PIP-II 800 MeV Booster Injection

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"Beam Physics with a Booster Accumulator Ring (BAR)"

15-DEC-2020

In partnership with:
India/DAE
Italy/INFN
UK/STFC
France/CEA/Irfu, CNRS/IN2P3

Outline

- Effort on Proton Source Upgrades for PIP-II Era

- Description of Booster Injection

- The Big Issues Status & plans

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Broad base effort to address Proton Source issues relating to PIP-II

- ➢ PIP-II Accelerator Physics Task
- ➢ PIP-II 800 MeV Booster Injection Tasks
- ➢ Accelerator Complex Studies Task Force   → discussed by C.Y. Tan (next talk)
    - ➢ Physics task force excluding PIP-II tasks → ongoing studies
    - ➢ Physics task force for PIP-II AIP tasks (collimator/dampers/CHG0/wide gap CFM for extraction) → interface with PIP-II
   - ➢ Infrastructure task force → E4R magnet measurement/girder

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800 MeV Booster PIP-II Injection System in the Long 11 straight
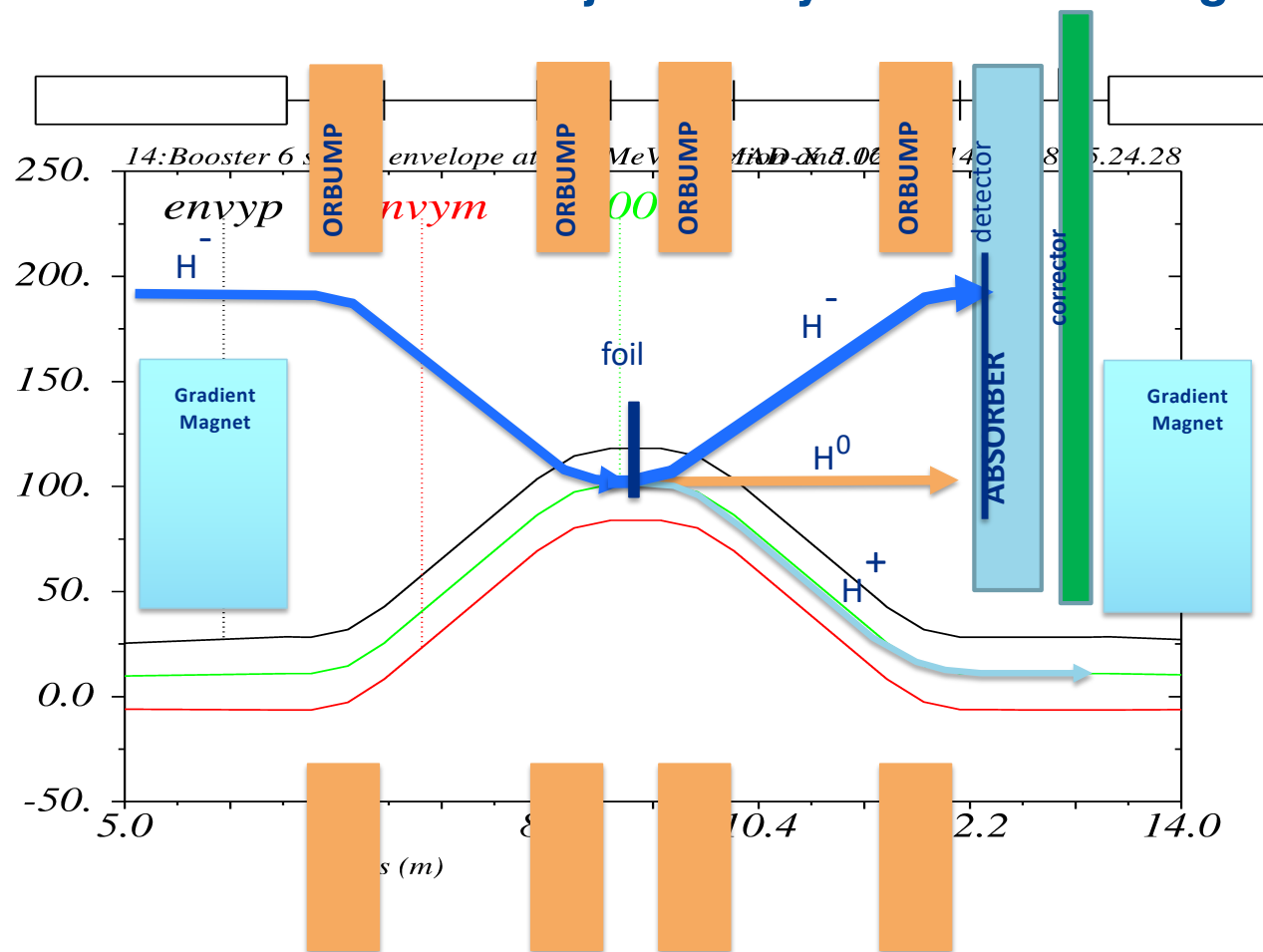
Key features:
- Straight increased by 1 meter
- Reduce "D" GM length by ~0.75 m (back-leg increased by 1")
- Vertical Injection
  - Elevation of inj beam at foil → dy (ORBUMP)+dy(V paint)
- Waste beam absorber Required
  - Current design very tight
  - Corrector should stay
- Dedicated phase space painting outside injection straight
- Foil heating checked, not an issue
- Lattice distortion negligible
- Convoy electron handling – TBD
- Large angle scattering
- Excited states of H0

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Lattice with new PIP-II injection insert
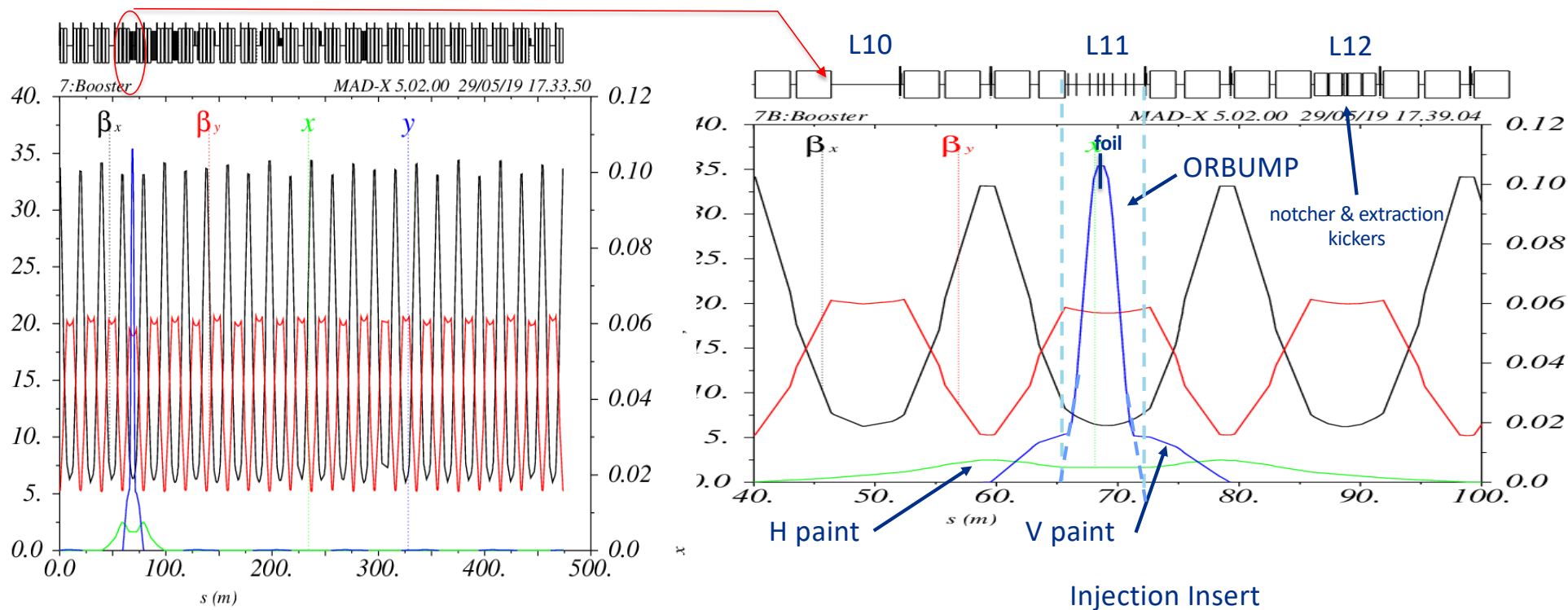
Booster lattice with reduced length gradient magnet

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Phase Space painting

- Current function (make tunable)
  - anti-correlated
  - Quarter sin-wave
- Mismatch lattice (minimize parasitic hits)
- H & V painting magnets outside straight section
- V painting magnets new design
- H painting magnets existing BMA in adjacent straights
  - Must work with flat lattice
- Painting simulations
  - pyORBIT
  - Synergia
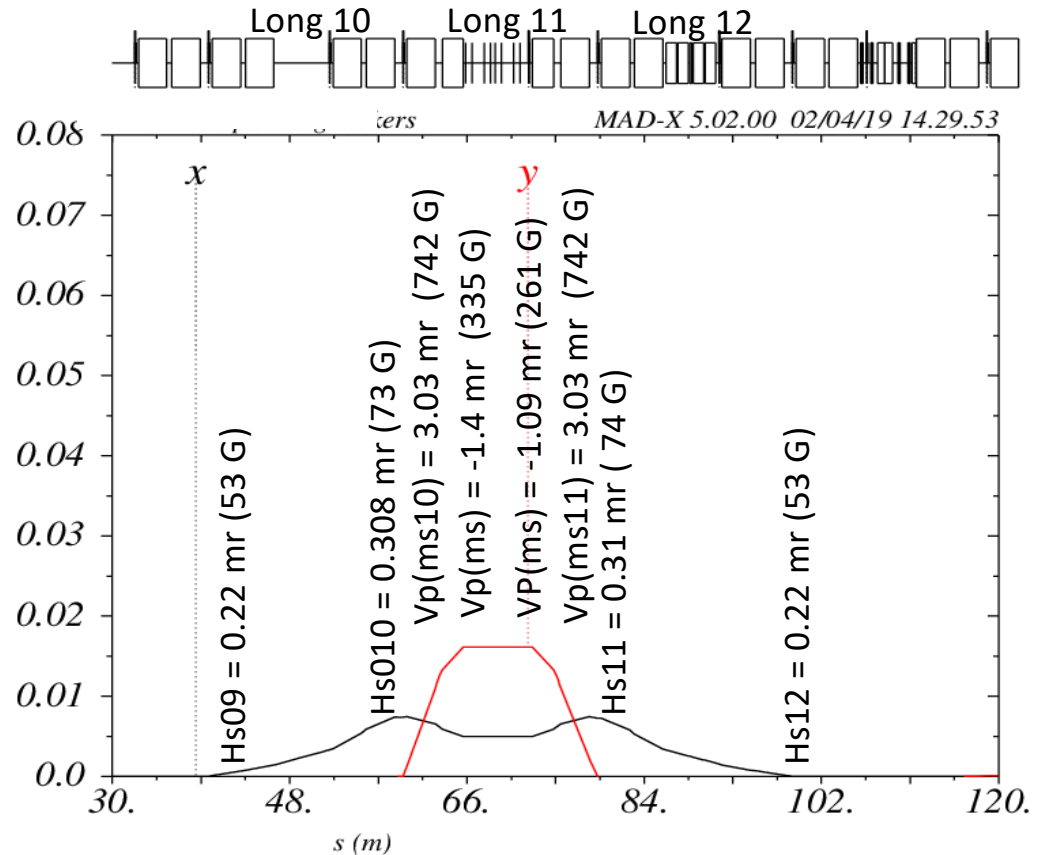
PIP-II Tasks → Component Design and Fabrication

- 800 MeV Injection Girder
  - ORBUMP   finished PDR → final design must wait for confirmation of backleg thickness
  - ORBUMP Power Supply - R&D → starts after magnet FDR
  - Injection Foil system - on hold
  - Injection Absorber - finished PDR → further optimization?

- Painting Magnets - start this spring

- Gradient Magnets – for injection & extraction – initial Poisson model & parameters → start this spring

- 800 MeV Installation -- Shutdown activities

- 20 Hz
  - Converting girders, gradient magnet @E4R, Booster chokes, Accelerator controls, Booster ps, integration (during Booster shutdown)

- Booster Dampers
  - Longitudinal - in process install summer 22
  - Transverse – start in FY22 install summer 24 (?) delayed to finish CHG0 first
  - CHG0   - in process install summer 21

- Booster 2-stage collimator - in process → install summer 22

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What are the big issues ? Status and Plans

- Reliability of Booster gradient magnets at 20 Hz → E4R magnet and girder test facility

- Design and manufacture of short gradient magnet required for injection & wide gap for extraction → these are new magnets based on 50 yro Wilson CFM.

- Stability of flat injection (Energy match) with flat injection

- PIP-II MEBT chopper efficiency → bunches out of Booster buckets → extraction notch depth → we've been guaranteed that these will work and should be no problem

- Longitudinal matching → require de-buncher in BTL → details in discussion

➢ Losses during Injection (ALARA)
  1. H- missing foil → load on absorber → BTL collimation
  2. H0 load on absorber → dependent on foil thickness
  3. Large Angle Scattering from foil
  4. H0* Stark states decaying in downstream ORBUMP

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Estimated Injection loss budget for PIP-II

Administrative Loss Limit 500 W → 25 J at 20Hz for entire cycle

	800 MeV PIP-II Injection loss budget							
injection	6.70E+12	rep rate	20	Hz		8.576E+02	1.715E+04	
	Energy	edfficicncy	neutrals	lost	injected			600 ug/cm²
Foil Thickness	505	ug/cm²						
Stripping Efficiency	8.00E+08	99.8300%	0.1700%	1.14E+10	6.69E+12			99.96%
		loss			lost	joules	watts	Watts
Lorentz Stripping (B ~3.7 kG)	8.00E+08	1.00E-06			6.70E+06	8.576E-04	0.02	0.02
Neutrals to absorber	8.00E+08	1.70E-03			1.14E+10	1.458E+00	29.16	7.55
H- to absorber (?)	8.00E+08	1.00E-02			6.70E+10	8.576E+00	171.52	171.52
Large angle coulomb scattering	8.00E+08	1.56E-04			1.05E+09	1.338E-01	2.68	2.74
Nuclear scattering	8.00E+08	2.00E-05			1.34E+08	1.715E-02	0.34	0.34
excited states	8.00E+08	6.50E-05			4.36E+08	5.574E-02	1.11	0.29
				beam power to absorber			200.68	179.00
				beam power lost in ring			4.15	6.00
TOTAL		1.19E-02	9.88E-01		8.00E+10	1.024E+01	204.83	185.00

As a point of reference:

current injection 4.5 kW : stripping eff 99.9% → 4.5 W in neutrals

H- missing foil ~10% power or neutrals

avg. (max) residual activation 350 (700) mrem/hr @1' on downstream GM

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BTL Collimation to reduce halo missing foil and reduce # parasitic hits

Goal to have <1% H- miss the foil thus reducing load on injection absorber
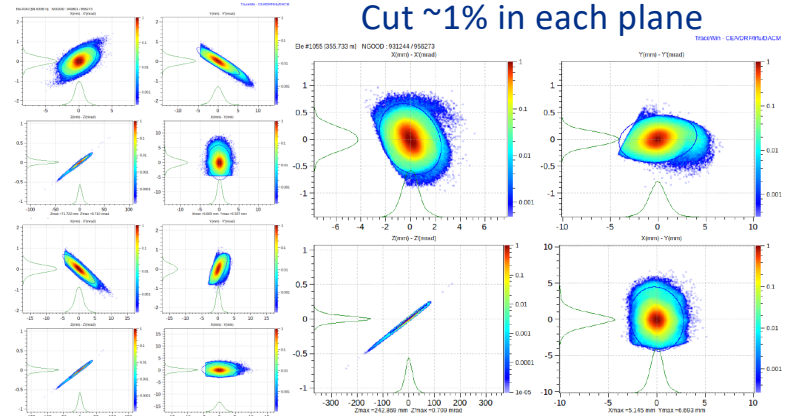
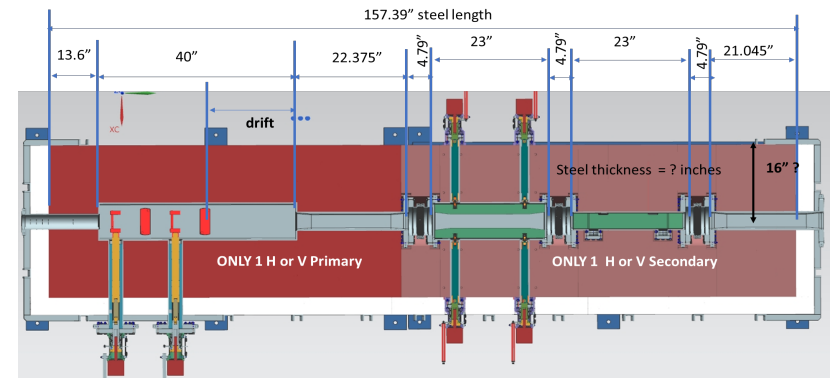**Beam Envelopes – Collimators in SS Cell 1 (V) and 6 (H)**

Injection Foil

Xmax =7.068 mm Ymax =6.753 mm

Xmax =5.145 mm Ymax =6.693 mm
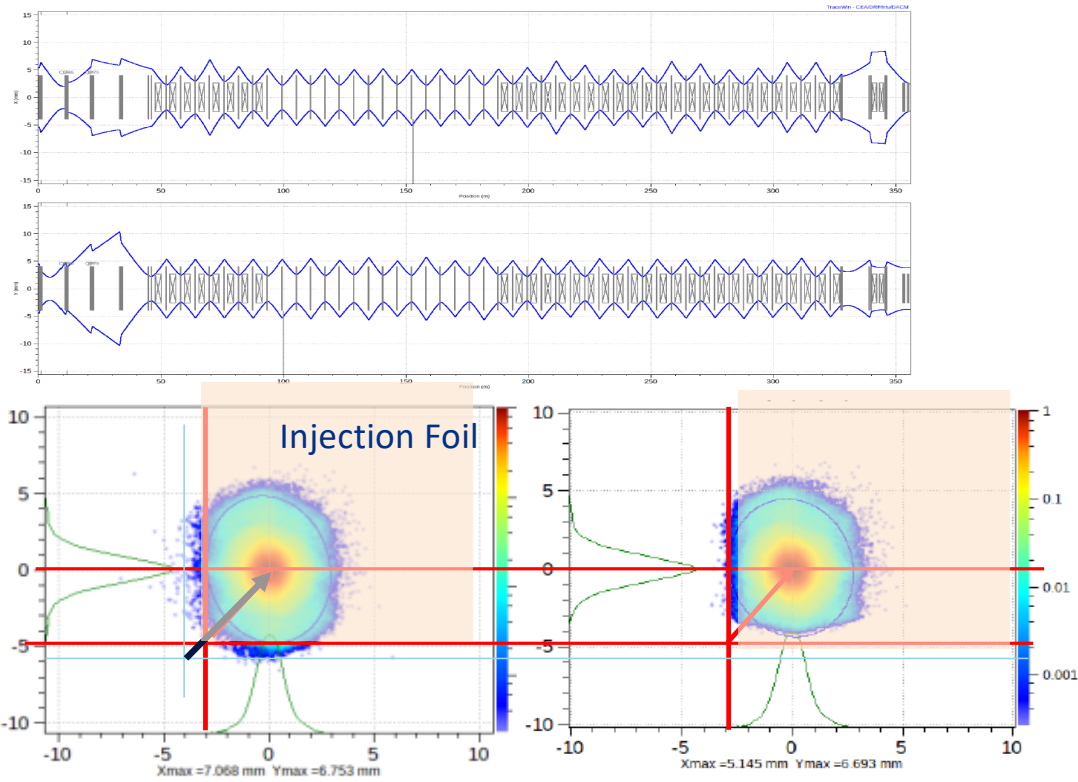
uncollimated   collimated

Collimation [2.5 sigma] SS Cell 1 [V] and Cell 6 [H]

Cut ~1% in each plane

3 x Rms sizes shown – 956 k Particles

157.39" steel length

13.6"   40"   22.375"   4.79"   23"   4.79"   23"   4.79"   21.045"

drift

Steel thickness = ? inches   16" ?

ONLY 1 H or V Primary   ONLY 1 H or V Secondary

Need to define vacuum pipe apertures in collimator for BTL

Simulations from Francois Ostiguy

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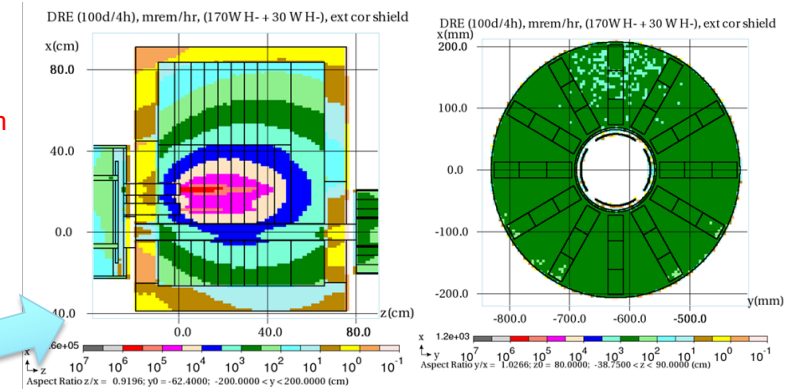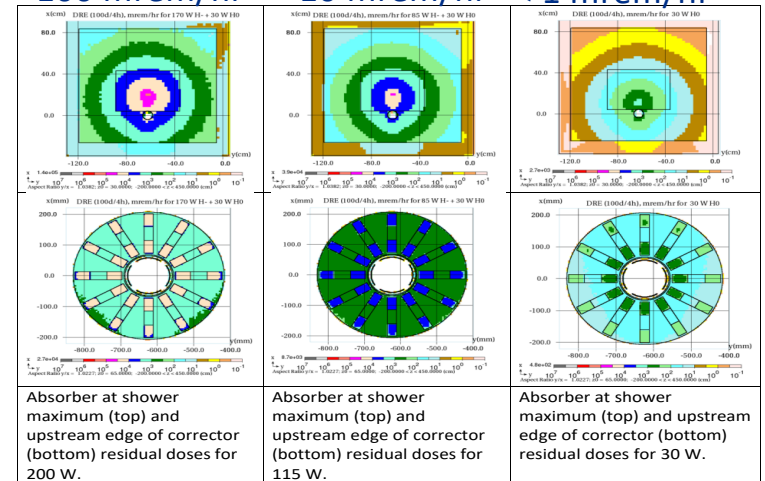
er (load & activation)

- Current design 60 cm steel absorber surrounded 10 cm marble (about 2" between Marble & up/downstream elements

- Beam load on absorber for design

  170 W H- (1% missing) & 30W H0 (from foil)

- **Space constrained**

- **Increase absorber by 15 cm reduced peak contact dose on corrector by x3 to ~450 mrem/hr → investigate new corrector OR increase ORBUMP field**

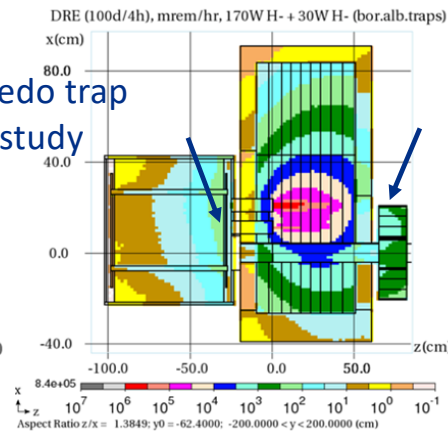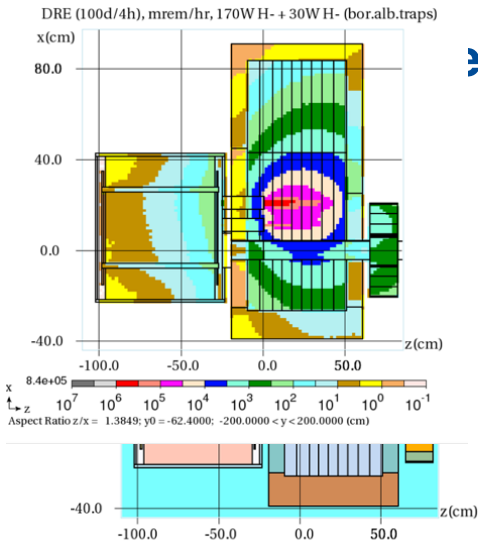DRE (100d/4h), mrem/hr, (170W H- + 30 W H-), ext cor shield

DRE (100d/4h), mrem/hr, (170W H- + 30 W H-), ext cor shield

Load
Marble surface

	200W	115W	30W
	< 100 mrem/hr	< 10 mrem/hr	< 1 mrem/hr

Mars modeling by Vitaly Pronskikh

Albedo trap study

DRE(100d/4h), mrem/hr, 170W H - + 30W H- (bor.alb.traps)

DRE (100d/4h), mrem/hr, 170W H - + 30W H- (bor.alb.traps)

Absorber at shower maximum (top) and upstream edge of corrector (bottom) residual doses for 200 W.

Absorber at shower maximum (top) and upstream edge of corrector (bottom) residual doses for 115 W.

Absorber at shower maximum (top) and upstream edge of corrector (bottom) residual doses for 30 W.

coils	> 10 rem/hr	~3 rem/hr	< 1 rem/hr

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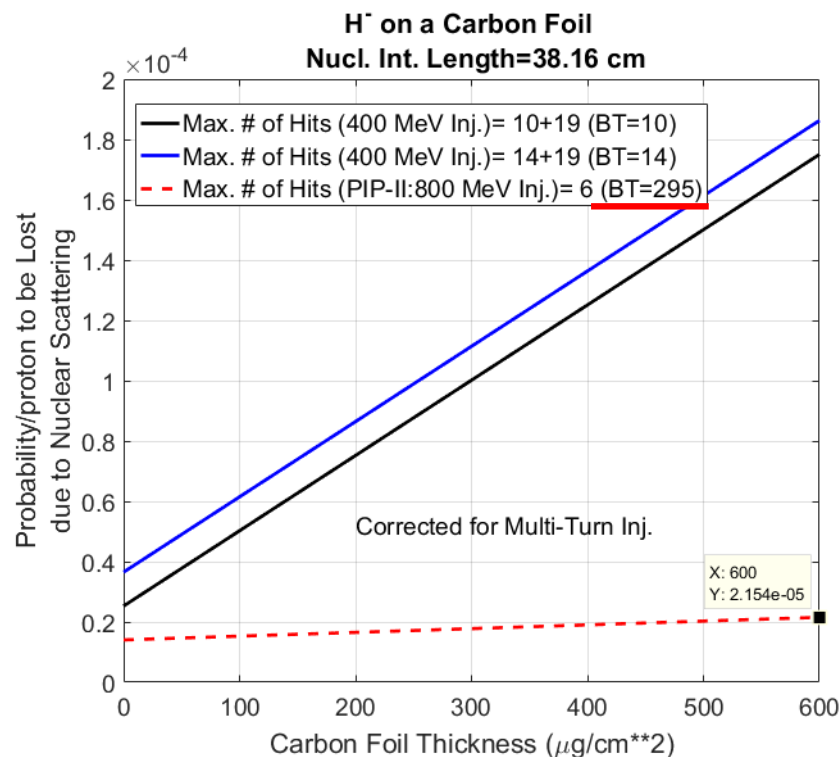
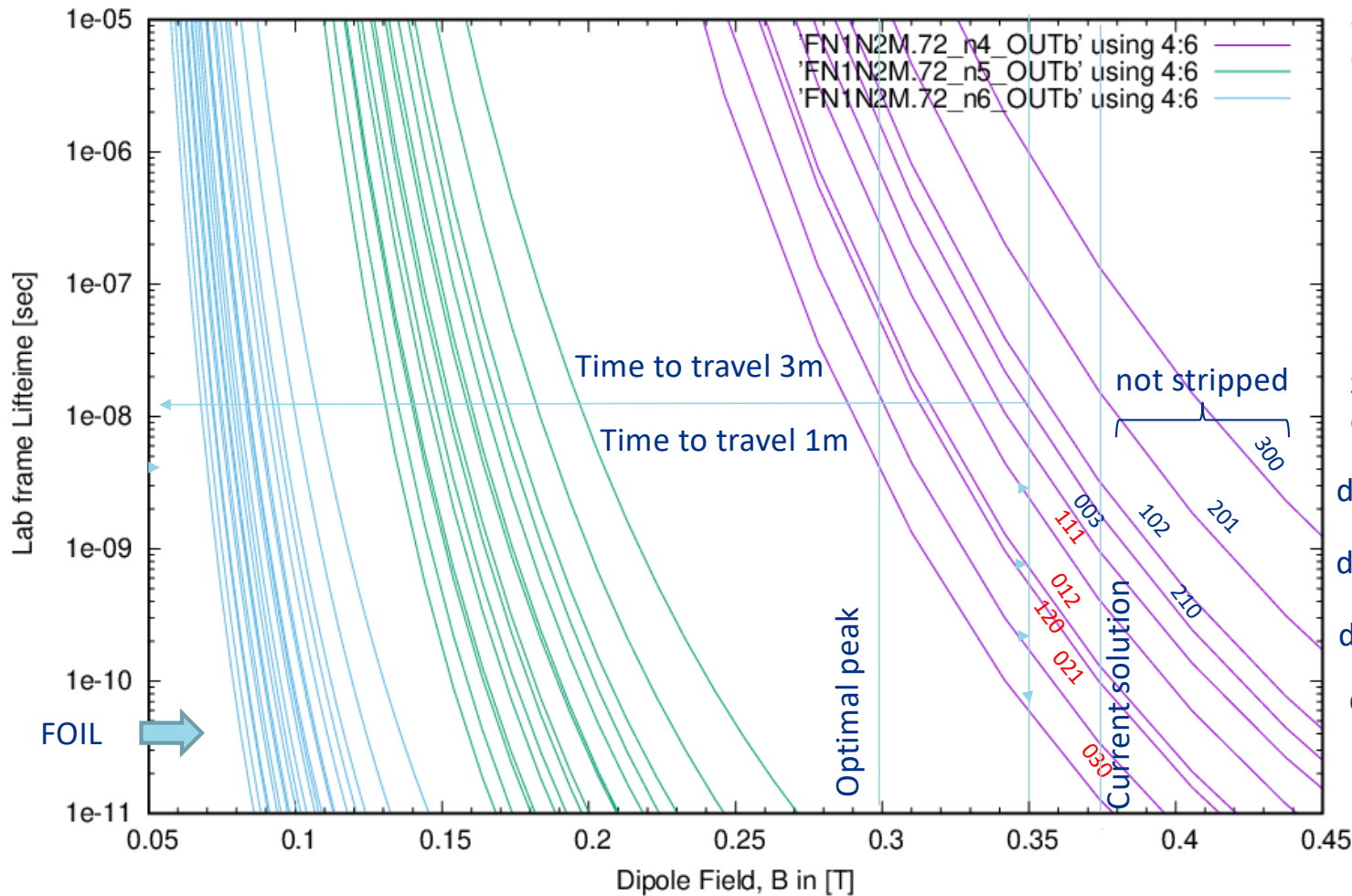# Losses due to LA Coulomb Scattering & Nuclear Scattering

Calculation by Chandra Bhat
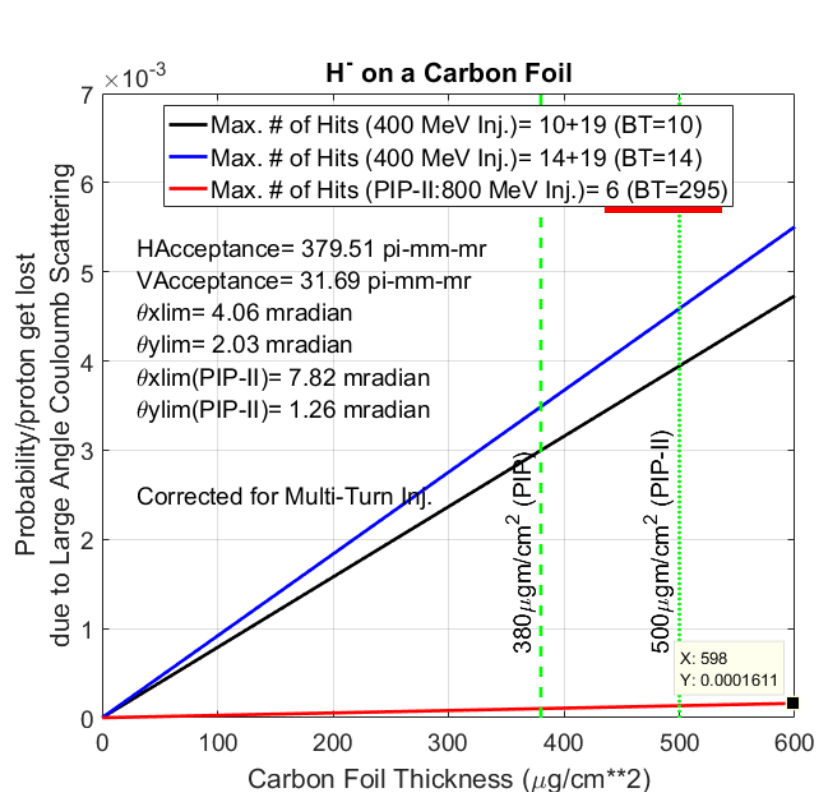
Loss = 1.6E-4 * 17 kW = 2.8W

Loss = 2.15E-5 * 17 kW = 0.37 W

Francois Ostiguy working with pyORBIT to understand implementation of Large angle scattering to predict loss distribution

3/27/2020

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Stark State Lifetime

Lifetime 800 MeV Excited States

Assume 17 kW

Depending on foil thickness
505 ug/cm² Yield n=4: 3.5E-5
600 ug/cm² Yield n=4: 9.1E-6
                Yield n=5: 4.9E-6
                Yield n=6: 2.9E-6

Power in state : n=4: 0.154 W
                       n=5: 0.083 W
                       n=6: 0.050 W

(n=4) 10 nondegenerate Stark states
Statistical population uniform: so
each state-> 10% total

d = 0.625 m

d = 0.15 m

d = 0.05 m

d = 0.015 m

n=4 →80% (0.154W) → 0.123W

Stripping of Stark States in ORBUMP after the Foil

John Johnstone looking at loss distribution

Approximation of end-field by exponential showing bend angle deficit

ORBUMP end-field from Vladimir Kashikhin
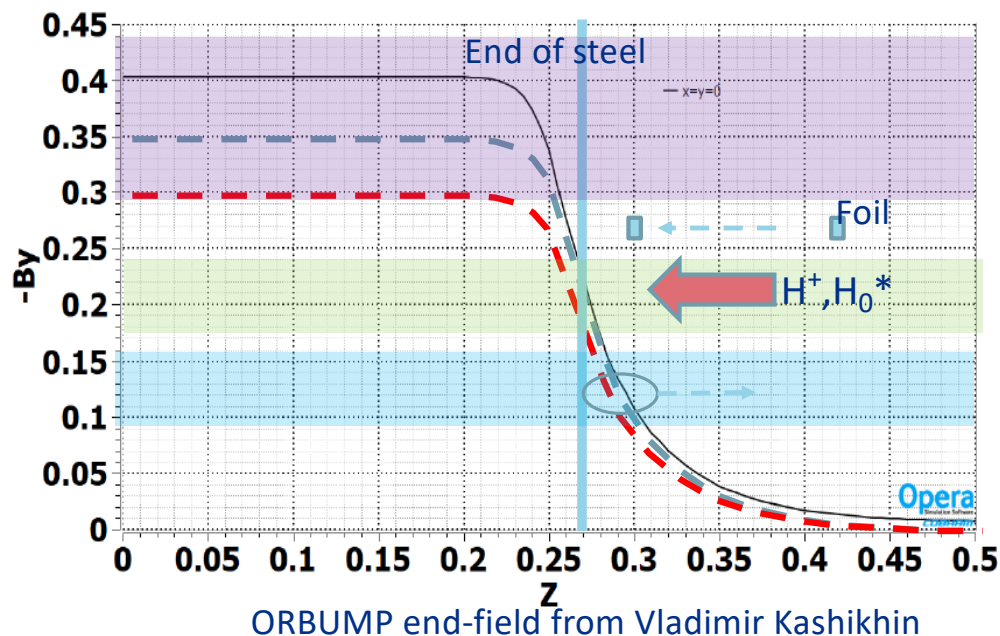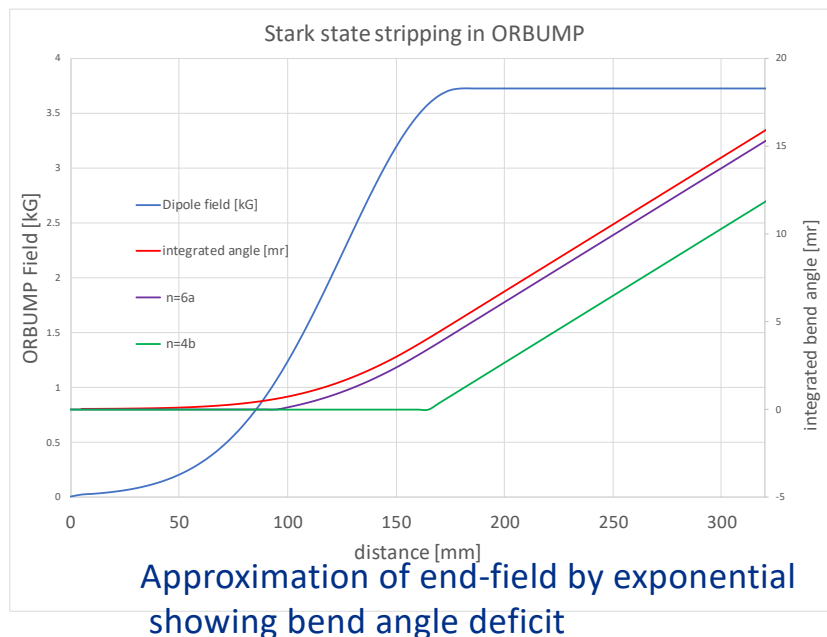
- Very preliminary results: indicate that the majority of n=5 states are lost before L12 while 19 of 21 n=6 states have no losses with only the most tightly bound lost just beyond L12

- What is the impact? Depends on the yield of each energy level

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Neutrals off the foil (2 scenarios)

Injection	1.70E+04	Watts	505	ug/cm2		600	ug/cm2	
			99.8300%	efficiency		99.9560%	efficiency	
			1.7000E-03	neutrals		4.4000E-04	neutrals	
	n	$n^{-2.8}$	yield	Power	WATTS	yield	Power	WATTS
	1	0.77199452	1.3124E-03	2.2311E+01		3.3968E-04	5.7745E+00	
	2	0.14358729	2.4410E-04	4.1497E+00	2.7794E+01	6.3178E-05	1.0740E+00	7.1937E+00
	3	0.04613818	7.8435E-05	1.3334E+00		2.0301E-05	3.4511E-01	
	4	0.02061731	3.5049E-05	5.9584E-01		9.0716E-06	1.5422E-01	
	5	0.01103784	1.8764E-05	3.1899E-01	1.1063E+00	4.8566E-06	8.2563E-02	2.8633E-01
	6	0.00662486	1.1262E-05	1.9146E-01		2.9149E-06	4.9554E-02	

*n=1,2,3 and some of 4 go to waste absorber   n= part of 4, 5, 6 are stripped in downstream ORBUMP

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Summary

- 800 MeV injection into Booster is very challenging on a number of levels

- Operation of accelerator complex at 20 Hz equally challenging (although not discussed here)

- Both AD & PIP-II are identifying the challenges and working to address

- Injection loss mitigation and understanding in progress
  - Space is very tight
  - No show-stoppers at this instant
  - Need to balance source & magnitude of losses
    - For example:
      - Increase foil thickness to reduce yield of H0 (increases LAS but reduces H0 load in absorber and reduced yield of higher excited states hence less power in Stark state stripping

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Thank you for your attention

Questions ?

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Lifetime of 800MeV H- at 800 MeV

lifetime $\tau 0(B) = (A/E) * exp(C/E)$
A= 2.47
C=4.494

lab frame lifetime
$\tau = \gamma\, \tau 0(B)$

mean decay length = $c\beta\gamma\tau 0$
fractional loss/m = $1/\beta c\tau$

— Lifetime
— loss/meter

4 kG , 7.44E-6

4 kG , 532 us

v (h-) =2.525E8 m/s
time/m = 3.459 ns/m
Leff ORBUMP +0.9m
DIstance to foil ~ 3m
Travel time to foil ~ 10.65 ns

v (h-) 10.65 ns << τ(h-) 532 us

current ORBUMP field

Lab frame lifetime [sec]

loss/m

B field [kG]

1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08

1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08

0   1   2   3   4   5