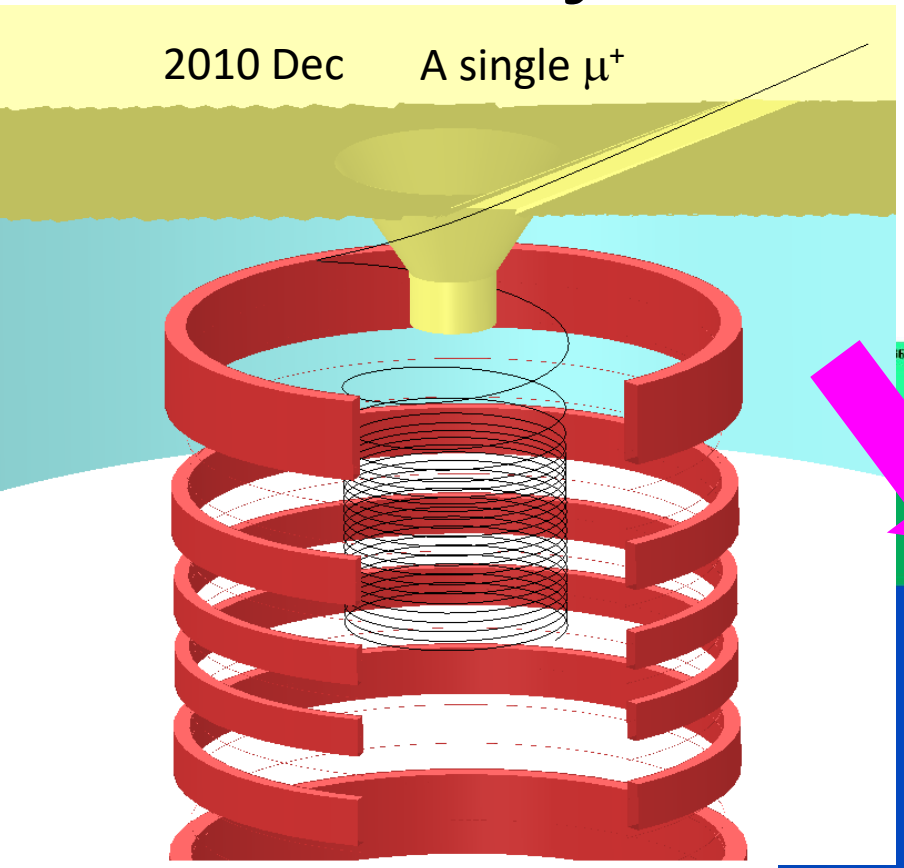
Injection and Kicker



Contents:
Two updates and one new activity

1. spiral Injection study
2. Kicker study updates
3. Weak focus and Spin tracking *(new!)*

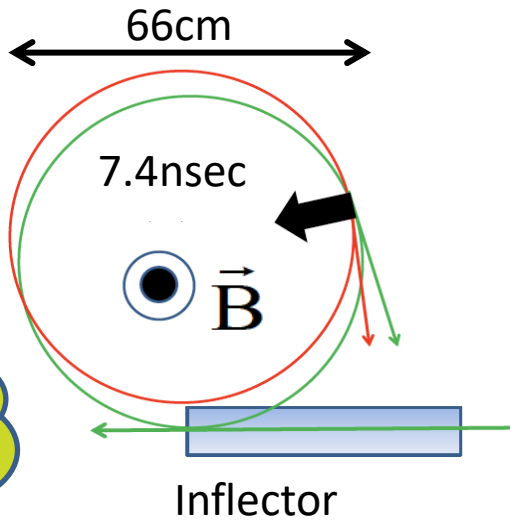
2011/06/30
Hiromi Iinuma for SIT48
Spiral Injection Team

SIT48

Brief review of Spiral Injection

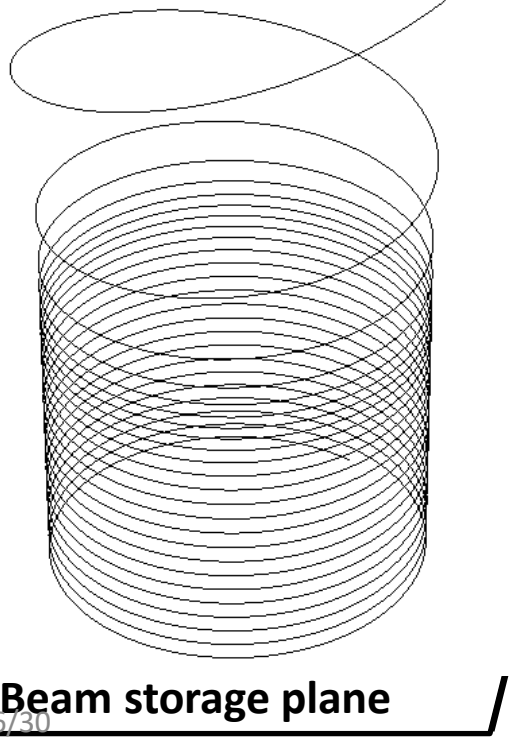
Technical difficulties:

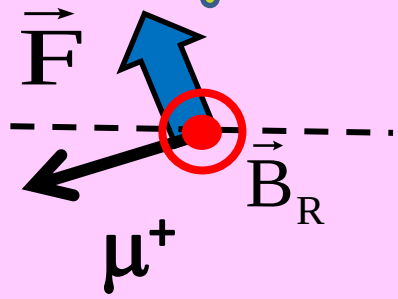
- ✓ 3T is too high to cancel fringe field by inflector,
- ✓ Required kick angle (~60 mrad) is too big.



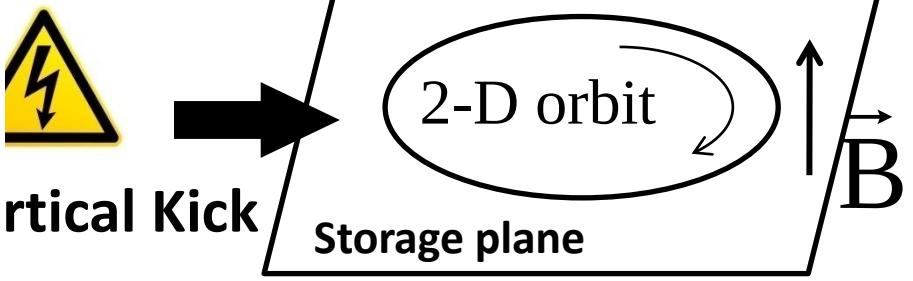
No effect on the storage field!!

Spiral trajectory



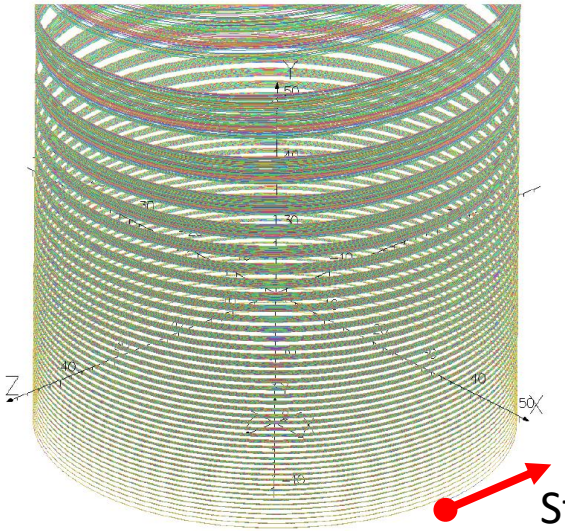


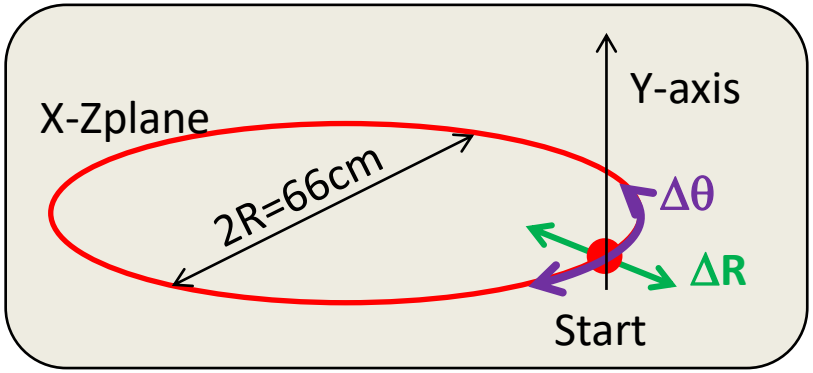
Apply proper radial fringe field to bend(or deflect) vertical motion to the horizontal

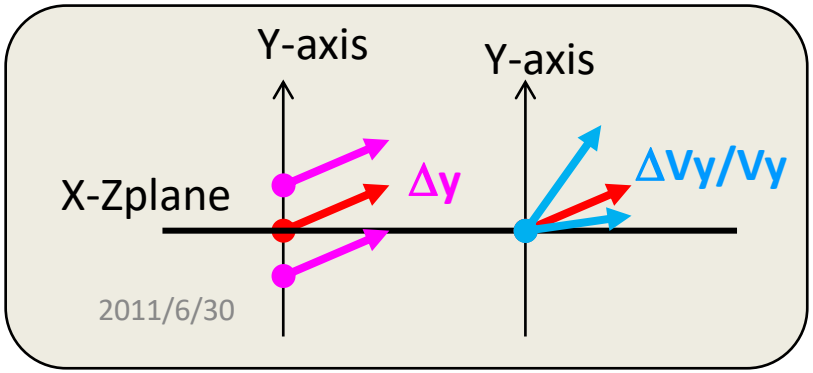


Vertical Kick

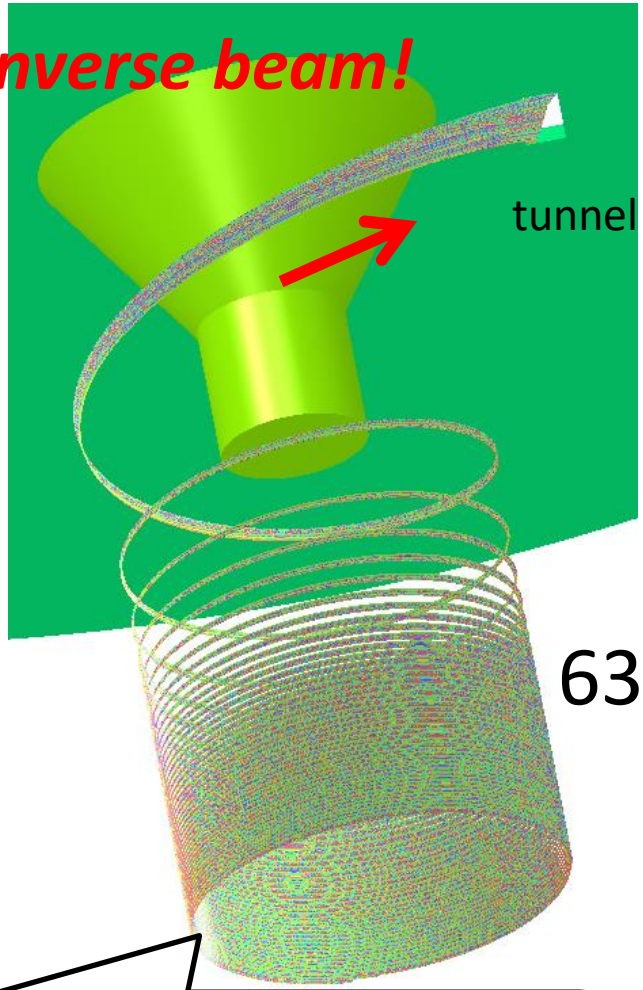
How to find a trajectory for a bunch of muons?







Try inverse beam!



631 μ^+

Base trajectory plus **4 parameters**

$\Delta R = \pm 20$mm

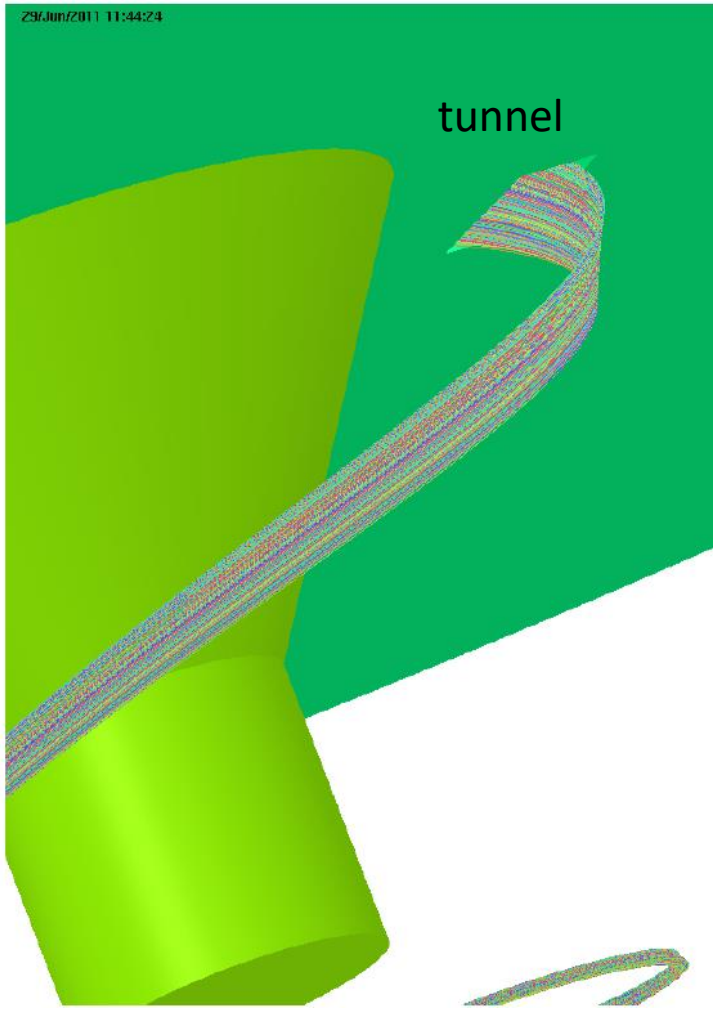
$\Delta\theta = \pm 0.3$rad

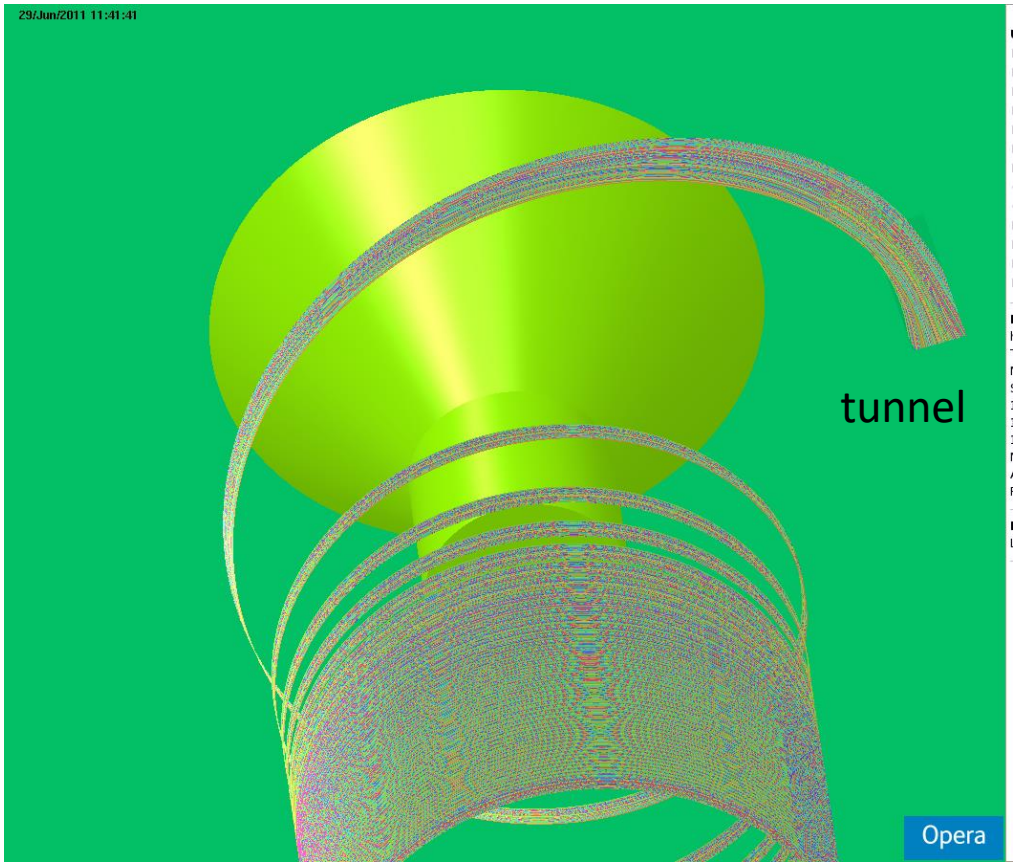
$\Delta y = \pm 2$mm

$\Delta Vy/Vy = \pm$ 3E-3 (~ $\pm$ 10μrad)

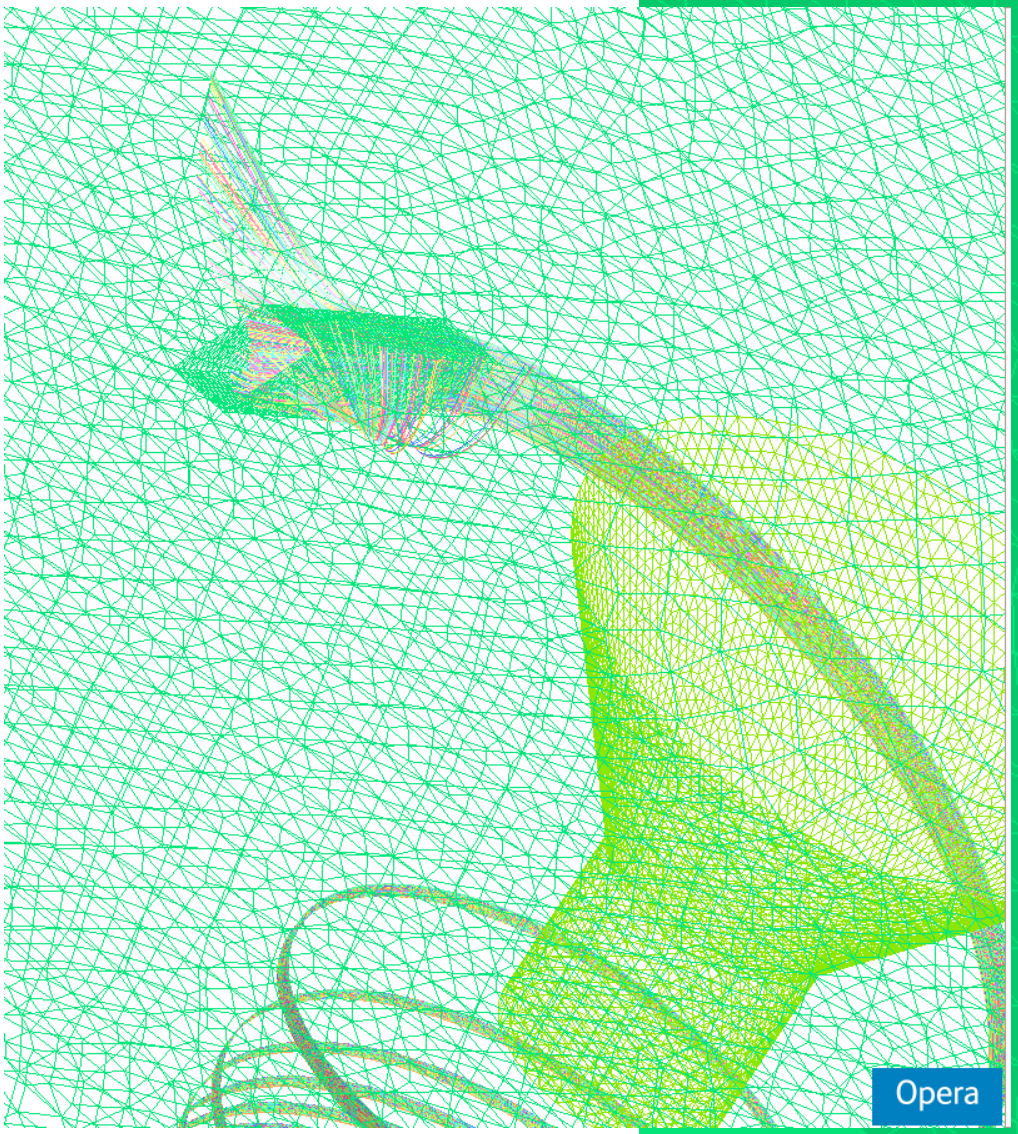
More pictures!

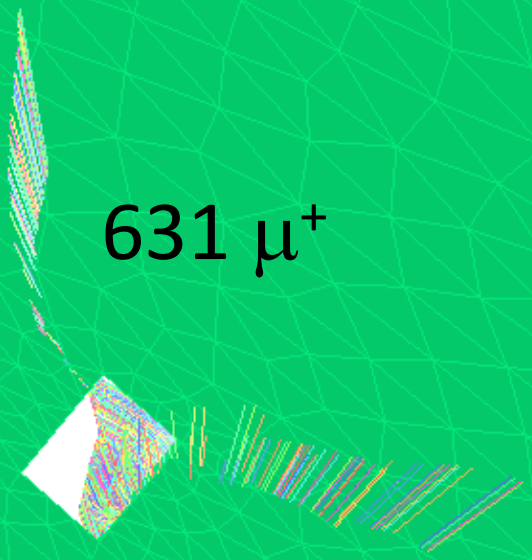
631 μ^+



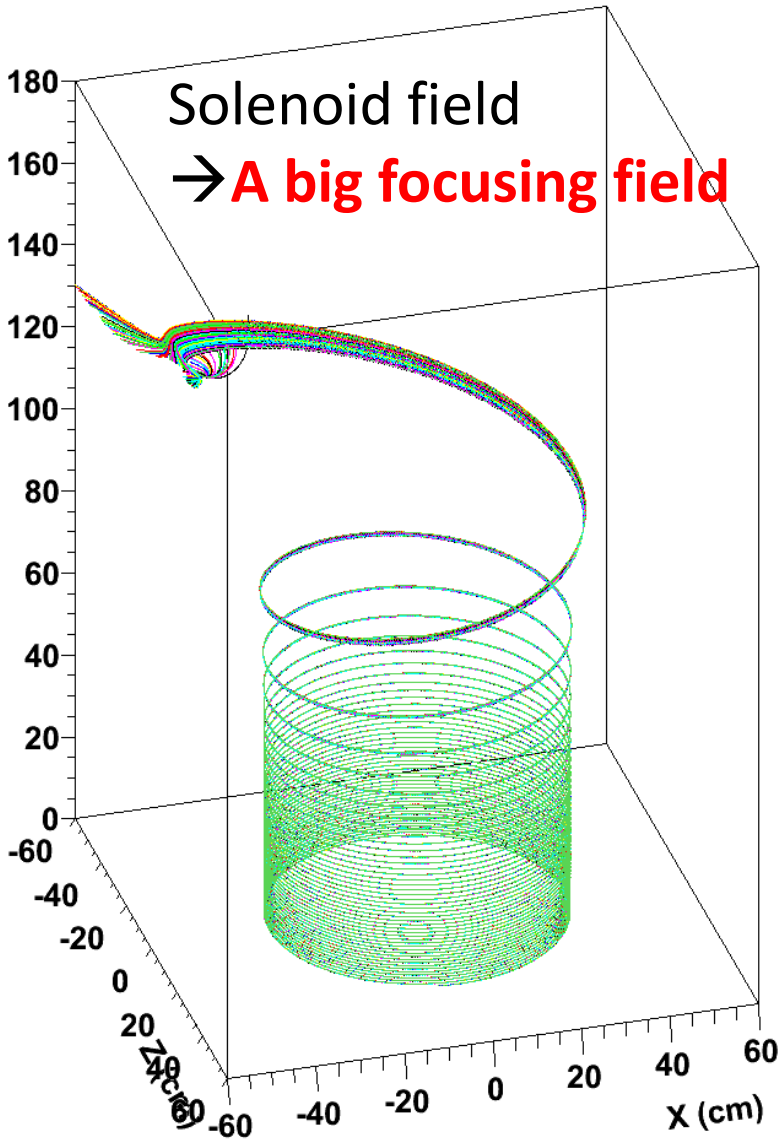


How about the other side?

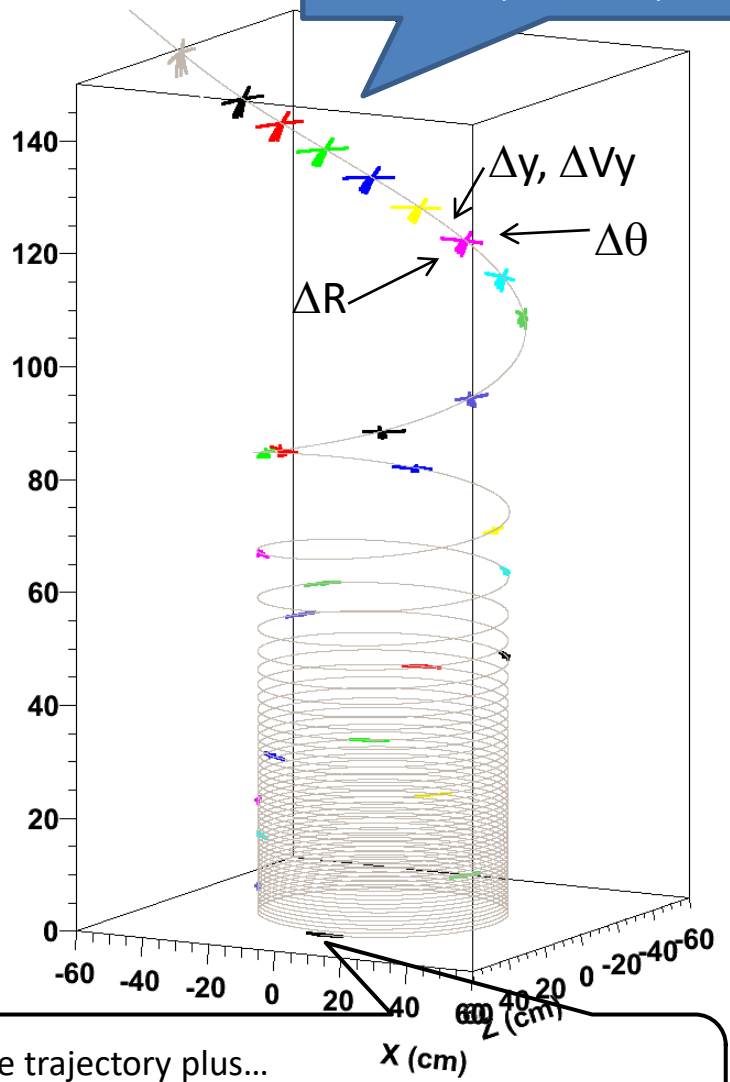




- **Majority is good!**
- **Straight tunnel does work!**
- **Need to work a bit for tunnel cross-section?**



Slice basic trajectory and get step numbers (=time) at Y=150cm, 145cm,……0cm

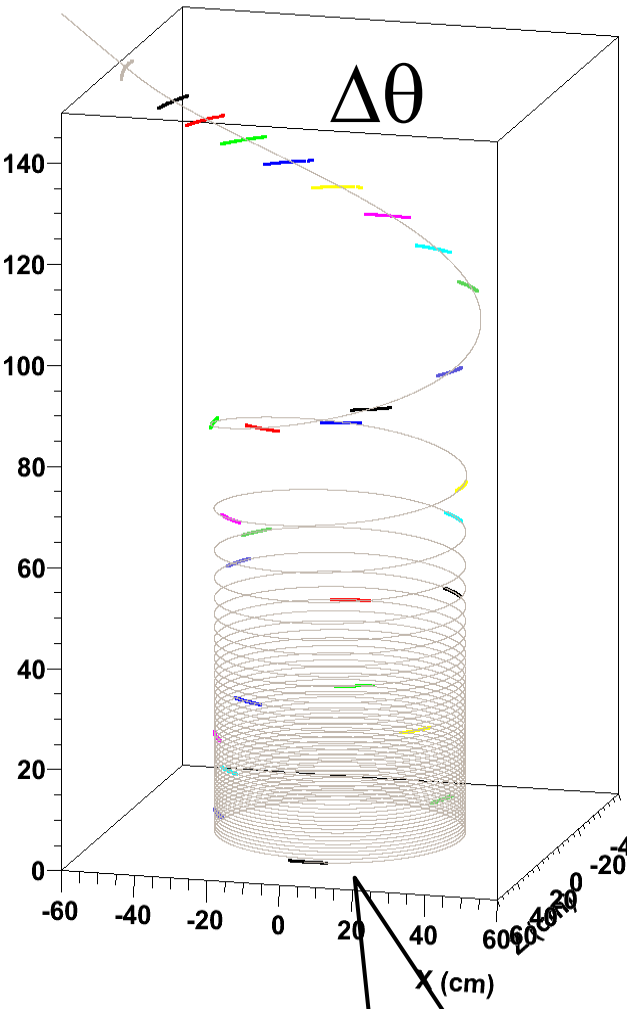


Base trajectory plus…

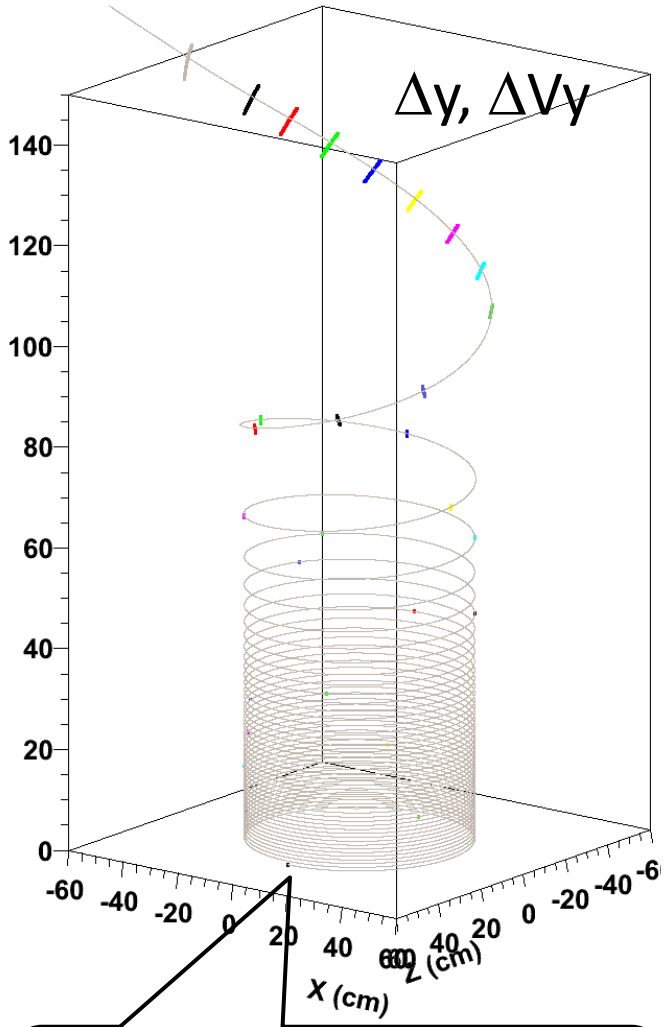
$\Delta y = \pm 2mm$, $\Delta Vy/Vy = \pm 3E\text{-}3$ ($\sim \pm 10\mu rad$)

$\Delta R = \pm 20mm$, $\Delta\theta = \pm 0.3rad$

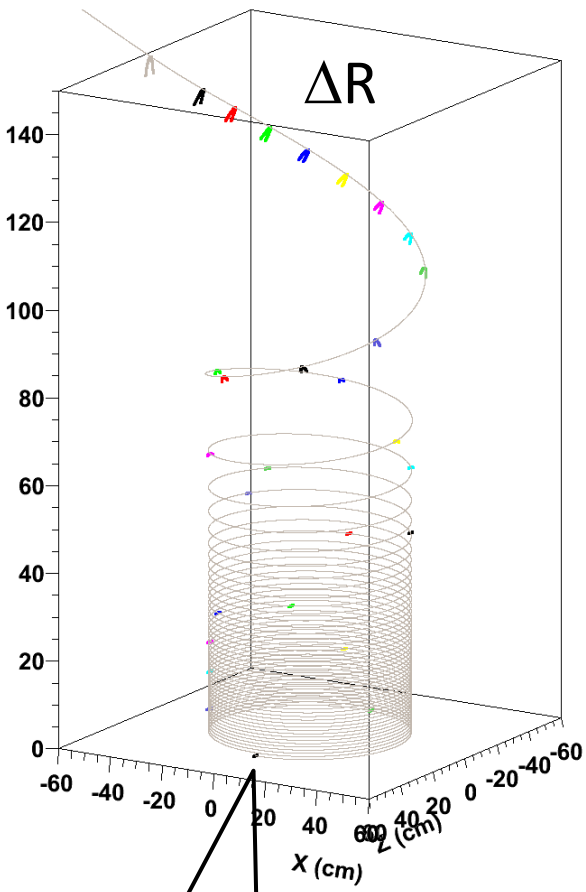
Sliced trajectories by step number (=time)



Base trajectory plus…
Δθ=±0.3rad



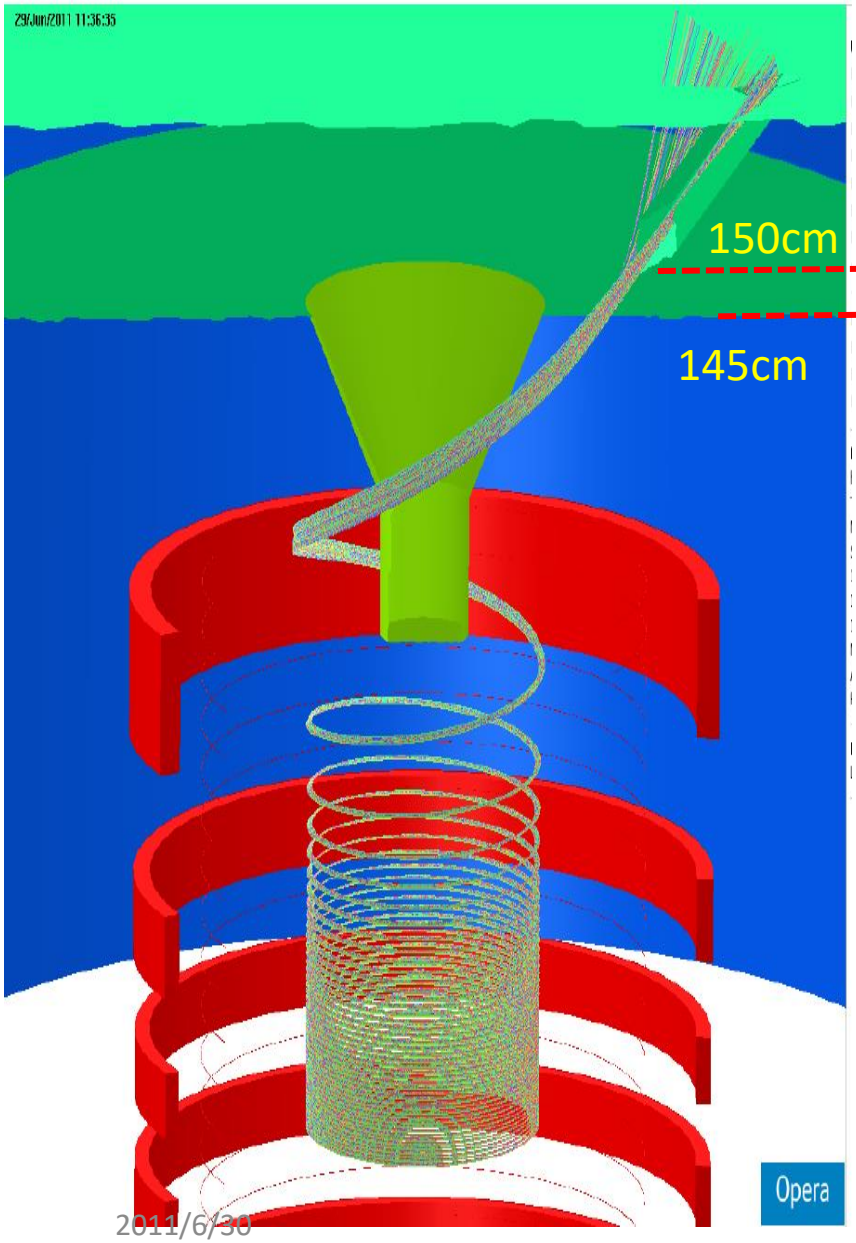
Base trajectory plus…
Δy= ± 2mm
ΔVy/Vy= ± 3E-3 (~ ± 10μrad)

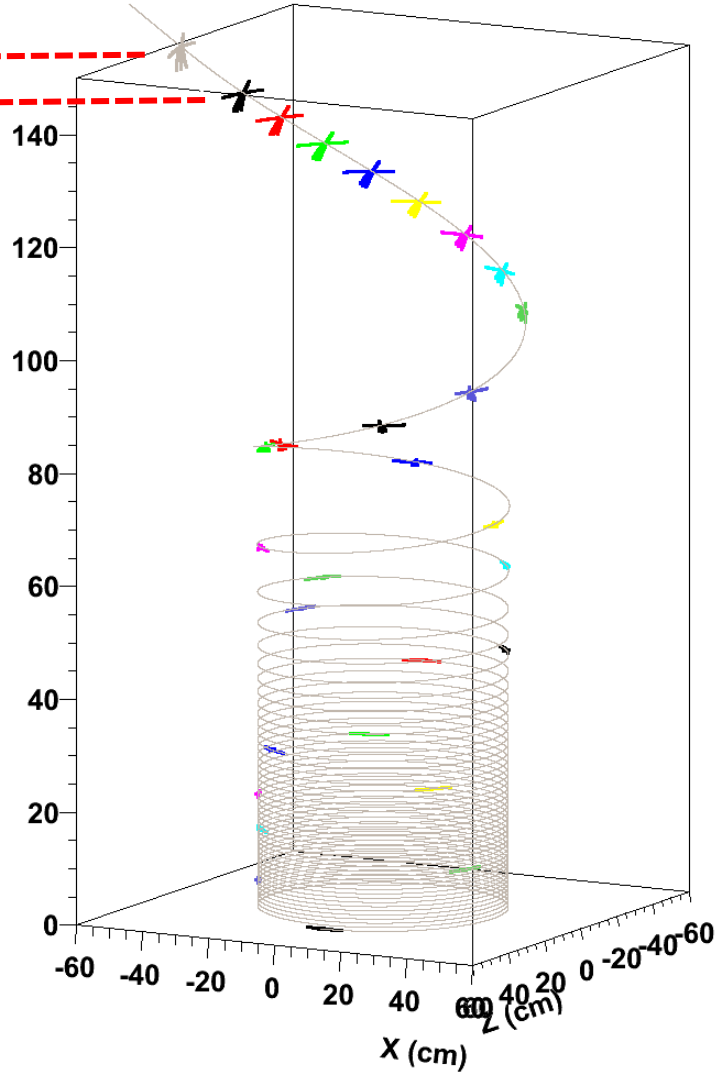


Base trajectory plus…
ΔR=±20mm

Next step for beam injection study

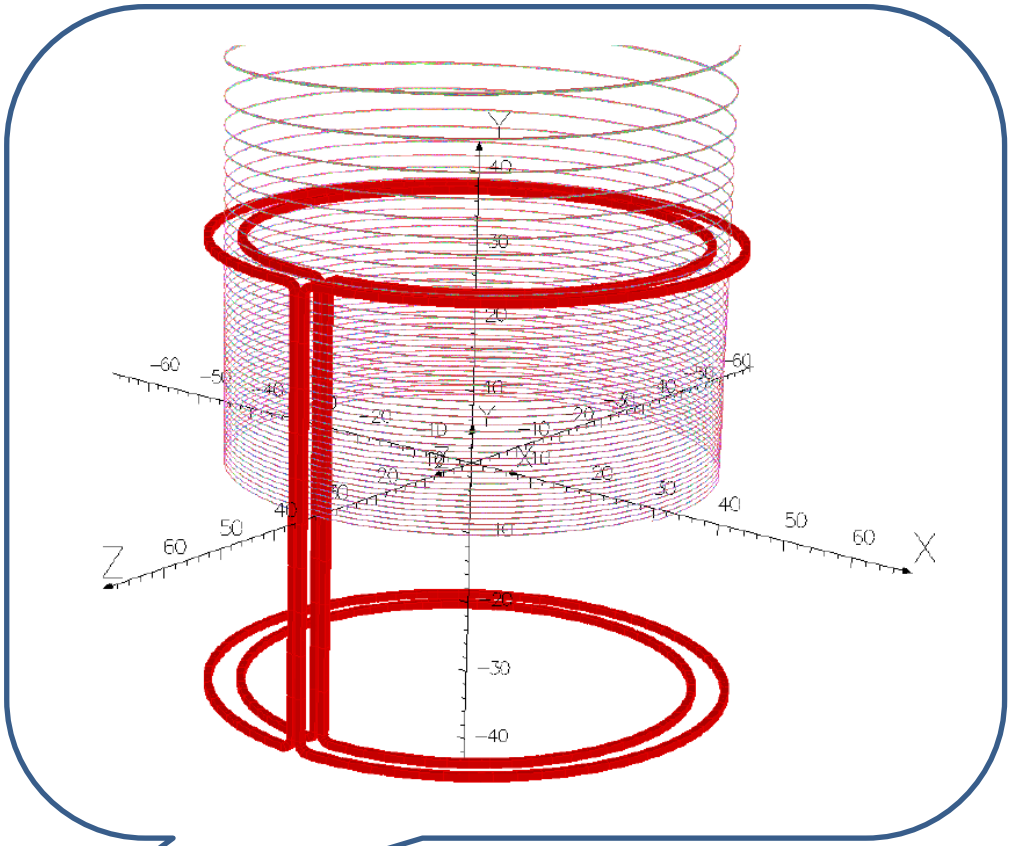
1. Study fine slices inside a tunnel: 145 < y <180cm
2. Straight but cone shape tunnel?
3. Estimate emittance in the field “free” space (y>=150cm) and pass parameters to LINAC team

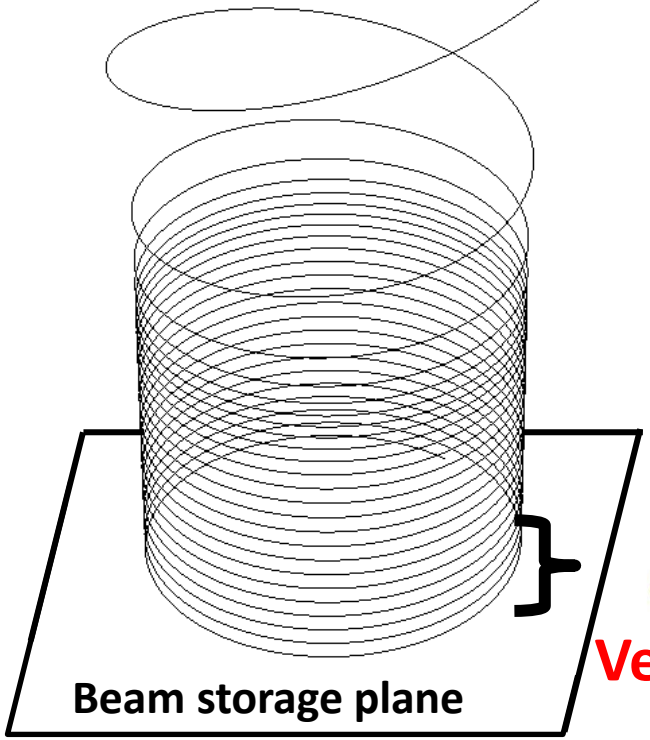




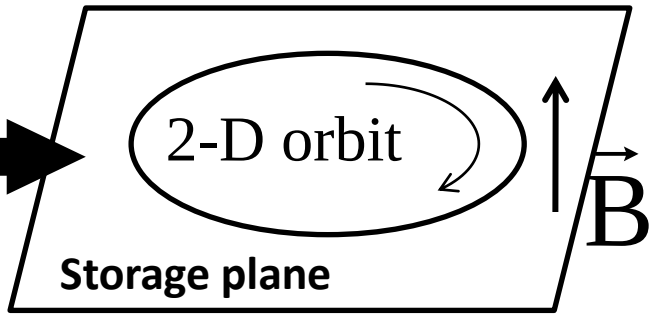
Kicker update

Stop the vertical motion by pulsed radial field





Vertical Kick



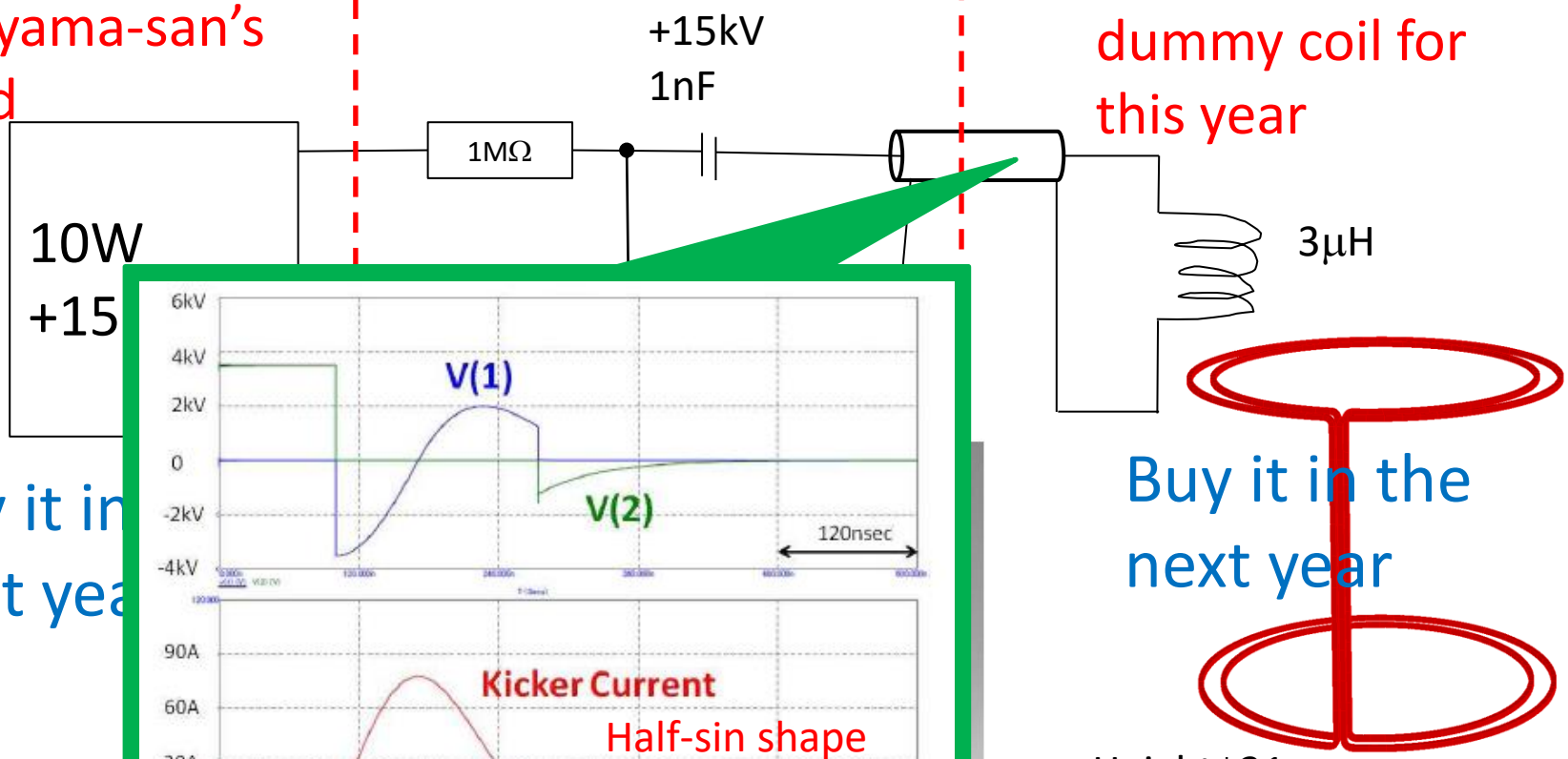
- Radial magnetic field ;$Br=B_0 \sin\omega_{kick} t$
- $T_{kick}/2$= ~150nsec
- Peak field B_0=1.5 gauss

Prototype kicker is ready by the end of July!

Already bought and my grant for this year is gone…

Borrow from Nakayama-san's friend

Hand-made dummy coil for this year

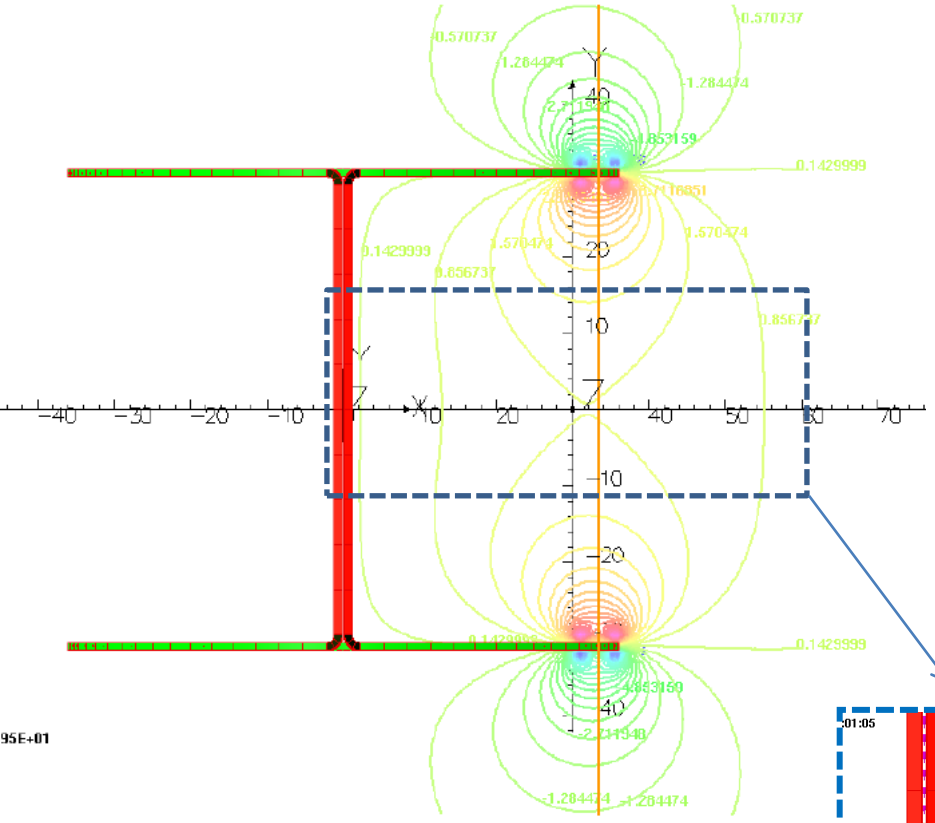


Buy it in the next year

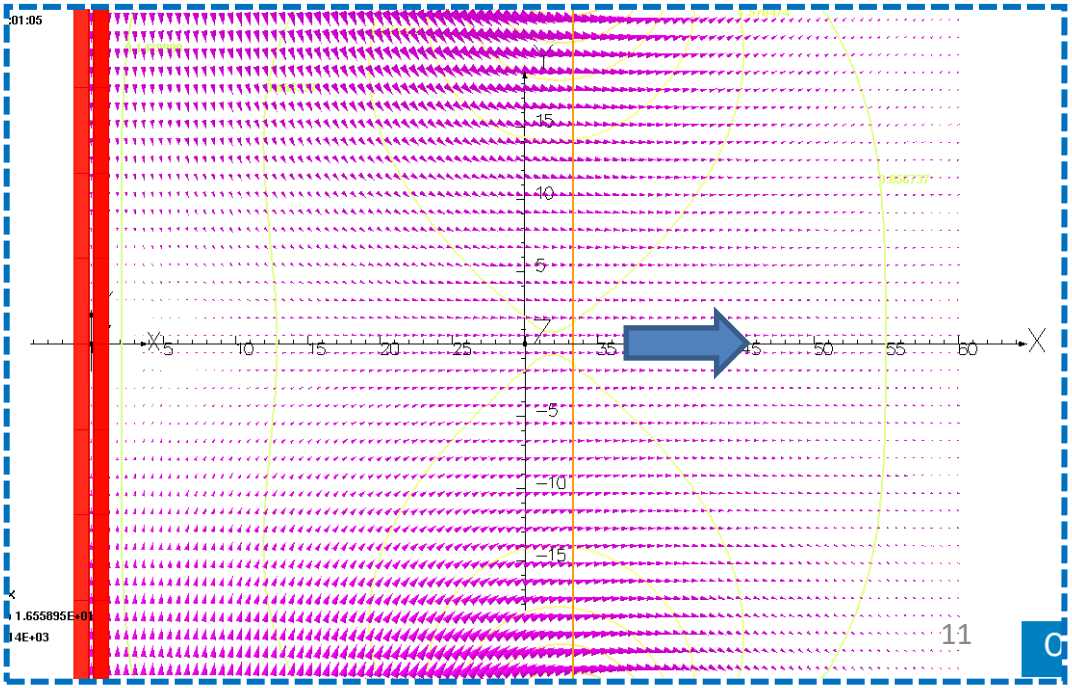
Buy it in the next year

- Height±31cm
- R=30.75,35.25cm
- Two pairs of single turn coil
- 5mmϕpipe

Kicker field



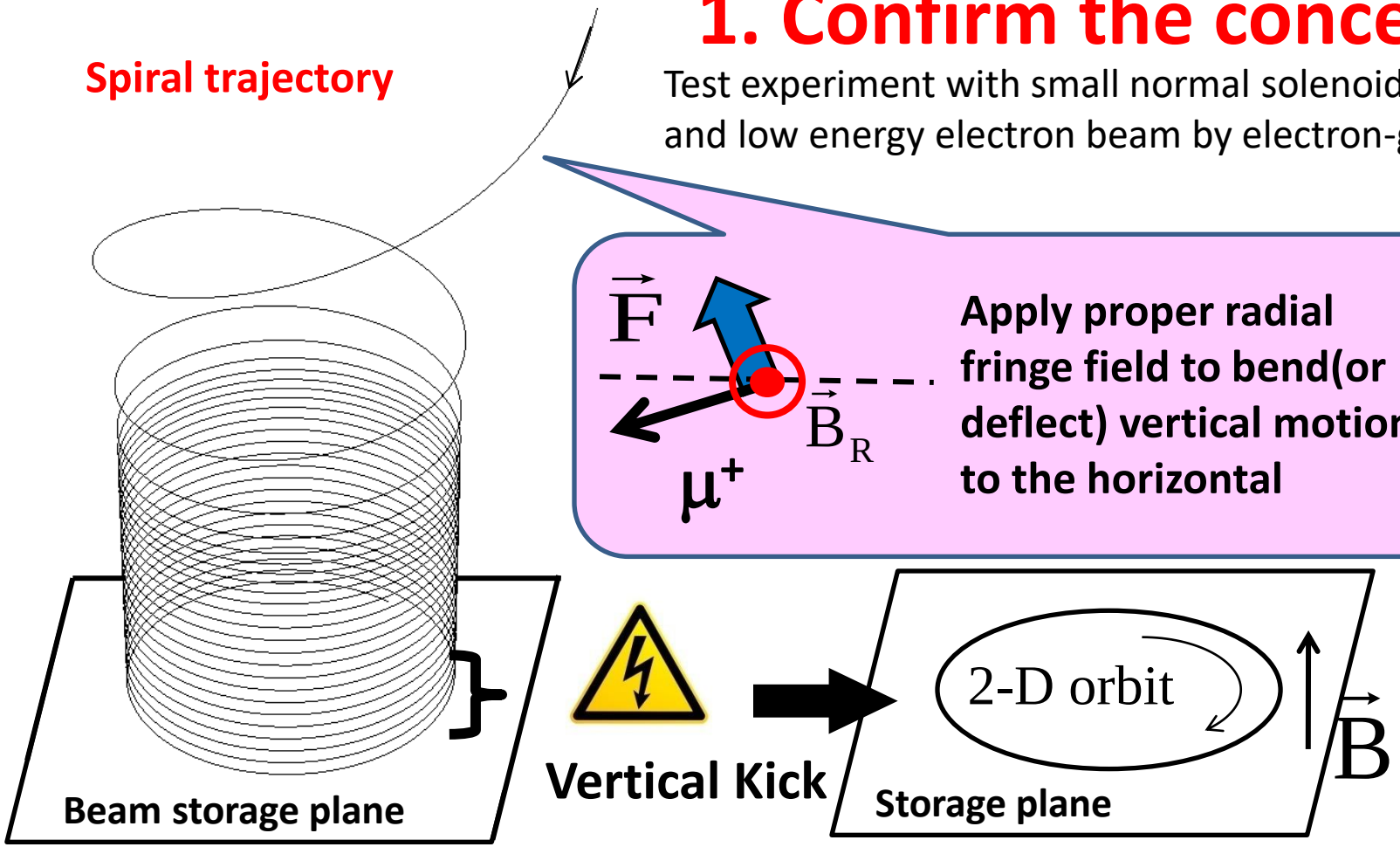
- Radial component ;
  $Br=B_0 \sin \omega_{kick} t$
- $T_{kick}/2$~150nsec
- Peak field B_0=1.5 gauss



Activities for second half of 2011

1. Confirm the concept!!

Test experiment with small normal solenoid magnet and low energy electron beam by electron-gun.



2. One path motion is OK. But…

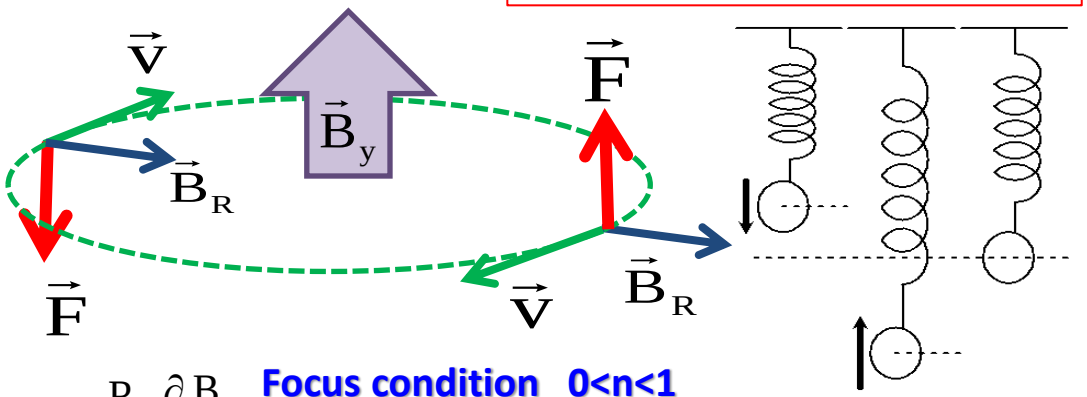
How to store a beam in uniform field?

Need weak focus in the storage area!

Unique field with tune=1 is unstable!
→Tiny field error can spread the beam!

Focusing beam horizontally and vertical y at **a time** by **a single unit**

Only weak focusing system does work!



$$n = -\frac{R}{B_{0y}}\frac{\partial B_y}{\partial r}$$

Focus condition 0<n<1
n<1: for radial direction
n>0 :solenoid axis direction

$$B_y = B_{0y}\left(1 - n\frac{r}{R}\right), \quad B_R = -n\frac{B_{0y}}{R}y$$

I learned from Oide-san recently…

The **Bevatron** was a historic particle accelerator — specifically, a weak-focusing proton synchrotron — at Lawrence Berkeley National Laboratory which began operating in **1954**.

http://en.wikipedia.org/wiki/Bevatron

How much field is needed?

If we require:

$$\frac{\partial B_y}{B_{0y}} = 0.1\text{ppm}\,,\ \partial r = 1\text{mm}$$

$$\left(\frac{\partial\omega}{\omega} \sim 0.1ppm\right)$$

$$n = -\frac{R}{B_{0y}}\frac{\partial B_y}{\partial r}$$

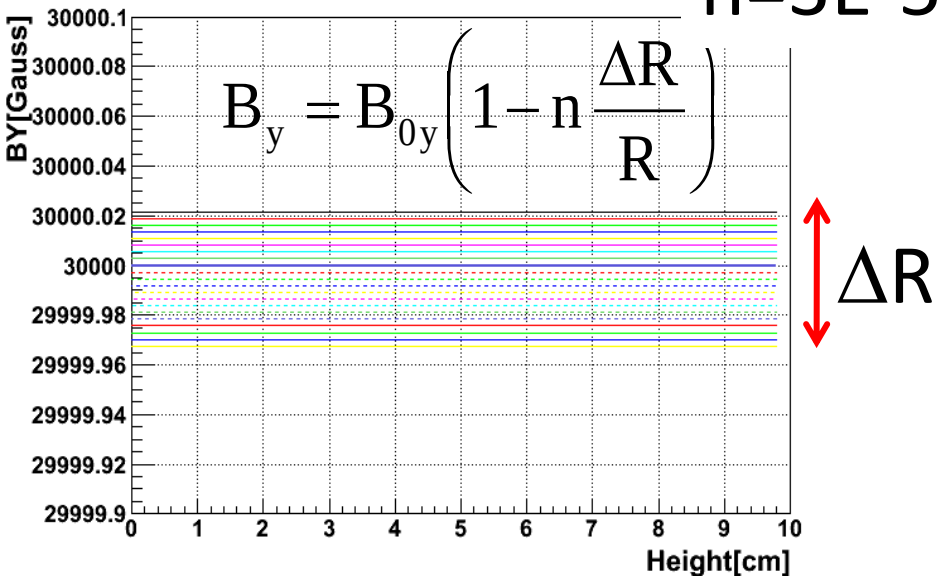
$$B_y = B_{0y}\left(1 - n\frac{r}{R}\right),\quad B_R = -n\frac{B_{0y}}{R}y$$

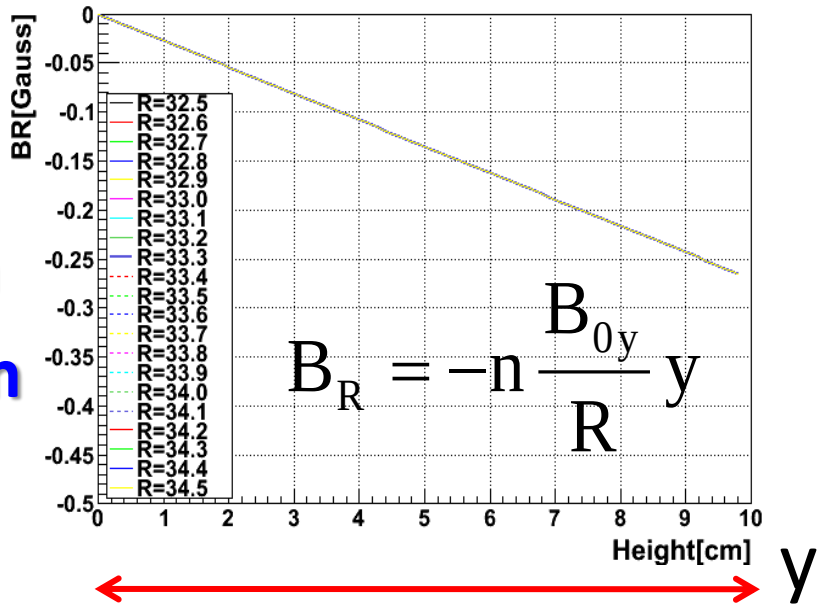
n<1: for radial direction

n>0 :solenoid axis direction

n~3E-5 fits our case

n=3E-5





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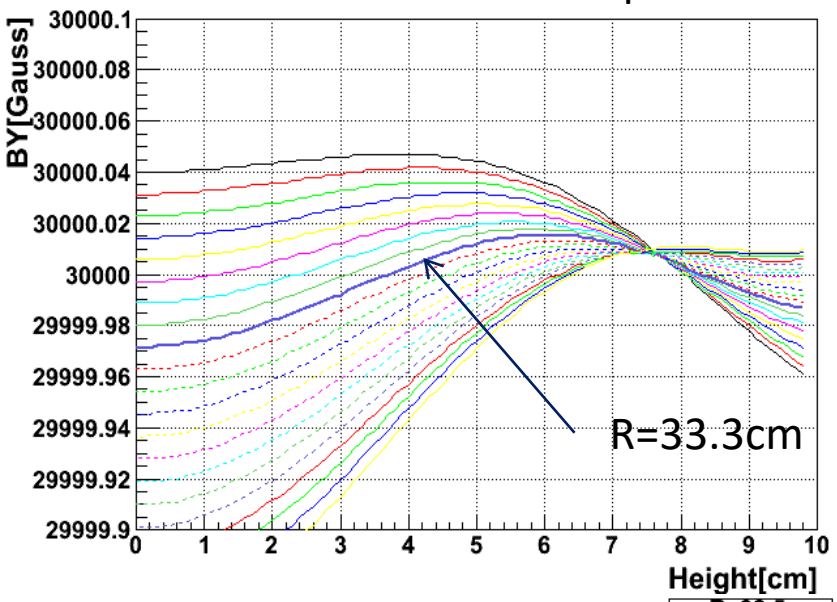
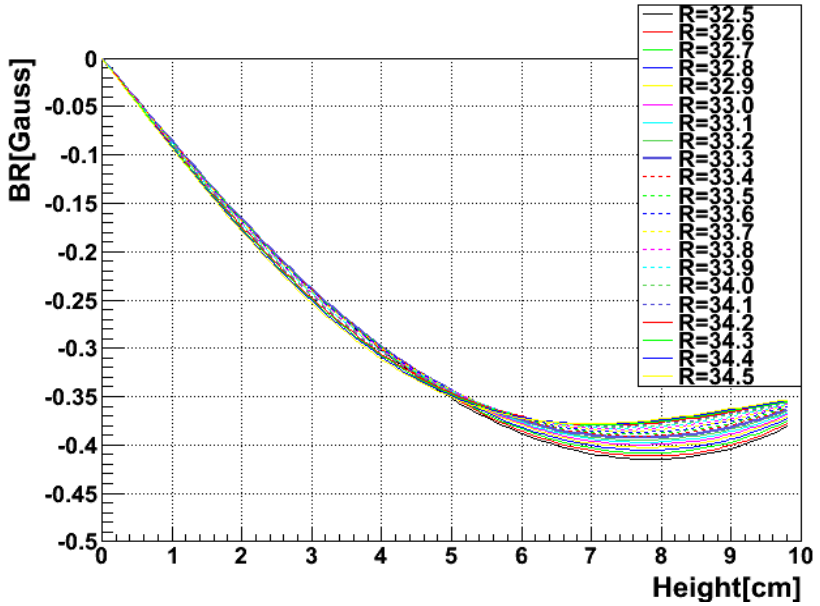
$$B_y = B_{0y}\left(1 - n\frac{r}{R}\right),\quad B_R = -n\frac{B_{0y}}{R}y$$

Weak field design is ongoing and…

Simulated sample field





New activity

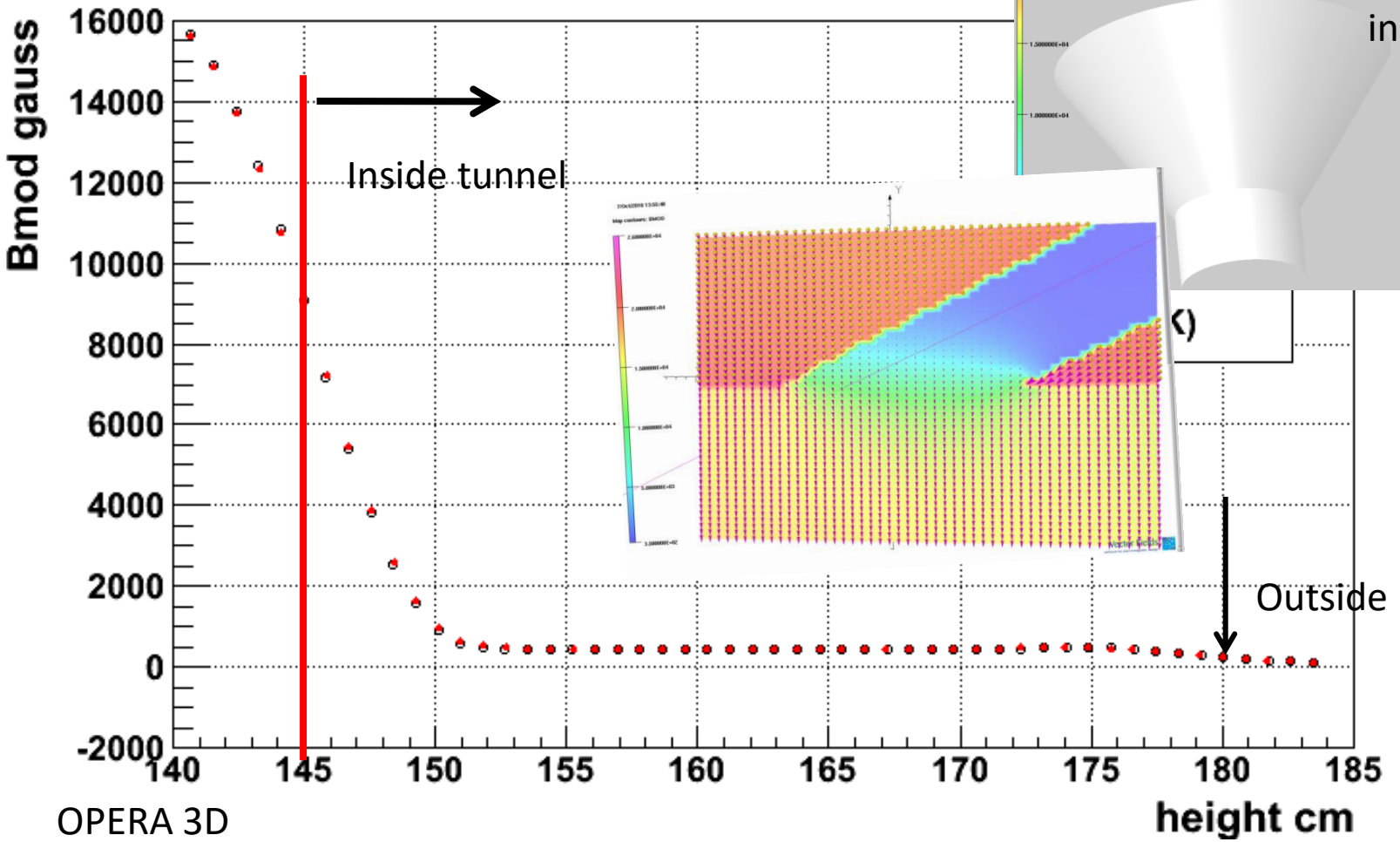
- Storage the beam for ~33μsec → 4400 turns.
- No one path solution anymore! (different from injection and kicker).
- Should not use integration (numerical) approach only.
- Analytical approach to get averaged orbit, momentum and spin is important!

- Prof. Forest joins us and start spin tracking.
- Now, I am a trainee for beam storage.

Thank you!

backup

Field inside beam tunnel



OPERA 3D

Straight tunnel does work!

Spin equation (T-BMT equation + EDM)

$$\frac{d\boldsymbol{s}}{dt} = \boldsymbol{\Omega} \times \boldsymbol{s}, \qquad \boldsymbol{\Omega} = \boldsymbol{\Omega}_{T-\mathrm{BMT}} + \boldsymbol{\Omega}_{\mathrm{EDM}},$$

$$\boldsymbol{\Omega}_{T-\mathrm{BMT}} = -\frac{e}{2m}\left\{\left(g-2+\frac{2}{\gamma}\right)\boldsymbol{B} - \frac{(g-2)\gamma}{\gamma+1}\boldsymbol{\beta}(\boldsymbol{\beta}\cdot\boldsymbol{B}) - \left(g-2+\frac{2}{\gamma+1}\right)(\boldsymbol{\beta}\times\boldsymbol{E})\right\}, \qquad (3)$$

$$\boldsymbol{\Omega}_{\mathrm{EDM}} = -\frac{e\eta}{2m}\left(\boldsymbol{E} - \frac{\gamma}{\gamma+1}\boldsymbol{\beta}(\boldsymbol{\beta}\cdot\boldsymbol{E}) + \boldsymbol{\beta}\times\boldsymbol{B}\right),$$

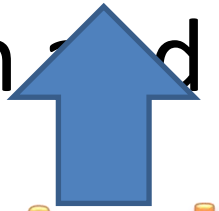
$$\frac{d\vec{s}}{dt} = -\vec{s}\times\vec{\Omega} = \frac{eB}{m\gamma}\left(a_\mu\gamma+1\right)\begin{pmatrix} s_y \\ -s_x \\ 0 \end{pmatrix} + \frac{eB\eta}{2m}\begin{pmatrix} s_z\beta_x \\ s_z\beta_y \\ -s_x\beta_x - s_y\beta_y \end{pmatrix}$$

Our case:

$$\vec{B}\cdot\vec{\beta} = \vec{E}\cdot\vec{\beta} = 0$$

$$\frac{ds_z}{dt} = -\frac{eB\eta}{2m}\vec{s}\cdot\vec{\beta}$$

How to control the beam into the storage region and how to keep it?



Vertical Kick by dynamic radial field

How to get peak field of kick?

$$\vec{F} = q\vec{v} \times \vec{B}, \quad \vec{F} = m_\mu \vec{a}$$

Longitudinal muon velocity
"v_L=const" at good field region

$$v_z(t) = v_{z0} + \frac{q}{m_\mu} v_L B_R(R,z) \int \sin(\omega \times t) dt$$

$$B_R(R,z) = -\frac{m_\mu}{2q} \frac{v_{z0}}{v_L} \omega = -\frac{m_\mu}{2q} \theta_{kick} \omega$$

$B_R(R,z)=17693.302\times\theta_{kick}\times\omega$ (gauss)

Ex. θ_{kick}= 5mrad, p_{z0}=1.5MeV/*c*,
T/2=150nsec stop

$B_R(R,z)$= 1.9 gauss
(Unique spatial distribution is ideal)

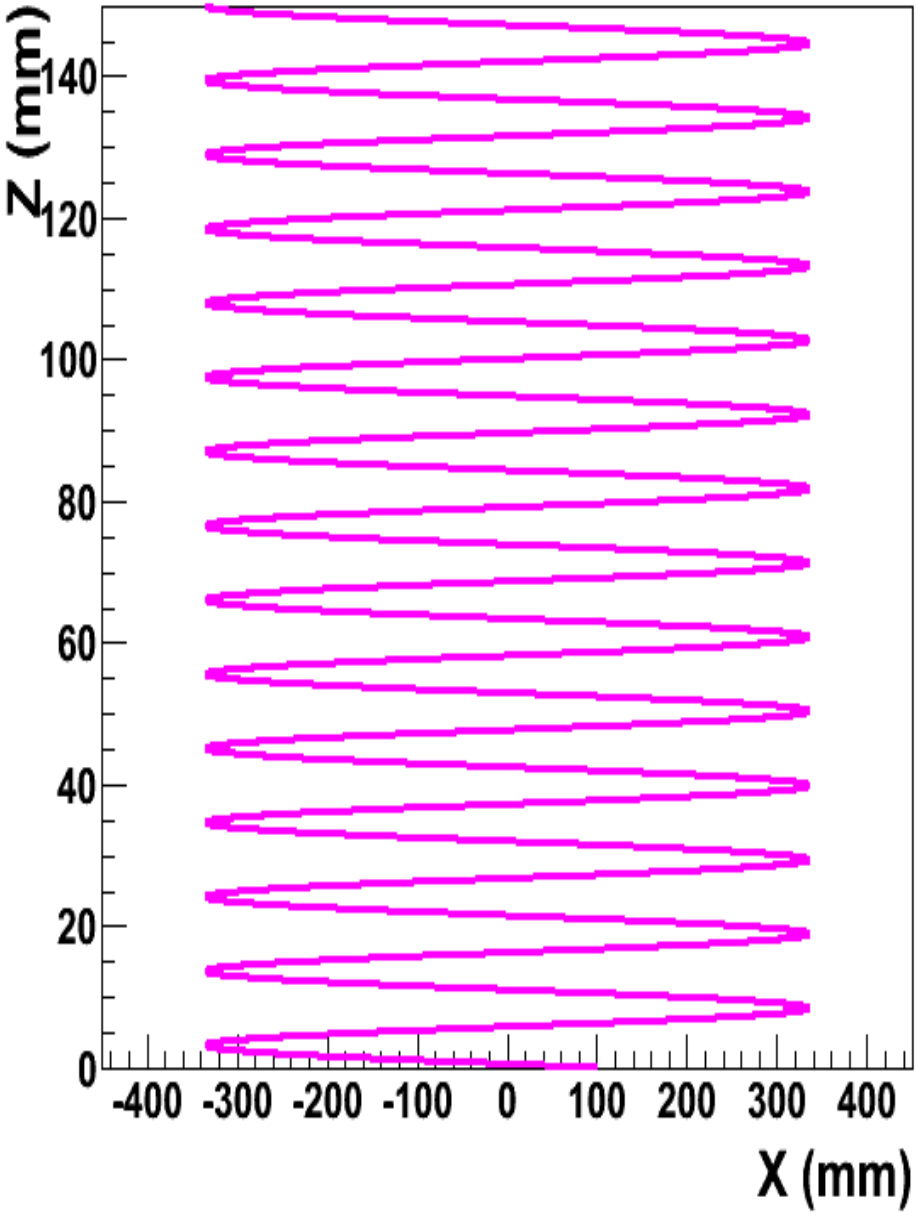
How much (vertical) volume, which has an unique spatial B_R distribution, with a given kick time period?

$$v_z(t) = \frac{v_{z0}}{2}\left[1+\cos\left\{\omega\times(t-t_0)\right\}\right] \quad \text{at } t > t_0$$

$$z_0 = -\int_{t_0}^{t_0+\pi/\omega} v_z(t)dt = \frac{v_{z0}\pi}{2\omega} = \frac{v_{z0}T}{4}\left(= \frac{c}{m_\mu \gamma_\mu}\frac{T}{4}p_{z0}\right)$$

ex. p_{z0}=1.5 MeV/*c*, T=300nsec (150nsec stop), wee need vertical volume Z_0=10.6cm

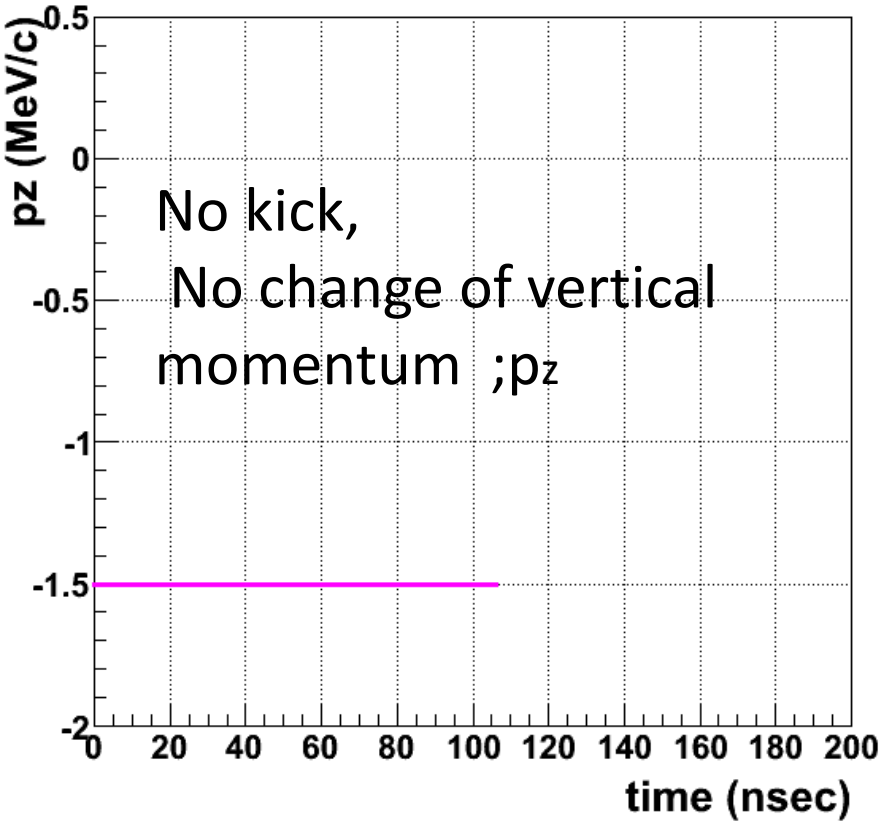
Scale for vertical and horizontal are not same



Analytic approach and simulation are consistent

T/2=150 nsec kick

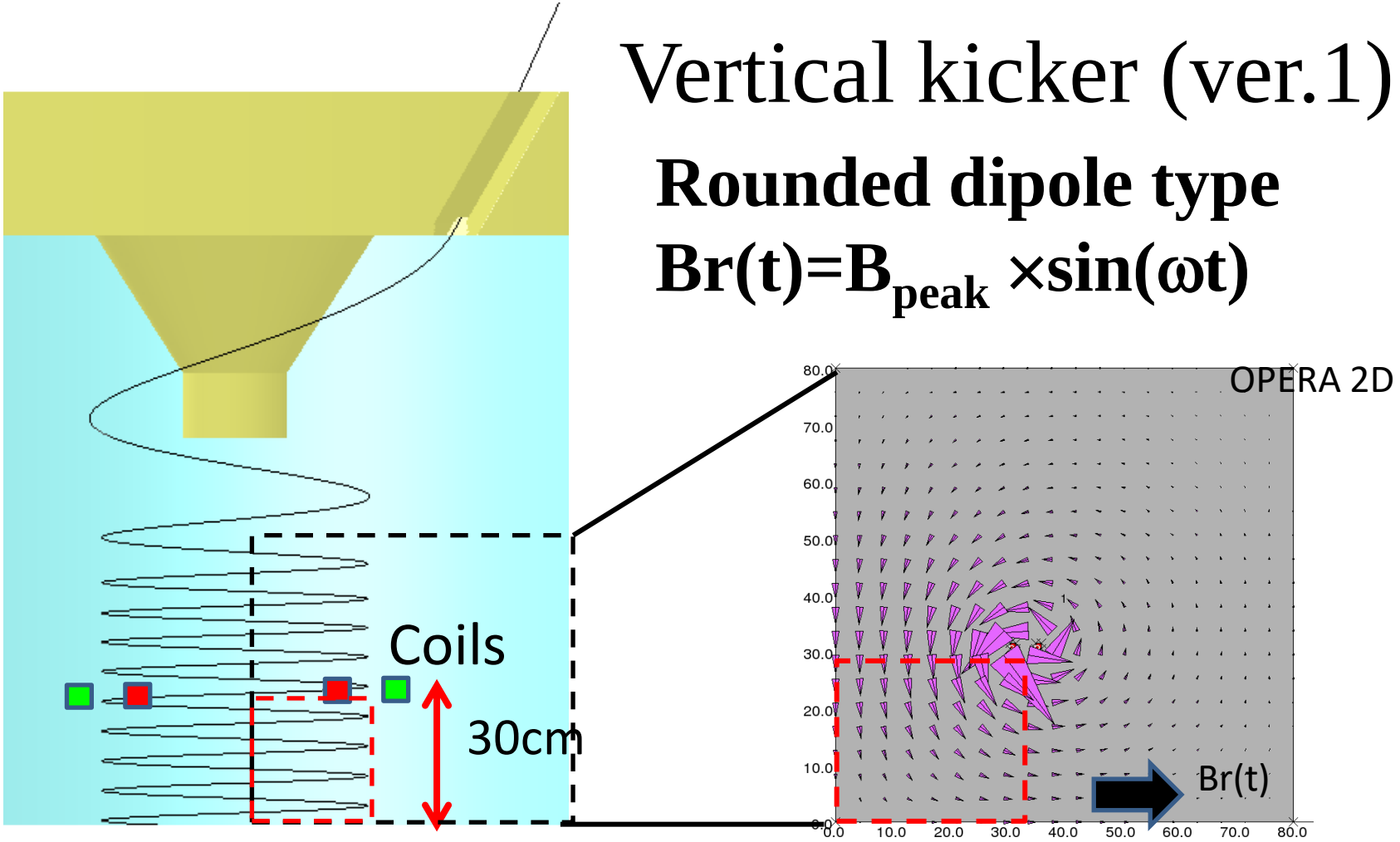
vertical volume Z_0=10.6cm



Vertical kicker (ver.1)

Rounded dipole type

$Br(t)=B_{peak} \times \sin(\omega t)$



- Do not interfere with detector/vacuum chamber
- Prototype kicker is being designed for test soon!

Requirements for Kicker

$$\mathbf{Br(t)=B_{peak} \times \sin(\omega t)}$$
$$\mathbf{\omega=\pi/T_{kick}}$$

✓Field strength:

B_{peak} = 1Gauss ~ 10 Gauss

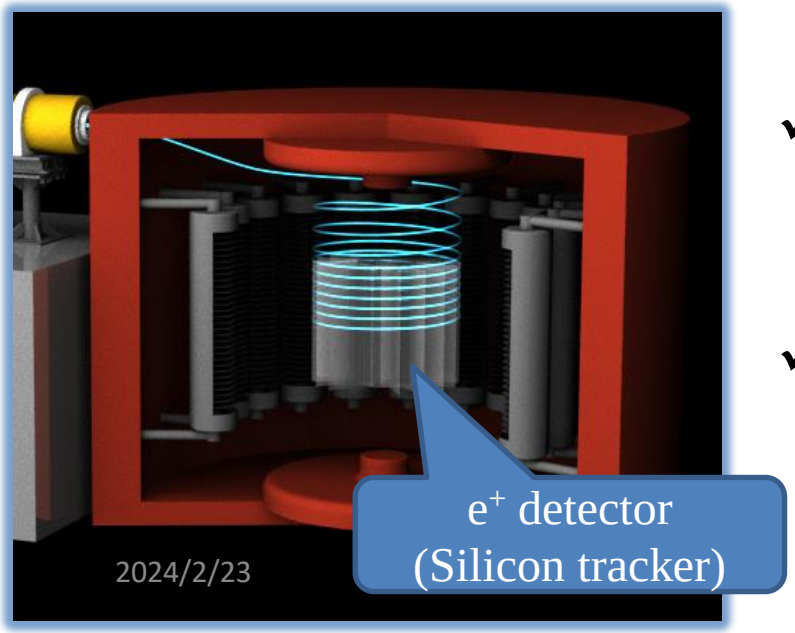
✓Time distribution:

T_{kick}=150 nsec (c.f. 20 cyclotron periods)

✓Spatial distribution:

33cm±5mm in radial direction, good uniformity (better than 1%)

±10cm(~ ±30cm?) in solenoid axis direction to reduce beam bunch shape



✓Possible sources for field distortion:

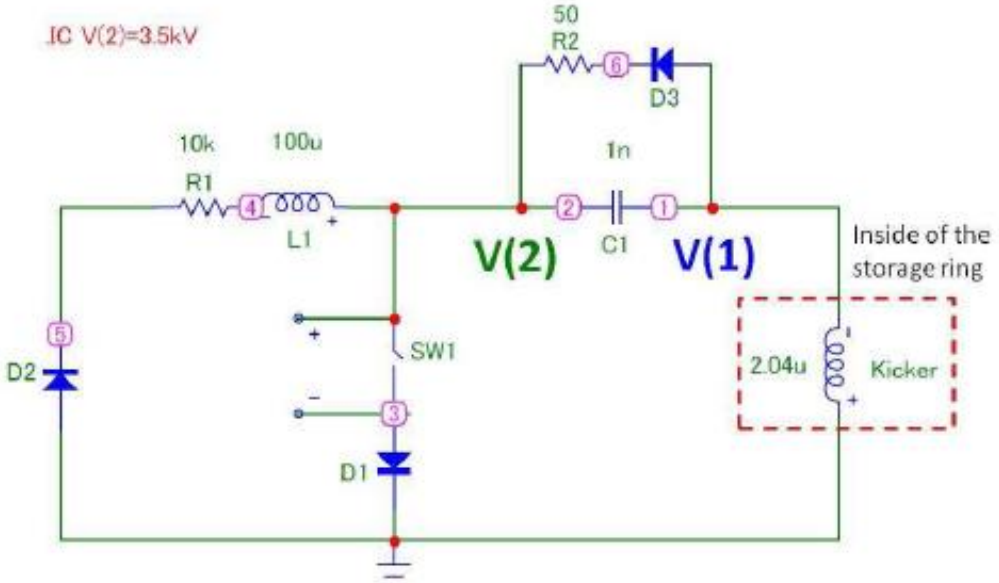
- Eddy currents on cryostat wall
- Peak field reduction by cryo. wall

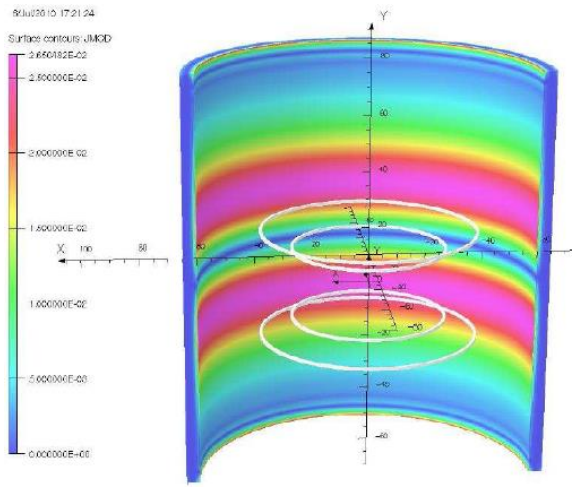
✓Minimal effect for positron detector:

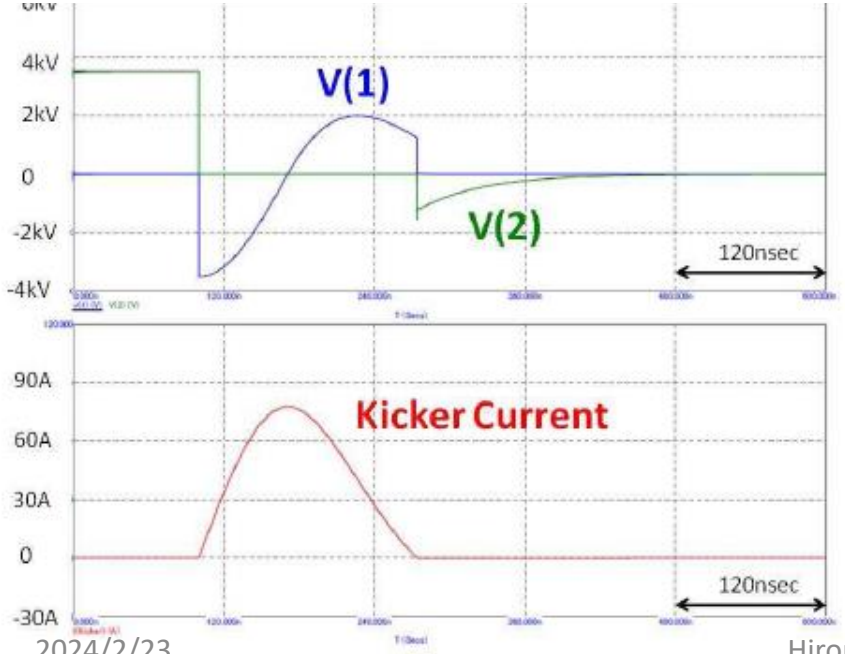
- Quench protection
- **Space problem**

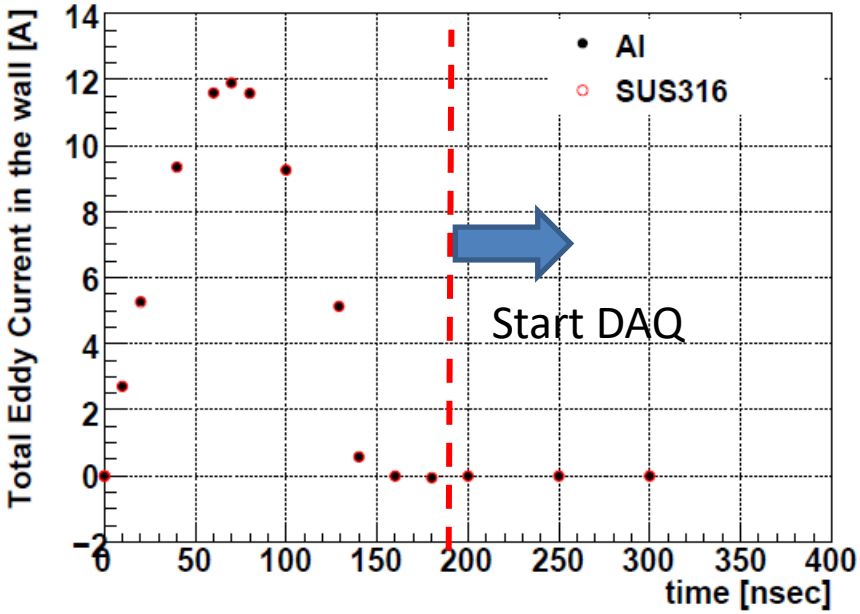
Kicker circuit and eddy current study

R=60cm
cryostat wall

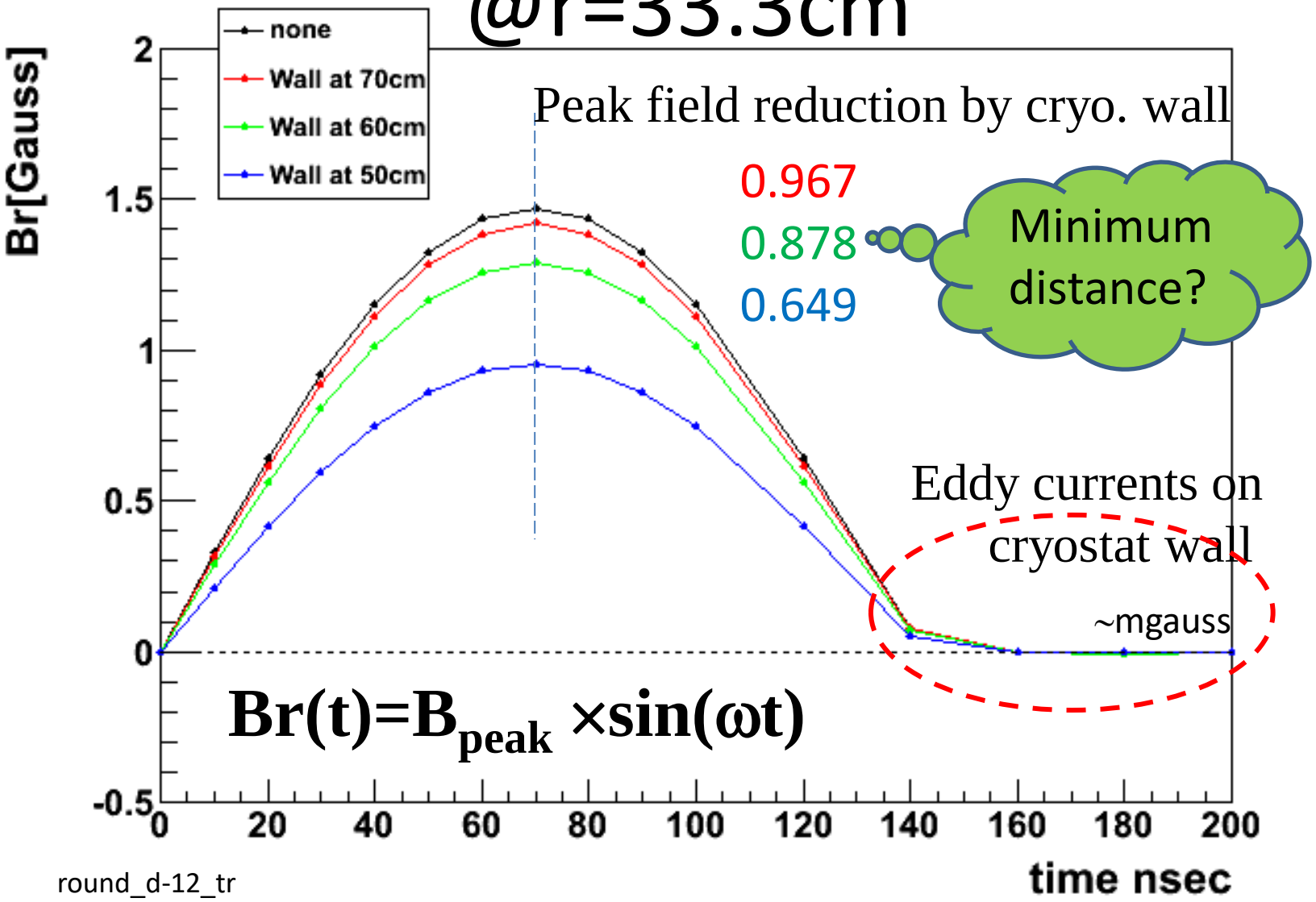






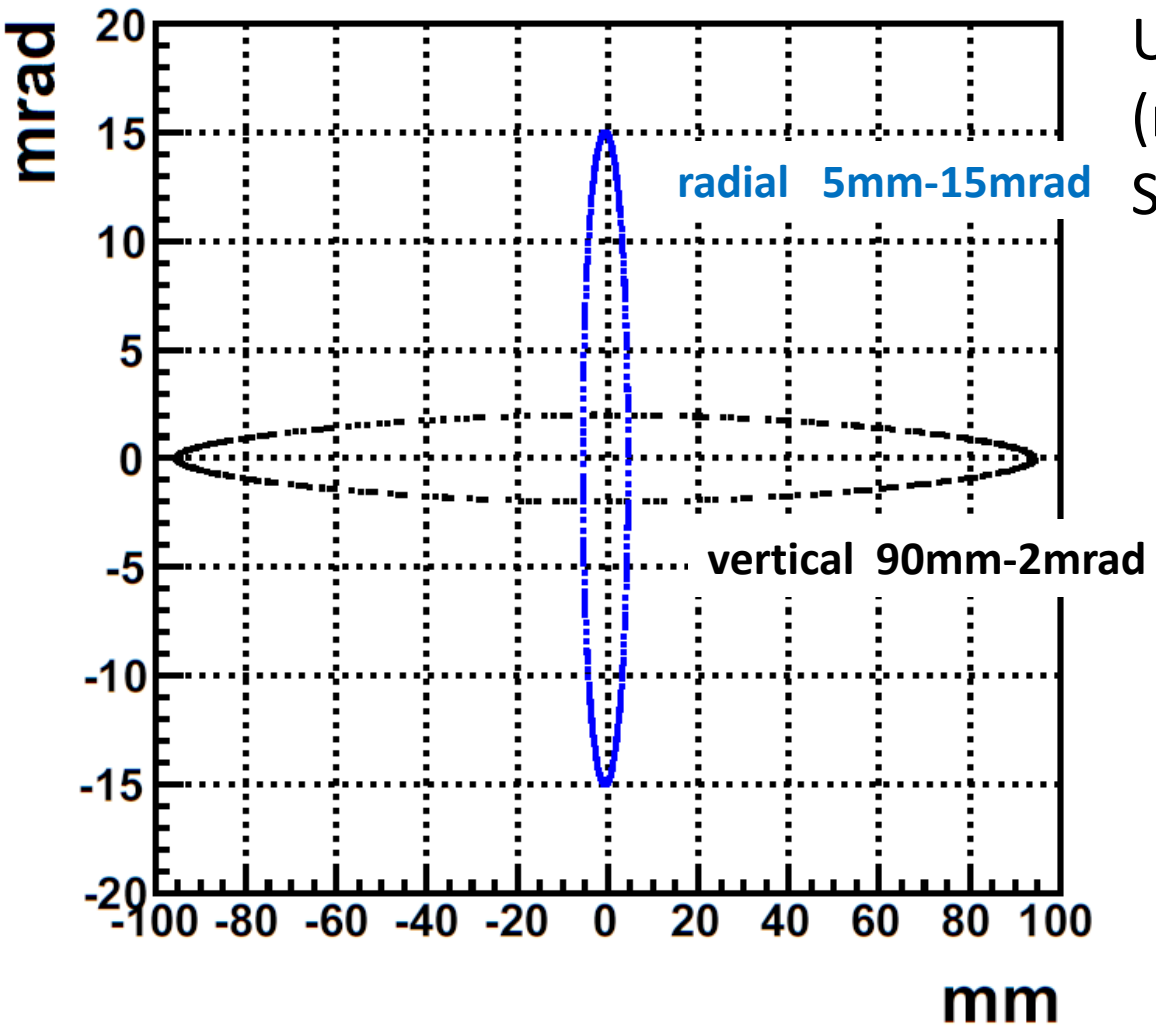


Ver.1 type Kick field @r=33.3cm



round_d-12_tr
round_d-12_wall-1,2,3_tr

Acceptable beam parameters for sample weak field



Use GEANT4
(numerical approach)
Satisfy $\Delta\omega/\omega<0.1$ppm