# g-2 Target Optimization MARS Study

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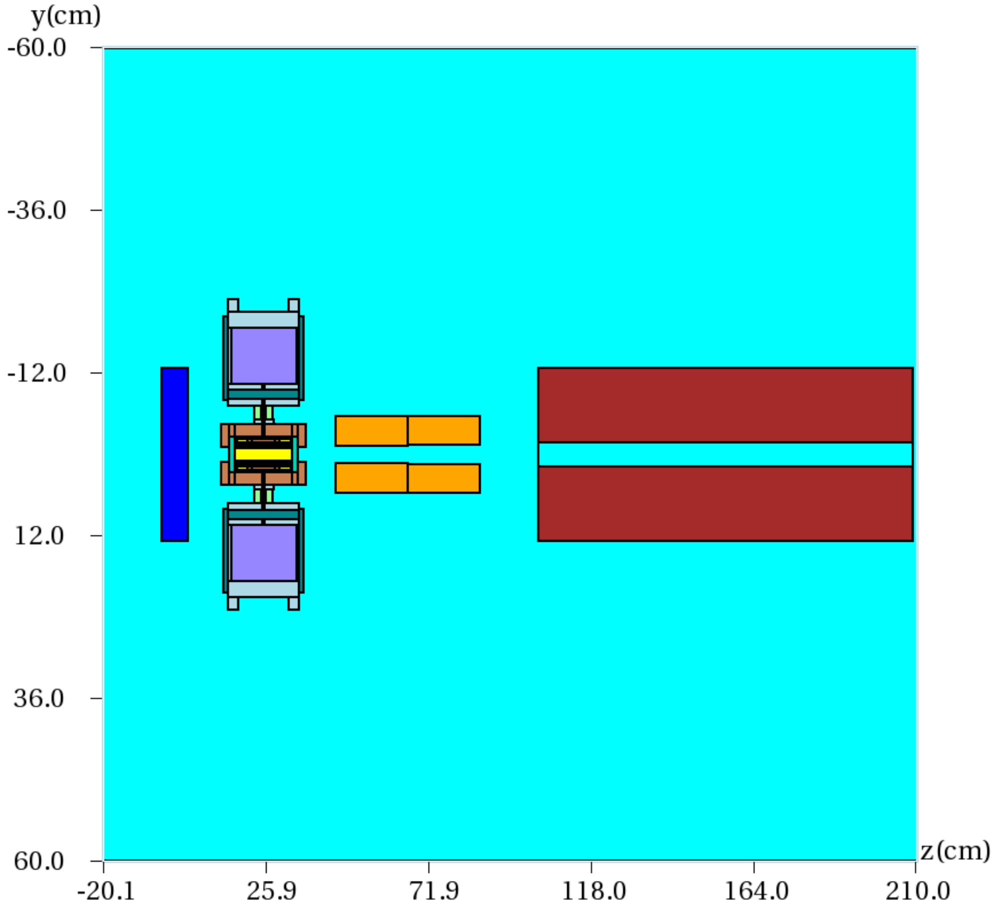
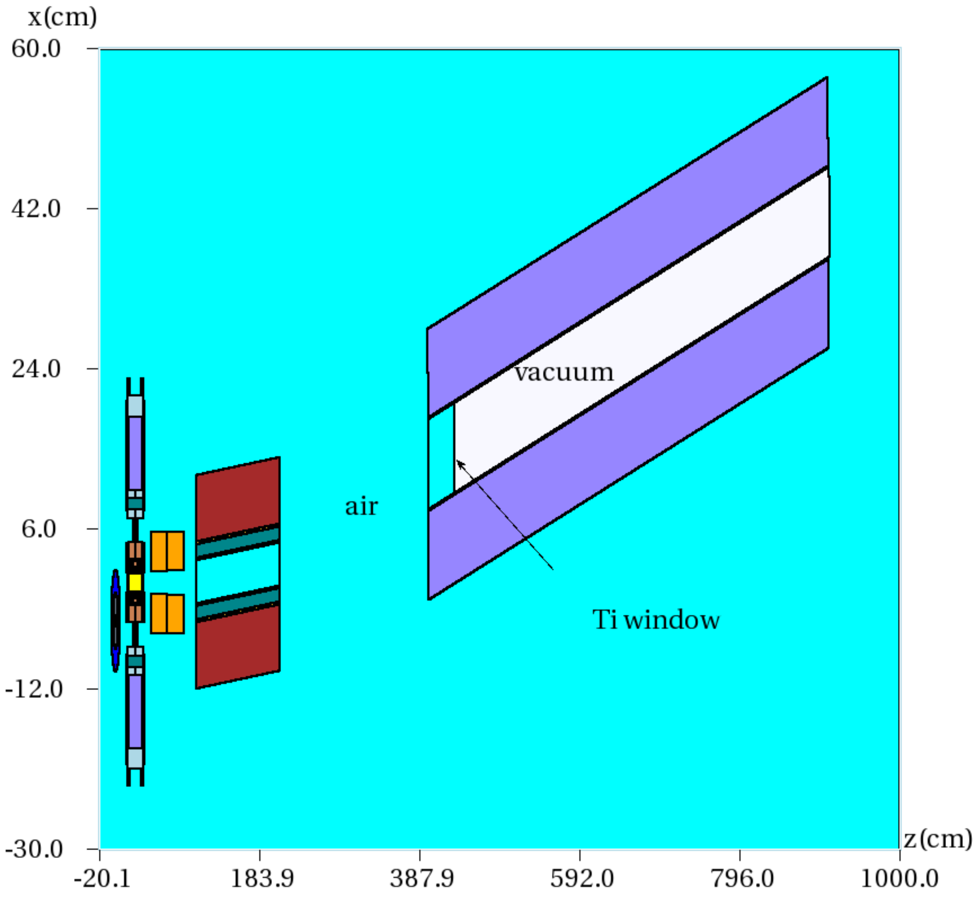
# Outline

- MARS15 description of g-2 target station
- Pion yield for different positions of current target
- Pion yield for other targets
- What we could gain by modification focusing and/or delivery layout

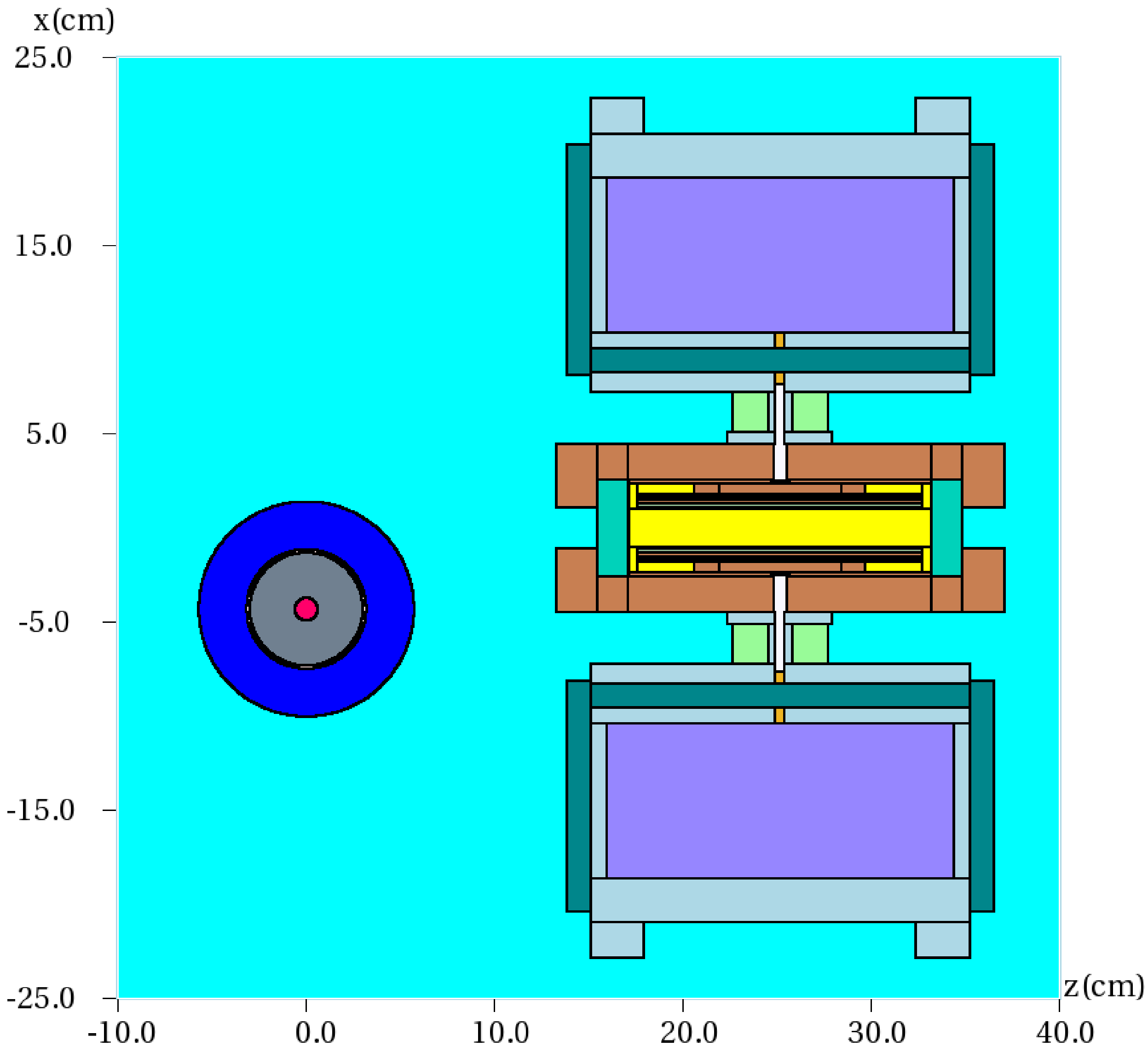
# Current setup



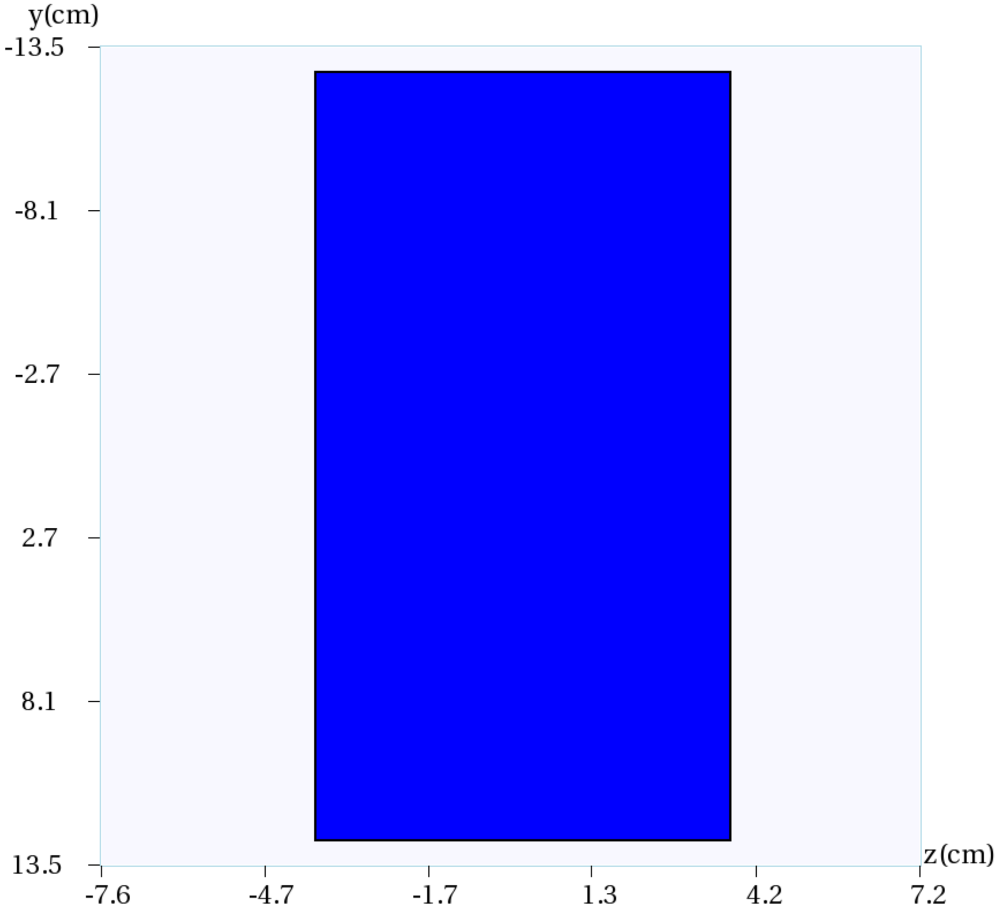

X-horizontal direction, Y-vertical direction, Z – along beam

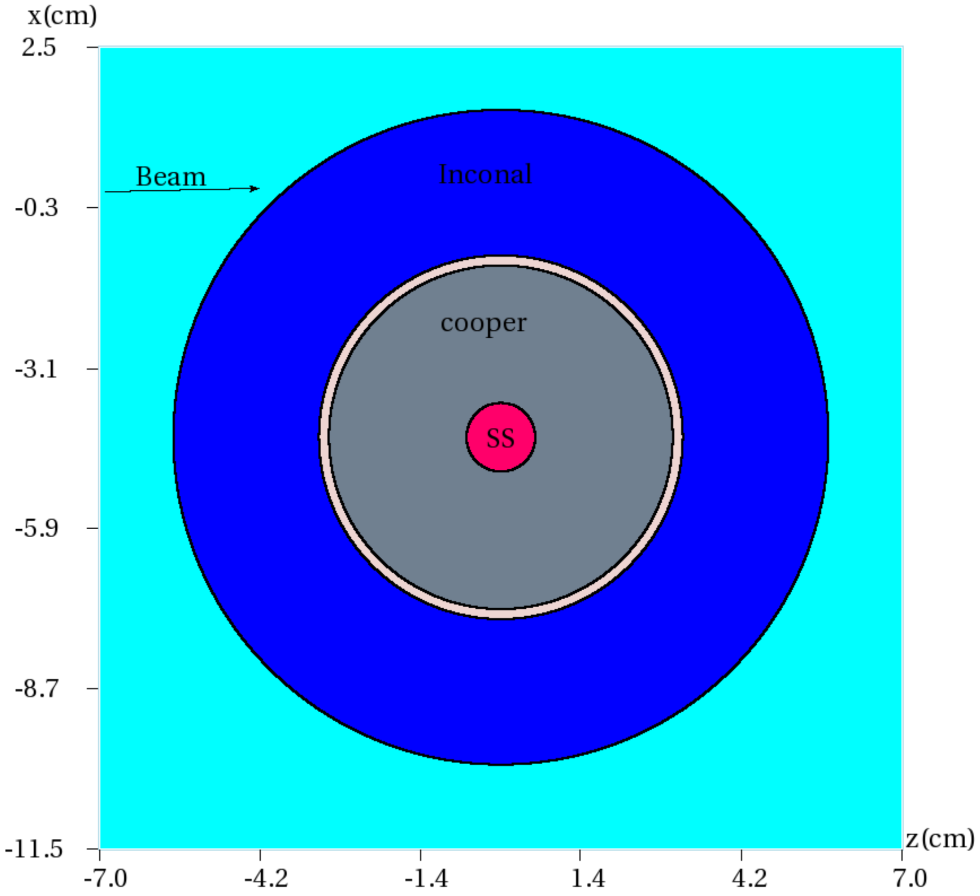
# Lithium lens




Length of magnetic field along beam – 16.077 cm
Radius of magnetic field around beam – 1 cm
Pbar distance between target and lens – 25.1495 cm
Pbar rescaled field gradient – 264.555 Tesla/m
Actual distance between target and lens – 30.5 cm
Actual field gradient – 235 Tesla/m (from Jim Morgan)
Maximal possible field gradient – ??????

Target: Inconel disk – 11.43cm diameter,  inside - Cu (diameter 6 cm), height – 25.4 cm.
Inconel chord length along beam of 7.506 cm (pbar rescaled)/6.2 cm (actual – Jim Morgan)

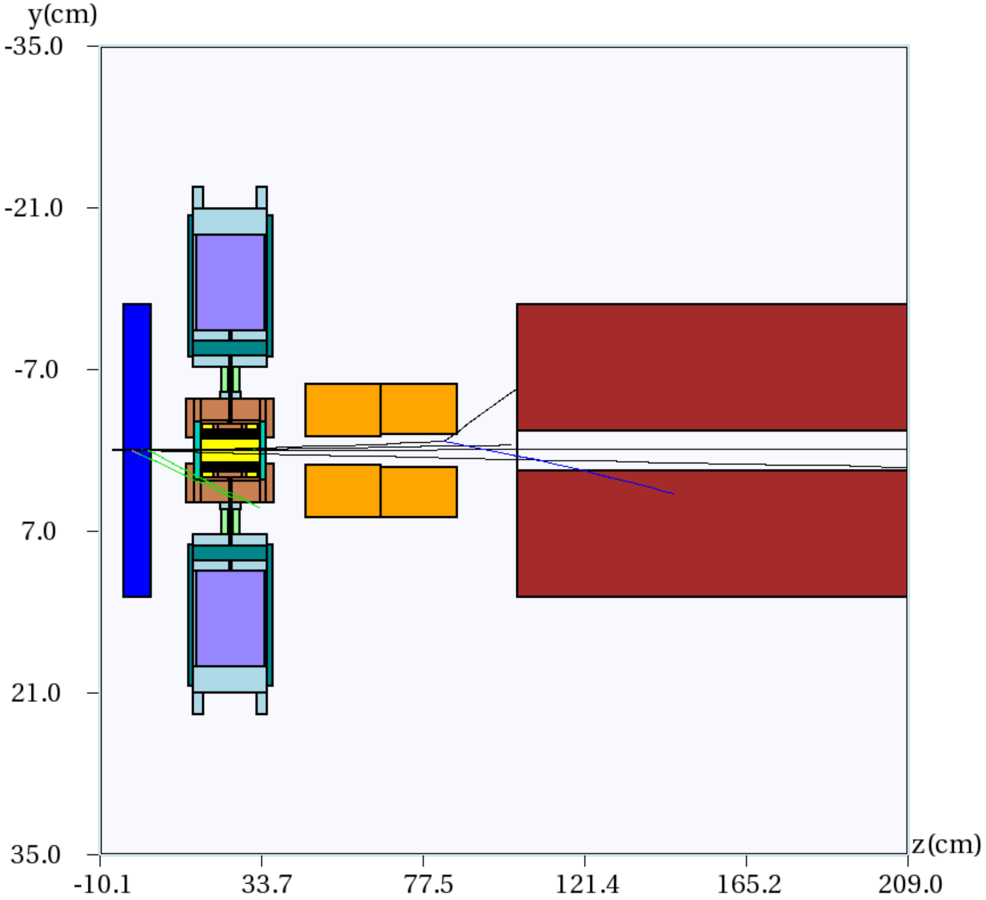


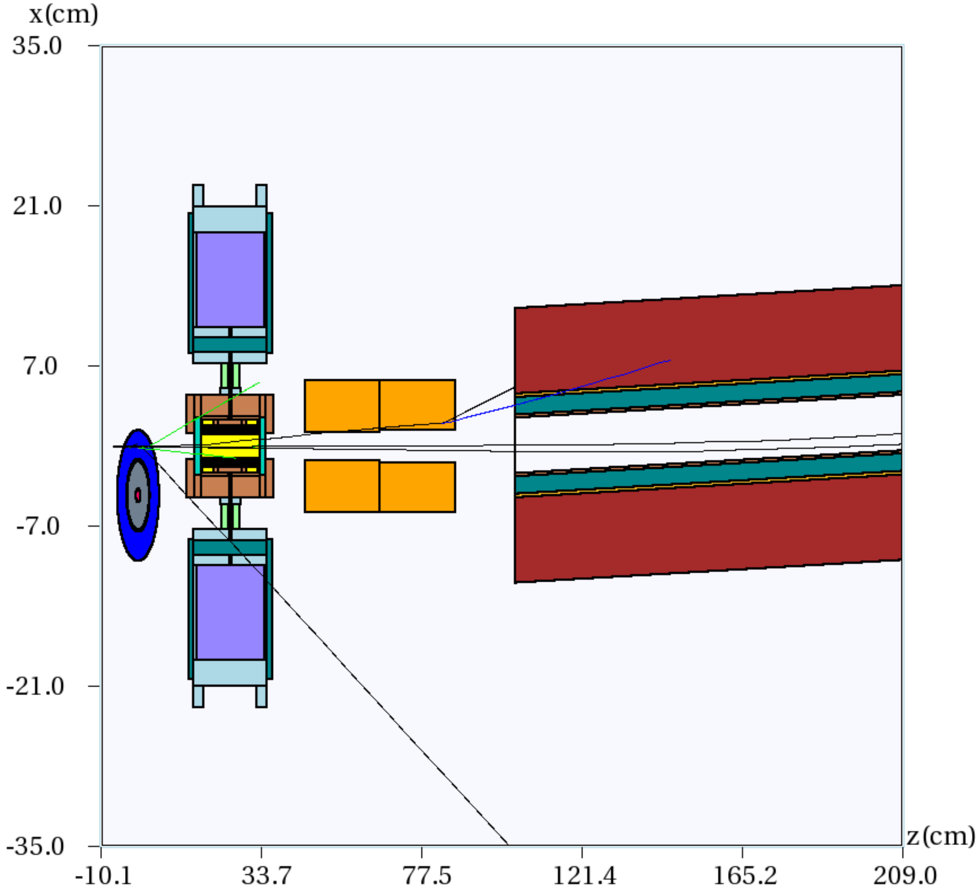




X-horizontal direction,  Y-vertical direction, Z – along beam

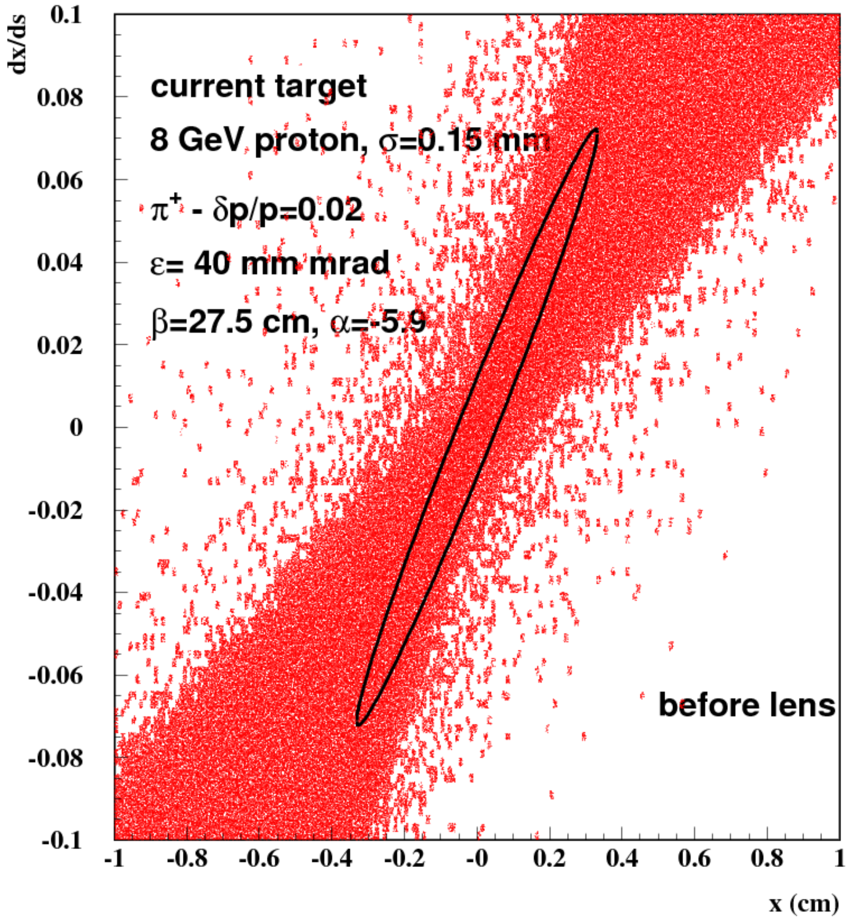
# Beam parameters:

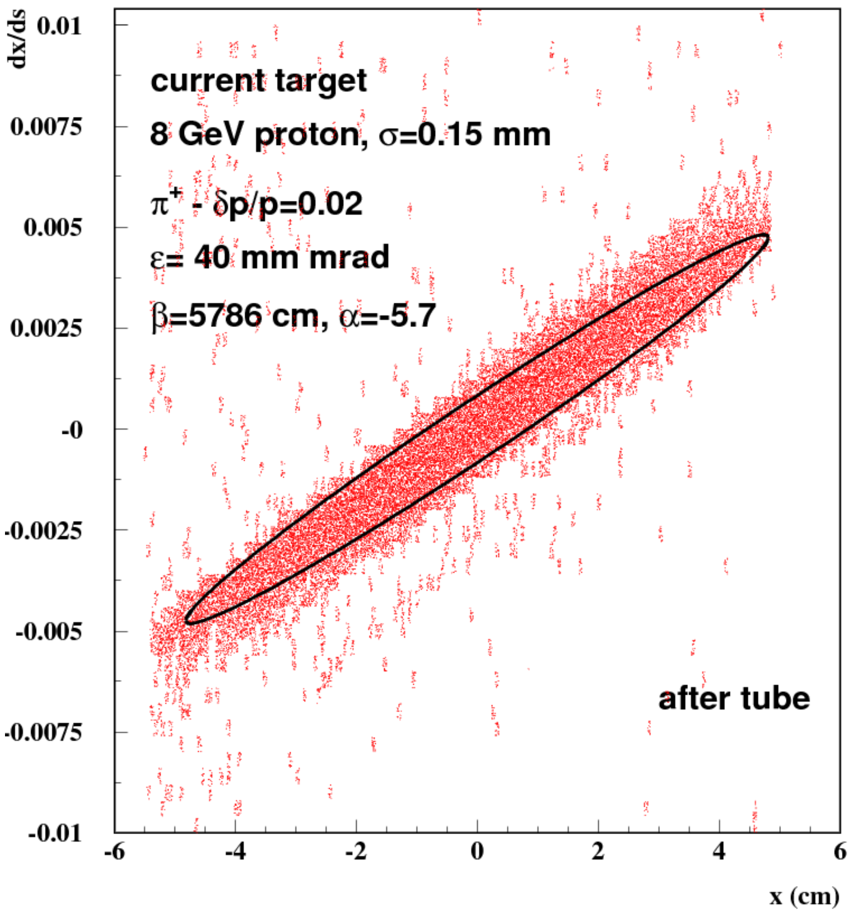
# 8 GeV kinetic energy, 0.3 mm mrad emittance, σ =0.15 -0.33 mm



# Figure of merit:
# number of pions with "magic" momentum (3 .1 095 GeV/c +- 2% ) inside 40 mm mrad emittance




Yield - number of pions near "magic" momentum inside ellipse which corresponds 40 mm mrad emittance. Yield does not change along beam line, if pions are inside aperture. Maximal angle remains unchanged if there are no focusing magnetic field.

# Unavoidable losses

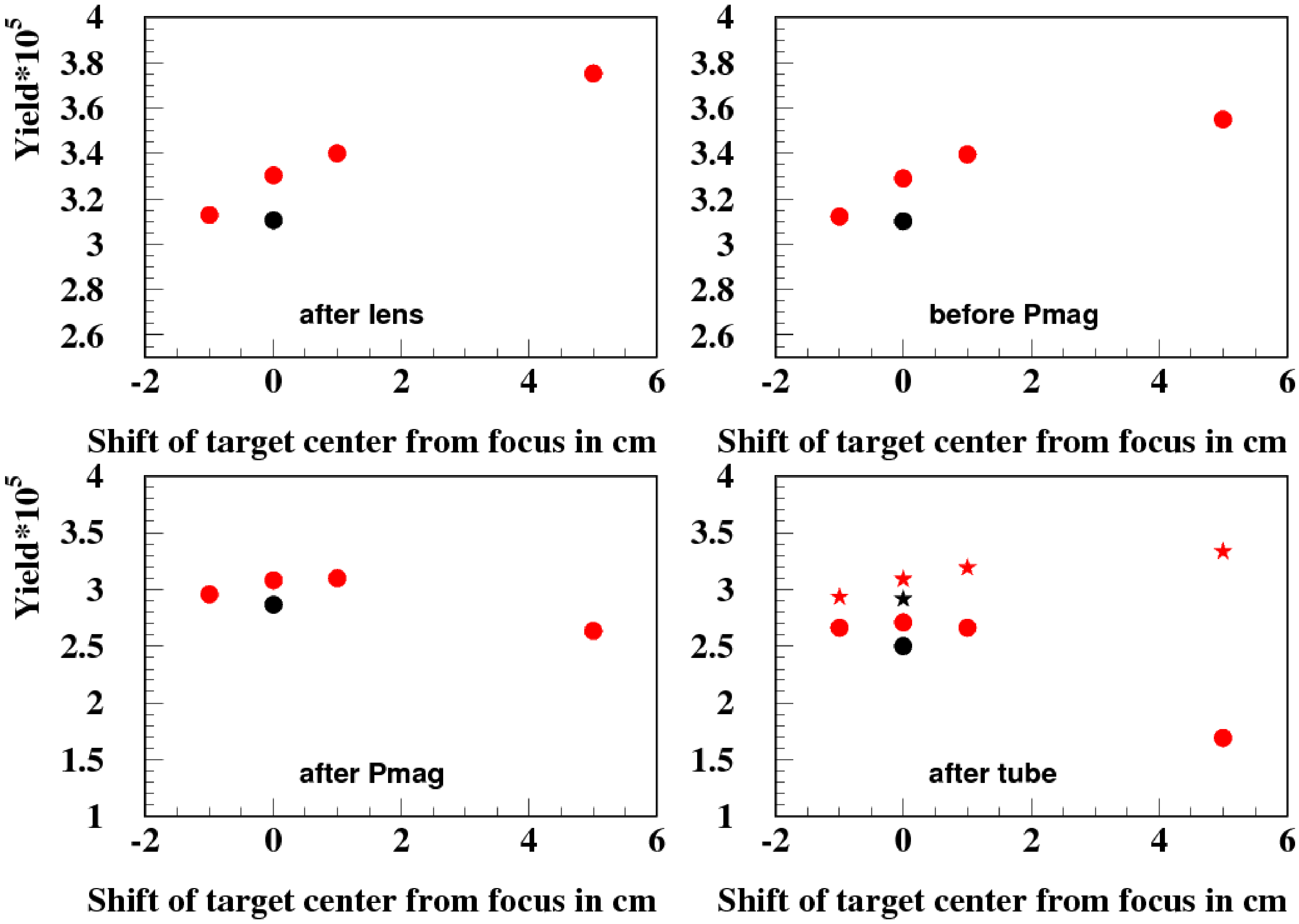
Pion decays: ~5% of pions decay between target and DS tube end.

Inelastic interaction with air: ~1.3% of pions are lost

Inelastic interaction with Li lens: ~9.3% of “useful” pions are lost, but ~(5-8)% are produced in lens.

Pion loss in optimal delivery system after lens should be ~6 %. Only ~10% produced pion should be lost in ideal focusing & delivery system.

# Yield dependence on disk target position
# (“pbar”265 Tesla/m gradient, “pbar” target spot size = 0.15 mm)



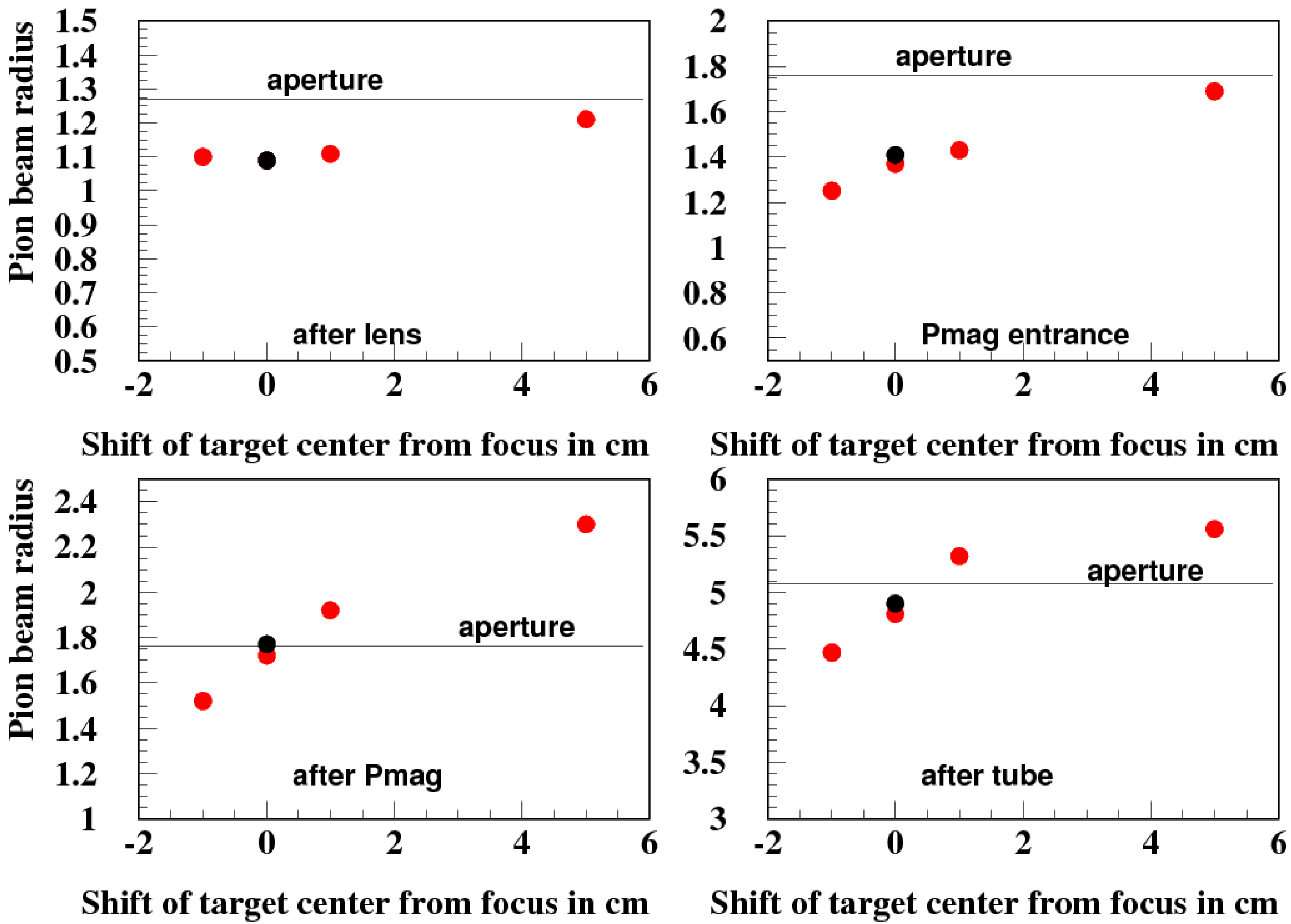

Red – target shifted along beam,

Black – target shifted 1cm left in horizontal direction

Stars – decay + interaction with air after lens only

Pbar focus position is optimal for 265 Tesla/m & layout

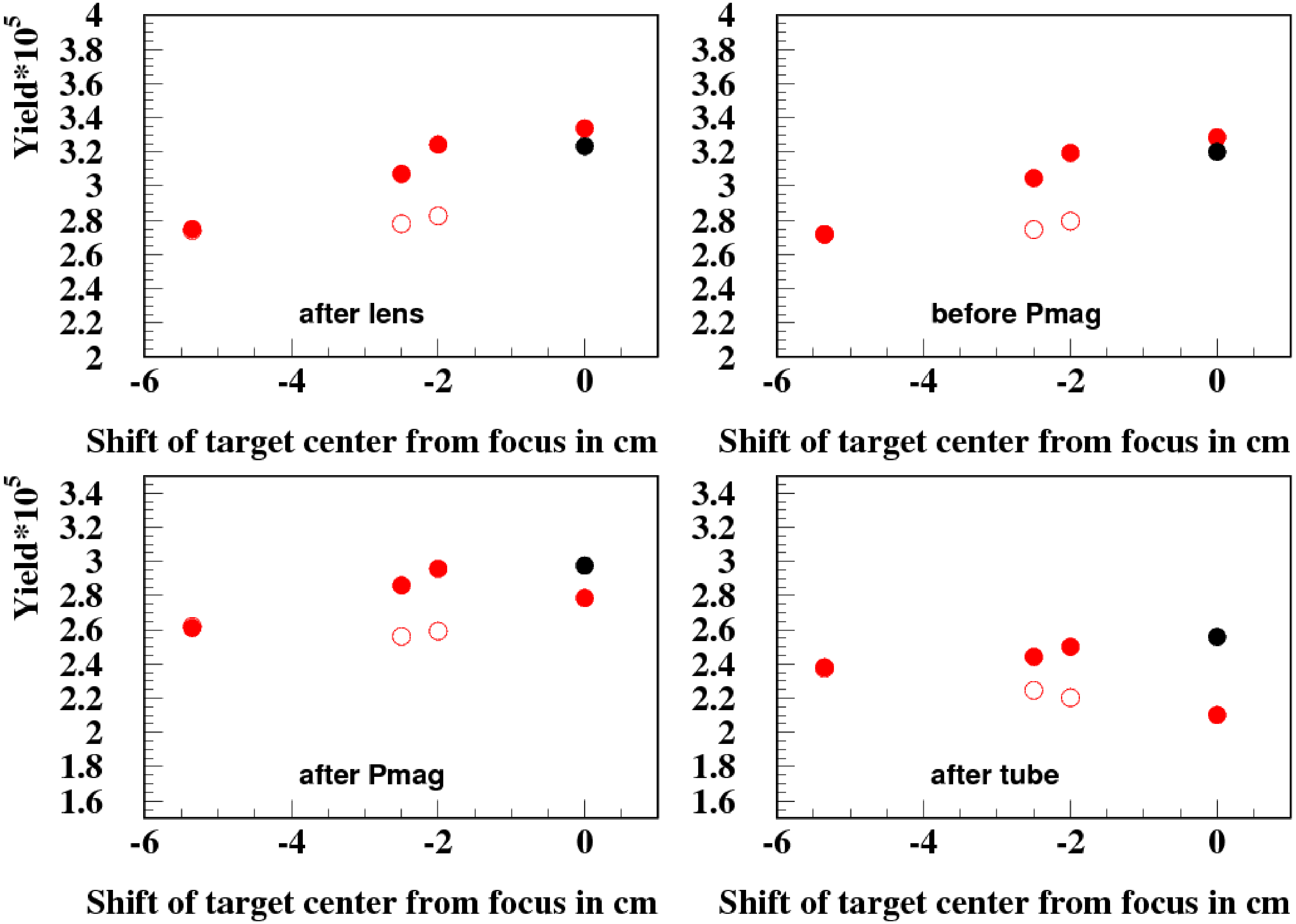
# 40 mm mrad pion beam size dependence on target position




Red circles– target shifted along beam. Black circles– target shifted 1cm left in horizontal direction.

For target positions closer to lens more pion go through lens. Pion yield is larger, but focusing is less. For these positions pion beam size is larger than aperture of Pmag and tube.

# Yield dependence on disk target position, beam size and lens magnetic field




Full red symbols – 235 Tesla/m gradient; chord = 62mm, beam size:
$\sigma_x$= 0.20 mm, $\sigma_y$= 0.23 mm

Black symbols – 265 Tesla/m gradient, chord = 76mm, beam size:
$\sigma_x$= 0.15 mm, $\sigma_y$= 0.15 mm

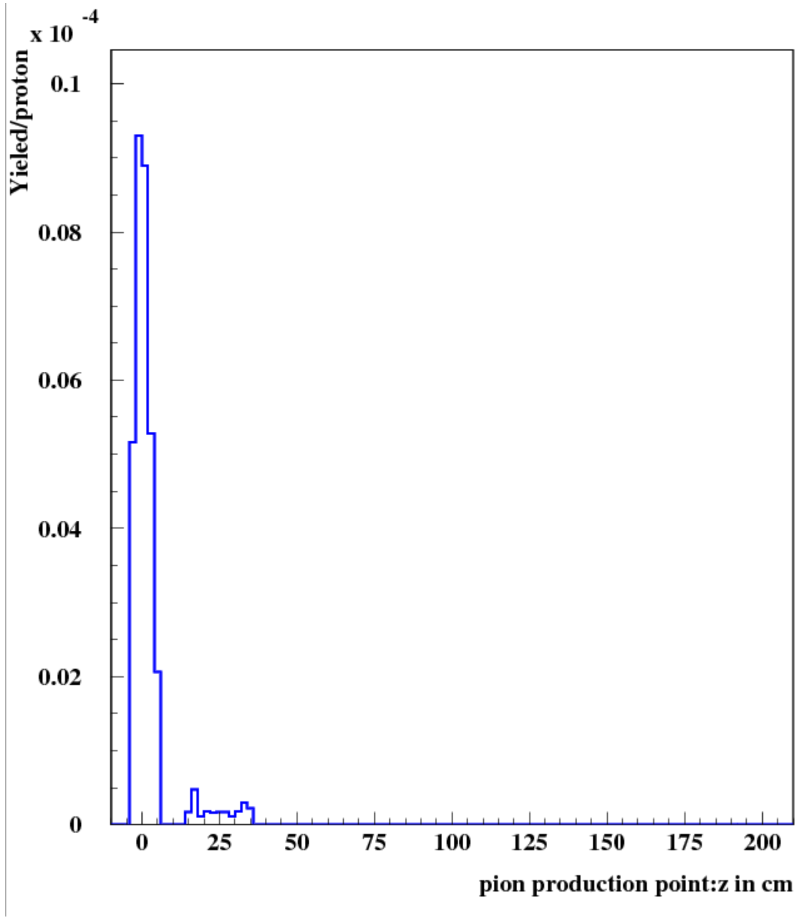
Open symbols – 235 Tesla/m gradient, chord = 62mm, beam size:
$\sigma_x$= 0.33 mm, $\sigma_y$= 0.33 mm

# Considered targets

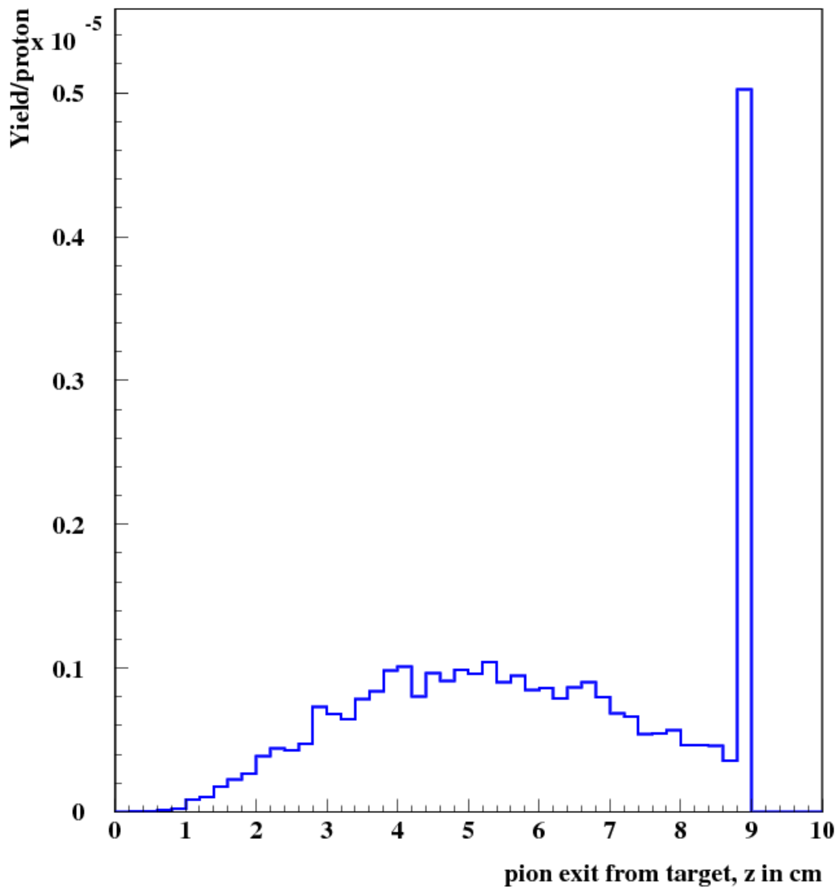
Our previous study (2012) showed that cylindrical Inconel target with radius = 3*beam sigma and 89 mm length provides maximum number of pions with "magic" momentum in 40 mm mrad emittance. Cory Yoshikawa got best results for horizontal slab. In this study we compare following targets:

- Plane target –horizontal slab: vertical size 0.06 cm, horizontal size-2 cm, length along beam -10.5 cm. Beam sigma=0.15 mm
- Cylindrical target – length 8.869 cm, radius 0.045 cm. Beam sigma=0.15 mm
- Inconel slab (2x63 and 2x98mm) coated by 3mm of graphite. Beam sigma=0.15 mm
- Inconel cylinder ( length from 20 to 125mm) and 1 mm radius coated by 5mm of graphite. Beam sigma 0.15-0.33 mm.

# Where are useful pion produced
# (cylindrical target - 89 mm length, 0.45 mm radius, 0.15 mm sigma)?

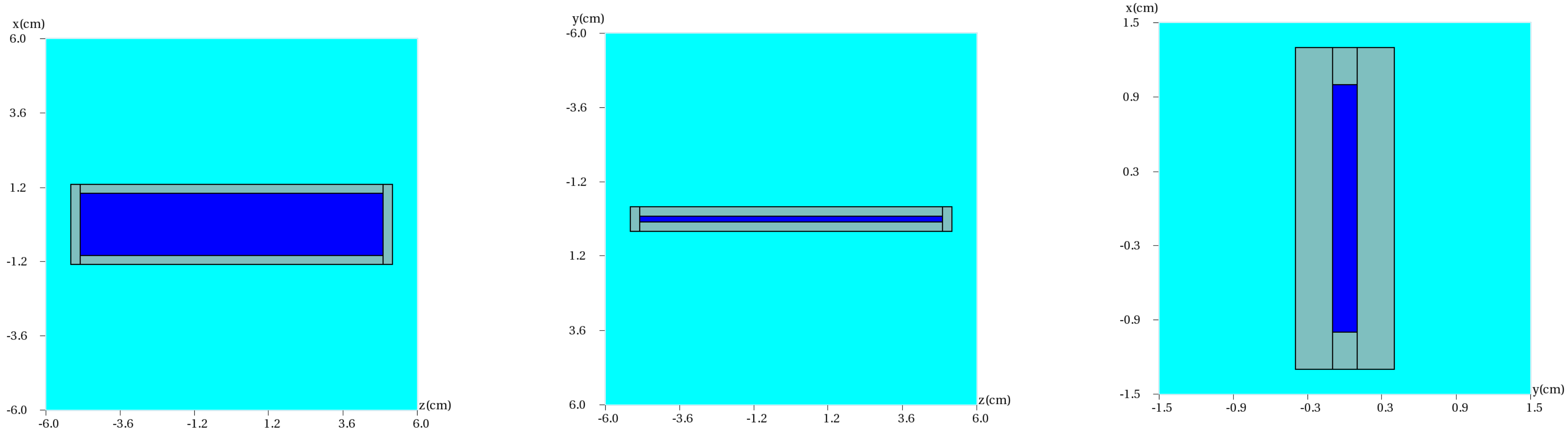



95% on target+5% from lens



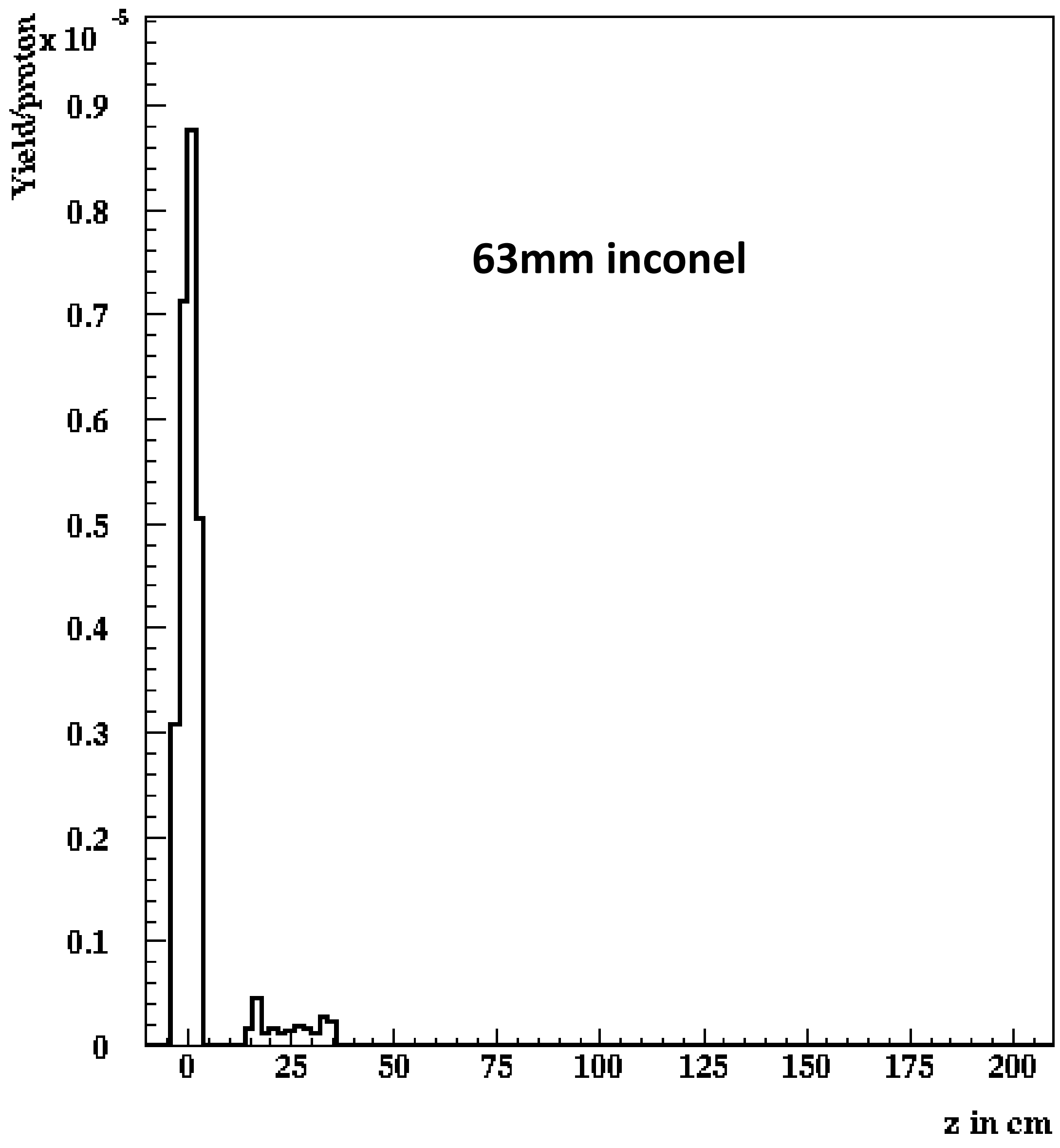

84% side+16% DS end of target

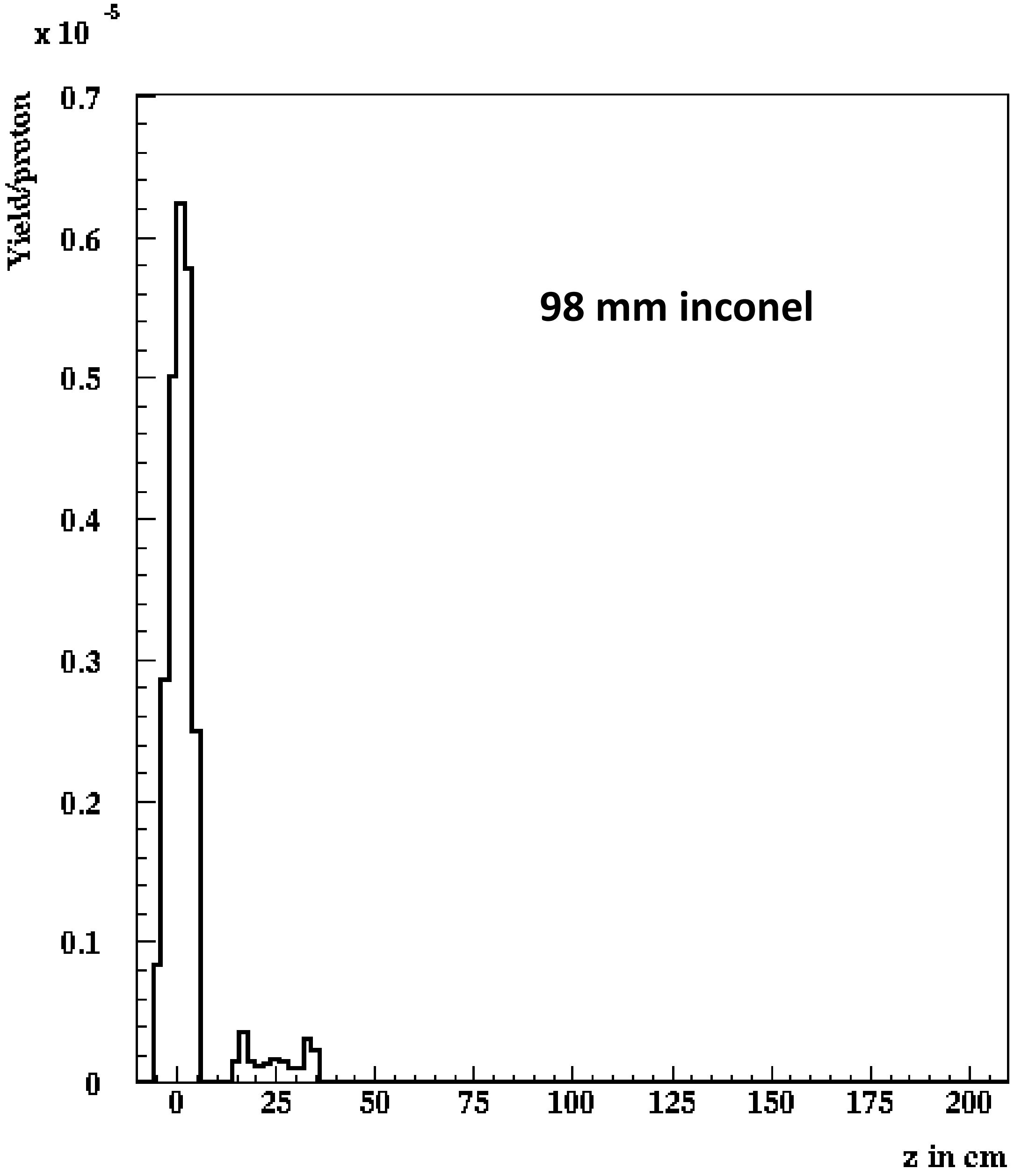
# Inconel slab (2x63 and 2x98mm) coated by 3mm of graphite



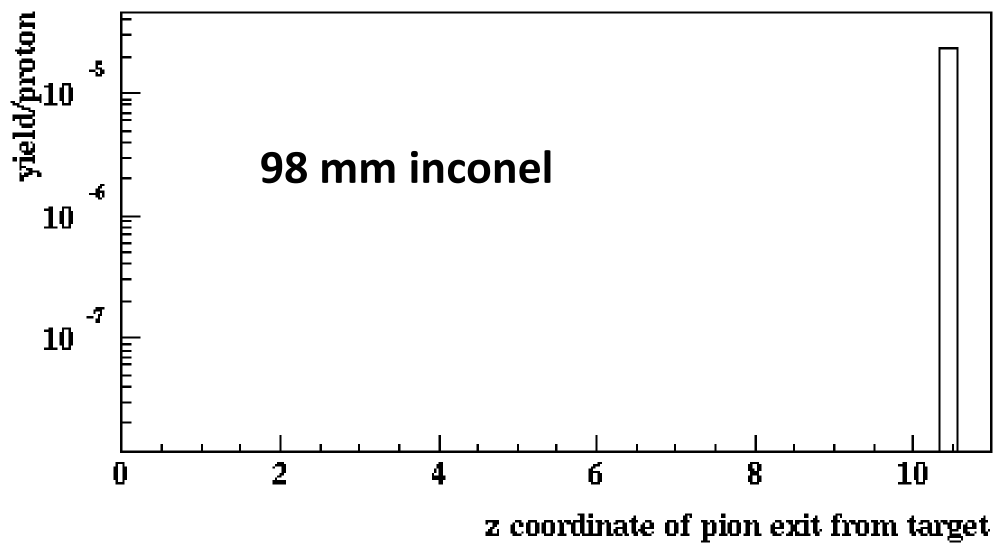

Graphite: density - 2.26 g/cm$^3$ , proton interaction length – 35.2 cm, pion interaction length – 45.4 cm
Inconel: density - 8.43 g/cm$^3$ , proton interaction length – 14.7 cm, pion interaction length – 17.5cm
Beryllium: density – 1.85 g/cm$^3$ , proton interaction length – 38.6 cm, pion interaction length – 50.6cm

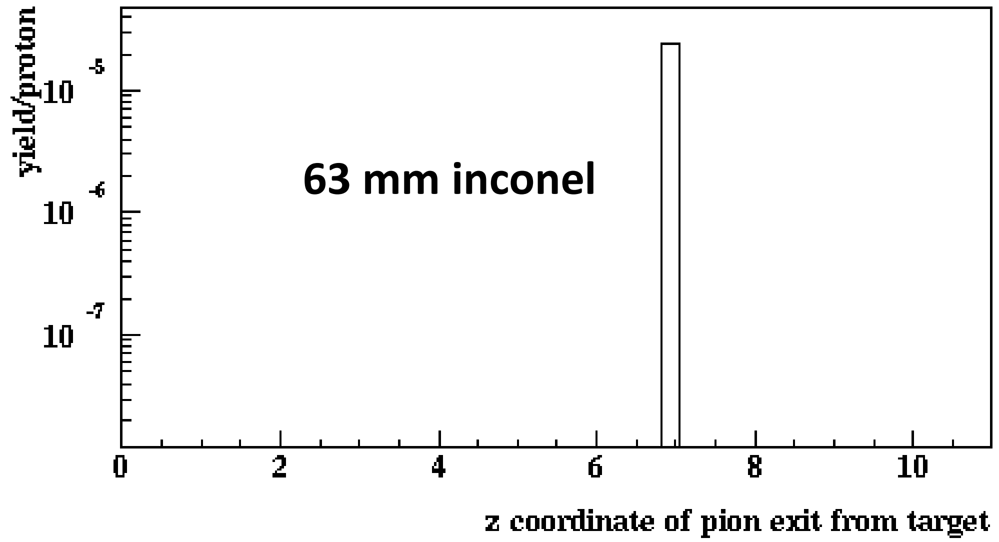
# Where useful pions are produced? 92% target + 8% lens

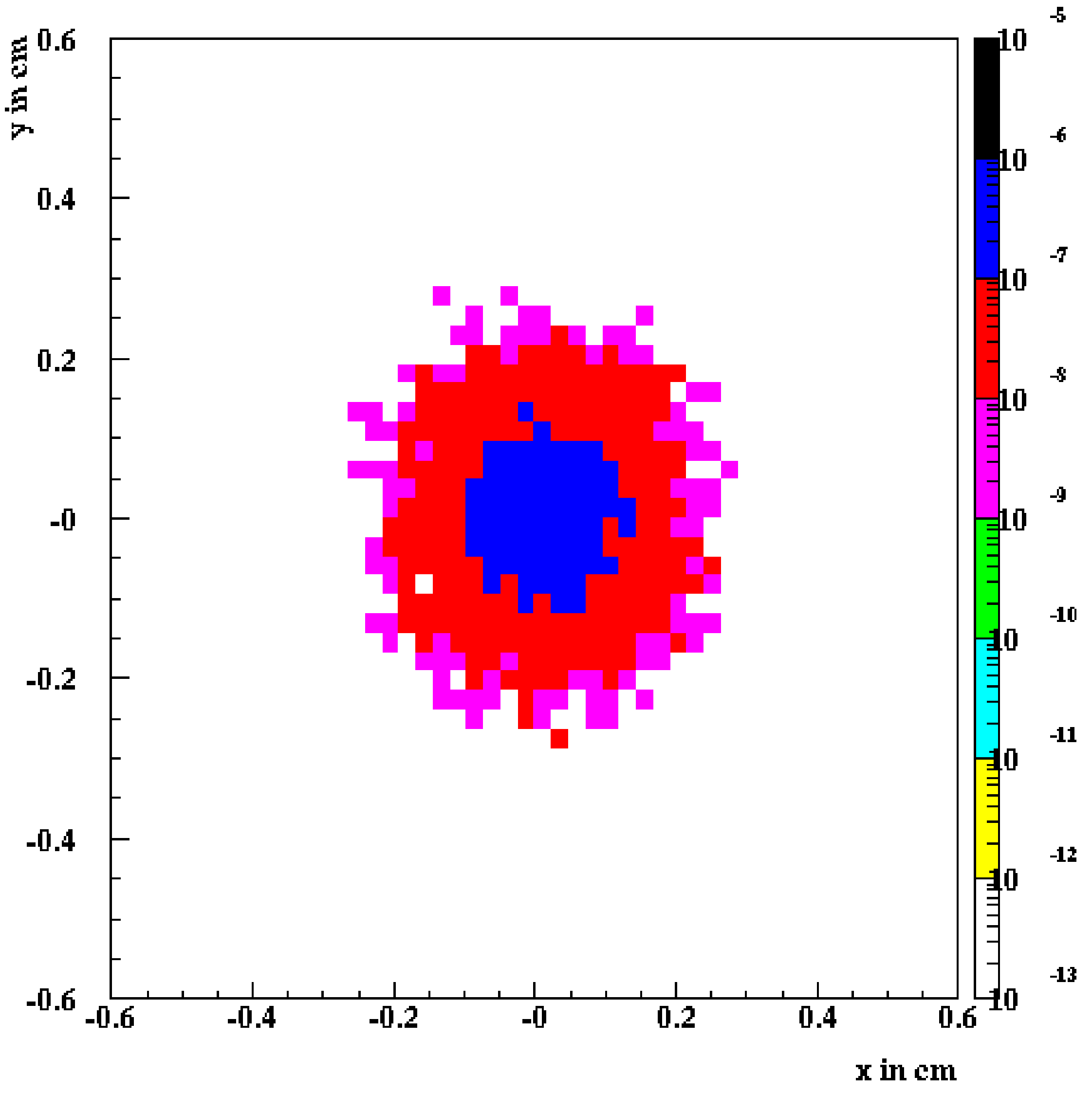


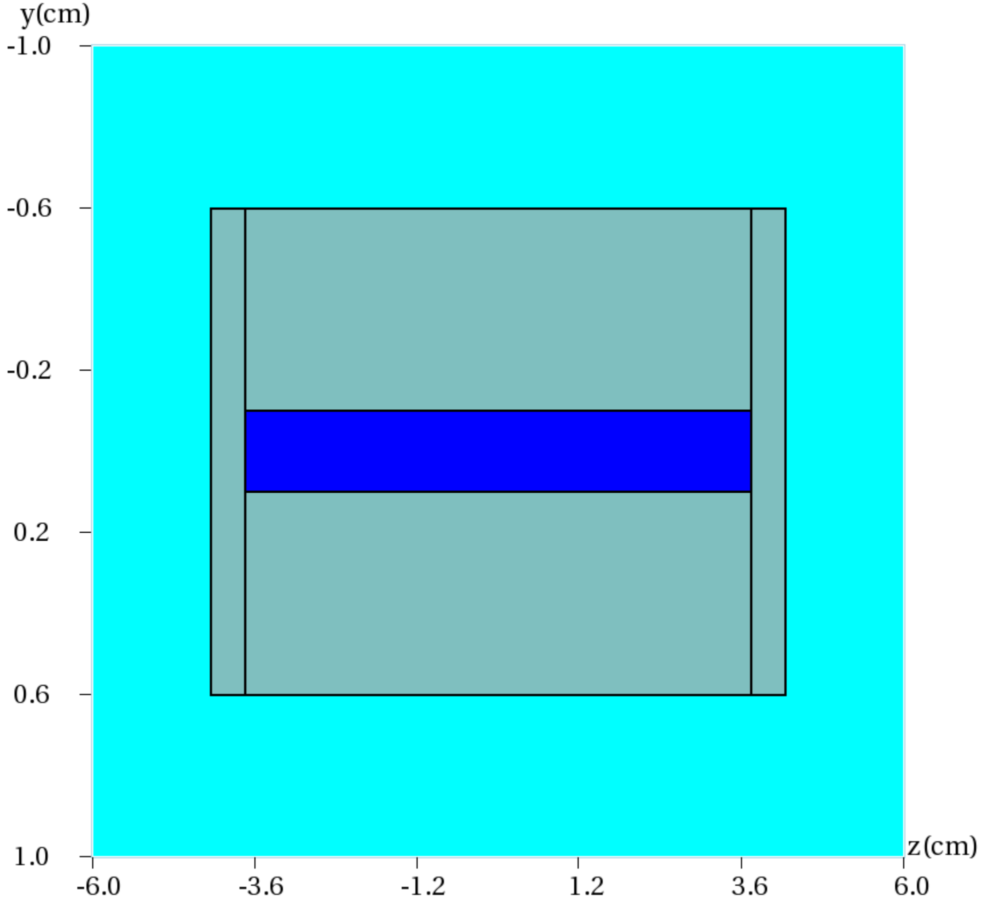
# Where useful pions exit target?

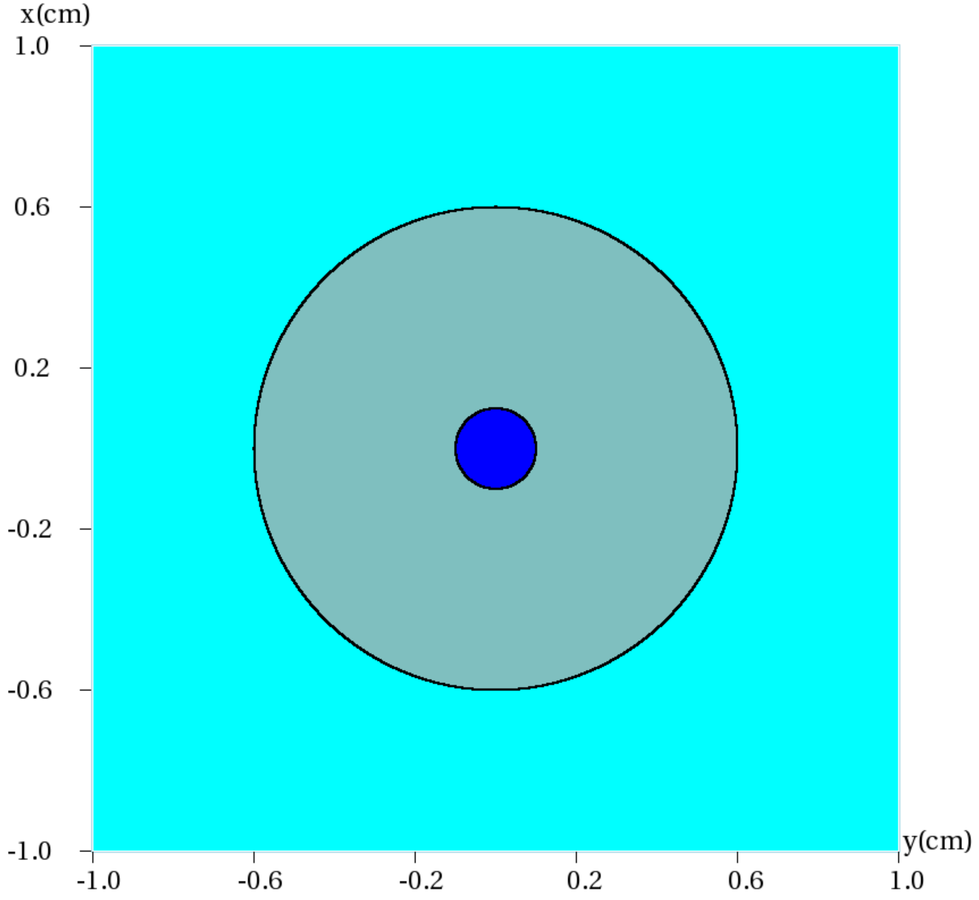


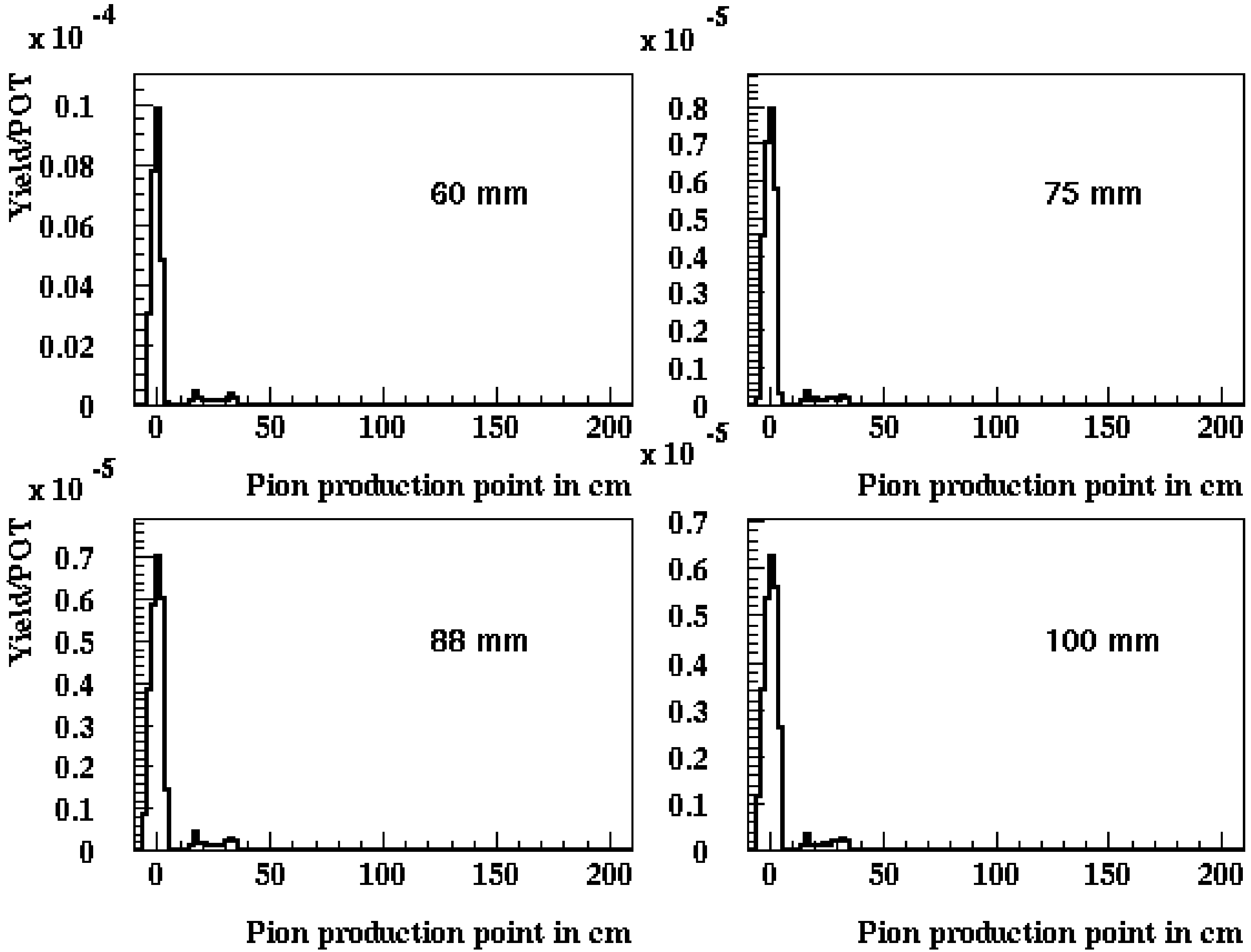



# Inconel cylinder ( length from 20 to 125mm) and 1 mm radius coated by 5mm of graphite

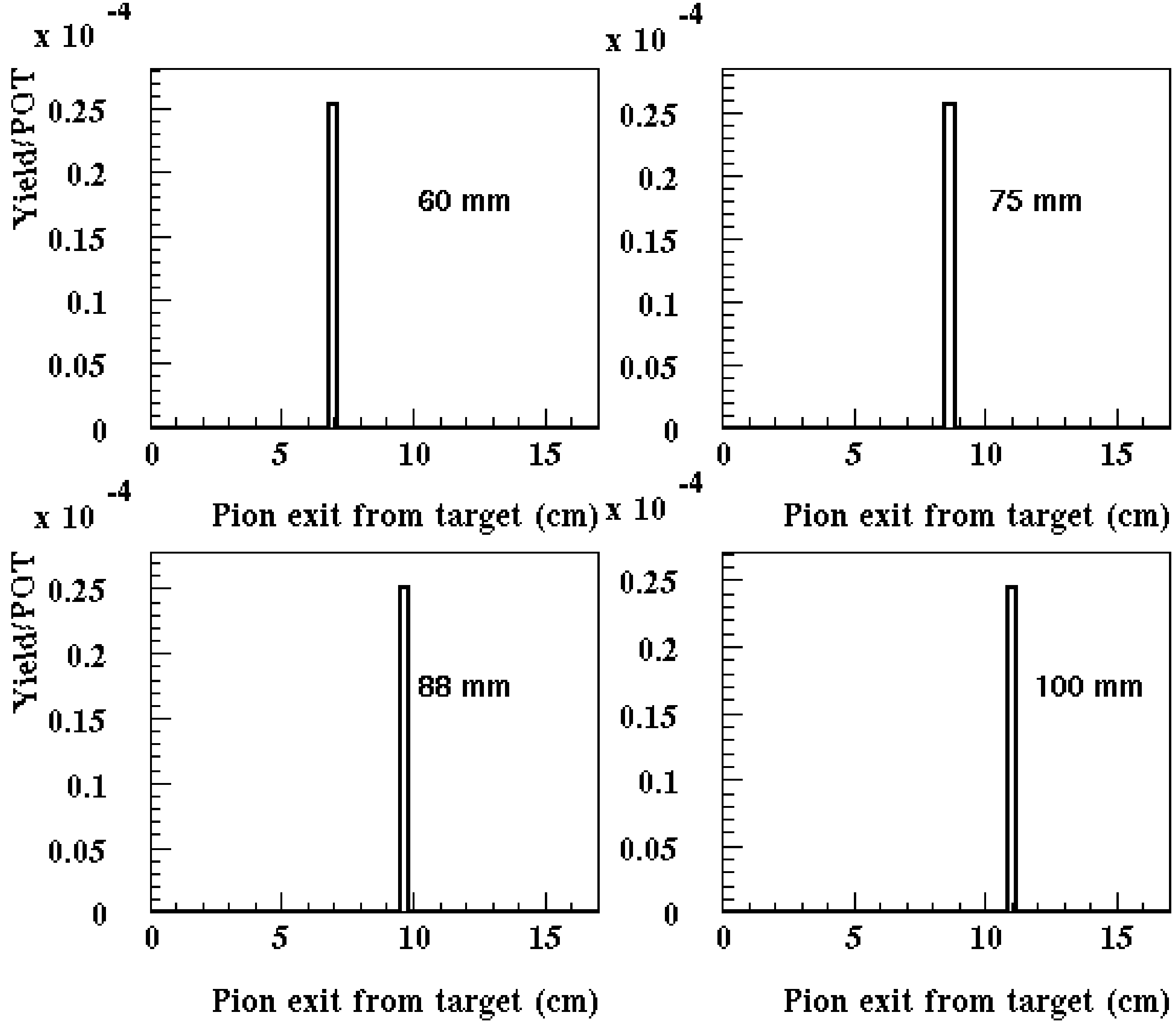


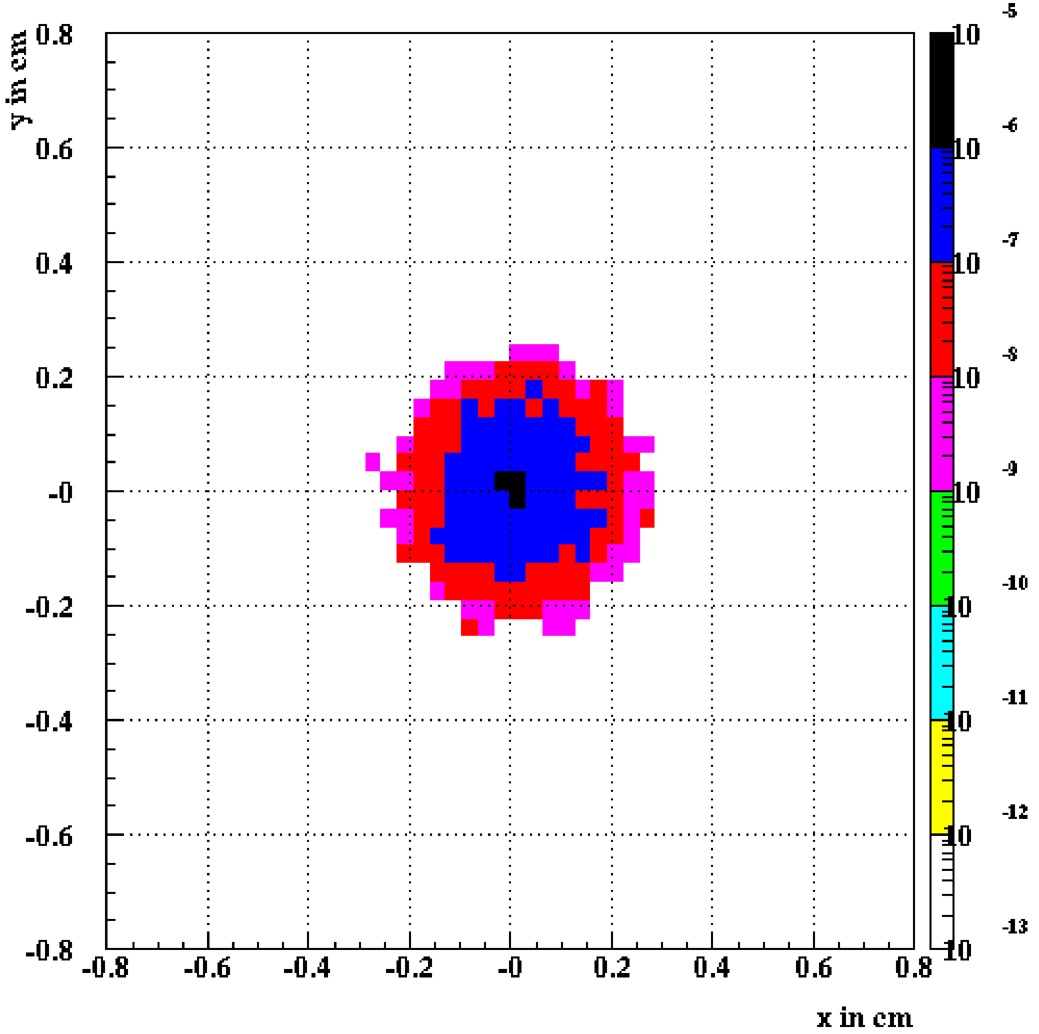



# Where useful pions are produced? 93% target + 7% lens

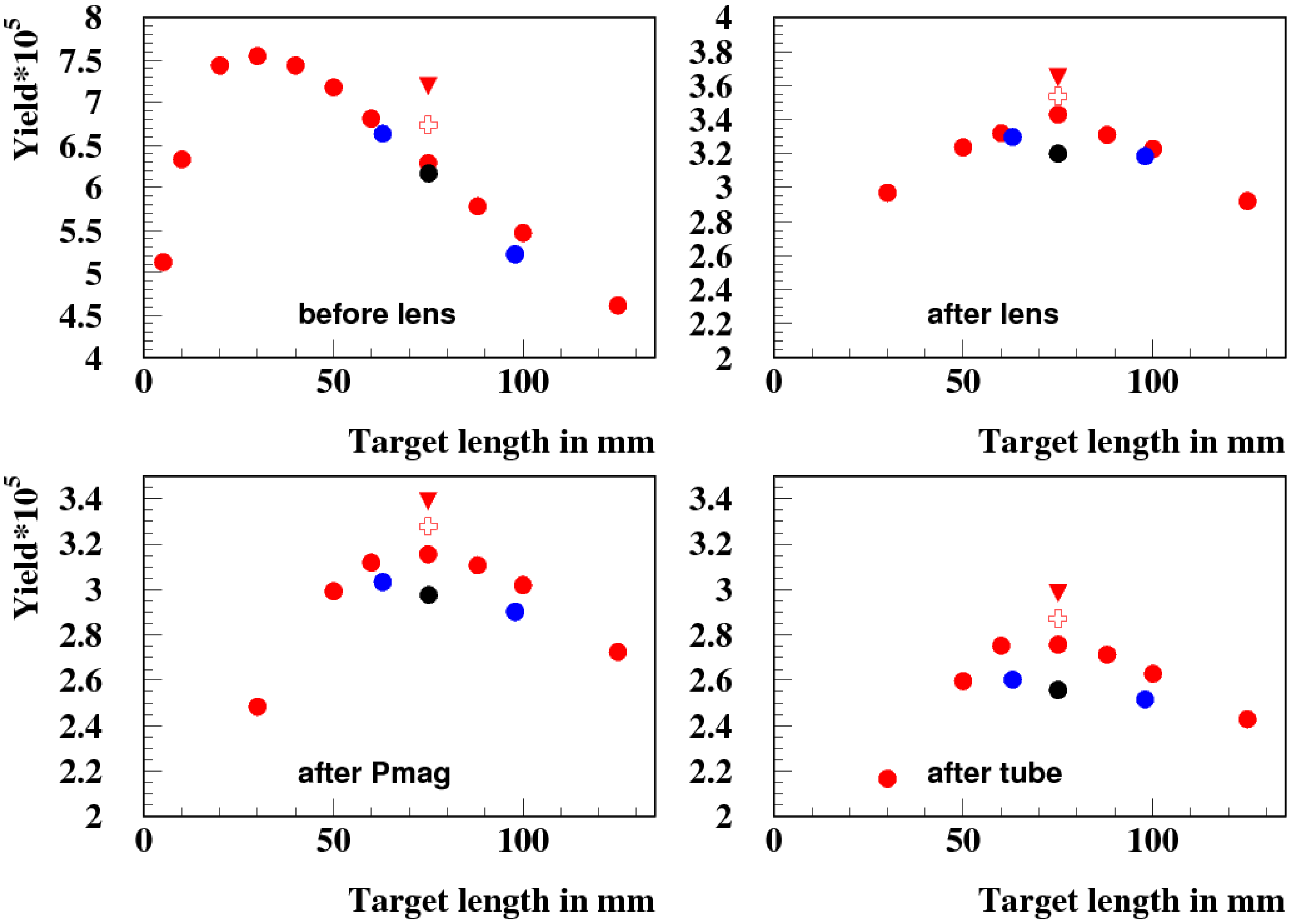


# Where useful pions exit target?



# Pion yield at different planes as function of target length



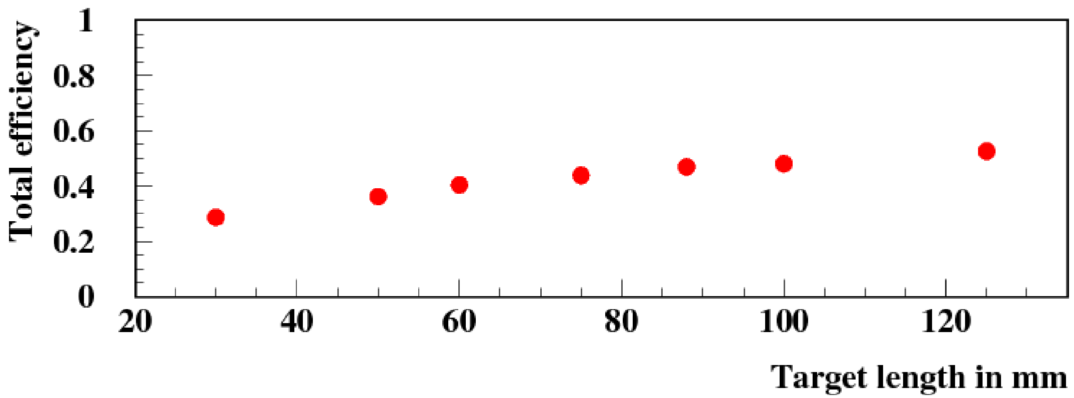

Red symbols:
Cylinders with
1mm radius - full circles
0.75mm radius - cross
0.5mm radius - triangle

Blue symbols – slabs

Black symbols – "pbar" disk target

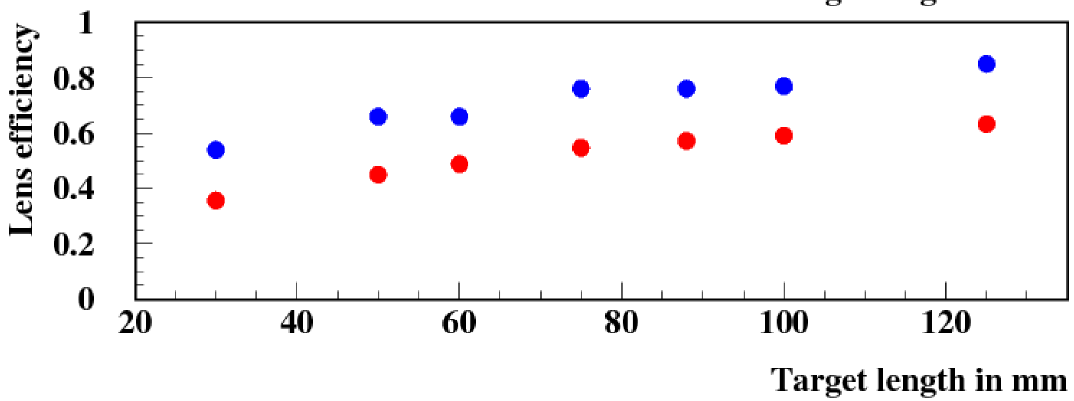
Target center is in "pbar focus"

# Where are "useful" pions lost?



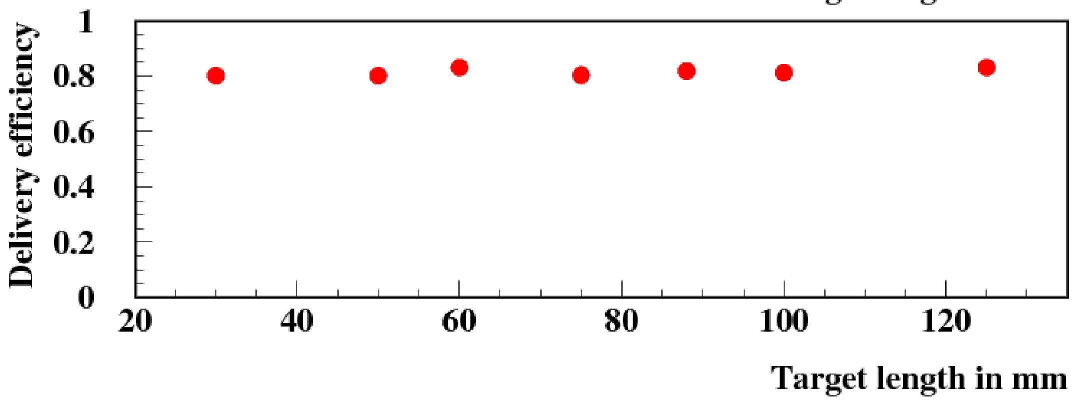

Yield = number of "useful" pion in 40 mm mrad acceptance

Red circles - ratio of yield after tube to yield after target




Blue circles- part of target yield going through whole lens

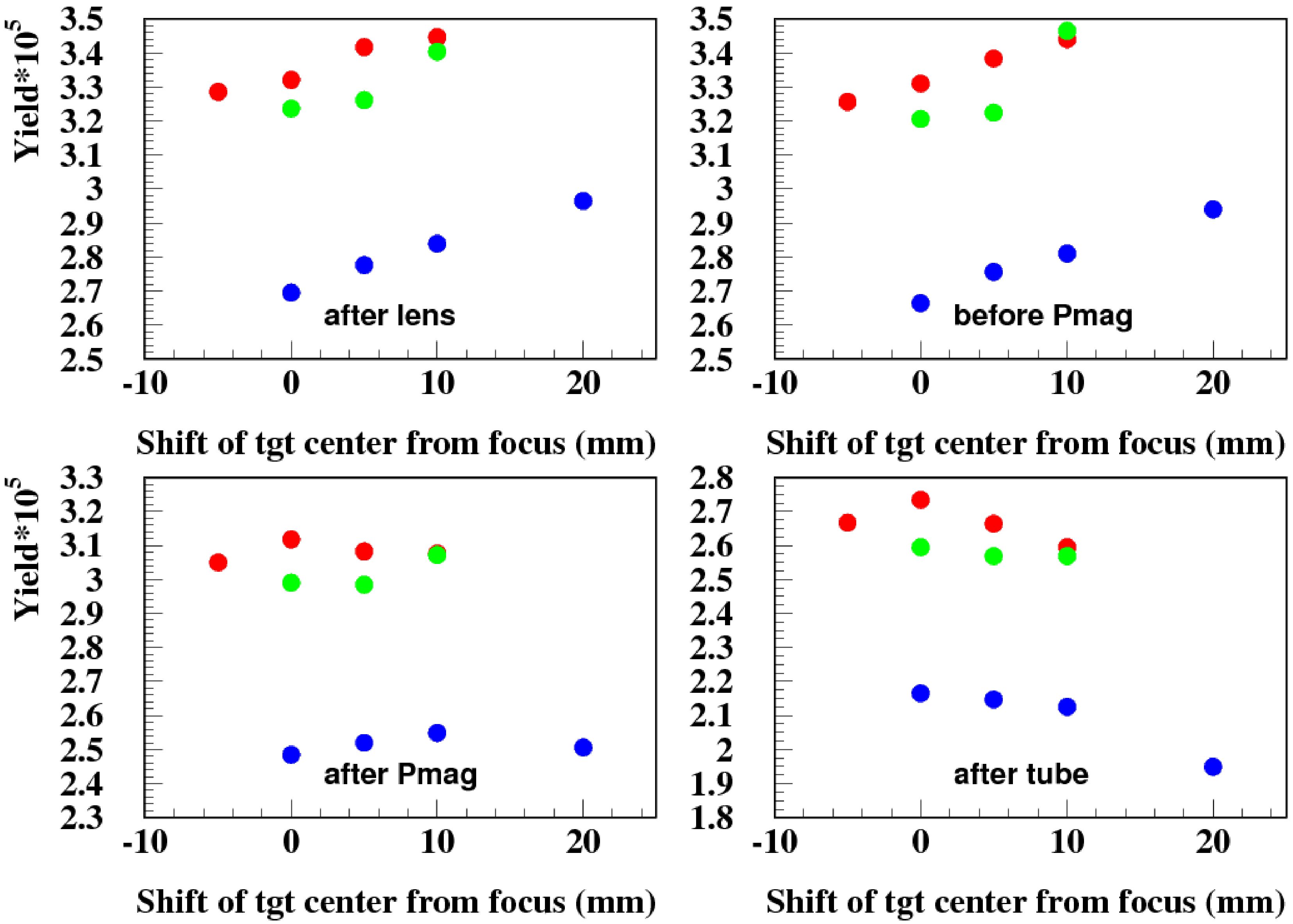
Red circles - ratio of yield after lens to yield after target




Red circles - ratio of yield after tube to yield after lens.

Maximal delivery efficiency is 94%

# Could moving target closer to lens increase yield?



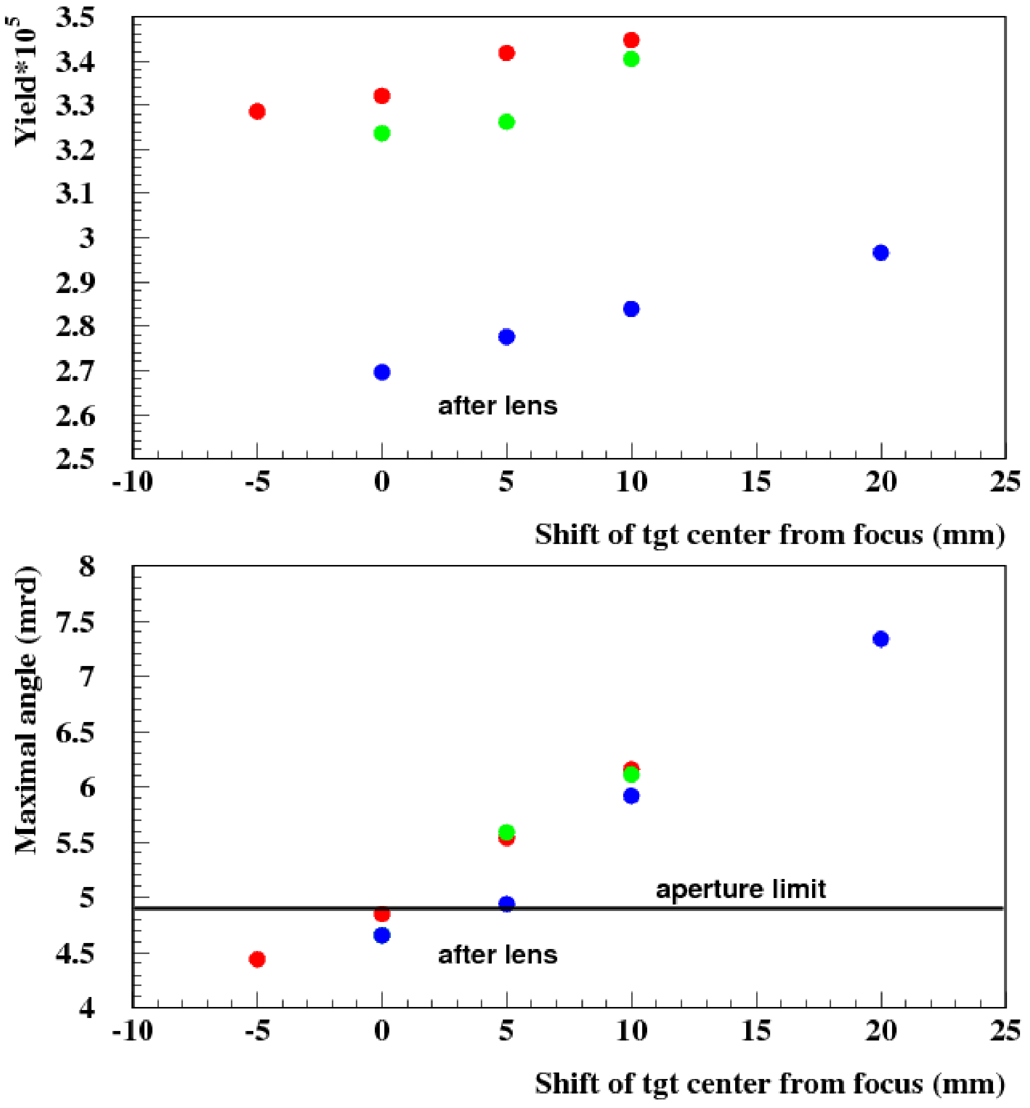

For 30,50 and 60 mm targets pion radiuses are smaller than limiting apertures. Is it possible to increase yield moving this target closer to lens?

Red circles – 60mm

Green circle – 50 mm

Blue circles – 30 mm

# Could moving target closer to lens increase yield-II




Red circles – 60mm

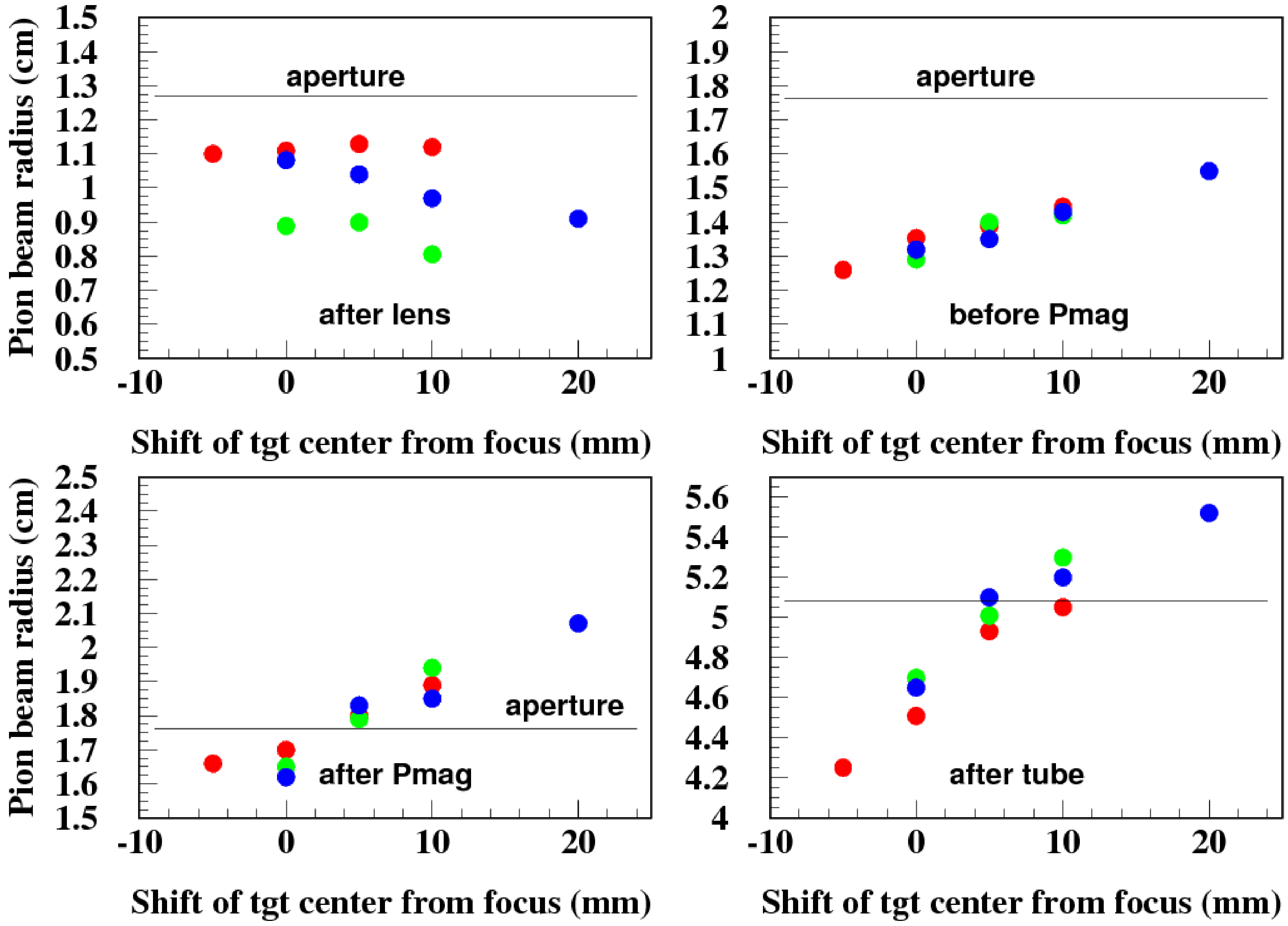
Green circle – 50 mm

Blue circles – 30 mm

Target movement towards lens increases yield after lens because more pions go through magnetic field. But, angular distribution of this pions become wider because more pion go though small magnetic field.

Maximal angle should be smaller 4.9 mrad to avoid losses

# Could moving target closer to lens increase yield-III




Moving target closer to lens increases yield just before Pmag. Pion beam radius becomes larger Pmag aperture even for 5mm shift.

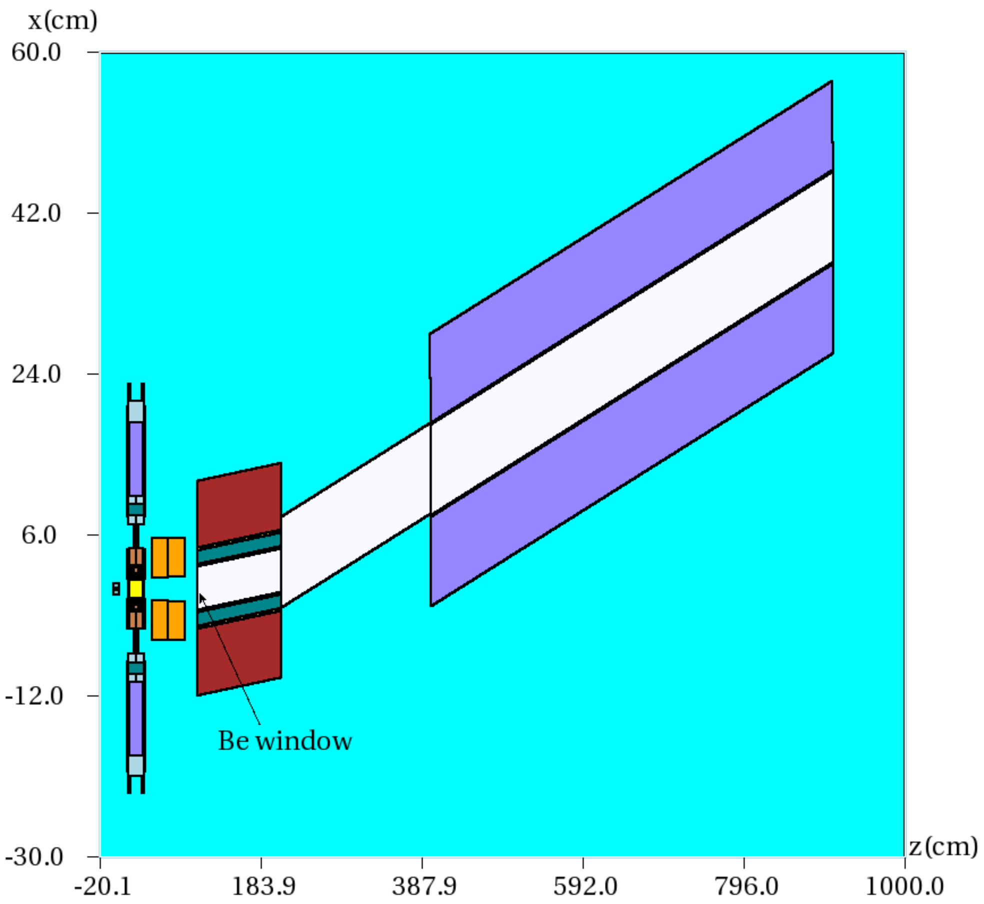
Red circles – 60mm

Green circle – 50 mm

Blue circles – 30 mm

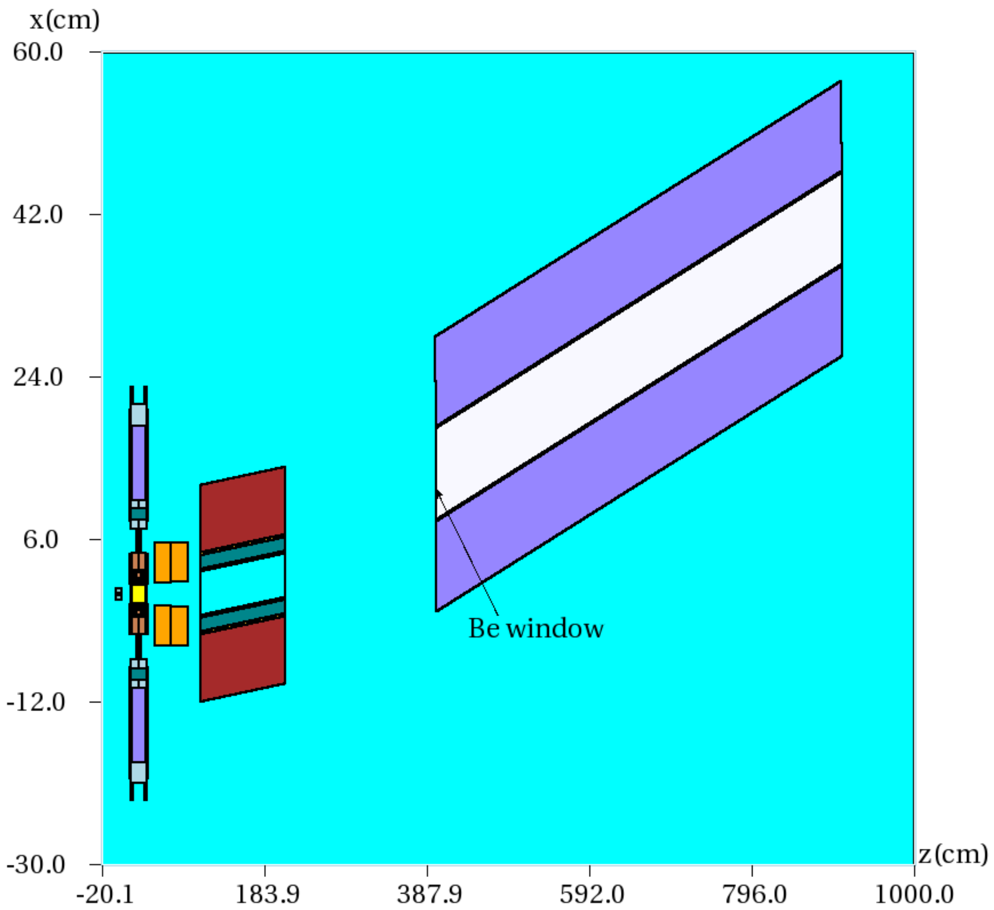
# 0.2mm Be windows instead Ti windows and more vacuum

Yield rises 7.4%




Setup 1 –Be window radius ~14 mm

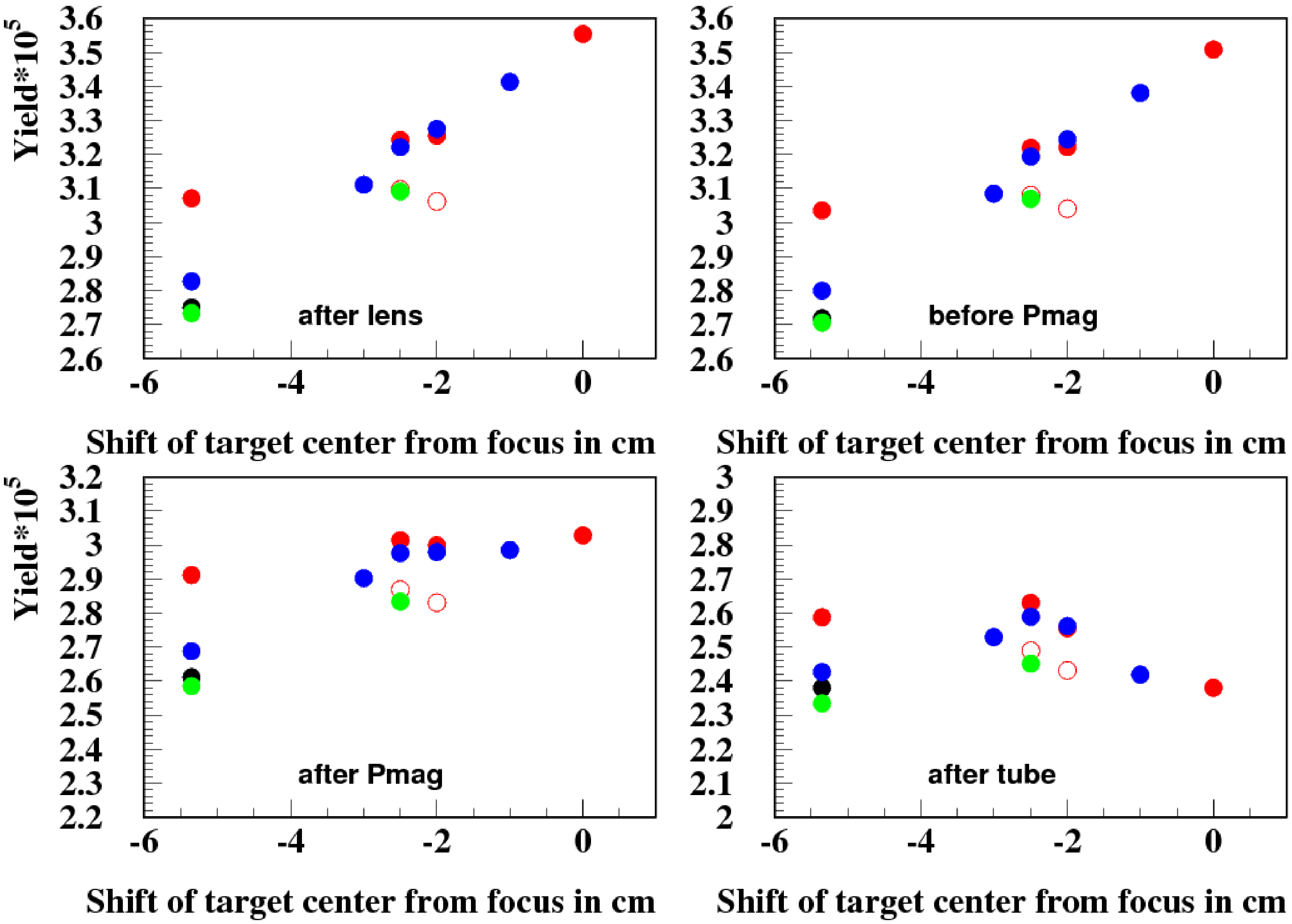
Yield rises 3%




Setup 2 – Be windows radius ~24 mm

Scattering angle on 0.2 mm Beryllium window is about 2 times smaller than for current titanium window

# Yield from 1 cm radius coated cylindrical targets. 235 Tesla/m gradient.




Full red circle -75mm length, g-2 beam (0.2x0.23 $mm^2$)

Full blue circle - 60 mm length,g-2 beam

Full green circle – 50 mm length, g-2 beam

Full black – g-2 disk target, g-2 beam

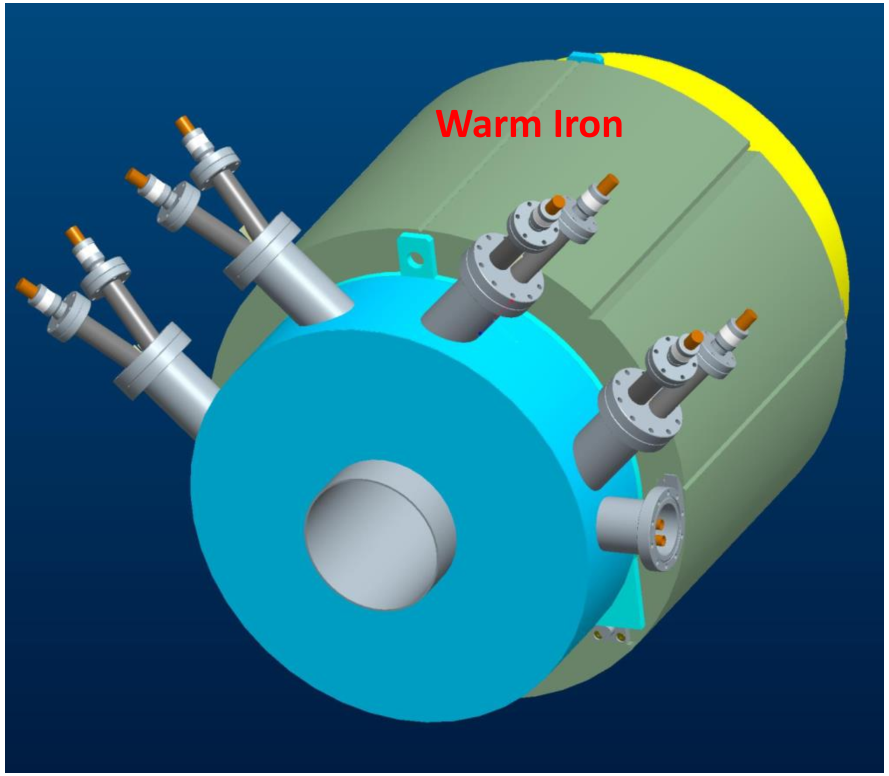
Open red circles – 75 mm length, beam sigma = 0.33 mm

# Best results for different gradients, beams and targets

| target | cover | beam | gradient | chord/length | radius | yield | beam radius |
|---|---|---|---|---|---|---|---|
| disk | no | $0.15x0.15mm^2$ | 265 T/m | 75 mm | NA | $2.59\ 10^{-5}$ | 4.88 cm |
| disk | no | $0.20x0.23mm^2$ | 235 T/m | 62 mm | NA | $2.38\ 10^{-5}$ | 3.25 cm |
| cylinder | no | $0.15x0.15mm^2$ | 265 T/m | 89 mm | 0.45 mm | $3.16\ 10^{-5}$ | 4.85 cm |
| cylinder | 5cm C | $0.15x0.15mm^2$ | 265 T/m | 75 mm | 1.00 mm | $2.76\ 10^{-5}$ | 4.30 cm |
| cylinder | 5cm C | $0.15x0.15mm^2$ | 265 T/m | 75 mm | 0.75 mm | $2.87\ 10^{-5}$ | 4.55 cm |
| cylinder | 5cm C | $0.15x0.15mm^2$ | 265 T/m | 75 mm | 0.50 mm | $2.99\ 10^{-5}$ | 4.31 cm |
| cylinder | 5cm C | $0.15x0.15mm^2$ | 294 T/m | 60 mm | 1.00 mm | $3.02\ 10^{-5}$ | 4.98 cm |
| cylinder | 5cm C | $0.20x0.23mm^2$ | 235 T/m | 75 mm | 1.00 mm | $2.63\ 10^{-5}$ | 4.89 cm |

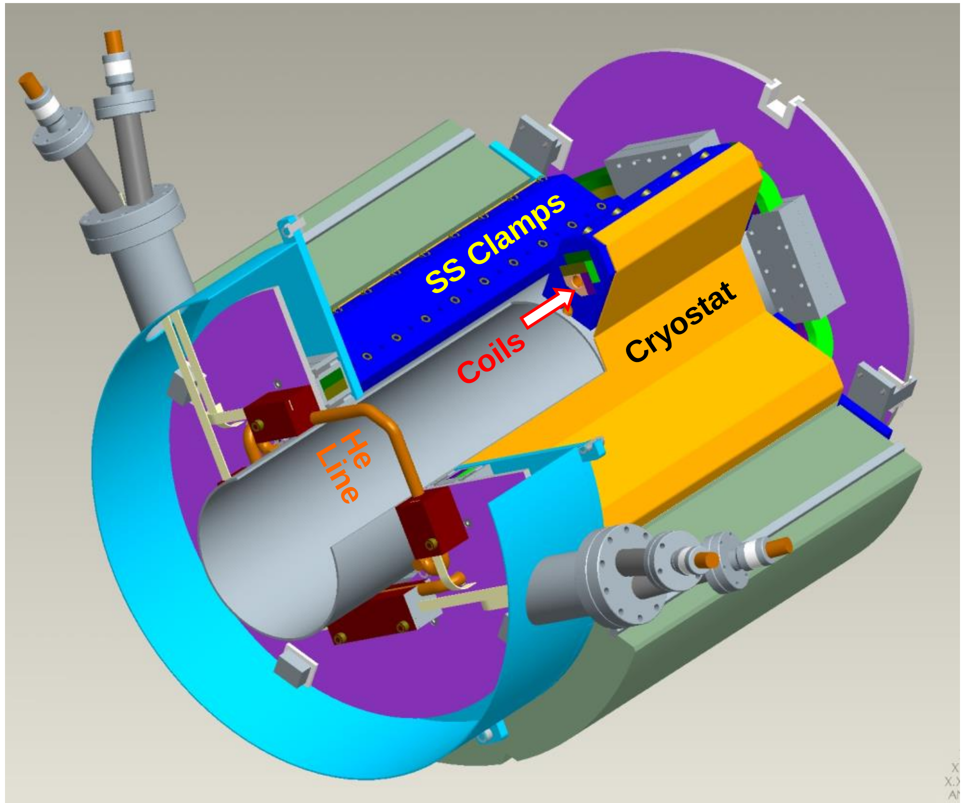
More "useful" pion could be produced from cylindrical target then from disk. Pion yield could be increased by reduction of Inconel target radius and/or rising magnetic field gradient in lithium lens.

# FRIB Quadrupole: add to AP0 after lens?! ( ~20% rise of gradient)
# Head load ~10 kW/m, Fluence 2.5 $10^{15}$ n/cm$^2$ per year, ~10 MGy/year
# Length – 60 cm, pole radius - 11 cm, design gradient – 15 T/m




**R&D Magnet in cryo-stat**

(allows independent testing of four HTS coils)




**Cut-away isometric view of the assembled magnet**

(compact cryo design allowed larger space for coils and reduction in pole radius)

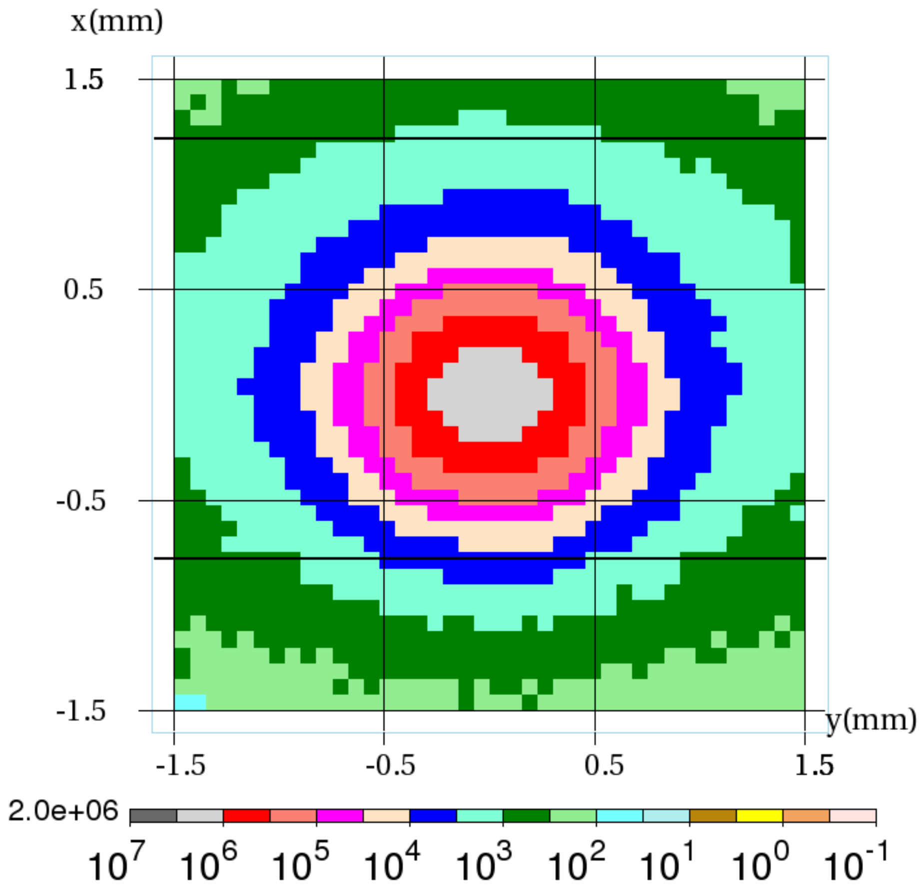
# Conclusion

- Yield from current disk target could be increased by increasing lens magnetic field gradient or/and decreasing beam size.
- More “useful” pion could be obtained by using cylindrical Inconel target coated by graphite. For current setup, about 10% rise could be reached with 1mm radius, 75 mm length coated Inconel target.
- Further improvement could be reached by decreasing Inconel radius/ beam size and increase of magnetic field.
- Lithium lens with current field does not reduce angular spread enough to take most of produced “useful” pion. Replacement of long collimator after lens by short one and FRIB like quadrupole could provide needed focusing.

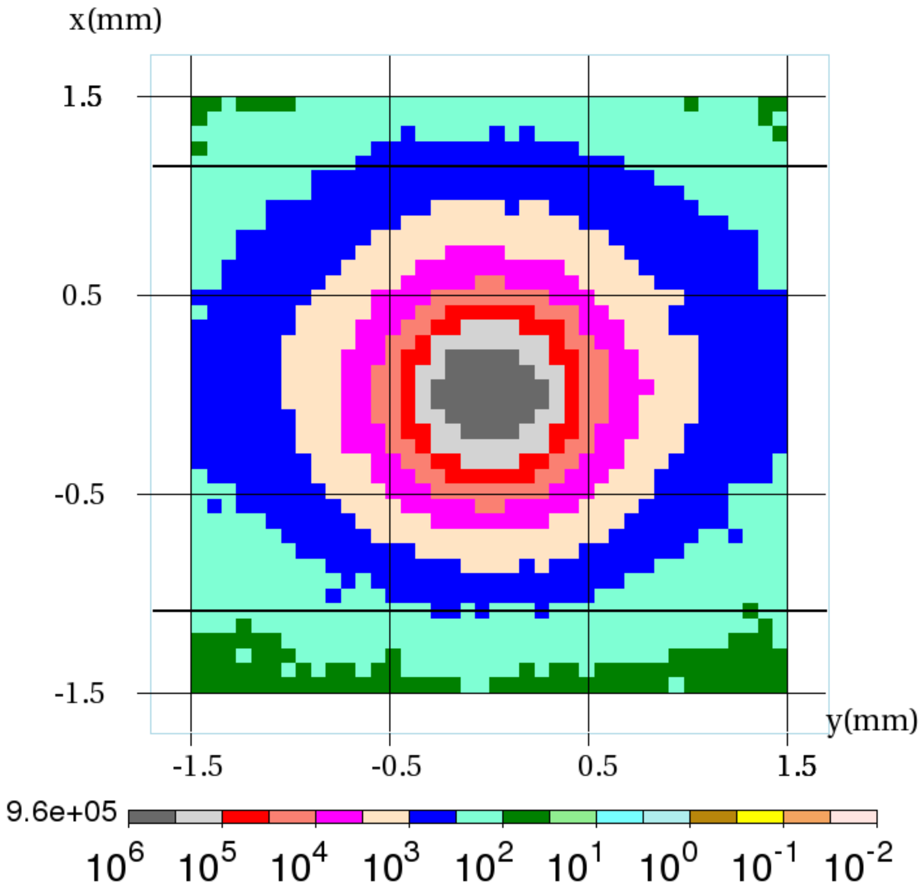
# Parameter List

| **Parameter** | **Value** |
|---|---|
| Pole Radius | 110 mm |
| Design Gradient | 15 T/m |
| Magnetic Length | 600 mm |
| Coil Overall Length | 680 mm |
| Yoke Length | ~550 mm |
| Yoke Outer Diameter | 720 mm |
| Overall Magnet Length(incl. cryo) | ~880 mm |
| Number of Layers | 2 per coil |
| Coil Width (for each layer) | 12.5 mm |
| Coil Height (small, large) | 26 mm, 39 mm |
| Number of Turns (nominal) | 110, 165 |
| Conductor (2G) width, SuperPower | 12.1 mm ± 0.1 mm |
| Conductor thickness, SuperPower | 0.1 mm ± 0.015 mm |
| Cu stabilizer thickness SuperPower | ~0.04 mm |
| Conductor (2G) width, ASC | 12.1 mm ± 0.2 mm |
| Conductor (2G) thickness, ASC | 0.28 mm ± 0.02 mm |
| Cu stabilizer thickness ASC | ~0.1 mm |
| Stainless Steel Insulation Size | 12.4 mm X 0.025 mm |
| Field parallel @design (maximum) | ~1.9 T |
| Field perpendicular @design (max) | ~1.6 T |
| Minimum $I_c$ @2T, 40 K (spec) | 400 A (in any direction) |
| Minimum $I_c$ @2T, 50 K (expected) | 280 A (in any direction) |
| Nominal Operating Current | ~280 A |
| Stored Energy | 37 kJ |
| Inductance | ~1 Henry |
| Operating Temperature | 50 K (nominal) |
| Design Heat Load on HTS coils | 5 kW/m$^3$ |

# Energy deposition density (mW/cm$^3$) in carbon cover of disk target.
# g-2 / pbar ~2




8 GeV, 0.2x0.23 mm$^2$ beam, 6.2 cm chord, 1.142 $10^{13}$ POT/s




120 GeV, 0.15x0.15 mm$^2$ beam, 7.5 cm chord, 3.4091 $10^{12}$ POT/s