Medium Energy Beam Transport Design for PXIE

A. Shemyakin, V. Lebedev, S. Nagaitsev
Fermilab

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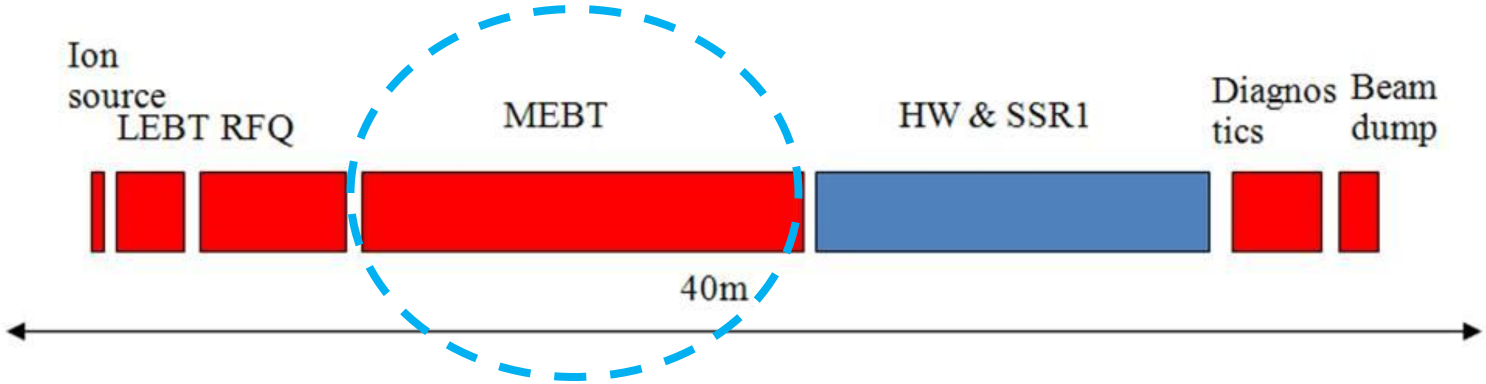
Project X collaboration meeting

PXIE MEBT



- Functions of MEBT
  1. Form the bunch structure required for CW Linac
  2. Match optical functions between RFQ and SRF
  3. Include tools to measure the properties of the beam coming out of RFQ and sent to SRF
  4. Protect SRF from accidents

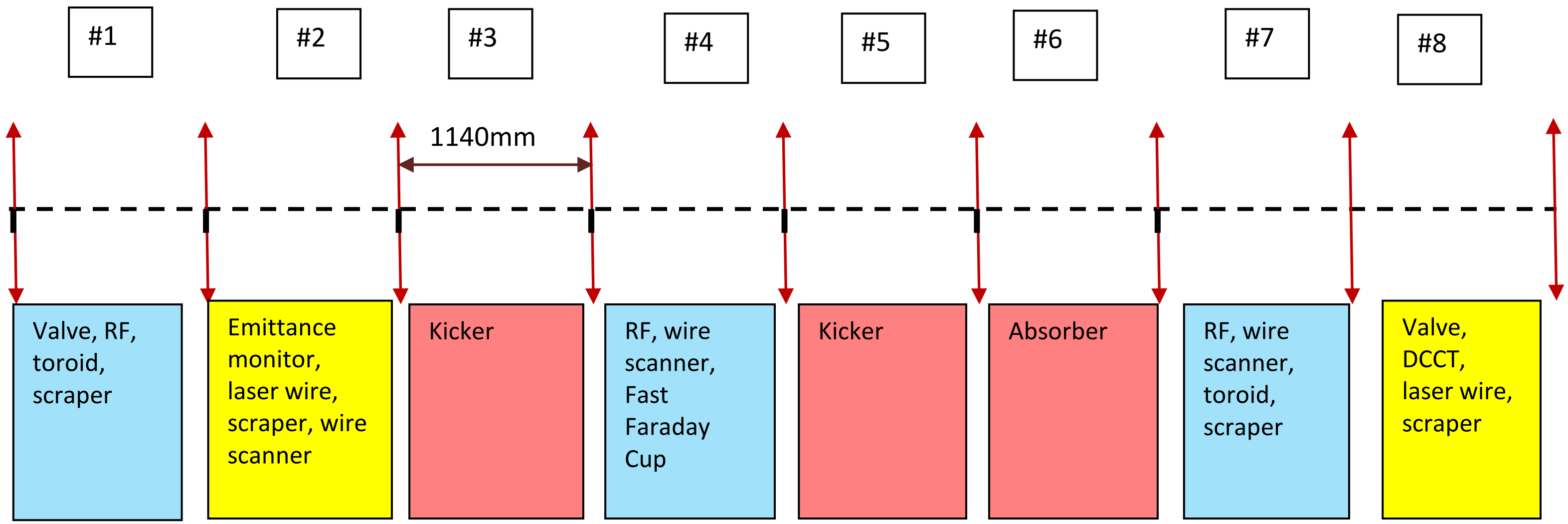
- Technically driven schedule
  - Jan 2012 – MEBT design layout is complete
  - May 2013 - all MEBT components are designed
  - May 2014- MEBT is assembled

Functional specifications for PXIE MEBT

Parameter	Unit	Value	Tolerance	Comment
Ion type		H-		
Output energy	MeV	2.1		Same as input
Operational input beam current	mA	1 - 10		
Nominal input beam current	mA	5		
Max frequency of bunches	MHz	162.5		
Average output current	mA	1	≤ 1	
Particles per bunch	E8	1.8	0.4 – 4	30 pC/bunch, nominal
Bunch selection: Pass-through or remove[&]		Bunch by bunch		Programmable
Residual charge of removed bunches *	Relative	$< 10^{-4}$		Relative to pass-through bunches
Beam loss of pass-through bunches *	Relative	< 5%		
Nominal transverse emittance*[#] (n, rms)	mm·mrad	0.27	0.1- 0.27	
Nominal longitudinal emittance*[#] (rms)	keV·nsec	0.8	≤ 1	
Beam displacement	mm	0	< 0.5	At the flange of HW cryomodule
Beam angle	mrad	0	< 0.5	
Scraping to transverse emittance[#] (n, rms)	mm·mrad	< 0.05		Pulse mode, 10 W average beam power

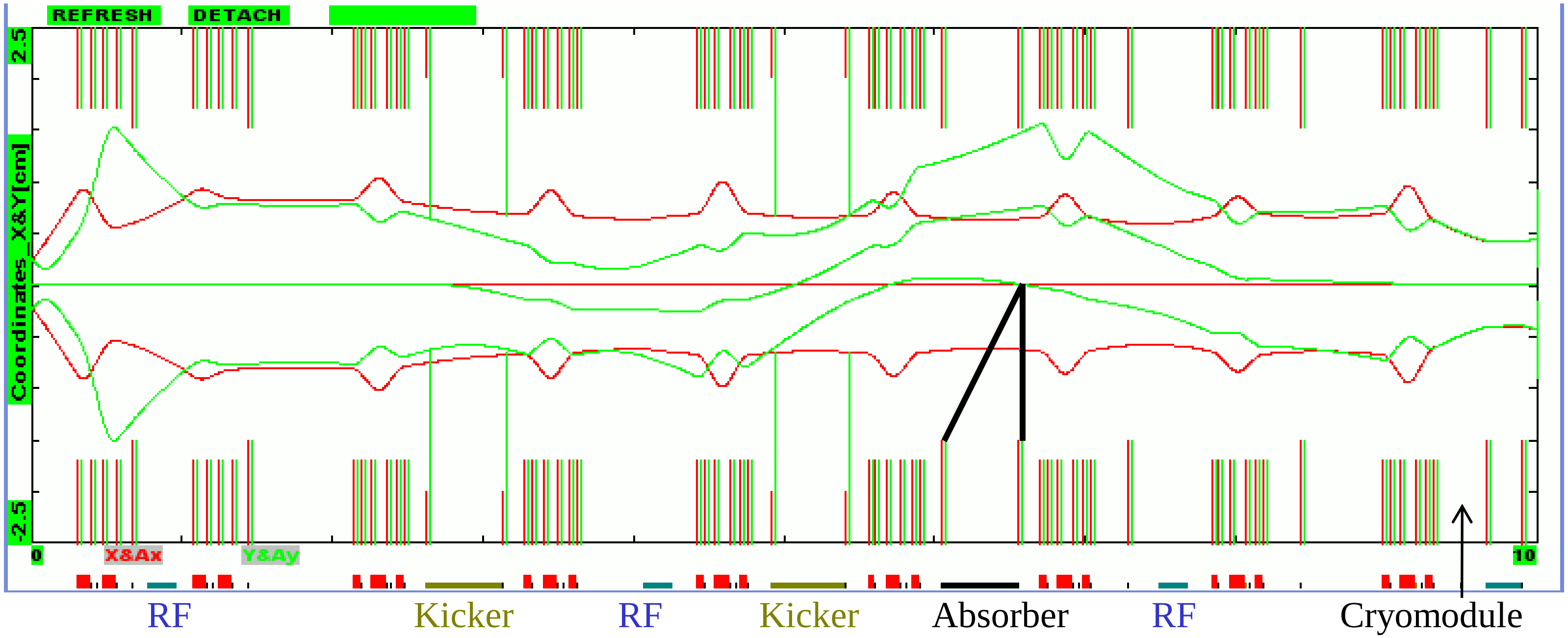
* - defined at the nominal parameters [#] - does not include a factor of π

Scheme



- MEBT consists of 8 sections bounded by doublets or triplets of quadrupoles (total length of 9.4 m)
  - 3 sections to form the bunch structure
  - 3 sections mainly for RF (re-bunching cavities)
  - 2 sections mainly for diagnostics
- The modular design will make easier possible adjustments at transition to Project X in a case of problems found at PXIE
  - E.g. : if the available kicker voltage is too low, it can be offset by installing an additional kicker section

MEBT optics

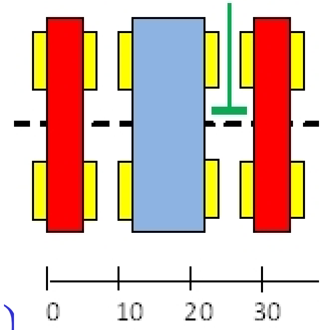


X and **Y** beam trajectory and envelopes of the bunches passing through. Preliminary simulation without space charge.

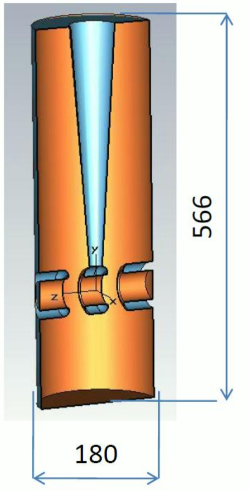
- The bunches to be passed go through the MEBT being deflected up, and the bunches to be dumped are deflected down
  - Allows to use the aperture more effectively
- V. Lebedev optics design
  - Incorporates some ideas from John Staples' proposal

Components

- Bunch selection system (chopper and absorber) – see next slides
  - The most challenging elements
- Quadrupoles
  - Round 1.5”OD vacuum pipe
    - Hopefully, air cooled
    - BPM in each focusing group
  - Stage: conceptual design (Vl. Kashikhin)



- RF (3 cavities needed)
  - 162.5 MHz re-bunching cavities, ~90 kV
  - Stage: detailed RF design (G. Romanov)
    - Report on October 25

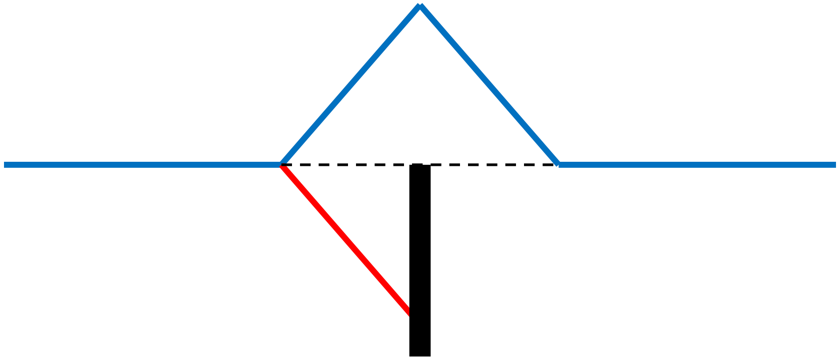


- Diagnostics
  - Stage: conceptual design (V. Scarpine)
    - Report on October 26
- Protection – conceptual design
- Vacuum system, controls - have not started yet

Chopper system: schemes

- Two kickers, with 50 cm effective length each, working in sync
- Three deflection schemes are being considered

#	Beam position at absorber with the kickers off	Plate voltage for the passing bunch	Plate voltage for the damped bunch	Flat top	Advantage
1	On axis	+250 V	-250 V	< 25 V	Low plate voltage
2	Completely off absorber	|Up| < 25 V	|Up| > 500 V	N/A	No flat top requirement
3	Completely on absorber	500 V	Up ≤ 0	< 25 V	Protection

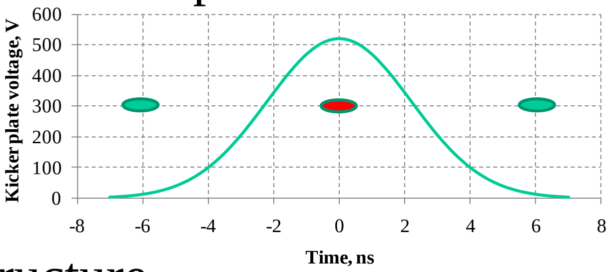


Assumptions:

1. 6σ bunch removal/passing for both longitudinal and transverse
2. 16 mm kicker plate (total) separation
3. 10% perturbation for the transverse rms emittance of the passing bunches
4. Nominal emittances; optics shown above
5. Voltage on both plates

Chopper: specifications

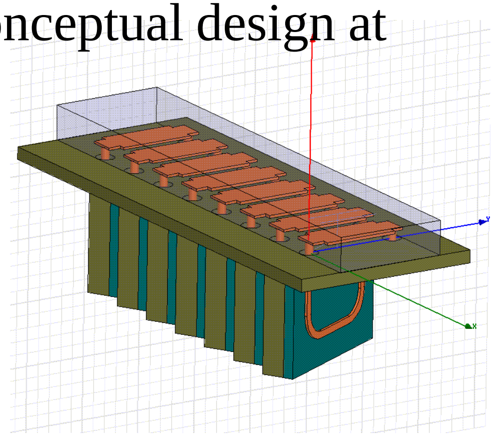
- Any bunch of the 162.5 MHz CW train can either pass or be removed.
- Voltages specified on the previous slide (250/500V; 25V) are applied for 6σ bunch length, 1.3 ns
- The chopper should survive a 10W CW beam halo loss and an accidental loss of a large portion of the beam with deposition of 10J

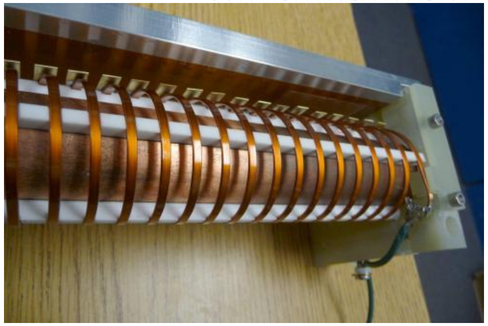


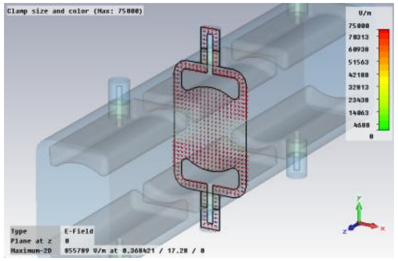
- Possible limitations on the required bunch structure
  - Portion of passing bunches is not more than 20%
    - During 1 μs element of periodicity, the total number of alterations (pass-> remove) or (remove->pass) is not more than (163/5) = 33
  - Beam removal for longer than 100 ns is made by LEBT kicker
    - Assumes ~50 ns rise/drop time in the LEBT kicker
  - Lower bandwidth of the chopper driver can be set to ~1 kHz
    - A DC offset is compensated with DC correctors
    - Requires turning the beam off for ~1 s to switch between timelines

Chopper: TW kickers

- Three versions of a TW kickers are in a stage of conceptual design at Fermilab
  - Separate plates connected by cables or strip lines
    - Ding Sun, V. Lebedev
    - 50 Ohm
    - 15 cm model has been measured with good results
    - A model with good cooling is under development
  - Helical structure with attached plates
    - G. Saewert
    - 200 Ohm
    - 50 cm model has been measured
    - No showstoppers yet
  - Individually driven plates
    - M. Wendt







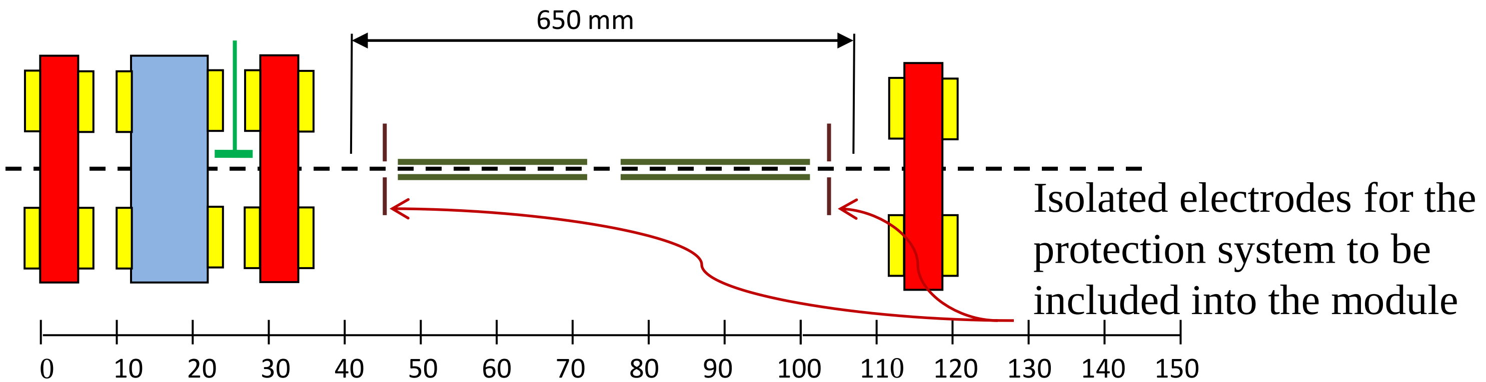
- Plan to design and manufacture prototype(s) in FY2012

Chopper: driver for the kickers

- At this stage, this is a critical path item
- At an early stage of a conceptual design
  - Fast switch
    - Voltage and average power for switching are the issues
  - Linear amplifier
    - Phase distortion
    - A pre-distortion is being considered

Chopper: protection

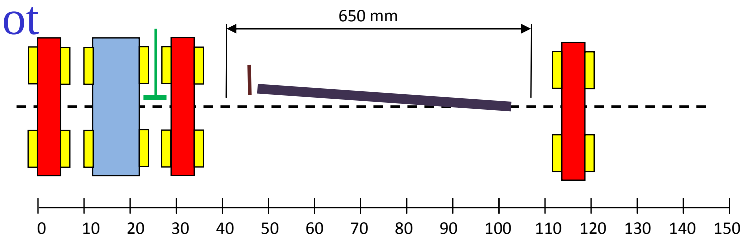
- The kickers can be damaged either by a CW loss from the beam halo or by an accidental loss
  - Plan to add isolated electrodes with current read-back on both sides of the kicker (A. Aleksandrov's suggestion)
    - 13 mm for the protection electrodes separation with 16 mm between plates
    - To turn the beam off in LEBT in a case of an accidental loss



- Two pairs of scrapers in two sections following RFQ, separated by ~90deg of the betatron phase
  - To remove possible beam halo
  - 50W per plate

Absorber: challenges

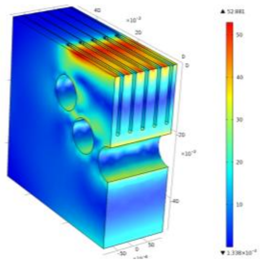
- High power density in the beam, up to 80 kW/cm^2 in the cross section
  - Requires an absorber at a small angle with the beam
    - See the next slide
- High CW beam power to absorb, 10 – 20 kW
  - Possible effect on the beam passing nearby
    - Restrictions to outgassing rates and mechanical stability
  - Sensitive equipment (e.g. RF) in neighboring sections can be affected by sputtering from the absorber surface
    - The reason to remove RF from the absorber section
- Protection
  - An isolated electrode to protect from the beam offset too far out
  - Discussing a possibility to detect an OTR light from the absorber to measure the average size of the beam spot
    - Requires a window across the absorber

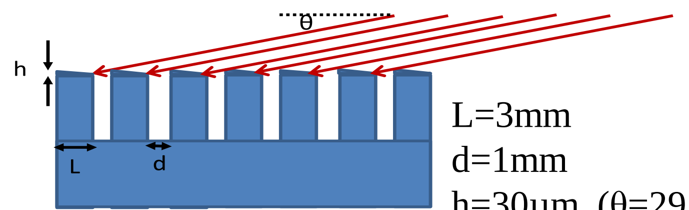


- Radiation
  - Activation should not be a problem at the lowered ion energy of 2.1 MeV

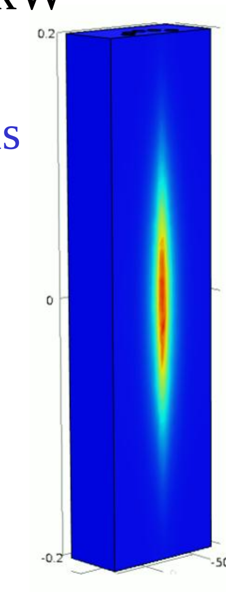
Absorber: thermal and stress simulations

- Several versions of the absorber have been simulated for 12.5 kW
  - ➢ M. Hassan et al.
  - ➢ Absorber surface has a small angle (~30 mrad) with the beam axis
    - The beam footprint becomes highly elliptical
    - The maximum power density is decreased by ~30 times
  - ➢ Slits to relieve the mechanical stress in the hottest area
  - ➢ Water channels right outside of the slits



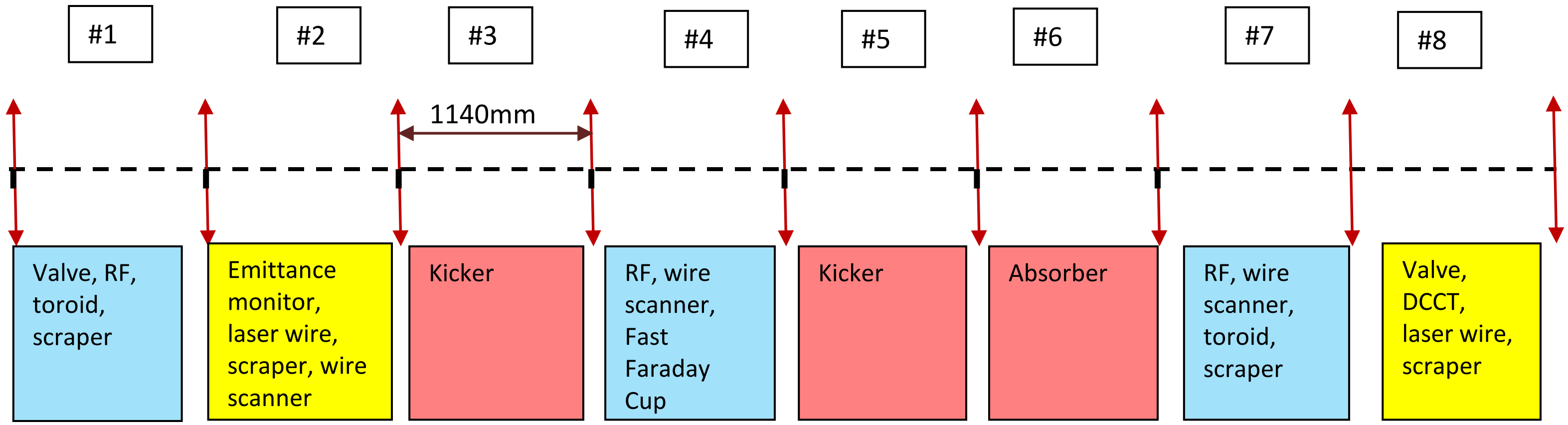


L=3mm
d=1mm
h=30μm (θ=29 mrad)



- For a copper absorber, the maximum stress is 75% of the limit
- An oxygen-free copper alloy with a significantly higher yield may be the solution
- We consider manufacturing a small absorber prototype and testing it with an electron beam

Possible commissioning scenario



- IS, LEBT, RFQ, and first two sections of MEBT are assembled with a bend and a temporary beam dump
  - Beam from RFQ tested
  - First, in a pulse mode (1-10 Hz, 1-5 μs); scraper in the section #2 is closed
    - Emittance measurements; BPMs, laser wire, and wire scanner commissioning
  - Then at CW up to the full power with the beam to the dump
- The entire MEBT is assembled; the bend and temporary dump are moved to the end
  - Commission everything in the pulse mode, then in CW
    - With the beam first to the dump and then to the absorber
    - Test the chopper

Summary

- Functional specifications of PXIE MEBT have been finalized
- The optical scheme of MEBT has been chosen
  - Modular design with periodic transverse and longitudinal focusing
- Conceptual design of most elements has started
- A significant increase of engineering efforts is required to stay on schedule