

Detector/Trigger challenge for SUSY Dark Matter Scenarios @ ILC



Z. Zhang



Based on

- 1) P. Bambade, M. Berggren, F. Richard & Z. Zhang (hep-ph/040610)
- 2) H-U. Martyn's contribution to LCWS'06 (presented by F. Sefkow at SUSY parallel session)

Outline

start with

- Motivation

illustrated with

- Two challenge scenarios @ ILC

showing

- Detector/trigger challenge on detector

Motivation

- Current precision on Dark Matter(DM) from WMAP: 10%
or in 2σ range: $0.094 < \Omega_{DM} h^2 < 0.129$
(Future precision expected from PLANCK: 2%)
- What are these non-baryonic DM?
- Can ILC reveal the nature of DM?

If yes,

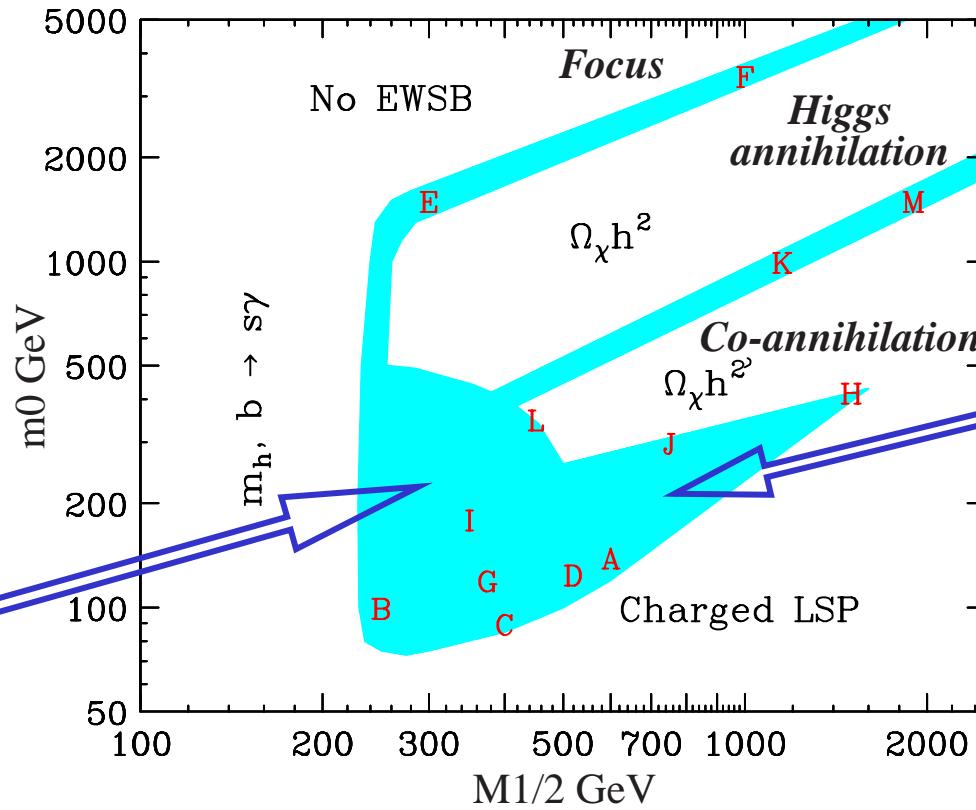
- What are requirements on the machine and detectors?
- How precise can one measure the DM relic density?

Scenario 1: DM=LSP χ in mSUGRA SUSY Model

Benchmark points:

Battaglia-De Roeck
 Ellis-Gianatti-Olive
 -Pape,
 hep-ph/0306219

$\chi\chi$ pairs
 annihilation



χ stau ($s\tau$)
 annihilation
 important
 when
 $\Delta M = m_{s\tau} - m_\chi$
 is small

→ The precision on SUSY DM prediction depends on ΔM & thus
 m_χ → Needs smuon (or selectron) analysis
 $m_{s\tau}$ → Needs stau analysis

Smuon Analysis

- Production:

$$e^+ e^- \rightarrow \tilde{\mu}^+ \tilde{\mu}^-$$

- Decay:

$$\tilde{\mu}^\pm \rightarrow \mu^\pm \chi$$

Final state

2 states giving
missing energy

LSP & Smuon Mass Measurement Using End-Point Method

Benchmark D:

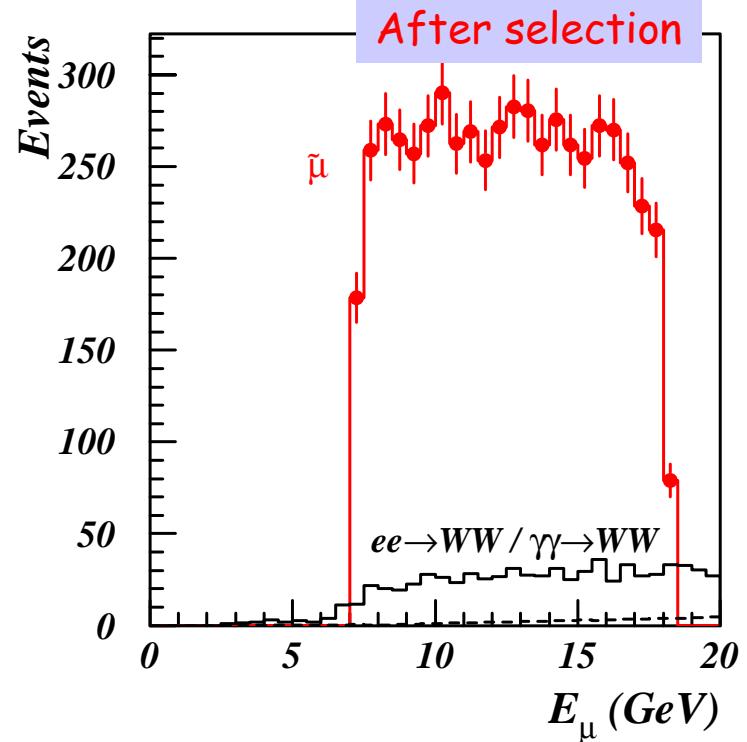
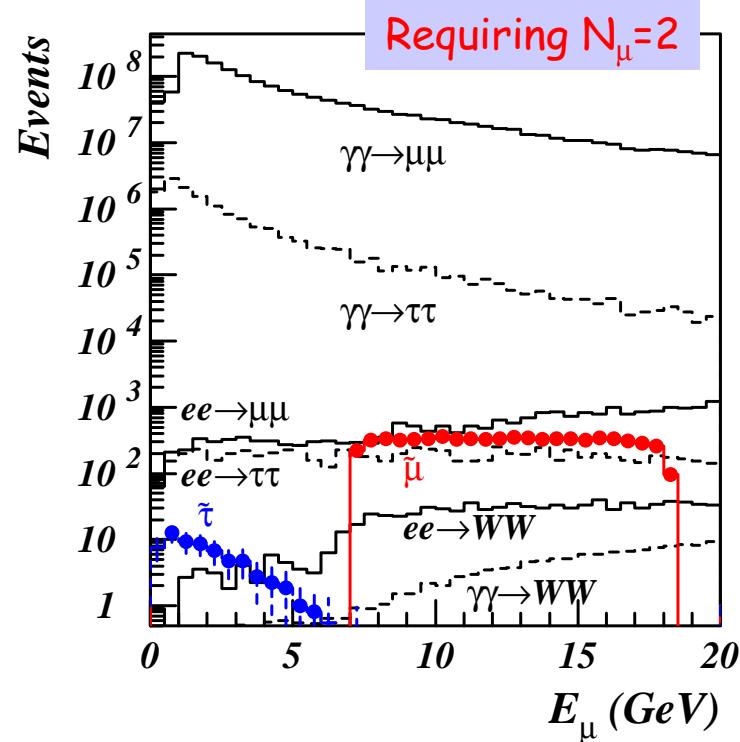
$m_{\text{smu}} = 224 \text{ GeV}$
 $m_{\chi} = 212 \text{ GeV}$
 $\rightarrow \Delta M = 12 \text{ GeV}$
 $E_{\text{cm}} = 500 \text{ GeV}$
 $L = 500 \text{ pb}^{-1}$

Signal:
 $\sigma = 7.2 \text{ fb}$

Backgrounds:
many orders
of magnitude
larger

Main cuts:
veto
 $P_{T,\text{miss}} > 5 \text{ GeV}$

$$E_{\text{max,min}} = \frac{m_{\tilde{\mu}}}{2} \left(1 - \frac{m_{\chi^0}^2}{m_{\tilde{\mu}}^2} \right) \gamma (1 \pm \beta) \quad \text{with } \beta = \sqrt{1 - \frac{4m_{\tilde{\mu}}^2}{s}}, \gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

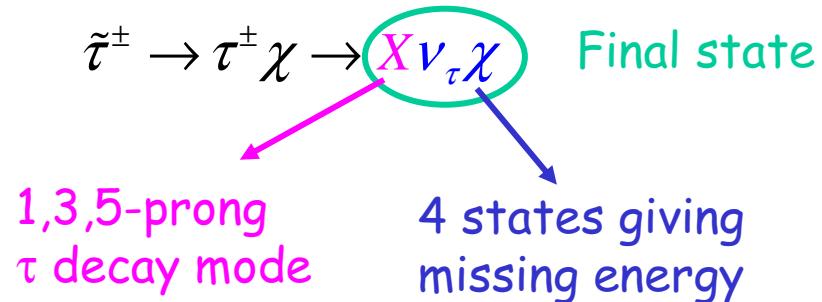


Stau Analysis

- Production:

$$e^+ e^- \rightarrow \tilde{\tau}^+ \tilde{\tau}^-$$

- Decay:



Very Soft Final State (FS)

Dominante 1-prong decay modes

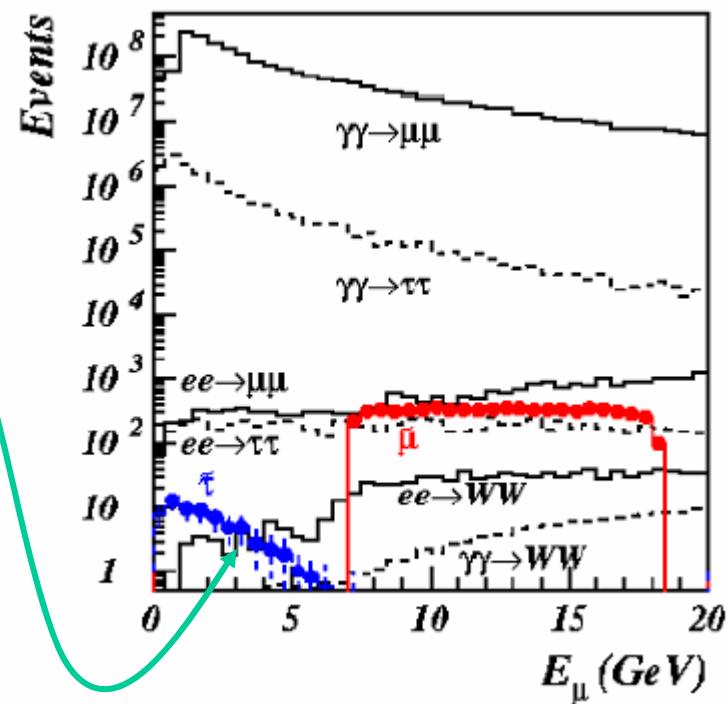
Mode (X)	B.R. (%)
e	17.8
μ	17.4
π	11.1
$\pi\pi^0$	25.4

Even more softer for 3 & 5-prong final states

$$m_{\text{stau}} = 217 \text{ GeV}, m_{\chi} = 212 \text{ GeV} \rightarrow \Delta M = 5 \text{ GeV}$$

Signal cross sections:

$$\sigma = 10 \text{ fb} \text{ @ } 500 \text{ GeV}, \sigma = 4.6 \text{ fb} \text{ @ } 442 \text{ GeV}$$



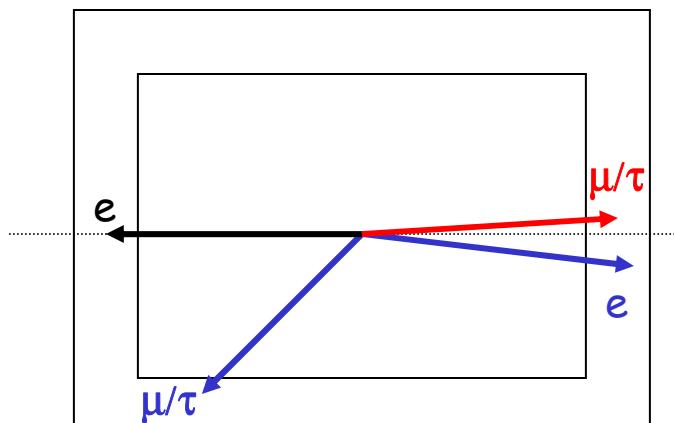
Vetoing Energetic μ/π Down to 20mrad?

Background free stau detection needs this capability:

$e\bar{e} \rightarrow e\bar{e}\mu\bar{\mu}$, $e\bar{e} \rightarrow e\bar{e}\tau\bar{\tau}$:

$\mu + e$ or $\tau + e$ visible in the detector \rightarrow signal like

Another e in the beam-pipe, another μ or $\tau \rightarrow \mu/\pi$ (energetic) @ low angle



→ New challenge in forward instrumentation !

Scenario 2: DM=Gravitino

- Mass scales set by SUSY breaking scale F and scale M_m of mediating interaction

$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_P}, \quad m_{\tilde{f}}, m_\lambda \sim \frac{F}{M_m}, \quad M_P = (8\pi G_N)^{-1/2} \simeq 2.4 \cdot 10^{18} \text{ GeV}$$

- Typical SUSY scenarios

mSUGRA	$M_m = M_P$	high $F \sim 10^{21} \text{ GeV}^2$	$m_{\tilde{G}} \sim \text{TeV} \dots \text{GeV}$
GMSB	$M_m \sim 10^5 \text{ GeV}$	low $F \sim 10^{10} \text{ GeV}^2$	$m_{\tilde{G}} \sim \text{keV}$
$\tilde{\chi}^{\text{MSB}}$	$M_m \sim 10^{17} \text{ GeV}$	high $F \sim 10^{20} \text{ GeV}^2$	$m_{\tilde{G}} \sim \text{GeV}$

- $\tilde{G} = LSP \Rightarrow NLSP = \tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^0$

- Dominant decay $\tilde{\tau} \rightarrow \tau \tilde{G}$ long lifetime

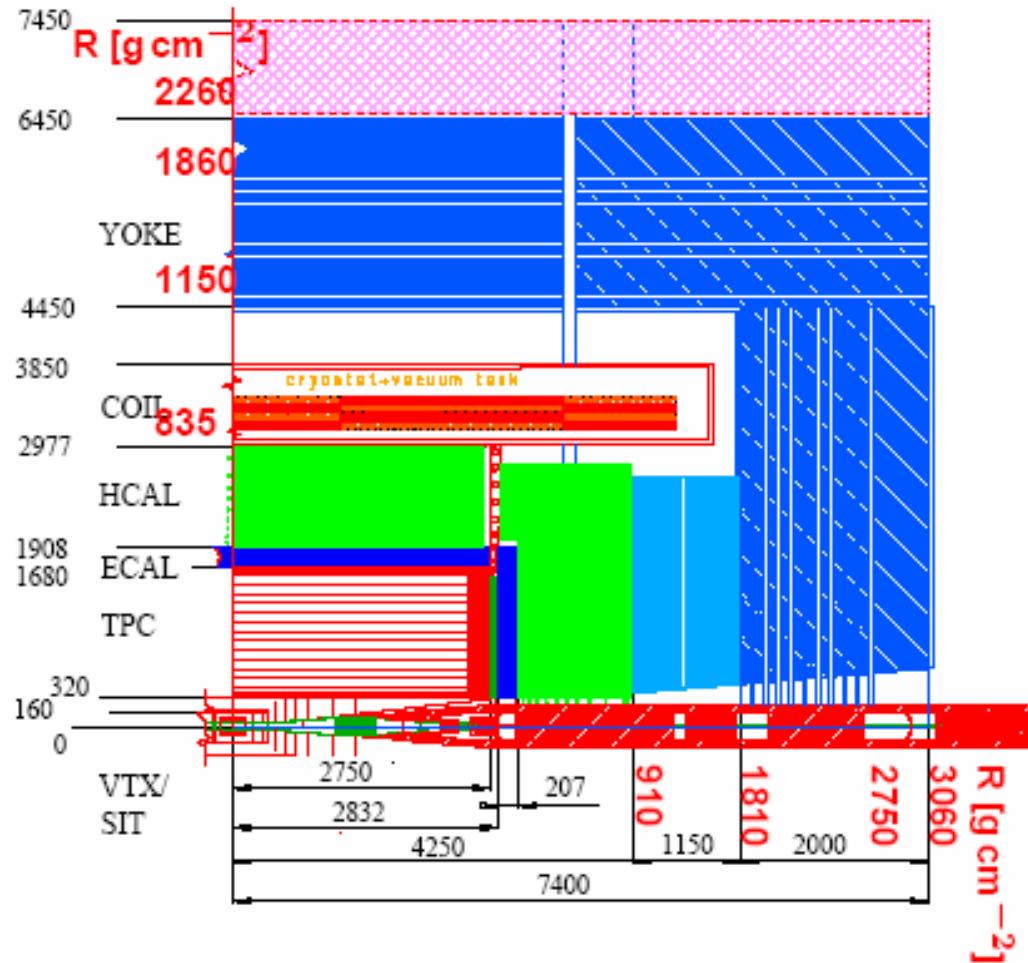
$$\Gamma_{\tilde{\tau} \rightarrow \tau \tilde{G}} = \frac{1}{48\pi M_P^2} \frac{m_{\tilde{\tau}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2} \right]^4$$

$$t_{\tilde{\tau}} \simeq 3.6 \cdot 10^8 \text{ s} \left[\frac{100 \text{ GeV}}{m_{\tilde{\tau}} - m_{\tilde{G}}} \right]^4 \left[\frac{m_{\tilde{G}}}{1 \text{ TeV}} \right]$$

$\tilde{\tau}$ ID in LDC detector

$\tilde{\tau}$ identification

1. heavy ionisation in TPC
 $-dE/dx \propto 1/\beta^2$
2. stop $\tilde{\tau}$ in HCAL & instrumented yoke
3. record $\tilde{\tau}$ location & time stamp t_{start}
4. wait until decay $\tilde{\tau} \rightarrow \tau \tilde{G}$ at t_{decay}
 $\Rightarrow \tilde{\tau}$ lifetime $t_{\tilde{\tau}} = t_{decay} - t_{start}$
5. measure τ decay products
 \Rightarrow gravitino mass $m_{\tilde{G}}$
6. rare radiative decay $\tilde{\tau} \rightarrow \tau \gamma \tilde{G}$
 \Rightarrow gravitino spin $J_{\tilde{G}}$



$\tilde{\tau}$ range out

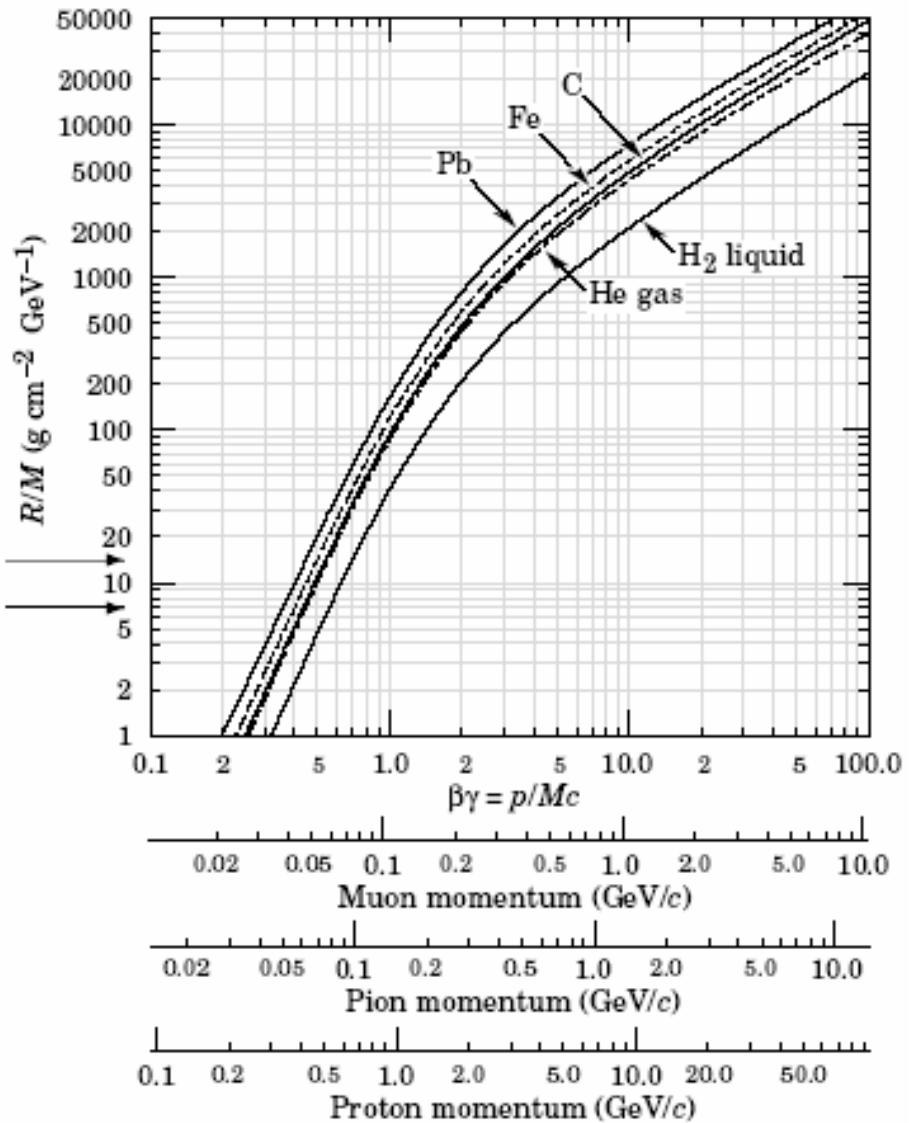
Range R of a heavy particle, mass M ,
due to ionisation loss

$$R(E') = \int_M^{E'} dE (dE/dx)^{-1}$$
$$R/M = f(p/M = \beta\gamma)$$

Max. momentum acceptance for
stopping particles $\beta \lesssim 0.5$

barrel

$$m_{\tilde{\tau}} = 120 \text{ GeV}$$
$$m_{\tilde{\tau}} = 250 \text{ GeV}$$



mSUGRA scenario GDM ϵ

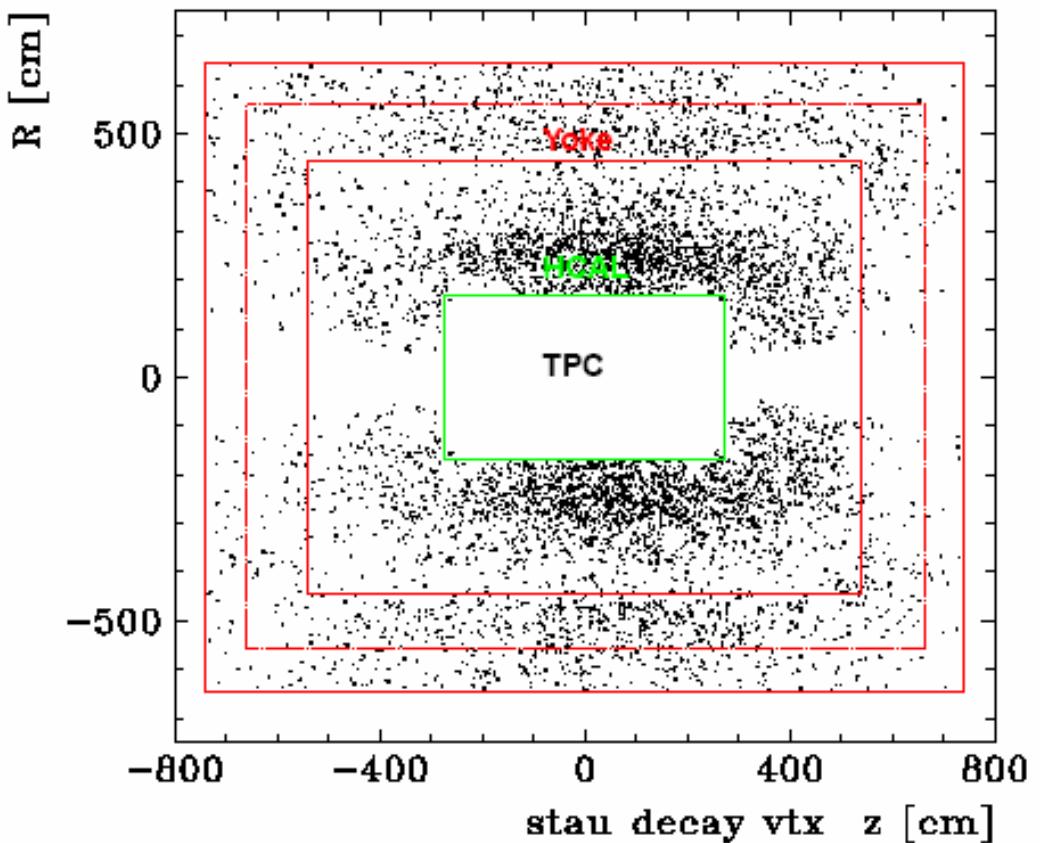
$\tilde{t}, \tilde{\chi}$	GDM ϵ
$\tilde{\tau}_1$	157.6
$\tilde{\tau}_2$	307.2
$\tilde{\nu}_\tau$	290.9
\tilde{e}_R	175.1
\tilde{e}_L	303.0
$\tilde{\nu}_e$	292.8
$\tilde{\chi}_1^0$	179.4
$\tilde{\chi}_2^0$	338.2
$\tilde{\chi}_1^\pm$	338.0
\tilde{G}	20

L=100fb $^{-1}$
@500GeV
 $\sigma=300\text{fb}$

Large samples of stopping $\tilde{\tau}$

	barrel	endcap	Sum
HCAL	3038	1055	4093
Plug		428	428
Yoke	1584	256	1840
Fid Vol	4092	1688	5780

Detect and measure gravitino via decays
 $\tilde{\tau} \rightarrow \tau \tilde{G}$
 and subsequent τ decays



Challenges

- Measure heavily ionization particle in event one
(to record t_{start} & stop location)
- Look for late tau decay signal in event two
(to identify tau & define t_{decay})
- Background rejection

Summary

(Challenging) DM scenarios put stringent requirement on both central and forward detectors in its

- Particle identification capability
- time resolution