Towards the realization of the CBM-Micro Vertex Detector: Technological challenges and detector response simulation

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Compressed Baryonic Matter (CBM)

The future Compressed Baryonic Matter (CBM) is a fixed target experiment, to be operated at the FAIR facility at Darmstadt, and aims at the exploration of the properties of baryonic matter at high μ_b and moderate T.

<u>Experimental goals:</u>
✓search for in-medium modifications of hadrons
✓study of the transition from hadronic to partonic degrees of freedom
✓experimental search for structures in the QCD phase diagram

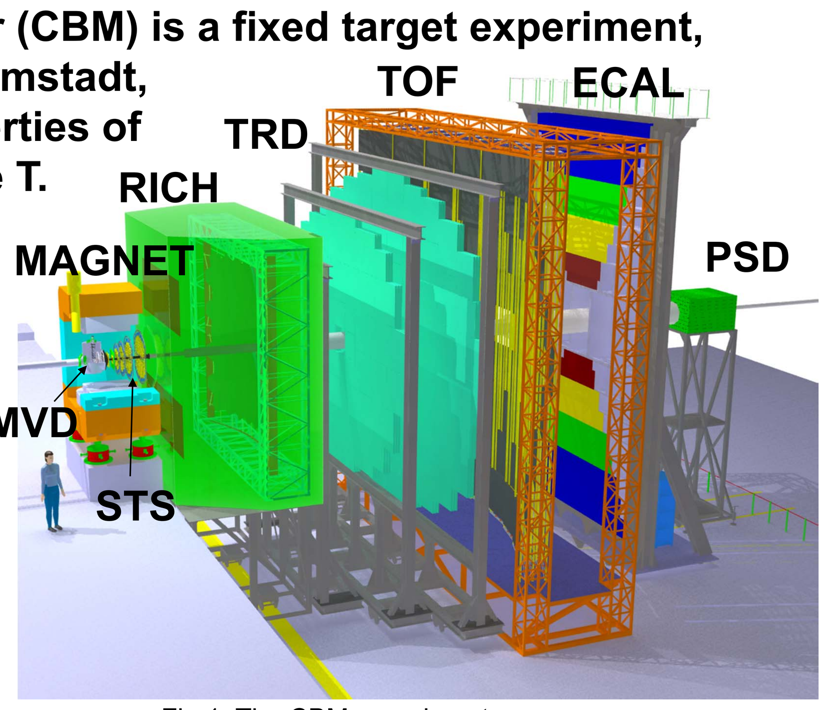


Fig.1: The CBM experiment.

CBM will study pA and AA collision systems (8-35 AGeV) with focus on rare diagnostic probes (i.e. open charm, dileptons) → **needs high interaction rates!**

Running conditions for the MVD

The Micro Vertex Detector (MVD) has to enable precise vertex reconstruction (~ 70 µm) for particles with short decay length e.g. : $D^0 \rightarrow \pi^+ K^-$, $c\tau$ = 123 µm.

For a central Au+Au collisions at 25 AGeV the predicted D^0 multiplicities are:
[1]HSD = 3.75×10^{-5}
[2]Statistical model = 2×10^{-4}
The multiplicities are ×3 larger for $\overline{D^0}$

Track density in the MVD stations can reach ~ 3/mm². The major contribution comes from δ-electrons from the target.

At interaction rates of 1 MHz substantial event pile-up is expected

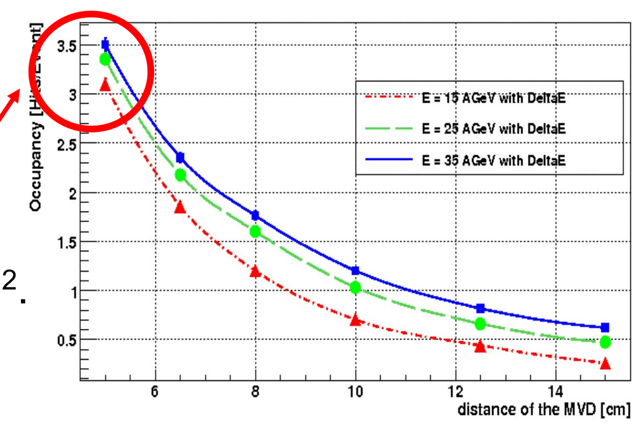


Fig.2: Hit density distribution on the hot spots for Au+Au collisions, 25AGeV at MVD stations located at different distances from the target.

<u>Dedicated detector and feasibility simulations are needed to demonstrate</u>
✓the feasibility of cluster finding and tracking in the MVD
✓the feasibility of reconstructing open charm

The Micro Vertex Detector: technological challenges

<u>Sensor technology</u>: Monolithic Active Pixels Sensors (MAPS) developed at IPHC Strasbourg

	Requirements CBM@SIS300	MAPS (2002) MIMOSA-5	MAPS (2010) MIMOSA-26	Improvement achieved
Single point res.	~5 µm	~2 µm	~3.5 µm	not required
Mat. Budget	< 0.05%X_0	< 0.1%X_0	< 0.05%X_0	x2
Rad. Tol. (non-io.)	>10^{13} n_{eq}/cm²	<10^{12} n_{eq}/cm²	>$1\cdot10^{13}$ n_{eq}/cm²	x10
Rad. Tol. (io.)	>3 MRad	< 0.2 MRad	0.3 MRad (Probably >1MRad*)	x5*
Readout time	~30 µs	~6000 µs	~100 µs	x60

* More than 1 MRad was demonstrated with small sensors. MIMOSA-26 was not optimized for this purpose but might reach this value if thermal annealing is applied (to be confirmed).

<u>Detector layout</u>: 2 stations of silicon pixel detector (5 cm and 10 cm from the target.)

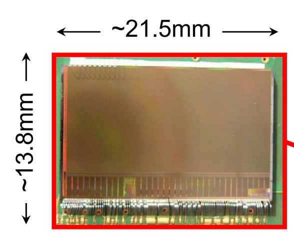


Fig.3a: Photograph of a MAPS sensor (MIMOSA-26). It consists of 1152×576 pixels of 18.4µm pixel pitch.

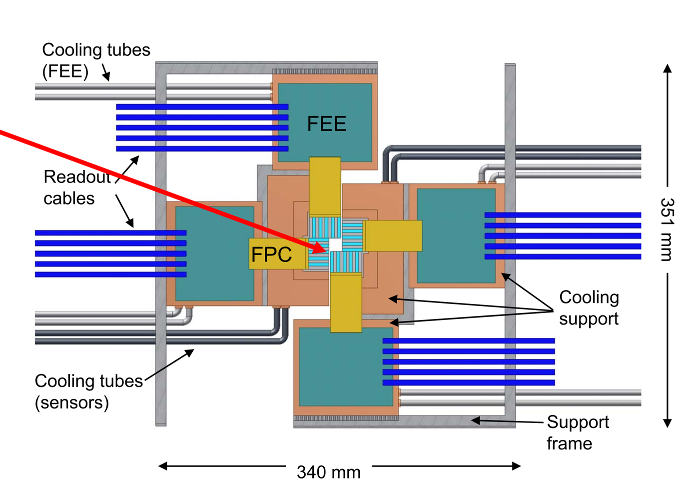


Fig.3: Illustration of the MVD detector with its cooling and support structure.

- Operation in vacuum, inside a magnetic field (1Tm).
- Material budget ~0.3%X_0 (needs ultra-thin detector technologies).
- Use CVD diamond as support to enhance lateral heat evacuation to an actively cooled heat sink located outside the CBM acceptance.
- Discriminate data on the sensor (demonstrated with MIMOSA-26).
- Build optical high performance network in synergy with HADES.

MAPS provide nowadays best compromise between precision and rate capability.
Their readout speed and radiation tolerance is under improvement.

Development of detector response model

- **Goal:** reproduce the measured response of MAPS for the CBM-MVD
- **Challenge:** Good description also for particles with high incident angles

Step1:
Charge of the full cluster taken from measured Landau distribution of collected charge.

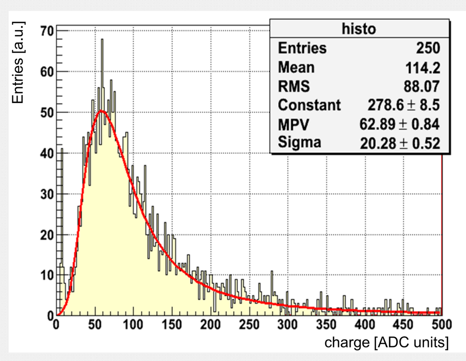


Fig.4: Measured Landau distribution of collected charge on 25 pixels

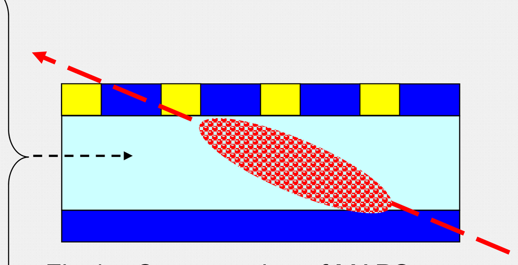


Fig.4a: Cross section of MAPS sensor.

Step2:
Subdivide particle trajectory into "ionisation points"
Distribute charge according to measured Lorentz distribution.

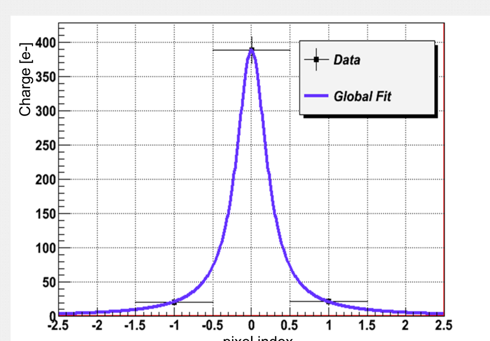
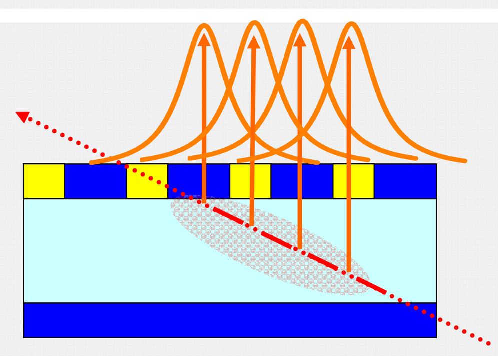


Fig.5: Measured Lorentz distribution



\+ Fast and flexible model, low uncertainties due to the use of measured data.
\+ Easily adaptable to various sensor configurations.
\- Model needs input from experimental data (+sizable data base available).

Benchmarking of the response model

- Reference data obtained from beam test at CERN-SPS, 120 GeV/c pions
- Reference MAPS sensor: MIMOSA 17 (30 µm pixel pitch)
- Data taken for various particle incident angles (0°-75°)

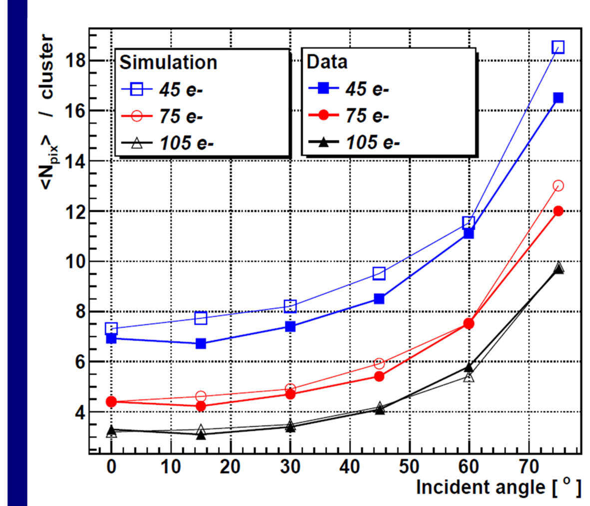


Fig.6: Average number of significant pixels for simulated and real data. The different colours correspond to various selection thresholds.

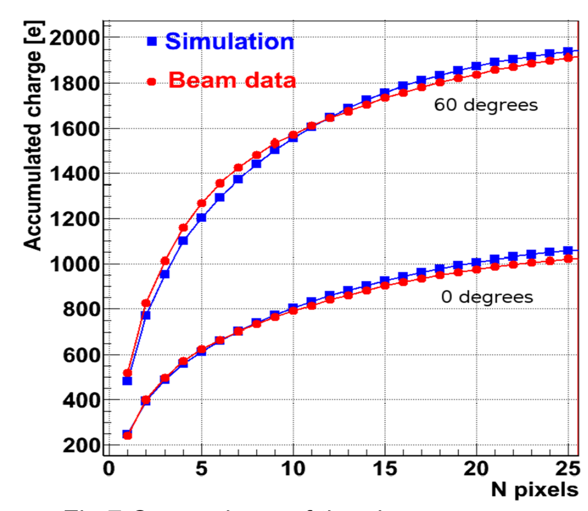


Fig.7 Comparison of the charge distribution among pixels inside a cluster. for two particle incident angles (0 and 60 degrees).

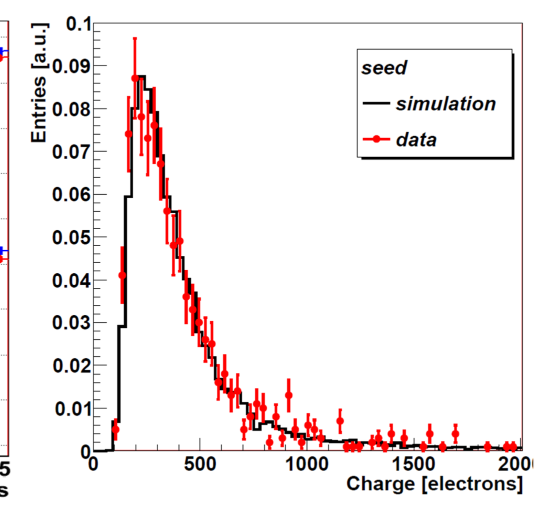


Fig.8 Comparison of the measured and simulated distribution of collected charge on the seed pixel.

Simulation matches experimental data within 10%.
✓ Good agreement for particles with high incident angles
✓ Good agreement for clusters with high pixel multiplicity

Physics performance studies

Demonstrate feasibility for open charm detection in conservative scenario.

- Benchmark observable : $D^0 \rightarrow \pi^+ K^-$ (meson with shortest decay length, **$c\tau$=123µm**)
- Production multiplicity (SHM) for Au+Au collisions at 25 AGeV
- Central collisions (open charm production in peripheral collisions ignored)
- Kaon identification capability of TOF not used; δ-electrons included
- Conservative collision rate, no pile up assumed: 3×10^4 coll./s (MVD may accept up to 5× higher collision rates, study ongoing.)
- 1.5×10^{11} collisions measured after 1 CBM run period (~8 weeks)

MVD simulated features (SIS-100/300 sensor):
- 18.4µm pixel pitch, 1-bit ADC readout
- readout time: 30µs
- UrQMD collisions for background
- Embedded D^0 decay for signal events

Expected statistics after one CBM run period (~8 weeks):
6 000 D^0+$\overline{D^0}$

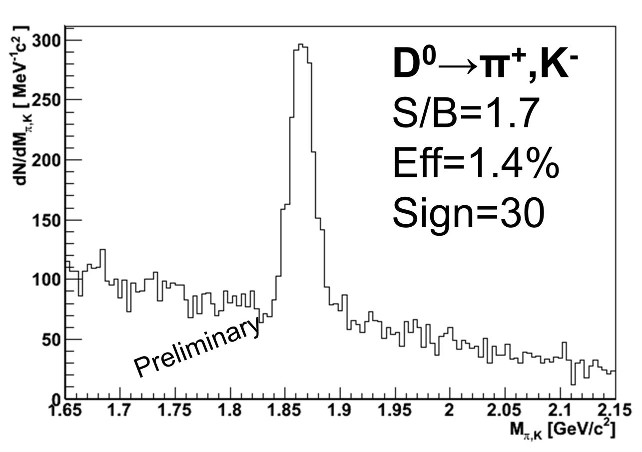


Fig.9: D^0 invariant mass spectra as expected after one CBM run period (5×10^6s).

Summary & Conclusion

✓The physics case of CBM requires a highly precise, radiation hard, fast and ultra thin MVD.

✓The detector concept foresees a silicon pixel detector based on MAPS which operate in vacuum.

✓A detector prototype is being developed based on state of the art sensors and a CVD diamond support.

✓A realistic response simulation model for the MVD is needed to validate the tracking and open charm reconstruction with this detector concept.

✓The model has been developed and shows better than 10% agreement with measured data for incident angles of up to 75 degrees.

✓The physics performance studies showed that with the given MVD concept CBM will be sensitive to open charm provided it is produced with the multiplicity predicted by current models.

References: [1] "The CBM Physics book", Lecture Notes in Physics, Vol. 814 1st Edition, 2011, ISBN: 978-3-642-13292-6 ;
[2] A.Andronic, personal communication

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