BEAM'07 Summaries

Mini-Workshop on LHC+ Beam Performance

Session 5: LHC+ beam generation,
injector upgrade & FAIR

held on Tuesday 02 October 2007, 9:00-13:00

Elena Shaposhnikova (CERN)

Session programme

1. LHC injector upgrade plan R. Garoby
2. Ultimate LHC beam G. Arduini
3. Generation and stability of intense long flat bunches F. Zimmermann

4. Slip stacking K. Seiya (FNAL)
5. BNL upgrade plans W. Fischer (BNL)
6. FAIR challenges P. Spiller (GSI)

LHC injector upgrade plan - R. Garoby

- Updated needs for SLHC (after LUMI’06) and list of new LHC injectors (after WP):
  - Linac4 (*new place*) → **LP**SPL (*low power*) → PS2 (*new size*) → (SPS) → SLHC (= LHC+)

- LHC beam generation with new injectors:
  1. ultimate intensity at 25 ns - OK
  2. 3 x ultimate at 50 ns - ?

LHC injector upgrade plan - R. Garoby

Updated needs of SLHC

Beam parameters [tentative…]	Bunch spacing [ns]	Protons per bunch* [10^{11}]	Transverse emittance in LHC [mm.mrad]	Intensity factor at PS injection*
Nominal	25	1.15 (1.4)	3.75	0.68 (0.81)
Ultimate	25	1.7 (2.1)	3.75	1 (1.2)
~~Ultimate & 12.5 ns spacing~~	~~12.5~~	~~1.7 (2.1)~~	~~3.75~~	~~2 (2.4)~~
2 x ultimate & 25 ns spacing	25	3.4 (4.1)	3.75 (blown-up to 7.5 in LHC)	2 (2.4)
3 x ultimate & 50 ns spacing	50	4.9 (5.9)	3.75	1.44 (1.73)
~~3.5 x ultimate & 75 ns spacing~~	~~75~~	~~6 (7.2)~~	~~3.75~~	~~1.17 (1.41)~~

Proposed maximum goal (→ 2 x ultimate & 25 ns spacing)

* Case of 100 % (80 %) transmission PS → LHC

LHC injector upgrade plan – R. Garoby

Today's performance of the LHC injector chain

	Maximum energy	Number of pulses for the next machine	Repetition period for LHC	Intensity/bunch within required emittances (at ejection)	Limitations
Linac2	50 MeV	1	1.2 s		▪ Too low energy
PSB	1.4 GeV	2	1.2 s	~ ultimate beam	▪ Too low injection energy (space charge)
PS	25 GeV	3-4	3.6 s	1.5 10^{11} p/b (~ 90 % of ultimate beam)	▪ Transition / Impedance ? ▪ Poor longitudinal match with SPS ▪ Reliability (age)
SPS	450 GeV	12	21.6 s	1.15 10^{11} p/b (nominal beam)	▪ Too low injection energy ▪ e-cloud ▪ Impedance
LHC				???	▪ Too low injection energy (DA, Snap-back) ? ▪ e-cloud ?

Unexpected beam loss: > 10 %

LHC injector upgrade plan – R. Garoby
Beam for "large Piwinski angle" scenario

- "3 x ultimate intensity at 50 ns spacing":
  - 80 % of this intensity by PS2 design (+losses)
  - PS2/1 – directly at PS2 injection (the best choice, needs 20 MHz RF system or tunable 40 MHz)
  - PS2/2 – bunch merging at extraction (alternative choice) → 2 x nominal longitudinal emittance
  - SPS/1 – bunch merging at injection
  - SPS/2 – non-adiabatic bunch merging
  - SPS/3,4 – momentum slip stacking at injection or at higher energy (in case of problems for PS-SPS transfer or acceleration in the SPS)
  - LHC/0 – excluded from consideration

Ultimate LHC beam – G. Arduini

Intensity limitations in the chain

- PSB: space charge ➔ Linac 4
- PS: e-cloud, beam losses which increase for more intense and short bunches
- SPS: TMCI, e-cloud, + ...

What can be achieved before SPL and PS2?

No margin for ultimate intensity in the PS

Nominal intensity at the limit in the SPS (ε_v)

➔ Studies and experiments started but need to be intensified (manpower and machine time)

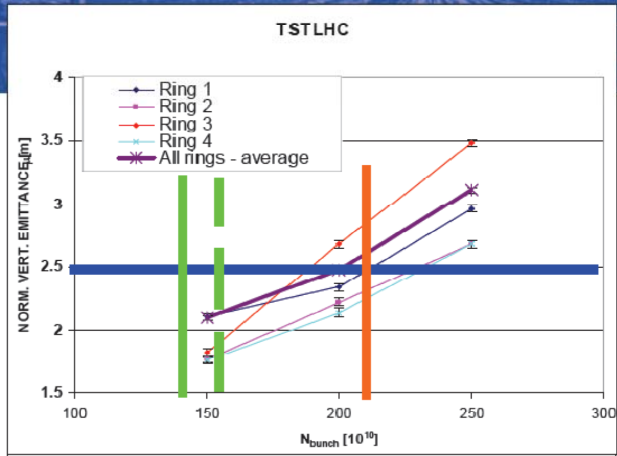
Ultimate LHC beam – G. Arduini

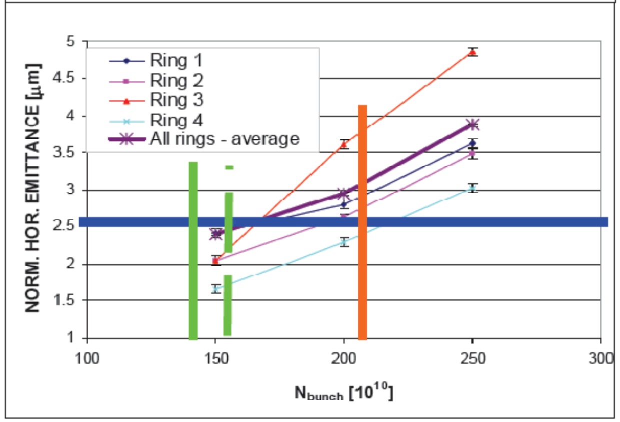
PSB limitations

Space Charge is considered to be the main limitation for:

- LHC beam brightness in PSB. Feasible for the NOMINAL beam in spite of the margin required to account for losses in PS and SPS (dashed line). Not within reach for the ULTIMATE beam.

Minimizing the losses in the downstream machines is mandatory!

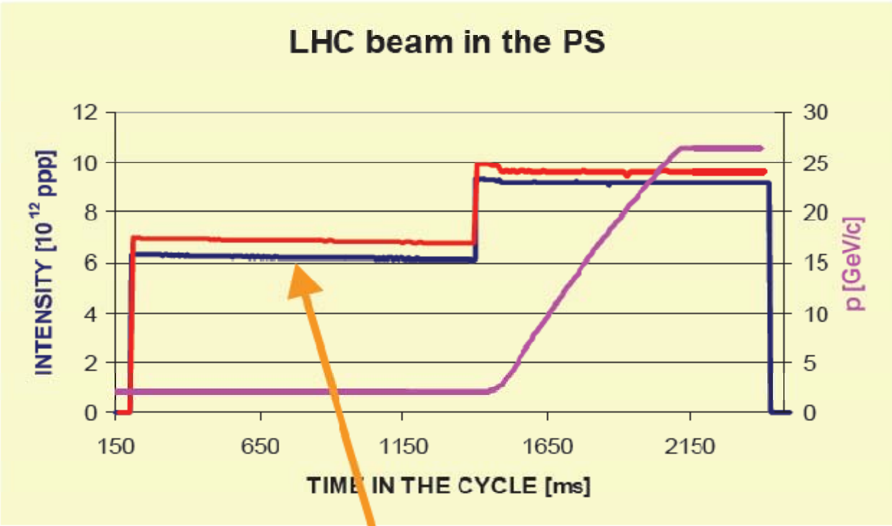


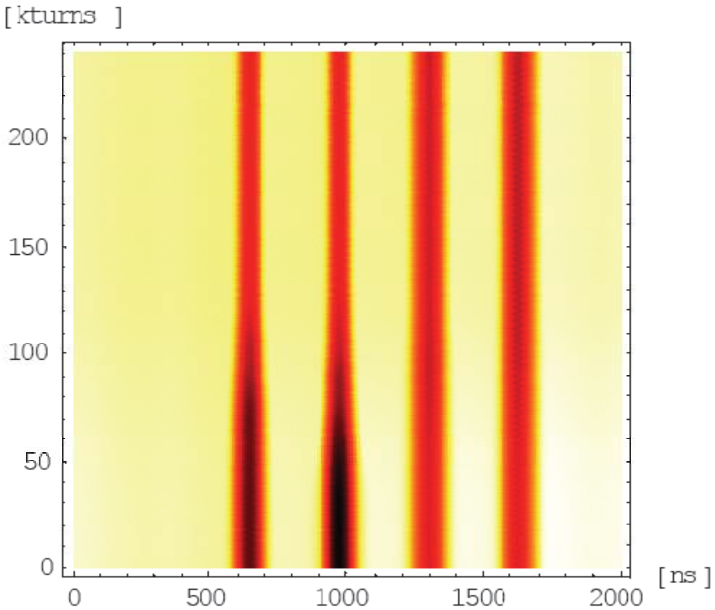


K. Hanke, B. Mikulec

Ultimate LHC beam – G. Arduini

S. Hancock, E. Métral





Losses mainly affecting more intense and/or shorter bunches due to space charge driven resonance trapping phenomena.

Generation and stability of intense long flat bunches - F. Zimmermann

the issues

- LPA upgrade scenario requires ~5x10^{11} protons per bunch, 50 ns spacing, flat longitudinal profile
- questions:
  - how & where can such intense bunches be generated?
  - how & where can they be made flat?
  - do they remain stable and to they preserve their longitudinally flat shape?

➔ in PS2

➔ in LHC

➔ MD studies and simulations needed

Generation and stability of intense long flat bunches - F. Zimmermann

how to make "flat" or "hollow" bunches?

modification of distribution or *change of potential*
in the LHC itself or *in the injector complex*

several techniques are available:

- **2nd harmonic debuncher in linac** [J.-P. Delahaye et al 1980]
- **empty bucket deposition in debunched beam** [J.-P.Delahaye et al 1980 , A. Blas et al 2000]
- **higher harmonic cavity** [J.-P.Delahaye et al 1980]
- **blow up by modulation near f_s + VHF near harmonic** [R. Garoby, S. Hancock, 1994]
- **recombination with empty bucket w double harmonic rf** [C. Carli, M. Chanel 2001]
- **redistribution of phase space using double harmonic rf** [C. Carli, M. Chanel 2001]
- **RF phase jump** [RHIC]
- **band-limited noise** [E. Shaposhnikova]

F. Zimmermann
Generation of flat bunches

redistribution of phase-space surfaces

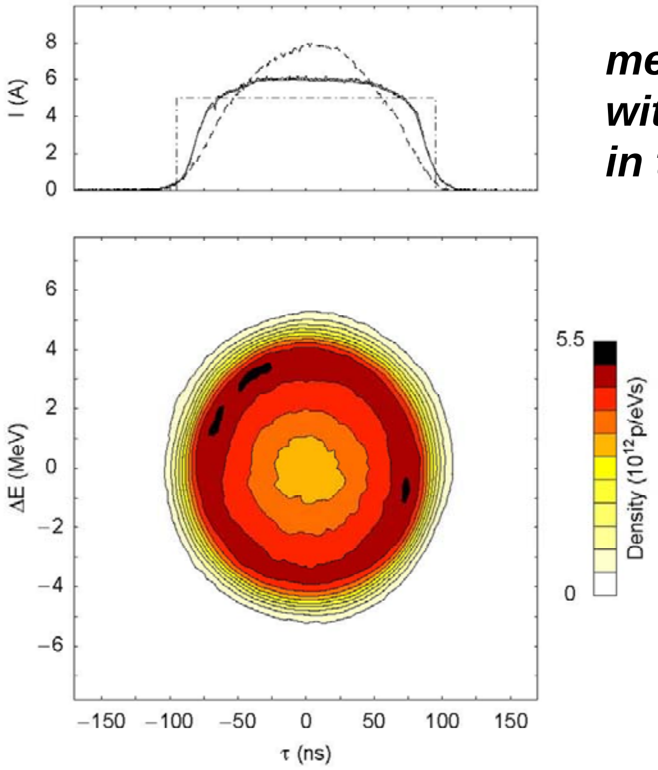


FIGURE 3. Tomographic reconstruction of the phase after redistribution of phase space surfaces.

measurement with $6x10^{12}$ p/bunch in the PS Booster

C. Carli, "Creation of Hollow Bunches using a Double Harmonic RF System", CERN/PS 2001-073 (AE); C. Carli and M. Chanel, HB2002 proceedings, AIP CP642

F. Zimmermann

Are flat or hollow bunches stable?

- Landau damping in a double RF system could be lost for long bunches ➔ experience in the SPS with 4th harmonic RF system
- Landau damping of flat bunches in a single RF system can be improved
- Hollow bunches can become unstable with RF phase loop closed (if too hollow)

- How long flat bunch will stay flat in a single RF system during coast? – IBS, noise, radiation damping...
- What degree of flatness can be achieved in reality?

40% increase in luminosity for pure restangular shape

F. Zimmermann

Stability of hollow bunches

unstable hollow bunches with rf & phase loop

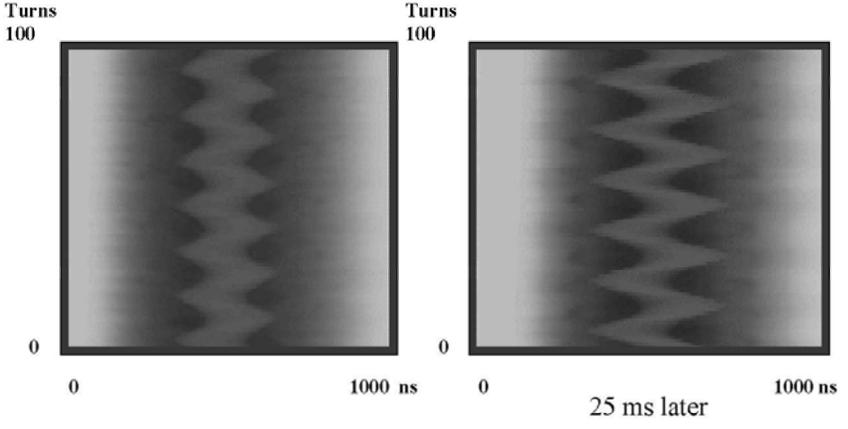


Figure 3: Development of an instability as the low-density central portion of a bunch is anti-damped. The plots consist of bunch profiles taken 25 turns apart plotted on the y-axis. On the x-axis, the intensity on a much shorter time scale along the bunch is represented as a grey-scale.

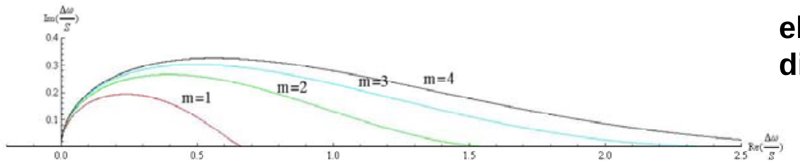
A. Blas, S. Hancock, M. Lindroos, S. Koscielniak, "Hollow Bunch Distributions at High Intensity in the PS Booster", EPAC 2000, Vienna

F. Zimmeremann

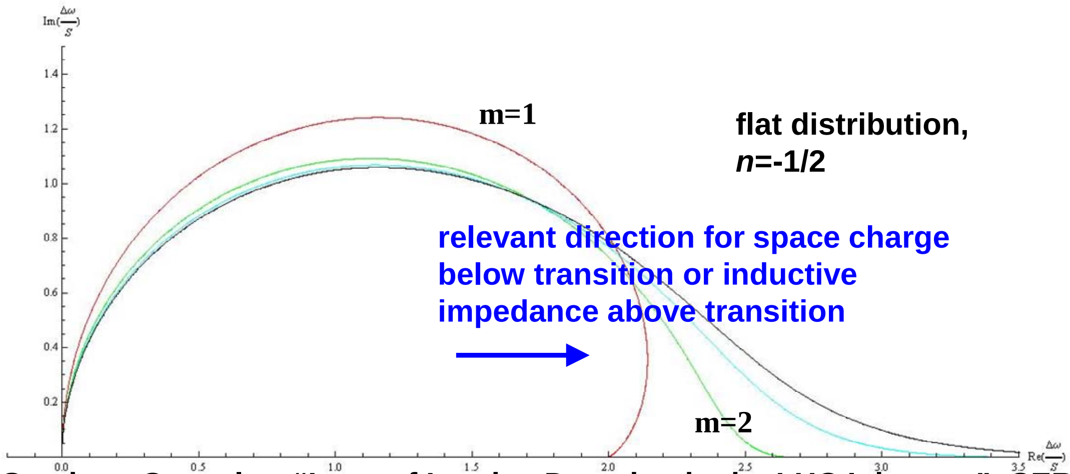
Flat bunches in a single RF system

Landau damping for flat bunches

stability diagrams from Sacherer dispersion relation

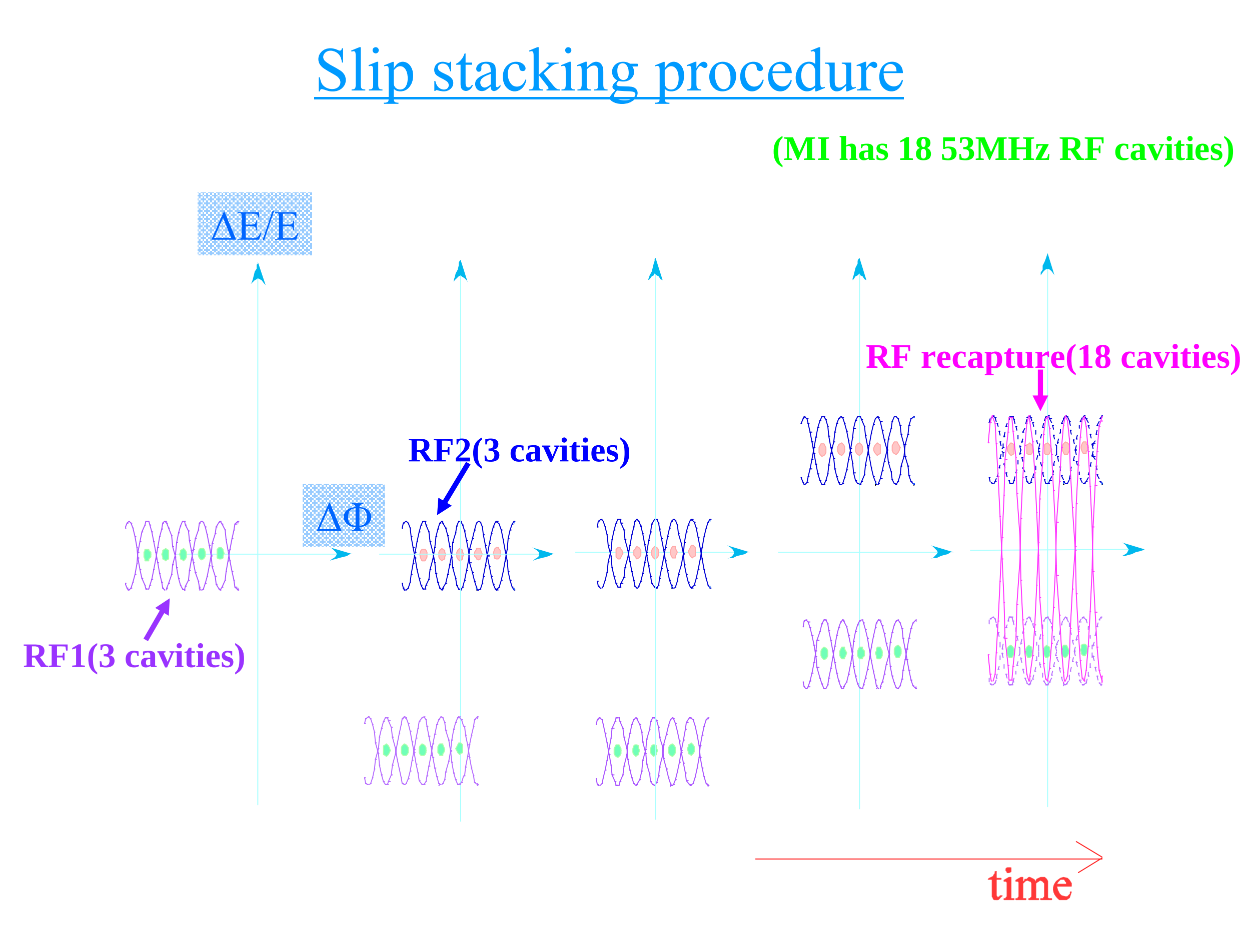


elliptical distribution, *n*=1/2



I. Santiago Gonzalez, "Loss of Landau Damping in the LHC Injectors", CERN AB Note to be published; see also F. Sacherer, IEEE Tr. NS 20,3,825 (1973), E. Metral, CERN-AB 2004-002 (ABP), K.Y.Ng, FERMILAB-FN-0762-AD (2005)

Slip stacking - K. Seiya (FNAL)

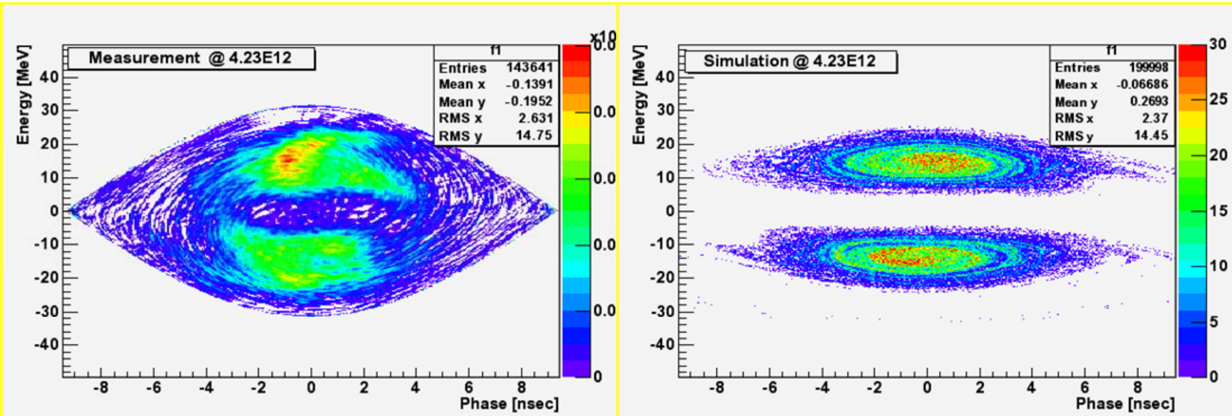


Slip stacking - K. Seiya

Beam at recapture

Recapture voltage: 1MV
Intensity: 8.5E12 @ Injection

Measurement ***Simulation***



Longitudinal emittance @ recapture ~ 0.35eV-sec
Beam loss ~ 5%

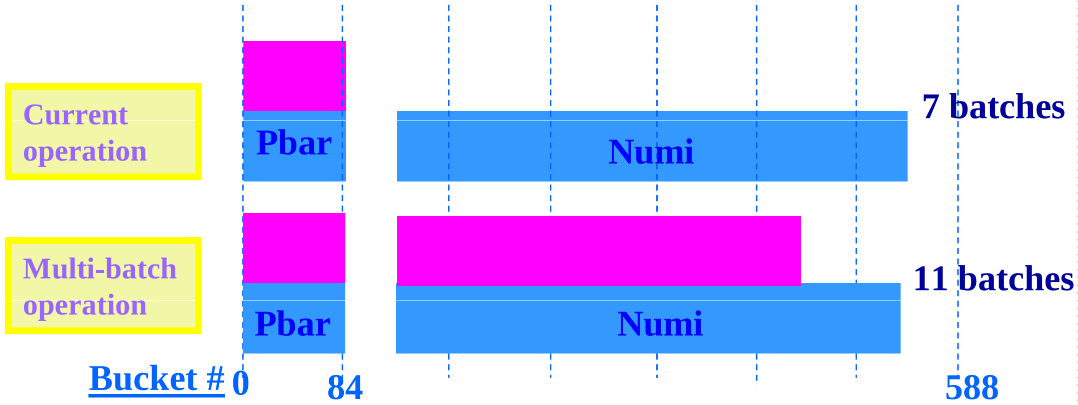
➔longitudinal emittance blow-up factor 3

➔total beam loss: 5% (8 GeV +ramp loss + kicker gap loss)

Slip stacking - K. Seiya

Proton Plan Goal

- Intensity @ injection : 4.3E12 ppp x 11
  @ extraction: 4.5E13 ppp
- Total beam power: 400kW 80kW → Pbar
  320kW→ Numi
- MI cycle rate < 2.2 sec
- Total beam loss: < 5%



→ In operation from 2004, pbar intensity increased by 70%

→Scheme was already verified, soon in operation

RHIC status and upgrade plans - W. Fischer

Status:

- Since 2000, 4 ion combinations, 8 energies
- Luminosity/year increased by >2 orders of magnitude
- Protons with 65% polarization at 100 GeV

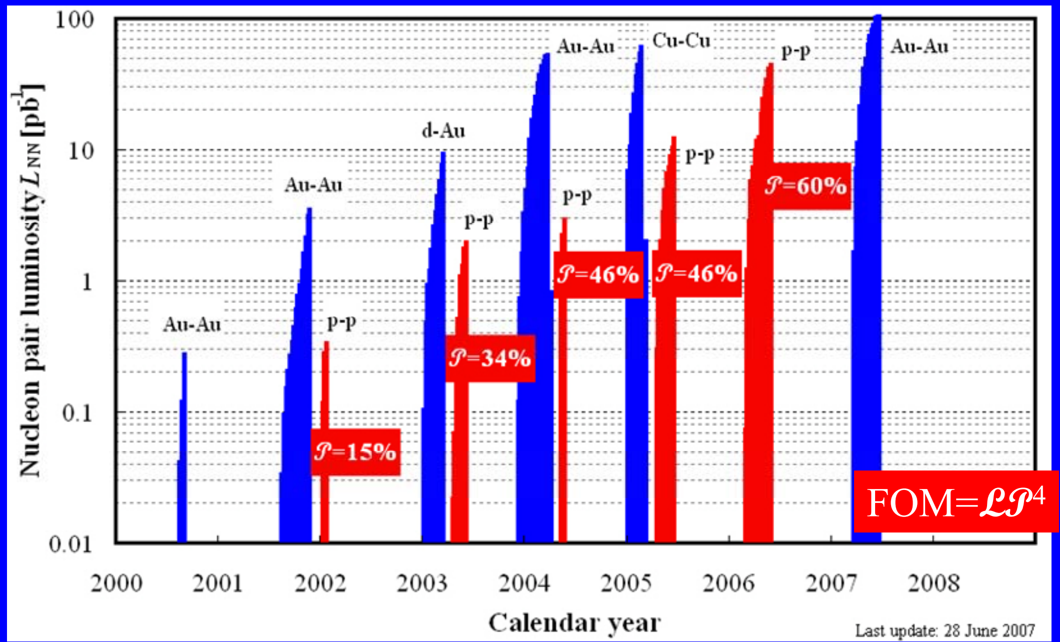
Planned upgrades:

1. Enhanced Design parameters (~2009)
2. EBIS (modern pre-injector, U and $^{3}H\uparrow$ 2009)
3. Low energy Au-Au operation (QCD critical point ≥ 2009)
4. RHIC II (order of magnitude increase in Au-Au $\mathcal{L}$ ≥2011)
5. eRHIC (high luminosity electron-ion collider ≥2014)

RHIC status and upgrade plans
W. Fischer

RHIC delivered luminosity

Delivered luminosity increased by >2 orders of magnitude in 5 years.



Delivered to PHENIX, one of RHIC's high-luminosity experiments.

RHIC status and upgrade plans

Performance limits - W. Fischer

- Lifetime due to IBS ➔ longitudinal stochastic cooling of bunched beam
- Transition crossing for heavy ions:
  - intensity limitation due to fast transverse single bunch instability
  - Intensity loss at the end of batches (e-cloud?)
- Polarization of protons
- Beam-beam for polarized protons

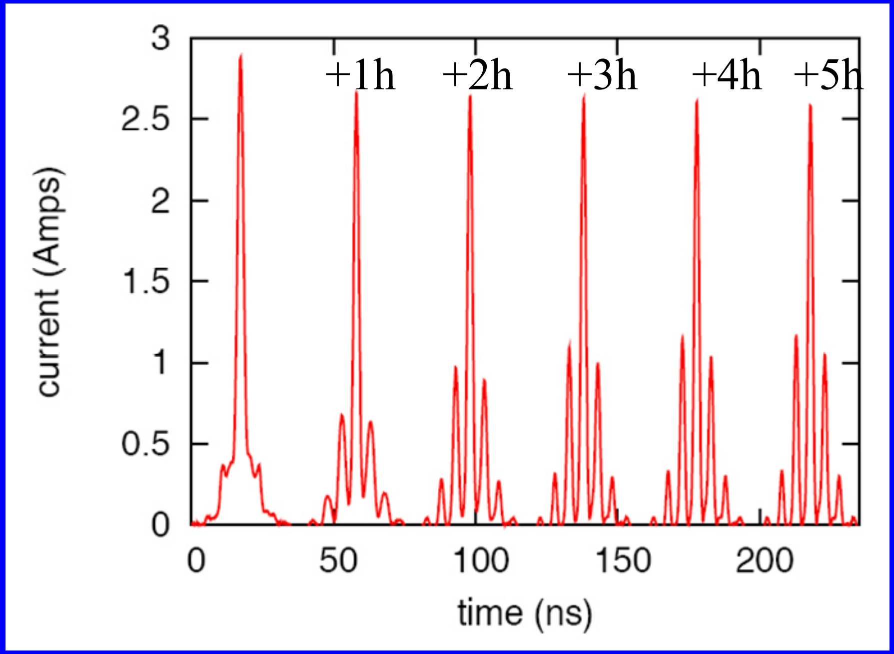
RHIC status and upgrade plans

W. Fischer

Longitudinal stochastic cooling in RHIC

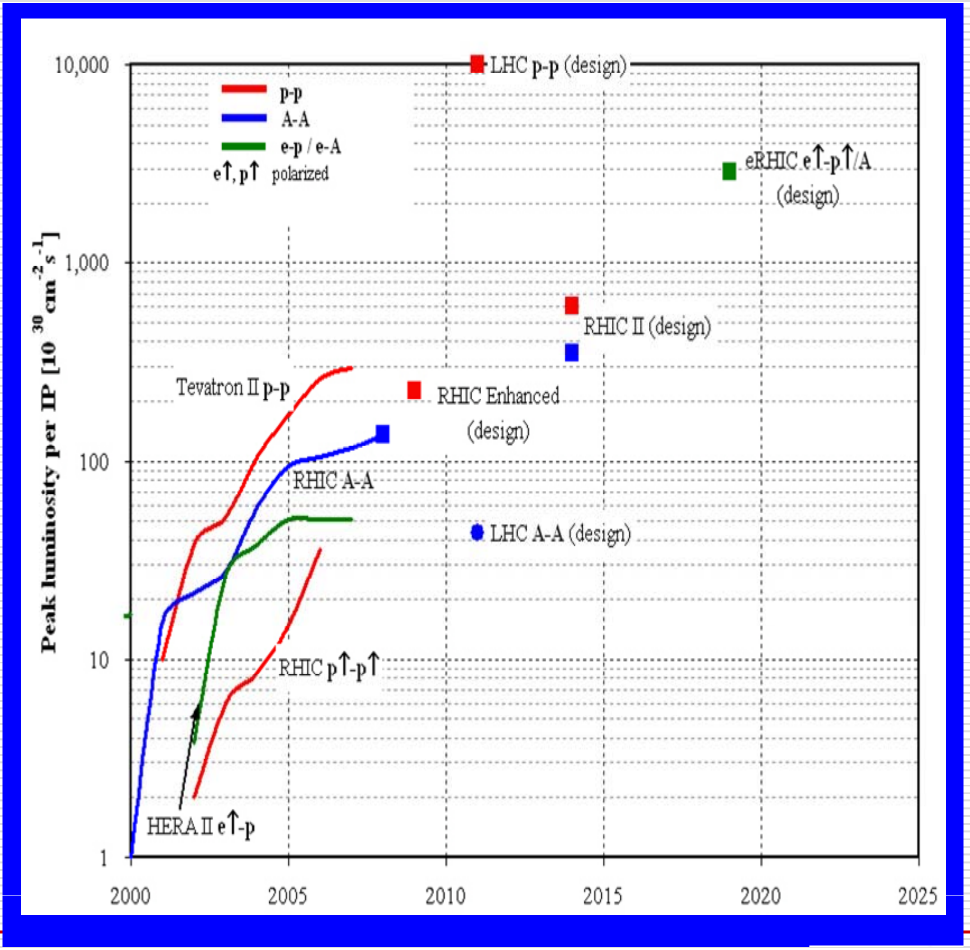
Evolution of longitudinal profiles over 5 hours

M. Blaskiewicz
M. Brennan
COOL'07



Satellites are result of 2 rf harmonics (360 + 7×360)

RHIC status and upgrade plans
W. Fischer



RHIC II – e-cooling, stochatic cooling

RHIC status and upgrade plans
- W. Fischer

New idea: Coherent Electron Cooling

V. Litvinenko, Ya. Derbenev
COOL'07

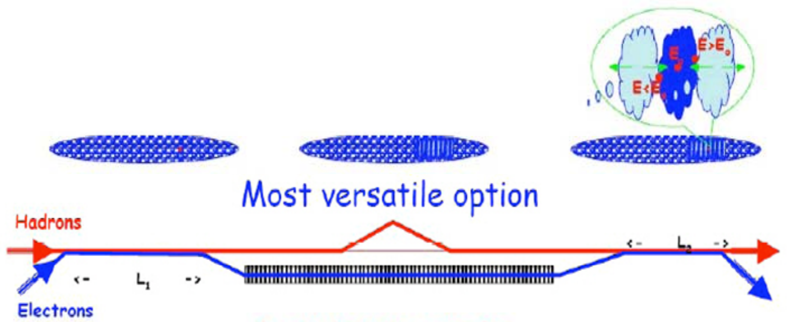
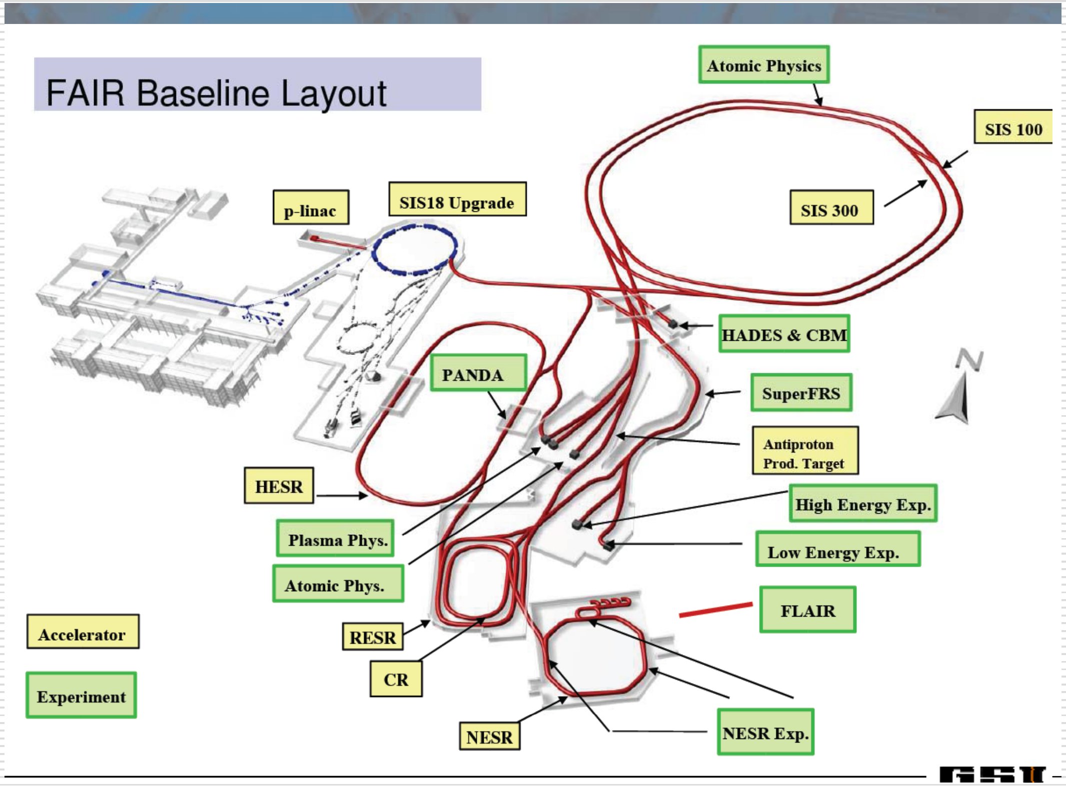


Table 1. Comparison of estimations for various cooling mechanisms in RHIC and LHC colliders. The sign ∞ is used to indicate helplessly long damping times.

Machine	Species	Energy GeV/n	Synchrotron radiation, hrs	Electron cooling, hrs	CEC, hrs
RHIC	Au	100	20,961 ∞	~ 1	0.03
RHIC	protons	250	40,246 ∞	> 30	0.8
LHC	protons	450	48,489 ∞	> 1,600	0.95
LHC	protons	7,000	13 (energy)/26 (transverse)	∞∞	< 2

To estimate electron cooling in LHC we used an energy scaling $\gamma^{7/2}$ typical for RHIC's electron cooler design [8,9], i.e., cooling protons in LHC at 7 TeV is ~10^{10} harder that cooling antiprotons in the Fermilab recycler [7]. Hence, our usage of ∞∞ in an appropriate column.

FAIR challenges
P. Spiller



R&D stage is completed end 2007 ➔ start of construction!

To be decided which ring comes first

FAIR challenges - P. Spiller

Magnets : high ramp rate of curved, s.c. magnets, long term mechanical reliability, together with sufficiantly good field quality

RF Systems : high voltages, low impedance, low frequency, as short as possible, moderate pulse power

UHV : huge pumping speed, low desorption rates, ultra high static vacuum highly efficient collimation system

Beam dynamics : low loss budget at highest heavy ion beam intensities and with impedances of huge extraction and rf systems (quenching, activation, desorption, life time of organic materials etc.)

Stochastic cooling : fast cooling of antiprotons and rare isotopes in a ring with different optical settings but same pick-ups structures

HE electron cooling : Electrostatic e-beam accelerator for appropriate e-beam quality

And others..........

SIS18 - Intensity requirements for FAIR - P. Spiller

Fair Stage	Today	0 (Existing Facility after upgrade)	1 (Existing Facilty supplies Super FRS, CR, NESR)	2,3 (SIS100 Booster)
Reference Ion	U^{73+}	U^{73+}	U^{73+}	U^{28+} (p)
Maximum Energy	1 GeV/u	1 GeV/u	1 GeV/u	0.2 GeV/u
Maximum Intensity	$3x10^{9}$	$2x10^{10}$	$2x10^{10}$	$2x10^{11}$
Repetition Rate	0.3 Hz	1 Hz	1 Hz	2.7 – 4 Hz
Approx. Year		2008/2009	2011/2012	2012/2013