

'Key Points' for Snowmass Report

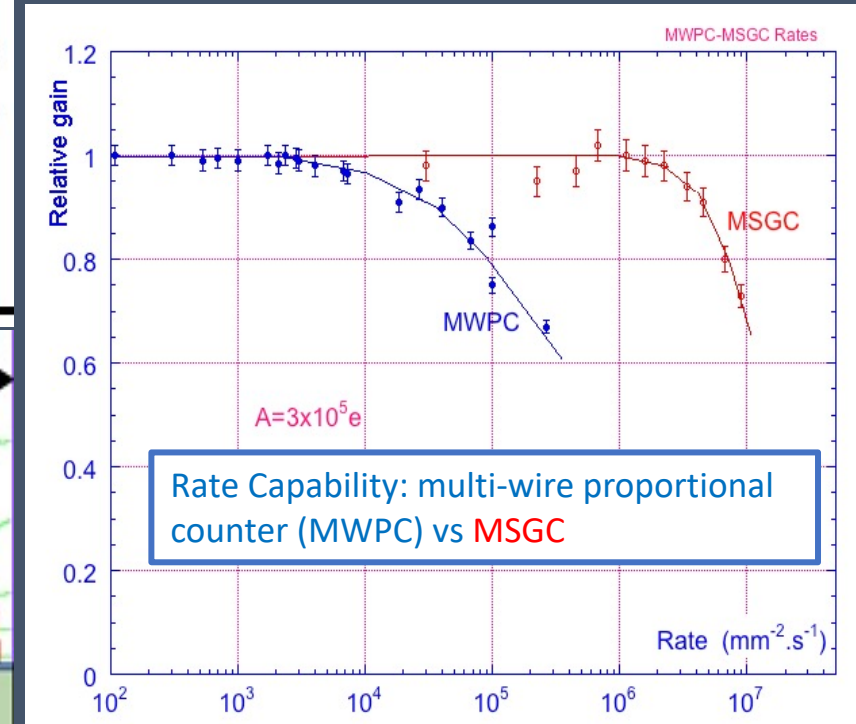
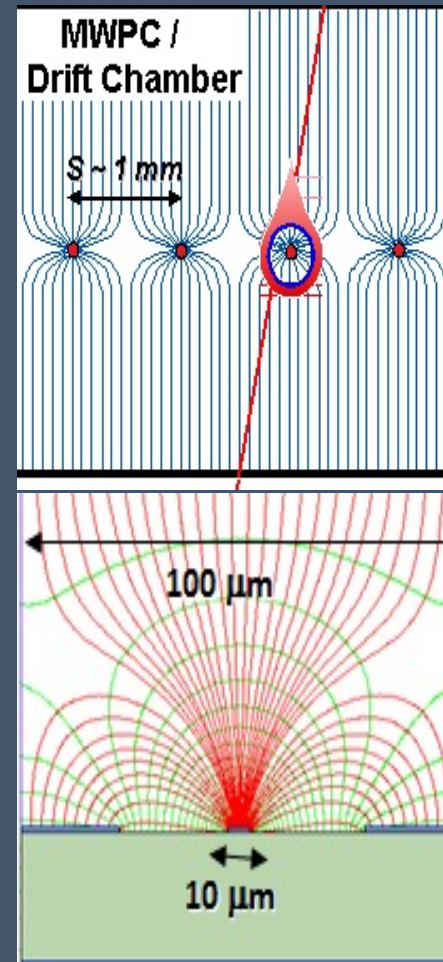
IF5: Instrumentation Frontier Topical group on Micro-Pattern Gaseous Detectors (MPGDs)

This Snowmass topical group has **documented recent developments** and identified **future needs** for MPGD technologies

Conveners: Bernd Surrow, Maxim Titov, [Sven Vahsen](#)

Introduction

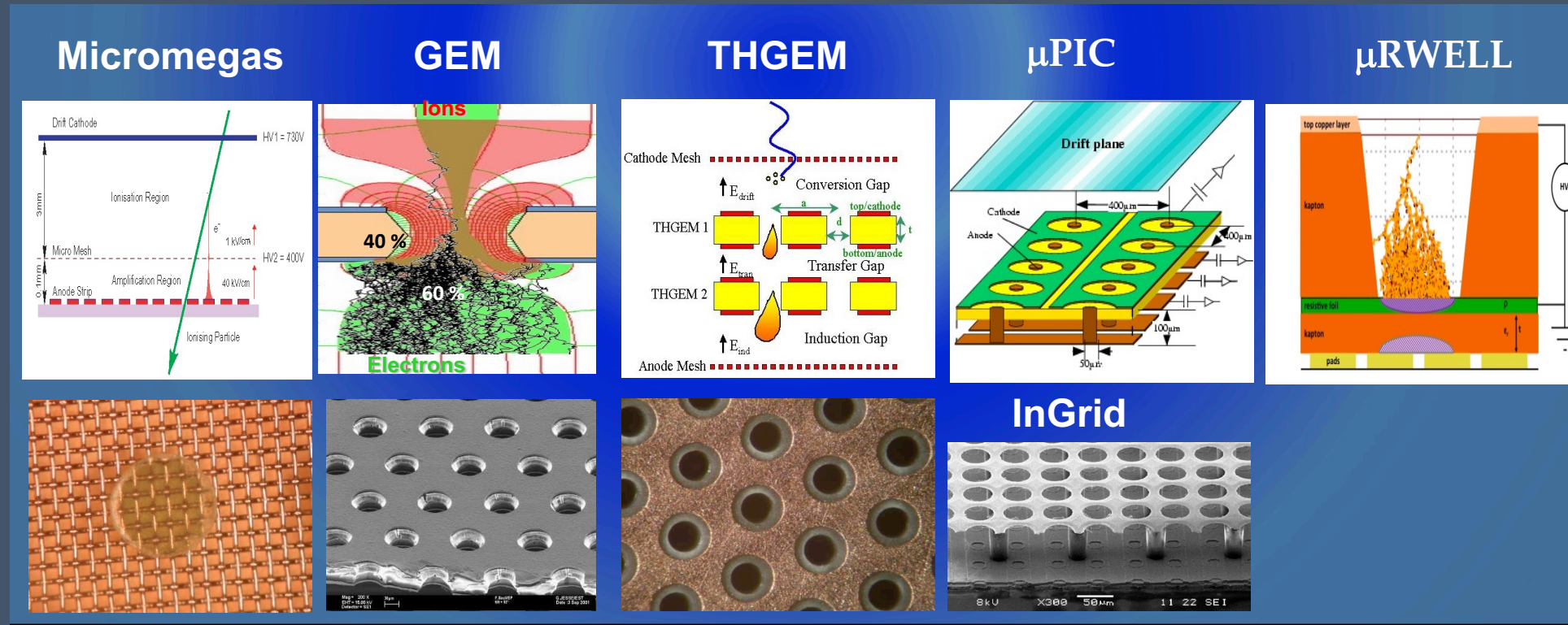
- MPGDs are gas-avalanche-based devices enabled by modern photolithography
- Higher rate capabilities and finer segmentation
- Flexible go-to-solution whenever particle detection w/ large area coverage, fine segmentation, and good timing are required
- Charged particle tracking, photon detection and calorimetry, neutron detection and beam diagnostics
- Of wide interest for NP and HEP, including neutrino physics, dark matter detection, and operation at cryogenic temperatures
- Widely applicable beyond fundamental physics, e.g. in material sciences, medical imaging, hadron therapy systems, and homeland security.



First: Micro strip gas chamber (MSGC), 1988

Current MPGD technologies

- In recent years, surge in the use of MPGDs.
- Now used in most international HEP collider experiments (e.g., ATLAS, CMS, and ALICE at the LHC)
- Used extensively in NP experiments in the U.S.
- In development for future NP and HEP facilities (e.g., EIC, ILC, FCC, and FAIR).



Examples of current MPGD technologies

IF5 White Papers

- 24 LOIs were submitted
- Distilled into five solicited White Papers
- One additional White Paper has further detail

	White Paper Topic	White Paper Leads
1	MPGDs: Recent advances and current R&D (and the European Strategy)	Klaus Dehmelt, Andy White
2	MPGDs for nuclear physics	Kondo Gnanvo, Matt Posik
3	Recoil imaging for directional detection of dark matter, neutrinos and BSM physics * Multi-frontier w/ CF1, NF10	Dinesh Loomba, Ciaran O'Hare
4	MPGDs for TPCs at future lepton colliders	Alain Bellerive
5	MPGDs for tracking and muon detection at future high energy physics colliders	Anna Colaleo, Kevin Black
6	A TPC-based tracking system for a future Belle II upgrade	Peter Lewis

Special thanks to the WP leads for their hard work and following material!

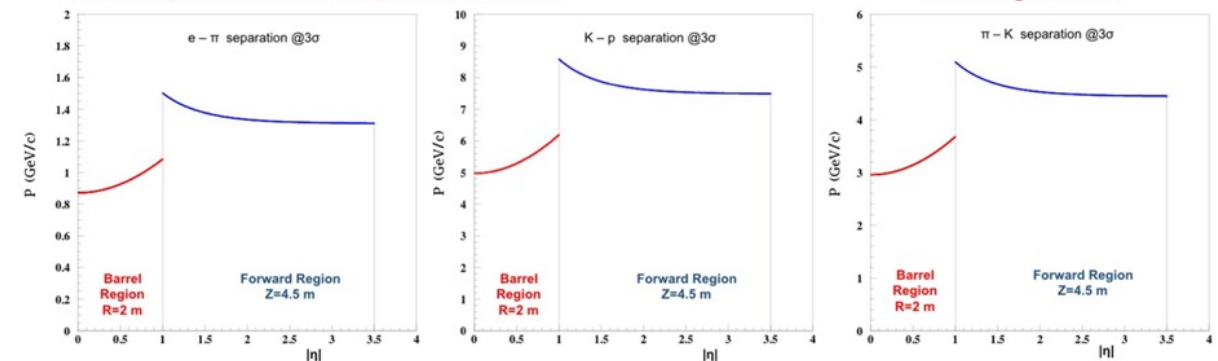
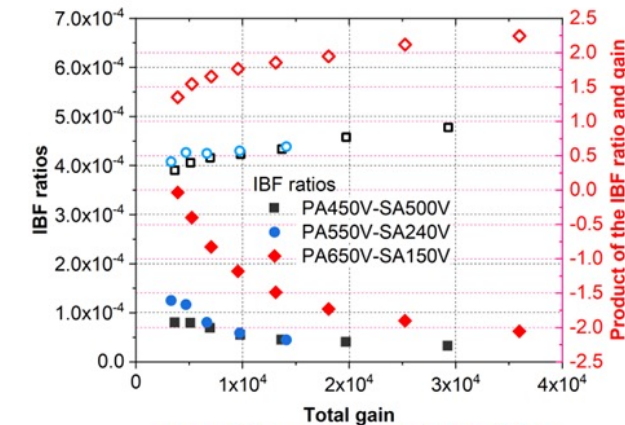
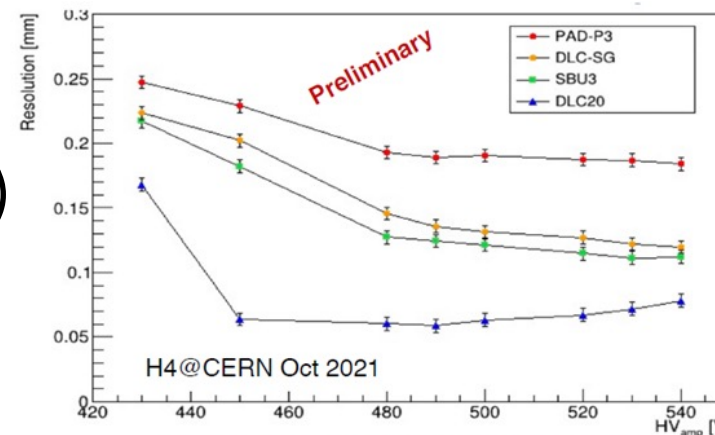
Only select examples from each WP today. For further detail, attend IF5 session Friday.

WP1: MPGDs: Recent advances, current R&D, and the European Strategy [2203.06562]

Klaus Dehmelt

- Motivation and goal for MPGD development: cost-effective, large-scale detectors with excellent position and timing resolution in high-rate applications
- State-of-the-Art detectors + R&D toward faster, better position resolution, cheaper, more robust
- MPGD development triggered new readout electronics development (“SRS”)
- MPGD activities have their home in the CERN RD51 collaboration
 - In 2023, after 15 years of existence RD51 will cease to exist in its present form
 - Restructuring and implementation within the ECFA Detector R&D roadmap

➔ U.S. planning should be synergistic with ECFA Detector R&D roadmap



PID performance for a MicroMegas PicoSec device

MPGDs in Nuclear Physics

- Many of DOE's nuclear multi-user facilities are making use of state-of-the-art MPGDs in their experiments and will continue to push MPGD development in future experiments.
- These facilities
 - Employ the use of rare isotope beams (FRIB), electron beam on fixed targets (CEBAF), or future electron-ion collisions (RHIC in the EIC era).
 - See very different environments with experiments ranging from low-rate and low radiation background to high-rate ($\approx \text{MHz}/\text{cm}^2$) and radiation harsh environments.
- These unique experimental environments drive the nuclear physics MPGD development

Key Critical R&D Areas

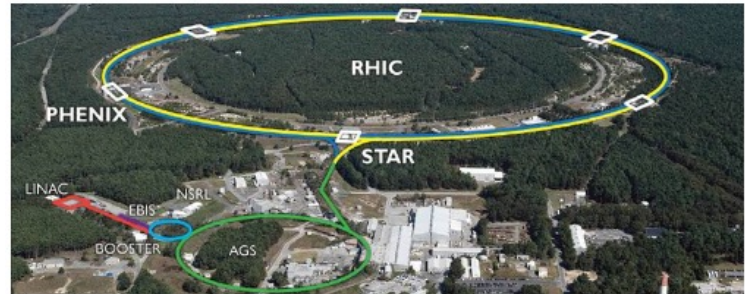
- Low material budget ($< 1\% X_0$) is critical for satisfying the nuclear physics program
- Large area ($> 1\text{m}^2$) high precision ($< 100 \mu\text{m}$) detectors (e.g. thin gap MPGDs.)
- High resolution and low channel count readout structures: resistive and capacitance sharing readout structures.
- MPGDs capable of PID: MPGD based transition radiation detectors, micro-TPCs, MPGD based photon detectors, etc.
- Minimizing ion-back flows
- Optimized for streaming readout



Facility for Rare Isotope Beams (FRIB)



Continuous Electron Beam Accelerator Facility (CEBAF)

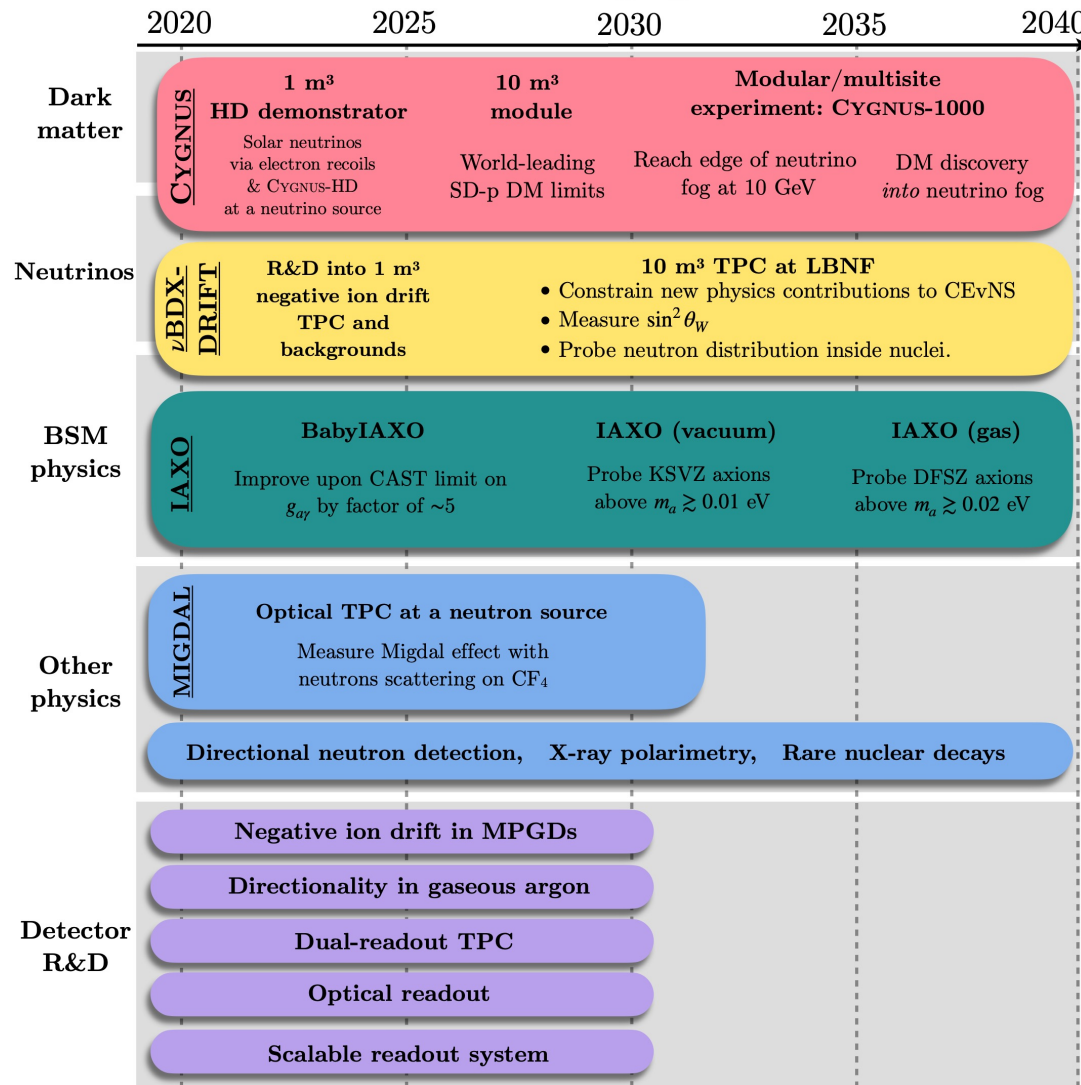


Relativistic Heavy Ion Collider (RHIC)

MPGD R&D needs of NP and HEP have large overlap

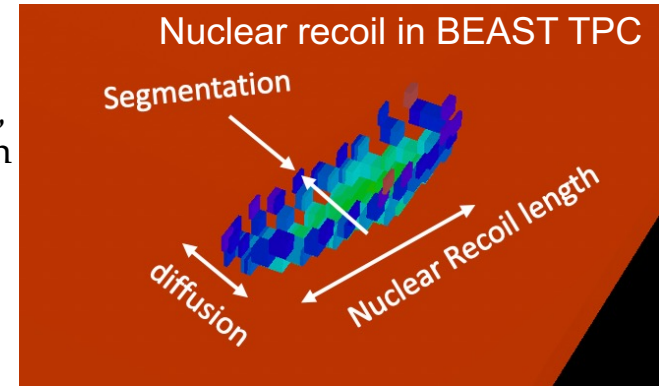
WP3: Recoil imaging for directional detection of dark matter, neutrinos and BSM physics [2203.05914]

Ciaran O'Hare



→ **Precise 3D reconstruction of nuclear recoil vector directions** with an angular resolution better than $\sim 30^\circ$, and $>75\%$ correct head/tail recognition at ~ 6 keVr energies and below.

→ **Excellent particle ID and track reconstruction of electrons** at $O(>1 \text{ keV})$ energies. Essential for DM and solar neutrinos



MPGD requirements to meet these goals

→ **High signal-to-noise electronic readouts** with $O(100 \mu\text{m}^3)$ voxel size and **use of negative ion drift gas mixtures**, e.g. He:SF₆, in next-generation MPGDs. Need to retain sufficient avalanche gain so as to **count individual electrons above the noise floor**

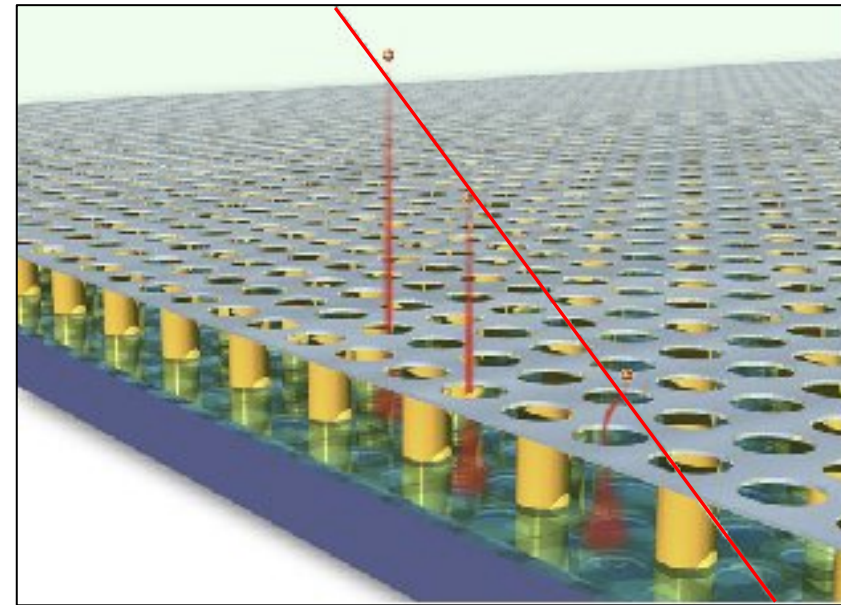
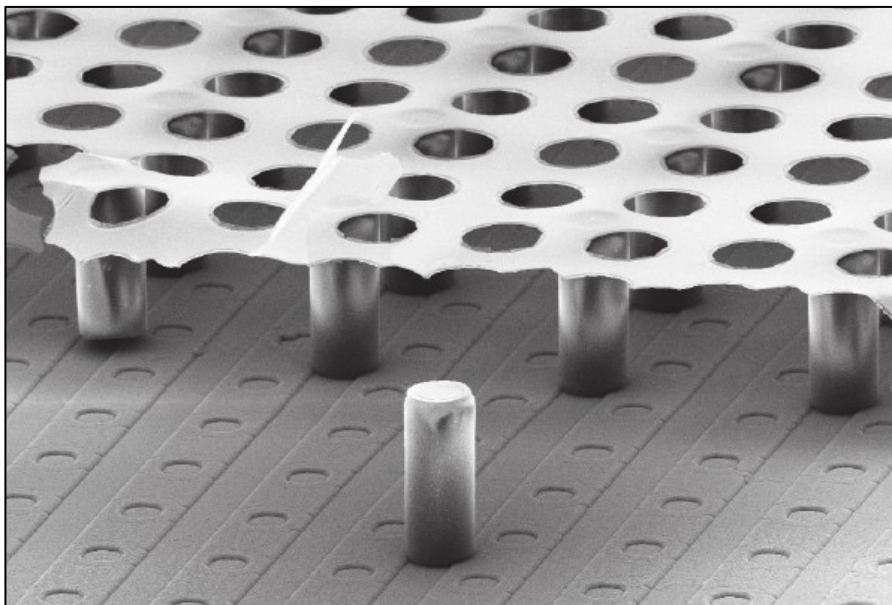
→ **Scalable readout electronics systems** suitable for the $O(\text{m}^2)$ readout planes. Highly multiplexed DAQs utilizing programmable, **topological triggers** will be key for cost reduction.

→ **MPGDs with improved radiopurity**, and eventually **mass-production** of such MPGDs for a large-scale experiment ($\sim 1000 \text{ m}^2$ readout)

Ideal near-term development: a 1 m³ HD TPC placed near to a neutrino source (e.g. SNS) for a first exploratory study with valuable BSM physics reach, followed by 10 m³ TPC in next decade

Technology choice for TPC readout: Micro Pattern Gas Detector

- no preference in track direction
- fast signal & high gain
- better ageing properties
- no $E \times B$ effect
- low ion backdrift
- easier to manufacture



- **Paper advocates the GridPix-based TPC for ILD at ILC, CEPC detector, and Belle II**
 - MPGD on a pixelchip (Timepix+Micromegas = **GridPix**) – see pictures above
 - Resistive protection layer (4-8 μm) on top of chip
 - Insulating pillars between grid & pixelchip – Synergy in electronics R&D
 - One hole above each pixel - Amplification directly above the pixelchip
 - **Enables continuous tracking with exceptional point resolution. 2% dE/dx resolution**
- Timepix: 256 x 256 pixels of size 55 x 55 μm^2 Low threshold level ~ 500 e- (90 e- ENC)

WP6: A tracking TPC for a future B factory [2203.07287]

Peter Lewis

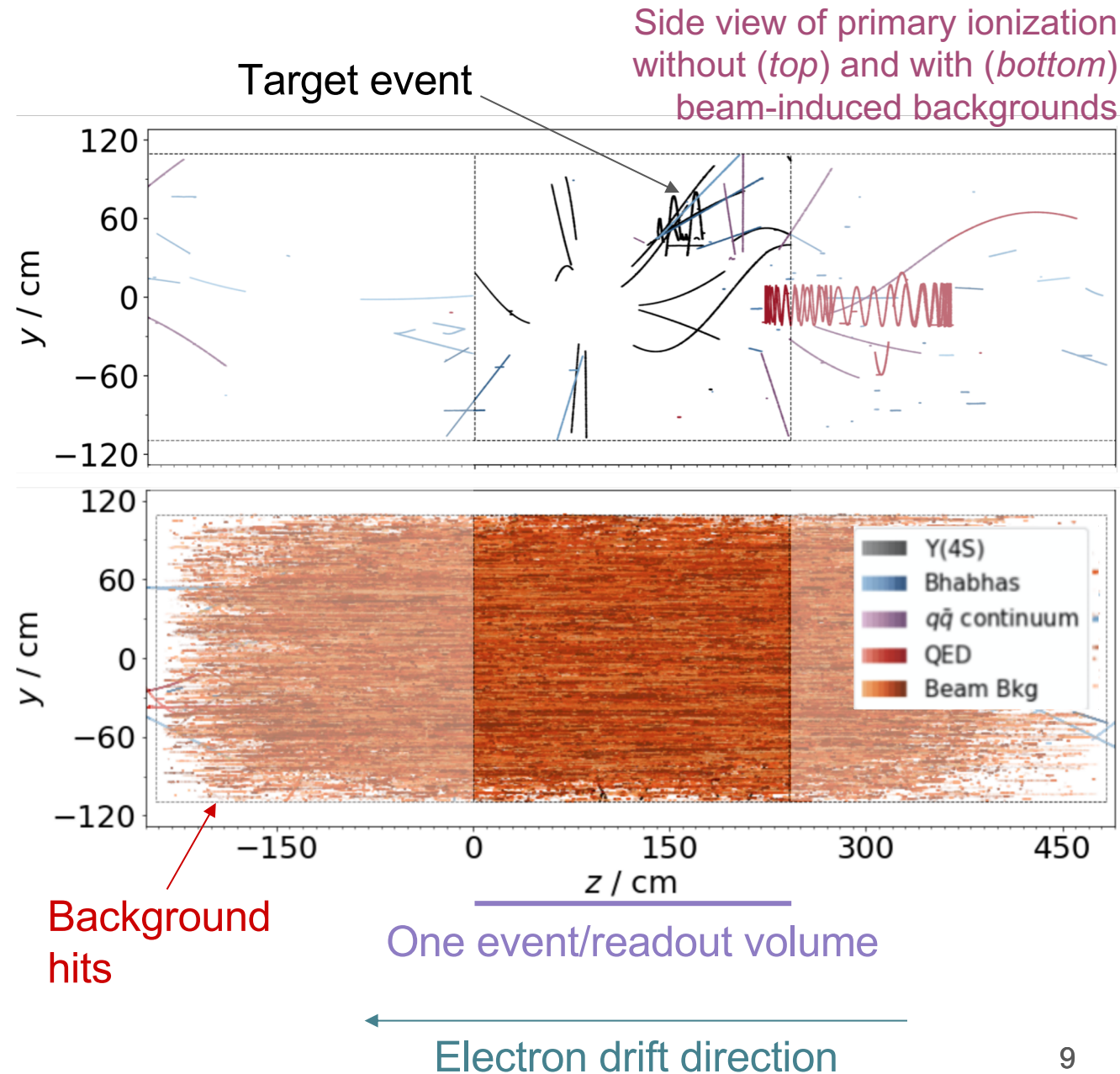
Concept

- Hypothesize a future SuperKEKB upgrade with five times its max design luminosity: $5 \times 6.5 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$
- **Question:** *can a TPC provide high-precision tracking at these rates/backgrounds?*
- **First:** study using simulation study Belle II software and existing MPGD technology (*GridPix*; $55 \times 55 \mu\text{m}$ pixels with MICROMEAS integrated grid), see previous slide

Main findings

- Such a detector **can work** (high-performance tracking in the presence of high backgrounds/ionization)...
- ...but it relies very heavily on the capabilities of *GridPix* (1:1 mapping of pixel:electron, low ion backflow, and excellent 3D resolution)

→ Development of a **purpose-built, low-cost, integrated grid** MPGD detector would allow tracking at ultra-high luminosity B-factories of the future (>2032)

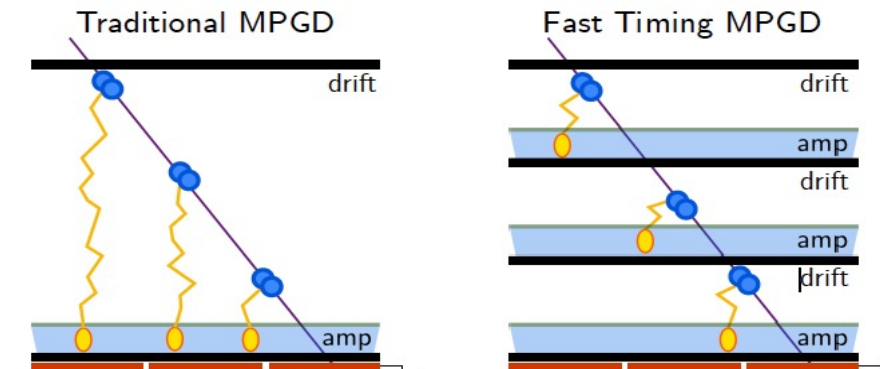


WP5: MPGDs for tracking and muon detection at future high energy physics colliders [2203.06525]

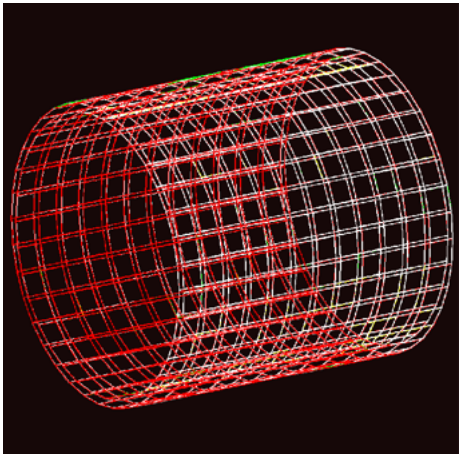
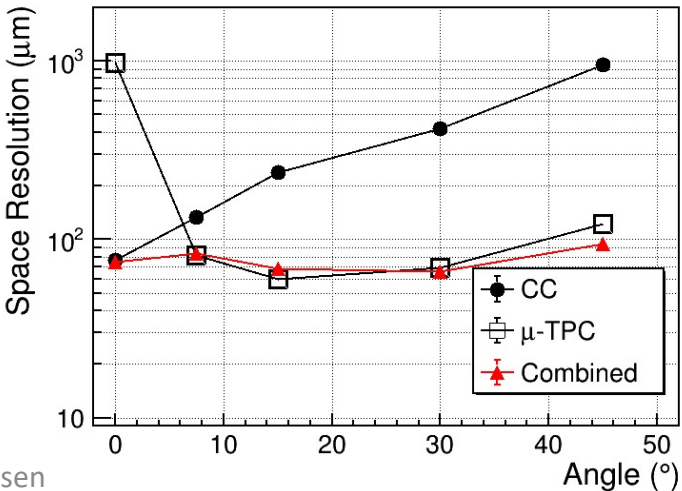
Kevin Black

Advanced concept fast timing MPGDs can allow for

- Sub nano-second timing resolution to allow separation from pileup (hadron colliders) and beam-induced background (muon colliders)
- development of micropatterns detectors with smaller structures allows sub-100-micron spatial resolution
- intrinsically radiation hard technology
- potential for 4D tracking to cover large areas with excellent spatial and timing resolution for future collider experiments



	Rise time	Sensitivity	ENC	Time jitter
VFAT2 [76]	22 ns	60 mV/fC	1500 e ⁻	12 ns
VFAT3 [75]	15-45 ns	48 mV/fC	620 e ⁻	12 ns
VMM3 [78]	25-200 ns	16 mV/fC	600 e ⁻	/
NINO [79]	1 ns	/	2000 e ⁻	25 ps
Cardarelli [80]	300-600 ps	2-3 mV/fC	4000 e ⁻	/
FATIC [77]	7 ns	50 mV/fC	500 e ⁻	300 ps



IF5 Key Points (Draft)

IF05-1: Micro-pattern gaseous detectors (MGPDs) constitute an enabling technology that is required to accomplish the planned U.S. HEP and NP programs.

- Flexible go-to-solution whenever particle detection w/ large area coverage, fine segmentation, and good timing are required

IF05-2: MPGD Technology is relatively young and should be advanced to its performance limits.

Such as:

- Pico-second timing for tracking layers in high-rate environments
- Low background, 3d single-electron-counting, with high readout segmentation, both for rare process and tracking TPCs
- Standardized electronics capable of topological triggers, for cost-effective scale-up to very large areas

IF05-3: The Global HEP community would benefit from U.S. / ECFA strategy coordination.

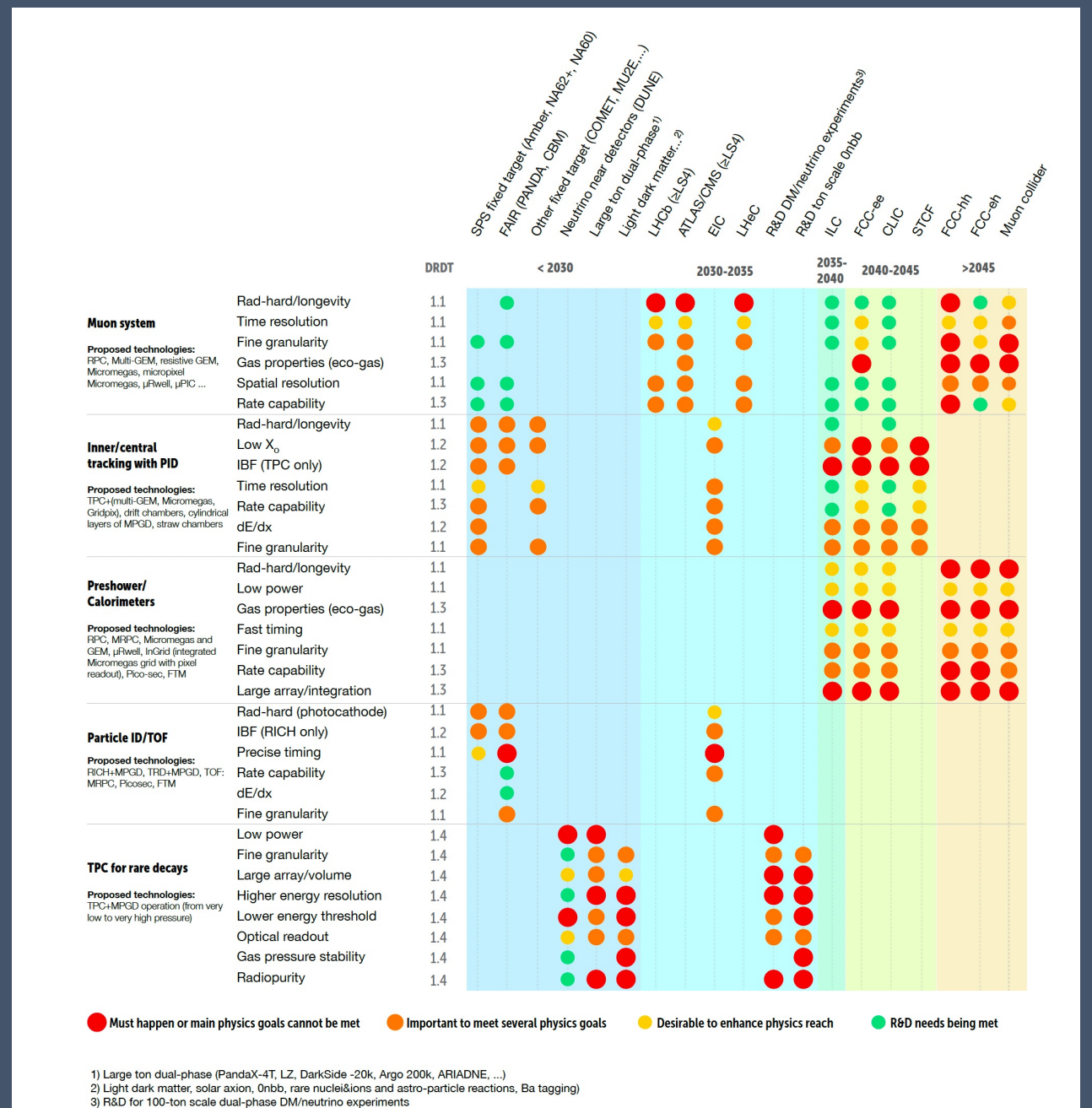
IF05-4: The U.S. NP and HEP communities would benefit strongly from a joint MPGD development and prototyping facility in the U.S.

- Interest from Jefferson Lab
- See presentation by Kondo Gnanvo on Thursday

Please attend IF5 session on Friday for further discussion and refinement of these key points.

BACKUP

ECFA Strategy



Submitted LOIs: 24 (links below are clickable)

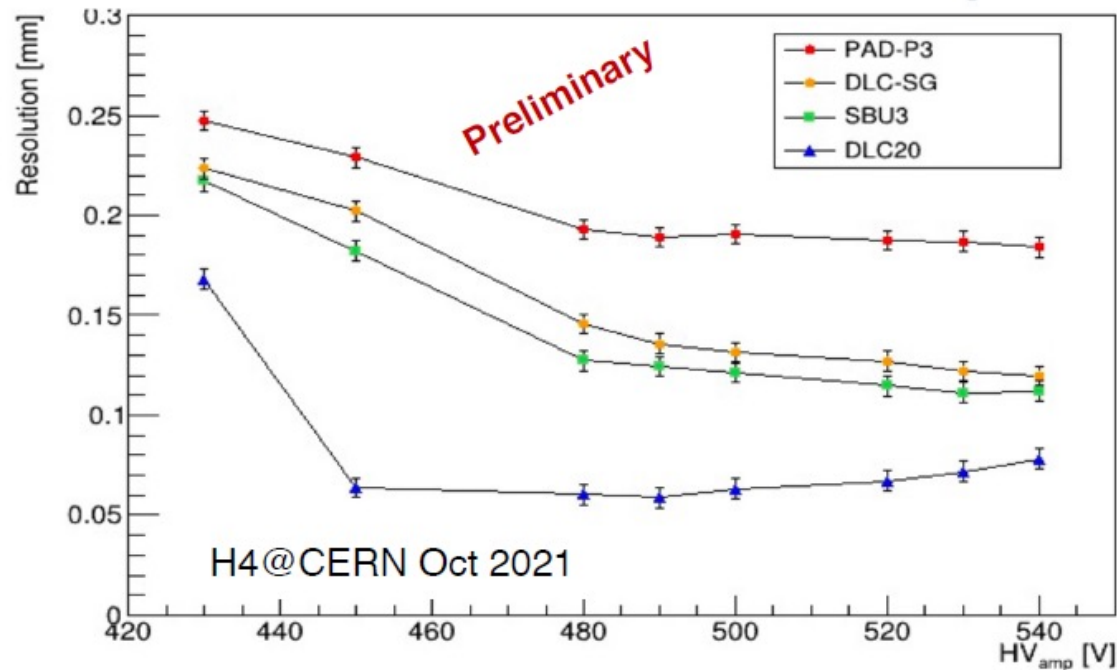
<https://snowmass21.org/instrumentation/mpgd>

1	<u>CF/SNOWMASS21-CF1_CF0-NF10_NF4-IF5_IF4_Vahsen-189.pdf</u>	31/08/2020
2	<u>EF/SNOWMASS21-EF3_EF4-IF3_IF5-031.pdf</u>	06/08/2020
3	<u>EF/SNOWMASS21-EF4_EF0-AF3_AF0-IF3_IF5_GrahamWilson-119.pdf</u>	30/08/2020
4	<u>IF/SNOWMASS21-IF2_IF7_IF3_IF4_IF5_IF6-056.pdf</u>	29/08/2020
5	<u>IF/SNOWMASS21-IF3_IF5-EF1_EF4-183.pdf</u>	01/09/2020
6	<u>IF/SNOWMASS21-IF3_IF5_Simone_Mazza-175.pdf</u>	31/08/2020
7	<u>IF/SNOWMASS21-IF5-005.pdf</u>	27/07/2020
8	<u>IF/SNOWMASS21-IF5-EF4-007.pdf</u>	07/08/2020
9	<u>IF/SNOWMASS21-IF5_CF2_AF5_Ferrer-Ribas-020.pdf</u>	27/08/2020
10	<u>IF/SNOWMASS21-IF5_IF0-057.pdf</u>	30/08/2020
11	<u>IF/SNOWMASS21-IF5_IF0-184.pdf</u>	01/09/2020
12	<u>IF/SNOWMASS21-IF5_IF0-193.pdf</u>	08/09/2020 late
13	<u>IF/SNOWMASS21-IF5_IF0_Brunbauer-096.pdf</u>	31/08/2020
14	<u>IF/SNOWMASS21-IF5_IF0_C.Lampoudis-098.pdf</u>	31/08/2020
15	<u>IF/SNOWMASS21-IF5_IF0_Gnanvo_Hohlmann_Posik_Surrow-044.pdf</u>	28/08/2020
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18	<u>IF/SNOWMASS21-IF5_IF0_Marco_Cortesi-103.pdf</u>	31/08/2020
19	<u>IF/SNOWMASS21-IF5_IF3-015.pdf</u>	24/08/2020
20	<u>IF/SNOWMASS21-IF5_IF6-EF4_EF0_COLALEO-068.pdf</u>	30/08/2020
21	<u>IF/SNOWMASS21-IF5_IF9-EF0_EF0-168.pdf</u>	31/08/2020
22	<u>IF/SNOWMASS21-IF6_IF5_Laktineh-Calice-050.pdf</u>	29/08/2020
23	<u>IF/SNOWMASS21-IF7_IF5_H.MULLER-101.pdf</u>	31/08/2020
24	<u>IF/SNOWMASS21-IF8_IF5-NF10_NF0_Ben_Jones-070.pdf</u>	30/08/2020

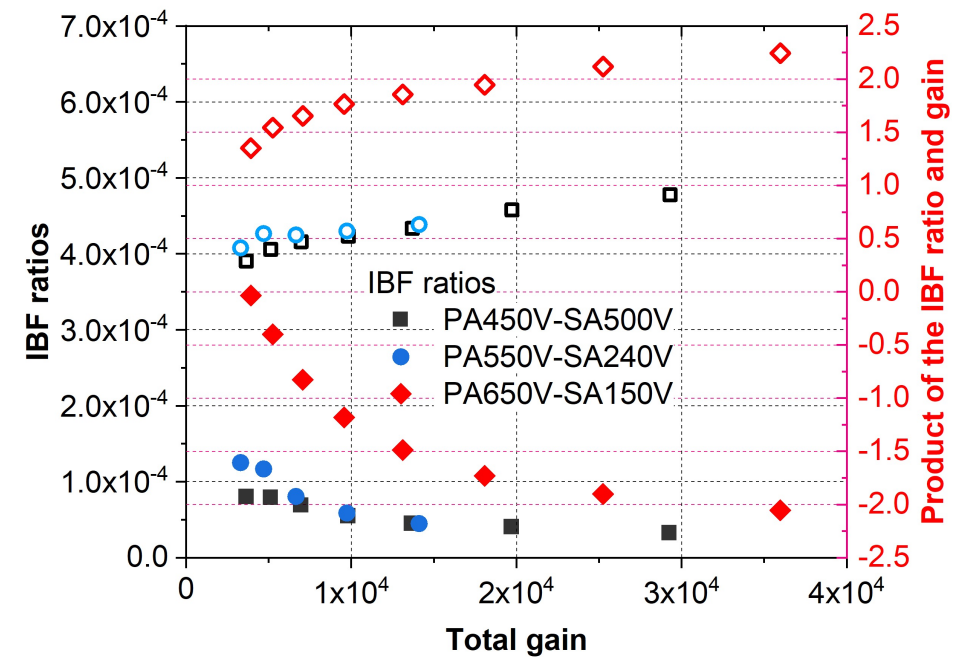
Link to IF05: Micro-pattern gas detectors

White Papers on arXiv

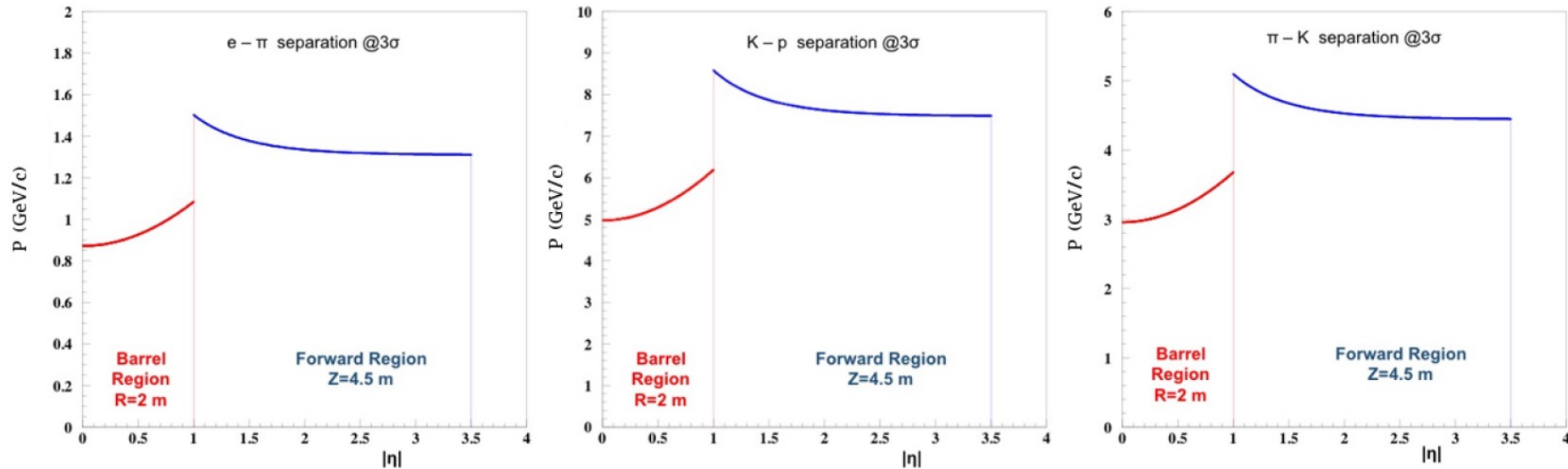
- K. Dehmelt, A. White, M. Alviggi, M. T. Camerlingo, V. Canale, V. D'amico, M. Della Pietra, et al. "MPGDs: Recent advances and current R&D", [arXiv:2203.06562 \[physics.ins-det\] \(pdf\)](#).
- Kondo Gnanvo, Matt Posik, Fernando Barbosa, Daniel Bazin, Francesco Bossú, Marco Cortesi, Silvia Dalla Torre, et al. "Micro Pattern Gaseous Detectors for Nuclear Physics", [arXiv:2203.06309 \[physics.ins-det\] \(pdf\)](#).
- C. A. J. O'Hare, D. Loomba, K. Altenmüller, H. Álvarez-Pol, F. D. Amaro, et al. "Recoil imaging for dark matter, neutrinos, and physics beyond the Standard Model", [arXiv:2203.05914 \[physics.ins-det\] \(pdf\)](#). (also under NF10, CF01)
- Alain Bellerive, Jochen Kaminski, Peter M. Lewis, Paul Colas, et al. "MPGDs for TPCs at future lepton colliders", [arXiv:2203.06267 \[physics.ins-det\] \(pdf\)](#).
- K. Black, A. Colaleo, C. Aimè, M. Alviggi, C. Aruta, M. Bianco, I. Balossino, et al. "MPGDs for tracking and muon detection at future high energy physics colliders", [arXiv:2203.06525 \[physics.ins-det\] \(pdf\)](#).
- Andreas Löschcke Centeno, Christian Wessel, Peter M. Lewis, Oskar Hartbrich, Jochen Kaminski, Carlos Mariñas, Sven Vahsen. "A TPC-based tracking system for a future Belle II upgrade", [arXiv:2203.07287 \[physics.ins-det\] \(pdf\)](#).



Position resolution for High Granularity Resistive Micromegas detector under high-rate irradiation



Ion-Backflow performance for multi-layer MicroMegas devices



PID performance for a MicroMegas PicoSec device

Time Projection Chamber (TPC) for future e^+e^- colliders



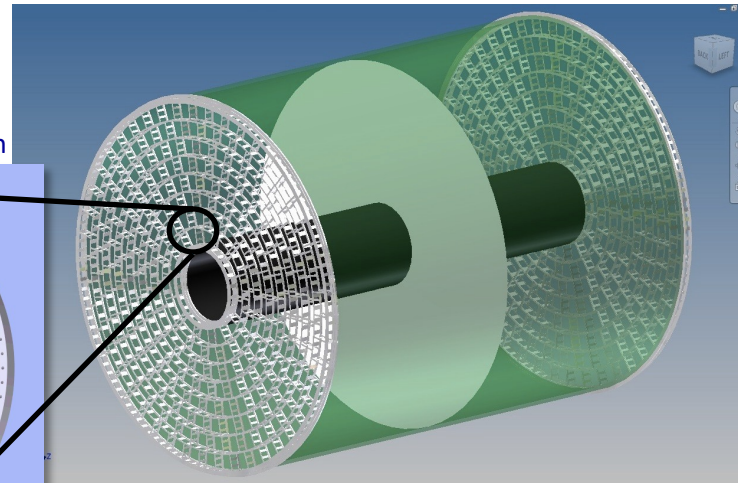
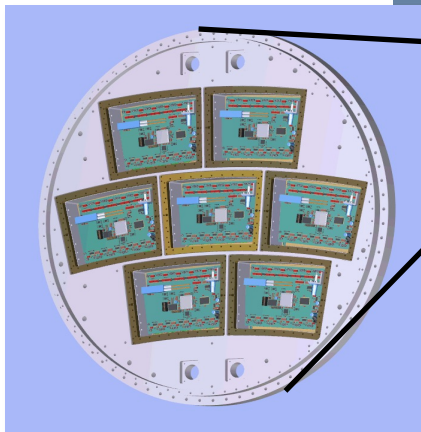
Main activities on micropattern gas detector (MPGD & RD51)

- Two options with similar resolution for endplate readout with **pads**:
 - **GEM**: $1.2 \times 5.8 \text{ mm}^2$ pads (**smaller pad – more electronics**)
 - **Resistive Micromegas**: $3 \times 7 \text{ mm}^2$ pads (**larger pads – less electronics**)
- Alternative: **pixel** readout with pixel size $\sim 55 \times 55 \text{ }\mu\text{m}^2$ (**ultimate TPC**)

LCTPC Collaboration on calorimetry R&D:

3 regions (America, Asia, Europe), 25 member institutions, 22 observer institutions

Large Prototype TPC
Endplate of 7 panels, $\phi = 80 \text{ cm}$



ILD TPC

