New particle mass spectrometry at the LHC : Resolving combinatoric endpoints

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Resolving every meaningful endpoints hidden in inclusive signature

(1) Amplification of the endpoint structure

Ref: arXiv0912.2354 [W.Cho, J.E. Kim, J. Kim]

(2) General combinatoric endpoints

[Work in progress with M. M. Nojiri]

→ New particle mass spectrometry at the LHC

Amplification of M_{T2} endpoints

- M_{CT2} ??   [ref) arXiv:0912.2354, Cho, Kim, Kim]

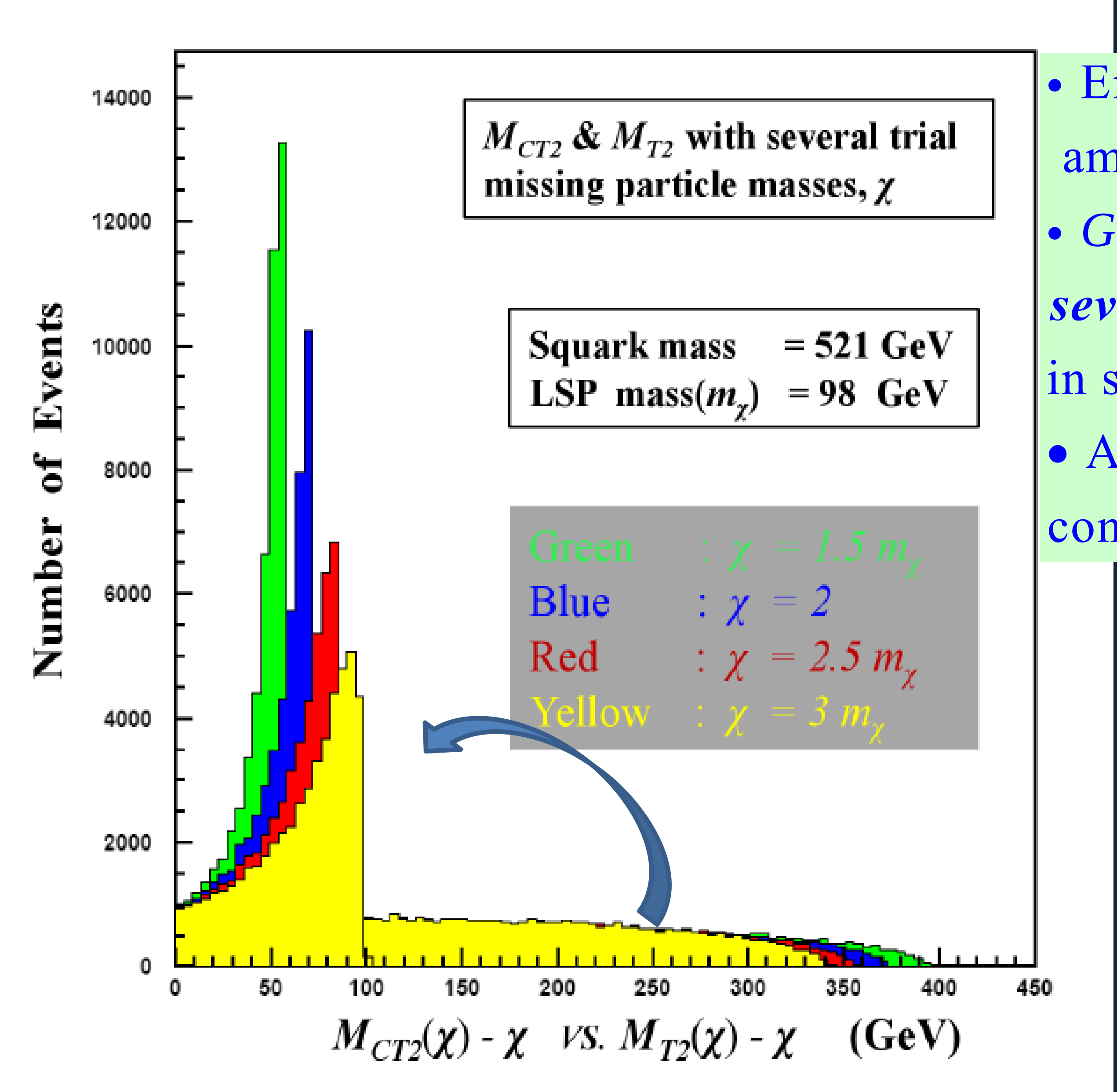
M_{CT2} **for**

$$Y\ Y \to \mathrm{V(p)}+\chi(\mathrm{k})\ +\ \mathrm{V(p)}+\chi(\mathrm{k})$$

$$M_{CT2}{}^2 \equiv \min[\max\{M_{CT}(Y_1), M_{CT}(Y_2)\}]$$

$$M_{CT} \equiv m_V{}^2 + m_\chi{}^2 + 2\sqrt{m_V{}^2 + |\mathbf{p_T}|^2}\sqrt{m_\chi{}^2 + |\mathbf{k_T}|^2} + 2\mathbf{p_T}\cdot\mathbf{k_T},$$

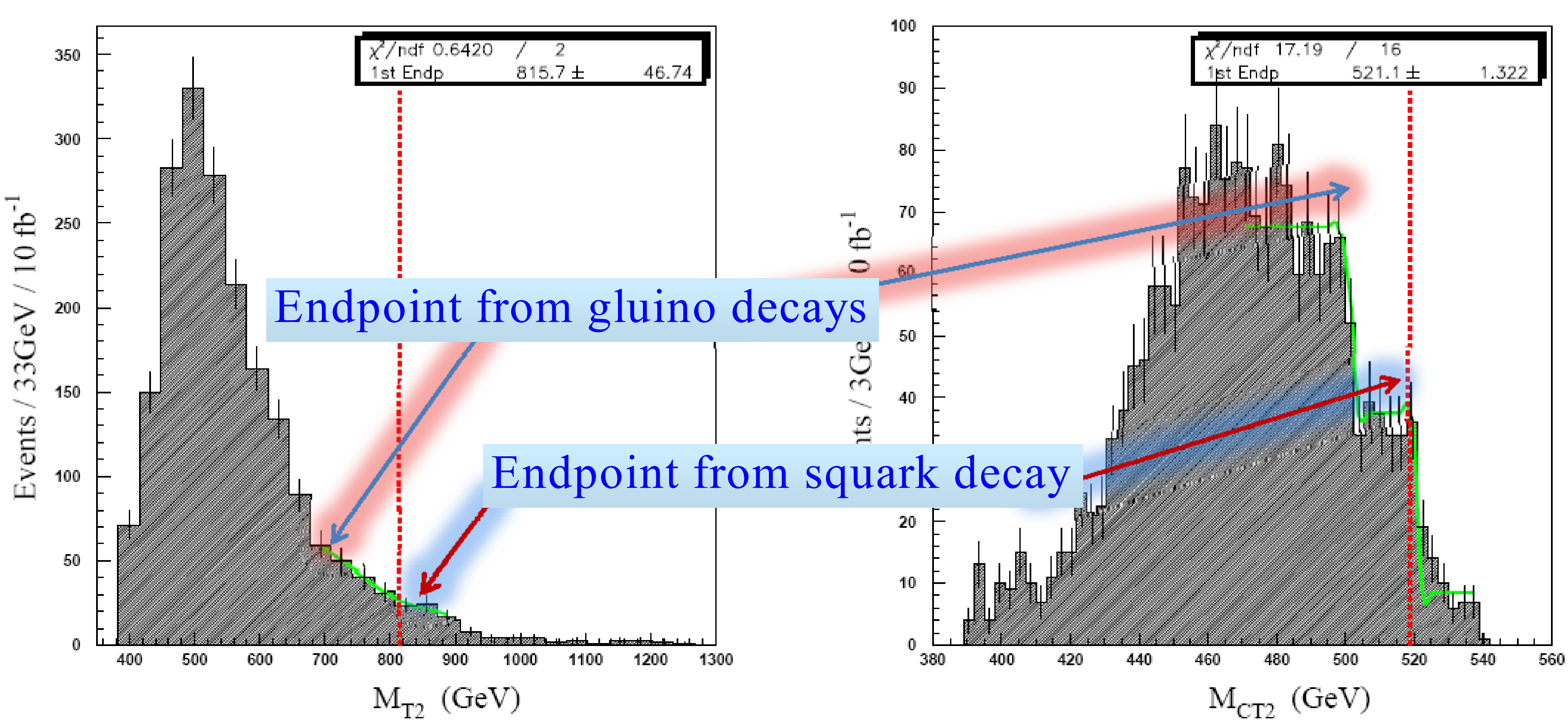
- $\mathbf{p_T}$ = visible transverse momenta ***in the LAB frame***
- min&max over all possible invisible missing momentum $\mathbf{k_T}$



- Endpoint structures are amplified.
- *Good* for ***accentuating several break points*** buried in several backgrounds.
- Amplification factor is controlled by test mass

Accentuating the buried break points in N-jet events

- $\tilde{q}\tilde{q} \rightarrow \tilde{g}q\ \tilde{g}q \rightarrow qqq\ \chi\ qqq\ \chi$



→ Systematic errors for physical constraints reduced by $O(1/J_{max})$ in local fitting of break points.

J_{max} : Jacobian factor near the endpoint region

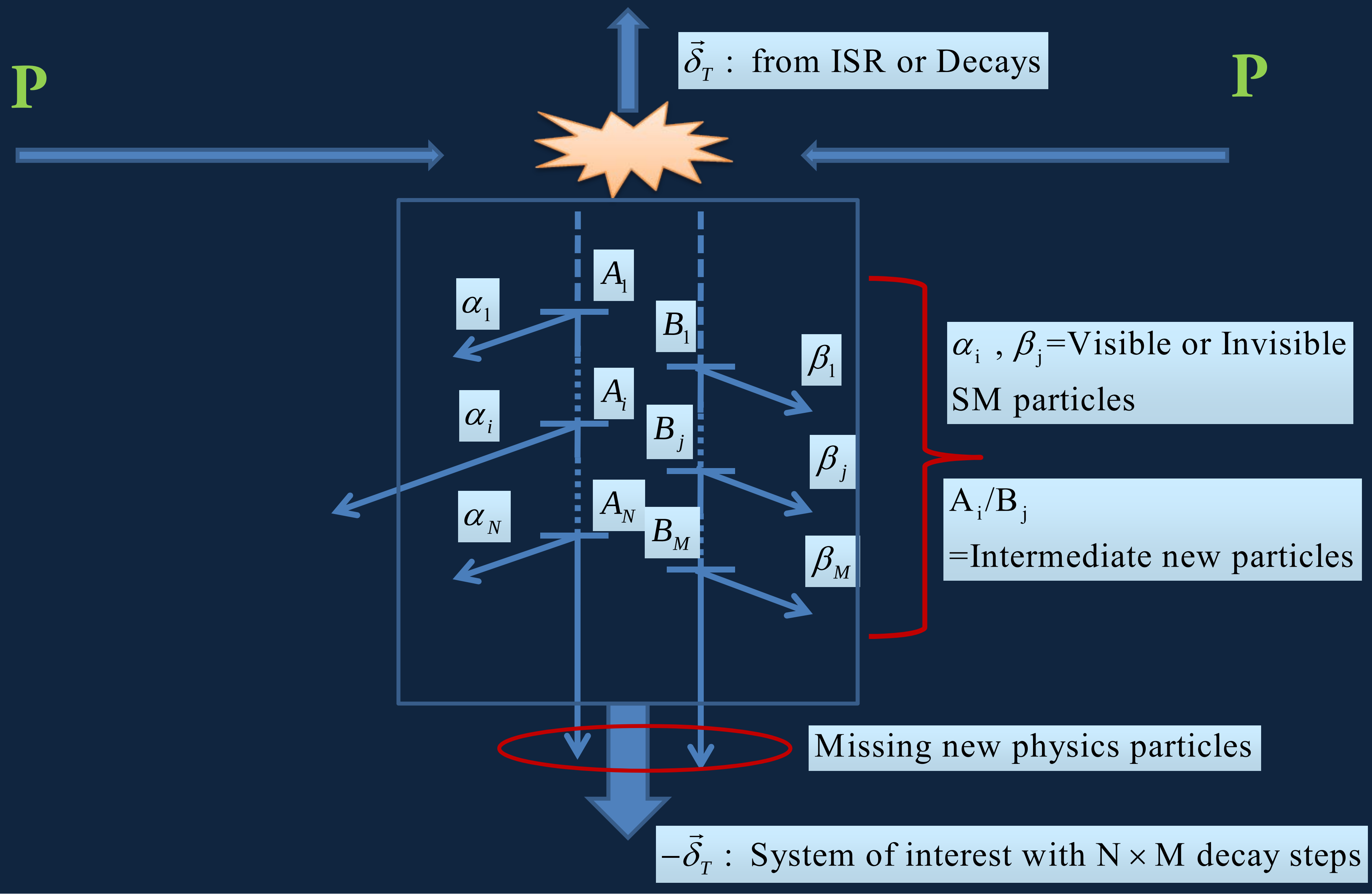
This enhances our observability for several endpoints.

(Previously)
Impose hard cut, and remove the BG events near the endpoint.

(Now)
Well, moderate cut & irreducible BGs are okay, as long as there exist dim BPs from signal endpoints. We can magnify it !

Then, what endpoints are to be amplified by M_{CT2} projection ???

Complex new physics event topology at the LHC



Decay chain crossing two particle endpoint functions as basic building blocks for mass reconstruction in N×M decay chains.

Along the decay lines

CM Energy is bounded above by decayed mother particles in a decay chain

$M(\alpha_i, \alpha_j / \beta_k, \beta_m) \leq M^{max}$

$\Rightarrow M_{A_i}, M_{A_j}, M_{B_k}, M_{B_m} \ldots$

Crossing the decay lines

CM Energy is not bounded in a event by event basis.

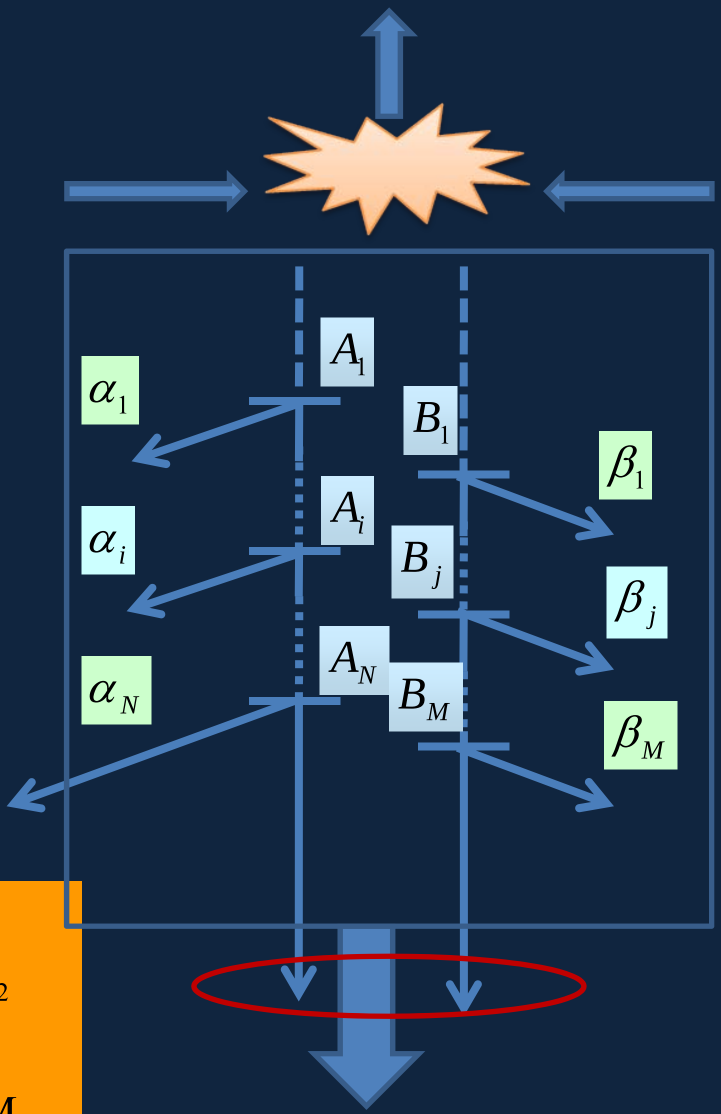
$f(\alpha_i, \beta_j)^{max}$ (??)$\Rightarrow M_{A_i}, M_{A_{i+1}}, M_{B_j}, M_{B_{j+1}}$

$f \sim M_{T2}, M_{CT}, M_{CT2} \ldots$

$\sim P_{\alpha_i} \bullet P_{\beta_j}$ ($\bullet$: *Euclidean* dot product)

Why two ?

1. Smallest combinatorics in NxM visibles
2. No internal combinatorics for $f = Combinatoric - M_{CT2}$
3. Single massless SM particle in each decay chains
   => Simple and Good for endpoint amplification for C-M_{CT2}



Combinatoric - $M_{CT2}(\alpha_i - \beta_j)$ [work in progress]

Let's take a system of interest with transverse momentum, **$-\delta_T$**.

$$\mathbf{pp} \rightarrow (\delta_T) + (\alpha_1,\ldots\alpha_\mathrm{i}\ldots\alpha_\mathrm{N}/\beta_1\ldots\beta_\mathrm{j}\ldots\beta_\mathrm{N}/\text{New physics missing PTLs})$$

$$\rightarrow (\delta_T) + (\alpha_\mathrm{i} \quad \beta_\mathrm{j} + \text{(assumed to be) missing particles}(\not{E}_\mathrm{T}'))$$

(i=1..N, j=1..M)

$$C - M_{CT2}{}^2(\alpha_\mathrm{i}\text{-}\beta_\mathrm{j}) \equiv \min[\max\{M_{CT}(A_i), M_{CT}(B_j)\}]$$

$$M_{CT} \equiv \chi^2 + 2\,|\,\mathbf{p_T}\,|\sqrt{\chi^2 + |\,\mathbf{k_T}\,|^2} + 2\mathbf{p_T}\cdot\mathbf{k_T},$$

- $\mathbf{p_T}$ = visible transverse momenta
- χ = ***universal test mass for*** $\mathrm{A}_{\mathrm{i+1}}$ & $\mathrm{B}_{\mathrm{j+1}}$(in general $\mathrm{M}_{\mathrm{A}_{\mathrm{i+1}}} \neq \mathrm{M}_{\mathrm{B}_{\mathrm{j+1}}}$)
- $\mathbf{k_T}(\alpha) + \mathbf{k_T}(\beta) = -(\alpha_{iT} + \beta_{jT}) - \delta_T = \not{E}_T'$
- min&max over all possible invisible missing momentum $\mathbf{k_T}$

C-$M_{CT2}(\alpha_i$-$\beta_j)$ has well-defined (amplified) endpoint value for general non-zero δ_T and univeral test mass, χ

Universal test mass, χ = Controlling parameter of the amplification

Utilizable for complex event topologies with additional missing particles

Totally asymmetric system

If $(M-1)(N-1) \geq 3$, all the masses can be measured only with C-M_{CT2}

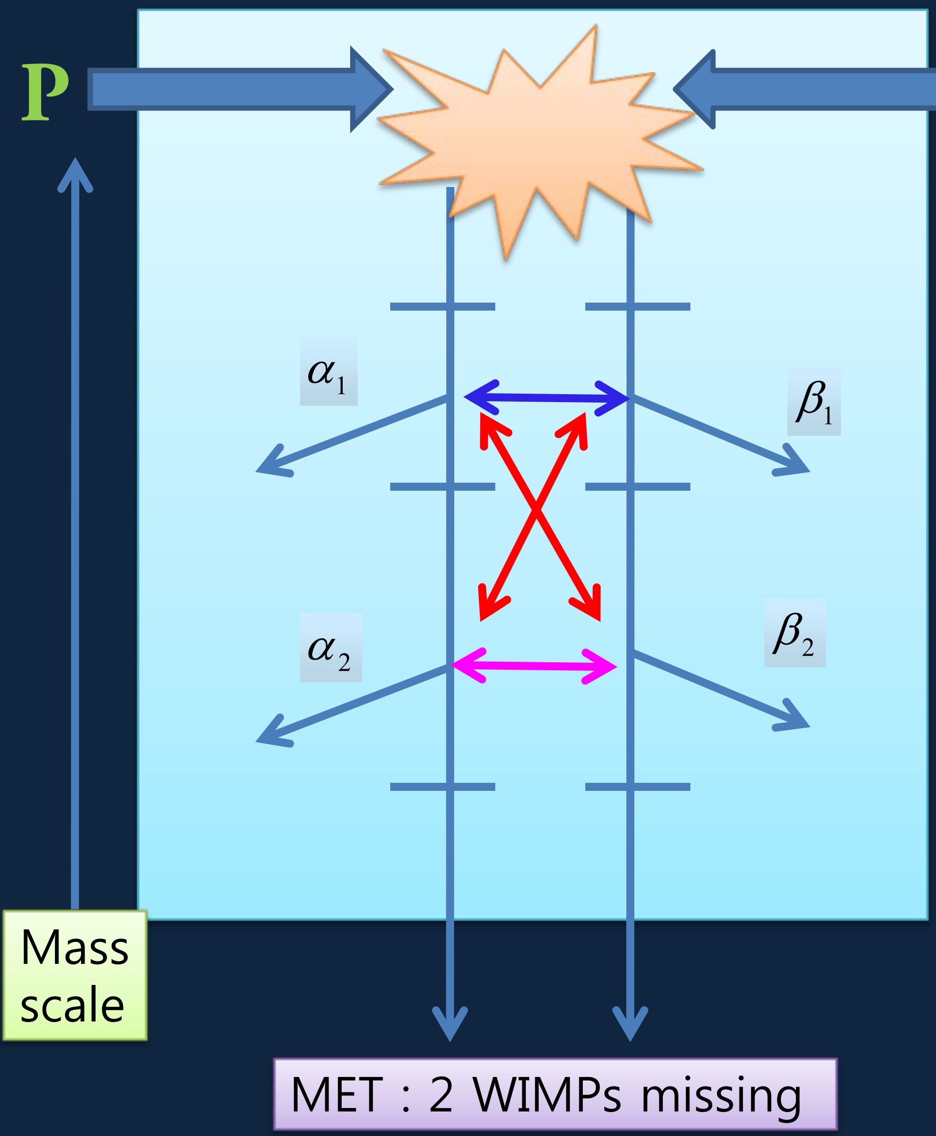
Totally symmetric case, N=M & intermediate particles with same masses.

If $M \geq 2$, all of the M+1 masses can be determined with C-M_{CT2}.

The additional vertical constraints ($M_{\alpha\alpha}/M_{\beta\beta}$) can be helpful, also.

Simple Example :

$$\tilde{g}\tilde{g} \to (q+\tilde{q})+(q+\tilde{q}) \to (qq\tilde{\chi}_1^0)+(qq\tilde{\chi}_1^0)$$



4jets➔ 6 possible pairs of jets / 3 Independent decay crossing pairs exist

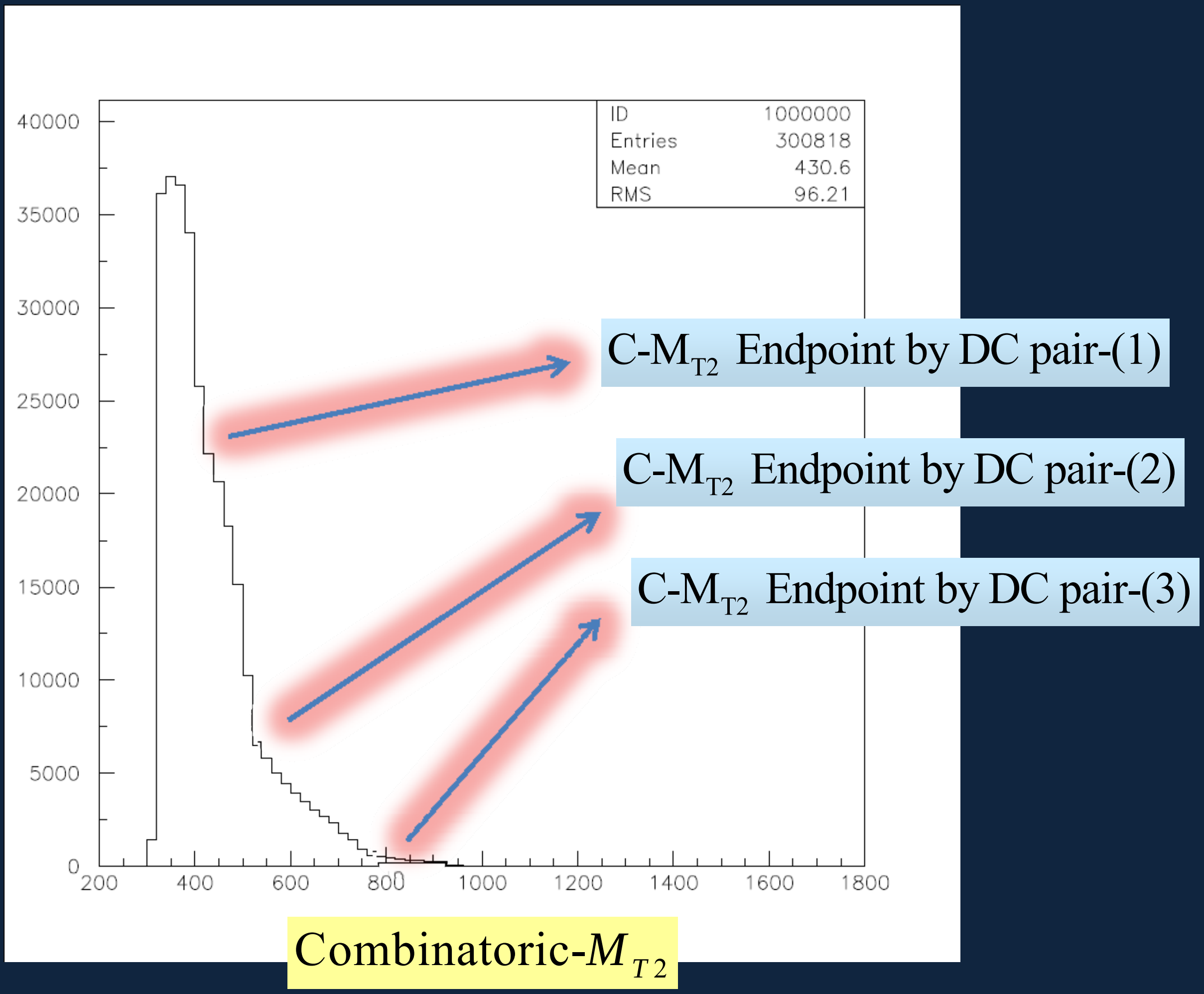
1) α(1)-β(1)
2) α(1)-β(2)/α(2)-β(1)
3) α(2)-β(2)

$$\tilde{g}\tilde{q} \to (qq\tilde{\chi}_1^0)+(q\tilde{\chi}_1^0)$$

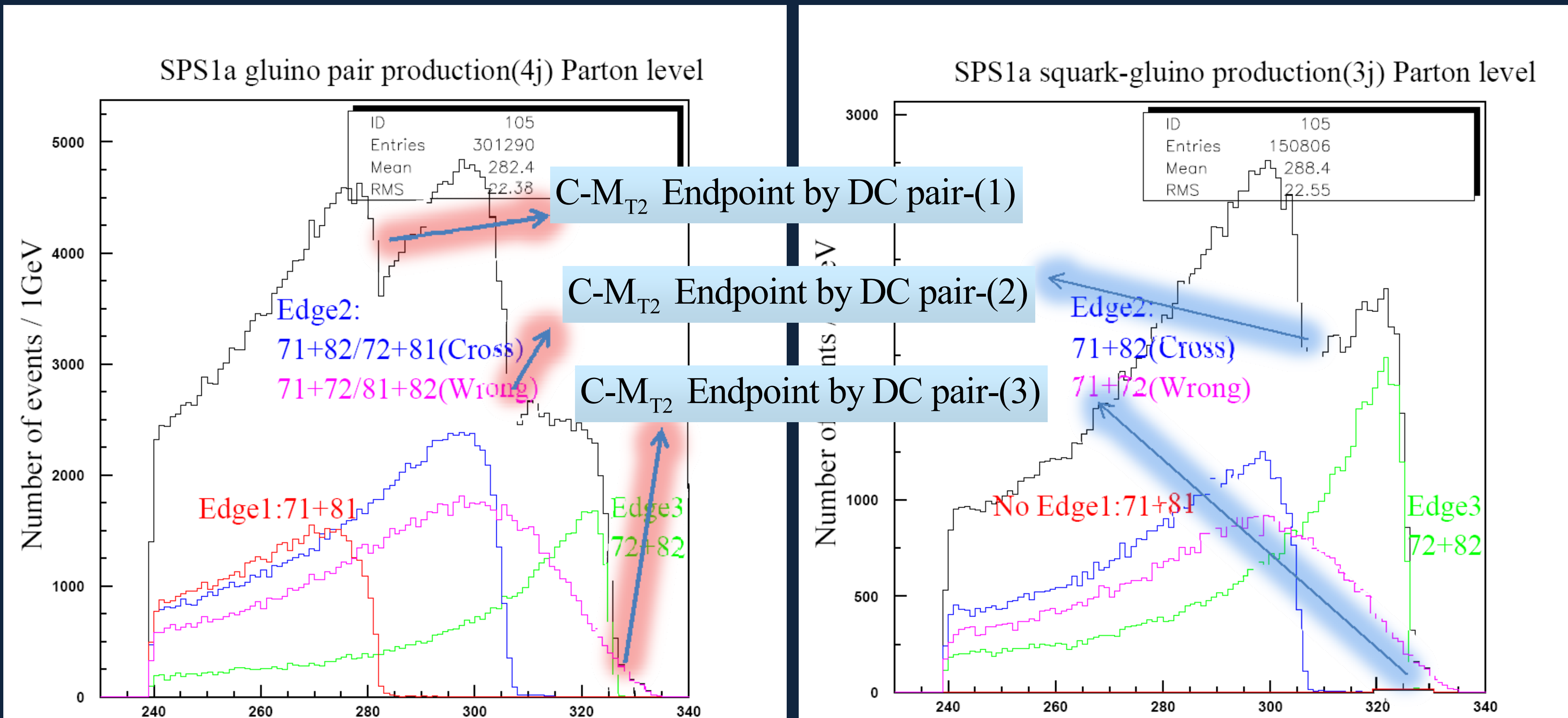
3 jets ➔ 3 pairs / 2 Independent decay crossing pairs exist

2) α(1)-β(2)/α(2)-β(1)
3) α(2)-β(2)

Partonic level results : C-M_{T2}



Partonic level results : C-M_{CT2}



Combinatoric-M_{CT2} Combinatoric-M_{CT2}

Conclusion

- M_{CT2} : impressive endpoint structure enhancement.
- Small slope discontinuities are amplified by $J(x)^2$, accentuating the breakpoint structures clearly.
- Extract the various constraints hidden in complex inclusive signatures
- Combinatoric-M_{CT2} has well-defined endpoints and power to accentuate them.
- With C-M_{CT2}, ordinary combinatoric background is not only background anymore. It provides mass information to be analyzed.
- Thus, C-M_{CT2} can be a useful tool for every new particle mass measurement in generic complex event topologies.

Back up slides

The event selection cuts were as follows:

(1) No leptons, no b jets in the event,

(2) Number of jets $= 6,\ 7$ with $P_T^{1\text{st},2\text{nd}} \geq 100$ GeV, $P_T^{6\text{th}} \geq 50$ GeV,

(3) $\not{E}_T \geq 100$ GeV,

(4) $\alpha^n \geq 0.45$ with $n(= 1, \cdots, 15)$ for the pairs of selected two jets,

(5) $\Delta_T(\equiv |\not{E}_T + \sum_{j=1,\cdots,6} \mathbf{p}_T^j|) \leq 30$ GeV,

- IF $m_{vis} \sim 0$, M_{CT2} (x) projection can have significantly amplified endpoint structure (x = Trial missing ptl mass)

- $J_{max}(x) \Rightarrow \infty$ as $x \Rightarrow 0$

- One can control $J_{max}(x)$ by choosing proper value of x

$$\sigma^{-1}\frac{d\sigma}{dM_{CT}(\chi)} \sim J\sigma^{-1}\frac{d\sigma}{dM_T(\chi)}$$

$$J = \frac{M_{CT}(\chi)}{M_T(\chi)}\frac{(e_\chi + |\mathbf{p}_{0T}|)^2}{(e_\chi - |\mathbf{p}_{0T}|)^2}$$

$$\rightarrow \begin{cases} \frac{M_C(\chi)}{M(\chi)}\frac{(E_\chi+|\mathbf{p}_0|)^2}{(E_\chi-|\mathbf{p}_0|)^2} & \text{Endpoint region, } J_{max} \\ 1 & \text{Minimum region} \end{cases}$$

- A faint BP(e.g. signal endpoint) with small slope difference amplified by large Jacobian factor :

$$\Delta a \Rightarrow \Delta a` = J_{max}^{2}(x)\, \Delta a$$

With the accentuated BP structure, the fitting scheme (function/range) can be elaborated, and it can significantly reduces the systematic uncertainties in extracting the position of the BPs !

$$\delta_{BP}^{\;2} \sim \frac{\sigma^2}{\Delta a^2}$$