Guaranteed Rates for Dark Matter Production at Colliders

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Dark Matter (DM)

- Non-baryonic
- Stable
- Neutral
- Cold

Ω_{DM} h^2=0.112 § 0.009

- Can not be any of the known particles
- microscopic identity of DM ?

WIMP and **superWIMP**

- appear in particle physics models motivated independently by attempts to solve EWSB
- relic density are determined by M_{pl} and M_{weak}
  - naturally around the observed value
  - no need to introduce and adjust new energy scale

WIMP

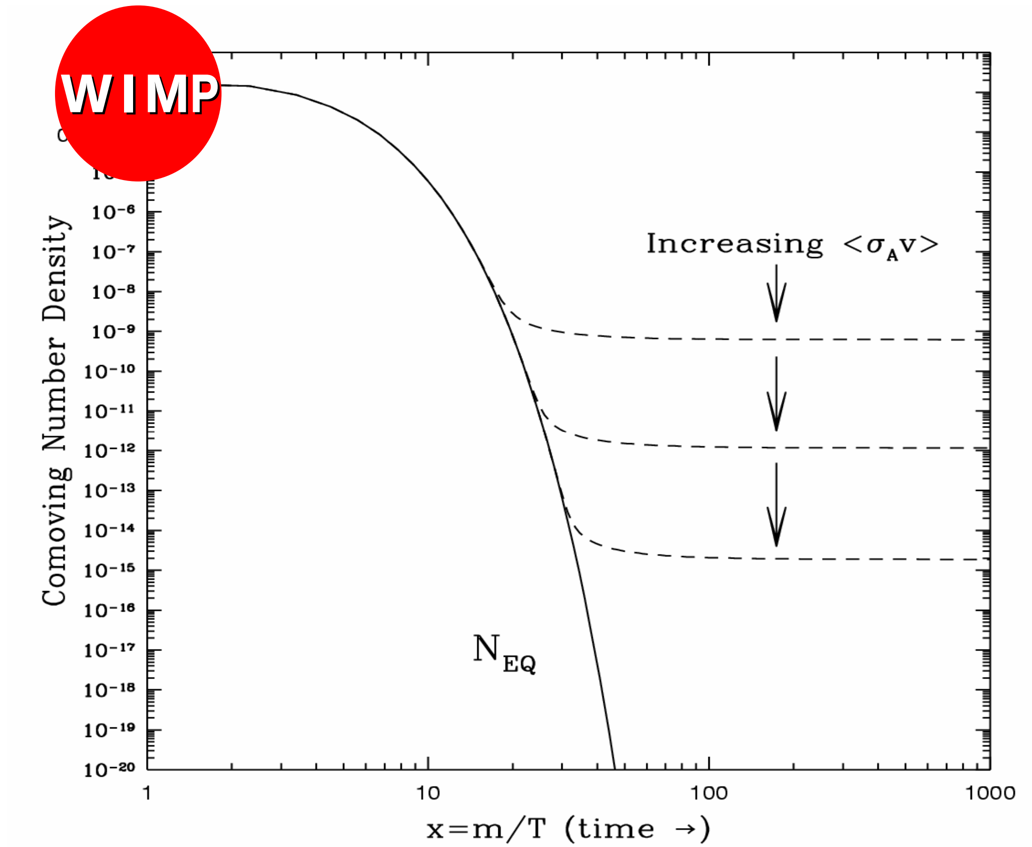
Neutral WIMP

- m_{WIMP}» M_{weak}
- σ_{an} » α_{weak}^{2} M_{weak}^{-2}

Ω_{WIMP} » h σ_{an}v i^{-1}

naturally around the observed value

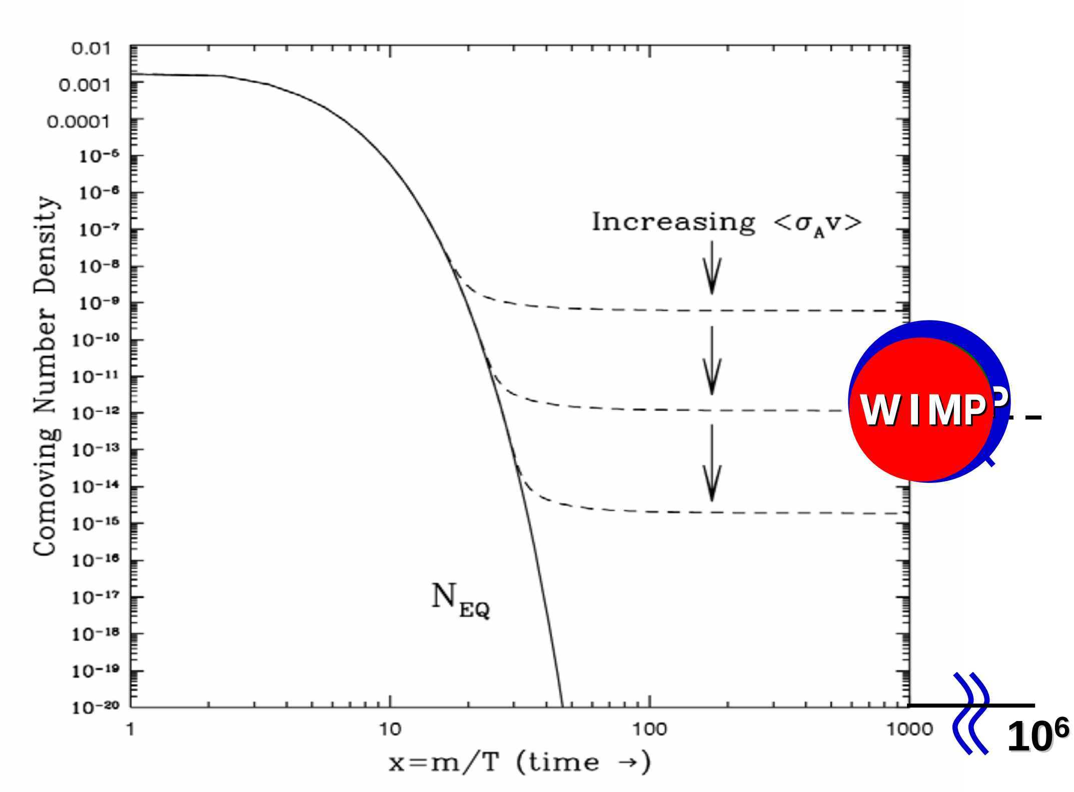
e.g. neutralino LSP



superWIMP

WIMP → superWIMP + SM particles

FRT hep-ph/0302215, 0306024



10^4 s < t < 10^8 s

$$\Omega_{\rm SWIMP} = \frac{m_{\rm SWIMP}}{m_{\rm WIMP}} \Omega_{\rm WIMP}$$

superWIMP

e.g. Gravitino LSP
LKK graviton

WIMP

- **neutral**
- **charged**

WIMP production (I)

$\Omega_{WIMP}, \Omega_{SWIMP} \leq \Omega_{DM}$

↓

WIMP annihilate efficiently in early universe

↓

WIMP be produced efficiently at colliders

Upper bound on Ω → Lower bound on rates

Birkedal, Matchev and Perelstein, PRD70, 077701 (2004)

- **neutral WIMP at ILC:** see Perelstein's talk
- **both ILC and LHC**
- **consider superWIMP scenario:** more promising

WIMP production (II)

WIMP annihilation

$$\sigma_{\rm tot} = \sum_{ij} \sigma(X\bar{X} \to ij; \hat{s})$$

X: WIMP

$$\langle \sigma_{\rm tot} v_X \rangle = \sigma_{\rm an} v_X^{2n} + \mathcal{O}(v_X^{2n+2}) = \sigma_0 x^{-n} + \mathcal{O}(x^{-n-1})$$

n=0: S-wave; n=1, P-wave

$x = m_{WIMP}/T$

WIMP relic density

$$\Omega_{\rm WIMP} h^2 \simeq 1.07 \times 10^9 \ {\rm GeV}^{-1} \frac{n+1}{\sqrt{g_*} M_{\rm Pl}} \frac{x_F^{n+1}}{\sigma_0}$$

$$\sigma_0 = \frac{1}{c^2 - 1} \sqrt{\frac{8}{45}} \frac{2\pi^3}{g} \frac{g_*^{1/2} x_F^{n+1/2}}{m_{\rm WIMP} M_{\rm Pl}} e^{x_F}$$

$x_F = m_{WIMP}/T_F$

WIMP pair production: via detailed balance

$$\sigma(ij \to X\bar{X}; \hat{s}) = \frac{\eta_{ij} v_X^2 (2S_X + 1)^2}{4(2S_i + 1)(2S_j + 1)} \sigma(X\bar{X} \to ij; \hat{s}) = \frac{\eta_{ij} (2S_X + 1)^2}{4(2S_i + 1)(2S_j + 1)} \kappa_{ij} \sigma_{\rm an} v_X^{2n+1}$$

η=1/2: i,j identical

η=1: otherwise

relative velocity of two WIMP in CM frame

spin

$$\kappa_{ij} = \sigma(X\bar{X} \to ij; \hat{s}) / \sigma_{\rm tot}$$

SuperWIMP with charged WIMP

LHC production

$V_X < V_{max}$, $V^2_{max} = 2$

$$\bar{\sigma}(pp \to X\bar{X}; s) = \int_{\frac{4m_X^2}{s}}^{\frac{4m_X^2}{s}\frac{1}{1-v_{\rm max}^2/4}} du \int_u^1 \frac{dx}{x}$$

$$\times \sum_{ij} \left[f^p_{q_i}(x) f^p_{\bar{q}_j}(u/x) + f^p_{\bar{q}_j}(x) f^p_{q_i}(u/x) \right] \times \bar{\sigma}(q_i\bar{q}_j \to X\bar{X}; us)$$

Leading cont…

No (loop indu…

No three body …

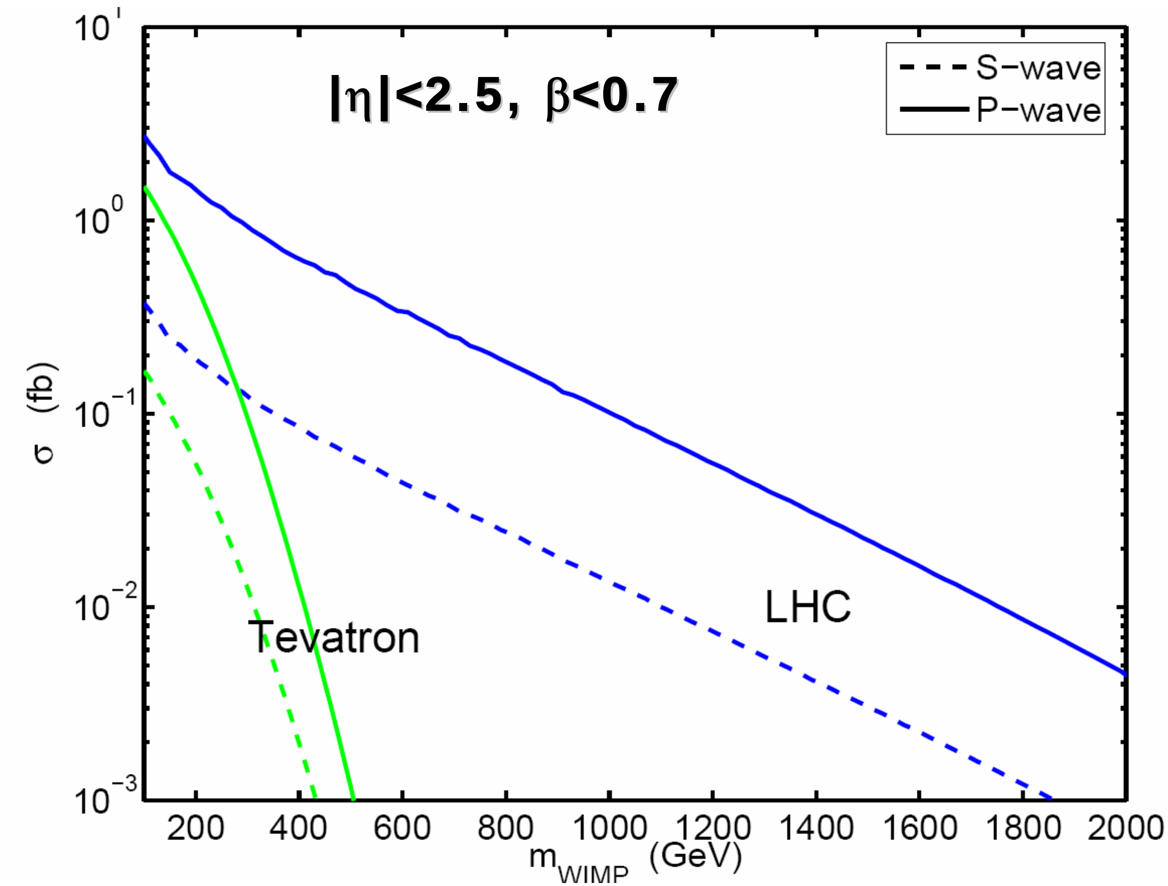
$$\bar{\sigma}(q_i\bar{q}_j \to X\bar{X}; us) = \frac{1}{N_c^2} \sum_{\rm color} \sigma(q_i\bar{q}_j \to X\bar{X}; us)$$

Signal: two isolated charged track, free of hadron activity

- **|η| < 2.5**
  detect the track
- **β < 0.7**
  ionization –dE/dx more than double minimum-ionizing

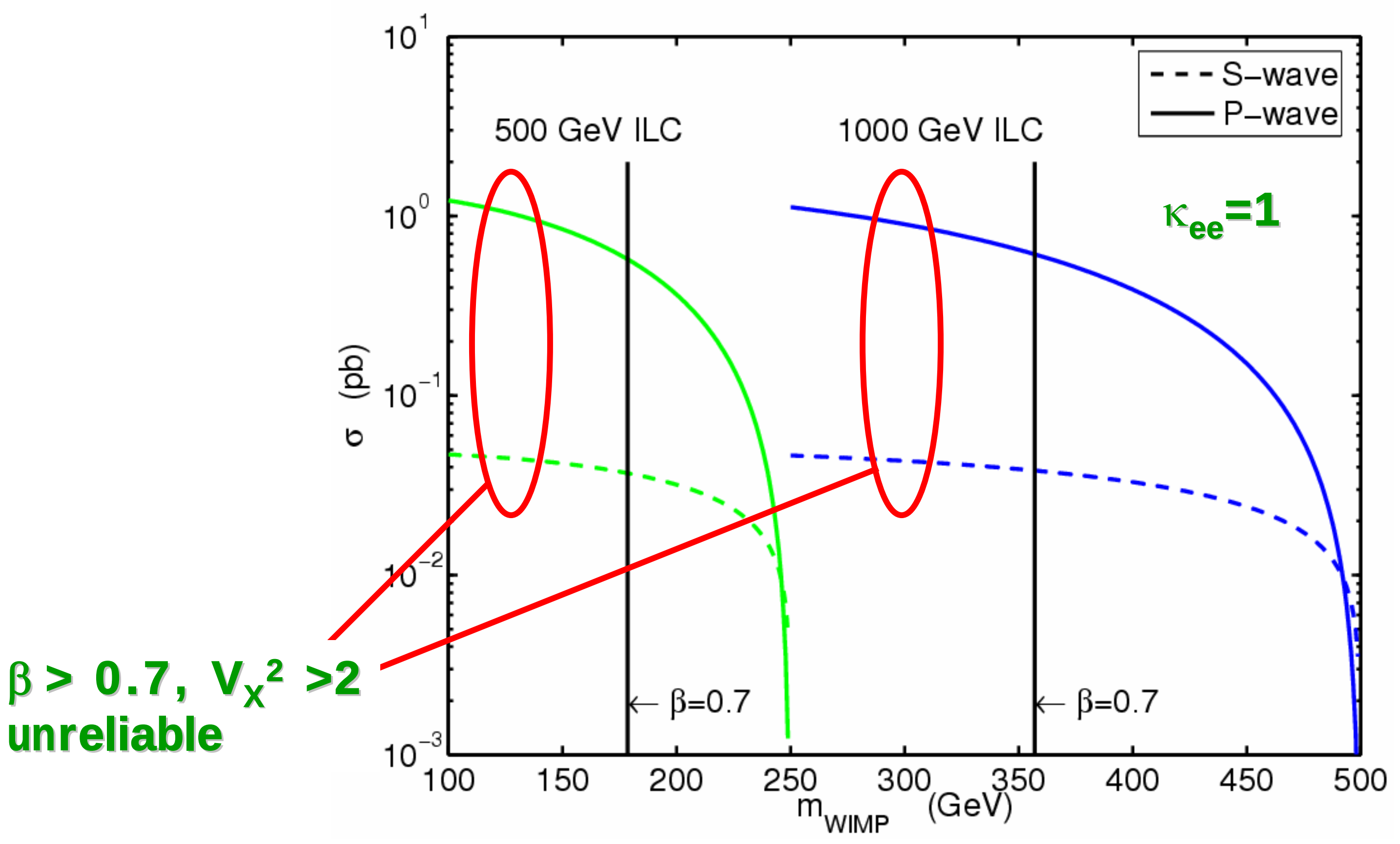
Background free !

SuperWIMP with charged WIMP at LHC

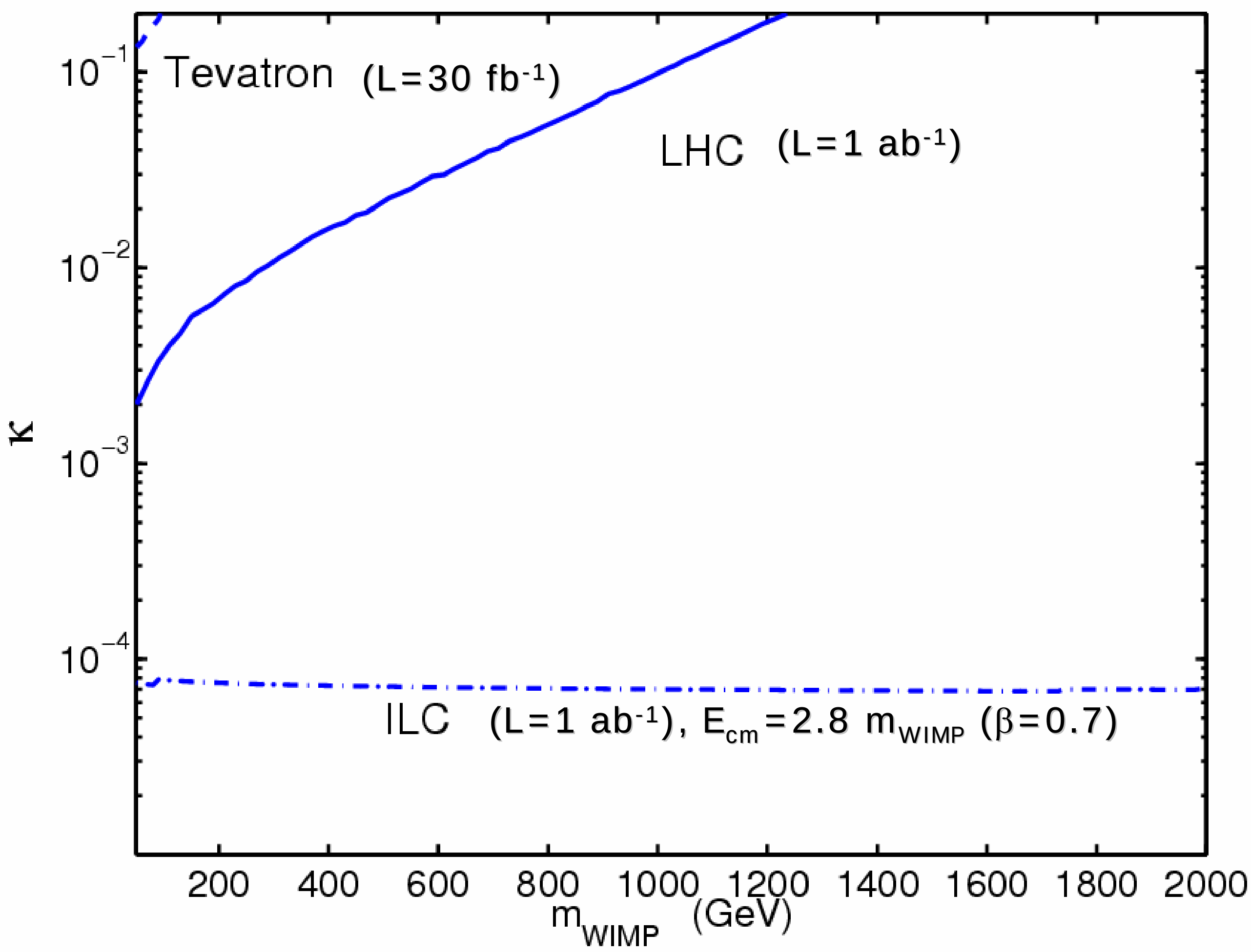


- **P-wave vs. S-wave**
  V_X^2 suppression compensated by σ_{an}
- **$S_X=0$**
  σ / $(2S_X+1)^2$
- **$\kappa_{q\bar{q}}=0.2$ for q=u,d,s,c.b**
  σ / κ_{qq} -
- **$m_{SWIMP}/m_{WIMP}=0.6$**
  σ / m_{SWIMP}/m_{WIMP}
- **isotropic distribution**
  10% variation for $\sin^2\theta$ or (1§ $\cos\theta)^2$
- **η_{CUT} dependence**
  drop by 20% for $|\eta|<0.5$
- **β_{CUT} dependence**
  drop by factor of 2-5 for $\beta<0.6$

SuperWIMP with charged WIMP at ILC



superWIMP: Discovery limit



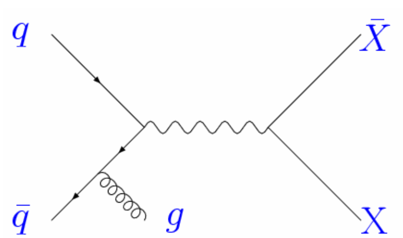
10 events reach

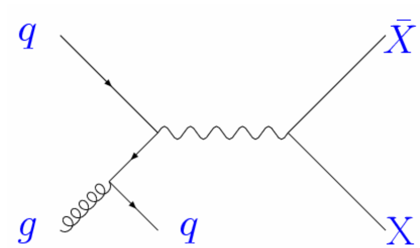
P-wave
S_X=0
m_{SWIMP}/m_{WIMP}=0.6

Scale as
$(2\ S_X+1)^{-2}$ and
$(m_{SWIMP}/m_{WIMP})^{-1}$

Neutral WIMP at LHC

- **WIMP pair production is invisible**
- **Consider monojet event: pp ! X $\bar{X}$ j**





$$\frac{d}{dz\,d\cos\theta}\bar{\sigma}(q(\bar{q}\to\bar{q}g)\to X\bar{X}g;\hat{s}) \approx F_{\bar{q}\to g}(z,\theta)\,\bar{\sigma}(q\bar{q}\to X\bar{X};(1-z)\hat{s})$$

$$\frac{d}{dz\,d\cos\theta}\bar{\sigma}(q(g\to\bar{q}q)\to X\bar{X}q;\hat{s}) \approx F_{g\to q}(z,\theta)\,\frac{2S_q+1}{2S_g+1}\bar{\sigma}(q\bar{q}\to X\bar{X};(1-z)\hat{s})$$

- **irreducible SM background: pp ! $\nu\bar{\nu}$ j**

Splitting function

$p_T^{\rm min}$		B	$S/\sqrt{B}$
30 GeV	19 fb	1300 pb	0.51
100 GeV	4.1 fb	130 pb	0.36

Difficult !

Conclusions

- **If stable WIMP or superWIMP exist, cosmology provides model-independent <u>lower</u> bounds on production rates of new particles at colliders.**

- **In superWIMP scenario with charged WIMP, spectacular signals at LHC and ILC.**

- **In standard WIMP scenario, $X\bar{X}j$ signal is swamped by monojet background.**