Magnet installation and alignment for the Fuji Test Beam Line at KEKB

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Introduction to Fuji Test Beam Line

- Need for a new GeV-class beam line after the KEK 12 GeV Proton Synchrotron shutdown in March 2006, at least until J-PARC is completed in 2009.
  - A decision to build a new beam line which uses the electrons circulating in the KEKB ring was made.

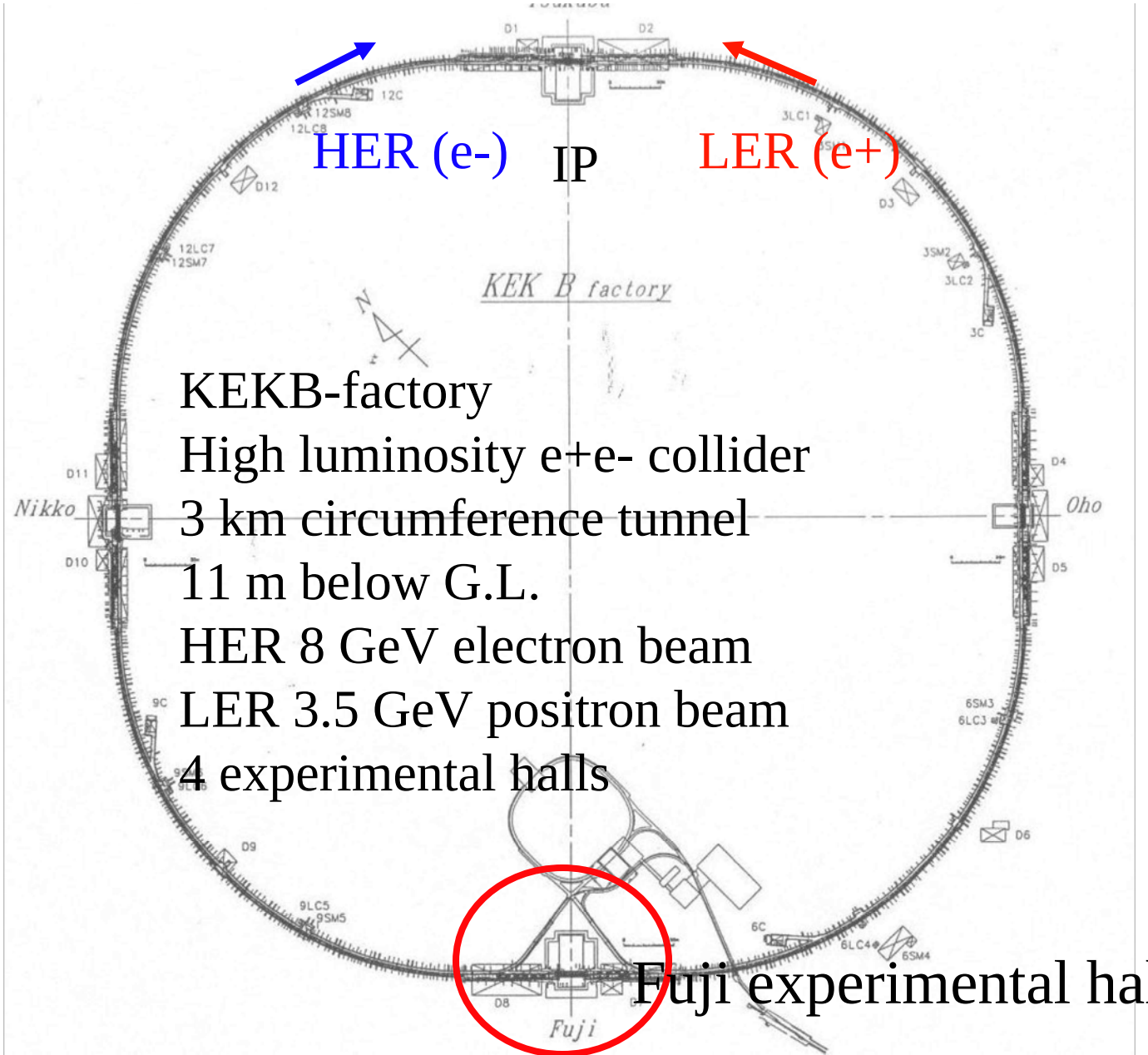
- How to make a GeV beam using the existing KEKB ring?
  - Bremsstrahlung photons generated by the interactions between the electrons and residual gas in the vacuum pipe are brought to a tungsten target to generate e+e- pairs.
  - The electrons are then guided out of the KEKB tunnel to the experimental hall (called Fuji) by a new beam line.
  - The generated electrons have a sharp forward peak, which is required for the test beam to be used for various R&D tests at the beam line.

Introduction to Fuji Test Beam Line

Beam line design

- As cheap as possible
  - Use retired magnets, power supplies and spare magnets in order to save money.
- Due to the limited space available for extracting the beam from the KEKB tunnel, the beam line was designed to have *a roller-coaster structure*, with all magnets rotated in all three rotational angles, at angles of up to 40 degrees.

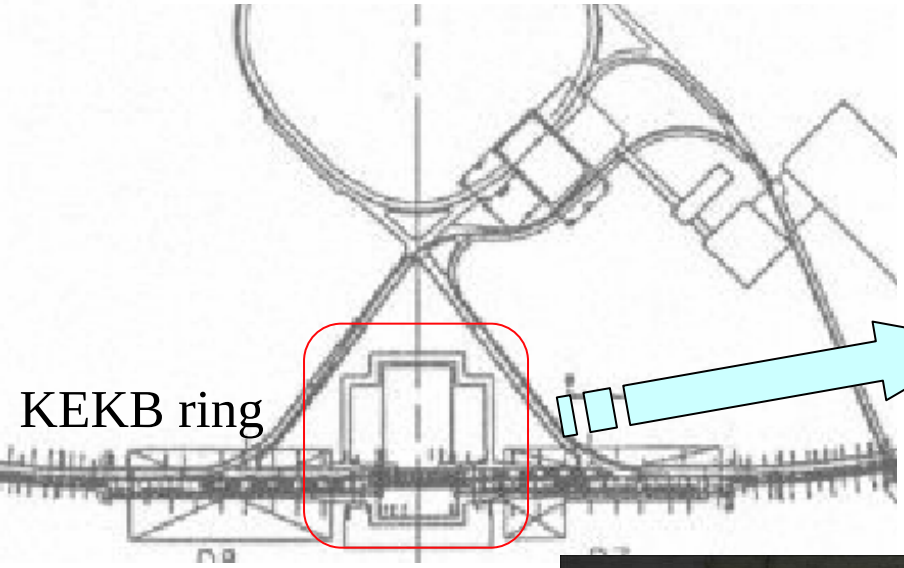
Introduction to Fuji Test Beam Line

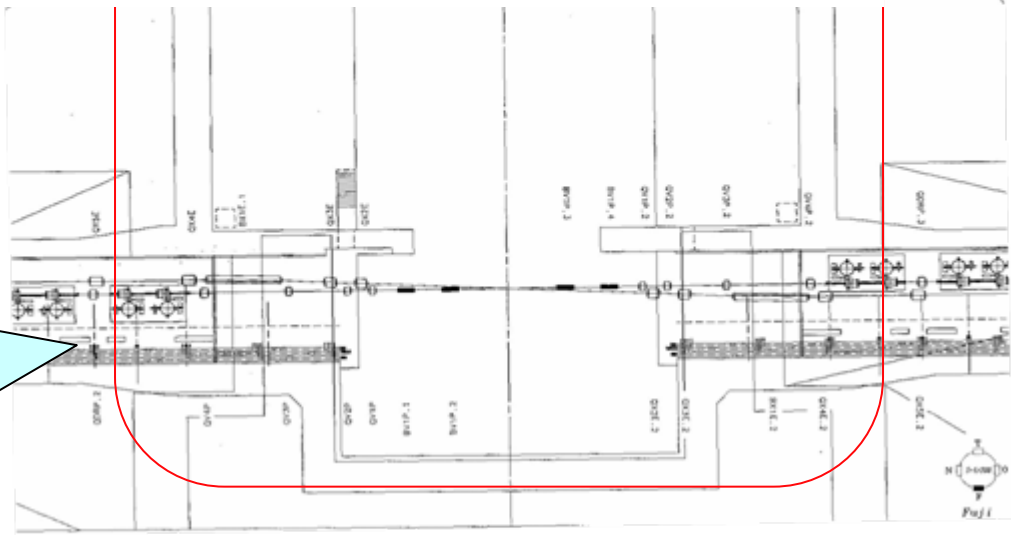


KEKB-factory
High luminosity e+e- collider
3 km circumference tunnel
11 m below G.L.
HER 8 GeV electron beam
LER 3.5 GeV positron beam
4 experimental halls

Fuji experimental hall

Introduction to Fuji Test Beam Line



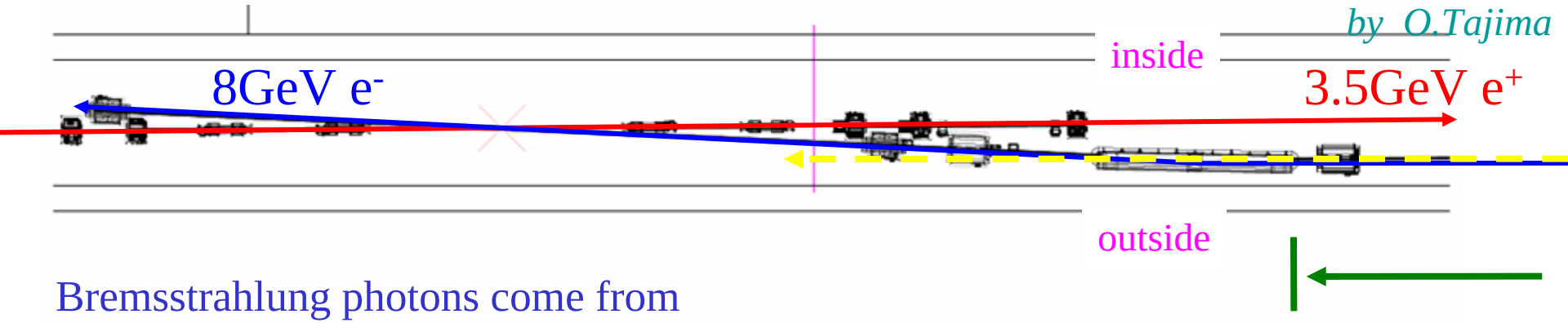


Exp. Hall (Fuji)

Concrete shield
40 tons each
2 m in width

Introduction to Fuji Test Beam Line

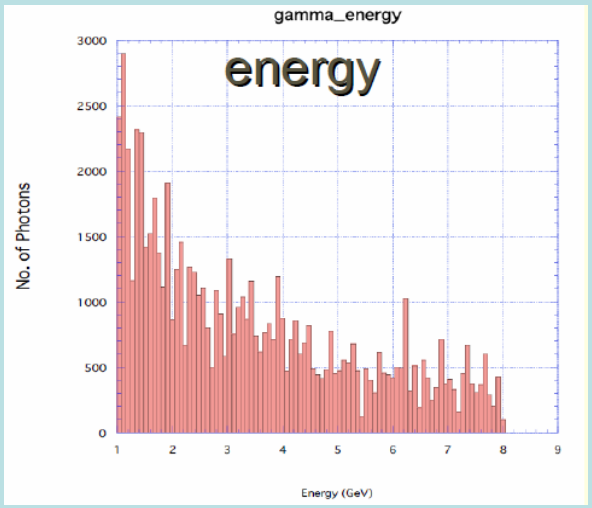
by O.Tajima

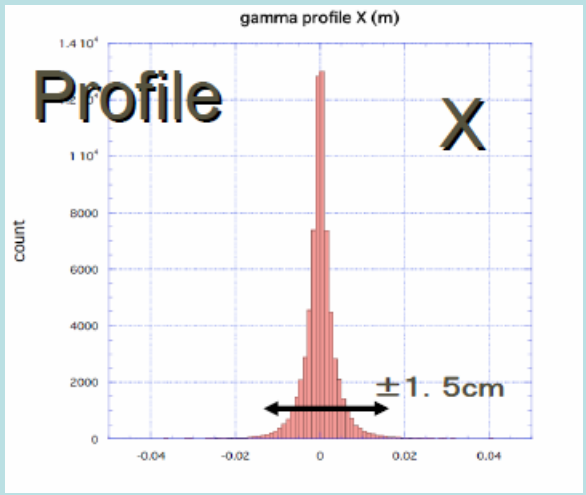


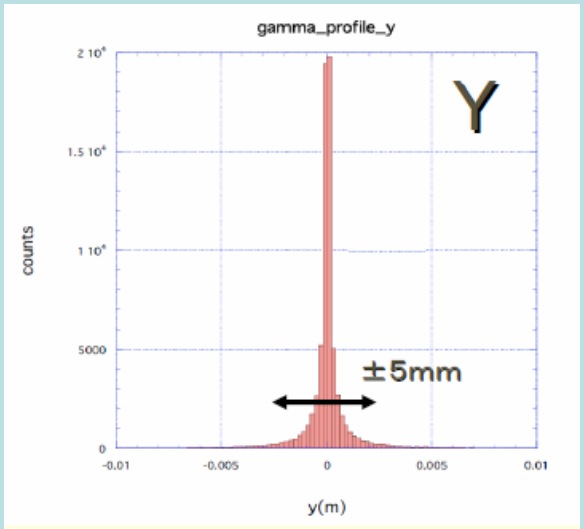
Bremsstrahlung photons come from
e^- beam vs. residual-gas scattering.
1.6×10^5 photons/sec (3×10^{-8}Pa is assumed)

Straight section
(100m)

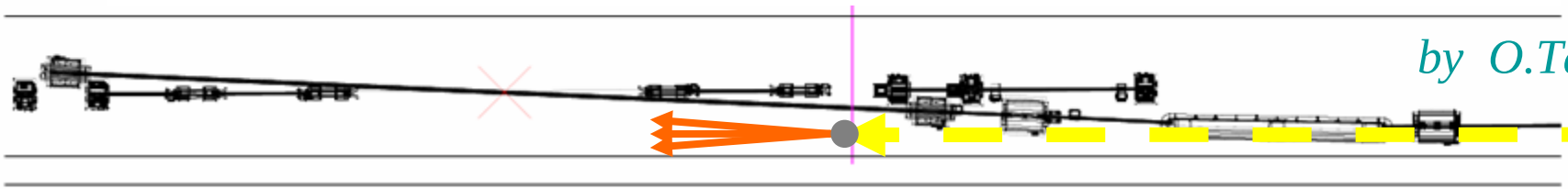
"Turtle" simulation for Bremsstrahlung photons *by T. Higuchi*







Introduction to Fuji Test Beam Line

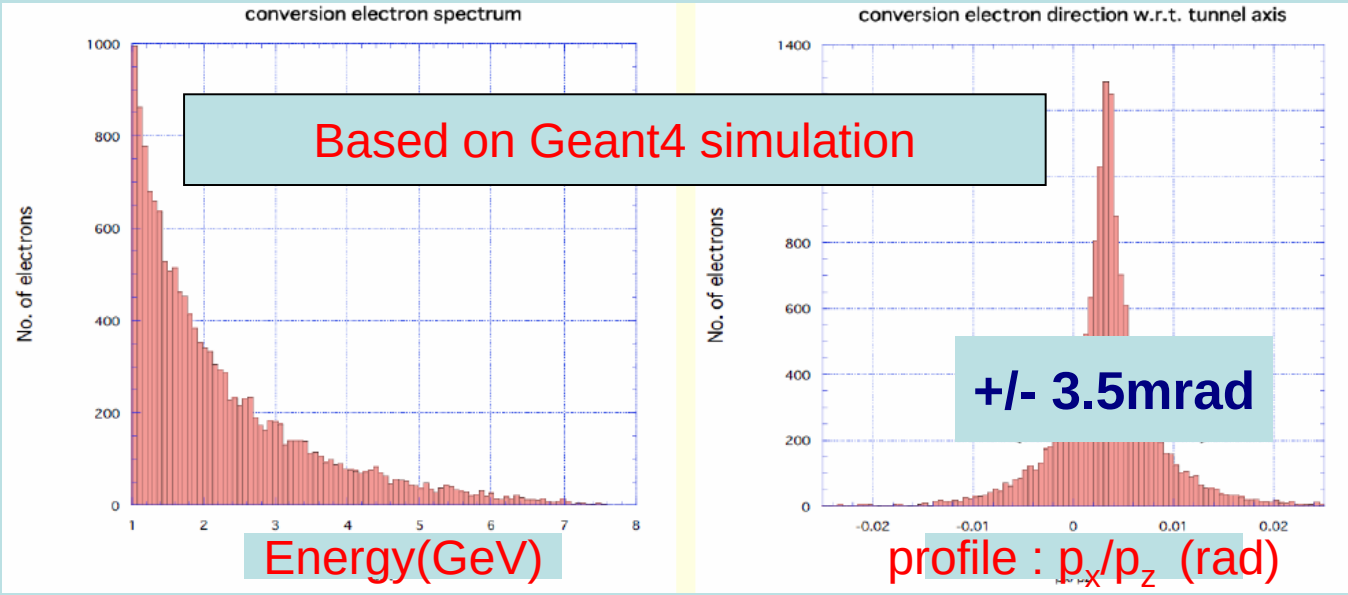


by O.Tajima

Brem. photons are converted to e^- / e^+ pairs by tungsten converter : 5mm (3mm ⇔ ~$1X_0$)
Sufficient electrons at a few GeV/c with a sharp forward peak are obtained.

Generated electron

by T. Higuchi



Introduction to Fuji Test Beam Line

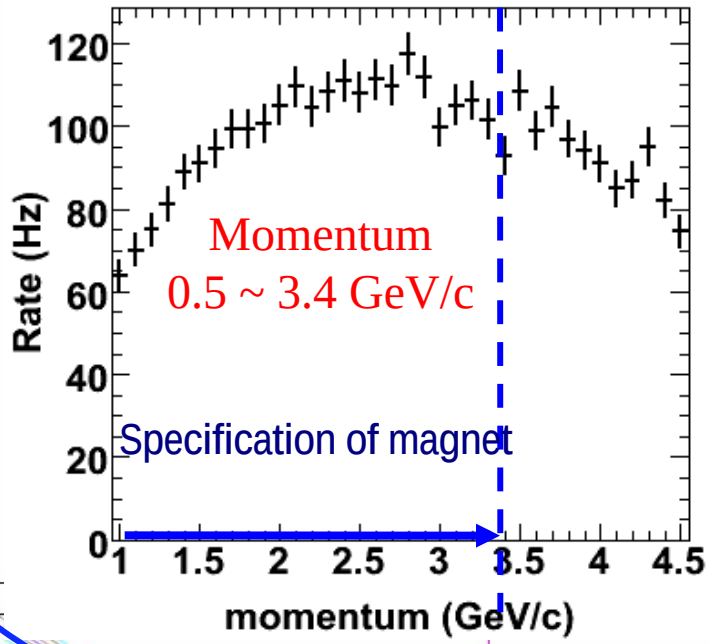
by Tajima

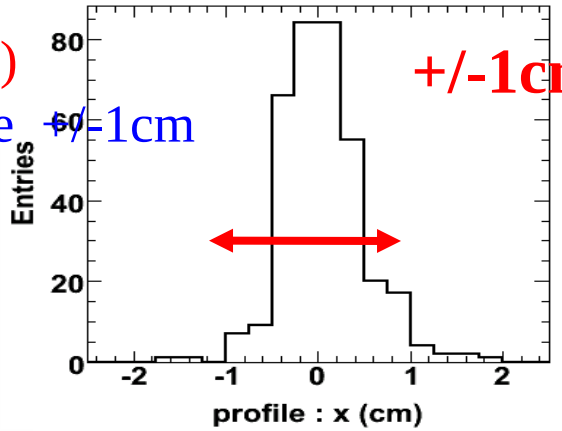
simulation

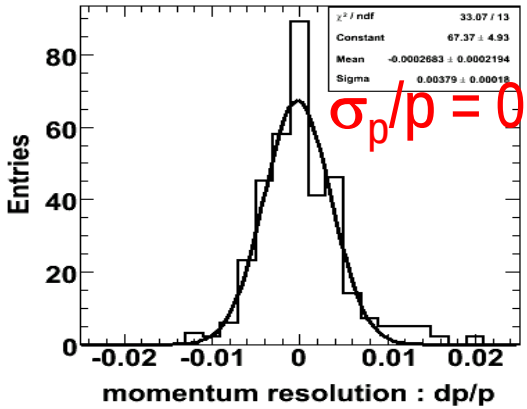
More than 100 electrons/sec (continuously)

p = 0.5 ~ 3.4 GeV/c, s_p/p ~ 0.4%, spot size +/-1cm

Floor for experiment (7m x 4m)







Converted electrons are extracted to outside of KEKB tunnel

BX1.2

Straight section (100m)

┐Beam line design

Some magnets are tilted more than 30° to the horizontal plane.

magnet rotation : θ_{rot} @ G_{xyz} = Rotate + Chi3

Bend	Rotate	Angle	Edge1	Edge2	Chi3
B1L	-30.246	-6.050	0.000	0.000	0.
B1S	-30.246	-3.048	0.000	0.000	
B2	-0.315	-9.706	0.000	0.000	
B3	-1.087	-9.706	0.000	0.0	
B4	-1.847	-9.706	0.000		.8473
B5L	-2.597	-6.471	0.0		2.5970
B6L	-3.091	-6.47		0	3.0910
B7L	38.173	-6		0.000	3.5818

8 bending magnets

No corrector magnets

Quad		-1]	L[m]	Bore[m]	
Q1	-5	0.515	0.525	0.050	0.3147
Q2	-54.2	0.365	0.525	0.050	0.3147
Q3	-59.712	-0.194	0.584	0.166	2.5970
Q4	-31.486	0.222	0.584	0.166	3.5818

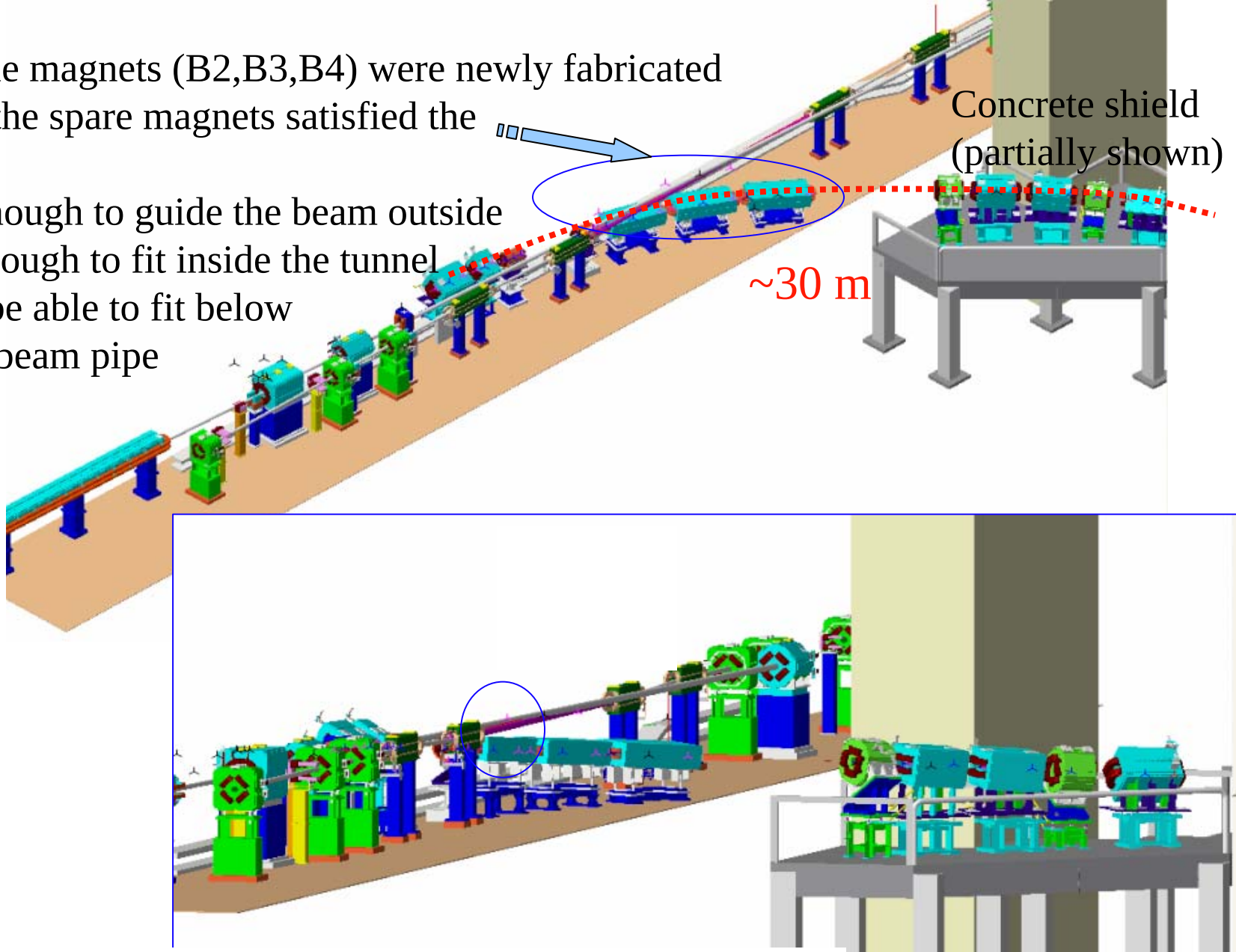
4 quad magnets

in degrees

Three dipole magnets (B2,B3,B4) were newly fabricated as none of the spare magnets satisfied the conditions:

1)Strong enough to guide the beam outside

2) Small enough to fit inside the tunnel width and be able to fit below the KEKB beam pipe



A 3D CAD program was indispensable for designing the beam line and for planning alignment strategy.

Construction

FTBL had to be completed during the summer shutdown of just 2 months (not only installation of magnets but also cooling water system, power supply cabling and so on had to be completed.)

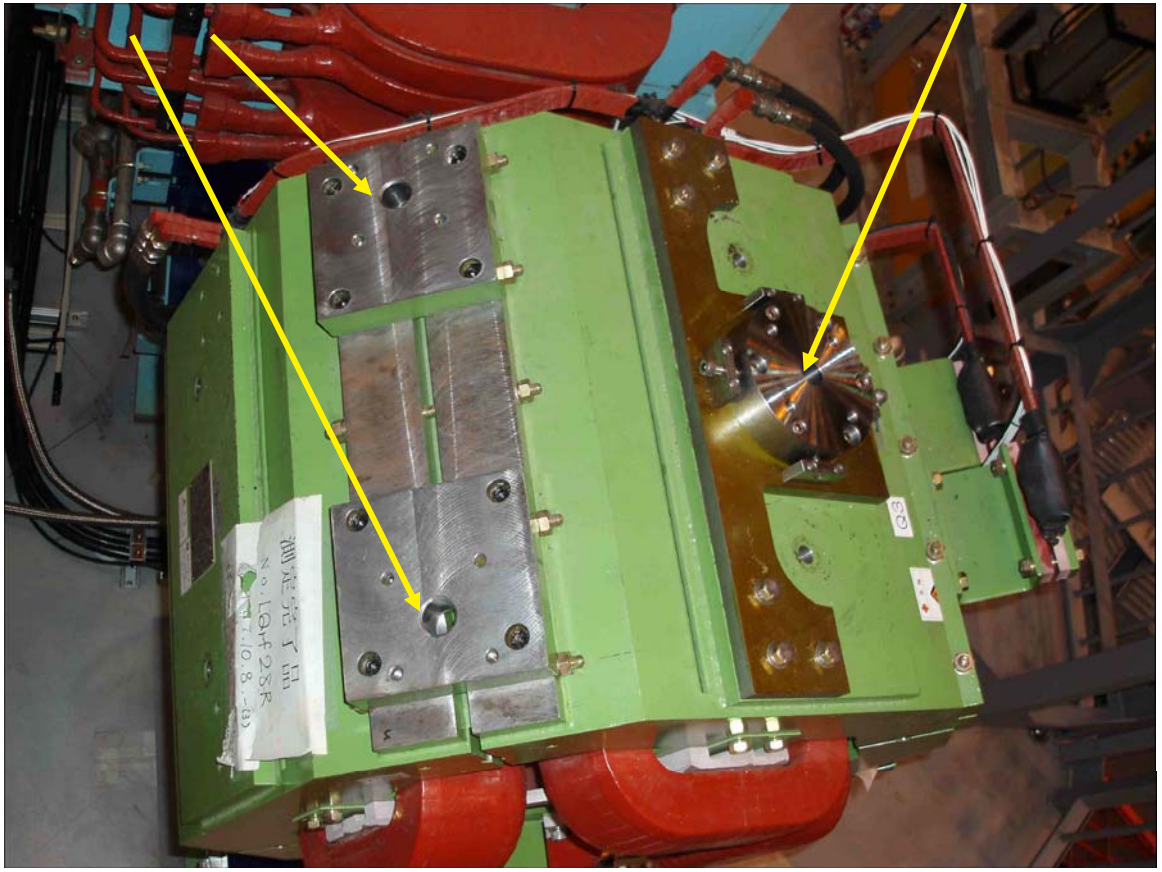
Three stages:

- Pre-alignment
  - Mount a magnet on a tilted stand to create a large tilt.
- Drawing of the beam line on the tunnel floor making use of the KEKB maintenance time (every other week).
  - This was needed to mark the exiting position of the beam on the concrete shield block.
    - The concrete shield blocks had to be removed on the 1st day of the summer shutdown to remove the vacuum pipes.
- Beam line construction
  - Magnet installation & alignment in the KEKB tunnel and Fuji experimental hall.

Pre-alignment

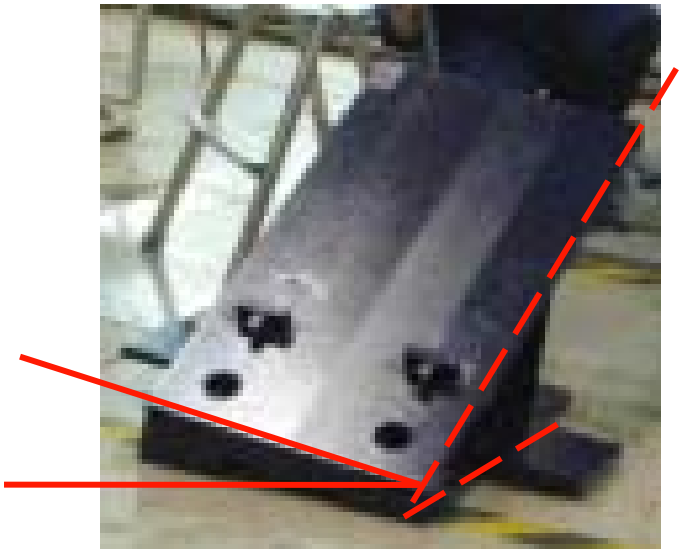
Holes for laser tracker target
on reference base plate
used for installation for KEKB

A 3rd reference plate
was added.



Top view of a quadrupole magnet (KEKB spare magnet)

Pre-alignment

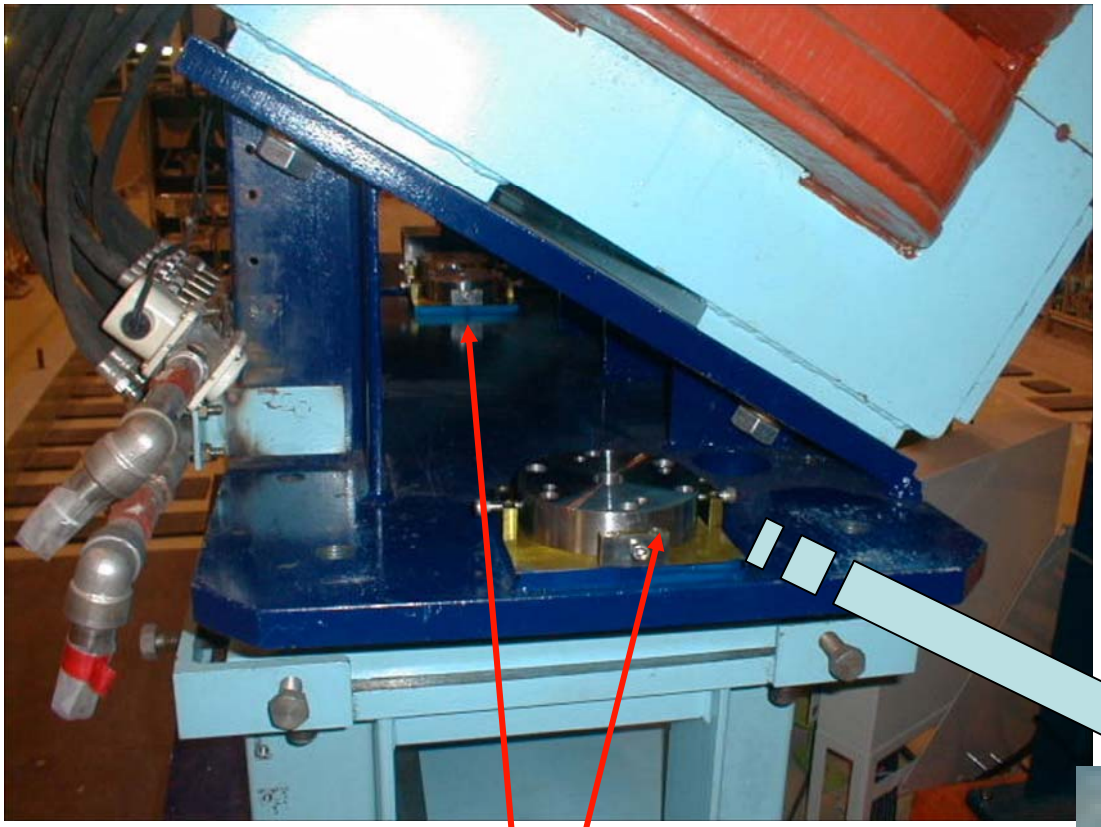


Additional tilted stand to create large tilt angle in two planes of a magnet. Each magnet has its own combination of angles.

Pre-alignment

Adjusting the bolts of the stand using a Laser tracker so that the magnet tilt matches the design tilt.

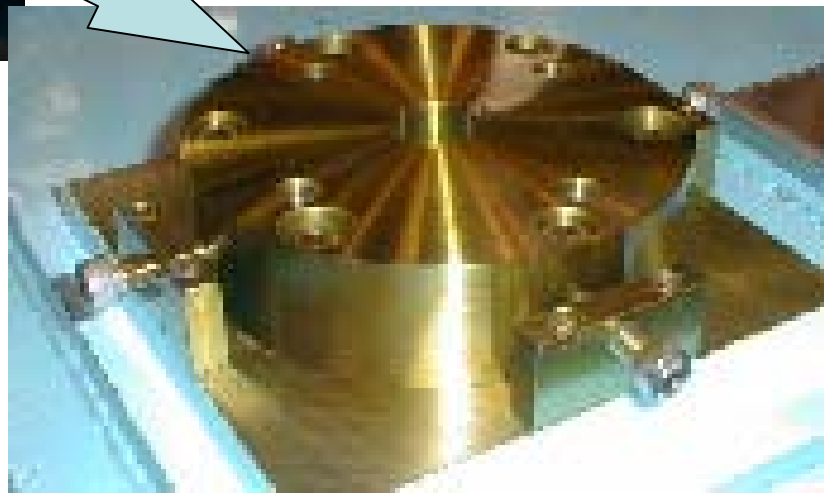
Pre-alignment (before moving the magnets to the beam line)



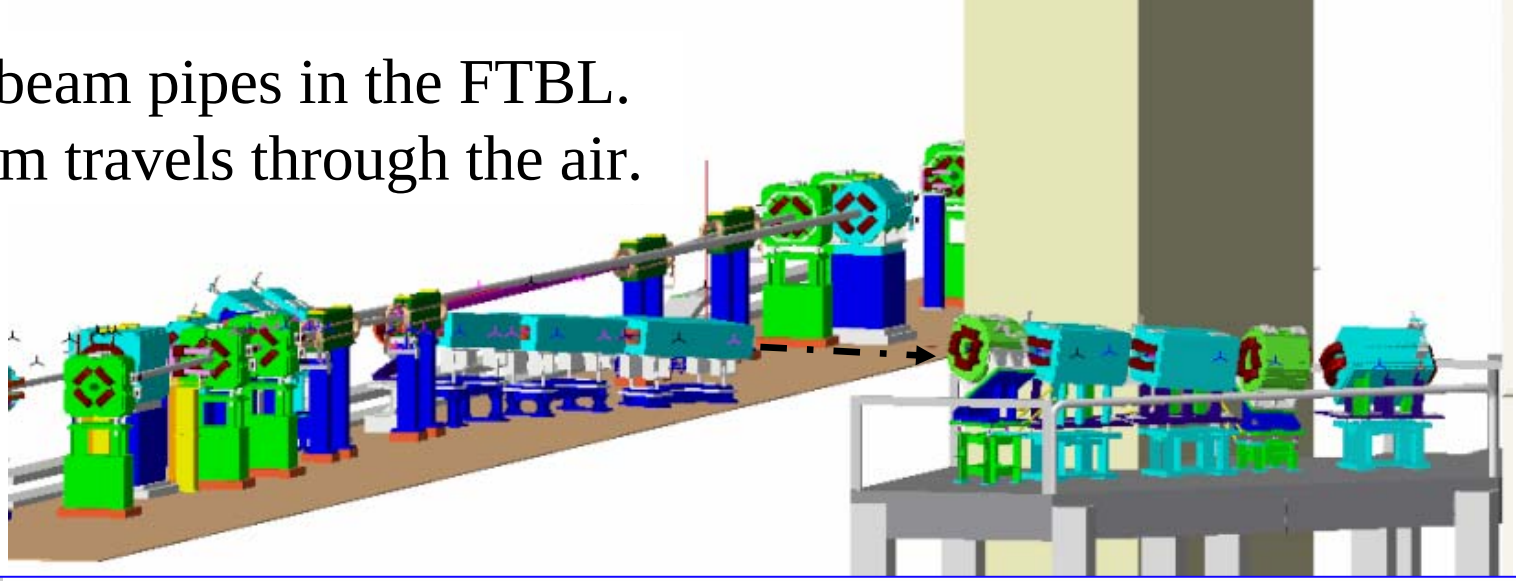
New reference plates on the magnet support stand.

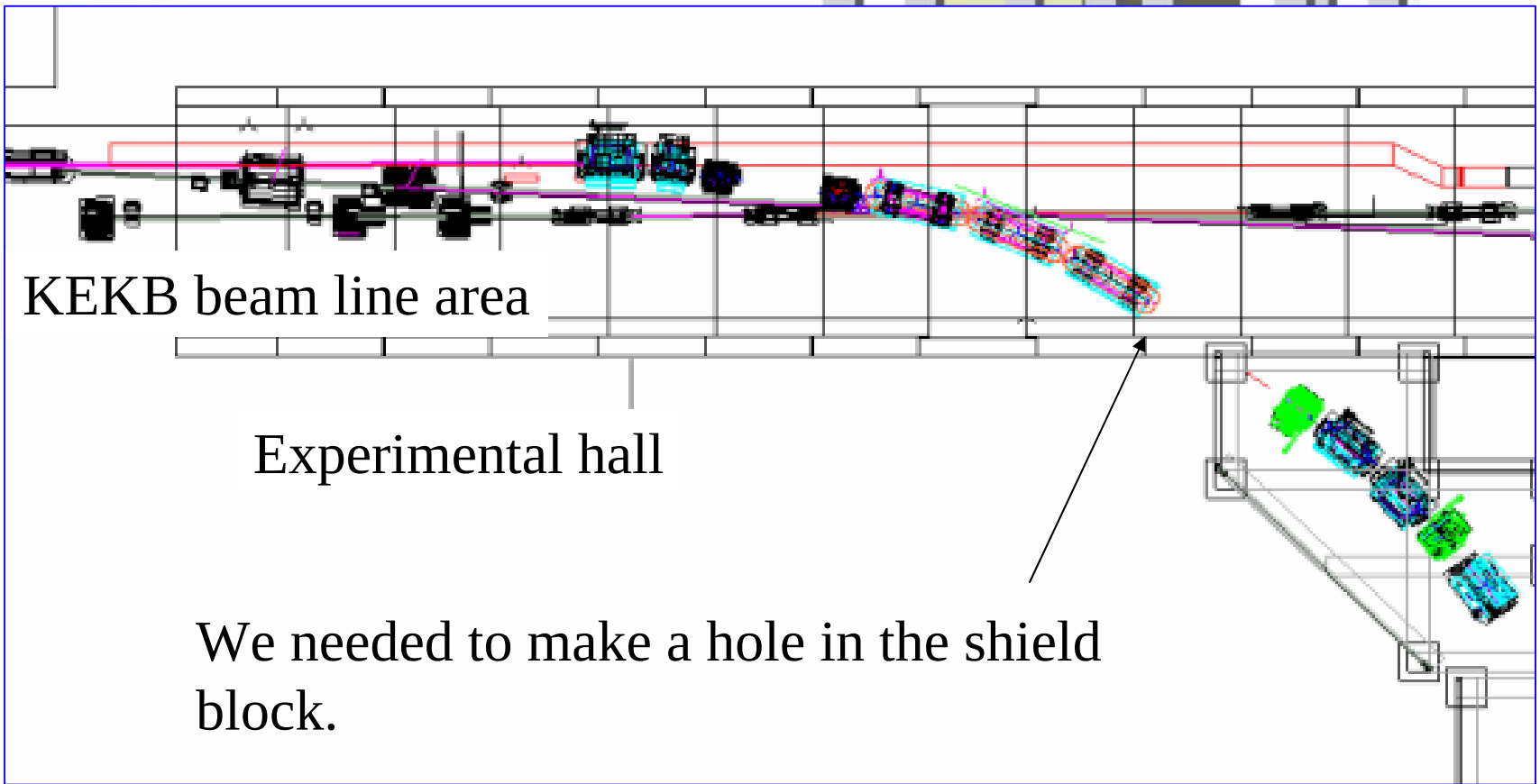
After adjusting the magnet rotation & tilt angles, new reference plates were added.
They were mounted on the magnet support table and fixed “level” using Carl Zeiss Nivel 20.

When aligning the magnets at the beam line, we used these plates for coarse alignment.



No beam pipes in the FTBL.
Beam travels through the air.





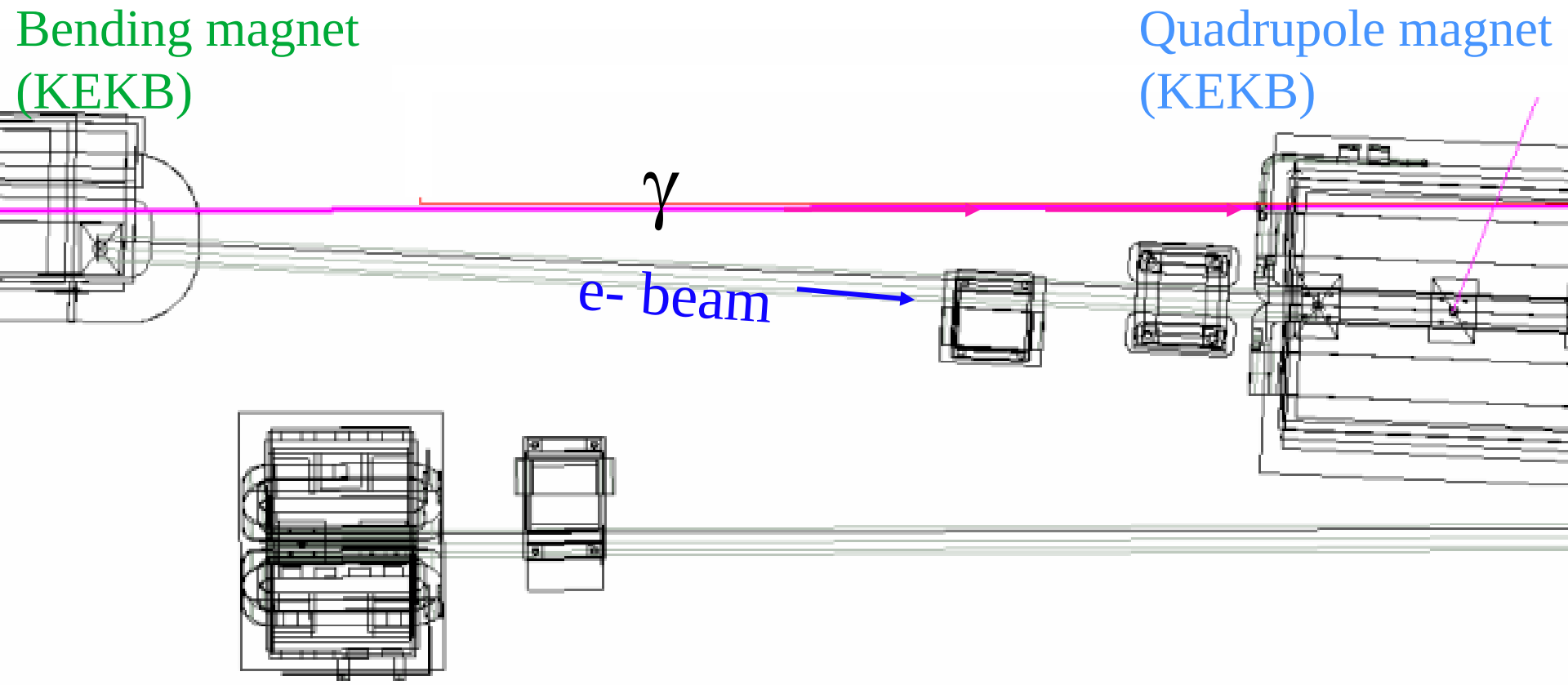
Beam line construction

- Concrete shield blocks had to be removed for magnet installation.
  - Beam hole position (100 mm ϕ) needed to be determined before removal of the shield block.
  - If the beam does not get through this hole …nightmare.
- KEKB vacuum pipes in the straight section were removed.
- Replace the upstream quadrupole magnet (KEKB magnet).

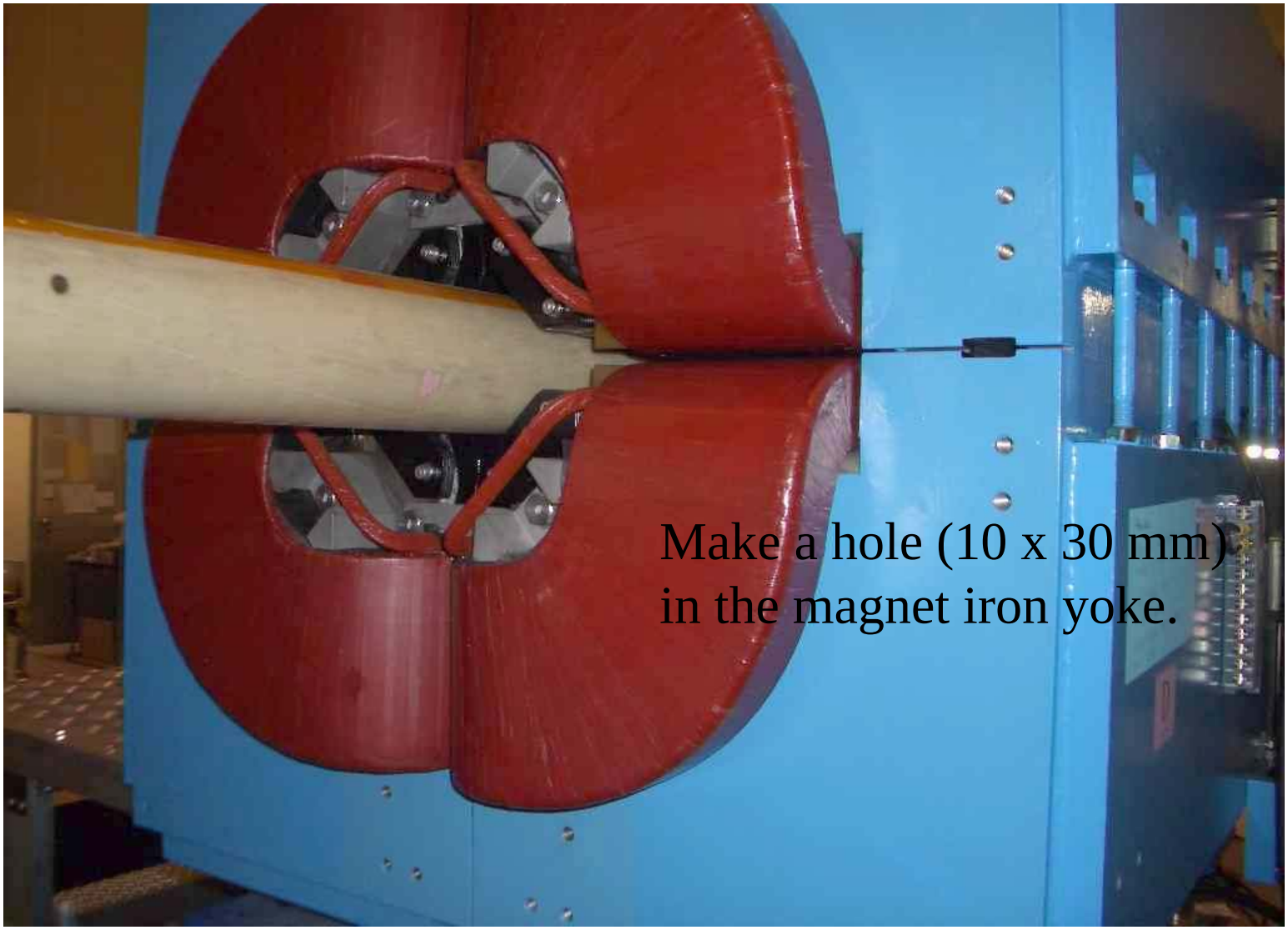
Bremsstrahlung photons

from HER 8 GeV e^- beam vs. residual-gas scattering.

1.6×10^5 photons/sec (3×10^{-8}Pa is assumed)

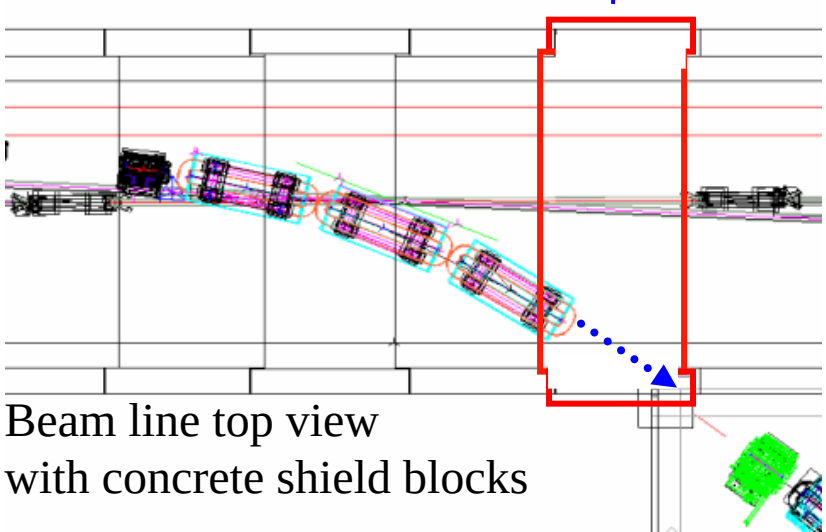


KEKB HER magnet, downstream of bending magnet, upsteam of the tungsten target for FTBL.



Magnet strength being measured with a harmonic coil system.

Drilling a hole in the concrete block shield.



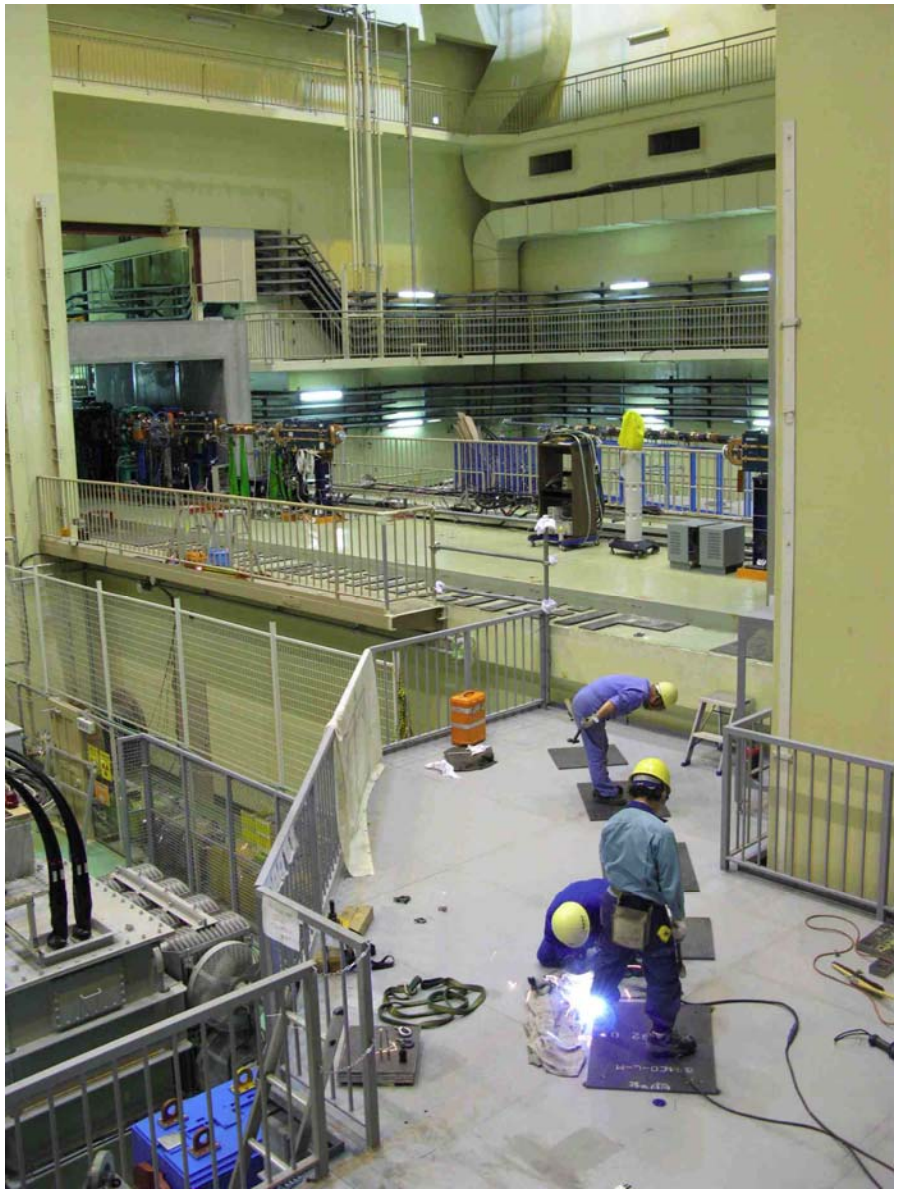
Beam line top view
with concrete shield blocks

Beam line construction

Marking the beam line on the “stage” floor.

Photos by Y.Ohsawa

Beam line construction

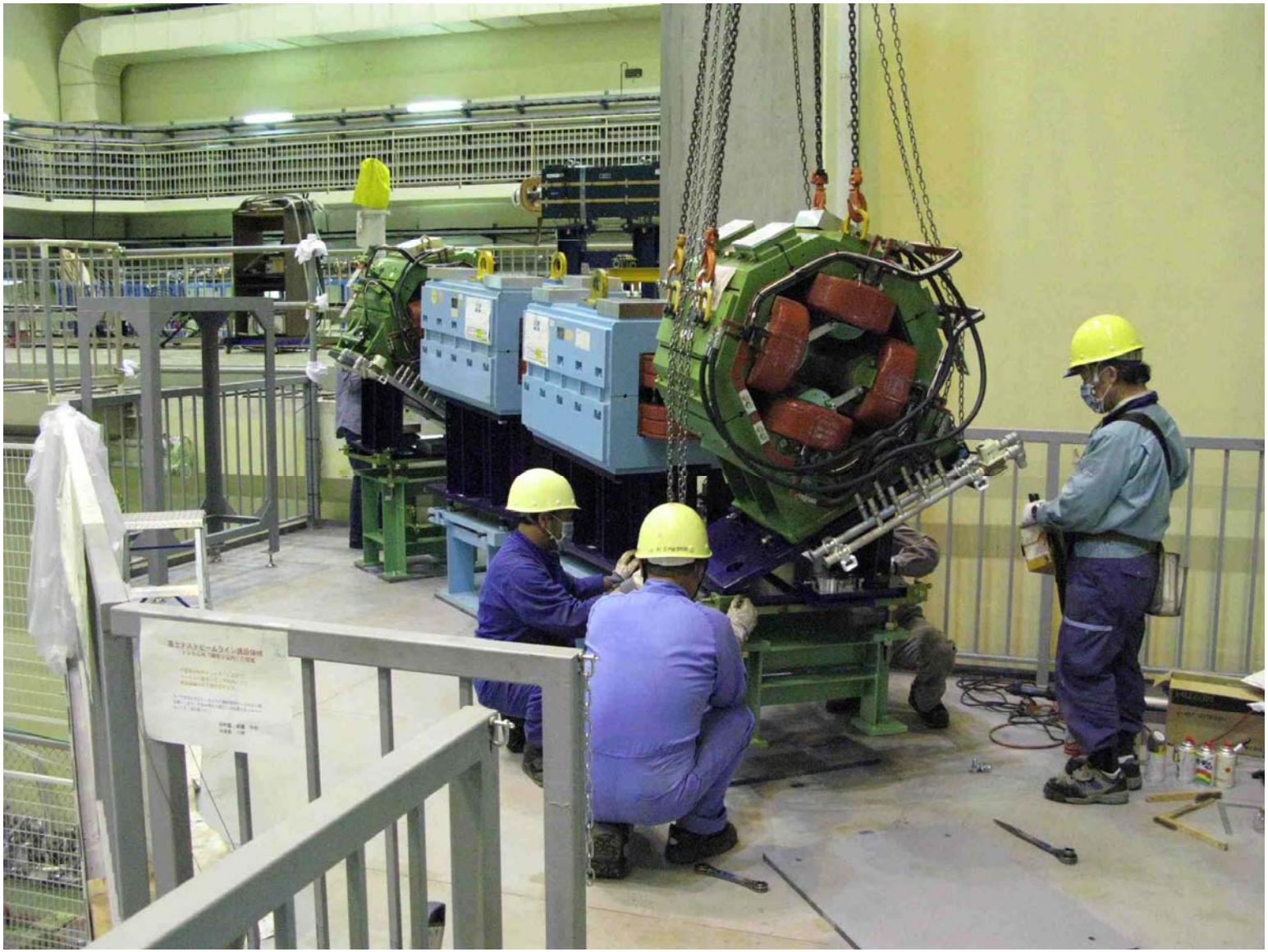


Welding iron plates on the stage.

Beam line construction

Installation started from the experimental hall side.

Beam line construction



Installing a pre-aligned (pre-tilted) magnet.

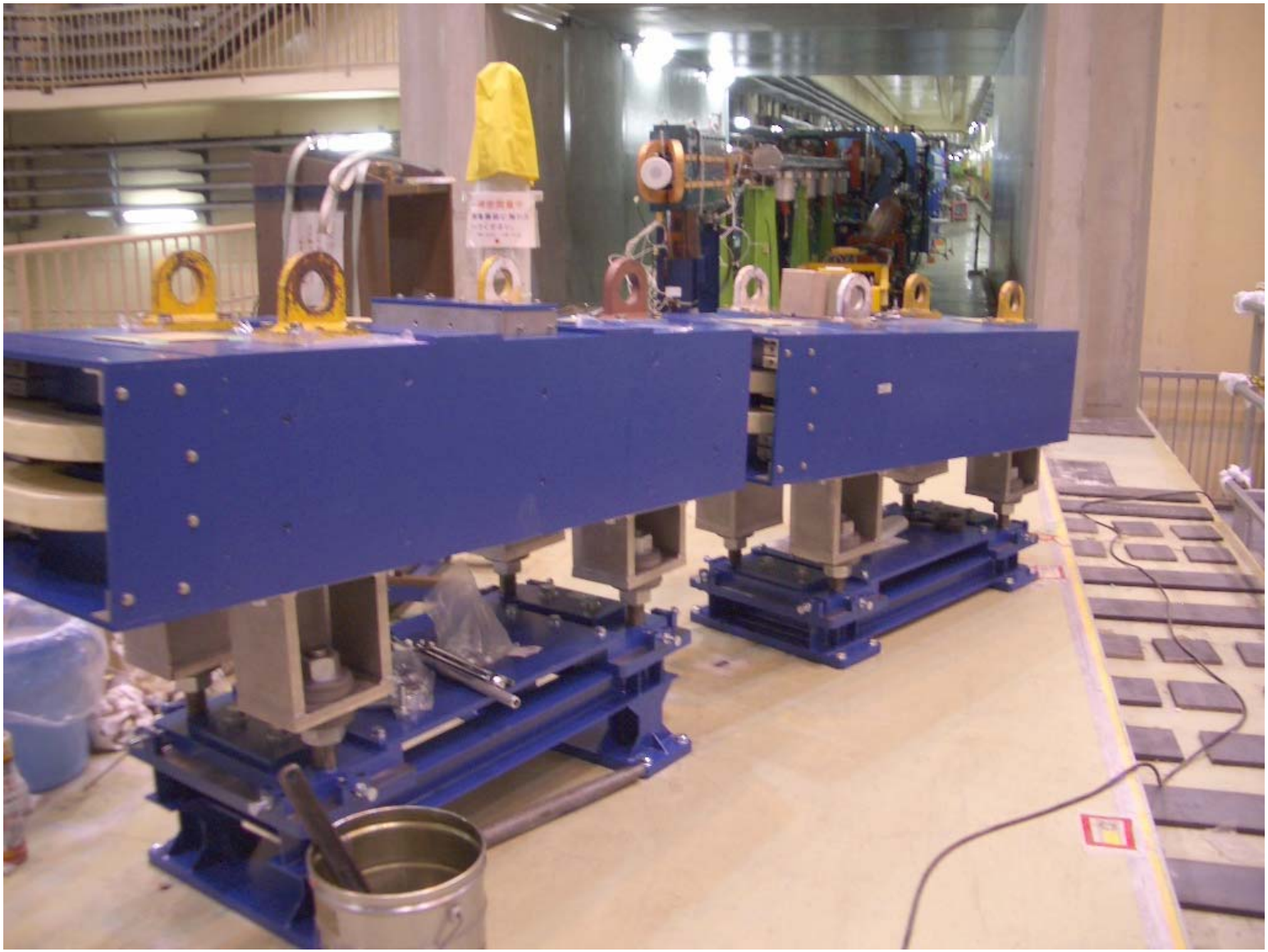
Beam line construction

The most downstream magnet of the FTBL.

Beam line construction

Magnet stands for three bending magnets, which guide the beam from the KEKB tunnel, through a hole in the concrete shield block (not shown) to the experimental hall.

Beam line construction

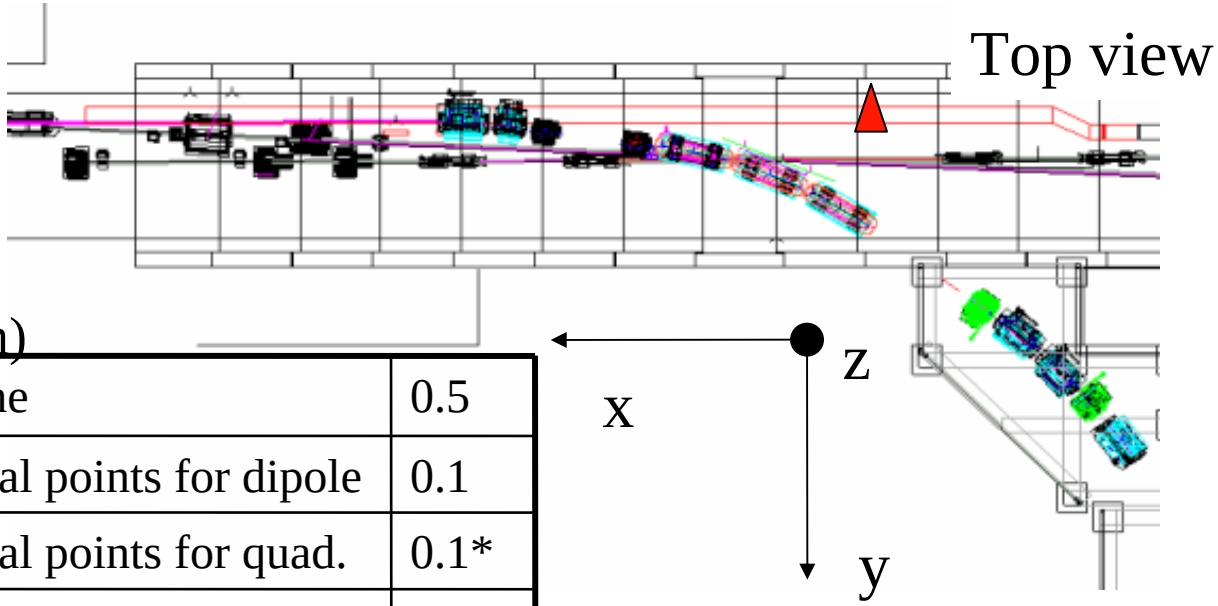


Beam line construction

Very tight

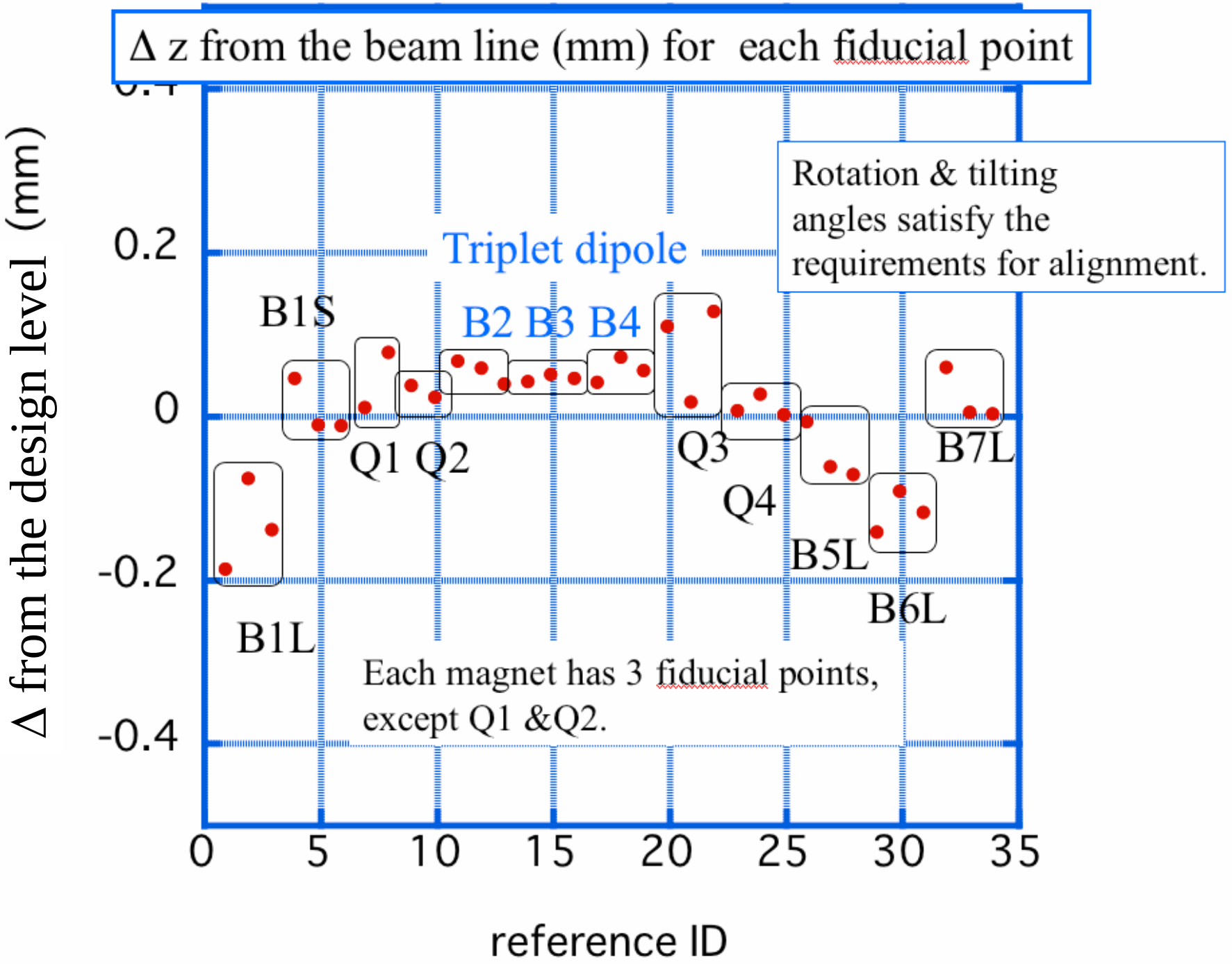
Alignment strategy

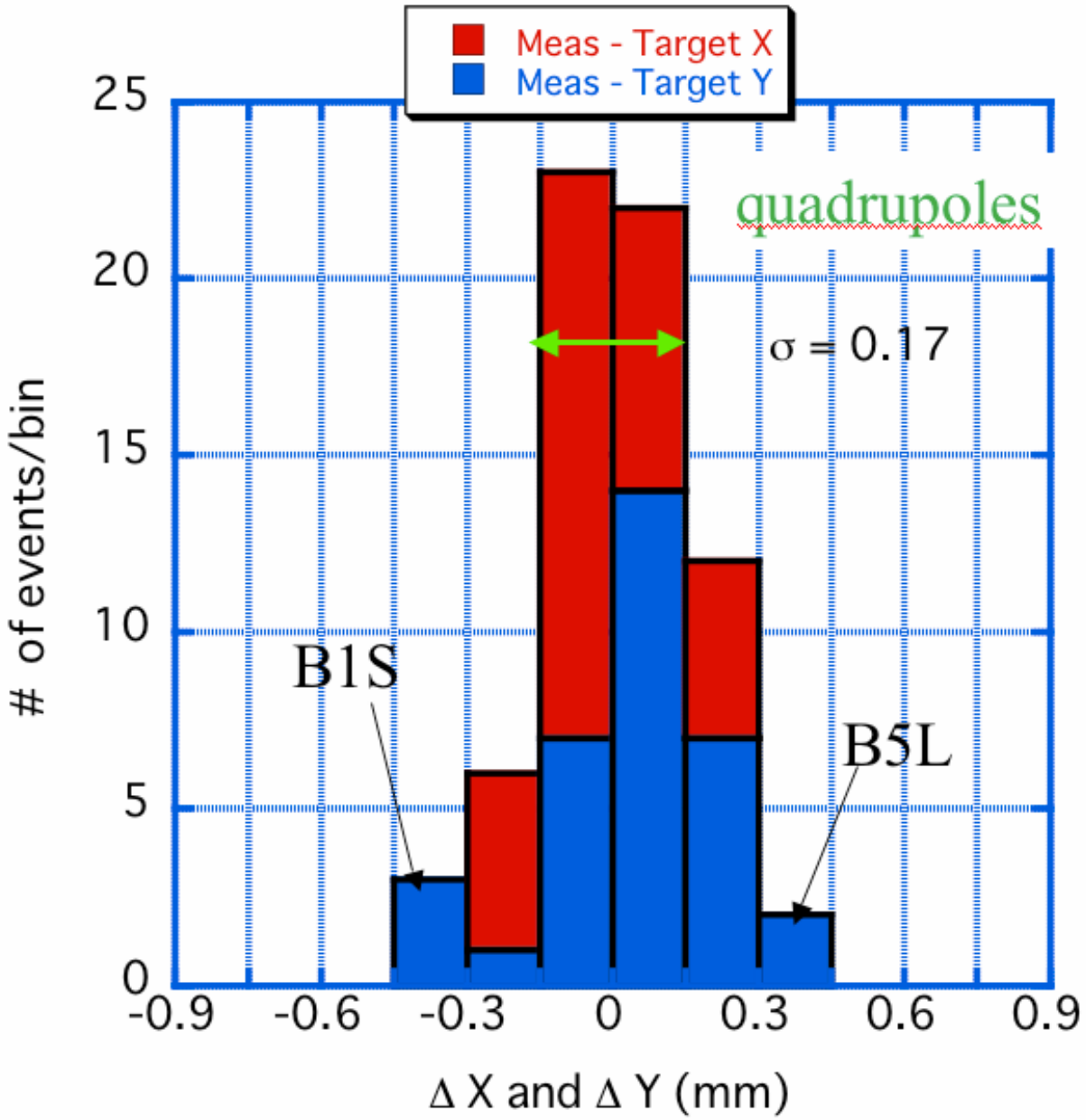
- Laser tracker for (x,y,z).
  - First time for us to use tracker output for measuring level.
  - We use N3 for measuring height.
- Use KEKB quadrupole magnet positions to determine the transfer matrix between the tracker and the lattice coordinates.



Tolerances (σ in mm)

Position along the beam line	0.5
Relative height of 3 fiducial points for dipole	0.1
Relative height of 3 fiducial points for quad.	0.1*
Qmag center, perpendicular to the beam line	0.15


Δ z from the beam line (mm) for each fiducial point
Rotation & tilting angles satisfy the requirements for alignment.
Triplet dipole
B1S
B2 B3 B4
Q1 Q2
Q3
Q4
B5L
B6L
B7L
B1L
Each magnet has 3 fiducial points, except Q1 &Q2.
Δ from the design level (mm)
reference ID
0.2
0
-0.2
-0.4
0
5
10
15
20
25
30
35



Requirements for alignment are satisfied.

Recap

- No corrector dipole magnets to steer the beam prepared by the beam line design group due to lack of space.
- The beam (a few cm in size) has to go through the 100 mmϕ hole on the concrete shield block.
- Had to get a GeV-class beam before J-PARC commissioning.
- KEKB operation resumed in the fall.

$\Rightarrow$We had just one shot at it.

- There was no intuitive way to cross check the magnet alignment. All digital. We had to trust our calculations and the tracker output.

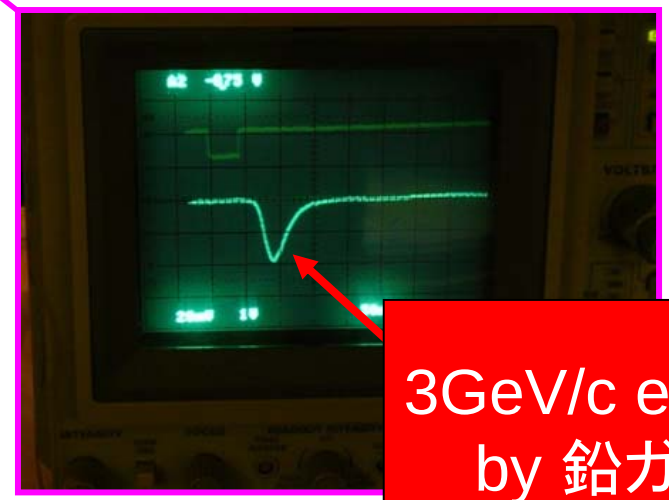
FTBL Commissioning

- Set the magnet strength at the design value on Oct.12.

FTBL : First Beam, Oct.12 !!

その場にいた人達で記念写真取っちゃいました。
増澤さん、江川さん、大澤さん、ゴメンナサイ

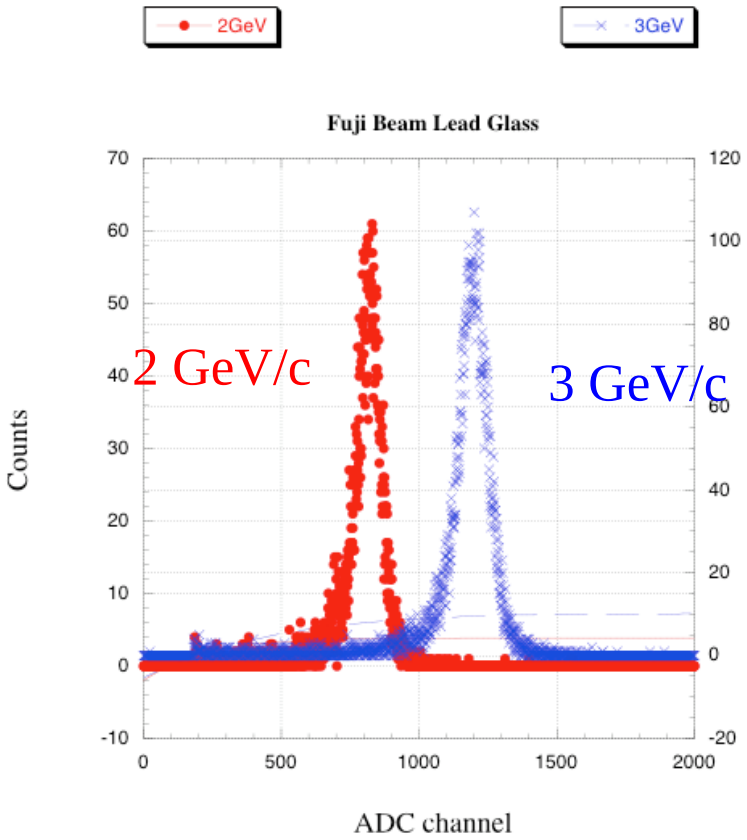
30Hz with HER 700mA
(→ ~100Hz with HER 1.3Aの見込み)

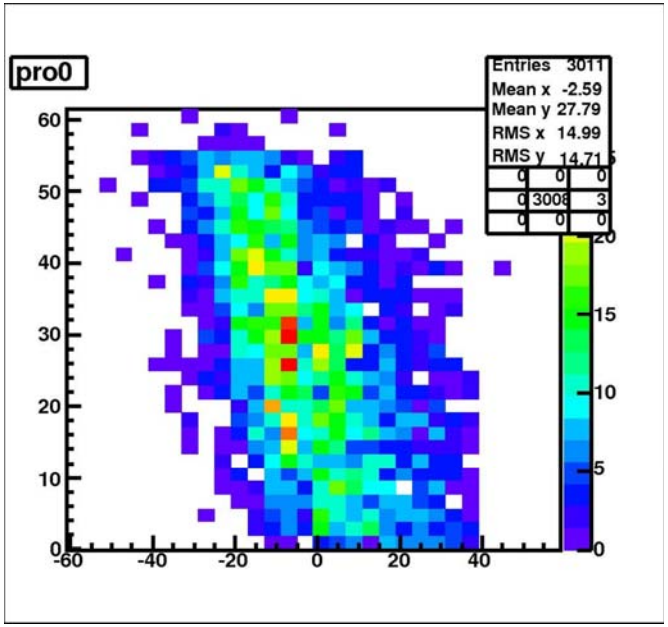


3GeV/c electron
by 鉛ガラス

コミッショニングの為に11個もモニターを配置しましたが、
マグネットを計算値で通電しただけで見えちゃいました。
KEKBチームの高い技術には感服 !!
ありがとうございます。
今後の運転へのご協力もよろしくお願い致します。

- The beam went through without any tweaking.
- We can receive 2 GeV beam, 3 GeV beam etc., by changing the dipole strength.
- We can run this beam line without degrading the KEKB luminosity.





beam profile @ the target