Extraction bumps and emittance studies for the ATF using pulsed magnets

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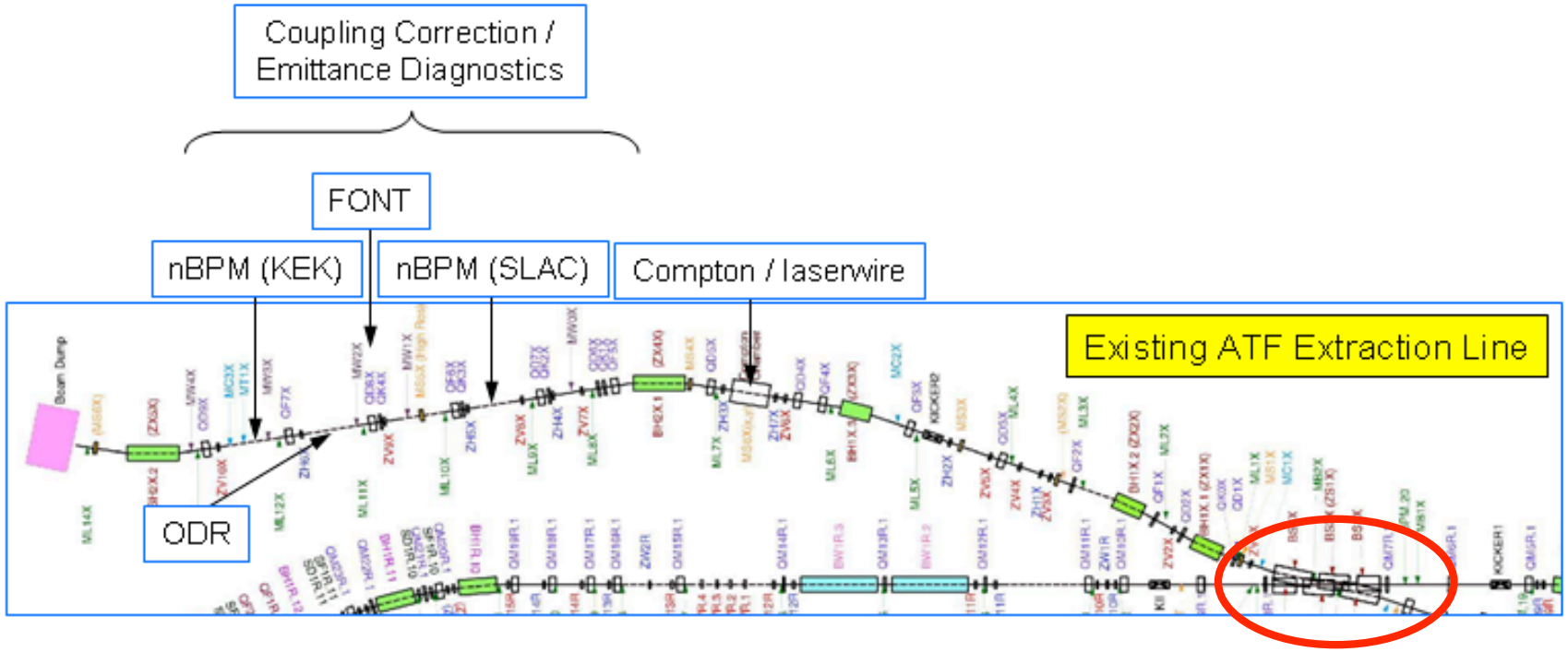
ATF2 meeting, LAPP, Annecy, France

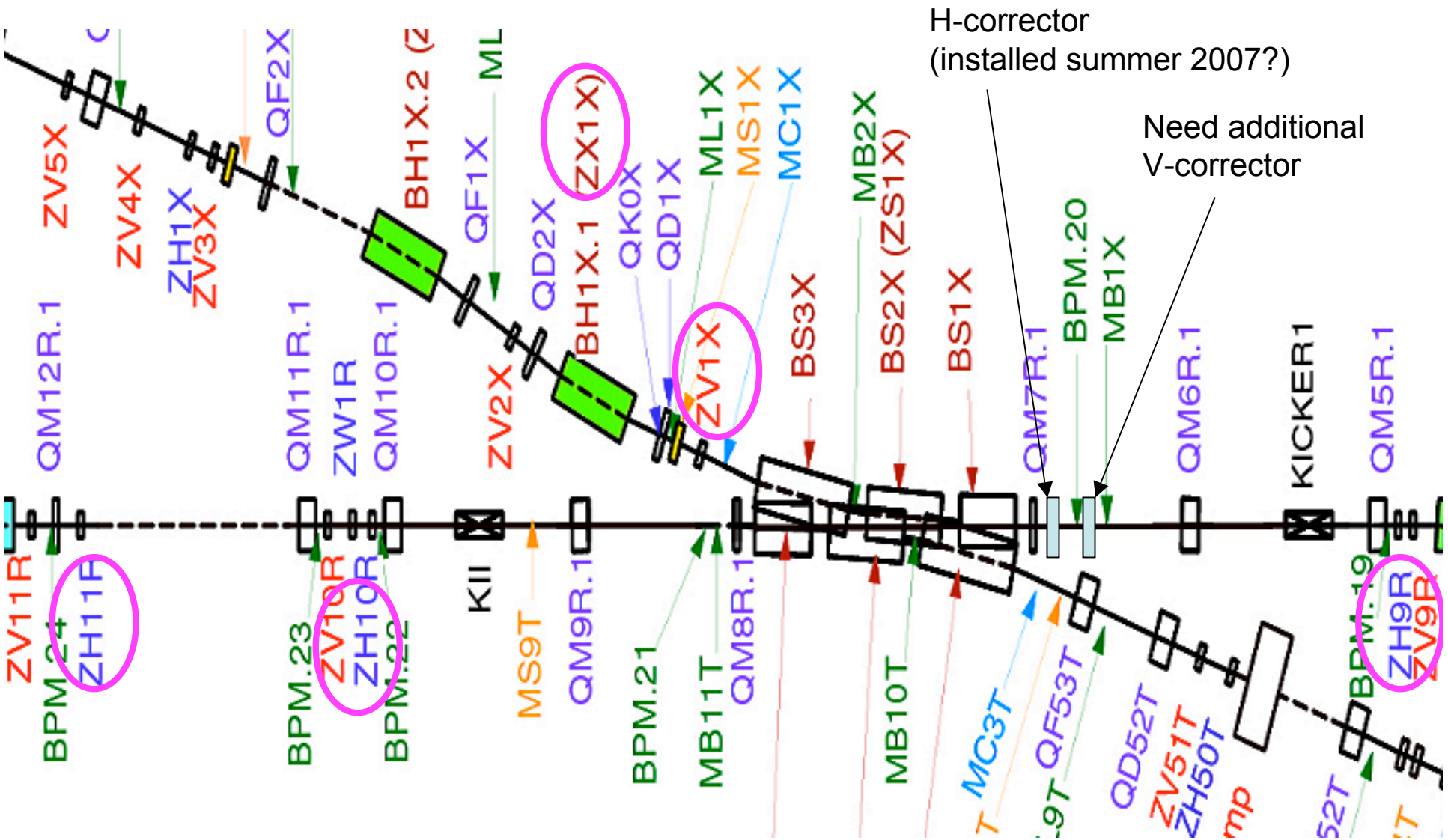
15/10/07

ATF extraction line

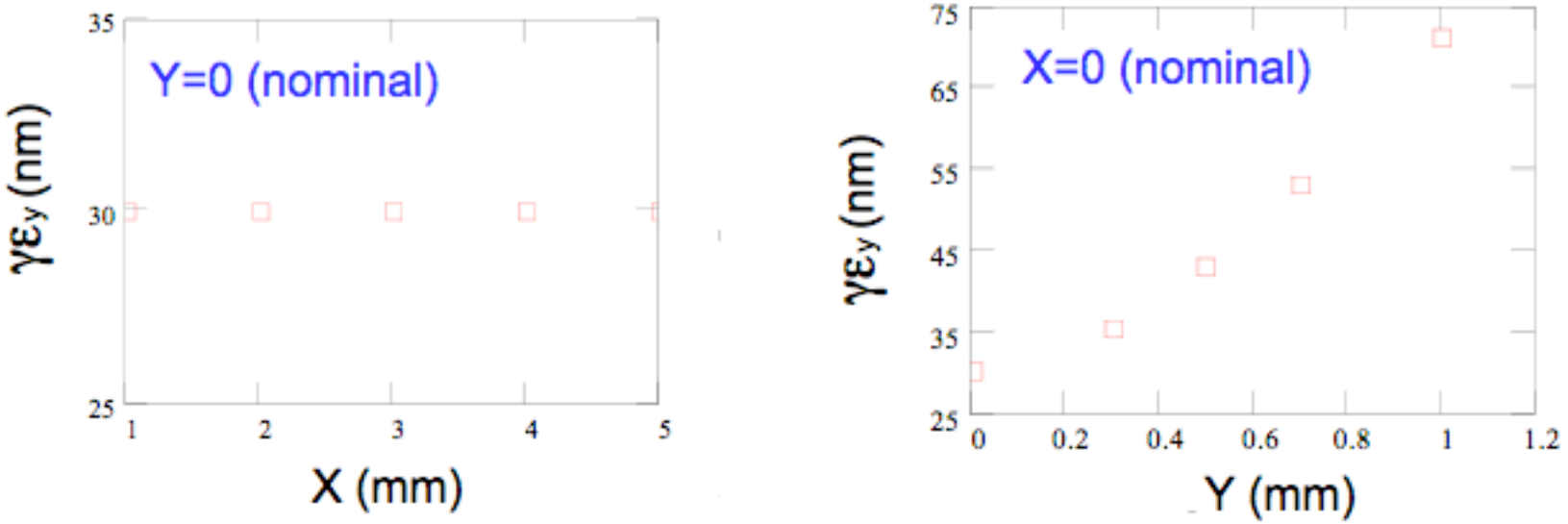


Measured vertical emittances are higher than expected, So study extraction magnet off-axis non-linear beam dynamics and possible wakefield effects to understand emittance source growth

Static bump (Woodley *et al*)



Static bump results (Woodley *et al*)



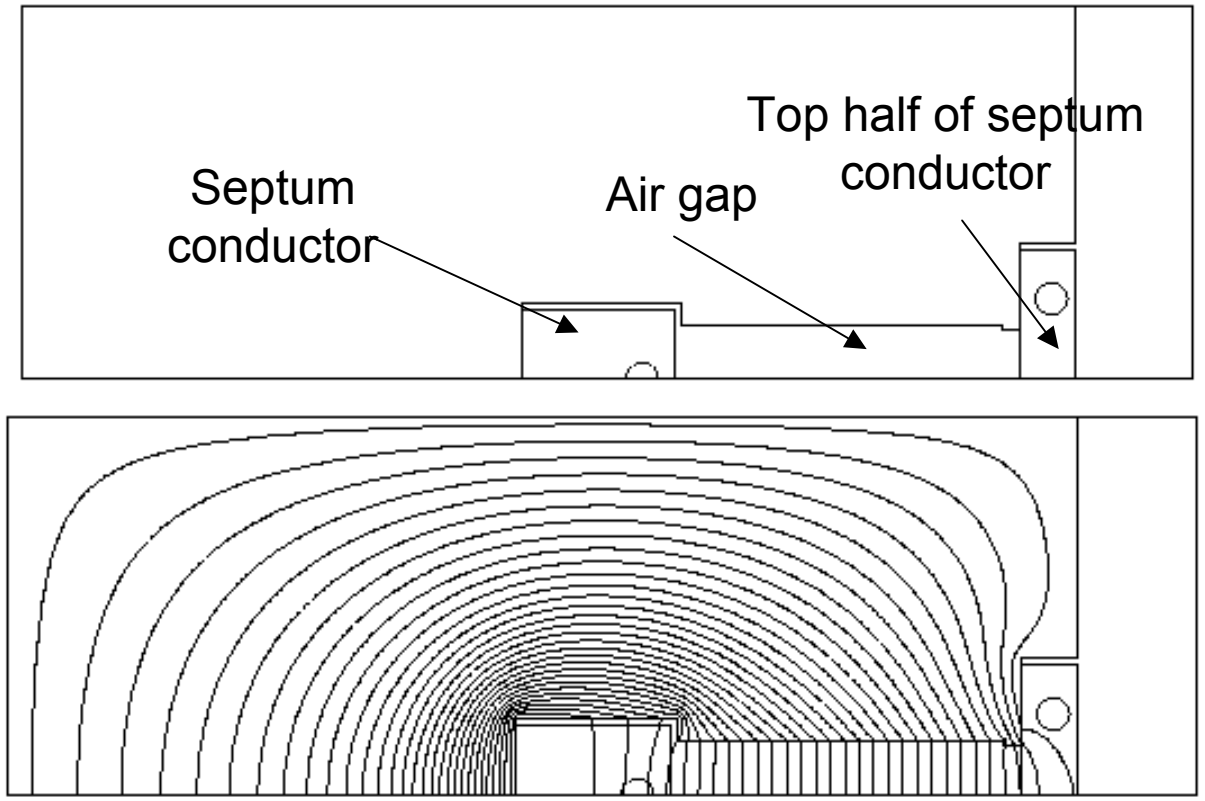
Not much sensitivity to horizontal bumps, but large sensitivity to vertical bumps.

⇒ Pulsed vertical kicker, giving offset of 1.5mm in QM7

Off-axis in extraction magnets

The beam passes off-axis through

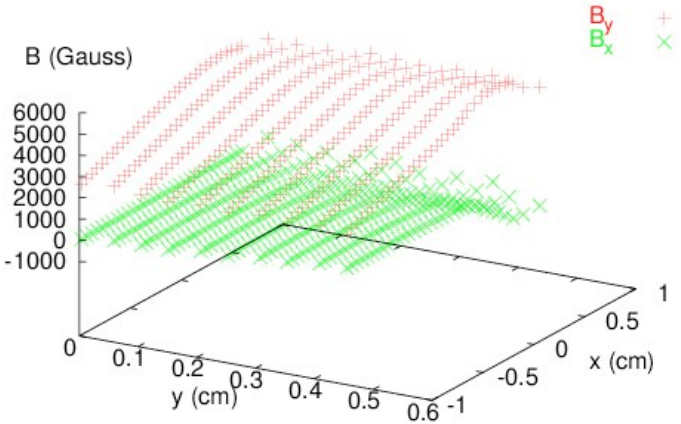
- QM6X, QM7X quadrupoles
- BS1X, BS2X and BS3X extraction septum magnets



Multipoles of QM7

Field map of a QM7-like quadrupole

x-2.25 cm



(Thanks to M. Alabau)

$$By = 0.461227 + 17.5409\,x - 975.611\,x^2 - 164998.\,x^3 - 1.83452\times10^{7}\,x^4 + 1.22734\times10^{9}\,x^5 + 1.03418\times10^{12}\,x^6 + 8.1599\times10^{13}\,x^7 - 3.15181\times10^{16}\,x^8 - 6.10052\times10^{18}\,x^9 + 6.81761\times10^{18}\,x^{10} + 8.79816\times10^{22}\,x^{11} + 8.10734\times10^{24}\,x^{12} + 2.33606\times10^{26}\,x^{13}$$

(B_x=0)

y=0 cm

(for L=6 cm)

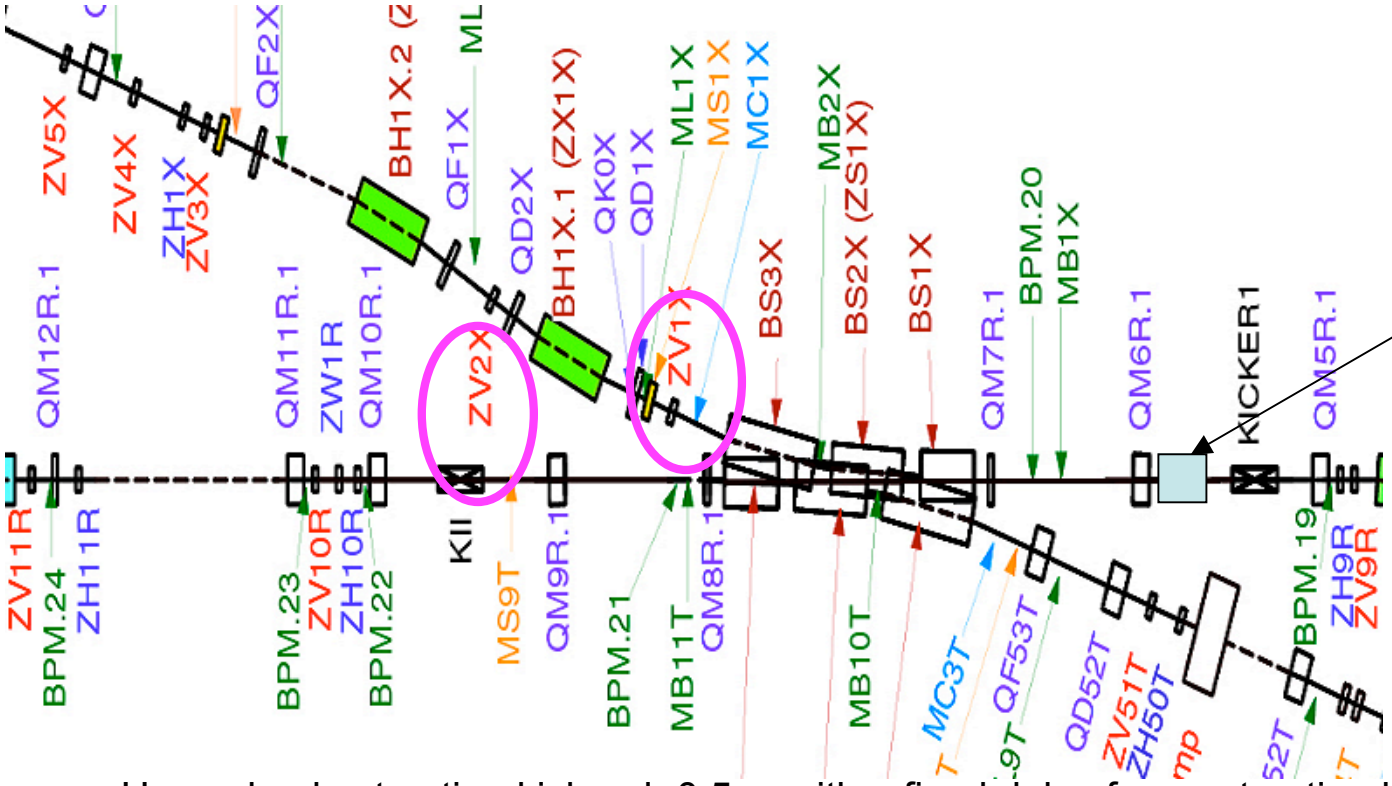
N	KN	MAD notation
1	0.00638	K0L
2	0.2427	K1L
3	-27.0	K2L
4	-1.37e4	K3L
5	-6.09e6	K4L
6	2.04e9	K5L

(for L=7.89 cm)

N	KN	MAD notation
1	0.00839	K0L
2	0.3192	K1L
3	-35.507	K2L
4	-1.80e4	K3L
5	-8.01e6	K4L
6	2.68e9	K5L

A common analysis for all ‘off-axis’ magnets in ATF would be beneficial for all studies of extracted bunch dynamics

Pulsed kicker scheme



New vertical kicker, located between kicker1 and QM6

Close bump with existing vertical correctors

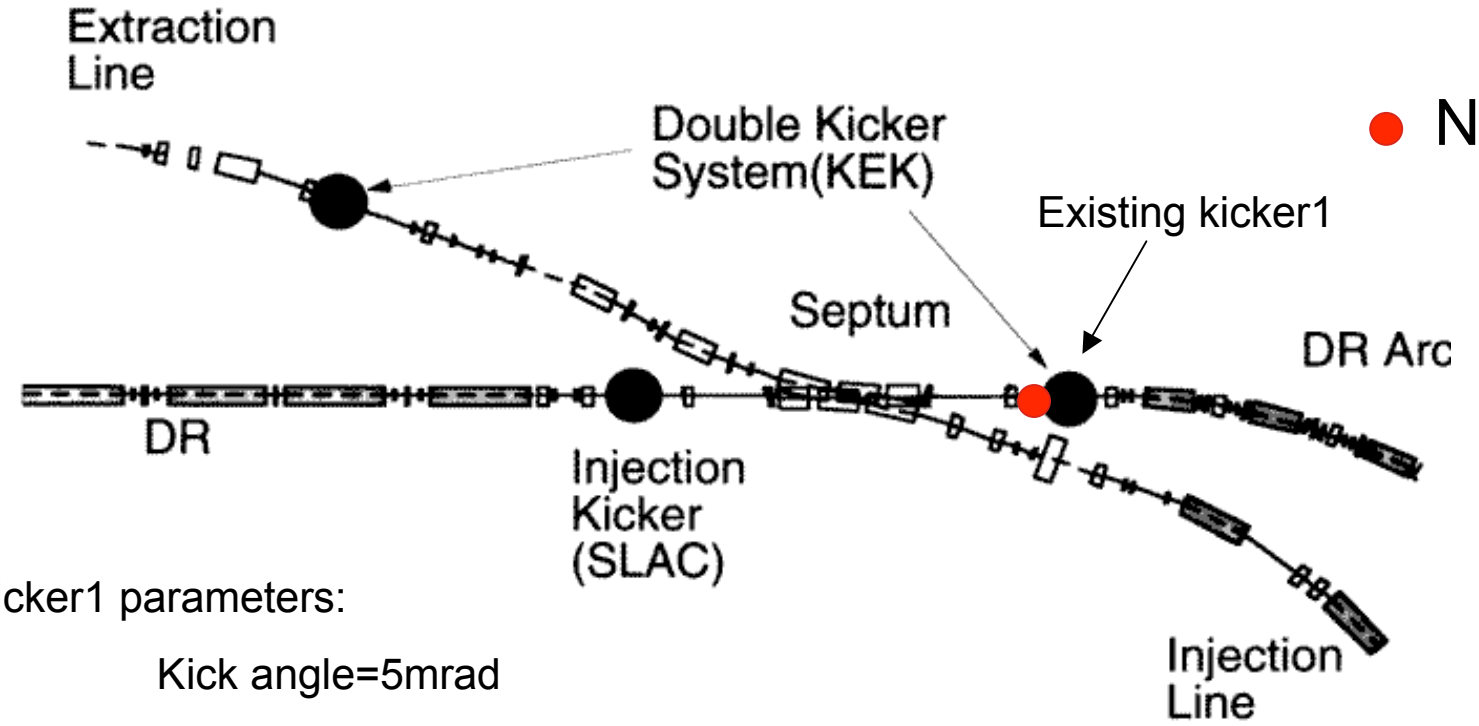
Use pulsed extraction kicker, l=0.5m, with a fixed delay from extraction kicker1, rotated into vertical plane to provide vertical bump for extracted bunches

Space exists between kicker1 and QM6R, and bump can be closed statically using ZV1X and ZX2X for extracted bunches.

Stored and injected bunches see no field, (c.f. static bump scheme), so injected bunches are unperturbed, and stored bunches get no cumulative effects over many turns i.e. No need to close any bumps for injected or stored bunches

Required strength is 20% of kicker1 (0.9mrad) for 1.5mm bump in QM7

Details of existing kickers



● New kicker

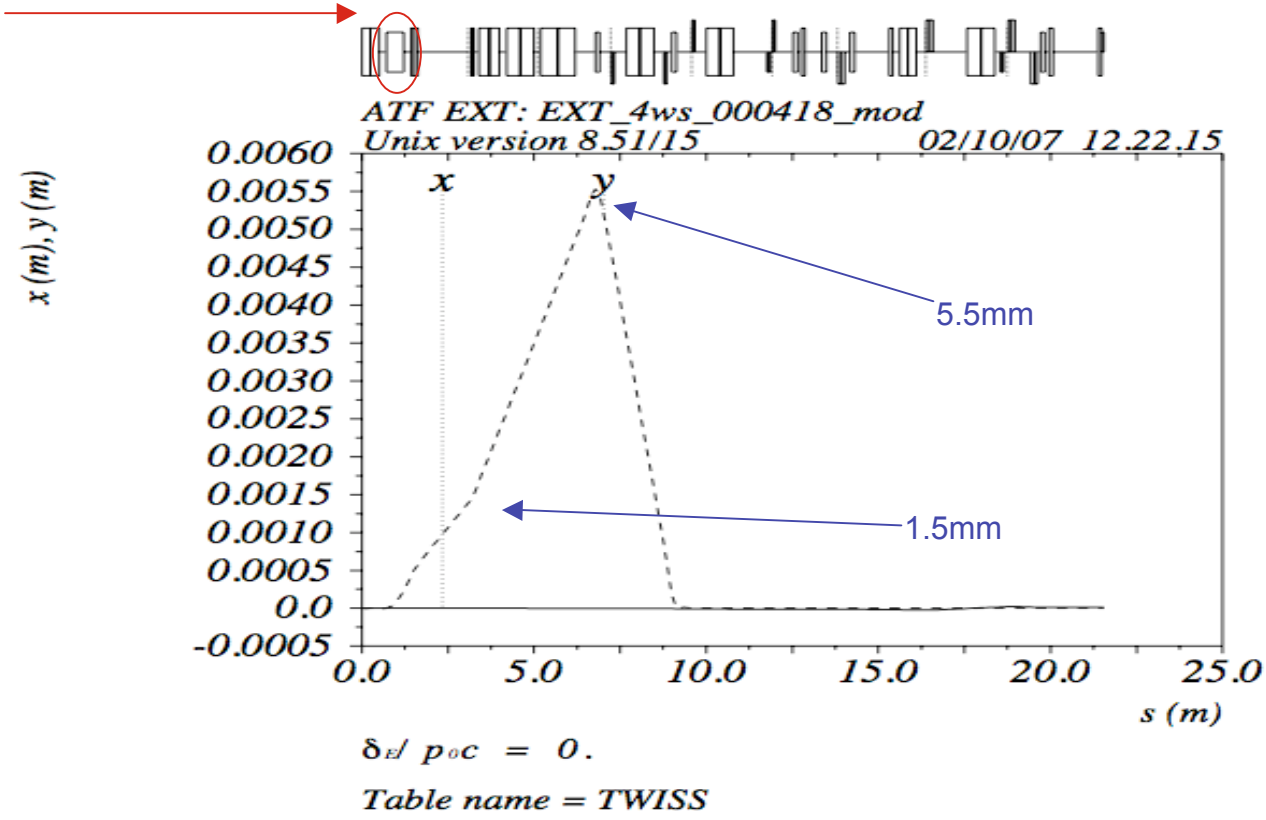
Kicker1 parameters:

- Kick angle=5mrad
- Length=0.5m
- Rise/fall time=60ns
- Flat top=60ns
- Max current=800A

Kicker system uses a single pulsed power supply, with a phase difference of π between kickers, to reduce jitter. New kicker needs 20% current of extraction kicker, and maybe use same power supply with a delay circuit. The required delay is 1ns (a length of wire?). The kicker availability needs to be checked (1mrad, 60ns rise/fall)

Optics to generate 1.5mm local bump at QM7

New pulsed magnet

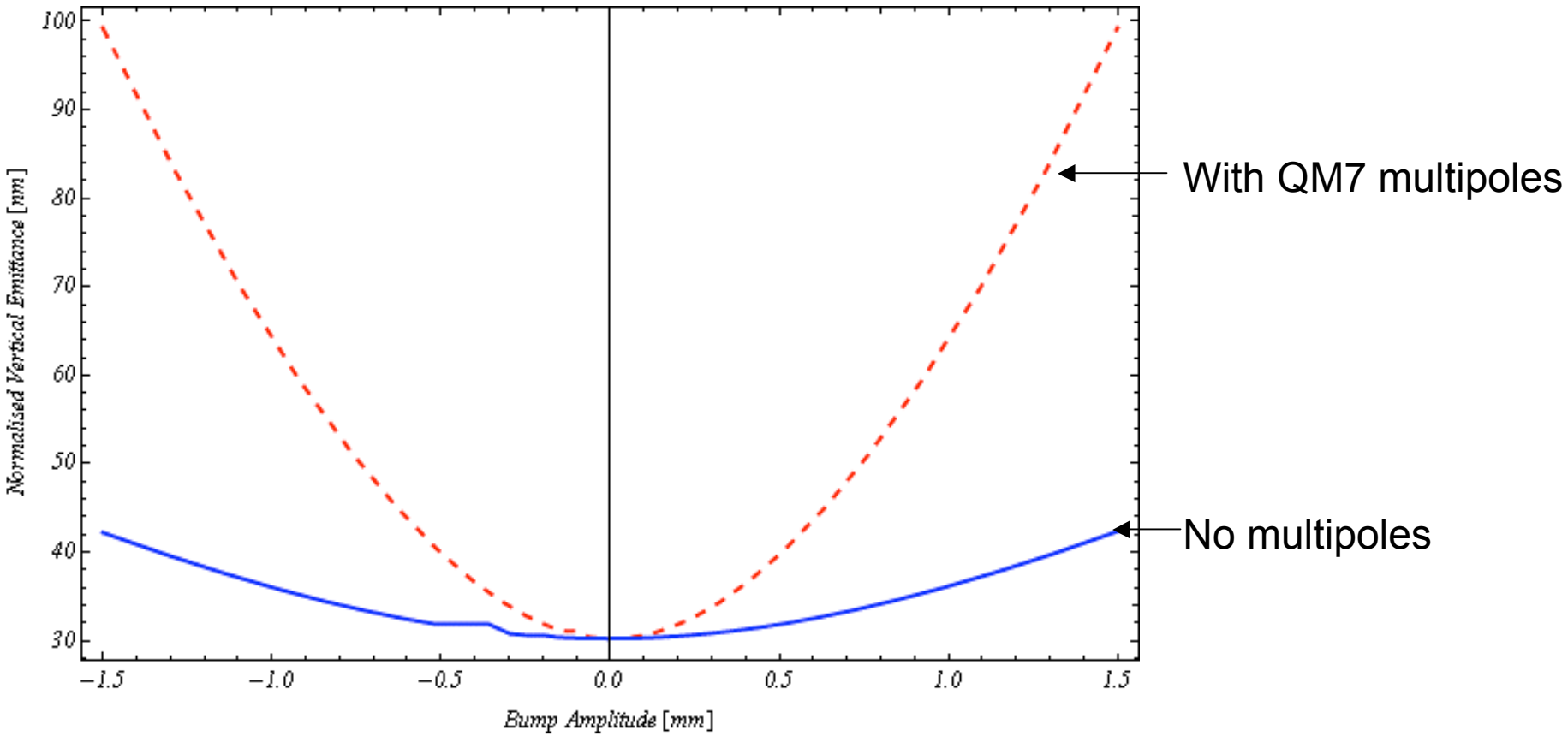


Septum half-gaps are 16mm, so plenty of vertical clearance

Sign of bump can be inverted to reduce vertical clearance requirements if needed

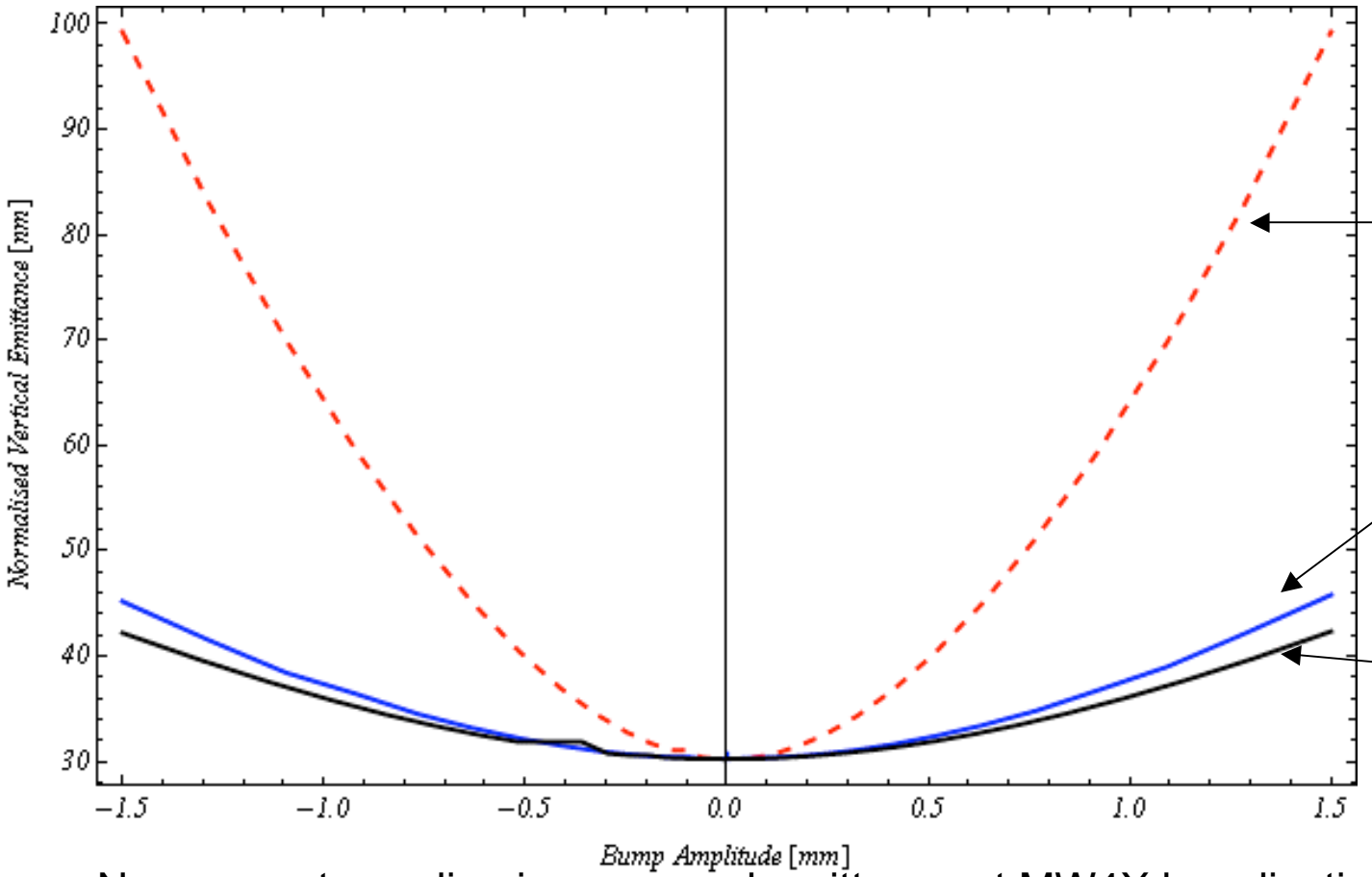
Strengths for Vkbump, ZV1X and ZV2X are 0.9mrad, -3mrad and 2.8mrad respectively (okay)

2D y-emittance growth for variable QM7 bump



Computed by tracking an extracted bunch through variable local bump optics using MAD. Emittance is computed at wire scanner MW4X. Extracted normalised emittance is 3.10^{-8} m rad. Emittance growth consistent with the static bump calculations for vertical offsets

2D y-emittance growth for variable QM7 bump with coupling correction



With QM7 multipoles

With QM7 multipoles + coupling correction (remaining is residual non-linear fields)

No multipoles (because of energy spread)

Now correct coupling in measured emittance at MW4X by adjusting four skew quadrupoles in diagnostic straight to minimise coupling induced in QM7 multipoles. Optimisation is achieved by minimising measured emittance at MW4X.

(Need to ensure vertical dispersion free - true here but will not be operationally.

Summary

- Initial $\gamma\varepsilon_y$ is 30nm rad, and the emittance is measured at MW4X with the inclusion of QM7 multipole fields and a local vertical bump
- Optics requires additional pulsed vertical kicker and utilises two existing static correctors to close the bump
- Tracking results show measurable increase of $\gamma\varepsilon_y$ for bumps of up to 1.5mm in QM7
- Coupling correction is possible using 4 skew quads
- A pulsed kicker beam test would be interesting
  - Requirements are a vertical pulsed magnet, of angle 1mrad and 60ns rise/fall time
  - Measure extracted emittance as function of local bump amplitude, with and without correction
  - Could use existing hardware for magnet pulser
  - 2/3 shifts would be needed, 1 for calibrating the pulsed magnet, 1 for understanding the bump and emittance measurement and 1 for data taking

To do…

- Check the multipole expansion of QM7 is valid for $y \neq 0$ (2D)
- Include multipoles of (through common analysis)
  - extraction kicker, bump kicker
  - QM6
  - Extraction septum dipoles
  - Multipole interactions may play a role
- Check availability and feasibility of
  - pulsed kicker magnet
  - delay circuit (trivially part of control system?)
  - Flat top/rise time change under 1mrad kick current (20%)
- The dipole and quadrupole multipole fields of QM7 differ from the design, and downstream optics needs refitting to absorb perturbations
- Emittance measurement should be properly modelled
- (Determine real gradient of QM7 from beam (for minimum of measured emittance) to rematch downstream optics)

Backup slides

Initial parameters (start of kicker1)

normalized emittances

E_0 (GeV)	1.3
$\gamma\varepsilon_x$ (m rad)	3.0×10^{-6}
$\gamma\varepsilon_y$ (m rad)	3.0×10^{-8}
σ_ε (%)	0.1
σ_z (mm)	8.0
$ß_{x\ (m)}$	7.212
$ß_{y\ (m)}$	2.903
$\alpha_{x\ (m)}$	1.151
$\alpha_{y\ (m)}$	-1.721