Detectors for Parity Violation Experiments

General Requirements & Concepts

HAPPEX

A4

G^0

Qweak

Future Experiments

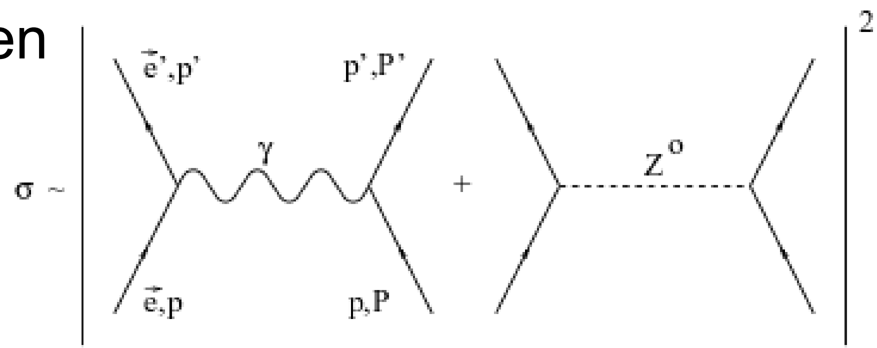
Two Photon Exchange

Summary

General Requirements & Concepts

Parity violating electron nucleon scattering:

Asymmetry arises from interference between Z and γ exchange, therefore
Asymmetries are tiny, ~ppm (Z mass!)



⟶ Need to control all (helicity correleted!) systematics very well

⟶ Need to switch electron beam helicity very often (make use of short term detector, target, and beam(?) stability!)

⟶ Need beam polarimetry

General Requirements & Concepts

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PV asymmetries ~10^{-6} → need N = 10^{16} counts for 1% uncertainty in A
(that's ~115 days @1GHz!)

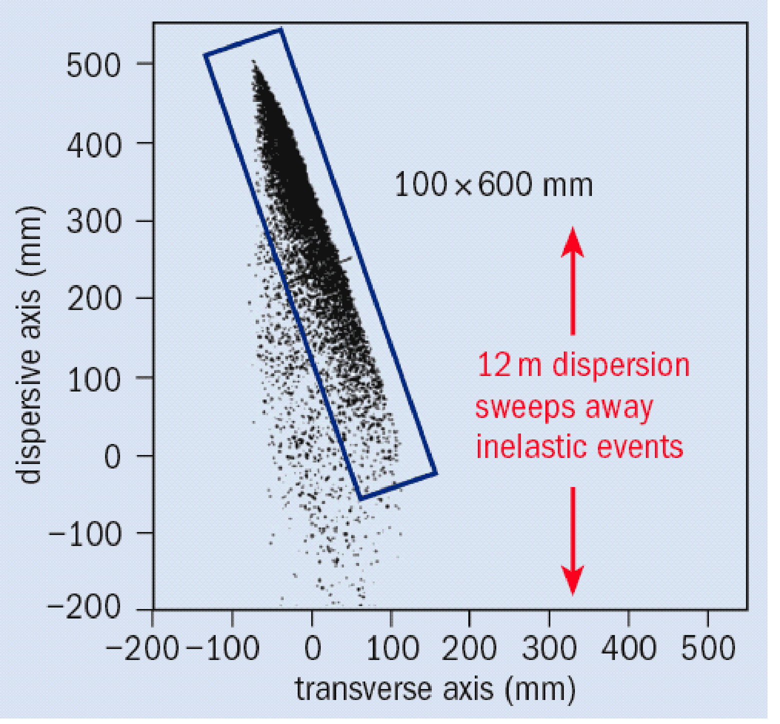
Example: A4 experiment for 0.23 GeV²/c² and θ=35°:
$A_{PV} = -6 \cdot 10^{-6}$
for a relative uncertainty of 5% and 80% beam polarization:
$2 \cdot 10^{13}$ elastic events needed
i.e. ~550 h @10MHz elastic rate

Two possibilities:
- classical counting experiment → huge rates need ultra-short deadtime!
- integrating measurement
  (e.g. measure current from PMT – instead of counting pulses)
  → still need fast detector (to prevent "afterglow" from previous helicity samples),
  → *but one gets 100% lifetime!*

HAPPEX

Designed to measure A_{PV} at Q^2 ~ 0.1 GeV^2

- employing the JLab hall A high resolution spectrometers for signal/background separation
- dedicated runs to measure remaining background contamination
- counting mode runs to check spectrometer optics, background, Q^2, ...
- integration of signal with total absorbing Cerenkov detectors
- 20 cm IH_2 target – heat load 500 W @100µA
- helicity pattern: +– –+/ –++– quadruples (30Hz)

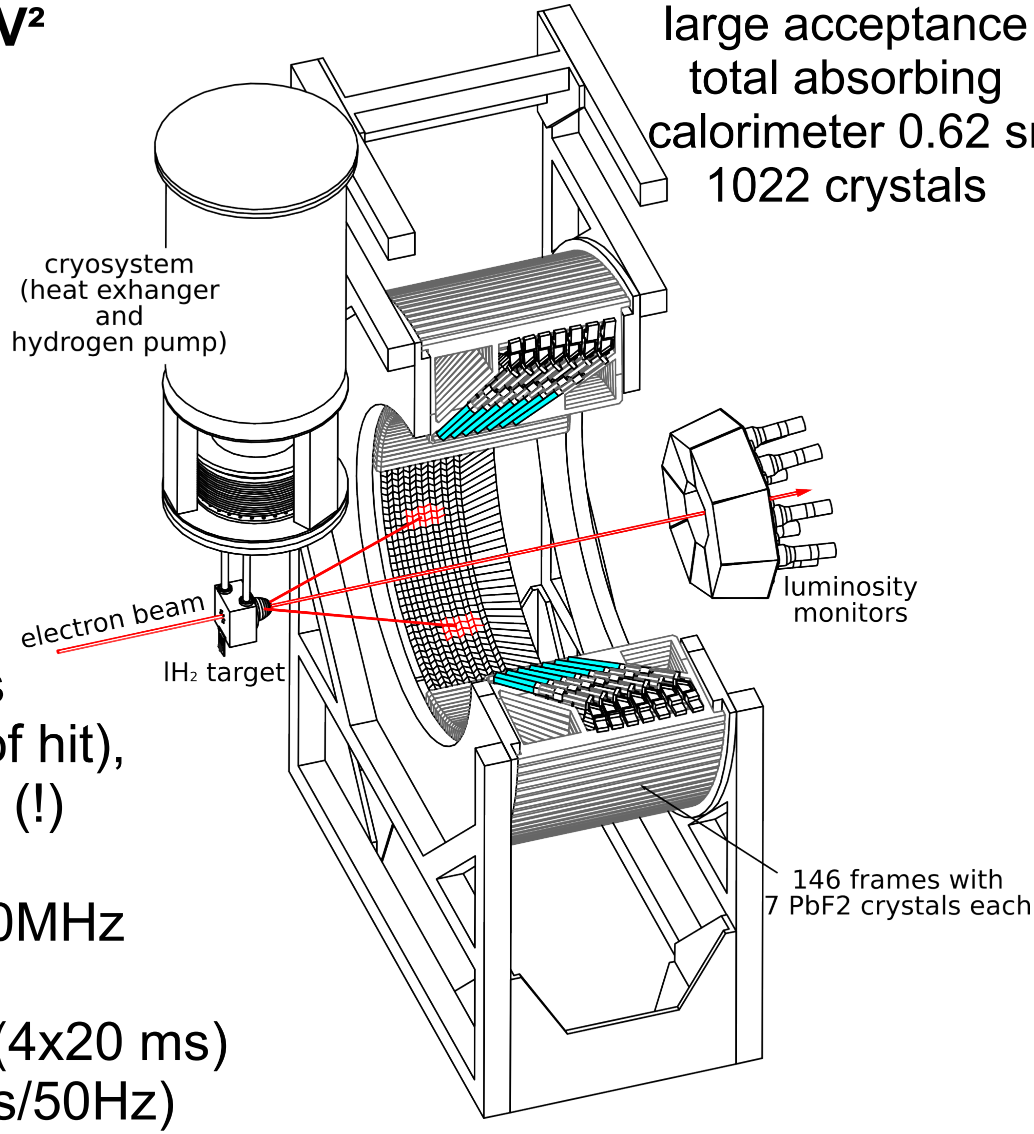


A4

Designed to measure A_{PV} at Q^2=0.23 GeV^2
(855 MeV beam energy @MAMI)

- 1st *counting* experiment (calorimeter) @up to 100MHz instantaneous rate (!) (90% background, 10% signal)
- 10 cm lH_2 target (later 23.3 cm lH_2 & lD_2) no rastering! Sub-cooled, high flow → no boiling (most of the time)
- highly interconnected readout electronics (pileup rejection, local maximum (center of hit), energy summation) with *20 ns* dead-time (!)
- histogramming 2044 energy spectra @50MHz
- helicity pattern: +– –+/ –++– quadruples (4x20 ms) PLL-locked to power line frequency (20ms/50Hz)

large acceptance total absorbing calorimeter 0.62 sr 1022 crystals



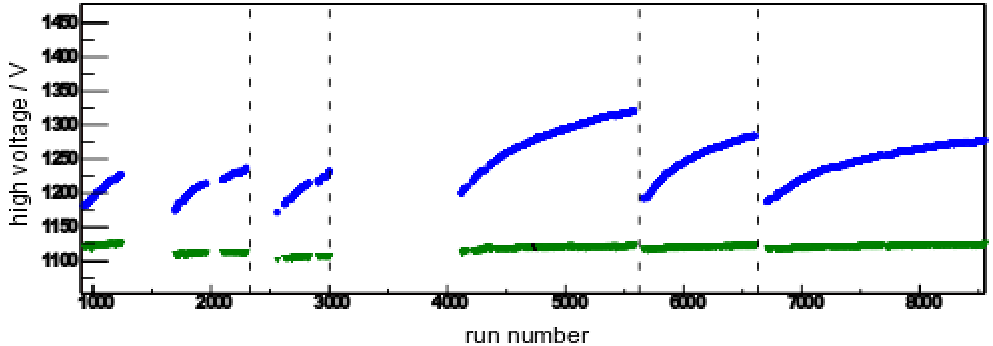
A4

Detector properties for a high rate parity violation counting experiment:

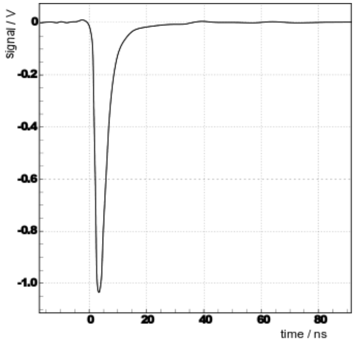
- high rate capability
  → radiation hardness
  → short dead time

- energy resolution
  → signal/background separation
  → suppress ~100% background
  → loose ~0% elastic counts

- stability against gain drifts/changes
  → calorimeter/crystals
  → electronics (thresholds, gains etc.)



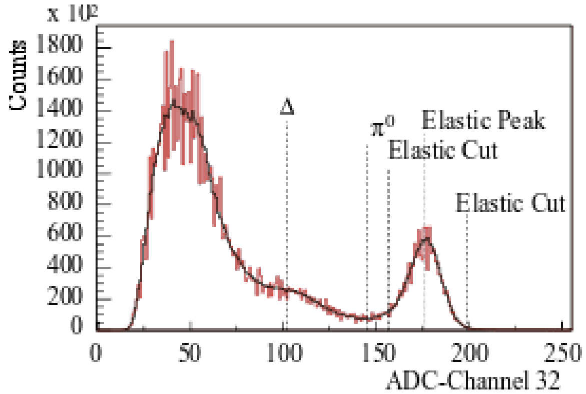
A4 experiment:



PbF2:
- radiation hard
- pure Cerenkov
- (20ns light pulses)

- energy resolution 3.9% @ 1GeV
- contribution to A_{PV} from π^0 decay
  (0.00±0.06) ppm

- HV calibration once per hour
- annealing between beamtimes
- air cooled electronics



A4

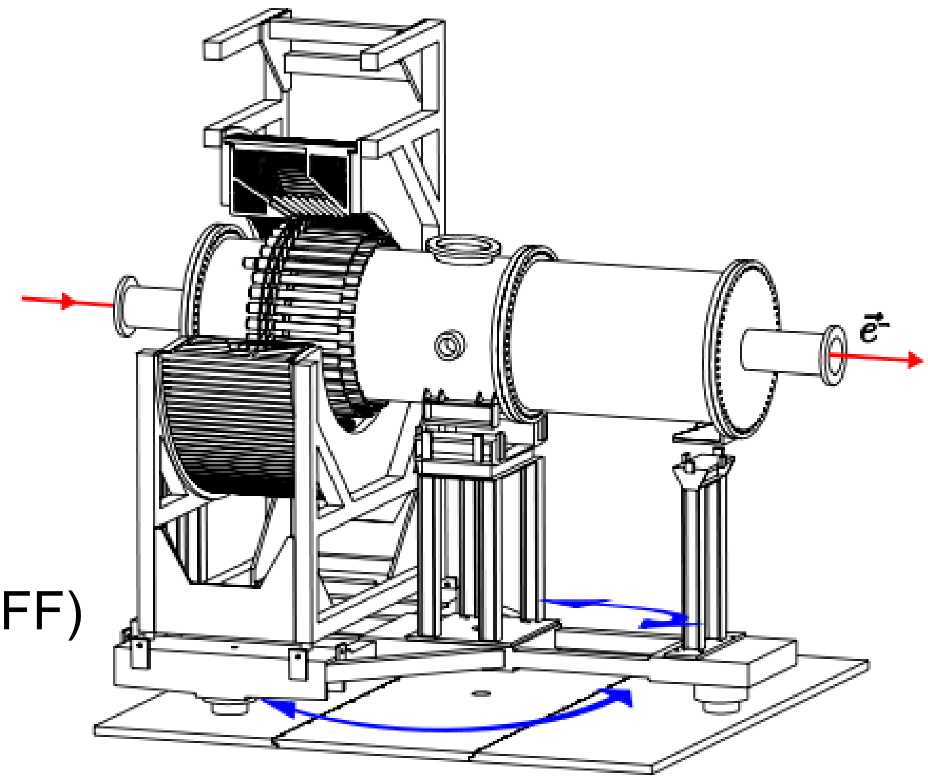
A4 ran successfully at various beam energies, with a number of different configrations:

- 855 MeV
- 570 MeV
- 315 MeV
- 1508 MeV
- 420 MeV
- 210 MeV

- liquid hydrogen
- liquid deuterium

- longitudinal spin (parity violation, strange FF)
- transverse spin (two-photon exchange)

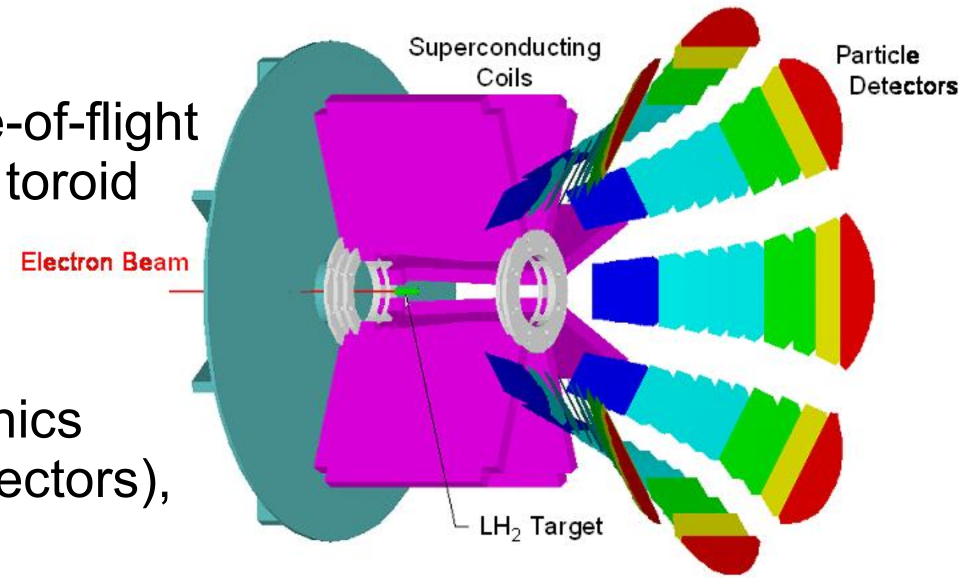
- forward angles 30° < θ < 40°
- backward angles 140° < θ < 150°
  → 72 plastic scintillators added for tagging of "charged" events (suppr. of γs from π^0 decay)

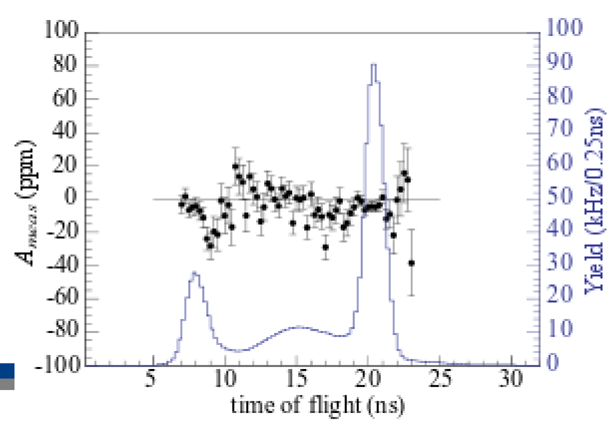


G^0

Designed to measure A_{PV} for $0.1 < Q^2 < 1.0$ GeV²

- counting experiment, detecting the *scattered protons* (forward angles), later electrons (for backward angle runs)
- separation of signal from background by time-of-flight method (TDC readout) with superconducting toroid
- plastic scintillators
- complementary detector and readout electronics instrumentation (4 NA sectors and 4 french sectors), providing systematics cross checks
- rates ~MHz – dedicated electronics for histogramming
- helicity pattern: +– –+/ –++– quadruples (30Hz) special 120Hz runs to check for 60Hz/harmonics noise





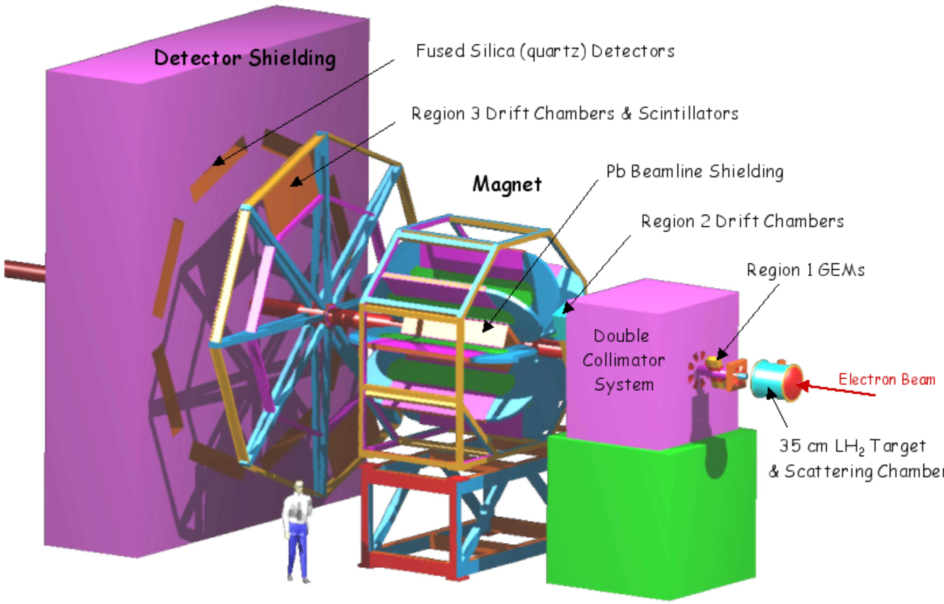
Qweak

Measurement of the weak charge of the proton

Experiment with even higher rates...

- 180μA beam current, 35cm liquid hydrogen
  → 2.5 kW cooling power (!) for the target
- toroidal magnetic spectrometer and collimators
  → separation of signal from background
- quartz bars for the main detector
  → pure Cerenkov
  → very radiation hard
  → 6.5 GHz total rate
- tracking detectors
  → determine Q^2 range
  → study detector response
- fast helicity flip (kHz), different patterns possible

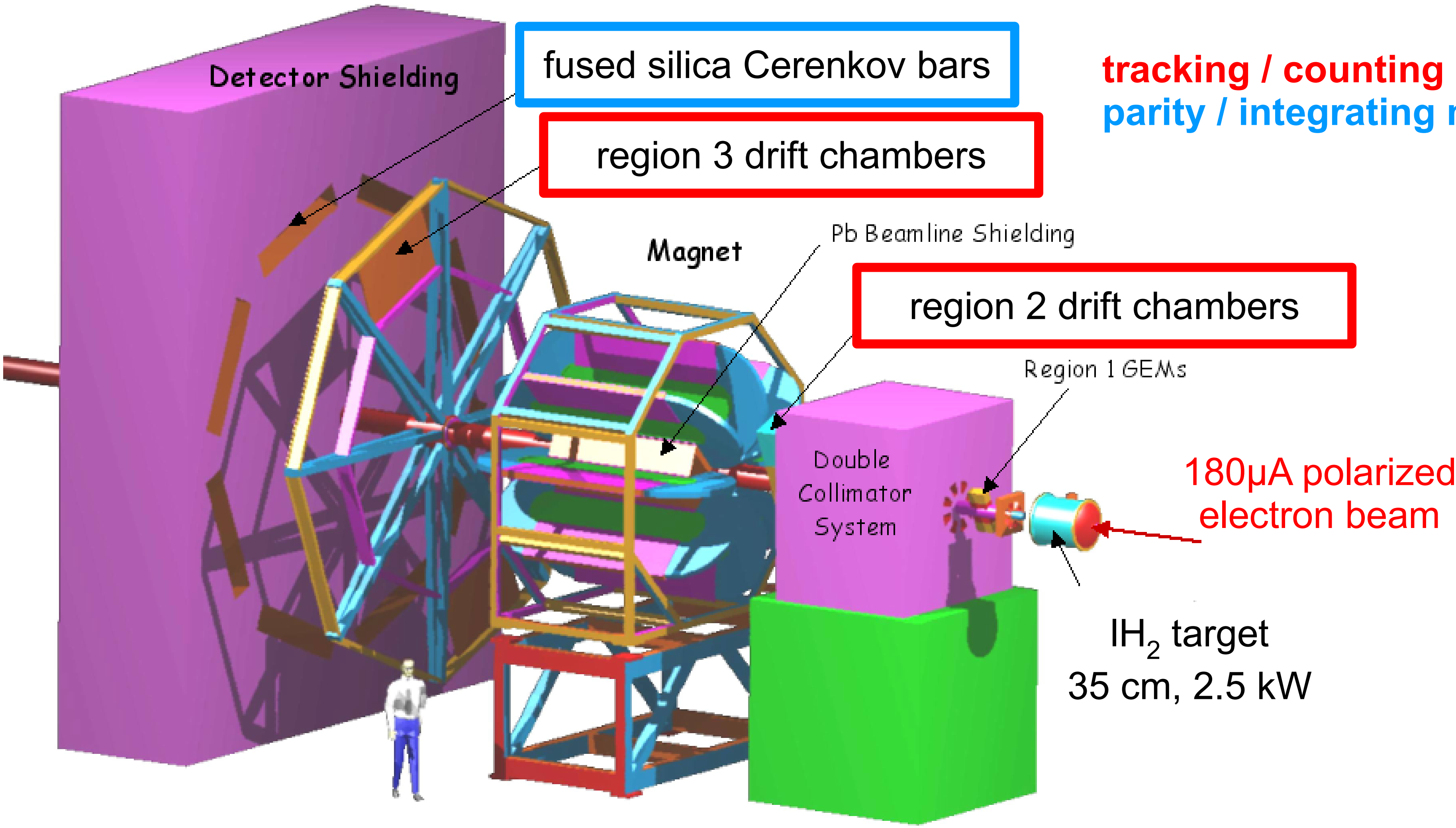
- Two modes of operation:
  → **parity/integrating mode**
  → **tracking/counting mode**



Challenges: physics asymmetry 0.2 ppm

- target boiling
- beam stability/systematics
- detector stability/systematics

Qweak



tracking / counting mode

parity / integrating mode

picture: QWeak technical design report

Future Experiments

A4 will finish next year (but: who knows?)

QWeak has to finish before the 12GeV upgrade

So what's next?

- MOLLER @Jlab:
  measure A_{PV} = 36 ppb in Moller scattering at 11GeV to 2.3%!
  integrating

- SOLID @Jlab: PVDIS (A_{PV} ~700ppm) and SIDIS
  ("slow") counting experiment

- P2 @MESA/Mainz: θ_W
  integrating

Two Photon Exchange – OLYMPUS

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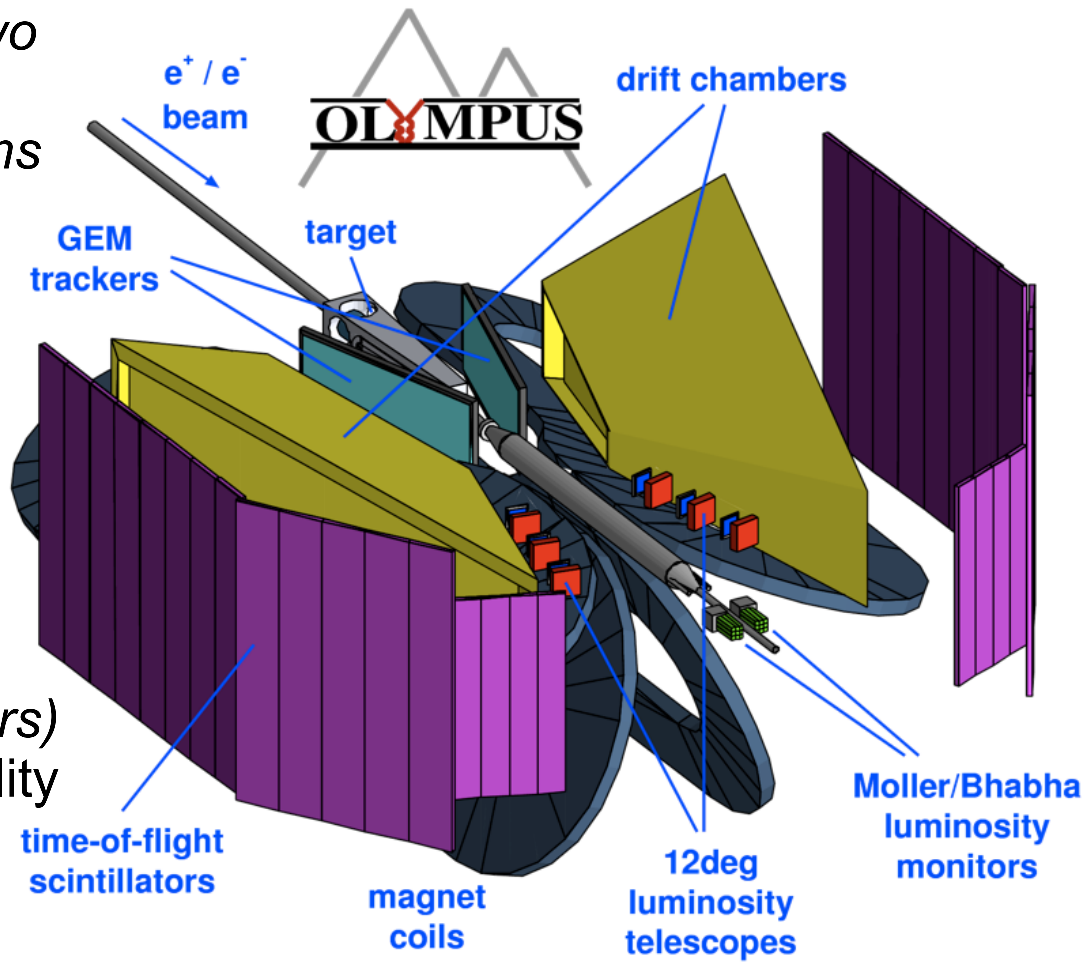
Determination of the elastic cross section ratio for e⁻p and e⁺p scattering (~% asymmetry expexcted):

Direct measurement of real part of the two photon exchange amplitude
→ *Complementary to transverse spin runs of sample, A4, HAPPEX, G^0*

Installed at storage ring DORIS at DESY/Hamburg in August 2011

First beam test with all subdetectors in August 2011, further beam tests in September (e^+, e^-)and October



Challenges:
- beam species: *only slow change (~hours)* → very good monitoring & control stability of all subdetectors needed
- only limited access to the experiment (DORIS synchrotron radiation runs)

Two Photon Exchange – OLYMPUS

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Productions runs

Feb 2012
Nov/Dec 2012

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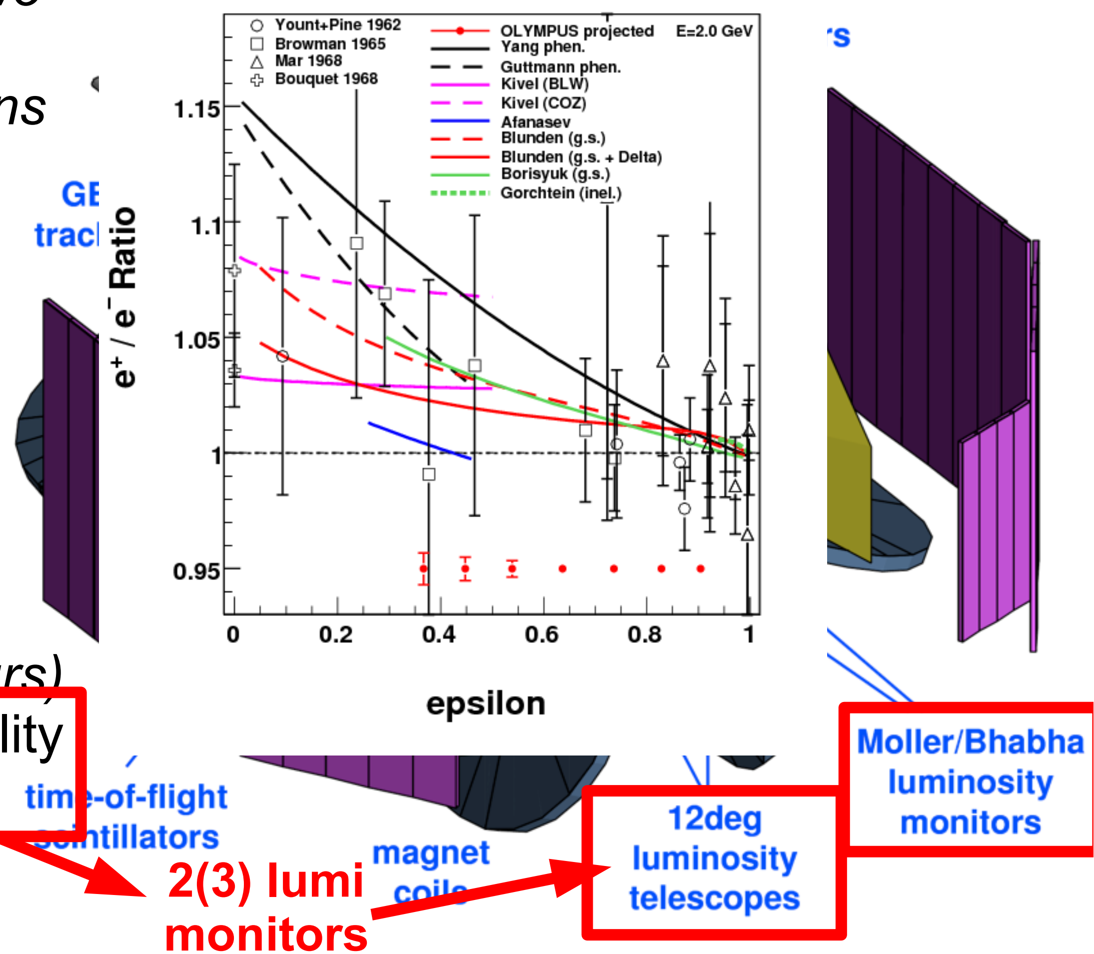
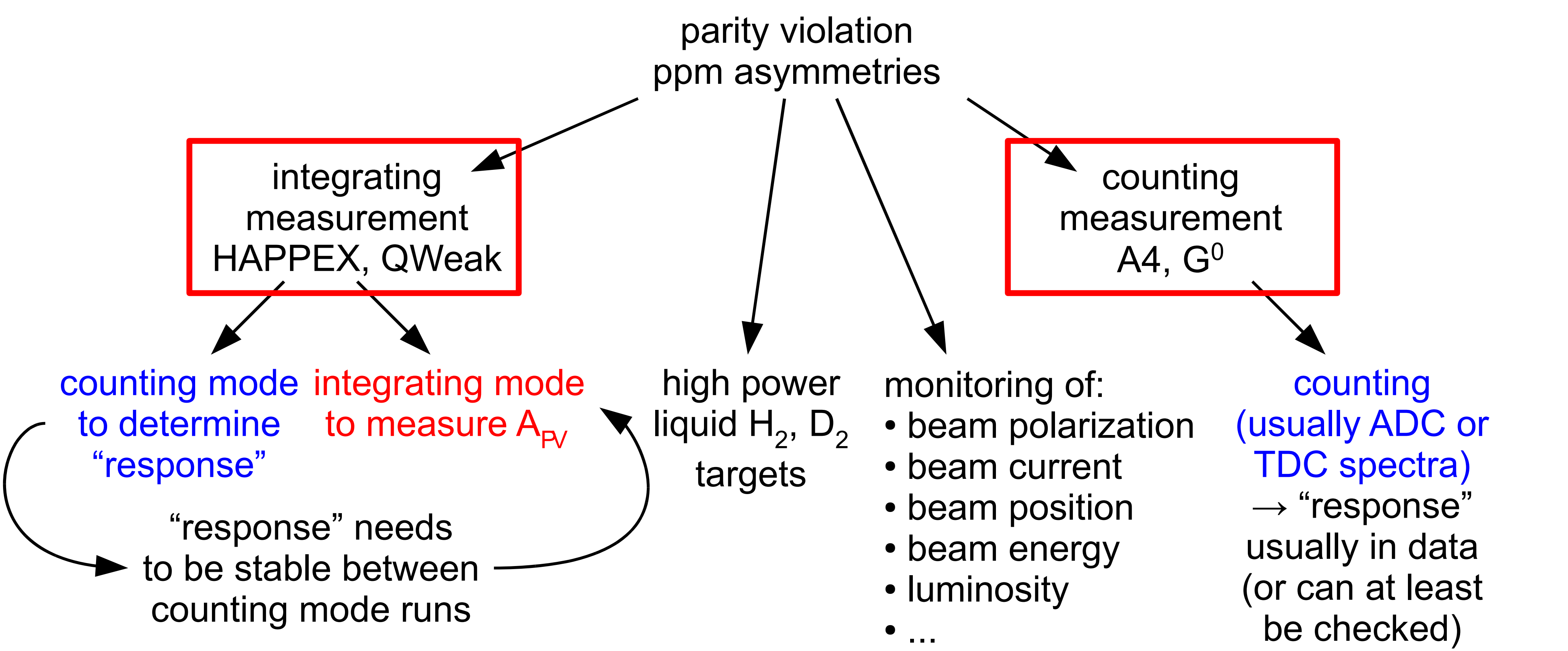


Summary I

Parity violation (strange FF, θ_W, …): large Z mass → small asymmetries
→ **extremely high rates**

Different concepts to get a measurement done in reasonable time:



Summary II

parity violation
ppm asymmetries

integrating measurement
HAPPEX, QWeak

counting measurement
A4, G^0

- custom integrating electronics
- detector linearity!
- electronics linearity!
- “response” stability!
- simpler(?) detector
  (less channels, electronics)
- highest rates possible

- granularity helps to keep rates reasonable
- fast detector (deadtime, pileup)
- special, fast electronics (A4) per channel (expensive)
- less simple detector (++channels)