Thoughts on crab cavity noise, Fritz Caspers, 26.02.2008

Bandwidth of cavity structure with loaded Q is nearly always MUCH higher than generator bandwidth. Typically 3 db generator bandwidth ~1 Hz and -60 db points (phase noise down to -60 dBc =-60 db below carrier) are ~10 to 100 Hz away. Unless mechanical vibration (Lorentz forces) **phase noise & jitter properties entirely determined by generator.**

"Phase noise" of the beam itself (synchrotron spectrum) is ALWAYS many orders of magnitude bigger than the phase noise of the generator.

Phase noise can easily be converted into jitter (one can find nice interactive applets for this on the web: http://www.jittertime.com/resources/pncalc.shtml)

Turn to turn jitter makes a huge difference wrt global jitter where you assume a infinitely stable reference source AND an infinite integration time. In the frame of turn to turn jitter the synchrotron motion is still visible but due to low synchrotron frequency it converts into very small time jitter numbers (short integration time)

There **is not only time jitter but also amplitude jitter** (AM noise as compared to phase noise) and AM-PM as well as PM- AM conversion.

As well known from BTF measurements, **excitation of beam with frequencies inside the particle distributions can lead to blowup**. But **we can also excite the beam in the imaginary part of the BTF** (just at the edge of the particle distribution) **and virtually have no blowup**.

Certain **analogies to stochastic cooling systems** → consider experimental verification with existing stoch. cooling systems . In particular to check the claimed sensitivity to very small jitter effect

If the crab cavity concept (with kick and antikick) is really that delicate wrt timing drift and jitter(a few femto seconds) (how about amplitude noise?) then it is from my point of view not robust enough to be used in this way.

But I have doubts that this is true … thus **we need practical experiment to check the validity** of this ..apply your formulae to londitudinal stochastic cooling(simple filter method) and make some predictions….there **we do have practical experience on hadron beams** ..or **we could do some MD in the AD in summer**.

If it turns out to be true (i.e. if timing is really that delicate) then we can probably work around it, **instead of operating the crab cavity exactly at the revolution harmonic we can use instead two sine waves (simultaneously) one slightly above and the other slightly below n x Frev**.(in the same cavity just taking advantage of the 3 db bandwith and the finite loaded Q of the cavity)

Then we can set those two frequencies precisely in the imag part of the longitudinal BFT and this way **get many orders of magnitude less blowup as compared to working with a single sinewave in the center**.

The price to be paid would be an **envelope having an amplitude modulation of Delta F**, (more precisely : amplitude modulation with suppressed carrier)i.e. a **time dependent crabbing** but in the worst case this cost a factor of 2 in crabbing efficiency and may have other benefits.

Last thought: crab cavity affects transverse phase space, but sits on longitudinal revolution harmonic ; therefore **it should not cause any transverse blowup**, since its frequency is far from the transverse Schottky bands, or only longitudinally via second order effects

CARE

HHH

LHC upgrade scenarios

emerging from CARE-HHH workshops

IR'07 Frascati

BEAM'07 CERN

LHC-LUMI-06 Valencia

LHC-LUMI-05 Arcidosso

HHH-2004 CERN

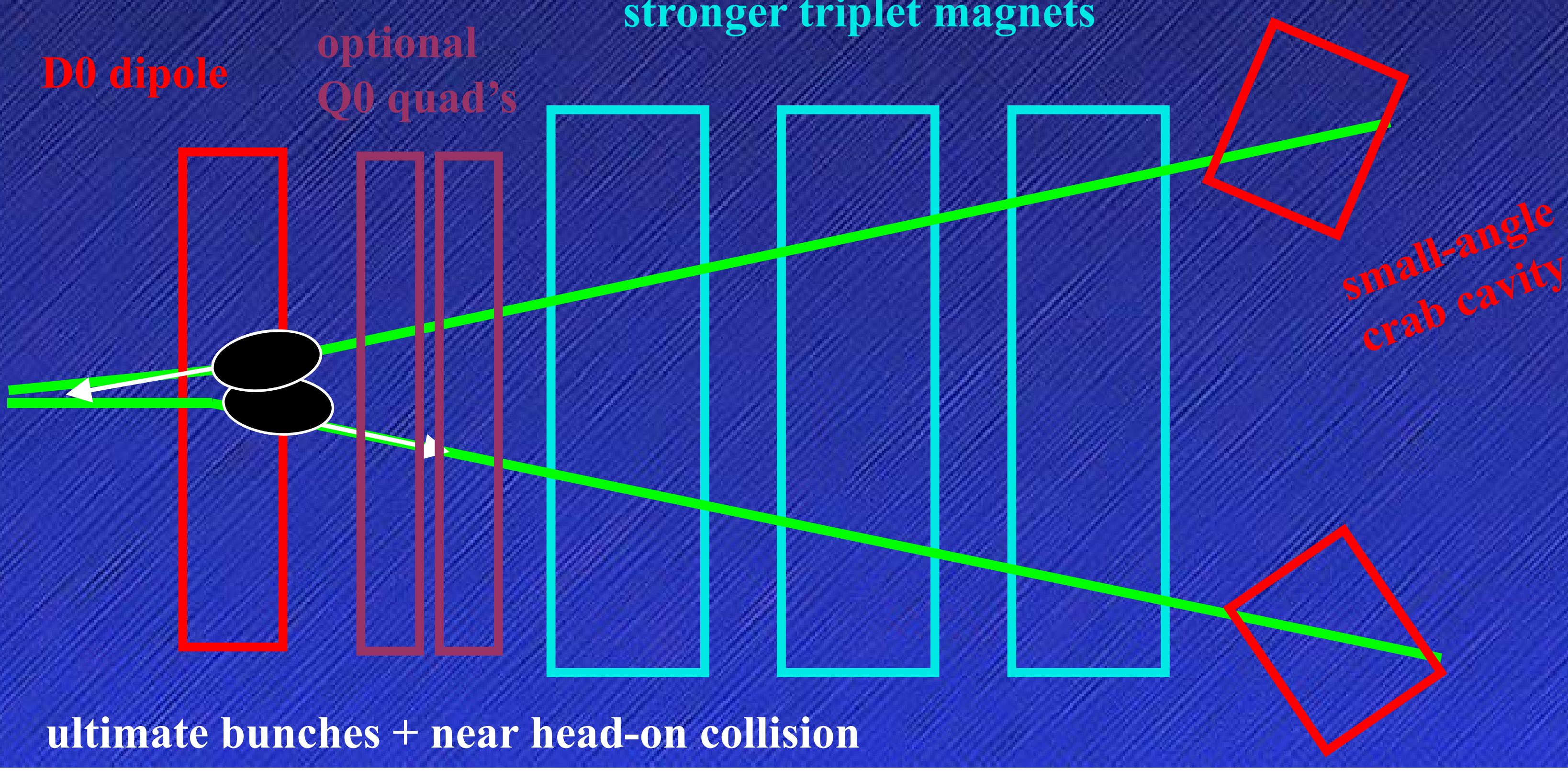
F. Ruggiero, W. Scandale, J.-P. Koutchouk, L. Evans, LARP, F. Zimmermann

LHC upgrade path 1: early separation (ES)

J.-P. Koutchouk

- ultimate LHC beam (1.7×10^{11} protons/bunch, 25 spacing)
- squeeze β^* to ~10 cm in ATLAS & CMS
- add early-separation dipoles in detectors starting at ~ 3 m from IP
- possibly also add quadrupole-doublet inside detector at ~13 m from IP
- and add crab cavities ($\phi_{Piwinski} \sim 0$)

→ hardware inside ATLAS & CMS detectors, first hadron crab cavities; off-δ β



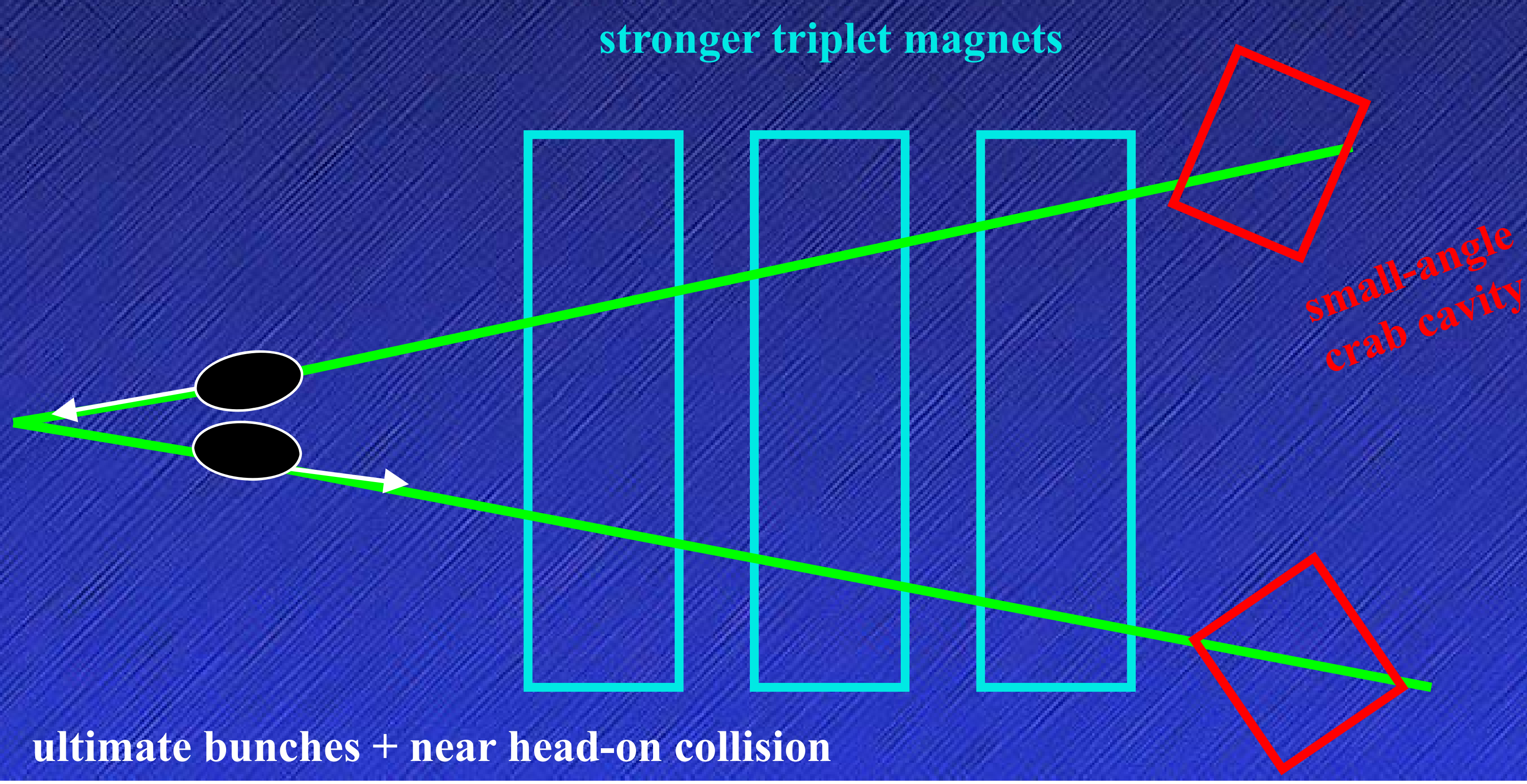
ultimate bunches + near head-on collision

LHC upgrade path 2: full crab crossing (FCC)

L. Evans,
W. Scandale,
F. Zimmermann

- <u>ultimate LHC beam</u> (1.7x10^{11} protons/bunch, 25 spacing)
- squeeze <u>β* to ~10 cm</u> in ATLAS & CMS
- and add <u>crab cavities</u> with 60% higher voltage than for ES ($\phi_{Piwinski}$~ 0)

→ first hadron crab cavities, off-δ β-beat

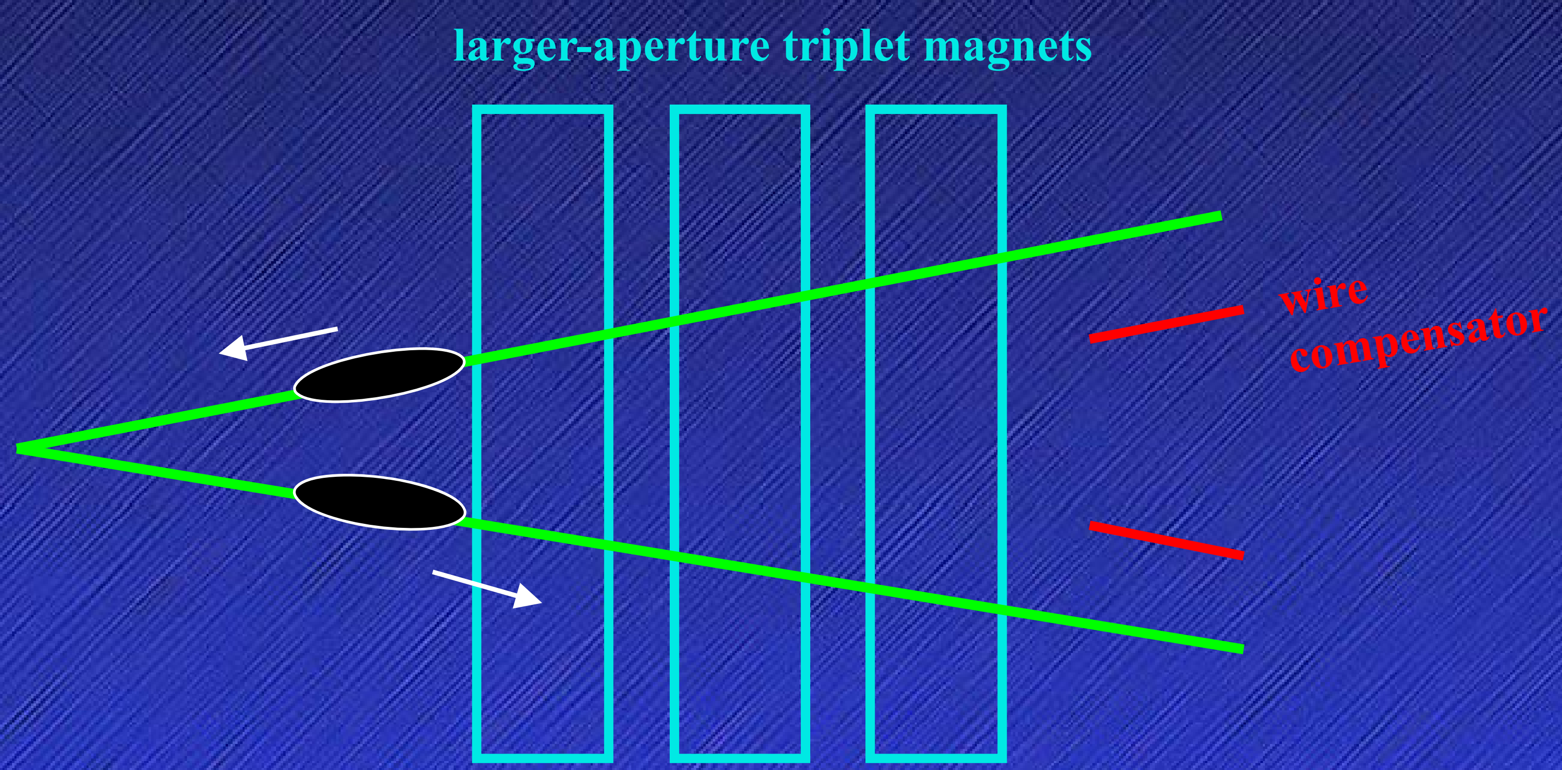


LHC upgrade path 3: large Piwinski angle (LPA)

- <u>double bunch spacing</u> to 50 ns, <u>longer & more intense bunches with $\phi_{Piwinski}$~ 2</u>
- <u>β*~25 cm,</u> do not add any elements inside detectors
- long-range beam-beam wire compensation

→ novel operating regime for hadron colliders, beam generation

F. Ruggiero,
W. Scandale.
F. Zimmermann



fewer, long & intense bunches + nonzero crossing angle + wire compensation

parameter	symbol	nominal	ultimate	Early Sep.	Full Crab Xing	L. Piw Angle
transverse emittance	ε [μm]	3.75	3.75	**3.75**	**3.75**	**3.75**
protons per bunch	N_b [10^{11}]	1.15	1.7	**1.7**	**1.7**	**4.9**
bunch spacing	Δt [ns]	25	25	**25**	**25**	**50**
beam current	I [A]	0.58	0.86	**0.86**	**0.86**	**1.22**
longitudinal profile		Gauss	Gauss	**Gauss**	**Gauss**	**Flat**
rms bunch length	σ_z [cm]	7.55	7.55	**7.55**	**7.55**	**11.8**
beta* at IP1&5	β^* [m]	0.55	0.5	**0.08**	**0.08**	**0.25**
full crossing angle	θ_c [μrad]	285	315	**0**	**0**	**381**
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	**0**	**0**	**2.0**
hourglass reduction		1	2.3	**0.86**	**0.86**	**0.99**
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	19	44	**15.5**	**15.5**	**10.7**
peak events per #ing		22	14	**294**	**294**	**403**
initial lumi lifetime	τ_L [h]	0.46	0.91	**2.2**	**2.2**	**4.5**
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	21.2	17.0	**2.4**	**2.4**	**2.5**
	$T_{run,opt}$ [h]	0.56	1.15	**6.6**	**6.6**	**9.5**
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	15.0	12.0	**3.6**	**3.6**	**3.5**
	$T_{run,opt}$ [h]	1.07 (0.44)	1.04 (0.59)	**4.6**	**4.6**	**6.7**
e-c heat SEY=1.4(1.3)	P [W/m]	0.17	0.25	**1.04 (0.59)**	**1.04 (0.59)**	**0.36 (0.1)**
SR heat load 4.6-20 K	P_{SR} [W/m]	0.15	0.33	**0.25**	**0.25**	**0.36**
image current heat	P_{IC} [W/m]	0.04 (0.38)	0.06 (0.56)	**0.33**	**0.33**	**0.78**
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	4.5	4.3	**0.06 (0.56)**	**0.06 (0.56)**	**0.09 (0.9)**
extent luminous region	σ_l [cm]			**3.7**	**3.7**	**5.3**
comment		nominal	ultimate	**D0 + crab**	**crab**	**wire comp.**

early separation (ES) — *full crab crossing (FCC)* — *large Piwinski angle (LPA)*

for operation at beam-beam limit with alternating planes of crossing <u>at two IPs</u>

↑ LPA
↑ ES/FCC

$$L = \frac{f_{rev}\gamma}{2r_p} n_b \frac{1}{\beta^*} N_b (\Delta Q_{bb}) F_{profile} F_{hg}$$

↓ LPA ↓↓ ES/FCC ↓ LPA ↑↑ LPA ↑ LPA ↓ ES/FCC

where (ΔQ_{bb}) = total beam-beam tune shift;

<u>peak luminosity</u> with respect to ultimate LHC (2.4 x nominal):

ES or FCC: x 6 x 1.3 x 0.86 = 6.7

LPA: ½ x2 x2.9x1.3 x1.4 = 5.3

what matters is the <u>integrated luminosity</u>

interrelations → *global effort*