Fast Timing Micro-Pattern Gaseous Detector for PET-TOF and future collider applications

P. Verwilligen [1], I. Vai [3], R. De Oliveira [2], M. Maggi [1], A. Sharma [2],
A. Colaleo [1], F. Fallavollita [3], P. Giacomelli [4], L. Guiducci [4], A. Ranieri [1],
M. Ressegotti [3], P. Vitulo [3]

[1] INFN Bari [2] CERN

[3] University & INFN Pavia

[4] University & INFN Bologna

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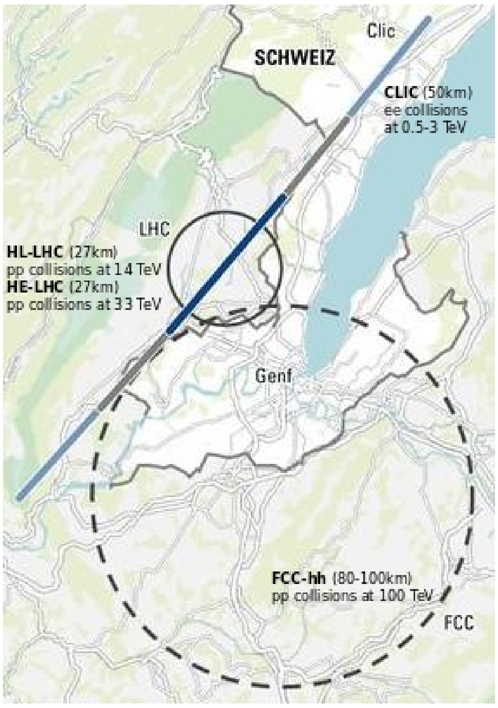
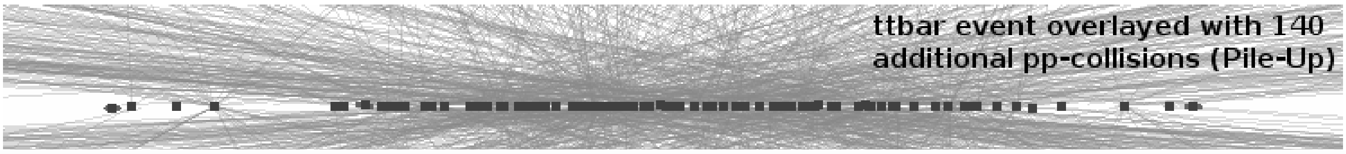
Future Challenges: High-$\mathcal{L}$ Collider Detectors



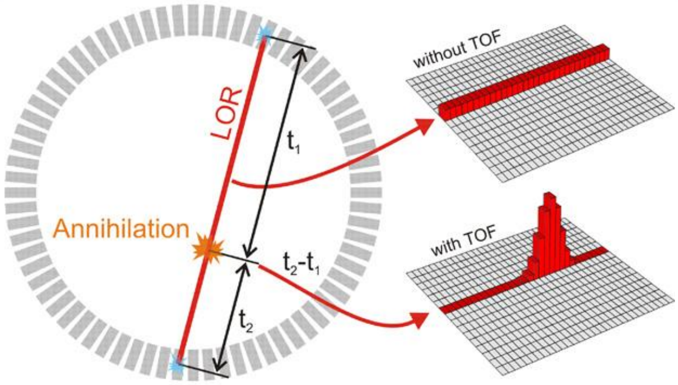
- Future Colliders (FC) will operate at higher $\sqrt{s}$ and $\mathcal{L}$
- For **muon detection** systems of FC experiments:

  $\frac{\Delta p}{p} \propto \frac{1}{BL^2} \Rightarrow$ high B field, large instrumented area

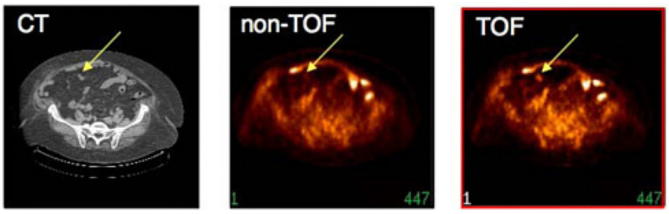
  $\mathcal{L} \Rightarrow$ higher rate capability, Pile-Up vertices
- To **instrument large areas**, gas detector technology will remain unchallenged
- Detectors need to have **high rate capability**
- These detectors are also suited for high granularity (digital) calorimetry at Future Colliders
- **Fast Timing will enable to identify the correct interaction** (at Future Colliders ≥ 200 collisions will overlap with the interesting collision = Pile-Up)



Future Challenges: Time-Of-Flight PET



PET principle, w/ & w/o TOF. [source: `sublima-pet-mr.eu/`]



PET scans of a patient with colon cancer. The use of TOF improves the lesion detectability (arrow). [source: J. Karp, U. Pennsylvania.]

PET is a **non-invasive** technique to visualize organs with **high metabolic activity** and is used to spot tumors

β^+	sugar (FDG) is administered to a patient and concentrates at regions of high metabolic activity (tracer)
e^+	is released and looses energy during travel ($\sim$1 mm) before annihilation
2 γ	(511 keV) are emitted back to back, their coincident detection determines the Line of Response (LOR)
w/o TOF	equal probability assigned to each point along the LOR
w/ TOF	few 100 ps measurement will lead to $\sim$ 5 cm precision along the LOR

the use of fast timing in PET results in high contrast images

Time-Of-Flight Positron Emission Tomography

An ideal TOF-PET detector should . . .

- ⇒ have **high detection efficiency** for γ
- ⇒ have **high spatial resolution** to determine precisely the LOR
- ⇒ have **good energy resolution** to reject scattered γ's
- ⇒ have **high time resolution** to increase the sensitivity / image constrast
- ⇒ be **inexpensive** to produce (instrument larger area, instrument more hospitals)

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technologies:	LYSO crystal
$\epsilon_{\text{detection}}$	high
σ_{space}	$\mathcal{O}(5)$ mm
σ_{energy}	good ($\lesssim 10\,\%$)
σ_{time}	400–600 ps
cost	**expensive**
operation	easy

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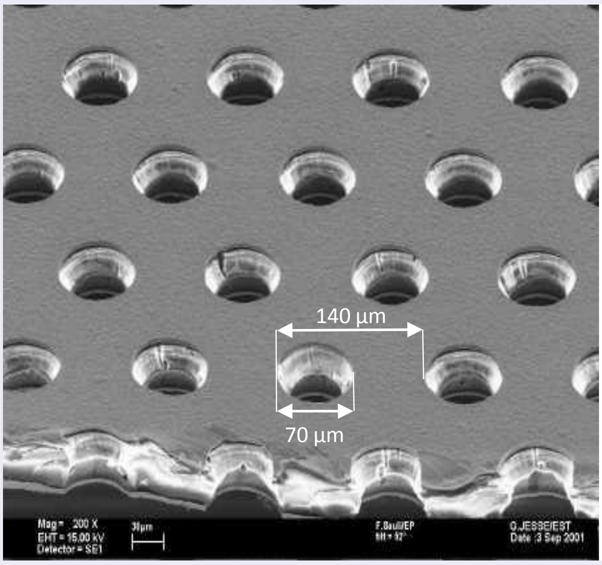
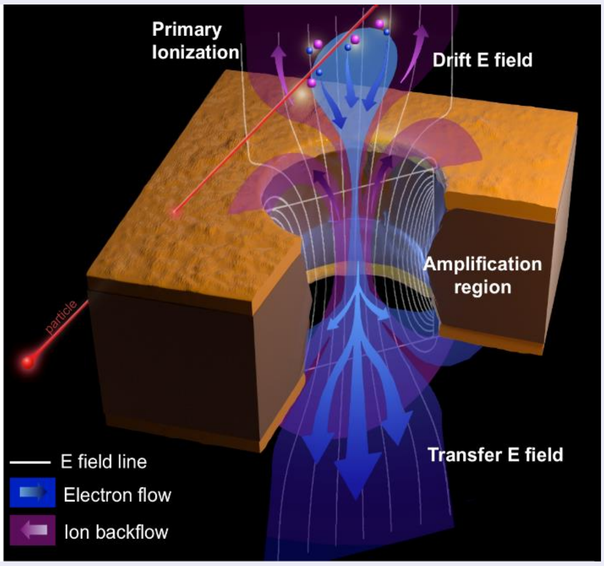
technologies:	LYSO crystal	MRPC	fast MPGD
$\epsilon_{\text{detection}}$	high	$\approx 0.66\,\%$ (4 layers)	to investigate
σ_{space}	$\mathcal{O}(5)$ mm	$\mathcal{O}(0.5)$ mm	$\mathcal{O}(0.1)$ mm
σ_{energy}	good ($\leq 10\,\%$)	**no σ_{energy}**	**moderate**
σ_{time}	400–600 ps	≤ 200 ps	$\mathcal{O}(200)$ ps
cost	**expensive**	cheap	**cheap**
operation	easy	**difficult (HV)**	**easy**

Micro Pattern Gaseous Detector (MPGD)

Example: Gas Electron Multiplier (GEM)





- Photo-lithographic techniques allowed to produce **Micro Patterned detectors**
- Main Characteristics: High rate capability ($> 50\,\mathrm{MHz/cm^2}$), good spatial resolution ($50\,\mu$m), high efficiency ($\geq 95\,\%$), time resolution of $\mathcal{O}(5\,\mathrm{ns})$
- flexible detector structures (cfr. cylindrical trackers for KLOE and BES-III)

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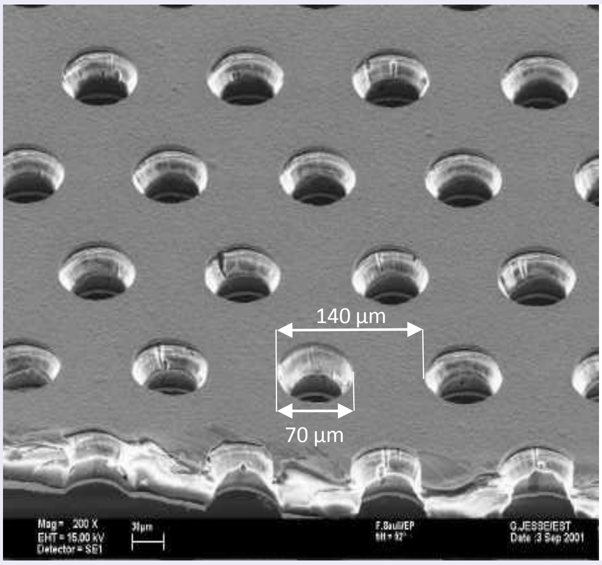
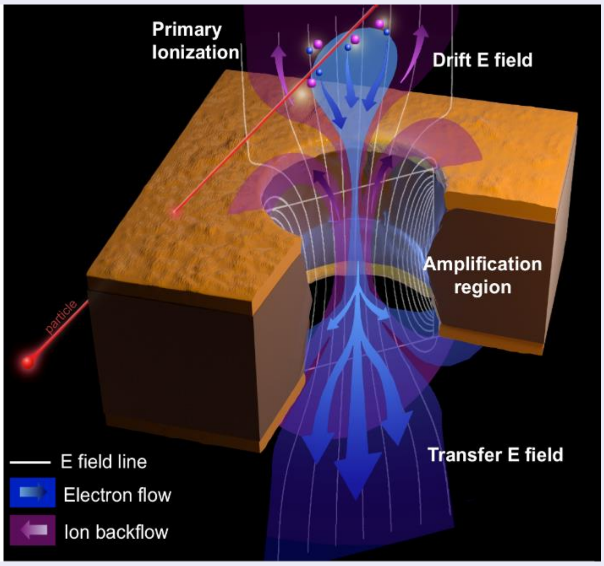
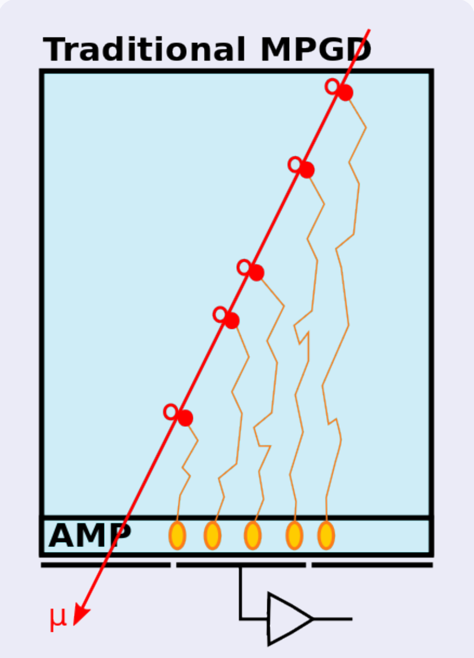




- Two separated regions: **drift region** (creation of electron-ion pairs) and **gain region** (multiply drifted electrons to observable electric signal)
- Rate capability is improved by fast collection of postive ions
- MPGD Time resolution driven by fluctuations in creation of electron-ion pairs

Fast Timing MPGD Principle



- time resolution driven by distance fluct's of $d_{\text{near}} = |e^{-}$ - amplific$|$
- $\sigma_t \propto 1/(\lambda v_{\text{drift}})$, $\lambda = \#$ primary cls
- electron-ion pairs created close to amplification structure result in fast signals
- **Fast Timing MPGD idea:** split drift volume in N layers, each with own amplific.structure $\sigma_t \propto 1/(\lambda v_{\text{drift}} N)$

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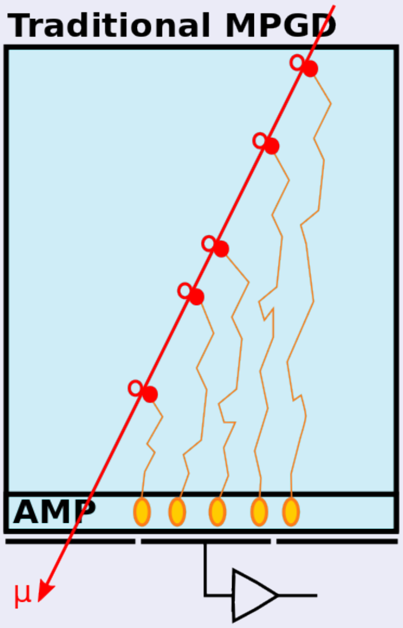

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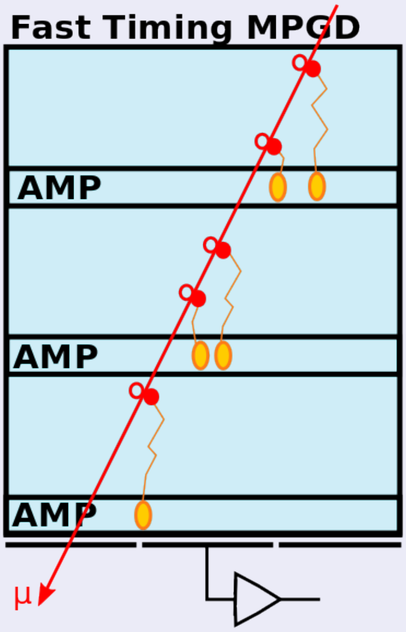

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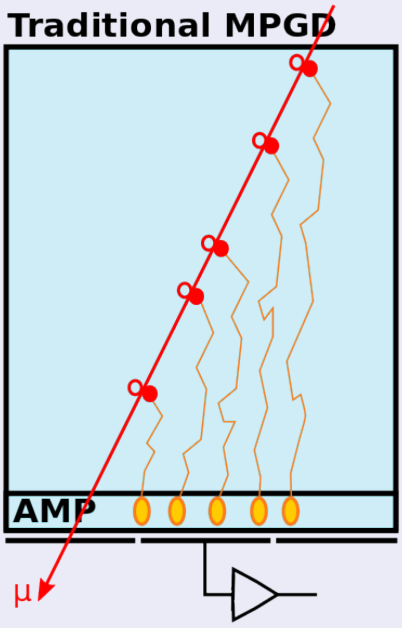

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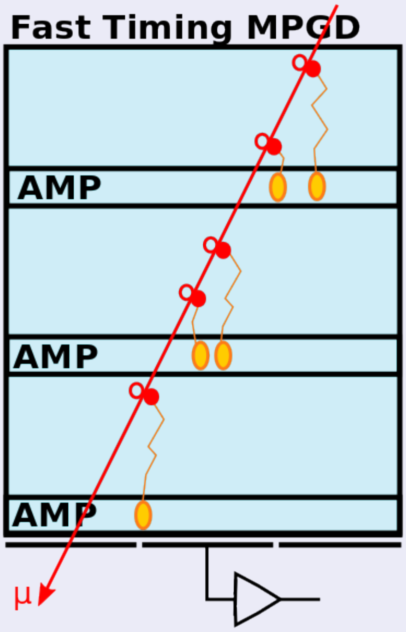
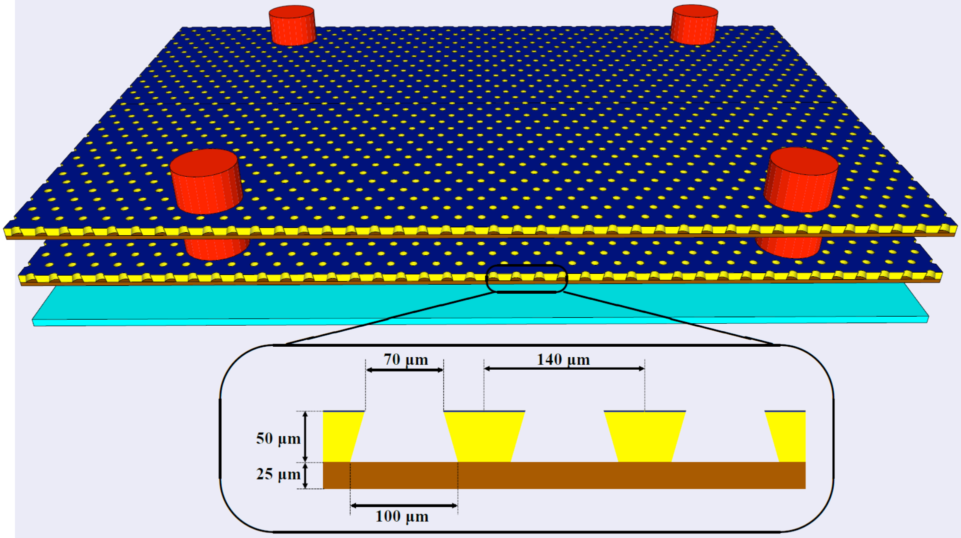
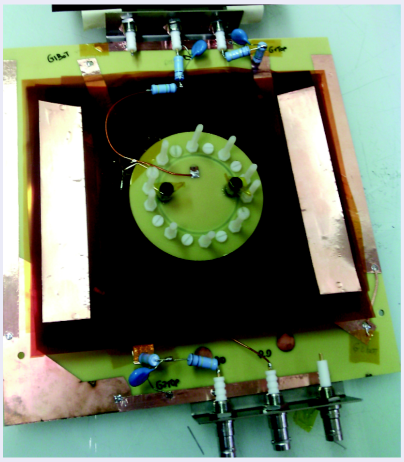


- **resistive structure ⇒ signal from any layer induced in readout**
- **time resolution improved by factor N = number of layers**

Fast Timing MPGD Prototype

2-layer prototype



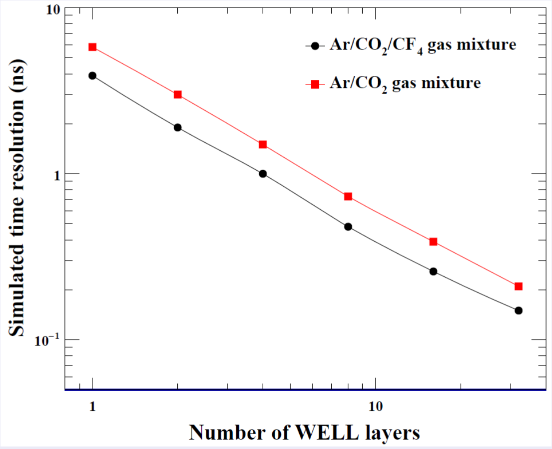


Single layer specifications:

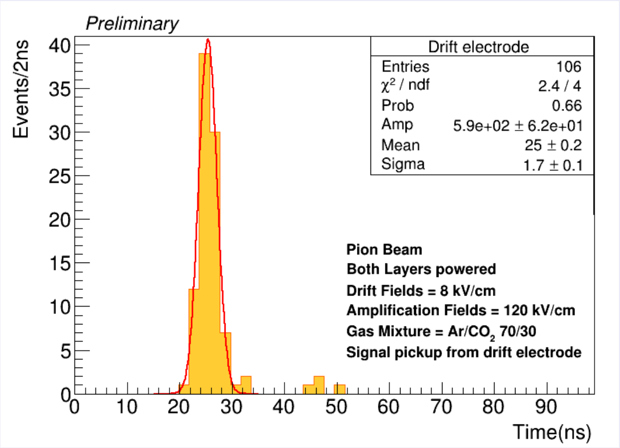
- Drift layer: 250 μm drift layer (Red: Dupont Coverlay spacers)
- Gain layer: 50 μm kapton (Yellow: GEM foil: 70 μm hole, 140 μm pitch)
- Resistive kapton: 25 μm (Brown: Dupont high resistivity Kapton XC)
- Resistive coating: 10–100 nm (Blue: Diamond Like Carbon: DLC)

Fast Timing MPGD First Results

GARFIELD Simulations & SPS Test-beam Results



[source: arXiv:1503.05330]

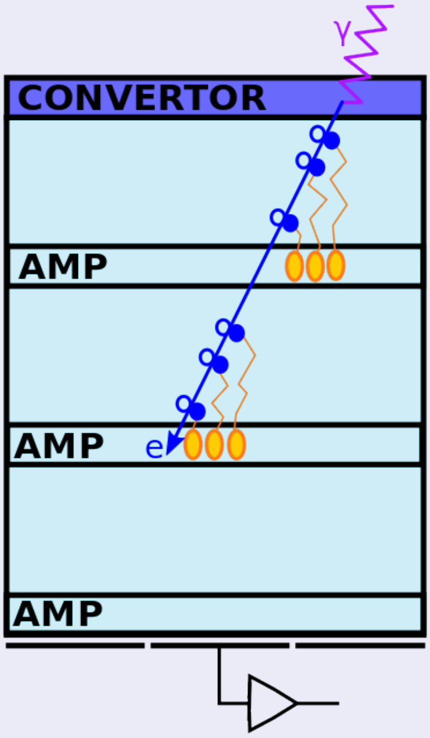


[source: CMS CR-2016/033 (VCI 2016 proceedings)]

- Simulations show time resolution decreasing for increasing number of layers
- Pion Test Beam results for 2 layer prototype show time resolution of 1.7 ns
- $\sigma_t = 1/(\lambda v_{\text{drift}} N)$ with $\lambda^{\text{MIP}}_{\text{Ar/CO}_2\ 70/30} = 33\,\text{cm}^{-1}$, $v_{\text{drift}} = 8\,\text{cm}/\mu\text{s}$, $N = 2 \Rightarrow \sigma_t = 1.9\,\text{ns}$

Fast Timing MPGD for photons

Adapt Fast Timing MPGD to detect 511 keV γ from PET



- photon conversion (Compton-e^-) in 200 μm soda-lime glass (optimal resitive material)
- inverted order of drift and gain region, allowing for fast signal from first electron-ion pair
- preliminar simulations indicate $\sigma_t = 500$ ps for $e^\pm$ from 200–400 keV with 4 layers
- Low-E electrons penetrate less layers, but have higher primary ionization density
- scheme left is starting point for simulation study: try to obtain maximal γ efficiency, fastest timing and best energy resolution
- final layout will be trade-off between fast time (many layers) & good E meas. (large gas gap)
- search for γ-converter efficient in 150–511 keV
- further ideas: use γ-converter glass to build amplification structures

Summary & Impact

TOF-PET with fast MPGD

- Demonstrating that MPGD detectors are suitable for PET purposes will revolutionize medical physics: PET scanners will become more affordable
- TOF-PET is most promising, therefore need very fast MPGD detectors
- We proposed a very fast MPGD ⇒ demonstrate the γ detection capabilities

HEP application for fast MPGD

- Future Colliders will require fast timing to deal with increasingly large backgrounds (neutron backgrounds and prompt particles from Pile-Up)
- $\leq 100\,\mathrm{ps}$ timing will allow to assign particles to the correct interaction
- Muon detectors will need this technology, but this technology will also be able to instrument future high-granularity (digital) hadron calorimenters

fast timing MPGD technology is worth investing time, money and brains to mature this idea into working full scale prototypes!