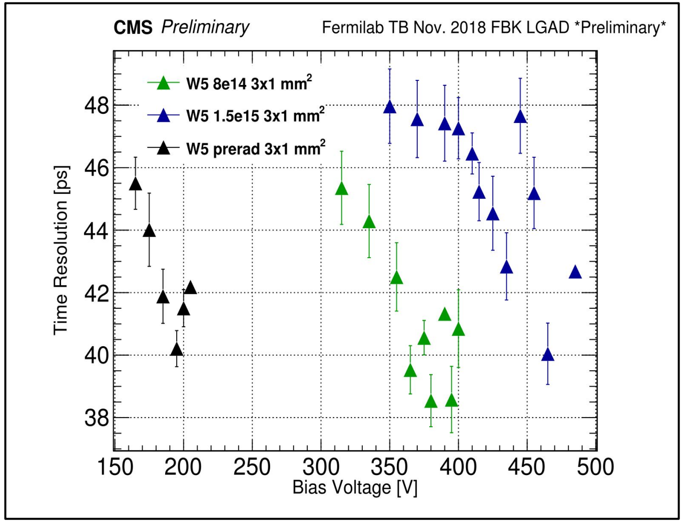




Sensor under test: W5 an W6 prototypes produced by the CNM and FBk companies



Carbon
Interstitial defects filled with Carbon instead of with Boron and Gallium



Controlled annealing to re-activate the gain layer

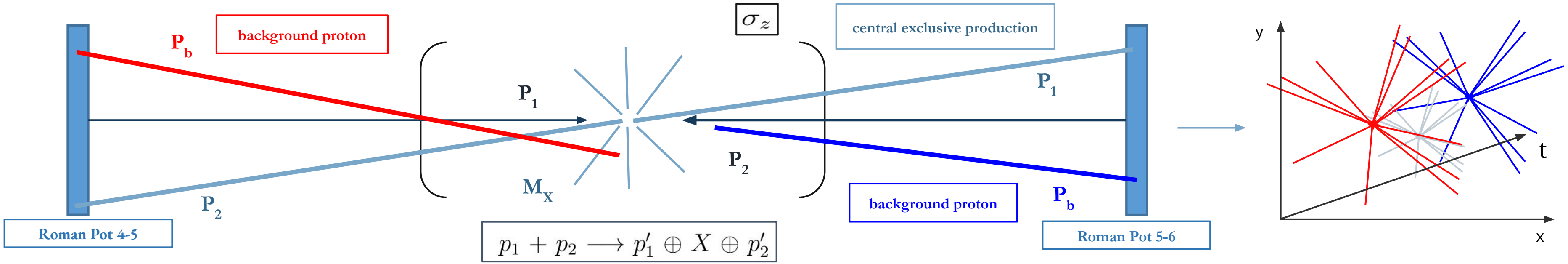
Precise detectors TOF and particle ID

TOTEM and PPS Diamond detectors

TOTEM and PPS

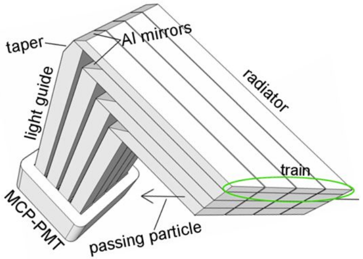
During their technical upgrade the PPS and TOTEM collaboration decided to introduce timing detector in their experimental apparatus. The experiments, situated in the forward zones of the CMS barrel (~ 220 m on both sides) help closing the kinematics of pp diffractive and non-diffractive events and rejecting the pile-up expected for higher luminosity runs.

ATLAS and CMS forward detectors represents a good example of TOF for pile up rejection (and not only)



$$p_1 + p_2 \longrightarrow p_1' \oplus X \oplus p_2'$$

The ATLAS Forward Proton Detector (AFP)



Quartic (Quartz bars + MCP readout)

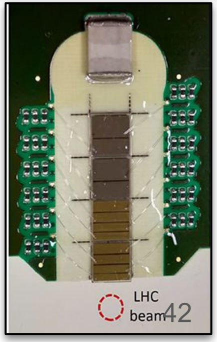
- High fill factor (>85% per layer)
- Despite the crosstalk resolution **< 25 ps**
- requirement: spatial resolution of **2.12mm**
- requirement: rate **5 MHz** per channel

ATLAS Forward Proton (AFP) time-of-flight (ToF) detector: construction & existing experience - T.Sykora

CMS Proton Precision Spectrometer

4 Layers of **sCVD Diamond detectors**

- Active area **~ 80 mm²**
- sustainable hit rate up to **few MHz/mm2**
- double sCVD design **~ 50 ps** resolution (per plane)
- resolution degradation ~ 20-50% (full 2018 data taking)
- stable time resolution in detecting 6–7 TeV protons



The CMS Precision Proton Spectrometer timing system: performance in Run 2, future upgrades and sensor radiation hardness studies - E.Bossini

Precise detectors TOF and particle ID

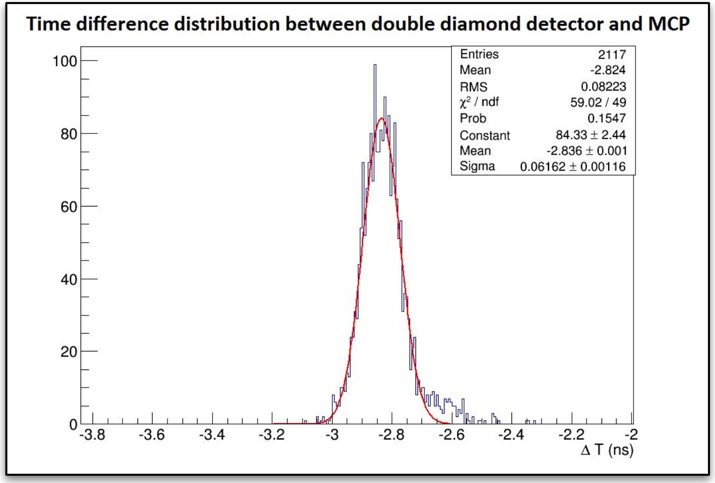
TOTEM and PPS Diamond detectors

Design of a Double Layer Diamond Detector

During 2017 TOTEM experiment test beam campaign, the collaboration developed a new prototype based on two layers of diamond detectors mounted on the same read-out card.

The prototype has:

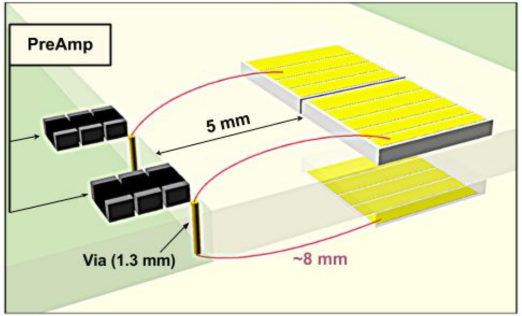
- Twice the signal amplitude
- Same charge collection time (same thickness)
- Same RMS noise (same preAmp)

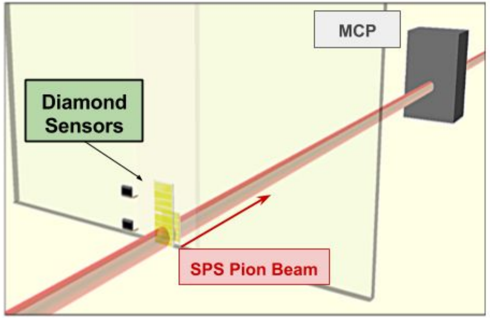


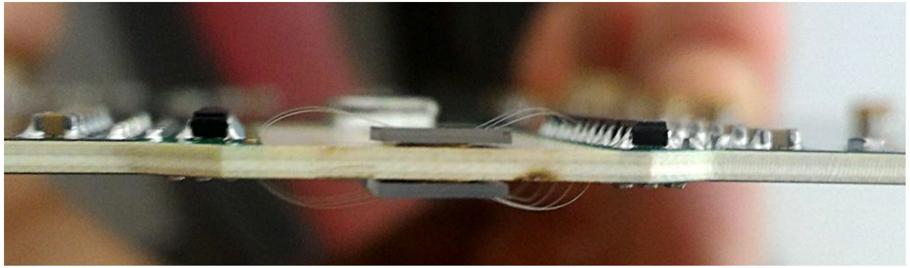
Time difference distribution between double diamond detector and MCP

$$\sigma^2_t \sim \sigma^2_{MCP} + \sigma^2_{DD} < 50 \text{ ps}$$

The new detectors are now installed and operating in the main TOTEM and PPS apparatus during standard dedicated and CMS runs.







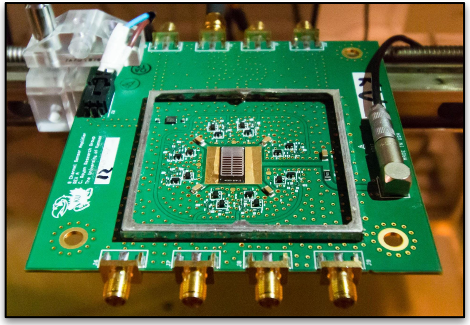
Timing Performance of a Double Layer Diamond Detector - M. Berretti, et al. - DOI: 10.1088/1748-0221/12/03/P03026

Fast detectors for HEP and applications

Beam monitoring and dosimetry in medical facilities

Fast detectors for high rates

Many commercial (and research) applications require the use of fast detector for single particle resolution measurements. The ability to precisely count the number of incident particle per unit of time (without distortions due to long integration time or efficiency drop) represents an invaluable tool for evaluating **radiation doses, study beams luminosities, calculate the polarization of particle bunches**...



Example: monitor of a medical linac and characterization of the beam profile

Electronic board designed @ KU and characterized using a 50 µm UFSD

> Fast time integration of 5-10 ns

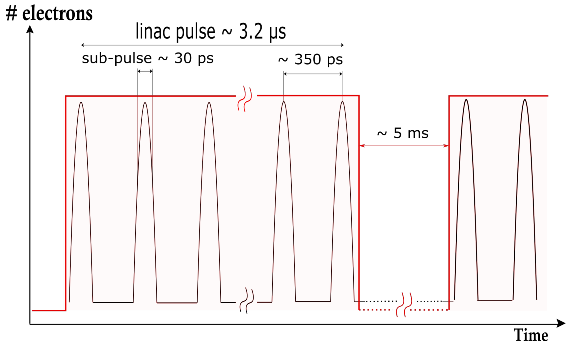
> Sensor's Area = 2.9 x 0.5 mm^2

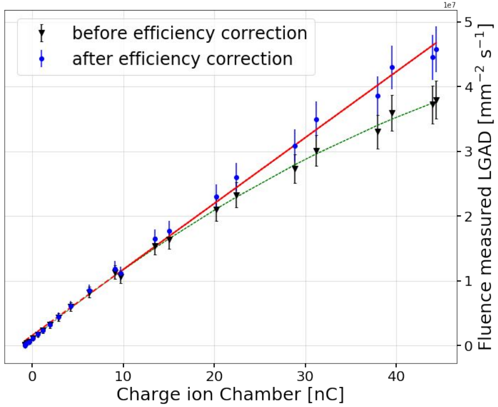
> Time precision < 30 ps @ V_{bias}= 220V

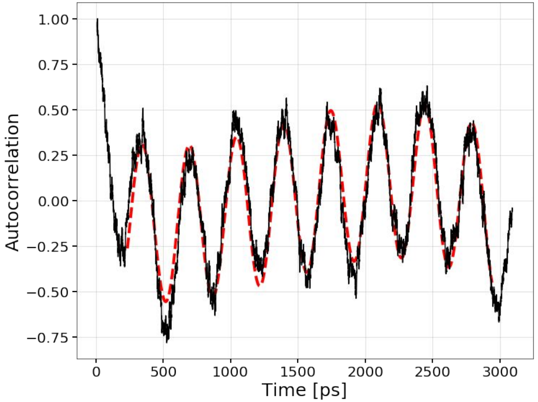
> Tested with a 6 MeV electron beam

> Pulse repetition = 200 Hz

> Fine structure frequency is 2.858 GHz







Note:

The test works as a proof of concepts for single particle resolution in new generation fast timing detectors (up to **tens of MHz** with the setup displayed).

The loss of efficiency due to multiple clustered event can be corrected with the post-processing procedures.

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