The existence of $M_{\Delta T2}$ endpoint s and shining buried new particles

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2009. 9. 3.

KIAS-KAIS-YITP Joint Workshop on DM, LHC and Cosmology

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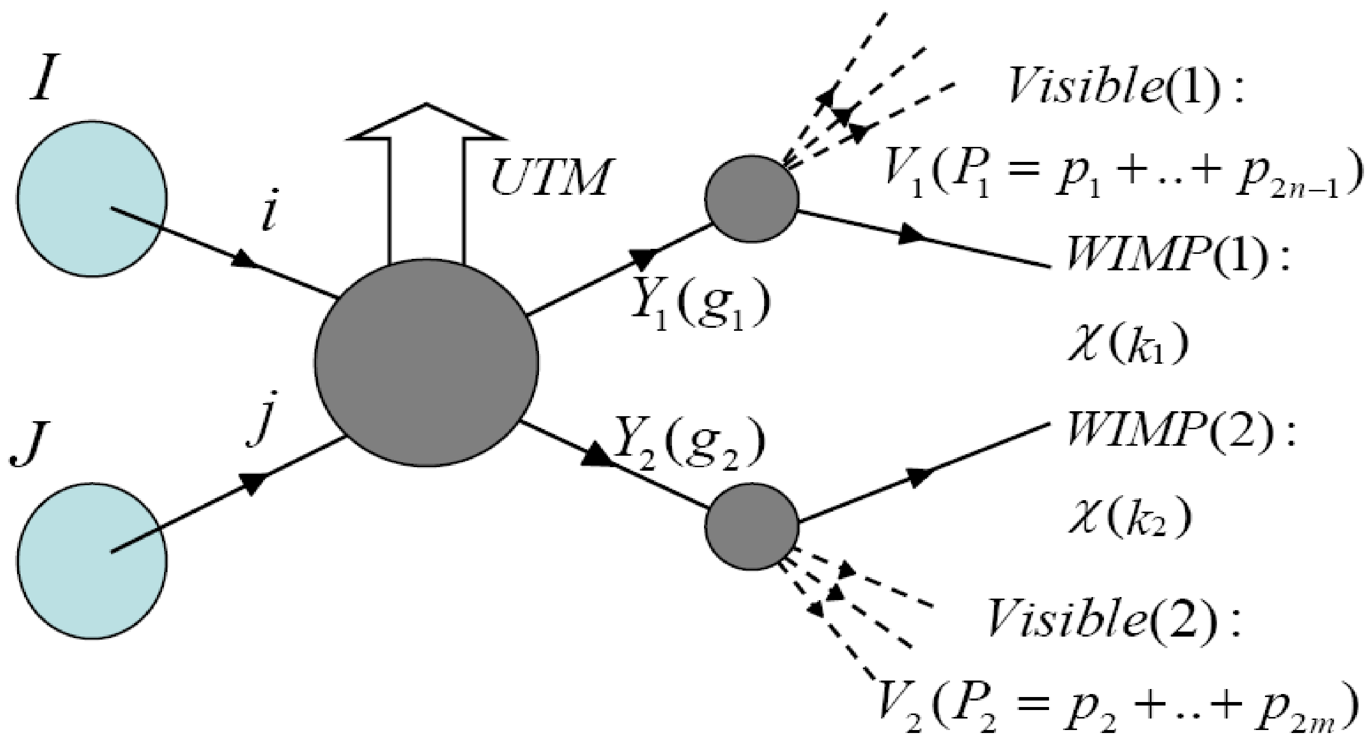
Event topology

- **Pair-produced new particle *Y* decaying into visible particles, *V* plus an invisible WIMP, χ :**

$$P(I)+P(J)\rightarrow Y_1+Y_2\rightarrow V_1+\ \chi_1\ +\ V_2+\ \chi_2$$

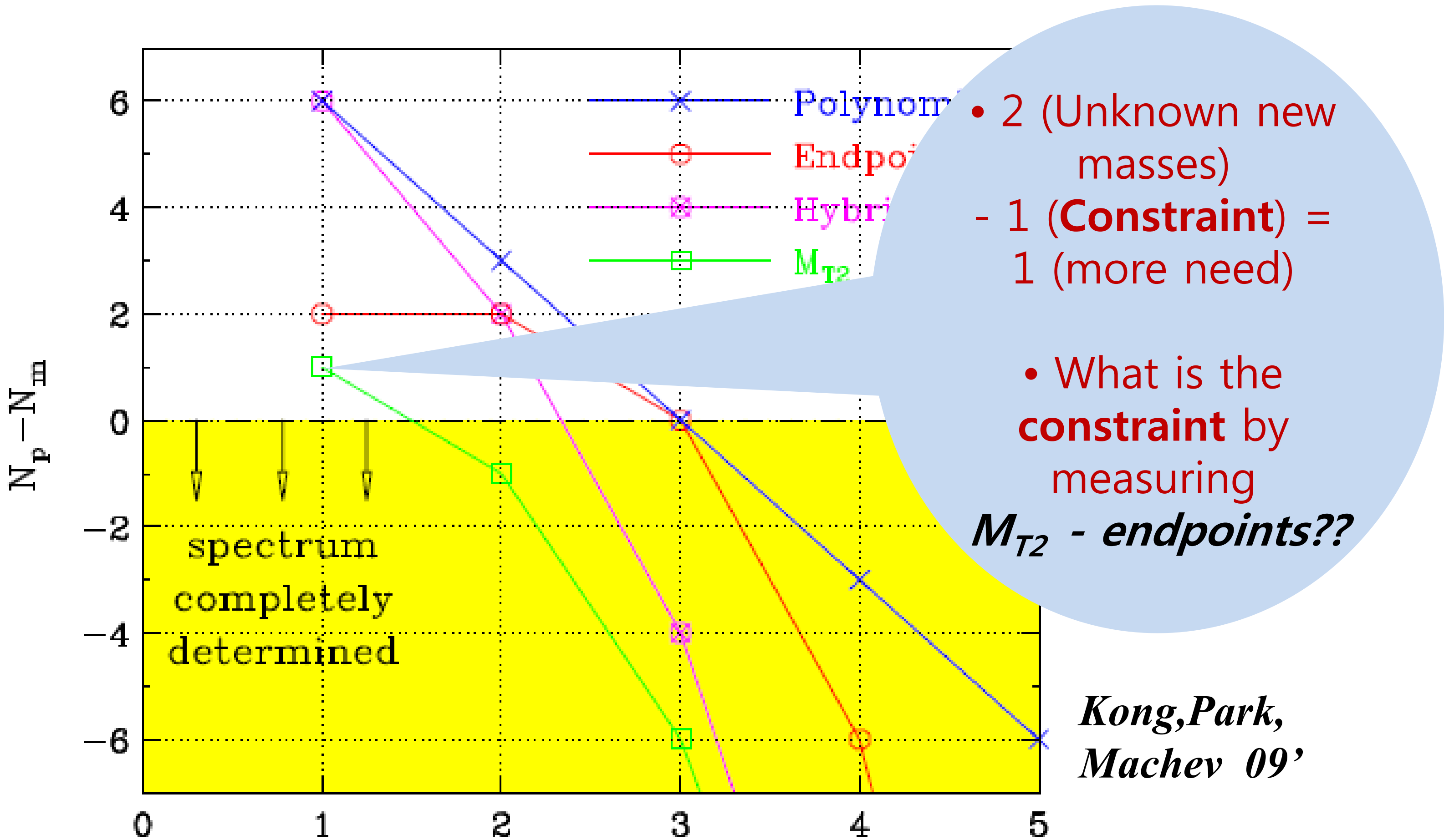


- **Measuring the new particle masses is not easy.**
  - **Partonic CM frame ambiguity (at HC)**
  - **Missing information from several missing particles (at least, 2 in several NP models with DM)**
  - **Complex event topologies**

- **Several methods**
  - **Using *Invariant mass edges, On-shell relations,* M_{T2} *- endpoints***
  - **Hybrids with states of art will be the best.**

- **Using the *'*M_{T2} *- endpoint'* has *strong power for mass measurement with short decay chains***

- **Possibility of mass measurement in various new event topology**



Kong,Park, Machev 09'

n (= number of visible particles in each decay chain)

- M_{T2} - the extension of the transverse mass, M_T for the event with two missing particles

Transverse mass of $Y \to V(p) + \chi(k)$

$$M_T{}^2 = m_V{}^2 + m_\chi{}^2 + 2\sqrt{m_V{}^2 + |\mathbf{p}_T|^2}\sqrt{m_\chi{}^2 + |\mathbf{k}_T|^2} - 2\mathbf{p}_\mathbf{T}\cdot\mathbf{k}_\mathbf{T}$$

$\Rightarrow$ Independent of the longditudinal momenta.

$\Rightarrow$ One may use an arbitrary trial WIMP mass m_χ to define M_T

(True WIMP mass = $m_\chi{}^{true}$)

Stransverse mass of $Y_1\, Y_2 \to (V_1(p_1) + \chi_1(k_1)) + (V_2(p_2) + \chi_2(k_2))$

$$M_{T2}{}^2 = \min[\max\{M_T(Y_1), M_T(Y_2)\}]$$

$\Rightarrow$ *Minimization* over all possible WIMP transverse momenta

- **For all events, $M_{T\,\&T2}(m_\chi{=}m_\chi{}^{true}) \leq m_Y{}^{true}$**

- **In the n=1 case, the constraint from M_{T2} - endpoint is p_0 [C.C.K.P.]**

$$M_{T2}^{max2}(x) = p^0 + \sqrt{p^{0\,2} + x^2},$$

x = trial WIMP mass

$$p^0 = \frac{m_Y^2 - m_x^2}{2m_Y},$$ the momentum of v & χ in the rest frame of Y

- **It's an interesting result of M_{T2} kinematics *because each of the two mother particles is not at rest in LAB frame!***

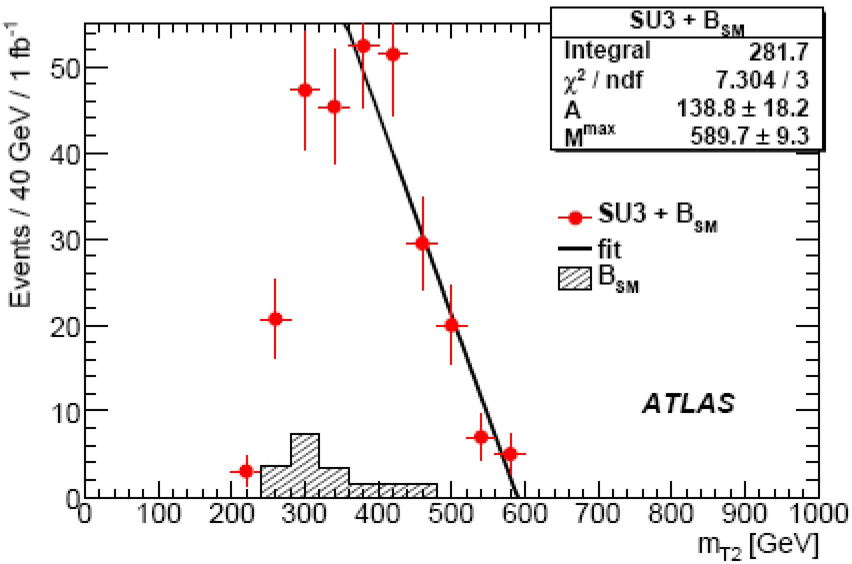
#Caution

It is only when total transverse momentum of 2 mother particle system is zero. ($p_T(Y_1) + p_T(Y_2) = 0$)

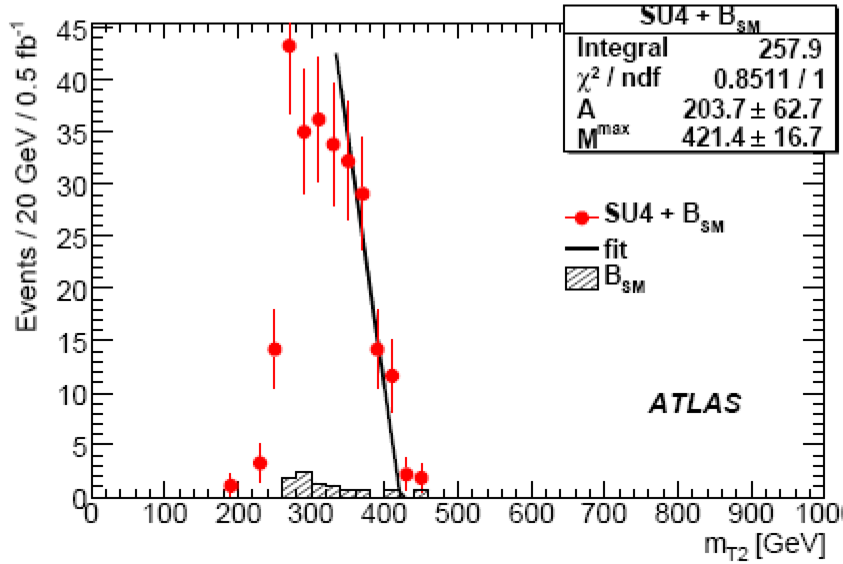
It is known that if (Y1Y2) system has non zero PT, then one can also get the boosted momenta as nontrivial constraints ***[B.Gripaios, A.Barr, C.Lester]***, providing the possibility to get the 2 unknown masses even with most simple 2-body kinematics (Practically hard to observe as lack of statistics of the event with a fixed 'highest boost'.)

- ***M_{T2}^{max} for n=1, m_x known***

ATLAS Technical Design Report 2009



$$m_{\tilde{q}_R} = 611 \text{ GeV}$$



$$m_{\tilde{q}_R} = 406 \text{ GeV}$$

M_{T2} -endpoint measurement usually has O(1~10%) systematic error from fitting process (fitting function, cuts, range …).

Then P^0 from other observable ?

M_T and $M_{\Delta T}$ (p)

Transverse mass(M_T) & invariant mass(M) of $Y \to V(p) + \chi(k)$

$$M_T^{\,2} = m_V^{\,2} + m_\chi^{\,2} + 2\sqrt{m_V^{\,2} + |\mathbf{p}_T|^2}\sqrt{m_\chi^{\,2} + |\mathbf{k}_T|^2} - 2\mathbf{p_T}\cdot\mathbf{k_T} \le M^2$$

$\Rightarrow$ Defined in any frame with fixed M_T endpoint, M.

Pseudo transverse mass ($M_{\Delta T}$) & pseudo invariant mass(M_Δ)

$$M_{\Delta T}^{\,2} = m_V^{\,2} + m_\chi^{\,2} + 2\sqrt{m_V^{\,2} + |\mathbf{p}_\mathbf{T}^0|^2}\sqrt{m_\chi^{\,2} + |\mathbf{p}_\mathbf{T}^0|^2} - 2(\mathbf{R}(\Delta)\mathbf{p}_\mathbf{T}^0)\cdot(-)\mathbf{p}_\mathbf{T}^0$$

$$\le M_\Delta^{\,2} (= m_V^{\,2} + m_\chi^{\,2} + 2\sqrt{m_V^{\,2} + |\mathbf{p}_\mathbf{T}^0|^2}\sqrt{m_\chi^{\,2} + |\mathbf{p}_\mathbf{T}^0|^2}\, Cosh\Delta\eta - 2(\mathbf{R}(\Delta)\mathbf{p}_\mathbf{T}^0)\cdot(-)\mathbf{p}_\mathbf{T}^0$$

R(Δ) is the rotation in transverse plain by anlge, Δ,

$\Delta\eta =$ rapidity difference between the visible and invisible particles

$\Rightarrow$ Defined in **the rest frame of Y** with fixed $M_{\Delta T}$ endpoint, M_Δ

$\Rightarrow$ Endpoint useful only for a **mother particle with $\mathbf{P_T = 0}$**

If it is possible, then the pseudo-transverse mass endpoint measurement will also provide us the P^0 .

$$M_{\Delta T}^{\max 2}(x) = m_V^{\ 2} + x^2 + 2\sqrt{m_V^{\ 2} + |\mathbf{p^0}|^2}\sqrt{x^{\ 2} + |\mathbf{p^0}|^2} + Cos\Delta\,|\mathbf{p^0}|^2$$

$x =$ trial WIMP mass

→ *How about the new mother particle pair, each with nonzero P_T ?*

- $M_{\Delta T}$ **endpoint can be visible using** $M_{\Delta T2}$ ***(pseudo-stransverse mass) variable defined in the LAB frame,*** **for the pair of mother particles with total** P_T**=0 !**

Def > Pseudo-stransverse mass ($M_{\Delta T2}$**) for**

$$Y_1 \; Y_2 \to (V_1(p_1) + \chi_1(k_1)) + (V_2(p_2) + \chi_2(k_2))$$

$$M_{\Delta T2}{}^2 \equiv \min[\max\{M_{\Delta T}(Y_1), M_{\Delta T}(Y_2)\}]$$

$$M_{\Delta T} \equiv m_V{}^2 + m_\chi{}^2 + 2\sqrt{m_V{}^2 + |\mathbf{p_T}|^2}\sqrt{m_\chi{}^2 + |\mathbf{k_T}|^2} - 2(\mathbf{R}(\Delta)\mathbf{p_T}) \cdot \mathbf{k_T},$$

$\mathbf{p_T}$ s' are visible transverse momenta in the LAB frame

min&max over all possible invisible momentum $\mathbf{k_T}$

- **Then, the endpoint behavior in trial WIMP mass, x, also provides the P^0**

$$M_{\Delta T2}^{\max 2}(x) = m_V{}^2 + x^2 + 2\sqrt{m_V{}^2 + |\mathbf{p^0}|^2}\sqrt{x^2 + |\mathbf{p^0}|^2} + Cos\Delta\,|\mathbf{p^0}|^2$$

$x =$ trial WIMP mass

- **This realization results from the same reason of $M_{T2}^{max}(x)$ being described by p^0 , as if each of the two mothers is transversely at rest in LAB frame.**

- **Condition for PST endpoint :**

$$\delta_T \equiv |P_T(Y_1 + Y_2)| = 0$$

- **Disadvantage of using PST (or PT) endpoint**

- Weak for nonzero δ_T (from ISR ..) effect even with correct WIMP mass input.
(always need δ_T upper bound cut)

- The nonzero δ_T effect on the endpoint :

The shifted endpoint of $M_{\pi T}(x)$ by δ_T

$$\Delta M_{\pi T}^{\max}(x)/M_{\pi T}^{\max}(x) \sim \tfrac{1}{2} f_\pi(\hat{x})\alpha\cos\phi, \quad (\text{small } \alpha)$$

$$\Rightarrow \quad \begin{Bmatrix} \sim \tfrac{1}{2}\cos\phi\alpha & (\hat{x} \ll 1) \\ \sim \quad 0 & (\hat{x} \gg 1) \end{Bmatrix},$$

where $\hat{x} = x/p_o$, $\alpha = \delta_T / M_Y$, and

ϕ = azimuthal angle of visible particle in the mother particle's rest frame.

However, even with nonzero deltaT, the multi peak differences can be preserved within the more suppressed shift!!

- **Advantage of using PST endpoint**

  - If *Δ=π and m_{vis}~ 0*, then *$M_{\pi T2}$(x)* projection of the events has extremely enhanced endpoint structure *with proper value of trial WIMP mass(x)*, originated from Jacobian factor between M_T and $M_{\pi T}$

$$\sigma^{-1}\frac{d\sigma}{dM_{\pi T}(x)} \sim J(M_{\pi T}(x), M_{\pi T}(x))\sigma^{-1}\frac{d\sigma}{dM_T(x)}$$

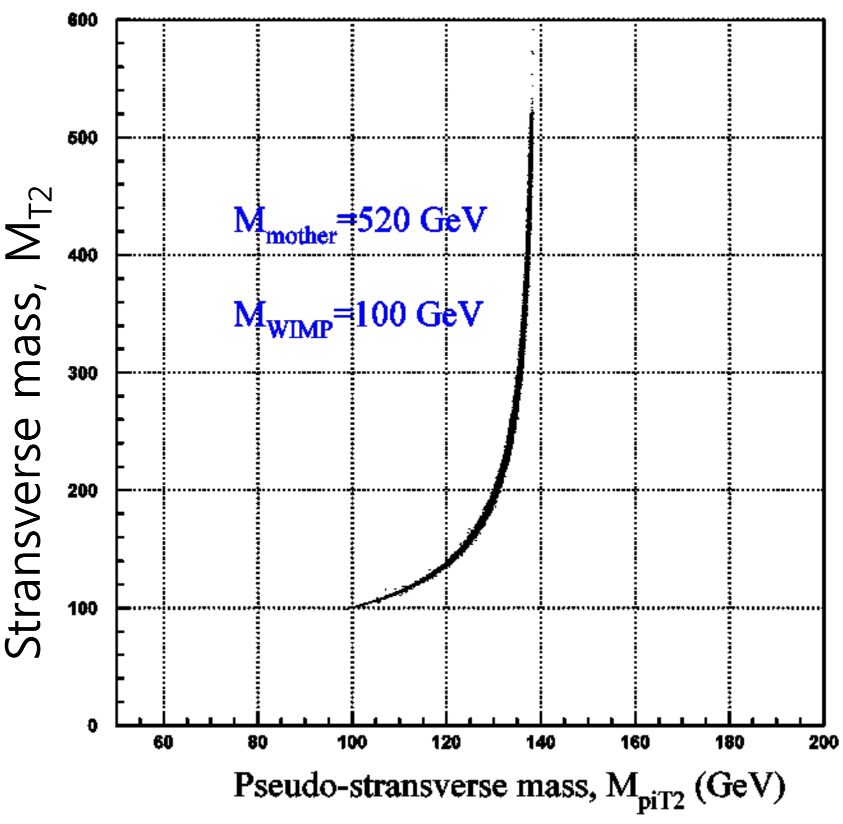
Then,

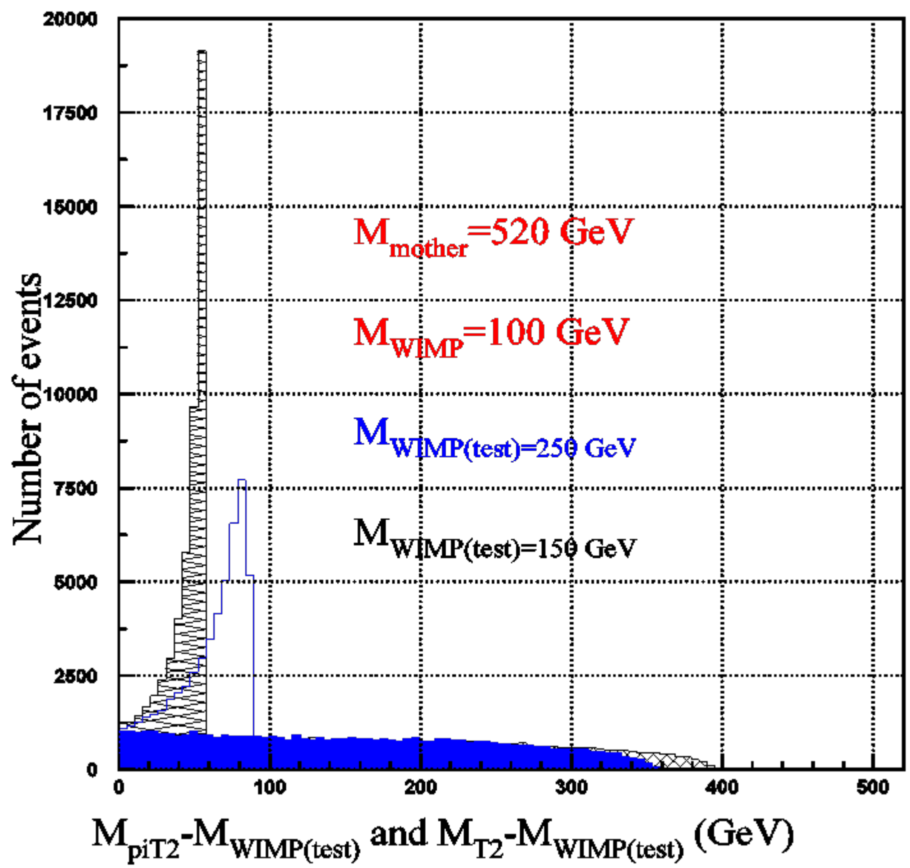
$$J \rightarrow \begin{cases} M_T \text{ max region}, (\frac{M_\pi(x)}{M(x)})^2(\frac{E_x + P_o}{E_x - P_0})^2 \sim \textit{finite} \\ M_T \text{ min region}, \frac{M_\pi(x)}{M(x)} \rightarrow 0 \quad (\text{small x}) \end{cases},$$

such that $J_{max} / J_{min} \rightarrow \infty$ for small x

ignoring the visible mass.

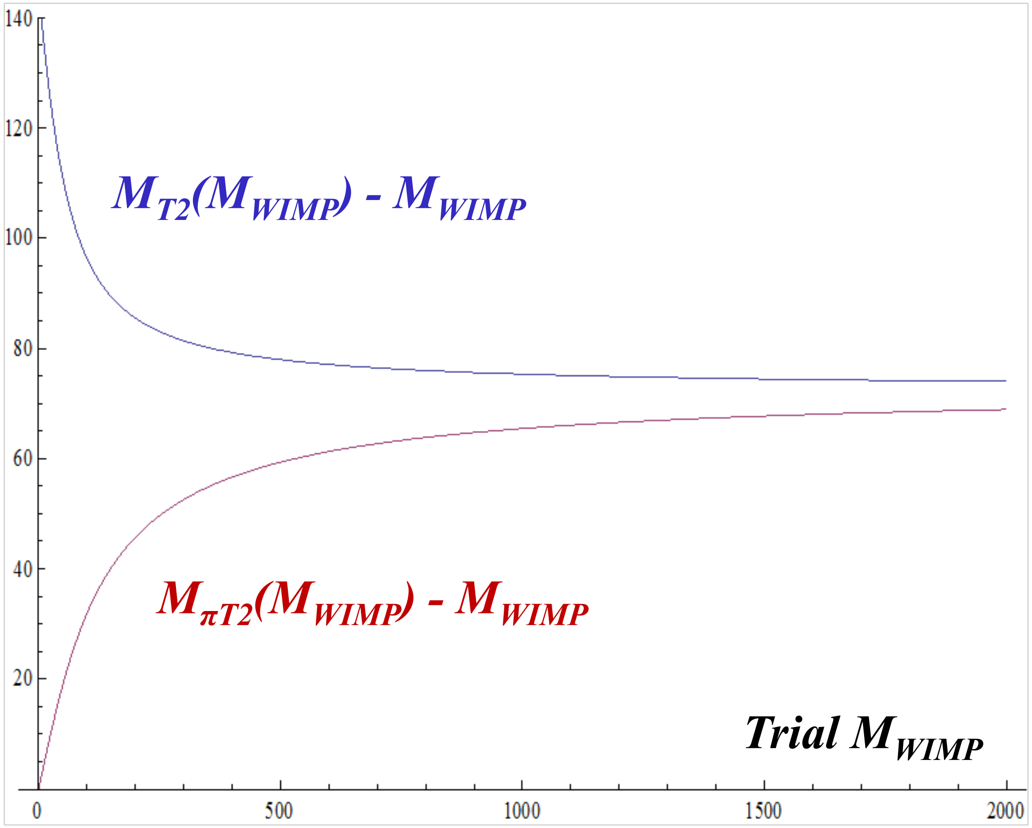
- **In result of very different compression rate, most of the large M_{T2} events are accumulated in narrow $M_{\pi T2}$ endpoint region**





- This sharp endpoint (effective triangular fit) can be rather free from the systematic errors of fitting ranges, cuts, and functions, as it shrink the higher range of M_{T2} distribution into very narrow region (depending on x)

- The ranges of M_{T2} and $M_{\pi T2}$ distribution in varying trial WIMP mass

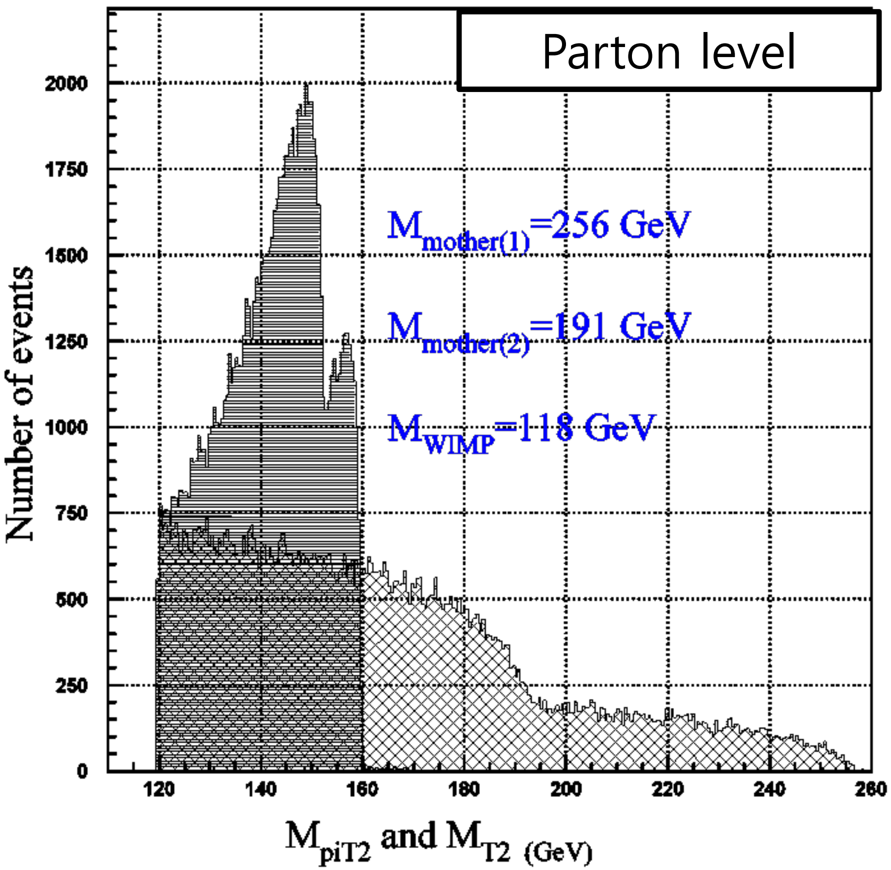


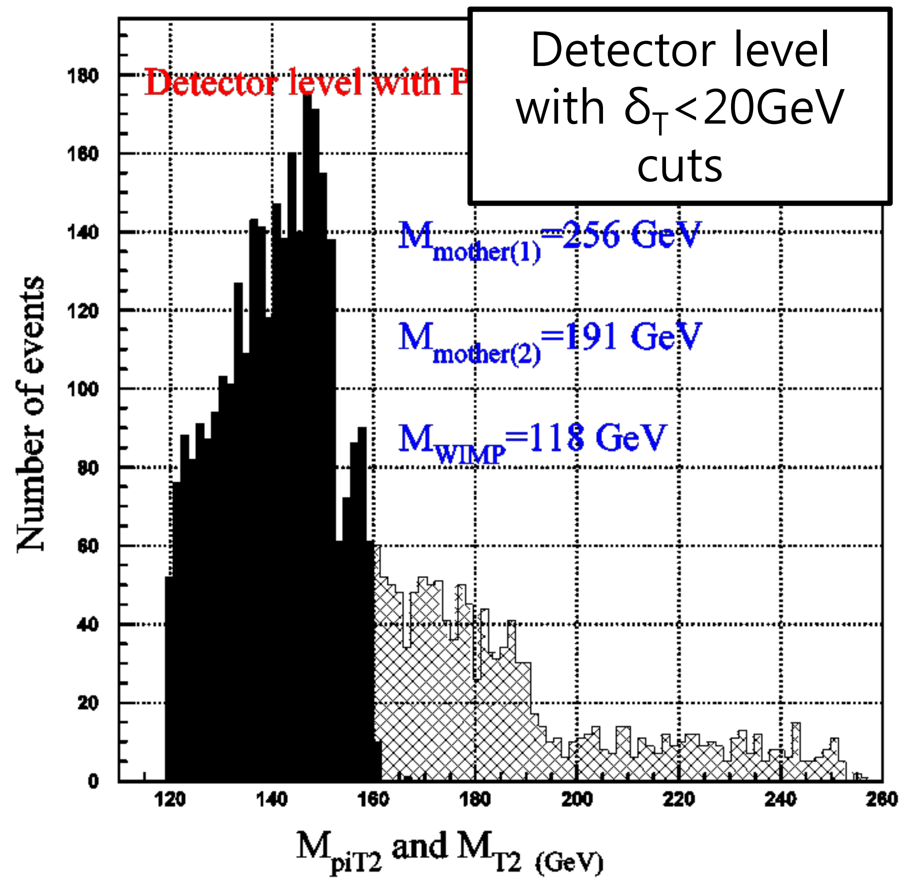
- **Uprise of buried new particle endpoints**

  - May be possible, depending on the mother particles' production rate and branching ratio, giving same signature (*2lepton/jet + MET*)

  - Measurement of mass differences precisely with small systematic fit errors

  - Example (1) ***LH or RH slepton pair production → 2l + 2chi10***

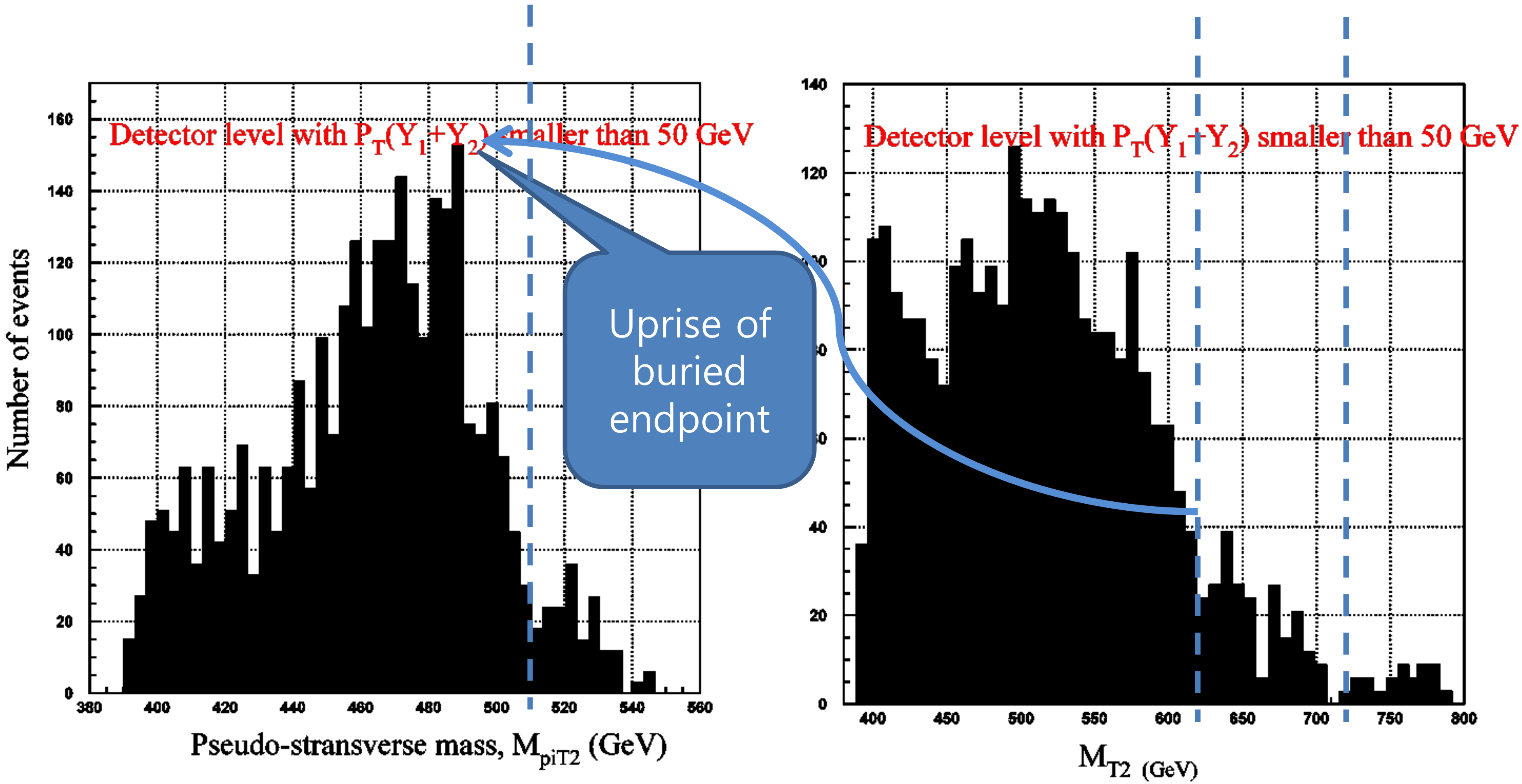




Example (2) *LH/RH squark* mass measurement using *2 jet + MET* signature

LH/RH squark mass = 722, 618 GeV

m_{LSP}(chi10)=400 GeV , with sizable bino and wino components



CUTs used :

1) ***Njet*** ≥ 2

2) ***No b-jets, No leptons***

3) $\delta_T = |P_T(Y_1) + P_T(Y_2)| < 20$ ***GeV***

4) P_T ***of*** 2^{nd} ***hardest jet*** > 80 ***GeV***

Conclusion

- ***Pseudo-stransverse mass(PST)*** **distribution has very impressive endpoint structure enhancement with respect to varying trial WIMP mass.**

- **It might give us a chance to measure the *p_0* constraint with reduced systematic uncertainties from endpoint fitting.**

- **In addition, the several buried endpoints can be uprised in the *PST projection*, enabling us to measure the mass differences between the different mother particles, buried in same signature (*2l*(*2jet*) + *MET*) (The multi PST endpoint differences are rather free from the δ_T effect)**

- **Optimal value of trial WIMP mass with good resolution power, should be studied.**