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Warm Front End Concept

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PIP-II Machine Advisory Committee
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Outline

- Warm front end performance requirements
- Design concept
- Required R&D

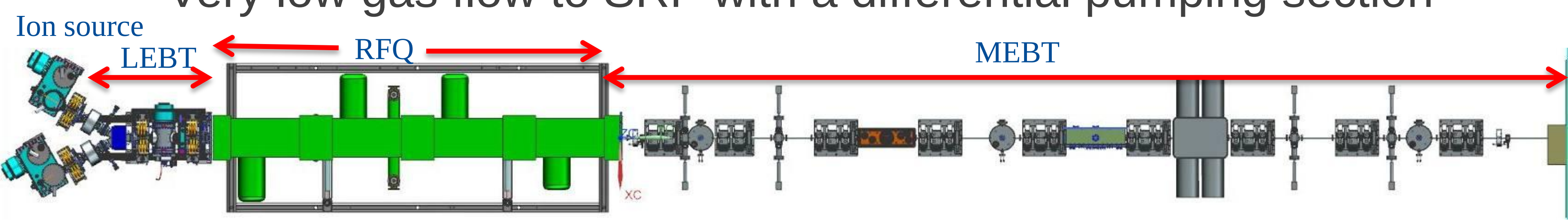
- Note
  - Since last MAC
    - many elements of the front end moved from ideas to technical designs or hardware
    - No significant changes in scheme or specifications
  - Therefore, this talk is to remind about main concepts as an introduction to reports by L. Prost and J. Steimel
    - Where technical details will be presented

Warm front end performance requirements

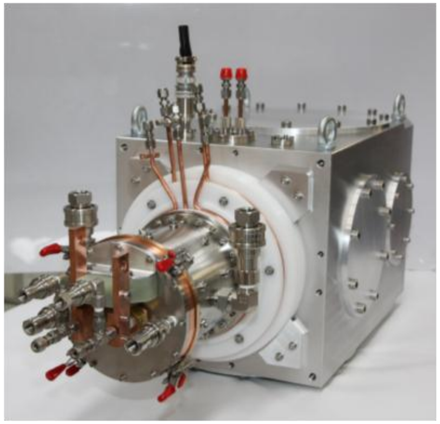
- PIP-II: 800 MeV SRF linac constructed of CW-capable accelerating structures and operated initially at 1% duty factor
- The warm front end prepares H- beam optimized for Booster injection and provides capabilities for future CW operation
  - Output energy 2.1 MeV
    - Below neutron production and high enough to mitigate space charge effects up to 10mA
  - Peak beam current up to 10 mA (from μs to CW)
    - 5 mA nominal; 4 mA in macropulse for Booster injection
  - Bunch-by-bunch selection capability
    - For into-bucket injection to Booster and for future CW multi-user operation
  - Output rms emittances: $\varepsilon_{\perp}$<0.23 μm, ε_{L}<0.31 μm
  - Proper vacuum, tails, and bunch extinction management

Design concept

- Ion source(s), LEBT, RFQ, MEBT
  - SRF (HWR cryomodule) directly follows MEBT
  - Long MEBT to accommodate the chopping scheme
- Attention to factors that may determine reliability and uptime
  - Two ion sources
  - Low gas flow to RFQ with a long LEBT
  - Proven-design RFQ
  - Low particle loss in RFQ
  - System of scrapers in LEBT and MEBT
    - Passive and active parts of MPS
  - Very low gas flow to SRF with a differential pumping section



Ion source



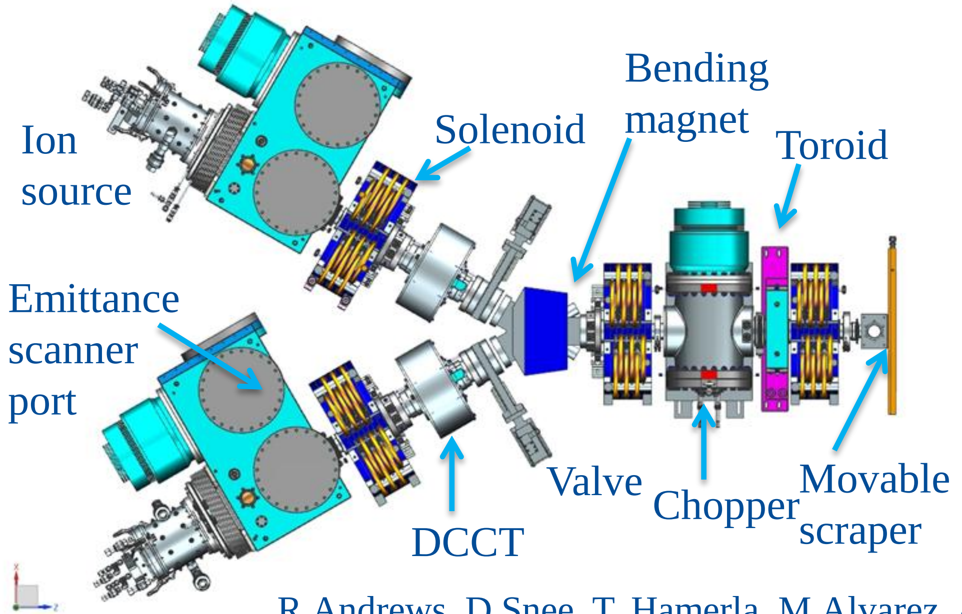
- DC H- source
  - 30 keV, ≥10 mA
  - Emittance ≤0.14 µm rms norm. (preferably ~0.1)
- PXIE: ion source from D-Pace, Inc
  - Satisfies all PIP-II requirements
    - Current can be modulated with extraction electrode voltage
  - Filament-driven, volume, no Cs
  - Life time ~300 hrs
- Alternative schemes are being developed by various groups
  - May provide a longer life time with the same other parameters
  - Using the LEBT scheme with two sources might be rational at longer life time as well
- Capability to service the ion source with accelerator operating would be highly beneficial

Low Energy Beam Transport (LEBT) requirements

- Purposes:
  - Beam matching, differential pumping, fast beam turn-off for machine protection, beam chopping, transverse tails scraping
- Requirements
  - Output emittance <0.18 µm rms norm. (30 keV, 5 mA)
  - Gas load to RFQ $\leq 10^{-4}$ Torr· l/s
  - DC or pulse operation
    - Up to 60 Hz for commissioning purposes; from 1µs to DC
    - Preferably, Twiss parameters changes during the pulse are small
  - Tools to control the beam current and position at the RFQ entrance
- Switching dipole magnet upstream of 2nd solenoid
  - Two ion sources, removal of neutrals and protons, personnel protection

LEBT concept

- Two identical legs
  – Ion source
  – differential pumping chamber with a port for emittance scanner
  – Solenoid
  – DCCT
  – Valve

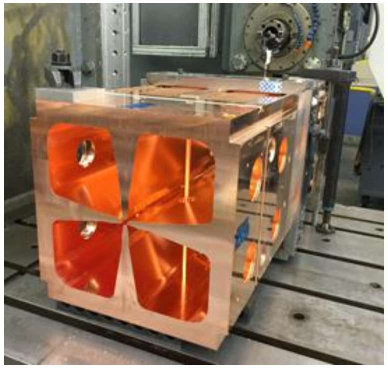


R.Andrews, D.Snee, T. Hamerla, M.Alvarez, A. Chen

- Partially neutralized transport
  – Un-neutralized transport downstream of Solenoid #2 may be a better solution for pulsed operation.
    - Vacuum at the ion source and RFQ differ by $\sim 10^3$. Hence, neutralization time changes from µs to ms.
    - Allows chopper between solenoids
  – See L. Prost’s report for details

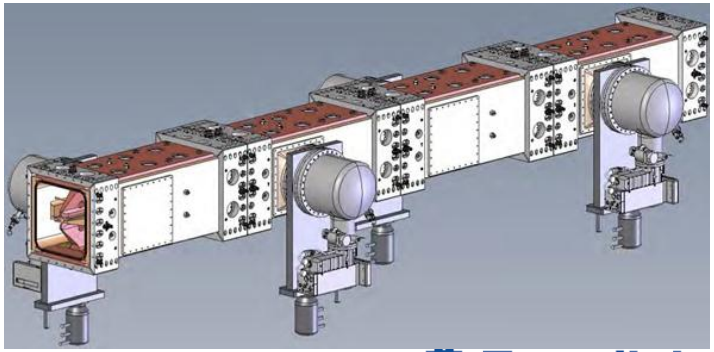
RFQ concept

- 2.1 MeV, 162.5 MHz CW RFQ
  - Expect to use the LBNL design
    - Detailed RF and beam simulations have been performed
      - output emittances $\varepsilon_\perp$<0.2 µm, ε_L<0.28 µm
    - The concept has been successfully implemented at IMP (Lanzhou, China) with protons
      - 10 mA CW delivered to (and through) cryomodules
      - 95% transmission reported
  - PXIE RFQ based on this concept is in production
    - See J. Steimel's report for details



- Expect good vacuum and low beam loss (<5%)
  - Should be beneficial for reliability

Images courtesy of LBNL

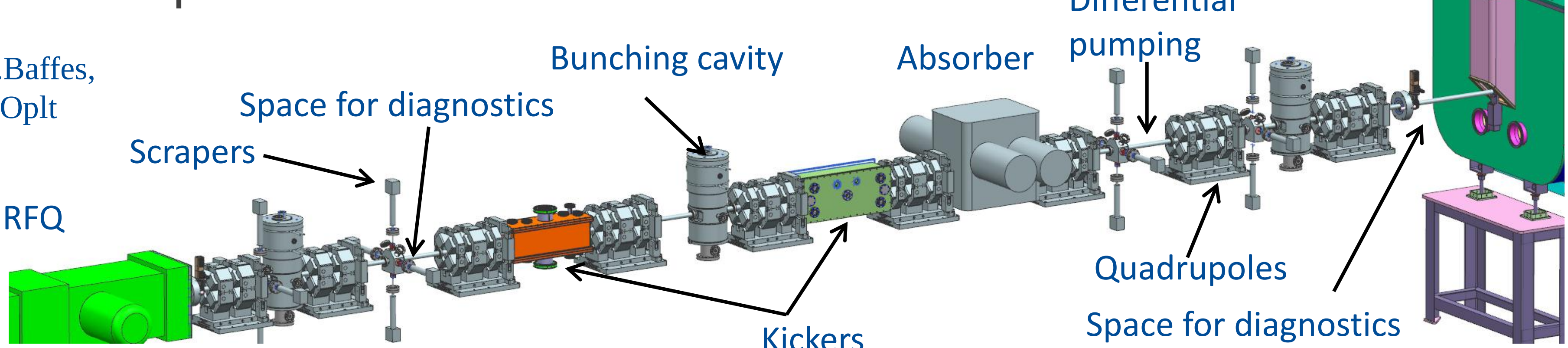


Medium Energy Beam Transport (MEBT) requirements

- Purposes:
  - Beam matching, differential pumping, transverse tails scraping
  - Bunch-by-bunch selection
- Requirements
  - 2.1 MeV, up to 10mA CW (5 mA nominal), <0.23 µm rms norm.
  - Compatibility with SRF
  - Bunch-by-bunch selection
    - Arbitrary bunch structure
    - Loss of pass-through bunches < 5%
    - Bunch extinction to ≤ 10^{-4}
  - Diagnostics to characterize the beam out of RFQ and to HWR

MEBT concept

- Chopping system (next slide)
- Transverse focusing with 2 doublets and 7 triplets
  - First short section for beam matching; 1.14 m period after
    - Determined by space required for kickers and absorber
- Longitudinal focusing with 3 bunching cavities
- Last ~2 m are dust-free, UHV
  - H_2 pressure at MEBT – HWR interface < $2\cdot10^{-10}$ Torr
- Scrapers



C.Baffes, S.Oplt

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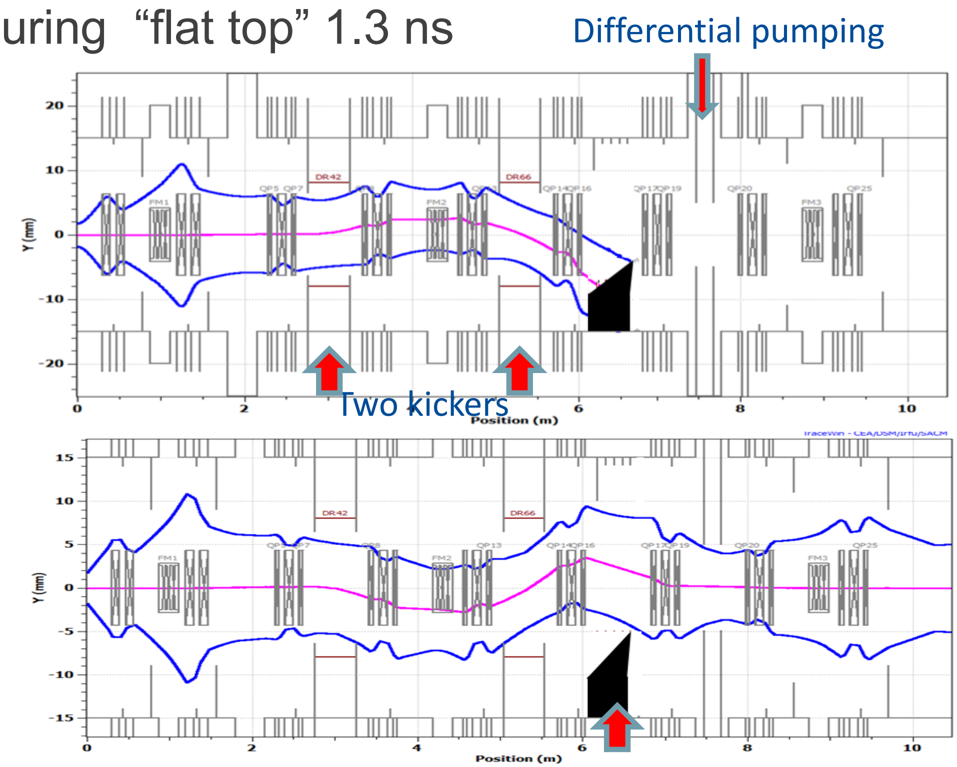
Chopping system

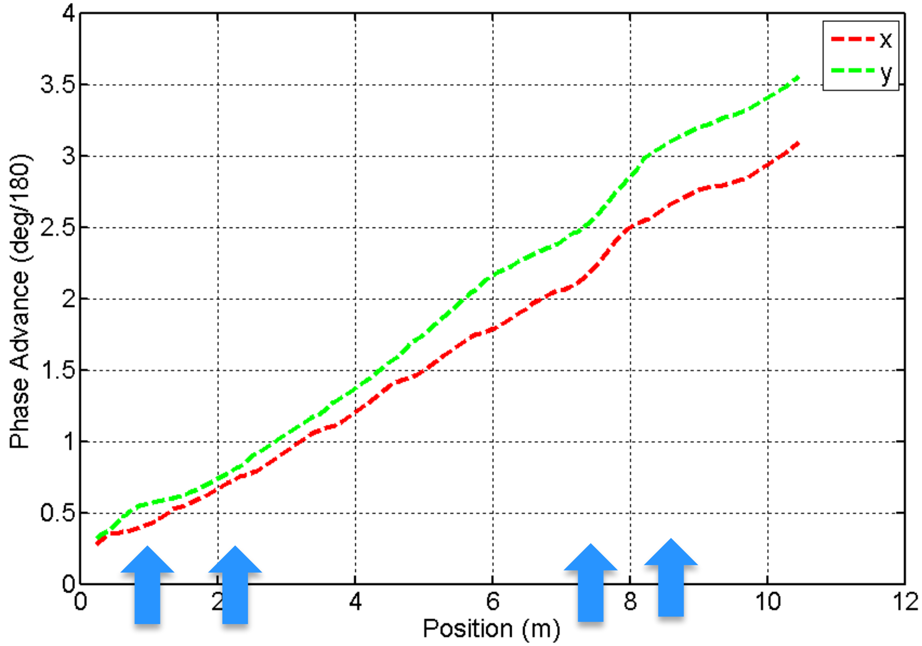
- Two kickers in sync + absorber
  - Two broadband travelling-wave kickers separate bunches by 6σ
    - 0.5 m plate length, 16 mm gap
    - Each plate potential changes by 500V between passing and removing states
      - Voltage variation <±25V during "flat top" 1.3 ns
      - 6.15ns between bunches
  - Absorber is rated for 21 kW
    - 0.5 m length plate
    - Beam comes at 29 mrad
      - To decrease the power density to 17 W/mm^2
  - Will be tested at PXIE



3σ Y beam envelopes for removed (top) and passing (bottom) bunches.
A. Saini

Scrapers

- 4 sets of scrapers, 4 jaws each
  - Independently movable, electrically isolated
  - Scraping, machine protection, beam size estimation
- With proper phase advance in pairs, all high transverse action particles can be removed
  - First pair makes the main scrape (~1%) and protects kickers
  - Downstream pair removes tails created by chopping and protects SRF



Phase advance along MEBT at 5mA and position of scrapers. A. Saini

Modes of the front end

- Beam for tuning: safe pulses
  - start with 5 µs single pulses; increase the pulse frequency to 60 Hz and pulse length to CW
    - 5 µs is enough for diagnostics and relatively safe for SRF
    - Ion source produces long enough pulses to reach neutralization in the upstream LEBT; LEBT chopper cuts the needed length; MEBT chopper trims the front of the pulse train if needed
      - Optimum for vacuum management
- Booster injection: 0.6 ms, 20 Hz pulses
  - The same combination of modulating and chopping
  - MEBT choppers creates a bunch sequence optimal for longitudinal painting of the Booster buckets
  - Not harmonically related RF systems for SC Linac and Booster
    - Lock of bunch chopper to Booster RF with LLRF
- CW: future multiple-user operation
  - MEBT choppers creates the required bunch sequence

R&D topics

- To be addressed by PXIE
  - LEBT with low emittance growth compatible with chopping
  - Reliable CW RFQ
  - Bunch-by-bunch selection in MEBT
  - Compatibility of high-power deposition in MEBT absorber with SRF several meters downstream

- Making the entire line reliable, predictable, tunable