KITP Muon Collider workshop

Workshop summary

Federico Meloni

Future Colliders @ DESY
28/04/2023

Why a workshop

The very strong presence of muon colliders (μC) in the Snowmass process triggered the Kavli Institute for Theoretical Physics (KITP) interest for hosting a **“rapid response” workshop**

- Reach out to the community and discuss frankly “distance from real axis”
- Input to “Elementary Particle Physics: Progress and Promise” study group by NAS, and P5 discussions

Nathaniel Craig as local organiser formed the coordinators team

Muon Collider Workshop

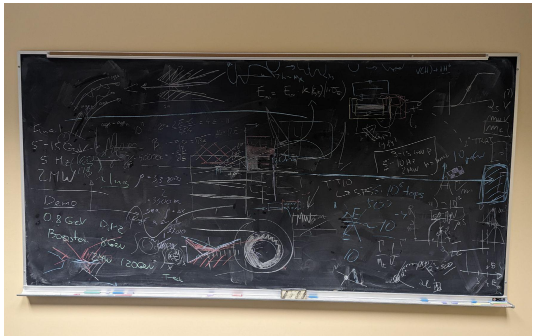
Coordinators: Nathaniel Craig, Sergo Jindariani, Federico Meloni, Isobel Ojalvo, and Andrea Wulzer

Application was submitted by the team and approved by KITP

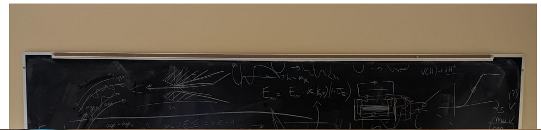
- KITP rapid response WS are 2-weeks, restricted participation events (<30 people total) aimed at discussions/collaborations
- Every participant gets an office and accommodation funded by KITP
- Format foresees order one talk plus one discussion session per day

The event took place in the weeks of February 27th - March 10th

The venue



The venue



Workshop programme

Links to videos and slides
https://online.kitp.ucsb.edu/online/muoncollider-m23/

Week 1 (2/27-3/3)

Monday, 2/27: Introduction & Overview of Muon Collider Efforts

[14:00-16:00] Tao Han (University of Pittsburgh), "Muon colliders at Snowmass and beyond"

Tuesday, 2/28: Precision Physics Case

[9:15-10:30] Dario Buttazzo (INFN), "Precision Physics at a Muon Collider"

[11:15-12:30] Markus Luty (UC Davis), Da Liu (UC Davis), "Primary Observables for Indirect Searches"

[14:00-16:00] Nathaniel Craig (UCSB), Markus Luty (UC Davis), Da Liu (UC Davis), Ian Low (Argonne/Northwestern University), Brian Henning (EPFL), Discussion: Electroweak symmetry at high energies

Wednesday, 3/1: New Physics Benchmarks & Signals

[9:15-10:30] Ian Low (Argonne/Northwestern University), "Physics Benchmarks for Muon Colliders"

[11:15-12:30] Rodolfo Capdevilla (Fermilab), "Signal Benchmarks for Muon Colliders"

[14:00-16:00] Cari Cesarotti (MIT), "Beam Dumps and Other Synergistic Detectors";

Maximilian Ruhdorfer (Cornell), "Very Forward Muon Detectors";

Discussion: Coordinating US Input to P5

Thursday, 3/2: Neutrino Synergies

[9:15-10:30] Marcos Dracos (IPHC-IN2P3/CNRS Strasbourg), "The European Spallation Source neutrino Super Beam and muon synergies"

[11:15-12:30] Zahra Tabrizi (Northwestern University), "Neutrino Opportunities at a Muon Collider"

[14:00-16:00] Scott Berg (BNL), Katsuya Yonehara (Fermilab), "The State of Ionization Cooling"

Friday, 3/3: Muon Collider Theory Needs

[9:15-10:30] Andrea Wulzer (IFAE), "Electroweak Radiation Challenges & Opportunities"

[11:15-12:30] Keping Xie (University of Pittsburgh), Yang Ma (INFN-BO), "Electroweak Factorization at High-Energy Muon Colliders"

Workshop programme

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Week 2 (3/6-3/10)

Monday, 3/6: Accelerator

[14:00-16:00] Mark Palmer (BNL), "Accelerator Overview";

Discussion: Staging possibilities

Tuesday, 3/7: Detectors

[9:15-10:30] Zhen Liu (Minnesota), "Physics requirements for the detector"

[11:15-12:30] Daniele Calzolari (CERN), "MDI and BIB mitigation"

[14:00-16:00] Roberto Franceschini (Roma Tre), Patrick Meade (Stony Brook), Michael Peskin (SLAC), Liantao Wang (U. Chicago), Theory Panel: Opportunities & Open Questions

Wednesday, 3/8: Detector++

[9:15-10:30] Lawrence Lee (Tennessee), "How to Build a Detector at a Muon Collider"

[11:15-12:30] Discussion: Unique R&D Directions

[14:00-16:00] Discussion: Coordinating US Input to P5

Thursday, 3/9: Accelerator Technology

[9:15-10:30] Chris Rogers (STFC), "Demonstrators overview"

[11:00-12:30] Sam Posen (Fermilab), "US accelerator technology capabilities for MuC"

[14:00-16:00] Patrick Meade (Stony Brook), "Sustainability Study"

Friday, 3/10: Muon Accelerator Panel & Closeout

[9:00-11:00] Sergey Belomestnykh (Fermilab), Young-Kee Kim (U. Chicago), Michiko Minty (BNL), Mark Palmer (BNL), Tor Raubenheimer (SLAC), Chris Rogers (STFC), Daniel Schulte (CERN), Vladimir Shiltsev (Fermilab), Muon Accelerator Panel

[11:30-12:30] Discussion: The Path Forward

[16:00-17:00] Nima Arkani-Hamed (IAS), KITP Blackboard Talk

Closing day: accelerator panel discussion

Friday, 3/10: Muon Accelerator Panel & Closeout

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Discuss only about Muon Collider technical feasibility to **expose and address real or perceived limitations**

Panel composed of “proponents” and “opponents”

- No recording to allow people to freely express their thoughts
- Transcript will be made available

In reality, “opponents” did not “oppose” much. More like a friendly discussion

- Nobody (among panelists) doubts that is it worth investing in μC
- However, it’s unclear if the event will help with skeptics

Globally, many participants have learnt at the workshop that the μC is more close to the real axis than they had thought

Broader-than-μC Highlights

Messaging for particle physics (1/3)

Many outlined the **need of a novel narrative for collider physics**

- Move away from “discovery stories” and specific BSM models

There are at least two ways to do this:

Ask the right questions [Ian Low’s wording]

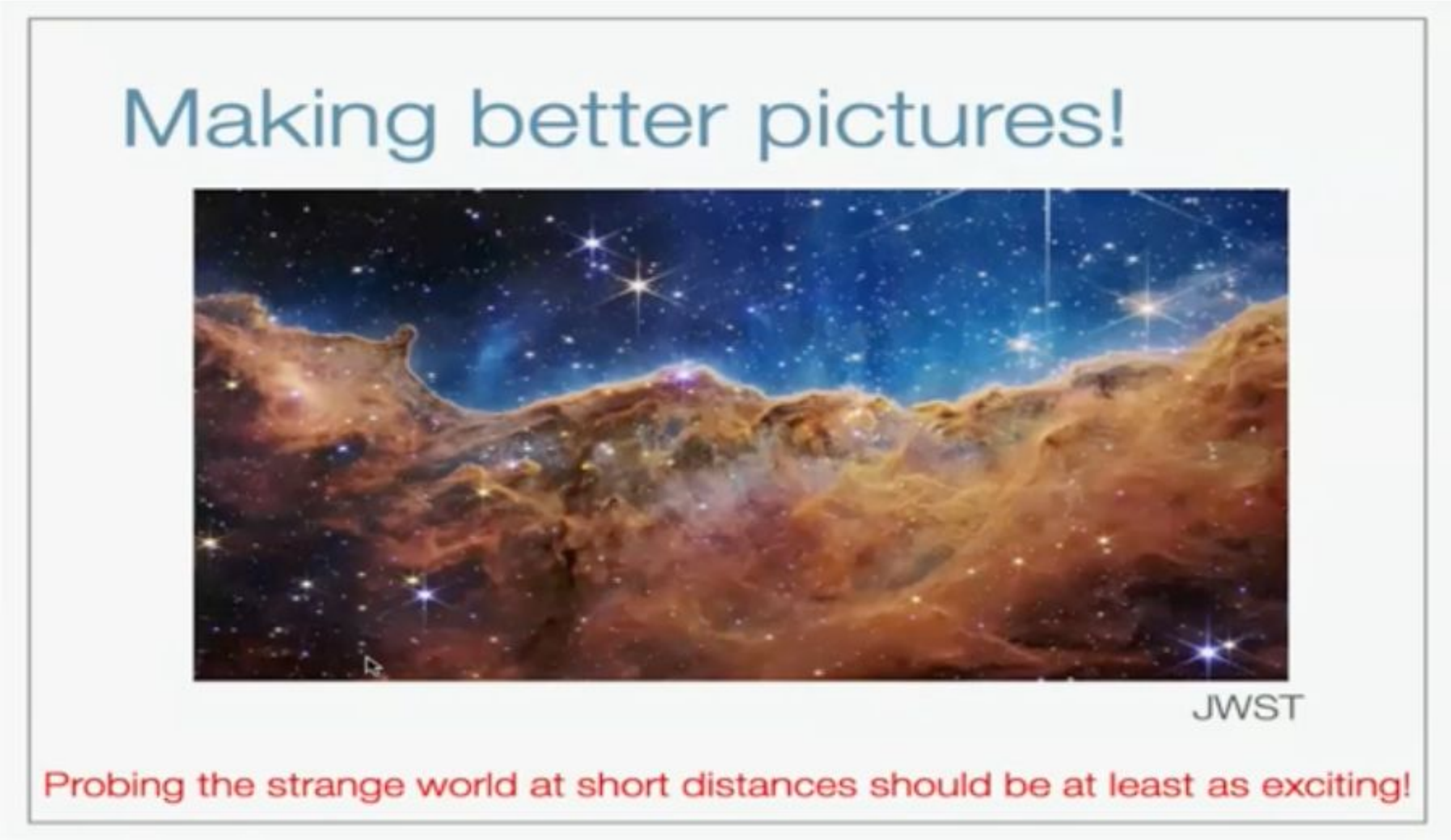
- Sharp conceptual or empirical questions the SM cannot answer to
- Of clear and general interest (e.g. Dark Matter, Composite Higgs, ...)
- BSM models are placeholders that illustrate possible answers, not our target

Define a SM physics case [Ian Low, Markus Luty, Nathaniel Craig, Andrea Wulzer]

- We are the only scientific community that is perceived as talking of its daily work (despite loving it!) as an uninteresting technicality towards the Big Thing
- Very difficult for us to spell out the excitement of predicting and observing new phenomena in the SM
- This attitude must change

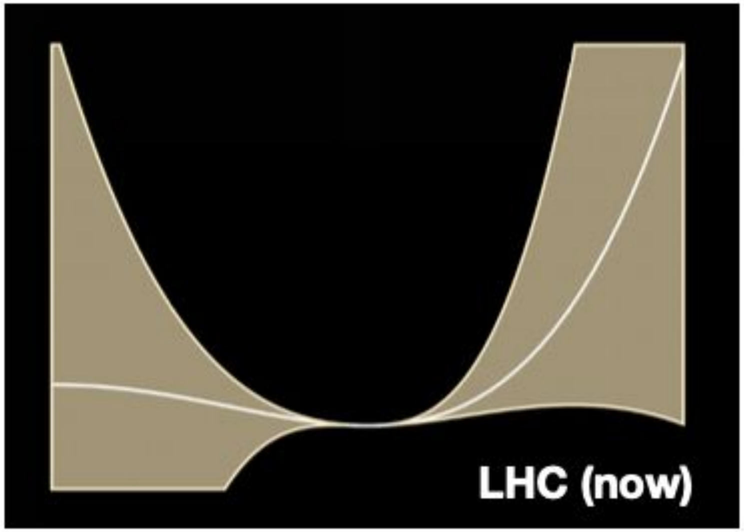
Plenty of opportunities at the μC: e.g. Electroweak Radiation and Electroweak Restoration

Messaging for particle physics (2/3)



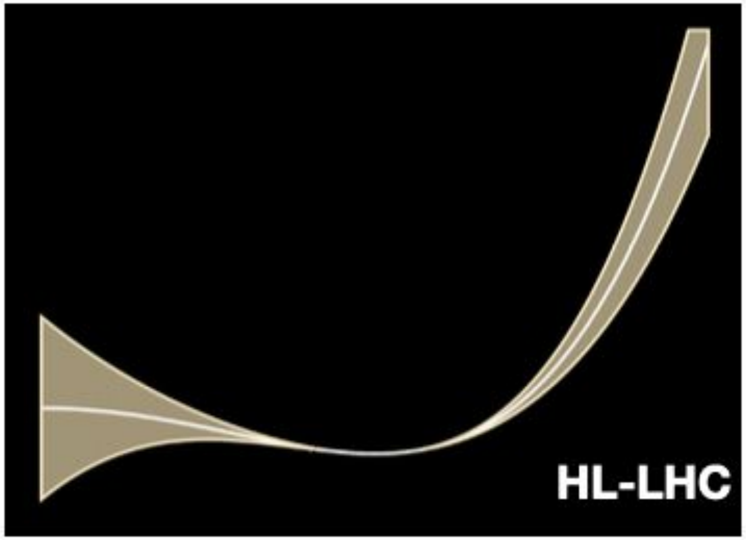
“We need to learn how to say that going into probing the world at short distances should be at least as exciting as looking deeper into the universe” - Liantao Wang

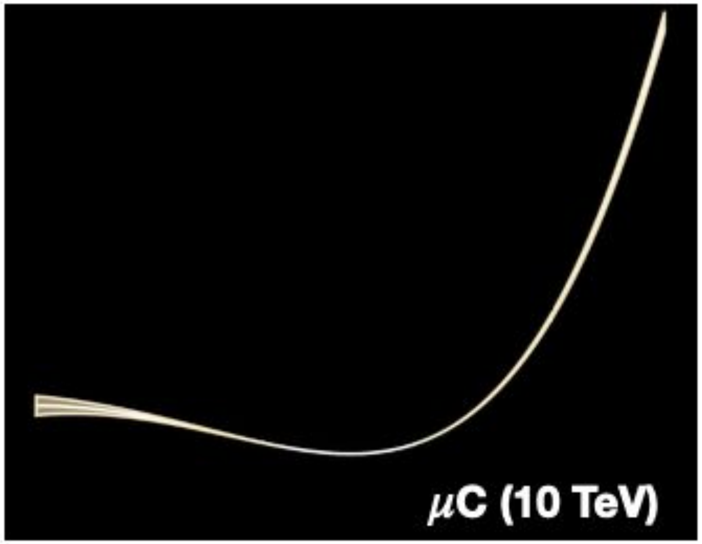
Messaging for particle physics (3/3)



Drawing precision physics (Higgs potential) [Nathaniel Craig]

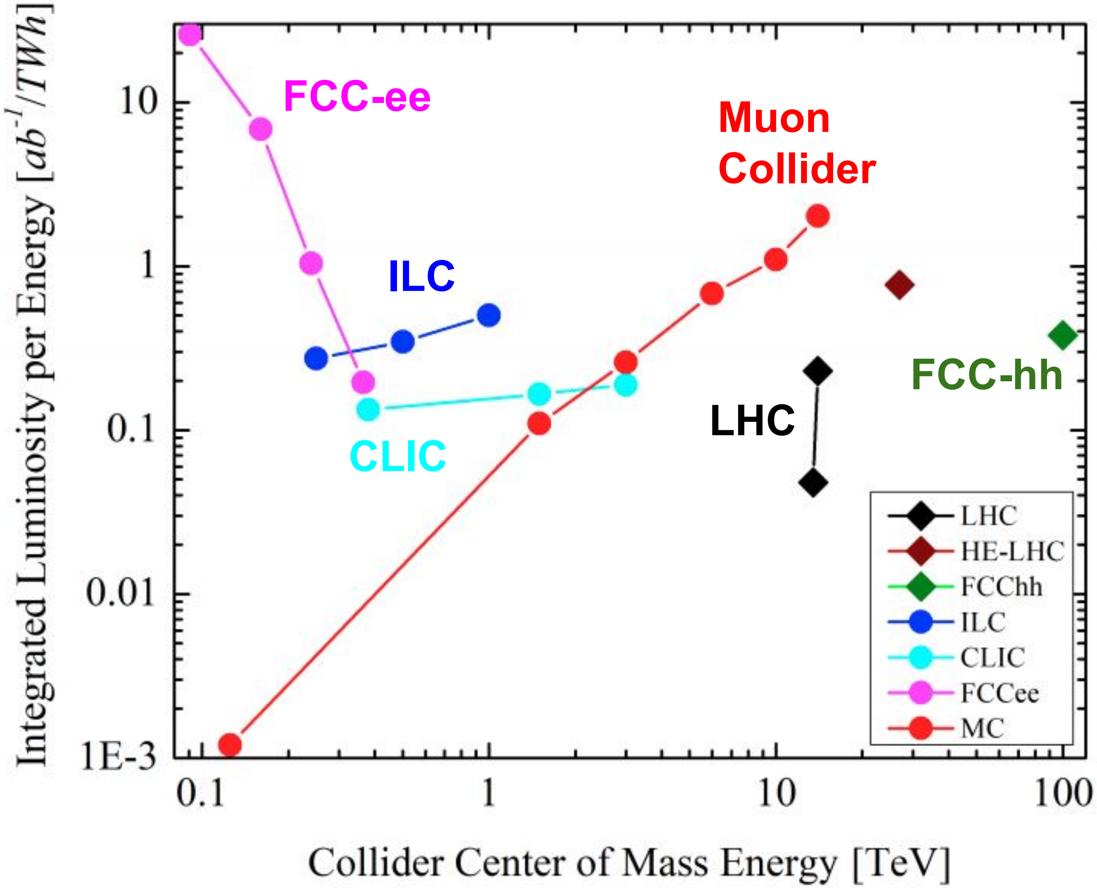
- Potential is not physical/measurable
- Drawing does not make experts happy
- But, makes the goal clear and accessible





Sustainability (1/2)

arXiv: 2007.15684
arXiv: 2003.09084



HEP's carbon footprint must be kept to a minimum

We know already that a μC is the most power-efficient option for the 10 TeV scale

- Power consumption is not the full story

Sustainability (2/2)

Recent study from P. Janot and A. Blondel (2208.10466) became very visible

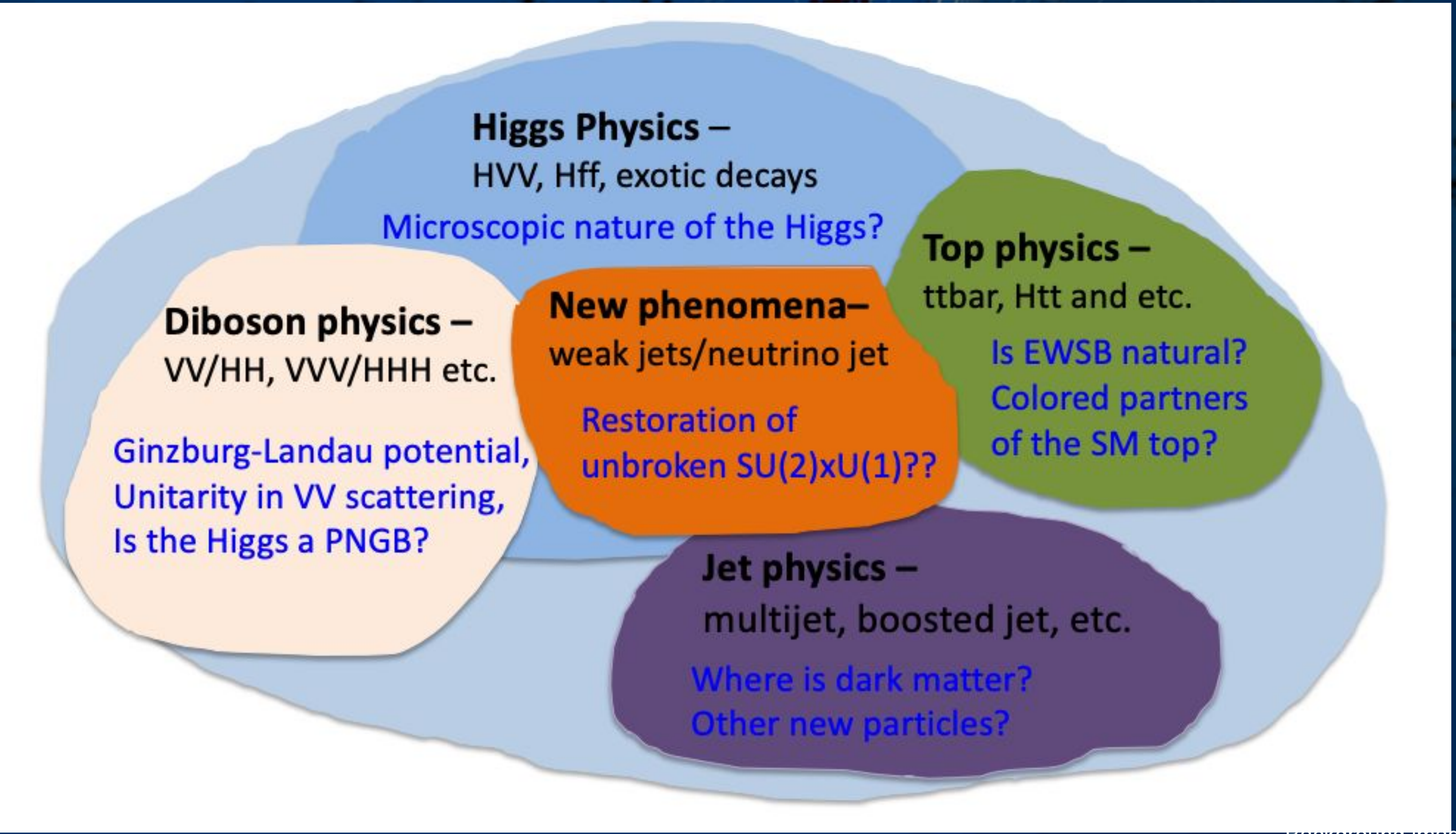
Triggered interest in conducting a systematic evaluation of future collider options

- Remove geographical dependence from estimates
- Start from unbiased numbers, agreed across collider projects
  - e.g. Snowmass ITF report (2208.06030)?
- Agree on figures of merit

Attempt to account for:

- Excavation
- Building and collider materials

Physics Highlights



Background image credit: L. Lee

Electroweak radiation

A. Wulzer

We will observe the nearly-massless EW gauge theory

$$E \gg m_W$$

Large muon collider energy ← E ; m_W → Small IR cutoff scale

Scale separation entails enhancement of Radiation effect.

Like QCD ($E \gg \Lambda_{QCD}$) and QED ($E \gg m_\gamma = 0$), **but:**

EW symmetry is broken:
EW color is observable ($W \neq Z$).
KLN Theorem non-applicable.
(inclusive observables not safe)

→ **Practical need** of computing EW Radiation effects

Enhanced by $\log^{(2)} E^2/m_{EW}^2$

EW theory is Weakly-Coupled
The IR cutoff is physical

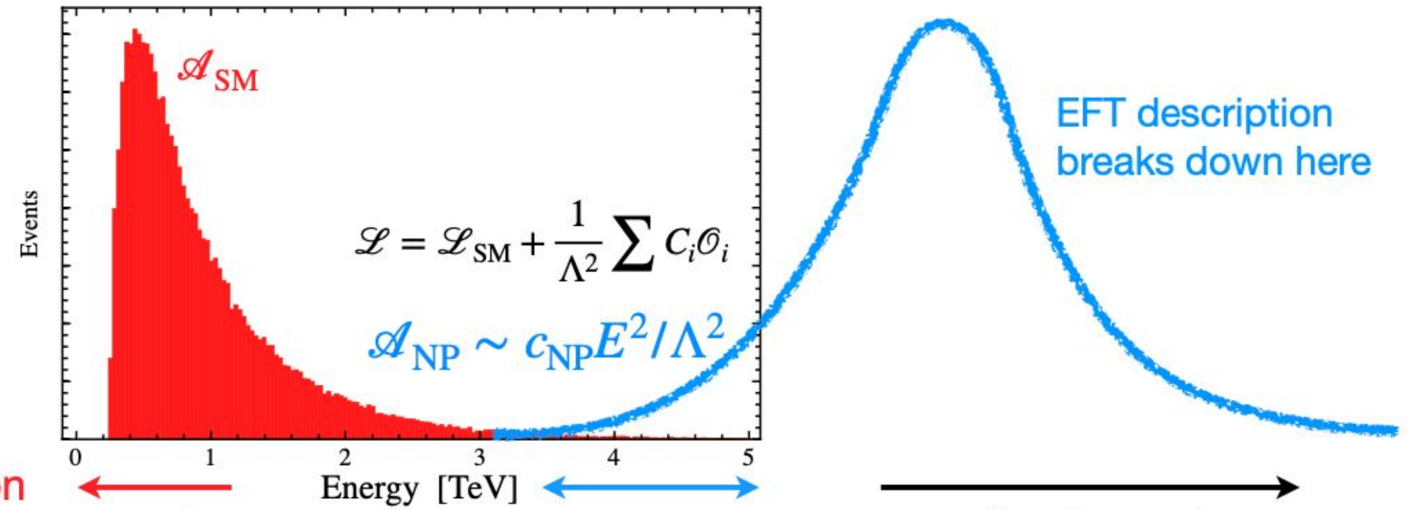
→ **First-Principle** predictions **must** be possible

For arbitrary multiplicity final state

High-energy probes

D. Buttazzo

- NP effects are more important at high energies



Precision
SM measurements

High energy (indirect) probes

direct searches

- As simple as this: $\frac{\Delta\sigma(E)}{\sigma_{SM}(E)} \propto \frac{E^2}{\Lambda^2_{BSM}} \approx \begin{cases} 10^{-6}, & E \sim 100\,\text{GeV} \\ 10^{-2}, & E \sim 10\,\text{TeV} \end{cases}$

- Effective at LHC, FCC-hh, CLIC: "energy helps accuracy"…

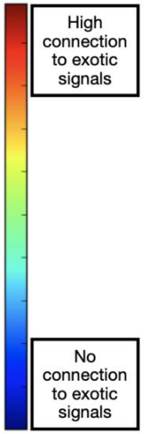
Farina et al. 1609.08157, Franceschini et al. 1712.01310, …

… taken to the extreme at a μ-collider with 10's of TeV!

Exotic signals

R. Capdevilla

Motivation	Theoretical scenario	Candidate particle(s)	Boosted objects	Small splittings	Stopping particles	Disappearing tracks	Displaced vertices	Exotic tracks	Emerging jets	Exotics in the mu system	Forward detector
			Exotic Signals (Potential Implications for Detector/Facility Design)								
Exotics	SM+singlet	S	7, 10, 13, 15, 16,				7, 10, 13, 15, 16,			7, 10, 13, 15, 16,	
	2HDM	$H^{\pm}$, H^{0}, A	1, 2, 4, 11,	1, 2, 4, 11,			1, 2, 4, 11,				
	New gauge groups	Z', W'	3, 20, 21, 30,	3, 20, 21, 30,		3, 20, 21, 30,					
	VLF	Q', L'	x	x				x			
	HNL	N_i	17, 19, 24, 25, 26,							17, 19, 24, 25, 26,	17, 19, 24, 25, 26,
	Leptoquarks	$\tilde{R}_2$, U_1 (UV motivated)	8, 12,	8, 12,							
	Quirks	$q'\bar{q}'$ (bound state)			x			x		x	x
	Hidden valleys						x	x	x	x	



1) Eichten, Martin, Phys. Lett. B 728 (2014) 125-130
2) Chakrabarty, Han, Liu, Mukhopadhyaya, Phys. Rev. D 91 (2015) 1, 015008
3) Huang, Queiroz, Rodejohann, Phys. Rev. D 103 (2021) 9, 095005
4) Han, Li, Su, Su, Wu, Phys. Rev. D 104 (2021) 5, 055029
5) Capdevilla, Meloni, Simoniello, Zurita, JHEP 06 (2021) 133
6) Bottaro, Strumia, Vignaroli, JHEP 06 (2021) 143
7) Al Ali et al., Rept. Prog. Phys. 85 (2022) 8, 084201
8) Asadi, Capdevilla, Cesarotti, Homiller JHEP 10 (2021) 182
9) Franceschini, Greco, Symmetry 13 (2021) 5, 851
10) Haghighat, Najafabadi, Nucl. Phys. B 980 (2022) 115827
11) Sen, Bandyopadhyay, Dutta, KT, Eur. Phys. J. C 82 (2022) 3, 230
12) Qian et al., JHEP 12 (2021) 047
13) Costantini, PoS EPS-HEP2021 (2022) 717
14) Casarsa, Fabbrichesi, Gabrielli, Phys. Rev. D 105 (2022) 7, 7
15) Capdevilla, Curtin, Kahn, Krnjaic, JHEP 04 (2022) 129
16) Bao, Fan, Li
17) Chakraborty,
18) Inan, Kissele
19) Liu, Han, Jin
20) Allanach, Lo
21) Das, Nomura
22) Franceschini
23) Lv, Cui, Li, I
24) Mekala, Reu
25) Kwok, Li, Li
26) Li, Liu, Lyu, eprint: 2301.07117
27) Li, Yao, Yuan, eprint: 2301.07274
28) Inan, Kisselev, eprint: 2301.08585
29) Jueid, Nasri, eprint: 2301.12524
30) Li et al., eprint: 2302.02203
…

Many exotic and long-lived signals are less developed at μC because we need to **study their interplay with beam-induced backgrounds**

Synergies with neutrinos

Z. Tabrizi

- We can use a neutrino detector for precision measurements on neutrino interactions (DIS x-section, weak mixing angle, etc.)
- Direct dark sector searches (HNL, ALPs, light DM, erc)
- We can probe very heavy particles by precisely measuring low-energy observables using the EFT formalism.
- Unlike other probes (meson decays, ATLAS and CMS analyses, etc.) a neutrino detector has the unique capability to identify the neutrino flavors. This is crucial complementary information in case excesses are found elsewhere in the future.
- We are NOT yet prepared to identify all the interesting things we can do!

The straight sections of the collider complex have a unique potential to study high-energy neutrino scattering

- 10^5 / m / bunch x 100 m x 10^5 kHz x 10^7 s/year = 2 x 10^{19} neutrinos year
- Neutrino interaction probability 4 x 10^{-10} x [E/TeV] x [L/m] x [density/g cm^-3]
- At 1 km, the neutrino beam section will be O(10 cm)

Detector Highlights

Background image credit: L. Lee

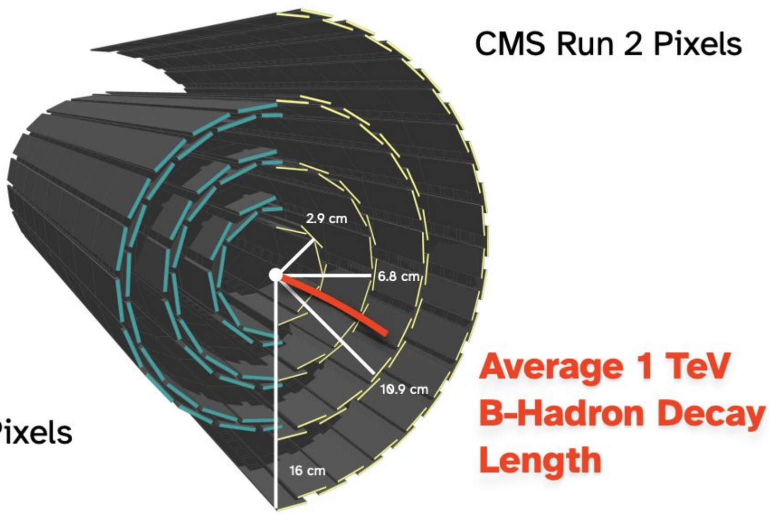
Detectors for 10 TeV

L. Lee

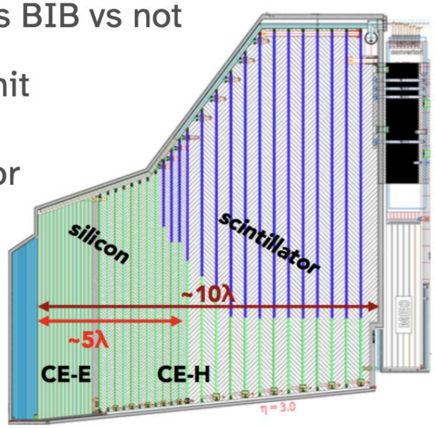
- **Energy Scale**
  - @ a 10 TeV μC, typical hard scatter at 10 TeV scale!
  - Multi-TeV objects will be the **norm** which will affect how to design the detector

To give a taste: Remember at 1 TeV, a B-hadron travels 10 cm into the detector

Physics reach of a **multi-TeV μC** relies on (among other things) **successful detector R&D program today**



- **CMS HGCal**
  - Precise measurements of shower evolution across 6.5M channels
  - This approach can give detailed view of what's BIB vs not
  - Can already hit O(10) ps resolutions for multi-MIP signals

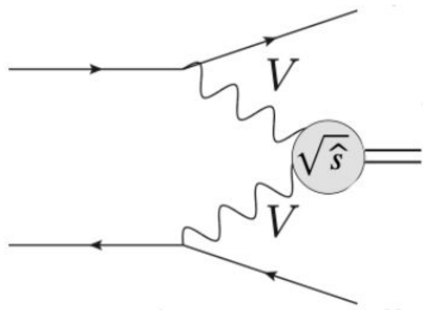


arXiv: 2303.14202

Forward muon detection

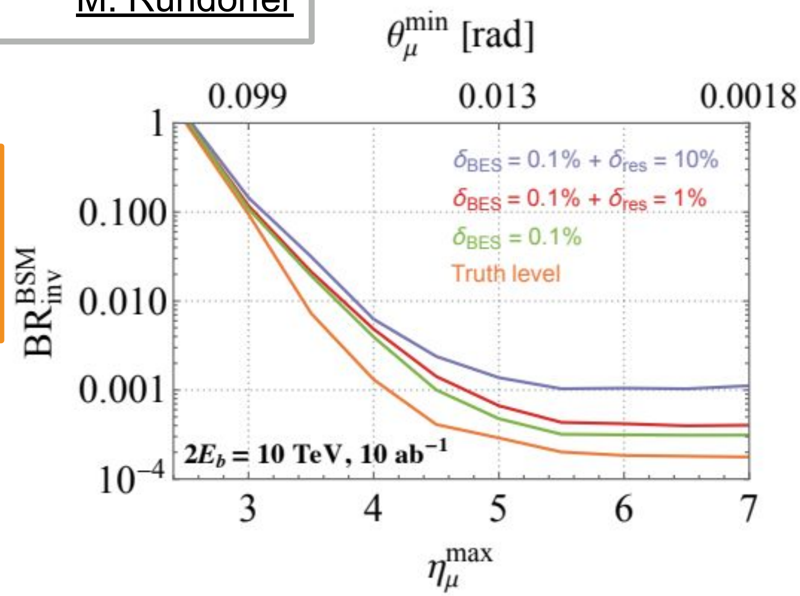
M. Ruhdorfer

- HE muon collider is a vector boson collider



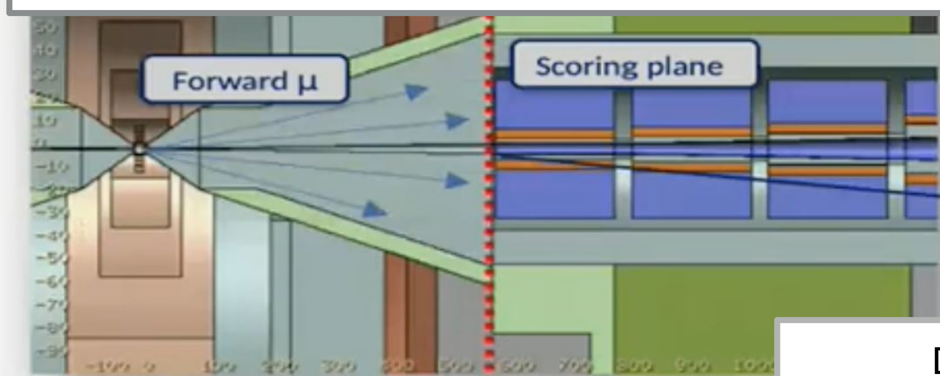
Taken from 2203.07256

Very forward products
Need to instrument the forward region!



- Resolving forward muons is essential for:

1. Precision physics (e.g. Higgs coupling measurements)
2. Studying signatures with invisible particles (DM, LLPs,…)



Studies with FLUKA

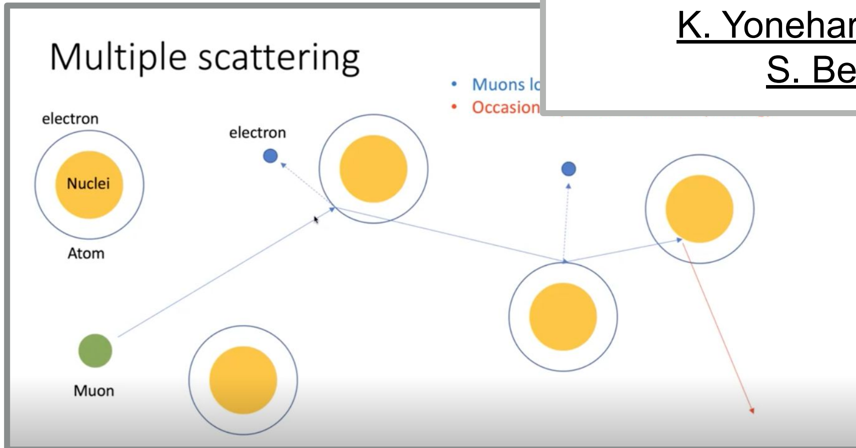
- Optimisation of IR region, nozzles
- Characterise muons passing through material

D. Calzolari

Accelerator Highlights

Background image credit: L. Lee

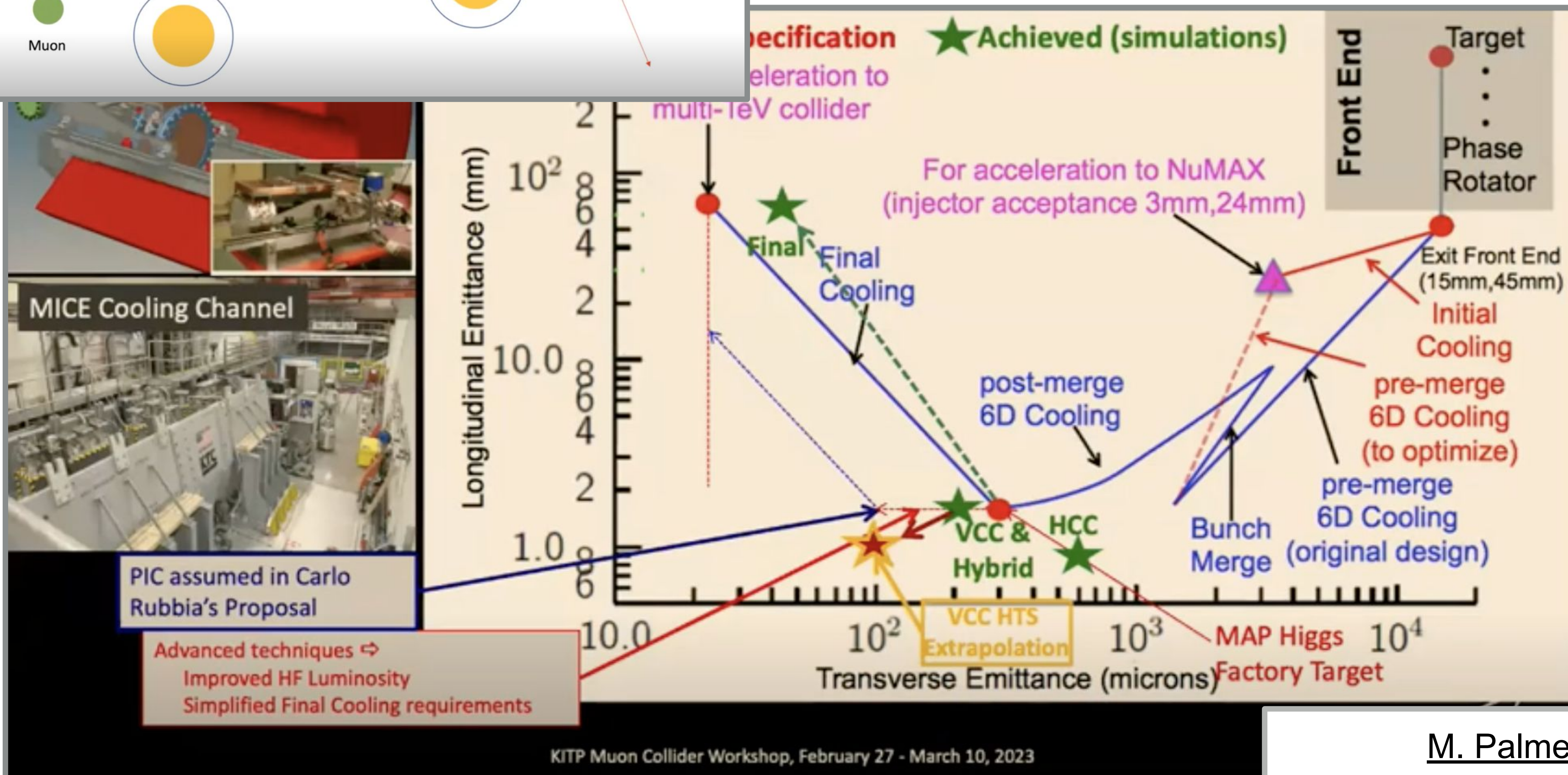
Cooling the beams



K. Yonehara, S. Berg

Exploit muon energy losses in material to cool beam, accelerate in desired direction

Principle demonstrated by MICE (0.9 reduction), repeat for O(1km)



M. Palmer

arXiv: 2303.08533

Physics > Accelerator Physics

[Submitted on 15 Mar 2023]

Towards a Muon Collider

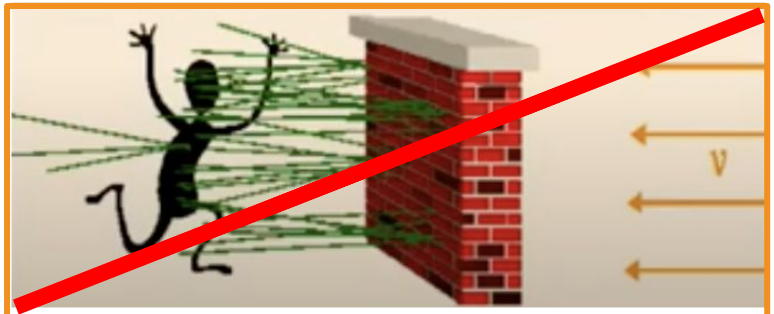
Carlotta Accettura, Dean Adams, Rohit Agarwal, Claudia Ahdida, Chiara Aimè, Nicola Amapane, David Amorim, Paolo Andreetto, Fabio Anulli, Robert Appleby, Artur Apresyan, Aram Apyan, Sergey Arsenyev, Pouya Asadi, Mohammed Attia Mahmoud, Aleksandr Azatov, John Back, Lorenzo Balconi, Laura Bandiera, Roger Barlow, Nazar Bartosik, Emanuela Barzi, Fabian Batsch, Matteo Bauce, J. Scott Berg, Andrea Bersani, Alessandro Bertarelli, Alessandro Bertolin, Fulvio Boattini, Alex Bogacz, Maurizio Bonesini, Bernardo Bordini, Salvatore Bottaro, Luca Bottura, Alessandro Braghieri, Marco Breschi, Natalie Bruhwiler, Xavier Buffat, Laura Buonincontri, Philip Burrows, Graeme Burt, Dario Buttazzo, Barbara Caiffi, Marco Calviani, Simone Calzaferri, Daniele Calzolari, Rodolfo Capdevilla, Christian Carli, Fausto Casaburo, Massimo Casarsa, Luca Castelli, Maria Gabriella Catanesi, Gianluca Cavoto, Francesco Giovanni Celiberto, Luigi Celona, Alessandro Cerri, Gianmario Cesarini, Cari Cesarotti, Grigorios Chachamis, Antoine Chance, Siyu Chen, Yang-Ting Chien, Mauro Chiesa, Anna Colaleo, Francesco Collamati, Gianmaria Collazuol, Marco Costa, Nathaniel Craig, Camilla Curatolo, David Curtin, Giacomo Da Molin, Magnus Dam, Heiko Damerau, Sridhara Dasu, Jorge de Blas, Stefania De Curtis, Ernesto De Matteis, Stefania De Rosa, Jean-Pierre Delahaye, Dmitri Denisov, Haluk Denizli, Christopher Densham, Radovan Dermisek, Luca Di Luzio, Elisa Di Meco, Biagio Di Micco, Keith Dienes, Eleonora Diociaiuti, Tommaso Dorigo, Alexey Dudarev, Robert Edgecock, Filippo Errico, Marco Fabbrichesi, Stefania Farinon, Anna Ferrari, Jose Antonio Ferreira Somoza, Frank Filthaut, Davide Fiorina, Elena Fol, Matthew Forslund et al. (197 additional authors not shown)

The 12 miracles

In the past (last P5), a list of “miracles” was seen as a substantial problem for a Muon Collider to happen

Today, none of these are miracles anymore

1. Pulse compression of multi-MW proton beam to a few ns-long bunch
2. Multi-MW, small cross-section area targets, at low energy (~10 GeV)
3. Many-Tesla capture solenoids in a high-radiation area
4. Many-Tesla cooling channel solenoids
5. High-gradient RF in solenoidal fields
6. 6D ionization cooling, and emittance matching
7. Very-Rapid-Cycling Synchrotron Dynamics
8. Very-Rapid-Cycling Synchrotron Magnets
9. Open aperture storage ring magnets
10. Extremely low-beta collider ring dynamics
11. Neutrino-induced radiation
12. Detector shielding and rates



Excellent example of physicists killing their own projects by miscommunication
Recommend to erase these pictures from existence

Closing notes

Background image credit: L. Lee

Preparation for P5

We had talks/discussion sessions about P5, that helped our US colleagues to set up their plans

US Muon Collider R&D Coordination Group

- In March, R&D Coordination Group was assembled to provide input to P5
- Focus on key elements of 10 TeV accelerator and detector design
- Develop R&D plan, activities, budget and deliverables

Chairs: Sergo Jindariani, Diktys Stratakis (FNAL), Sridhara Dasu (Wisconsin)

Detector R&D Focus Areas:
Tracking Detectors:
Maurice Garcia-Sciveres (LBNL), Tova Holmes (Tennessee)

Calorimeter Systems
Chris Tully (Princeton), Rachel Yohay (FSU)

Muon Detectors
Melissa Franklin (Harvard), Darien Wood (Northeastern)

Electronics/TDAQ
Darin Acosta (Rice), Michael Begel (BNL), Isobel Ojalvo (Princeton),

MDI+Forward Detectors:
Kevin Black (Wisconsin), Karri DiPetrillo (Chicago), Nikolai Mokhov (Fermilab)

Detector Software/Simulations/ML:
Simone Pagan Griso (LBNL), Walter Hopkins (ANL), Liz Sexton-Kennedy (Fermilab)

Physics Case Development:
Patrick Meade (Stony Brook), Nathaniel Craig (UCSB)

Accelerator R&D Focus Areas:
Muon source:
Mary Convery (Fermilab), Jeff Eldred (Fermilab), Sergei Nagaitsev (JLAB), Eric Prebys (UC Davis)

Machine design:
Frederique Pellemoine (Fermilab), Scott Berg (BNL), Katsuya Yonehara (Fermilab)

Magnet systems:
Steve Gourlay (Fermilab), Giorgio Apollinari (Fermilab), Soren Prestemon (LBNL)

RF systems:
Sergey Belomestnykh (Fermilab), Spencer Gessner (SLAC), Tianhuan Luo (LBNL)

International Liaisons:
Donatella Lucchesi (INFN), Federico Meloni (DESY), Chris Rogers (RAL), Daniel Schulte (CERN),

+ communication with DOE, CPAD, ECFA

19 S. Jindariani, BNL P5 Townhall Fermilab

Would you like to know more?

Come to the next IMCC annual meeting

International MUON Collider Collaboration

19–22 Jun 2023
Europe/Zurich timezone

IMCC Annual Meeting 2023

Enter your search term

- Overview
- Registration
- Fees & Payment
- Travel info
  - Accommodation
  - Insurance and VISA
- Meeting Rooms
- Committees
- Synergies workshop (22-23 June)
- IMCC website
- Privacy Information

Muon Collider Secretariat
muon.collider.secretariat...

The second Collaboration Meeting of the Muon Collider Study will take place from June 19 to June 22, 2023. The meeting will be held in person at IJCLab in Orsay (France) and it is organized by CEA, CERN and IJCLab.

We plan to cover at the meeting all areas of study and development, allowing ample time for both plenary and parallel sessions.

The main goals of the meeting will be to report on the progress of the study, in accordance with the defined work programme, and consolidate the share of tasks among all Collaborators, including the activities within the scope of the EU-funded MuCol Design Study. We especially wish to use this opportunity to address interfaces and integration among the various activities. The meeting is an opportunity for the Collaboration to review activities, advances and plans.

The final plenary and close-out session of the Collaboration Meeting will be followed by the first session of the Muon Collider Synergies Workshop.

This meeting is also supported by MUST, the MUon collider STrategy network, a part of the I.FAST European project, whose specific objective is to review advances and promote collaboration on the moun source.

cea irfu

CERN

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Funded by the European Union

19-22 June 2023

Free for virtual attendance

Register here!

Summary

Overall, this was one of the most (if not the most) productive workshop I ever participated in.

- Format very different from the "usual" HEP workshop or conference
- Incredible level of enthusiasm from participants, from early-career researchers to researchers-who-won't-see-any-future-collider

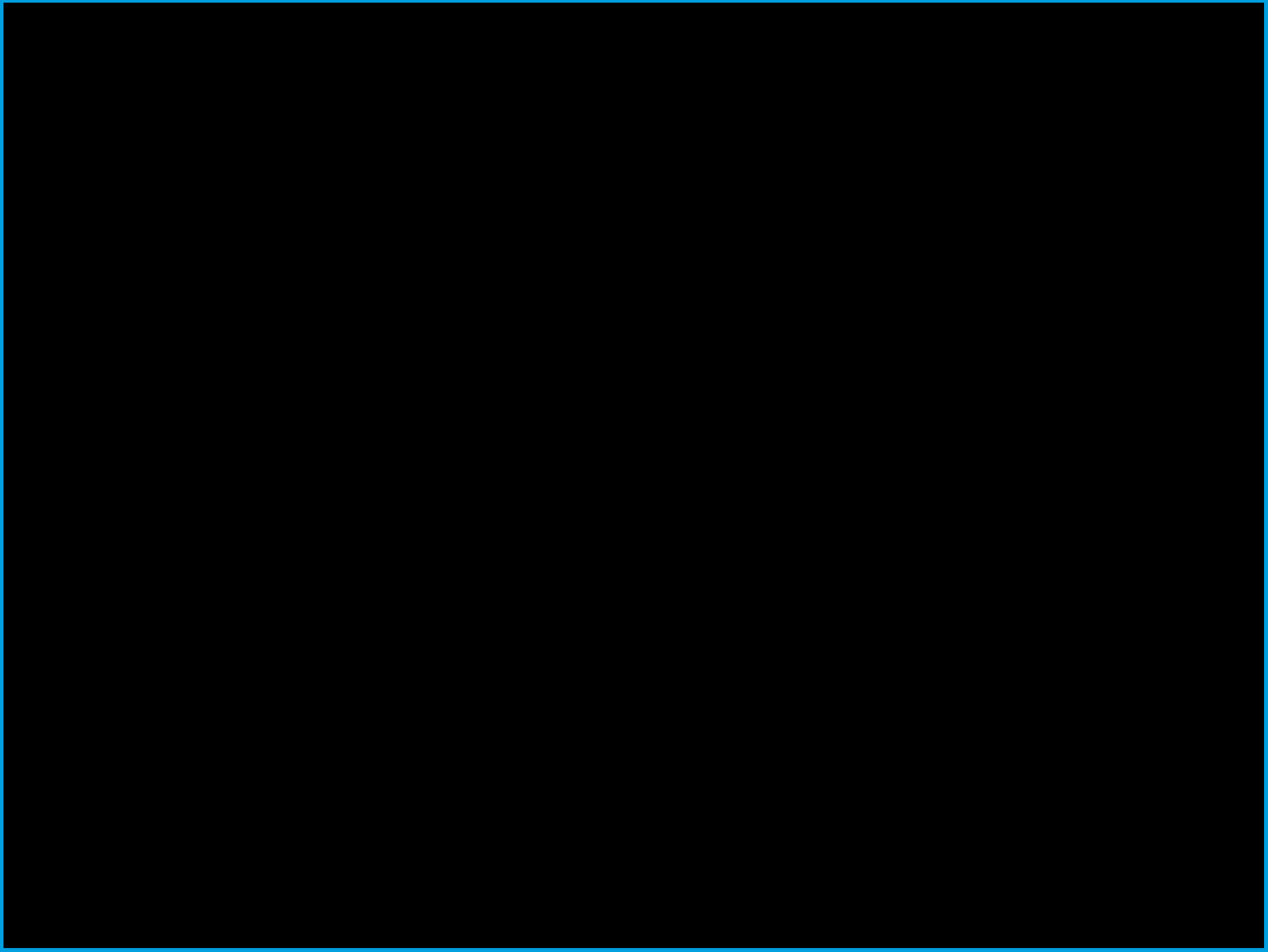
Impact on the immediate and medium term

- Started US Muon Collider R&D Coordination Group
- Will start a set of "Muon Collider Physics Studies" meetings within IMCC
- NAS panel long-term vision will help with medium-to-long term perspectives

I've only highlighted a few of the MANY interesting topics that were discussed

Find out more at https://online.kitp.ucsb.edu/online/muoncollider-m23/

Thank you!



N. Arkani-Hamed full talk

The 12 ~~miracles~~ challenges

Many thanks to S. Jindariani, D. Schulte, and M. Wing for inputs and useful discussions

	Target	Status	Notes	Future work
Pulse compression	1-3 ns	SPS does O(1) ns	Need higher intensity. O(30) ns loses only factor 2 in the produced muons.	Refine design, including proton acceleration. Accumulation and compression of bunches.
High-power targets	2 MW	2 MW	Available for neutrino and spallation neutrons. Aim for 4 MW to have margin.	Develop target design for 2 MW, O(1) ns bunches create larger thermal shocks. Prototype in 2030s.
Capture solenoids	15 T	13 T	ITER central solenoid.	Study superconducting cables and validate cooling. Investigate HTS cables.
Cooling solenoids	50 T	30-40 T	30 T leads to a factor 2 worse transverse emittance with respect to design.	Extend designs to the specs of the 6D cooling channel. Demonstrator.
RF in magnetic field	>50 MV/m	65 MV/m	MUCOOL published results. Requires test in non-uniform B.	Design to the specs of 6D cooling. Demonstrator.
6D cooling	10^{-6}	0.9 (1 cell)	MICE result (no re-acceleration). Emittance exchange demonstrated at g-2.	Optimise with higher fields and gradients. Demonstrator.
RCS dynamics	-	-	Simulation. 3 TeV lattice design in place.	Develop lattice design for a 10 TeV accelerator ring.
Rapid cycling magnets	2 T/ms 2 T peak	2.5 T/ms 1.81 T peak	Normal conducting magnets. HTS demonstrated 12 T/ms, 0.24 T peak.	Design and demonstration work. Optimise power management and re-use.
Ring magnets aperture	20 T quads	12-15 T (Nb_3Sn)	Need HTS or revise design to lower fields.	Design and develop larger aperture magnets, 12-16 T dipoles and 20 T HTS quads.
Collider dynamics	-	-	3 TeV lattice in place with existing technology.	Develop lattice design for a 10 TeV collider.
Neutrino radiation	10 μSv/year	-	3 TeV ok with 200 m deep tunnel. 10 TeV requires a mover system.	Study mechanical feasibility of the mover system impact on the accelerator and the beams.
Detector shielding	Negligible	LHC-level	Simulation based on next-gen detectors.	Optimise detector concepts. Technology R&D.

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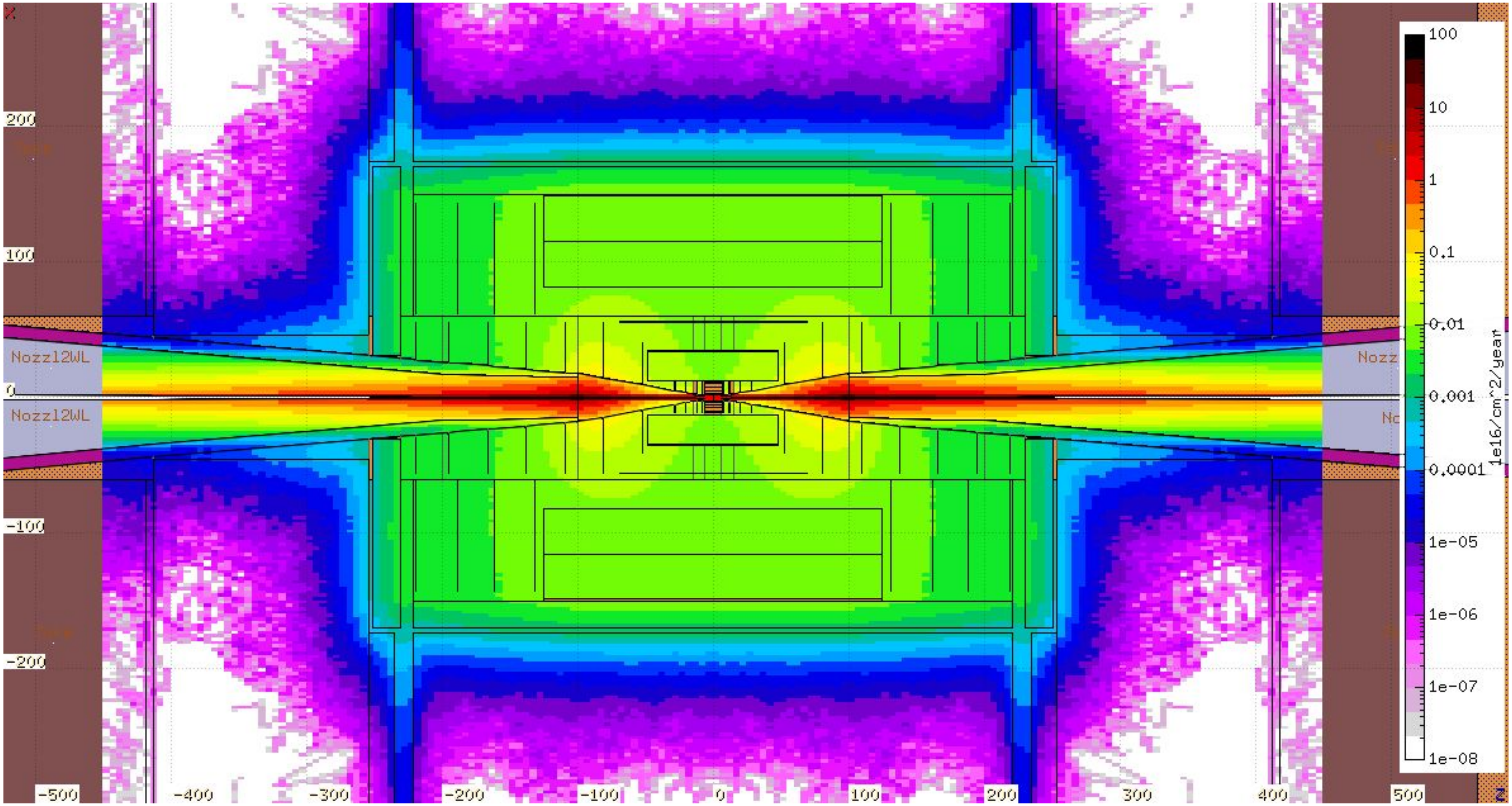
Detection Environment

1-MeV-neq fluence for one year of operation (200 days)

FCC-hh requirements
$\sim 10^{18}/cm^2$



Expected (FLUKA simulation) to be approximately: $\sim 10^{14-15}/cm^2/y$ in the tracker
$\sim 10^{14}/cm^2/y$ in the ECAL

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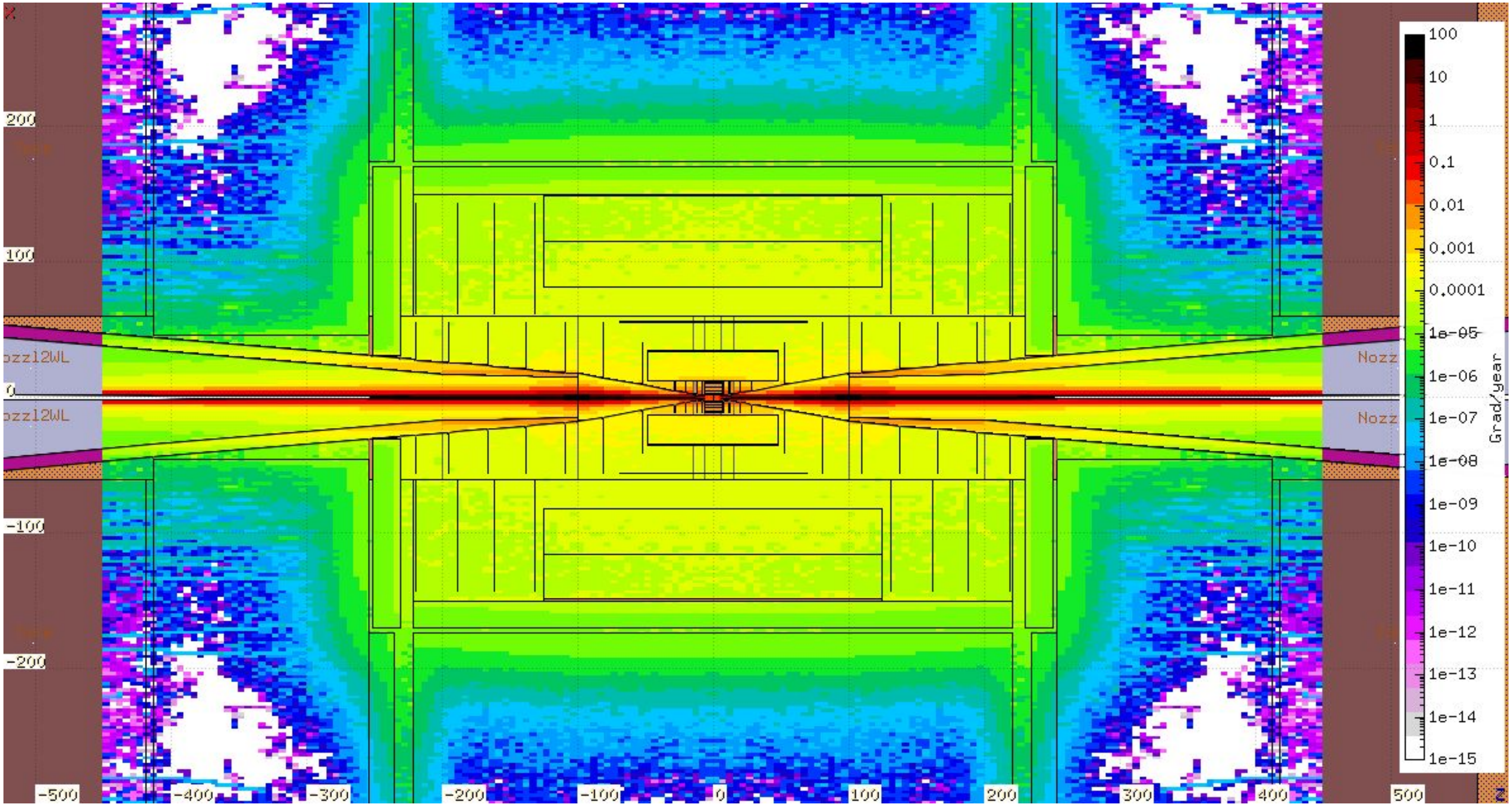
Detection Environment

Total Ionizing Dose for one year of operation (200 days)



Expected (FLUKA simulation) to be approximately: ~10^{-3} Grad/y in the tracker

~10^{-4} Grad/y in the ECAL