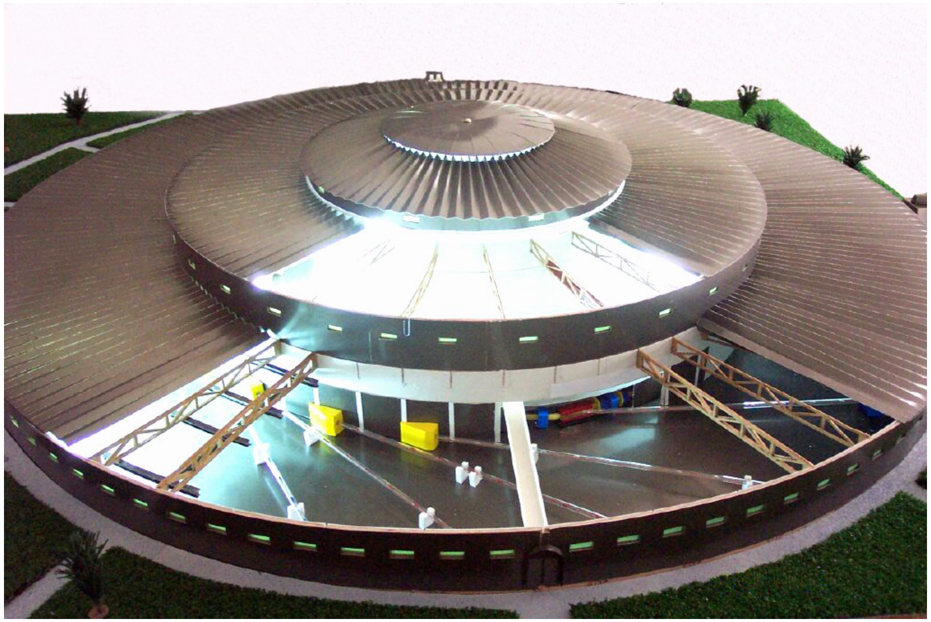


Low Emittance CANDLE Storage Ring

A. Sargsyan

Outline

- Historical overview
  - Generations of SR Sources
  - CANDLE 3rd generation SR Source project
- Scenarios for low emittance upgrade
  - 4BA + LGB lattice option
  - Comparison
- Next Steps

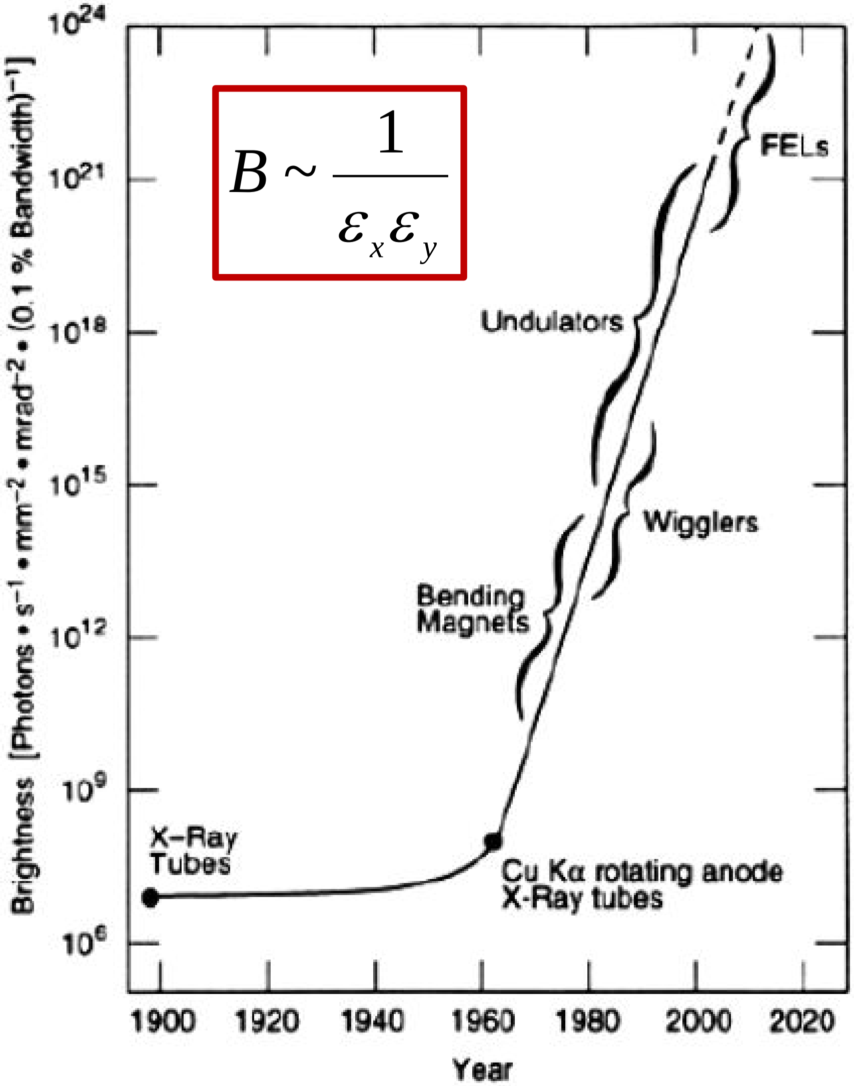
Generations of SR Sources

- 1st generation SR sources
  - Built for High Energy Physics used parasitically for synchrotron radiation (First experiments using synchrotron light took place at Cornell, US in 1956).

- 2nd generation SR sources
  - Built originally as synchrotron light sources (The first dedicated X-ray producing SR source started operating in Daresbury, UK in 1981).

- 3rd generation SR sources
  - Optimized for high brightness with low emittance beam and IDs (The first 3rd generation SR source, the ESRF in Grenoble, France, inaugurated in 1994).

Generations of SR Source



$$B \sim \frac{1}{\varepsilon_x \varepsilon_y}$$

Beam emittance

1980 ~ 100 nmrad
1990 ~ 10 nmrad
2000 ~ 3 nmrad
2010 ~ 1 nmrad
…
2020 ~ 0.1 nmrad

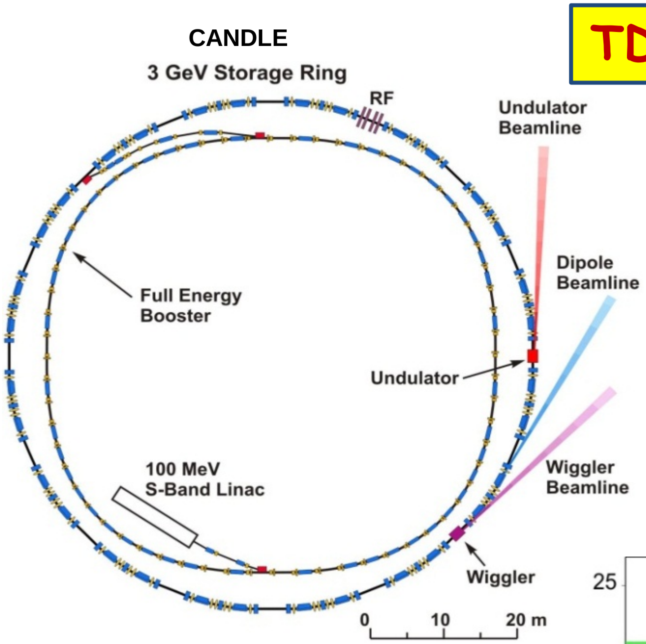
$$\varepsilon_{x,y} \sim \frac{\lambda}{4\pi}$$

so-called **diffraction limit**

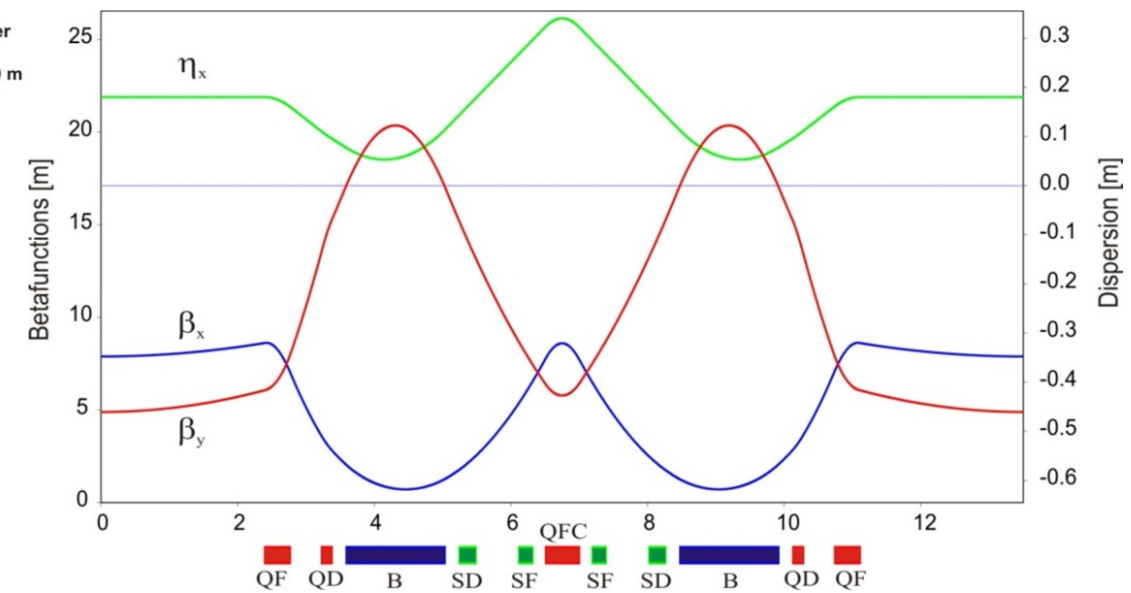
For X-ray range – from several 10s to several 100s pm

CANDLE 3rd generation SR Source project

TDR in 2002



Parameter	Value
Circumference (m)	216
Number of DBA cells	16
Straight section length (m)	4.8
Beam current (mA)	350
Beam Energy (GeV)	3
Hor. emittance (nm rad)	8.4
RF momentum acceptance (%)	2.4
Betatron tunes (h/v)	13.22/4.26
Natural chromaticities (h/v)	-18.9/-14.9



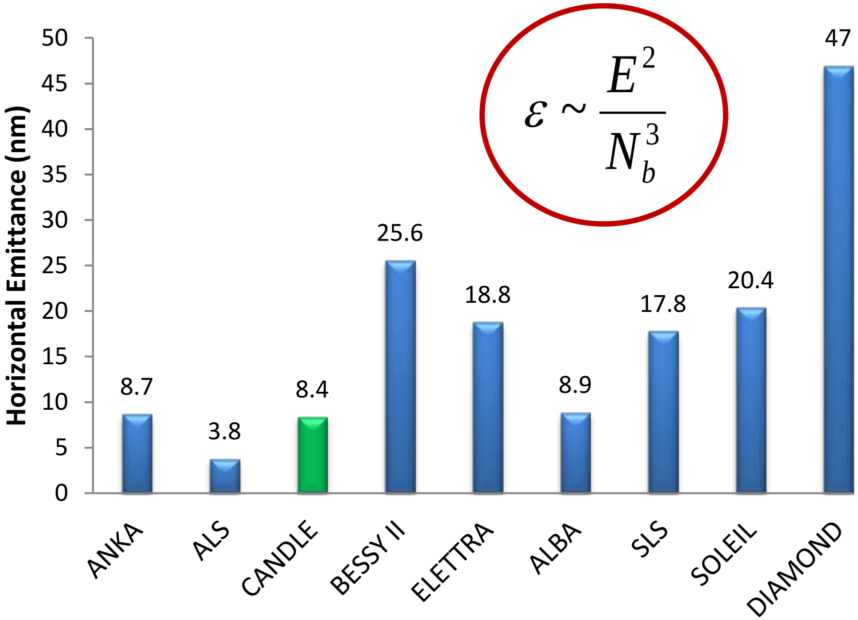
CANDLE 3rd generation SR Source project

A non-complete list of 3rd generation moderate energy storage rings

Name	Lattice type	Emit. (nm)	Energy (GeV)	Circ. (m)
ANKA	DDBA	46	2.5	110
ALS	TBA	2	1.9	197
CANDLE	DBA	8.4	3.0	216
BESSY II	DBA	6	1.7	240
ELETTRA	DBA	7	2.4	259
ALBA	DBA	4.6	3.0	269
SLS	TBA	4.8	2.4	288
SOLEIL	DBA	3.9	2.75	354
DIAMOND	DBA	2.7	3.0	560

$$\varepsilon = C_q \gamma^2 \frac{I_5}{I_2 - I_4}, \qquad \sigma_\delta^2 = C_q \gamma^2 \frac{I_3}{2I_2 + I_4}$$

Beam emittance in case of 216m circumference and 3 GeV energy



$$\varepsilon \sim \frac{E^2}{N_b^3}$$

$$I_2 = \oint_{bend} \frac{1}{\rho^2} ds, \quad I_4 = \oint_{bend} \frac{\eta_x}{\rho}\left(\frac{1}{\rho^2} + 2k_1\right) ds, \quad k_1 = \frac{e}{P_0}\frac{\partial B_y}{\partial x}$$

$$I_5 = \oint_{bend} \frac{H_x}{|\rho|^3} ds, \qquad H_x = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$$

Scenarios for low emittance upgrade

Next (4th) generation SR sources

Name	Lattice type	Emit. (pm)	Energy (GeV)	Circ. (m)
ANKA upgrade study	4BA	8600	2.5	110
ALS upgrade study	6-10BA	100	2.0	200
ELETTRA upgrade study	6BA	280	2.0	260
SLS upgrade studies	Hybrid 7BA	135	2.4	288
SIRIUS	5BA	280	3.0	518
MAX-IV	7BA	326	3.0	528
DIAMOND upgrade	4BA	280	3.0	562
ESRF upgrade	Hybrid 7BA	132	6.0	844
APS upgrade	Hybrid 7BA	65	6.0	1104
SPRING 8 upgrade study	6-10BA	68	6.0	1436

- Implementation of MBA lattice cells ⟶ minimize I_5
- Implementation of LGBs ⟶ minimize I_5 further
- Implementation of vertically focusing bending magnets ⟶ maximize $J_x = 1 - I_4/I_2$
- Implementation of damping wigglers ⟶ strengthen the radiation damping

Scenarios for low emittance upgrade

Recent developments in low emittance lattice design and magnet technology encouraged us to launch a continuous process for CANDLE storage ring lattice improvement.

Considered approaches

1. use more compact magnets with combined fields and keep the type of cells and the length of the ring circumference unchanged
2. apply MBA concept
3. implement LGBs and anti-bends

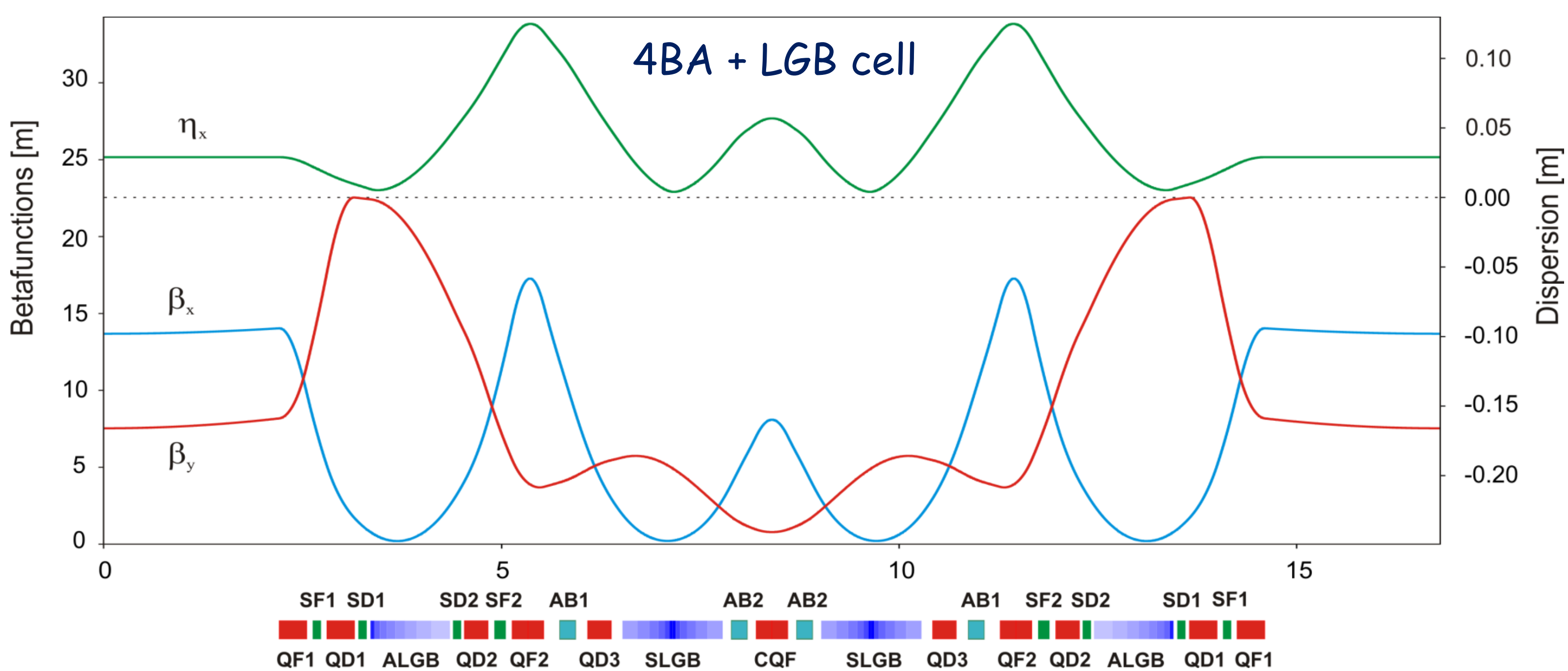
Solutions so far

1. Emittance reduction from 8.4 nm to 5.2 nm
2. 4BA lattice providing 1.1 nm beam emit. within 258 m circumference
3. 4BA lattice providing 0.435 nm beam emit. within 268.8 m circumference

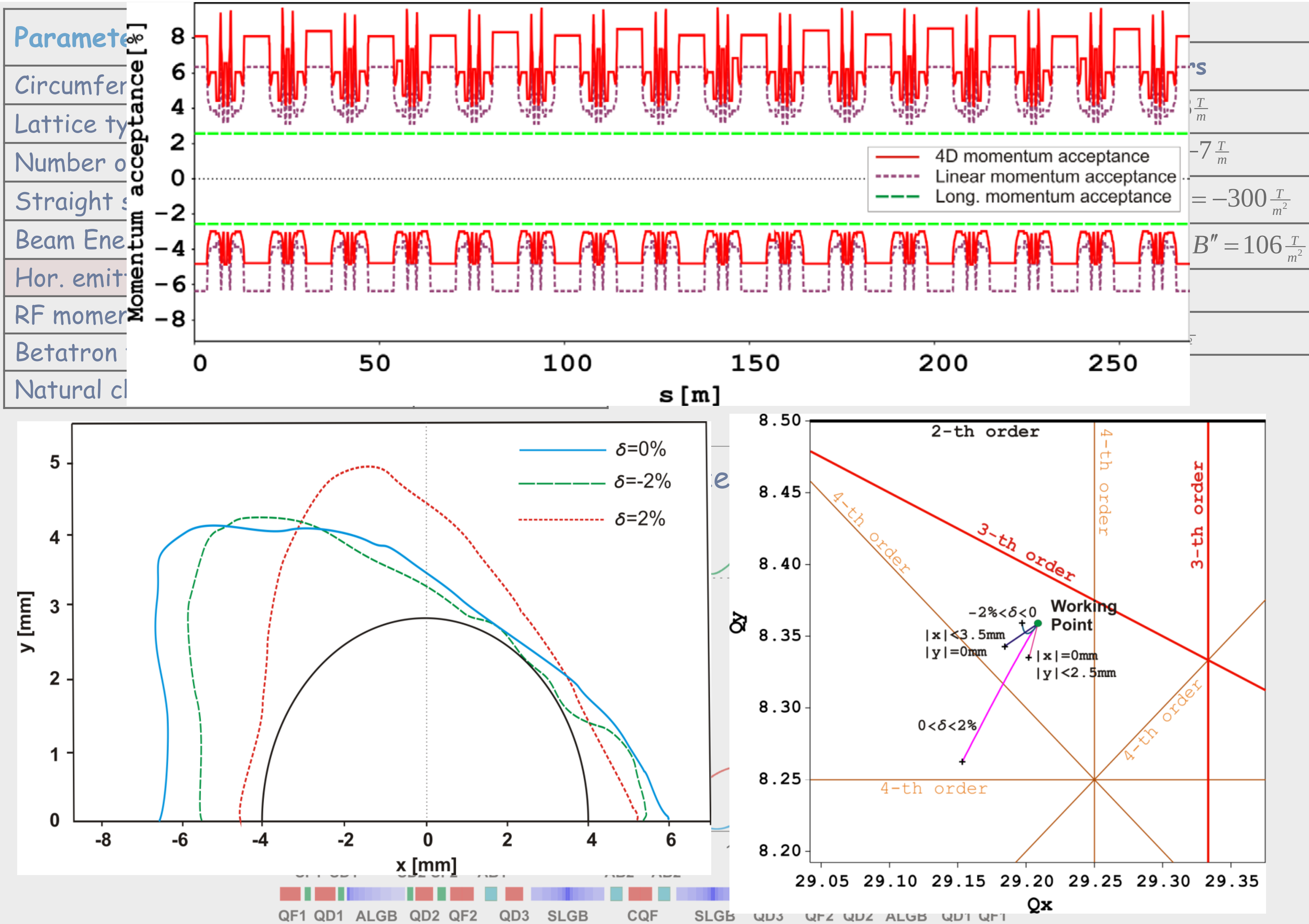
4BA + LGB lattice option

Parameter	Value
Circumference (m)	268.8
Lattice type	4BA
Number of periods	16
Straight section length (m)	4.4
Beam Energy (GeV)	3
Hor. emittance (nm rad)	0.435
RF momentum acceptance (%)	2.6
Betatron tunes (h/v)	29.2/8.36
Natural chromaticities (h/v)	-95.16/ -33.92

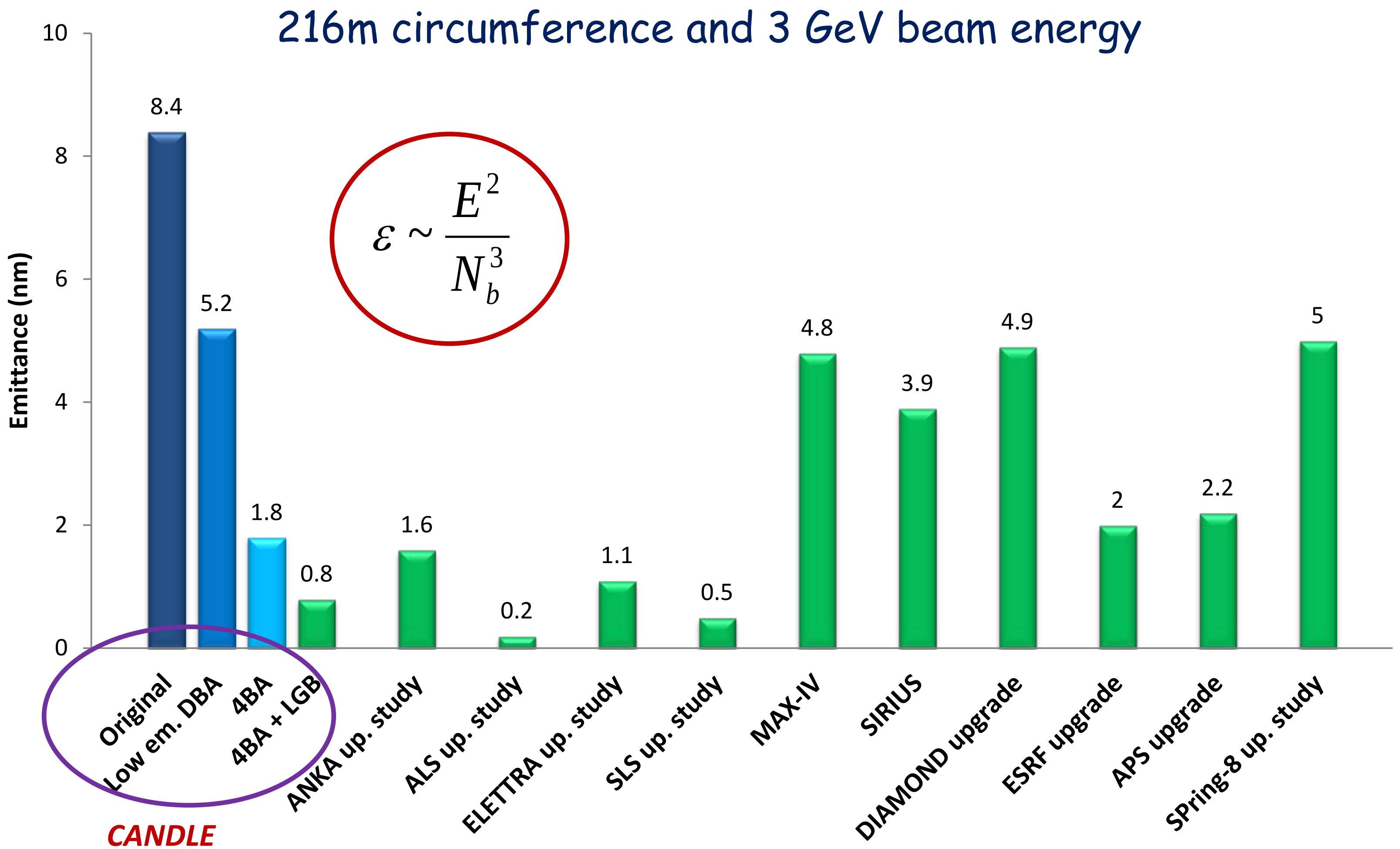
Magnets	Length [m]	Main parameters
ALGB	1	$\alpha = 5^o; B' = -3\frac{T}{m}$
SLGB	1.26	$\alpha = 7.91^o; B' = -7\frac{T}{m}$
Anti-bend (AB1)	0.2	$\alpha = -0.6^o; B' = 5.5\frac{T}{m}; B'' = -300\frac{T}{m^2}$
Anti-bend (AB2)	0.2	$\alpha = -1.06^o; B' = 13.3\frac{T}{m}; B'' = 106\frac{T}{m^2}$
Quadrupoles	0.3-0.4	$\lvert B' \rvert \le 36\frac{T}{m}$
Sextupoles	0.1-0.14	$\lvert B'' \rvert \le 260\frac{T}{m^2}$



4BA + LGB lattice option



Comparison



A. Sargsyan, G. Zanyan, V. Sahakyan, V. Tsakanov, NIM A, 2016, 832, 249-253.

Next steps

1. Nonlinear beam dynamics optimization based on MOGA.

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3. Search for other optimal low emittance solutions.

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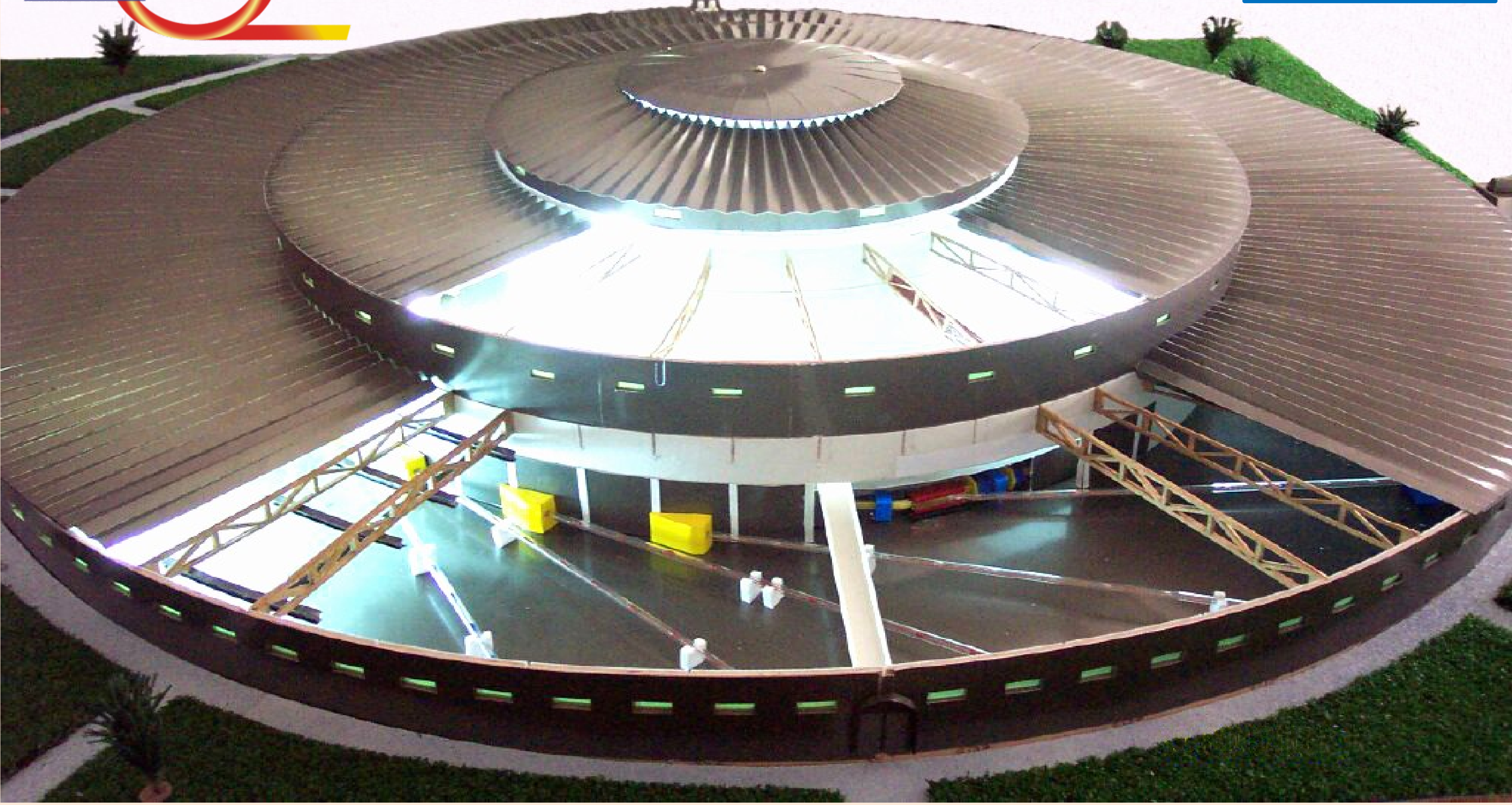
2. Examination of emittance additional reduction possibility using damping wigglers.
3. Search for other optimal low emittance solutions.
4. **Never lose hope.**

CANDLE

15 years



THANK YOU FOR ATTENTION