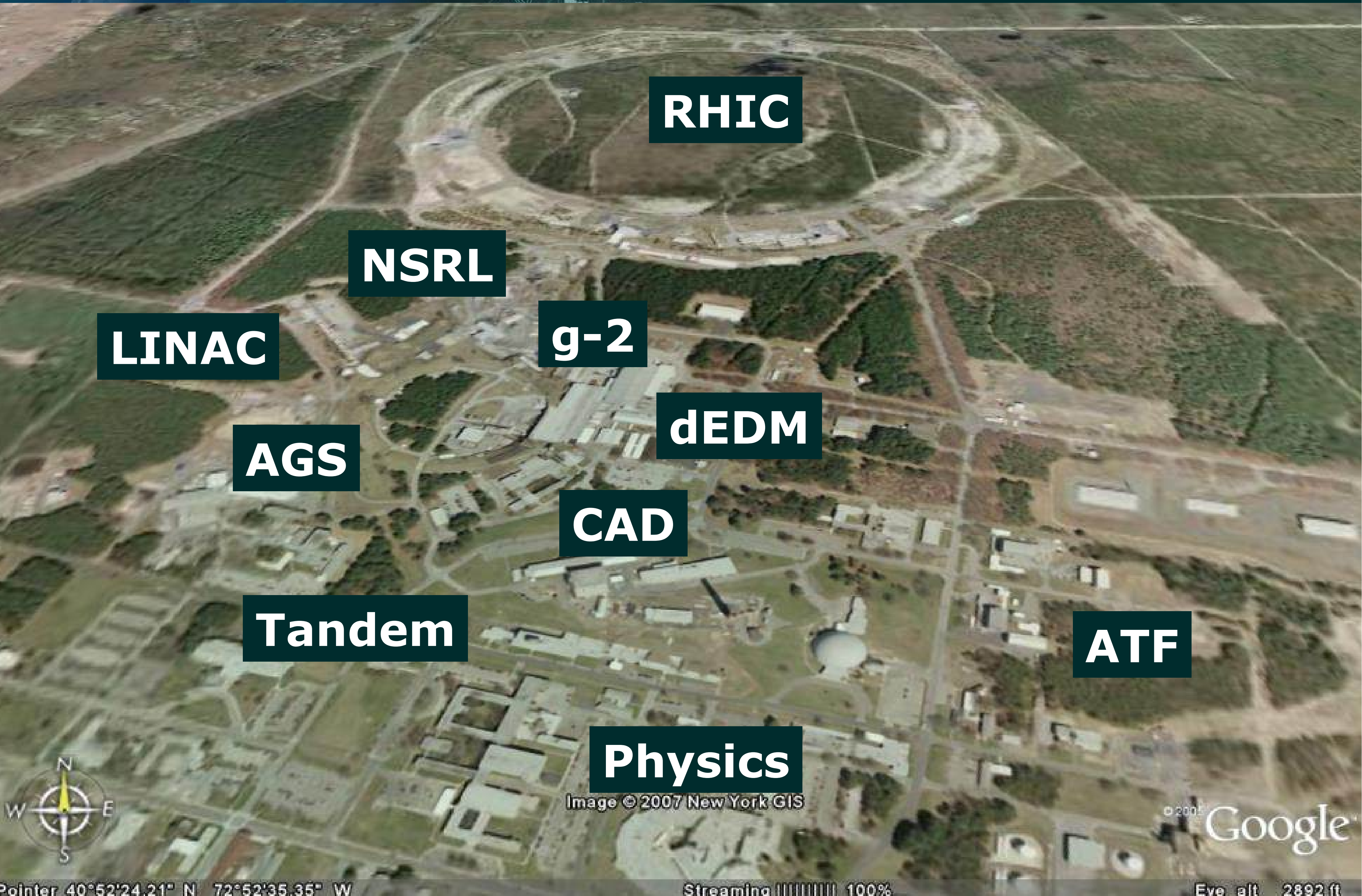
2007 RHIC & AGS Annual Users' Meeting
June 18-22, 2007 at Brookhaven National Laboratory

News from Experiments besides RHIC

Gerco Onderwater
KVI/University of Groningen, The Netherlands

The RHIC/AGS User's Group is an organization of scientists whose research makes use of one of Brookhaven National Laboratory's five user facilities. The largest of these facilities is the Relativistic Heavy Ion Collider (**RHIC**), others include the Alternating Gradient Synchrotron (**AGS**), the **Tandem van der Graaff**, the Accelerator Test Facility (**ATF**), and the NASA Space Radiation Laboratory (**NSRL**).


RHIC
NSRL
LINAC
g-2
dEDM
AGS
CAD
Tandem
ATF
Physics
Image © 2007 New York GIS
Google
Pointer 40°52'24.21" N 72°52'35.35" W
Streaming 100%
Eye alt 2892 ft

non-RHIC related Nuclear and High Energy Physics

conveners: Yannis Semertzidis & Gerco Onderwater

Work at the accelerator test facility (ATF) of BNL related to the International Linear Collider
Vitaly Yakimenko (BNL/ATF)

The muon g-2 experiment: a comprehensive update
Bill Marciano (BNL/HEP-TH)

Electric dipole moments (EDMs) as sensitive probes of physics beyond the SM
Adam Ritz (Univ. of Victoria/Canada)

The deuteron EDM experiment at BNL
Ed Stephenson (IUCF PH/Ω)

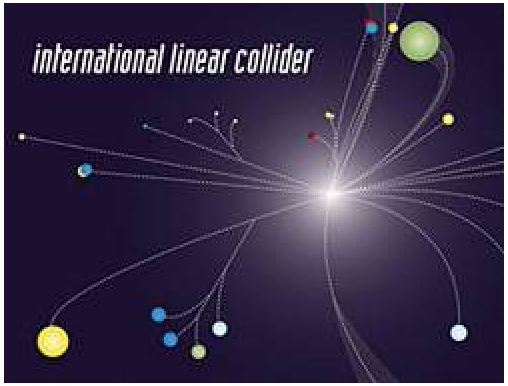
Long Baseline neutrino oscillations
Milind Diwan (BNL/EDG)

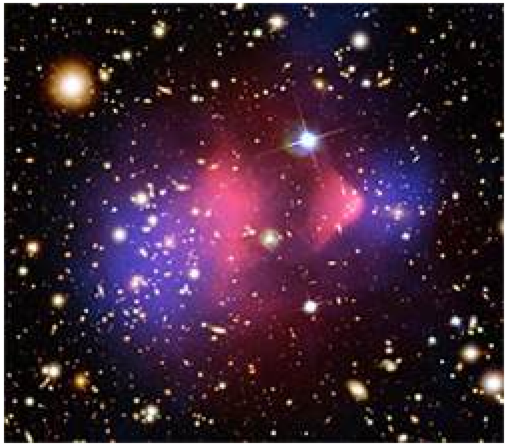
Muon Collider: an update
Robert Palmer (BNL/AAG)

International Linear Collider (ILC)

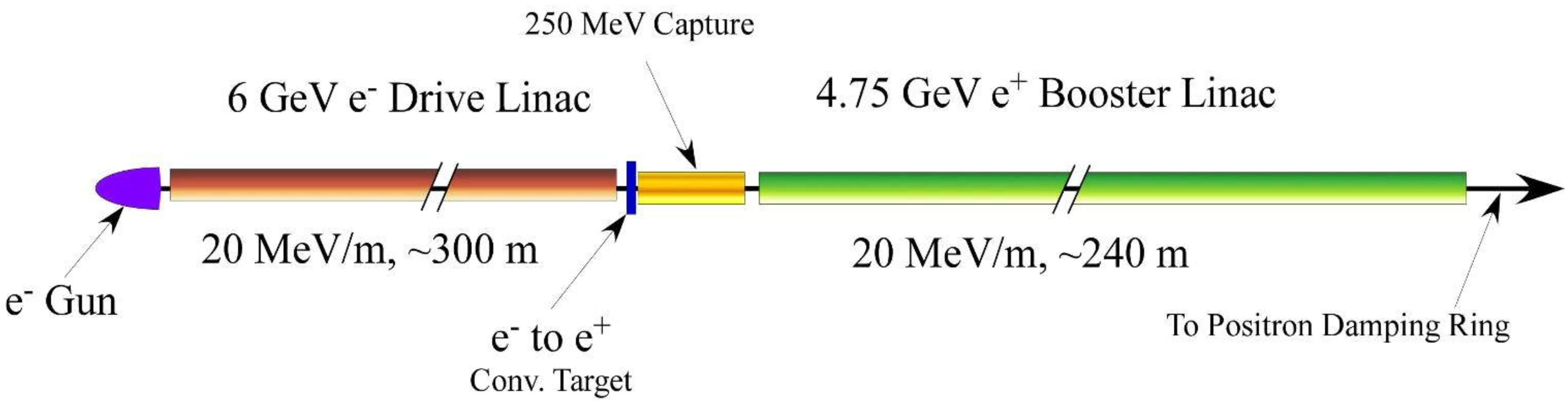
e^+e^- collider @ 500 - 1000 GeV

"The International Linear Collider will give physicists a new cosmic doorway to explore energy regimes beyond the reach of today's accelerators. A proposed electron-positron collider, the ILC will complement the Large Hadron Collider, a proton-proton collider at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, together unlocking some of the deepest mysteries in the universe. With LHC discoveries pointing the way, the ILC—a true precision machine—will provide the missing pieces of the puzzle."

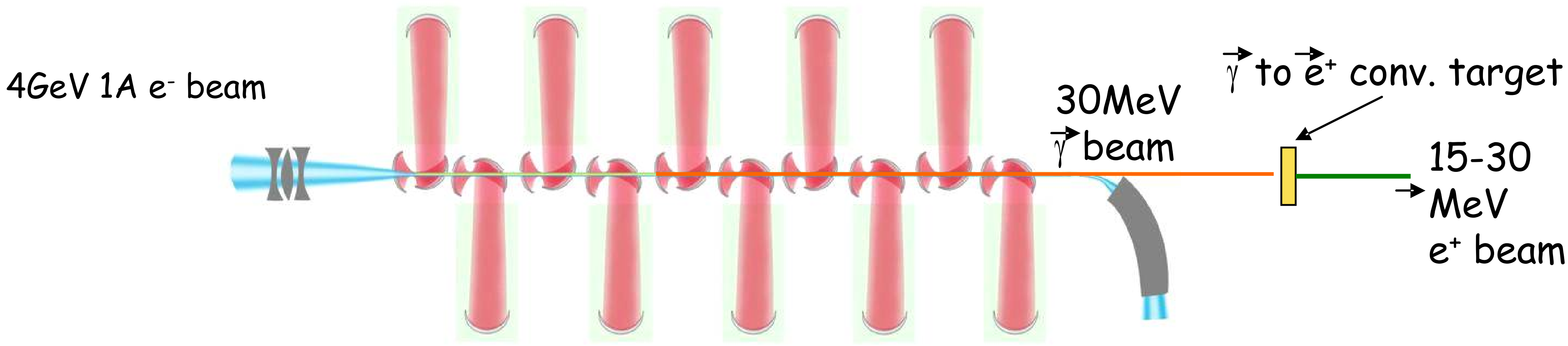




Conventional unpolarized positron source



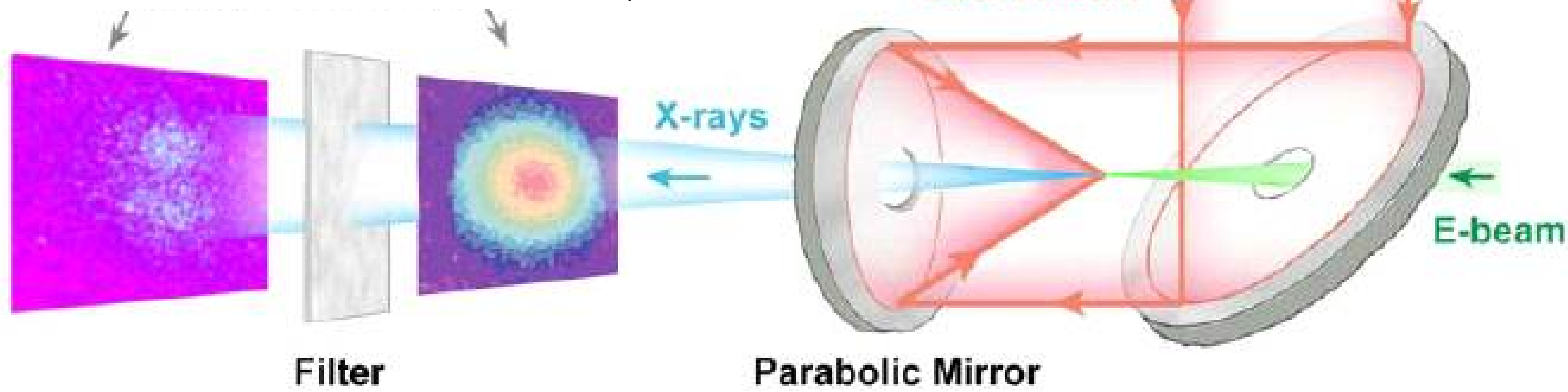
Towards a polarized positron source



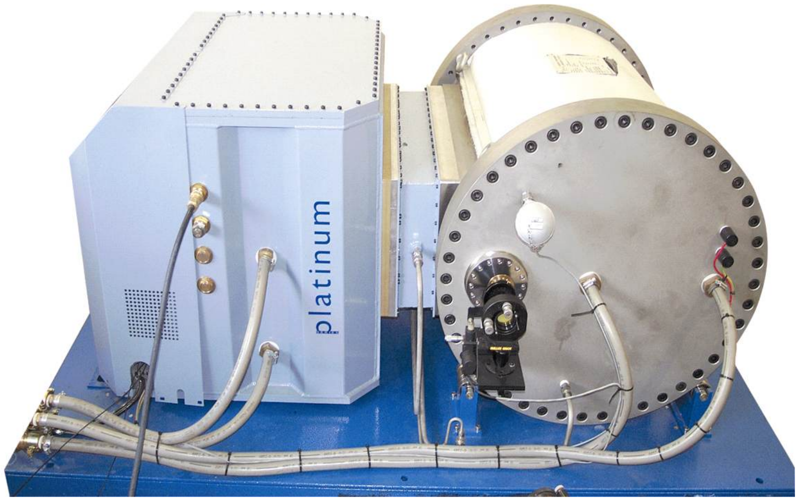
Proposal

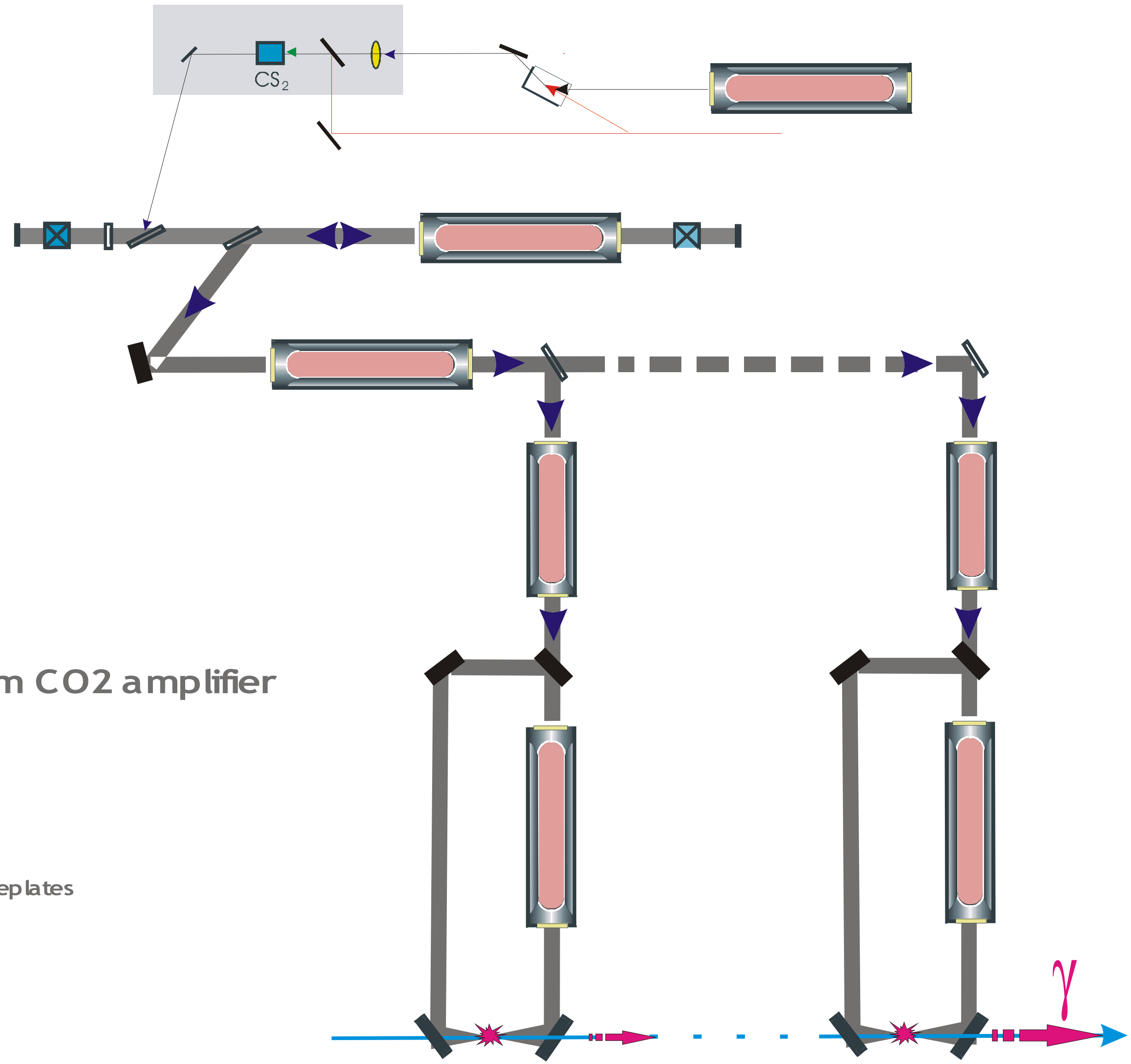
- Polarized γ-ray beam is generated in Compton backscattering inside optical cavity of CO_2 laser beam and 6 GeV e-beam produced by LINAC.
- The required intensities of polarized positrons are obtained due to 10 times increase of the "drive" e-beam charge (compared to non polarized case) and 5 to 10 consecutive IPs.
- Laser system relies on commercially available lasers but need R&D on a new mode of operation.
- 5ps, 10J CO_2 laser is operated at BNL/ATF.

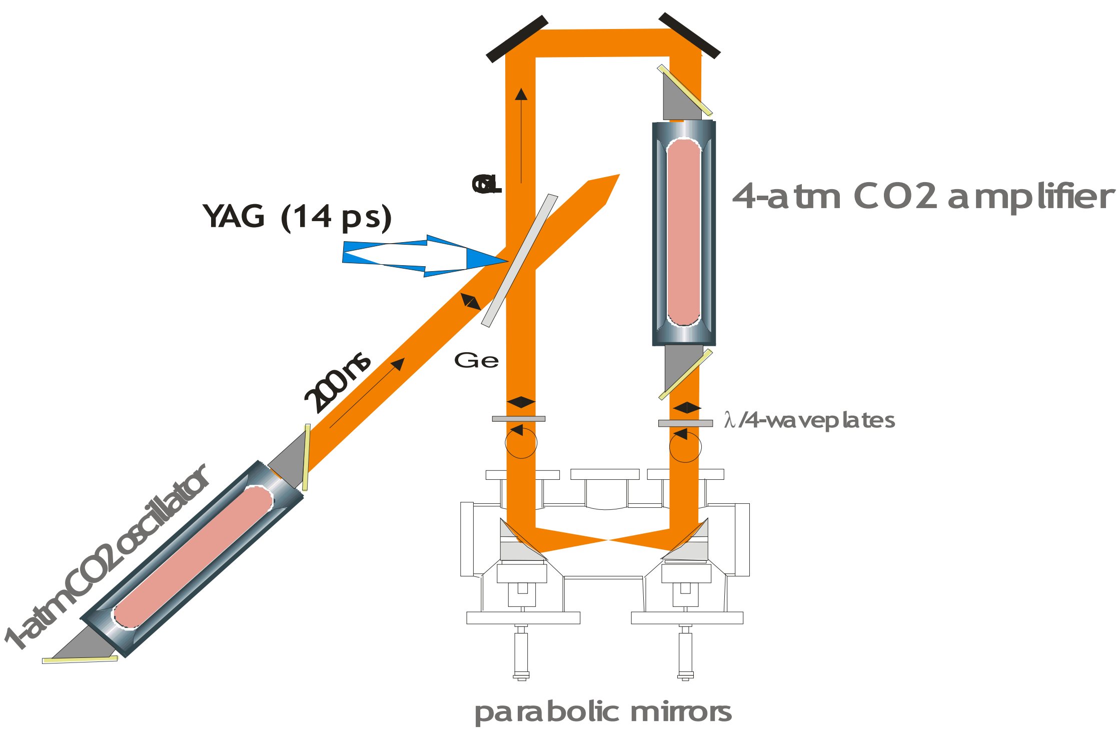
Real CCD images
Nonlinear and linear x-rays



- More than 10^8 of x-rays were generated in the experiment N_X/N_{e-} ~0.35.
- 0.35 was limited by laser/electron beams diagnostics
- Interaction point with high power laser focus of ~30μ m was tested.
- Nonlinear limit (more then one laser photon scattered from electron) was verified. PRL 2005.


platinum


CS2
γ


YAG (14 ps)
4-atm CO2 amplifier
Ge
200ns
1-atm CO2 oscillator
λ/4-waveplates
parabolic mirrors

Conclusion

Compton based gamma ray source based on the CO_2 laser cavity offers unprecedented intensities useful for many applications

Polarized positron source can be realized without need for 150-200 GeV electron beam and therefore offers more flexibilities in the collider design

SuperB factory positron beam requirements can be satisfied with the same source

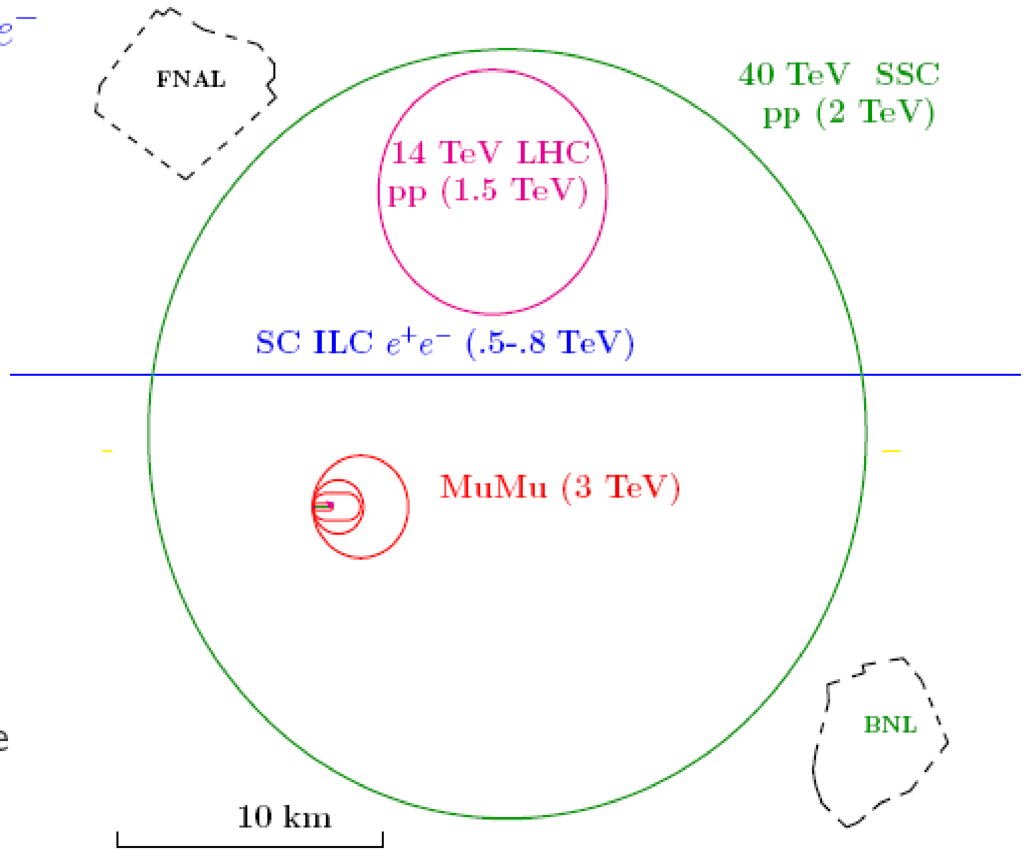
INNOVATIVE SOLUTIONS, WITH APPLICATIONS OUTSIDE HEP/NP

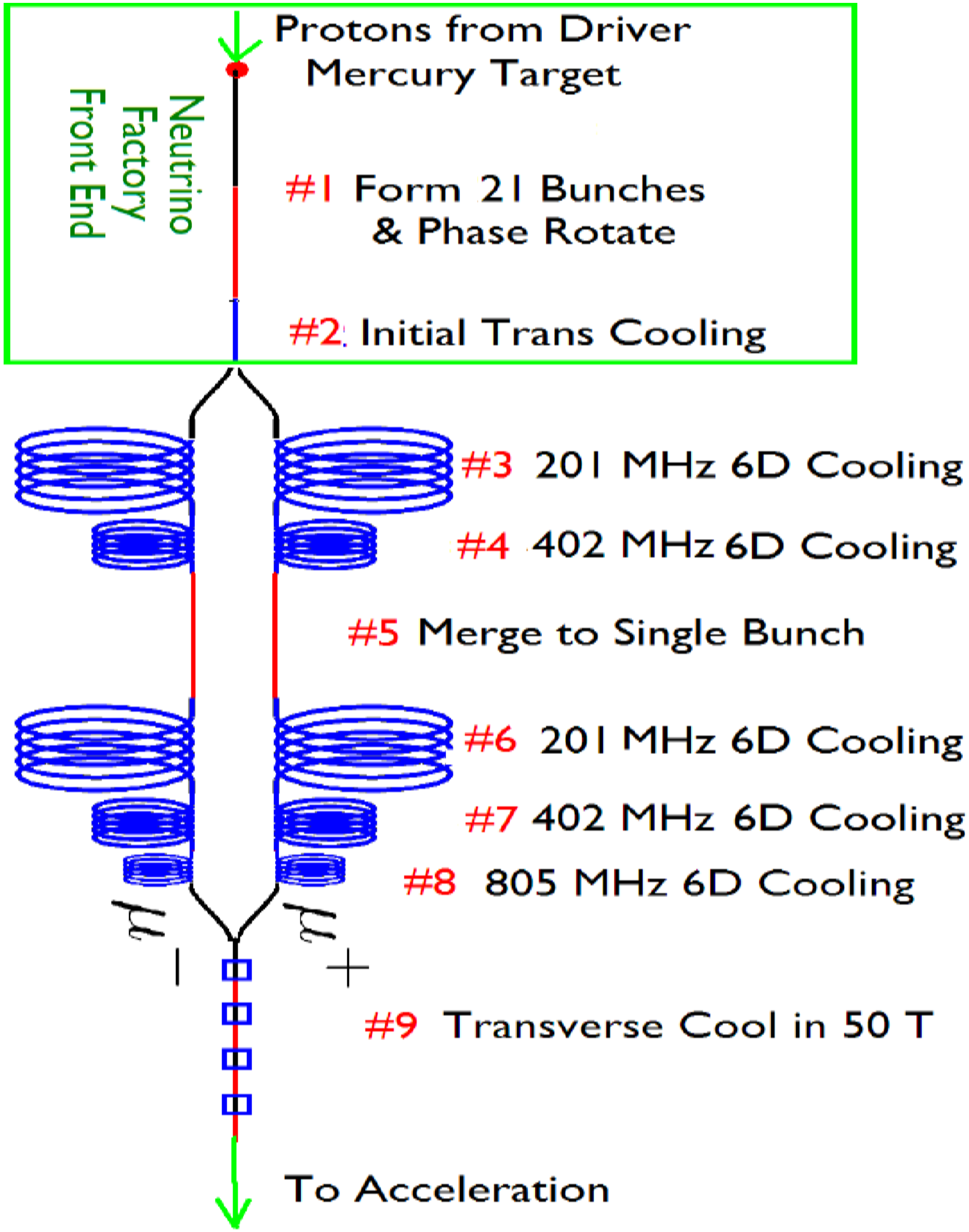
Vitaly Yakimento (ATF), Ilan Ben-Zvi (CAD), Vladimir Litvinenko (CAD), William Morse (Physics Dept.), Igor Pavlishin (ATF), Igor Pogorelsky (ATF), Patric Muggli (USC), …

Muon Collider & Neutrino Factory

- Point like interactions as in e^+e^-
- Negligible synchrotron radiation:
  Acceleration in rings vs. linear e^+e^-
  Small footprint
- Collider is a Ring
  $\approx$ 1000 interactions per bunch
  Larger spot for same luminosity
  Easier tolerances
- Negligible Beamstrahlung
  Narrow energy spread
- 40,000 greater S channel Higgs
  Study widths

  BUT
- Muons from pion decay are diffuse
  Need cooling
- Muons decay
  No time for ordinary cooling
  Acceleration must be rapid



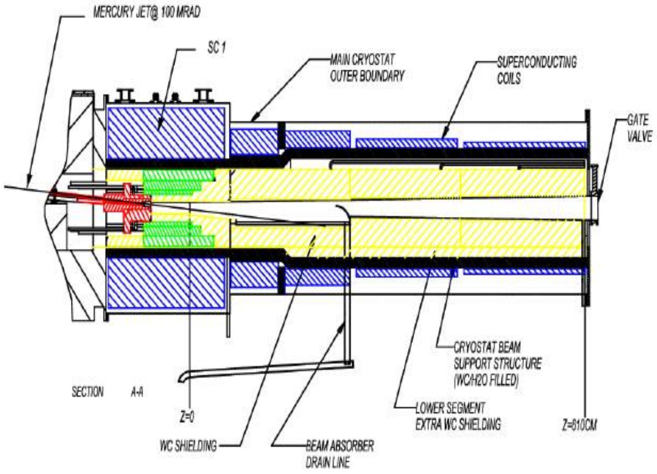


"A COMPLETE SCHEME OF IONIZATION COOLING FOR A MUON COLLIDER"

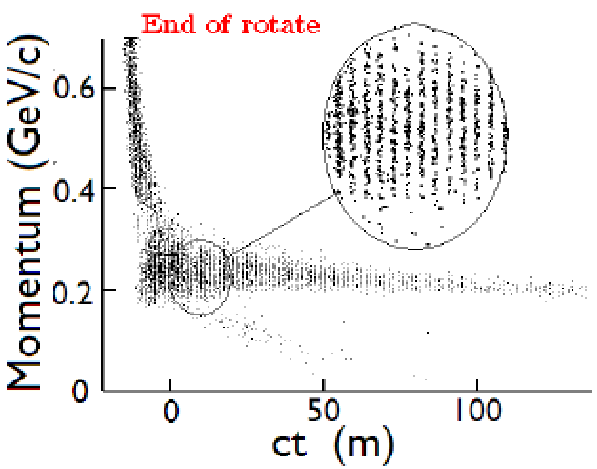
Robert B. Palmer, J. Scott Berg, Richard C. Fernow, Juan C. Gallardo (BNL)
Yuri Alexahin, David Neuffer (FNAL)
D. Summers (Mississippi University)
Stephen A. Kahn (Muons Inc.)

Neutrino Factory Front-End

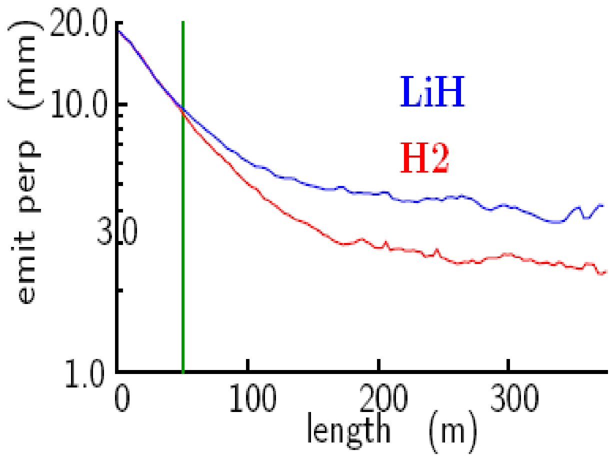
Liquid mercury target
20T tapered magnet
MERIT@CERN will test



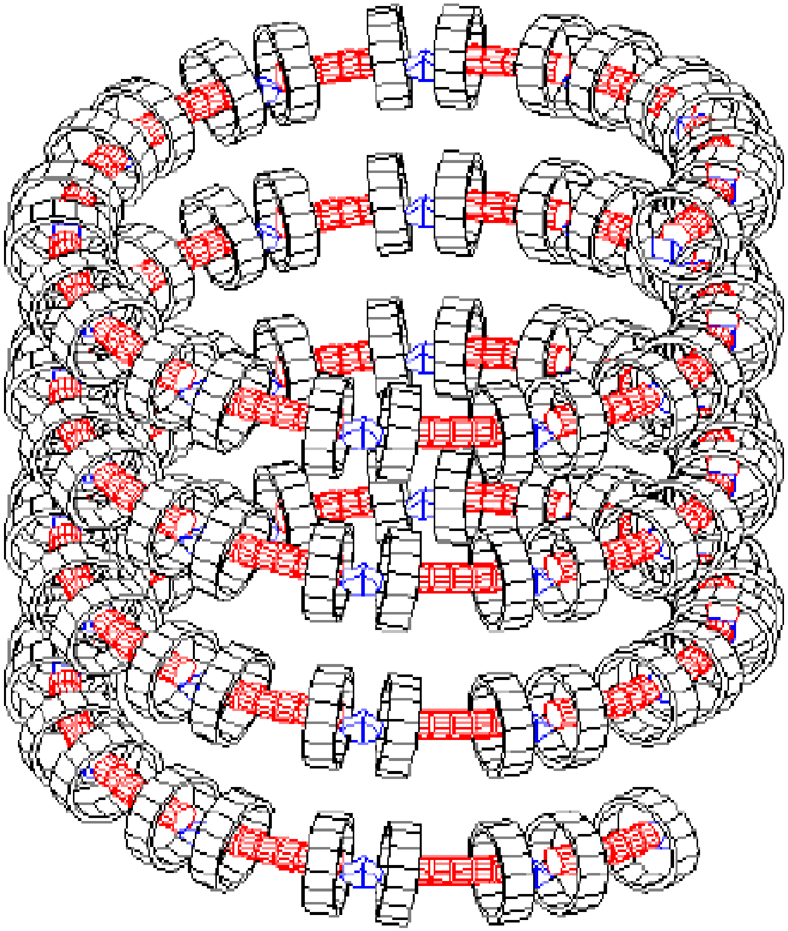
Phase rotation to reduce momentum spread &
Bunch Formation



Only Ionization Cooling fast enough
MICE@RAL will test



6D-Cooling in "Guggenheim" Helices

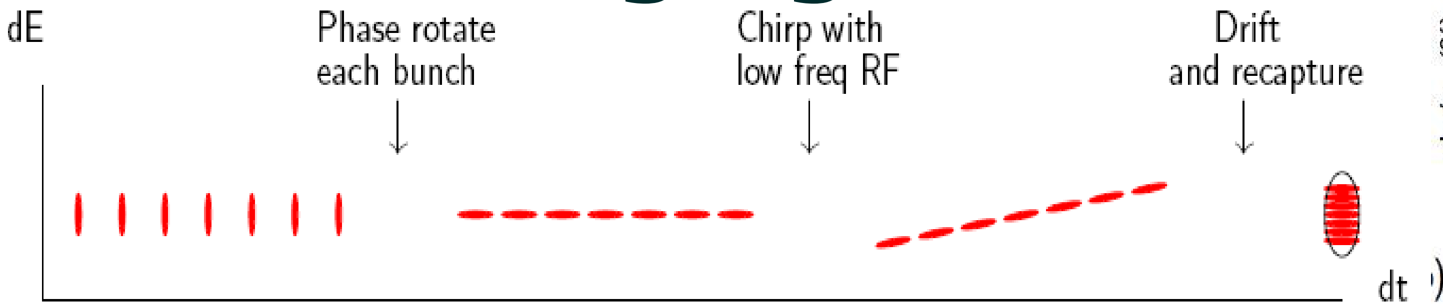


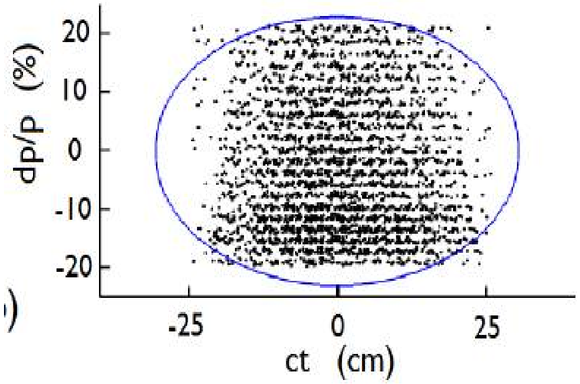
Bends provide dispersion

Longitudinal ↔ Transverse emittance exchange with wedges

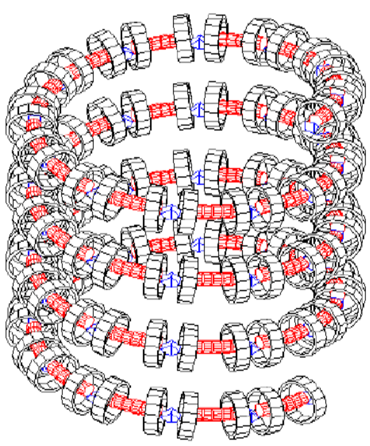
Longitudinal + transverse cooling

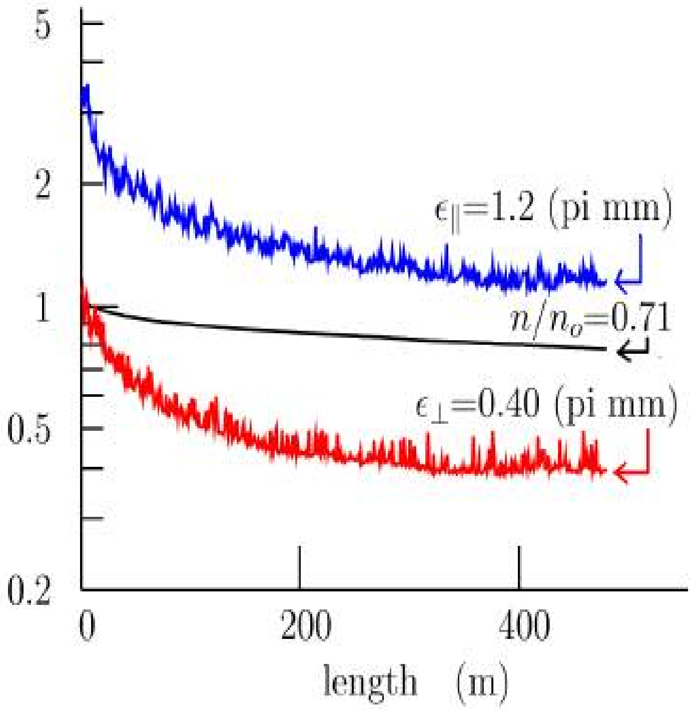
Bunch merging





Second phase 6D cooling





Ongoing Studies

- Fuller simulations
- Space charge tune shifts (moderate, but not in simulations)
- Possible breakdown of vacuum RF in the specified magnetic fields

- Being studied experimentally by MUCOOL Collaboration

- Possible solution 1) Gas filled cavities

works for earlier cooling lattices experiment needed for beam breakdown

- Possible solution 2) Open Cavities with coils in irises (see next)

works in simulation experiment needed for breakdown

- Planar wiggler lattice to replace Guggenheims (cools both muon signs)
- Fast Helical cooling in hydrogen gas

Another alternative to RFOFO Guggenheims being studied by Muons Inc

but difficult to introduce required rf

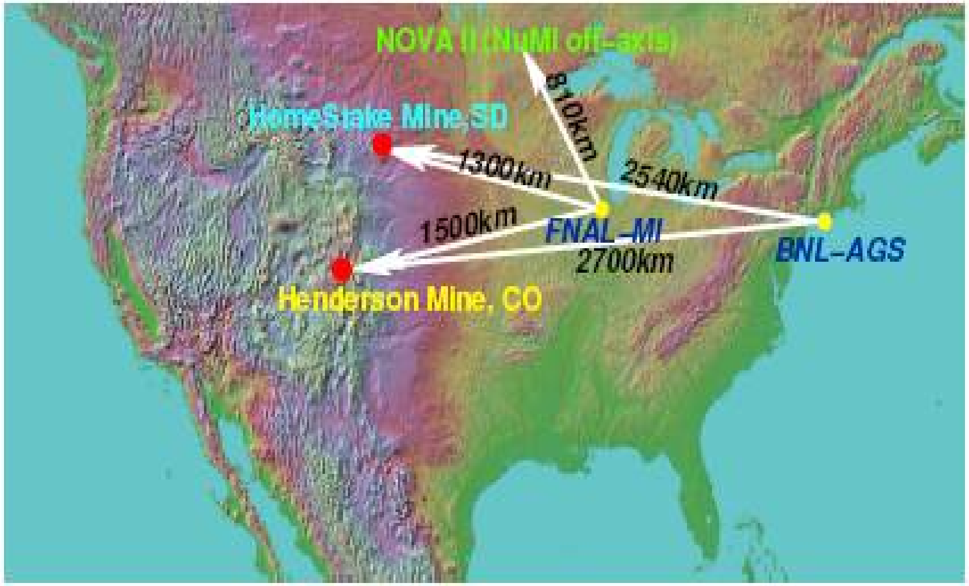
- Design of 50 T solenoids
- Use of more, but lower field (e.g. 35 T) final cooling solenoids
- Design detector shielding

BNL MAINTAINING A LEADERSHIP POSITION IN ACCELERATOR PHYSICS

BNL neutrino physics effort

Three overlapping efforts, focused on the same physics:

- MINOS
  running
- Daya Bay
  to be constructed
- DUSEL based large detector
  proposed



Recent milestone: report on US long baseline neutrino experiment study

Key Event Rate in 100kT·MW·10^7s

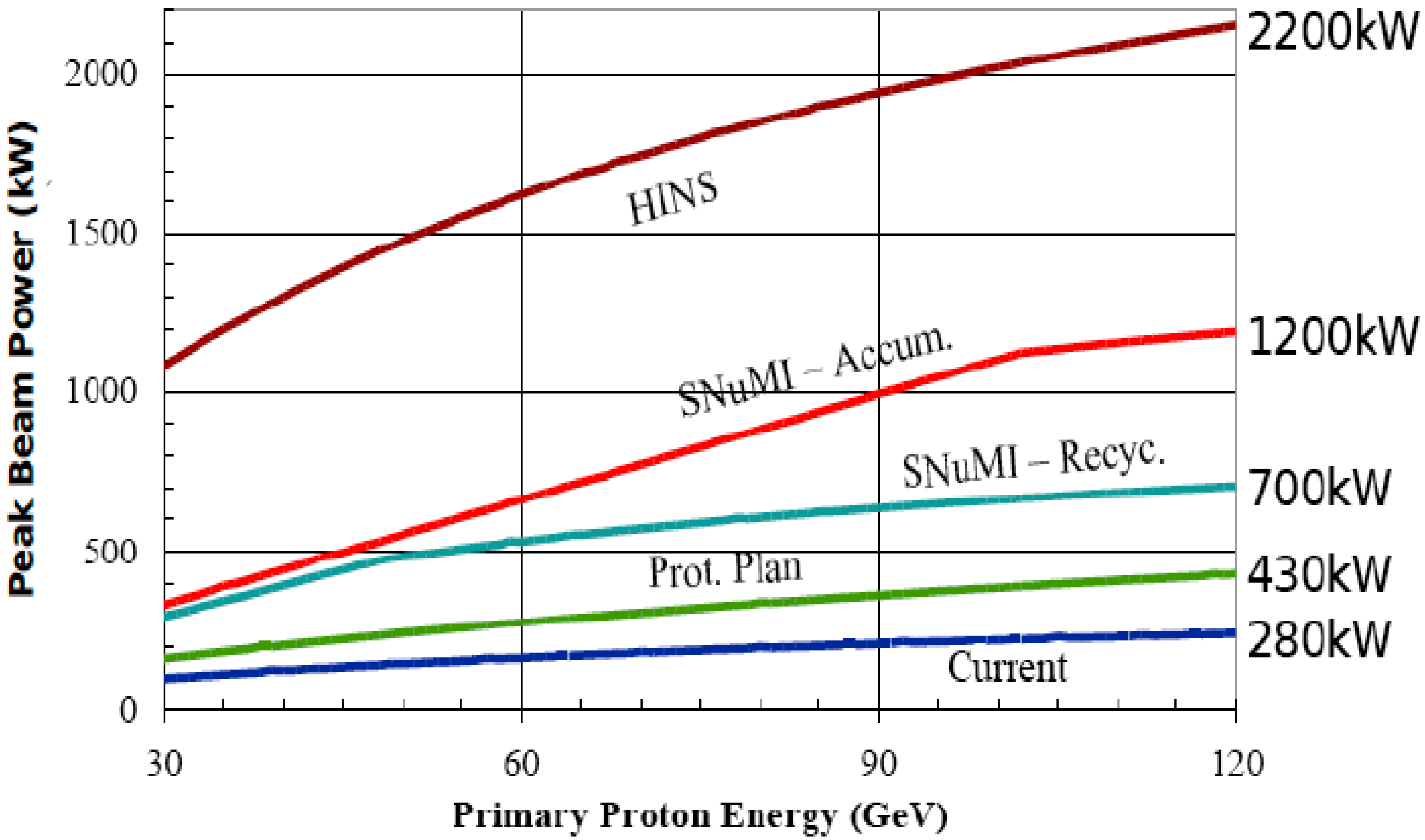
$$\nu_\mu \longrightarrow \nu_e$$

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3} eV^2$ $\sin^2 2\theta_{12,23} = 0.86, 1.0$ $\sin^2 2\theta_{13} = 0.02$

$$\delta_{CP}$$

	$sgn(\Delta m^2_{31})$	0 deg	+90 deg	180 deg	-90 deg
NuMI-15mrad (810km)	+	76	36	69	108
NuMI-15mrad (810km)	-	46	21	52	77
WBLE (1300km)	+	87	48	95	134
WBLE (1300km)	-	39	19	51	72

Towards a MW proton driver (FNAL)



A 100kT Detector

Cosmic rays become issue in detector placement

BNL study: Water Cherenkov @ DUSEL

Intime cosmics/yr	Depth (mwe)
5×10^7	0
4230	1050
462	2000
77	3000
15	4400

Signal ~ 50/yr

- Known, successful technology with wide dynamic range (5 MeV-50GeV).
- Can perform both p-decay, astrophysical sources, and accelerator nus.
- R&D on large caverns already in progress (part of the study).
- PMT R&D and costing in progress.
- Can be deployed deep scaled up: 50kT to fewX100kTon.
- MODEST DEVELOPMENT NEEDED FOR PROPOSAL.

(cf. liqAr studied at FNAL)

Deep Underground Science & Engeneering Lab

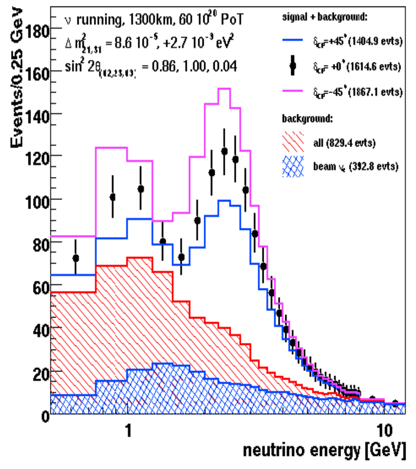
PRO

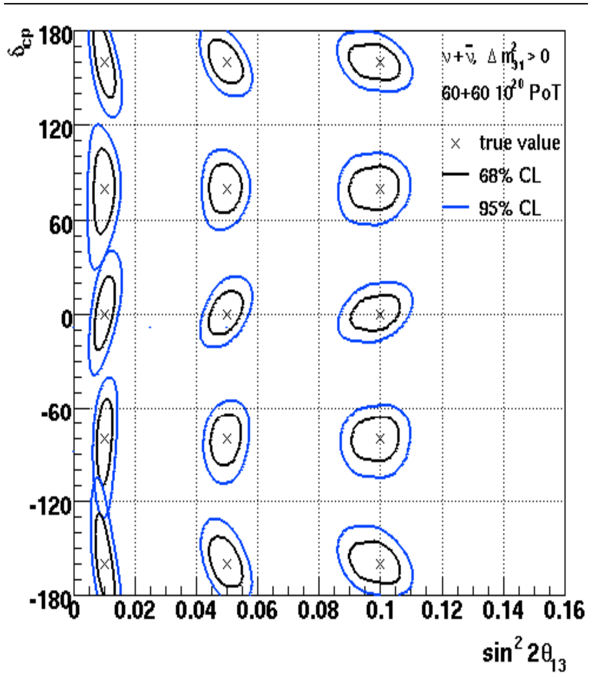
- Possible to put large detectors at depth with proven technology.
- Currently planned accelerator upgrade enough to get first physics because of detector size. But it is even more attractive with a Proton Driver
- Full energy spectrum for oscillation pattern and parameter measurement without ambiguities.
- There has been good progress in water Cherenkov pattern recognition.
- Broader physics program includes proton decay and astrophysics.

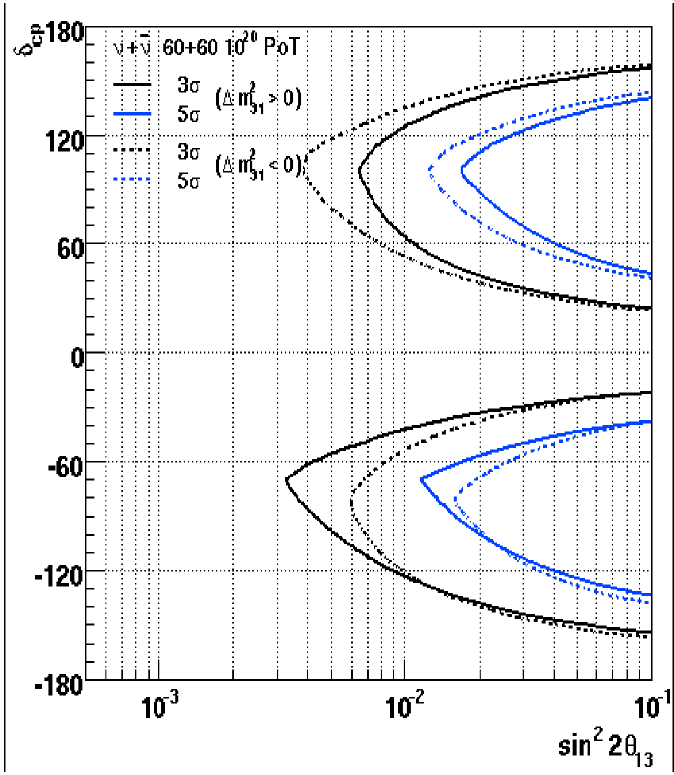
CON

- Needs new beamline
- Coupled to DUSEL with uncertain timeline and funding.
- Near detector cannot be water Cherenkov.

Great Discovery Potential!







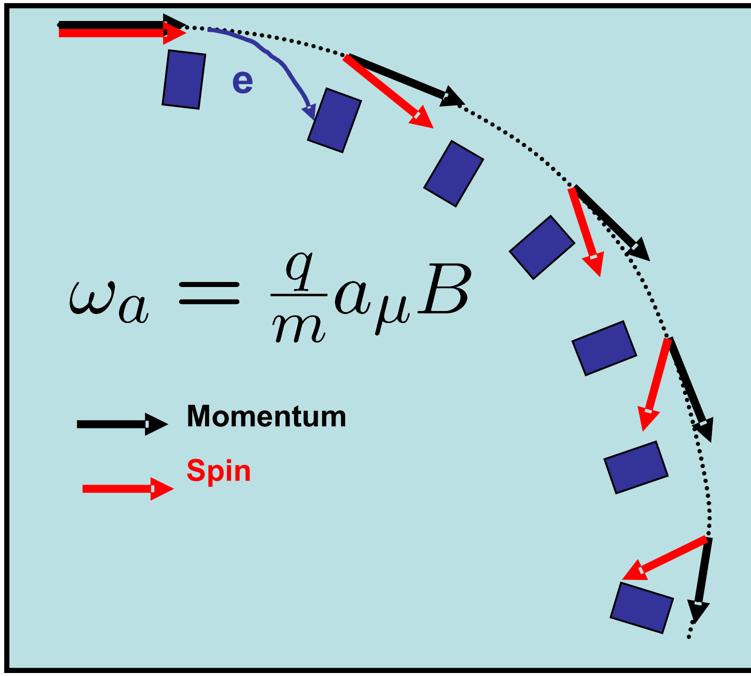
θ_{13}

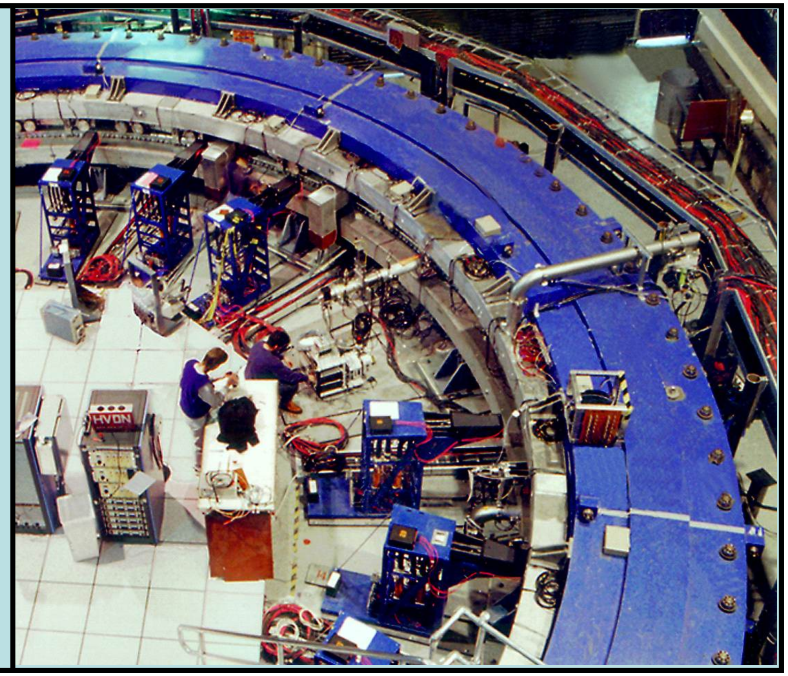
δ_{CP}

mass ordering

Talk by **Milind Diwan**, BNL

Precision Frontier: Muon g-2





$$\Delta a_\mu^{(\text{today})} = a_\mu^{(\text{Exp})} - a_\mu^{(\text{SM})} = (295 \pm 88) \times 10^{-11}$$

The last two years:

Final report (E821): Bennett et al, PPRD **73**, 072003 (2006)

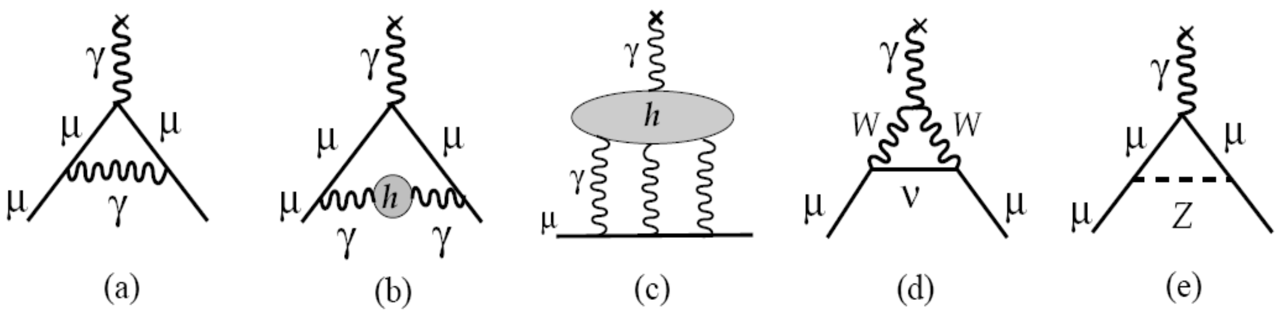
Future: BNL E969; increase of precision by >factor 2

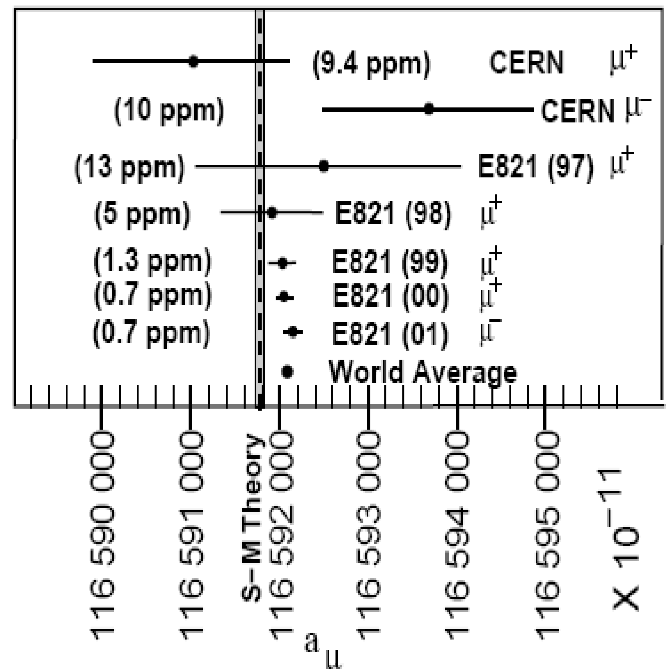
Theory: Reduced uncertainty; increased consistency

1300 citations to project papers

Probing all forces

$$a_\mu^{(\mathrm{SM})} = a_\mu^{(\mathrm{QED})} + a_\mu^{(\mathrm{hadronic})} + a_\mu^{(\mathrm{EW})}$$





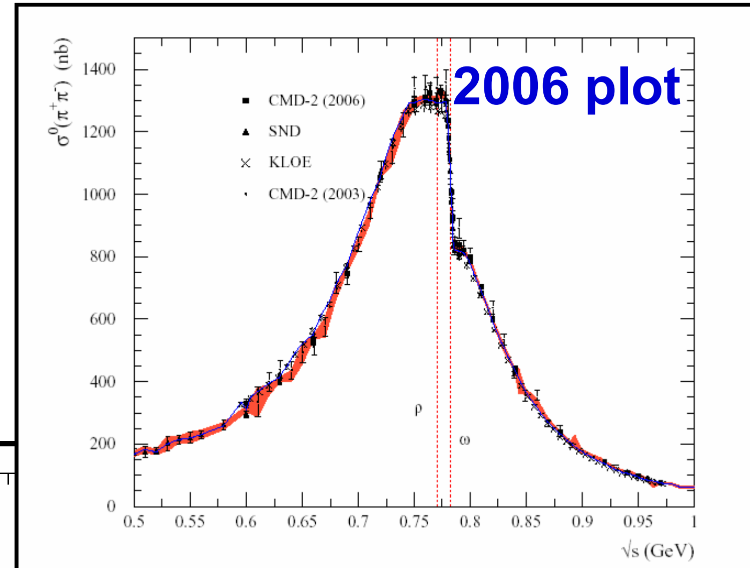
Expt. & Theory error comparable

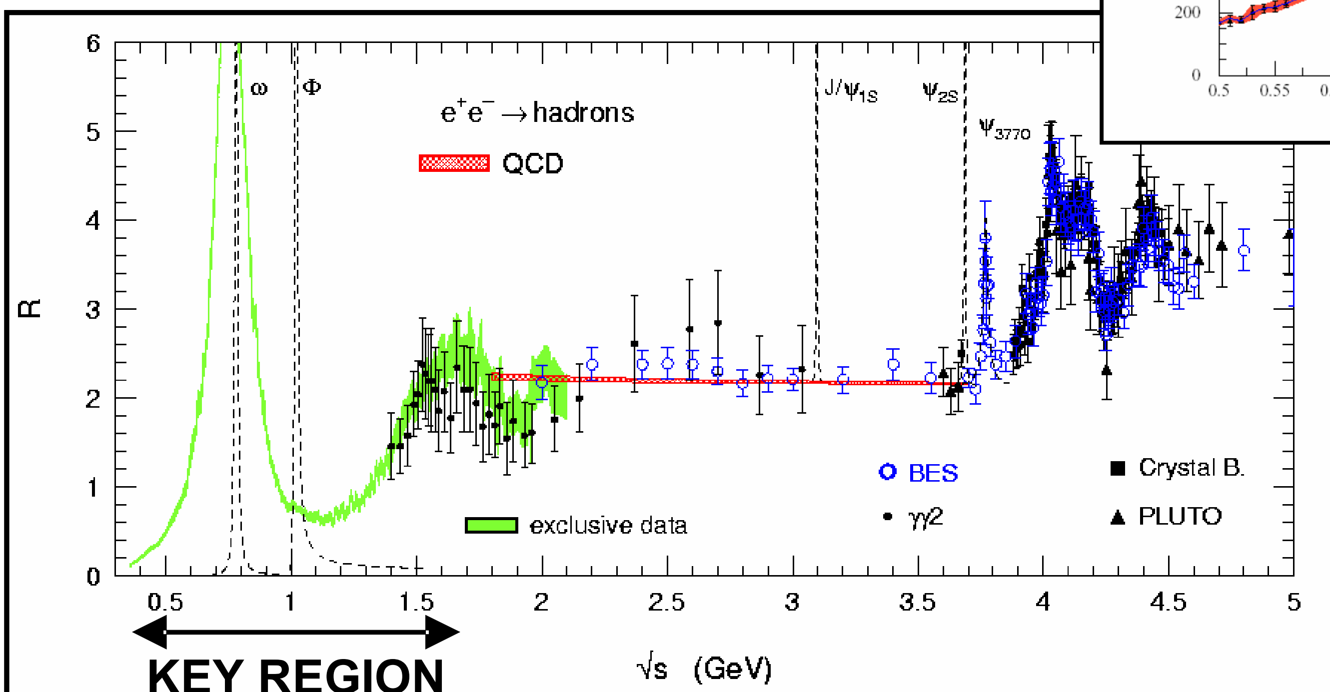
Effect	*Contribution* $\times 10^{11}$	*Future* σ
QED	$(116\,584\,718.09 \pm 0.14_{5\mathrm{loops}} \pm 0.08_\alpha \pm 0.04_{\mathrm{masses}}) \times 10^{-11}$	
Hadronic (lowest order)	$a_\mu^{(\mathrm{HVP;1})} = (6901 \pm 42_{\mathrm{exp}} \pm 19_{\mathrm{rad}} \pm 7_{\mathrm{QCD}})$	$\pm 30_{\mathrm{exp}} \pm 8_{\mathrm{rad}} \pm 7_{\mathrm{QCD}}$
Hadronic (higher order)	$a_\mu^{(\mathrm{HVP;h.o.})} = (-97.9 \pm 0.9_{\mathrm{exp}} \pm 0.3_{\mathrm{rad}})$	
Hadronic (light-by-light)	$a_\mu^{(\mathrm{HLLS})} = (110 \pm 40)$	16.5
Electroweak	$a_\mu^{(\mathrm{EW})} = (154 \pm 2_{M_H} \pm 1_{\mathrm{had}})$	

Hadronic Contribution

$$a_{\mu}^{had,1} \propto \int_{2m_{\pi}}^{\infty} ds \frac{K(s)}{s} R(s)$$

$$R(s) = \frac{\sigma\left(e^{+}e^{-} \rightarrow \text{hadrons}\right)}{\sigma\left(e^{+}e^{-} \rightarrow \text{muons}\right)}$$





Continuing effort to resolve **e+e-→hadrons** & **τ→hadrons** discrepancy

Physics Case for new g-2 Experiment

The Physics Case for the New Muon $(g-2)$ Experiment

David W. Hertzog[3], James P. Miller[1], Eduardo de Rafael[4], B.Lee Roberts[1], Dominik Stöckinger[2]

[1]Department of Physics, Boston University, Boston, MA 02215, USA
[2]Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
[3]Department of Physics, University of Illinois, Urbana-Champaign, IL 61801, USA
[4]Centre de Physique Théorique, CNRS-Luminy, Case 907, F-13288 Marseille Cedex 9, France

Executive Summary

This White Paper briefly reviews the present status of the muon $(g-2)$ experiment and the physics motivation for a new effort. The present comparison between experiment and theory indicates a tantalizing 3.4 σ deviation. An improvement in precision on this comparison by a factor of 2—with the central value remaining unchanged—will exceed the "discovery" threshold, with a sensitivity above 6 σ. The 2.5-fold reduction improvement goal of the new Brookhaven E969 experiment, along with continued steady reduction of the standard model theory uncertainty, will achieve this more definitive test.

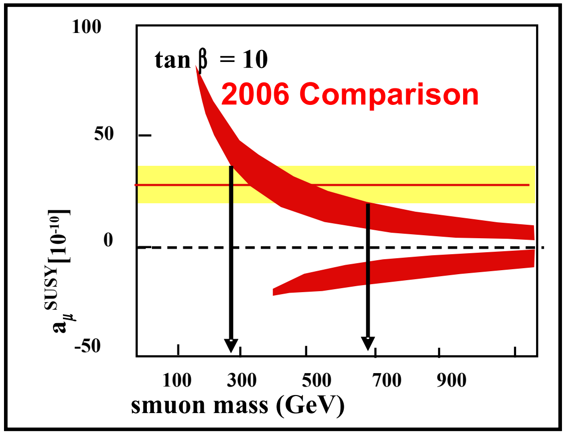
Already, the $(g-2)$ result is arguably the most compelling indicator of physics beyond the standard model and, at the very least, it represents a major constraint for speculative new theories such as supersymmetry or extra dimensions. In this report, we summarize the present experimental status and provide an up-to-date accounting of the standard model theory, including the expectations for improvement in the hadronic contributions, which dominate the overall uncertainty. Our primary focus is on the physics case that motivates improved experimental and theoretical efforts. Accordingly, we give examples of specific new-physics implications in the context of direct searches at the LHC as well as general arguments about the role of an improved $(g-2)$ measurement. A brief summary of the plans for an upgraded effort complete the report.

g-2 & new physics in LHC era
- definite benchmark for new physics
- particularly sensitive to quantities that are difficult to measure at LHC
- inclusive measurement of quantum effects of all particles
- is a very clean observable
- is a simple & beautiful quantity

Year	Polarity	$a_\mu \times 10^{10}$	σa_μ [ppm]
1997	μ^+	11 659 251(150)	13
1998	μ^+	11 659 191(59)	5
1999	μ^+	11 659 202(15)	1.3
2000	μ^+	11 659 204(9)	0.7
2001	μ^-	11 659 214(9)	0.7
Avg.		11 659 208.0(6.3)	0.54

Statistics dominated

Conclusion



Experiment

plan in place to improve precision by factor 2 or more – high efficiency, higher intensity

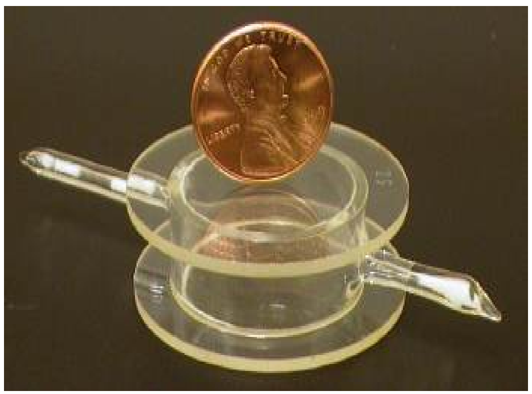
Theory

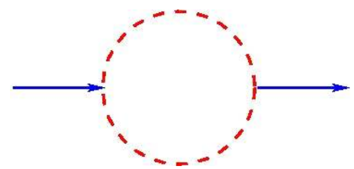
robust calculations of QED & Weak contributions
dedicated efforts to improve hadronic uncertainty

Arguably the strongest experimental evidence of physics beyond the Standard Model

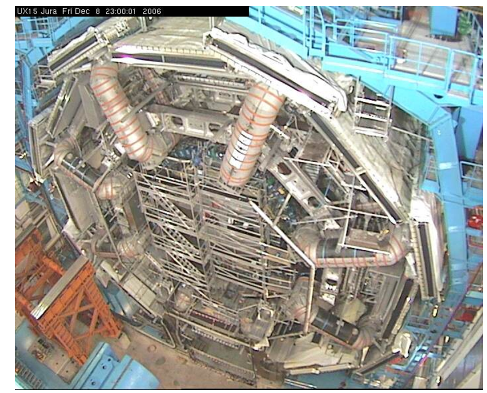
Probing new CP-odd thresholds with EDMs

Precision searches for new physics (at E-scale Λ)





$$\frac{\Delta E}{E} \sim \left(\frac{m}{\Lambda}\right)^n$$



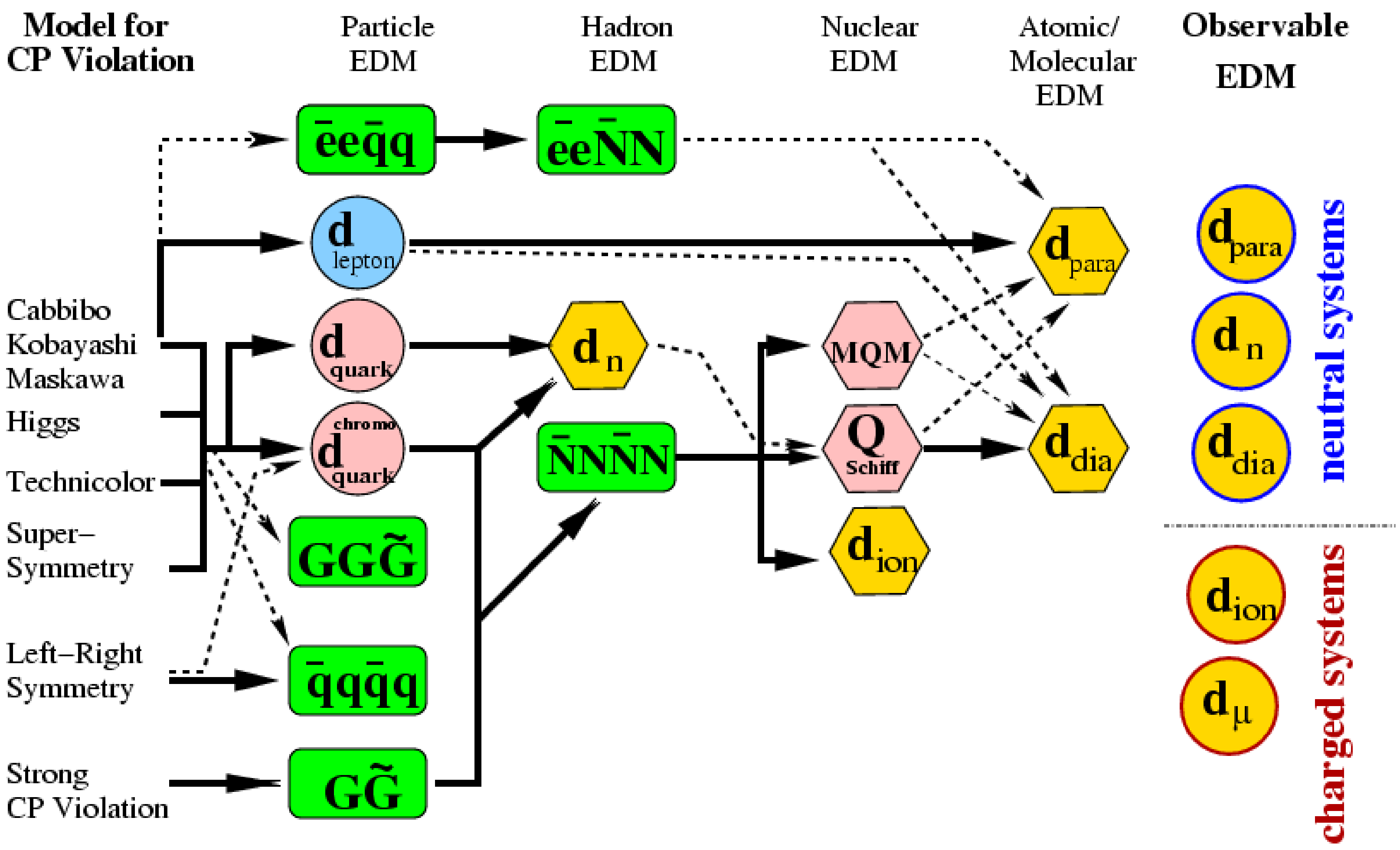
Especially powerful for tests of "symmetries" of the SM:
e.g. Baryon no., Lepton no., Flavour, **T** (or **CP**), etc.

Standard Model CP Violation in CKM
explains K & B meson mixing and decay
predicts EDMs ~0

EDMs » d(SM)

BUT: Baryogenis needs more & ~all >SM add more!

The origin of EDMs



TeV QCD nuclear atomic

Implications of current limits

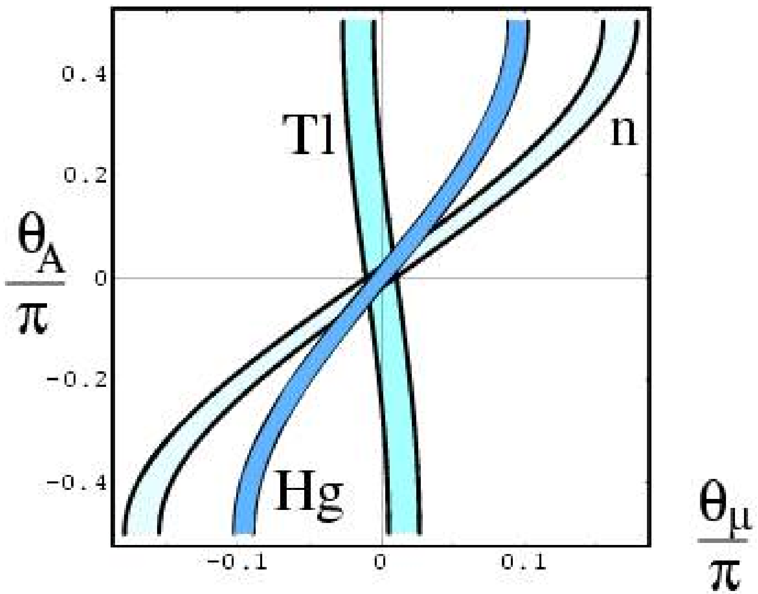
Tl $\left| d_e + e(26 MeV)^2 \left(3\frac{C_{ed}}{m_d} + 11\frac{C_{es}}{m_s} + 5\frac{C_{eb}}{m_b} \right) \right| < 1.6 \times 10^{-27}\, e\, cm$

n $\left| e(\tilde{d}_d + 0.5\tilde{d}_u) + 1.3(d_d - 0.25 d_u) + O(\tilde{d}_s, w, C_{qq}) \right| < 2 \times 10^{-26}\, e\, cm$

Hg $e\left| \tilde{d}_d - \tilde{d}_u + O(d_e, \tilde{d}_s, C_{qq}, C_{qe}) \right| < 2 \times 10^{-26}\, e\, cm$

Sensitivity: $d_f \sim e\frac{m_f}{M_{CP}^2}$

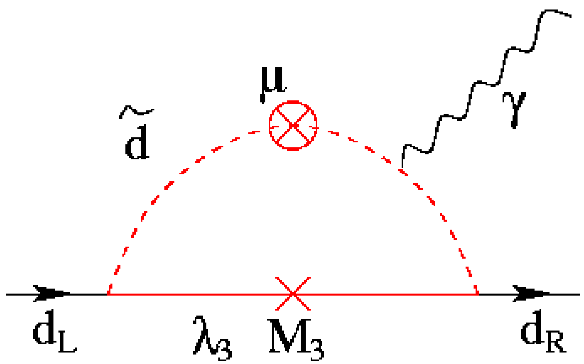
$M_{CP} \geq \mathcal{O}(10 - 50)\, TeV$



$M_{soft} = 500\, GeV$

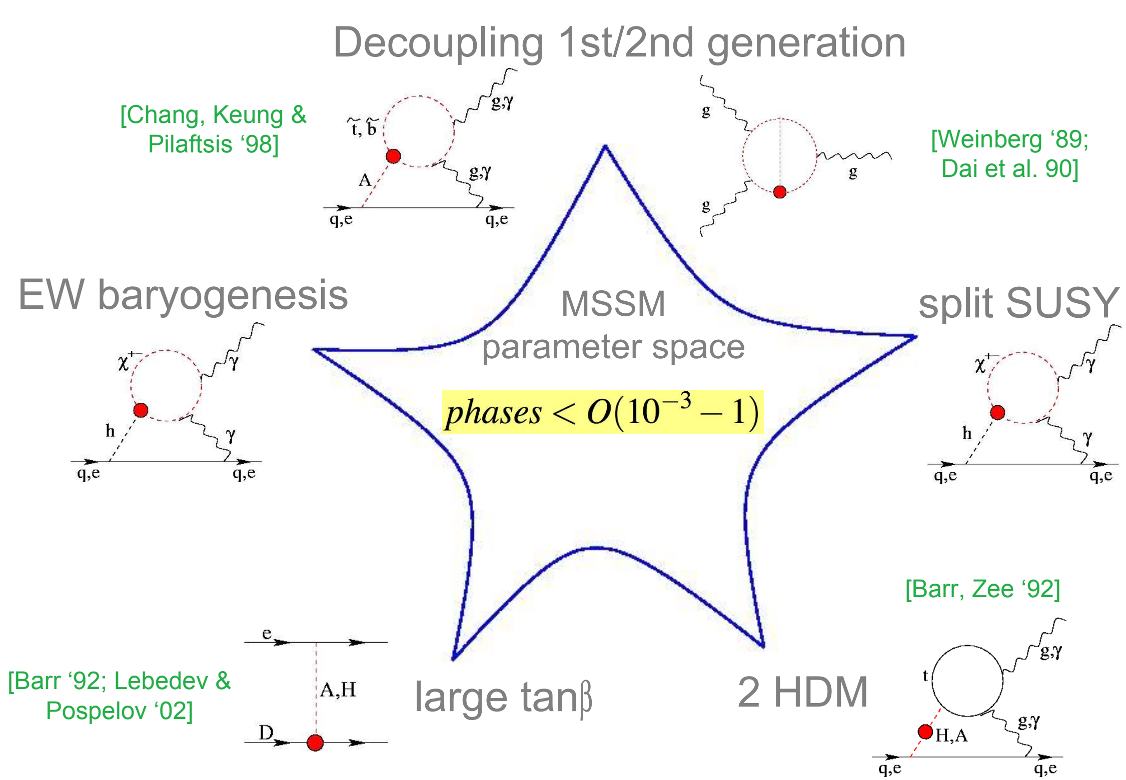
Link to SUSY

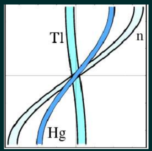
operator	sensitivity to Λ (GeV)	source
Y^{qe}_{3311}	$\sim 10^7$	naturalness of m_e
$\mathrm{Im}(Y^{qq}_{3311})$	$\sim 10^{17}$	naturalness of $\bar{\theta}$, d_n
$\mathrm{Im}(Y^{qe}_{ii11})$	$10^7 - 10^9$	Tl, Hg EDMs
Y^{qe}_{1112}, Y^{qe}_{1121}	$10^7 - 10^8$	$\mu \to e$ conversion
$\mathrm{Im}(Y^{qq})$	$10^7 - 10^8$	Hg EDM
$\mathrm{Im}(y_h)$	$10^3 - 10^8$	d_e from Tl EDM



$$\frac{d_d}{m_d} \sim \frac{1}{16\pi^2} \frac{\mu m_{\tilde{g}}}{M^4} \sin\theta_\mu$$

M~sfermion mass





Concluding Remarks

- Precision tests can play a crucial role in probing fundamental symmetries at scales well beyond the reach of colliders.
- EDMs currently provide stringent constraints on CP-phases in the soft-breaking sector of the MSSM.
- If the soft sector is real, EDMs and other precision flavor physics provides impressive sensitivity to new SUSY thresholds.

next generation tests will push the scale close to that of RH neutrinos, etc.

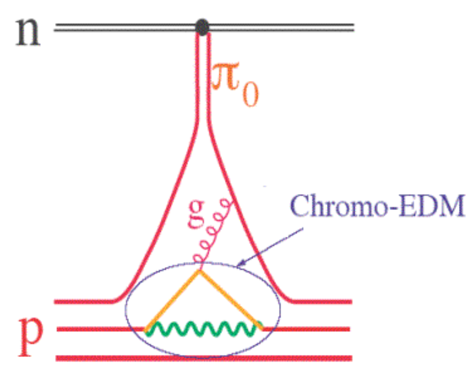
- Current EDM bounds still allow for electroweak baryogenesis in a minimal dim=6 extension of the SM.

next-generation expts will provide a conclusive test.

Deuteron EDM Search

First of a new class of EDM searches on charged particles using the E=γvxB field in a storage ring

Deuterons first because



Technically

Polarized ion sources make intense beams
Polarization >90%
Forward angle scattering very sensitive to polarization

Physically

Special sensitivity to chromo-EDMs

c.f. Neutrons

$$d_n = 0.83e\left(d_d^c + d_u^c\right) + 0.27e\left(d_d^c - d_u^c\right)$$

$$d_d = -0.2e\left(d_d^c + d_u^c\right) + 6e\left(d_d^c - d_u^c\right)$$

At 10^{-29} e.cm:
Equiv. mass 10^3 TeV
Sensitivity to CP phase: 10^{-5}
(beyond LHC reach)

Status of Letter of Intent
presented to fall 2006 PAC

Please find below the recommendation of the NPP PAC from September.

LoI: Search for a Deuteron Electric Dipole Moment Using a Charged Particle Storage Ring

This letter proposes a search for a deuteron electric dipole moment using a stored beam. The goal is a statistical precision of about 10^{-29} e·cm; an appropriate level for an experiment we expect would take a number of years to develop. In this experiment, a longitudinally polarized beam develops a vertical spin component due to the torque of the motional electric field in the ring bending magnets acting on the electric dipole moment. The PAC is enthusiastic about this ingenious new approach to electric dipole moment searches. Because it is a new technique, however, there will be a daunting new set of false edm effects and associated systematic errors to consider. We believe it is very important to identify the most important of these difficulties and address them with a combination of simulation and measurement. We strongly encourage the collaboration to investigate the options for measurements in existing rings with polarized deuteron beams. Development of a program of simulations and tests should include, but not be limited to, complete characterization (intensity, size, energy, polarization) of the tails of the beam and their effects on the measurement, investigations of resonant extraction, considerations of correlations between energy and position in the 'extraction' region, and characterization of the effects of common lattice imperfections. Indeed, short of implementing the resonant enhancement of vertical polarization described in the proposal, measurements of zero left-right asymmetries at the requisite level must be demonstrated. A clear plan for near-term milestones including consideration of these issues (over perhaps a two-year period) should accompany any request to the laboratory for continued support.

Clearly there is enthusiasm for your continuing development of this experiment and I look forward to a plan as suggested in the last sentence of the recommendation.

The PAC is in favor of the physics goals.

The PAC favors an R&D program of ring simulations and polarimeter tests.

(supported again in spring 2007)

BNL plans to provide LDRD

From the Netherlands: 600 K€ already granted

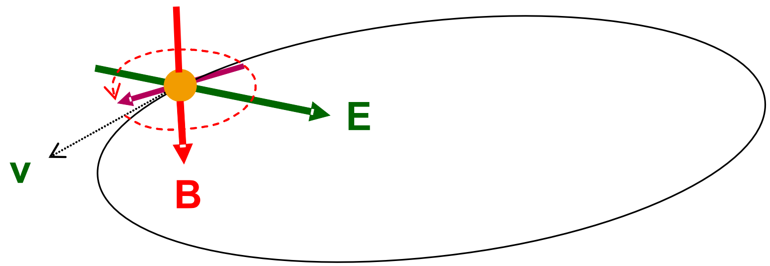
Goal: demonstrate feasibility of technique

(Included in nuclear physics long-range plan)

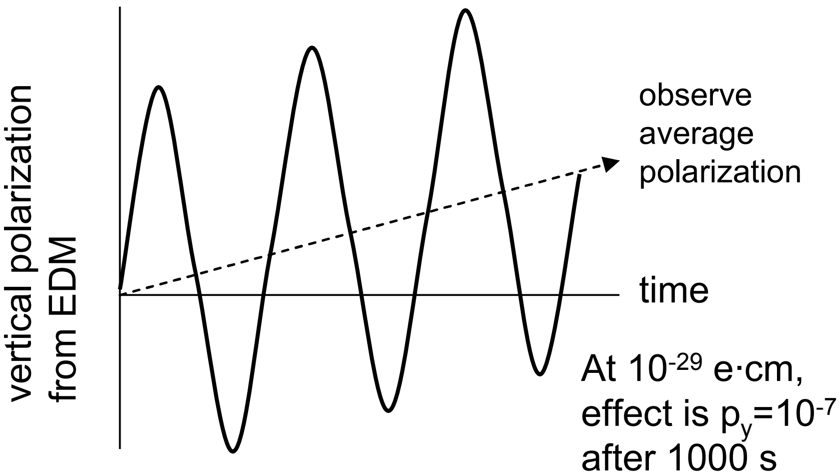
Concept Storage Ring

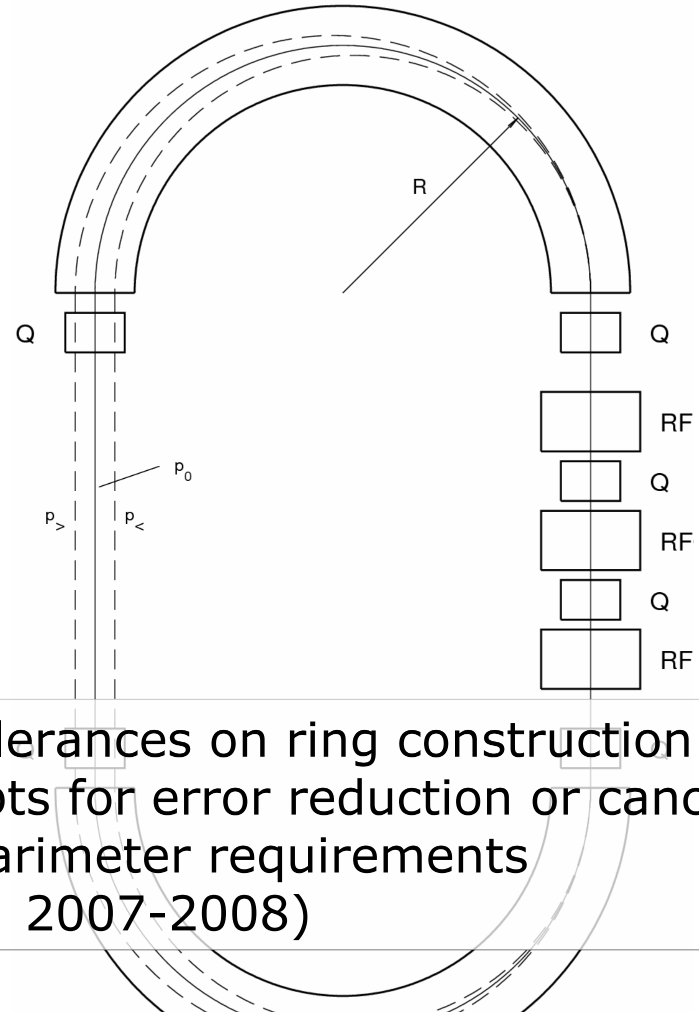
EDM Signal: observe precession of spin in large electric field.

Technique: create large E field from $\gamma \mathbf{v} \times \mathbf{B}$ on polarized beam circulating in a ring.



Experiment: watch for spin that starts out along **v** to acquire a vertical component.





Examine tolerances on ring construction
Test concepts for error reduction or cancelation
Specify polarimeter requirements
(time table: 2007-2008)

DOING SIMULATIONS

Polarimetry

(COSY/KVI)

Results from COSY PAC

May, 2007

The long term goal behind the polarimeter development described in this proposal is a test of the Standard Model of particle physics by means of a precision measurement of the electric dipole moment of the deuteron. The method proposed is novel and involves measuring the build-up of vertical polarization in a storage ring. The signal would allow unprecedented accuracies for the deuteron electric dipole moment, namely at the level of 10^{-29} e·cm. The PAC is intrigued by this possibility and expresses its strong support toward this very rewarding goal.

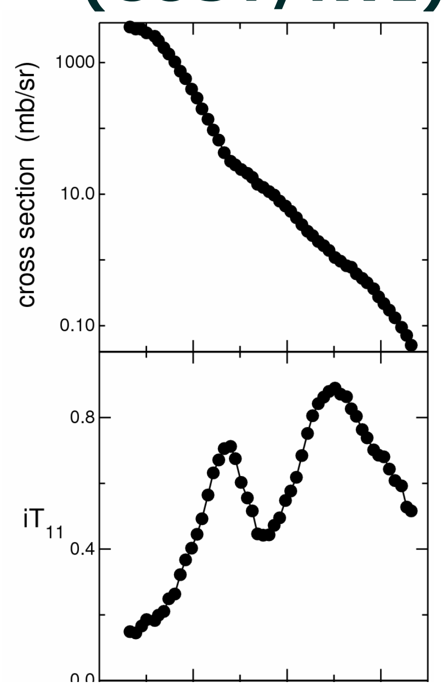
In order to achieve the necessary sensitivity, new methods have to be developed for the polarization measurement as well as for a detailed understanding of the spin dynamics of the ring. So far, it is estimated that a total 8 weeks of beam-time will be required. The spin studies will need to be based on quantitative modeling of the spin motion in the ring as well as on spin manipulations like the ones that are performed by the SPIN@COSY project. It appears highly advisable to coordinate the programs among the two groups.

As a first step the development of a highly efficient polarimeter making use of the EDDA target station and the EDDA scintillator is proposed. A thick annular carbon target is to be designed and placed at the EDDA position. While the PAC accepts and supports this development effort by granting one week of beam-time it appears unlikely that the measurement can be performed in the next period. In particular, the collaboration first has to become familiar with the EDDA and COSY setups so that it will be able to make efficient use of the limited beam-time. The PAC therefore encourages members of the collaboration to participate in scheduled runs at COSY. The PAC appreciates the effort to involve more people in the project and asks the collaboration to prepare detailed plans of the next steps including quantitative milestones and manpower resources for its next meeting. In the meantime, the collaboration can be assured of the continuing support of the PAC.

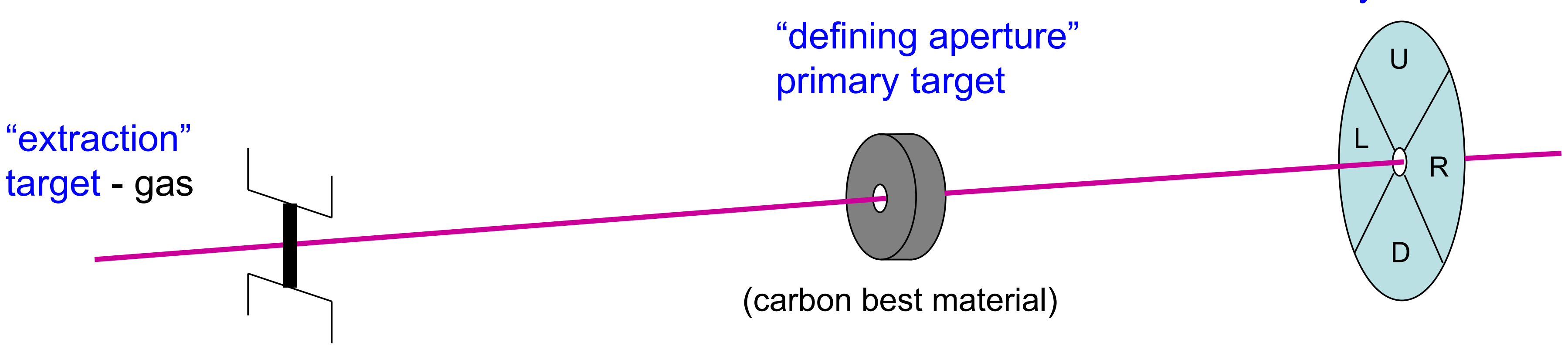
Support for the physics goals.

Beam time granted (but not scheduled) for first goal: high efficiency polarimeter with annular carbon target.

Remaining goals:
- make horizontal polarization
- measure in-plane precession
- check sensitivity to synchrotron oscillations
- measure cross section and analyzing power for deuteron-induced reactions



Running to be scheduled in early 2008 through 2010



Status of dEDM Project

Resonant method seems feasible, statistical limit ~10^{-29} e.cm

BNL PAC supports physics goals, R&D to determine feasibility

- Spin tracking to test ring lattice design
- Polarimeter proof-of-principle tests

Future:

- Technical Review
- Full Proposal

Talk by **Ed Stephenson**, IUCF

Conclusion

BNL has a diverse physics program, including

... RHIC as a QCD spearhead

... next-generation accelerator development

ILC, Mu-Collider, ...

... forefront neutrino experiments

minos, DUSEL, ...

... ambitious SM tests & new physics searches

muon g-2, dEDM, ...

... complemented with world class theory support