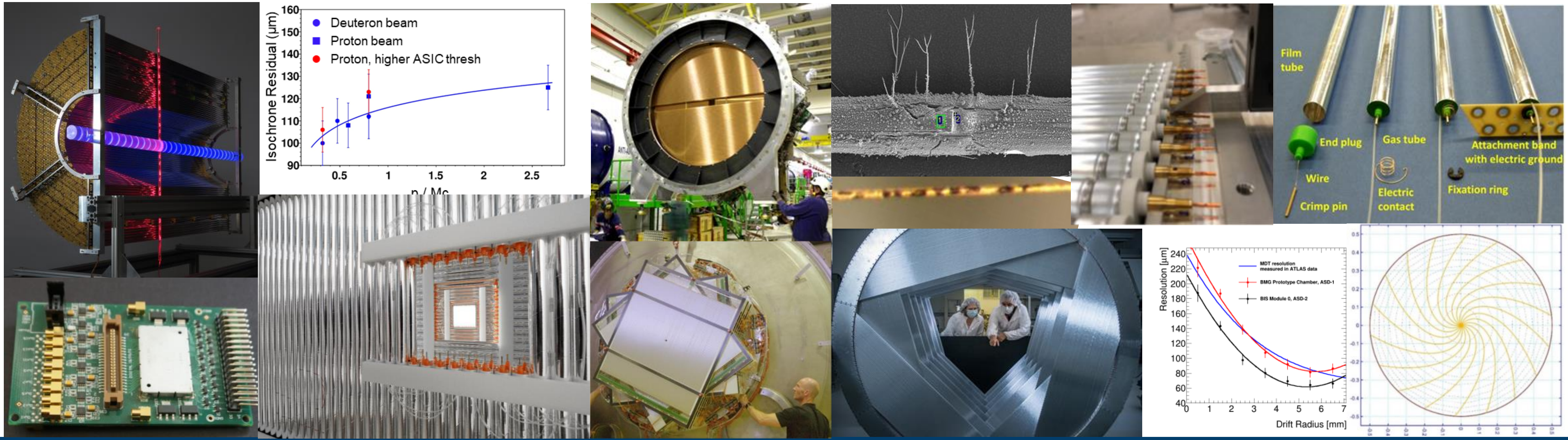


Straw Chamber Technologies for FAIR and in DRD1

Peter Wintz (IKP, FZ Jülich)

Dec-1st, 2023 | GSI/FAIR Gaseous Detector Meeting

Overview Straw Chamber Technologies

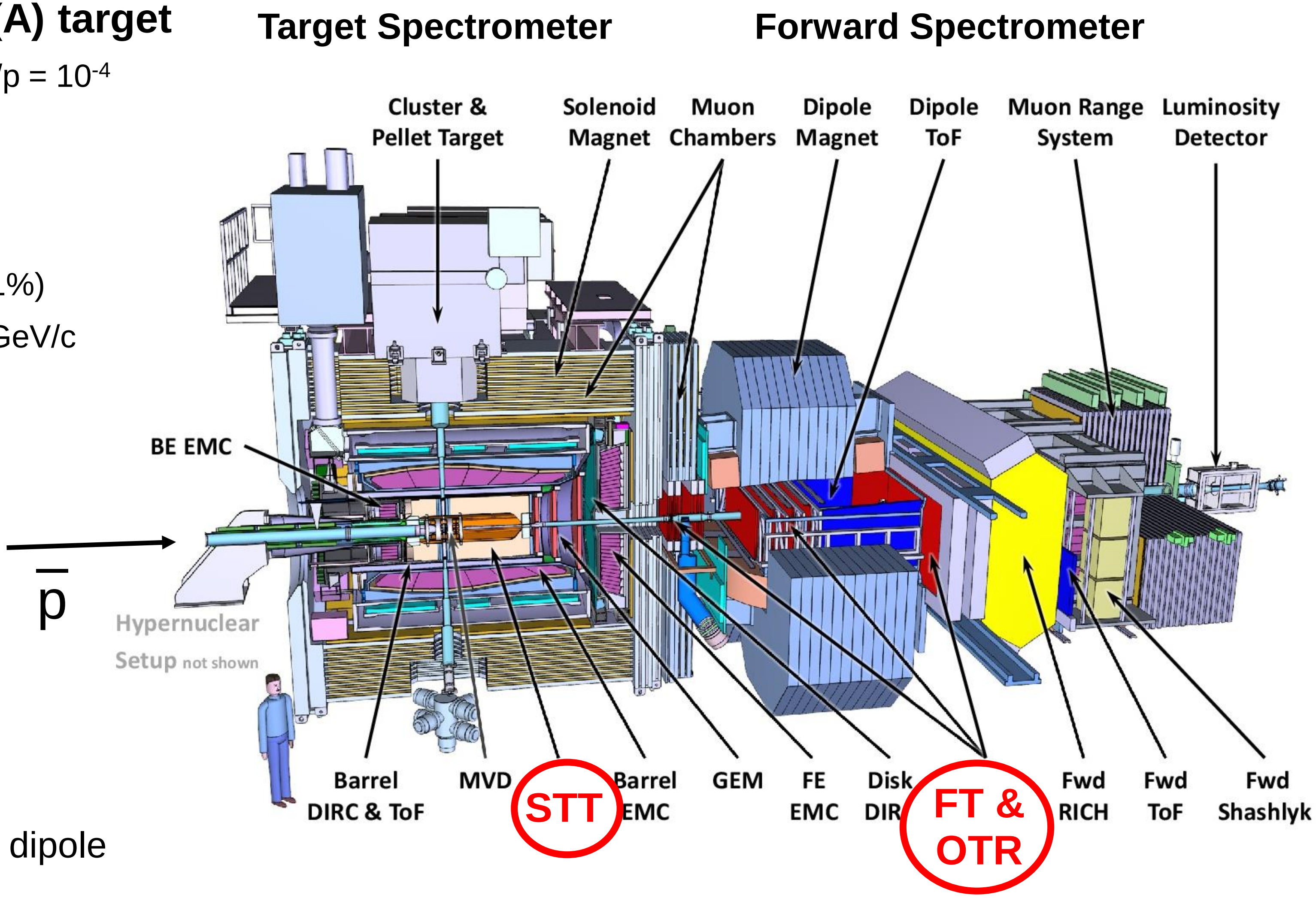
- Straw systems for FAIR
  - PANDA-STT (contact: Peter Wintz, FZJ)
  - PANDA-FT (contact: Jerzy Smyrski, JU Krakow)
  - LHCb-OTR for PANDA-FT5/6 (contact: Tassos Belias, GSI)
  - HADES-STS1/STS2 (contacts: Peter, Jerzy)
  - PANDA Straw Tube Readout Chip (PASTTREC) (contact: Marek Idzik, AGH Krakow)

- Straw technologies in DRD1 (ECFA roadmap)
  - Long-term, strategic R&D trends ..

Straw Tubes in PANDA-Spectrometer at FAIR

Anti-proton beam (1.5-15 GeV/c) on p(A) target

- $\sqrt{s} \approx 2.2 - 5.5$ GeV, L=2×10^{32} $cm^{-2}s^{-1}$, beam $\Delta p/p = 10^{-4}$
- 2x10^7 s^{-1} anti-p p interactions at full luminosity
- ~4π coverage and detecting all particle species
- 2T solenoid (TS) and 2Tm dipole (FS)
- Good charged particle tracking (mom. resol. ~ 1%)
  - broad momentum range: ~ 100 MeV/c to 8 GeV/c
  - delayed vertices (up to ~ O(10 cm))
- Particle identification (γ, e, μ, π, K, p), calorimetry and muon detection

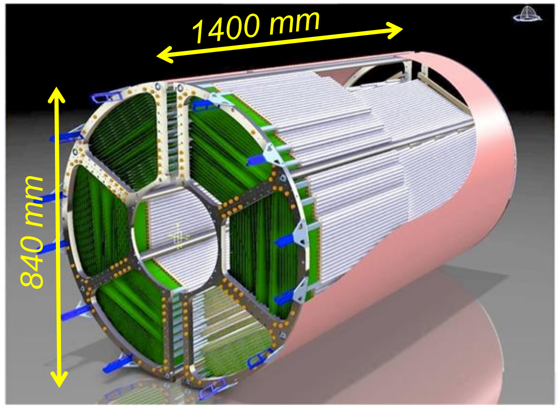


Straws tubes

- **STT:** central tracker with PID around IP
- **FT:** four forward tracker stations
- **OTR:** two forward tracker stations behind dipole

PANDA-STT Straw Tube Tracker

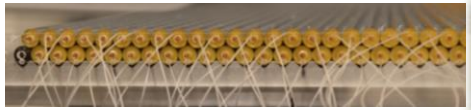
(4D + PID Central Tracker)



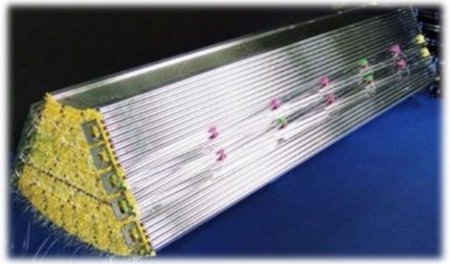
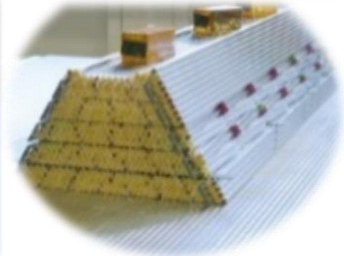
PANDA-STT (3D-view)

STT in 2T solenoid B-field

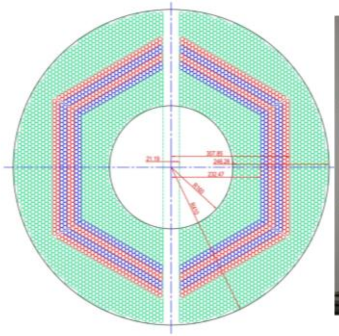
- **4224 straws**, ∅=10mm, 27µm Al-mylar film, 1400mm (L)
- **19 axial + 8 stereo-layers** (±3°) **in 6 sectors**
- Ar/CO_2 at 2 bar (absolute)
- **0.04% X_0 per layer** (~1.3% STT)
- **Δp/p ~ 1-2 %** (with MVD)
- **Drift time and charge readout for PID** (ASIC)
- **σ(r) < 150µm, σ(z) ~ 2-3mm**, **π/K/p-sep. < 1GeV/c**
- Rates: < 10 kHz/cm^2, < 1 MHz/straw



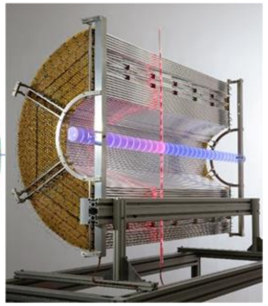

Close-packed layers (<50µm gap), gluing to self-supporting modules.

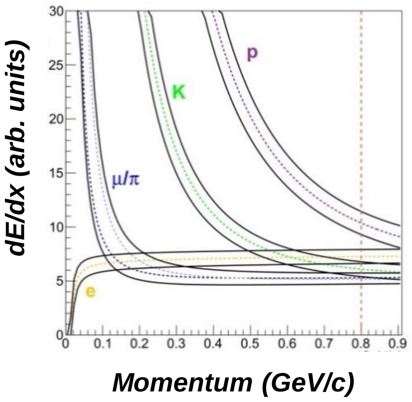
Self-supporting hexagon prototype sector (left) and with 3×3kg Pb bricks on top (right).

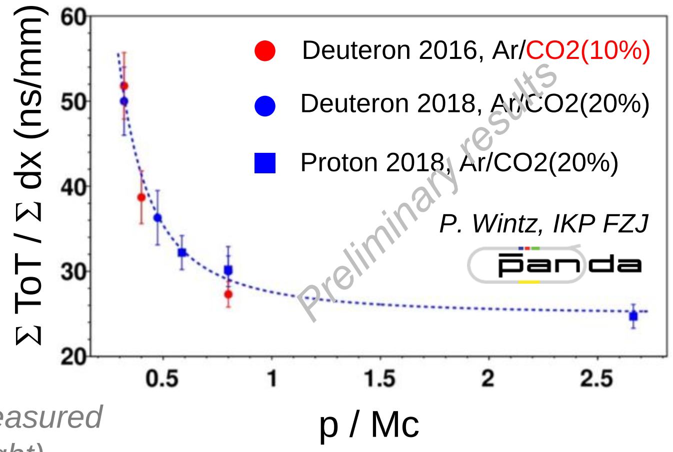


Straw layout (cross-view), stereo layers in red/blue.

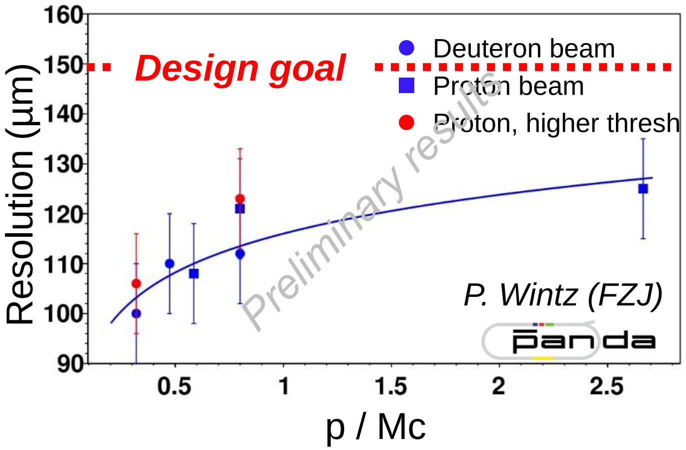


STT-protoype





PID by dE/dx simulation (left) and measured separation by time-over-threshold (right).

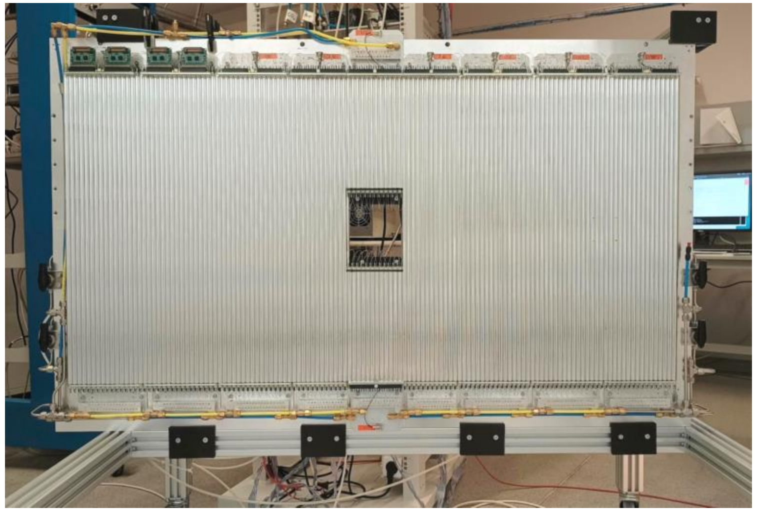


PANDA-FT Forward Tracker

(Large Area Forward Straw Trackers)

FT forward tracker

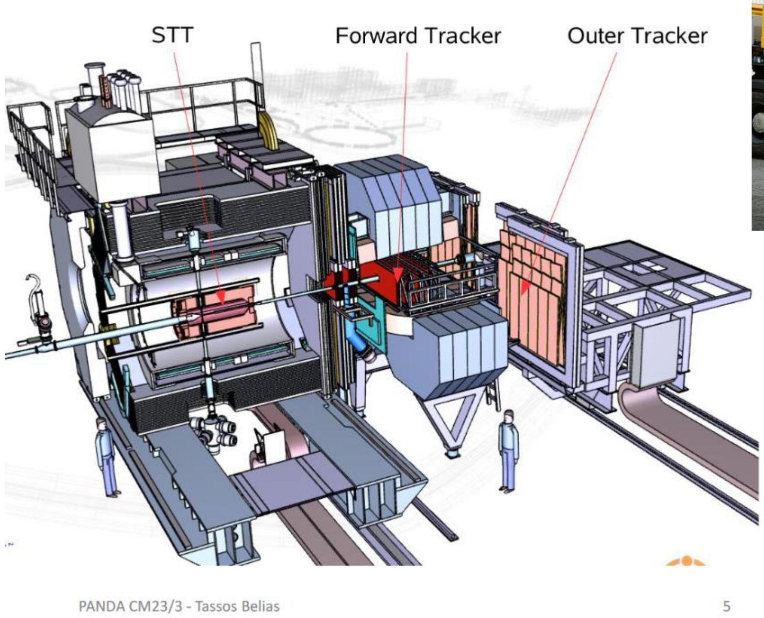
- **2+2 planar stations** (in front/inside dipole)
- **5632 straws**, ∅=10mm, 27µm Al-Mylar
- 640-767 mm length
- Ar/CO2 at 2 bar (absolute)
- 0.04% X_0/layer
- 4 DL (x,u,v,x) per station (0°, ±5°)
- Δp/p ~ 1.5%, rates < 25 kHz/cm^2



FT1/2 (two left/right half frames for beam pipe cut out).

Outer Tracker (LHCb OTR)

- **10800 straws**, ∅=5mm
- Inner half-length modules (2.4m)
- 0.1% X_0/layer
- 4 DL (x,u,v,x) per station
- LHCb ASIC readout + interface



.. please contact Tassos Belias (GSI) for more info about LHCb OTR at GSI

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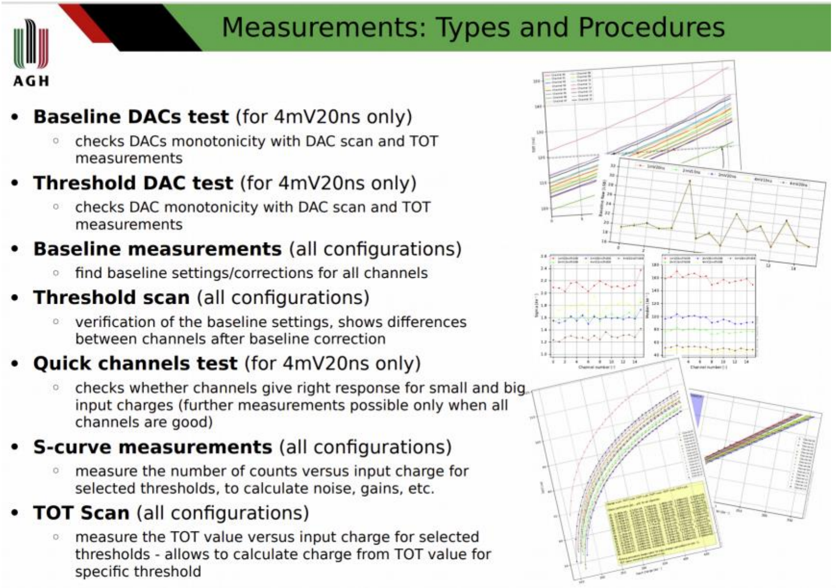
PASTTREC-ASIC and Readout Development

(M. Idzik, AGH Krakow; G. Korcyl, JU Krakow; and GSI E-Lab)

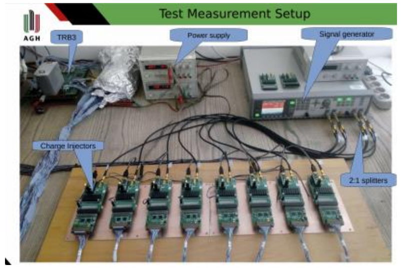
- **Full verification** by STS1/2 systems in phase-0 HADES beamtime
- **ASIC: PASTTRECv1** (CMOS 350) with LE-/TE-time measurement
- **SW control** (via TRB FPGA)
  - Variable gain (0.67, 1, 2, 4mV/fC) and peaking time (15, 20, 30ns)
  - Adjustable baseline level per channel (±32mV range) and discr. threshold per 8-ch ASIC
  - Ion tail cancellation and shaping

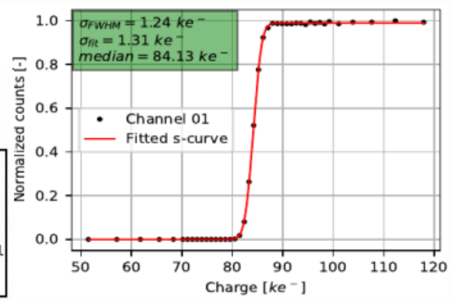
- **Baseline tuning method established** (noise level scan)
- **QA procedure established**
  - Seven QA tests, database for each ASIC/channel results

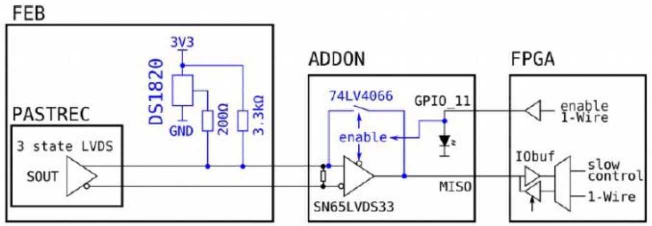
- Final FEBv4 verified, AddOn for temp./chip ID readout
- TRB3sc/TRB5sc readout system (GSI design, ELab)
- **Ready for final order**

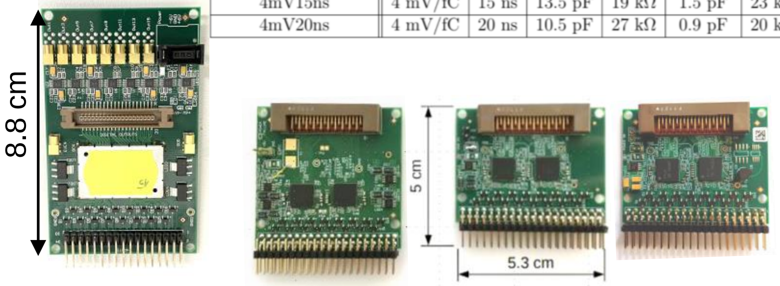


Configuration name	Gain	T_{peak}	TC_{C1}	TC_{R1}	TC_{C2}	TC_{R2}
1mV20ns	1 mV/fC	20 ns	6.0 pF	23 kΩ	0.6 pF	11 kΩ
2mV15ns	2 mV/fC	15 ns	15.0 pF	7 kΩ	0.6 pF	8 kΩ
2mV20ns	2 mV/fC	20 ns	7.5 pF	27 kΩ	0.75 pF	17 kΩ
4mV15ns	4 mV/fC	15 ns	13.5 pF	19 kΩ	1.5 pF	23 kΩ
4mV20ns	4 mV/fC	20 ns	10.5 pF	27 kΩ	0.9 pF	20 kΩ









FEBv1 prototype with analog out *FEBv2* *FEBv3* *new FEBv4 (T & chip ID)*

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Straw Tubes in HADES-Spectrometer for FAIR Phase 0

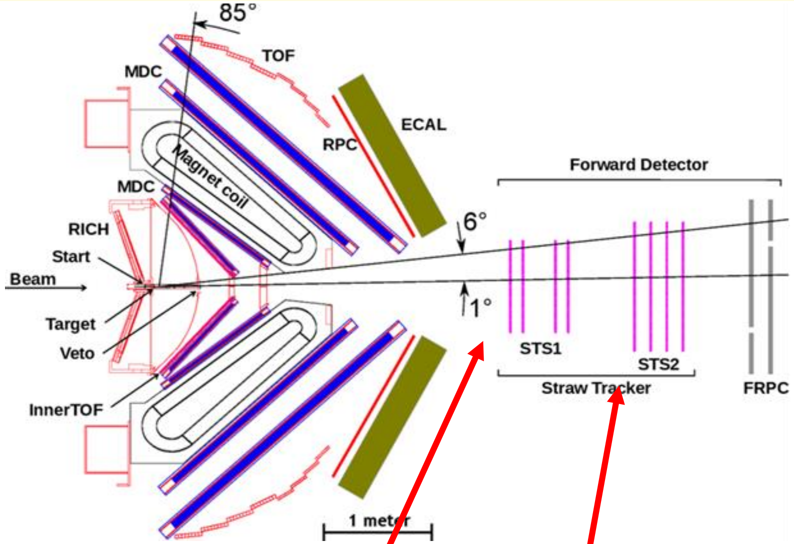
(Upgrade Small Polar Angle Region for Hyperon Tracking)

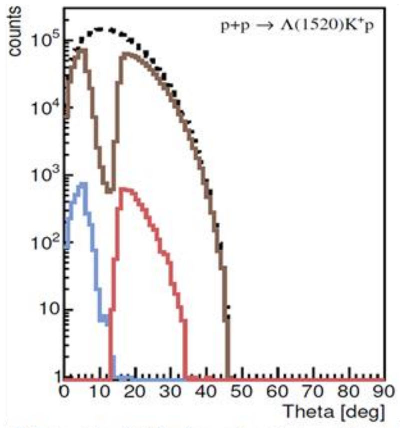
New Straw Tracking Station STS1 to upgrade HADES

Physics: hyperon production and decay

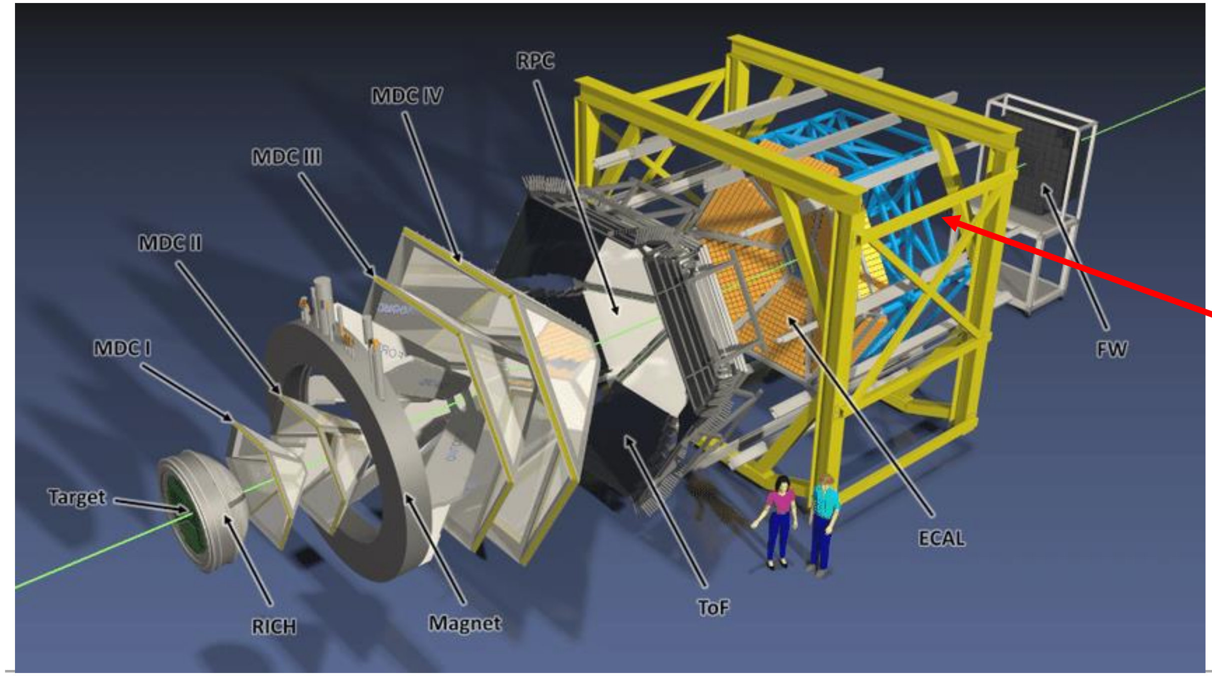
HADES production run (4 PhDs ..)

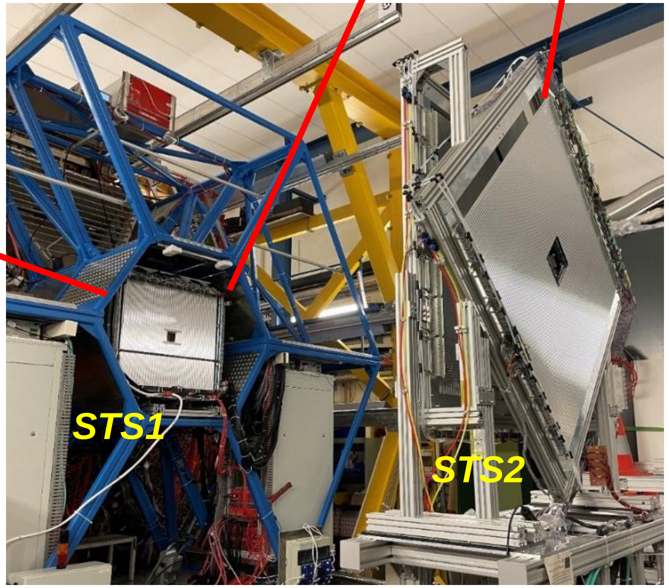
- 4 weeks beamtime in February/March 2022:
- Proton beam from SIS18 at E_{kin} = 4.5 GeV
- LH_2 target





Polar angle distribution of protons emitted from the Λ(1520) decay

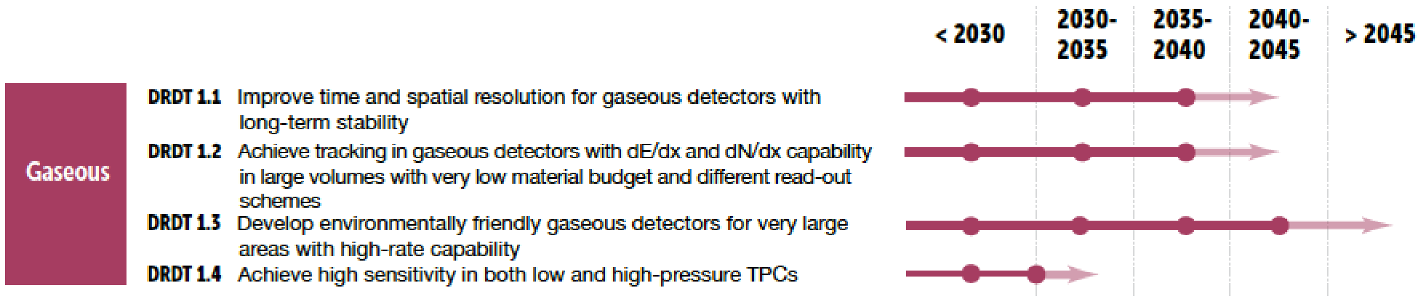




STS1 (FZJ) and STS2 (JU Krakow) installed at HADES

Perspectives of Straw Technologies in DRD1

(ECFA Roadmap: Strategic, Long-term Future Research and Development)



DRD1

DRD1 EXTENDED R&D PROPOSAL
Development of Gaseous Detectors Technologies
v1.5

Abstract

This document, realized in the framework of the newly established Gaseous Detector R&D Collaboration (DRD1), presents a comprehensive overview of the current state-of-the-art and the challenges related to various gaseous detector concepts and technologies. It is divided into two key sections.

The first section, titled "Executive summary", offers a broad perspective on the collaborative scientific organization, characterized by the presence of eight Working Groups (WGs), which serve as the cornerstone for our forthcoming scientific endeavours. This section also contains a detailed inventory of R&D tasks structured into distinct Work Packages (WPs), in alignment with strategic R&D programs that funding agencies may consider supporting. Furthermore, it underlines the critical infrastructures and tools essential for advancing us towards our technological objectives, as outlined in the ECFA R&D roadmap.

The second section, titled "Scientific Proposal and R&D Framework," delves deeply into the research work and plans. Each chapter in this section provides a detailed exploration of the activities planned by the WGs, underscoring their pivotal role in shaping our future scientific pursuits. This DRD1 proposal reinforces our unwavering commitment to a collaborative research program that will span the next three years.

On-line version: https://cernbox.cern.ch/s/QOTuKXTQQ9FQV0Y
DRD1 Website: https://drd1.web.cern.ch/

Geneva, Switzerland
November 29, 2023

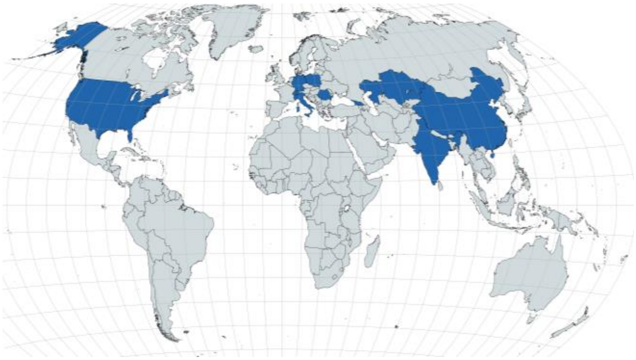
JÜLICH Forschungszentrum

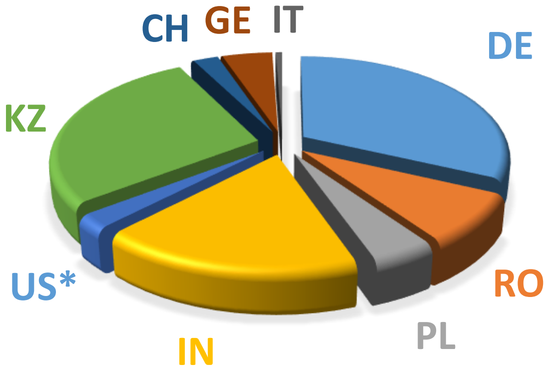
Straw Technologies in DRD1

(DRD1: Gaseous Detector Research and Development)

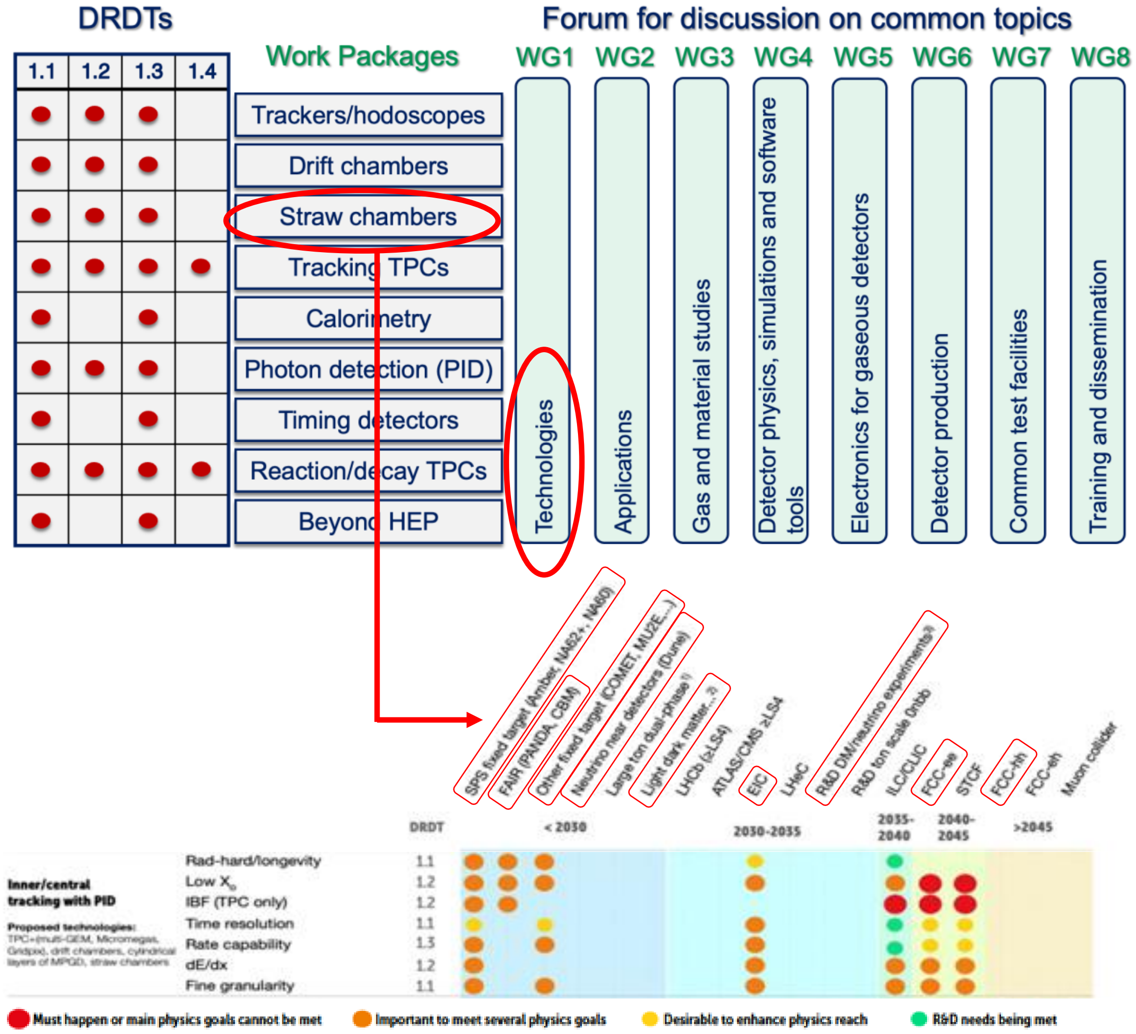
- Scientific organization of DRD1
  - 9 Work packages addressing application-specific R&D
  - 8 Work groups covering common topics
  - DRDT: R&D themes defined in ECFA Roadmap

- WP#3 – Optimization of Straw Chamber Technologies
  - 26 institutes in 9 countries (+ China)
  - 6 work-package projects





US resources not yet final



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WP#3 - Straw Workpackage in DRD1

(R&D Tasks, Performance Goals and Contributing Institutes)

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable 12M	24M	36M	Institutes
T1	Optimize straw materials and production technologies	- Thin film materials - Film metallization - Low cross-talk - Resistance to ageing - Production techniques	WG1, WG2, WG3, WG4, WG5, WG6, WG7, WG8	1.1, 1.2, 1.3	**M1** **Work plan consolidation:** finalise work package objectives and decide final straw designs including simulation studies. Setting up laboratories, production and test facilities. Tendering and procurement of materials **[T1-T7].**	**M2.1** **Prototype design and construction:** optimization of straw materials, designs and production technologies for low radiation length, thin-wall tubes, small diameter tubes, long tubes and straws with enhanced longevity. **[T1-T3, T6].** **M2.2** **Optimization of the prototype mechanical system** with low material budget and high mechanical precision. Development of the alignment method **[T3, T5, T7].** **M2.3** **Optimization of front-end electronic and ASIC design** based on existing ASICs and simulation studies for fast timing, signal leading and trailing edge time readout with high resolution and charge measurement for PID **[T4, T5].**	**D** **Prototype tests and results:** performance of prototype designs and measurement resolutions (3D-space <150 μm, time t0 of $\mathcal{O}$(1 ns), dE/dx < 10%) **[T1-T7].** Evaluation of WP tasks with review of further enhancement and new potential **[T1-T7].**	GTU, FZJ-GSI-U Bochum, U Hamburg, MPP, IITG, IITK, NISER Bhubaneswar, U Delhi, U Punjab, INFN-TO, INP-Almaty, JU-Krakow, IFIN-HH, CERN, U South Carolina, U Duke, BNL, FIT, JLab, U Massachusetts, Amherst, U Michigan, UC Irvine, UW–Madison, Tufts
T2	Develop straw tubes of 5mm diameter	- Thin film wall - Fast timing < 100 ns - Rates $\simeq$ 50 kHz/cm^2						
	Develop straw with ultra-thin film walls	- Film wall < 20 μm - X/X0 $\simeq$ 0.02% / straw - Film metallization						
	Develop ultra-long straws with thin film walls	- 4-5 m tube length - Film walls < 30 μm - Good mechanical properties						
	Develop straws with ultra-small diameter	- Diameter < 4mm - Rates > 500 kHz/cm^2 - Fast timing <50ns - Charge load > 10 C/cm						
T3	Optimize the detector mechanical system	- Develop self-supporting modules - Control material relaxation - Straw alignment method						
T4	Optimize the front-end electronics (ASIC) and readout system	- Leading and trailing edge time readout - Charge readout - Time readout with sub-ns precision						
T5	Enhance the tracker measurement information (3D/4D and PID via dE/dx)	- Spatial resolution < 150 μm - Time t0 extraction with O(ns) resolution - dE/dx resolution < 10% - p/K/π-separation						
T6	Enhance the detector longevity	Ageing resistance up to - 1 C/cm for thin-wall straws - >10 C/cm for straws for highest particle rates						
T7	Optimize the online-/offline software	- Straw tube simulation - Straw calibrations - Tracking simulation - Pattern recognition - Tracking and PID - Tracker alignment						

Table 3: WP3 - a work package on inner and central tracking with PID (Straw and Drift Tube Chambers). Area of application: future electron colliders (FCC-ee, CEPC), FCC-hh, FAIR, Dark Matter, rare event searches, and neutrino physics.

FFN
(FAIR Forschung in NRW,
Head: Prof. J. Ritman)

our contribution

Table 1: Institutes, their contribution to the R&D tasks and contact person.

Institute	Contribution T1	T2	T3	T4	T5	T6	T7	Contact persons
CERN	X	X	X					Hans Danielsson, Massimiliano Ferro-Luzzi
FZJ			X	X	X		X	Peter Wintz
GSI					X		X	Jenny Taylor
GTU	X	X	X		X			Zviadi Tsamalaidze
IFIN-HH			X	X	X		X	Mario Bragadireanu
IITG	X	X	X	X	X		X	Bipul Bhuyan
IITK				X	X			Navaneeth Poonthottathil
INFN-TO				X				Maxim Alexeev, Chiara Alice
INP-Almaty	X	X	X	X	X	X	X	Nurzhan Saduyev, Yerzhan Mukhamejanov, Temur Enik
JU Krakow		X				X		Jerzy Smyrski
MPP	X	X	X	X	X			Oliver Kortner
NISER	X		X					Sanjay Kumar Swain
RU Bochum			X	X	X		X	Peter Wintz
U Hamburg	X	X	X			X		Daniel Bick
U Punjab	X		X	X				Vipin Bhatnagar
U South Carolina		X	X	X	X		X	Roberto Petti
U Duke		X						Seog Oh
U Delhi	X	X		X				Ashok Kumar
BNL				X				US Cluster: Markus Hohlmann, Georgios Iakovidis, Bing Zhou
FIT				X				
JLab				X				
U Mass. Amherst				X				
U Michigan	X	X	X	X				
UC Irvine				X				
U Wisconsin				X				
Tufts University	X	X	X					

WP#3 Annexes in DRD1 Proposal

(Workpackage and Project Descriptions incl. Milestones, Funding, .. 49p)

DRD1 WP3 – Optimization of Straw Chamber Technologies

Participating institutes:

Georgian Technical University (GTU) and Institute of quantum physics and engineering (IQPE), Tbilisi, Georgia
Forschungszentrum Jülich GmbH (FZJ), Germany
Gesellschaft für Schwerionenforschung GmbH (GSI), Germany
Hamburg University, Germany
Max-Planck Institute for Physics (MPP), Garching, Germany
Ruhr-Universität Bochum (RUB), Germany
IIT Guwahati (IITG), Guwahati, India
IIT Kanpur (IITK), Kanpur, India
NISER (NISER), Bhubaneswar, India
University of Delhi (U Delhi), Delhi, India
Punjab University (U Punjab), Chandigarh, India
Torino section of INFN and Università degli studi di Torino (INFN-TO), Italy
Institute of Nuclear Physics (INP-Almaty), Almaty, Kazakhstan
Jagiellonian University, Krakow (JU Krakow), Poland
Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
European Organization for Nuclear Research (CERN), Switzerland
University of South Carolina (U South Carolina), Columbia, SC, USA
Duke University (U Duke), Durham, NC, USA
US Cluster
(Brookhaven National Laboratory, Florida Institute of Technology, Jefferson Lab, University of Massachusetts Amherst, University of Michigan, University of California Irvine, University of Wisconsin-Madison, Tufts University), USA

Description of the work package

Straw chamber and drift tube technologies are widely used in particle physics experiments and can cover a broad range of future applications from high-energy physics (HEP) and hadron physics at future accelerators (e.g. FCC-ee, CEPC, FCC-hh, FAIR) to Dark sector, rare event searches and neutrino physics experiments. An application-specific optimization of straw chamber technologies is required including the development of straw tube and detector designs, materials, production techniques, electronic readout with ASIC design, prototype or demonstrator setups with test measurements. Software algorithms for data analyses and simulation in parallel will be developed. Various simulation software packages and frameworks will be used for the mechanical detector and electronics designs and further developed.

Main straw specifications are the wire and tube material, tube diameter and wall thickness, straw length, end-cap design and electric contacting, gas mixture and the straw signal measurement information registered by the electronic readout. The front-end electronics (e.g. ASIC design) and readout system must be developed taking into account particle rates and timing requirements. In addition to the straw signal time for the spatial track information, the measurement of the particle-specific ionization (dE/dx) can be used for particle identification (PID) in the lower momentum region.

1

The optimization of straw tube materials focuses on thin films with less than 30µm and less than 20µm (maybe 12µm) thickness to reduce the radiation length of a straw to below 0.02% (X/X_0). Then, the contribution from the tube wall is comparable to the gas volume (for a 10mm tube diameter and 2bar absolute gas pressure). Different types of metallization of such thin films will be investigated with respect to high particle rate capability (up to 1MHz/tube), improved ageing and corrosion resistance, and low cross-talk between adjacent tubes. High purity and ageing resistance of all materials are mandatory to extend detector longevity. Tube diameters of 20mm, 10mm, and 5mm will be studied, the latter for fast timing (< 80ns) and high particle rates up to 50kHz/cm^2. The assembly of thin-wall straws with up to 5m length will be developed. New straw production technologies include assembly techniques, all tools, and definition of quality assurance (QA) methods during the production steps, important for future experiments requiring series production of hundred-thousands of straw tubes.

The mechanical detector system has to support and precisely align the straws with up to 5m length. Such ultra-long straws require innovative mechanical support techniques, like carbon-fibre suspension, constant-force springs or self-supporting cemented packs of straws. The use of very thin straw films for minimal material budget requires R&D on the film properties under mechanical stress and over a long time to investigate long-term material relaxation and creeping and develop methods for compensation. A unique application of straw detectors is their operation in surrounding vacuum due to their robust mechanical shape if the gas inside the thin film tubes is at over-pressure of about 1bar. This technology allows very large detection areas (~ 50sqm) together with thin foils (< 30µm) in vacuum. The control of gas leakage and change of the gas mixture ratio by a difference in the molecular permeation through the thin film wall are key aspects.

Various prototype straw and drift tube detectors will be set up with electronic readout consisting of new, custom-specific designed ASICs. ASICs for time and charge readout and for high or moderate particle rates will be developed. A demonstrator inner tracking straw detector consisting of 10mm diameter tubes arranged in about 20 close-packed layers will be built to perform and optimize 4D+PID track measurements (3D-space, time t0, dE/dx). The dE/dx information by the signal time-over-threshold will be used for particle identification (PID) in the lower momentum region. The 4D+PID track reconstruction and detector alignment software algorithms will be developed including simulation and data analysis.

Part of this work package is the set up of a new straw series production facility (at INP Almaty) with the technique of ultrasonic welding of thin film tubes of different diameter, different film tube thickness, and lengths up to 5m and including quality control procedures. This contribution is very important for this work package, but might also be of benefit for the whole straw detector community in future.

The 2021 ECFA detector research and development roadmap

The work package covers the following DRD themes (DRDT) which have been defined by the ECFA Detector R&D Roadmap Process Group. CERN-ESU-017. CERN, 2020, p. 248. DOI: 10.17181/CERN.XDPL.W2EX

- **DRDT 1.1** - Improve time and spatial resolution for gaseous detectors with long-term stability.
- **DRDT 1.2** - Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes.
- **DRDT 1.3** - Develop environmentally friendly gaseous detectors for very large areas with high-rate capability.

2

List of R&D tasks of the work package

The R&D topics in this work package consists of seven tasks. **Table 1** lists the institutes with associated tasks.

- **T1**: Optimize straw materials and straw production technologies
- **T2:** Improve straw tube designs
  - **T2a:** Straw tubes of 5mm diameter
  - **T2b:** Straws with ultra-thin film wall
  - **T2c:** Ultra-long straws (up to 5m)
  - **T2d:** Straw tubes with < 4mm diameter
- **T3:** Optimize the detector mechanical system
- **T4:** Optimize the front-end electronics (ASIC) and read-out system
- **T5:** Enhance the tracker measurement information (3D, t0, dE/dx)
- **T6:** Enhance the longevity of the detector
- **T7:** Optimize the online-/offline software

Work package organization

The work package is organized in work projects, which address certain R&D aspects for the respective application, but also the formation of collaborating sub-groups and common project description for funding application.

The first four projects (A-D) refer to drift tube and straw chamber technologies for applications at future accelerators, including also non-HEP applications, like Dark Sector and neutrino physics experiment installations. Projects E and F have a more general approach.

Project A - Drift tube developments for new high-rate applications
Contact person: Oliver Kortner (kortner@mppmu.mpg.de)

Project B - Straw chamber technologies for hadron physics applications
Contact person: Peter Wintz (p.wintz@fz-juelich.de, pwintz@cern.ch)

Project C - Large area straw detector for Dark Sector applications
Contact person: Daniel Bick (daniel.bick@desy.de)

Project D - Straw chamber technologies for neutrino physics applications
Contact person: Roberto Petti (Roberto.Petti@cern.ch)

Project E - Optimization of straw materials and production technologies
Contact person: Temur Enik (temur.enik@cern.ch)

Project F - Optimization of electronic readout
Contact person: Katerina Kuznetsova (ekaterina.kuznetsova@cern.ch)

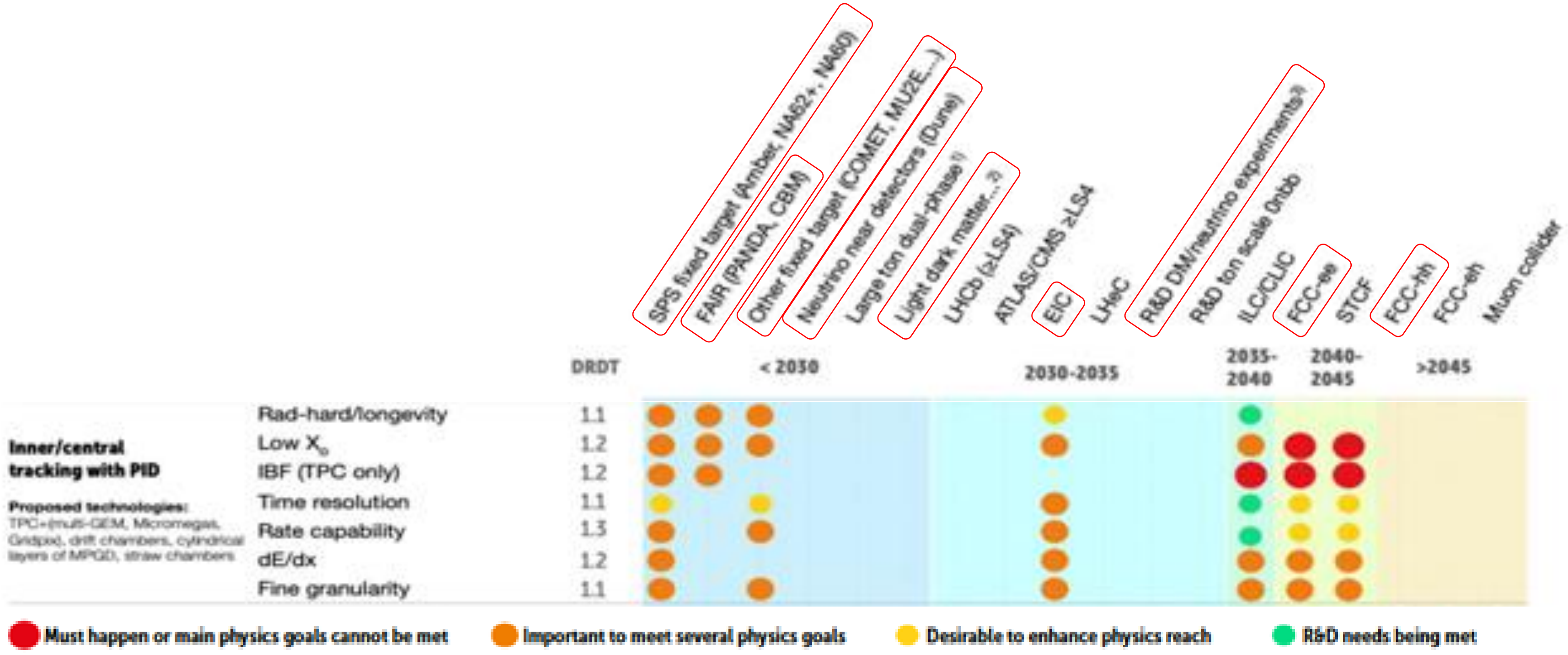
3

Straw R&D in DRD1

- ***Strategic R&D projects***
  - *Drift tube developments for high-rate applications*
    *(FCC-ee/hh, **small diameter sMDT**, large area muon tracker)*
  - *Straw chamber technologies for hadron physics*
    *(**4D+PID central tracker**, SW trigger RO, **low overall X0**)*
  - *Large area straw detector for Dark Sector applications*
    *(**4m long thin-wall straws**, 50 sqm in vacuum)*
  - *Straw chamber technologies for neutrino physics*
    *(new concepts, **“solid H2-target” detector** by stacked layers of targets and “transparent” straws, dE/dx, electron TR, .. ASICs)*
  - *Optimization of straw materials & production technologies*
    (e.g. standardization of materials, designs, productions ..)
  - *Optimization of electronic readout*
    (new ASIC designs, versatile applications, time and charge RO)

- ***WP3: merging straw technology innovations***
  - *(very) Different application fields (HEP, .. DM, neutrino, ..)*
  - *Foster emerging of new concepts*
  - *Two (new) straw production sites*

- ***Technology trends:***
  - *Thinner film walls (e.g. X0 similar to gas contribution)*
  - *Smaller diameter, ultra-long straws with thin film wall*
  - *Robust thin-film metallization and clean materials (e.g. PET film US welding)*
  - *Standardize straw materials and prod. technologies*
  - *4D + dE/dx tracker, t0 - extraction*
  - *Large area detectors in vacuum is unique application*
  - *ASIC design optimization*
  - *New concepts, new materials, new technologies, ..*



Thank you very much for your attention!

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