A Future Muon-Ion Collider at Brookhaven National Laboratory

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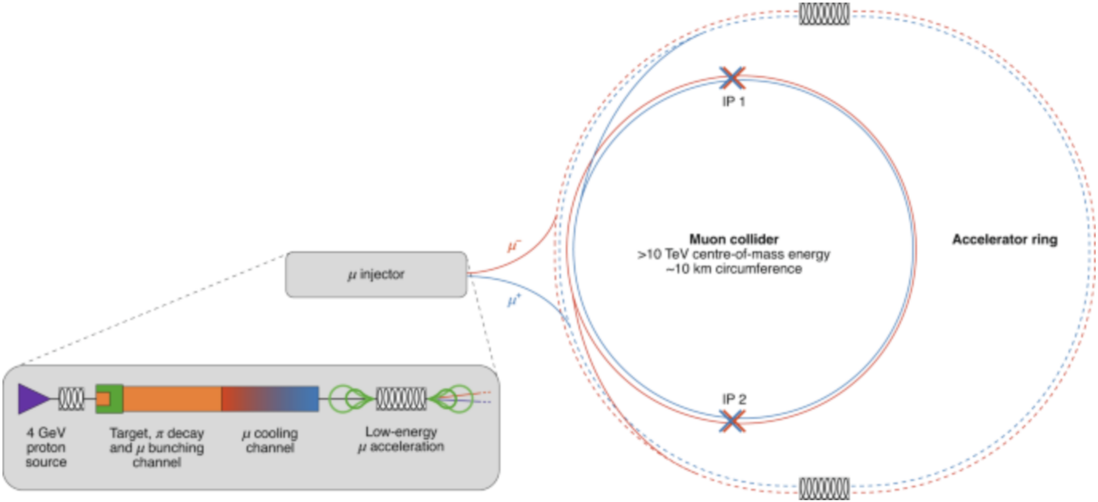
A Future Muon Collider

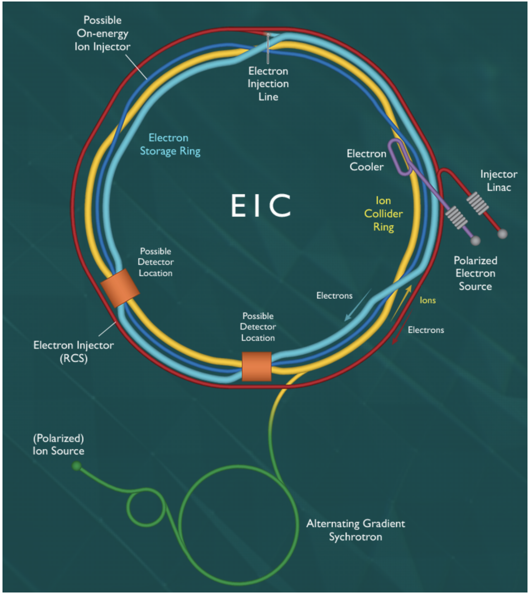


https://muoncollider.web.cern.ch/node/25

A Future Muon Collider

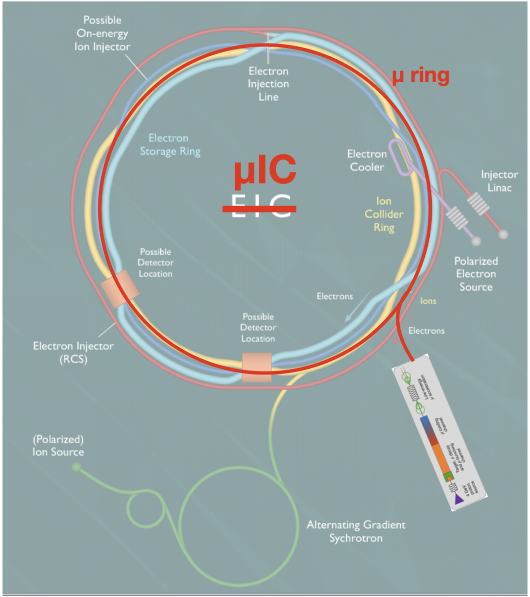
- A future muon collider has strong interest in the community
- Wide physics reach at $\sqrt{s} = 10$ TeV and beyond
- Several papers submitted as part of SNOWMASS process
- Significant R&D work necessary to prove feasibility
- MICE project at Rutherford lab demonstrated 6D cooling
- There is a rich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

The EIC



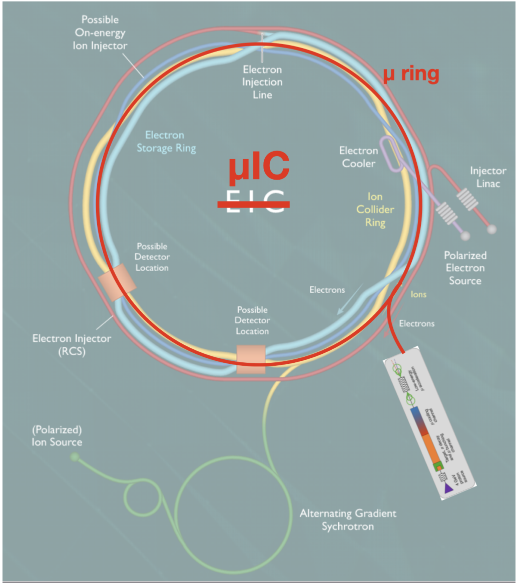
https://www.bnl.gov/eic/machine.php

A μIC!



Possible
On-energy
Ion Injector
Electron
Injection
Line
μ ring
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

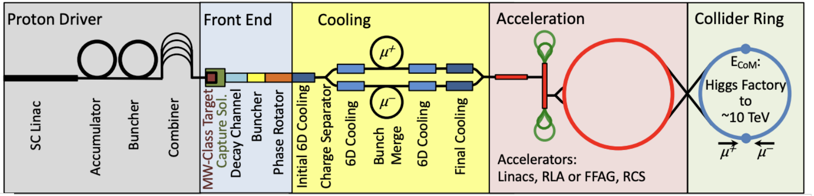
A μIC!



- Build μ frontend as "proof of concept" for $\mu^+\mu^-$ collider
- Reuse EIC Ion beam
- Design to have variable μ energy, 18 GeV - 200 GeV

Muon Generation

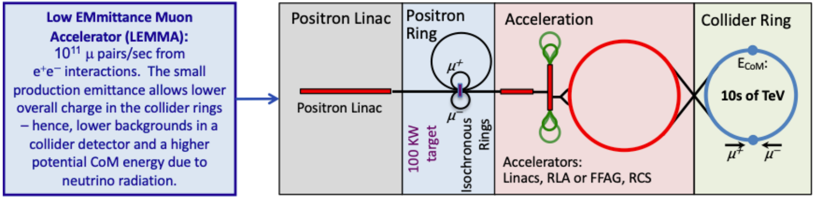
- Proton driven scheme
  - Proton on high Z target, produce π's which decay to μ's
  - μ's have wide emittance, need to be cooled
  - Preferentially produce μ^+
  - Selecting polarized μ's reduces luminosity



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

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



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

Muon Generation

- $\mu^+\mu^-$ production from high energy photons (Gamma Factory)
  - Impinge laser pulses on ion beam
  - $N_\gamma \approx 10^{16}$/s backscattered photons at $\approx$ 400 MeV
  - Impinge γ's on stationary target to perform exclusive pion production $\gamma + p \rightarrow \pi^+ + n$ followed by pion decay
  - Cooling not required as π production phase space significantly restricted

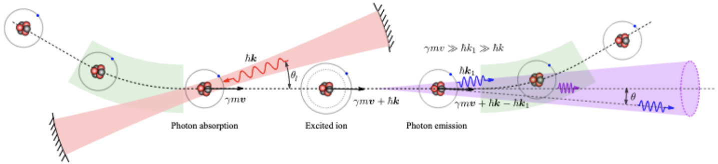


FIG. 20: The Gamma Factory concept: laser photons with the momentum k collide with ultrarelativistic partially stripped ions (with the relativistic Lorentz factor γ_L, mass m, velocity $v = \beta c$, where c is the velocity of light) circulating in a storage ring; resonantly scattered photons with the momentum $k_1 \gg k$ are emitted in a narrow cone with an opening angle $\theta \approx 1/\gamma_L$ in the direction of motion of the ion beam.

Gamma Factory - A. Apyan, M. Krasny, W. Płaczek, https://arxiv.org/pdf/2212.06311.pdf

Muon Generation

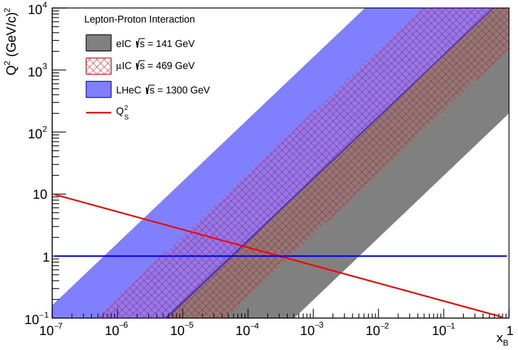
- $\mu^+\mu^-$ production from high energy photons (BACKGAMMON)
  - Impinge laser pulses on 20 GeV electron beam - Compton scattering
  - $N_\gamma \approx 10^{13}$/s backscattered photons at $\approx$ 5 GeV
  - Impinge γ's on stationary target to pair-produce $\mu^+\mu^-$ at high energy without need for cooling,
  - Can create longitudinally polarized μ's with circularly polarized photons
  - **Could use future EIC electron beam!**

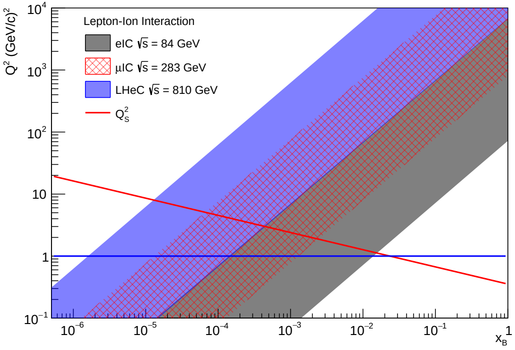
E (GeV)	10	20	30
ω_2 (GeV)	1.54	5.33	10.59
σ_C (10^{-25} cm^2)	5.48	4.74	4.25
$\mathcal{L}$ (10^{38} cm^{-2}-s$^-1$)	1.04	1.04	1.04
R (10^{13} s^{-1})	5.72	4.95	4.43

Backscattered photon energy, total Compton cross section, luminosity and production rate of backscattered photons as function of incident electron energy. Numbers from S. Mtingwa.

BACKGAMMON - S. Mtingwa and M. Strikman, Phys. Rev. Lett. 64, 1522 (1990)

Physics Reach





Left: Kinematic Reach of μIC for μp collisions. Right: 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
    - See talk by D. Acosta this afternoon!

Luminosity in Proton Driven Scheme

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

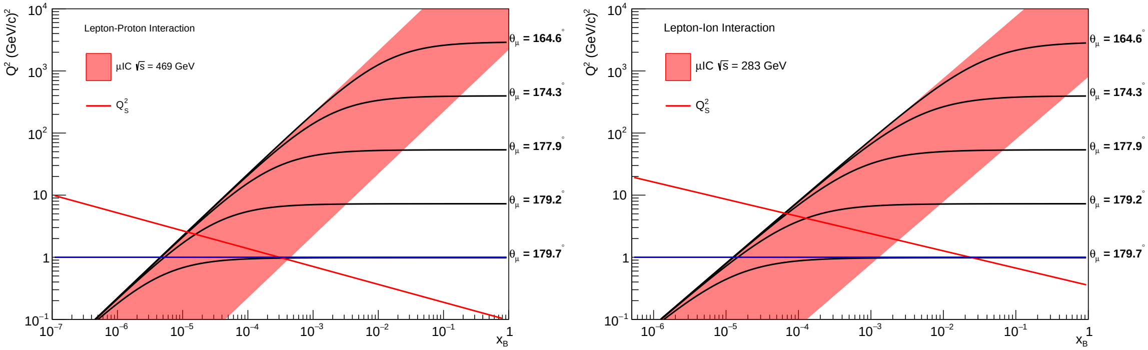
$$\sigma_{x,y} = \sqrt{\beta * \varepsilon / \gamma} \quad (2)$$

$$f_c^\mu = N_{\mathrm{laps}*f_{\mathrm{rep}}} \quad (3)$$

	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

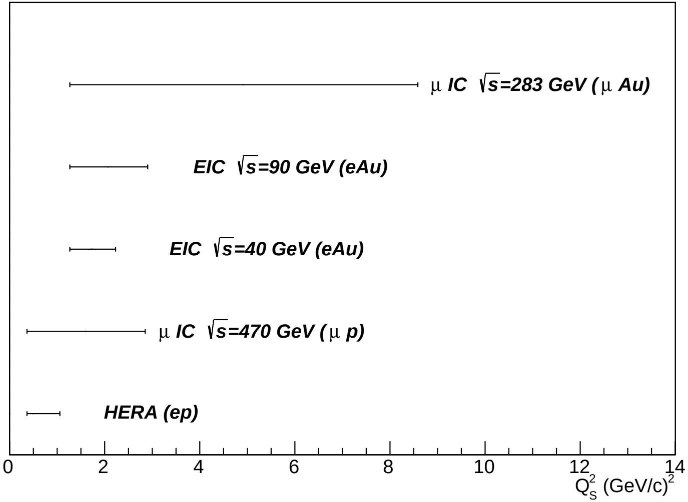
Scattered Muon Reach



Left: Lines of constant θ at the μIC for μp collisions. Right: Lines of constant θ at the μIC for μAu collisions.

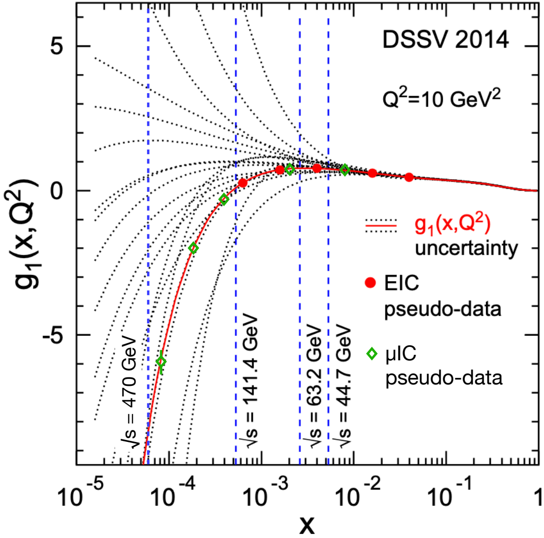
Saturation Scale

$x \leq 0.01$



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
- See talk by D. Acosta later this afternoon

CFNS Workshop

Using muons from backscattered photons on targets for various studies at the EIC

5 April 2023
Remote
US/Eastern timezone

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- Registration
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Local Organizer

ethan.cline@stonybrook...

Most proposals involving the use of muon beams utilize protons on targets to produce pions, which then decay into muons for various studies. Such muon beams usually require emittance cooling before they are useful. However, an alternative is to use muon beams produced by backscattered photon beams on suitable targets, thereby obviating the need for muon beam cooling. Preliminary studies indicate that the EIC's electron beam of ~20 GeV yields ~5 x 10^13 photons/sec of energy ~5 GeV. Simulations are currently being performed to understand the kinematics of muons produced from the EIC backscattered photons on various targets.

In this workshop, we will look deeper into muon beams from backscattered photons on various targets and discuss physics implications from their use. This should be an important extension of the EIC.

Starts 5 Apr 2023, 06:00
Ends 5 Apr 2023, 23:00
US/Eastern

Remote
Zoom link TBA

Paul Gueye
Sekazi Mtingwa

There are no materials yet.

The call for abstracts is open
You can submit an abstract for reviewing.
Submit new abstract

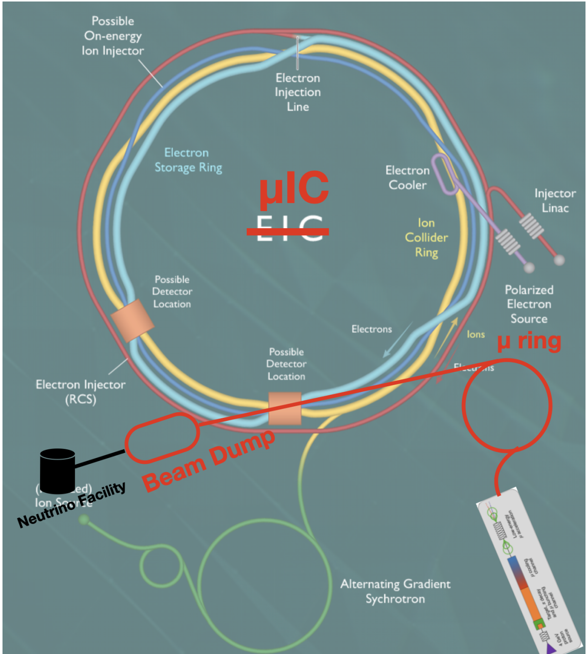
Registration
You are registered for this event.
10
See details

https://indico.bnl.gov/event/17909/

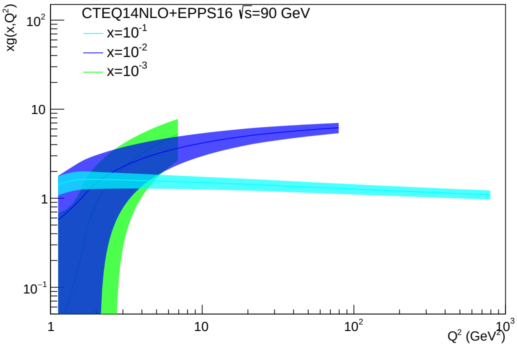
Thank you!

Any Questions?

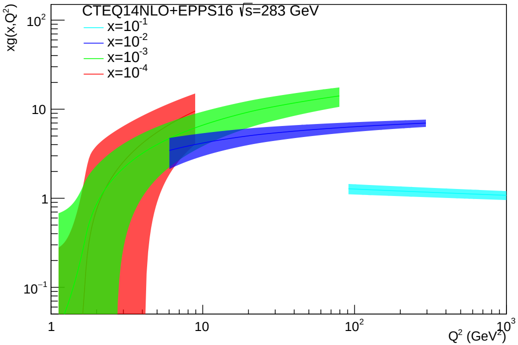
A μIC v2!


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

Measuring the Gluon PDF in Ions



EIC coverage for *xg*



μIC coverage for *xg*