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HADRON PHYSICS IN HORIZON EUROPE

New approaches in phenomenology and experiment

Amar Kapic

on behalf of the University of Montenegro

02.07.2025.

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Outline

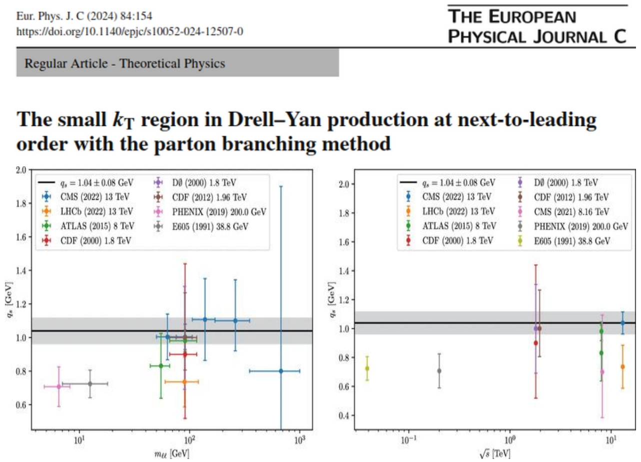
- **Phenomenology in HEP**
  - Research summary of Strong 2020 project
  - Determination of α_s in the non-perturbative region
- **Experimental analysis**
  - Explore new jet substructure techniques to study jet evolution in vacuum and in presence of the QGP
- **LHC Phase II Contribution**
  - The CMS GEM Phase II Detector Control System
- **Budget Estimation and Collaboration**

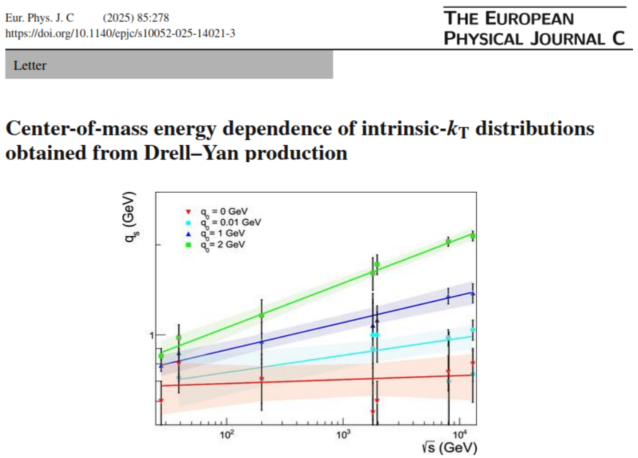
Phenomenology

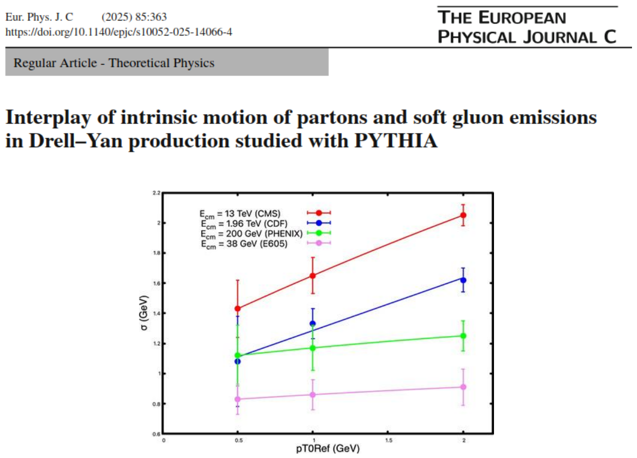
Pheno contributions from Strong2020

- A **powerful phenomenological framework** based on Drell-Yan production studies done during **Strong 2020**
  - Serving as a bridge between theory, precision measurement, and model development

- **Our key Milestones Achieved:**


Eur. Phys. J. C (2024) 84:154
https://doi.org/10.1140/epjc/s10052-024-12507-0
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics
The small k_T region in Drell–Yan production at next-to-leading order with the parton branching method

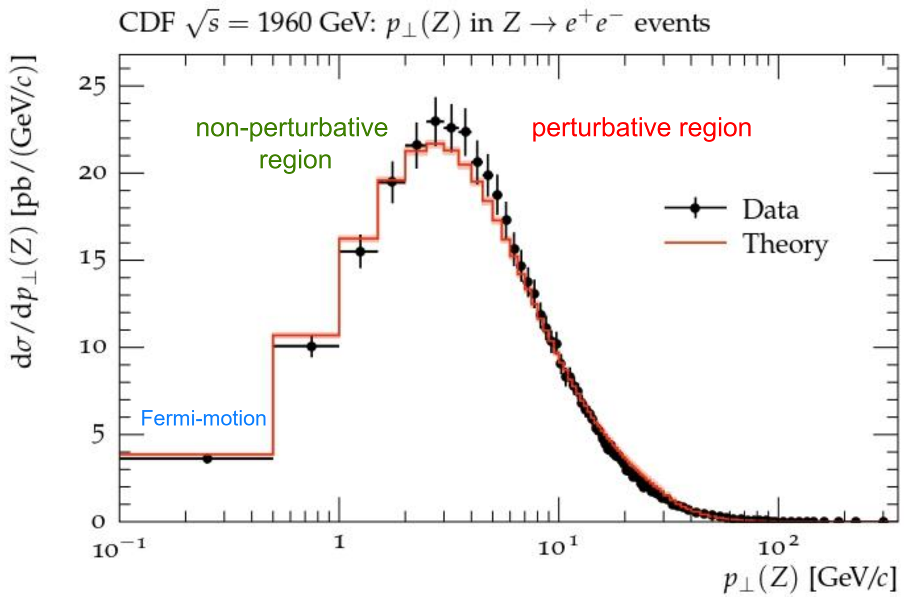

Eur. Phys. J. C (2025) 85:278
https://doi.org/10.1140/epjc/s10052-025-14021-3
THE EUROPEAN PHYSICAL JOURNAL C
Letter
Center-of-mass energy dependence of intrinsic-k_T distributions obtained from Drell–Yan production


Eur. Phys. J. C (2025) 85:363
https://doi.org/10.1140/epjc/s10052-025-14066-4
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics
Interplay of intrinsic motion of partons and soft gluon emissions in Drell–Yan production studied with PYTHIA

- Determination of the intrinsic transverse momentum of partons inside hadrons (intrinsic-kT) using the **Parton Branching (PB) method** based on Transverse Momentum Dependent (TMD) parton densities
- **Comparative study** of the TMD approach used in the PB method versus collinear parton shower generators in the non-perturbative region
- **Interplay of intrinsic transverse motion and soft gluon emissions** using the PYTHIA event generator

Parton evolution with α_s at small kT and Drell-Yan (DY) pT

- DY pT dsitribution has region sensitive to Fermi-motion (intrinsic kT), non-perturbative region (all-order gluon resummation) and perturbative regions:



- Intrinsic (Fermi-motion) should be parameterized
- non-perturbative region: Transverse Momentum Dependent parton densities (or initial state parton showers) → sensitive to α_s at small scales
- perturbative region → higher order calculations → α_s at larger scales

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α_s at small scales q

$$\alpha_s(q^2) \sim \frac{1}{\log q^2/\Lambda^2_{QCD}}$$

- Landau pole at $\boldsymbol{q = \Lambda_{QCD}}$
- different treatments for $\boldsymbol{q < \Lambda_{QCD}}$
  - **freeze $\boldsymbol{\alpha_s}$** for $q < q_0$
  - **taming $\boldsymbol{\alpha_s(q^2)}$** $\rightarrow \alpha_s(q^2 + q_0^2)$
  - **analytic continuation** into non-perturbative region

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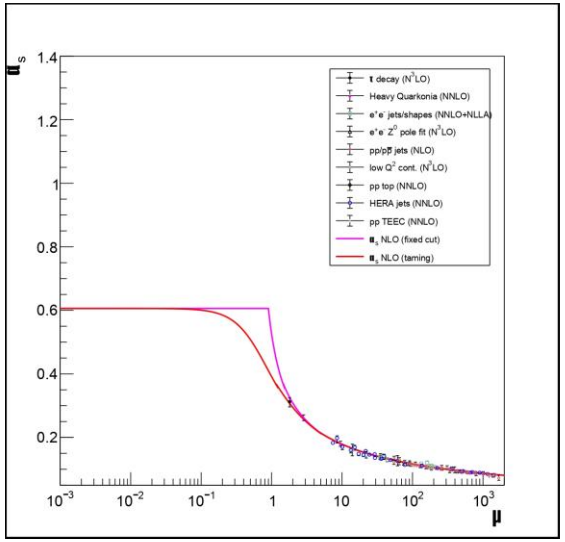
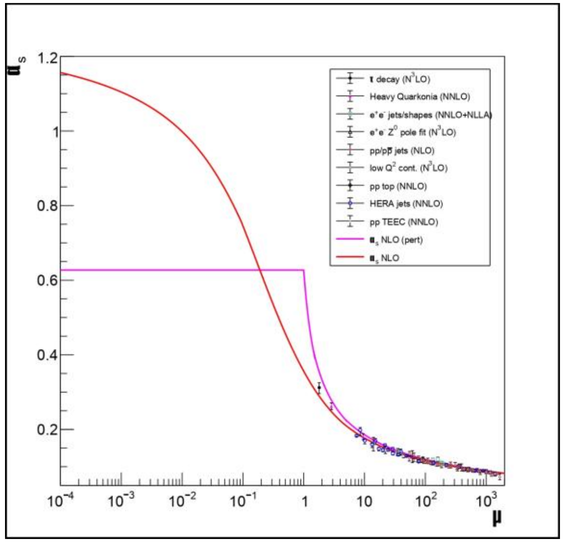
α_s at small scales q

- **α_s with extension to small k_T region:**





- **freezing**
- with **taming** parameter:

$$\alpha_s(q^2) \rightarrow \alpha_s(q^2 + q_0^2)$$

- with **analytic continuation**
  - Kotikov, A. V. and Zemlyakov, I. A. (2023). Fractional analytic QCD beyond leading order, J. Phys. G, 50(1), 015001

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Determination of α_s in the non-perturbative region

- **α_s determination from parton density fit to deep-inelastic cross section**
  - **combined determination of α_s from DIS and DY low pt measurements**
    - test different assumptions of extrapolation into the non-perturbative region
  - **determination of Fermi motion** – is it universal or process (DIS, DY) and energy dependent?

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Experimental analysis

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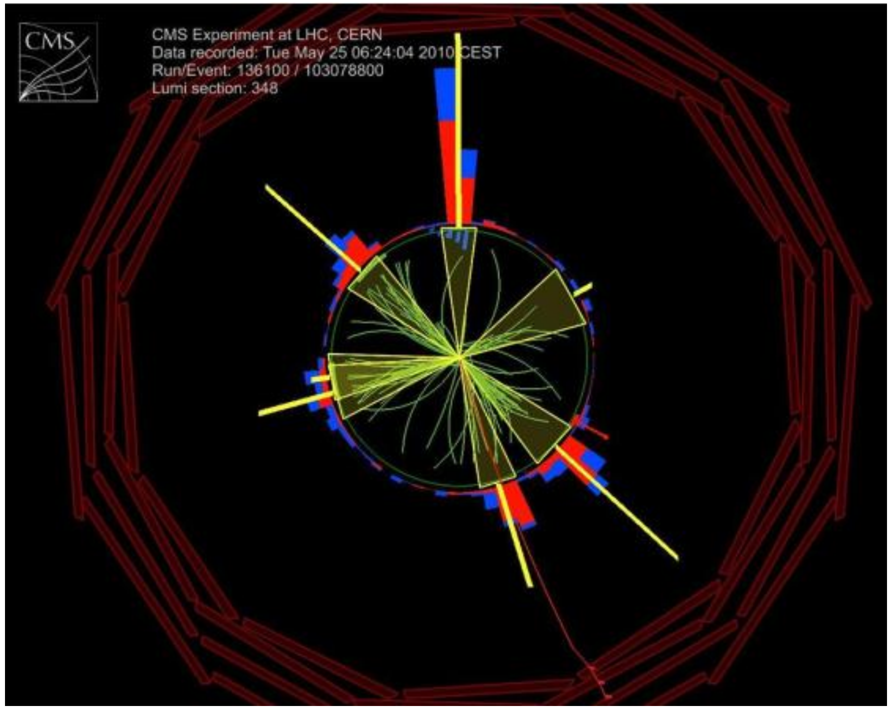
Jet substructure (1)

- **Jets** - very important for understanding LHC physics
- Information about **radiation pattern of the jets** can be obtained by studying their **internal structure** using **jet substructure techniques**
- Jet substructure provides numerous innovative new ways to search for **new physics** and to **probe the Standard Model** in extreme regions of phase space
- Experimental precision to challenge state-of-the-art pQCD analytical calculations and to constrain parton shower & hadronization models of Monte Carlo generators



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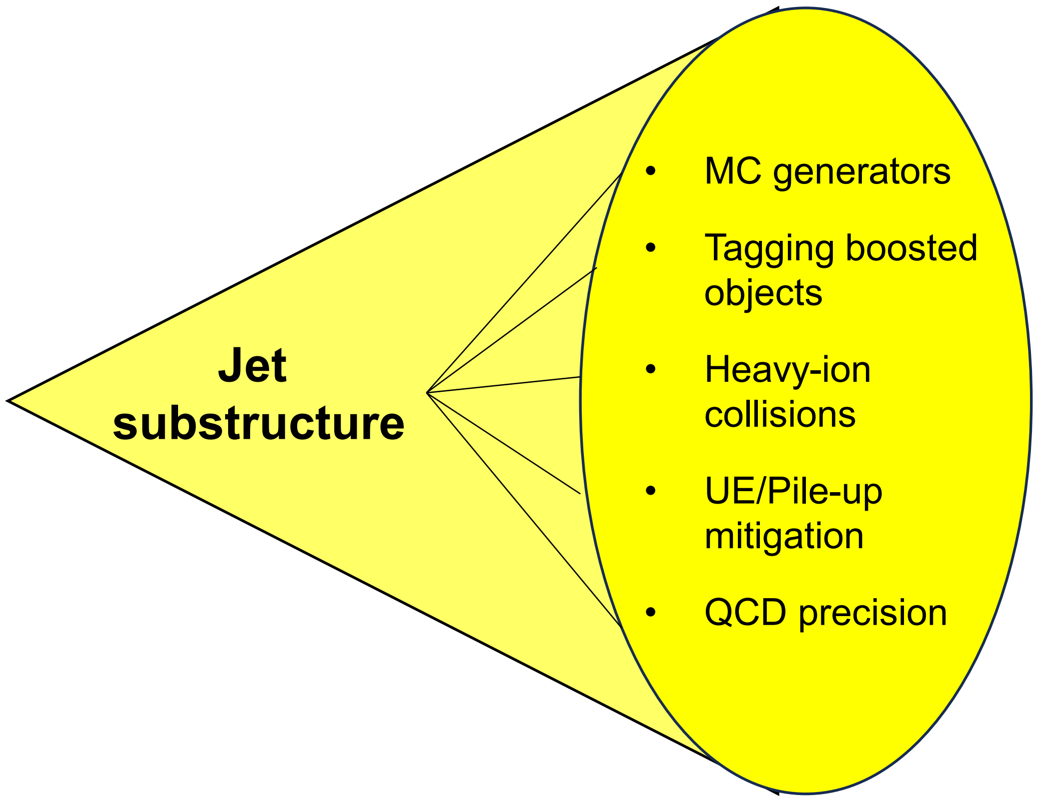
Jet substructure (2)



- Over recent years many experimental and theoretical techniques have been developed to exploit the substructure of jets
- Development of declustering techniques allowed to **access the jet splitting tree** and using grooming techniques perturbative branches can be isolated
- Number of measurement performed so far by LHC experiments: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCJetSubstructureMeasurements
- Exploit new developments and observables in order to study jet evolution in vacuum and its evolution in presence of the QGP with data collected by CMS experiment

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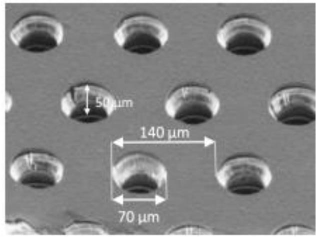
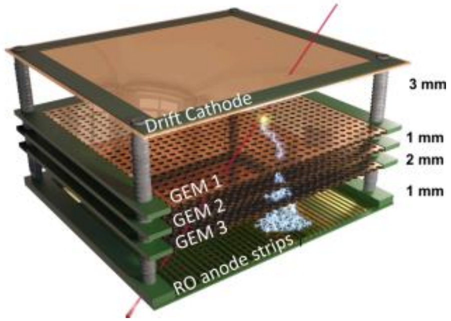
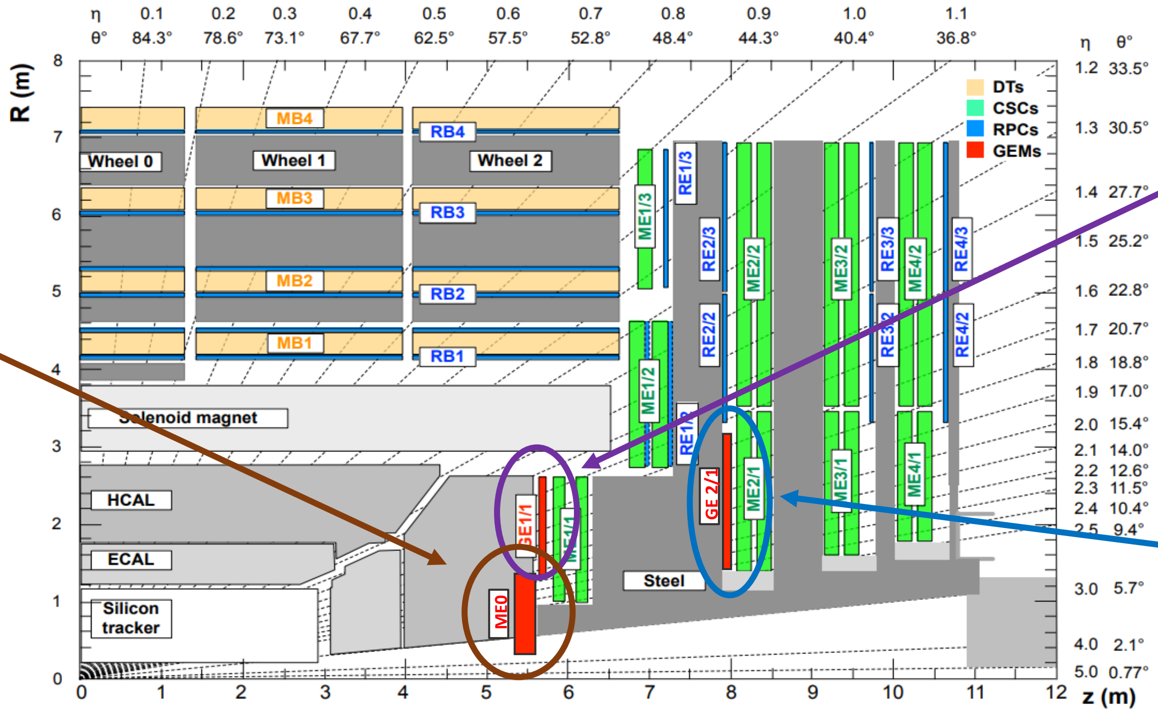
LHC Phase II Contribution

The CMS GEM Project

- **Triple Gas Electron Multiplier technology**
- To cope with High Luminosity-LHC environment, which will deliver proton-proton collisions at **5 - 7.5 times the nominal LHC luminosity**







ME0:
- Muon tagger at highest η
- 2.4 < |η| < 2.8
- 6 layers of Triple-GEM
- Each chamber spans 20°
- Installation: LS3

GE1/1:
- 1.6 < |η| < 2.1
- 36 super-chambers per endcap
- Each chamber spans 10°
- Installation: LS2 (2019-21)

GE2/1:
- 1.55 < |η| < 2.45
- 18 staggered super-chambers per endcap
- Each chamber spans 20°
- Installation: YETS 23-24, YETS 24-25, YETS 29-30

The CMS GEM DCS

Hardware requirements:

HV system

- 12 x SY4527 MF
- 108 x A1515TG HV boards
- 1512 HV channels

LV system

- 1 x SY4527 MF
- 4 x A1616 Branch Controllers
- 16 x MAOs
- 16 x EASY3000
- 68 x A3009 LV boards = 648 ch.

Gas system

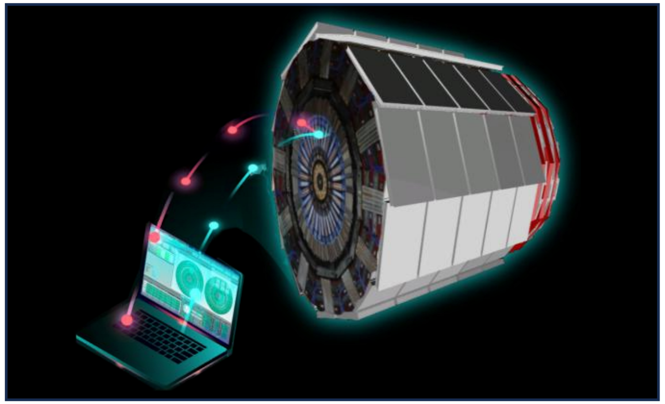
- 120 pressure sensors

FOS temperature system

- > 500 FOS temp. sensors

etc…

- **Detector Control System (DCS)** main purposes:
  - **set a safe and effective configuration**
  - **provide control and monitoring** over the sub-detector



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The CMS GEM Phase II DCS

- The **existing GEM DCS** project **lacks scalability**, and it is not straightforward to add more stations

- The GEM Phase II DCS will be developed from **scratch** to ensure **modularity** and **full compatibility** with **all three GEM Stations**
  - Ensure **system-wide consistency** aligned with **CMS DCS standards** (naming, colors, alarms, code style, etc.).
  - **Maximize use of JCOP and CMS framework components** to simplify integration and development, making it more maintainable and scalable.

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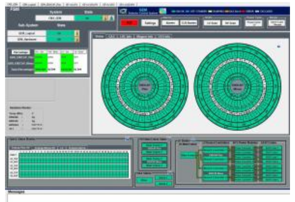
GEM DCS Phase II Components

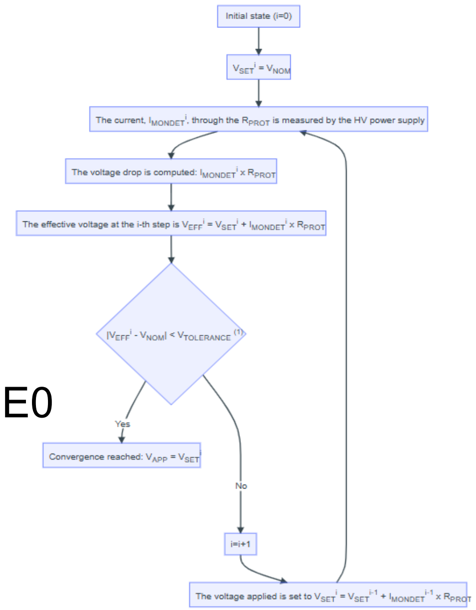
User Interface (UI) component

- Graphical representation of the system status



CAEN component

- HV/LV configuration
- HV compensation for ME0
- Automatic recovery

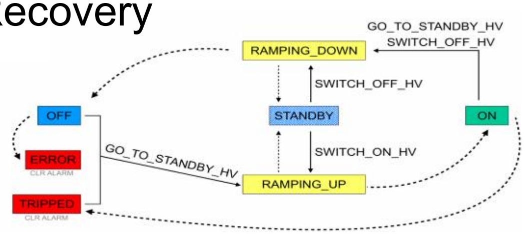


Gas component

- Gas difference monitoring
- Gas protection mechanism

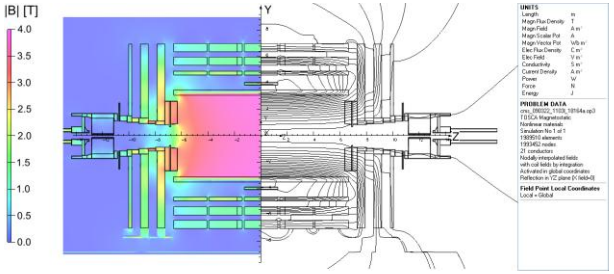
Finite State Machine (FSM) component

- Abstract behaviour modelling
- Automation & Error Recovery



Detector Protection component

- Magnet protection
- LHC handshake
- LHC beam



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Budget Estimation & Collaboration

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Budget estimation and Collaboration

- **Estimated budget request:**
  - 3 years post-doctoral **~ 75 k€**
  - 3 years doctoral student **~ 55 k€**
  - TA – 3-4 days per month during 4 years (or cumulatively) **~ 20 k€**
  - Travel support (mainly for participating in conferences) **~ 24 k€**

Total: ~ 174 k€

- **Partner institutions:**

CERN

DESY.

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Thank you for your attention!

Questions?