A Future Muon-Ion Collider at Brookhaven National Laboratory

Ethan Cline

ethan.cline@stonybrook.edu

Center for Frontiers in Nuclear Science
Department of Physics and Astronomy
Stony Brook University

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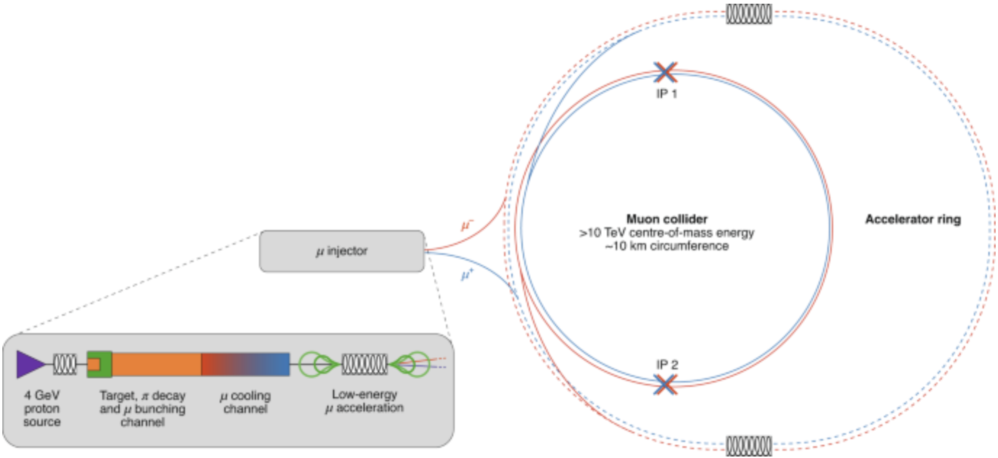
A Future Muon Collider

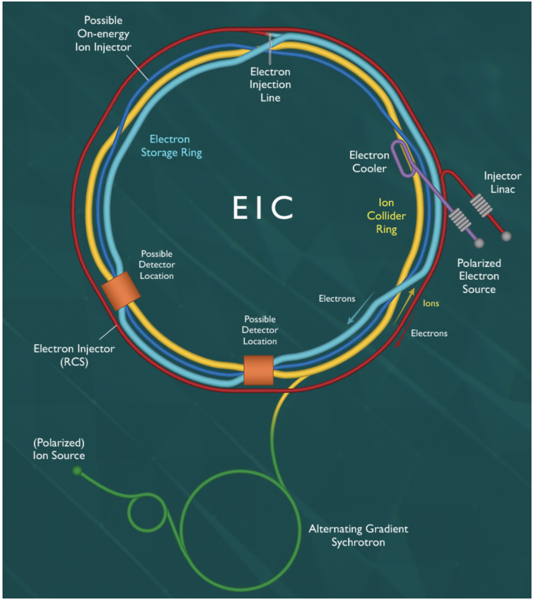


https://muoncollider.web.cern.ch/node/25

A Future Muon Collider

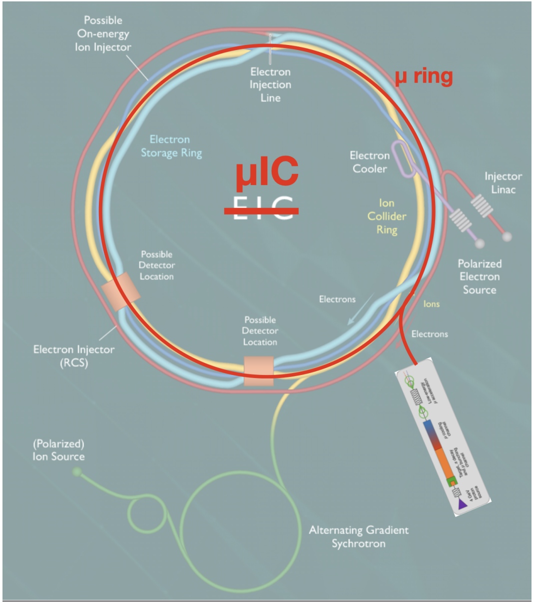
- A future muon collider has strong interest in the community
- Wide physics reach at $\sqrt{s} = 10$ TeV and beyond
- Several papers submitted as part of SNOWMASS process
- Significant R&D work necessary to prove feasibility
- MICE project at Rutherford lab demonstrated 6D cooling
- There is a rich physics program possible along the way to realizing a muon collider!

The EIC



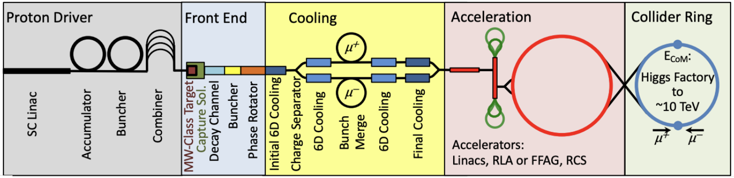
https://www.bnl.gov/eic/machine.php

A μIC!


Possible
On-energy
Ion Injector
μ ring
Electron
Injection
Line
Electron
Storage Ring
μIC
EIC
Electron
Cooler
Injector
Linac
Ion
Collider
Ring
Possible
Detector
Location
Polarized
Electron
Source
Electrons
Ions
Electrons
Possible
Detector
Location
Electron Injector
(RCS)
(Polarized)
Ion Source
Alternating Gradient
Sychrotron

Muon Generation

- Proton driven scheme
  - Proton on high Z target, produce π's which decay to μ's
  - μ's have wide emittance, need to be cooled
  - Aim for a 200 GeV μ beam
  - Access to μ^+ and μ^-
  - Spin polarized



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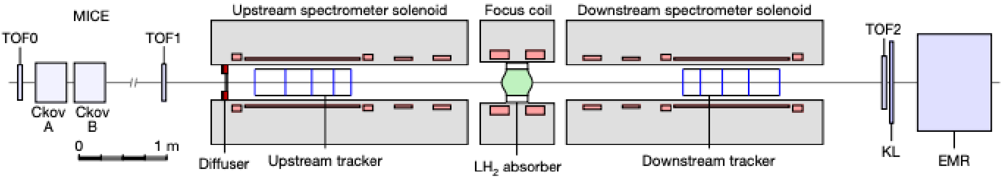
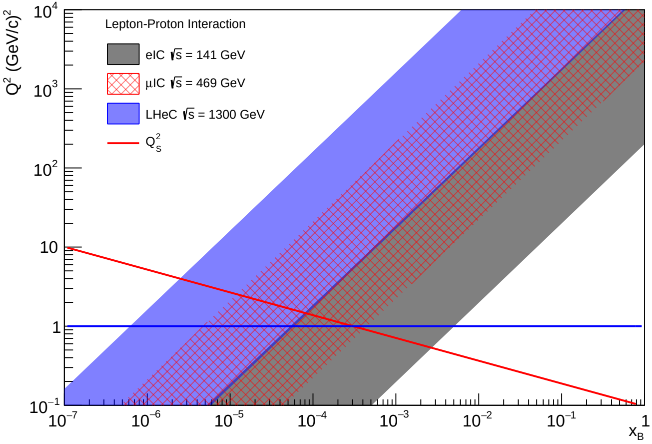
Muon Cooling



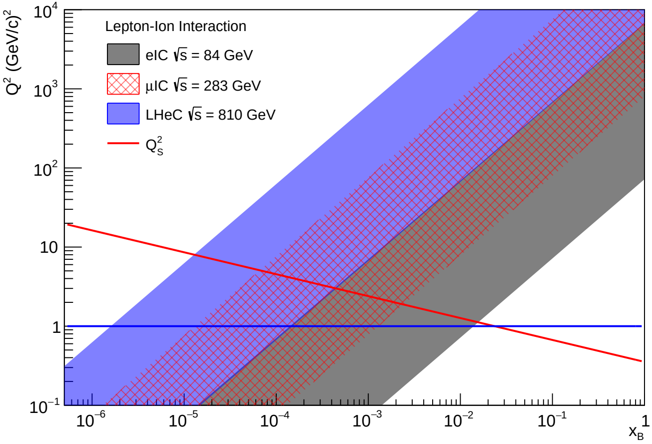
Nature 578, 53–59 (2020). https://doi.org/10.1038/s41586-020-1958-9

Physics Reach



Kinematic Reach of μIC for μp collisions.

LHeC: https://arxiv.org/pdf/2007.14491.pdf
EIC: https://arxiv.org/pdf/2103.05419.pdf



Kinematic Reach of μIC for μAu collisions.

LHeC: https://arxiv.org/pdf/2007.14491.pdf
EIC: https://arxiv.org/pdf/2103.05419.pdf

Muon Decay

- μ lifetime is 2.2×10^{-6} s
- At a beam energy of 18 GeV, this is extended to 3.6×10^{-4}s
- 33 laps around the RHIC ring in 1 lifetime (370 laps at 200 GeV beam)
  - Point in favor for a separate ring?
- Luminosity and storage are a problem
- Electrons from decay go almost in beam direction, are uniformly distributed, have unknown energy, and scatter with beam hadrons
  - Vertical chicane helps here, but detailed study needed for these kinematics

Luminosity in Proton Driven Scheme

$$\mathcal{L}_{\mu p} = \frac{N^{\mu} N^{p} \min[f_c^{\mu}, f_c^{p}]}{4\pi \max[\sigma_x^{\mu}, \sigma_x^{p}] \max[\sigma_y^{\mu}, \sigma_y^{p}]} H_{hg} \tag{1}$$

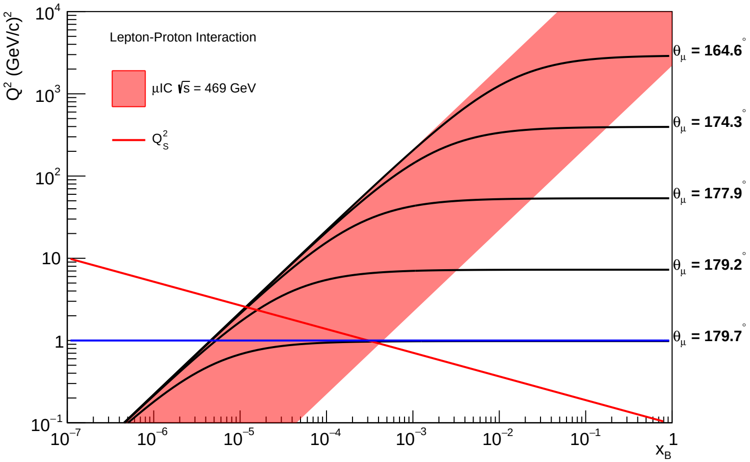
$$\sigma_{x,y} = \sqrt{\beta * \varepsilon / \gamma} \tag{2}$$

$$f_c^{\mu} = N_{\mathrm{laps} * f_{\mathrm{rep}}} \tag{3}$$

	proton driven muon production	proton
E (GeV)	200	275
$N^{\mu,p}$ (10^{11})	30	3
γ	2000	275
ε (μm)	140 (25)	0.2
β (cm)	1.3 (1)	5
$\sigma_{x,y}$ (μm)	30 (10)	6
Number of laps	680	∞
f_c^{μ} (s^{-1})	10,350	N/A
$\mathcal{L}_{\mu p}$ ($cm^{-2}s^{-1}$)	8×10^{31} (5×10^{32})	

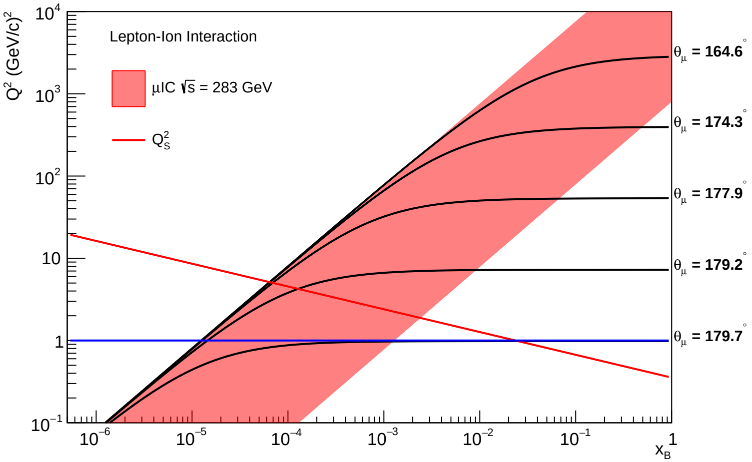
Luminosity of μp collisions

Physics Reach



- Kinematic Reach of μIC for μp collisions
- $E_\mu = 200$ GeV, $E_p = 275$ GeV

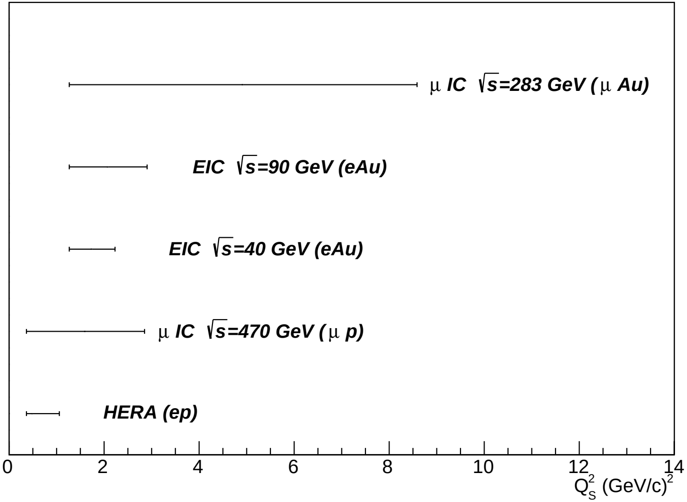
Physics Reach



- Kinematic Reach of μIC for μAu collisions
- $E_\mu = 200$ GeV, $E_{Au} = 110$ GeV/nucleon

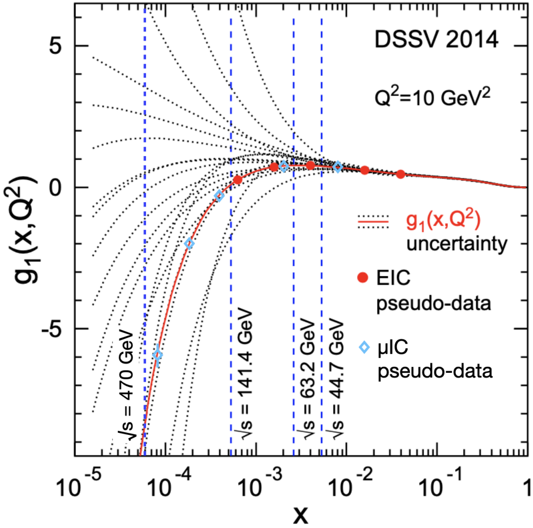
Saturation Scale

$x \leq 0.01$



Saturation scale in the GBW model

g1



- Extraction of g1 from DSSV collaboration
- EIC pseudo-data 10 fb^{-1} sampled luminosity, μIC pseudo-data from 0.9 fb^{-1}
- Figure reproduced from: https://arxiv.org/abs/1708.01527

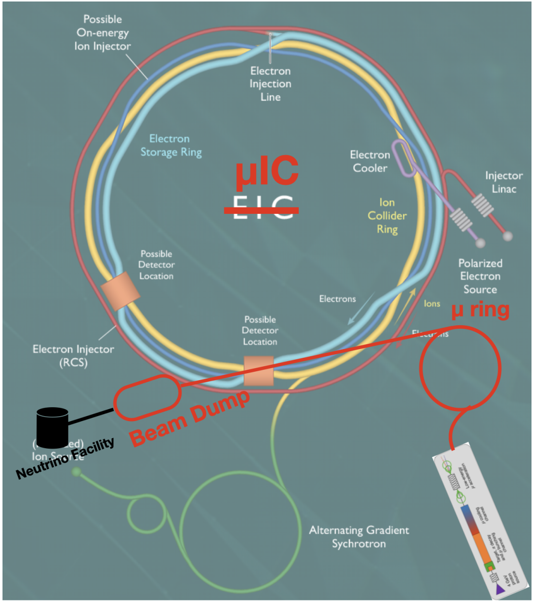
Summary

- Muon collider collaborations have clearly demonstrated need for future collider
- R&D on a high-energy, high-intensity source of muons is desirable
- EIC design underway via CD process
- Possible synergy between nuclear and particle physics community at the site of the future EIC
- Rich physics program with μIC

Thank you!

Any Questions?

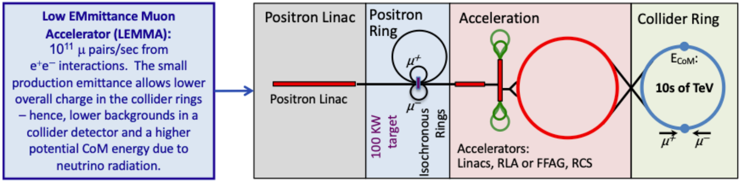
A μIC v2!



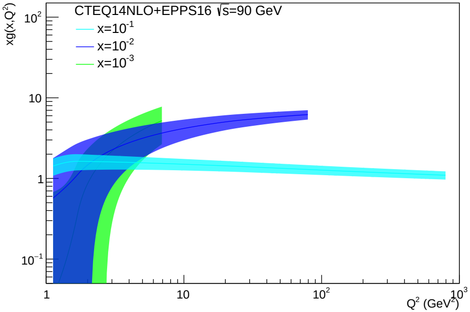
*Not to scale

Muon Generation

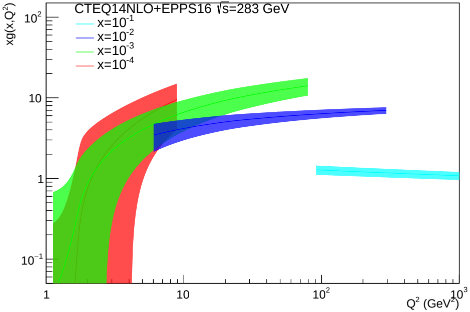
- e^+e^- annihilation scheme (LEMMA)
  - Muons produced at high energy
  - Low emittance, no cooling needed
  - Requires 45 GeV positron beam on electron target
  - Target heating and luminosity difficulties



Measuring the Gluon PDF in Ions



EIC coverage for xg



μIC coverage for xg