



# 自己結合とダークマター

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# やろうとしていること

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- 自己結合の精密測定
  - 3点4点結合の測定ができるか？
  - 兼村さん(富山)とEW Bariogenesis の検証？
- Higgs Portal DM
  - 直接観測
  - 尾田欣さん+PD+学生のグループと。

# Double- triple- H 生成

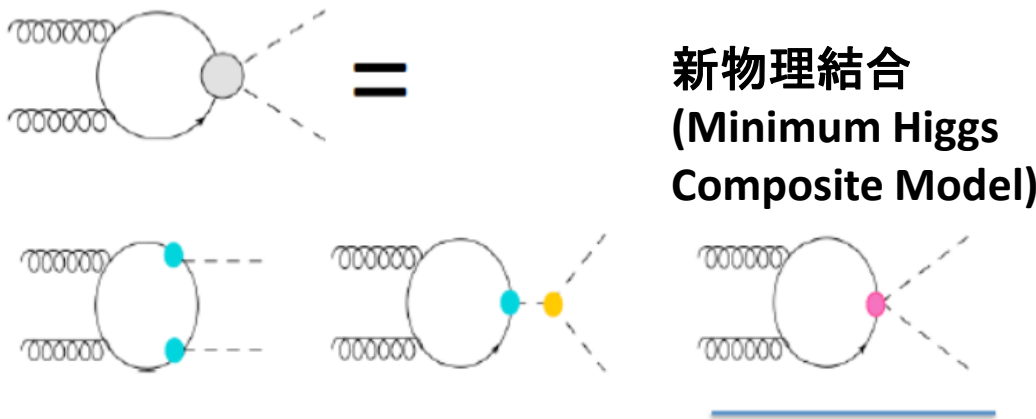
LHC3000迄SMライクだったらヒッグスポテンシャル位しか動かさない

⇒ ILC では様々なヒッグス結合  $h\gamma\gamma$ ,  $hVV$ ,  $hff$ , ... の詳細測定と  
ヒッグス3点結合を測る!

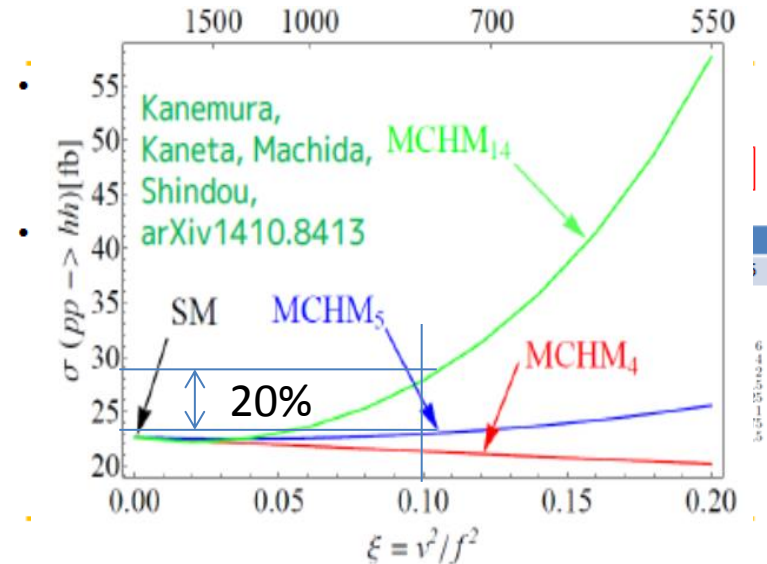
⇒ ILCが承認されないとき: 100TeVコライダーで自己結合(3点に加えて4点)を測ることができるか?

## 4点と3点結合

3点に加えて4点結合の情報はヒッグスポテンシャルの情報を得る上で重要  
くりこみ可能な理論のループ補正では**4点結合のズレは3点のズレの4倍!**

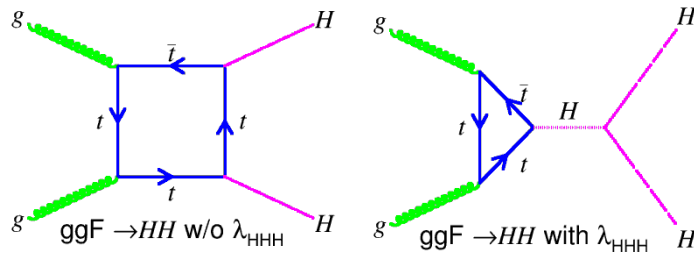


hhhを抜き出せなくてもhh断面積のズレはみれる



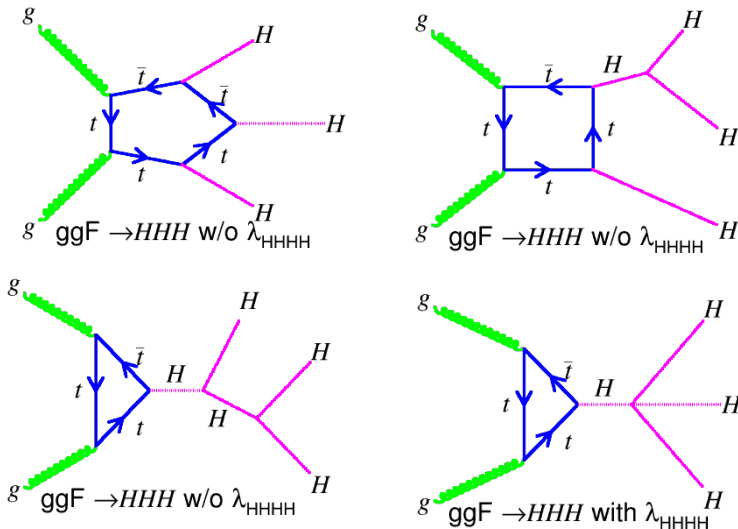
# Higgs 3点/4点結合？

## Di-Higgs 生成(3点結合)



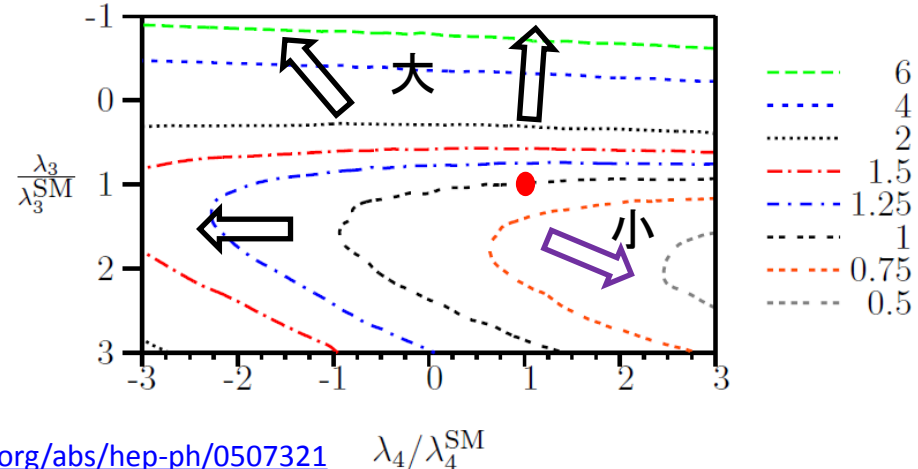
	HL-LHC	HE-LHC	VLHC
$\sqrt{s}$ (TeV)	14	33	100
$\int \mathcal{L} dt$ (fb $^{-1}$ )	3000	3000	3000
$\sigma \cdot \text{BR}(pp \rightarrow HH \rightarrow b\bar{b}\gamma\gamma)$ (fb)	0.089	0.545	3.73
$S/\sqrt{B}$	2.3	6.2	15.0
$\lambda$ (stat)	50%	20%	8%

## Tri-Higgs 生成(4点結合)

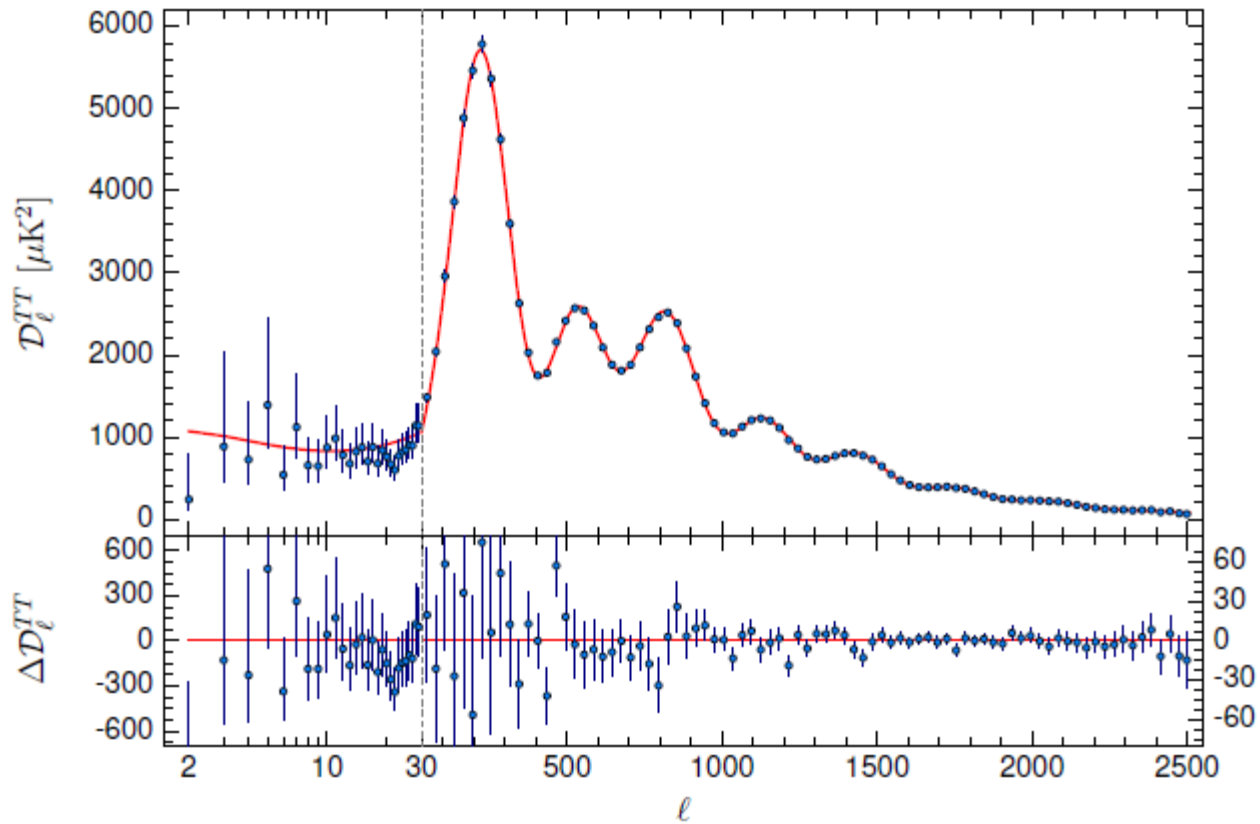


$\sigma$ [fb]	pentagon	Box	Triangle	Total
14TeV	0.171	0.082	0.0046	0.0625

100TeV : **8.0 fb**    200TeV : **9.5 fb**

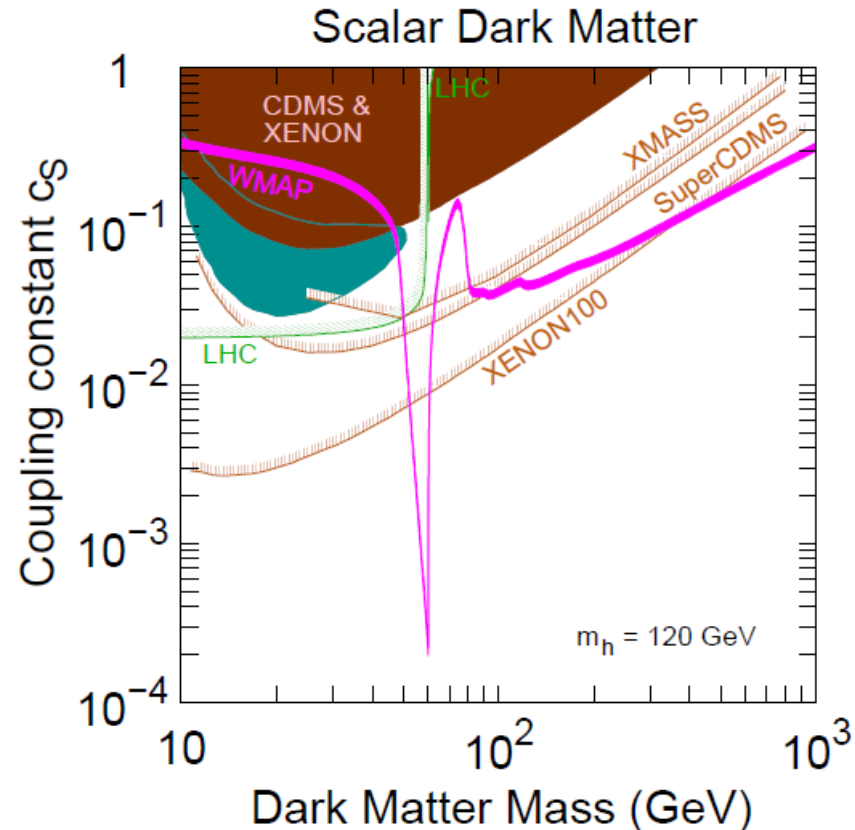
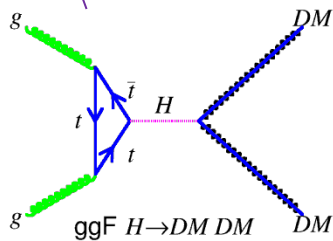
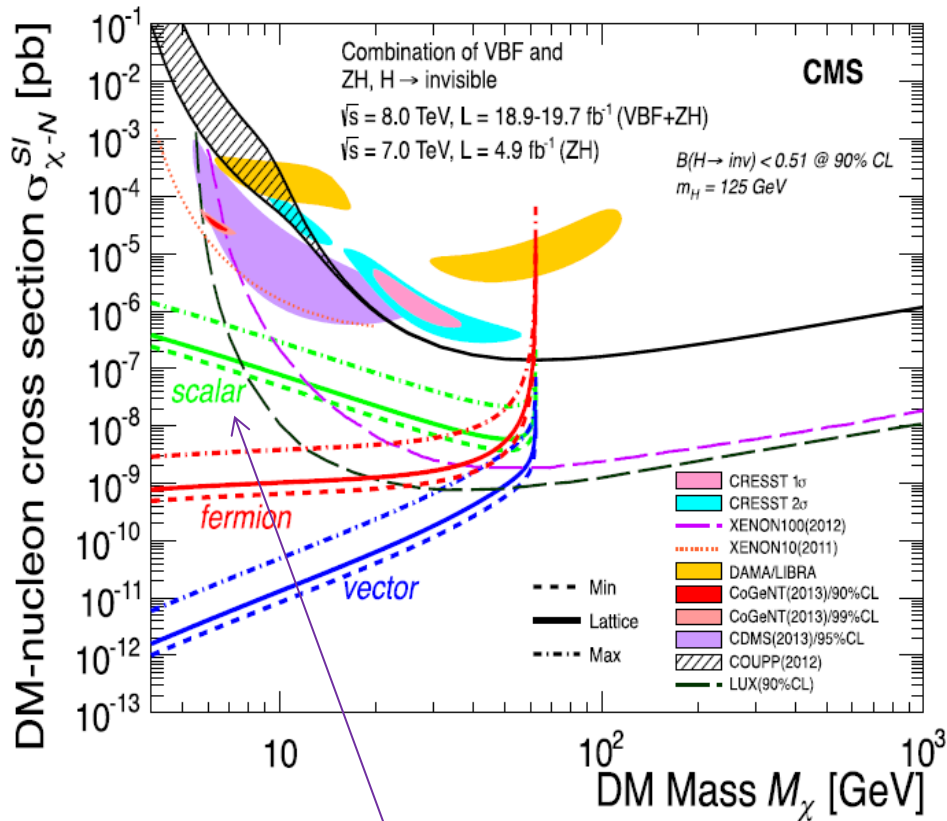


<http://arxiv.org/abs/hep-ph/0507321>  
<http://arxiv.org/abs/hep-ph/0608057>



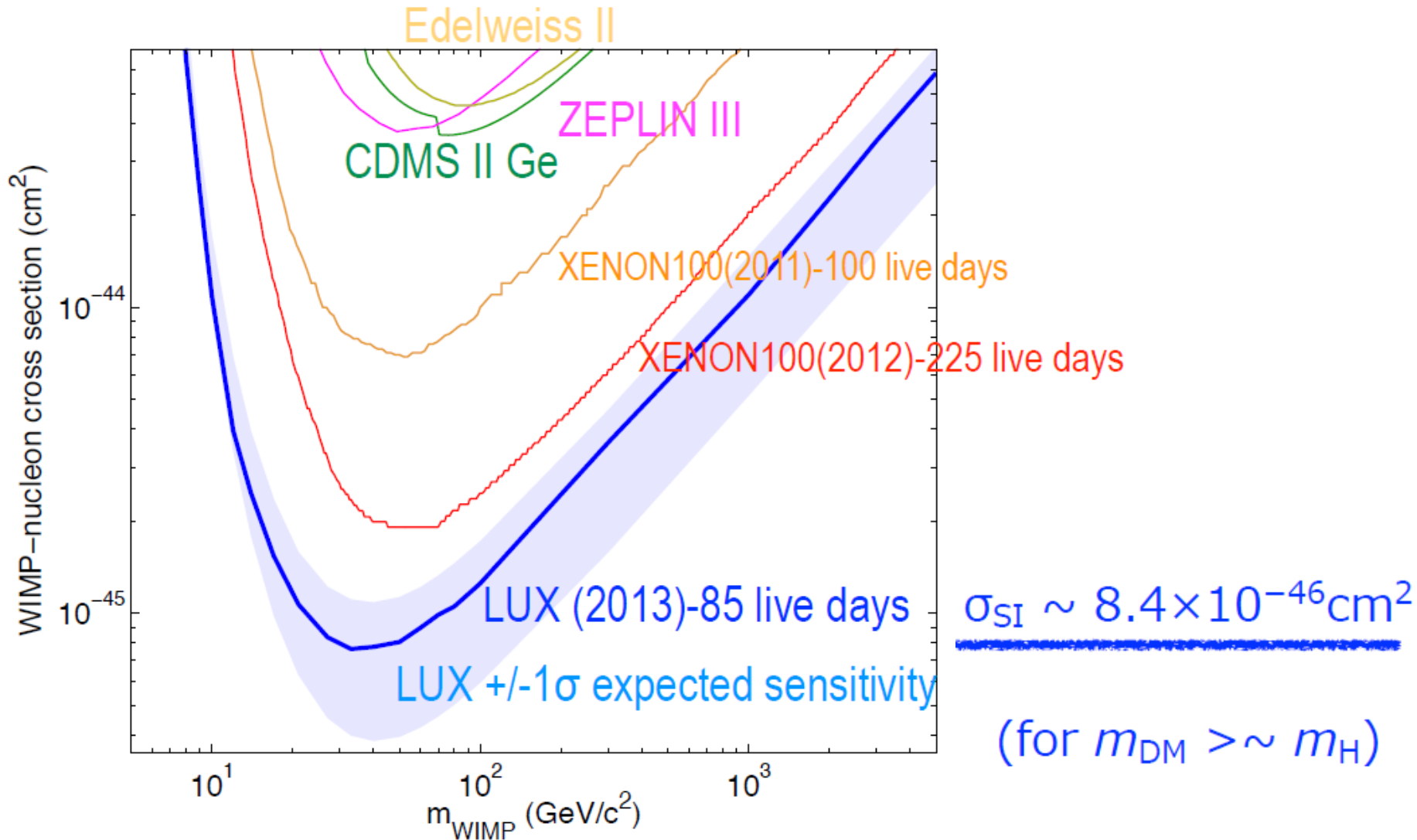
Parameter	[1] Planck TT+lowP	[2] Planck TE+lowP	[3] Planck EE+lowP	[4] Planck TT,TE,EE+lowP	([1] - [4])/σ <sub>[1]</sub>
$\Omega_b h^2$	$0.02222 \pm 0.00023$	$0.02228 \pm 0.00025$	$0.0240 \pm 0.0013$	$0.02225 \pm 0.00016$	-0.1
$\Omega_c h^2$	$0.1197 \pm 0.0022$	$0.1187 \pm 0.0021$	$0.1150^{+0.0048}_{-0.0055}$	$0.1198 \pm 0.0015$	0.0
$100\theta_{MC}$	$1.04085 \pm 0.00047$	$1.04094 \pm 0.00051$	$1.03988 \pm 0.00094$	$1.04077 \pm 0.00032$	0.2
$\tau$	$0.078 \pm 0.019$	$0.053 \pm 0.019$	$0.059^{+0.022}_{-0.012}$	$0.079 \pm 0.017$	-0.1
$\ln(10^{10} A_s)$	$3.089 \pm 0.036$	$3.031 \pm 0.041$	$3.066^{+0.046}_{-0.041}$	$3.094 \pm 0.034$	-0.1
$n_s$	$0.9655 \pm 0.0062$	$0.965 \pm 0.012$	$0.973 \pm 0.016$	$0.9645 \pm 0.0049$	0.2
$H_0$	$67.31 \pm 0.96$	$67.73 \pm 0.92$	$70.2 \pm 3.0$	$67.27 \pm 0.66$	0.0
$\Omega_m$	$0.315 \pm 0.013$	$0.300 \pm 0.012$	$0.286^{+0.027}_{-0.038}$	$0.3156 \pm 0.0091$	0.0
$\sigma_8$	$0.829 \pm 0.014$	$0.802 \pm 0.018$	$0.796 \pm 0.024$	$0.831 \pm 0.013$	0.0
$10^9 A_s e^{-2\tau}$	$1.880 \pm 0.014$	$1.865 \pm 0.019$	$1.907 \pm 0.027$	$1.882 \pm 0.012$	-0.1

# Higgs Portal DM



- Thermal Abundance からの制限
  - $m(\text{DM}) \sim 60 \text{ GeV}$  を除くと
  - $m(\text{DM}) > 200 \text{ GeV}$  ?

# 直接探索と予想断面積

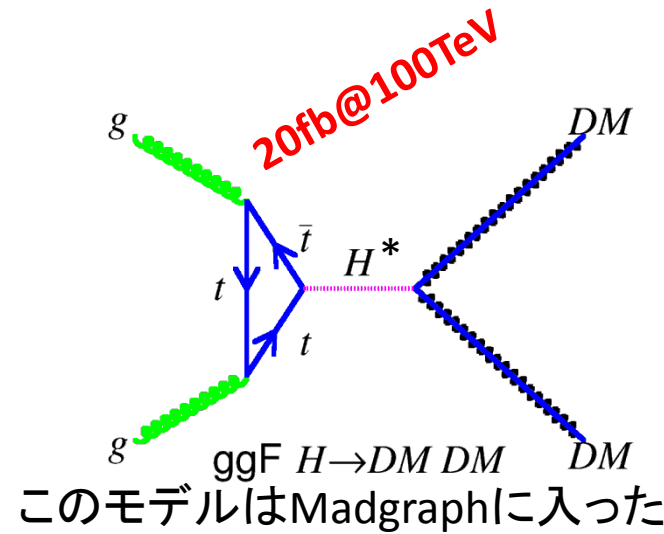


# 2TeV Higgs Portal DM @ Collider

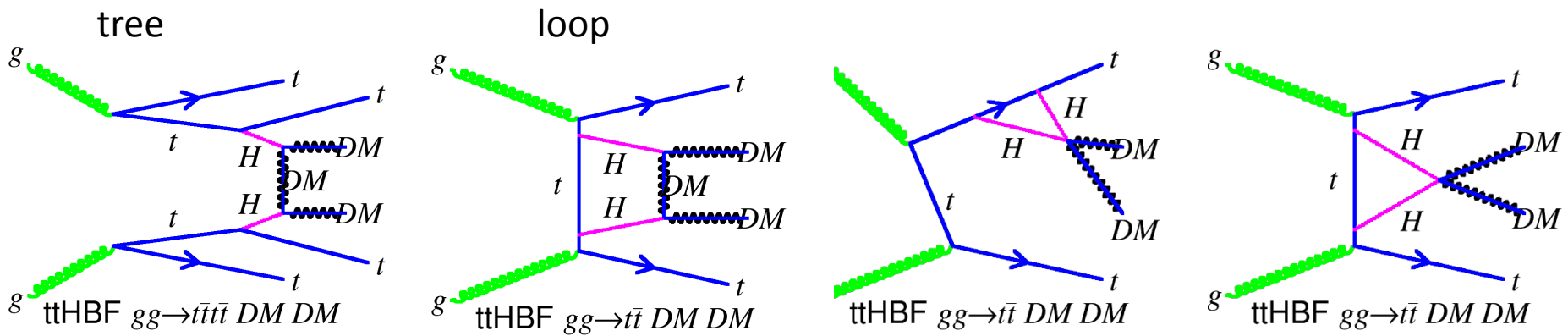
- Higgs をoff-shell にしてDM対の生成断面積を計算

- 2TeV Scalar DM
- 100TeV :  $10^{-7(\pm 2)}\text{fb}$
- やはりs-channel off-shell だと厳しい
- Fermion DM :  $10^{-4} \times (v/\Lambda)^2 \sim 10^{-4}\text{fb}$

K. Oda (2015.3)



- Higgs Fusion Diagram?





# Madgraph

- **EVNT files**

- /data/maxi165/atljphys/kojin/EvGen/Madgraph/EVNT/mc15\_100TeV/  
mc15\_100TeV.900000.MadGraphPythia8EvtGen\_CTEQ6L1\_ttDMDM\_inc.EVNT.e01  
mc15\_100TeV.900100.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hhh\_inc.EVNT.e01  
mc15\_100TeV.900110.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hhh\_bbbbbbb.EVNT.e01  
mc15\_100TeV.900200.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hhh\_lam3H0\_inc.EVNT.e01  
mc15\_100TeV.900300.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hhh\_lam3H2\_inc.EVNT.e01  
mc15\_100TeV.901000.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hh\_inc.EVNT.e01  
mc15\_100TeV.901100.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hh\_lam3H0\_inc.EVNT.e01  
mc15\_100TeV.901200.MadGraphPythia8EvtGen\_CTEQ6L1\_gg\_hh\_lam3H2\_inc.EVNT.e01  
mc15\_100TeV.902000.MadGraphPythia8EvtGen\_CTEQ6L1\_ggFHNLO\_inc.EVNT.e01  
mc15\_100TeV.902050.MadGraphPythia8EvtGen\_CTEQ6L1\_VBFHNLO\_inc.EVNT.e01  
mc15\_100TeV.902100.MadGraphPythia8EvtGen\_CTEQ6L1\_WHNLO\_inc.EVNT.e01  
mc15\_100TeV.902150.MadGraphPythia8EvtGen\_CTEQ6L1\_ZHNLO\_inc.EVNT.e01  
mc15\_100TeV.902200.MadGraphPythia8EvtGen\_CTEQ6L1\_ttHNLO\_inc.EVNT.e01  
mc15\_100TeV.902250.MadGraphPythia8EvtGen\_CTEQ6L1\_bbHNLO\_inc.EVNT.e01  
mc15\_100TeV.902300.MadGraphPythia8EvtGen\_CTEQ6L1\_tHNLO\_inc.EVNT.e01  
mc15\_100TeV.910010.MadGraphPythia8EvtGen\_CTEQ6L1\_ttbarnLO\_inc.EVNT.e01  
mc15\_100TeV.910020.MadGraphPythia8EvtGen\_CTEQ6L1\_singletopSchNLO\_inc.EVNT.e01  
mc15\_100TeV.910030.MadGraphPythia8EvtGen\_CTEQ6L1\_singletopTchNLO\_inc.EVNT.e01  
mc15\_100TeV.910040.MadGraphPythia8EvtGen\_CTEQ6L1\_singletopWtNLO\_inc.EVNT.e01  
mc15\_100TeV.920010.MadGraphPythia8EvtGen\_CTEQ6L1\_WmWmjjNLO\_inc.EVNT.e01  
mc15\_100TeV.920020.MadGraphPythia8EvtGen\_CTEQ6L1\_WpWpjjNLO\_inc.EVNT.e01  
mc15\_100TeV.920030.MadGraphPythia8EvtGen\_CTEQ6L1\_WpWmNLO\_inc.EVNT.e01  
mc15\_100TeV.920040.MadGraphPythia8EvtGen\_CTEQ6L1\_WZNLO\_inc.EVNT.e01  
mc15\_100TeV.920050.MadGraphPythia8EvtGen\_CTEQ6L1\_ZZNLO\_inc.EVNT.e01  
mc15\_100TeV.930100.MadGraphPythia8EvtGen\_CTEQ6L1\_WjetsNLO\_inc.EVNT.e01  
mc15\_100TeV.930200.MadGraphPythia8EvtGen\_CTEQ6L1\_ZjetsNLO\_inc.EVNT.e01  
mc15\_100TeV.930300.MadGraphPythia8EvtGen\_CTEQ6L1\_GamjetsNLO\_inc.EVNT.e01

# 100TeVの断面積

- ttDMDM : 0.019991 +- 5.55e-05(pb)  
gg\_hhh : 0.0028848 +- 6.86e-06(pb)  
gg\_hhh\_lam3H0 : 0.0076795 +- 8.42e-06(pb)  
gg\_hhh\_lam3H2 : 0.0025178 +- 3.16e-06(pb)  
gg\_hh : 0.80647 +- 0.00104(pb)  
gg\_hh\_lam3H0 : 1.5582 +- 0.00215(pb)  
gg\_hh\_lam3H2 : 0.40647 +- 0.00127(pb)  
ttbarNLO : 28840 +- 241(pb)  
singletopSchNLO : 3741.3 +- 30.6(pb)  
singletopTch : 3088.1 +- 14.1(pb)  
##### singletopWt : 51147 +- 51.1(pb)  
ggFHNLO : 334.92 +- 0.447(pb)  
VBFH : 40.398 +- 0.152(pb)  
WHNLO : 14.745 +- 0.0327(pb)  
ZHNLO : 8.0189 +- 0.0174(pb)  
ttHNLO : 31.713 +- 0.206(pb)  
bbHNLO : 11.62 +- 0.908(pb)  
WpWmNLO : 1087.9 +- 4.19(pb)  
WZNLO : 556.24 +- 1.55(pb)  
ZZNLO : 146.08 +- 0.63(pb)  
WmWmjNLO : 3.5419 +- 0.0275(pb)  
WpWpjNLO : 5.1792 +- 0.047(pb)  
ZjetsNLO : 1.6678e+05 +- 4.02e+03(pb)

3ab-1?

30ab-1?

# これから

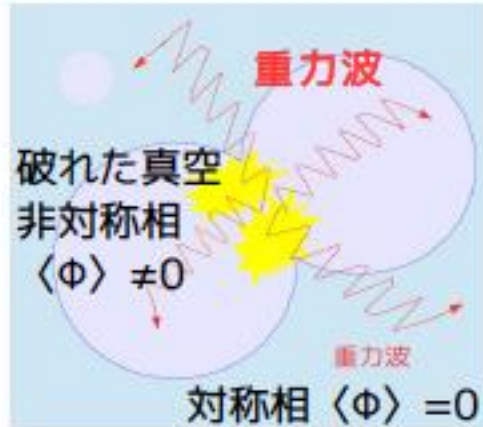
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- それぞれ、簡単に感度出してみる
  - やるかちがあるか？
  
- 検出器開発
  - CMOSモノリシックpixel検出器

# backup

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# 重力波と強い一次的電弱相転移



① 泡の衝突:  $\Omega_{\text{coll}} h^2 \sim 10^{-8} \left[ \frac{H_t}{\beta} \right]^2 \left[ \frac{\alpha}{1 + \alpha} \right]^2$

② プラズマ乱流:  $\Omega_{\text{turb}} h^2 \sim 10^{-4} \left[ \frac{H_t}{\beta} \right]^2$

2つの機構で重力波発生!

泡が衝突し重力波発生

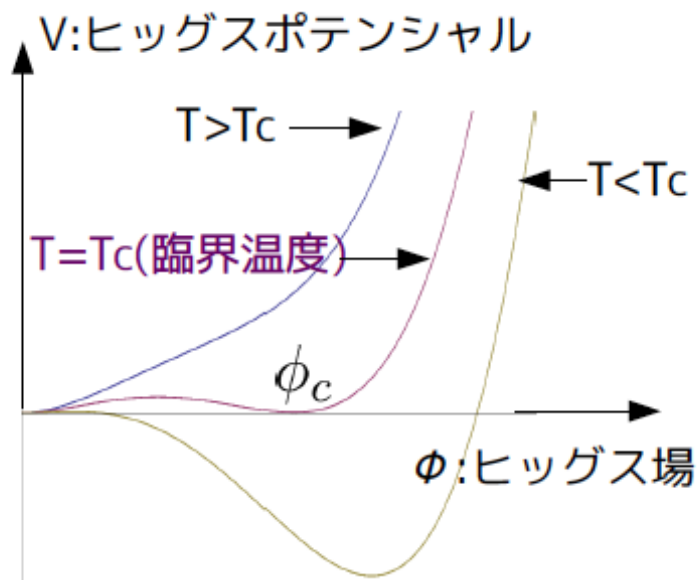
半解析的計算 J. Kehayias and S. Profumo (2007)

1. 潜熱  $\epsilon_t = V(v(T), T) + T \frac{d}{dT} V(v(T), T) \Big|_{T_t}$   $\alpha \equiv \frac{\epsilon_t}{\rho_{\text{rad}}(T_t)}$   $\left( \rho_{\text{rad}}(T) = \frac{\pi^2}{30} g(T) T^4 \right)$

2. 相転移継続時間  $\beta^{-1}$   
 $\frac{\beta}{H_t} \equiv T_t \frac{d(S_3(T)/T)}{dT} \Big|_{T_t} \approx \frac{4G(\beta_1 + 2\beta_2 + 4\beta_3(ET_c - e)) (1 - \epsilon)}{F^2 T_c \epsilon^3}$  (高温近似)  $\begin{matrix} \beta_1 = 8.29 \\ \beta_2 = -5.53 \\ \beta_3 = 0.82 \end{matrix}$

3. 相転移温度  $T_t \approx T_c (1 - \epsilon)$   $T_c = \frac{-\sqrt{D\lambda(T_c)((D\lambda - E^2)T_0^2)}}{E^2 - D\lambda(T_c)}$

$F = \frac{4D\lambda(ET_0^2 - eT_c)T_c}{(e - ET_c)}$   $G = \frac{64\sqrt{2}\pi}{84\lambda^{3/2}}$   $\epsilon \approx \sqrt{\frac{2G(\beta_1 + 2\beta_2 + 4\beta_3)(ET_c - e)}{140F^2 T_c}}$  **13**



高温展開( $T \gg m$ )での有効ポテンシャル

$$V(\phi, T) = D(T^2 - T_0^2)\phi^2 - (ET - e)\phi^3 + \frac{\lambda}{4}\phi^4$$

$$\rightarrow \frac{\phi_c}{T_c} = \frac{2E}{\lambda} \left( 1 - \frac{\lambda e}{ET_c} \right)$$

$$\phi_c/T_c \geq 1 \text{ 強い一次相転移}$$

シナリオB. ツリーレベルで三点結合( $|e|$ )を大きくするシナリオ

例: 標準理論 + 実シングレット場

• ポテンシャル中の三点結合  $\rightarrow e$

• シングレット模型

ヒッグスダブルレット場:  $\Phi = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v_0 + h) \end{pmatrix}$  実シングレット場:  $S = x_0 + s$

ツリーレベルポテンシャル

$$V = -\mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2 + \frac{a_1 \Phi^\dagger \Phi S + a_2 \Phi^\dagger \Phi S^2 + b_2 S^2 + b_3 S^3 + b_4 S^4}{2}$$

$\rightarrow |e|$

$|a_1|$  が大きくなるほどに  $\phi_c/T_c$  の値も大きくなる