1-Ring / 2-Ring Issues

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History

表 1: 世界の主な衝突型加速器

加速器	所在地	粒子	型[a]	ビームエネルギー (GeV)	ルミノシティ ($10^{30}cm^{-2}s^{-1}$)	年 (衝突実験)
AdA	Frascati (伊)	e^+ / e^-	S	0.25	$\sim 10^{-5}$	1962
VEP-I	Novosibirsk (露)	e^- / e^-	D	0.13	$\sim$ 0.001	1963–1965
CBX	SLAC (米)	e^- / e^-	D	0.5		1963–1968
ACO	Orsay (仏)	e^+ / e^-	S	0.5	0.1	1966
Adone	Frascati (伊)	e^+ / e^-	S	1.5	0.6	1969–1993
ISR	CERN (スイス)	p / p	D	3.2	130	1971–1983
SPEAR	SLAC (米)	e^+ / e^-	S	4	12	1972–1990
VEPP-2/2M	Novosibirsk (露)	e^+ / e^-	S	0.7	13	1974–
DORIS	DESY (独)	e^+ / e^-	D	5.6	33	1974–1993
DCI	Orsay (仏)	e^- / e^-	D	1.8	2	1976–2003
PETRA	DESY (独)	e^+ / e^-	S	19	30	1978–1986
VEPP-4M	Novosibirsk (露)	e^+ / e^-	S	7	50	1979–
CESR	Cornell (米)	e^+ / e^-	S	6	1,300	1979–2002
PEP	SLAC (米)	e^+ / e^-	S	15	60	1980–1990
$Sp\bar{p}S$	CERN (スイス)	p / $\bar{p}$	S	315	6	1981–1990
TRISTAN	KEK (日)	e^+ / e^-	S	32	37	1986–1994
Tevatron	Fermilab (米)	p / $\bar{p}$	S	980	400	1987–2011
BEPC	IHEP (中)	e^+ / e^-	S	2.2	13	1989–2005
LEP	CERN (スイス)	e^+ / e^-	S	46	24	1989–1994
SLC	SLAC (米)	e^+ / e^-	L	46	3	1989–1998
HERA	DESY (独)	$e^\pm$ / p	D	30 / 920	75	1992–2007
DAΦNE	Frascati (伊)	e^+ / e^-	D	0.7	440	1997–
LEP2	CERN (スイス)	e^+ / e^-	S	105	100	1995–2000
PEP-II	SLAC (米)	e^+ / e^-	D	3.1 / 9	12,000	1999–2008
KEKB	KEK (日)	e^+ / e^-	D	3.5 / 8	21,100	1999–2010
RHIC	BNL (米)	重イオン	D	100/n	0.003[b]	2000–
CESR-c	Cornell (米)	e^+ / e^-	S	1.9	60	2002–2008
VEPP-2000	Novosibirsk (露)	e^+ / e^-	S	0.5	120	2006–
BEPCII	IHEP (中)	e^+ / e^-	D	2.1	710	2007–
LHC	CERN (スイス)	p / p	D	4,000	7,700	2008–

[a] S: 単リング, D: 複リング, L: 線形

[b] 金・金衝突時

(PEP-II, KEKB)/CESR
≈ (9, 16)

BEPC-II/BEPC
≈ 55

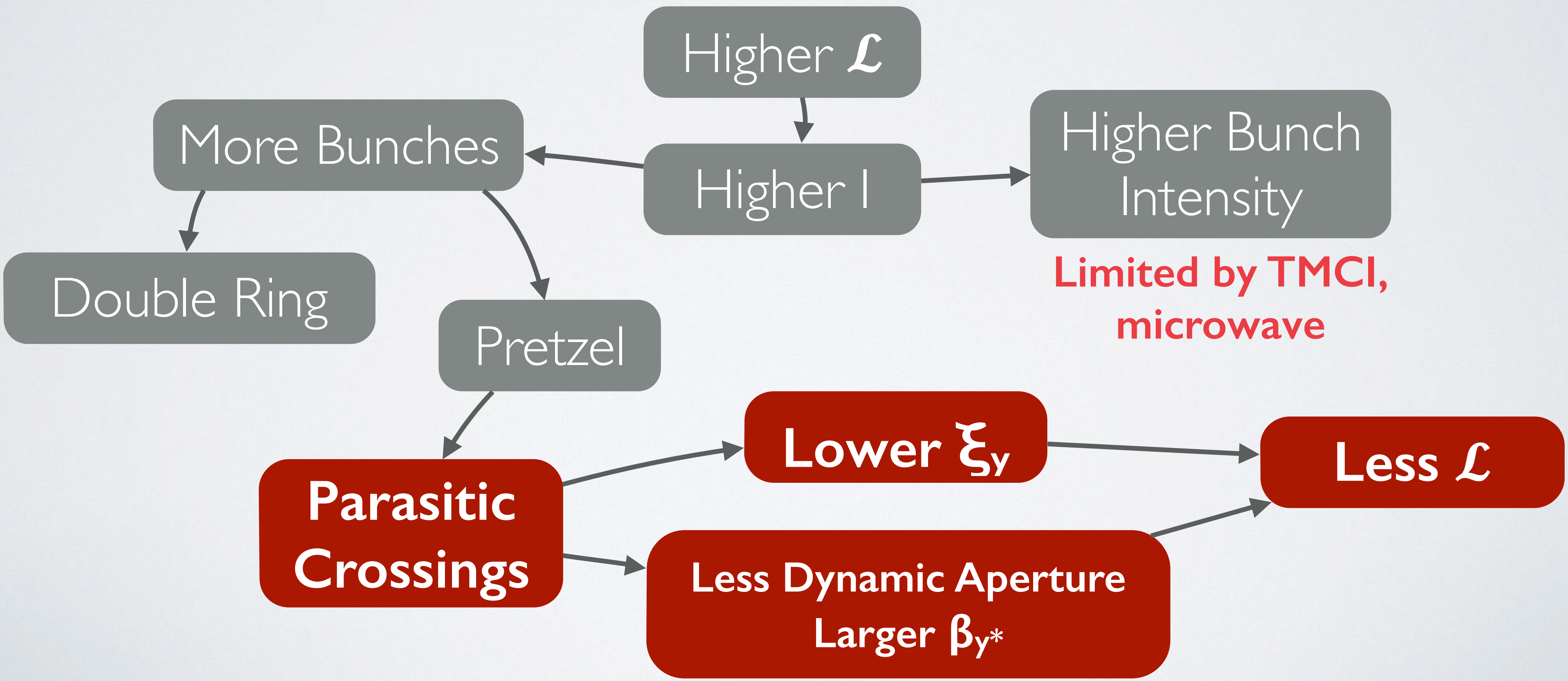
[LHC/Tevatron
≈ 19]

Luminosity formula

$$\mathcal{L} \approx \frac{1}{2er_e}\left(\frac{\gamma I \xi_y}{\beta_y^*}\right)_{\pm}\left(\frac{R_{\mathcal{L}}}{R_y}\right)$$

(flat beam)

- There is no explicit dependence of luminosity on the number of bunches or rings in the above, but…



Beam-beam parameter by parasitic crossings:

$$\xi_{x,y}^{\mathrm{PC}} = \mp \sum \frac{r_e N}{2\pi\gamma R^2}\beta \approx \mp \frac{r_e N N_b}{2\pi\gamma n_{\mathrm{sep}}^2 \varepsilon_x} = \mp\xi^{\mathrm{PC}}$$

by assuming all PCs are equivalent.

R, β : horizontal separation, β at PC

$$R = n_{\mathrm{sep}}\sqrt{\beta\varepsilon_x}$$

N : particles/bunch

N_b : bunches/ring

Then the luminosity is expressed as:

$$\mathcal{L} = \frac{\pi c}{C}\left(\frac{\gamma n_{\mathrm{sep}}}{r_e}\right)^2 \frac{\xi_y \xi^{\mathrm{PC}} \varepsilon_x}{\beta_y^*}$$

C : circumference

$$\mathcal{L} = \frac{\pi c}{C}\left(\frac{\gamma n_{\rm sep}}{r_e}\right)^2 \frac{\xi_y \xi^{\rm PC} \varepsilon_x}{\beta_y^*}$$

With the FCC-ee numbers at Zh:

$$\mathcal{L} = \frac{c\pi}{r_e^2}\left(\frac{100\ \mathrm{km}}{C}\right)\left(\frac{\gamma}{(120\ \mathrm{GeV})}\right)^2\left(\frac{n_{\rm sep}}{5}\right)^2\left(\frac{\xi_y}{0.1}\right)\left(\frac{\xi^{\rm PC}}{0.1}\right)\left(\frac{\varepsilon_x}{1\ \mathrm{nm}}\right)\left(\frac{1\ \mathrm{mm}}{\beta_y^*}\right)$$
$$= 1.6 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

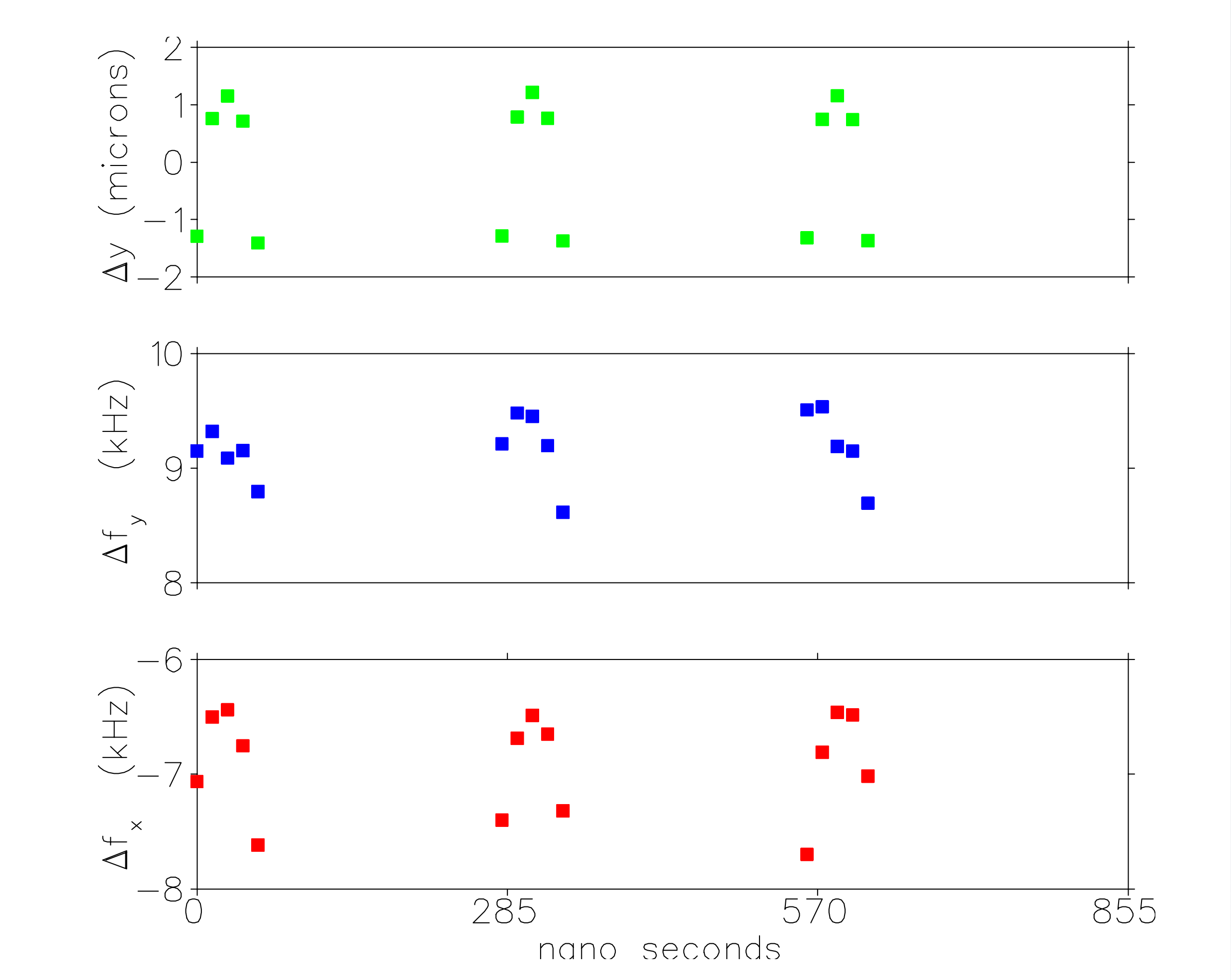
FCC-ee: 5e34/IP

And at Z:

$$\mathcal{L} = \frac{c\pi}{r_e^2}\left(\frac{100\ \mathrm{km}}{C}\right)\left(\frac{\gamma}{(46\ \mathrm{GeV})}\right)^2\left(\frac{n_{\rm sep}}{5}\right)^2\left(\frac{\xi_y}{0.1}\right)\left(\frac{\xi^{\rm PC}}{0.1}\right)\left(\frac{\varepsilon_x}{29\ \mathrm{nm}}\right)\left(\frac{3\ \mathrm{mm}}{\beta_y^*}\right)$$
$$= 2.3 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

FCC-ee: 27e34/IP

ξ^{PC} ~ 0.3 was achieved at CESR:



M. Palmer et al, Snowmass 2001

Figure 1: Calculated tune shifts in one beam due to the LRBBI with the opposing beam are shown in the bottom two plots. There are 9, 5-bunch trains with 7.5 mA/bunch in each beam and 14ns bunch spacing. The revolution frequency is f_{rev} = 390.1kHz. The difference in the vertical orbits at the IP for the two beams is shown in the top plot.

More possible issues with pretzel:

Orbit stability:

- The closed orbit is distorted by the parasitic crossings, and the magnitude depends on the bunch current.
- Even with a top-up operation, each bunch current varies due to the short lifetime.
- The disturbed orbit will be different bunch by bunch, so as the optics of each bunch.
- With the FCC-ee Zh parameter:

$$\frac{\langle \Delta x^2 \rangle}{\beta \varepsilon_x} \sim \frac{4\pi r_e}{\gamma \varepsilon_x} N \xi^{\mathrm{PC}} \left(\frac{\Delta N}{N} \right)^2$$

$$\approx (12\%)^2 \qquad \text{with } N = 10^{11},\ \Delta N/N = 10\%,\ \xi^{\mathrm{PC}} = 0.1.$$

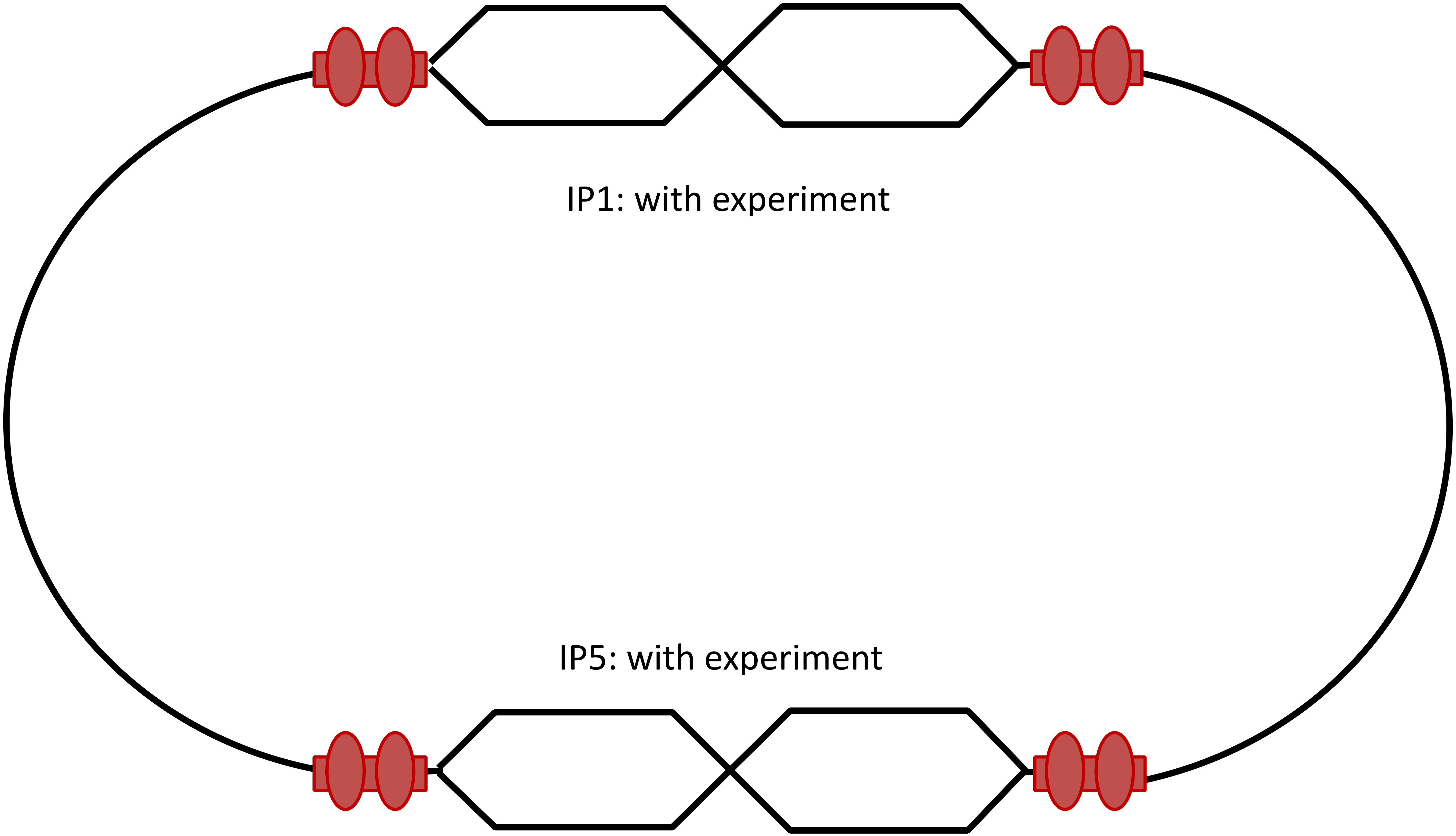
can be significant for $\xi^{\mathrm{PC}} \gg 0.1$

More possible issues with pretzel:

Optics deformation:

- Optics is deformed by the pretzel, due to orbit shift in sextupoles.
- If we switch the polarity of pretzel across the IP, it may be possible to correct the deformation for the both beams simultaneously, by confining the deformation within an arc.
- The local CCS is common, it does not leak the deformation outside due to *-I*, except for the dispersions.
- If arc sextupoles are all paired with *-I*, only dispersion leak matters.
- The energy sawtooth will complicate the issue, but its magnitude is less than the pretzel anyway.
- Bunch-by-bunch deformation needs attention.
- "Wire compensation of PC" can be conceivable, but it does not solve this issue nor the orbit fluctuation.

Bunch train scheme for the CEPC



15/2/2015

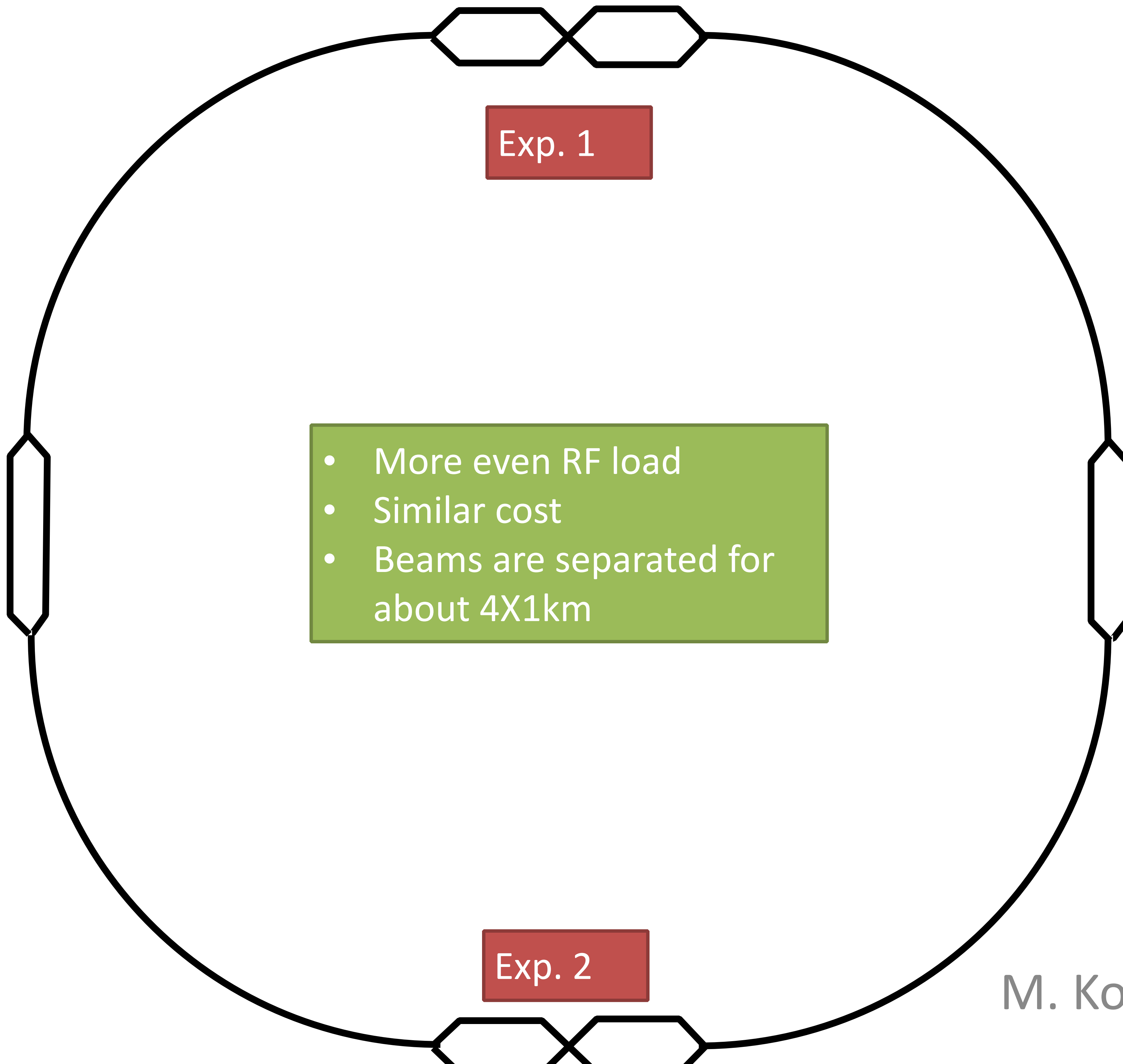
Mike Koratzinos

The scheme

- One beam pipe in the arcs
- Electrostatic separators in two straight sections around the two experiments. Magnetic elements take over when separation is sufficient.
- Slightly longer straight section than the rest of the straight sections: 2km compared to ~800m
- RF still in single pipe
- Freedom to use interaction region scheme: crab waist, small crossing angle, etc.
- Avoids Pretzel scheme altogether
- RF loading is not uniform (4% full ring, 96% empty)
- Extra cost: 4kms in 50kms with double beam pipe

M. Koratzinos

If RF load problems, next suggestion with 4 separation points



M. Koratzinos

	Double Ring	Single Ring Pretzel	Bunch Train Separation
Common Arc		😄	😄
Parasitic crossing		😓	
Orbit stability		😓	
Common Local CCS		😒	
Common RF		😄	😄
RF uneven loading			😒
Electrostatic Separators		😒	😒
Optics deformation		😓	
E-cloud / ions	😒	😒	only in separated sections 😒
Energy sawtooth	solvable 😄	😒	😒

Discussions

- A single-ring scheme with pretzel is cheaper in construction, but the overall cost to achieve the goal of integrated luminosity is not necessarily cheaper.

- The complexity in the design and operation may severely limit the performance of the pretzel scheme.

- The bunch-train separation scheme can be a good compromise, but may not have an ultimate performance esp. for Z/WW modes.