Status of MEG: an experiment to search for the $\mu^+ \rightarrow e^+ \gamma$ decay

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on behalf of the MEG collaboration

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Outline

- Physics motivation for a $\mu \rightarrow e\gamma$ experiment
- The $\mu \rightarrow e\gamma$ decay
- The detector
  - Overview of sub-detectors
  - Calibration methods
- Status
  - Run 2008
  - Next year(s)
The $\mu \rightarrow e\gamma$ decay

- The theoretical framework has been thoroughly covered by the previous speaker;
- The $\mu \rightarrow e\gamma$ decay in the SM is radiatively induced by neutrino masses and mixings at a negligible level

$$\Gamma(\mu \rightarrow e\gamma) \approx \frac{G_F^2 m_\mu^5}{192\pi^3} \left(\frac{\alpha}{2\pi}\right) \sin^2 2\theta \sin^2 \left(\frac{1.27 \Delta m^2}{M_W^2}\right)$$

$\mu$ – decay \hspace{1cm} $\gamma$ – vertex \hspace{1cm} $\nu$ – oscillation

Relative probability $\sim 10^{-55}$

- All SM extensions enhance the rate through mixing in the high energy sector of the theory (other particles in the loop...)

- Clear evidence for physics beyond the SM
  - (SU(5), SU(10), SUSY...)

\[ B. \]

The unified third generation Yukawa coupling $\lambda(M_G)$
Historical perspective

Each improvement linked to the technology either in the beam or in the detector

Always a trade-off between various elements of the detector to achieve the best “sensitivity”
Connection with neutrino physics was apparent at the beginning of the $\mu \rightarrow e \gamma$ search.

Looking at LFV under a different angle.

To better understand why MEG was designed the way it is we have to understand exactly:

- what are we searching for? signal
- in which environment? background
- which handles can we use for discrimination?
Signal and Background

The accidental background is dominant and it is determined by the experimental resolutions.

<table>
<thead>
<tr>
<th>Exp./Lab</th>
<th>Year</th>
<th>ΔEe/Ee (%)</th>
<th>ΔEγ/Eγ (%)</th>
<th>Δτeγ (ns)</th>
<th>Δθeγ (mrad)</th>
<th>Stop rate (s⁻¹)</th>
<th>Duty cyc. (%)</th>
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<td>3 x 10⁷</td>
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<td>2 x 10⁻¹³</td>
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</table>

FWMH
MEG experimental method

Easy signal selection with $\mu^+$ at rest

$\theta_{e\gamma} = 180^\circ$

$e^+ \mu^+ \gamma$

$E_e = E_\gamma = 52.8$ MeV

- $\mu$: stopped beam of $>10^7 \mu$/sec in a 175 $\mu$m target
- $e^+$ detection
  magnetic spectrometer composed by solenoidal magnet and drift chambers for momentum
  plastic counters for timing
- $\gamma$ detection
  Liquid Xenon calorimeter based on the scintillation light
  - fast: 4 / 22 / 45 ns
  - high $LY$: $\sim 0.8 \times NaI$
  - short $X_0$: 2.77 cm
Machine

- “Sensitivity” proportional to the number of muons observed
- Find the most intense (continuous) muon beam: Paul Scherrer Institut (CH)
- 1.6 MW proton accelerator
  - 2 mA of protons - towards 3 mA (replace with new resonant cavities!)
  - extremely stable
  - > 3 x 10⁸ muons/sec @ 2 mA
πE5 beam line at PSI
Optimization of the beam elements:
• Muon momentum \( \sim 29 \text{ MeV/c} \)
• Wien filter for \( \mu/e \) separation
• Solenoid to couple beam and spectrometer (BTS)
• Degrader to reduce the momentum for a 175 \( \mu \text{m} \) target

\( \mu/e \) separation 11.8 cm (7.2 \( \sigma \))
\( R_\mu \) (exp. on target)
\( \mu \) spot (exp. on target)

\( \sigma_x = 11 \text{ mm} \)
\( \sigma_y = 11 \text{ mm} \)
Target

- **Stop** muons on the **thinnest** possible target 175 μm CH₂:
  - need **low energy** muons (lots of multiple scattering) but...
  - the **MS** of the decaying positron is minimized: precise direction/timing
  - **bremsstrahlung** reduced
  - the **conversion** probability of the photon in the target is negligible

Holes to study position reconstruction resolution
COBRA spectrometer

- The emitted positrons tend to wind in a uniform magnetic field
  - the tracking detector becomes easily "blind" at the high rate required to observe many muons
- A non uniform magnetic field solves the rate problem
- As a bonus: CONstant Bending RAdius

| Uniform field | Constant $|p|$ track | High $p_T$ track |
|---------------|---------------------|------------------|
| CoBRa:        | Constant bending    |                  |
|               | quick sweep away    |                  |

![Diagram showing constant and high $p_T$ tracks with and without uniform magnetic field.]
COBRA spectrometer

Non uniform magnetic field decreasing from the center to the periphery

Compensation coil for LXe calorimeter

$|\vec{B}| < 50 \text{ G}$

- The superconducting magnet is very thin $(0.2 \times X_0)$
- Can be kept at 4 K with GM refrigerators (no usage of liquid helium)
Positron tracker

- Excellent momentum **resolution** at ~50 MeV
- The energy is very low hence the **multiple scattering** is important
  - we tend to **loose** position/energy **resolution**
  - $MS \sim \sigma$
- The **volumes** of the chambers are **independent**
  - too much high-Z gas otherwise ($\text{He/C}_2\text{H}_6$ vs $\text{He}$)
  - find a clever way for a good $z$-reconstruction
Positron Tracker

- 16 chambers radially aligned with 10° intervals
- 2 staggered arrays of drift cells
- 1 signal wire and 2 x 2 vernier cathode strips made of 15 μm kapton foils and 0.45 μm aluminum strips
- Chamber gas: He-C$_2$H$_6$ mixture

- Within one period, fine structure given by the Vernier circle
Drift chambers

- Drift chambers
- Final step
- R Position Resolution - transverse
- R resolution is studied by using CR alignment data.
- Residual "reconstruct - fit"
- Slice by 0.5 mm intervals in drift distance, position dependence of R resolution is studied.
- 170~350 micron in sigma is achieved (good DC).
Timing Counter

- Must give excellent rejection
- Two layers of scintillators:
  - Outer layer, read out by PMTs: timing measurement
  - Inner layer, read out with APDs at 90°: z-trigger
- Obtained goal $\sigma_{\text{time}} \sim 40$ psec (100 ps FWHM)

<table>
<thead>
<tr>
<th>Exp. application</th>
<th>Counter size (cm)</th>
<th>Scintillator</th>
<th>PMT</th>
<th>$\lambda_{\text{an}}$ (cm)</th>
<th>$\sigma_{\text{meas}}$</th>
<th>$\sigma_{\text{exp}}$</th>
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Best existing TC
The calorimeter

- γ Energy, position, timing
- Homogeneous 0.8 m$^3$ volume of liquid Xe
  - 10% solid angle
  - 65 < r < 112 cm
  - |cosθ| < 0.35  |ϕ| < 60°
- Only scintillation light
- Read by 848 PMT
  - 2” photo-multiplier tubes
  - Maximum coverage FF (6.2 cm cell)
  - Immersed in liquid Xe
  - Low temperature (165 K)
  - Quartz window (178 nm)
- Thin entrance wall
- Singularly applied HV
- Waveform digitizing @2 GHz
  - Pileup rejection
Calorimeter construction
Liquid Xenon was chosen because of its unique properties among radiation detection active media.

- Z=54, ρ=2.95 g/cm$^3$ ($X_0$=2.7 cm), $R_M$=4.1 cm
- High light yield (similar to NaI)
  - 40000 phe/MeV
- Fast response of the scintillation decay time
  - $\tau_{\text{singlet}}$ = 4.2 ns
  - $\tau_{\text{triplet}}$ = 22 ns
  - $\tau_{\text{recomb}}$ = 45 ns
- Particle ID is possible
  - $\alpha$ ~ singlet+triplet, $\gamma$ ~ recombination
- Large refractive index n = 1.65
- No self-absorption ($\lambda_{\text{Abs}}=\infty$)
Xenon purity

- Energy resolution strongly depends on absorption.
- We developed a method to measure the absorption length with alpha sources.
- We added a purification system (molecular sieve + gas getter) to reduce impurities below ppb in gas and liquid.
Trigger

- 100 MHz waveform digitizer on VME boards that perform online pedestal subtraction
- Uses:
  - $\gamma$ energy
  - $e^+$ - $\gamma$ time coincidence
  - $e^+$ - $\gamma$ collinearity
- Built on a FADC-FPGA architecture
- More performing algorithms could be implemented

[$\bullet$] Beam rate $\sim 3 \times 10^7$ s$^{-1}$
[$\bullet$] Fast LXe energy sum $> 45$MeV $2 \times 10^3$ s$^{-1}$
  - $\gamma$ interaction point (PMT charge)
  - $e^+$ hit point in timing counter
[$\bullet$] time correlation $\gamma - e^+$ 100 s$^{-1}$
[$\bullet$] angular correlation $\gamma - e^+$ 10 s$^{-1}$

FitCharge energy Thr=815

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<tr>
<th>hf0</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
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<td>13</td>
<td>8.1</td>
</tr>
</tbody>
</table>
**Readout electronics**

2 GHz waveform digitization for all channels

- **DRS chip** (Domino Ring Sampler)
  - Custom sampling chip designed at PSI
  - 2 GHz sampling speed @ 40 ps timing resolution
  - Sampling depth 1024 bins for 8 channels/chip
  - Data taken in charge exchange test to study pile-up rejection algorithms
For (almost) all channels, for each sub-detector we have two waveform digitizers with complementary characteristics.
It is understood that in such a complex detector a lot of parameters must be constantly checked.

We are prepared for redundant calibration and monitoring.

Single detector
- PMT equalization for LXe and TIC
- Inter-bar timing (TIC)
- Energy scale

Multiple detectors
- relative timing
**Calibrations**

**Proton Accelerator**

- Li(p,γ)Be
- LiF target at COBRA center
- 17.6MeV γ
- ~daily calib.
- also for initial setup

**Alpha on wires**

- PMT QE & Att. L
- Cold GXe
- LXe

**Xenon Calibration**

- π^0 → γγ
- π^0 → γγ (55MeV, 83MeV)
- π^- + p → γ + n (129MeV)
- LH2 target

**Laser**

- relative timing calib.

**LED**

- PMT Gain
- Higher V with light att.

**Nickel γ Generator**

- Illuminate Xe from the back
- Source (Cf) transferred by comp air → on/off

**µ radiative decay**

- Lower beam intensity < 10^7
- Is necessary to reduce pile-ups
- A few days ~ 1 week to get enough statistics
The calorimeter is equipped with blue LEDs and alpha sources.

Measurements of light from LEDs:

\[ \sigma^2 = g (q - q_0) + \sigma_0^2 \]

Absolute knowledge of the GAIN of ALL PMTs within few percents

\[ g = 10^6 \] for a typical HV of 800 V

QEs determined by comparison of alpha source signal in cold gaseous xenon and MC determined at a 10% level.
\(\alpha\)-sources in Xe

- Specially developed Am sources:
  - 5 dot-sources on thin (100 µm) tungsten wires
- SORAD Ltd. (Czech Republic)

\[ R_{\alpha} = 7 \text{ mm} \]
\[ d_{\text{wire}} = 100 \text{ um} \]

\[ R_{\alpha} = 40 \text{ um} \]
\[ d_{\text{wire}} = 100 \text{ um} \]
α-sources in Xe

- Used to
  - QE determination
  - Monitor Xe stability
  - Measure absorption
  - Measure Rayleigh scattering

GXe: MC & data
LXe: MC & data

λ_{Abs} > 300 cm

Preliminary
Energy scale calibrations

- A reliable result depend on a constant calibration and monitoring of the apparatus
- We are prepared for continuous and redundant checks
  - different energies
  - different frequency

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy</th>
<th>Frequency</th>
</tr>
</thead>
</table>
| Charge exchange    | $\pi^- p \rightarrow \pi^0 n$  
$\pi^0 \rightarrow \gamma \gamma$ | 55, 83, 129 MeV  
year - month |
| Proton accelerator | $^7\text{Li}(p, \gamma_{17.6})^8\text{Be}$ | 14.8, 17.6 MeV  
week |
| Nuclear reaction   | $^{58}\text{Ni}(n, \gamma_9)^{59}\text{Ni}$ | 9 MeV  
daily |
| Radioactive source | $^{60}\text{Co, AmBe}$ | 1.1 - 4.4 MeV  
daily |
CEX measurement

\[
\pi^- p \rightarrow \pi^0 n
\]
\[
\pi^0 \rightarrow \gamma \gamma
\]

- The monochromatic spectrum in the pi-zero rest frame becomes flat in the Lab
- In the back-to-back configuration the energies are 55 MeV and 83 MeV
- Even a modest collimation guarantees a sufficient monochromaticity
- Liquid hydrogen target to maximize photon flux
- An “opposite side detector” is needed (NaI array)
• In the back-to-back raw spectrum we see the correlation
  • $83 \text{ MeV} \Leftrightarrow 55 \text{ MeV}$
  • The $129 \text{ MeV}$ line is visible in the NaI because Xe is sensitive to neutrons (9 MeV)
The Cockcroft-Walton accelerator of the MEG experiment

...should deserve a presentation on its own!
The Cockcroft-Walton is an extremely powerful tool, installed for monitoring and calibrating all the MEG experiment.

Protons of up to 1 MeV on Li or B:
- Li: high rate, higher energy photon
- B: two (lower energy) time-coincident photons

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Peak energy</th>
<th>$\sigma$ peak</th>
<th>$\gamma$-lines</th>
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</thead>
<tbody>
<tr>
<td>Li(p,\gamma)Be</td>
<td>440 keV</td>
<td>5 mb</td>
<td>(17.6, 14.6) MeV</td>
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<tr>
<td>B(p,\gamma)C</td>
<td>163 keV</td>
<td>2 x 10^{-1} mb</td>
<td>(4.4, 11.7, 16.1) MeV</td>
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</table>
CW - daily calibration

- This calibration is performed every other day
- Muon target moves away and a crystal target is inserted
- Hybrid target ($\text{Li}_2\text{B}_4\text{O}_7$)
- Possibility to use the same target and select the line by changing proton energy

When p energy increases B lines appear
Daily monitoring

- Monitor Xe light yield
- liquid/gas purification studies
- stability studies

< 1% knowledge of l.y. and energy scale

**Diagram:**
- Alpha and Lithium peak as a function of the date
  - Li line
  - $\alpha$-peak
  - $\pi^0$ test
  - Study of systematics

**Graph:**
- Measured charge (a.u.) vs. Energy (MeV)
  - CW
  - $\pi^0$ data
  - Preliminary
CW and timing counter

- The simultaneous emission of two photons in the Boron reaction is used to
  - determine relative timing between Xe and TIC
  - Inter-calibrate TIC bar (LASER)

![Graph showing Xe energy vs. TICP cluster energy with marked 4.4 and 11.6 MeV Compton Edges.]

![Graph showing offset (ns) vs. bar # with data points and error bars.]

2008: First run of the experiment
(... after a short engineering run in 2007)

Time schedule

Winter - Spring
- detector dismantling
- improvement (after run 2007)
- re – installation

Spring - Summer
- LXe purification
- CW and $\pi^0$ calibration
- beam line setup

September – December
- MEG run
- short $\pi^0$ calibration

Running conditions

MEG run period
- Live time ~50% of total time
- Total time ~ 7x10^6 s
- $\mu$ stop rate: 3x10^7 $\mu$/s
- Trigger rate 6.5 ev/s ; 9 MB/s

The missing 50% is composed of:
- 17% DAQ dead time
- 14% programmed beam shutdowns
- 7% low intensity Radiative muon decay runs (RMD)
- 11% calibrations
- 2% unforeseen beam stops
Muons on target

We also took RMD data once/week at reduced beam intensity

Programmed beam shutdowns

Cooling system repair

Air test in COBRA
From the LXe single event trigger we do not observe any unforeseen background in the µ-beam.

• Both the spectrum shape and the absolute rate are correctly reproduced
  • $3 \times 10^7 \mu^+/s$ stopping rate
  • the $\gamma$ detection efficiency is understood
  • cosmic muons and event pile-up are under control
Xe light yield

- Large light yield increase (40%) during MEG run
- Approaching the expected 27000 ph.el.
- LY change monitored with the calibration system
- Different time constants for $\alpha$ and $\gamma$ scintillation pulses (as it should be)

**17.6 MeV peak as a function the date**

- $\pi^0$ runs
- 40%
- purification & stability test
- $\mu$ data taking

- = liq.phase purif.
- = gas purif.
Energy resolution

- 180° coincidence selects 55 MeV and 83 MeV in LXe and NaI
- Resolution evaluated on all calorimeter surface
- Not yet as expected but we are improving it at analysis level
- Background level quite different from $\mu \rightarrow e\gamma$
- pile-up

\[ \langle \text{FWHM} \rangle = 5\ldots6\% \]
In-run changes

- Despite the continuous change in LXe light yield we could follow
  - how the performance changes during the run
  - the energy resolution as a function of the time
  - the efficiencies

- Information to extract systematics
  - rescale all runs

- Refinements in progress

Li peak position

**FWHM ~ 7%**

**σR~ 3%**
Intrinsic time resolution

\[ T_0 = T_{iTw} - \frac{\rho_{\text{int}}}{c} - \frac{|\vec{R}_{\text{int}} - \vec{P}_{i}|n_{Xe}}{c} - T_{PMT} - T_{dly} \]

- Divide the PMTs in **two groups**
- Odd / Even
- Top / Bottom
- \( t_a = \sum t_{2k} \frac{Q_{2k}}{\Sigma Q} \quad t_b = \sum t_{2k+1} \frac{Q_{2k+1}}{\Sigma Q} \)
- \( \sigma_t = \text{VAR}(\frac{1}{2}(t_a - t_b)) \)
- The **two analyses** agree well
- \( \sigma_t(\text{intrinsic}) \approx 50 - 60 \text{ ps at 52.8 MeV} \)
- still some dependence on **cuts**, geometry...

![Diagram](image)
TC time resolution

\[ \Delta T = T_A - T_B \]

- Not yet corrected for positron track length
- Upper limits on \( \sigma \sim 60-90 \text{ ps} \)
- Time-walk correction applied

- Stability over the run period
- Further improvement in 2009 with the new digitizers (DRS4)

\[ \Delta T_{\gamma\gamma} \] (ns)

\[ \alpha \Delta T_{\gamma\gamma} / \sqrt{2} \] [ns]

- Preliminary

Runs 24xxx
Runs 25xxx
Runs 26xxx
Runs 27xxx
Runs 29xxx
Runs 30xxx
Runs 31xxx

\[ \Delta T_{\gamma\gamma} \] (ns)

relative to bar 17

bar #
DCH performance

- Few DCH experienced high voltage (HV) trips
- The tracking efficiency & resolution were not optimal
- Resolution evaluated on the edge of the positron (Michel) spectrum

Reconstructed Spectrum (MEG Trig.)

$E_{\text{edge}} = 52.81 \pm 0.10$ MeV/c

$\alpha_p = 488 \pm 62$ keV/c

“bad” chamber planes

Preliminary
DCH HV performance

- The chambers are operated in He/ethane 50%/50% mixture
- They are immersed in He atmosphere

- In June-July the situation was ok:
  - 30 / 32 planes >1800 V
  - 2 planes showed problems right from the beginning

- In September, after the $\pi^0$ calibration, the situation started to deteriorate but we decided to start anyhow data taking (September 12th)

- During MEG run (September – December):
  - further deterioration of HV performance

- At the end of MEG run
  - 11 / 32 planes >1800 V
  - 7 / 32 planes 1700-1800 V

- The problem is tricky because it does not show up immediately but only after some time: helium penetration in HV distribution
• The fraction of events with at least one reconstructed track at high momentum is a measure of relative (not absolute) tracking efficiency

Average absolute efficiency > 30%
DCH repair

1) The chambers are dismounted and operated in laboratory in He atmosphere

2) The potting glue for the HV protection was inadequate: change on all chamber to epoxy glue

3) The PCB has vias close to ground plane, partially filled with araldite to fix PCB to the Carbon fiber frame: new PCB design

4) Open all chambers, replace the PCB and the wires, saving the cathodes

5) Test of the chambers in laboratory as soon as they are ready

Estimated time: ready to mount in August
Analysis

- We decided to adopt a blind-box likelihood analysis strategy
- The blinding variables are $E_\gamma$ and $\Delta t_{\gamma}$
- Usage of the sidebands justified by the fact that our main background comes from accidental coincidences

PDF

- **Signal**: from detector resolutions
- **Accidental background**: from data
- **Prompt background**: from simulation and from RMD data sample
Radiative decay signal

The radiative $\mu$-decay events are:

- good sample to check the LXe-TC timing
- good sample to control the efficiencies
- the second source of background: we want to validate our pdf

Search in dedicated low $\mu$-beam intensity runs

Event selection
1. Reject cosmic muons
2. Reconstructed track matching the TC
3. LXe energy $>30$ MeV
   
   \[
   S/N \text{ ratio} = 0.8
   \]
4. Kinematical constraint
   
   \[
   S/N \text{ ratio} = 2.8
   \]

\[
M_{2\nu}^2 = E_{2\nu}^2 - \hat{p}_{2\nu}^2 = (M_\mu - E_e - E_\gamma) - (\hat{p}_e + \hat{p}_\gamma)
= M_\mu^2 - 2(E_e + E_\gamma) M_\mu + 2E_e E_\gamma \sin^2 (\theta / 2) \geq 0
\Rightarrow xy \sin^2 (\theta / 2) \geq x + y - 1
\]

实物：428 events

\[
\mu \rightarrow e\bar{\nu}\nu\gamma
\]
Radiative $\mu$-decay signal

- The observed number is compatible with the estimated detectors efficiencies
- The measured angular dependence of $e^+ \gamma$ pair is in agreement with the expectations

Search in normal MEG runs

1. Reject cosmic muons
2. Reconstructed track matching the TC
3. Kinematical constraint
4. LXe energy $>30$ MeV

LXe energy $>40$ MeV

$\sigma(\Delta t) = 178 \pm 29$ ps

$\sigma(\Delta t) = 114 \pm 30$ ps
# Sensitivity for 2008 run

**Efficiencies**

<table>
<thead>
<tr>
<th>(%)</th>
<th>“Goal”</th>
<th>2008 Provisional Lower Limits</th>
<th>2009 Provisional Prospects</th>
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</thead>
<tbody>
<tr>
<td><strong>Gamma</strong></td>
<td>&gt; 40</td>
<td>&gt; 50 x (65 x 85)</td>
<td>&gt; 50 x 90</td>
</tr>
<tr>
<td><strong>e+</strong></td>
<td>65</td>
<td>30 x 40</td>
<td>85 x 50</td>
</tr>
<tr>
<td><strong>Trigger</strong></td>
<td>100</td>
<td>100 x 99 x 80</td>
<td>&gt; 99</td>
</tr>
<tr>
<td><strong>Selection</strong></td>
<td>90⁴ = 66</td>
<td>90³ x 95 = 69</td>
<td>69</td>
</tr>
<tr>
<td><strong>DAQ</strong></td>
<td>(&gt; 90 )</td>
<td>&gt; 80 x 93</td>
<td>&gt; 90 x 99</td>
</tr>
<tr>
<td><strong>Calibration Run etc</strong></td>
<td>(&gt; 95 )</td>
<td>~70</td>
<td>90</td>
</tr>
<tr>
<td><strong>Running Time (week)</strong></td>
<td>100*</td>
<td>11.5**</td>
<td>11.5</td>
</tr>
<tr>
<td><strong>Single Event Sensitivity (10⁻¹³)</strong></td>
<td>0.5</td>
<td>&lt; 30 - 50</td>
<td>&lt; 3 - 5</td>
</tr>
</tbody>
</table>

*1 week = 4x10⁸ sec (66%)*  
**CEX runs not included**

**CAUTION:** All 2008 numbers are provisional.

Still lots of things to learn from the data:
- Blue numbers likely to change
- Grey numbers may vanish
## Resolutions for 2008 run

Resolutions are improving as we understand the detectors better.

<table>
<thead>
<tr>
<th>(in sigma)</th>
<th>“Goal”</th>
<th>2008 Provisional</th>
<th>2009 Provisional Prospects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Energy (%)</td>
<td>1.2 - 1.5</td>
<td>&lt; 2.3</td>
<td>&lt; 1.7</td>
</tr>
<tr>
<td>Gamma Timing (ps)</td>
<td>65</td>
<td>&lt; 100*</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Gamma Position (mm)</td>
<td>2 - 4</td>
<td>5 - 6.5</td>
<td>5</td>
</tr>
<tr>
<td>e+ Momentum (%)</td>
<td>0.35</td>
<td>1.5 - 2.0</td>
<td>0.7 - 0.8</td>
</tr>
<tr>
<td>e+ Timing (ps)</td>
<td>45</td>
<td>&lt; 60 - 90</td>
<td>60</td>
</tr>
<tr>
<td>e+ Angle (mrad)</td>
<td>4.5</td>
<td>9 - 18</td>
<td>11</td>
</tr>
<tr>
<td>mu Decay Point (mm)</td>
<td>0.9</td>
<td>3 - 4</td>
<td>2</td>
</tr>
<tr>
<td>Gamma - e+ Timing (ps)</td>
<td>80</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Background (10^{-13})</td>
<td>0.1 - 0.3</td>
<td>-</td>
<td>&lt; 0.6 - 3</td>
</tr>
</tbody>
</table>

* clock error of ~80ps included

**CAUTION: All 2008 numbers are provisional**
Conclusion

• Despite 2008 run suffered from detector instabilities we demonstrated our ability in seeing $\mu \rightarrow e \gamma$ events (IB process observed in normal data taking)

• We are gaining better knowledge of our detectors systematics: resolutions are (almost daily) improving

• We are working to have analysis results on 2008 data ready by this summer

• We are making all efforts to reach stable DCH operation for the 2009 run: we believe the strategy presented will eliminate HV discharges

• We will need to run until the end of 2011 for reaching the target sensitivity
A 2008 candidate event

• A good hint for this year!

Thanks
Back-up
DC: PCB nella testbox

since Fri nov 7th: HV in helium atmosphere (~99% from reading $O_2$ sensors)
Selected results from 2007 engineering run

• We are presently taking data but I cannot show you any plot from this year “physics” data set

• Our strategy is masking some of the data
  • blind analysis
  • likelihood analysis
First: the rates

- Since our is a counting experiment we must be sure to have the background under control
- The *trigger* rate scales as expected
- Absolute wire rate in the chambers ok, details to be understood

**calorimeter energy spectrum**

**rate on DCH wires**
The expected spectrum

- The simulated expected spectrum in the calorimeter contains several contributions

\[ R_\mu = 3.2 \times 10^7 \text{ s}^{-1} \]
LXe energy and timing

- Determined during CEX run
- Energy resolutions contains still a large contribution from pedestal
  - solved this year
- XEC intrinsic timing resolution

<table>
<thead>
<tr>
<th>Energy Resolution (FWHM)</th>
<th>4.9 ± 0.4 %</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Timing Resolution (FWHM)</th>
<th>100 ps</th>
</tr>
</thead>
</table>

- PMT with higher QE
LXe energy and timing

- Determined during CEX run
- Energy resolutions contain still a large contribution from pedestal
  - solved this year
- XEC intrinsic timing resolution

\[ \Delta E/E \text{ (FWHM)} = 6.5 \% \text{ without QE} \]
Pedestal

- Residual large (2%) contribution of pedestal due to ghost pulses in DRS2

- Should be solved with new version of chip (to be installed end 2008)
TIC timing resolution

- Michel positrons crossing two adjacent TC bars
- Difference of the two bar timings
  - Time walk
  - DRS timing calibration

\[ \sigma_{\text{time}} = 52 \text{ps} \]
...a comment

- In 2007 we had an **engineering run** with (almost) all the apparatus running for ~1 month
  - no fiber TC detector, no laser, no QEs
  - Xe light yield < than expected
  - DCH failures, noisy electronics
- In 2008 run
  - intensive study of detector **stability** (LXe) l.y. almost recovered
  - all detector & **calibrations** operational
  - “new” electronics available only at the end of the run
  - DCH system: some **sparking** chambers
  - but... **more months** of data taking to get a physics result!
## Background and Sensitivity

<table>
<thead>
<tr>
<th></th>
<th>&quot;Goal&quot;</th>
<th>Perspectives for 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Simulated</td>
</tr>
<tr>
<td><strong>Gamma energy %</strong></td>
<td>4.5 – 5.0</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Gamma Timing (ns)</strong></td>
<td>0.15</td>
<td>0.27*</td>
</tr>
<tr>
<td><strong>Gamma Position (mm)</strong></td>
<td>4.5 – 9.0</td>
<td>15</td>
</tr>
<tr>
<td><strong>Gamma Efficiency (%)</strong></td>
<td>&gt;40</td>
<td>&gt;40</td>
</tr>
<tr>
<td><strong>e⁺ Timing (ns)</strong></td>
<td>0.1</td>
<td>0.12*</td>
</tr>
<tr>
<td><strong>e⁺ Momentum (%)</strong></td>
<td>0.8</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>e⁺ Angle (mrad)</strong></td>
<td>10.5</td>
<td>17.**</td>
</tr>
<tr>
<td><strong>e⁺ Efficiency (%)</strong></td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td><strong>Muon decay Point (mm)</strong></td>
<td>2.1</td>
<td>3.**</td>
</tr>
<tr>
<td><strong>Muon Rate (10⁸/s)</strong></td>
<td>0.3</td>
<td>0.3***</td>
</tr>
<tr>
<td><strong>Running Time (weeks)</strong></td>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td><strong>Single Event Sens (10⁻¹³)</strong></td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td><strong>Accidental Rate (10⁻¹³)</strong></td>
<td>0.1–0.3</td>
<td></td>
</tr>
<tr>
<td># <strong>Accidental Events</strong></td>
<td>0.2–0.5</td>
<td></td>
</tr>
<tr>
<td><strong>90% CL Limit</strong></td>
<td>2 x 10⁻¹³</td>
<td></td>
</tr>
</tbody>
</table>

1 week = 4 x 10⁵ s  
* Added 250 ps due to present estimate of DRS systematics  
** Very pessimistic  
*** The muon rate is optimized to improve the limit
Perspective

- We had an engineering run in 2007 and a second engineering and calibration run between April and August 2008;
- We started the physics data taking on 9/12;
  - the detector is getting more and more in its optimal shape
- We expect first results in 2009
  - use the beginning of 2009 to deal with few upgrades
- We are confident to reach a sensitivity of few $\times 10^{-13}$ in $\mu \rightarrow e\gamma$ BR in 3 years of acquisition time.
Back-up slides