SNS Beam Loss, Activation, and Collimation

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Snowmass, July 7 2001

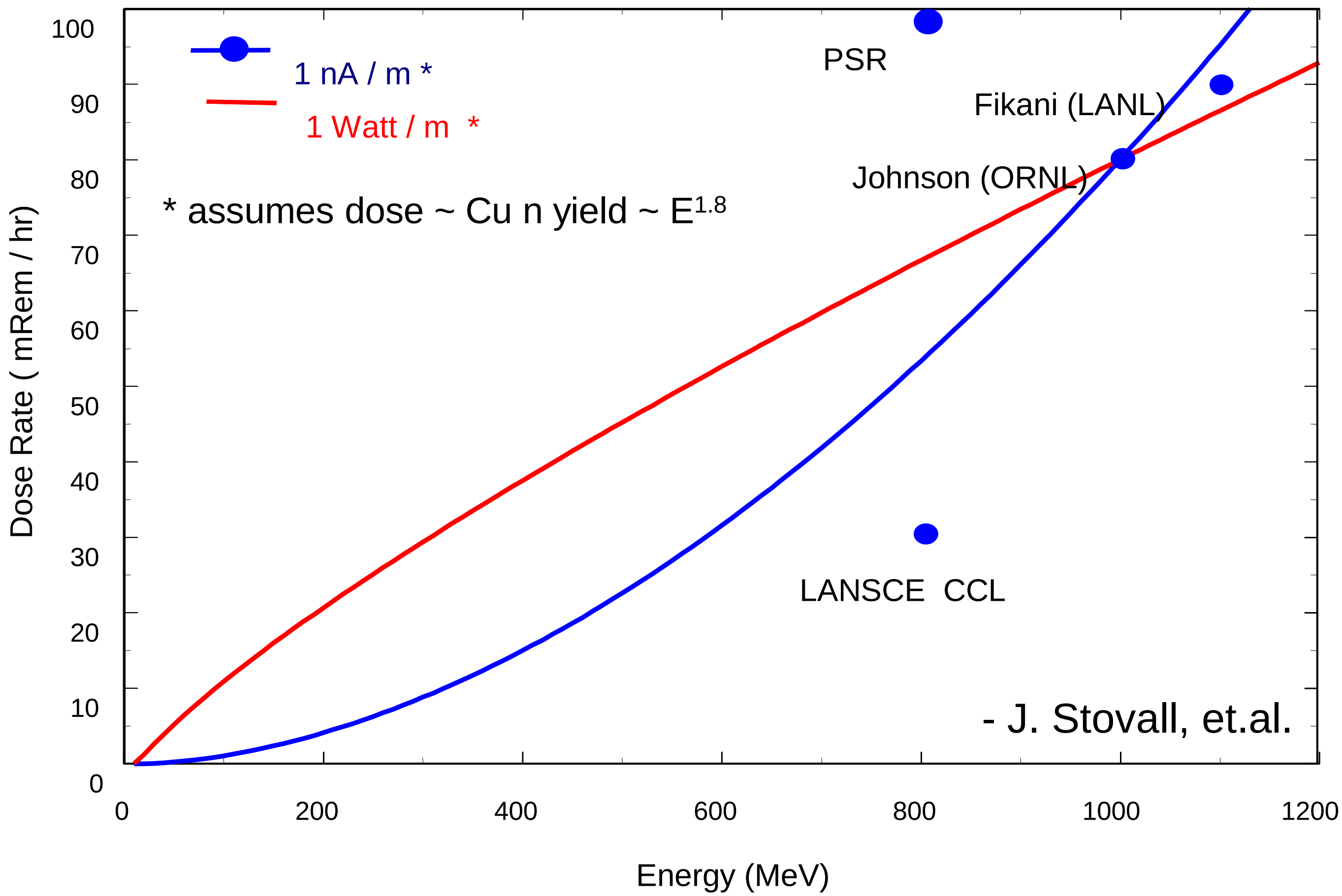
Outline

- Uncontrolled losses
  - Hands on maintenance (< 100 mrem/hr at 1 ft. 4 hrs after shutdown)
- Controlled losses / collimation
  - Local shielding, may require some remote maintenance
- Dose implications

Loss requirements

- Most of the SNS accelerator is designed as hands-on-maintenance
  - implies radiation below 100 mrem/hr at one foot, four hours after shutdown
  - this limit will dictate the SNS beam power
- Accelerator losses can be grouped as:
  - controlled losses: localized losses with adequate local shielding - may not be hands-on-maintenance.
  - uncontrolled losses
- SNS has developed a loss policy
  - expected losses are quantified as a function of position
  - serves as a guide for machine operations

Dose from beam loss vs. Energy:
(at 1 ft after 4 Hours)



- High energy losses produce more dose rate

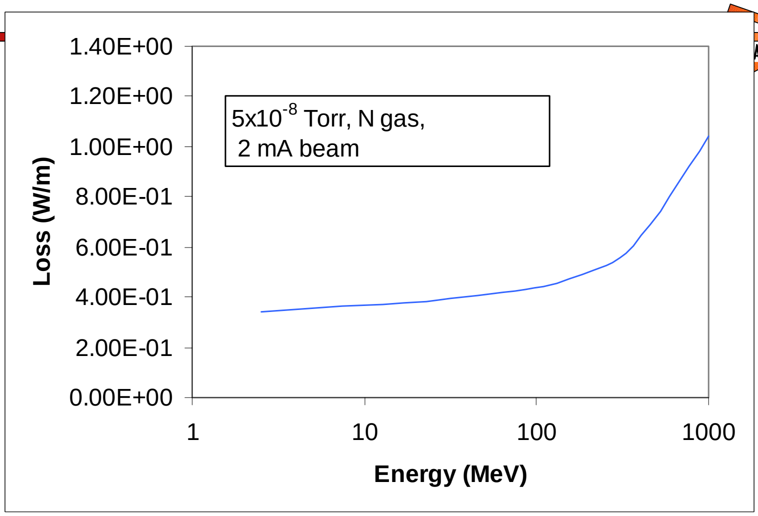
Front End Losses

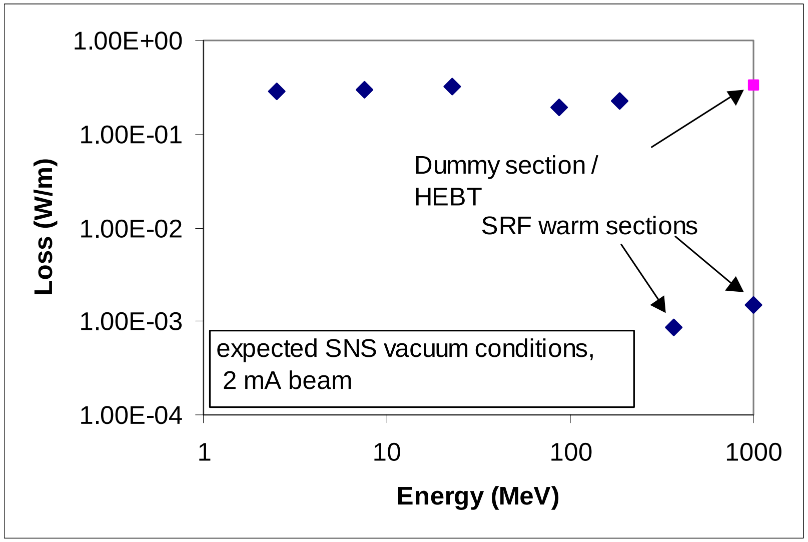
- Controlled losses (chopping)
  - LEBT: 28-32% from chopping (0.8 mA 65 keV)
  - MEBT: Up to 4% from chopping (0.1 mA at 2.5 MeV)

- Uncontrolled losses
  - RFQ: up to 20% of the beam (0.5 mA < 2.5 MeV)
  - MEBT: gas stripping ~ 1.5 W/m at 2.5 MeV

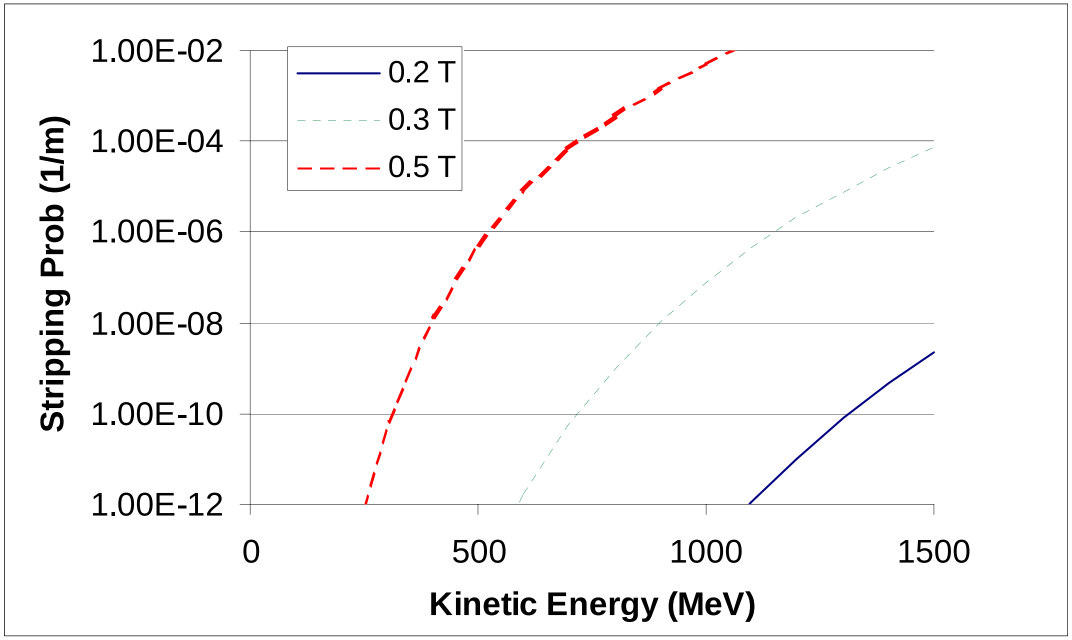
H$^-$ Loss mechanisms (gas stripping)

- Gas stripping
  - $\sigma \sim 1/\beta^2$
  - keep vacuum low
- SNS vacuum levels (Torr)
  - MEBT: $2.5\text{x}10^{-7}$
  - DTL: $9\text{x}10^{-8}$
  - CCL: $5\text{x}10^{-8}$
  - SRF warm section: $1\text{x}10^{-9}$
  - HEBT: $5\text{x}10^{-8}$
- Note: loss point is downstream of stripping region.





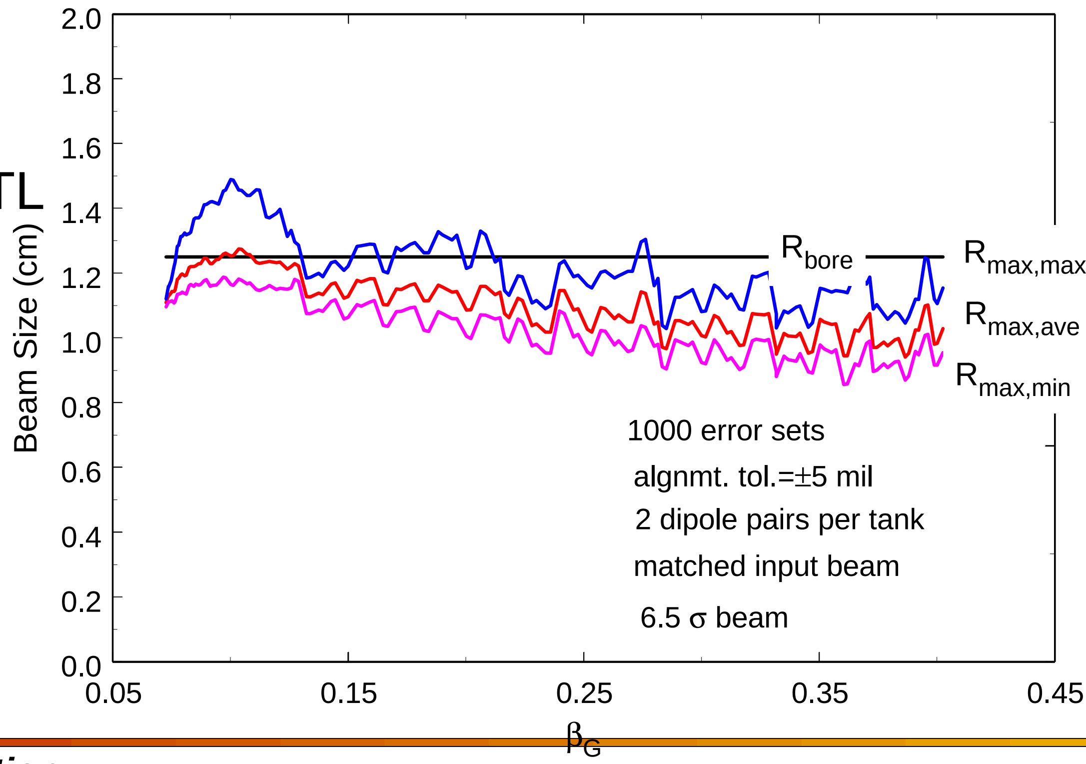
H^- Loss mechanisms (magnetic stripping)



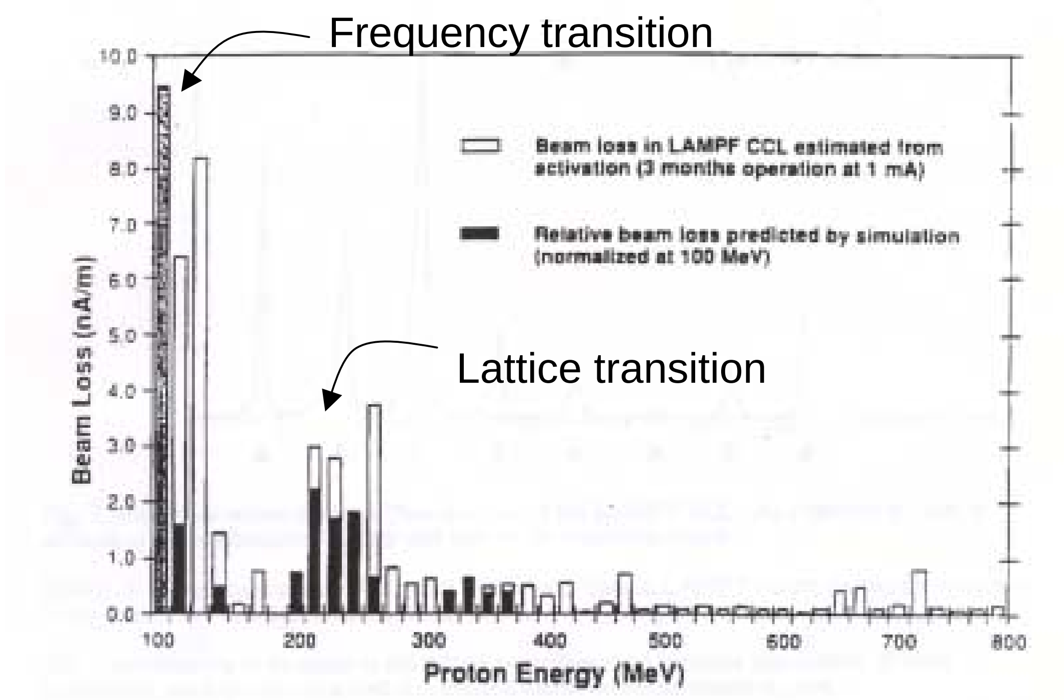
- Magnetic stripping
  - ~ B exp(-C/βγcB) (A. Jason, LANL)
  - design field so that losses are < 10^{-8}/m

H⁻ Loss mechanisms(halo losses)

- Multiparticle tracking indicates beam at ~ 6-7 rms with well matched waterbag input
- Error studies indicate beam at 6.5 σ intercepts aperture at DTL tank 1
- No model losses downstream from DTL
- Scale losses from LANSCE



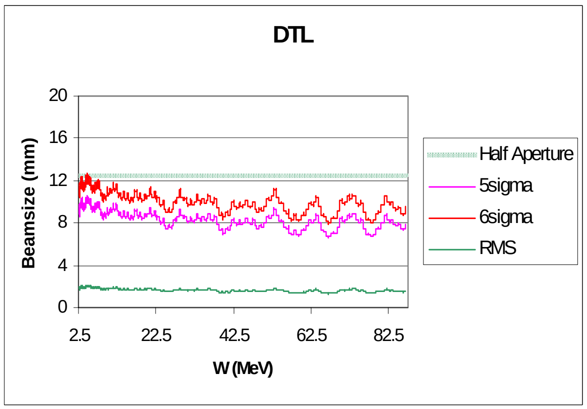
LANSCE Losses

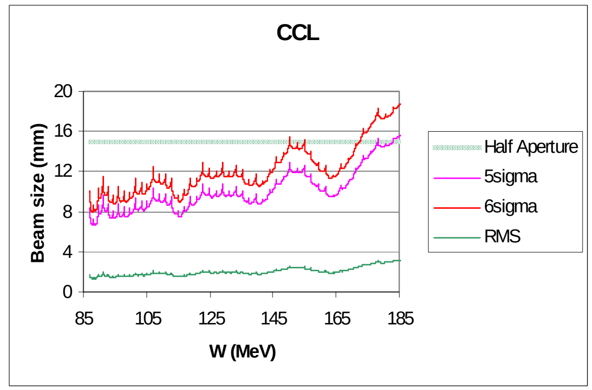


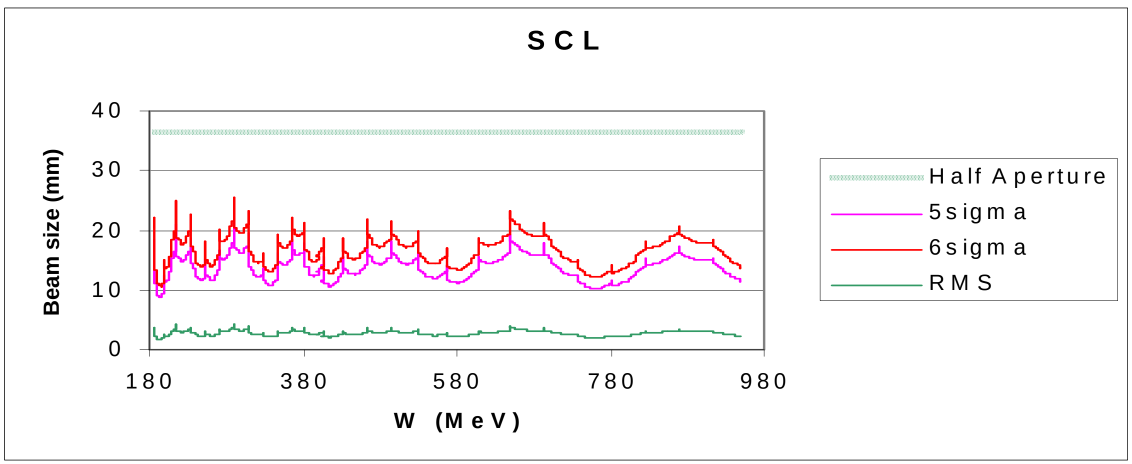
R. Garnett, R. Mills, T. Wangler, LANL

- Losses are peaked after structure transitions
- SNS halo losses are scaled from these: 1 nA/m background with peaks after DTL, CCL transitions, and at end of the CCL

SNS Linac Beam Size vs. Aperture





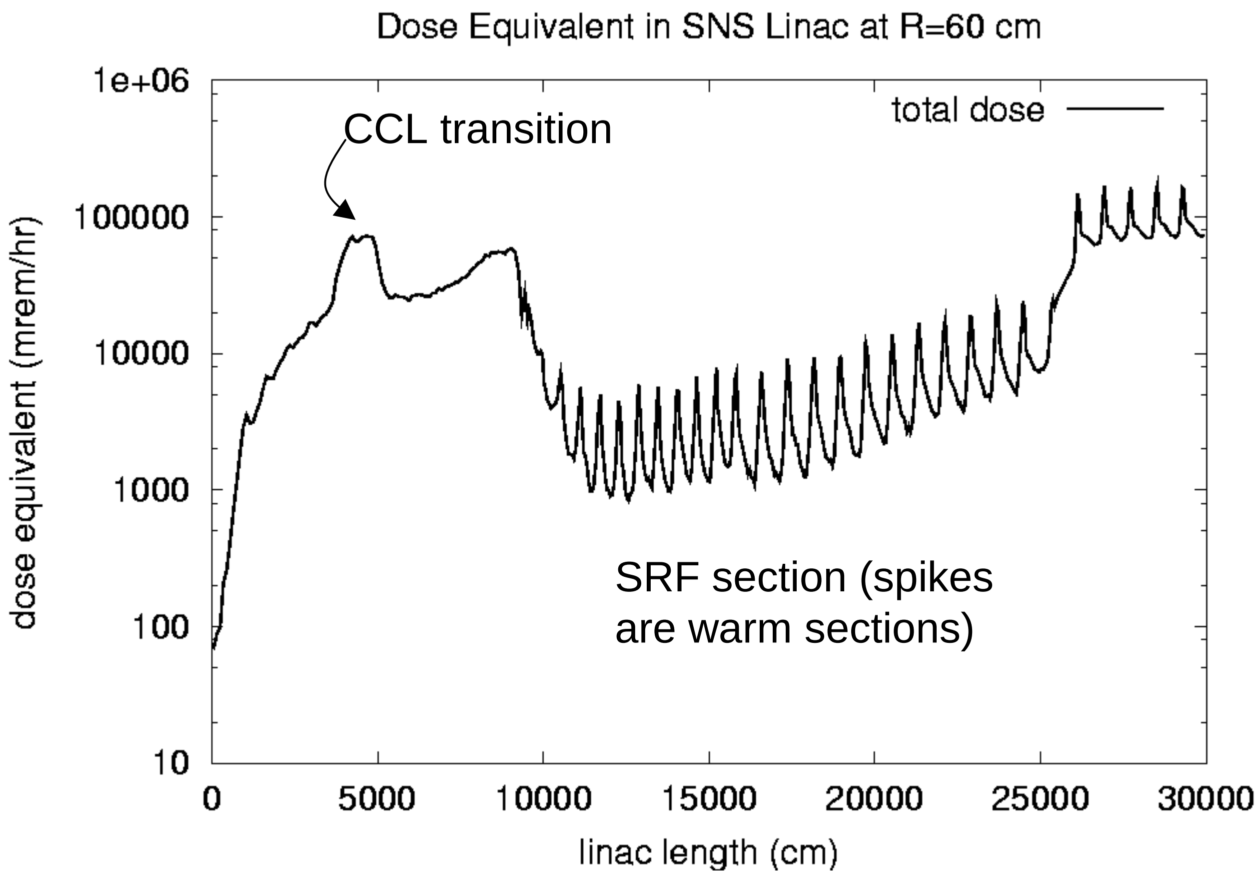


- Beam closest to pipe at start of DTL and end of CCL

Linac Losses

POSITION	*ENERGY RANGE (MeV)*	*LENGTH (m)*	*STRIPPING LOSS RATE (nA/m)*	*HALO LOSS RATE (nA/m)*	*TOTAL LOSS RATE (nA/m)*	*Av.Tot. LOSS RATE (W/m)*
MEBT	2.5	3.6	623	***	623***	1.56
DTL tank 1	2.5- 7.5	4.2	112	32	144	0.72
DTL tank 2	7.5- 22.3	6.1	40	8	48	0.72
DTL tank 3	22.3- 39.8	6.3	14	1	15	0.47
DTL tank 4	39.8- 56.6	6.4	8	1	9	0.44
DTL tank 5	56.6- 72.5	6.3	6	1	7	0.45
DTL tank 6	72.5- 86.8	6.3	4.5	1	5.5	0.44
CCL module 1	86.8-107.2	11.8	2.3	8	13.6	1.32
CCL module 2	107.2-131.1	13	1.9	1	2.9	0.35
CCL module 3	131.1-157.2	14	1.5	1	2.5	0.36
CCL module 4	157.2-185.6	15	1.2	2	3.2	0.55
SCL low beta*	185.6-379	18	<0.005	<0.2	<0.2	<0.06
SCL high beta*	379 -1000	19	<0.003	<0.2	<0.2	<0.14
Suppl. 9 periods	1000	71	<0.150	<0.2	<0.35	<0.35

Linac dose rate



- Dose is ~ 1000 times lower 4 hrs. after shutdown.

HEBT Losses (D. Raparia)

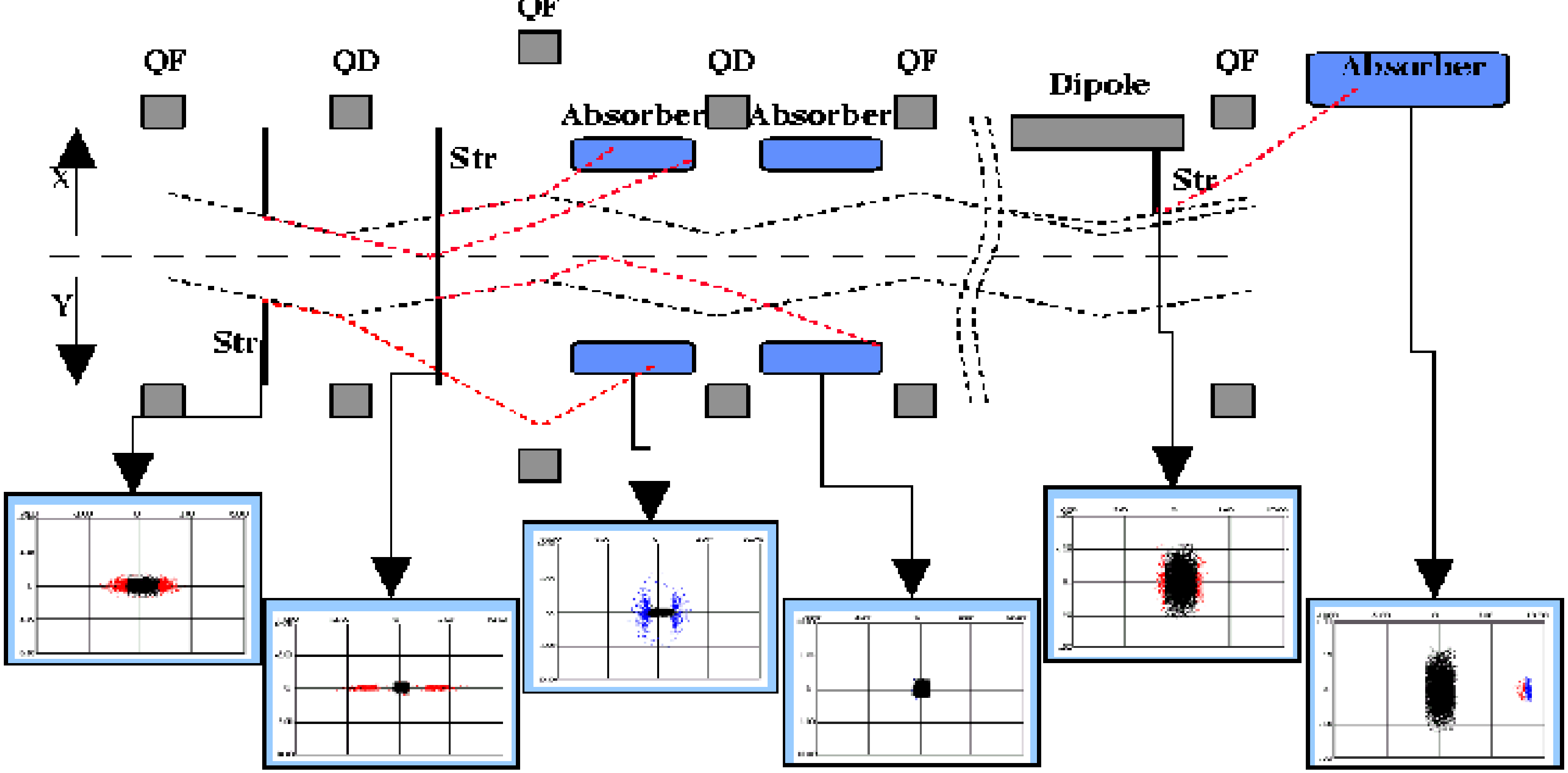
- Uncontrolled Losses
  - Vacuum: 5×10^{-8} Torr, losses are ~ 2×10^{-7}/m
  - Magnetic stripping: < 10^{-8}/m

- Controlled losses:
  - Transverse collimation
    - 2 adjustable foils + 2 absorbers
    - Designed for 10^{-2} beam, expect < 10^{-4}
  - Longitudinal collimation:
    - 1 adjustable foil set (at max. dispersion in arc)
    - 1 absorber external to beamline (10^{-3} capacity)

HEBT Collimation

(D. Raparia)

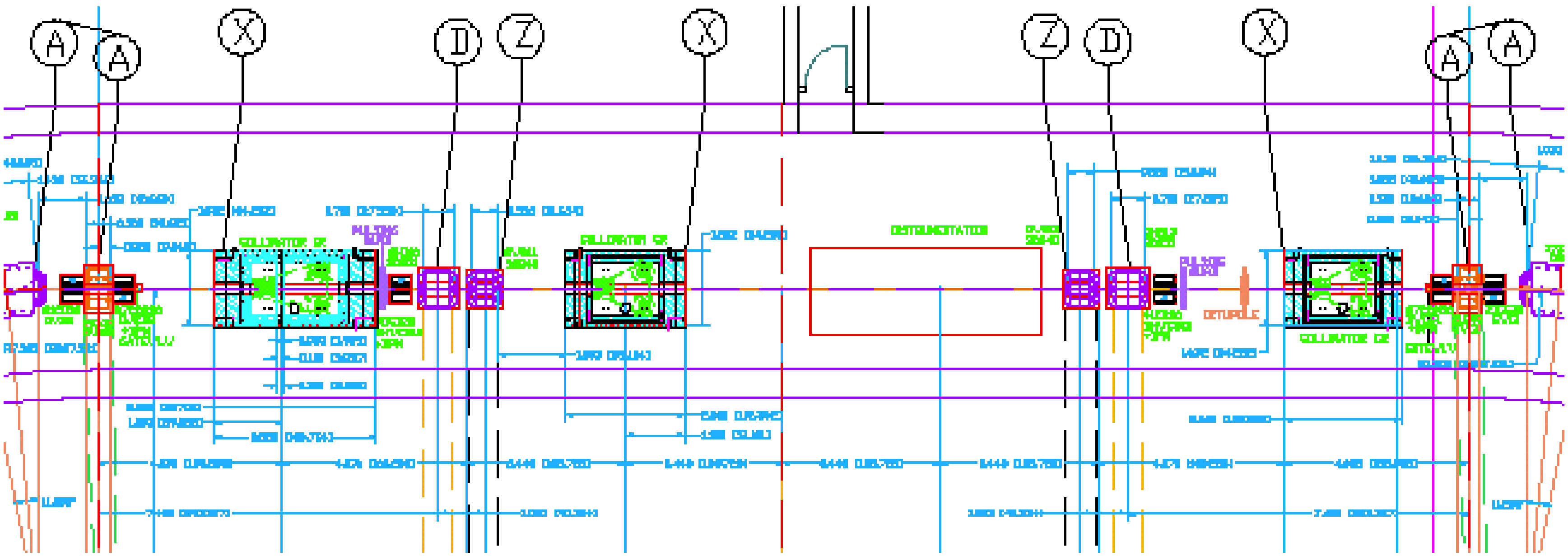
- Two scrapers + two absorbers for betatron collimation
- One scraper + one absorber for momentum cleaning
- Cleans transverse halo and momentum tails from linac



Ring Uncontrolled Losses

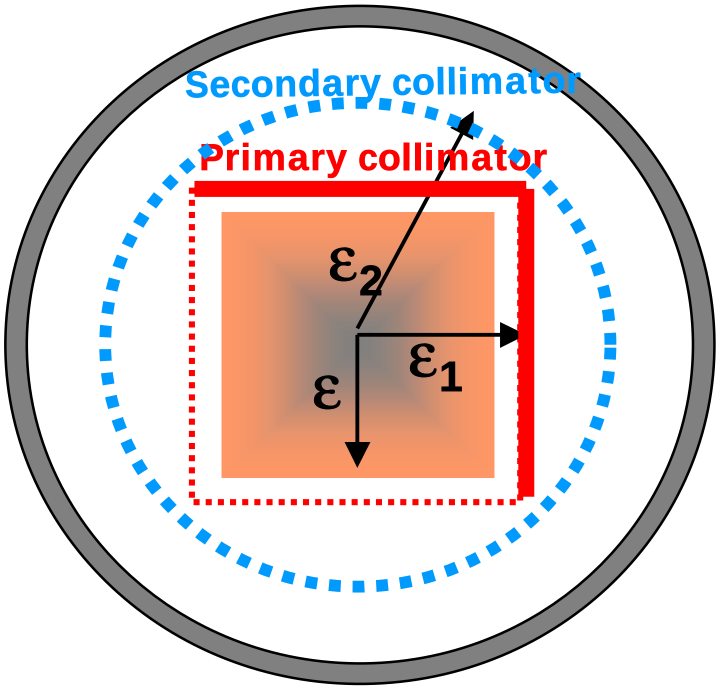
- Uncontrolled injection losses
  - Nuclear scattering from foil traversals
  - ~ 7 traversals/particle nominally, 300 $\mu g/cm^2$ foil, $\Rightarrow$ $4x10^{-5}$ loss
  - Magnetic stripping in injection dipole $\approx 10^{-5}$ loss
  - Excited state H^o loss $\approx 10^{-5}$ loss
- Ring uncontrolled losses
  - ~ $2x10^{-3}$ of beam is in tails and intercepts collimator
  - Collimator is estimated to be > 95% efficient
  - $\Rightarrow 10^{-4}$ beam lost (distributed around the ring).

Ring transverse collimation
B Superperiod layout



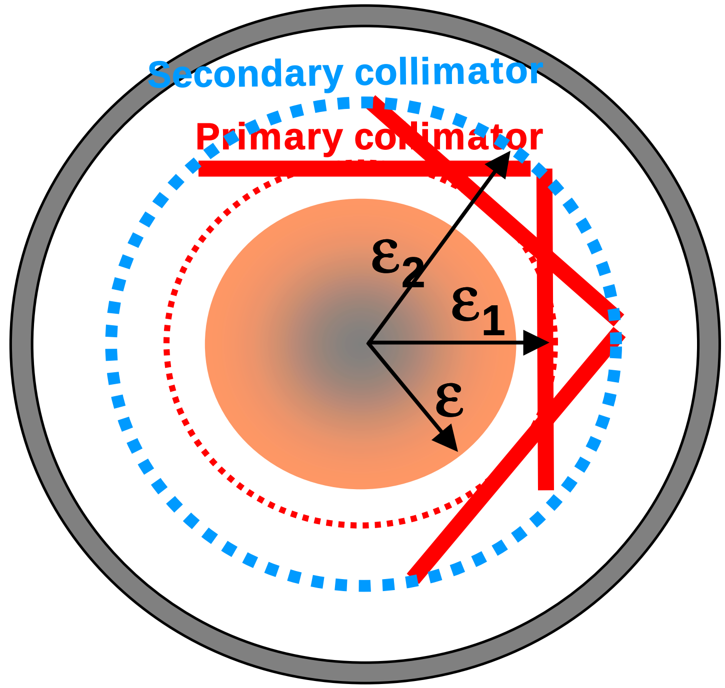
Correlated and Anti-correlated Collimation Schemes (N. Catalan Lasheras)

Correlated painting



$$\varepsilon_1 > \varepsilon = 120 \;\; ; \;\; \varepsilon_2 > 2\varepsilon_1$$

Anti-correlated painting

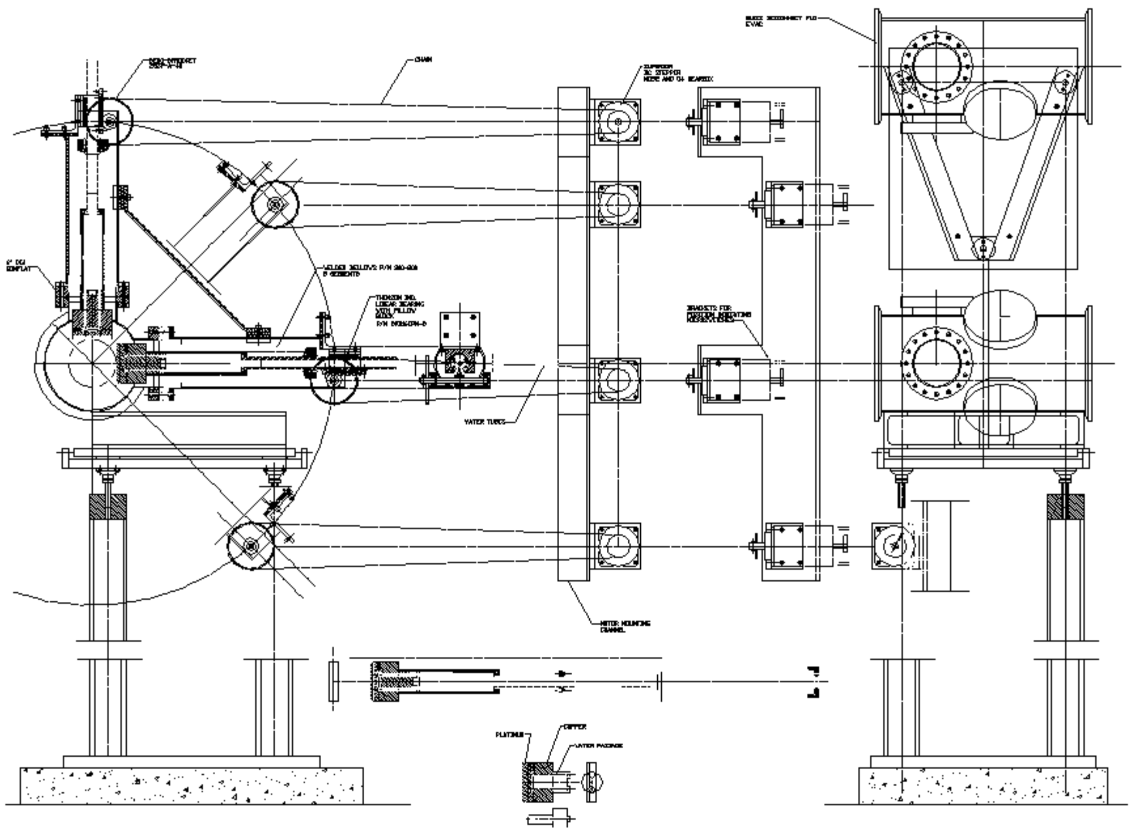


$$\varepsilon_1 > \varepsilon = 160 \;\; ; \;\; \varepsilon_2 > \varepsilon_1$$

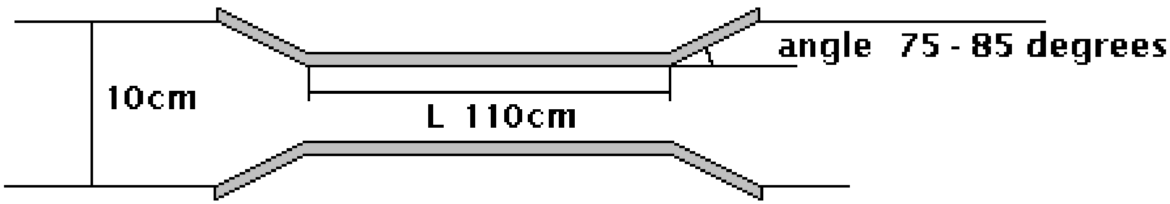
$$\varepsilon_1 = 140; \; \varepsilon_1 = 180; \; \varepsilon_2 = 300$$

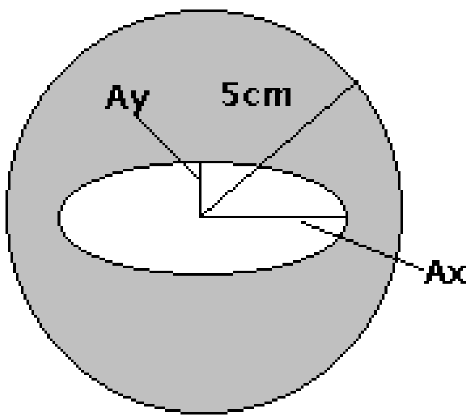
Primary Collimator Movable Scraper (J. Brodowski)

- Platinum scrapers 0.55cm thick, mounted on copper support
- Moveable in the range 100 -300π μm
- Two or four scrapers inside the beam



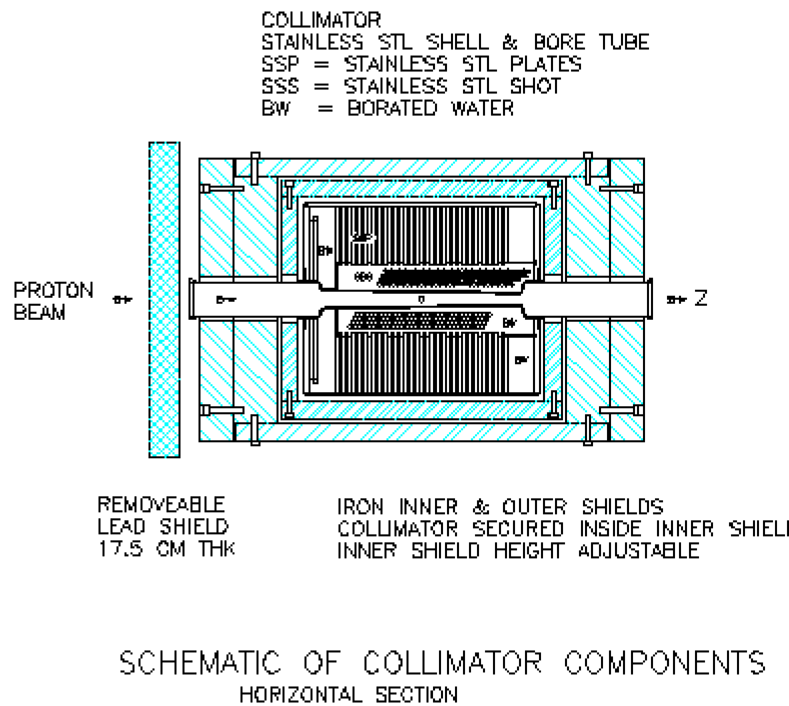
Secondary collimators
Absorbers (N. Simos)





Secondary 1
Ax ~= 4.7cm
Ay ~= 5.6cm

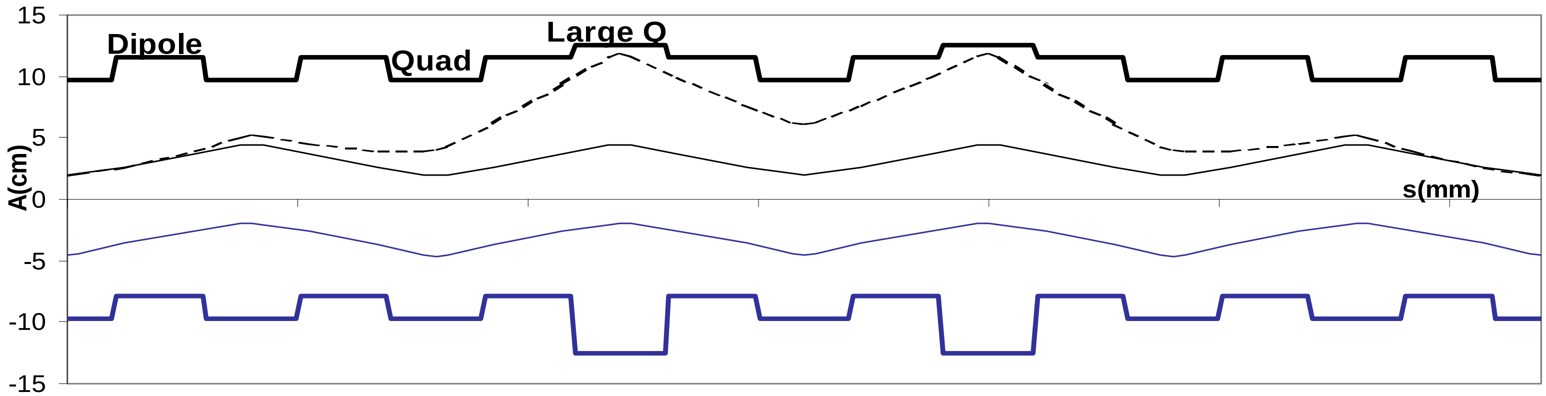
Secondary 2
Ax ~= 7.0cm
Ay ~= 4.1cm



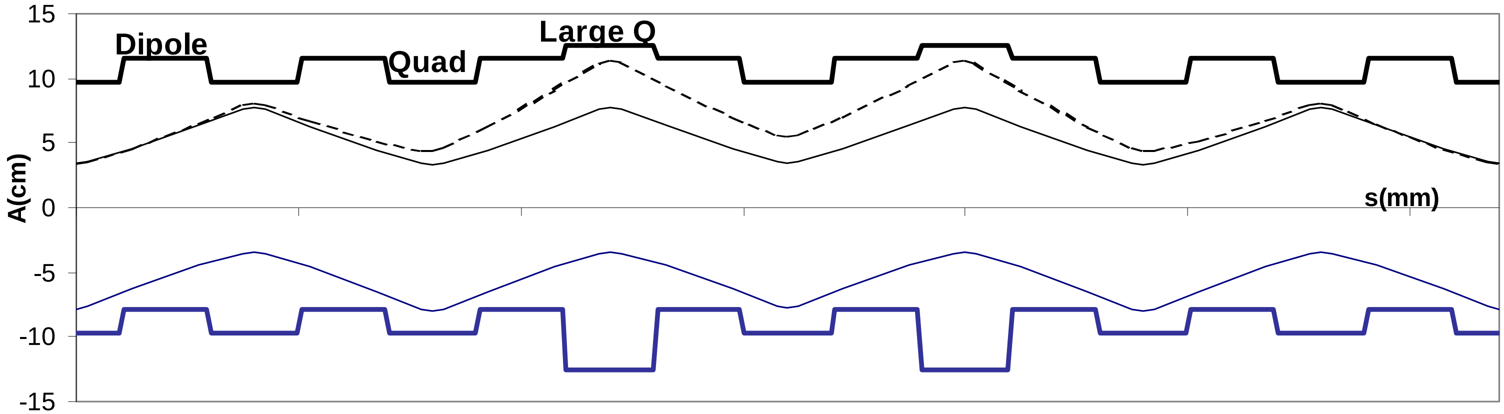
- Aperture 300π μm Section changing along the collimator following β

New Baseline
Arc Acceptance

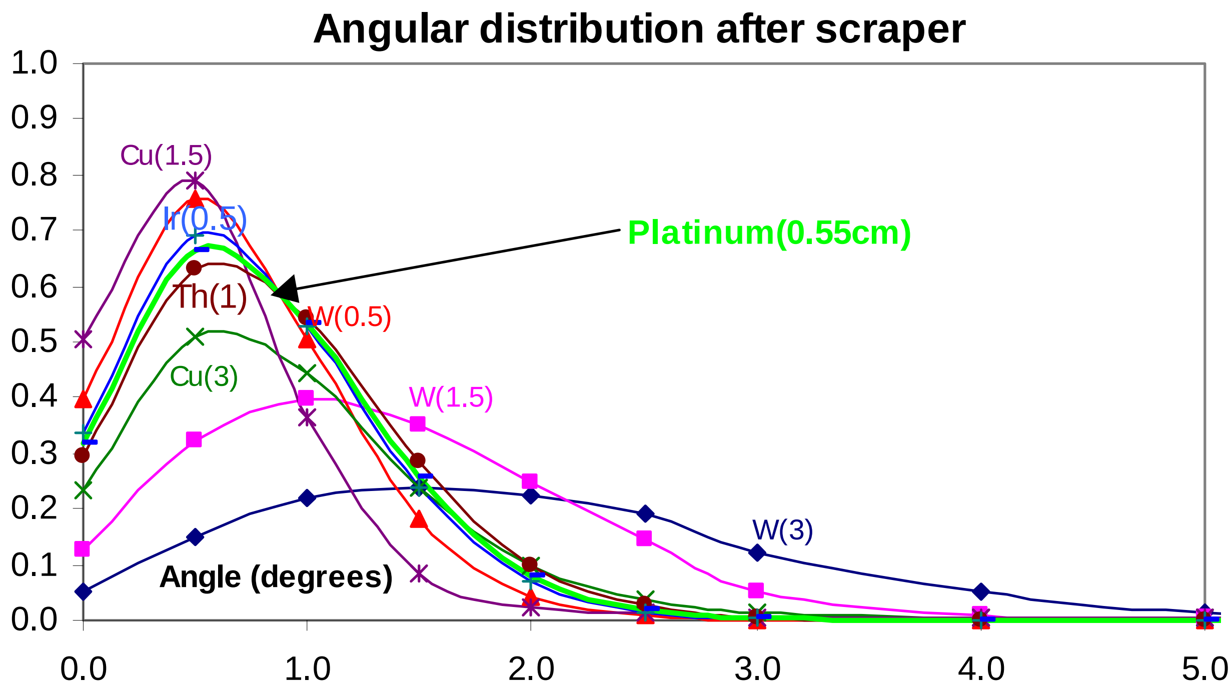
- 160π µm @ dp/p0=0.02



- 480π µm @ dp/p0=0.01

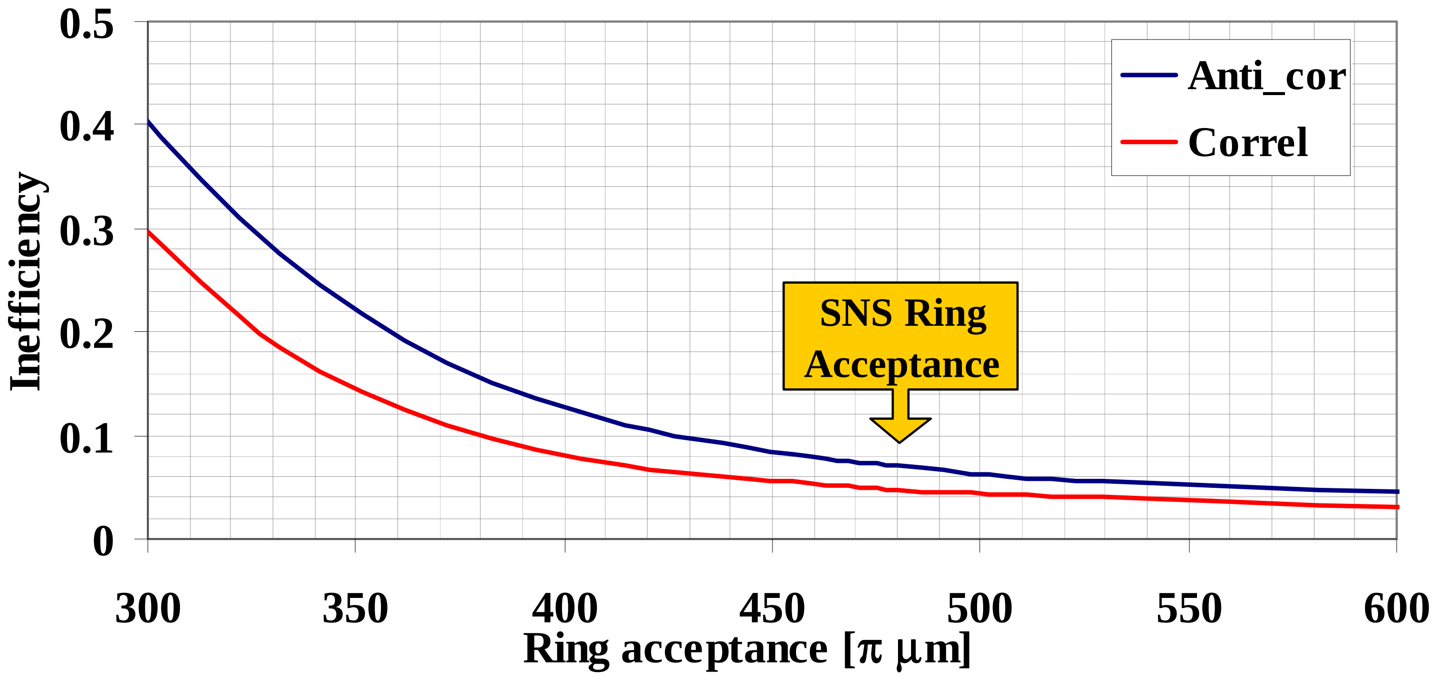


Collimation System Optimization
Scraper Material (N. Catalan Lasheras)



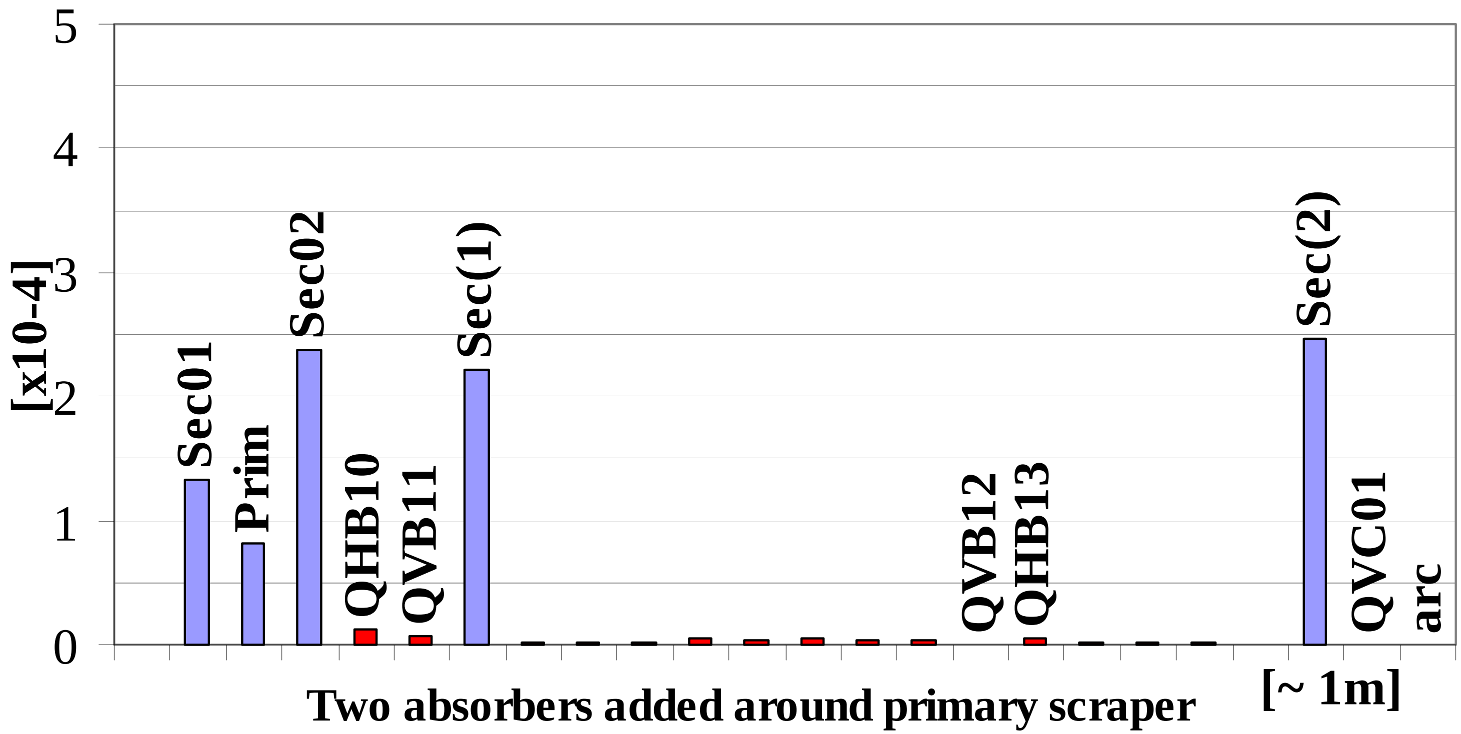
- Material length adjusted for an energy loss $\delta p/p_0 < 1\%$
- Large coulomb scattering required
- Platinum chosen as scraper material (high melting point, high thermal conductivity)

Collimation system efficiency
Simulation results (N. Catalan Lasheras)



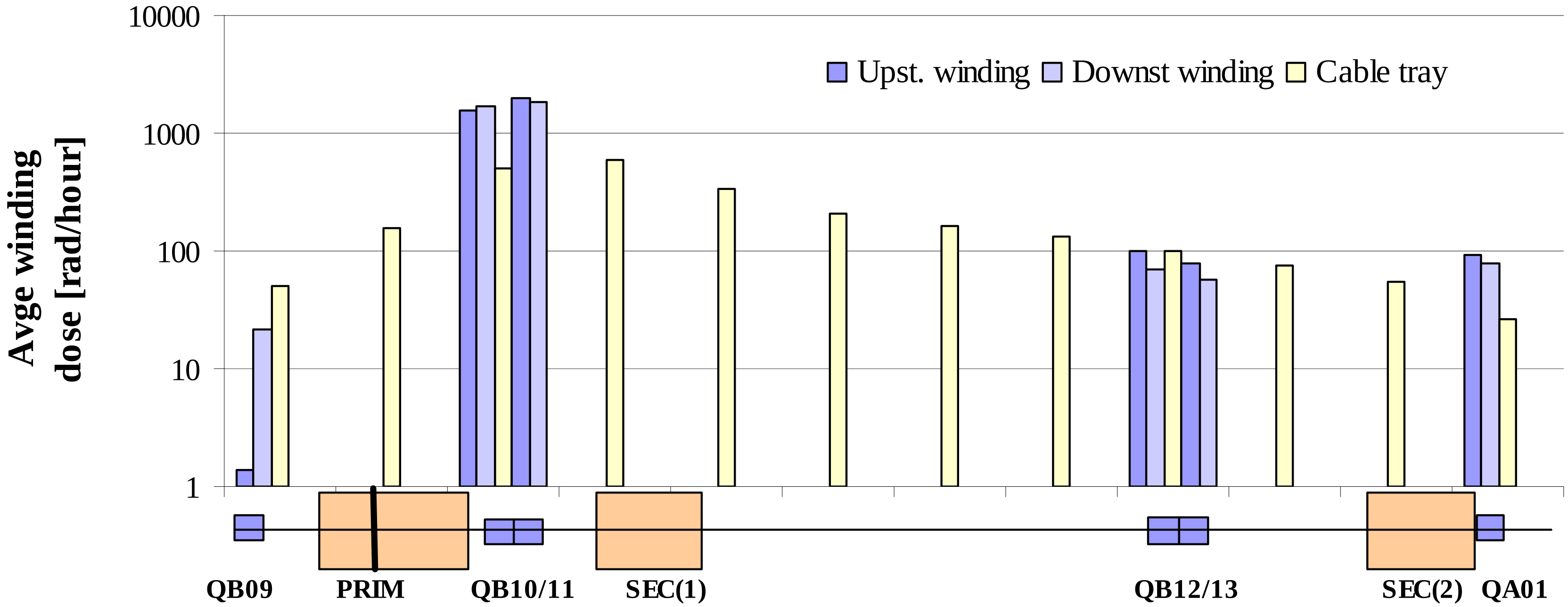
- Fraction escaping the collimation system above the machine acceptance is consider as uncontrolled loss
- Cleaning efficiency about 95%
- Uncontrolled loss about 10^{-4} of the total beam

Loss distribution along the collimation section (N. Catalan Lasheras)



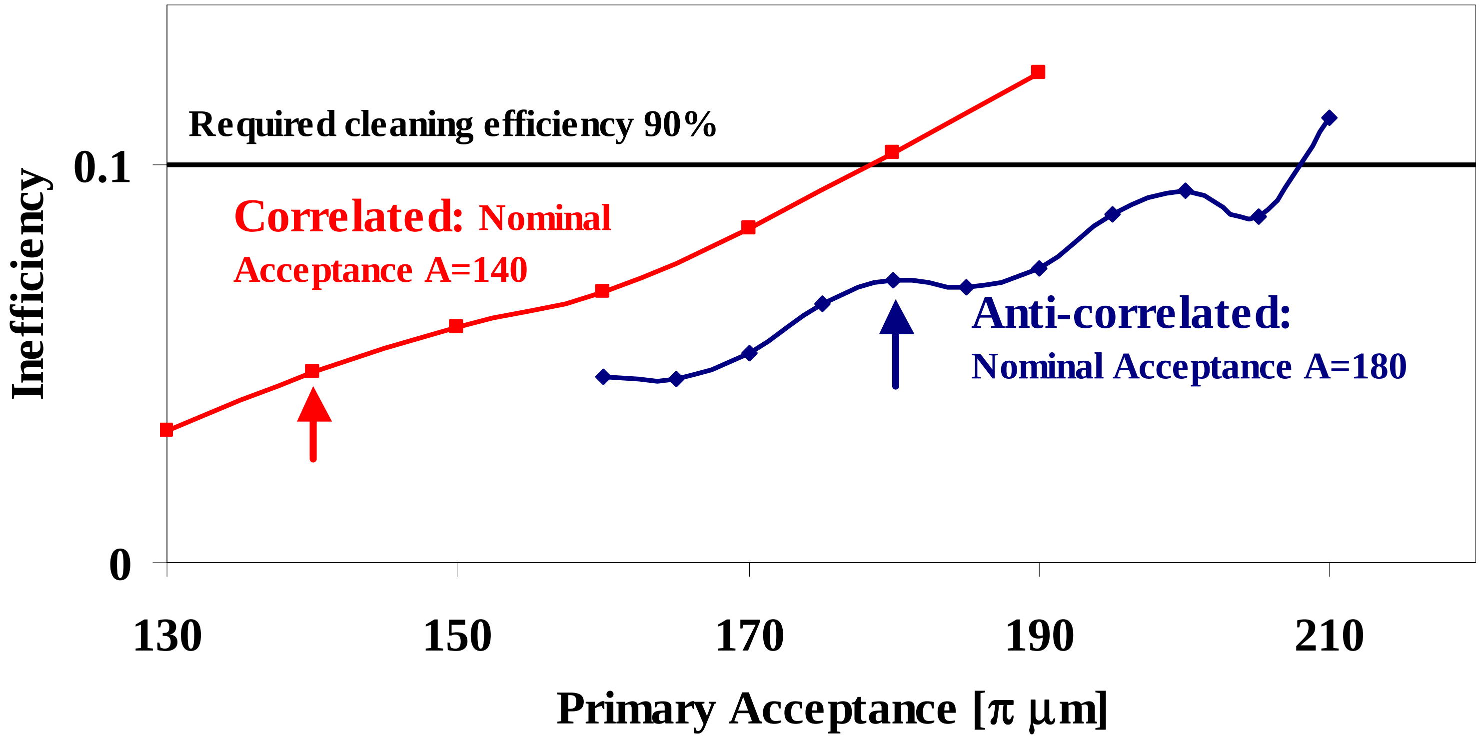
- Assuming 0.1% of the beam in the halo
- New absorber structure around primary collimator, added shielding before QHB10.

Collimation section dose during operation (H. Ludewig)



- Earth berm dose < 2mrem/hour
- Lifetime estimates for insulator
  - Cable winding 1-2x10^5 hours. Cable trays 7x10^4 - 4x10^5 hours

Cleaning efficiency vs. primary scraper position



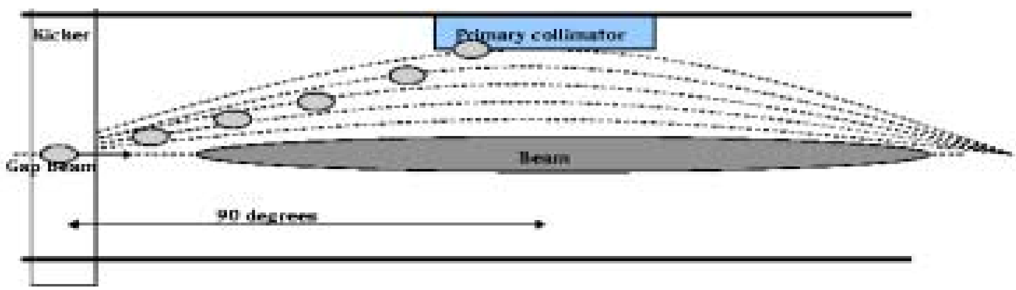
- The scraper can be opened up to 180/ 205 π μm keeping the cleaning efficiency above 90%

Longitudinal collimation
Beam-In-Gap kicker (S. Cousineau, J. Holmes)

Cleaning of longitudinal losses

- Kick the beam-in-gap vertically and drive it into the primary collimator

"Unbunched beam cleaning in HERA-p"
C.Montag, J.Klute (EPAC'00)

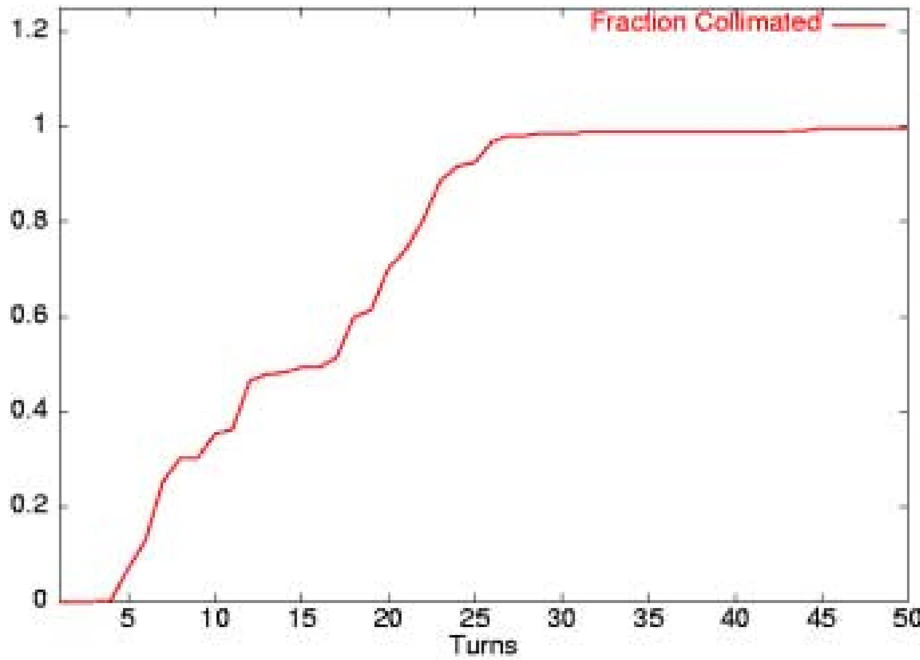


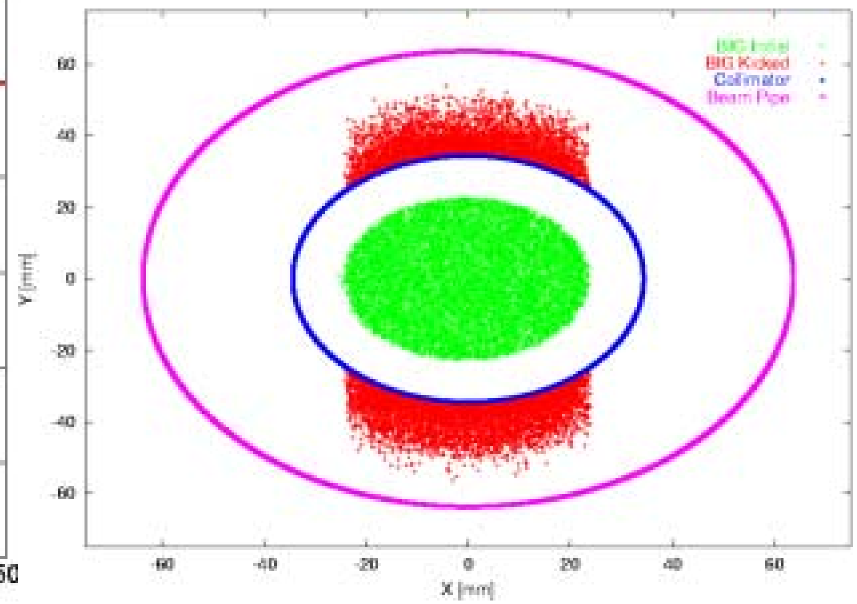
- Five fast kicker modules after the extraction channel
- Operate at the revolution frequency
- Same strength, polarity changes according to the tune

Process modeled using ORBIT

- Tracking 10^4 protons for 50 turns
- BIG emittance: 60π μm
- Primary aperture:140π μm
- Angular kick: 1mrad
- Kick sequence: 26 kicks, sweeping over resonance tunes 5.7-5.9
- Central tune ν_y = 5.8 (tune spread between 5.7-5.9)

Beam-In-Gap kicker
Preliminary results

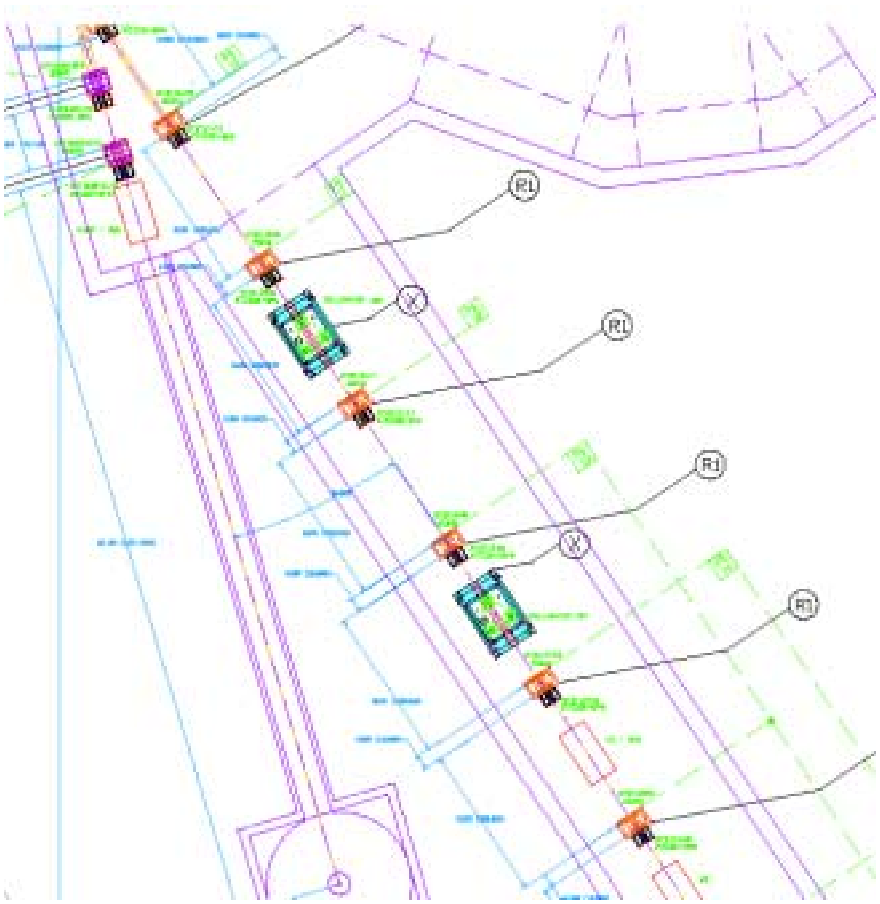




- First results:
  - 100% absorption in 50 turns
  - No losses in the beam pipe around the machine
  - Large impact parameters at primary collimator (good efficiency)
- Error studies in progress

RTBT Collimation

(D. Raparia)



- Protects the target in case of failure of the extraction kicker
- Scrapes 10% of the beam when two kickers misfire
- Design to take the full beam
- Two absorbers as for the ring, 3m long, 90 degrees apart
- Collimation aperture 400π μm

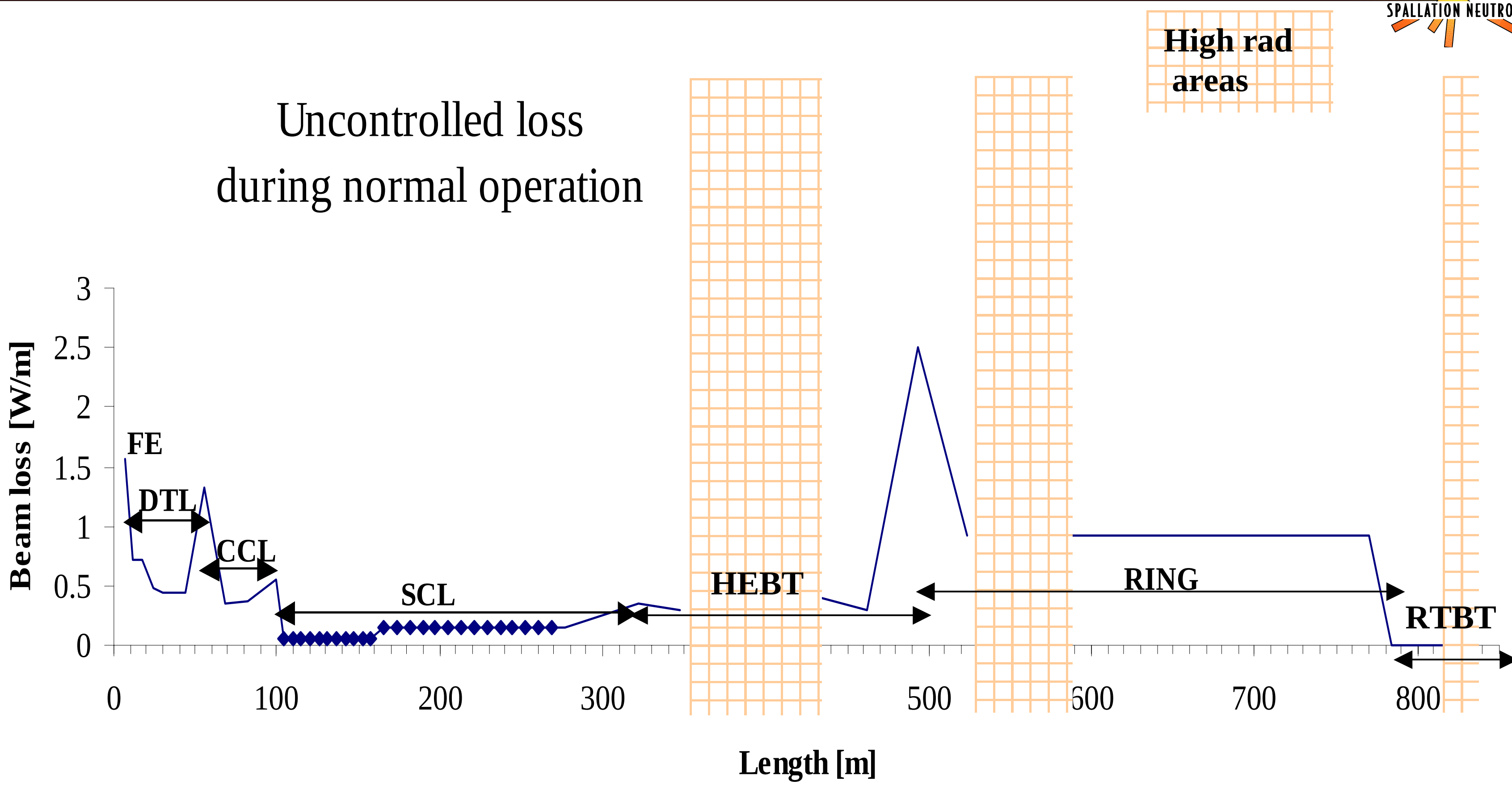
Controlled losses

Mechanism	Location	Fraction	Energy	Power
FRONT END				
Unbunched beam	**LEBT chopper**	**27.7 e-2**	**0.065 MeV**	**36 W**
Unbunched beam	**MEBT chopper**	**3.4 e-2**	**2.5 MeV**	**215 W**
HEBT				
H^0 ionization in the Linac	**Linac dump**	**1.0 e-5**	**< 1 GeV**	**20 W**
Linac transverse tails	**x-y collimator**	**1.0 e-5**	**1 GeV**	**20 W**
Energy jitter/spread	**z collimator**	**1.0 e-3**	**1 GeV**	**2 kW**
RING				
Beam in gap	**Collimators**	**1.0 e-4**	**1 GeV**	**200 W**
Excited H0 at foil	**Collimator**	**1.3 e-5**	**1 GeV**	**26 W**
Partial ionization/foil miss	**Injection dump**	**1.0 e-2**	**1 GeV**	**20 kW**
Space-charge halo	**Collimator**	**1.9 e-3**	**1 GeV**	**3.8 kW**
Energy straggling at foil	**Collimator**	**3.0 e-6**	**1 GeV**	**6 W**
RTBT				
Kicker missfire	**Collimator**	**1.0 e-5**	**1 GeV**	**20 W**

Uncontrolled losses

Mechanism	Location	Fraction	Energy [MeV]	Length [m]	Power [W/m]
Front End					
RFQ transmission	**Uniform**	**2.0 e-1**	**0.75**	**3.7**	**80.7**
Drift Tube Linac (DTL)					
Emittance growth	**End of Tank 1**	**6.6 e-5**	**2.5 – 7.5**	**4.2**	**0.24**
Emittance growth	**End of Tank 2**	**2.42 e-5**	**7.5 - 22**	**6.1**	**0.18**
Couple Cavity Linac (CCL)					
Double H- stripping	**CCL module 1**	**1.9 e-5**	**86.5 - 107**	**12**	**0.35**
Emittance growth	**CCL module 1**	**4.7 e-5**	**86.5 - 107**	**12**	**0.86**
Super Conducting Linac (SCL)					
Emittance growth	**Warm sections**	**3.7 e-6**	**< 1000**	**37**	**<0.2**
Emittance growth	**Supl. 9 Periods**	**1.24e-5**	**< 1000**	**71**	**0.35**
High Energy Beam Transport (HEBT)					
Collimator out-scattering	**Achromat**	**7.5 e -6**	**1000**	**15**	**0.1**
Accumulator Ring					
Magnetic H- striping	**INJB2**	**1.3 e-7**	**1000**	**1**	**0.3**
Nuclear scattering at foil	**Foil**	**3.7 e-5**	**1000**	**30**	**2.5**
Collimator inefficiency	**All ring**	**1.0 e-4**	**1000**	**218**	**0.9**
Ring to Target Beam Transport (RTBT)					
Nuclear scatt. at window	**Window**	**4.0 e-2**	**1000**	**--**	**??**

Beam loss distribution (N. Catalan Lasheras)



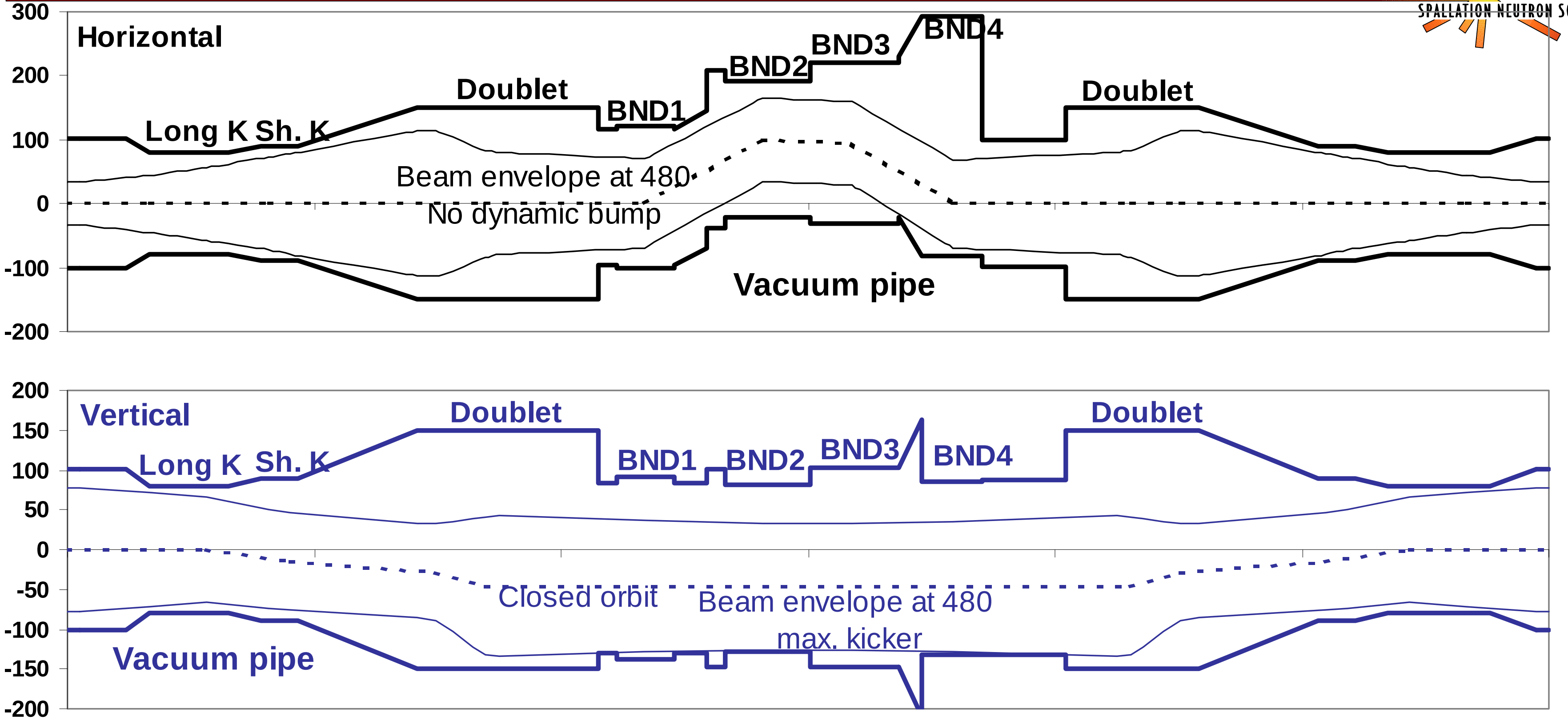
- AP input to operations planning (G. Dodson)

Summary

- SNS expects to maintain losses below ~ 1 W/m over most of the accelerator in order to allow hands-on maintenance
  - Important loss mechanisms include gas stripping, magnetic stripping and halo generation
  - Dose rates < 100 mrem/hr, 4 hours after shutdown at 1 foot

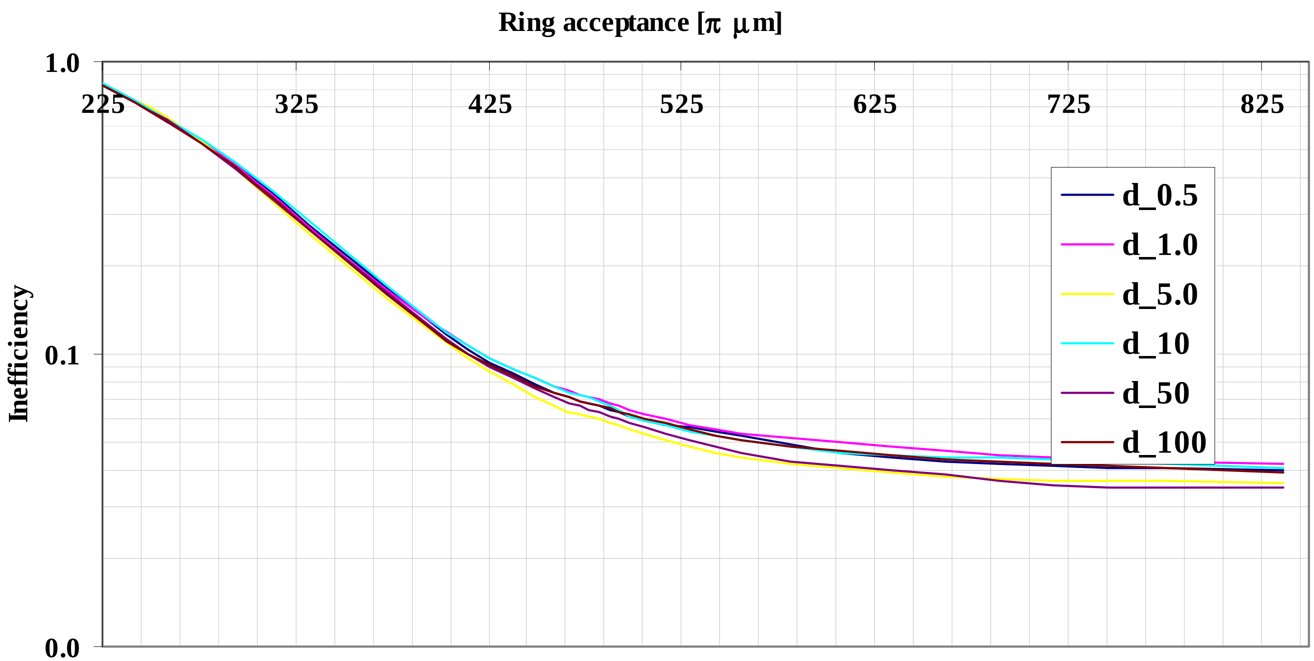
- Controlled loss points (collimation) in the HEBT, Ring and RTBT will require additional shielding.

New Baseline
Injection Section Acceptance



- Designed for correlated and anti-correlated painting
- Limited by the chicane; 480π mm·mrad required

Sensitivity to halo growth velocity



- Actual impact parameters are small but not yet known
- One jaw system is very sensitive to the beam impact parameter
- Two stage system efficiency shows no variation against changes within three orders of magnitude

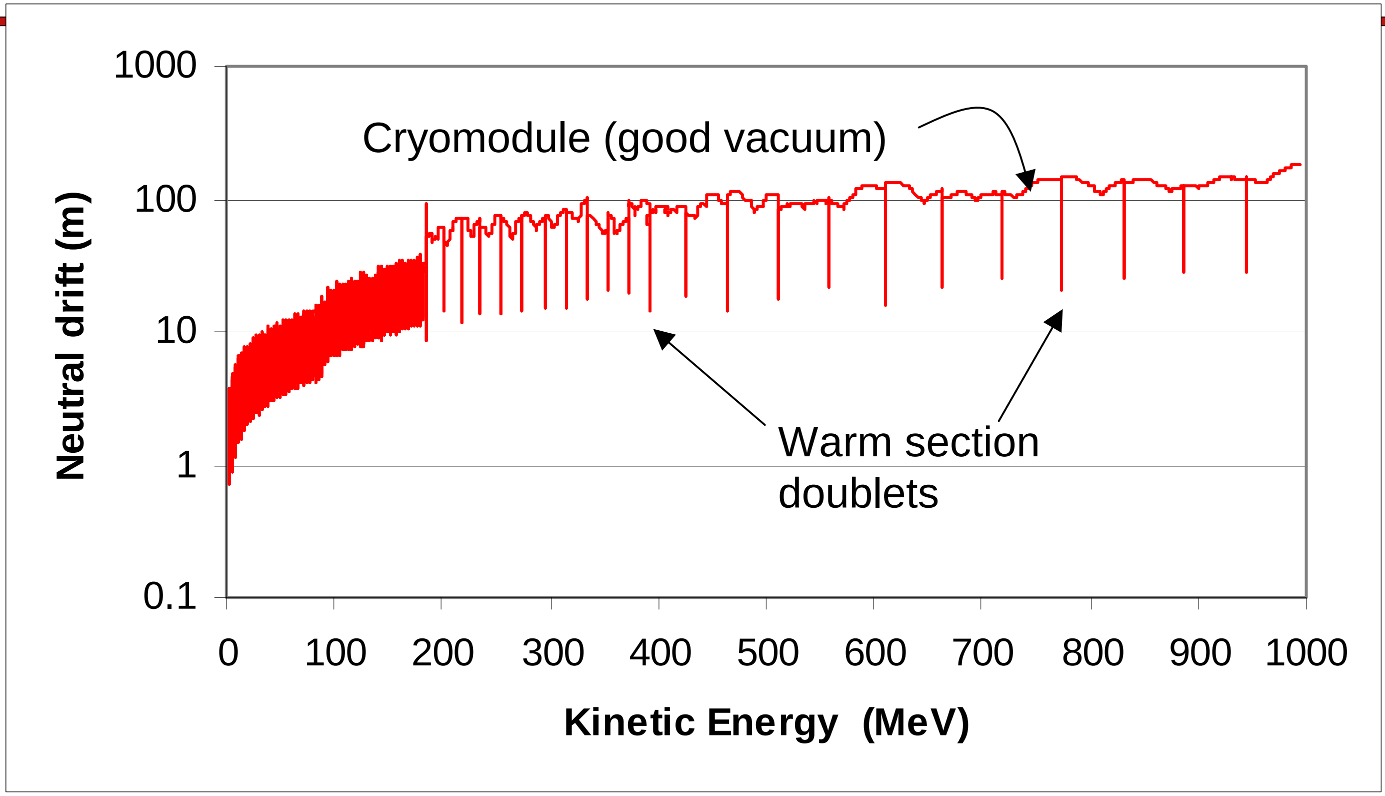
Collimators inventory (N. Catalan Lasheras)

Name	Device	Description	Aperture [$\pi\mu m$]	Power [Watt]
HEBT	Scr (4)	C Foil exchange (H^-) transverse cut	13	55
HEBT	Abs	Proton absorber	20mm	150
HEBT	Scr(4)	C Foil exchange (H^-) transverse cut	13	55
HEBT	Abs	Proton absorber	20mm	150
HEBT	Scr (2)	C Foil exchange (H^-) Longitudinal cut	0.5 – 10.0	550
HEBT	Abs	External proton absorber	N/A	2000
RING	Abs	Secondary collimator, shielding	300	600
RING	Scr (4)	Primary collimator (Pt target) transverse cut	100-300	200
RING	Abs	Secondary collimator, shielding	300	1000
RING	Abs	Secondary collimator	300	1000
RING	Abs	Secondary collimator	300	1000
RTBT	Abs	Primary collimator transverse cut	400	
RTBT	Abs	Primary collimator transverse cut	400	

- Absorbers designed to stand 2kWatt continuous operation
- Up to two consecutive pulses ($2\cdot10^{14}$ ppp)

Assuming 2MW operation

H^o Drift After Stripping



- Rms beam divergence ranges from 20 to 0.5 mrad
- Aperture ranges from 1.25 cm to 3.65 cm
- ~ 10 W stripped in dummy sections lost in HEBT bend.