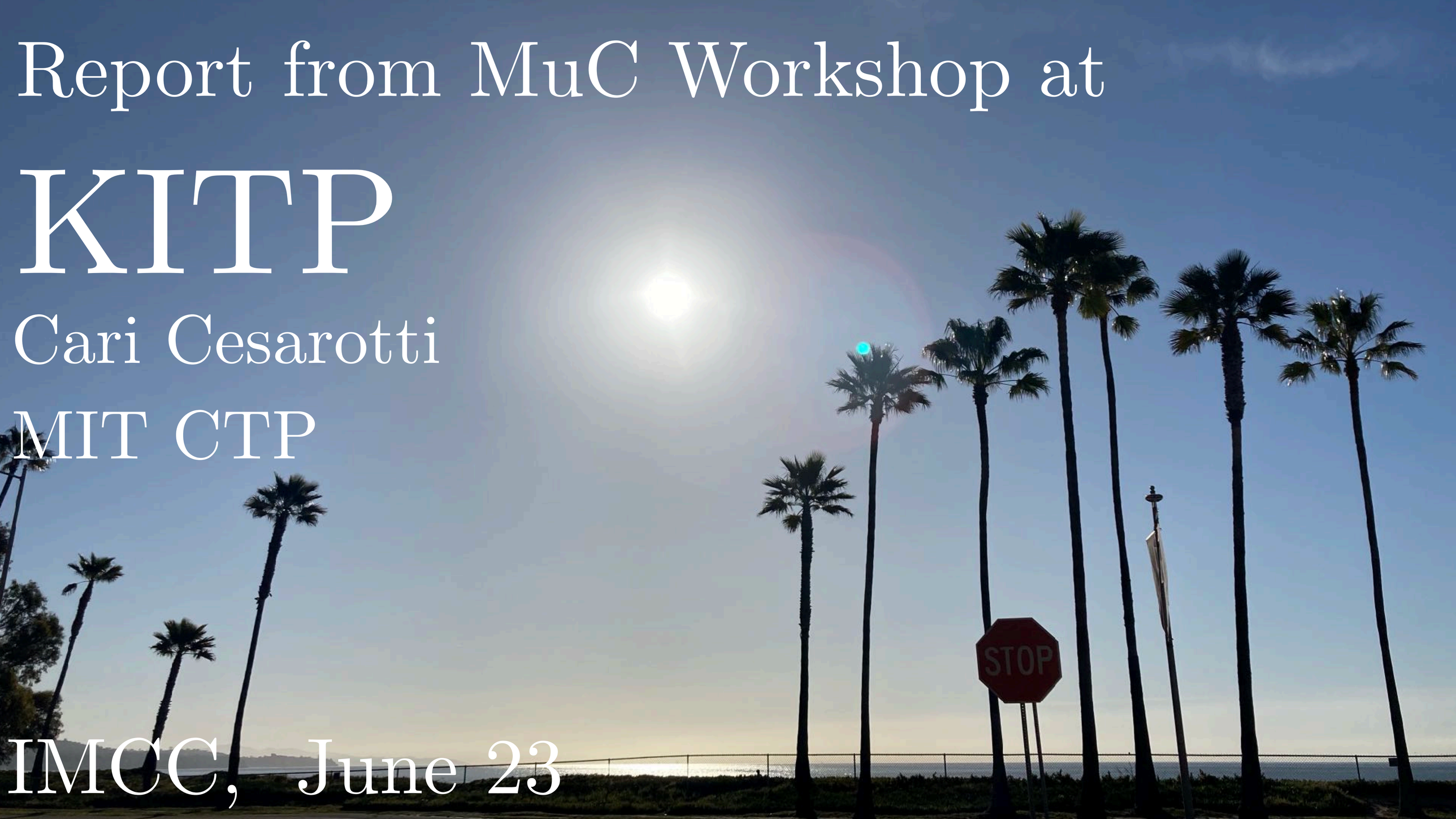
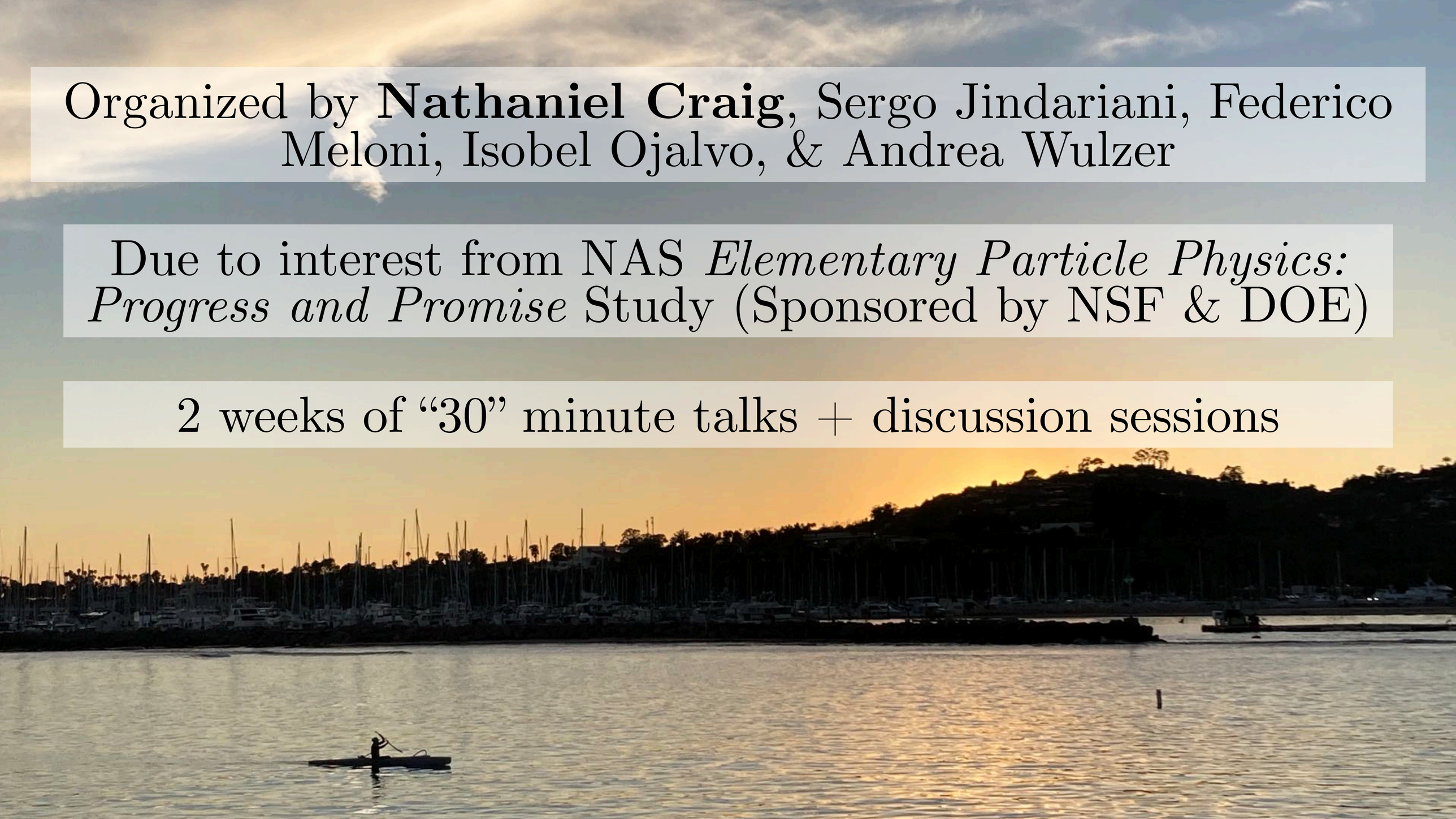
Report from MuC Workshop at KITP

Cari Cesarotti
MIT CTP

IMCC, June 23



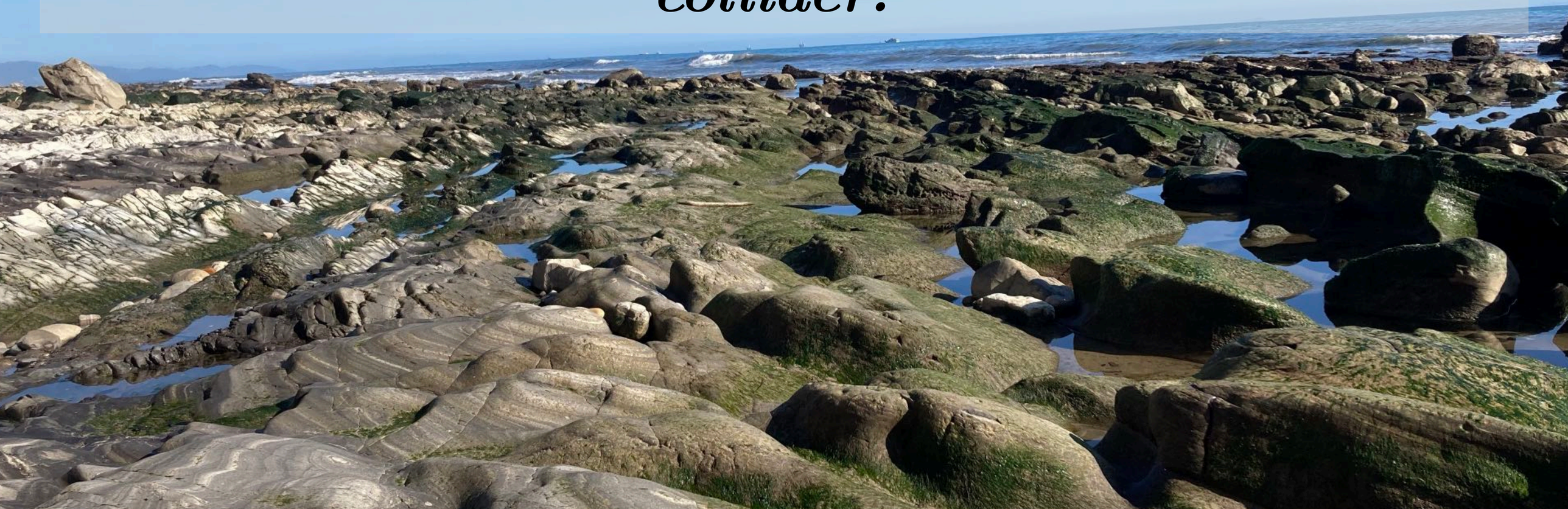


Organized by **Nathaniel Craig**, Sergo Jindariani, Federico Meloni, Isobel Ojalvo, & Andrea Wulzer

Due to interest from NAS *Elementary Particle Physics: Progress and Promise* Study (Sponsored by NSF & DOE)

2 weeks of "30" minute talks + discussion sessions

“This rapid response program will bring together theorists, experimentalists, and accelerator physicists with the ultimate goal of charting a collaborative international path for a muon collider.”



"This rapid response program will bring together theorists, experimentalists, and accelerator physicists with the ultimate goal of charting a collaborative international path for a muon collider."

Coordinating efforts among **international** collaborations

Developing the physics case for a **demonstrator** facility

Assessing the **central needs** and opportunities for theory, experiment, and accelerator physics

Building bridges to the **broader particle physics community**.

Physics Program

Week 1

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

Tuesday, 2/28: Precision Physics Case

Wednesday, 3/1: New Physics Benchmarks & Signals

Thursday, 3/2: Neutrino Synergies

Friday, 3/3: Muon Collider Theory Needs

Week 2

Monday, 3/6: Accelerator

Tuesday, 3/7: Detectors

Wednesday, 3/8: Detector++

Thursday, 3/9: Accelerator Technology

Friday, 3/10: Muon Accelerator Panel & Closeout

Links to slides & videos

Central Discussion Points

What are the deliverables of a Muon Collider?

What are the technical challenges?

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Precision & Energy Frontier

Electroweak SM Physics

BSM at High Energy*

Neutrino Synergies

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Achieving sufficient Luminosity

Beam induced background

Detector performance/acceptance

Money

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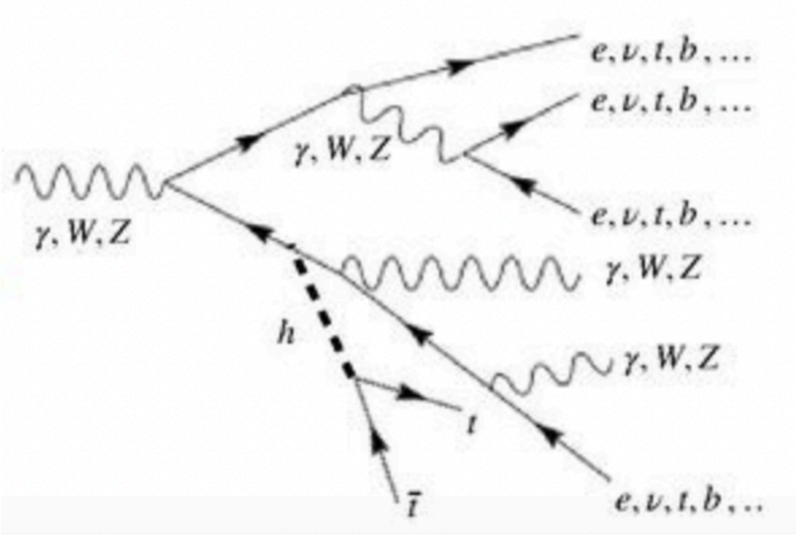
"No Showstoppers Identified"

Physics Summary: Electroweak

246 GeV — 1 TeV — 10 TeV



[Craig, Liu, Luty, Wulzer]

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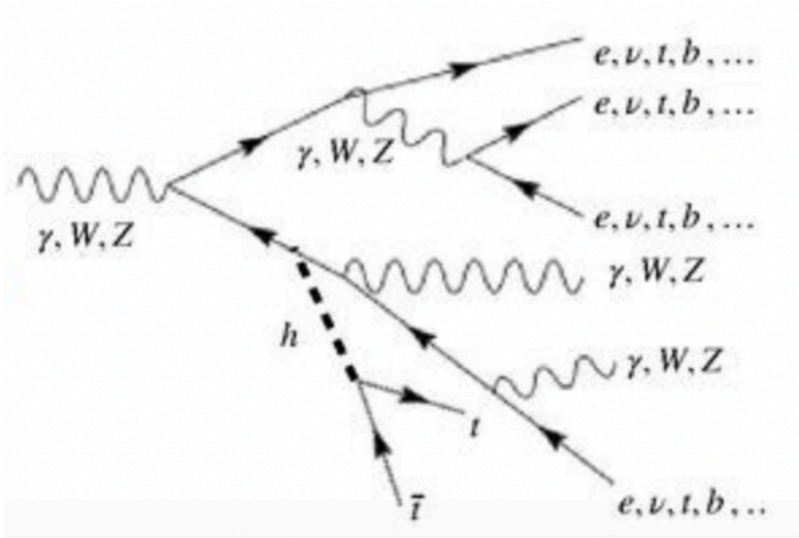
Non-decoupling new physics preventing EW restoration?



[Craig, Liu, Luty, Wulzer]

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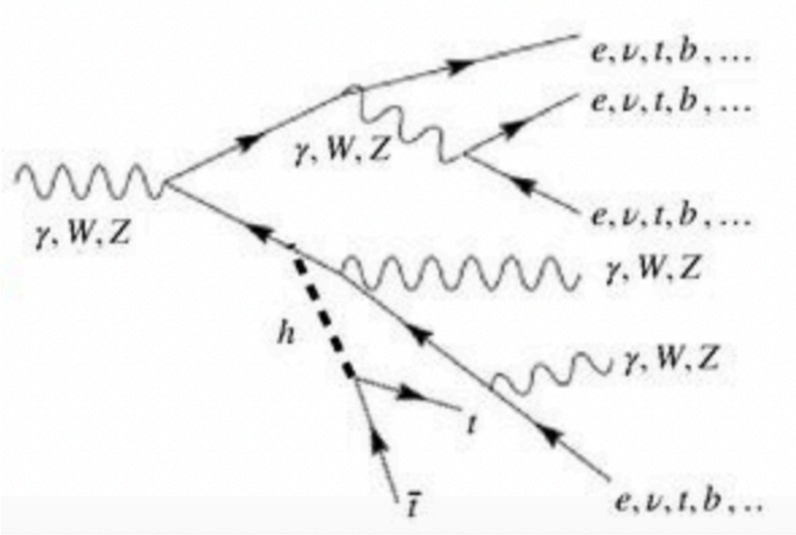

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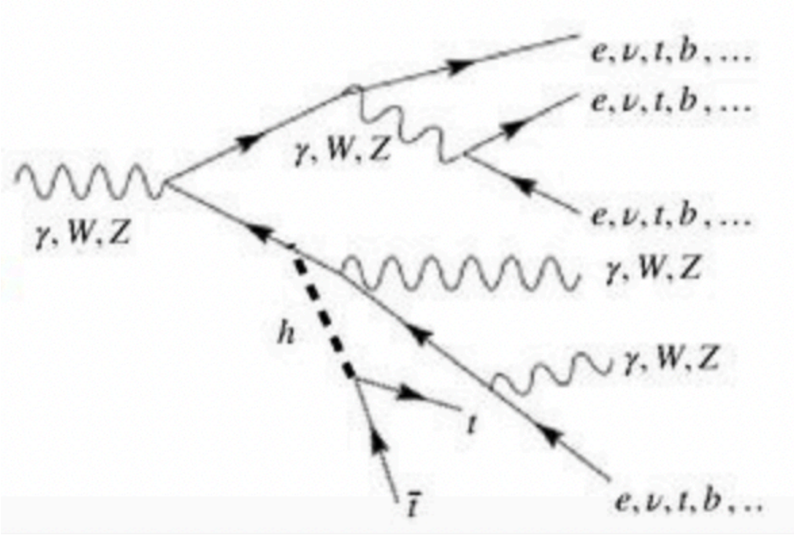


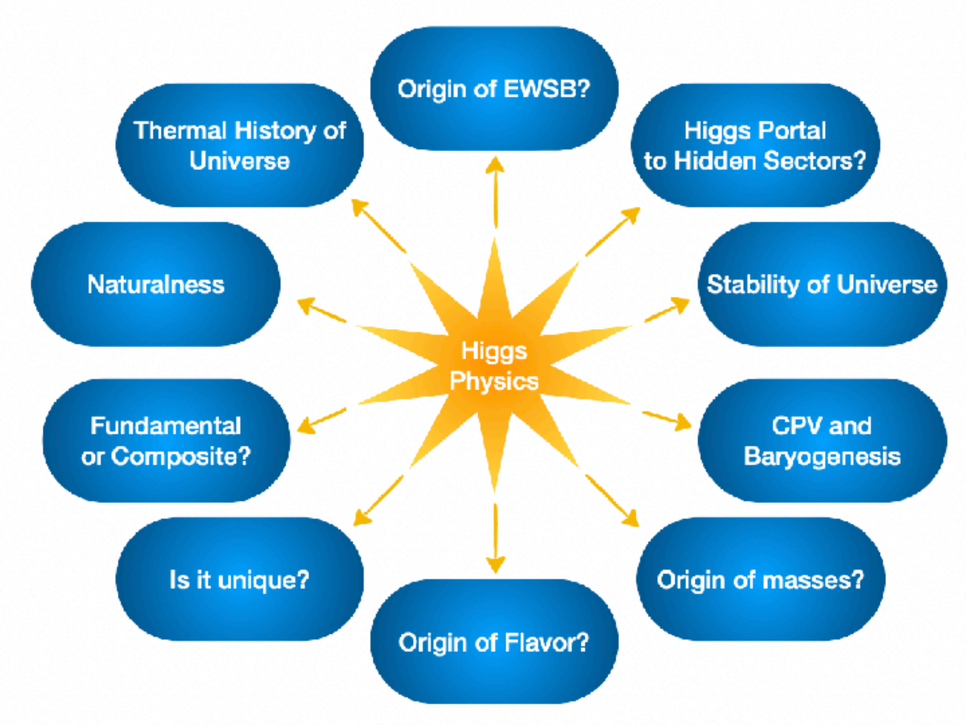
10 TeV

EW radiation for precision calculations or novel signatures?

[Craig, Liu, Luty, Wulzer]

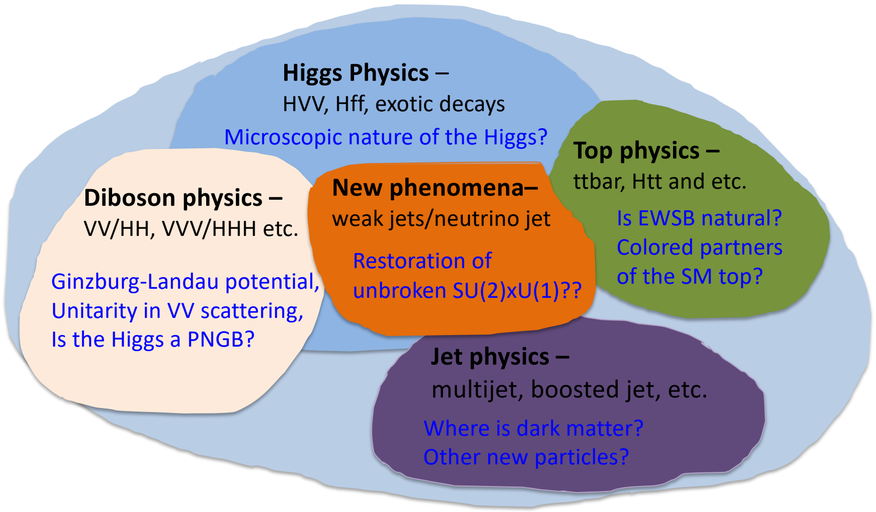
Physics Summary: SM as Deliverables

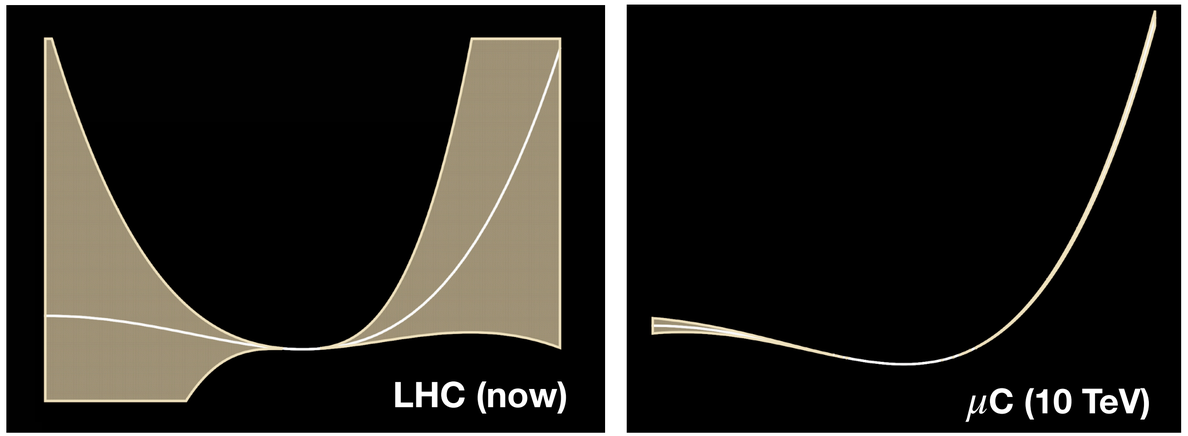
"Higgs is the key to everything"



What is the physics case for Muon collider?

Standard Model is our no-lose theorem!!





[Craig, Low, Meade]

Physics Summary: Neutrino Synergies

Where there are **muons**, there are **neutrinos**

$$\mu \leftrightarrow \nu$$

[Tabrizi] [Dracos]

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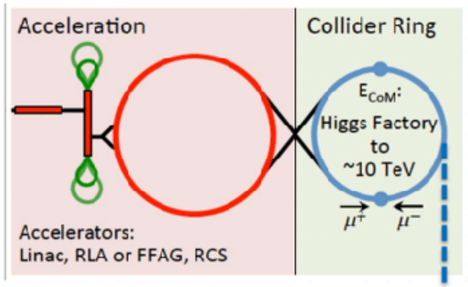
Neutrino Fixed Target Experiment at a Muon Collider

Why would a Muon Collider Help?

No oscillation, but:



~ 500 m

ν_e / ν_μ

Neutrino Detector

- Very high beam luminosity
- Precisely known energy spectra
- Equal numbers of e/μ (anti)neutrinos
- Very well determined beam intensity

- Ideal to investigate rare/new neutrino interactions
- Search for BSM physics

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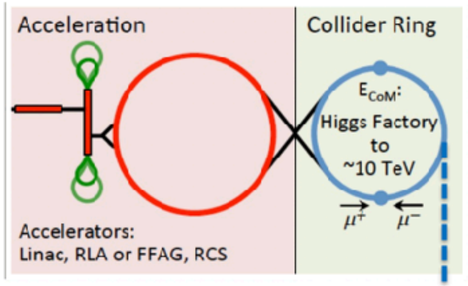

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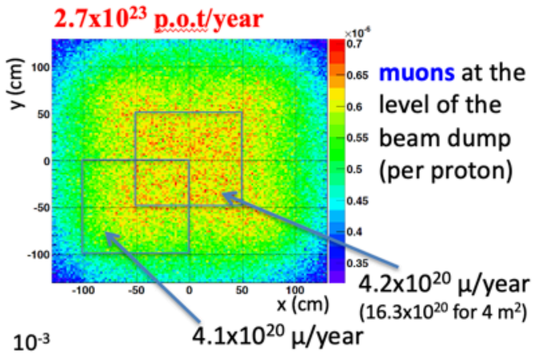
[Dracos]

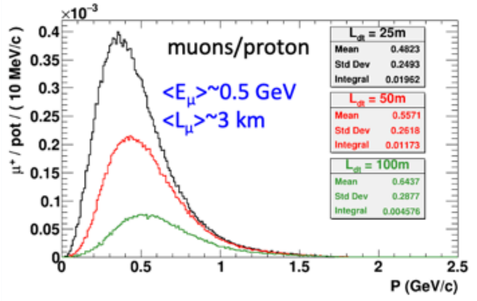
Muons at the level of the beam dump

ESSνSB — ESS Neutrino Super Beam Plus



muons at the level of the beam dump (per proton)

more than 4x10^{20} μ/year from ESS compared to 10^{14} μ used by all experiments up to now (10^{18} μ for COMET in the future).



- input beam for future 6D μ cooling experiments,
- low energy nuSTORM,
- Neutrino Factory,
- **Muon Collider**.

Physics Summary: BSM

An energy frontier machine is a **discovery** machine

[Capdevilla]

[Cesarotti]

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Motivation	Theoretical scenario	Candidate particle(s)	Exotic Signals (Potential Implications for Detector/Facility Design)								
			Boosted objects	Smal splittings	Stopping particles	Disappearing tracks	Displaced vertices	Exotic tracks	Emerging jets	Exotics in the mu system	Forward detector
Exotics	SM+singlet	S, a	x								x
	2HDM	$H^{\pm}, H^{0}, A$	x	x		x	x		x	x	
	New gauge groups	Z', W', γ'	x								x
	VLF	Q', L'	x	x		x					
	HNL	N_i				x	x			x	x
	Leptoquarks	R_2, U_1 (UV motivated)	x	x							
	Quirks	$q'\bar{q}'$ (bound states)			x			x	x		
	Hidden valleys	$g'g'$					x	x	x	x	
Hierarchy problem	SUSY	$\tilde{l}, \tilde{q}, \tilde{g}$ (colored)	x	x	x						
		$\chi^{\pm}, \chi^{0}, \tilde{\tau}$ (not colored)	x	x		x		x		x	
	Composite	$X_{5/3}, T_{2/3}$	x	x							
	Extra dimensions	G_{KK}	x								
	Neutral naturalness	Glueballs, sQuirks			x		x	x	x	x	x
DM	Z portal	EWkinos-like (inelastic)				x	x	x			
	H portal	S (Z2 symmetric)									
	Nu portal	ν_s									x
	U(1) portal	$U(1)_{u-t,-t_4}$					x			x	x

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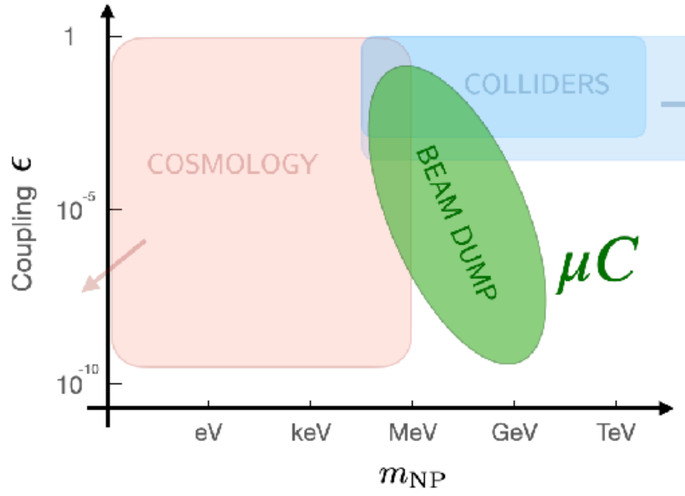
[Cesarotti]

Future multi-TeV μC provides a complementary physics program



Auxiliary / Synergistic Experiments

Physics Summary: Detectors

Novel challenges with TeV-scale **everything** & **BIB**

[Lee] Power consumption, size, nozzles, timing… [Liu]

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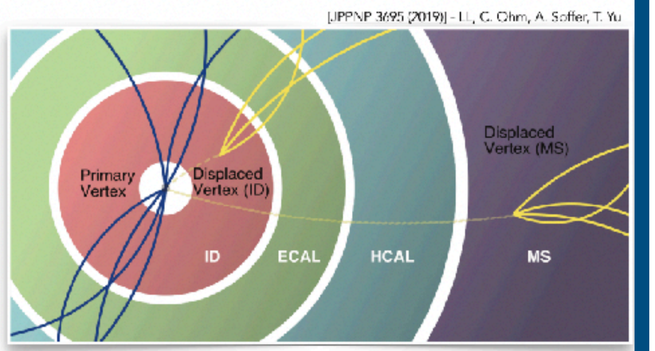
Quick aside: When defining detector requirements, **be more signature-inclusive.**

E.g. the now-bloomed **LHC Long-Lived Particle program** stretches capability of LHC detectors designed decades ago.



Over-optimization can hurt future flexibility. In retrospect, would have designed LHC experiments differently...

Be inclusive of more signatures than we can come up with.

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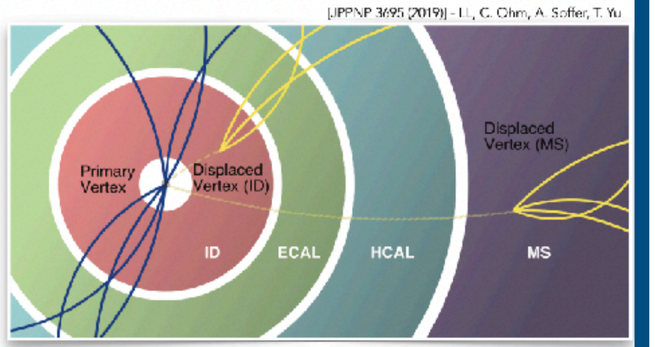

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[Liu]

Zeroth Order

Let's get a high-energy muon collider running!

- Energy Resolution (comparable to current)
- Granularity (comparable to current)

(Any reasonable detector performance would deliver baseline physics goals)

Dive deeply into the 10~TeV realm.

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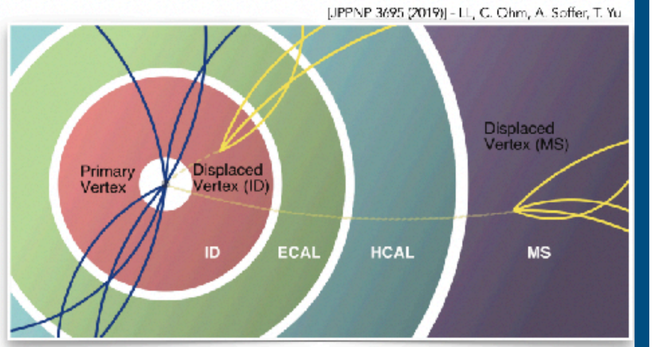

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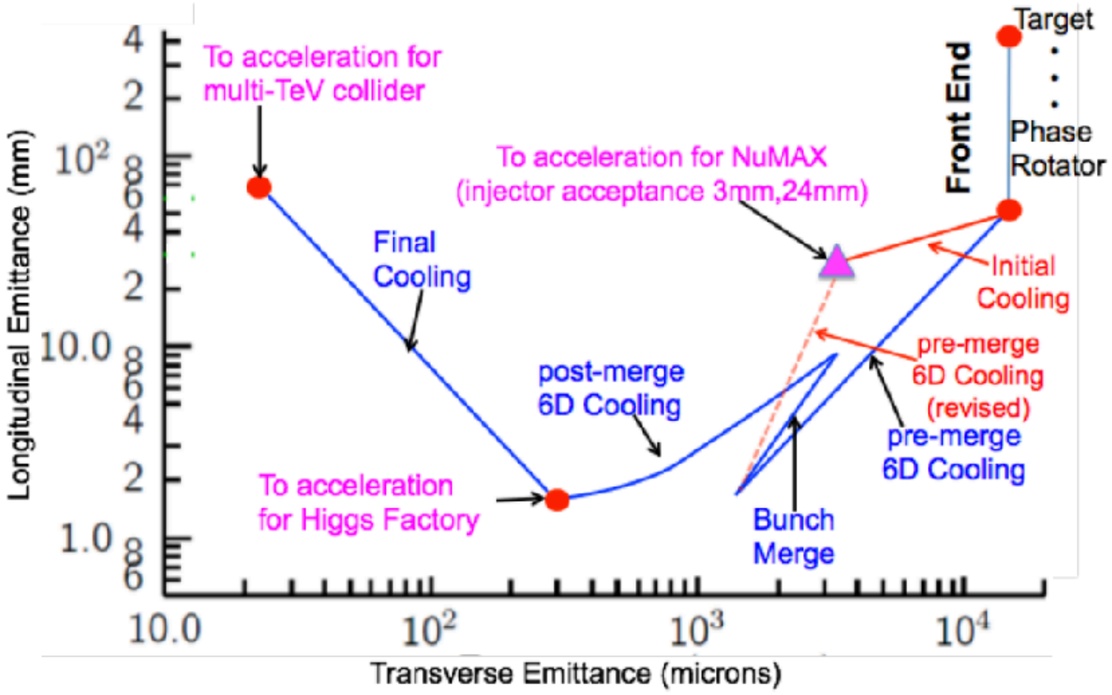
Synergies with FCCee/hh detectors

Need R&D funding

Physics Summary: Accelerator

Red Team vs. Blue Team Accelerator Panel



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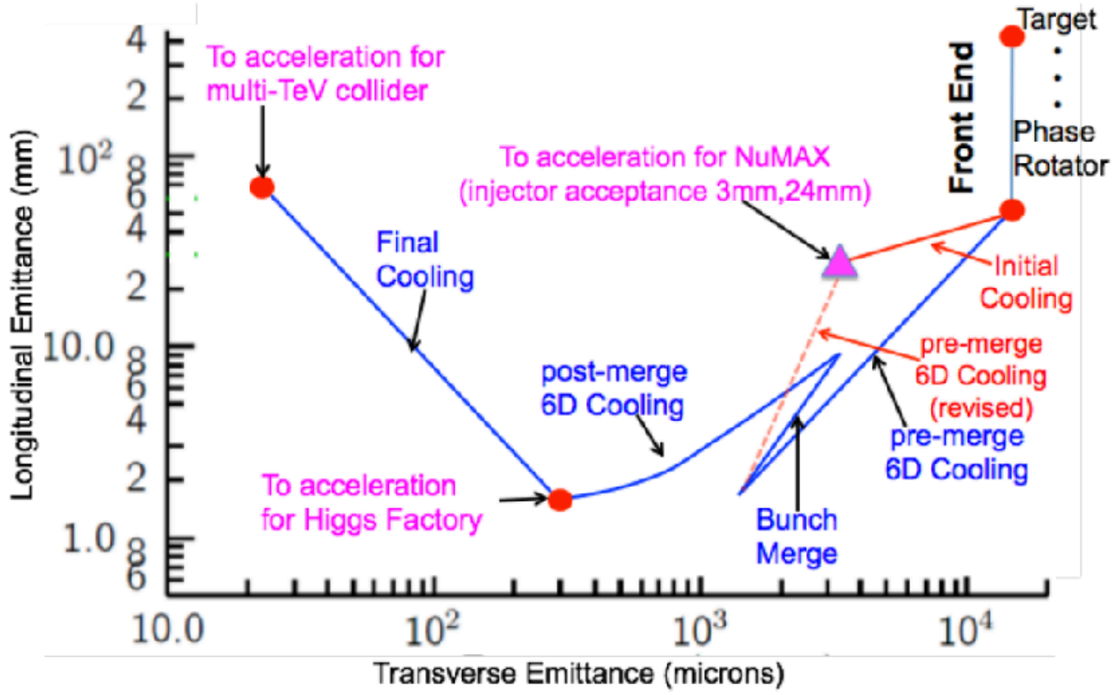

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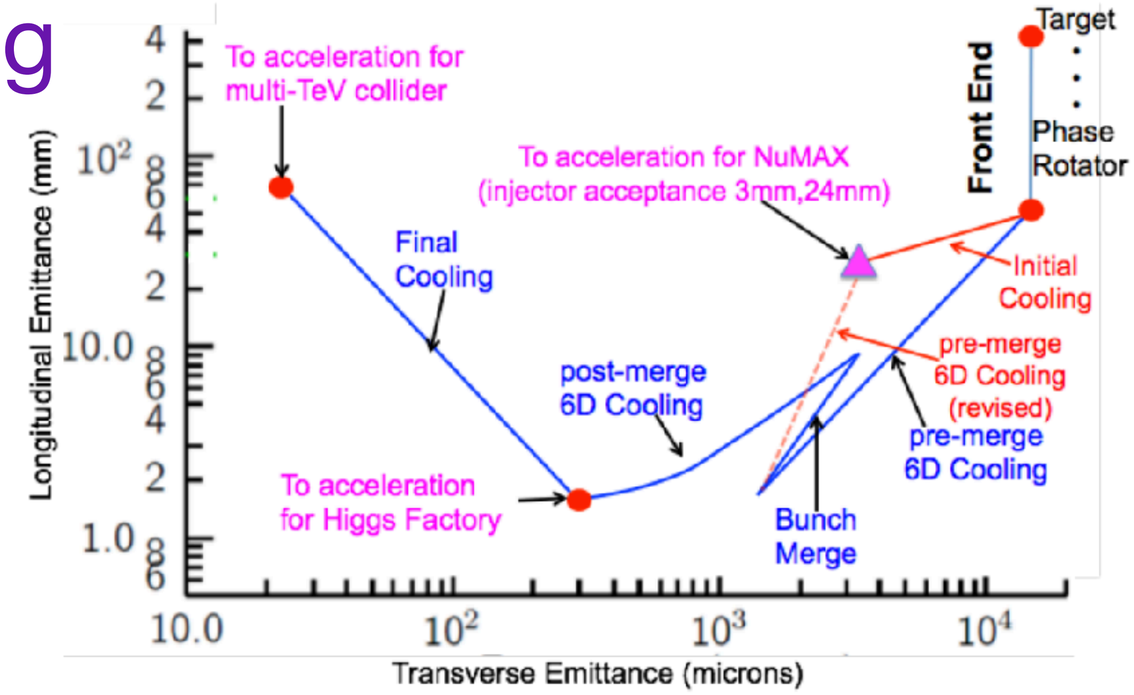

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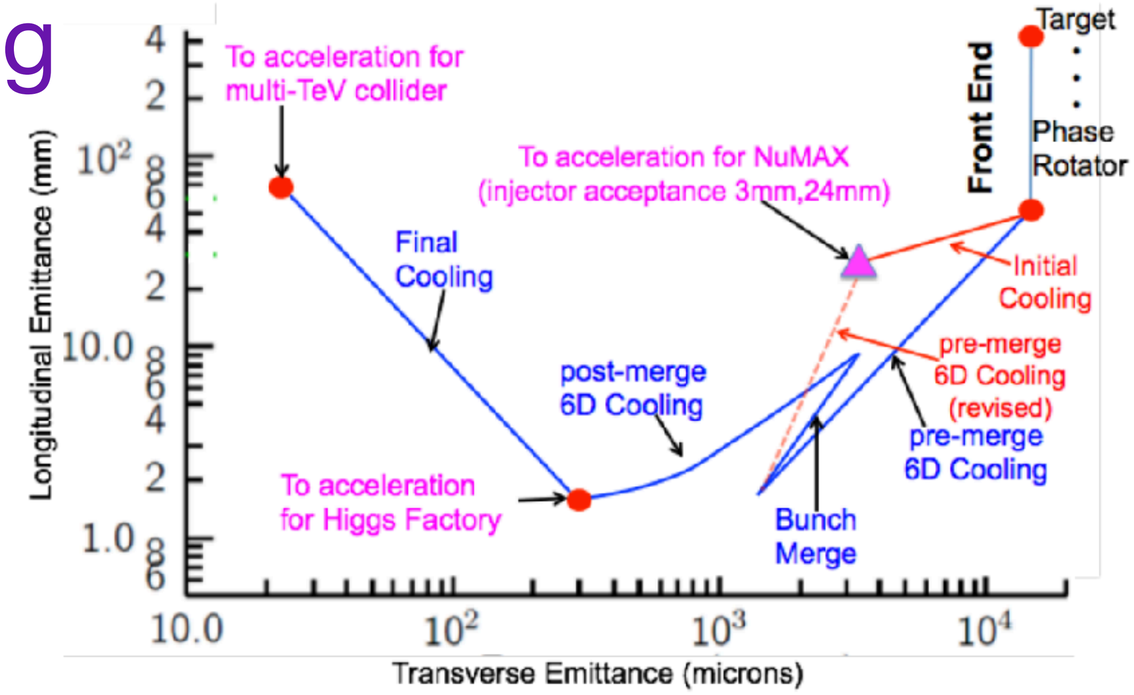

Physics Summary: Sustainability

FCC claims of sustainability can be **misleading**

[Holmes & Meade]

[Bullard]

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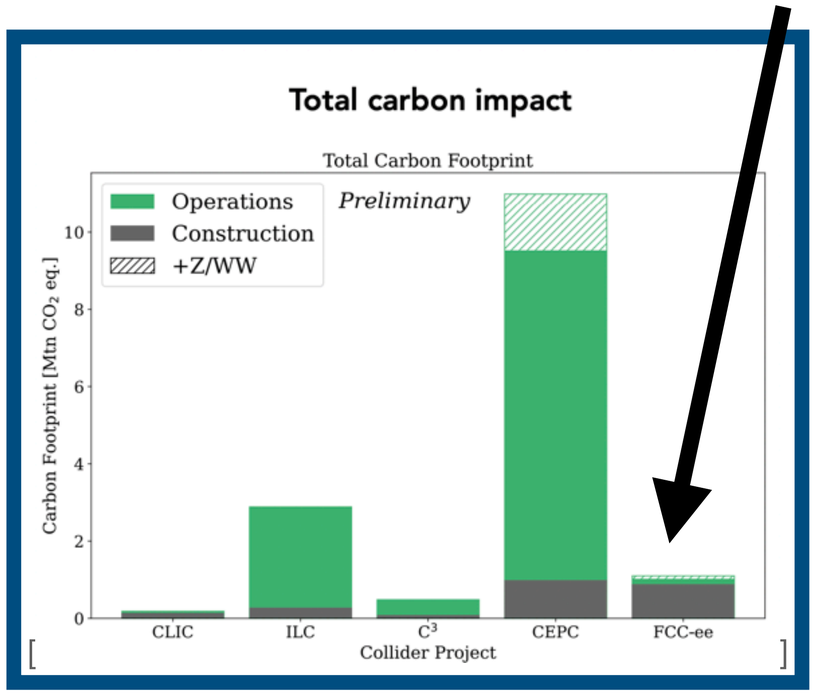
- Review Blondel & Janot study - all based on power consumption at some level



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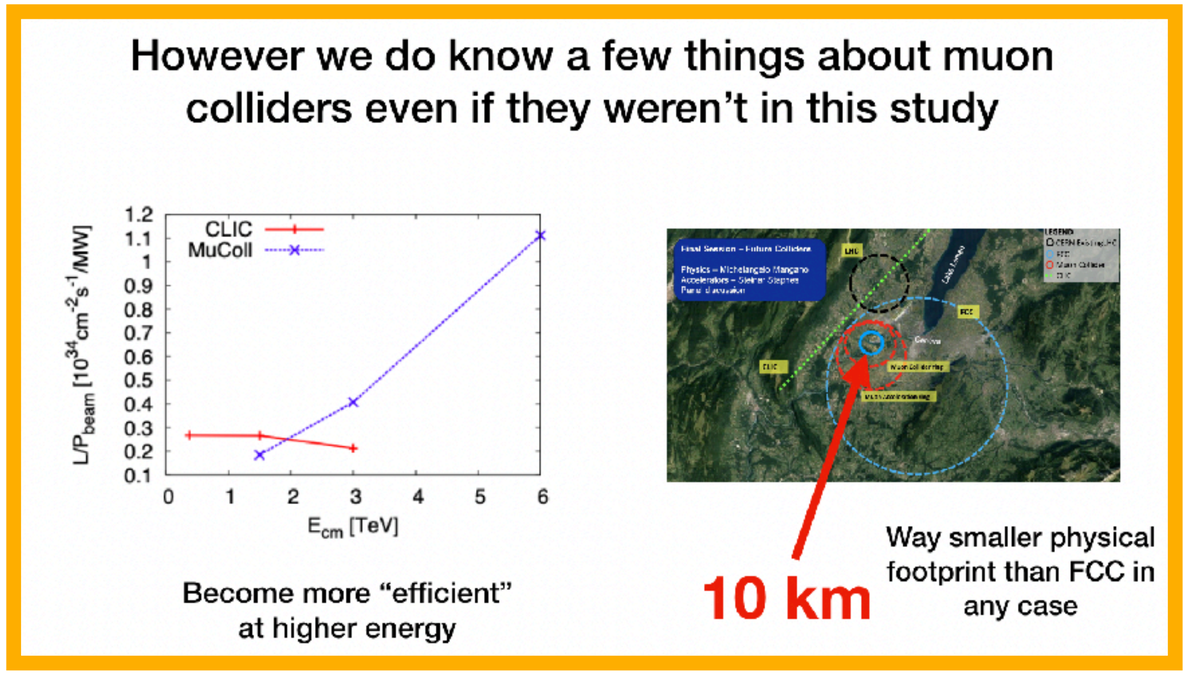

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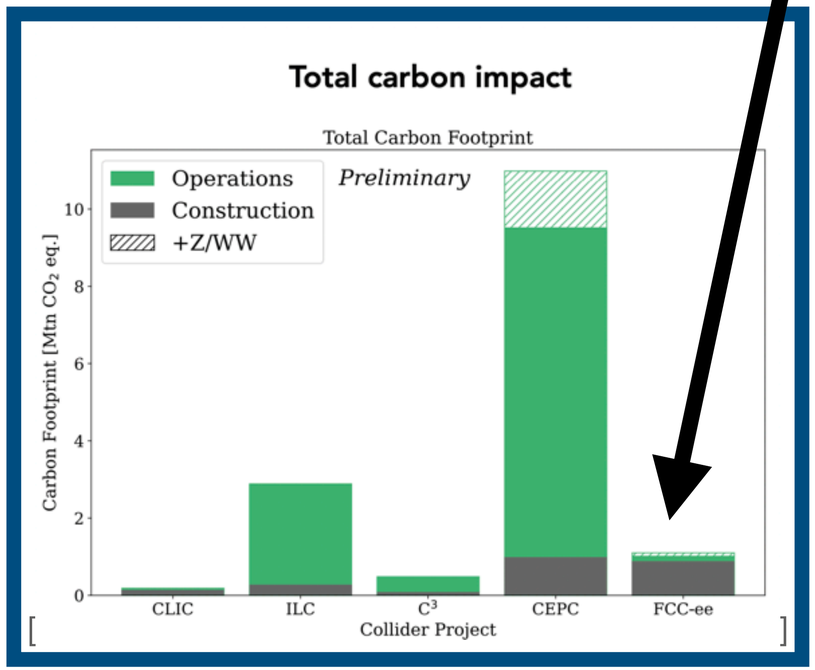

[Bullard]

Muon Colliders are **compact**, **efficient** machines

We need an arXiv-level sustainability study for MuC

Early Career Perspectives

Physics case is most important.

Develop sharp physics goals to motivate staging rather than warp physics to “easiest/cheapest” options.

We need to play nice with others.

A muon collider—as compelling as we all think it is—is an expensive risk. If we can build an honest physics case for why other fields benefit, or how we can synergies with other experiments, *that is our best chance at funding.*

The US wants a MuC.

We are collaborating and competing; internationally we can pool resources and develop a more complete case for getting this machine built.

We know it’s hard—
We still want to do it.

To retain talent and enthusiasm in the field, we need to value EC perspectives & convince others this is a feasible option.


A **Muon Collider** is Possible—
Now is the time to go for it