Phyics program with a low energy e-γ collider and *e* beam on target at IRIDE

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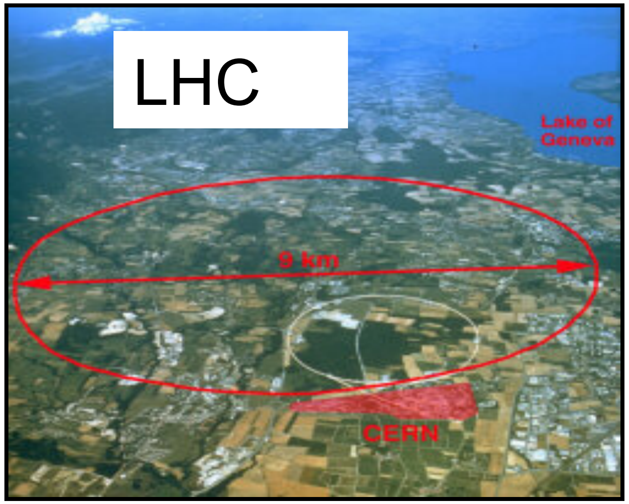
Often: Direct answers are found at the *Energy Frontier*



1. Higgs !!

2. But, sources of CP?

3. And, so far data is almost behaving as expected …

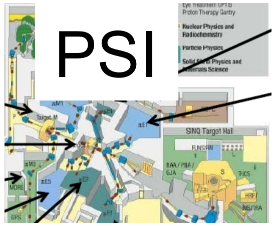
And, if it was the case: How would we interpret some kind of BUMP at hundreds of GeV or at a TeV?

Today: Indirect evidence from the *Precision Frontier*

CERN-SPS

Underground

PSI



BNL

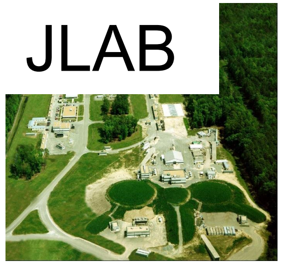
Mainz

B factories

τ/c-factories

ϕ-factories

JLAB



1. Higgs (just a bit on mass range from EW)

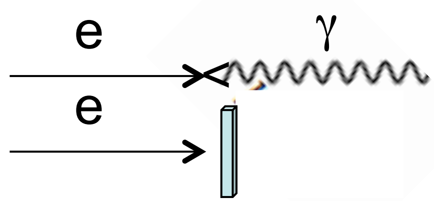
2. CP: CKM, EDMs, $0\nu\beta\beta$

3. New Physics? Maybe: g-2; Dark photons, Parity-violations?...

Will require a model that addresses all data from high- and low-energy observables to really nail down any new physics

At IRIDE we will consider two different scenarios:

- e-γ interaction, E_e~0.1-1.5 GeV; E_γ:1-50 MeV
- Electron beam on target, E_e~0.1-3 GeV



Physics case:

- Precision tests of QED, QCD, EW sectors of the SM at low energy
- Search for Physics beyond SM
- Test of QM
- Other motivations

Theory is the Standard Model:

$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ **local gauge theory**

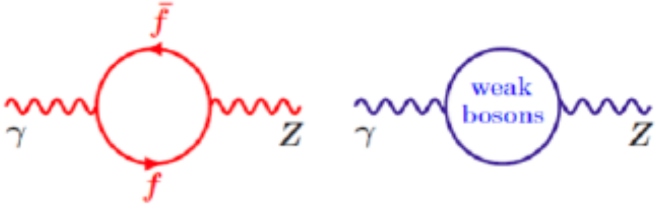
broken to $SU(3)_{\rm QCD} \otimes U(1)_{\rm QED}$

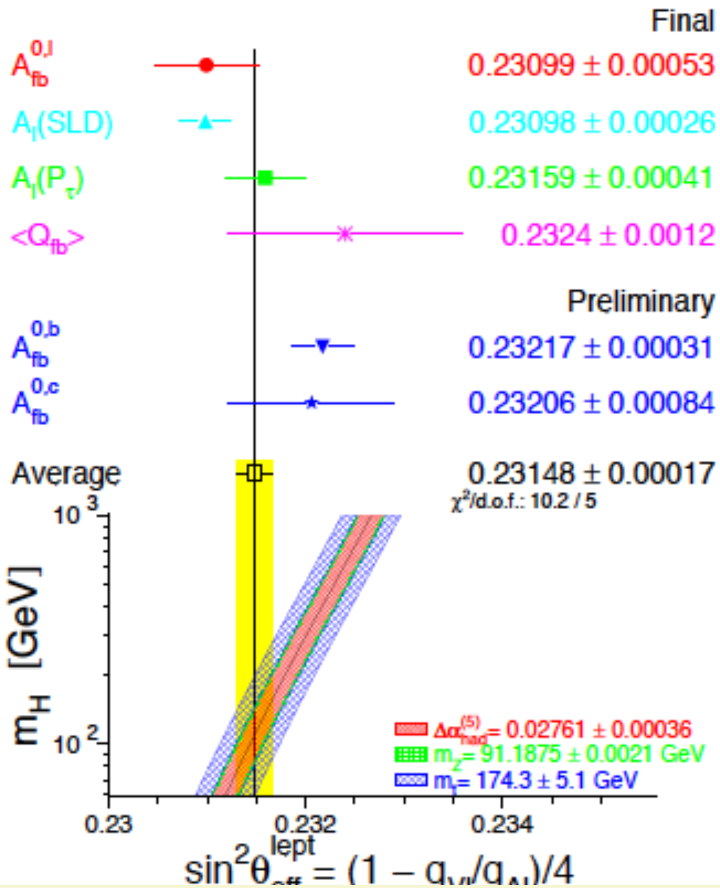
by the Higgs mechanism

Testing EW sector at IRIDE

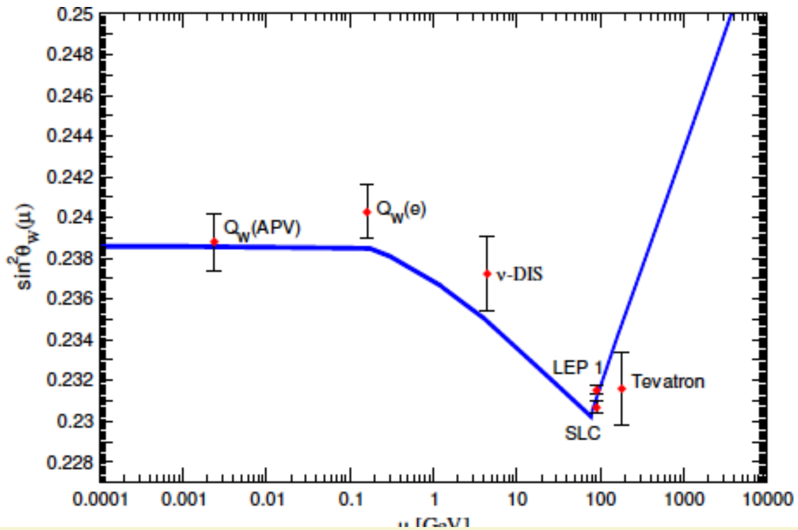
Precision Test of the EW sector of the SM

- $\sin^2\theta_W = (e/g)^2 = 1 - (M_W/M_Z)^2$ a key parameter of the SM
- Incorporates: $SU(2)_L \times U(1)_\gamma$ + Higgs Mechanism + Renormalizability
- Rad. Corrections strongly correlated with masses of top quark, Higgs, New Physics!





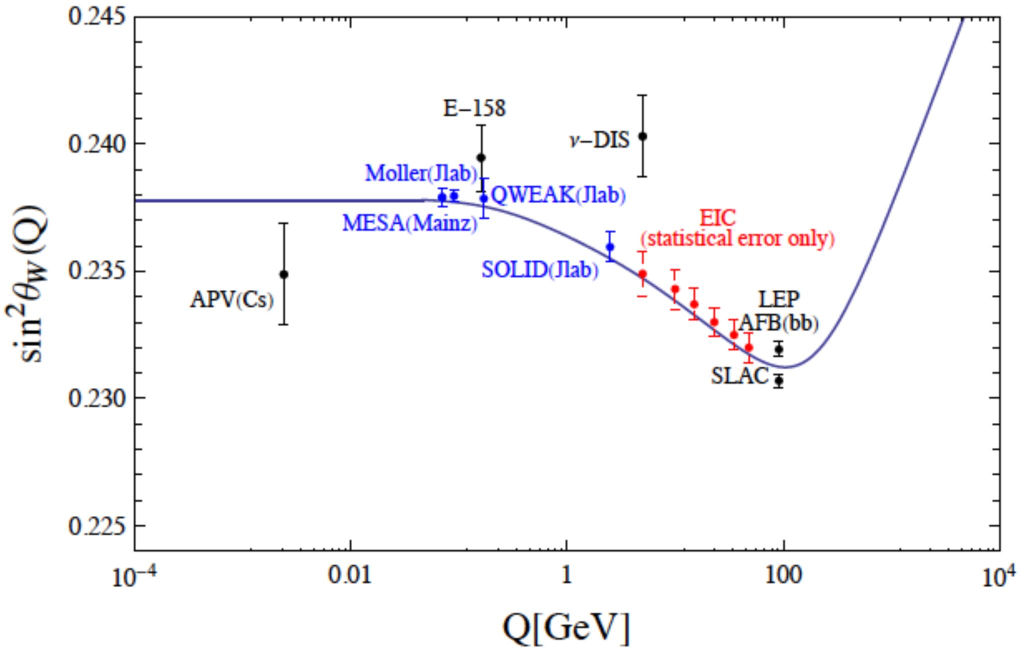
- Low $Q^2 \Rightarrow$ *High sensitivity to New Phyisics*

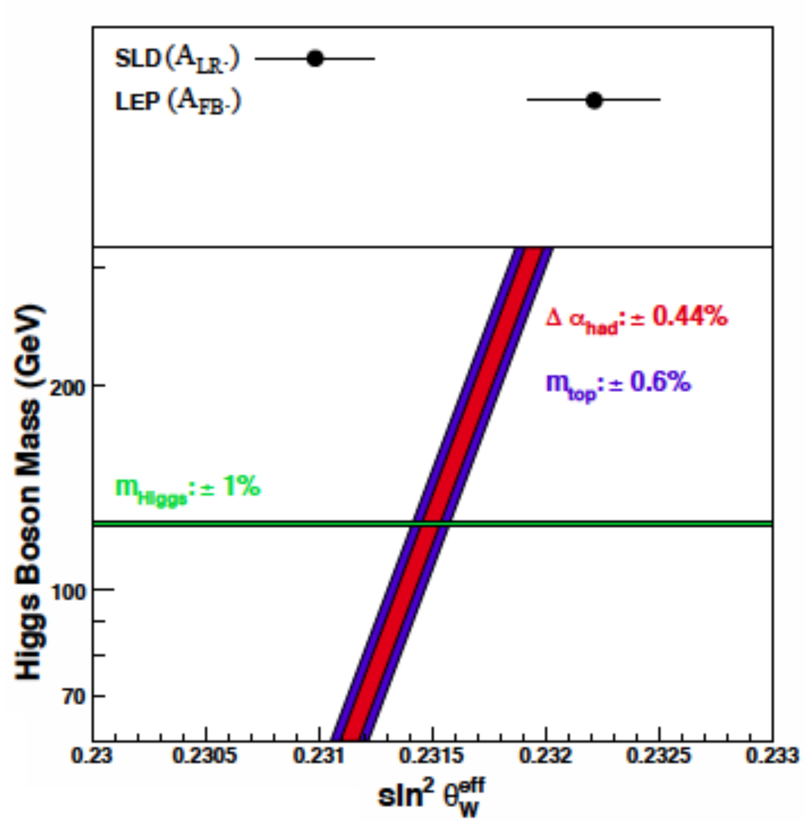


See e.g. 2011/12 Review of Particle Properties: Sec. 10. ELECTROWEAK MODEL AND CONSTRAINTS ON NEW PHYSICS (Erler & Langacker)

EW Precision Physics after Higgs Discovery

K.S.Kumar, S.Mantry, W.J.Marciano and P.A.Souder,
``Low Energy Measurements of the Weak Mixing Angle''
arXiv:1302.6263 [hep-ex].





Experimental status:

-2 precision measurement at LEP and SLC/SLD on Z pole
-Low Energy experiments (e-e-, Neutrino scattering, APV)
-New measurements at JLAB and Mainz (e- on p target)

A Low-Q2 Measurement of $\sin^2\theta_w$ at IRIDE

- Scattering of longitudinally polarized electrons on unpolarized protons

➔ Z boson exchange in e-p scattering introduces parity-violating effect

➔ Measure parity-violating Left-Right cross section Asymmetry A_{LB}

$$A_{LR} = \frac{\sigma(e\uparrow) - \sigma(e\downarrow)}{\sigma(e\uparrow) + \sigma(e\downarrow)} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W - F(Q^2)\right)$$

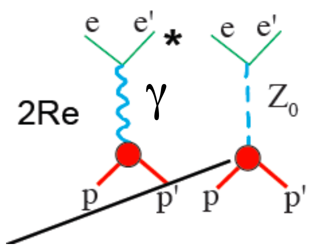
$$Q_W = 1 - 4\sin^2\theta_W(\mu)$$

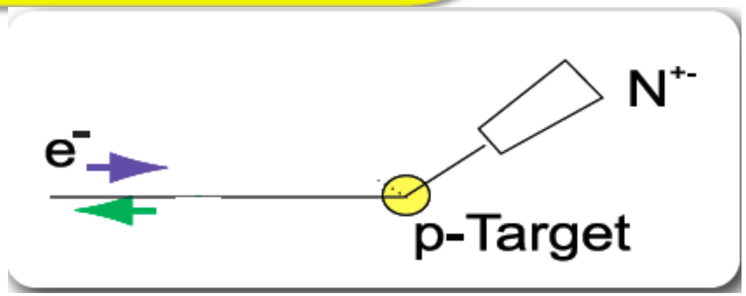
hadron structure

IRIDE Goal:

Measure A_{LR} of with ~1-2% precision

V-A: parity violating asymmetry



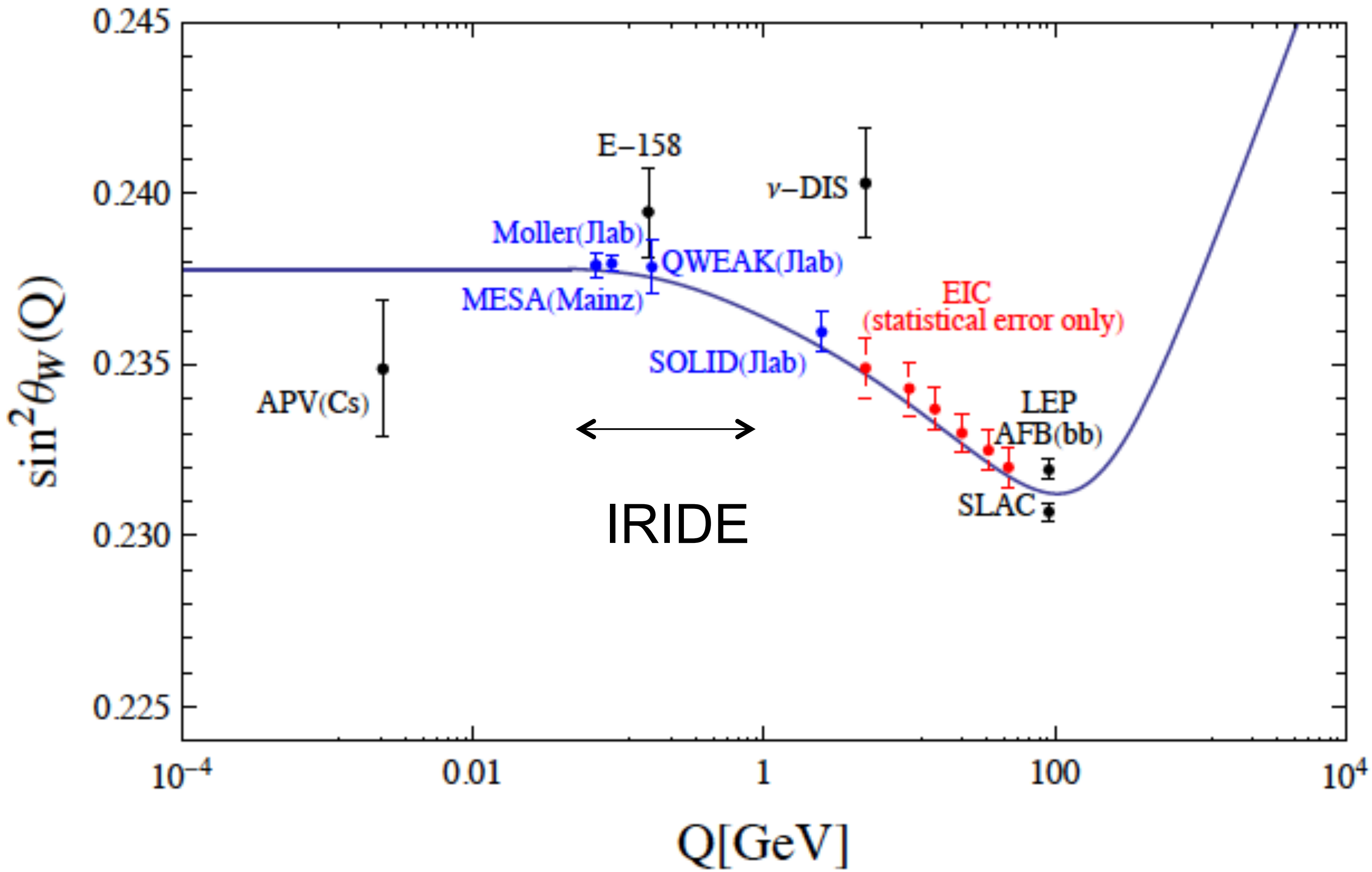


Comparison with present and future experiments:

PARAM.	QWEAK @JLAB (2006-2012)	P2@MAINZ (>2017)	IRIDE
E_e (GeV)	~1.1	0.2	0.1-3
P_e	89%	85%	?
Curr (μA)	180	150	>300
θ_e (deg)	8	20	
Q^2 (GeV^2)	0.03	0.0048	0.001-1
Apv (ppm)	0.28	0.02	
δApv (%)	$2.1_{sys}+1.3_{sta}$	1.7	Goal:1-2%
δs_w (%)	0.3	0.15	Goal: ~0.1%
Rate (TH)	6.4 $\times 10^{-3}$	0.5	
Time (h)	2×10^3	10^4	
H_2 Target (cm)	35	60	

Very challenging measurement:

- Control of the electron beam and target density fluctuations.
- Control of e- beam polarization
- False Asymmetries
- Systematics of the detector at <1% level



IRIDE: $Q^2 = 0.001 GeV^2$ (E_e=100 MeV) ÷ 1 GeV^2(E_e=3 GeV)

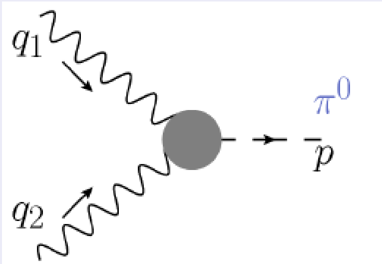
(Assuming θ=20°) Q~40 MeV ÷ 1 GeV

Testing QCD sector at IRIDE

Precision Test of fundamental prediction of QCD: Measurement of π^0 decay width

- This is a very important measurement which tests the QCD behaviour at low energy. The transition is mainly due to the axial current anomaly (Adler, Bell, Jackiw):

Massless QCD exact prediction



$$\Rightarrow \frac{\alpha}{\pi\ f_0} \epsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta$$

f_0 — pion decay constant in the chiral limit
(we don't know the value of f_0)

- There are theoretical corrections which bring $f_0 \rightarrow f_\pi = 92.42 \pm 0.25$ MeV, leading to non perturbative QCD prediction (leading order)

$$\Gamma(\pi^0 \rightarrow \gamma\gamma) = \frac{\alpha^2 m_\pi^3}{64\ \pi^3\ f_\pi^2} = (7.725 \pm 0.044)\mathrm{eV}$$

Corrections to pion decay width

- NNLO ChPT [Kampf, Moussallam, PoS (CD09) 039 (2009)]
- NLO ChPT $\oplus$ $1/N_c$ [Goity, Bernstein, Holstein, Phys.Rev. D66 076014 (2002)]
- QCD sum rules [Moussallam, Phys. Rev. D51, 4939(1995)]

✓ agree very well, theory uncertainty $\sim 1\%$

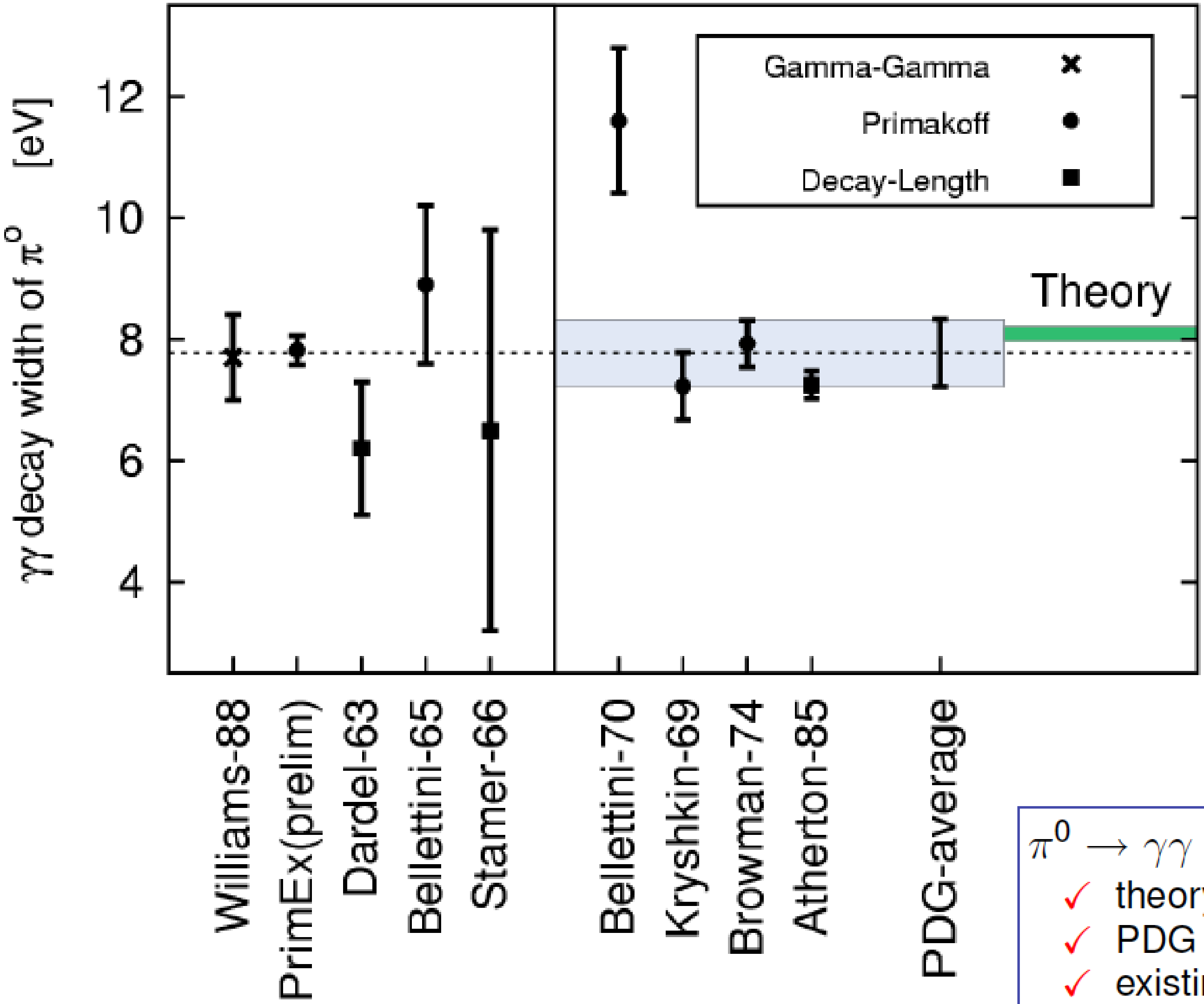
NNLO theory prediction

$$\Gamma(\pi^0 \to \gamma\gamma) = (8.09 \pm 0.11)\mathrm{eV}$$

[K.Kampf, B.Moussallam, PoS (CD09) 039 (2009)]

(including isospin breaking and mixing)

Experimental status of $\pi^0 \rightarrow \gamma\gamma$ width

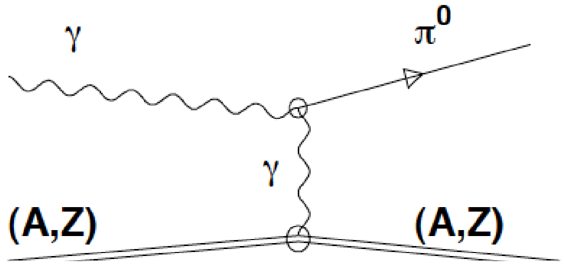


$\pi^0 \rightarrow \gamma\gamma$ decay width (π^0 lifetime)

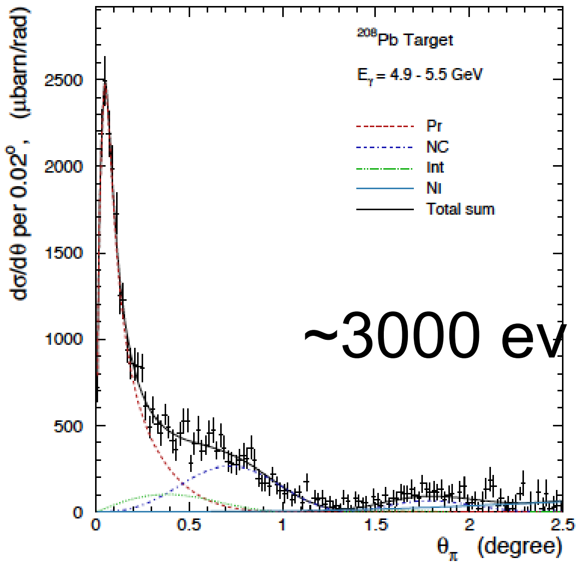
- ✓ theory prediction uncertainty $\sim 1\%$
- ✓ PDG error $> 7\%$
- ✓ existing data are over 25 years old

Current experimental activities to measure $\Gamma(\pi^0 \to \gamma\gamma)$ at 1%

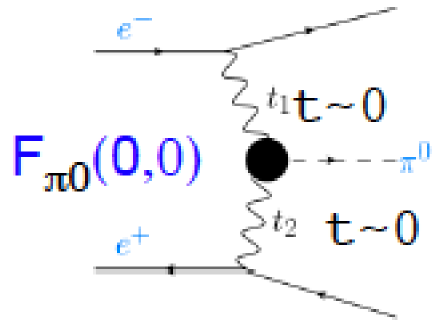
Primex (JLAB): $\gamma N \to \pi^0 N$



$$\frac{d\sigma_{Pr}}{d\Omega} = \Gamma(\pi^0 \to \gamma\gamma)\frac{8\alpha Z^2}{m^3}\frac{\beta^3 E^4}{Q^4}|F_{EM}(Q)|^2 \sin^2\theta_\pi$$



KLOE-2 (LNF): $ee \to \pi^0 ee$



$\Gamma(\pi^0 \to \gamma\gamma) \propto |F_{\pi 0}(0,0)|^2$

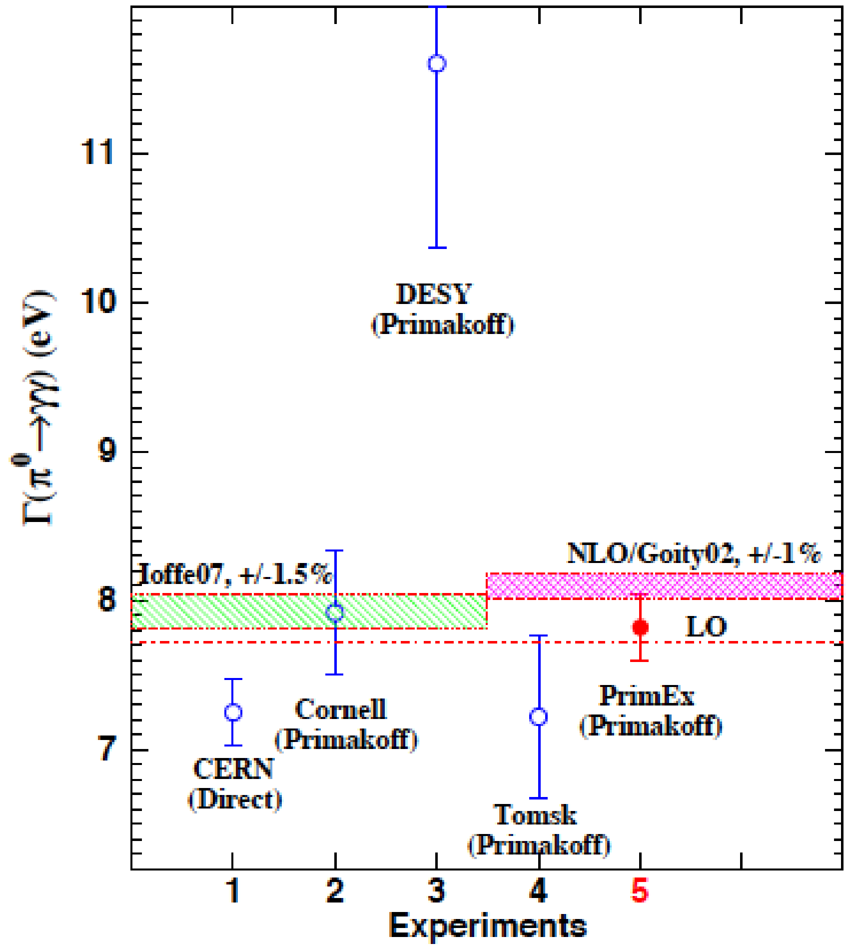
σ_{obs}~3 pb

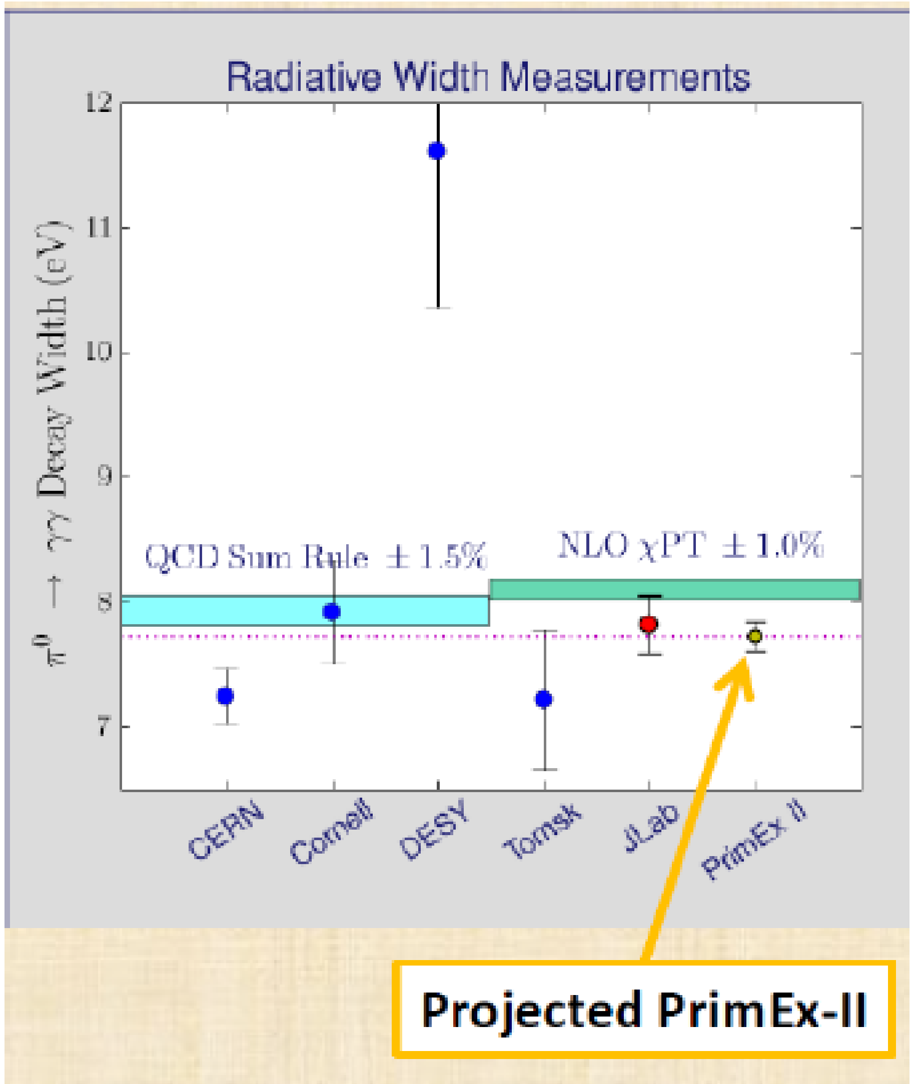
10^4 events with L~3 fb^{-1}

1% is a challenging measurement!!!

Primex result: PRL 106 (2011) 162303

$\Gamma(\pi^0 \to \gamma\gamma) = 7.82 \pm 0.14\ (\text{stat.}) \pm 0.17\ (\text{syst.})\ \text{eV}.$





2.8% total error (before was 7%!)

Goal of 1.4% (0.4% stat)

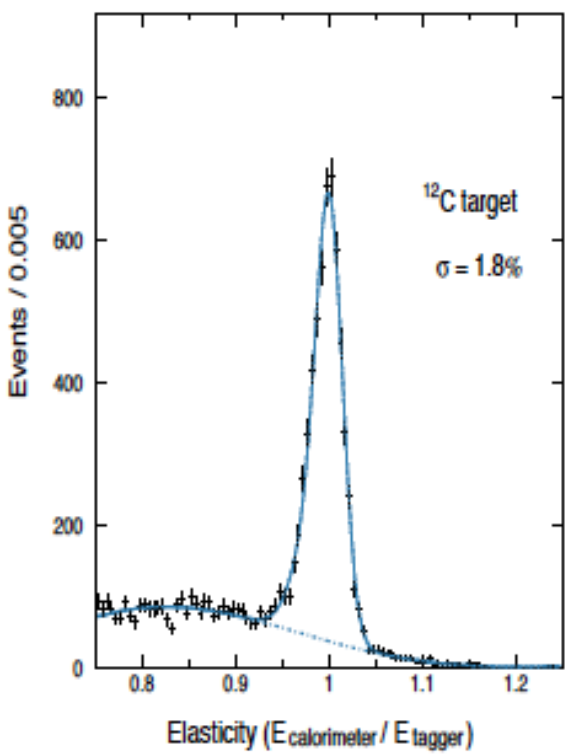
Primex result: PRL 106 (2011) 162303

angular bin. The typical background in the event selection process was only a few percent of the real signal events (see Fig. 2). However, the uncertainty of 1.6% in the background extraction in this much upgraded experiment still remained one of the largest contributions to the total systematic uncertainty.

Nuclear background is an issue!

ward angles. The cross section of this process can be expressed by four terms: Primakoff (Pr), nuclear coherent (NC), interference between strong and Primakoff amplitudes (Int), and nuclear incoherent (NI):

$$\frac{d\sigma}{d\Omega} = |\, T_{Pr} + e^{i\varphi} T_S \,|^2 + \frac{d\sigma_{NI}}{d\Omega}$$
$$= \frac{d\sigma_{Pr}}{d\Omega} + \frac{d\sigma_{NC}}{d\Omega} + \frac{d\sigma_{Int}}{d\Omega} + \frac{d\sigma_{NI}}{d\Omega},$$



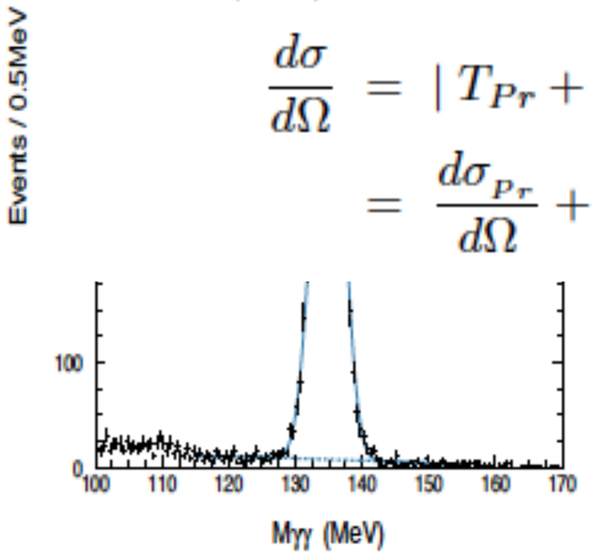


FIG. 2: Typical distribution of reconstructed "elasticity" (left panel) and $M_{\gamma\gamma}$ (right panel) for one angular bin.

1.6% syst error comes from uncertainty on background (nuclear) subtraction

How $\Gamma(\pi^0 \to \gamma\gamma)$ measurement at IRIDE would compare with Primex?

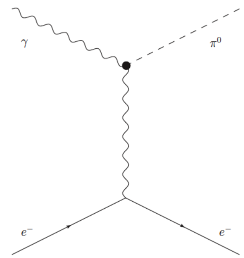
- Both uses **Primakoff** scattering
- Electron (IRIDE) vs Nuclear target (Primex)
- E_γ =10-20 MeV (IRIDE) vs E_γ~5 GeV (Primex)
- Much cleaner enviroment at IRIDE.
- Higher intensity photon beam at IRIDE compensates for the lower cross section ($d\sigma$ Primakov $\sim Z^2$ (~10000)):

  $\approx \sigma$ ~1-2 nb (500-750 MeV) at IRIDE.
- With a luminosity of **10^{30} cm^{-2} sec^{-1}** and 50% detector efficiency: **$N_{ev} \sim 10^4$ evts/year**, sufficient to reach 1% stat error in one year.

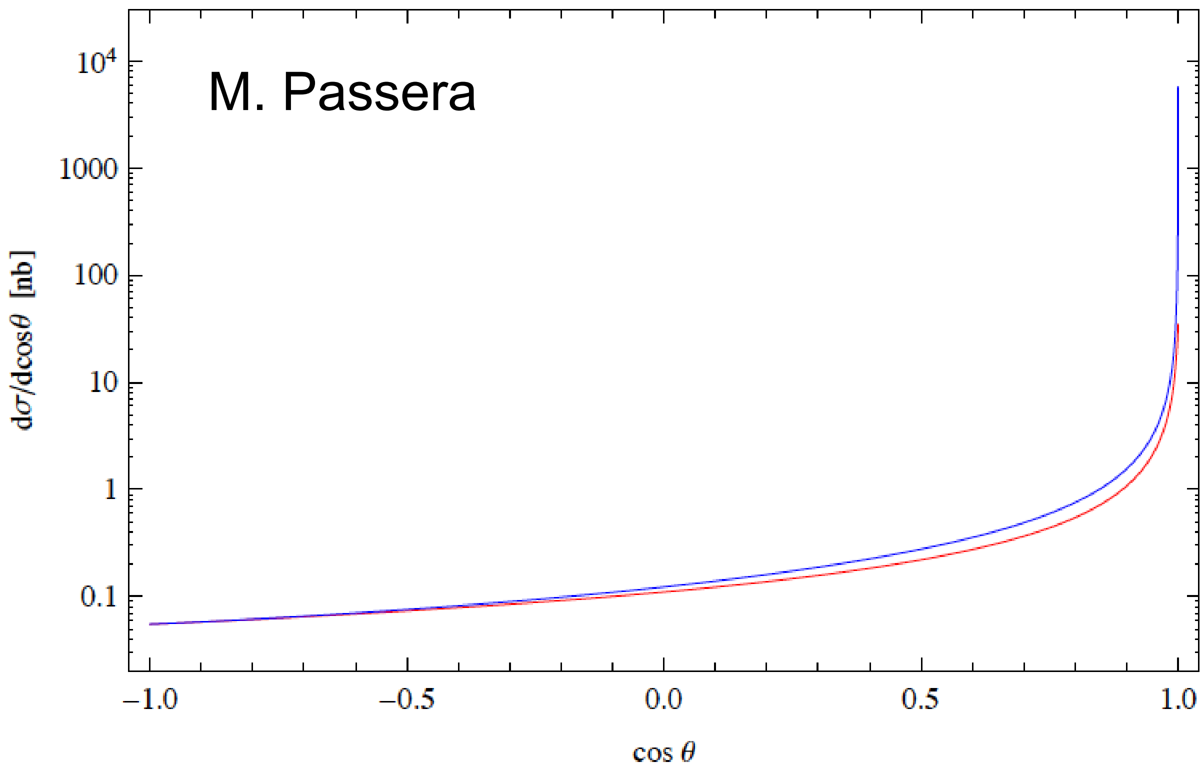
Competitive to Primex but in a much cleaner enviroment ➔ important for the systematics

$\Gamma(\pi^0 \to \gamma\gamma)$ important also for HLbL (it fixes $|F_{\pi 0}(0,0)|^2$)

The scattering $\gamma + e^- \rightarrow \pi^0 + e^-$



$$\frac{d\sigma}{d\cos\theta} = \frac{\alpha^3}{32\pi^2 f_\pi^2} \frac{\left[\left((M-m)^2 - s\right)\left((M+m)^2 - s\right)\right]^{\frac{1}{2}}}{st\,(m^2 - s)} \left[\left(M^2 - s - t\right)^2 + s^2 + 2m^2\left(M^4/t + m^2 - M^2 - 2s\right)\right],$$



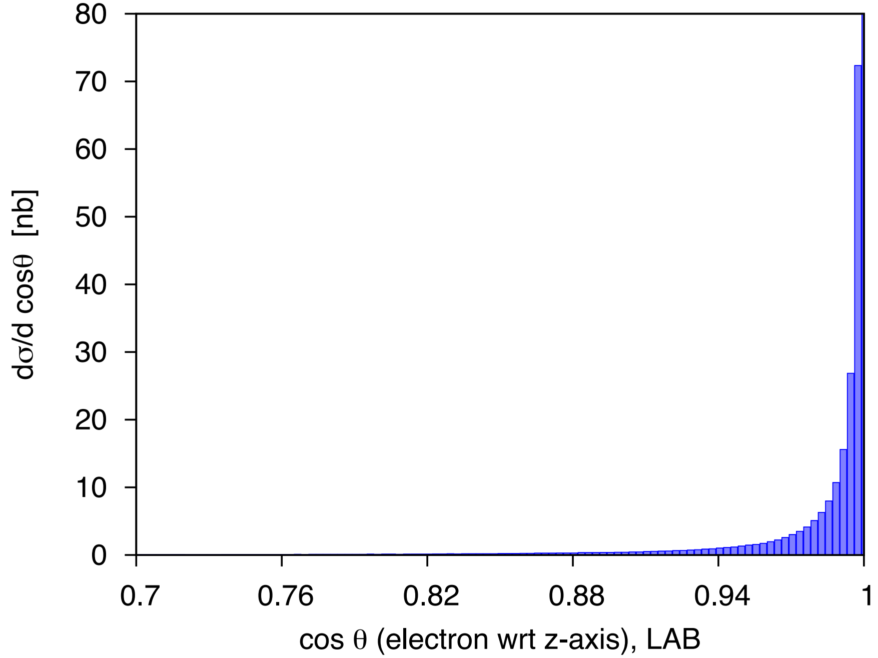
E_e=750 MeV
E_γ=20 MeV
σ=2nb

E_e=500 MeV
E_γ=10 MeV
σ=0.7 nb

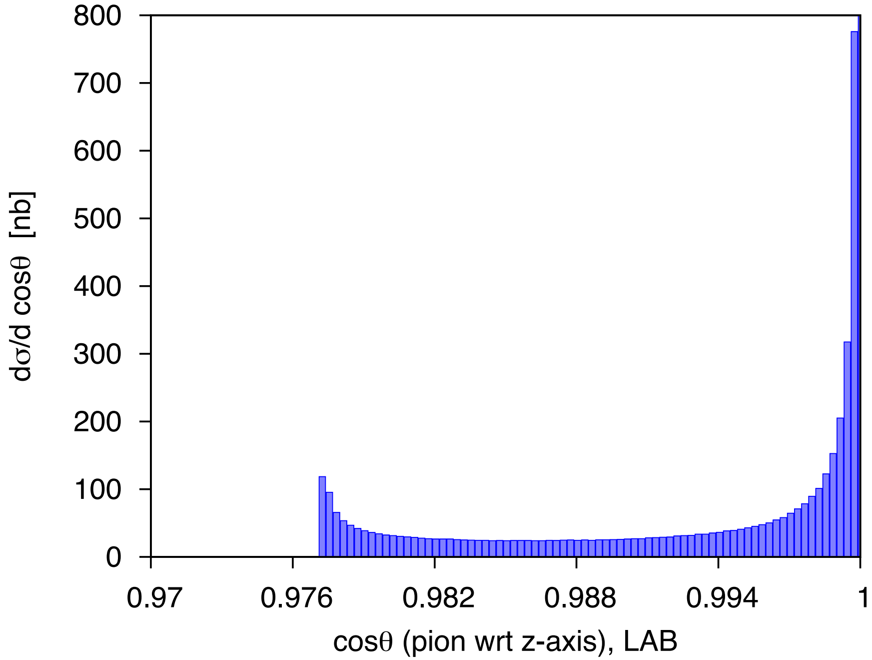
A feasibility study is going on with a MC generator (S. Ivashyn)

“Preliminary” results from MC:

Courtesy of S. Ivashyn

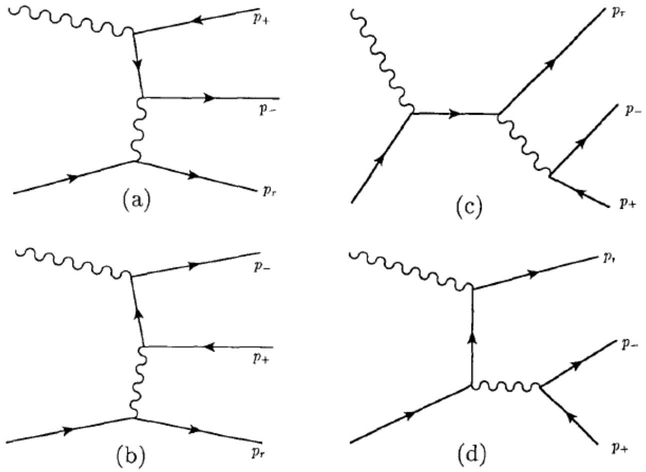


E_e=750 MeV
E_γ=20 MeV
σ=2nb



Testing QED at IRIDE

Precision test of QED prediction: Triplet photoproduction $e^-\gamma \rightarrow e^-\gamma^* \rightarrow e^-e^+e^-$



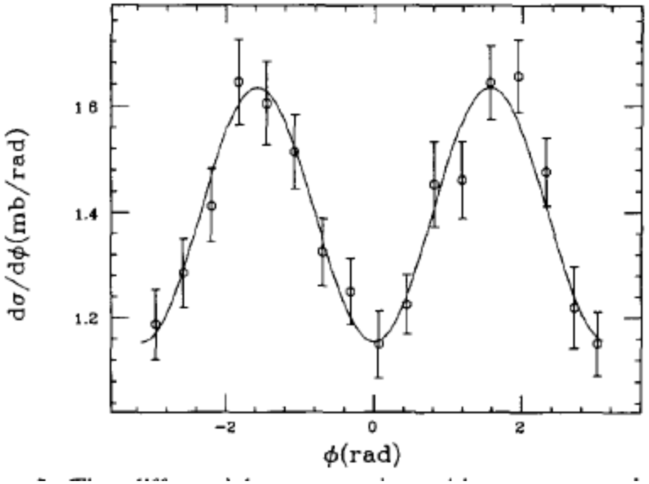
-This process is very important to determine the linear polarization of the photon (at $E\gamma$>500 MeV). It has astrophysical implications (Gamma-rays Polarization)

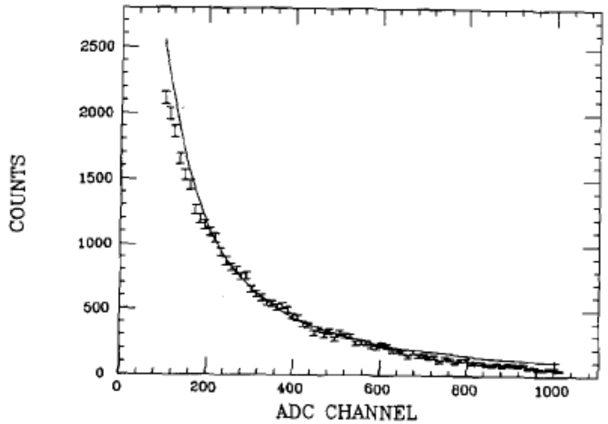
$$\frac{d\sigma}{d\varphi} = \frac{\sigma_0}{2\pi}\left(1 + P_\gamma \lambda \cos(2\varphi)\right)$$

λ=analyzing power

- Existing measurements differ from theor

Azimutal angle of e-





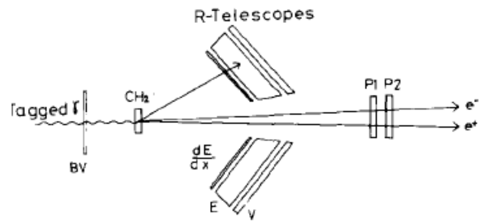


Fig. 1. Experimental layout.

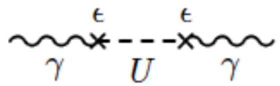
I.Endo et al. NIM A280 (1989) 144

Search for New Physics at IRIDE

Search for physics BSM

- In the recent years, the existence of new light weakly interacting bosons (**"u bosons**") has been proposed to explain "puzzling" astrophisical observations (Integral, Pamela, Atic, Fermi, WMAP, Hess, Dama/Libra)
- This u boson can communicate with the SM through a kinetic mixing term of the form:

$$\mathscr{L}_{\text{mix}} = -\frac{\epsilon}{2} F^{\text{em}}_{\mu\nu} F^{\mu\nu}_{\text{DM}} \qquad (\epsilon \ll 1)\ .$$



- It could explain the **3.6σ deviation between the SM and experimental value of $(g\text{-}2)_\mu$**

- This boson is light (M$_U$ ~MeV-GeV scale) and can be searched in e^+e^- collider and at fixed target experiments

⇒A lot of experimental activities (and theo. papers)!

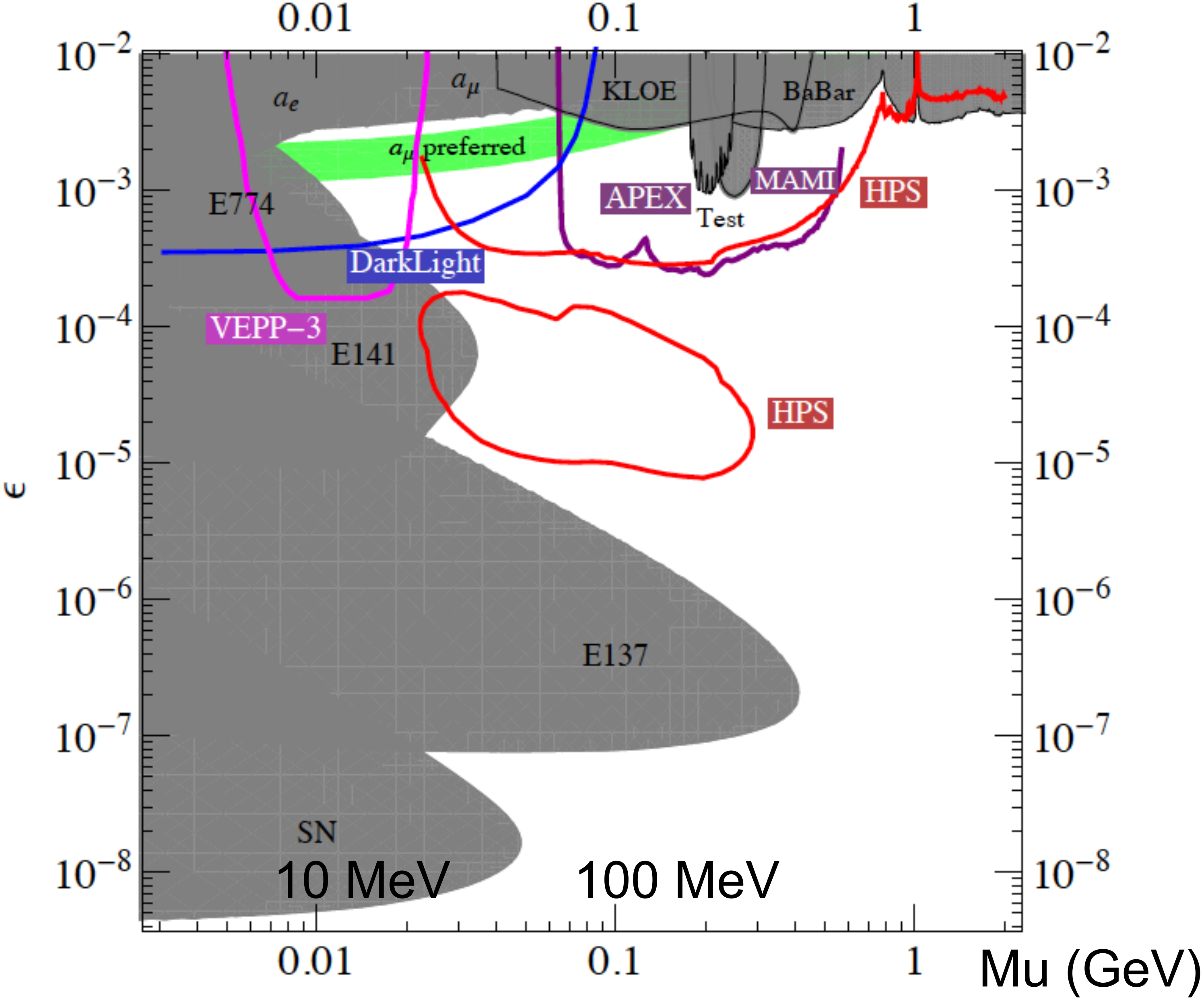
arXiv:1205.2709v1

The Muon Anomaly and Dark Parity Violation

Hooman Davoudiasl*, Hye-Sung Lee†, and William J. Marciano‡
Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, USA
(Dated: May 2012)

The muon anomalous magnetic moment exhibits a 3.6σ discrepancy between experiment and theory. One explanation requires the existence of a light vector boson, Z_d (the dark Z), with mass $10 - 500$ MeV that couples weakly to the electromagnetic current through kinetic mixing. Support for such a solution also comes from astrophysics conjectures regarding the utility of a $U(1)_d$ gauge symmetry in the dark matter sector. In that scenario, we show that mass mixing between the Z_d and ordinary Z boson introduces a new source of "dark" parity violation which is potentially observable in atomic and polarized electron scattering experiments. Restrictive bounds on the mixing $(m_{Z_d}/m_Z)\delta$ are found from existing atomic parity violation results, $\delta^2 < 2 \times 10^{-5}$. Combined with future planned and proposed polarized electron scattering experiments, a sensitivity of $\delta^2 \sim 10^{-6}$ is expected to be reached, thereby complementing direct searches for the Z_d boson.

90% Exclusion plots: dashed are published meas.; lines are new projects (arXiv:1205.2671v1)



U bosons can be searched at flavor factories and fixed target experiment

JHEP 0907 (2009) 051

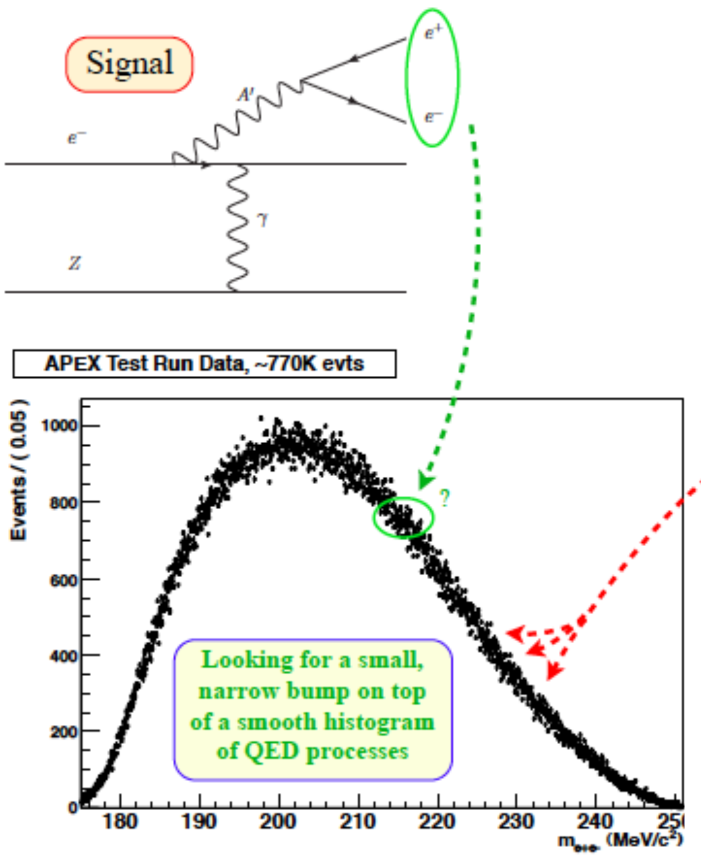
Searching for the light dark gauge boson in GeV-scale experiments

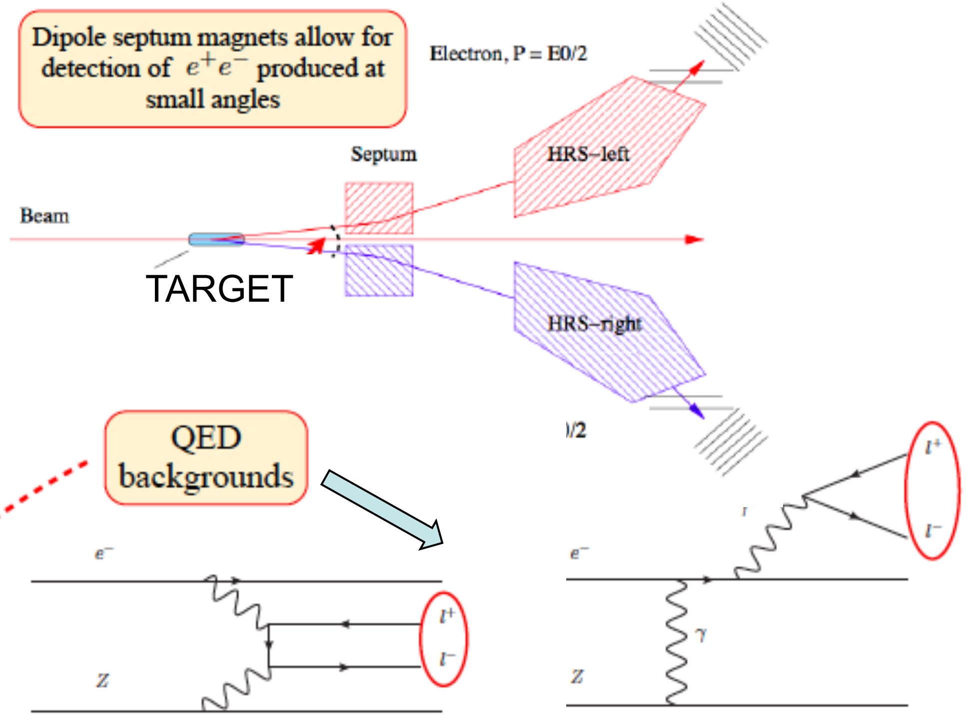
Matthew Reece[1,*] and Lian-Tao Wang[2,†]

We study current constraints and search prospects for a GeV scale vector boson at a range of low energy experiments. It couples to the Standard Model charged particles with a strength $\leq 10^{-3} - 10^{-4}$ of that of the photon. The possibility of such a particle mediating dark matter self-interactions has received much attention recently. We consider searches at low energy high luminosity colliders, meson decays, and fixed target experiments. Based on available data, searches both at colliders and in meson decays can discover or exclude such a scenario if the coupling strength is on the larger side. We emphasize that a dedicated fixed target experiment has a much better potential in searching for such a gauge boson, and outline the desired properties of such an experiment. Two different optimal designs should be implemented to cover the range of coupling strength $10^{-3} - 10^{-5}$, and $< 10^{-5}$ of the photon, respectively. We also briefly comment on other possible ways of searching for such a gauge boson.

U bosons search at IRIDE with e- beam on fixed target: Experimental signature

- Produce low mass hidden gauge bosons with weak coupling to SM via high intensity electron beam incident on fixed high-Z target
- U decays to e+e- pair with opening angle decays to pair with opening angle ~m_U/E_b





- This search possible at IRIDE
- Excellent mass resolution required ($\leq 1MeV$

U bosons can be searched in e-gamma collisions?

JHEP 0907 (2009) 051

Searching for the light dark gauge boson in GeV-scale experiments

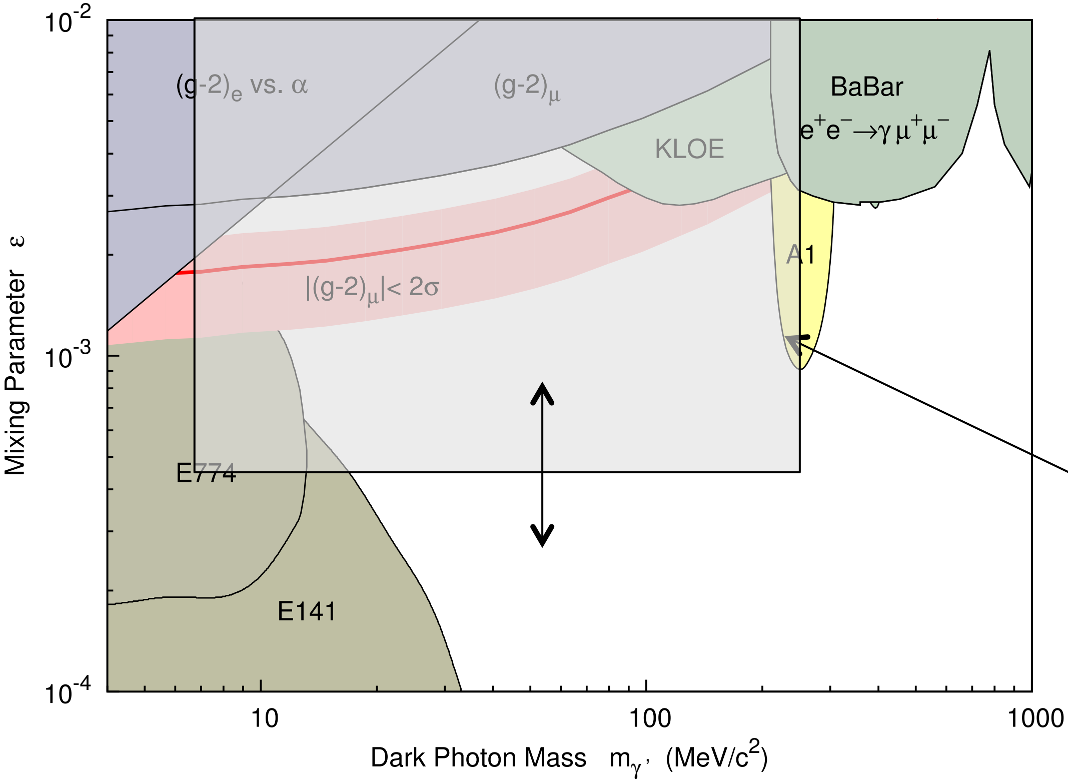
Matthew Reece[1,*] and Lian-Tao Wang[2,†]

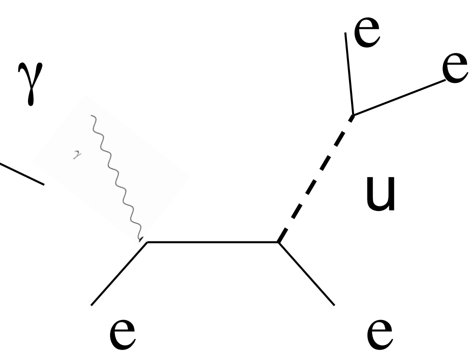
Another option is to consider the process $e^- \gamma \to e^- U$. However, it is easy to see that current facilities do not offer a reasonable chance to probe this channel. Because we want a center of mass energy on the order of hundreds of MeV or a few GeV, light sources that supply hard X-rays are insufficient; one would need a gamma ray source. Gamma rays are at Brookhaven [66] and the HIγS facility at Duke [67], at rates on the order of 10^6 to 10^8 photons per second collimated in spots of about 1 cm. Such beams are insufficient for our purposes.

At IRIDE we could achieve some order of magnitude better, making this search realistic

Search for u boson at IRIDE (Mu<250 MeV)

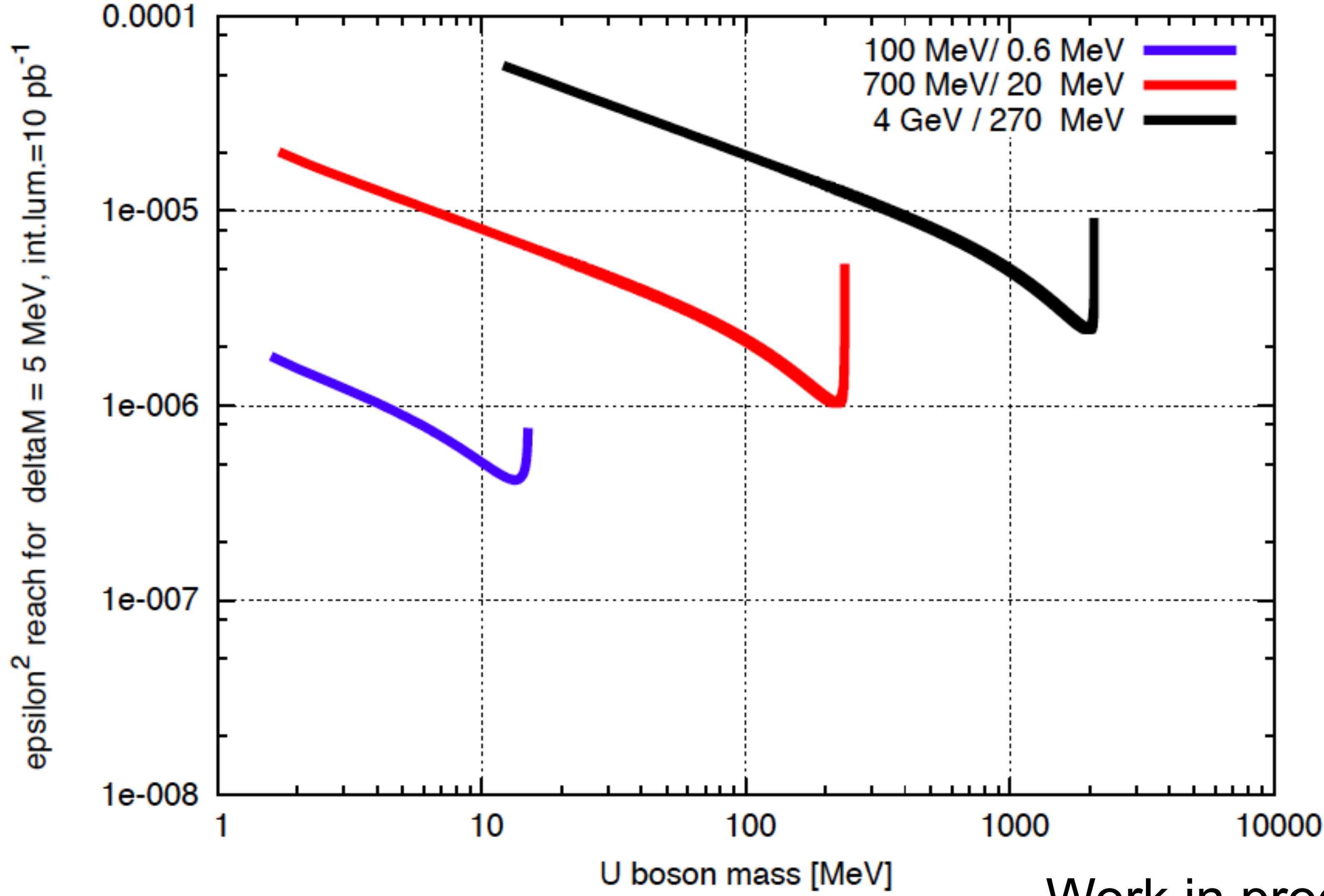
$\gamma + e^- \rightarrow u + e^-$ E_e=100-3000 MeV and E_γ=10-50 MeV,





Sensitivity on ε must be estimated (work is in progress)

Very preliminary: sensitivity with e-γ collisions
(courtesy of Ivashyn and Shekhovtsova)



Work in progress

L>10^{30} needed

Testing QM at IRIDE

Test of QM at IRIDE?

Triple Compton effect: A photon splitting into three upon collision with a free electron

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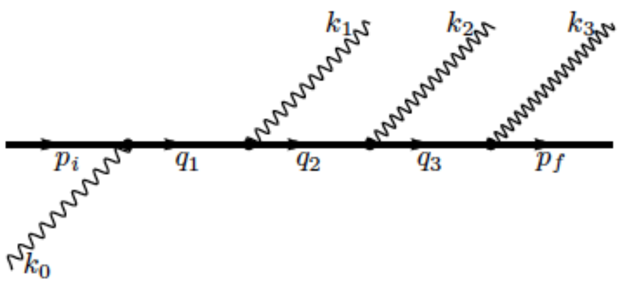
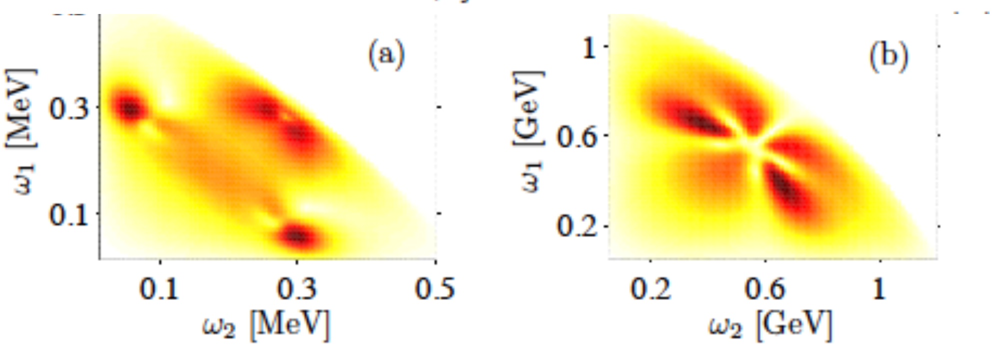
The process in which a photon splits into three after the collision with a free electron (triple Compton effect) is the most basic process for the generation of a high-energy multi-particle entangled state composed out of elementary quanta. The cross section of the process is evaluated in two experimentally realizable situations, one employing gamma photons and stationary electrons, and the other using keV photons and GeV electrons of an x-ray free electron laser. For the first case, our calculation is in agreement with the only available measurement of the differential cross section for the process under study. Our estimates indicate that the process should be readily measurable also in the second case. We quantify the polarization entanglement in the final state by a recently proposed multi-particle entanglement measure.

$$\langle \lambda_1 \lambda_2 \lambda_3 | \varrho | \lambda'_1 \lambda'_2 \lambda'_3 \rangle = N \sum_{r_i, r_f} M(\lambda_1 \lambda_2 \lambda_3)\, M^*(\lambda'_1 \lambda'_2 \lambda'_3),$$

$$e^- + \gamma \longrightarrow e^- + \gamma + \gamma + \gamma.$$





Conclusion (I)

- The physics case offered by an e-γ collider with E_e=0.1-1.5 GeV and E_γ=1-50 MeV and electron beam on target with E_e up to 3 GeV at IRIDE is very compelling. It would allow to test EW and QCD sectors of the SM, QED, MQ and search for New Physics. Other motivations are ee, $\mu\mu$ and $\pi\pi$ production at threshold, and search for new (Pseudo)scalar states

- IRIDE parameters (current, luminosity) look very suited for these precision measurements, making these searches competitive with existing and planned experiments. For $\sin^2\theta_W$ polarization of e beam is needed!

- The e-γ collider would be an unique feature of this facility

Conclusion (II)

- Detailed studies **MUST** be done. Request on precision (machine, detector) very demanding.

- We are studing in details this physics program. It is very promising with strong opportunities for involvement.
- If you are interested you are very welcome!

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Past, Current and future experiments