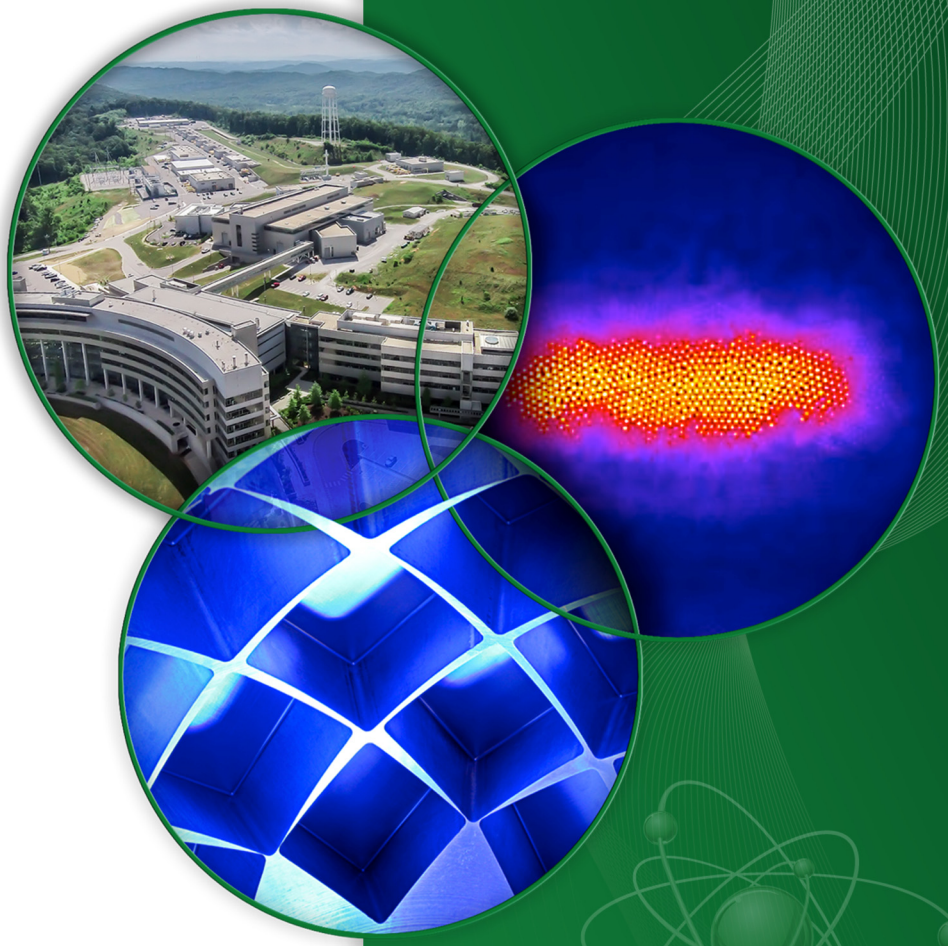
A Crab-Crossing Scheme for Laser-Ion Beam Applications



A. Aleksandrov

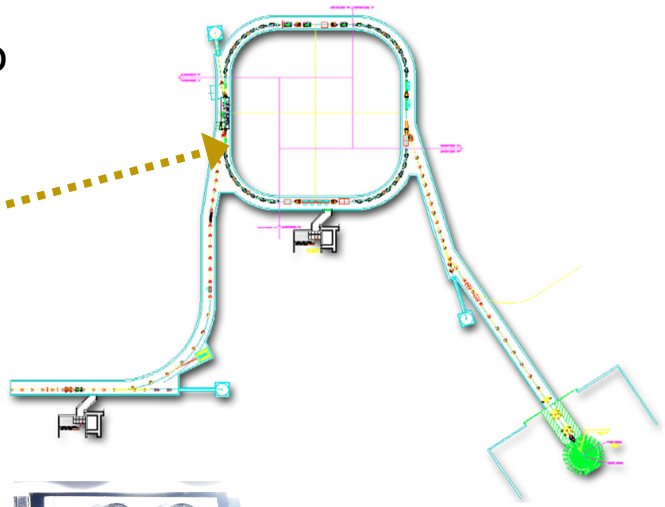
Oak Ridge National Laboratory,
Tennessee, USA

ORNL is managed by UT-Battelle
for the US Department of Energy

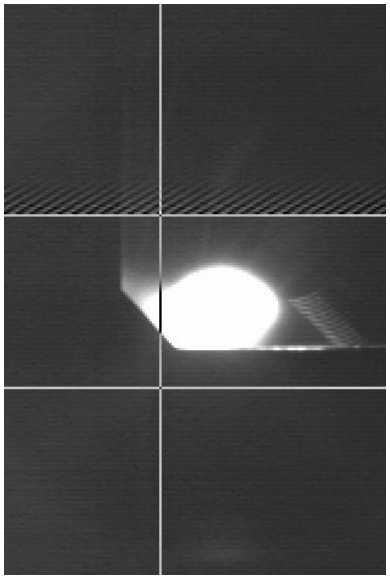
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Stripping foil scattering and life-time can limit beam power increase >1MW for conventional charge-exchange injection scheme

H- ion is converted to proton by stripping two electrons in thin foil



new

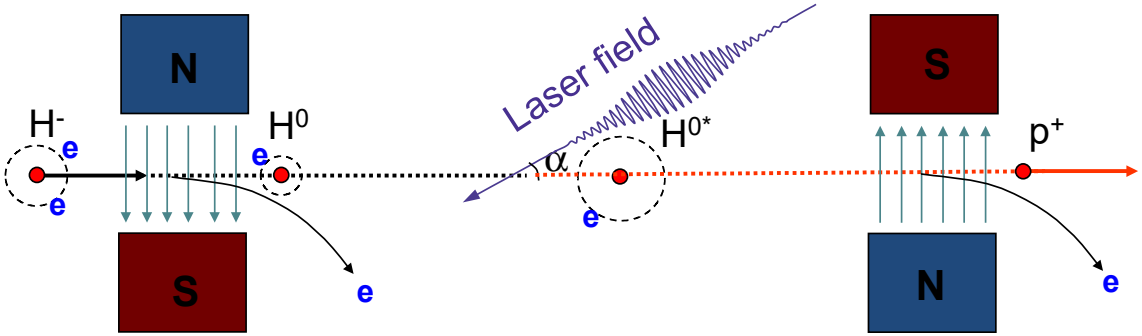


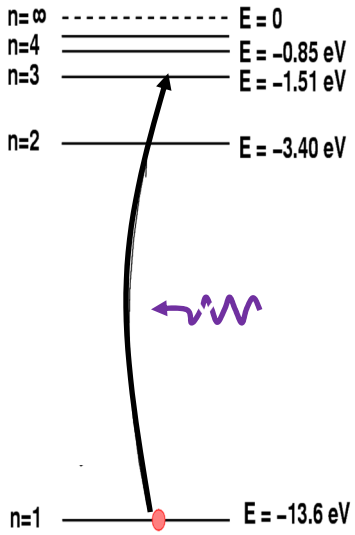
in operation

used

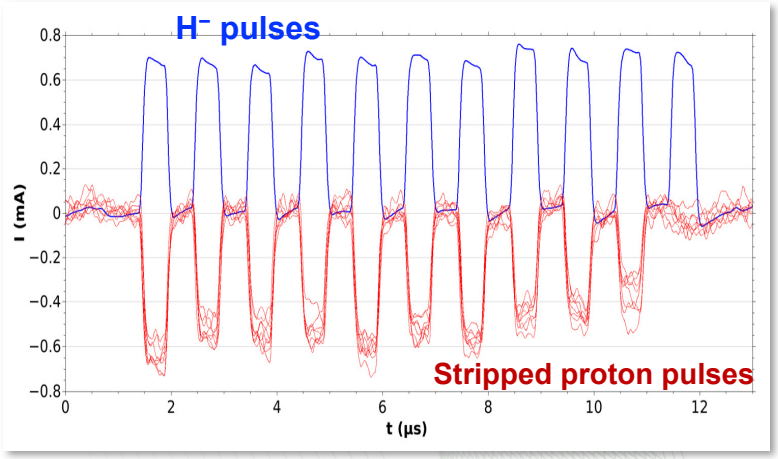
WEYBB2

Laser-assisted charge exchange injection aka ‘laser stripping’ is being developed at SNS to replace stripping foil





- Required laser beam power is main hurdle
- Series of technology development experiments at 1GeV:
  - with progressively longer ion beam pulse
  - with progressively lower laser beam power
- Practical implementation at SNS now seems feasible after 1.3GeV PPU upgrade



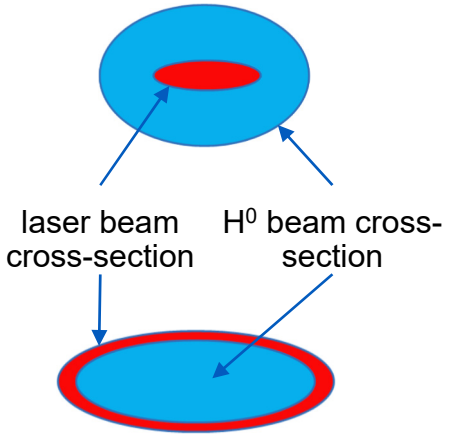
TUYBB2, WEPLH10

Laser-ion interaction basics

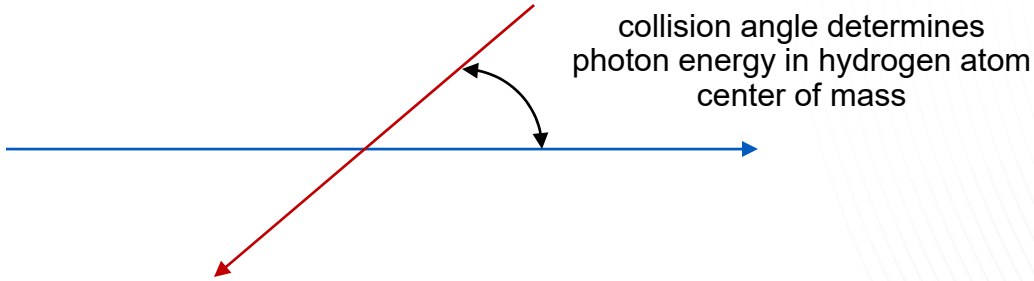
- Laser-ion interaction efficiency is proportional to laser power density

$$p = \frac{Q}{a_x a_y a_z}$$

- Reducing the laser beam size increases laser power density
- Ion bunch size must have same size or smaller to ensure full overlap
- Collision angle must be precisely controlled for efficient resonant excitation in laser stripping



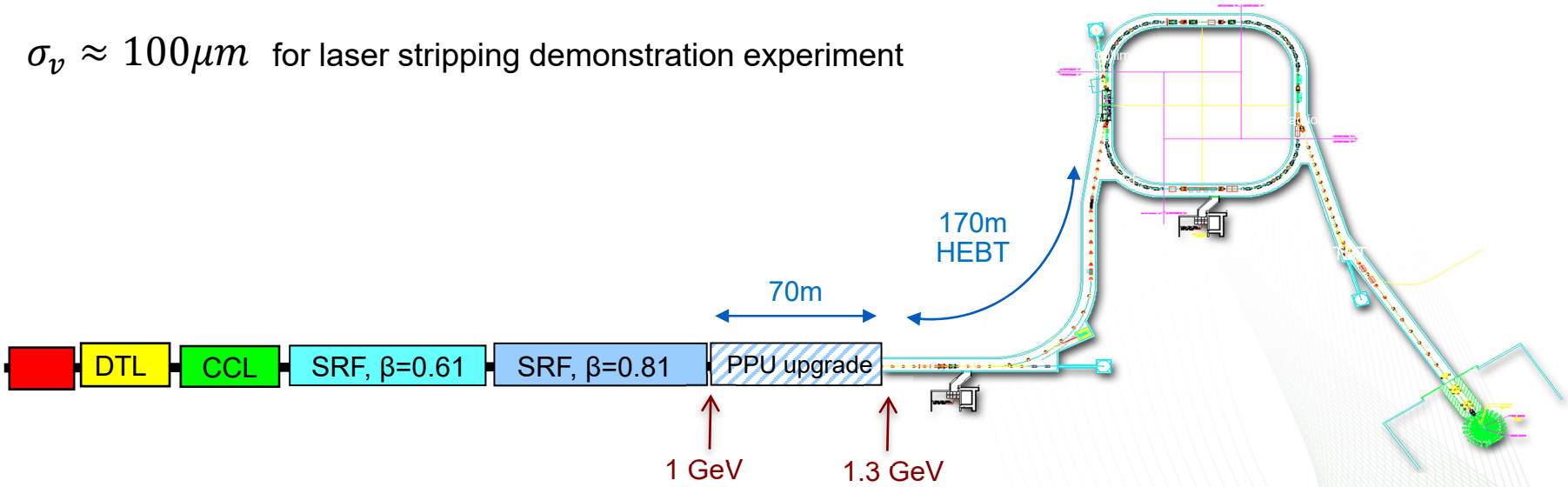
Need optimal overlap between ion and laser beams



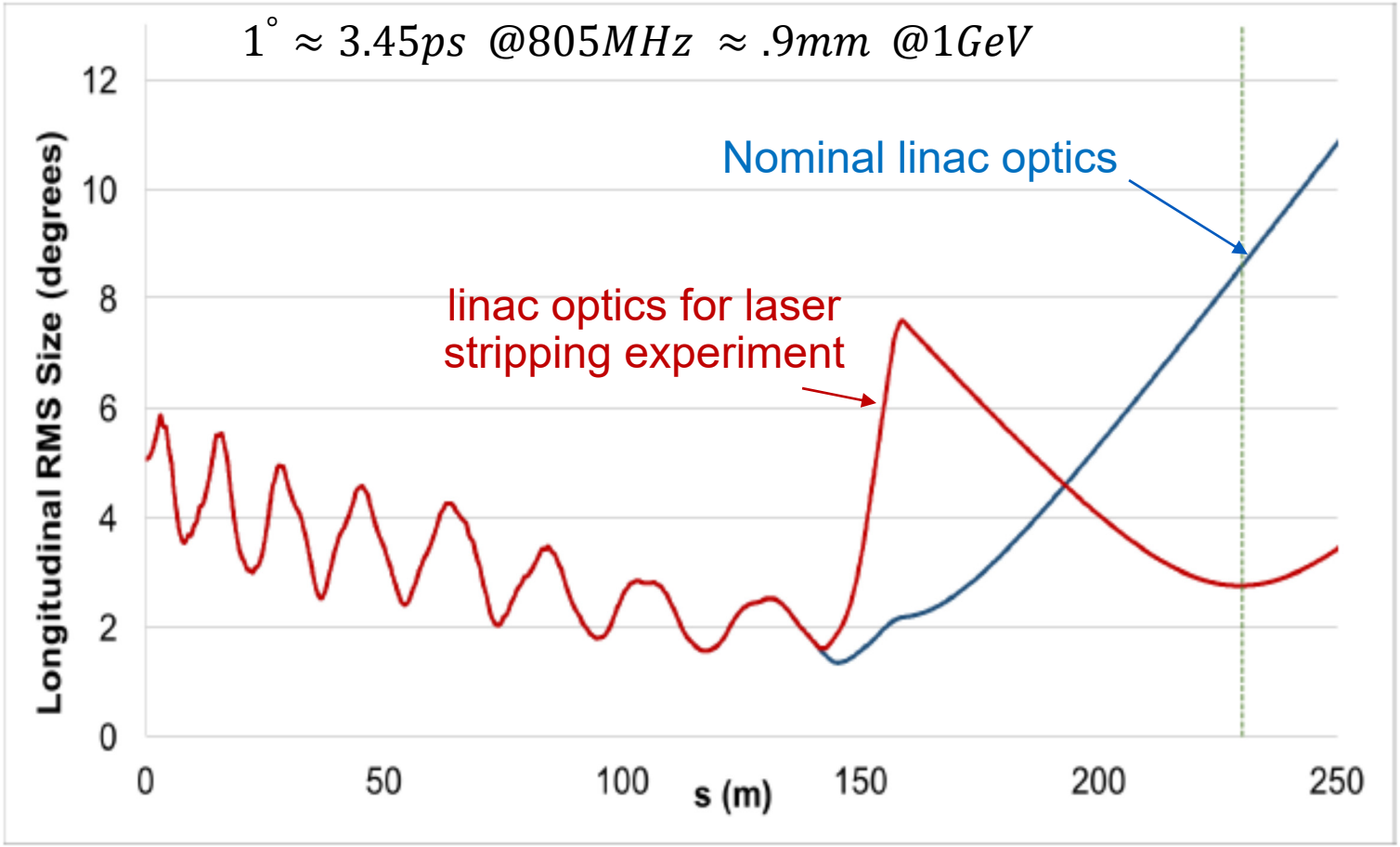
Transverse ion beam size squeeze

- Transverse size is squeezed down using HEBT quadrupoles
- Minimum vertical beam size is determined by the ion beam emittance
  - Sufficiently small for practical laser stripping cases above 1GeV
- Horizontal beam size is less critical due to intersection geometry
- Existing SNS HEBT beam optics flexibility is enough for laser stripping demonstration experiment and, most probably, real laser stripping injection

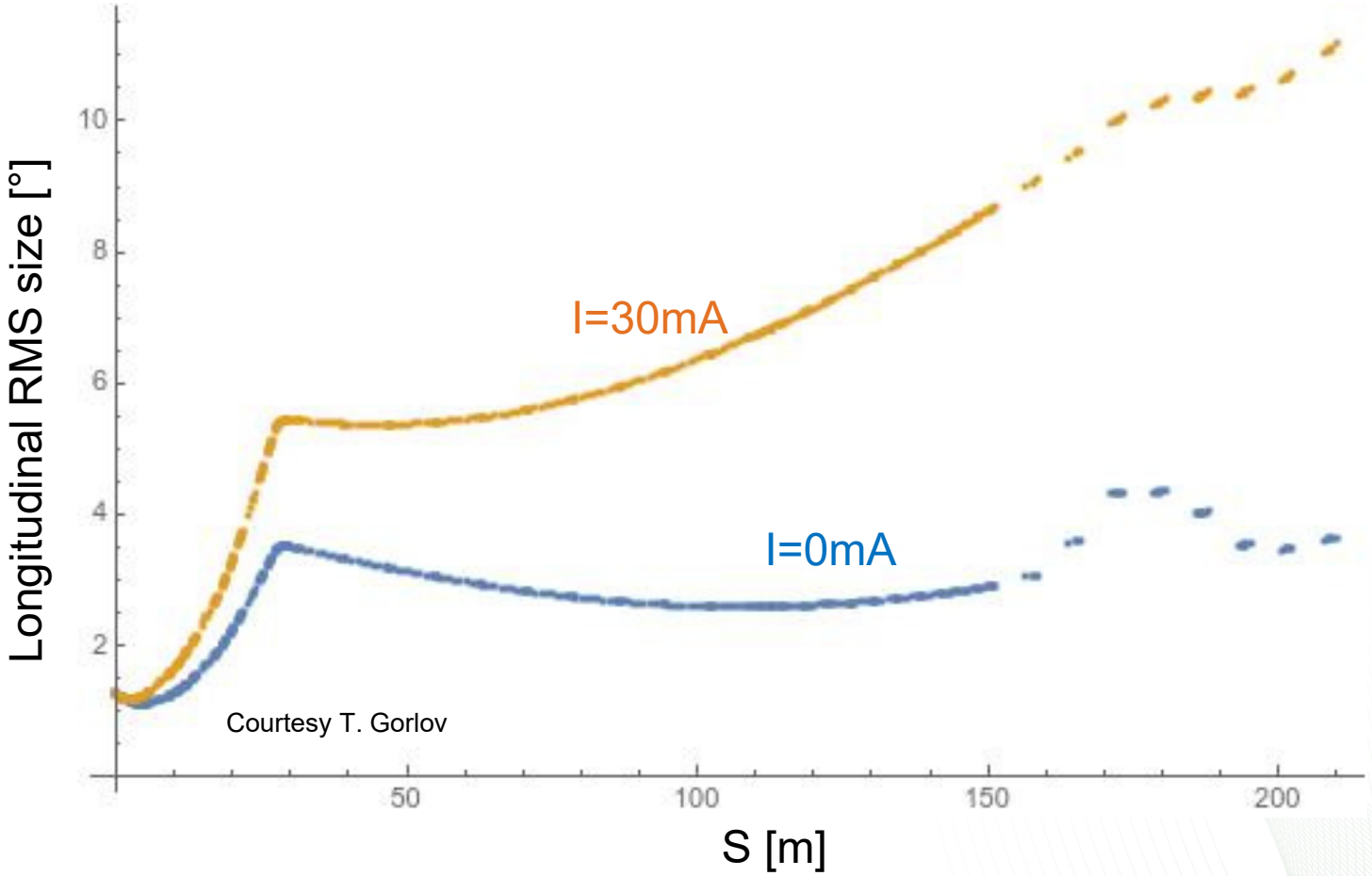
$\sigma_v \approx 100\mu m$ for laser stripping demonstration experiment



SNS SRF Linac has individually controlled RF cavities that can be used for longitudinal bunch focusing

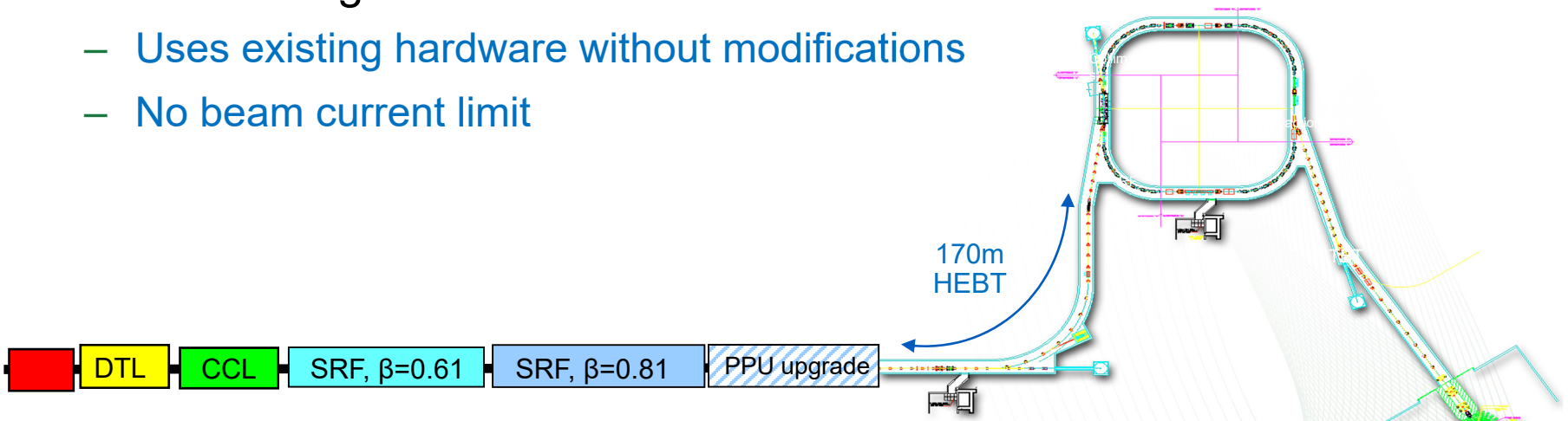


Space charge effect prevents focusing at large distance

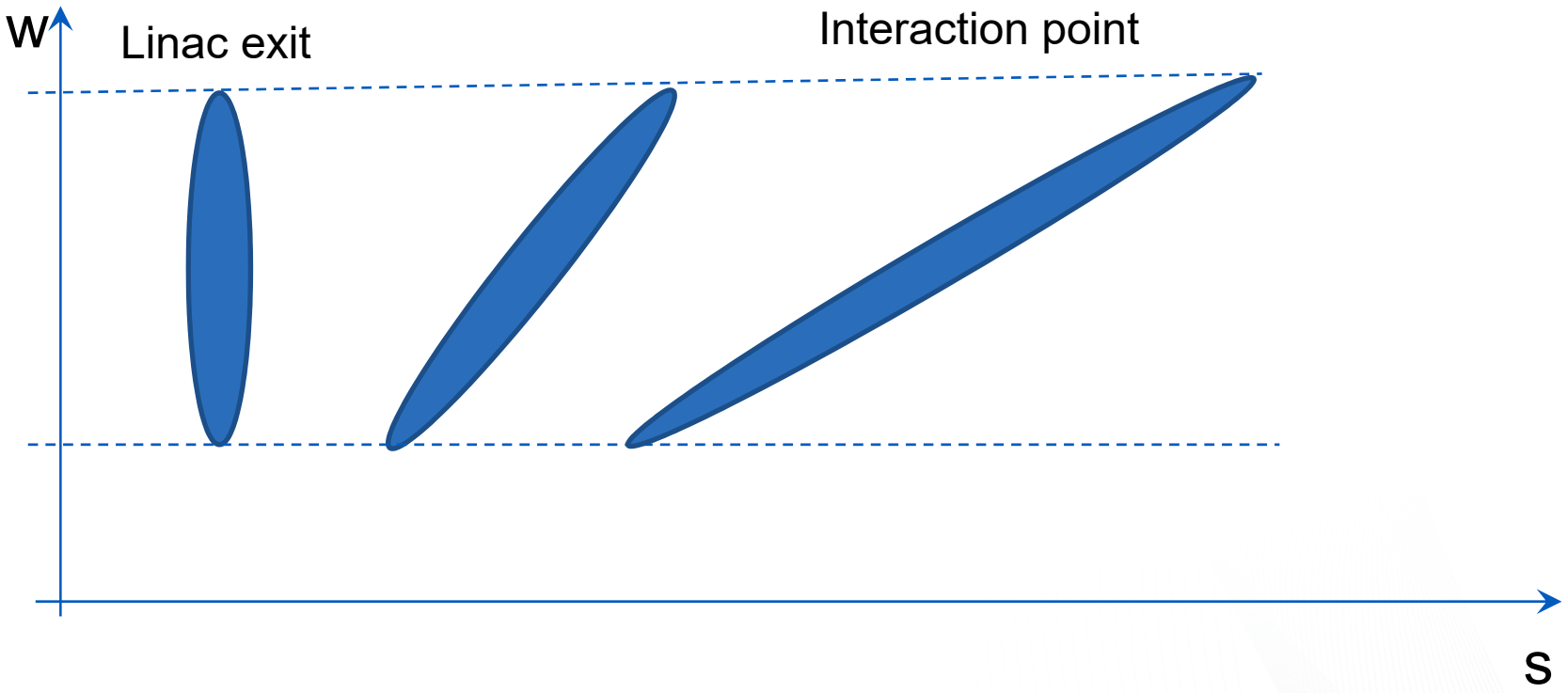


Options for longitudinal bunch squeeze

- Focusing using last linac cavities
  - Space charge limited
- Focusing using a dedicated RF cavity closer to I.P.
  - Cavity voltage of >15MV is required.
  - Very expensive to build within existing real estate constraints
- Longitudinal compression in HEBT bend, $m_{56} \leq 0$
  - Unable to find solutions within existing magnets strength constraints
- Crab-crossing collision scheme
  - Uses existing hardware without modifications
  - No beam current limit

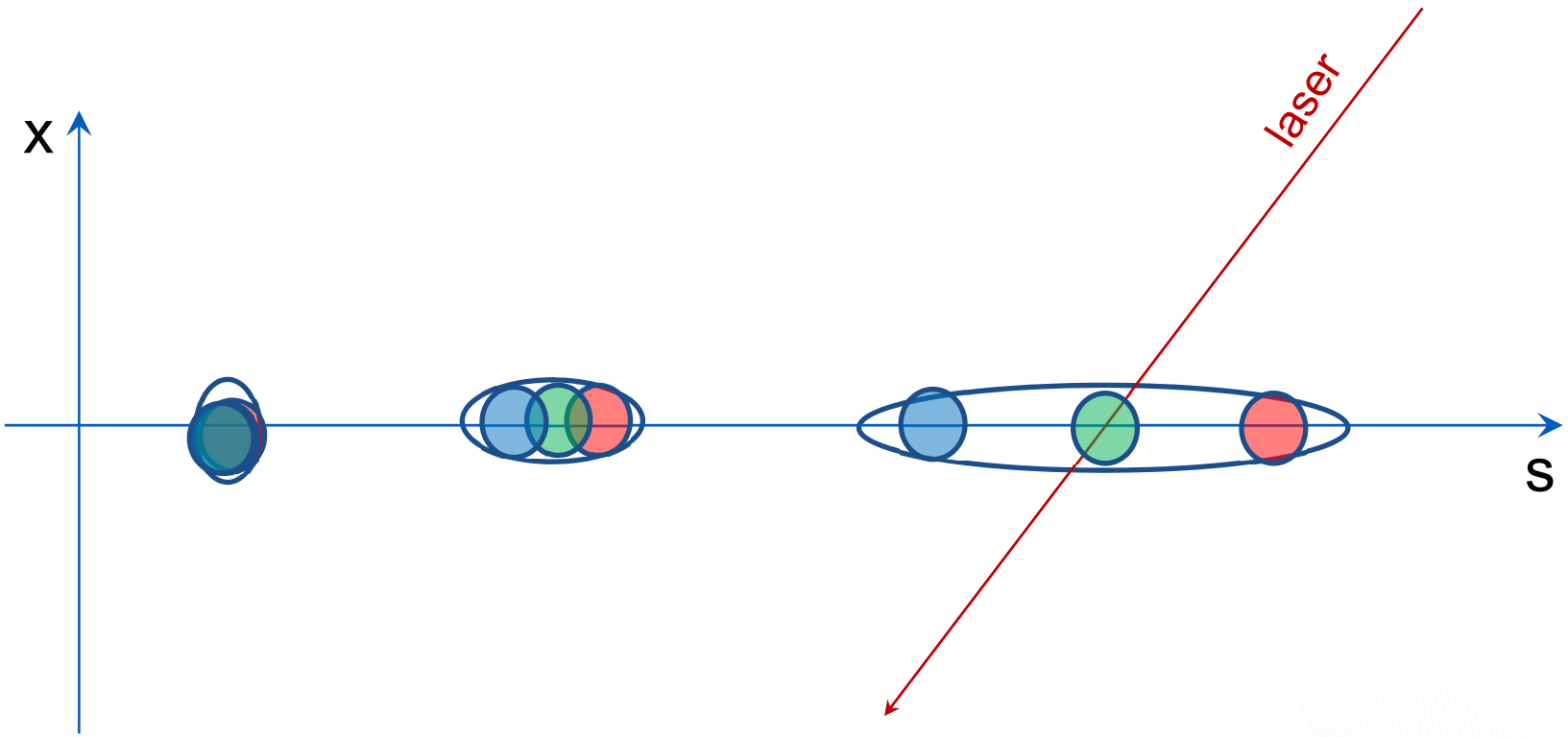


Bunch evolution in longitudinal phase-space



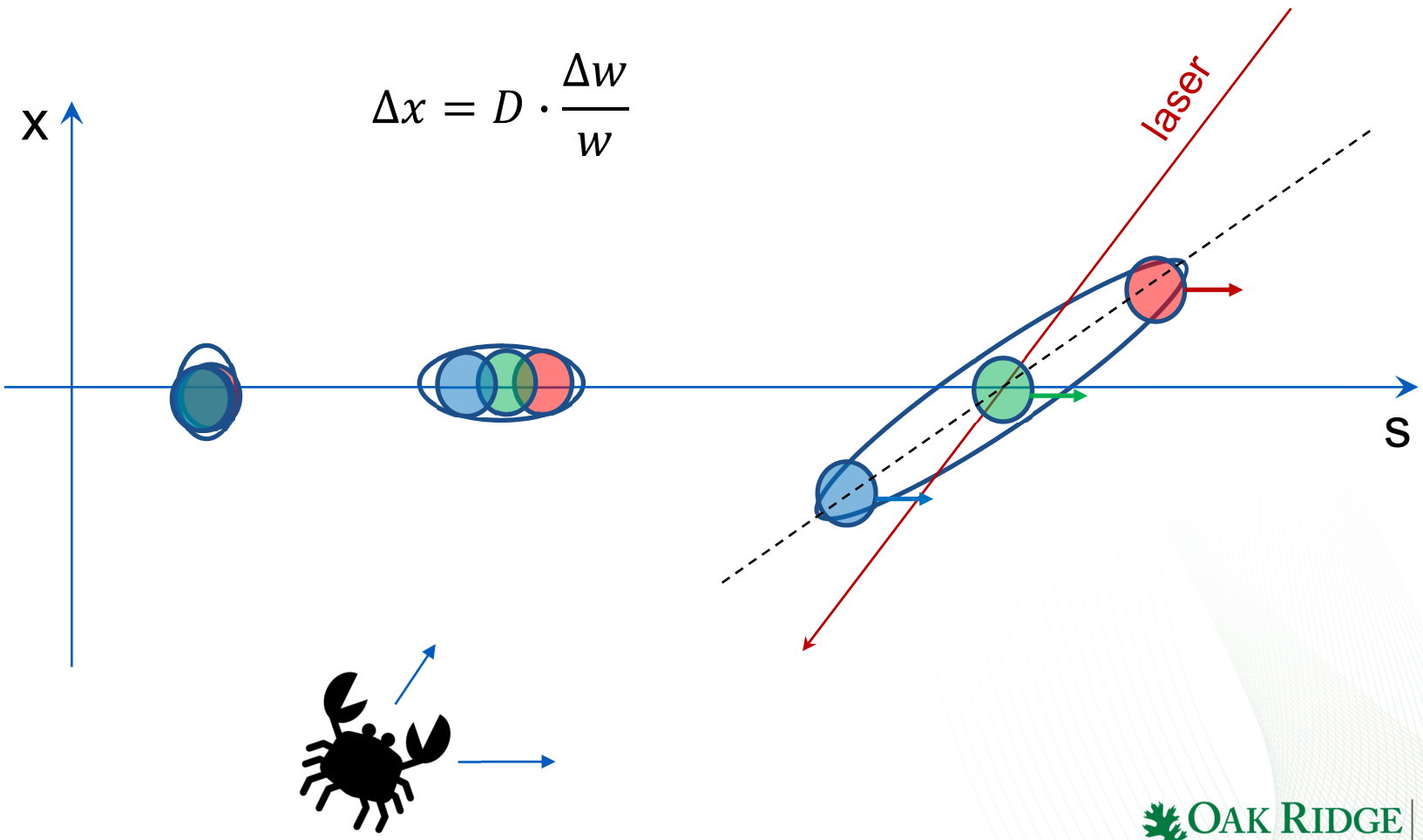
Longitudinal phase-space is strongly correlated at I.P.

Bunch evolution in real space. View from above

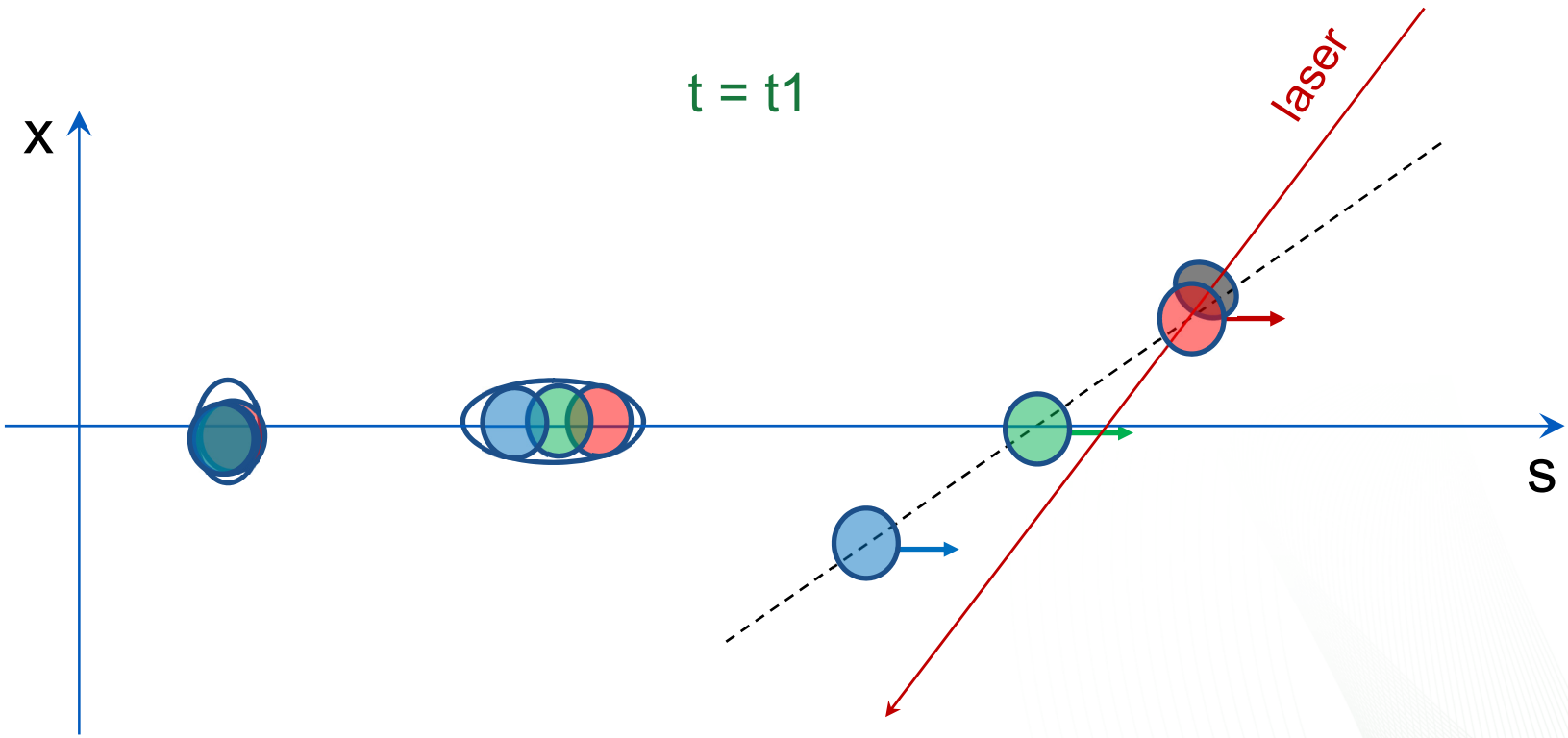


Bunch evolution in real space.
View from above.
Adding dispersion at I.P. allows implementation of ‘crab-crossing’ collision

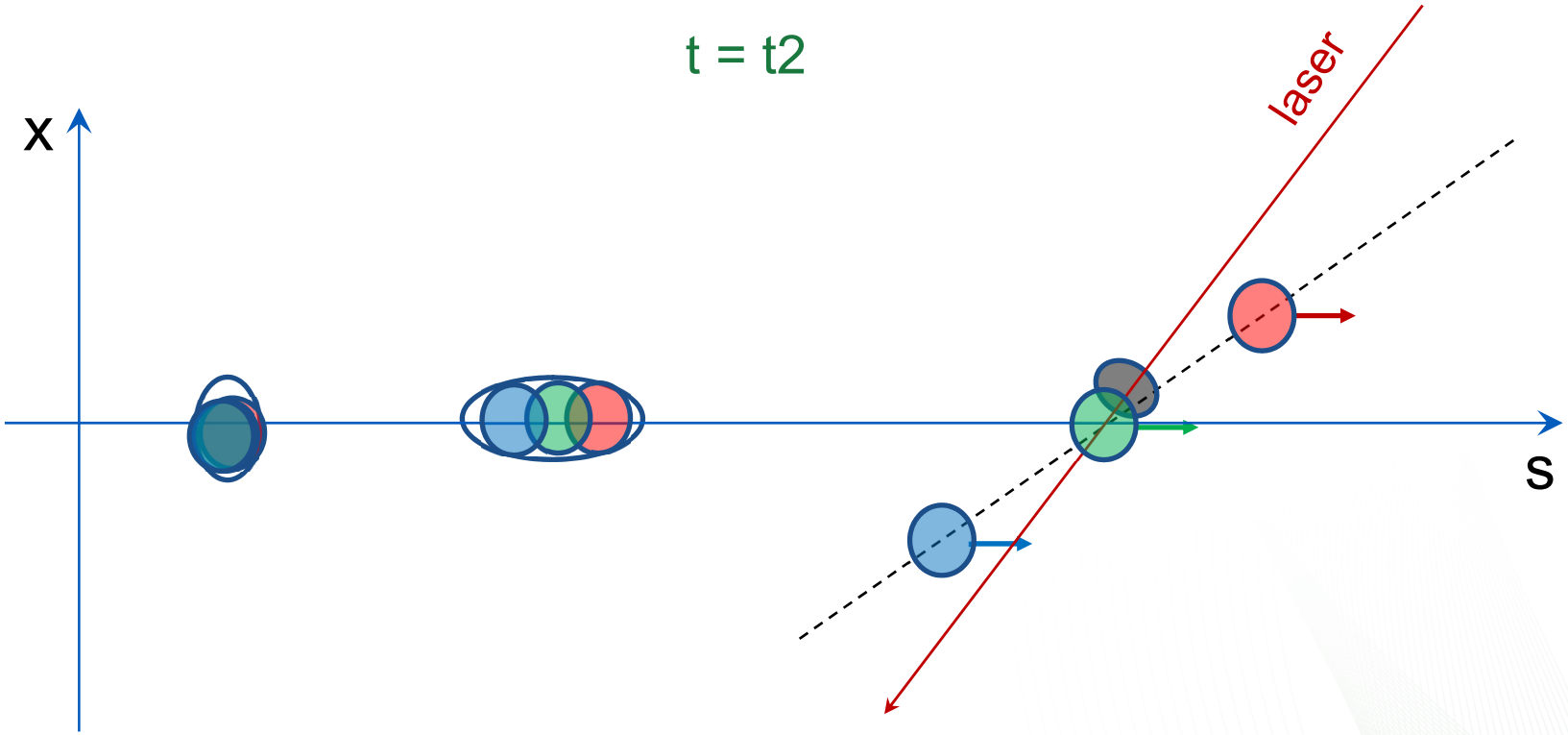
$$\Delta x = D \cdot \frac{\Delta w}{w}$$



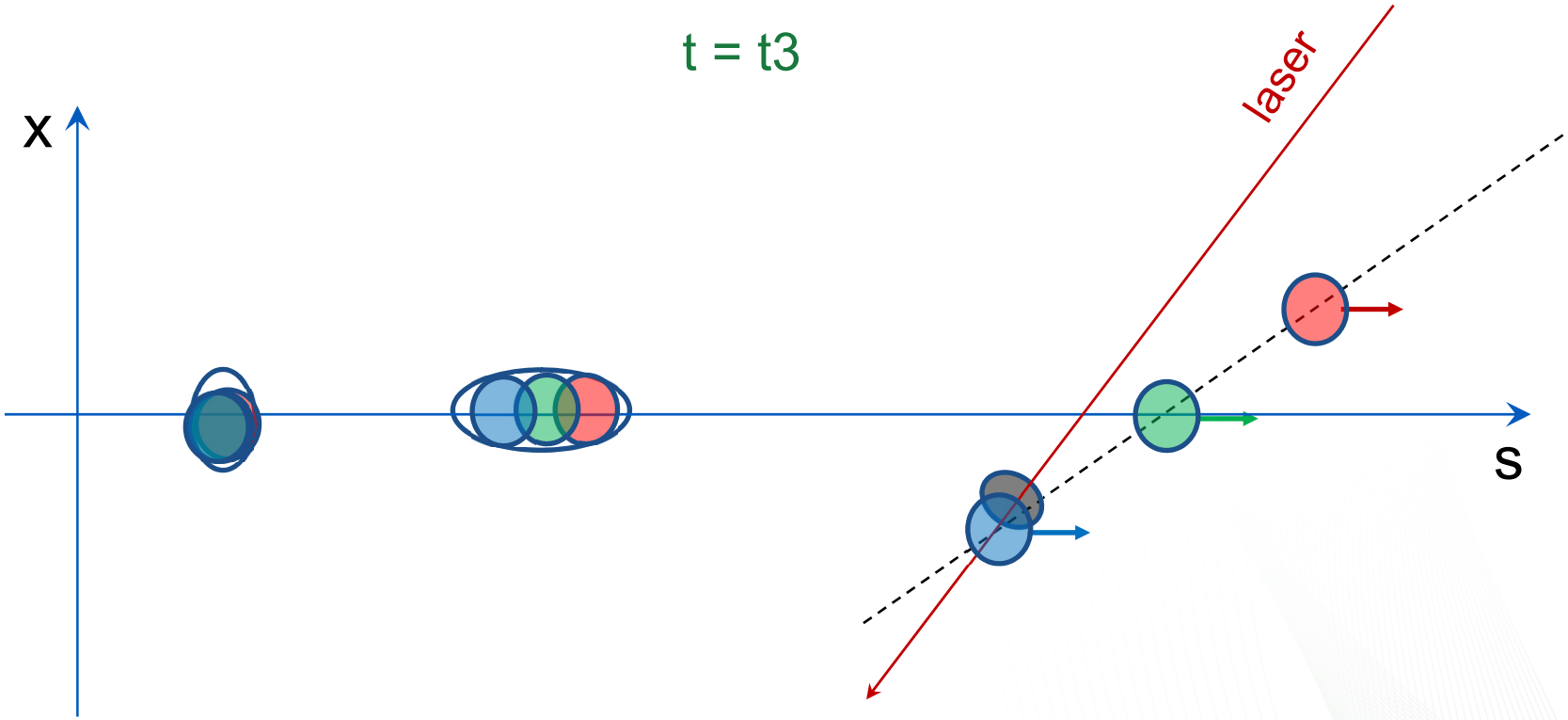
Bunch evolution in real space.
View from above.
Time evolution of interaction with short laser pulse



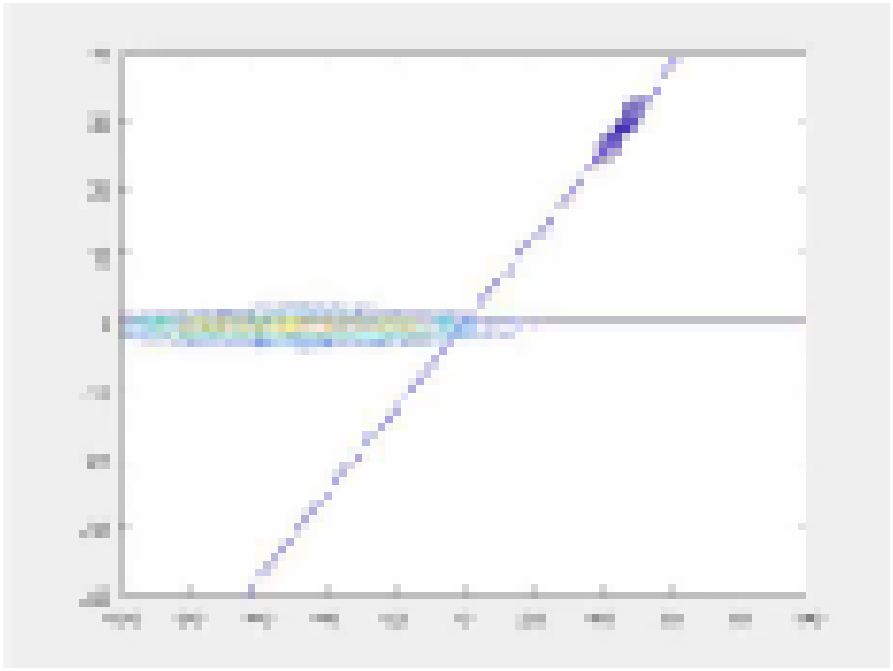
Bunch evolution in real space.
View from above.
Time evolution of interaction with short laser pulse

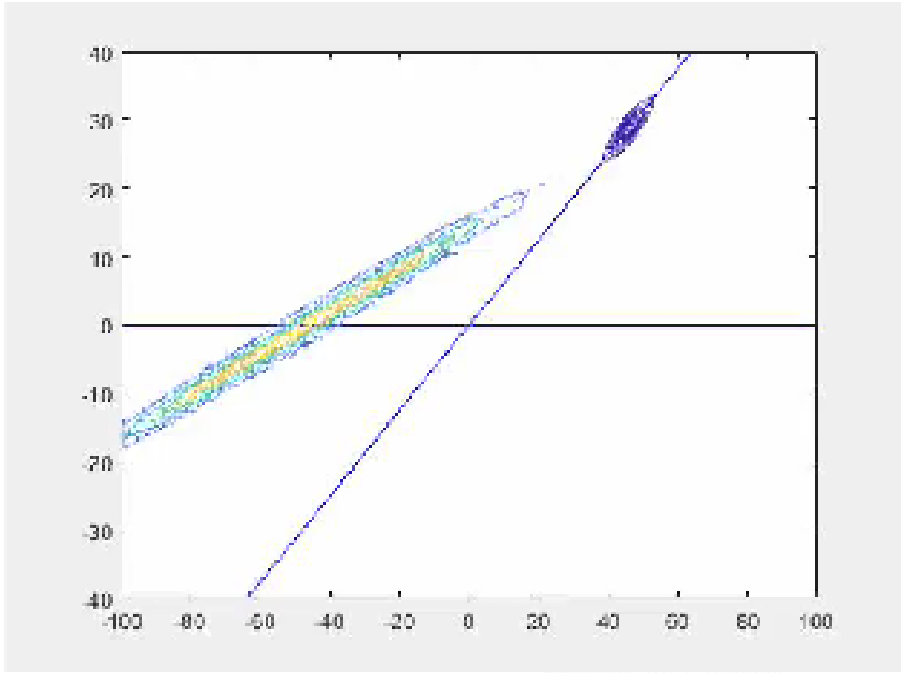


Bunch evolution in real space.
View from above.
Time evolution of interaction with short laser pulse

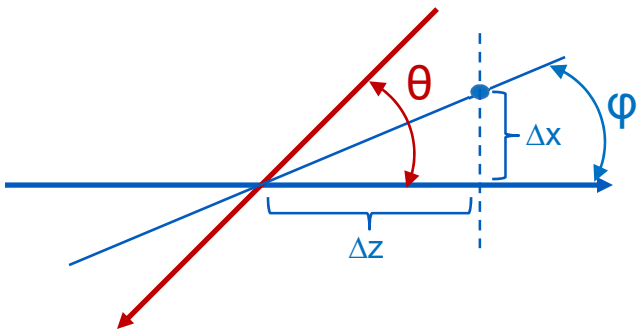


Straight vs. ‘crab-crossing’ collision





Dispersion function requirements are feasible to implement in SNS HEBT



$$\tan\varphi = \frac{\sin\theta}{\beta + \cos\theta}$$

Kinematic relation for synchronous motion

$$\tan\varphi = \frac{\Delta x}{\Delta z} = \frac{D \cdot \Delta w/w}{\Delta z}$$

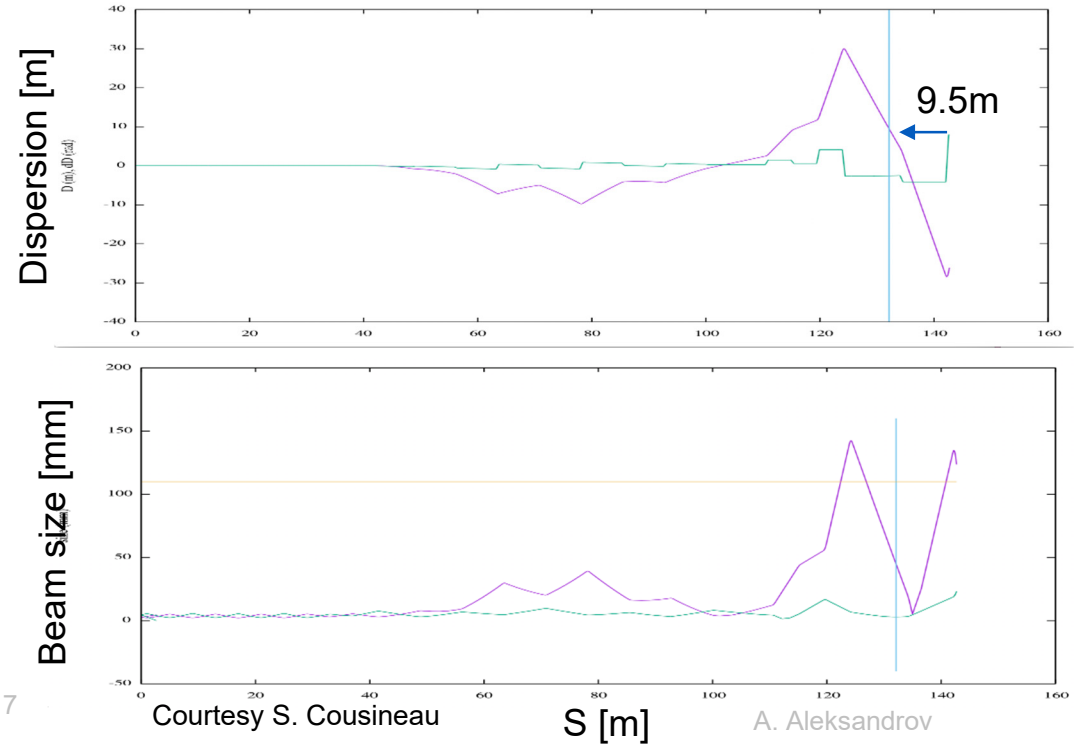
From definition of dispersion function

$$D = \frac{\Delta z}{\Delta w/w}\,\frac{\sin\theta}{\beta+\cos\theta} \approx \frac{L}{\gamma(\gamma+1)}\,\frac{\sin\theta}{\beta+\cos\theta}$$

- PPU laser stripping parameters of W = 1.3GeV, L=170m, θ=23° require D≈4.6m
- Nominal dispersion function in SNS HEBT 6.8m; in SNS Ring 4.0m
  - SNS HEBT magnets have enough margin to achieve required dispersion function

Crab-crossing collision proof-of-principle experiment planning

- Repeat previous 10us pulse experiment at 1GeV with crab-crossing and 10-30mA beam current
  - No modification to existing experiment hardware
  - No longitudinal bunch squeezing
  - New ion beam optics with D≈9.5m at I.P. (W = 1GeV, L=220m, θ=37°)
- About 1-year timeline to resurrect all required equipment



Courtesy S. Cousineau

A. Aleksandrov

Thank you for your attention!

Stay tuned for news from the experiment

Summary

- A laser stripping technology is being developed at SNS
- Reducing ion bunch size allows to reduce laser power requirements
- Reducing longitudinal bunch size at interaction point is difficult for SNS beamline layout
- Crab-crossing collision arrangement allows to mitigate ion bunch expansion in long beamline
- Only modification of ion beam optics within available range of existing magnets is required to implement crab-crossing collision
- Proof-of-principal experiment is being prepared
- Crab-crossing technique can be used in other laser-ion beam applications as well