Preliminary Design of a 700MeV Spiral Ring for KURRI FFAG Complex

(i) Motivation
(ii) Parameters search
(iii) Magnet design with TOSCA

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Motivation

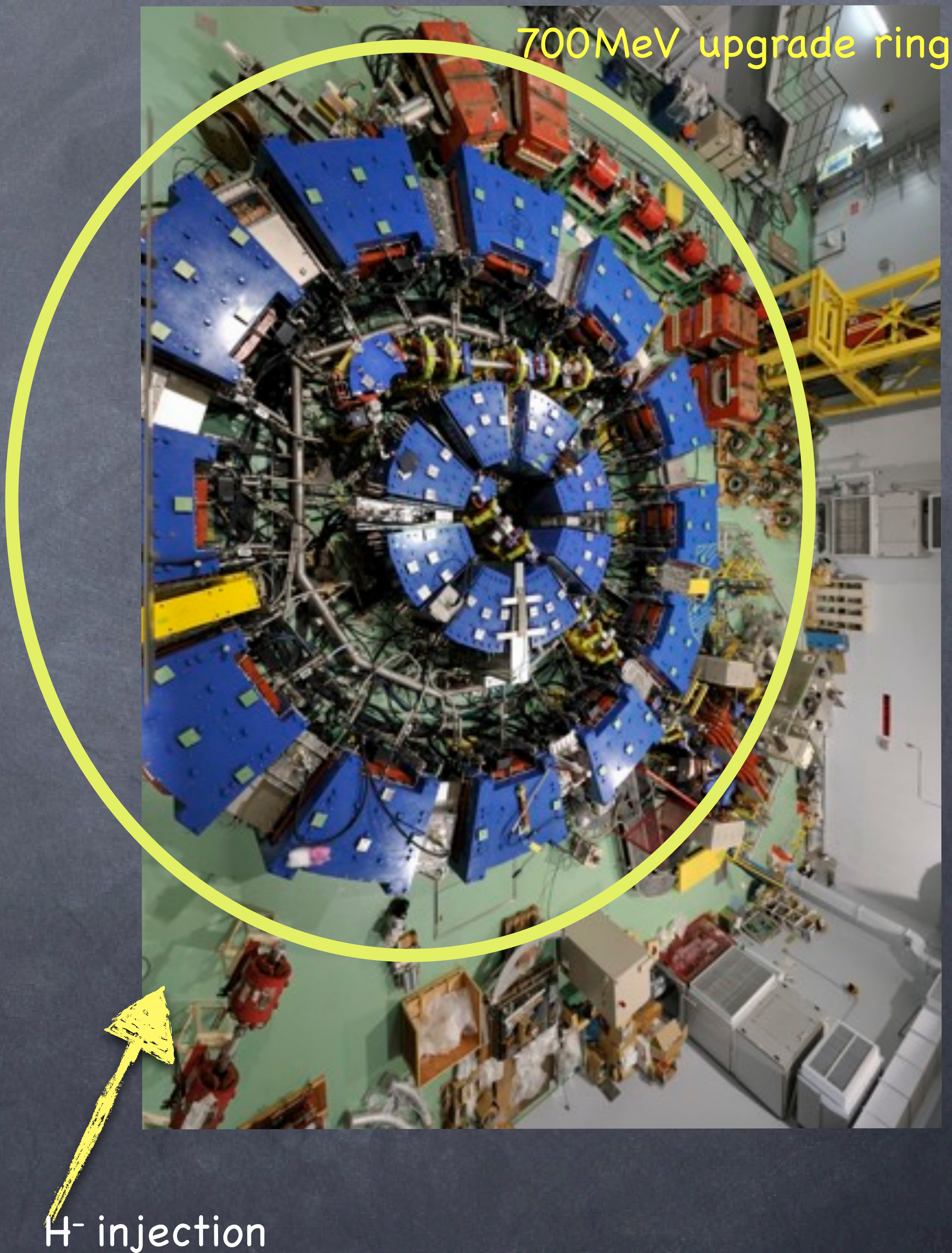
- March 2009, First ADSR experiment was performed in KURRI with 100MeV/0.1nA proton beam delivered by FFAG complex

- To increase spallation neutron intensity S

$$P \propto \frac{S}{1 - k_{eff}}$$

i) High proton beam intensity: Replace injector (ion-beta + booster) with the H^- ERIT-Linac injector

ii) Higher beam energy to increase neutrons produced by per primary proton, 100MeV -> 700MeV => about a factor of 30

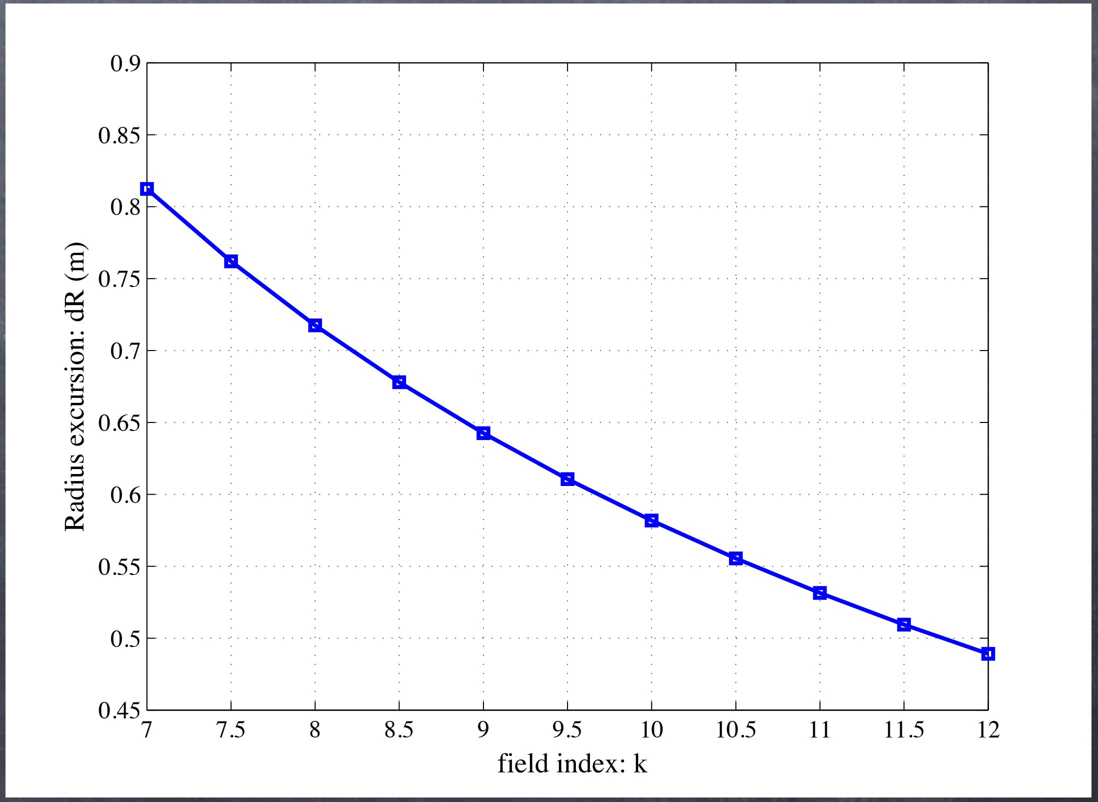


Considerations for the 700MeV FFAG Ring

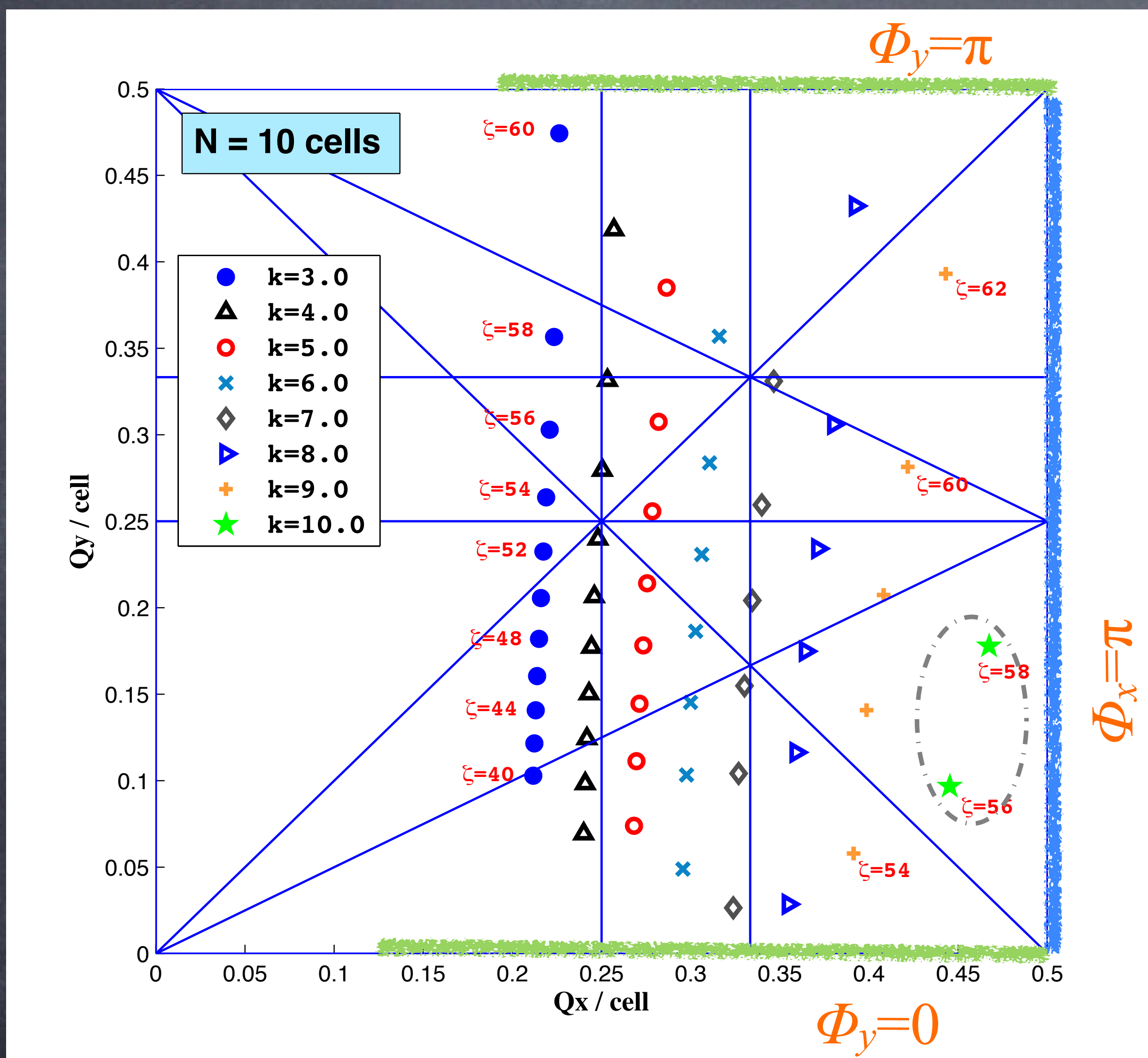
- Compact and simpleness: Spiral type scaling FFAG with variable gap shape (RACCAM)
- Spiral angle < 60 deg., for RF cavity etc.
- High field index to abbreviate field excursion

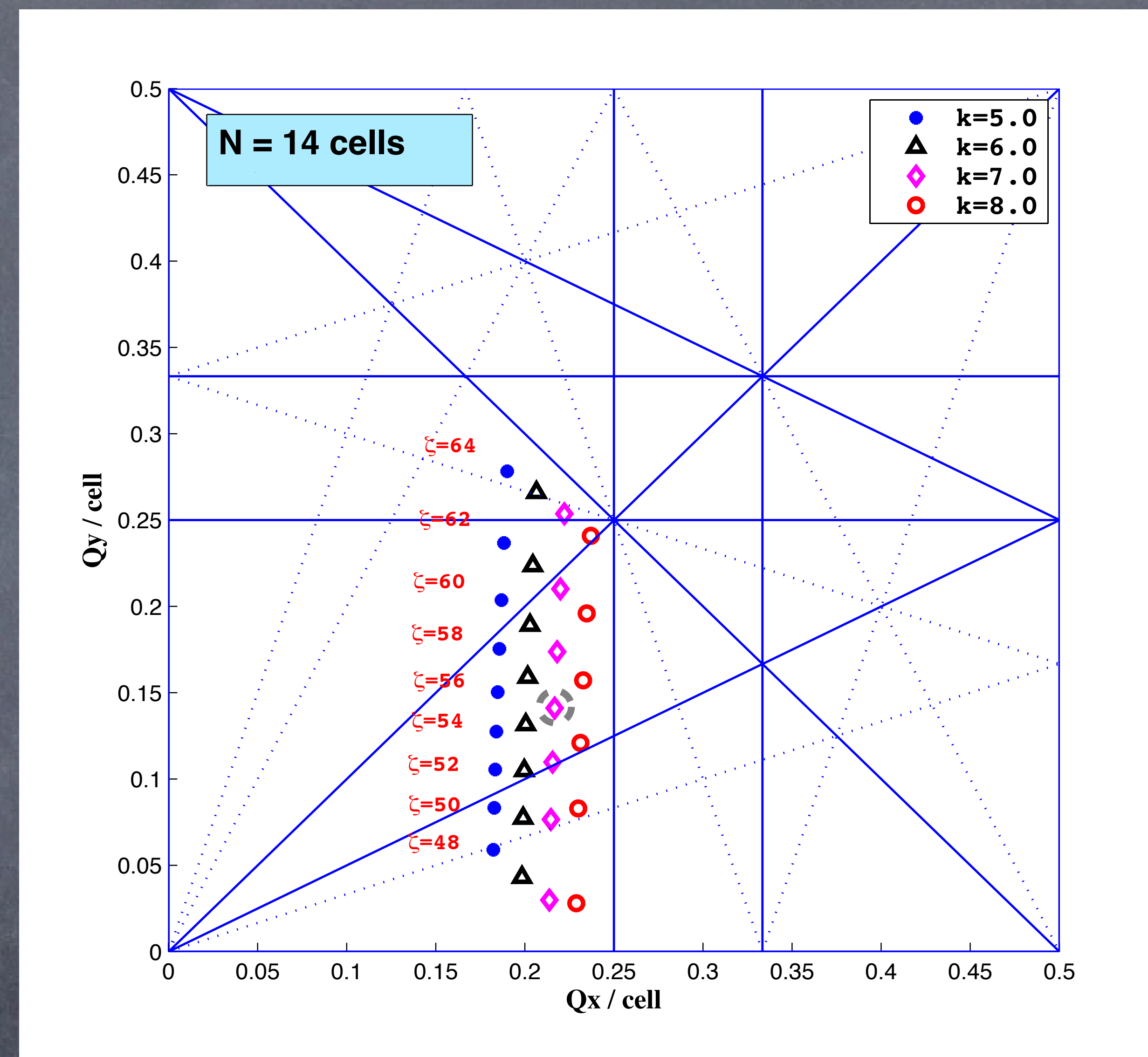
$$\Delta R = ((P_{ext}/P_{inj})^{\frac{1}{1+k}} - 1) \cdot R_0$$

P_{700MeV}/P_{150MeV}=2.43, for R0=6.9m,
k>6.0 to maintain dR<0.9m



Parameters Search with cell number N=8~16, pf=0.4

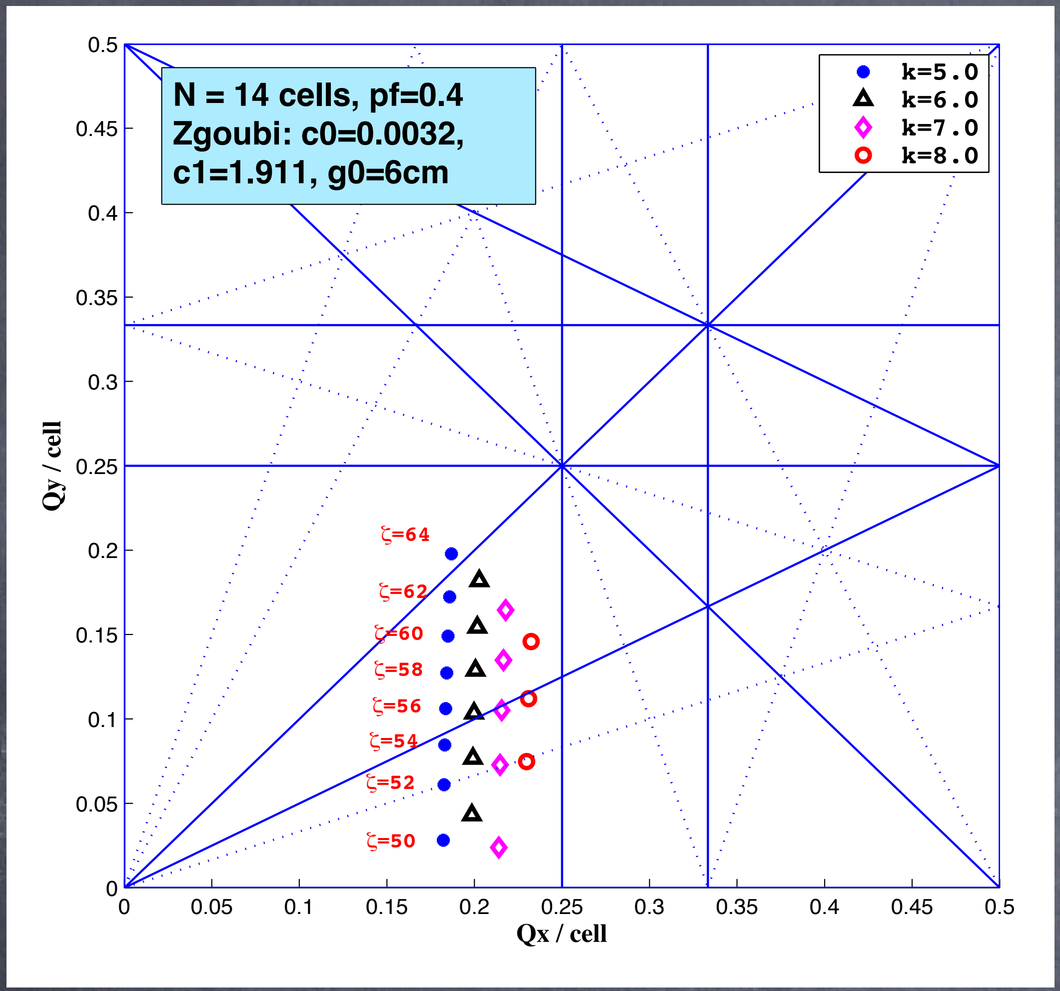




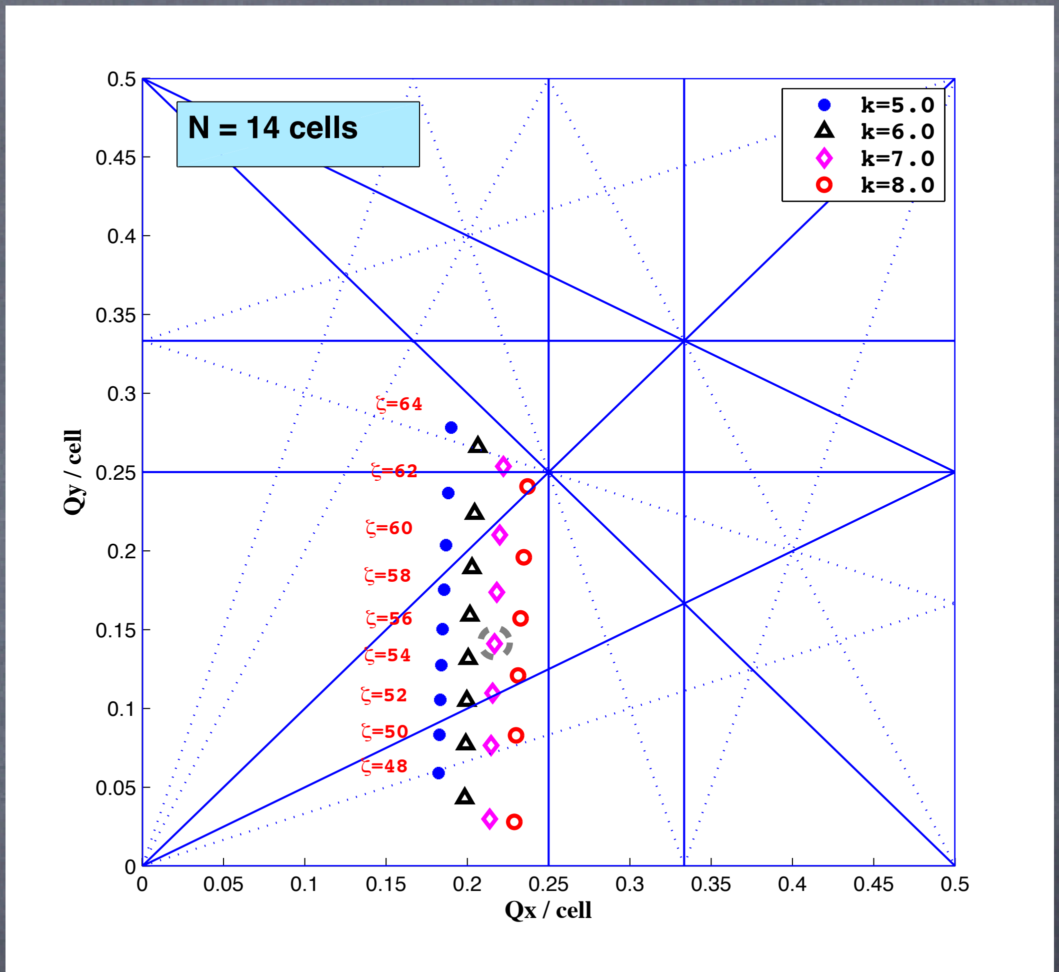
N=10 case, k=10 seems interesting, but the tune is too sensitive to local k & zeta.

More practical N=14 case, (k=7, zeta=58deg. => Qx=0.22, Qy=0.14) is selected as the working point.

Model validation with Zgoubi code



Zgoubi FFAG-SPI



Matrix method

- Qz decreases due to fringe field: $Qz^2 = -k+F(1+2\tan^2(zeta))$, F=1/pf in hard edge model
- To compensate Flutter drop down, packing factor should be decreased in realistic model to maintain the same working point

Lattice and Magnet Parameters

Table 1: Parameters of the 700MeV ring (Theoretical)

Lattice type	spiral sector, scaling FFAG
Cell number	14
Injection / Extraction energy	150 / 700 MeV
Momentum ratio (P_{ext}/P_{inj})	2.43
Field index	7.0
Spiral angle	58.0 degree
Packing factor	0.4
R_{inj}/R_{ext}	6.9 / 7.7 m
$B_{max}@R_{ext}$	1.45T
ν_x/ν_z per cell	0.22 / 0.14
β_x min/max	1.4 / 4.0 m
D_x min/max	0.65 / 1.0 m

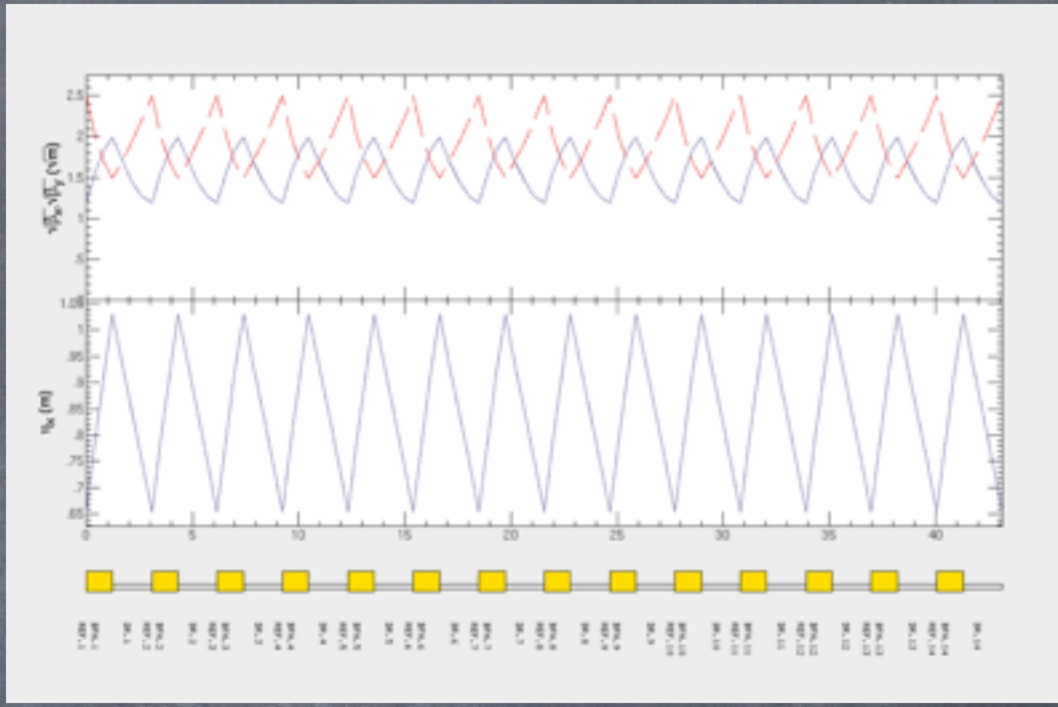
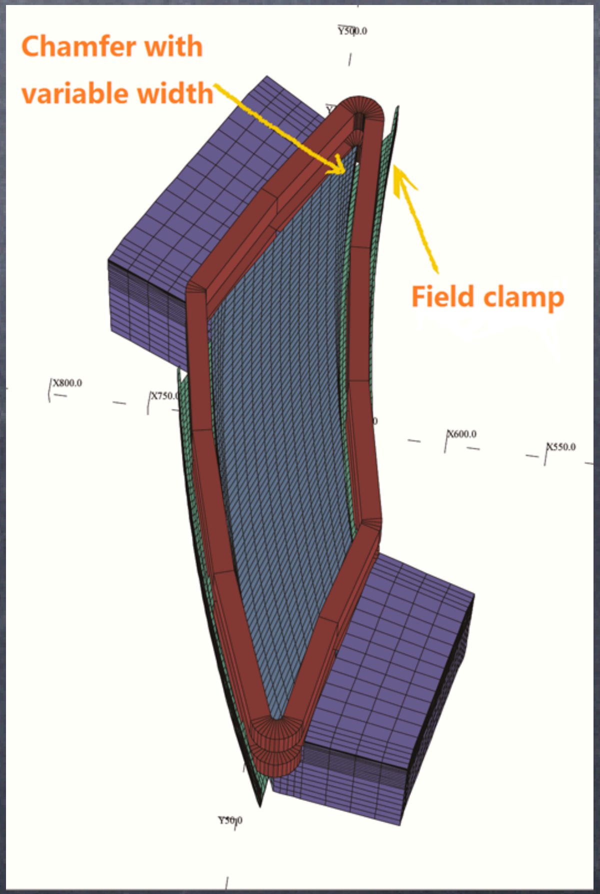
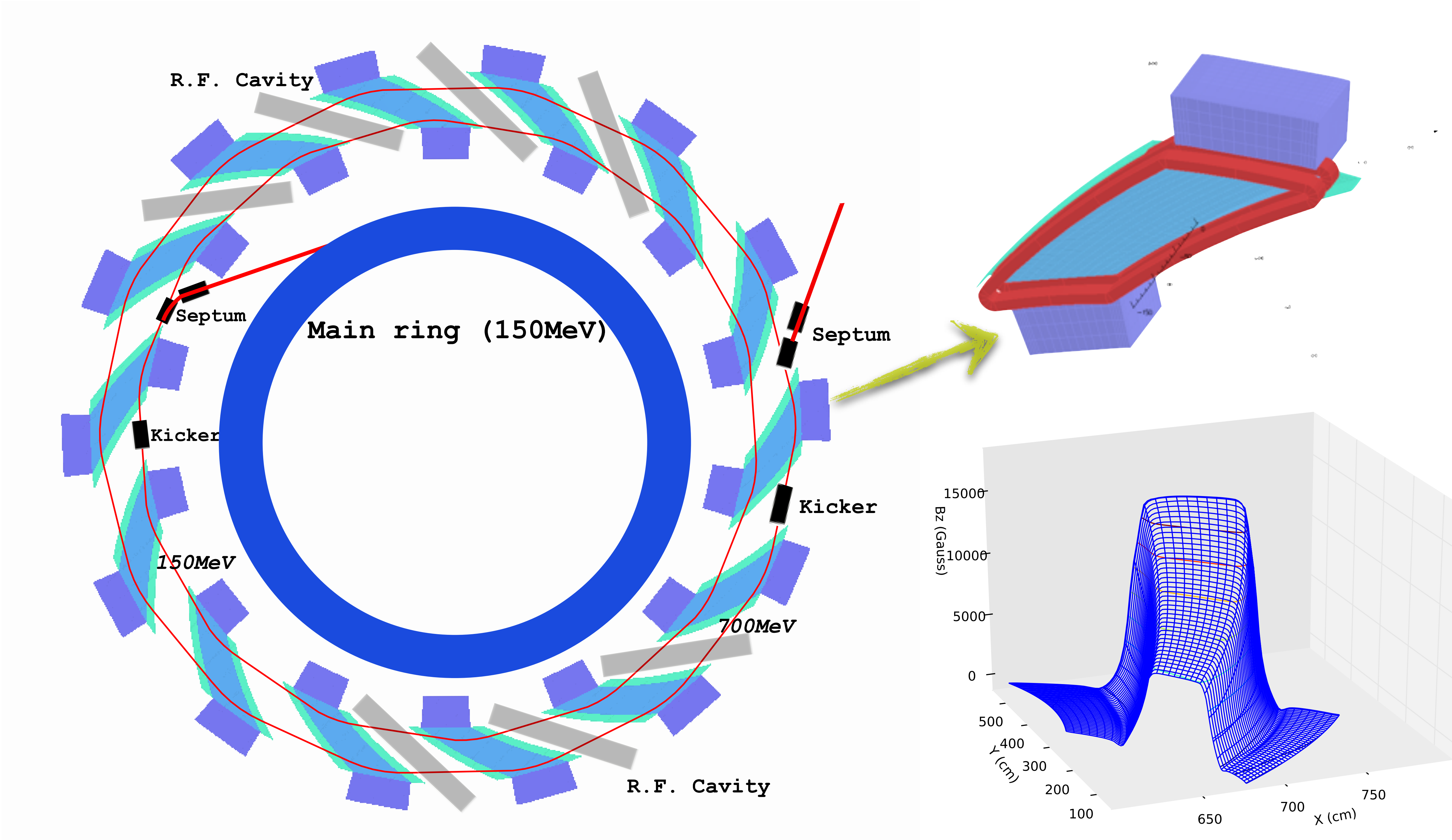


Table 2: Parameters of the magnet (TOSCA model)

Field index	6.2
Spiral angle	58.0 degree
Packing factor	0.38
ν_x/ν_z per cell	0.20 / 0.13
R_{inj}/R_{ext}	6.85 / 7.75 m
$B_{max}@R_{ext}$	1.55T
Half gap size	2.0cm @ extraction
Coil current density	$1.52A/mm^2$
Coil cross section	$160mm \times 100mm$
Approx. weight of magnet	20 t





Schematic view of spiral FFAG ring (N=14)

Control of vertical tune shift

Compared with the flat pole magnet sector using trim coils (Ion-beta), the vertical tune shift is enlarged in the variable gap scheme, due to the decreasing fringe extend at higher beam energy.

Some experiences such as the RACCAM prototype magnet has shown the possibility to modulate this tune shift by model optimization.

3 methods employed during 700MeV spiral magnet design:

(1) Introducing pole chamfer with variable width and field clamp to mitigate fringe field extent change duo to variable gap geometry:

- ➡ Since $g(r) = g_0 \cdot (r_0/r)^k$, the pole decreases with radius, which contradicts to the requirement for scaling pole gap with radius (to keep constant vertical focusing).
- ➡ The chamfer width should be increased with radius, to compensate this effect.

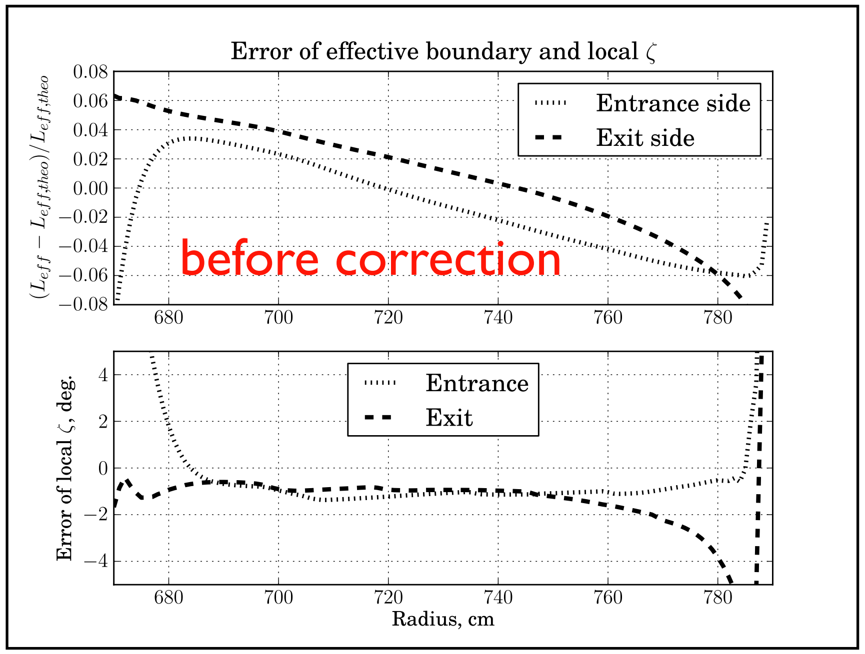
Control of vertical tune shift (cont.)

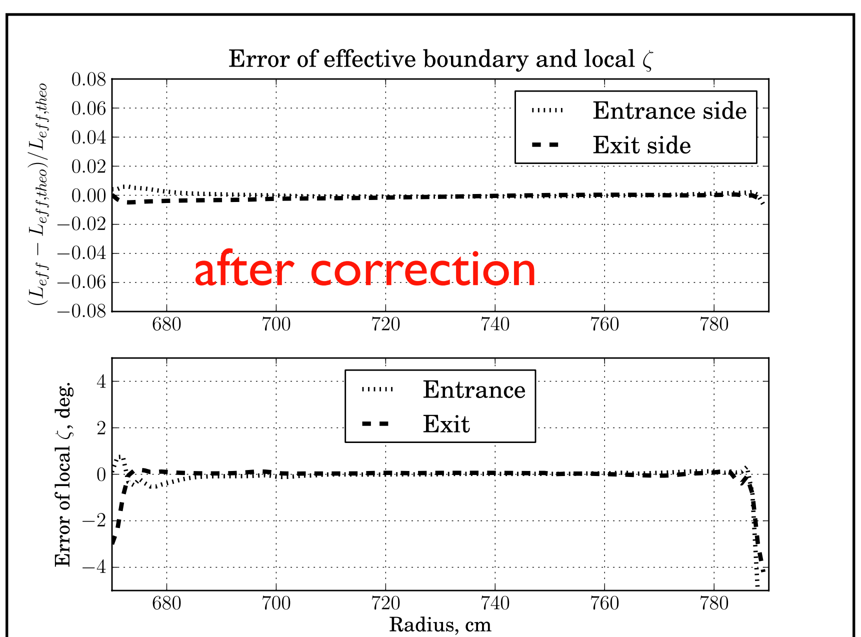
(2) Effective magnetic field boundary correction based on the field integrals: to align local field index (make $k_{BL} = k_{CENTER}$) and local spiral angle.

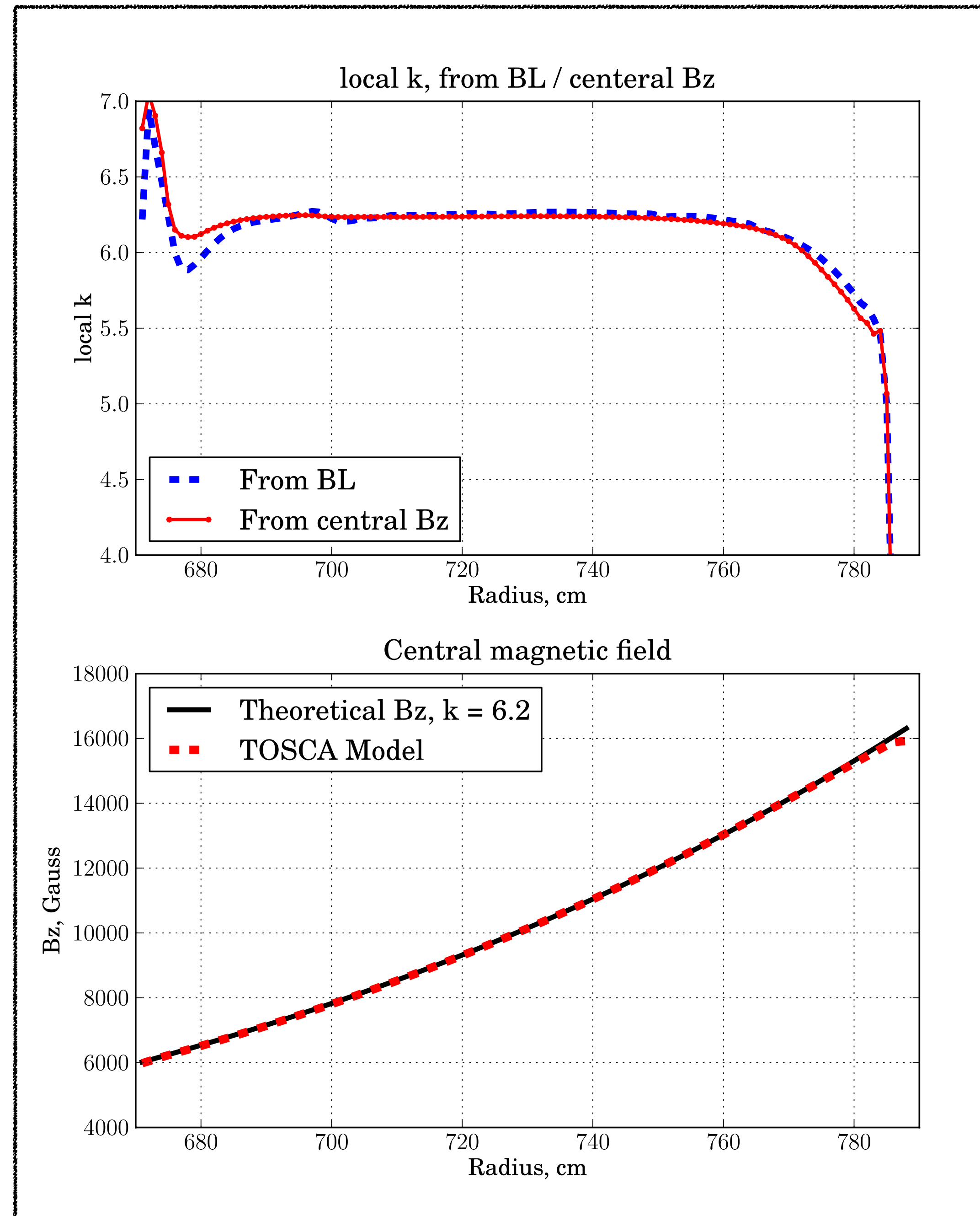
$$L_{eff,\,entrance} = L_{eff,\,exit} = L_{eff,\,theo}(\pi/N) \cdot R \cdot pf$$

$$L^{MODEL}_{eff,\,entrance\,|\,exit} = (\int B_z \cdot dl)_{entrance\,|\,exit} / B_{z,\,center}$$

$$\rightarrow \quad (Bl)_r = (Bl)_{r0} \times (\frac{r}{r0})^{1+k_{local}}$$







Control of vertical tune shift (cont.)

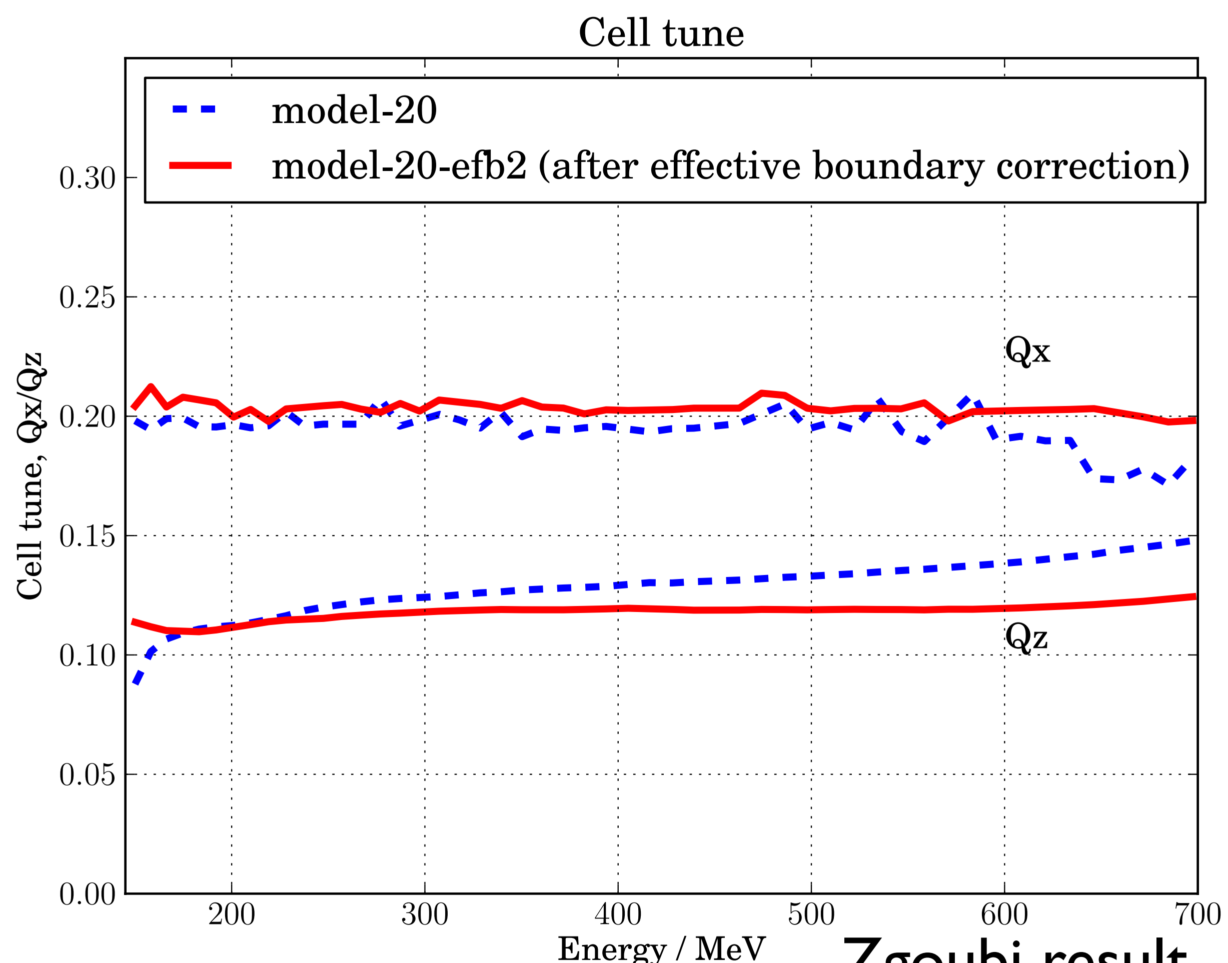
(3) Minute modification on local spiral angle, for final compensation on the vertical tune shift (depends on the result after EFB correction). The required $d\zeta$ can be estimated by:

- numerical data of the field flutter F

$$\nu_z^2 = -k + \frac{N^2}{N^2-1} \cdot F \cdot (1 + 2\tan^2\zeta)$$
$$\approx -k + F \cdot (1 + 2\tan^2\zeta) \qquad if\ N \gg 1$$

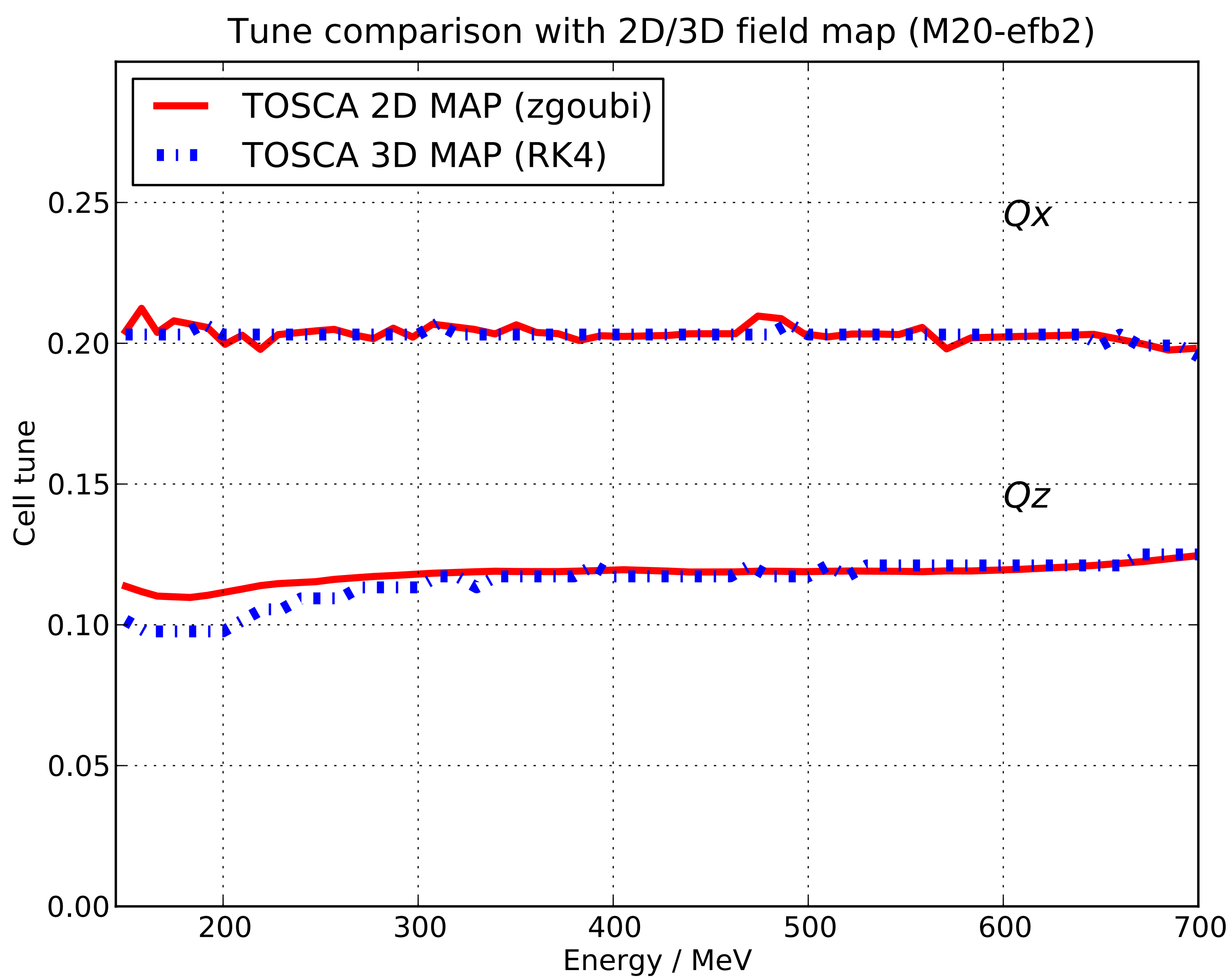
$$\Longrightarrow \quad \frac{d\nu_z}{d\zeta} = \frac{2F \cdot \tan\zeta}{\sqrt{-k + F(1 + 2\tan^2\zeta)} \cdot \cos^2\zeta}$$

- or, from tune variation using linear model

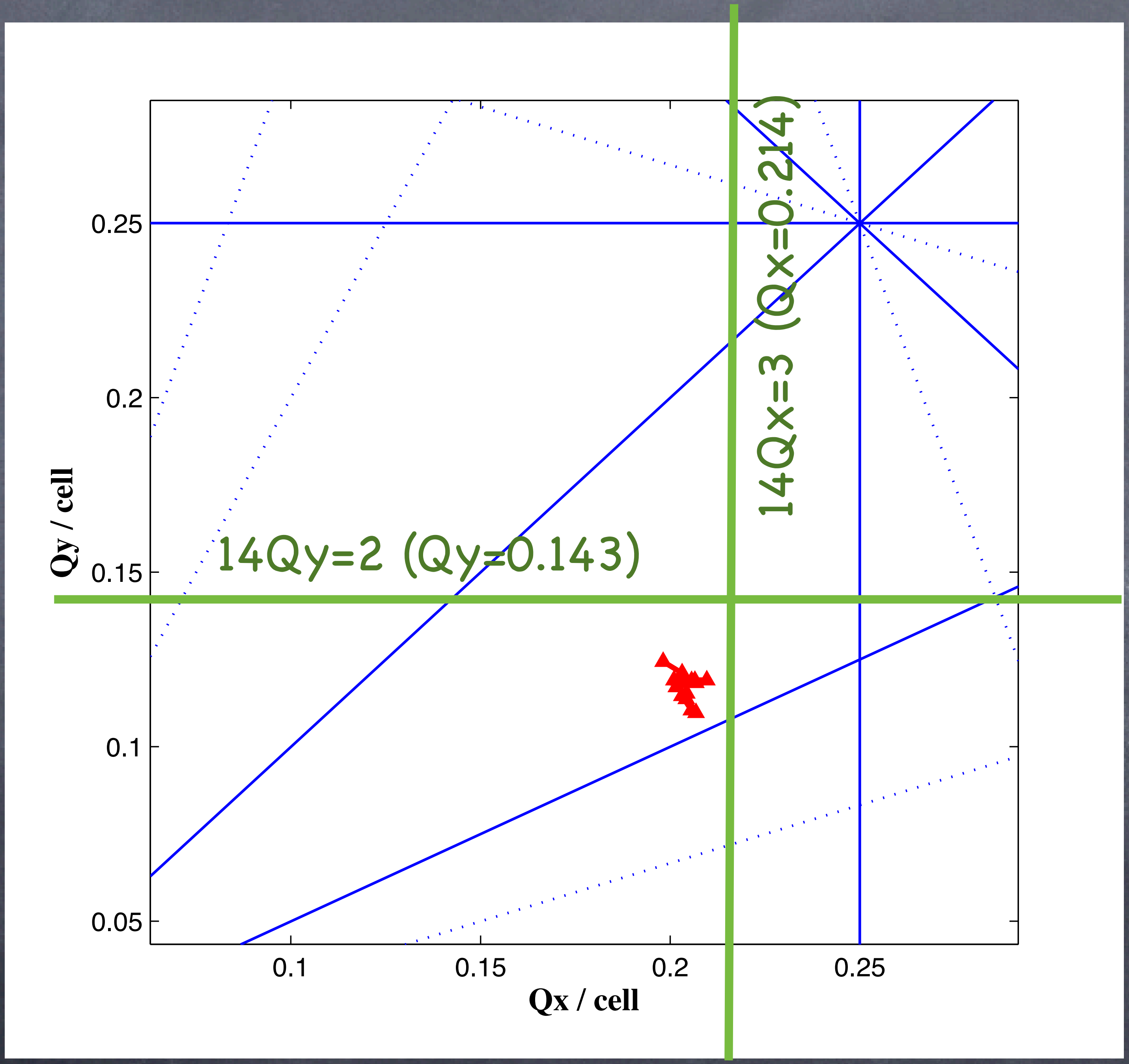


Zgoubi result

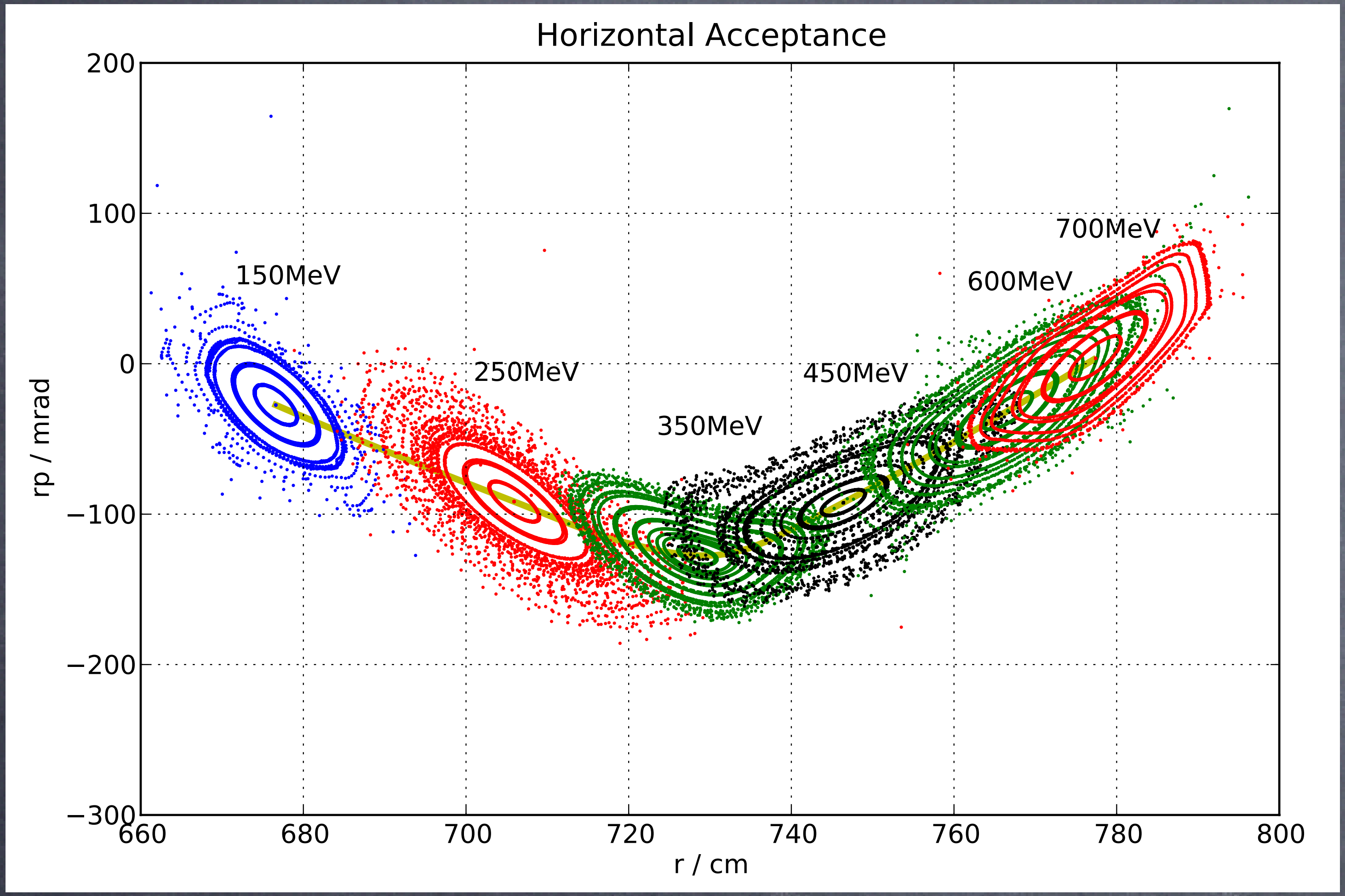
Comparison of tune calculation in 2D/3D tosca maps

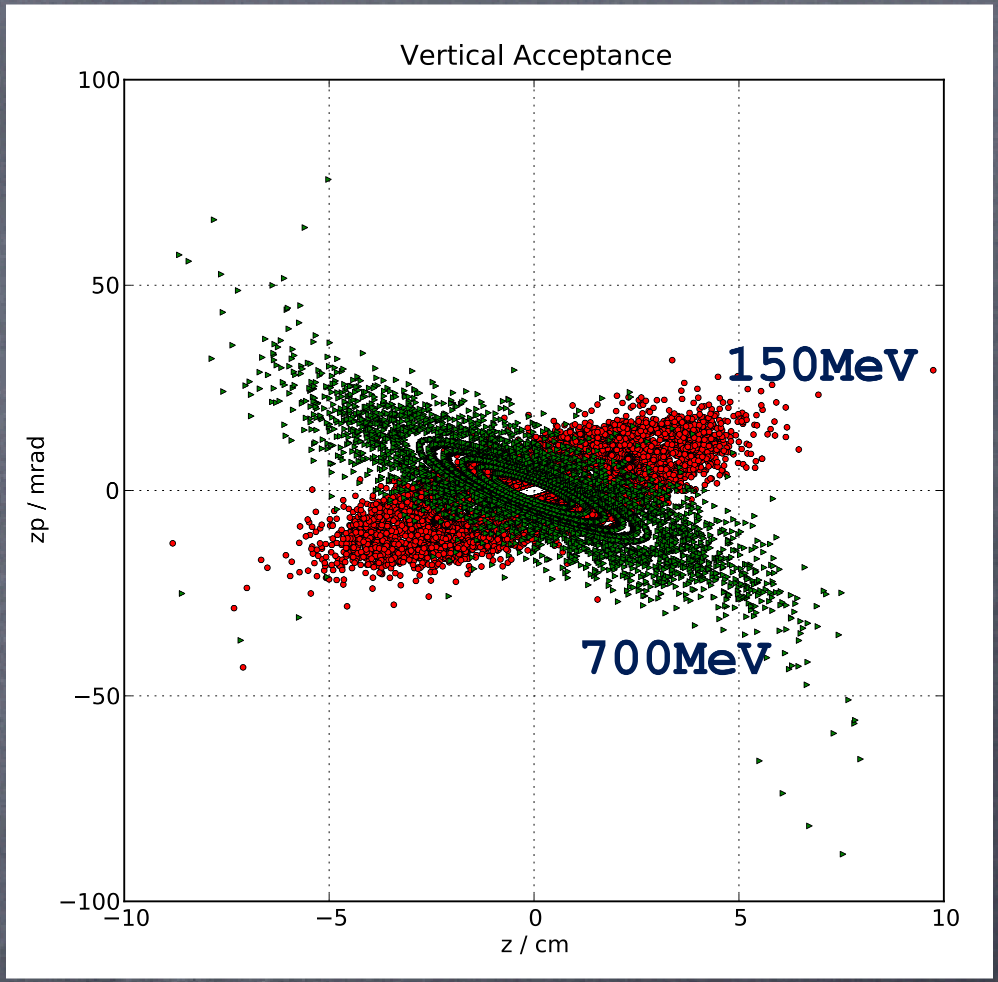


Tune diagram



Transverse Acceptance (Zgoubi result)





- Hori. acceptance ~ 10000 pi-mm-mrad
- Verti. acceptance ~ 2000 pi-mm-mrad

Conclusion

- Preliminary design of a spiral-sector FFAG upgrade ring (150MeV ~ 700MeV) for neutron source
  - Lattice parameters search
  - TOSCA model study
    - tune shift control
    - acceptance survey
- Next...
  - Optimization on tune shift
  - Longitudinal tracking
  - Design for injection / extraction

Thank you

for your attention!