Charged Lepton Flavour & Dipole Moments

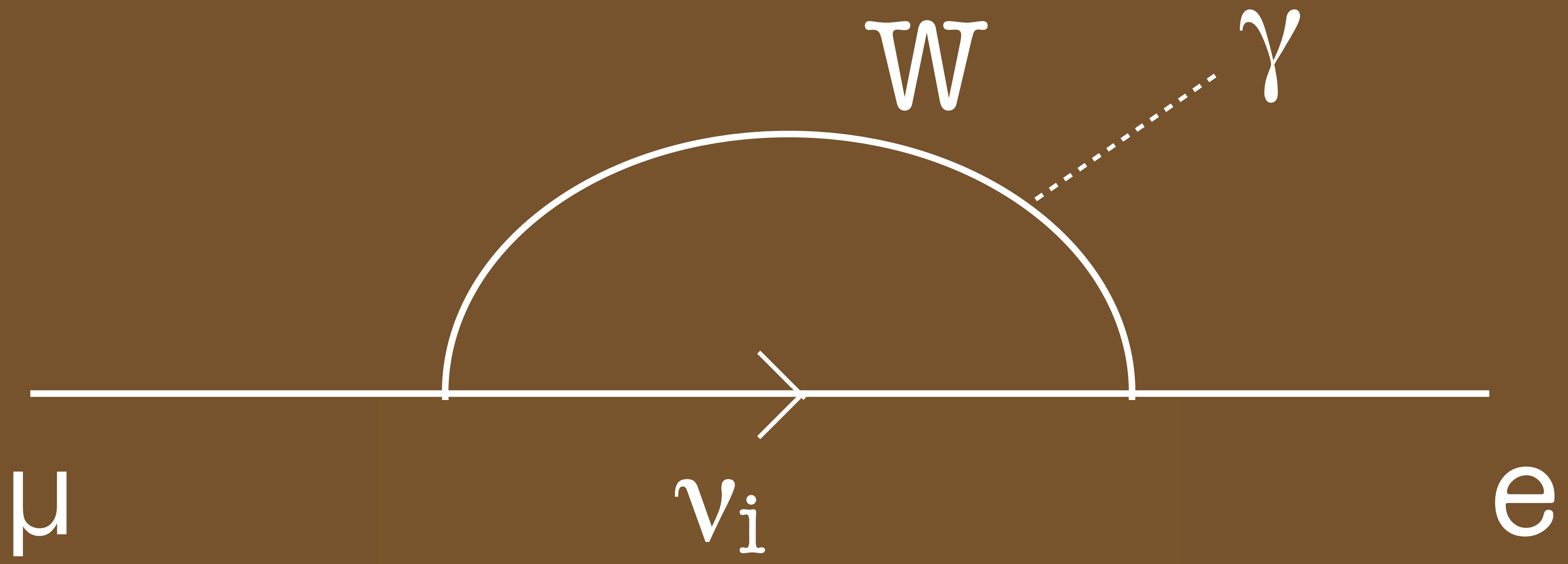
T. Mori
The University of Tokyo

EPS-HEP 2011 Grenoble

- This talk reviews the experiments which study:
    - charged lepton flavour violation (CLFV)
    - electric dipole moments (EDM)

CLFV & EDM

definite evidence of new physics

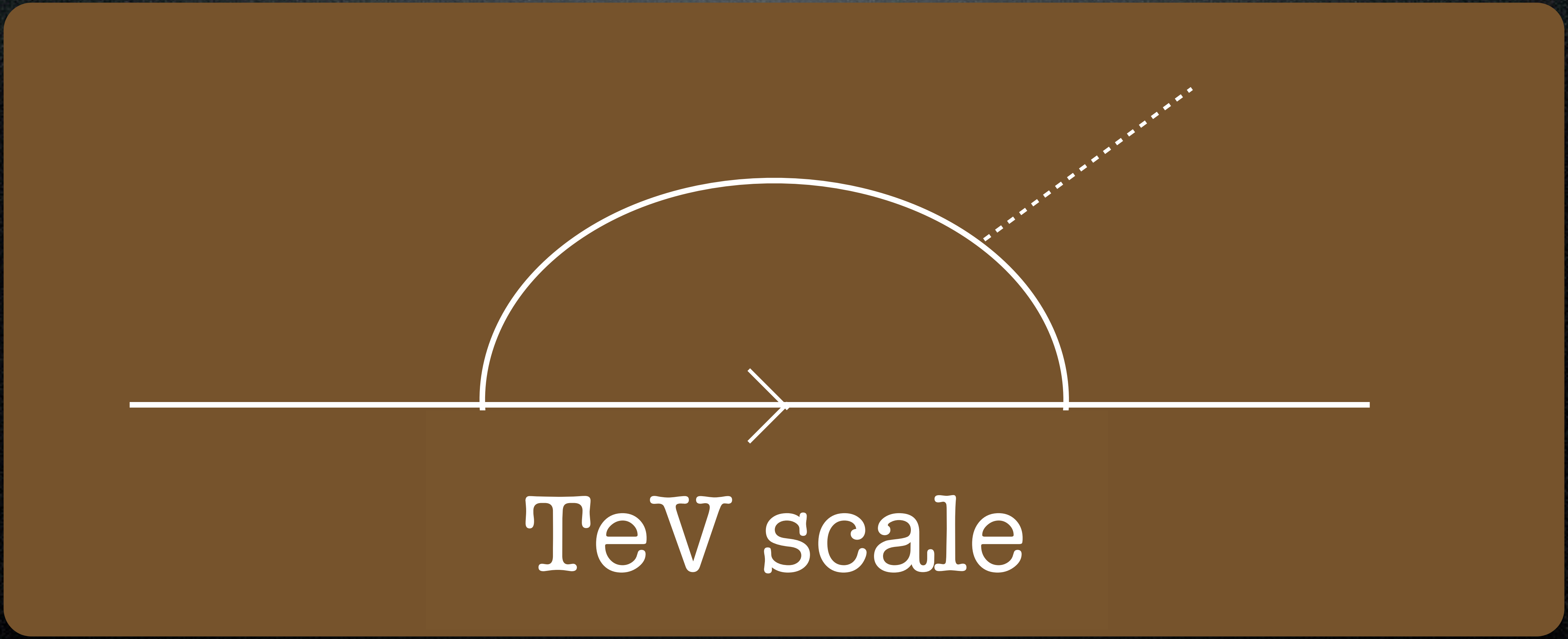


$$\frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i}\left(\frac{m^2_{\nu_i}}{M^2_W}\right)U_{ei}\right|^2 \leq 10^{-45}$$

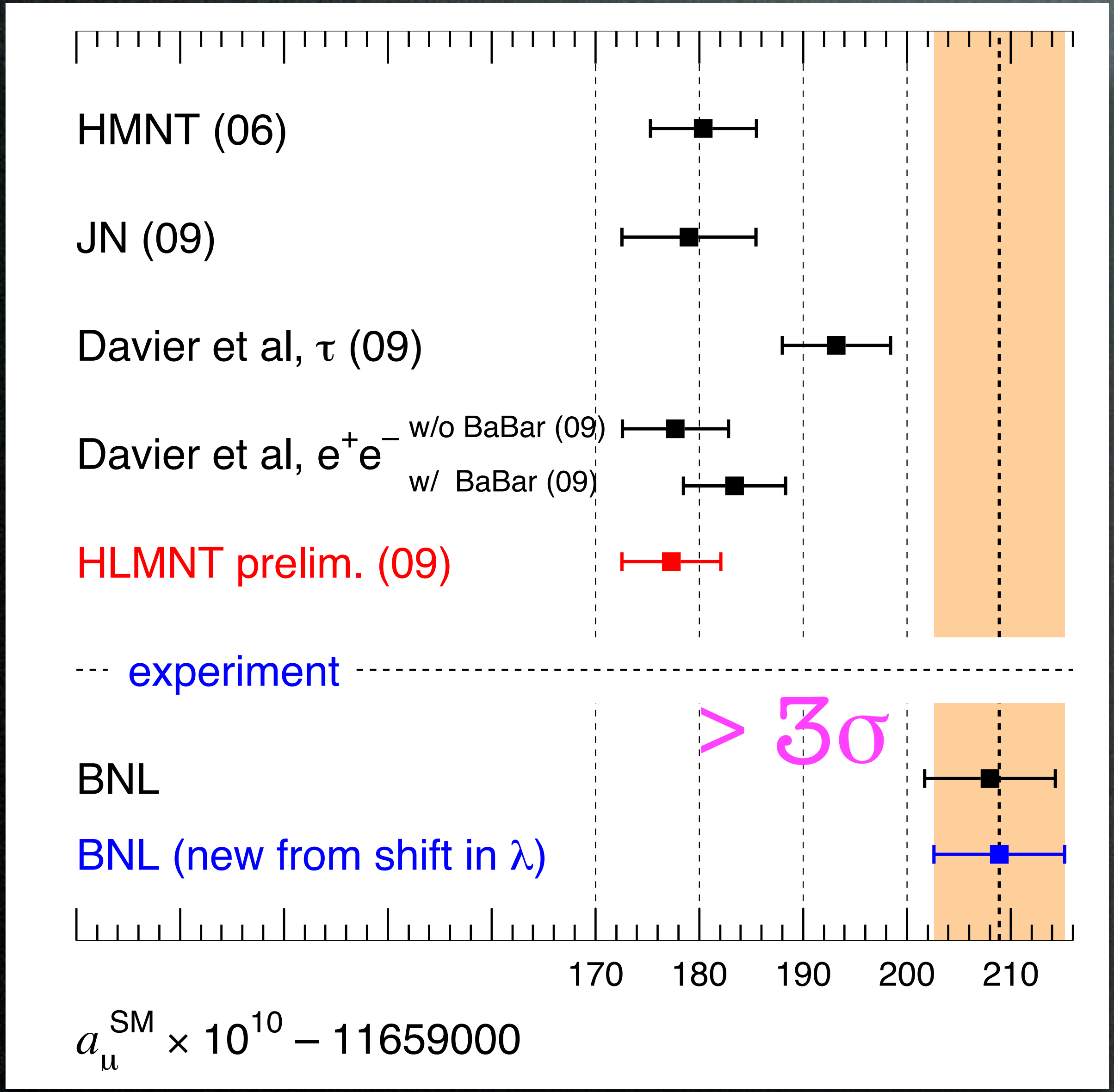
The SM effects are very tiny!!

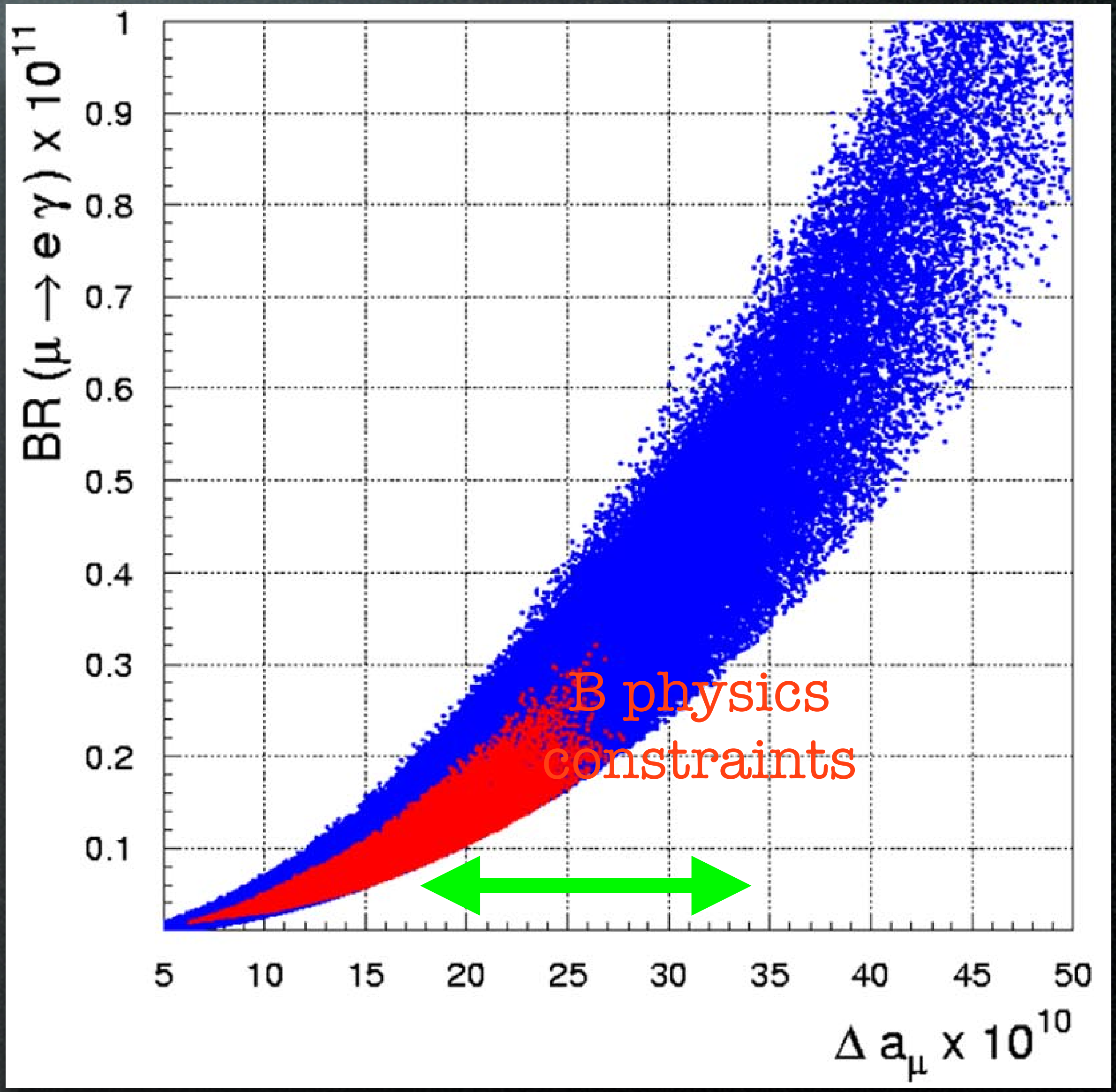
CLFV & EDM

- Experiments to search for new physics
  - TeV scale new physics (and beyond)
    = sources of CLFV and EDM
  - competitive & complementary to LHC



- We might be already seeing them...
  - some B asymmetry variables
  - muon’s anomalous magnetic moment





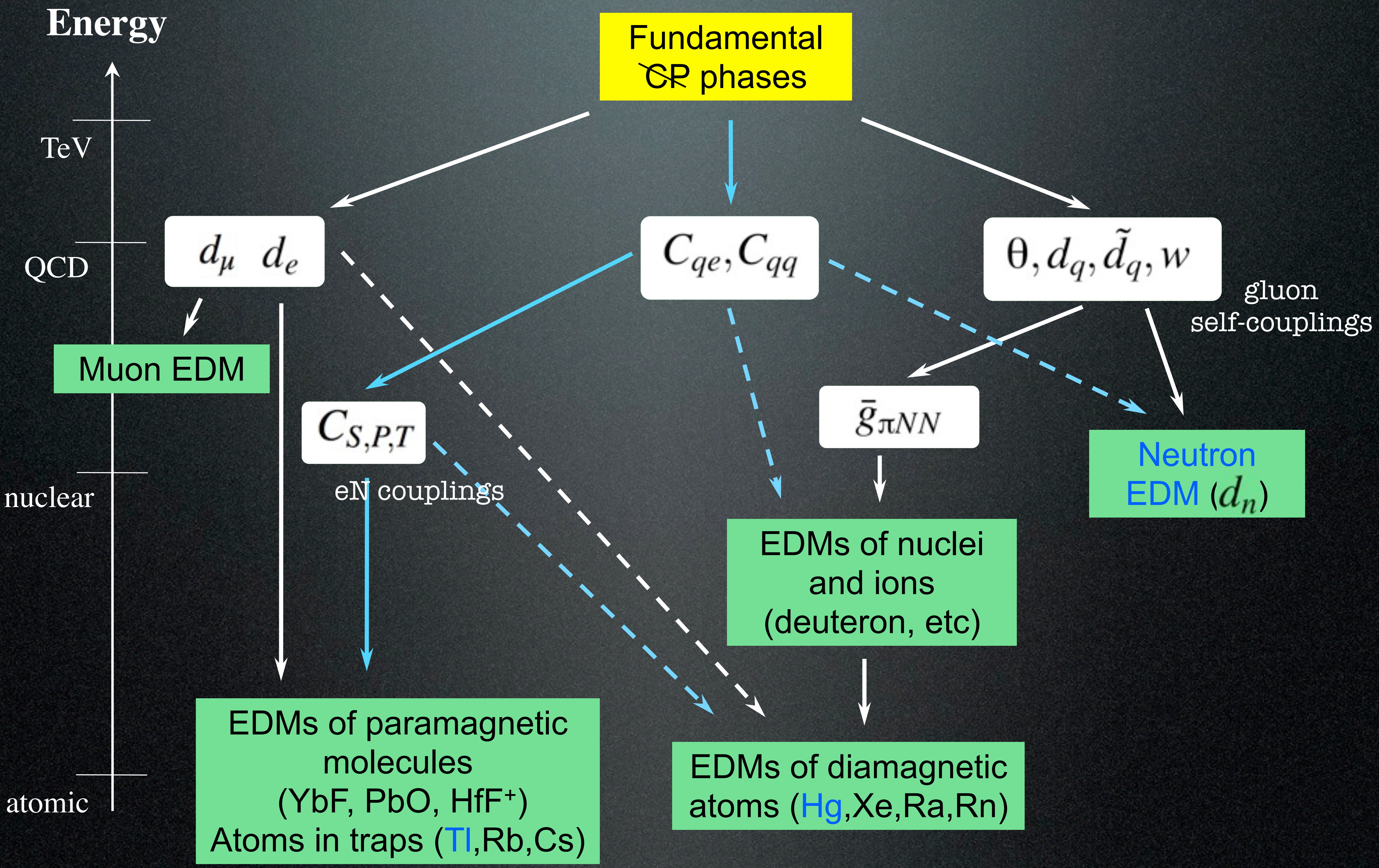
G.Isidori et al. PRD75, 115019

Topics

- EDM
  - electron EDM - new development
  - neutron EDM - coming soon
  - muon EDM - new idea
- CLFV
  - tau decays - B factories finishing up
  - muon decays - new MEG result

EDM

Origin of the EDMs



Energy

TeV

QCD

nuclear

atomic

Fundamental
$\not{CP}$ phases

$d_\mu \quad d_e$

C_{qe}, C_{qq}

$\theta, d_q, \tilde{d}_q, w$

gluon
self-couplings

Muon EDM

$C_{S,P,T}$

eN couplings

$\bar{g}_{\pi NN}$

Neutron
EDM (d_n)

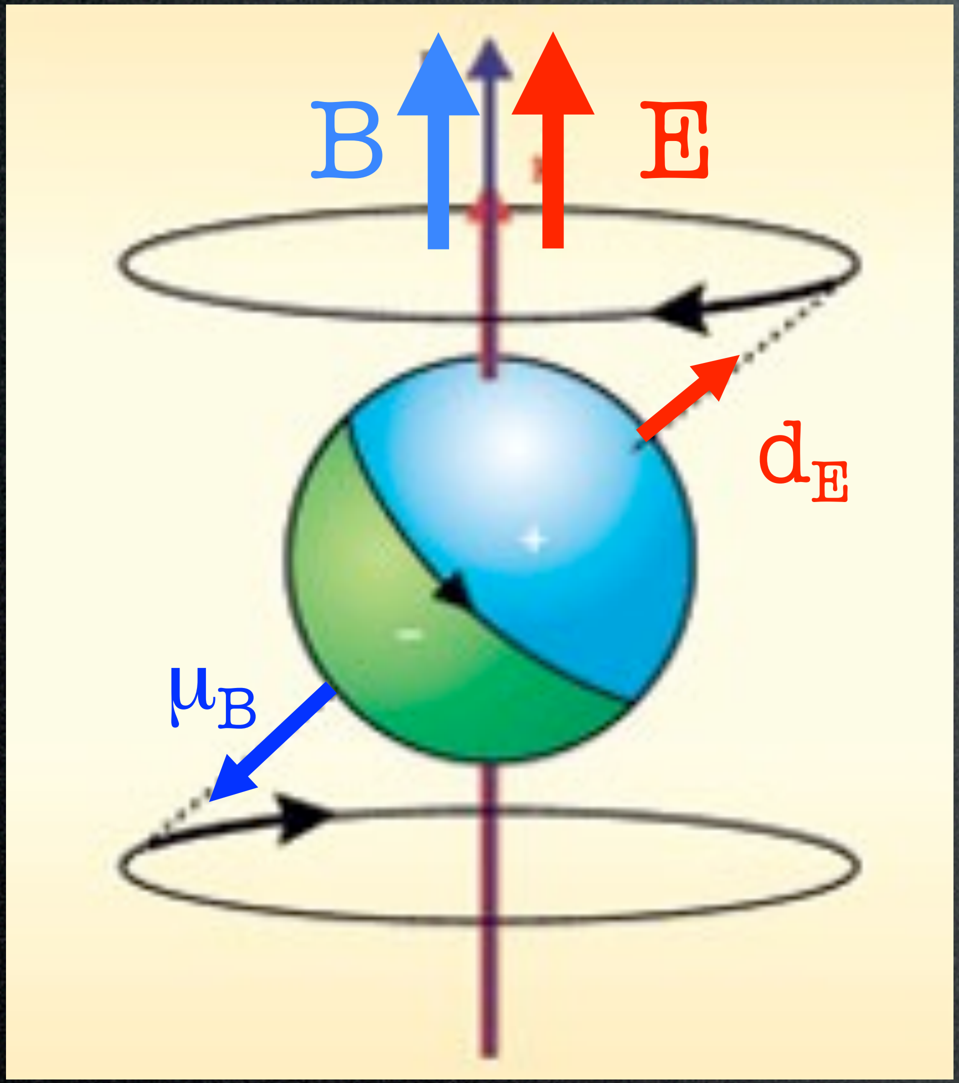
EDMs of nuclei
and ions
(deuteron, etc)

EDMs of paramagnetic
molecules
(YbF, PbO, HfF$^+$)
Atoms in traps (Tl,Rb,Cs)

EDMs of diamagnetic
atoms (Hg,Xe,Ra,Rn)

Pospelov Ritz, Ann Phys 318 (05) 119

Technique to measure EDM



- precesses with Larmor freq

$$\omega_B = -\frac{2\mu_B B}{\hbar}$$

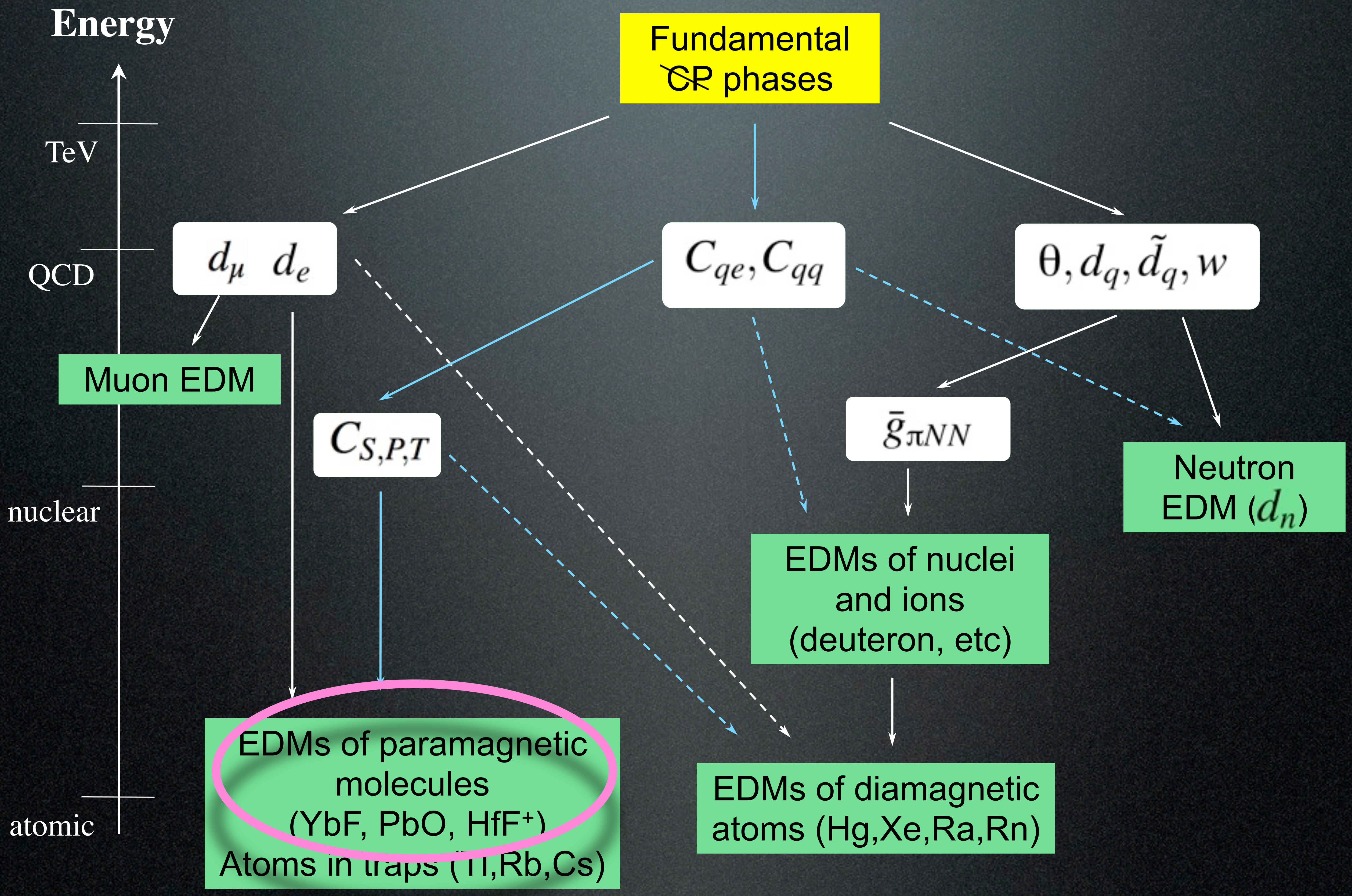
- additional precession

$$\omega_E = \frac{2d_E E}{\hbar}$$

- flip E and measure the difference

$$\omega_{E\|B} - \omega_{E\,anti-\|B} \equiv \Delta\omega = \frac{4d_E E}{\hbar}$$

Origin of the EDMs



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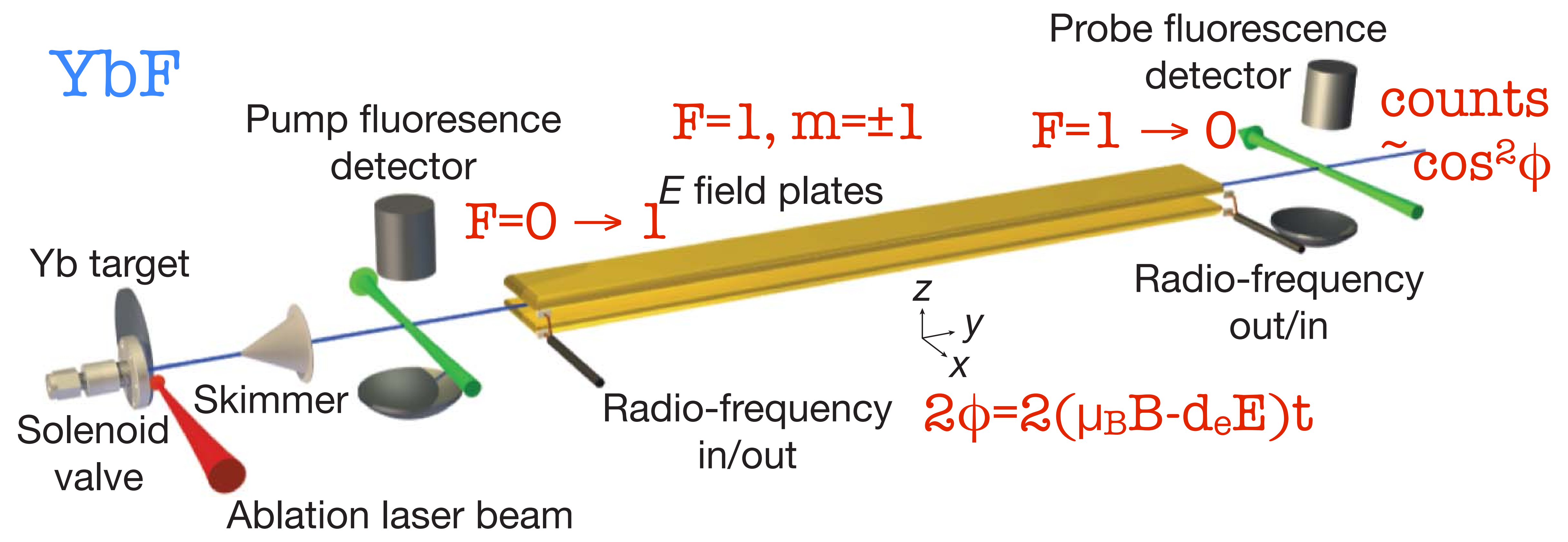
(YbF, PbO, HfF$^+$)
Atoms in traps (Tl,Rb,Cs)

EDMs of diamagnetic
atoms (Hg,Xe,Ra,Rn)

EDM of dipolar molecules YbF

- Easier to polarize molecules than atoms
- Enhances effective E field seen by the unpaired electron by a factor up to 10^5
- Look for interferometer phase shift of the two spin states (hyperfine levels of the ground state) when E reversed
- “Schiff shielding” strongly violated by relativistic effects

YbF



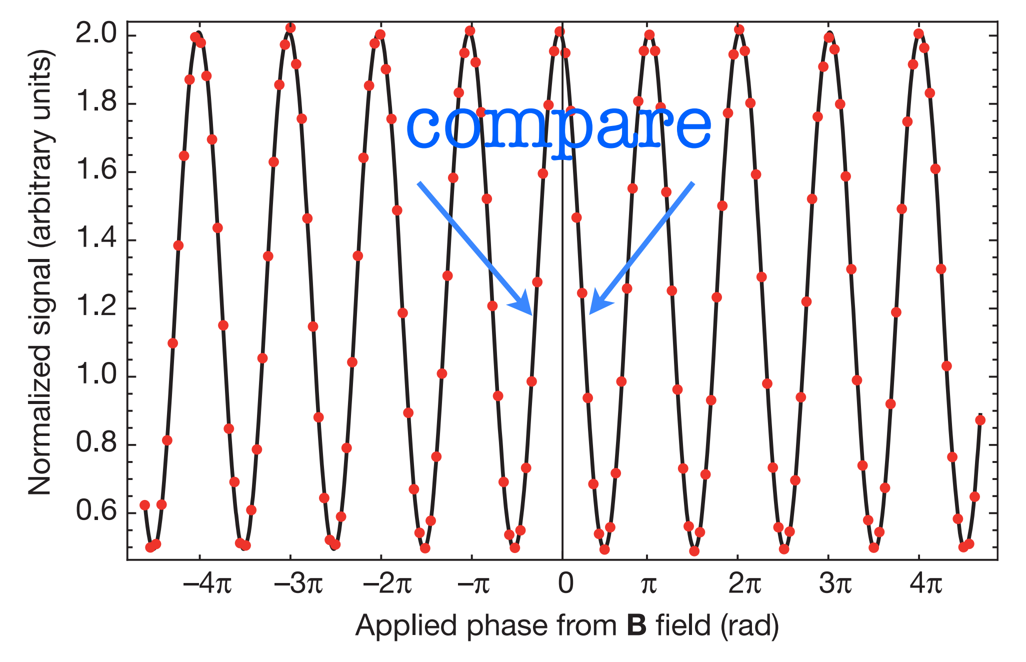
F=0 → 1

F=1, m=±1

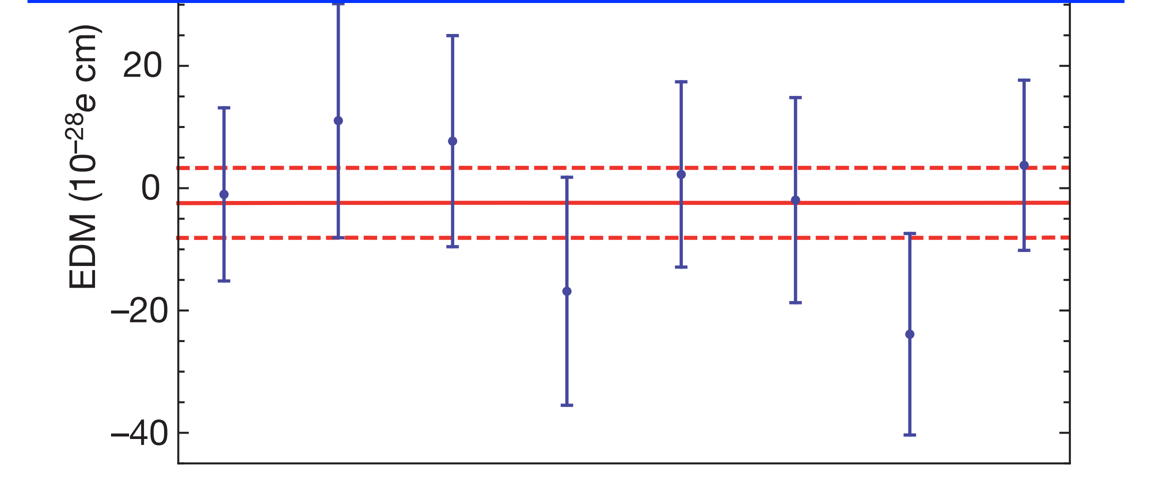
F=1 → 0

counts ~$\cos^2\phi$

$$2\phi = 2(\mu_B B - d_e E)t$$



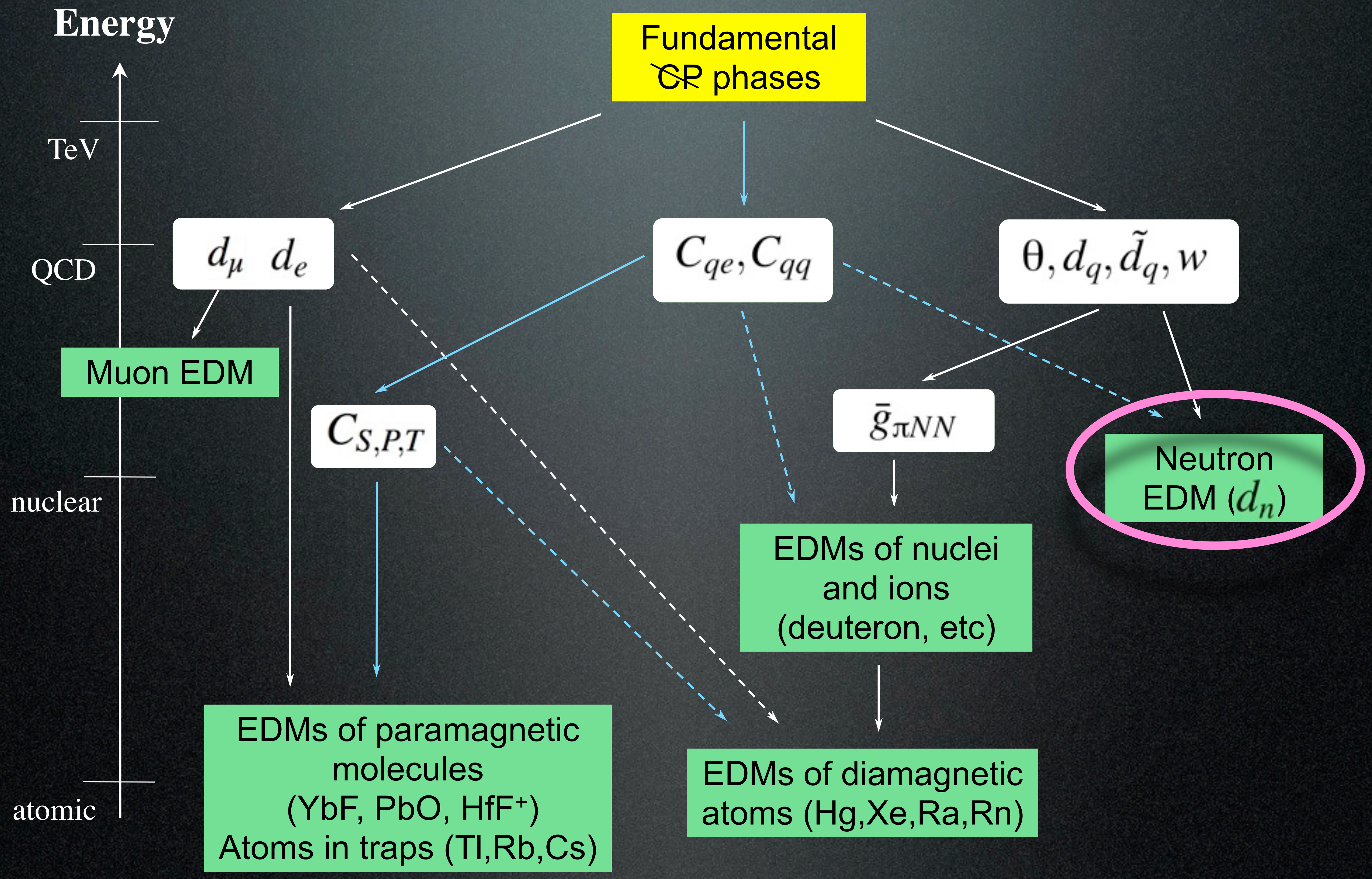
$$d_e = (-2.4 \pm 5.7_{\text{stat}} \pm 1.5_{\text{syst}}) \times 10^{-28} e\text{cm}$$



$$|d_e| < 10.5 \times 10^{-28} e\text{cm} \quad 90\% \text{ C.L.}$$

- a pioneering work of the new method, though a modest 1.5× improvement over the previous Tl experiment
  - still statistically limited
- × 10 improvement within a few years; × 100 expected eventually
  - several groups working

Origin of the EDMs



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Muon EDM

$C_{S,P,T}$

$\bar{g}_{\pi NN}$

Neutron EDM (d_n)

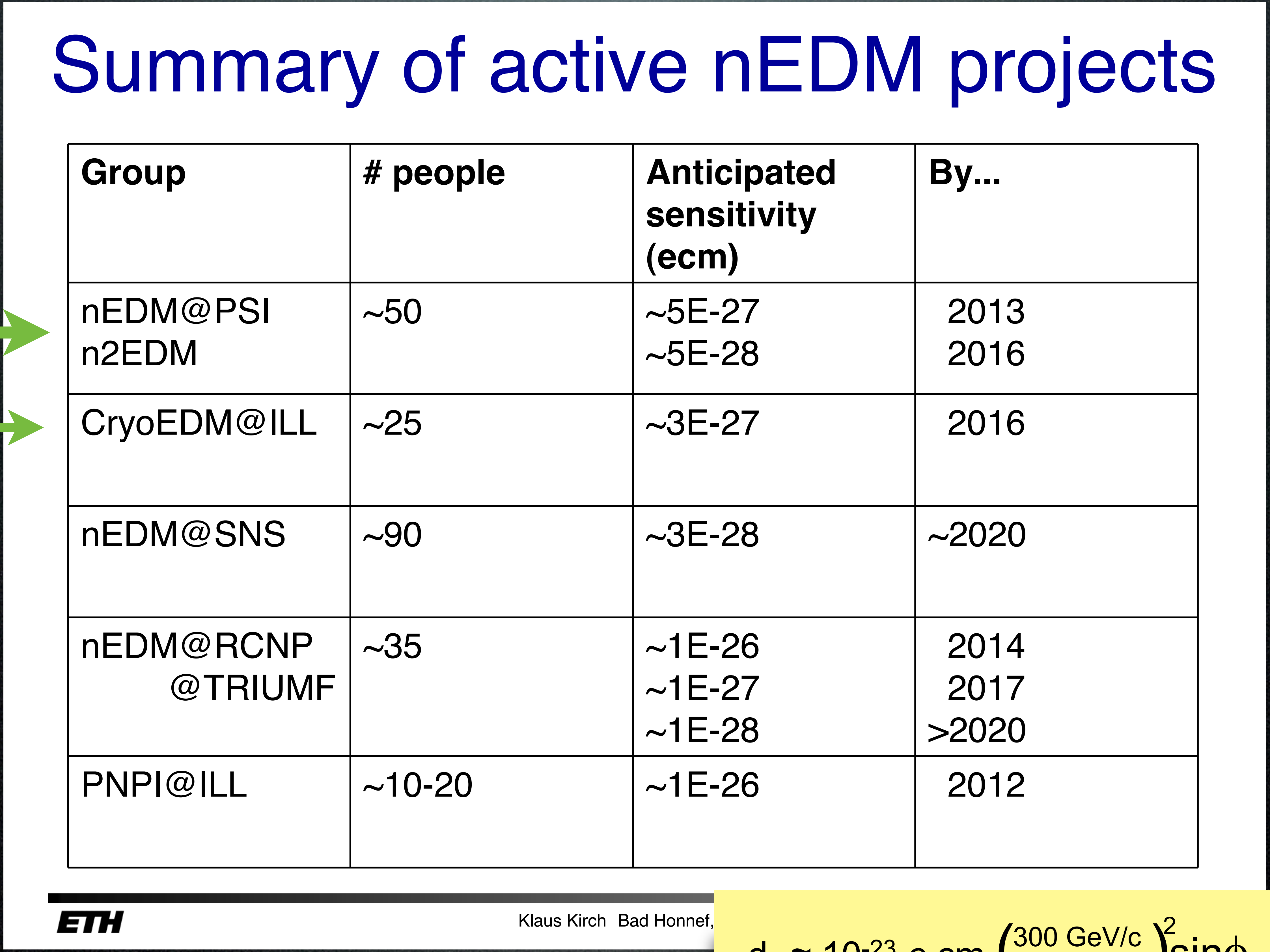
EDMs of nuclei and ions (deuteron, etc)

EDMs of paramagnetic molecules (YbF, PbO, HfF⁺)
Atoms in traps (Tl,Rb,Cs)

EDMs of diamagnetic atoms (Hg,Xe,Ra,Rn)

Present limits $< 2.9\times10^{-26}$ecm

C.A.Baker et al, PRL 97 (2006) 131801

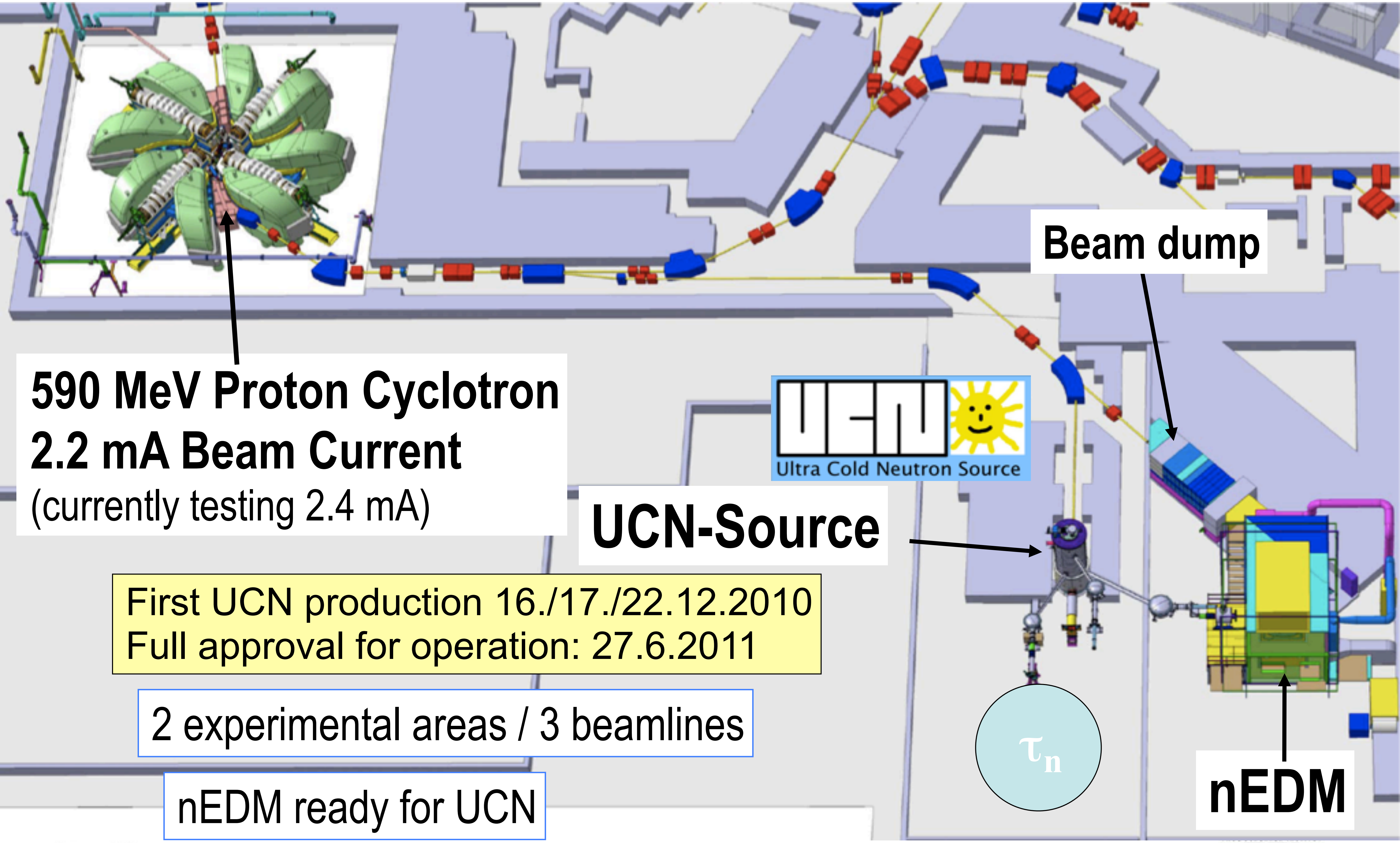


Summary of active nEDM projects

Group	**# people**	**Anticipated sensitivity (ecm)**	**By...**
nEDM@PSI n2EDM	~50	~5E-27 ~5E-28	2013 2016
CryoEDM@ILL	~25	~3E-27	2016
nEDM@SNS	~90	~3E-28	~2020
nEDM@RCNP @TRIUMF	~35	~1E-26 ~1E-27 ~1E-28	2014 2017 >2020
PNPI@ILL	~10-20	~1E-26	2012

$$d_n \approx 10^{-23}\, e\ \mathrm{cm} \left(\frac{300\ \mathrm{GeV/c}}{M_{SUSY}}\right)^2 \sin\phi_{SUSY}$$

High Intensity Proton accelerator & UCN Source



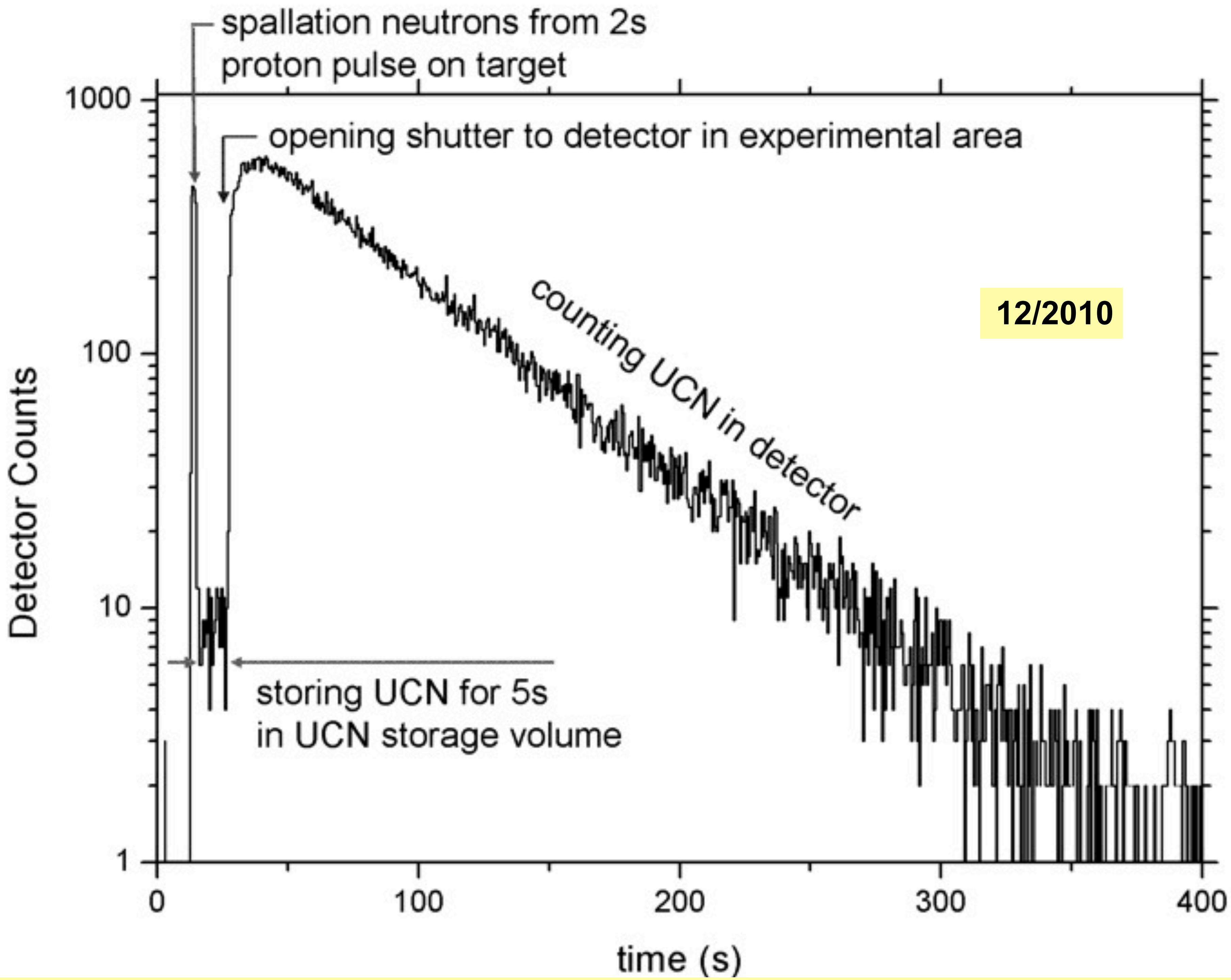
590 MeV Proton Cyclotron
2.2 mA Beam Current
(currently testing 2.4 mA)

First UCN production 16./17./22.12.2010
Full approval for operation: 27.6.2011

2 experimental areas / 3 beamlines

nEDM ready for UCN

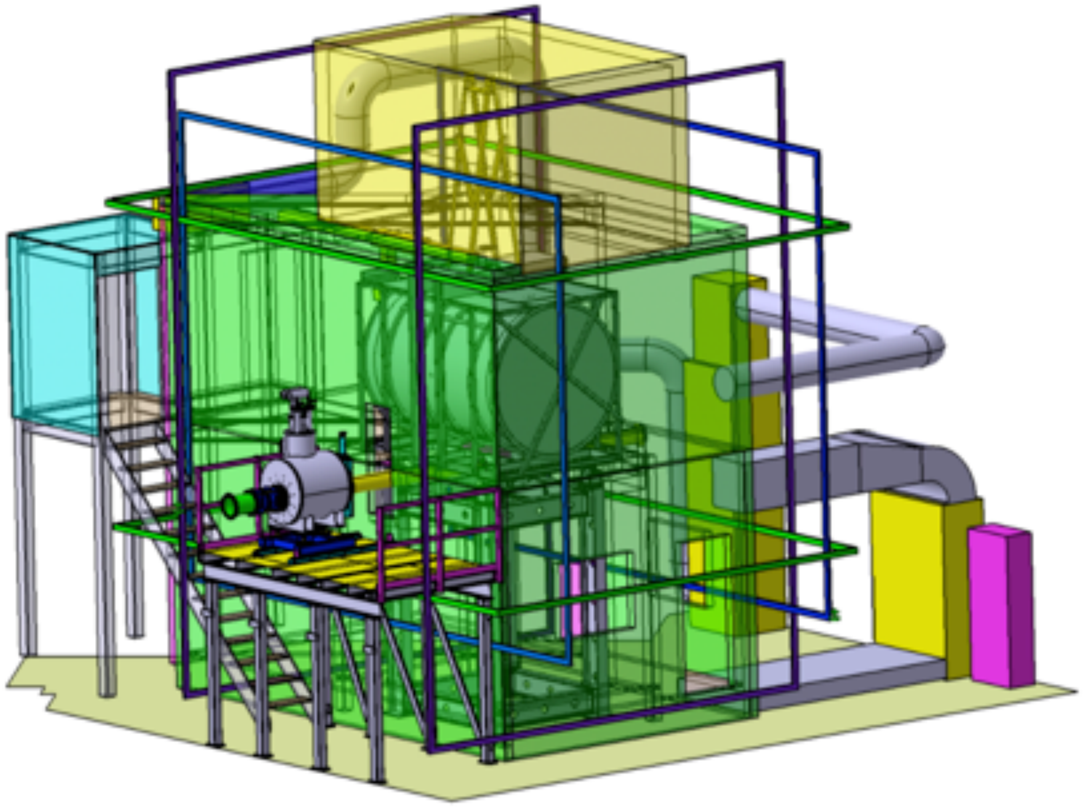
UCN produced by 1.8mA, 2s pulse



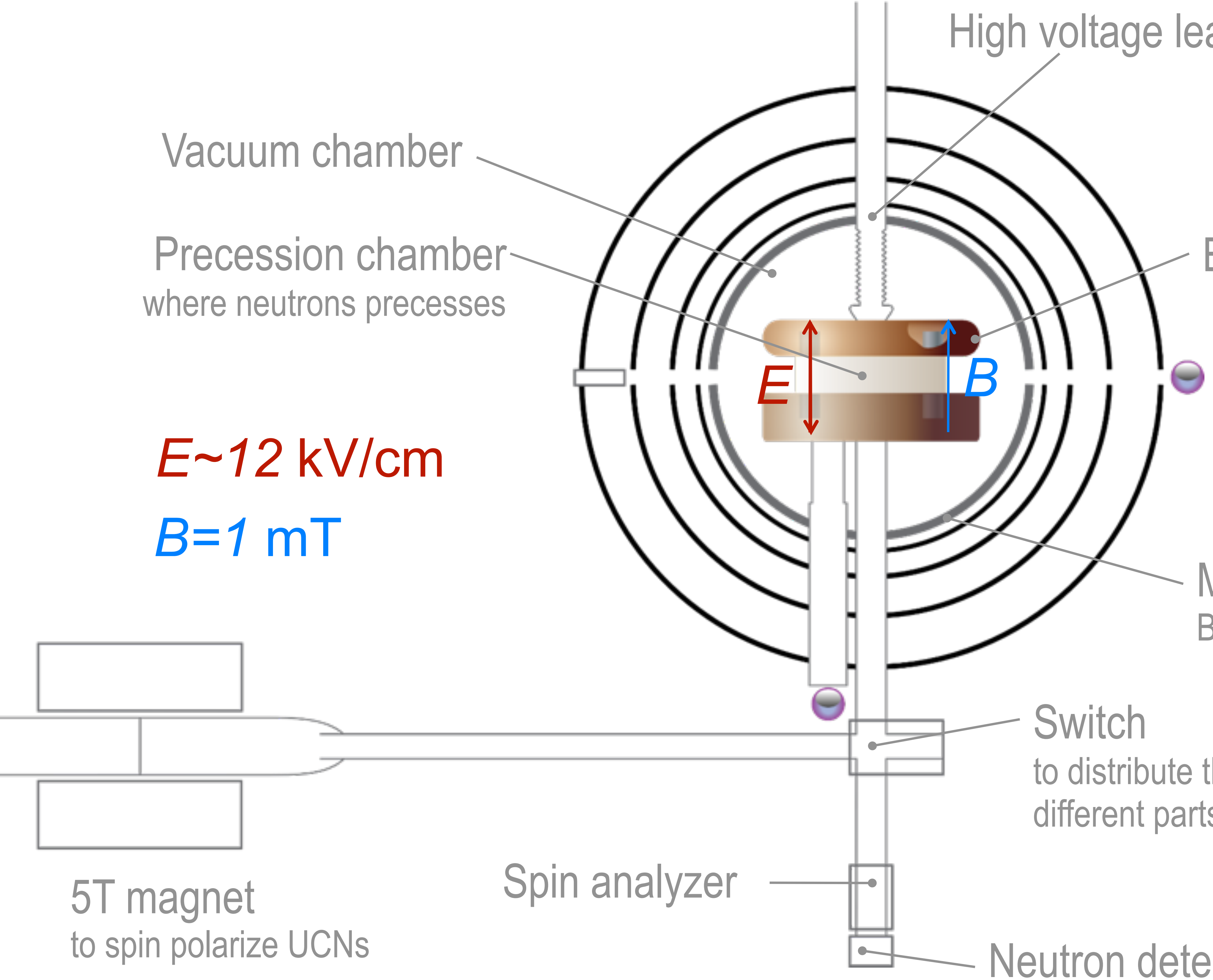
- Approval for full operation obtained by Swiss federal authorities end of June 2011
- Presently commissioning, expect more routine UCN production soon

Installing nEDM at PSI in 2009

Coming from ILL
Sussex-RAL-ILL collaboration
PRL 97 (2006) 131801



Apparatus



High voltage lead

Vacuum chamber

Precession chamber
where neutrons precesses

Electrode (upper)

E~12 kV/cm

B=*1* mT

Magnetic field coils
B_0-correction coils

Switch
to distribute the UCNs to different parts of the apparatus

5T magnet
to spin polarize UCNs

Spin analyzer

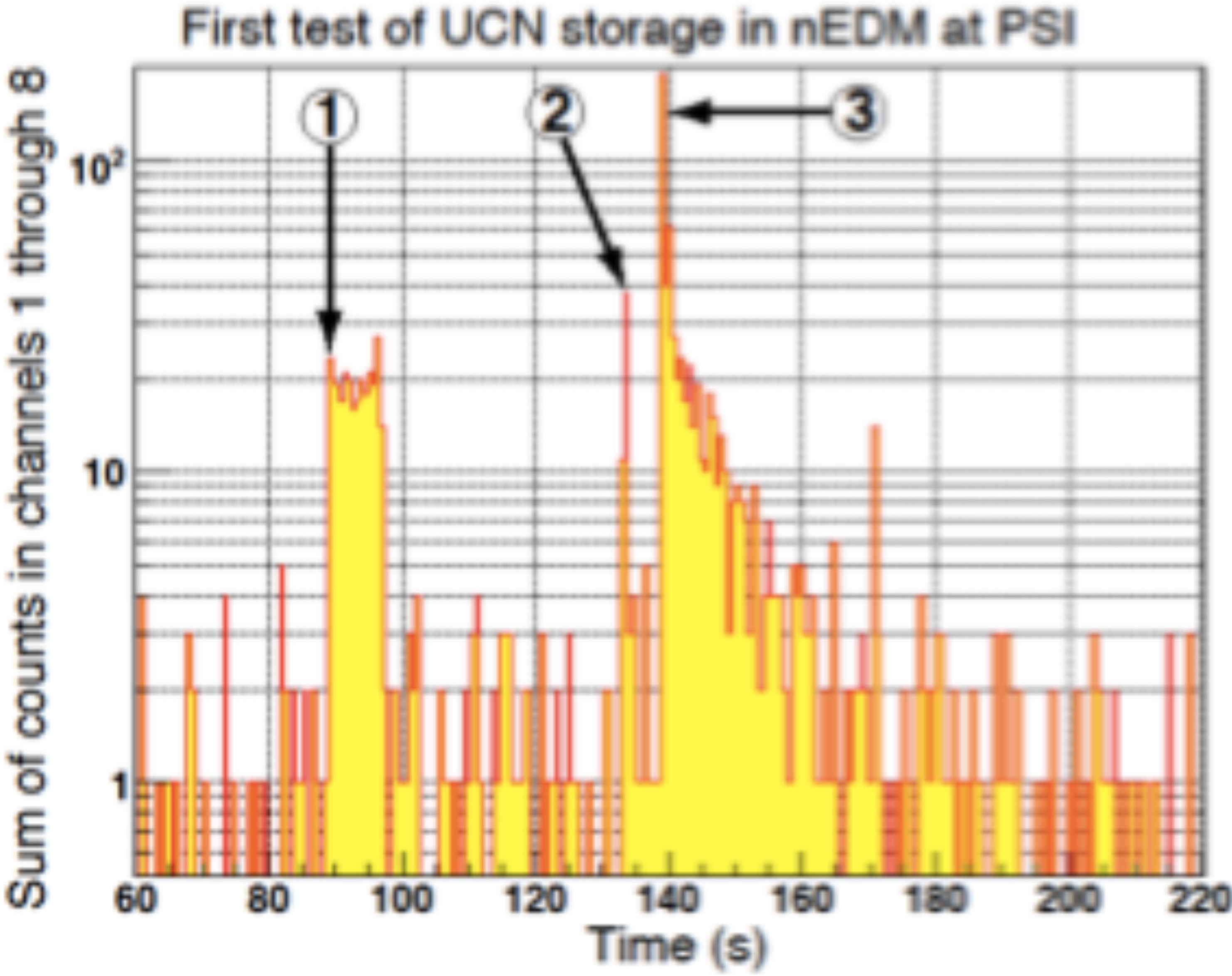
Neutron detector


01/06/2011

UCN stored

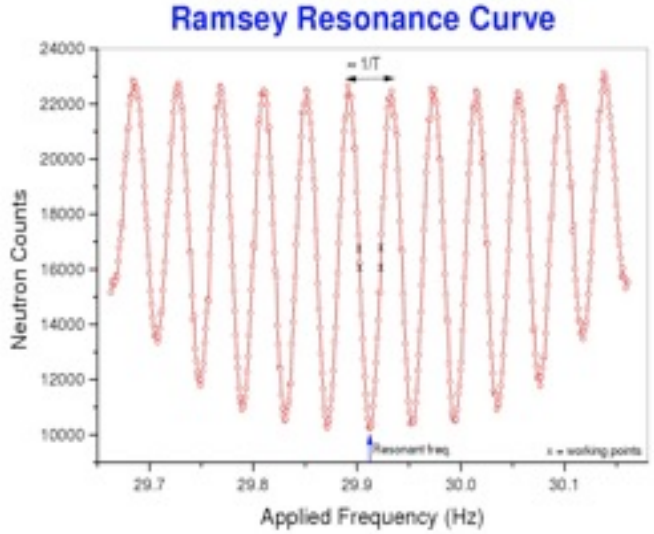
First UCN stored in apparatus @ PSI: Wednesday, December 22nd, 2010

- 8s Pulse on target ①
- 40s filling
- Closing of UCN shutter
- Turning switch in emptying position ②
- Opening of shutter ③
- Emptying into detector



Statistical Sensitivity

$$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$



α = 0.75

E = 12 kV/cm

T = 150 s

N = 350′000

Performance needs to be demonstrated

$\sigma(d_n)$ = 4 x 10^{-25} ecm / cycle

400 s

= 3 x 10^{-26} ecm / day

= 3 x 10^{-27} ecm / year

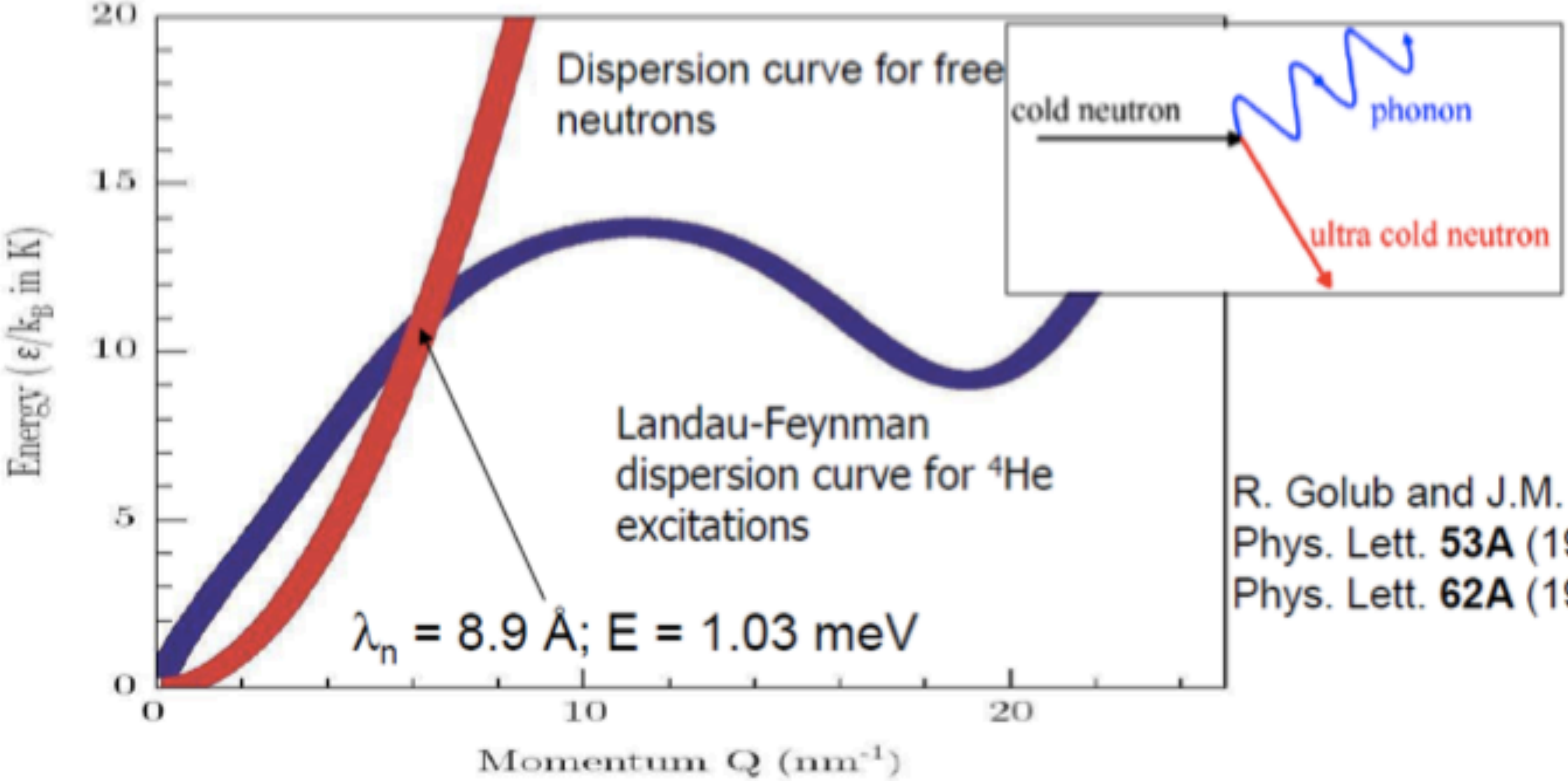
200 nights

Obtain same figures with
E=10kV/cm, T=130s, 200s cycle

After 2 years*, statistics only
$d_n = 0$: $|d_n| < 4 \times 10^{-27}$ ecm (95% C.L.)

* 200 nights each

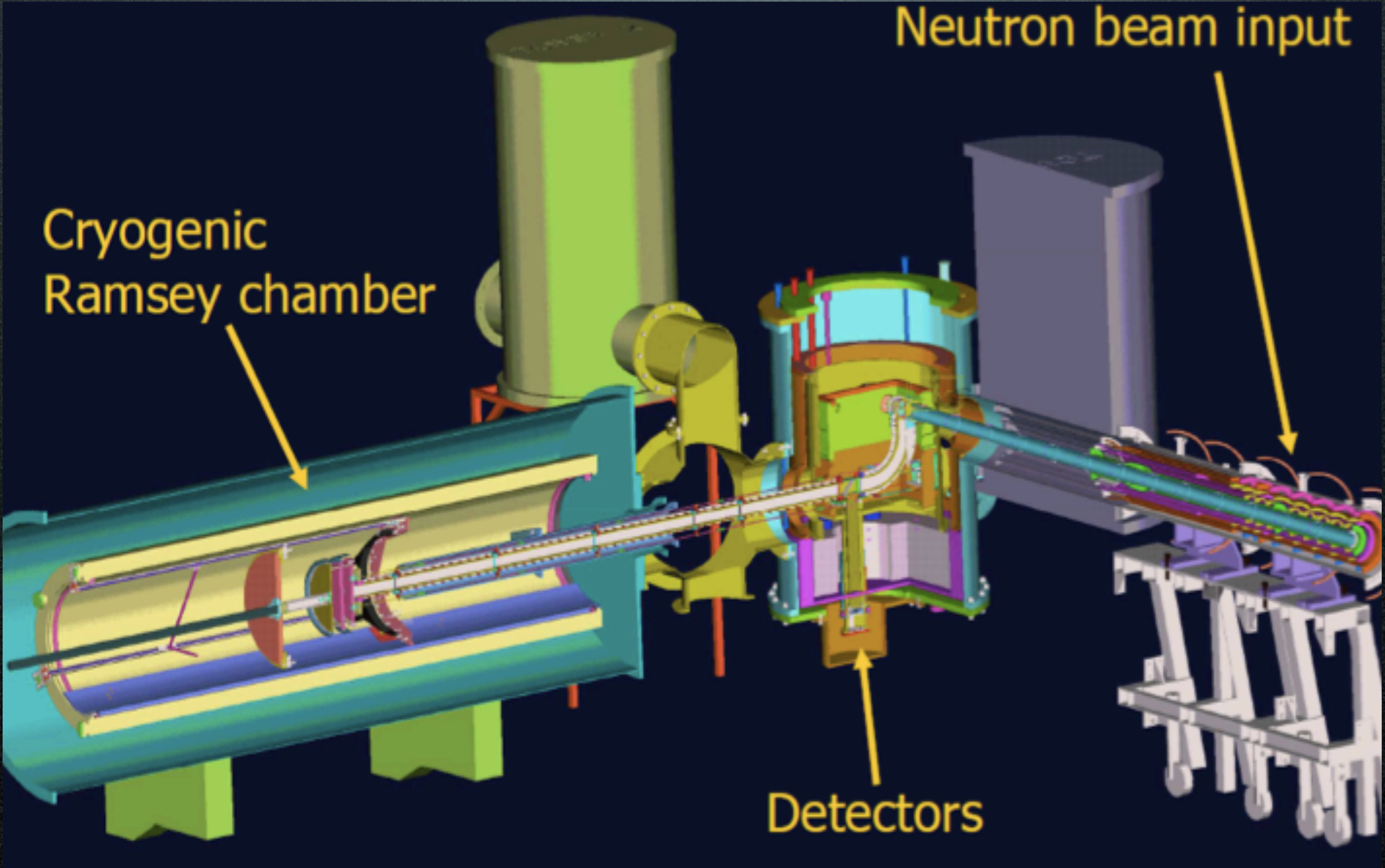
UCN production in liquid helium



R. Golub and J.M. Pendlebury
Phys. Lett. **53A** (1975),
Phys. Lett. **62A** (1977)

- 1.03 meV (11 K) neutrons downscatter by emission of phonon in liquid helium at 0.5 K
- Upscattering suppressed: Boltzmann factor $e^{-E/kT}$ means not many 11 K phonons present

CryoEDM at ILL



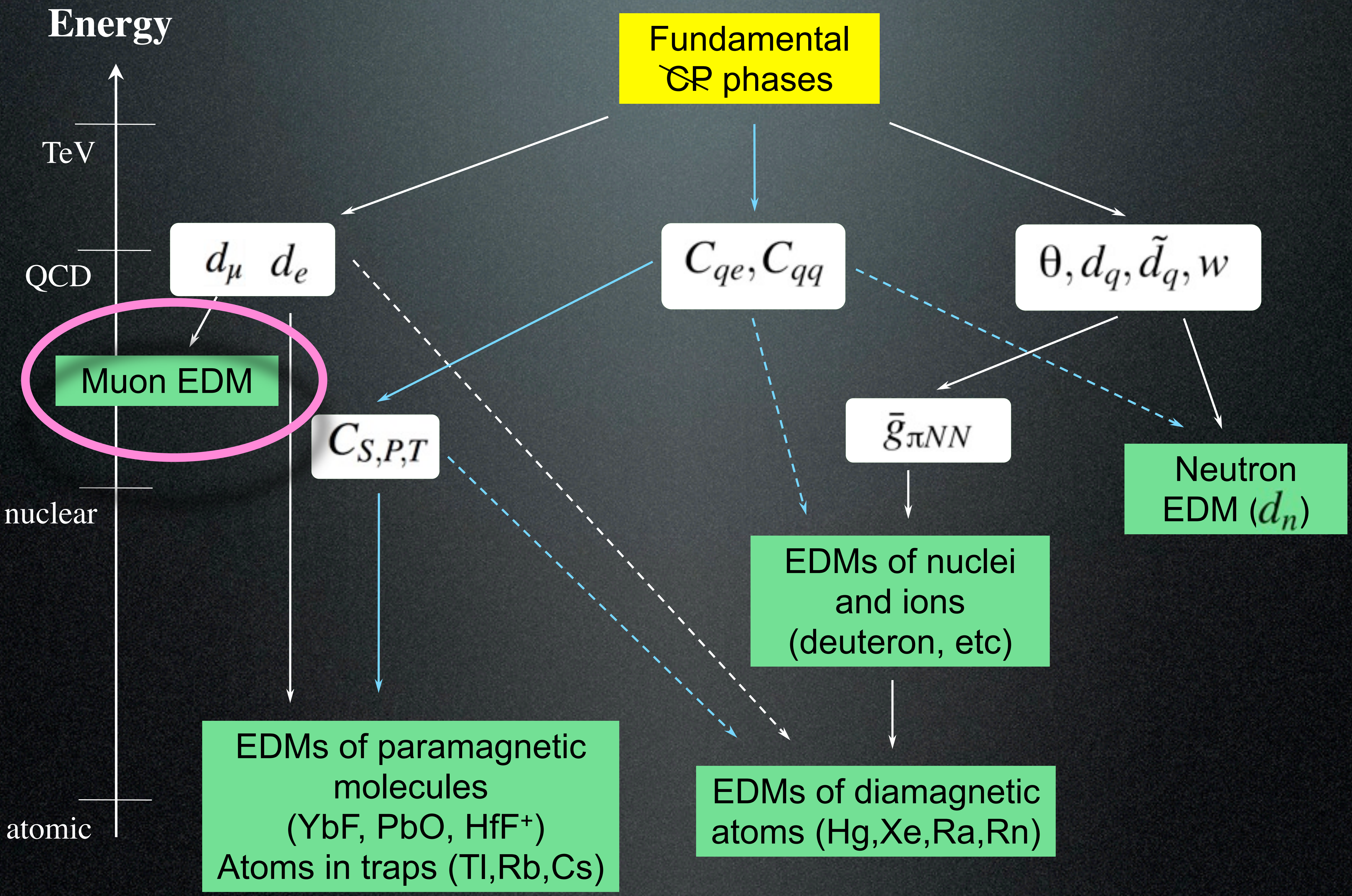
successful production/storage - need to reduce losses
E field/polarization/efficiency/B stability to be improved

RAL/Sussex/Oxford/ILL/Kure

neutron EDM - Prospects

- Sensitivity is expected to improve
  - by a factor of 5 in a couple of years
  - by two orders of magnitude within the next decade

Origin of the EDMs



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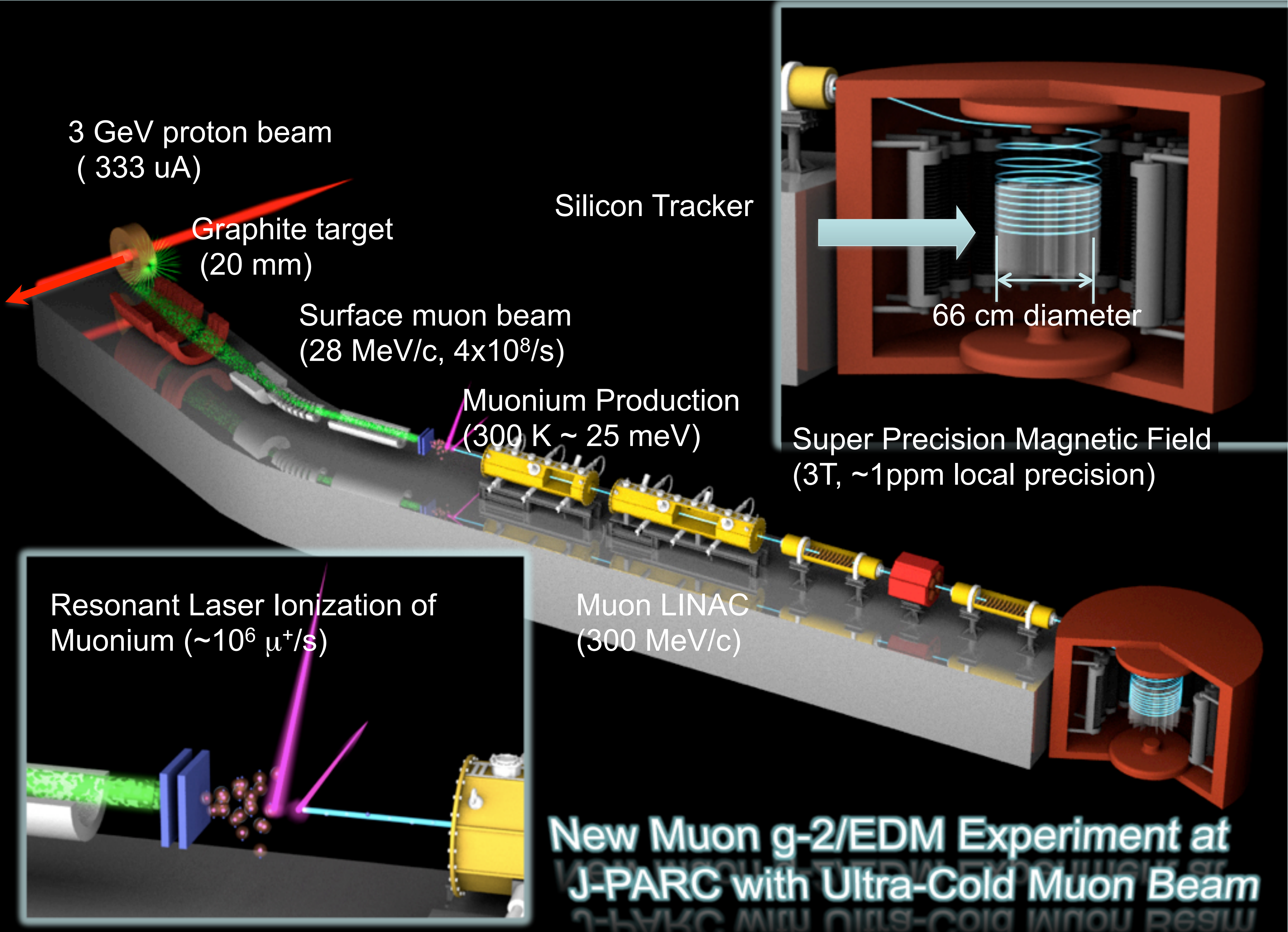
New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam



3 GeV proton beam
(333 uA)

Graphite target
(20 mm)

Surface muon beam
(28 MeV/c, 4x10^8/s)

Muonium Production
(300 K ~ 25 meV)

Silicon Tracker

66 cm diameter

Super Precision Magnetic Field
(3T, ~1ppm local precision)

Resonant Laser Ionization of
Muonium (~10^6 μ^+/s)

Muon LINAC
(300 MeV/c)

Spin Rotation and EDM

- Precession frequency vector with g-2 and EDM

$$\vec{\omega} = -\frac{e}{m}\left[\underbrace{a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

Choose B, E and γ to cancel g-2 rotation

ex. $p_\mu = 125\ \mathrm{MeV}/c$

$B = 1\ \mathrm{T},\ \ E = 0.64\ \mathrm{MV/m}$

Spin Frozen mode

$$\vec{\omega} = -\frac{e}{m}\left[\frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

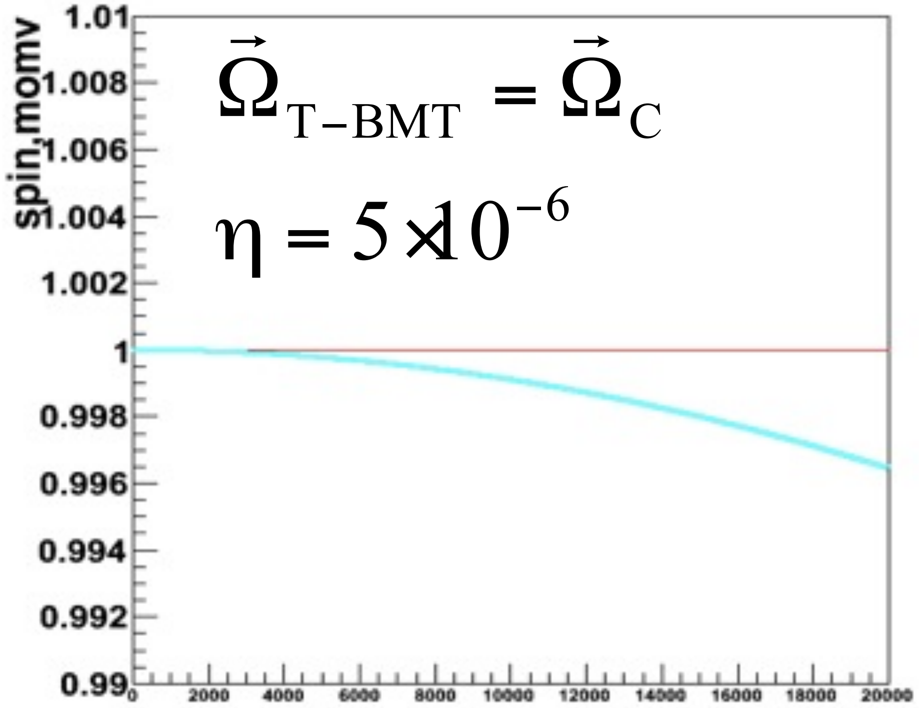
Eliminate E-field with Ultra-cold muon beam

E=0, spin // B

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

Spin Rotation and EDM

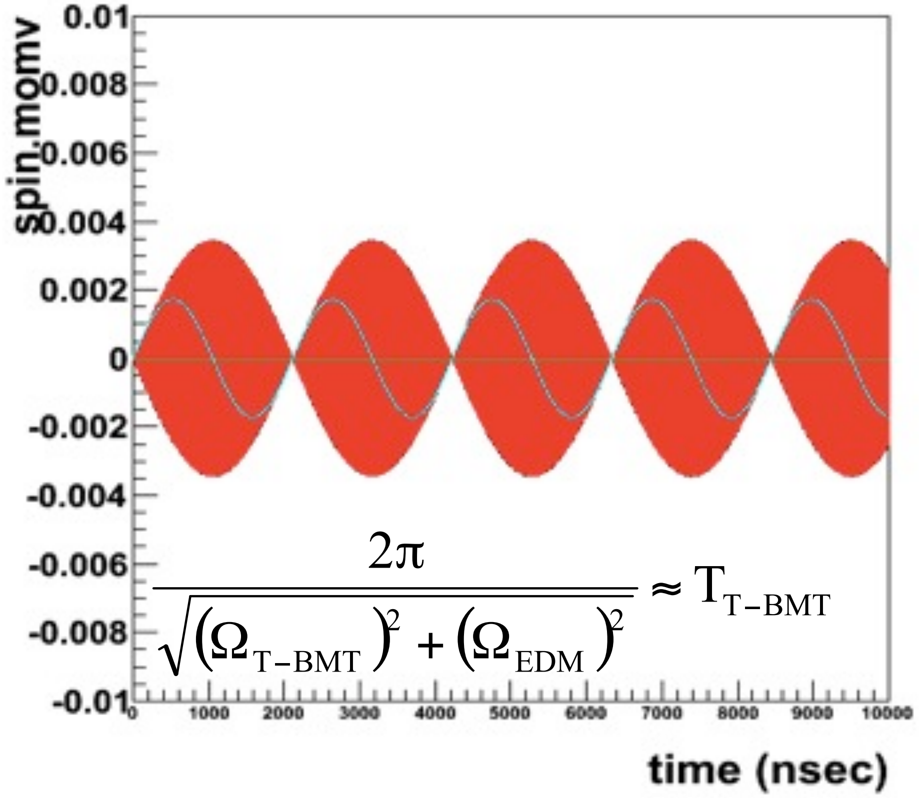
- “Spin Frozen” method and and “E=0” method



Spin Frozen case

pure EDM effect can be extracted if “frozen condition” is satisfied precisely.

$$\vec{\omega} = -\frac{e}{m}\left[\frac{\eta}{2}\left(\vec{\beta}\times\vec{B}+\frac{\vec{E}}{c}\right)\right]$$



E=0 with spin // B case

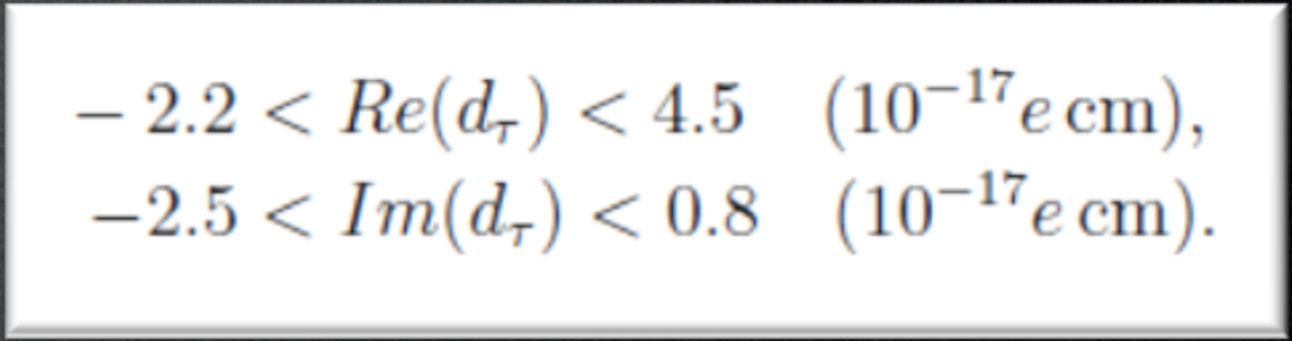
“beat” with g-2 frequency with amplitude proportional to EDM → Use g-2 rotation as systematics control

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu\vec{B}+\frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

Muon EDM Prospects

- Present limit ~10^{-19} ecm
- J-PARC g-2/EDM experiment could push it down to ~10^{-21} ecm

cf. τ



$$-2.2 < Re(d_\tau) < 4.5 \quad (10^{-17} e\,\mathrm{cm}),$$
$$-2.5 < Im(d_\tau) < 0.8 \quad (10^{-17} e\,\mathrm{cm}).$$

Belle Collaboration (K. Inami et al.).
Published in Phys.Lett.B551:16-26,2003.

CLFV

B-factories

τLFV

B-factoies : E at CM = Y(4S)

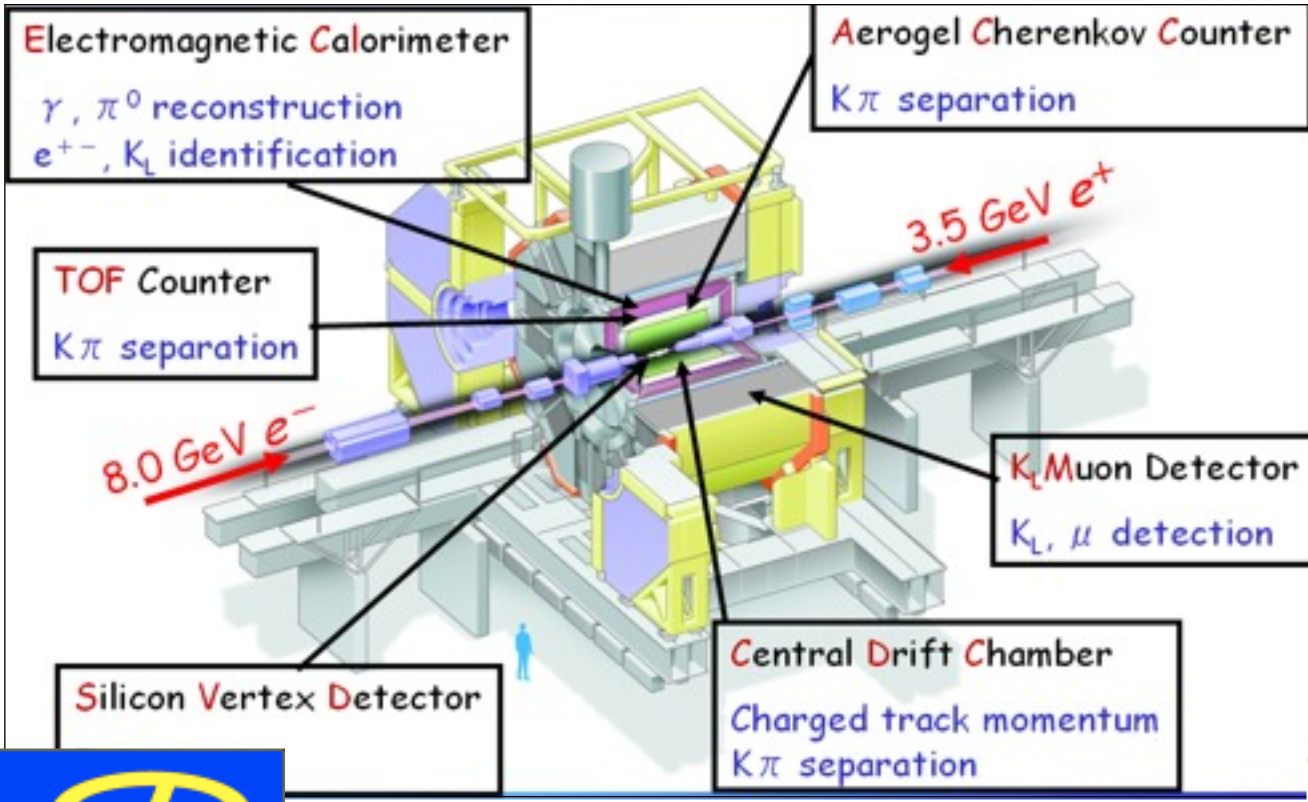
e^+(3.5 (3.1) GeV) e^-(8 (9) GeV) for KEKB (PEP II)

$\sigma(\tau\tau)$~0.9nb,$\sigma(bb)$~1.1nb

A B-factory is also a τ-factory!

Detector: Good track reconstruction and particle identification

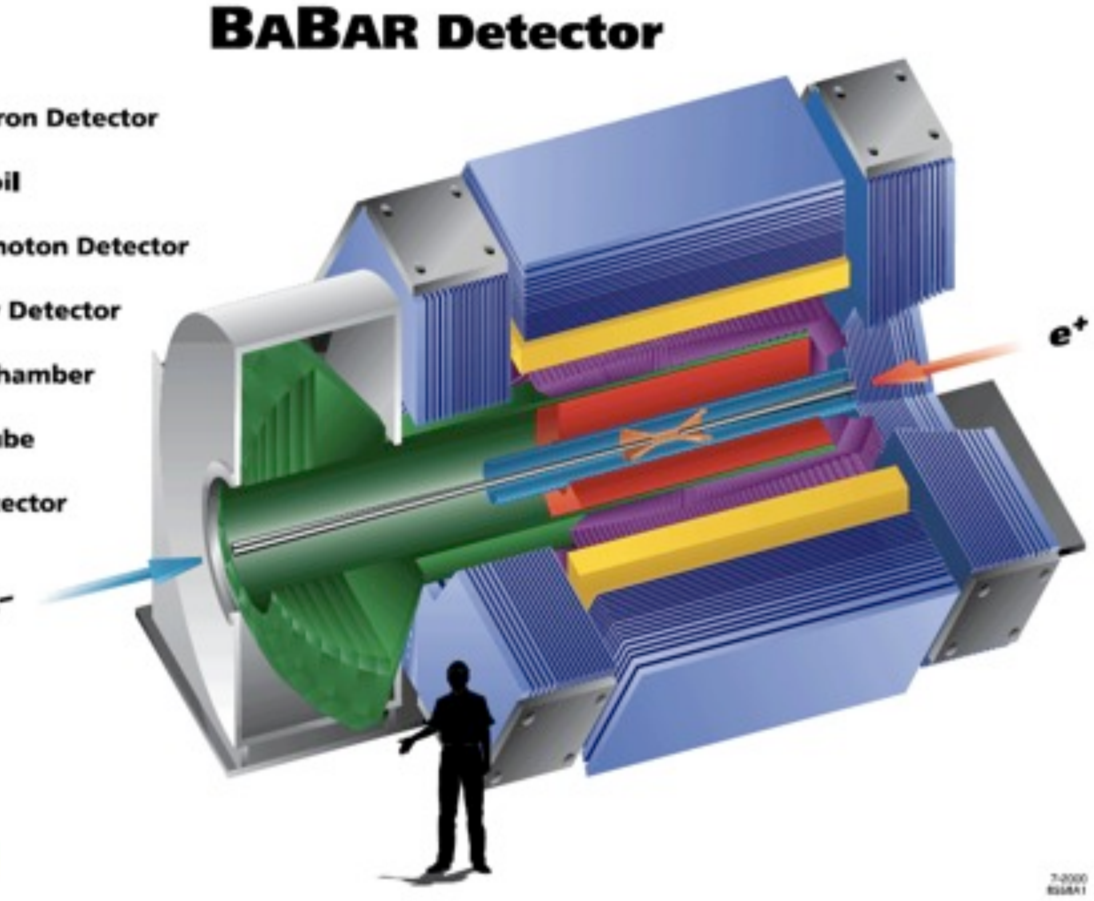
Lepton ID ~ (80-90)%
Fake ID ~ O(0.1-1)%



~9x10^8 ττ at Belle

BABAR Detector

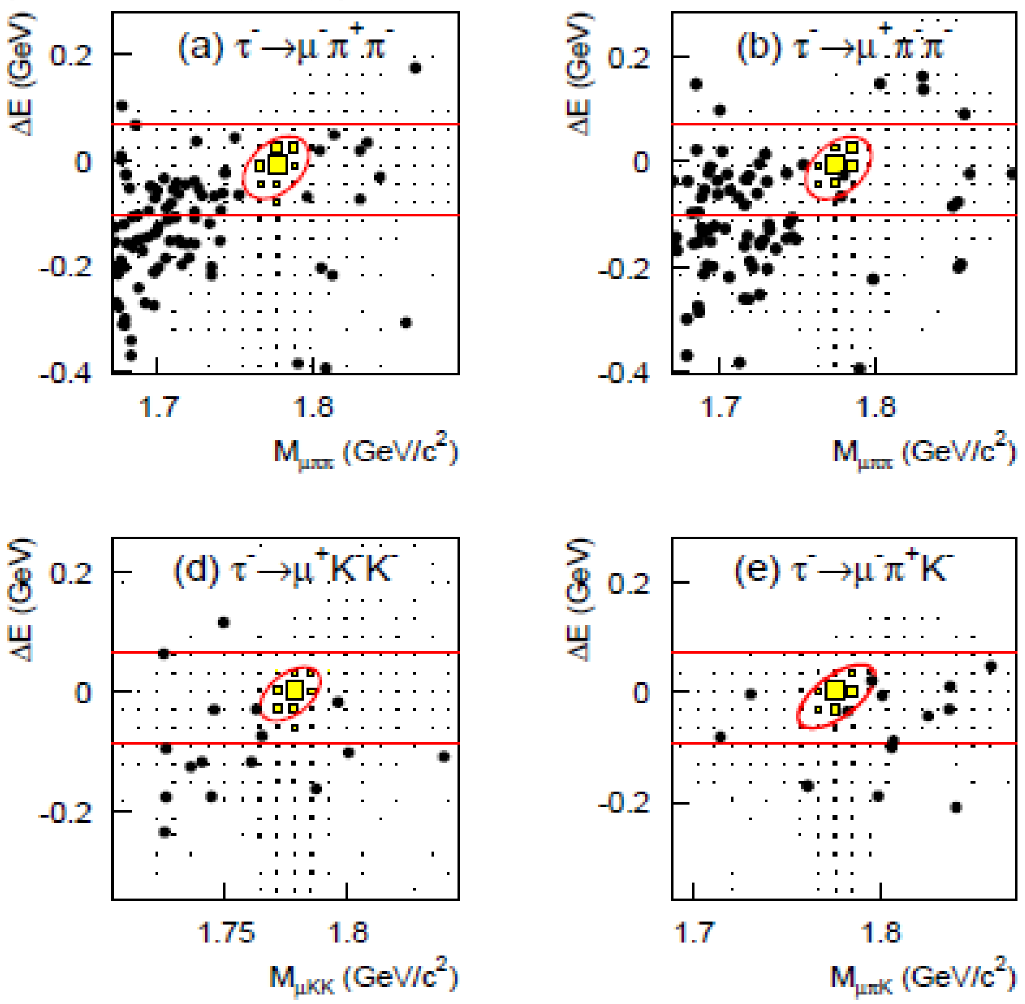
- Muon/Hadron Detector
- Magnet Coil
- Electron/Photon Detector
- Cherenkov Detector
- Tracking Chamber
- Support Tube
- Vertex Detector



~4.8x10^8 ττ at BaBar

Results for $\tau \to \ell hh'$

(preliminary)



In the signal region

1 event : in $\mu^+\pi^-\pi^-$ and $\mu^-\pi^+K^-$

no events: in other modes

⇒ no significant excess

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}$ (10^{-8})
$\tau^- \to \mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	5.3	0	1.87	2.1
$\tau^- \to \mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	5.3	1	4.02	3.9
$\tau^- \to e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	5.4	0	1.94	2.3
$\tau^- \to e^+\pi^-\pi^-$	6.56	0.37 ± 0.18	5.4	0	2.10	2.0
$\tau^- \to \mu^-K^+K^-$	2.85	0.51 ± 0.18	5.9	0	1.97	4.4
$\tau^- \to \mu^+K^-K^-$	2.98	0.25 ± 0.13	5.9	0	2.21	4.7
$\tau^- \to e^-K^+K^-$	4.29	0.17 ± 0.10	6.0	0	2.28	3.4
$\tau^- \to e^+K^-K^-$	4.64	0.06 ± 0.06	6.0	0	2.38	3.3
$\tau^- \to \mu^-\pi^+K^-$	2.72	0.72 ± 0.27	5.6	1	3.65	8.6
$\tau^- \to e^-\pi^+K^-$	3.97	0.18 ± 0.13	5.7	0	2.27	3.7
$\tau^- \to \mu^-K^+\pi^-$	2.62	0.64 ± 0.23	5.6	0	1.86	4.5
$\tau^- \to e^-K^+\pi^-$	4.07	0.55 ± 0.31	5.7	0	1.97	3.1
$\tau^- \to \mu^+K^-\pi^-$	2.55	0.56 ± 0.21	5.6	0	1.93	4.8
$\tau^- \to e^+K^-\pi^-$	4.00	0.46 ± 0.21	5.7	0	2.02	3.2

Set upper limits @90%CL:

Br($\tau \to \ell hh'$)< (2.0-8.4)x10^{-8}

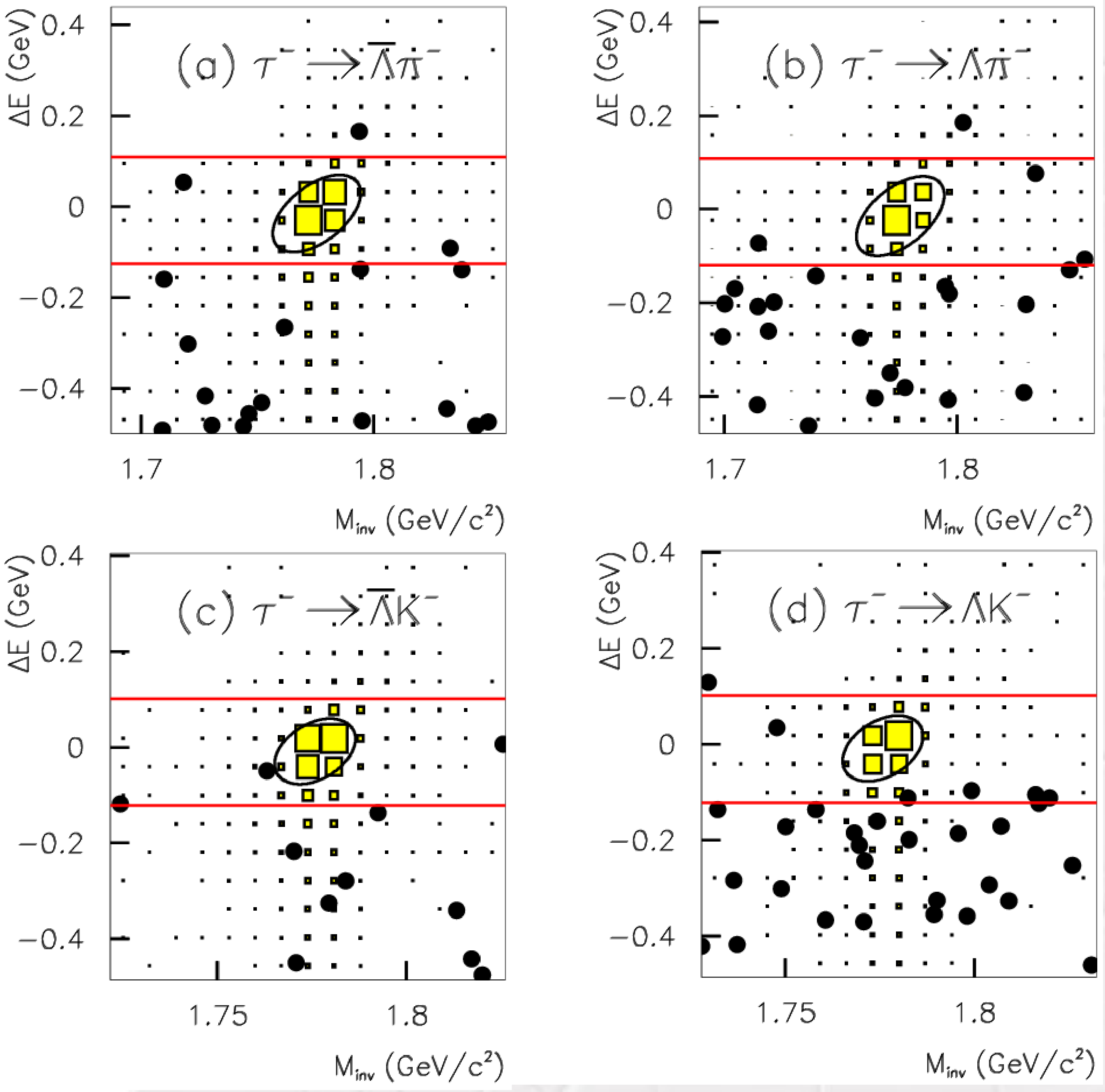
(preliminary)

→most sensitive results

Improve our previous results by a factor of 1.8 on average

Results for $\tau \rightarrow \Lambda h / \bar{\Lambda} h$

(preliminary)



In the signal region

no candidate event are found

⇒ no significant excess

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}
$\tau^- \rightarrow \bar{\Lambda}\pi^-$	4.80	0.21 ± 0.15	8.2	0	2.3
$\tau^- \rightarrow \Lambda\pi^-$	4.39	0.31 ± 0.18	8.2	0	2.2
$\tau^- \rightarrow \bar{\Lambda}K^-$	4.11	0.31 ± 0.14	8.6	0	2.2
$\tau^- \rightarrow \Lambda K^-$	3.16	0.42 ± 0.19	8.6	0	2.1

Set upper limits@90%CL:

$\mathrm{Br}(\tau^- \rightarrow \bar{\Lambda}\pi^-) < 2.8 \times 10^{-8}$
$\mathrm{Br}(\tau^- \rightarrow \bar{\Lambda}K^-) < 3.1 \times 10^{-8}$ } (B-L) cons.
$\mathrm{Br}(\tau^- \rightarrow \Lambda\pi^-) < 3.0 \times 10^{-8}$
$\mathrm{Br}(\tau^- \rightarrow \Lambda K^-) < 4.2 \times 10^{-8}$ } (B-L) viol.

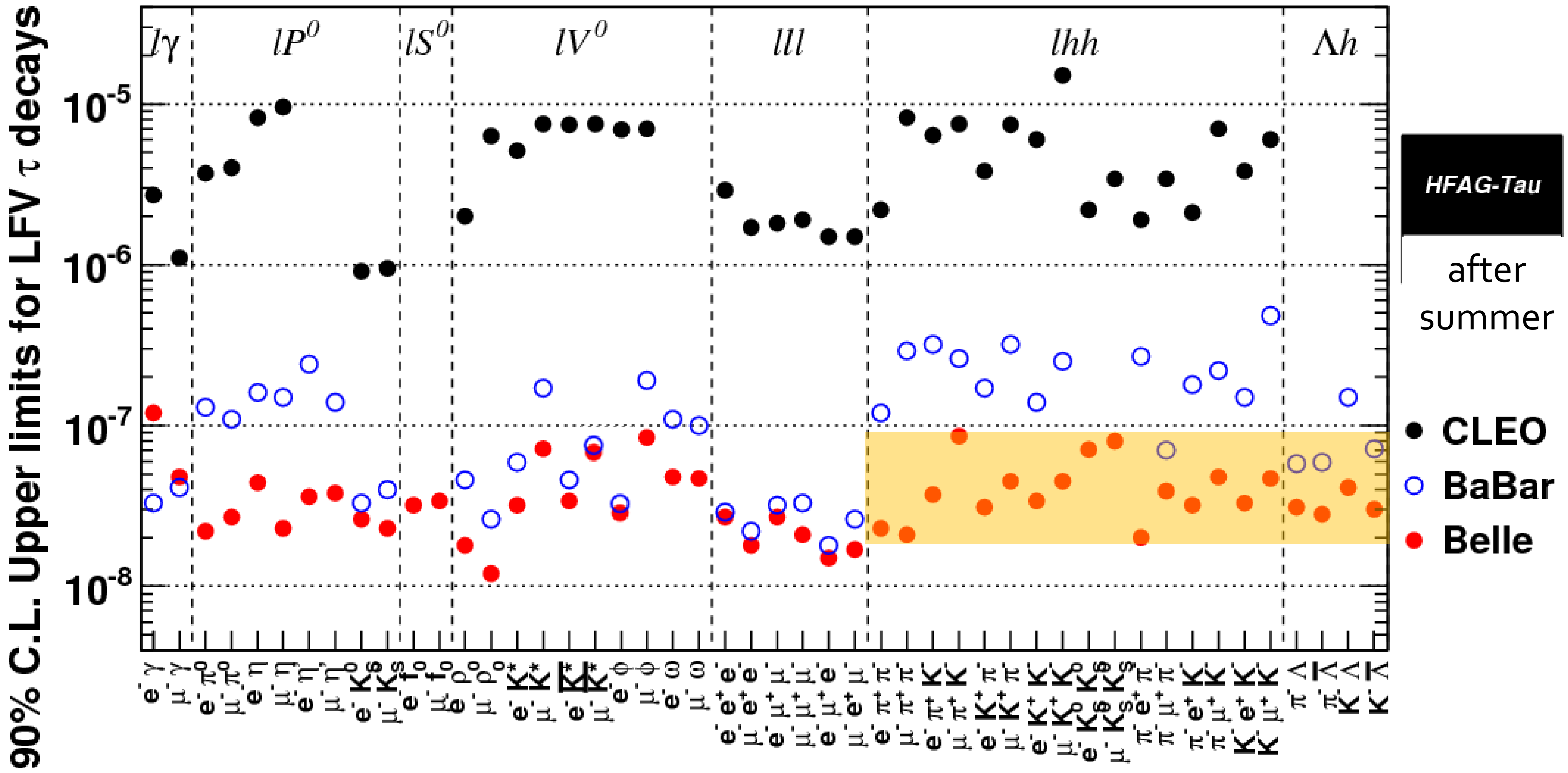
(preliminary)

→most sensitive results

Around x(2-3) improvement from the previous BaBar results

K. Hayasaka

New Upper Limits on τ LFV Decay



Reach upper limits around 10^{-8} ~100x more sensitive than CLEO

Update using full data samples will be finalized soon!

K. Hayasaka, A. Adametz

LFV Sensitivity for future prospects

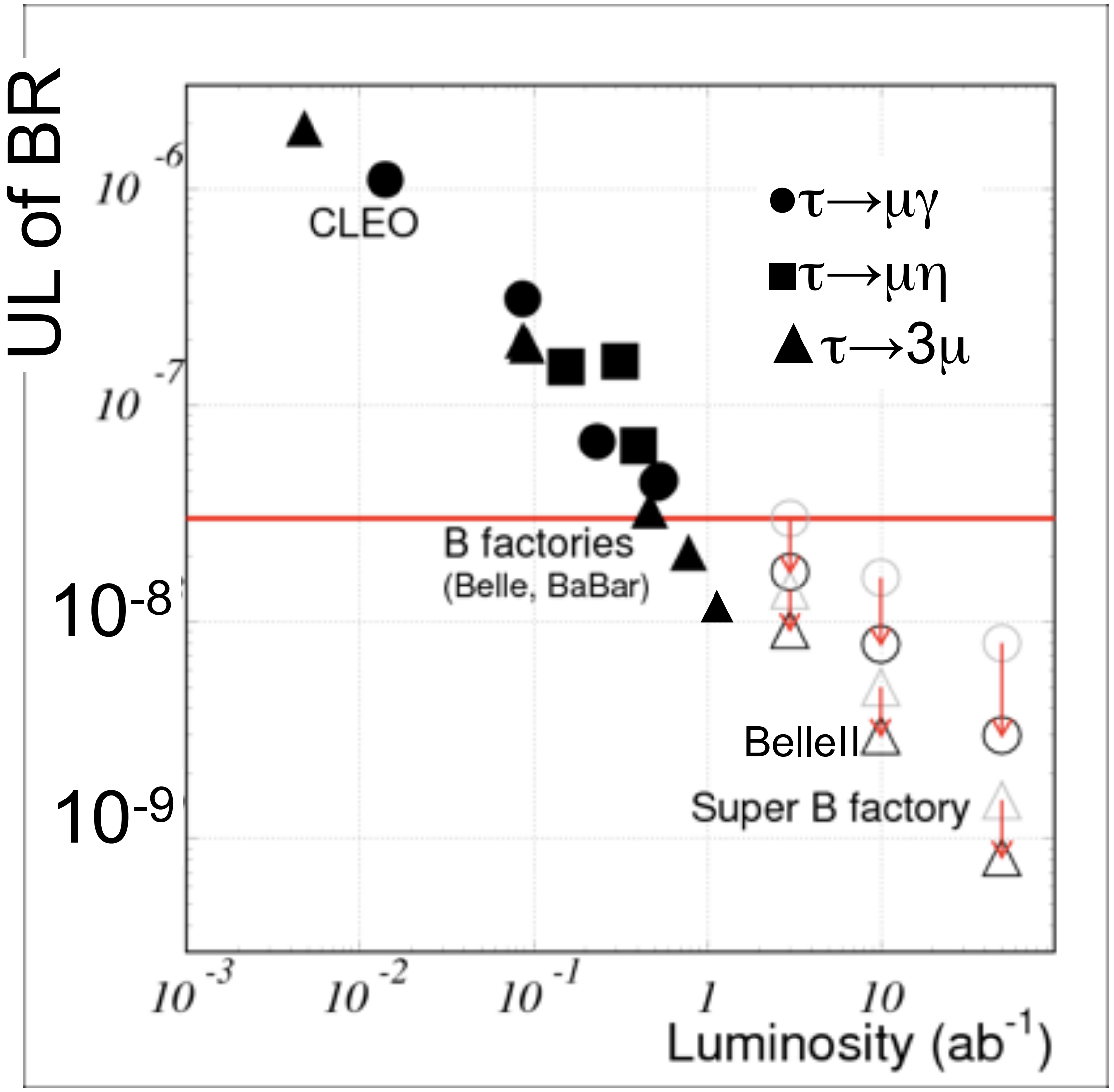
BelleII @SuperKEKB･Super B-factory:(10~50) ab^{-1}

LFV sensitivity

- τ→lγ,

→ Sensitivity currently limited due to background from $\tau^+\tau^-\gamma$ events

scale as ~1/√L ⇒ Br~O($10^{-(8-9)}$)



- τ→3leptons, l+meson

  Negligible background at $1ab^{-1}$ due to good particle identification and mass restriction to select meson

scale as ~1/L ⇒ Br~O($10^{-(9-10)}$)

Y.Miyazaki

The MEG Experiment

$$\mu^+ \rightarrow e^+ \gamma$$

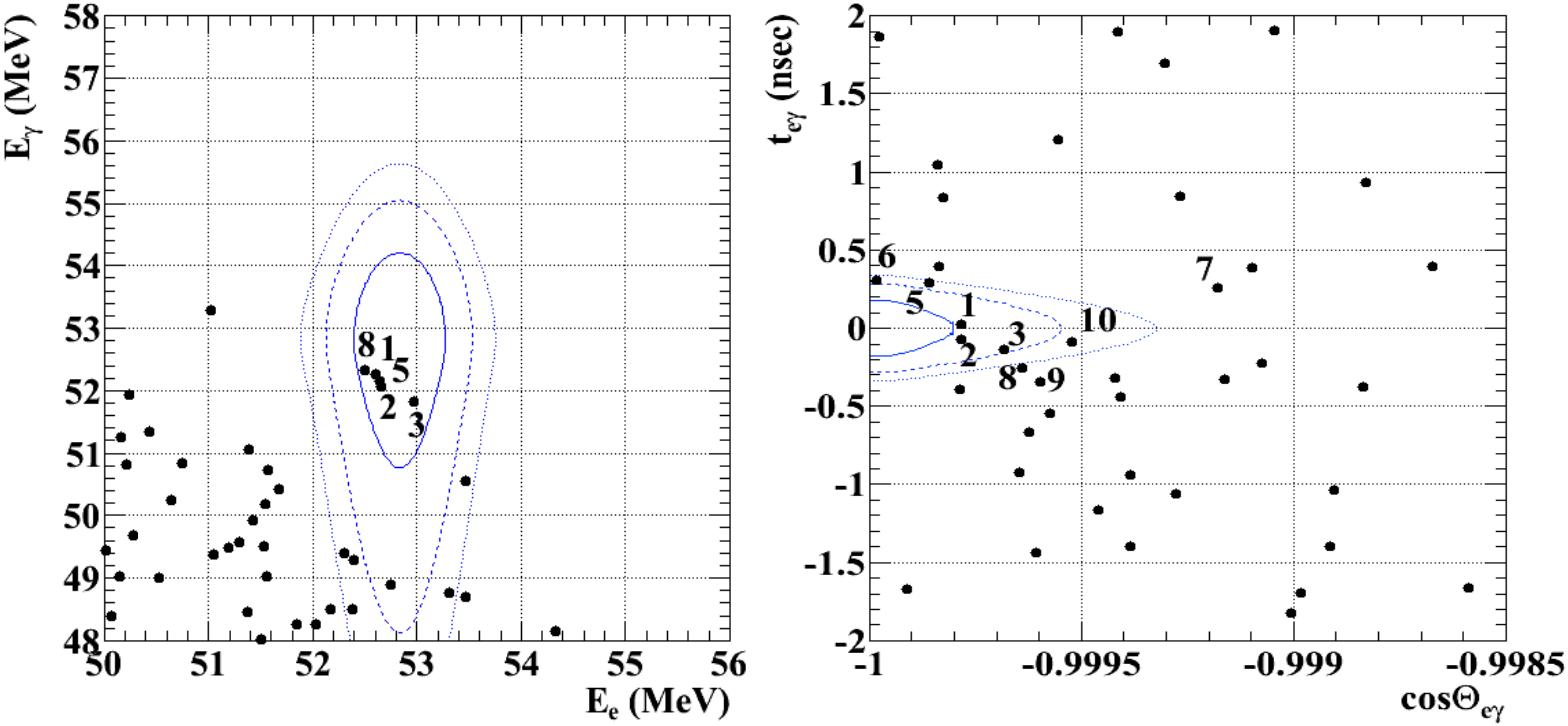
SHOWN AT ICHEP 2010

Event distribution after unblinding

$BR < 1.5 \times 10^{-11}$ @90%CL

6.1×10^{-12} expected

Nsig = 3.0



preliminary result of MEG 2009 data

Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.

For each plot, cut on other variables for roughly 90% window is applied.

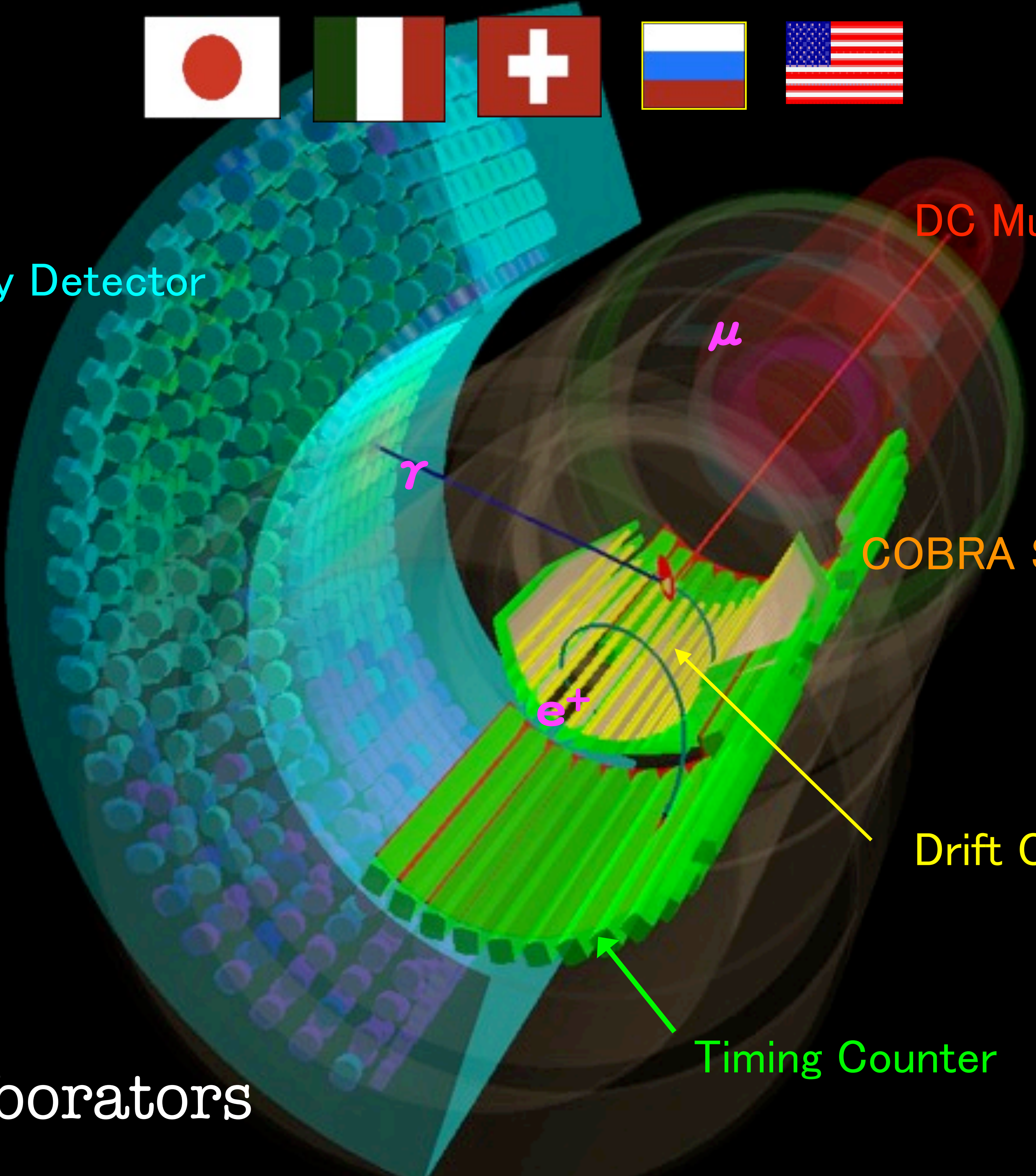
Numbers in figures are ranking by $L_{sig}/(L_{RMD}+L_{BG})$. Same numbered dots in the right and the left figure are an identical event.

WHAT'S NEW

- New data:
  - 2010 data = 2 × 2009 data
- Better calibrations of data:
  - alignments inside/among detectors
  - applied to both 2009 & 2010 data
- Analysis methods:
  - N_{BG} constrained by side bands
  - profile likelihood intervals

Feldman-Cousins

The MEG Experiment



DC Muon Beam

LXe Gamma-ray Detector

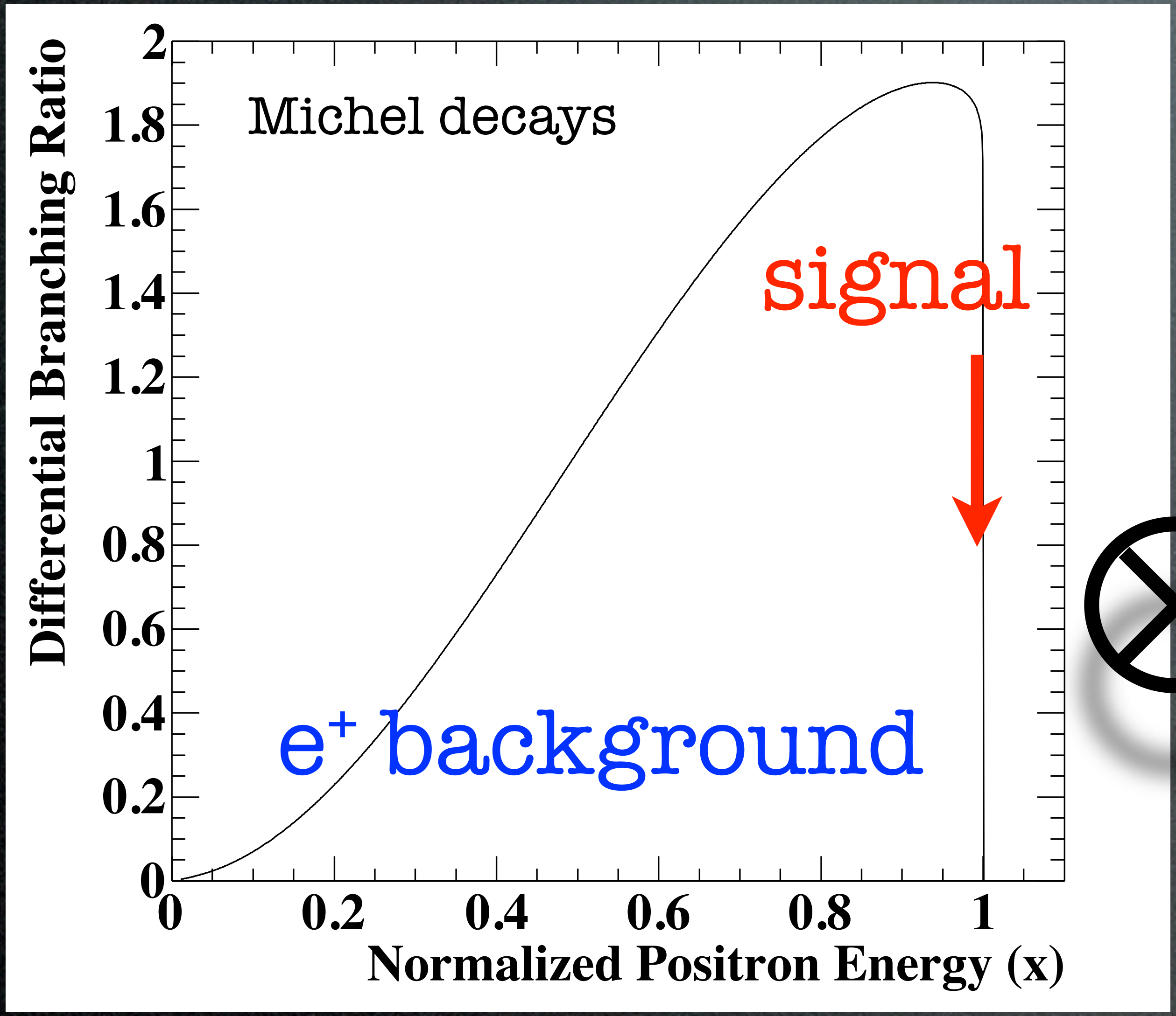
COBRA SC Magnet

Drift Chamber

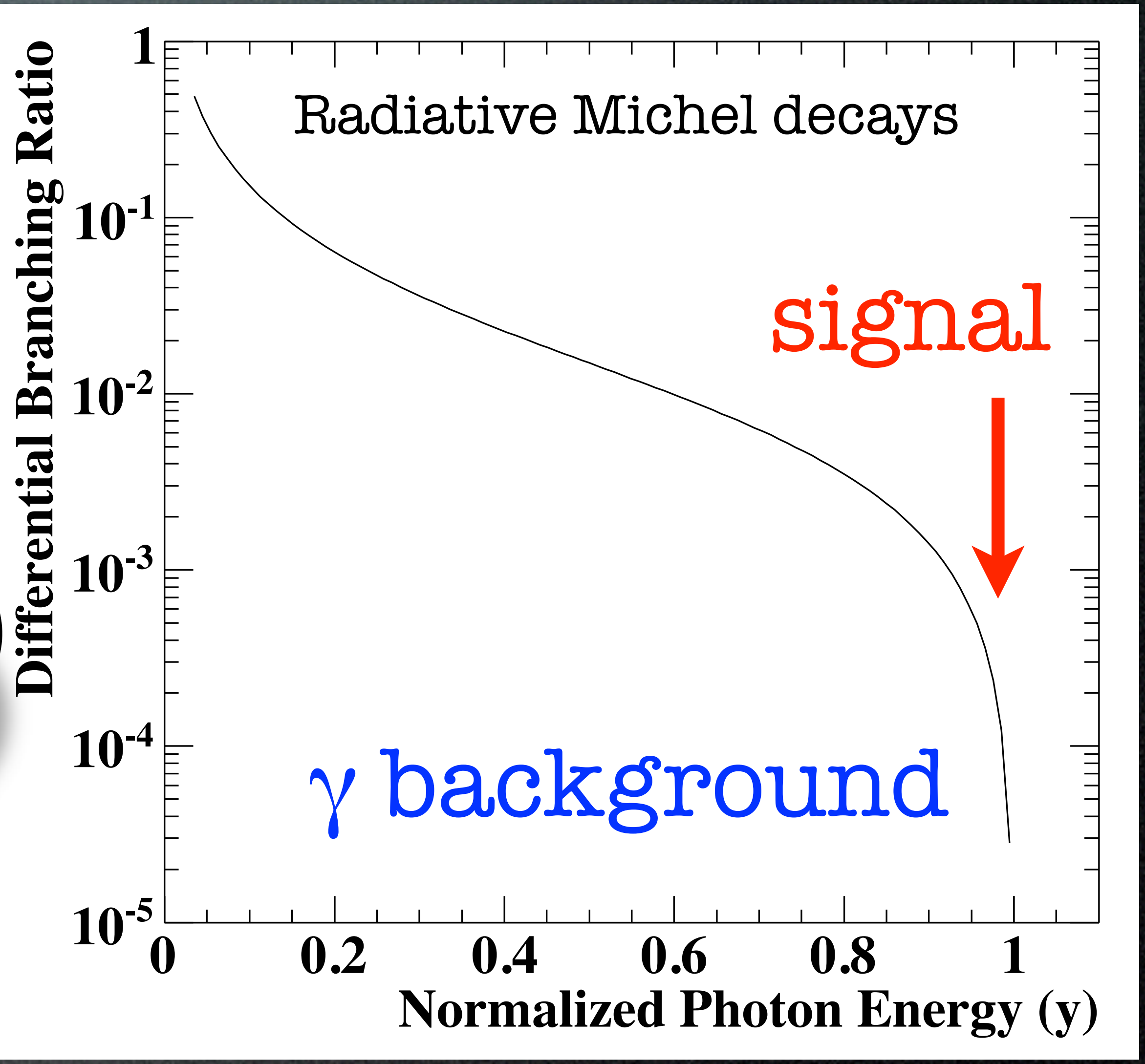
Timing Counter

~55 collaborators

Dominant Background Is Accidental



$\otimes$

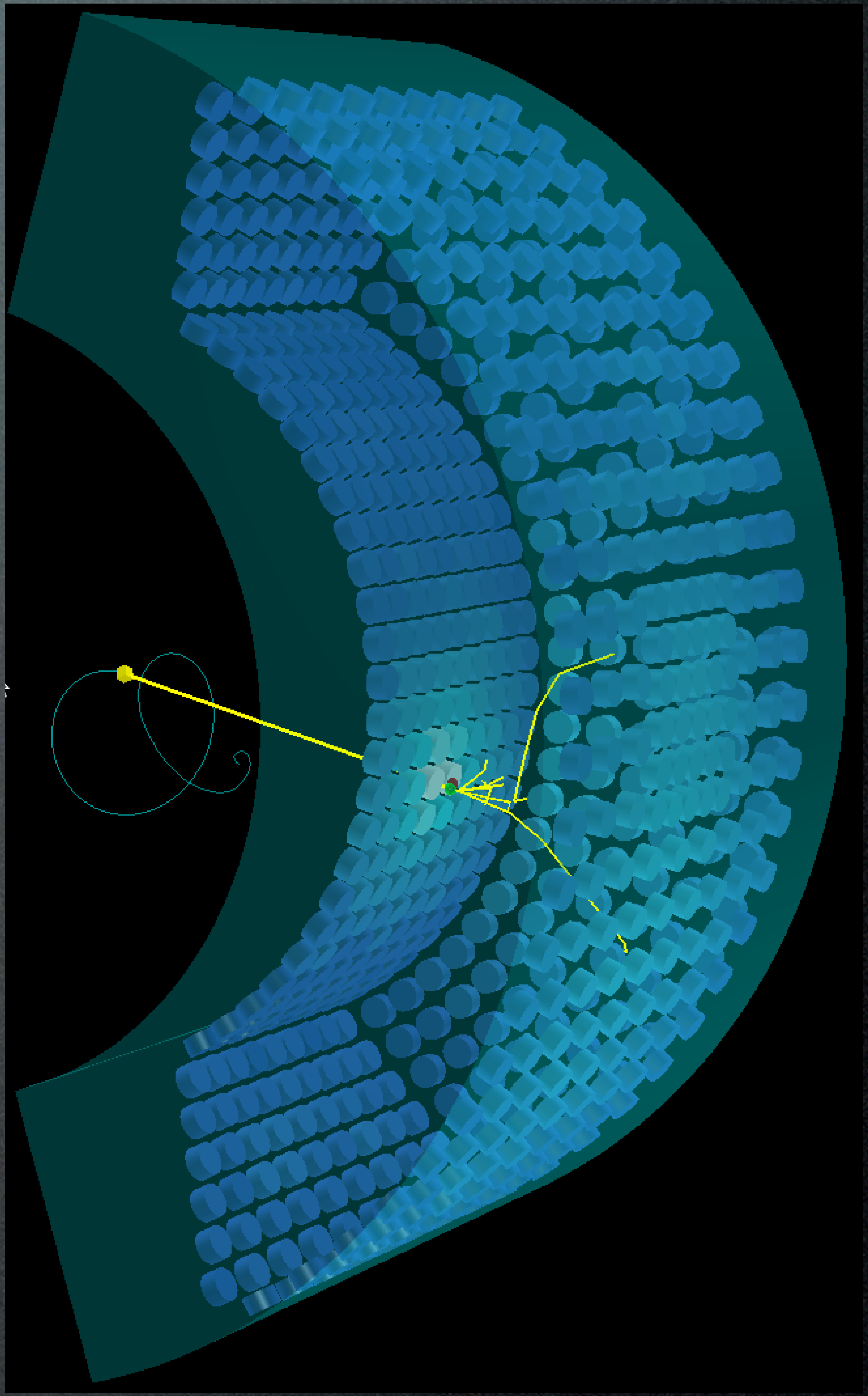


must manage high rate e^+

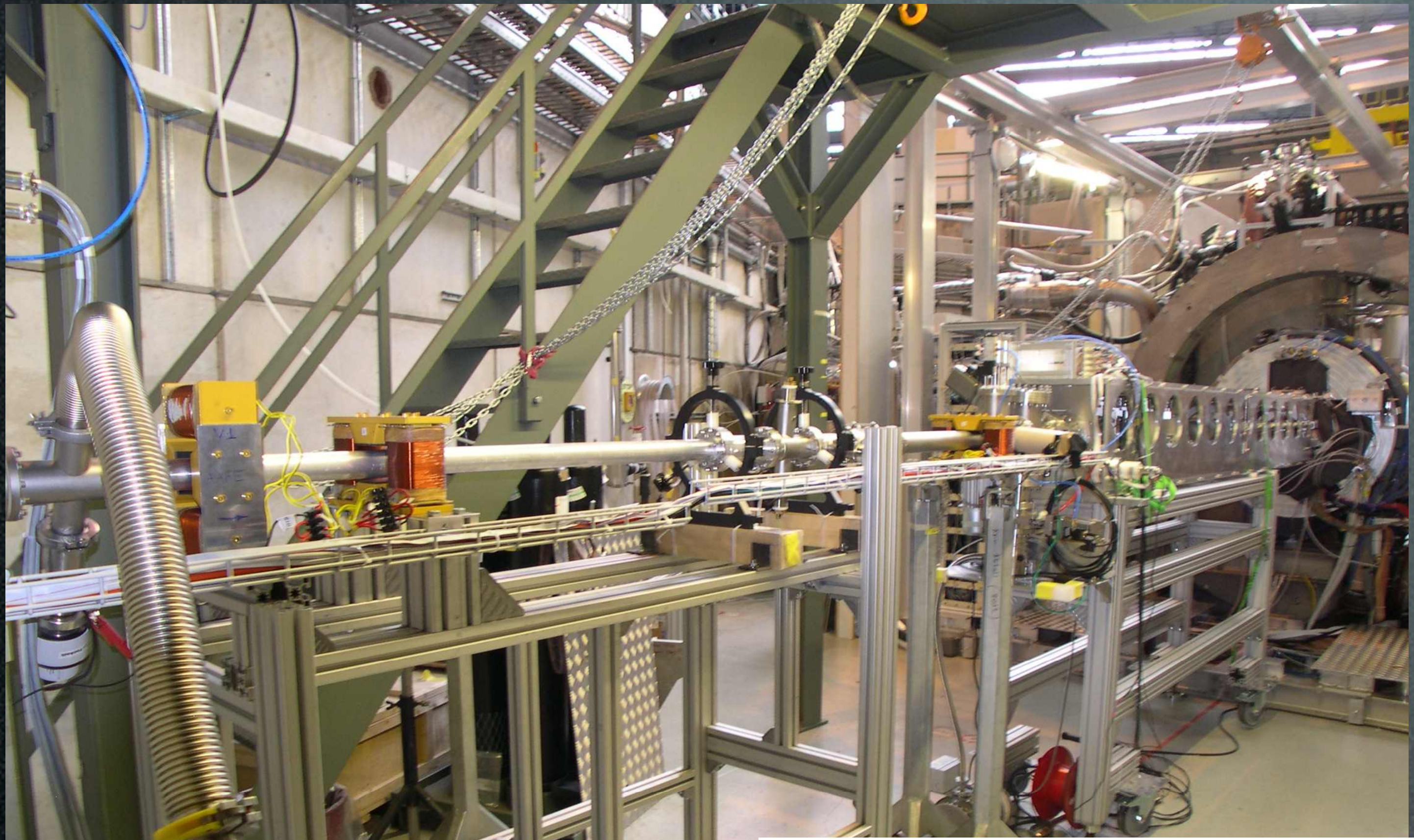
good γ resolution is most important !

2.7t Liquid Xenon Photon Detector

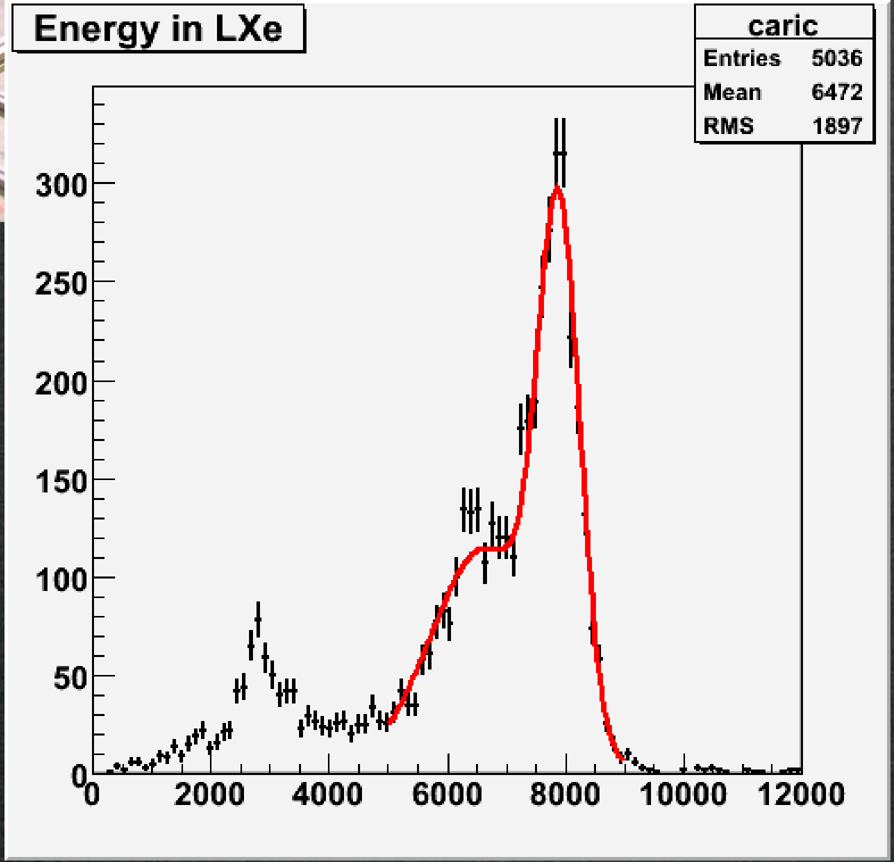
- Scintillation light from 900 liter liquid xenon is detected by 846 PMTs mounted on all surfaces and submerged in the xenon
- fast response & high light yield provide good resolutions of E, time, position
- kept at 165K by 200W pulse-tube refrigerator
- gas/liquid circulation system to purify xenon to remove contaminants



Monitor E_γ during Run



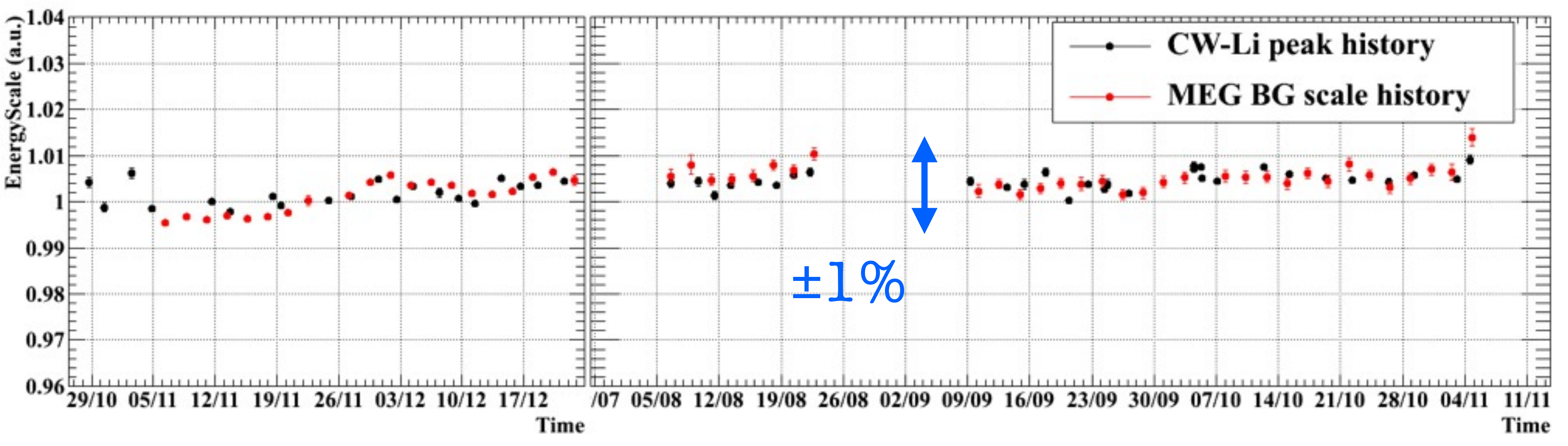
remotely extendable
beam pipe of
CW proton beam
(downstream of
muon beam line)



17.67MeV Li peak

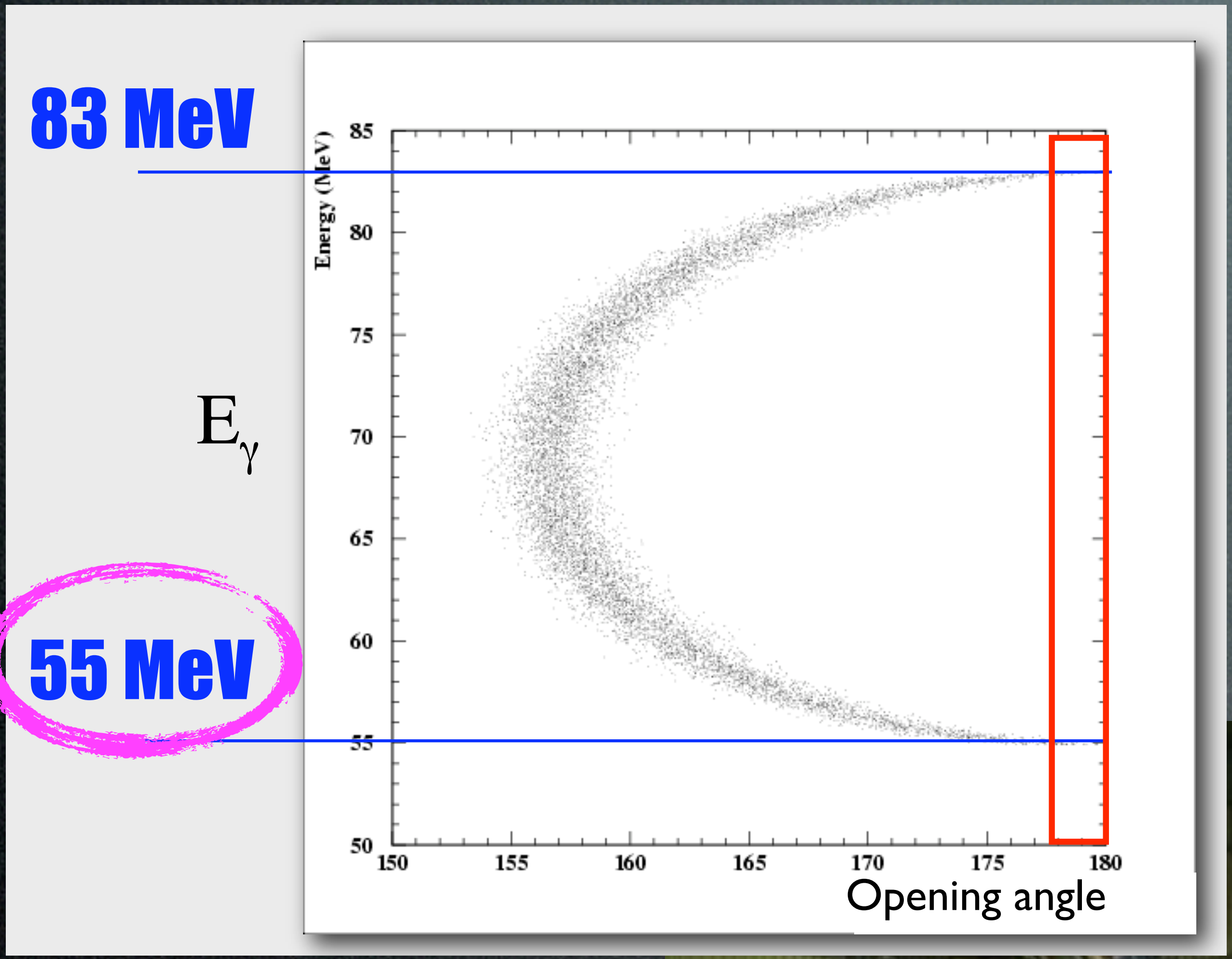
- sub-MeV proton beam produced by a dedicated Cockcroft-Walton accelerator (CW) are bombarded on $Li_2B_4O_7$ target.
- 17.67MeV from ^{7}Li
- 2 coincident photons (4.4, 11.6) MeV from ^{11}B: synchronization of LXe and TC
- Short runs two-three times a week

Stability of E_γ Scale



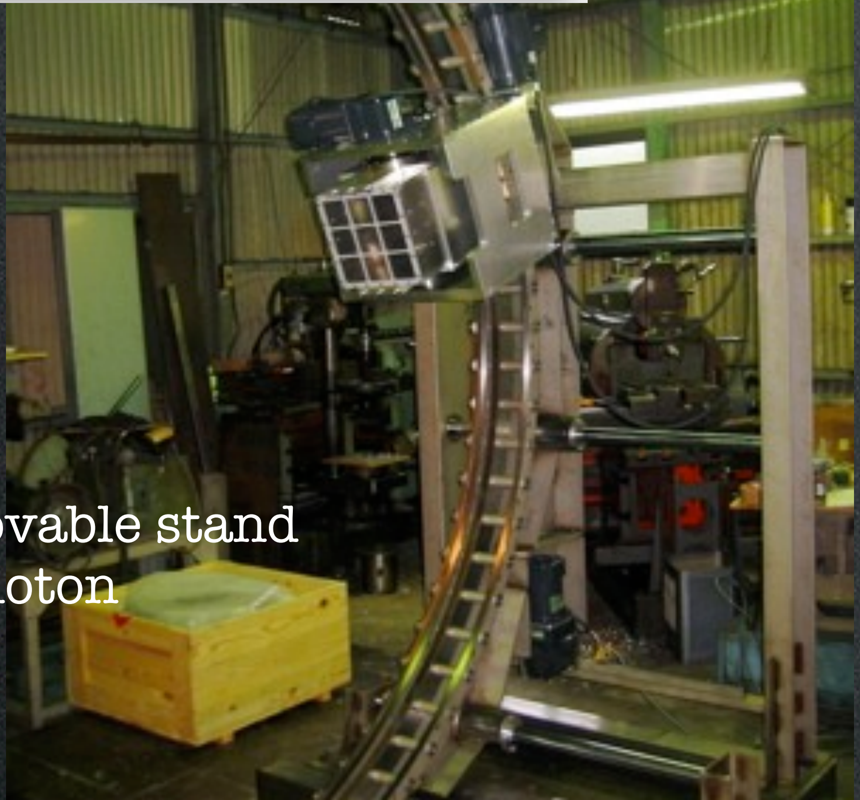
rms ~0.3%

Absolute E_γ Calibration

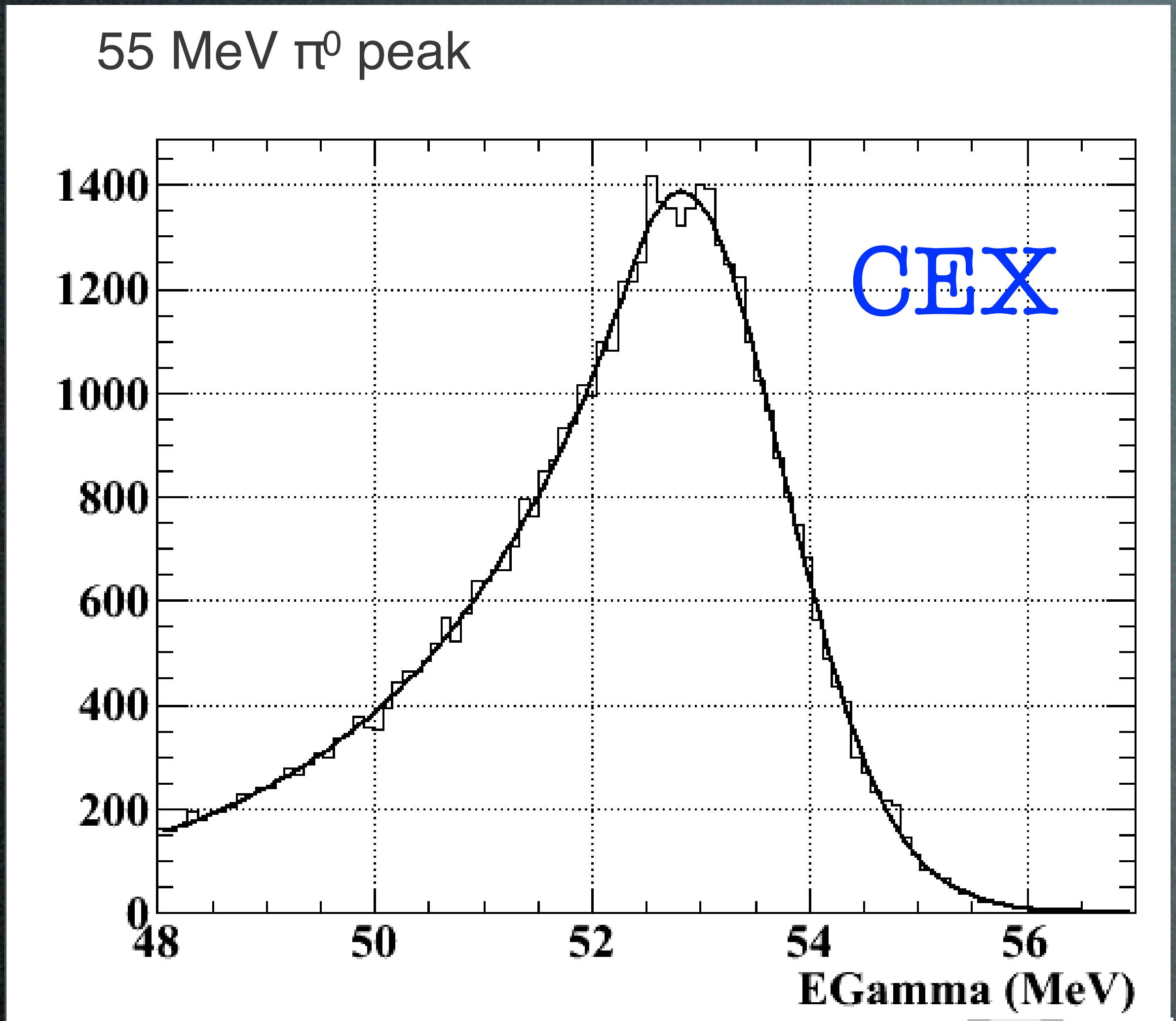


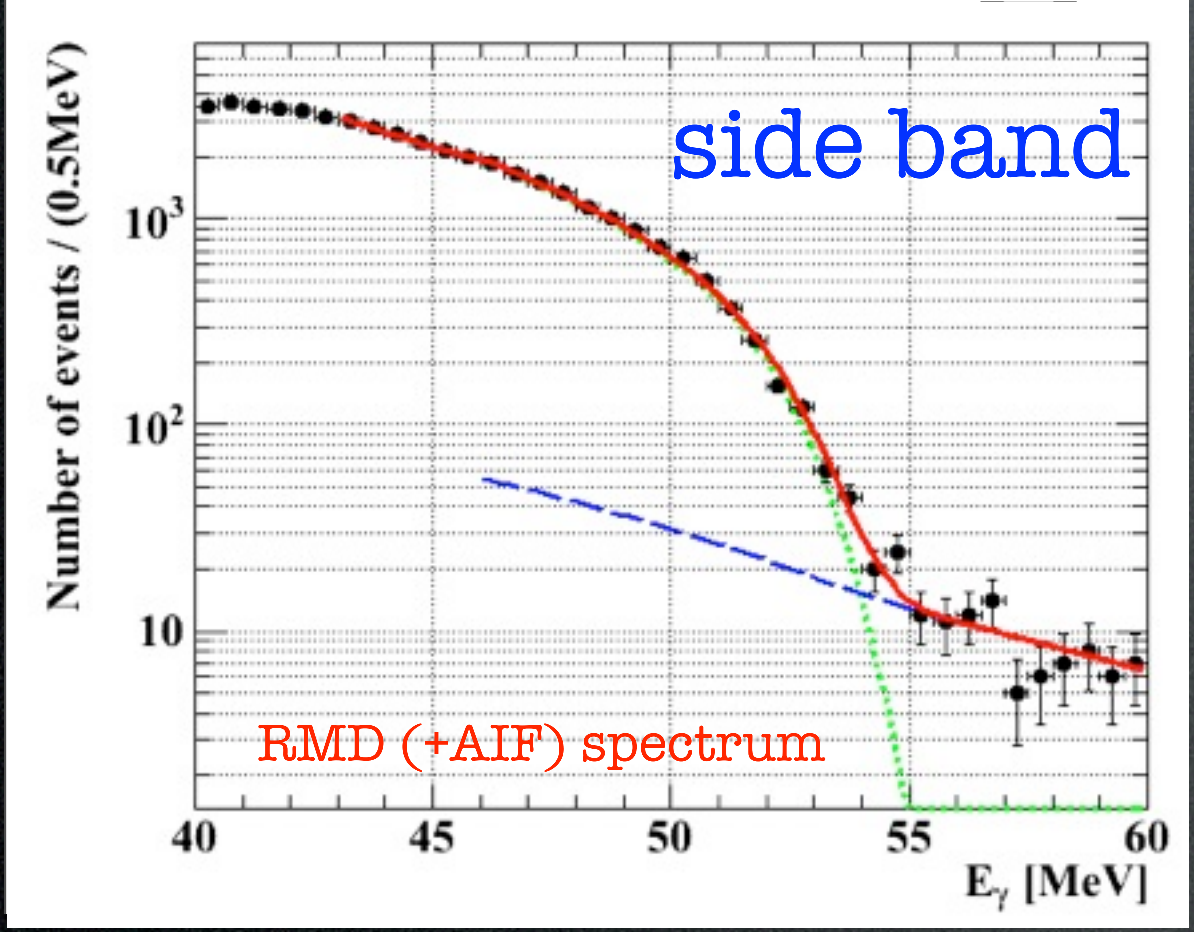
$$\pi^- p \to \pi^0 n \to \gamma\gamma n$$

- negative pions stopped in liquid hydrogen target
- Tagging the other photon at 180° provides monochromatic photons
- Dalitz decays were used to study positron-photon synchronization and time resolution: $\pi^0 \to \gamma e^+ e^-$



NaI crystal array on a movable stand
to tag the other photon

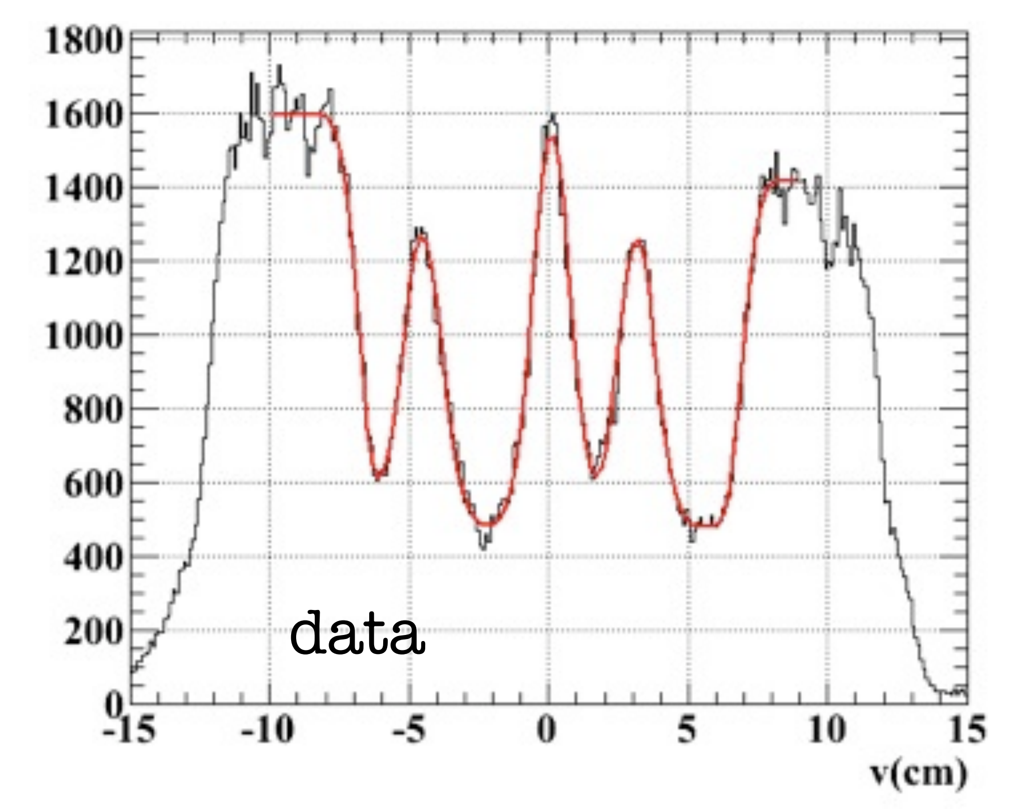


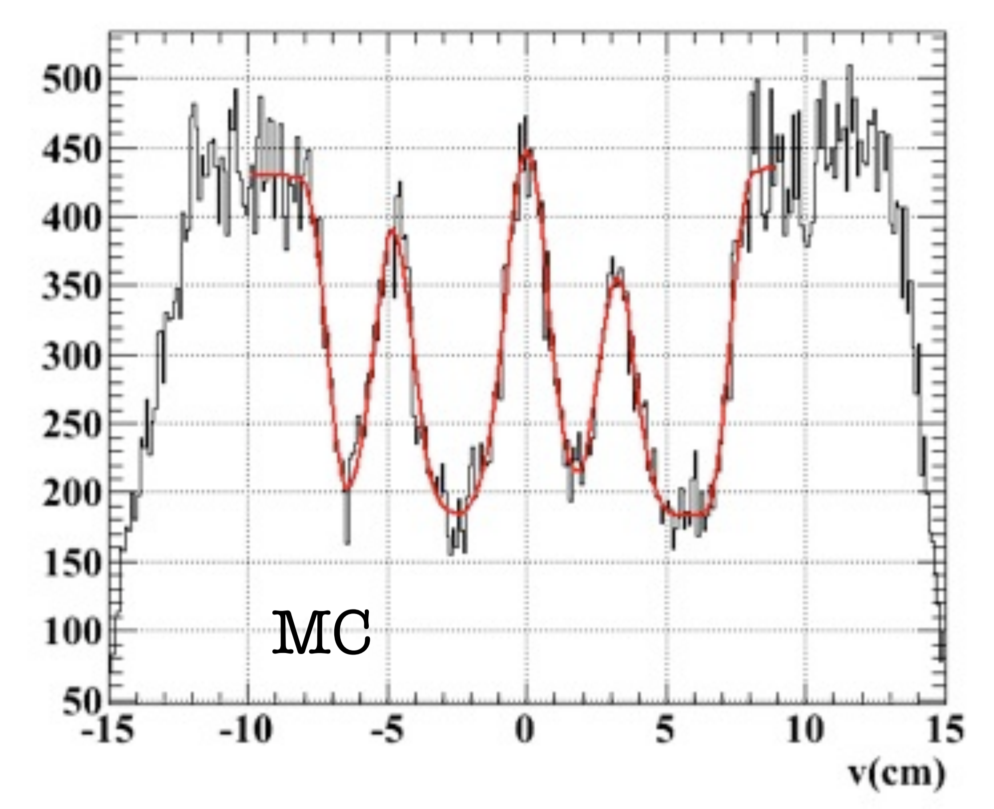


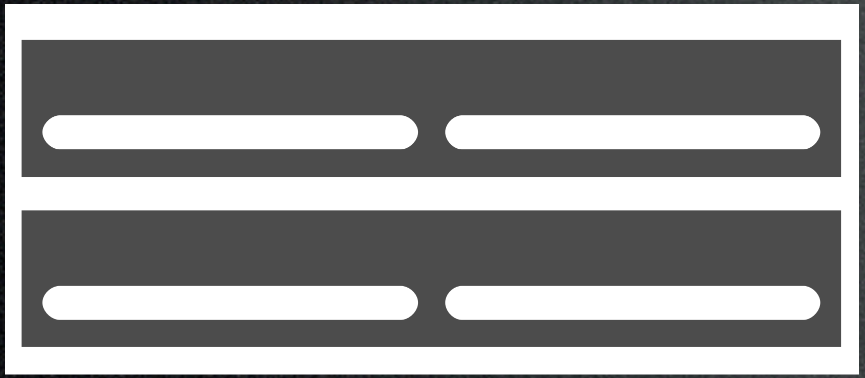
Gamma ray energy

- Signal PDF from the CEX data
- Accidental PDF from the side bands
- Scale & resolutions verified by radiative decay spectrum
- systematic uncertainty on energy scale: 0.3%

Photon Conversion Position



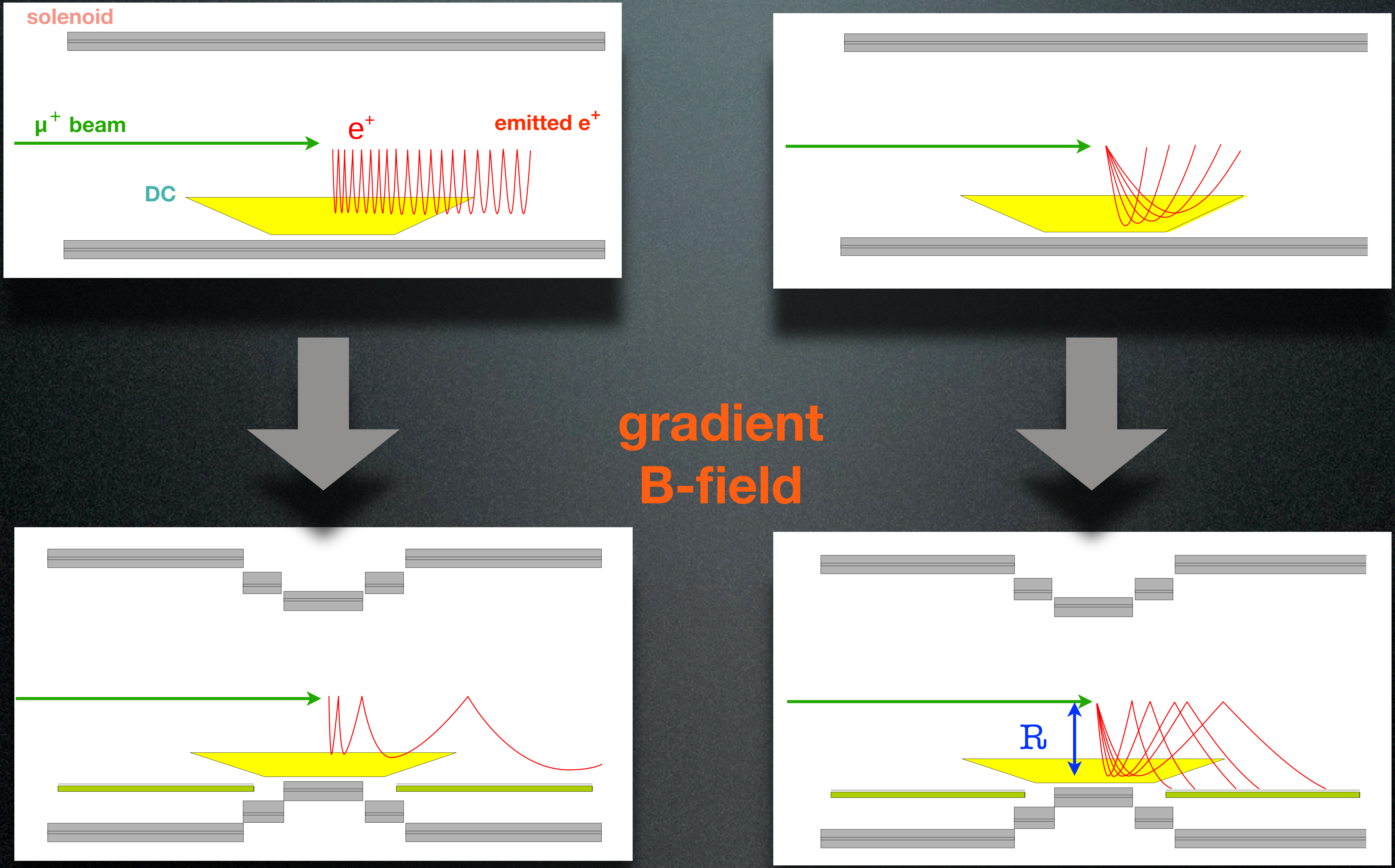




Pb collimator

- Resolution for photon conversion position was evaluated by CEX run with Pb collimators
- ~ 5mm

uniform B-field

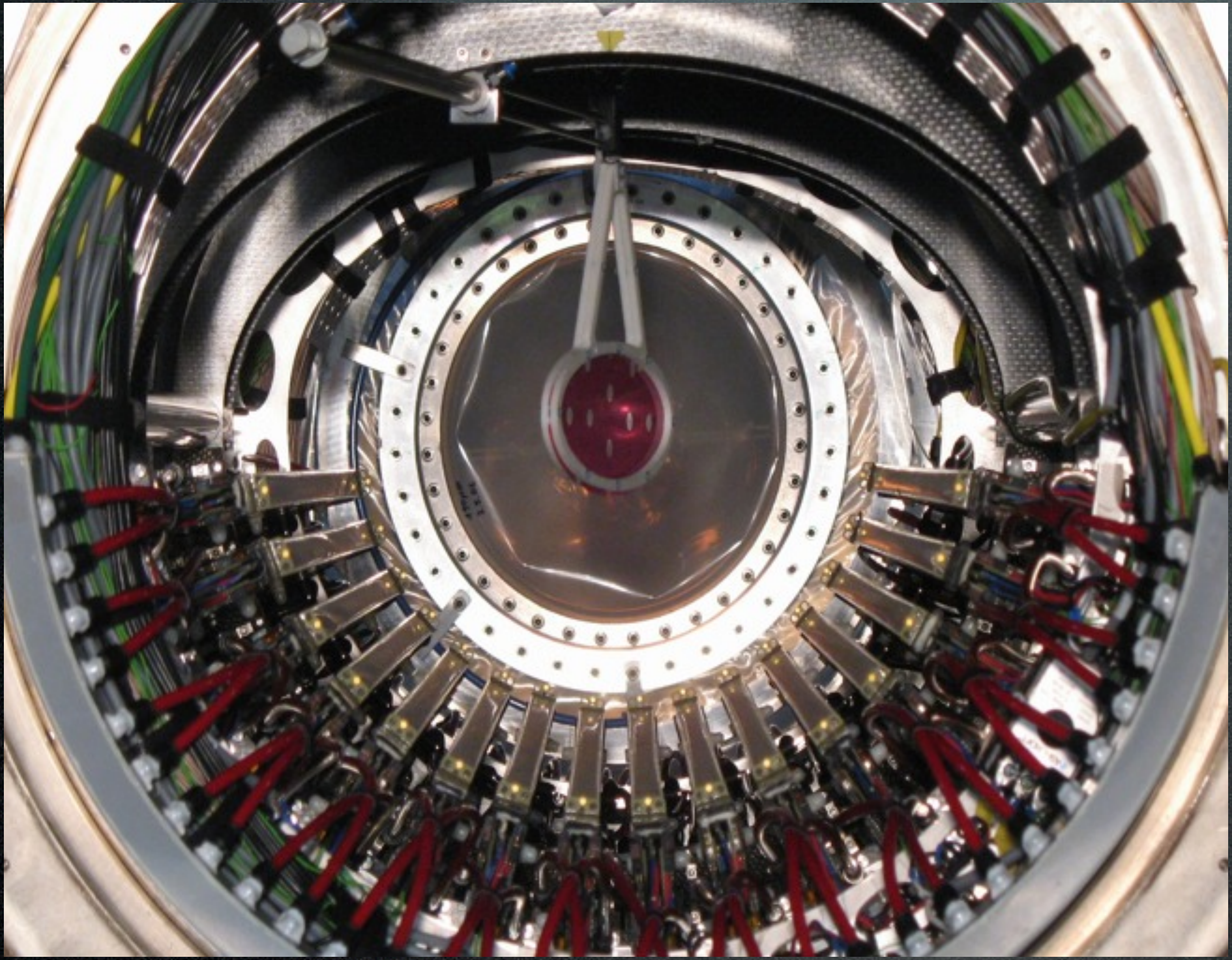


gradient B-field

Low energy positrons quickly swept out

Constant bending radius independent of emission angles

Drift Chambers

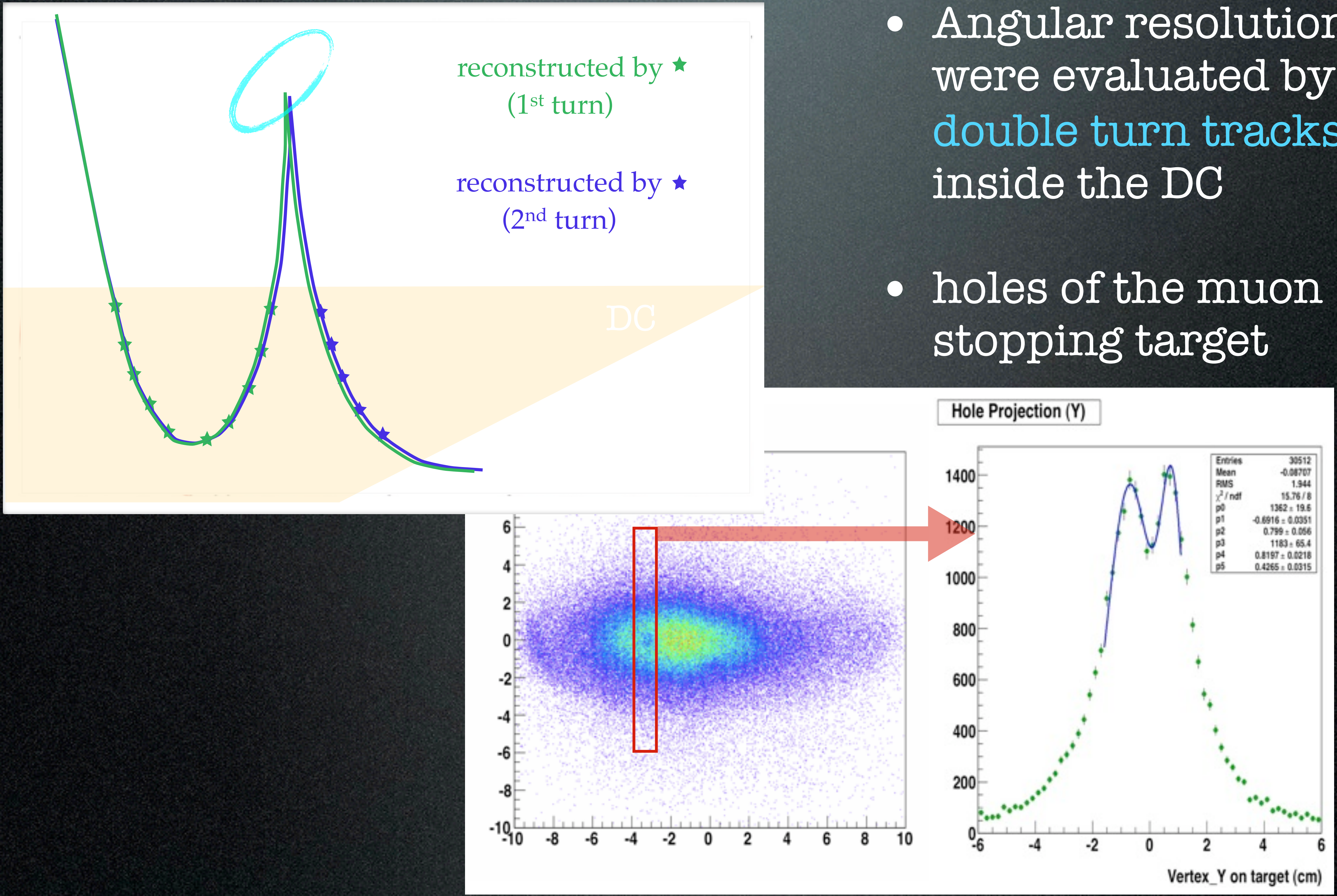


filled with He inside COBRA

- 16 radially aligned modules, each consists of two staggered layers of wire planes
- 12.5um thick cathode foils with a Vernier pattern structure
- He:ethane = 50:50 differential pressure control to COBRA He environment
- ~2.0×10^{-3} X_0 along the positron trajectory

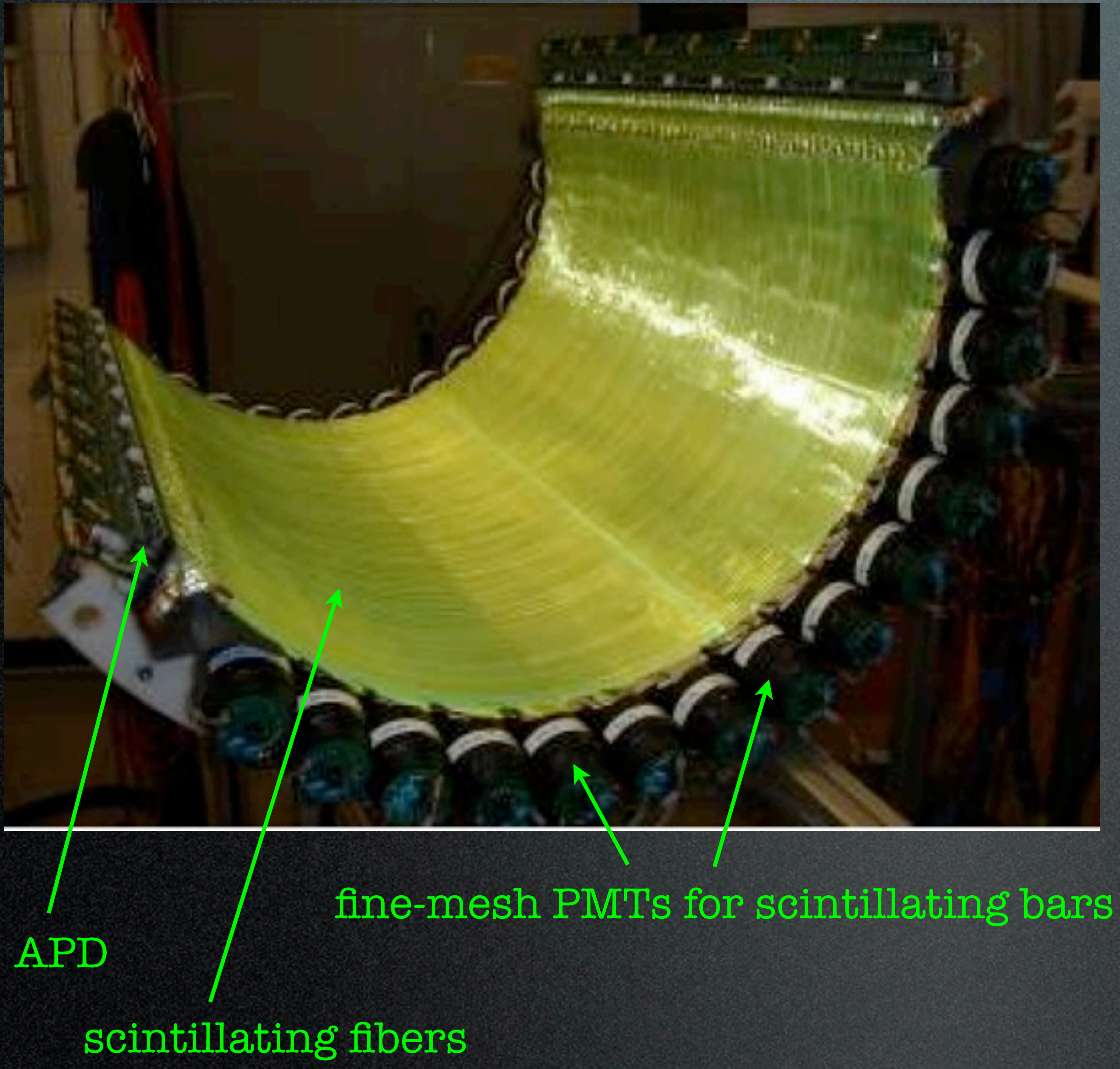
Positron Angle & Muon Decay Point

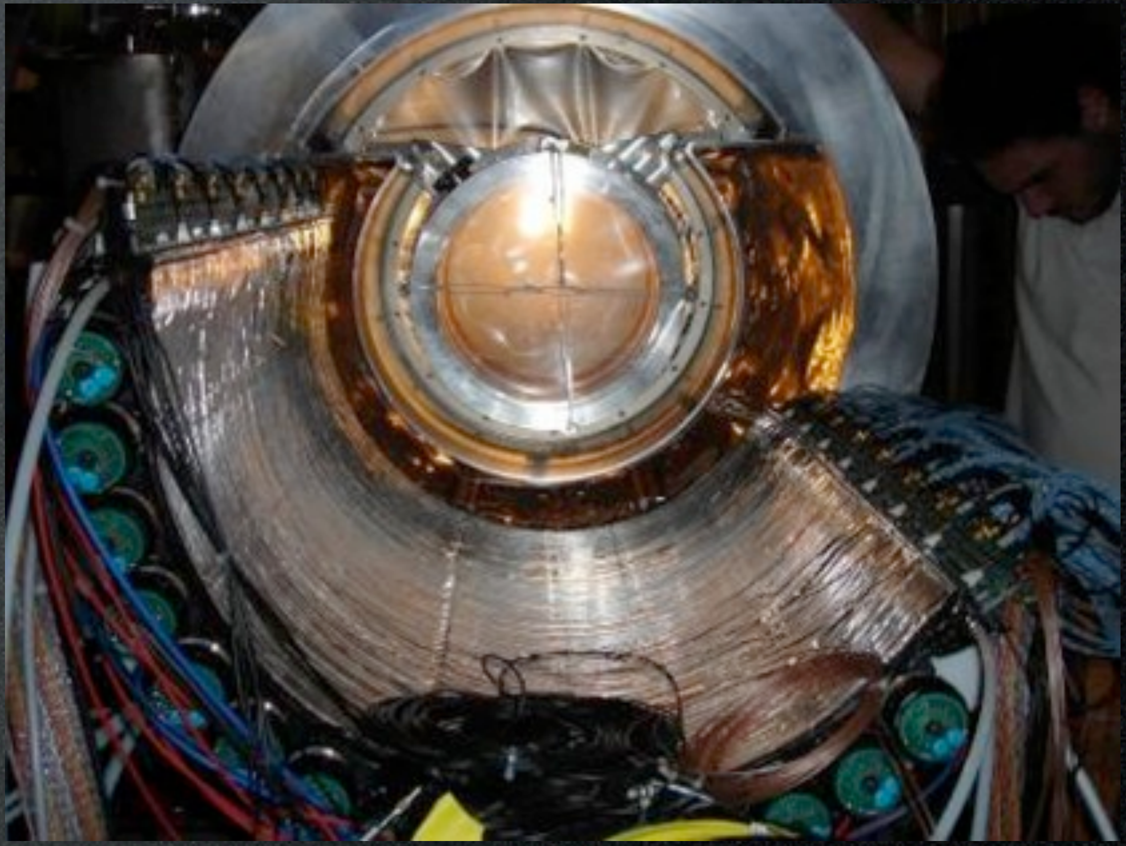
- Angular resolutions were evaluated by the double turn tracks inside the DC
- holes of the muon stopping target



Timing Counters

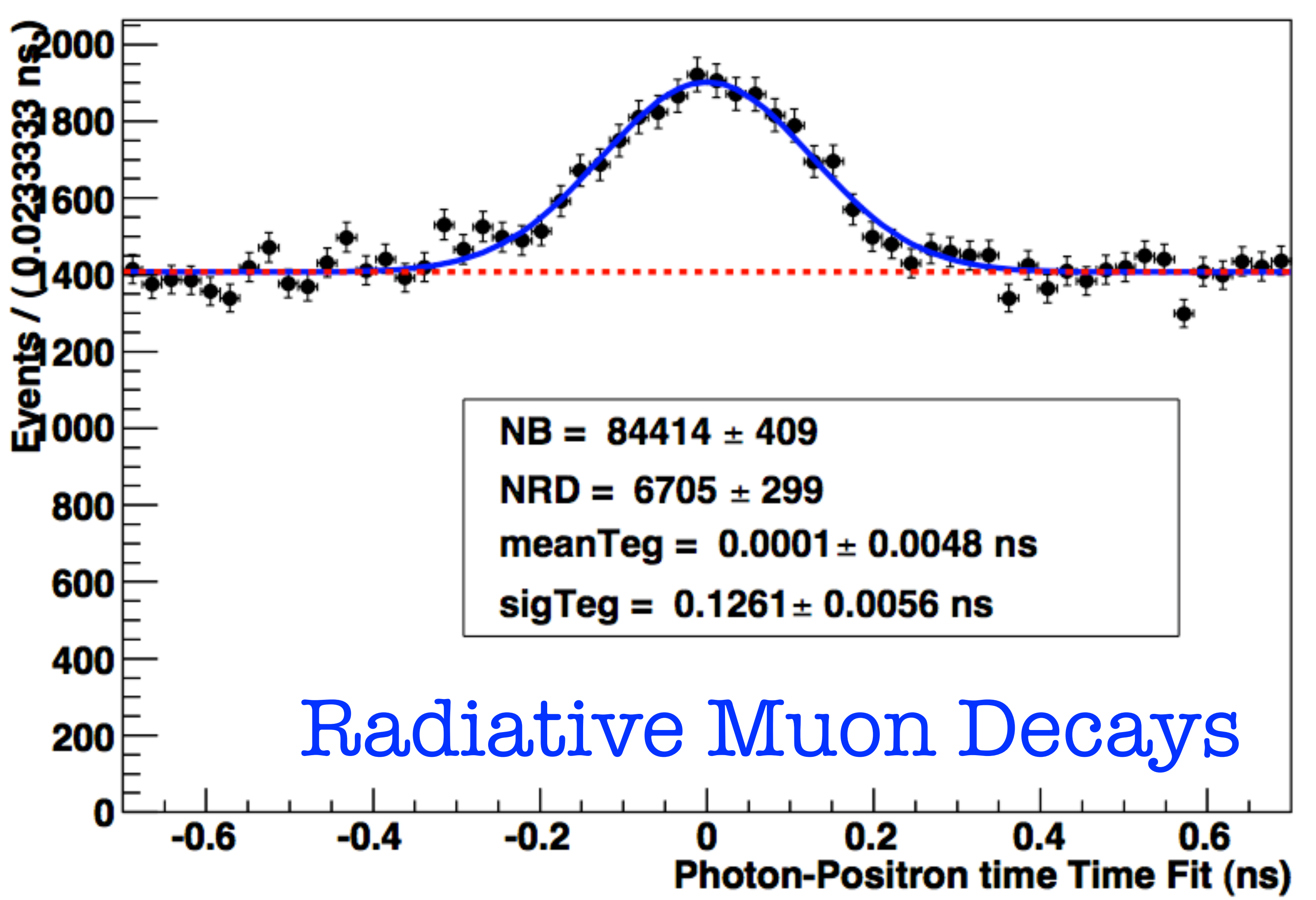
- Scintillator arrays placed at each end of the spectrometer
- Measures the impact point of the positron to obtain precise timing





installing inside COBRA

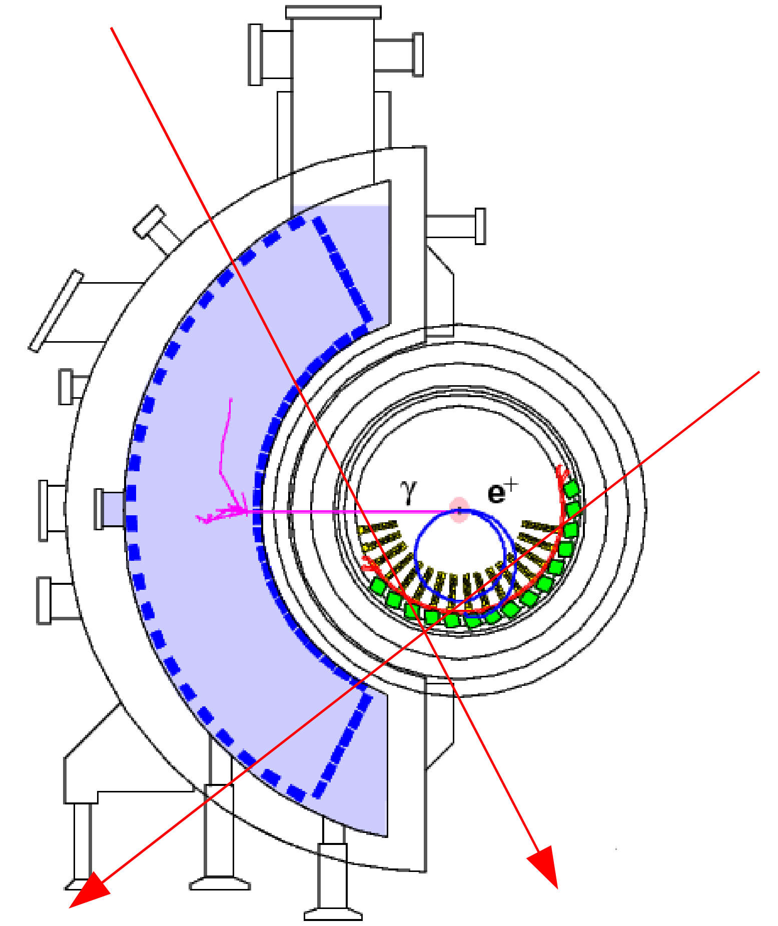
Positron - Photon Timing

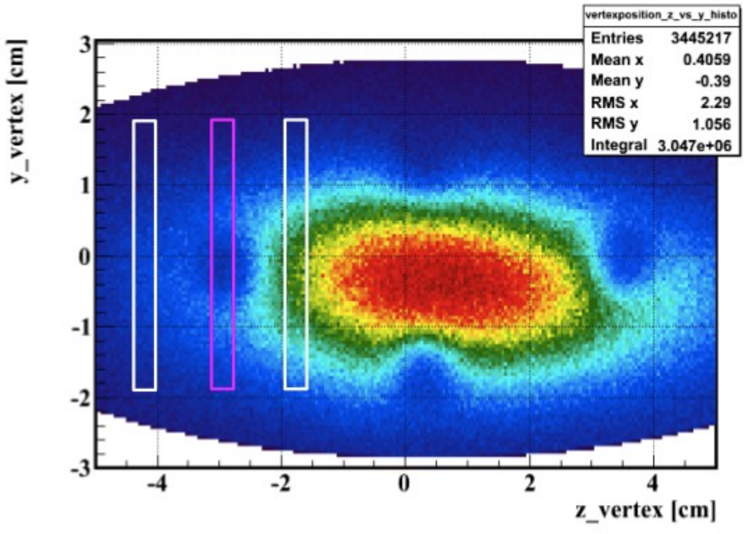


- Positron time measured by TC and corrected by ToF (DC trajectory)
- LXe time corrected by ToF to the conversion point
- RMD peak in a normal physics run corrected by small energy dependence; stable < 20ps

Improved calibration & analysis

- alignment by CR & Michel e^+
  - DC - B field - target - LXe
  - optical surveys
  - DC: MILLEPEDE (a la CMS)
  - target holes
  - LXe: Pb collimators
- more detailed implementation of e^+ correlations

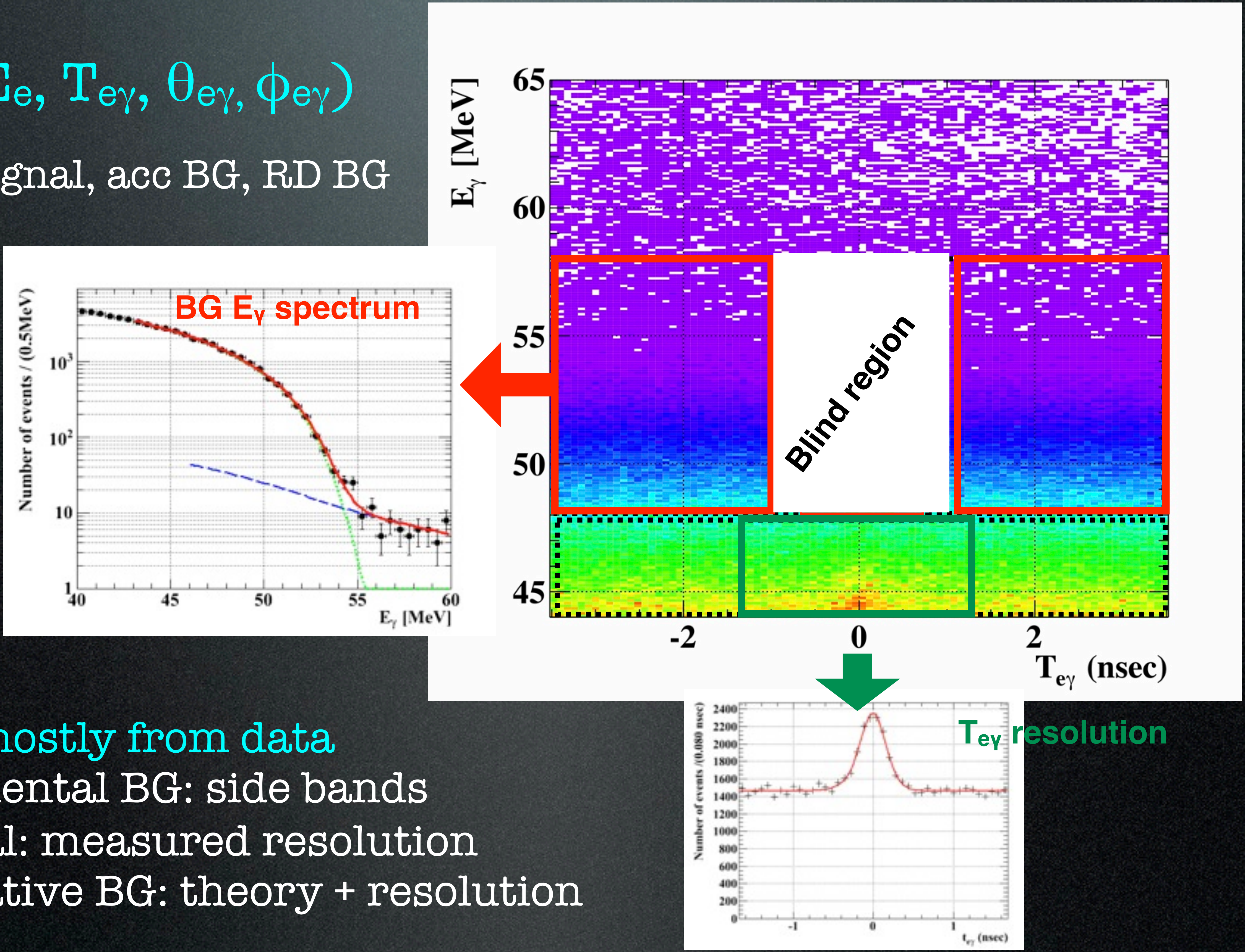




Blind & Likelihood Analysis

(E_γ, E_e, $T_{e\gamma}$, $\theta_{e\gamma}$, $\phi_{e\gamma}$)

→ signal, acc BG, RD BG



PDFs mostly from data

accidental BG: side bands

signal: measured resolution

radiative BG: theory + resolution

Likelihood Fit

- fully frequentist approach (Feldman & Cousins) with profile likelihood ratio ordering

$$
\begin{aligned}
&\mathcal{L}\left(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}\right) = \\
&\quad \frac{e^{-N_{\mathrm{obs}}}}{N!} e^{-\frac{1}{2}\frac{(N_{\mathrm{BG}}-\langle N_{\mathrm{BG}}\rangle)^2}{\sigma^2_{\mathrm{BG}}}} e^{-\frac{1}{2}\frac{(N_{\mathrm{RMD}}-\langle N_{\mathrm{RMD}}\rangle)^2}{\sigma^2_{\mathrm{RMD}}}} \times \\
&\quad \prod_{i=1}^{N_{\mathrm{obs}}} \left(N_{\mathrm{sig}} S(\vec{x}_i) + N_{\mathrm{RMD}} R(\vec{x}_i) + N_{\mathrm{BG}} B(\vec{x}_i)\right),
\end{aligned}
$$

$$
\begin{aligned}
&LR_p(N_{\mathrm{sig}}) = \\
&\quad \frac{\max_{N_{\mathrm{BG}},N_{\mathrm{RMD}}} \mathcal{L}(N_{\mathrm{sig}}, N_{\mathrm{BG}}, N_{\mathrm{RMD}})}{\max_{N_{\mathrm{sig}},N_{\mathrm{BG}},N_{\mathrm{RMD}}} \mathcal{L}(N_{\mathrm{sig}}, N_{\mathrm{BG}}, N_{\mathrm{RMD}})}.
\end{aligned}
$$

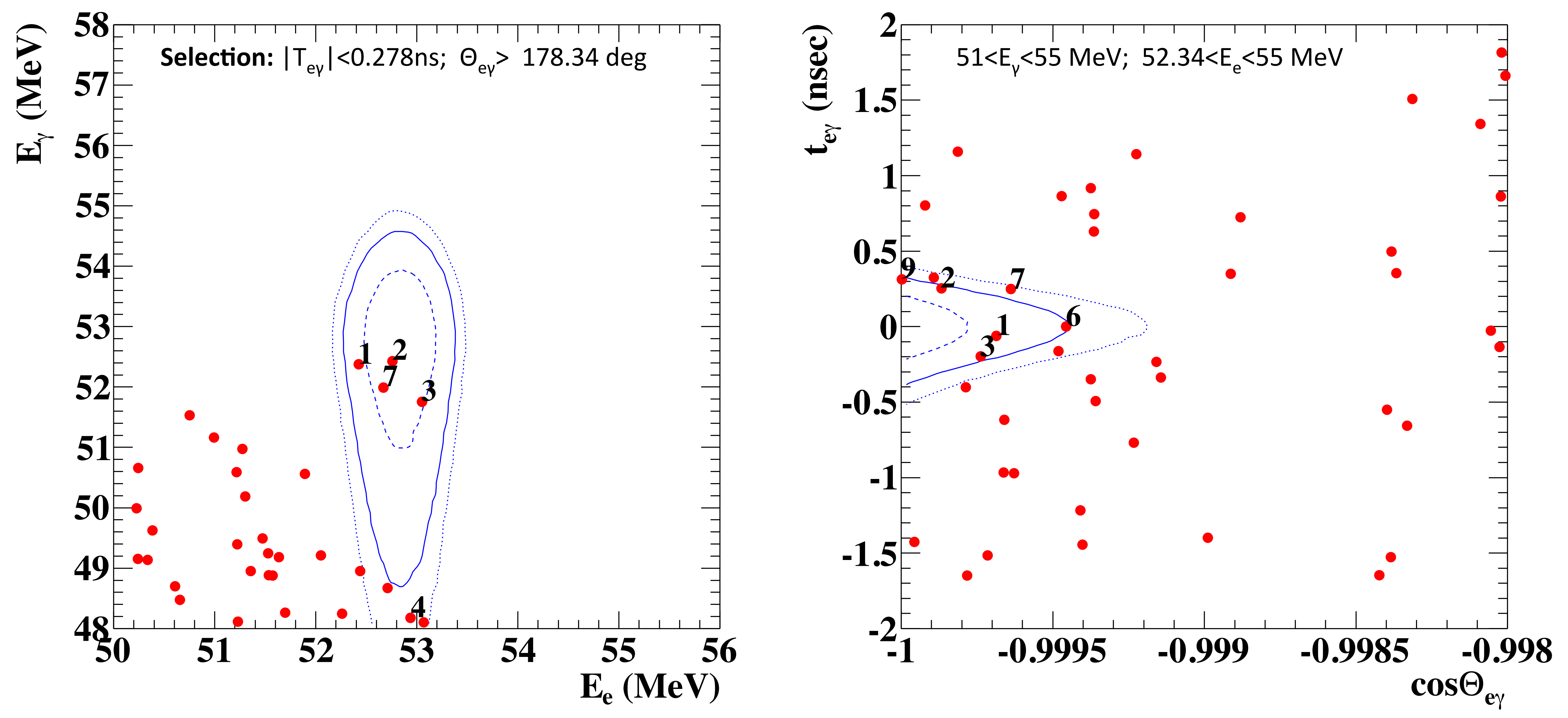
Performance Summary

	2009	2010
Gamma Energy (%)	1.9	1.9
Gamma Timing (psec)	96	67
Gamma Position (mm)	5 (u,v), 6 (w)	5 (u,v), 6 (w)
Gamma Efficiency (%)	58	59
e$^+$ Timing (psec)	107	107
e$^+$ Momentum (keV)	310 (80% core)	330 (79% core)
e$^+$ θ (mrad)	9.4	11.0
e$^+$ ϕ (mrad)	6.7	7.2
e$^+$ vertex Z/Y (mm)	1.5 / 1.1 (core)	2.0 /1.1 (core)
e$^+$ Efficiency (%)	40	34
e$^+$-gamma timing (psec)	146	122
Trigger efficiency (%)	91	92
Stopping Muon Rate (sec^{-1})	2.9×10^{7}	2.9×10^{7}
DAQ time/ Real time (days)	35/43	56/67
Expected 90% C.L. Upper Limit	3.3×10^{-12}	2.2×10^{-12}

Timing improvement by waveform digitizer upgrade in 2011;
The e+ tracking slightly worse due to DC noise problem in 2011

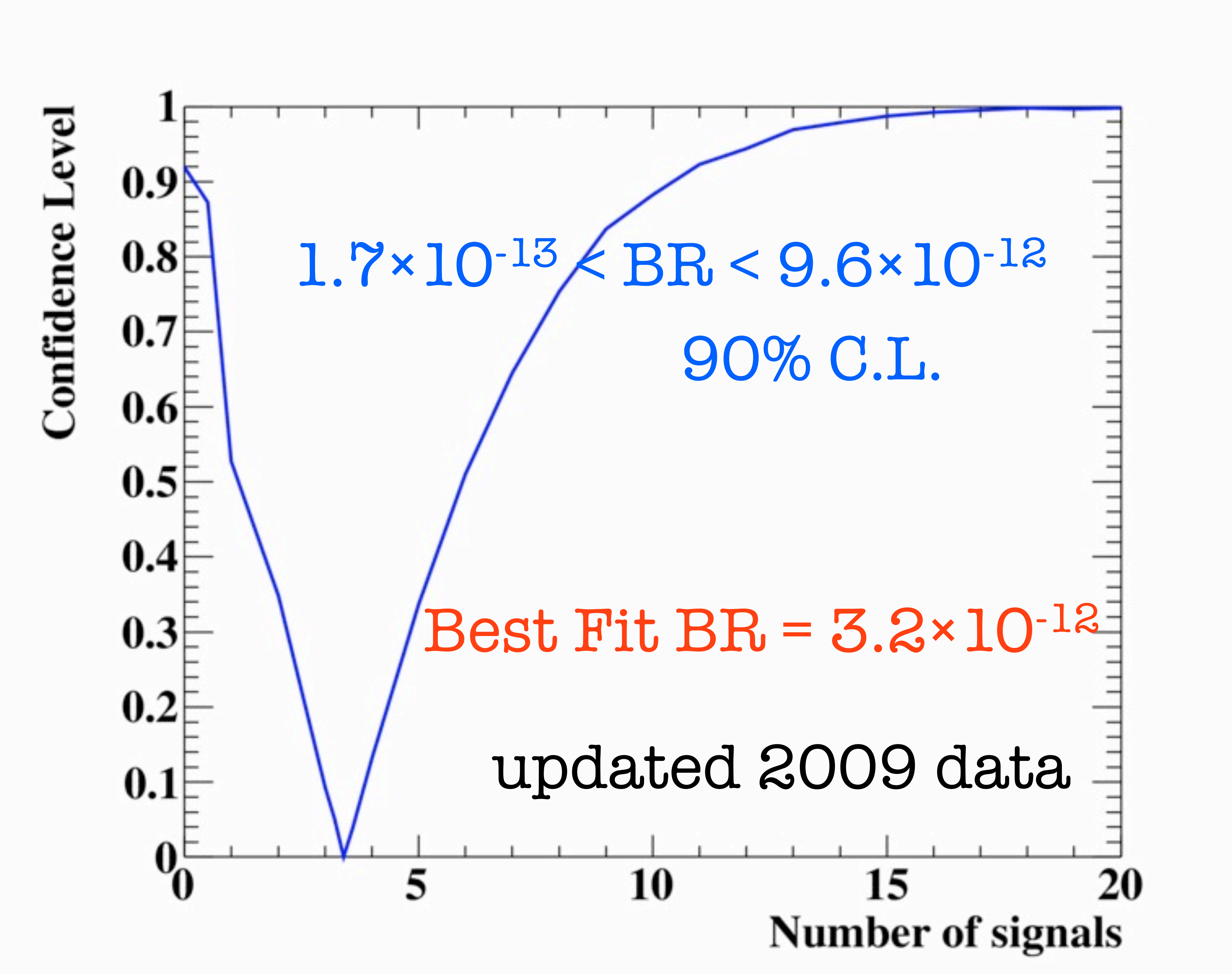
2009 data update

2009 data update



Nsig = 3.0 → Nsig = 3.4

Likelihood Analysis



$1.7\times10^{-13} < BR < 9.6\times10^{-12}$

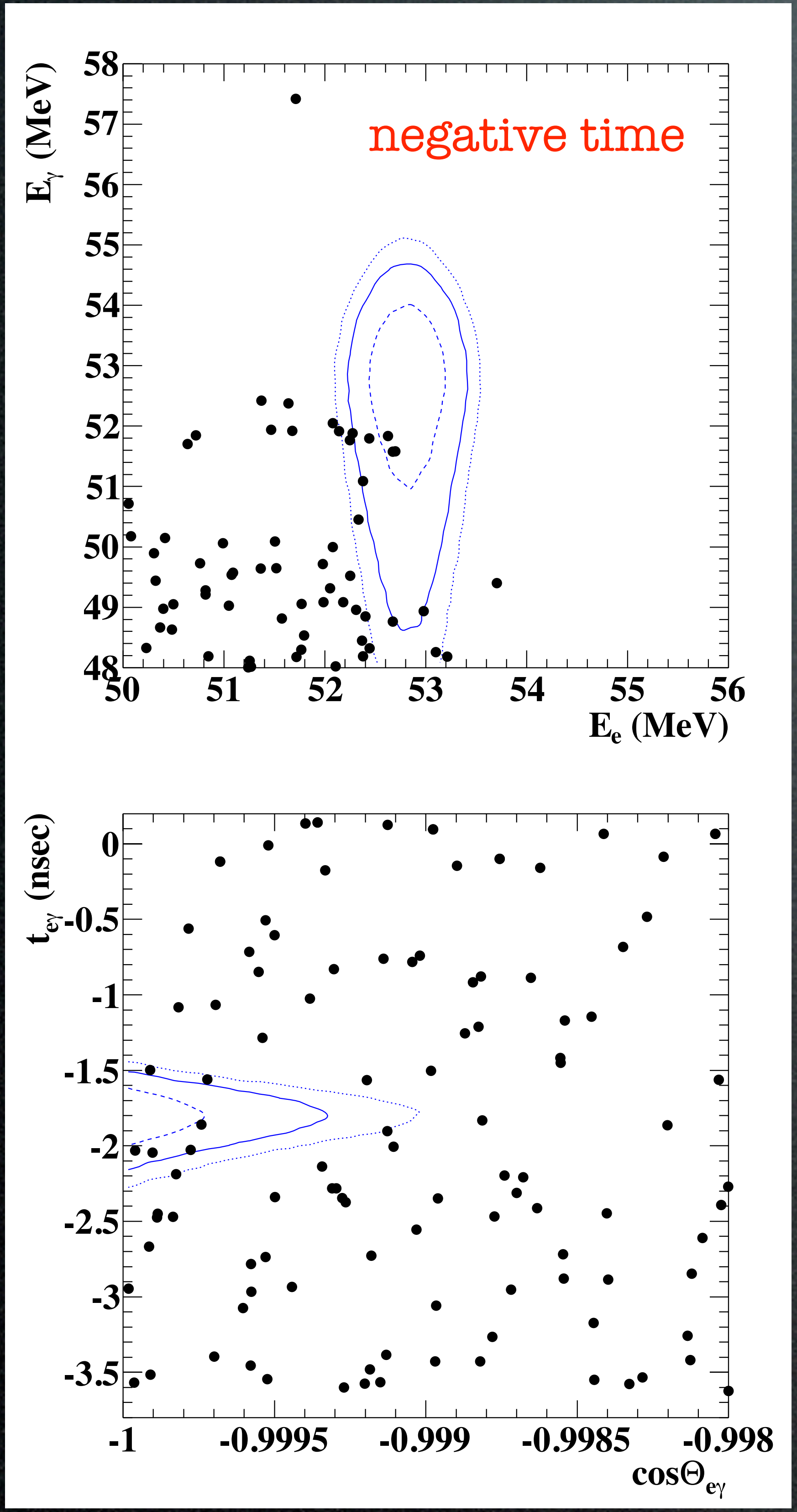
90% C.L.

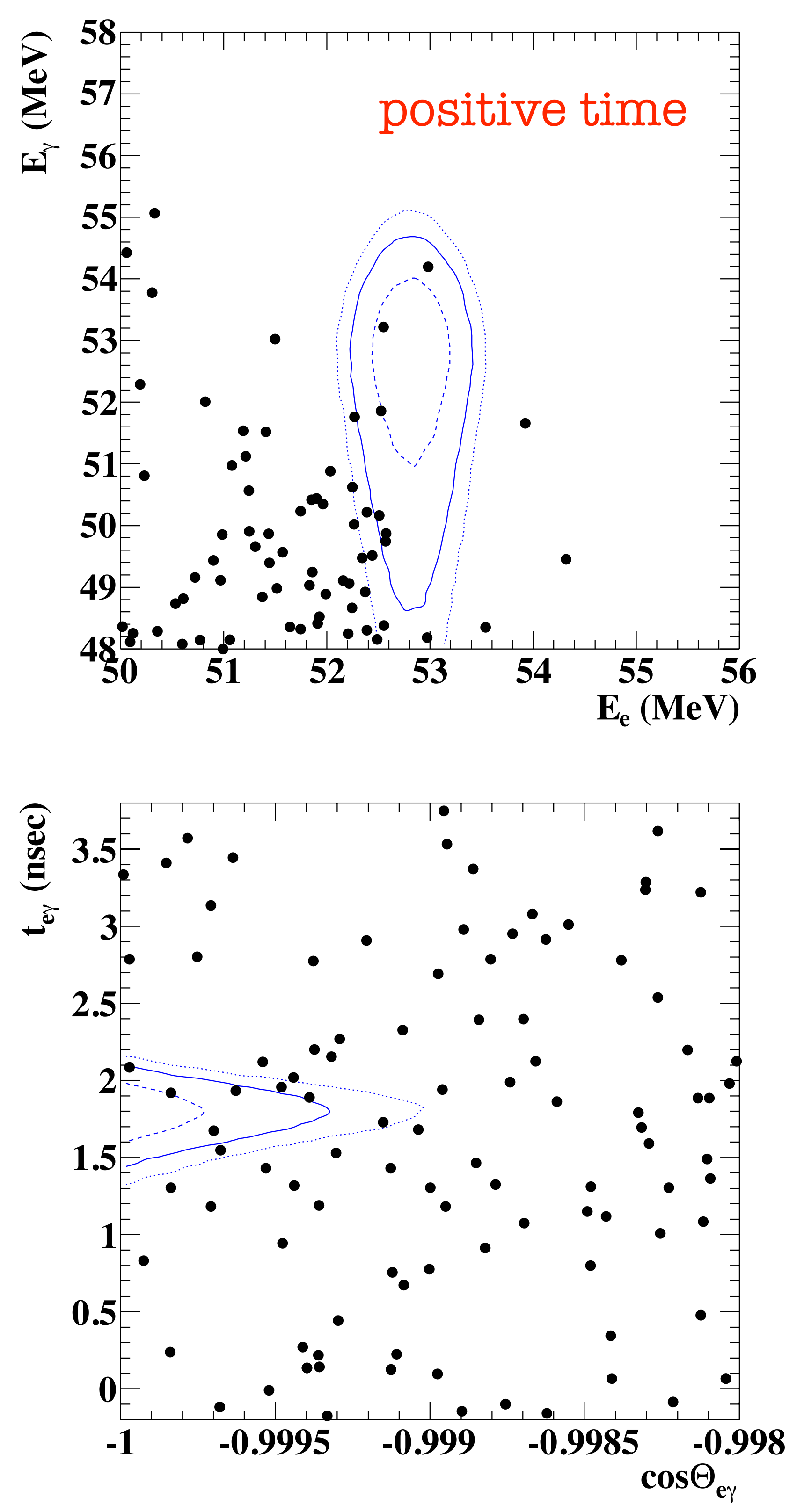
Best Fit BR = 3.2×10^{-12}

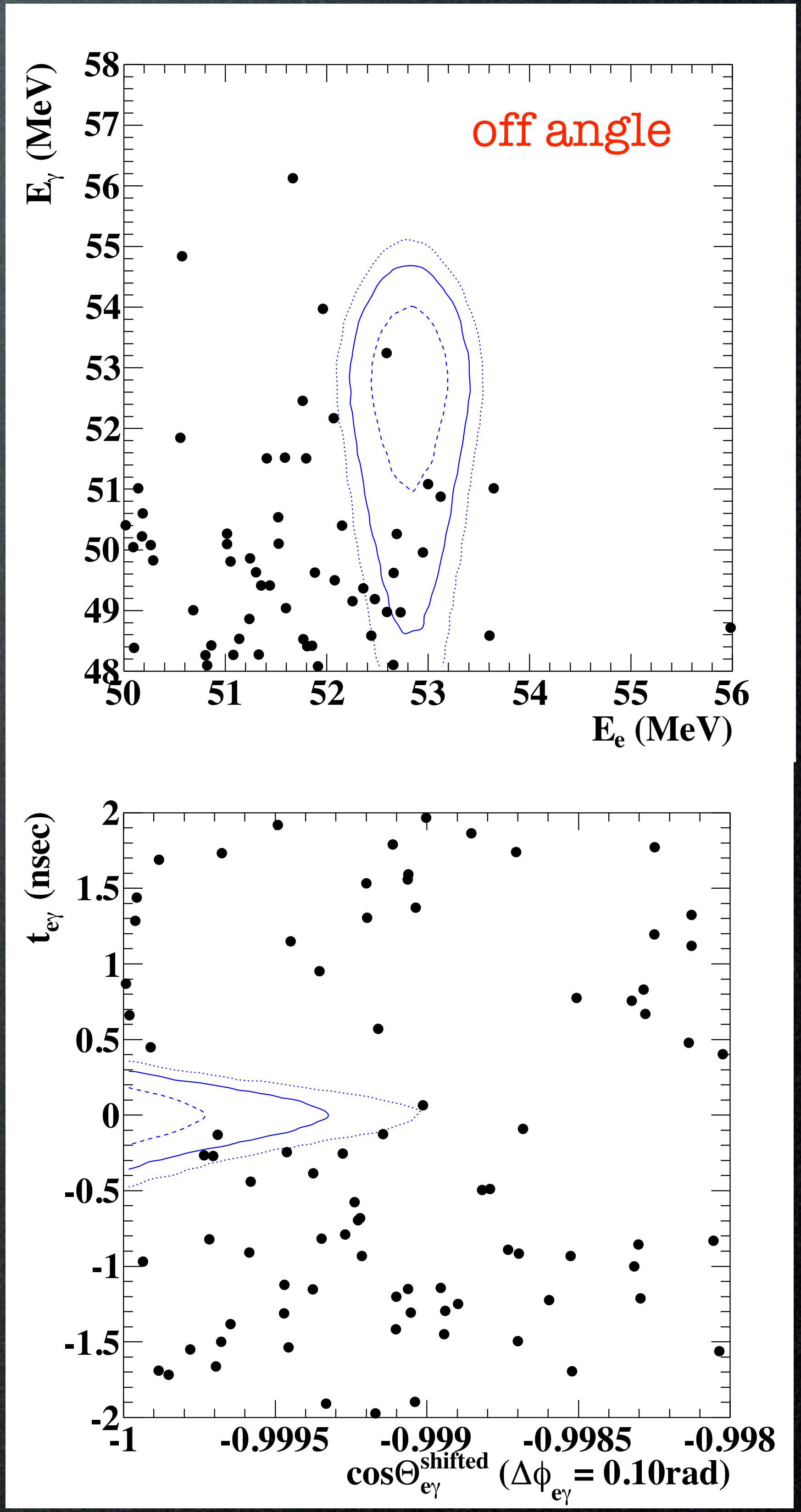
updated 2009 data

2010 data

Side band data analyzed

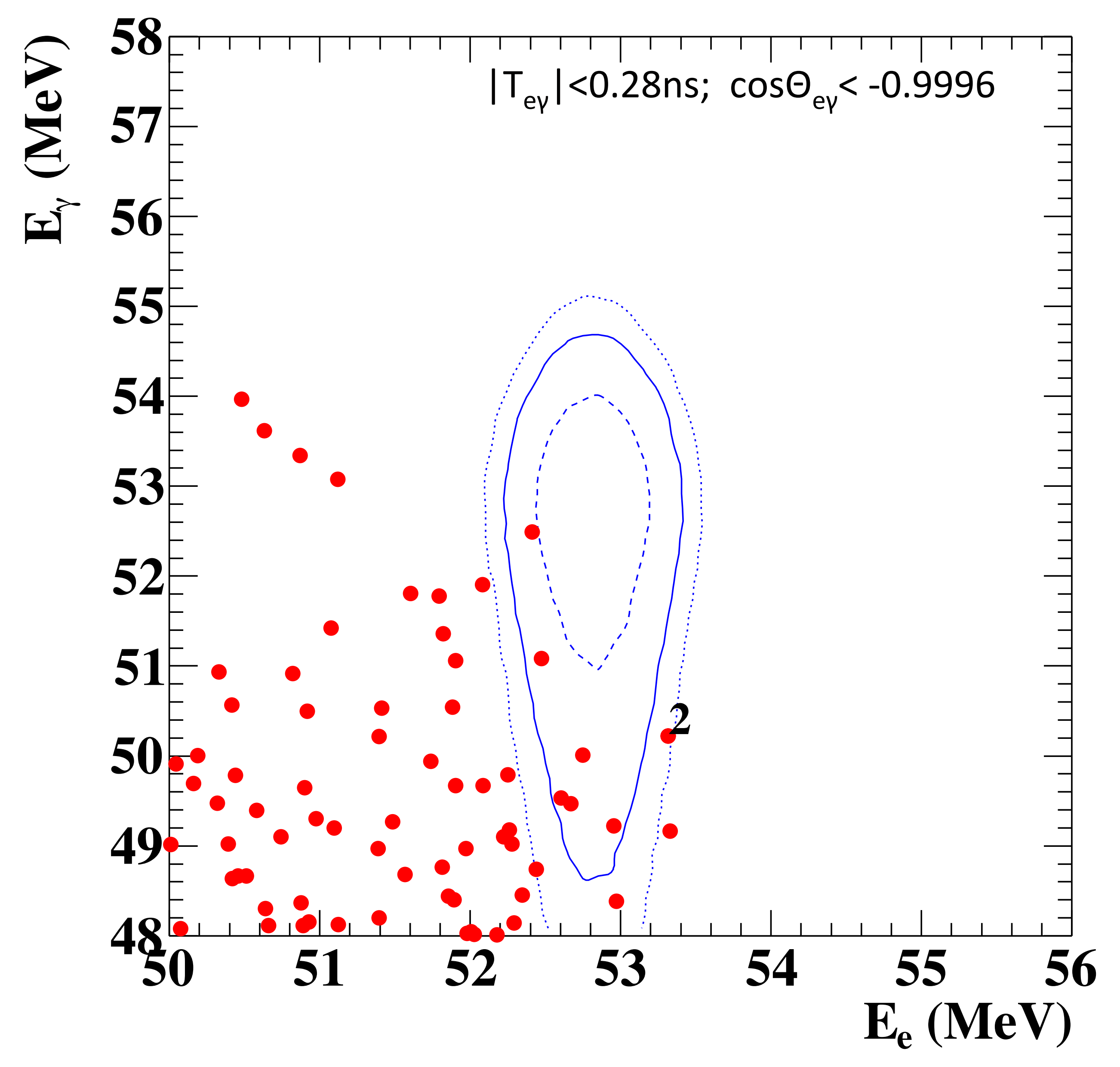


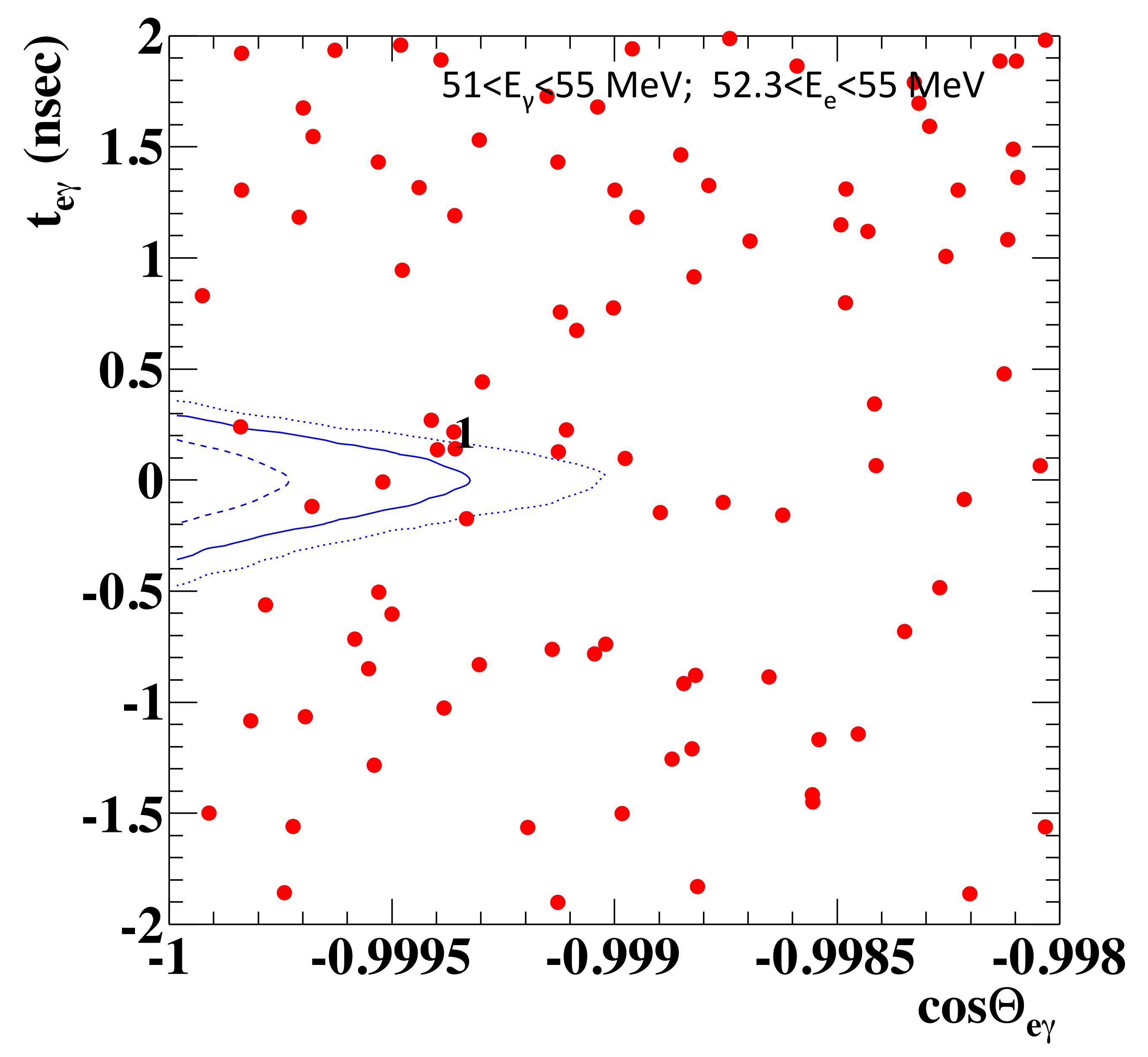




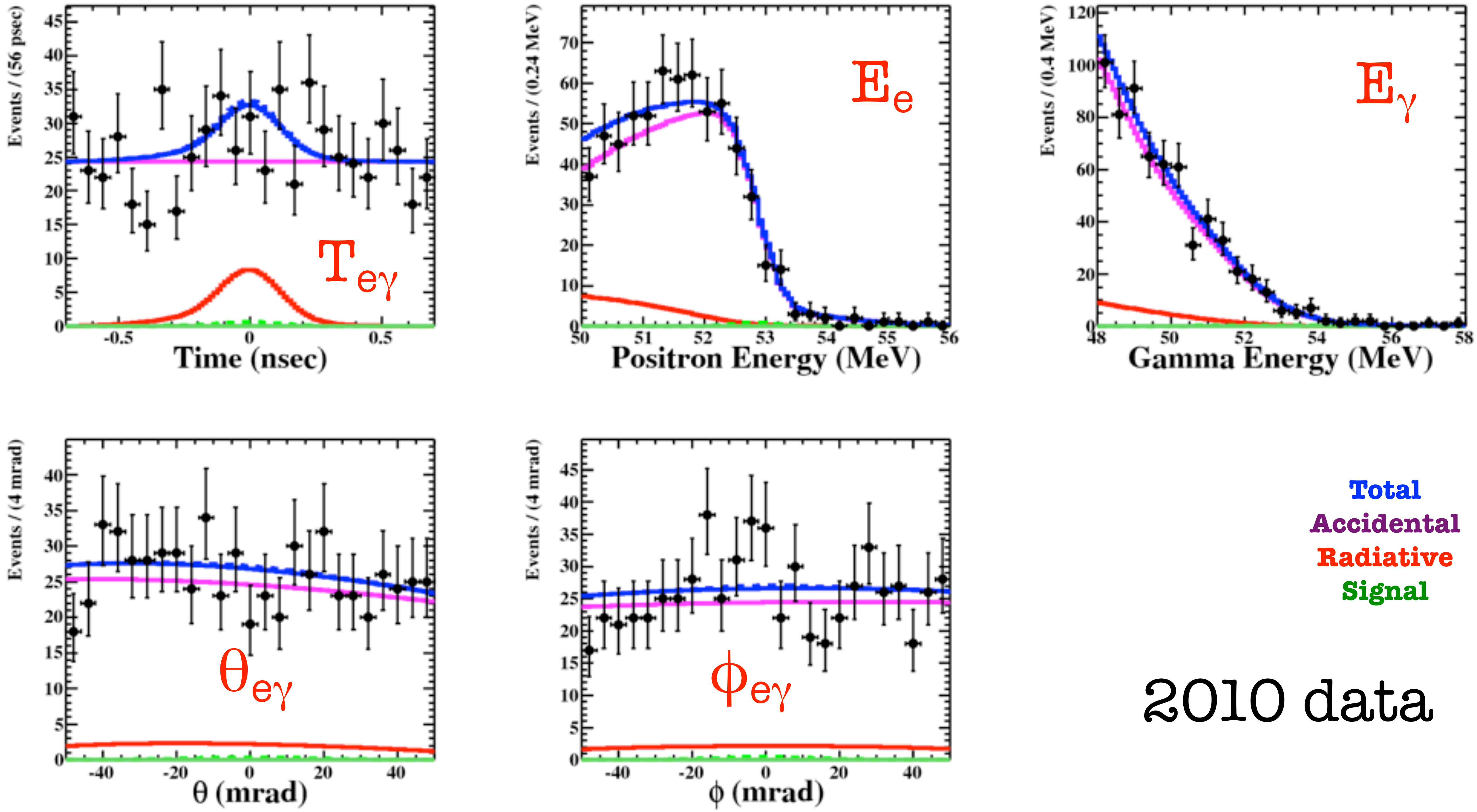
consistent with expected sensitivity = 2.2×10^{-12} @90% C.L.

2010 data unblinded on July 5th



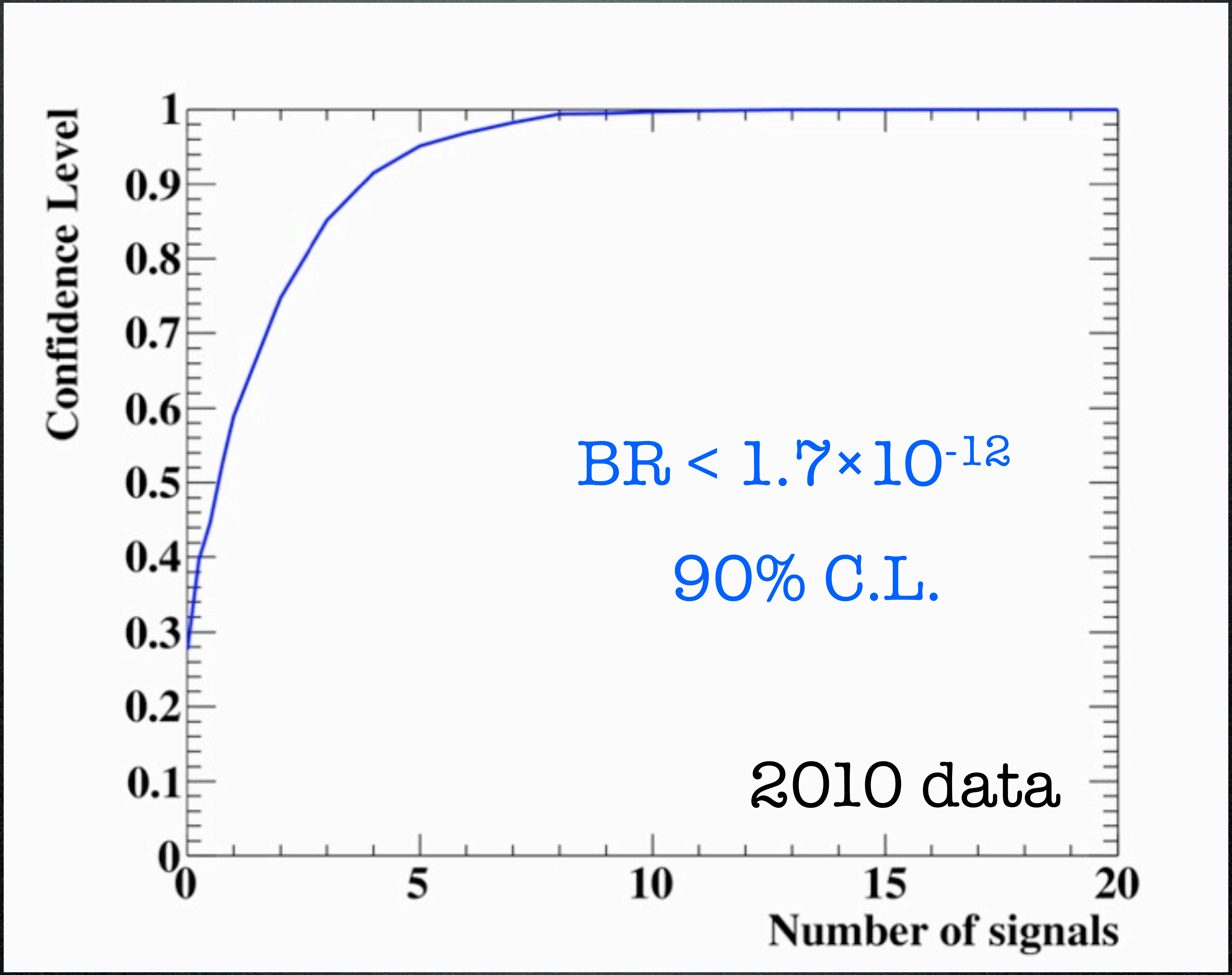


Likelihood Fit - 2010 Data



2010 data

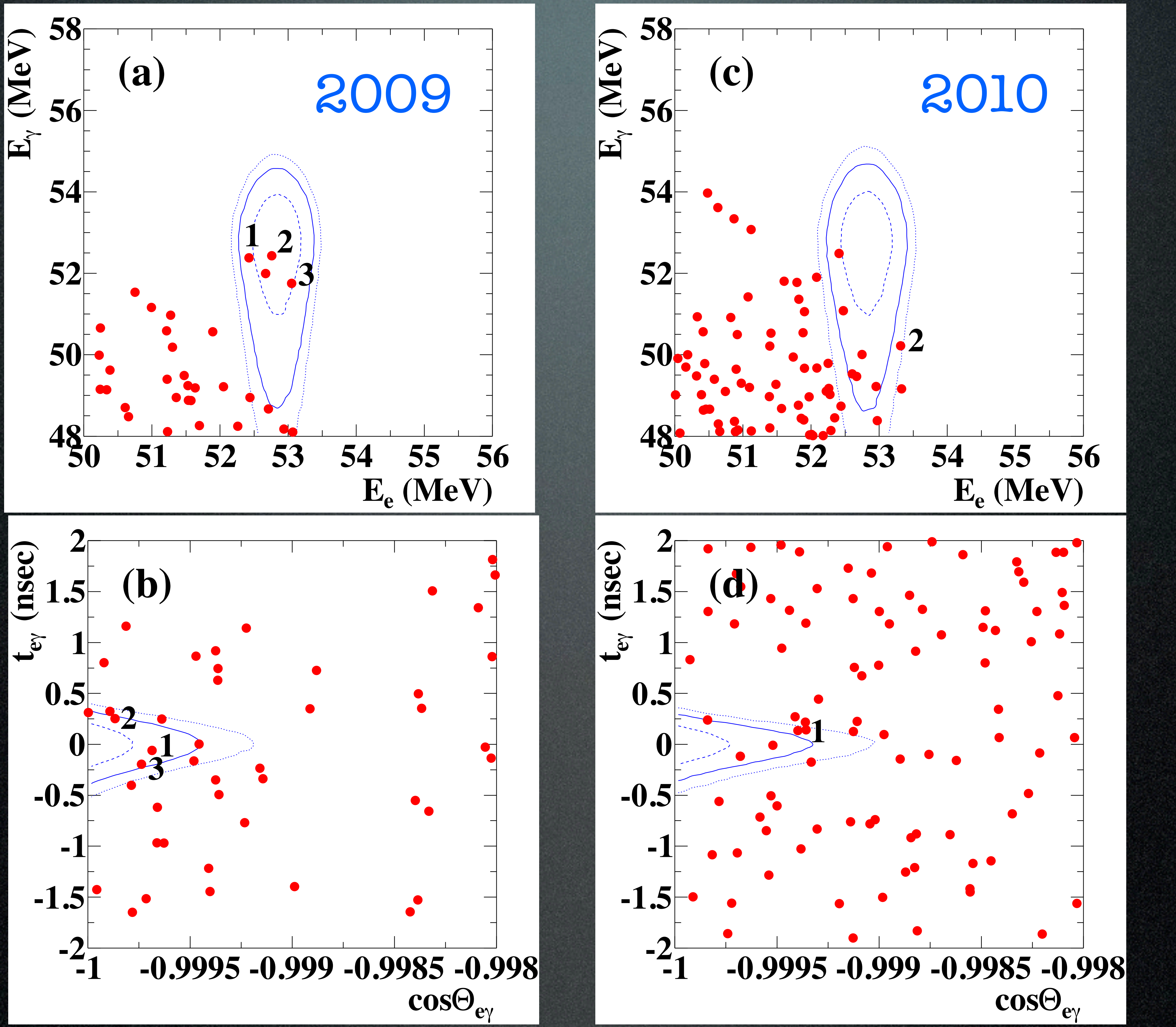
Likelihood Analysis



BR $< 1.7\times10^{-12}$

90% C.L.

2010 data


(a)
2009
E_γ (MeV)
58
56
54
52
50
48
50
51
52
53
54
55
56
E_e (MeV)
1
2
3
(b)
t_eγ (nsec)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.9995
-0.999
-0.9985
-0.998
cosΘ_eγ
2
1
3
(c)
2010
E_γ (MeV)
E_e (MeV)
2
(d)
t_eγ (nsec)
cosΘ_eγ
1

Likelihood Analysis Results

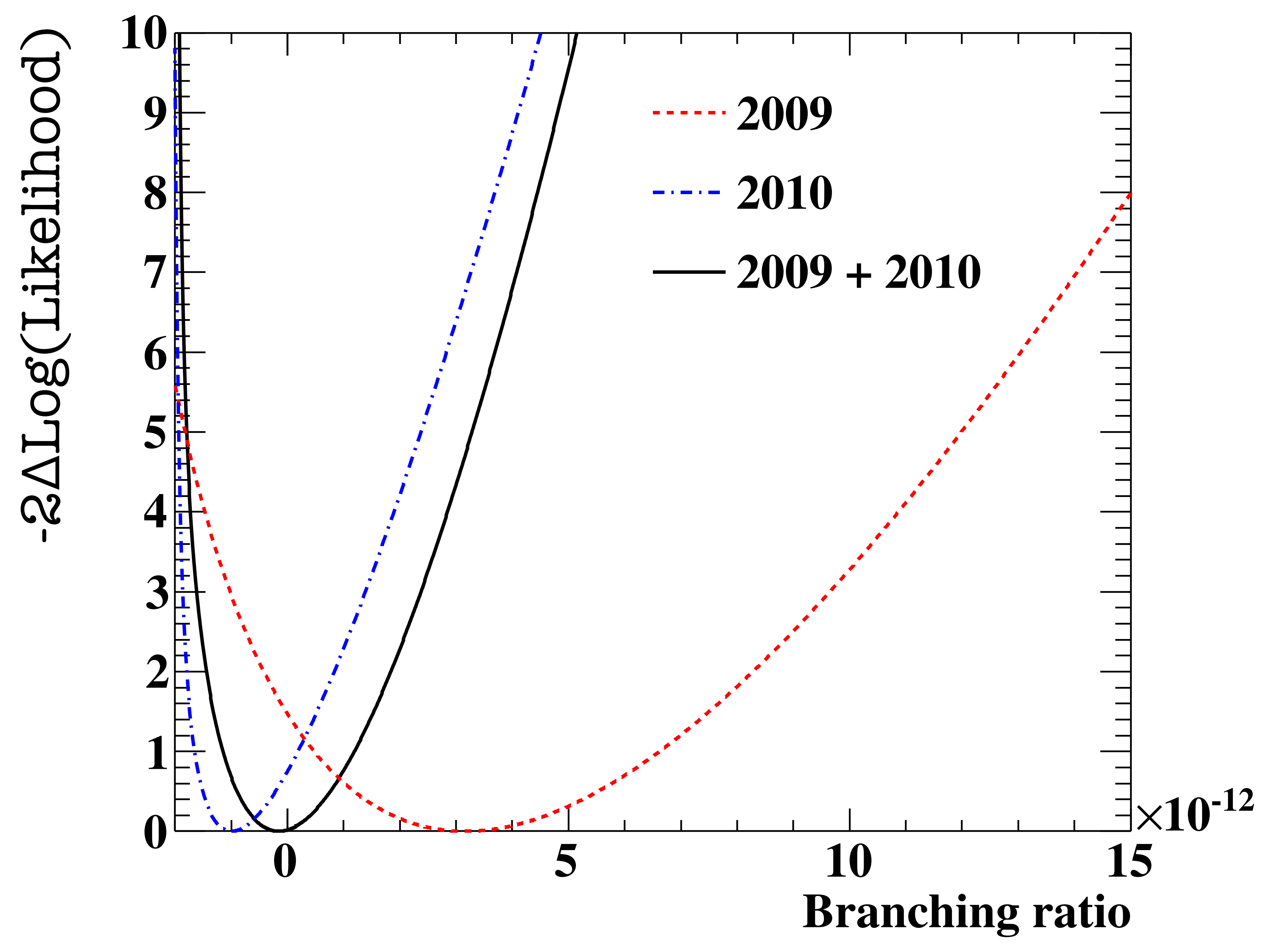
	BR(fit)	LL 90%	UL 90%
2009	3.2×10^{-12}	1.7×10^{-13}	9.6×10^{-12}
2010	-9.9×10^{-13}	--	1.7×10^{-12}
2009+2010	-1.5×10^{-13}	--	$\underline{2.4\times10^{-12}}$

combined result

(2009+2010expected UL = 1.6×10^{-12})

- systematic errors (in total 2% in UL) include:
    - relative angle offsets
    - correlations in e^+ observables
    - normalization

Profile Likelihood Curves



Note these curves are not directly used to derive the U.L. which are obtained in a frequentist approach.

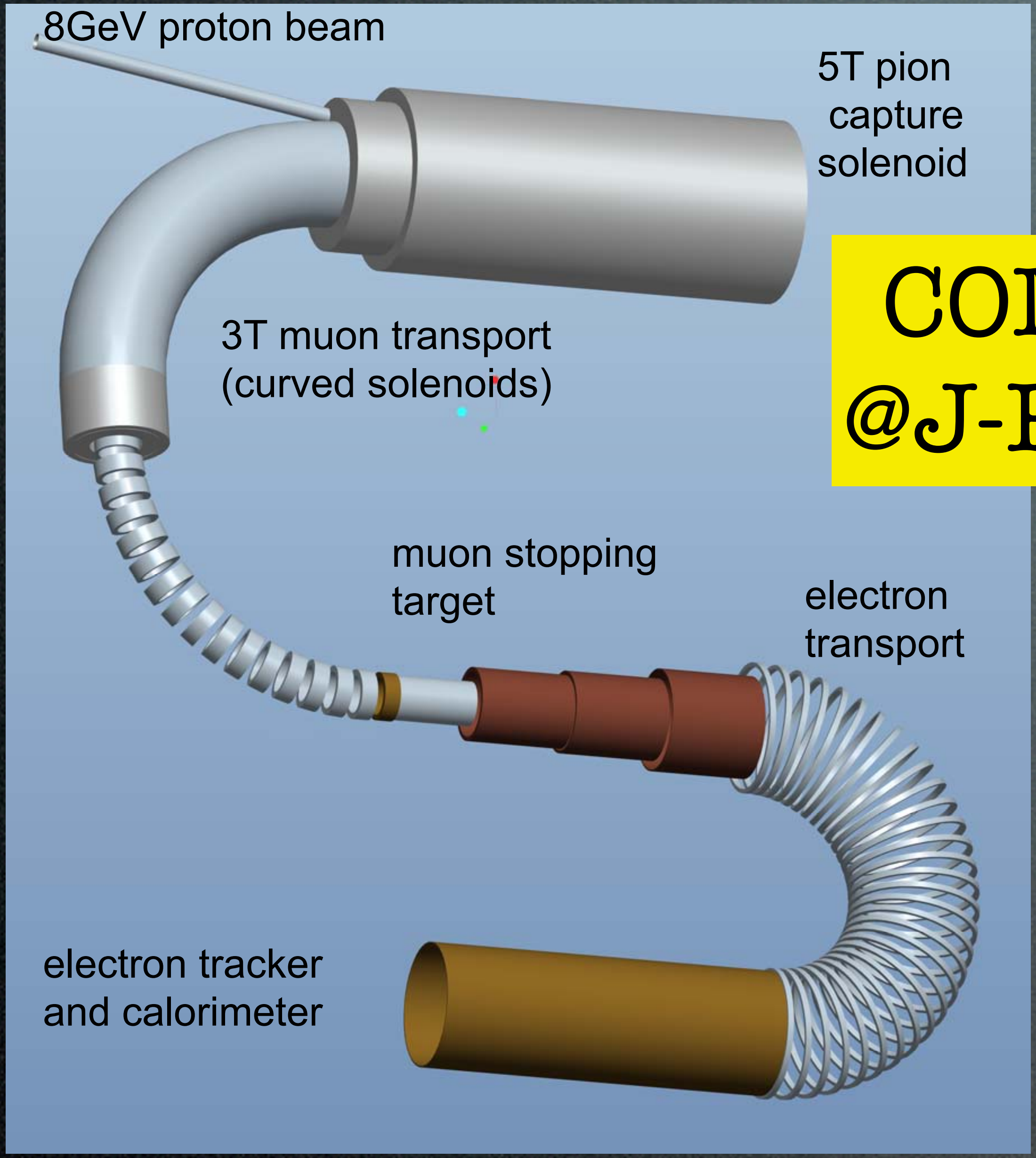
MEG summary

- 2009+2010 data consistent w/ no signal
- New physics is now constrained by 5× tighter upper limit:
  $BR < 2.4\times10^{-12}$ @90% C.L.
  (Preprint will be posted at arXiv today)
- MEG is accumulating more data this and next year to reach $O(10^{-13})$ sensitivity;
  So stay tuned!
- Detector improvements/upgrades

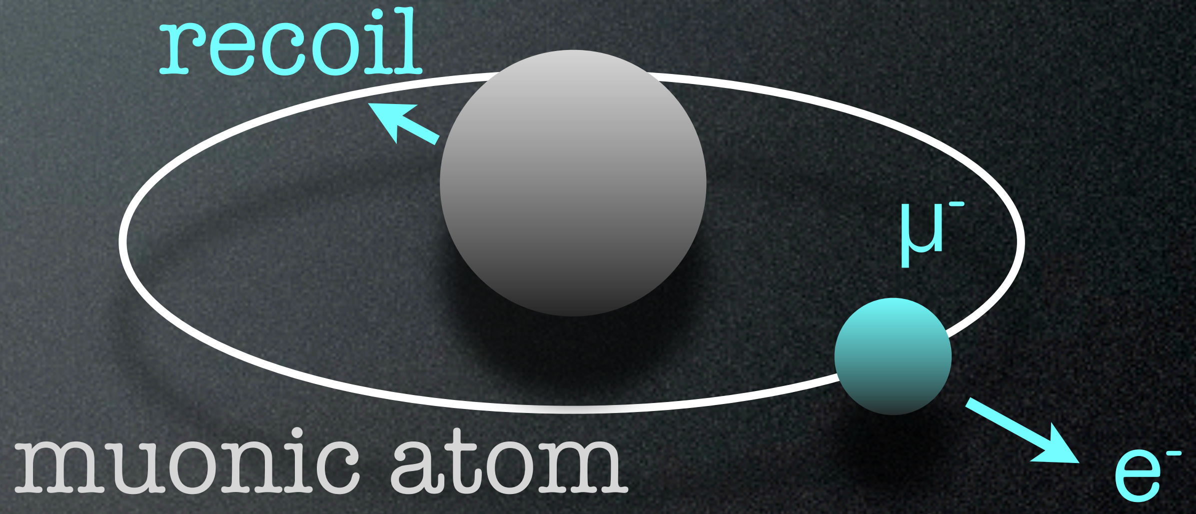
CLFV in further future

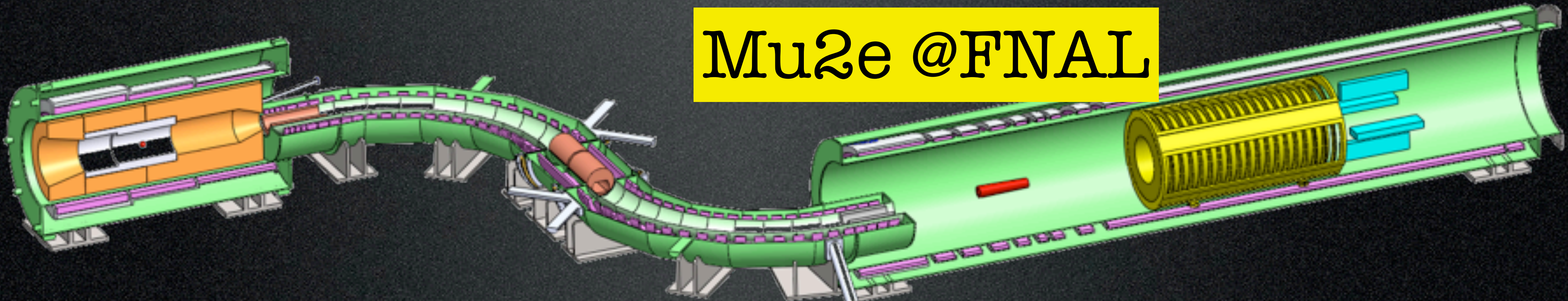
$\mu \rightarrow e$ conversion at 5×10^{-17}

~1/390 × $\mu^+ \rightarrow e^+\gamma$ (Al)



COMET @J-PARC





Mu2e @FNAL

Conclusion

- CLFV & EDM experiments are low energy probes for new physics as powerful as LHC
- MEG is now exploring TeV-scale physics; EDM experiments will follow within next few years
- More to come in the next decade