

Low-Energy RHIC electron Cooling (LEReC)

A. Fedotov on behalf on LEReC team

RHIC Retreat July 25-26, 2013

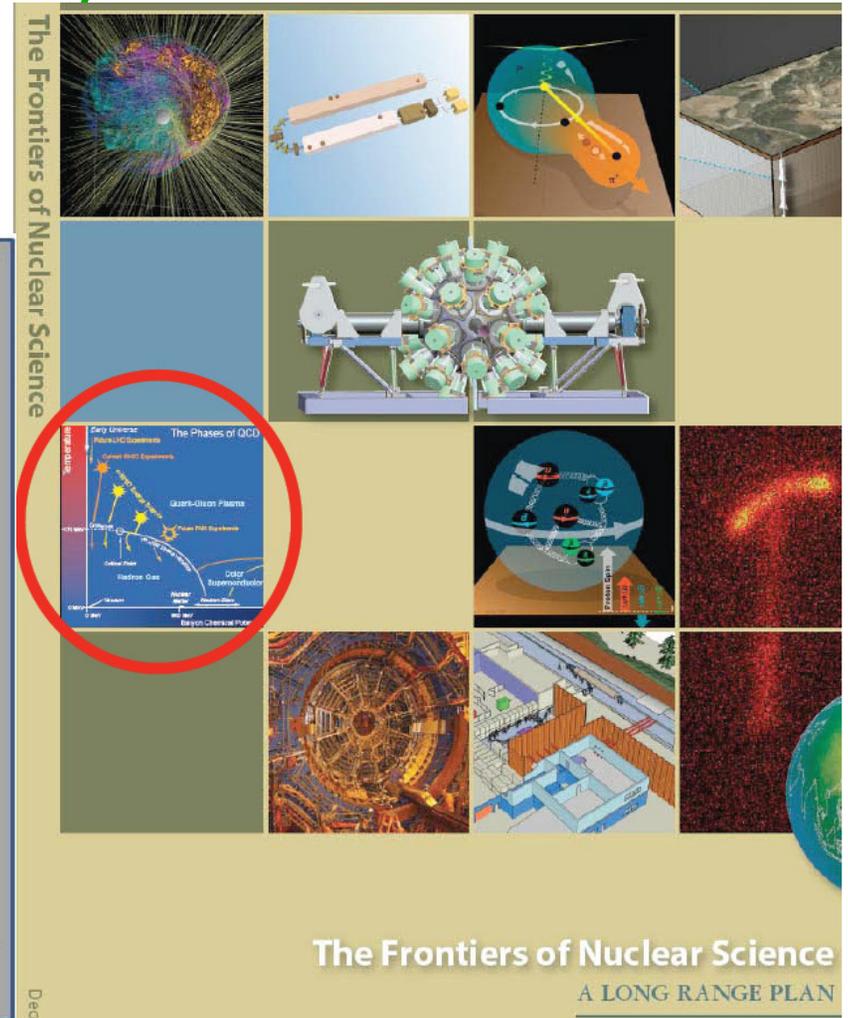
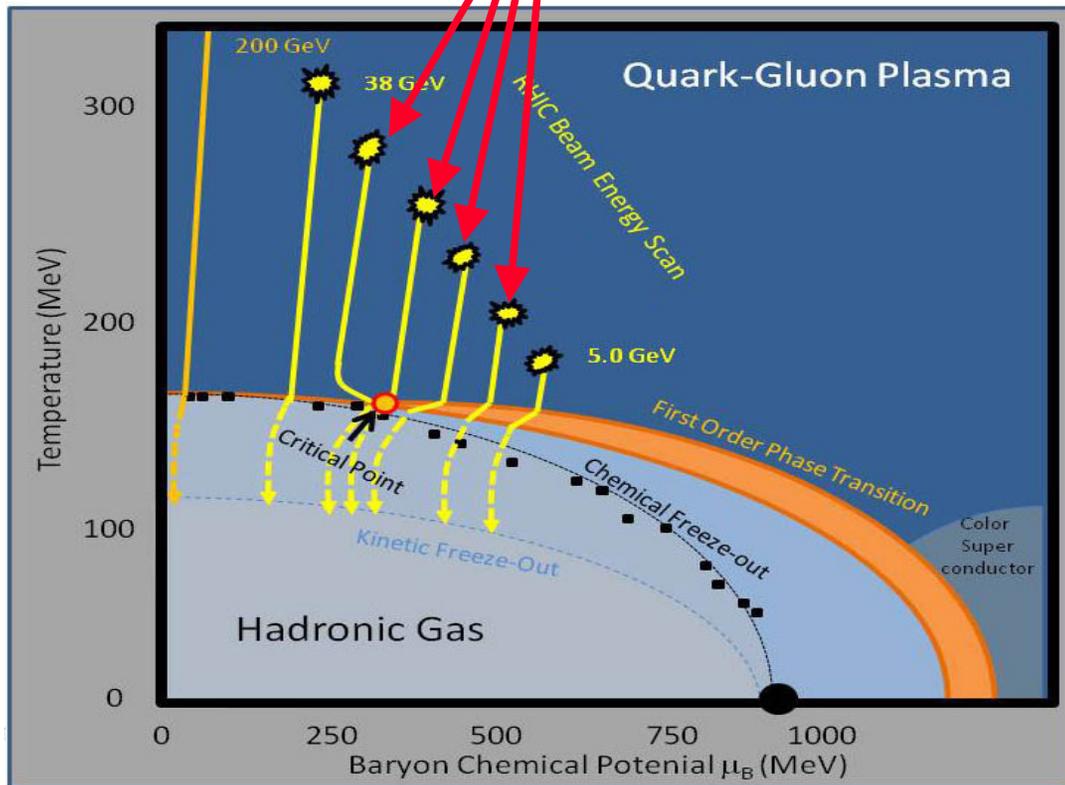
Low-Energy RHIC program: Operation with heavy ions to search for QCD phase transition Critical Point.

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Low-Energy scan, c.m. energies:

$$\sqrt{s_{NN}} = 5, 6.3, 7.7, 8.8, 11.5, 18, 27 \text{ GeV/n}$$

(2010 & 2011 RHIC runs)

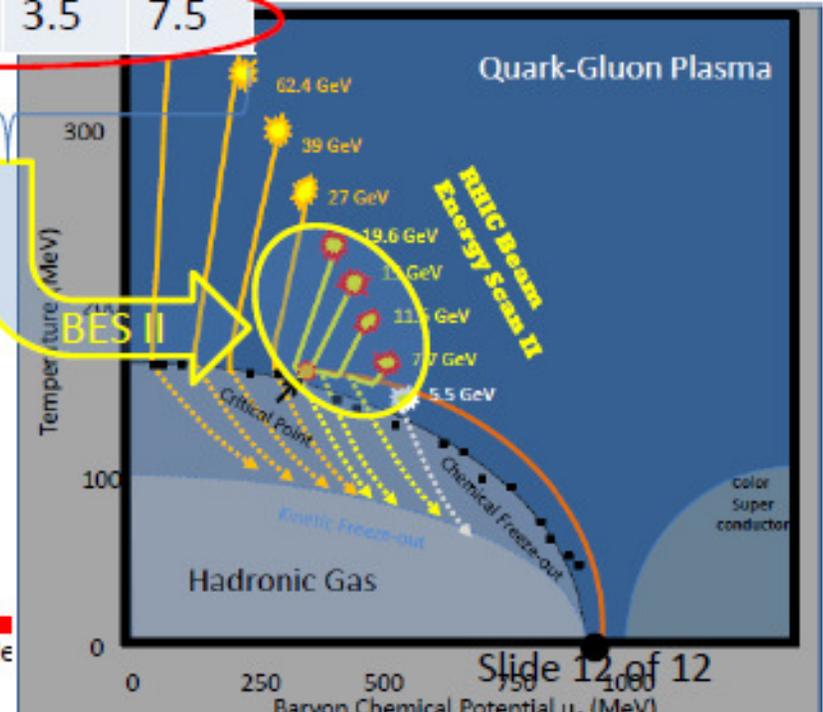


Beam Energy Scan II

\sqrt{s}_{NN} (GeV)	62.4	39	27	19.6	15	11.5	7.7
μ_B (GeV)	70	115	155	205	250	315	420
BES I (MEvts)	67	130	70	36	---	11.7	4.3
Rate(MEvs/day)	20	20	9	3.6	1.6	1.1	0.5
BES II (MEvts)	---	---	---	400	100	120	80
eCooling factor	---	---	---	8	6	4.5	3
Beam (weeks)	---	---	---	2.0	1.5	3.5	7.5

Add a week between each energy, and BES II program will take about **17 weeks**

- BES II will focus on the most interesting regions of the phase diagram
- Electron cooling is key to the feasibility of this program; without cooling, BES II would take **~70 weeks**



Low-energy RHIC operation

Electron cooling (a well known method of increasing phase-space density of hadron beams):

- “cold” electron beam is merged with ion beam which is cooled through Coulomb interactions
- electron beam is renewed and velocity spread of ion beam is reduced in all three planes

requires co-propagating electron beam with the same average velocity as velocity of hadron beam.

Energy scan of interest:

$\sqrt{s_{NN}} = 5, 6.3, 7.6, 8.6, 12, 16, 20$ GeV

At low energies in RHIC luminosity has a very fast drop with energy (from γ^3 to γ^6). As a result, achievable luminosity becomes extremely low for lowest energy points of interest.

However, significant luminosity improvement can be provided with **electron cooling** applied directly in RHIC at low energies.

Electron accelerator:

$$E_{e,kinetic} = 0.86-4.9 \text{ MeV}$$

Improvement from cooling

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- At energies $\gamma=6$ and above one can project significant improvement from cooling.
- To have improvement from cooling below $\gamma=6$:
 - need more transverse acceptance ($> 3*\sigma$)
 - try to limit space-charge tune spread to about 0.05 or less (not very strict)
 - have beams with smaller dp/p

Operation with long bunches (low frequency RF) together with electron cooling should help to address these issues:

C-A/AP/449 (February 2012)

C-A/AP/476 (January 2013)

C-A/AP/477 (February 2013)

Projection (maximum possible "ideal") for luminosity improvement (low-frequency RF and long ion bunches compared to Run-10)

C-A/AP/449 (February 2012)

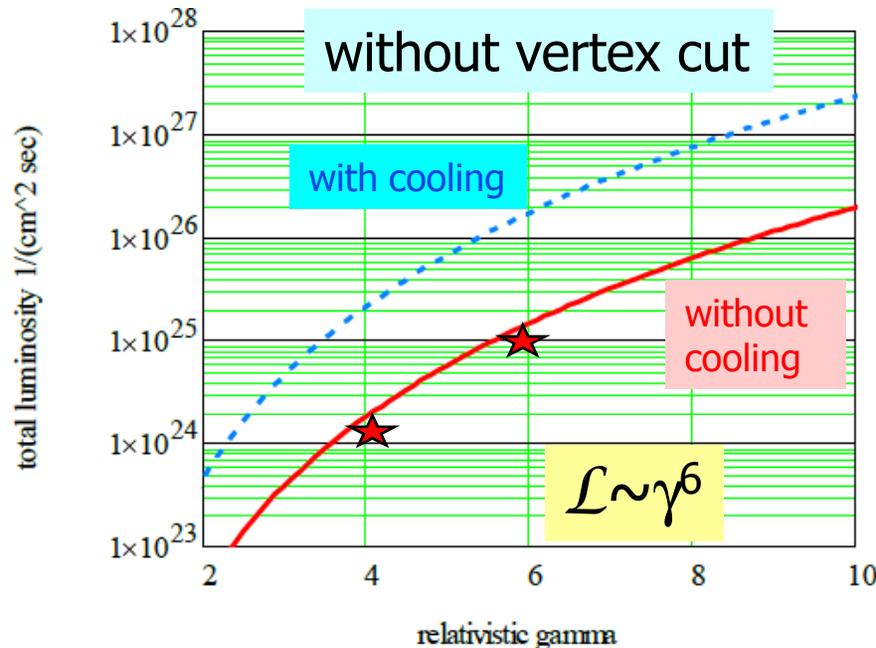


Fig. 8. Projection of total (without vertex cut) luminosity for 111 bunches of Au ions in RHIC for the space-charge tune spread of $\Delta Q_{sc}=0.05$ with electron cooling and long bunches (blue, dash upper curve) and without cooling (red, solid lower curve).

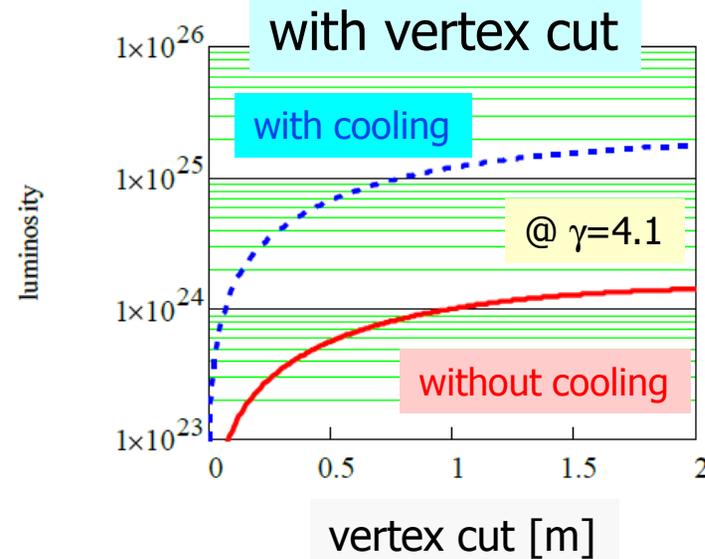
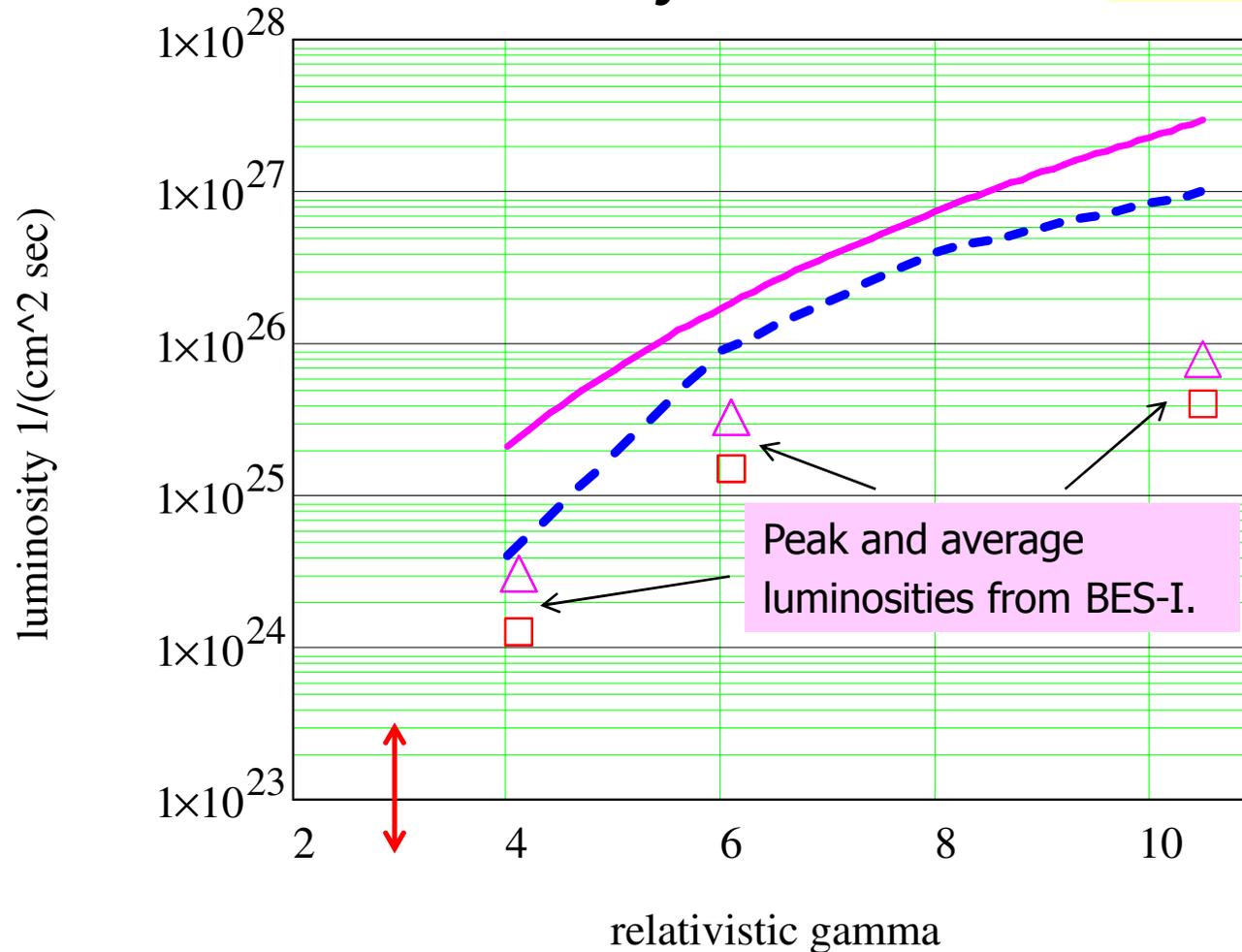


Fig. 6. Average luminosity for 111 bunches of Au ions in RHIC at $\gamma=4.1$

Up to about factor of 10 gain in total luminosity for all low energies with longer bunch length may be expected from electron cooling (*assuming that observed beam lifetime due to present limitations will improve with such an approach).

Luminosity projection for present 28 MHz and new 4.5 MHz RF system

C-A/AP/481 (April 2013)



Expected improvement with electron cooling:

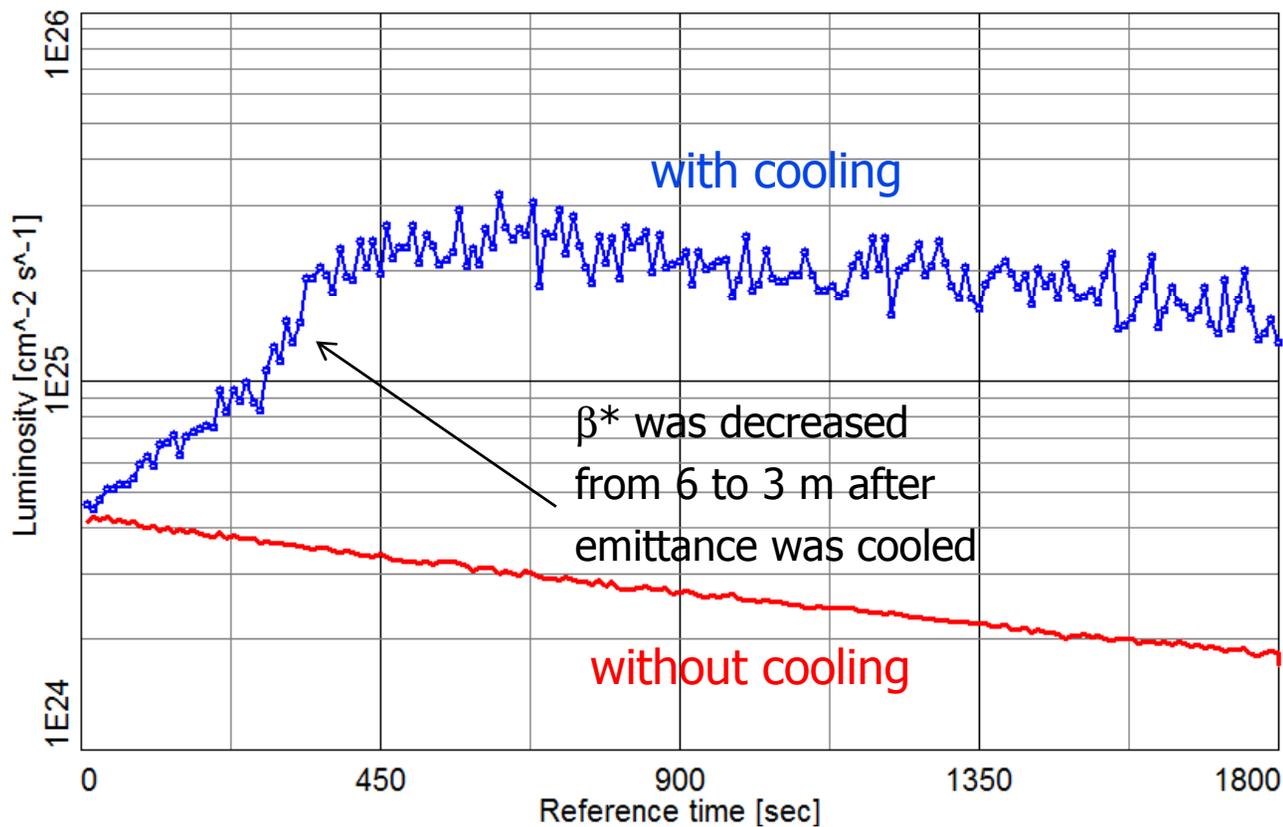
Blue-dash line: possible luminosity improvement with present limitations and 28 MHz RF.

Magenta: maximum possible improvement if limitations are mitigated by using longer bunches (with new RF system)

$\gamma@4.1$ (sqrt[s]=7.7 GeV), Simulations assuming new 4.5 MHz RHIC RF system

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- Luminosity (simulations) with longer bunches (4.5 MHz)



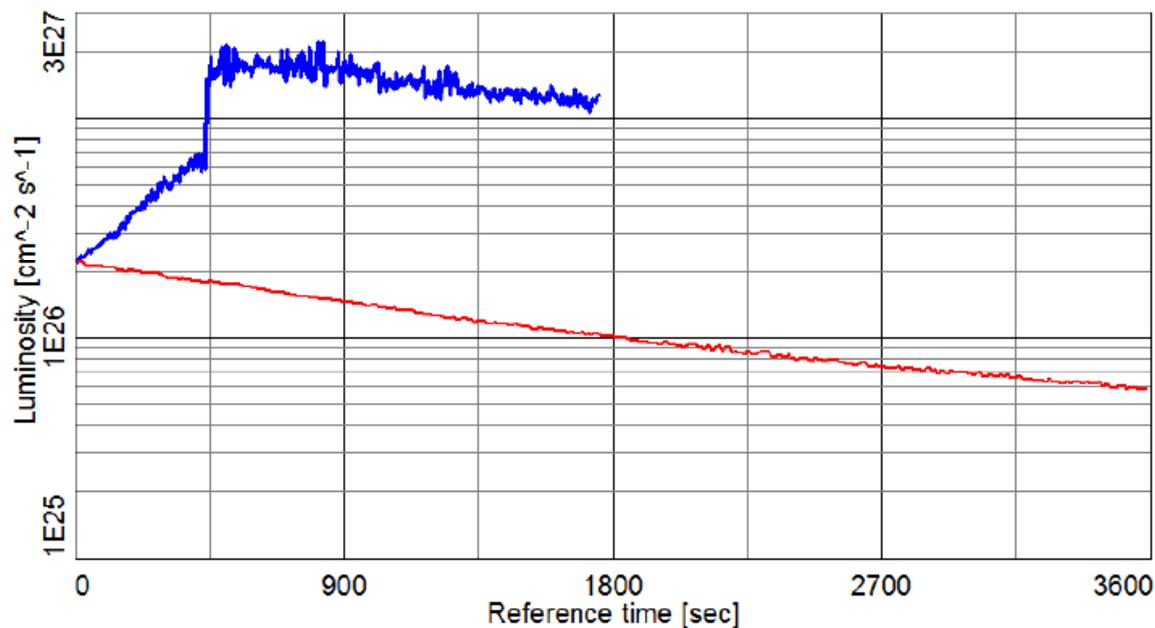
Initial bunch parameters:
 $N=0.75e9$,
 $\sigma_s=5.8$ m (rms length)
 $\Delta Q_{sc}=0.019$ (space-charge spread)

Allows to cool transversely and decrease β^* .

Even larger luminosity than shown since we should be able to start with smaller β^* from the beginning.

$\gamma@10.7$ (sqrt[s]=20 GeV)
(can use both new 4.5 and present 28 MHz RHIC RF)

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Better luminosity improvement is expected for higher energy points of proposed BES-II, since we do not have strong limitation from space charge or physical/dynamic aperture.

Figure 2. Luminosity at $\gamma=10.7$ and 28 MHz RF (450 kV) for initial $\beta^*=3\text{m}$, 111 bunches with $1.5 \cdot 10^9$ bunch intensity and transverse 95% normalized emittance of 15 mm mrad. Red curve: IBS and losses from RF bucket only; blue curve: IBS, losses from RF bucket and electron cooling.

Low-Energy RHIC electron Cooler (LEReC)

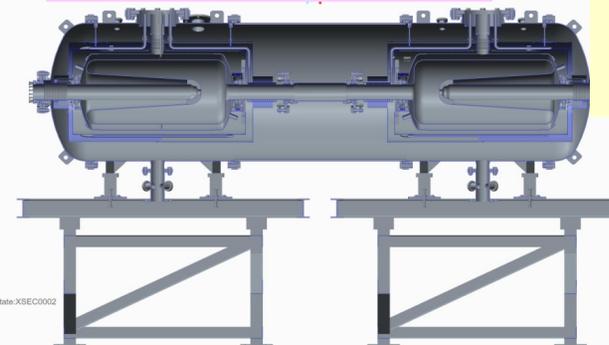
Different approaches are possible:

BNL C-AD Tech Note C-A/AP/307 (April 2008)

1. DC accelerator (Pelletron from FNAL) →
suitable for cooling: $< \sqrt{s_{NN}} = 20$ GeV
was baseline approach until
September 2012
2. RF-gun bunched beam electron cooler -
(100 MHz SRF gun and booster →
cavity)
designed to reach $\sqrt{s_{NN}} = 20$ GeV
**present baseline approach since
September 2012**



compact approach:



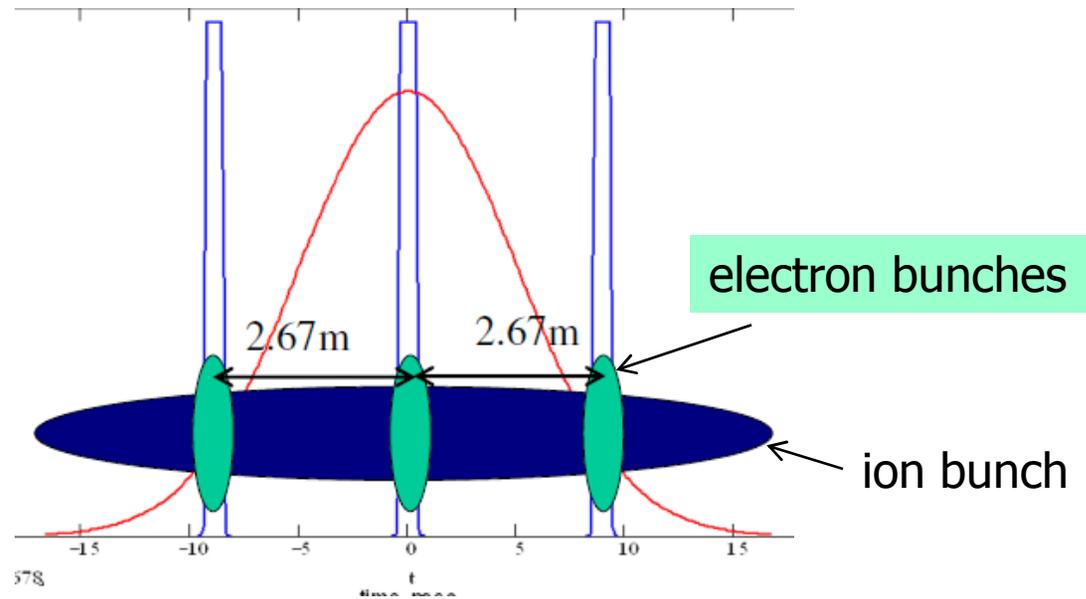
Layout by
B. Martin

Bunched beam electron cooling

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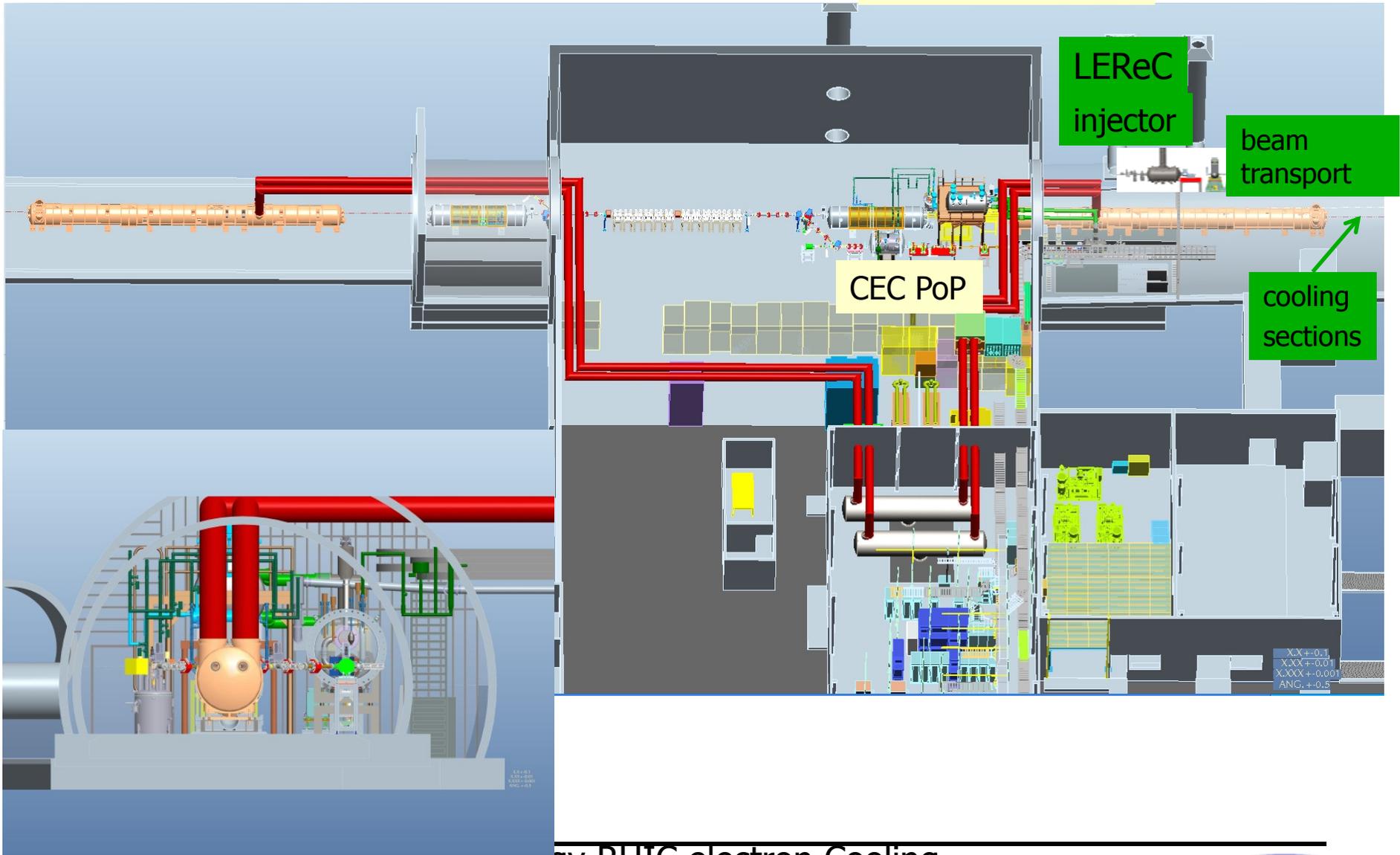
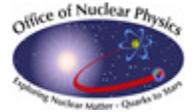
- First bunched beam electron cooling
- First electron cooling in a collider
- Opens roadmap for electron cooling at high energies

Putting a “train”
of electron bunches
on a single ion bunch.



LEReC at IP2 in RHIC

J. Tuozzolo,
B. Martin et al.



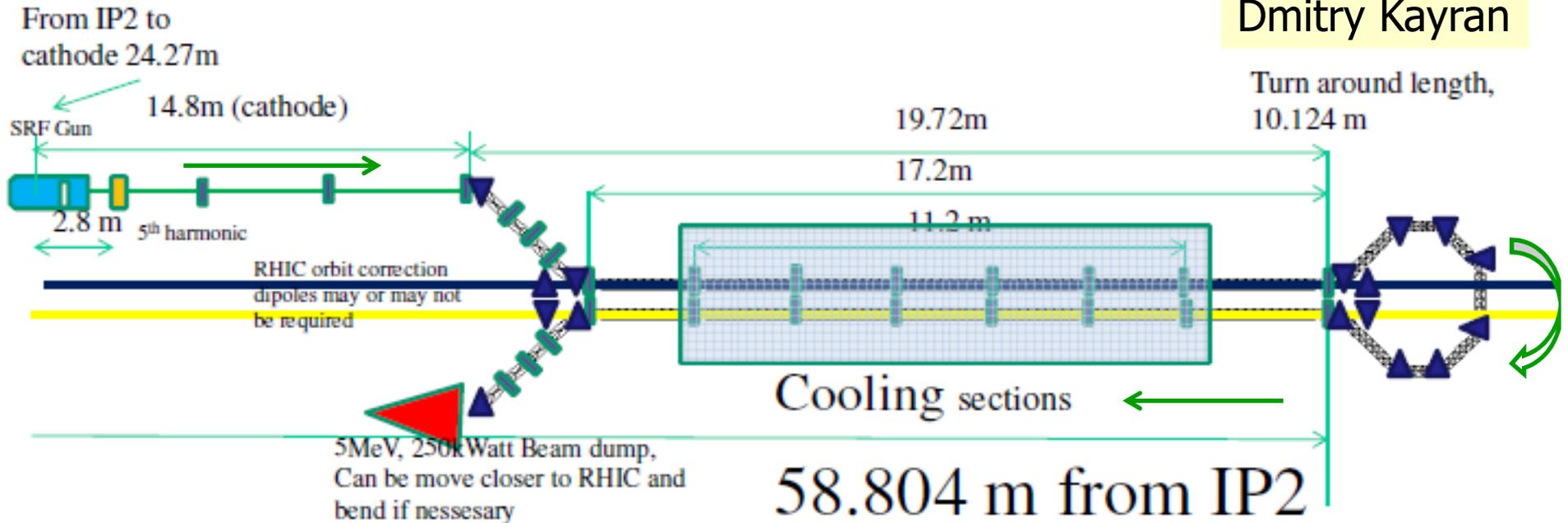
Scope of LEReC project

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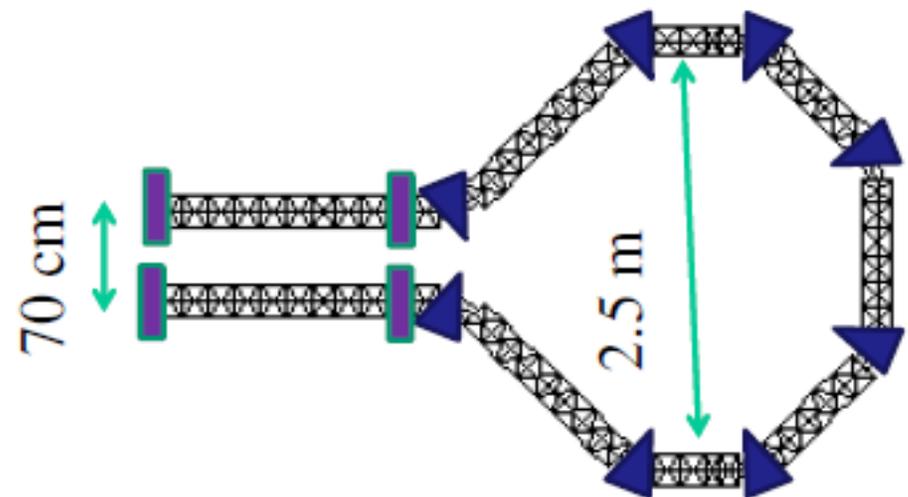
1. 100 MHz SRF gun with maximum energy of 2.5 MV.
2. 2.5 MV booster 100 MHz SRF cavity in the same cryostat with the gun.
3. Solenoid inside the cryostat between the gun and cavity.
4. 500 MHz energy correction warm cavity (5th harmonic).
5. Electron beam transport from IR2 section to the cooling section in Warm Sector 2.
6. Cooling section in Blue RHIC ring – 14 m long. Short (10cm) correction solenoids (200G) located every 2m. Free space between the solenoids is covered by mu metal to shield magnetic field to a required level or Helmholtz coils for active correction.
7. U-turn between cooling section in Blue and Yellow Rings.
8. Cooling section in Yellow Ring.
9. Dump for the electron beam (250 kW).
10. Beam transport magnets and diagnostics.

LEReC schematic layout

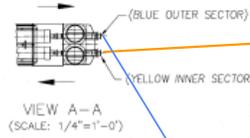
Dmitry Kayran



-  HTS Solenoid inside gun cryomodule
-  Solenoids, (20 cm effective length)
-  45 degrees chevron magnets (30 cm length)



Right 2:00 Sector



Cooling sections

Beam Direction
YELLOW INNER SECTOR 2
VIEW LOOKING OUT FROM RING CENTER

VIEW LOOKING OUT FROM RING CENTER

Beam Direction
BLUE OUTER SECTOR 2
VIEW LOOKING OUT FROM RING CENTER

Will require relocation of several diagnostic devices (ARTUS, IPM)

REV	NO.	DESCRIPTION	DATE	BY	CHK	APP	APP
A	00000	INITIAL RELEASE					
J	00001	AS PER ECN					
K	00002	AS PER ECN					
L	00003	AS PER ECN					
M	00004	AS PER ECN					
N	00005	AS PER ECN					
O	00006	AS PER ECN					
P	00007	AS PER ECN					

FOR REFERENCE ONLY
NOT ALL COMPONENTS ARE SHOWN
COMPONENT LOCATION MUST BE
VERIFIED IN THE RING

L SOCK UP	LONGITUDINAL SOCK PICKUP	71011043
TWC	TRAVEL WAVE CAVITY	71016556
IPM	ION PROFILE MONITOR-HORIZ	82035008
IPM	ION PROFILE MONITOR-VERTICAL	82035134
NEG	NEG PIPE	43035019-1
TMK V	TUNE METER KICKER VERTICAL	82045005
TMK H	TUNE METER KICKER HORIZONTAL	82045005
GCK	GAP CLEANING KICKER	82045005
MBPM2	2ND MOVABLE BEAM POSITION MONITOR	81015211 (NOT RELEASED)
KKR-2	KICKER	01055715-2
KKR-1	KICKER	01055715-1
CFC	CROSS FOR CARBON FIBER	VA-FC0600
LM	LUM MONITOR	01055721
SFU	CROSS FOR SCOTTKY CAVITY	LR2118453
EDV	TEE FOR ELECTRON DETECTOR-VERTICAL	KUJ509352-1-05
WCM	WALL CURRENT MONITOR	82015000 (NOT RELEASED)
MBPM	MOVABLE BEAM POSITION MONITOR	81015132
BBPM	BUTTON BEAM POSITION MONITOR	82015004
	REMOVED	
	REMOVED	
XF	DC CURRENT MONITOR	82025002
TRDX	ASS'Y, TRIPLET/DX/TRANSFER LINE	01055685-05
TRIP	ASS'Y, TRIPLET MAGNET	01053300-05
DX	ASS'Y, DX MAGNET	01058114-02
DXDO	DXDO WARM BORE CHAMBER	42035021-02
ZDC	ZERO DEGREE CALORIMETER	01035009

ABBREVIATION DESIGNATION DWG. NO.

INTERVIEW & ORIGINAL APPROVAL WITH	DATE	BY	CHK	APP	APP
UNLESS OTHERWISE SPECIFIED					
DESIGNER USE IN HOUSE ONLY (NO RELEASE)					
APPROVED BY					
USED ON ORIGINAL OR COPY, FOR ANY APPLICATION	125				

COLLIDER-ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
UT-RNL-11-100

RHC
ALLOTMENT, SPACE, IP02
SECTOR 02

01055549
AutoCAD

Beam Loss Monitor

David Gassner et al.

ILL B3Q PU

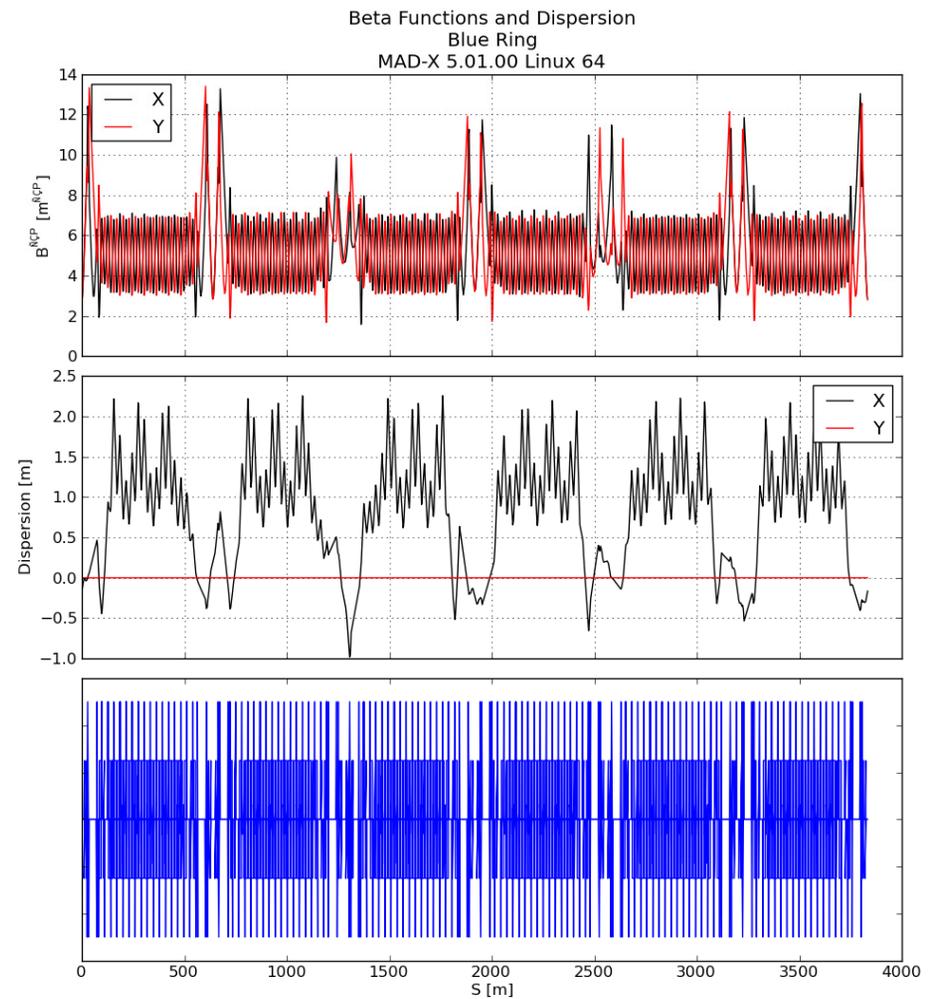
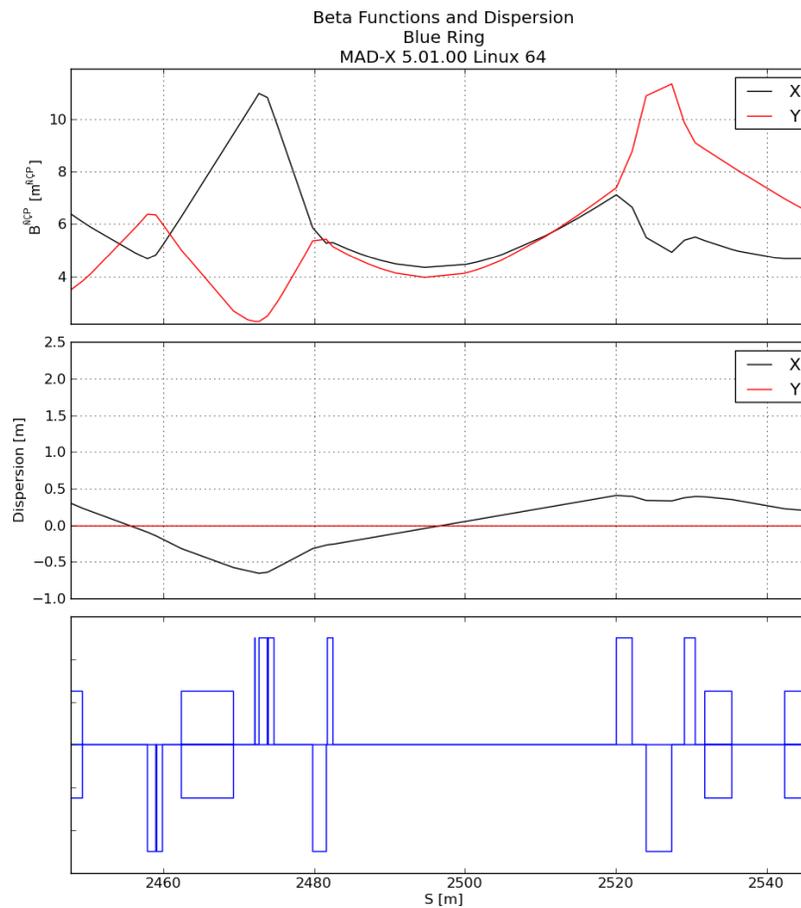
	42	2599.3	KKR-2 Hybrid Kicker	2599.1	KKR-2	(Moveable)
43	42.9	2600	matching of electron beam (2m)			17
45		2602	starting of cooling section	2601.0		ARTUS Kicker
	46.8			4	TMKH	Horizontal (start)
				2603.0		ARTUS Kicker
	48.8			4	TMKH	Horizontal (end)
	49	2605.2	EDV Electron Det V		EDV	Electron Det V
			ARTUS Kicker V(or B-by-B			Lumi-Mon (6-way
	53m	2608	TMKV longit damper)		LM	cross only)
			ARTUS Kicker V(or B-by-B	2610.0		B-Ionization PM
	55	2610	TMKV longit damper)	4	IPM-V	Vertical
						Beam Loss Monitor
56	56.6			2611.6	TWC	Traveling Wave Cavity
59		2616	end of cooling section (full length including space for solenoids 14m)			
			start of turn around of e-beam			
		2617	Future ARTUS Kicker V	2617		Future ARTUS Kicker H
		2619	Future ARTUS Kicker V	2619		Future ARTUS Kicker H
			end of turn around of e-beam			

RHIC lattice for LEReC

Steve Tepikian

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Blue:



Timeline of LEReC project

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- Accelerator Physics Design Review of LEReC project:
August 13-14, 2013

Requires very aggressive schedule:

- Engineering, fabrication, installation: 2013-2014-16
- Installation & commissioning: 2017
- Luminosity improvement: 2018

Summary

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1. Electron cooling can provide significant luminosity improvement for low-energy RHIC operation.
 2. Present electron cooler design is based on SRF gun bunched beam cooling. Electron accelerator is similar to CEC PoP accelerator and will use the same cryo system developed at IP2.
 3. New low-frequency RF system (4.5 MHz) is being planned for low-energy RHIC operation with electron cooling, to maximize potential luminosity gains and provide good beam lifetime.
- Implementation of electron cooling for RHIC operation at low energies is expected to take about 4 years.

Thank you.