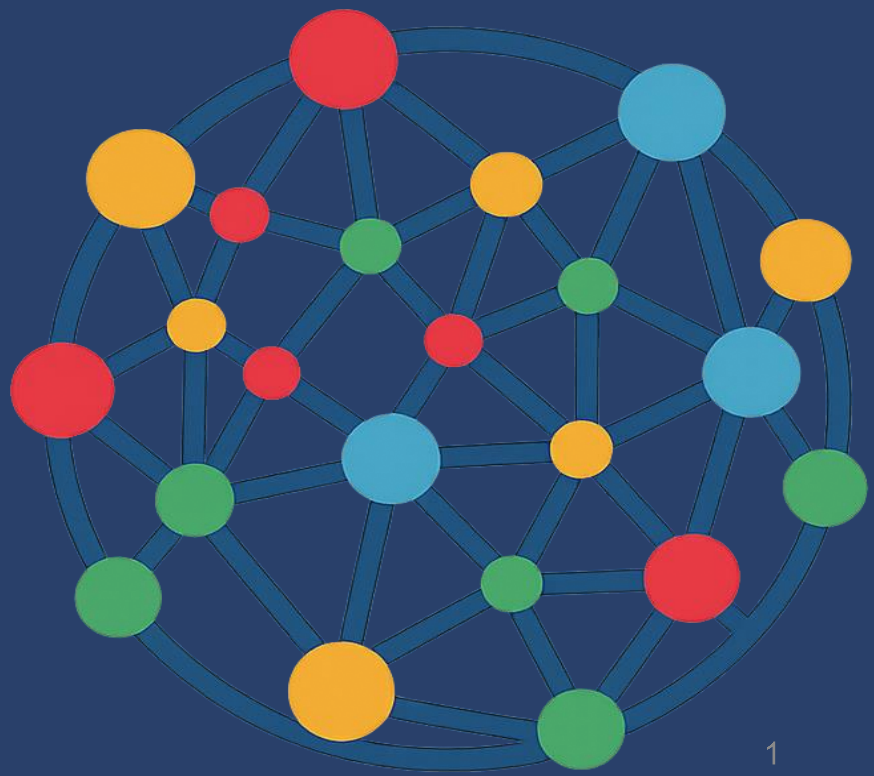
GSI Helmholtzzentrum für Schwerionenforschung

FAIR

Bundesministerium für Forschung, Technologie und Raumfahrt

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Bridging Domains: AI-Driven Agnostic Reconstruction Frameworks for Irregular High-Dimensional Data

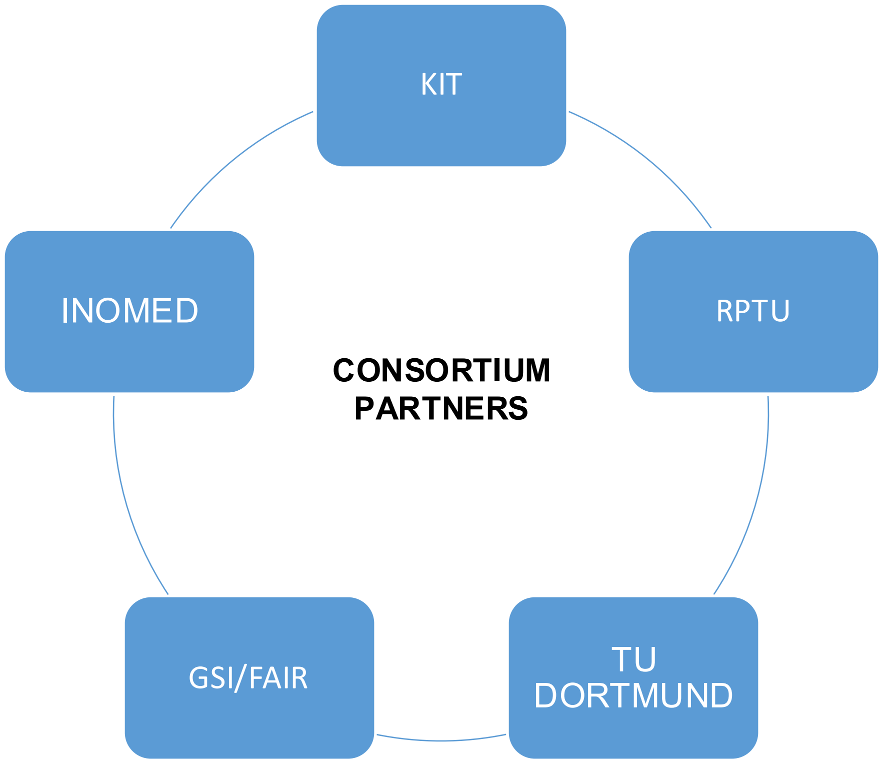


Smiriti Sharma
PhD
Goethe University Frankfurt/GSI

31 JULY 2026

BRAID and its consortium partners

The consortium brings together **computer science, HEP, astroparticle physics, hadron & nuclear physics,** and industry applications such as medical monitoring. Common methods are developed in the computer-science core and challenged and refined by the application domains.



WHY BRAID?

BRAID CORE - COMPUTER SCIENCE

Physics-informed ML

- **Graph & message passing methods**
  Represent detector hits as a relational structure rather than a fixed image-like grid.
- **Physics constraints**
  Encode locality, symmetries and domain knowledge as inductive bias.
- **Adaptive dimensionality reduction**
  Reduce the number of relevant inputs while retaining information needed for reconstruction.
- **Attention & information propagation**
  Propagate information between related detector responses before object reconstruction.

DETECTOR-AGNOSTIC RECONSTRUCTION

From detector signals to physics objects

Irregular inputs	Sparse detector hits, timing and signals
Learn structure	Dynamic graph construction and information propagation
Reduce intelligently	Adaptive local dimensionality reduction
Reconstruct	Particles / objects with physics constraints

PHYSICS DOMAINS (APPLICATION)

ENERGY

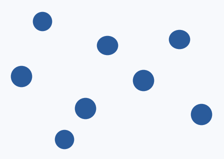
- **ASTROPARTICLE PHYSICS**, TU DORTMUND (ICECUBE)
- **HIGH ENERGY PHYSICS**, KIT (CERN / HL-LHC / FCC)
- **HADRON AND NUCLEAR PHYSICS**, GSI/FAIR (CBM and PANDA)

What BRAID is building

FROM DETECTOR RESPONSES TO RECONSTRUCTED PHYSICS OBJECTS

Irregular inputs

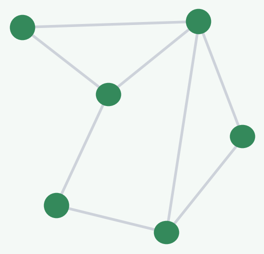
Sparse hits, timing + signals



No fixed grid: sparse detector responses are represented directly.

Learn the relevant structure

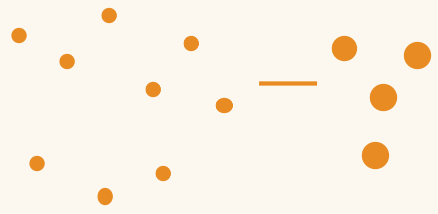
Dynamic graph construction



Learn relations between related detector responses through graph connectivity and information propagation.

Reduce early

Adaptive, local dimensionality reduction



Reduce the representation adaptively while preserving information needed for reconstruction.

Reconstruct

Particles / objects with physics constraints

Use the reduced representation to reconstruct physics objects under physics constraints.

BRAID at GSI/FAIR

FAIR provides a common experimental environment in which beam lines, targets and detector systems can vary substantially.

Picture: ion42, D. Fehrenz, GSI/FAIR

SHARED CHALLENGES

Different beams

Proton, heavy-ion and antiproton beams lead to different event topologies and particle multiplicities.

Different detector layouts

Tracking and muon systems differ in geometry, granularity and absorber configuration.

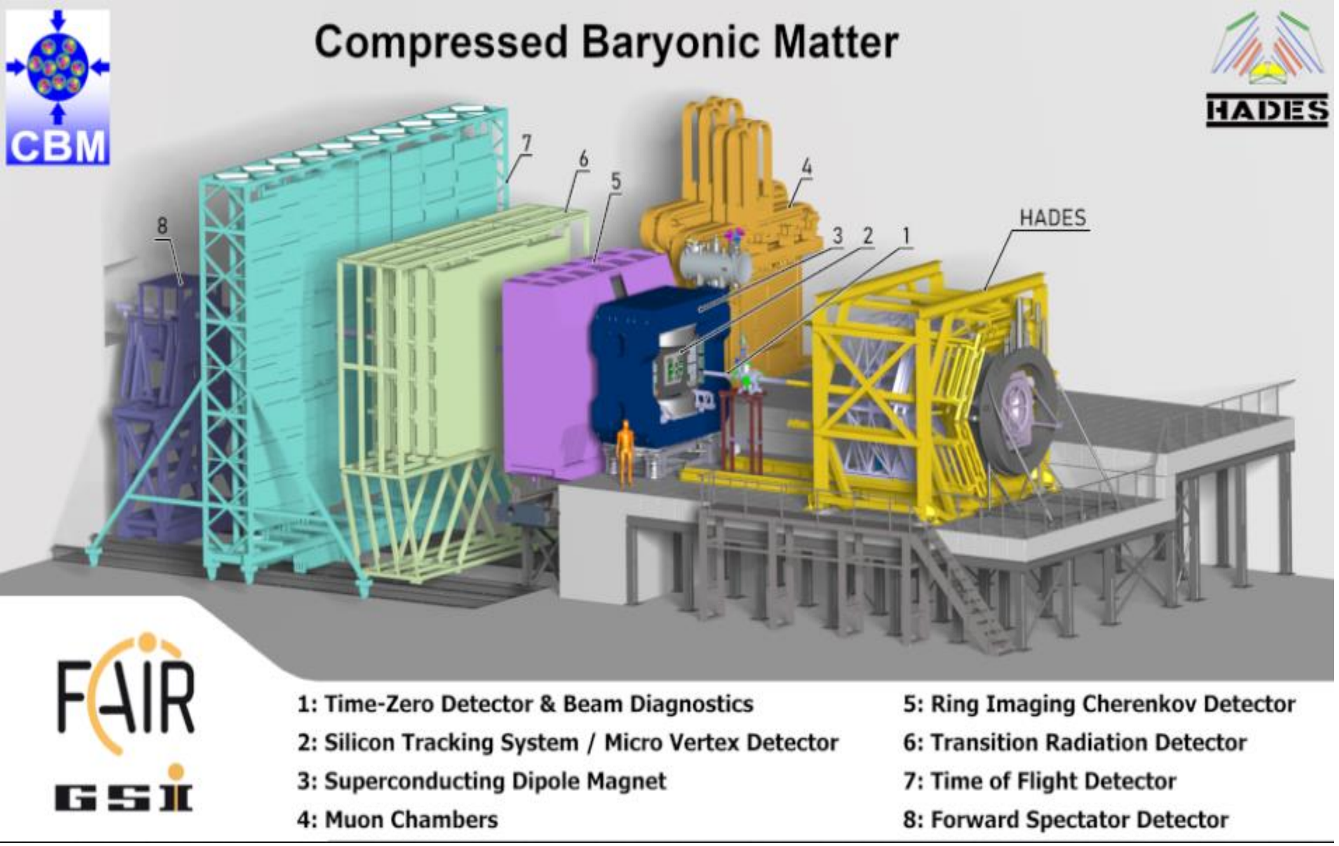
Changing conditions

Reconstruction must remain robust as operating conditions and detector configurations change.

Common reconstruction goal

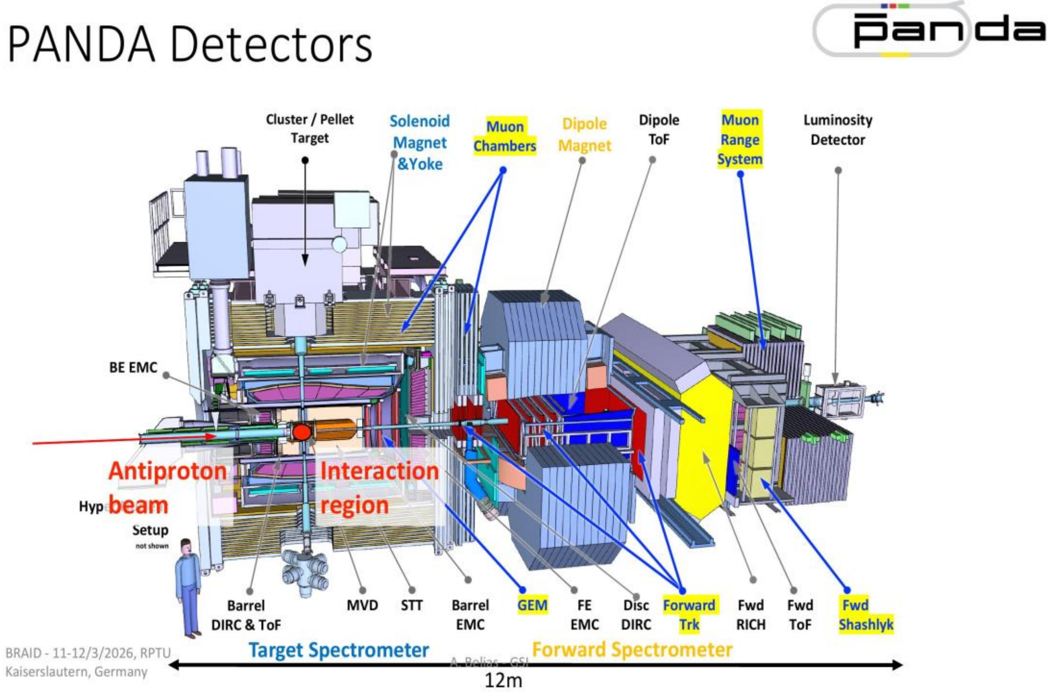
Infer particle-level information from sparse detector responses while maintaining robust performance.

BRAID use cases: Muon detectors in different experiments at FAIR



First in CBM

SIS100 fixed-target heavy-ion collisions
- High rates and complex backgrounds
- Muon identification with MuCh / MuSt



Later at PANDA

HESR Antiproton proton collisions
- Tracking + particle identification
- Multiple muon detector systems (FT, MRS)

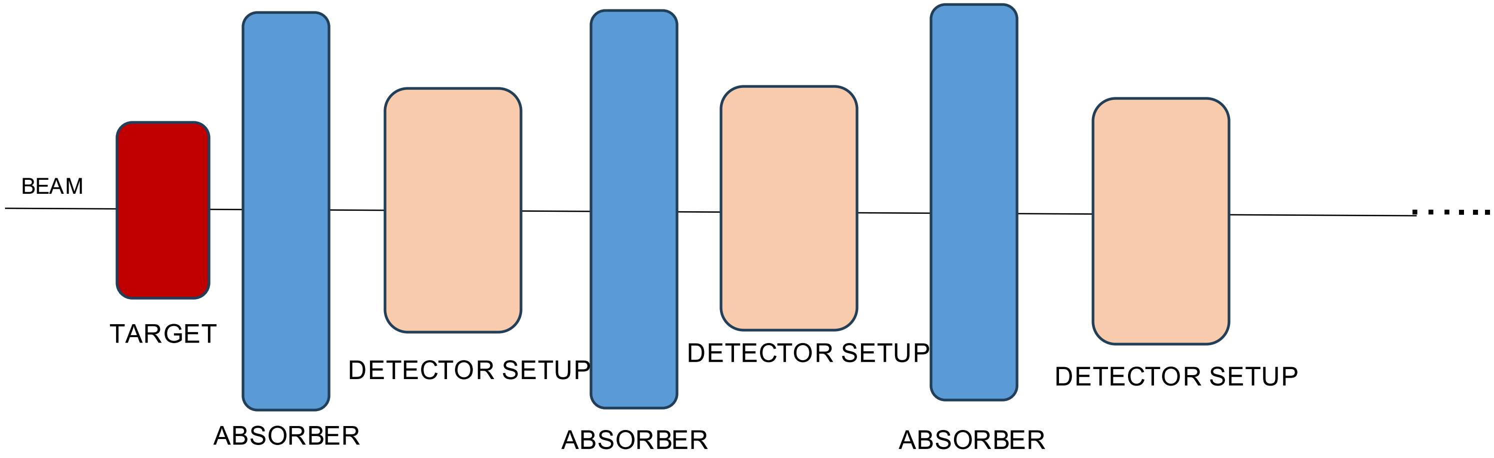
OPTIMIZED INSTRUMENTATION

CHALLENGE

The reconstruction challenge is to infer the muon hypothesis from correlated detector responses in the presence of background.

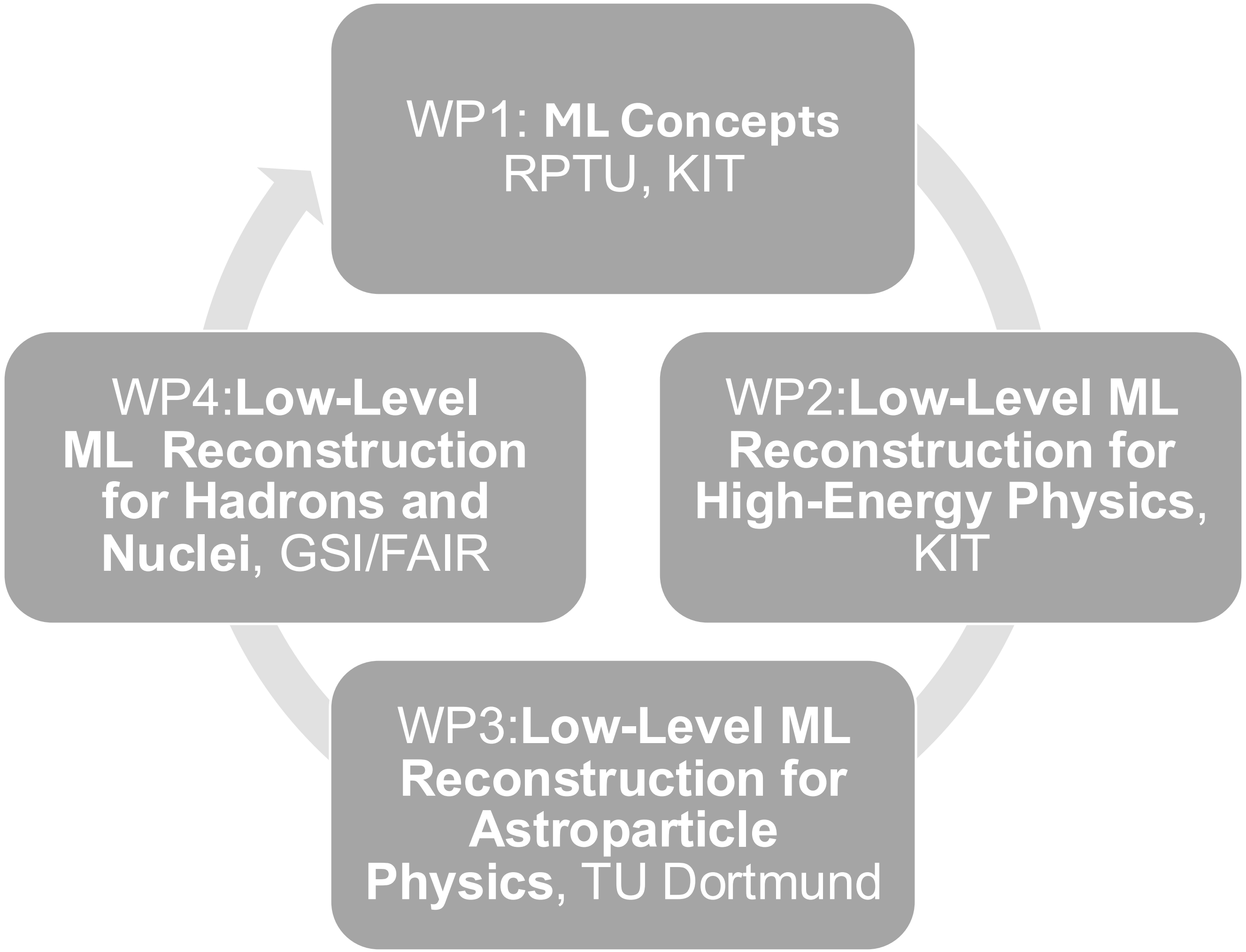
- **Muons can traverse absorber material and leave signals in downstream layers.**
- **Hadronic interactions and secondaries can create background hits and false candidates.**
- **Forward systems can combine gaseous detectors, straw tubes and absorbers.**
- **The ML representation must exploit hit correlations while remaining robust to geometry changes.**

EXAMPLE



Particle propagation → detector response → correlated hits → track / candidate → muon identification

WORK PACKAGES



Work Packages in BRAID

WP1a — Physics-informed ML architectures, KIT: Construct **graph topologies** for sparse detector responses. Develop **message-passing architectures** for information propagation. Incorporate physics constraints and locality as inductive bias.Investigate attention / **information propagation.Develop architectures transferable** across detector configurations.

WP1b — Adaptive reduction & discrete optimisation, RPTU : Develop **adaptive dimensionality reduction** with minimal information loss .Combine **classical algorithms with ML** where useful.Address thresholding, clustering and other non-differentiable operations.Learn discrete / combinatorial decisions. Provide reduction mechanisms for **adaptive reconstruction.**

WP4 — Hadron & Nuclear Physics, GSI/FAIR: Applies the ML methods from **WP1** to FAIR physics, mainly **CBM and also** PANDA Works on **fast and adaptive reconstruction**, simulation datasets, and physics-performance studies Also looks at how different **detector geometries** affect the reconstruction FAIR provides the physics cases where the ML methods can be **tested and improved under different experimental conditions**

THANKYOU