The Compressed Baryonic Matter (CBM) Experiment at FAIR

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Quark Matter 2018, Lido di Venezia

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Overview

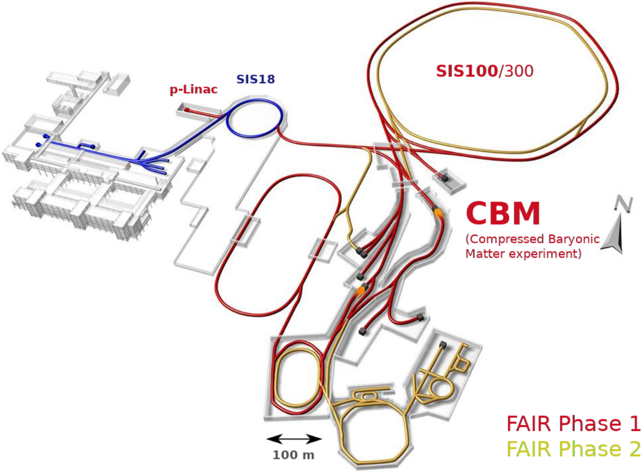
- **The Compressed Baryonic Matter Experiment**
- **CBM Subdetectors**
  STS, MVD, MuCh, RICH, TRD, TOF, ECAL, PSD
- **Free-Streaming Readout and Computing**
- **FAIR Phase 0: System Performance Tests at Beam Facilities**

The CBM Experiment at FAIR

- FAIR Phase 1 / SIS100 currently in construction
- **Compressed Baryonic Matter** (CBM) is one of the pillars of FAIR

SIS100 beam energies:

beam	Z	A	E (AGeV)
p	1	1	29
d	1	2	14
Ca	20	40	14
Ni	28	58	13.6
In	49	115	11.9
Au	79	197	11
U	92	238	10.7



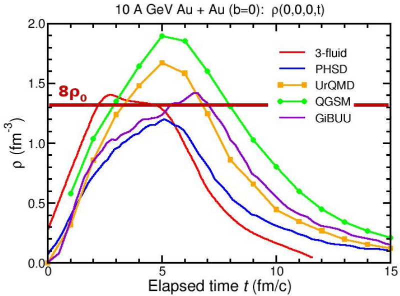
Collision energies: $\sqrt{s_{NN}} = 2.5...5$ GeV

FAIR Construction Status

FAIR construction site, excavation of the SIS100 tunnel, April 2018.

Detector installation and commissioning: 2021–2024, commissioning with beam: 2024, beam operation: 2025.

CBM Baryon Densities



Phys. Review C ***75*** *(2007) 034902*

Exploration of the QCD phase diagram at high baryonic densities:

- Fixed-target experiment
- Investigation of the properties of dense QCD matter
- Transport calculations at SIS100 energies: $\epsilon \leqslant 2.5$ GeV fm^{-3} and $5 \ldots 8\rho_0$, expecting to reach neutron-star densities
- Long time ($\geqslant 5$ fm/c) in dense QCD regime

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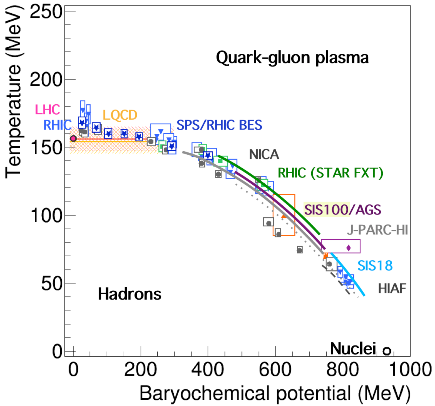

Plot: T. Galatyuk

Becattini et al., Phys. Lett. B ***764*** *(2017) 241*
STAR, Phys. Review C ***96*** *(2017) 044904*
Andronic et al., arXiv:1710.09425 and refs. therein

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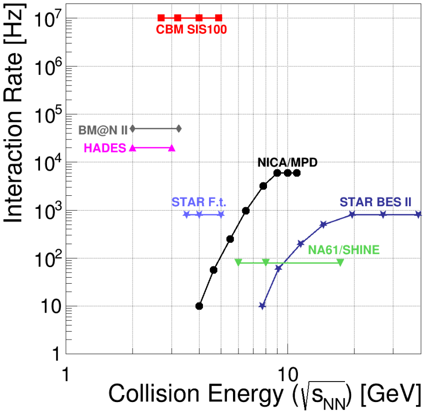
High Rates with the CBM Experiment

Heavy-ion interaction rates (heavy systems) up to 10 MHz. Access to rare observables, probing the medium in an unprecedented level of precision:

- Low-mass vector mesons by di-lepton pair reconstruction
- Excitation functions of multi-strange hyperons near expected phase boundary
  (e.g. $\overline{\Omega}^{+}$/week: $\sim 10^5$ @ $\sqrt{s_{NN}} = 3.5$ GeV)
- Access to collective flow of multi-strange hyperons
- Single and double hyper-nuclei programme, including discovery potential
- Critical point search using event-by-event fluctuations of conserved quantities



Challenges in QCD matter physics – The scientific programme of the Compressed Baryonic Matter experiment at FAIR, Eur. Phys. J. A **53** (2017) 60 and arXiv:1607.01487

Poster: E. Bechtel, ELW-03

CBM Subdetectors

STS
Silicon Tracking System*

MVD
Micro Vertex Detector*

* magnetic field

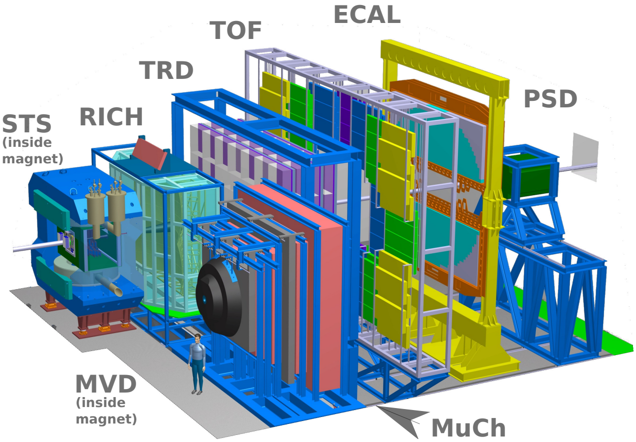
MuCh or RICH
MuonChamber System/
Ring Imaging Cherenkov Detector

TRD
Transition Radiation Detector

ToF
Time-of-Flight Detector

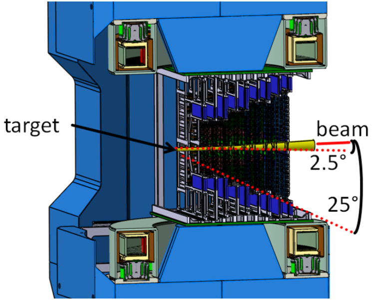
ECAL
Electromagnetic Calorimeter

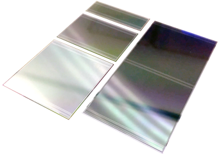
PSD
Projectile Spectator Detector

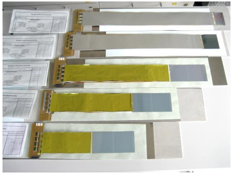


Electron setup: RICH in line, muon setup: MuCh in line.

CBM Silicon Tracking System







- Final sensors and module assembly developed
- Detector construction: 2019 to 2022
- Installation into CBM: 2023

Detector testing at COSY, February 2018:

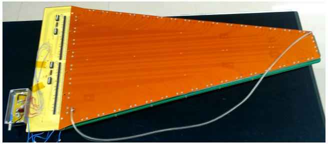
- Signal to noise 15 ± 3
- Hit efficiency $>$ 95 % in 1.7 GeV proton beam

- Charged particle tracking, momentum measurement in 1 Tm dipole field
- Double-sided silicon strip sensors, 8 stations, total 4 m^2
- Position resolution about 25 microns, time resolution about 5 ns

Poster: J. Heuser, INS-14

CBM Muon Chambers

- 4 stations and 4 + 1 absorbers
- GEM detector technology (3 mm Ar/CO_2)
- Graphite absorber (magnet), followed by Fe
- Geometrical acceptance: 5.7 – 25 degree



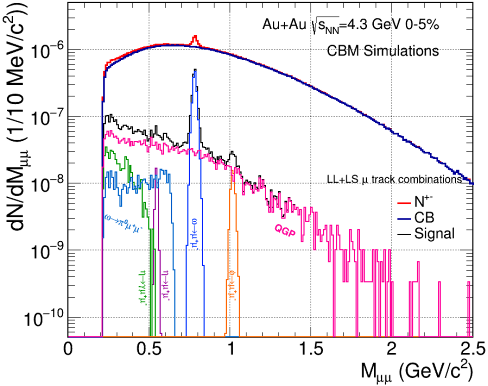
Real-size (80 x 40 cm^2) GEM detector module

Detector testing at CERN-SPS, November 2016:

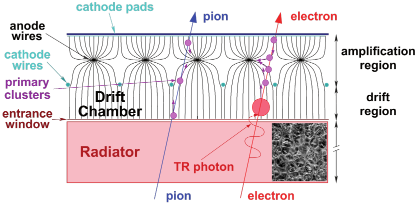
- Large-size chambers succesfully operated in fixed-target testbeam (Pb+Pb)

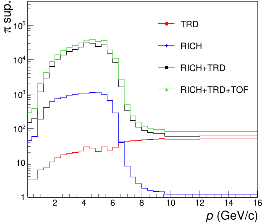
Poster: A. Kumar, A. Dubey, INS-17

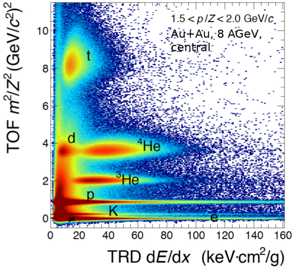
- Reconstruction of di-muon cocktail: 8 *A*GeV Au+Au
- Track selection: associated hits in STS and MuCh, track χ^2 at STS/MuCh/prim. vertex, TOF mass cut



CBM Transition Radiation Detector





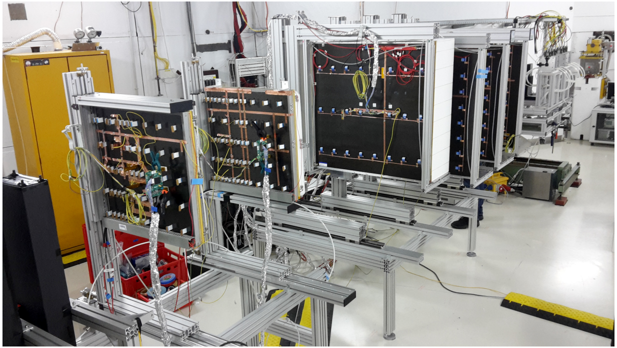


- Multi-wire proportional chambers (12 mm Xe/CO_2), fast design, PE foam foil radiator
- Read-out: mirror charge on cathode-pads
- Electron detection due to absorption of TR photons additional to particle energy loss
- Pion suppression by four TRD layers
- Separation of light nuclei, e.g. d $\leftrightarrow {}^4$He (reconstruct: ${}^5_\Lambda\text{He} \rightarrow {}^4\text{He} + p + \pi^-$ // ${}^6_{\Lambda\Lambda}$He)

Poster: C. Blume, INS-05

TRD Electron Testbeam

- DESY electron beam (1 – 4 GeV), directly through detectors
- Full set of four MWPCs and radiators
- MWPC tracking station and scintillator coincidence reference
- $Xe\text{-}CO_2$ 80:20 as detector gas
- Slow data recorded for correlation with detector characteristics: HV, gas oxygen content, temperature, pressure



Measurement programme:

- Detector response to electrons, TR spectrum
- Electron detection efficiency
- Track reconstruction

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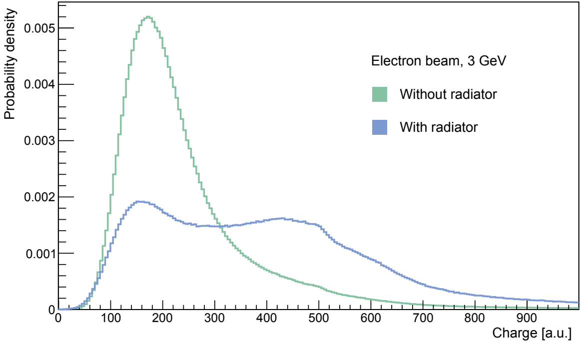

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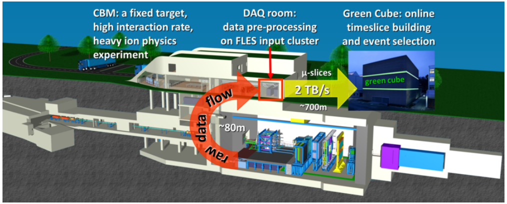
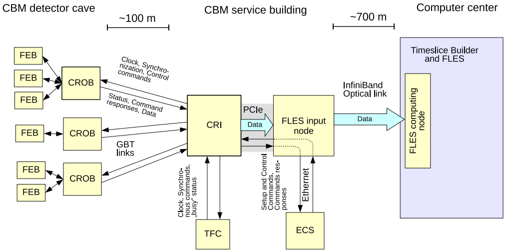
CBM Readout and Computing

- CBM-DAQ is free-streaming and self-triggered based on innovative frontend electronics
- Interaction rates resulting in high computing requirements

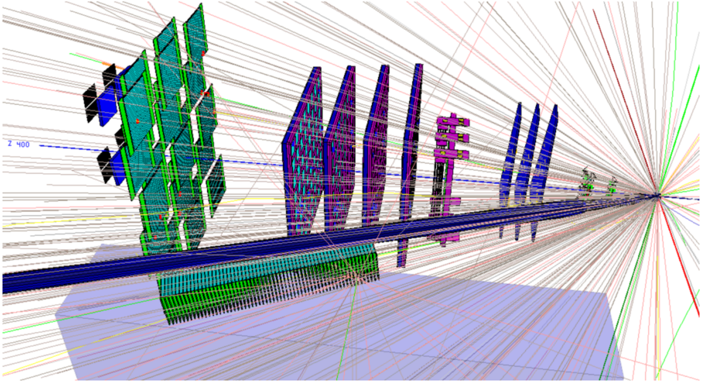


- FPGA-based readout chain (feature extraction) complemented by high-performance computing in the *Green Cube*
- Early reconstruction of self-contained units, data processing: in FPGA, FLES, online software
- Event definition: online in 4D-tracking from overlapping time-slices (First-Level Event Selector)



Poster: D. Emschermann, INS-10

FAIR Phase 0 Projects



- Detectors and read-out well-tested and confirmed separately
- Integration at beam facilities: eTOF at STAR/RHIC, RICH at HADES, STS and PSD at BM@N/JINR and operation of CBM detectors at mCBM/SIS18 starting in 2018, full free-streaming CBM-DAQ
- mCBM: full event reconstruction, online tracking and selection, Λ reconstruction as performance

Summary and Outlook

Physics Programme:

- Probing QCD matter at high net-baryon densities
- Rich physics programme, measurements with unprecedented statistical precision
- Comprehensive performance studies in progress

Development and Construction:

- High rates challenging to detectors and DAQ, preparation measurements
- FAIR civil construction for SIS100 in progress

Detector and System:

- Subdetectors and electronics tested at beam facilities
- Full system test-setup FAIR phase 0 started

More CBM on QM2018

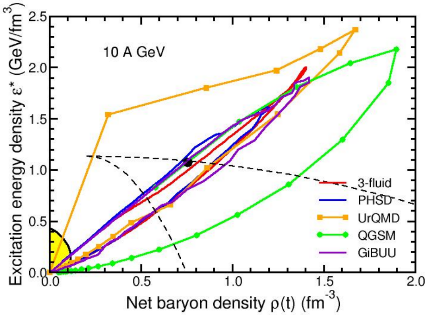
- Perspectives on strangeness physics with the CBM experiment at FAIR, Iouri Vassiliev

- Test and developm. of the front-end electronics for the Silicon Tracking System of the CBM experiment, Adrian R. Rodriguez
- Large area triple GEM chambers for muon tracking at CBM experiment at FAIR, Anand Kumar Dubey
- Performance and Design of the Transition Radiation Detector for the CBM Experiment, Christoph Blume
- The free-streaming data acquisition system for the Compressed Baryonic Matter experiment at FAIR, David Emschermann
- Emissivity of baryon-rich matter – dilepton spectroscopy in CBM, Etienne Bechtel
- The Projectile Spectator Detectors for the CBM at FAIR and NA61/SHINE at CERN, Fedor Guber
- The CBM Time-of-Flight system, Ingo Deppner
- The Silicon Tracking System of the CBM experiment at FAIR, Johann Heuser
- The RICH detector for the CBM experiment at FAIR, Jordan Bendarouach
- Multi-differential analysis with KF Particle Finder in the CBM experiment, Maksym Zyzak
- News from the Micro Vertex Detector of CBM, Philipp Sitzmann
- Time-based particle reconstruction and event selection in the CBM experiment, Valentina Akishina
- Performance for anisotropic flow measurements of the future CBM experiment at FAIR, Viktor Klochkov
- Performance of the new DiRICH based readout chain for MAPMTs in test beam data, Vivek Patel

Thank you for your attention!

BACKUP

CBM Baryon Densities



Clockwise evolution, 1 step is 1 fm/c. Excitation energy density means energy density minus mass density. Dashed line: possible area of phase coexistence.

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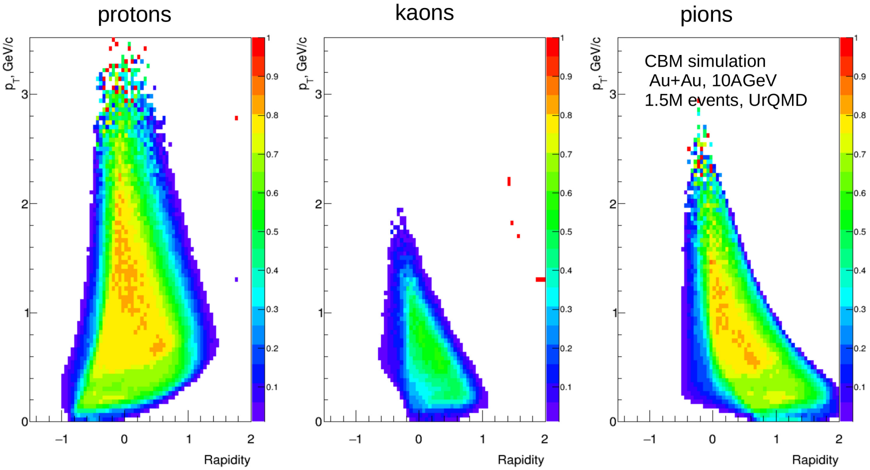
CBM Rapidity Coverage



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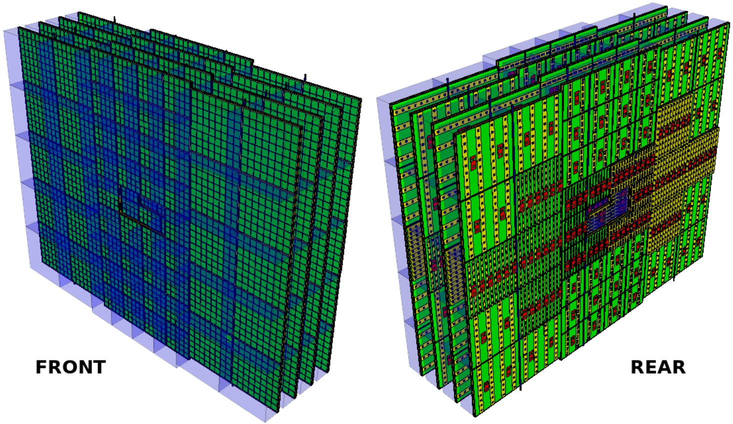

TRD station with four layers of radiator/MWPC. 6.25 x 5.15 m^2, four types of detector modules suiting the hit density distribution. Each 2^{nd} layer rotated by 90 degree.

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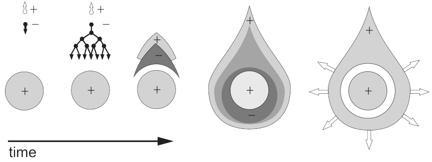
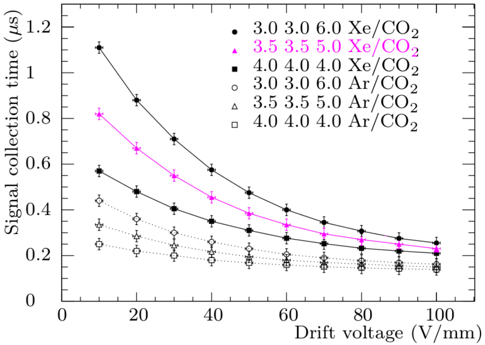


Sauli, CERN lectures 1977



Veenhof, NIMPR A ***A419*** *(1998) 726-730*

TRD Electron Testbeam

Radiator prototypes:

- Full-size radiator boxes, 30 cm depth
- PE foam foils of 2 mm each
- Rohacell housing (8 mm)
- Stabilised by polymer filament grid
- Contacting directly to entrance window, additional 15 mm

Electrical scheme:

- Detector chambers electrically isolated against support structure

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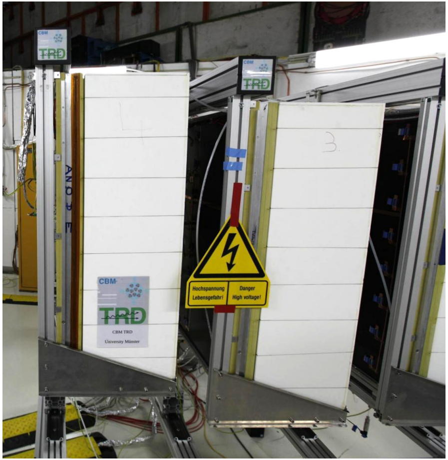

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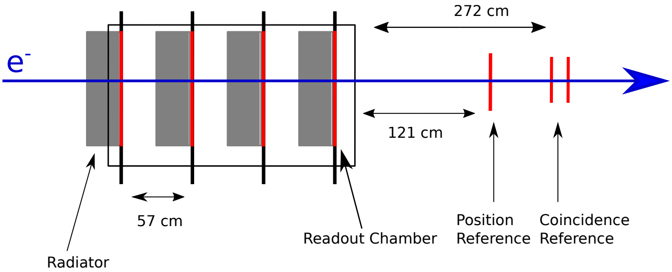
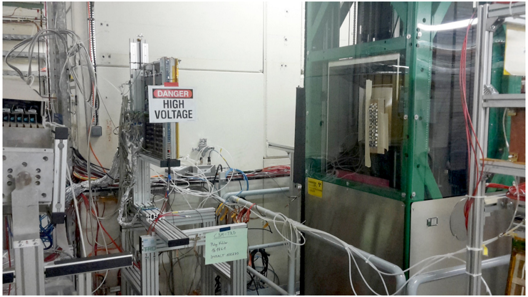
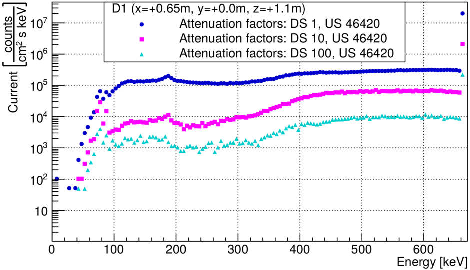


Installed read-out:

- Four SPADIC 2.0 on beam positions of each TRD, one SPADIC 2.0 for gas gain monitoring
- Two SPADIC 2.0 on reference MWPCs, one LEMO-SPADIC 2.0 on Scint/PMTs
- New shaping time of 240 ns, 16 MHz sampling, up to 32 samples read
- Four AFCK boards, IPbus controls, FLES data recording

TRD High-Rate Test at CERN-GIF

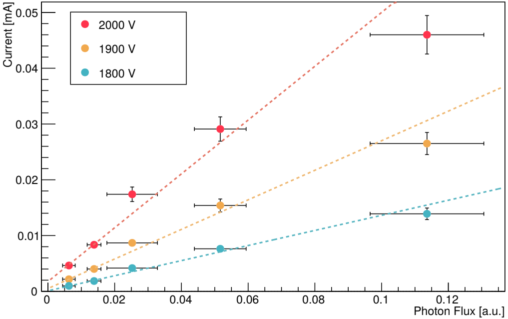




Simulated gamma spectrum in empty GIF bunker, three attenuator levels, *GIF*

- ^{137}Cs source, 13 TBq
- Three-level attenuator system to control photon rate over large scale
- γ emission of 662 keV,
  interactions with material
- TRD prototype: 1 cm^2 cathode-pad size
- Xe-CO_2 80:20 as detector gas, controlled in pressure and oxygen contamination

TRD High-Rate Test at CERN-GIF



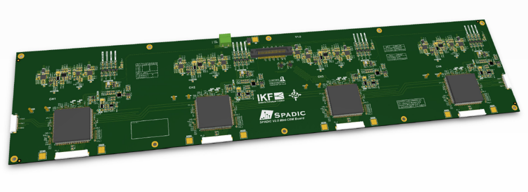
Measured anode currents with respect to photon flux

Measurement programme:

- Detector load in the CBM domain and above: exclusion of space-charge effects
- DAQ chain at highest loads
- Homogeneity of detector

TRD Read-Out and Electronic Status

- SPADIC front-end: 16 MHz/8 B sampling, self-triggered and free-streaming
- *Forced-Neighbour Read-Out* for efficient charge reconstruction
- Tail cancellation and multi-hit flagging
- e-link via GBTx (on module) to FPGA layer in entry nodes, feature extraction on-site



Quad-FEB, four SPADIC 2.0, 4 x 32 channel, inter-chip and inter-FEB neighbour-trigger (rendering)

Current integration branches:

- Quad-FEB based on SPADIC 2.0 with inter-chip neighbour-trigger
- Commissioning of SPADIC 2.1-based read-out: optimisation of protocol usage
- C-ROB (“Read-Out Board”, GBTx) integration

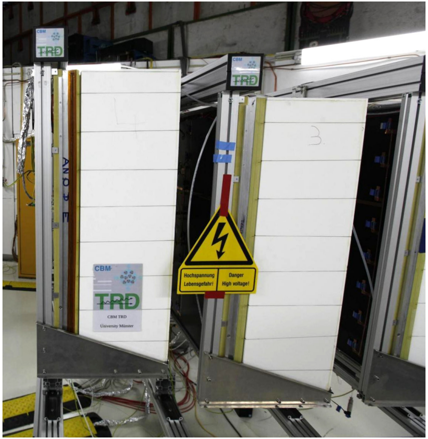
TRD Lab and In-Beam Tests

Lab measurements

- Electronic integration
- Front-end setting optimisation
- Oxygen/humidity levels in detector gas
- Gas gain confirmation

In-beam tests

- Earlier tests at SIS18, CERN-PS, CERN-SPS
- Electron testbeam at DESY II, 2017
- High-rate test at *Gamma Irradiation Facility* CERN-GIF^{++}, 2017
- High-rate test at CERN-GIF^{++} including muon beam, 2018
- miniCBM at SIS18, in installation



TRD prototypes at DESY, MWPCs + Radiators