



# 3D calculations of large aperture opposite field septum magnet

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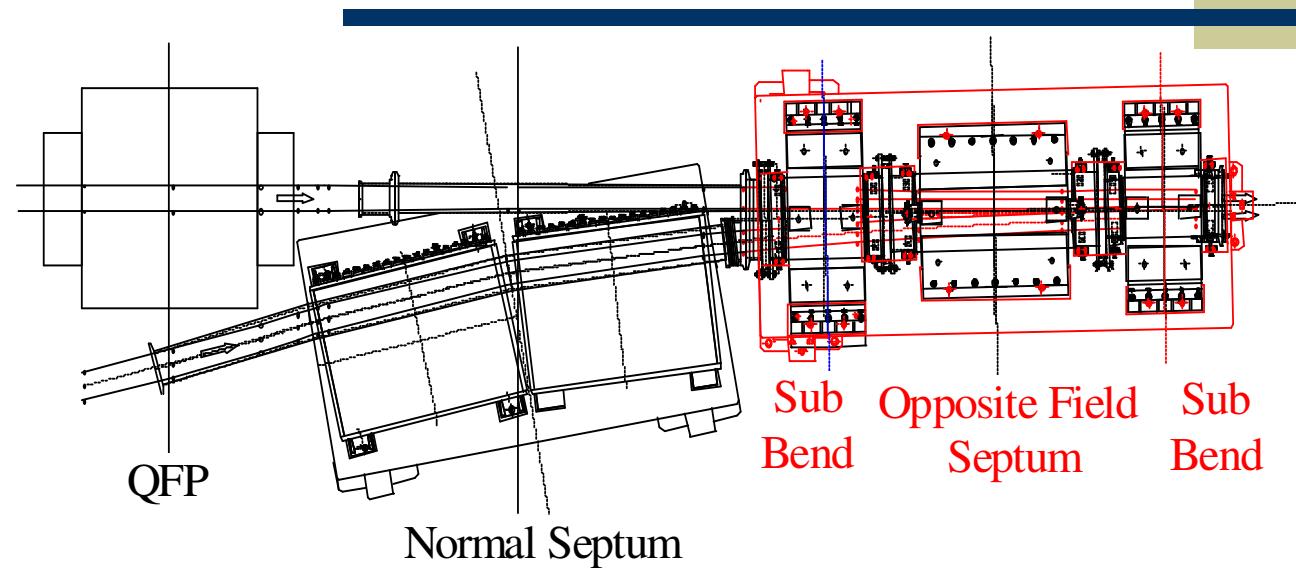
# Outline

- ◆ Introduction
- ◆ 3d Calculations
- ◆ Comparison with measurement
- ◆ Summary

# Introduction

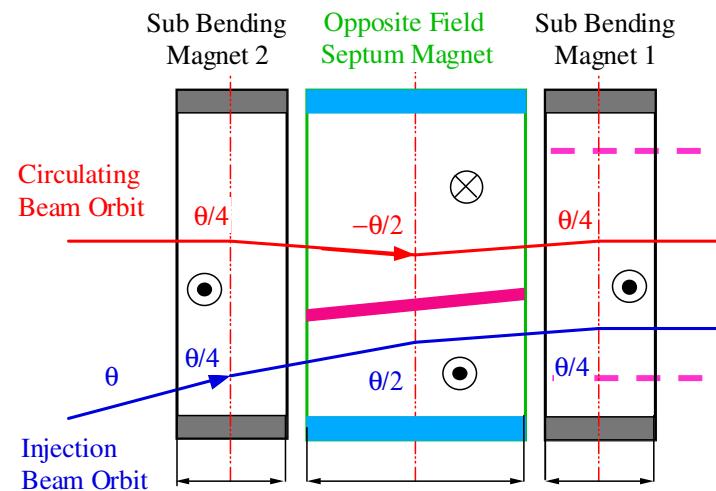
- ◆ High intensity proton synchrotron needs large aperture magnets
  - space charge effect causes large beam size
- ◆ Inj./Extr. System
  - Septum magnet system is divided into several groups. (beam separate effectively )
  - Each septa becomes shorter (gap/length is larger)
    - End field becomes severe (nonlinear field affects beam quality)
- ◆ 3D calculation is important
  - Estimate the detail field distribution.

# J-PARC 50GeV injection Septum magnets



- ◆ Injection septum magnet system
  - ◆ High field septum, **normal structure, 1.36T**
  - ◆ Medium field septum, **opposite field structure, 0.6T**
- ◆ The septa system is simple (benefit from opposite septa)

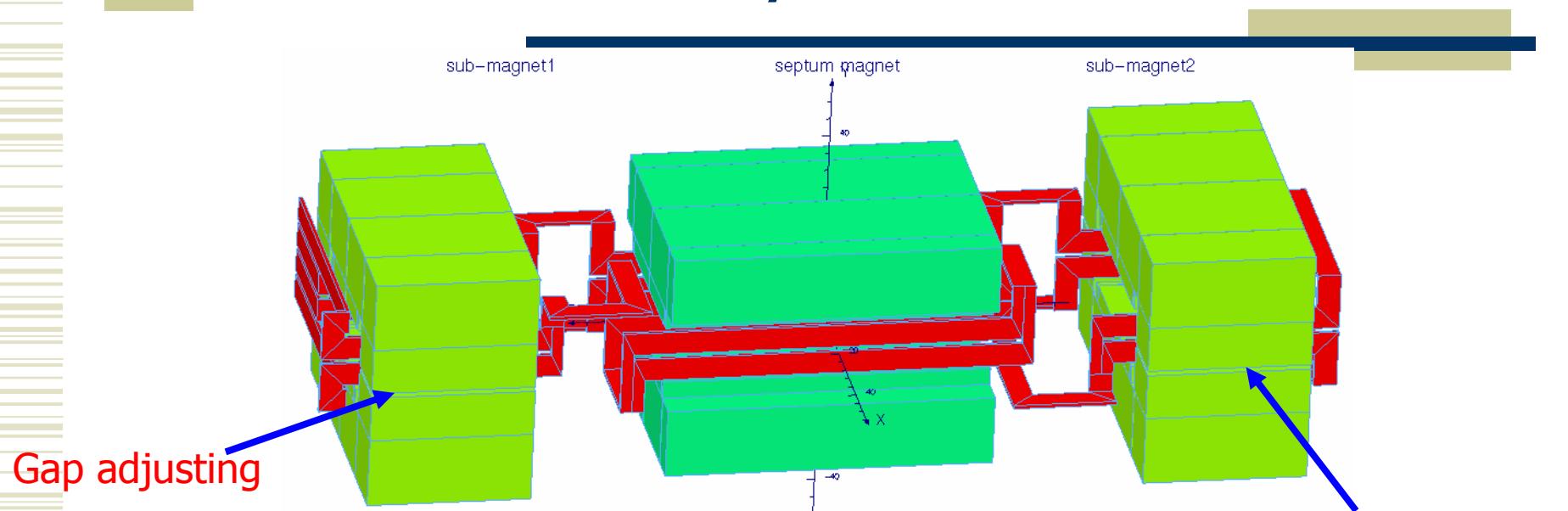
# Opposite field septum magnet system



	Sub Bend 2	Opposite Field Septum	Sub Bend 1
Pole length	mm	350	700
Pole gap	mm	120	120
Pole width	mm	374	355

- ◆ The system consists of 3 magnets
  - The total length of sub-magnet is the same as septum magnet
  - Sub-magnets increase By for inj. beam(**same polarity**)
  - Sub-magnets cancel By field for circulating beam
- ◆ Force free of septum
  - Thin, support easily, pulse mode operation, heat problem...

# 3D model of the septum magnet system

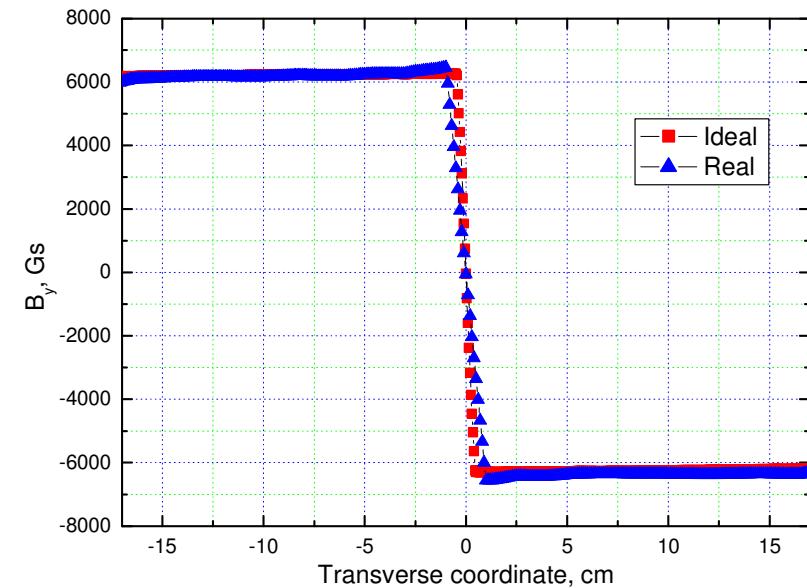
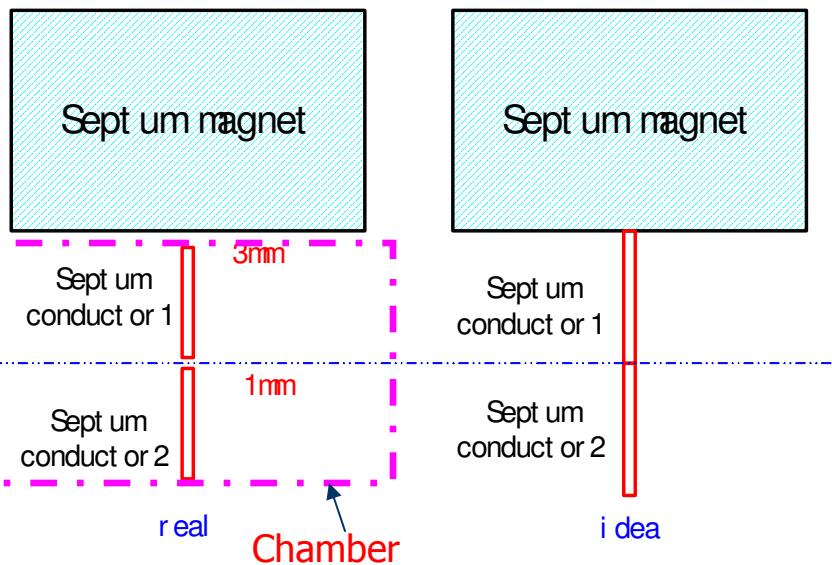


Gap adjusting

Gap adjusting

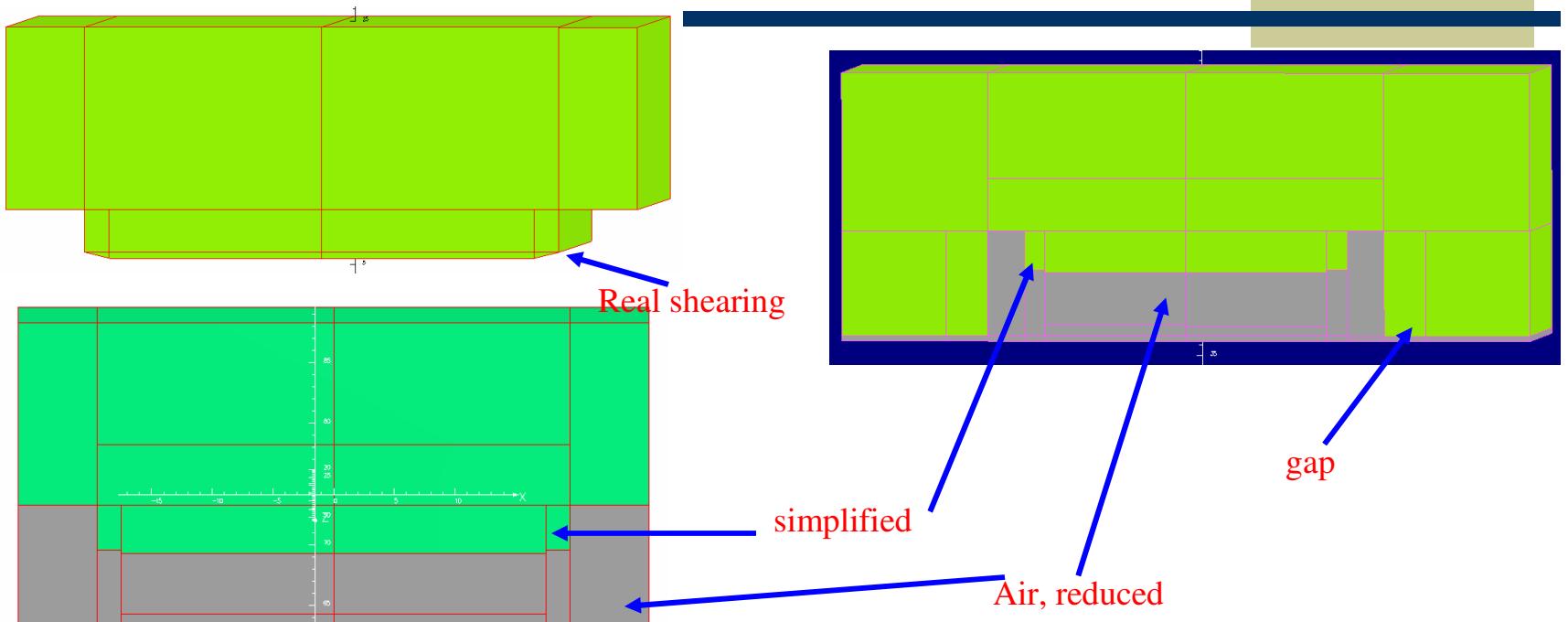
- ◆ Septum magnet is fixed (septum conductor in vacuum chamber)
- ◆ Integral  $B_y$  of sub-magnets is larger (effective length long)
  - ◆ increase the sub-magnet gap (**important feature**)
  - ◆ If the integral  $B_y$  of sub-magnet is lower, how to do?
    - ◆ Cut sub-magnet / increase septa gap ?

# Septum conductor position affects field distribution



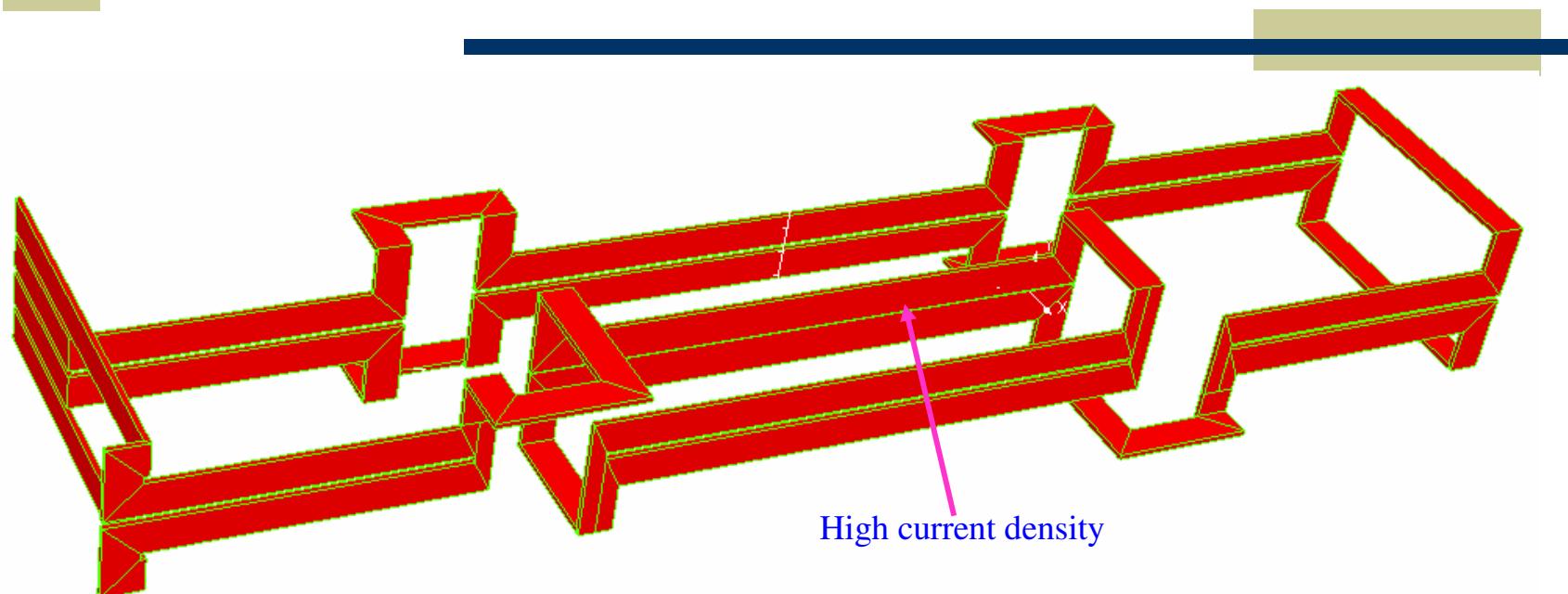
- ◆ In real case, the magnet field near septum not uniformity
  - Gap between core and septum conductor.

# Simplify the model of septum



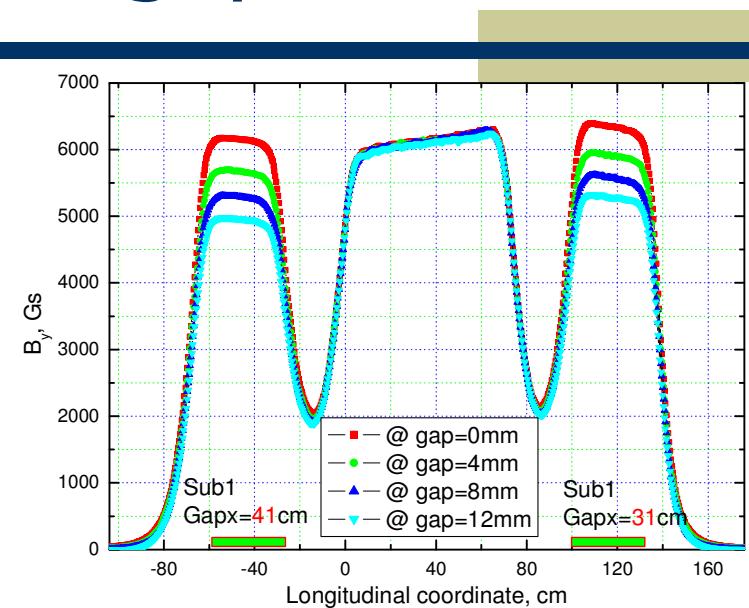
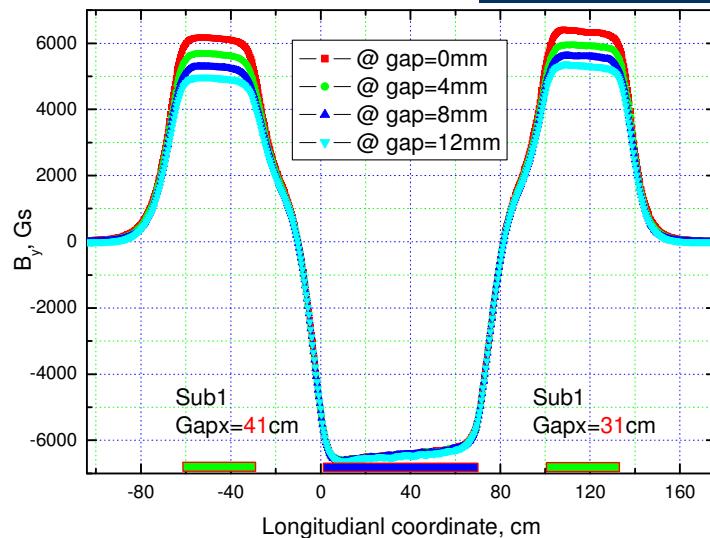
- ◆ Simplify the structure
  - Make the volume mesh easy
  - Without much precise loss

# Real structure of the conductor

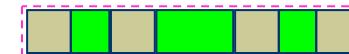


- ◆ Conductor shape, 70 8-node bricks
- ◆ Current 60kA

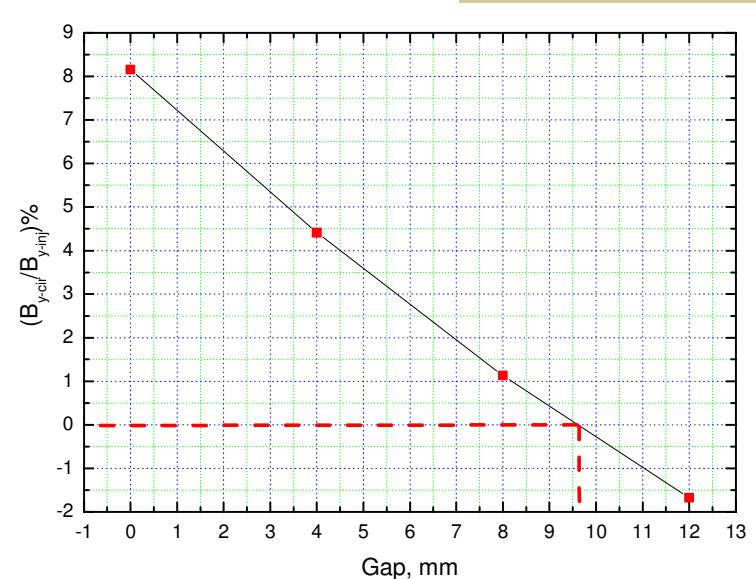
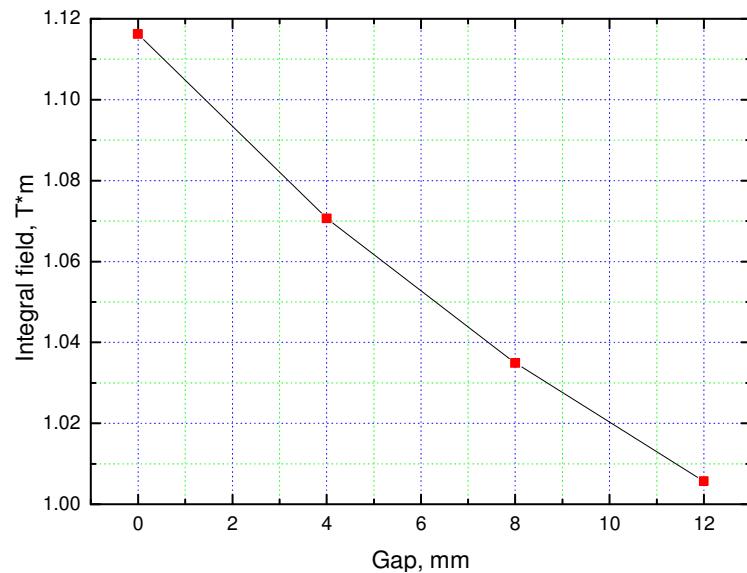
# Longitudinal magnetic field with different gap



- ◆  $B_y$  distribution with different Sub-magnet gap.
  - Sub-magnet field decreases, septum doesn't change
- ◆  $B_y$  inside septa not uniform Longitudinally
  - Sub-magnet not symmetry
  - Reduced potential only near conductor
  - Background volume smaller, large mesh size. (100,000nodes—1day)

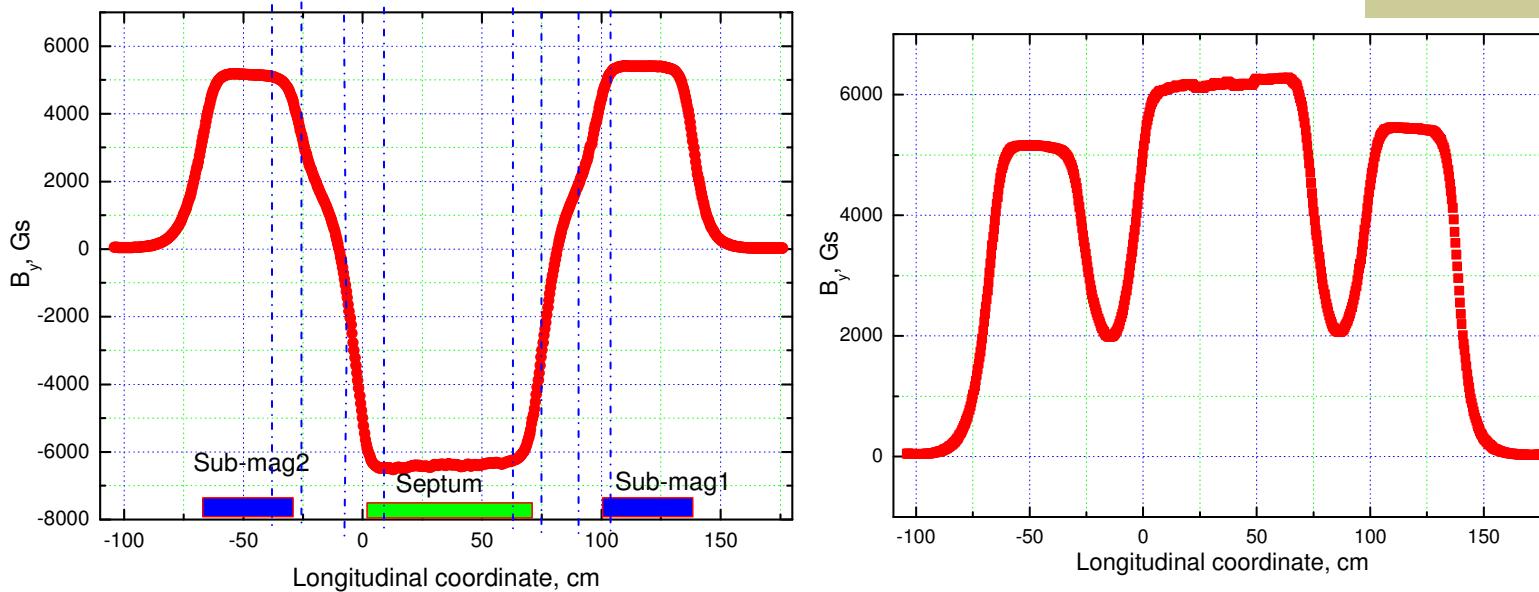


# Integral field with different sub-magnet gap



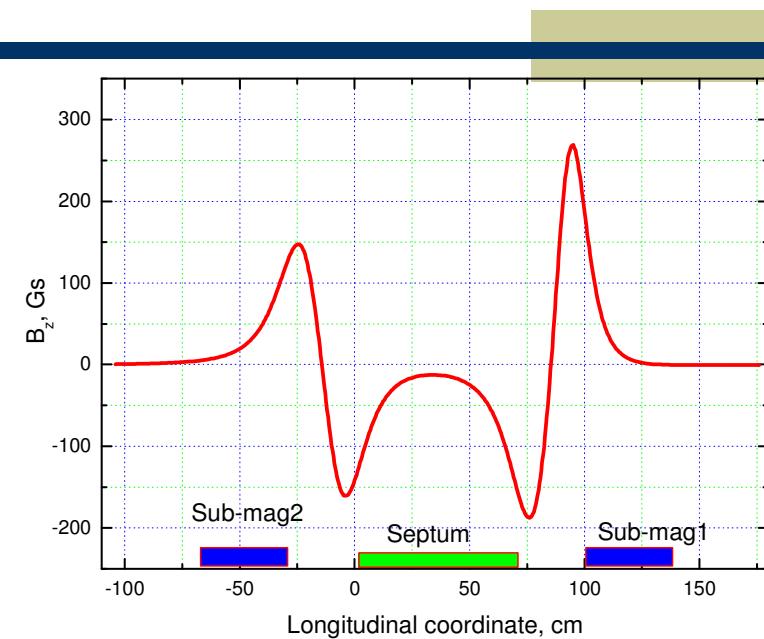
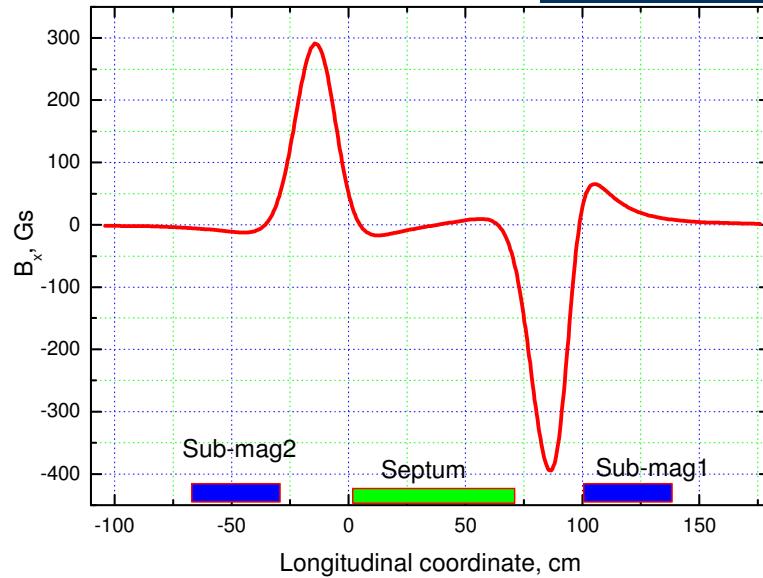
- ◆ Increase sub-magnet gap
  - Integral field at injection side decrease (5cm from center)
  - If the gap=9.6mm,  $B_{\text{cir}}/ B_{\text{inj}}=0$

# Longitudinal magnetic field distribution



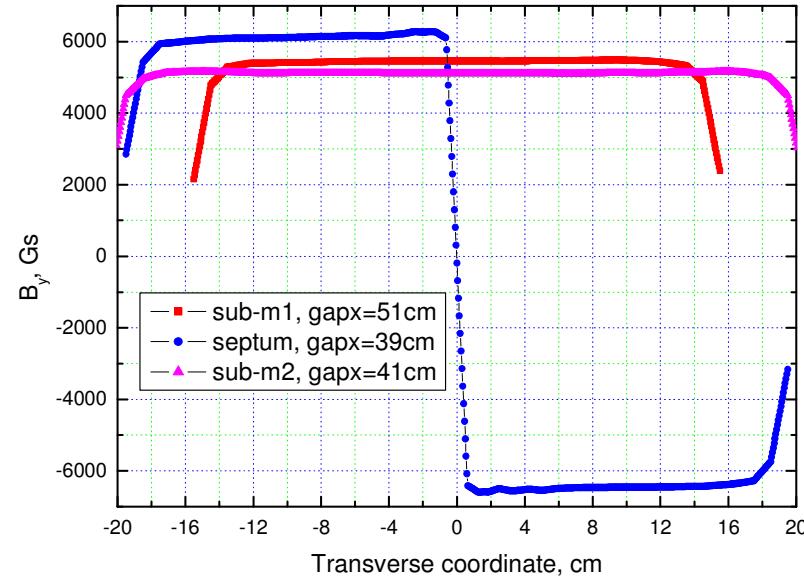
- ◆ Fine mesh at end of magnet (end field)
- ◆  $B_y$  in septum magnet not uniform longitudinally
  - Sub-magnet affect
  - Background volume small?

# B<sub>x</sub>, B<sub>z</sub> Longitudinal distribution



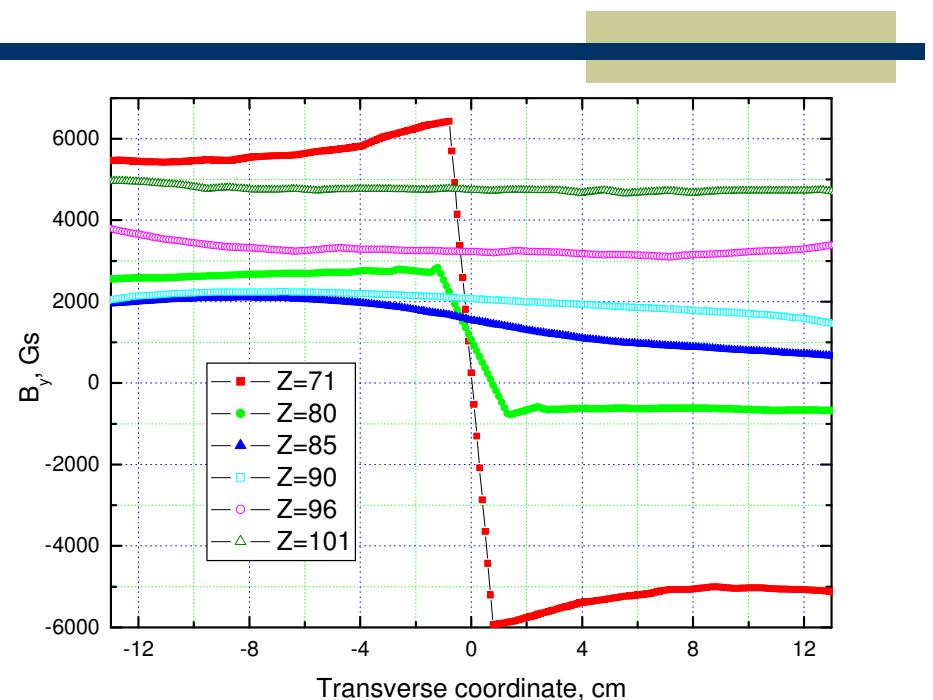
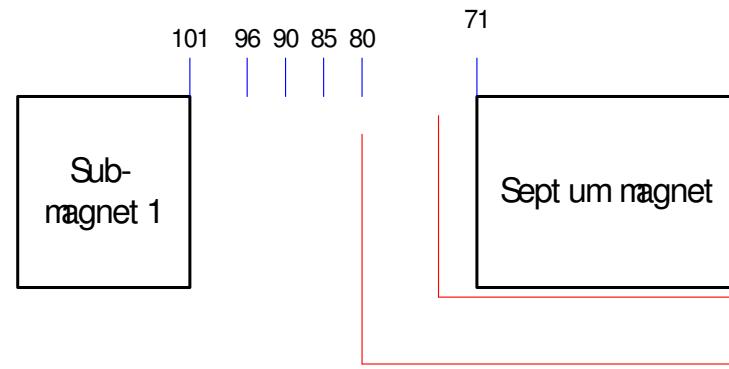
- ◆ Integral B<sub>x</sub> and B<sub>z</sub> at the center of circulating beam not zero
  - Complicated conductor.
  - $B_x L = -108 \text{ Gs.cm}$ ,  $B_z L = 13.6 \text{ Gs.cm}$
  - $B_y L = 1.02 \times 10^6 \text{ Gs.cm}$

# Transverse magnetic field distribution



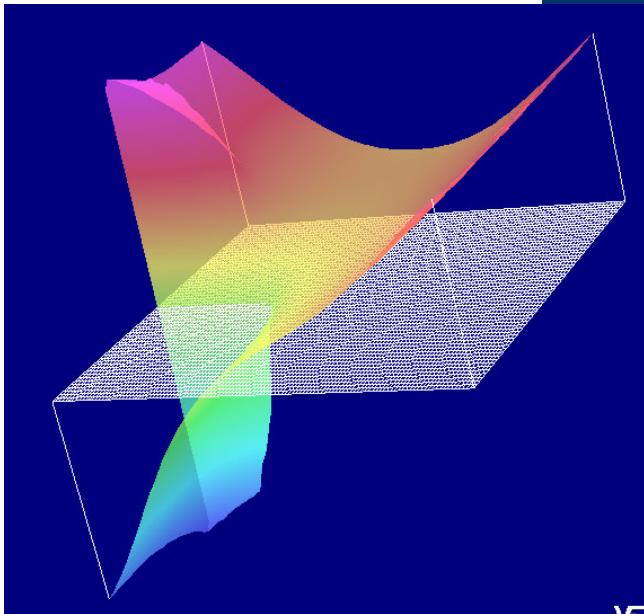
- ◆  $B_y$  distribution @ sub-magnet uniform
- ◆  $B_y$  near septum conductor not uniform
  - Gap between core and septum conductor

# By distribution of end field

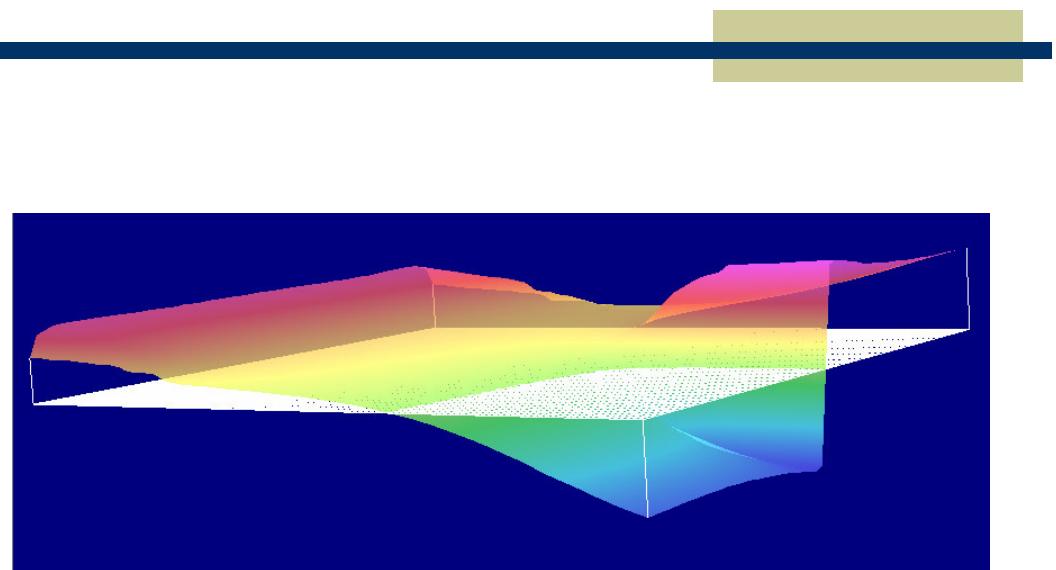


- ◆ The end field changes much
  - High vertical gap, Sub-magnet (12/35), septum magnet (12/70)

# 3D $B_y$ distribution of end field



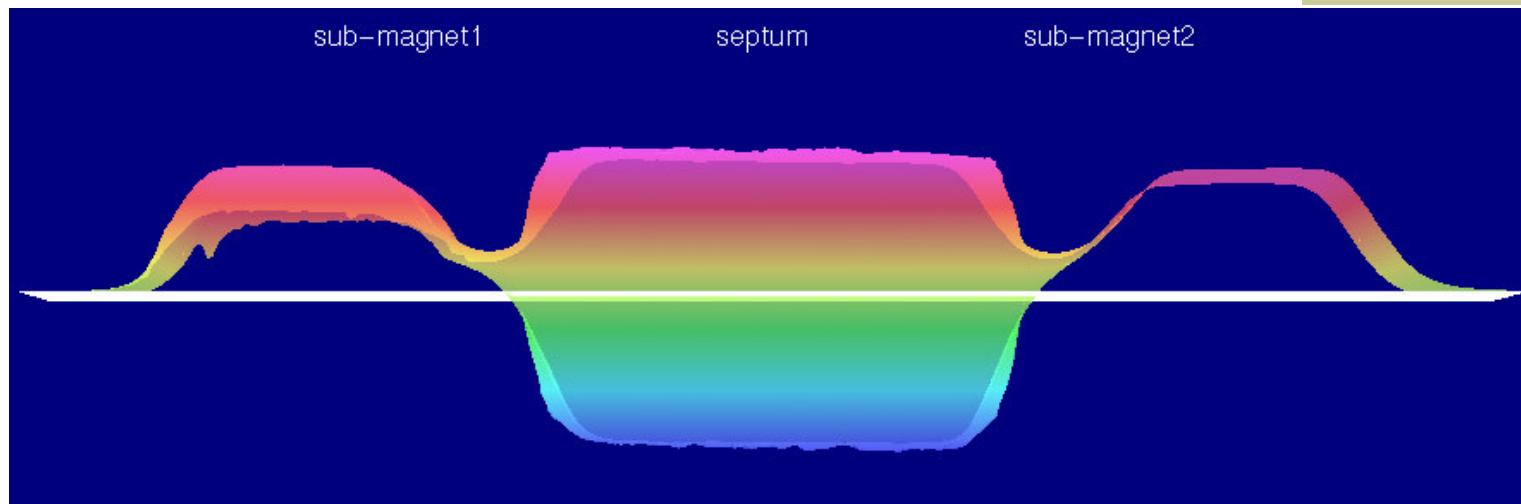
Sub-magnet2- septa



Sub-magnet1 - septa

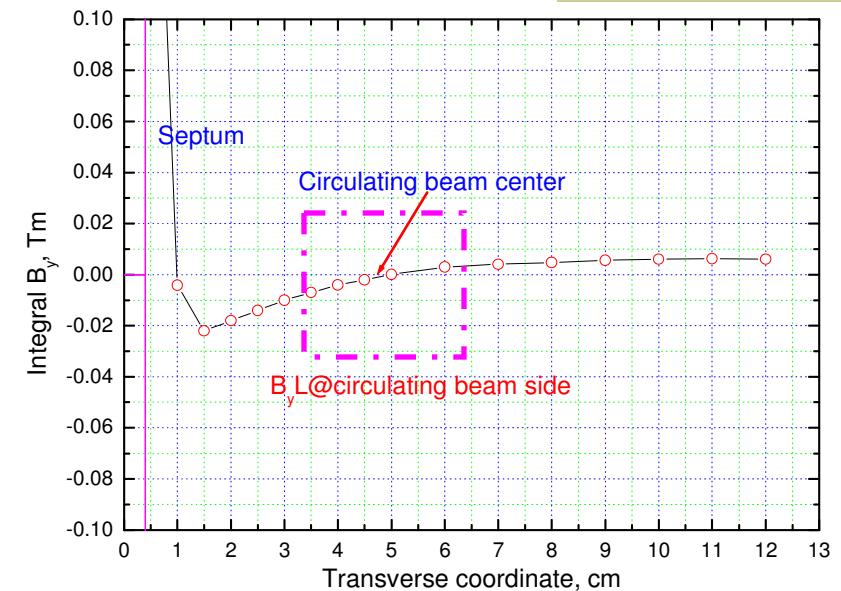
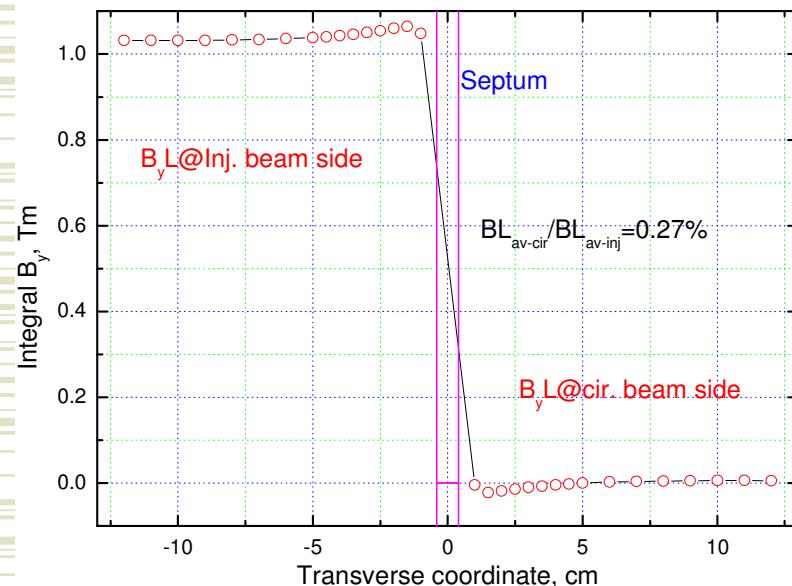
- ◆ Three dimensional  $B_y$  distribution at both end of septa

# 3D $B_y$ distribution of the whole magnet system



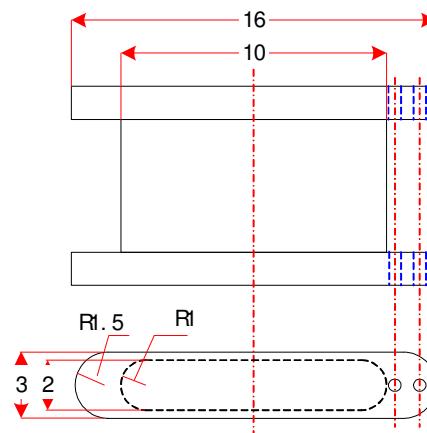
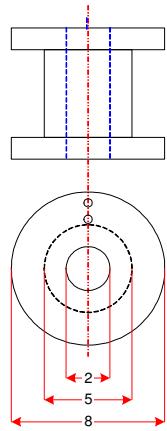
- ◆ Three dimensional  $B_y$  distribution of the whole system

# Transverse distribution of integral magnetic field

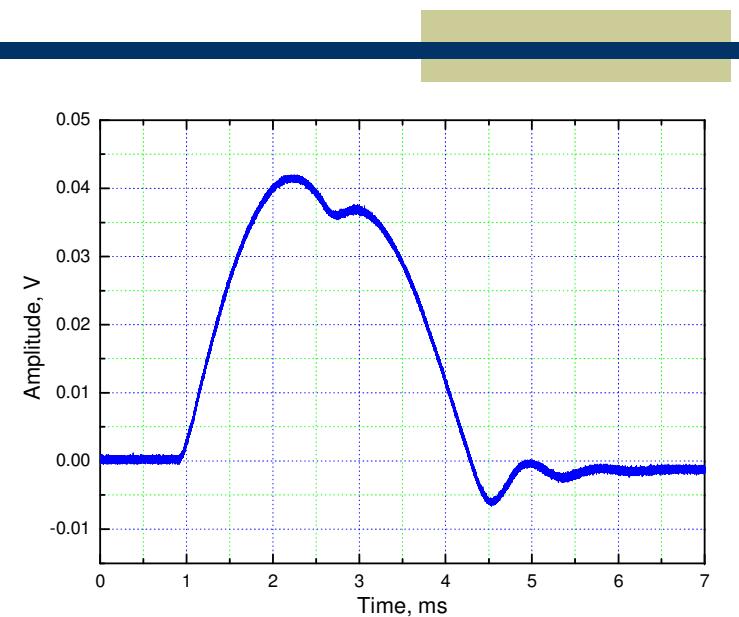


- ◆ Integral  $B_y$  distribution at both sides not bad
  - The BL close to zero at the center of circulating beam
  - Nonlinear field, quadrupole...

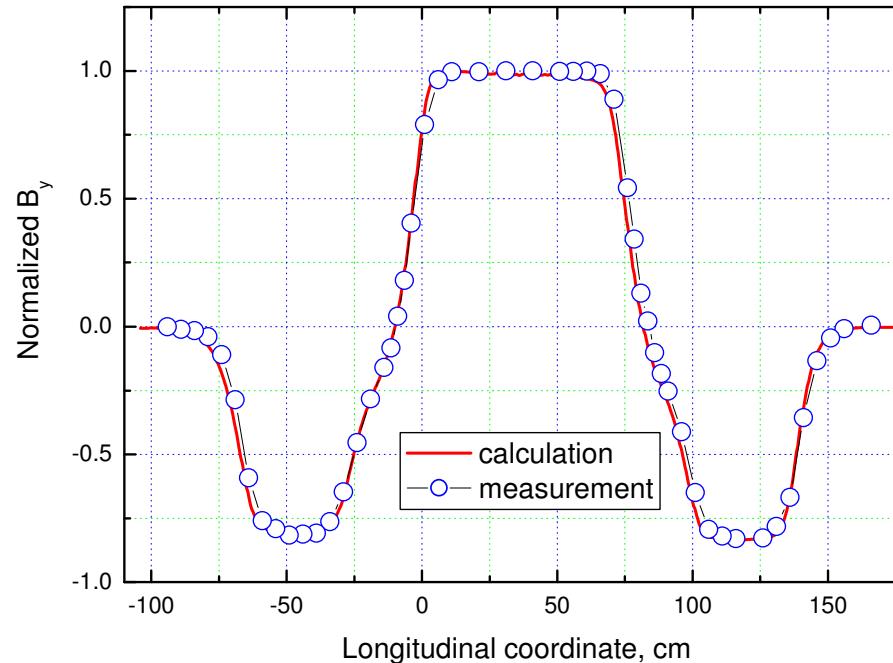
# Comparison with initial measurement



- ◆ Long search coil.
  - Integral field as reference, in case of non-stable power supply
- ◆ Short search coil
  - 2 types coils
  - $\text{dB}/\text{dt}$  is small,  $N=300$  turns

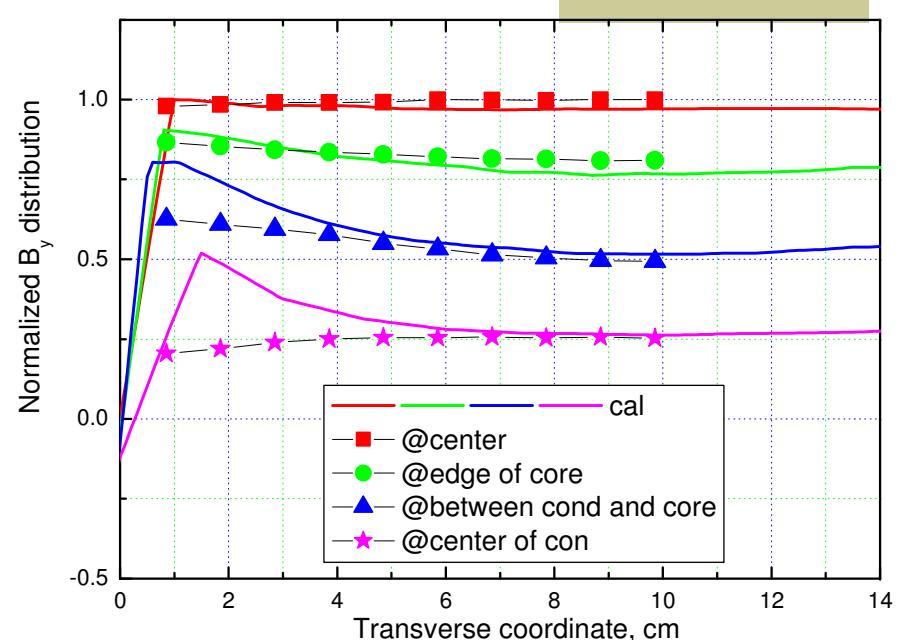
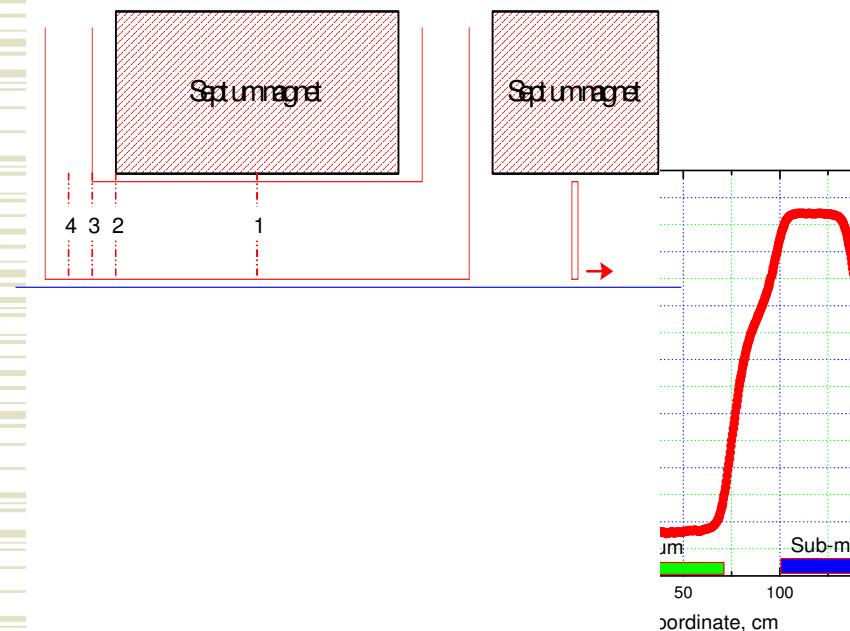


# Comparison of longitudinal field distribution



- ◆ Normalized  $B_y$  longitudinal distribution
  - ◆ Measured data supports the calculation
  - ◆ Error comes from search coil position measurement

# Transverse distribution



- ◆ Inside septum, the measured data agrees the calculation
- ◆ End field does not agree
  - Longitudinal distribution changes much, search coil size



# Summary

- ◆ The 3D calculations examine the design of opposite field septum magnet.
- ◆ Initial measurement data supports the calculation.
- ◆ **The next work**
  - Exact measurement
  - Beam optics calculations
  - Eddy current calculation