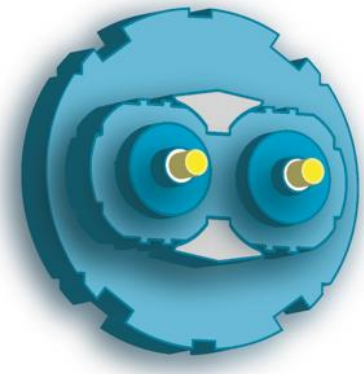

High Luminosity LHC

RLIUP Session5 Summary

Massimiliano Ferro-Luzzi and Oliver Brüning

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Session Goal:

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- Review the HL-LHC upgrade plans related to the ion physics program and summarize the required machine upgrades.
- Analyze the options for extended ion runs during the connection of LINAC4 to the PSB.
- Review the schedule and operation options for the ion beam operation during the HL-LHC period.

Session Content:

- Experiment perspective.
- Performance of the injectors with ions after LS1.
- [Options for running the LHC with ions during the LINAC4 connection].
- How to run ions in the future?
- Future heavy-ion performance of the LHC.

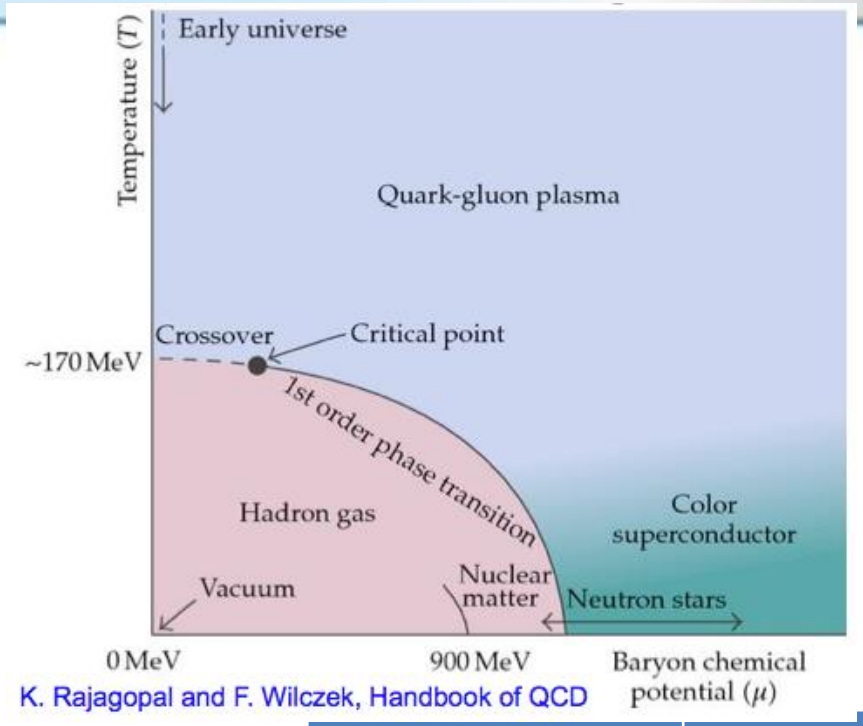
Experiments: [Emilio Meschi]

- Physics highlights:
  - Quark-Gluon plasma and phase transition and the search for the critical point.

- Physics requirements - wishes:
  - Need for control experiments (p-p data taking and p-Pb runs and runs at intermediate beam energies [e.g. Pb-Pb @ 5Tev, 5.5 TeV, p-Pb @ 5 TeV and 8.2 TeV]).

    ➔ all asymmetric collision configurations imply configuration change between Beam1 and Beam2!

    ➔ requires different machine configurations as compared to p-p operation!
  - p-p runs require 5 order of magnitude lower luminosity in ALICE as for the GP experiments ➔ Is it worth the effort?
  - Background considerations require a vacuum of 5 10^{-9} or better.



Physics:

Run 2: ALICE

Year	System	Luminosity
2015	pp – min bias (24 weeks)	10^{29}-10^{30} $cm^{-2}s^{-1}$
	Pb Pb – 4 weeks	10^{27} $cm^{-2}s^{-1}$ - leveled
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2018	LS 2	

Experiments Perspective:

- Performance wishes:
  - 3nbarn^{-1} by LS3 in ATLAS. All experiments like to collect at least 1nbarn^{-1} during RunII.
  - 10nbarn^{-1} for ALICE after upgrade during LS2.
  - LHCb: p-Pb NOT at the end of ion program of RunII ➔ compatibility with ALICE plan?
  - ALICE requires leveling during Pb-Pb and p-Pb (while ATLAS and CMS do not) ➔ coordination!!!
  - The Pb-Pb runs in 2015 and 2016 can NOT be grouped (trigger configurations) ➔ what is the minimum run separation times?
  - LHCb would like 10 times more integrated luminosity with p-Pb as compared to Run1.
  - All experiments prefer NOT to group the ion runs
  - ALICE polarity reversals on regular basis.
- Performance wishes after LS2:
  - Different beam species: Pb-Pb, p-Pb, Ar-Ar, p-Ar
  - 10 fold increase in beam performance expected from ALICE ➔ collimation upgrade and vacuum conditions?
  - LHCf interested in running with Nitrogen and Oxygen? ➔ Physics case @ LHCC required!

Performance of the injectors with ions after LS1: [Django]

- Performance summary of RunI:
  - 2 bunches with 200ns spacing in the PS ➔ 24 bunches in the SPS ➔ 360 bunches in the LHC @ collision
- Upgrade Plans:
  - Increasing the bunch intensity is not a viable option (IBS and luminosity burn off)
  - 100ns batch compression in the SPS (already envisaged for RunII in the PS but without the SPS injection upgrade ➔ 432 bunches for RunII).
  - Increasing the number of injections would increase the injection time and thus the emittance growth ➔ keep the number of PS injections into the SPS at 12 ➔ requires SPS injection system upgrade (recuperated equipment from PSB energy upgrade, not requiring new kicker magnets) ➔ 624 bunches in the LHC @ collision
  - Requires higher bunch intensities in LEIR (already above design and currently limited) ➔ further studies required
  - Slip stacking in the SPS to be re-evaluated ➔ smaller bunch spacing (e.g. 50ns?)
  - LINAC3 pulsing @ 10Hz (source already pulsing @ 10Hz)

How to run ions in the future? [Detlef Kuchler]

- Performance summary of RunI:
  - Records:
    - 215 eμA Pb^{27+} out of the spectrometer
    - 31 eμA Pb^{54+} at the end of the linac
  - Operational:
    - 100-120 eμA Pb^{29+} out of the RFQ
    - 20-25 eμA Pb^{54+} at the end of the linac (TRA25) (≈ 50% of the design value)
    - Changing ion species takes time (4 weeks Pb-> Ar & 10 weeks Ar -> Pb)
- Upgrade Plans:
  - 10Hz operation of the LINAC3 (source already running @10Hz)
  - Multi-charge acceleration.
  - New Oven design and test-stand (ca. 5MCHF)!
- Wishes and requirements:
  - Dedicated ion run in 2015 for Machine Development and tests

Future heavy-ion performance of the LHC: [John Jowett]

- RunII performance projections:
  - Bunch-by-bunch luminosity model (IBS and SPS injection)
  - 2.8 10^{27} cm^{-2} s^{-1} for ATLAS and CMS for Pb-Pb @ 6.5 Z TeV with 2011 scheme
  - 3.7 10^{27} cm^{-2} s^{-1} for ATLAS and CMS for Pb-Pb @ 6.5 Z TeV with 100ns BC.
  - Changing the magnetic configuration wrt the standard p-p run will take 1 to 2 days.
  - Before ALICE upgrade luminosity needs to be leveled at 1 10^{27} cm^{-2} s^{-1} (ATLAS and CMS are not limited in peak luminosity).
  - Luminosity decay dominated by burn-off
  - p-Pb: 2.5 - 7 10^{29} cm^{-2} s^{-1} @ 4 Z TeV/c and 4.3 - 12 10^{29} cm^{-2} s^{-1} @ 7 Z TeV/c

    ➔ BPM resolution!
- RunIII projections:
  - 6 10^{27} cm^{-2} s^{-1} for Pb-Pb @ 6.5 Z TeV with 100ns batch compression and SPS injection system upgrade (6 x design).
- Peak luminosity limitations:
  - Bound Free Pair Production and Electro Magnetic Disintegration and resulting secondary beams ➔ DS collimators
  - IBS!!! ➔possibility of Stochastic Cooling a la RHIC, 200MHz and 800MHz RF in LHC?

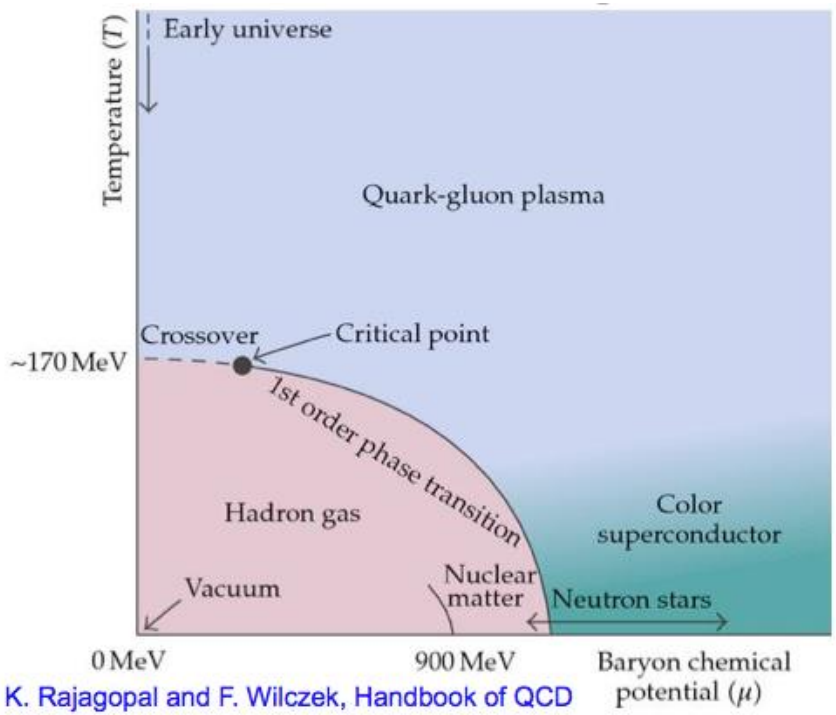
Summary and Questions:

- LS1.5 (9month shutdown between LS1 and LS2) is not desired by experiments.
- ALICE needs a clear commitment to a 'standard running scenario' but exceptional modifications for a given year are possible.
- Promising upgrade options for the machine should be further pursued (e.g. Stochastic cooling, 200MHz and 800MHz RF).
- Operation with different ion species needs to be requested well in advance! LHCC recommendation?
- Beam rigidity and machine configuration requests?
- DS collimators for IR1 and IR5 not yet foreseen!
- Injector: one could connect LINAC4 (50MeV protons) in 12 weeks but at reduced performance and without gain for LS2

  ➔ LINAC2 backup and BCMS still to be analyzed
- LS2 duration with LINAC4 connection (as H- injector) will take 20.5 month (LINAC4 proper will take 9 month)

Reserve Transparencies

Heavy Ion Physics



K. Rajagopal and F. Wilczek, Handbook of QCD

- pp physics probes quarks and gluons as "free particles"
- Nuclear physics studies the bound states
- HI physics studies the intermediate phases of QCD matter which prevailed shortly after the big-bang

- QGP: what is it
  - A theoretical model of the phase of matter where partons are not (completely) confined
  - Produced in High-energy nucleus-nucleus interactions
  - Large energy density (~15 GeV/fm^3 at LHC) over a large volume (~ 5000 fm3 at LHC)
  - Very high equivalent temperature (T~300 MeV)
  - Strongly interacting
- How it is studied
  - **Jets:** energy loss mechanism - collective effects in QCD, medium density
  - **Heavy flavour:** mass dependence of energy loss - probe the medium transport properties
  - **Quarkonium:** quarkonium dissociation and regeneration - probes deconfinement and medium temperature
  - **Low-mass di-leptons:** thermal radiation γ (→e+e-) - to map temperature and evolution
  - **Proton-Ion**: collective effects

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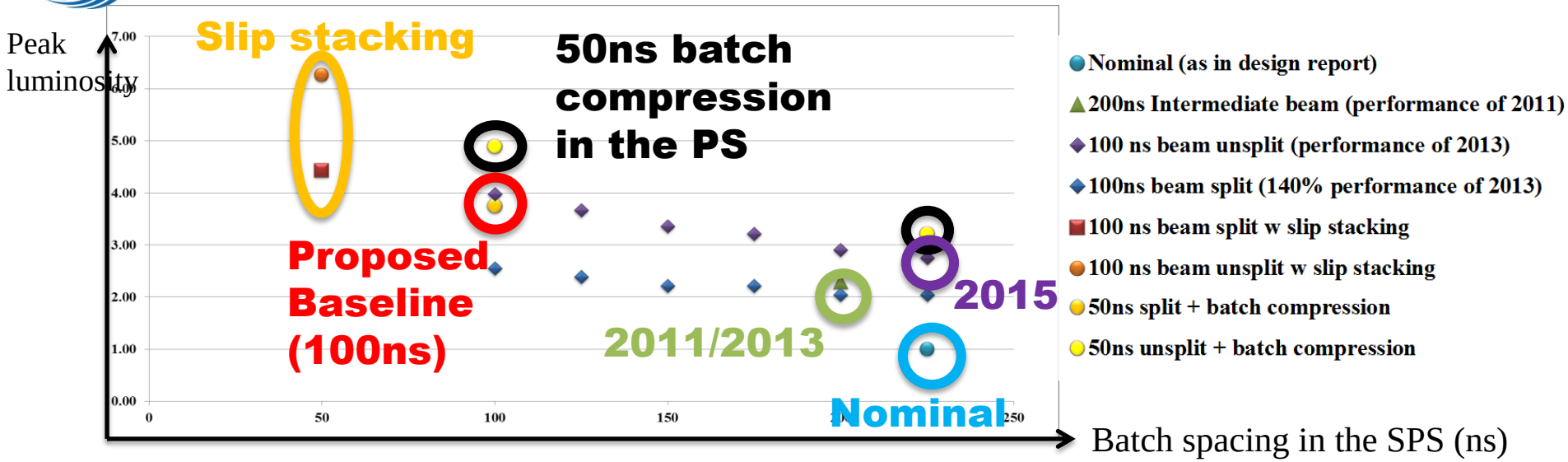
2018	LS 2	

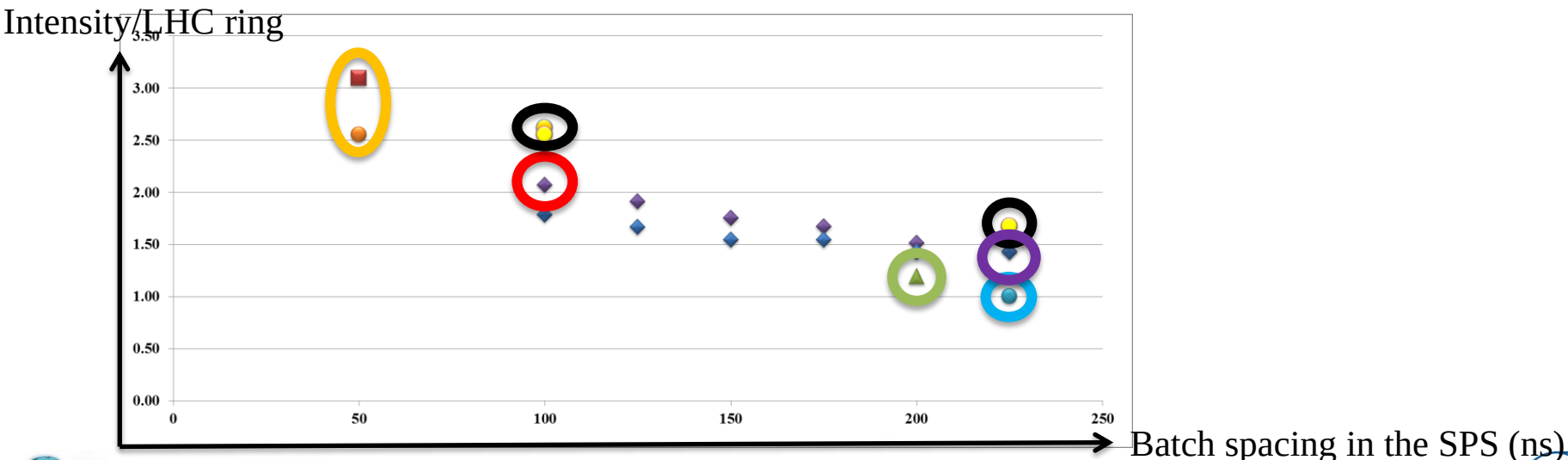
- For 2015 pp need 5 orders of magnitude luminosity reduction in IP2
  - no filling scheme tricks available at 25ns ~all bunches collide in ALICE (except effect of abort gap)
  - Larger β* not an option due to aperture issues in IP2
  - A separation of order 5σ seems to be needed
  - Would the level of background in IP2 be lower than signal? Will depend on quality of vacuum
- ALICE studied the beam-gas background conditions in LSS2-L assuming a 5 10^{-9} vacuum.
  - the result is a rather strong MB trigger contamination (~50%) at L=1 10^{29}. on the other hand the contamination at L=1 10^{30} is ~10%, but a pileup of 10 in the TPC is the price to pay.
  - Further studies of optimization will be performed based on these results

Upgrades and studies

- Linac 3: increase intensity
  - ✓ 10Hz pulsing (included in consolidation - PIC)
  - ? multiple charge acceleration (unsure of benefit for LEIR)
- LEIR: Intensity limitation
  - ? ~+40% needed for additional splitting, but cause presently unknown
- PS: 50ns splitting or batch compression near transition
  - ✓ ? Tests of 2-bunch batch compression to 50ns with Ar
  - ? New cavity (Finemet)
  - Transition-distortion optics; imperfections?
- SPS
  - ✓ PFL on MKP + MSI-V septum for 100ns rise time injection / batch spacing
  - ? New beam control allowing RF gymnastics for slip-stacking
  - Are resulting imperfections after slip stacking acceptable by the LHC?
  - ✓ Improvement of beam behaviour on flat bottom (RF noise…)

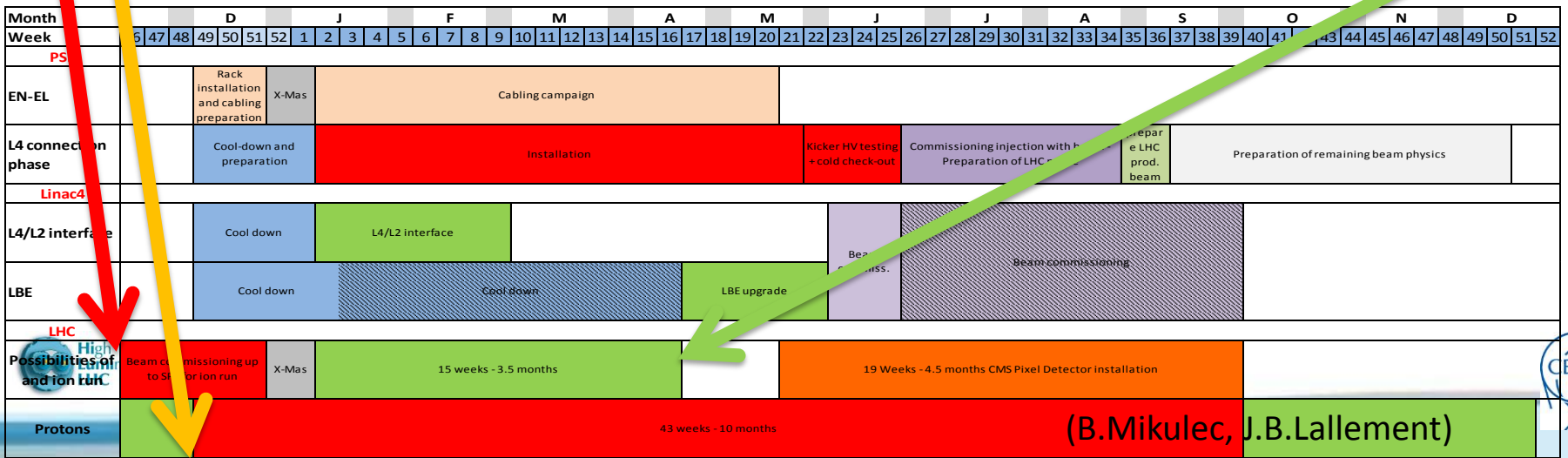
Pb-Pb Summary: Peak luminosity & intensity (w.r.t. nominal) according to different schemes





Schedule with LS1.5

- Ar 2014-2015 … first Pb-Pb run in November 2015 same as baseline
- Xe commissioning (Linac3/LEIR/PS/SPS) start early 2016 + FT Run in September 2016
- Switch to Pb November 2016, recommission Pb ion chain
- Stop protons 3 weeks before Xmas break
- Pb source standby during Xmas (cf Xmas 2012)
- Restart Pb ion chain in January
- 3.5 (max) months Pb run:
  - Ion MDs in chain
  - Primary Pb in NA
  - 8+ week LHC Pb-Pb run (grouping of 2016 & 2017 “November” runs)
- Restart with protons, next Pb ion run as p-Pb just before LS2 (2019?)



(B.Mikulec, J.B.Lallement)

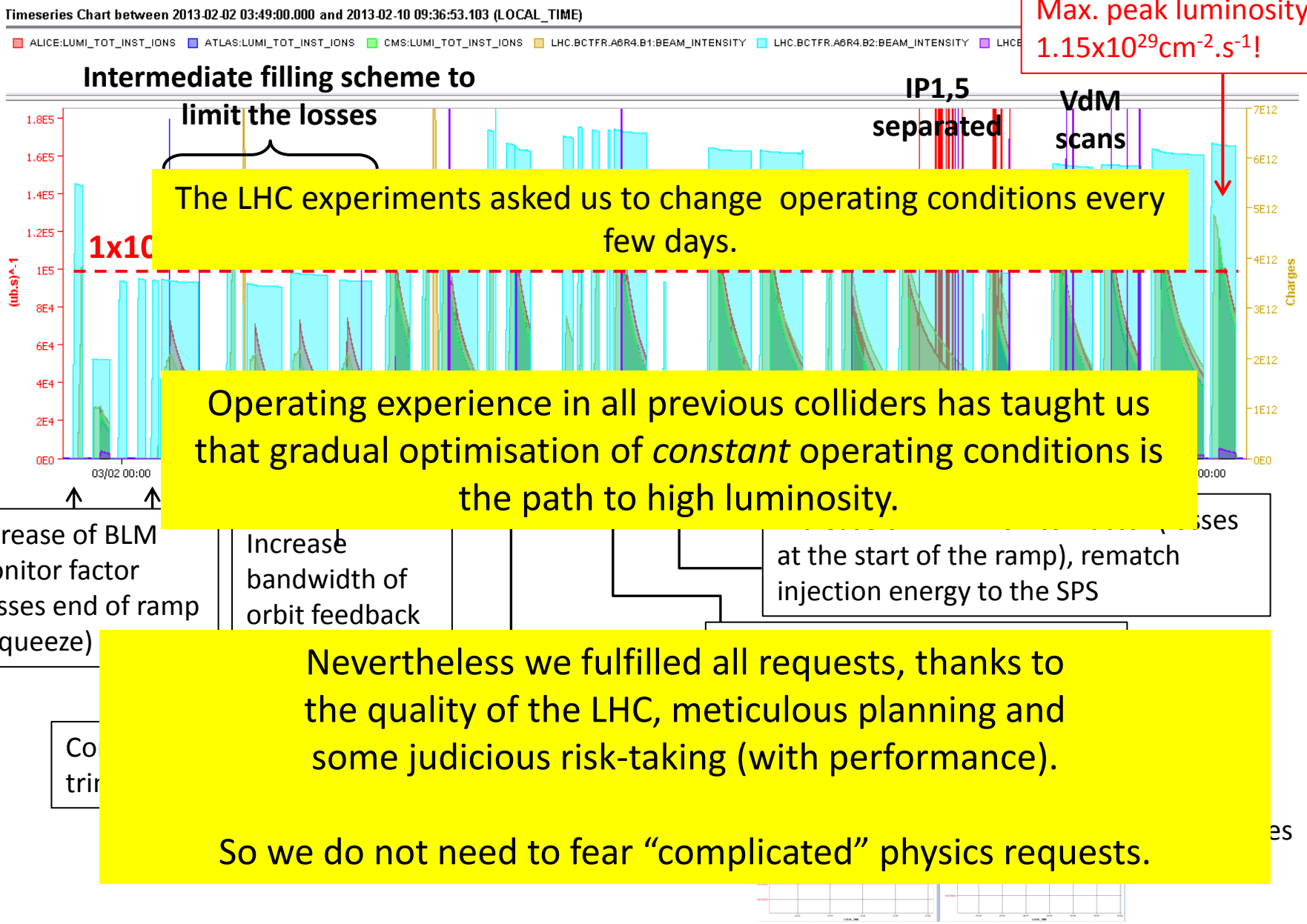
Design Baseline and Performance Achieved

"p-Pb not part of baseline"

	Pb-Pb				p-Pb	
	Baseline	**Injection 2011**	**Collision 2011**	**Injection 2013**	**physics case paper**	**2013**
Beam Energy [Z GeV]	7000	450	3500	450	7000	4000
No. Ions per bunch []	0.7				0.7	
Transv. normalised emittance []	1.5	---			1.5	---
RMS bunch length []	7.94				7.94	
Peak Luminosity []	1	---		---	115	110

$= 2 \times$ design scaled with E^2

Reminder: Pb-p luminosity production in 2013



Performance for p-Pb in Run 2

E (Z GeV/c)	4	7
	4264	7463
(10^{10} protons/bunch)	1.8–5?	1.8–5?
(10^{8} ions/bunch)	1.6	1.6
	430	430
(m)	0.5	0.5
(μm.rad)	3.5	3.5
(μm.rad)	1.5	1.5
(kHz)	11.245	11.245
(10^{29} cm^{-2}.s^{-1})	**2.5–7?**	**4.3–12**
(nb^{-1})	**60 (up to 180?)**	**110 (up to 300?)**

- Increasing the proton intensity is constrained by Pb stability (moving long range encounters), and arc BPMs capabilities (still uncertain),
- 5 10^{10} p/bunch is the maximum reachable in any case,
- Number of bunches per beam is taken from "baseline scenario" for Pb-Pb run in 2015-2016,
- Integrated luminosity assumes same integrated over peak luminosity ratio as in 2013.
- ALICE will level at ~10^{28} and 10^{29} cm^{-2}s^{-1} in Run 2