Momentum Setup and Measurement for PEPPo

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July 10, 2013

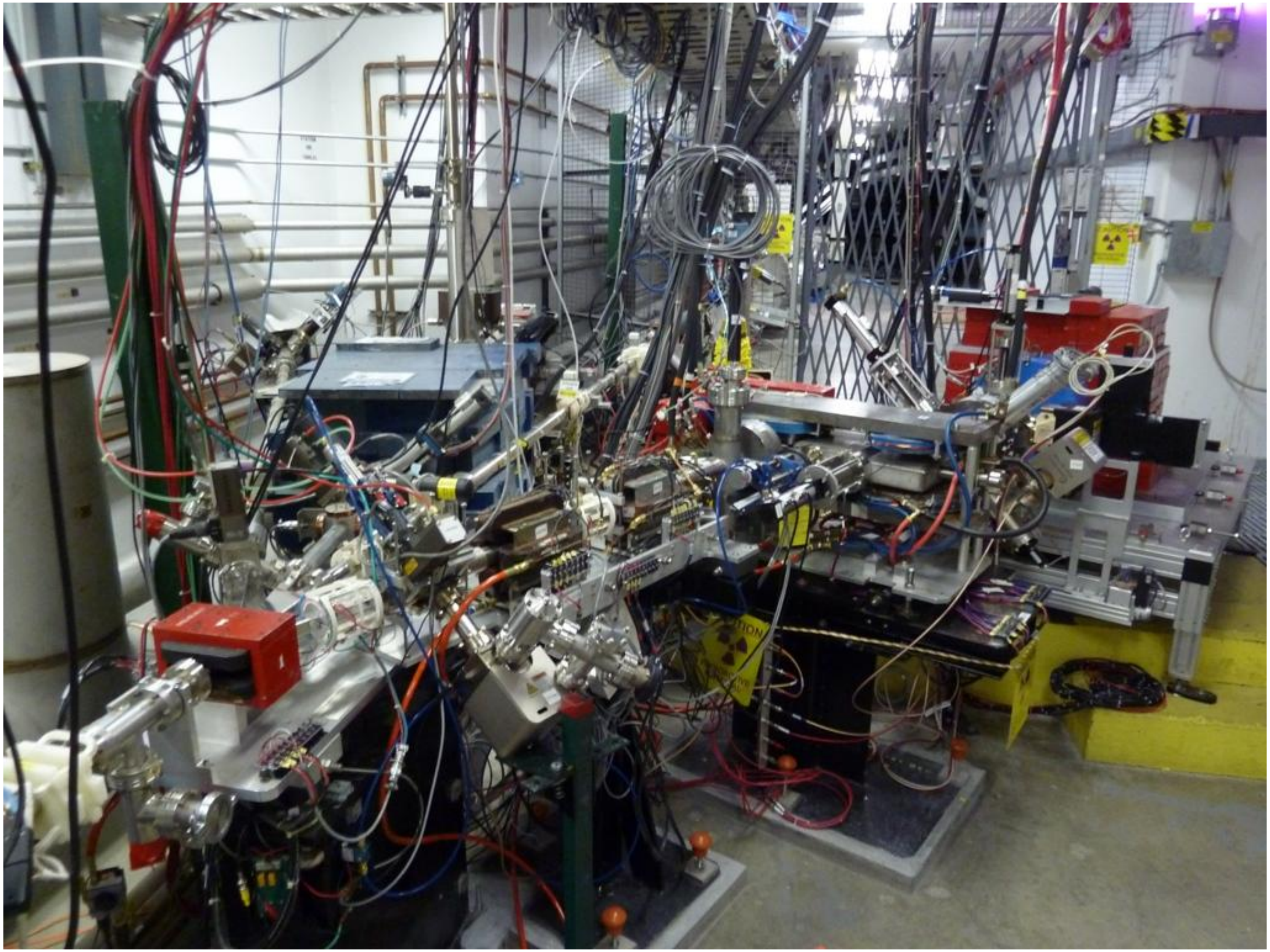
- ✓ Recollection of conditions
- ✓ Beam line elements
- ✓ Momentum analysis

Recollection of conditions

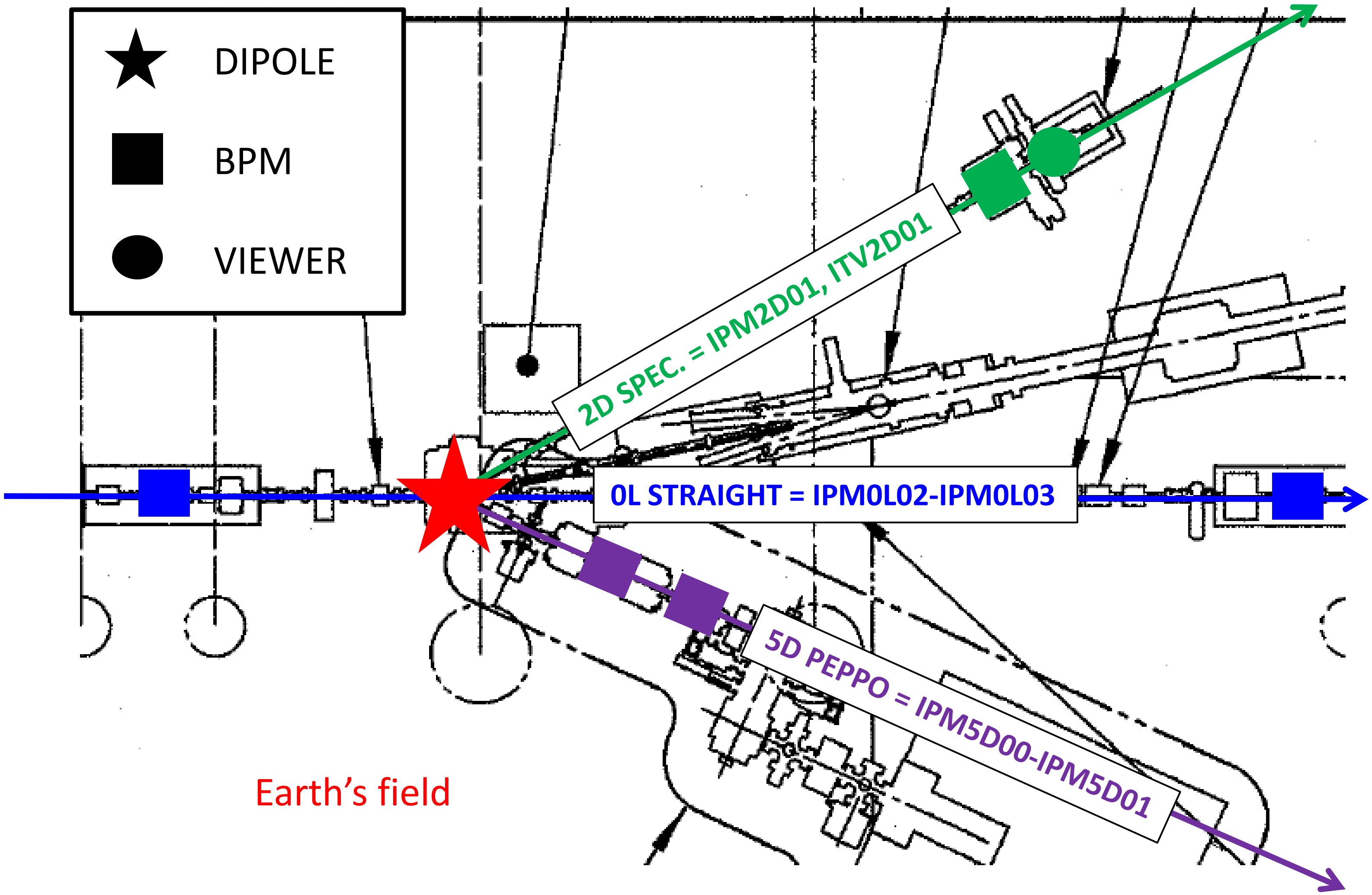
History…

- Configuration momenta “names” only approximate
- 21 optimized cryounit settings were determined
- 6 cryounit settings used for PEPPo experiment
    - Mott Electron Polarimetry (5.5)
    - Compton Analyzing Power Calibration (3.2, 4.2, 5.5, 6.3, 7.3)
    - Positron Production (8.2)
    - Positron Polarimetry (3.2, 4.2, 5.5, 6.3) twice
- e- beam defined momentum, even for e+ collection
- A formula between momentum and dipole current was used during the experiment
- A more detailed analysis is presented now

Beam line elements - photo



Beam line elements - layout



Momentum analysis – contributing factors

1. Dipole magnetic field
   - model
   - current dependence
   - spatial uniformity
   - settling time and reproducibility

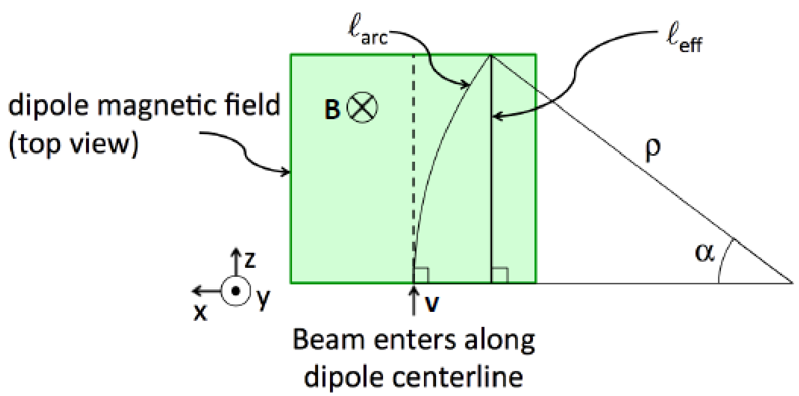
2. Dipole magnet power supplies
   - field mapping
   - tunnel operation

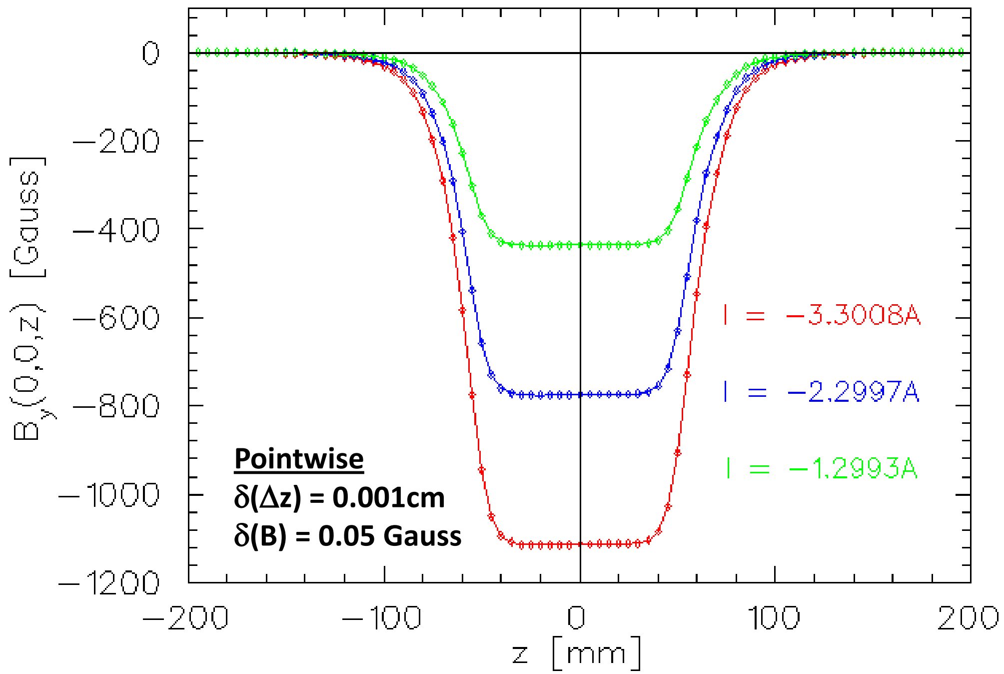
3. Alignment of elements
   - surveys
   - BPM calibration

4. Diagnostic accuracy
   - BPM vs. viewer

5. Stray magnetic fields
   - (un)shielded beam line
   - fixed steering coils

Dipole magnetic field – model



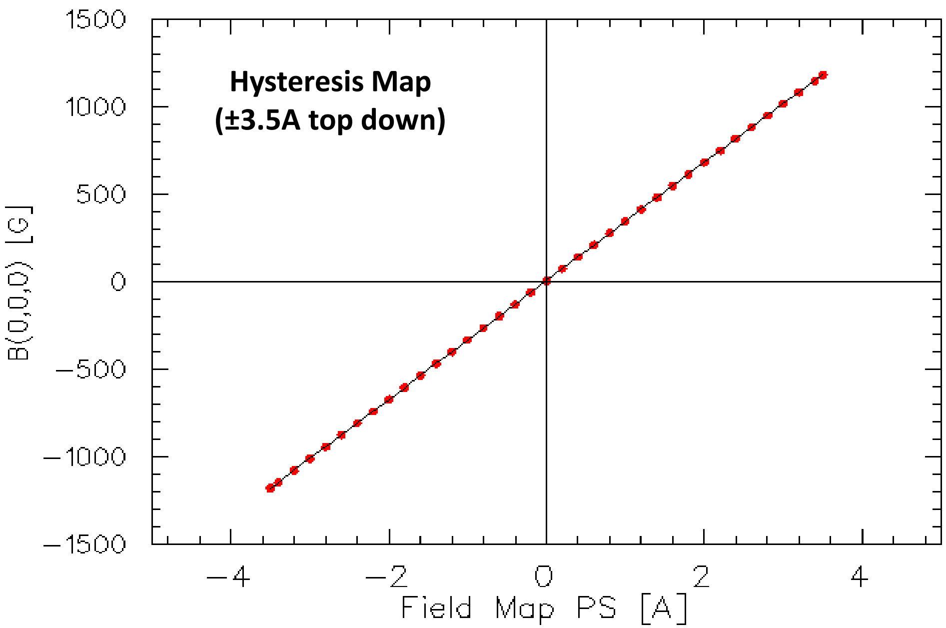


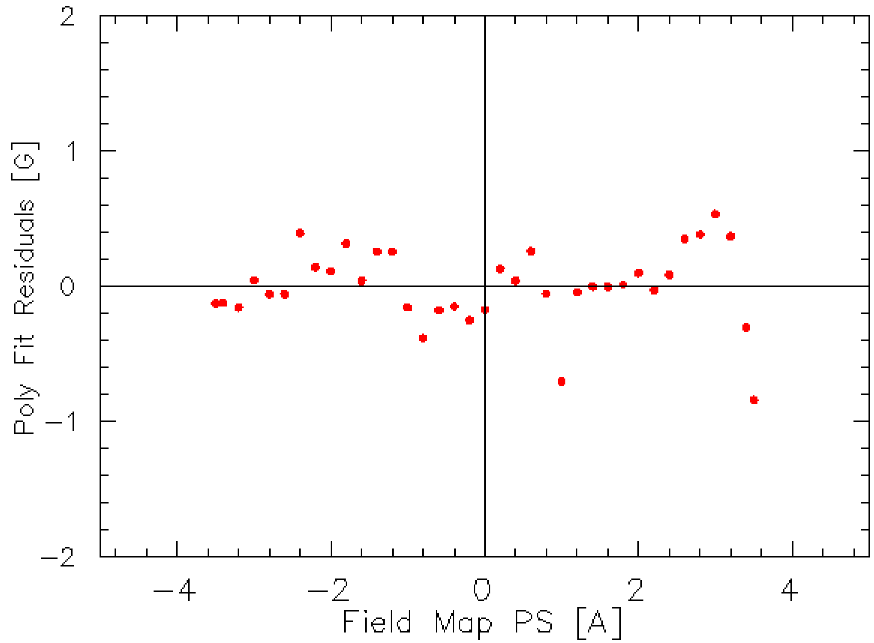
$$L_{eff} = [\ \int B_y(0,0,z)\,dz\ ] \,/\, B(0,0,0)$$

L_{eff} = 12.599 ± 0.031 cm
L_{eff} = 12.588 ± 0.031 cm
L_{eff} = 12.565 ± 0.031 cm

L_{eff} = 12.584 ± 0.018 cm ⇒ $\delta L_{eff}/L_{eff}$ = 0.14%

Dipole magnetic field – current dependence





$$B = U_0 + U_1 \cdot I^1 + U_2 \cdot I^2 + U_3 \cdot I^3$$

$U_0 = 6.5659 \pm 0.0737$
$U_1 = 339.78 \pm 0.06$
$U_2 = -0.47767 \pm 0.01222$
$U_3 = -0.19932 \pm 0.00672$

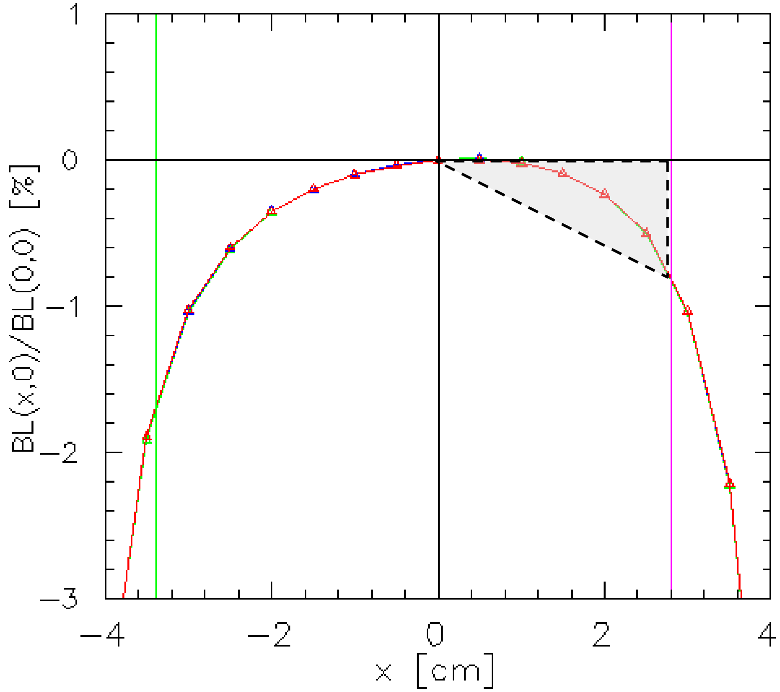
$\Rightarrow$ $\delta B/B < 0.2\%$

Dipole magnetic field – spatial dependence

HORIZONTAL

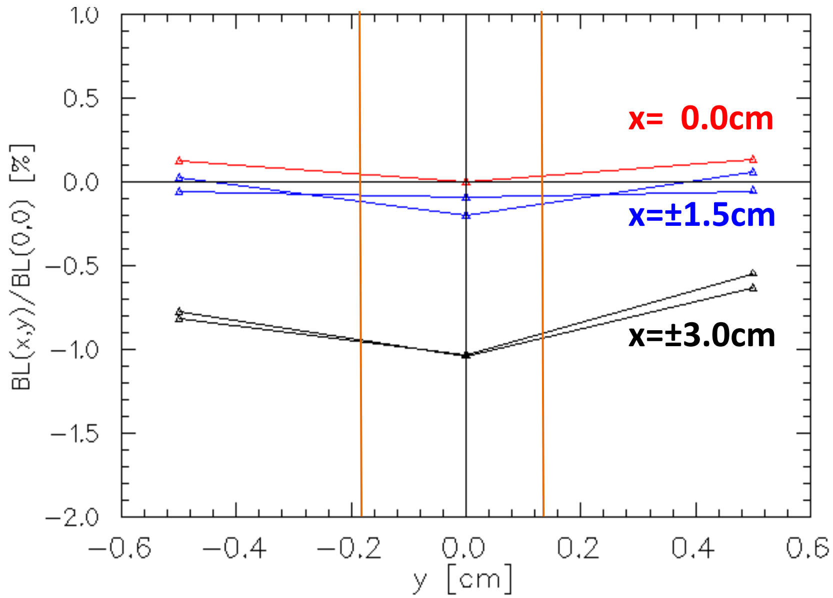
Spectrometer α = -30 deg
$\rho = L_{eff}/\sin(\alpha)$ = 25.2 cm
$\Delta x = \rho\,(1-\cos(\alpha))$ = -3.4 cm

PEPPo α = 25 deg
$\rho = L_{eff}/\sin(\alpha)$ = 29.8 cm
$\Delta x = \rho\,(1-\cos(\alpha))$ = +2.8 cm



VERTICAL

BPM's Y <0.15mm



$\Rightarrow$ $\delta BL/BL < 0.5\%$

Dipole magnetic field – settling time and reproducibility

SETTLING TIME

Part 3: Core Magnetic Field Data

Instruction: Cycle magnet current to +/- 3.5A twice and measure dipole field B vs. t at -2.3A.

Elapsed Time (min:sec)	I (A)	B (G)
00:05	-2.300	-774.85
00:20	-2.300	-774.85
01:00	-2.300	-774.85
02:00	-2.300	-774.85
03:00	-2.300	-774.85
04:00	-2.300	-774.85
05:00	-2.300	-774.85

REPRODUCIBILITY

Instruction: Cycle magnet current to +/- 3.5A twice and measure dipole field at -2.3A. Next, immediately remove power to magnet. After restoring power, cycle magnet current to +/- 3.5A twice and measure dipole field at -2.3A.

Run	B (G)	Deviation from Average (%)
0	-774.90	-0.09%
1	-774.25	-0.01%
2	-773.90	0.04%
3	-773.95	0.03%
4	-774.30	-0.01%
5	-773.85	0.04%
6	-774.05	0.02%
7	-774.30	-0.01%
Average	-774.19	

$\Rightarrow$ $\delta B/B < 0.1\%$

Dipole magnet power supplies

Field Mapping

- Magnet was mapped in 2008 with 10 Amp power supply
- Reported power supply accuracy <1mA

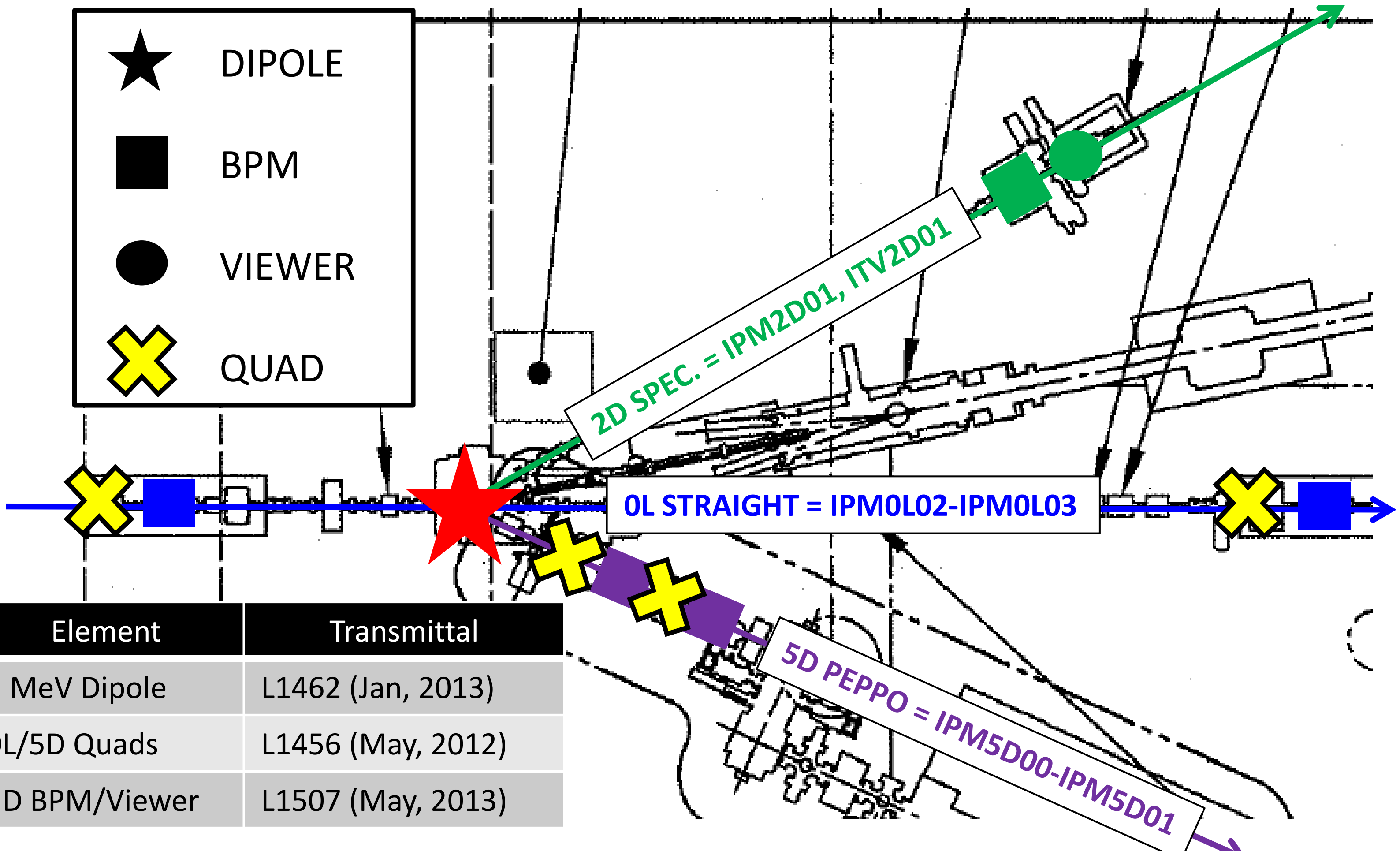
Tunnel Operation

- Standard 10 Amp trim power supply used (IN02B26-9)
- Typical accuracy of most recent calibration <5mA

⇨ $\delta I/I = 0.05\%$

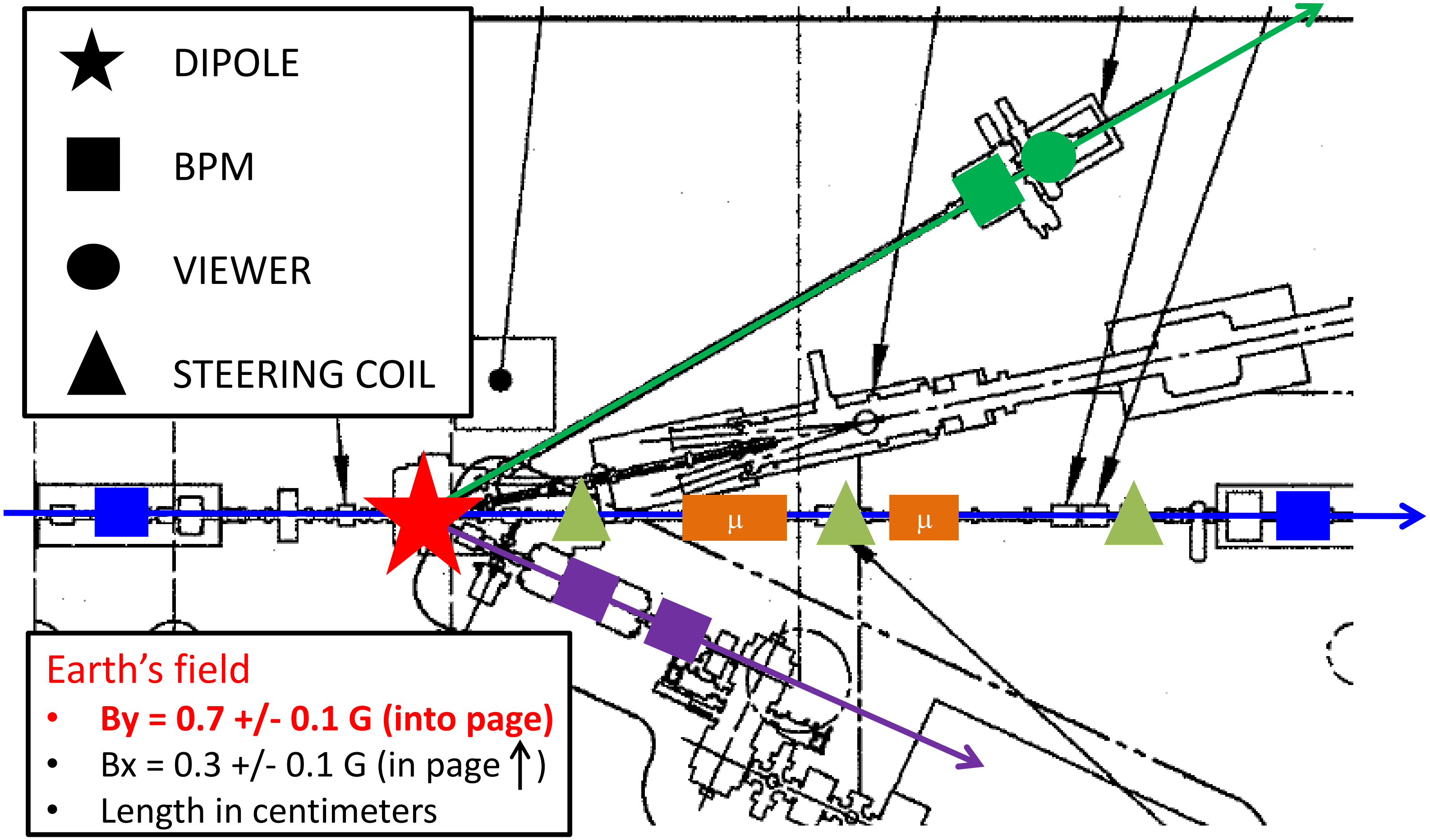
Alignment of elements – surveys and BPM calibration

- ✓ Elements are surveyed to < 0.2mm
- ✓ BPM's are calibrated to upstream quad
- ✓ BPM resolution is <0.02mm; typical beam jitter <0.05mm
- ✓ Viewer resolution estimated at 2.5mm



Element	Transmittal
5 MeV Dipole	L1462 (Jan, 2013)
0L/5D Quads	L1456 (May, 2012)
2D BPM/Viewer	L1507 (May, 2013)

Stray magnetic fields - issues



- ➢ 3 steering coils remained ON and fixed throughout e- momentum measurements
- ➢ The purpose of the coils is to compensate the Earth's field over long distance

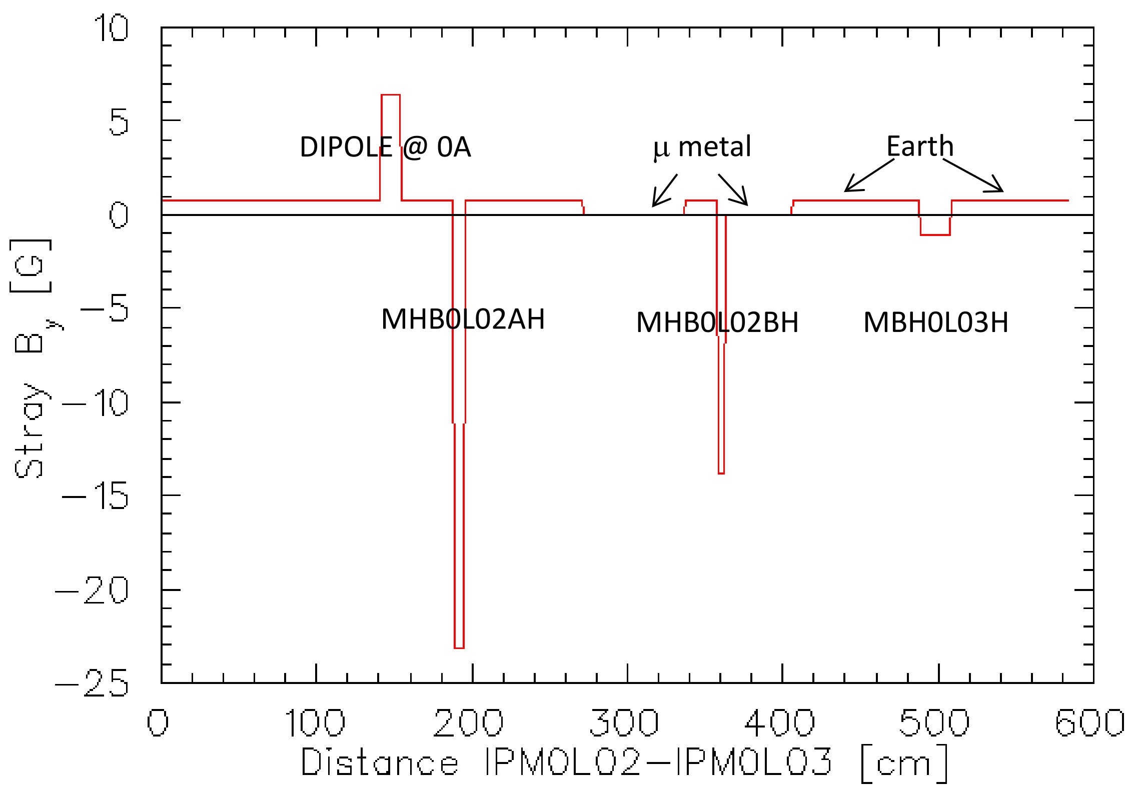
The stray magnetic fields represent the largest factor in the momentum analysis

Stray magnetic fields – straight section

1. Divide 584cm distance between IPM0L02 and IPM0L03 into 1cm steps

2. Assign fixed stray magnetic field into each 1cm step according to table

Element	Field [G]	Region
Earth	0.7 ± 1	globally
μ metal	<0.1 => 0	2 spans
MHB0L02AH	-23.15 + E	7cm
MHB0L02BH	-13.86 + E	7cm
MBH0L03H	-1.05 + E	11cm
DIPOLE @ 0A	+6.356	13cm



Note: integrated Earth and steering coils fields are 400G-cm and -271 G-cm respectively

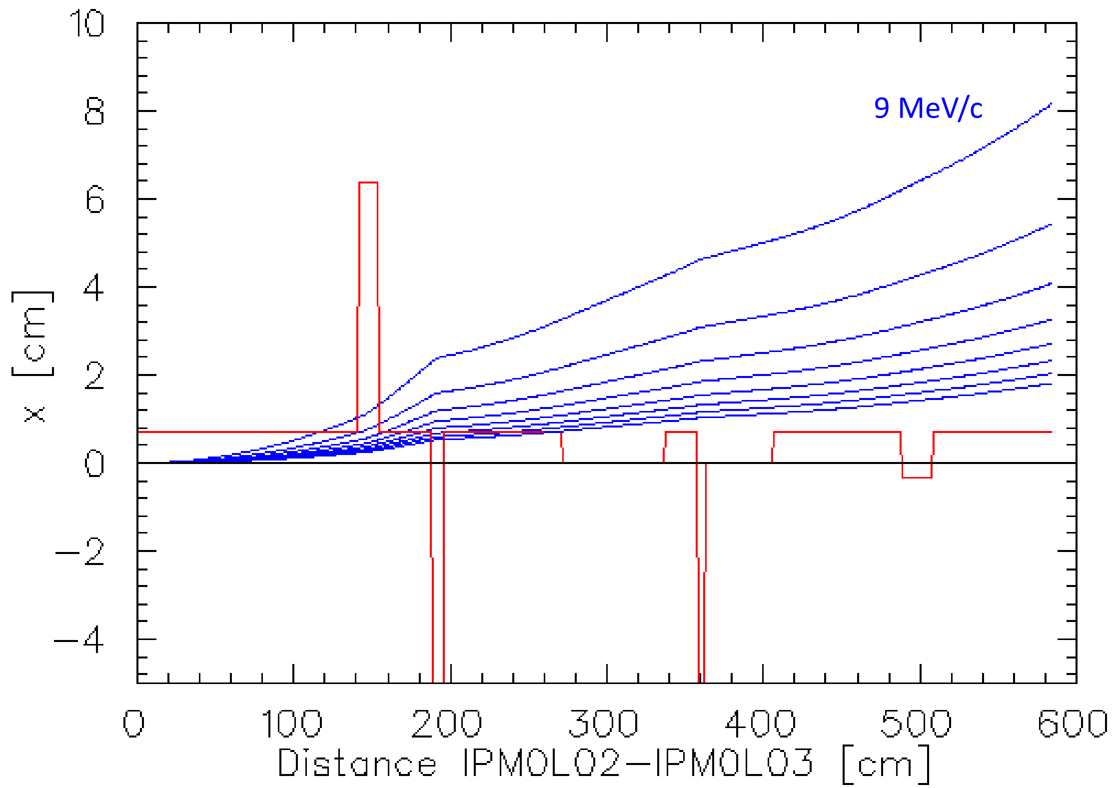
Stray magnetic fields – straight section

3. Assuming a normal launch ($x_0 = x'_0 = 0$) calculate trajectory from 2-9 MeV/c

4. Experimentally both x_0 and x_F were zero within <0.02 cm

5. This was achieved by variable "allowed" steering coils upstream of IPM0L02

P [MeV/c]	X(final) [cm]	XP(final) [deg]	XP(steer) [deg]
2.00000	8.15268	1.43291	-0.79985
3.00000	5.43513	0.95527	-0.53324
4.00000	4.07635	0.71646	-0.39993
5.00000	3.26108	0.57316	-0.31994
6.00000	2.71757	0.47764	-0.26662
7.00000	2.32934	0.40940	-0.22853
8.00000	2.03818	0.35823	-0.19996
9.00000	1.81171	0.31842	-0.17775



Stray magnetic fields – straight section

5. Applying the calculated steering correction achieves measured BPM values

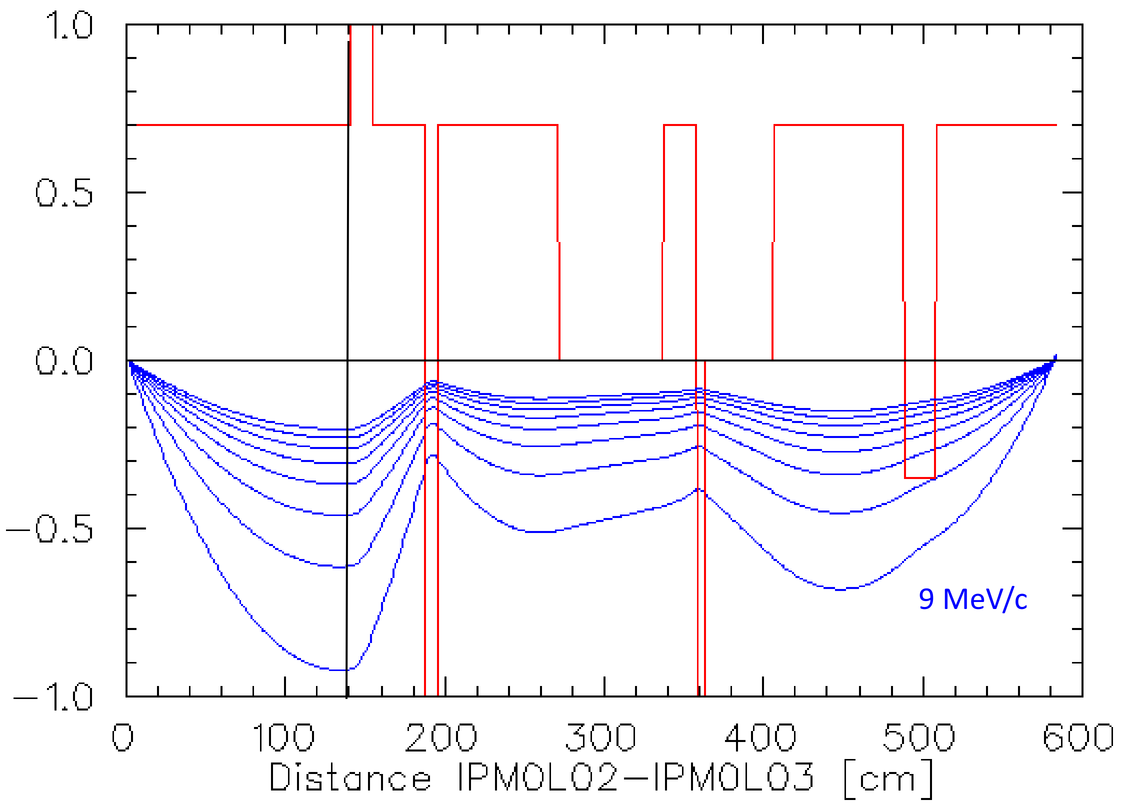
6. The relevant values for momentum calculation are x_{dipole} and x'_{dipole} at z=141cm

Application of Steering

P [MeV/c]	XP(steer) [deg]	X(final) [cm]	XP(final) [deg]
2.00000	-0.79985	0.01400	0.63306
3.00000	-0.53324	0.00927	0.42203
4.00000	-0.39993	0.00696	0.31653
5.00000	-0.31994	0.00561	0.25322
6.00000	-0.26662	0.00464	0.21102
7.00000	-0.22853	0.00399	0.18087
8.00000	-0.19996	0.00353	0.15827
9.00000	-0.17775	0.00306	0.14067

Position and Angle at Dipole

P [MeV/c]	X(dipole) [cm]	XP(dipole) [deg]
2.00000	-0.91874	0.04184
3.00000	-0.61251	0.02788
4.00000	-0.45938	0.02091
5.00000	-0.36750	0.01673
6.00000	-0.30626	0.01394
7.00000	-0.26250	0.01195
8.00000	-0.22968	0.01046
9.00000	-0.20418	0.00929



Stray magnetic fields – straight section

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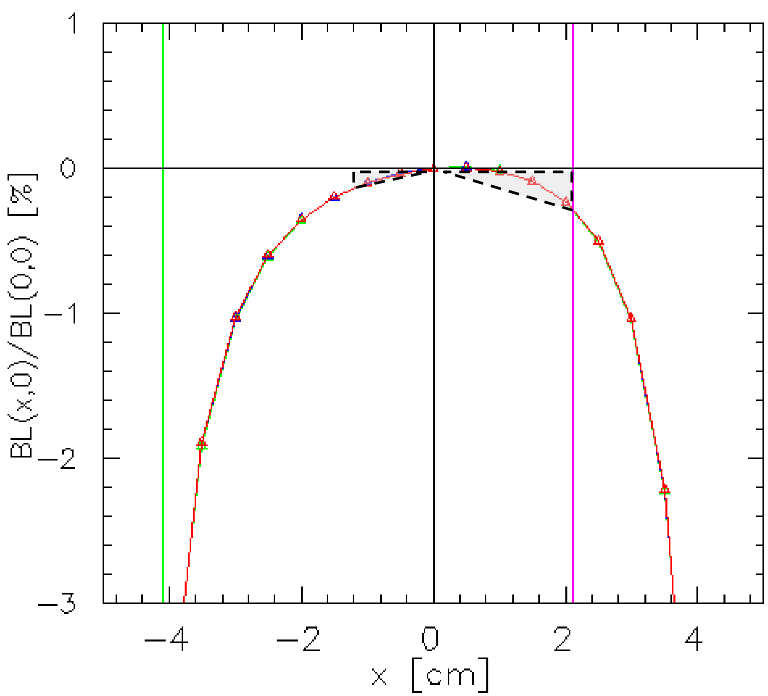
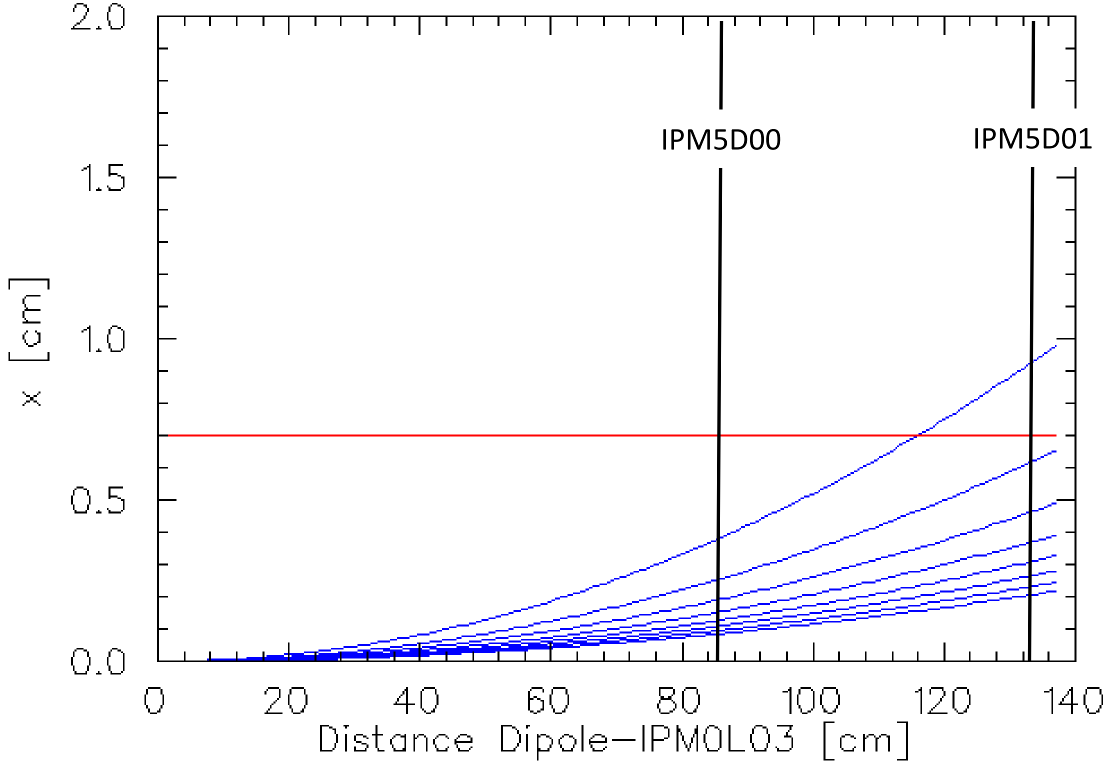
1. Calculations are accurate to 10%
2. Position correction < -0.7cm improves spatial uncertainty
3. Angle correction <0.1% so added as uncertainty



$\Rightarrow$ $\delta BL/BL < 0.3\%$

Stray magnetic fields – PEPPo section

P [MeV/c]	Earth [deg]
2.80000	0.48311
3.00000	0.45090
3.20000	0.42272
3.40000	0.39786
3.60000	0.37575
3.80000	0.35598
4.00000	0.33818
4.20000	0.32207
4.40000	0.30743
4.60000	0.29407
4.80000	0.28181
5.00000	0.27054
5.20000	0.26014
5.40000	0.25050
5.60000	0.24156
5.80000	0.23323
6.00000	0.22545
6.20000	0.21818
6.40000	0.21136
6.60000	0.20496
6.80000	0.19893
7.00000	0.19324
7.20000	0.18788
7.40000	0.18280
7.60000	0.17799
7.80000	0.17342
8.00000	0.16909
8.20000	0.16496



Momentum analysis - parameters

Parameter	Correction	Uncertainty
Dipole – L_{eff}	no	$\delta L_{eff}/L_{eff} = 0.14\%$
Dipole – field map	no	$\delta B/B < 0.2\%$
Dipole – spatial	no	$\delta BL/BL < 0.3\%$
Dipole – settle/reproduce	no	$\delta B/B < 0.1\%$
Dipole – power supplies	no	$\delta I/I < 0.05\%$
Position - beam	no	<0.25 mm
Stray magnetic field	yes	10% of correction

Momentum analysis - typical calculation @ "5.5MeV/c"

	MBVM [A]	A5 [deg]	dA5 [deg]	0L02x [mm]	0L02y	0L03x	0L03y	5D00x	5D00y	5D01x	5D01y
STRAIGHT	0.000	0	0	-0.100	-0.090	0.099	-0.099	0.000	0.000	0.000	0.000
PEPPO	1.744	0.255	0.005	-0.041	-0.244	0.000	0.000	-0.346	-0.225	0.438	0.058

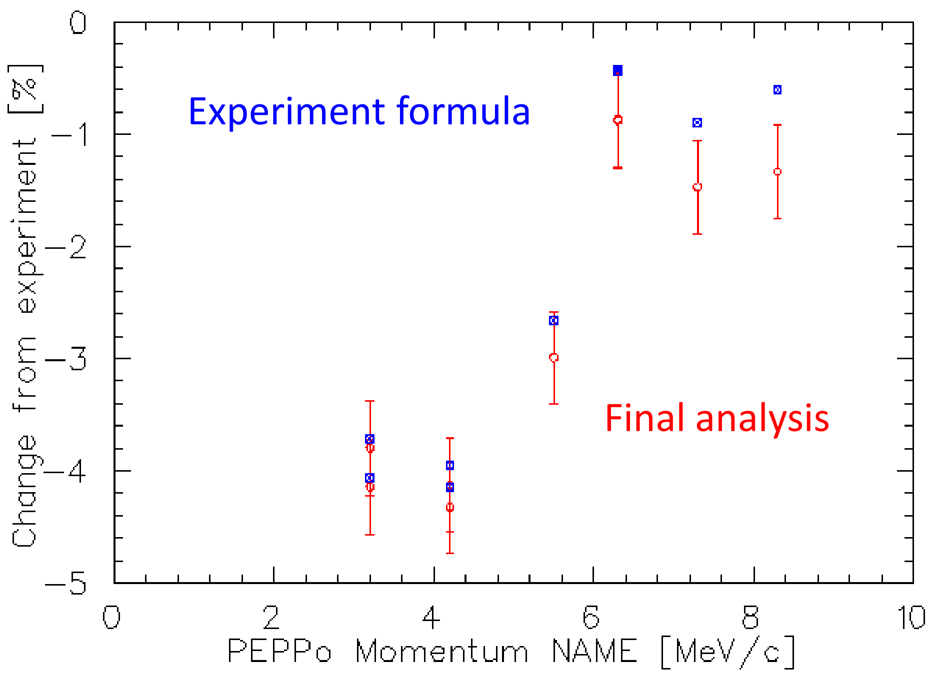
$$\Delta(BL) = (B_{DIPOLE}L_{eff})_{PEPPO}$$

$$\Delta\Theta = (\Theta_{PEPPO\text{-}MEAS} - \Theta_{PEPPO\text{-}CORR} - \Theta_{STRAIGHT\ CALCULATED})$$

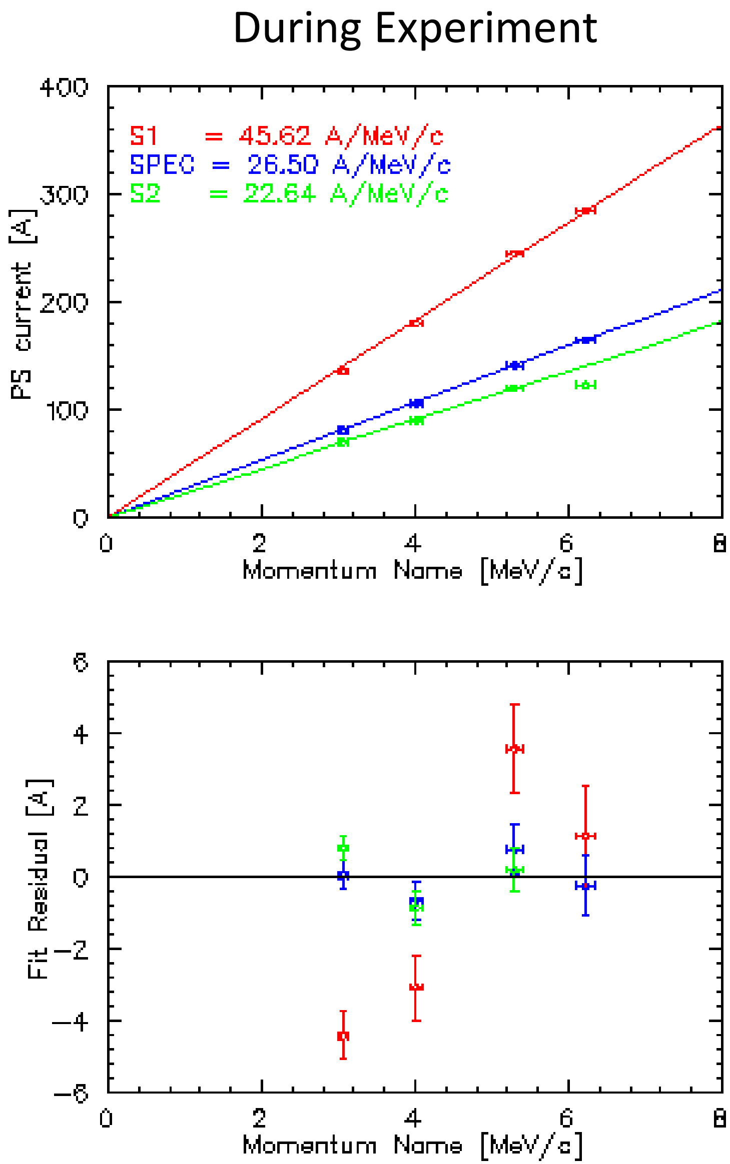
$$p\ [MeV/c] = 2.9980E\text{-}4 \cdot \Delta(BL[G\text{-}cm]) / \sin(\Delta\Theta)$$

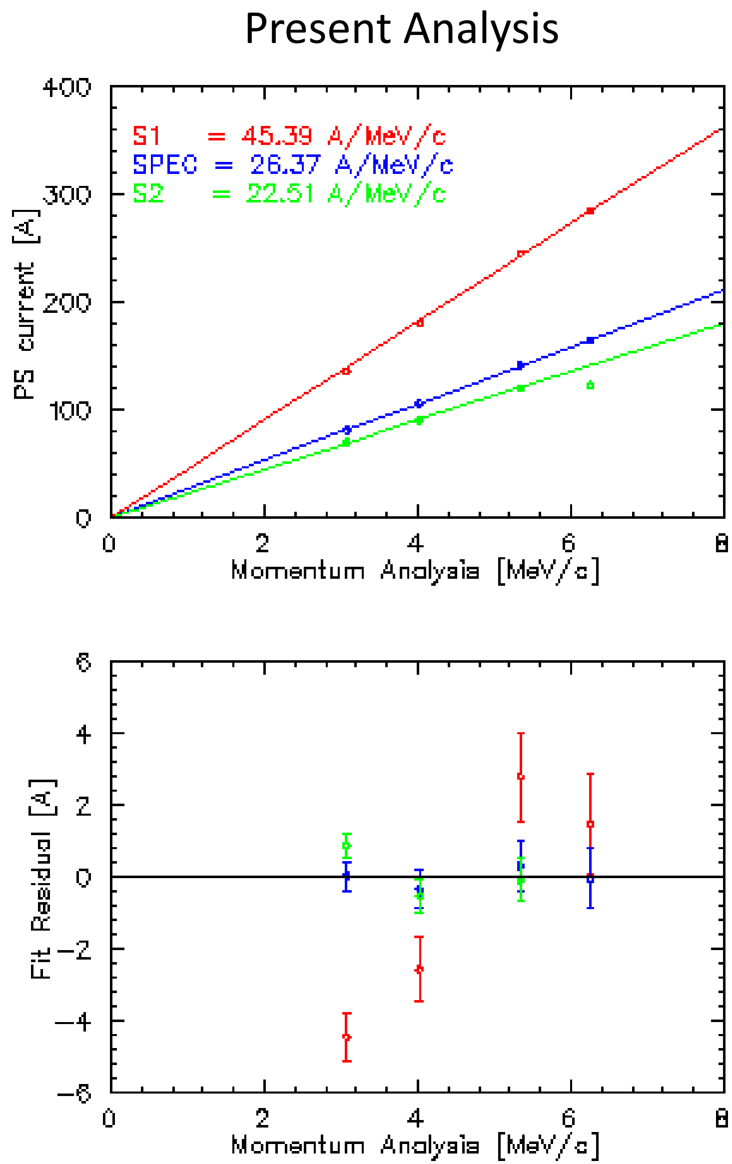
Momentum analysis - results

Name	Cryounit Gradients & Phases (MV & deg)				BL ± δBL (Gauss-cm)		Θ ± δΘ (deg)		P ± δP (MeV/c)		δP/P (%)
5.5	6.49	121.3	3.31	-154.4	7508.0	30.23	24.95	0.04	5.336	0.023	0.424
4.2	3.56	131.7	3.31	-131.8	5634.0	22.69	24.86	0.04	4.018	0.017	0.430
6.3	8.06	120.0	3.81	-158.4	8784.2	35.37	24.94	0.04	6.245	0.027	0.425
3.2	4.87	127.3	0.00	-158.4	4303.1	17.33	24.78	0.05	3.078	0.014	0.444
7.3	8.06	119.6	5.81	-159.9	10128.1	40.78	24.97	0.04	7.193	0.030	0.424
8.3	8.40	119.1	7.21	-162.2	11538.3	46.46	24.99	0.04	8.189	0.035	0.424
4.2	3.56	131.7	3.31	-131.8	5646.7	22.74	24.86	0.04	4.027	0.017	0.430
6.3	8.06	120.0	3.81	-158.4	8784.2	35.37	24.94	0.04	6.246	0.027	0.425
3.2	4.87	129.2	0.00	-162.2	4290.3	17.28	24.79	0.05	3.067	0.014	0.444



Momentum analysis - connection to collection magnets





Summary

Momenta for Mott polarimetry, Compton electron calibration, positron production and positron collection determined with uncertainty < 0.5%

There appears to be no significant conflict with collection magnet settings

Recommendations for future momentum measurements…

- shield stray magnetic field
- eliminate steering coils
- improve model or dipole with regard to spatial profile
- remember to null spectrometer dipole magnet for straight-ahead
- add BPM and means for beam calibration to spectrometer line

I did not complete the cryounit momentum calibration analysis