SUMMARY OF WORKING GROUP A:

BEAM DYNAMICS IN HIGH-INTENSITY CIRCULAR MACHINES

G. Franchetti (GSI), J. Holmes (ORNL) and E. Métral (CERN)

- **29 WG-A + 1 WG-A+C = 30 (excellent) talks! => The other 4 WG-A+C talks are summarized in WG-C. Many thanks to all the speakers!**
  - **ASIA-RUSSIA: 8 (3 IHEP Beijing, 3 J-PARC, 1 KEK, 1 JNR) => ~ 27%**
  - **EU: 11 (7 CERN, 2 GSI, 2 RAL) => ~ 37%**
  - **North America: 11 (1 BNL, 3 FNAL, 1 ORNL, 2 LBNL, 1 UMD, 1 JLAB, 1 SLAC, 1 TRIUMF) => ~ 37%**
- **Overall program**
- **Discussion session**
- **Summary**
- **Appendix**

PROGRAM WG-A (1/3)

1) Simone Gilardoni (CERN): Simone.Gilardoni@cern.ch => The high intensity / high brightness upgrade program at CERN: status and challenges

2) Oliver Boine-Frankenheim (GSI): o.boine-frankenheim@gsi.de => Status of collective effects at GSI

3) Thomas Planche (TRIUMF): tplanche@triumf.ca => Space charge effects in cyclotrons

4) Hiromi Okamoto (J-PARC): okamoto@sci.hiroshima-u.ac.jp => Plasma traps for space charge studies: status and perspectives

5) Nicolo Biancacci (CERN): Nicolo.Biancacci@cern.ch => Impedance studies of 2D azimuthally symmetric devices of finite length

6) Benoit Salvant (CERN): Benoit.Salvant@cern.ch => LHC impedance model: experience with high intensity operation in the LHC

7) Lan Huang (IHEP): huangls@ihep.ac.cn => Resistive-wall Instability in the CSNS/RCS

8) Elena Chapochnikova (CERN): Elena.Chapochnikova@cern.ch => Longitudinal instabilities in the SPS and beam dynamics issues with high harmonic RF systems

9) Hannes Bartosik (CERN): Hannes.Bartosik@cern.ch => Low gamma transition optics for the SPS: simulation and experimental results for high brightness beams

10) Fanouria Antoniou (CERN): Fanouria.Antoniou@cern.ch => Optics design optimization for IBS dominated beams

11) Alexey Burov (FNAL): burov@fnal.gov => Circular modes and flat beams for LHC

12) K.Y. (Bill) Ng (FNAL): ng@fnal.gov => Scaling properties of resonances in non-scaling FFAGs

13) Alexander Molodozhentsev (KEK): molodxx@gmail.com => PTC+ORBIT studies for the CERN LHC Injectors Upgrade project

14) Giuliano Franchetti (GSI): g.franchetti@gsi.de => Effect of self-consistency on periodic resonance crossing

PROGRAM WG-A (2/3)

15) Chris Warsop (RAL): chris.warsop@stfc.ac.uk => Simulation and measurement of half integer resonance in coasting beams in the ISIS ring

16) Helga Timko (CERN): Helga.Timko@cern.ch => Longitudinal beam loss studies of the CERN PS-to-SPS transfer

17) Masahito Yoshii (J-PARC): masahito.yoshii@kek.jp => Acceleration of high-intensity protons in the J-PARC synchrotrons

18) Rami Kishek (UMD): ramiak@umd.edu => Longitudinal space charge phenomena in an intense beam in a ring

19) Stefan Paret (LBNL): sparet@lbl.gov => Measurement and simulation of luminosity leveling in LHC via beam separation

20) Yun Luo (BNL): yluo@bnl.gov => RHIC beam-beam effects

21) Shou Yan Xu (IHEP): xusy@ihep.ac.cn => Effects of magnetic field tracking errors and space charge on beam dynamics at CSNS/RCS

22) Jinfang Chen (IHEP): chenjf@ihep.ac.cn => Dual-harmonic acceleration studies at CSNS RCS

23) Robert Williamson (RAL): rob.williamson@stfc.ac.uk => High intensity longitudinal dynamics studies for an ISIS injection upgrade

24) Yuhong Zhang (JLAB): yzhang@jlab.org => Quest for superior ion beams for Electron-Ion Collider

25) Valeri Lebedev (FNAL): val@fnal.gov => Test of optical stochastic cooling in Fermilab

26) Kazuhito Ohmi (J-PARC): ohmi@post.kek.jp => Measurement of Extended Twiss parameters and space charge effects

27) Oleg Kozlov (JINR): okozlov@jinr.ru => Space charge effects in the NICA collider ring

28) Claudio Rivetta (SLAC): rivetta@slac.stanford.edu => Broad-band transverse feedback against e-cloud or TMCI: status and plan

PROGRAM WG-A (3/3)

29) Ji Qiang (LBNL): jqiang@lbl.gov => Fully 3D long-term simulation of the coupling resonance experiments at the CERN PS

PROGRAM WG-A+C JOINT

30) Jeffrey Holmes (SNS): holmesja1@ornl.gov => Beam loss due to foil scattering in the SNS accumulator ring

1) David Johnson (FNAL): dej@fnal.gov => Injection design for Fermilab Project X

2) Youjin Yuan (IMP): Study of intense beam injection and extraction from ion synchrotrons

3) Bruce Brown (FNAL): bcbrown@fnal.gov => Beam loss control for the Fermilab Main Injector

4) Xiaoyu Wu (MSU/FRIB): xwu@nscl.msu.edu => The design and commissioning of the accelerator system of the rare isotope reaccelerator - ReA3 at Michigan State University

DISCUSSION SESSION (1/2)

- R. Kishek: Transverse dynamics at UMER. Also, $Q_y = 7$
- P. Baudrenghien
  - Why is the evolution of LHC bunch length in physics different in 2012 wrt 2011?
  - *Long-lasting dipole oscillations at injection => Small amplitude, seems independent of bunch and batch intensity and batch spacing… => Not discussed*
- Colliders and storage rings
  - Circular modes questions (A. Burov) => Can they survive SC, luminosity, IBS, dispersion, nonlinearities, perturbations? What about Montague resonance => All this should be studied
  - LHC luminosity leveling with transverse offsets (S. Paret) => theory + sim + meas agree during MD, but in operation mode there are instabilities that must be understood
  - Beam-beam in RHIC (Y. Luo) => No emittance BU: thought to be due to very small DA. Reason of fast losses at beginning of stores? Suppression of Pi-mode in H: proposition to make a test with $Q_x < Q_y$. Ongoing discussions
  - Understanding of the LHC transverse instabilities at collision energy (B. Salvant)? => Seems more critical with 2 beams than with 1 beam… Interplay with LHC damper?
  - IOTA (V. Lebedev) => Can Optical Stochastic Cooling be used in the LHC? Should we put some effort? What about jitters (A. Chao)? General IOTA status.
  - Power loss estimations (B. Salvant)? As it is used a lot and we don't cross-check it with simulations etc. Linked also to thermal analysis.

DISCUSSION SESSION (2/2)

- **Computer Codes and Simulation**
  - **Benchmarking (I. Hofmann): Theory <=> Models <=> Experiment. Verification and validation**
  - **Machine design vs analysis of dedicated experiments**
  - **New model G. Franchetti: frozen + Markovian ansatz to approximate self-consistency**
  - **H. Timko => Longitudinal simulation codes for complicated RF, Z, and SC?**
  - **S-POD (H. Okamoto, Hiroshima) as simulator. Ideas for benchmarks?**
  - **A. Molodozhentsev: Can "halo" from simulation be measured?**
- **Broad-band feedback (C. Rivetta) => Where will it work?**
- ***What about IBSt with LINAC4 H^- (R. Schmidt)? => Not discussed but not an issue and was studied (R. Garoby)***
- ***RCS vs. Linac? => Not discussed but was studied for instance in detail at CERN (R. Garoby)***
- ***Neutron sources and nuclear physics: Accumulator ring vs. RCS (K. Yamamoto)? => Not discussed***
- ***Measured optics with SC (K. Ohmi) => Re-explain the general approach. How is the coupling known? => Not discussed***
- ***Other… => Not discussed***

SUMMARY (1/3)

- New interests / ideas: beam-beam and circular modes!
- Physics of colliders, storage rings, synchrotrons
  - IOTA and possible OSC for LHC
  - LHC luminosity leveling with transverse offsets
  - Understanding of the LHC transverse instabilities at collision energy?
  - Why is the evolution of LHC bunch length in physics different in 2012 (saturating and even decreasing) wrt 2011 (increasing)
  - Solving collective effects by proper optics => Q20
  - Need to study incoherent and coherent collective effects together
- "Table-top" experiments
  - UMER
  - S-POD

SUMMARY (2/3)

- **Upgrades / new machines**
  - CSNS => Things are moving in China!
  - ISIS
  - LIU and HL-LHC
  - FAIR
  - NICA
  - CEBAF and MEIC
  - RHIC
  - Trend to inject at higher energies
- **Codes and simulation**
  - Verification and validation
  - Towards long-term self-consistency?
  - Simulations with measured parameters

SUMMARY (3/3)

- End of ESME or re-birth? Important for the community

- Montague resonance => PS experiments well explained
- Wide-band feedbacks
- Losses due to injection foil
- Analytical longitudinal impedance computation with finite length (FM + MM)
- New scaling laws for emittance growth and beam loss when crossing the 3rd order resonance

- Follow-up of last HB2010
  - Van Kampen modes seem to be confirmed by simulations and could explain observations in the SPS during ppbar

MANY THANKS TO THE ORGANIZERS
FOR THE GREAT TIME IN BEIJING

AND

ALL THE PARTICIPANTS FOR ALL
THE VERY INTERESTING DISCUSSIONS!

APPENDIX

The high intensity / high brightness upgrade program at CERN: status and challenges (Simone Gilardoni)

- LIU (LHC Injectors Upgrade) project to deliver reliably to the LHC the beams required to reach the goals of the HL-LHC (High-Luminosity LHC) project
- The injectors are quite old: PS is 53, PSB is 40 and SPS is 36 years old
- LHC currently produces ~ 1 fb^{-1} / week. ~ 1-2 fb^{-1} / day will be needed for HL-LHC => More beam brightness needed from the injectors
- Relatively good understanding of the many collective effects and possible cures => Detailed upgrade plan for the injectors has been clearly defined
  - LINAC4 (160 MeV H^-) will replace LINAC2 (50 MeV H^+) => Factor 2
  - To profit from this in PS => Increase PSB extraction kinetic energy from 1.4 to 2 GeV => Factor 1.6
  - Detailed studies of space charge (SC) effects in PSB, PS and SPS (collaboration with KEK, GSI, LBNL…)
  - Longitudinal and transverse instabilities to be cured in all the machines
  - RF limitations to be overcome, etc. What about IBSt with LINAC4 H^-?
- Example of a successful implementation these days of transverse damper in the PS
- Current goal: main LIU interventions foreseen during 2018 to start commissioning for HL-LHC in 2019 of basically 4 new machines

Status of collective effects at GSI (Oliver Boine-Frankenheim)

- In FAIR SIS-18 and SIS-100 different incoherent / coherent effects occur simultaneously => Important interplay of incoherent and coherent collective effects are studied with different simulation codes together with dedicated MDs in GSI SIS-18 and CERN PSB/PS
- Effects: incoherent SC, impedances (image currents), IBS, secondary particles
- Codes: MICROMAP, PATRIC, LOBO, VORPAL, CST Particle Studio + external tracking codes with collective effects: HEADTAIL, PTC-ORBIT, pyORBIT
- The thin resistive beam pipe is expected to be the major source for the head-tail instabilities in SIS-100
- Tune spectra for high intensities (i.e. with SC) have been studied and theory (with air-bag model) extended to include effect of the image currents (important for thick beams) => Good agreement between new theory, PATRIC simulations and measurements in SIS18 for thin beams. For thick beams, broadening of the lines (=> more Landau damping) and in this case a self-consistent space charge model is required (PATRIC simulations needed)
- Dual RF bucket: Simulations show pronounced (low-order) head-tail modes in the presence of SC (similar indications in CERN PSB experiment) => to be continued

Space charge effects in cyclotrons (Thomas Planche)

- Injection current limitation => Vertical space charge (since vertical tune generally much smaller than the horizontal one, the current limit is reached when the vertical focusing nearly vanishes) => No hard limit but a price to pay (pushing the SC limit by increasing the injection energy and the vertical focusing)
- Extraction current limitation => Longitudinal space charge: (1) No phase stability => Energy gain accumulates + (2) Non-zero dispersion => Longitudinally dependent radial motion + (3) Simplecticity => The longitudinally dependent radial motion comes with an azimuthally dependent radial motion => The beam is rotating (looking like “galactic arms”)
  - For short bunches, the charge distribution which is cylindrically symmetric is stationary. How much current you can extract depends only on how well you can match the charge distribution to the stationary one at injection!
  - Effects of the presence of neighboring turns or for long bunches (fragmentation effects) => “Gray zone”
  - The ultimate current limit of cyclotrons has not been found yet!
- SC in TRIUMF cyclotron are being revisited with a 3D simulation tool including effect of neighboring turns, using periodic boundary conditions in the radial direction => Considerably reduce the computation time

Plasma traps for space charge studies: status and perspectives (Hiromi Okamoto)

- S-POD = Simulator for Particle Orbit Dynamics (at Hiroshima University) = Tabletop experimental tool for the various SC effects in high-intensity and high-brightness hadron beams => Use of non-neutral plasmas physically equivalent (as governed by a similar Hamiltonian) to charged-particle beams in periodic AG channels
  - 3 linear Paul ion traps (operational: S-POD I, II and III) => Using a RF electric quadrupole field for transverse confinement. Longitudinal confinement by RF or electrostatic potential
  - 1 Penning electron trap (operational: S-POD IV) => Using an axial magnetic field for transverse confinement. Longitudinal confinement by electrostatic potential (+ magnetic mirror)
  - 1 new Penning trap for beam halo experiments is under construction
- Why traps? => Very compact (Paul traps shorter than ~ 20 cm in axial length), low cost (few k$), extremely wide parameter range, high resolution and precision measurement and no radio-activation
- Labview control => All experimental procedures are automatized
- Recent experiments: Collective resonance excitation; Lattice dependence of stop bands; Resonance crossing; Halo formation; Ultralow-emittance beam stability
- Experiment proposals, suggestions, and comments welcomed!

Beam loss due to foil scattering in the SNS accumulator ring (Jeffrey Holmes)

- SNS now operating at ~ 1 MW with > 10^{14} p/p @ 60 Hz and > 900 MeV
- *Overall beam loss is small and most of it downstream the ring injection stripper foil (with the 20 m) => ORBIT simulations (with full SNS ring lattice and apertures)*
- *3 # foil scattering models: 1) No scattering; 2) Small angle Coulomb scattering only; 3) Full scattering model: Small angle Coulomb scattering + Rutherford scattering + Nuclear elastic scattering + Nuclear inelastic scattering*
- *2 carbon foil thicknesses: 390 and 18000 µg/cm²*
- Results
  - Linear dependence of the beam losses on foil thickness confirmed
  - Total losses = ~ $1.8 \times 10^{-8}\,\tau$, where τ is the foil thickness in μg/cm², during the first turn following foil scattering: ~ 44% from small angle Coulomb scattering and ~ 33% from nuclear inelastic scattering
  - Full scattering model, activation measurements, and BLM readings very similar
  - Injection region losses concentrated toward outside (beam left) and above center, consistent with injection painting
  - More quantitative analysis of foil scattering and BLM results started but several unknown: BLM calibration, # of foil hits / p, etc. To be continued

Impedance studies of 2D azimuthally symmetric devices of finite length (Nicolo Biancacci)

- Model = Cylindrical cavity loaded with a toroidal material connected to circular infinite beam pipes
- Method = Find 4 vectors by using Field Matching for magnetic field (to have 3) + Mode Matching for electric field (to have the 4th)
  - Field matching: Continuity of EM field components on separating surfaces
  - Mode matching: Decomposition of the fields in summation of modes and matching of each mode coefficient by proper field projection on the correspondent mode
- Longitudinal impedance computed => Possibility to study effects of
  - Finite length
  - Non-relativistic beam velocity
  - Material
- Several successful tests performed: Thick-wall formula, CST simulations, Shobuda-Chin-Takata's model, Mounet's model
- Some applications: SPS enamel flange (thin insert), non-relativistic effects
- Next step => Transverse impedance

LHC impedance model: experience with high intensity operation in the LHC (Benoit Salvant)

- Many colleagues involved, inside and outside CERN => Many thanks!
- Transverse impedance well advanced (main focus of the last years) => Seems to be within factor ~ 2 from different measurements (1 injection equipment, TDI, is worse)
- Longitudinal impedance model should be improved (and is being improved)
- 2 current harmful limitations due to machine impedance
  - Beam induced heating of individual equipments => Can we continue and increase the beam intensity? What will happen after the restart in 2014 at ~ 7 TeV with shorter bunch spacing (25 ns instead of 50 ns) and possibly shorter bunch length (4σ nominal is 1 ns instead of ~ 1.25 used currently). Effect of ferrite under study
  - Transverse beam instabilities at collision energy (4 TeV) => Can we understand what is happening and find solutions to continue and push the performance?
    - Interplay between octupoles and beam-beam on the stability diagram => Under study
    - Interplay of impedance, octupoles, damper and chromaticity => Under study
    - 1-beam and 2-beam (impedance) MDs
    - Etc.

Resistive-wall Instability in the CSNS/RCS (Lan Huang)

- CSNS (upgrades) => Power of 100/200/500 kW @ 1.6 GeV and 25 Hz
- Resistive-wall instability studied by simulation and theory => Agreement for both injection and top energy and rise-times of few ms are obtained for 0 chromaticities
- With chromaticities smaller than 0 by few units => Horizontal and vertical instabilities are depressed entirely. The sextupoles are designed for the chromaticity correction in CSNS/RCS, and the chromaticity can be corrected to a negative value close to zero
- *Suggestion from Valeri Lebedev: Invest on a transverse damper (as we never know…)*

Longitudinal instabilities in the SPS and beam dynamics issues with high harmonic RF systems (Elena Chapochnikova)

- Longitudinal instabilities are one of the main intensity limitations and much higher intensities are required in future => LIU project
- Single RF system = 200 MHz
  - Multi-bunch effect, intensity threshold ~ 2-3 10^{10} p at flat top (450 GeV/c), short-range wake suspected (SPS TW RF systems with low Q of 150-300?)
  - Cures:
    - Active damping: RF feedback, feed-forward, longitudinal damper
    - 4th harmonic RF system (800 MHz) in Bunch-Shortening (BS) mode
    - Larger injected emittance (H. Timko's talk) + controlled blow-up
    - New Q20 optics (H. Bartosik's talk) => Double RF + blow-up still needed
    - Impedance reduction => HOMs in 2 RF systems will be studied
- High harmonic RF = 800 MHz (4th harmonic)
  - Bunch lengthening mode => Loss of Landau damping (for long bunches)
  - Bunch shortening mode => FF and FB should improve stability at high energies
- Loss of Landau damping in BL-mode for inductive impedance above transition during ppbar => Confirmation of the Van Kampen modes (Alexey Burov): meas + sim + theory

Low gamma transition optics for the SPS: simulation and experimental results for high brightness beams (Hannes Bartosik)

- **Motivation: Instabilities in the SPS, whose thresholds can be raised by operating further away from transition => Lower gamma transition to increase the absolute value of the slip factor (which is the important parameter in the beam dynamics)**
- **Old optics called Q26 (as [Q] = 26) and new one called Q20 (as [Q] = 20)**
- **TMCI**
  - **TMCI for Q26 ~ 1.6 10^{11} p/b for ~ 0 chromaticity**
  - **Simple scaling would predict a TMCI for Q20 at ~ 3.5 10^{11} p/b for ~ 0 chromaticity**
  - **No indication for TMCI with Q20 for intensities up to 4 10^{11} p/b yet**
- **Space charge**
  - **Smaller tune spread in Q20 due to larger dispersion**
  - **As chromaticity can be kept close to 0, less prone to incoherent losses**
- **Ecloud**
  - **No measurements available (as it is not a problem anymore) but more margin for Q20 from theory/simulation (factor 2)**
- **Longitudinal instabilities (Elena Chapochnikova's talk)**
- **Switch to Q20 optics for LHC filling presently in preparation…**

Optics design optimization for IBS dominated beams (Fanouria Antoniou)

- Review of IBS and calculations assuming Gaussian distributions and no coupling
- Studies for the CLIC DR (Damping Ring) = Racetrack configuration with 2 arc sections filled with TME (Theoretical Minimum Emittance) cells and 2 long straight sections filled with FODO cells, accommodating the wigglers, necessary for the fast damping and the ultra-low emittance
- TME (analytically parameterized) optimization wrt IBS => Systematic optics design optimization is important in order to mitigate the effect of IBS, which becomes important in high-brightness machines and becomes a limitation for their performance
- IBS simulation tools: SIRE (Vivoli-Martini), taking into account vertical dispersion, and CMAD-IBStrack (Demma-Pivi), which has the advantage that it can run in // mode. Work for taking into account the betatron coupling is already in progress => Hope to have it installed at CERN within the next year
- Benchmarking of the 2 codes made for CLIC DR
- IBS measurements at the SLS (ideal test bed for IBS studies as it has in particular the record vertical emittance of 1 pm rad at nominal energy of 2.4 GeV) and at the SPS with ions
- *Discussion about past work, including betatron coupling (Valeri Lebedev)*

Circular modes and flat beams for LHC (Alexey Burov)

- Can coupled optics be helpful for the LHC complex?
- Conventional X / Y betatron oscillations can be referred to as a planar optics
- Instead of X / Y eigenmodes in uncoupled case, we may have clockwise / counter-clockwise optical modes = Circular optics
- To have circular optics => Focusing has to be rotationally invariant in the transverse plane. This is provided by solenoids as focusing elements and bending magnets with special field index. With skew quads, optics could be approximately circular
- For the circular modes, emittances are nothing else as rms angular momentums for each of the modes => Beam angular momentum is their difference
- A planar-circular (linear) transformation exists from Slava Derbenev => 3 skew quads
- 2 possible applications, which need to be studied in detail (IBS issues etc.)
  - Space charge => Limit from bigger emitt. (circular) vs. smaller emitt. (planar)!
  - Luminosity => Inversely proportional to the sqrt of smaller emittance
- *Preservation of circular optics in the presence of dispersion (Giuliano Franchetti)? Of any other perturbation?*
- *Conservation of the sum of the transverse emittances? (Ingo Hofmann)*
- *Comment from Simone Gilardoni about alternating crossing in the LHC (for partial compensation of BBLR effects) => Would have to be removed…*

Scaling properties of resonances in non-scaling FFAGs (K.Y. (Bill) Ng)

- During ramping of an FFAG, betatron tunes cross many nonlinear resonances => Study here of emittance growth and beam loss crossing the 3rd-order resonance
- Past work from Chao et al. and Aiba et al.
- Experimental results not yet fully understood / explained
- Setting 20% as tolerable emittance increase or 2.5% as tolerable trap-fraction in resonance crossing, scaling laws for critical allowable resonance strength are derived (by solving Hamilton's equations of motion by perturbation)
- Pretty good agreement with experimental measurements
- This new scaling law can be useful in design of high power accelerators, estimate of emittance growth in cyclotron, and estimate of requirement of slow beam extraction using 3rd-order resonance
- A non-scaling FFAG has recently been commissioned => Experiment test suggested

- *Suggestion from Giuliano Franchetti: Try and compare with results from Aiba et al.*

PTC+ORBIT studies for the CERN LHC Injectors Upgrade project (Alexander Molodozhentsev)

- **Why PTC-ORBIT code? => To have a common environment for the single-particle dynamics (lattice analysis and resonance compensation) and multi-particle dynamics (collective effects)**
- ***Detailed space charge convergence studies made for 4 machines: PSB, PS , SPS and RCS (alternative to the CERN PS Booster upgrade and to study in particular the effect of the super-periodicity on SC) => Rms emittances and halo evolutions***
- ***Several MDs performed and PTC-ORBIT benchmarking***
  - ***Goal => Reproduce the measured beam evolutions at 160 MeV by simulations***
  - ***Good agreement was reached***
- **Multi-turn injection for the PSB with LINAC4**
  - **H- stripping injection in the H-plane, effects of the edge-focusing of the 'slow' bump-magnets, changing during the chicane reduction, compensation of V beta-beating effect, double harmonic RF system with longitudinal stacking of bunches**
  - **Next steps: Effects of FOIL, Aperture limitation and machine imperfections**
- **Space charge effects and machine resonances studies started in the PS**
- **RCS studies => Emittance growth larger for smaller symmetry…**

Effect of self-consistency on periodic resonance crossing (Giuliano Franchetti)

- PIC simulations are affected by noise, which may compete with the physical mechanisms one tries to simulate => More macro-particles => Only short-term tracking
- Long-term => Frozen SC model (i.e. source of detuning with amplitude remains unaffected by beam loss) under the assumption of small beam loss => No noise effect!
- Beam loss mechanism = periodic crossing of a resonance (due to long. motion) => Larger crossing speed through strong resonances make the similar effect of smaller crossing speed through weak resonances
- In the case of adiabatic crossing => Particles follow a dynamics determined by fixed points (trapping, Chao1976)
- In the case of non-adiabatic crossing => Particles seem to rotate around a moving point (attraction point). If the attraction point exists, then the particles are carried away by the attraction point (trapping) otherwise they are scattered by the resonance crossing
- "The close to resonance collapse" => Most dangerous case: tunes close to resonance
- Markovian ansatz (update of the beam intensity) + Markovian mapping => The "close to the resonance collapse" does not happen => In this approach, self-consistency seems to mitigate the impact on beam losses on SIS100 (good!). To be continued... + new benchmarking data in the CERN PS

Simulation and measurement of half integer resonance in coasting beams in the ISIS ring (Chris Warsop)

- ISIS developments and upgrades
  - Ongoing operations, improvements (0.2 MW)
  - Upgrade 1: New 180 MeV Linac (~0.5 MW)
  - Upgrade 2: New 3.5 GeV RCS (~1+ MW)
  - Upgrade 3: New 800 MeV Linac (2-5 MW)
- Limiting Factors: Injection, SC, Instabilities, etc. => Half integer is an important factor for all
- MD an experiment as simple as possible to try and have a straight forward observation of essential behaviour => Simplified machine and push beam towards 2 Q_y = 7 and measure beam loss and transverse profiles
- ORBIT model => halo predicted and measured on profiles (same features)
- => Promising results, but there is much further to go. To be continued

Longitudinal beam loss studies of the CERN PS-to-SPS transfer (Helga Timko)

- Continuous efforts in the past to optimise the PS-SPS transfer to reduce losses (~ 20-40% in 2004)
- Now only ~ 5 % losses for the nominal intensity (long. optimisation + less e-cloud). However, relative losses increase with intensity and a larger long. emittance is desirable for stability in the PS & SPS
- In measurements till 2011 no loss reduction could be achieved by changing the PS bunch rotation settings (S-shape phase space) => Why?
- Simulations made with ESME => All the RF manipulations included using real (measured) bunch distributions etc. but without intensity effects
- Measurements => Using the spare 40 MHz or the spare 80 MHz cavity to increase the rotation voltage (in operation: 1 40 MHz + 2 80 MHz cavities used)
- Results
  - Simulations and measurements are in good agreement and results of previous years are now also understood
  - Optimized scheme with 40 MHz RF cavity can improve transmission or margin
- Next steps => Look at intensity effects (need a tracking code with an accurate impedance model and complex longitudinal RF manipulation capabilities) + test optimized scheme with spare 40 MHz RF cavity under operational conditions

Acceleration of high-intensity protons in the J-PARC synchrotrons (Masahito Yoshii)

- **Transition-free lattice and non AC-line synched timing system allow to realize clean and high quality beam operation, which also owes to the stabilities of the linac energy and bending field of both synchrotrons**
- **Thanks to the MA (Magnetic Alloy) loaded RF systems**
  - **More than 20 kV/m of high field gradient**
  - **Dual harmonic operation in the RCS**
  - **No radial tuning loop and the full digital LLRF offer simple, precise and reproducible longitudinal beam control**
  - **Time-jitter of extracted beam from the RCS is only 1.7 ns**
- **Multi-harmonic RF feedforward system has been developed to compensate a heavy beam loading => The systems are used for the routine operations at RCS and MR and reproducible and offer an excellent suppression of impedance seen by the beam**

Longitudinal space charge phenomena in an intense beam in a ring (Rami Kishek)

- UMER is a research machine of 3.7 m diameter, using low energy e^-, to study space charge effects
- After 1/2012 a better transmission was obtained (initial fast losses were removed) thanks to re-alignment
- Motivation for this talk => What happen to a “noisy beam”?
- 2 recent longitudinal studies: SC induced Multi-Stream instability and Solitons in SC-dominated beams
- SC induced Multi-Stream instability
  - Predicted by Hoffman1990
  - Experimental observation for short bunches by Appel&Boine-Frankhenheim2012
  - UMER new results for long bunches
- Solitons in SC-dominated beams
  - Solitary waves (i.e. large-amplitude waves that persist and retain their shape for long distances) were discovered by J. Scott Russell in 1834. Then…
  - UMER new observation of solitons (when nonlinear steepening balances wave dispersion) and soliton-soliton interaction => Very good agreement between meas. and simulation

Measurement and simulation of luminosity leveling in LHC via beam separation (Stefan Paret)

- Collisions with transverse offset and/or crossing angle => Reduction of L
- Leveling with transverse offset is a possibility for HL(High-Luminosity)-LHC => Discussed here
  - Loss of symmetry => Coherent BB kick (deflection) + decoherence (emittance growth)
- Measurements done in the LHC
  - Collisions in 4 Interaction Points (IPs)
  - Separation varied in IP8 from 0 to 2.5 σ_x in 0.5 σ_x steps
  - Measurement of emittance and L at all IPs
- Simulations done with BeamBeam3D with a simplified collision scheme
- Conclusions
  - Luminosity vs. offset (in IP8) => Very agreement between theory, sim. and meas.
  - Luminosity leveling with offset has been demonstrated
  - No side effects have been observed

- *Comment: discussions about the last point as during operation, the beam became often unstable over the last few months with few σ sep. => Not yet fully understood*

RHIC beam-beam effects (Yun Luo)

- Maximum BB parameters
  - Au-Au (heavy ions) runs => 0.003 with NAu = 1.3E9
  - p-p (polarized) runs => 0.017 with Np = 1.7E11 (and trans. emitt. ~ 2.5 microm)
- Current nominal working point (28.695, 29.685): between 2/3 and 7/10 resonances
- When beams brought into collision => Fast beam loss in the first 1-2 hours (mechanism still to be understood) and then small loss in the rest of store
- BB is the dominant factor for beam lifetime with collision
- No clear transverse emittance growth observed in the store => Particles lost in the transverse plane due to limited dynamic aperture
- In 2011-2012 p-p runs, ~ 20% bunch lengthening measured in the typical 8 h store. IBS should contribute only ~ half
- Beam-beam coherent mode was routinely measured with a phase-lock-loop tune meter kickers. Pi-mode can only be seen in the vertical plane
- Other limitations: low beta* lattices, $3Q_{x,y}$ resonances, 10 Hz orbit oscillation
- Next luminosity goal is to double current luminosity by increasing the proton bunch intensity from 1.7E11 up to 3.E11 with an upgraded polarized proton source
- e- lens project (HOBB compensation) => Started installation in 2012 and expect up to 2 times more luminosity

Effects of magnetic field tracking errors and space charge on beam dynamics at CSNS/RCS (Shou Yan Xu)

- The preferred working point of CSNS/RCS is (4.86, 4.78), which can avoid the major low-order structure resonances. But because of the chromatic tune shift, space-charge incoherent tune shift and the tune shift caused by magnetic field tracking errors, some structure resonances are unavoidable
- These 3 factors induce beta function distortion, and influence the physical acceptances, the acceptances of collimators and the painted emittances for the case that the collimator aperture and the painting scheme remain unchanged
- There are serious beam losses when the magnetic tracking errors are not compensated. Maybe, by the optimizations of painting, the beam losses can be decreased
- The tracking errors can be adjusted within 0.1 % by compensating by using higher frequency waves for the prototype quadrupole magnet. The simulation results show that there is no serious beam loss for the tracking errors less than 0.3%

Dual-harmonic acceleration studies at CSNS RCS (Jinfang Chen)

- Dual-harmonic acceleration schemes designed for CSNS-II (500 kW) and CSNS-I (100 kW) => Simulated tune shifts considerably improved
- Special θ pattern designed for CSNS-II to have
  - Largest bunching factor at low energy stage
  - Largest bucket area at middle and high energy stages
- Stationary-injection method (which unlocks the RF with main magnet field during the injection time and locks them again after injection) is found useful to obtain a good longitudinal painting after injection
- Self-made code: RAMADH

High intensity longitudinal dynamics studies for an ISIS injection upgrade (Robert Williamson)

- ISIS above KSB circle threshold by a factor ~ 6
- Coasting beam criterion (KS) exceeded during injection
- 3 injection schemes studied
- Longitudinal constraints met
- In-house dynamics code developed
- Results suggest 180 MeV injection feasible
- 3D dynamics studies ongoing
- Further instabilities research required
- Current work and plans
  - Experimental program to investigate longitudinal instabilities
  - Storage ring mode, DC main magnet:
    - With RF on at fixed frequency (KSB test)
    - With RF off (KS test)
  - In-house 3D PIC code being developed

Quest for superior ion beams for Electron-Ion Collider (Yuhong Zhang)

- CEBAF upgrade to 12 GeV
- Conceptual design of an electron-ion collider (MEIC) was completed
- Ion beams with ultra high bunch repetition rate, low intensity but high brightness must be produced and stored to support the high luminosity of the collider (up to 1.4 10^{34}). Such beams have never been produced before
- The design concept of a new ion complex has been developed to specifically address these challenging issues, including suppressing space charge and intra-beam scatterings
- Circular optics considered to realize the matched electron cooling for diminishing the space charge impact
- A test facility based on JLab ERL FEL was proposed for a proof-of-principle experiment for the ERL-circulator electron cooler design concept. Expect to complete this experiment in 3 years
- Design optimization (cost reduction/staging option) and other R&D are also in progress

Test of optical stochastic cooling in Fermilab (Valeri Lebedev)

- Follow-up of the talk given 2 years ago (Optical stochastic cooling in Tevatron)
- Optical stochastic cooling proposed
  - Suggested by Zolotorev, Zholents and Mikhailichenko (1994) but never tested experimentally
  - Same as normal stochastic cooling except the much larger BW (~ 200 GHz) => Undulators replace PU and Kicker
- IOTA = Test ring for Non-Linear Optics and Optical Stochastic Cooling => Experimental study planned to validate the cooling principles
- Optical stochastic cooling looks as a promising technique for the LHC => Would allow well controlled luminosity leveling + potentially can double its average luminosity

Measurement of Extended Twiss parameters and space charge effects (Kazuhito Ohmi)

- Measurement of Extended Twiss (E-Twiss) parameters using turn-by-turn monitor in J-PARC MR
- Linear envelope theory using the measured E-Twiss parameters
- Simulation of SC effects using the measured E-Twiss parameters
  - x-y coupling at sextupoles seems dominant for the beam loss

Space charge effects in the NICA collider ring

(Oleg Kozlov)

- Construction at JINR of a new accelerator facility
- 2 regimes
  - SC-dominated: $\tau_{cool} < \tau_{IBS}$ => 1-3 GeV/u
  - IBS-dominated: $\tau_{cool} = \tau_{IBS}$ => 3-4.5 GeV/u
- Beam cooling techniques are used
- Stochastic cooling sufficient for IBS suppression and beam stacking
- Electron cooling can be used for cooling in the total energy range
- Electron cooling can provide effective stacking at small energy only

- *Comment from Alexey Burov: the beam brightness is usually not limited by coolers but by instabilities, which should be carefully studied (Tevatron experience)*
- *Comment from Elena Chapochnikova: careful study of beam loading*

Broad-band transverse feedback against e-cloud or TMCI: status and plan (Claudio Rivetta)

- Motivation: Control electron-cloud (ECI) and Transverse Mode Coupled (TMCI) instabilities in SPS and LHC via broad-bandwidth feedback system
- Important progress in the different R & D areas of the project during the last year
- Building a proof-of-principle channel for closed loop tests in SPS before the 2013 shutdown, using existing kicker and pick-up
- Kickers => LNF-INFN, LBL and SLAC Collaboration. Excellent progress 2012, and goal is to evaluate 3 proposals
  - Stripline (Arrays? Tapered? Staggered in Frequency?)
  - Overdamped Cavity (transverse mode)
  - Slot and meander line (similar to stochastic cooling kickers)
- Nice SPS MD results driving a single bunch
- Macro-particle simulation codes being performed with a realistic feedback system
  - CMAD, HEADTAIL and WARP

- *Comment: Try and re-do the SPS measurements at much lower intensity (to reduce considerably SC) to see if the lower head-tail modes can be excited*

Fully 3D long-term simulation of the coupling resonance experiments at the CERN PS (Ji Qiang)

- SC effects is a dominant factor limiting the bunch intensity
- Montague resonance can lead to particle loss in plane of smaller emittance / aperture
- 2 MDs in PS used since as benchmarking experiments
  - Static
  - Dynamic
- Simulation studies with 1) # ramping times but fixed synchrotron period and 2) different synchrotron periods but fixed ramping time => Only partial transverse emittance exchange was found already in the past
- IMPACT code => Many improvements over the last years and used in many projects
  - // PIC code using z as independent variable, split-operator, etc.
- Simulations done for the PS for all the measurements performed
  - The 3D self-consistent SC simulation reproduce all the experiment data reasonably well