Dark Matter Direct Detection in Electron Accelerator

Masato Senami
(ICRR, University of Tokyo)
senami@icrr.u-tokyo.ac.jp

Collaborated with
Junji Hisano (ICRR)
Minoru Nagai (ICRR)
Mihoko M. Nojiri (YITP)

hep-ph/0504068

- 2007: LHC will discover SUSY particle.
- 201?: Linear Collider will measure precisely some property of the SUSY particles.

- 202?:

Neutralino astronomy

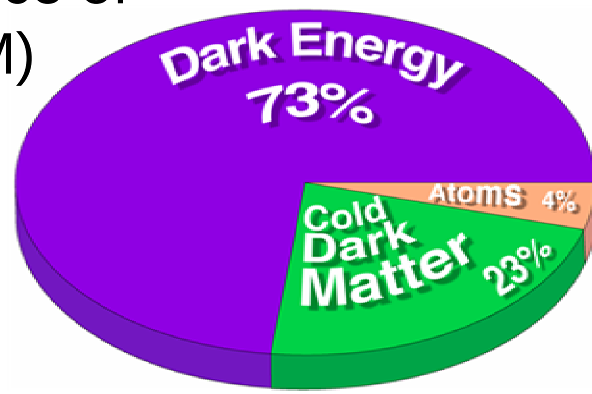
I will propose one possibility.
An alternative direct detection of neutralino and the measurement of parameters of the dark halo

Cold dark matter

- WMAP result establish the existence of non-baryonic cold dark matter (DM)
- In the MSSM, the lightest supersymmetric particle is a candidate for dark matter. (stable due to R-parity)
  - neutralino

$$\tilde{\chi}^0 = N_{\tilde{B}}\tilde{B} + N_{\tilde{W}}\tilde{W} + N_{\tilde{H}_1}\tilde{H}_1 + N_{\tilde{H}_2}\tilde{H}_2$$

  - gravitino, ...
- Other candidates
  - LKP in UED models — M.K, Sh.M, Y.S, M.S. PRD 71 (2005)
  - axion …

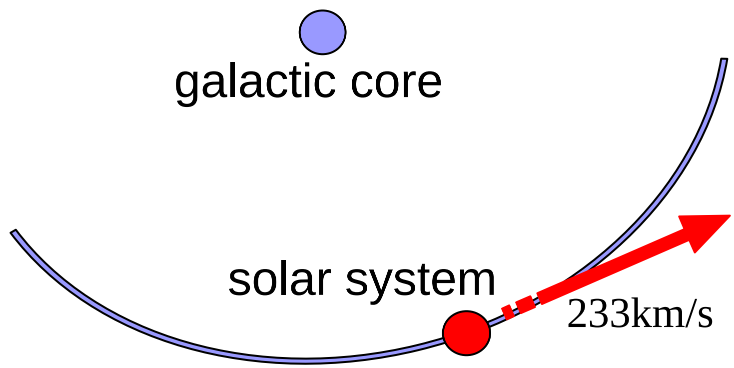


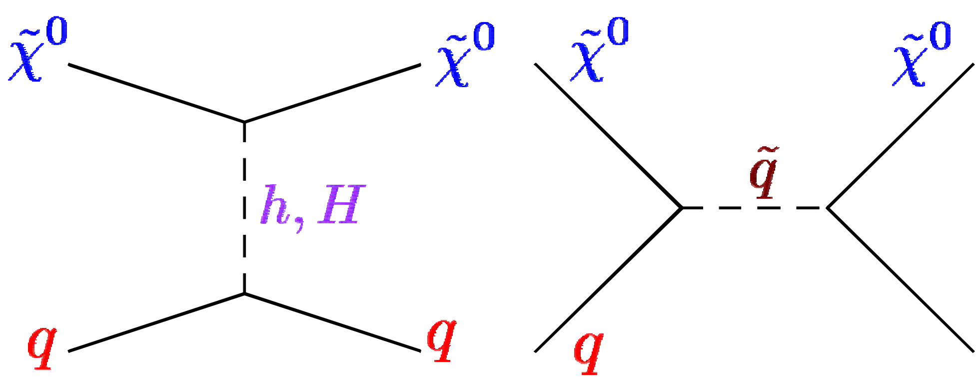
http://lambda.gsfc.nasa.gov

Dark matter direct detection

The solar system moves in the galactic halo. Then, DM passes thorough the earth's surface. DM will be detected by observing nuclear recoil after DM-nucleus scattering.

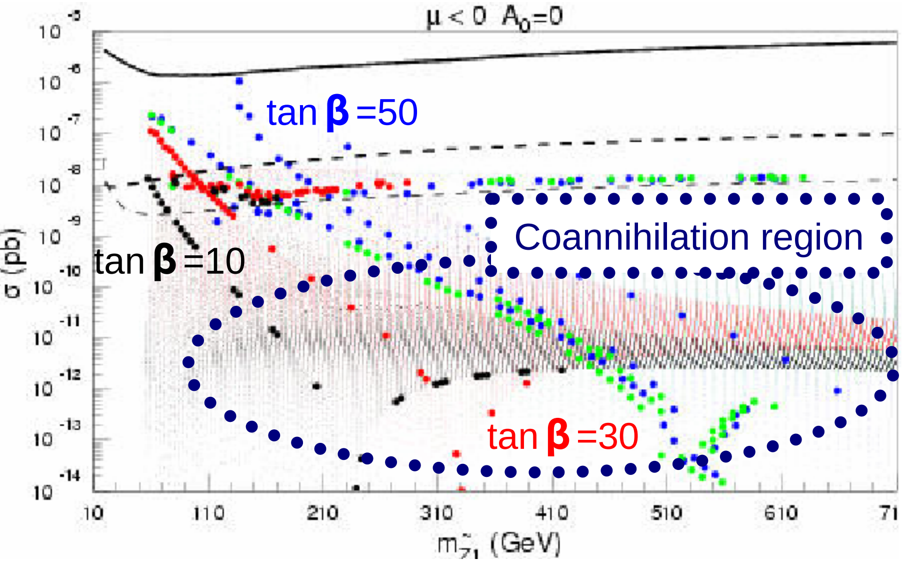
- Direct detection
  - uncertainty of hadronic matrix element
  - dependent on MSSM parameters

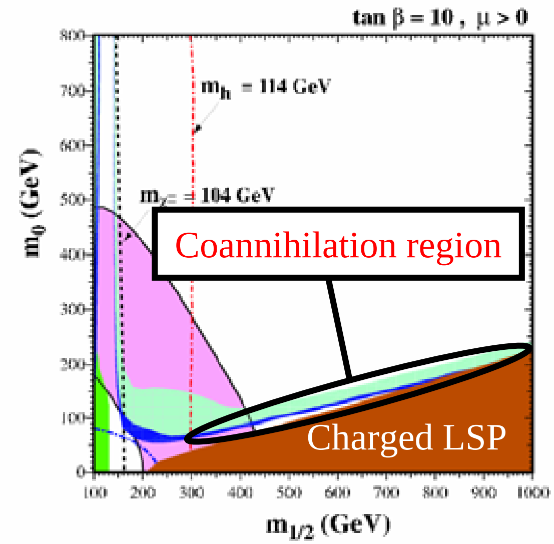




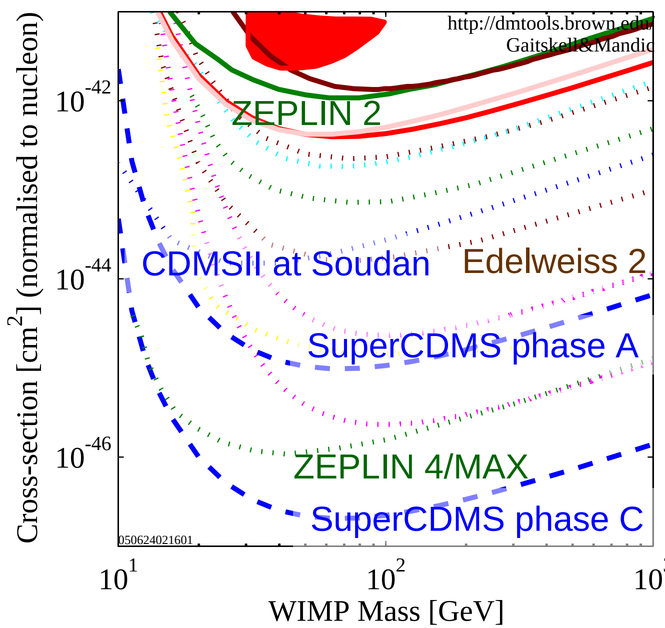
Direct detection

Baer, Balazs, Belyaev and O'Farrill JCAP 0309 (2003)

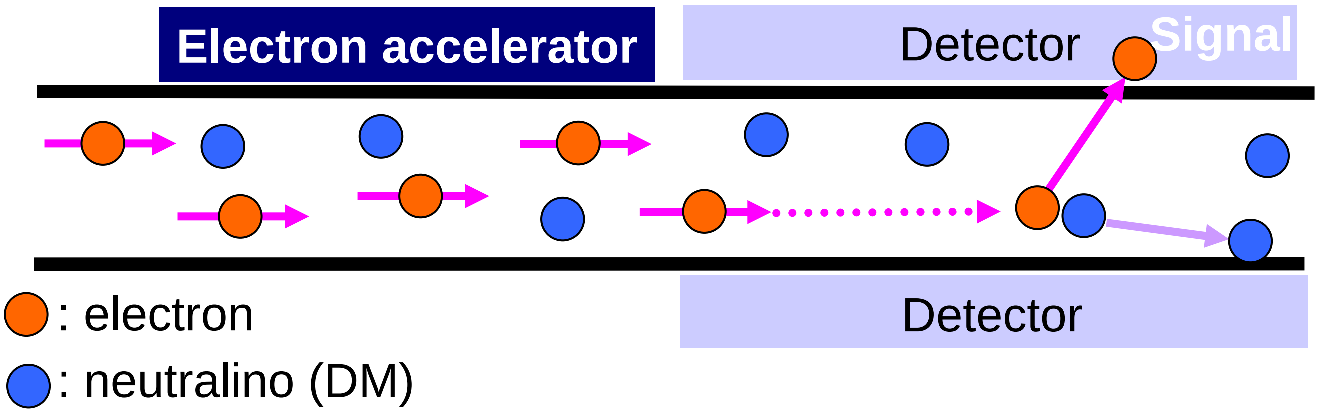


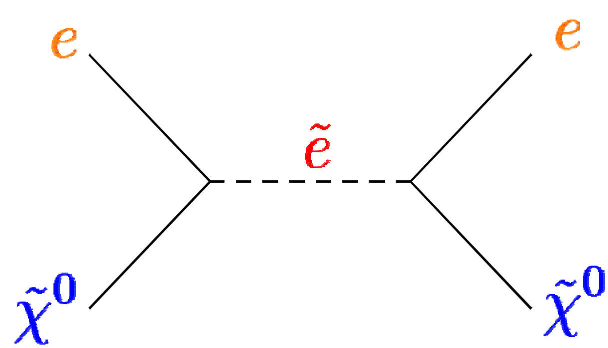


10^{-9}pbarn = 10^{-45}cm^2



New direct neutralino detection

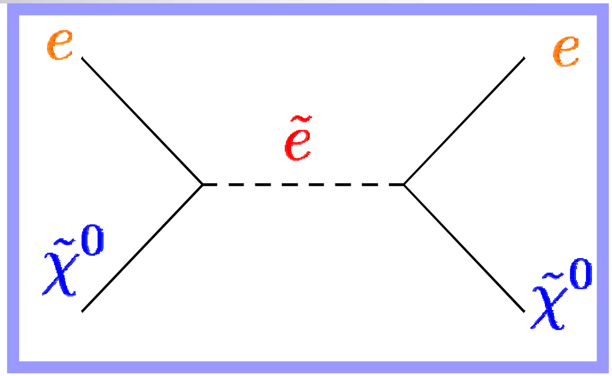




- Recoiled electron
  - Energy is monochromatic
  - spherical angular distribution

⇒ **Background free**

Cross section



- Electron-neutralino elastic scattering induced by s-channel exchange of selectron
  - Beam energy is tuned to the mass difference
  - Elastic scattering is dominated by on-pole selectron exchange
- If selectron and neutralino masses are almost degenerate and beam energy E_{beam} is tuned to $s - m_{\tilde{e}}^2 = 0$, cross section is suppressed by Δm^2,

$$E_{\text{beam}} = \overline{E}_{\text{beam}}$$

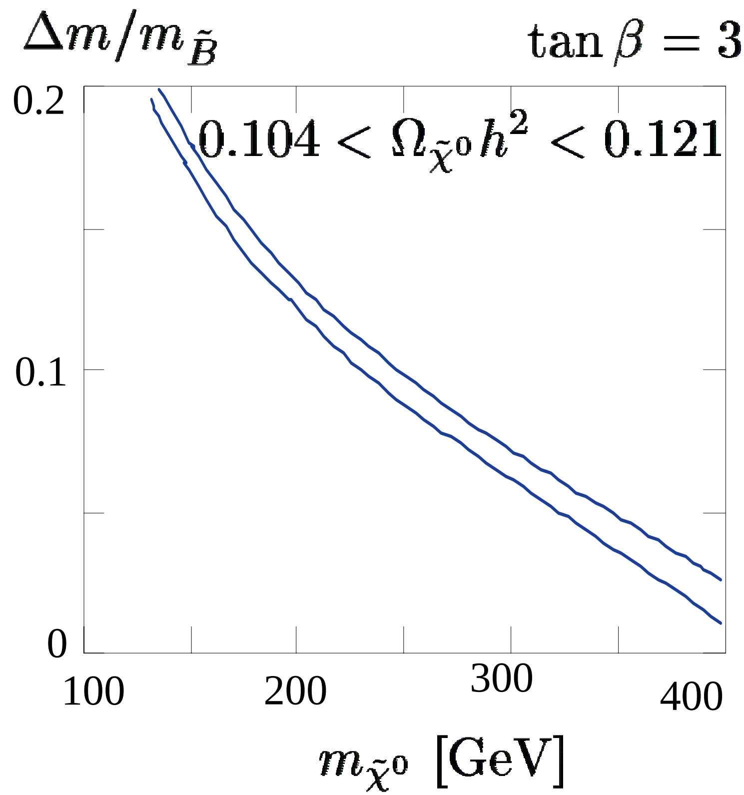
$$\frac{d\sigma}{d\cos\theta} \simeq \frac{\pi}{2(m_{\tilde{e}} - m_{\tilde{\chi}^0})^2} + O\left(\frac{\Delta m}{m_{\tilde{\chi}^0}}\right)$$

$\Delta m \equiv m_{\tilde{e}} - m_{\tilde{\chi}^0}$
$\bar{E}_{\text{beam}} \equiv \frac{m_{\tilde{e}}^2 - m_{\tilde{\chi}^0}^2}{2m_{\tilde{\chi}^0}}$

Small mass difference

- It occurs naturally in many SUSY models which explain the thermal DM abundance
- Bino-stau coannihilation
- In such a case,

  O(10)% level of mass degeneracy can be expected.



Expected event number

- Expected number of events *N*

$$N = 73 \times \left(\frac{\Delta m}{10\mathrm{GeV}}\right)^{-2}\left(\frac{m_{\tilde{\chi}^0}}{100\mathrm{GeV}}\right)^{-1}\left(\frac{j}{100A}\right)\left(\frac{T}{1\ \mathrm{year}}\right)\left(\frac{L}{1\ \mathrm{km}}\right)$$

j : beam current

T : duration of experiment

L : detector length

$$\rho_{\mathrm{DM}} = 0.3\mathrm{GeV}/\mathrm{cm}^3$$

- High beam current ~ 100A is required
  - KEKB
    - 3.5 GeV positron 1.861A
    - 8.0 GeV electron 1.275A
  - SuperKEKB
    - 9.4A and 4.1A is proposed

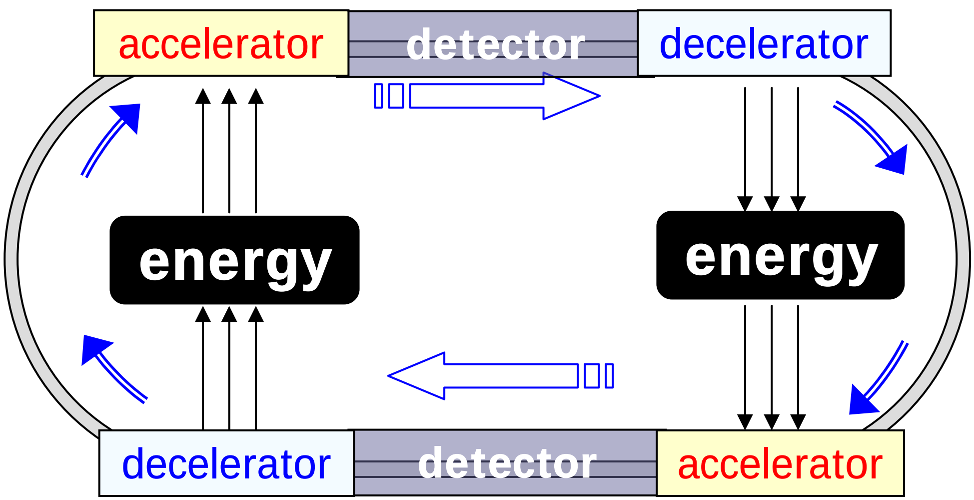
Energy Recovery Linac (ERL)

- High beam currents   Storage ring ~ O(100)A

  Important problem

- Synchrotron radiation
  - damage beam pipe
  - causes beam power loss

In ERL, the beam energy is lowered at the arc sections to reduce the SR, and this power is used to increase the beam power after the arc sections.

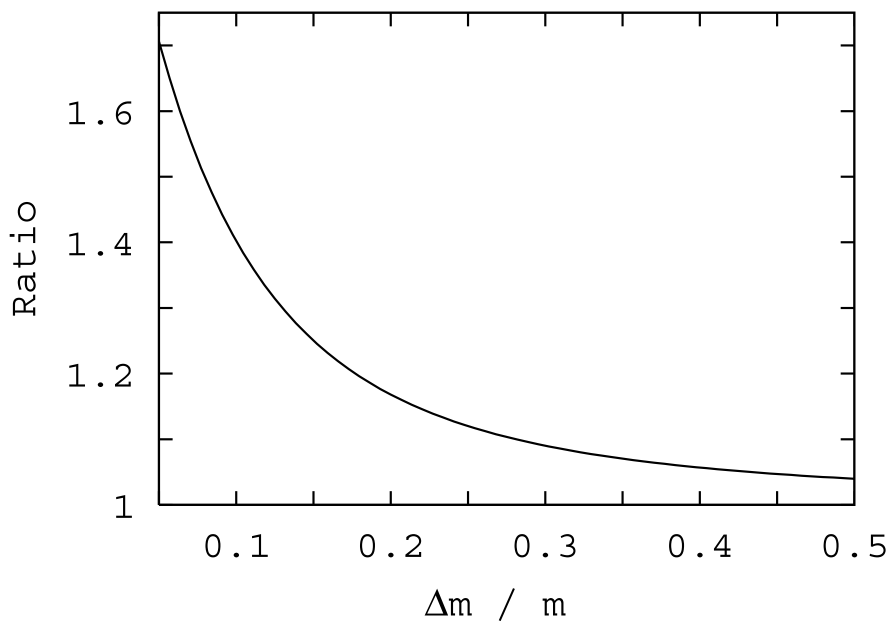


Further information

- DM Parameter decision
  - ρ_{DM}, σ_h, velocity and direction of DM wind
- These may be measured by changing
  - beam axis
    - Perpendicular
    - Parallel
    - Others
  - beam energy

The ratio of the cross sections

Beam axis is Perpendicular / Parallel to the DM wind

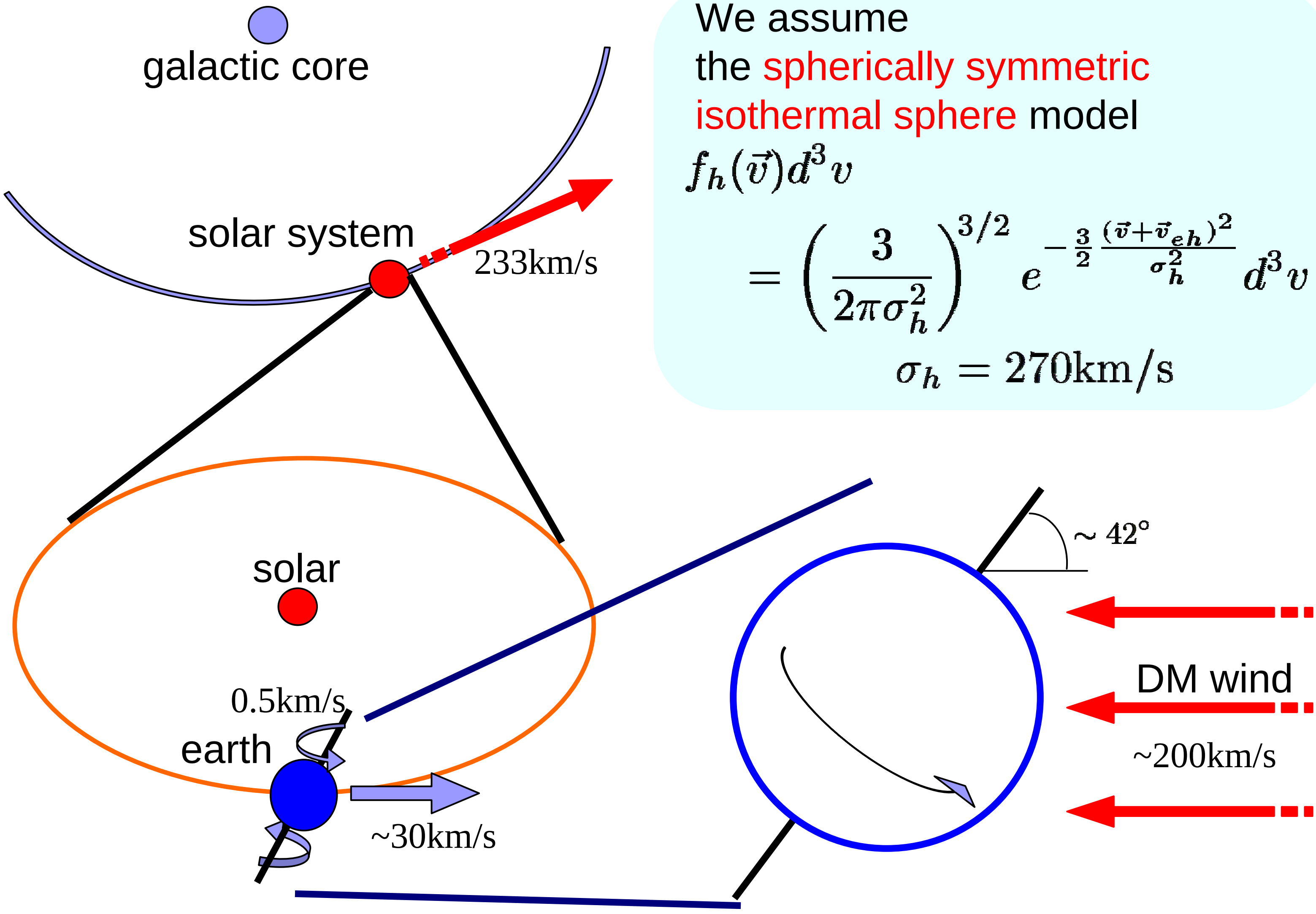


Beam axis dependence

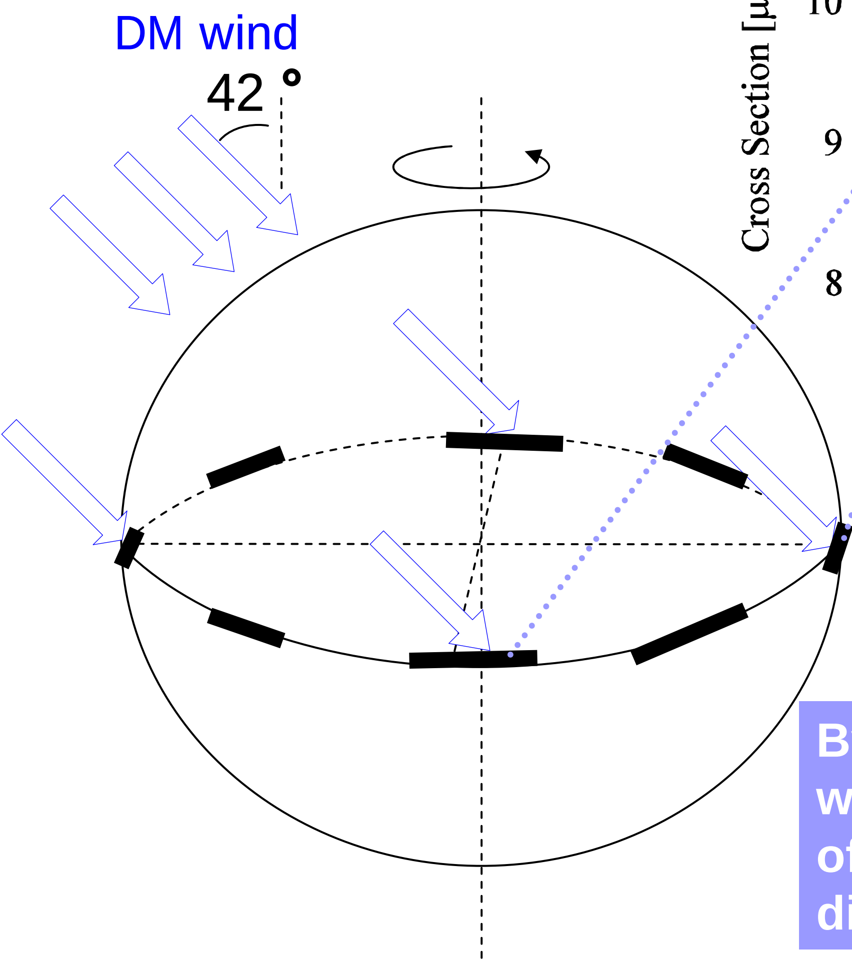
We assume
the spherically symmetric
isothermal sphere model

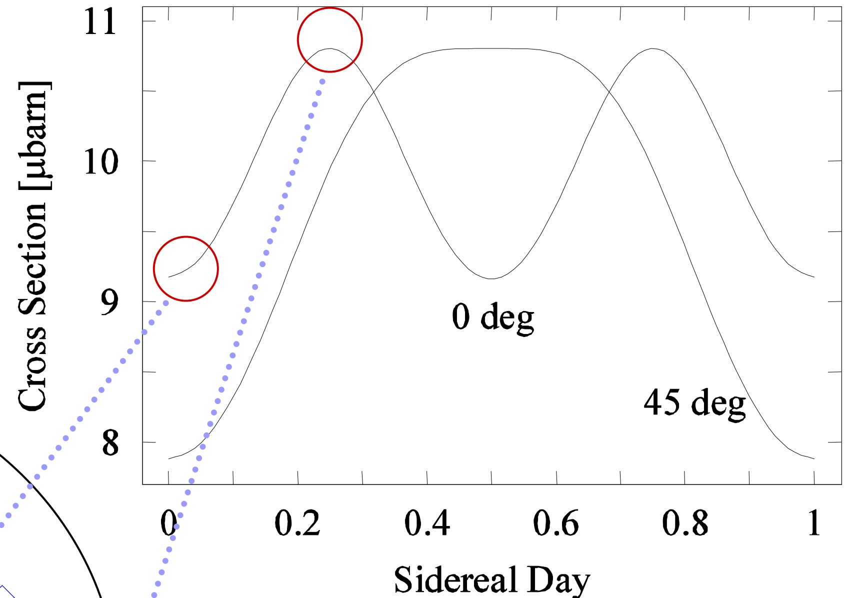
$$f_h(\vec{v})d^3v = \left(\frac{3}{2\pi\sigma_h^2}\right)^{3/2} e^{-\frac{3}{2}\frac{(\vec{v}+\vec{v}_{eh})^2}{\sigma_h^2}} d^3v$$

$$\sigma_h = 270\mathrm{km/s}$$



Daily modulation

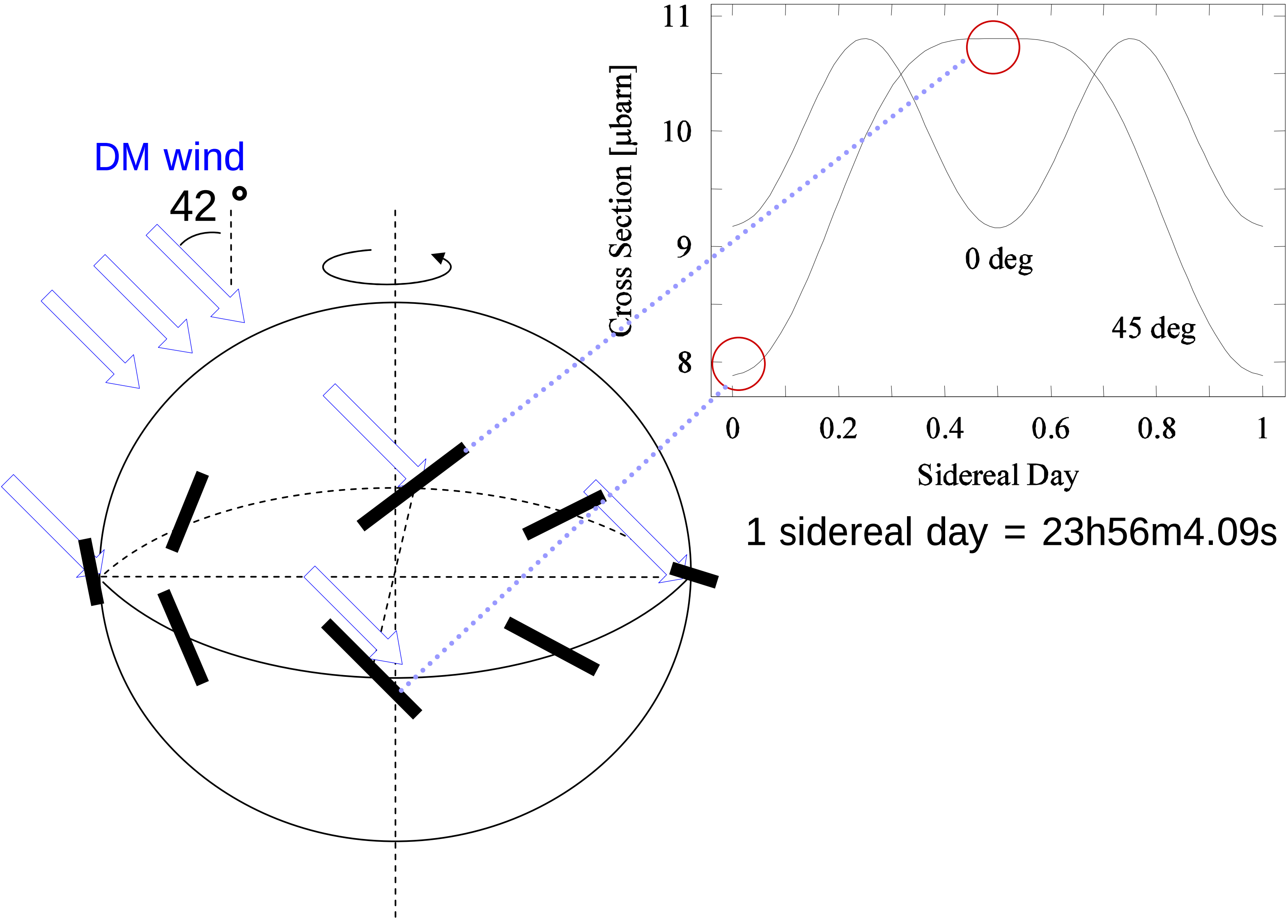




1 sidereal day = 23h56m4.09s

By this daily modulation, we may measure some property of dark halo, $\rho_{\rm DM}, \sigma_h$ and the direction of DM wind and so on.

Daily modulation

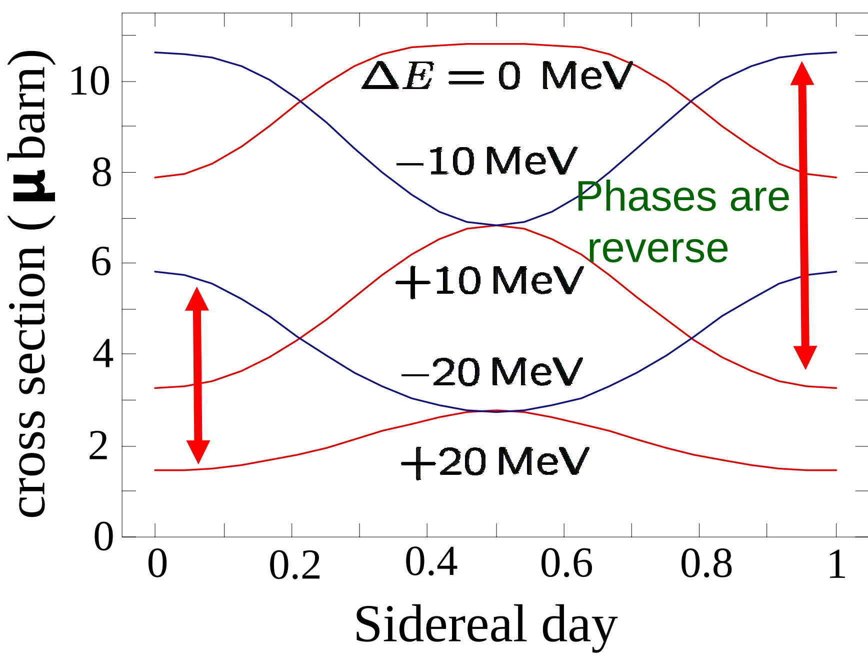


1 sidereal day = 23h56m4.09s

Beam energy

- Measurement of mass difference
  - LHC ~ a few GeV, LC ~ 50 MeV
- Precision measurement *O*(10MeV) is important and very challenging.
  - Scan the beam energy to find the signal
  - Phases are reverse in the negative and positive energy deviation

$$\Delta E = E_{\mathbf{beam}} - \overline{E}_{\mathbf{beam}}$$



Conclusion

- We proposed an alternative neutralino DM direct detection in electron accelerators.
  - Neutralino and selectron masses are degenerate.
- The local DM density and velocity distribution may be measurable.
- Our proposal is applicable to other DM candidates, which are coupled with an electron and a new particle with mass degenerate with it.

  For example,
  the lightest Kaluza-Klein particle in the UED model

Velocity dependence

$$\frac{d\sigma}{d\cos\theta} = \frac{2\pi}{(m_{\tilde{e}}^2 - m_{\tilde{\chi}^0}^2)^2} \frac{m_{\tilde{e}}^4}{m_{\tilde{\chi}^0}^2} \frac{(m_{\tilde{e}}\Gamma_{\tilde{e}})^2}{(s - m_{\tilde{e}}^2)^2 + (m_{\tilde{e}}\Gamma_{\tilde{e}})^2} \frac{1}{(1 + A(\cos\theta))^2}$$

Subleading

$$A(\cos\theta) = \frac{m_{\tilde{e}}^2 - m_{\tilde{\chi}^0}^2}{2m_{\tilde{\chi}^0}^2}(1 - \cos\theta) = O(\Delta m / m_{\tilde{\chi}^0})$$

Angular distribution is spherical

- $\sqrt{s} - m_{\tilde{e}} \sim 10\text{MeV} \times \left(\frac{\langle v_{||}\rangle}{10^{-3}}\right)\left(\frac{\Delta m}{10\text{GeV}}\right)$

  $\langle v_{||}\rangle$: the average of DM velocity along the beam axis.

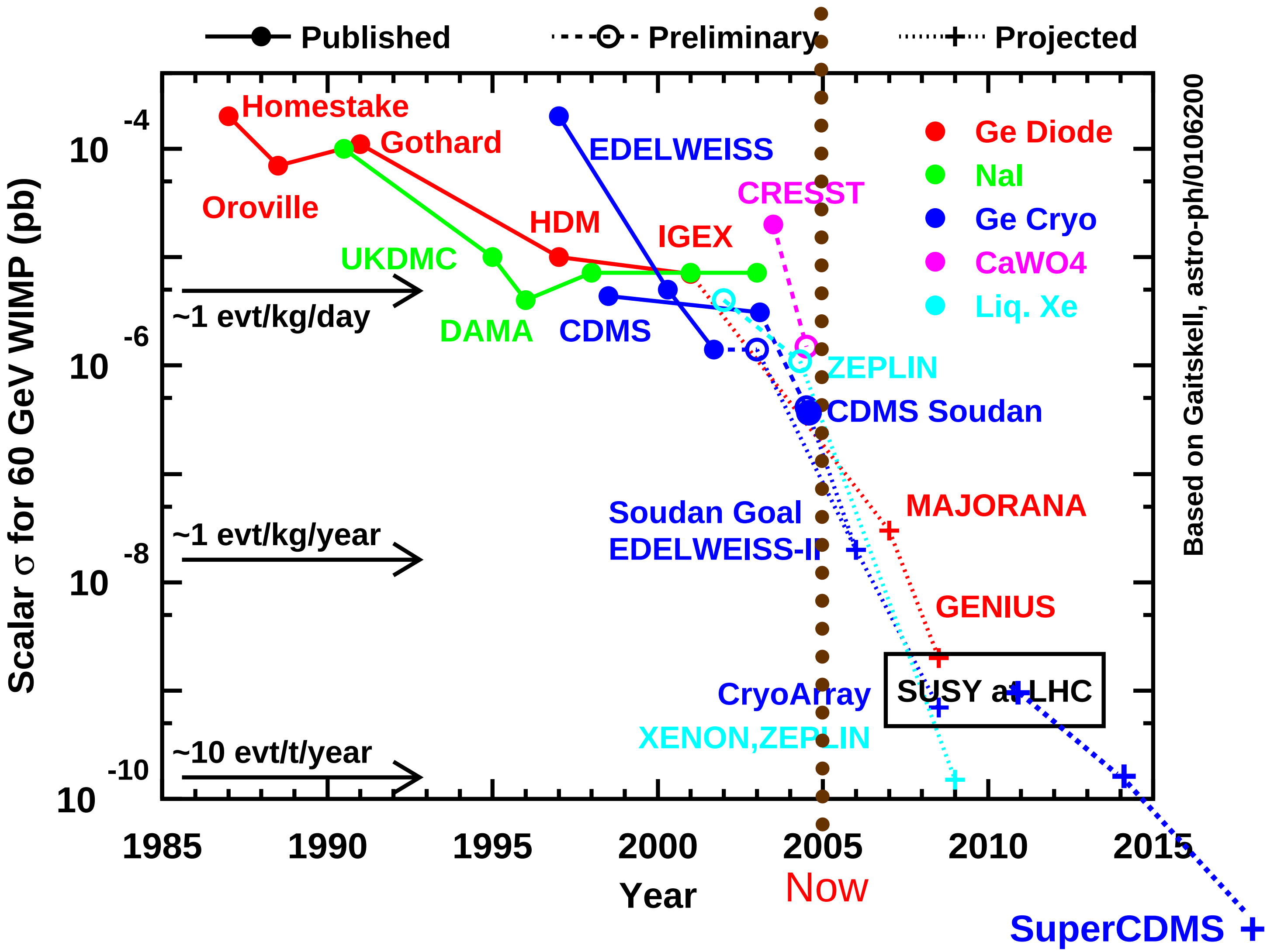
- $\Gamma_{\tilde{e}} = 20\text{MeV} \times \left(\frac{\Delta m}{10\text{GeV}}\right)^2 \left(\frac{m_{\tilde{e}}}{100\text{GeV}}\right)^{-1} = \frac{g_Y^2 Y^2}{8\pi}(O_{11})^2 \frac{(m_{\tilde{e}}^2 - m_{\tilde{\chi}^0}^2)^2}{m_{\tilde{e}}^3}$

  Bino-like neutralino

These two values are comparable to each other.

⇒ **The DM velocity distribution affects the expected number of events.**

Time schedule



Background free

- Recoiled electron
  - Angular distribution is spherical
  - Energy is monochromatic
- Background sources
  - Electron scattering by the beam gas
    - Low transverse momentum $p_T \ll E_{\mathrm{beam}}$
    - Discriminate by measuring the transverse momentum
  - **π**-- production from photo-nucleon interactions
    - $\pi^- - e^-$ separation ability is required

Advantage of this experiment

- Velocity information
  - Ordinary direct detection
    - annual modulation ~ 30km/s
    - the projection of the revolution plain
    - DRIFT (gas detector) has sensitivity to the DM wind
  - This experiment
    - the revolution of the sun ~ 300km/s
    - the earth rotation = the angle modulation between the beam axis and the direction of the DM wind
- Density information
  - Ordinary direct detection
    - uncertainty of the cross section
    - the dark matter particle can not be identified
  - This experiment
    - cross section is known
    - identifiable of the dark matter particle

SI cross section (Light higgs exchange)