



# LHC Injectors Upgrade





## LHC Injectors Upgrade

# LIU-PSB&PS: Main 2015 Findings and Achievements and Main Objectives for 2016

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G. Sterbini

The LIU-PSB and LIU-PS Working Groups

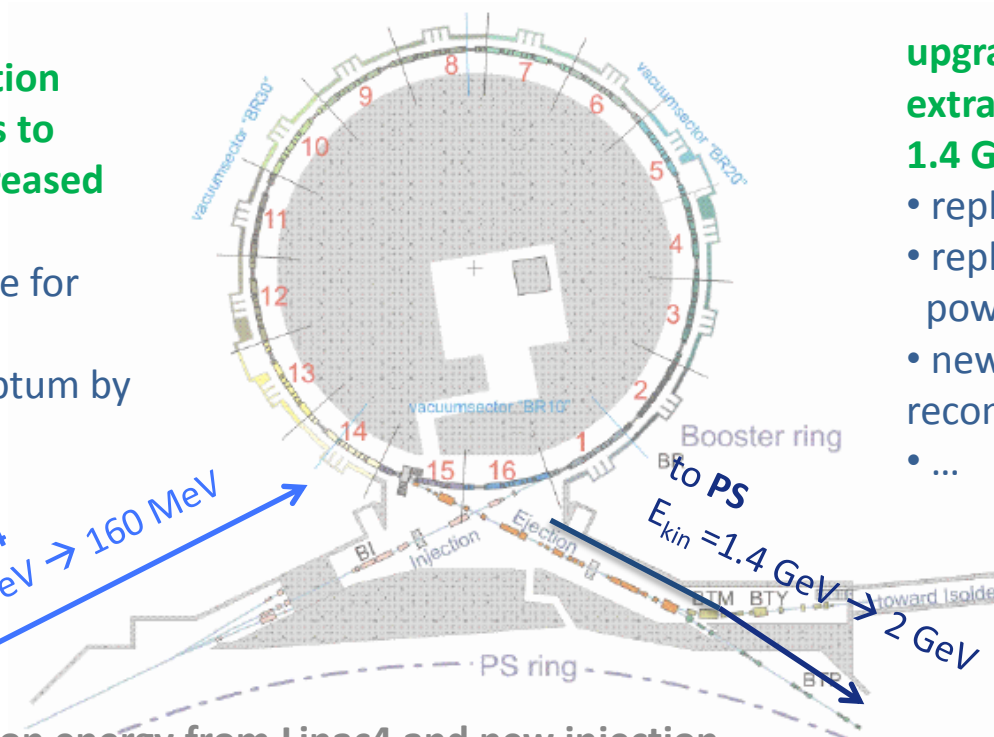


# LIU PSB/PS Upgrade Concept

## upgrade of PSB injection from 50 MeV protons to 160 MeV H<sup>-</sup> with increased intensity

- re-build injection line for 160 MeV
- replace injection septum by stripping foil
- injection bumps
- diagnostics
- ...

from Linac4  
 $E_{kin} = 50 \text{ MeV} \rightarrow 160 \text{ MeV}$



## upgrade of PSB rings and extraction / transfer from 1.4 GeV to 2.0 GeV

- replace main power supply
- replace number of smaller power supplies
- new extraction and recombination elements
- ...

to PS  
 $E_{kin} = 1.4 \text{ GeV} \rightarrow 2 \text{ GeV}$

## 1. increased injection energy from Linac4 and new injection scheme

- higher injection energy (160 MeV) leads to increased brightness
- H<sup>-</sup> injection, essentially loss free and allows to tailor emittances

## 2. increased PSB top energy (2 GeV)

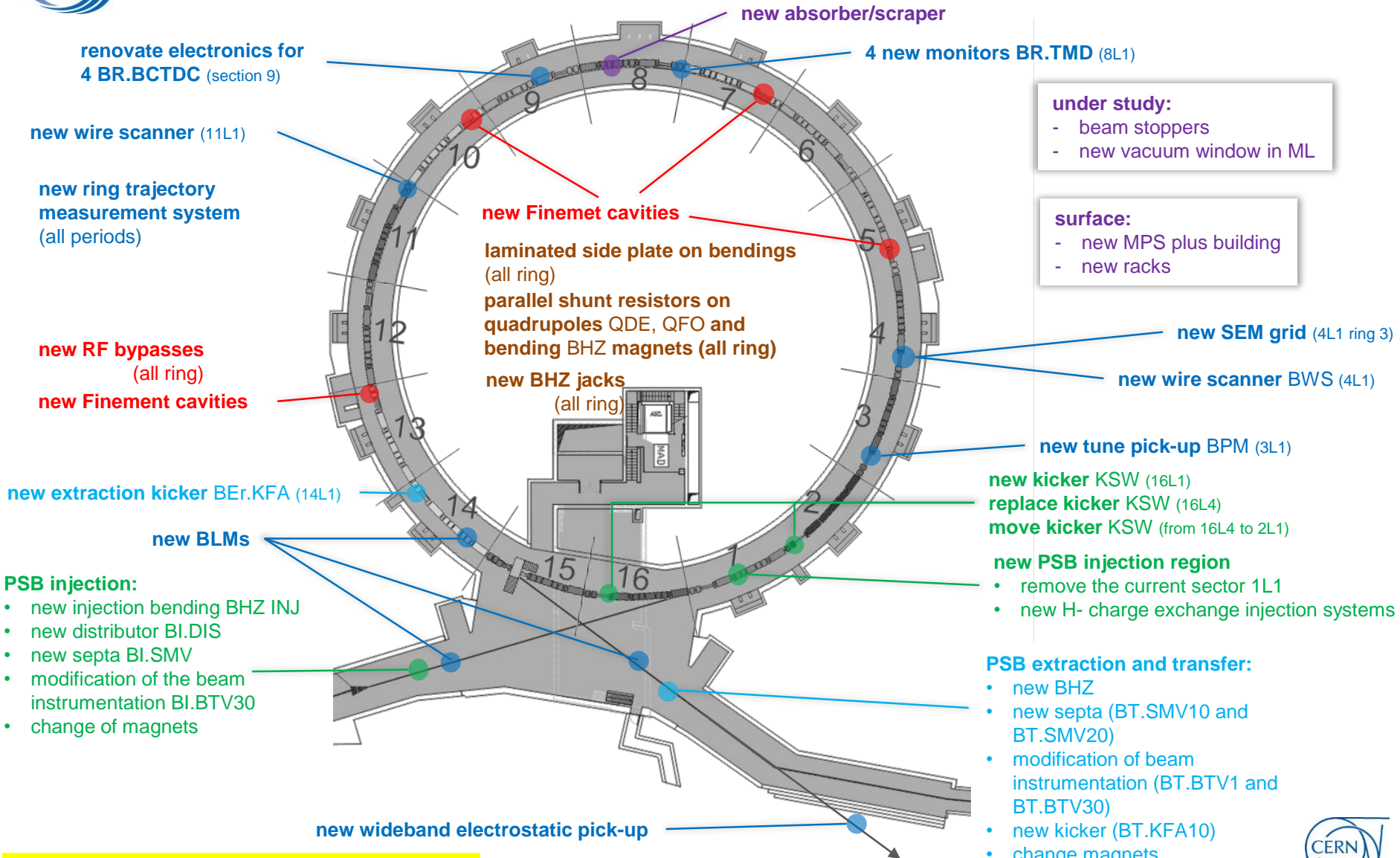
## 3. increased PS injection energy (2 GeV)

- reduces space charge effects at PS injection

## upgrade of PS injection from 1.4 GeV to 2.0 GeV

- rebuild injection region
- replace number of low-energy correctors
- some upgrades in ring for high brightness beams
- consolidate TT2
- ...

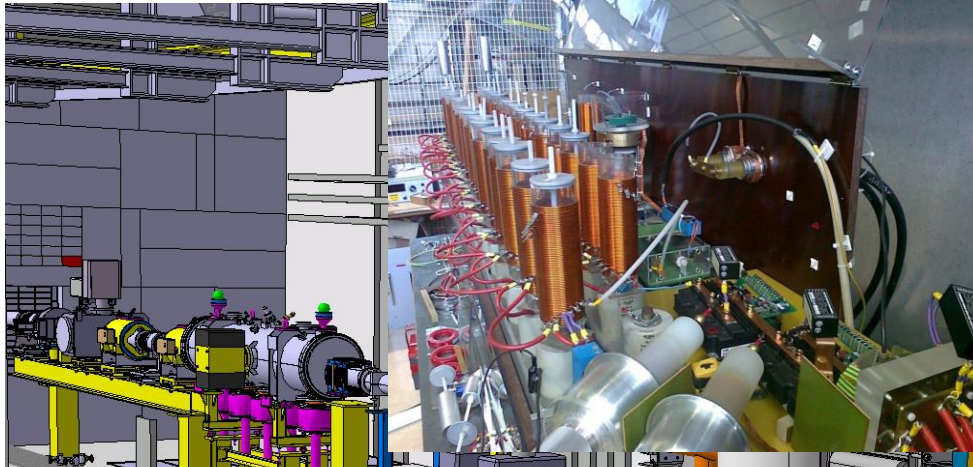
# LIU PSB Overview of Upgrade Items







# PSB New Injection Line

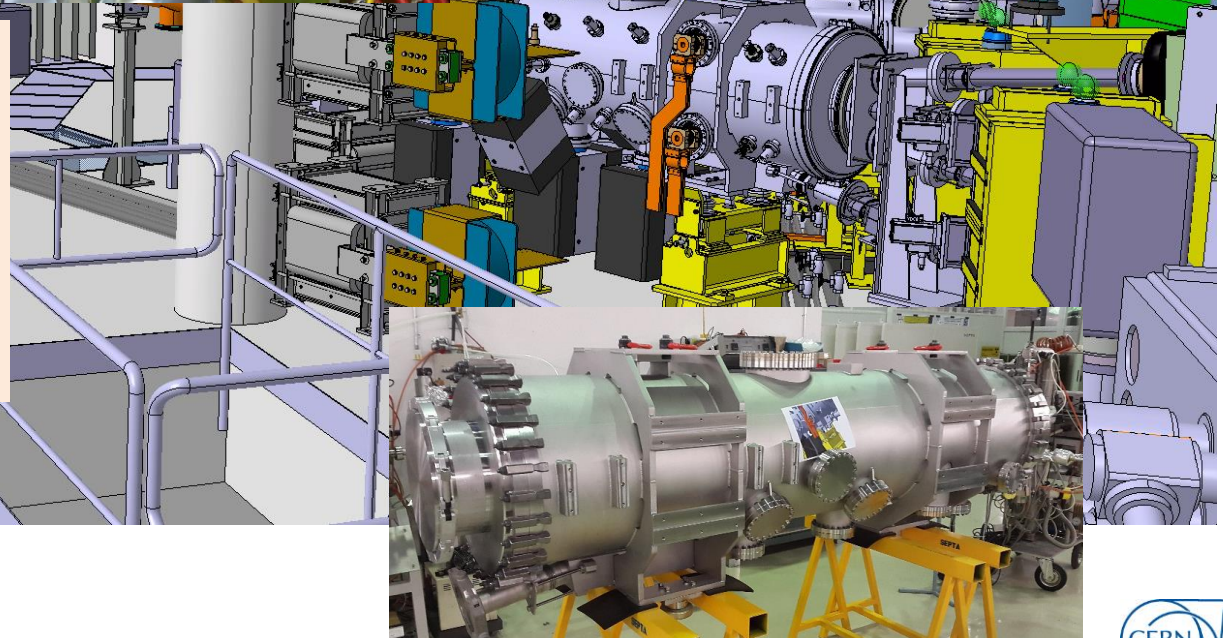


## new vertical septum status:

- being built, tanks have been delivered
- diagnostics ready for inst.
- on track for end-2016

## new distributor status:

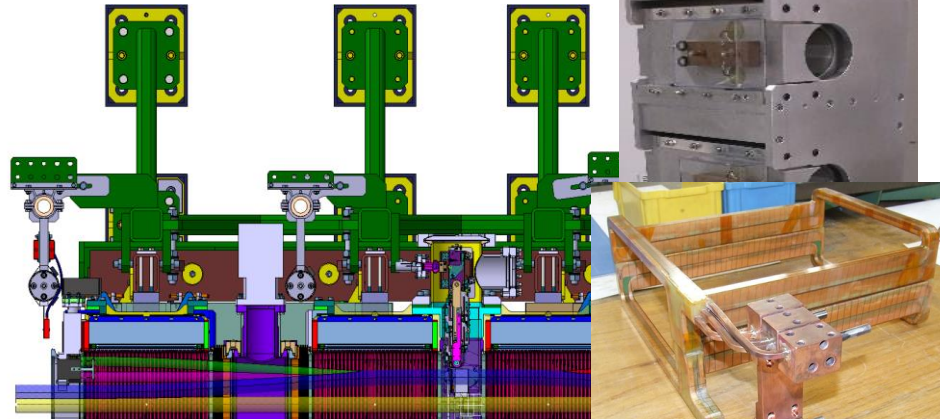
- 2 magnets available
- PFN prototype needs validation for series order by end 2015
- on track for end-2016



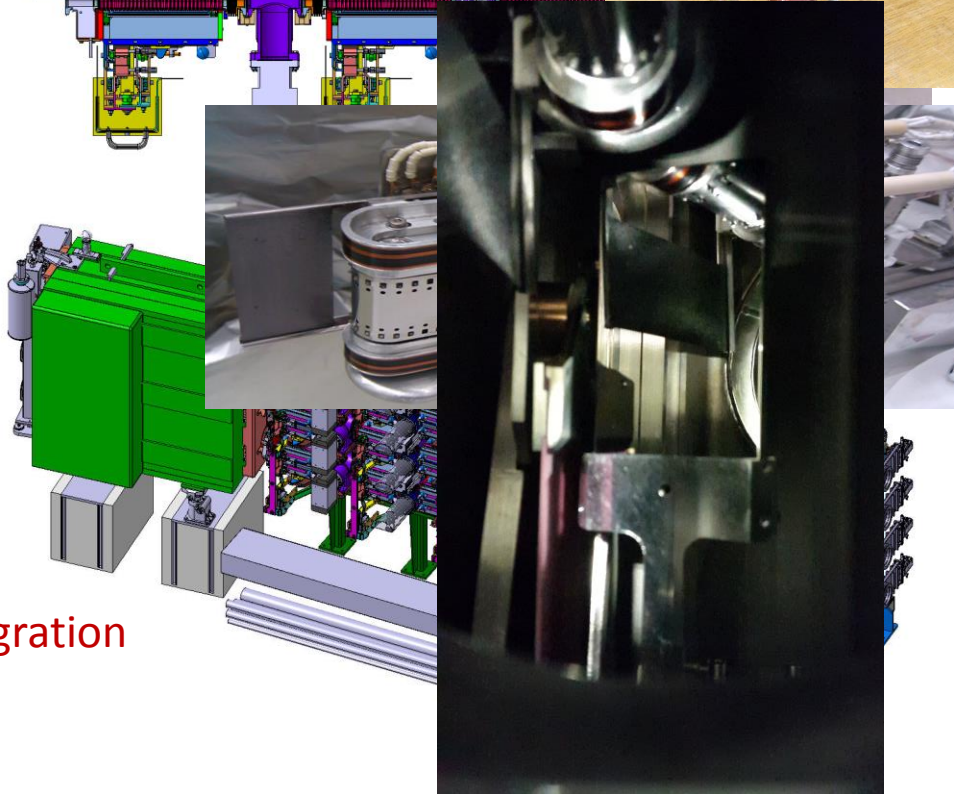


# PSB New Injection

top view



3-D integration



## painting bump

- (partially) new equipment
- 2 stacks ready
- on track for end-2016

## chicane bump

- new equipment
- prototype manufacturing started
- on track for end-2016

## foil actuator

- new equipment
- design tested and finalized
- stripping foil test stand is ready for installation
- on track for end-2016

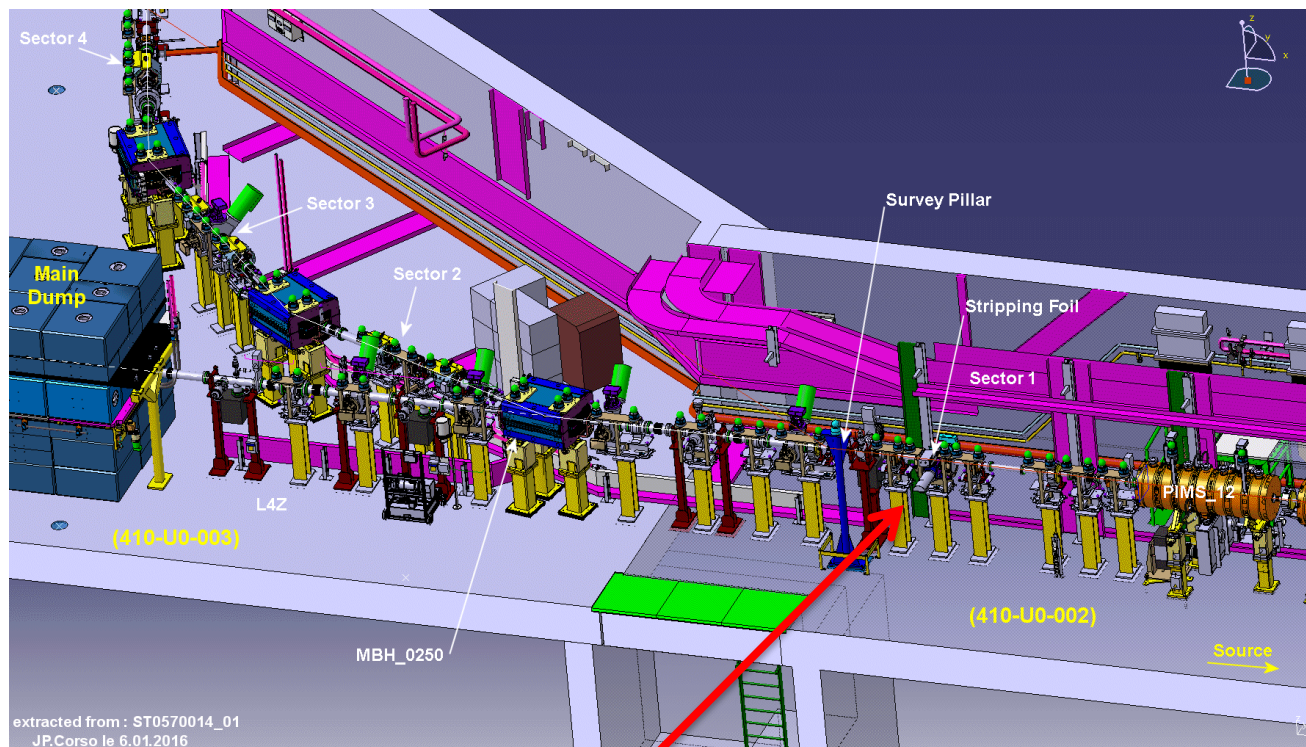
## diagnostics & dumps

- 1 dump current monitor being assembled
- components for screens available
- all 8 Ti dumps manufactured
- on track for end-2016



# Stripping Foil Test

- permanent installation of one  $H^-$  stripping foil + screen unit in L4 transfer line; new vacuum sector created (to confine debris from potential stripping foil breaks)
- test different foil materials, thicknesses, instrumentation and mechanical control



Courtesy J-P. Corso

location of  
 $H^-$  stripping foil unit

B. Mikulec

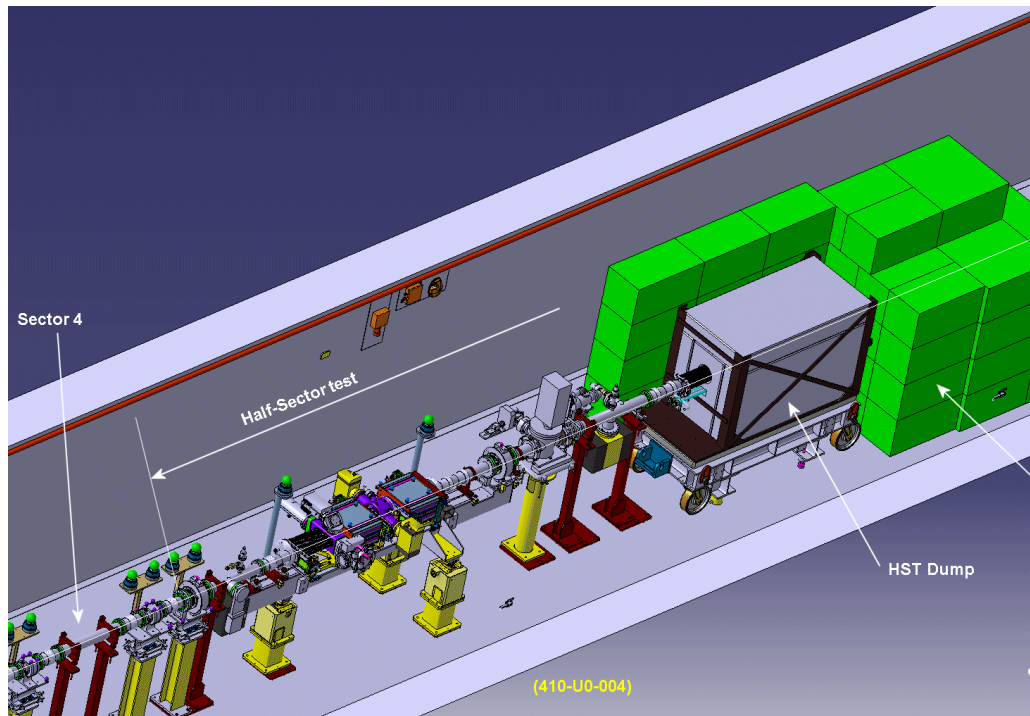




# Half Sector Test

temporary installation of half of the future PSB  $H^-$  injection chicane in Linac4 transfer line (stripping foil unit, 2/4 chicane magnets with internal  $H^0/H^-$  dump and instrumentation) + external dump with shielding

- full assembly and functional test
- early debugging at detail level before permanent installation in PSB
- extremely important test which must not be further delayed if it is supposed to feed back into the hw design



## HST status

- layout drawing approved
- rack area in b.400 modified
- cables pulled and infrastructure prepared
- engineering specifications OK
- FLUKA simulations performed
- equipment will be ready for installation
- preparation of applications/controls started
- scheduling: see J. Coupard presentation



# PSB Injection Summary

all equipment for injection of 160 MeV H<sup>-</sup> ions from Linac4 must be ready by end 2016 to allow for Linac4 connection in the unlikely event of an anticipated longer LHC shutdown

item	status	prospect
vertical septum	tanks delivered	on track for end 2016
distributor	<ul style="list-style-type: none"> <li>• 2 magnets available</li> <li>• PFN prototype being tested</li> </ul>	on track for end 2016
painting bump	2 new stacks ready, one being refurbished	on track for end 2016
chicane bump	coils ready	on track for end 2016
foil changer	design and tests finished, now manufacturing	on track for end 2016
injection dumps	manufacturing ongoing	on track for end 2016
diagnostics	in progress	on track for end 2016
vacuum	under control	on track for end 2016



# PSB new Main Power Supply

new building 245 including infrastructure (C&V, electrical systems, cranes, etc.)  
new reference magnet



May 2015



October 2015



January 2016



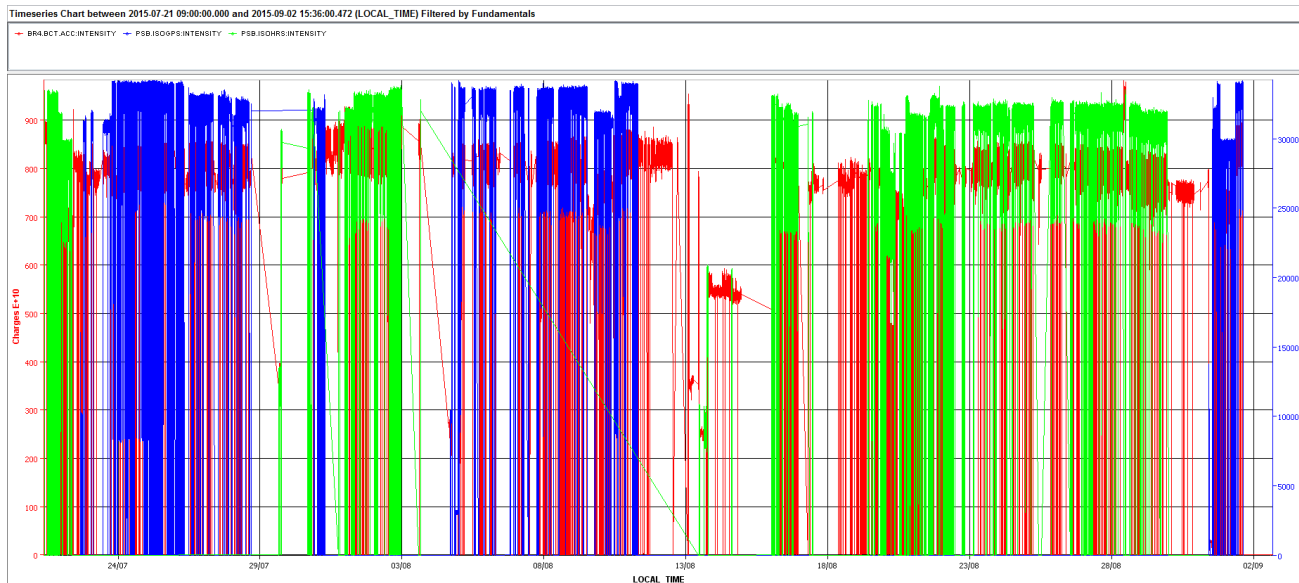


# PSB new RF System

more details:  
presentation  
H. Damerau

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- successful beam tests with prototype cavity in ring 4
- beam tests proved the system ability to produce intense beams with today's parameters
- ISOLDE beam delivered with Finemet system replacing one of the Ferrite systems
- system capable of operation at h1, h2 and h10.
- second review held September 2015
- full replacement of the C02, C04 and C16 systems approved



prototype Finemet  
cavity installed in Ring  
4 of the PSB

Finemet reliability run: **R4 BCT accelerated with Finemet system**, **GPS total intensity on target**, **HRS total intensity on target**

A. Findlay, M.  
Paoluzzi et al.





# PSB Extraction and Transfer

## extraction kicker KFA.14L1

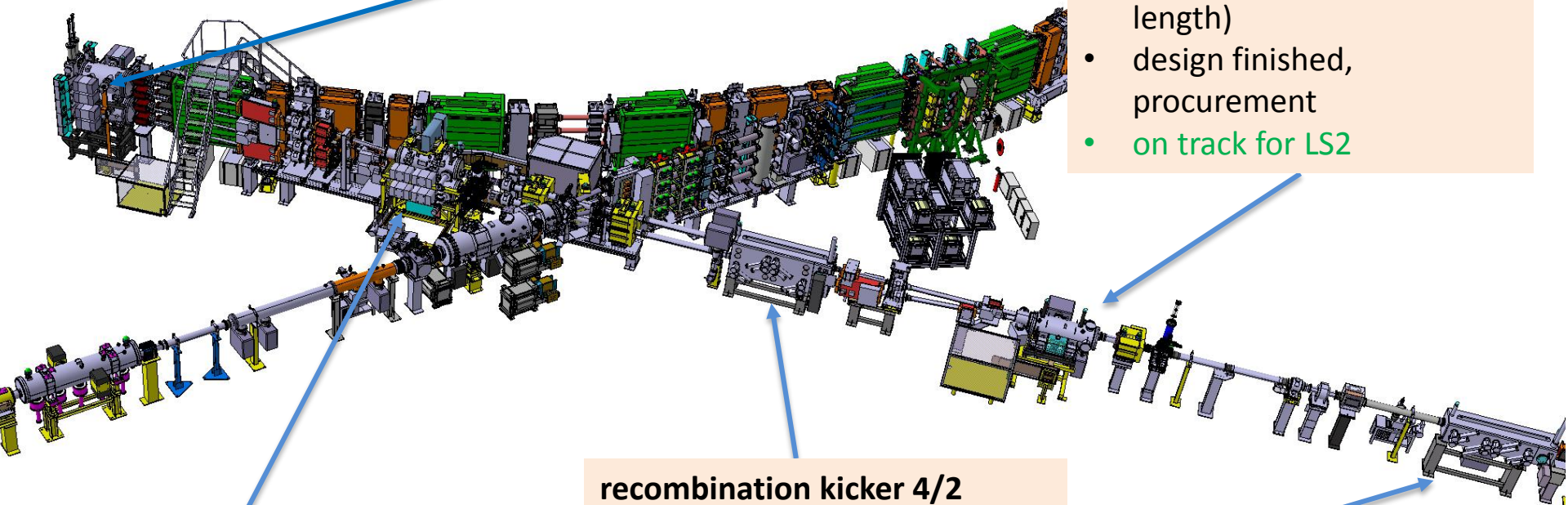
- OK for 2 GeV operation; spare being built
- on track for LS2

## extraction septum

- modify existing equipment (higher current, cooling)
- on track for EYETS/LS2

## recombination septum 2/1

- new equipment (increased length)
- design finished, procurement
- on track for LS2



## recombination septa 4/2

- new equipment (increased length)
- design finished, procurement
- on track for LS2

## recombination kicker 4/2

- existing system measured
- upgrade system being prepared for deployment in LS2

## recombination kicker 2/1

- just within specs for 2 GeV
- ways to increase margin being studied

J. Borburgh





# PSB Rings & Extraction Summary

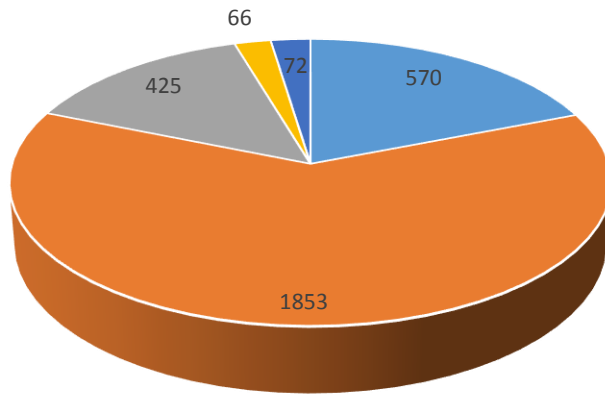
item	status	prospect
new RF system	MDs successful, final decision taken	on track for LS2
magnets	modifications to main bends being put in place	on track for LS2
extraction kicker	OK; spare being built	on track for LS2
extraction septum	modifications being implemented	on track for EYETS
recombination septa 4/2	procurement phase	on track for LS2
recombination kicker 4/2	upgrade in progress	on track for LS2
recombination septum 2/1	procurement phase	on track for LS2
recombination kicker 2/1	just within spec, margin improvement under study	on track for LS2
transfer line	optics reviewed and consolidated, integration ongoing	on track for LS2





# PSB Status of De-cabling

## Obsolete cables: Booster summary on January 21st



- Disconnected and Orphan (19 %)
- Disconnected by groups (62 %)
- Still under investigation (14%)
- In used (2%)
- Already removed (3%)

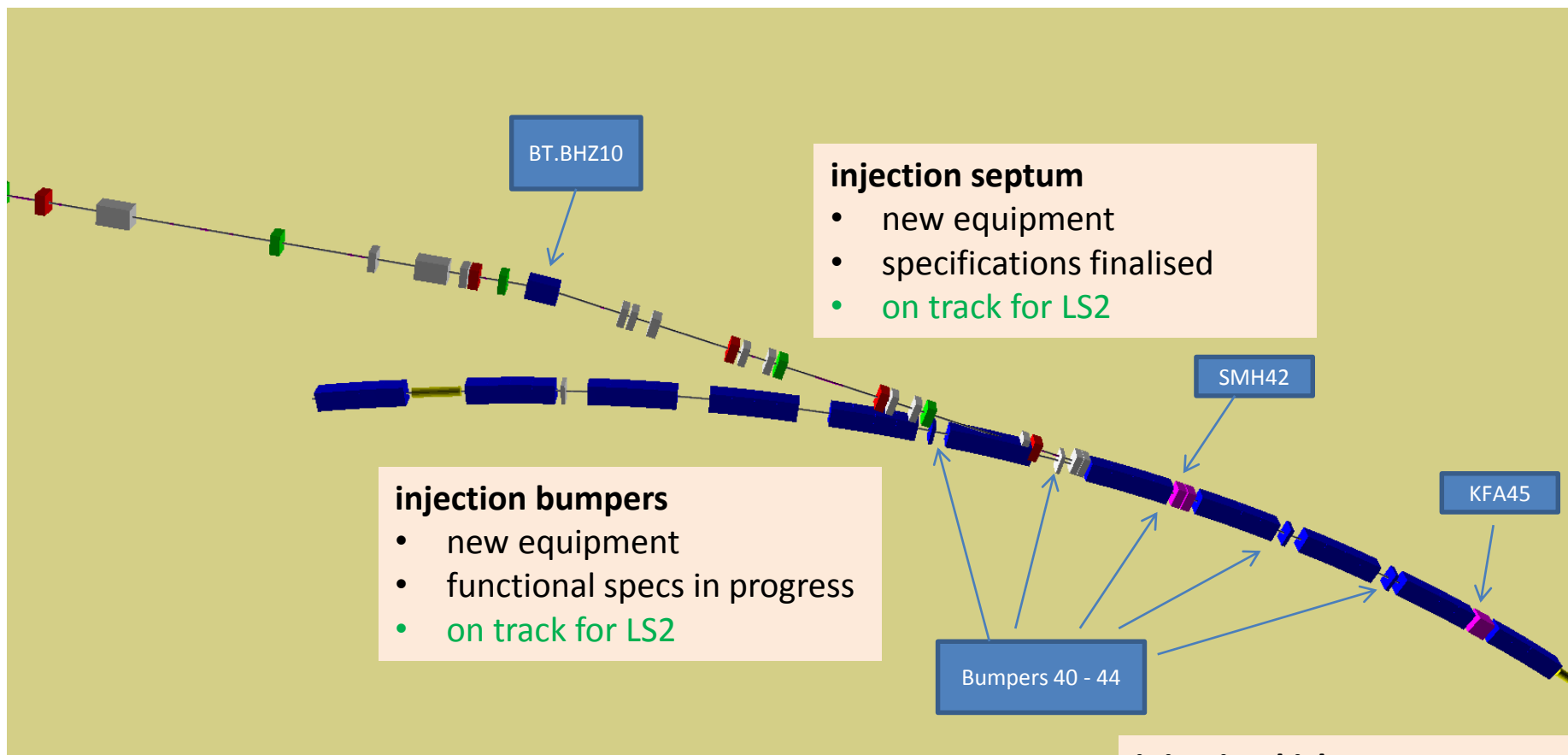
S. Evrard



PSB: ~1800 new cables for LIU – no more space on cable trays

cable clean-up in stages:

- 2014/15: cable identification and marking
- YETS 2015/16: cable disconnection
- EYETS: cable removal
- out of 3000 expected obsolete cables, 2400 are now ready for removal and 400 still under investigation



**status January 2015:**  
reviewed several times, all design choices frozen  
specification documents in progress  
on track for LS2, partially EYETS

## injection kicker

- upgrade existing system
- implementation in EYETS
- on track for EYETS

J. Borburgh





# PS RF Upgrade

more details:  
presentations  
H. Damerau /  
W. Hoefle

## 10 MHz System

upgrade of feedback amplifiers

→ prototype feedback amplifier being installed on spare cavity for test with beam in 2016

## 80 MHz System

new fast tuner against beam loading and for fast change to operation with ions

→ prototype validated on 88 MHz test cavity (outside ring); next prepare infrastructure on one 80 MHz cavity during YETS for installation

## LL RF:

- new 1-turn delay feedbacks for 10/20/40/80 MHz cavities
- coupled-bunch feedback and beam loading compensation for Finemet cavity
- replace existing beam control by fully digital beam control; activity started

## Transverse Damper:

new power amplifiers for the transverse damper

next: finalise design of in-house power amplifiers and re-launch investigation with J-PARC for commercial power amplifiers

## Longitudinal Damper:

Finemet cavity to damp longitudinal coupled bunch instabilities

4/6 gaps available for tests; successful damping of all 20 modes on the flat-top

next: make all gaps available; deploy the system in parallel with the existing one

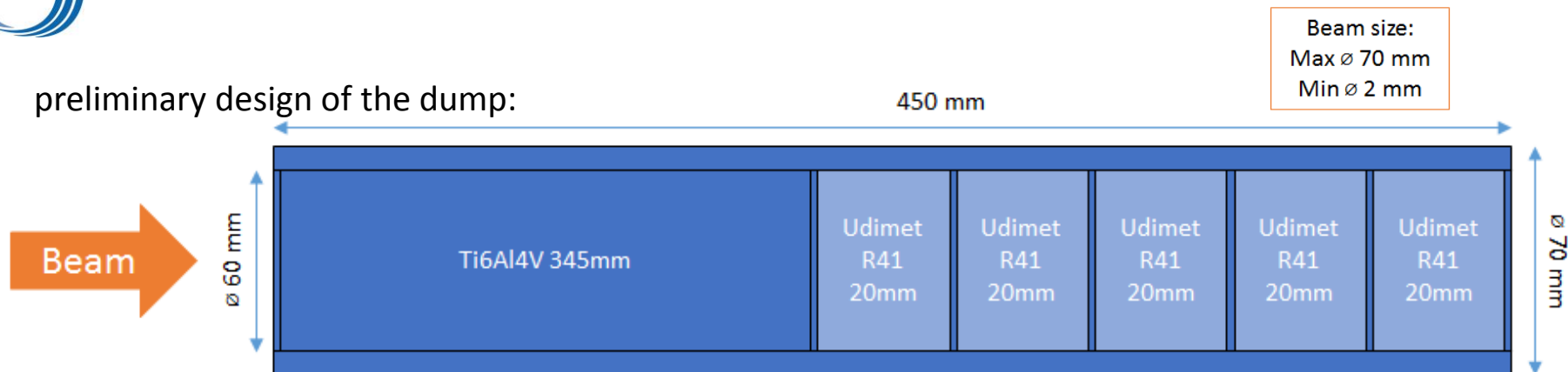




# PS Internal Dump

16

preliminary design of the dump:



refinement of design necessary due to high compressive stresses in the worst case scenario (ten impacts with  $5e13$  p+ fully debunched @ 26 GeV/c as accidental case).

## Ongoing work:

- finalization of the preliminary design of the dump
- clear up of the final position of the dump system (possible locations: SS47, SS48, SS31, SS75)
- solve problem of high cumulative dose for epoxy on downstream magnet
- start of the detailed design of the dump
- start with the design of the actuation system
- continue construction of the new shielding (modular construction for easy disassembly)

T. Polzin, F.-X. Nuiry, P. Garcia Ortega,  
V. Vlachoudis, W. Kozłowska

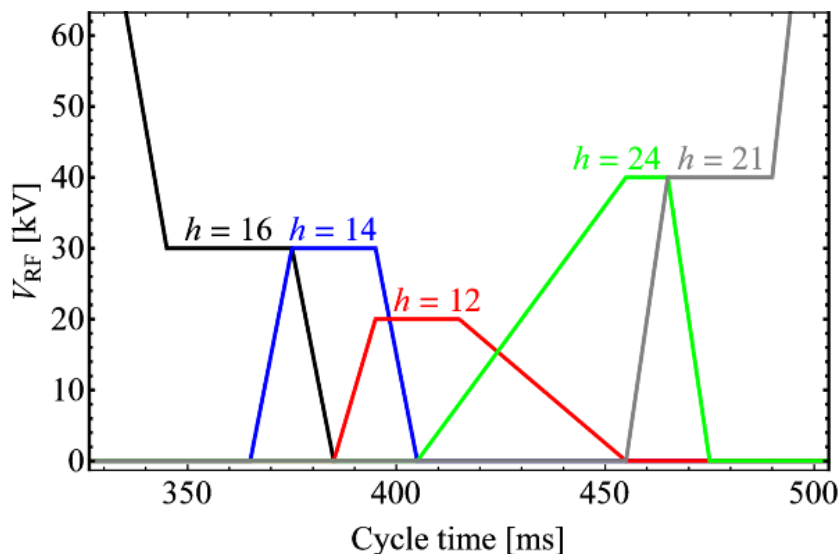


- [illegible]

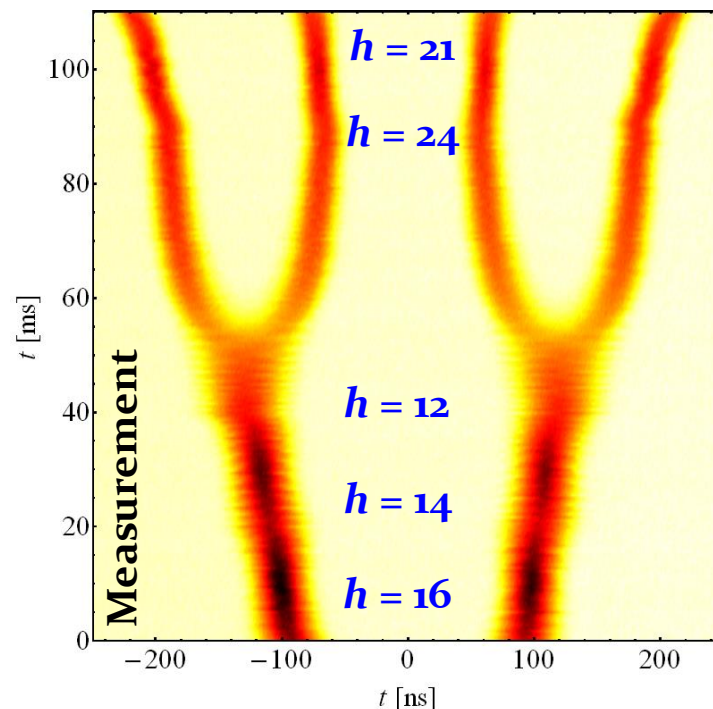
# Nominal 100 ns Pb54+ Beam: LIU baseline

- Original '**nominal beam**' (LHC Blue Book, CERN-2004-003-V-3)
  - 2 bunches from LEIR injected at  $h = 16$
  - Batch expansion, splitting, expansion:  $h = 16 \rightarrow 14 \rightarrow 12 \rightarrow 24 \rightarrow 21$
  - Re-bucketing to 80 MHz,  $h = 21 \rightarrow 169$  (flat-top)
  - Extraction of 4 bunches spaced by about 100 ns

Voltage program



Expansion and splitting



→ Operationally set-up from 2010-2012

→ Revive in 2016, no issues expected

S. Hancock, H. Damerau

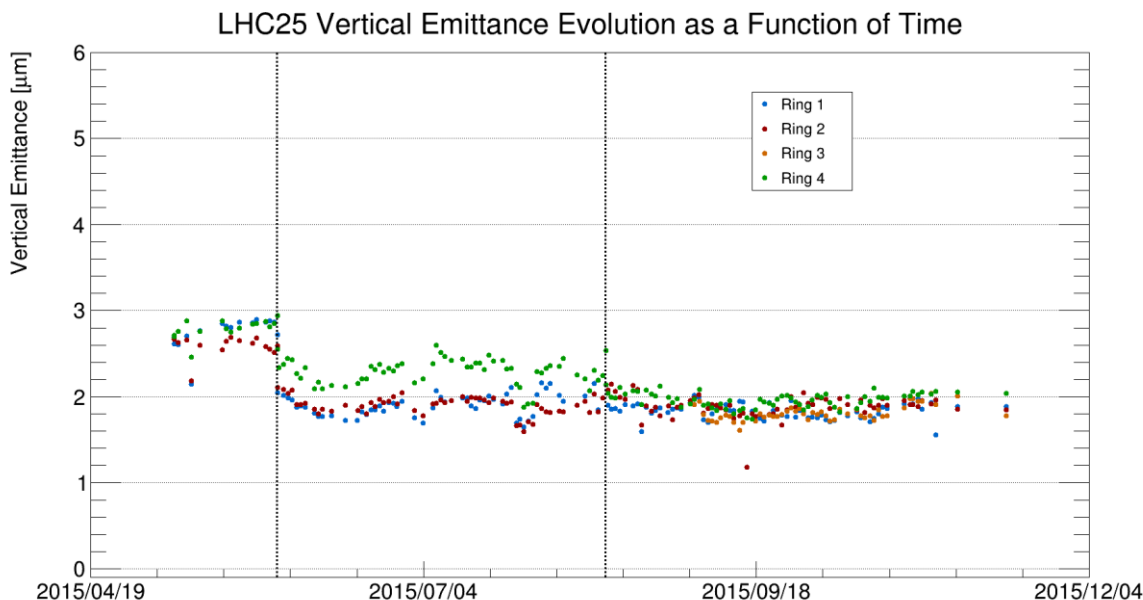
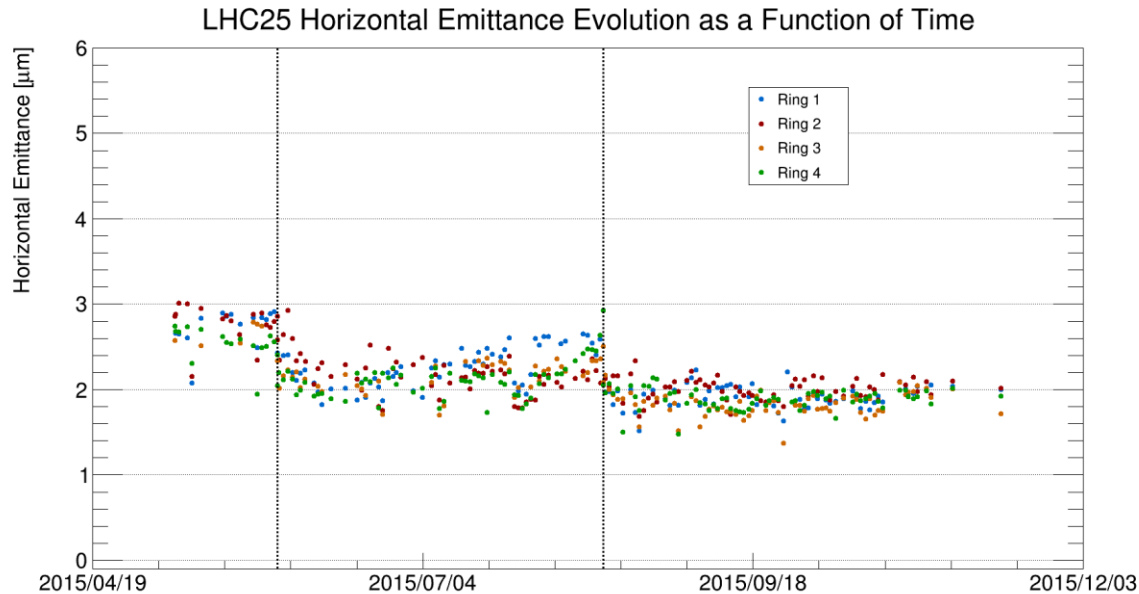


# PS Summary

item	status	prospect
2 GeV injection	hardware specified, production phase	on track for LS2
transverse damper	working on amplifier	on track for LS2
longitudinal damper (Finement cavity and LL RF)	tests promising, endorsed by review	on track for LS2
HL RF	modifications being implemented	on track for LS2
LL RF	1-turn delay feedbacks beam control upgrade	OK before LS2 installation in LS2
beam instrumentation	- Progressing well	installation before LS2
power converters	- procurement phase - low energy magnet power converters being deployed	installation before LS2
internal dump	design phase	design to be finalised 2016
PS-SPS transfer line	recently included	technically no issues



# 2015 LHC Beam Performance in PSB



2015 operational transverse emittance evolution of the 4 PSB rings:

**2 major working point changes** throughout the year (grey vertical markers) have **reduced spread and emittance**

performance of 4 rings equalised for 25ns LHC run  
 → stable emittances below 2 mm mrad for all PSB rings

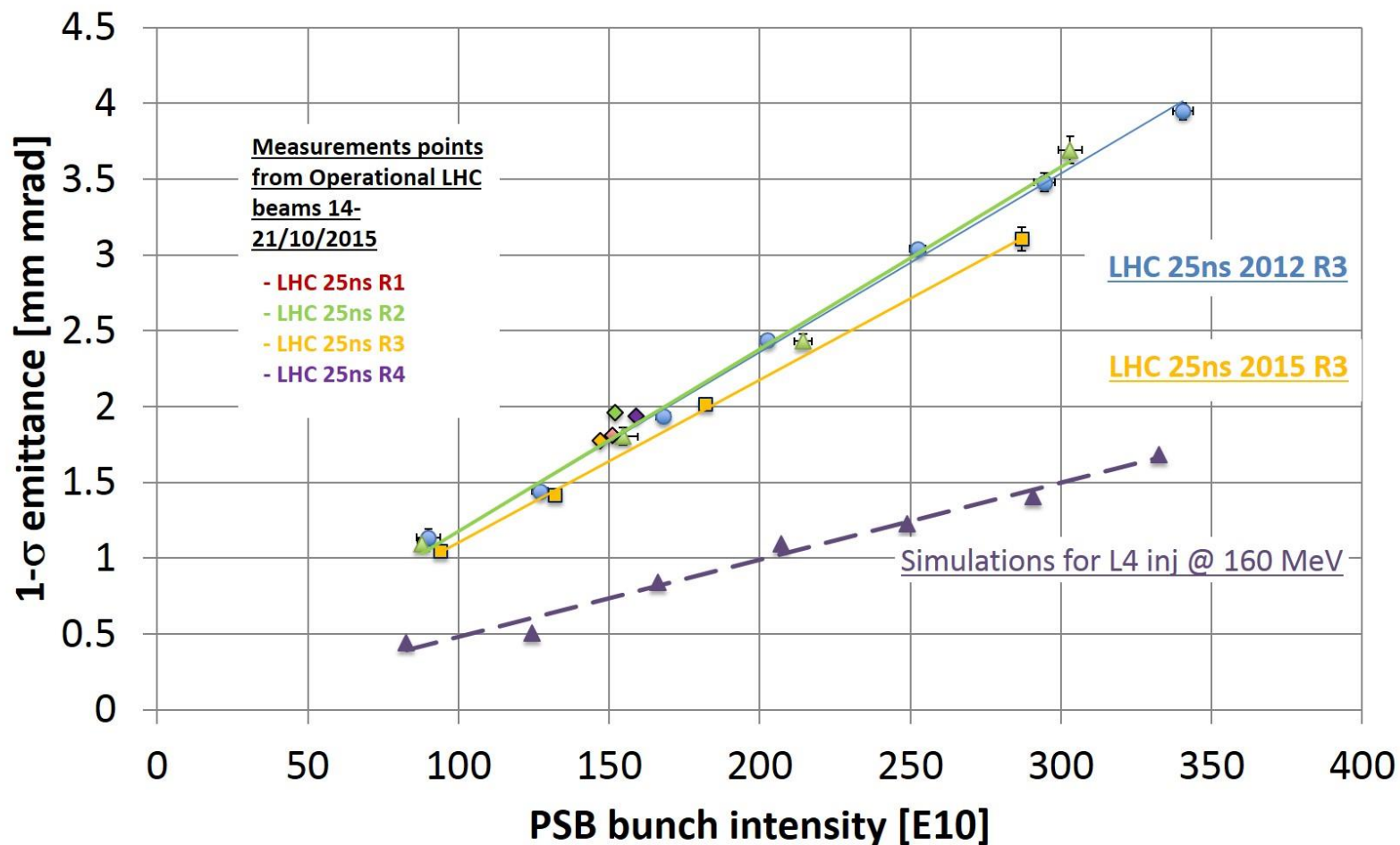
E. Benedetto,  
 J-L. Sanchez,  
 G.P. Di Giovanni,  
 B. Mikulec



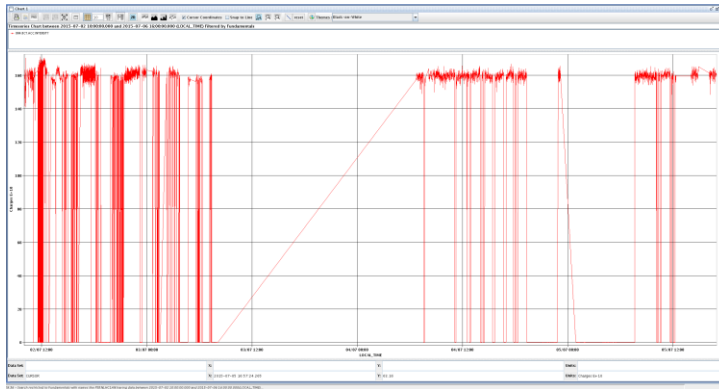
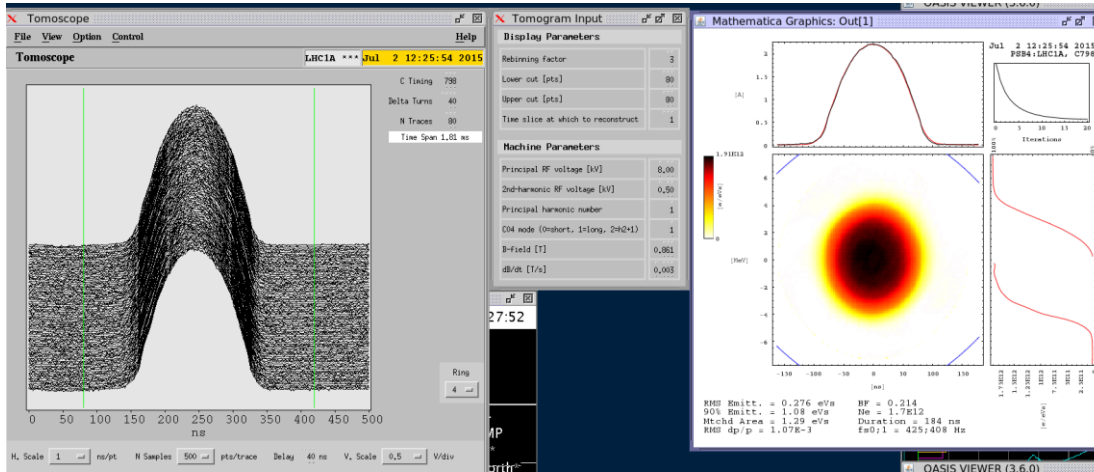
# 2015 LHC Beam Performance in PSB

measured around current and future LHC beam intensities

could confirm 2012 linear dependence with intensity and good performance



# 25 ns LHC Beam Performance with Finemet



set up R0 beam control in 2015 with Finemet® cavity as an H=2 system for the operational LHC25 & 50 ns beams

the LHC25ns (and LHC50ns) beam was accelerated and delivered from R4 with Finemet® cavity from 10H00 2<sup>nd</sup> July to 16H00 6<sup>th</sup> July

successful Finemet® reliability run

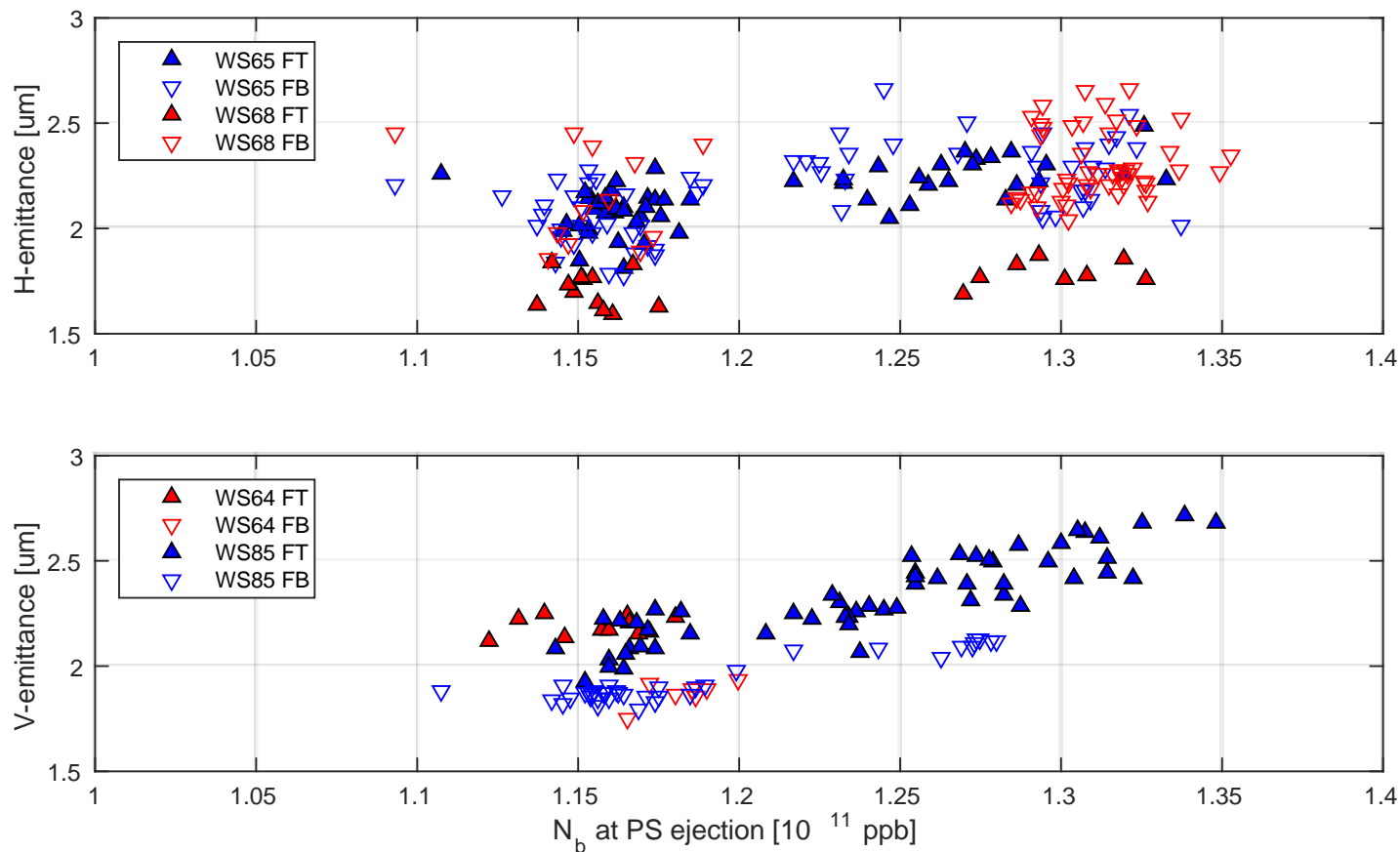
	Intensity	Bunch Length	Emittance (matched Area)	$\Delta p/p$ (1 sigma)
LHC25A&B	165E10	180ns	1.3eVs	1E-3
LHC25A&B with Finemet® H=2	165E10	185ns	1.3eVs	1.1E-3

A. Findlay et al





# 2015 LHC Beam Performance in PS



- space-charge limit for the PS understood: 8th order vertical resonance excited by space charge limits maximum Laslett tune shift—> major achievement to understand brightness limit
- new working point with T-damper and low chromaticity successfully tested (upgrade of the T-damper)





# Conclusions and Main Goals for 2016

- the upgrade of the PSB and PS machines is in full swing
- in 2015 the last remaining design choices have been reviewed and settled
- the project is in the execution phase (procurement, manufacturing, installation)
- 2016 will see procurement and manufacturing continue (continuous and careful tracking)
- the Half Sector Test is one of the next milestones
- other important milestones will be met as for example the completion of bldg. 245
- there will be important LIU activities taking place in the machines during EYETS (2016-17), e.g. PSB cable clean-up



# SPARE SLIDES



# PS Transverse and Longitudinal Damper

## Transverse Damper:

new power amplifiers for the transverse damper

### progress 2015:

existing T-damper used in operation to improve LHC brightness

new firmware for selective excitation tested in V plane

### next steps:

finalize design of in-house power amplifiers and re-launch investigation with J-PARC for commercial power amplifiers

## Longitudinal Damper:

Finemet cavity to damp longitudinal coupled bunch instabilities

### progress 2015:

4/6 gaps available for tests; successful damping of all 20 modes on the flat-top up to  $1.7 \cdot 10^{11}$  ppb

better theoretical modelling / understanding of instability

### next steps:

make all gaps available

deploy the system in parallel with the existing one

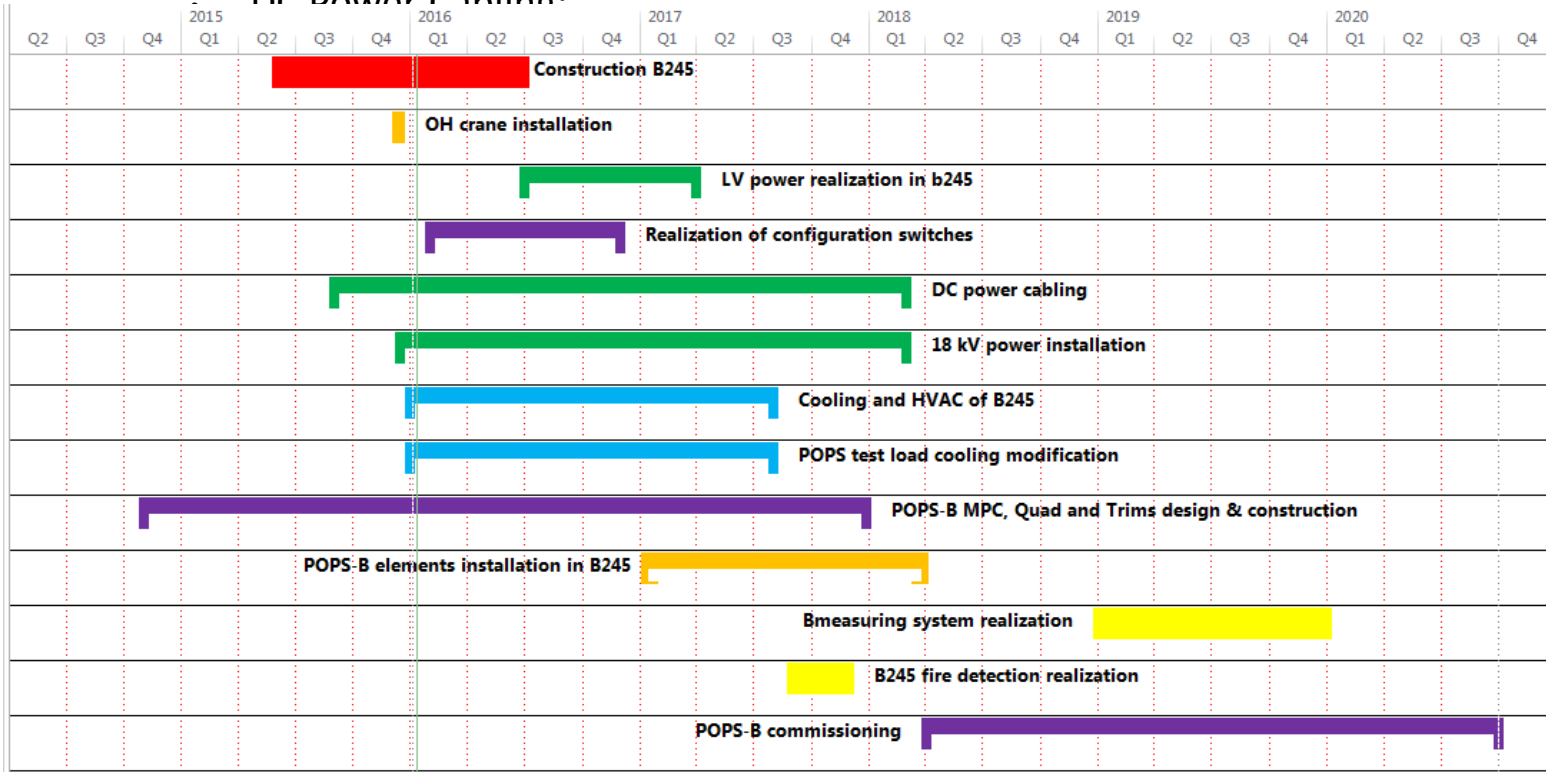
more details:  
presentation  
H. Damerau



# PSB new Main Power Supply

- Building 245 under construction. **Completion foreseen May 2016;**
- LV power: design started
- Configuration switches: PO foreseen 03/2016

## DC Power Cabling:



- POPS-B Storage Capacitors:
  - **Prototypes for qualification ordered;**
  - FC June 2016;
- POPS-B Transformers: design started.



# PSB Beam Instrumentation (Injection & HST)

## observables:

beam position in vertical septum; current of unstripped ions;  
beam profile on stripping foil and foil inspection; stripping foil  
status; beam loss; beam profile

## unstripped ions:

dedicated monitor in front of H0/H- dumps based on charge  
deposition in Ti plates

## status:

mechanics ready for assembling with BSW4 dump; prototype  
board under test

## foil observation:

special rad hard ThermoFisher cameras and dedicated cabling

## status:

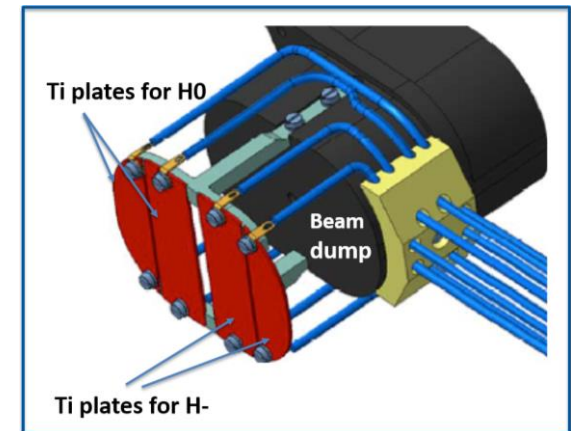
mechanics+cameras: ready, Interlock: tested, FESA class ready.

## beam loss:

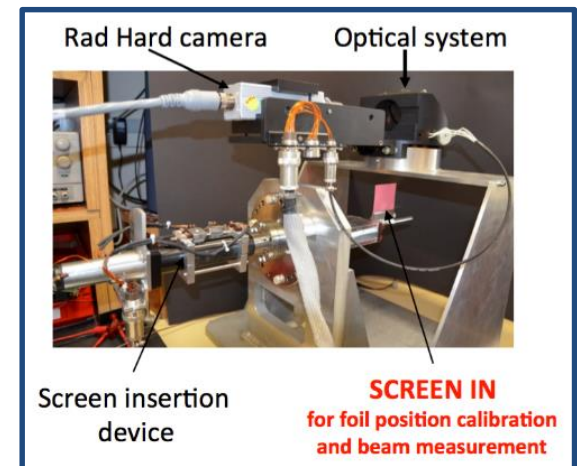
ionisation chambers (slow) and diamond detectors (fast, for  
interlocks)

## status:

BLMs and electronics procured



Current monitor for H0/H- ions



Mock up of beam profile  
monitor and foil inspection

J. Tan





# PSB Beam Instrumentation (Rings)

## observables:

turn-by turn profile for injection matching; beam intensity;  
beam profile and emittance; beam loss; trajectories; tune, ...

## beam profile & emittance:

new wire scanners; replace existing scanners by new generation

## status:

design nearly completed, production of a prototype for  
installation during YETS 2016-2017

## turn by turn profile for injection matching

SEM grid with fast read-out of ~20 consecutive profiles, ring3  
only (H+V)

## status:

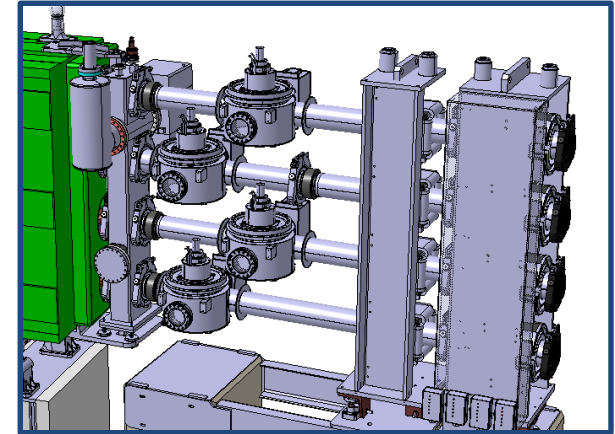
just started; installation in YETS 2017-2018

## bunch-by-bunch, turn-by-turn trajectories

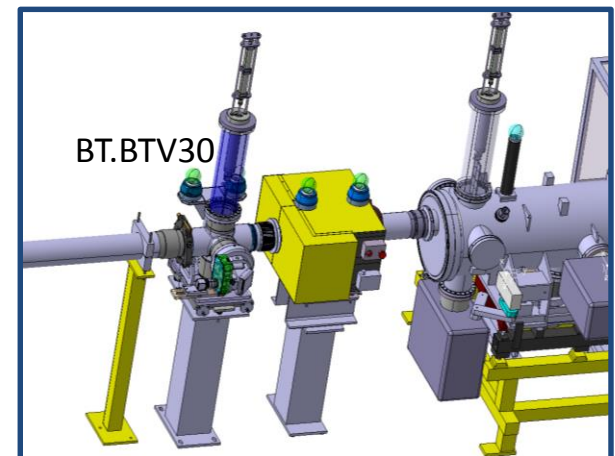
new front-end electronics

## status:

head amplifier being improved for low intensity beams;  
procurement of processing modules



Fast Wire Scanners in 4L1



Integration of the new BTV housing



# PS Beam Instrumentation

## **turn-by-turn transverse profile**

SEM grids with fast acquisition card

### **status:**

card being manufactured

## **transverse beam profile & emittance**

new generation wire scanners; injection SEM grid, new BGI (IPM)

### **status:**

LS2 for the replacement of the scanners and grid (sept 42), H monitor IPM to be installed in 2016

## **beam loss**

ionisation chambers (slow) and diamond detectors (fast)

### **status:**

fast detectors at CERN, installation asap

slow monitors: installation foreseen during LS2, but maybe earlier

## **longitudinal beam profile**

2 new wall current monitors

### **status:**

instruments installed and cabling being done (YETS15)

