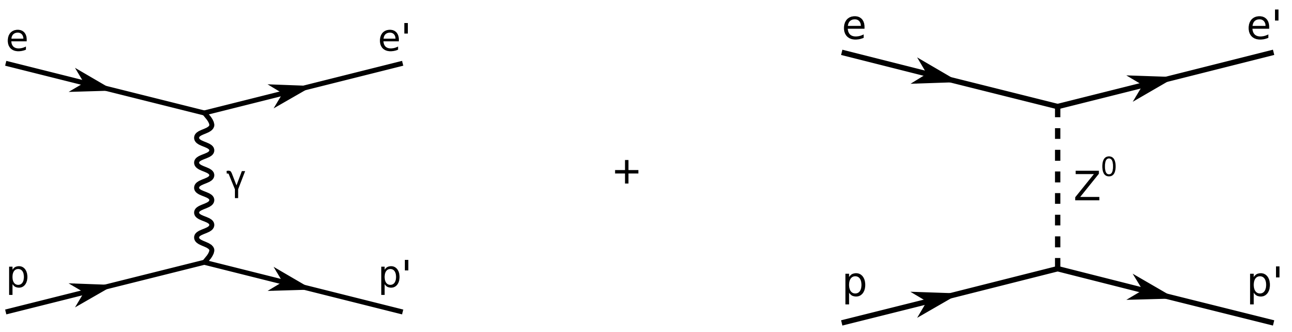
Measurement of the beam normal single-spin asymmetry of ^{12}C

Weak Mixing Angle

- Weinberg angle / weak mixing angle:
  - Important parameter in standard model
  - Relative coupling strength of weak and electromagnetic force

    $e = g \cdot \sin \theta_W$

- Measurement by Parity Violation (PV):
  - Polarised electrons, scattered on protons
  - Cross section dominated by electromagnetic interaction
  - Small contribution from Z^0 exchange → Parity violation
  - Measurement of PV asymmetry → Z^0 contribution



Parity conserving
Large cross section

Parity violating
small cross section

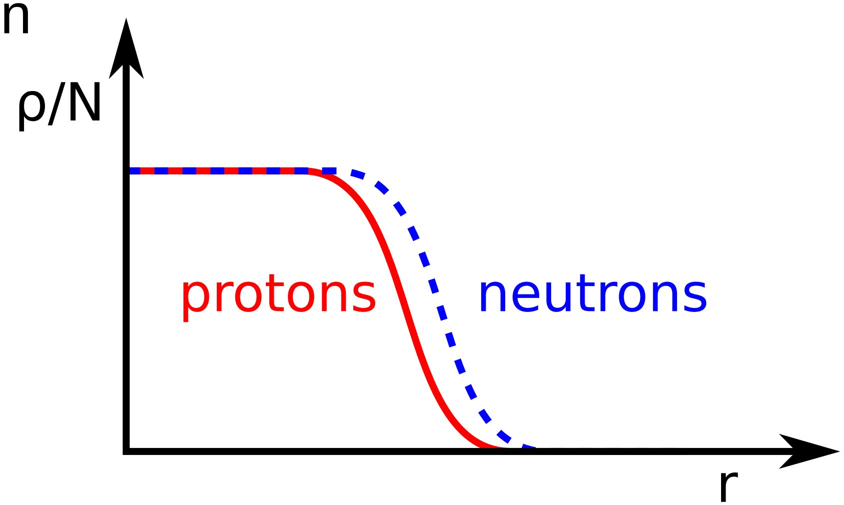
Neutron Skin

- Heavy nuclei contain more neutrons than protons
- Spacial distribution of neutrons might be larger

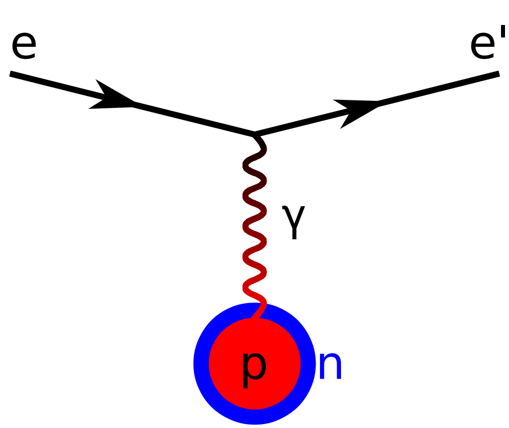
- Z^0 Boson couples more strongly to Neutron

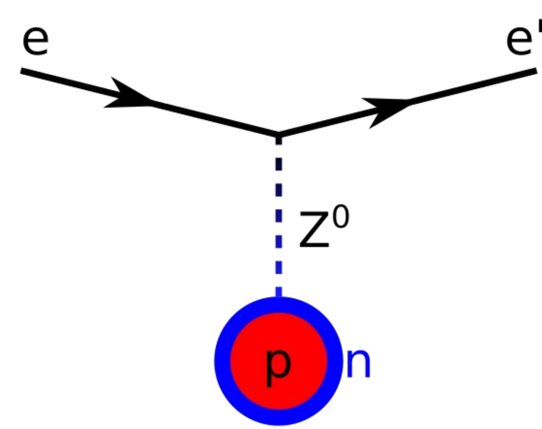
  $Q_W^n \approx -0.99$

  $Q_W^p \approx 0.07$



- Measurement by parity violation:
  - Electron scattering on nuclei
  - Parity violating contribution to cross section from Z^0 exchange
  - Measurement of PV asymmetry
    → Neutron distribution

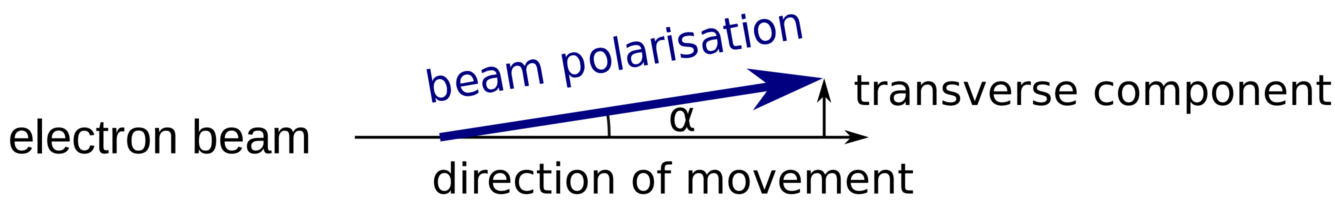




Beam Normal Asymmetry

- Difficulties of PV measurements:
  - Large electromagnetic cross section, small asymmetry ~ 10^{-6}
  - Long run times
  - Necessary: Good understanding of background
  - Especially: Helicity correlated background

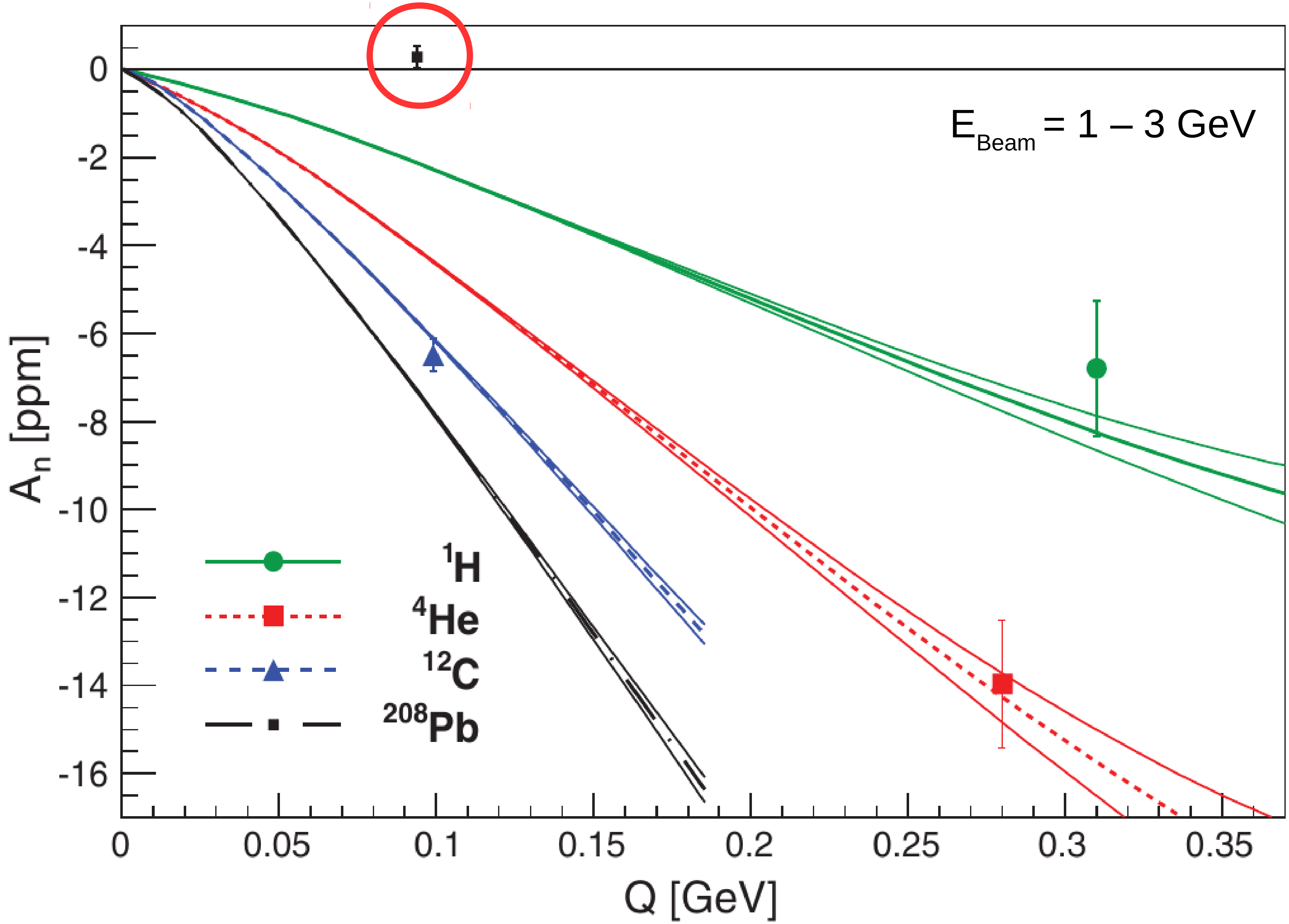
- Beam normal (single spin) asymmetry:
  - Helicity correlated background contribution
  - Caused by transversal polarisation component



  - Necessary to measure for all targets used in PV experiment

Measurement at PREX

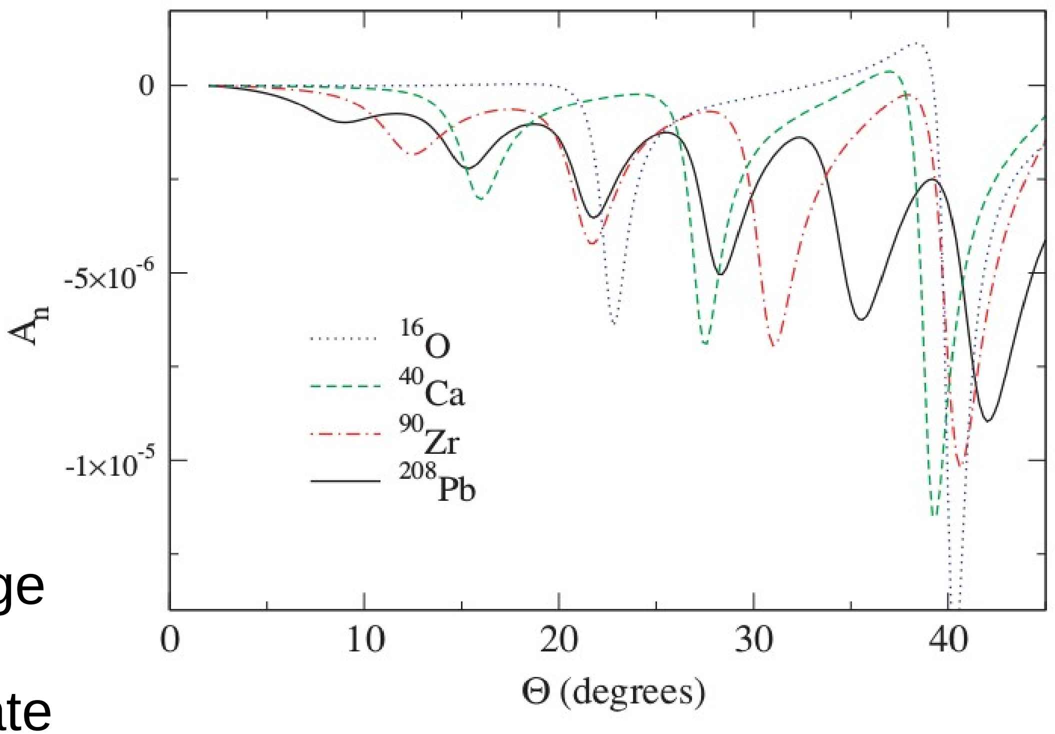
- Measurement of beam normal single spin asymmetry at PREX



Theoretical Predictions

- Origin of asymmetry
  - Interference of 1 and 2 photon exchange

- Calculations:
  - Gorchtein & Horowitz
    [Phys. Rev. C77, 044606 (2008)]
    - Two photon exchange approximation
    - Including full range of inter-mediate excitation states
  - Cooper & Horowitz
    [Phys. Rev. C72, 034602 (2005)]
    - All orders of photon exchange
    - Coulomb distortion effects
    - Only elastic intermediate state

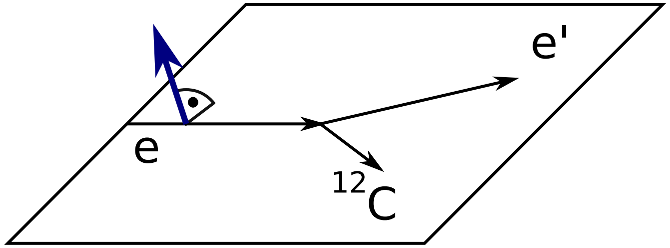


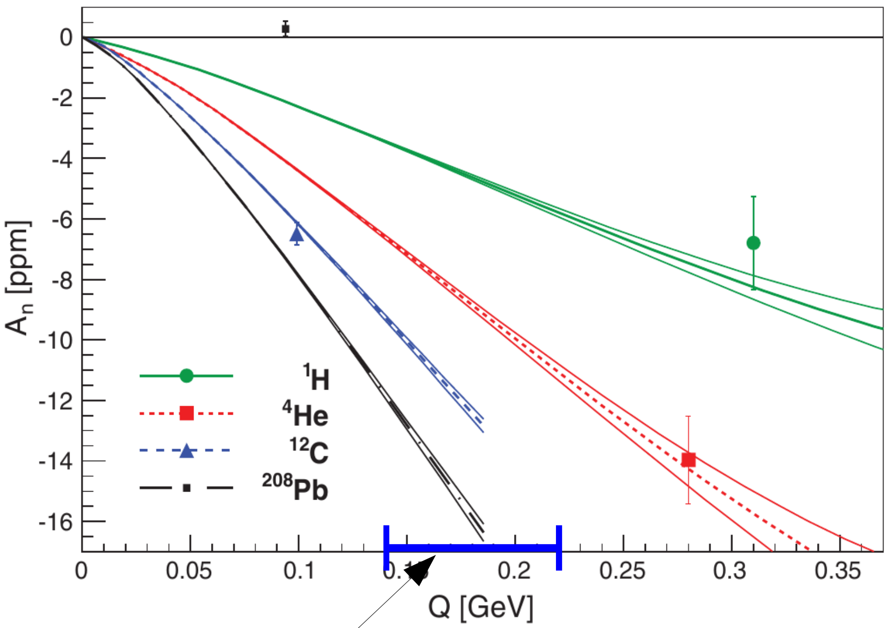
$E_{Beam} = 850$ MeV

=> No consistent Theory but
- Contribution to every PV experiment
- Contribution to other measurements (e.g. proton radius)

Mainz Measurement

- Measurement of beam normal asymmetry on ^{12}C
  - E_{Beam} = 570 MeV
  - Scattering angles = 15° - 26°
  - $Q^2 = 0.02 – 0.05\ GeV^2/c^2$
    ($Q = 0.14 – 0.22\ GeV/c$)





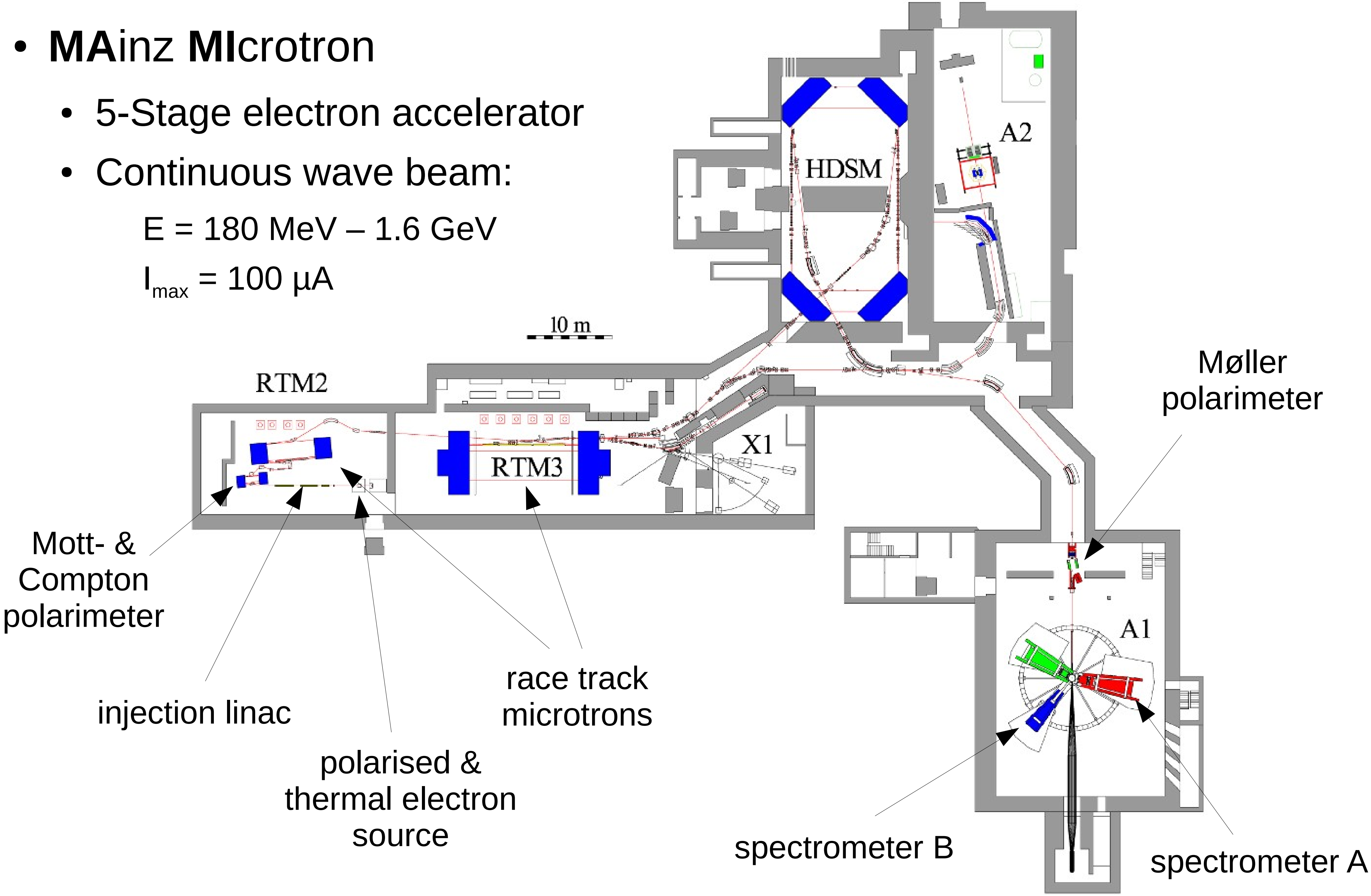
kinematic range of this experiment

- Requirements:
  - High quality transversely polarised electron beam of known polarisation
  - High rate capable detector system

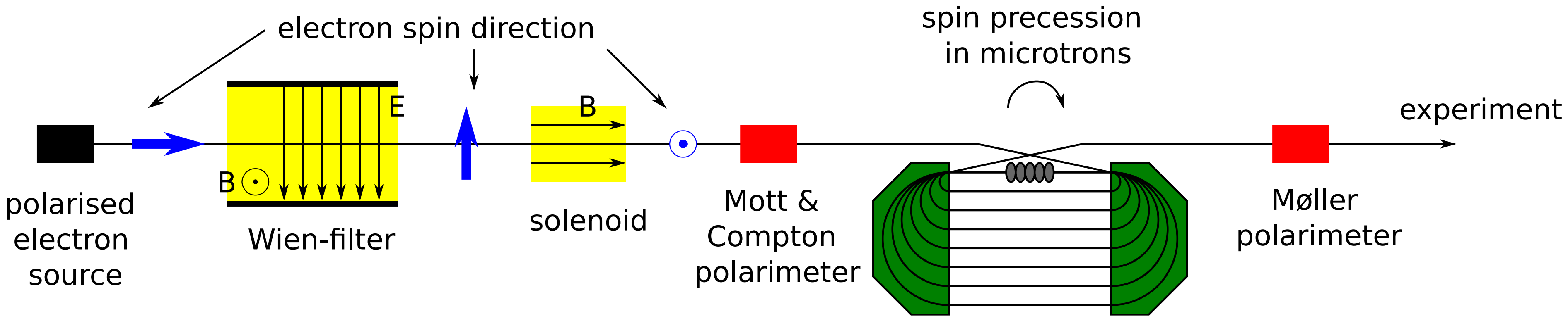
- **MA**inz **MI**crotron
  - 5-Stage electron accelerator
  - Continuous wave beam:

    E = 180 MeV – 1.6 GeV

    I_{max} = 100 µA



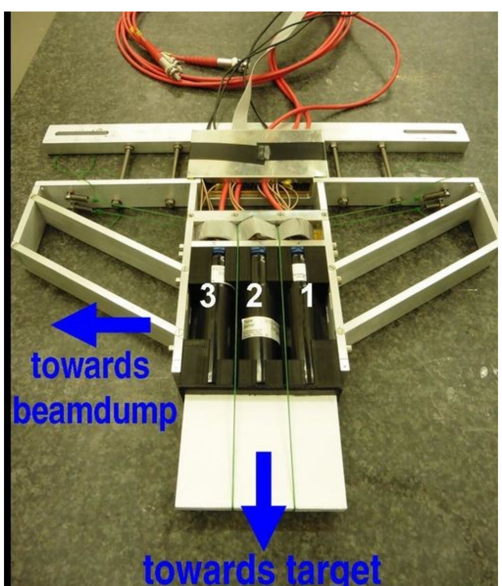
Polarised Electron Beam

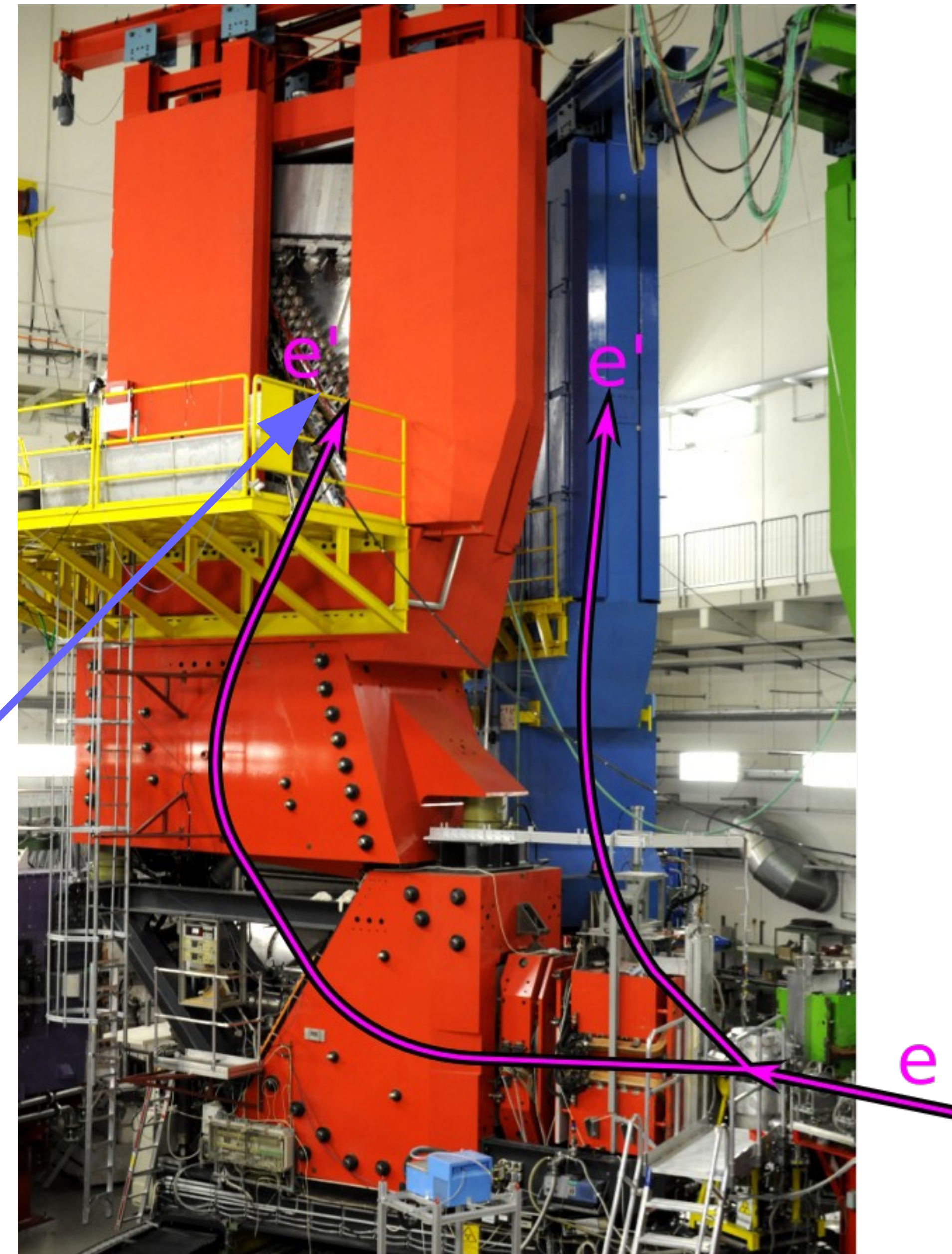


- No polarimeter for direct vertical transversal polarisation measurement available
  - Mott: horizontal transversal @ source
  - Compton: longitudinal @ source
  - Møller: longitudinal @ target
- Polarimetry:
  - Maximise and measure longitudinal polarisation at target
  - Maximise transversal horizontal component at source
  - Minimise longitudinal and horizontal component at source and target

Experimental Set-up

- Electron Beam:
  - E = 570 MeV
  - I = 20 µA
- Target:
  - 10 mm ^{12}C
- Magnetic Spectrometers:
  - Define angular acceptance (angles 15.11° - 25.9°)
  - Select elastic events
- Detectors:
  - Quartz-Cherenkov-Detectors
  - Reduced amplification
    → High rate capability

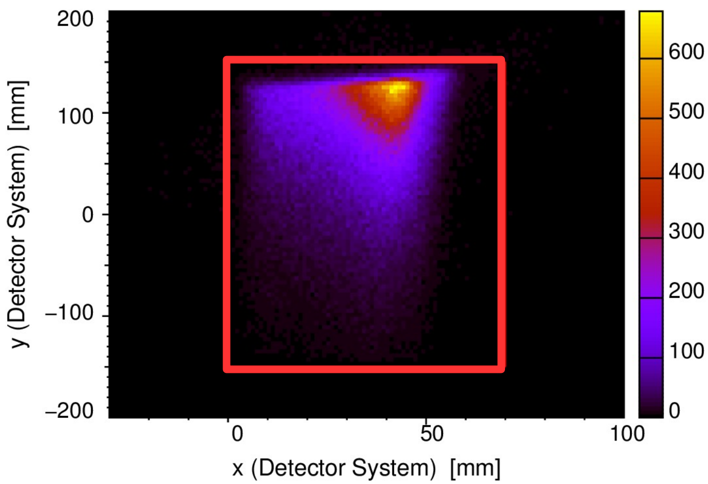


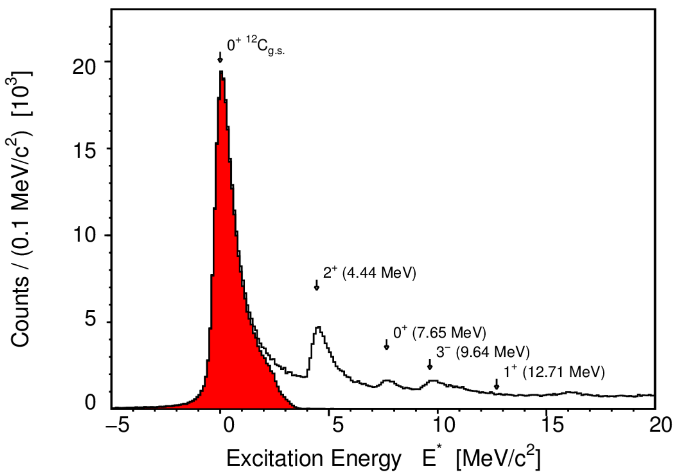


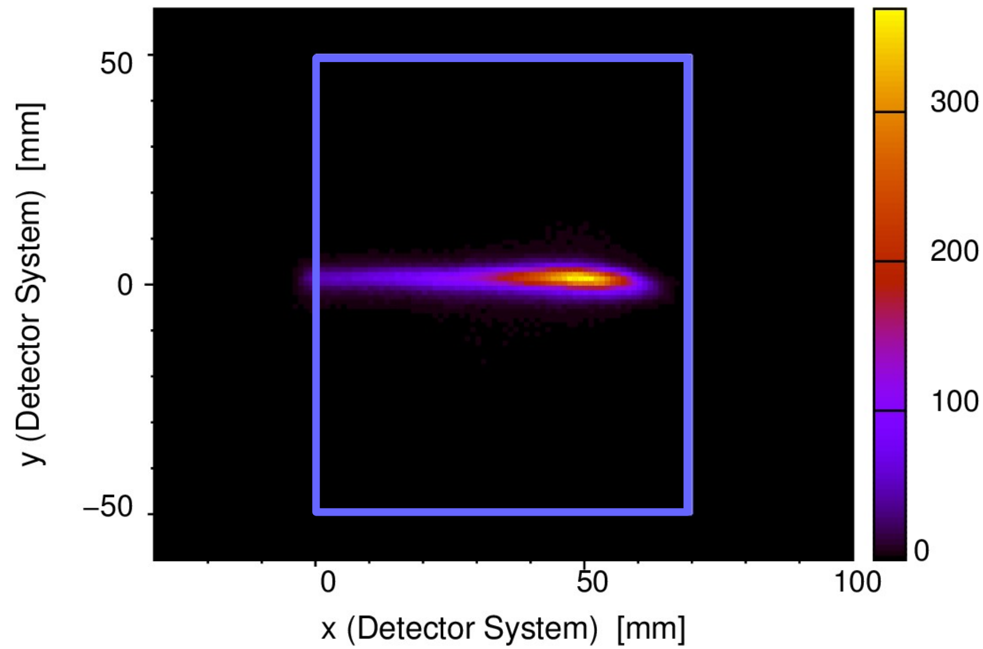
Benefits of the Spectrometers

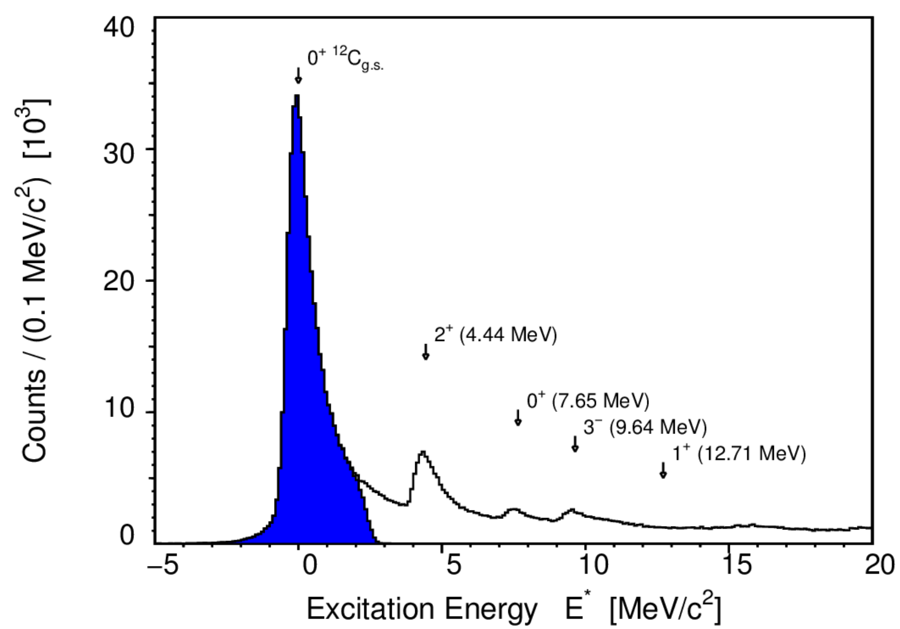
Low rate particle tracking mode:

Precise positioning of detectors & magnetic field setting
→ Only elastic line in detector acceptance







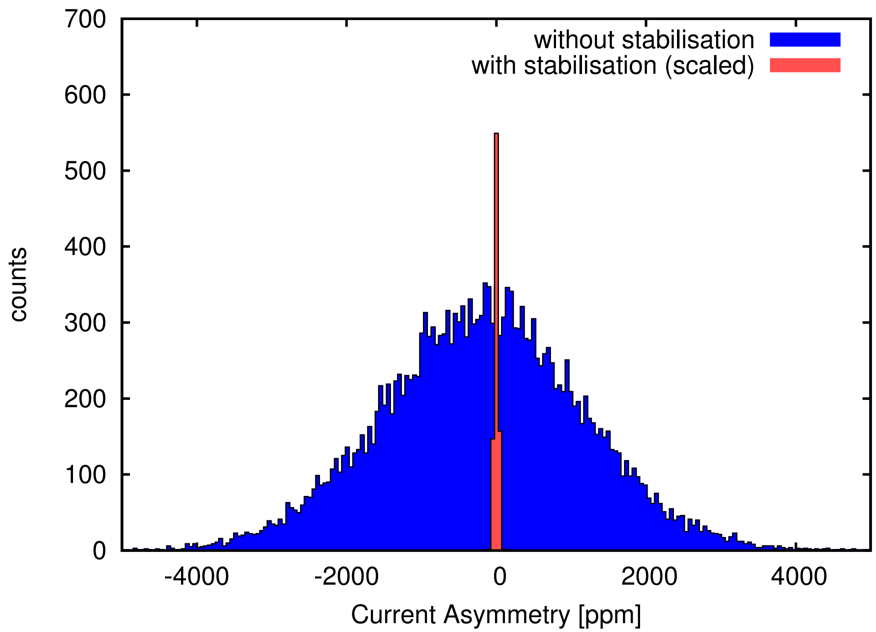


Minimising False Asymmetries

Beam related sources:

- beam current, energy, position, angle

=> beam stabilisation



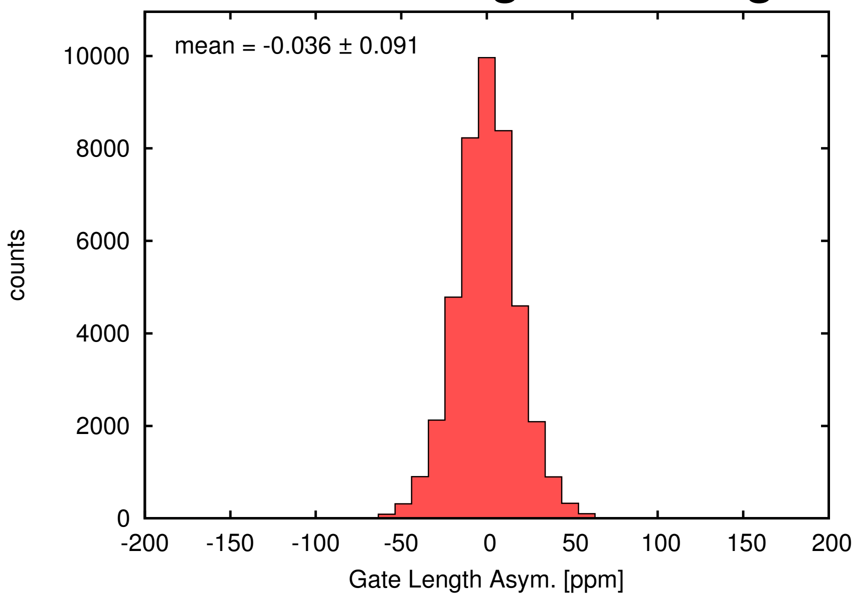
- Remaining asymmetry:
  beam current: ~ 1 ppm
  other parameters: < 0.1 ppm

=> Correction in offline analysis

Non beam related sources:

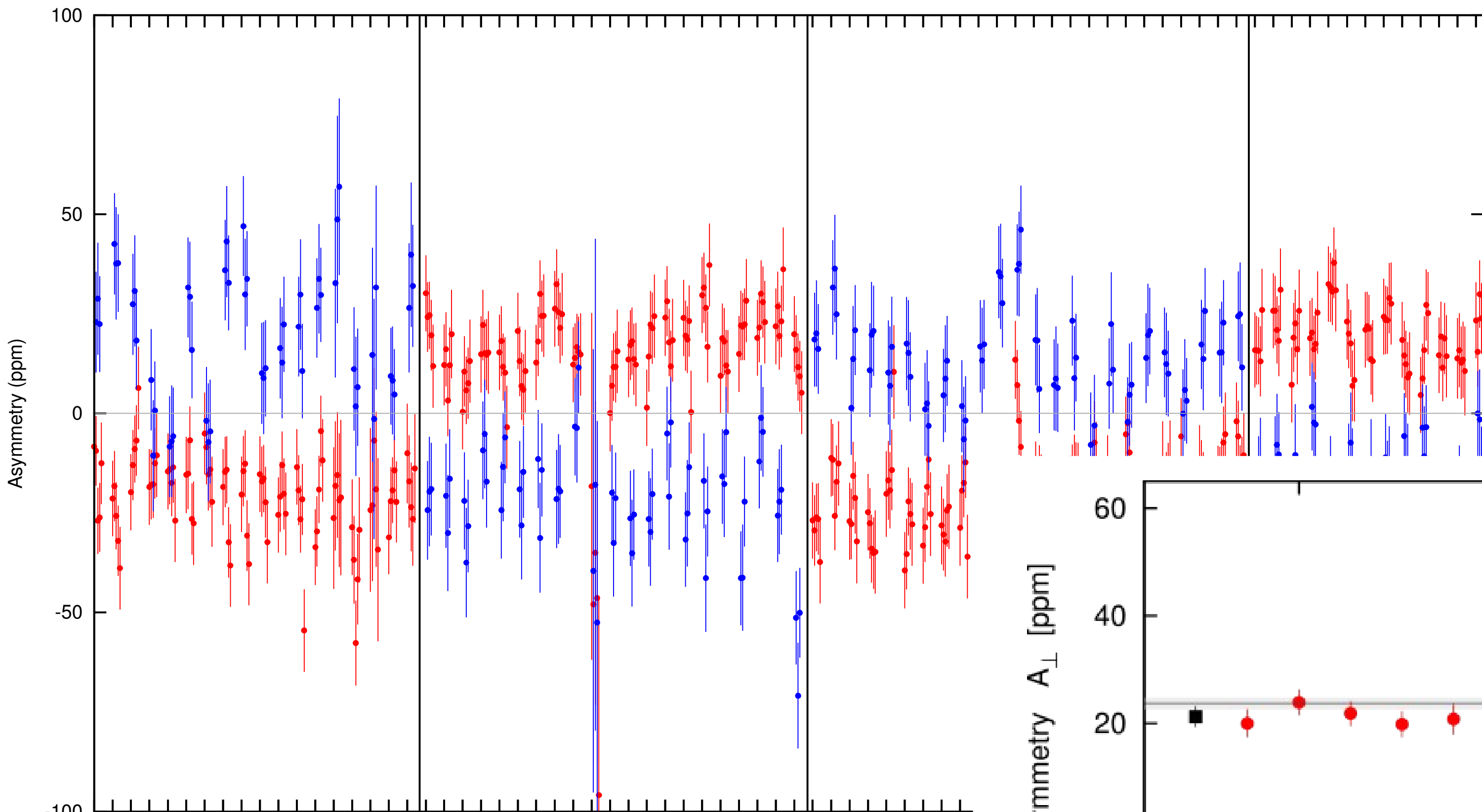
- Ground noise,
- Gate length fluctuations,
- Electrical cross talk

- Hardware suppression
  - Synchronised with power grid
  - Random polarity sequence
  - Inversions of general sign



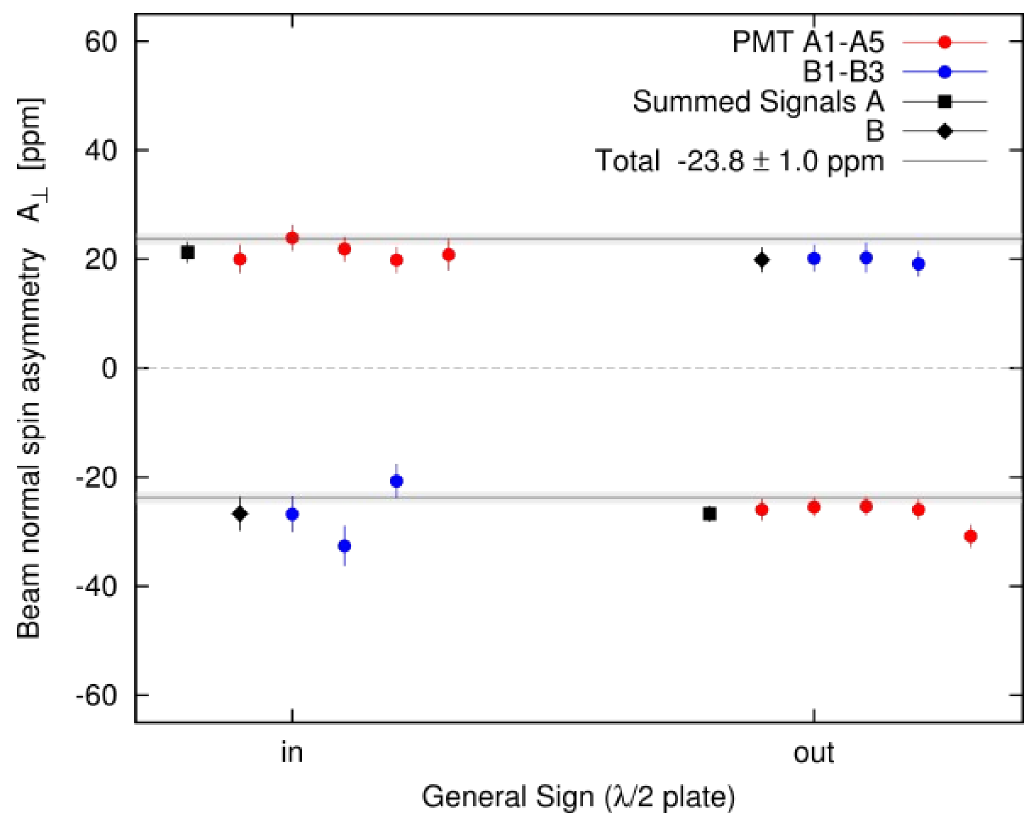
=> Offline corrections

Results



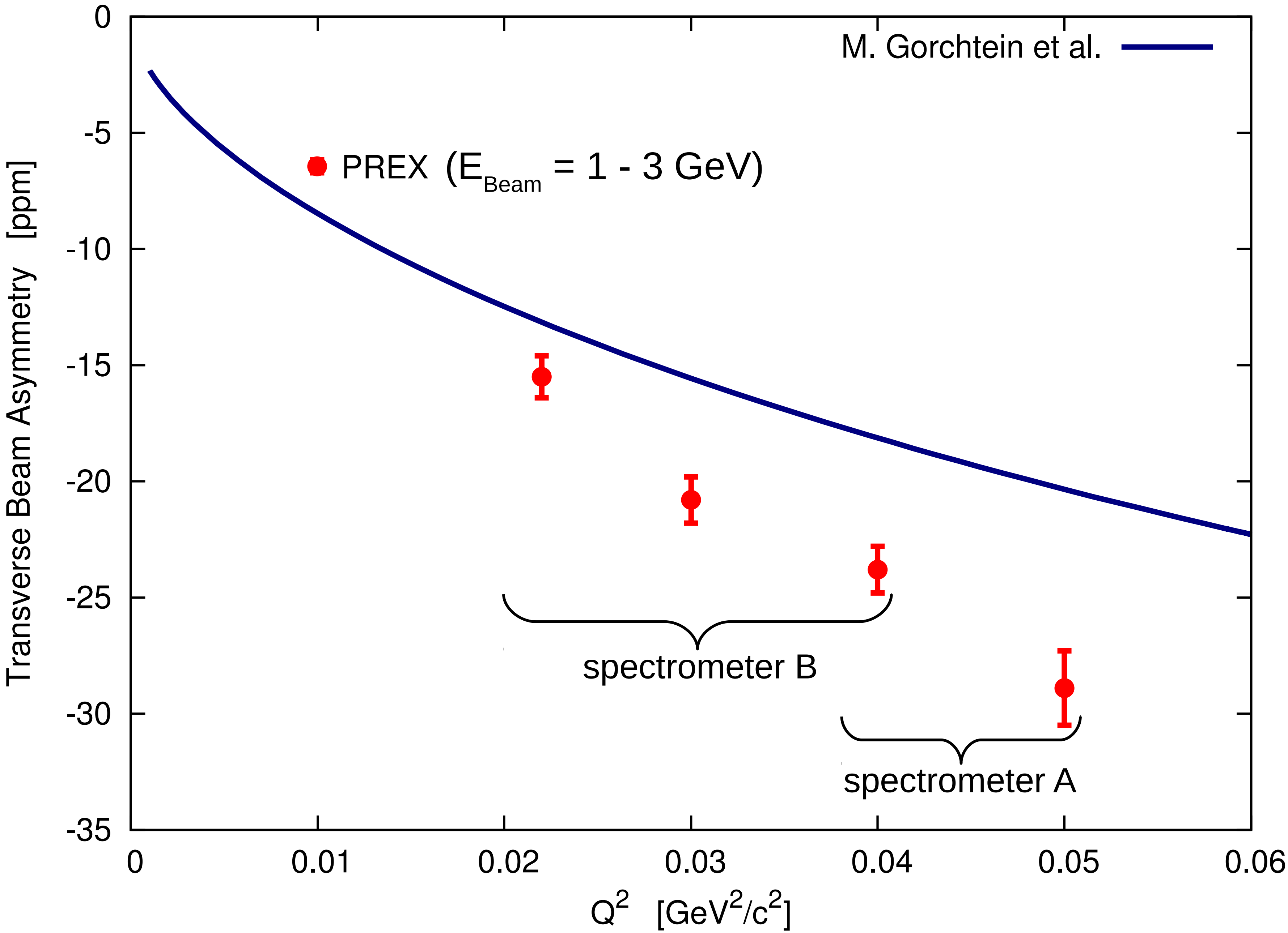
run number

Runs with equal spectrometer angles



Inversion of general sign

Results

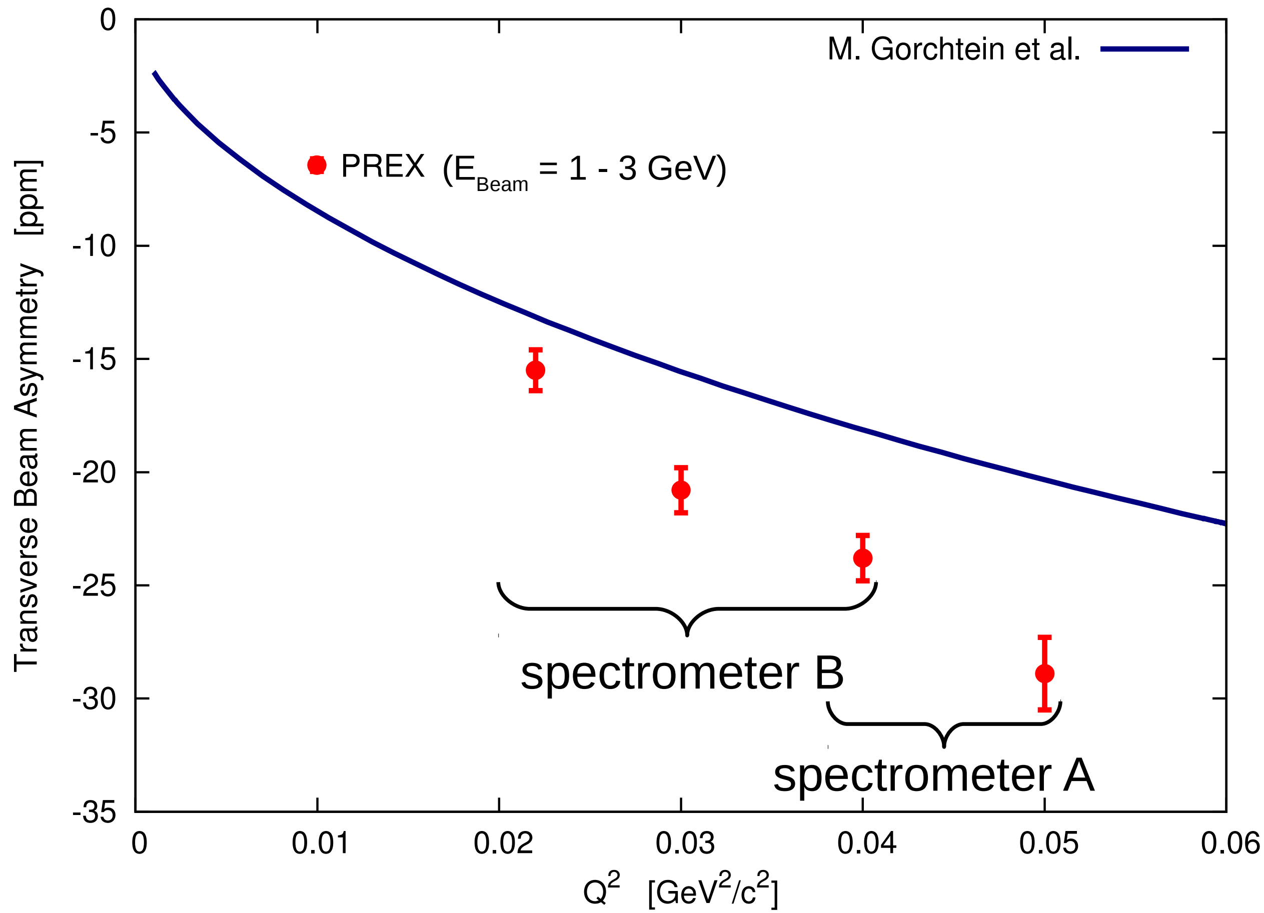


M. Gorchtein et al.
PREX (E_Beam = 1 - 3 GeV)
spectrometer B
spectrometer A
Transverse Beam Asymmetry [ppm]
Q^2 [GeV^2/c^2]
0
-5
-10
-15
-20
-25
-30
-35
0
0.01
0.02
0.03
0.04
0.05
0.06

Implications

- Observations
  - Data points don't agree with theory
  - Data shows different slope

- Theory limitations
  - Only 2 photon exchange
  - No Coulomb distortion effects included
  - Nuclear structure for heavy nuclei similar to hydrogen
  - Scattering angle: Θ ≈ 0



=> Theory present in many physical measurements needs to be improved

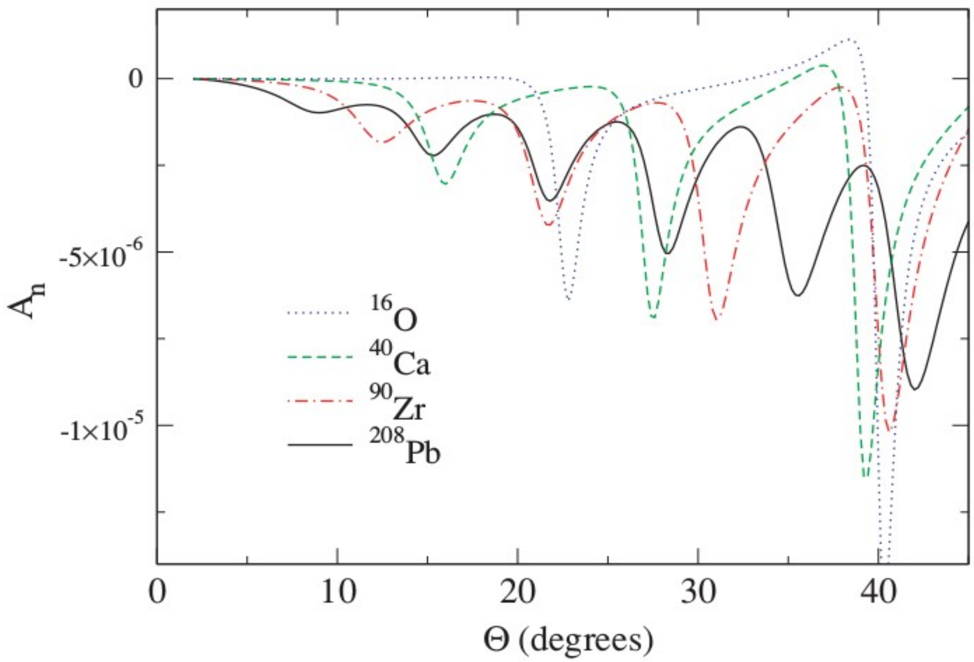
Summary & Outlook

- Parity violation experiments allow measurement of
  - Weinberg angle
  - Neutron Skin
- Beam-normal asymmetry:
  - important background
  - Direct probe for two-photon exchange
- Experiment:
  - Vertically polarised electron beam & Elaborate polarisation measurement
  - Spectrometers to select elastic events & Quartz Cherenkov detectors
  - Suppression & Correction for false asymmetries
- Disagreement between theoretical prediction and measurement
- Continuation of program:
  - Upcoming beam time in April:
    - Energy dependence of asymmetry
    - Different target material: Silicon

Backup

Theoretical Calculations

- Cooper and Horowitz
  [Phys Rev C 72, 034602 (2005)]
  - All orders of photon exchanges
  - Coulomb distortion effects
  - Only elastic intermediate state

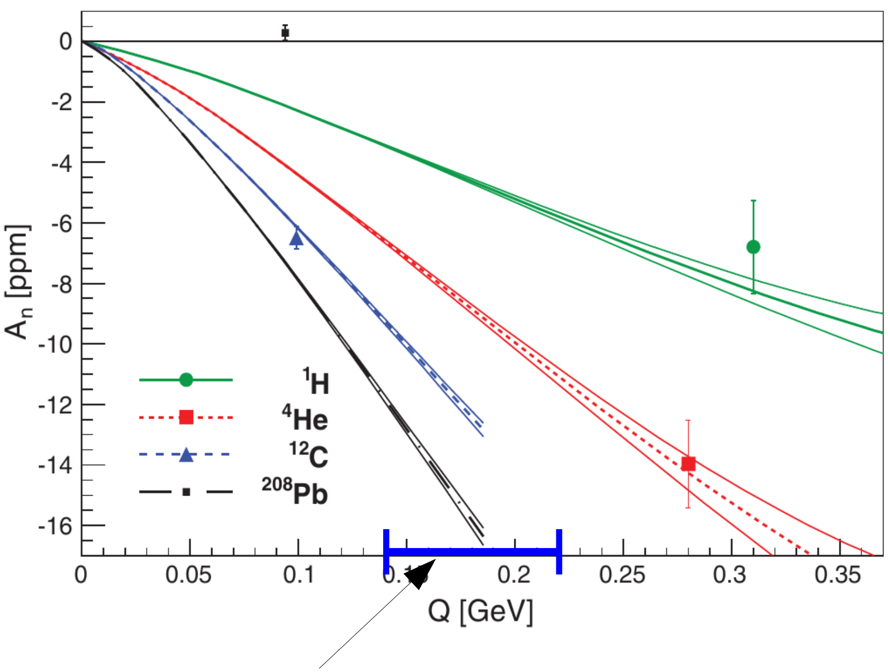


E_{Beam} = 850 MeV

Gorchtein and Horowitz
[Phys Rev C 77, 044606 (2008)]
- Two photon exchange approximation
- Including full range of intermediate excited states

Data from:
HAPPEX / PREX @ J-Lab

E_{Beam} = 1 – 3 GeV



kinematic range of this experiment

Prevention of False Asymmetries

- Intrinsic reduction of false asymmetries:
  - Spin flip synchronised with power grid frequency

    → ground noise
  - Polarity patterns: ↑↓↓↑ or ↓↑↑↓

    → low frequency noise, monotonous changes
  - Random sequence of Polarity patterns

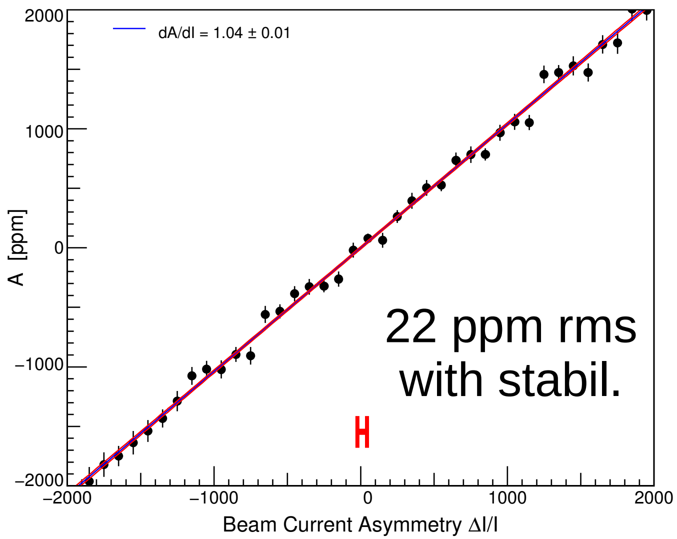
    → monotonous changes
  - Inversion of … pola inverter every 5 minutes

    → electrical cross-talk in DAQ electronics
  - Inversion of absolute sign every day

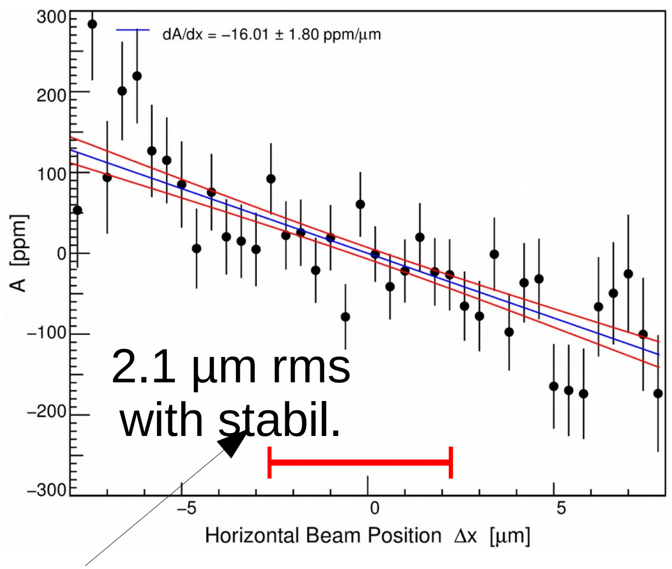
    → Unknown sources of false asymmetries
- Random Variations of beam parameters cancel out
- Offline correction of remaining false asymmetries

Beam Stability

Current stabilisation disabled



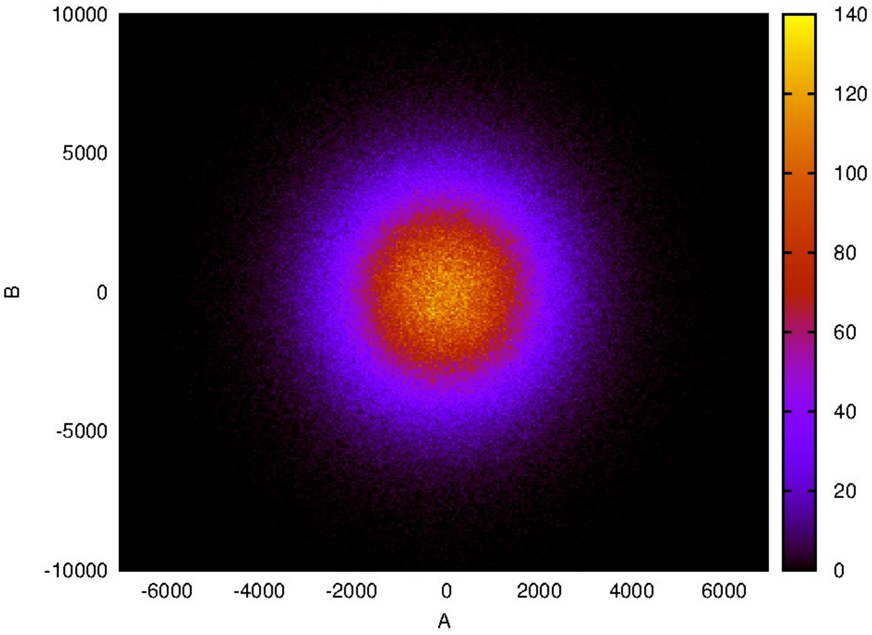
Position stabilisation disabled



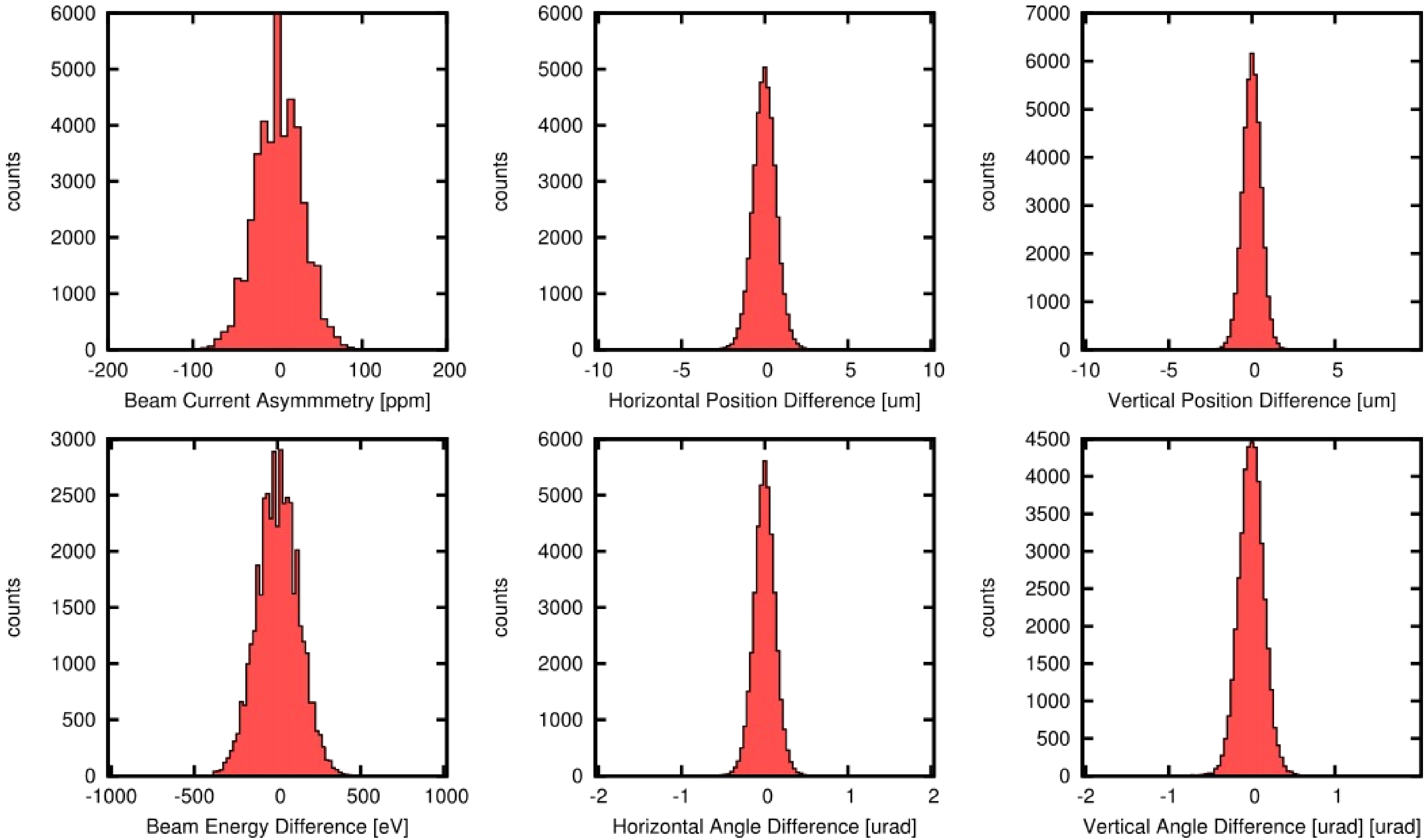
Active beam stabilisation:

- Current (AC / DC)
- Position (AC / DC)
- Energy

Correlation of asymmetries in both spectrometers



Polarity Correlated Beam Variations



Correction of False Asymmetries

- Polarity-correlated variations cause false asymmetries:
  - Beam-current: directly influences measure Asymmetry
  - Beam-energy & beam-angle influence cross-section
  - Beam position on target influences Spectrometer-acceptance
- Correction factors:
  - Calculated: Current, Energy, Angle
  - Simulated: Beam Positions

	Correction Factor	Mean Value	Correction [ppm]
Beam Current	1 ppm / ppm	-0.94 ppm	-0.94
Beam Energy	-3.517 ppm/keV	0.0023 keV	-0.0079
Hor. Position	-19.9 ppm / µm	-0.002 µm	0.0398
Vert. Position	0.061 ppm /µm	-0.013 µm	-0.0008
Hor. Angle	-8.95 ppm/µrad	-0.0007 µrad	0.006
Vert. Angle	0 ppm / µrad	-0.011 µrad	0