PXIE DIAGNOSTIC AND DUMP LINE

David Johnson
For PXIE D&D Team*
Project X Collaboration Meeting
November 28, 2012

*Curtis Baffes, J.-P. Carneiro, A. Chen, Y. Czajowski, Y. Eidelman,I. Gonin, V. Kashikhin, V. Lebedev, A. Leveling, A. Makarov, R. Pasequinelli, G. Romanov, A. Saini, V. Scarpine, N. Solyak, I. Terechkine , Y. Yakovlev

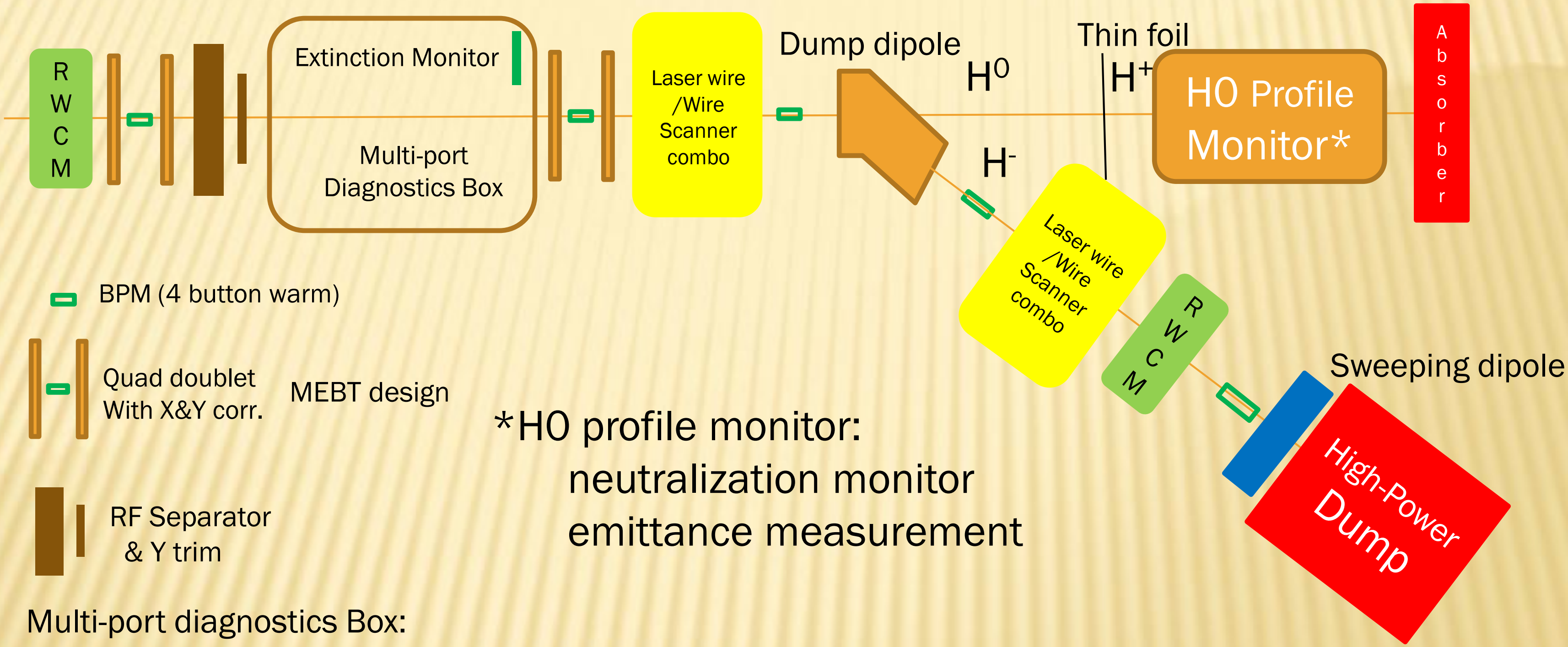
TOPICS

- Overview
- Vacuum system
- Beam measurements and instruments
- Beam dump
- Summary

INTRODUCTION

- The high energy diagnostic line
  - is designed to accommodate the beam diagnostics required to measure
    - the beam properties and
    - the beam extinction for RF buckets emptied by the MEBT chopper.
    - and quantify the successful operation of PXIE
- A variety of diagnostic tools will be installed throughout the PXIE beam line to support commissioning and the R&D program.

CURRENT DIAGNOSTIC LINE CONCEPT



*H0 profile monitor:

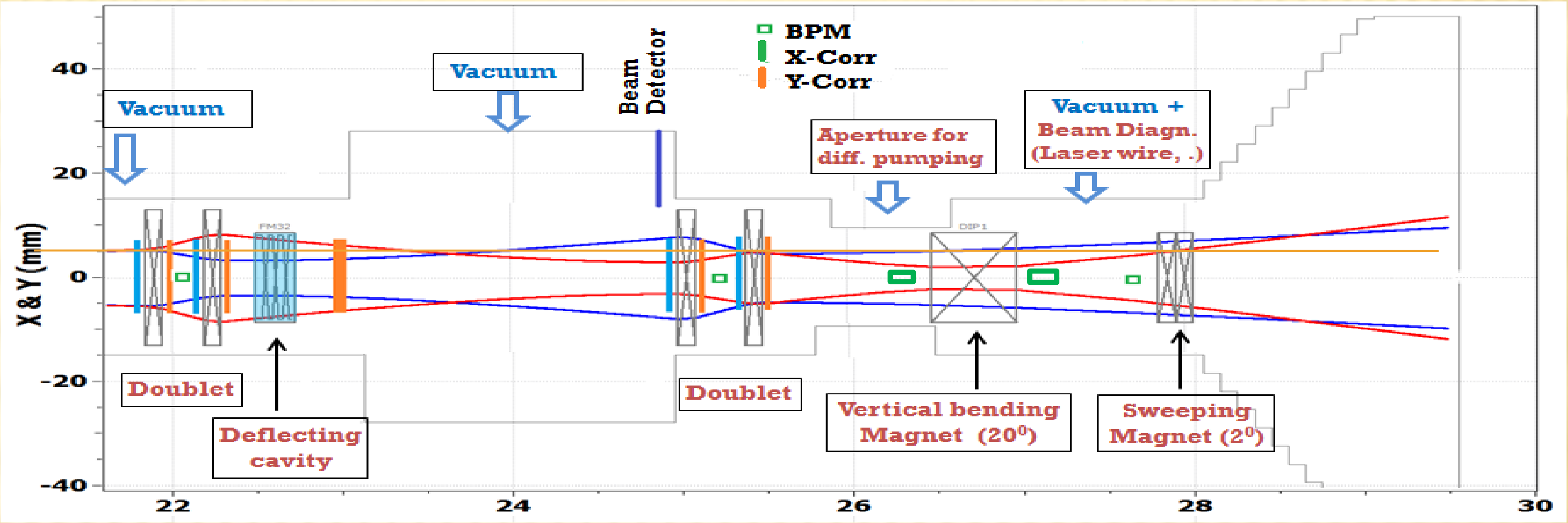
neutralization monitor

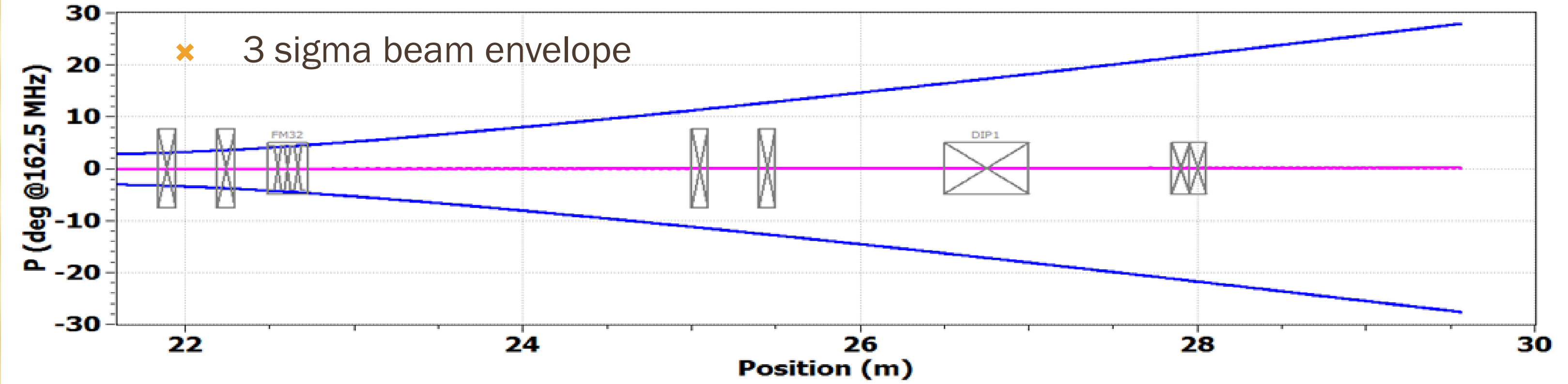
emittance measurement

Multi-port diagnostics Box:

- emittance slit/detector
- wire scanner (are these needed here if dedicated system exists?)
- laser wire (are these needed here if dedicated system exists?)
- halo monitor
- longitudinal bunch shape monitor
- future “unknown” diagnostics

BEAM SIZES THROUGH DIAGNOSTIC LINE

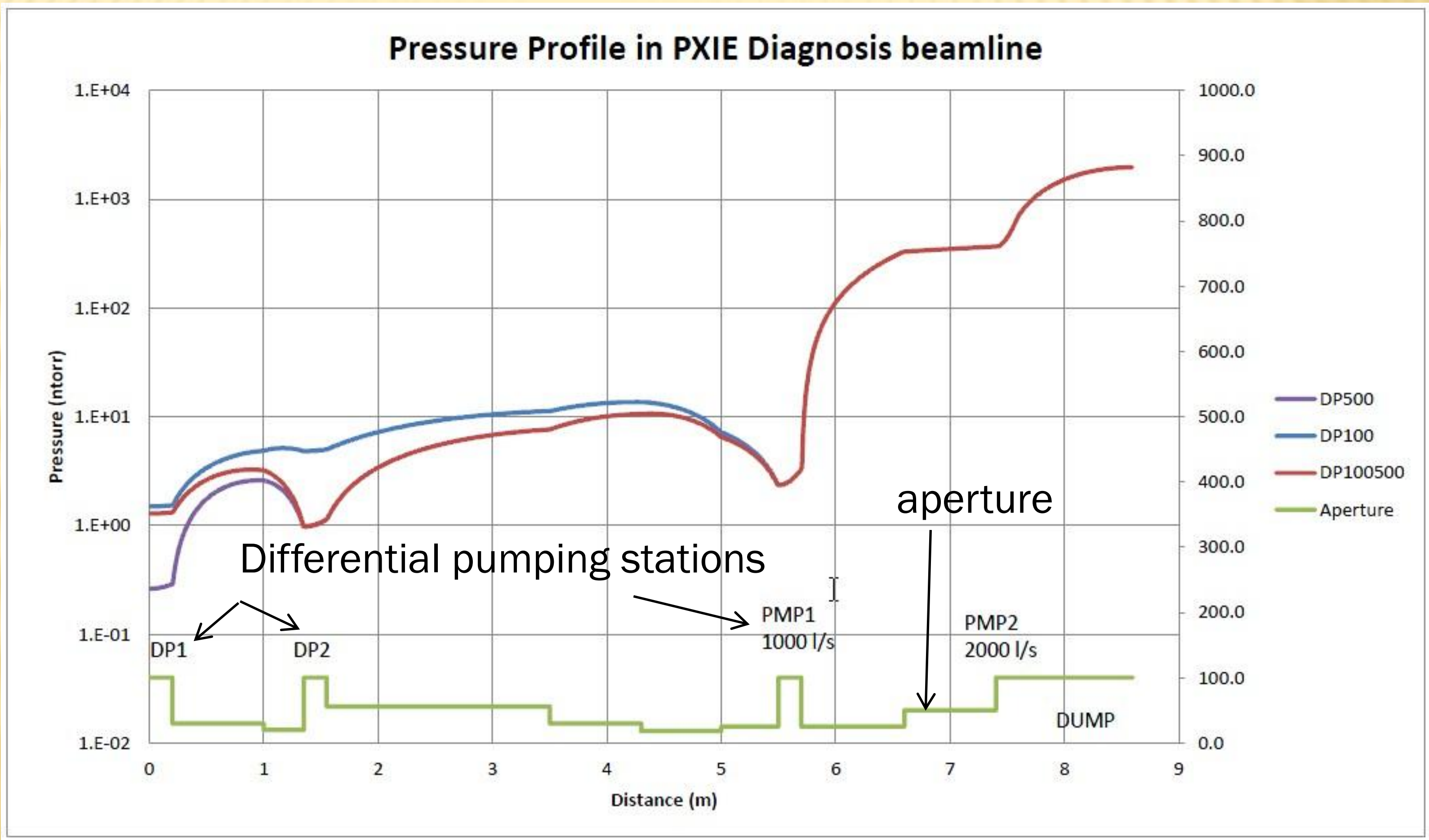




PRELIMINARY VACUUM ASSESSMENT

Alex Chen

Initial assessment of vacuum profiles in D & D line including differential pumping section and dump pumping.



EXPECTED BEAM PARAMETERS (IN D&D LINE)

Parameter	Unit	Value	Range	Comment
Beam Energy	MeV	25	15 – 30	
Bunch frequency	MHz	162.5	20 -162.5	What is the real range of bunch frequencies?
<Beam Current>	mA	1	0.5 – 2	During 1 us created through chopping
Particles/bunch	10^8	1.8	0.4 - 4	30 pC/bunch, nominal (5 mA source current)
Residual charge of removed bunches	relative	10^{-4}	?	Relative to un-chopped bunches
Transverse emittance (rms)	π-mm-mr	0.2	0.17-0.4?	Out of SSR1 for 5 mA peak
Longitudinal emittance (rms)	π-mm-mr	0.35	0.25 -0.4?	Out of SSR1 for 5 mA peak
Beam power	kW	25	7.5 - 60	To be limited to 50 kW

BEAM MEASUREMENTS (IN D&D LINE)

- Beam properties
  - Position
    - Warm bpm's similar to those used in A0/NML (4 button pick up) and PXIE MEBT
  - Current
    - Two high bandwidth RWCM -- like MEBT
  - Energy/Energy spread
    - Time of flight using BPM's
    - Transverse profile after the 20 deg bend magnet. (Note: this needs study – beam size and divergence will effect energy spread resolution
  - Emittance
    - Transverse : wire scanner / laser wire / high resolution double slit scanner similar to SNS
    - Longitudinal: Franchenko emittance monitor
- Special measurements
  - Beam extinction
  - Beam halo
  - Beam neutralization
- Beam loss (machine protection) – types of monitors for photons and neutrons to be defined (sealed gas ionization chambers for photons/ what about neutrons?)
- Measurement specifications (sensitivity, precision, resolution, etc) --- need to be documented
- Background documentation (Vic Scarpine) → Details of instruments found in:
  - Beam Diagnostic Instrumentation for PXIE 17Jan2012 v2.pdf doc 984
  - PXIE Instrumentation Update – 12 June 2012.pdf doc 1068

INSTRUMENTATION STATUS

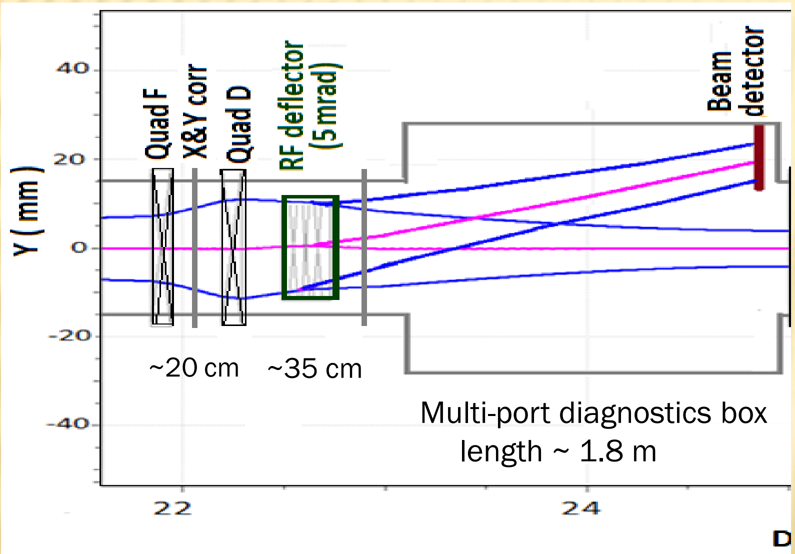
Summarized from Vic Scarpine presentations and conversations

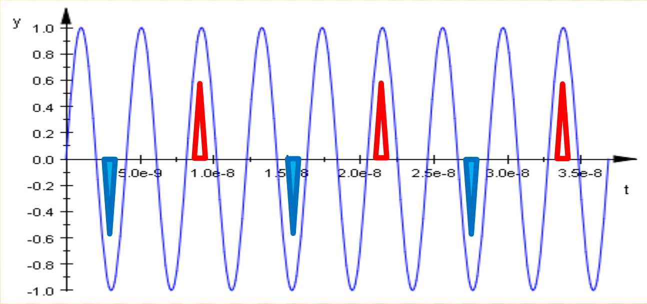
- Most of the operational diagnostic equipment for PXIE has been identified (including devices in D&D line)
- Instrumentation device leaders have been identified for most devices
- Further development of a PXIE commissioning plan will help resolve outstanding issues on required sensitivity and resolution
- Risk items
  - Laser diagnostics
    - (laser development on going/ optics chamber design/ high or lower-power laser/ longitudinal or transverse measurements or both
  - Extinction measurements
    - (need to define beam parameters/technique)
  - Loss of key people (and limited resources)
    - (software designer/BPM expert/new ME)
- Currently low priority in AD
- No funds in RLS till 2016 for further instrumentation development

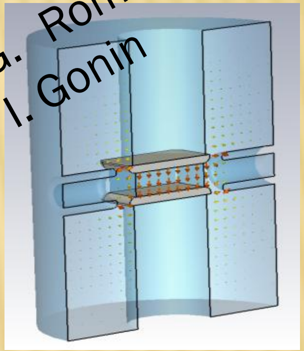
BEAM EXTINCTION MEASUREMENTS

- Measure population of empty buckets produced by the MEBT chopper
  - Prepare special pattern by removing every other bunch (burst mode macro bunches ?)
  - Use room temp copper RF deflector cavity to kick un-populated bucket (red) vertically upward and populated bucket (blue) downward
  - Secondary DC trim amplifies positive kick and compensates negative kick

G. Romanov
I. Gonin







$$f_{RF} = (n+0.5)\, f_{bunch}$$

Select n=1

Parameter	243_Baseline gap 30 mm
Frequency, MHz →	243.75
Inner height, mm	363
Inner diameter, mm	260
Flange-to-flange (approx.), mm	350
Gap, mm	30
E_surf_max, MV/m	5.2
E_y_max, MV/m	3.04
Power losses, kW	2.9
Q	12575
Kick voltage, MV	1.07
Proton β (23.5 MeV)	0.22
Deflecting angle, mrad →	5.0

Detector: TBD

particle counting (@80MHz) ?

resolution? Dynamic range ?

TRANSVERSE BEAM HALO

- At what level is halo to be measured, how much beyond 3σ ?
- Concept for LEBT halo monitor
  - Electrically isolated sleeves inside vacuum chamber.
    - Giant antennas, very noisy, what kind of sensitivity is required?
  - Will this work at high energy?
- Other techniques?
  - Laser wire (Vic Scarpine)
    - with scintillator to measure electrons / less sensitive to RF noise
  - Vibrating wire? (trying this at HINS) (Moses Chung)
  - Diamond detectors ? (Arden Warner)
- Various techniques under investigation
  - need beam time to test ideas.

BEAM DUMP (1)

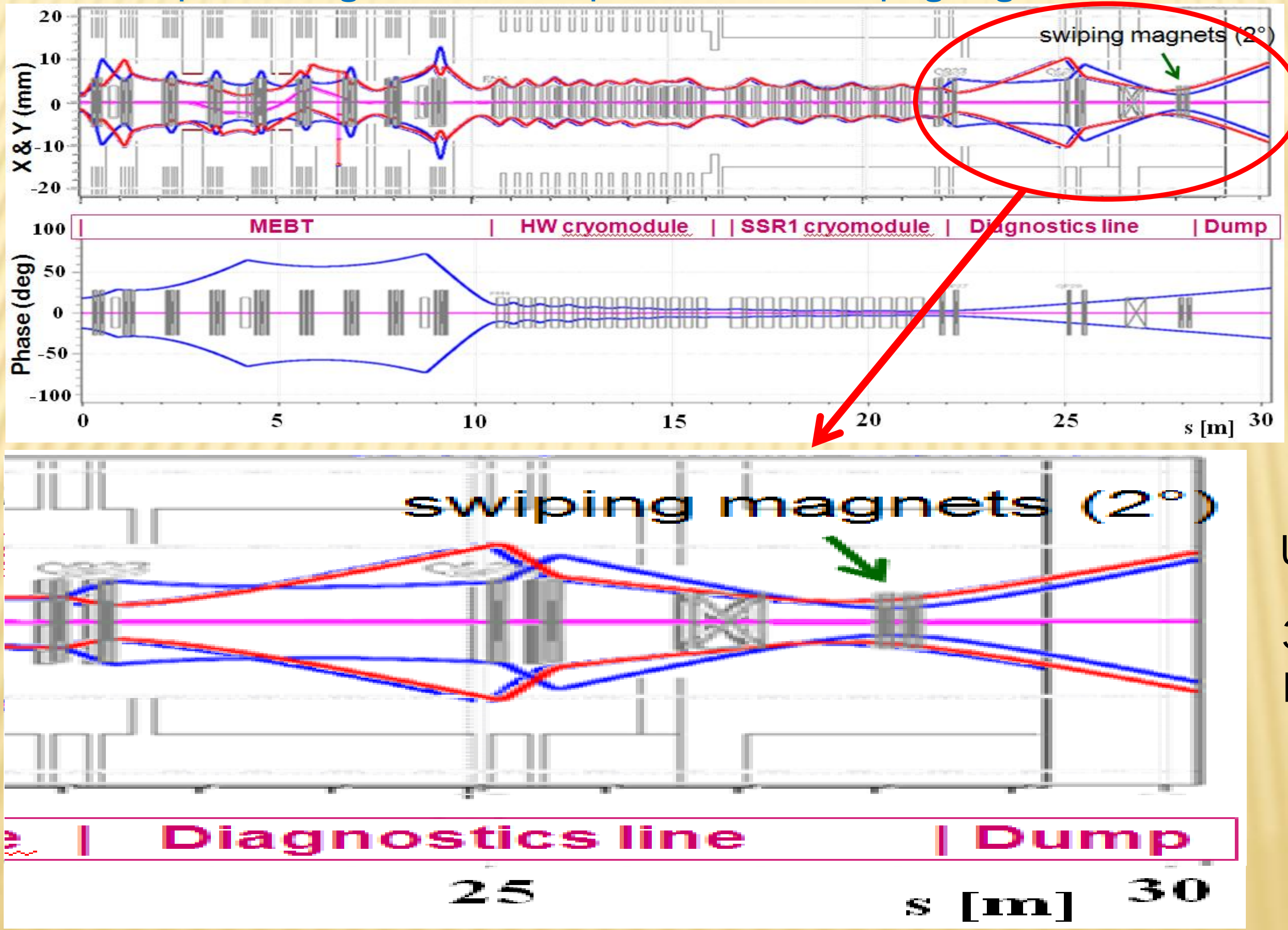
- Located at the end of the diagnostic line after a 20º vertical deflecting magnet.
- Positioned to be above the floor elevation at the end of the enclosure.

Parameter	Value	Units
Energy	30	MeV
Beam current	1.7	mA
Beam power	50	kW
H^- flux	3.7×10^{19}	Ions/hr
Operation time	2300	hrs/year
Total particles to absorber	8.5×10^{22}	Ions/year

- Shielding to protect accelerator equipment and personnel outside the PXIE enclosure
  - prompt dose levels < 0.05 mrem/hr around outside of enclosure
  - Prompt dose levels < 0.25 mrem/hr on ceiling
- What are acceptable prompt radiation levels inside enclosure
  - particle types and energy -> impact on instrumentation
- Residual radiation should be significantly less than 100 mrem/hr to facilitate hands on maintenance. Simulations in progress.
- Absorber lifetime requirement 5 years.

DUMP (2) OPTICS FOR DUMP DESIGN

- PXIE optics from Design handbook (HW & SSR1 module design stable)
  - Optical tuning in D & D line to place waste at sweeping magnets



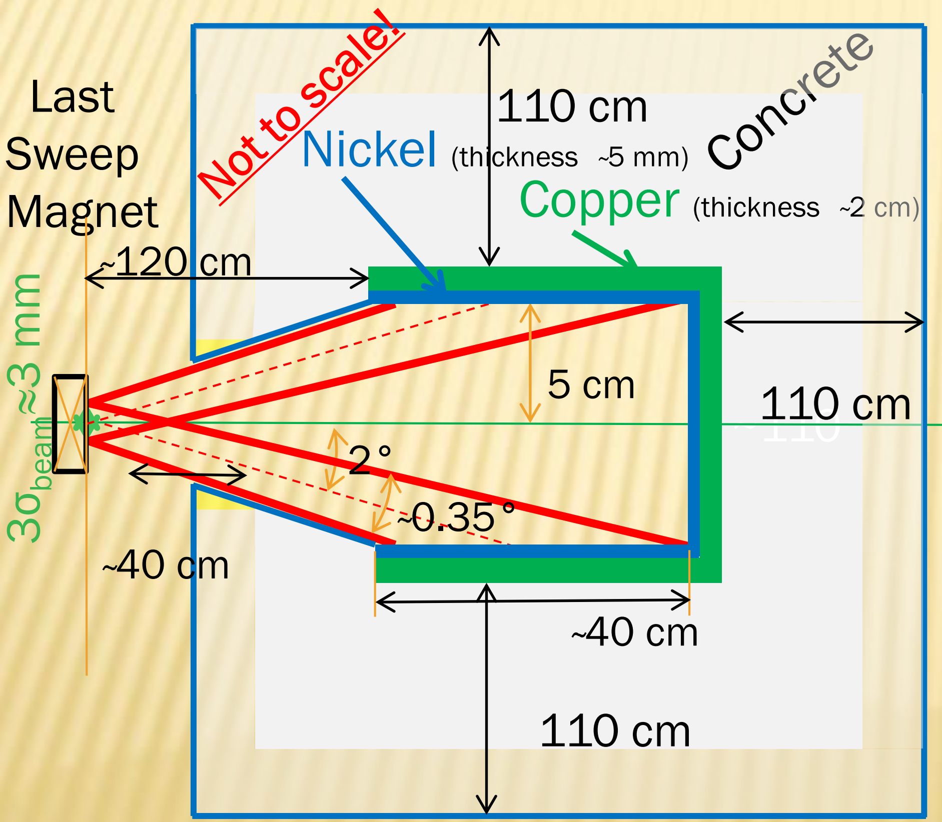
Use for dump design

$3\sigma \sim 3$mm
Divergence ~ 3 mr

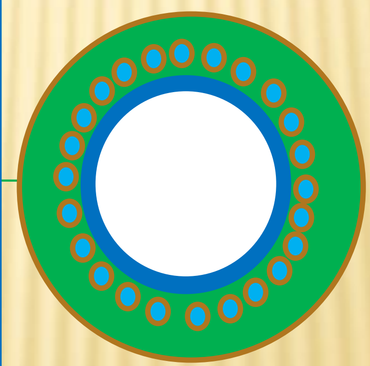
DUMP (3) ABSORBER AND SHIELDING GEOMETRY

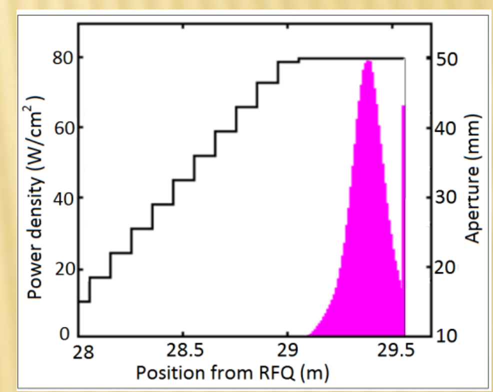
Dump design: Y. Eidelman

- Inside stopping surface ~ 5mm Ni braised to copper cooling channel
- Geometry based on ε_T~0.2π-mm-mr and beam waste at sweeping magnet with a σ_y~1mm and y' ~3 mr
- Need to verify operation with abnormal parameters, double emittance, zero divergence, double divergence, etc
- Dump Instrumentation (thermocouples, loss monitors, etc) need to be specified



Range of 30 MeV proton in Ni = 1.95 mm (at 2° stopping range is 70 um.





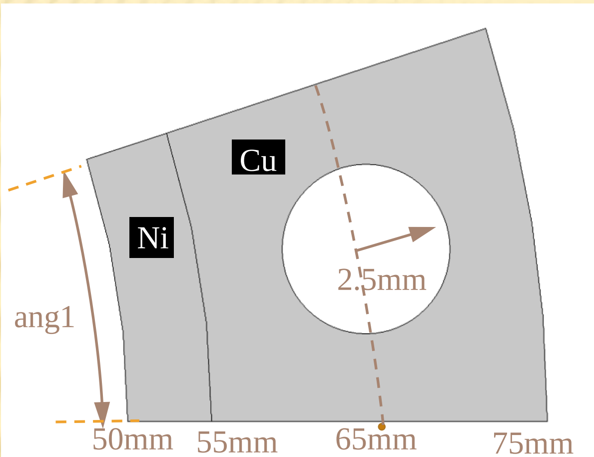
Sputtering in Ni evaluated (Y.Eidelman) doc 1091
-> negligible in terms of the expected operational duration
Blistering estimated to be not an issue.

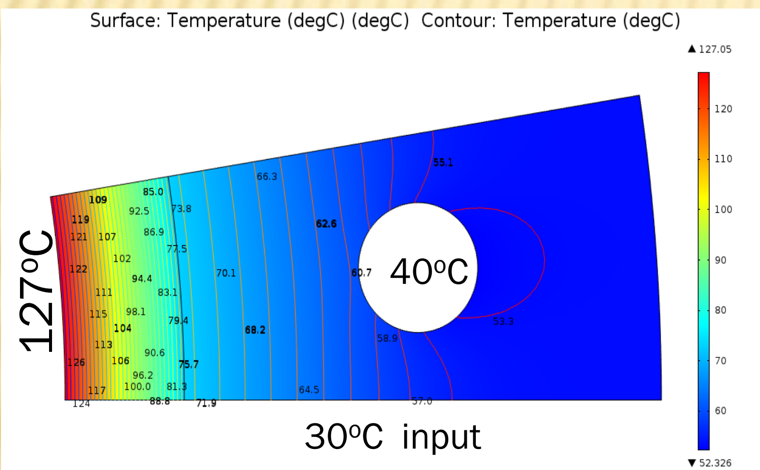
DUMP (4) THERMAL CALCULATIONS

Pavel Avrakhov/Nikolay Solyak

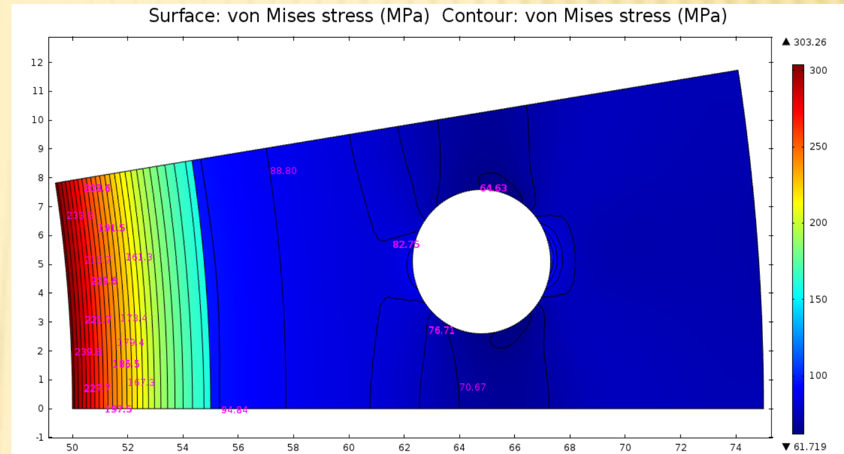
(Example: calculations using COMSOL)

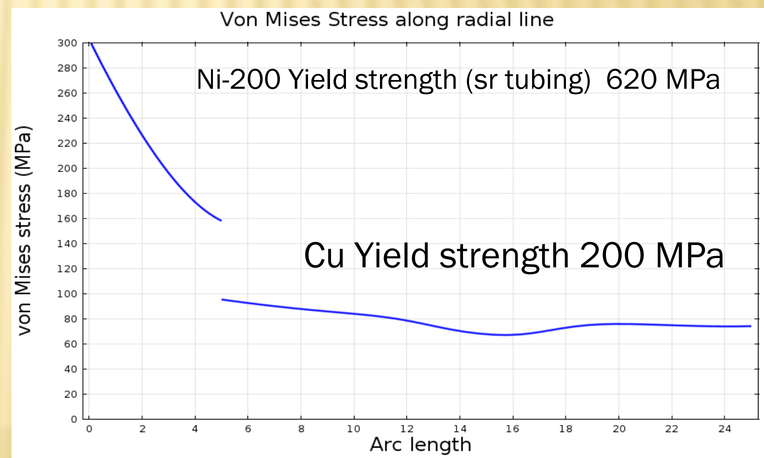
Absorber: Ni-200 Heat flux 80 W/cm^2





Thermal Stresses





Copper cooling channels outside the Ni ($\Delta T \sim 30\text{-}40^{o}$ C), inside NI surface expected below 130^{o} C, hence cooling not an issue.

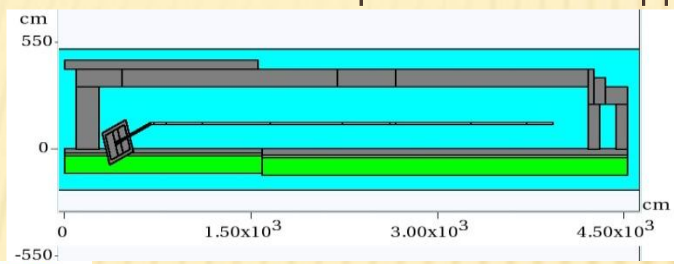
Requires stand alone RAW system

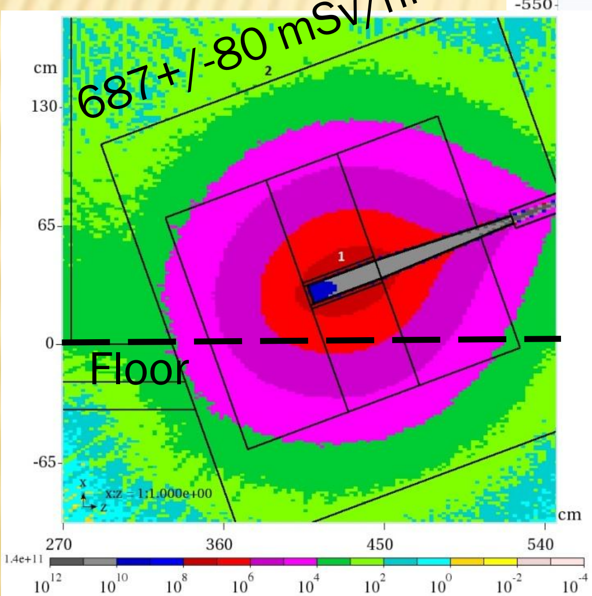
BEAM DUMP (5) MARS SIMULATION

Y. Eidleman

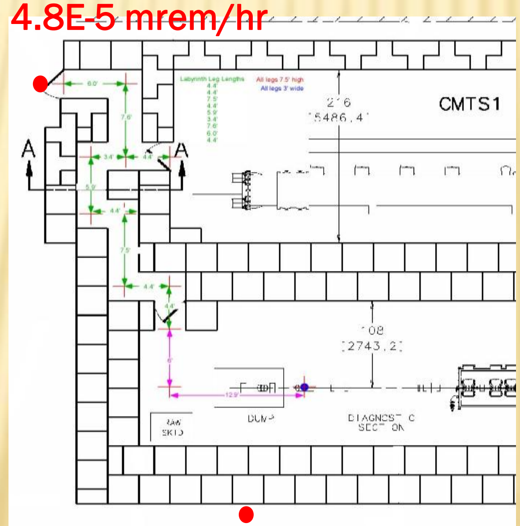
- Current shielding meets or exceeds required shielding for prompt dose outside labyrinth (10) by factor ~1000… Can shielding be reduced, use of borated concrete?
- Residual dose calculations at the surface of the shielding are underway.
- Current shielding requires the creation of a pit in the floor approximately 2.5 m x 2.5 m x 1 m deep.

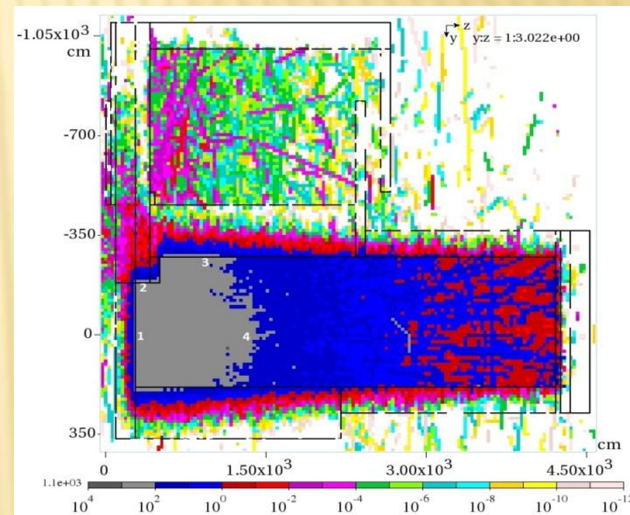
R(2/1) ~1.6×10^{-5} for 110 cm
~1.3×10^{-4} for 80 cm

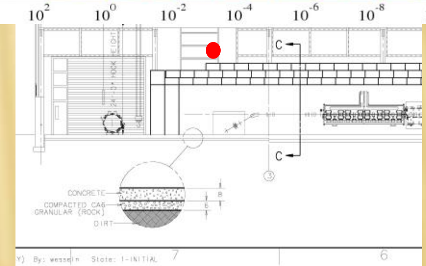




Prompt dose





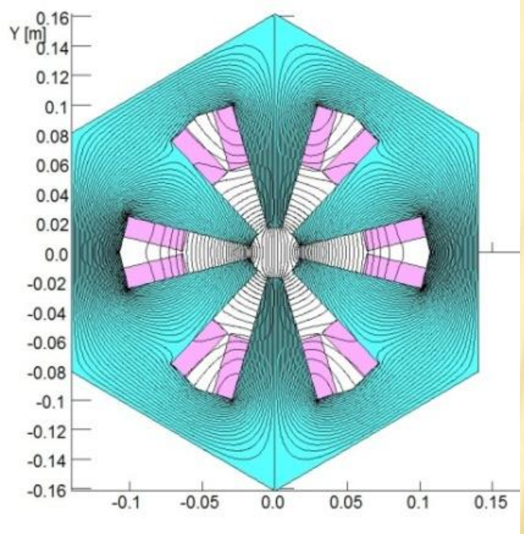


Shield thickness just meets at 1
X2 at other points

BEAM DUMP (6) SWEEPING MAGNET

- Six-pole sweeping magnet (3 phase 60 Hz) to paint the beam on the inside surface of the cylinder. (2^{o} deflection) Constant amplitude

V. Kashikhin



Parameter	Unit	Value
Magnet aperture (diameter)	mm	34
Integrated dipole peak field	T-m	0.04
Magnet effective length	mm	200
Good field area diameter	mm	23
Field homogeneity at 11.5 mm radius	%	± 16
Peak dipole field in the magnet center	T	0.2
Peak / R.M.S. current at 60 Hz	A	250 /177
Total power	W	810
Copper conductor with the cooling hole	mm	6.5x6.5 dia. 3.0
Coil number of turns		12
Power source		AC, 3-phase, 60 Hz
Magnet width / length	mm	280 / 260
Water pressure drop	MPa	0.4
Water temperature rise	°C	24

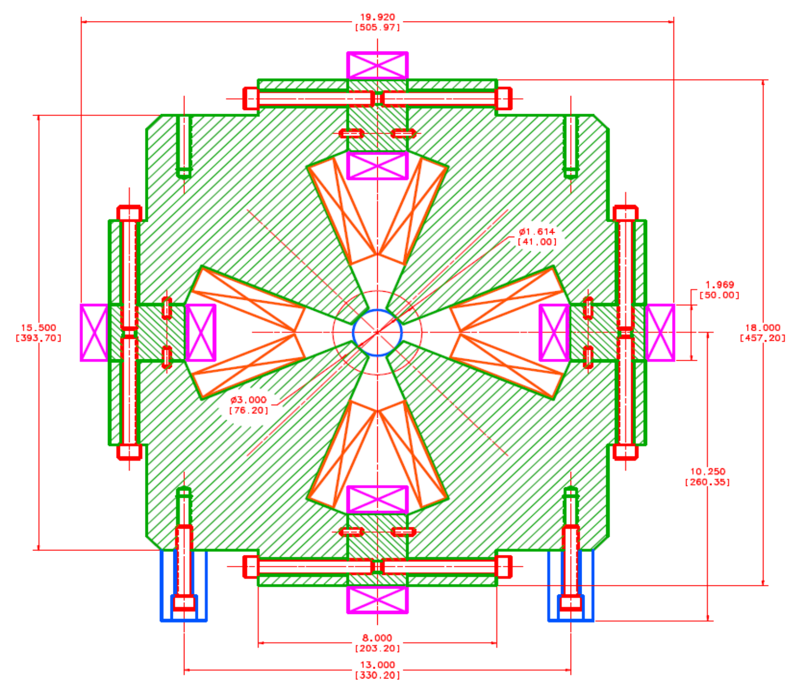
SUMMARY

- Operational diagnostics and manpower have been identified.
- A general concept of measurements and many of the required instruments have been identified.
- Need to define functional measurement specifications (sensitivity, precision, resolution, etc)
- Conceptual design for vacuum pumping requirements complete
- A significant amount of simulation for the design of the dump absorber and shielding has been accomplished.
  - Thermal management simulations indicate conceptual design is OK
  - Sputtering and blistering do not seem to be an issue for this beam energy/power
  - Proposed shielding level exceeds requirements. Investigate reducing shielding on bottom of dump to eliminate excavation of floor.
  - Engineering design needs to verify construction of absorber, water and vacuum connections and constructability of shielding. Instrumentation for monitoring temperature and losses need to be addressed.
- Further component design and development on hold till at least 2014 due to lack of funds (2016 for instrumentation)

THANK YOU FOR YOUR ATTENTION

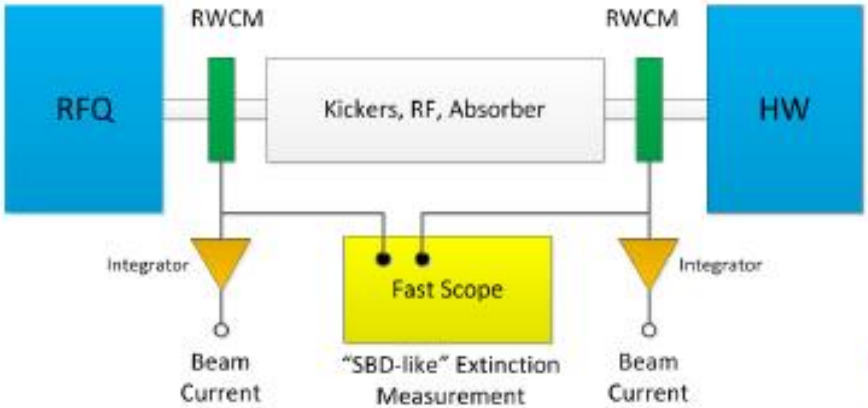
BACK UP SLIDES

MEBT Quad

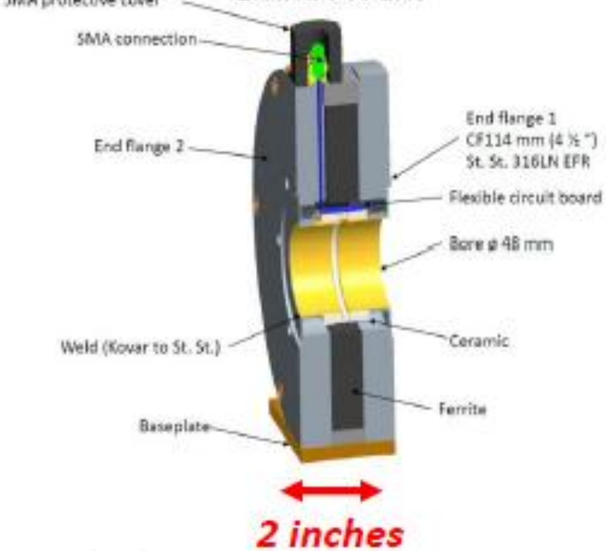


19.920 [505.97]
ø1.614 [41.00]
1.969 [50.00]
15.500 [393.70]
18.000 [457.20]
ø3.000 [76.20]
10.250 [260.35]
8.000 [203.20]
13.000 [330.20]

Extinction + Current Monitor

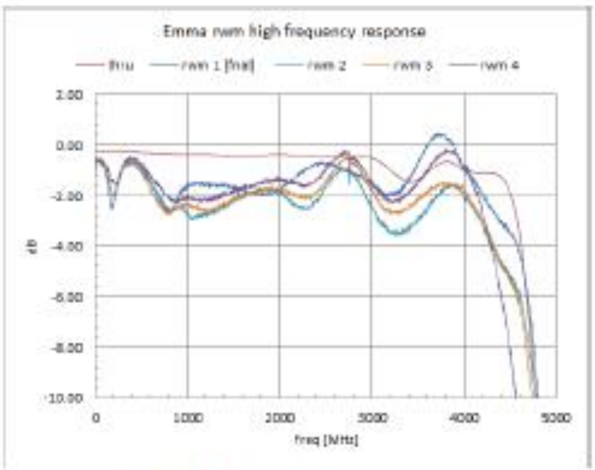


EMMA WCM



Use upstream and downstream Resistive Wall Current Monitors (RWCM)

- Extinction -> 'SBD-like' monitor
  - Average over many bunches
  - < 1 Hz BW
  - Measure impact on adjacent bunches
- Beam current
  - Fast integrator
  - ~ MHz BW
- Flat freq response, 10 KHz – 4 GHz
- Already designed, ~ $10k/detector
  - May require adjustment for PXIE beam pipe diameter



1/17/2012 Project X Meeting 9

Project X doc 984 Vic Scarpine

Warm BPMs

Button BPM design similar to A0/NML

- May need small redesign
- Can fit in limited size

Direct digitization readout

- Undersampling of 1st & 2nd harmonics
- Operation over 360 degrees of cavity phase needs study
  - Debunching effects phase measurement
- Synchronize to laser modulation

Development and testing at HINS would be helpful to understand system performance

ect X Me ... 1

Project X doc 984 Vic Scarpine

Transverse Emittance + Wirescanner + Laser Wire Unit

Three instruments located just before first kicker:

1. Slit/Multi-wire Transverse Emittance Monitors – pulsed operation
2. Three-wire (Horz, Vert, Diag) transverse wire scanner – pulsed operation
3. Transverse and Longitudinal Laser Wire – CW operation

Wire scanner + laser wire in single can – SNS design

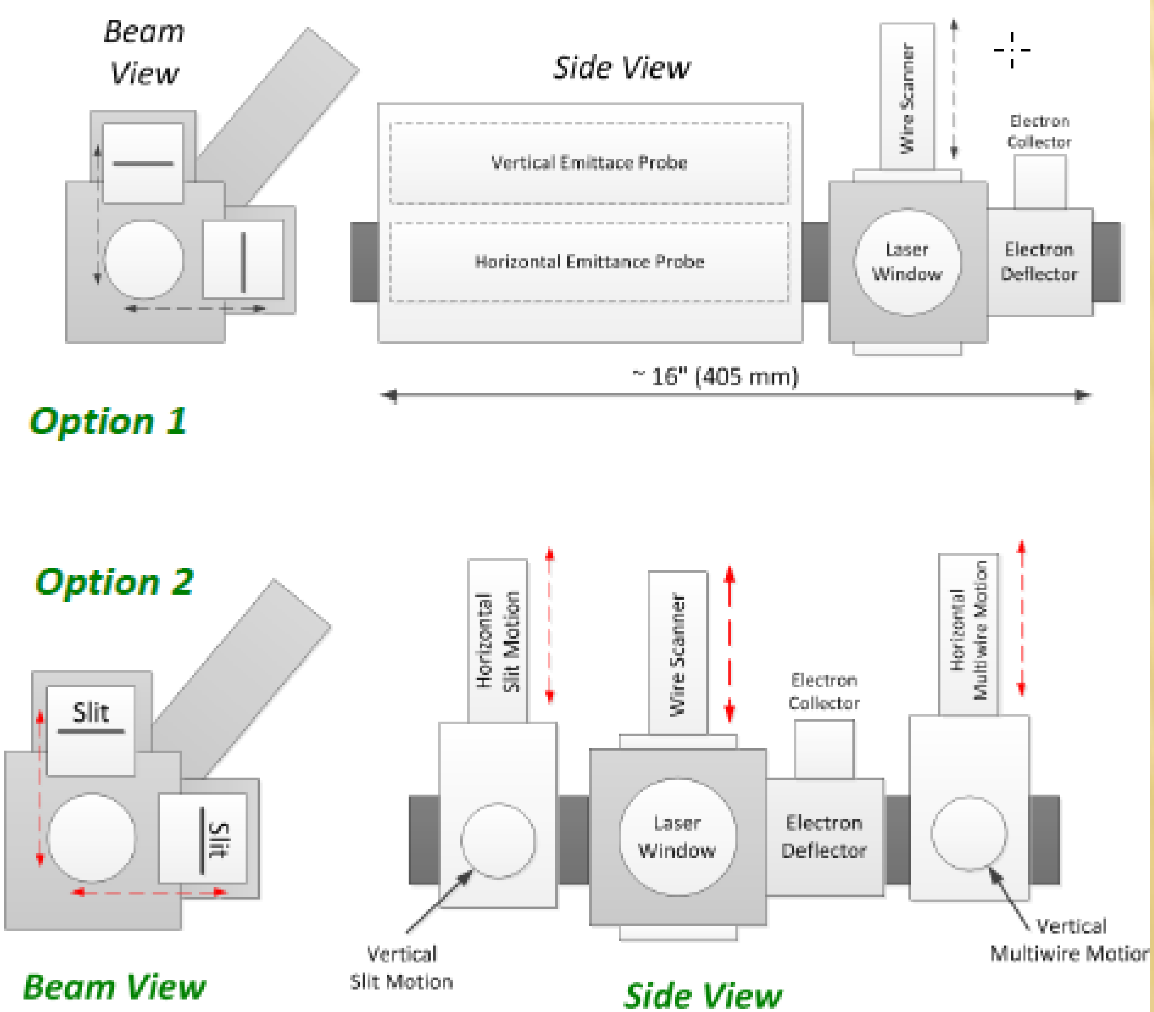
- Unit can be used between cryomodules without electron collector

Option 1:

- Use Fermilab-like emittance probes
  - Familiar system

Option 2:

- Use separate slit and multiwire
  - Can dither multiwire
- Allows for laser wire to go between – save space

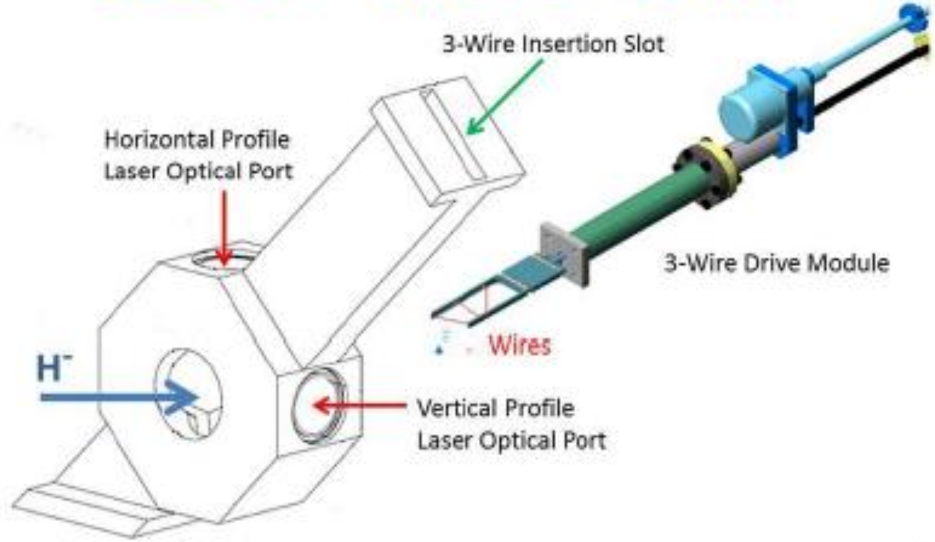


Project X doc 984 Vic Scarpine

Wire Scanner + Laser Wire Unit

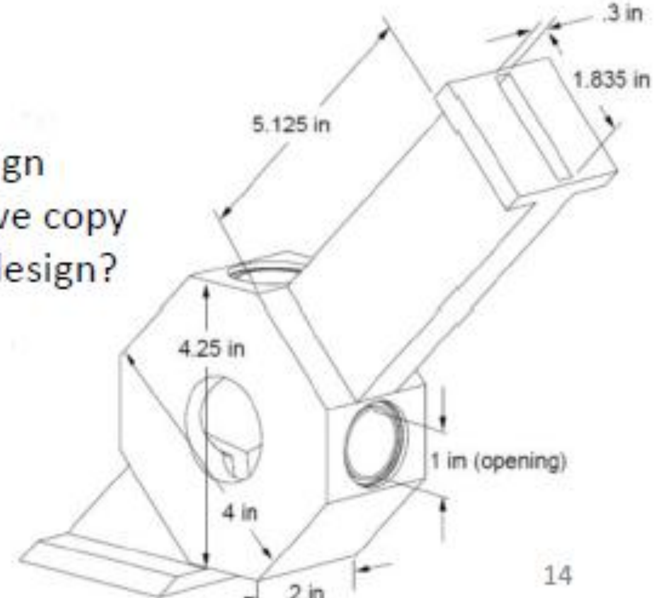
Transverse 3-wire wire scanner plus laser wire module

- Hybrid wire scanner with laser ports
  - Modified version of SNS design
- Wire scanner in pulsed beam operation only
- Laser wire in either pulsed or CW beam operation
- Laser wire can measure transverse and longitudinal profiles
  - *Will different lasers be required for transverse versus longitudinal measurements?*
  - *Will different electron collection detectors be required for transverse versus longitudinal measurements?*
- Is profile measurement across entire aperture required?
  - Can wires or lasers measure profile tails/halo?
  - What size optical windows are required?
  - What is transverse resolution requirement?
    - 10% of one sigma?
  - What is longitudinal resolution requirement?
    - 10% of one sigma?



SNS Design

- Can we copy SNS design?



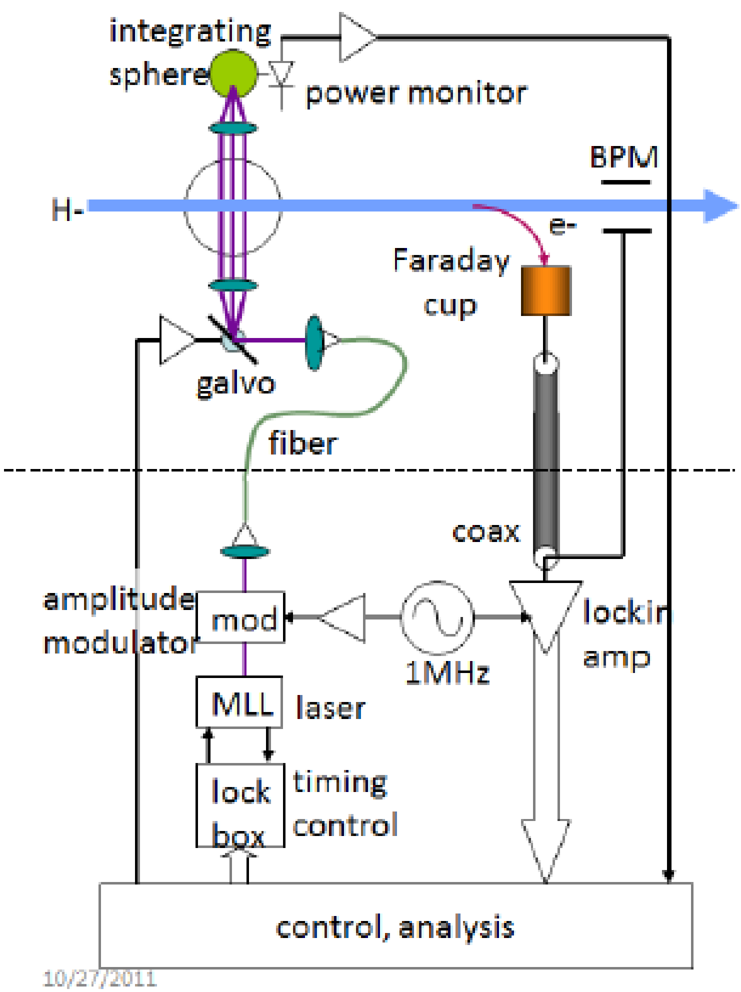
Transverse and Longitudinal Laser Wire

Mode-locked psec laser used to measure both transverse and longitudinal profiles

- Laser rep-rate is locked to 162.5 MHz RF
- Distribute laser via fibers
- Narrow band lockin amp detects modulated signal
- Upper components are in tunnel, lower are in a laser hutch
- Measure profiles by either:
  - Collection of electrons
  - Use BPM as notched-beam pickup would allow laser monitor to fit between cryomodules

Questions:

- What is the photodissociation efficiency?
- What are the noise issues?
- What are the nonlinear limits to power in the fiber?
- What signal-to-noise ratios and averaging times are practical?
  - *R&D at HINS would be valuable*



Project X doc 984 Vic Scarpine