HHH

Super-LHC

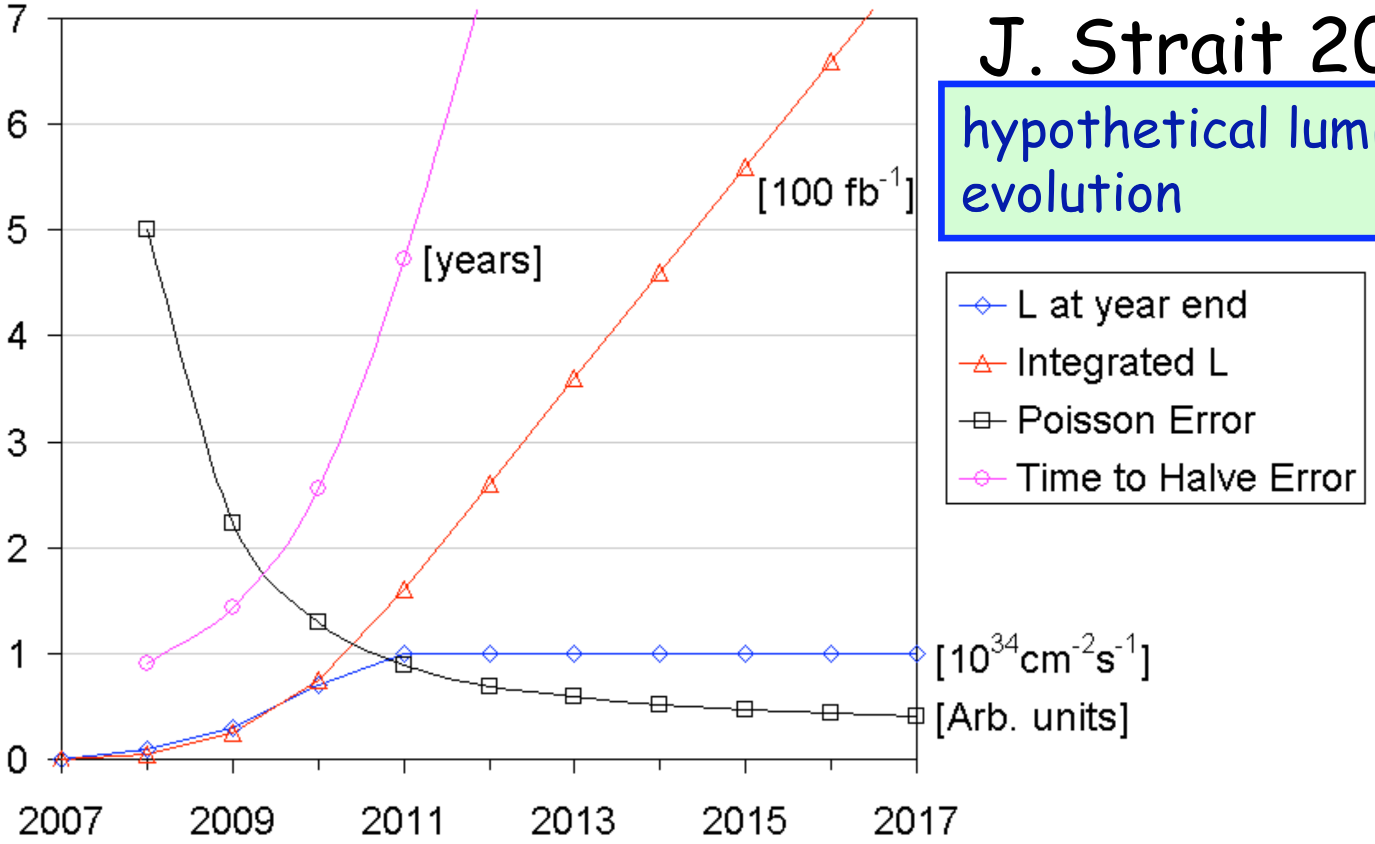
W. Scandale, F. Zimmermann

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)

outline

- ✓ motivation & staged approach
- ✓ 3 upgrade scenarios
- ✓ luminosity levelling
- ✓ injector upgrade & schedule
- ✓ detector upgrade
- ✓ crab cavities
- ✓ beam-beam & e-cloud mitigation
- ✓ complementary advanced schemes
- ✓ strategy for “phase-2”

Three Strong Reasons for LHC Upgrade



J. Strait 2003

hypothetical luminosity evolution

1) after few years, **statistical error** hardly decreases

2) **radiation damage** limit of **IR quadrupoles** (~700 fb^{-1}) reached by ~2016⇒ time for an upgrade!

3) ***extending physics potential***!

staged approach to LHC upgrade

"phase-1" 2013:

new triplets, D1, TAS, β^*=0.25 m in IP1 & 5,
reliable LHC operation at ~2-3x luminosity;
beam from new Linac4

"phase-2" 2017: ***+ injector upgrade***

target luminosity 10x nominal,
possibly Nb_3Sn triplet & β^*~0.15 m

complementary measures 2010-2017:

e.g. long-range beam-beam compensation,
crab cavities, new/upgraded injectors, advanced
collimators, coherent e- cooling??, e- lenses??

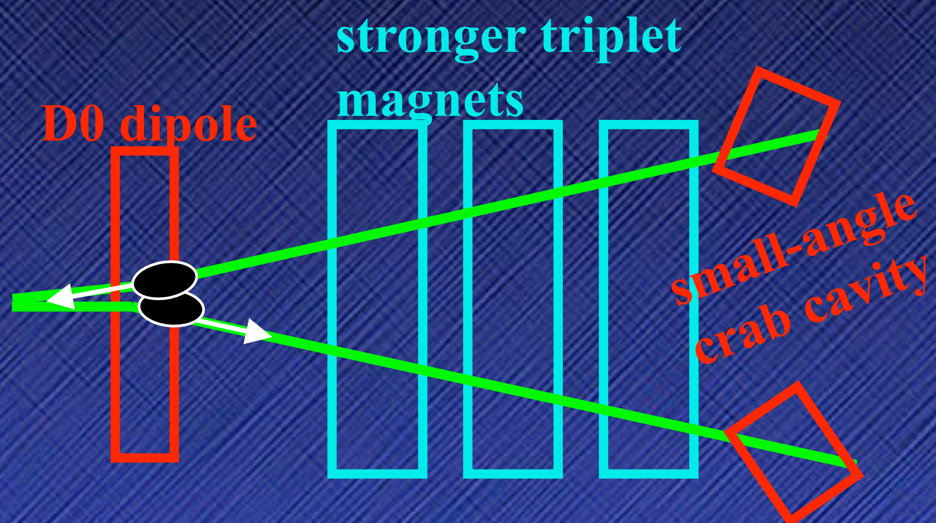
phase-2 might be just phase-1 plus complementary measures

longer term (2020?): energy upgrade, LHeC,…

LHC upgrade paths for IP1 & IP5

early separation (ES)

J.-P. Koutchouk

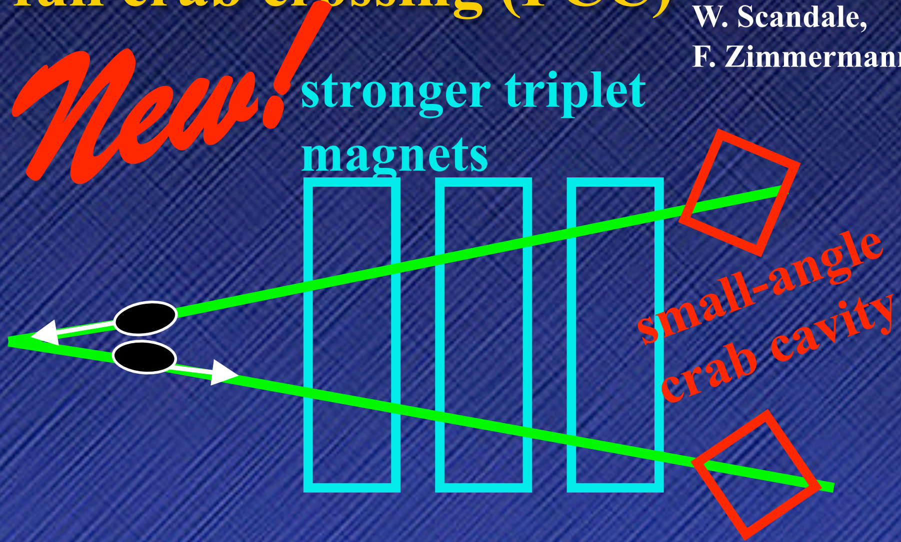


- ultimate beam (1.7x10[11] protons/bunch, 25 spacing), β* ~10 cm
- early-separation dipoles in side detectors , crab cavities

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

full crab crossing (FCC)

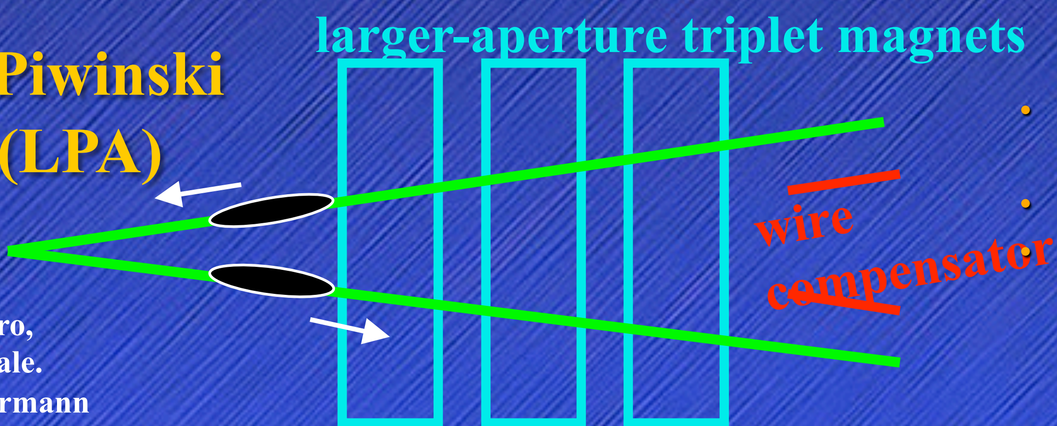
L. Evans,
W. Scandale,
F. Zimmermann



- ultimate LHC beam (1.7x10[11] protons/bunch, 25 spacing)
- β* ~10 cm
- crab cavities with 60% higher voltage

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

large Piwinski angle (LPA)



F. Ruggiero,
W. Scandale.
F. Zimmermann

- 50 ns spacing, longer & more intense bunches (5x10[11] protons/bunch)
- β*~25 cm, no elements inside detectors
- long-range beam-beam wire compensation

→ novel operating regime for hadron colliders, and for beam generation

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		1.0	1.0	**0.86**	**0.86**	**0.99**
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	**15.5**	**15.5**	**10.7**
peak events per #ing		19	44	**294**	**294**	**403**
initial lumi lifetime	τ_L [h]	22	14	**2.2**	**2.2**	**4.5**
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.46	0.91	**2.4**	**2.4**	**2.5**
	$T_{run,opt}$ [h]	21.2	17.0	**6.6**	**6.6**	**9.5**
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.56	1.15	**3.6**	**3.6**	**3.5**
	$T_{run,opt}$ [h]	15.0	12.0	**4.6**	**4.6**	**6.7**
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	**1.04 (0.59)**	**1.04 (0.59)**	**0.36 (0.1)**
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	**0.25**	**0.25**	**0.36**
image current heat	P_{IC} [W/m]	0.15	0.33	**0.33**	**0.33**	**0.78**
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	**0.06 (0.56)**	**0.06 (0.56)**	**0.09 (0.9)**
extent luminous region	σ_l [cm]	4.5	4.3	**3.7**	**3.7**	**5.3**
comment		nominal	ultimate	**D0 + crab**	**crab**	**wire comp.**

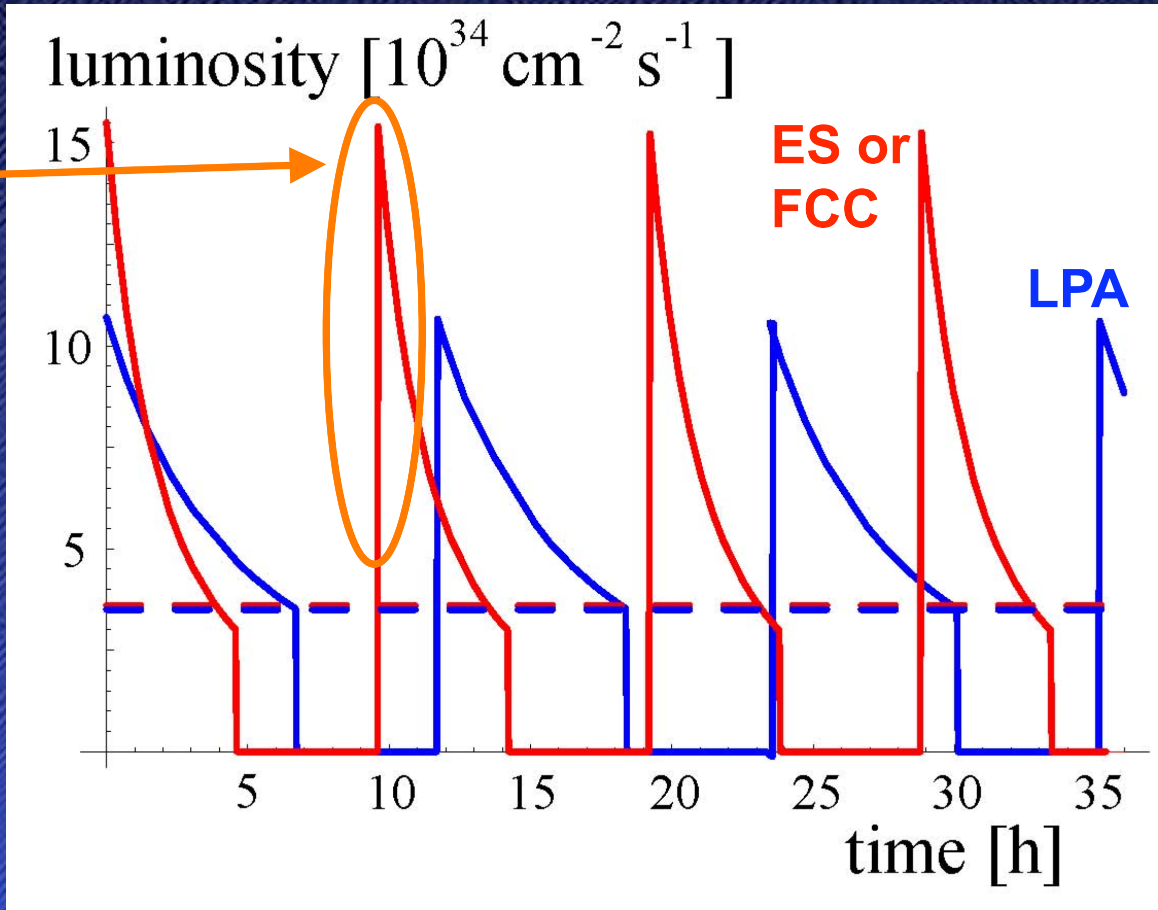
early separation (ES)

full crab crossing (FCC)

large Piwinski angle (LPA)

luminosity leveling

initial luminosity peak may not be useful for physics (set up & tuning?)



experiments prefer ~constant luminosity, less pile up at start of run, higher luminosity at end

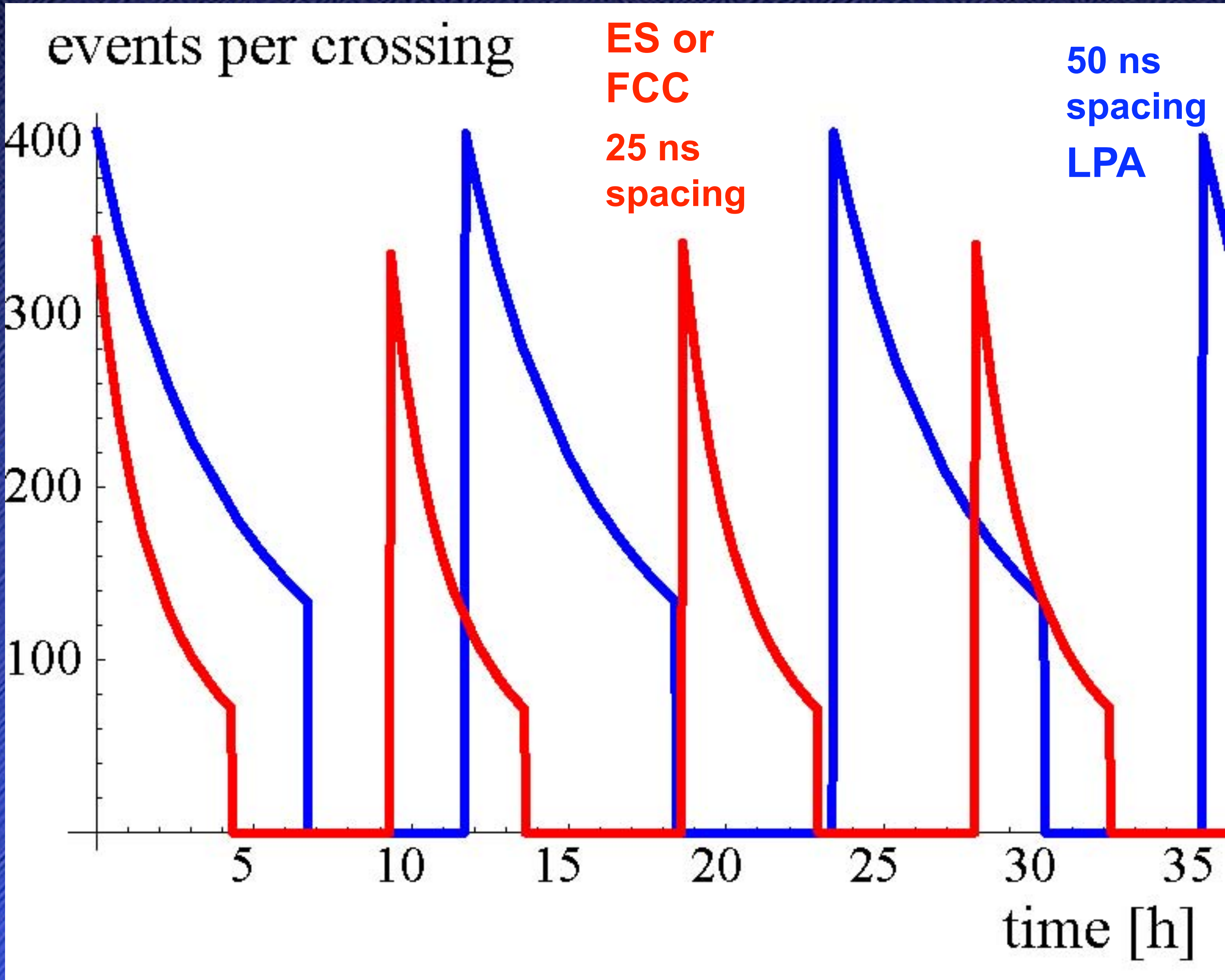
average luminosity

how can we achieve this?

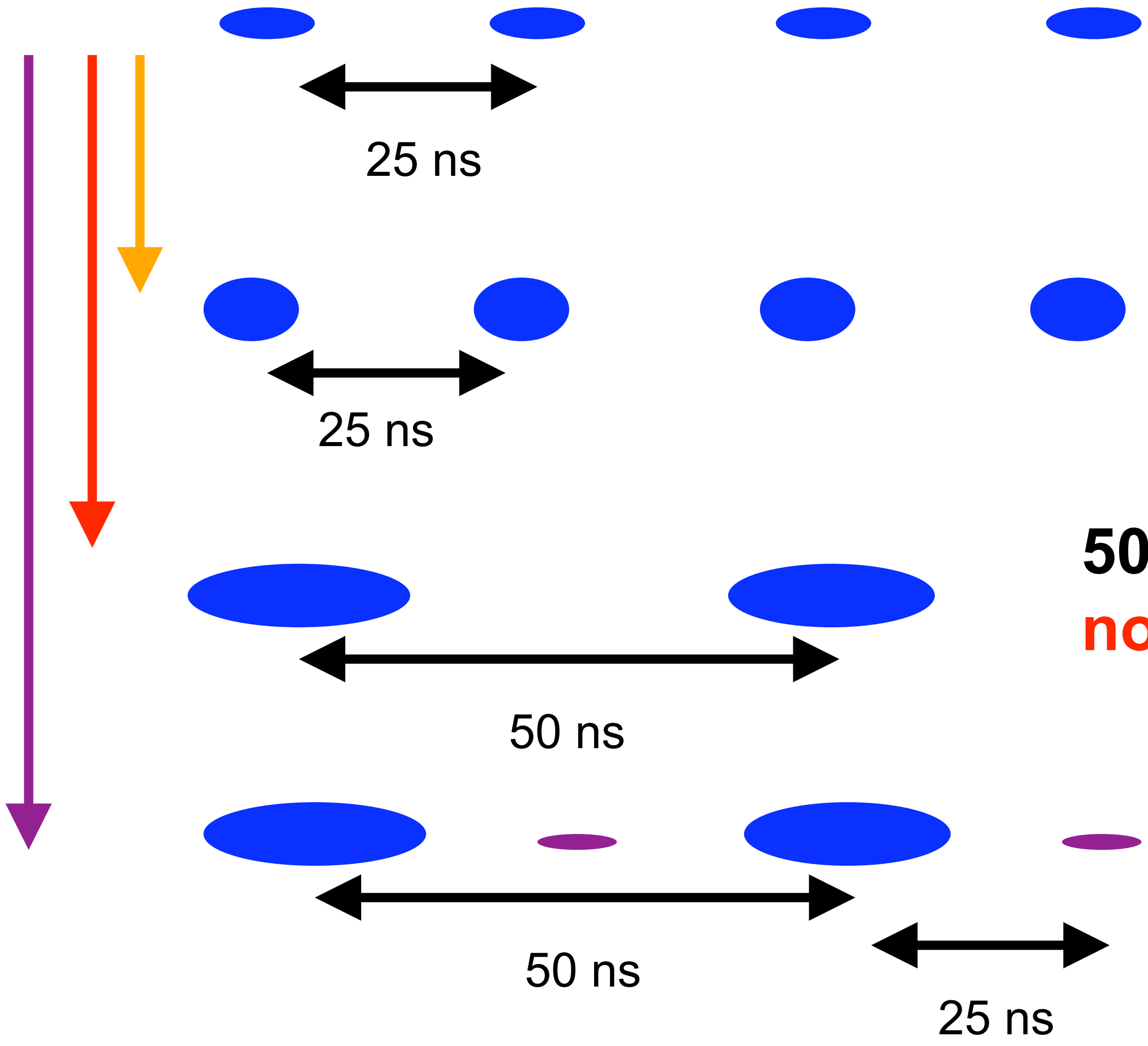
ES or FCC: dynamic β squeeze, or dynamic θ change (either IP angle bumps or varying crab voltage)

LPA: dynamic β squeeze, or dynamic change of bunch length

IP1& 5 event pile up for 25 & 50-ns spacing w/o leveling



upgrade bunch structures



nominal

ultimate
& 25-ns upgrade
(ES & FCC)

50-ns upgrade (LPA),
no collisions in LHCb!

50-ns upgrade
with 25-ns
collisions
in LHCb

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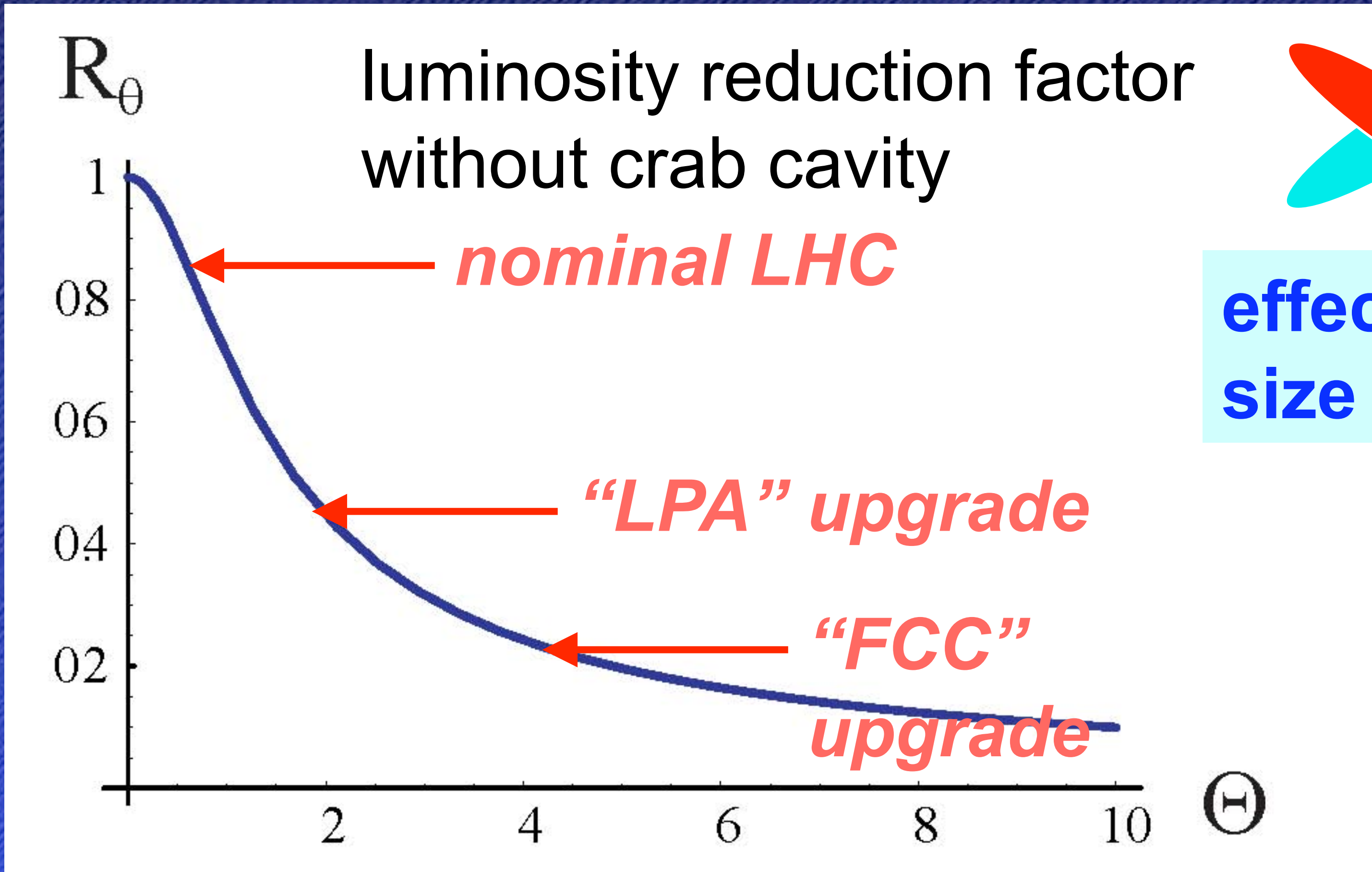
experimenters' choice (LHCC July 2008)

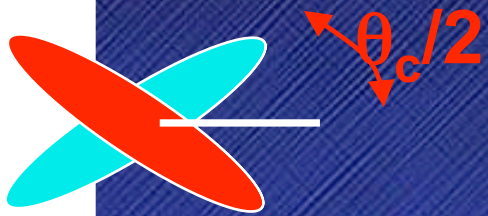
✓ no accelerator components inside detector
✓ lowest possible event pile up
✓ possibility of easy luminosity levelling

→ **full crab crossing upgrade** *New!*

crab cavity motivation →HHH→

$$R_\theta = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$ *"Piwinski angle"*





effective beam size $\sigma \rightarrow \sigma / R_\phi$

CARE-HHH
LHC Crab Cavity Validation
Mini-Workshop, 21 August 2008

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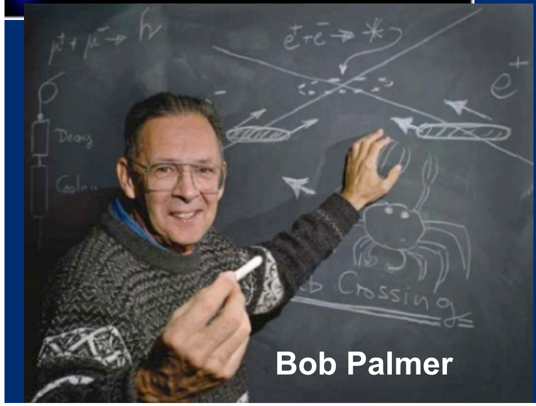
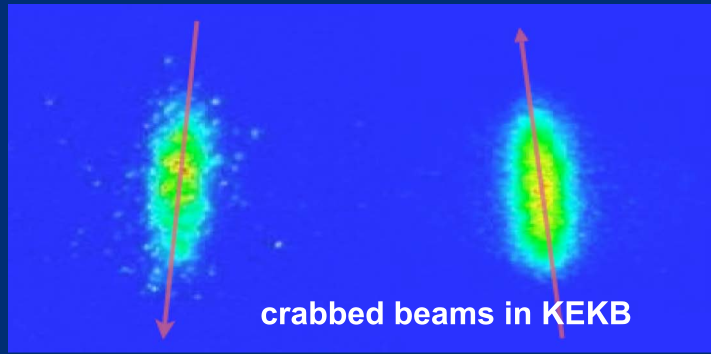
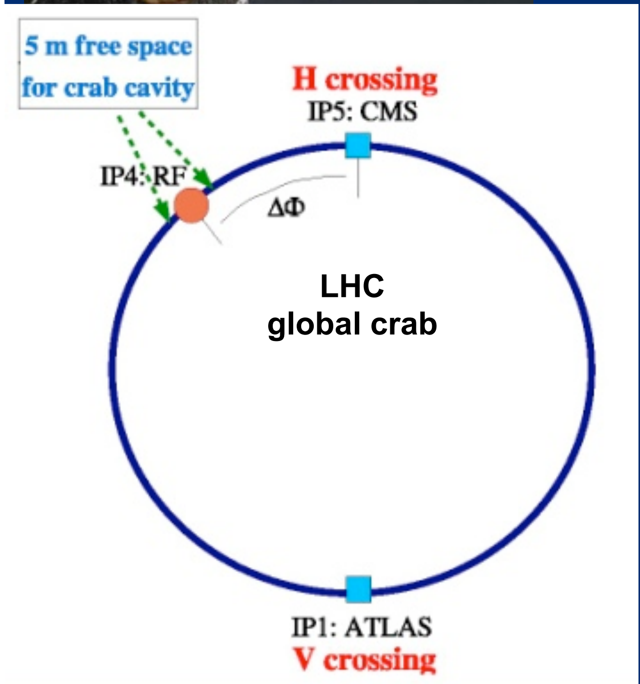
New!

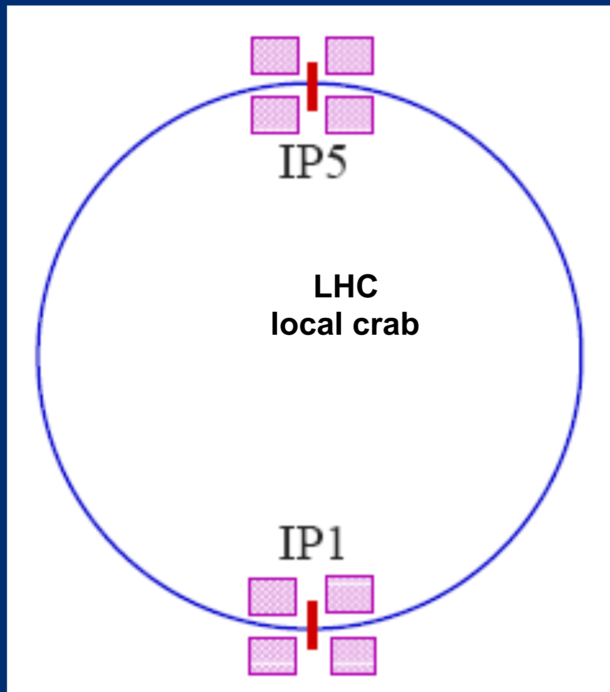


invention
1988

first use in operating
ring collider 2007







- KEKB experience
- R&D plan
- phased approach:
  (1) prototype
  (2) “global” crab cavity test in IR4,
  (3) “local” crab cavities in IR1 & 5
- EuCARD, US-LARP & international collaboration

global & local schemes considered for LHC

tentative schedule for crab-cavity prototype & first beam tests

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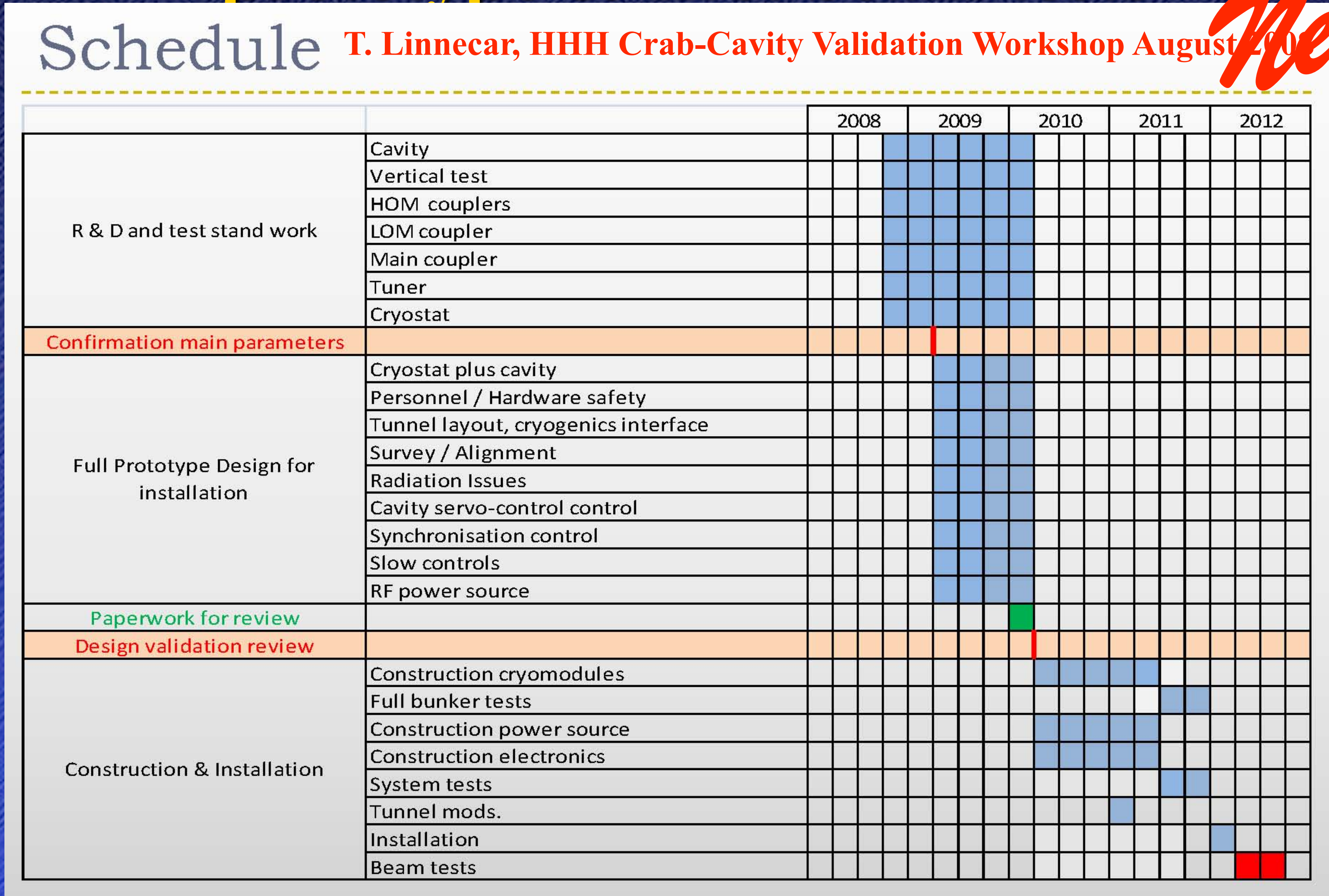
New!



local crab cavities together with IR phase-2 ~2017 ?

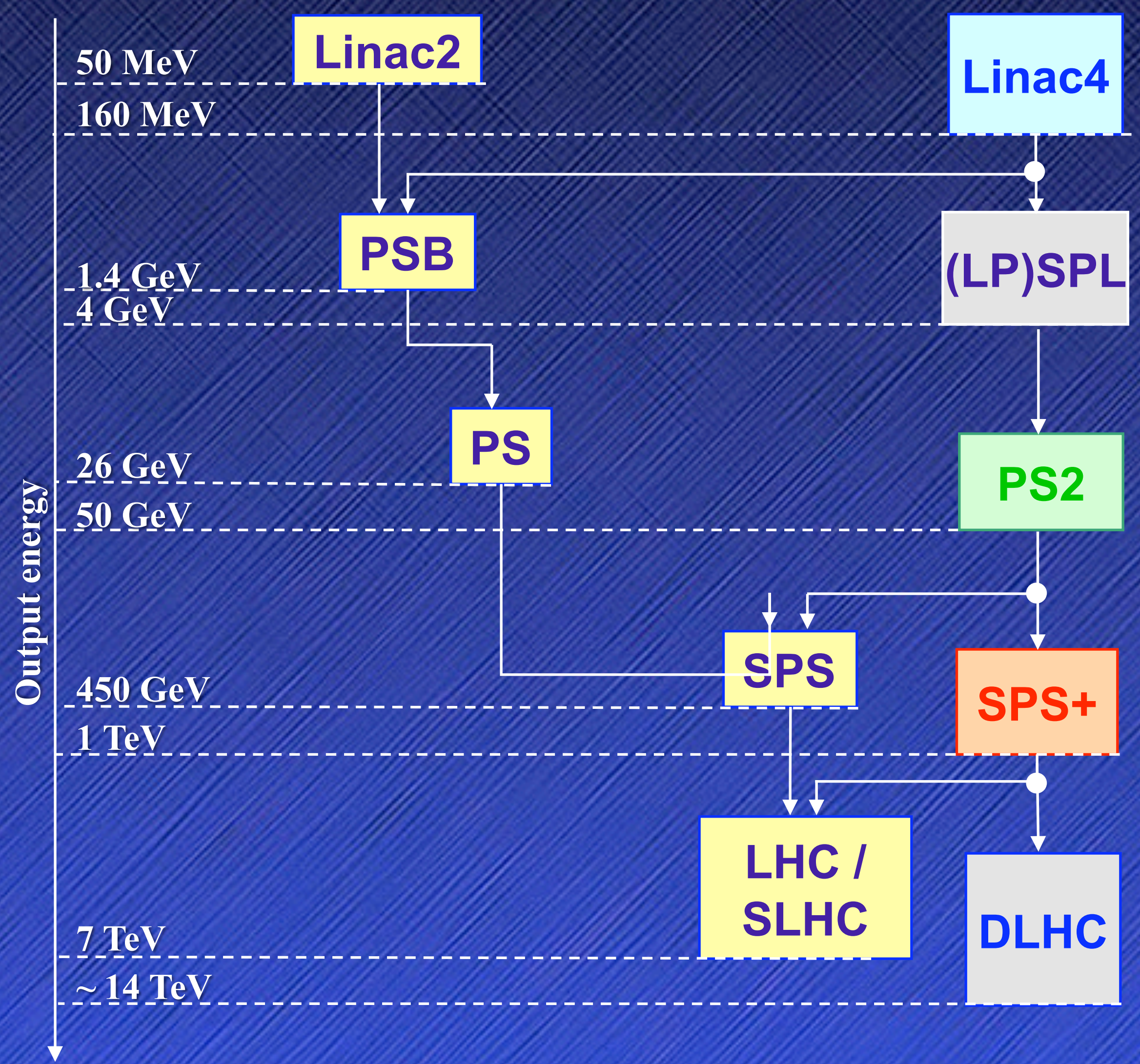
LHC injector upgrade

Reasons:

- need for **reliability**:
  - accelerators are old

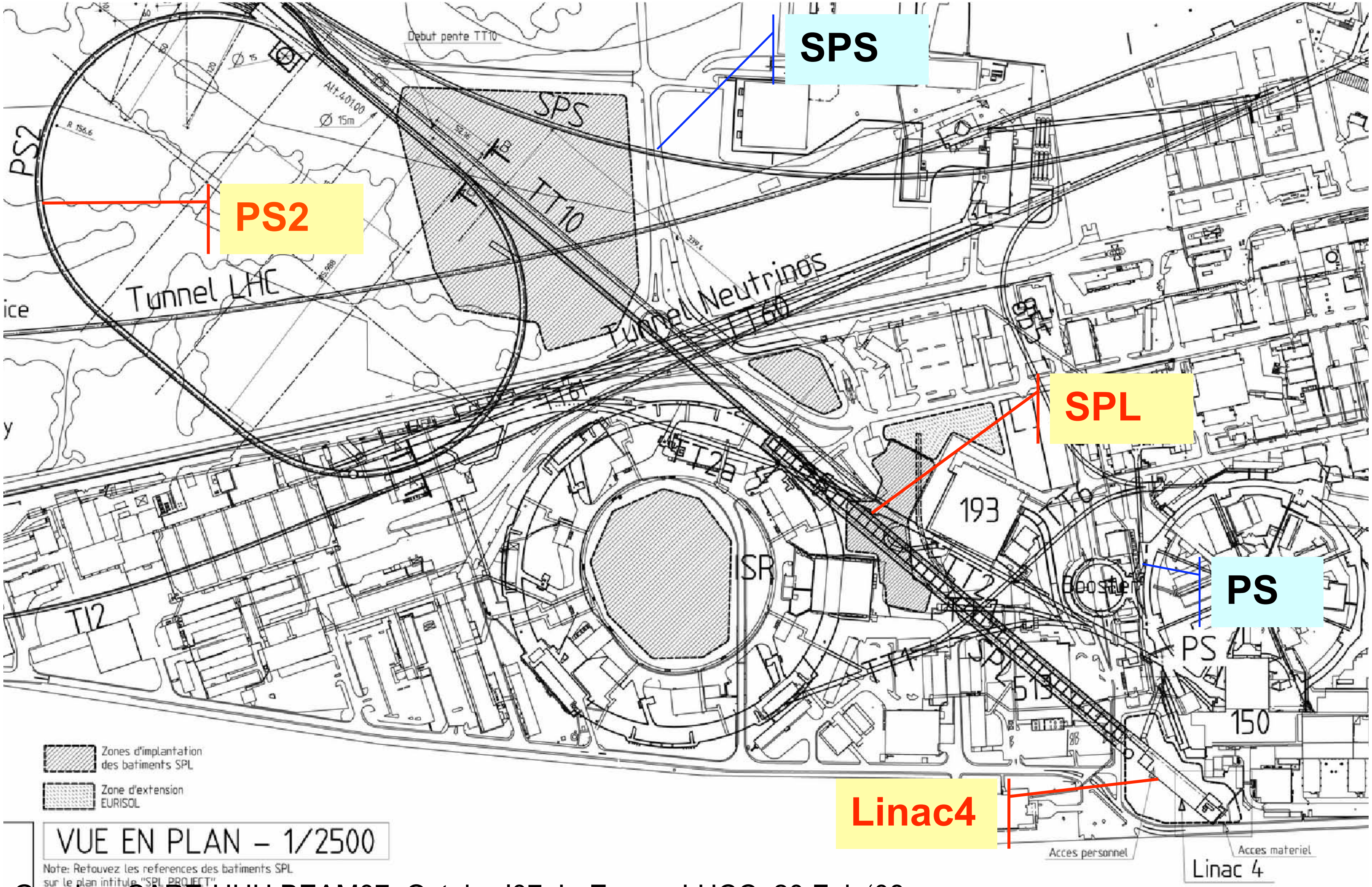
    [Linac2: 1978, PSB: 1975, PS: 1959, SPS: 1976]
  - they operate far from their design parameters and close to hardware limits
  - the infrastructure has suffered from the concentration of resources on LHC during the past 10 years
- need for **better beam characteristics**

present and future injectors



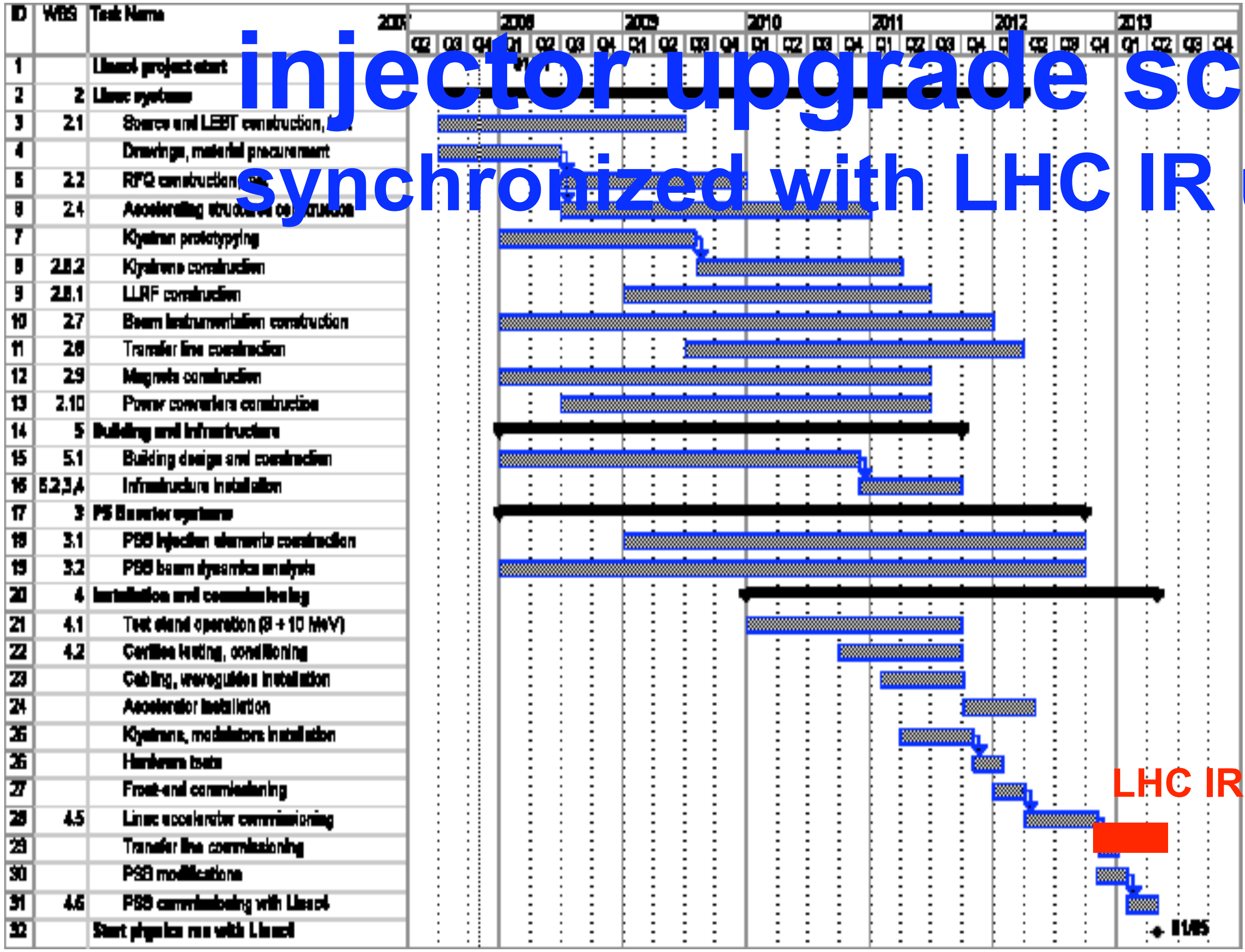
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)

layout of the new injectors



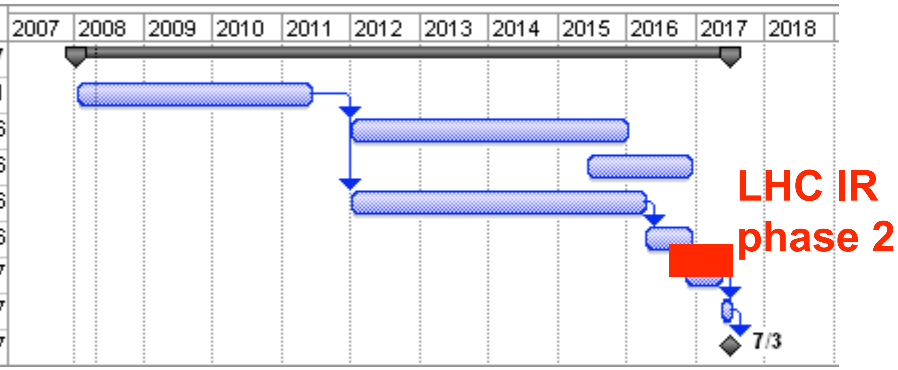
R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

injector upgrade schedule
synchronized with LHC IR upgrades

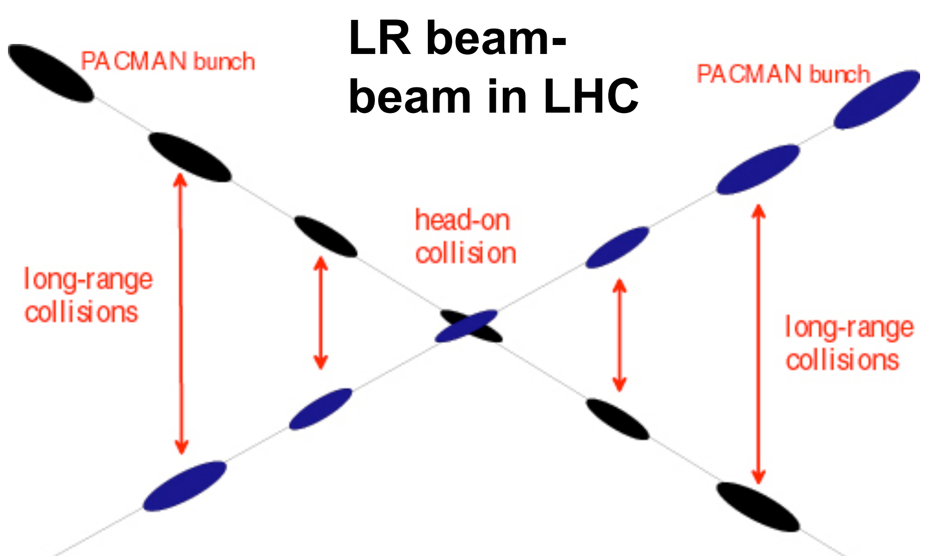


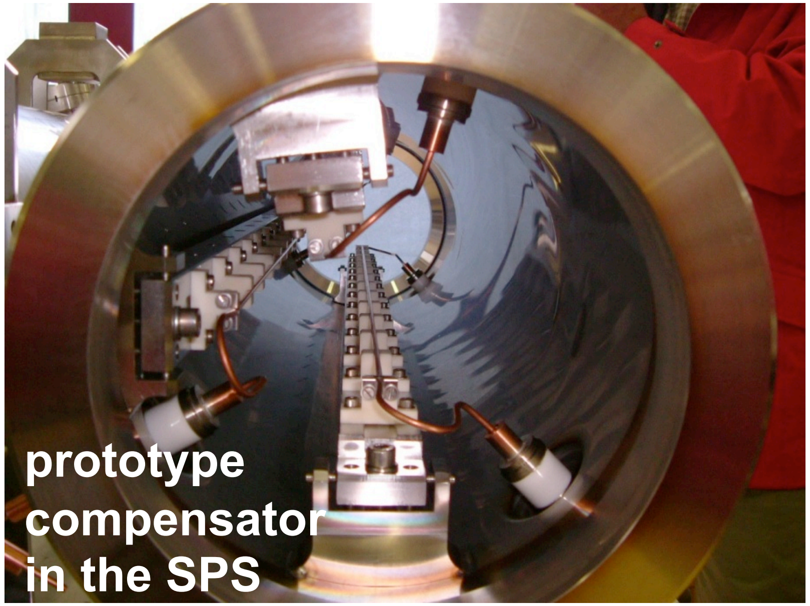
R. Garoby,
LHCC 1 July 2008

ID	Task Name	Start	Finish
1	**SPL + PS2**	**Mon 1/7/08**	**Mon 7/3/17**
2	Design	Mon 1/7/08	Wed 6/1/11
3	SPL Construction	Mon 1/2/12	Fri 1/1/16
4	SPL beam commissioning	Mon 6/1/15	Fri 12/2/16
5	PS2 construction	Mon 1/2/12	Fri 4/1/16
6	PS2 beam commissioning	Mon 4/4/16	Fri 12/2/16
7	SPS modification	Fri 11/4/16	Fri 5/5/17
8	SPS beam commissioning	Mon 5/8/17	Fri 6/30/17
9	Start operation for physics	Mon 7/3/17	Mon 7/3/17

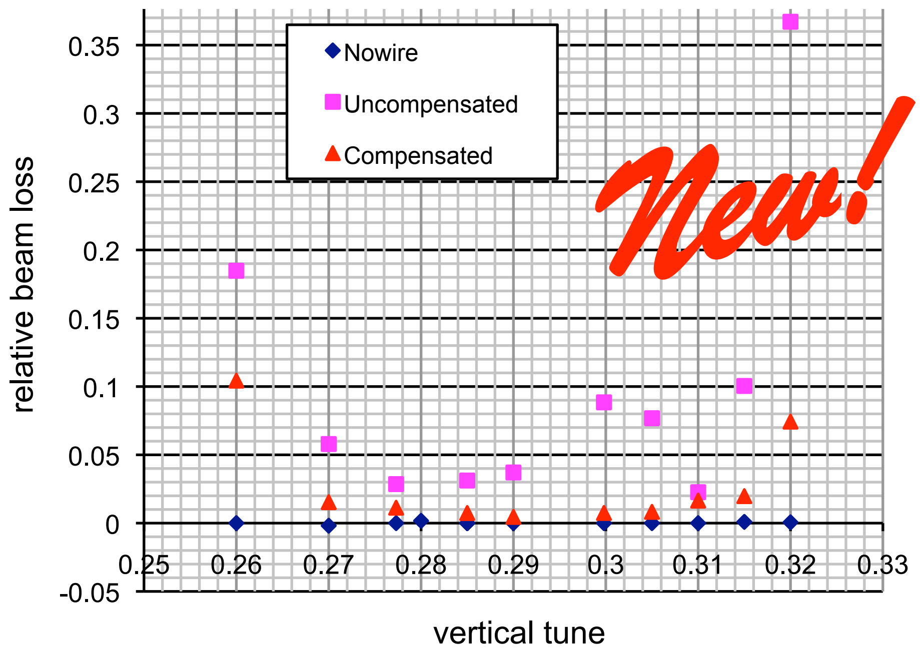


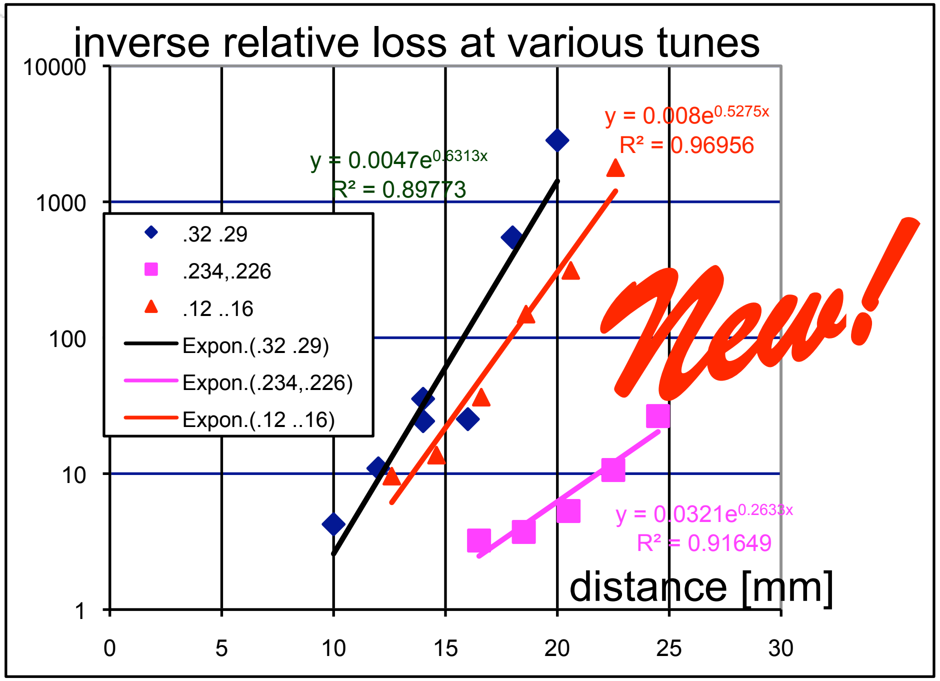
long-range beam-beam compensation





G. Sterbini, J.-P. Koutchouk U. Dorda, et al, SPS MD August 2008





electron lens

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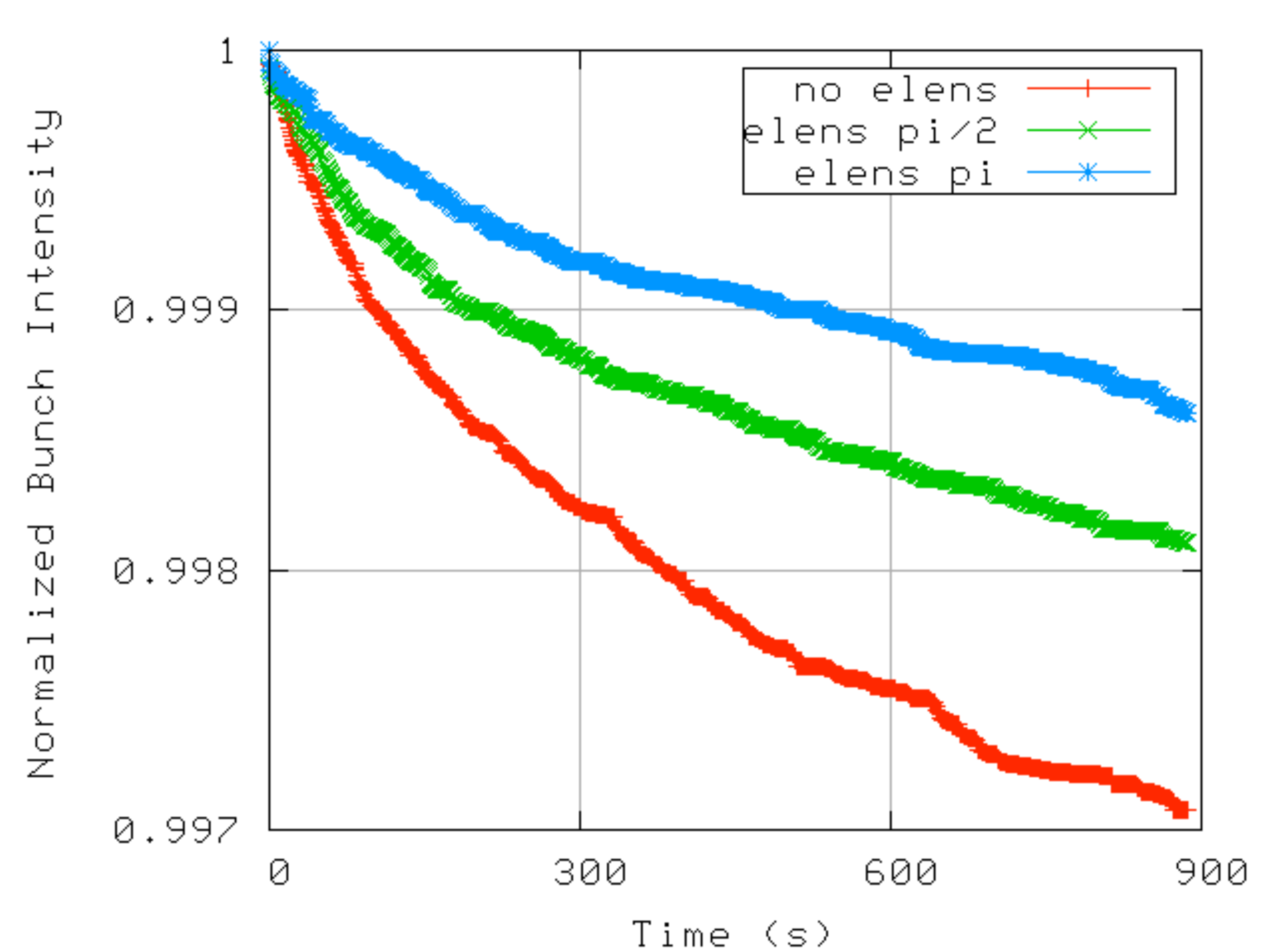
use of e-lens as tune-spread compressor improves simulated LHC beam lifetime (phase to IP important)



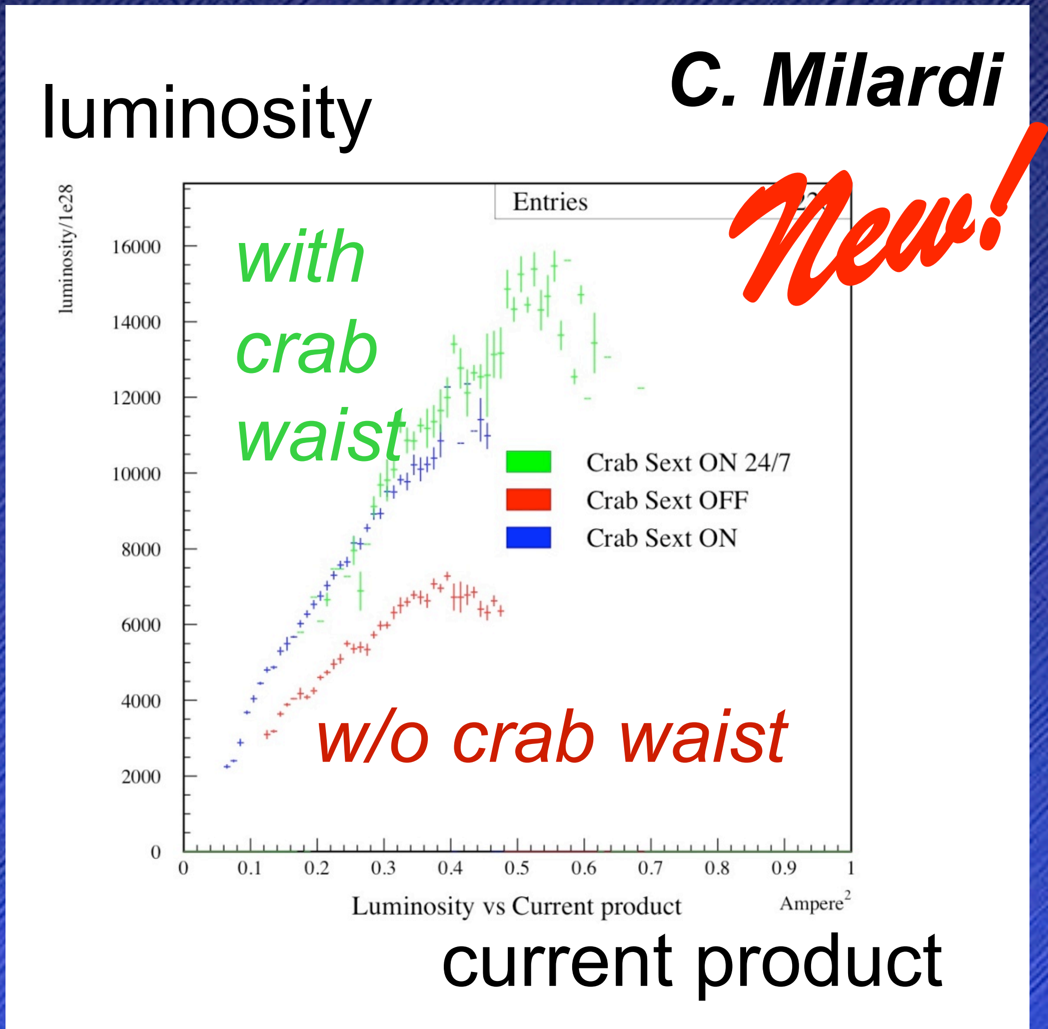
A.Valishev, CARE-HHH mini-workshop on beam-beam Compensation, 28 August 2008

New!

HHH

"crab-waist" collisions at DAFNE

(note: no crab cavities but sextupoles!)



can we make use of crab waists at the LHC?

crab waist in LHC?

HHH

K. Ohmi
CARE-HHH
mini-workshop
28 August '08

one example:

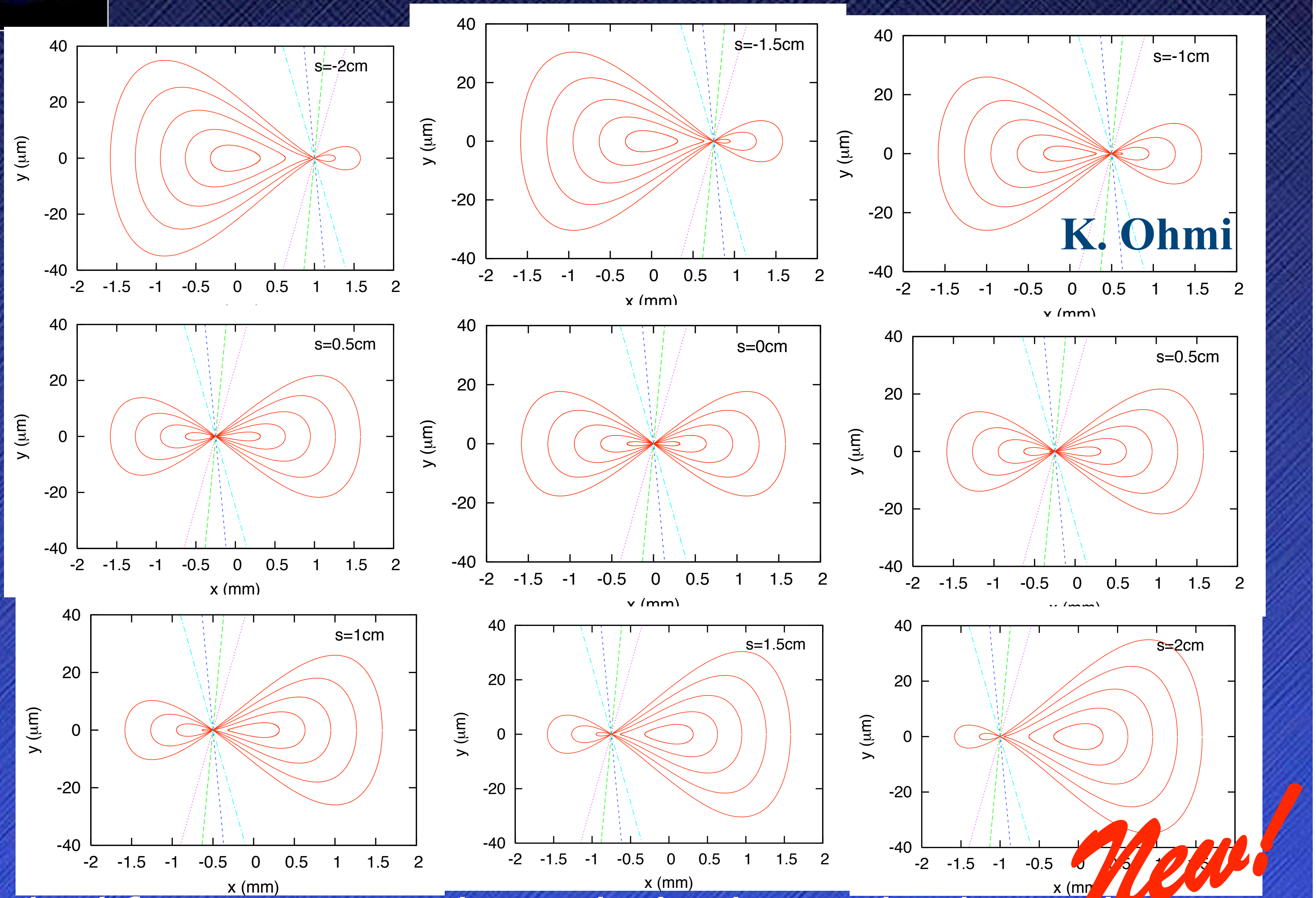
ϕ=3.5 in LPA option
β_y squeezed to σ_x/ϕ=2.1cm (*extreme!*)

→ L increases $(14/2.1)^{1/2}$=2.6 times
→ ξ_y decreases and ξ_x is small for LPA

→ "crab waist has a chance to work!"

New!

crab-waist collisions → HHH →



vertical focus moves through the beam horizontally

e-cloud mitigation

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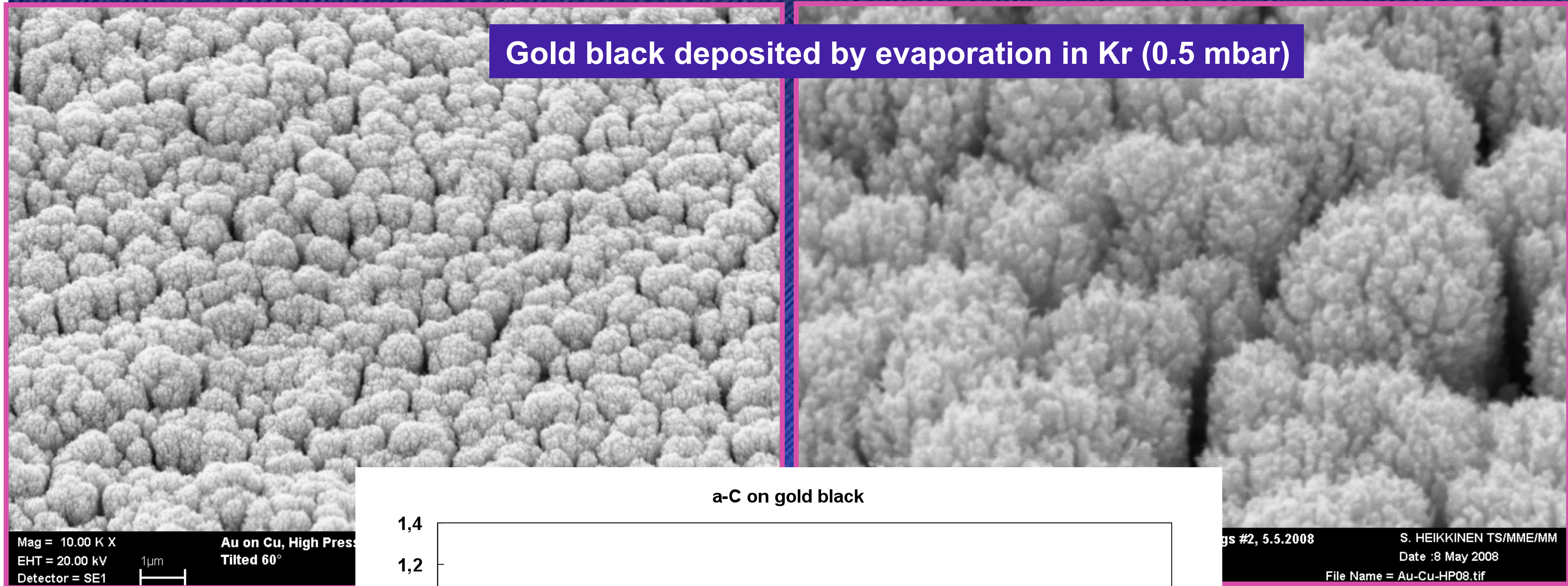
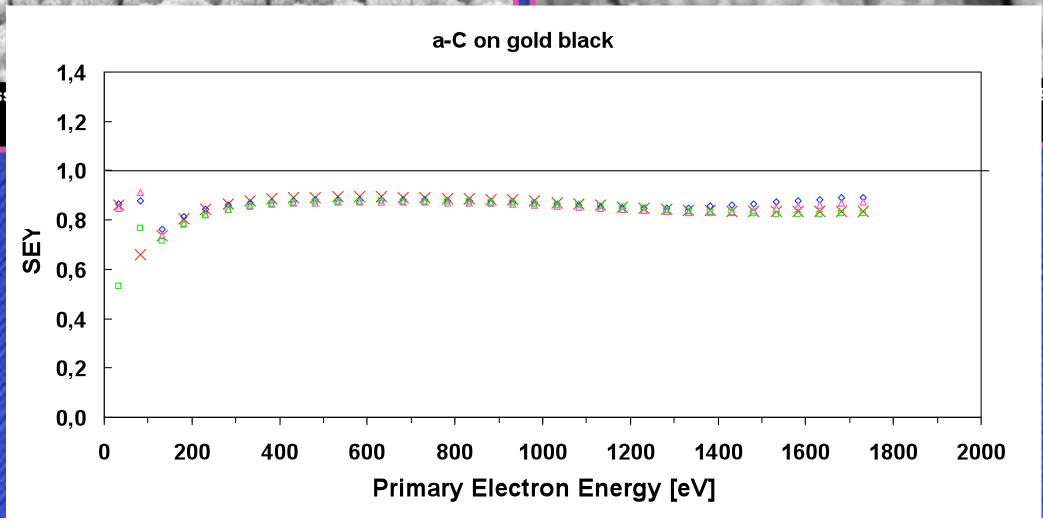
Evaporation of metals in relatively high pressure of a rare gas produces very rough and porous films. Already mentioned in the literature, "gold black" has been produced and characterized.

Gold black deposited by evaporation in Kr (0.5 mbar)





for PS2 and SPS upgrade; effort triggered by HHH ECL'2 workshop

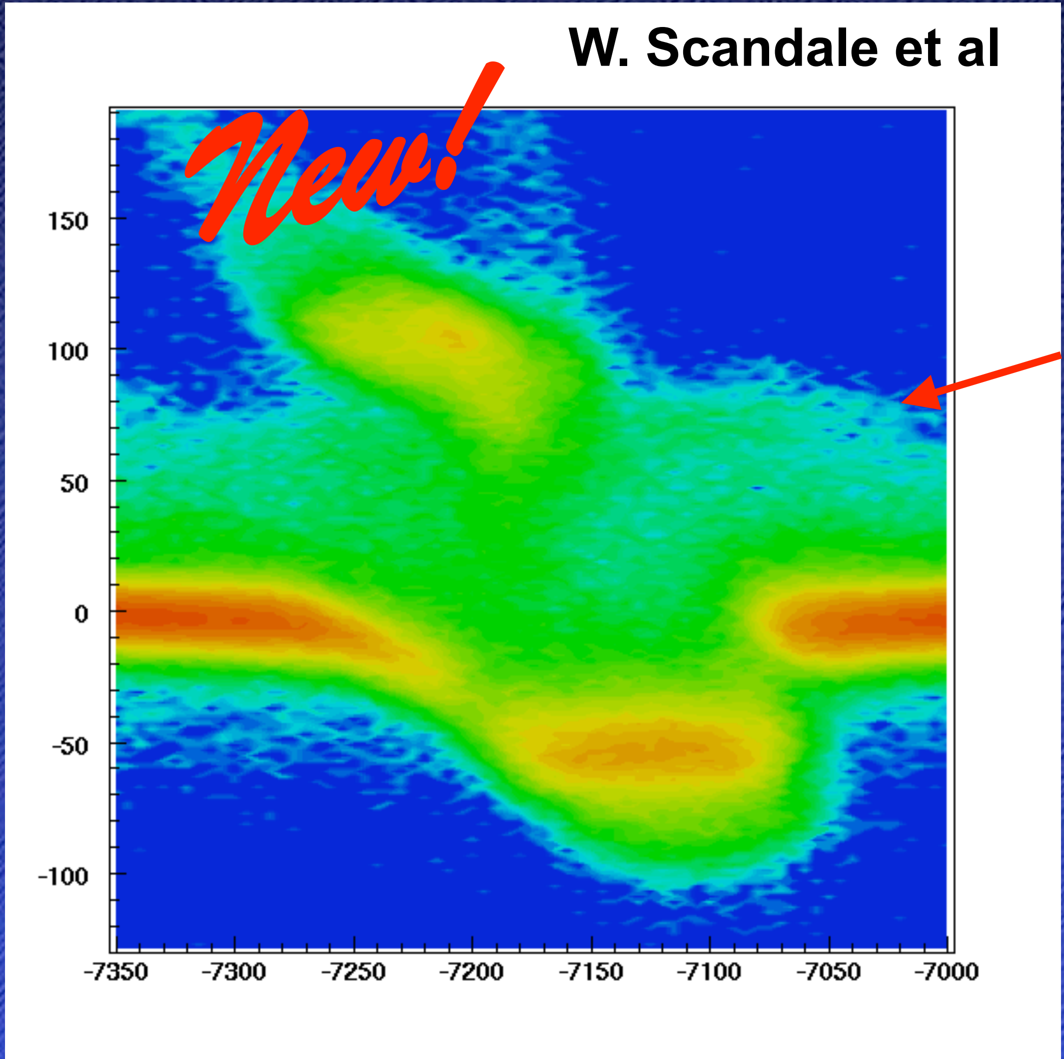
P. Chiggiato et al

New!

promising: graphite coating on black gold substrate

crystal collimation

→HHH→



experiments in SPS North area since 2006

2008 result: crystal deflection of 450 GeV protons with an array of five aligned crystals

parallel simulation effort

approved experiment in SPS ring proper

lower beam emittance →HHH→

- can compensate for luminosity loss due to large crossing angle [R. Garoby]
- may be provided by new injectors
- and/or by "coherent e- cooling" [V. Litvinenko]

damping times in hours:

Collider	Species	Energy, GeV/n	Synchrotron radiation	Electron cooling	**Coherent electron cooling**
RHIC	Au ions	100	$\sim 2\ 10^4$	~ 1	**0.015**
RHIC	proton	2,750	$\sim 4\ 10^4$	> 30	**0.3**
LHC	Pb ions	450	10	$> 4\ 10^4$	**0.15**
LHC	protons	7,000	13	∞	**~ 1**

promise of 1-hr damping time at 7 TeV!

CeC proof-of-principle experiment at RHIC in 2012

strategy for "phase 2"

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- ✓pursue vigorous R&D program for larger-aperture higher-field magnets
- ✓ parallel crab-cavity development and testing
- ✓ design, production & installation of wire compensator already in phase-0
- ✓ exploration of complementary schemes, like crab waist, coherent e-cooling, e-lenses, crystal collimation; integrate them into upgrade plan when they become available
- ✓ establish generation method long flat bunches
- ✓ identify main limitations of the real LHC
- ✓ LHC machine studies to explore upgrade scenarios, e.g. large Piwinski angle
- ✓ close coordination with detector upgrades