Notes on the design of the FAST proton LEBT

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Outline

- Beam specifications
- What is known about FAST/HINS proton source
- Possible versions of the FAST LEBT and comparison

- Result of reading papers, multiple discussions, and Jean-Paul’s simulations

Beam parameters at the FAST proton line exit

- From A. Romanov’s e-mail on March 2, 2020

Parameter	Nominal	Min	Max	Units
Energy	2.5	2.4	2.8	MeV
Current	5	1	10	mA
Pulse length	2	1	10*	µs
Repetition frequency	0.1	1/60	1	Hz
Transverse emittance, rms n, both planes	0.24**	0.1	0.3	µm
Energy spread, rms***	0.5	0.2	0.6	%

  – * Might be better to increase to 50 µs
    - Boundary of low risk for thermal stress
  – ** Noticeable lower than the worst scenario from the ion source
  – *** Might be not very relevant for the LEBT/RFQ discussion since a bunching cavity is expected in MEBT

HINS results

- Most relevant details are in V. Scarpine's report
  - APC talk, 2011, https://indico.fnal.gov/event/4654/
    - Also in Tam's dissertation
  - LEBT
    - 40% p, 30% H2+, 30% H3+ (slide 10)
    - ε_rms_n ~0.5 µm @7 mA of p; dirty profiles (slide 11)
      - Increases linear with current, 0.2 µm @1.5 mA
      - Larger than requirements for IOTA injection
  - MEBT
    - Maximum reported current of 11 mA; clean profiles;
    - ε_rms_n ~0.1 µm @6 mA; nearly constant after ~10 µs
      - Slide 20: ε_rms_g ~ 1.5 µm, βrel=0.073
      - Emittance (n) is by 5 times lower than measured in LEBT
        - May contradict to some later measurements

HINS duoplasmotron

- No reliable data on parameters at the ion source exit
  - HINS simulations were based on numbers found in papers of the end of 1980s
    - E.g. ε_rms_n =0.47 µm @22 mA, α=-3, β=0.49 m

- LINAC’00 paper for the same ion source: ~0.5 µm @92 mA
  - https://www.slac.stanford.edu/econf/C000821/TUD16.pdf
    - (2.4 -3) π mm*mrad for 95% norm.; $\varepsilon_{95\%} = 6 \cdot \varepsilon_{rms}$

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Proton source at FAST

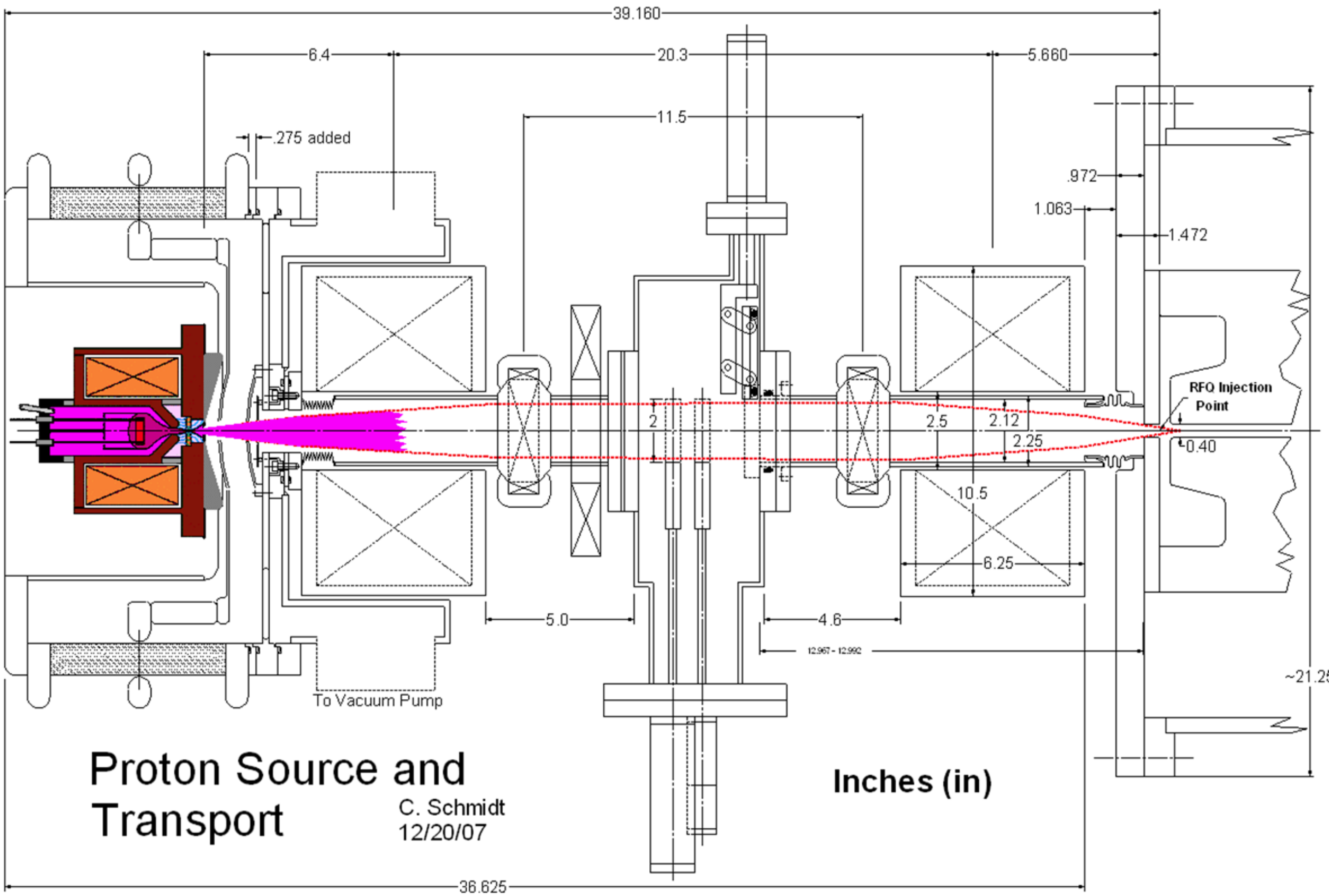
- The same as at HINS: Ion Source, 1st solenoid, RFQ
  - An extraction electrode modulator is being added
- Completely different MEBT
- The LEBT may be different or similar
  - 2nd solenoid of a larger size
  - Additional elements might be added
- Reasons to thinks about deviation from HINS
  - IOTA needs only ~1 µs. If a 0.3 ms pulse from IS is accelerated, to 2.5 MeV, it may create a thermal shock where it is lost
    - Not clear how short can be the RFQ pulse
  - A bend in LEBT would be a critical device and proton separator
  - Improving neutralization might be beneficial

Proton source at FAST: versions

- Three versions are being considered
  - “1”: Mainly replicate the HINS LEBT
  - “2”: more complicated line
    - + 30^{o} bend
      - with a Faraday Cup to measure the Ion Source current
  - “3”: even more complicated, “2” with
    - Chopper upstream of Sol2
    - Two EID (electrically isolated diaphragms)
      - One to separate areas with neutralization and without
      - One in front of the RFQ

Version 1

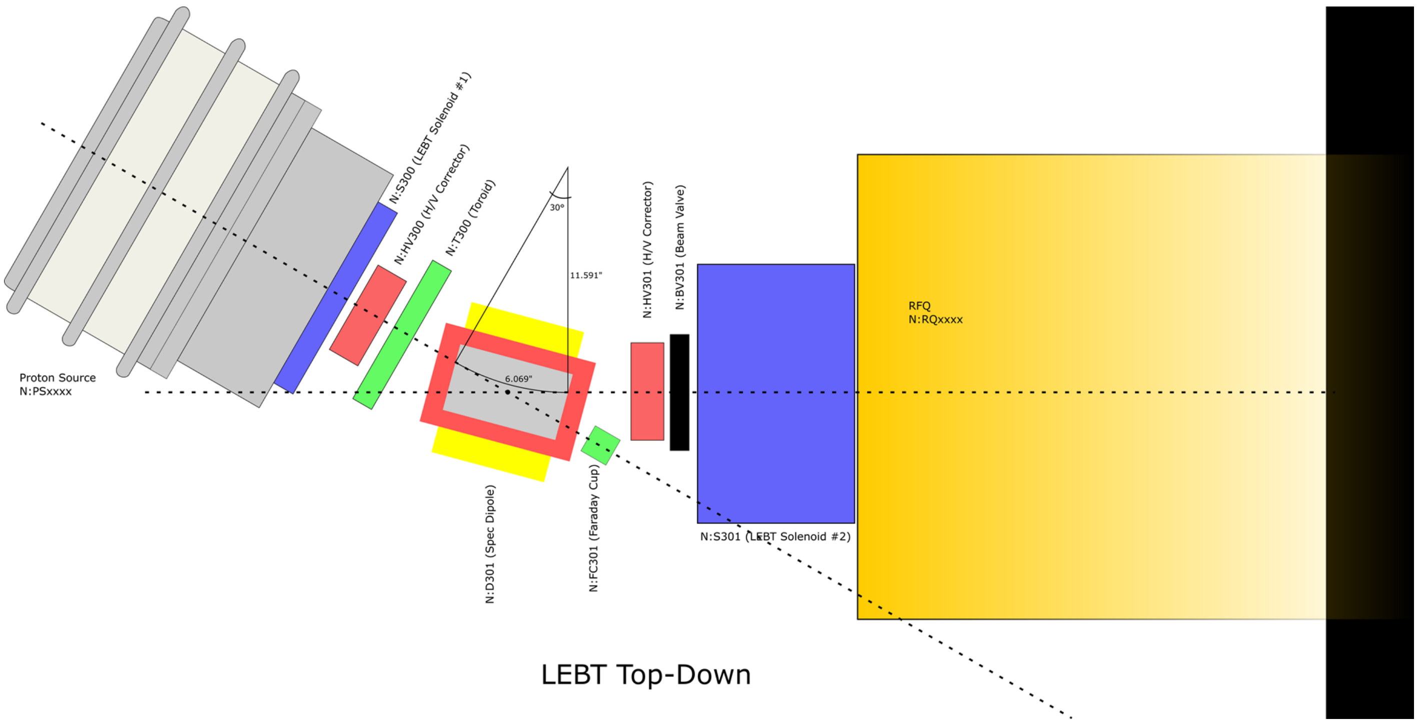
- With replacement of Sol 2



C. Schmidt's HINS LEBT schematic. The beam is obviously shown as an illustration.

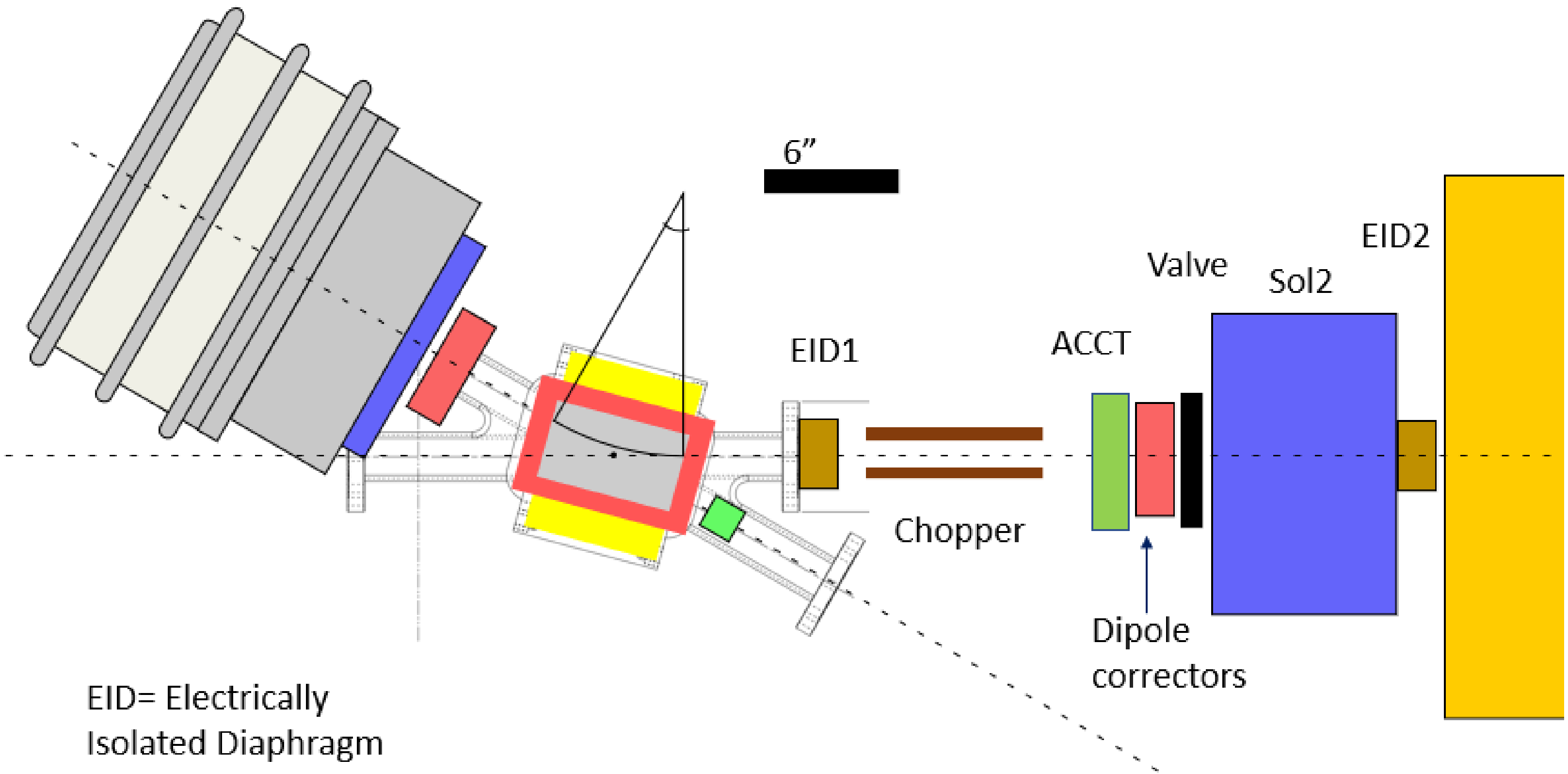
Version 2

- Chip's suggestion to install a bend
  - As a critical device
  - To remove early H2+, H3+



Version 3

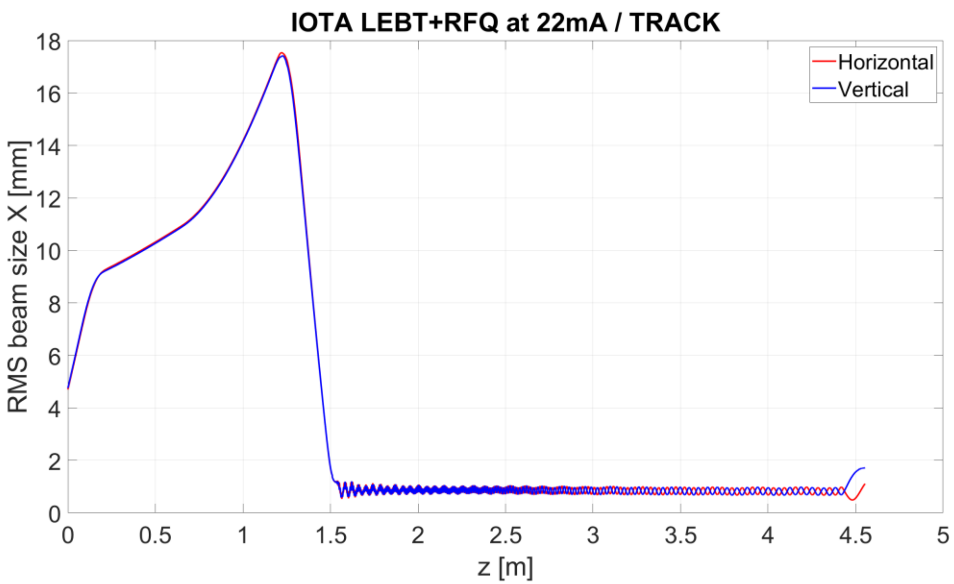
- Chopper to define the pulse length and EIDs to control neutralization, similar to PIP2IT LEBT
  - Design of the chopper and EID may be based on PIP2IT's



EID= Electrically
Isolated Diaphragm

Simulation of Version 3

- J.-P. Carneiro, TRAC, 21-Feb-2020
  - Initial conditions are the same as P. Ostroumov used for HINS simulations
    - ε_rms_n =0.47 µm, I= 22 mA (the worst scenario)
  - For this longer LEBT, no solution for transport with full space charge
  - With upstream portion neutralized, the beam is still large



Rms envelope. J.-P. Carneiro, TRAC. The upstream portion (~65 cm) is with zero space charge, and 22 mA in the downstream portion. The initial distribution is Water Bag.

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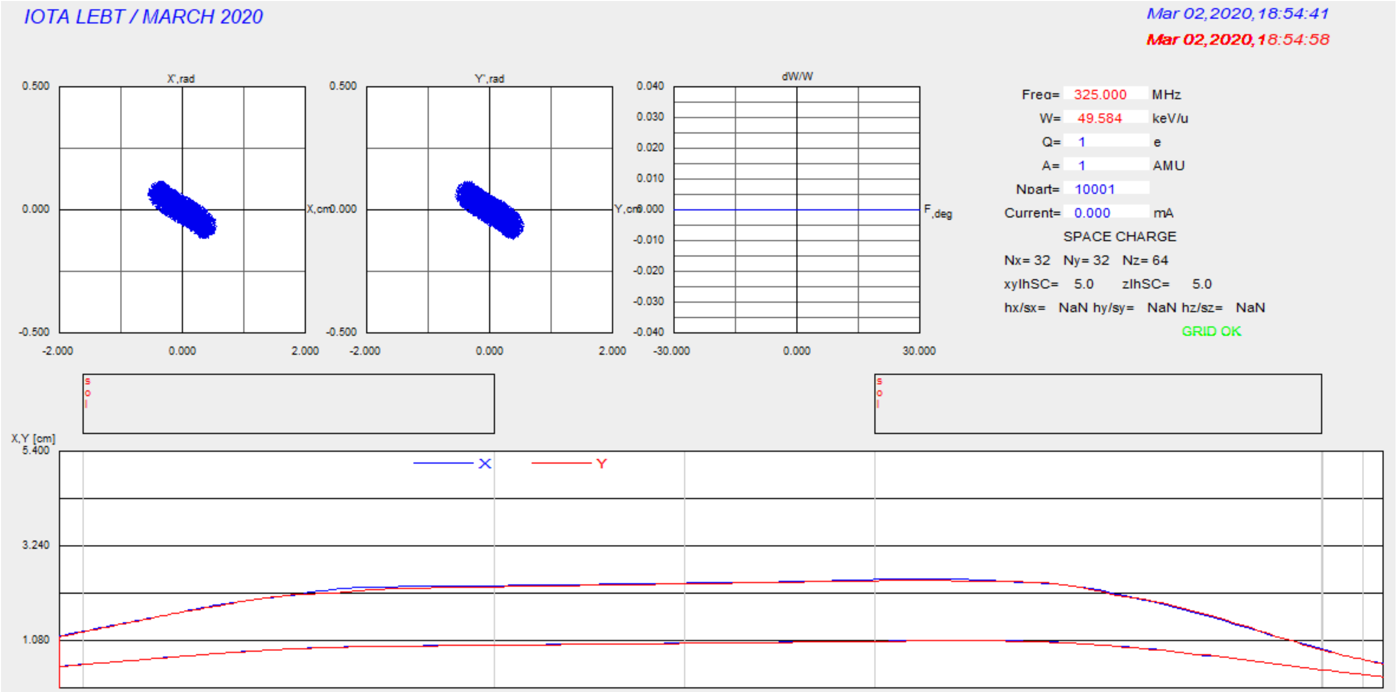
Version 3, partially neutralized

- Beam size is too large to have a chopper
  - No easy solution to make a chopper without significant scraping (U=10 kV, L=150 mm). Note that relative separation between envelops of the beam passed and beam removed is ~1/ ε_rms
- Difficult to pass through the existing dipole magnet (2” gap).
- No proper matching into the RFQ
  - 50% of the beam is lost at the entrance diaphragm (10 mm ID)
- Reasons for troubles:
  - Increased distance between RFQ and center of Sol 2
  - High space charge from 22 mA
  - Very high initial emittance
  - Unknown initial distribution
- While in reality the beam parameters might be more favorable, it feels too risky to proceed with this version

Version 1

- In the "HINS" version, assuming full neutralization, the beam looks reasonable
  - A big uncertainty with initial conditions and possible degree of neutralization
    - Predicts scraping already in the first solenoid



Rms and full envelopes for WB initial distribution. J.-P. Carneiro, TRAC. No space charge. ε_rms_n=0.47 μm.

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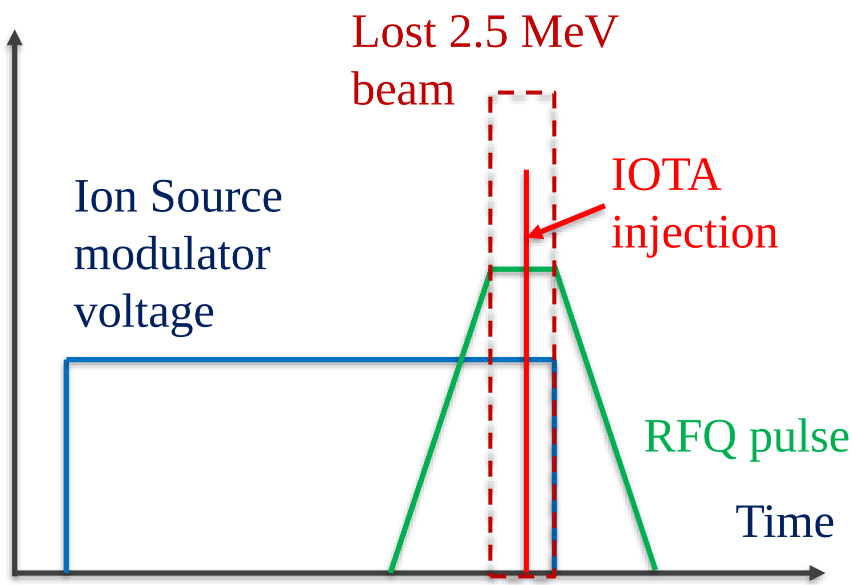
Discussion

- Version 3 seems to be too risky considering big uncertainties with the initial beam properties
  - Also, more expensive
- Version 2 (with bend)
  - Not clear how beneficial is the bend
    - Seems to create an aperture restriction
  - Beam profiles reported from the HINS MEBT are clean; no indications of contamination by H2+, H3+
    - Likely lost in LEBT and RFQ
- Version 1 (replicating HINS): the most likely to work
  - one still might consider adding an EID to improve neutralization
  - Need to understand options with a critical device
    - Can one use interlocking of the RFQ power?

Possible timing

- The issue of a possible thermal stress may be alleviated by shifting the RFQ pulse with respect to IS's
  - Its duration can be likely decreased to <50 μs
    - In Vic's talk, ~30 μs seems to be enough for parameters to settle
      - Slide 19



If to go with Version 1

- Does it need a pumping station in between?
- Can an EID be installed inside Sol2?
- Can the beam pipe inside Sol2 be made significantly larger?
  - E.g. 3” ID vs 1.25”
  - Requires new dipole correctors upstream of Sol2
- Any diagnostics to add? (e.g. scrapers from PIP2IT)