Status of Ecloud Build-Up Simulations for the FNAL MI – Sept. 2009

Miguel A. Furman

LBNL

Project-X Collab. Mtg.

Fermilab, 11-12 Sept., 2009

Summary

- Motivation and goals
- Previous work and new results
- Essential simulation input parameters
- POSINST code features
- Energy ramp simulations for 5/7-full ring (420 bunches at $N_b=1x10^{11}$)
  - — field-free region and dipole bend
  - — gaussian vs. flat longitudinal bunch profile
- Compare f_{RF}=53 MHz vs a hypothetical 4x53=212 MHz
  - — for E_b=9 and 120 GeV (but not in between)
  - — field-free region and dipole bend
- Compare MI upgrade with proposed CERN PS2
- Conclusions

My gratitude to I. Kourbanis and R. Zwaska

Previous work: M. Furman et al, CBP-TN-386, CBP-TN-387, CBP-TN-390, CBP-TN-392, PAC09-TH5PFP032, PAC09-FR5RFP078

Motivation and goals

- Conventional 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: $N_b >= 6\times10^{10}$ (N_{tot}~$(3\text{-}5)\times10^{13}$ ppp)
- N_b~1.1×10^{11} achieved (but with < 6 trains)
  - e^- cloud is observed, but is not an operational limitation
- Goal:
  - Increase N_b to 3×10^{11} with ~500 bunches (N_{tot}~1.6×10^{14} ppp)
  - Will e^- cloud be a limitation?
  - If so: mitigate
- Upcoming run: new instrumentation and more measurements of ecloud
  - New RFA's, coated/uncoated chamber sections, more microwave transmission measurements (previous talks by Kourbanis, Eddy, Zwaska)
  - Should provide further calibration of our simulations and allow more robust extrapolations to higher intensity

Previous work and new results

- Previous simulations focused mostly on:
  - —Selected values of the beam energy
  - —Field-free regions (initial RFA location)
  - —Established peak SEY =~1.3
- New results presented here: fix peak SEY=1.3, and assess:
  - —Full energy ramp
  - —Dipole bending magnets
  - —Fill pattern of 5/7-full ring
- Surprise: ecloud in dipole bends shows a non-monotonic dependence on beam intensity

"POSINST" code build-up simulations

- Simulate individual sections of the ring, one at a time
  - — Field-free (round pipe, R=7.3 cm)
  - — Dipole bend (elliptical pipe, (a,b)=(6.15,2.45) cm, B[T] = 0.0115p[GeV/c])
- Compute instantaneous and average ecloud density and many other quantities over 1 machine revolution
  - — this is long enough for sensible time averages: ecloud reaches steady state typically in ~0.1-0.2 turns
- Simulate a specific beam fill pattern for each case
- Use actual values for N_b, σ_x, σ_y, σ_z for each E_b
- Use actual chamber geometry

- N.B.: effects of the ecloud on the beam have to be done separately with some other code
  - — Work to start soon

SEY curve

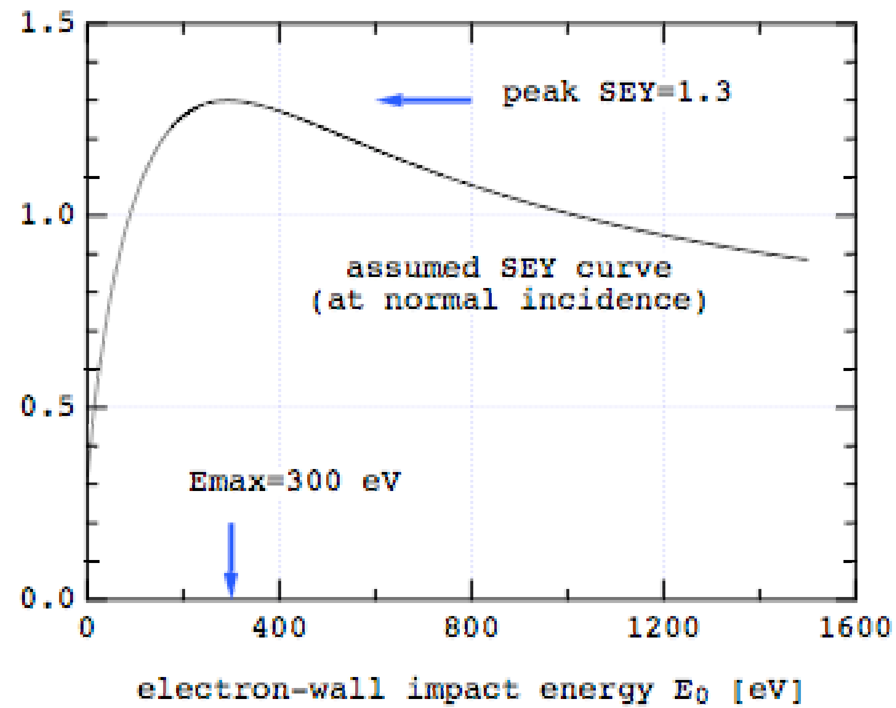
— This curve is an essential input to our simulations
- Ecloud density is quite sensitive to SEY

— We have explored peak SEY=1.2-1.5

— 1.3 is clearly favored by one set of RFA measurements for the MI chamber (eg., PAC09-TH5PFP032)
- And consistent with other StSt chambers (PSR, SPS)

— E_{max}=300 eV is less certain
- comes from old SLAC bench measurements
- could vary from ~250 to ~350 eV

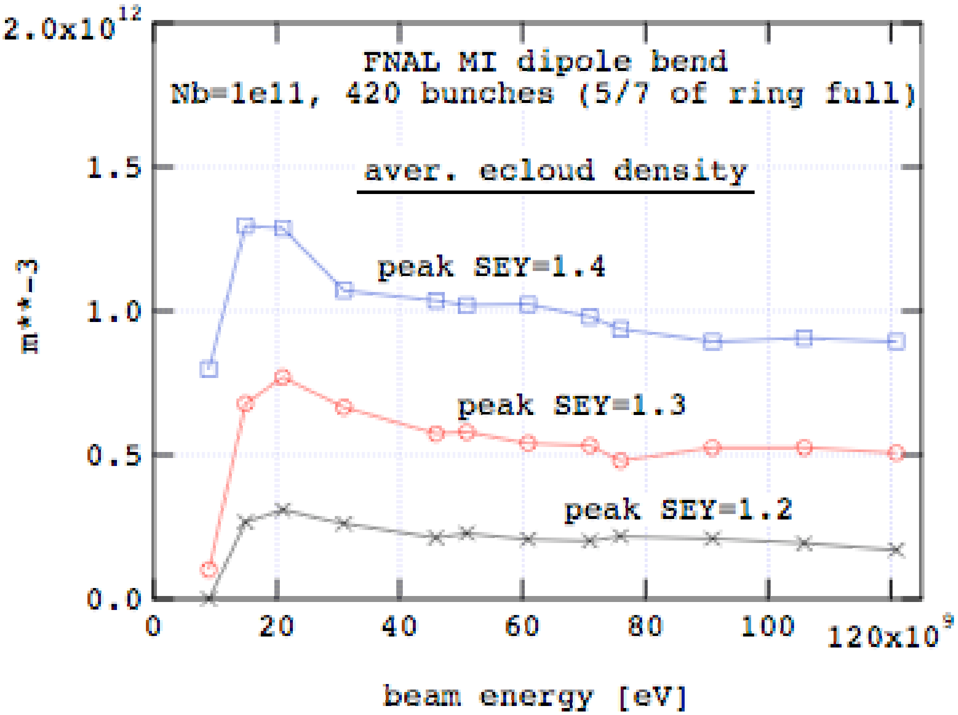
— Certain detailed new predictions are sensitive to E_{max}



SEY sensitivity example

aver. ecloud density in a dipole bend

- A change of 0.1 in peak SEY leads to ~x2 average ecloud density
- Assume peak SEY=1.3 for the remainder of this talk



Bunch length during ramp

— This plot is an essential input to our simulations

— C=3319.4 m

— T_{RF}=18.8 ns

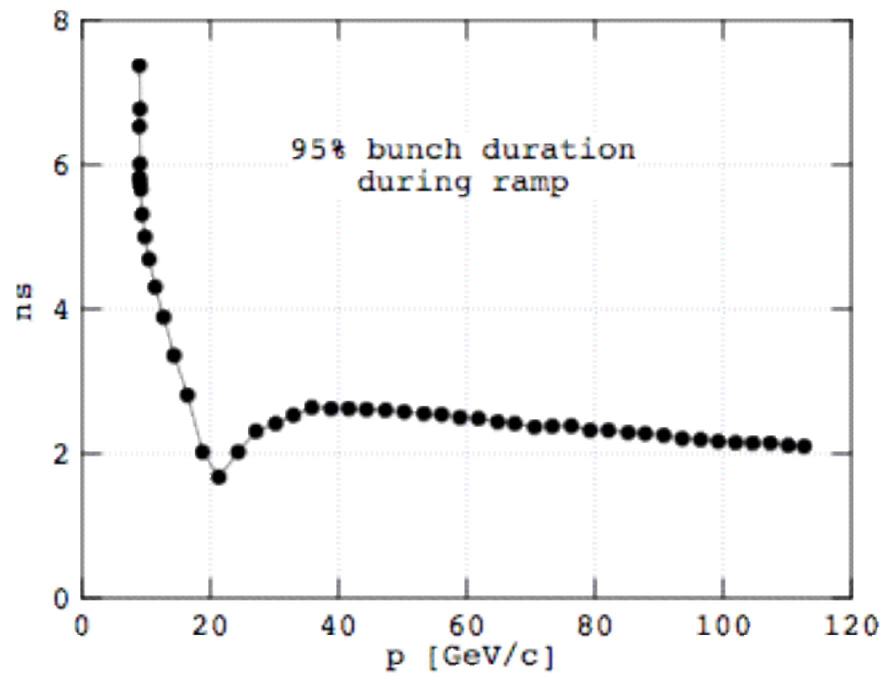
— T_{rev}=11.1 μs

— ramp:

- beam energy E_b=9–120 GeV in ~0.5 s

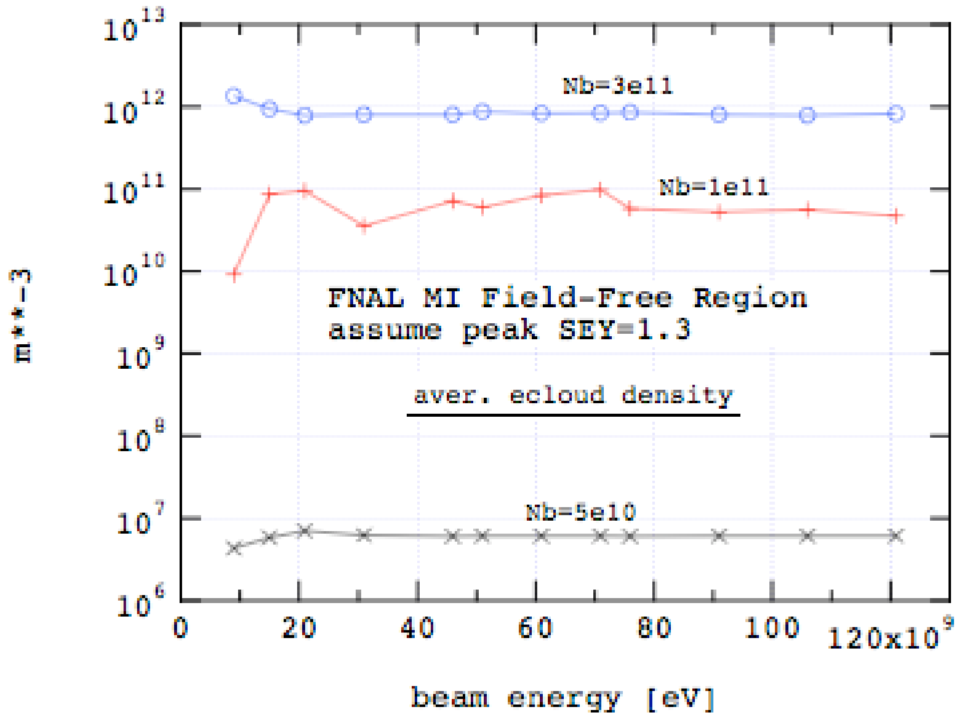
— transition at ~21 GeV

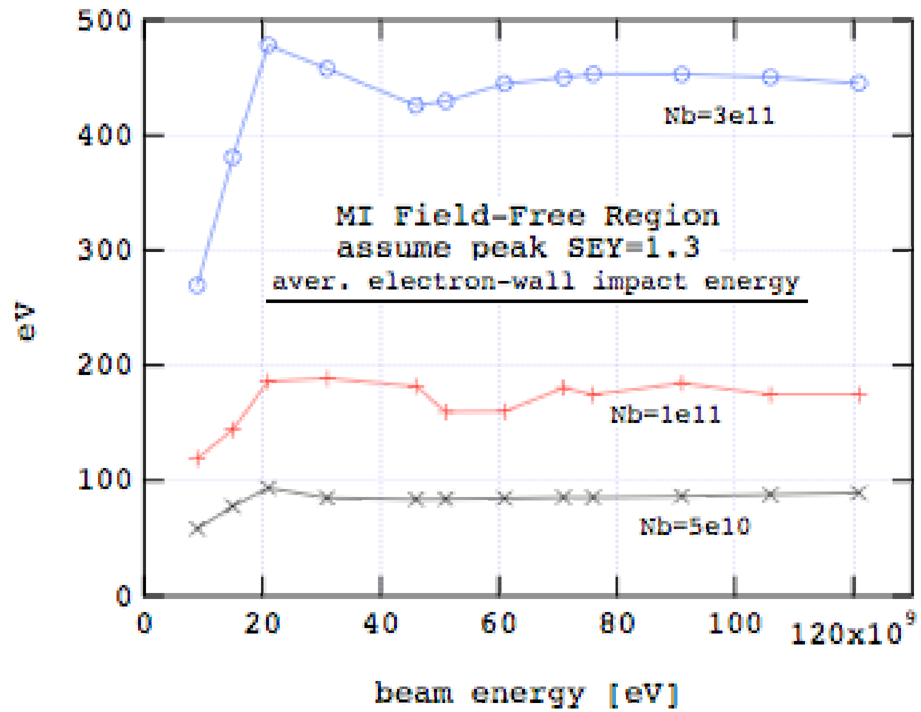
— we assumed $\varepsilon_{95\%}$=15π mm-mrad in all simulation results presented here



data from I. Kourbanis report, ~26 Aug. 2007

Energy ramp: 5/7-full ring – field-free region
420 consecutive filled buckets + 168 empty

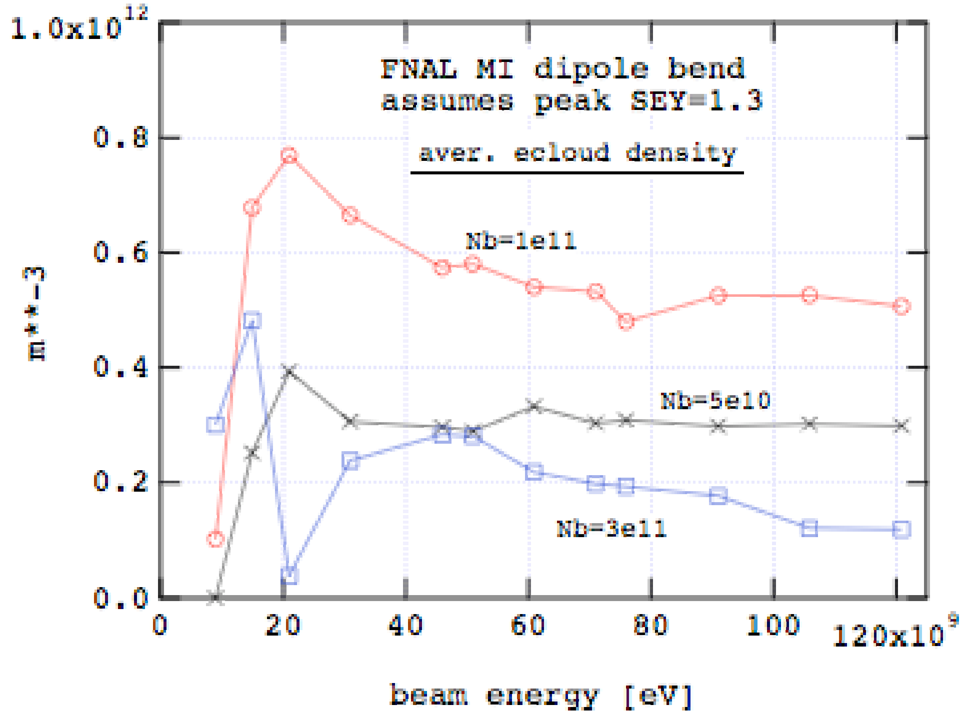


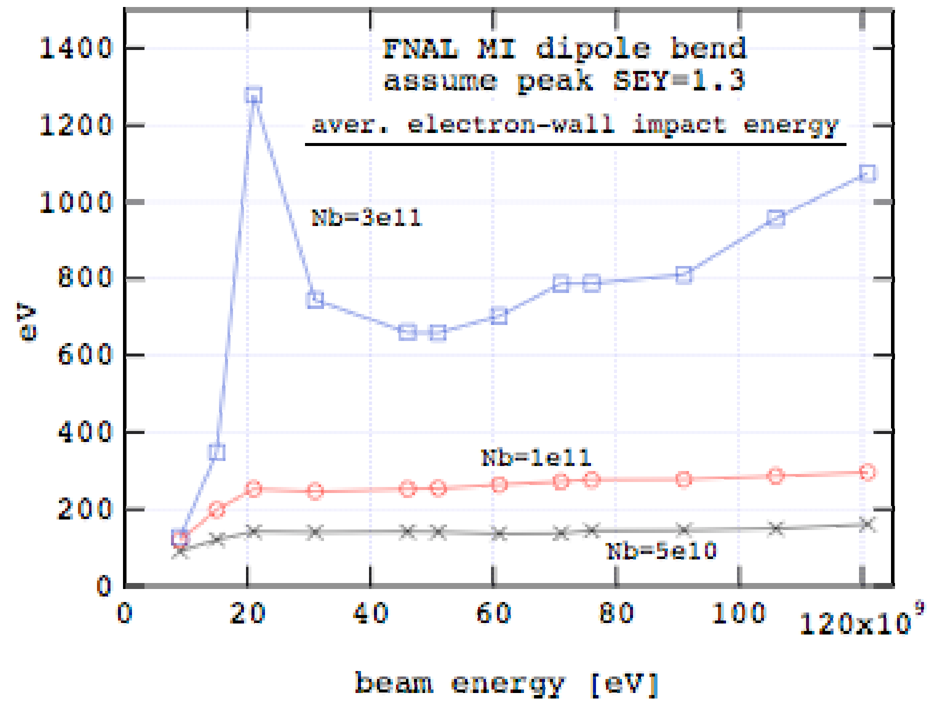


- Ecloud density n_e essentially independent of E_b except near transition
- Clear threshold behavior in N_b in range (5-10)x10^{10}
- Somewhat correlated with e^--wall impact energy E_0 as it approaches (and exceeds) E_{max}=300 eV
- N.B.: n_e~10^{12} m^{-3} is a rough estimated threshold for significant emittance growth (LBNL-767E, 9 June 2008). Aver. beam neutralization ~1-10%

Energy ramp: 5/7-full ring – dipole bend

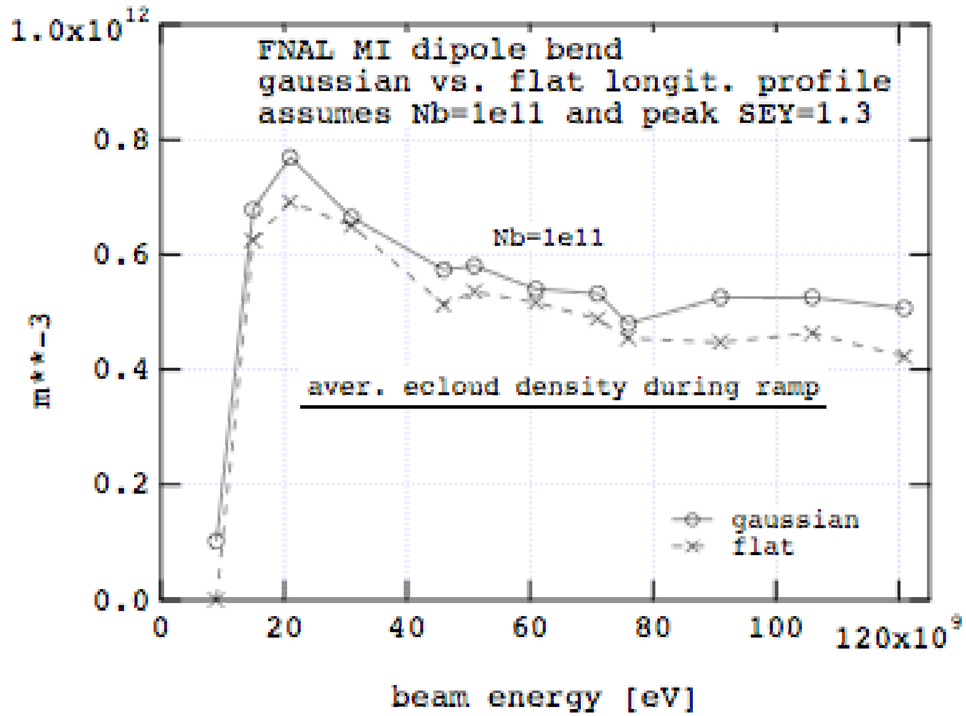
420 consecutive filled buckets + 168 empty

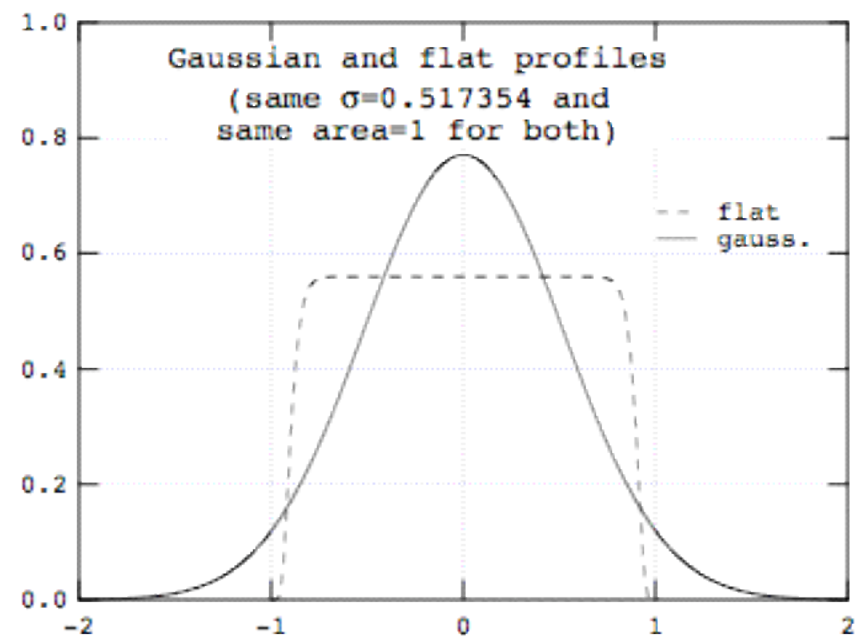




- Aver. ecloud density n_e essentially independent of E_b except near transition
- No threshold behavior in N_b
- Non-monotonic dependence on N_b
  - — $N_b=1x10^{11}$ leads to larger n_e than $5x10^{10}$ or $3x10^{11}$
- Correlation with e^--wall impact energy (~300 eV at N_b~10^{11})

Gaussian vs. flat longitudinal beam profile
energy ramp: 5/7-full ring – dipole bend
420 consecutive filled buckets + 168 empty





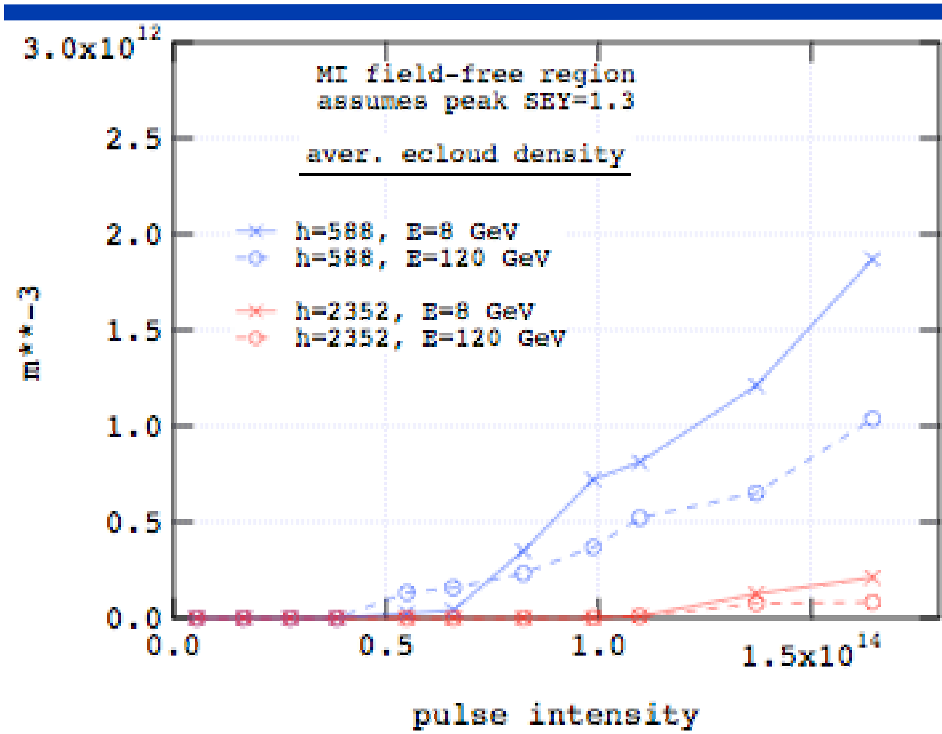
- Longitudinal bunch profile is likely to deviate from gaussian
  - But most simulations assume gaussian
- Exercise: compare flat(*) vs. gaussian with all else fixed
- Conclusion: not much difference
  - also looked at $N_b=5\text{x}10^{10}$ and $3\text{x}10^{11}$; similar conclusions

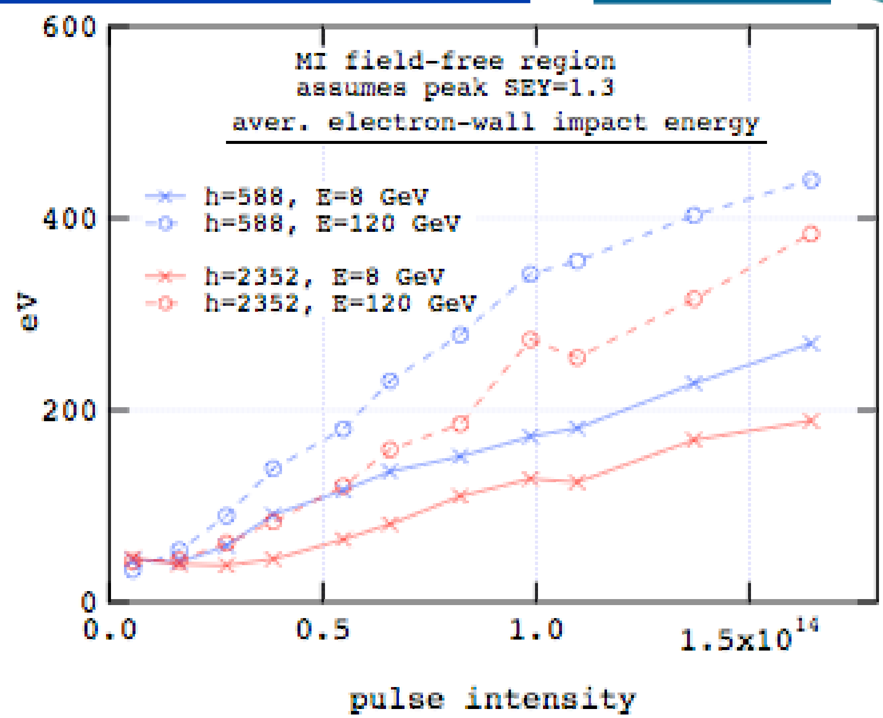
(*) precise definition of “flat” in: proc. LUMI06 (LBNL-61925, CBP Note-762)

53 MHz vs 212 MHz
(h=588 vs. h=2352)

- Question: is a higher RF frequency better than 53 MHz vis-à-vis ecloud?
  - My naïve guess was: yes
- Exercise: compare f_{RF}=53 MHz vs. a hypothetical f_{RF}=212 MHz at same pulse intensity N_{tot}
- Preliminary results presented at Pr.X coll. mtg (Nov. '08) and PAC09
- Explored:
  - Field-free region and dipole bend
  - Beam energy E_b=9 GeV and 120 GeV (but not in between)
- Assumptions:
  - fill pattern:
    - f_{RF}=53 MHz: 548 full + 140 empty
    - f_{RF}=212 MHz: 2192 full + 560 empty
  - when going from f_{RF}=53 to 212 MHz:
    - $N_b \to N_b/4$, $s_b \to s_b/4$, $\sigma_z \to \sigma_z/4$, $\sigma_E \to \sigma_E$, $\varepsilon_{tr} \to \varepsilon_{tr}$

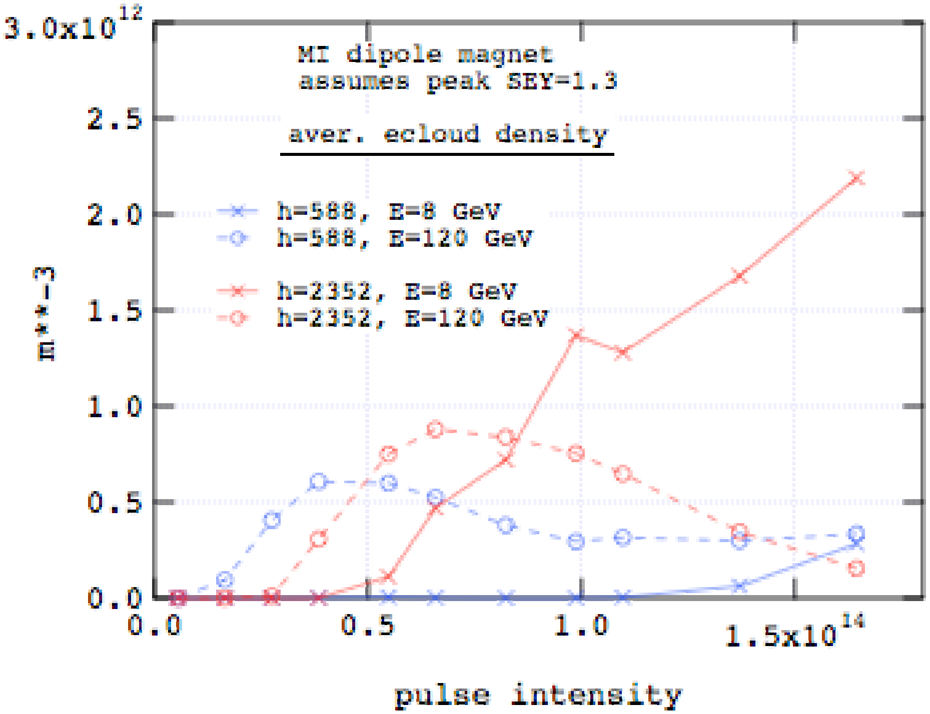
53 MHz vs 212 MHz – field-free region
(h=588 vs. h=2352)

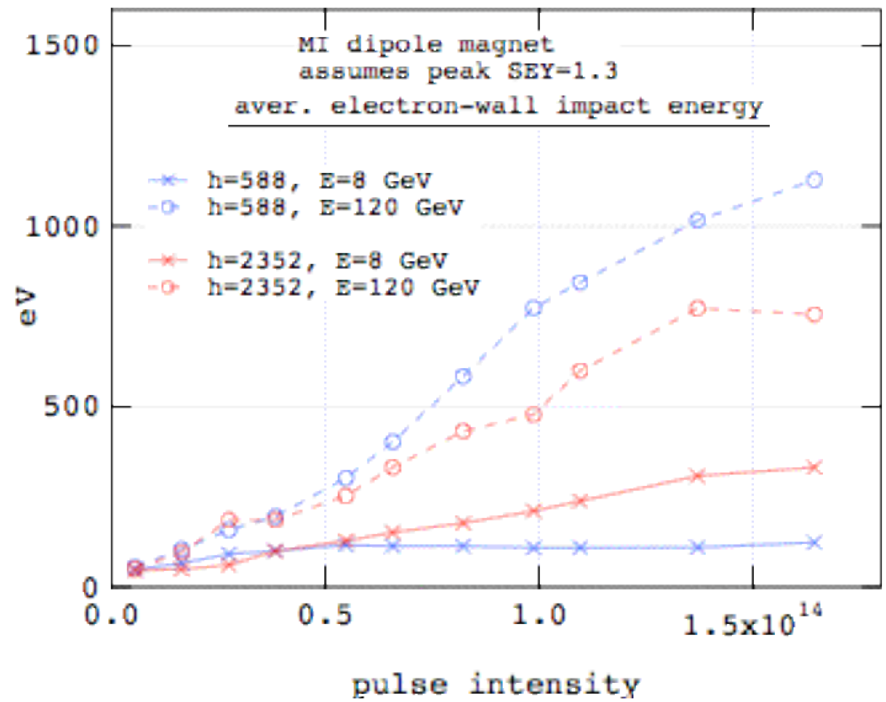




- Monotonic behavior with a clear threshold in N_{tot}:
  - — f_{RF}=212 MHz favored over 53 MHz both at 8 and 120 GeV
  - — but only by a factor of ~a few at $N_{tot}=1.6\times10^{14}$
- Behavior not fully explained by e^{-}-wall impact energy crossing E_{max}=300 eV
- A better understanding seems desirable

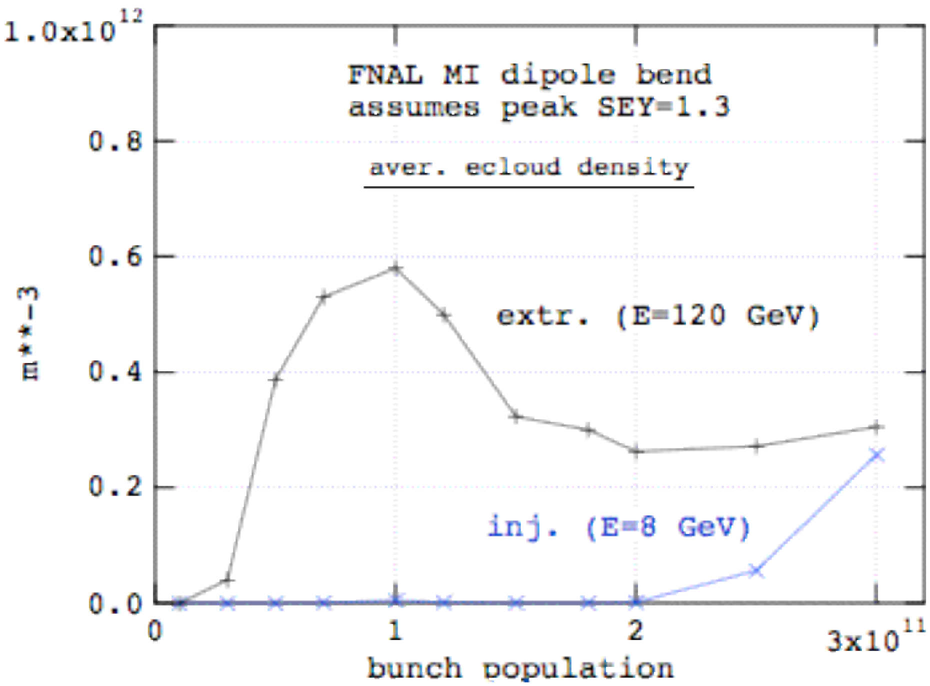
53 MHz vs 212 MHz – dipole bend
(h=588 vs. h=2352)

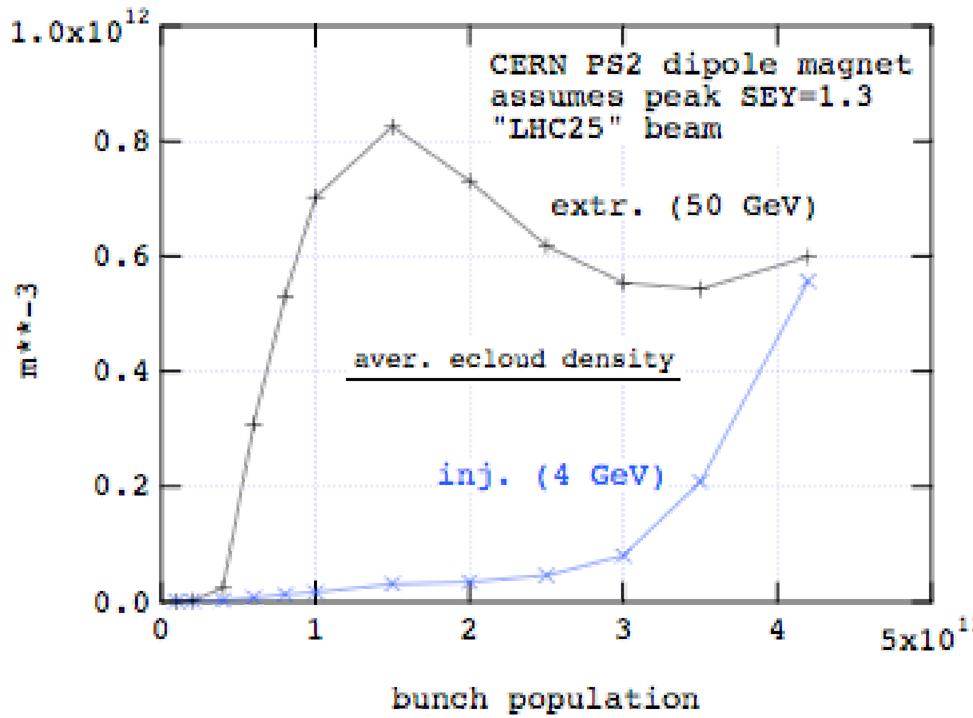




- Unexpected non-monotonic behavior:
  - — f_{RF}=212 MHz slightly favored over 53 MHz at 120 GeV
  - — f_{RF}=53 MHz strongly favored over 212 MHz at 8 GeV
- Behavior qualitatively explained by e⁻-wall impact energy crossing E_{max}=300 eV
- Which implies a sensitivity to E_{max}
  - — Caveat: E_{max} is not well known!

MI upgrade and PS2: dipole bend
injection and extraction beam energy





- Similar behaviors in CERN PS2 and MI upgrade
- Non-monotonicity qualitatively explained from e^--wall impact energy E_0: E_0 crosses E_{max}=300 eV at N_b~1x10^{11}

Conclusions (1)

- Average ecloud density n_e typically in range 10^{10} – 10^{12} m^{-3}
  - — With strong time and local fluctuations
  - — $n_e=10^{12}$ m^{-3} corresponds to ~1%–10% average beam neutralization
  - — Preliminary simulations (not shown here) suggest that 10^{12} m^{-3} is a threshold for significant effects on the beam dynamics
- Energy ramp: n_e roughly independent of beam energy E_b except near transition
  - — Both for field-free regions and dipole bends
  - — This shows a sensitivity to bunch length
  - — Consistent with microwave transmission measurements
  - — Field-free: function $n_e(N_{tot})$ is monotonic and shows clear threshold when N_{tot} is in range (3-15)x10^{13}
  - — Bends: function $n_e(N_{tot})$ is *non-monotonic* and shows no threshold in this range
    - $N_b=3x10^{11}$ has *lower* n_e than $1x10^{11}$
  - — These behaviors can be qualitatively explained from the electron-wall impact energy E_0 as E_0 crosses E_{max}=300 eV when N_b varies around ~10^{11}
    - This implies a sensitivity to E_{max}

Conclusions (2)

- Not much difference between gaussian and flat longitudinal beam profiles
- f_{RF}=212 MHz vs. 53 MHz:
  - Field-free regions: 212 MHz favored over 53 MHz
  - Dipole bends: ambiguous (depends on E_b) due to non-monotonic behavior
  - In any case, advantage of 212 over 53 MHz appears to be only a factor of ~2-5 lower n_e at $N_{tot}=1.6\times10^{13}$ (when there *is* an advantage)
- MI upgrade and proposed PS2 share strong similarities vis-à-vis ecloud
  - Not unexpected due to similarities in the beams and vacuum chamber
  - R&D on one leverages the other
- What's next:
  - Analyze new measurements
    - Especially to determine E_{max} and confirm peak SEY=1.3
    - Confirm non-monotonic dependence of n_e in dipole on N_b
  - Assess sensitivity to various parameters, especially to E_{max}
  - Explore other sections of the ring (ie., quads)
  - Begin assessing effects on the beam

Extra material

Energy ramp: 5/7-full ring – dipole bend
420 consecutive filled buckets + 168 empty

- Aver. beam neutralization is significant (~1% – 20%)
- Smaller at $N_b=3\times10^{11}$ than at 5×10^{10} or 1×10^{11}
- Caveat: beam dynamics is sensitive not to the *average* neutralization but to the *local* neutralization (near the beam)