multiple scattering and GBL

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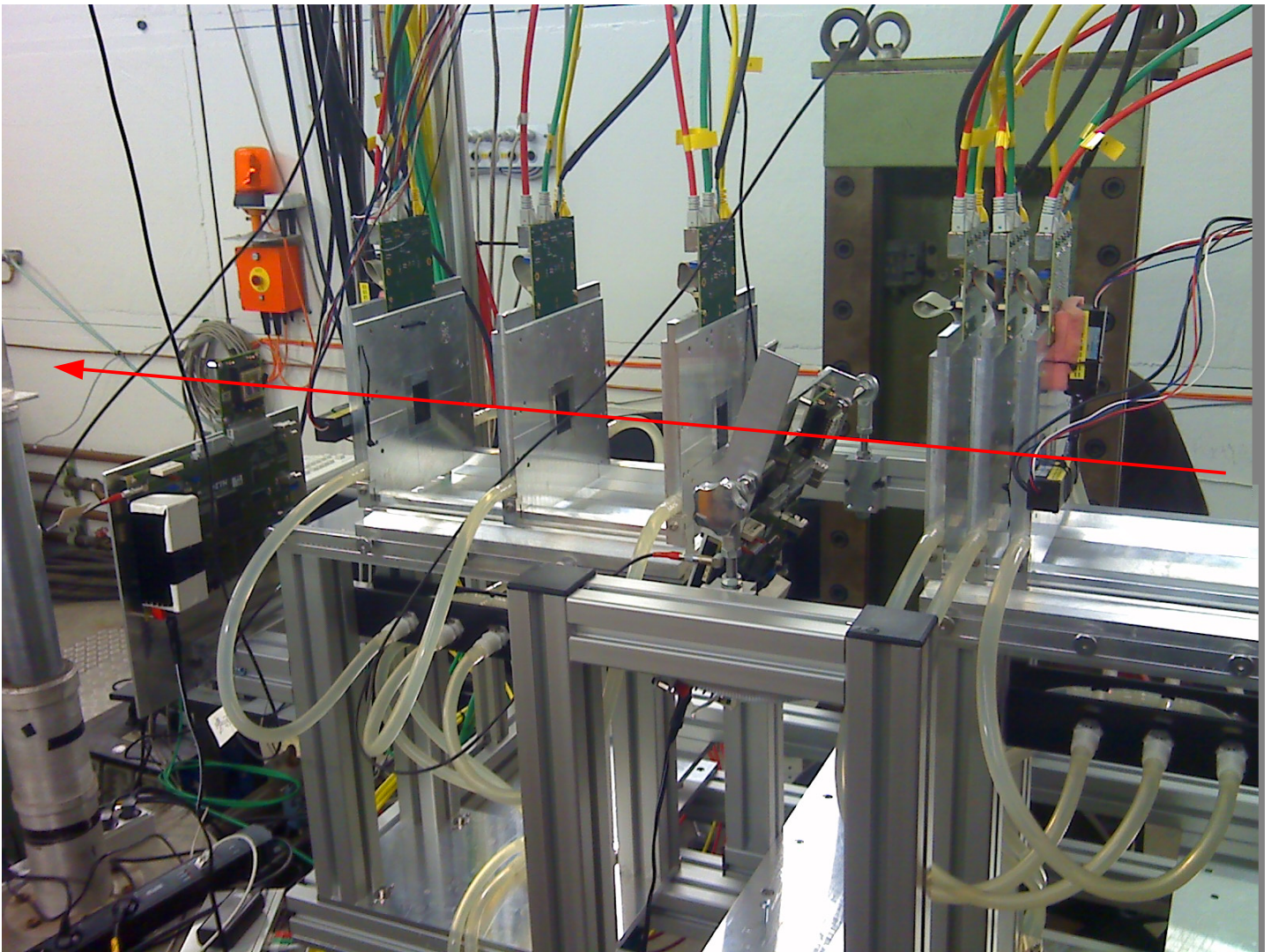
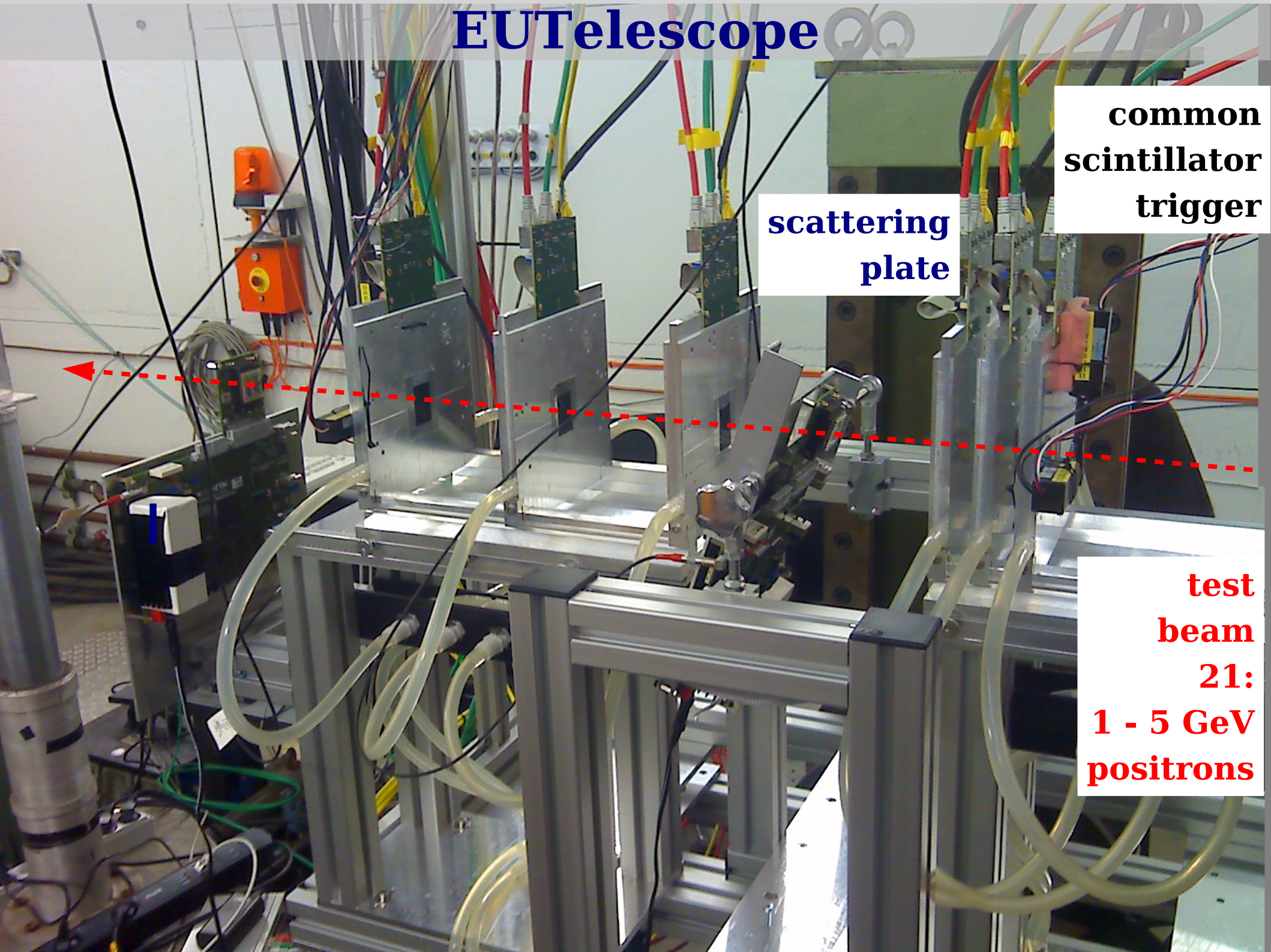
CMS Pixel Upgrade, 9.3.2012

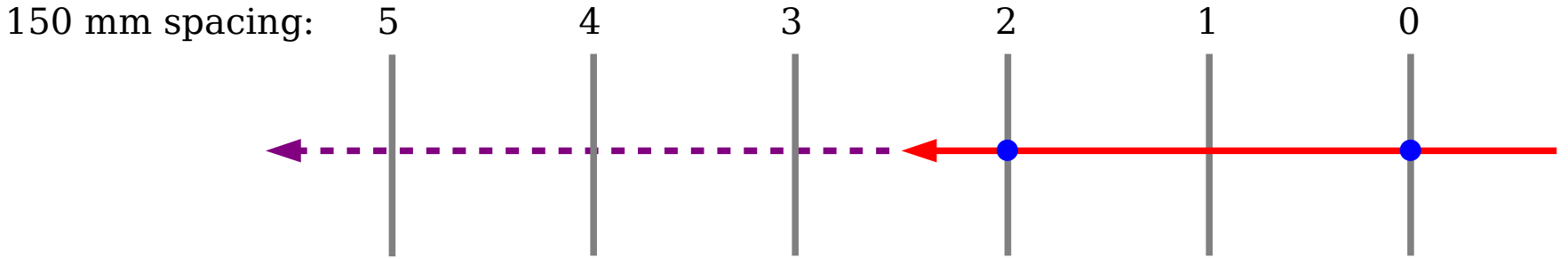


- set-up
- General Broken Lines
- resolution vs momentum
- scattering plates inserted

EUTelescope



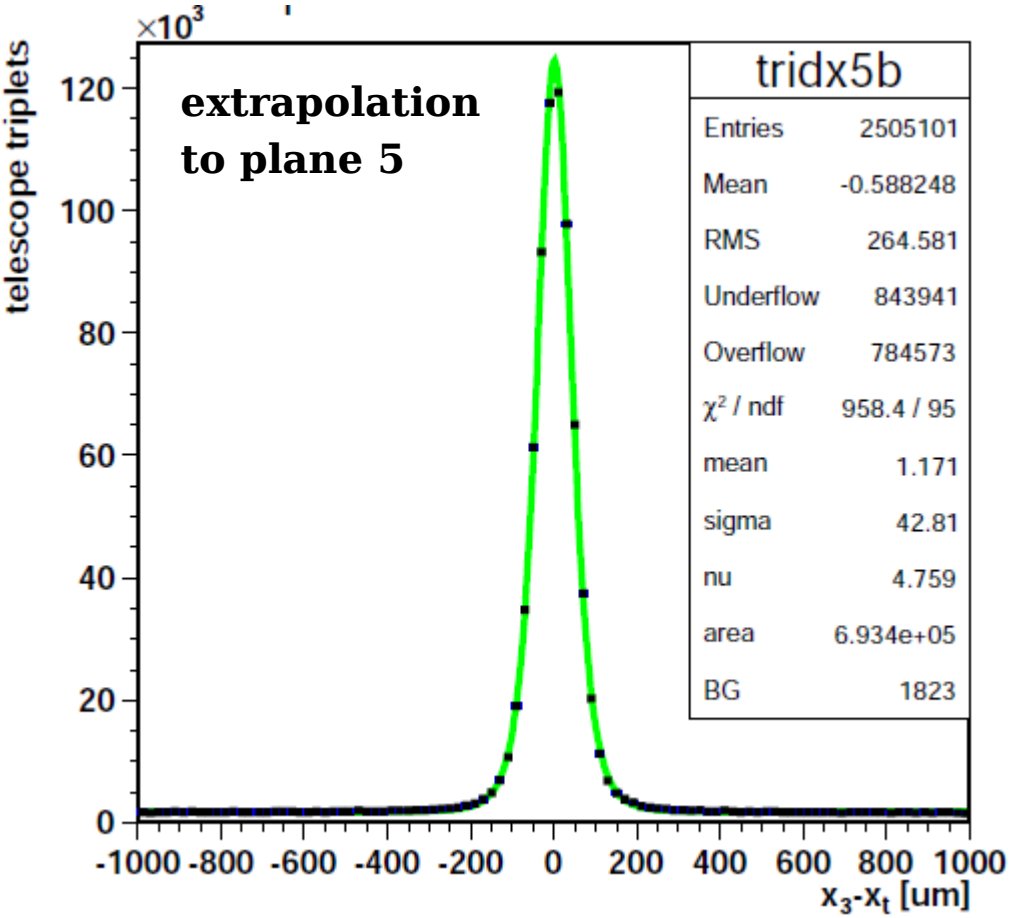
telescope tracking

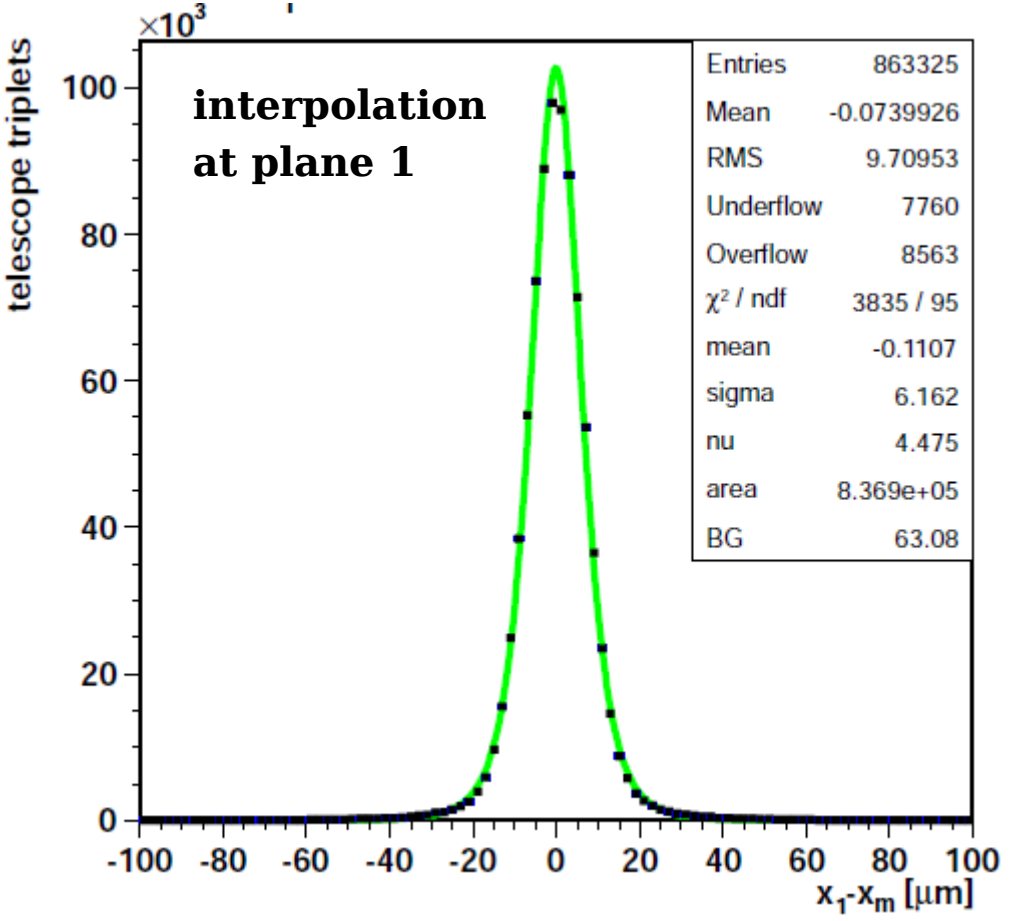


extrapolation planes

planes 2 and 0 define the track, verified by plane 1

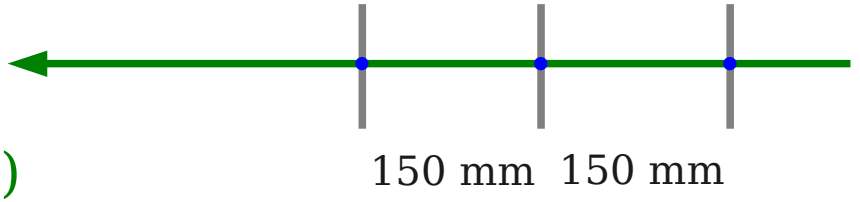
run 196: 4.4 GeV





multiple scattering: Si and air

- Air at NTP (20°C, 1 bar):
  - $\rho X_0 = 36.6$ g/cm^2
  - $\rho = 1.2$ mg/cm^3
  - $X_0 = 305$ m (cosmic air showers!)
  - 150 mm air ≙ 0.50‰ X_0
  - approximated by thin scatter in the middle



- Telescope planes:
  - 50 um Si ≙ 0.54‰ X_0
  - black Kapton foil ≈ 0.2‰ X_0
  - described by thin scatter

PDG: $$\langle\theta\rangle[rad] = \frac{0.0136}{p[GeV/c]}\sqrt{d/X_0}\left(1 + 0.038\ \ln(d/X_0)\right)$$

General Broken lines

Track model: broken line from V. Blobel, generalized by C. Kleinwort.
Takes multiple scattering and intrinsic resolution into account.
Covariance matrix of track parameters is calculated.
The General Broken Line fit is equivalent to a Kalman filter, but faster, exploiting the bordered band matrix structure of the problem.
GBL solves the entire track fit in one step; outlier rejection requires iteration.

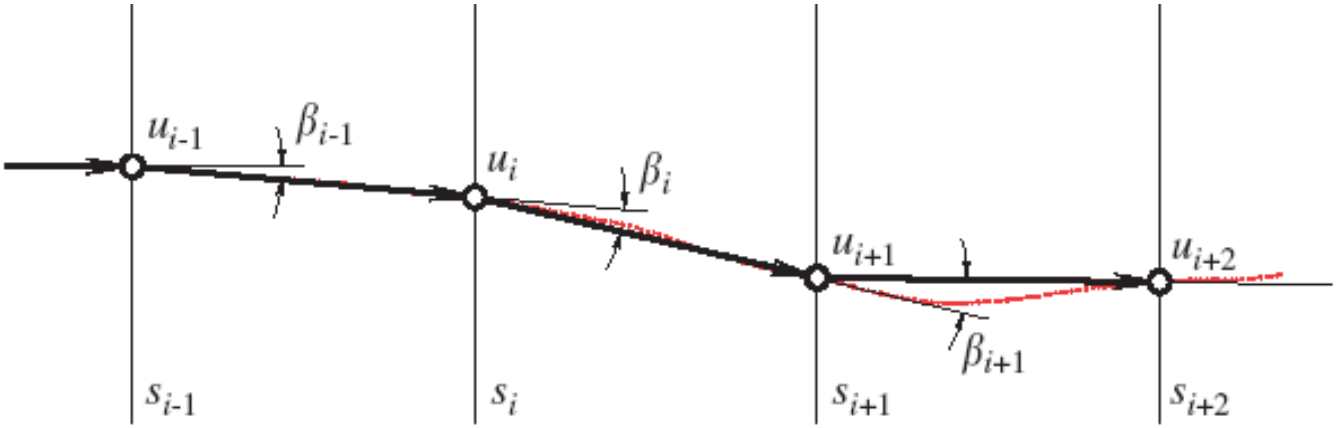


Fig. 3. Particle trajectory with fitted residuals u_i and kink angles β_i.

Volker Blobel: Software alignment for tracking detectors, NIM A566 (2006) 5-13
Volker Blobel: A new fast track-fit algorithm based on broken lines, NIM A566 (2006) 14-17
V. Blobel, C. Kleinwort, F. Meier: Fast alignment of a complex tracking detector using advanced track models, Comp Phys Comm 182 (2011) 1760-3
C. Kleinwort, F. Meier: Alignment of the CMS silicon tracker, NIM A 650 (2011) 240-4
Claus Kleinwort: General broken lines as advanced track fitting method, NIM A 673 (2012) 107-10
https://www.wiki.terascale.de/index.php/GeneralBrokenLines
http://www.desy.de/~kleinwrt/GBL/html/

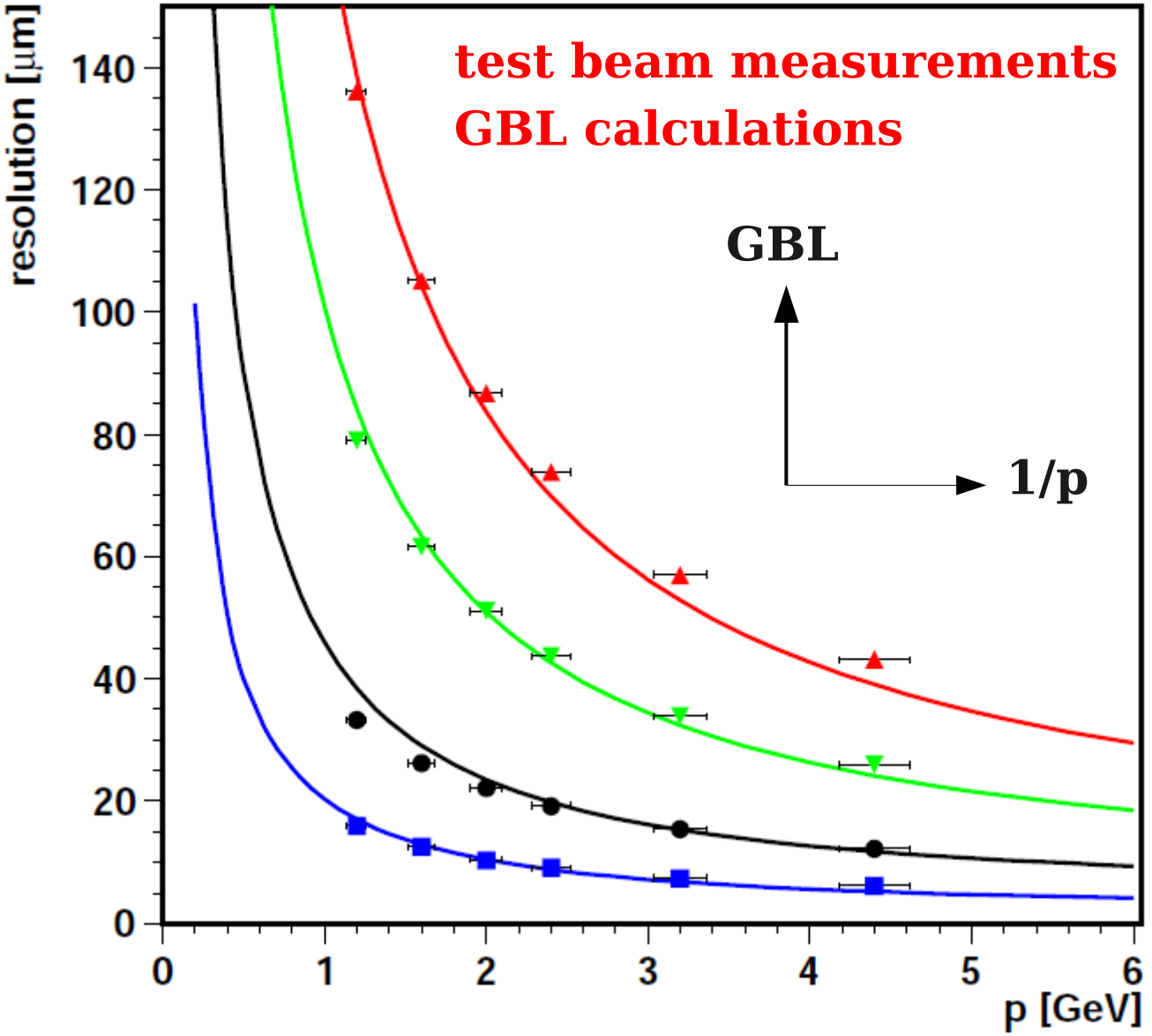
General Broken Lines for resolution study

```
GblTrajectory traj(false); // curvature = false (straight line track)
double measRes = 3.5E-3; // [mm]
double p = 3.2; // [GeV]
double X0Si = 60e-3 / 94; double X0Air =  50 / 304E3; // [mm]
double tetSi = 0.0136 * sqrt(X0Si) / p * ( 1 + 0.038*log(X0Si) );
double tetAir = 0.0136 * sqrt(X0Air) / p * ( 1 + 0.038*log(X0Air) );
double step = 150; // [mm] spacing

  // Si plane 0:
  GblPoint *point = new GblPoint(jacPointToPoint);
  point->addMeasurement( unit, 0, 1/measRes/measRes );
  point->addScatterer( 0, 1/tetSi/tetSi );
  unsigned int iLabel = traj.addPoint(*point); delete point;

  // Air:
  jacPointToPoint = Jac5( 0.5*step ); // Jacobian for track parameters
  point = new GblPoint(jacPointToPoint);
  point->addScatterer( 0, 1/tetAir/tetAir );
  iLabel = traj.addPoint(*point);
  ...
// fit:
traj.fit( Chi2, Ndf, downWeight );
traj.getResults( iLabel, Corrections, Covariance );
extrapolationErrorX = sqrt(Covariance(3,3)); // [mm] traj = (k, x', y', x, y)
```

Test beam data

- Run 192 – 201 taken Mon 27.2.2012
- Anemone telescope alone (no device under test)
  - Mimosa threshold 8
  - Spacing 150 mm (maximum)
- e^+ momentum 1.2 .. 4.4 GeV in test beam area 21
- telescope scintillator trigger (4-fold coincidence)
  - up to 800k triggers per run, 0.4 – 2.4 kHz depending on energy
- data processed with EUTelescope software:
  - convert raw to lcio format
  - make clusters
  - make hits
  - millepede alignment
  - track analysis

Telescope resolution (0.1% X0/plane)



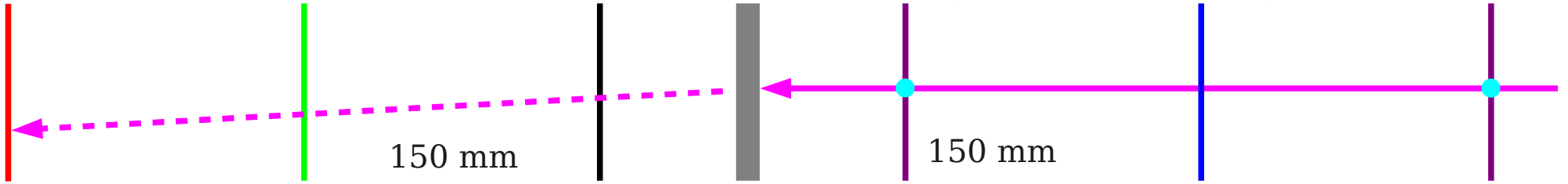
Data well described by GBL calculation using adjusted material:
65 μm Si + Kapton
2×25 mm air (?)

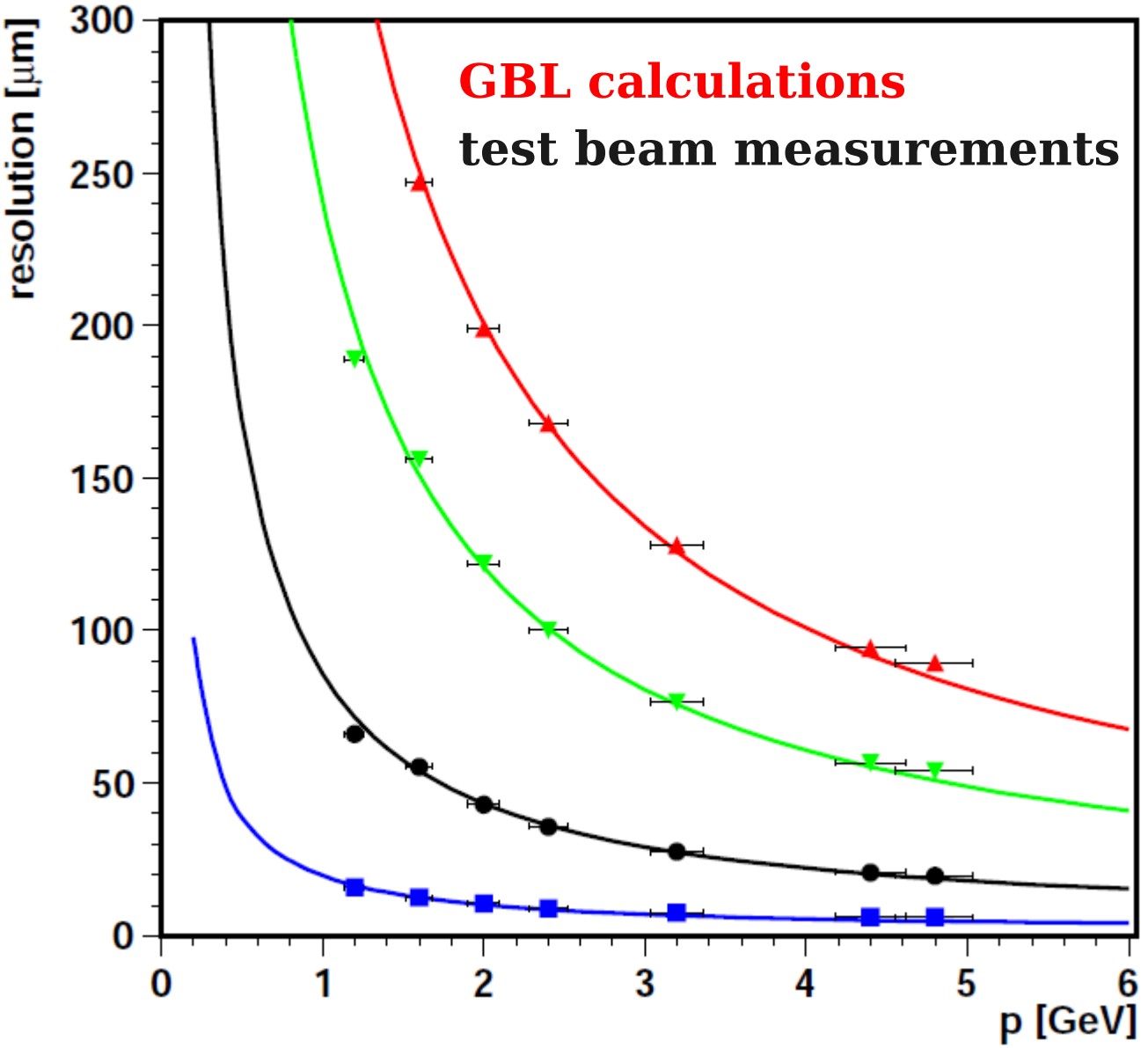
extrapol 3×150 mm
extrapol 2×150 mm
extrapol 1×150 mm
interpol

more Data

- 1 mm Al plate
  - Runs 202 – 210 taken Mon 27.2.2012
- 1 mm Cu plate
  - Runs 217 – 223 taken Thu 1.3.2012
- Spacing of downstream telescope planes reduced:
  - from 150 mm to 38 mm
  - more acceptance at large scattering angles
  - 1 mm Cu, runs 246 - 254 taken Fri 2.3.2012
  - 0.4 mm Cu, runs 255 – 260 taken Fri 2.3.2012
  - 4 mm Al, runs 263 – 268 taken Fri 2.3.2012

1 mm Al inserted (1.1% X0)





Data well described by GBL calculation with reduced Al: 0.7 instead 1.0 mm. PDG formula?

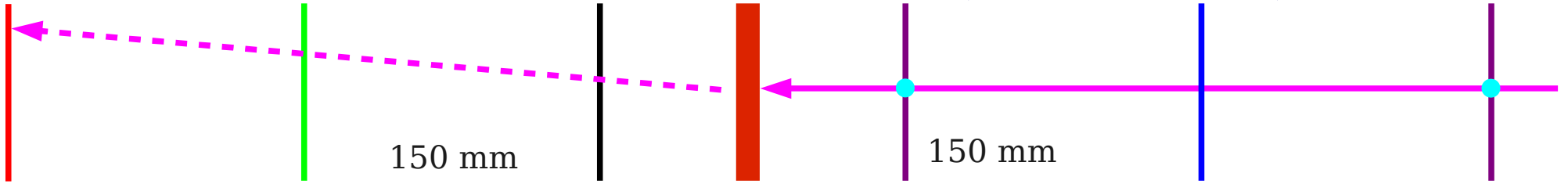
extrapol 3×150 mm

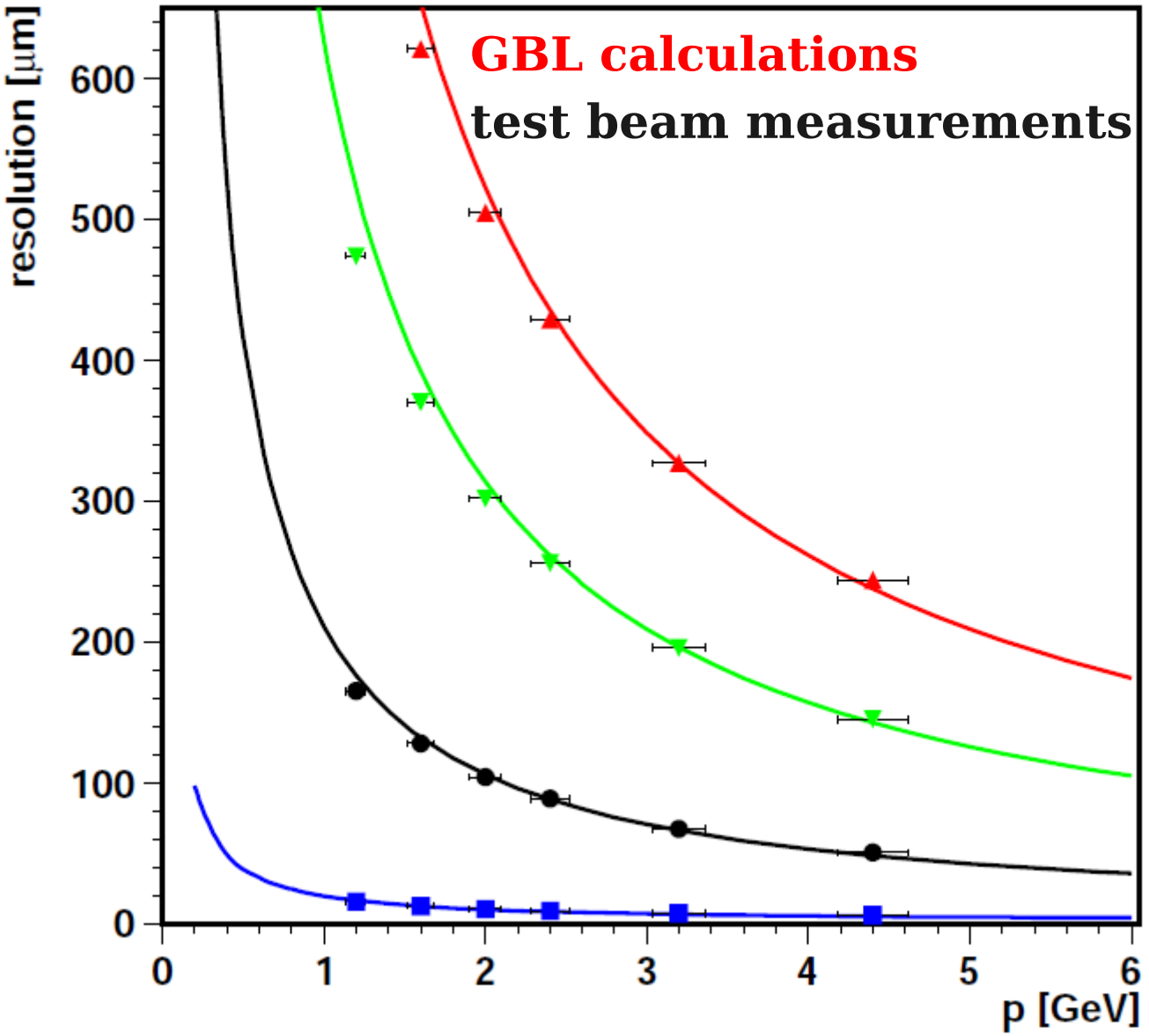
extrapol 2×150 mm

extrapol 1×150 mm

interpol

1 mm Cu inserted (7.0% X0)





Data well described by GBL calculation with reduced Cu: 0.75 instead 1.0 mm.

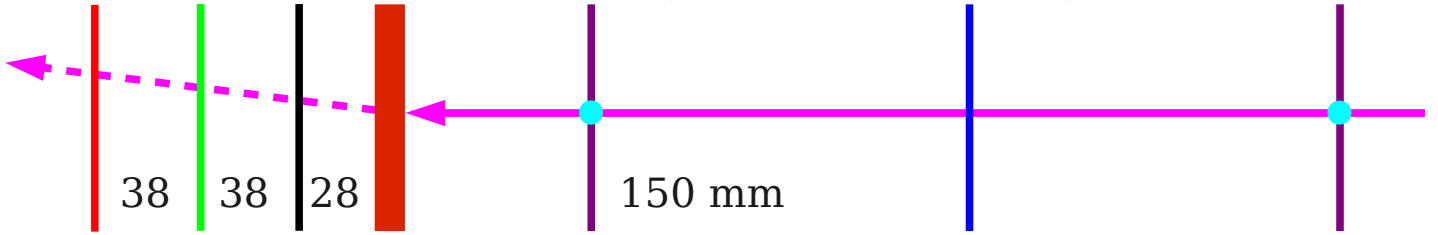
extrapol 3×150 mm

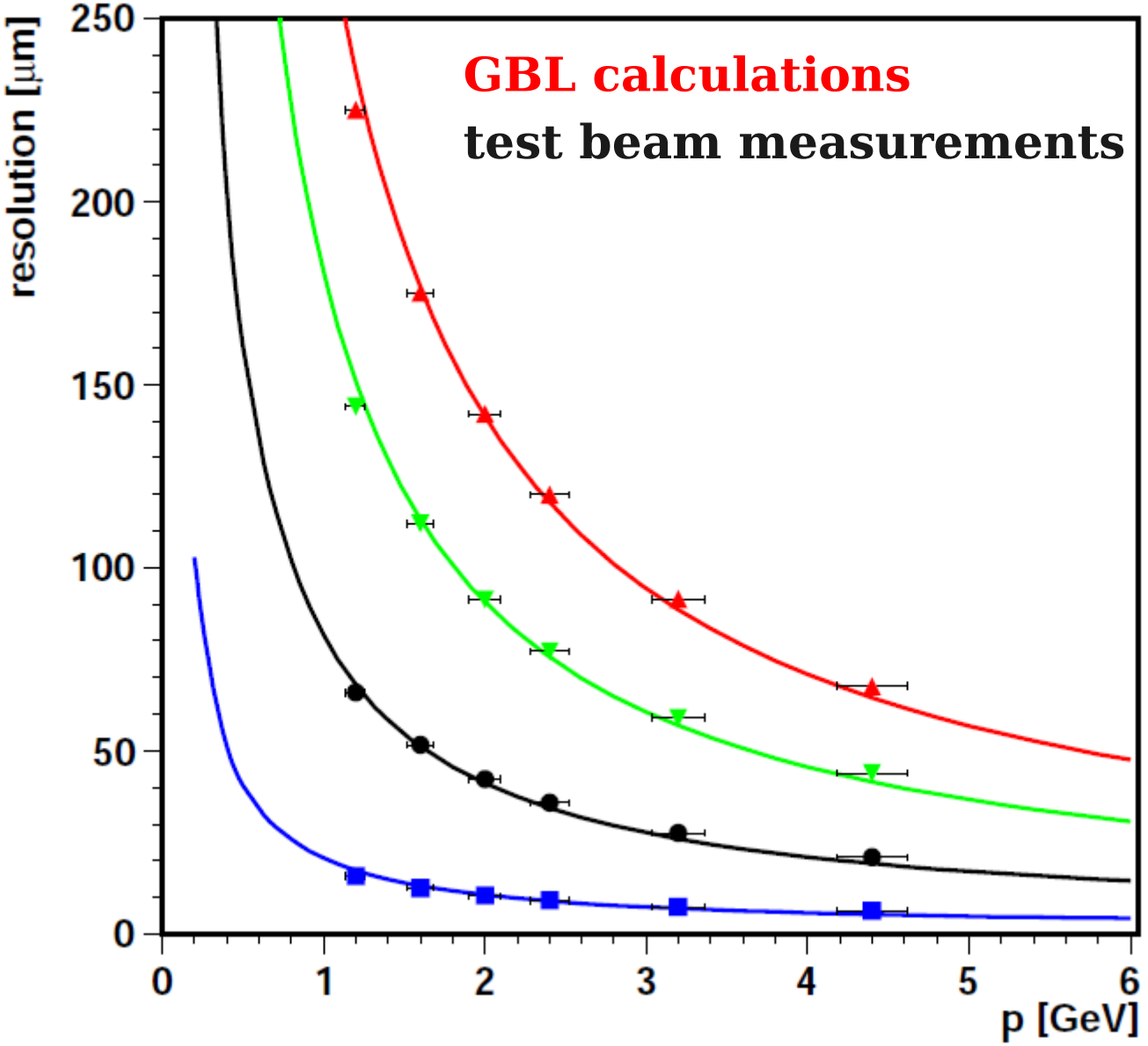
extrapol 2×150 mm

extrapol 1×150 mm

interpol

1 mm Cu inserted (7.0% X0)

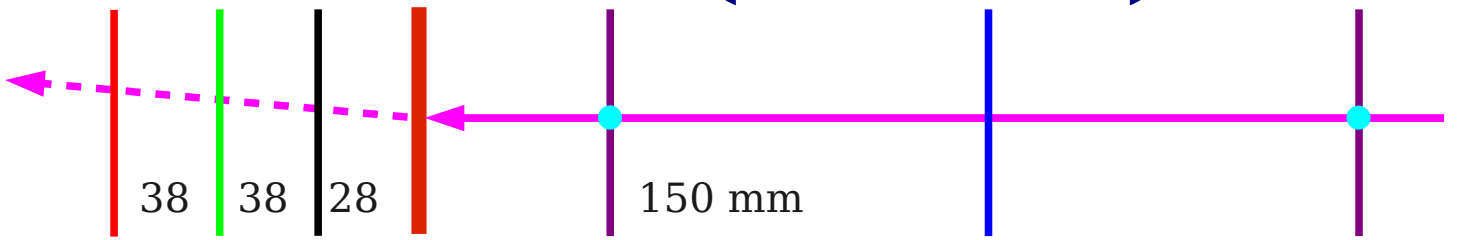


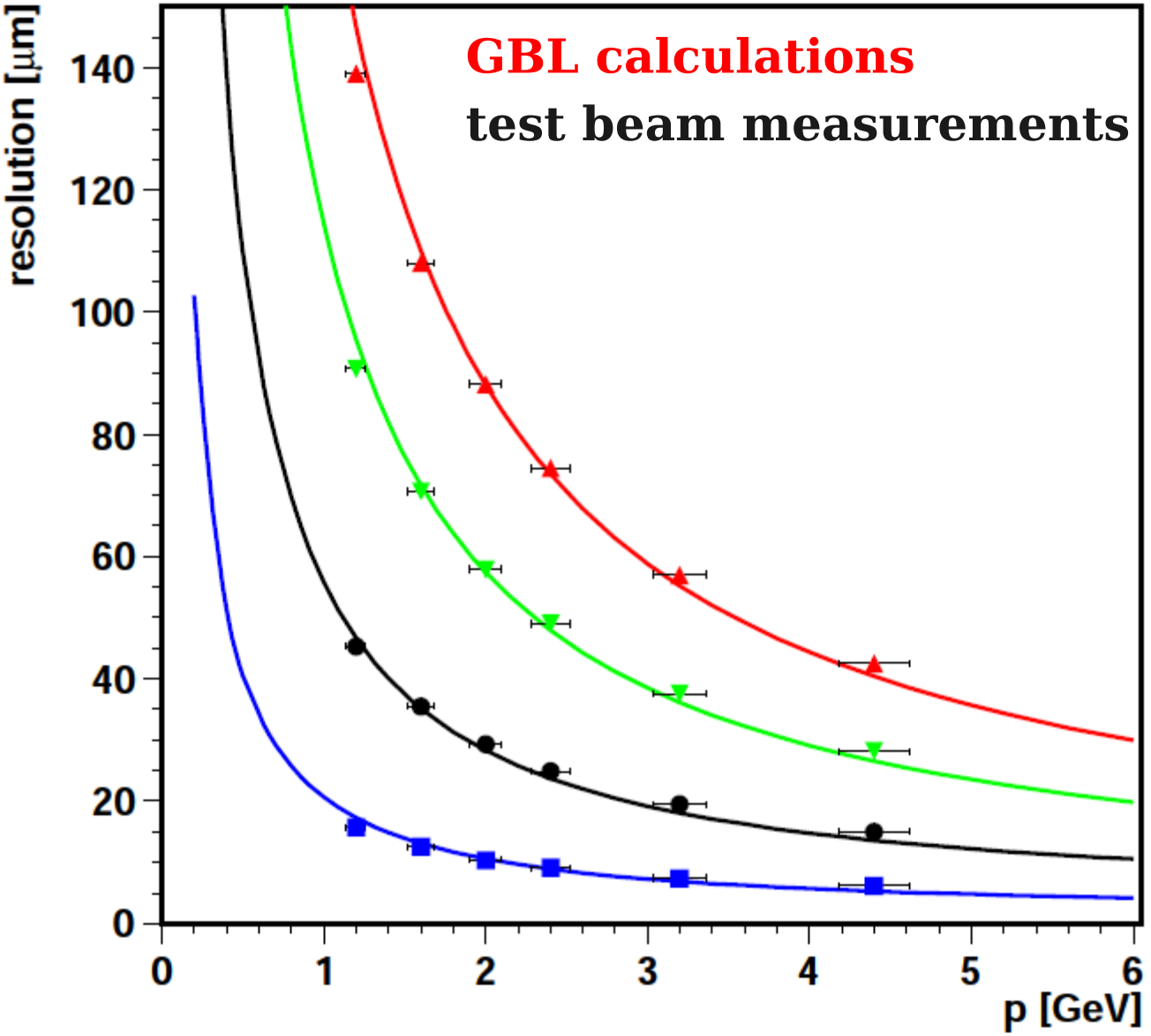


Data well described by GBL calculation with reduced Cu: 0.7 instead 1.0 mm.

extrapol 104 mm
extrapol 66 mm
extrapol 28 mm
interpol

0.4 mm Cu inserted (2.8% X0)





Data well described by GBL calculation with reduced Cu: 0.27 instead 0.4 mm.

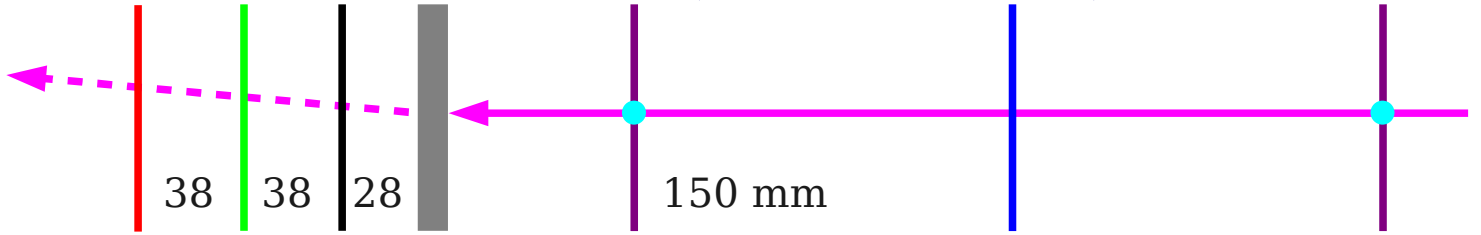
extrapol 104 mm

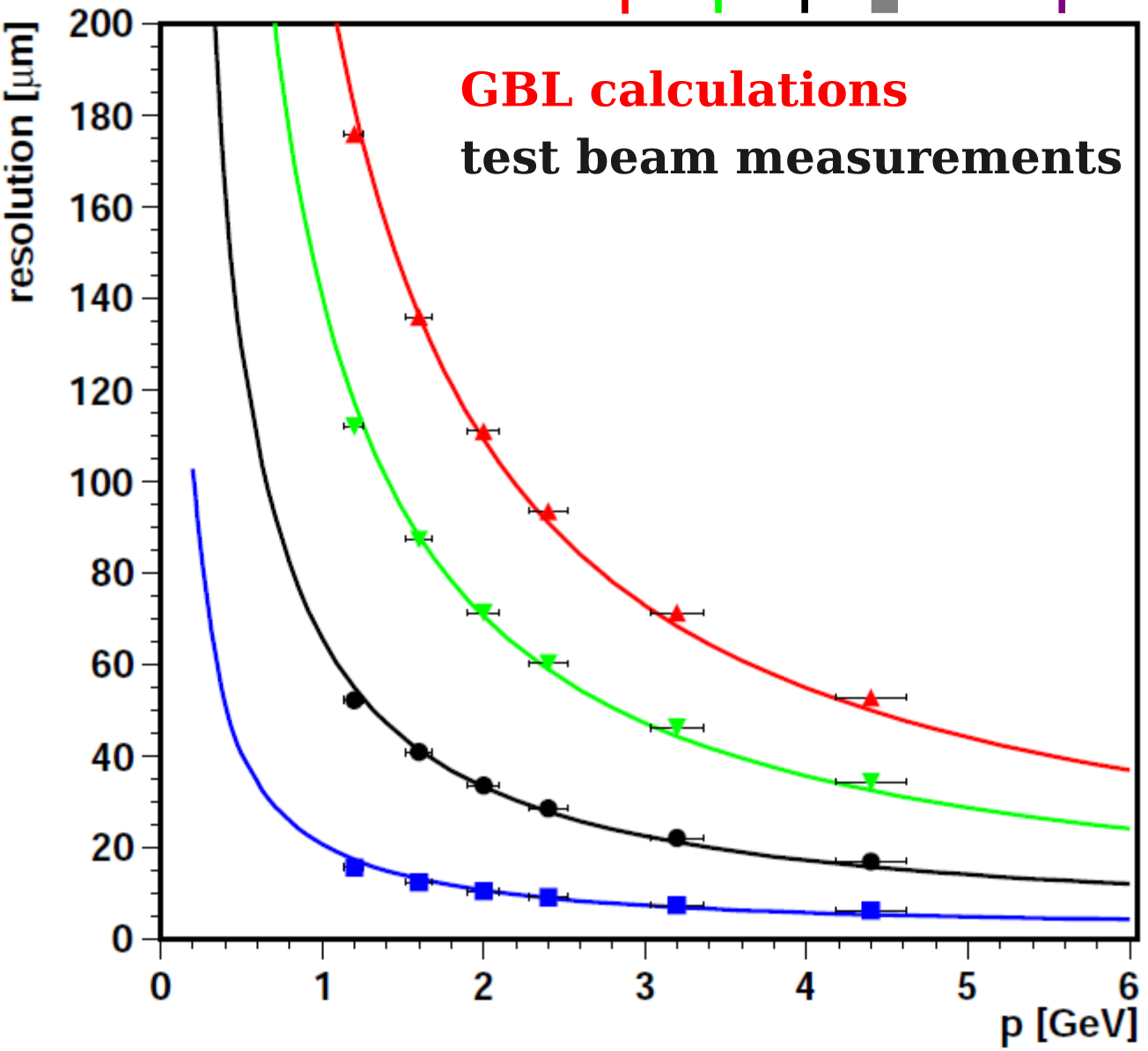
extrapol 66 mm

extrapol 28 mm

interpol

4 mm Al inserted (4.5% X0)





Data well described by GBL calculation with reduced Al: 2.6 instead 4.0 mm.

extrapol 104 mm
extrapol 66 mm
extrapol 28 mm
interpol

Summary

- Multiple scattering measured in the test beam telescope
- General Broken Lines used for error propagation
- Resolution as function of momentum and scattering planes quite well described by GBL calculation using
  - 3.5 µm intrinsic resolution
  - 65 µm Si + Kapton per plane (0.05% X0)
  - 50 mm equivalent air between planes at 150 mm spacing (?)
- Al and Cu plates inserted (1 – 7% X0):
  - momentum and geometry dependence well described by GBL calculations
  - when reducing the thickness by a factor 0.65 - 0.75.
  - Problem with PDG multiple scattering formula for thin layers?
  - difference between RMS and Gaussian core?