V. Shiltsev 9/13 - 9/14:

μ2e Slow Extraction from Recycler bunch-by-bunch:

whole process takes ~ 7 Booster ticks = $\frac{7}{15}$ s = 0.5 s

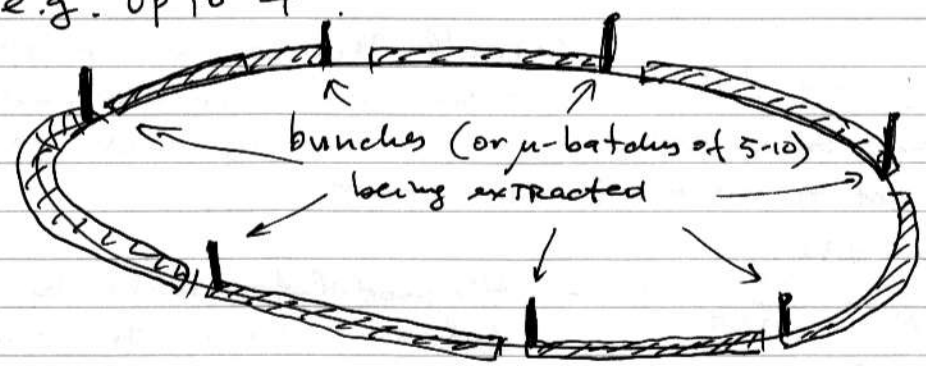
0.5 s = 500 ms ~ 50,000 turns

Simplest case: one Booster Batch in RR, 4e12 p's
80 bunches

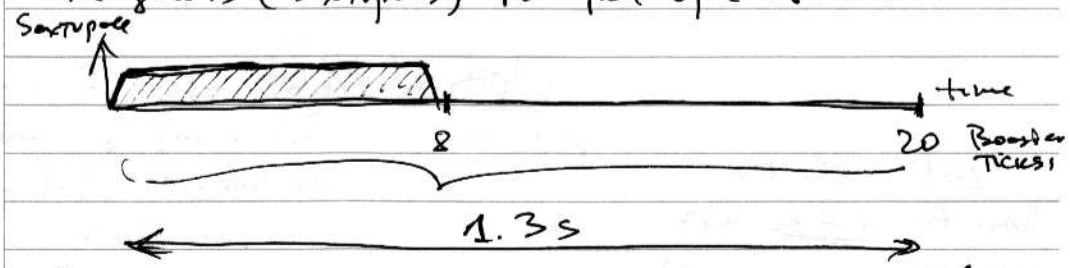
- if slow extract bunch-by-bunch: THEN
  each bunch takes ~ 50,000/80 = 600 TURNS

- in principle, experiment can allow extracting from 5-10 bunches simultaneously →
  ($t_{radiation}$ = (5-10)·20 ns = 100 - 200 ns) →
  so each μ-batch extraction time can be 3,000-6,000 turns
  (THAT is 30-60 msec)

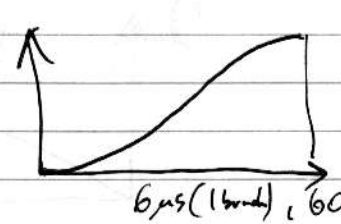
- if extraction DEVICE allows, several batches can be injected in RR & extracted simultaneously, e.g. up to 7:



- slow extraction will require add'l NON-LINEAR magnets (sextupoles) ramped up & down

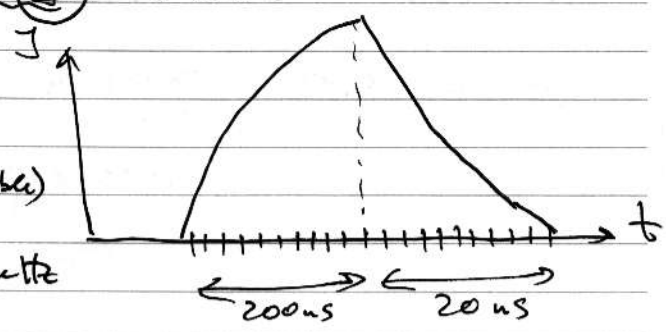


- effect of extracting device on each bunch should change in time, e.g. →



or pulse should slide onto next bunch

Extracting Device Option (1a): TEL



- TEL pulse covers minimum 10+10 bunches or more (programmable)

Note: see also Shiltsev, Marriner PAC'01, p. 1468 (2001)

- TEL works CW $f_{rep} = 150$ kHz that corresponds to be able to extract out of $\frac{150\,\text{kHz}}{100\,\text{kHz}} \cdot \frac{1}{D.F._{\leftarrow 0.4}} = 3.2$ bunches simultaneously.

- TWO (existing) TELs can extract out of 6-7 Booster batches circulating in RR

- TUNEshift by TEL: $\Delta Q_{x,y} = \frac{\beta_{x,y}}{4\pi}\left(1+\beta_e^{\sim 0.2}\right)\cdot\frac{G\cdot L}{B\rho}$ $\quad B\rho = 28\,T\cdot m = 2.8\cdot 10^5\,G\cdot m$

electric field $E = \frac{2I}{\beta e r} = \frac{0.2\,I(A)}{0.2\,r(cm)} = 1\,G/cm\cdot J(A) \rightarrow$

$\Delta Q = 0.0027\cdot J(A)$ if $r_e = 3\sigma_p \simeq 10$ mm, $L = 2$ m, $U_e = 10$ kV

for $\Delta Q = 0.016$ one needs $J \simeq 6$ A (pulsed)

Note: $r_e = 3\sigma_p$ to cover all particles

Note: I took $\beta_x = 40$ m for $\beta_x = 60$ m, $J_e = 4$ A

- Currently, TELs can deliver approx that much current (actual limit is collector power of ~ 50 kW $= U_e \cdot J_e$ (ave)) so at $U_e \sim 10$ kV $\langle J\rangle$ (average) ≤ 5 A. We tested up to $\langle J\rangle = 3$ A

Note that physics limit on max current is set by perveance of beam pipe:

$$\mu P = \frac{25}{1+2\ln\frac{b}{a}} \sim 8$$

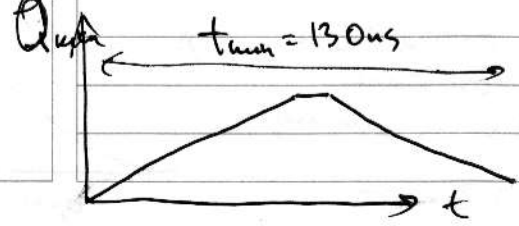
i.e. 8 A max (peak) @ 10 kV

- HV modulator built by G. Saewert & H. Pfeffer delivers 24/7 programmable waveform with $f_{rep} = 150$ kHz & $U_{max} \sim 5$-6 kV (8 max?) and $\Delta t_{min} \sim 400$-500 ns. Voltage is stable turn-to-turn $< 0.1\%$; NO reflections

Option (1b): use RR e-cooler for same purpose:

- one needs to modulate its current, i.e. to have HV (5-10 kV) modulator @ 4.4 MeV in Pelletron

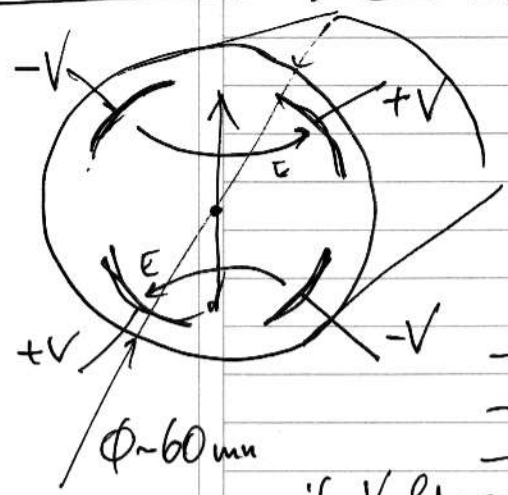
- $\Delta Q = 0.034\cdot J(A)$ (peak) ← that's OK

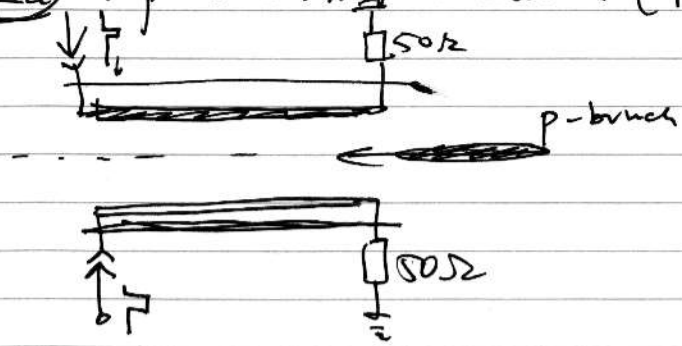


- caveat: due to length of inter. section, minimum coverage is 130 ns (or 7 bunches) no matter how short the current pulse is

Note: electrons have to collide with protons

Extracting Device Option (2a): pulsed Strip Line Quad (PSLQ)





- Sends EM pulse onto p-bunch
- pulse propagated @ speed of light
- Both electric & magnetic force act on beam
- if Voltage is V (kV), aperture (radius) a [cm]

Then

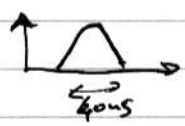
tune shift $\Delta Q = 0.015 \cdot \frac{V}{a}$ (assume $L = 2m$)

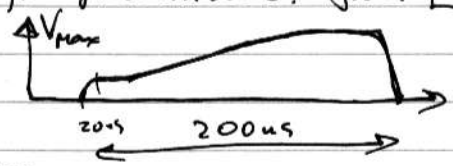
- assuming 96 mm x 44 mm RR vacuum pipe one can use $a = 20$ mm $= 2$ cm for estimates
- assuming that $\Delta Q = 0.03$ is needed →

  $V_{max} = 4$ kV for $L = 2$ m

  or $V_{max} = 1.5$ kV for $L = 6$ m
- required after pulse/reflection level < 5%
- stability pulse-to-pulse : < 1%
- rep rate : at least 90 kHz

  at most 7×90 kHz = 630 kHz
- Number of units : 1 to 7 (TBD)
- pulse form to be programmable: from to larger one, e.g.



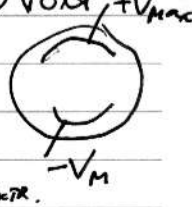


- it may be required to grow from 0 to V_{max} in 30–60 ms (TBD)

an example of 50Ω very fast kicker - see B. Grishanov, NIMA396 (1997) p.28

Option (2b): as proposed by V. Lebedev $V_{max} \sim 100$ Volt

pulsed source can drive dipole oscillations and blow up emittance, e.g. ± 100 V/4cm



L = 2m

- Dipole kick will lead to amplitude increase of

  $\Delta X = \beta_x \cdot \Delta\theta = 50$ m · 5 μrad/turn = 0.25 mm/turn – n.b. enough for extr.
- That process is different from usual slow extraction and needs to be simulated