FSD plans for TDR

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For FSD group

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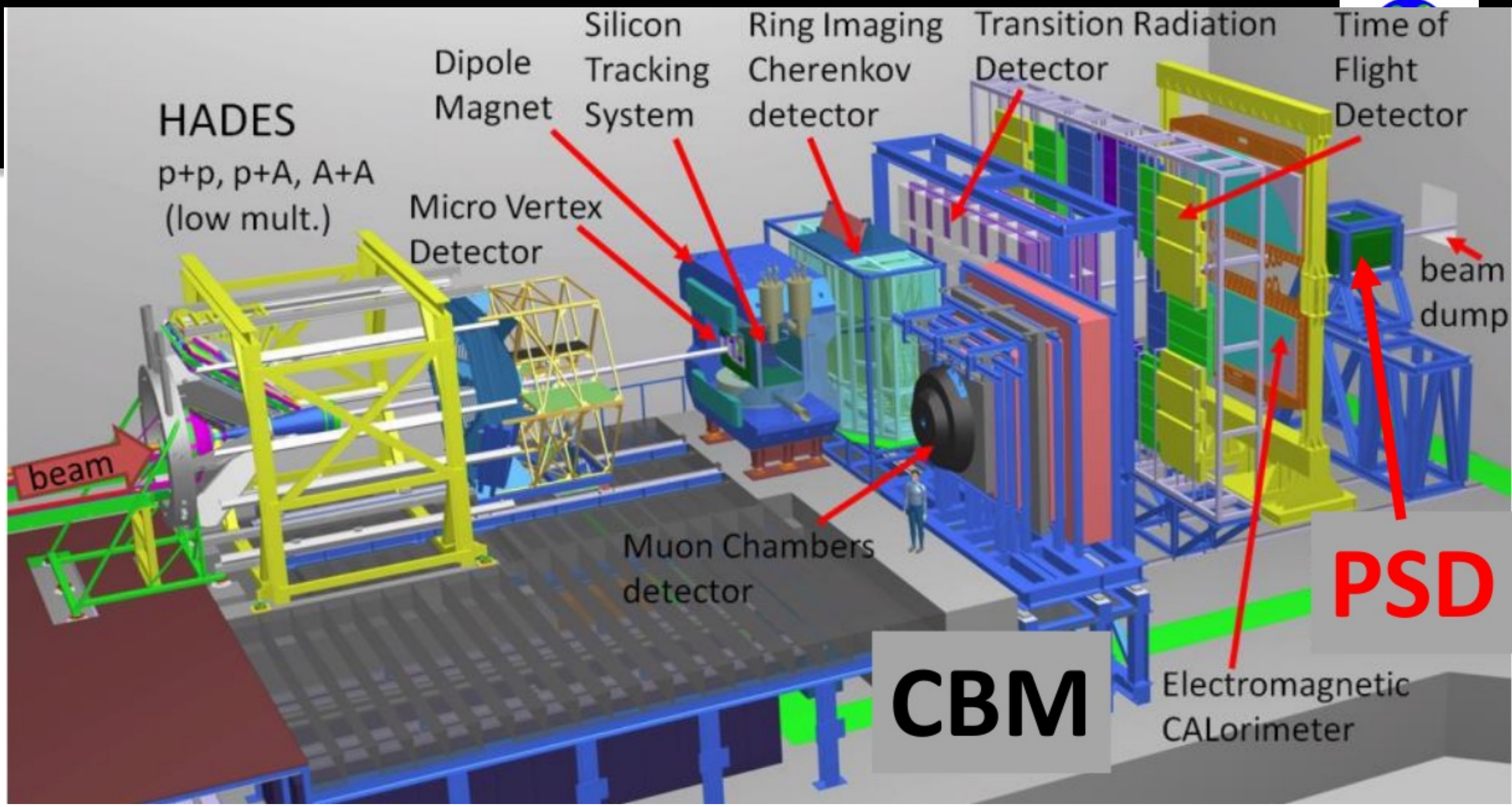
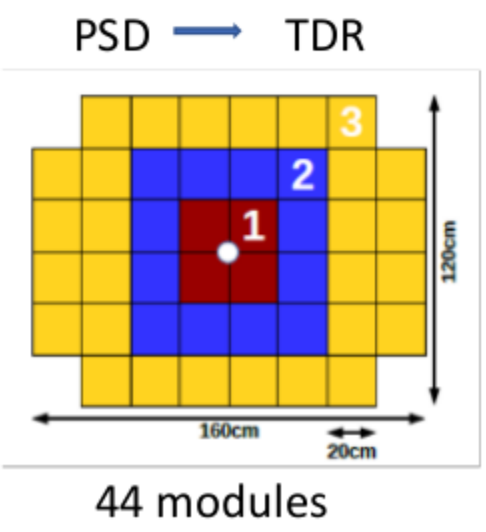
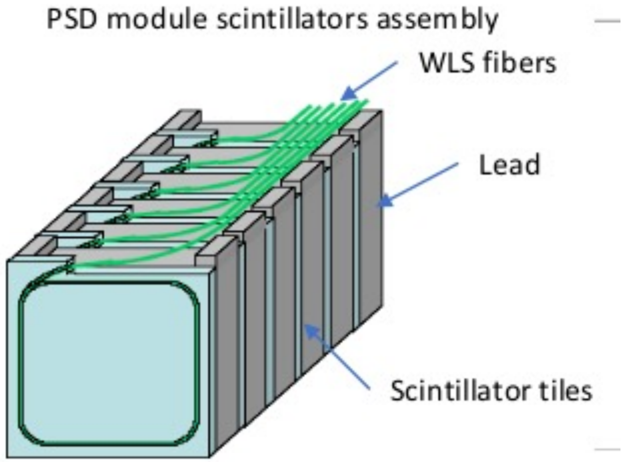
Before FSD

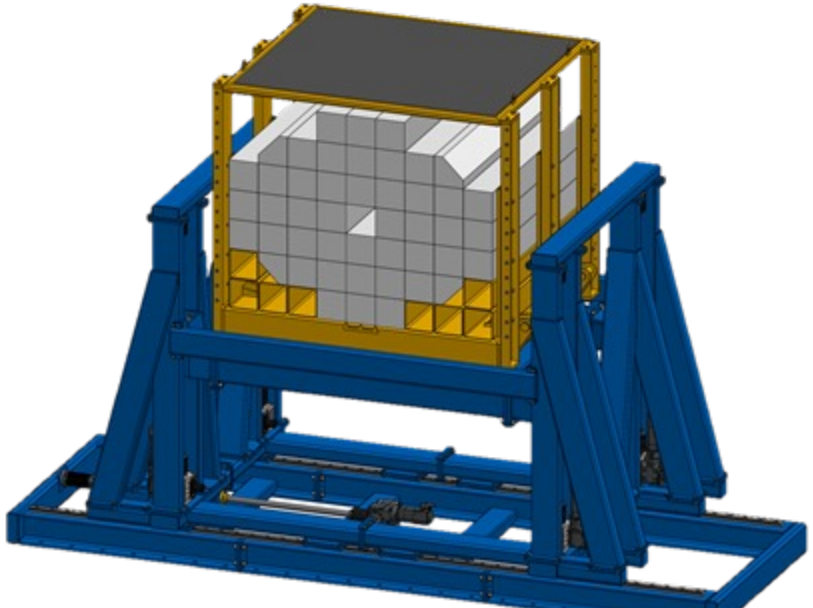


PSD – Proton Spectator Detector

- Sampling calorimeter with SiPM readout
- Spectator detection in the beam energy range of Eb = 2 – 35 AGeV
- Reaction plane and centrality determination
- **Project canceled in 2022**
  - Mechanical positioning platform already delivered to GSI







Forward Spectator Detector (FSD)

Proposing scintillator hodoscope:

- Similar in function to HADES FWALL or CEE- ZDC
- Detecting charged hadrons in forward rapidity
- Increasing granularity closer to the beam
- Sensitive to charged particles
  - protons and spectator fragments
- Centrality and event plane measurements
  - independent of mid-rapidity

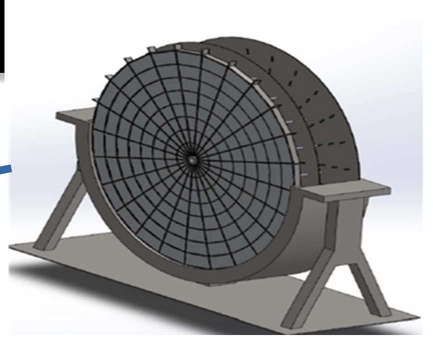
Design consideration:

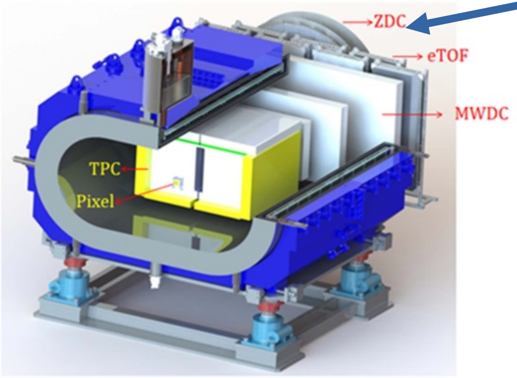
- Radiation hardiness
  - fast readout by PMT
- Based on proven technology, reuse maxim knowledge gained from PSD
  - DiRICH based readout
  - software simulation stack
- Reasonable budge
  - plastic scintillators

FSD project and group

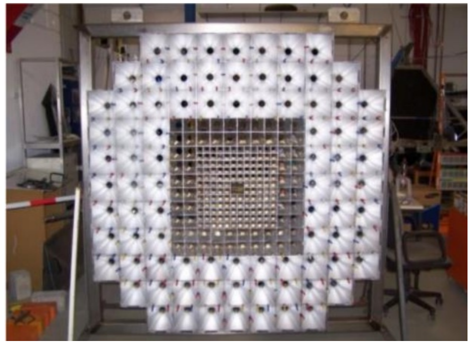
- Official project since 2023
- Collaborators: Czech Tech. Uni, Nuclear Physics Inst. Rež, GSI, Bochum University

CEE-ZDC

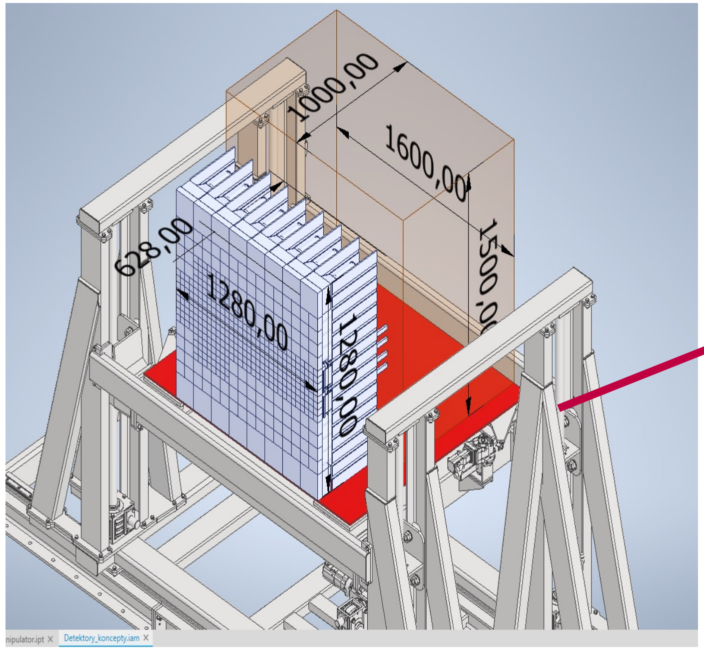


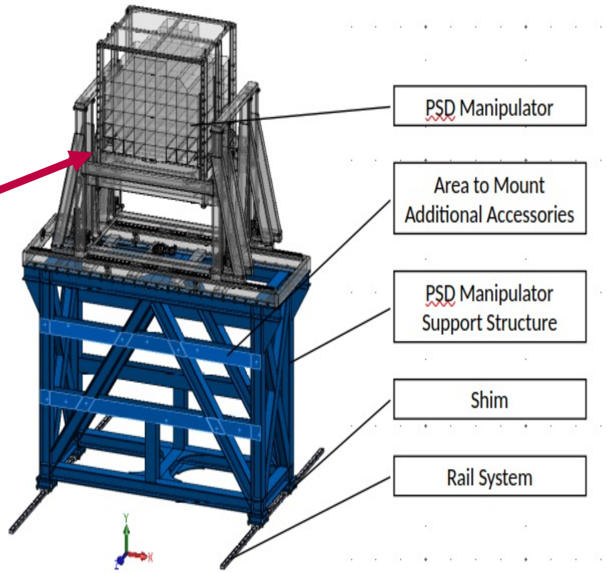


HADES hodoscope



CBM - FSD

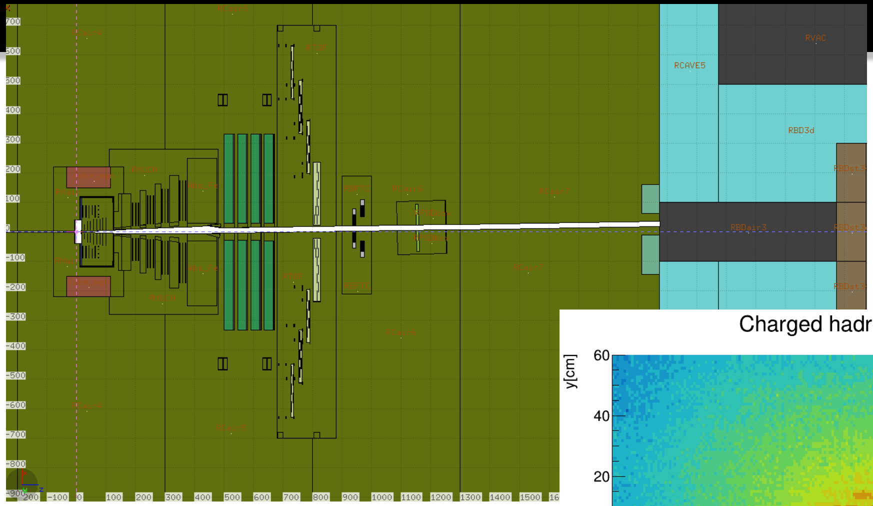




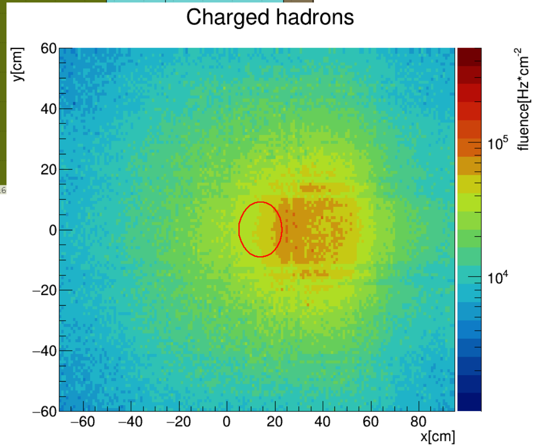
Bacgkround studie

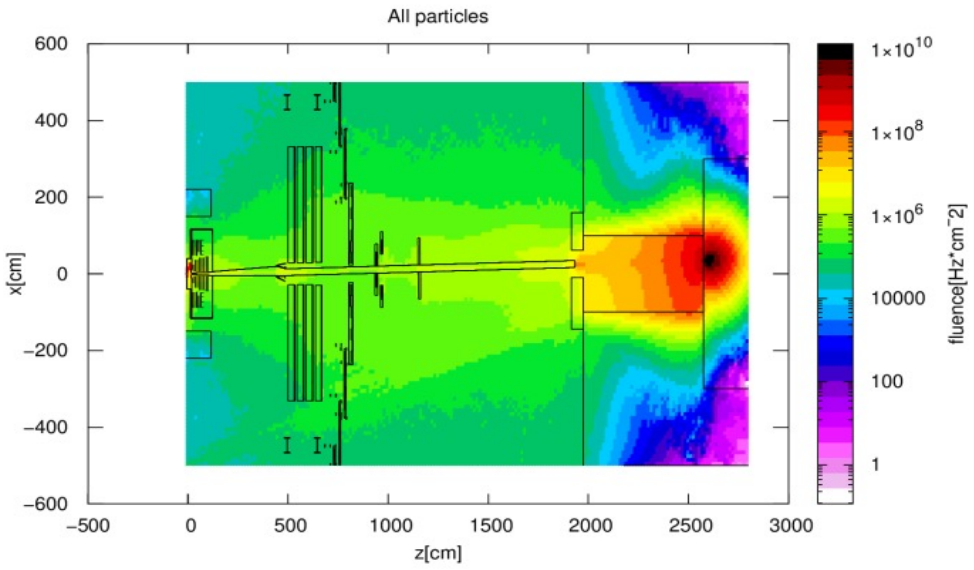
Extensive FLUKA studies od particle flux and doses

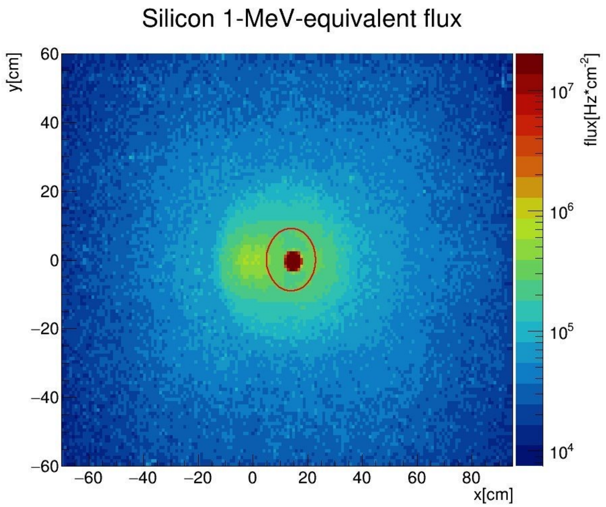
- Charged particle flux up to $10^5/(cm^2s^{-1})$ for 10 Mhz Au+Au
- Expected dose to scintillator max 10kGy/2months
  - exchanged after one year
- Increased granularity around beampipe
  - max occupancy ~20% per channel
- Neutron flux ~10^{11} 1MeV eq/2months
  - too harsh for SiPM
  - considering shielding of electronics

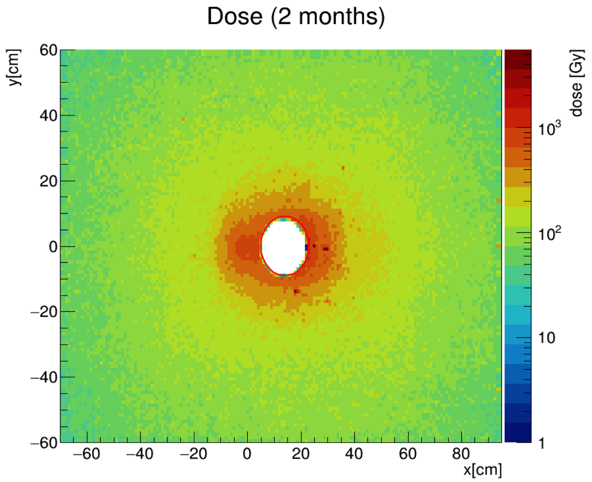


FSD









Forward Spectator Detector (FSD)

Basic design :

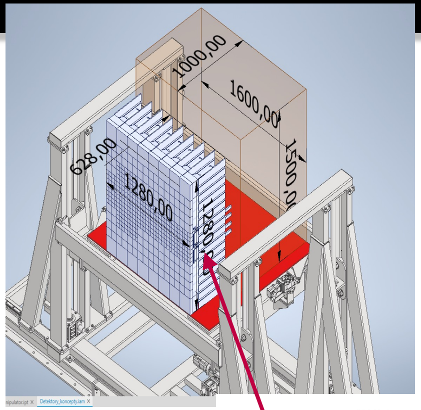
- 6x6 array of 22cm module blocs
  - different granularity 5x5,4x4,3x3
- Total of ~350 scintillator pads+PMT
- PMT available as Bochum in-kind contribution
  - 2" inch Philips XP2020
  - 1" Hamamatsu R1924

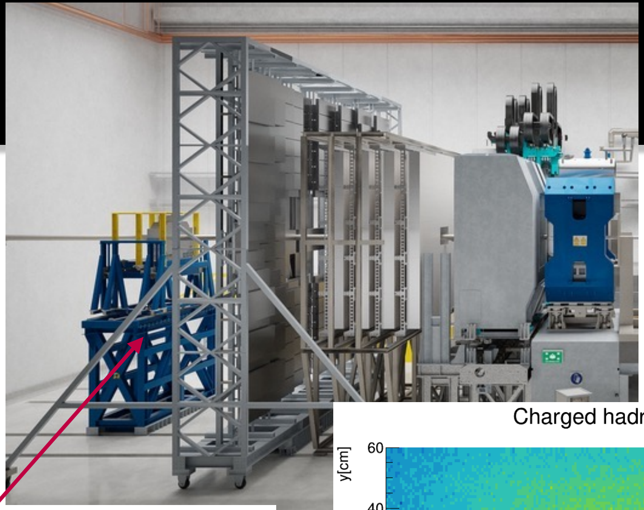
Readout via DiRICH

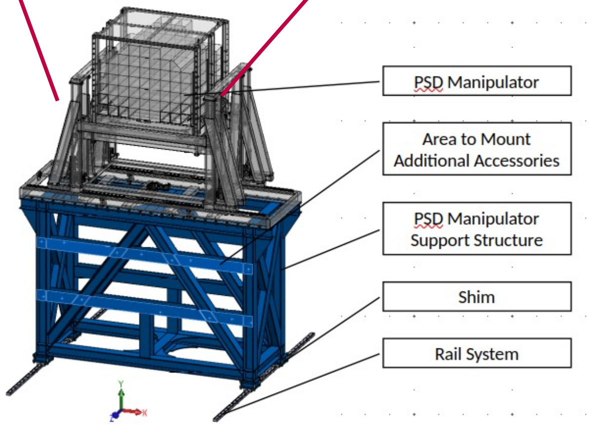
- GSI in-house solution, shared solution with RICH
- Tested up to 1Mhz hit rate

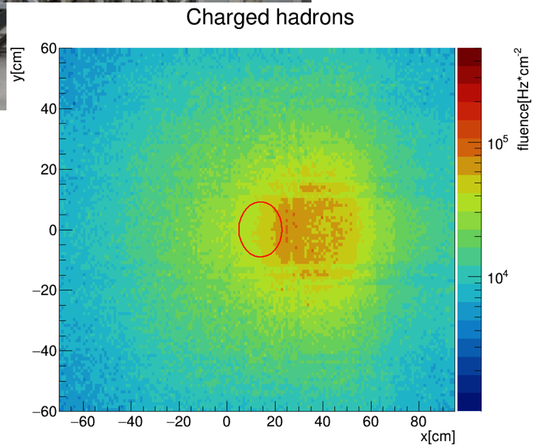
Mechanical:

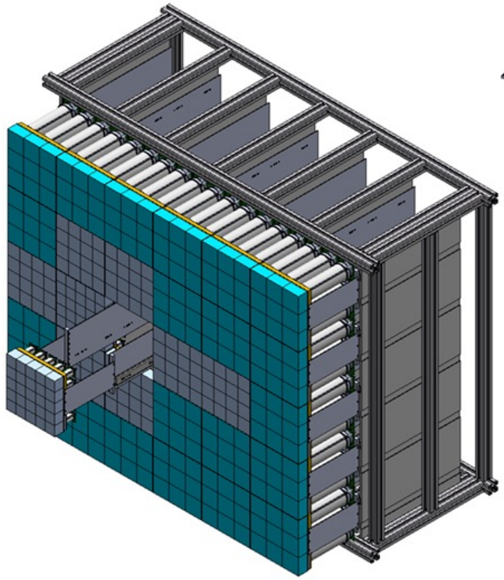
- Modular design with removable sections
- Reusing FSD manipulator
- Support platform will be designed
- Optimized design of beam pipe to minimize background

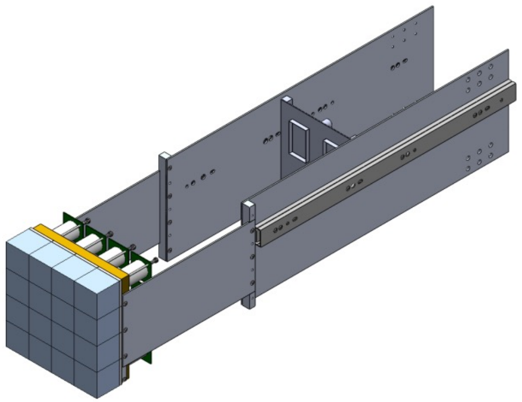


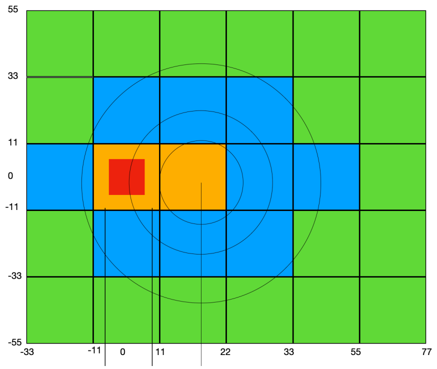












171 canals: 7.3x7.3 cm
144 canals: 5.5x5.5 cm
25+10? canals 4.4x4.4 cm

Event plane reconstruction with FSD

Goal – event plane reconstruction from spectators

- Independent from flow measured at mid-rapidity

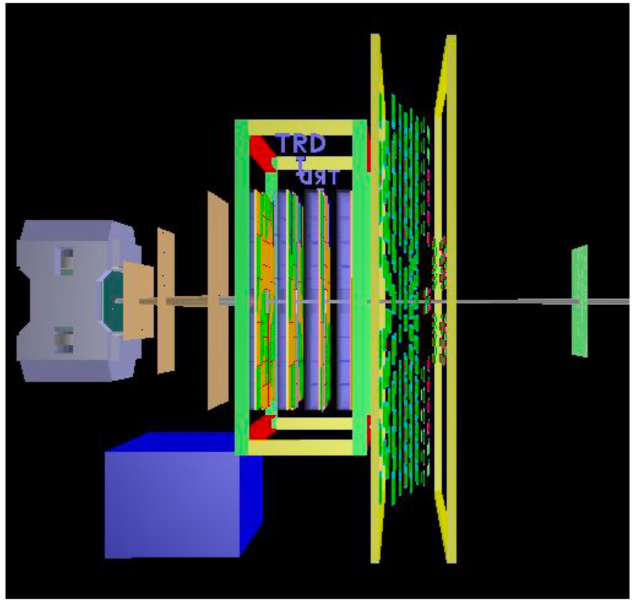
Challenge – dipole magnetic field

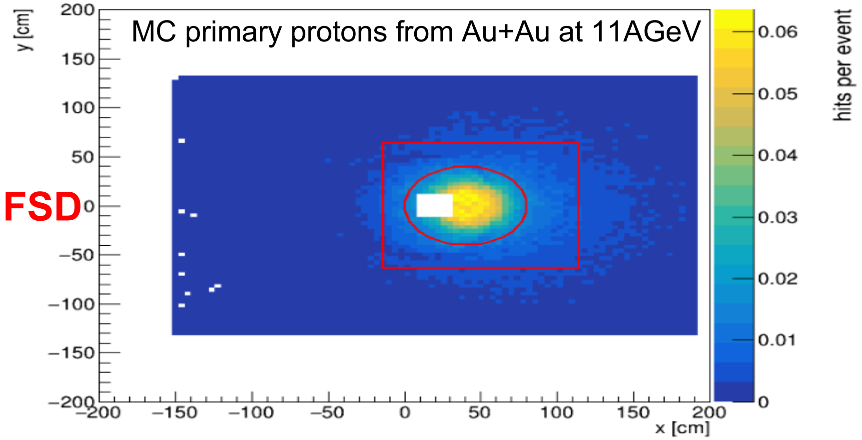
- Different rapidities centered in different x position due to the magnetic field
- Non uniform acceptance
  - mixing of rapidity, pt, phi
  - depends on charge/mass ratio
- FSD - only dE/dx information

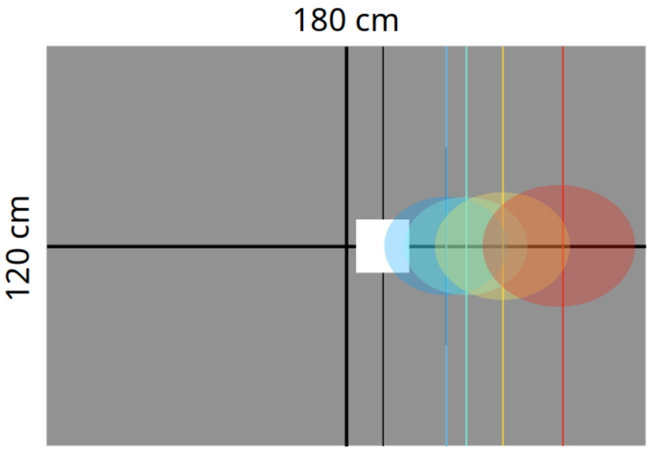
Flow extraction using Q_N vector framework

- Integrated with CBM Analysis framework
- 3 or 4 subevent correlations
- Correction for non-uniform acceptance
  - recentering, twist, rescaling
- Q vector (subevent selection) must be done carefully
  - correlated background can induce bias
  - no PID and tracking in forward direction

CBM GEANT model







- y=[3.3-3.6] -> x = 30.6 cm
- y=[3.0-3.3] -> x = 36.6 cm
- y=[2.7-3.0] -> x = 46.8 cm
- y=[2.4-2.7] -> x = 64.7 cm

Event plane reconstruction with FSD

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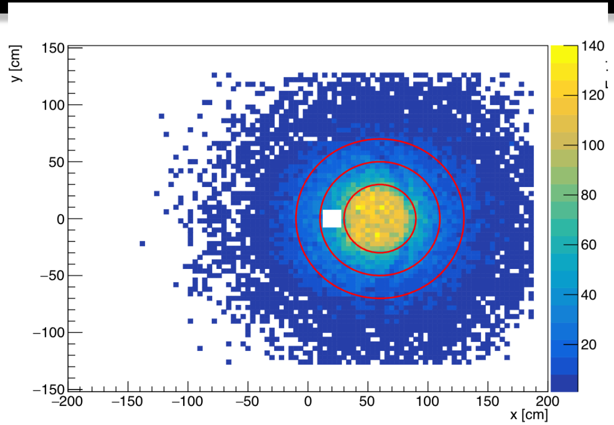
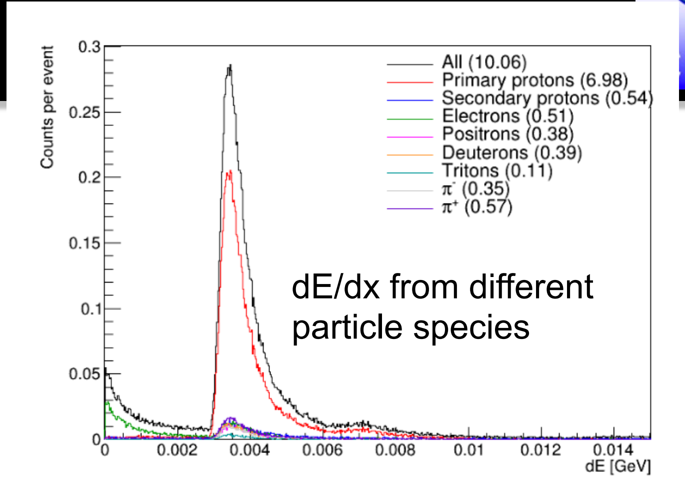
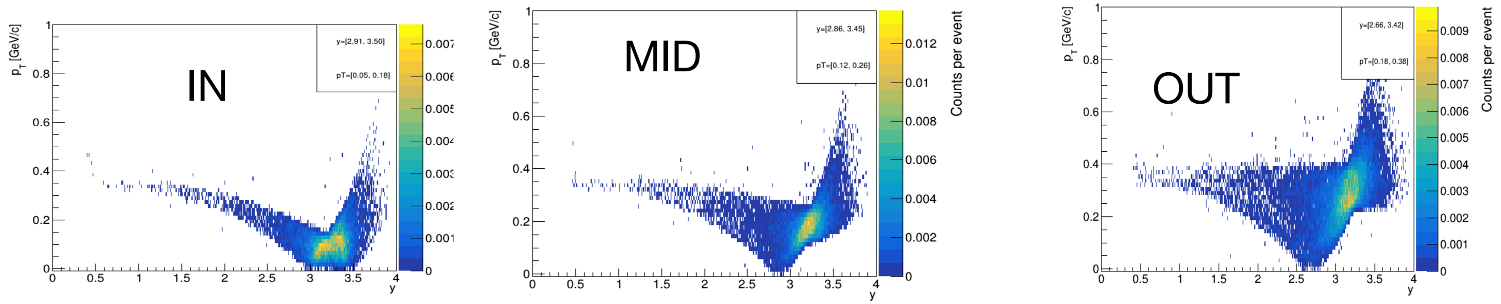
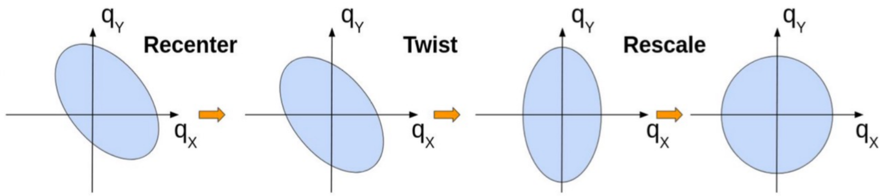






$$\mathbf{u}_n = \{\cos n\varphi,\ \sin n\varphi\}, \quad \mathbf{Q}_n = \sum_{i=1}^{N} w_i \mathbf{u}_{n,i},$$



Event plane resolution:

$$R^A_{n,\alpha} = \sqrt{\frac{\langle Q^A_{n,\alpha} Q^B_{n,\alpha}\rangle \langle Q^A_{n,\alpha} Q^C_{n,\alpha}\rangle}{\langle Q^B_{n,\alpha} Q^C_{n,\alpha}\rangle}},$$

v_1:

$$v_{n,\alpha} = \frac{2\langle q_{n,\alpha} Q_{n,\alpha}\rangle}{R_{n,\alpha}},$$

Event plane reconstruction with FSD

v_1 from Qn vector

- Separately using three subevents and x, y component
  - 6 independent (technically) values
- Handle on systematics

MC input x simulation agreement

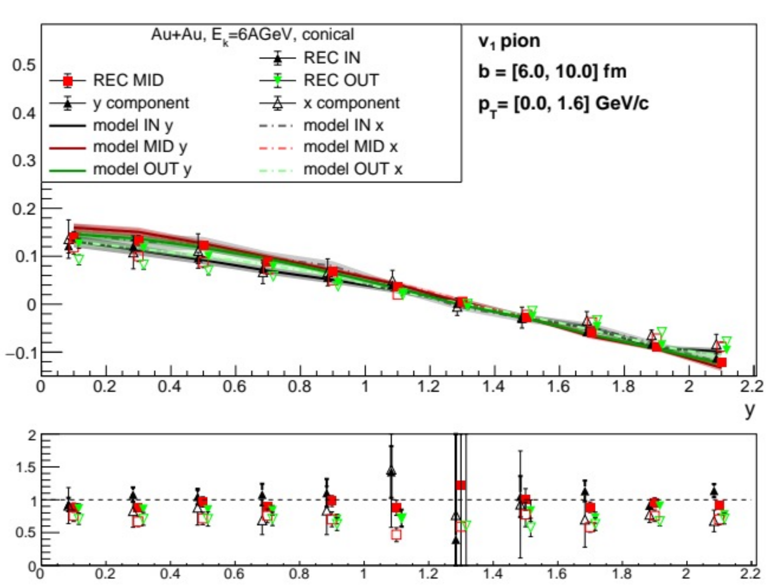
- Event plane extracted from spectator protons
  - at lower collision subevent from fragments
- Systematics under control
  - difference likely due to simplified subevent selection in MC

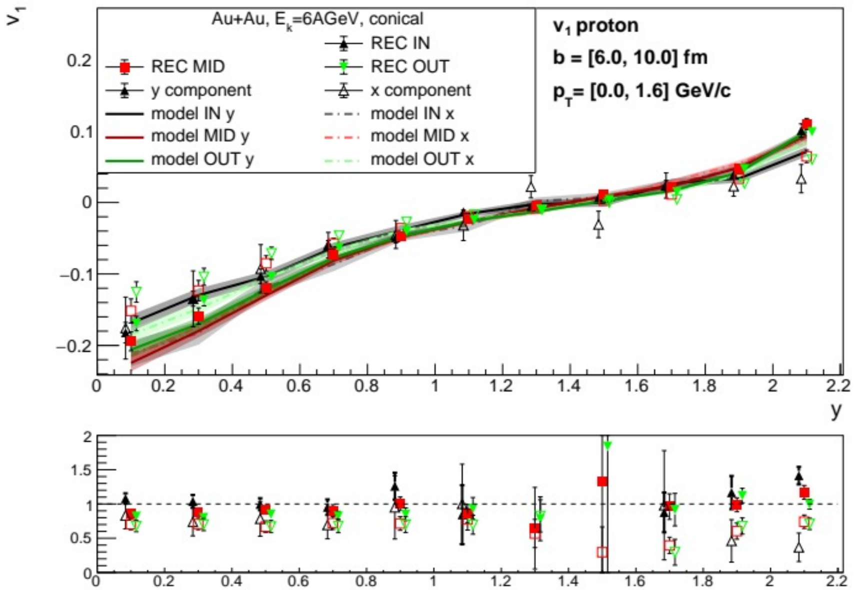
Extensive studies of systematics

- Background from other detectors
- Correlated background from fragments passing traversing beampipe wall
- Beam divergence effect

FSD will provide independent measurement of event plane from forward rapidity spectators.

DCM-QGS-SMM Au+Au, E_{kin}=6AGev





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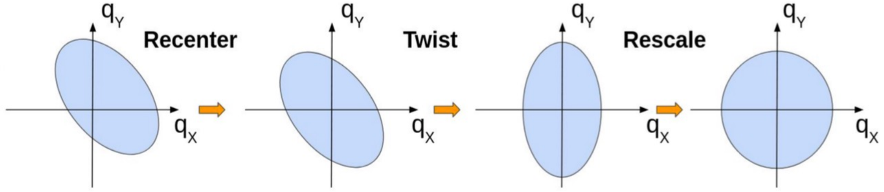

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v1:

$$v_{n,\alpha} = \frac{2\langle q_{n,\alpha} Q_{n,\alpha}\rangle}{R_{n,\alpha}},$$

Centrality measurement with FSD

Centrality from FSD

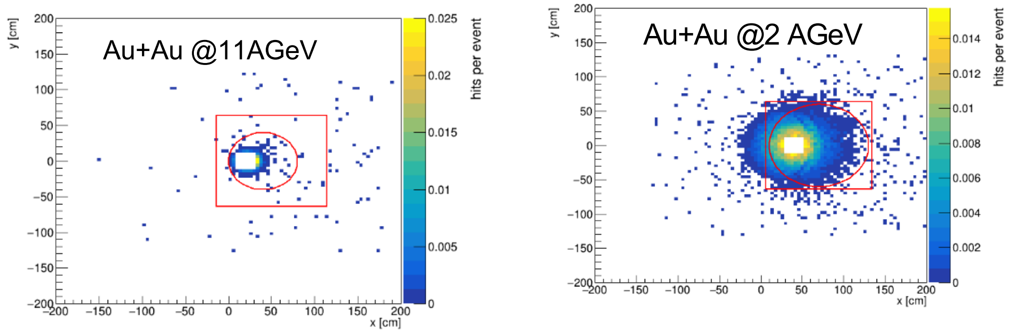
- Using forward fragments - crucial for mid-rapidity fluctuation measurements
- Obtained from number of charged particles in FSD
- Insensitive to neutrons
- Correlation between detector regions (subevents)
- Studied classical cut selection and machine learning methods

Effect of central beam hole

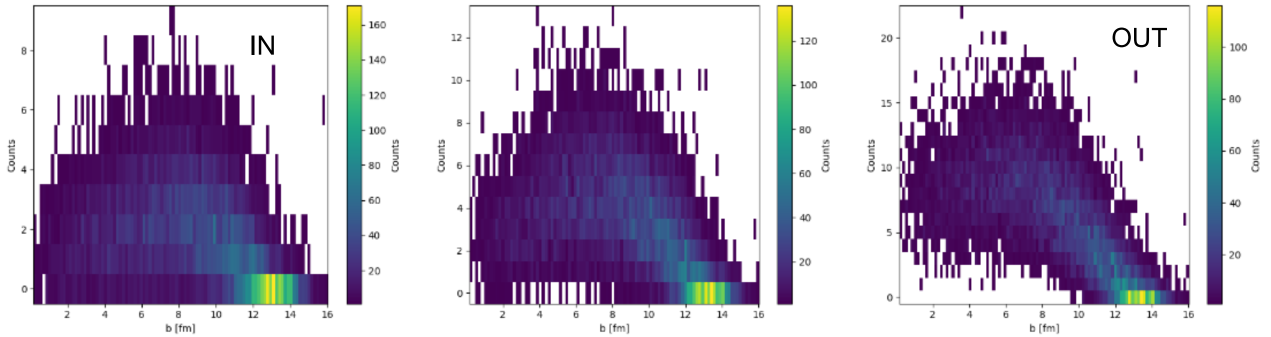
- Must accomodate beam + halo
  - not fully accounted for in past PSD studies
- Loss of fragment with Q/m close to beam particles
  - model dependent in simulation
- Driven by beam divergence
  - intrinsic beam divergence (<5 mrad)
  - 2 mrad from elastic statering in target

FSD will be able to provide an independent measurement of collision centrality.

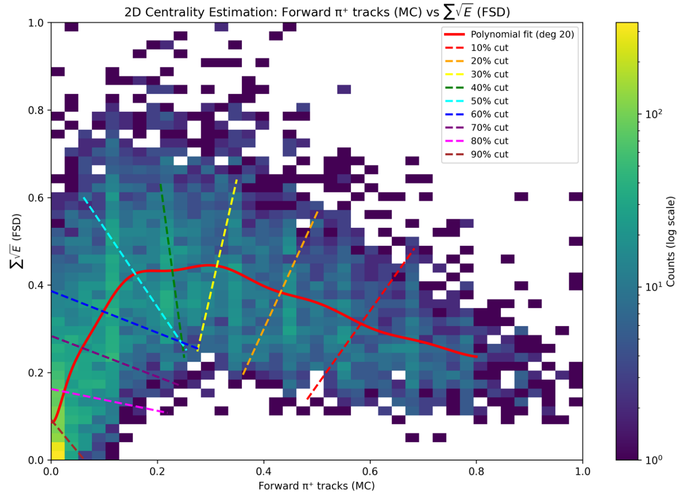
Fragments (Q>1) in FSD from DCM-QGSM-SMM Au+Au



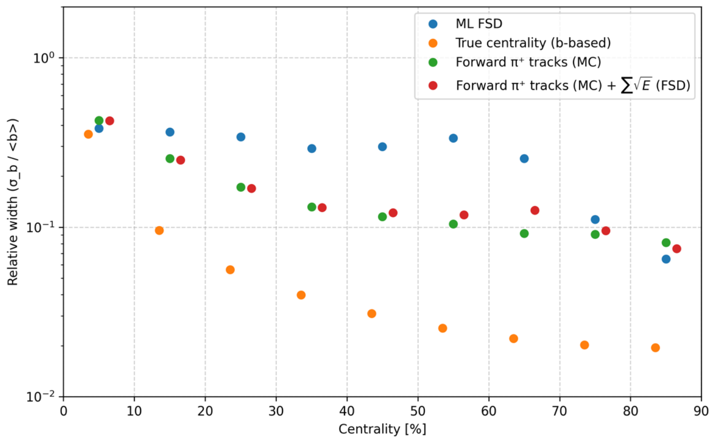
Au+Au @11AGeV – hits in FSD



STS y>2.8 vs FSD signal (scaled); Au+Au @ 11AGeV



Centrality resolution



Electronics and readout

Leveraging existing electronics

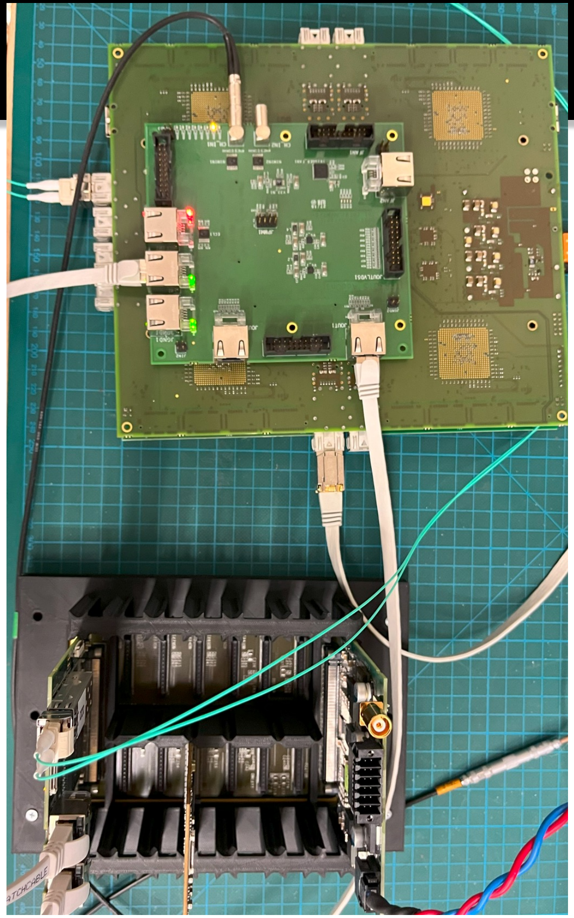
- Use of the DiRICH readout boards - originally the TRBNet version
- Advantage: already implemented in the CBM DAQ
- Cheap, scalable and reliable technology
- Tests started with version with concentrator, with plan to go towards standalone version of DiRICH5

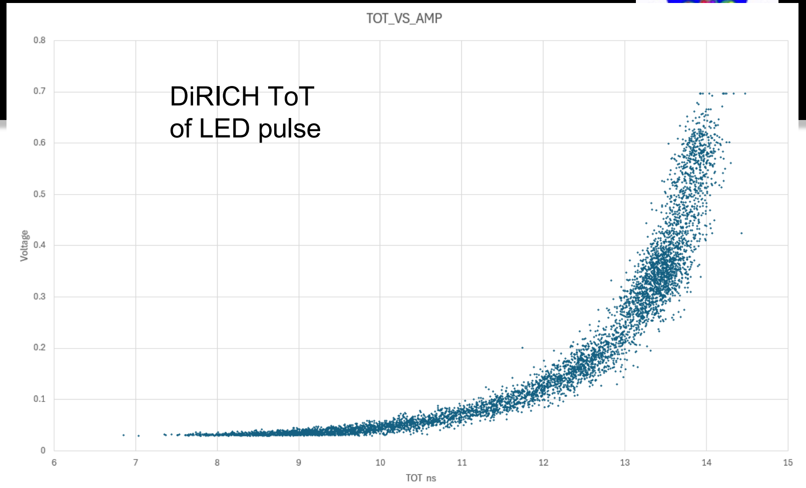
Challenges

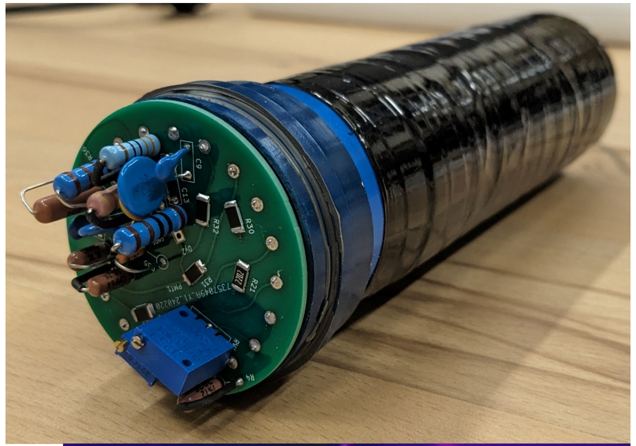
- Possible issues in high radiation environment near the beam dump
  - readout boxes at the cave ground level
- High rate in the central channels
  - current version of DiRIch tested up to 1Mhz

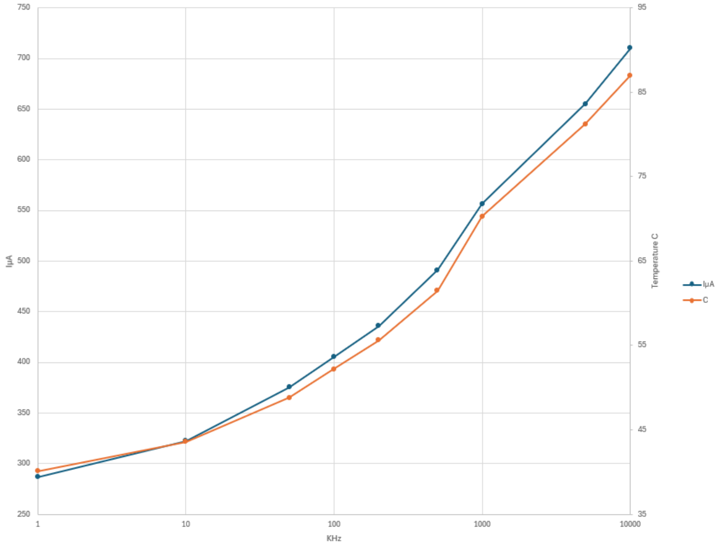
New PMT dividers

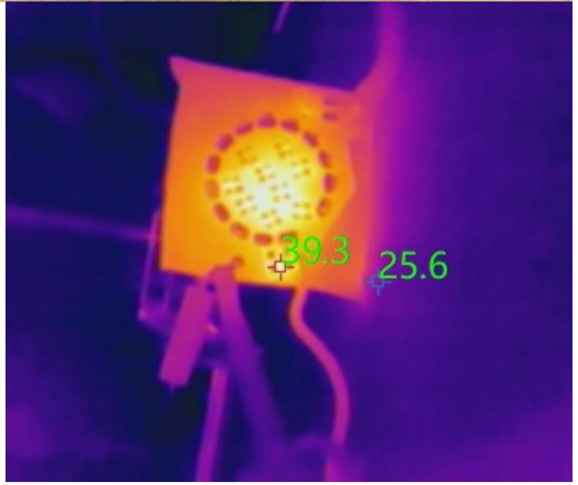
- Optimized for timing,fast readout, power dissipation and small, footprint
- Lab and cosmics testing
  - XP2020 ≈ 150ps
  - R1924 ≈ 300ps
- High-rate testing for power dissipation











Testing @ mCBM

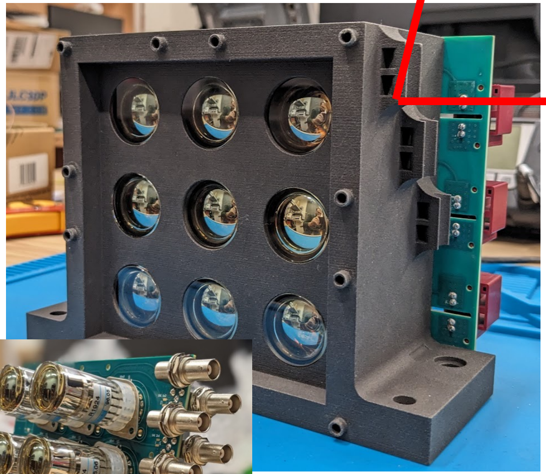
mCBM – full system test with SIS18 beam

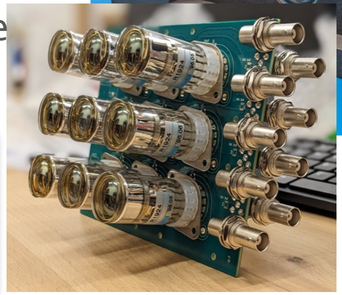
- Test and pre-series detector components
- Including FSD test module
- Realistic downscaled version CBM DAQ with free-streaming readout
  - High-rate test

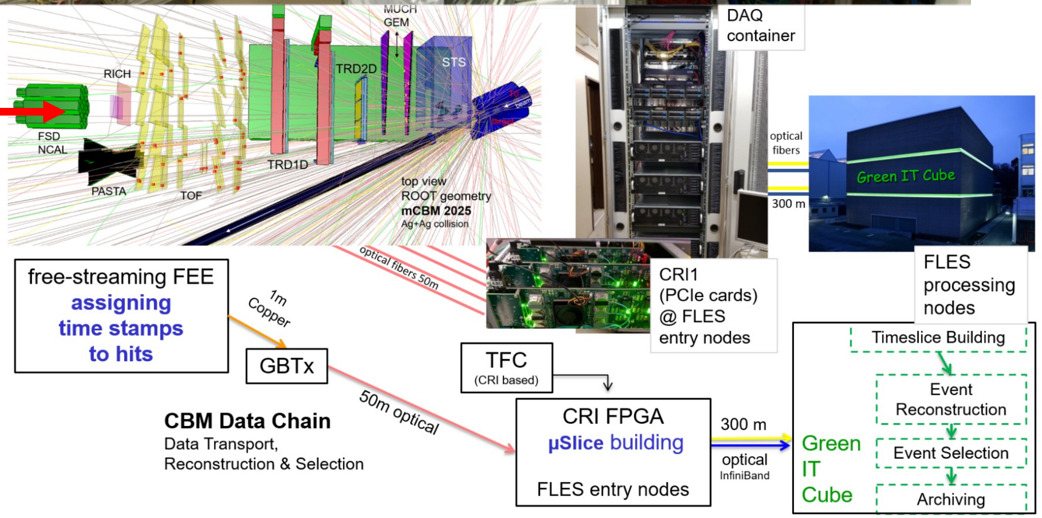
FSD + DiRICH tested

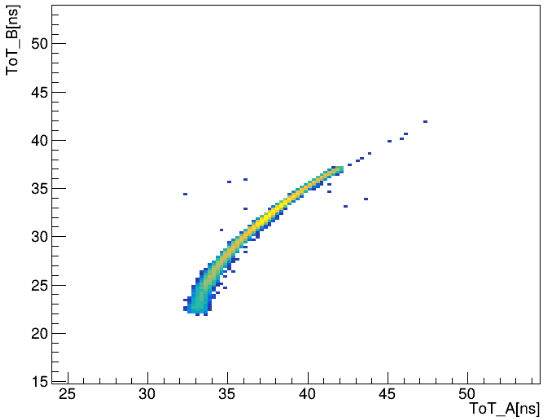
- Smooth inclusion in RICH data stream
- Gaining experience with free streaming readout
- Work on optimization of timing and charge resolution

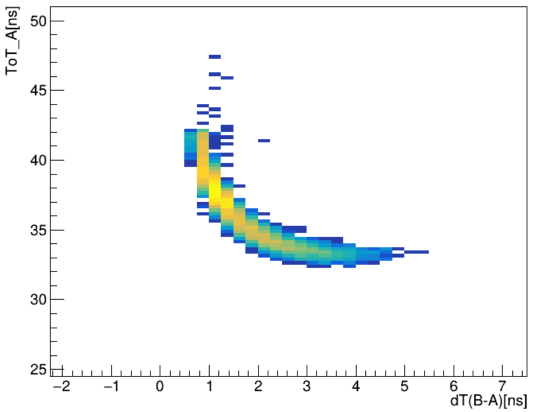
Successful integration of FSD readout into CBM DAQ











Potential upgrade to DOGMA DAQ

- Standalone concept of DiRICH with optical communication over Ethernet
- Improved radiation hardness and self recovery

Towards TDR

Planned content of the TDR:

Expected physics performance

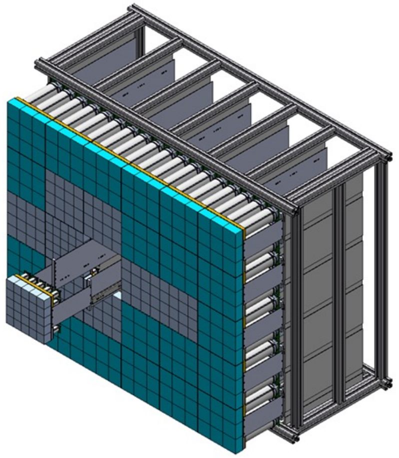
- Operational environment studied
- Expected physics performance evaluated
  - Event plane and centrality measurement from forward spectators
  - Study of systematic effects

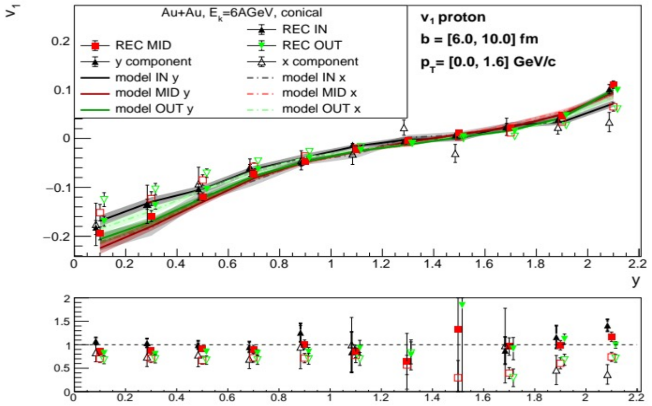
Detector design concept

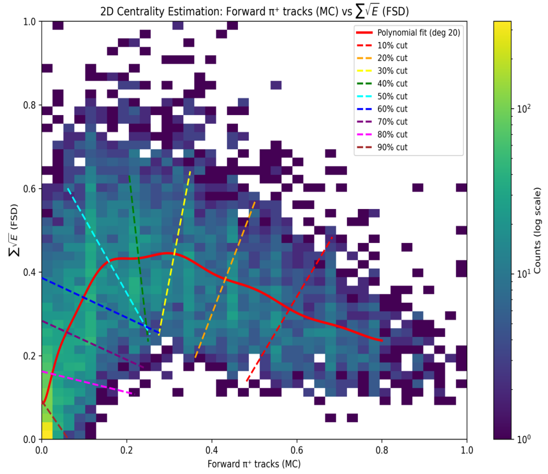
- Basic concept developed
- Mechanical design advancing
  - detector modules, support
- Electronics
  - based on proven technologies
  - test results

Time plan:

- First draft ready
- **Collaboration review – January 2026**
  - finalizing performance studies for centrality determination
- **Submission to ECE – February/March 2026**







After TDR

Further R&D

- Pre-series modules
  - testing and optimization
  - mCBM commisioning runs
- Electronics
  - Speed and resolution optimization
- Design support frame

Milestone	2026	2027	2028
TDR submission	January		
Electronics CDR submission	Q2		
Design finalization			
Detector module PRR	Q4		
Electronics PRR	Q4		
Mechanical support → PRR	Q4		
Procurement			
TRB + ROBs → FAT		Q2	
Scintillator modules → FAT		Q1	
Support → FAT → SAT		Q3	
Assembly			
Detector modules → FAT		Q3	
Assembly at FAIR → SAT			Q1

Available resources

- Secured ~124k EUR from Czech Ministry of Education
- ~500k FAIR budget (previously as PSD in-kind, Moscow) upon FS+ approval
- In-kind from FZ Jülich (PMTs)

Table 1: Components/services to be procured for the completion of the CBM science programme, their estimated costs (current price level) and their latest date for procurement/expense to keep the timeline.

1	EXP	CBM SC Dipole magnet	4-5 Mio. €	July 2023
2	EXP	CBM Silicon Tracker System	0,9 Mio. €	Q3 2024
3	EXP	CBM PSD	0,5 Mio. €	Q4 2024
4	EXP	CBM RICH	1,0 Mio. €	Q2 2025
5	EXP	CBM MUCH	2,0 Mio. €	Q3 2025
6	ACC	CBM beamline magnets	4,2 Mio. €	Q4 2024
7	ACC	CBM beamline vacuum comp.	2,3 Mio. €	Q4 2024
8	S&B	TGA CBM cave	14,3 Mio. €	Q2 2024
9	S&B	TGA CBM cave risks	7 Mio. €	2024/2025
		Sum	**ca. 37 Mio. €**	

Estimated costs (w/o spares)

- Modules: 60k (cable track tbd.)
- Power and DAQ: 250k
- Mechanics: 250k
- NCAL not included