CERN

SPS aspects

Gamma Factory meeting
March 2019

Y. Dutheil, B. Goddard, F. Velotti

Layout

- SPS operational considerations
- Phase 1 : resonance finding
- Phase 2 : photon flux optimization
- Phase 3 : cooling demonstration
- Accurate resonant energy measurement
- Conclusion

Operational considerations

- The SPS may run in two different modes
  - Coasting mode where the beam is injected, accelerated and maintained for any length of time
  - A cycled mode where the beam is maintained for up to 10/20s
- Cycled operation is favored as it allows multiple user to use the SPS in parallel
  - Cycles (up to 10/20s) with a repetition rate of 30/60s
  - Phase 1 resonance finding could make best use of cycled operation
- Coasting mode imposes the dedication of the SPS to the experiment
  - Allocated in shifts of 8/10 hours for up to maybe 3 shifts per year
  - Considered for end of phase 2 + phase 3

Phase 1, resonance finding

- Multiple dimension overlap required to achieve excitation
  - Horizontal & vertical positions matching
  - Energy matching
  - Time matching

- All dimensions need simultaneous overlap to induce ion excitation and observe the emitted photons
  - Ion-laser interaction off the resonance cannot be observed

Phase 1, resonance finding : procedure

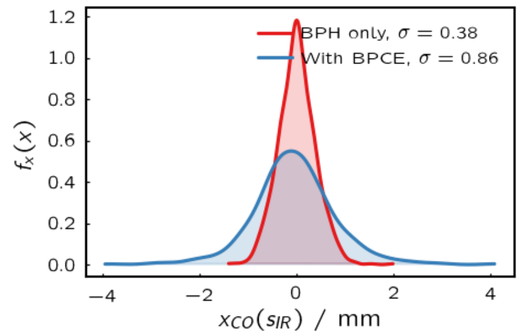
- Use a cycled SPS
  - Relaxed time constraints as it is operated in parallel with other users
  - SPS systems functions are preloaded
    Beam shape (optics) and position cannot be changed during the cycle based on observations (feedback)

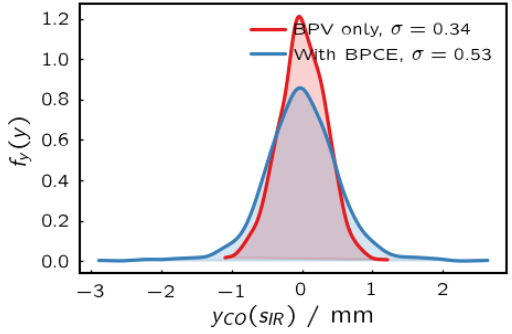
- Systematic scanning in 4 dimensions of the parameters space
  - Fully automatized, from parameter set to beam and instrumentation recording.
    Intrinsically possible to be done with the SPS control but requires development time

Phase 1, resonance finding : beam position

- Beam position accuracy is dominated by BPMs and quadrupole misalignment while reproducibility is limited by magnet field an current changes
  - Preliminary estimations place the beam position accuracy to ~0.5mm in both planes and its reproducibility to less than ~0.2mm/0.05mm for horizontal and vertical planes.
  - Initial resonance finding may require a scan of the ion beam position by up to 2.5mm or 5 steps of 0.5mm in each plane for a total of 25 positions.

- Beam position may be changed within 10ms allowing the space to be scanned within 0.25s
- Once the maximum overlap position is identified the reproducibility should have a small, but non negligible, effect





Phase 1, resonance finding : ion beam energy

- Beam energy accuracy is dominated by the uncertainty on the integrated dipole field along the beam trajectory
    - Accounting for ion beam energy accuracy, stability and interaction angle preliminary estimation places the upper bound of the uncertainty at 0.1%
    - Reproducibility of the energy should be better than 0.03%, small compared with the laser bandwidth of 0.1%

- Energy of the beam may be changed Constant-Optics scaling
    - was recently developed for slow extraction and allows energy change independent from beam optics or position
    - We consider a scanning of the energy over a range of ±0.1%, in 10 steps
    - Each energy step could take 10ms so the complete energy scan may take 0.1s

Phase 1, resonance finding : ion bunch timing

- Laser pulse is up to 100ps at 40MHz and Ion bunch is 210ps, at most at 13MHz
  - Initial overlap cannot be known but reproducibility should be very good and much lower than the ion bunch length of 210ps

- Systematics scanning of the timing will be needed for initial resonance finding
  - Specifics and procedure to be discussed as it depends on the approach agreed to synchronize the laser to the ion bunch

Phase 1, resonance finding : scanning plan

- Scanning if 4 dimension
  - 25 steps in transverse beam position
  - 10 steps in energy
  - For instance 10 steps in timing
  - Total of 2500 sets, possibly explored in as little as 25s if we consider 10ms per setting

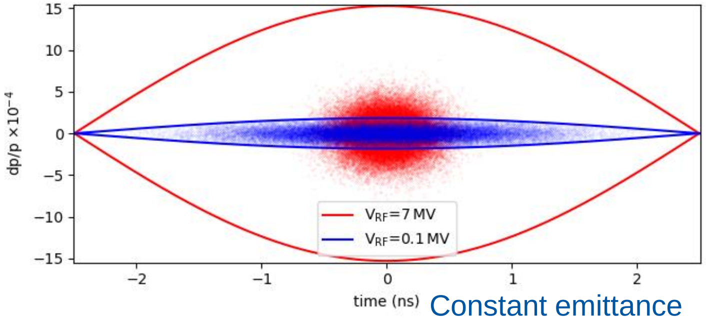
Table 11.2: Parameters, scanning ranges and steps for resonance finding stage

Parameter	Unit	Value	Spread/error	Scan steps	Step size
Laser pulse phase	ns	0	-	50	0.5
SPS γ_R		96.3	± 0.05	10	0.02
Laser wavelength	nm	1034	± 0.5	-	-
H/V beam position	mm	0	± 2.5	5	0.5

- Cycled operation would make even such large number of machine settings easily explored
  - Will require a full automation of the machine setting generation and clean recorded data storage
  - Photon detection system capable of measuring ~0.1% of maximum flux within 10ms

Phase 1, resonance finding : dilution plan

- In addition or instead of systematic scanning one could consider beam dilution to achieve the first ion excitation
  - In the transverse plane the existing damper could be used to increase the transverse beam size up to the machine acceptance of ~42x18mm at the IR
  - In the time dimension, the voltage could be reduced to increase the bunch length up to the bucket length of 5ns
- This technique is limited by the instrumentation, in particular the photon detection system
  - Details and limits will can only be discussed once the photon detection system will have been decided



Constant emittance

Phase 2 : optimizing the photon flux

- Phase 2 aims at optimizing the ion beam excitation and photon production
  - To maintain resonant conditions for arbitrary long times
  - To reliably reproduce optimum resonant conditions
  - To reliably target specific parts of the beam in energy
- In practice phase 1 will produce one set of optimum machine settings
  - Systematic scanning near this set will provide the optimum machine setting
  - Continuous measurement will provide information on stability and reproducibility
- Switch to coasting SPS operation
  - Do we expect more stability and reproducibility issues ?
  - Do we need to consider a live feedback system (on ion momentum, timing and position) to maintain the resonant condition?

Phase 3 : cooling demonstration

- Using coasting operation and long flat-top times (~100s)
- We could consider using the existing wall current monitor to observe the longitudinal cooling. It has a resolution of 5ps and enough sensitivity to detect the ion beam

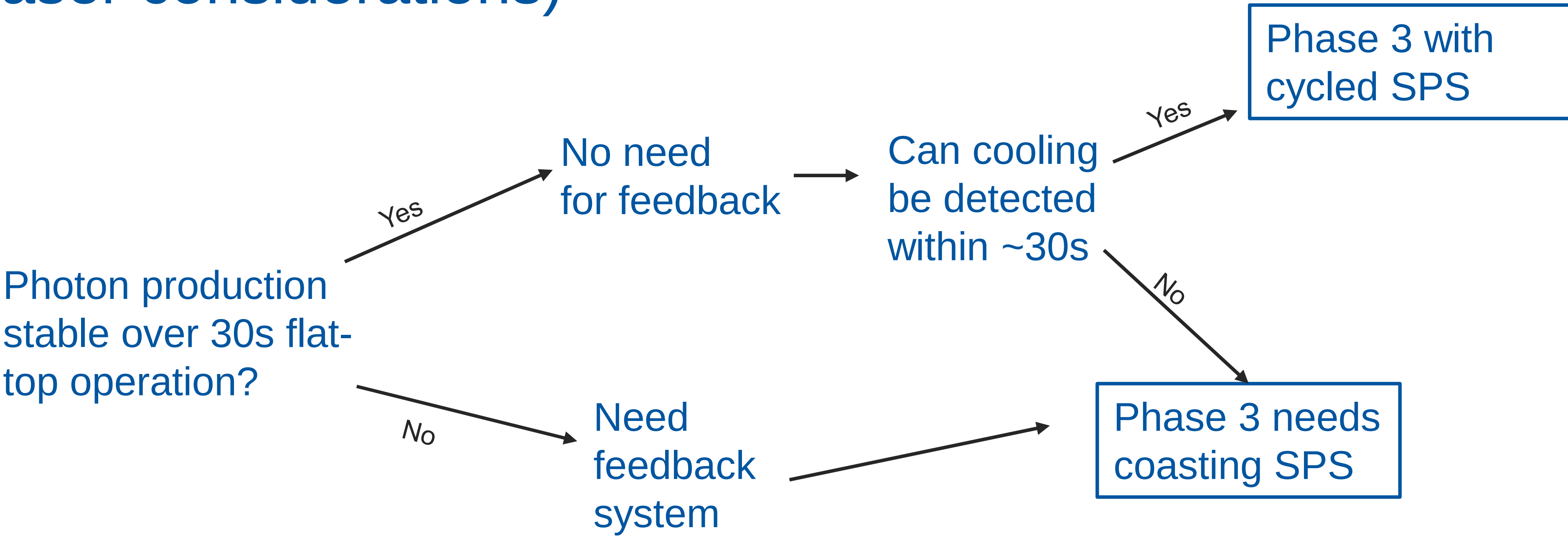
- Can we consider observing cooling with cycled SPS operation and up to 20/30s flat-top?

Accurate transition energy measurement

- The accurate measurement of the resonant energy mainly depend on the understanding of all the systematics influencing the ion beam energy

- No specific steps is foreseen but much of the work will be carried on in parallel such as energy calibration using two different partially striped ion species.

Cycled/coasting operation decision tree (disregarding laser considerations)



*Machine parameters cannot be changed in cycled operations

SPS parameters

- Continuously updated parameter table available on the SharePoint Workspace
  - https://espace.cern.ch/PBC-acc-GammaFactory/default.aspx
  - https://espace.cern.ch/PBC-acc-GammaFactory/Documents%20tracked/PoP_parameters_table.xlsx?Web=1
  - Version controlled so anyone can change it directly

Category	Parameter	Unit	Value
Geometry	Laser-beam angle	deg	2.60E+00
	Cavity length	m	
	IR S-location	m	
Beam parameters	Energy	GeV	18652.59
	Rigidity	T.m	787.53
	Equivalent proton energy	GeV	251.63
	Intensity	ions/bunch	2.00E+08
	H/V normalized emittance	mm.mrad	1.5
	Momentum spread rms		2.00E-04
	Bunch length σ	ps	210.00
	σx	mm	0.990
	σy	mm	0.946
SPS paramters	Revolution time	s	2.30E-05
	RF voltage	V	7.00E+06
	Harmonic number		4.62E+03
	Transition energy	GeV protons	2.28E+01
Lattice paramters at IR in LSS6 616	alphaX	rad	1.2915
	betaX	m	62.4
	alphaY	rad	-1.205
	betaY	m	57.5
	Dx	m	-0.4445
	D'x	rad	-7.85E-04
	Dy	m	0
	D'y	rad	0

Conclusion

- A path to the PoP experiment is proposed and so far no show-stopper has been identified
  - Work on the controls, data logging and operational software can start now for tests after the shutdown, in 2021

- Next steps :
  - Detailed specifications of the controls and operational software capabilities
  - Precisely quantify beam position and energy accuracy and reproducibility. Some measurements with beam can be done in 2021

Thank you