Detector R&D Requirements for
Strong Interaction Experiments at Future Fixed Target Facilities

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19.02.2021

Strong Interaction Experiments at Future Fixed Target Facilities

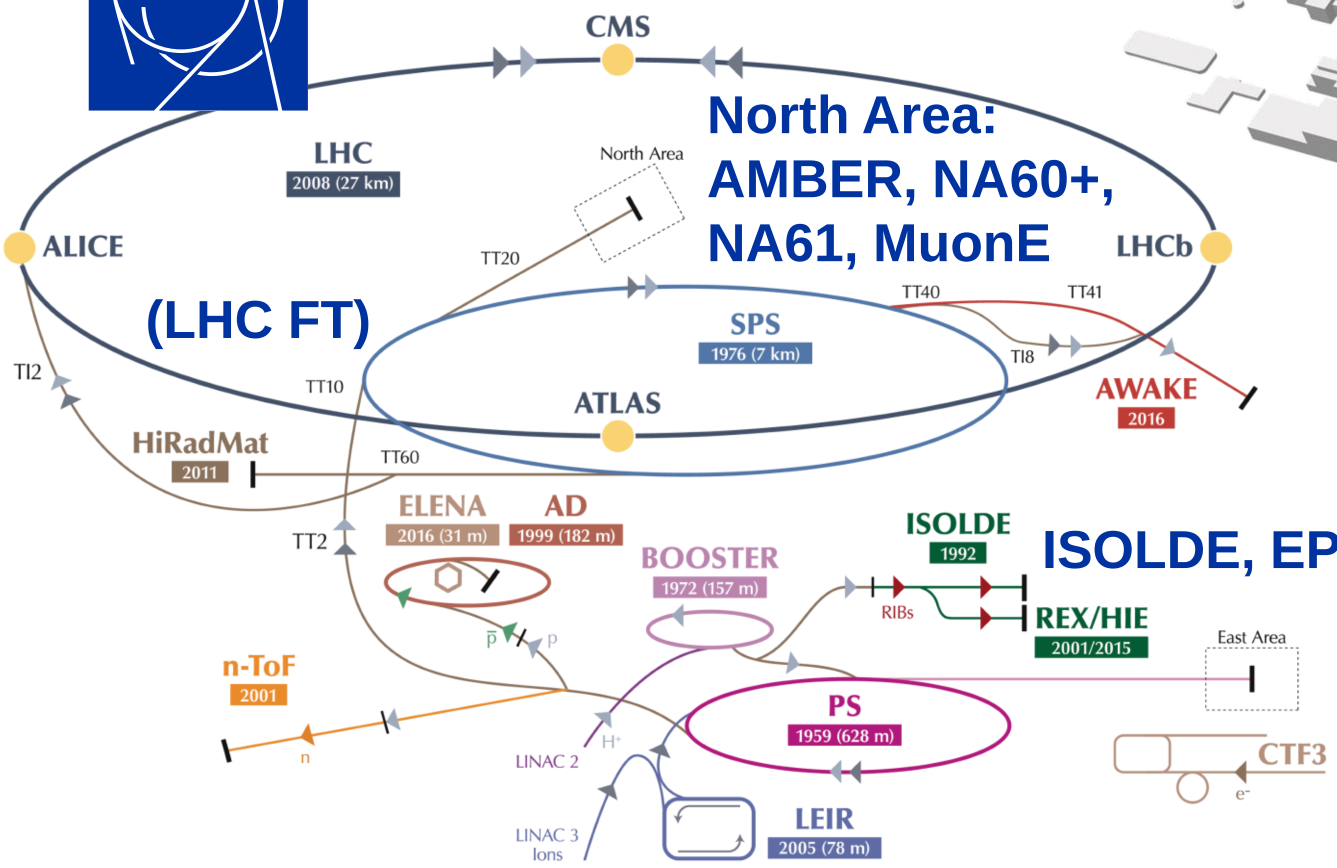
- General Considerations
- Overview on Facilities
- Experiments and Projects at
  - FAIR/GSI
  - ISOLDE/CERN
  - SPS/CERN
- Some Remarks on Software
- Some Remarks on Test Beam Facilities
- Summary

Gratefully acknowledging input from G. Schnell, G. Neyens, S.Gilardoni, L. Schmitt, H. Flemming, T. Stockmanns, M. Moritz, M. Deveaux, S. Pulawski, M. Gazdzicki, S. Levorato, E. Scomparin, G. Usai, G. Venanzoni and many others.

General Considerations

- Fixed target physics, and in particular experiments focusing on strong interaction physics, are working on the **precision and intensity frontier**.
- For medium to high energies, experimental set-ups can be very long (up to 100 m) and cover mainly the forward direction due to the boost of the particles.
- This means that detectors close to the interaction point (the target) are small and need **high spatial resolution** and **precise timing**.
- They need to **stand high fluxes** of all kinds of secondary particles **over long times of operation**.
- The further away, the larger detectors become. As an example, a typical detector size for a CERN North Area experiment at the target is about 5 x 5 cm^2, while typical muon detectors at the far end of the experiment **have large areas** of about 5 x 5 m^2.
- Strong interaction experiments typically rely heavily on **particle identification over a large momentum range**, often in a staged approach (e.g. several RICH detectors, multiple calorimeters).

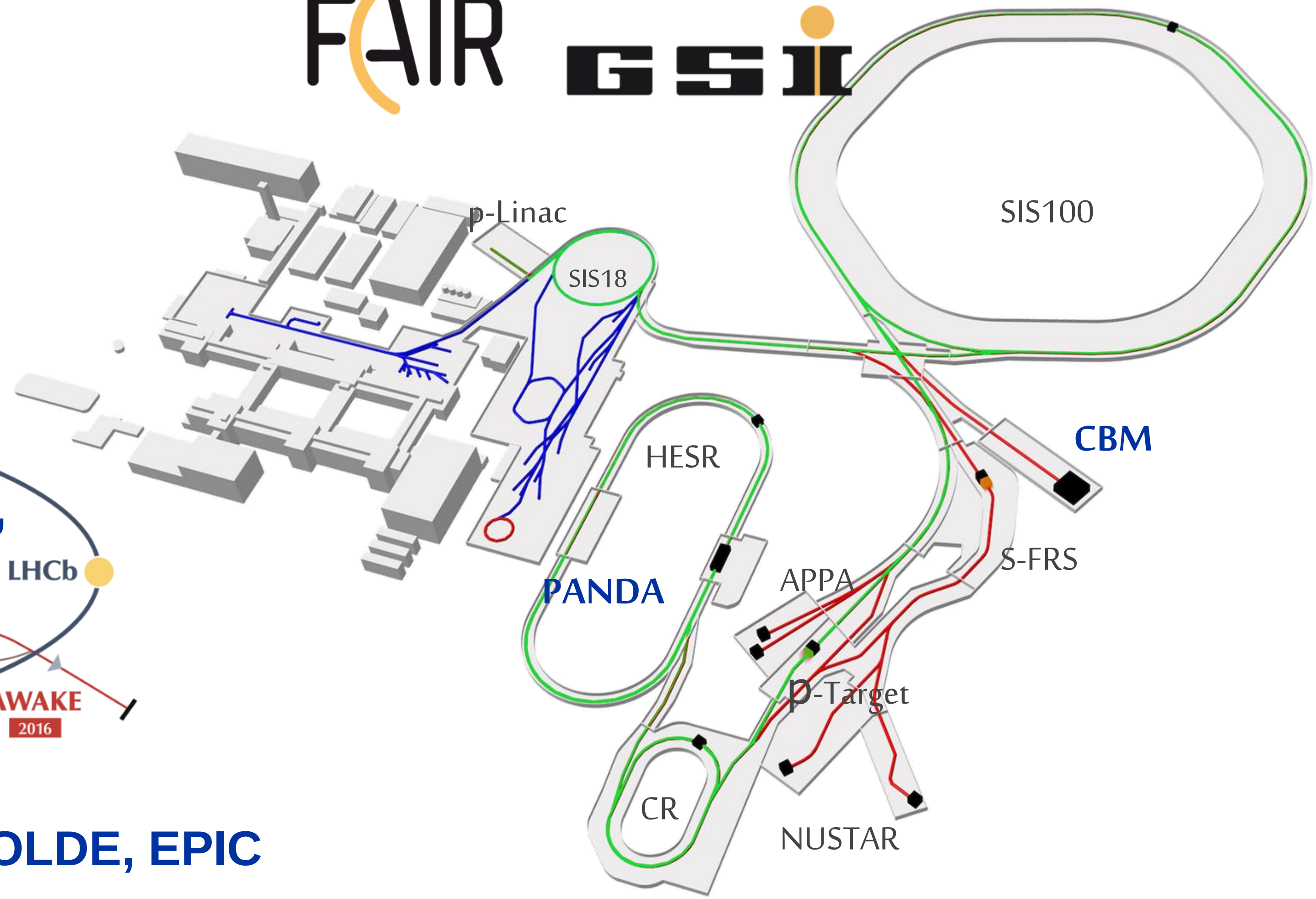
Overview on Facilities



North Area: AMBER, NA60+, NA61, MuonE

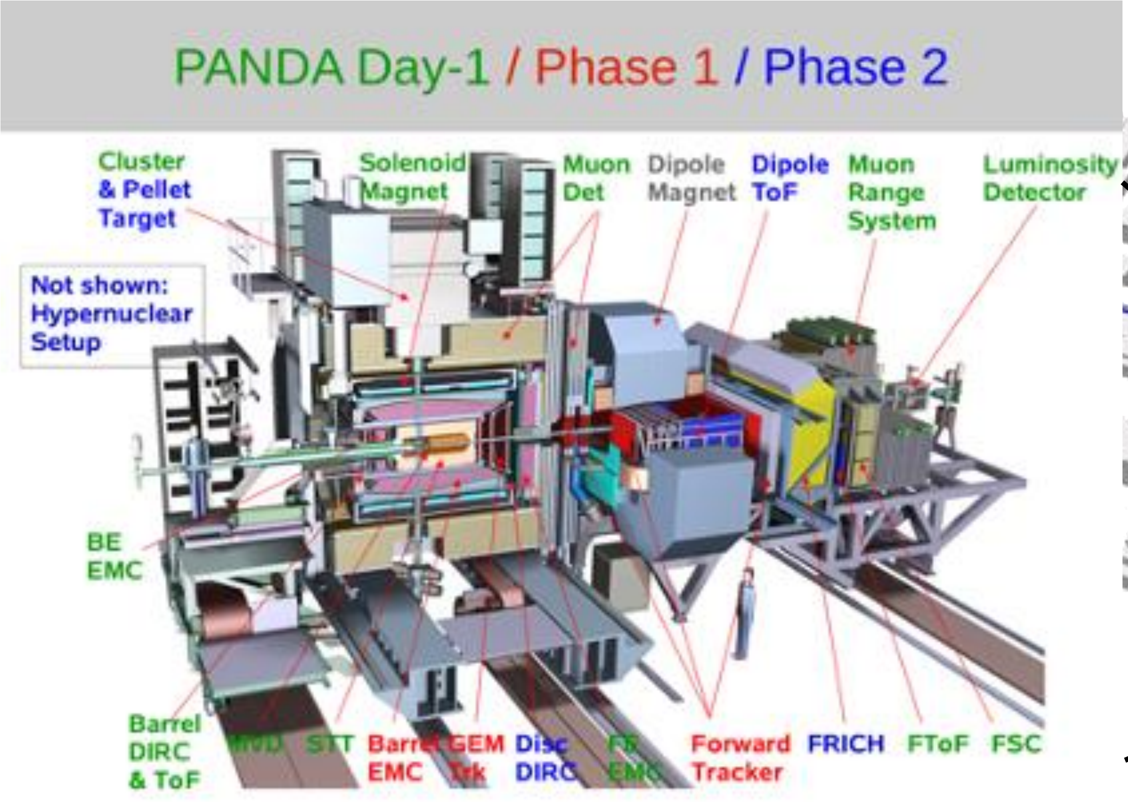
(LHC FT)

ISOLDE, EPIC

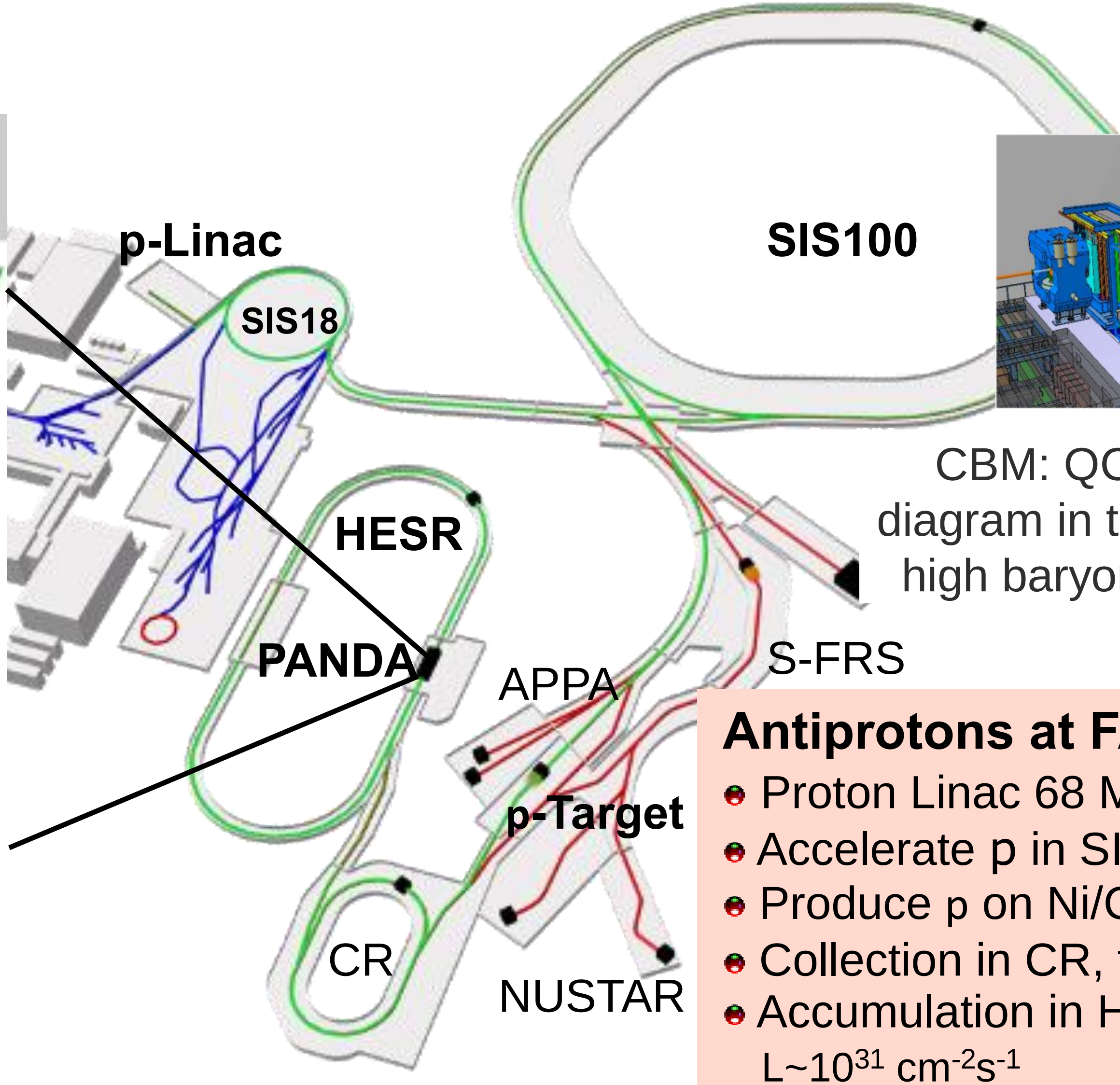


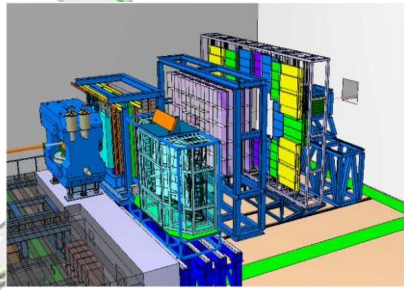
Disclaimer: Not all existing facilities, projects and experiments covered today, partly still awaiting input and most probably inadvertently forgot some.

QCD Physics at FAIR



PANDA: Hadron physics with cooled antiprotons at FAIR





CBM: QCD phase diagram in the region of high baryon densities

Antiprotons at FAIR

- Proton Linac 68 MeV
- Accelerate p in SIS18 / 100
- Produce p on Ni/Cu target
- Collection in CR, fast cooling
- Accumulation in HESR, $L \sim 10^{31}$ $cm^{-2}s^{-1}$

Contacts: L. Schmitt & H. Flemming, GSI Darmstadt;
T. Stockmanns, FZ Jülich; M. Moritz, JLU Gießen

PANDA / FAIR

Micro Vertex Detector

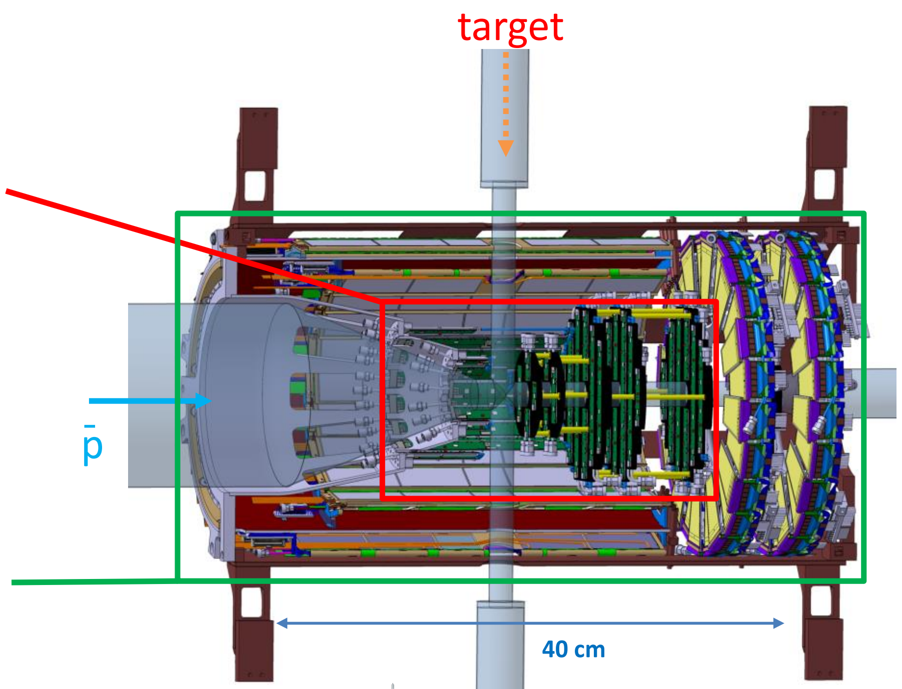
Current Design

Pixels

- Hybrid silicon pixels
- 10 million pixels
- 2 barrel layers
- 6 disks

Strips

- Silicon micro-strip
- In total 296 sensors and 200,000 strip channels
- 2 barrel layers
- 2 disks



TF3, TF7

Requirements

- Spatial resolution in: r-phi < 100 µm; z ≈ 100 µm
- Time resolution **< 10 ns**
- Amplitude measurement for PID
- Radiation length ≈ 1 % / layer
- Radiation hardness ≈ 10^{14} n_{eq}/cm^2; ≈ 10 MRad
- **Continuous readout**

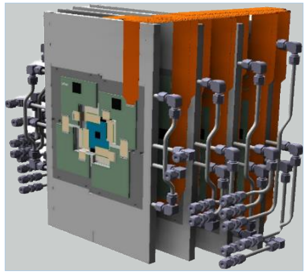
Upgrade Goals

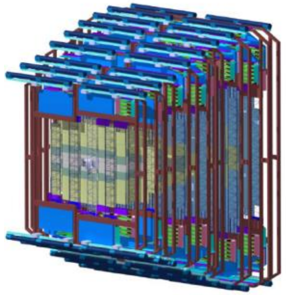
- Spatial resolution in: r-phi < **50 µm**; z **≈ 50 µm**
- Time resolution < 10 ns
- Amplitude measurement for PID
- Radiation length **≈ 0.1 % / layer**
- Radiation hardness ≈ 10^{14} n_{eq}/cm^2; ≈ 10 MRad
- Continuous readout

- Combination of continuous readout, high time resolution, high spatial resolution and low radiation length hard to achieve:
  - Current approaches favor monolithic pixel detectors with a framewise readout which allows high spatial resolution and a low radiation length but with only a moderate time resolution
  - To improve the time resolution would mean to increase the power consumption and therefore the cooling needs and the radiation length of the detector.

CBM / FAIR

CBM@FAIR
Micro Vertex Detector

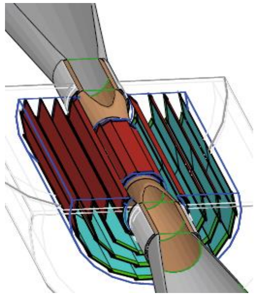




CBM@FAIR
Silicon Tracking System (upgrade)

Common requirements:

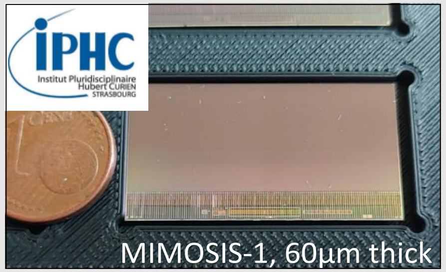
- ~5 µm spatial resolution
- 0.1 – 5 µs time resolution
- few 0.1% X0 per layer
- <100 mW/cm² power
- O(100 MHz/cm²) rate



ILC Vertex Detector

Higgs/Charm factories

MIMOSIS CMOS Sensor



Design goal:
~ 5 µm spatial resolution
< 5µs time resolution
< 100 mW/cm²
20/80 MHz/cm² (mean/peak)
Full size prototype under test.

In synergy/collaboration with:

ALICE ITS2 / ITS3

EP division R&D initiative WP1.2

AIDA innova

CREMLIN PLUS

and many others

Technologies under exploration:
180 nm TJ (modified).
65 nm TJ.
Stitching.
Double Tier integration.

TF3, TF7

Contact: G. Neyens, CERN

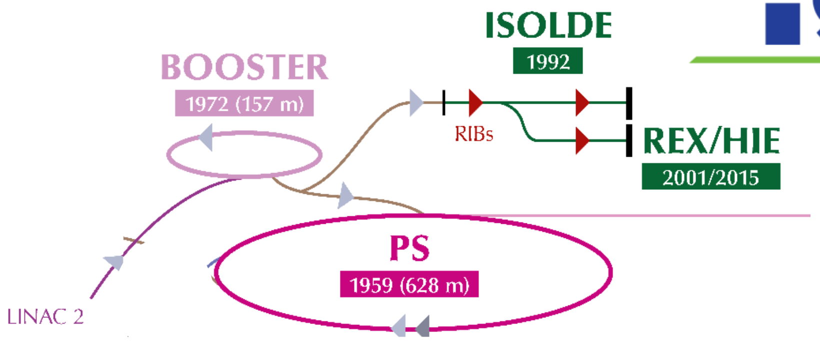
ISOLDE / CERN

ISOLDE: approved by CERN council in 1964

Started operation in 1967

Initially used 600 MeV protons from SC

Later 1.0 GeV (and 1.4 GeV) protons from PSB



UNIQUE worldwide thanks to 1.4 GeV protons on thick targets (20 cm)

More than 50 years of experience in production of pure radioactive isotopes and beams

- >1000 isotopes available already (of 3000 known)
- >70 different elements
- >10 different permanent experimental set-ups (and new ones coming!)

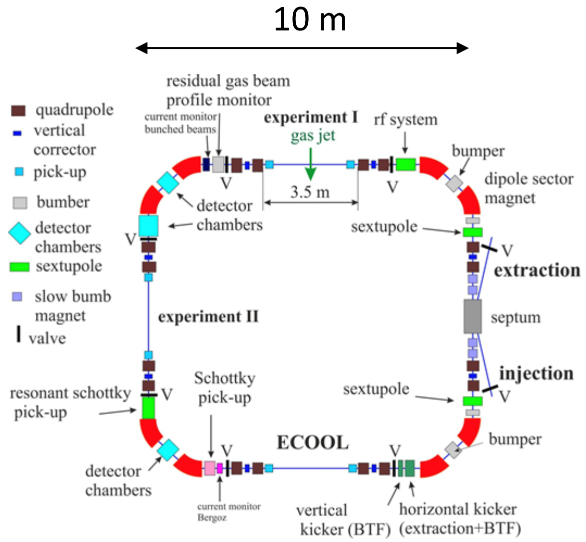
Since 2001: re-acceleration of RIB's with REX and HIE-ISOLDE (NC and SC Linac)

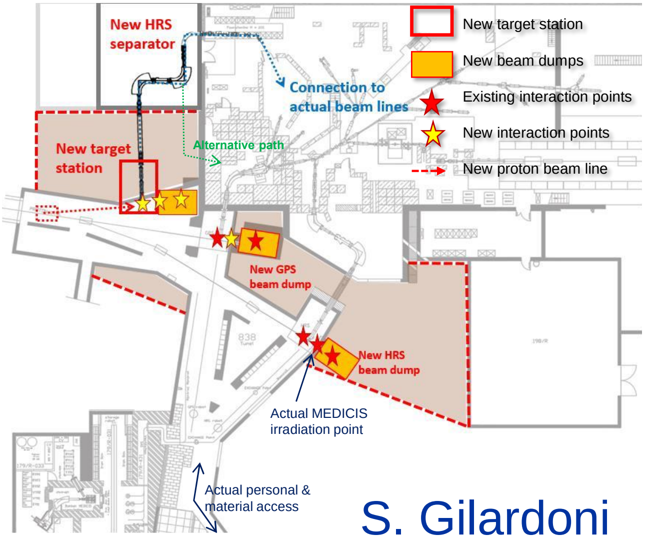
- Beams up to 9.5 MeV/nucleon
- Doubled the users community (reactions with RIB's)
- More than 45 experiments for more than 500 users/year (from 43 countries)

(>**1300 registered ISOLDE users**)

Contact: G. Neyens, CERN

ISOLDE / CERN





S. Gilardoni

The EPIC project @ ISOLDE

Exploiting the Potential of ISOLDE at CERN

1. **Take advantage of LHC Injector Upgrades: proton BOOSTER energy and intensity increase**
   → gain a factor of 2-10 in radioactive beam intensity

2. **Install additional target station(s): allow parallel beams**
   → double the beam time for increasing amount of users
   (more than 80 accepted experiments, typically 30 new per year coming)

3. **Install a 'Storage Ring' for short-lived (low-energy) isotopes – unique worldwide**
   → new opportunities in atomic, nuclear and fundamental (new) physics

4. **A new experimental hall** (new experiments coming – mostly low-energy for searching new symmetries/interactions)
   - **MIRACLS** (ultrapure beams)
   - **PUMA** (interactions between exotic matter/anti-matter)
   - **Set-up/Trap for RaF molecules** (eEDM and other symmetry violations)
   - **Large superconducting magnet** for materials studies

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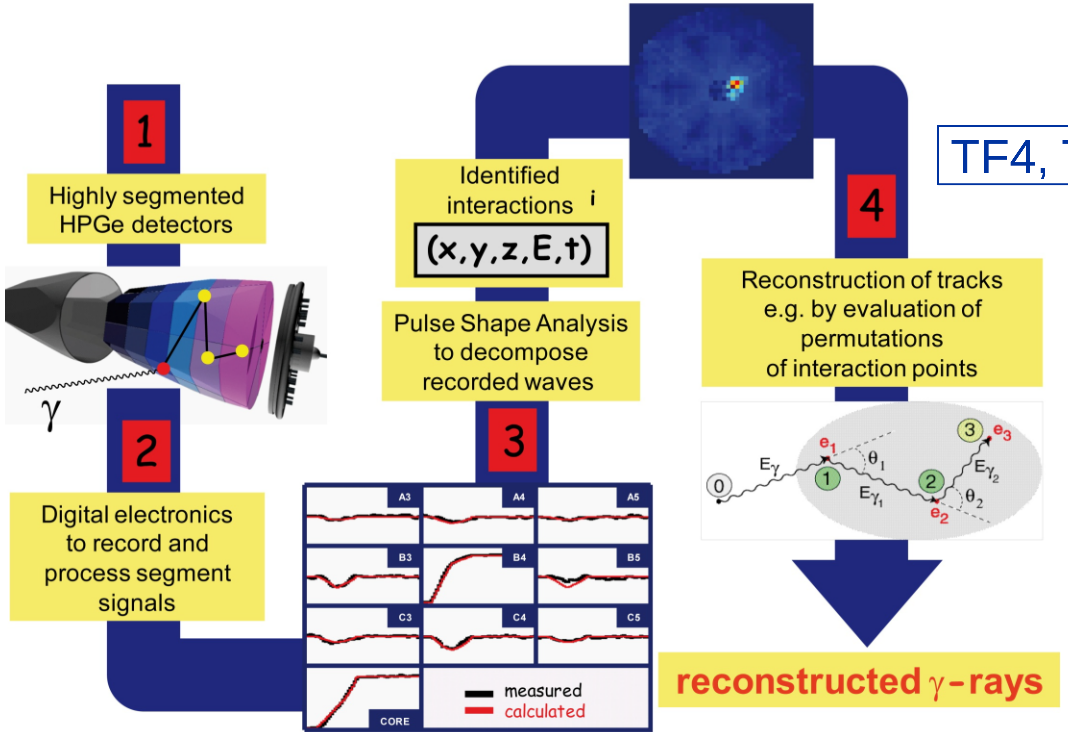
Contact: G. Neyens, CERN

ISOLDE / CERN

- Upgrades being studied for potential 2 GeV/c operation (EPIC), mostly on the infrastructure
- New instrumentation being considered (some examples, more input to follow):

AGATA: Advanced Gamma Tracking Array

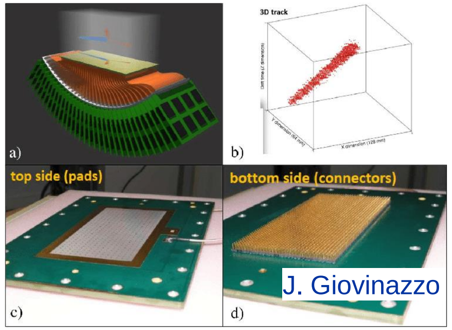


TF4, TF7

+ possible quantum-based detectors TF5

active targets (ACTAR-TPC, SPECMAT, ...)

- e.g. Micromega-based TPCs

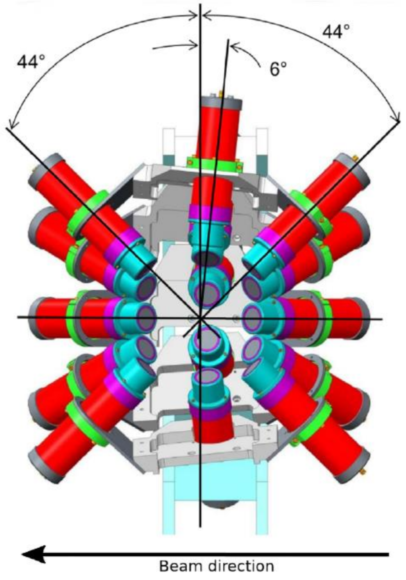


TF1, TF7

fast timing detectors

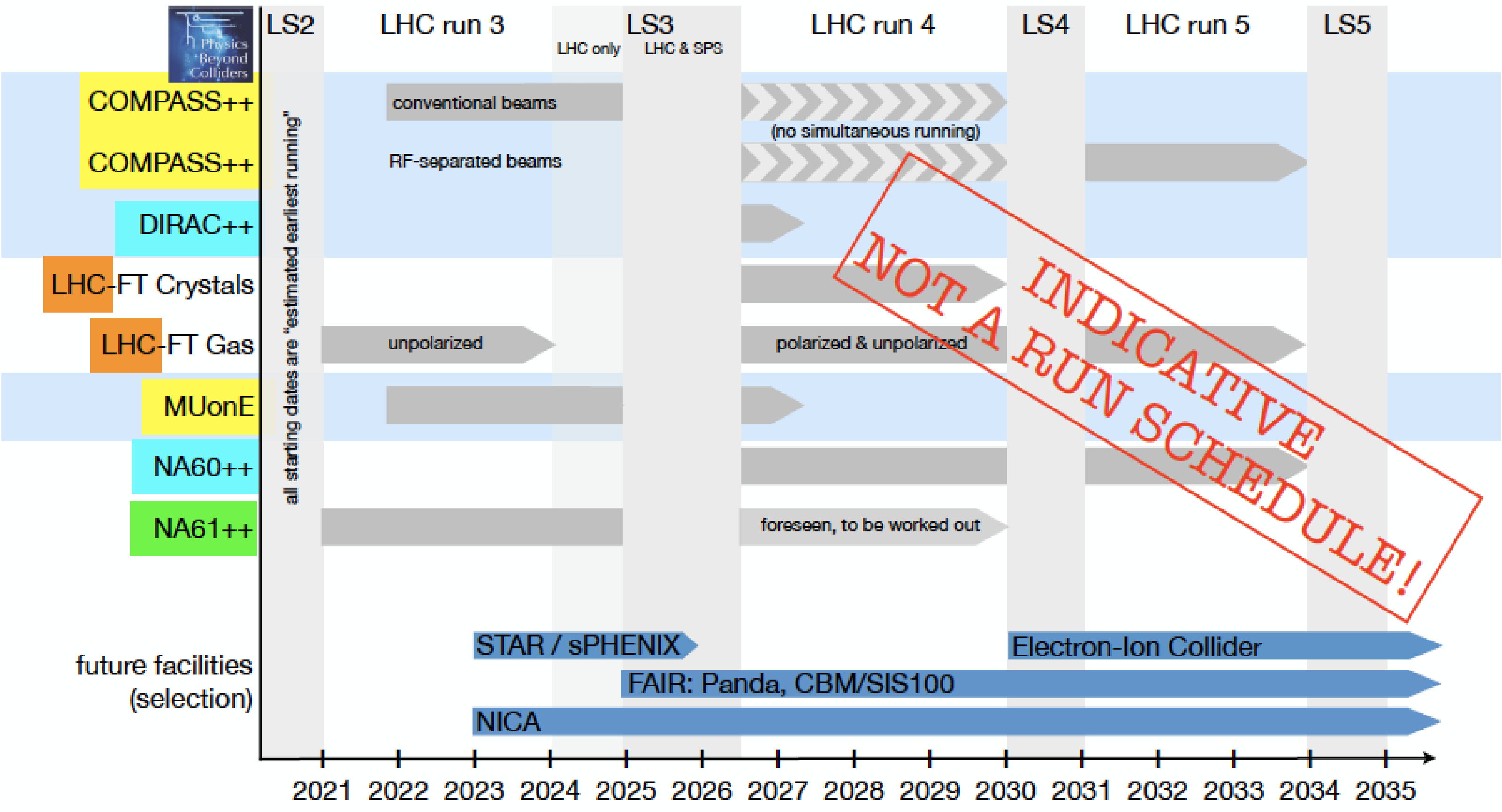
- e.g. FATIMA at DESPEC (GSI/FAIR), LaBr3(Ce) crystals with PMT readout

TF4



North Area at CERN and Physics Beyond Colliders

time lines and (possible!) locations of PBC-QCD projects



Some literature

- PBC Summary
- QCD WG Report
- Conventional Beams Report
- LHC FT Report

G. Schnell

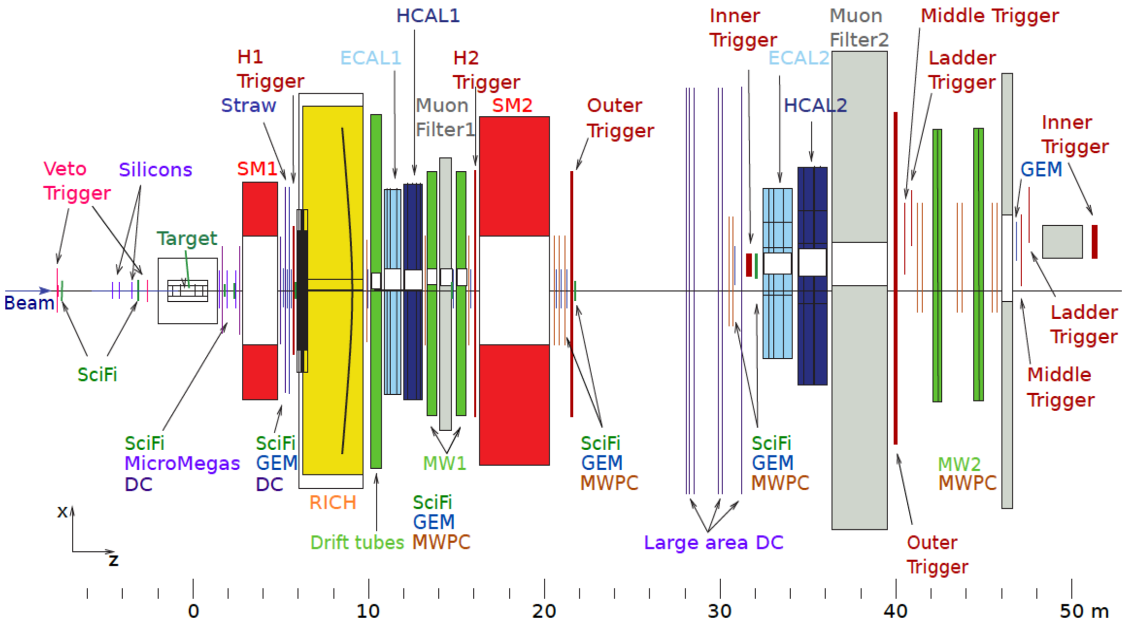
M2 beamline | H2 beamline | ECN 3 cavern: presently used by NA62

Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

AMBER / CERN

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisa-bility & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

- Successor of the COMPASS experiment at the M2 beam line
- Ambitious QCD programme spanned over the next 15+ years with both muon and hadron beams



arXiv:1808.00848

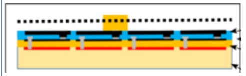
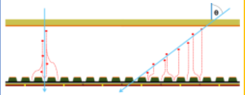
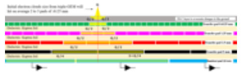
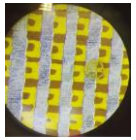
Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München; V. Andrieux, U of Illinois; O. Denisov, INFN Torino

AMBER / CERN

- Detector R&D for many components planned, some examples
  - 0.5 – 2 m diagonal-sized MPGD based trackers study (MWPCs substitution)
  - Large size silicon tracker inside of polarised target (cryogenic environment)
  - R&D on MPGD based photon detectors after the RICH-1 hybrid THGEM+MM upgrade (1.4 m^2 2016)
  - R&D on high space resolution gaseous photon detectors for compact RICH approach
  - Active targets

Tracking

Technologies candidates under investigation

High rate (center)		High resolution low channel count (periphery)		Low material budget anode
Resistive high granularity Micromegas	uRWELL	Capacitive charge sharing	"Zig-zag"	Al on polymer PCB
				
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TF1, TF3, TF7

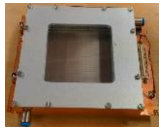
There are significant technological challenges in producing a large area mixed technologies detector

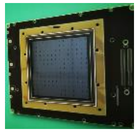
A combination of the ongoing technological R&Ds would most probably satisfy our requirements

0.5 – 2m diag size MPGD based trackers study (MWPCs substitution)

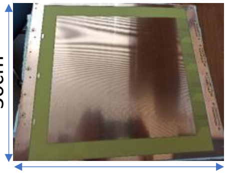
- For the running of the AMBER program, we evaluate the possibility to substitute of a part of MWPCs with MPGD based detectors

- The motivation is to substitute the structurally aged MWPC, to be able to optimize the acceptance coverage with a variable size detector. We would like to be able to cover both the high-rate central beam area and the external part of the aperture with a single detector taking advantage of the MPGDs anode flexibility





- The new detectors should be ready for the new trigger less DAQ and one of the possible R/O options could be the TIGER ASIC that was developed specifically to be used with MPGD detectors. Several other options like the VMM ASIC has to be investigated



30cm

30cm

- Presently small size prototypes are under test to validate the R/O and the production technics

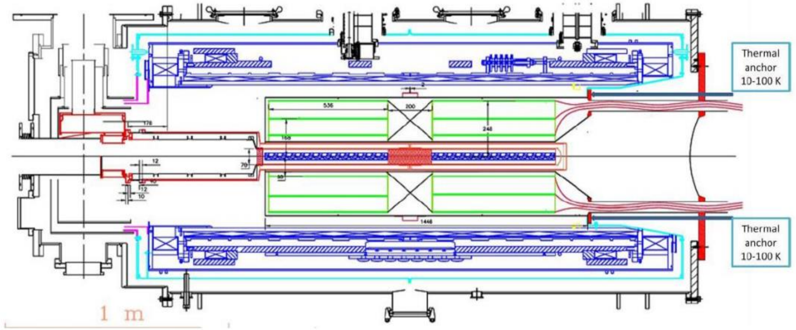
❑ **We would like to produce the first prototypes of a size ~55x55 cm^2 in 2022**

Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

AMBER / CERN

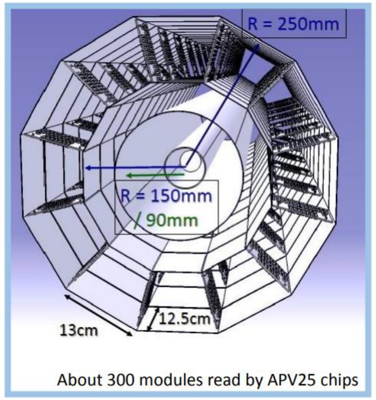
Large size tracker at cryogenic temperature

The target can be adapted to include a recoil proton detector
between the target surrounded by the modified MW cavity *and* the polarizing magnet



An important Issue: operation of SI and evacuation of the heat of the read out electronics

A second design: SI detectors in a separate block warmed at ~70K and "warm" chips fixed on the flange at the room temp (use of 1.25m long flat aluminium-polyimide multilayer flexible buses)



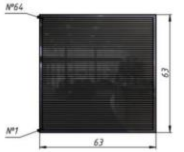
MW cavity r = 90mm
1st inner SI det r = 150 mm (thickness=300μm)
2nd outer SI det r = 250 mm (thickness=1000μm)
About 300 modules read by APV25 chips

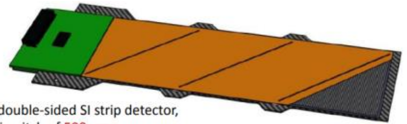
Si strip pitch size for optimum position resolution about 1.3cm (inner) and 2.2cm (outer) (for $\Delta\phi$=5°)
× 1 cm (for Δz=3mm)

resolution improved by about a factor 3 compared to the present CAMERA

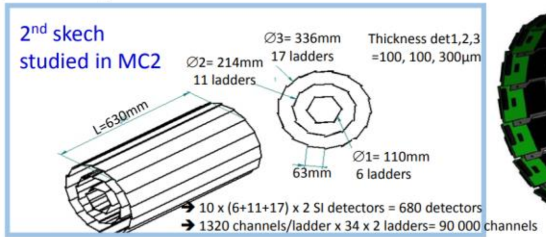
➔ less than 10 000 channels

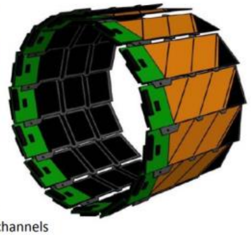
Thermal load
very first estimate ~ 10 Watts





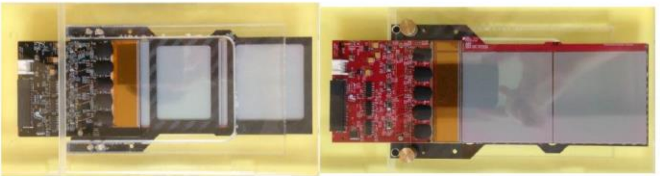
The ladder supporting the double-sided SI strip detector, 63x63 mm each, with a strip pitch of 500 μm





TF3, TF7

A technology developed at JINR for NICA



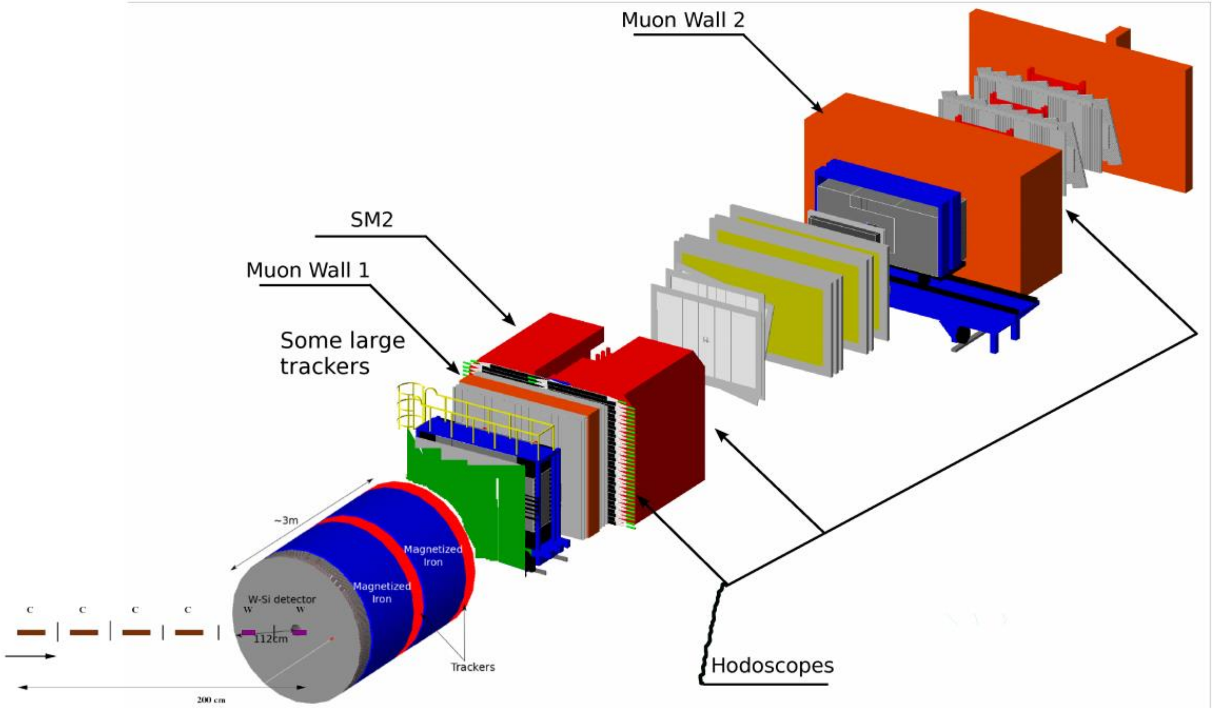
The Silicon detector unit developed for BM@N experiment at NICA. The unit contains electronics for 640 strips.
The front-end electronics is based on a charge sensitive preamplifier chip VATAGP7 (IDEAS)

Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

AMBER / CERN

Active Target

- The future DY data taking needs a new detector with large dilepton acceptance



Keep the spectrometer as compact as possible by having a muon detector that is also stopping hadronic products, immersed in a magnetic field

muon tracker with good (x,y) resolution < 200µm
• large acceptance: > 250 mrad
• momentum measurement
• capable of detecting also DY e+e− pairs
• compact, with large X/X0

- BabyMIND detector,
M. Antonova et al., arXiv:1704.08079
- W-Si detectors, as at BNL AnDY and PHENIX detectors

TF1, TF3, TF7

Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

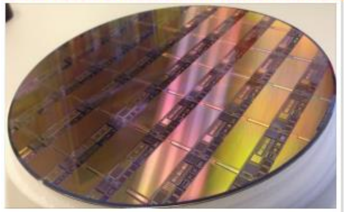
AMBER / CERN

Technologies candidates under investigation

Alice ITS3 MAPS sensor : Wafer-scale chip

Chip size is traditionally limited by CMOS manufacturing (“reticle size”)
- typical sizes of few cm2
- modules are tiled with chips connected to a flexible printed circuit board

200 mm ALPIDE prototype wafer



New option: stitching, i.e. aligned exposures of a reticle to produce larger circuits
- actively used in industry
- a 300 mm wafer can house a chip to equip a full half-layer

The next chip
baseline specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 µm	20-40 µm
Pixel size	27 x 29 µm	O(10 x 10 µm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 µs	~ 200 ns
Time resolution	~ 1 µs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake-hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

ALPIDE is a great starting point, samller technology node will open further possibilities!

Magnus Mager (CERN) | Sensor development for the ALICE ITS upgrade in LS3 | DAQFEET-2021 | 08.02.2021 | 22

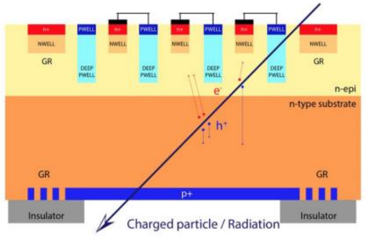
Key elements
- Few microns pixelated space resolution
- ns time resolution
- Triggerless RO compatible

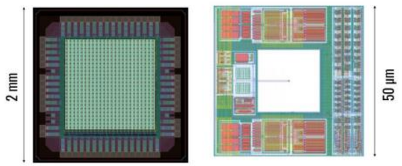
TF3, TF7

Magnus Mager DAQFEET-2021 (https://indico.cern.ch/event/974424/)

Small-scale demo: MATISSE

INFN





MATISSE   Pixel CAD Layout

PIXEL ELECTRONICS	DESIGN	RESULTS
Technology	CMOS 110 nm	
Voltage Supply	1.2 V	
Measurements	Hit Position, Energy Loss	
Number of Channels	24 × 24	
Input Dynamic Range	Up to 24 ke$^-$	
Sensor Capacitance	~20 fF	
Analog Gain	131 mV/fC	116 mV/fC
CSA Input Common Mode	> 600 mV	
Local Memories	2 (~70 fF each)	
Noise	< 100 e$^-$	~40 e$^-$
Shutter Type	Snapshot	
Readout Type	Correlated Double Double Sampling	
Readout Speed	Up to 5 MHz	
Other Features	Internat test pulse, Mask Mode, Baseline Regulation	

- Pixel size 25 µm x 25 µm: process, back-side pattern and geometry validated in silicon (both MATISSE and pseudo-matrices, electrical, laser, radioactive source and microbeam).
- Matrix core 512 x 512, “side-abuttable” to accomodate a 1024 x 512 silicon active area (2.56 x 1.28 cm^2). Matrix and EoC architecture, data links and payload ID: scalable to 2048 x 2048*
- Triggerless binary data readout, event rate up to 10-100 MHz/cm^2

Da Rolo DAQFEET-2021 https://indico.cern.ch/event/974424/

Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

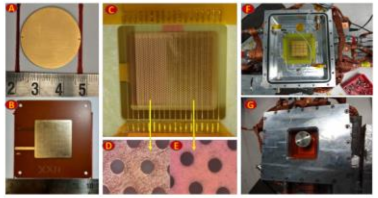
AMBER / CERN

PID

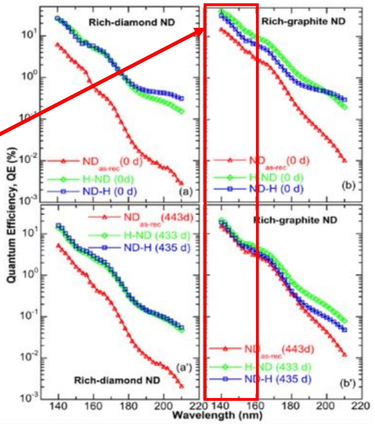
R&D on MPGD based photon detectors after the RICH-1 hybrid THGEM+MM upgrade (1.4 m² 2016)

New photoconverting material approach using Hydrogenated Diamond nano grains
Velardi et al., Diamond and Related Materials 76(2017)1 ;

Robust and efficient photoconverter never used for photon detectors of large size (~ m²)



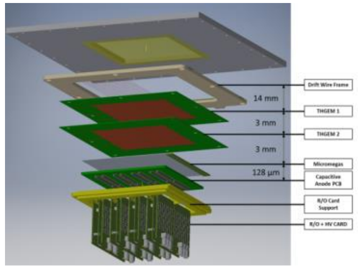
Being tested with THGEM based detector as replacement of CsI for RICH windowless approach (VUV)

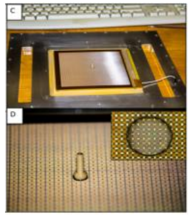


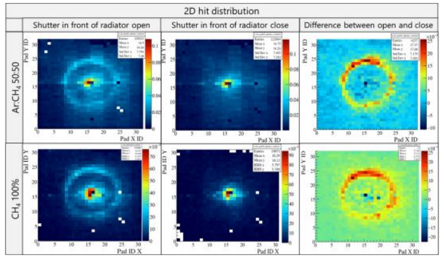
RD51 Workshop on Gaseous Detector Contributions to PID 16-17 February 2021 https://indico.cern.ch/event/996326/
-MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond
Chandradoy Chatterjee
-Nanodiamond photocathode for MPGD-based single photon detectors at the future EIC
Daniele D'Ago

R&D on high space resolution gaseous photon detectors for compact RICH approach

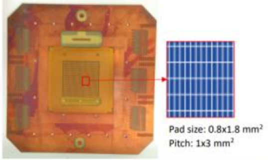
Prototype of modular scalable mini pad hybrid PD, INFN Trieste approach

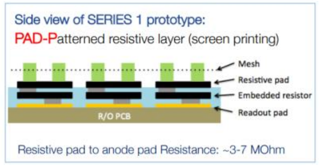




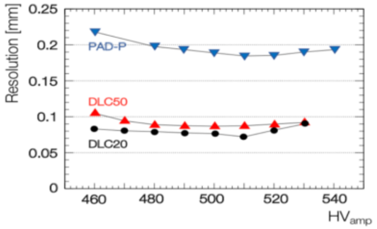


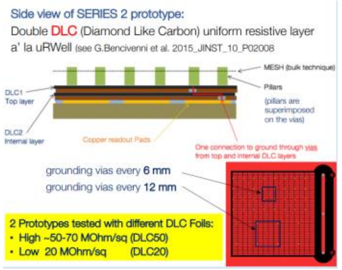
Prototypes of modular scalable mini pad resistive MM
INFN Roma Tre approach





Space resolution ~200 µm per PAD-P, down to **80 µm for DLC option**

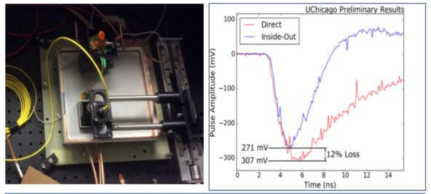




Vacuum approach for single photon detection

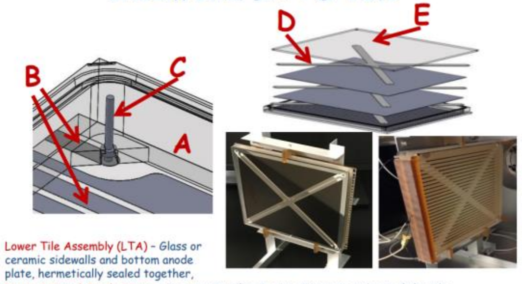
Motivation

- Large Area: 200 x 200 mm²
- Flat Geometry
- PMT Sensitivity: QE >20% w/bi-alkali photocathode
- Picosecond Timing: resolution <60 pS, <100pS for SPE
- Sub-mm spatial resolution
- Lower Cost per Unit Area



A thin metal layer anode serves as a DC ground inside of the detector. 88% of an MCP fast signal pulse was capacitively coupled through the ceramic, to strips or pads on the outside.

Incom Inc. LAPPD V2.0

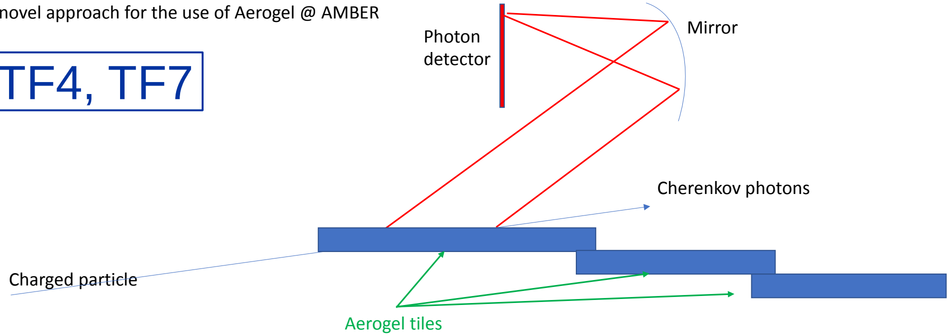


A. Lower Tile Assembly (LTA) - Glass or ceramic sidewalls and bottom anode plate, hermetically sealed together,
B. Power & Signal Anode Strips - "penetration free" connection into and out of the tile.
C. Internal Power Pins - deliver voltage to the top and bottom of each MCP
D. X-Spacers - restrain window deflection under pressure, control critical spacing, support getters,
E. Borosilicate or Fused Silica Window - Hermetically sealed to sidewalls

B.W. Adams,et al, "An internal ALD-based high voltage divider and signal circuit for MCP-based photodetectors", Nuclear Instruments and Methods in Physics Research A 780 (2015) 107–113

TF1, TF3, TF4, TF7

A novel approach for the use of Aerogel @ AMBER



The idea is to use the aerogel maximizing the amount of Aerogel crossed by the charged particle and minimizing the amount of Aerogel crossed by the Cherenkov photon → large number of emitted photons from the Aerogel tile
Extremely good control on refractive index and Aerogel uniformity response → R&D needed!

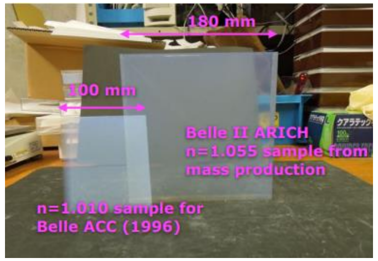
Contact: S. Levorato, INFN Trieste; J. Friedrich, TU München;
V. Andrieux, U of Illinois; O. Denisov, INFN Torino

AMBER / CERN

Technologies candidates under investigation

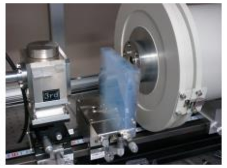
The Intermediate momenta (3 to 20 GeV/c) range particle identification requires high quality new Aerogel Materials

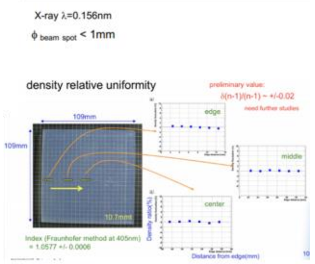
The size issue



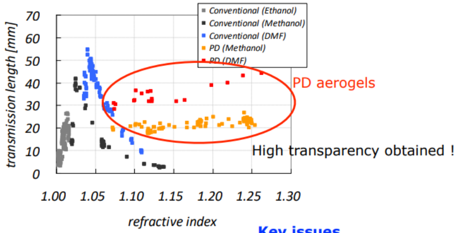
M.Tabata et al., The Journal of Supercritical Fluids, Vol.110, April 2016, Pages 183-192

The uniformity control





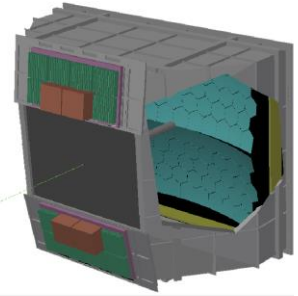
The transparency issue

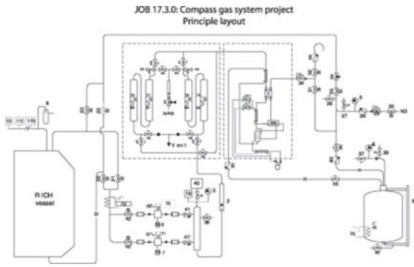


Key issues

Tile size and uniformity
Duration of production

Technologies candidates under investigation





Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Perfluorinated compounds				
Sulfur hexafluoride	SF_6	23,900	22,800	23,500
Nitrogen trifluoride	NF_3		17,200	16,100
PFC-14	CF_4	6,500	7,390	6,630
PFC-116	C_2F_6	9,200	12,200	11,100
PFC-218	C_3F_8	7,000	8,830	8,900
PFC-318	$c\text{-}C_4F_8$	8,700	10,300	9,540
PFC-31-10	C_4F_{10}	7,000	8,860	9,200
PFC-41-12	C_5F_{12}	7,500	9,160	8,550
PFC-51-14	C_6F_{14}	7,400	9,300	7,910
PCF-91-18	$C_{10}F_{18}$		>7,500	7,190
Trifluoromethyl sulfur pentafluoride	SF_5CF_3		17,700	17,400
Perfluorocyclopropane	$c\text{-}C_3F_6$			9,200

~ 90 m^3 C4F10 gaseous radiator,
Gas recovery at the end of operation (once per year) in closed loop mode
Unavoidable losses (3%) determined by the achievable P (7 bar) and T (-32 C) of the liquefier system. Vapor pressure at -32 C is 0.2 bar

→ Improving the Gas recovery system efficiency or use new technology approach: molecular membranes
→ Search for Green gas alternatives

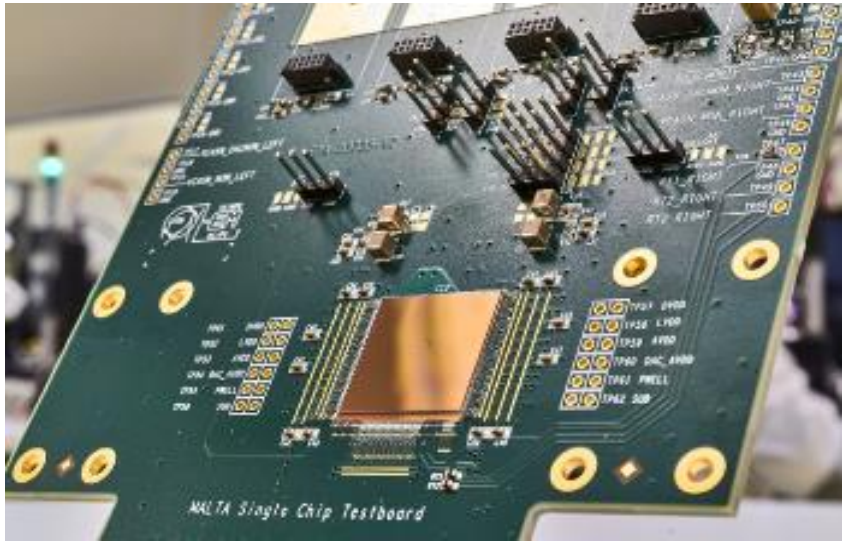
TF1, TF4, TF7

MuonE / CERN

Silicon sensors for MUonE

Requirements:

- Good spatial resolution (< 5 ∝m)
- High efficiency (ε ≥ 99.9%)
- High uniformity (< 10^{-5}) over an area of 10x10 cm^2
- Capable to sustain high rate (~70 MHz)
- Low material budget (< 0.001 X_0)



Promising technology : DMAPS
(Depleted Monolithic Pixel Sensors)

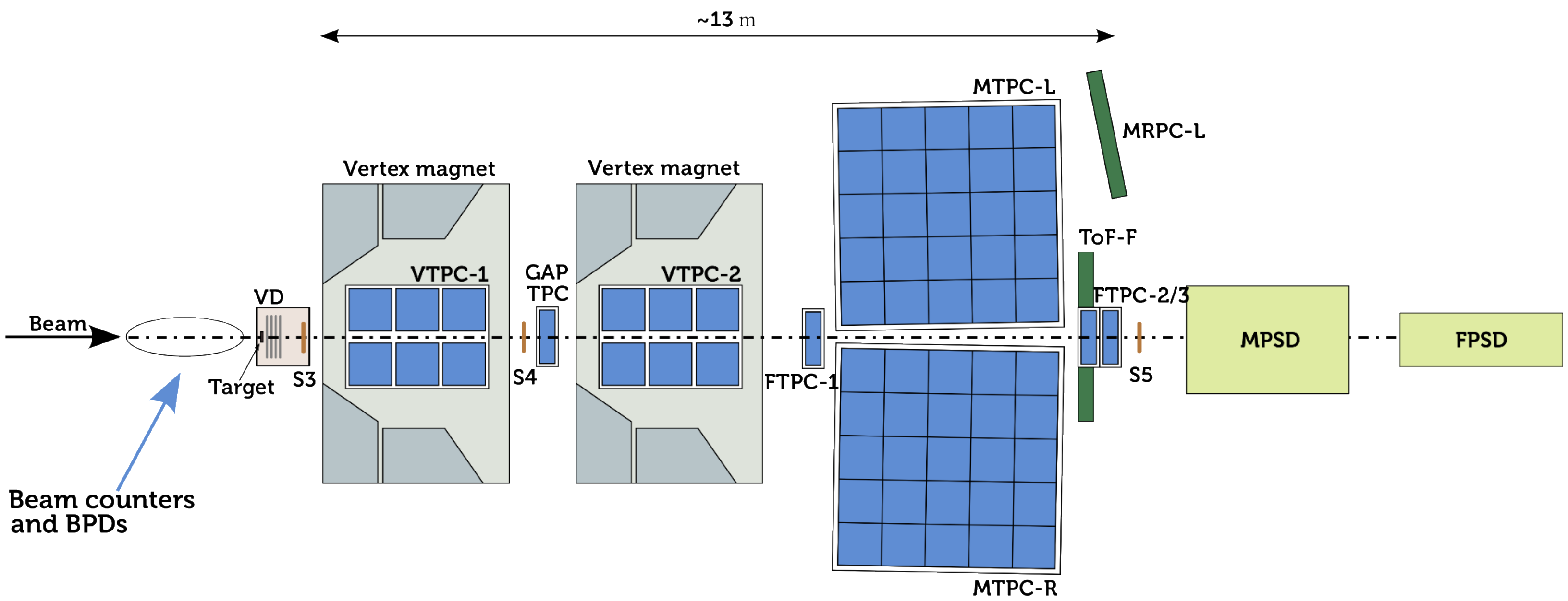
TF3, TF7

(for more details https://cds.cern.ch/record/2677471/files/SPSC-I-252.pdf)

NA61 / CERN

Overview of the upgraded NA61/SHINE detector

Fixed target experiment located at the CERN SPS accelerator



Beams:

- ions (Be, Ar, Xe, Pb)

  p_{beam}=13*A*–150*A* GeV/*c*
- hadrons (π, K, p)

  p_{beam}=13–400 GeV/*c*
- $\sqrt{s_{NN}}$= 5.1–16.8 (27.4) GeV

Large acceptance hadron spectrometer –
coverage of the full forward hemisphere, down to $p_T = 0$

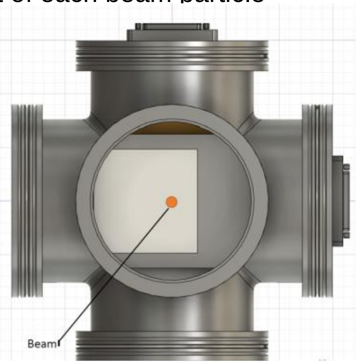
NA61 / CERN

Beam position detectors

NA61/SHINE, as a fixed target experiment, has to monitor the beam's interaction point with the target. This required direct position measurement of each beam particle.

- Detector/detectors should work with beams from p to Pb beams.
- The detector should determine the position of the X and Y hit of each beam particle (probability of pileup should be minimized).
- The accuracy of the position measurement is expected to be better than 250 micrometers.
- The detector should be installed in a vacuum.
- Material on the beamline should be minimized.
- Large active area for low energy beams.

Need for beam detectors with a time resolution better than 40 *ps* for particle mass measurements at low beam momenta

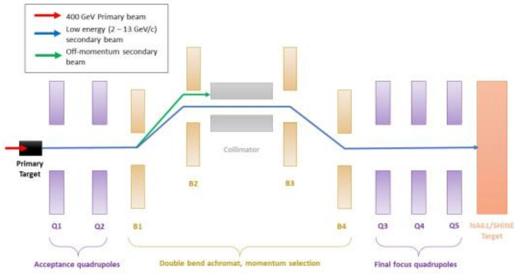


TF3, TF4, TF7

Very Low Energy Beamline

All of the interested physics communities (accelerator-based neutrino, atmospheric neutrino, and spallation source experiments) have strongly requested studying and building a Very Low Energy (VLE) beamline.

- Taking into account the community's request, NA61/SHINE with the strong support of EN-EA experts, will therefore aim to construct the VLE beamline



Future calorimeter

TF4, TF6, TF7

- Recently used calorimeters have to have a hole for ion beams due to limited radiation hardness.
- Hole in the calorimeter acceptance limits acceptance of projectiles and complicated determination of the centrality of the collision.
- Development of radiation hard (Pb beam at 158*A* GeV/c with intensity up to 100 kHz) compensating calorimeters.

Low Energy Ion Beam

Improvement in the ion beams' quality at low momenta (below 40AGeV/c)

- An improvement of the ion emittance from the machine would be necessary, but this seems to require studies from the machine side to understand the possibilities that can be made available for that.
- Beam quality could be improved by the **implementation of Gabor-Lenses** (GL) into the existing beamline. Therefore, experiments are planned to test to what extent the luminosity can be improved using this type of lens. Gabor-Lenses use a static confined electron column for the focusing and manipulation of positively charged particle beams.

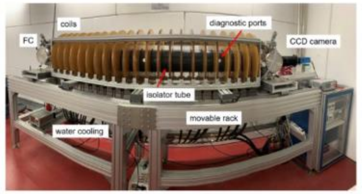


Figure 27: Gabor-lens prototype GL2000 on its test bench at Goethe-University Frankfurt. It is equipped with several diagnostic tools to characterize the properties of the confined electron column.

Contacts: E. Scomparin, INFN Torino; G. Usai, U Cagliari

NA60+ / CERN

NA60+

- Measurement of dileptons and heavy quark production in nuclear collisions at the CERN SPS, with a beam energy scan
- Expression of Interest submitted to SPSC in May 2019 https://cds.cern.ch/record/2673280
- Based on a muon spectrometer, coupled to a vertex telescope
- Matching of muon tracks upstream and downstream of a thick hadron absorber
- Flagship measurements

- Thermal dimuons from Quark-Gluon Plasma

→ caloric curve for first order transition

- ρ-a_1 modifications

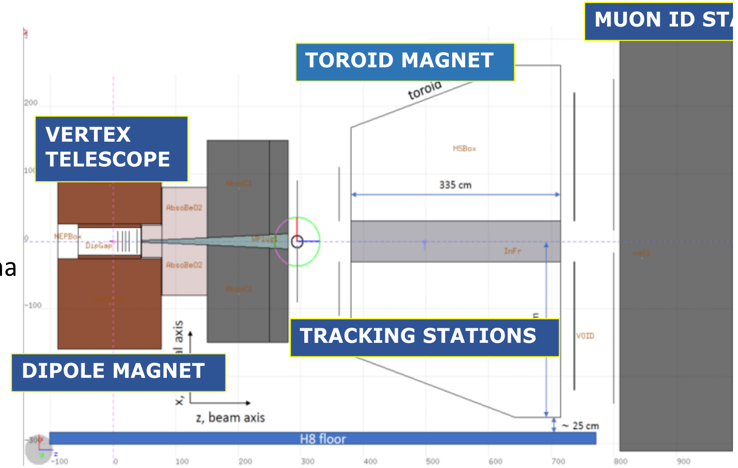
→ chiral symmetry restoration

- Quarkonium suppression:

→ signal of deconfinement

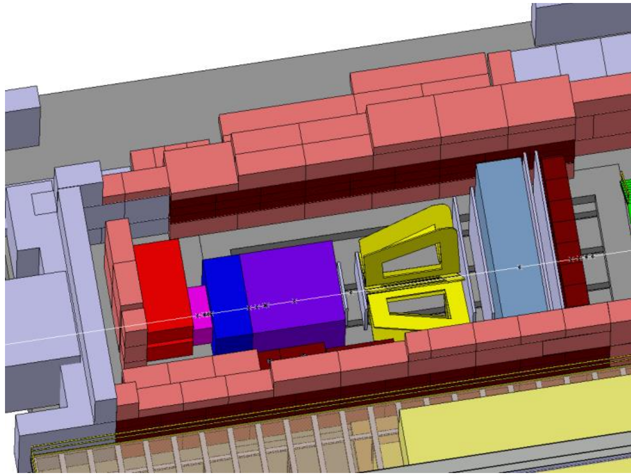
- Hadronic decays of charmed mesons/baryons:

→ QGP transport coefficients



NA60+

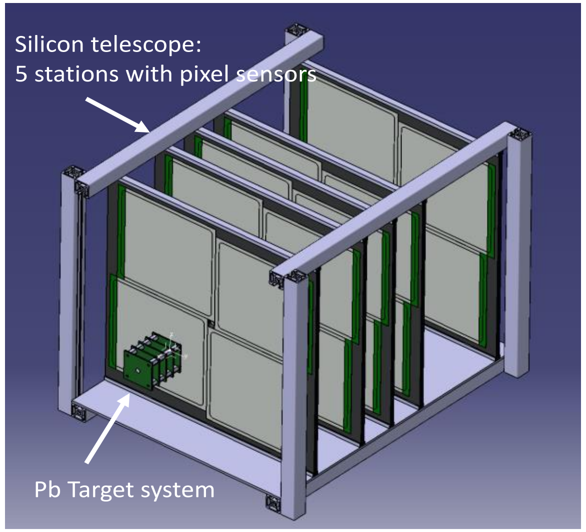
- Measurement of rare processes requires high beam intensity
  → Aim is ~ 10^7 Pb ions/ 20 s spill , which can be obtained in the H8 beam line at CERN SPS
- High charged particle multiplicity in Pb-Pb collisions (up to $dN_{ch}/d\eta = 450$) requires
  → High granularity, fast and radiation hard detectors in the vertex region
- High resolution needed for the muon measurement requires
  → Good resolution (~200 µm) for muon detectors (~140 m^2 total surface)
- Current choice (see next slides)
  - Stitched MAPS for vertex spectrometer
  - GEM detectors for muon spectrometer
- Next steps
  → Submit Letter of Intent by 2021
  → Build experiment and start data taking after LHC LS3 (2027)



Contacts: E. Scomparin, INFN Torino; G. Usai, U Cagliari

NA60+ / CERN

The NA60+ Silicon vertex telescope

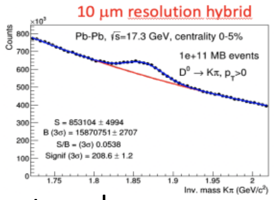


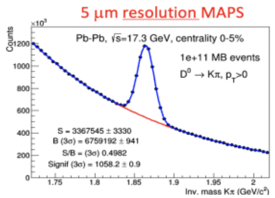
Use of state-of-the-art Monolithic Active Pixel Sensors

Motivation:

- Sensor thickness: few tens of microns of silicon
- New large area sensors (based on stitching):
  - No support under sensitive area → material budget <0.1% X_0
  - Stations with just few sensors → simpler mechanics
- Spatial resolution 5 µm or even better

TF3, TF7

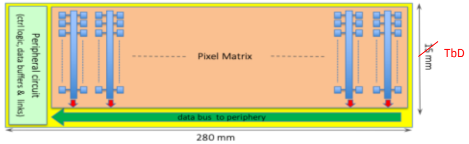


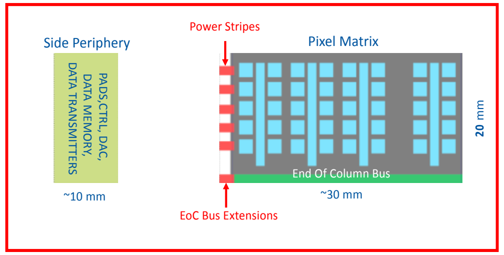


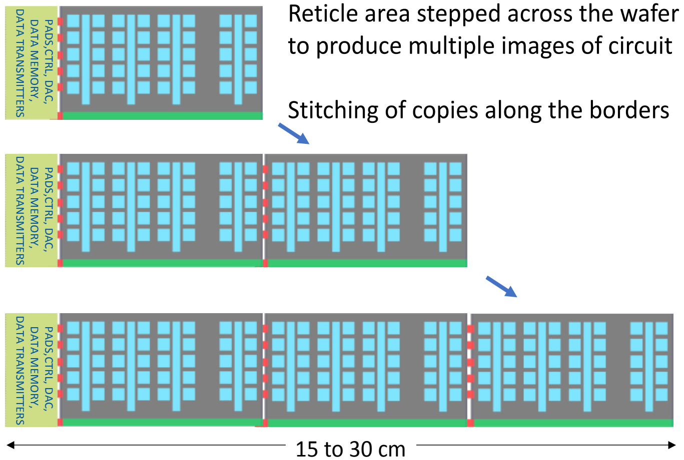
Stitching: new key idea for wafer-scale MAPS

Challenging R&D started, in synergy with ALICE experiment and with an aggressive schedule for the next 3 yrs

New promising state-of-the-art imaging technology TowerJazz 65 nm







Reticle area stepped across the wafer to produce multiple images of circuit

Stitching of copies along the borders

Sensor of arbitrary size, just limited by wafer borders

NA60+ GEM-based muon tracker

Motivation for GEMs:

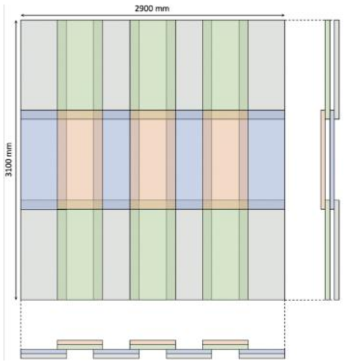
- Position resolution 100-200 µm
- Good timing resolution (<10 ns)
- Rate capability (in NA60+ max 10 kHz/cm²)
- Excellent radiation hardness
- Large area tracker 140 m²
  ->Use components that can be mass produced by industry

Current foreseen geometry for GEM modules:

- ≈50x110 cm² rectangle (CMS, ALICE)
- ≈ 330 modules
- Baseline: one tracking layer per station

New emerging technologies for large scale trackers might also be considered → started contacts with RD51

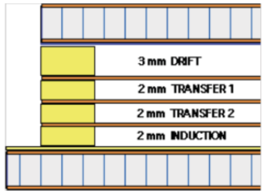
Tracking station with GEM rectangular modules



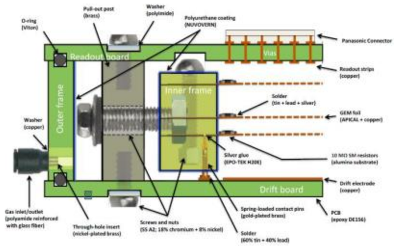
- Staggering: ≈ 10 cm overlap in each direction
- Up to ≈20 cm between the layers

Proposed NA60+ GEM module

Triple GEM chambers



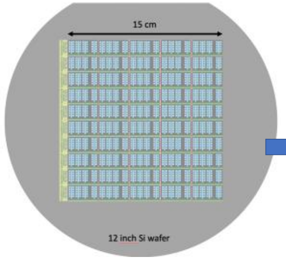
NS2 assembly technique



- Ar-CO_2 o Ar-CO_2-CF_4 mixtures
- 2D strip readout
  - 200 µm to 1 mm resolution
    → 0.8 mm to 3.5 mm pitch
  - Optional: pads in the innermost region, zig-zag strips, etc.
- VFAT3 or VMM3 readout

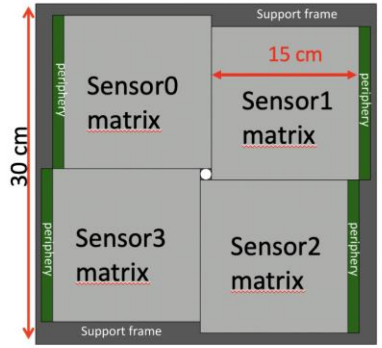
TF1, TF7

Possible wafer-scale sensor for NA60+



Wafer-scale sensor

Pixel station with 4 wafer-scale sensors



Few Remarks on Software / Simulation

- Most experiments are interested in the continuous development of software packages such as Geant4 and Fluka.
- Due to the demands on ultimate precision, implementation of higher order effects are required more and more, e.g. describing the tails of multiple scattering for MuonE.
- Benchmarking with data, in particular at lower energies (GeV range), is also often mentioned as being important by the experiments.

Few Remarks on Test Beam Facilities

- From the Physics Briefing Book: “In the past few years, the **demand for access** to the largest test-beam facilities such as those at CERN, DESY, Fermilab and SLAC **has remained high**. The CERN test-beam facilities, for example, are at present used at full capacity. It is expected that the **development of instrumentation for approved and future projects will maintain, even possibly increase, the need of the community to have access to these types of facilities**. Yet, the future medium- to long-term availability of some of the test-beam facilities currently used by the community is at present uncertain. Furthermore, parts of these facilities, for example at CERN, are also ageing and **will require adequate maintenance and/or upgrade** in the coming years to continue to support the community.”
- Demand is being addressed currently, for instance by the East Area Renovation Project and the upcoming North Area Consolidation at CERN.
- It is important to also get an **input from the community on the requirements for test beam facilities**, which should be ideally included in the detector R&D roadmap.

Summary

- Fixed target experiments with focus on strong interaction physics all over Europe have compelling programmes for data taking in the next decades that will require substantial detector R&D on basically all technologies.
- The demands are very wide spread on detector requirements[1]:
  - Very precise timing
  - High radiation levels
  - Ultimate precision
  - Very large surfaces or volumes
  - High demands on particle ID
- Today, by far not all experiments and topics could be covered, for instance LHC fixed target experiments as well as the ones situated at accelerators in universities, e.g. Bonn and Mainz.
- There is also some ongoing effort on the European level on collaboration of QCD-related experiments, which also includes detector R&D besides transnational access (e.g. STRONG2020). It might be worth to explore synergies and gather input from these, as well.

[1] see e.g. L. Linssen's and G. Schnell's talks at the Granada ESPPU symposium

Thank you very much for your attention!

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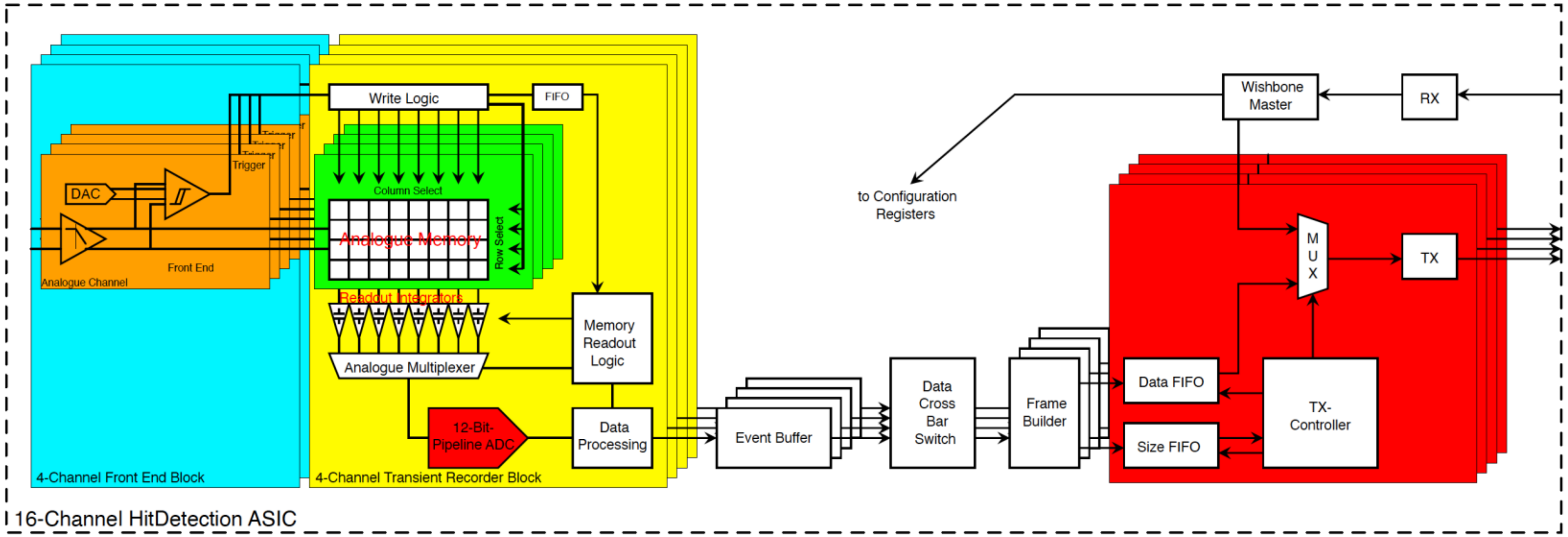
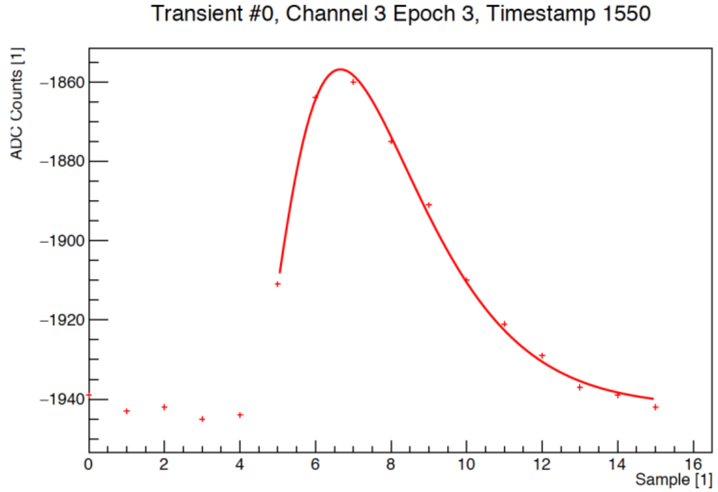
BACKUP SLIDES

Contacts: L. Schmitt & H. Flemming, GSI Darmstadt;
T. Stockmanns, FZ Jülich; M. Moritz, JLU Gießen;

PANDA / FAIR

Analogue Transient Recorder





- Recorded transient with fit
- High time and amplitude precision by trace analysis

- Analogue Transient Recorder:
  (power) efficient use of ADC resources
- Large dynamic range for spectroscopic use
- Free-streaming as well as triggered operation
- First application: PANDA EMC readout

TF7

Contacts: L. Schmitt & H. Flemming, GSI Darmstadt;
T. Stockmanns, FZ Jülich; M. Moritz, JLU Gießen;

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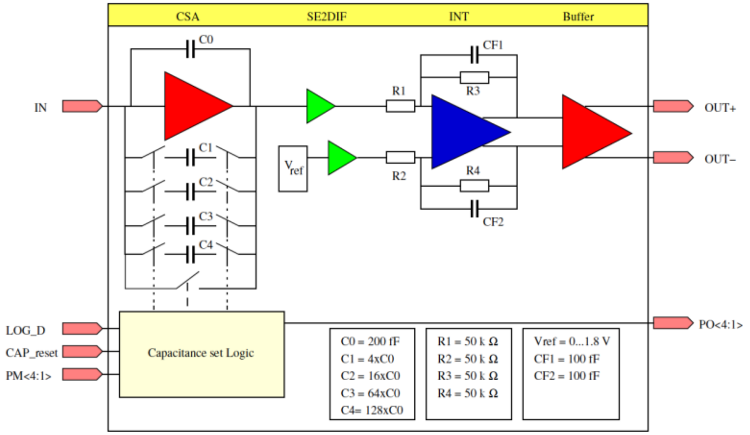
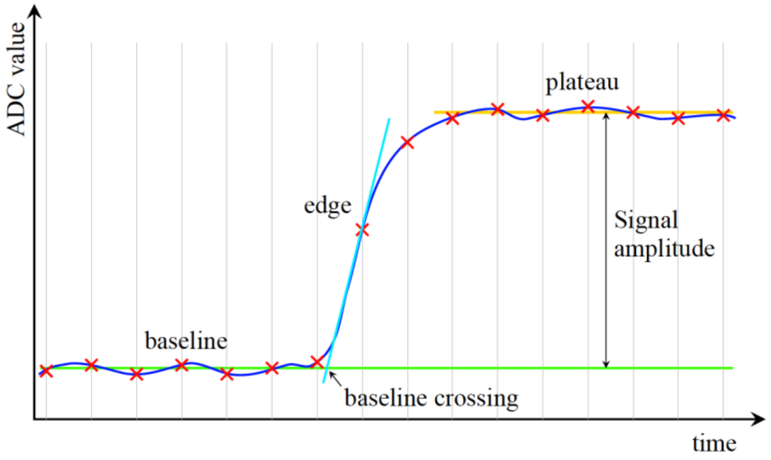
Transient Recorder Applications





- Charge sensitive amplifier with adaptive feedback
- Large dynamic range ≥10^5
- Control logic integrated in DAQ for analogue transient recorder

TF7

- Frontend fits to many different detectors
  - MWPC
  - Drift chambers
  - GEM detectors
  - Semiconductor detectors
- First applications:
  - PANDA GEM Tracker, SFRS GEM-TPC

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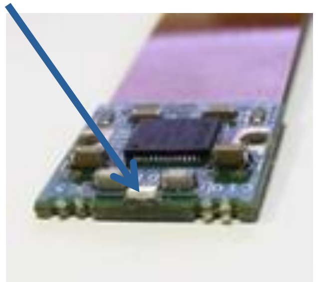
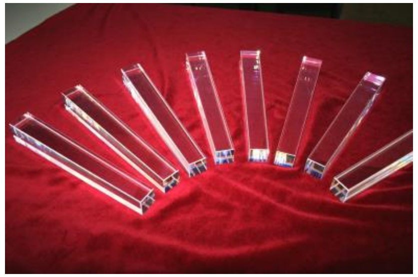
PWO Annealing with Light

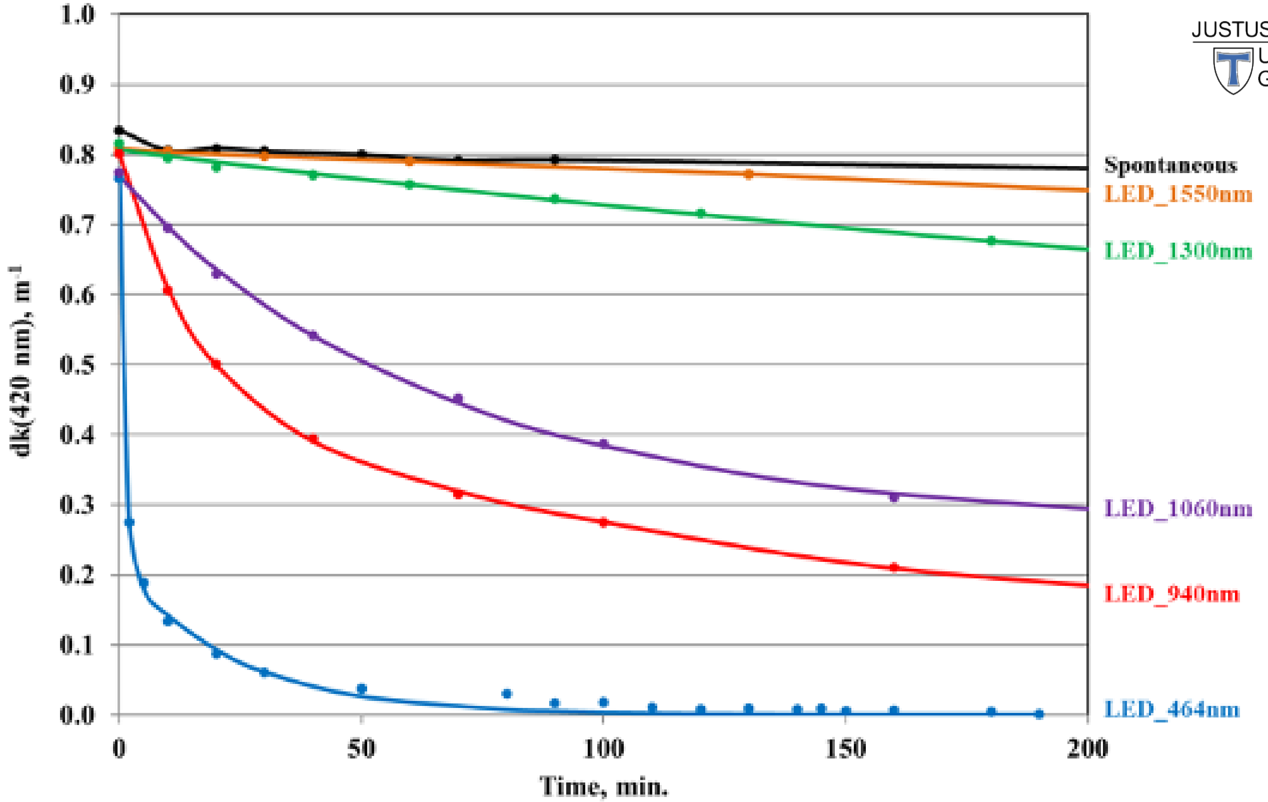


annealing led



PWO crystals

TF6



- Stimulated recovery of PWO radiation damage
- Annealing with LED light, with blue faster than with red

More input from CBM

This mail is sent in response to your request for input concerning detector activities for fixed target experiments in the field of strong interaction physics but also to show up the synergies of the related detector research with the field of e+/e- colliders including Higgs factories.

Our research focuses on the development of highly granular and ultra-light and low-power CMOS Monolithic Active Pixel Sensors. As a mid-term goal, it aims for fulfilling the needs of the Micro Vertex Detector of the Compressed Baryonic Matter (CBM) Experiment at FAIR [1] but lays simultaneously the foundations for detector technologies, which respond to the requirements of vertex detectors of e+/e- experiments [2] and future upgrades of FAIR experiments. It is worth mentioning that this activity contributed also to the installation of the NA61/SHINE Small Acceptance Vertex Detector [3].

CBM is a future, high rate heavy ion experiment, which will study the phase diagram of hadronic matter in the regime of highest baryonic densities. The fix-target experiment must reconstruct tracks in a high track-density environment and enable the reconstruction of numerous rare probes, including multi-strange particles and possibly open charm particles, from up to 11 AGeV Au+Au and 28 GeV p+A collisions. Doing this at a collision rate of 100 kHz Au+Au or 10 MHz p+A calls for a precise vertex detector, which should feature a high granularity, a spatial precision of ~5µm, a time resolution of <5µs at a peak rate capability of 70 MHz/cm². Despite being operated in vacuum, the total material budget of the detector stations should not exceed 0.3% X0. Therefore, the power budget of the sensors at maximum load should remain well below 100 mW/cm².

To cope with those requirements, the PICSEL group of IPHC Strasbourg [4], the Goethe University Frankfurt am Main and GSI are developing the so-called MIMOSIS CMOS sensor [5]. This sensor is derived from the ALPIDE sensor known from the ALICE ITS2 upgrade. It is being enhanced aiming for substantially increased bandwidth and radiation tolerance while essentially keeping the low power budget and the high granularity of this chip. It is our understanding that this improved technology platform approaches (of even fulfills) the requirements of future Higgs factories in terms of low material budget, high granularity and O(µs) time resolution as required for b/c/tau tagging, low pT jet momentum, vertex and jet charge determination. Some of the partners, namely IPHC Strasbourg, are committed to this application.

In a longer prospective, the CBM collaboration considers to upgrade the Silicon Tracking System of the experiment. The first version of this tracking detector relies on 8 layers of fine pitch, double sided silicon strip detectors. Its physics performance could be improved by replacing the strips by CMOS sensors, aiming for reduced material budget and an increased granularity of the stations. The precise requirements for this upgrades remain to be determined. It appears evident that it should target the lightest reasonably possible material budget (i.e. few 0.1% X0 per station), targeting <O(100 ns) time precision and a rate capability of >O(100 MHz/cm²) for the most exposed sensors. The power dissipation should remain once more below 100mW/cm² to allow for a light cooling system. Moreover, a tolerance to a radiation load of several 1e14 neq/cm² and beam ion impacts will be required. At present, additional applications of CMOS Sensors are being identified within GSI/FAIR.

Our research is carried out in active collaboration with CERN R&D programs including the ALICE ITS3 Upgrade program (WP3) and the EP division R&D initiative (WP1.2) aiming for building next generation wafer size CMOS sensors based on 65nm imaging CMOS processes and stitching. Moreover, it is embedded into a strong CMOS-sensor R&D network including IRL, AIDAinnova and the EU - CREMLIN+ program, which aims to make the technology available for big research installations of nuclear and hadron physics within the EU, Eastern Europe and Russia.

[1] M. Koziel, NIM-A Vol 845 (2017) P 110-113, https://doi.org/10.1016/j.nima.2016.05.093

[2] M. Winter et al., PoS (Vertex2019) 045

[3] M. Deveaux for NA61/SHINE, EPJ Web of Conferences 171, 21001 (2018), https://doi.org/10.1051/epjconf/201817121001

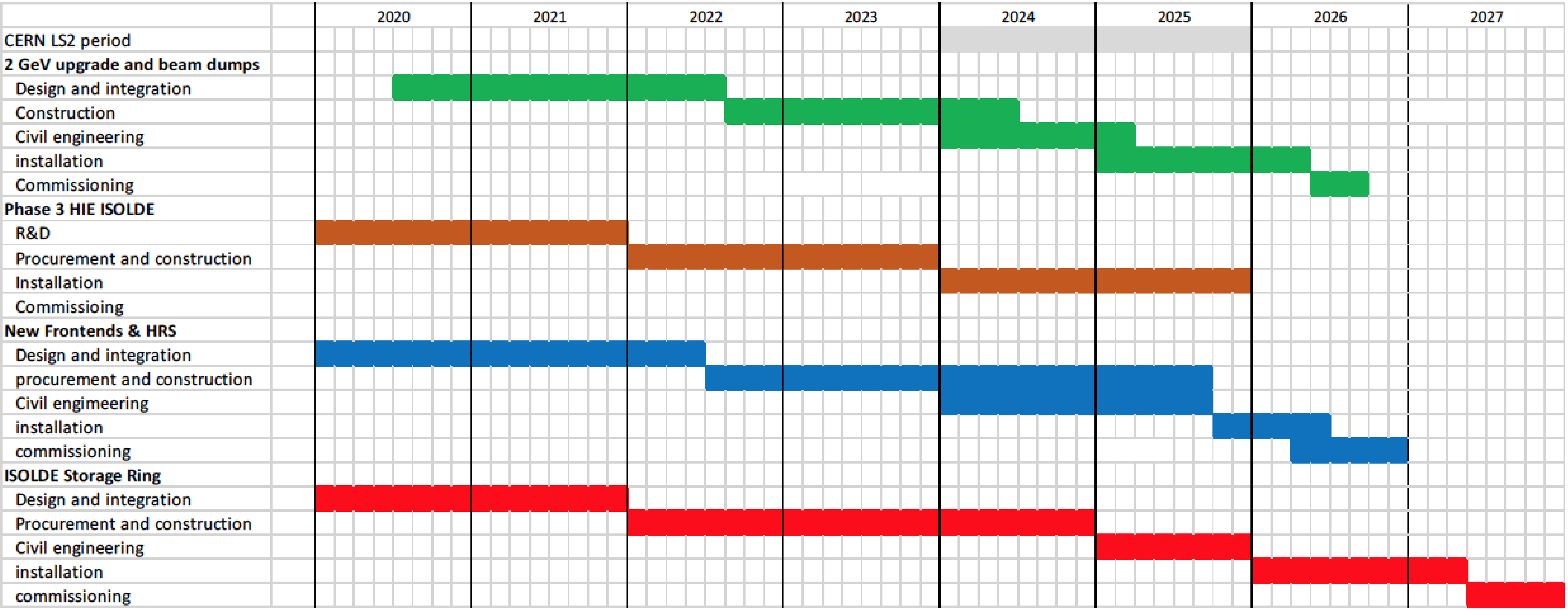
[4] http://www.iphc.cnrs.fr/-PICSEL-.html

[5] M. Deveaux et al., NIM-A Volume 958, 2020, 162653, https://doi.org/10.1016/j.nima.2019.162653

TF3, TF7

Contact: G. Neyens, CERN

EPIC Timeline



From ESPPU contribution no. 39, EPIC addendum