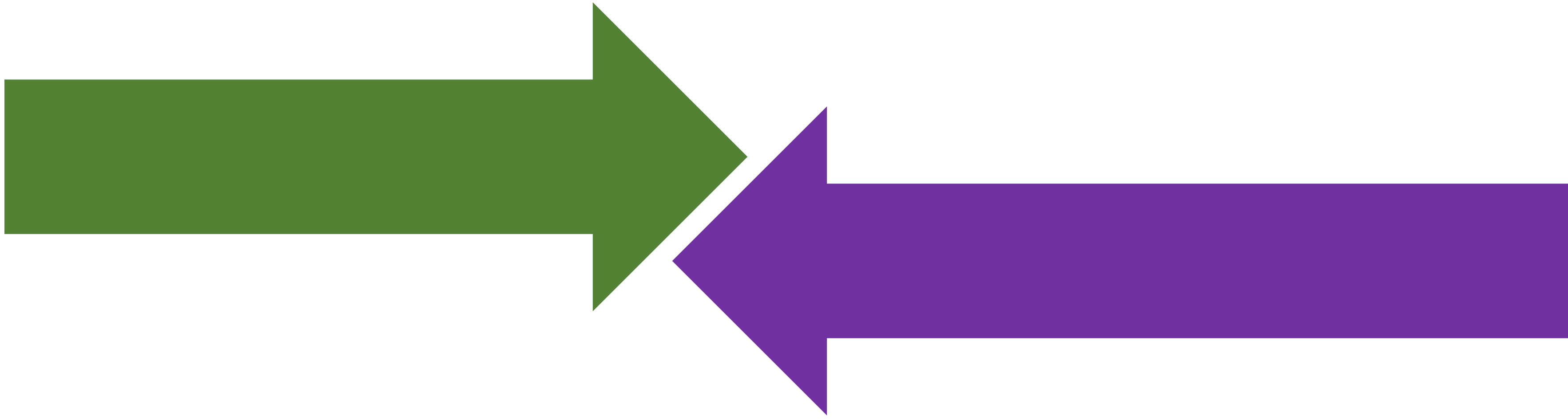

Proposal for CW-colliders development at Budker INP

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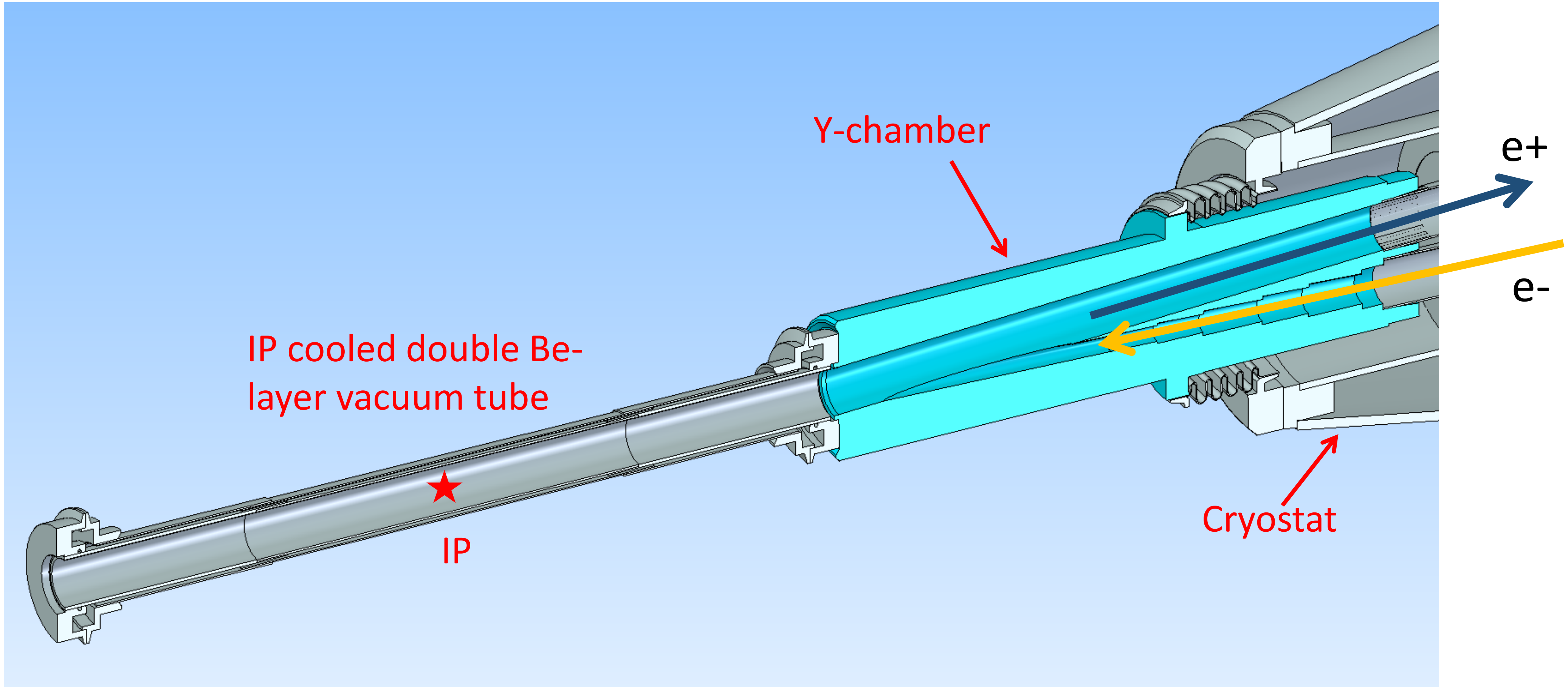
Motivation

- A flagship BINP collider project is Super Charm Tau Factory. It is large, expensive, long-running and risky project.
- Crab Waist is a novel and promising colliding technology but the only attempt to fully implement it at Super KEKB is still far from completion. (At DAΦNE large emittance has not allowed to apply the full scheme.) Many issues should be studied. Many systems should be optimized.
- We need a program to develop key elements and to study essential effects before start of SCTF.
- Main points of the program: (1) critical equipment design, development, prototyping and testing; (2) partial CW insertion at VEPP-4M; (3) BINP infrastructure and injection facility modernization; (4) medium size and energy CW collider development at BINP; (5) full scale SCTF.

Critical equipment

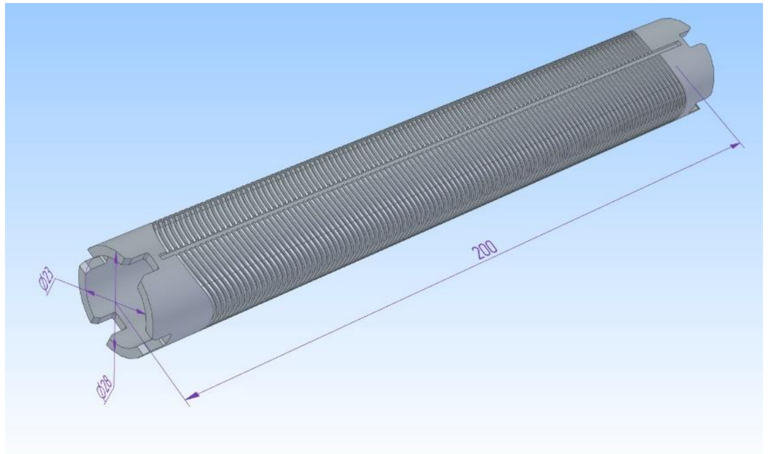
IR and FF design is most essential to reach the CW collider parameters. In our new FF design the Y-chamber is joined to the cryostat saving space between the IP and QD0.

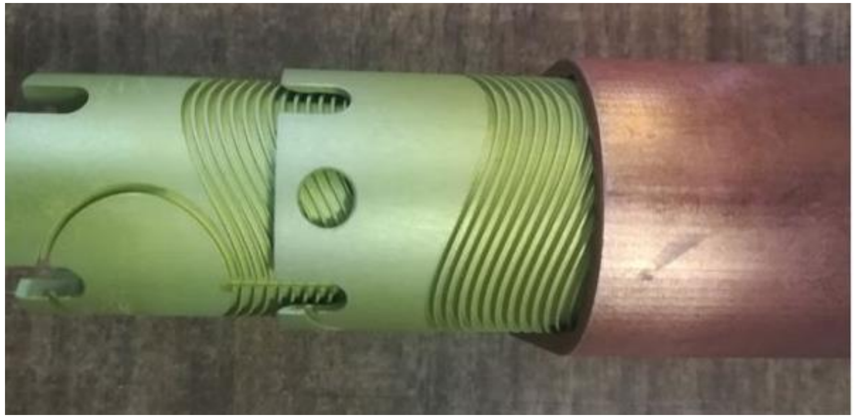


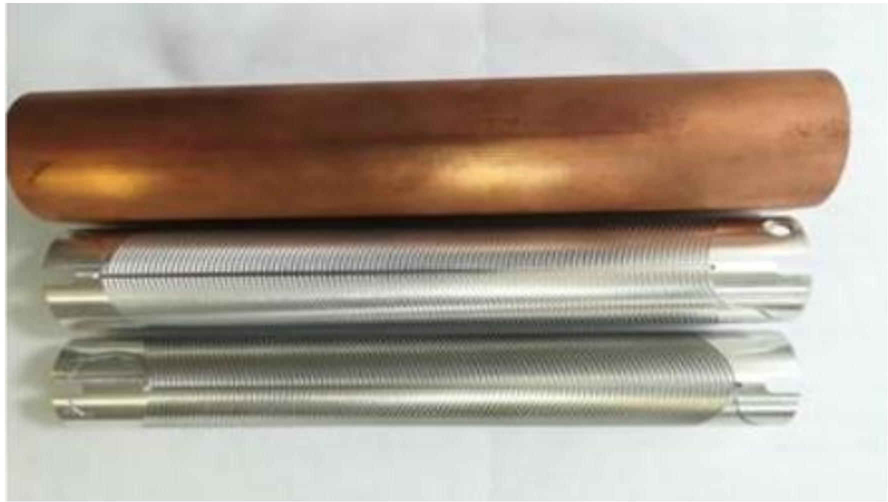
FF quadrupole-1

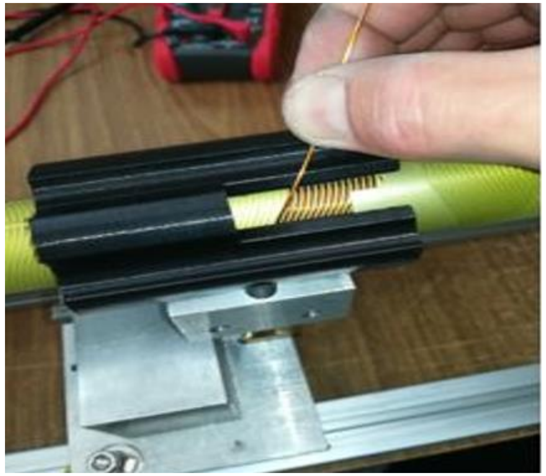
At BINP we built the first in Russia superconducting CCT-technology quadrupole.

Max gradient, T/m	40
Inner coil ∅, mm	29
Outer coil ∅, mm	34
Winding modulation ampl., mm	4
Superconductor ∅, mm	0.92
Wind interval, mm	1.6
Winding No	100
Quad length, mm	160



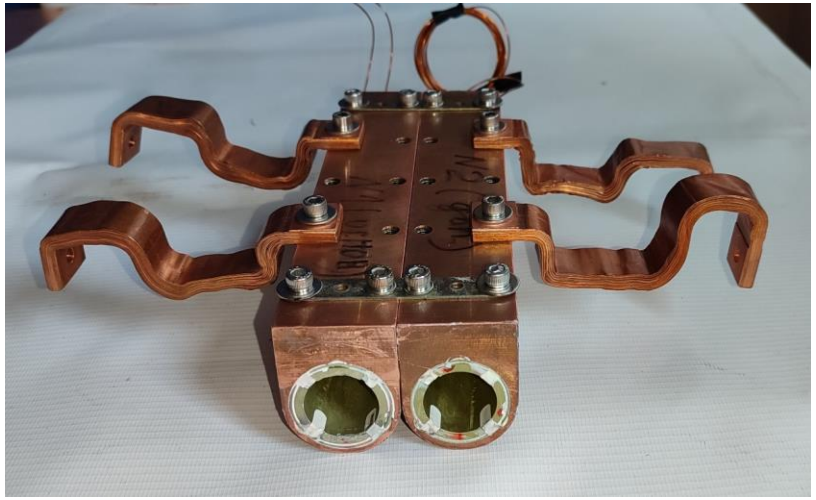






FF quadrupole-2

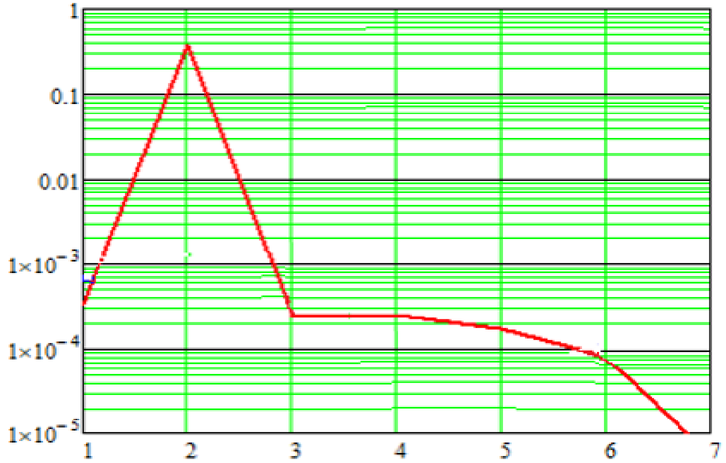
…and successfully tested it reaching 40 T/m at 1500 A current with only two quenches.



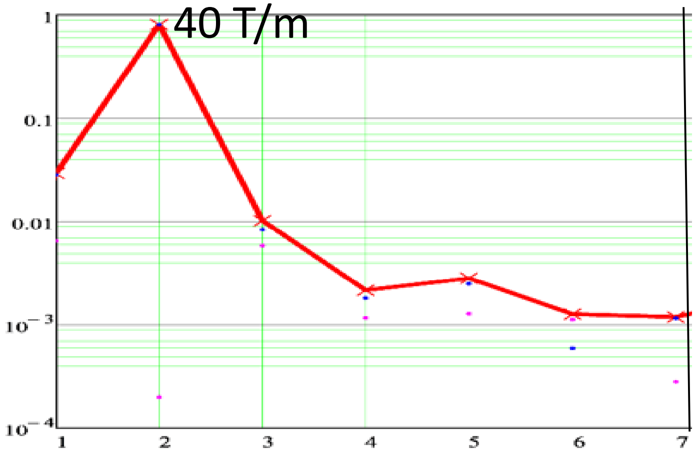
Twin-barrel CCT quad

Rotating coils

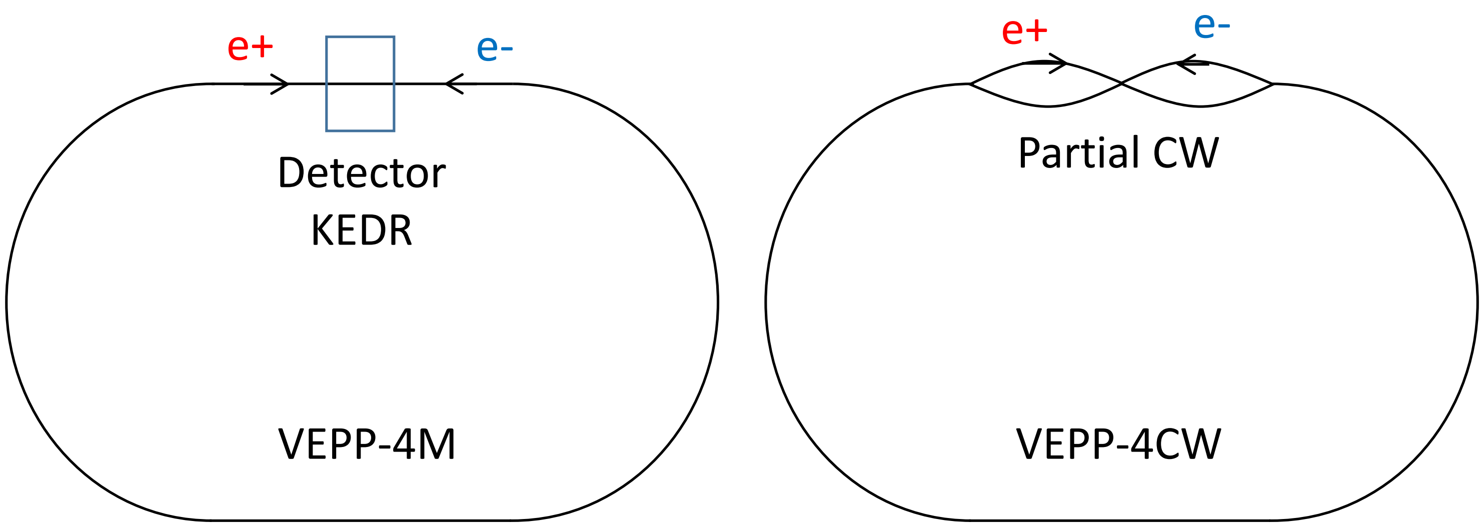
Testing cryostat (He free)

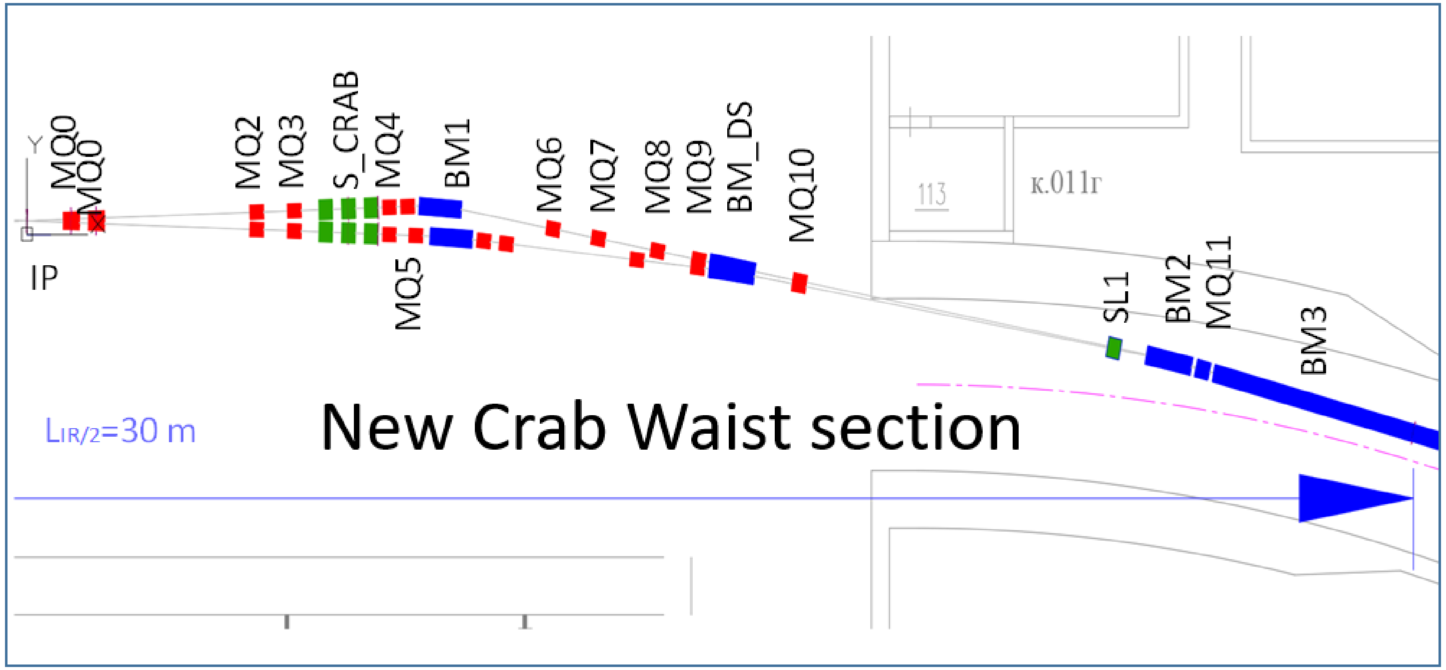


Harmonic number



VEPP-4CW – partial crab waist



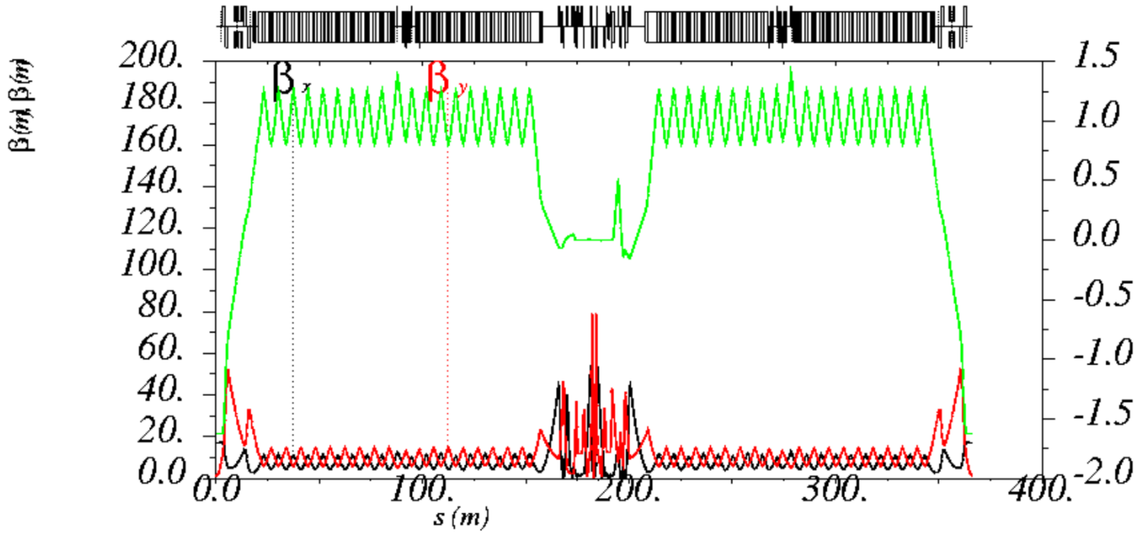


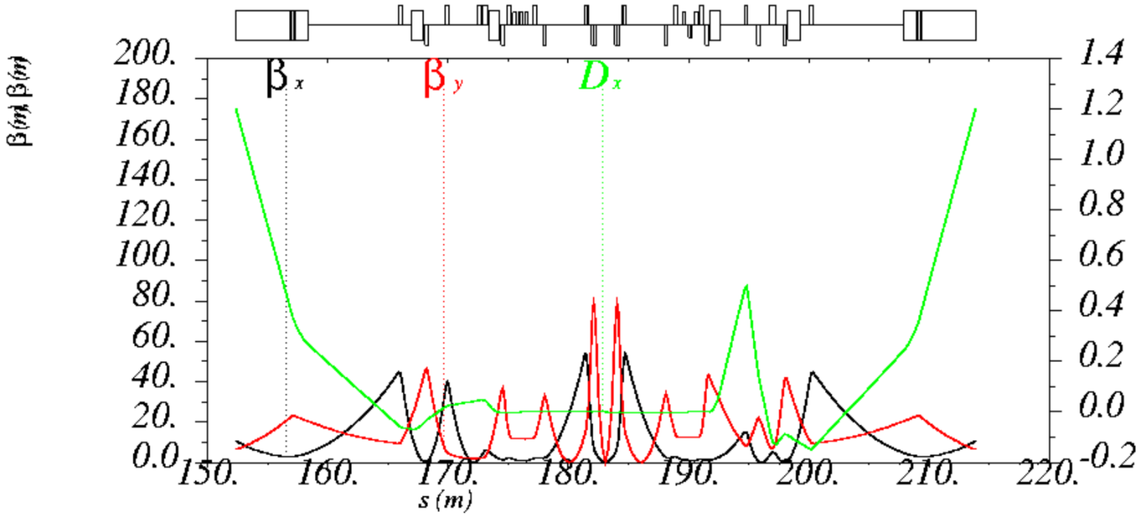
Long (~30 m) straight section is modified. Electrostatic separation of e+ and e- beams. 6 additional sextupoles.

What can we study?
- IR and FF design
- FF cryo-system, vacuum system, etc.
- BB effects, large ξ_y
- Parameters with energy
- Solenoid field influence
- Crab sextupole influence
- FF impedances
- Nonlinear beam dynamics
- Particle loss and background
- Luminosity tuning and measurement
- Etc.

Partial CW is the idea by our Chinese colleagues for early CEPC (Jie Gao).

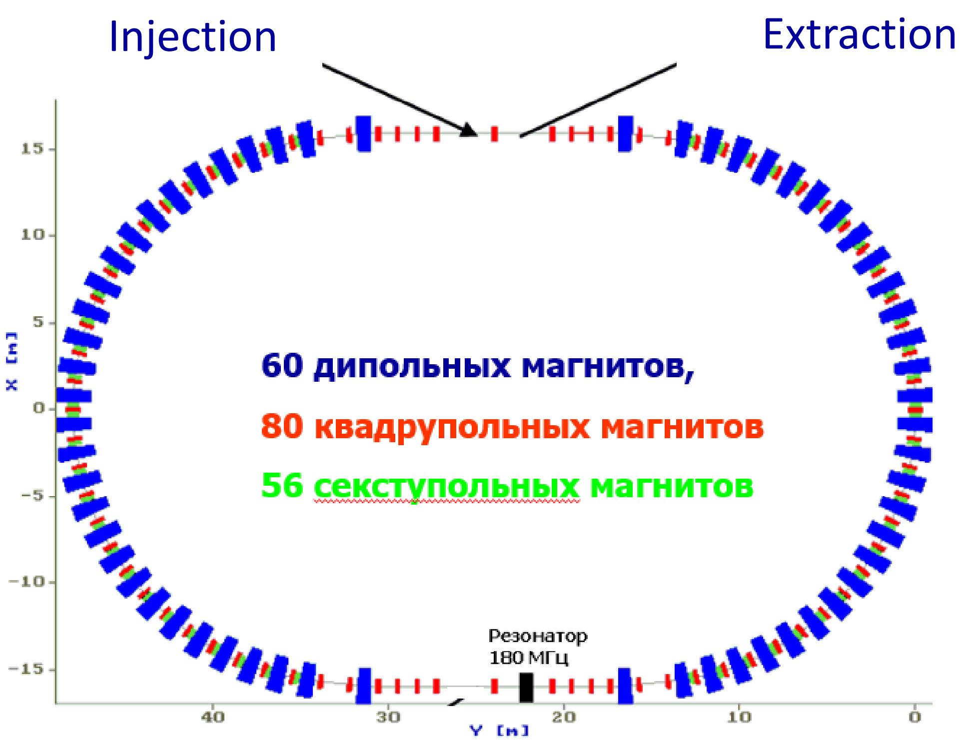
VEPP-4CW parameters





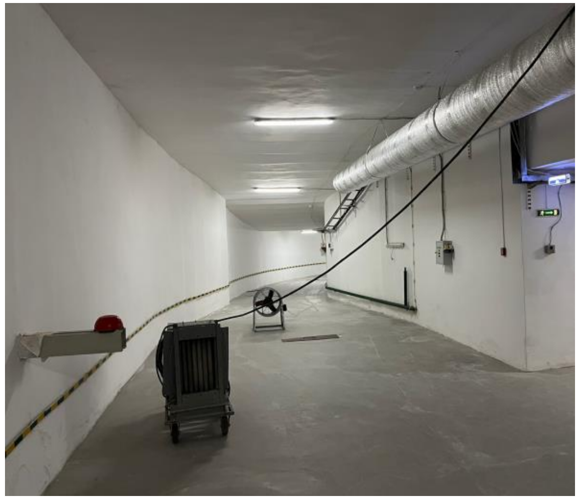
	ВЭПП-4М	ВЭПП-4К	ВЭПП-4К
E, ГэВ		1.85	
П, м	366.09	366.21	366.21
θ, мрад	0	±30	±30
I, мА	3.3	15.7	20.0
$N_e \times 10^{-10}$	2.5	12	15
N_b	1	1	1
Q_x/Q_y	8.54/7.58	11.54/7.58	11.54/7.58
C_x/C_y	-14/-20	-27/-43	-27/-43
$\alpha \times 10^2$	1.7	1.6	1.6
ε_x, нм	25.7	27.5	27.5
κ	0.1	0.05	0.05
$\sigma_e \times 10^4$	3.0	4.3	4.3
σ_s, мм	27.8	33.1	33.1
$\beta_x^*/\beta_y^*/D^*$, см	65/6/80	15/1/0	15/1/0
ξ_x/ξ_y	0.026/0.053	0.003/0.045	0.004/0.057
$\tau_x/\tau_y/\tau_e$, с	0.14/0.14/0.07	0.11/0.11/0.06	0.11/0.11/0.06
L, $см^{-2}с^{-1} \times 10^{-30}$	1	29	46

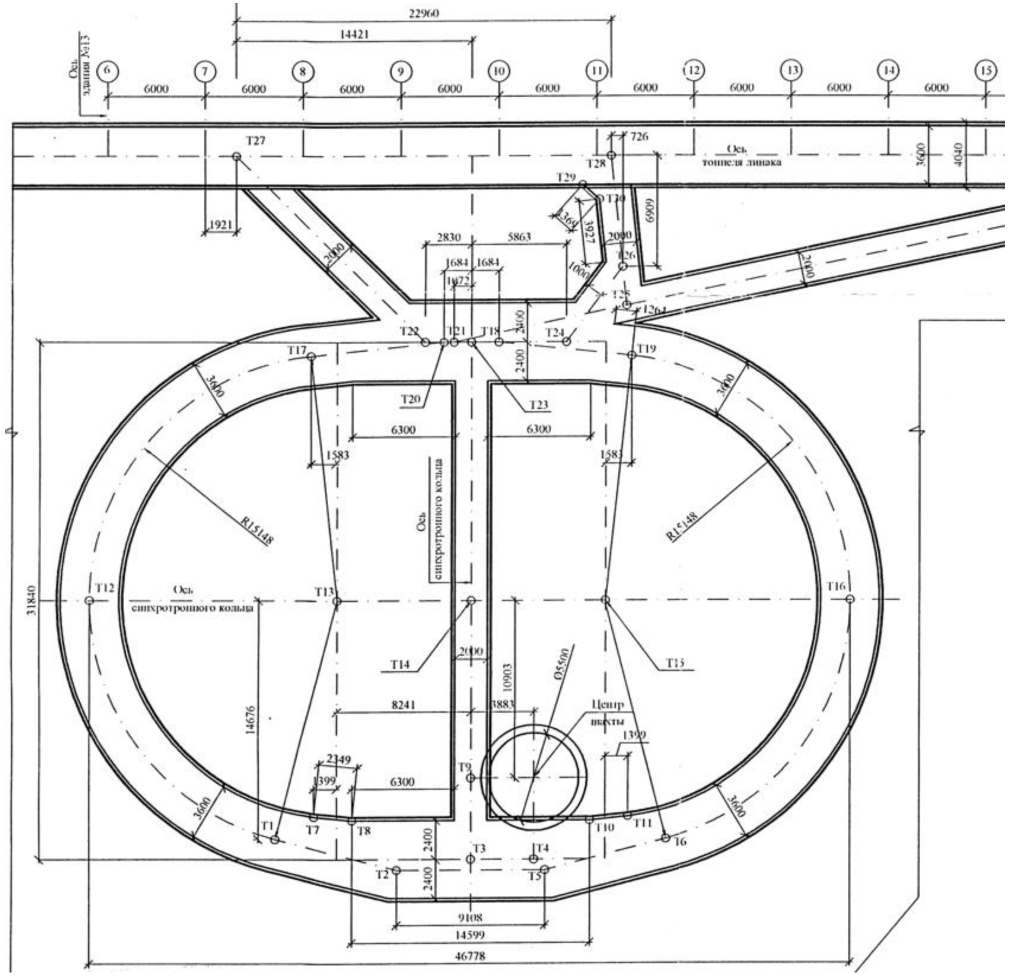
Booster synchrotron



	Injection	Extraction
Energy, MeV	510	2500
Circumference, m	132	
Damping time		
- vertical, ms	501	4.259
- horizontal, ms	523	4.449
- longitudinal, ms	245	2.085
Emittance, nm	$2.4 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
Energy spread	$1.67 \cdot 10^{-4}$	$8.2 \cdot 10^{-4}$
Energy loss/turn, keV	0.859	517

Booster synchrotron infrastructure





The tunnel for the booster synchrotron is ready. To save time and money, we plan to apply as much as possible technologies and systems from the SKIF light source booster synchrotron.

New CW collider at BINP. Main problem

Piwinski expression for the Touschek lifetime

$$\frac{1}{T_t} = \frac{r_e^2 c N_e}{8\pi\gamma^3\sigma_s\varepsilon_x^{3/2}\kappa^{1/2}}\langle\frac{C(\epsilon_m)}{{\beta_y}^{1/2}\delta_m^2 B^{1/2}}\rangle_s \qquad B = 1 + \frac{\sigma_E^2}{\varepsilon_x}H(s)$$

δ_m is the energy aperture

Inserting a CW tune shift parameter (θ<<1)

$$\xi_y \approx \frac{r_e N_e}{2\pi\gamma}\sqrt{\frac{\beta_y^*}{\varepsilon_y}}\frac{1}{\sigma_s\theta},$$

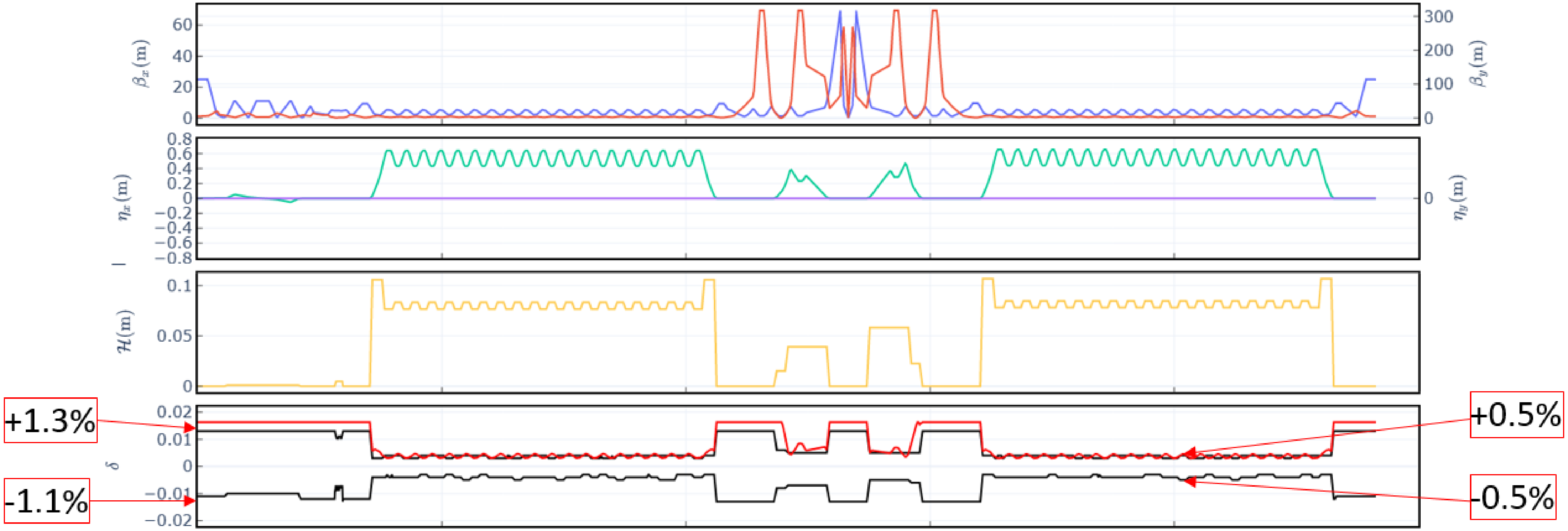
one can obtain

$$\frac{1}{T_t} = \frac{r_e c}{4\pi\gamma^2}\xi_y\frac{\theta}{\varepsilon_x\beta_y^*}\langle\frac{C(\epsilon_m)}{{\beta_y}^{1/2}\delta_m^2 B^{1/2}}\rangle_s.$$

Touschek lifetime reduces with the tune shift (luminosity) increase and is very sensitive to the beam energy and to the energy aperture (γ^2, δ_m^2). Also Touschek lifetime reduces with β_y^* decreasing.

Touschek lifetime for low energy CW collider

CW collider local momentum aperture



One should be careful estimating Touschek lifetime and use LMA.

CW collider at 0.5 GeV

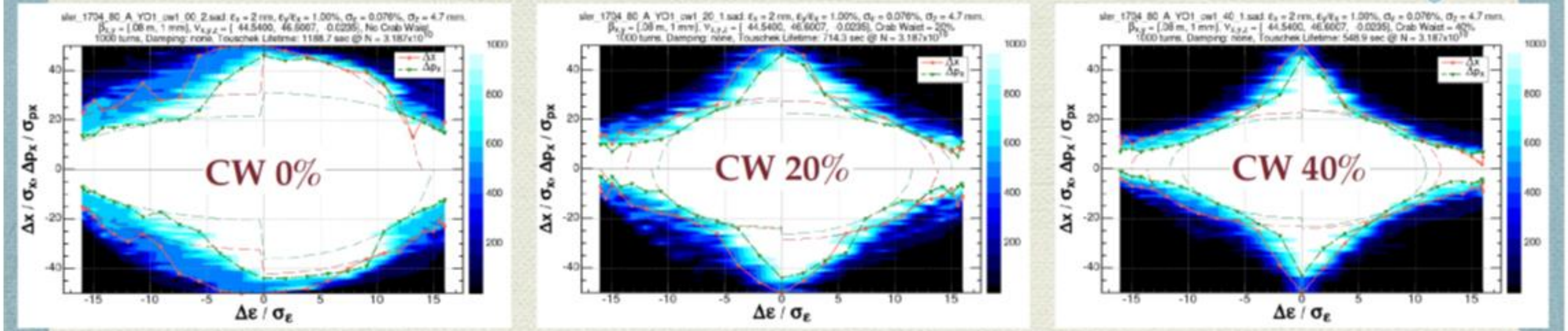
	MADX ($\delta_{RF} = 1.63\%$)	ELEGANT (LMA, $\delta_{RF} = 1.63\%$)
$\tau_{Touschek}$ (s)	9879	302

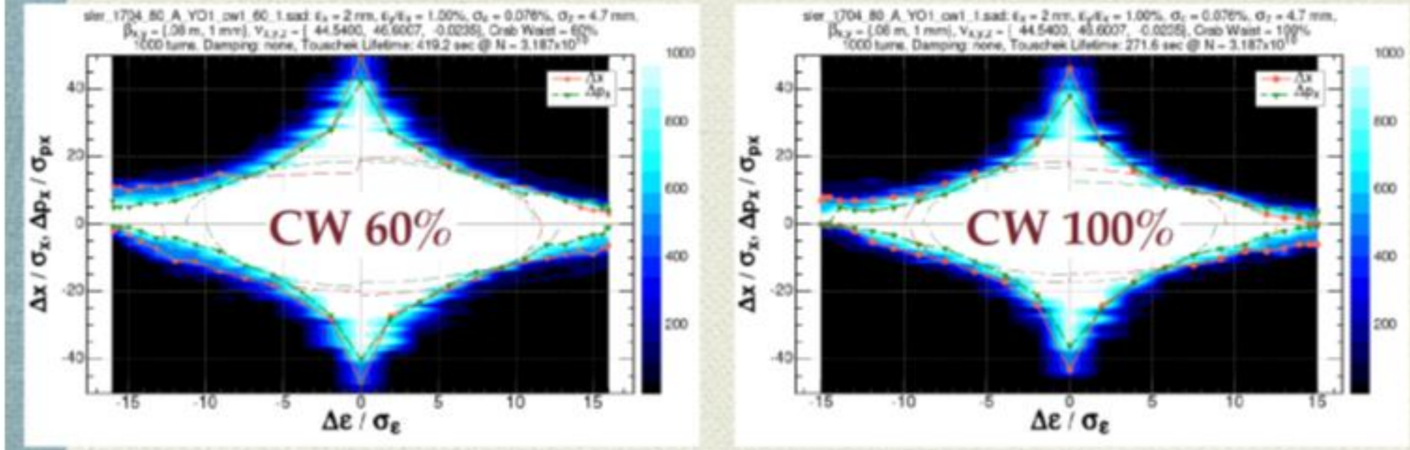
CW collider at 1.55 GeV

	MADX ($\delta_{RF} = 1.58\%$)	ELEGANT (LMA, $\delta_{RF} = 1.58\%$)
$\tau_{Touschek}$ (s)	9078	566

Katsunobu Oide, Super KEKB, 2020 simulation

Dynamic aperture for various CW ratios ($\beta_y^* = 1$ mm)





CW%	0	20	40	60	100
Touschek (s) for N = 3.2 x 10^{10}	1190	710	550	420	270

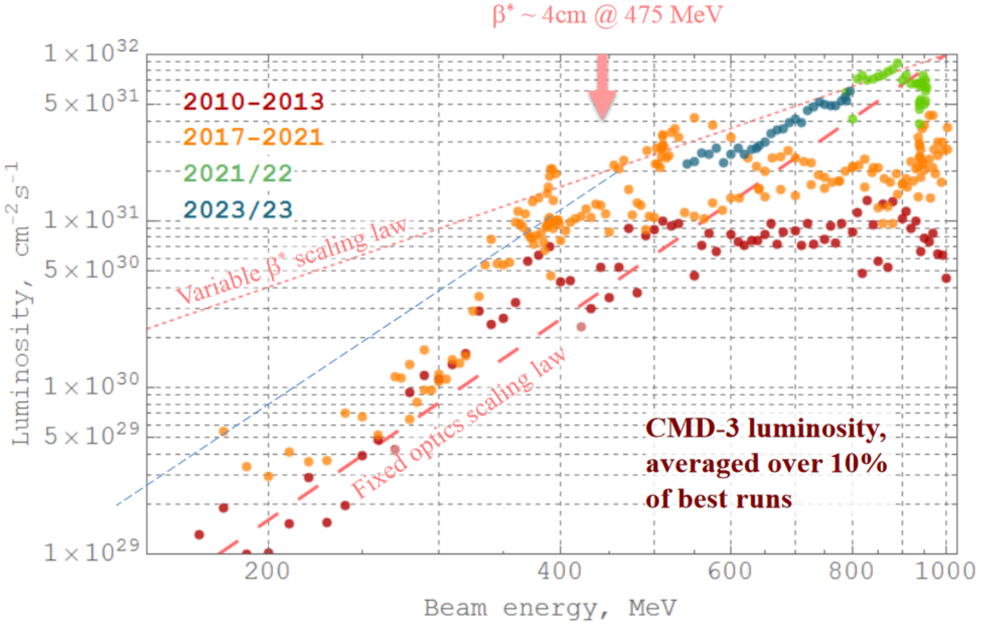
$15\sigma_\varepsilon = 1.14\%$!!!!
E=4 GeV

- chromaticities in α^*, β^* are corrected

Concept of new CW collider at BINP

- Crab Waist collision.
- Full beam energy interval from 0.5 GeV to 2 GeV. Luminosity optimization interval from 1 GeV to 1.55 GeV. (From VEPP-2000 to Super Charm Tau Factory).
- Apply **certainly achievable** beam parameters (emittance, current, lifetime, etc.) and see if the luminosity is interesting for physics program?
- Compact and cheap as it is possible.
- Use as much as possible existing BINP technologies and infrastructures (injection facility, tunnels, electrical and cooling water systems, etc.)

Luminosity references



Current absolute record peak luminosity: $L_{peak} = 9\times10^{31}$ $cm^{-2}s^{-1}$ @ 890 MeV

Best luminosity performances during SIDDHARTA and KLOE-2 experim

Parameter	SIDDHARTA	KLOE-2
Peak luminosity [$cm^{-2}s^{-1}$]	4.53×10^{32}	2.13×10^{32}
Electron beam current [A]	1.52	1.13
Positron beam current [A]	1.00	0.88
Number of bunches	105	105
Specific luminosity [$cm^{-2}s^{-1}mA^{-2}$/bunch]	3.13×10^{28}	2.25×10^{28}
Integrated luminosity [pb^{-1}/day]	14.98	14.03

DAΦNE 510 MeV: $2\cdot10^{32}$ $cm^{-2}c^{-1}$

VEPP-2000 1000 MeV: $5\cdot10^{31}$ $cm^{-2}c^{-1}$

BEPC II 1550 MeV: $3\cdot10^{32}$ $cm^{-2}c^{-1}$

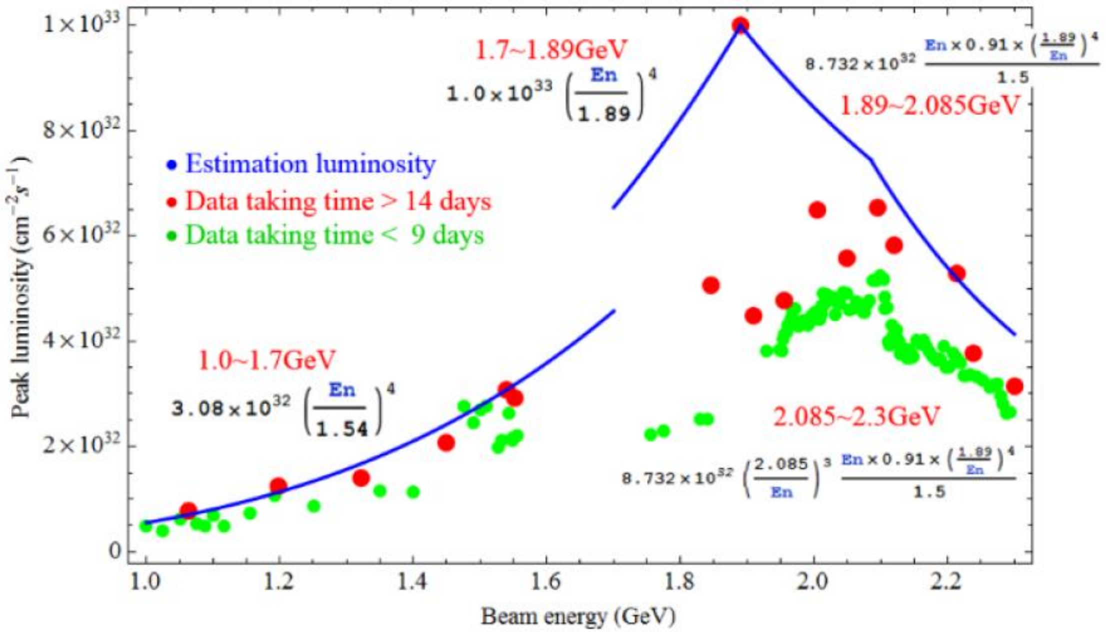
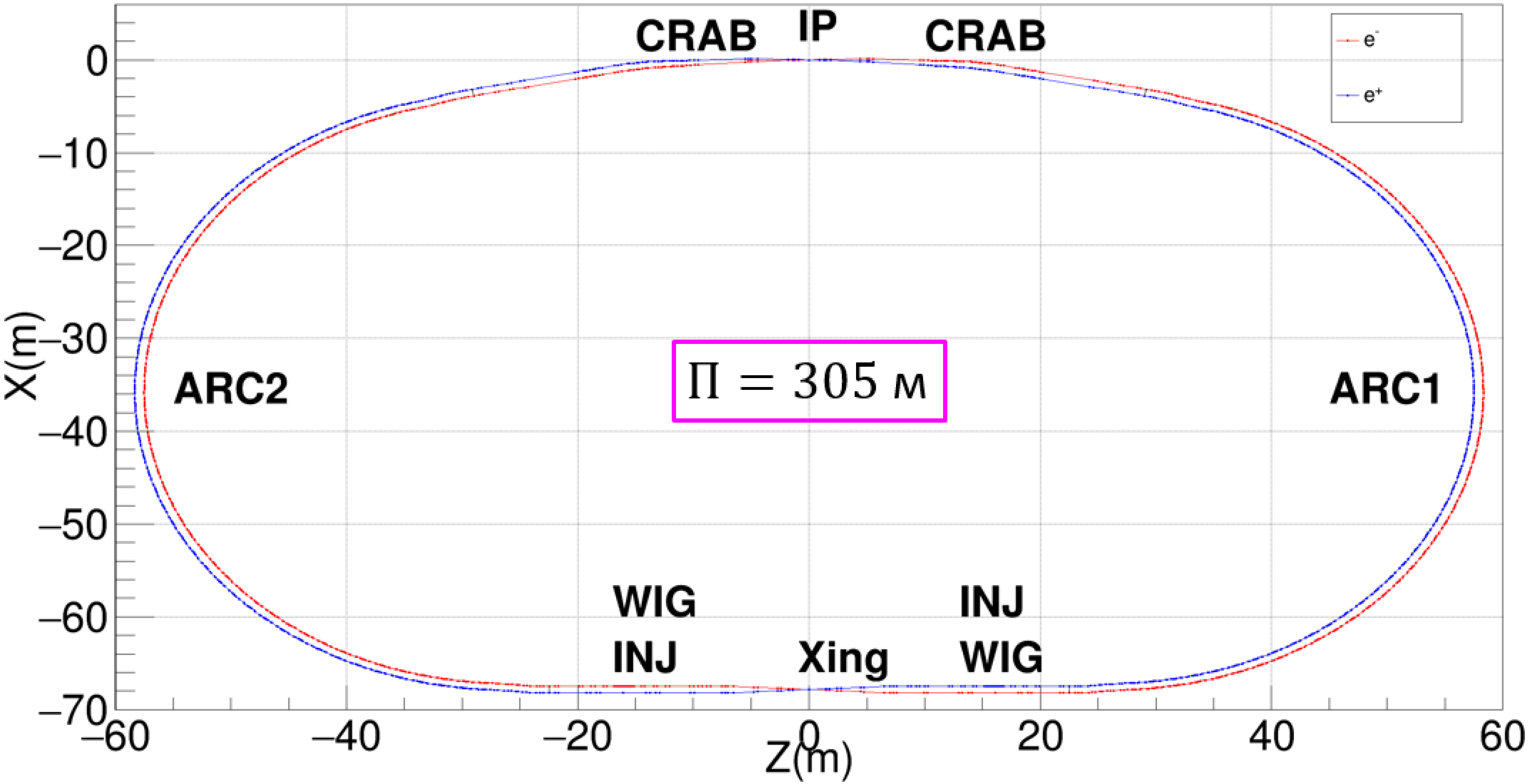


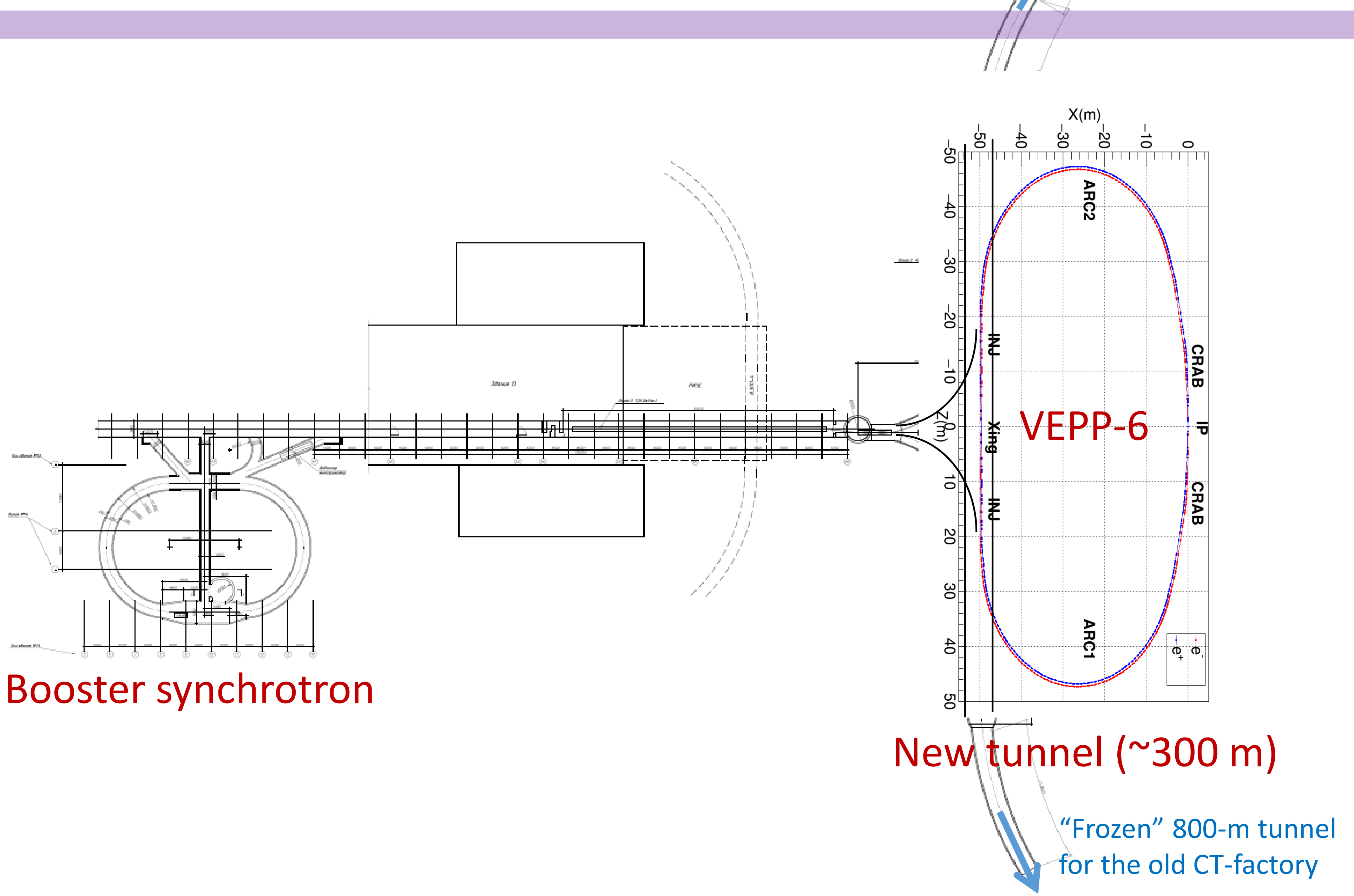
Figure 8: The peak luminosity from 1.0 GeV to 2.3 GeV. BEPCII is optimized at 1.89 GeV

VEPP-6 v.19

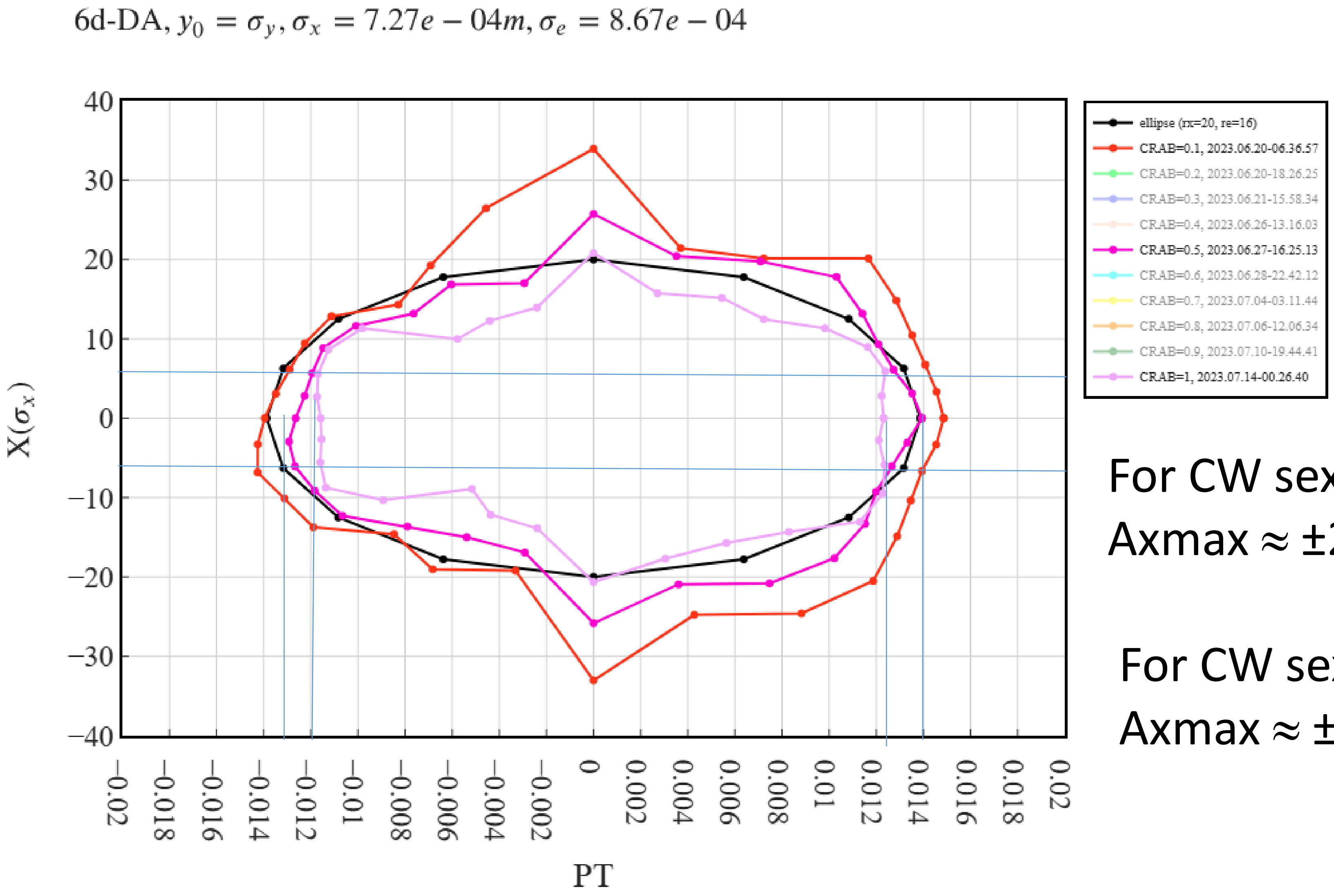

CRAB
IP
CRAB
e⁻
e⁺
ARC2
ARC1
П = 305 м
WIG
INJ
Xing
INJ
WIG
X(m)
Z(m)
0
−10
−20
−30
−40
−50
−60
−70
−60
−40
−20
0
20
40
60

VEPP-6 v.19 location

e+e- from
injector →



VEPP-6 v.19 energy aperture



For CW sextupoles = 1

Axmax ≈ $\pm 20\sigma_x$ $\delta_m \approx \pm 1.2\%$

For CW sextupoles = 0.5

Axmax ≈ $\pm 25\sigma_x$ $\delta_m \approx \pm 1.3\%$

VEPP-6 v.19 parameters

E(MeV)	500	1000	1550	2000
Π(m)	**305.27**			
F_{RF}(MHz)	359.6			
2θ(mrad)	60			
β_x^*/β_y^* (mm)	100/3			
I(A)	0.3	0.3	1.5	1.5
$N_{e/bunch} \times 10^{-10}$	0.6	0.6	3.8	7
N_b / q	320 / 356	320 / 356	250 / 356	136 /356
U_0(keV) / V_{RF}(kV)	6.6 / 540	35 / 1125	122 / 1850	275 / 2550
ν_s	0.022	0.022	0.023	0.024
δ_{RF}(%)	1.56	1.56	1.56	1.56
$\sigma_e \times 10^3$ (SR/IBS+WG)	0.15 / 0.7	0.3 / 0.8	0.5/0.8	0.59 / 0.87
σ_s(mm) (SR/IBS+WG)	3 / 13	5 / 13	8/14	9 / 14
ε_x(nm) (SR/IBS+WG)	2 / 19	8 / **7**	19 / **11**	31 / **20**
$\varepsilon_y/\varepsilon_x$	**0.02**	0.02	0.02	0.02
$L_{HG} \times 10^{-34}(cm^{-2}s^{-1})$	**0.02**	**0.035**	0.8	1
ξ_x/ξ_y	0.003 / 0.02	0.001 / 0.016	0.003/0.05	0.005 / 0.05
$\tau_{Touschek}$ (s)	339	**806**	**711**	**1510**
$2\ \dot{N} \times 10^{-10}$	1.1	0.5	2.7	1.3
$N_{cells}(\mu)$	$24(\pi/3)$			

$E_{beam} = 0.5$ GeV:
$\mathcal{L} \approx (0.5 - 1) \times$ DAΦNE

$E_{beam} = 1$ GeV:
$\mathcal{L} \approx 7 \times$ VEPP2000

$E_{beam} = 1.55$ GeV:
$\mathcal{L} \approx 30 \times$ BEPCII

$E_{beam} = 2$ GeV:
$\mathcal{L} \approx 10 \times$ BEPCII

Conclusion

Super Charm Tau Factory is large, expensive and risky project (the same with Super Tau Charm Factory ☺). To reduce risk we are going to start a preparative step-by-step program aiming to develop all critical technologies needed to realize a low energy CW collider with unprecedented parameters.

To support our new program, we need an international collaboration and invite foreign laboratories, which are interested in developing the CW collision technologies and making physics at such exciting facilities. We believe that such collaboration would be mutually beneficial for all participants.