Venice, November 6, 2024

# Needed R&D for running a TPC at a circular collider

P. Colas (CEA/Irfu U. Paris Saclay)

FCC Italy-France workshop

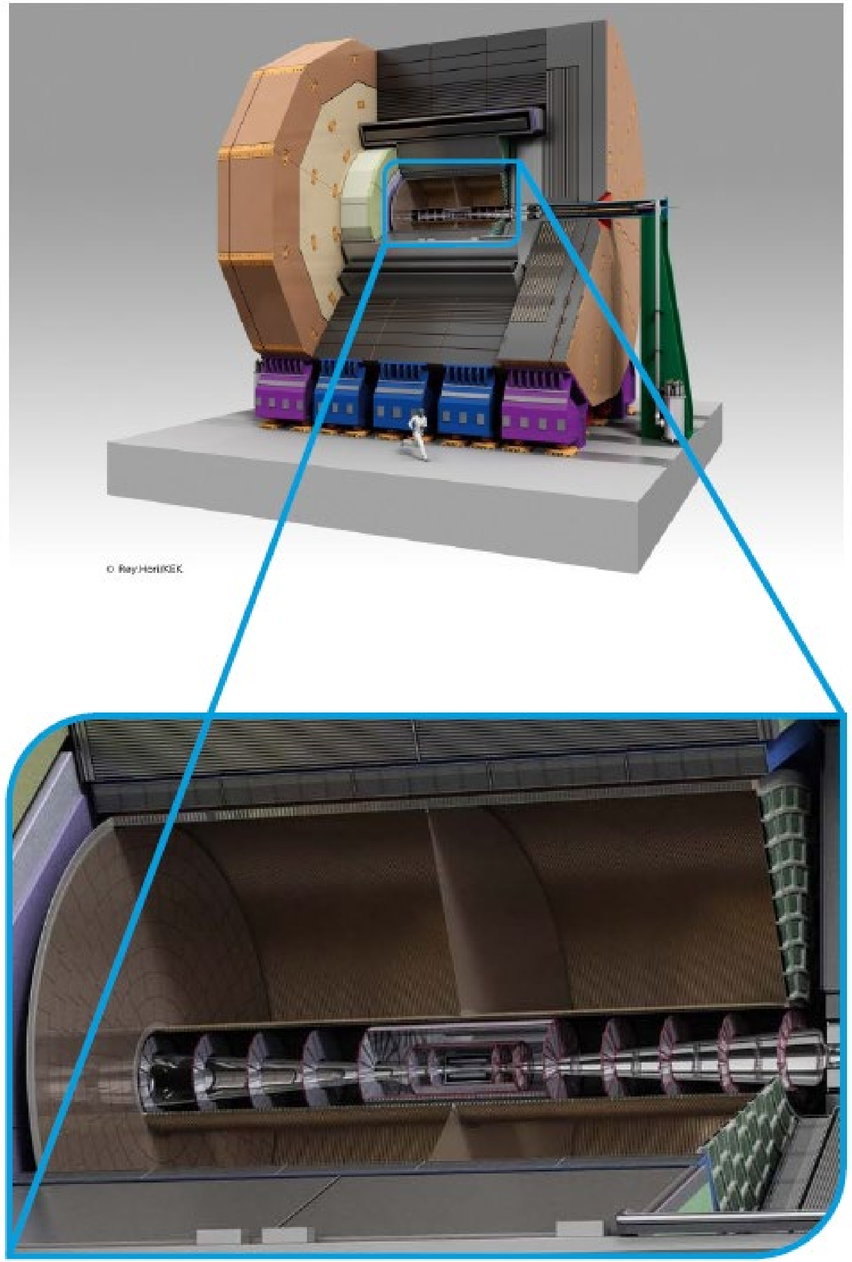

…and strategy for the future

# Not in this talk : MPGD muon chambers and other MPGD trackers

- See presentation by Fabien Jeanneau on Micromegas muon chambers (à la ATLAS/NSW) at the FCC-France meeting in Strasbourg
- See talk by Gianni Bencivenni yesterday on use of µRWell for muon tracking
- Possibility of Micromegas or GEM for muon chambers, or cylindrical MPGD trackers
- This talk will focus on a TPC with pad or pixel readout, with or without charge sharing.

# ILD and ILD’

- The ILD collaboration is preparing an EOI to be submitted to the ESPPU
- It will contain two parts
  - ILD for ILC : very little changes with respect to the previous Interim Design Report. Mainly : a digital pixel TPC (GasPix) is now prioritized
  - ILD’ : modifications in the silicon forward region to adapt to FCC, adding passive ion feedback suppression for the TPC, improvement of the ECAL cooling and reduction of power consumption.
- Next ILD meeting on November 12.

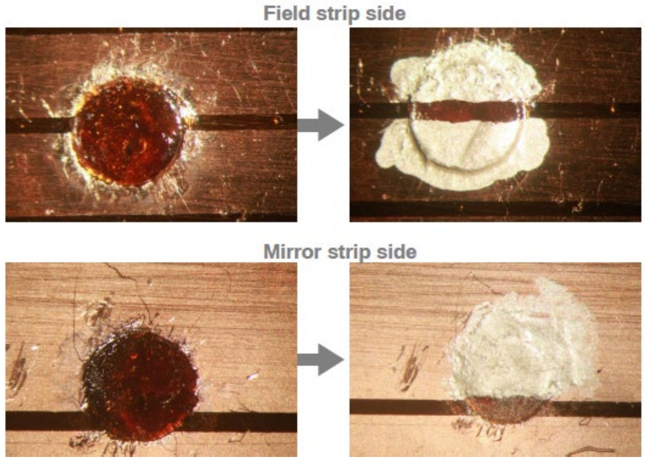


# CEPC Reference detector


- To request funding and a green light for the project in the 15th 5-year plan of China, Physics community unite in a ‘toy’ detector to start things and prioritize technological R&Ds (not neglecting fall-back solutions)
- For the time being, ~290 physicists (90 from IHEP) are working under the leadership of Yfang Wang, Jianchun ‘JC’ Wang and Xinchou Lou.
- They organized an International Detector R&D Review, October 21-23 in Beijing, linked to the CEPC workshop in Hangzhou. Chaired by Daniela Bortoletto, the Review Committee includes about 20 physicists from around the world, of which 3 Italians and 4 French.

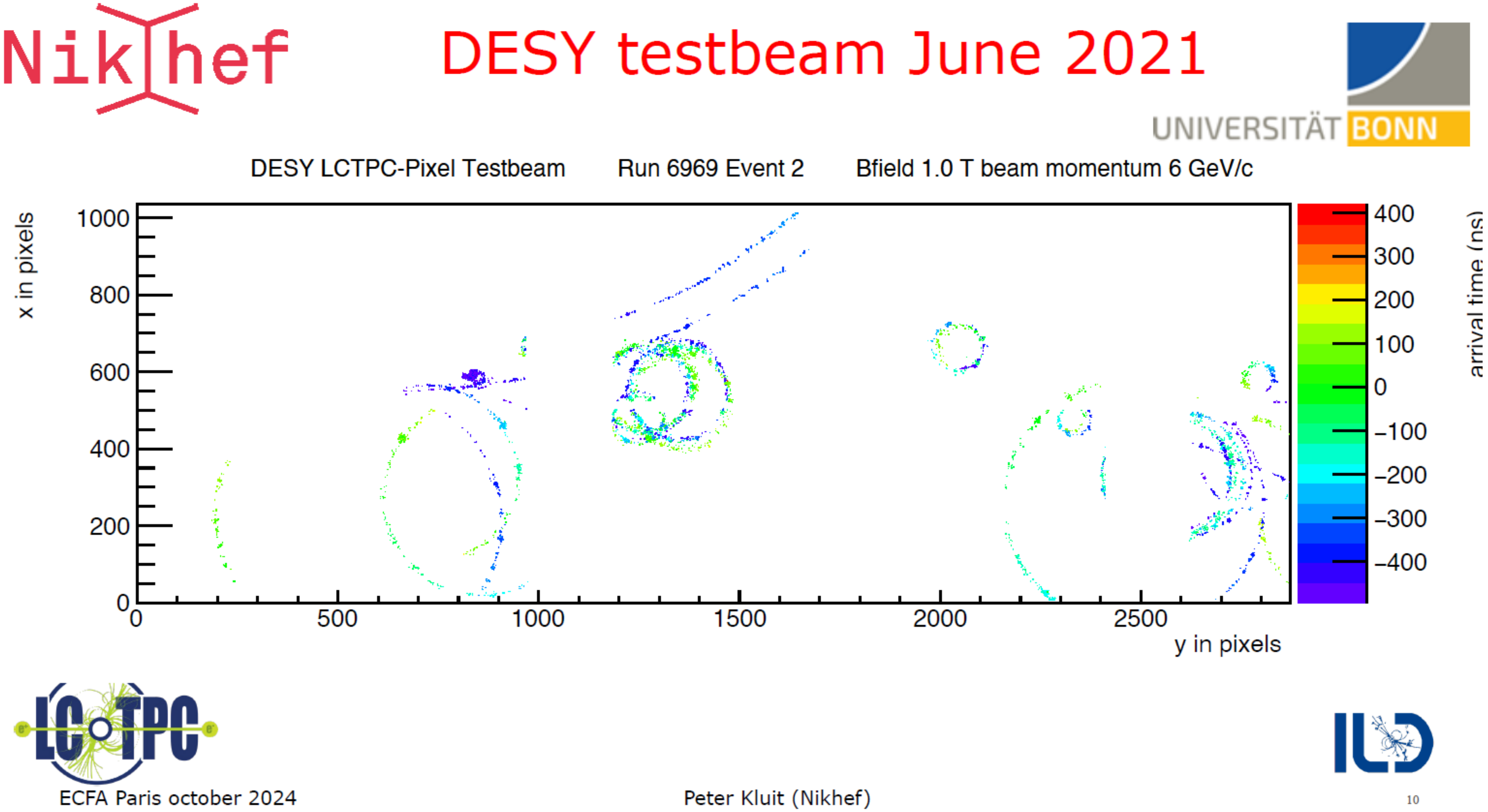
# Field cage

- Talk by Oliver Schäfer at LCWS2024 in Tokyo
- New prototype field cage being built at DESY
  - Previous one used until 2019 was skewed
  - Keep in-house know-how
  - New precision mandrel
  - HV stability issues 2020-21 now solved
  - Simplified stip pattern with negligible impact on field homogeneity : 1-piece foil produced at CERN




# Pixel readout

Peter Kluit



# A bit of history :
## Ingrid and GridPix, 20 years ago

By post-processing on silicon wafers, with Twente and Nikhef colleagues, we were able to deposit 0.8 µm Al meshes. The ‘Integrated Grid’ InGrid was born.

**The definition of InGrid 1**

Design Committee: Tom Aarnink
Paul Colas
Yannis Giomataris
Harry van der Graaf
Jurriaan Schmitz
Jan Timmermans
Jan Visschers

Version 2, April 2004

**Basic layout**

The base of InGrid 1 is a Si wafer, covered first with an insulating layer, followed by a strip-segmented conductive (anode) layer. This is the dummy TimePix. On top of the

**An electron-multiplying ‘Micromegas’ grid made in silicon wafer post-processing technology**

M. Chefdeville[a], P. Colas[b], Y. Giomataris[b], H. van der Graaf[a], E.H.M Heijne[c], S. van der Putten[a], C. Salm[d], J. Schmitz[d], S. Smits[d], J. Timmermans[a,*], J.L. Visschers[a]

[a]*NIKHEF, Amsterdam, The Netherlands*
[b]*DAPNIA, CEA Saclay, Gif sur Yvette, France*
[c]*CERN, Geneva, Switzerland*
[d]*University of Twente/MESA+, The Netherlands*

# A bit of History
# TimePix

The first tests were carried out with Medipix. By adding a clock distributed in all the pixels, we changed the ‘grey level’ for photon counting into a time measurement on all pixels, changing the imaging chip into a TPC (digital) readout.

We could fund this, from the chip design (Xavier Lloppart) to the wafer production, and tests (David Attié) within an EU project, EUDET, from 2006 on.

TimePix Proposal Nov 2004

**The TimePix R&D Collaboration**

Harry van der Graaf, Jan Timmermans *, Jan Visschers
NIKHEF, Amsterdam, The Netherlands

Michael Campbell, CERN, Geneva, Switzerland

Paul Colas, DAPNIA, CEA Saclay, France

**1. Introduction**

Ongoing miniaturization of electronics circuits has caused the “digital revolution”: in a state-of-the-art deep submicron chip, operations can be performed at higher than 1 GHz clock frequency and at exceedingly low power consumption. Signal processing and data conversion circuits have become so small that they can be included on the pixel-level, and this is presently causing a revolution in the world of micro patterned semi-conducting

In the following years, we carried out many studies using TimePix : Octopuce, an 8-chip module, study of avalanche fluctuations (Michael Lupberger), many studies on Micromegas (Max Chefdeville), and improved the protection against sparks with a 15 µm resistive layer…

# CEPC reference detector

- CEPC Reference Detector team chose a TPC for the high energy running (first 10 years + 6 years of top) : excellent choice, following ALEPH, DELPHI at LEP success, and ALICE at LHC.
- They opted for a pixel TPC : small pads give low electronic noise. Then digital TPC becomes possible : necessary to optimize pad size for momentum resolution and cluster counting.
- Choice of a digital chip : timepix 3 or 4, or else?
- Study protection against sparks (for instance 15 µm or $Si_xN_y$) bulk resistivity ~$10^{13}$ $\Omega$.cm and test with prototype.

# Gas choice

- Base gas :
  - Ar for largest ionization : 97 e-ion pairs in ~35-40 clusters
  - He for well-separated clusters easing dN/dx (but cannot set field to the maximum drift velocity over 2 m)

- Additional gases
  - Isobutane : quencher, cuts UVs to avoid avalanche propagation
  - $CF_4$ : increases electron drift velocity and reduces diffusion in magnetic field by a factor of ~10 at 3.5 T and ~5 at 2T.
  - Low e attachment (keep $O_2$ and $H_2O$ below ~10 ppm to drift over 2m) velocity)

- T2K gas Ar:CF4:Isobutane 95:3:2 satisfies all requirements for a TPC

- Note that the optimal gas is not the same for cluster counting (He) and for space resolution (large $\omega\tau$ for low diffusion: 'fast gas')

# Other needs

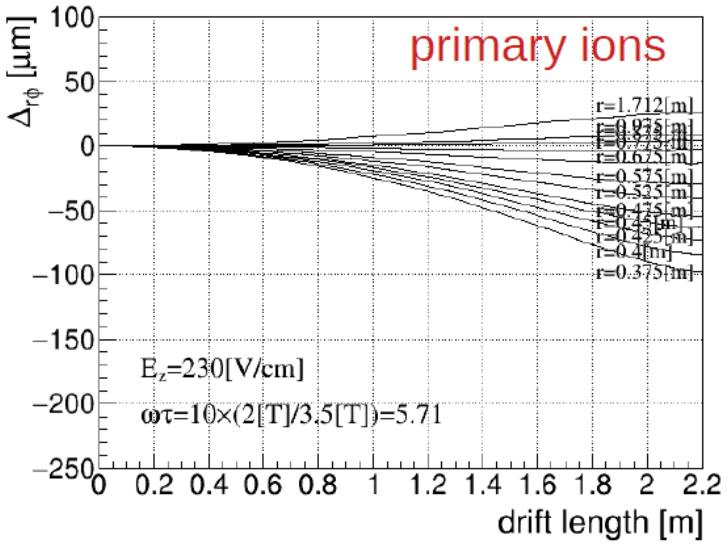
- Make sure that a $\mathbf{t_0}$ can be obtained (from silicon enveloppe) and associated to the TPC track (non-trivial as the drift time in the TPC is several tens of µs)
- Study **mechanical quality** of the endplate at the few tens of µ if possible, and define a strategy to correct by software if not reached
- Define the **cooling strategy** (Nikhef's with Saclay's 2-phase CO2 3D-printed cooling plate)
- Carefully study **interfaces** with other subdetectors: heating by the Ecal? Each subdetector should remove the heat it produces, but this might be impossible -> assess what is acceptable

# Distortions from ion space charge

- Large ionization at the Z peak produces a large ion density. As ions drift very slowly (O(m/s)) the TPC integrates a high ion space charge, which causes a transverse electric field, which in turn makes large distortions of the ionization electrons paths.
- These have been calculated (K. Fujii, S. Ganjour et al.) and amount to ~60 µm at the HZ for ILC, and O(mm) distortions for the tracks at the Z pole at the TeraZ, counting only the ionization from physics events.
- Correcting for this is necessary and is similar to what Alice attempts to do at the Pb-Pb run
- See my talks at HKUST 2024,  FCC workshop in Krakow, etc…

# Beamstrahlung background at ILD and FCC

- **Daniel Jeans** presented simulation results at LCWS2024 in July, and again at a FCC detector concept meeting on September 9 and also at the ECFA workshop in Paris
- Beamstrahlung BG produced ~200 times more ionization than hadronic Z decays (20mm distortions)
- Beamstrahlung higher at ILC, but MDI more intrusive at FCC. Optimization of MDI necessary if one is to use a TPC at TeraZ




Distortion calculation by **K. Fujii**

- For the time being, forget about using a TPC at the Z at 2. $10^{36}$ lumi, and go directly to HZ, as CEPC plans

# Can a TPC be aligned/calibrated?

- Maybe not enough cosmics
- ILD studies : can go to 91 GeV (large Z cross-section). But to be done at very ‘low’ luminosity ($10^{34}$ /cm²/s ?) to keep similar environment as for the HZ signal. One month enough to obtain $2.10^5$ $Z \to \mu\mu$.
- But also Z returns (e+e- -> Z$\gamma$) in the 240 GeV sample can be used for alignment and dN/dx calibration.

Alice is facing similar distortions in Run3 Pb-Pb collisions at 50 kHZ. We contact them to try and learn from their experience in correcting space charge distortions

# Summary

Jens Wiechula, talk at LCTPC annual meeting in January 2023

ALICE

- Different types of distortions present in the TPC (static, charge-up, space-chare)
  - Different scaling over time and detector load to be taken into account
- Large distortions due to space-charge expected O(5-10cm)
  - Correction down to intrinsic tracking precision envisaged O(few 100um)
- Two main ingredients for distortion corrections
  - Direct measure of distortions via interpolation from external detector points
  - Measure of fluctuations using continuously integrated digital currents on the pad plane (IDCs)
- Different procedures foreseen for corrections
  - Scaling of absolute distortion map
  - Scaling of local derivative distortion map
  - Linear regression / ML using derivative map and 1D FFT coefficients of IDCs
  - ML using NDim IDC fluctuation information

15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPC68

# ALTERNATIVE SOLENOID COMPENSATION SCHEME FOR THE FCC-EE INTERACTION REGION *

A. Ciarma†, M. Boscolo, INFN-LNF, Frascati, Italy
H. Burkhardt, CERN, Geneva Switzerland and Univ. Freiburg, Germany
P. Raimondi, Fermilab, Chicago, USA

*Abstract*

We present the optics design of the solenoid compensation scheme at the FCC-ee. The 2 T solenoids of the experiments can generate many kW of synchrotron radiation power and induce coupling on the beams resulting in an increase of the vertical emittance. We propose a modified compensation scheme to minimize these effects. A Screening Solenoid is placed around the Final Focus Quadrupoles (FFQ) to shield them from the experiment's field. A skew quadrupolar com-

dard" solenoid compensation scheme. It would allow for the removal of the −5 T Compensating Solenoids, resulting in benefits such as reduced SR, increased available space in the MDI area and an overall simplification of the hardware requirements. This scheme uses skew quadrupolar components winded around the FFQs to minimize the vertical emittance increase, and weak correctors in the IR to close the orbit bumps generated by the beams passing with an

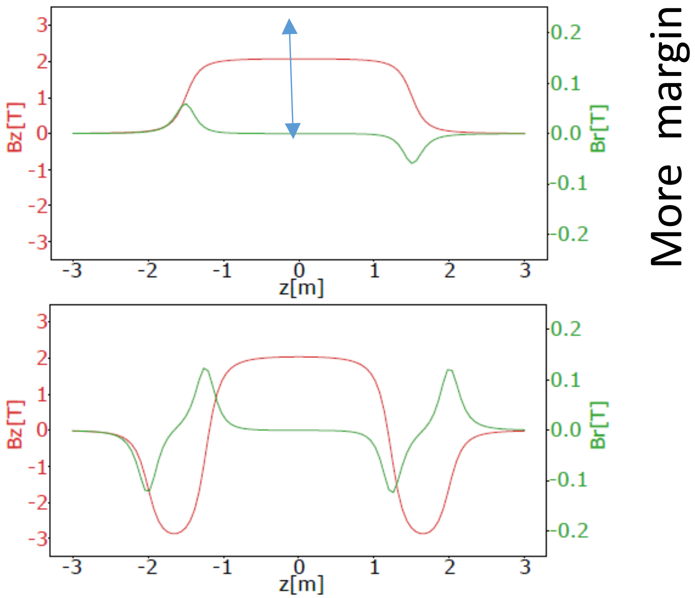


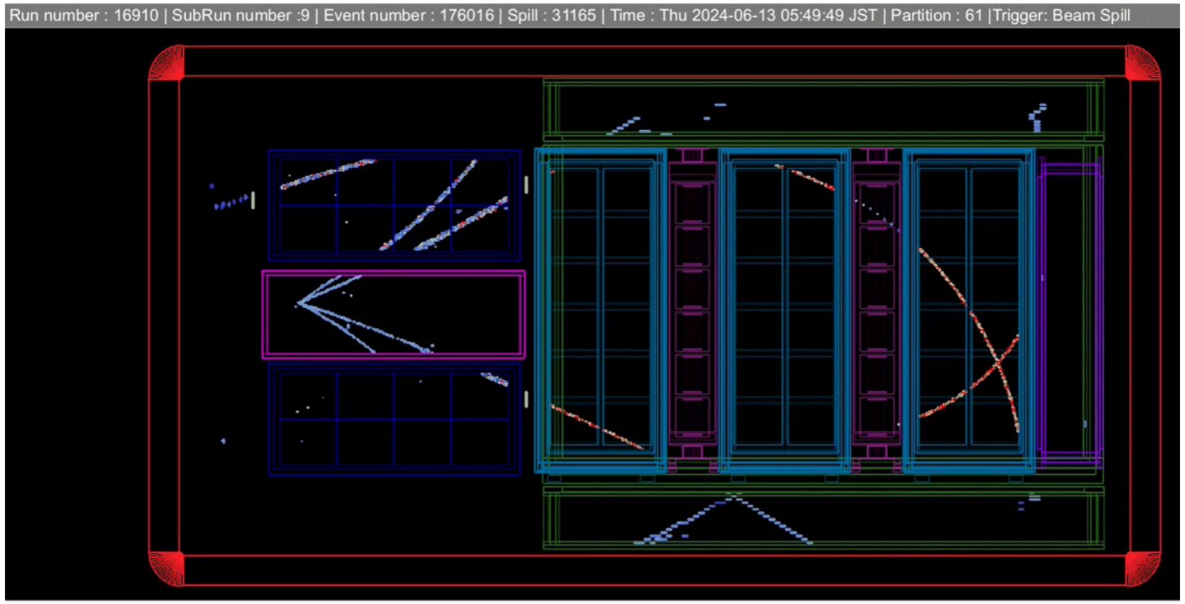

Figure 1: Longitudinal (red) and radial (green) magnetic fields along the 15 mrad axis in the two compensation schemes (standard proposed here on the top, baseline on the bottom).

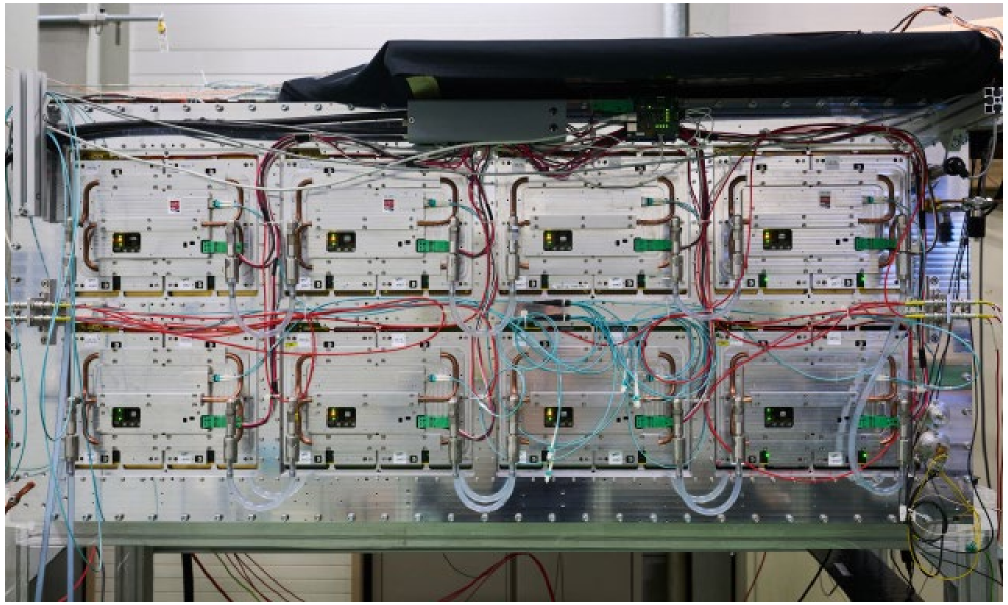
**In the newly proposed scheme, the compensating solenoids are further apart and leave more margin to increase the B-field to 3T or even 3.5 (thanks to F. Zimmermann and K. Oide)**

Thus, one detector, with the TPC, could use this compensation scheme and have 3 T field at the Z and a 3.5 T field at HZ, allowing a large ωτ

# Alternative : Micromegas with charge sharing

- T2K built two TPCs for ND280 upgrade, with the new resistive-capacitive charge spreading developped for ILC
- Started operation in September 2023 and May 2024 at JPARC
- Gained experience in operating, calibration and measuring the RC parameter which governs the charge spreading

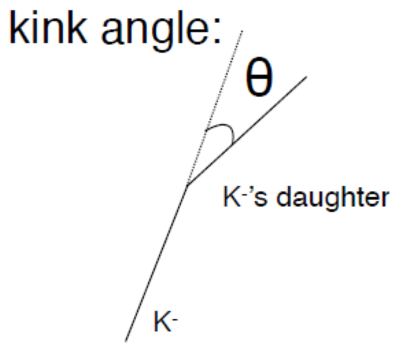


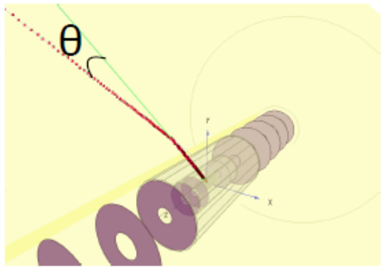



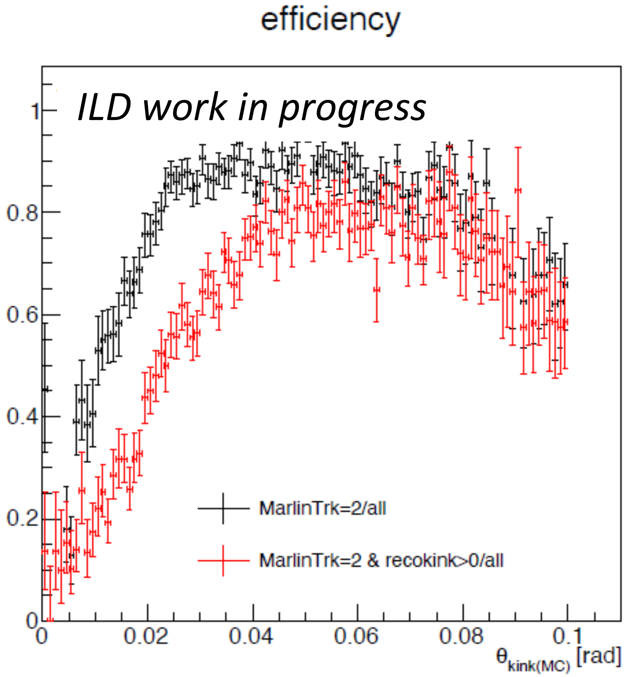
# Application to Long-Lived Particles (LLP) search

- The continuous tracking allowed by a TPC can help finding a LLP signal by revealing kinks (Daniel Jeans, Jurina Nakajima, KEK/SOKENDAI)
- Presentation at LCWS2024 by Jurina
- MC study of $K^- \rightarrow \pi^- \pi^0$ . Trackfinder in MarlinTPC: efficiency 80% at $p_K$=10 GeV/c

Institute of Particle and Nuclear Studies




$$m_{kink} \equiv \sqrt{(E_{chg2} + E_0)^2 - P^2_{chg1}}$$

- Estimate of $\Delta$m between track1 and track2
- Next : extend to other momenta, kinematic fitting
- Interpretation in BSM

# A word on worldwide strategy for the future

- Circular collider is good for EW and Higgs Physics, but limited for top and higher energy
- Linear collider is complementary, as it can go to higher energy. A collider starting at the toponium energy (340-360 GeV) and extending to at least 550 GeV would have a lot of interest.
- The idea that the toponium does not form because the free quark lifetime as given by electroweak partial width calculation is smaller than the bound state orbiting time might be wrong (as the lifetime of many neutron-containing nuclei is much more than the neutron lifetime ~15 minutes)
- There is a hint at CMS for a narrow toponium (John Ellis's interpretation of CMS data presented at the 50th anniversary of J/psi discovery, IHEP, 20th of October).
- e+e- physics requires **two colliders**, a circular one at very high luminosity for EW physics and a linear, with polarized beam, at higher energy for ttbar, toponium spectroscopy and multi-Higgs. There is lot of fundamental physics there, at the meeting point of weak and strong interactions.