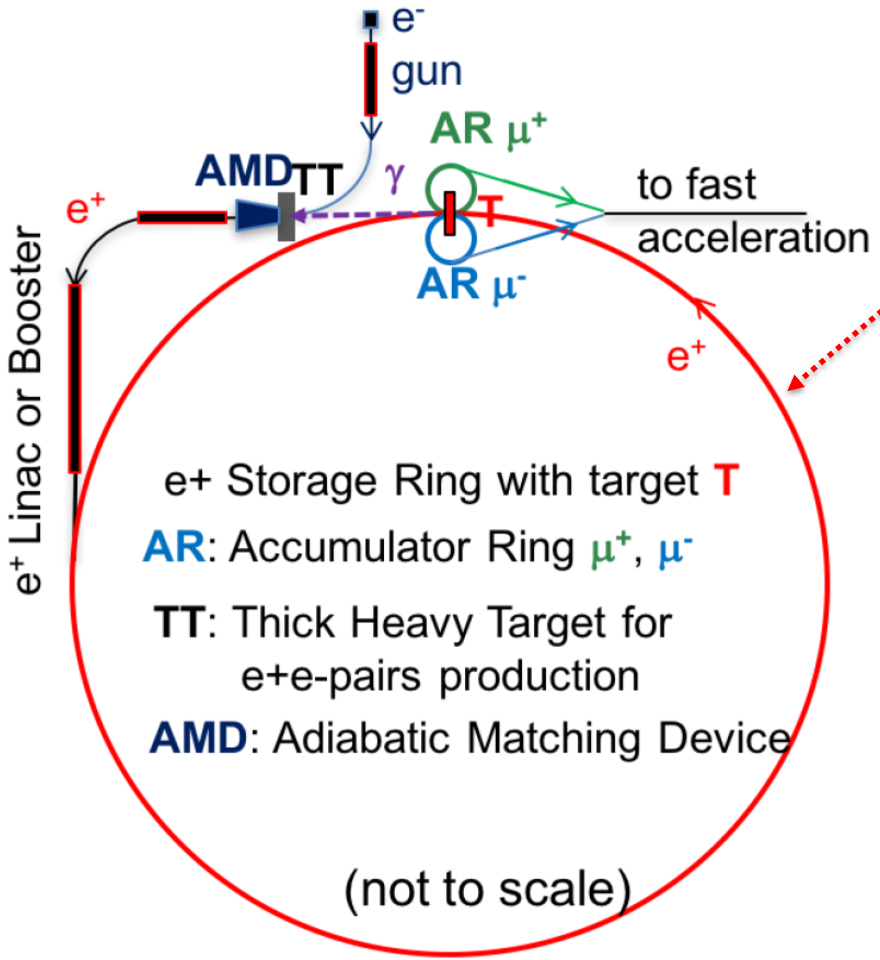
LEMMA e^+ ring:

- e^+ ring lattice
- target insertion
- tracking with target
- momentum acceptance
- 6km, 27km, # of cells

S.Liuzzo, ESRF, Moun collider workshop, Padova, Italy, 1-3 July 2018

45 GEV POSITRON RING

Image and table from: Manuela Boscolo et al. STUDIES OF A SCHEME FOR LOW EMITTANCE MUON BEAM PRODUCTION FROM POSITRONS ON TARGET. http://accelconf.web.cern.ch/AccelConf/ipac2017/papers/weoba3.pdf

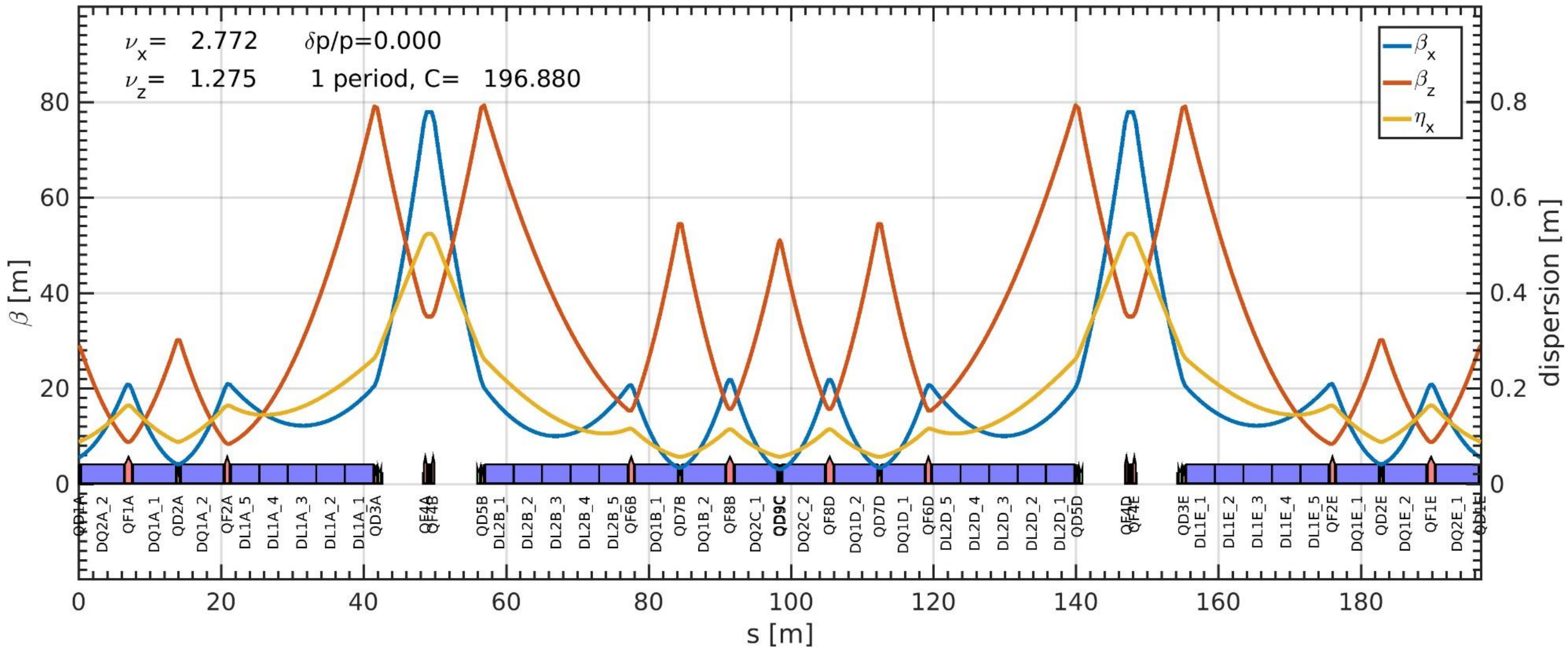


We speak about the positron ring

Table 1: Positron Ring Parameters

Parameter	Units	
Energy	GeV	45
Circumference	m	6300
Coupling(full current)	%	1
Emittance x	m	5.73×10^{-9}
Emittance y	m	5.73×10^{-11}
Bunch length	mm	3
Beam current	mA	240
RF frequency	MHz	500
RF voltage	GV	1.15
Harmonic number	#	10508
Number of bunches	#	100
N. particles/bunch	#	3.15×10^{11}
Synchrotron tune		0.068
Transverse damping time	turns	175
Longitudinal damping time	turns	87.5
Energy loss/turn	GeV	0.511
Momentum compaction		1.1×10^{-4}
RF acceptance	%	± 7.2
Energy spread	dE/E	1×10^{-3}
SR power	MW	120

LATTICE CELL 1/32



Lattice cell designed by P.Raimondi

REQUIRED MAGNET STRENGTHS

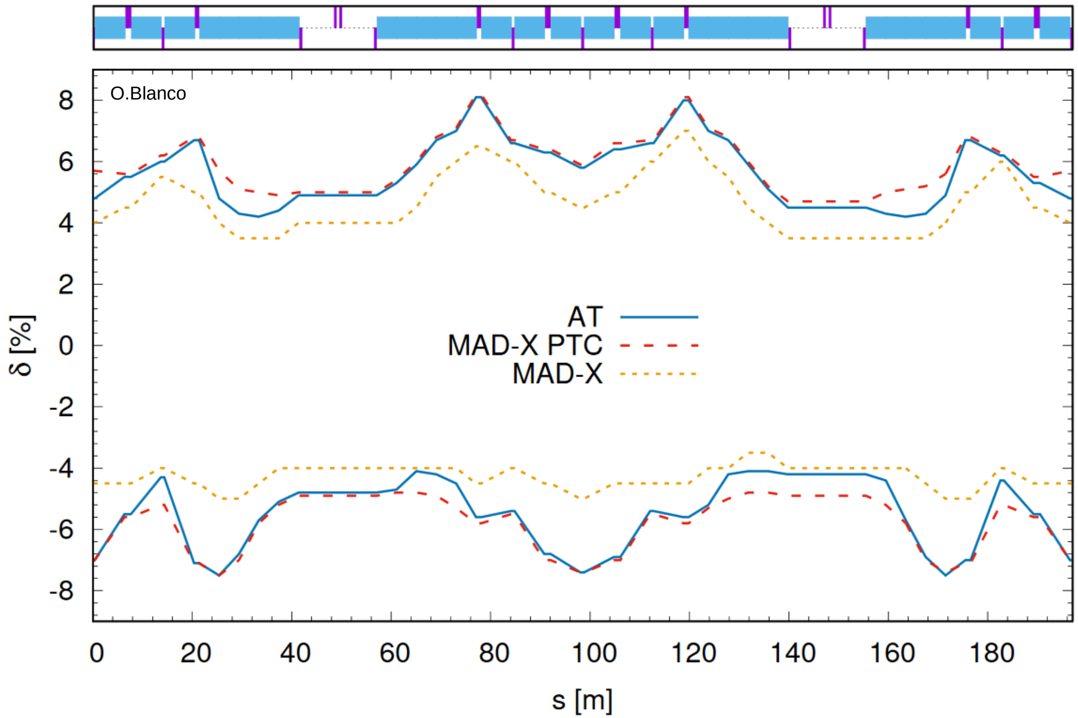
Magnet strengths are within available technology.

Still large space to optimize the lattice basic cell.

name	L [m]	$\rho\,[m]$	$\theta\,[rad]$	$B0\,[T]$	$b2\,[T/m]$	$b3\,[T/m^2]$	$b4\,[T/m^3]$	$\beta x\,[m]$	$\beta y\,[m]$	$\eta x\,[m]$
QD1A	0.200				-57.1			5.50	29.00	0.088
DQ2A 2	6.000	3858.882	0.002	0.233				5.73	27.91	0.090
QF1A	1.000				29.7			19.97	9.12	0.160
DQ1A 1	6.000	3858.882	0.002	0.233				19.04	9.48	0.158
QD2A	0.400				-58.8			4.08	30.05	0.088
DQ1A 2	6.000	3858.882	0.002	0.233				4.20	29.32	0.089
QF2A	0.720				30.7			19.84	8.80	0.160
DL1A 5	4.000	2285.714	0.002	0.263				20.55	8.48	0.162
DL1A 4	4.000	320	0.001	0.188				15.21	13.74	0.144
DL1A 3	4.000	4210.526	0.001	0.143				12.51	23.33	0.151
DL1A 2	4.000	5333.333	0.001	0.113				12.44	37.26	0.175
DL1A 1	4.000	6956.522	0.001	0.086				15.00	55.52	0.213
QD3A	0.400				-33.5			20.45	79.05	0.263
SD1A	0.400					-162.9	0.0	22.73	77.53	0.278
QF4A	0.400				26.8			75.70	36.02	0.516
SF2A	0.400					146.3	0.0	77.87	35.00	0.523
QF4B	0.400				26.8			77.85	35.00	0.523
OF1B	0.150						0.0	74.01	36.80	0.510
SD1B	0.400					-117.1	0.0	24.79	74.43	0.292
QD5B	0.400				-30.6			21.59	78.71	0.272
DL2B 1	4.000	6956.522	0.001	0.086				19.79	78.54	0.259
DL2B 2	4.000	5333.333	0.001	0.113				13.45	60.03	0.201
DL2B 3	4.000	4210.526	0.001	0.143				10.32	44.46	0.155
DL2B 4	4.000	320	0.001	0.188				10.41	31.85	0.121
DL2B 5	4.000	2285.714	0.002	0.263				13.71	22.19	0.106
QF6B	0.720				34.8			20.52	15.29	0.115
DQ1B 1	6.000	3858.882	0.002	0.233				18.88	16.87	0.110
QD7B	0.400				-54.9			3.35	54.36	0.056
DQ1B 2	6.000	3858.882	0.002[1]	0.233				3.48	53.20	0.057
QF8B	1.000				35.4			20.67	16.57	0.111
DQ2C 1	6.000	3858.882	0.002	0.233				19.83	16.96	0.109
QD9C	0.400				-52.6			3.06	50.29	0.056

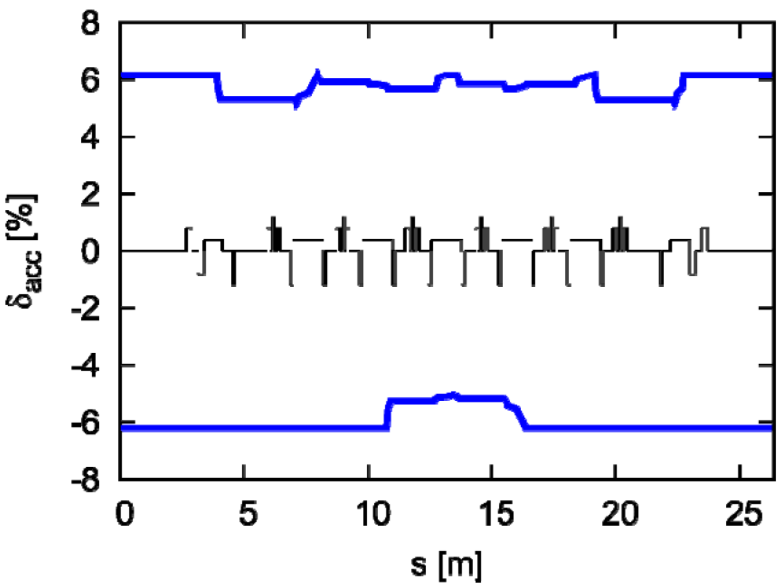
MOMENTUM ACCEPTANCE

Positron ring design must allow for maximum energy acceptance, in order to minimize the scattered positrons lost after the interaction with the target.



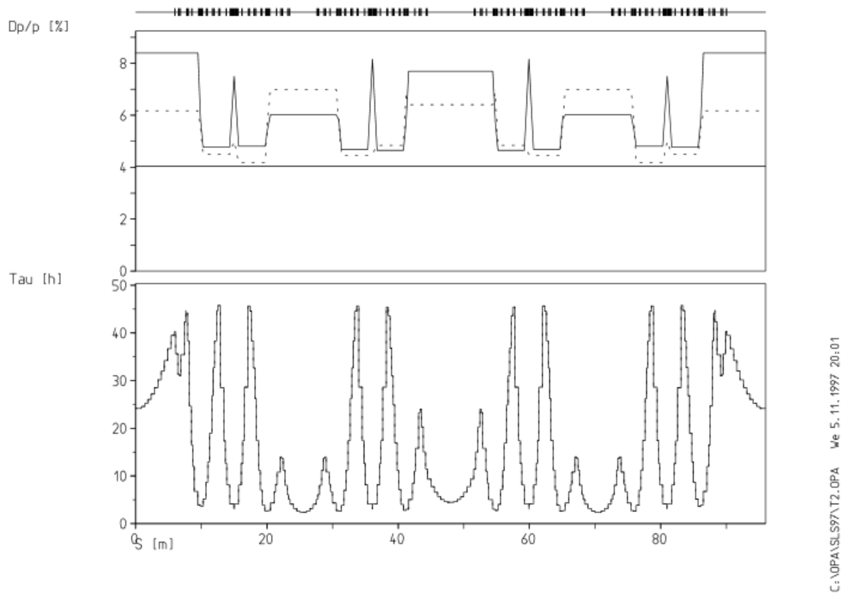
M.Boscolo et al. Low Emittance Muon accelerator studies with production from positrons on target, PRAB, 2018

MOMENTUM APERTURE FOR OTHER LATTICE CELLS



MAXIV 3GeV ring, MBA lattice, ~ 6%

From: DETAILED DESIGN REPORT ON THE MAX IV FACILITY



SLS 3GeV, TBA lattice, >8% in straight

A.Streun, http://slsbd.web.psi.ch/pub/slsnotes/sls1897a.pdf

NOT scaled to 6km, 45GeV.

TARGET OPTICS TO MINIMIZE EMITTANCE INCREASE AT TARGET (S. GUIDUCCI)

A particle which looses an energy Dp/p gains a betatron oscillation with maximum amplitude, $x_{max} = \sqrt{H_{inv}\beta_x}$ Dp/p, with H_{inv} *the invariant*.

The corresponding emittance is $\varepsilon_x = H_{inv}\, Dp/p\ ^2$

To reduce the emittance increase the dispersion function at the target has to be zero

In the 3 mm Be target the rms scattering angle is σ'_t ~1e-4 rad

The rms angle after the target is $\sigma'_a \cong \sqrt{\sigma'^2_b + \sigma'^2_t}$

With σ'_b the rms positron angle before the target

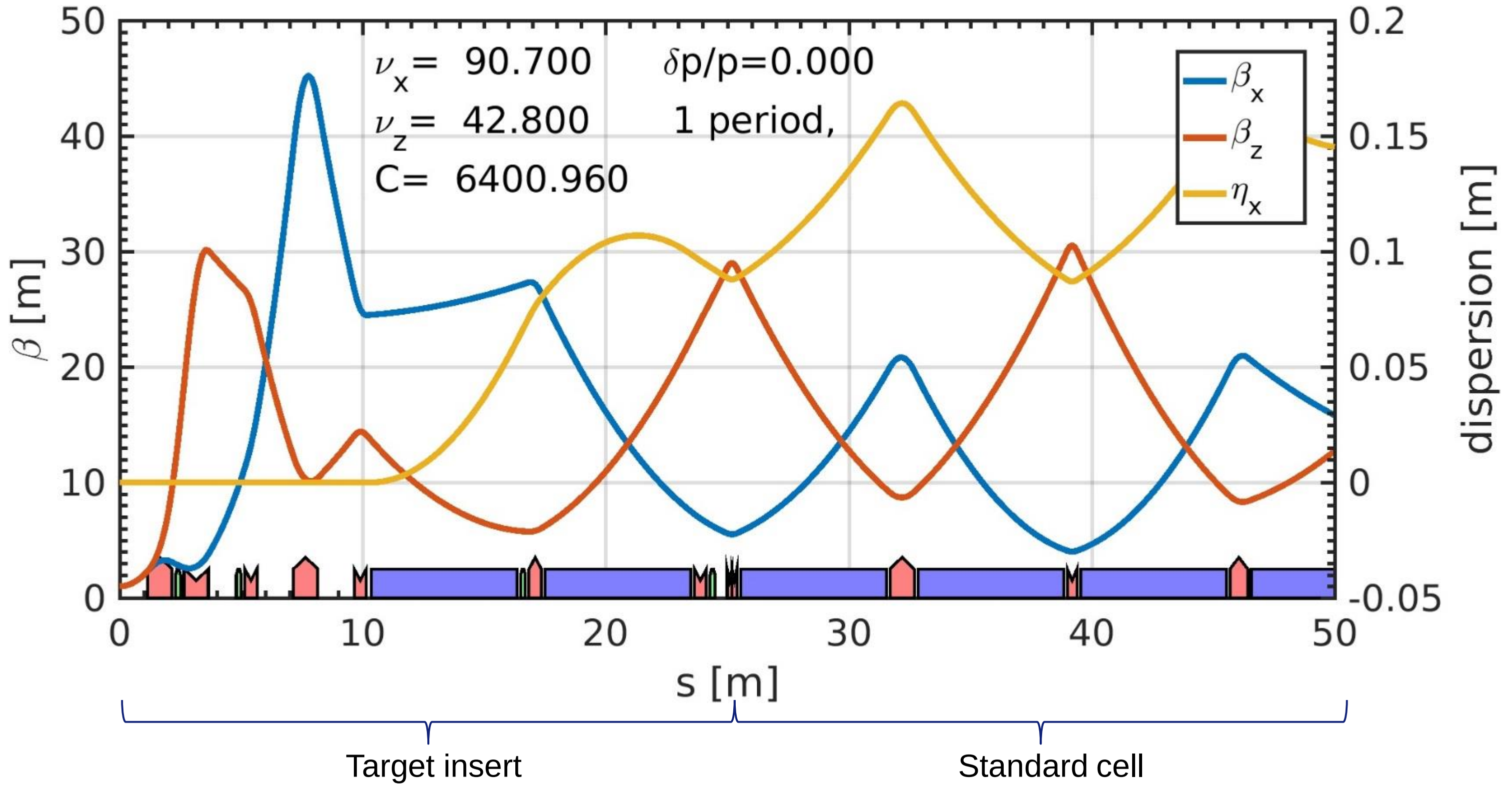
For $\alpha_{x,y}$~0 the emittance after the target is $\varepsilon_a \sim \sigma_a\ \sigma'_a$

To minimize the emittance increase σ'_b has to be larger (or at least of the same order of the scattering angle) $\boldsymbol{\sigma'_b \geq \sigma'_t}$

ε_b = 6e-9 m

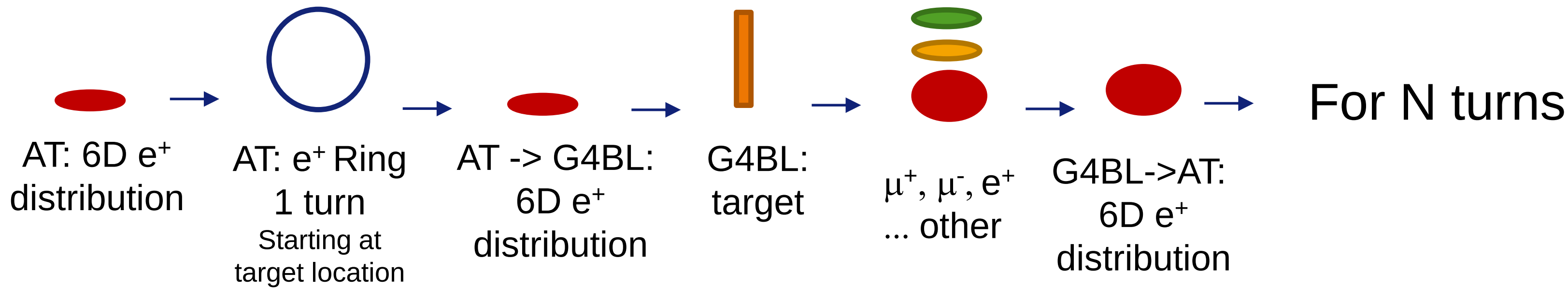
k	betx (m)	bety (m)	sigbx (micron)	sigby (micron)	spot area (mm^2)	epsx aft (m)	epsy aft (m)
0.01	0.3	0.003	42	0.4	1.80E-05	7.35E-09	7.35E-11
0.01	1.66	1.8	100	10	1.04E-03	1.16E-08	1.04E-09
1	3.35	0.035	100	10	1.03E-03	1.05E-08	3.17E-09

TARGET V11



Target optics designed only to study target interaction with given optics functions.
The target interaction region optics, including dipoles for positron-muon beam separation and adequate chromaticity correction, need to be designed.

INCLUDING THE TARGET EFFECT IN AT



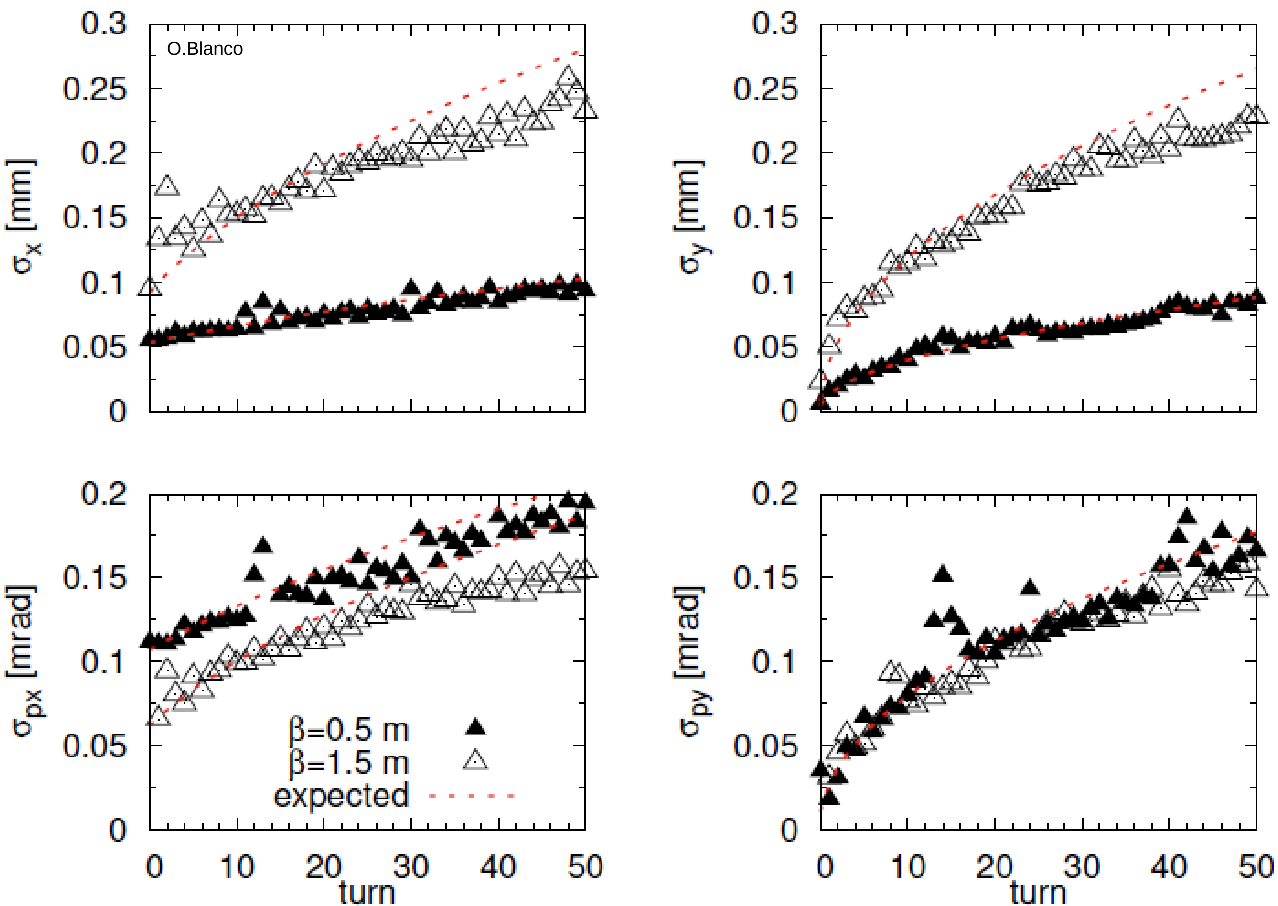
At each turn:

1. **Accelerator Toolbox (AT, matlab) tracks any 6D e+ distribution**
2. **The 6D e+ distribution is converted to Geant4BeamLine* (G4BL) units**
3. **The 6D distribution is tracked trough the target in G4BL**
4. **The G4BL output 6D positron distribution is converted back to AT**

The intial 6D distribution is obtained using the equilibrium emittances in AT

* Gean4BeamLine, Muons Inc.
http://muonsinc.com/muons3/g4beamline/G4beamlineUsersGuide.pdf

BEAM SIZE DEGRADATION VS BETA@TARGET, FIXED DISPERSION



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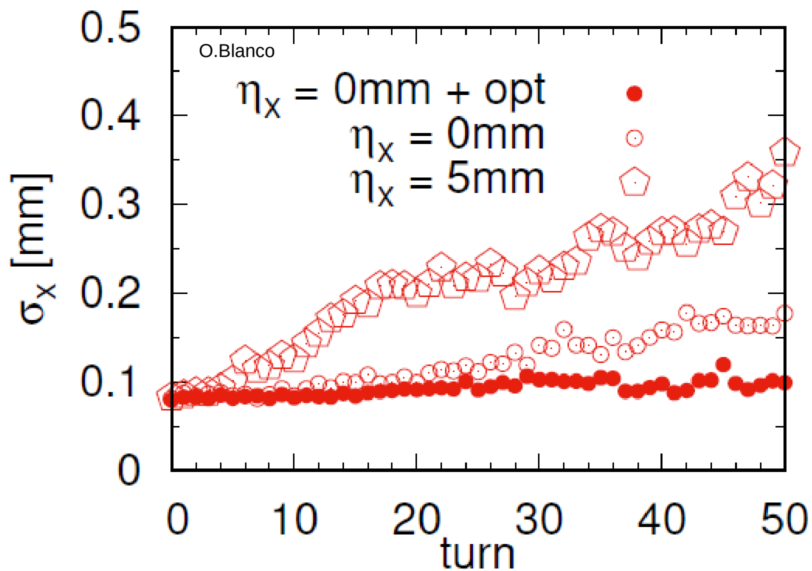
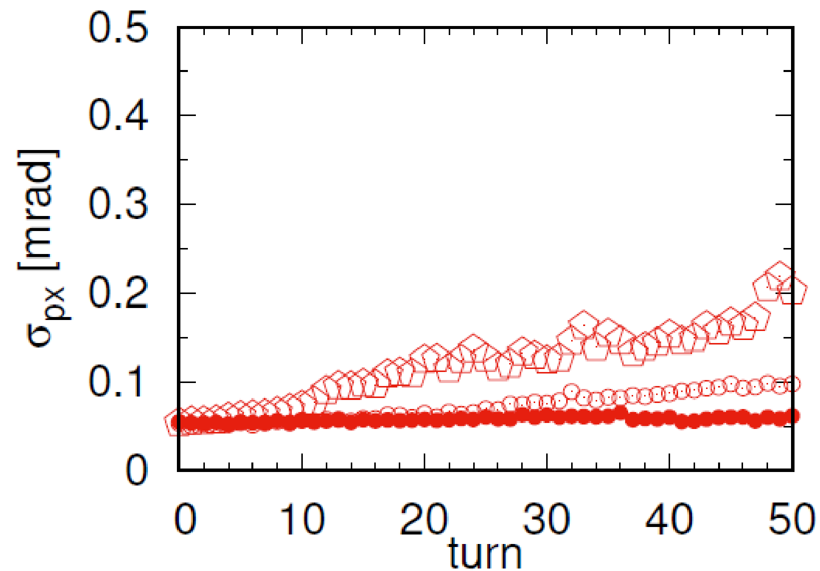
BEAM SIZE DEGRADATION VS DISPERSION@TARGET, FIXED BETA@TARGET





Tracking simulations confirm that the small beta functions and zero dispersion at the IP cancel the degradation of the positron beam size due to the interaction with the target.

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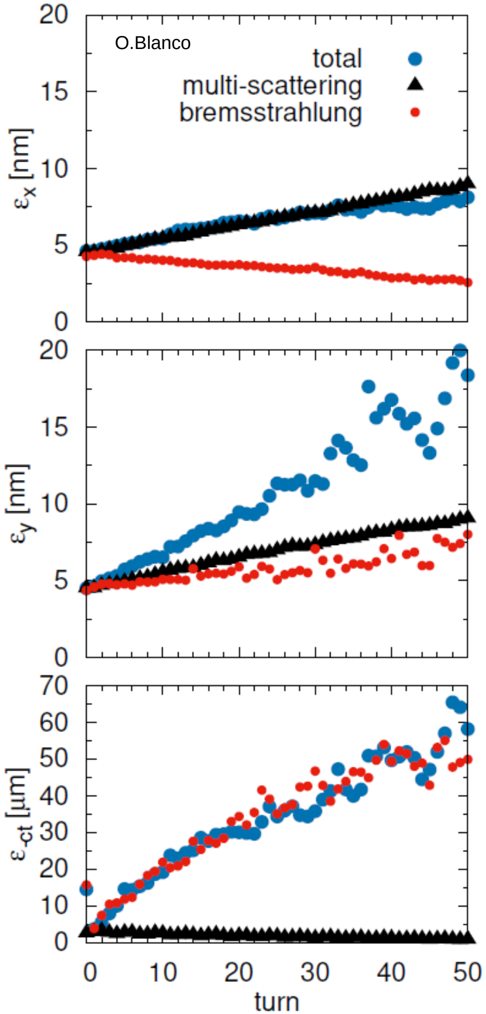
POSITRON EMITTANCE EVOLUTION INTERACTING WITH TARGET



Positron beam interaction with 3mm Be target: separated contributions of multiple scattering and bremsstrahlung.

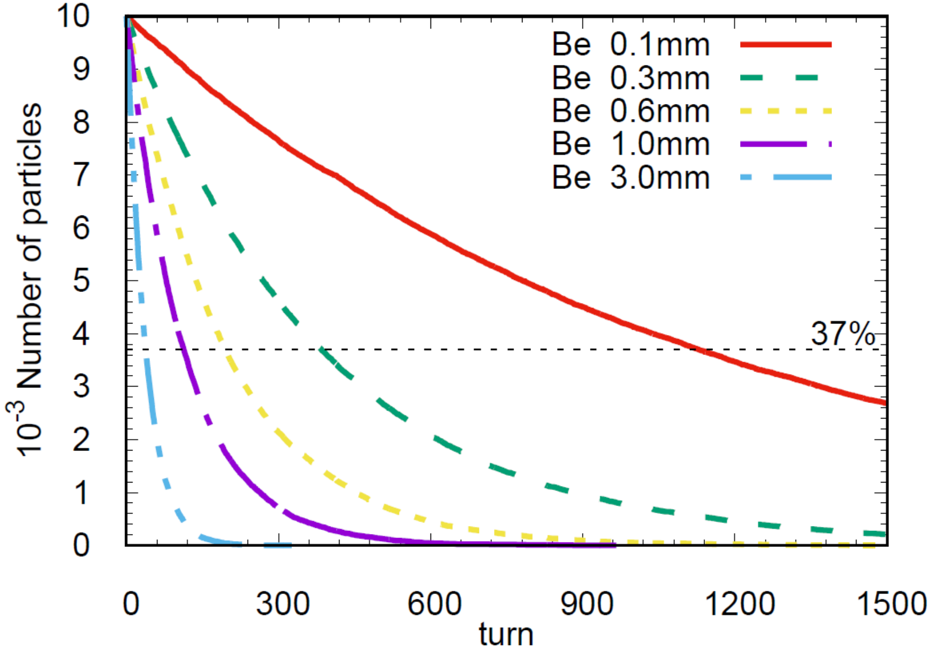
The horizontal emittance increase is dominated by multiple scattering

The longitudinal emittance increase is dominated by bremsstrahlung

Target optics $\beta_{x,y}$ = 0.5m, η_x = 0.0m

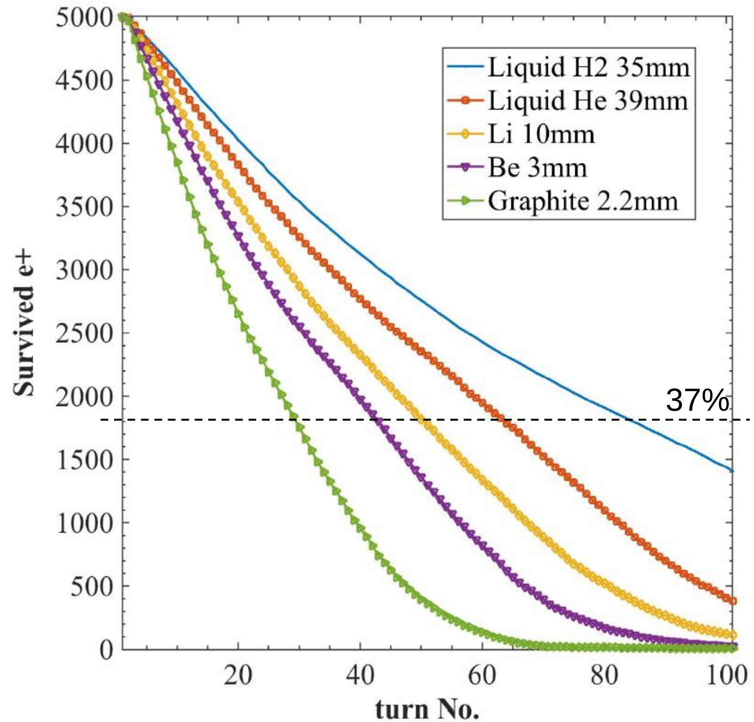
M.Boscolo et al. Low Emittance Muon accelerator studies with production from positrons on target, PRAB, 2018

POSITRON BEAM INTERACTION WITH THE TARGET



Beam lifetime and target thickness are inversely proportional

Lengths defined for constant muon yield



Improved Lifetime for LH2, LHe and Li but larger thickness increase multiple scattering and thus the intrinsic muon emittance

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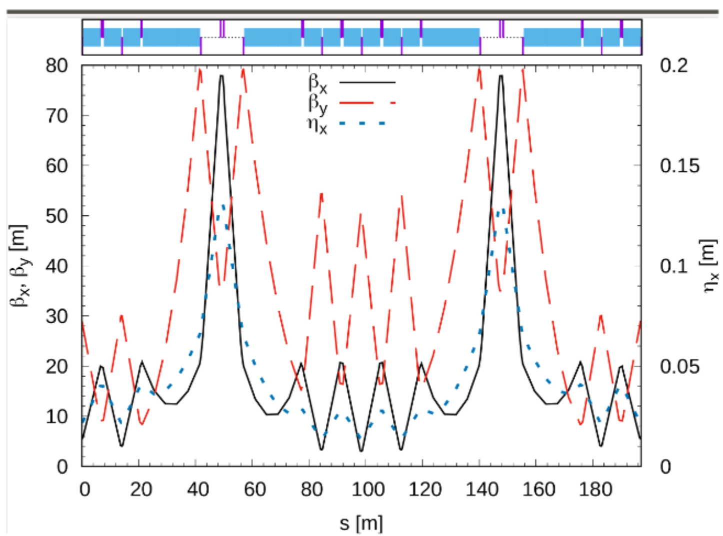
ALTERNATIVE LATTICE LENGTH / NUMBER OF CELLS

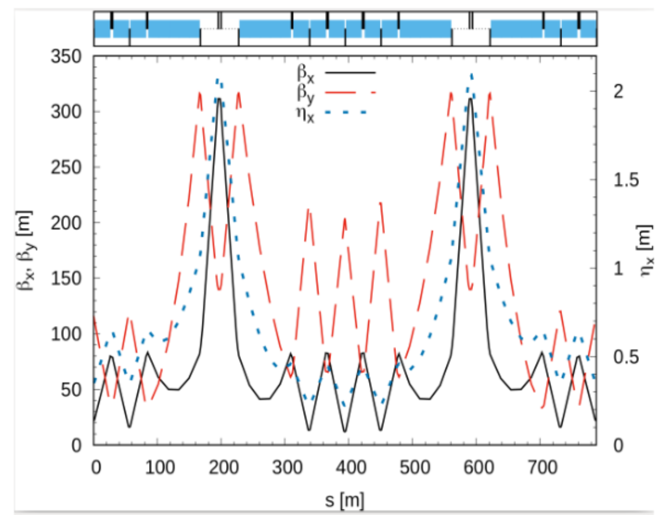
Change length of lattice and number of cells.

Scale all magnets by factor DL/L, adjust angles for 360deg, scale quadrupole gradients by (DL/L)^2

136 cells
Cell is 197m long
Dispersion function is ~0.15m



34 cells
Each Cell Element * 4 = 788m
Dispersion function is ~2.1m



O. Blanco

HMBA LIKE LATTICE VARYING NUMBER OF CELLS AND LATTICE LENGTH

	C	Cells	ε_x	Sext K_2	D.A.	M.A.	Dpp*Dx	Lifetime	α_c	damping	Bunch length	U0
	Km	#	nm	T/m²	mm (hor.)	% (max)	mm (max)	Turns@37%	e-6	ms, (HV-S)	mm	MeV
	27	32	5.72	1.82	12.0	1.5	33	24	104	68-34	2.3	121
	27	64	0.7	29.2	12.0	7.3	40	40	29.0	68-34	1.2	119
	27	134	0.08	552	2.0	7.9	10	29	6.8	68-34	0.6	119
	27	268	0.01	1e4	0.0	7.8	2.3	19	1.7	68-34	0.3	119
	6.3	16	45.8	9.0	12.0	1.4	30	38	403	3.7-1.9	4.1	511
Current lattice	6.3	32	5.86	140	12.0	8.5	44	40	114	3.7-1.8	2.2	511
	6.3	64	0.71	2260	2.0	7.6	10	29	30	3.7-1.9	1.1	509

without target optics
3mm Be @ RF

Common parameters:
f_{rf} = 500MHz
$V_{rf} = 3U_0$
Q = [0.7 0.8]
$\xi = [\,0\ 0\,]$
$\Delta\phi/2\pi$ (sext) $= 1.5/0.5$
$\Theta = 2\pi$

27km lattice with 64 cells has, similar lifetime and smaller: emittance, sextupole's strengths, U_0, bunch length, α_c

Dynamic aperture (D.A.) and momentum aperture (M.A.) tracking for 256 turns, with circular apertures 50mm

PARAMETERS FOR 6.3KM AND 27KM LATTICE

e^+ 45 GeV	Units	Parameters for positron ring different scenarios				
C	Km	6.3	6.3	**27**	27	27
N cells	#	32	32	32	**64**	64
n_e (bunches)	#	100	100	428	428	428
n_μ (bunches)	#	1	**2**	1	1	**2**
ε_x	nm	6	6	6	0.7	0.7
Current	A	0.24	0.24	0.24	0.24	**0.14**
$C_{m,acc}$	m	63	126	63	63	**126**
Turns for accumulation	#	25	12	6	6	3
N_{e+} / n_e	e+11	3	3	3	3	1.8
N_μ / n_μ	e+7	3.4	1.2	5.3	5.3	0.8
N_μ^2 * n_μ / ε_x	-	1 (ref)	x 0.25	x 2.5	x 20	x 1.0
U_0	GeV	0.51	0.51	0.12	0.12	0.12
Synch. power	MW	122	122	29	29	16.8

$\tau_{\mu,\ store}$ = 0.5ms

τ_{pos}= 37 turns

σ_μ =0. 74e-7 mu/e+

3mm Be @ 45GeV

27km gives potentially equivalent muons beams to the 6.3km lattice, with less positrons on target for a shorter time, and longer muon accumulator.

$$N_\mu = \sum_{it=0}^{t_e} \frac{C_e I_e}{c n_e q_e} \cdot \sigma_\mu \cdot \frac{n_e}{n_\mu} \cdot e^{-\frac{C_e it}{c\tau_e}} \cdot e^{-\frac{C_\mu n_e (t_e - it)}{c n_\mu \tau_\mu}}$$

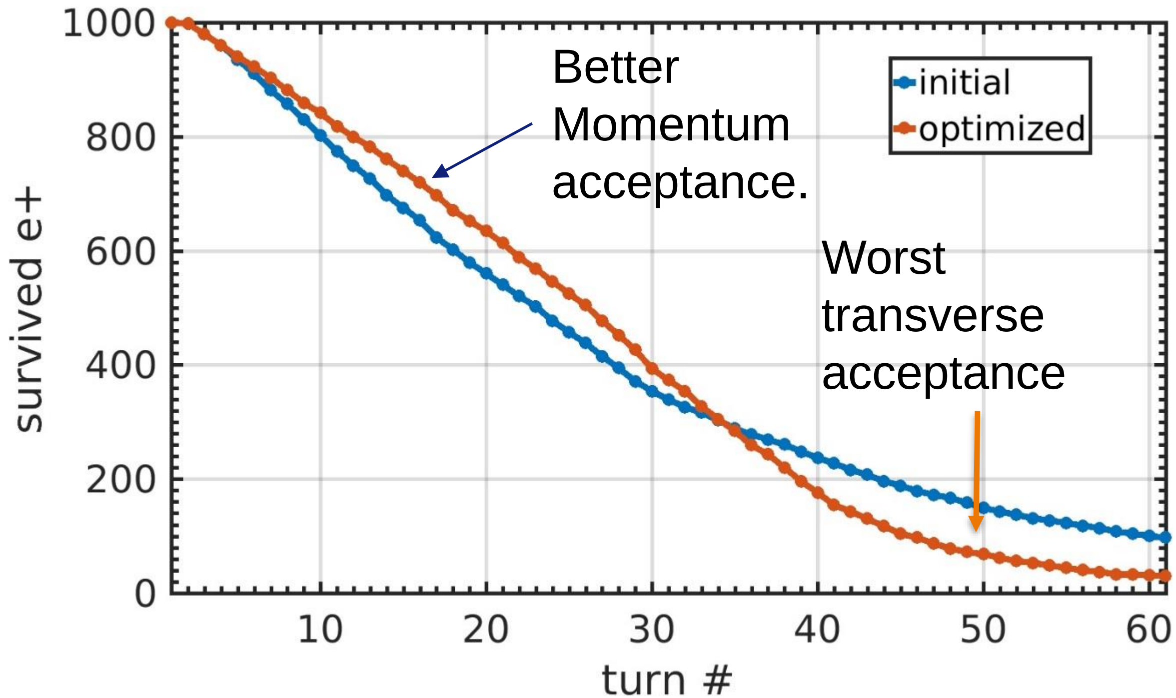
Muon lifetime considered only every positron ring turn

MOMENTUM APERTURE OPTIMIZATION “AT TARGET WITH TARGET” (RCDS)

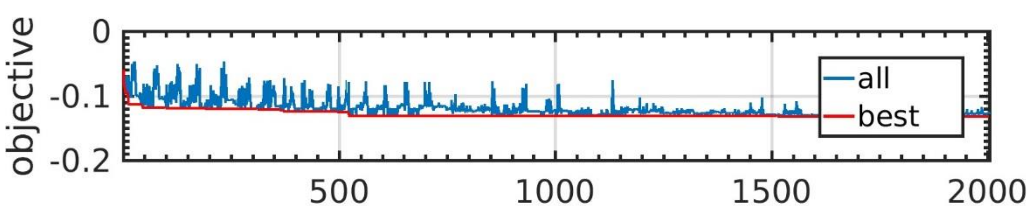
Sextupole families optimized to increase MA at target location using RCDS (X.Huang, SLAC).

Chromaticity free.

Optimized sextupoles in cell and in target.



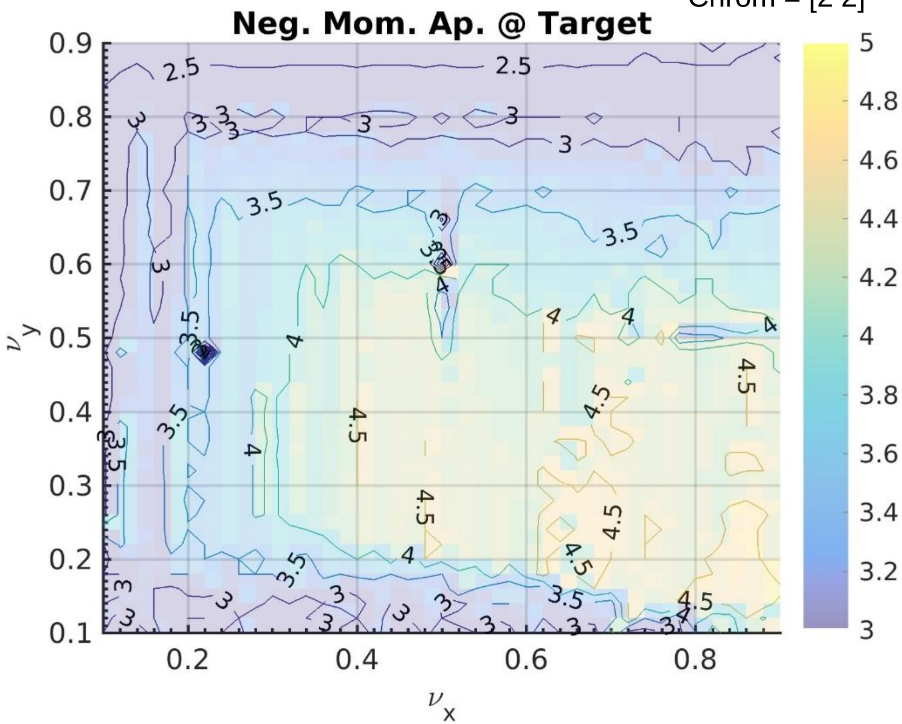
Objective:
64 turns MA at Target



Objective to be redefined in future optimizations

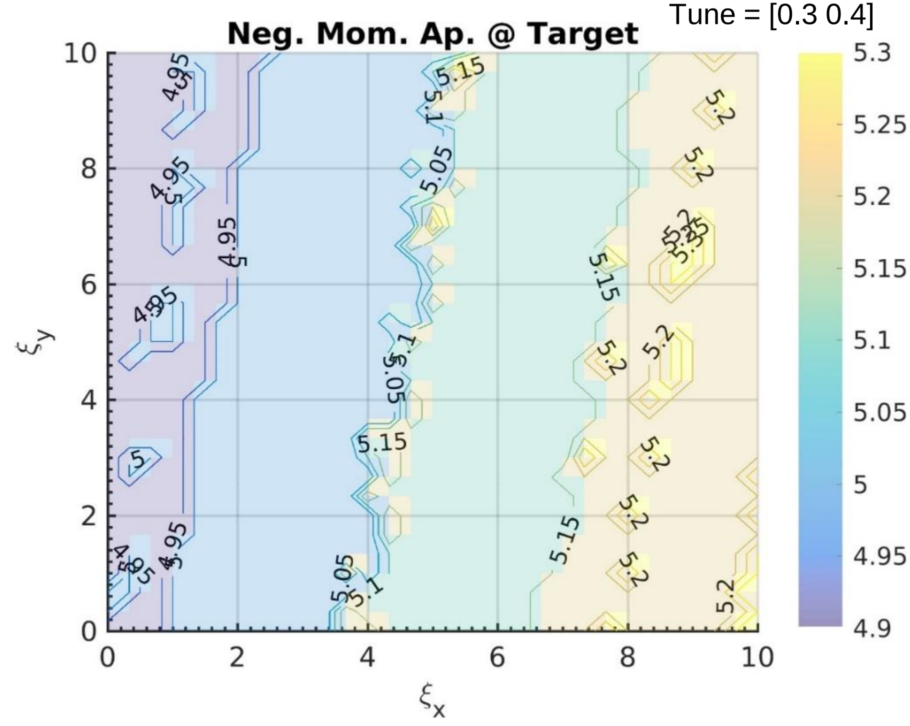
TUNE AND CHROMATICITY OPTIMIZATION FOR 6.3KM 32 CELLS + TARGET

Chrom = [2 2]



Tune = [0.74 0.22]

Tune = [0.3 0.4]

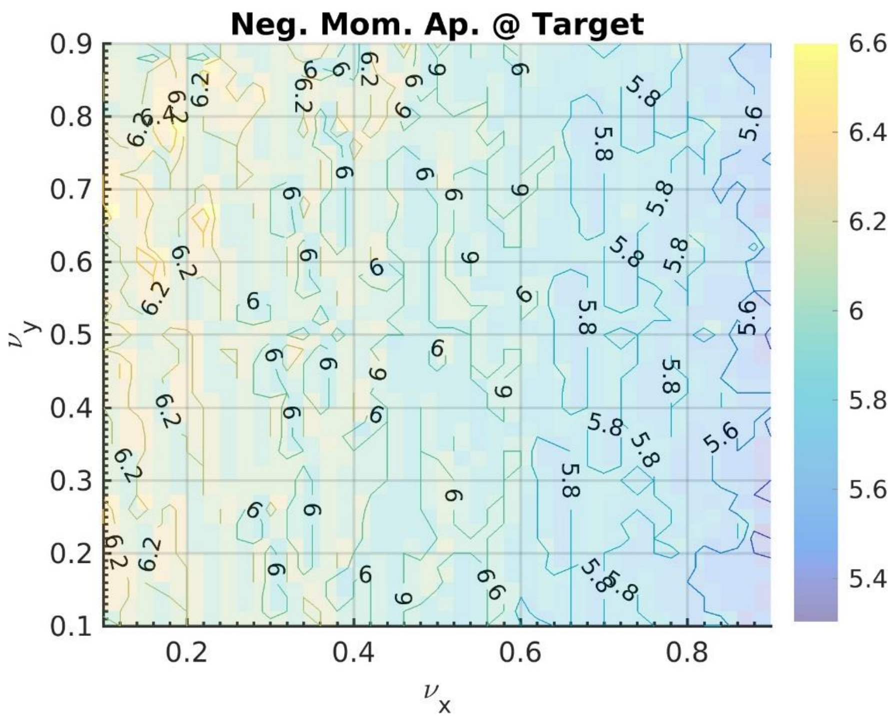


Chromaticity = [9 0];

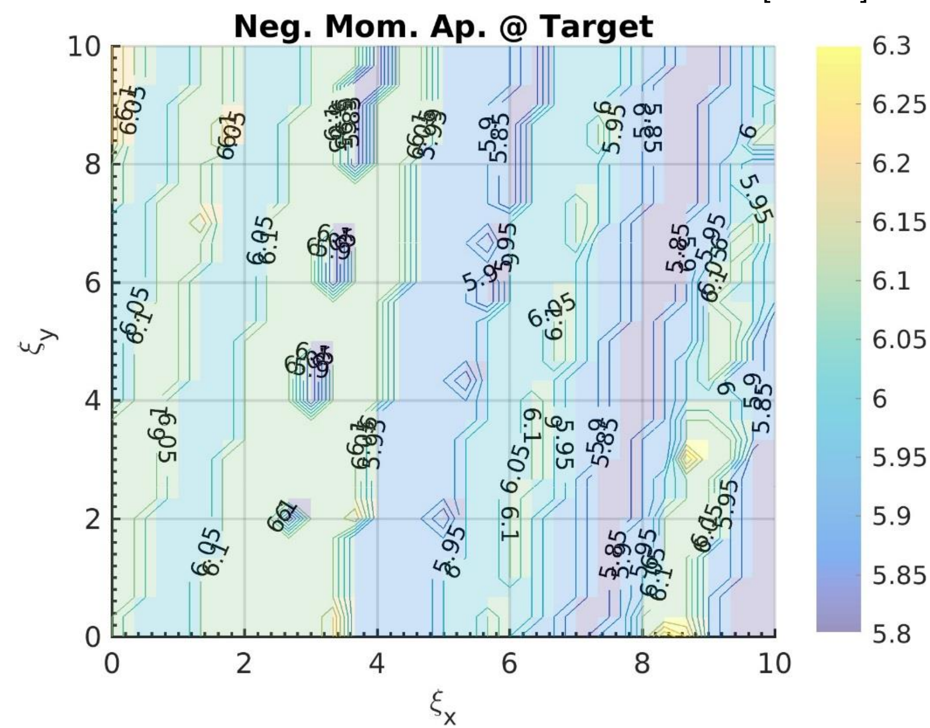
No errors

TUNE AND CHROMATICITY OPTIMIZATION FOR 27KM 64 CELLS NO TARGET

Chrom = [2 2]



Tune = [0.3 0.4]



Tune = [0.2 0.8]

Chromaticity = [2 2];

No errors

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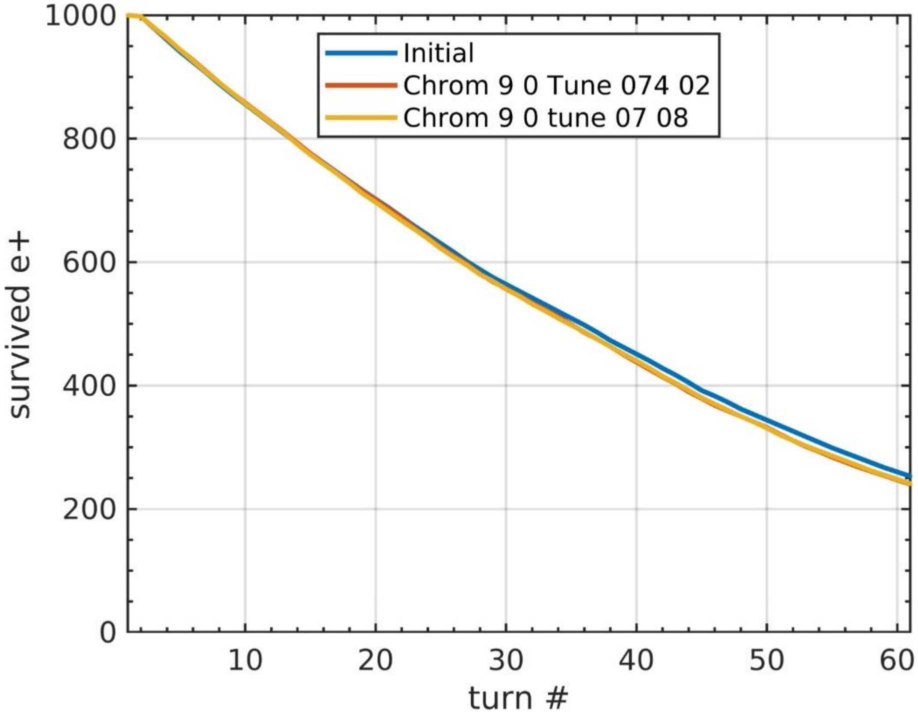
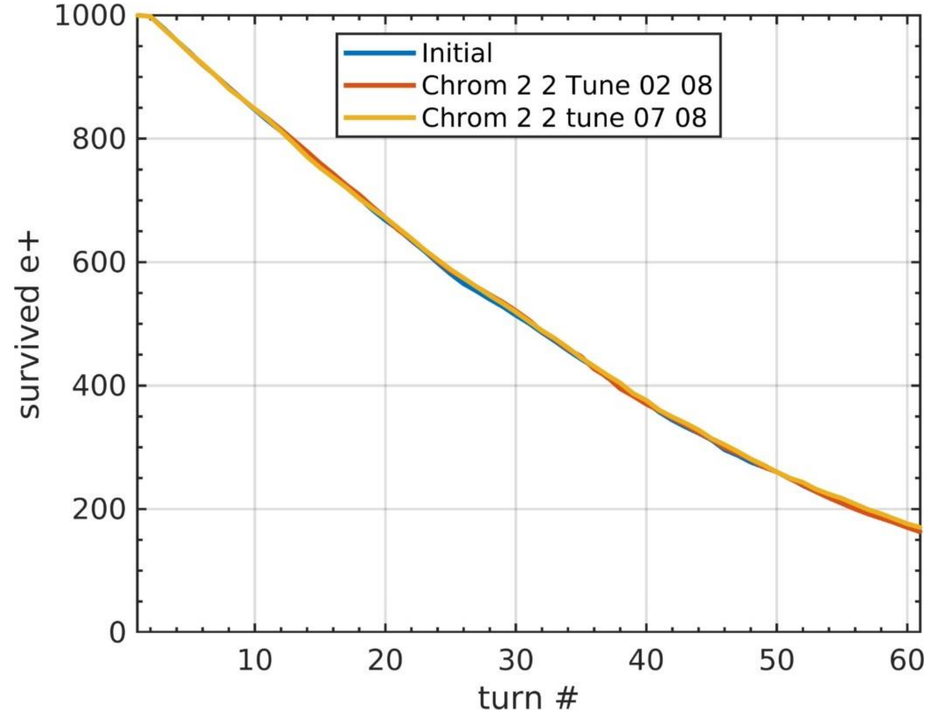
POS. LIFETIME WITH OPTIMAL TUNE AND CHROMATICITY: NO IMPROVEMENT.



6.3km, target in first RF drift space



27km, target in first RF drift space

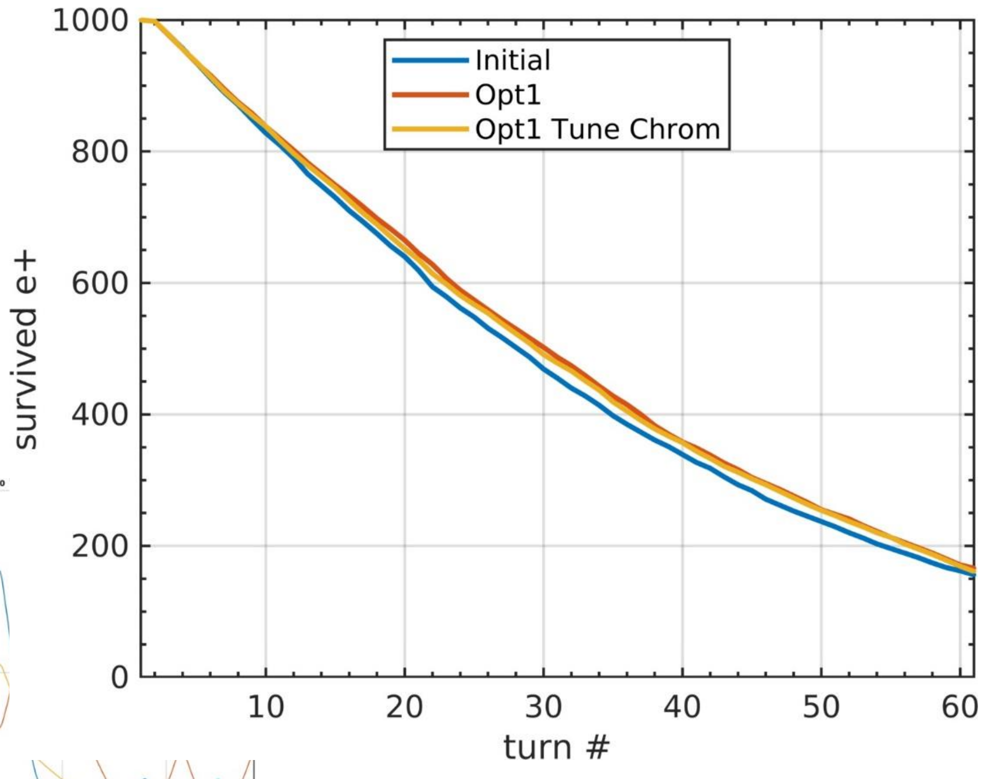
Tune and chromaticity optimization does not seem to impact positron lifetime

ARCA CELL OPTIMIZATION

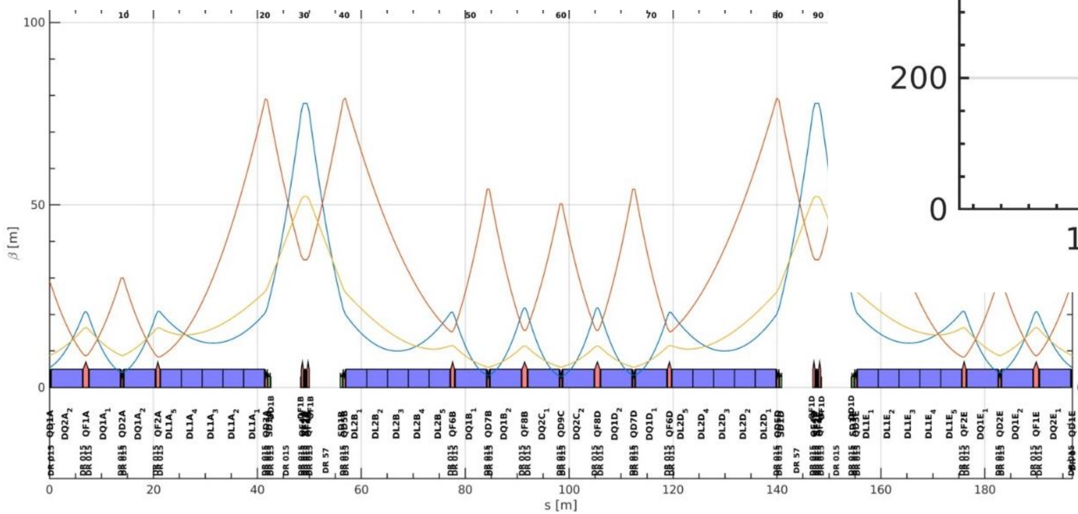
Optimized cell optics for larger momentum acceptance and constant DA:

Optics at sextupoles,
Sextupoles, octupoles,
Phase advance between sextupoles

No net improvement, M.A. similar to original



Target in RF straight



SUMMARY AND OUTLOOK TO FUTURE STUDIES

A positron ring with target has been studied. The optimal optics parameters at the target have been obtained and tested in simulations.

Different target materials and thicknesses have been considered in terms of impact on the positron beam lifetime.

Several lattice designs have been scaled and show that horizontal emittance and synchrotron radiation power can reach acceptable values for a 27km lattice with 64 cells. Relaxed design parameters can also help in the design of the muon accumulator and target.

Several optimizations of the positron lattice optics and non linear fields have been performed. For the moment without success in increasing significantly the positron lifetime.

For the future:

Study other lattice options: TME, DBA, SLS upgrade

25% energy acceptance is still challenging

Final-Focus like interaction region.

MANY THANKS FOR YOUR ATTENTION

Special thanks to all the LEMMA team for their help and contributions to this presentation.

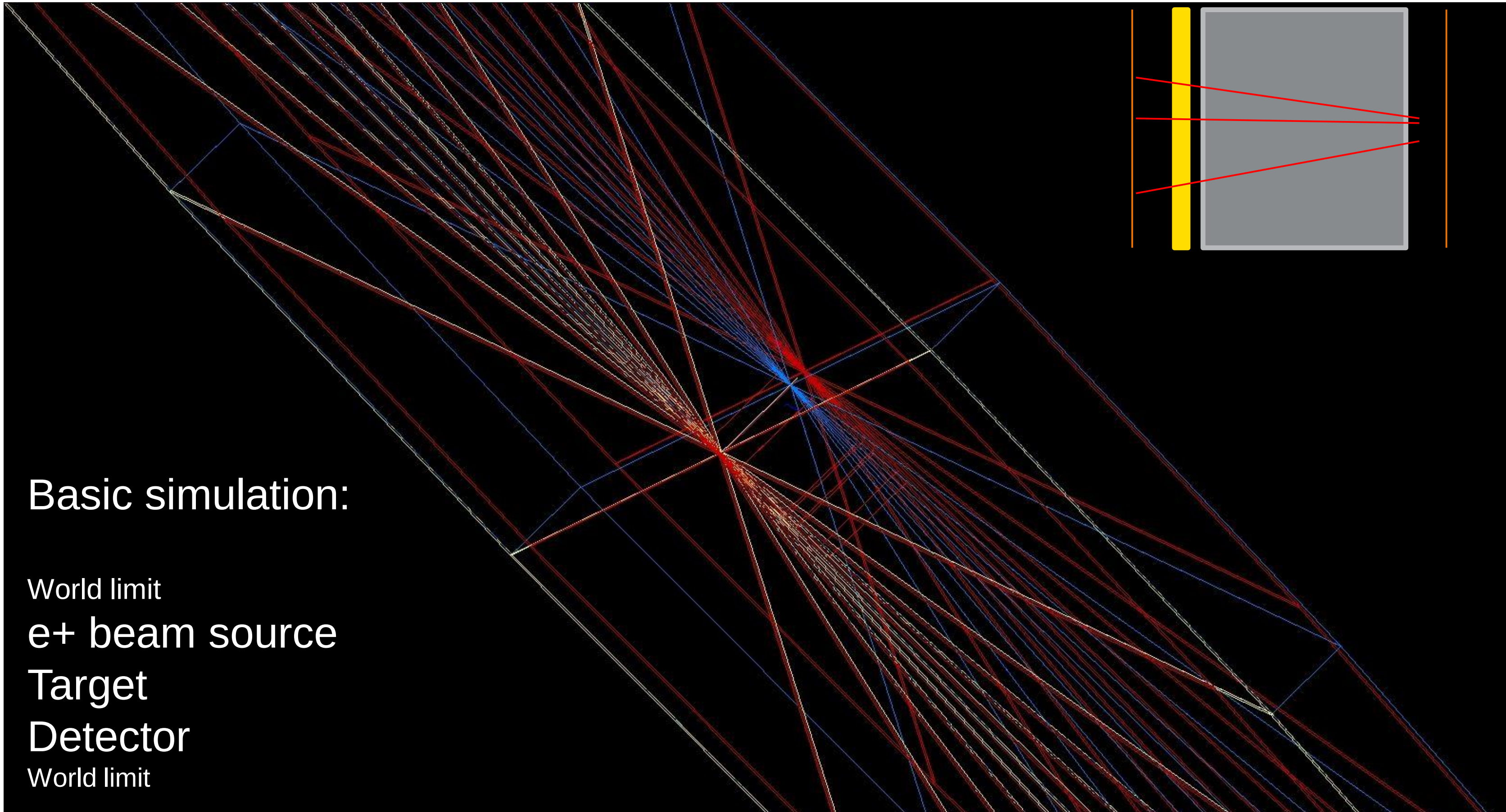
BACKUP

HAMILTONIAN APPROXIMATION FOR DELTA 25%?

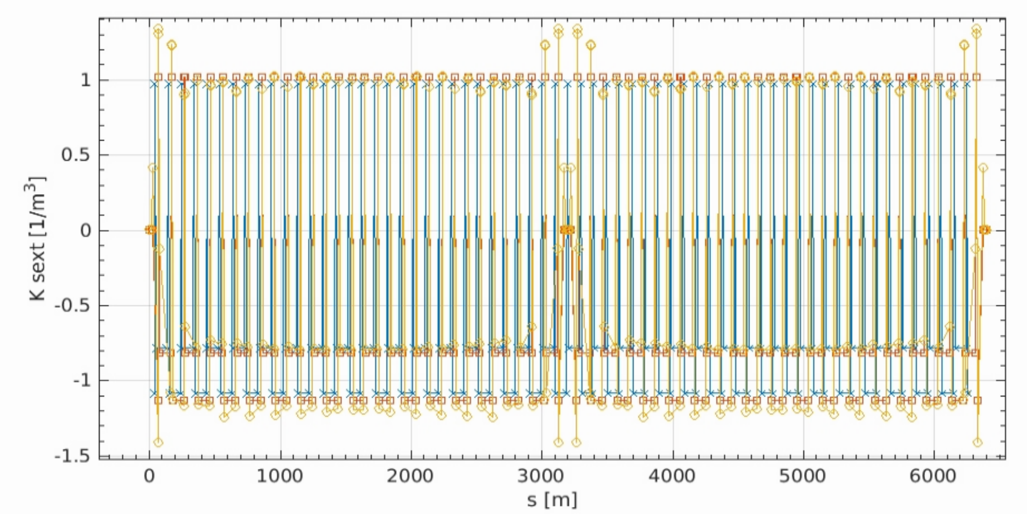
Dpp coordinate at 25% could be bracking the “small delta p /p” approximations throughout the expansion of the Hamiltonian.

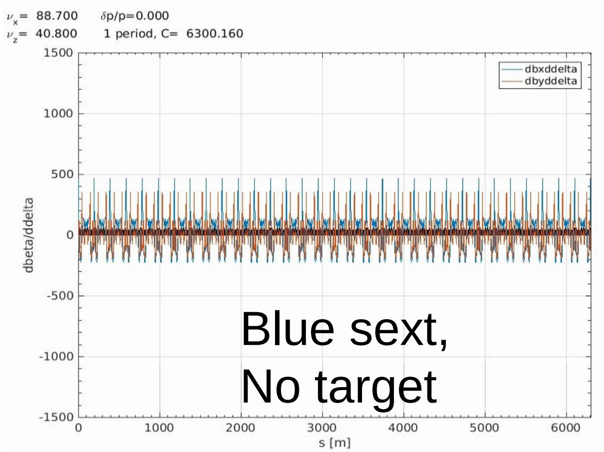
Tracking with E changed, and dipoles restored to nominal field using kicks?

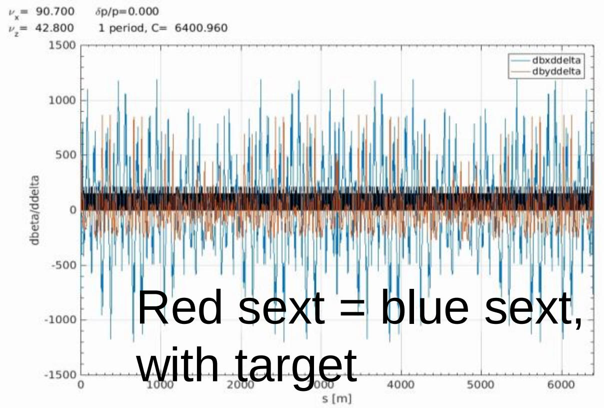
GEANT4BEAMLINE (MUONS INC.) TARGET SIMULATION

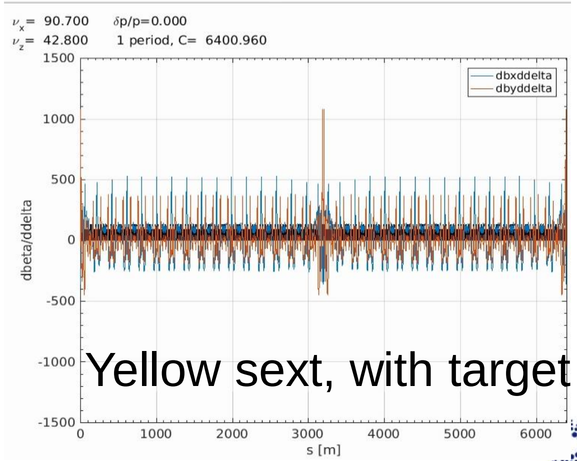


SEXTUPOLES TUNING









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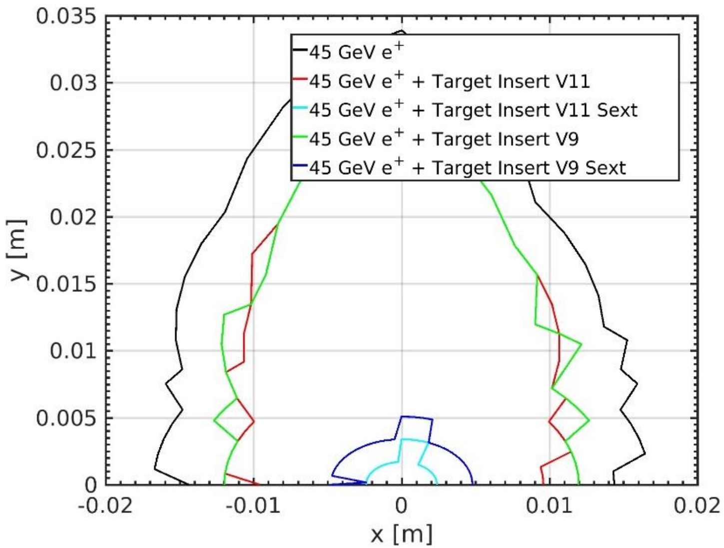
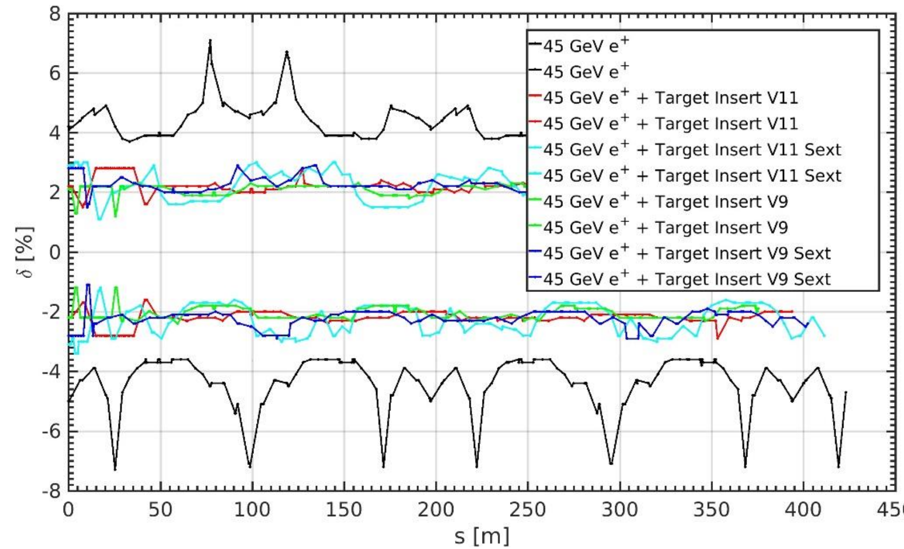
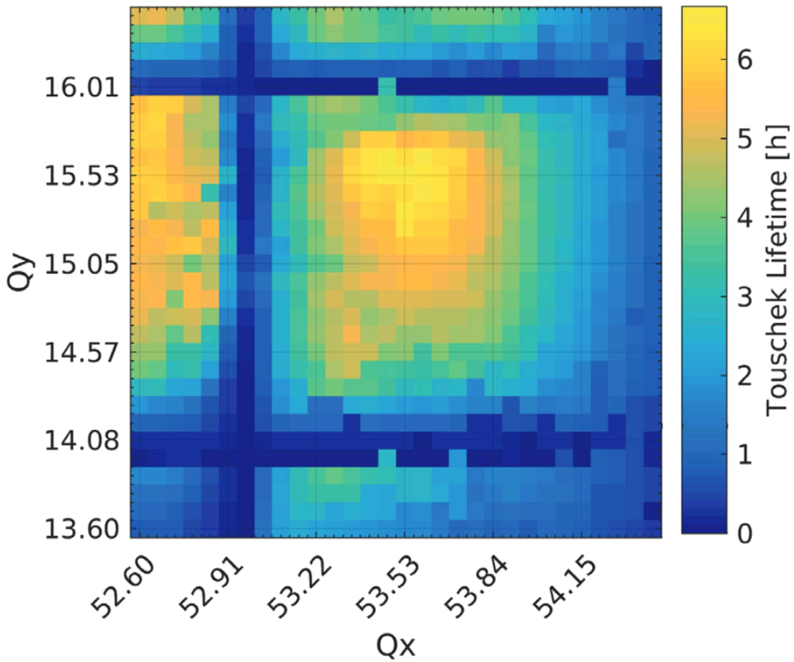
DA, MA

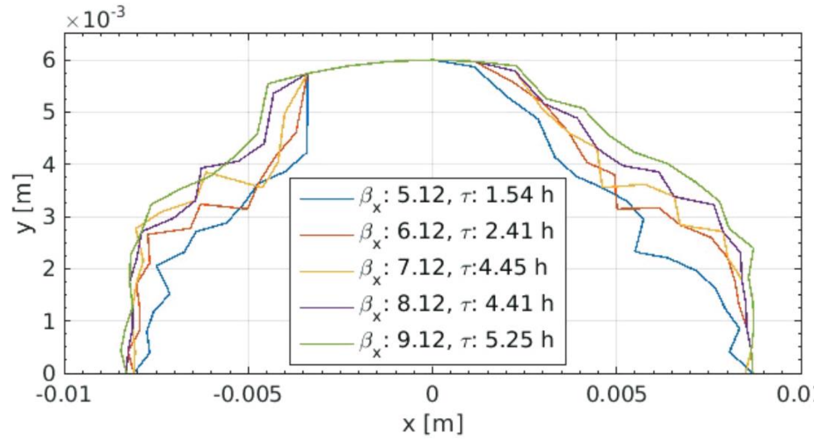


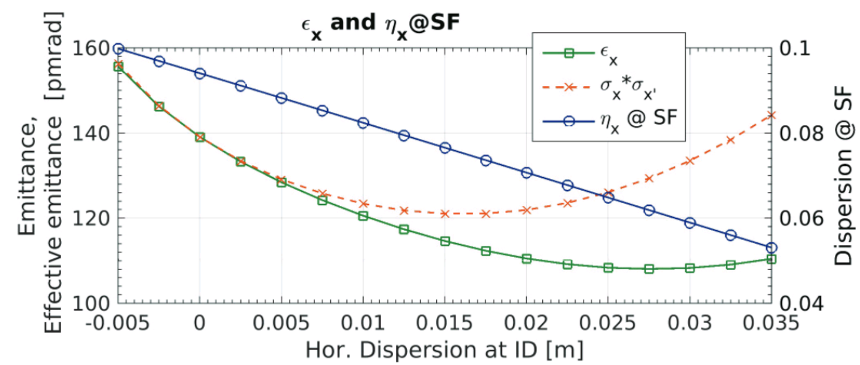


Sextupole tuning does not improve MA much, but cancels DA.
S=0 = target location

EXAMPLE OF OTHER OPTICS OPTIMIZATION FOR 3GEV HMBA







ALL THIS OPTIMIZATIONS SHOULD BE DONE ALSO FOR THE 45GeV positron rings.

Images from:
http://accelconf.web.cern.ch/accelconf/ipac2016/papers/wepow006.pdf