Benchmarking of ECLOUD

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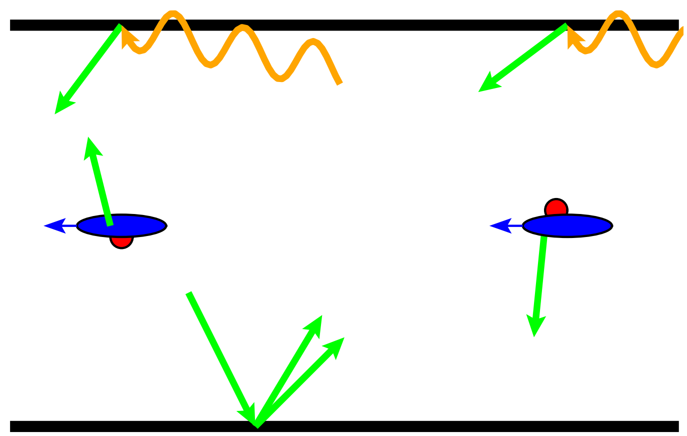
Code work done in collaboration with F. Zimmermann

Thanks to: G. Arduini, V. Baglin, B. Jenninger, J. M. Jimenez, J.-M. Laurent, A. Rossi, F. Ruggiero

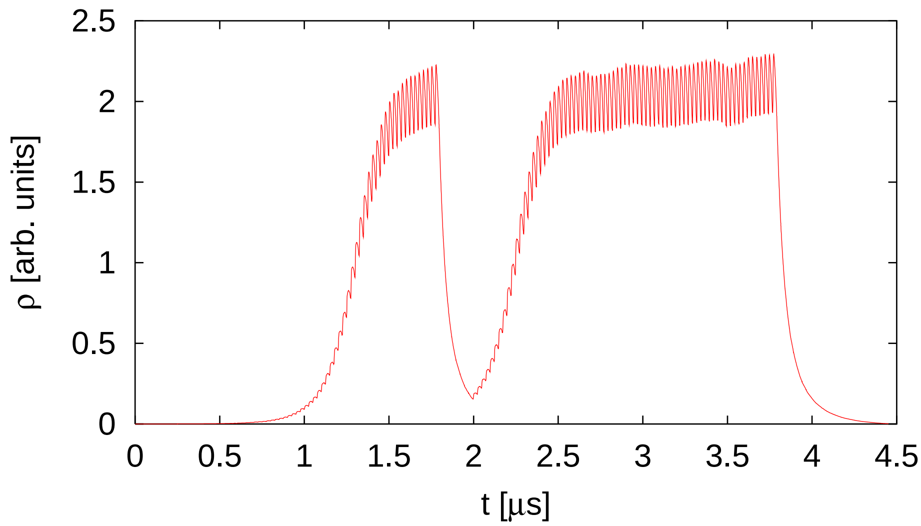
Introduction



The simulation code must

- model the primary electron source
- model the secondary production
- determine fields generated by beam and electron cloud
- track electrons through fields

Typical Cloud Build-Up



- SPS beam in dipole field, $\delta_{max} = 1.3$ (secondary emission yield), $r = 1$ (low energy reflectivity)
  - nominal spacing $25\,\mathrm{ns}$ between bunches
  - $225\,\mathrm{ns}$ between trains
- The cloud builds up exponentially
- It saturates when its own space charge about compensates the beam field
- Rise in the second train can be faster than in the first one due to seed electrons

⇒ has been exploited for measurements by modifying train distances in the SPS

Code-to-Code Comparisons

- Comparisons of different codes

  $CSEC(N.Blaskiewicz), ECLOUD, EPIandPEI(K.Oh$

  indicated

  - Saturation levels and rise times can vary by factors of a few

- POSINST and ECLOUD comparison lead to 20% agreement level for the same surface model

- Different models result in differences of a factor 2

- At ECLOUD04 it was felt that

  - the tracking is well understood

  - the surface physics and modelling is less so

$\Rightarrow$ The benchmarking against experiments is vital

- We use improved ECLOUD

  verification of modules, secondary emission modelling, boundary conditions, speed ($\mathcal{O}(10+)$)

Benchmarking Problems and Strategy

- The machine is changing (scrubbing)
- Detectors differ
  - Vacuum chamber size
  - Magnetic field
  - Detector effects

  ⇒ They scrub differently
- Cannot measure δ_{max} and r locally in all detectors

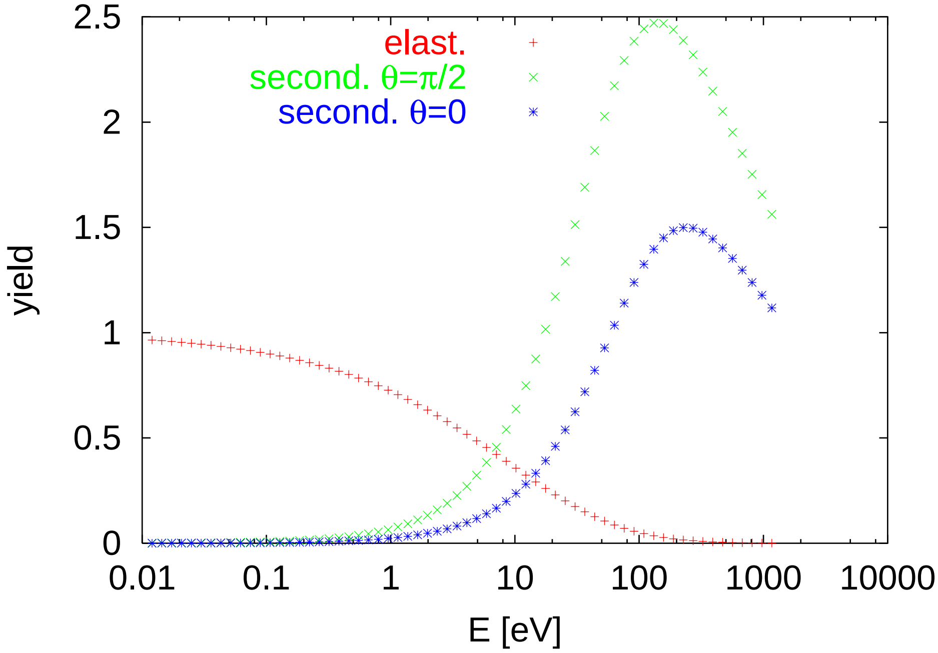
  ⇒ No straightforward model verification

  ⇒ Try to fit parameters from simulation and ensure consistency

⇒ Concentrate on a few of the existing detectors to understand each of them better, more will follow

- Attempt to predict the heat load in the LHC assuming the same surface conditions

Secondary Electron Generation



Consider two contributions

- true secondaries (N. Hilleret, M. Furman)
- elastically scattered electrons (R. Cimino, I. Collins)

- Significant uncertainties exist
  - level of reflection
  - changing surface (scrubbing)
- parameters used: δ_{max} and r

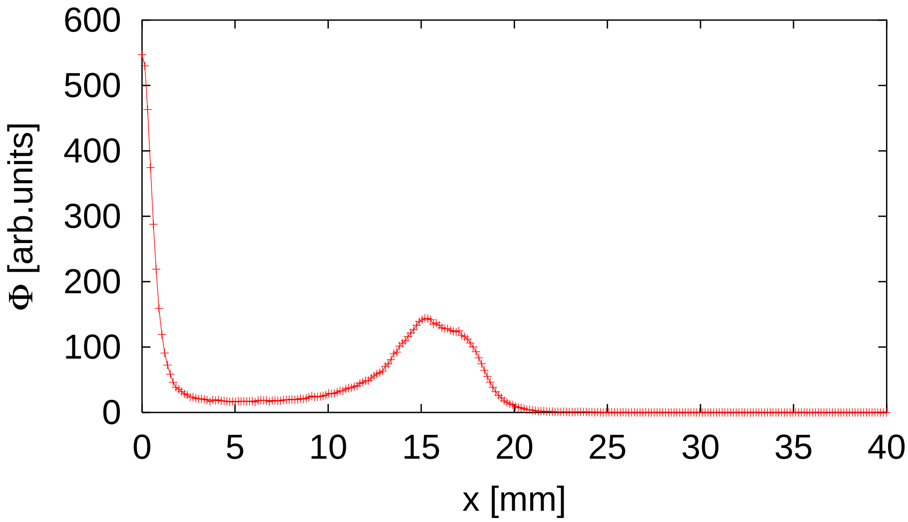
$\Rightarrow$ use different train spacings to estimate reflection

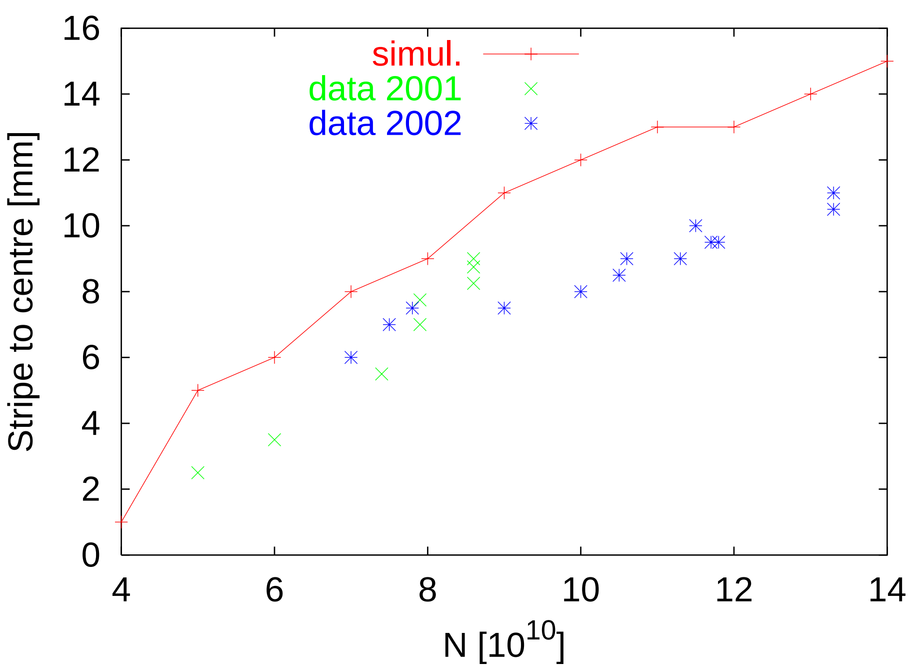
The Considered Detectors

Three detectors are considered here

- COLDEX (no magnetic field)
  - can measure power
  - and flux in screened monitor and chimney monitor
- Cold (and warm) strip detectors in dipole field
  - flux
  - vertical beam pipe dimension close to LHC value
- Strip detector in quadrupole field
  - flux

Benchmarking of Tracking



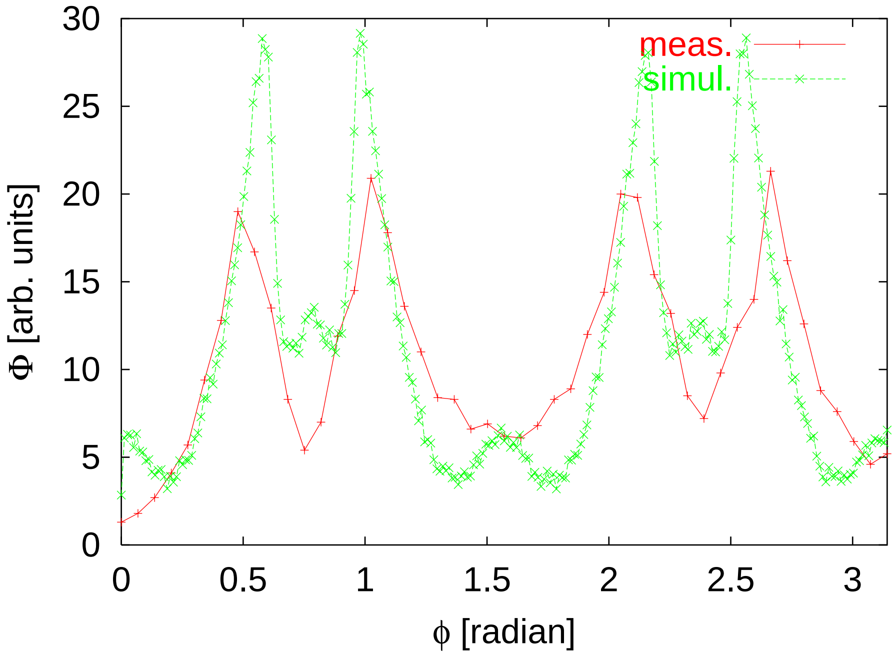


- SPS, warm strip detector, dipole field

$\Rightarrow$ seems to be modelled reasonably well

- no difference between $25\,\mathrm{ns}$ and $75\,\mathrm{ns}$ spacing predicted

Loss Pattern in Quadrupole



- Pattern comparison for now (likely wrong δ_{max})

  $\Rightarrow$ Need to do quantitative ones later

- Observation for increasing field

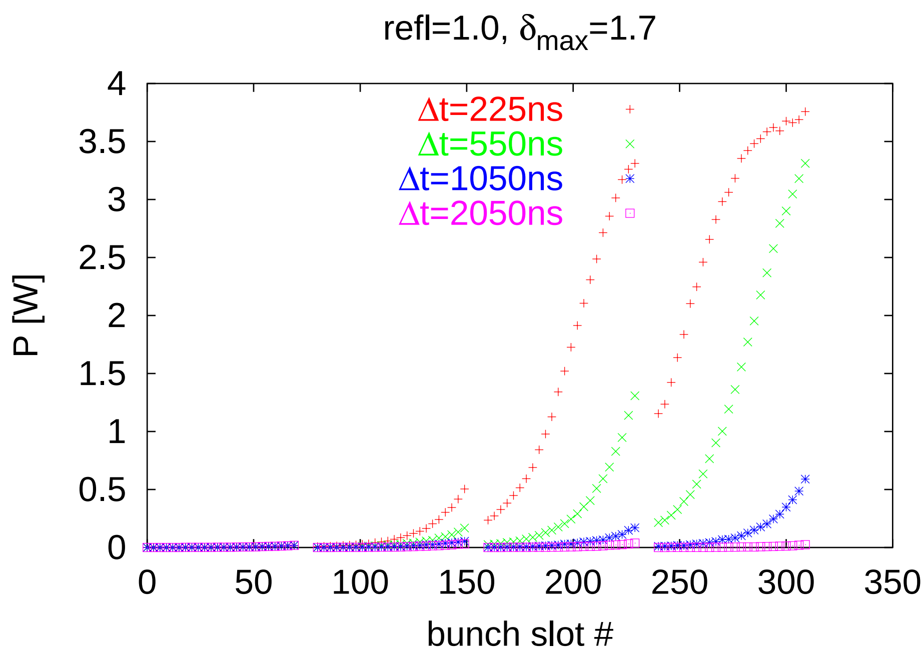
  - flat distribution at no field
  - maximum between poles
  - two stripes per pole
  - one stripe per pole

- Good agreement for pattern at $0.1\,\mathrm{T/m}$
- levels need to be checked

Experimental Result (COLDEX)

Early in run, $75\,\mathrm{ns}$ bunch spacing:

- $\Phi(550\,\mathrm{ns})/\Phi(225\,\mathrm{ns}) \approx 60\%$
- Almost no flux for $1050\,\mathrm{ns}$ train spacing



$\Rightarrow$ Find δ_{max} and r consistent with experiment

δ_{max}	r	$\Phi(550\,\mathrm{ns})/\Phi(225\,\mathrm{ns})$	$P\,[\mathrm{mW/m}]$
1.75	1.0	0.55	167
1.8	0.95	0.56	172
1.9	0.85	0.57	175

- Measured heat load about $200\,\mathrm{mW/m}$ for nominal train spacing is consistent with simulation

Result After Scrubbing (COLDEX)

Observation with 25 ns bunch spacing:

- $\Phi(2050\,\mathrm{ns})/\Phi(225\,\mathrm{ns}) \approx 0.8$
- heat load about $1.5\,\mathrm{W/m}$ for nominal beam

δ_{max}	r	$\Phi(2050\,\mathrm{ns})/\Phi(225\,\mathrm{ns})$
1.25	1.0	0.7
1.3	0.8	0.65
1.4	0.5	0.6

Integrated electron flux roughly sufficient for improvement down to $\delta_{\mathrm{max}} \approx 1.3$ (V. Baglin)

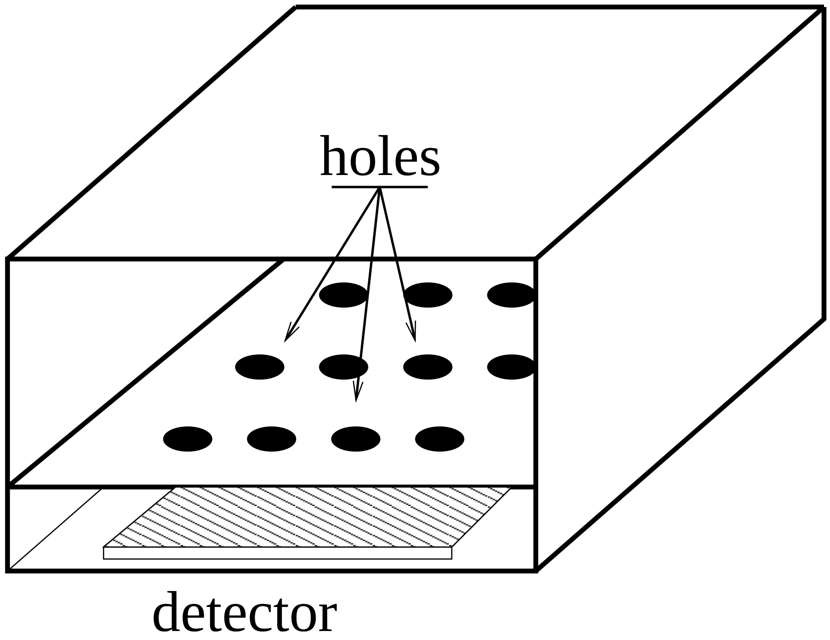
$\Rightarrow$ Experiment and simulation are consistent with achievement of $\delta_{max} = 1.3$ in COLDEX but do not prove this

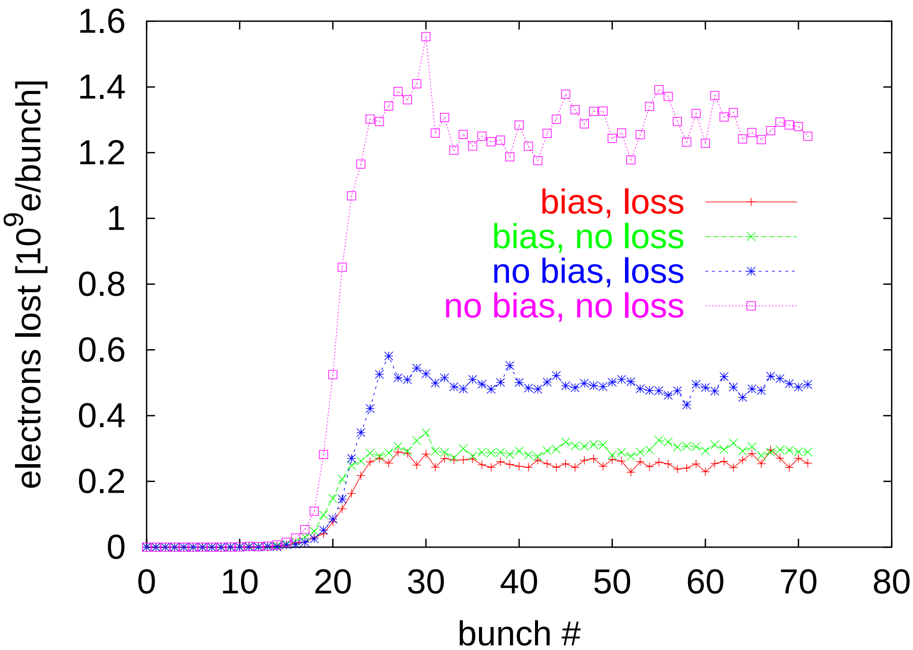
- Simulated absolute flux consistent with chimney detector, but screened detector measures twice the flux

$\Rightarrow$ reasonable agreement

- but flux at $75\,\mathrm{ns}$ needs to be investigated (detectors scale differently)
- detector effects are important

Example Detector Effect





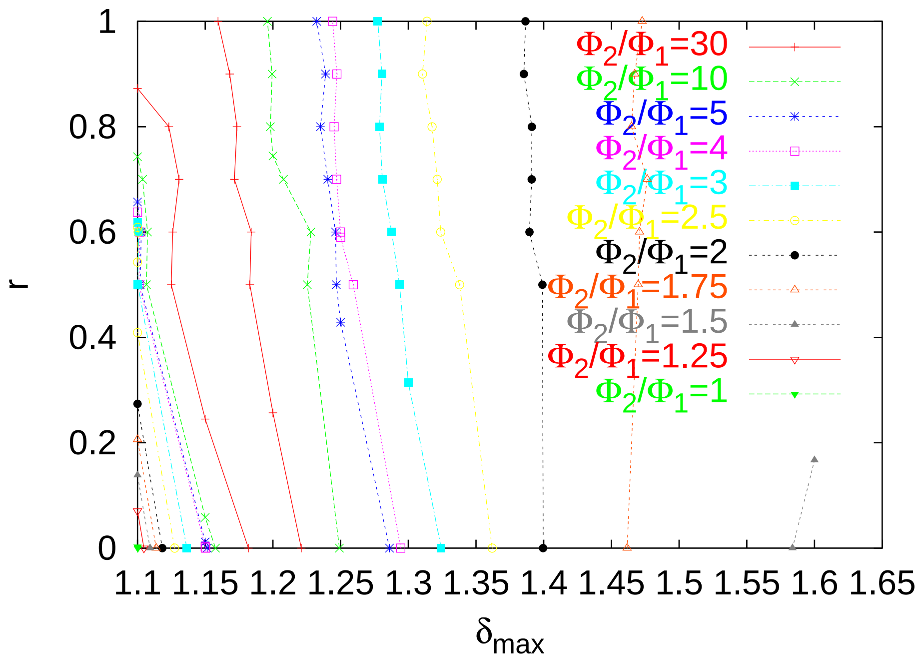
- Strip detector in dipole field, $\delta_{max} = 1.5$, $r = 1$

Result for Cold Dipole

- Can measure train to train

  Observation in the middle of the run

  - electron flux for one train $\Phi_1 \approx 2.4\times10^{-4}\,\mathrm{A/m}$
  - electron flux for two trains $\Phi_2 \approx 7.2\times10^{-4}\,\mathrm{A/m}$

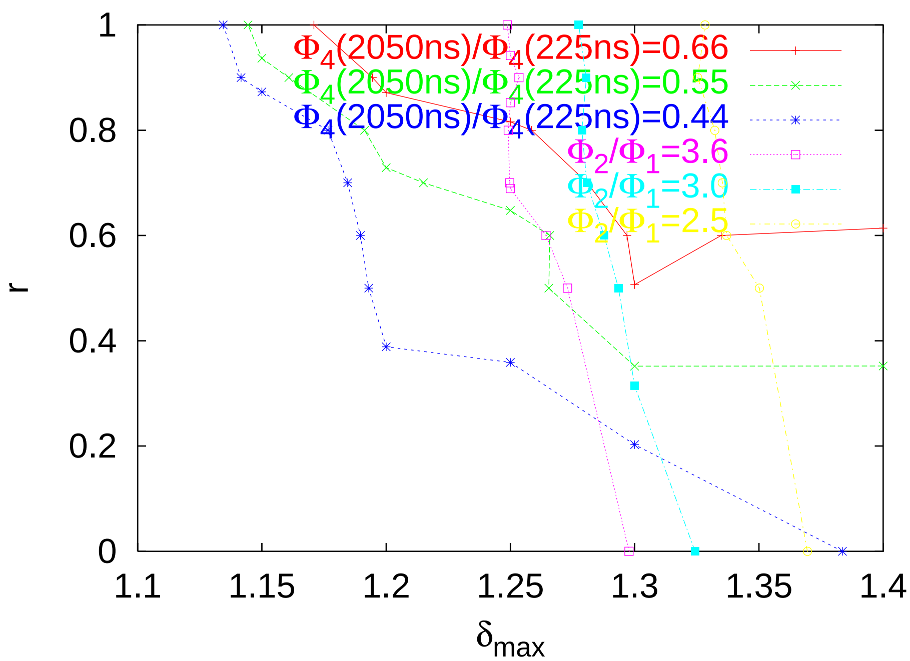


$\Rightarrow$ Simulation yields: $\delta_{max} \approx 1.3$

- but r is important to estimate heat load
- to be checked for sensitivity to other parameters (vacuum, etc.)

Variation of Flux

- Reduction of flux $\Phi(2050\,\mathrm{ns})/\Phi(225\,\mathrm{ns}) \approx 0.55$



$\Rightarrow$ Best fit seems $\delta_{max} = 1.3$, $r = 0.4$

- Cross check with absolute simulated level yields $\Phi_1 + \Phi_2 \approx 10 \times 10^{-4}\,\mathrm{A/m}$

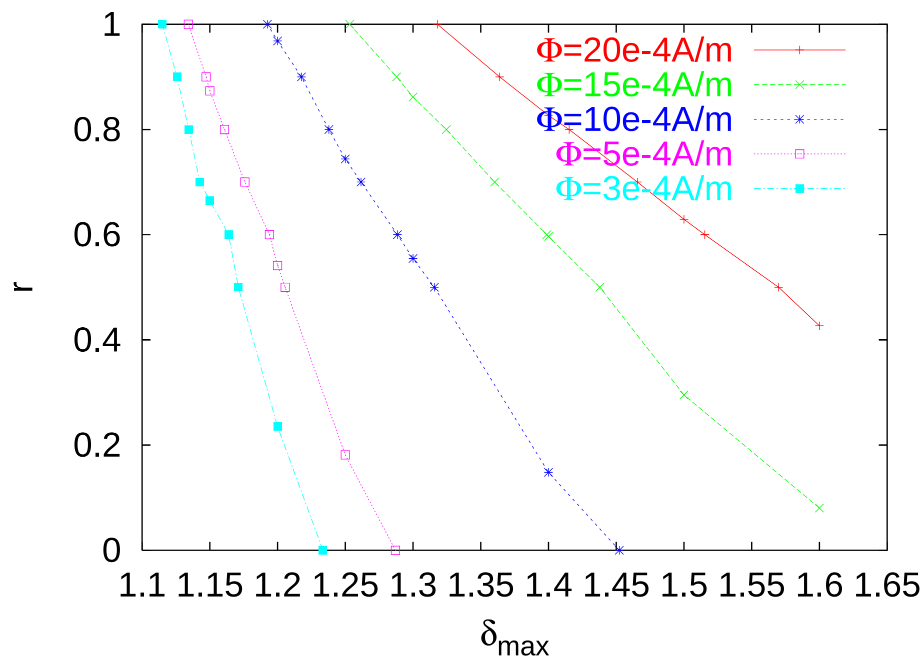
$\Rightarrow$ Reasonable agreement, but need to check detector modelling

- Need to perform error analysis

- Need to determine secondary emission in the early phase

After Further Scrubbing

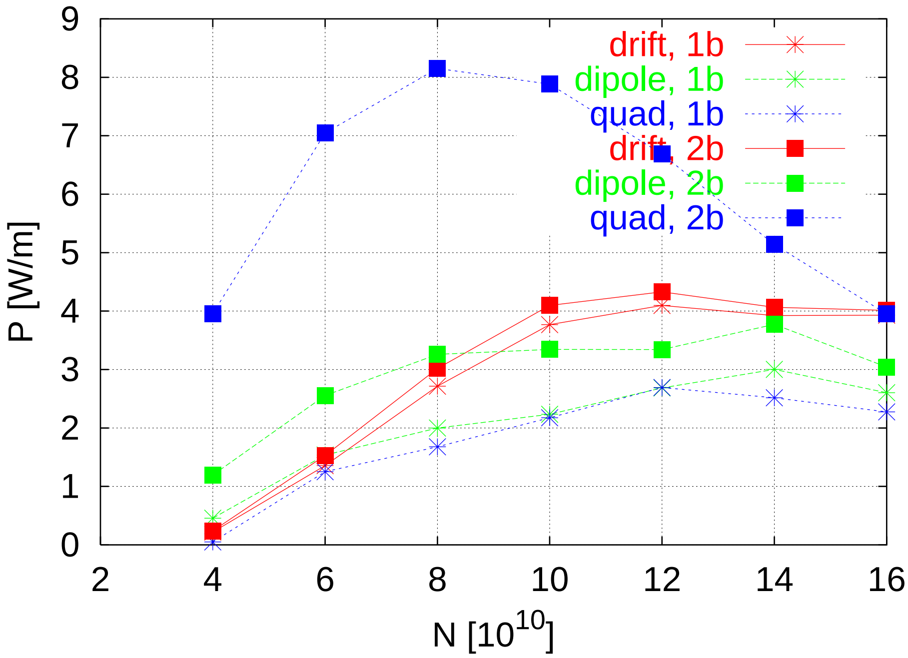
- Flux below 3×10^{-4} A/m for two trains, Φ_2/Φ_1 difficult to measure



$\Rightarrow$ using Φ only and extrapolation seems to lead to $\delta_{max} \approx 1.2$ for $r = 0.4$

- But still preliminary, needs cross checks and error analysis

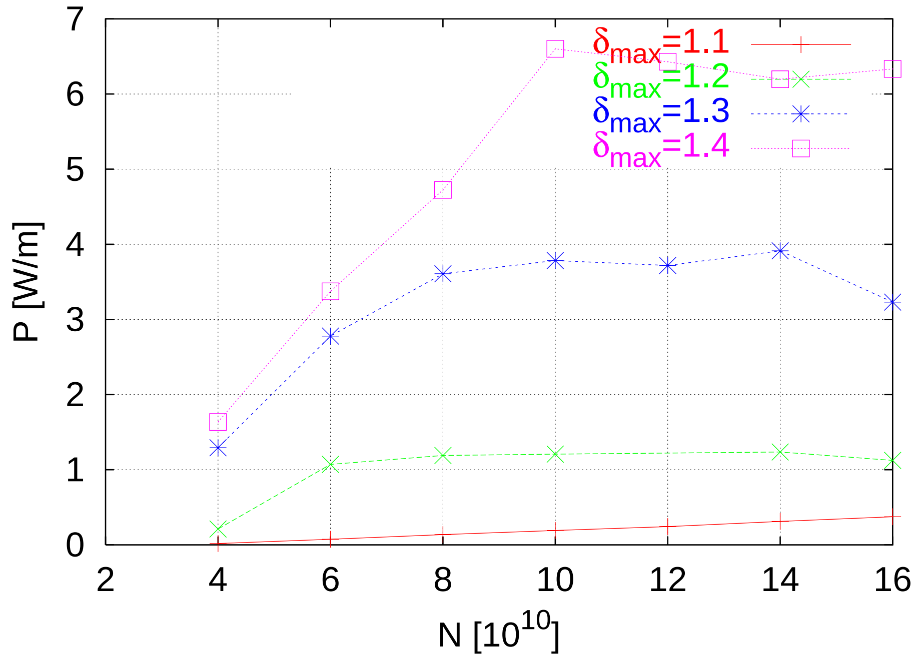
LHC Heat Load



- Top energy
- Parameters used $\delta_{max} = 1.3$, $r = 1$
- Bunch spacing $25\,\mathrm{ns}$, two trains
- Primary electron source is synchrotron radiation
- Second train produces higher heat load, in particular in quadrupoles

$\Rightarrow$ Now assume second train is representative for all, but will be checked

LHC Heat Load



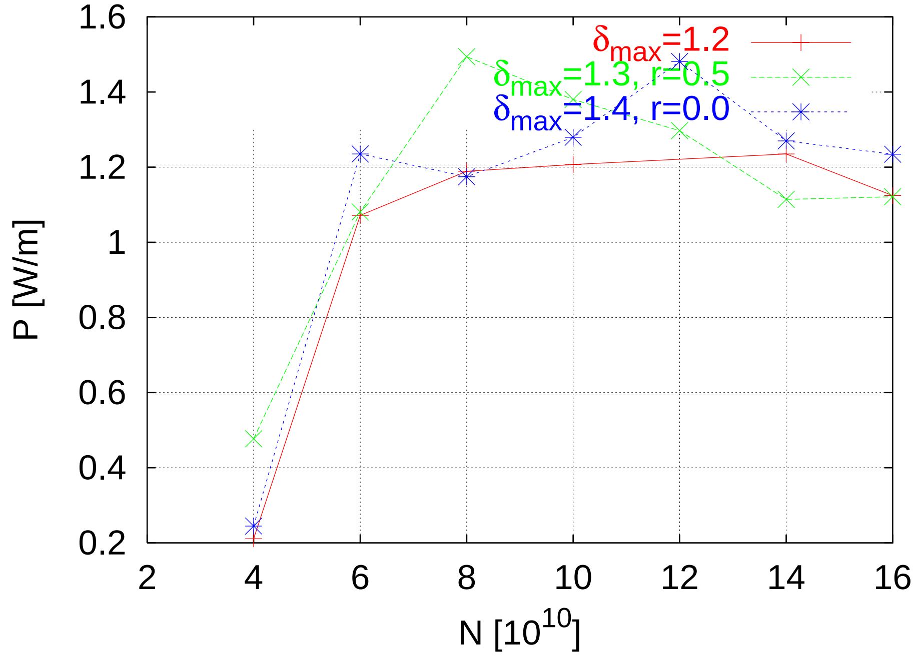
- Heat load average over an arc cell for top energy, $25\,\mathrm{ns}$ bunch spacing
- Assume second train is representative
- $r = 1$ assumed

$\Rightarrow$ Require $\delta_{max} < 1.2$

- Some statistical uncertainty ($\approx 10\%$–20%, quadrupoles)

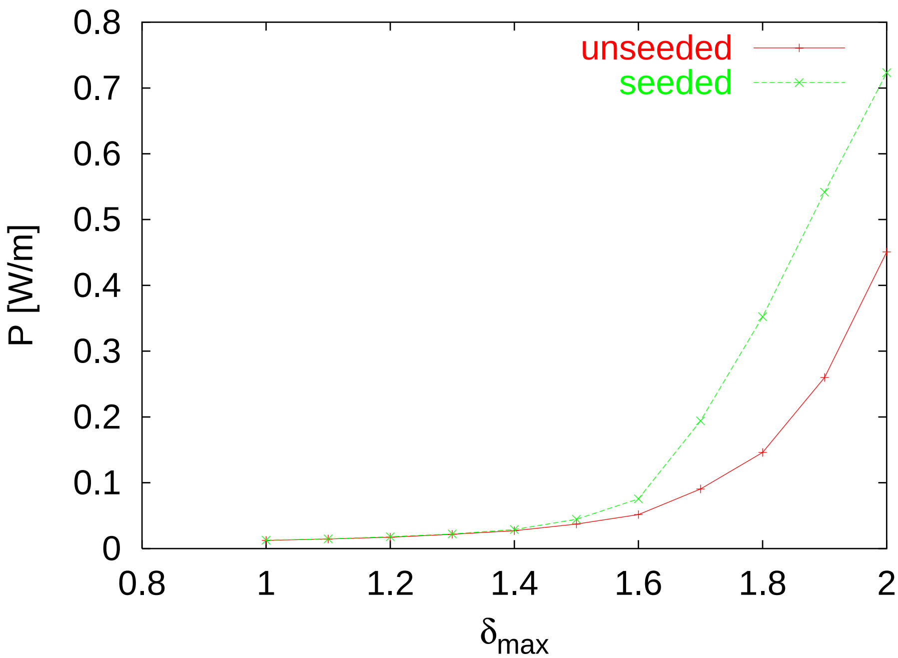
$\Rightarrow$ need to redo with more statistics

Different Reflectivities



- Bunch spacing of $25\,\mathrm{ns}$ and two trains used
- Seem to have equivalent heat load for
  - $\delta_{max} = 1.2$, $r = 1$
  - $\delta_{max} < 1.3$, $r = 0.5$
  - $\delta_{max} < 1.4$, $r = 0$
- corresponds to uncertainty in experimentally determining δ_{max} and r

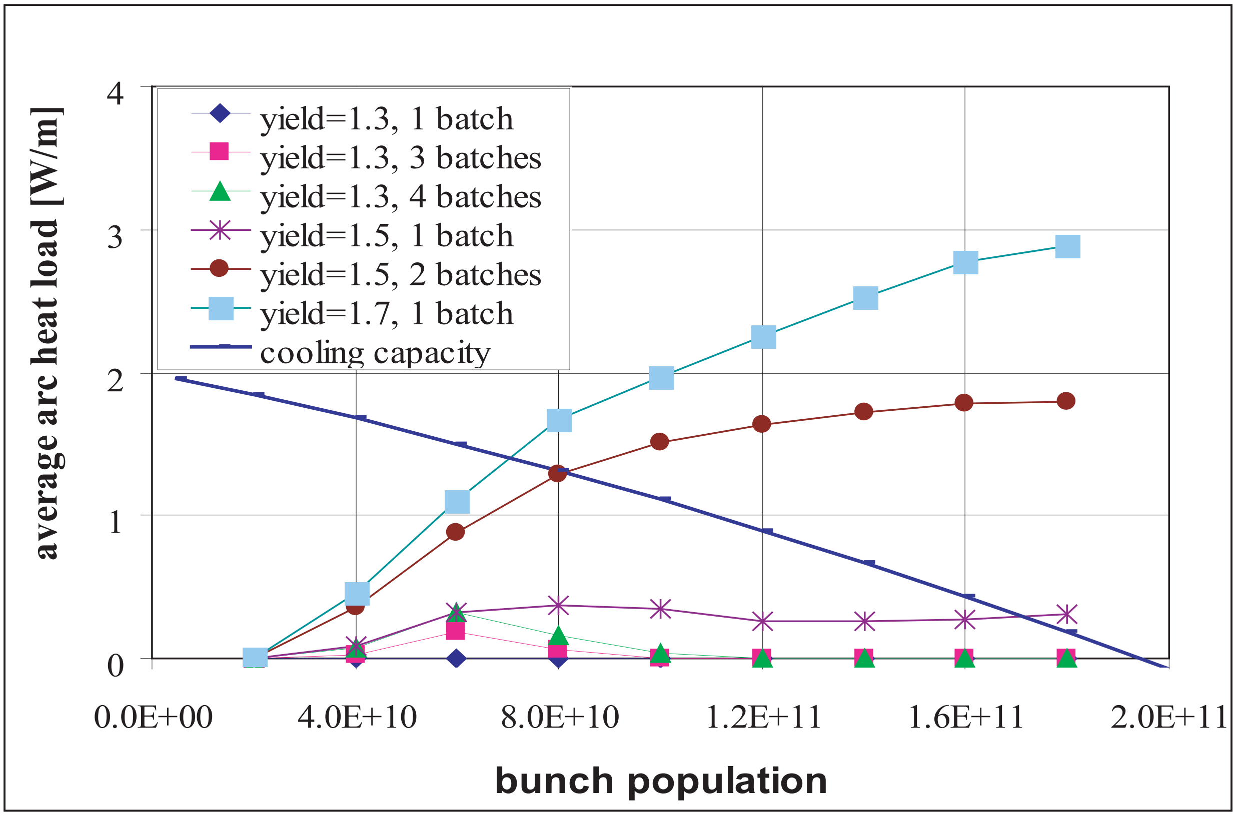
Bunch Spacing of 75ns



- Heat load at top energy (without quadrupoles) with nominal bunch intensity
- Is even lower at injection
- $r = 1$ used

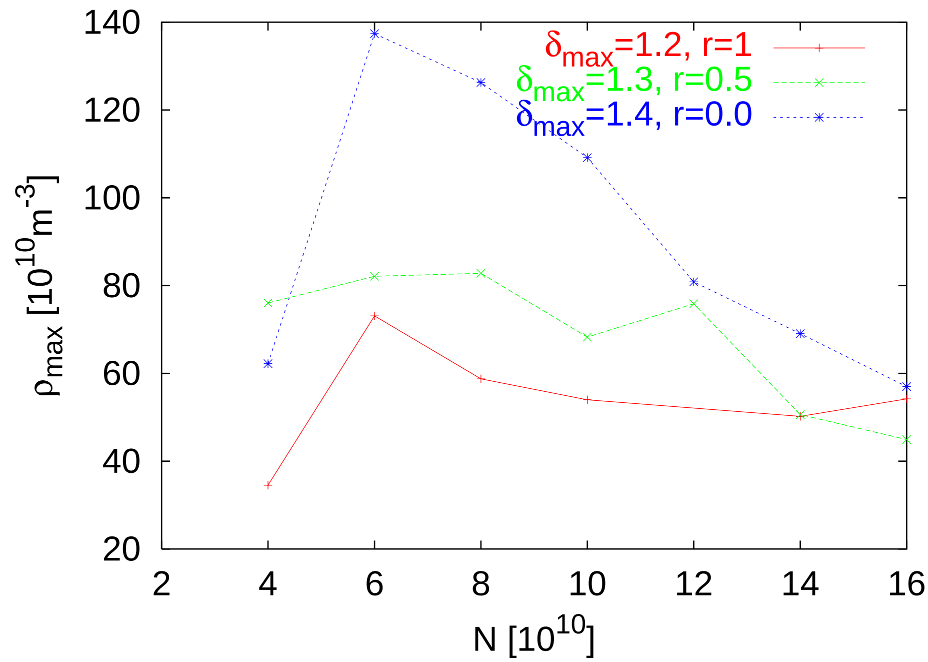
$\Rightarrow$ Heat load should be no problem at a bunch spacing of $75\,\mathrm{ns}$

LHC Heat Load at Injection



- $r = 1$ assumed throughout
- Cloud intensity increases from first to second train
- Heat load at injection is lower than at top energy
- With $\delta_{max} = 1.3$ full intensity can be reached

Electron Cloud Density



- Top energy in dipole field
- Averaged over whole vacuum chamber

Conclusion

- The simulation code has been improved noticeably
- It seems to be able to reproduce current experiments

  $\Rightarrow$ more data will be used for comparison
- In the SPS secondary emission yields of the order of $\delta_{max} = 1.3$ were likely reached in cold conditions
- For the LHC at nominal parameters $\delta_{max} < 1.2$–1.4 (for $r = 1$–0) is required
- Using a bunch spacing of $75\,\mathrm{ns}$ leads to an acceptable heat load
- At injection the heat load should be smaller than at top energy
- More work will be done to verify benchmarking (e.g. error analysis and taking into account more measurements)