Electron cloud heat load studies for the LHC

Master Proposal Presentation

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Improving our understanding of e-cloud buildup

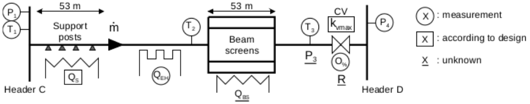
- data from run 2 (since 2015) available
  ↪ 25 ns bunch spacing
  ↪ especially heat load (HL) data
  ↪ best measurements for e-cloud effects in LHC
- simulations
  ↪ compare results to measurements
  ↪ accurate model of cryogenic cells, especially arcs
  ↪ include photoemission seeding by synchrotron radiation

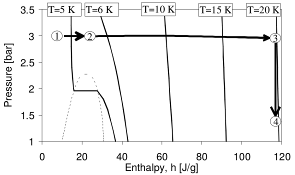
Heat load recalculation

Heat load recalculation

- with the help of TE-CRG and BE-ICS, in particular thanks to B. Bradu

$$\dot{Q}_{BS} = \dot{m} \cdot (h_3 - h_1) - \dot{Q}_{EH} - \dot{Q}_S$$





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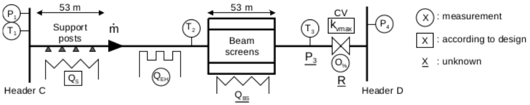
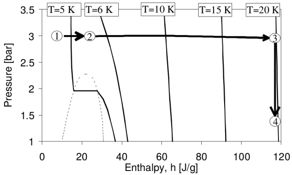




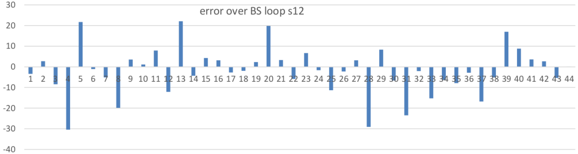
needed parameters

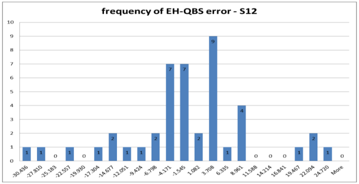
calculated:	$\dot{m}$, P_3
measured:	T_1, T_2, T_3, P_1, P_2, P_4, $\dot{Q}_{\mathrm{EH}}$, CV
by design:	$\dot{Q}_{\mathrm{S}}$ ($\approx$ 7.5 W in arcs)
from tables:	helium properties h, μ, obtained from tables
valve characteristics:	R, K_{V}

- calculation P_3 can be omitted $\rightarrow$ $P_1 \approx P_3$

Why recalculate?

- relevant parts at LHC unchanged since installation
- if better valve constants available now after tests:
  $\hookrightarrow$ recalculation of old data preferred
- logged heat loads remain $\rightarrow$ comparison invalid if calculation changes
- example of heat load test for arc 12 (reproduce measured valve opening with electrical heater)

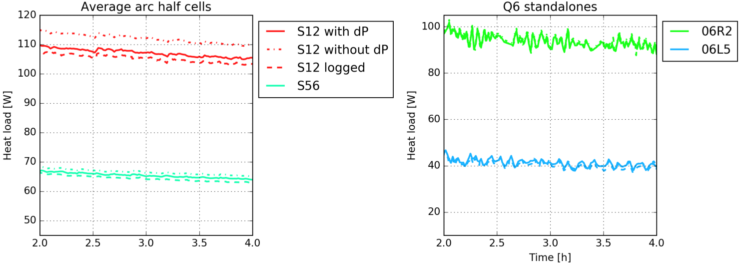




B. Bradu, e-cloud meeting 12.12.16

Comparison of results

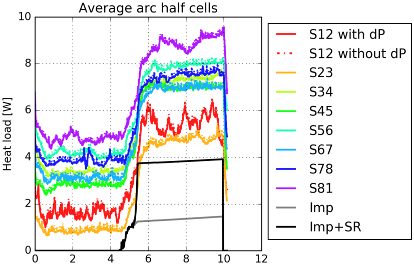
- comparison of logged values (without dP), recalc. with and without dP

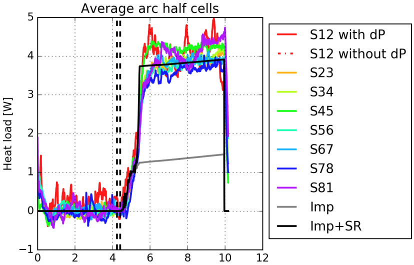


- barely any differences for Q6
  ↪ correct reimplementation
  ↪ small pressure drop
- arc averages: logged $\neq$ recalc. without dP
  ↪ different handling of cells with failing sensors
  ↪ 16 of these cells in LHC, ignored in new module
- arcs recalc.: with dP $<$ without dP
  ↪ over proportional for high HL arcs
  ↪ neglecting dP to be avoided for $\dot{Q}_{BS} > 100$ W *CERN-ATS-2013-009*

Heat load offset

- 100 ns fill → no large e-cloud effects expected → low heat loads

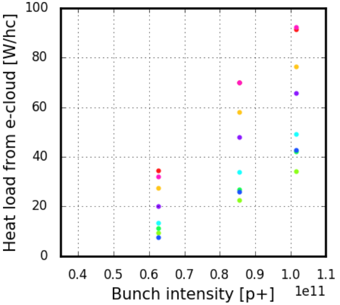


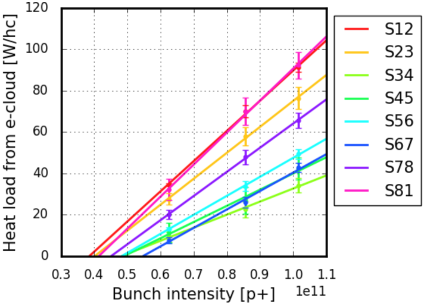


- with offset subtraction: expected HL - average measured < 1 W
- without offset subtraction: difference by 6 W
- valid also for high heat load fills?
- large outliers on cell by cell level

Uncertainty estimation

- intensity dependence from MD in August 2016
- uncertainties needed for future studies
- here: error bars = offset + 3% of measured HL





- configuration tests for arcs done without dP?
- heat distribution different during these tests → implications?
- offset subtraction?

↪ expert opinion necessary

Data analysis

Heat load dictionary for systematic data analysis of many fills

- from recalculated data, data dictionary created
- recalculated HL and beam parameters
- nested python dictionary with self-descriptive keys

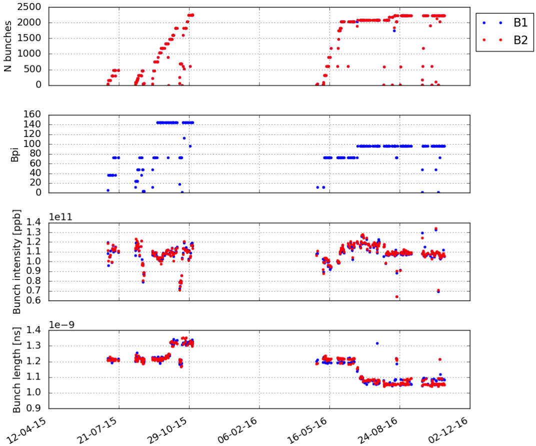
	once or	multiple times per fill	Note
fill number	x		e.g. 5219
filling pattern	x		e.g. '25ns_2220b_2208_1940...'
top energy	x		
bunches per injection	x		bunches per injection from the SPS
heat load offset	x		for all cells and the arc averages
sum of fill heat load	x		for all cells and the arc averages
heat loads		x	for all cells and the arc averages
heat load from Imp./SR		x	for both beams
time points		x	in seconds after 1970 (Unix time)
average bunch length		x	for both beams, from FBCT
bunch length standard deviation		x	for both beams
number of bunches		x	for both beams, from FBCT
Total intensity		x	for both beams, from BCT

time points:

- the beginning of the fill
- the beginning of the proton injection, which corresponds to the "Injection Physics Beam" mode
- the beginning of the energy ramp
- the end of the beam size squeeze process
- the declaration of stable beams
- every hour afterwards for up to 24 hours

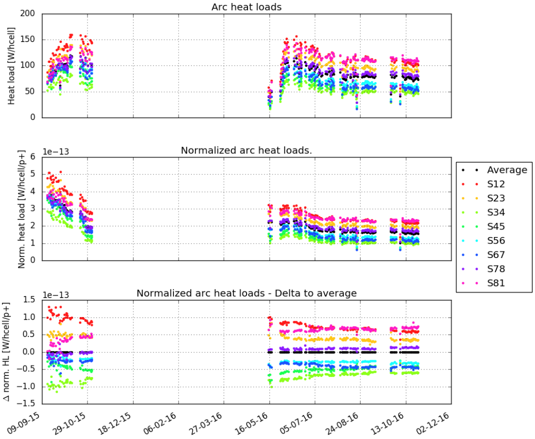
Fills that reached stable beams

- 282 fills since 2015
- very fast plotting, few seconds



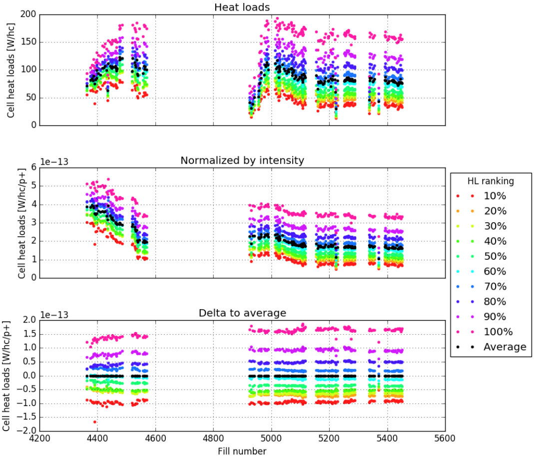
Heat load hierarchy

- heat load at stable beams
- for more details, see e-cloud meeting 24.02.2017



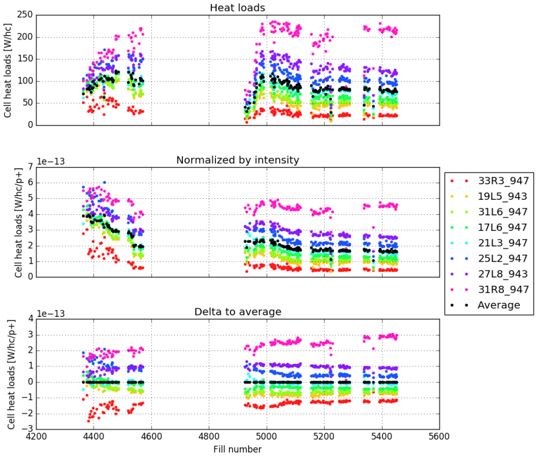
Deciles

- individual cell data now easily accessible
- ranking based on 10 last fills of 2016



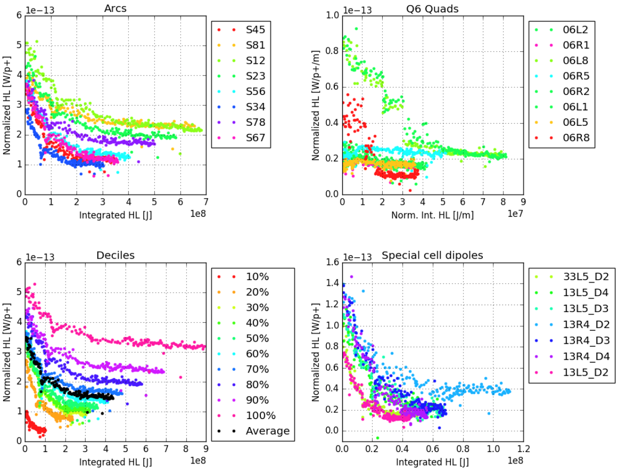
Single cells

- every 50th cell from the ranking



Scrubbing curve

- 2 special cells: HL from single magnet



SEY model parameter scan

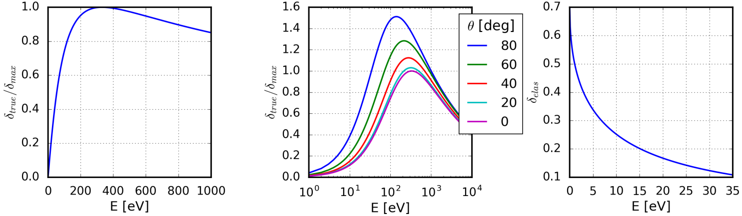
Secondary electron emission model

$$\delta(E,\theta) = \delta(E,\theta)_{\text{true}} + \delta(E)_{\text{elas}} = \frac{I_{\text{Emit}}}{I_{\text{imp}}(E,\theta)}$$

$$\delta_{\text{true}}(E,\theta) = \delta'_{\text{max}}(\theta) \frac{s \frac{E}{E'_{\text{max}}(\theta)}}{s - 1 + \left(\frac{E}{E'_{\text{max}}(\theta)}\right)^s}$$

$$\delta'_{\text{max}}(\theta) = \delta_{\text{max}} \; e^{\frac{1-\cos\theta}{2}}$$

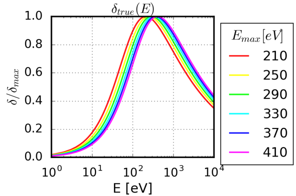
$$E'_{\text{max}}(\theta) = E_{\text{max}} \, (0.3 + 0.7 \cos\theta)$$

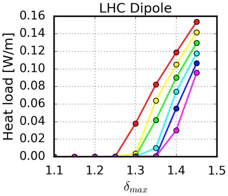


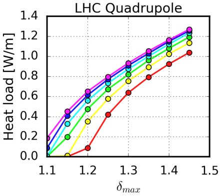
- variation of E_{max}
- variation of θ dependence of $\delta_{\text{max}}(\theta)$

Variation of E_{max}

- E_{max}, s normally at 330 eV, 1.35

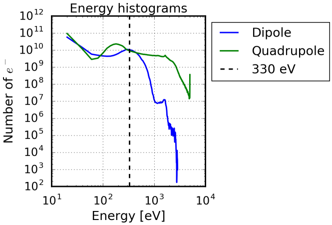






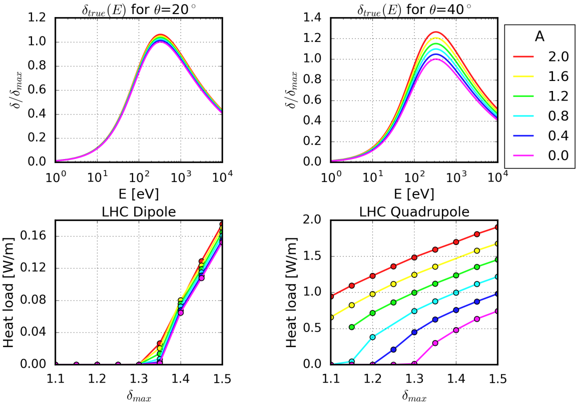
PyECLOUD simulations

- $E_{max} = 330$ eV
- δ_{max} 1.45
- bunch intensity $1.1 \cdot 10^{11}$ ppb
- initial seeding
- 4 batches à 72 bunches



Variation of angular dependence of $\delta'_{\text{max}}(E_{\text{max}}, \theta)$

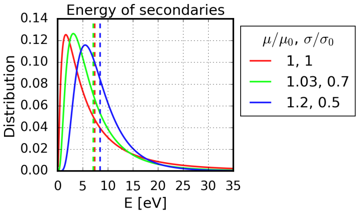
$$\delta'_{\text{max}}(\theta) = \delta_{\text{max}}\ e^{A\ \frac{(1-\cos\theta)}{2}}$$

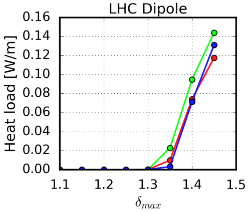


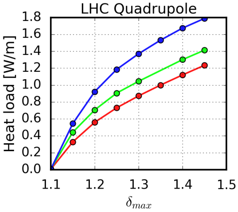
- magnetic bottle: transverse momentum increase towards higher B-fields
- possible to introduce θ logging in PyECLOUD

Variation of secondary electron energy

$$\frac{\mathrm{d}n_{\mathrm{true}}}{\mathrm{d}E} = \frac{1}{E\sigma\sqrt{2\pi}} e^{-\frac{(ln(E)-\mu)^2}{2\sigma^2}}$$



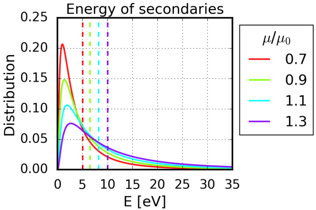


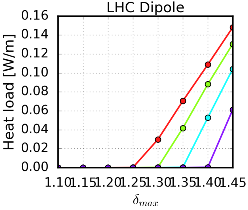


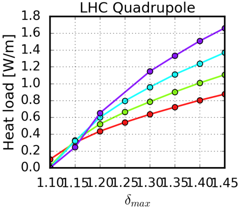
- impact on trapping of e^- in quadrupoles?

Variation of secondary electron energy 2

$$\frac{\mathrm{d}n_{\mathrm{true}}}{\mathrm{d}E} = \frac{1}{E\sigma\sqrt{2\pi}} e^{-\frac{(ln(E)-\mu)^2}{2\sigma^2}}$$





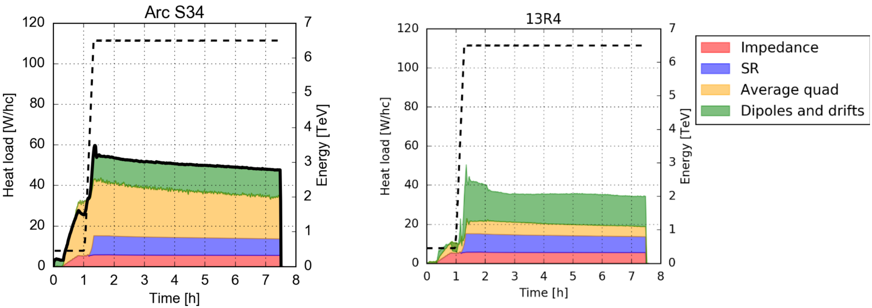


- both devices affected

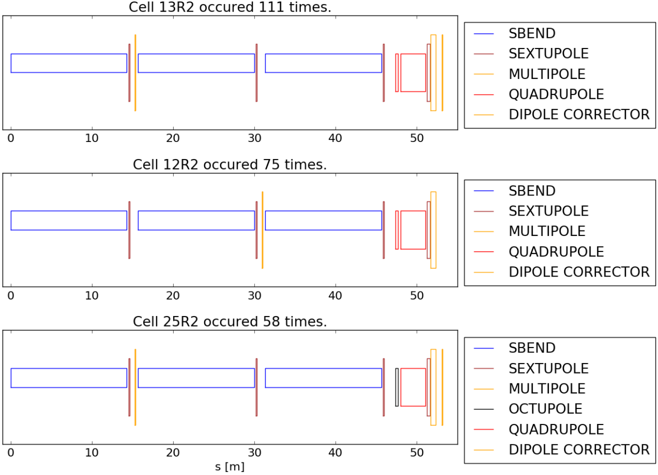
Proposed future work

Data analysis

- upcoming scrubbing run
- warmed up and vented sector 12
- new specially instrumented cell in arc 12 (high heat load)
- reminder: difference between Q6 standalones and special cell quadrupoles

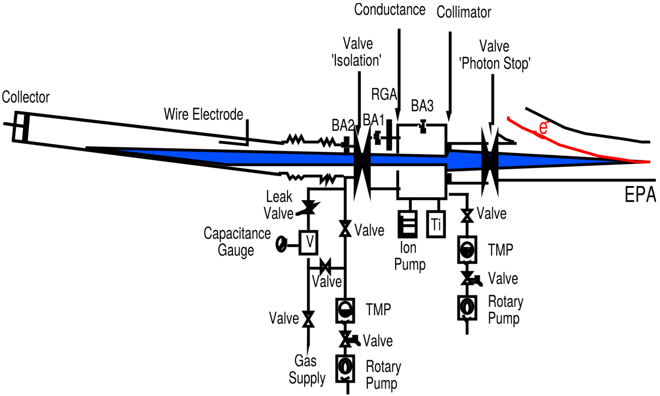


Improve model of cryogenic cells



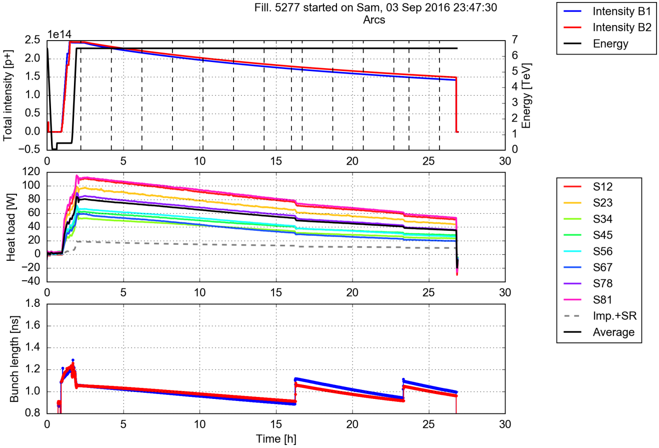
- from MADX file
- drifts? interconnections and higher order magnets

Effect of synchrotron radiation



- V. Baglin, I.R. Collins, O. Gröbner *LHC Project Report 206*, 1998
- measurements of photon reflectivity and electron yield for Cu co.-lam
- possible to simulate in PyECLOUD

Long fill



- simulations have been run but not yet analyzed
- derive dependence on intensity & bunch length

Summary

work done so far

- heat load recalculation
- data dictionary
- SEY parameter scan
- special cells

to-do list

- complete simulation work!
- photoemission seeding
- higher order magnets
- suggestions?

thanks to
Oliver Boine-Frankenheim, Benjamin Bradu, Giovanni Iadarola, Annalisa Romano, Giovanni Rumolo