Investigating the role of photoemission in the e-cloud formation at the LHC

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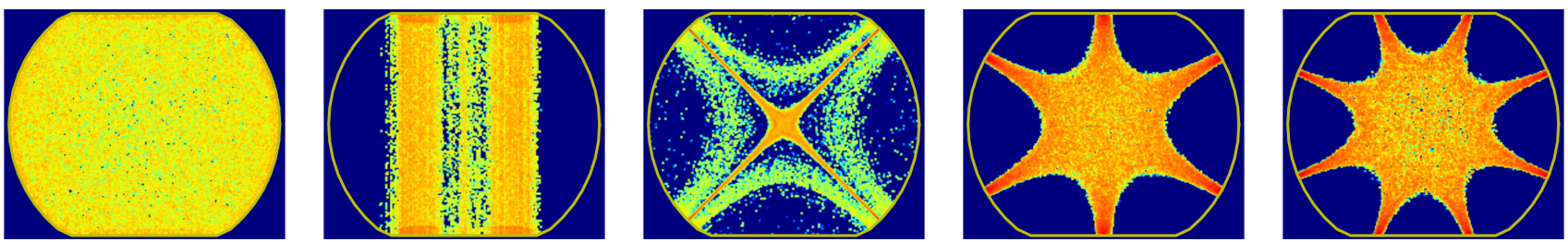

Many thanks to my former colleagues at CERN
G. Iadarola, L. Mether, A. Romano, G. Rumolo, G. Skripka
Thanks to my superiors at PSI
S. Reiche, T. Schietinger and D. Kiselev

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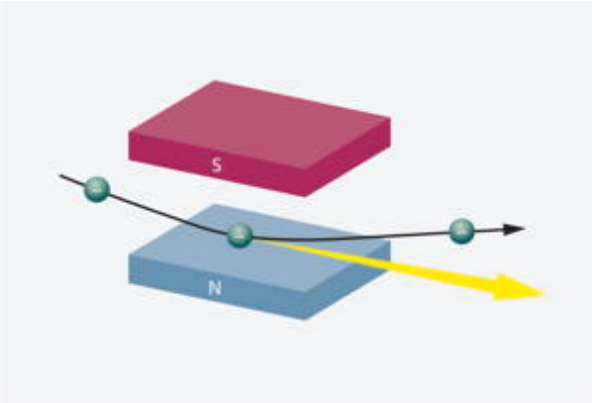
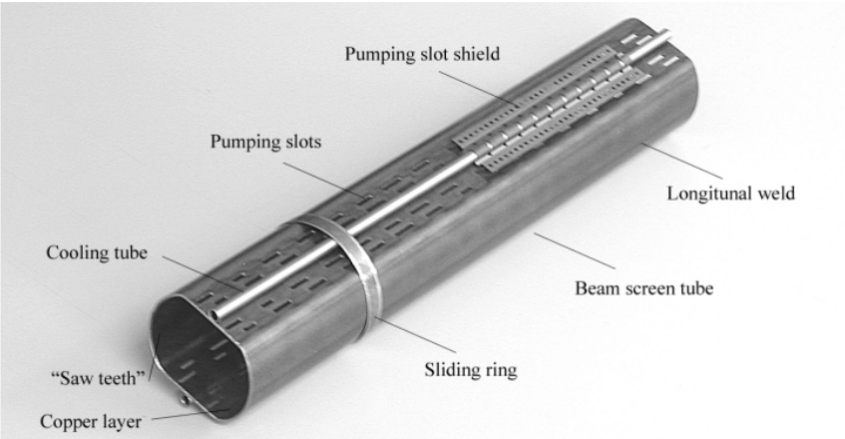
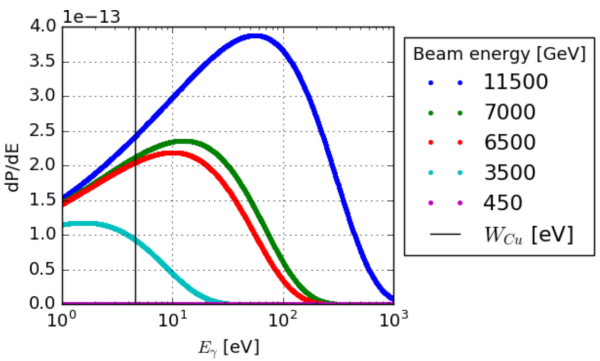
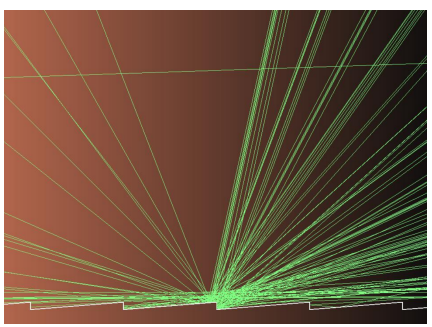
Photoelectrons in the LHC









↪ How many photoelectrons?

↪ How are photoelectrons distributed in the chamber?

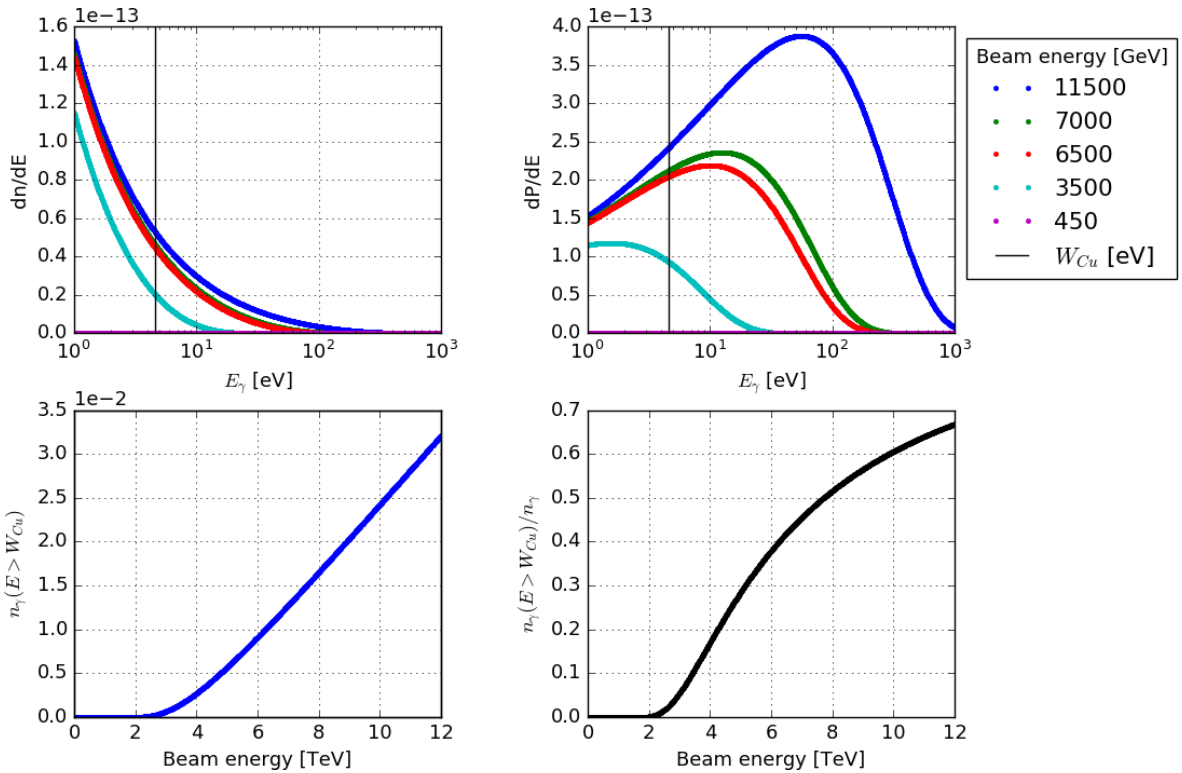
↪ In simulations, what is the effect on the heat load or strength of the electron cloud?

Relevant CERN note: CERN-ACC-NOTE-2017-0057 `https://cds.cern.ch/record/2289940`

Emitted photons by a proton beam in the LHC

Plots for LHC bending radius (Formulas in photoemission note):

- Photon spectrum
- Power spectrum
- Number of photons higher than the Cu work function per proton and meter bend
- Share of photons above the Cu work function w.r.t. all photons



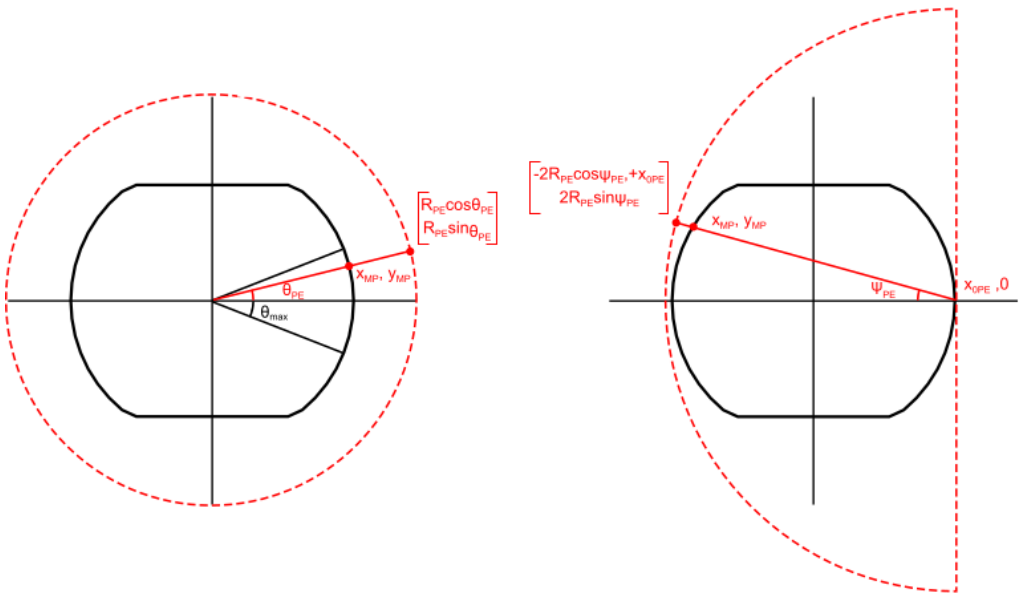
↪ Also calculate total power of synchrotron radiation, which loads the cooling systems
↪ 7 and 6.5 TeV look relatively similar

Modelling of photoelectrons in PyECLOUD

- The number of photons emitted by the beam can be calculated
- Absorption of electrons and the number of photoelectrons depends on surface properties
- Photoelectron generation in parallel to the beam charge

PyECLOUD input:

- total number of photoelectrons to generate
- share of photoelectrons created by reflected photons
- spatial distribution of reflected photons

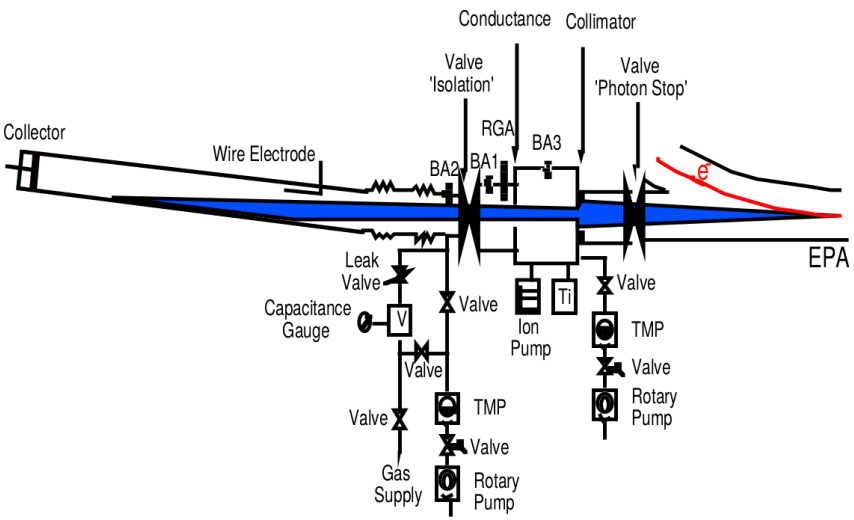


Used parameters

- Literature review of published measurement campaigns from 1998-2004

Published measurement results - yields

- Baglin, Collins, Gröbner: "Photoelectron yield and photon reflectivity from candidate LHC vacuum chamber materials with implications to the vacuum chamber design" (1998) - LHC Project Report 206
- Measurements at EPA at CERN
- Measure **Yield per incoming photon** Y, **Reflectivity** R and calculate **Yield per absorbed photon** $Y^* = \frac{Y}{1-R}$
- Only reflectivity in forward direction
- Measurements only valid for the employed photon spectrum

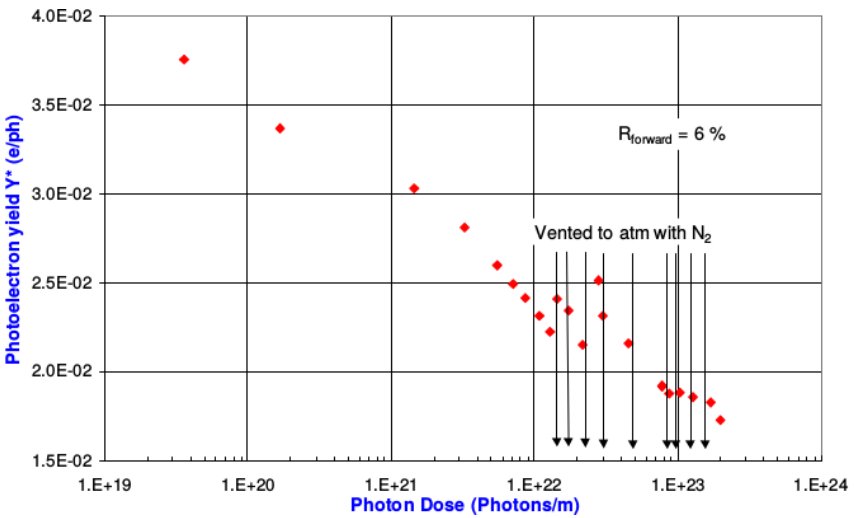


		7 TeV		11.5 TeV	
		45 eV		194 eV	
Surface	Status	R (%)	Y* (e/ph)	R (%)	Y* (e/ph)
Cu	as-received	80.9	0.114	77.0	0.318
co-lam.	air baked	21.7	0.096	18.2	0.180
Cu elect.	as-received	5.0	0.084	6.9	0.078
Cu	as-received	1.8	0.053	-	-
sawtooth	150°C, 9h	1.3	0.053	1.2	0.052
	150°C, 24h	1.3	0.040	1.2	0.040

↪ Use these yields for conservative estimate
↪ Scale from 7 TeV to 6.5 TeV with number of photons with energy higher than the Copper work function

Published measurement results - surface conditioning

- Baglin, Collins, Gröbner, Grünhagel: "Measurements At EPA Of Vacuum And Electron-Cloud Related Effects" (2001) - 11th Chamonix Workshop (CERN-SL-2001-003)
- Measurements at EPA at CERN
- Measure Y, R and calculate $Y^* = \frac{Y}{1-R}$
- Only reflectivity in forward direction
- Measurements only valid for the employed photon spectrum
- Estimate effect of photon scrubbing



Sawtooth Cu

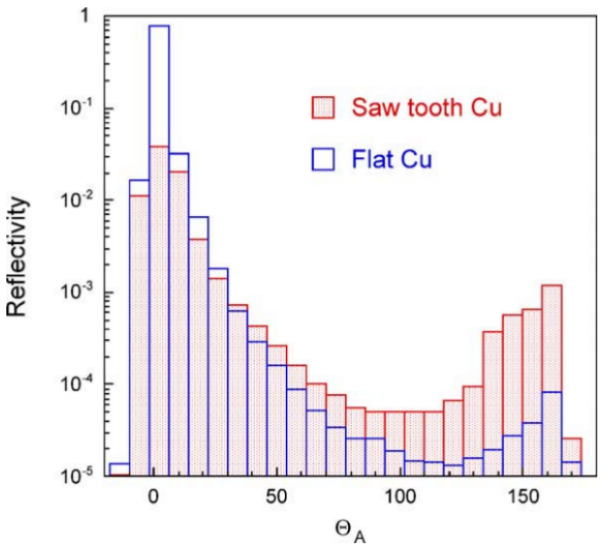
	45 eV		194 eV	
Dose (ph/m)	R (%)	Y* (e/ph)	R (%)	Y* (e/ph)
~ 2 10^{19}	8	0.029	7	0.040
1.5 10^{22}		0.015		0.022

↪ Only results from sawtooth material are published
↪ Sharp decrease in yields

↪ Use these yields (∼-50%) for optimistic estimate
↪ Also scale the yields from non-sawtooth materials by the same factor

Published measurement results - reflectivities

- Mahne, Baglin, Collins et al.: "Photon reflectivity distributions from the LHC beam screen and their implications on the arc beam vacuum system" (2004) - LHC Project Report 668
- Measurements at ELETTRA in Italy
- Measure reflectivities only, but in all directions and for different photon energies

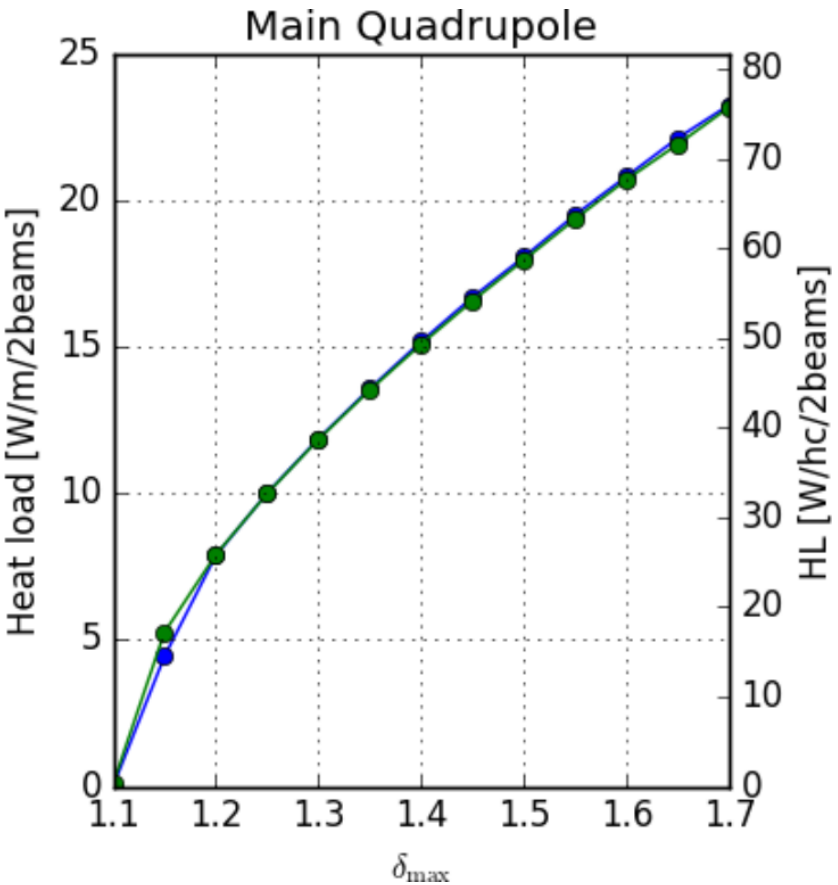


	Flat sample	Saw-tooth sample
Forward scattering (%)	80	4
Back scattering (%)	0	2
Diffused (%)	2	4
Total	82	10

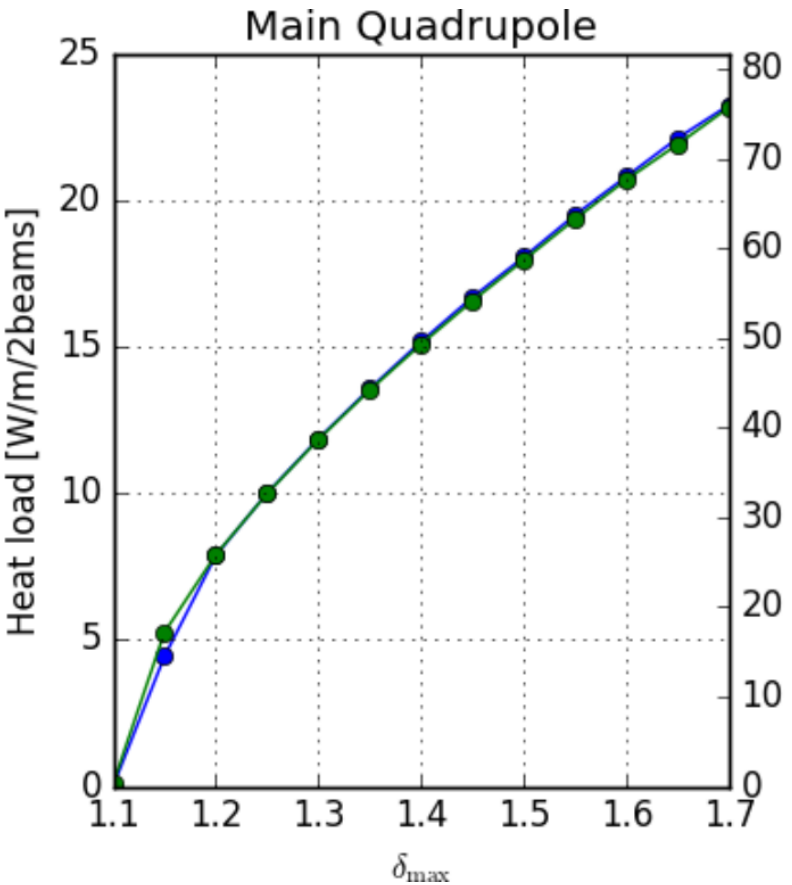
↪ Use these reflectivities and recalculate $Y^* = \frac{Y}{1-R}$

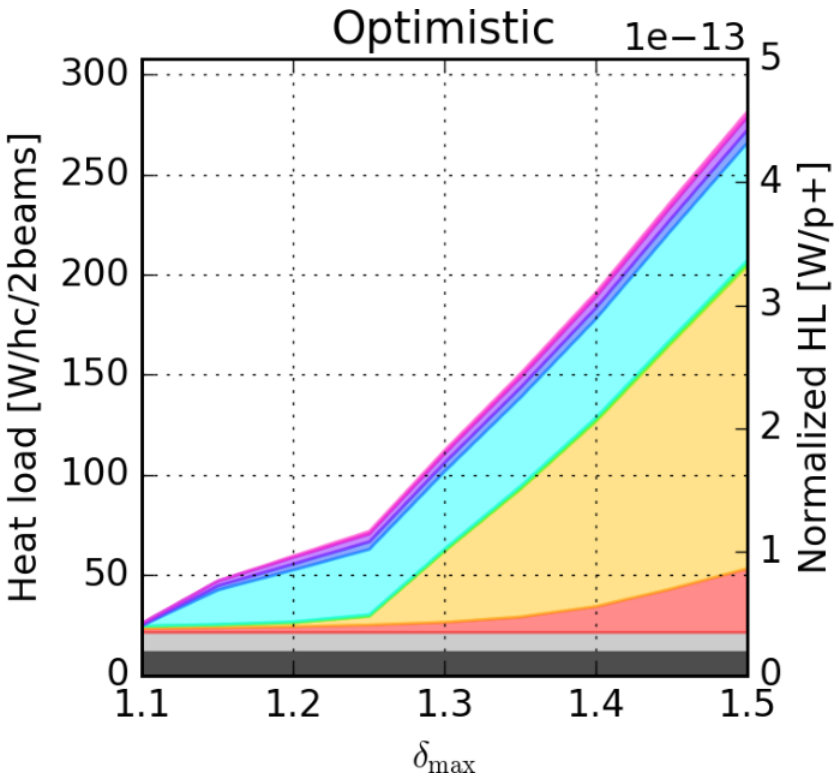
↪ After doing calculation, 20% share of reflected photoelectrons

Explanation of plot



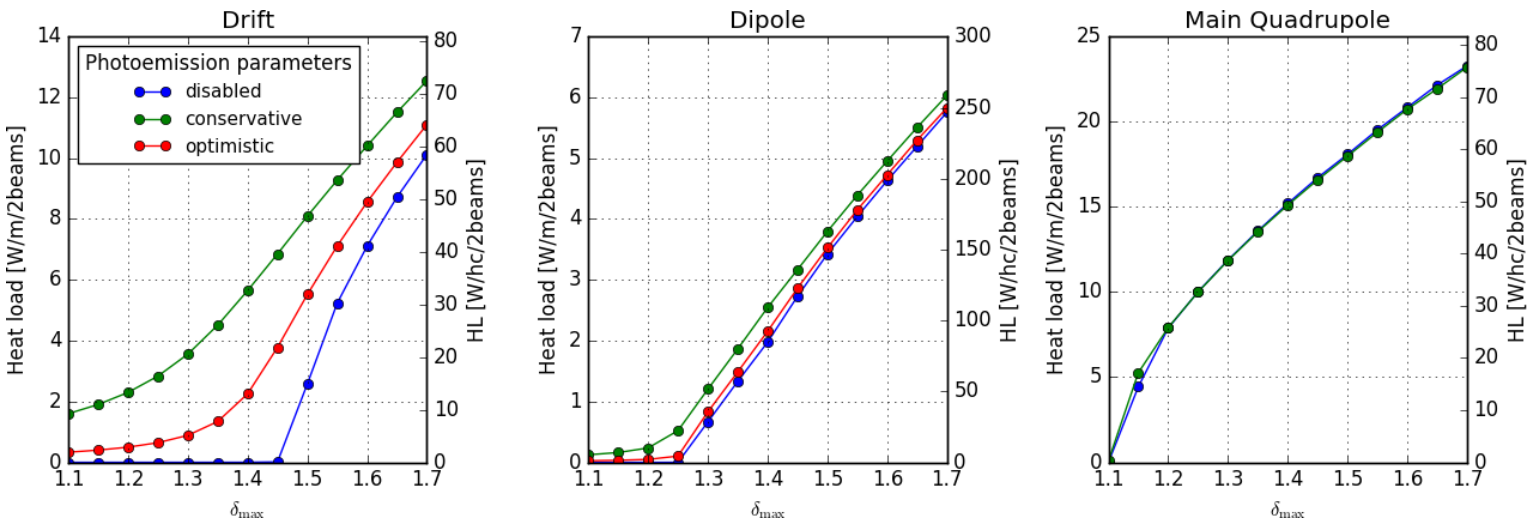
Explanation of plot



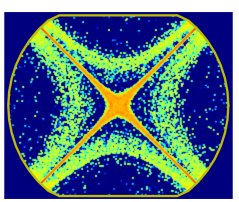


Simulation results

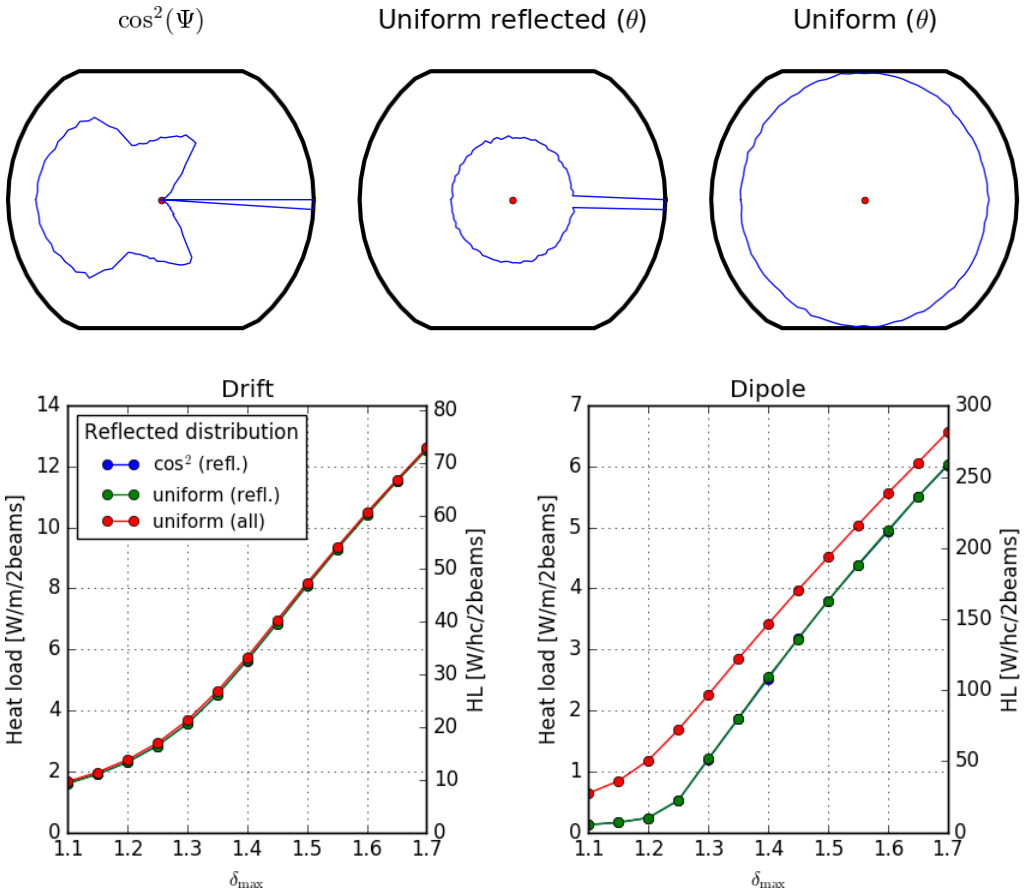
- An initial distribution of electrons was used for simulations without seeding mechanism
- Uniform distribution of photoelectrons generated from reflected photons (∼20%)
- Reminder:
  "Conservative" ↔ as-received surface
  "Optimistic" ↔ after photon scrubbing in the lab
  "Disabled" ↔ Initial electron distribution, no seeding mechanism



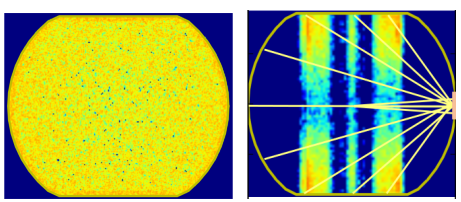
↪ Only drifts and dipoles are sensitive to the presence of photoelectrons
↪ Quadrupoles and higher order magnets are not sensitive



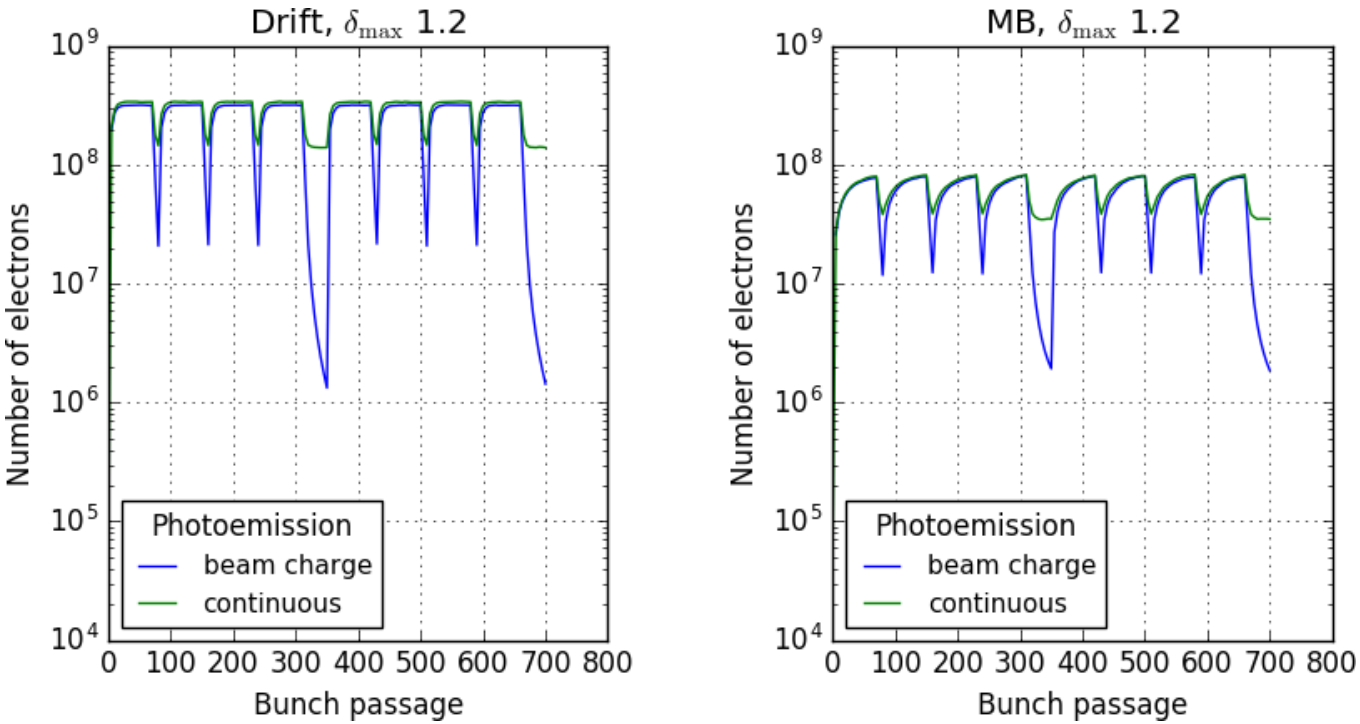
Influence of spatial distribution



- Spatial distribution only matters in the dipolar magnetic field (for LHC chamber and simulation parameters)

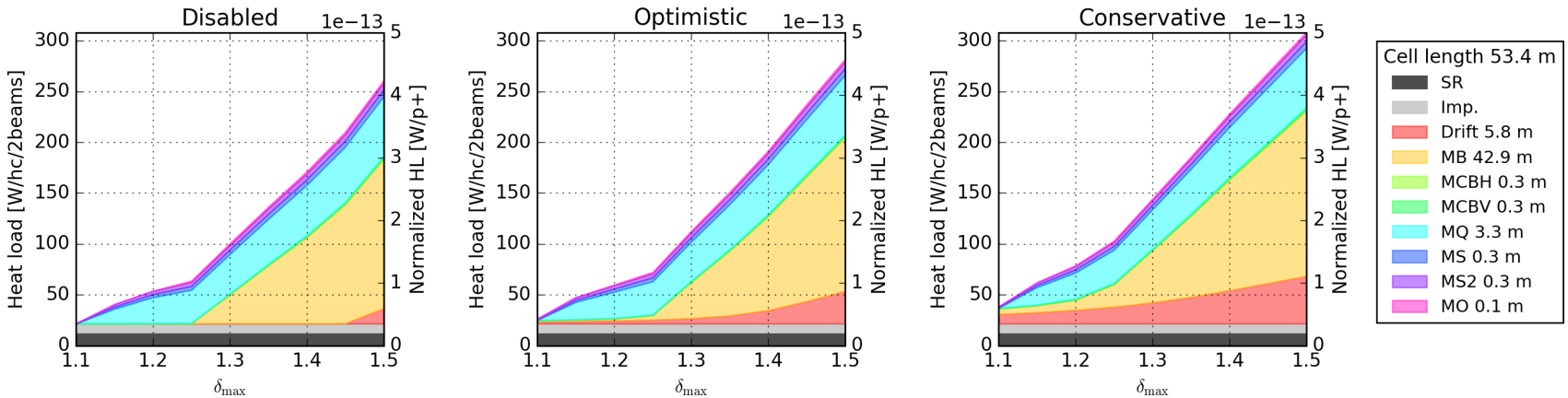


Time-continuous photoemission



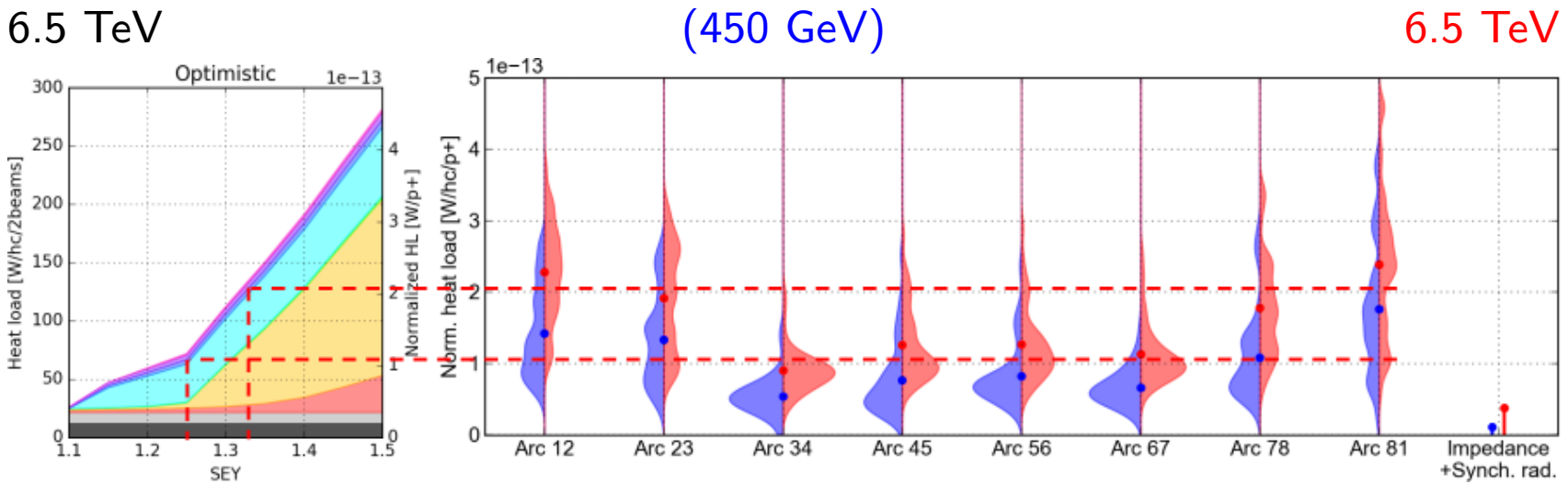
- In PyECLOUD, the photoelectrons are usually generated in parallel with the beam charge
- A time-continuous generation of photoelectrons does not change the results (for LHC chamber and simulation parameters)

Comparison to measured heat loads (more details in talk of G. Iadarola)



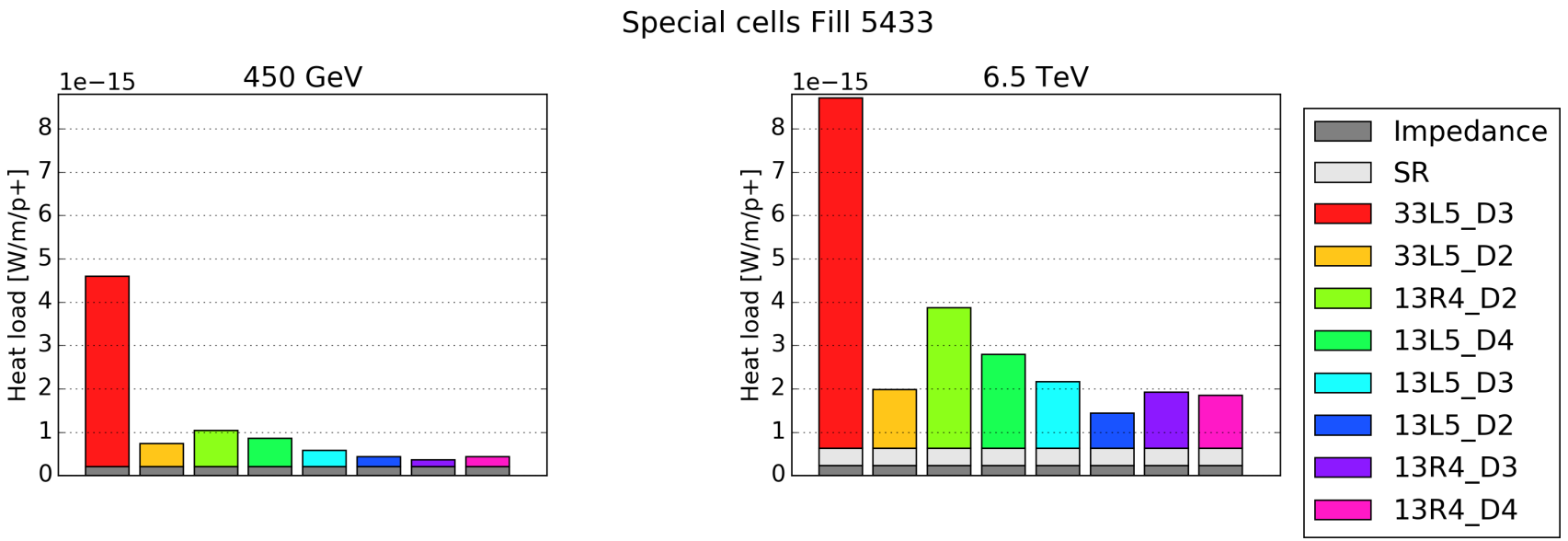
- Simulations: 25 ns case and different photoemission parameters
- Reminder: "Conservative" $\leftrightarrow$ as-received surface, "Optimistic" $\leftrightarrow$ after photon scrubbing in the lab
- Difference of 20%-30% going from no photoelectrons to "conservative" estimation.

Comparison to measured heat loads (more details in talk of G. Iadarola)



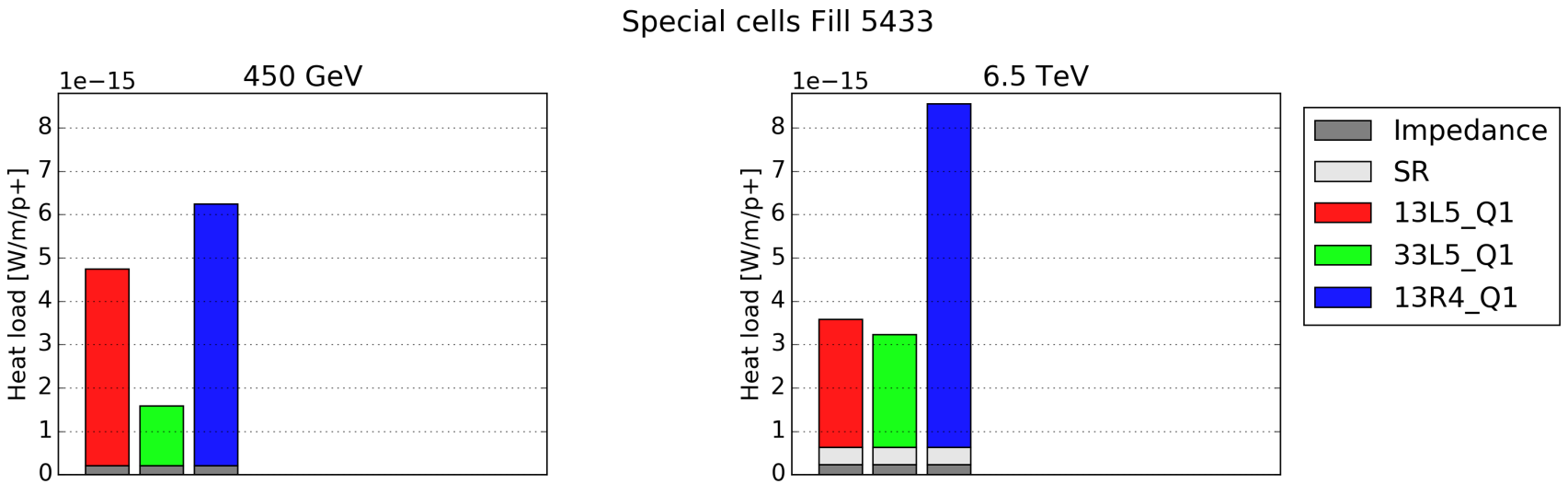
- Variations between cells are larger than simulated impact of photoemission seeding
- $\delta_{\max}$ of $\sim$1.15 **compatible with** low heat load cells
- $\delta_{\max}$ of $\sim$1.32 **compatible with** high head load cells
- Also higher heat load from impedance and synchrotron radiation at high energy

Special instrumented cells - Dipoles



- Large differences in measured heat loads
- Reminder: also higher heat load from impedance and SR

Special instrumented cells - Quadrupoles



- Large differences in measured heat loads, again!
- Overall less effect of photoelectrons than in dipoles
- But higher total EC heat load, consistent with simulations
- Strong magnetic field changes e-cloud dynamics and suppresses photoelectron contribution

Summary

- Measurements of LHC beam screen materials were shown
- PyECLOUD simulation parameters were explained and deduced
- Simulation results with and without seed electrons from photoemission were shown
- The impact is at the level of 20% - 30%, mostly because of drift spaces
- Simulation results were compared with measured heat loads from the LHC

Summary

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Some further notes

- Photon spectra change with beam energy
- Published measurement results were for 7 TeV LHC radiation
- More measurements necessary to make predictions for e.g. FCC

Thank you for your attention

Bonus material: .gif file of a PyECLOUD sextupole buildup simulation on indico