Status of Ecloud Build-Up Simulations for the FNAL MI

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Summary

- MI parameters
- Summary of e^- cloud observations at MI with RFA (~mid-2007)
- Brief description of simulation technique
- Fit simulations to measurements of e^- flux (J_e)
  - Extract peak SEY, δ_{max}=~1.3
- Compare f_{RF}=53 MHz vs 212 MHz
- Ecloud thresholds as function of no. of bunches (M) for high bunch intensity (N_b)
- Conclusions

Refs: M. Furman, CBP-TN-386, CBP-TN-387, CBP-TN-390, CBP-TN-392

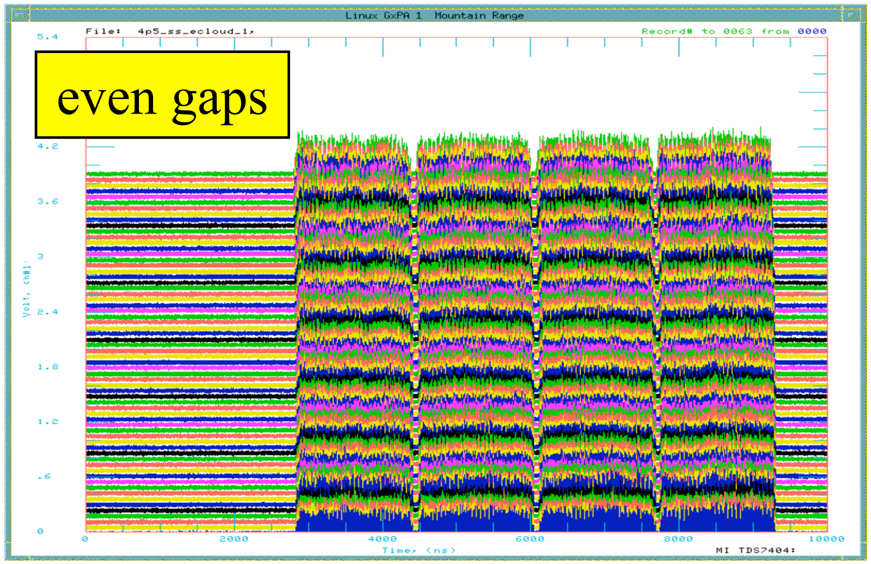
My gratitude to I. Kourbanis and R. Zwaska

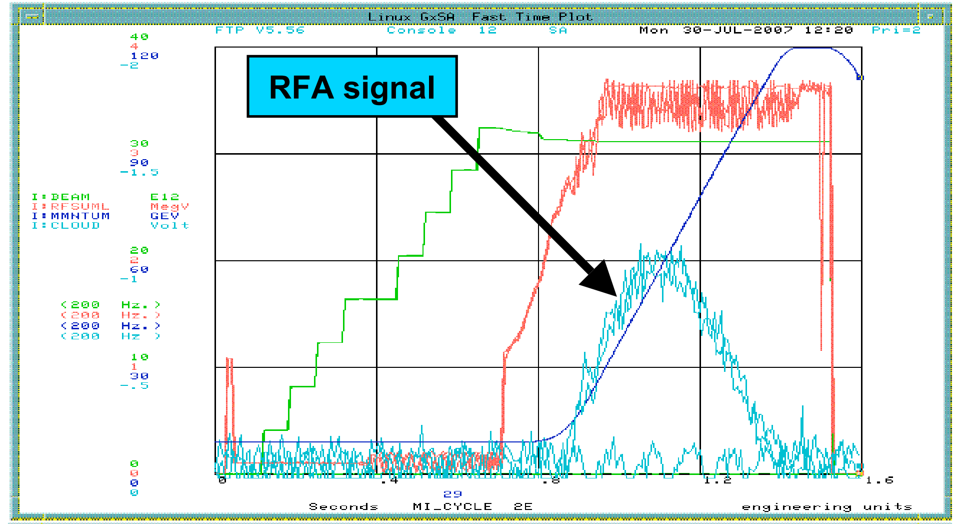
NB: recent measurements of n_e via microwave dispersion not addressed here

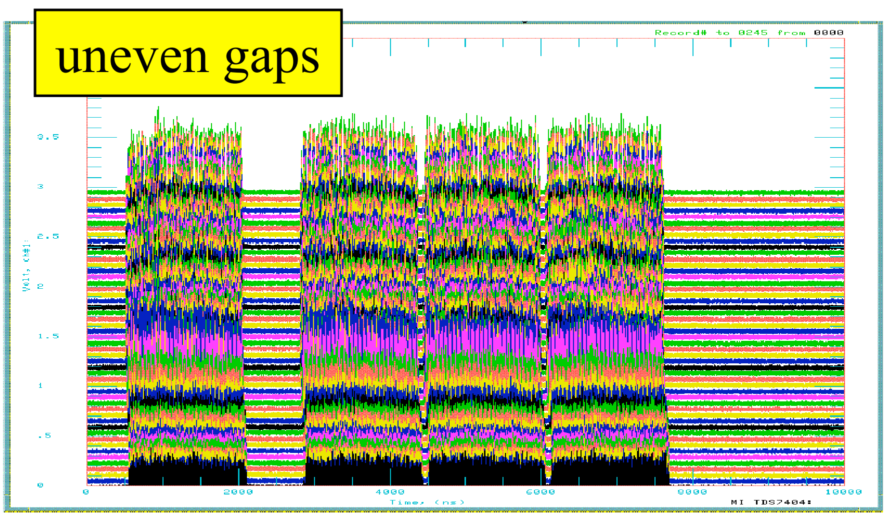
Motivation: plans to increase MI intensity for neutrino program

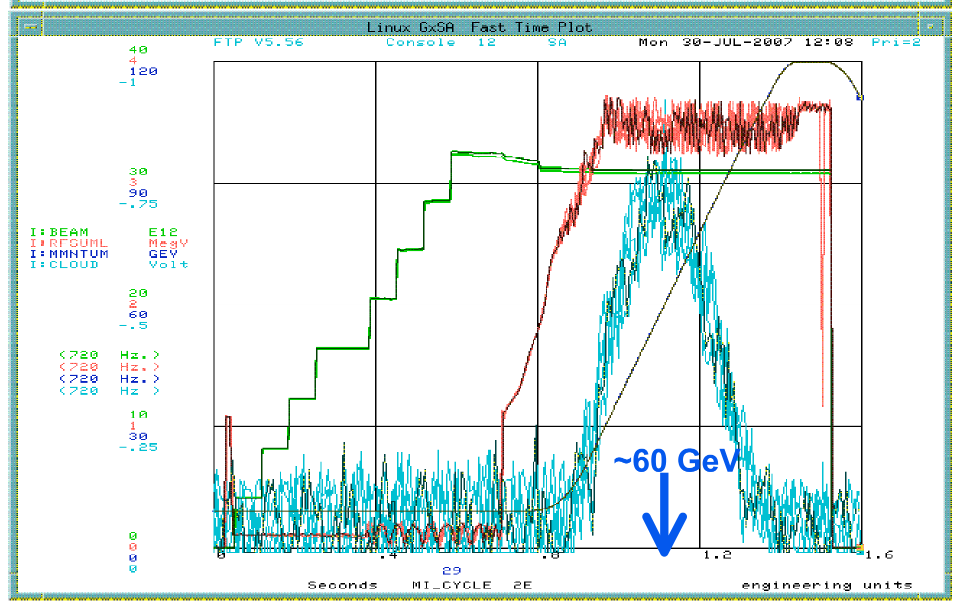
- Nominal operation:
  - —6 trains of 81 bunches ea. (f_{RF}=53 MHz, h=588)
  - —Gaps: 5 empty buckets in between trains + abort gap of 77 buckets
  - —Intensity: N_b~6×10^{10}/bunch (~3×10^{13} protons/pulse)
  - —Have achieved N_b~11×10^{10} (but with 4 or 5 trains)
  - —e^- cloud observed, but is not an operational limitation
- Goal:
  - —Increase N_b to 30×10^{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)



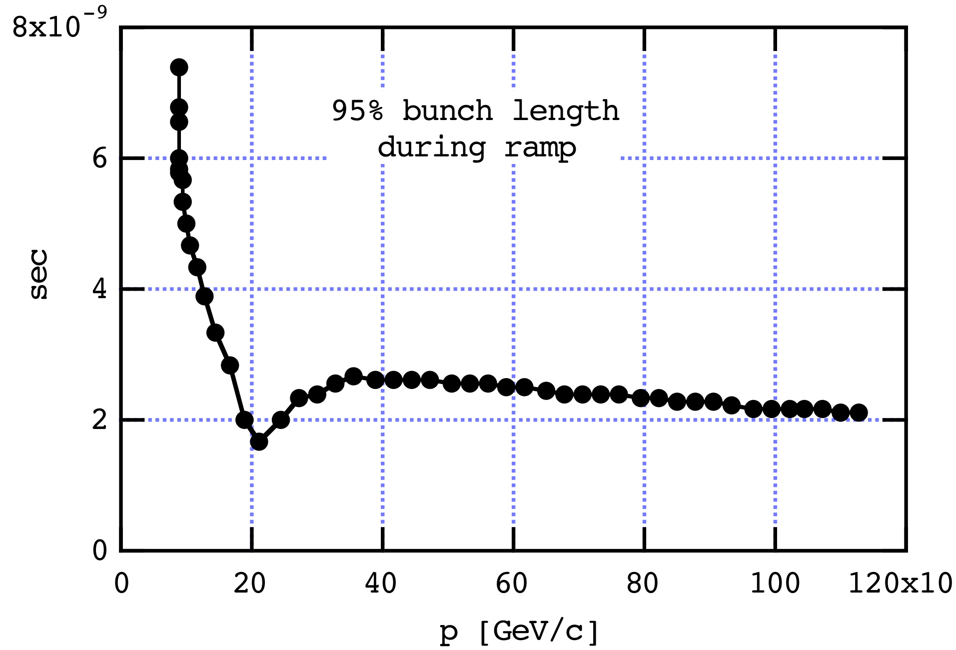






Bunch length during ramp
(from I. Kourbanis report, ~26 Aug. 2007)

- —C=3319.4 m
- —T_{RF}=18.8 ns
- —T_{rev}=11.1 μs
- —ramp:
  - KE_b=8–120 GeV in ~0.5 s
- —transition at ~20 GeV

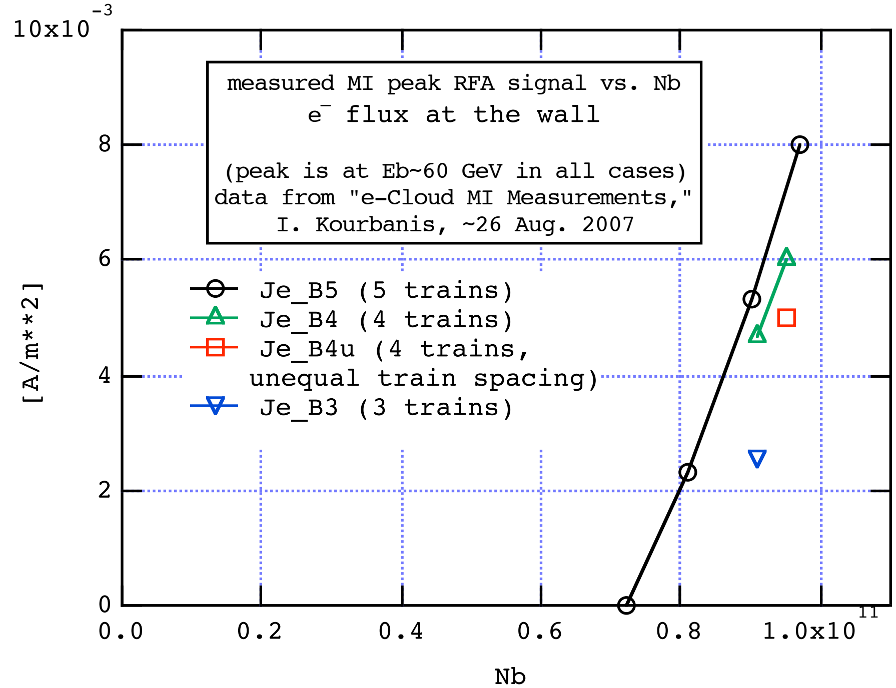


Measured 95% bunch length vs. momentum for N_b=9.5x10^{10}

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

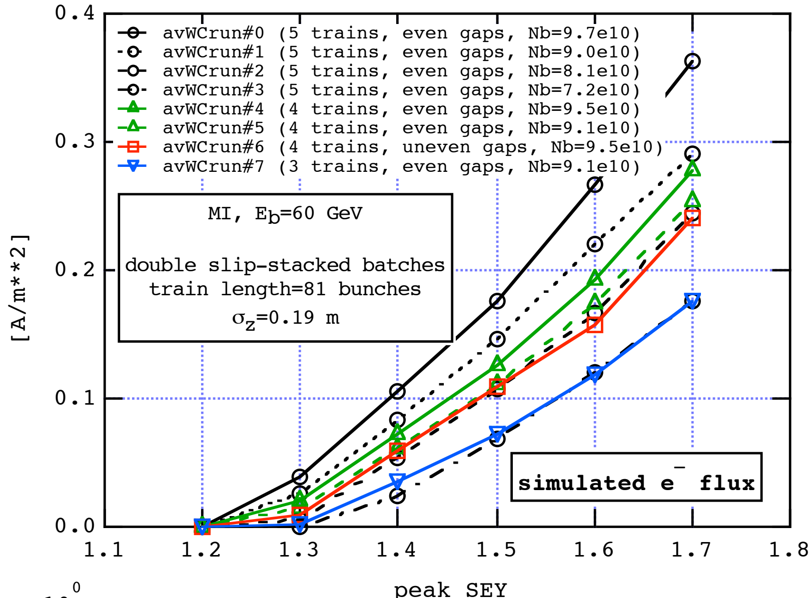
e^- flux at RFA vs. N_b for various fill patterns (E_b=60 GeV all cases)

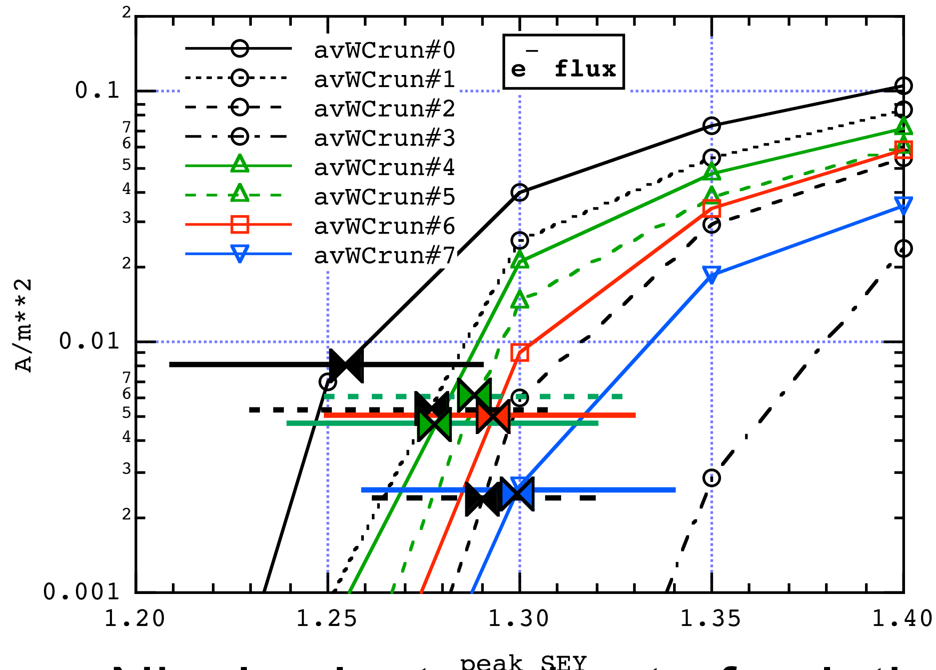


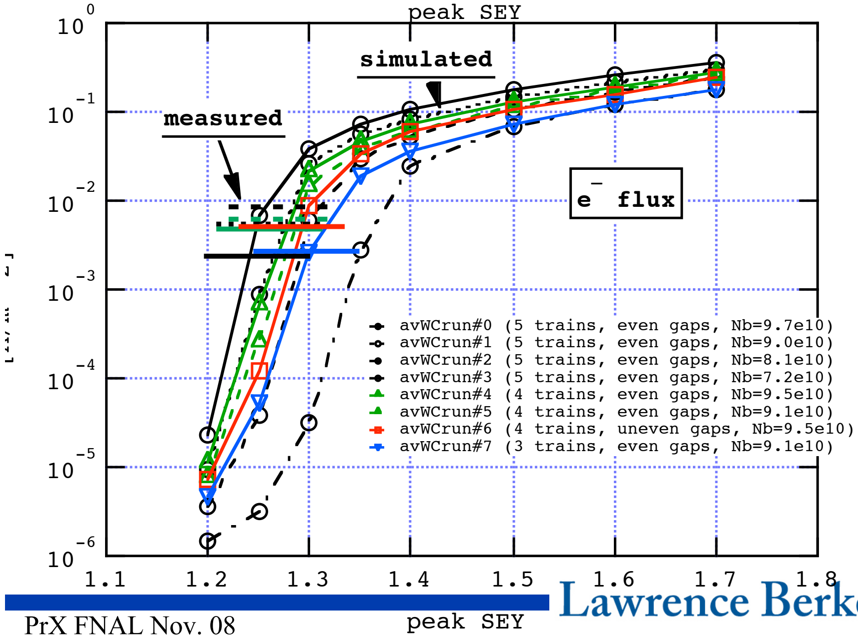
"POSINST" code build-up simulations

- Simulate the actual fill pattern for each case
- Use actual values for N_b, σ_x, σ_y, σ_z for each E_b
- So far, done only E_b=8.9, 20, 45, 60 and 90 GeV
- RFA location:
  —Field-free
  —Round pipe, R=7.3 cm
- Dipole bend:
  —B=0.092 T at KE_b=8 GeV
  —Elliptical pipe, (a , b)=(6.15 , 2.45) cm
- Compute average J_e and n_e over 1 turn
  —this is long enough for sensible time averages

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







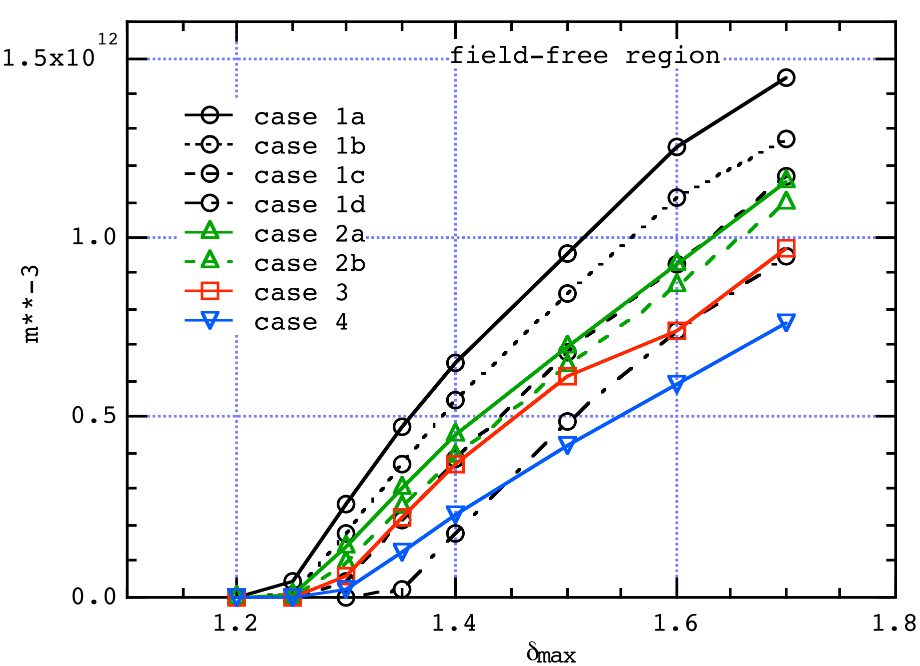
- Nicely clustered set of solutions for δ_{max}
  - —1.25 <~ δ_{max} <~ 1.30
  - —Indicates consistency in the model and the measurements

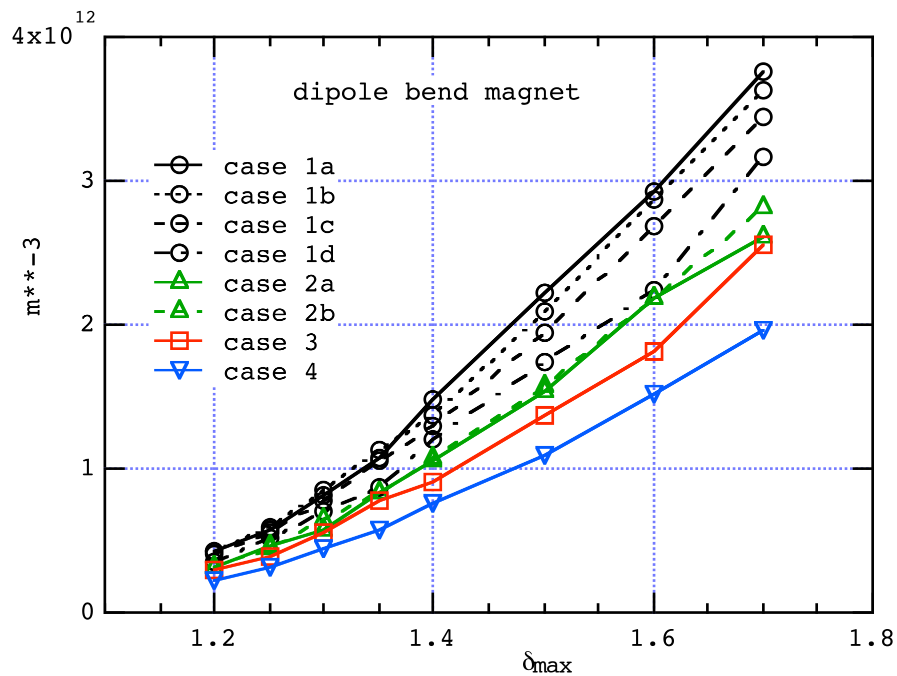
Infer e^- density from simulations

- Conclude $\langle n_e \rangle \sim 10^{10}$–$10^{11}$ m^{-3} in the RFA region at E_b=60 GeV
- This range is typically considered "low"
  - — << aver. beam neutralization level
    - no significant effect on the beam expected
  - —consistent with observations

Compare field-free vs. dipole bend

n_e vs. δ_{max} (E_b=60 GeV, same fill patterns, σ_z=19 cm)

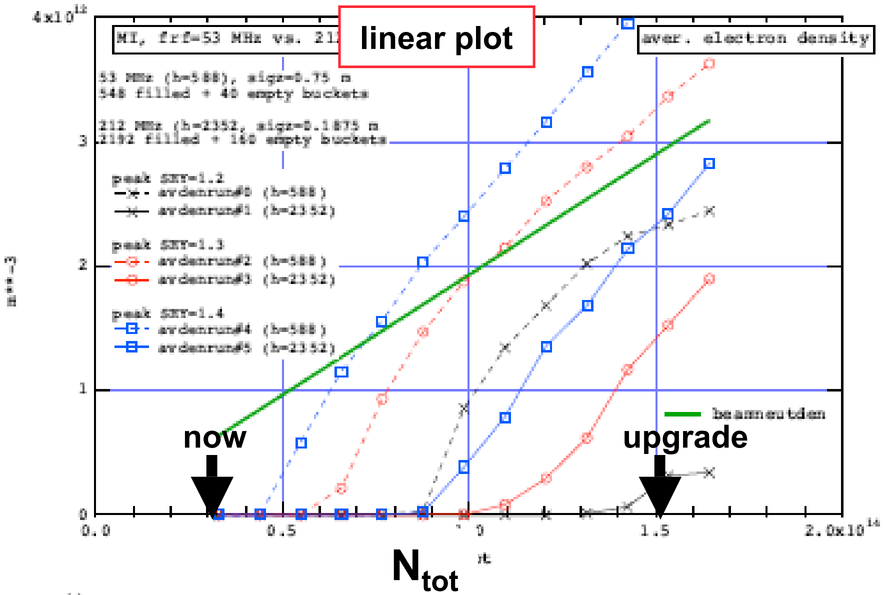


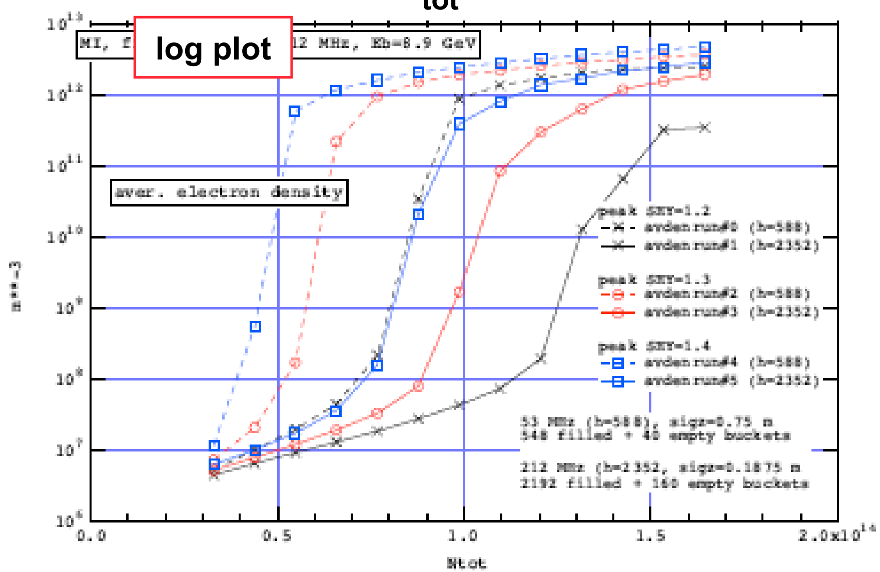


- Threshold as a f. of δ_{max} in field-free region
- No threshold in dipole
- n_e in dipole ~3 times larger than in F.F. region
  —not yet explained

Compare f_{RF}=53 MHz vs 212 MHz(*)

n_e vs. N_{tot} (RFA region, KE_b=8 GeV, δ_{max}=1.2, 1.3, 1.4)





- 53 MHz (dotted lines):
  - —bunches/pulse=M
  - —bunch pop.=N_b
  - —RMS bunch len.=σ_z
- 212 MHz (solid lines):
  - —bunches/pulse=4xM
  - —bunch pop.=$N_b/4$
  - —RMS bunch len.=$\sigma_z/4$
- $N_{tot}=MxN_b=(3–15)x10^{13}$
  - —field-free region
  - —KE_b=8 GeV (injection)
  - —SEY: δ_{max}=1.2, 1.3, 1.4

(*) fill pattern slightly different from previous simulations

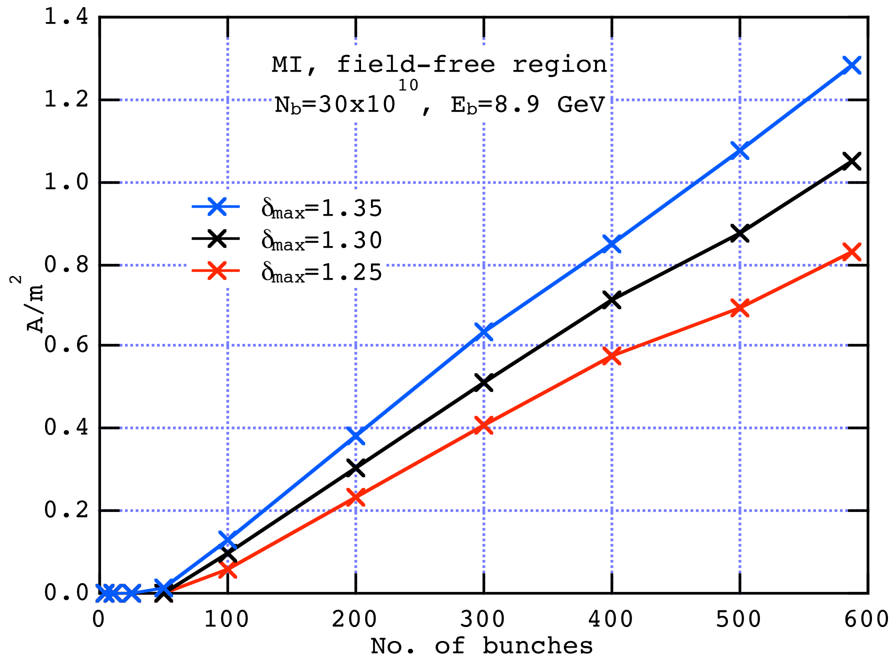
Compare f_{RF}=53 MHz vs 212 MHz(*)

n_e vs. N_{tot} (RFA region, KE_b=8 GeV, δ_{max}=1.2, 1.3, 1.4)

- Conclusion:
  - —Threshold as a function of N_{tot} for both 53 and 212 MHz
  - —$N_{tot,th}$ is ~2x higher for 212 than 53 MHz
  - —212 MHz better than 53 MHz, but gain is only factor ~2 above threshold
  - —For δ_{max}=1.3 and 53 MHz, ecloud reaches aver. beam neutralization level at N_{tot}=~10×10^{13}

M-dependence at N_b=30x10^{10}

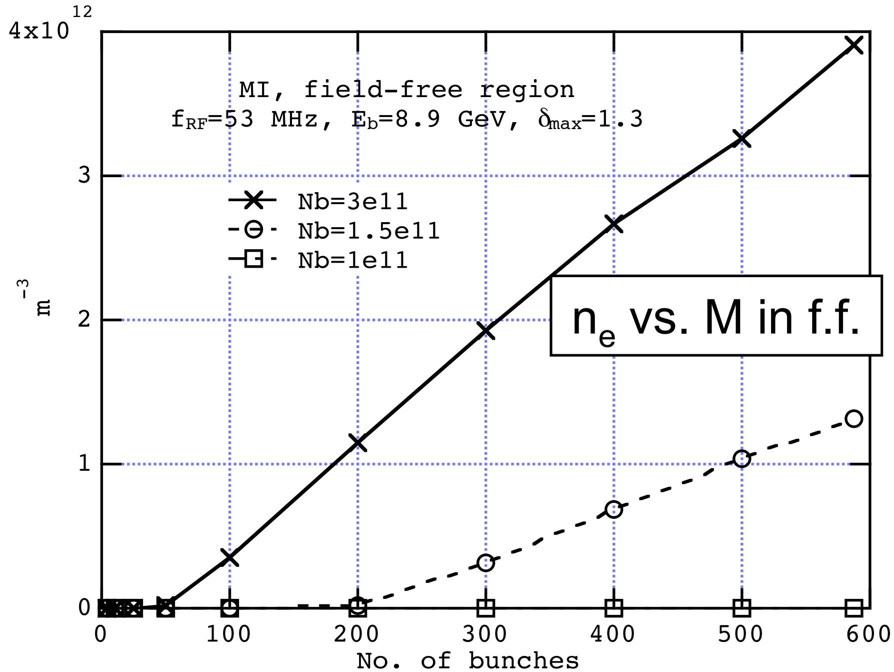
J_e vs. M (RFA, KE_b=8 GeV, continuous train of bunches)

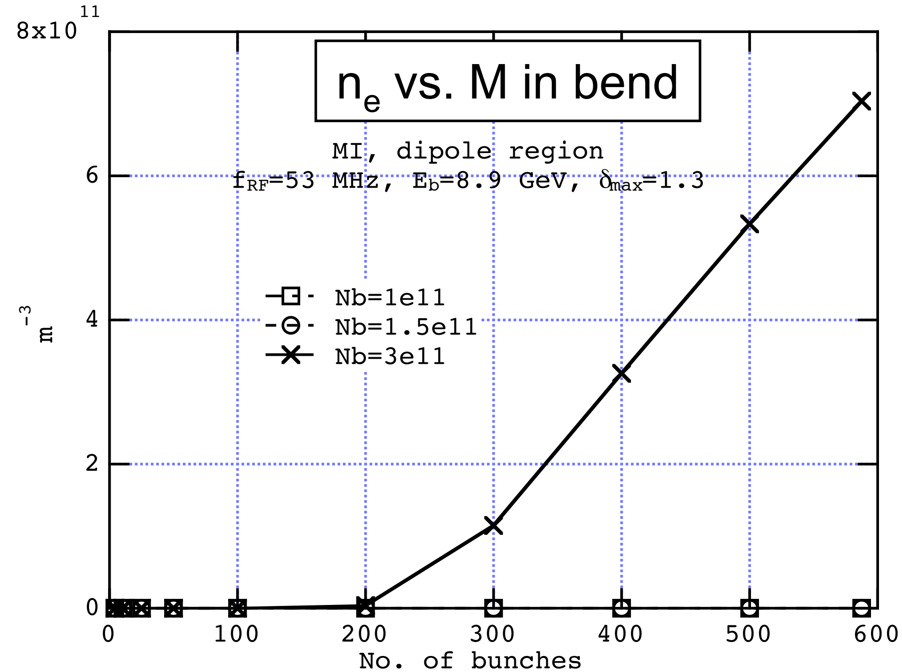


- Q: how long a bunch train do you need to start seeing appreciable ecloud at N_b=30x10^{10} and KE_b=8 GeV? (I. K.)
- A: about 50 in a f.f. region

M-dependence at N_b=(10-30)x10^{10}

n_e vs. M (KE_b=8 GeV, continuous train of bunches)



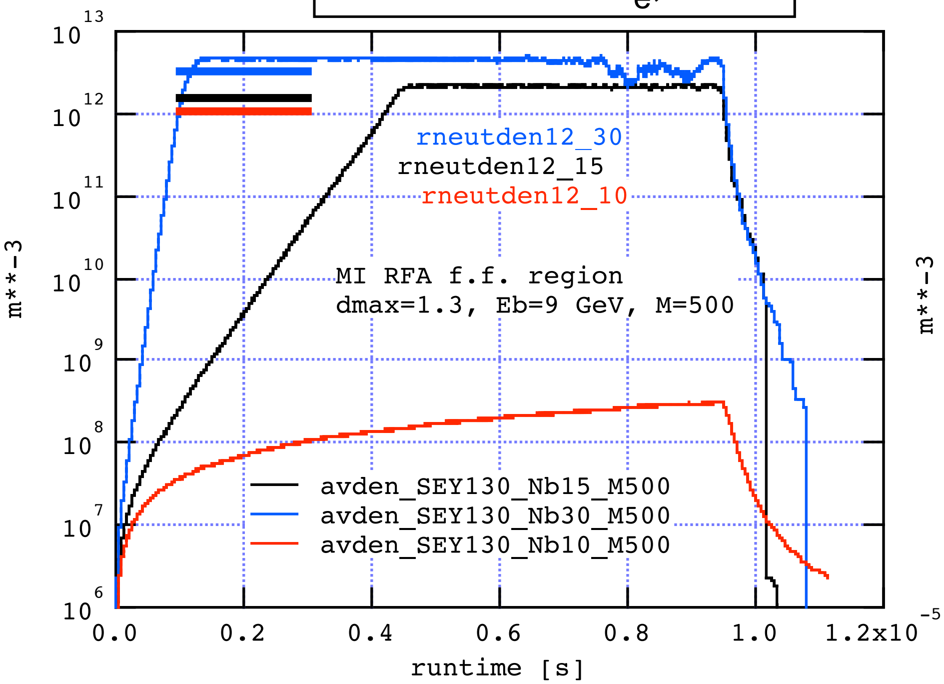


- Threshold in M strong function of N_b:
  - —M_{th}=50 for N_b=30x10^{10}
  - —M_{th}=200 for N_b=15x10^{10}
- For a dipole, M_{th}=200 for N_b=30x10^{10}

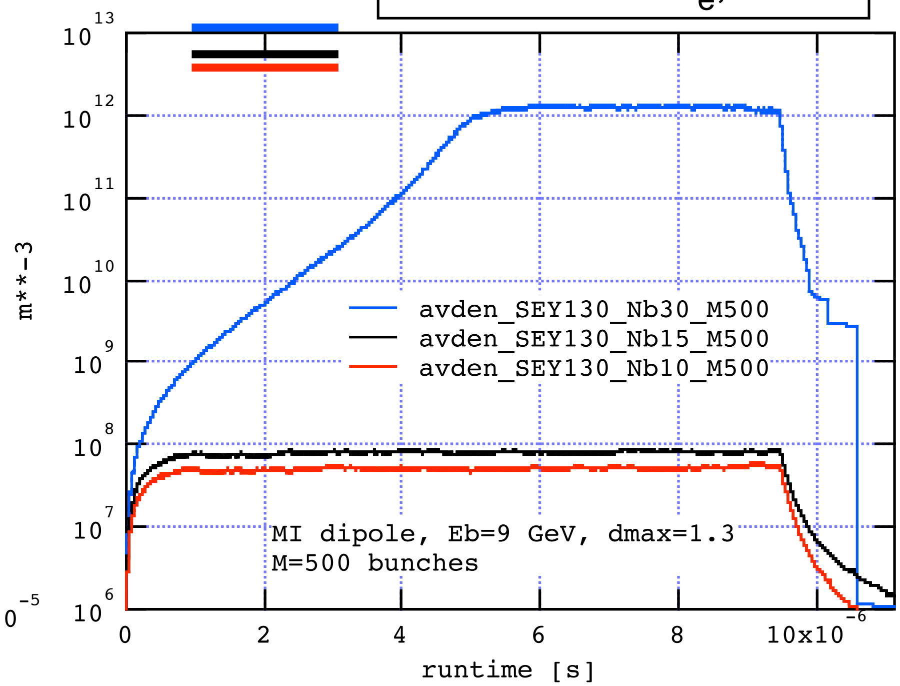
M-dependence at N_b=(10-30)x10^{10}

J_e vs. M (KE_b=8 GeV, continuous train of bunches)

time evol. of n_e, RFA



time evol. of n_e, bend



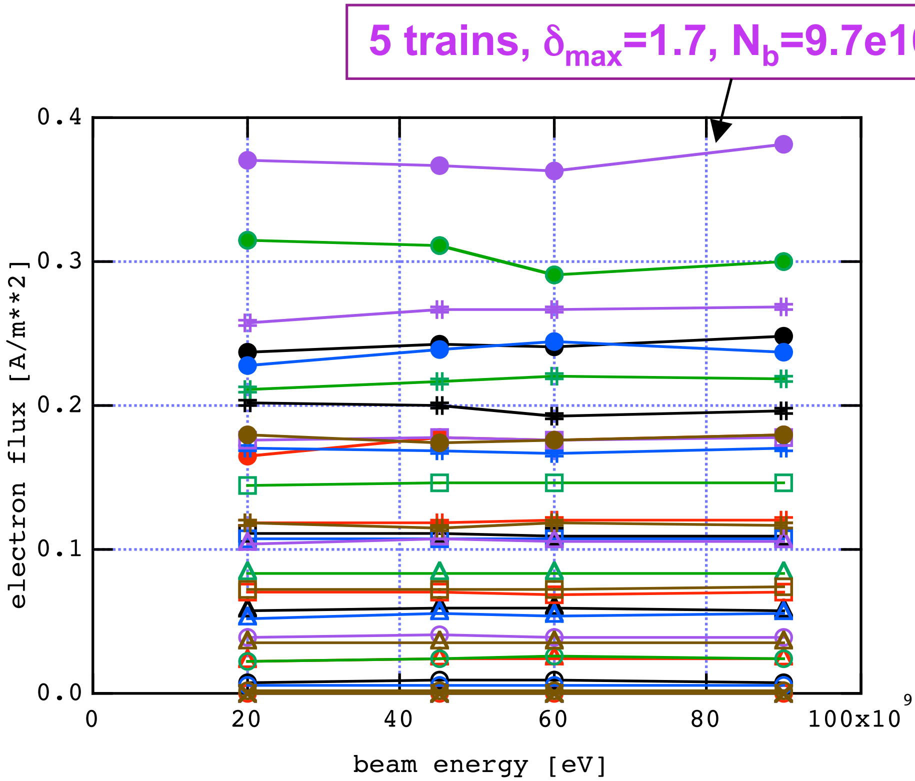
- Explanation of threshold in M:
  - —It takes about 1 μs (=~50 bunches) for ecloud to reach saturation at N_b=30x10^{10} (f.f. region)

Conclusions

- Nice, consistent set of results at a given beam energy
  - — Results from E_b=60 GeV data imply δ_{max}~1.25–1.30 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
- Ecloud in MI upgrade expected to go through a strong threshold in N_{tot} in range (3-15)x10^{13}
  - — Threshold ~2x higher for f_{RF}=212 MHz than for 53 MHz
  - — e^- density only lower by a factor ~ x2 above threshold
- RFA simulations (f.f. region) are ~insensitive to E_b
  - — In qualitative disagreement with measurements
  - — But E_b sensitivity consistent with SPS observations (Arduini, ECLOUD04)
- However, in dipole, n_e is ~3x larger than f.f. at E_b=60 GeV
  - — But n_e is ~5-10x smaller than f.f. at E_b=8.9 GeV
  - — ?
- More research (and funding) is needed!

Extra material

RFA simulations insensitive to E_b

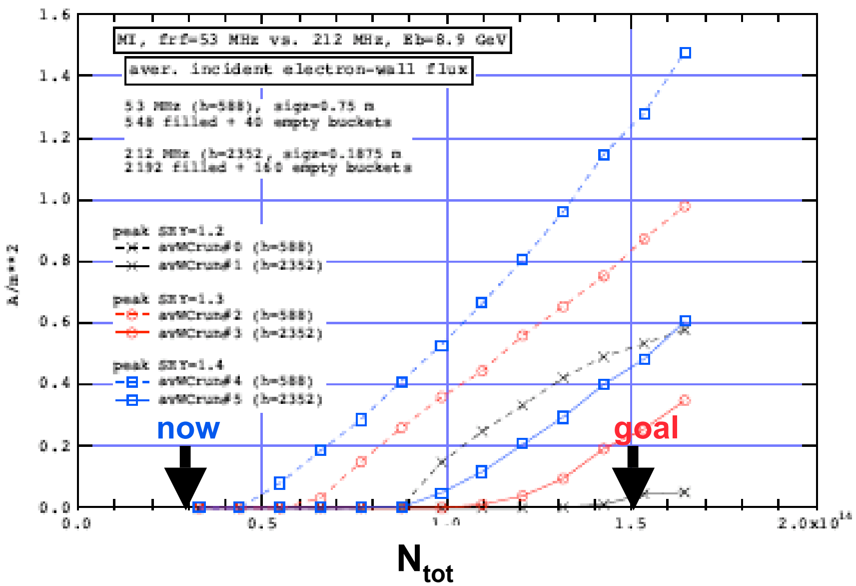


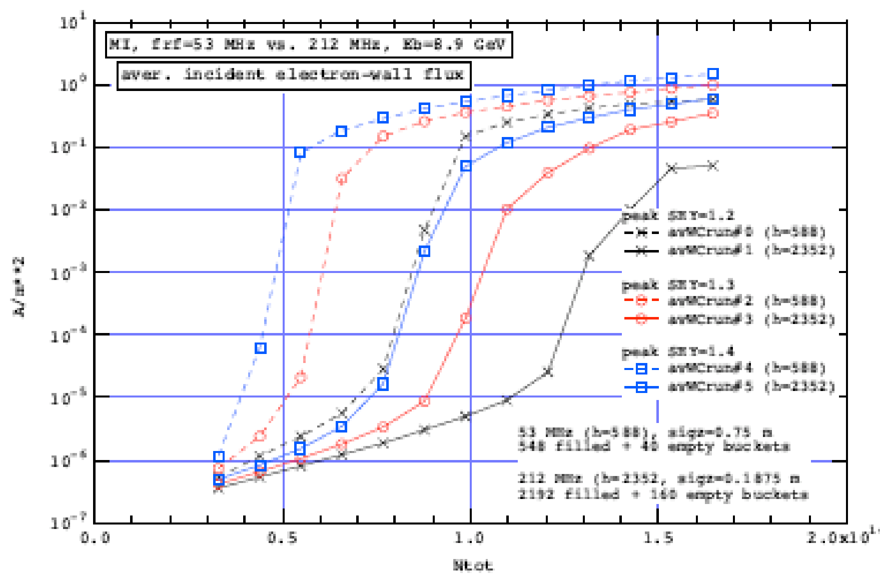
Qualitatively inconsistent with measurements

- Simulated results for RFA (f.f. region) 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

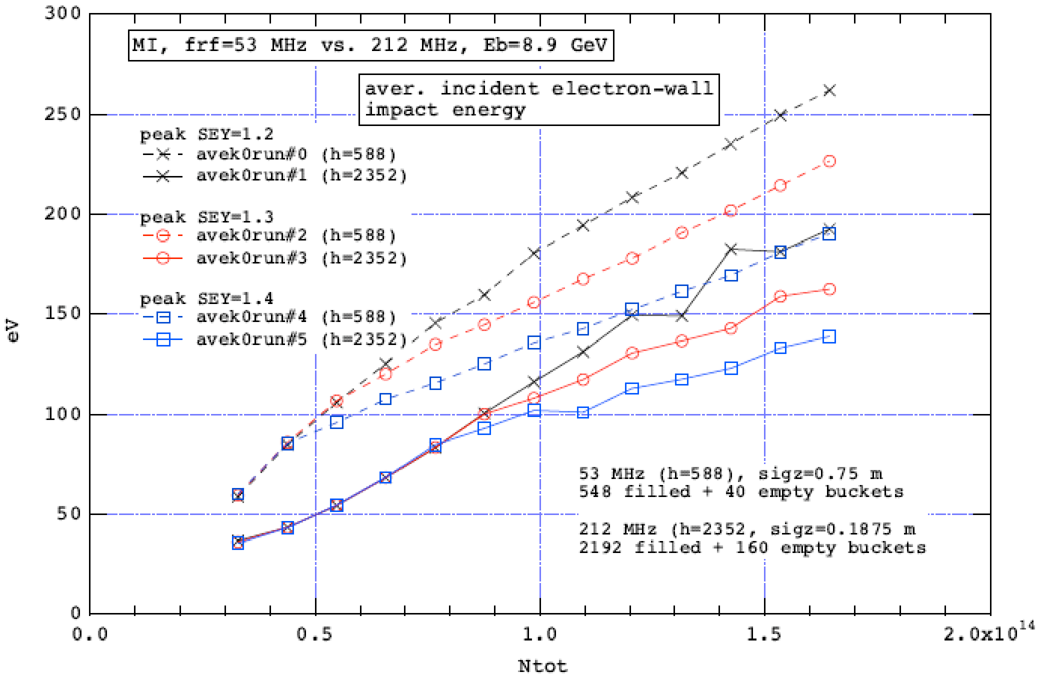
simulated e⁻ flux at the wall vs. N_{tot} at RFA





- 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

Explanation



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

J_e vs. M for RFA and Dipole