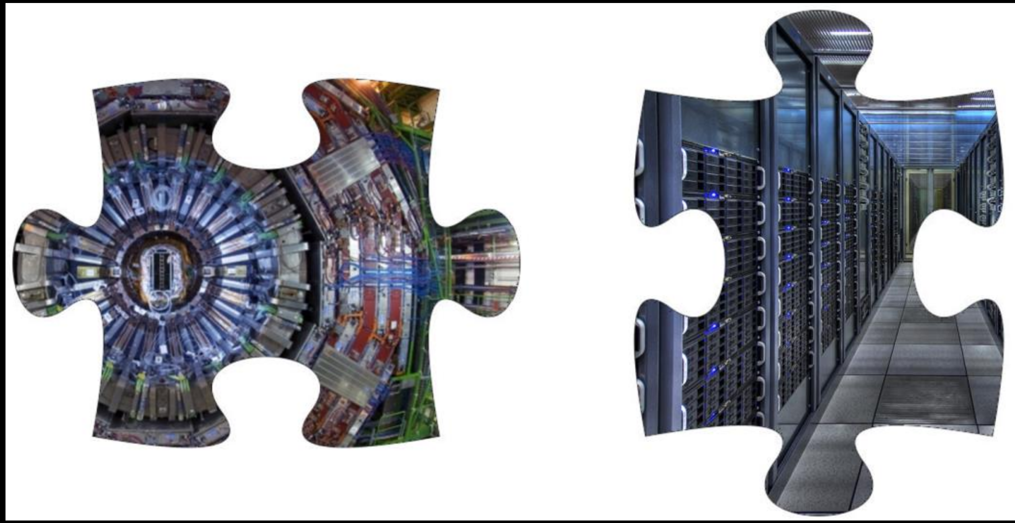
EuCAIF, December 19, 2024

WG2 – Codesign Kick-off Meeting



Tommaso Dorigo, Pietro Vischia

First researcher @ INFN, Sezione di Padova

Guest Professor @ Luleå Techniska Universitet

President @ Universal Scientific Education and Research Network

WELCOME BACK !

We have let some months pass since the Amsterdam conference

In the meantime, our group has grown – at least on paper – but it is not clear yet if we can organize a concrete effort toward the goals we set

- Our mailing list eucaif-WG-Codesign includes 36 members
  - But many generals, few soldiers…

Let us recap the reasons why we formed this group

Three Objectives of WG2

- 1) Identify existing design paradigms for particle and astroparticle physics instruments which have become obsolete in the AI era, and assemble software strategies and research paths to overtake them

- 2) Support the development of simulation tools that constitute enablers of co-design approaches to holistic optimization for detector use cases in HEP, astro-HEP, nuclear and neutrino physics.

- 3) Understand physical limits of information generated by particle interactions in granular calorimeters and conditions for its lossless extraction, as a preliminary step toward the AI-assisted hybridization of calorimeters and tracking detectors into optimized variable-density systems.

Should we add / remove something ?

Round of introductions

Let us go around the table to introduce ourselves to the rest of the group!

Please spend 3 minutes to let us know your name and position, your research interests and current involvement, your interest in EUCAIF and WG2 activities

What is Co-Design?

Realizing that the achievement of a goal may require to tailor each part of a system to all others: synergy

What is Co-Design?

Realizing that the achievement of a goal may require to tailor each part of a system to all others: synergy

Enabling the simultaneous optimization of all parts, to maximize a global utility in a high-dimensional design space: holistic optimization

What is Co-Design?

Realizing that the achievement of a goal may require to tailor each part of a system to all others: synergy

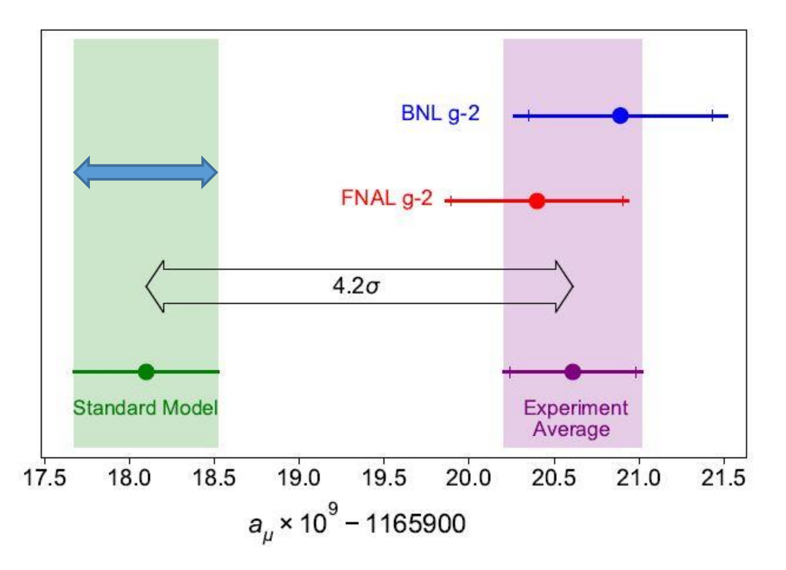
Enabling the simultaneous optimization of all parts, to maximize a global utility in a high-dimensional design space: holistic optimization

Bringing together diverse components, technologies, or expertise to create a unified and cohesive system, ensuring seamless interoperability and coordination: integration

One Example of the Importance of Co-Design : MUonE

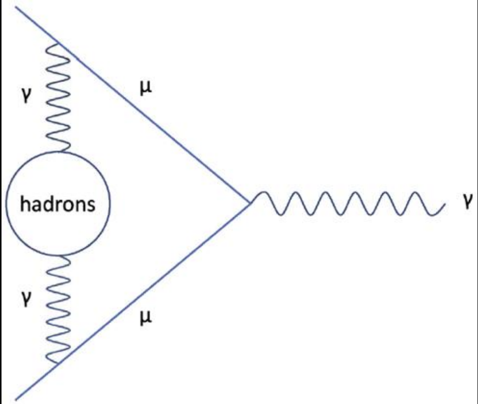
MUonE aims to determine with high precision the probability of elastic muon-electron scattering, as this number may reduce the theory systematics of the g-2 muon anomaly

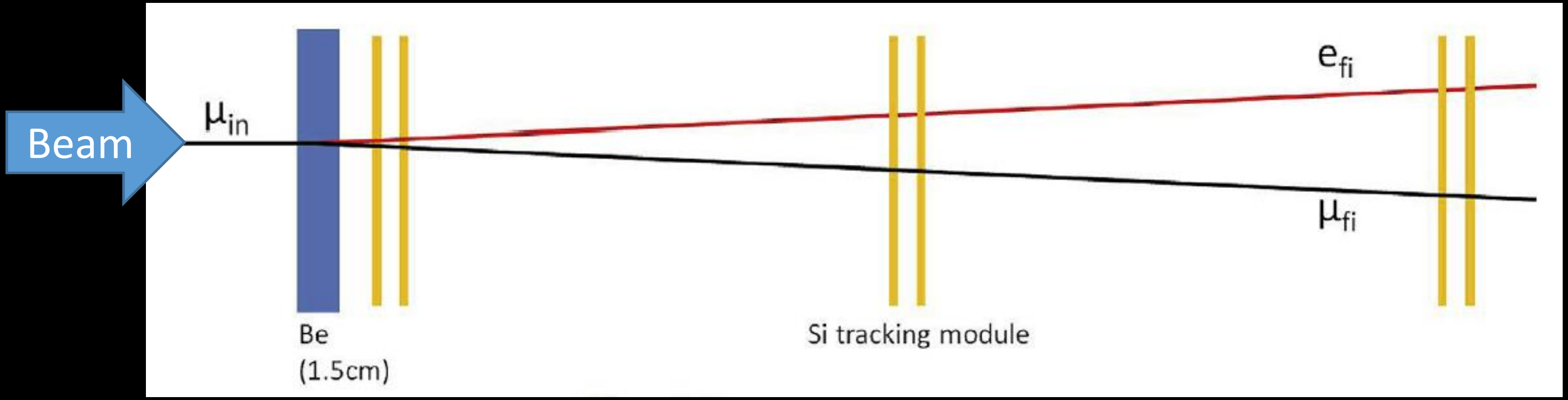
The experiment must be sensitive to the rate of interactions as a function of momentum transfer, with 10^{-4} precision



Above: *a long-standing anomaly in the Standard Model, the muon g-2 value*

Below: *a muon-photon interaction, with a hadronic quantum loop*



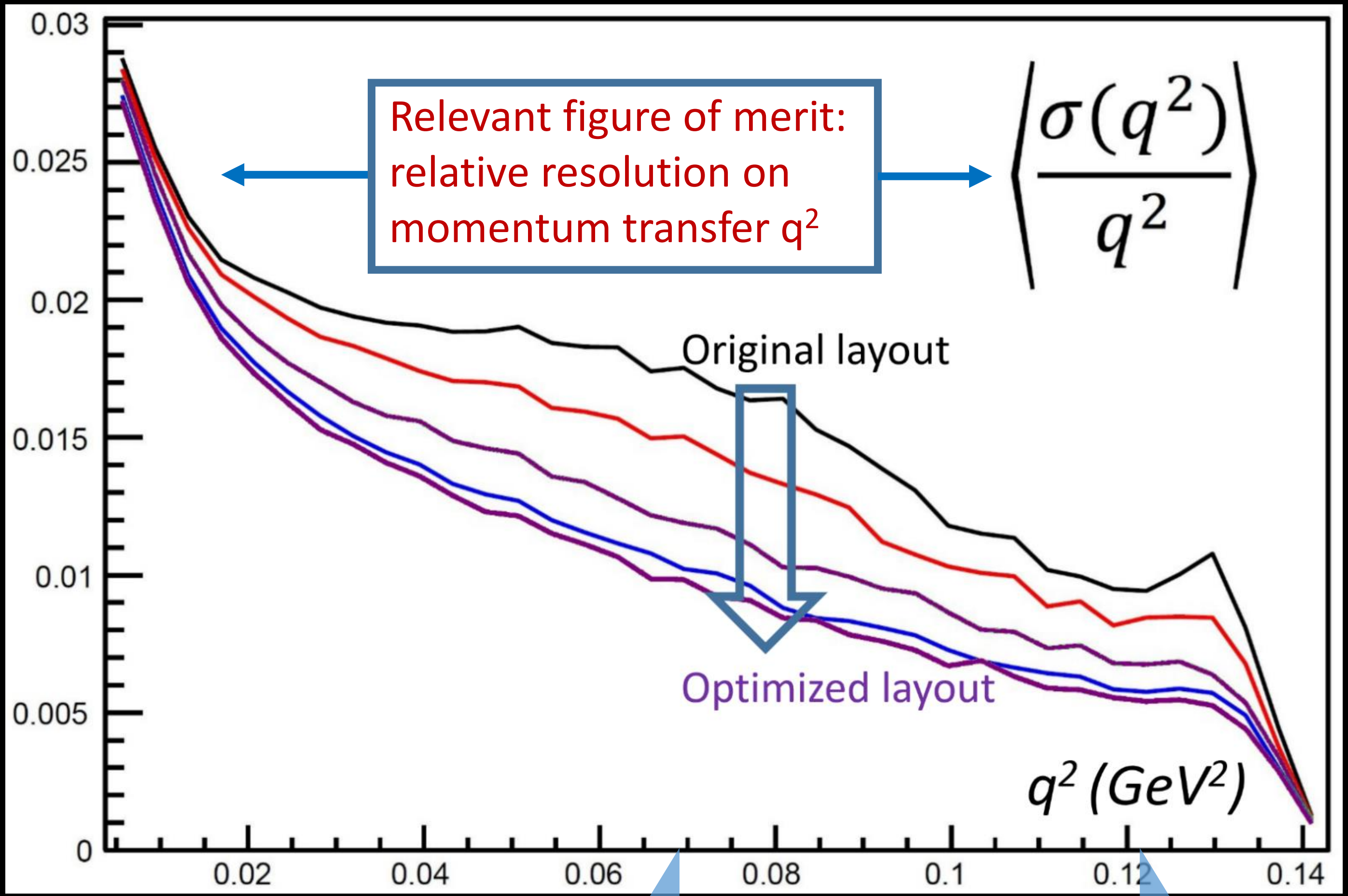


Above: *layout of one of 40 1m-long MUonE stations, as per original design proposal*

MUonE Optimization

The original design of the MUonE stations was good, but it failed to use the constraining potential of the 3-particle vertex (a co-design exploitable!) and the strong dependence on geometry of q^2 resolution (the relevant metric)

A factor of two (!) gain was achieved by discrete optimization scans



Region sensitive to hadronic loop contributions

T. Dorigo, *Geometry Optimization of a Muon-Electron Scattering Experiment*, Physics Open 4 (2020) 100022.

Scale of Optimization Problems in Physics and Elsewhere

Task	Number of parameters	Year	Status
Typical LHC new physics search	20-50	2012-	OK
MUonE detector station geometry	20	2019-2020	OK
SWGO Cherenkov tanks layout	O(100)	2023-2024	In progress
AlexNet (for ImageNet challenge)	62,300,000	2012	OK
kNN for muon energy regression in granular calo	66,000,000	2022	OK
ChatGPT 3.5	150,000,000,000	2023	OK
ChatGPT 4.0	1,700,000,000,000	2023	OK

Scale of Optimization Problems in Physics and Elsewhere

Task	Number of parameters	Year	Status
Typical LHC new physics search	20-50	2012-	OK
MUonE detector station geometry	20	2019-2020	OK
SWGO Cherenkov tanks layout	O(100)	2023-2024	In progress
FDFLC **(a future detector for a future large collider)**	**O(10,000)**	**?**	Not presently contemplated
AlexNet (for ImageNet challenge)	62,300,000	2012	OK
kNN for muon energy regression in granular calo	66,000,000	2022	OK
ChatGPT 3.5	150,000,000,000	2023	OK
ChatGPT 4.0	1,700,000,000,000	2023	OK

A Walk in the Jungle…

- We need new competences
- The detector experts community is largely not enthused by AI
- Some parts of the design decisions cannot, and will never, be automated

→ Engage computer scientists in our problems

→ Start easy, prove new technology by targeting low-hanging fruits

→ Pursue “human in the middle” approach

Reminder:
EUCAIF Conference, 16-20 June 2025

6-20 June 2025, T Hotel, Cagliari, Sardegna, Italy

We are happy to announce the second "European AI for Fundamental Physics Conference" (EuCAIFCon), which will be held in Cagliari, Sardinia, from 16 - 20 June 2025. The event aims to provide a platform for establishing new connections between AI activities across various branches of fundamental physics, by bringing together researchers that face similar challenges and/or use similar AI solutions. The conference will be organized "horizontally": sessions are centered on specific AI methods and themes, while being cross-disciplinary regarding the scientific questions.

EuCAIFCon 2025 is organized by EuCAIF, and with the support of INFN Cagliari, the University of Cagliari and the University of Sassari. EuCAIF is a new European initiative for advancing the use of Artificial Intelligence (AI) in Fundamental Physics. Members are working on particle physics, astroparticle physics, nuclear physics, gravitational wave physics, cosmology, theoretical physics as well as simulation and computational infrastructure.

Important dates:

Opening abstract submission (Mon, 6 Jan 2025)
Opening registration (Mon, 3 Feb 2025)
Closing abstract submission (Sun, 16 Feb 2025)
Abstract acceptance notification (Fri, 28 Feb 2025)
Closing early bird registration (Mon, 31 Mar 2025)
Closing registration (Sat, 31 May 2025)

Conference (Mon-Fri, 16-20 June 2025)

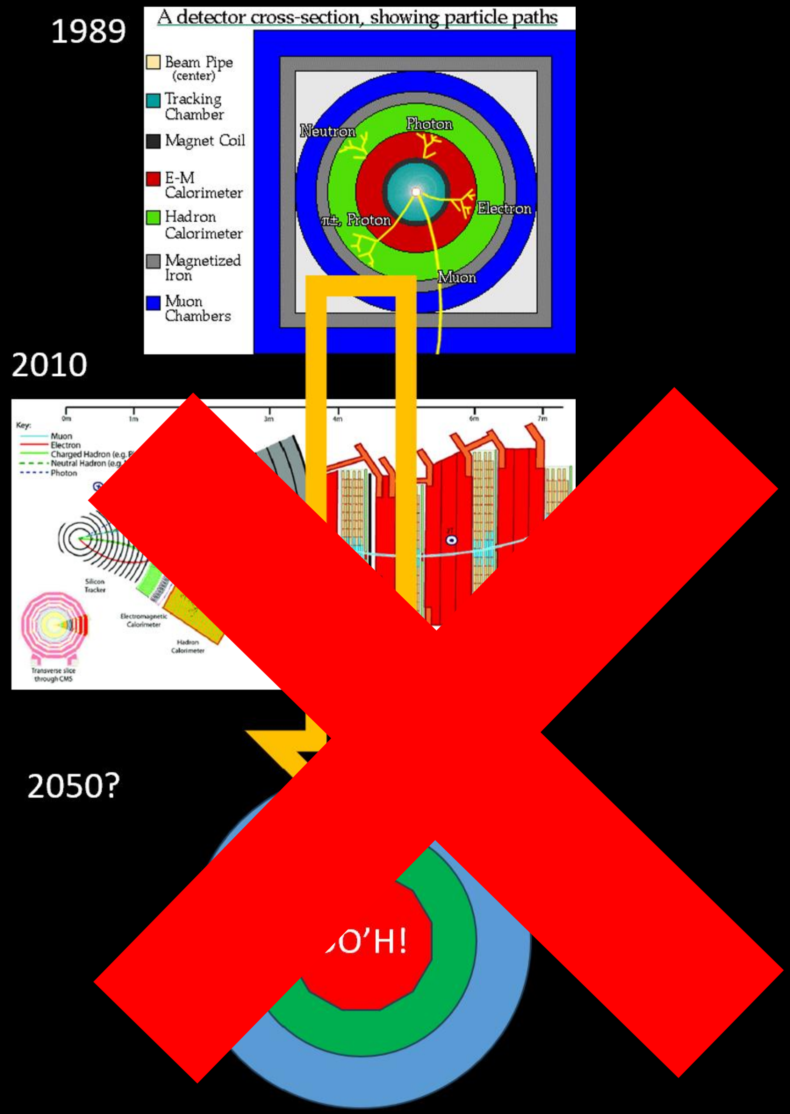
EuCAIF

For more details see https://eucaif.org and https://agenda.infn.it/event/43565/

Recent work: Exploring the limits of Calorimetry

One good example of non-evolution in fundamental science: the design of collider detectors

Clearly something we should try and direct forces to overcome!



Recent work: Exploring the limits of Calorimetry

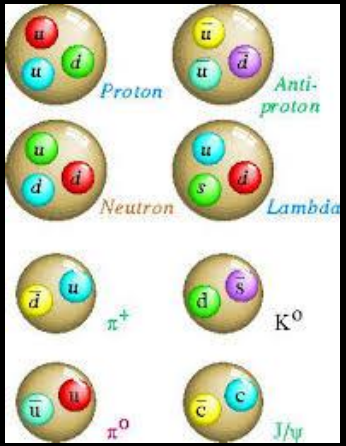
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

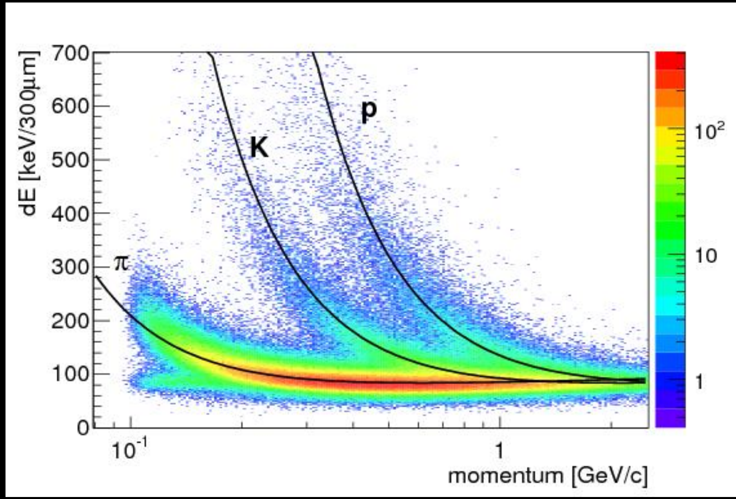
1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

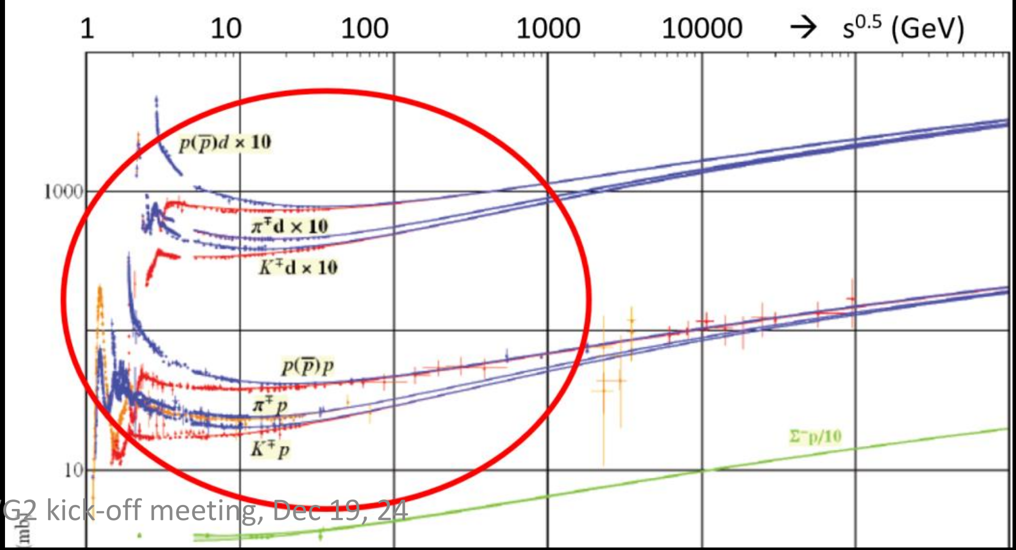
3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?





Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia



Hadrons are different, and their interactions could in principle distinguish them!

Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

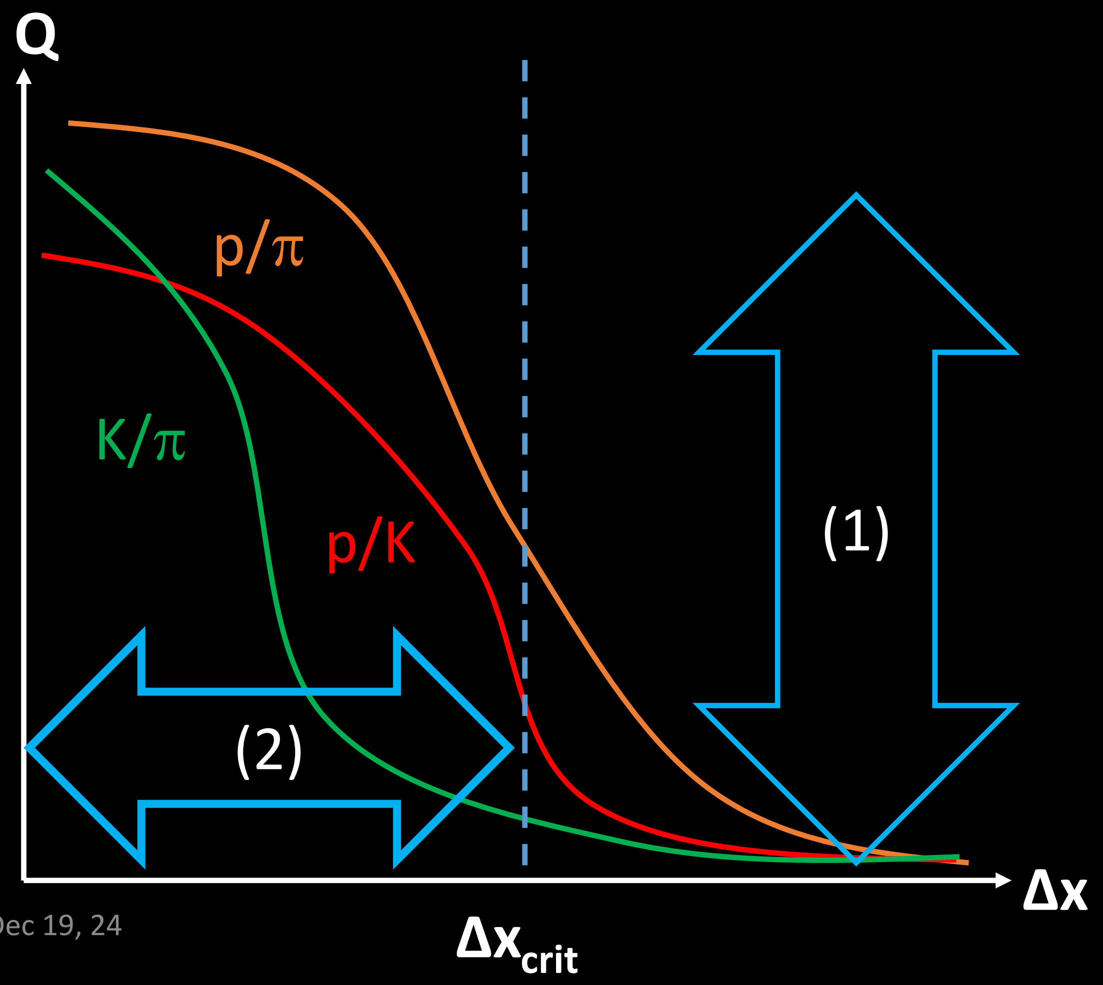
- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia



Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

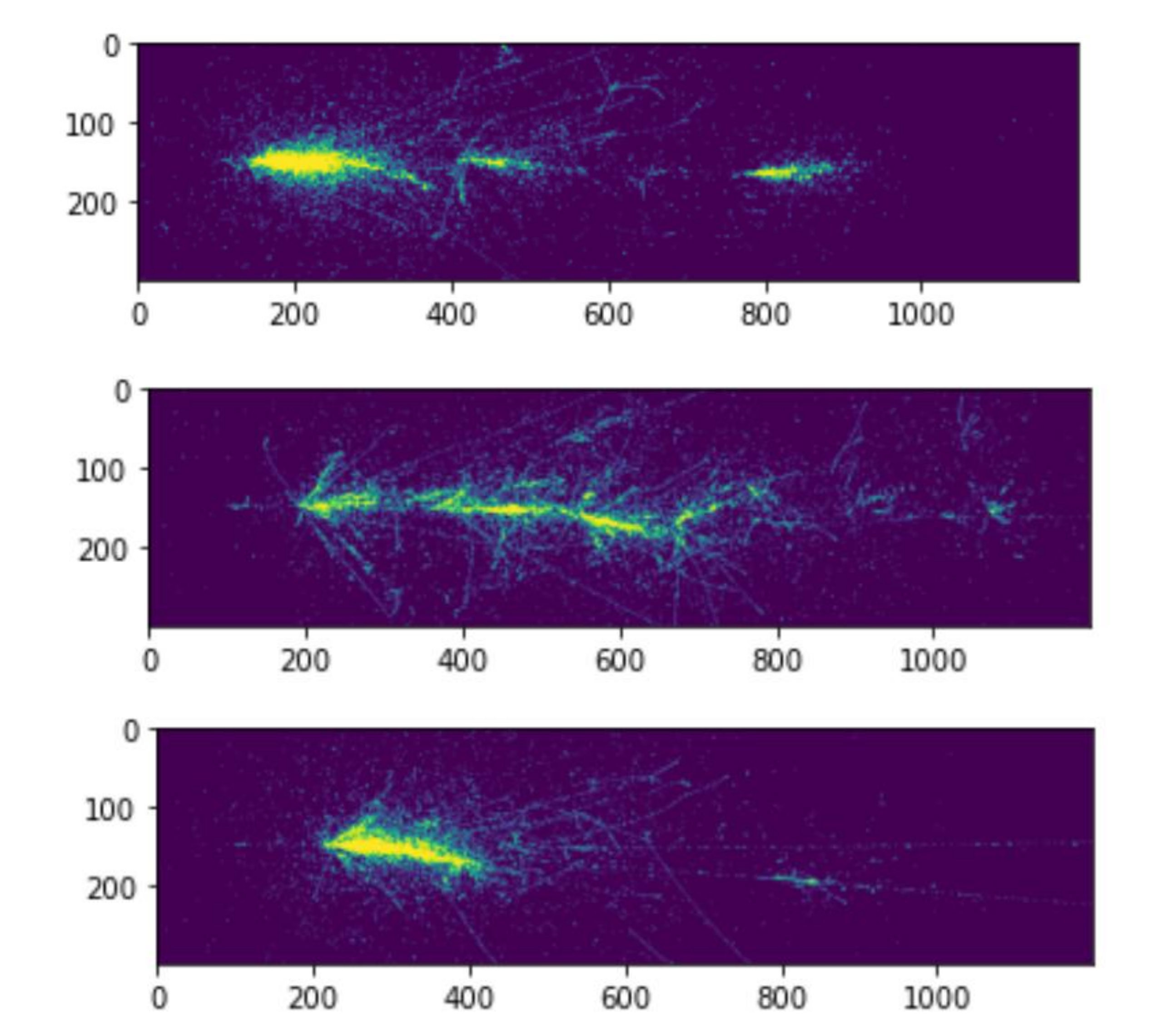
2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

100 GeV Proton, kaon, pion energy deposits



Recent work: Exploring the limits of Calorimetry

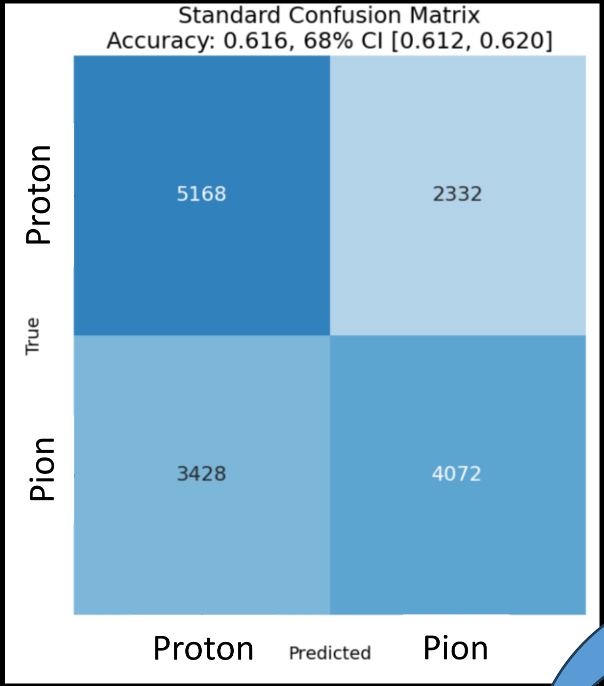
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

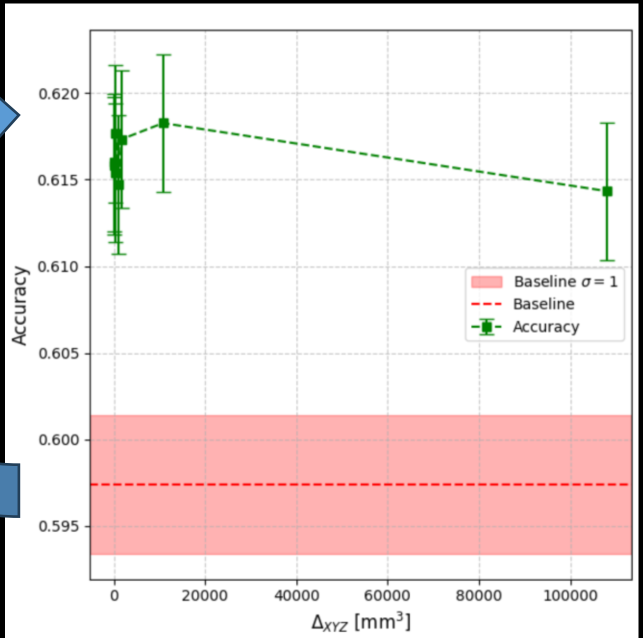
2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?



Discrimination up to 65% between protons and pions @ 100 GeV

How does it degrade with cell size?



Appraisal of PID information gain from granularity

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

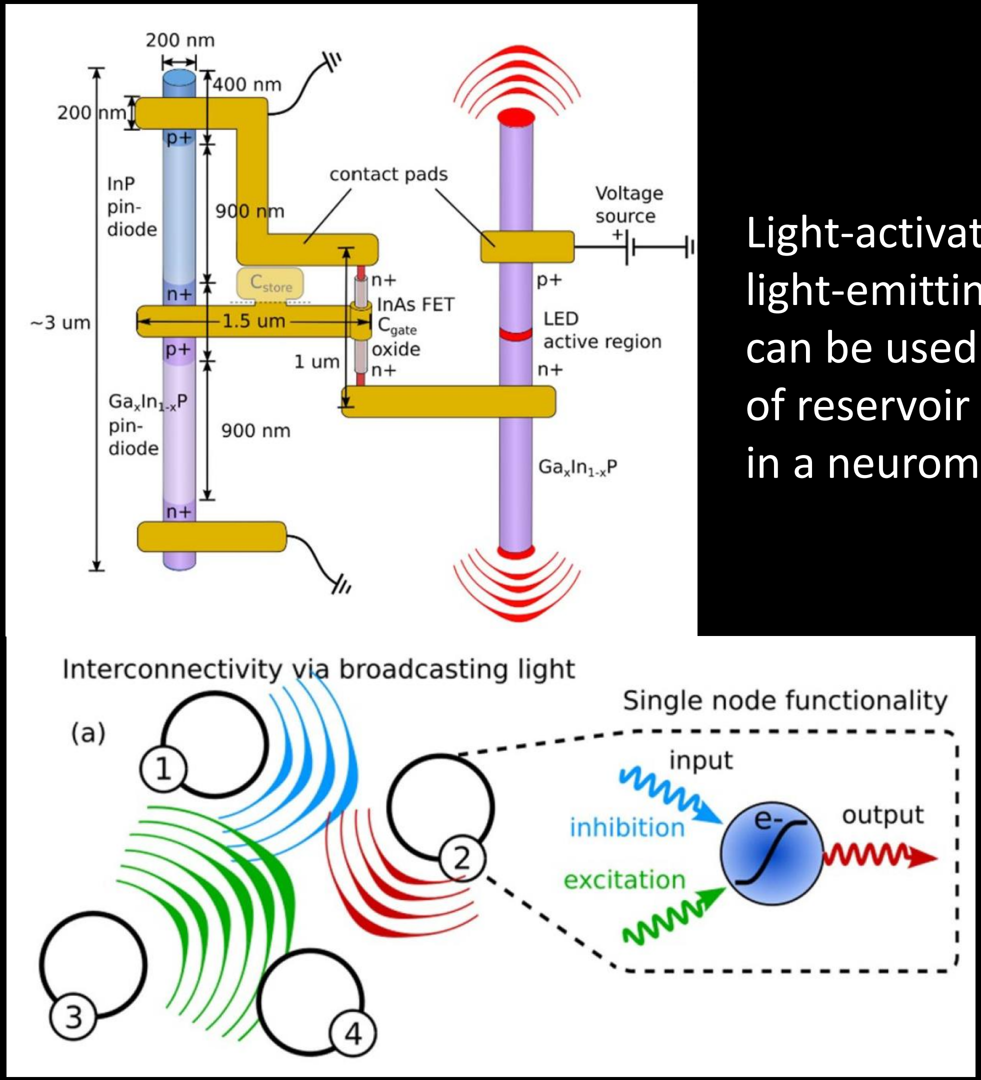
- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia



Light-activated and light-emitting nanowires can be used as elements of reservoir computing in a neuromorphic system

D. Winge et al., *Neuromorph. Comput. Eng.* **3** (2023) 034011

Recent work: Exploring the limits of Calorimetry

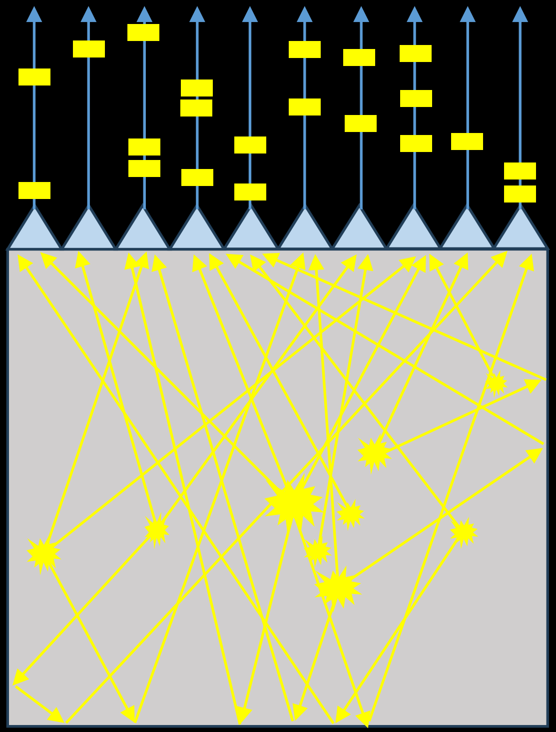
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

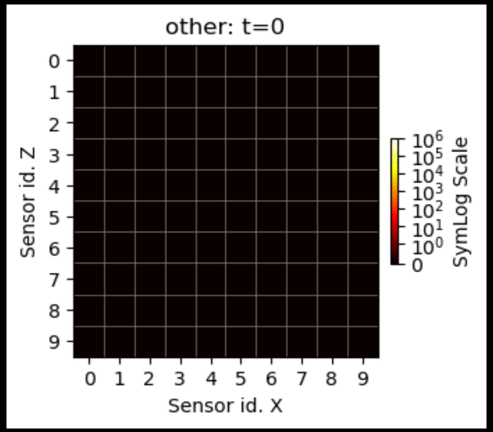
1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?





200 ps-sampled time of arrival of photons to receptors

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

Read out scintillator block through array of nanowire receptors, directly coupled to neuromorphic network learning energy patterns
→ Native photonics, no amplification!

Recent work: Exploring the limits of Calorimetry

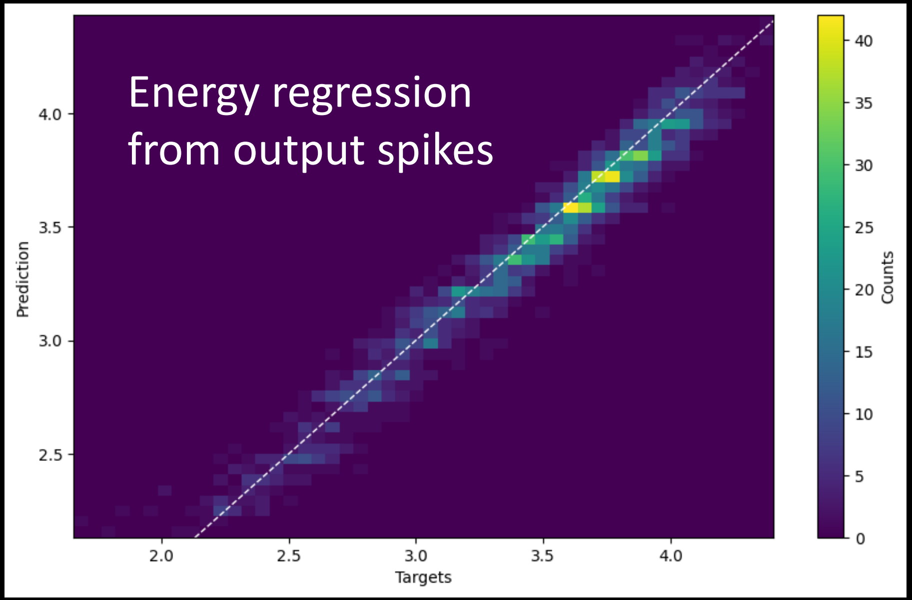
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

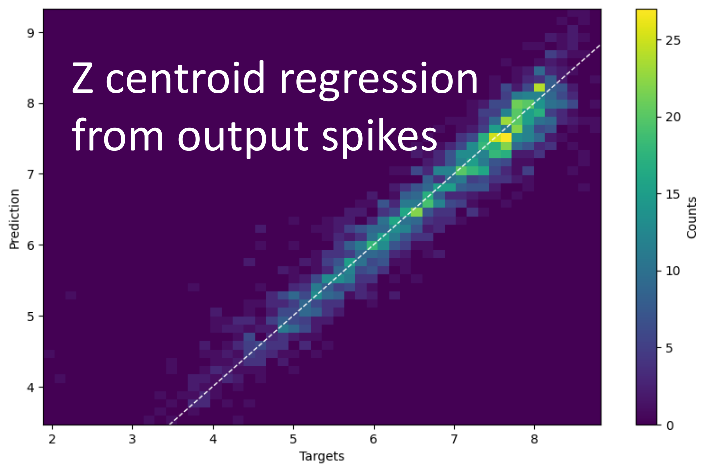
3) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?



Ultra-fast and energy-efficient detection and computation !

Exploit time structure of produced information

Can regress total energy deposited in calorimeter block as well as moments of energy distribution
→ Image showers without having to segment device!



Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

Recent work: Exploring the limits of Calorimetry

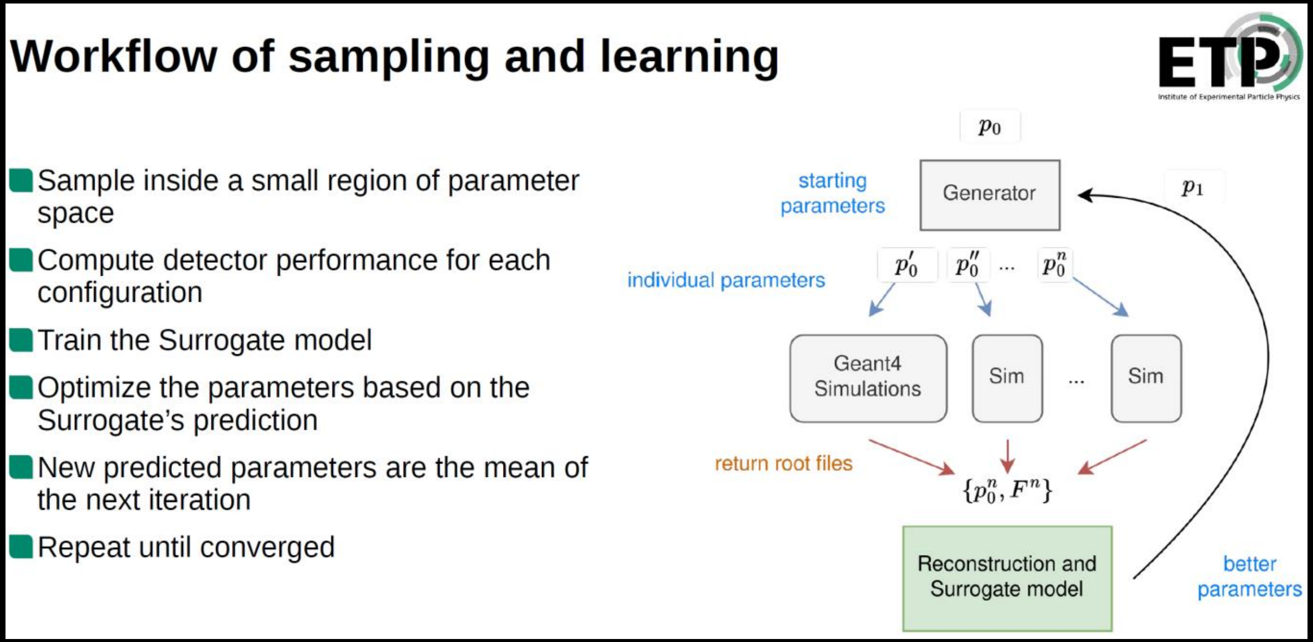
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we use a diffusion model to learn the best arrangement of active and passive layers?



Work by Kylian Schmidt (under supervision of J. Kieseler)

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

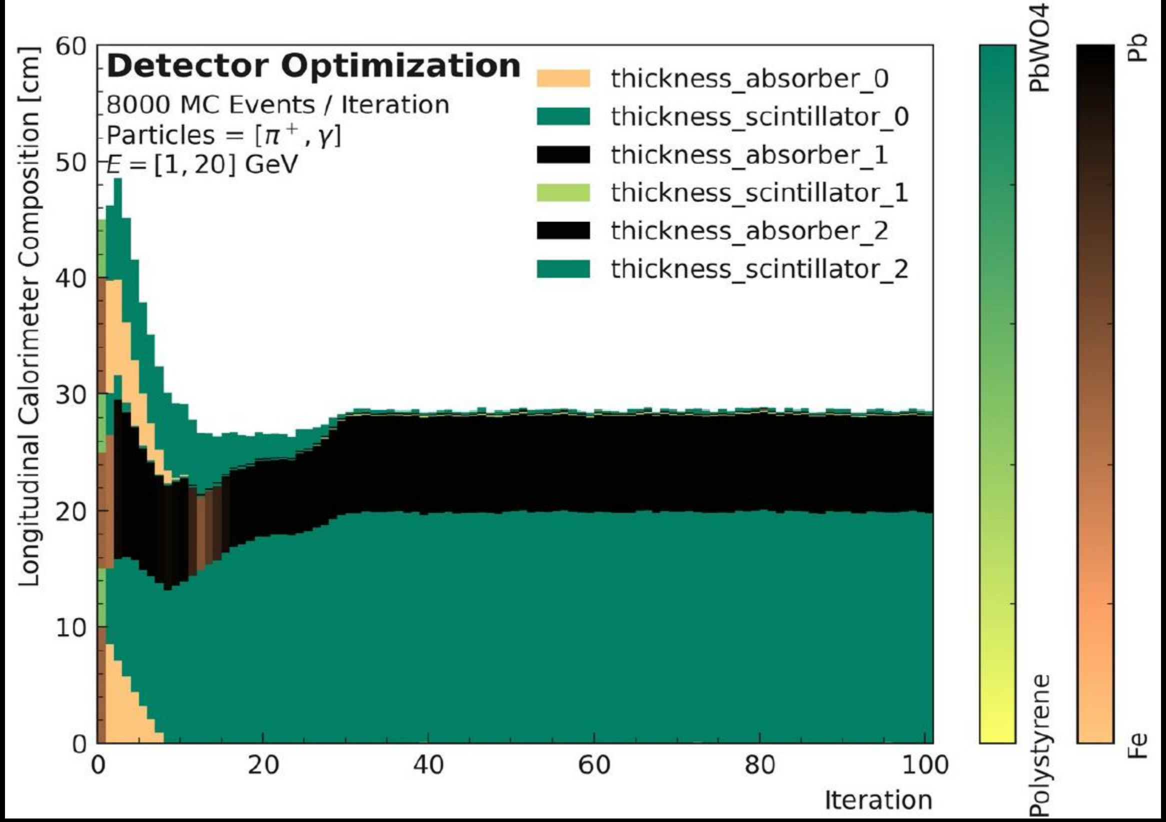
- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we use a diffusion model to learn the best arrangement of active and passive layers?

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia



Work by Kylian Schmidt (under supervision of J. Kieseler)

Recent work: Exploring the limits of Calorimetry

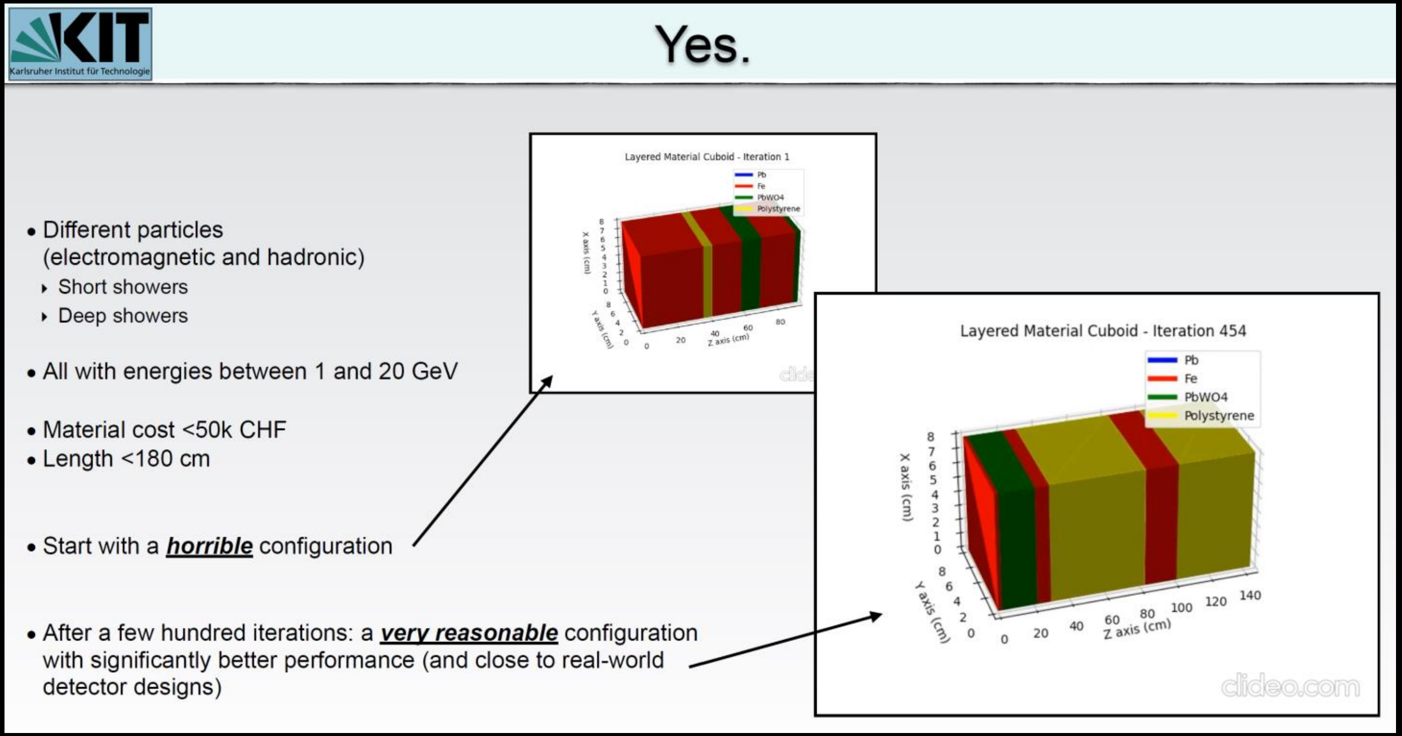
In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we use a diffusion model to learn the best arrangement of active and passive layers?



See presentation by J. Kieseler at 4th MODE Workship, Valencia Sep 24

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia

Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

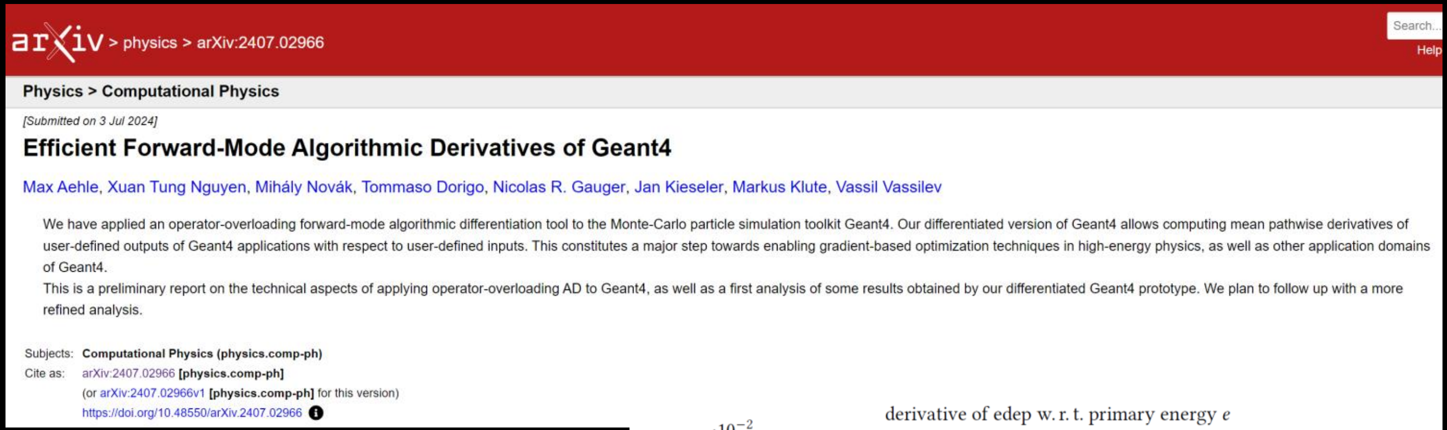
2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we use a diffusion model to learn the best arrangement of active and passive layers?

4) Can we differentiate Geant4?

Studies within group INFN/UOV/LTU/KIT/RPTU/Lund:

Abhishek, M. Awais, M. Aehle, L. Chen, Abhijit Das, A. de Vita, TD, N. Gauger, R. Keidel, J. Kieseler, E. Lupi, A. Mikkelsen, F. Nardi, XT. Nguyen, M. Pizzocaro, K. Schmidt, J. Wilmore, F. Sandin, P. Vischia


arXiv > physics > arXiv:2407.02966

Search...
Help

Physics > Computational Physics

[Submitted on 3 Jul 2024]

Efficient Forward-Mode Algorithmic Derivatives of Geant4

Max Aehle, Xuan Tung Nguyen, Mihály Novák, Tommaso Dorigo, Nicolas R. Gauger, Jan Kieseler, Markus Klute, Vassil Vassilev

We have applied an operator-overloading forward-mode algorithmic differentiation tool to the Monte-Carlo particle simulation toolkit Geant4. Our differentiated version of Geant4 allows computing mean pathwise derivatives of user-defined outputs of Geant4 applications with respect to user-defined inputs. This constitutes a major step towards enabling gradient-based optimization techniques in high-energy physics, as well as other application domains of Geant4.

This is a preliminary report on the technical aspects of applying operator-overloading AD to Geant4, as well as a first analysis of some results obtained by our differentiated Geant4 prototype. We plan to follow up with a more refined analysis.

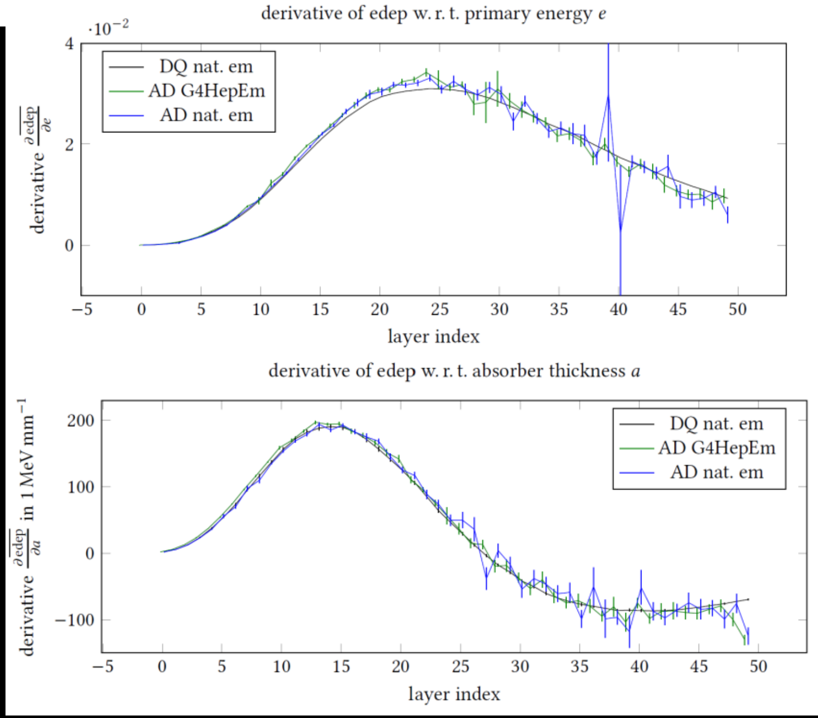
Subjects: Computational Physics (physics.comp-ph)

Cite as: arXiv:2407.02966 [physics.comp-ph]

(or arXiv:2407.02966v1 [physics.comp-ph] for this version)

https://doi.org/10.48550/arXiv.2407.02966

EM part of a shower's energy deposition emulated with AD code



Recent work: Exploring the limits of Calorimetry

In connection with the DRD6 group activities, we are exploring the boundary of information extraction from granular calorimeters

1) Can we do particle ID in a highly-granular calorimeter?

- What is the largest cell size that retains that information?

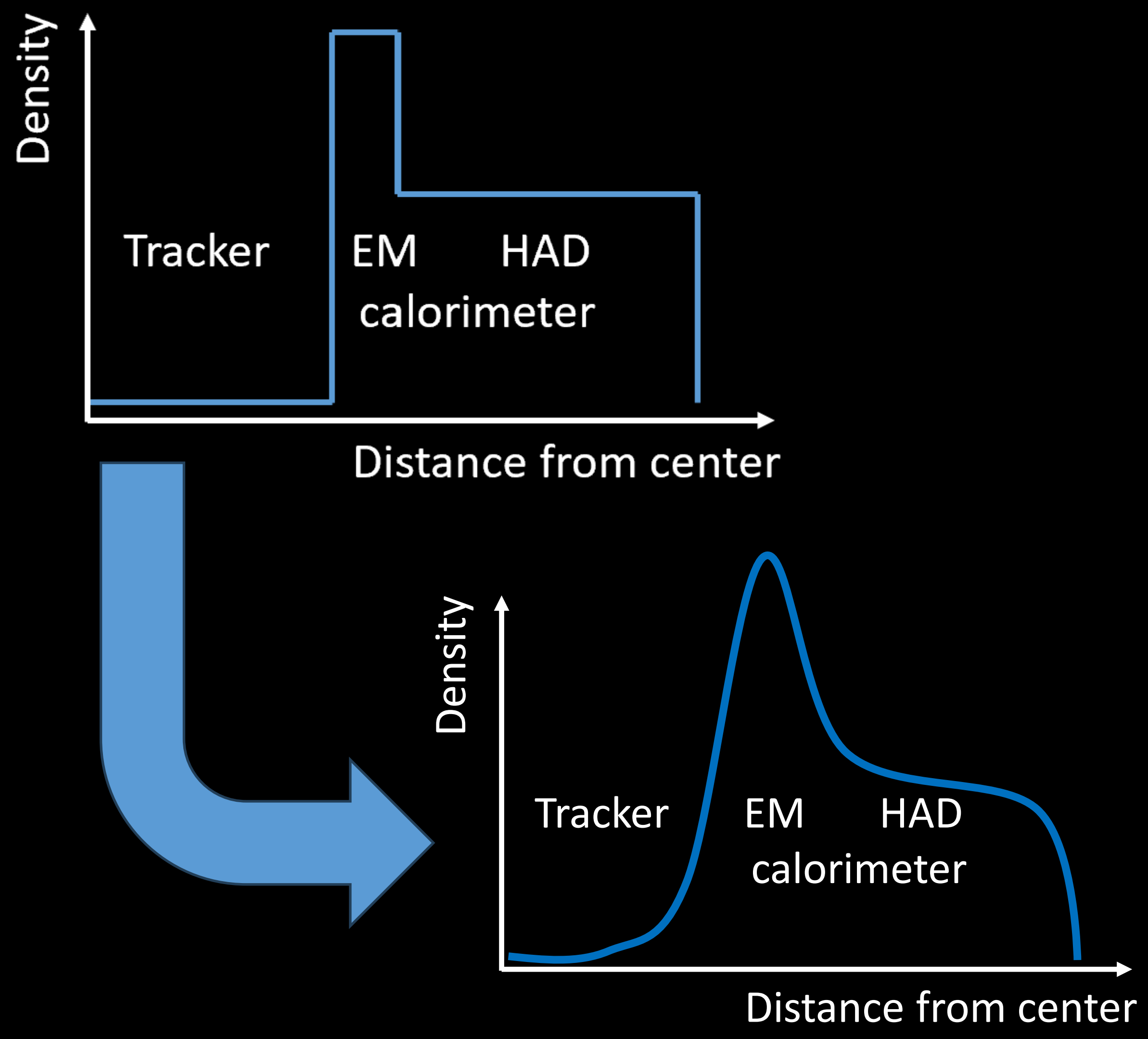
2) Can we overcome granularity by having a neuromorphic readout and local processing using nanophotonics?

3) Can we use a diffusion model to learn the best arrangement of active and passive layers?

4) Can we differentiate Geant4?

5) Can we hybridize a tracker and a calorimeter, learning the optimal layout with a diffusion model?

(Current work with A. de Vita, J. Kieseler, and K. Schmidt)



In Summary

The community should invest resources at all levels to

- Foster co-design studies
- Facilitate collaboration with computer scientists
- Push toward development of trustable differentiable Monte Carlos and suitable surrogates
- Integrate AI in workflows of design strategies
- Consider what information-extraction capabilities will be there in 20 years, and adapt detector design to them

Funding agencies should support these activities, and push toward the incorporation of this new transforming technology in the design activities for new experiments. It does not happen overnight – strategic decisions must be taken

EUCAIF-WG2-CODESIGN should be a container of all activities we generate to reach the above goals

Two Proposals: 1) NC for Calorimetry

The study of neuromorphic readout for calorimeters, possibly employing reservoir learning, qualifies as a co-design topic, and

- It constitutes a blue-sky research topic where we do not need to "belong" to some pre-defined collaboration or experiment
- It looks promising as a new technology
- It employs innovative concepts (nano-photonics, neuromorphic computing)

Goals:

- Short-medium term: Explore the design space, determine show-stoppers, evolve to a workable solution, optimize system
- Produce article describing results
- Eventually prepare for prototyping on hardware

2) Using drones to study atmospheric showers

One of the main limiting factors in ground-based detection of cosmic rays is the determination of the shower core (X_{max}).

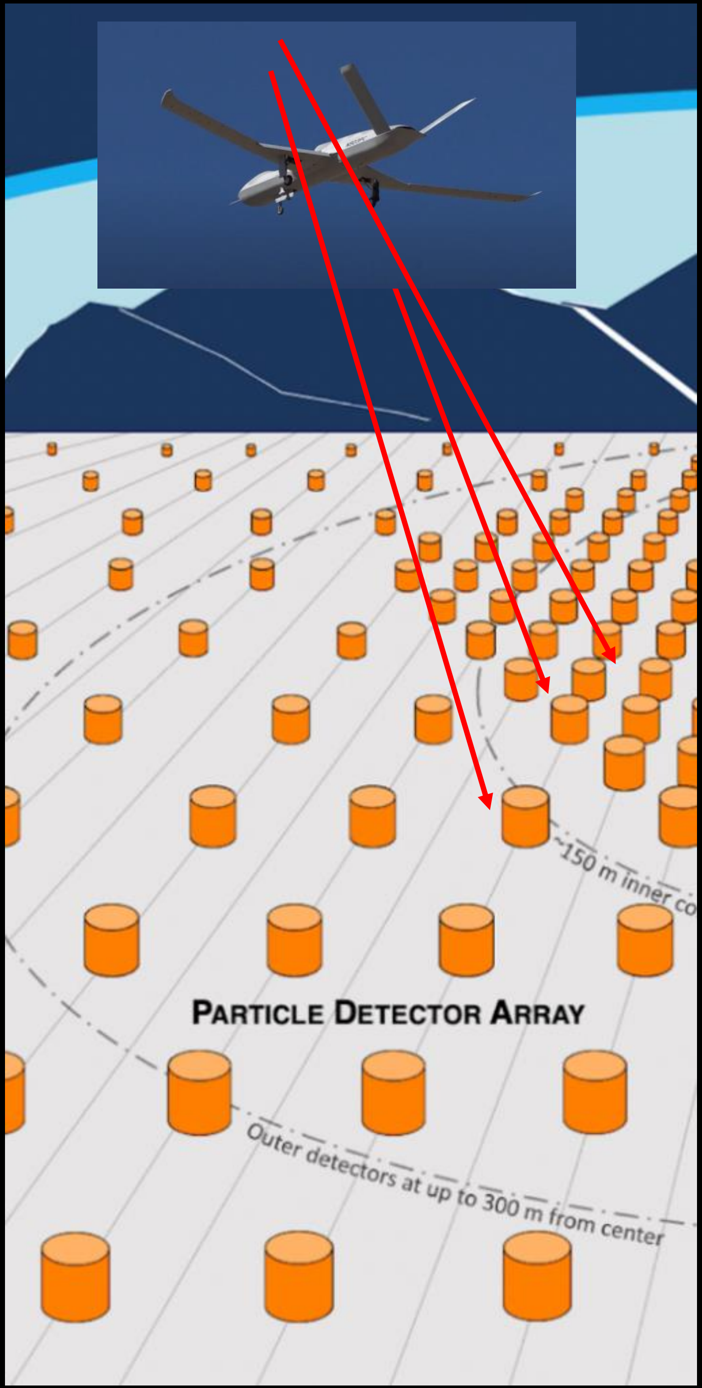
Drones can now fly for weeks at a time at very high altitude (10-20km), and carry 300kg of payload or more.

A mouthful of applications!

Coupling a planned or existing array on the ground (e.g. SWGO, HAWK, LHAASO…) with drone-carried detectors could

- improve p/nucleus discrimination
- reduce E uncertainty
- strongly improve angular resolution
- The system would be fast to "align" toward transient localized emitters, enhancing the capability of the ground based instrument and of networks of multimessenger experiments
- Cosmic shower composition studies could be boosted by this technology
- Refine models of air showers

The drone-ground array synergy could revolutionize cosmic ray research, providing insights into particle astrophysics and the atmosphere's role in high-energy phenomena



Other Co-Design study ideas

Let us add other ideas to compile a list of possible projects that can be aggregators of work we can coalesce a collaboration around…

The Survey

Let us look at the survey we created to collect information on our members' interests, personpower, and availability

	Areas	Status	PM involv. (PM)	Other PM
M. Koppel	HEP, B, HI-HEP, DET	PD	1-2	-
A. Giammanco	HEP, Muography	Staff	0.5-1	4-12
T. Golling	HEP, DET, Tracking, Calorim.	Staff	0.5-1	>12
T. Belias	HEP, NUCL, DET, HI-HEP	Staff	2	1-3
M. Tosi	HEP, Tracking, DET	Staff	-	
W. Stummer	HI-HEP, Accelerators	PD	-	-
K. Potamianos	HEP, Tracking, Pheno	Staff	0.5-1	1-3
S. Caron	HEP, Astro, GW, Pheno	Staff	-	-
C. Weniger	GW, Cosmology	Staff	<0.5	-
P. Vischia	HEP, Pheno, Astro, Calorim.	Staff	1-2	1-3
T. Dorigo	HEP, Astro, Calorimeters	Staff	2-3	4-12

Thank you for your time!

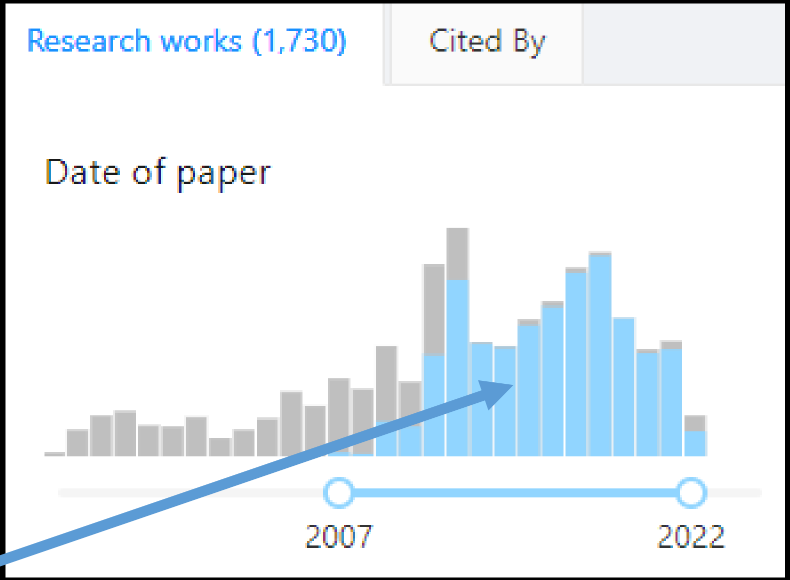
Backup

Optimal for What?

The reason why detectors are complex is not only that the studied physics is complex: Science is a demanding job.

We want to study *everything* and do it *better* than previously

CMS has over 4000 members, who use the data for a LARGE number of *different* measurements and searches...



So, what does it mean for a detector to be *optimal*?

What loss function do we aim to minimize?

Does it make sense to speak of an experiment-wide utility function?

Concerning the last question: I will convince you that it does

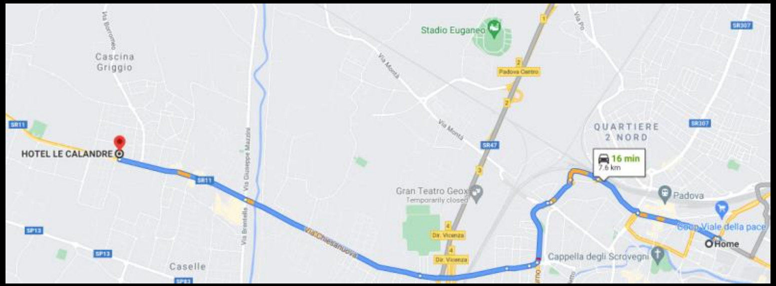
Recipe for a Perfect Dinner









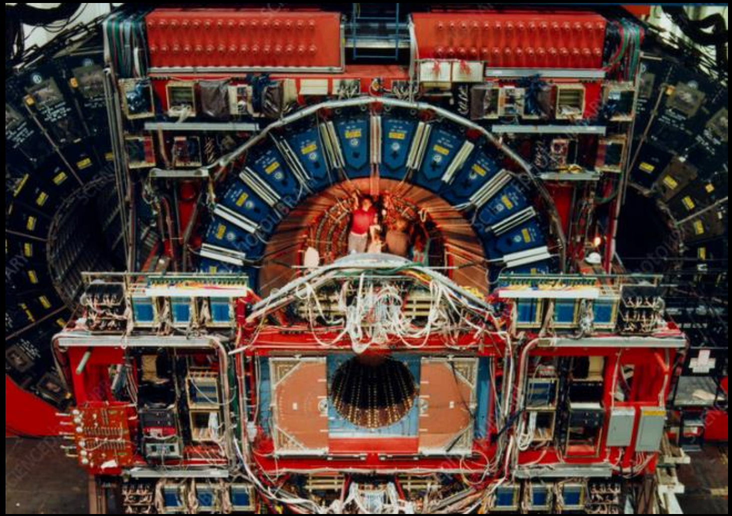
We are not alien to confidently taking complex decisions in a **multi-objective space**. We actually do it routinely...

Of course, we are not deterred by knowing that the exact form of our optimization target is arbitrary

Recipe for a Perfect Trigger

Similarly, we are actually *used* to create multi-target optimization strategies, e.g. when we allocate resources for the trigger menu of a collider detector.

Consider CDF, Run 1 (1992-96): taking in a rate of 300 kHz of proton-antiproton collisions and having to select 50 Hz of writable data created some of the most heated scientifically-driven, rationally motivated, painfully well argumented, and littered with 4-letter words debates I ever listened to



The top quark had to be discovered, but it was not the only goal of the experiment...