The possible experiments with internal thin targets at the BEPCII storage rings

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New Vistas in Low-Energy Precision Physics
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Outline

Main purpose: possible experiments using a thin gas (Hydrogen or Deuteron or Helium) targets internal to the BEPCII electron/positron storage ring.

- Introduction: BEPCII
- Possible experiments

✓ Elastic electron–deuteron scattering

✓ Two-body deuteron photodisintegration

✓ Coherent photoproduction of π^0 on the deuteron

✓ ABC effect in photoproduction of $\gamma d \rightarrow d\pi\pi$

✓ Two-photon exchange and the proton electromagnetic form factors

✓ Charge radius of proton

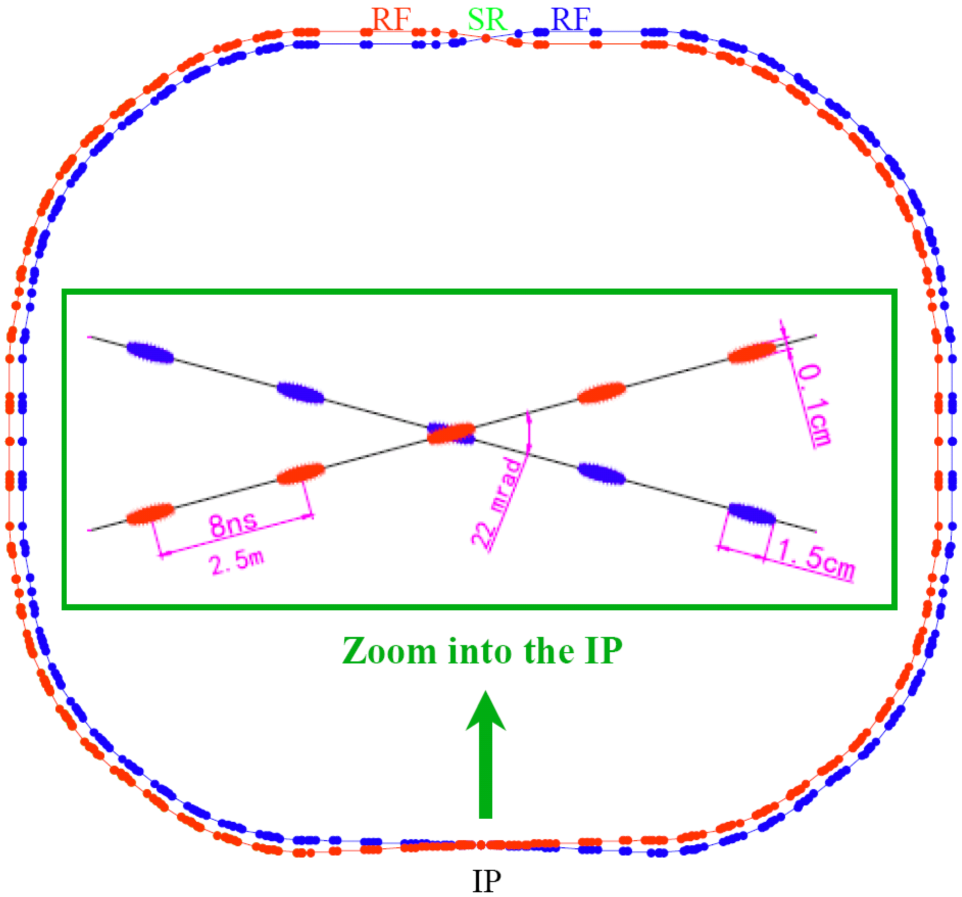
✓ Charged Lepton Flavor violation (cLFV): electron to $\mu(\tau)$ conversion:

$$e\,N \rightarrow \mu(\tau)\,N$$

✓ Dark photon in $e^+e^- \rightarrow \gamma A'$ at low mass 10-50 MeV

- Summary

The BEPCII electron-positron double storage rings



Beam energy: 1.0-2.3 GeV
Design Luminosity: 1×10^{33} $cm^{-2}s^{-1}$
Optimum energy: 1.89 GeV
Energy spread: 5.16×10^{-4}
No. of bunches: 93
No. e^+ or e^-/bunch 4.5×10^{12}
Bunch length: 1.5 cm
Bunch distance 2 m
Beam size σ_x/σ_y 380/5.7 μm
Current/bunch 9.8 mA
Total current: 0.91 A
Circumference： 237m
Injection rate for e+ 50 mA/s
Injection rate for e- 200 mA/s

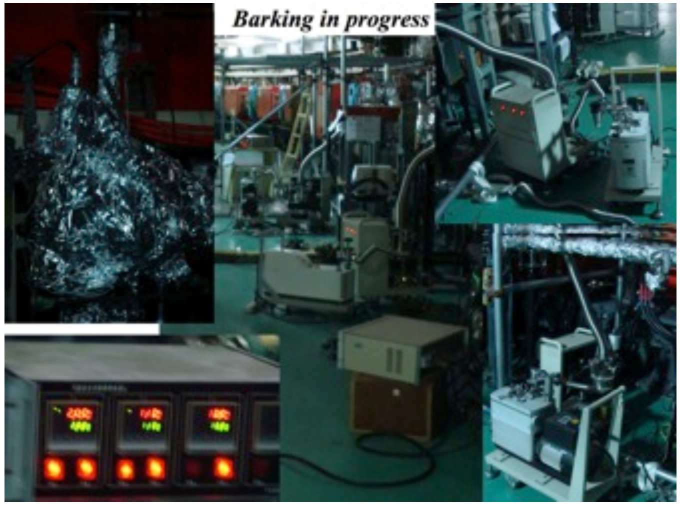
Only running experiment: BESIII
Start data taking: 2009
Estimated end of BESIII life time: 2022
Can we do more experiments using BEPCII?

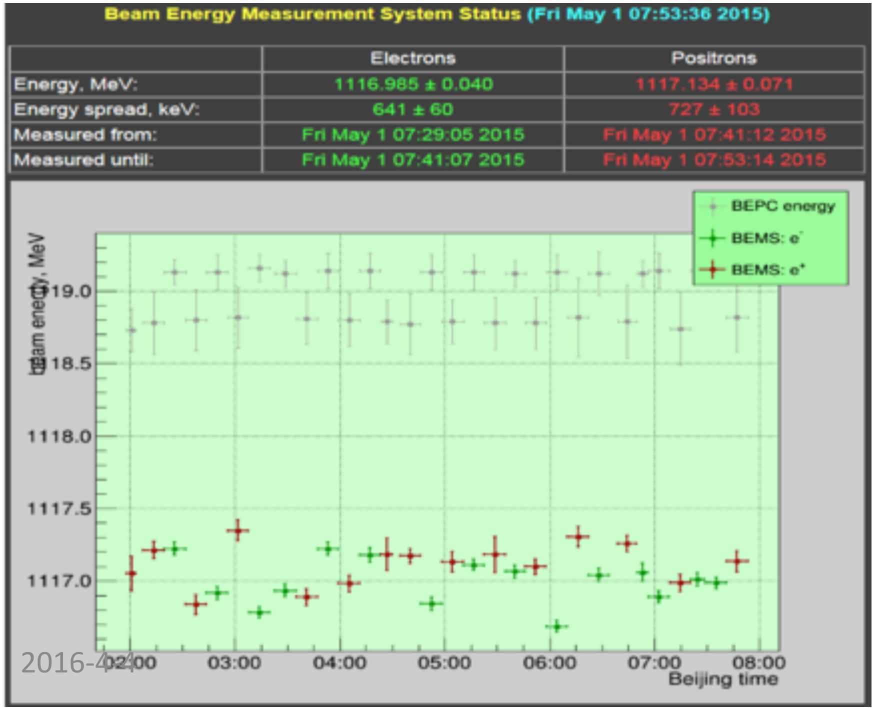
Beam energy measurement

- Reconstruction of the beam energy from an energy spectrum of laser photons backscattered on beam particles:

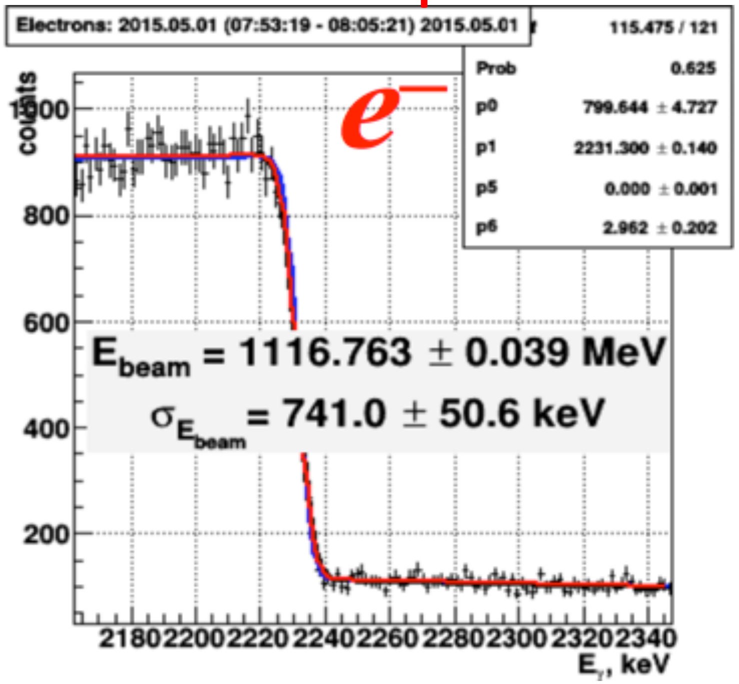
$$E_{beam} = \frac{\omega_{max}}{2} \times (1 + \sqrt{1 + m_e^2/\omega_0\omega_{max}})$$

- Achieved accuracy is $\Delta E/E \approx 4 \times 10^{-5}$
- This allows us to monitor the beam energy, and to apply corrections during data analysis .





Photon spectrum



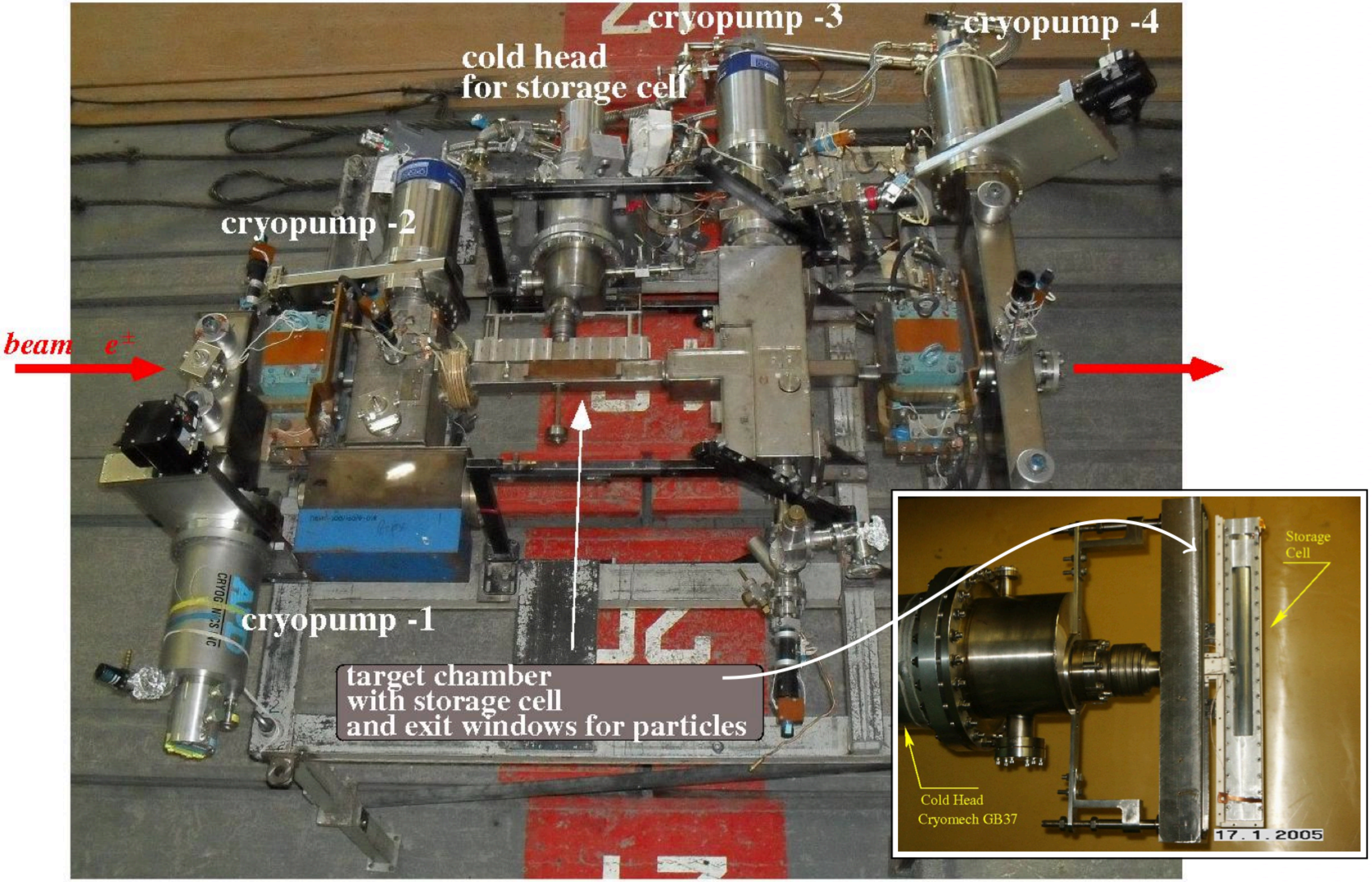
Method of a superthin internal target

- Consider the case of a target installed inside a storage ring, the beam crosses the target repeatedly
- In the case of a “superthin” internal target, additional energy losses of the beam are compensated by a RF cavity
- The method was proposed, first tested (at VEPP-1), and further developed (at VEPP-2 and VEPP-3) in Novosibirsk, starting from the late 1960s
- Later, the method was used in many laboratories worldwide, both at electron (NIKHEF, MIT-Bates, HERMES and OLYMPUS experiments at DESY, etc.) and ion (IUCF, CELSIUS, TSR Heidelberg, COSY Jülich, RHIC, etc.) rings
- The method allows one to substantially increase the efficiency of utilization of the target material and beam particles
- Therefore, the method makes it feasible to perform measurements
  – with exotic targets: polarized ones; of rare isotopes, etc.
  – with exotic beams: positrons; antiprotons; rare-isotope ions, etc.
  – detecting slow, heavy, or strong-ionizing reaction products in coincidence

Slides from Alexander V. Gramolin

Internal target session at VEPP3

Polarized atomic beam sources (ABS)



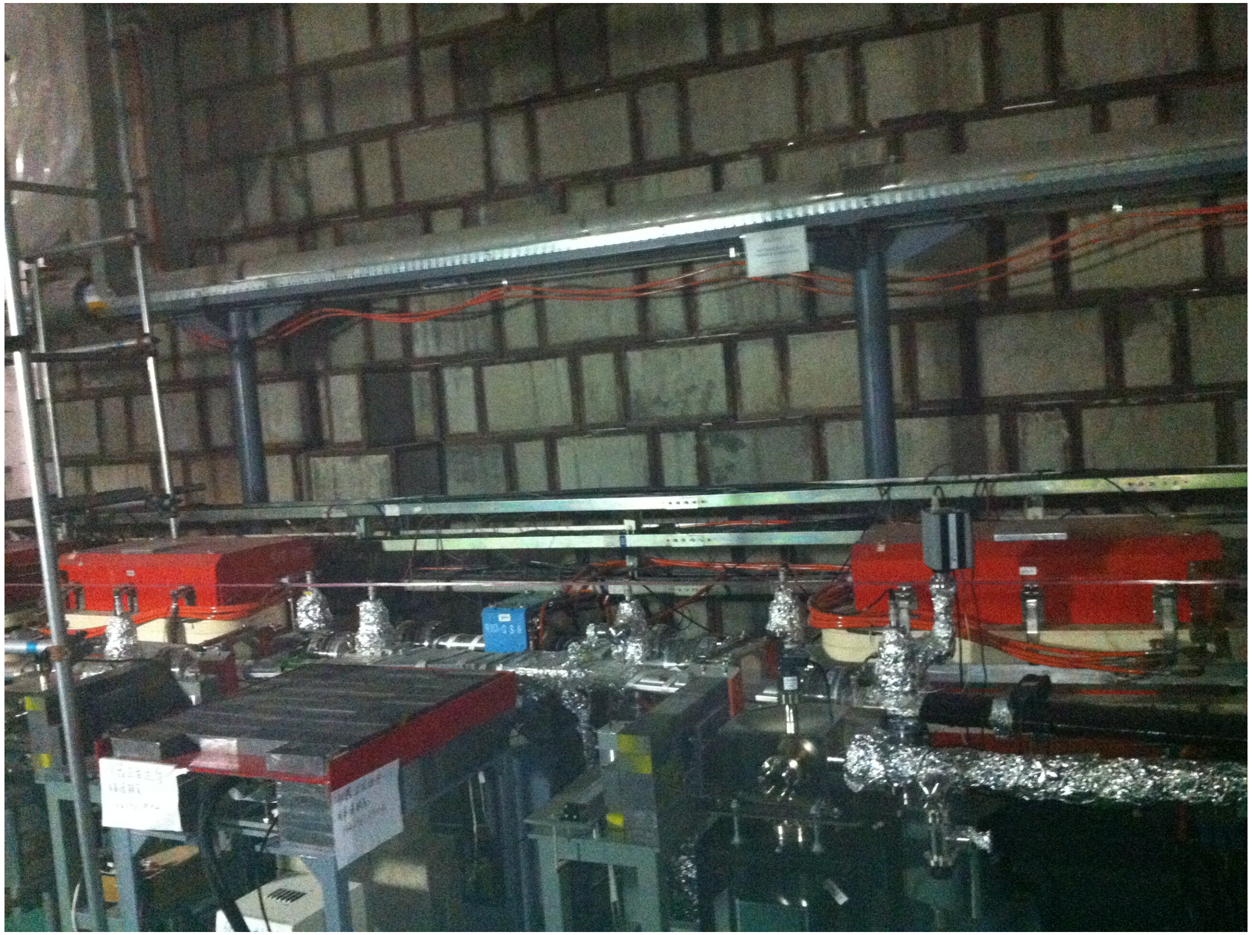
target thickness $\approx 10^{15}$ at/cm^2, luminosity $\approx 10^{32}$cm^{-2}s^{-1}

Highlights of the internal-target program at VEPP-3

1. Measurement of the tensor analyzing power T_{20} in elastic $e\vec{d}$ scattering at $Q^2 = 4{-}9\ \mathrm{fm}^{-2}$. The first use of a storage cell to increase the target thickness.
   R. Gilman *et al.*, Phys. Rev. Lett. **65**, 1733 (1990)
   R. Gilman *et al.*, Nucl. Instrum. Methods A **327**, 277 (1993)
2. Measurement of the tensor T_{20}, T_{22} and vector T_{11} analyzing powers in deuteron photodisintegration at $E_\gamma = 40{-}550$ MeV and $\theta_p^{cm} \approx 88^\circ$.
   S. I. Mishnev *et al.*, Phys. Lett. B **302**, 23 (1993)
3. Development of a new internal polarized deuterium target based on a cryogenic atomic beam source with superconducting sextupole magnets.
   L. G. Isaeva *et al.*, Nucl. Instrum. Methods A **411**, 201 (1998)
   M. V. Dyug *et al.*, Nucl. Instrum. Methods A **495**, 8 (2002)
4. Measurement of T_{20} and T_{21} in elastic $e\vec{d}$ scattering at $Q^2 = 8{-}22\ \mathrm{fm}^{-2}$.
   D. M. Nikolenko *et al.*, Phys. Rev. Lett. **90**, 072501 (2003)
5. Measurement of the tensor analyzing powers T_{20}, T_{21}, and T_{22} in deuteron photodisintegration at $E_\gamma = 25{-}600$ MeV and $\theta_p^{cm} = 24^\circ{-}48^\circ$, $70^\circ{-}102^\circ$.
   I. A. Rachek *et al.*, Phys. Rev. Lett. **98**, 182303 (2007)
6. The first measurement of T_{20}, T_{21}, and T_{22} in the process $\gamma\vec{d} \to \pi^0 d'$.
   D. M. Nikolenko *et al.*, JETP Letters **89**, 432 (2009)
7. Precise measurement of the two-photon exchange contribution to elastic $e^\pm p$ scattering.
   I. A. Rachek *et al.*, Phys. Rev. Lett. **114**, 062005 (2015)

Possible position for the target in the ring

North collision point (not used, BESIII in south point)



But a lot of work to rearrange the components of the rings

Possible position for the target in the ring

West injection region

Enough space, and less work to rearrange the magnets

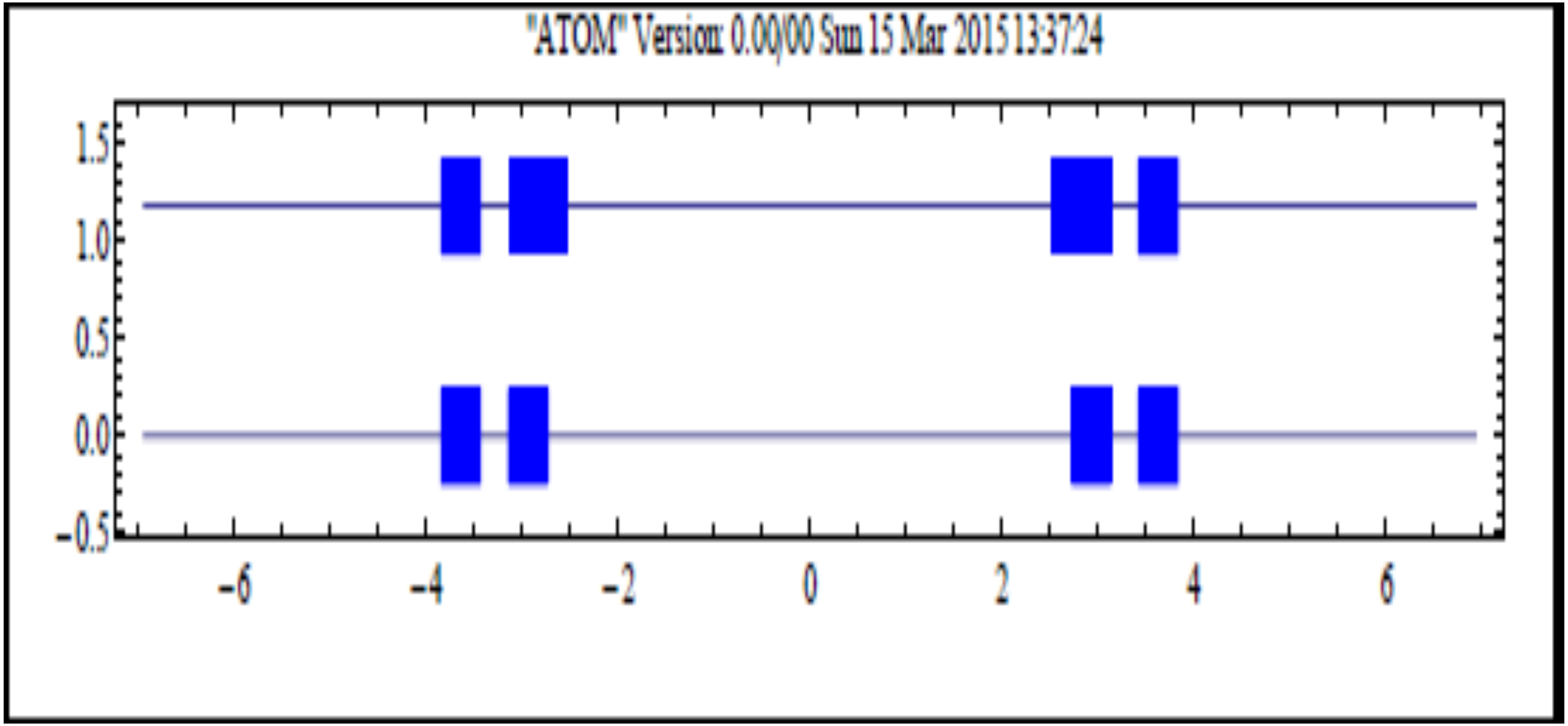
Possible position for the target in the ring

- Electron beam only:
  Injection region of inner ring (west injection)
  need re-arrange several magnets in that region;

- Both electron and positron beam:
  only detector region (south IP) only after the BESIII experiments

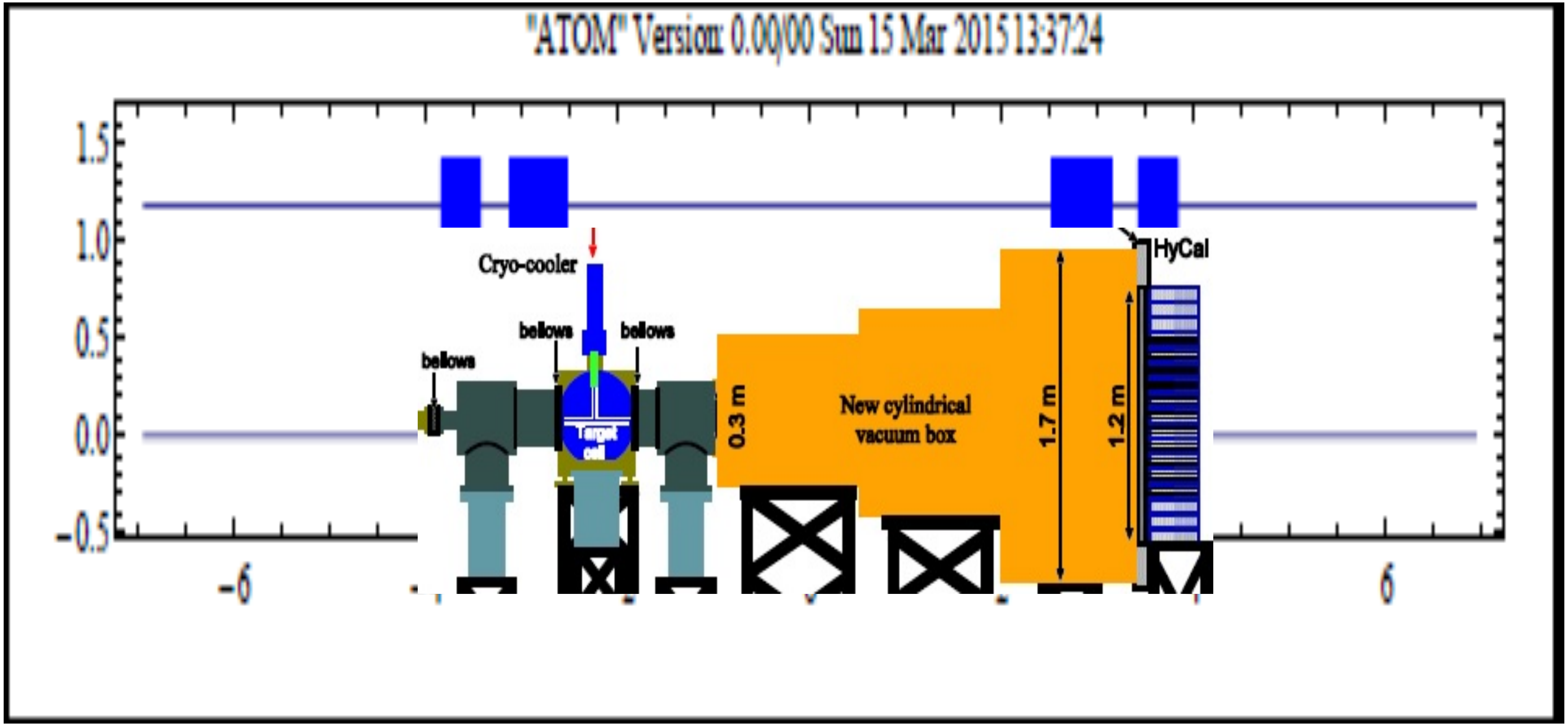
West injection region

Example for :



West injection region

Example for :



Beam with internal targets

Switch between electron and positron beams:

The electron and positron can not be switched in a short time because BEPCII power supply is not bipolar. It may take a couple of weeks to change the polarity.

- ✓ Life time decreasing:
  - Electron gas (H_2) Inelastic scattering :
    - with nucleus σ_A 10^{-29};
    - with outer electrons σ_B 10^{-29}
  - Electron gas (H_2) elastic scattering
    - with nucleus σ_C 10^{-24}
    - with outer electrons σ_D ($\sigma_C >> \sigma_D$)
- ✓ Beam halo increasing

Target material for example:
2×10^{13} at/cm^2

Beam life time

For the BEPCII and BESIII experiment, the dynamic pressure is about 10^{-9} Torr . The lifetime is about 10 hours, and the gas scattering is dominated by the N_2 or CO(10% of all) in the ring.

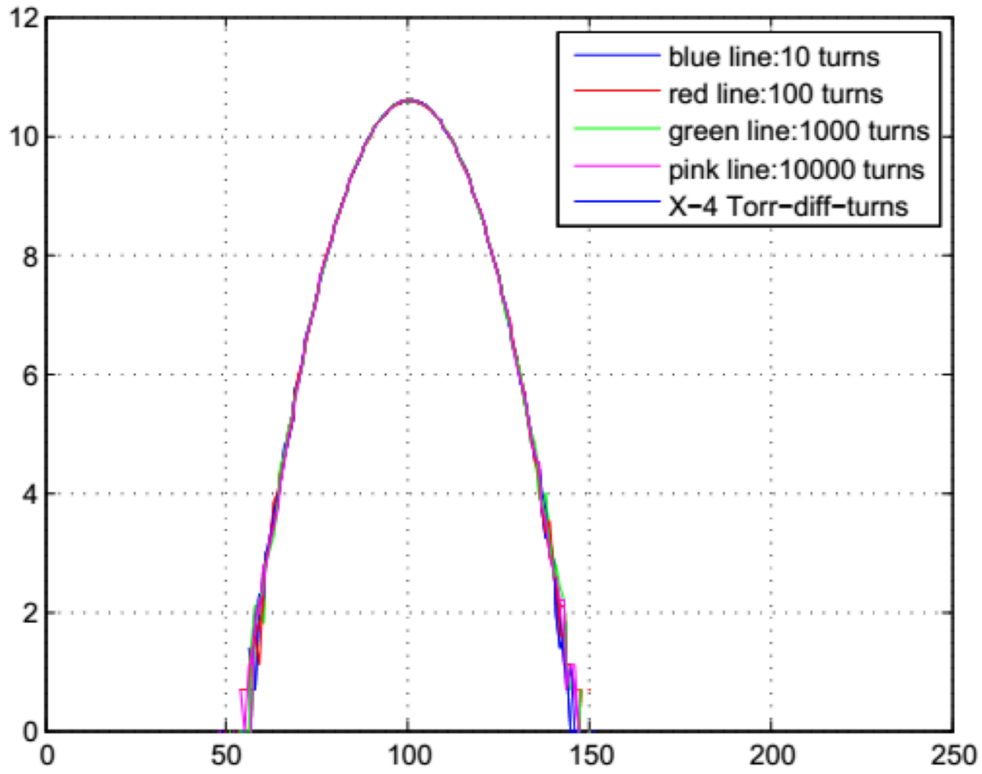
For the H_2 gas target (10 cm long, and 10^{-4} Torr in the target region), it is equivalent to 10^{-7} Torr in the whole ring, and results in a lifetime of 1 hour.

So the beam lifetime is good enough for experiments with internal gas targets.

Beam halo issue

Due to the beam dumping, the core of the beam should be Gaussian -like. According to Monte Carlo simulation, we consider the elastic scattering effect in the internal gas target (H_2 pressure 10^{-4} Torr) . Negligible beam halo is seen:

Horizontal-halo



H2 pressure 10^{-4}Torr， different turns

Beam halo issue

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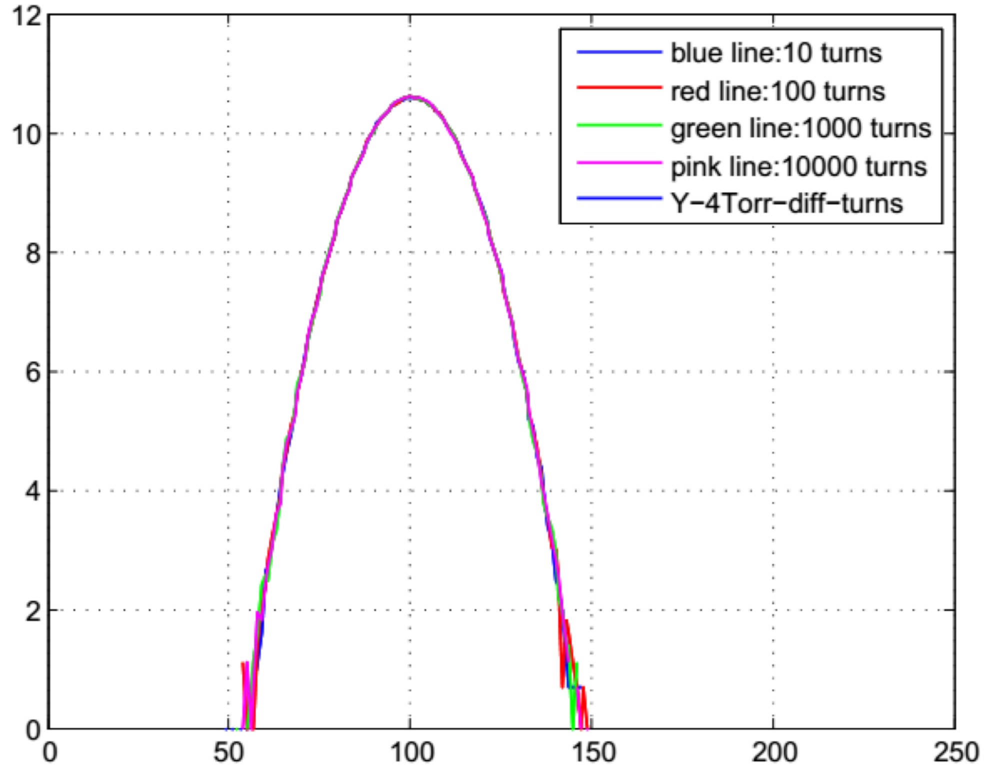
Vertical halo

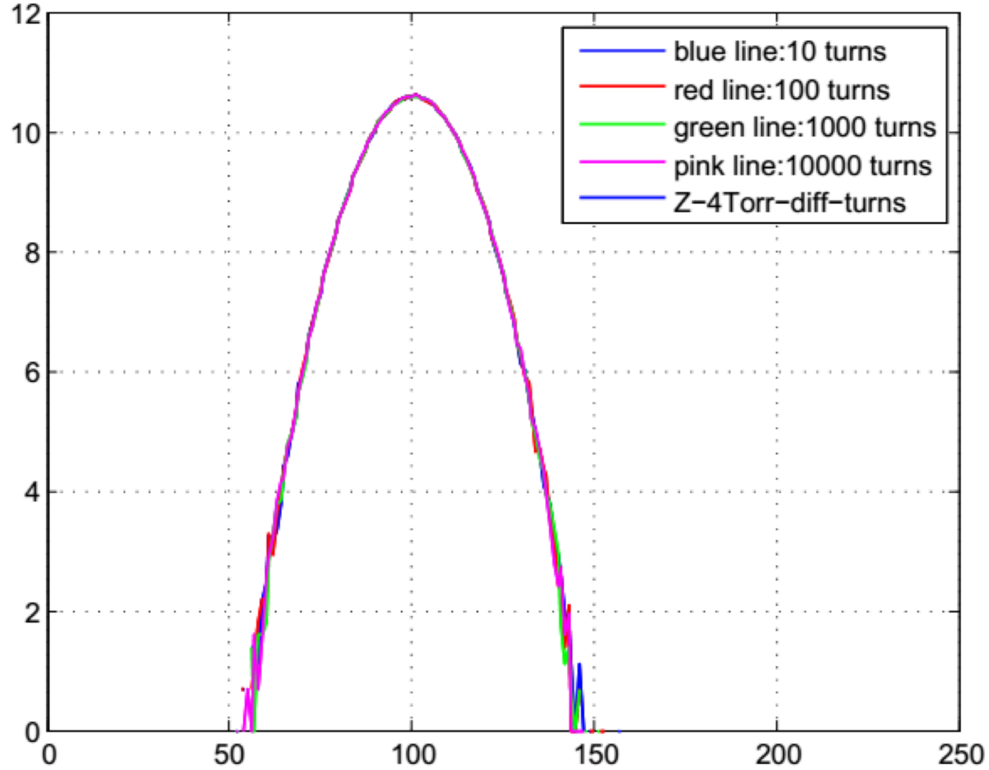


H2 pressure 10^{-4}Torr， different turns

Beam halo issue

Due to the beam dumping, the core of the beam should be Gaussian -like. According to Monte Carlo simulation, we consider the elastic scattering effect in the internal gas target (H_2 pressure 10^{-4} Torr) . Negligible beam halo is seen:

Longitudinal halo



H2 pressure 10^{-4}Torr，different turns

Luminosity with internal targets

- Since all quadrupoles are independently powered, the beta functions at the target are tunable. Many other parameters are also tunable. Some parameters need input from experimental side.
- The luminosity for internal target also depends on the beam current and thickness of target.
- With 900 mA, 10^{15} at/cm^2, luminosity could be 5×10^{35} /cm^2/s.

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- Summary

Elastic electron-deuteron scattering

- The deuteron is the simplest nucleus, the only two-nucleon bound state
- Elastic *ed* scattering is a powerful tool to study the deuteron
- In the case of unpolarized (spin-averaged) *ed* scattering:

$$\frac{d\sigma_0}{d\Omega} = \frac{d\sigma_{\text{Mott}}}{d\Omega}\left[A(Q^2) + B(Q^2)\tan^2\frac{\theta_e}{2}\right],$$

$$A = G_C^2 + \frac{8}{9}\tau^2 G_Q^2 + \frac{2}{3}\tau G_M^2, \quad B = \frac{4}{3}\tau(1+\tau)G_M^2, \quad \tau = \frac{Q^2}{4M_d^2}$$

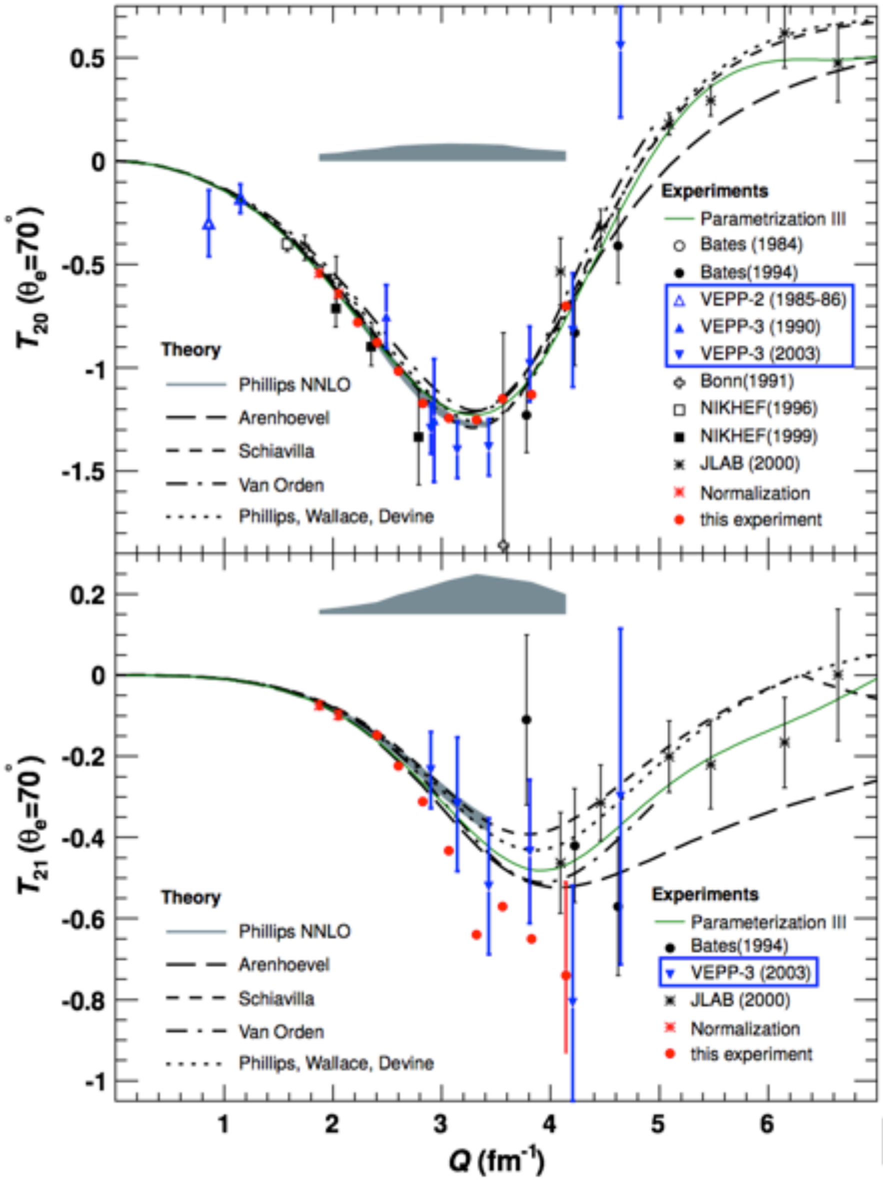
- Three form factors of the deuteron, G_C (charge monopole), G_Q (quadrupole), and G_M (magnetic), completely describe its electromagnetic structure
- In the case of scattering on a tensor-polarized deuterium target:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left\{1 + \frac{P_{zz}}{\sqrt{2}}\left[\frac{3\cos^2(\theta_H) - 1}{2}T_{20} - \sqrt{\frac{3}{2}}\sin(2\theta_H)\cos(\phi_H)T_{21} + \sqrt{\frac{3}{2}}\sin^2(\theta_H)\cos(2\phi_H)T_{22}\right]\right\},$$

where T_{20}, T_{21}, and T_{22} are the deuteron tensor analyzing powers
- The form factors G_C and G_Q can be separated only using polarized scattering

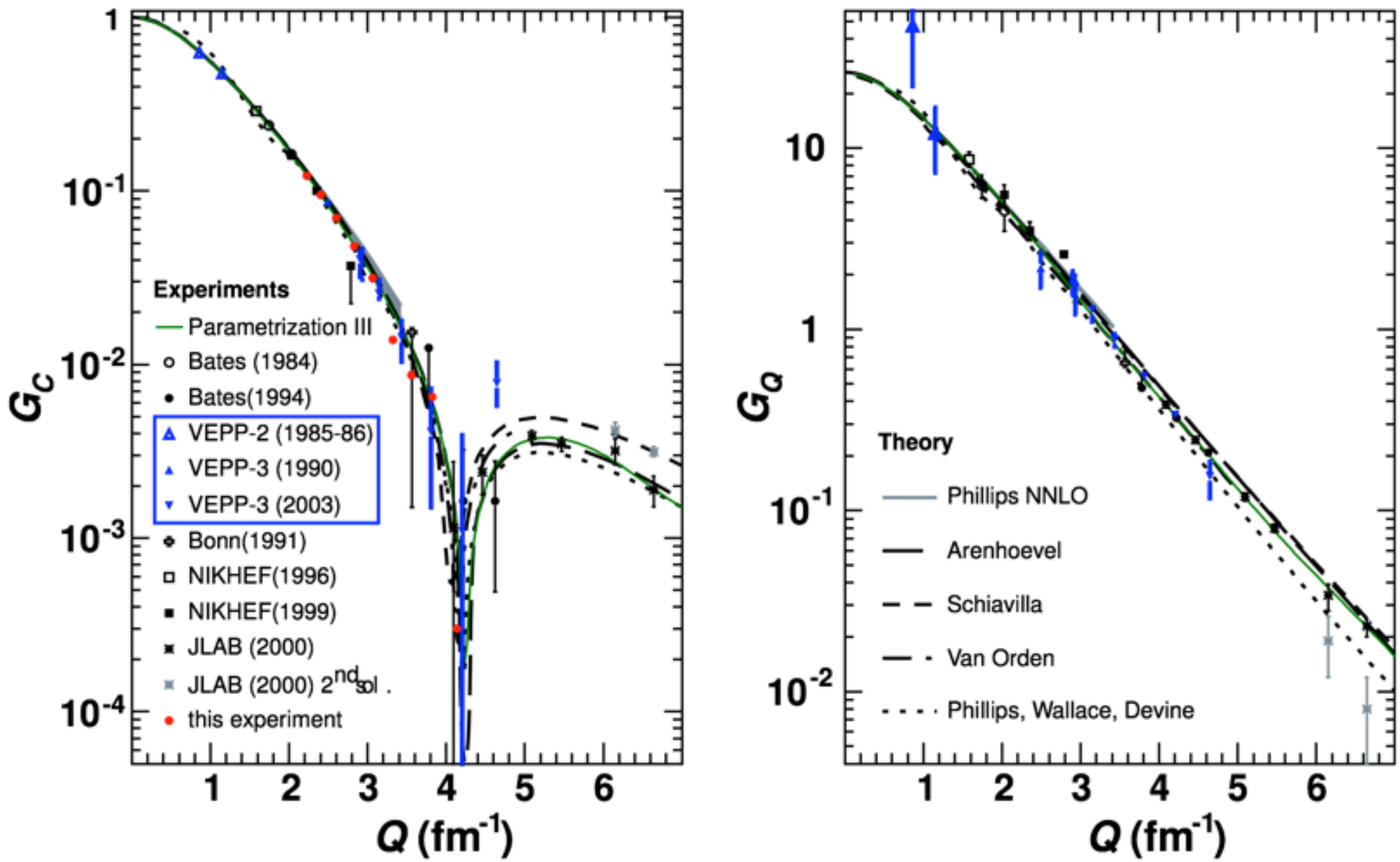
Slides from Alexander V. Gramolin

The world data for $T_{20}(Q)$ and $T_{21}(Q)$



From PRL **107**, 252501

The world data for $G_C(Q)$ and $G_Q(Q)$



The figures are from C. Zhang et al., Phys. Rev. Lett. 107, 252501 (2011)

The form factors can be measured between Q= 3 – 5 fm^{-1} at BEPCII with 2.5 GeV electron beam.

Two-body deuteron photodisintegration

Deuteron photodisintegration: $\gamma d \to pn$

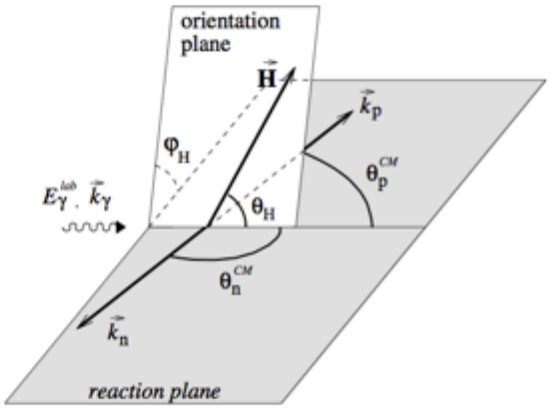
In the case of polarized spin-1 target and unpolarized photon beam:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\Bigg\{1 - \sqrt{\frac{3}{4}}\, P_z \sin(\theta_H)\sin(\phi_H)\;\; T_{11}(E\gamma, \theta_p^{CM})$$
$$+\sqrt{\frac{1}{2}}\, P_{zz}\Bigg[\frac{3\cos^2(\theta_H) - 1}{2}\;\; T_{20}(E\gamma, \theta_p^{CM})$$
$$-\sqrt{\frac{3}{8}}\sin(2\theta_H)\;\cos(\phi_H)\;\; T_{21}(E\gamma, \theta_p^{CM})$$
$$+\sqrt{\frac{3}{8}}\sin^2(\theta_H)\;\cos(2\phi_H)\;\; T_{22}(E\gamma, \theta_p^{CM})\Bigg]\Bigg\}$$

$P_z = n_+ - n_-$ – degree of vector polarization: $-1 \ldots +1$

$P_{zz} = 1 - 3 \cdot n_0$ – degree of tensor polarization: $-2 \ldots +1$

n_+, n_-, n_0 – population numbers for the spin projections $+1$, -1 and 0, respectively



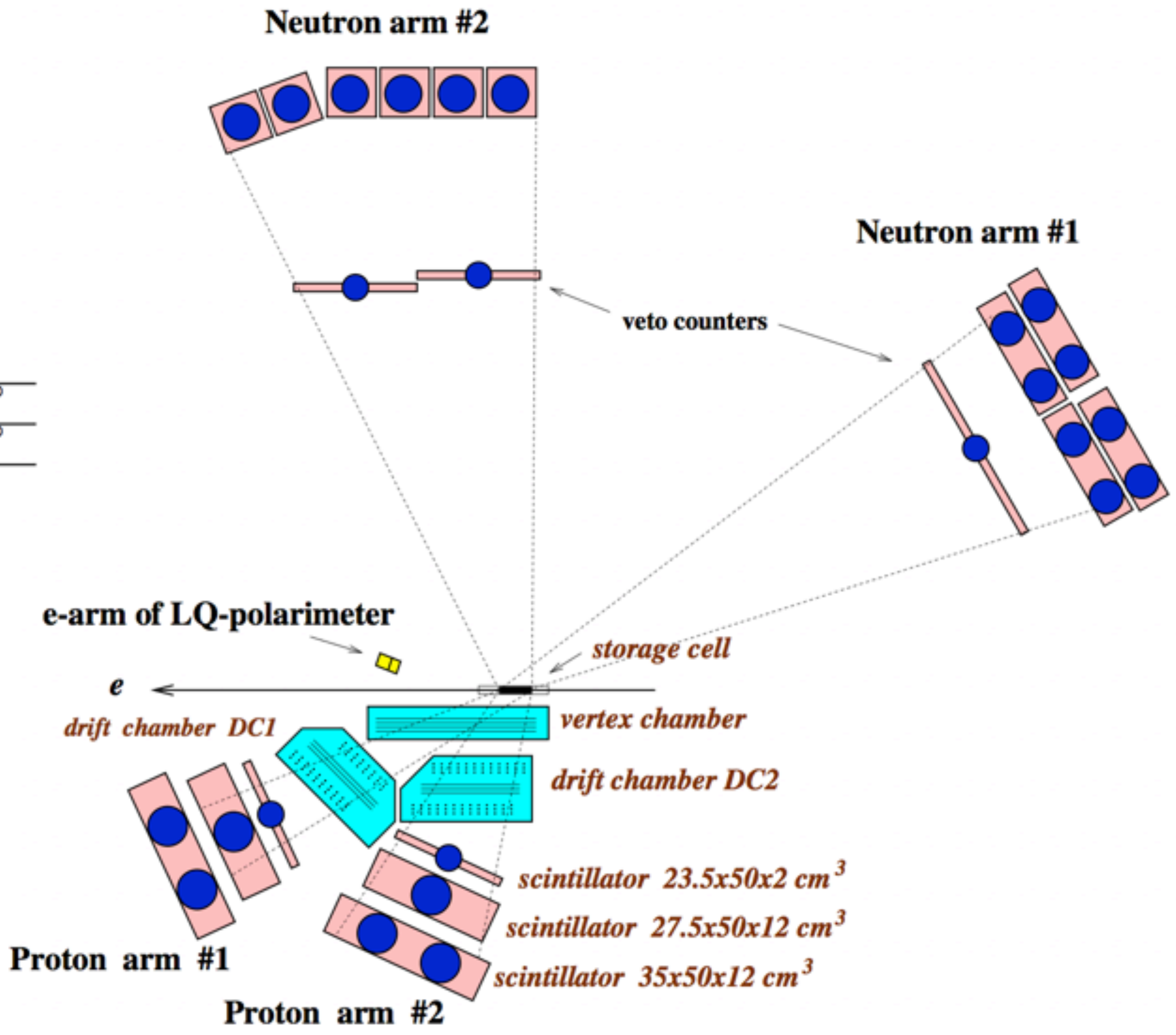
Detector layout for deuteron photodisintegration

- 2 pairs of arms in vertical plane:

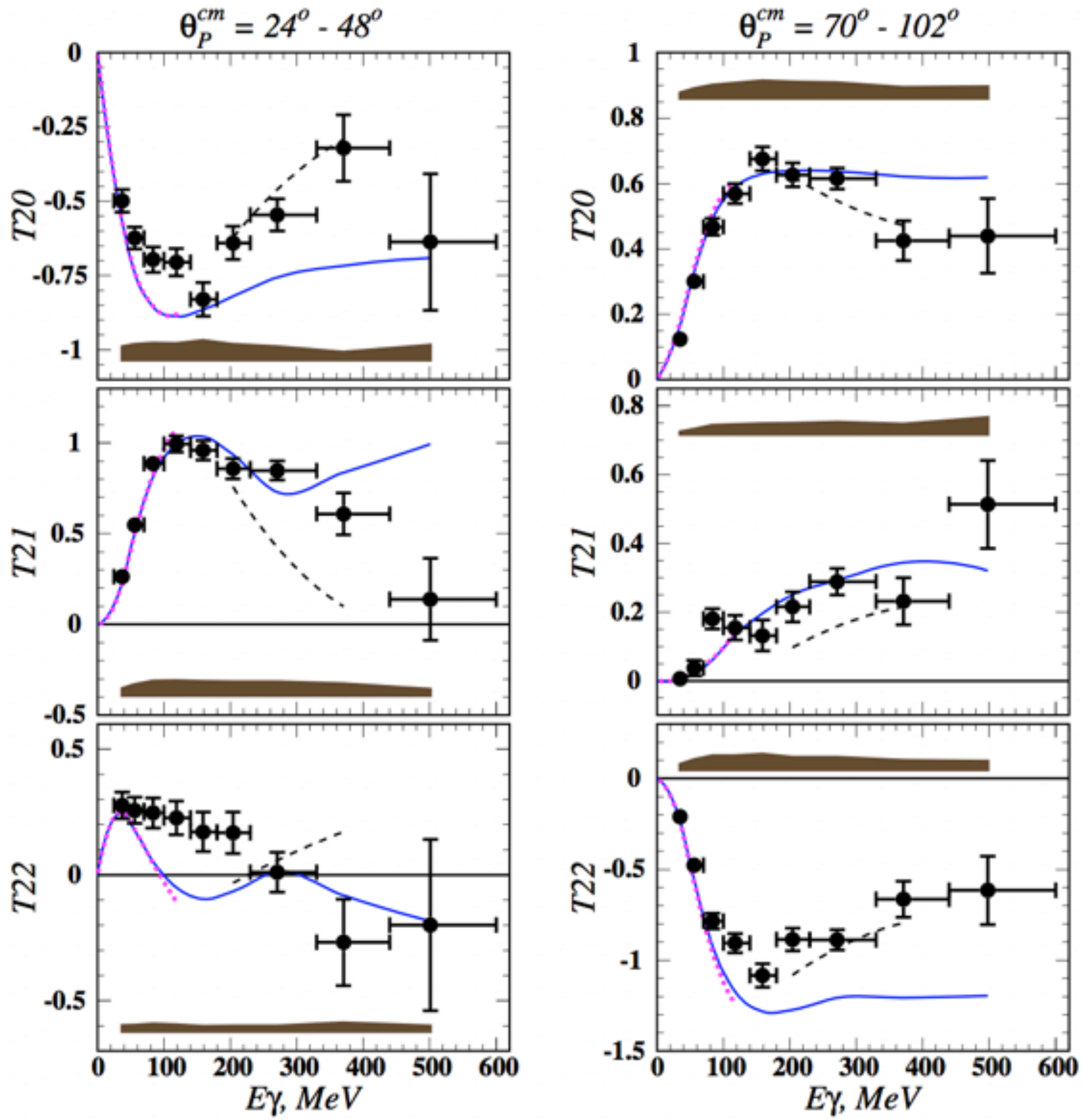
arm	I	II
θ_p	20°-40°	55°-95°
θ_n	127°-145°	68°-92°
Δ_ϕ	25°	19°

- proton arm:
drift chambers + 3 scintillator layers

- neutron arm:
thin veto-counter + thick scintillator



Results: T_{20}, T_{21}, and T_{22} as functions of E_γ



vertical bars – statistical errors

horizontal bars – bin sizes

shaded bands – systematic errors

Theoretical curves:

solid – K.-M.Schmitt & H.Arenhövel (1990), full calculation

dotted – M.Levchuk (1995), full calculation

dashed – M.Schwamb (2006)

Experiments at BEPCII will improve the precision with 2.5 GeV electron beam.

I. A. Rachek *et al.*, Phys. Rev. Lett **98**, 182303 (2007)

Coherent neutral pion photoproduction on the deuteron

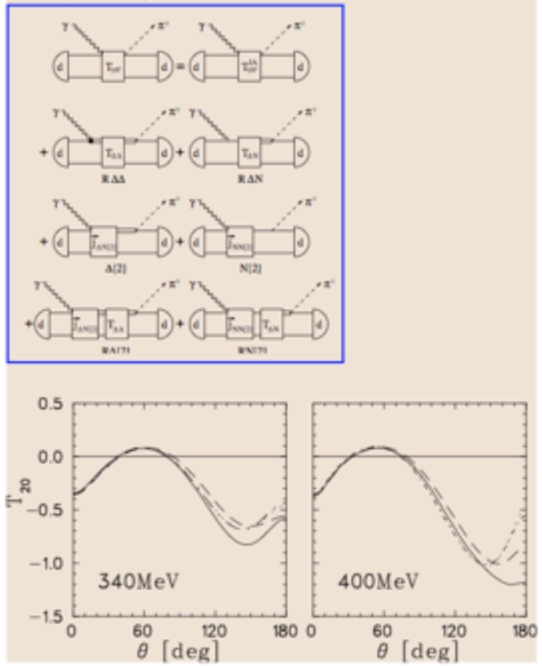
$$\gamma + \vec{d} \rightarrow \pi^0 + d$$

One of the simplest photonuclear reactions, the only pion photoproduction process off the deuteron having two final-state particles

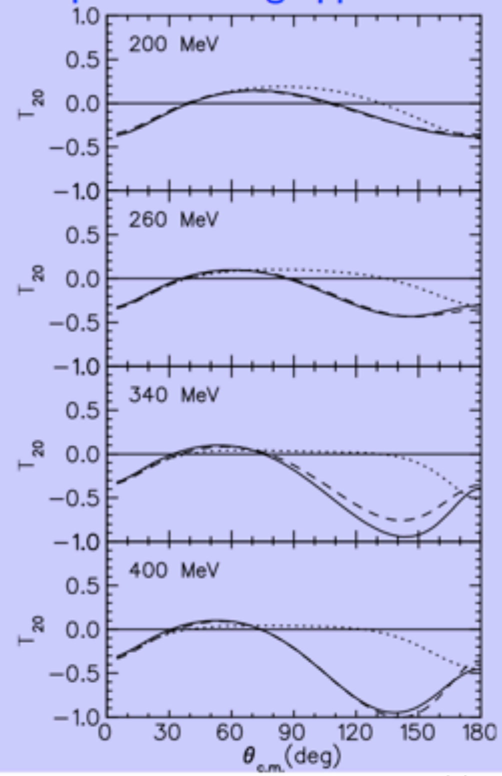
Issues addressed:

- deuteron structure
- π^0 – deuteron elastic scattering
- pion photoproduction off neutron
- at threshold – chiral dynamics on neutron
- . . .

P.Wilhelm and H.Arenhövel, Nucl. Phys. A **609**, 469 (1996)
couple-channel approach: NN, $N\pi$, $N\Delta$



S.S.Kamalov, L.Tiator and C.Bennhold, Phys. Rev. C **55**, 98 (1997)
with FSI treated in the KMT multiple scattering approach

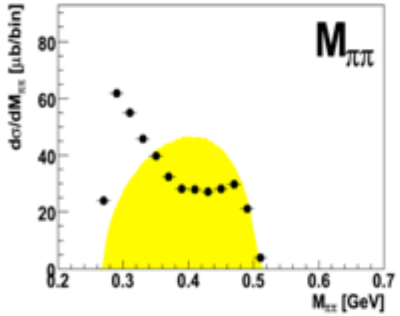


With E_b=2.5 GeV, BEPCII allows measurement of the Form factors between E_γ=200-600 MeV

ABC effects in $\gamma d \to d\pi\pi$?

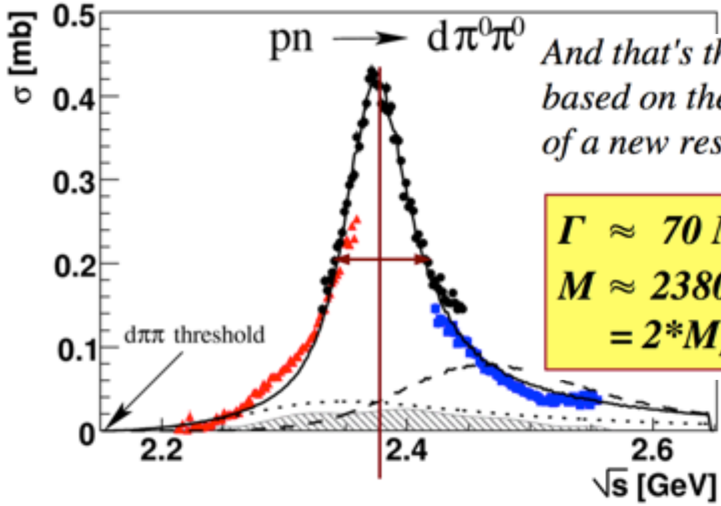
Many theoretical prediction:
F. Wang et al
Z. Y. Zhang et al.
…

$pn \to d\,\pi^0\,\pi^0$
@ $\sqrt{s}$ = 2.38 GeV



P. Adlarson et. al
PRL 106:242302, 2011

Phasespace (always)



And that's the model, based on the assumption of a new resonance.

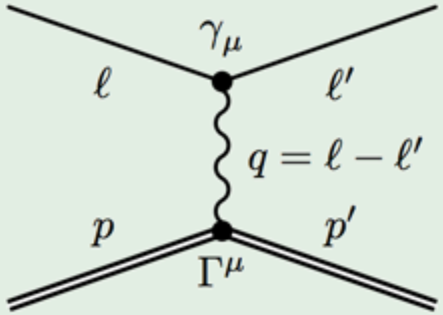
Γ ≈ 70 MeV « 2*Γ_Δ
M ≈ 2380 MeV
= 2*M_Δ – 80 MeV

$$\gamma d \to d\pi\pi$$

The real photon energy will be at least 0.6 GeV
Can we do it at BEPCII with internal gas deuteron targets with 2.5 GeV electron beam?

Proton electromagnetic form factors (spacelike region)

Elastic *ep* scattering in the one-photon exchange (Born) approximation



Vertex operator $\Gamma^\mu(q)$

$$\Gamma^\mu(q) = \gamma^\mu F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M} F_2(q^2)$$

$F_1(q^2)$ – non-spin-flip Dirac form factor
$F_2(q^2)$ – spin-flip Pauli form factor

Sachs form factors

- Electric form factor:
  $G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4M^2} F_2(Q^2)$
- Magnetic form factor:
  $G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$
- Dipole formula:
  $G_E \approx \frac{G_M}{\mu} \approx \left(1 + \frac{Q^2}{0.71}\right)^{-2}$

In the Breit frame, G_E and G_M describe
charge and magnetization distributions in proton

Two methods of measuring the proton form factors

- The Rosenbluth separation method at constant Q^2

Rosenbluth Formula *Rosenbluth, 1950*

$$\frac{d\sigma}{d\Omega} = \frac{1}{\varepsilon(1+\tau)}\left[\varepsilon G_E^2 + \tau G_M^2\right]\frac{d\sigma_{\text{Mott}}}{d\Omega},$$

where $\boxed{\tau = Q^2/4M^2}$ and $\boxed{\varepsilon = \left[1 + 2(1+\tau)\tan^2(\theta/2)\right]^{-1}}$

- Polarized beams and targets or recoil polarimeters

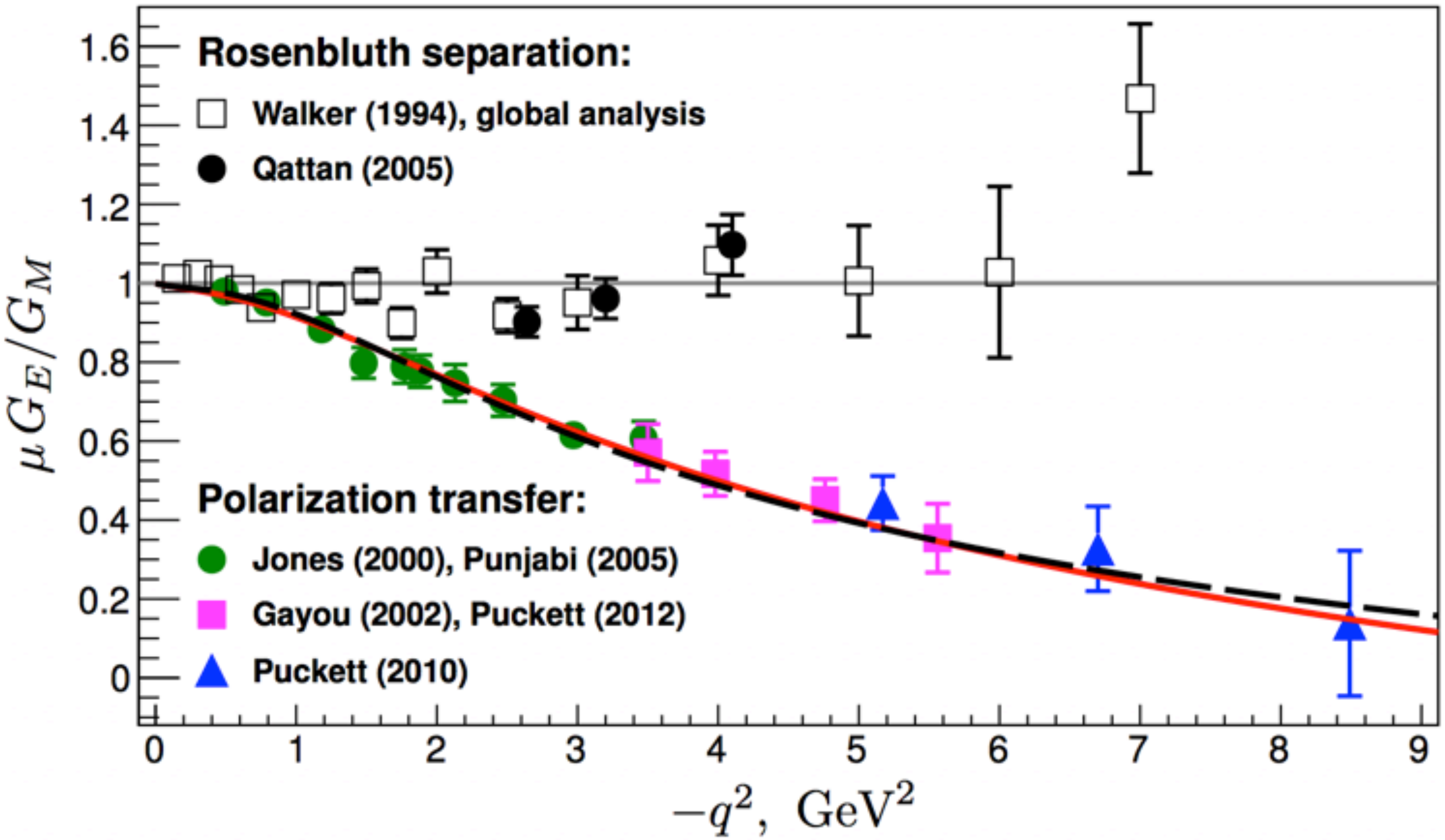
Form factor ratio from polarization transfer *Akhiezer & Rekalo, 1968*

$$\frac{G_E}{G_M} = \frac{P_T}{P_L} \times K,$$

where P_T and P_L are transverse and longitudinal polarization components of the proton, $K = -\sqrt{\tau(1+\varepsilon)/2\varepsilon}$ is a kinematic factor

Inconsistency?

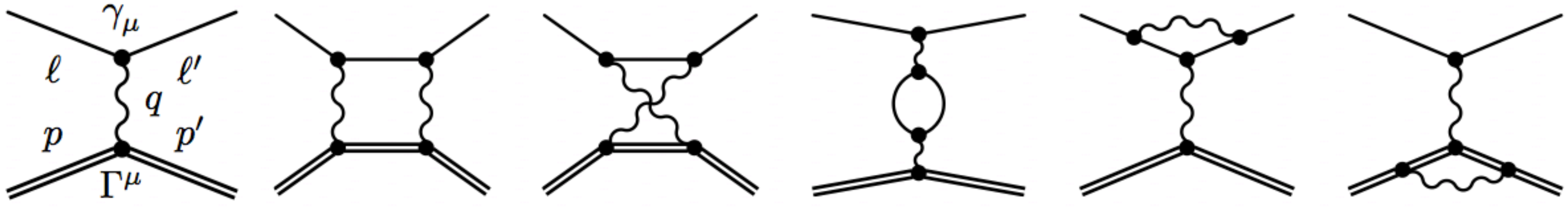
A clear discrepancy between the two experimental data sets was observed:



Radiative corrections, in particular a Two-Photon Exchange (TPE) effect, is a likely origin of the discrepancy

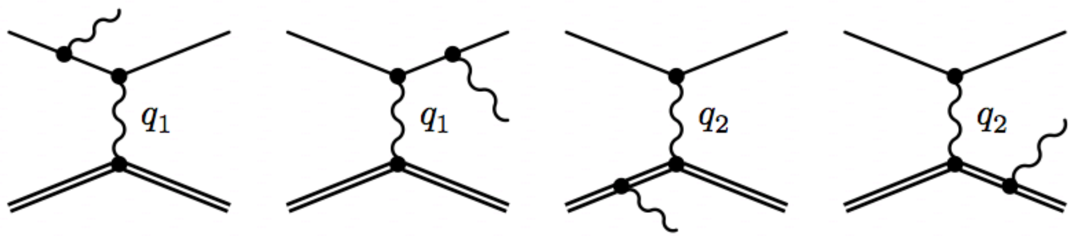
First-order radiative corrections to elastic *ep* scattering

"Elastic" scattering ($e^{\pm}p \to e^{\pm}p$):



$\mathcal{M}_{\text{Born}}$ $\mathcal{M}_{2\gamma}$ $\mathcal{M}_{\text{vac}}$ $\mathcal{M}^{\ell}_{\text{vert}}$ $\mathcal{M}^{p}_{\text{vert}}$

First-order bremsstrahlung ($e^{\pm}p \to e^{\pm}p\,\gamma$):



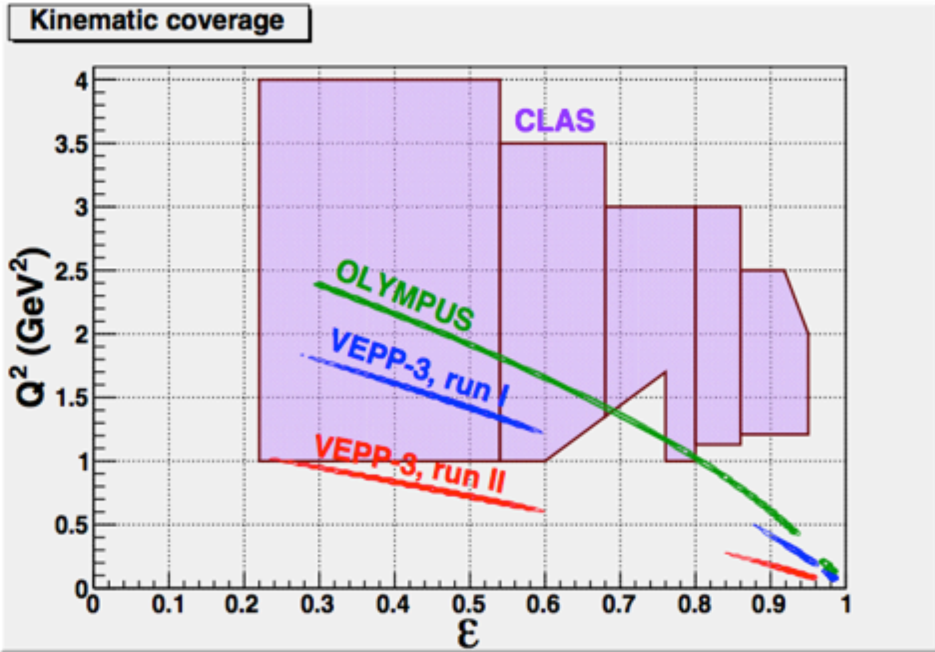
$\mathcal{M}^{\ell}_{\text{brems}}$ $\mathcal{M}^{p}_{\text{brems}}$

$$\sigma(e^{\pm}p) \propto |\mathcal{M}_{\text{Born}}|^2 \pm 2\,\text{Re}\left(\mathcal{M}^{\dagger}_{\text{Born}}\mathcal{M}_{2\gamma}\right) + 2\,\text{Re}\left(\mathcal{M}^{\dagger}_{\text{Born}}\mathcal{M}_{\text{vac}}\right) + 2\,\text{Re}\left(\mathcal{M}^{\dagger}_{\text{Born}}\mathcal{M}^{\ell}_{\text{vert}}\right) + 2\,\text{Re}\left(\mathcal{M}^{\dagger}_{\text{Born}}\mathcal{M}^{p}_{\text{vert}}\right) + |\mathcal{M}^{\ell}_{\text{brems}}|^2 + |\mathcal{M}^{p}_{\text{brems}}|^2 \pm 2\,\text{Re}\left(\mathcal{M}^{\ell\dagger}_{\text{brems}}\mathcal{M}^{p}_{\text{brems}}\right) + \mathcal{O}(\alpha^4)$$

✓ Cancellation of infrared divergences (corresponding terms are marked in color)

✓ Some of the terms are of different signs ("$\pm$") for $e^{+}p$ and $e^{-}p$ scattering

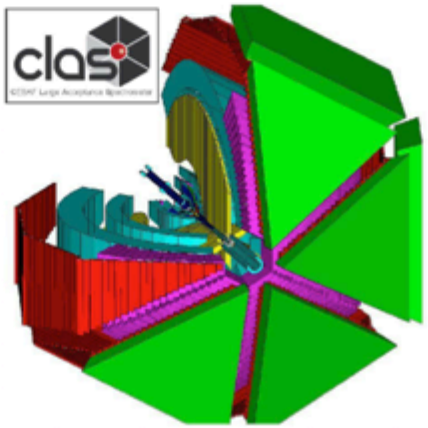
Three new experiments to measure $R = \sigma(e^+p)/\sigma(e^-p)$

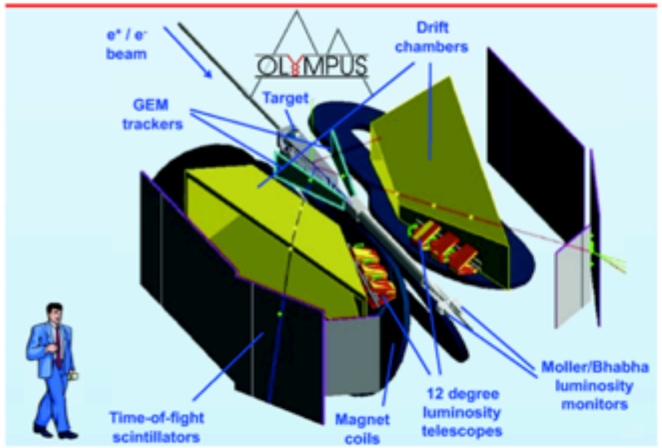


1. Novosibirsk: VEPP-3
   Two runs: $E_{\mathrm{beam}} = 1.6$ and 1.0 GeV
2. JLab: CLAS at Hall B
   $E_{\mathrm{beam}} = 0.5\text{—}4$ GeV
3. DESY: OLYMPUS at DORIS
   $E_{\mathrm{beam}} = 2$ GeV

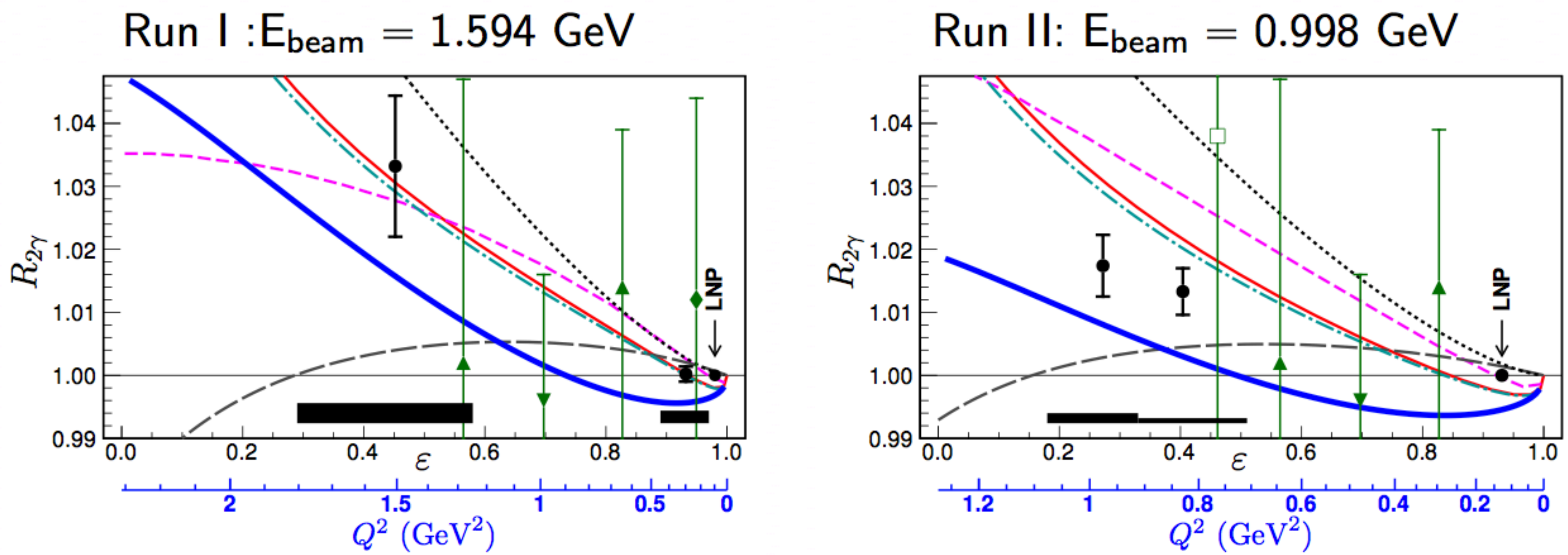
$$\delta_{2\gamma} = \frac{2\mathrm{Re}\left(\mathcal{M}_{1\gamma}^{\dagger}\mathcal{M}_{2\gamma}^{\mathrm{hard}}\right)}{|\mathcal{M}_{1\gamma}|^2}$$

$$R_{2\gamma} = \frac{1-\delta_{2\gamma}}{1+\delta_{2\gamma}}$$





Results of the Novosibirsk TPE experiment



Curves:

solid red line	*P. G. Blunden, et al.,*	Phys. Rev. **C72** (2005) 034612	:hadronic TPE calculation
dash-dot line	*D. Borisyuk and A. Kobushkin,*	Phys. Rev. **C78** (2008) 025208	:dispersion relations
grey dashed line	*E. Tomasi-Gustafsson, et al.,*	Phys. Atom. Nucl. 76 (2013) 937	:"analytical model"
magenta dashed line	*J. Arrington and I. Sick,*	Phys. Rev. **C70** (2004) 028203	:Coulomb corrections
dotted line	*I. A. Qattan, et al.,*	Phys. Rev. **C84** (2011) 054317	:Parametrisation
thick blue line	*J. Bernauer, et al.,*	Phys. Rev. **C90** (2014) 015206	:Global *ep*-data fit

Data: □ SLAC, 1965; ▾ Cornell, 1966; ♦ DESY, 1967; ▲ Cornell, 1968; ● VEPP-3, 2015.

- LNP – Luminosity Normalization Point – set to $R_{2\gamma} = 1$
- Error bars are statistical errors, shaded bands show ε-bin width and systematic uncertainties
- The radiative corrections are applied according to J. Phys. G **41**, 115001 (2014)

Search for cLFV $e^+ + N \rightarrow \mu^+(\tau^+) + N$

$$L_{\mathrm{CLFV}} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_{\mathrm{R}}\sigma^{\mu\nu}e_{\mathrm{L}}F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_{\mathrm{L}}\gamma^\mu e_{\mathrm{L}})(\bar{q}_{\mathrm{L}}\gamma_\mu q_{\mathrm{L}})$$

Photonic (dipole) interaction

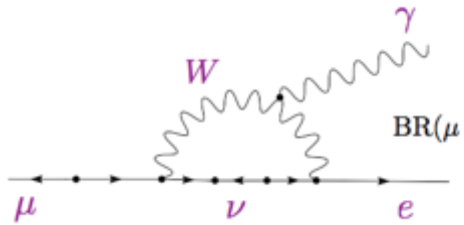
cLFV is a SM-free process

Contact interaction

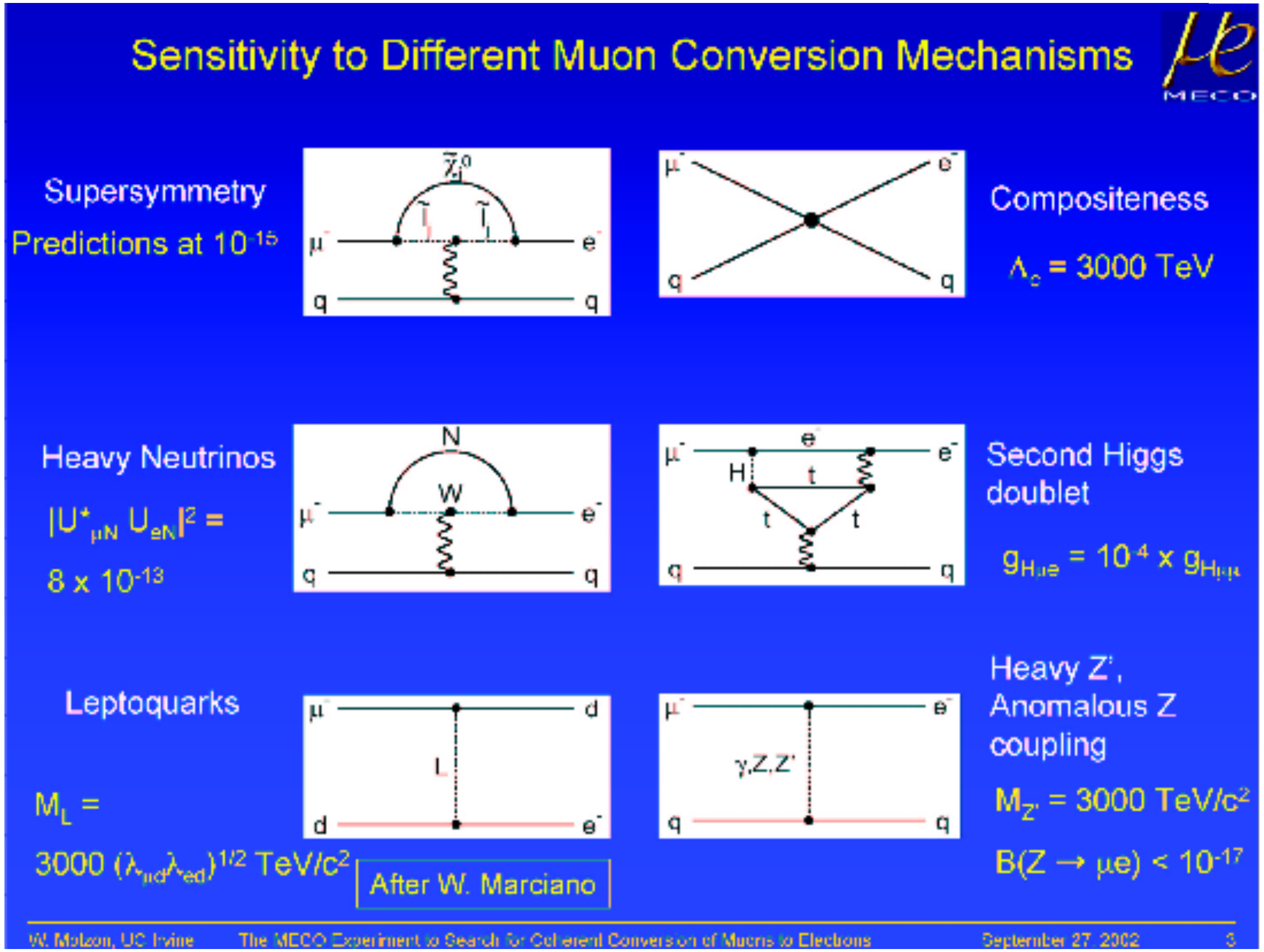
process	present limit	future	
$\mu \rightarrow e\gamma$	$<5.7 \times 10^{-13}$	$<10^{-14}$	MEG at PSI
$\mu \rightarrow eee$	$<1.0 \times 10^{-12}$	$<10^{-16}$	Mu3e at PSI
$\mu N \rightarrow eN$ (in Al)	none	$<10^{-17}$	Mu2e / COMET
$\mu N \rightarrow eN$ (in Ti)	$<4.3 \times 10^{-12}$	$<10^{-18}$	PRISM
$\tau \rightarrow e\gamma$	$<1.1 \times 10^{-7}$	$<10^{-9}$ - 10^{-10}	superKEKB
$\tau \rightarrow eee$	$<3.6 \times 10^{-8}$	$<10^{-9}$ - 10^{-10}	superKEKB
$\tau \rightarrow \mu\gamma$	$<4.5 \times 10^{-8}$	$<10^{-9}$ - 10^{-10}	superKEKB
$\tau \rightarrow \mu\mu\mu$	$<3.2 \times 10^{-8}$	$<10^{-9}$ - 10^{-10}	superKEKB/LHCb

SM and New physics contributions

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{l}(V_{MNS})^{*}_{\mu l}(V_{MNS})_{el}\frac{m^{2}_{\nu_l}}{M^{2}_{W}}\right|^{2}$$



SM: BR~O(10^{-54})



Many new physics model can make sizable and measurable contributions .

e to μ(τ) conversion: $e^+ + N \rightarrow \mu^+(\tau^+)+N$ at BEPCII

Typical cLFV processes with different targets

Mini. E_{beam} for tau production

$$e^+ + p \to \mu^+(\tau^+) + p$$

E_{beam} > 3.5 GeV for τ

$$e^+ + d \to \mu^+(\tau^+) + d$$

E_{beam} > 2.6 GeV for τ

$$e^+ + He \to \mu^+(\tau^+) + He$$

E_{beam} > 2.2 GeV for τ

- **2.5 GeV positron/electron beam incident on the targets**
- **Estimated luminosity reaches 10^{35} $cm^{-2}s^{-1}$ → 1 ab^{-1} /year**
  (Beam current of 900 mA, and target thickness of 5×10^{15} atom/cm^2

Rough estimations of the expected sensitivities for E_{beam}=2.5 GeV:

$$\sigma(e^\pm + p \to \mu^\pm + p) <\sim 30ab$$

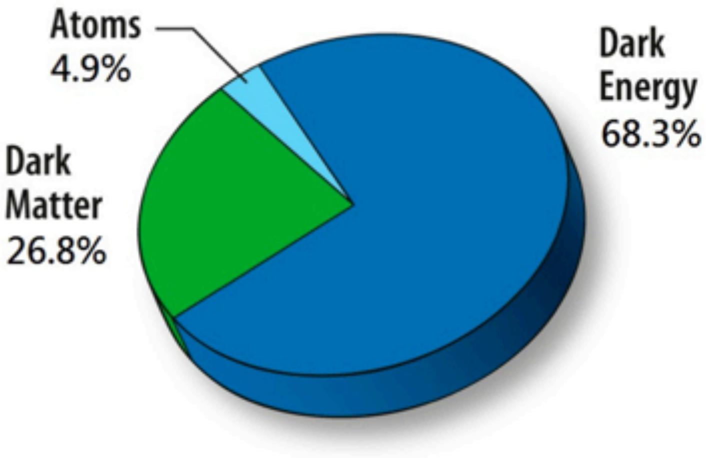
$$\sigma(e^\pm + d \to \mu^\pm + d) <\sim 20ab$$

$$\sigma(e^\pm + He^4 \to \mu^\pm(\tau^\pm) + He^4) <\sim 10ab(0.1-1.0)fb$$

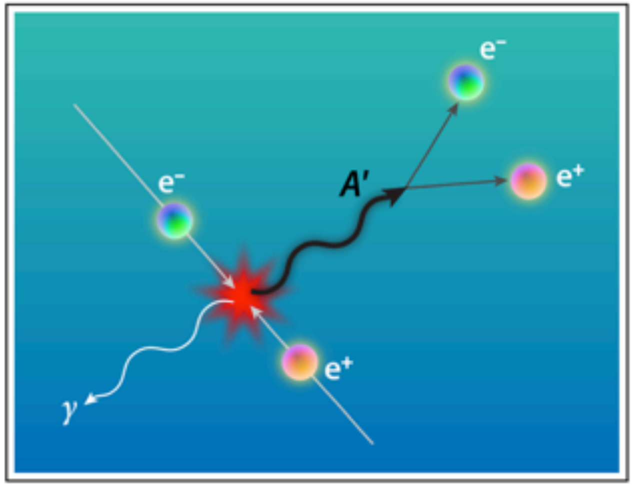
Argon or Nitrogen target should be better!

The QED and beam-related backgrounds should be studied, and theoretical estimations from different New Physics models are important!

Search for dark photon at BEPCII



Wikipedia



APS/Alan Stonebraker

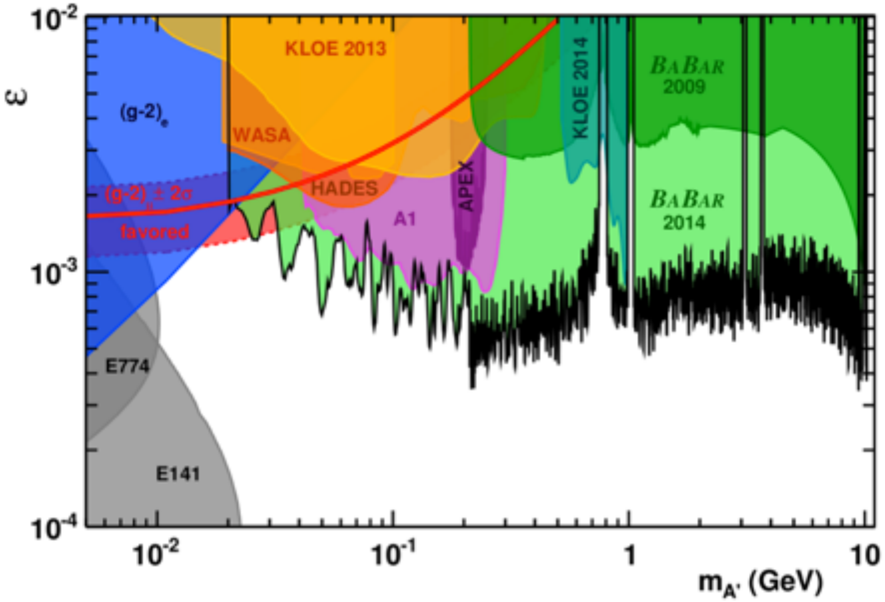
- One needs to extend the Standard Model to explain Dark Matter
- Additional $U'(1)$ symmetry is one of the simplest extensions:

$$\boxed{U(1)_Y \times SU(2)_W \times SU(3)_s} \times \boxed{U'(1)_D}$$

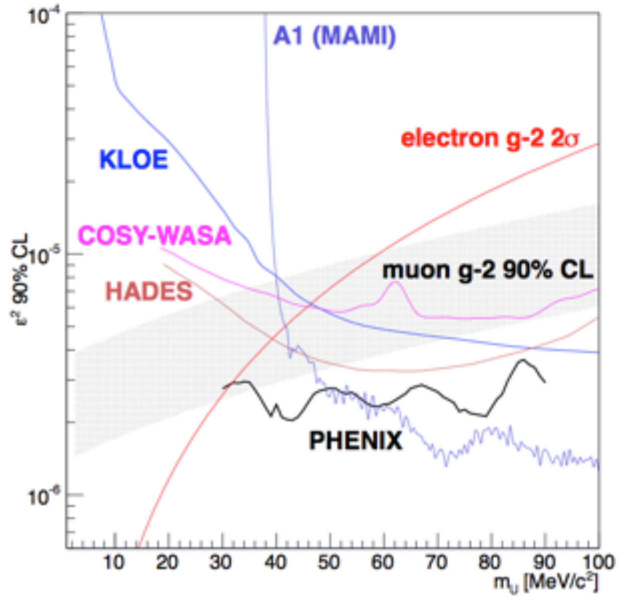
- It requires a new gauge boson, A' ("dark photon"), with the mass $m_{A'} > 0$
- A' may couple to SM particles via kinetic mixing with the photon
- Expected: $m_{A'} = 1 \ldots 10^4$ MeV, $\varepsilon = 10^{-6} \ldots 10^{-2}$ (kinetic mixing parameter)
- Both collider and fixed-target experiments can search for A'

Recent experimental constraints

BABAR (2014): $e^+e^- \to \gamma A', A' \to e^+e^-, \mu^+\mu^-$



PHENIX (2014): $\pi^0, \eta \to \gamma e^+e^-$



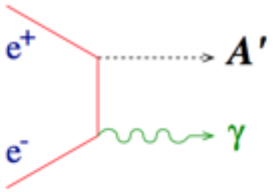
Recent experimental results (2013–2015):

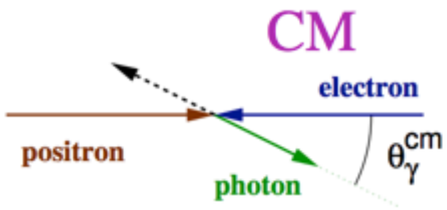
WASA 2013	$\pi^0 \to \gamma(e^+e^-)$	PLB 726 (2013) 187
KLOE 2013	$\phi \to \eta(e^+e^-)$	PLB 720 (2013) 111
KLOE 2014	$e^+e^- \to \gamma(\mu^+\mu^-)$	arXiv:1404.7772
MAMI-A1 2014	$e^-N \to e^-N(e^+e^-)$	PRL 112 (2014) 221802
PHENIX 2014	$\pi^0, \eta \to \gamma(e^+e^-)$	arXiv:1409.0851
HADES 2014	$pN \to X(e^+e^-)$	PLB 731 (2014) 265
KLOE 2015	$e^+e^- \to \gamma(e^+e^-)$	arXiv:1501.05173

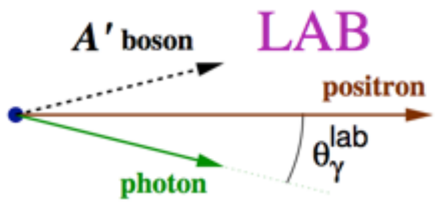
No evidence of A' so far!

A' from the process $e^+e^- \to \gamma A'$

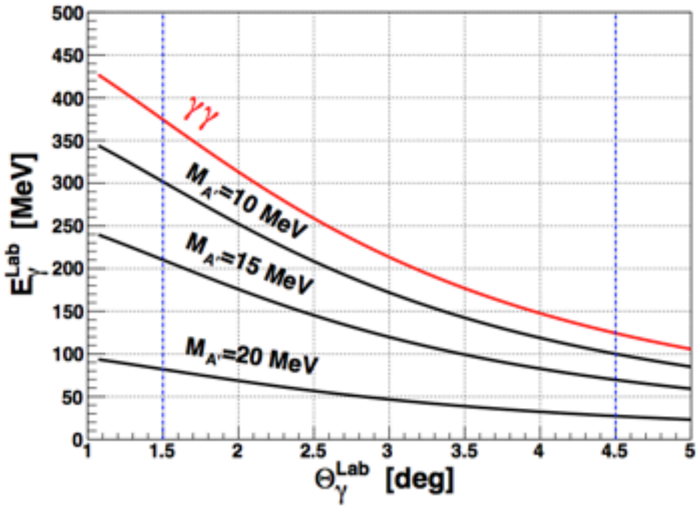
The process $e^+e^- \to \gamma A'$ is similar to the two-photon annihilation $e^+e^- \to \gamma\gamma$:

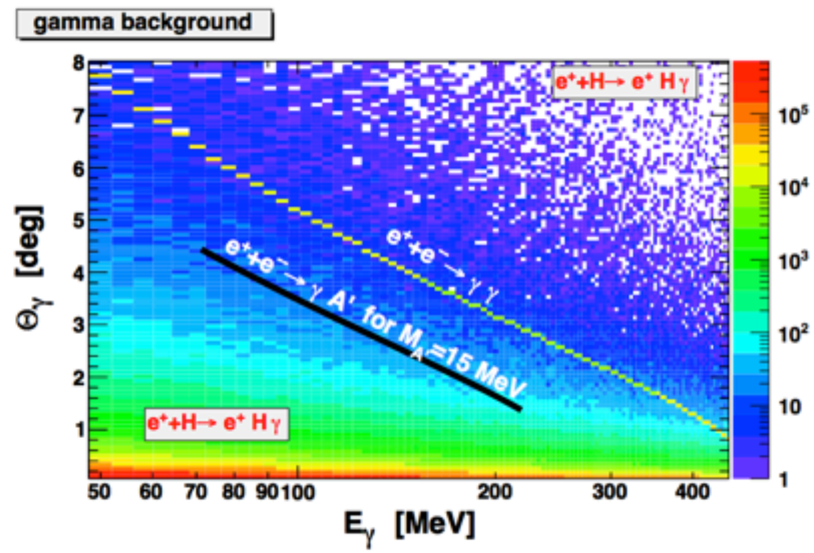






The photon energy, E_γ^{lab}, depends on its polar angle, θ_γ^{lab}, the mass of the second particles $(\gamma \;\; or \;\; A')$. In the case of $E_{beam} = 1.0 - 2.5\,GeV$ $(\sqrt{s} = 31.5 \sim 50\,MeV)$.



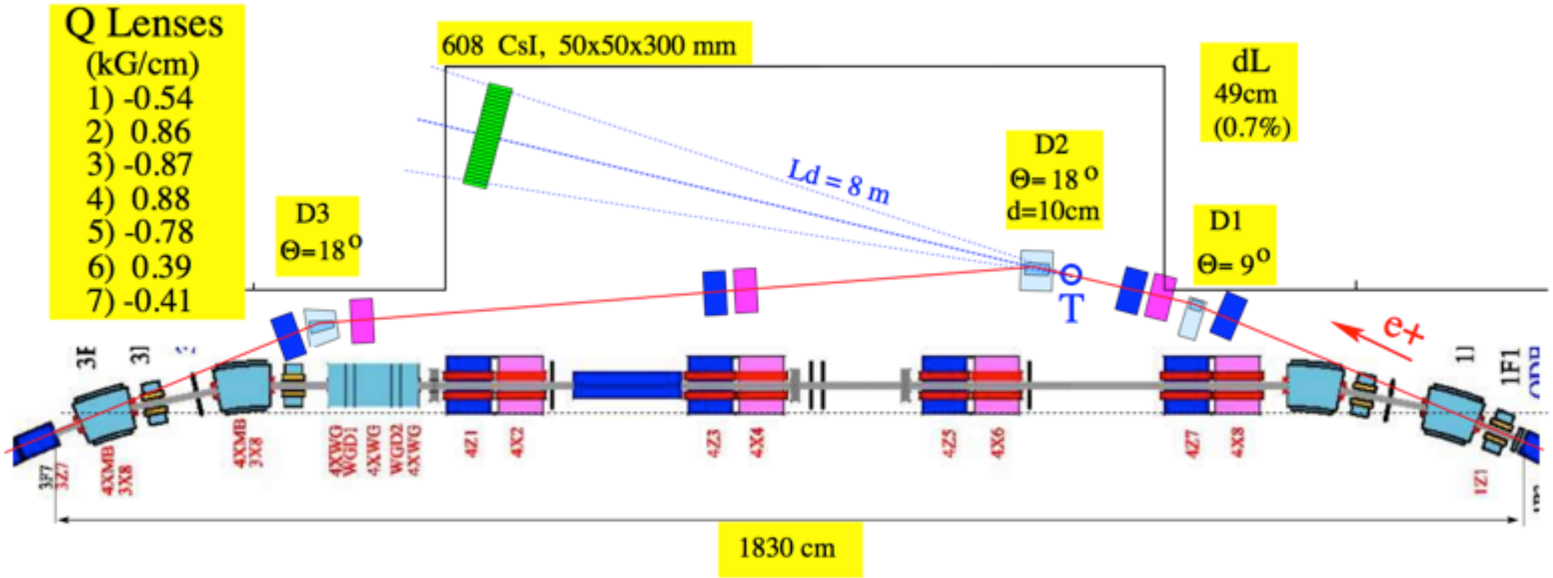


Therefore, one can search for dark photons measuring $E_\gamma \, and \, \theta_\gamma$ of the photon.
However, there are large QED backgrounds:

$$e^+p \to e^+p(\gamma), \;\; e^+e^- \to e^+e^-(\gamma), \;\; e^+e^- \to \gamma\gamma(\gamma).$$

Concept of the experimental technique

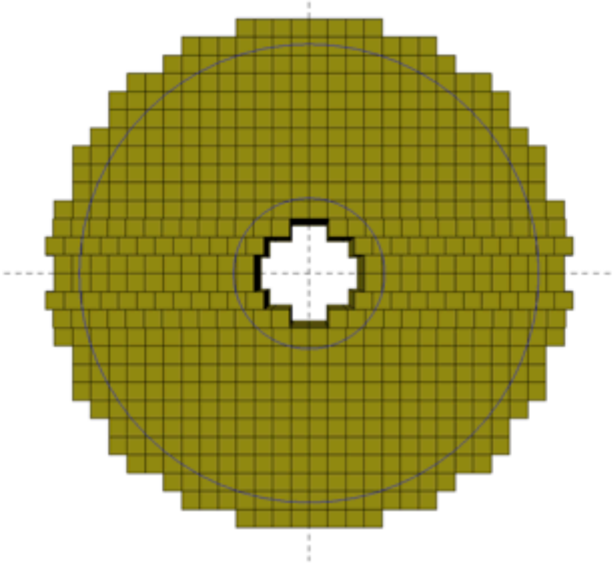
Example of the concept design from VEPP3 (arXiv:1207.5089)

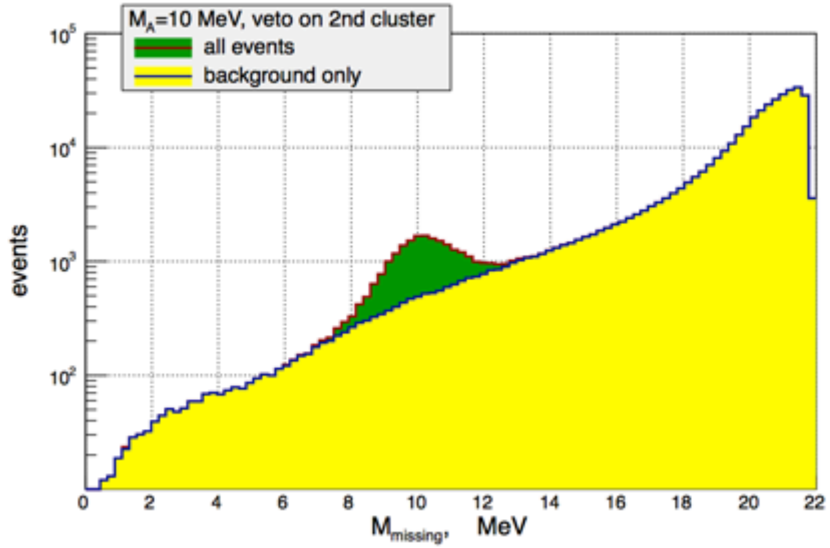


- ✧ **2.0 GeV positron beam incident on an internal hydrogen target**
- ✧ **Estimated luminosity reaches 10^{35} cm^{-2}s^{-1}**
  (Beam current of 900 mA, and target thickness of 5×10^{15} atom/cm^2
- ✧ **New bypass bending the beam and directing photons to the calorimeter**
- ✧ **Segmented EM calorimeter placed at a distance of 8-10 m from the target**

Concept of the experimental technique

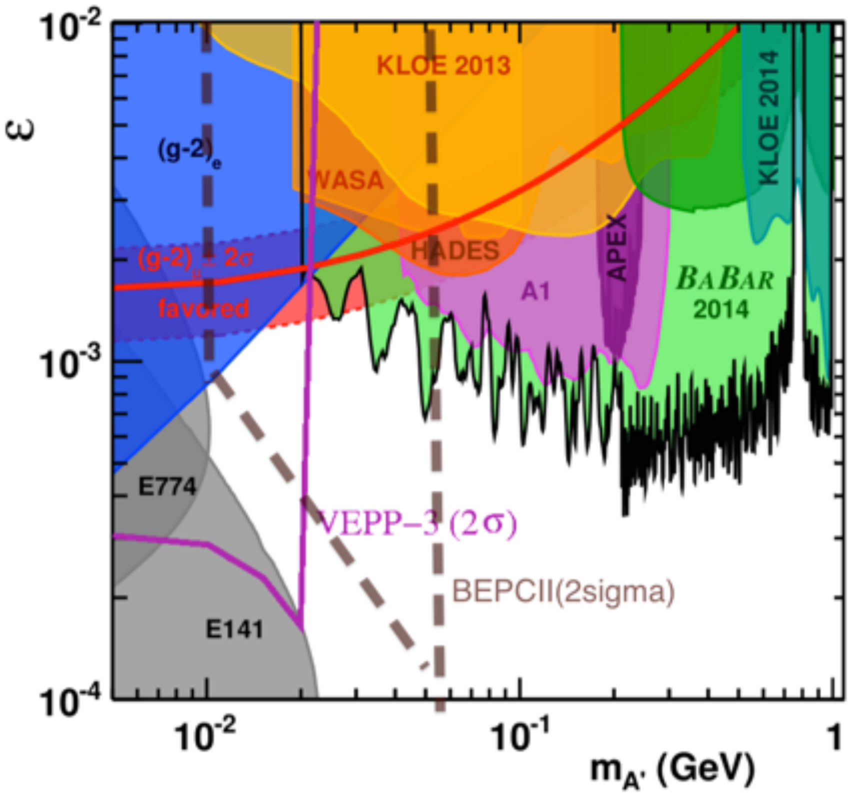
Example of the concept design from VEPP3 (arXiv:1207.5089)





- Energy resolution required: $\sigma_E/E < 0.5\%\ for\ E_\gamma = 100 - 600 MeV.$
- Angular acceptance: $\theta_\gamma = 1.5^0 - 5.0^0$ (corresponding to $\theta_\gamma^{CM} = 90^0 \pm 30^0$)
- 800 crystals from BESIII?
- The peak width is determined by the calorimeter resolutions
- An accurate Monte Carlo simulation of the QED background is required
- Some of the background processes can be substantially suppressed
- The experiment will cover a mass range $m_{A'} = 10 - 40\, MeV.$

Sensitivity of the BEPCII experiments



If there is a light dark matter particle, χ, with the mass $m_\chi < 0.5 m_{A'}$, then the invisible decay $A' \to \chi\bar{\chi}$ can be dominant!

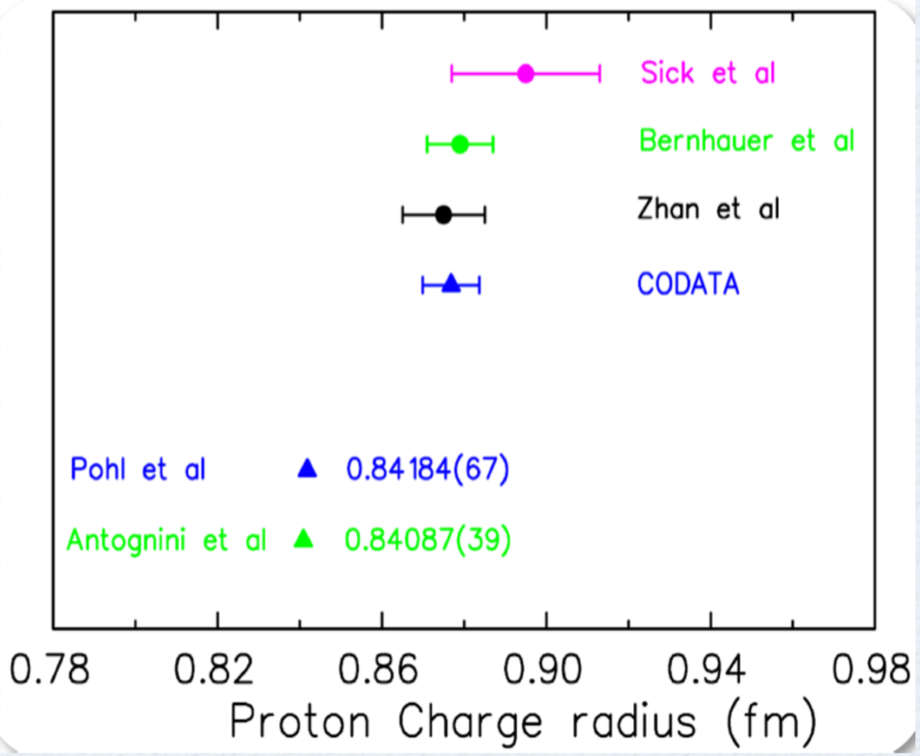
Existing constraints:

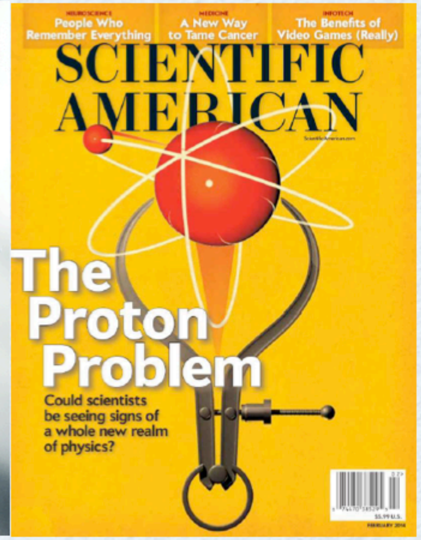
- $(g-2)$ of the muon
- $(g-2)$ of the electron
- BaBar: $\Upsilon(1S) \to \gamma A'$
- BNL: $K \to \pi A'$

Proposed new measurements:

	$\mathcal{L}$, $cm^{-2}s^{-1}$	Duration, s
VEPP-3	10^{33},	10^7
CESR	10^{34},	10^7
DAΦNE	10^{28},	$2 \cdot 10^7$
DarkLight	$6 \cdot 10^{35}$	$2 \cdot 10^6$
BEPCII	**1 10^{35}**	**10^7**

Proton radius puzzle





μH data: $R_E = 0.8409 \pm 0.0004$ fm

Pohl et al. (2010)

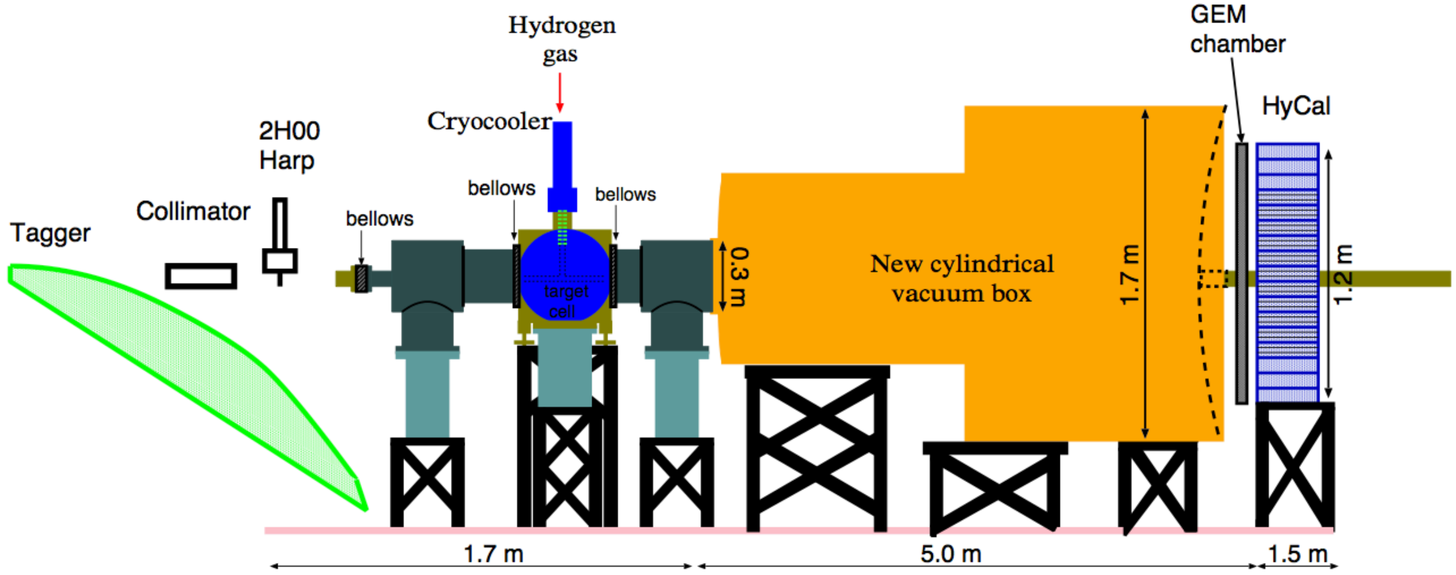
Antognini et al. (2013)

7 σ difference !?

ep data: $R_E = 0.8775 \pm 0.0051$ fm

CODATA (2012)

PRad Experimental Setup in Hall B at JLab



- **High resolution, large acceptance calorimeter**
- **Windowless H_2 gas flow target**
- **Simultaneous detection of elastic and Moller electrons**
- **GEM detectors**
- **Q^2 range of 2×10^{-4} – 0.14 GeV^2**

Future sub 1% measurements:
(1) ep elastic scattering at Jlab (PRad)
(2) μp elastic scattering at PSI - 16 U.S. institutions! (MUSE)
(3) ISR experiments at Mainz

Ongoing H spectroscopy experiments

Summary

- Possibilities of physics programs are discussed at BEPCII with internal thin gas targets after BESIII shutdown
- Among them, cLFV, dark photon, and charge radius of proton are competitive and strong motivated.
- We need detailed MC simulations to dig out important physics which should be done as soon as possible
- BEPCII was there, cost of these projects will be relative cheap, and the BEPCII life time will be extended, and we may achieve more important physics.
- A proposal should be considered before BESIII shutdown, and some of them may run simultaneously with BESIII.

Preliminary discussions

- Refine/optimize physics
- Detectors: many arms (forward, SA, MA, LA)
- Internal gas targets (polarization):
  atomic beam sources, polarimeter, scattering chamber
- The luminosity monitor
- Upgrade of BEPCII?
- Prepare framework for MC simulations
- Collaboration between theorists and experimenters
- A focused workshop at IHEP in Beijing?

Thanks!

Thanks for many useful discussions with Jianping Chen, Haiyan Gao, Jianping Ma, and Feng Yuan