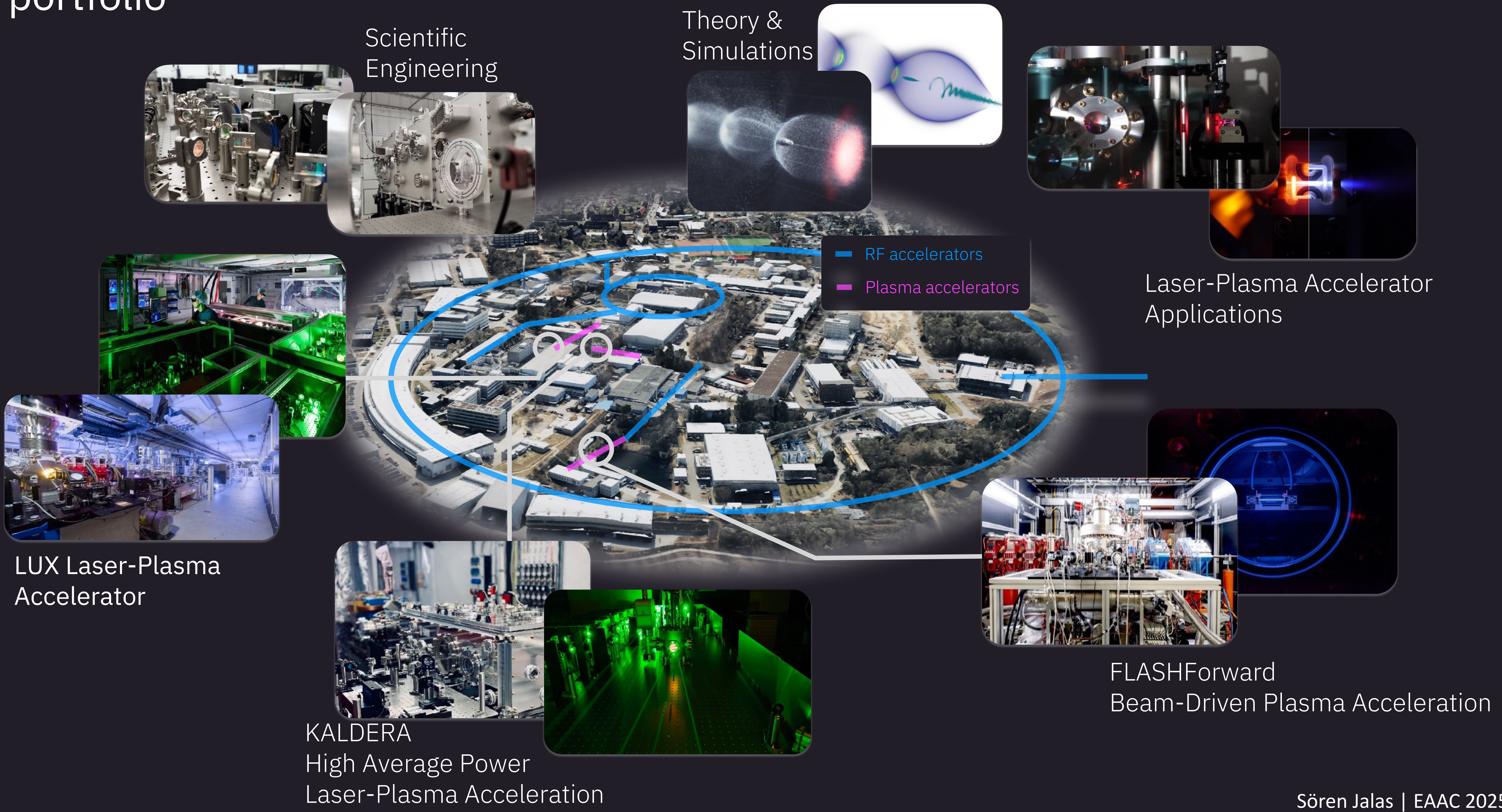
Data-Driven Exploration of High Average Power Laser-Plasma Accelerators

7th European Advanced Accelerator Conference–Elba 2025

Sören Jalas

Plasma accelerator research at DESY

Our portfolio



Plasma accelerator research at DESY

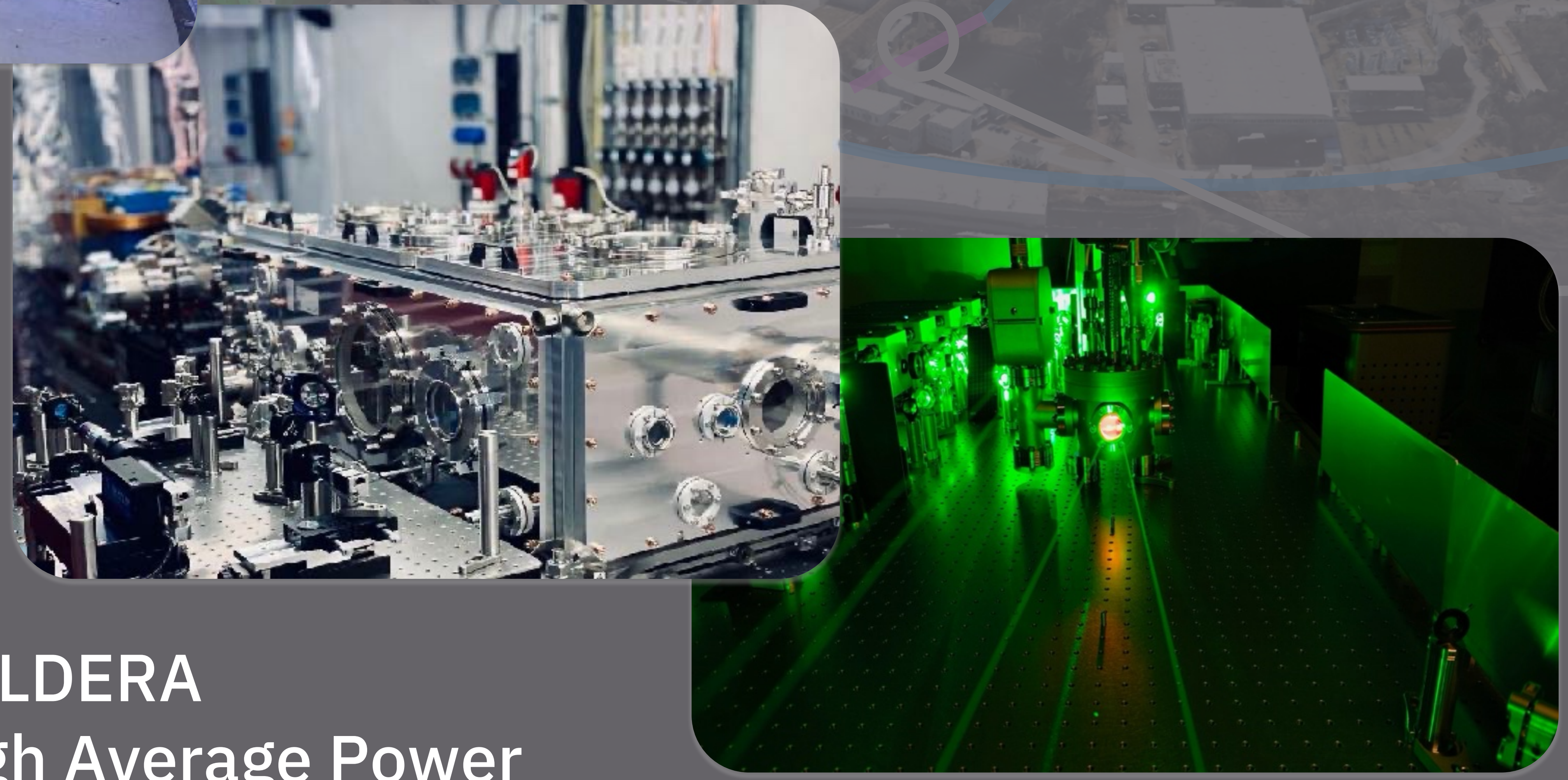
Our portfolio

Scientific Engineering

Theory & Simulations

Laser-Plasma Accelerator Applications

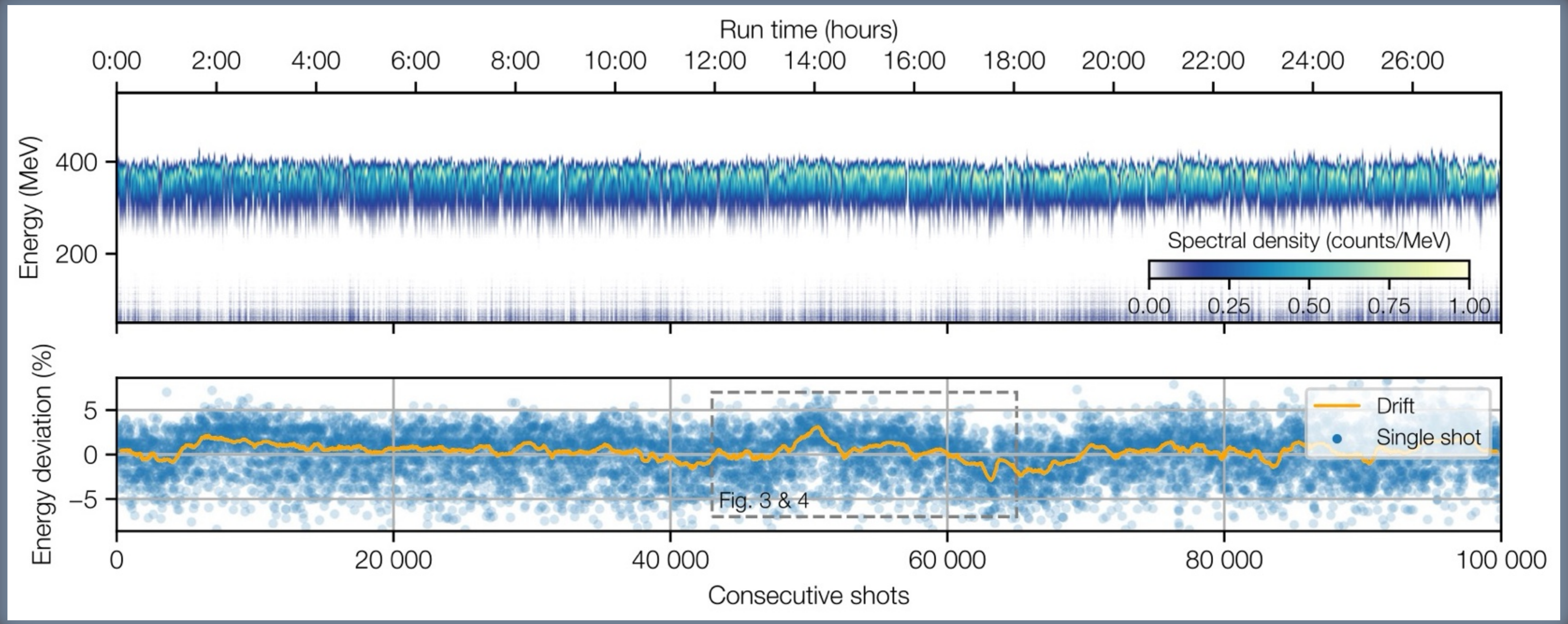
LUX Laser-Plasma Accelerator



KALDERA
High Average Power
Laser-Plasma Acceleration

FLASHForward
Beam-Driven Plasma Acceleration

LUX Accelerator



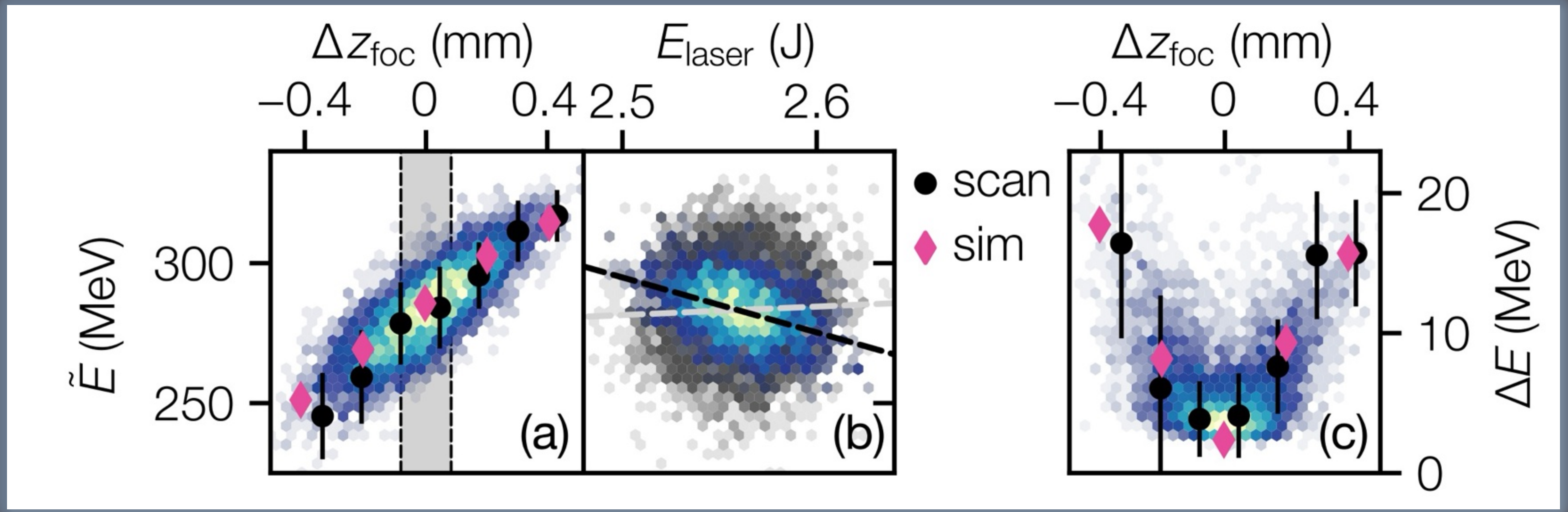
A. R. Maier et al. Phys. Rev. X (2020)

Reliable 1 Hz operation over hours and days

Enabled by thorough engineering and laser drift compensation systems

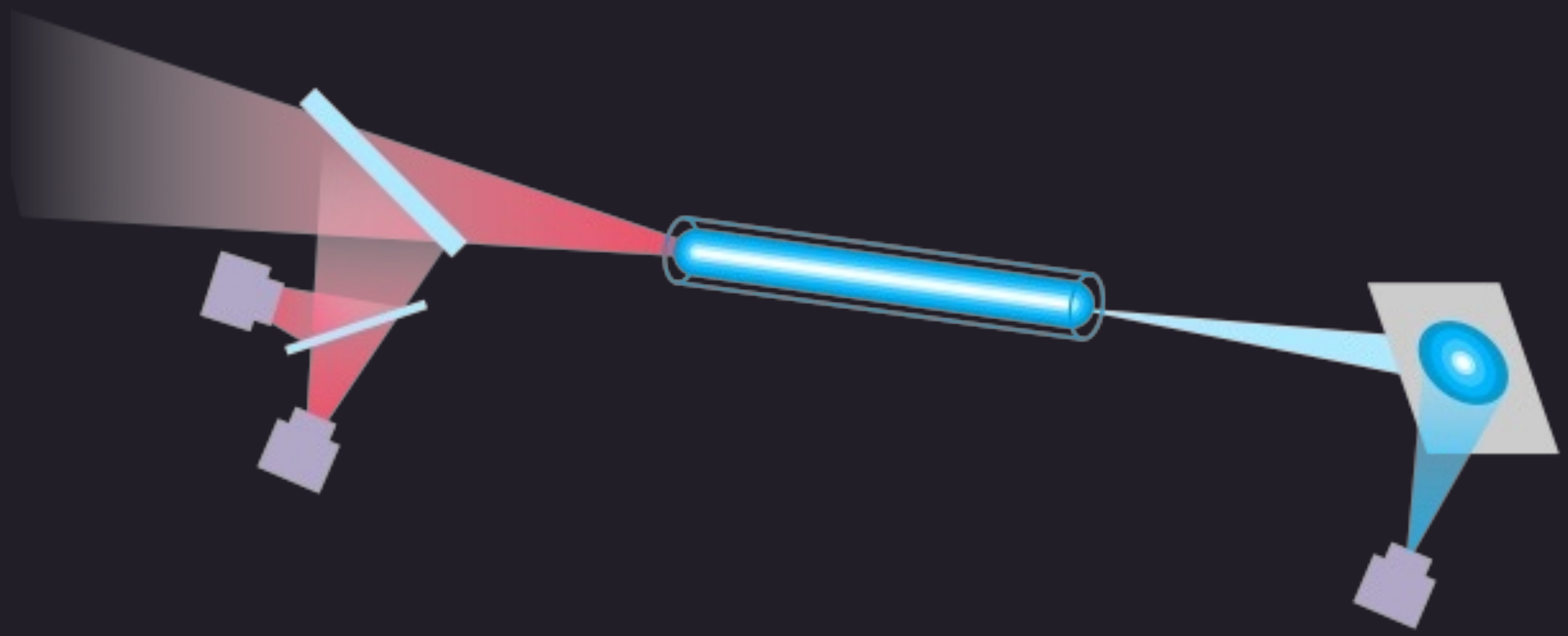
Shot-to-shot diagnostics of laser and electrons

Provide insight into intrinsic correlations and dynamics of laser-plasma interaction



M. Kirchen et al. Phys. Rev. Lett (2021)

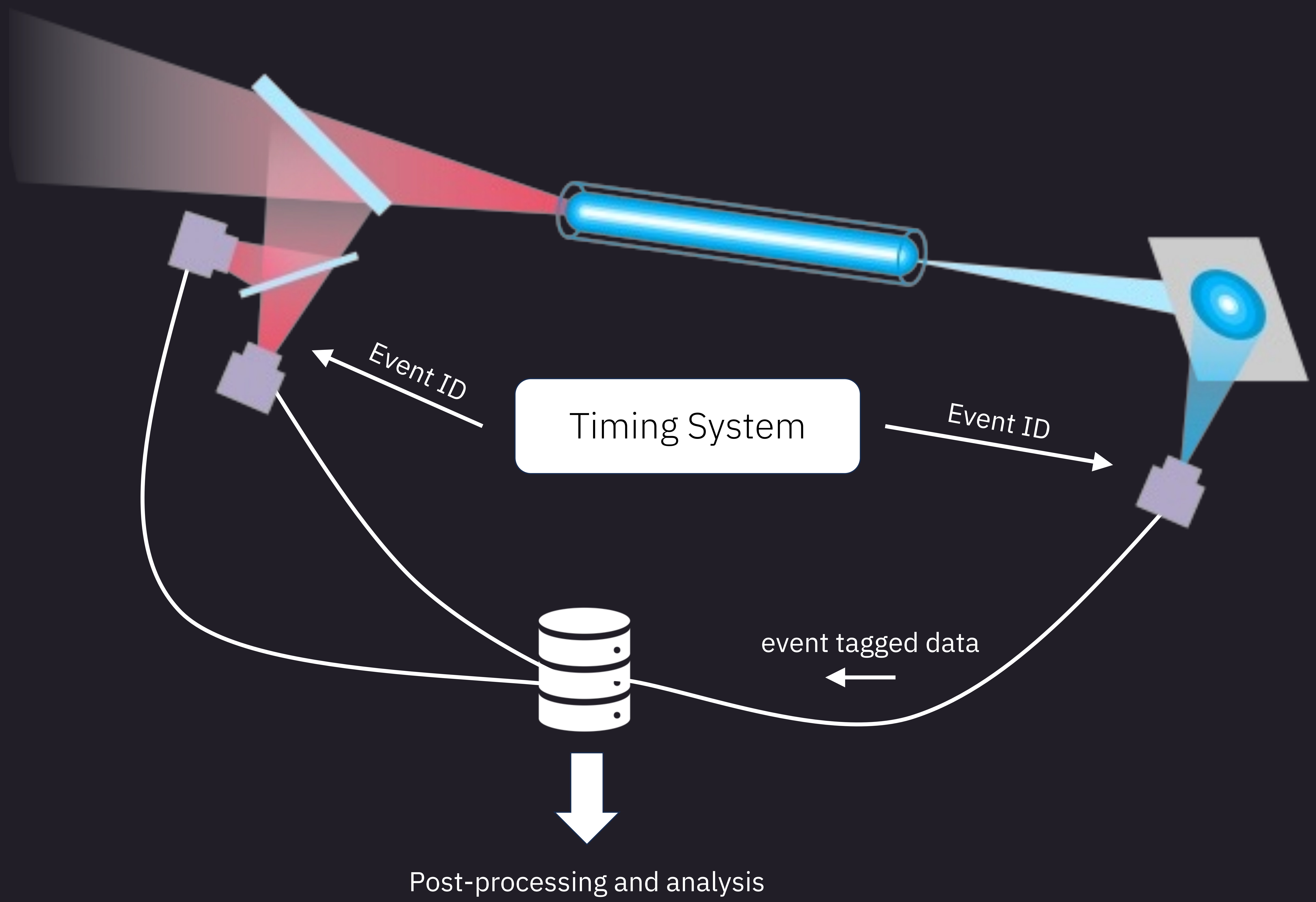
Data Acquisition Strategies



Diagnostics

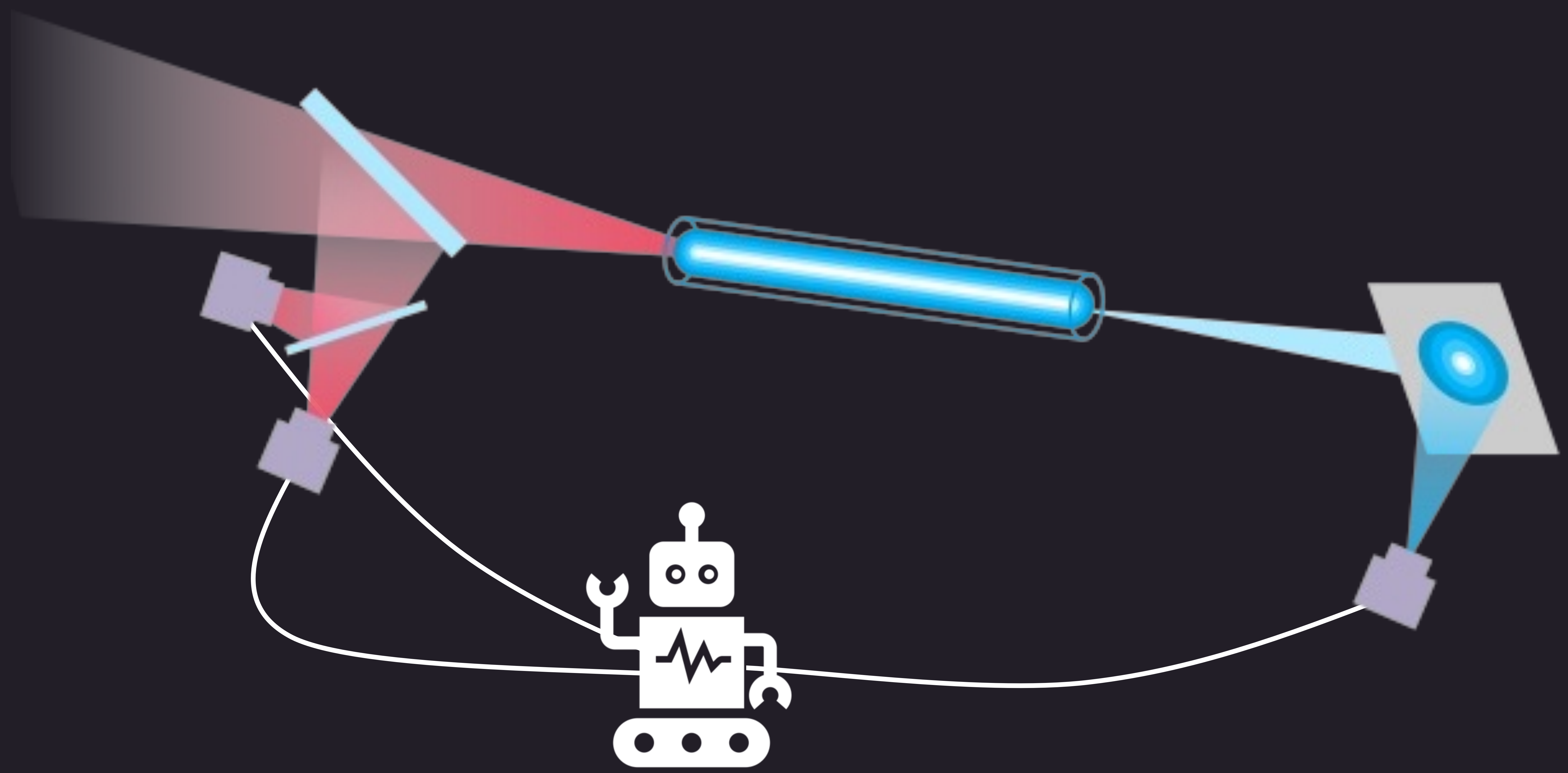
100s of cameras throughout laser and LPA
Beam position monitors
Charge monitors
Pressure and flow sensors
Laser energy meters
Spectrometers Wavefront sensors ...

Data Acquisition Strategies
The centralized approach



Data Acquisition Strategies

Advanced algorithms



Kaldera & Magma

Magma

Compact platform for high average power LPA

Interaction Chamber

Electron Transport & Diagnostics

Laser Diagnostics

High average power laser-plasma acceleration

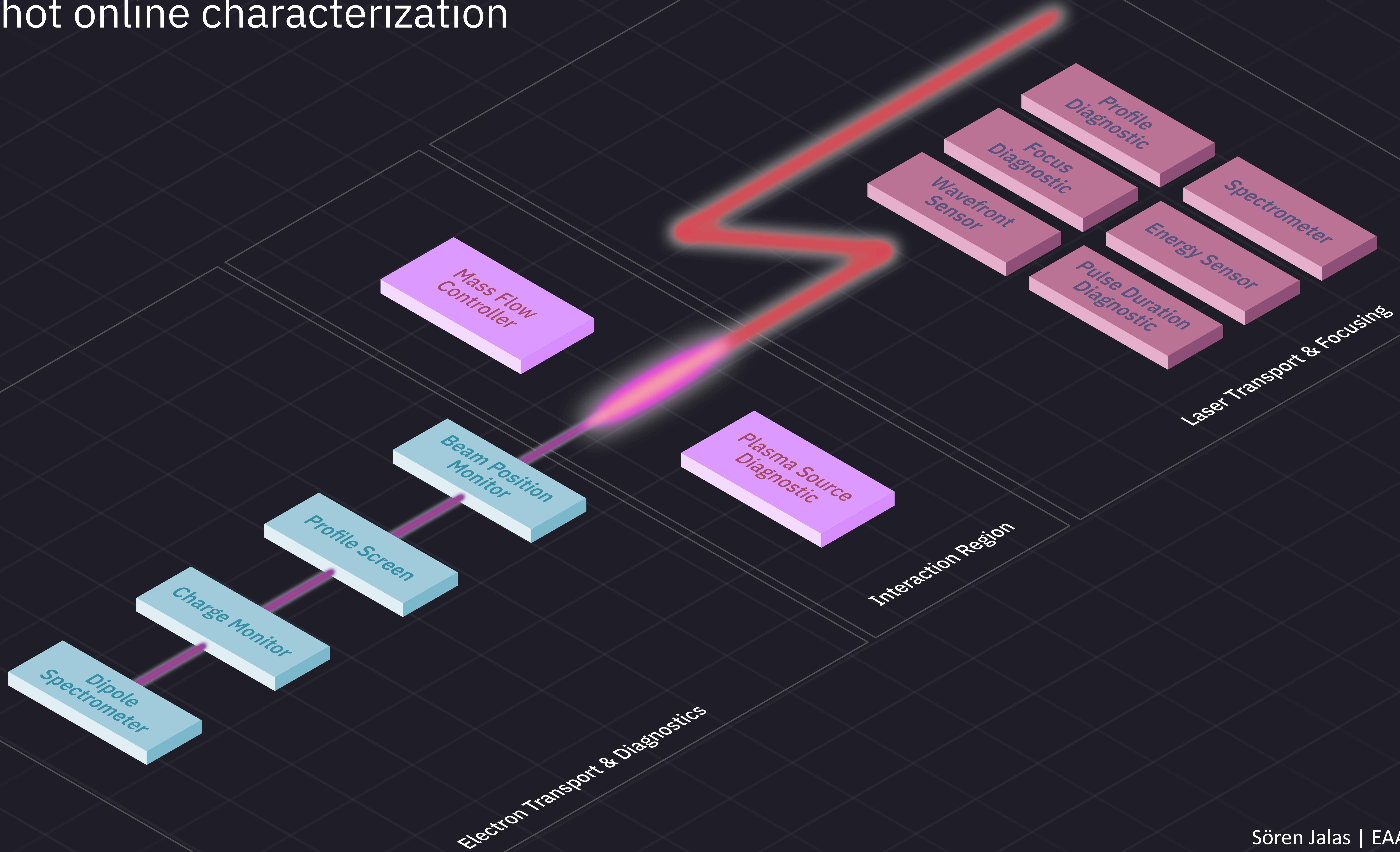
100 Hz acceleration of electron beams using the Kaldera drive laser system

Active stabilization and feedback control

Leverage high repetition rate for fast feedback to compensate acoustic and thermal variation within the system

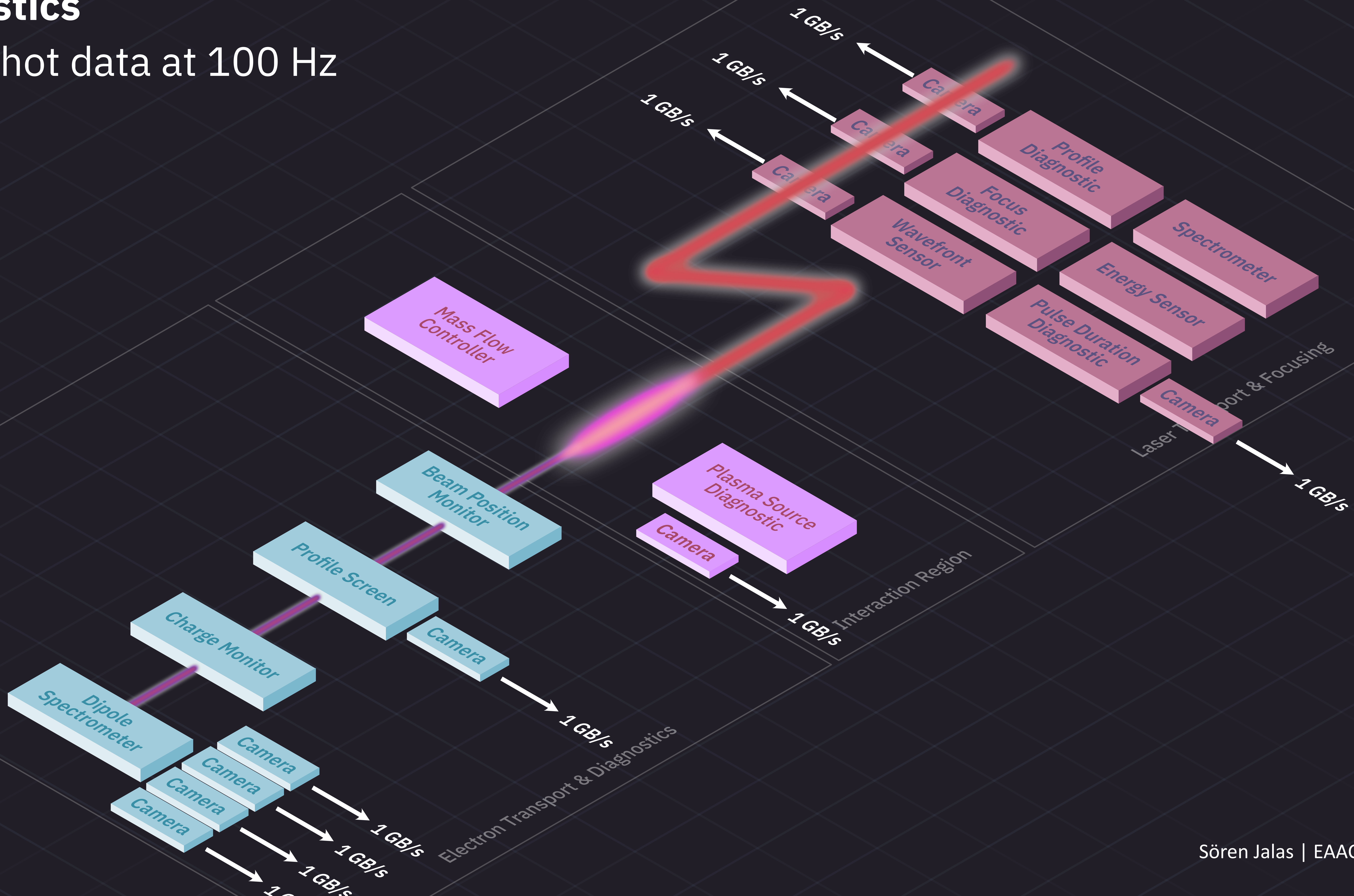
Diagnostics

Single shot online characterization



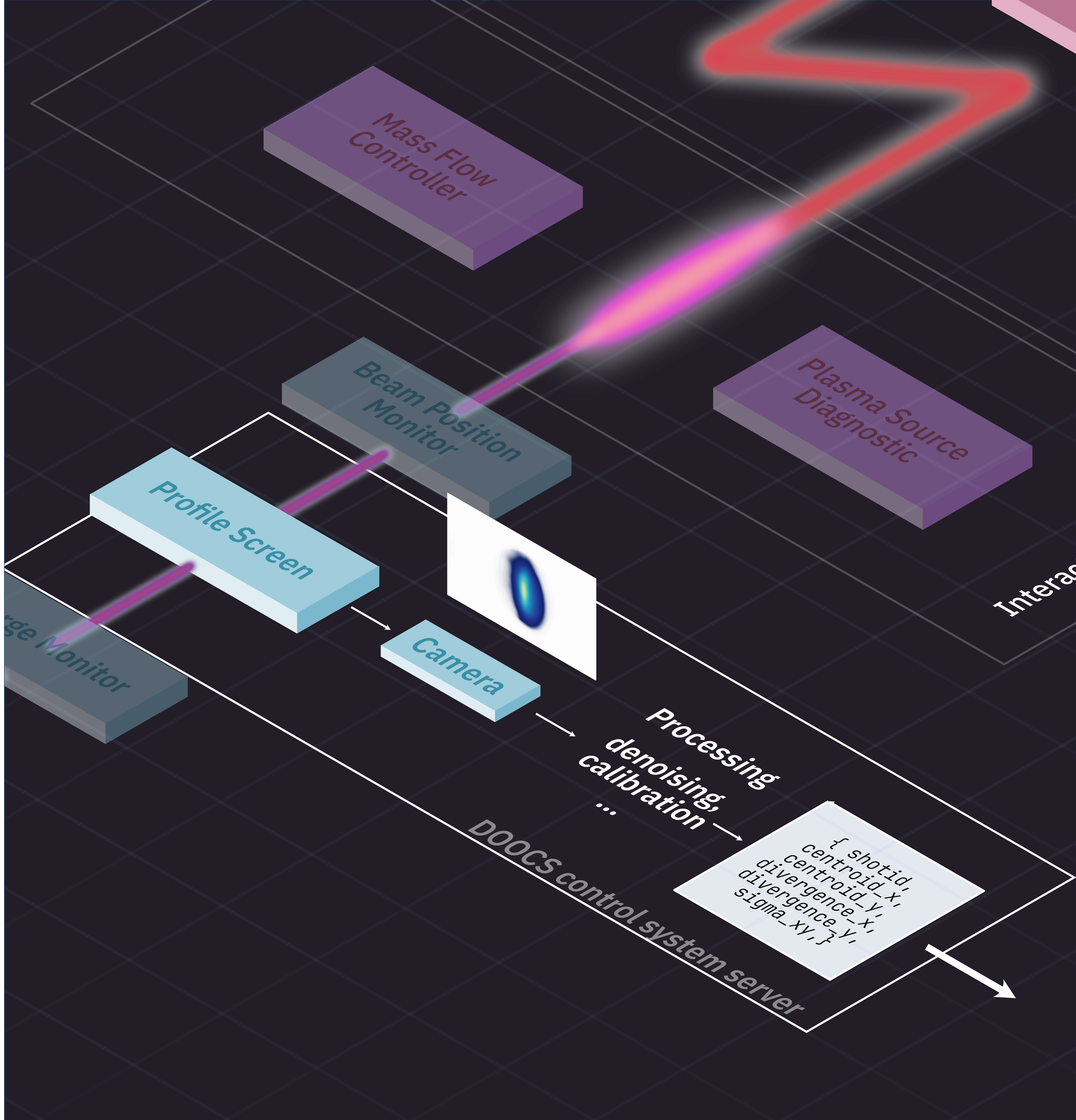
Diagnostics

Single shot data at 100 Hz



Online Data processing
Data reduction and processing

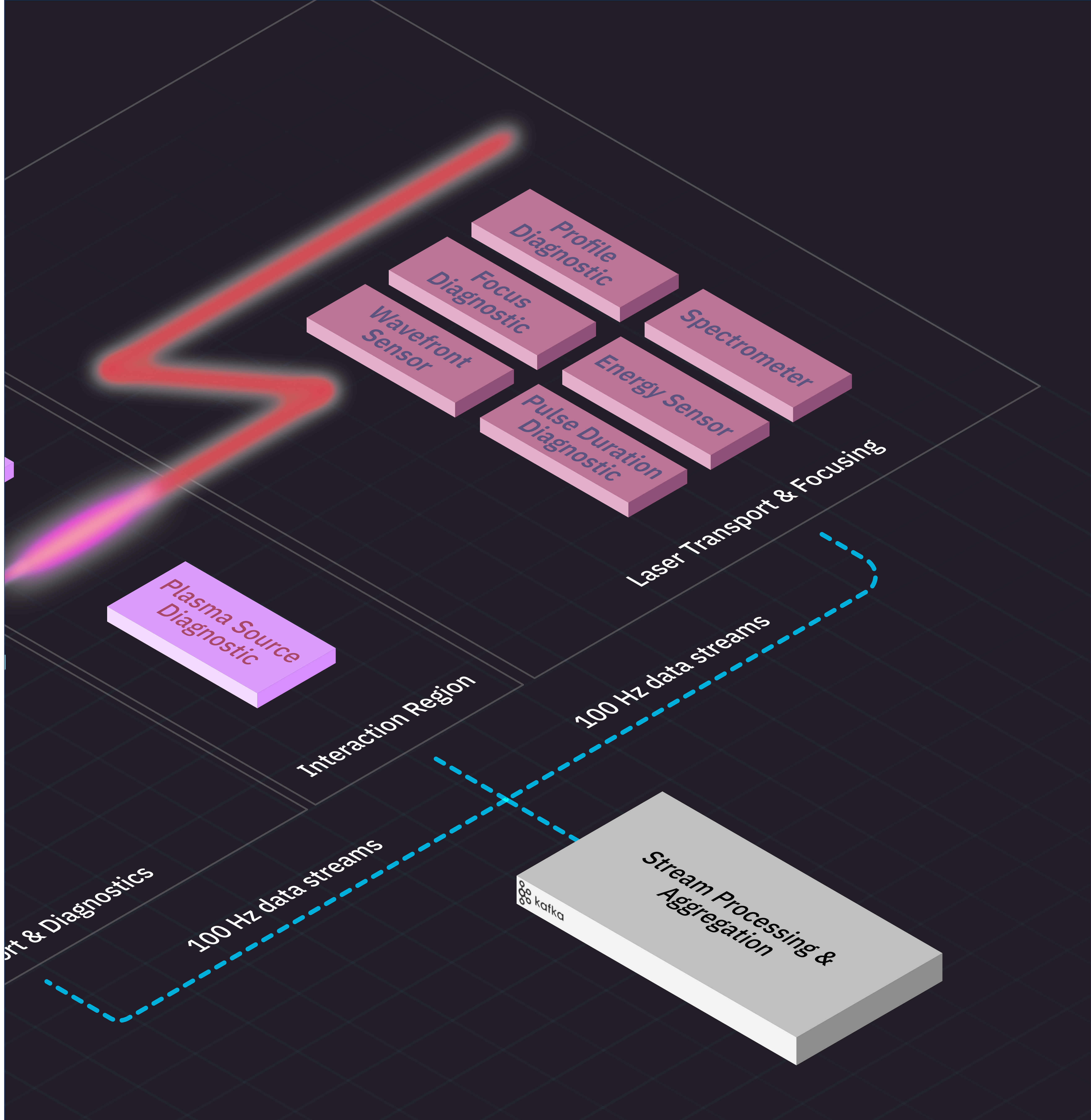
- Distributed data collection and processing
- Event id tagged data at 100 Hz repetition rate
- Full image streams on demand, subsampled streams for monitoring



Stream processing

Collecting and joining data streams

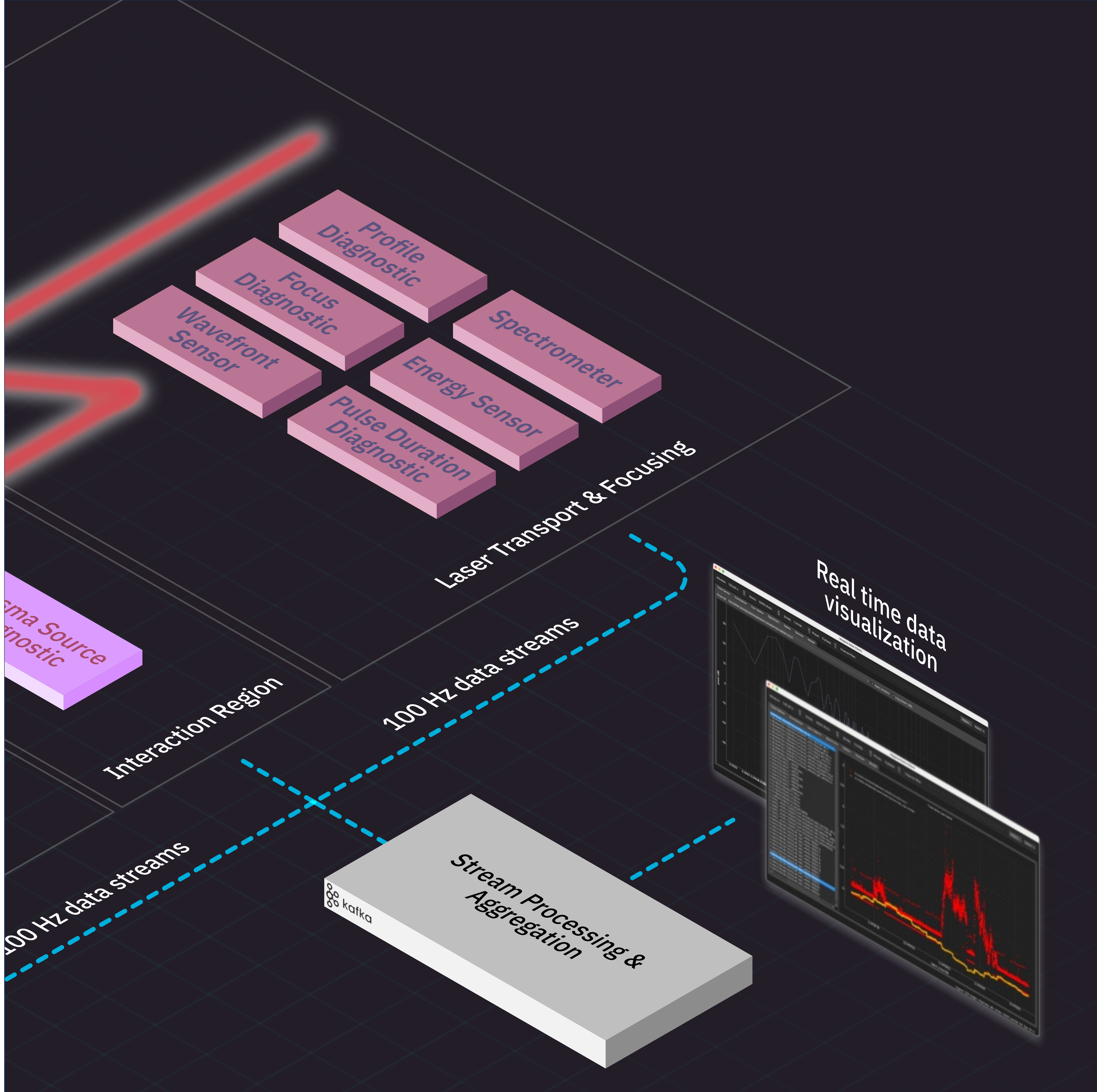
- Use centralized message broker to collect processed data from all diagnostics
- Join data by common event id
- Provide combined data stream for the full experiment



Stream processing

Online visualization and analysis

- Data exploration in the control room
- Find relevant control parameters
- Study correlations & dependencies



Real Time Data Access

Online visualization and analysis

100 Hz Data streaming

Real time monitoring of all diagnostics

Real Time Data Access

Online visualization and analysis

Frequency analysis

Identify paths to active stabilization

Real Time Data Access

Online visualization and analysis

Tagged Data

Event based joined data for online correlations

Real Time Data Access

Online visualization and analysis

Live Correlation Tables

All important parameters at a glance

Real Time Data Access

Online visualization and analysis

Online modeling

Fit linear models to streaming data to find parameter dependencies and partial derivatives

Data Storage

Short- and long-term archiving

Multi-tier storage system

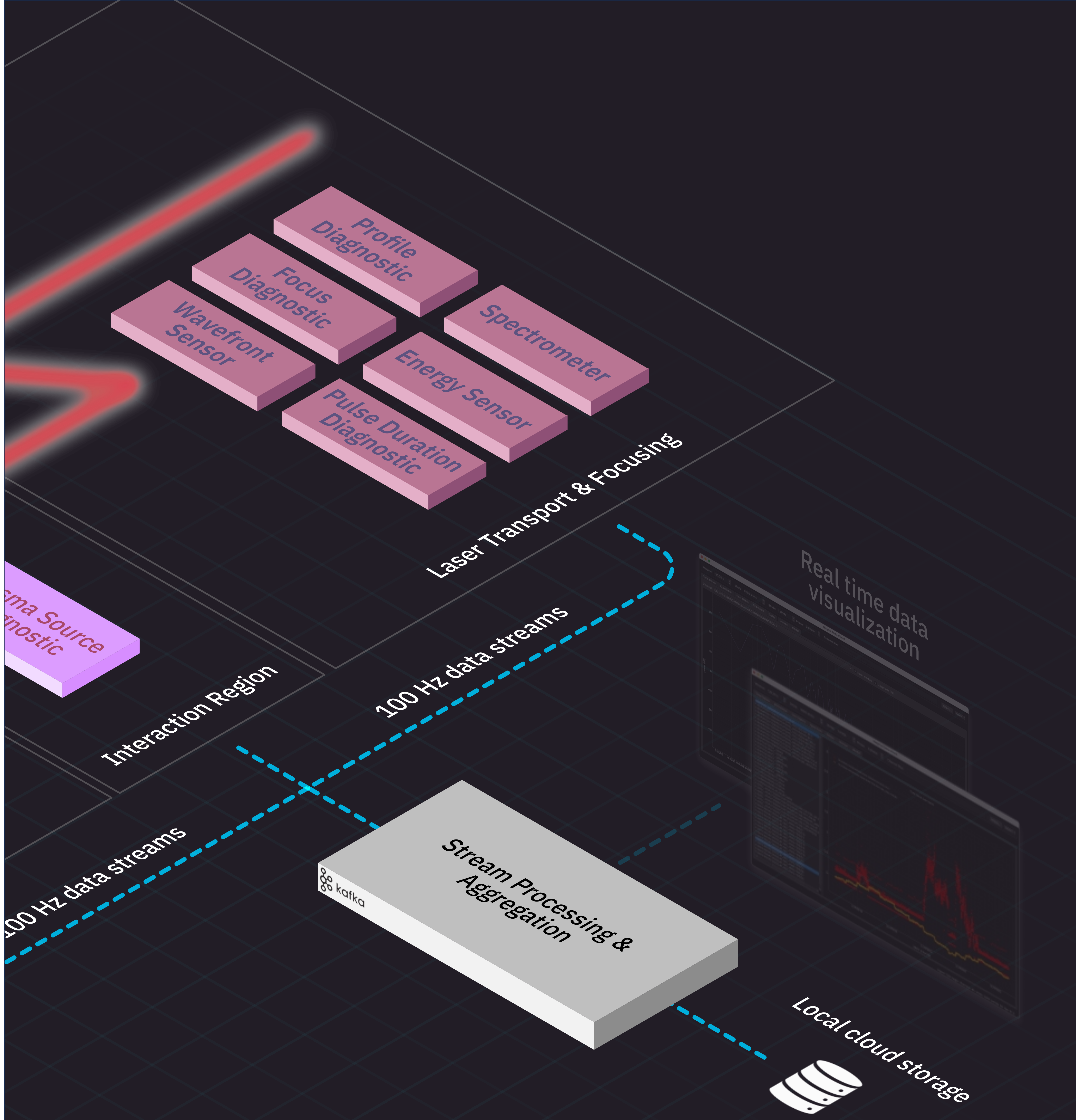
Short term storage (7 days)

All data at any time

↓

Permanent storage

Controlled by trigger conditions (e.g. laser energy threshold, ...)



Data Storage and Access

Easy remote access to processed datasets

```
import polars as pl

df_q = (
        pl.scan_parquet(
            "s3://magma-production/topics/kaldera.diag_damon_magma.damon1/"
            "year=2025/month=05/day=14/",
            storage_options={
                "access_key_id": "soeren",
                "secret_access_key": "o.0",
                "endpoint_url": "http://kaldera.desy.de:9000",
            },
        )
        # explode all metadata sub-fields into top-level columns
        .unnest("metadata")
        # now pick only what you need
        .select(
            [
                "ident",
                "sec",
                "usec",
                "data",
            ]
        )
        # rename data to q
        .rename({"data": "q"})
    ).collect()
```

Compatible with e.g.: pandas DuckDB Polars

Processed data saved to local cloud storage

Fast access to full dataset during and after experiment

Single command to read data

Data Access

Curated data set readily available

Data Access

Curated data set readily available

Preliminary Result

Prediction $R^2 = 0.97$