Electron-Cloud Build-Up Simulations for the FNAL Main Injector

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Summary

- MI parameters
  —present conditions and future goals
- Summary of current e^- cloud observations at MI (~mid-2007)
- Fit simulations to measurements
  —infer e^- density and predict at higher beam intensity
- Compare f_{RF}=53 MHz vs 212 MHz at same beam intensity
- Conclusions

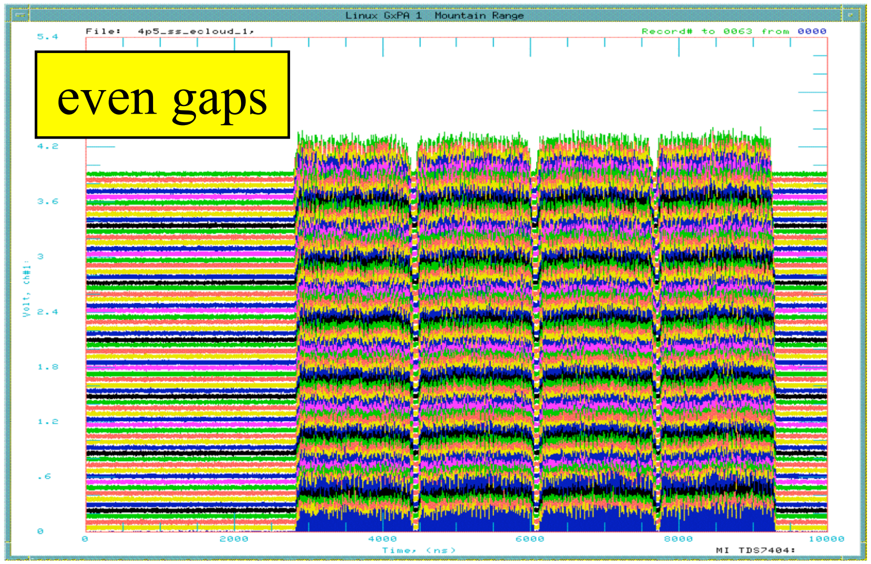
(more from Bob Zwaska later in this session)

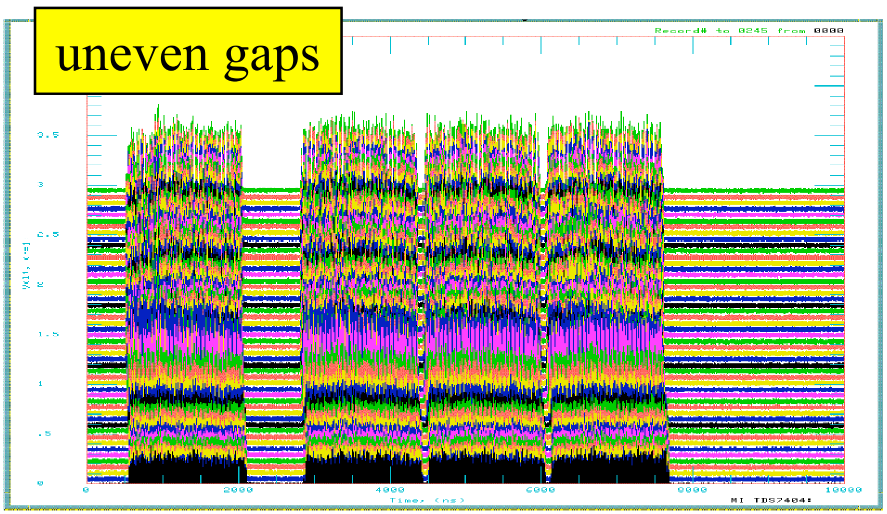
Motivation: plans to increase MI intensity for neutrino program

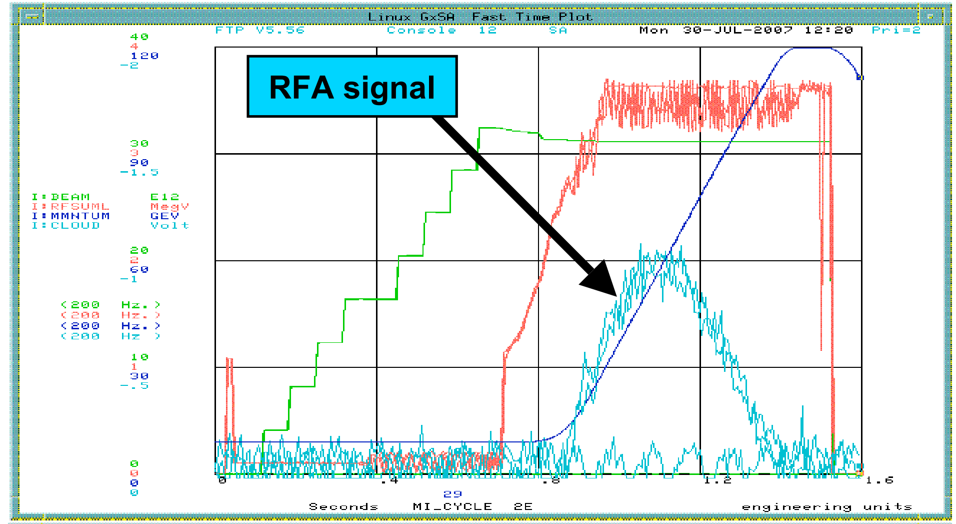
- Nominal operation:
  - —6 trains of 81 bunches
  - —Gaps: 5 empty buckets in between trains + abort gap of 77 buckets
  - —f_{RF}=53 MHz (h=588; C=3319.4 m ; T_{RF}=18.8 ns; T_{rev}=11.1 μs)
  - —Intensity: N_b~6x10^{10}/bunch (~3x10^{13} protons/pulse)
  - —Ramp: E_b=9 GeV to E_b=120 GeV in ~1 sec
    - Transition at E_b~20 GeV
  - —Have achieved N_b~11x10^{10} (but with 4 or 5 trains)
  - —e^- cloud observed, but is not an operational limitation
- Goal:
  - —Increase N_b to 30x10^{10}
  - —Will e^- cloud be a limitation?
  - —If so: mitigate
    - Possibly change f_{RF}
    - Possibly replace or coat chamber with low-SEY material

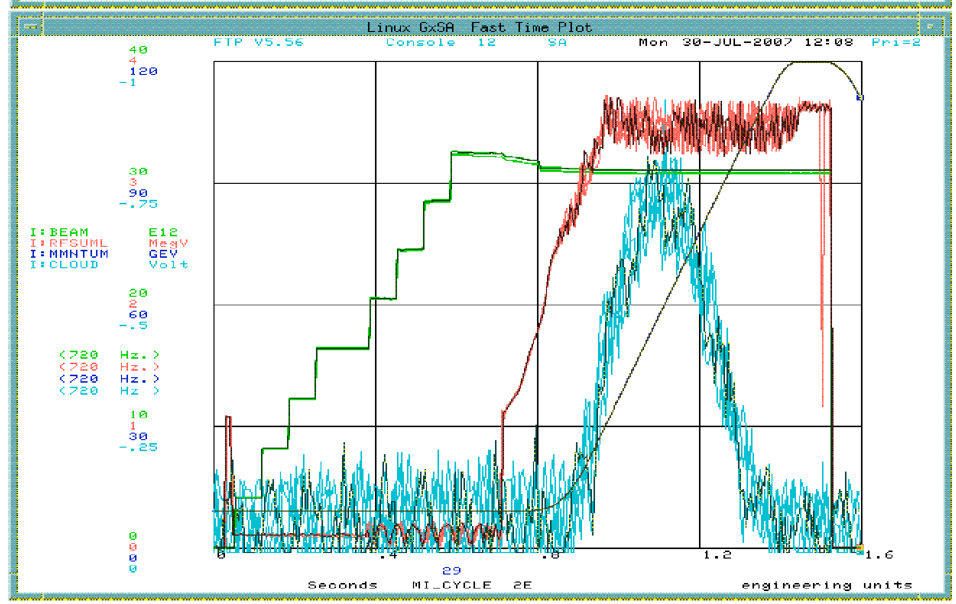
Example: 4 trains, N_b=(9.1–9.5)e10

(from I. Kourbanis report, ~26 Aug. 2007)









Bunch length during ramp
(from I. Kourbanis report, ~26 Aug. 2007)

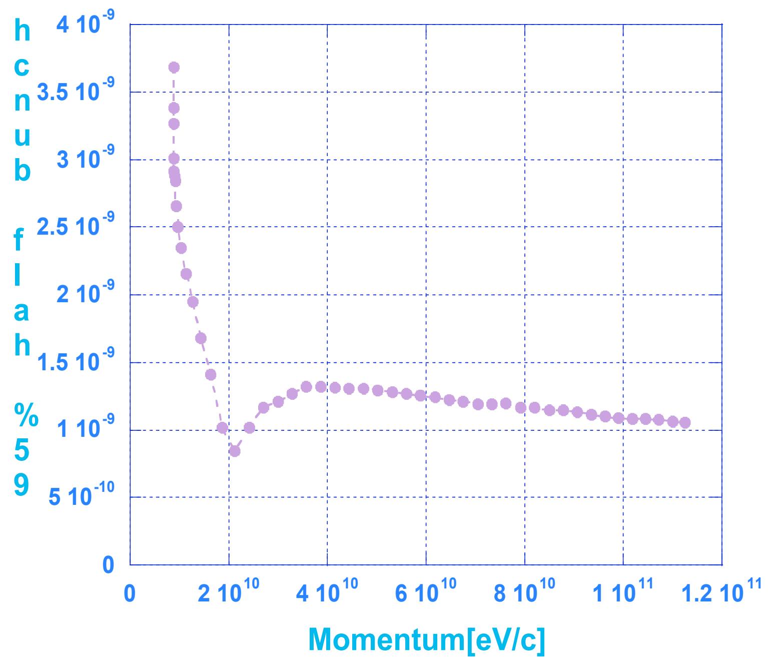
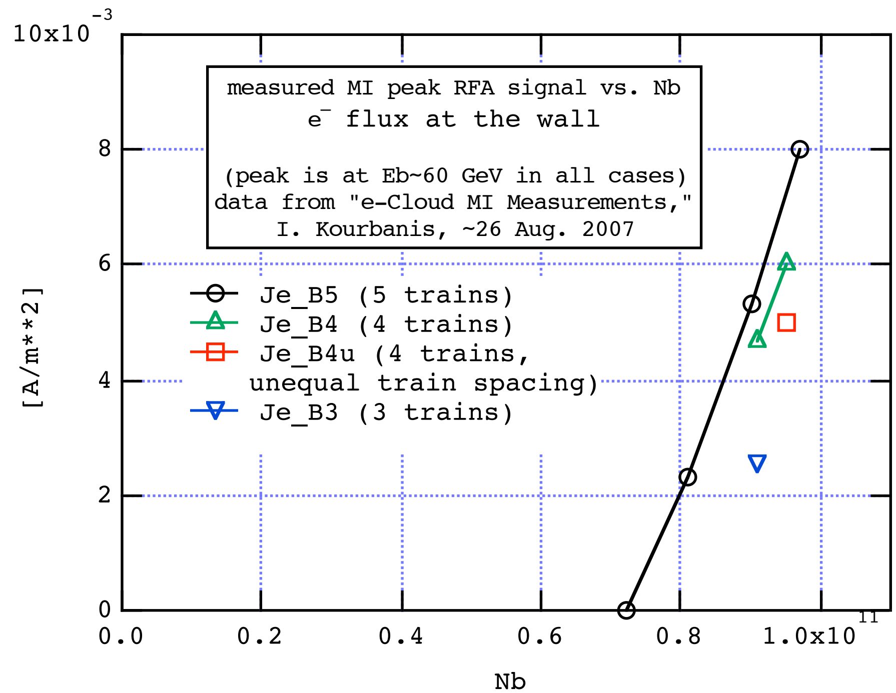


Fig. 9: Bunch length vs. momentum for 9.5E10 p/bunch. The bunch length in the above plot represents the average 95% half bunch length.

Summary of RFA measurements
(extracted from I. Kourbanis report, ~26 Aug. 2007)

- For this exercise, take measured RFA signal only at E_b=60 GeV
  - —this is the peak signal for all cases
- To convert RFA voltage signal to e⁻ flux (R. Zwaska):
  - —assume 1 μA/V
  - —divide by 1.5 cm^2
    - this assumes 30% area efficiency
  - —Typical: a few mA/m^2
- E-cloud is not an operational limitation at present

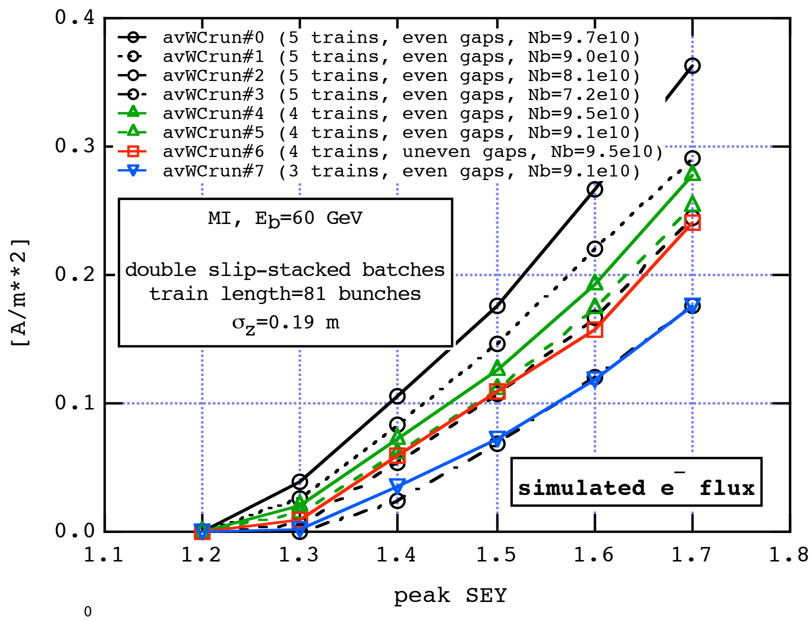
e⁻ flux at RFA vs. N_b for various fill patterns (E_b=60 GeV all cases)

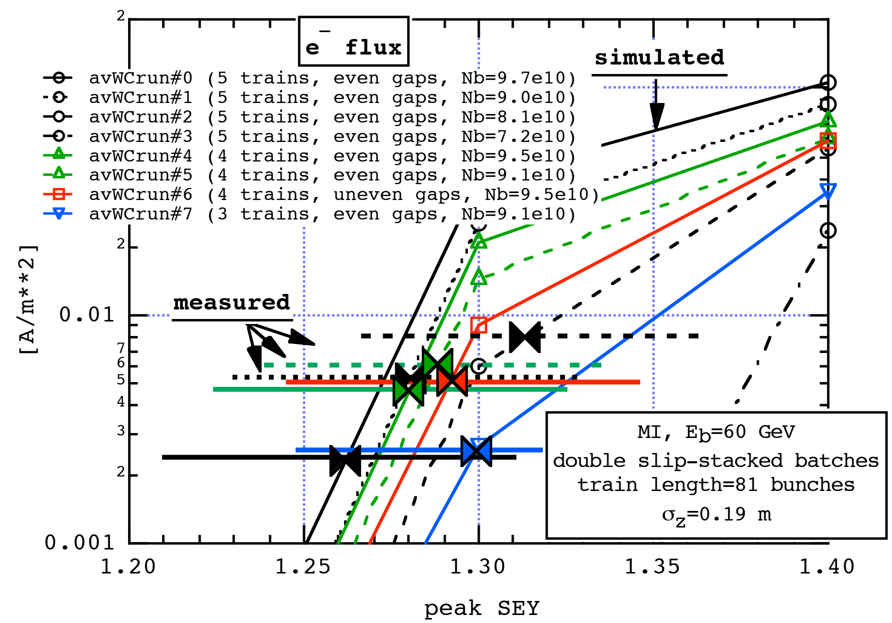


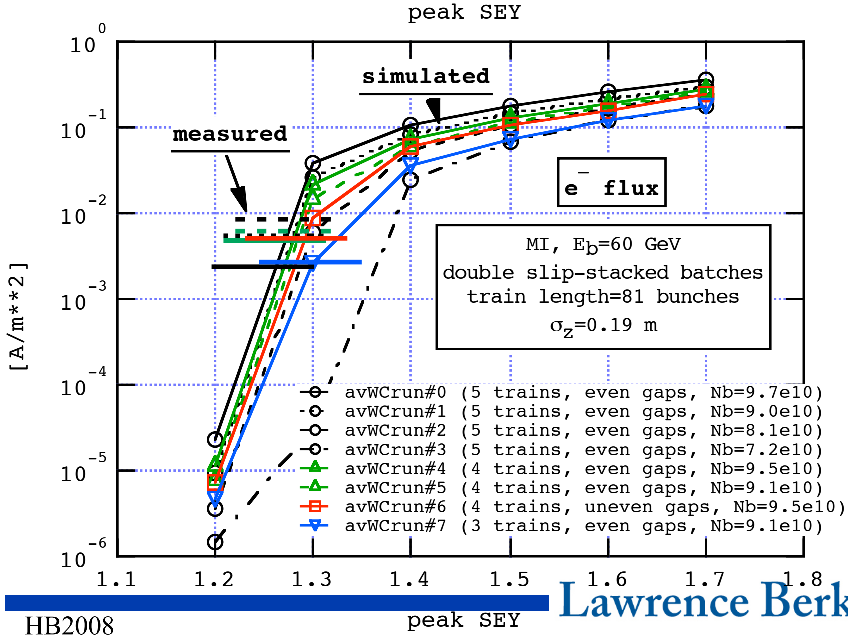
“POSINST” code build-up simulations

- Use actual fill pattern for each case
  - —81 bunches/train
  - —train gap = five 53-MHz empty buckets
    - except for “UG” case: one long gap of 42 empty buckets
- So far, done only E_b=20, 45, 60 and 90 GeV
- Use actual values for N_b, σ_x, σ_y, σ_z for each E_b
- Field-free region (RFA location); pipe=7.3 cm radius
- Average ecloud flux and density over 1 turn
  - —this is long enough for sensible time averages

Simulated electron flux vs. peak SEY at E_b=60 GeV



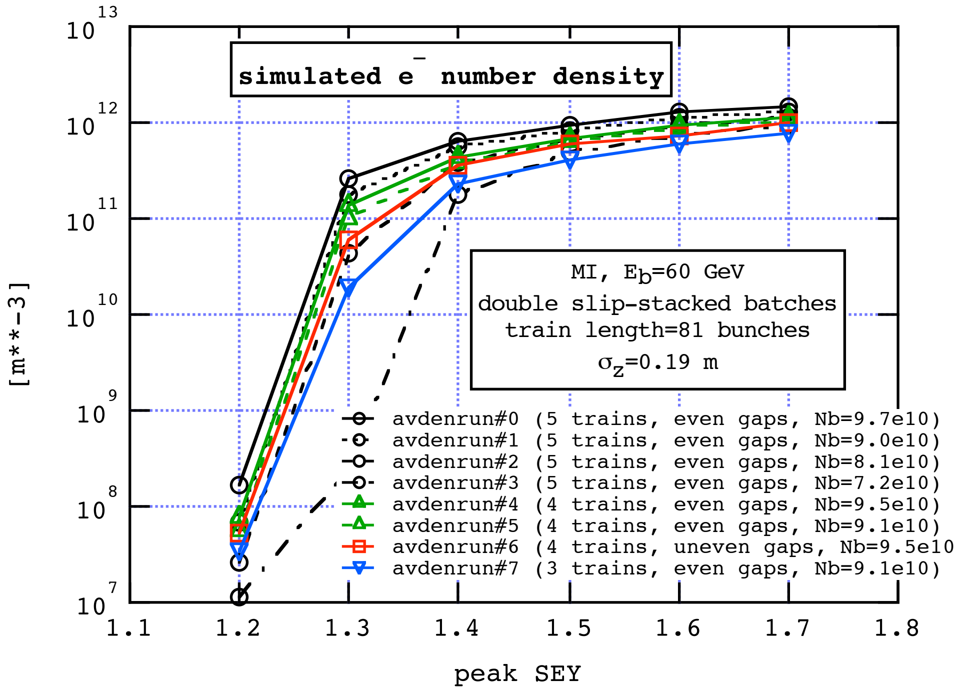




- Nicely clustered set of solutions for δ_{max}
  - —Indicates consistency in the model and the measurements

$1.25 < \delta_{max} < 1.35$

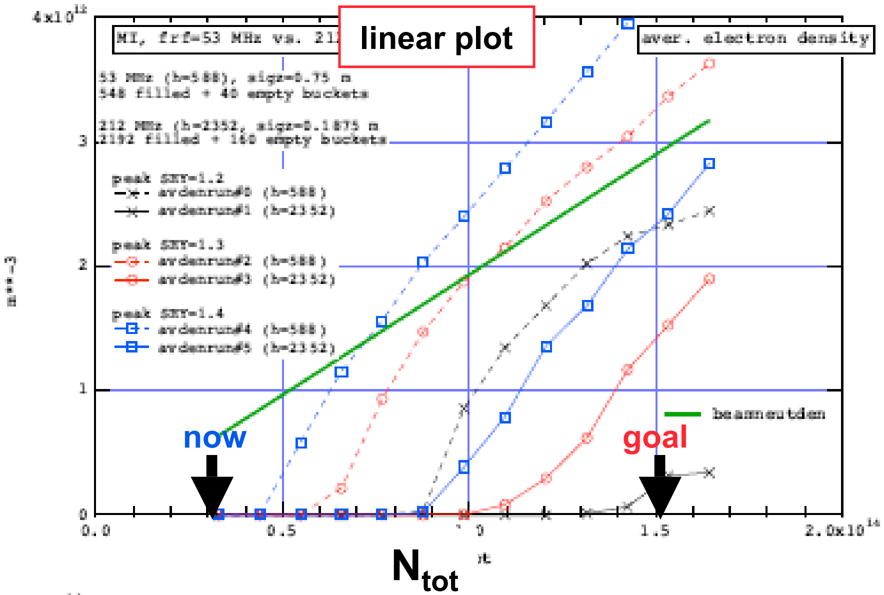
Infer e⁻ density

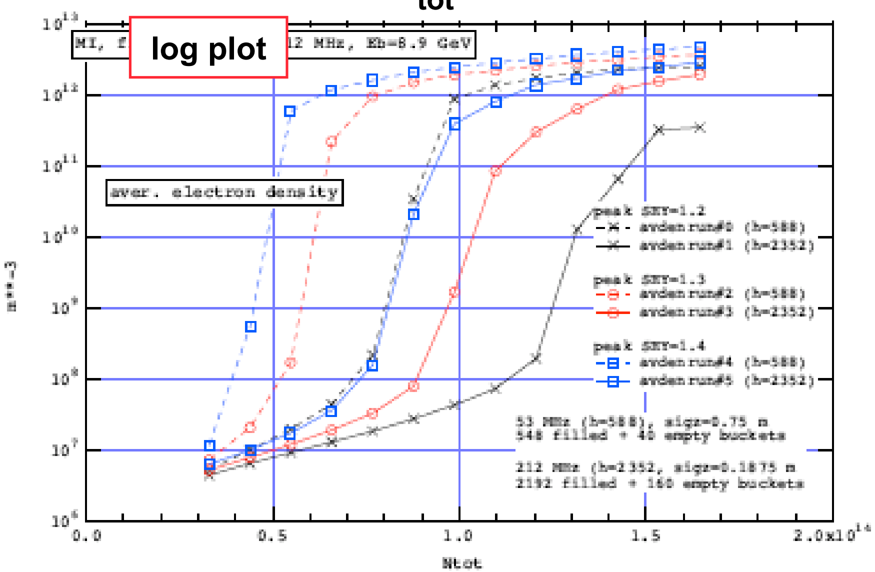


- From J_e results (previous slide), conclude $n_e \sim 10^{10}–10^{11}$ m^{-3}
- This range is considered “low”
  - — << aver. beam neutralization level
  - —not surprising that has no significant effect on the beam

53 MHz vs 212 MHz(*)

simulated aver. e^- density vs. N_{tot}





Dotted line: 53 MHz

Solid line: 212 MHz

So far explored only:

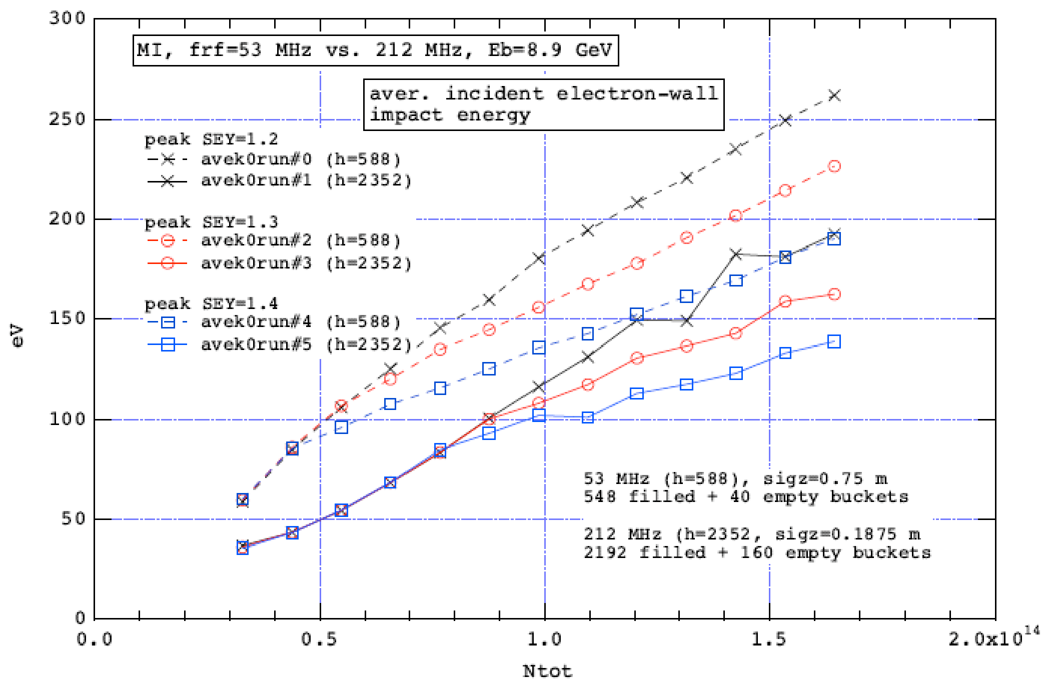
- Field-free region
- E_b=9 GeV
- SEY: St.St., δ_{max}=1.2, 1.3, 1.4

Conclusion:

- $3\times10^{13} < N_{thresh} < 15\times10^{13}$
- 212 MHz is better than 53 MHz, but gain is only factor ~2 above threshold

) fill pattern slightly different from previous simulations

Explanation



- For f_{RF}=212 MHz, electron-wall collision energy is < than for 53 MHz, hence effective SEY smaller

Conclusions

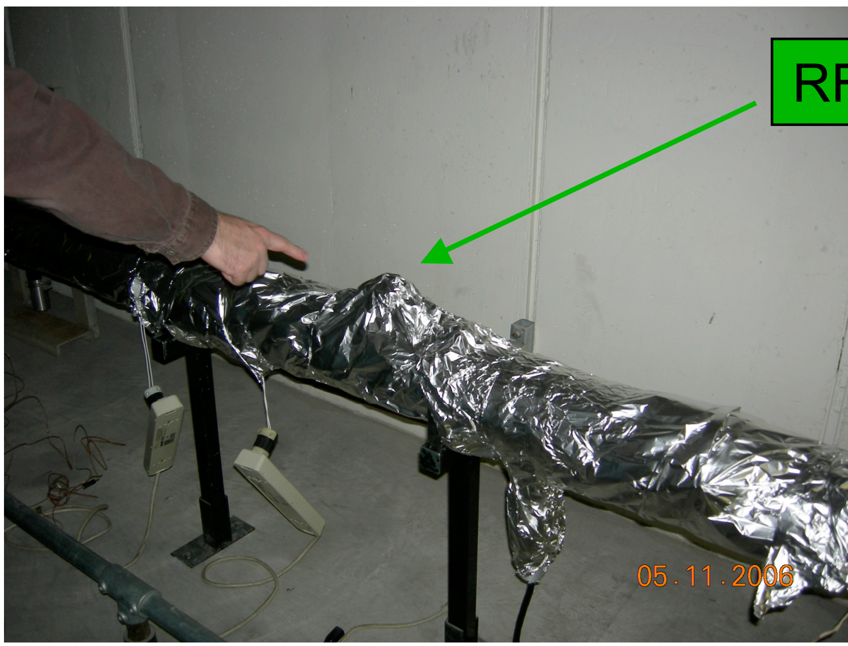
- Nice, consistent set of results at a given beam energy
  - — Results from E_b=60 GeV data imply δ_{max}~1.25–1.35 and n_e~10^{10}–10^{11} m^{-3} on average at RFA location
    - Caveat: actual numbers depend on other assumed SEY parameters, eg., E_{max} and SE emission energy spectrum
    - But qualitative picture doesn't change much
- Strong threshold expected for N_{tot} in range $3x10^{13}$ – $15x10^{13}$
- Threshold higher by ~ x2 for f_{RF}=212 than for 53 MHz
  - — e^- density only lower by a factor ~ x2 above threshold
- However, simulations ~insensitive to E_b
  - — In qualitative disagreement with measurements
  - — Mystery to me
  - — But consistent with SPS observations (Arduini, ECLOUD04)
- What next:
  - — Verify numerical convergence (but most likely okay as is)
  - — Repeat for TiN coating instead of St. St.
  - — Look at dipoles, quads, etc.

Extra material

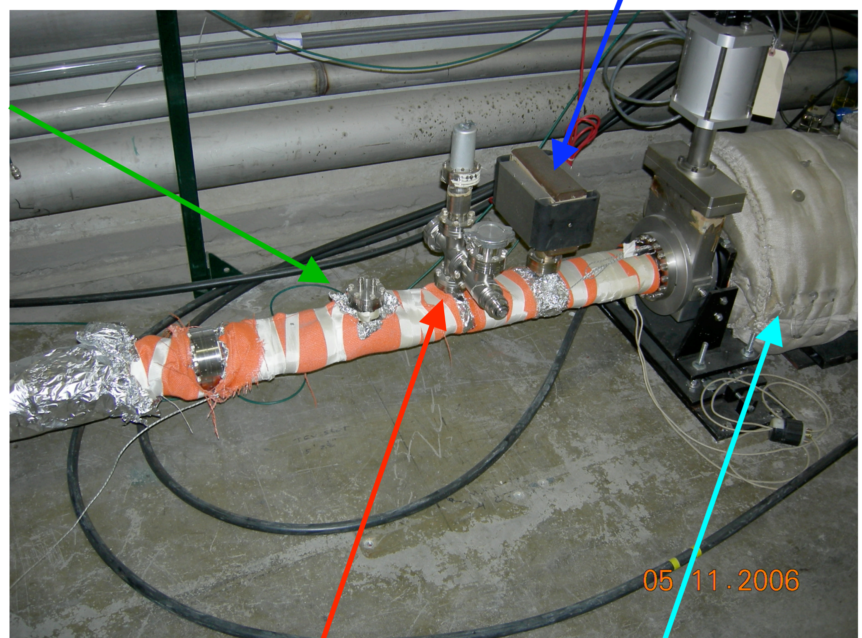
RFA detectors

RFA e^- detectors (ANL design; Rosenberg-Harkay)
measure flux and energy spectrum

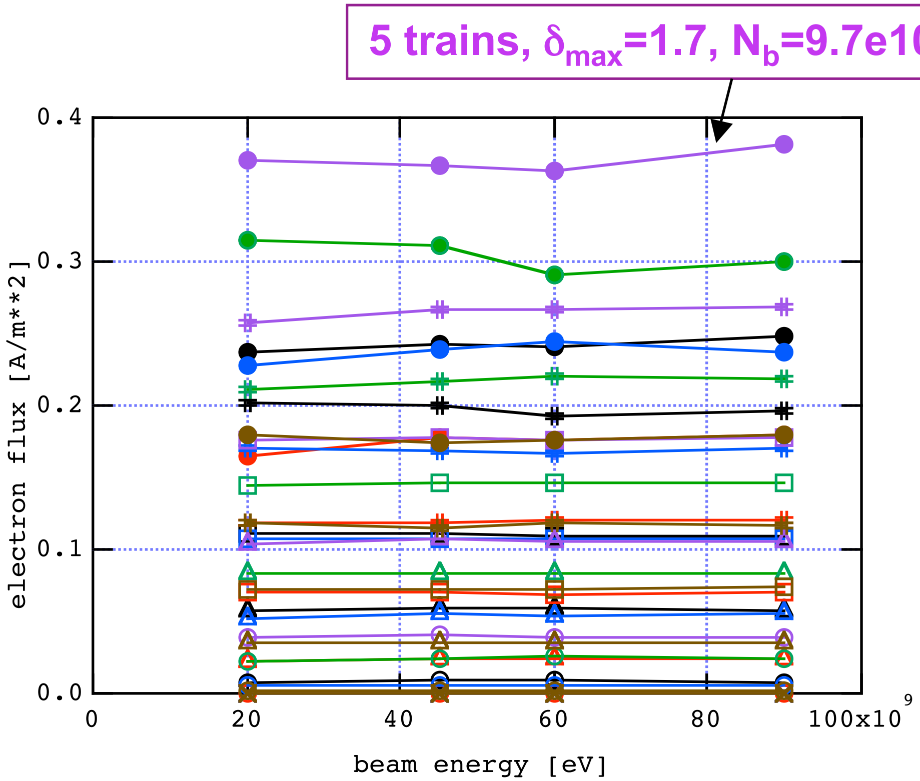
Main Injector



Tevatron



However…

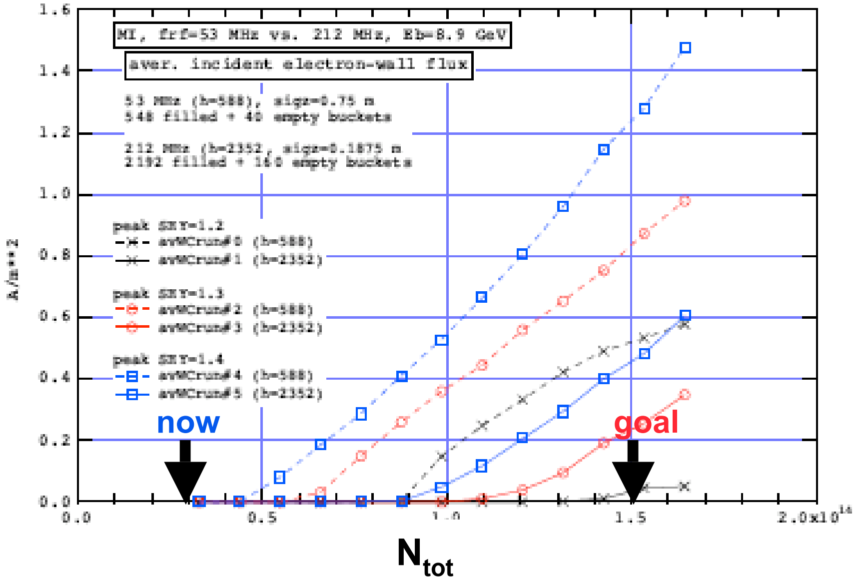


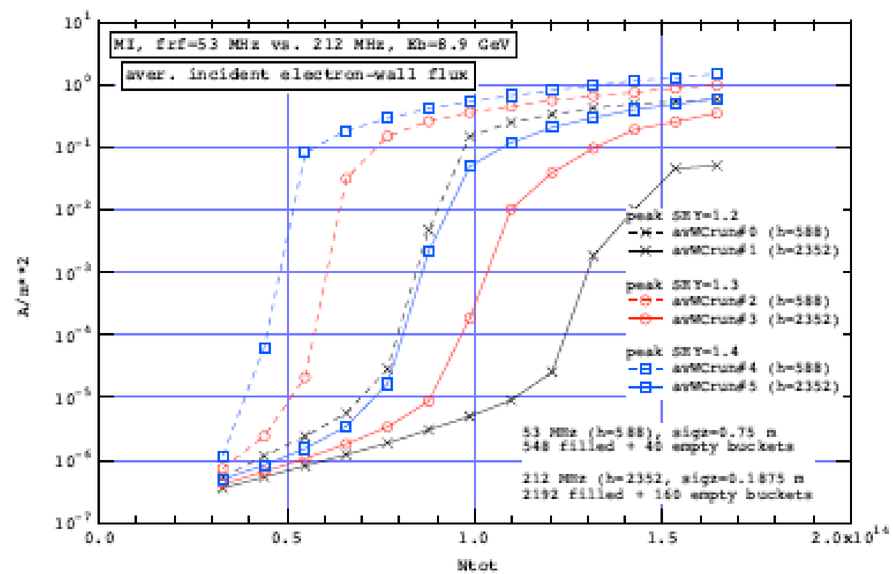
Qualitatively inconsistent with measurements

- Simulated results insensitive to E_b
  — Qualitatively similar results when vary E_{max} and SE energy spectrum
- E_b enters only indirectly in the model, primarily through σ_z
  — Therefore, not too surprising (to me) to see weak dependence on E_b
- However: measurements show strong dependence on E_b

53 MHz vs 212 MHz

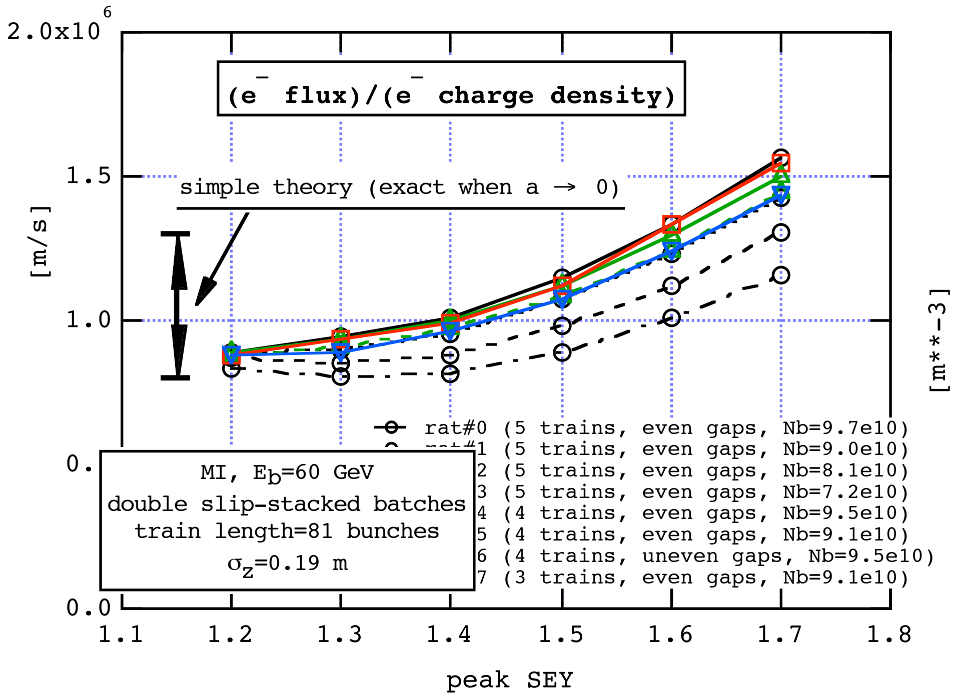
simulated e⁻ flux at the wall vs. N_{tot}

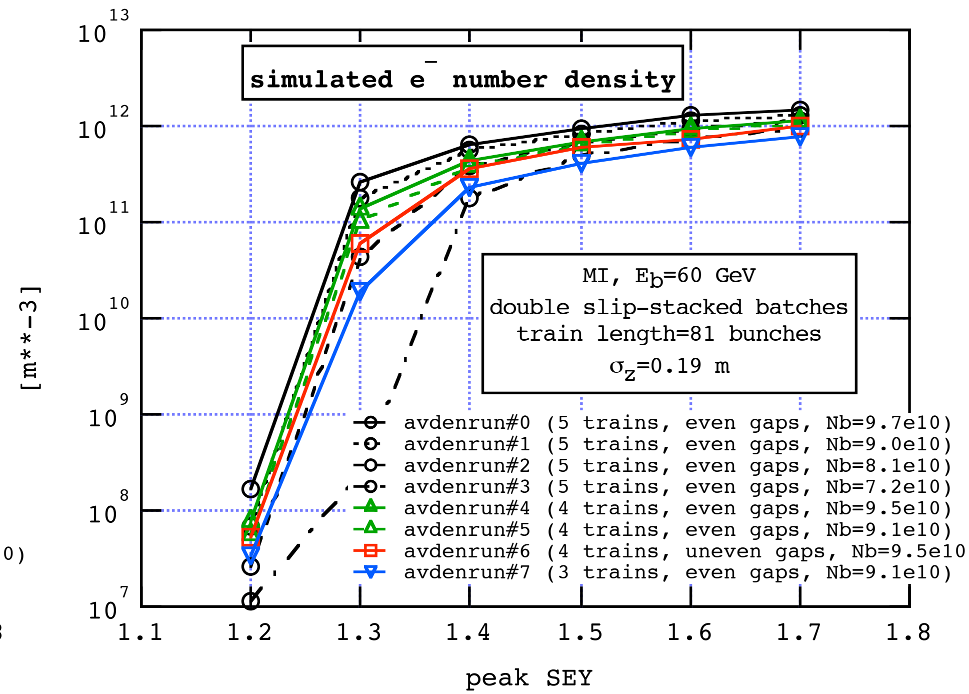




- Dotted line: 53 MHz
- Solid line: 212 MHz
- So far explored only:
  - —Field-free region
  - —E_b=9 GeV
  - —StSt SEY, δ_{max}=1.2, 1.3, 1.4

Furthermore…





- Flux/density consistent with simple theory, as expected
  - — $J_e/\rho_e \approx a/(2t_b)$ (R. Zwaska)
    - This becomes exact in the limit $a \to 0$
- From J_e results (previous slide), conclude $n_e \sim 10^{10}$-10^{11} m^{-3}