E-303: Generation and Acceleration of Positrons at FACET-II

FACET-II Science Workshop 2019
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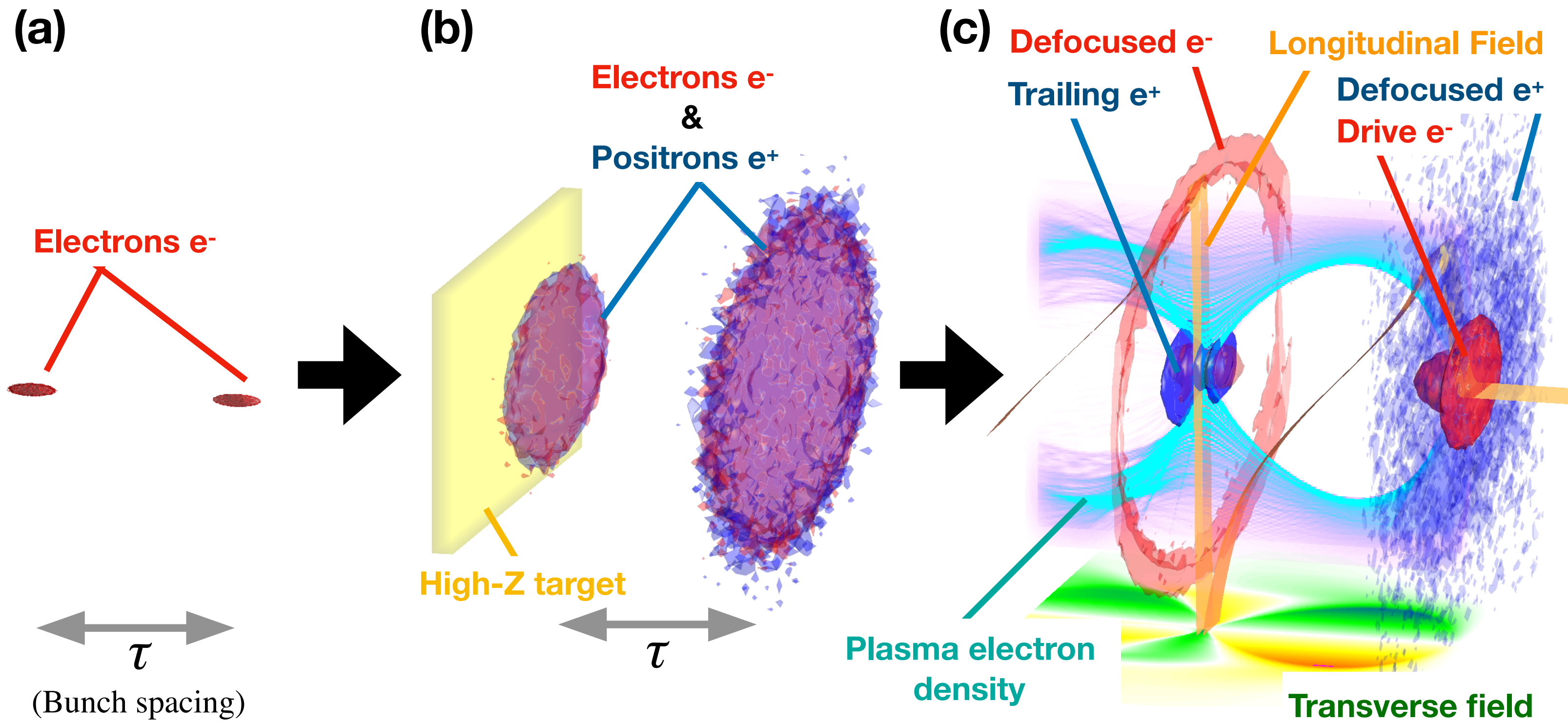
E-303 Experiment Review

Review of E303 PAC proposal.
Expected results.
Milestones to success.

New results and experiment plans

What we have learned lately. PRAB
New physics issues

E303 Positron acceleration experiment using high-Z target

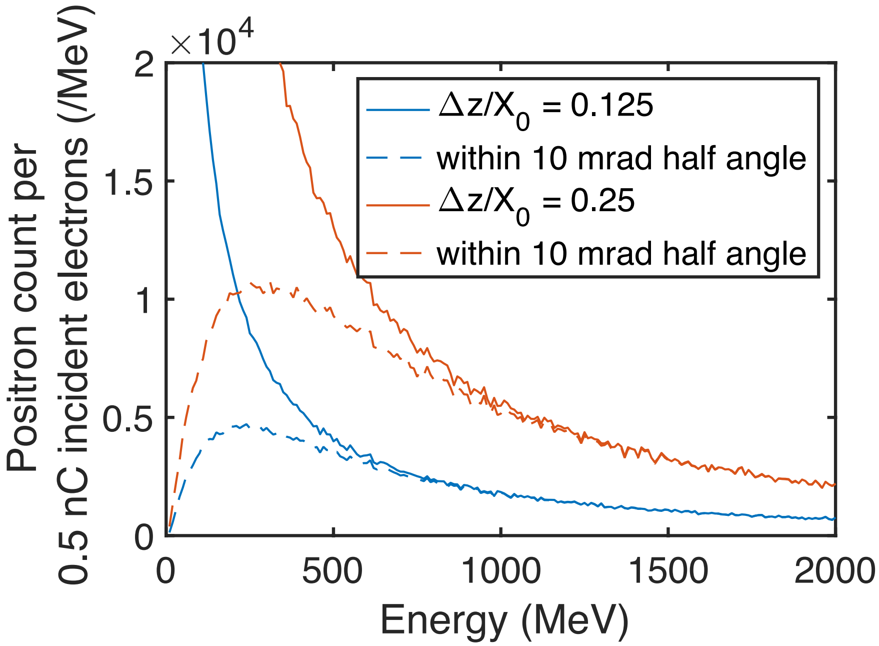


- E303 PAC proposal.
  1. As part of E305, characterize the drive electrons and secondary e^--e^+ pair production. Compare the Geant4 result with the experimental result. Assess target damage.
  2. Combine target with plasma source
  3. Observe the acceleration signature in the positron energy spectrum

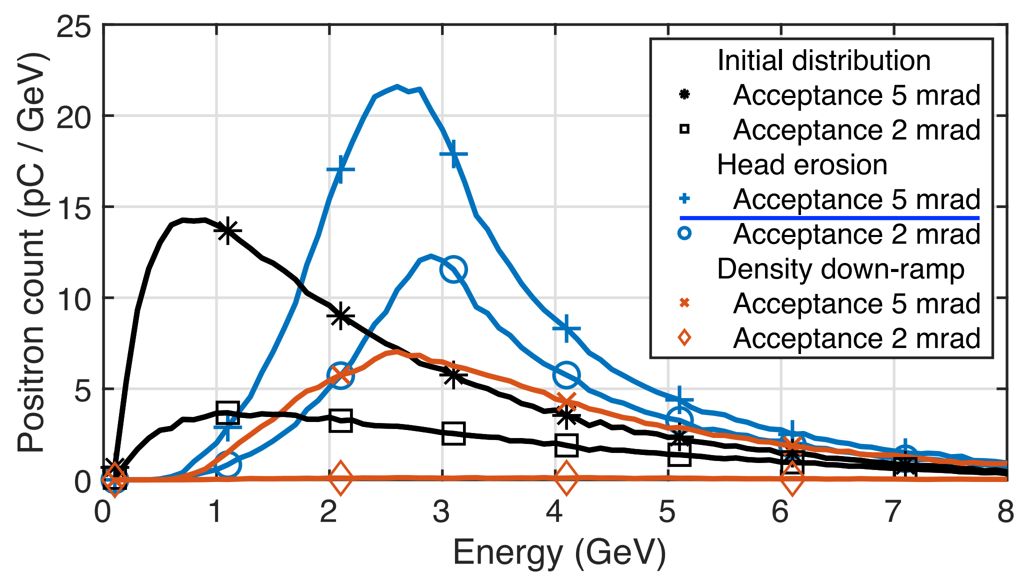
Expected positron yield and energy spectrum

- The initial spectrum is broad.
- Low energy positrons have large divergences
- We would expect to have acceleration signature in 0.5~5.0 GeV

Initial distribution spectrum (solid line) limited by half angle (dashed line)



Example of accelerated spectrum limited by the acceptance



Milestones to success

1. Working E300 (Chan Joshi yesterday)

2. New two bunch parameters for E303

3. Characterization of positrons from Ta foil source (Hiroki Fuji tomorrow)

4. Combine positron source with plasma

5. Demonstrate positron acceleration with e-beam driver

New physics issues

- Up ramp physics
  - Defocusing of trailing electrons before Ta foil
  - Foil blocks lithium vapor flow which creates a step ramp.
- Down ramp physics. Topics of PRAB2019.
  - Defocusing to positrons. Ring beams
  - Head erosion exit
- Physics of foil exit plasma boundary
  - Down ramp trapping and beam loading

Evolving beam parameters

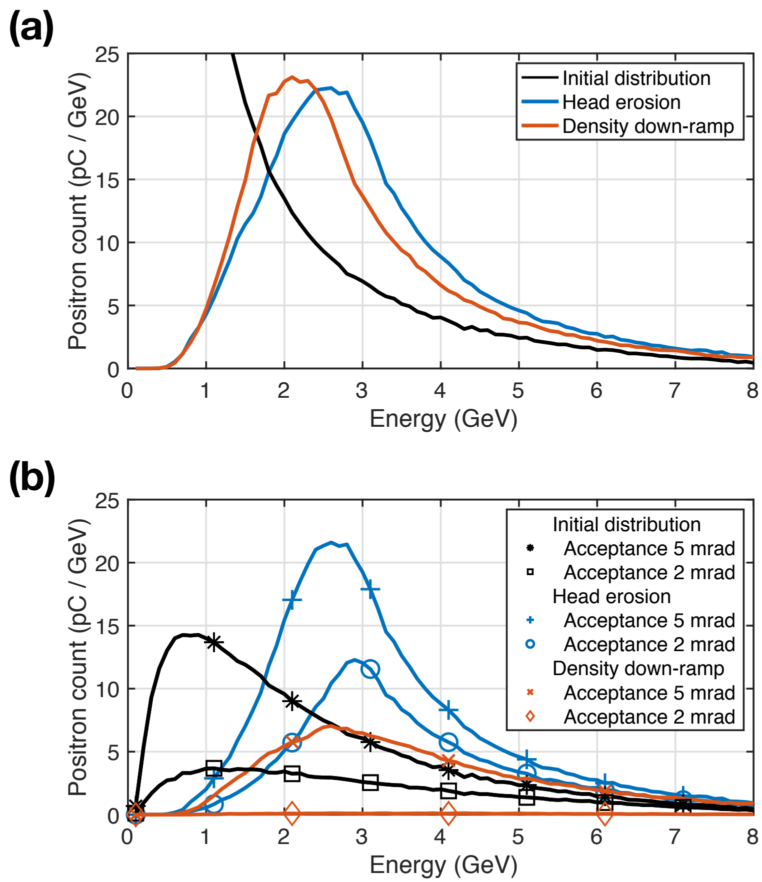
Beam Parameters based on E300 presented at PAC	Beam size σ_r [μm]	Length σ_z [μm]	Normalized emittance [mm-mrad]	Charge [nC] Current kA
Drive electron beam	< 2 .0*	6.5	20	1.6, 30
Trailing electron beam	< 2.0*	6.5	20	0.5, 10

Beam Parameters used for PRAB	Beam size σ_r [μm]	Length σ_z [μm]	Normalized emittance [mm-mrad]	Charge [nC] Current kA
Drive electron beam	2.2	6.5	20	1.0, 20
Trailing electron beam	2.2	6.5	20	0.5, 10

***Beam size focused by density up ramp**

Reduced current to produce more linear wake

Expected Results from PRAB



Positron beam quality dependence on Λ

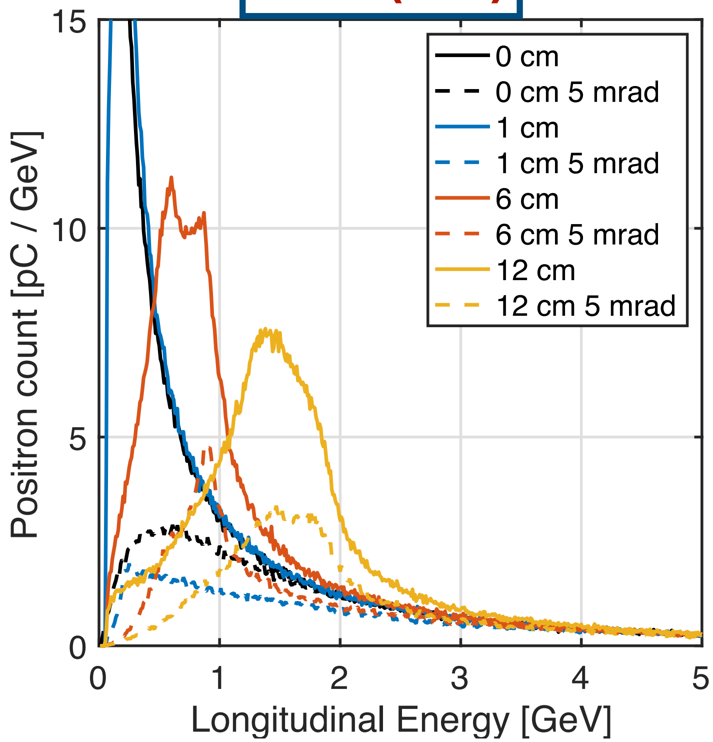
Normalized charge per unit length

$$\Lambda = \frac{4}{(2\pi)^{1/2}} \frac{eN}{\sigma_z/c} \frac{e}{mc^3}$$

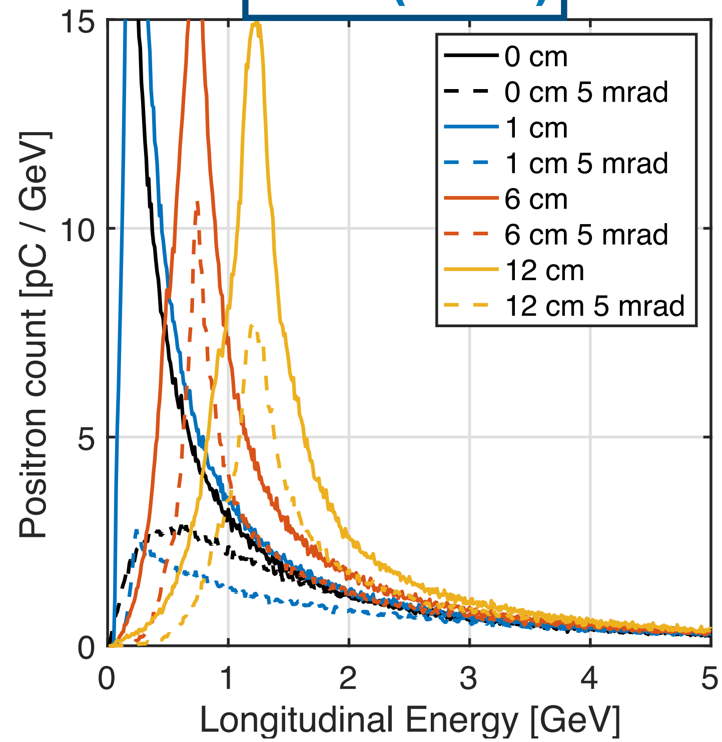
	PRAB	Set 1	Set 2
σ_z, σ_r (um)	6.5, 2.2	15, 4	22, 4
Drive charge [nC]	1.0	1.6	1.6
Trail charge [nC]	0.5	0.5	0.5
Λ	4.3	3.0	2.1

Positron spectrum simulated for the uniform plasma density of n_0=5.0x10^{16} cm^{-3}
After Propagating in uniform plasma for 12 cm.

Set 1 (Λ=3)



Set 2 (Λ=2.1)



New beam parameter requirements

- E303 requires different beam parameters than E300. Can we run longer bunches?
- Initial emittance needs to be small to make σ_r ~ 2um at foil.
- Foil thickness determines final emittance and head erosion limited energy gain.
- We can reduced beam current to produce more linear wake and therefore a more narrow energy spread.

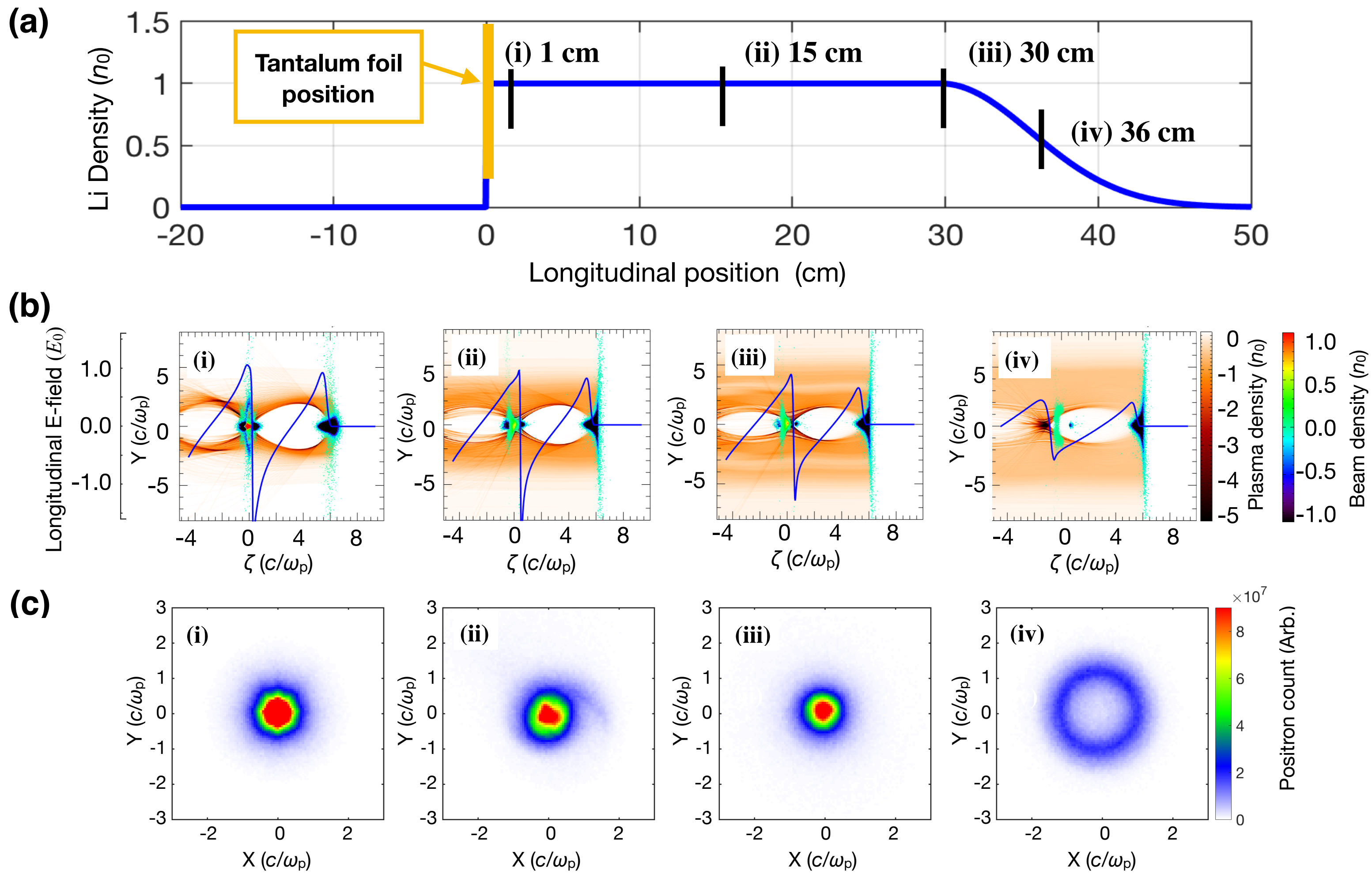
Diagnostic requirements

- Same as E300
  - Charge, BPM’s, OTR’s and wires,
  - SYAG
  - EOS
  - TCAV
- Dump table diagnostics.
  - LFOV, Cherenkov. Positron energy 0.5-5.0 GeV
- Pair spectrometer (aka Coffin chamber Lanex screens if available)

Plasma exit effects.
Topic of PRAB special issue

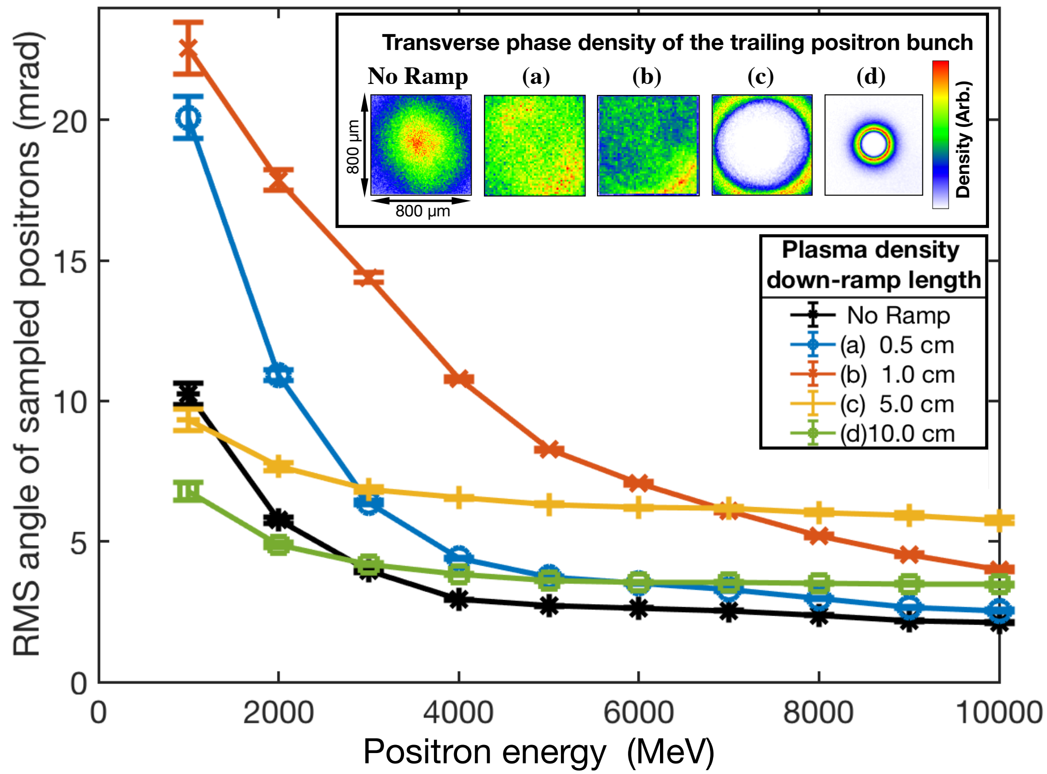
- Down ramp exit and defocusing
  - Creates ring beam
  - Low divergence depending on phase
- Head erosion exit comparison

Plasma defocusing in down ramp creates positron ring beam



PRAB2019

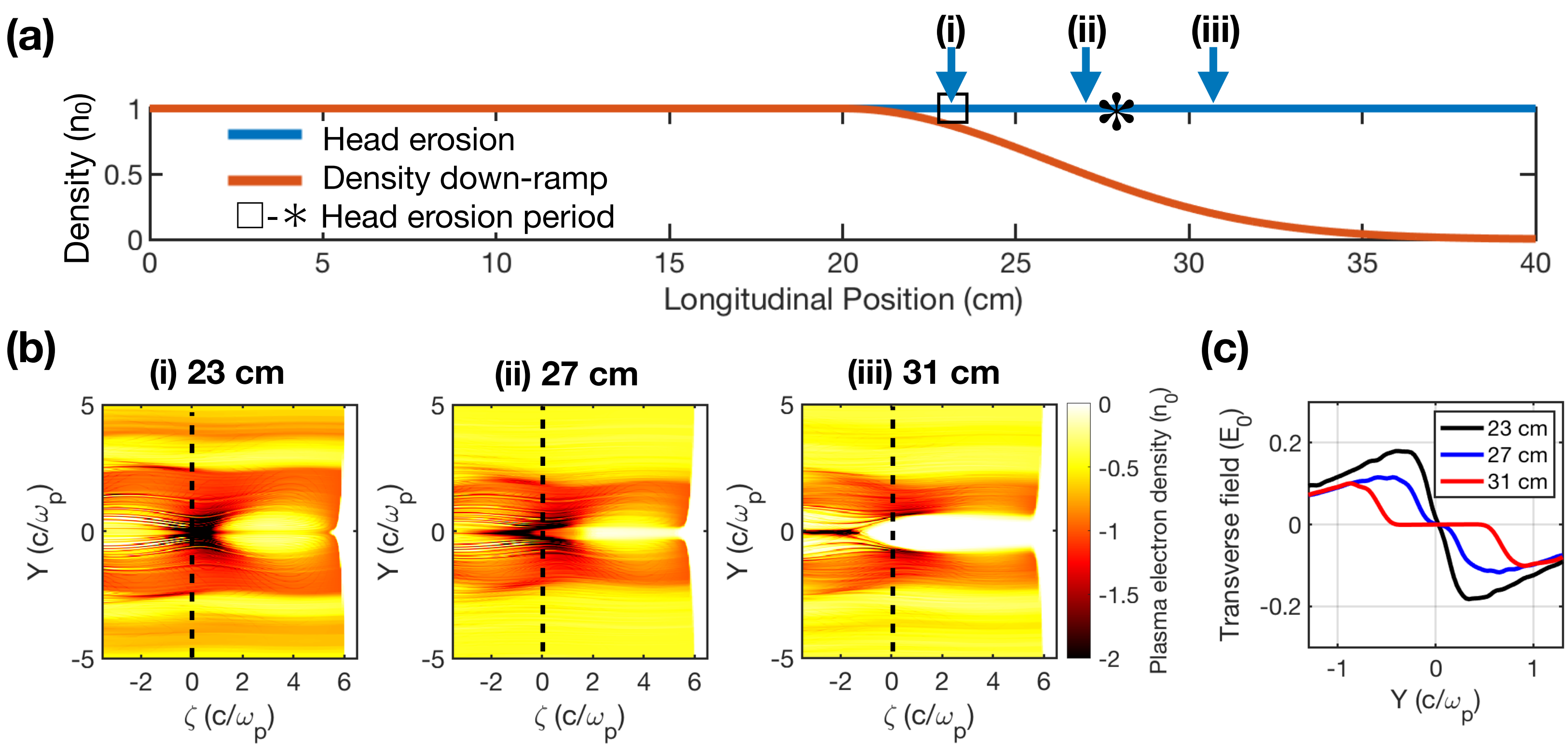
Positron ring can still have low divergence and be transported to dump



Beam ring and divergence depends on exit phase

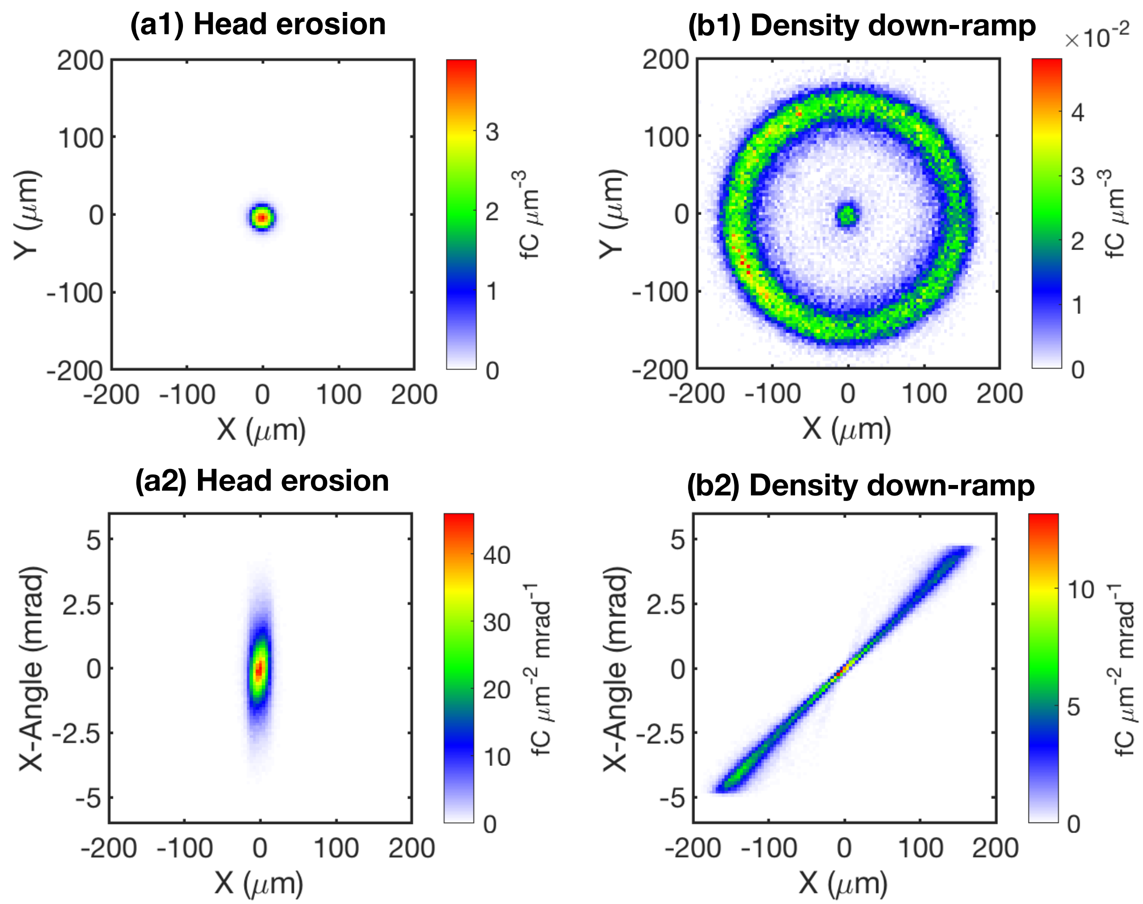
PRAB2019

Exit with head erosion, Blue



PRAB2019

Exit, Head erosion verses density down ramp



PRAB2019

Up ramp and beam foil boundary

- Electrons can defocus in wake before reaching foil.
    - If electrons are at positron focusing then they defocus in approximately one centimeter.
- Trapping effects at the foil plasma exit boundary.
    - Beam loading

Sorry for the big note here

The density up ramp is very useful for focusing the beam to a small spot. But, as electrons move up the ramp the bubble shortens and the trailing electrons “move” into a defocusing phase just before reaching the foil. To prevent this a step foil boundary is required. Without the density ramp we will need a small beta and strong quadrupole focusing to reach the required spot size of ~3 um.

Plasma foil boundary.
In the 2 bunch set up, the first bunch makes a high density plasma in the foil and there is large density step at the foil exit. Preliminary results show large down ramp trapping and beam loading. Down ramp trapping could load the wake reducing Ez and also extend the bubble could defocus the positrons. Near the back surface, the bubble shape is different and has large B field.

These foil plasma boundary effects could be studied more easily by placing the Ta foil on a hydrogen gas cell. Although head erosion limits the energy gain this arrangement can access more parameter space than using a Ta foil with lithium oven.

Ramps studied by X. Wang Phd Thesis

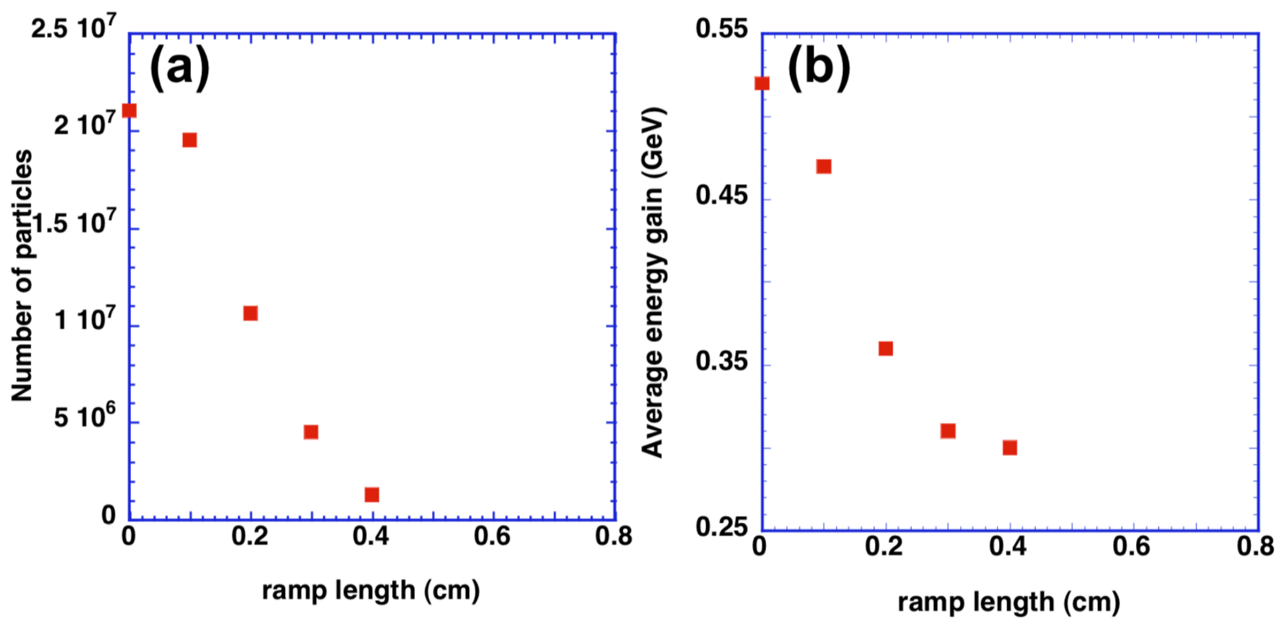


Figure 38: The number of positrons in the beam load (a), the average energy (red square) (b) of the beam load versus the ramp length at a propagation distance of 12cm.

These issues can be best studied in an H2 filled gas cell

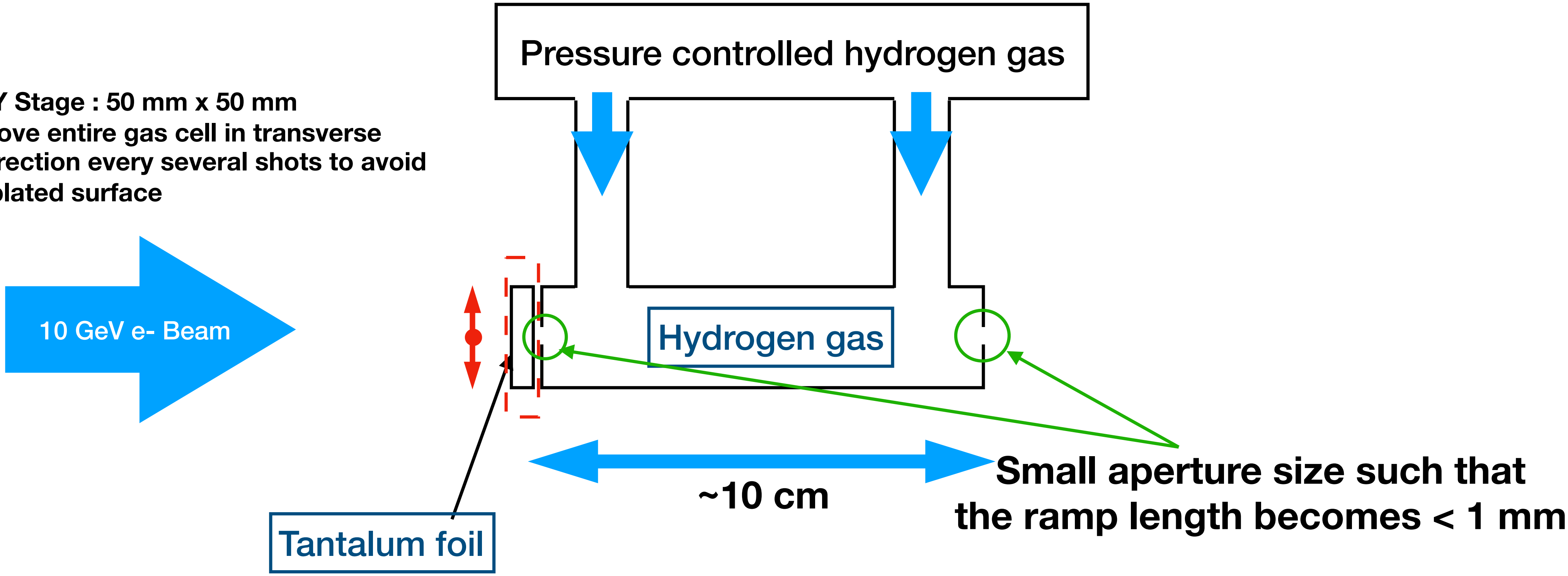
Up ramps and down ramp effects can be studied by varying the cell apertures.

The down ramp trapping issue can be studied single bunch. Electron defocusing should be observable.

Head erosion will limit the plasma length
Thin Ta target to control emittance

Hydrogen gas cell with small aperture

XY Stage : 50 mm x 50 mm
Move entire gas cell in transverse direction every several shots to avoid ablated surface



Allow gas leak at the each end of gas cell
Block down-ramps by Titanium at the exit.

Pros : Least effort to make the target movable and replaceable.

Cons : We would still see some effect of density ramp.
Higher ionization potential compared to Li

Run plan year 1?

Run plan for year 1 will mainly be positron production measurements (details tomorrow H. Fuji)

Study foil plasma boundary effects. This can be done with single bunch static fill gas cell