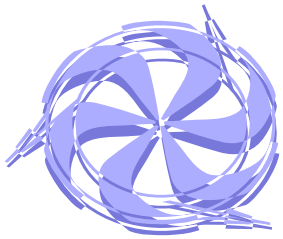
Loss Simulation in the BetaBeam Decay Ring

1. Review of motivation and requirements
   - Loss simulation -- an overloaded term
   - What's in the toolbox?

2. Accsim code and the Decay Ring
   - Tracking, decay and loss processes
   - Bunch merging
   - Injection and momentum stacking
   - Tracking and loss of secondary ions

3. Code development issues
   - Tracking and physics
   - Connections with other codes

4. Next activities
   - Accsim tasks
   - Beta+Accsim, and further studies



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Motivations for Tracking/Simulation

- Decay Ring has100% beam loss.
- Dynamics of the ring operation (injection, bunch merging, decay) and the variability of machine parameters suggest that a comprehensive computer model incorporating 3D multiparticle tracking, ring dynamics (injection, stacking, etc.) and interactions in matter would be useful…
  - To predict, moderate, and control losses
  - Identify high-loss areas in an operating scenario
  - Provide input to activation studies
  - Evaluate and optimize collimation/collection schemes and other relevant design features
- How far does “loss simulation” go?
  - ⇨ Loss profile + traditional activation study (FLUKA)
  - ⇨ ⇨ Tracking/simulation preprocessor for FLUKA, MARS, G4
  - ⇨ ⇨ ⇨ Tracking/simulation incorporates geometry & P.I.M.

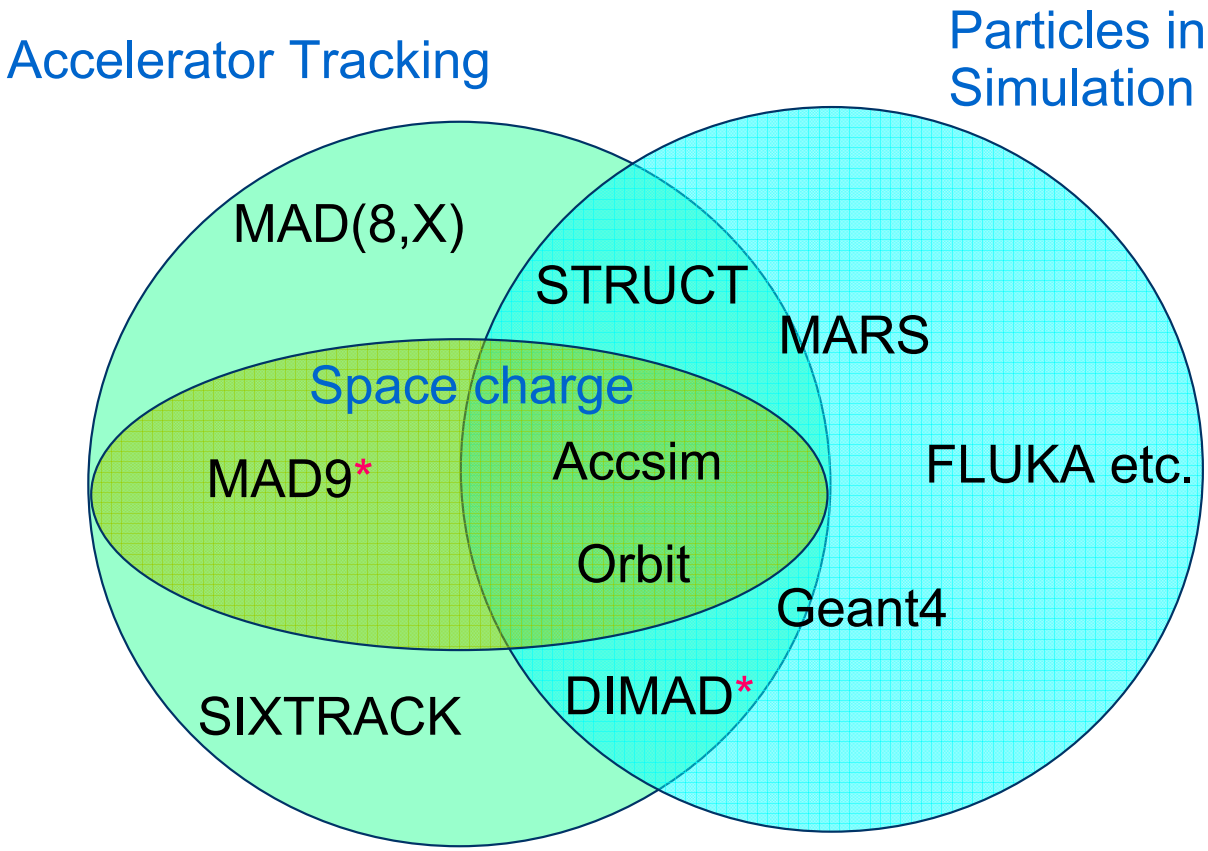
Simulator's toolbox

- Lattice/injection design
  - Beta (J.Payet & A.Chance)
    (has many other capabilities & supports Mad-file output)

- Multiparticle (3D) tracking with ring dynamics (multiturn injection, orbit bumps, rf gymnastics) and loss detection
  - Accsim (□ Beta)
  - Orbit (ORNL, SNS) comprehensive, "open" source
  - ? STRUCT (MARS spinoff)

- Multiparticle tracking in a ring with interactions in matter
  - Accsim: stepping model with geometry for collimators, vacuum chamber walls, etc. Physics limited to ~0.1-10 GeV protons, EM and elementary nuclear interactions.
  - Orbit: collimator model for low-energy protons, adapting from CERN K2 code (Jeanneret).
  - STRUCT (equiv. Protons). Efficiency not known.

Codes: Map of the territory



* Variant versions

Accsim in a nutshell

- A 3D tracking and simulation code with space charge (longitudinal and transverse) and some particle interactions in materials (protons)
  - Foils, collimators, wire septa, vacuum chambers, internal targets
  - Detailed loss tabulation and summaries
- Fast basic tracking engine using matrix/thin-lens model
- Feature-laden: many additions to support specific studies
- Easy to modify and customize
- Multiturn injection and RF gymnastics are specialties
- Some applications: LANL-PSR, SNS, CSNS Beijing, CERN-PSB, Hitachi medical synchrotron, KEK-PS, J-PARC 3GeV & 50GeV, European HIDIF (multi-RF multi-species)
- Validation: comparison with measurements, other codes, and theory
  - LANL PSR loss profiles, KEK 12 GeV PS profiles with space charge, effects, J-PARC 3GeV ring STRUCT comparison, CERN-PS space charge benchmarks (Hofmann et al.), TRIUMF resonance studies.
- (Relatively) fast set-up makes it useful for “one-off” studies.

Accsim: Ion decay and loss processes

- Generalization for ions (primary and secondary): input particle charge, rest mass and number of nucleons.
  - Easy to just do everything on per-nucleon basis, but leads to trouble…
  - New rule: all coordinates and ♎'s based on total ion energy!
- Particle decay: input half-life
  - Actual lifetime is sampled at injection
  - Matrix transport instrumented to detect decay, track to decay point and convert to secondary ion, with tagging for "stop" or "continue tracking".
- Some considerations
  - Injection interval (SPS cycle) time (8 s.) is ~350000 turns
  - 6He: half-life of primary ion is ~3.5 million turns
  - Fill time (~1000 s.) is ~43.5 million turns
  - Ultra-Supercomputer needed! Unless…
  - ⇨ ***Work in stages, artificially shortening the time scale as appropriate.***

Bunch merging

- From ESME to Accsim

RF program for bunch merging

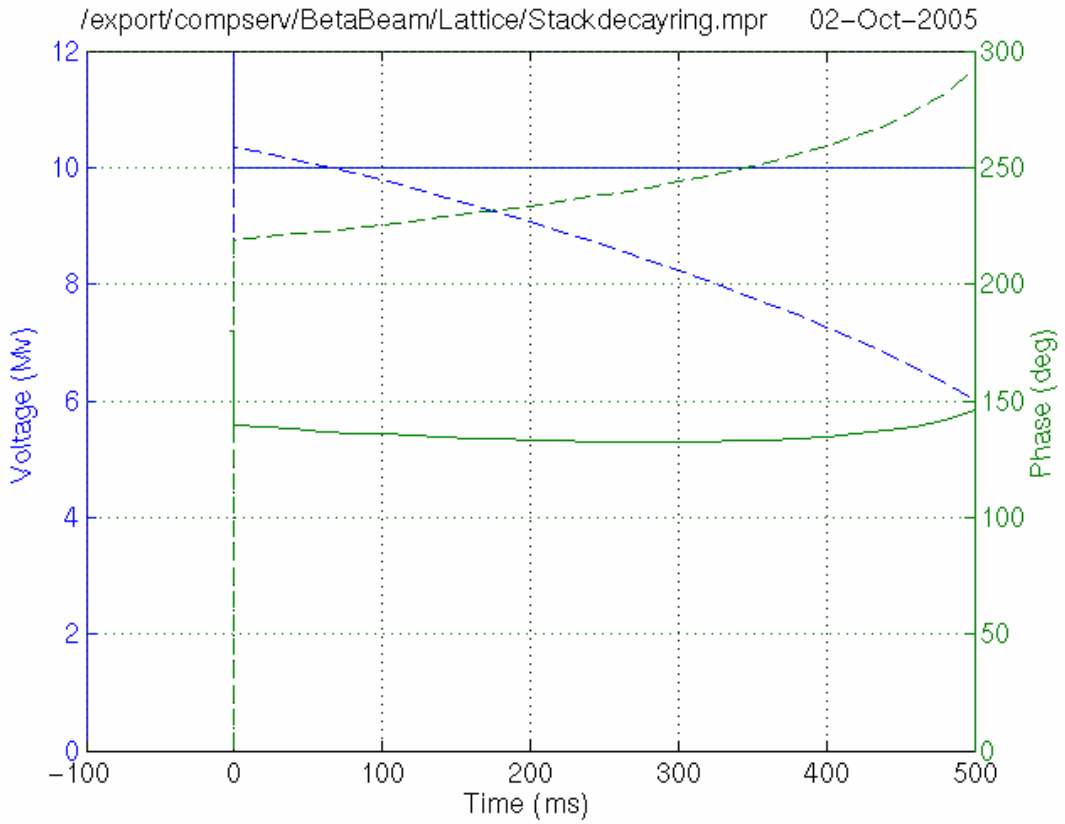
(courtesy of S.Hancock)

Voltage: ____ Main RF

- - - - 2nd harmonic

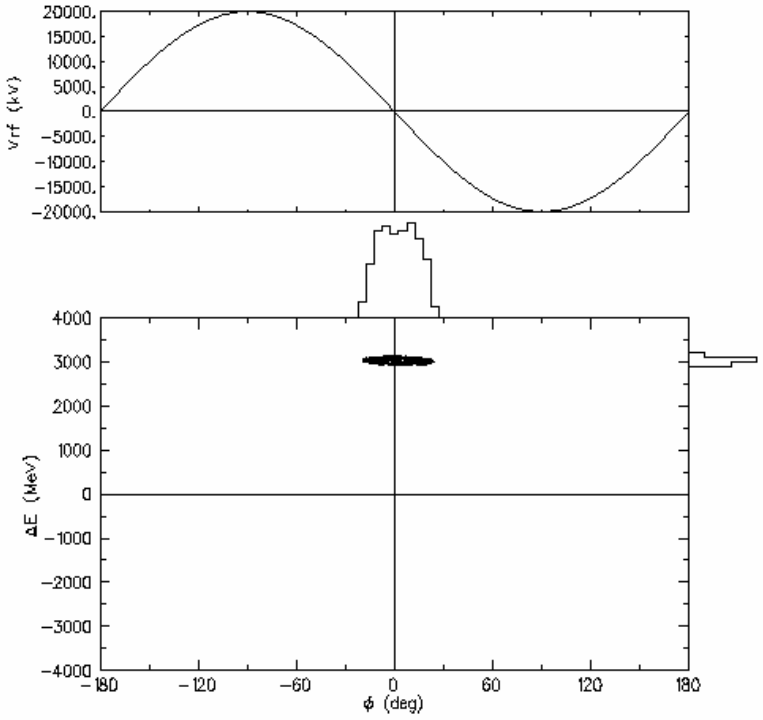
Phase: ____ Main RF

- - - - 2nd harmonic



- Injecting 6He Bunches from the SPS at γ_0=100 (557.3 GeV)
  - 1 eV-s, $\Delta p/p$=0.4E-3, offset ΔE=3.027 GeV (no tilt yet)
- Next: generate Accsim distribution input file from ESME SPS stage, for better cross-check.

Decay ring bunch merging -- first 1/4 turn



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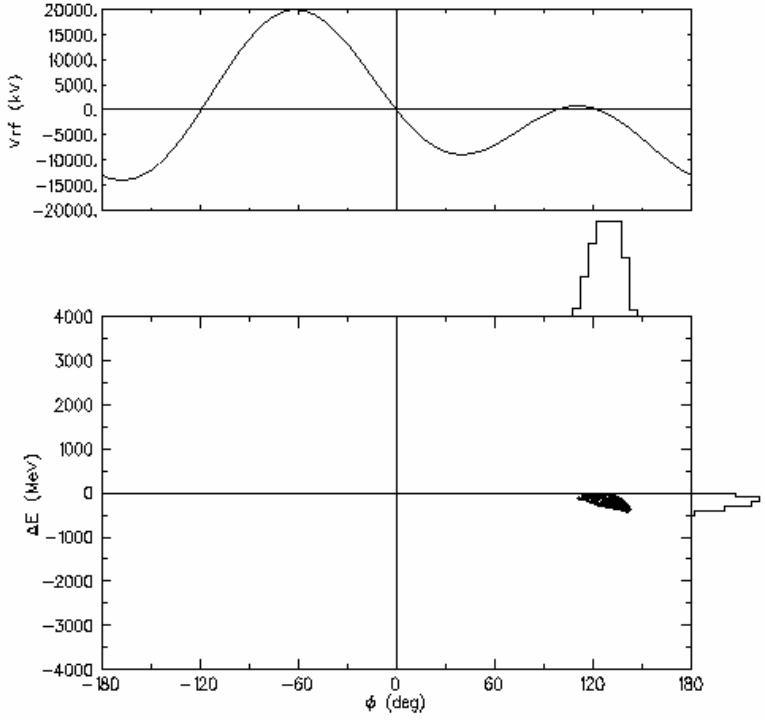
ETAx, ETAxp 8.18494606 -3.31139338E-09
Ts, DEO [MeV] 557326.438 3027.65991
Vrf [kV] 20000.
CO bump [mm] 36.182724 -8.35862011E-08
Hits: total, average 0 0
Particles plotted, lost 1001 0
Real particles in circulating beam: 1.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING
Sep 27 13:16:45 2005
ACCSIM v4.0beta.14



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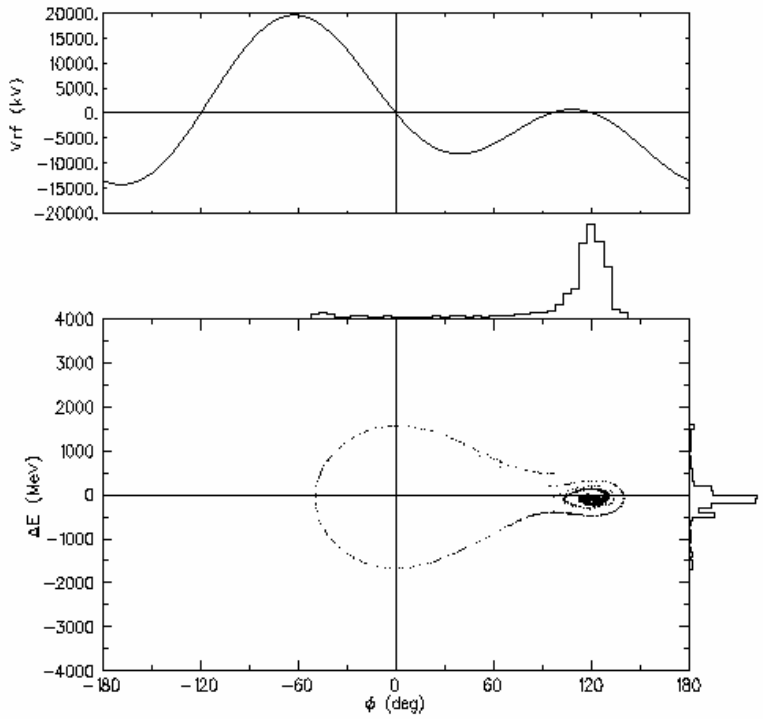
Vrf [kV] 10000.
CO bump [mm] 36.182724 -8.35862011E-08
Hits: total, average 0 0
Particles plotted, lost 1001 0
Real particles in circulating beam: 1.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING
Sep 27 13:16:45 2005
ACCSIM v4.0beta.14

Decay ring bunch merging cont'd.



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Ts, DEO [MeV] 557326.438 3027.65991
Vrf [kV] 10000.
CO bump [mm] 36.182724 -8.35882011E-08
Hits: total, average 0 0
Particles plotted, lost 1001 0
Real particles in circulating beam: 1.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING
Sep 27 13:16:45 2005
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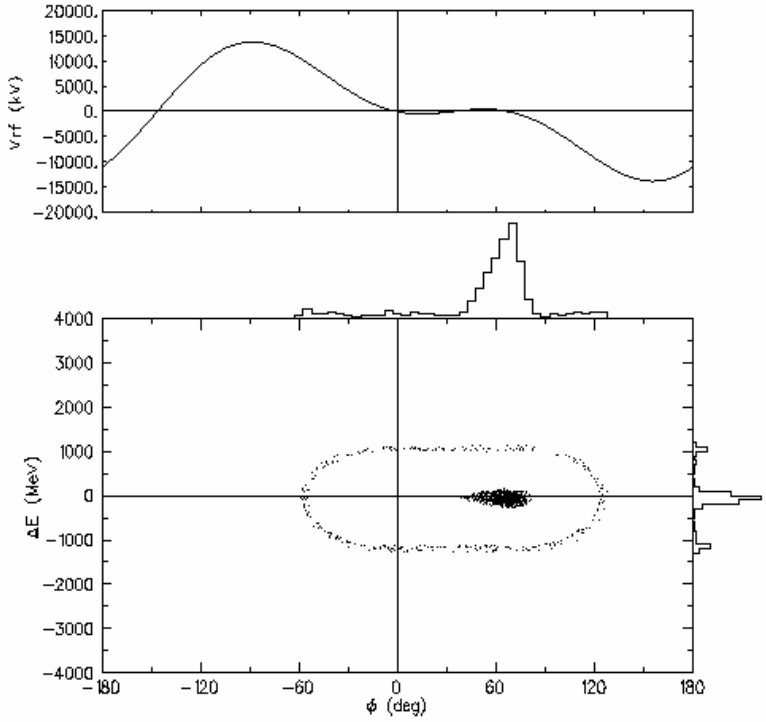

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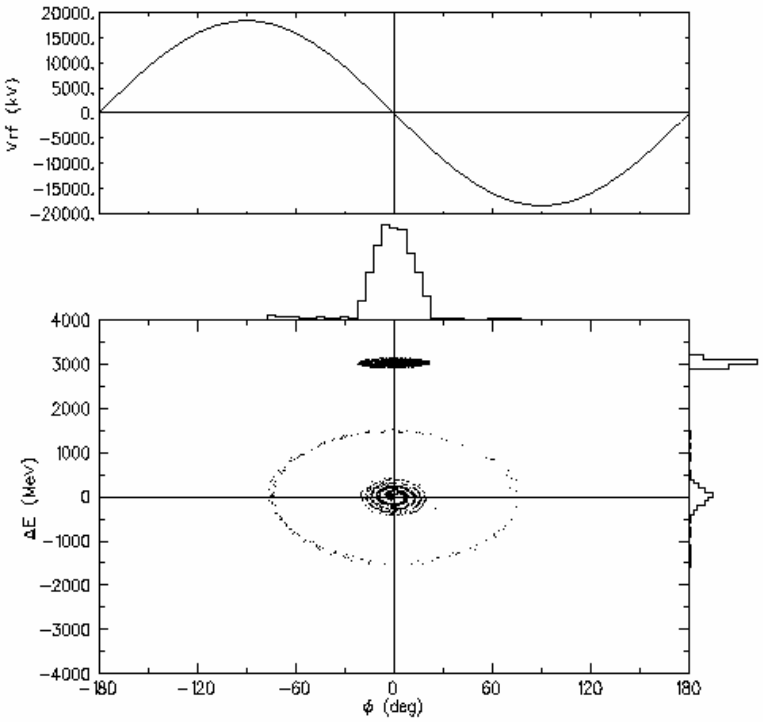
Ts, DEO [MeV] 557326.438 3027.65991
Vrf [kV] 10000.
CO bump [mm] 36.182724 -8.35882011E-08
Hits: total, average 0 0
Particles plotted, lost 1001 0
Real particles in circulating beam: 1.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING
Sep 27 13:16:45 2005
ACCSIM v4.0beta.14

On into terra incognita…



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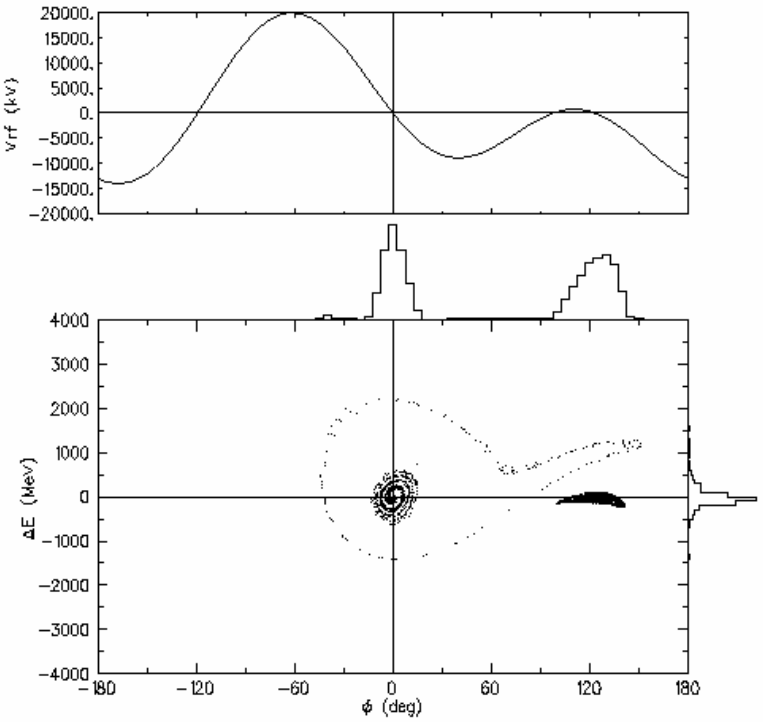
Vrf [kV] 20000.
CO bump [mm] 27.2200241 2.42143869E-08
Hits: total, average 0 0
Particles plotted, lost 2001 0
Real particles in circulating beam: 1.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING and STACKING
Oct 7 19:31:01 2005
ACCSIM v4.0beta.14



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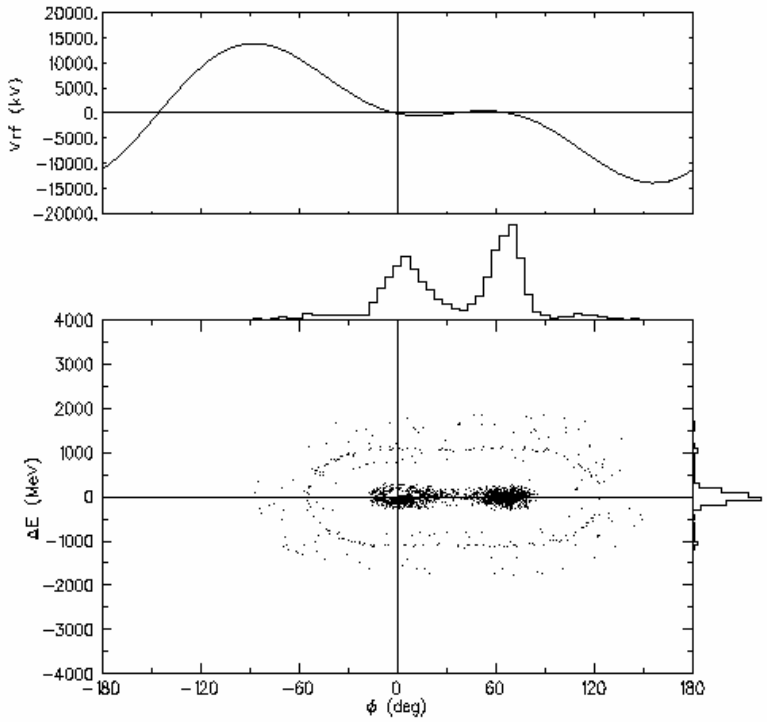
Ts, DE0 [MeV] 557326.438 3027.65991
Vrf [kV] 10000.
CO bump [mm] 3.43425199E-08 6.90342858E-08
Hits: total, average 0 0
Particles plotted, lost 2001 0
Real particles in circulating beam: 2.00100001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING and STACKING
Oct 7 19:31:01 2005
ACCSIM v4.0beta.14

And on…



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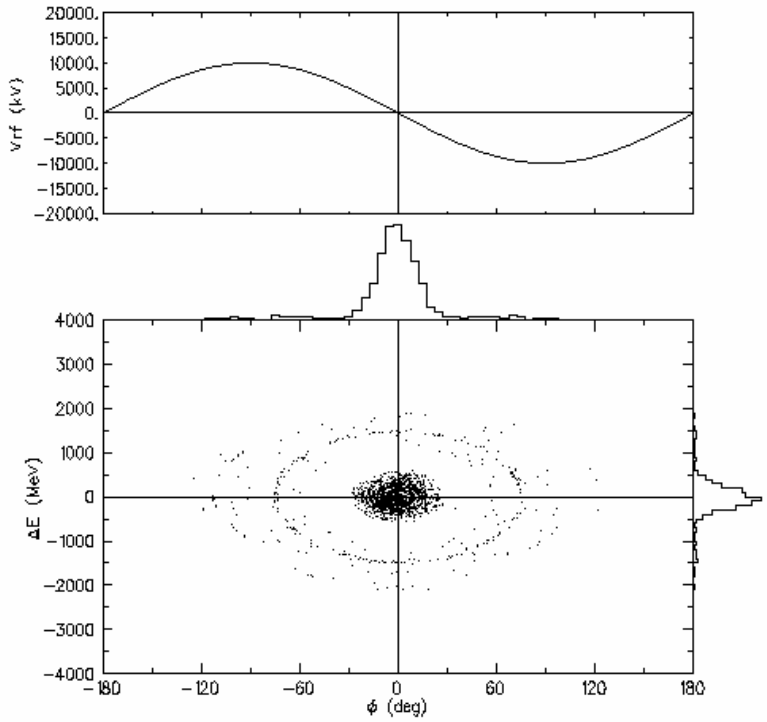
Vrf [kV] 10000.
CO bump [mm] 3.43425199E-08 6.90342858E-08
Hits: total, average 0 0
Particles plotted, lost 2001 0
Real particles in circulating beam: 2.0010001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING and STACKING
Oct 7 19:31:01 2005
ACCSIM v4.0beta.14



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Ts, DE0 [MeV] 557326.438 3027.65991
Vrf [kV] 10000.
CO bump [mm] 3.43425199E-08 6.90342858E-08
Hits: total, average 0 0
Particles plotted, lost 2001 0
Real particles in circulating beam: 2.0010001E+13

BETA BEAM DECAY RING 2nd version with BUNCH MERGING and STACKING
Oct 7 19:31:01 2005
ACCSIM v4.0beta.14

Injection and momentum stacking

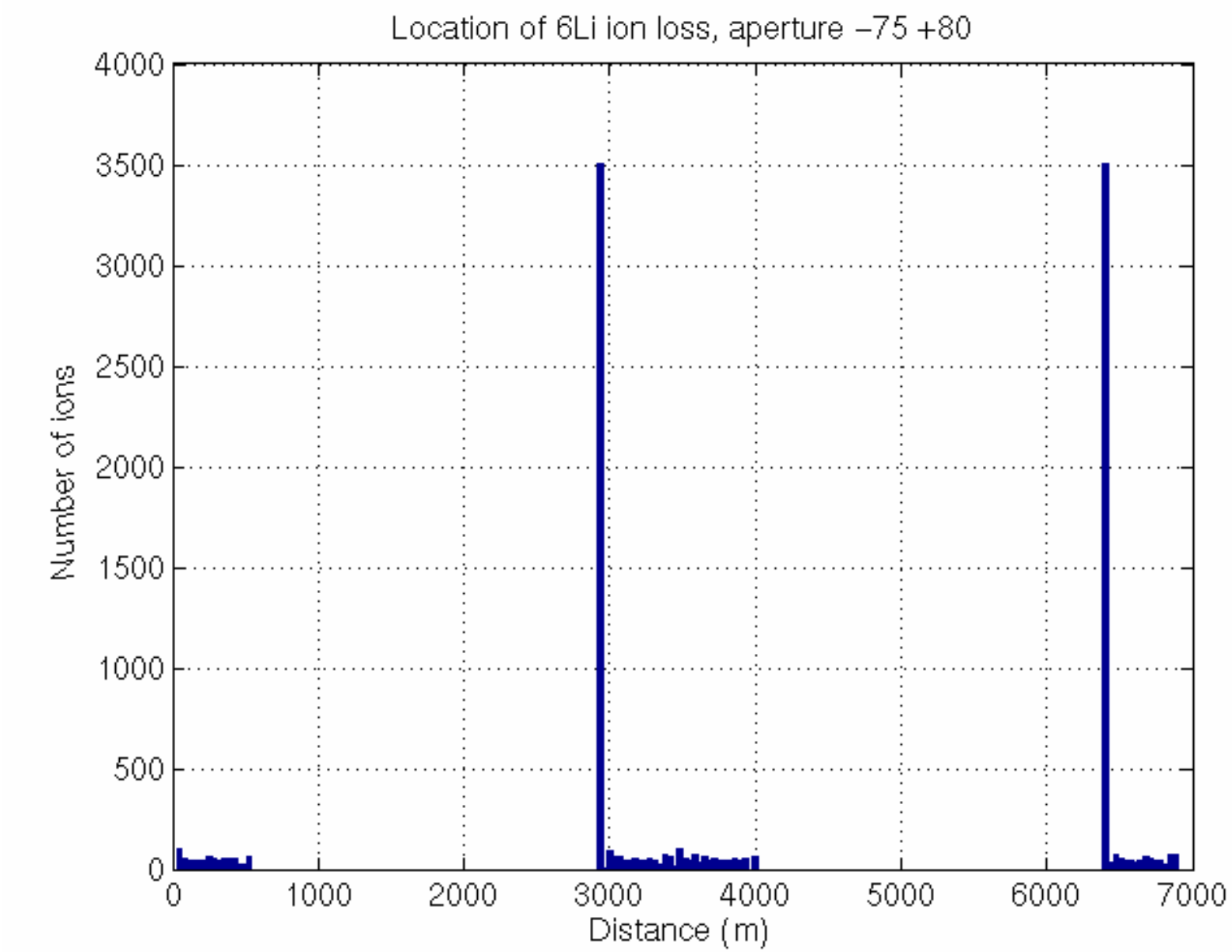
- Injection sequence
  - Inject off-momentum on dispersion-matched orbit
  - 1/4 turn at 20 MV rf removes momentum offset
  - Collapsing orbit (injection bump + dispersion) helps circulating bunches to clear septum
- To-do for stacking
  - Determine complete merging cycle and evolution to next injection.
  - Look at multiple merges, filling, and accumulated emittances (within computing resource constraints).
- Septum losses ?
  - Accsim has “injection septum” element (w/ proton physics, or can just record hits).
  - Could do pre-processing for more detailed study of septum region with Mars or Geant4.

Decay, tracking, and secondary ions

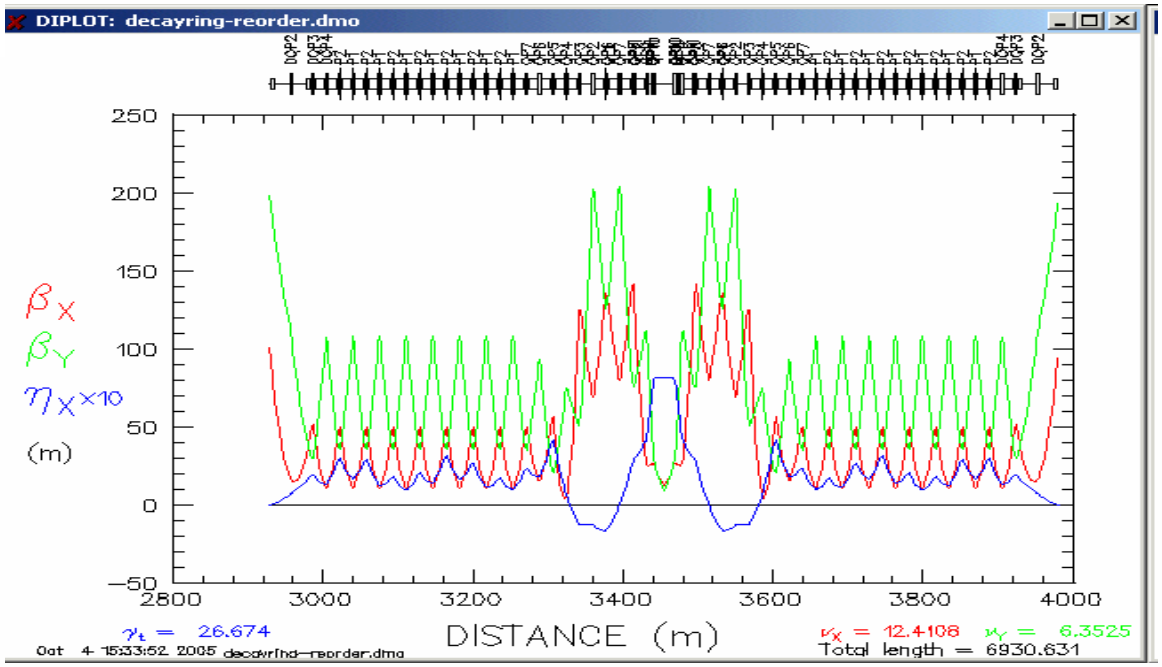
- Matrix transport + decay: split element matrix to determine decay coordinates.
- User option for secondary ions:
  1. The ions are tagged, removed from tracking, and coordinates are exported for external tracking.
  2. The ions are tracked until lost, adjusting **ΔE coordinate for new reference momentum. At present, tracking in linear lattice only**.
- Need to validate tracking with large momentum deviation (cf. FFAG)

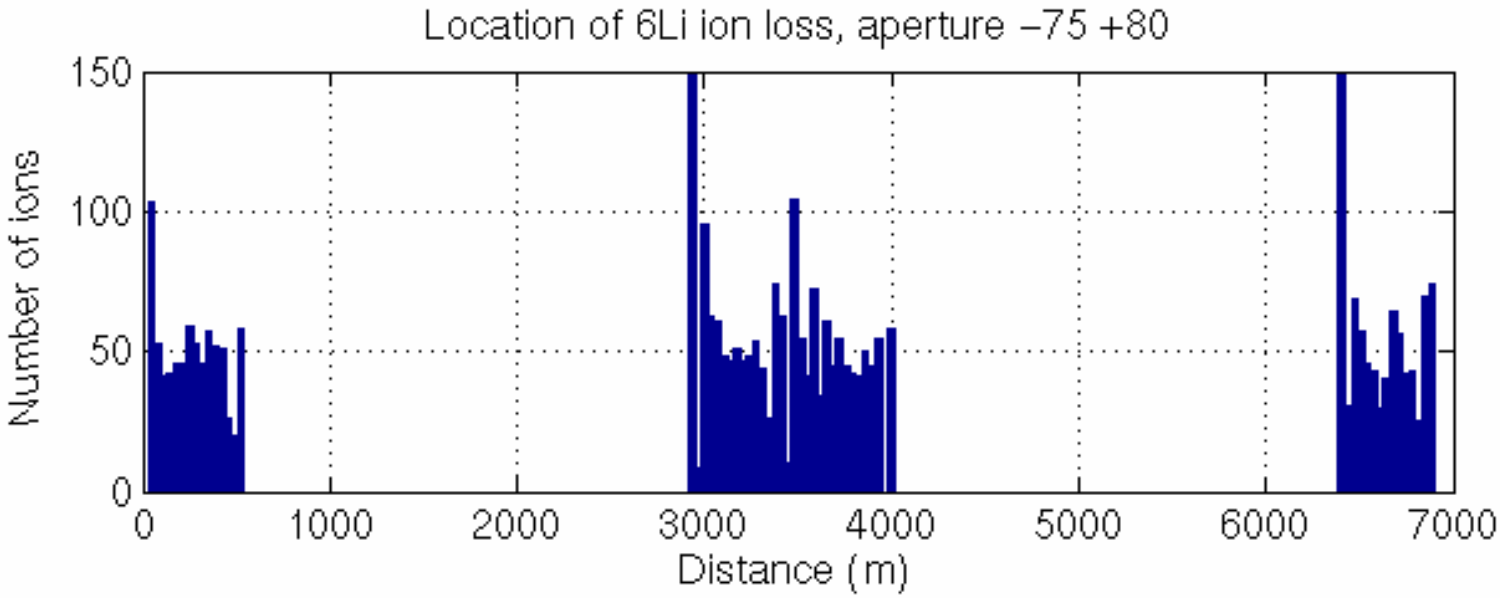
```
Primary and secondary ions
   Charge                        2.           3.
   Rest mass (GeV)               5.60548306   5.60146379
   Ref orbit energy (GeV)        557.326416   838.773071
   Ref orbit momentum (GeV/c)    562.903992   844.355957
   B*rho (Tm)                    938.822632
 Secondary ion
   Actual energy (GeV)    556.926819
   Energy deviation      -281.846252
   Dp/p                  -0.333811343
```

Tracking of secondary ions in linear machine (preliminary)



Tracking of secondary ions in linear machine (preliminary)





Code development issues

- Tracking
  - Linear optics + thin multipoles: can model e.g. discrete thin dipoles and quads, but not a complete description.
  - Possibility of all-thin representation… MAD-X “makethin” output is adaptible to Accsim.
  - SNS Orbit code (Accsim’s cousin) offers validated thin-multipole routines and a basis for comparison.
  - Thin-multipoles vs. $\Delta p/p \sim 35\%$ …limitations and computational cost not known.

- Physics
  - Many physics processes to account for -- what can be included and what can be left to other codes?
    - Strahlsim, Mars, Geant4…
    -  High-energy ion physics toolkit

Code development issues (cont'd.)

- Accsim as pre- and post-processor for other codes
  - Beta: lattice input, post-decay tracking
  - Strahlsim: use accumulated 3D distributions from Accsim?
  - Event generator for P.I.M. codes (Mars, Geant4)
  - Need to distinguish processes:
    - Transient or cyclic: injection, stacking, filling -- may require "real time" simulation with large numbers of macroparticles
    - Steady-state: slow loss of stored beam -- simulate enough turns to gather statistics

- It may not be possible to cleanly separate physics and tracking
  - Hits arising from slow growth (e.g. bucket losses?) may entail re-entry and survival for multiple turns.

Next

- Experimental runs with multiple merge/fill operations, consistent with further ESME study.
- Loading more features and improvements in Accsim
  1. Investigate secondary ion tracking method
  2. ⇨ Optimized in-element loss detection
  3. Better diagnosis and recording of losses
  4. Different loss breakdown options, with graphics
  5. New aperture input methods, global and by element class
- Use of Beta and Accsim together
  - Exploit the complementarity wherever possible
  - Try to streamline the design/simulation cycle
- Estimate of requirements for Accsim-style macroparticle simulation vs. use of more specialized codes and analytical methods. How to handle stacking/filling with finite resources?
- Monitor the (developing) state of ion physics in Mars and Geant4.