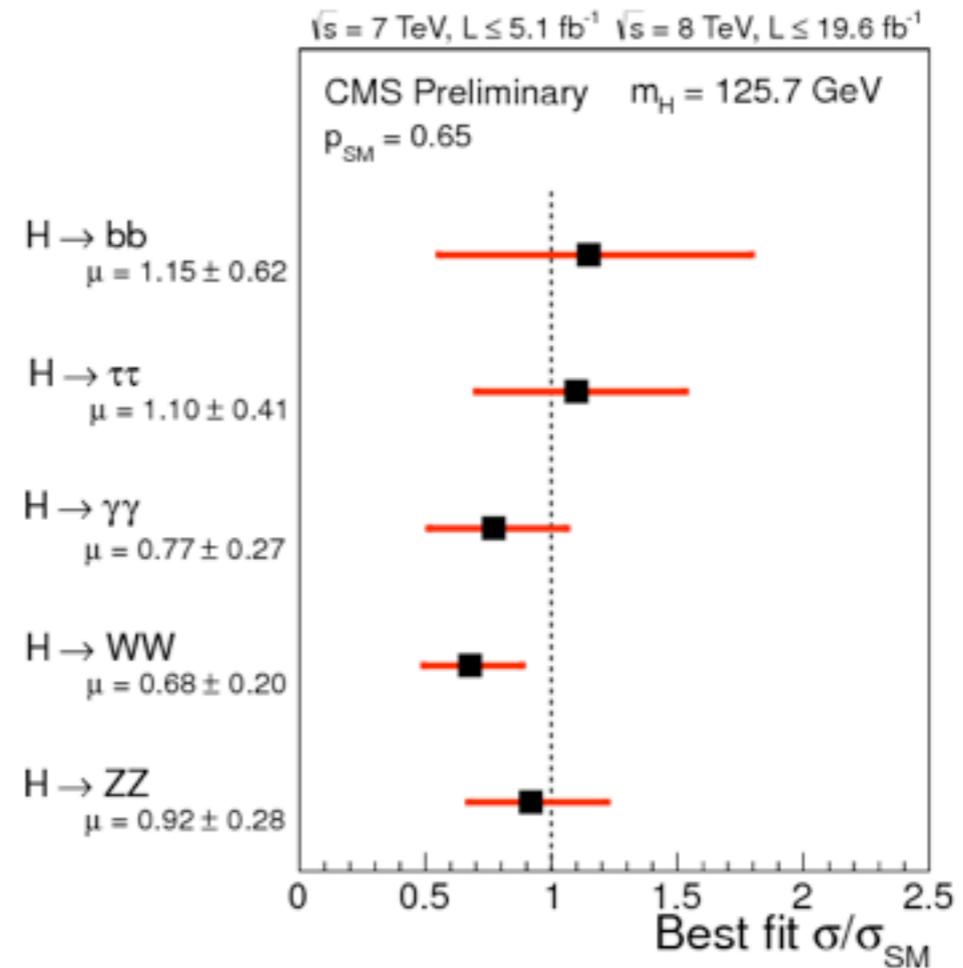
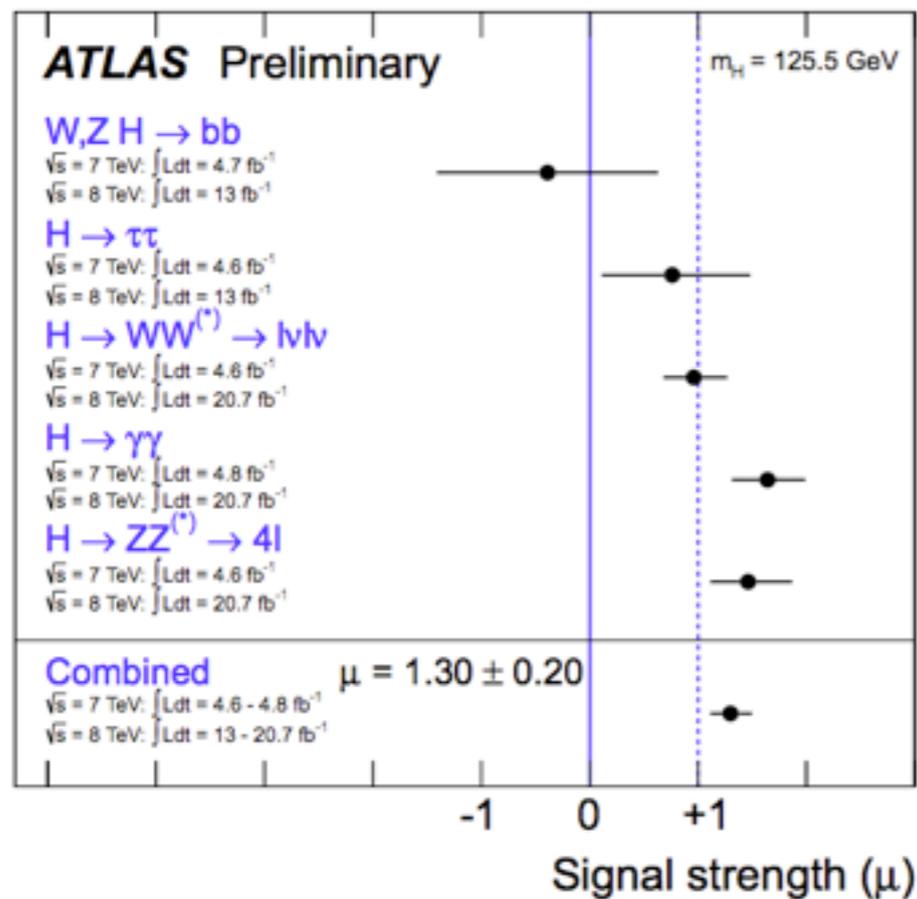


Boosted Tops and Higgs at LHC

竹内道久 (King's College London)

ヒッグスの発見

- だいたい標準模型の予言通り。面白いのはこれから。



- 主要な生成はtop loopによる：トップ湯川結合を間接的に測定

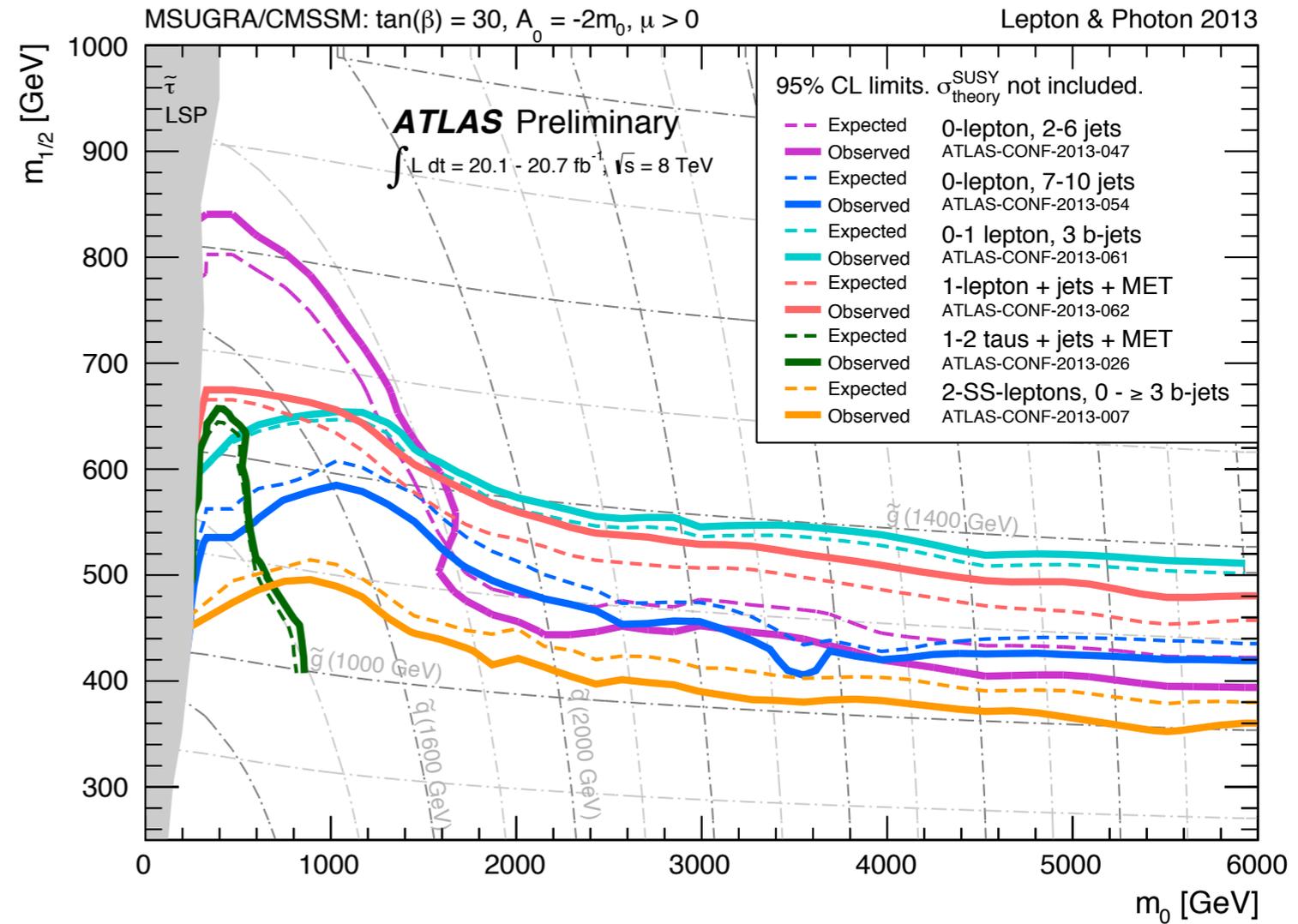
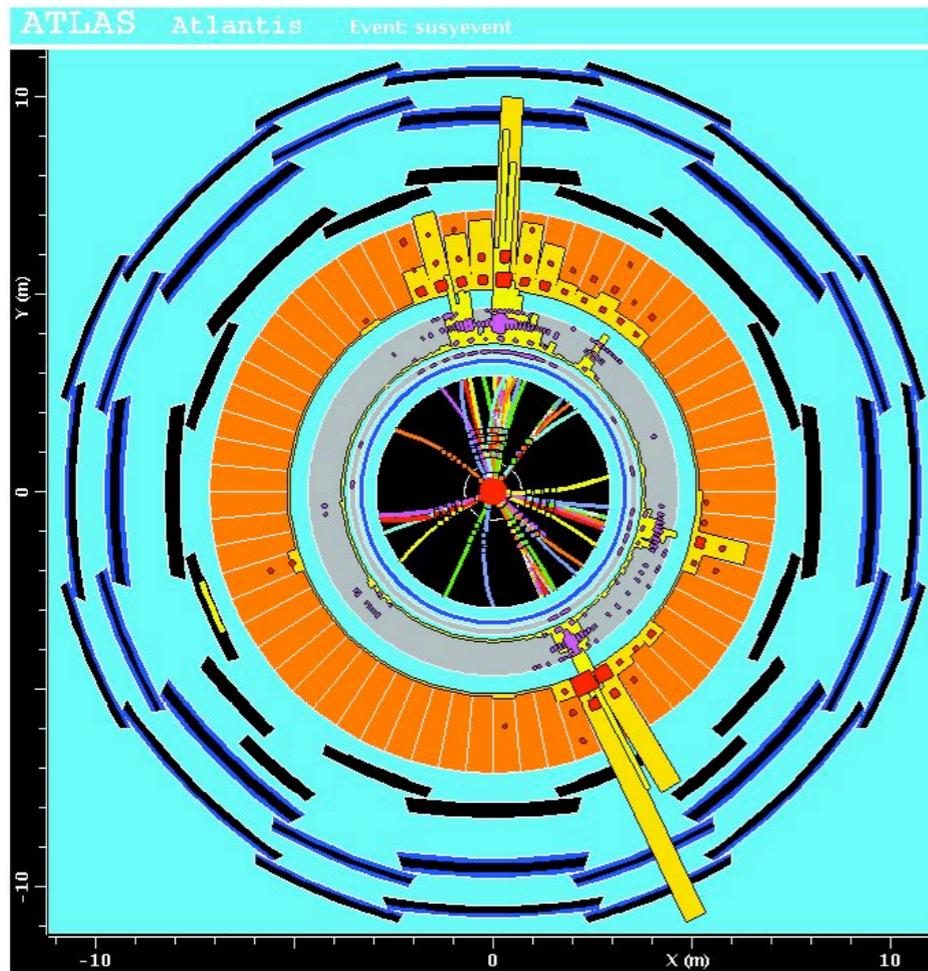
階層性問題

$$\delta m_h^2 \sim \text{---} \overset{h^0}{\text{---}} \left(\text{---} \overset{t}{\text{---}} \text{---} \right) \text{---} \overset{h^0}{\text{---}} \text{---} - \frac{3}{4\pi} y_t^2 \Lambda_{\text{SM}}^2$$

- ヒッグスが見つかったからと言って、他に何もないと特に質的には解決せず
- 125GeV: SUSYなら結構重そう (むしろ自然? $\tilde{g}\tilde{g} \rightarrow t\bar{t}t\bar{t}\chi\chi$ [arXiv:1111.6594])
- 軽いパートナーがいる方が自然 → トップパートナー (stopもmixingで可能)
- ヒッグスと強く結合しているトップセクターに注目
トップセクターは精密にはわかってない、アノマリーがあるかも

SUSYは簡単に見つかる予定だった

- もしTeV くらいに都合の良いSUSY模型があれば。



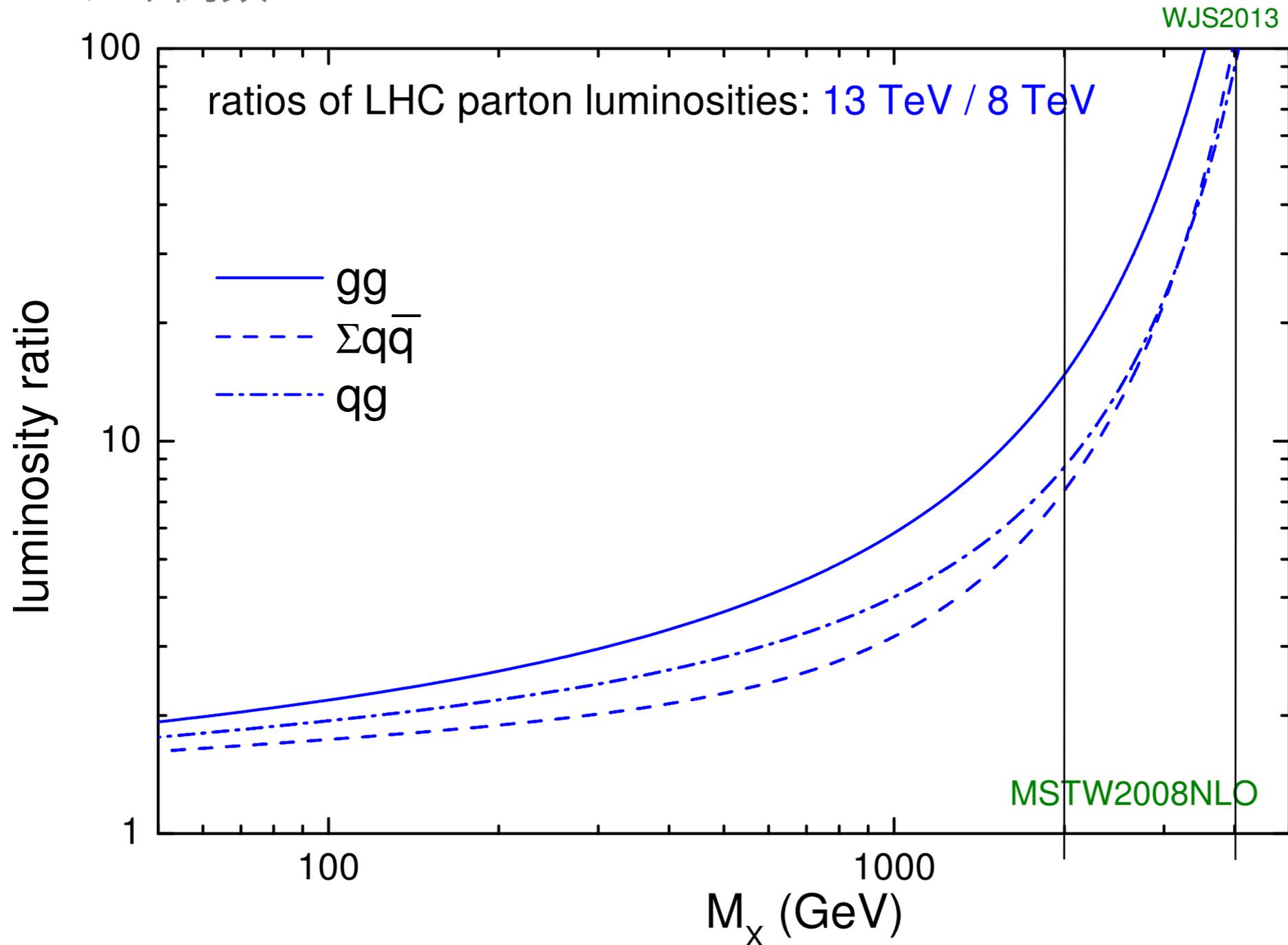
でも、SUSYは簡単に見つからなかった

- そもそも重くて作れてない (Higgs at LEP~0.008pb ~1個)
- 作ってたけど、良くわからなかった (Higgs at Tevatron~1pb~1万個~ 3σ)
- 来年あっさり見つかるかも (Luminosity function増える)

13TeVになると

- ルミノシティ関数

<http://www.hep.phy.cam.ac.uk/~wjs/plots/plots.html>



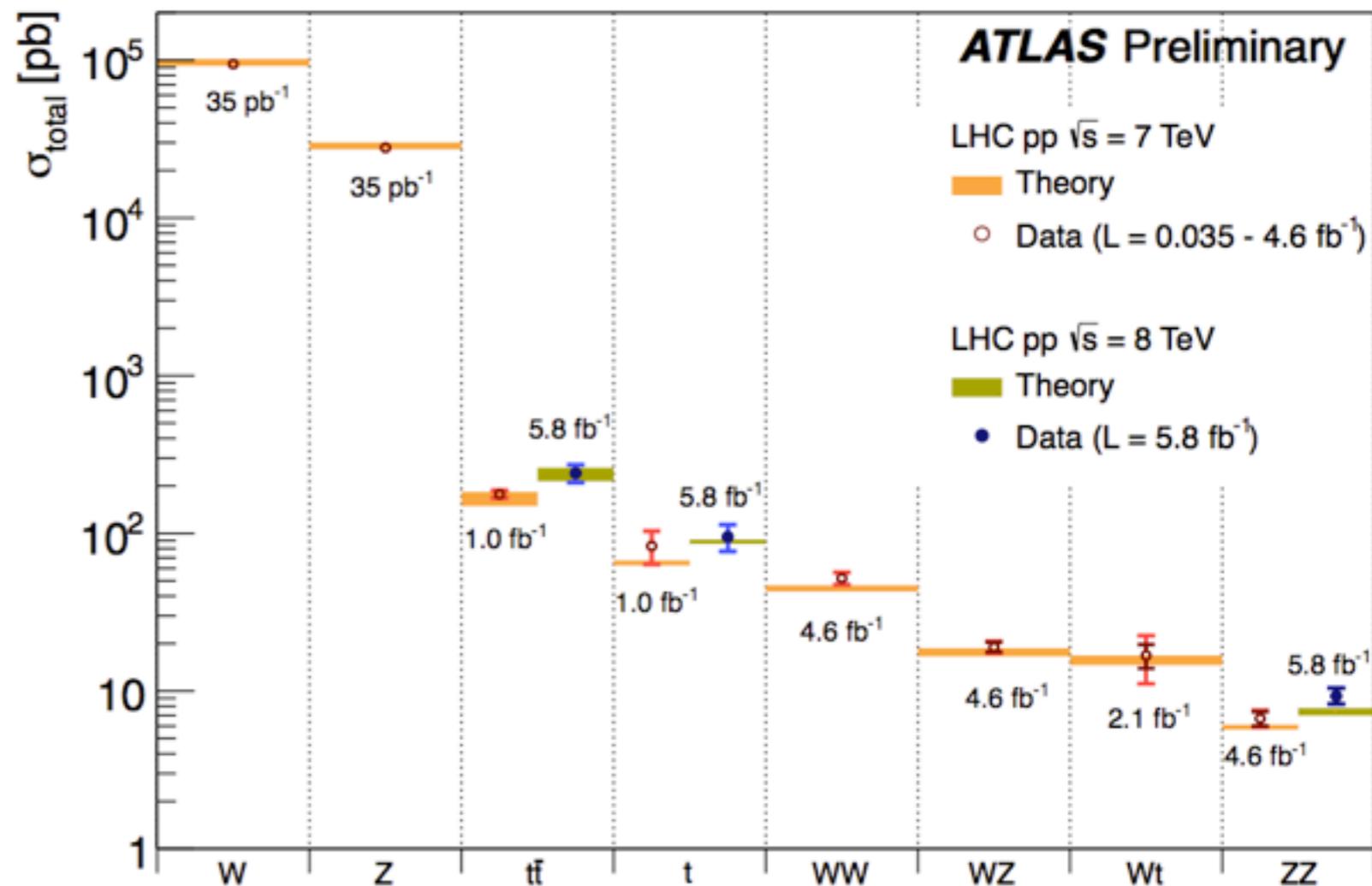
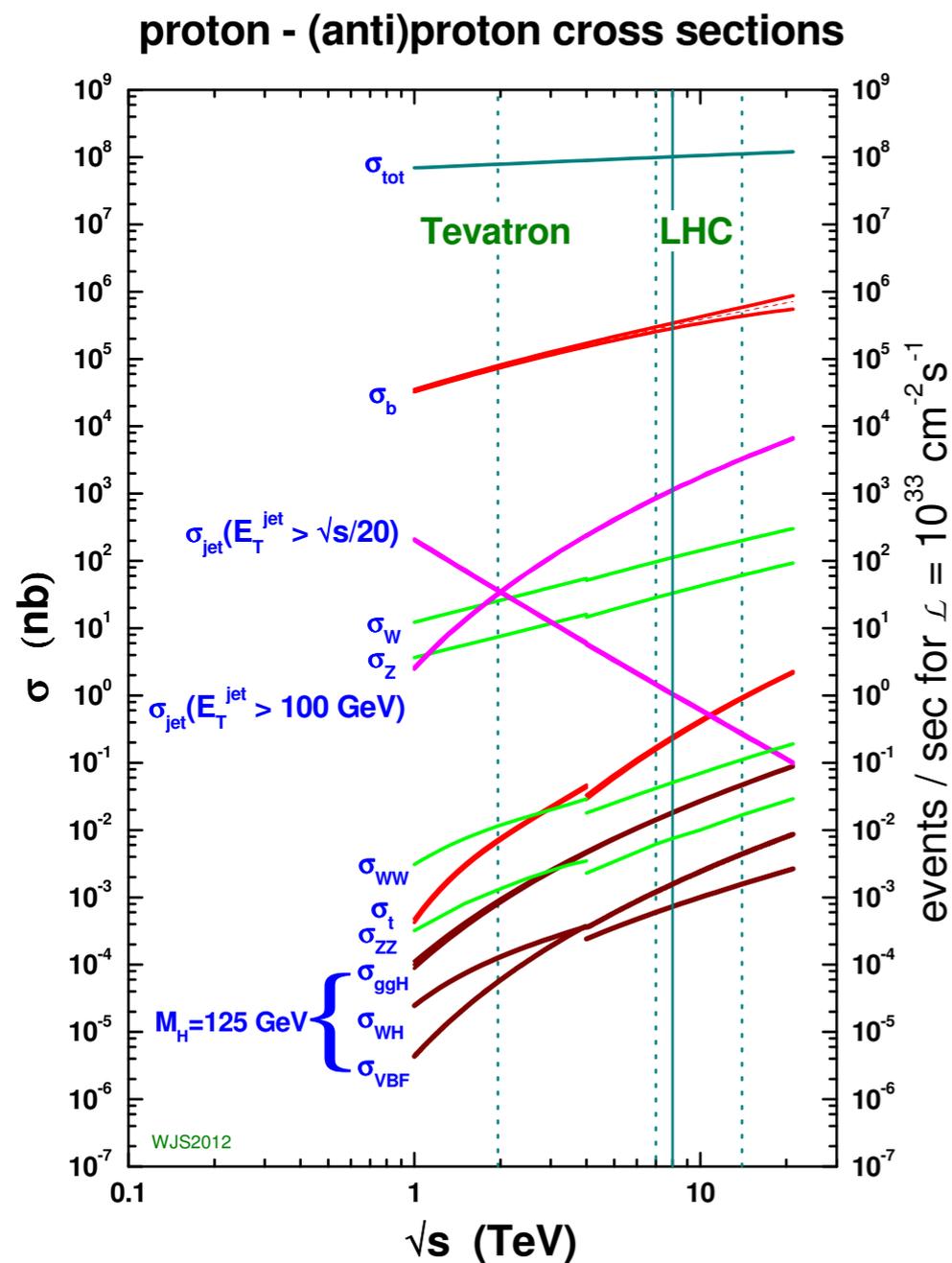
- 2TeVなら約10倍の効果、4TeVなら約100倍（重い粒子に有利、SMは軽い）

でも、SUSYは簡単に見つからなかった

- そもそも重くて作れてない (Higgs at LEP~0.008pb ~1個)
- 作ってたけど、良くわからなかった (Higgs at Tevatron~1pb~1万個~今は 3σ)
- 来年あっさり見つかるかも (Luminosity function増える)
- LHCで重くて作れてないなら、厳しい。
- 何か起きてるけど、良くわかってないと期待して気合を入れて探す (精密測定)
- ILCができるまで待つ

どう、気合を入れて探すか

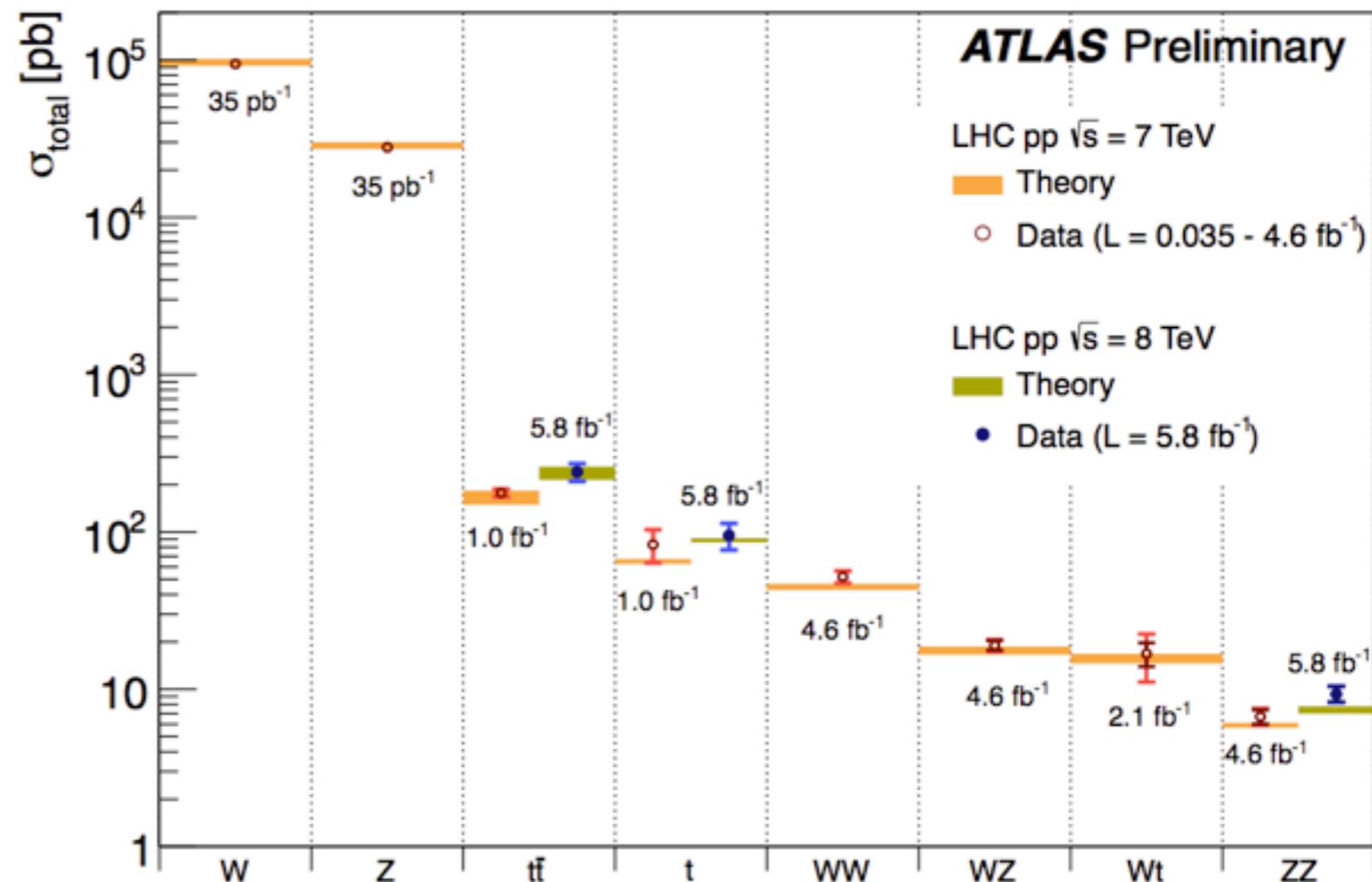
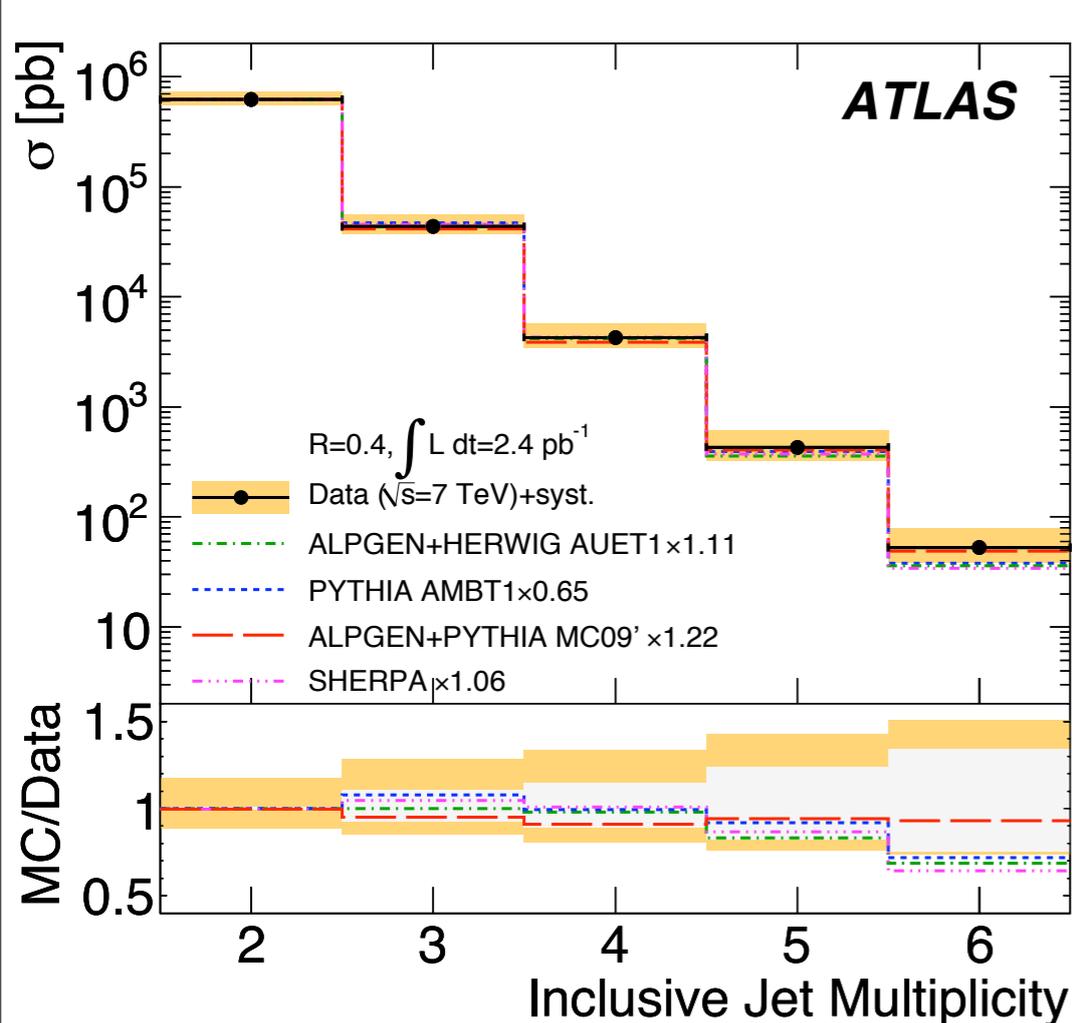
- SMの検証だけでも気合（精密さ）が必要：桁で違う断面積



new physics は典型的には1fb~1pb

どう、気合を入れて探すか

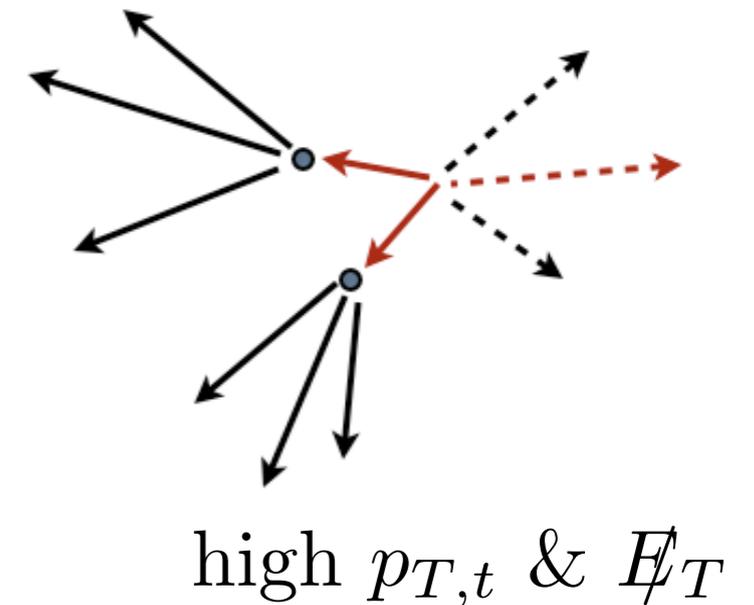
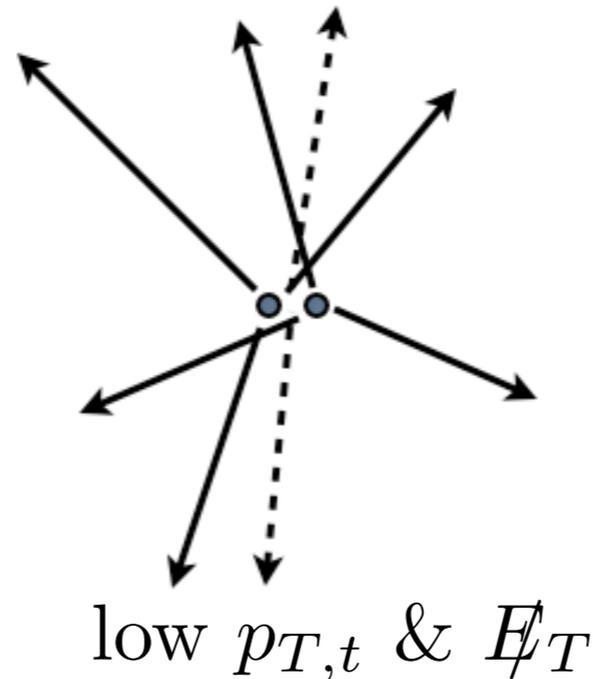
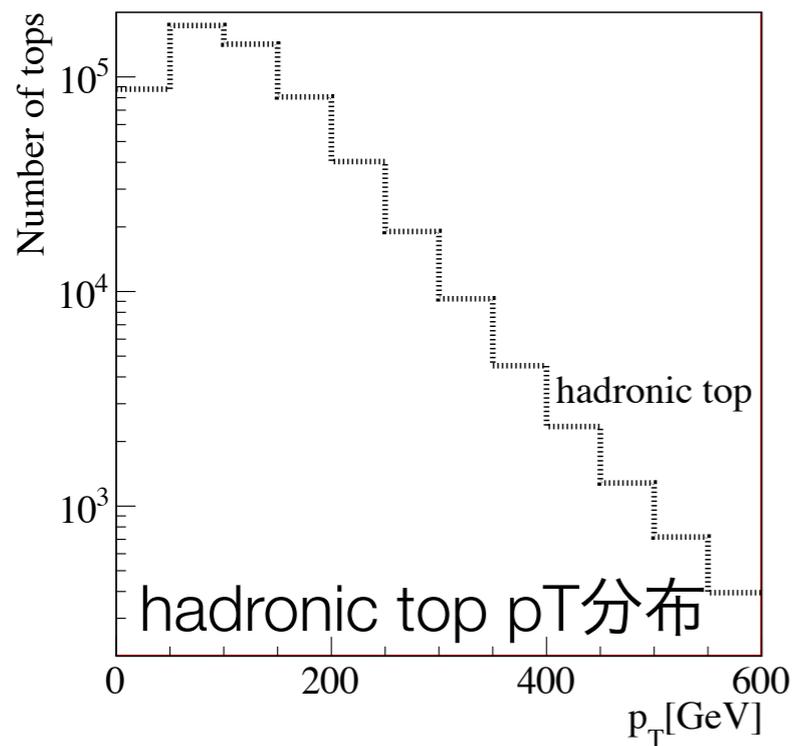
- SMの検証だけでも気合（精密さ）が必要：桁で違う断面積



- pQCDの計算精度の向上：NLO, matching: しかし、LOでも6ジェットまで
- BGサブトラクションが必要: leptons, b-tag, \cancel{E}_T & 特殊なkinematicsを利用
- topは全部持ってる（バックグラウンドとしては迷惑）

どう、気合を入れて探すか

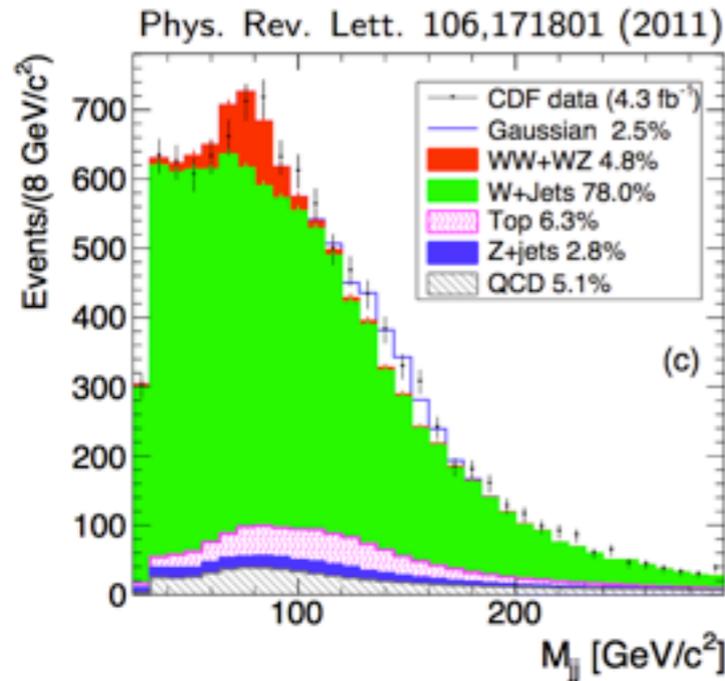
- SMの検証だけでも気合（精密さ）が必要：桁で違う断面積
- 同じプロセスでもpT分布はexpで落ちる:high pT成分は全断面積には効かない



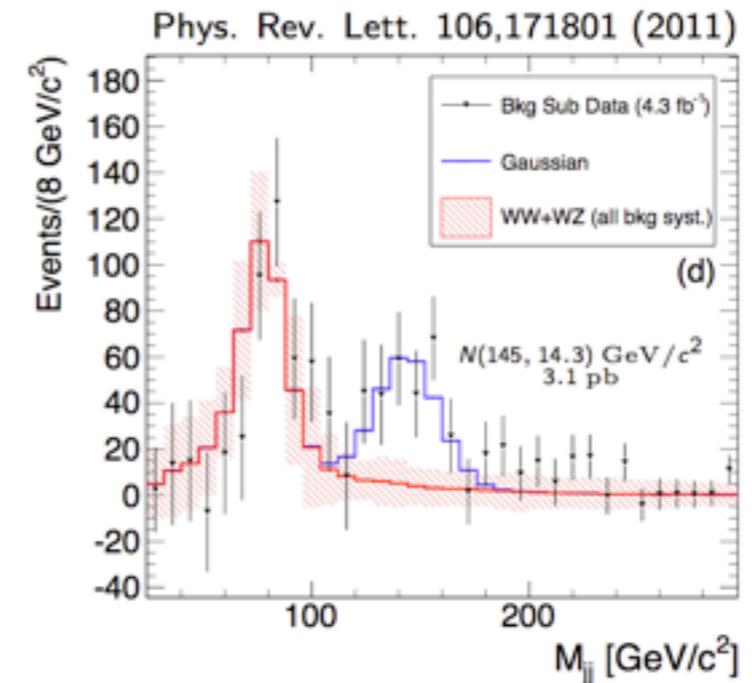
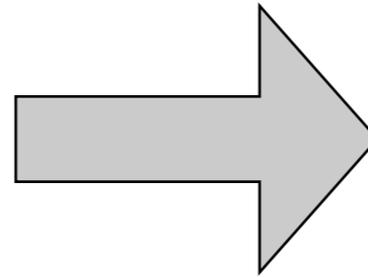
- New physics search で重要なのは主にhigh pT側

知ってるはずの部分を間違えると

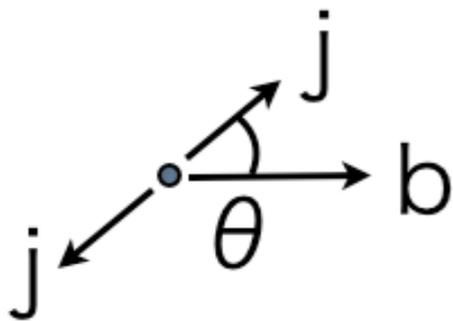
- 存在しないピークを作ってしまうかも (CDF Wjj)



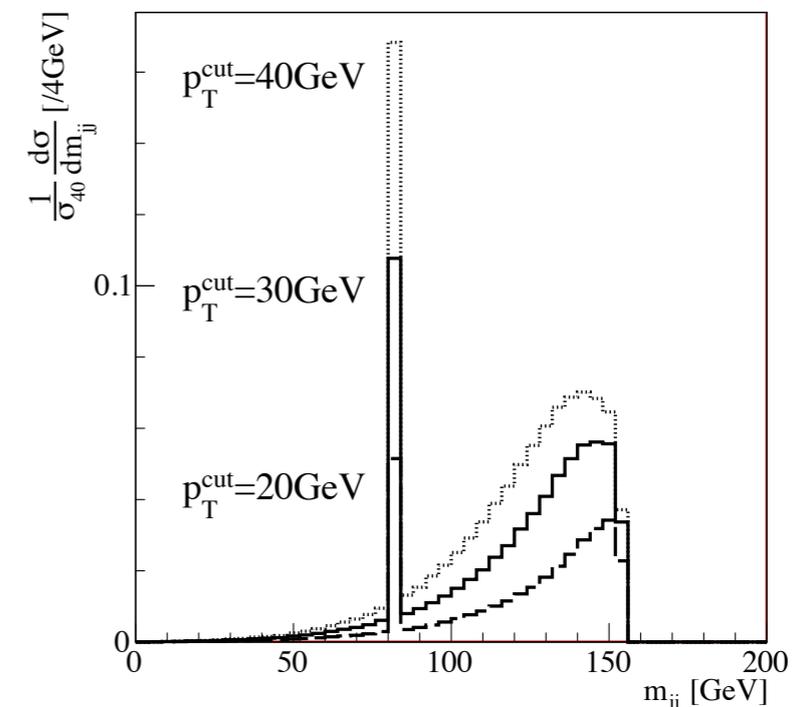
サブトラクション



- バックグラウンドとしてのトップ

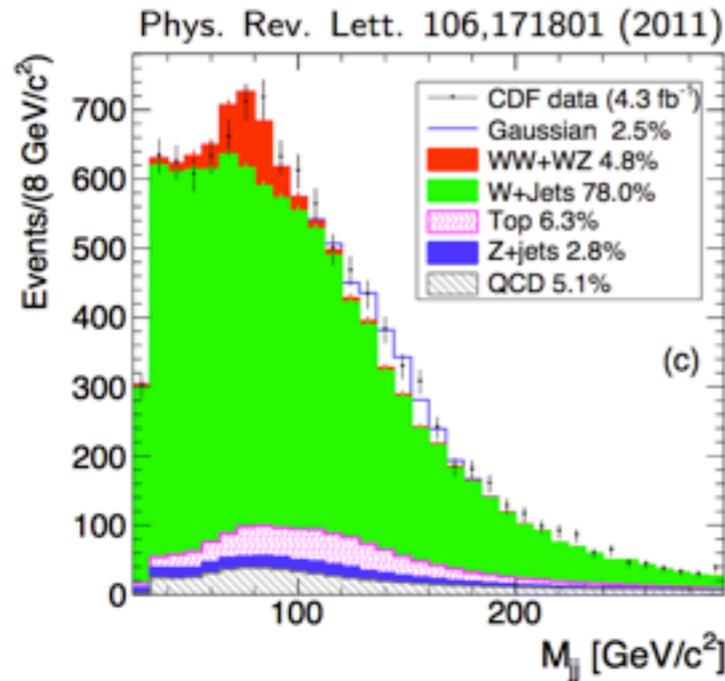


- 逆もある？ (存在するピークを消してしまう)

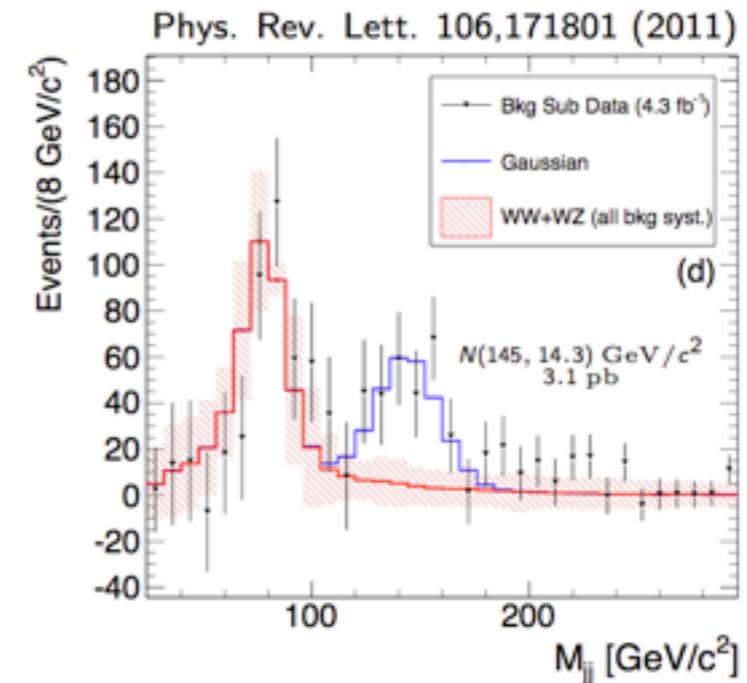
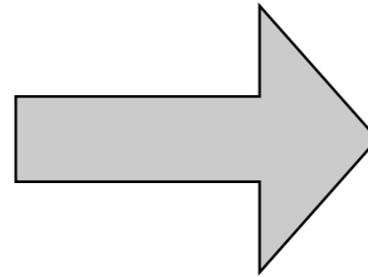


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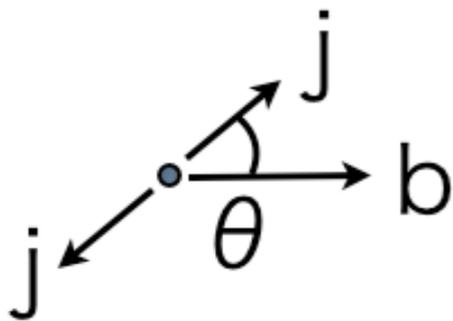
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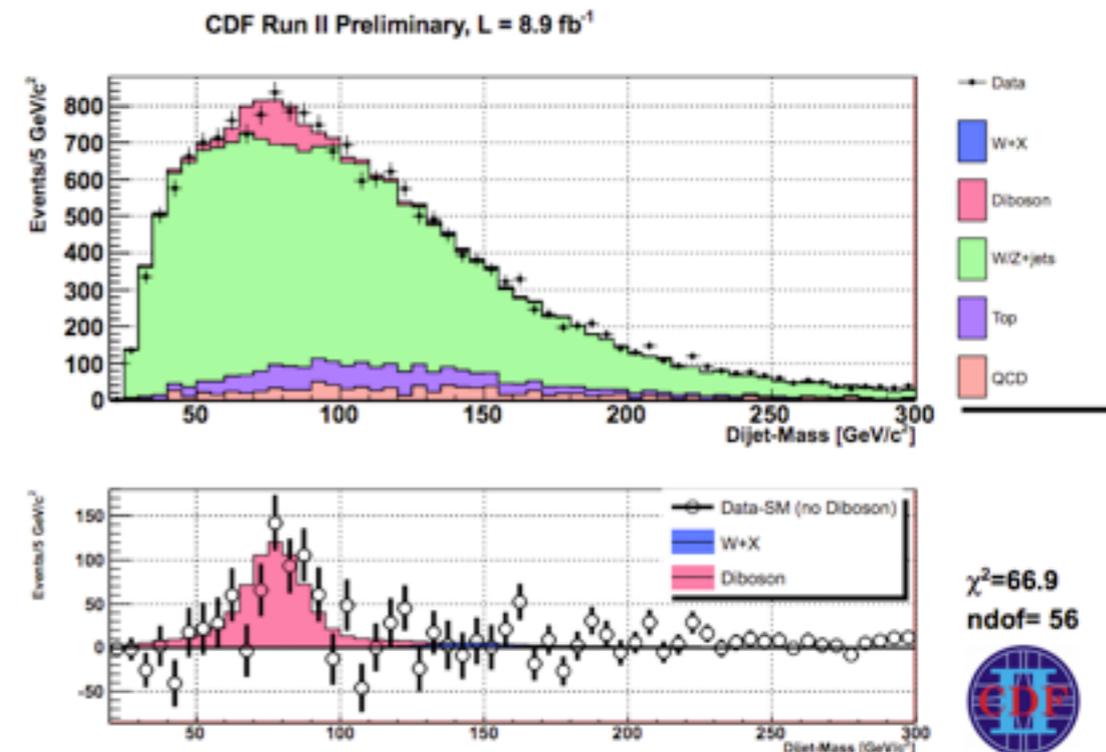
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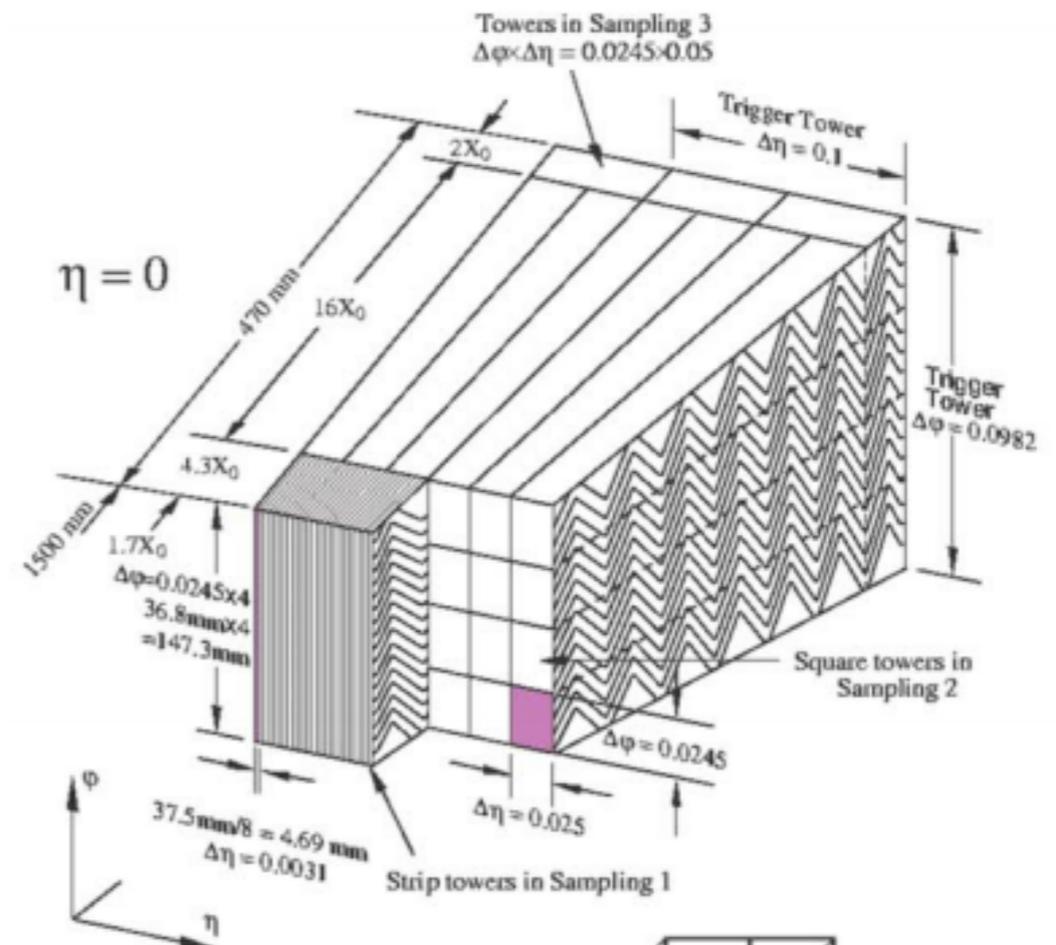
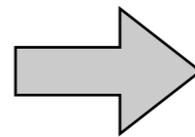
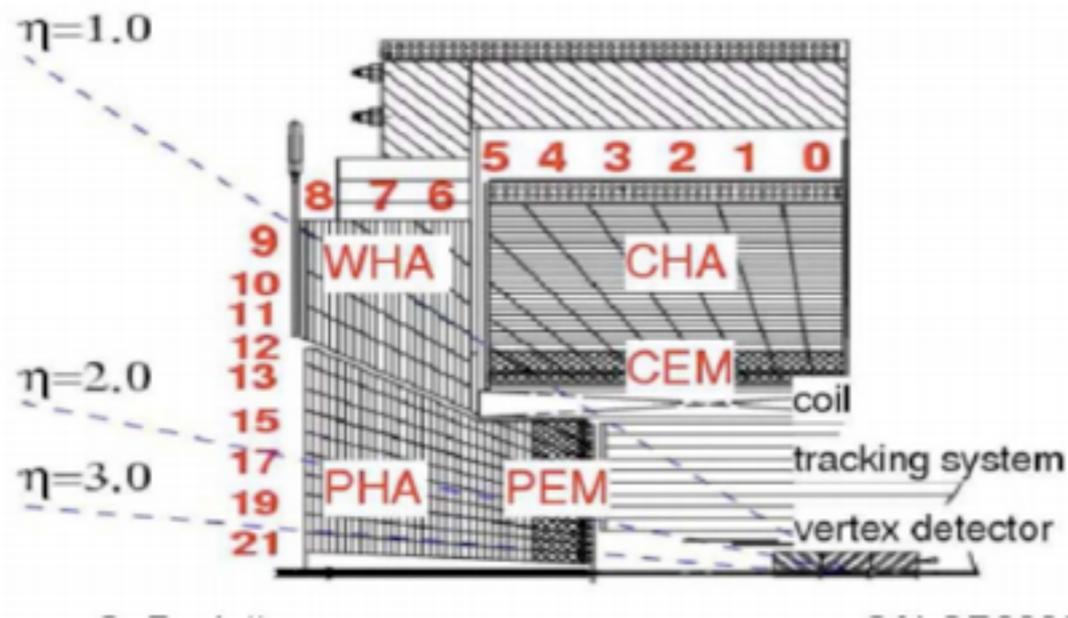


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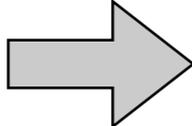
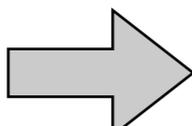
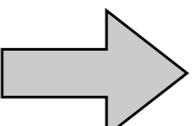
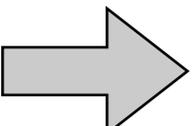


今までの違い

- 衝突エネルギー大 → 重い粒子もhigh p_T になる、W, Z, H, t
- 検出器の性能 → ジェットの内部を細かく見れる



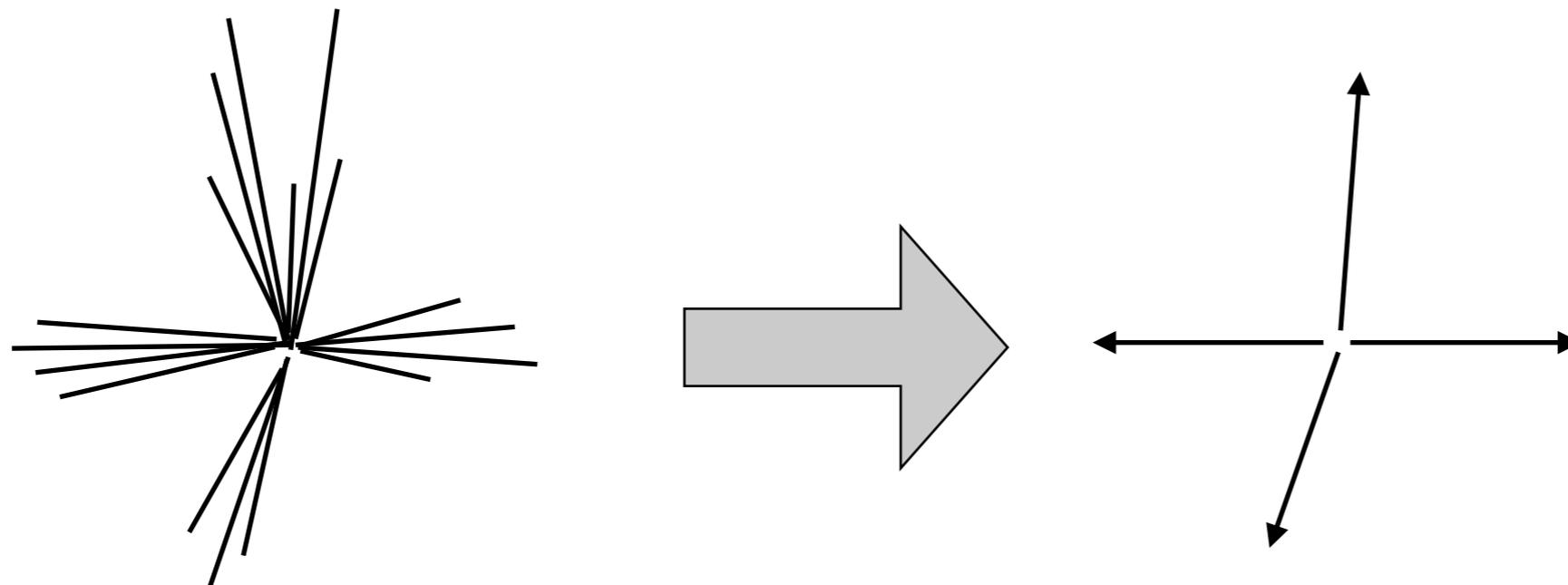
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- 検出器の性能  ジェットの内部を細かく見れる
- コンピュータの性能の向上
 pQCDの計算精度の向上、ME+parton shower matching
クラスタリングアルゴリズム：Fastjetにより現実的に
- わかってるものの精度をあげないと、未知のものは見えない
 Boosted ObjectのIDにJet substructureを利用

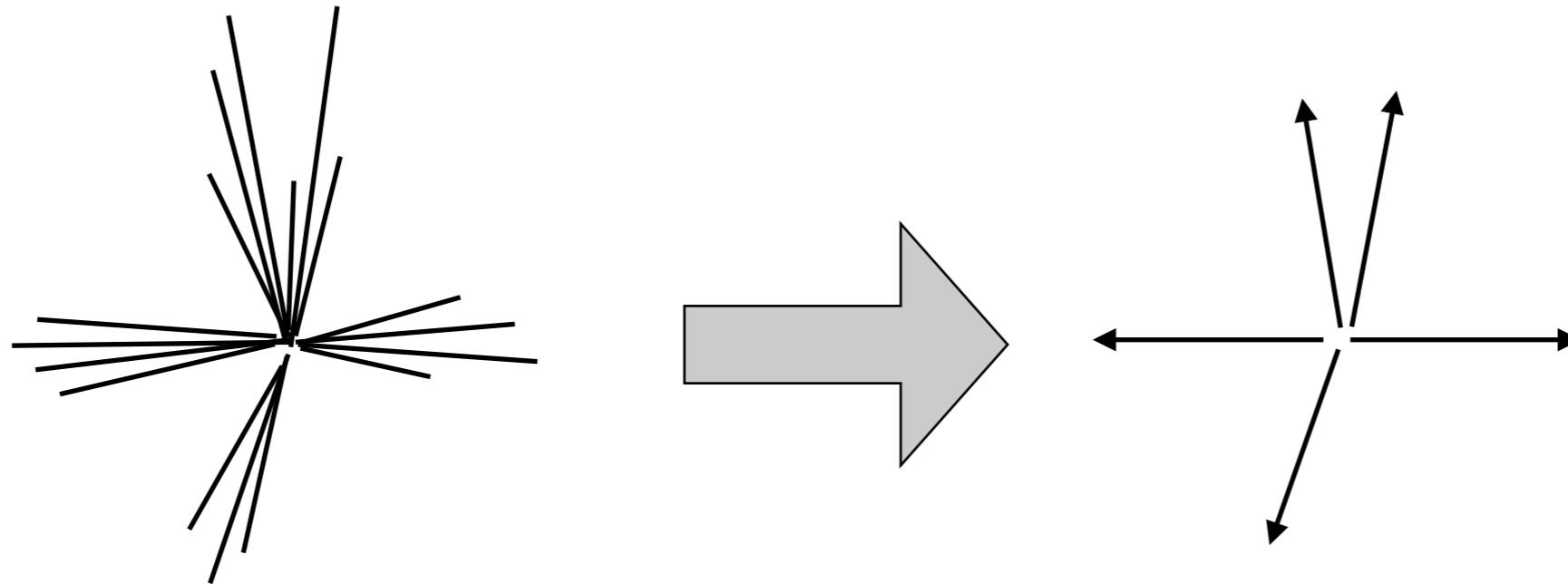
Jet substructure の利用

- ジェットの定義
- mass drop criterion
- filtering

ジェット：定義が必要

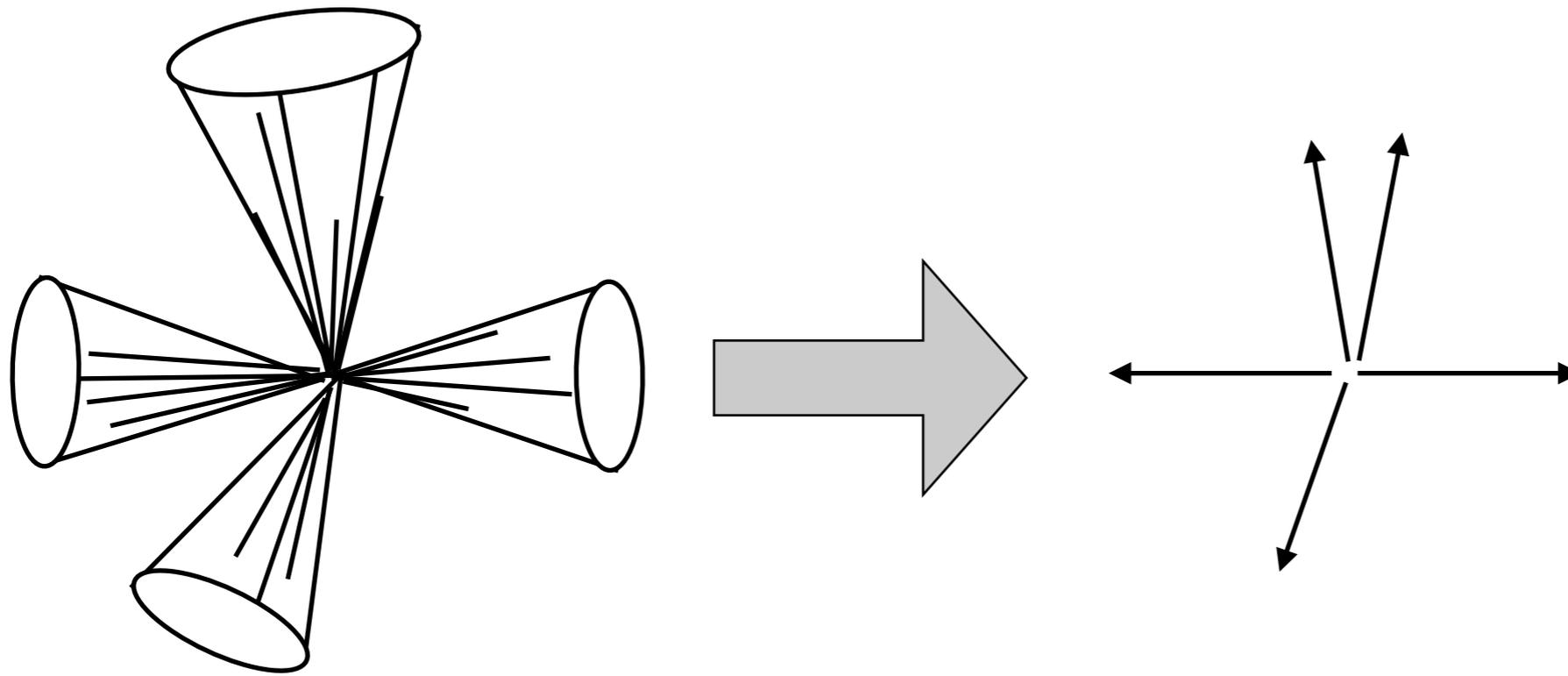


ジェット：定義が必要



唯一の定義はない

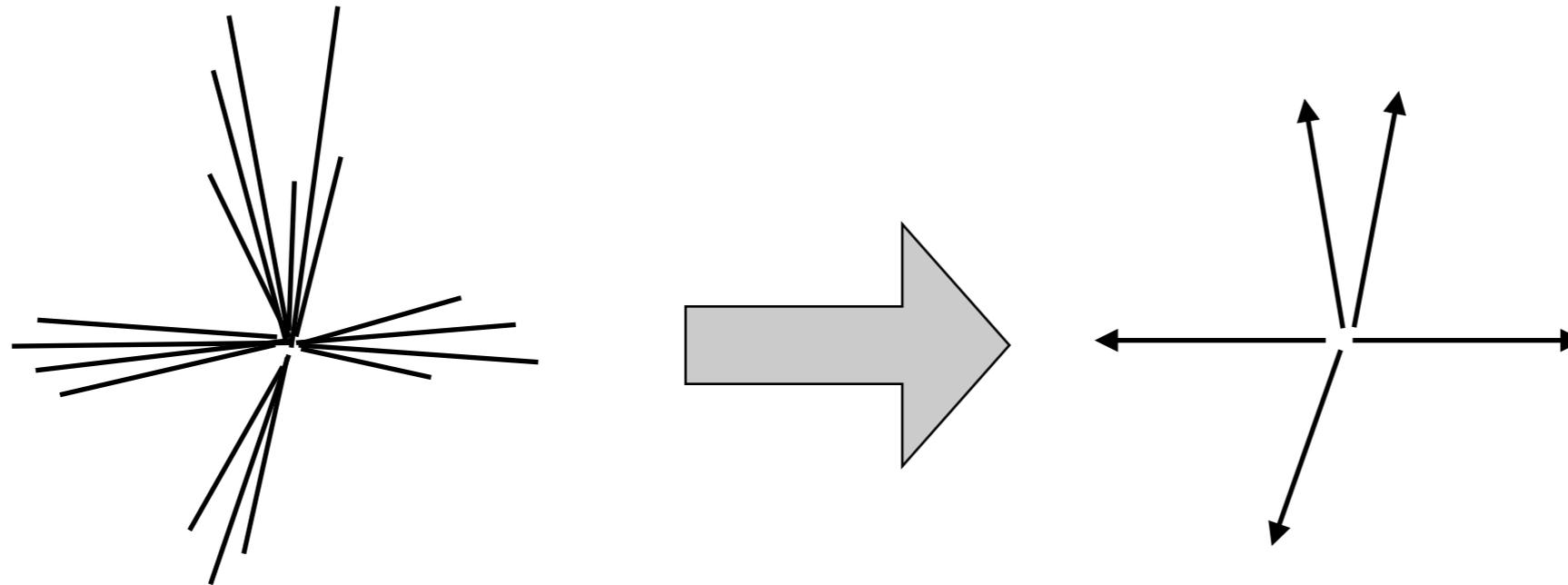
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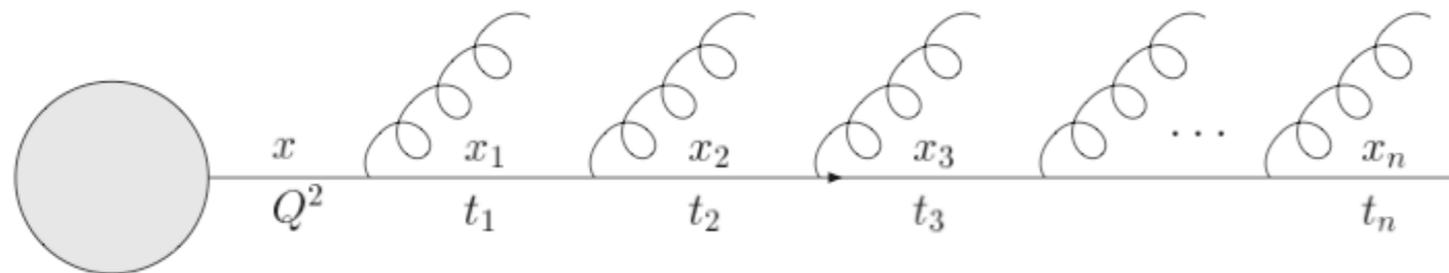
唯一の定義はない

今までは、コーンジェットがメイン

ジェット：定義が必要



- QCDジェットはparton shower近似で記述可能



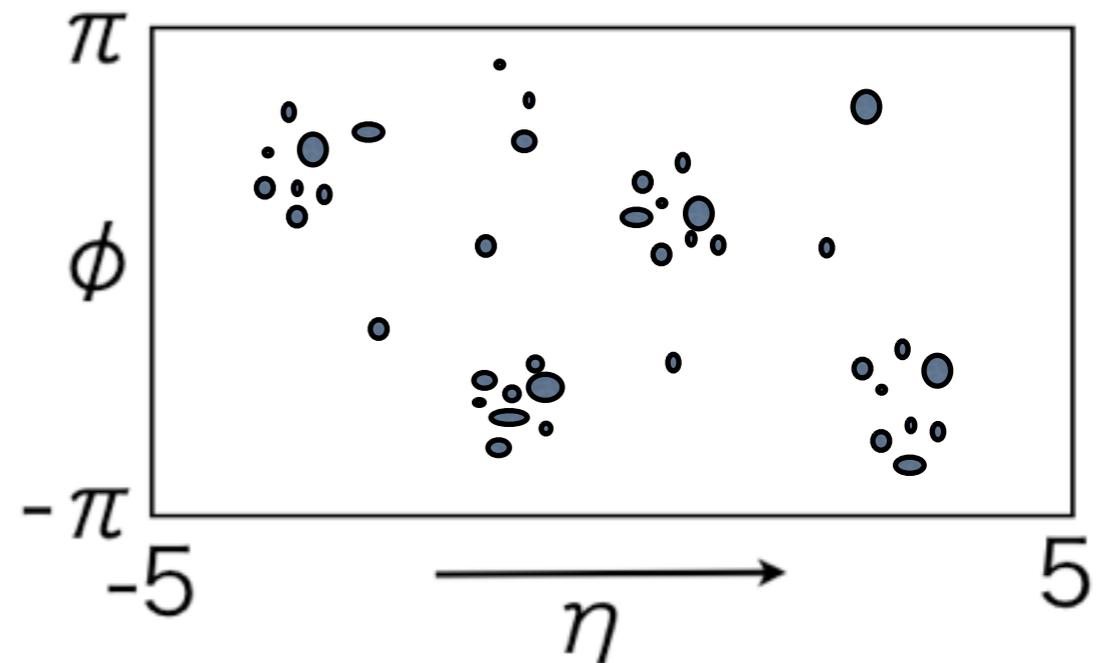
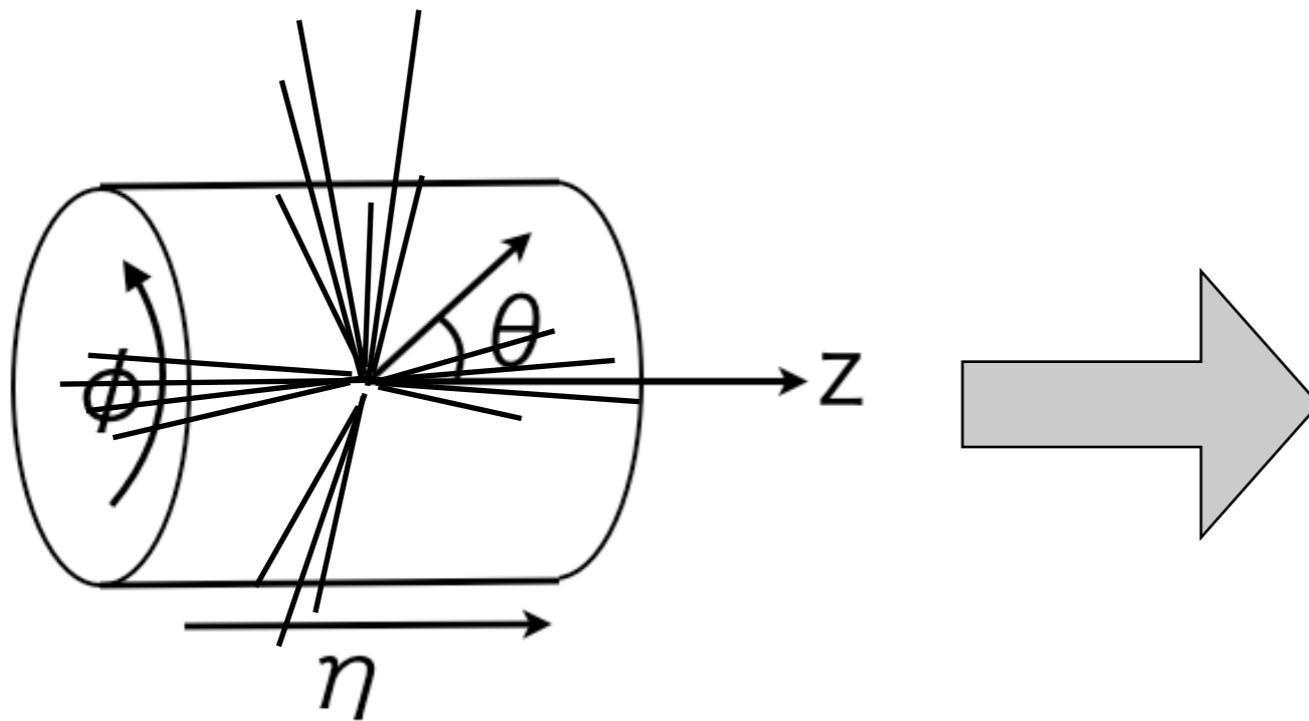
$$Q^2 > t_1 > t_2 > \dots$$

$$t = E_1 E_2 (1 - \cos \theta) \sim E^2 \theta^2 / 2$$

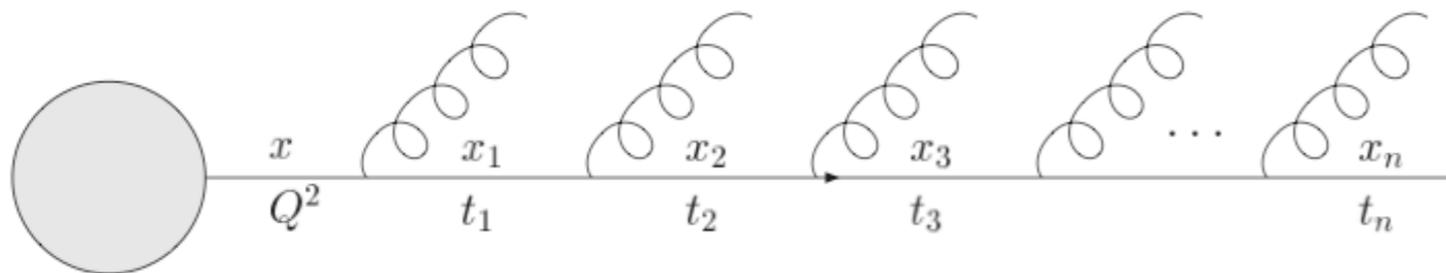
$$\mathcal{M} \propto \frac{1}{t_1} \frac{1}{t_2} \dots$$

soft-collinear singularity

ジェット：定義が必要



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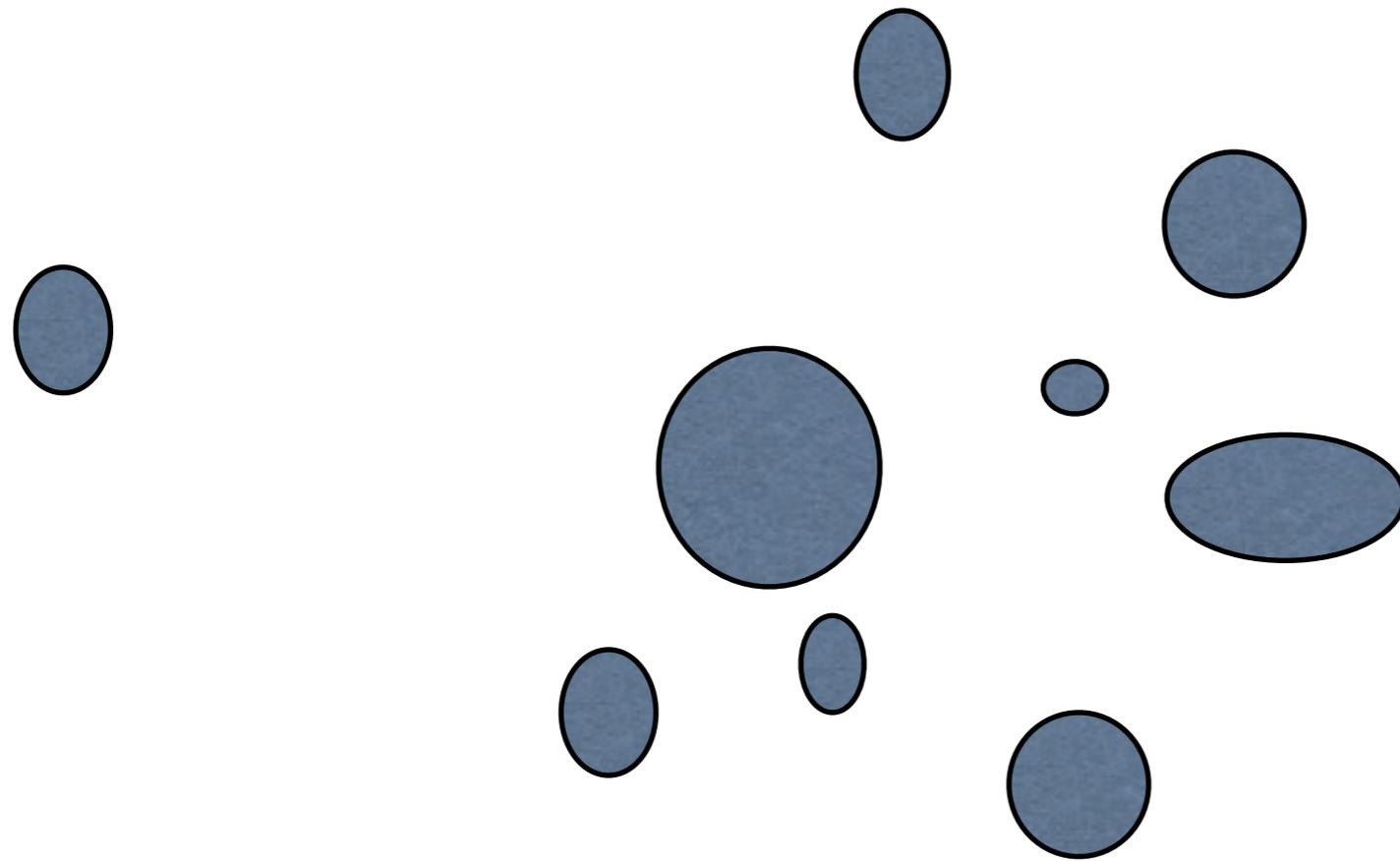
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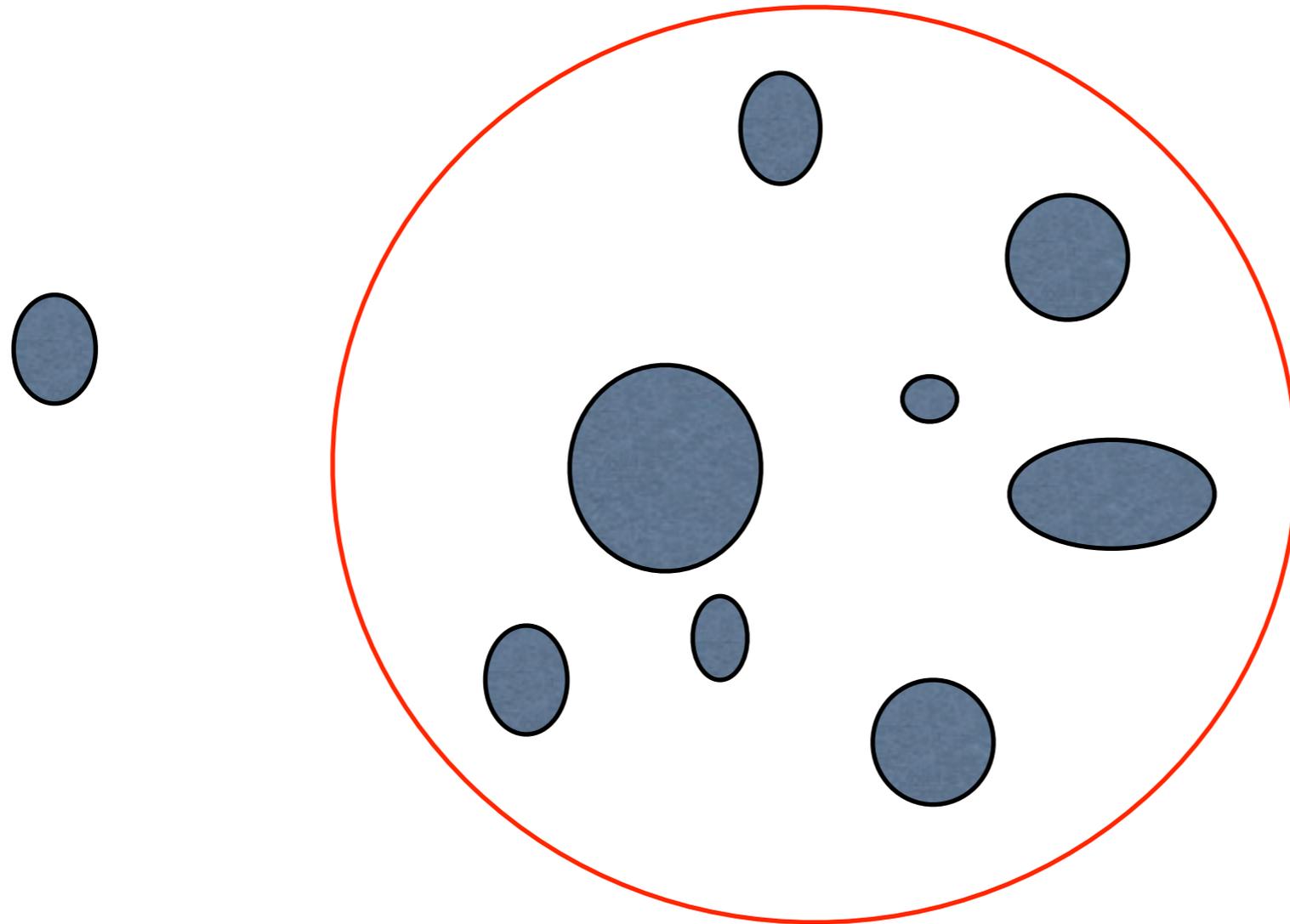
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soft-collinear singularity

クラスタリングジェット



クラスタリングジェット

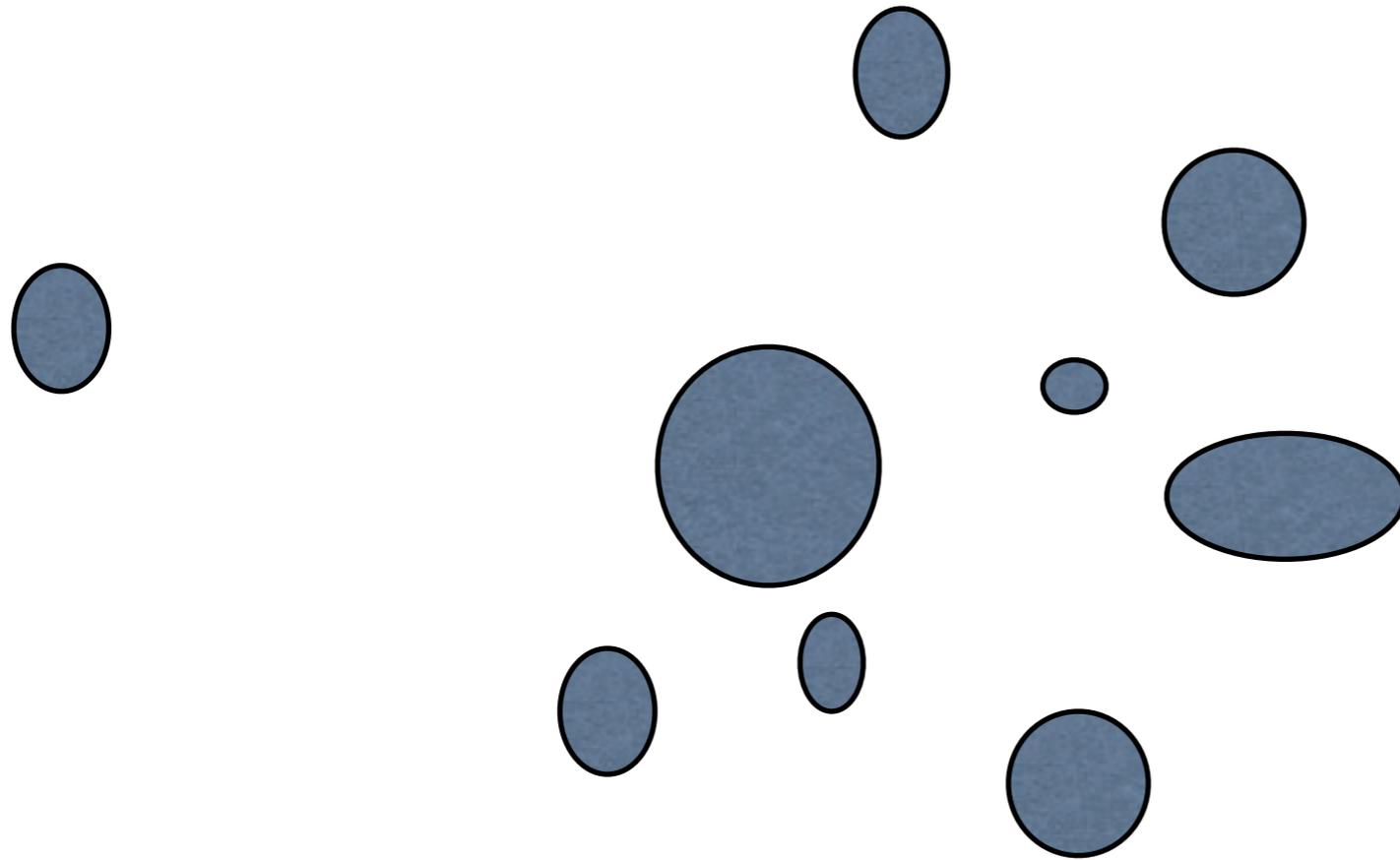


どの構成要素をジェットに含むかを定める定義が必要

コーンアルゴリズムだと円を描いて入ったものを全部足してジェットとする

ジェット運動量、ジェット質量を定義出来る

クラスタリングジェット



1. 最小の d_{ij} ペアを探す
2. $d_{ij} < d_{iB}$ なら i, j をくっつける
3. なくなるまで繰り返す

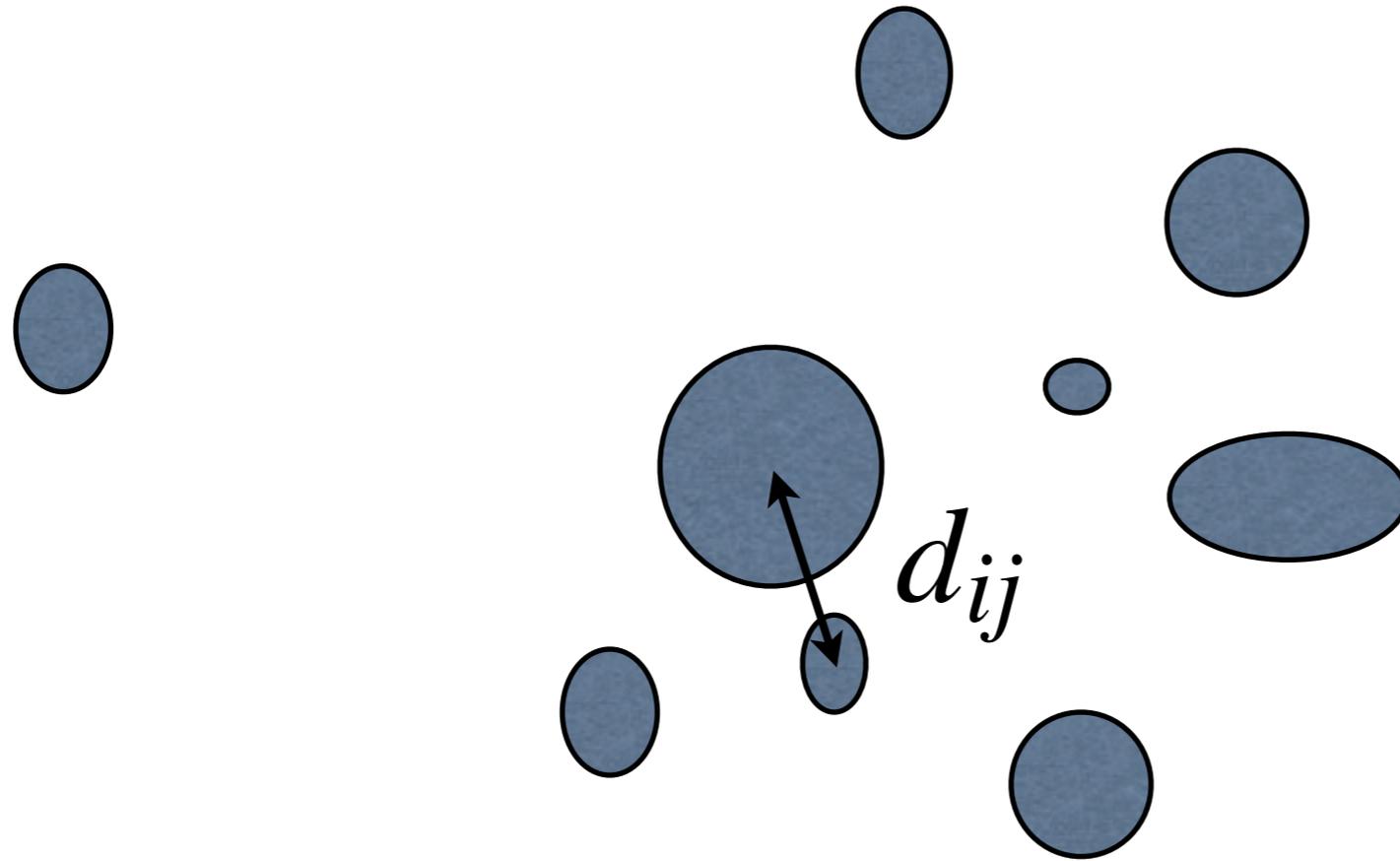
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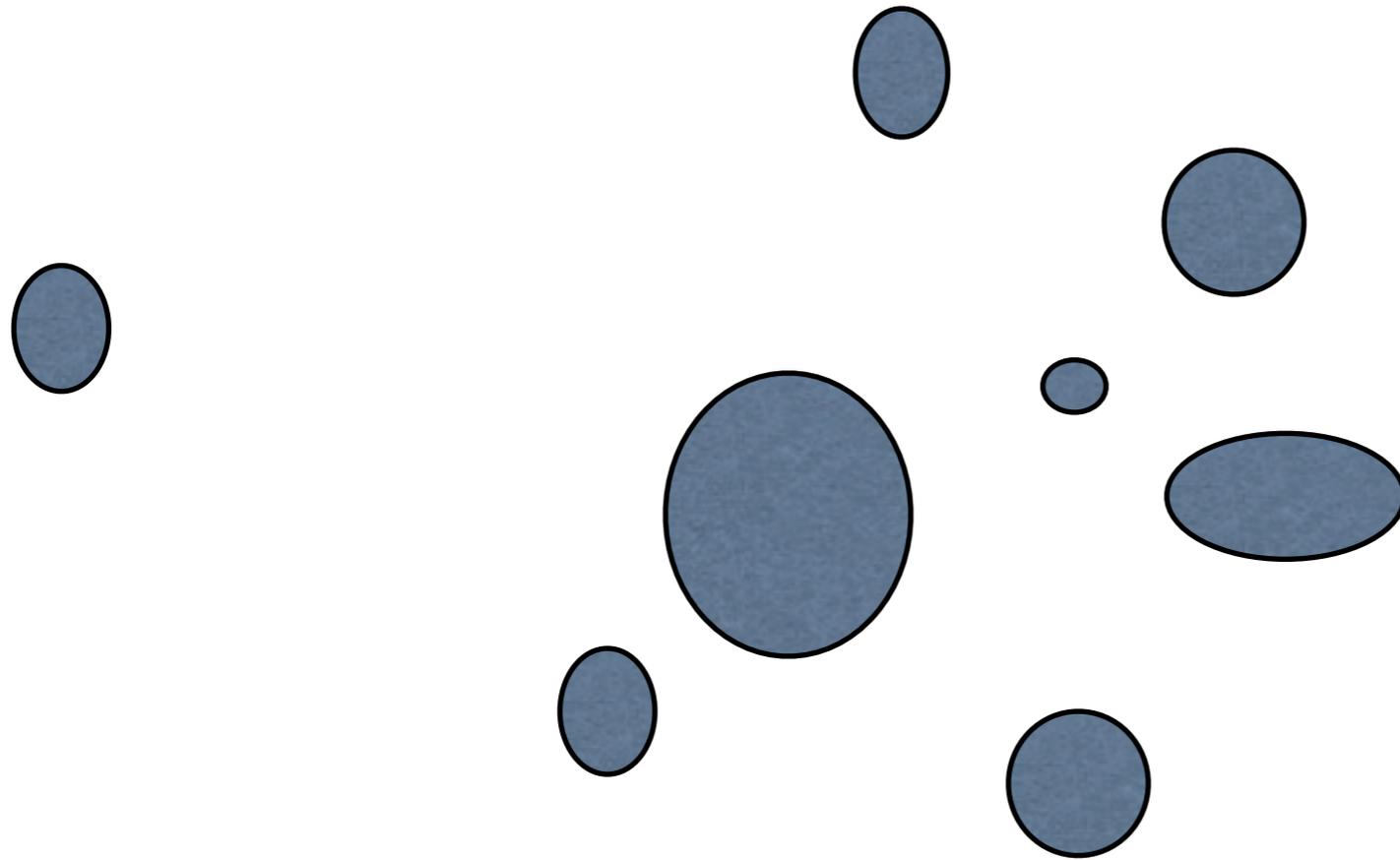
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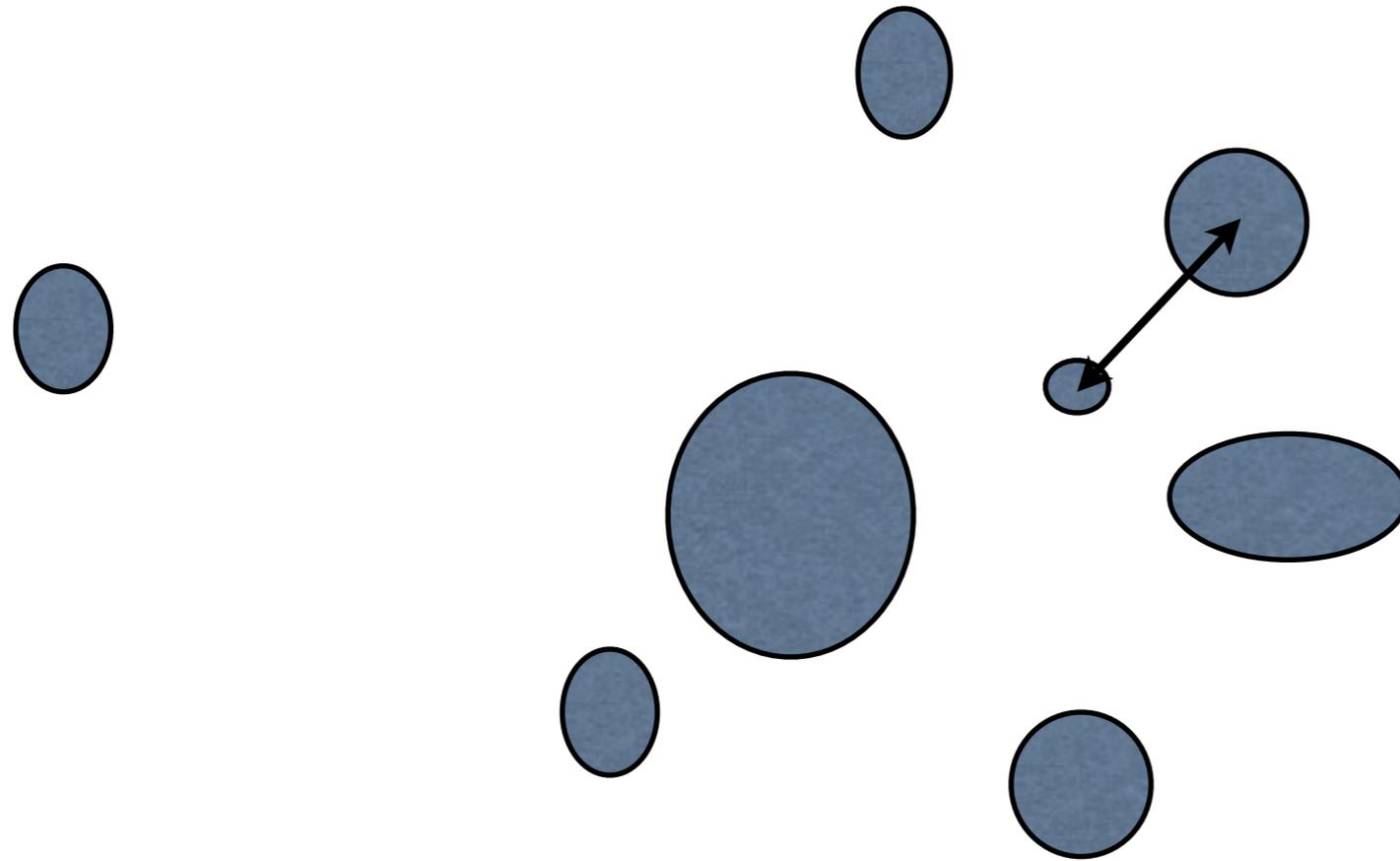
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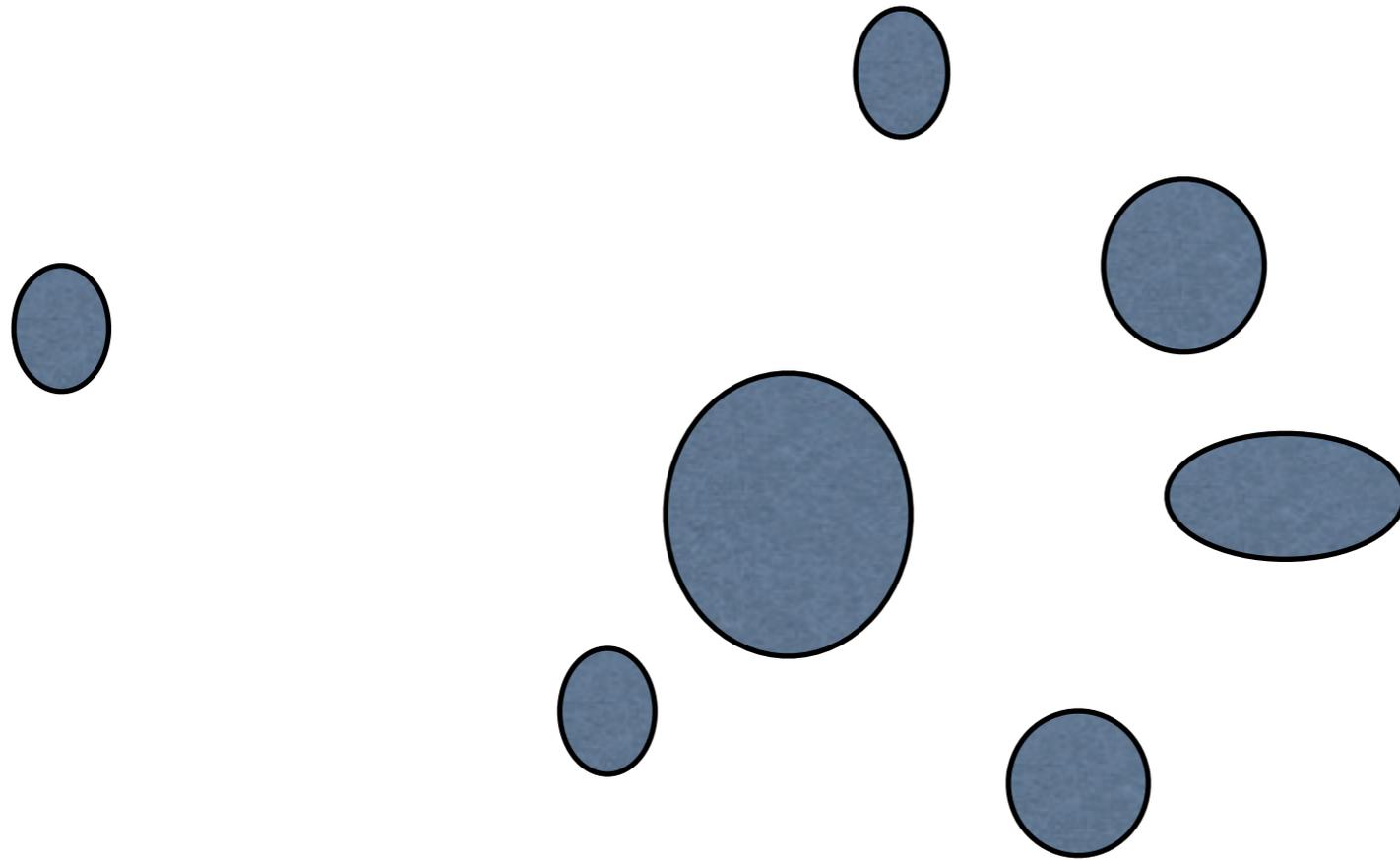
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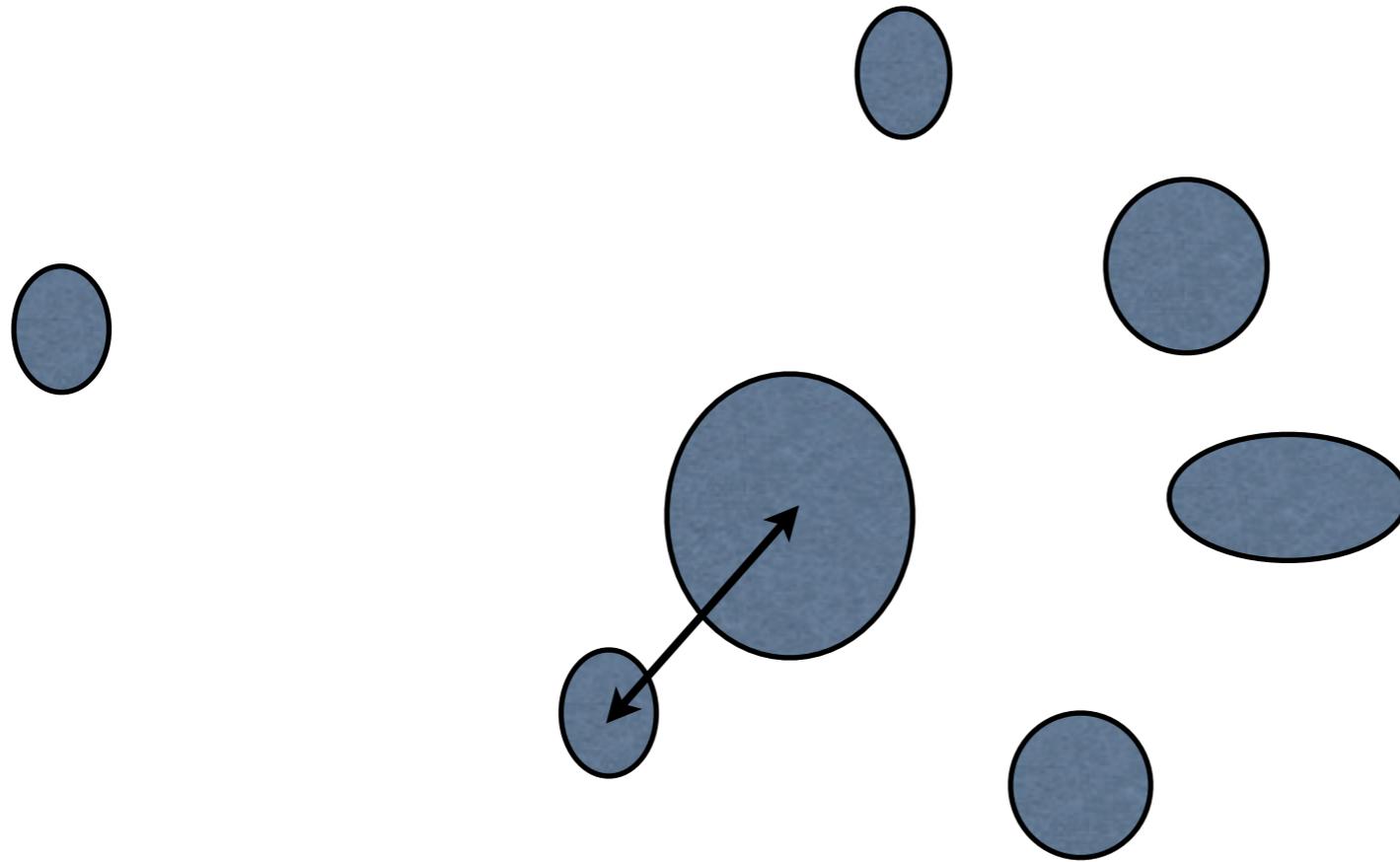
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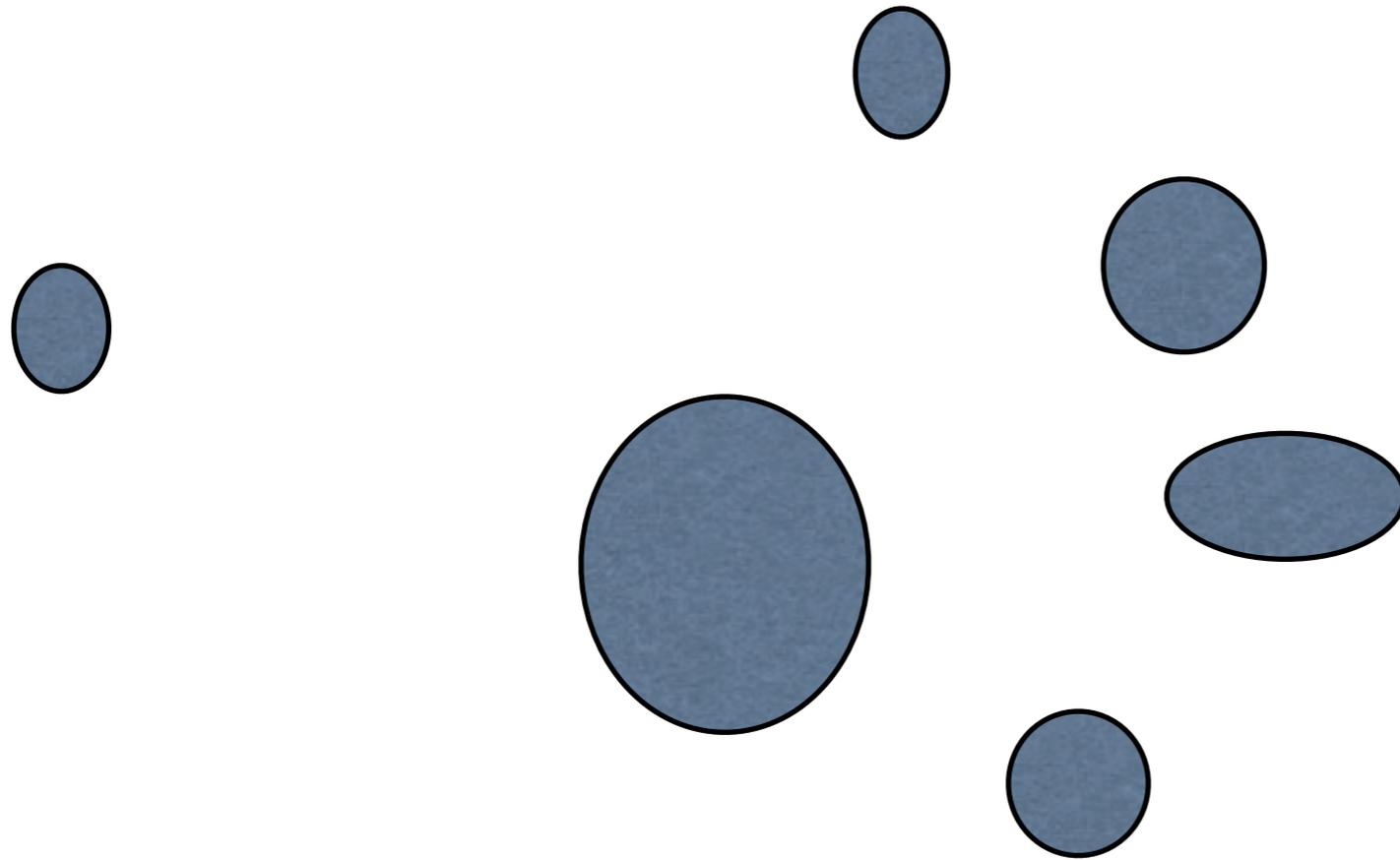
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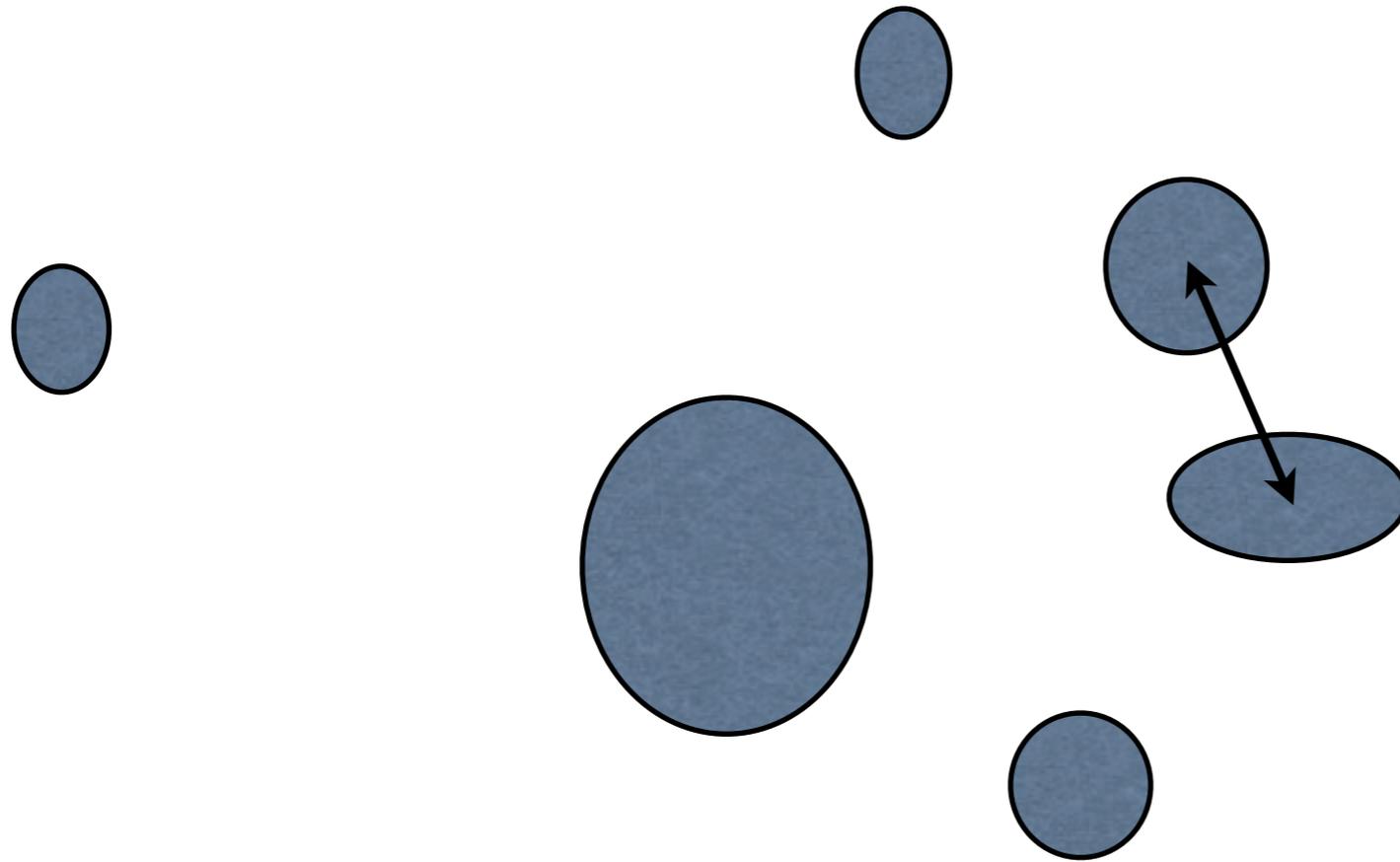
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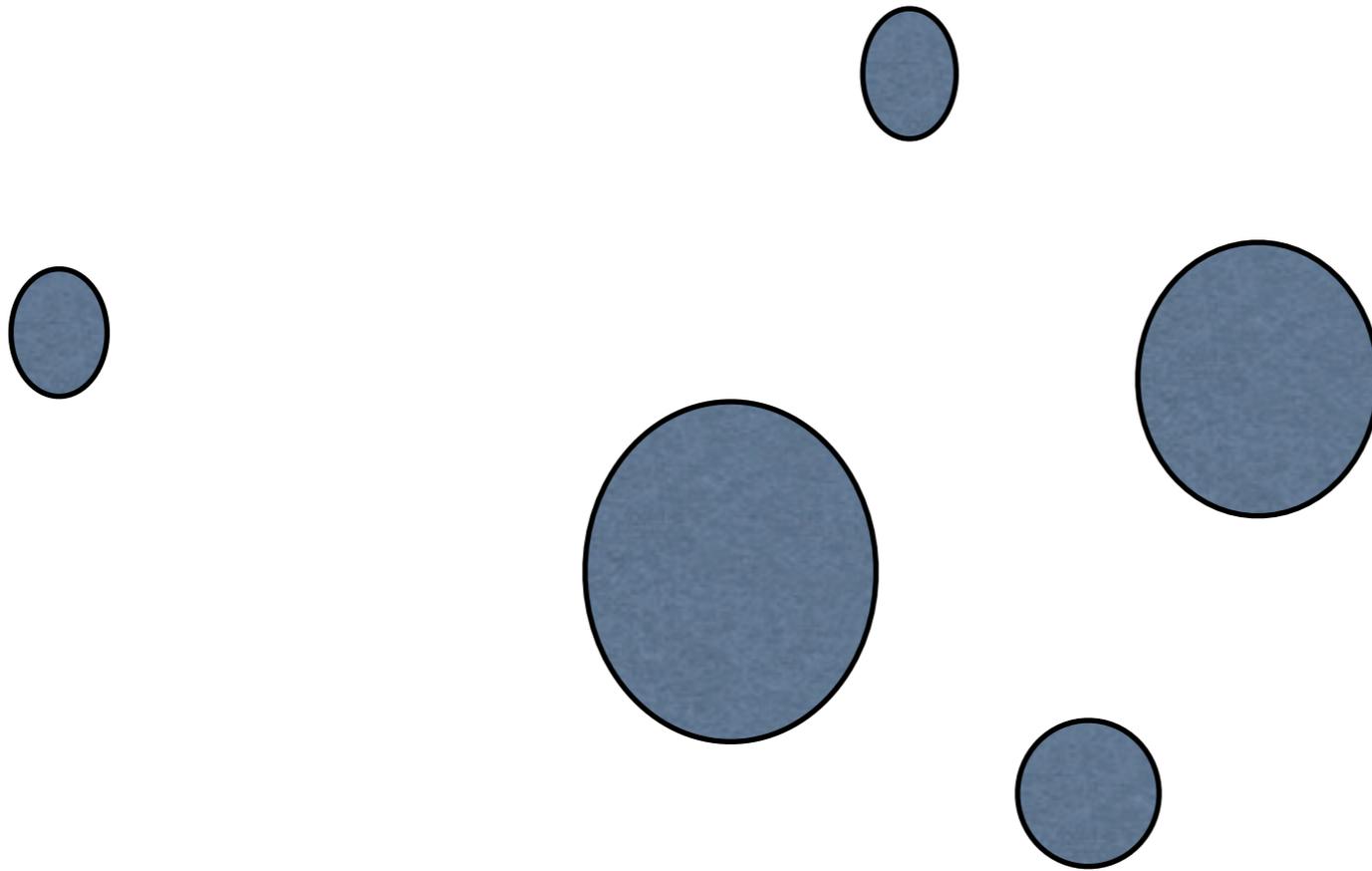
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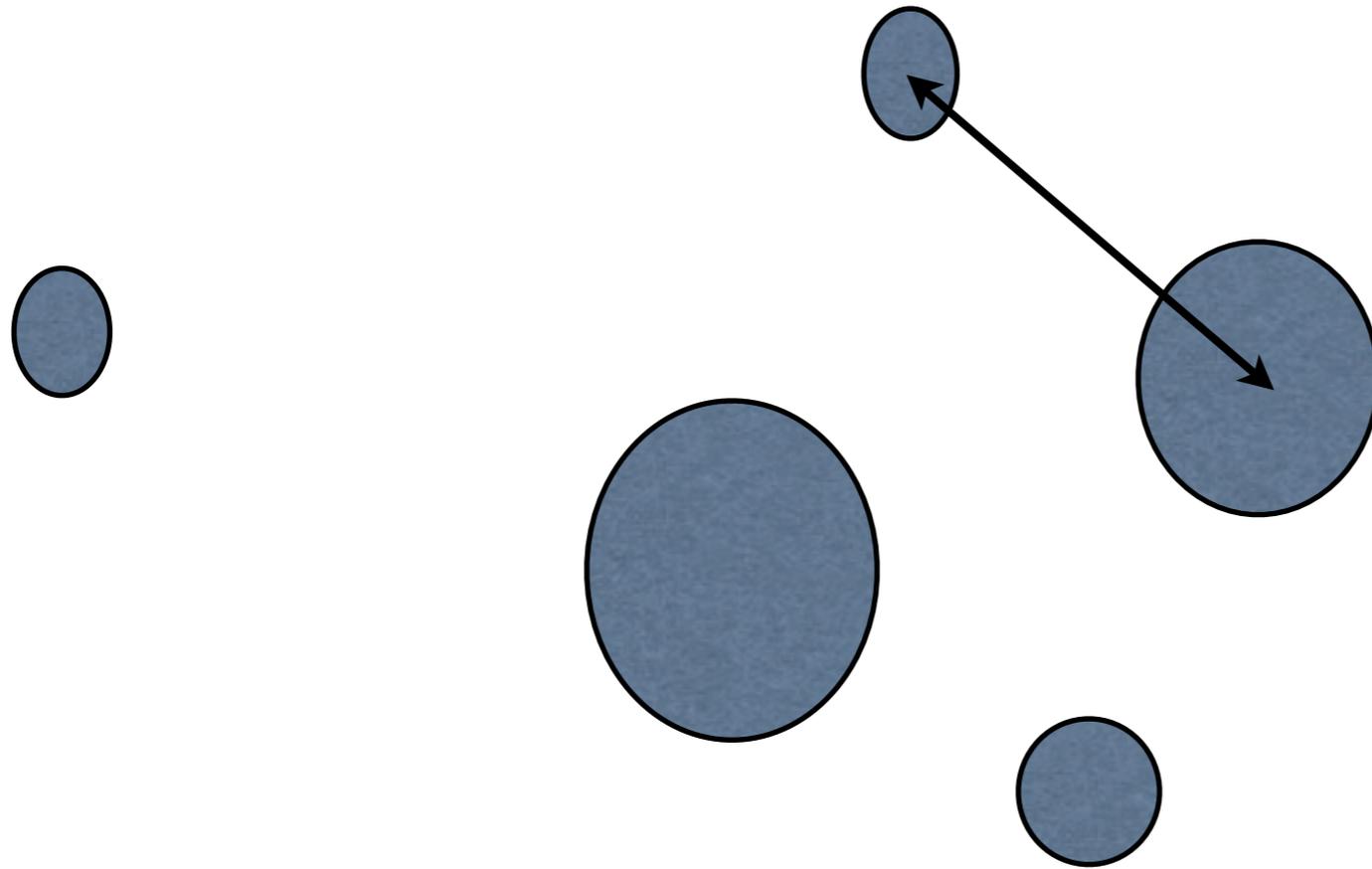
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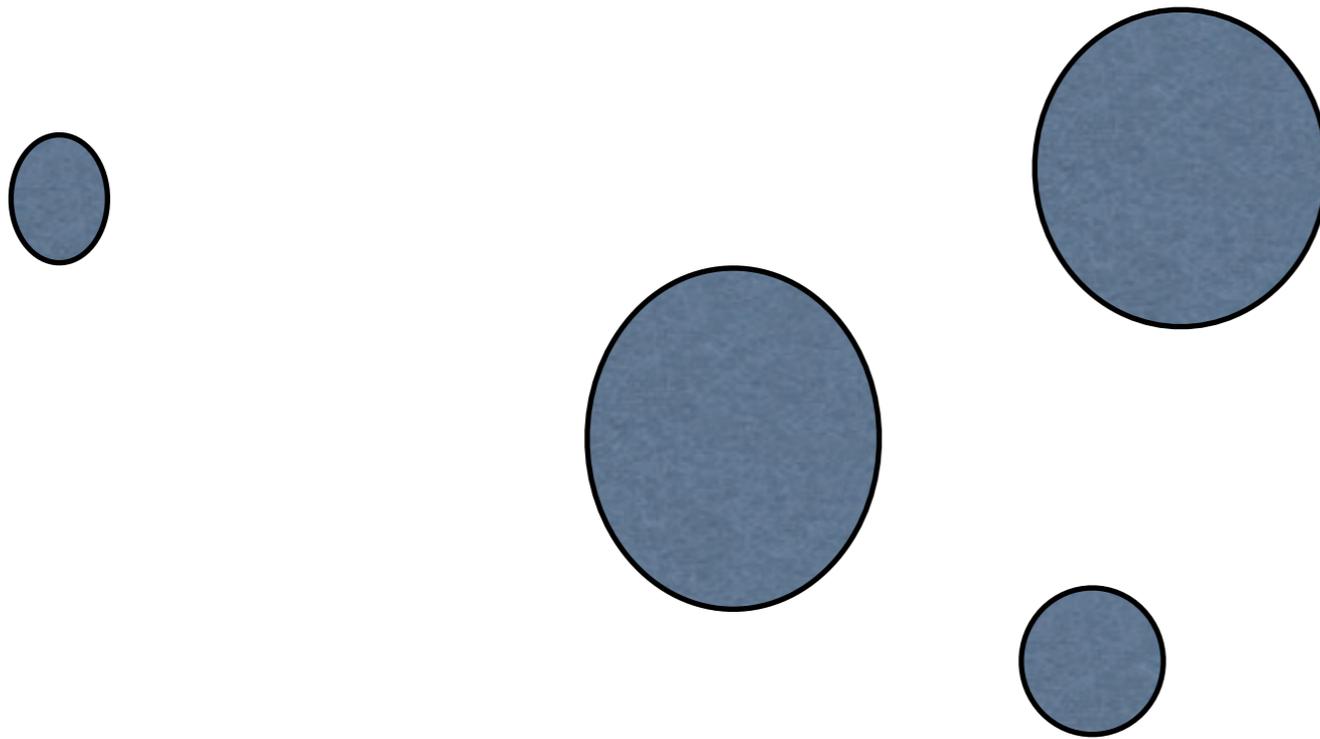
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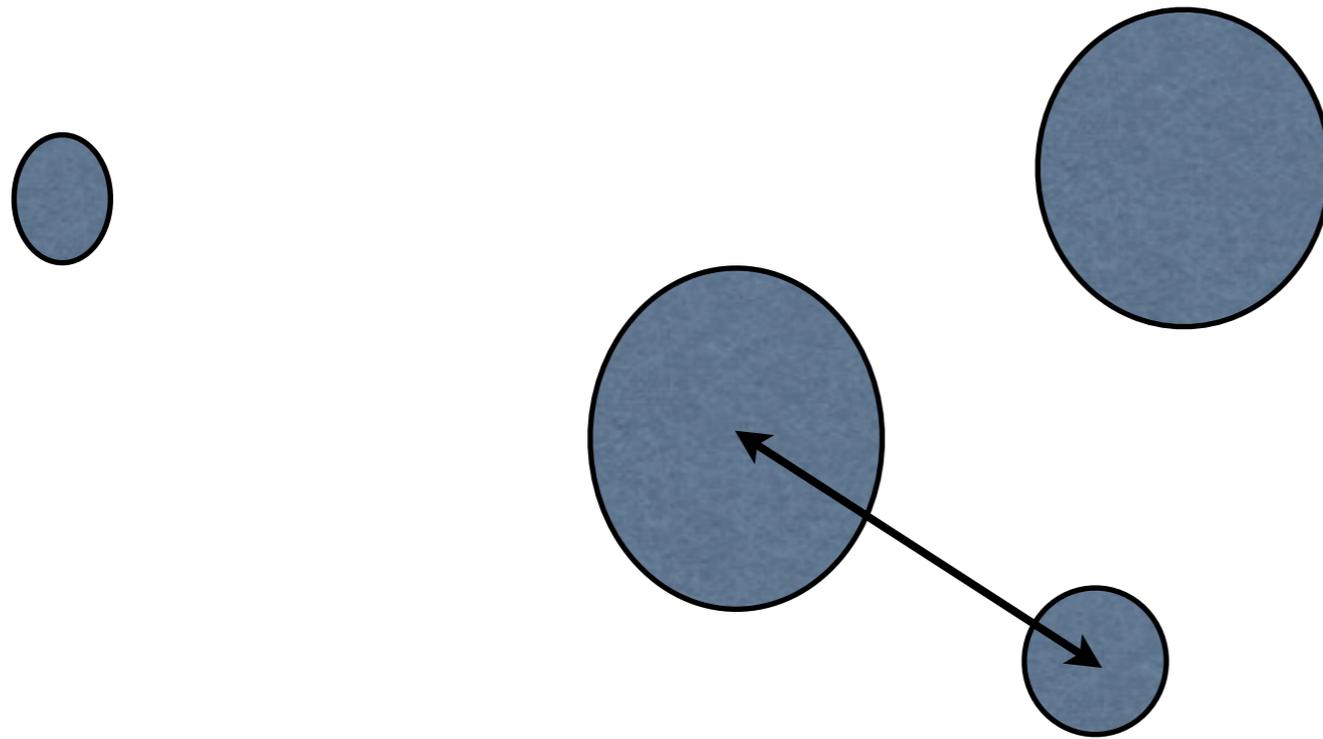
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$$\mathcal{M} \propto \frac{1}{t_1} \frac{1}{t_2} \dots$$

$$C/A: d_{ij} = \frac{\Delta R_{ij}^2}{R^2}, d_{iB} = 1$$

クラスタリングジェット



1. 最小の d_{ij} ペアを探す
2. $d_{ij} < d_{iB}$ なら i, j をくっつける
3. なくなるまで繰り返す

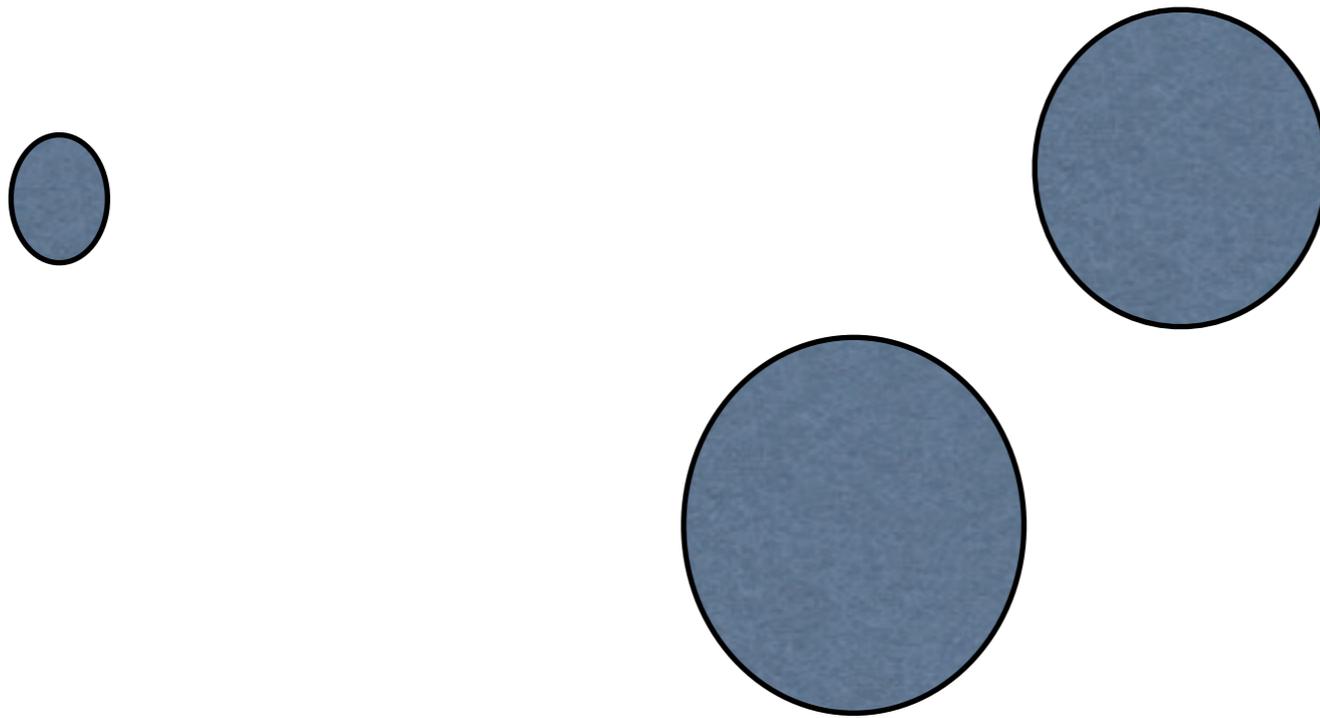
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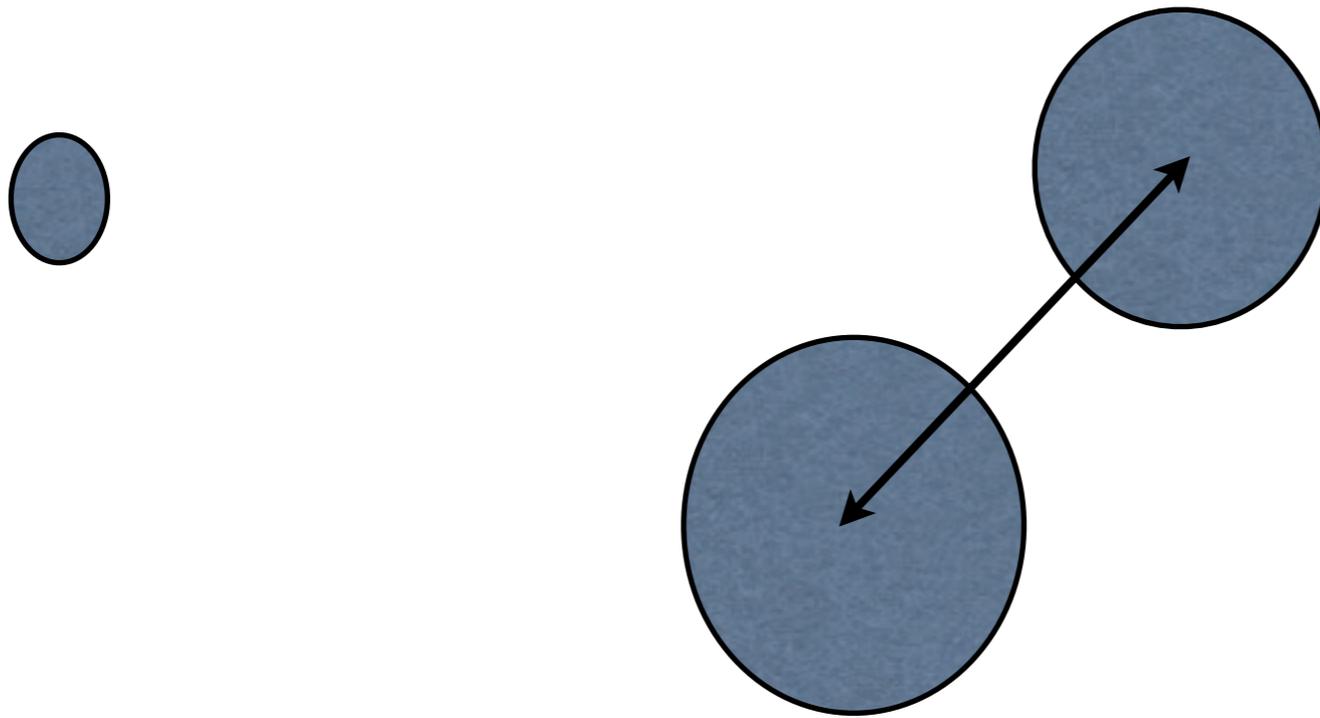
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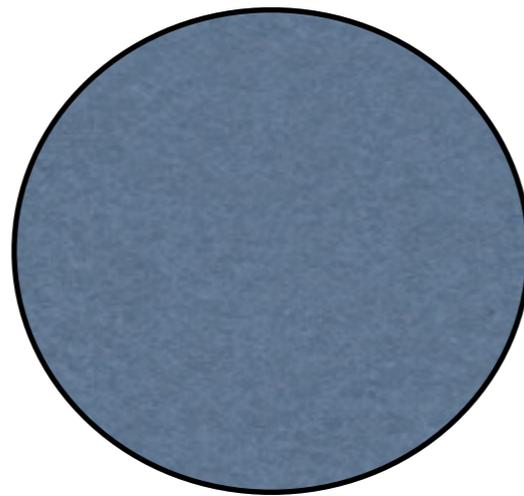
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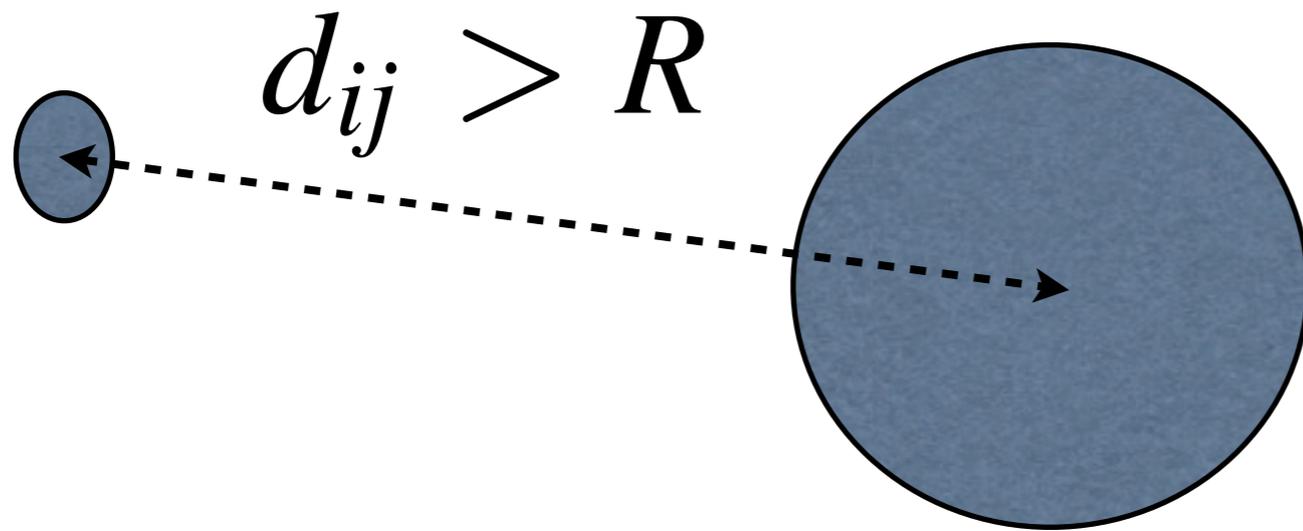
$$C/A: d_{ij} = \frac{\Delta R_{ij}^2}{R^2}, d_{iB} = 1$$

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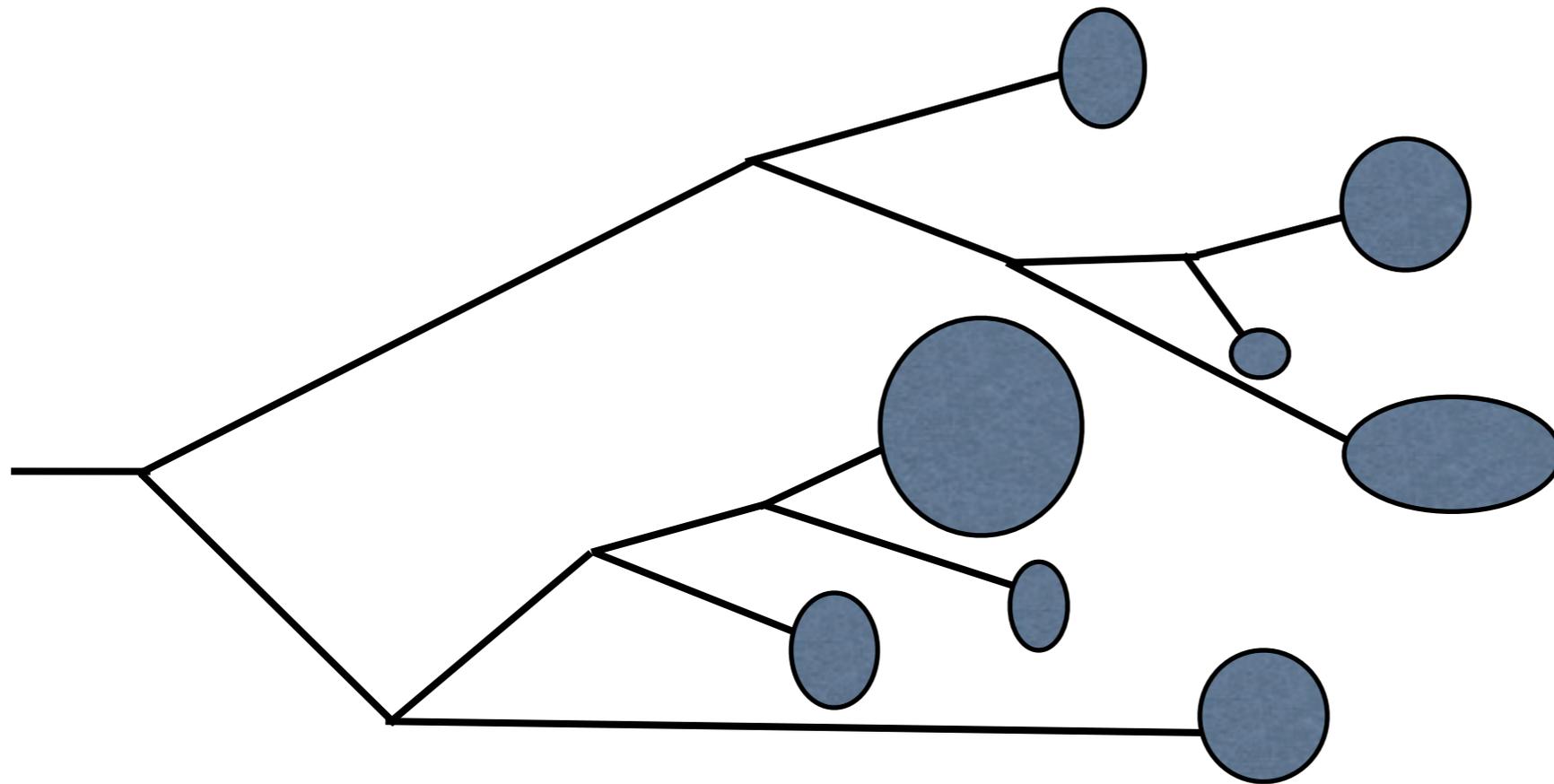
$$C/A: d_{ij} = \frac{\Delta R_{ij}^2}{R^2}, d_{iB} = 1$$

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$$\mathcal{M} \propto \frac{1}{t_1} \frac{1}{t_2} \dots$$

クラスタリングジェット



QCDで最も効くMEを探す作業

構成要素の集合とともに、
クラスタリングヒストリーも
自動的に得られる

今までは捨てていた情報

1. 最小の d_{ij} ペアを探す
2. $d_{ij} < d_{iB}$ なら i,j をくっつける
3. なくなるまで繰り返す

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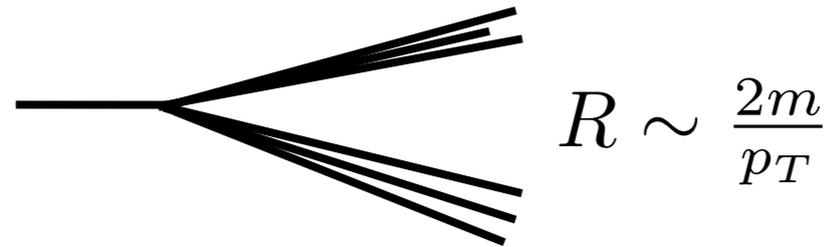
$$t = E_1 E_2 (1 - \cos \theta) \sim E^2 \theta^2 / 2$$

$$\mathcal{M} \propto \frac{1}{t_1} \frac{1}{t_2} \dots$$

Boosted Object

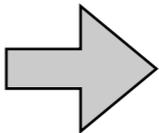
- 衝突エネルギーが高くなると、重いゲージボソンもブーストし始める

- W,Z,h: 質量~100GeV

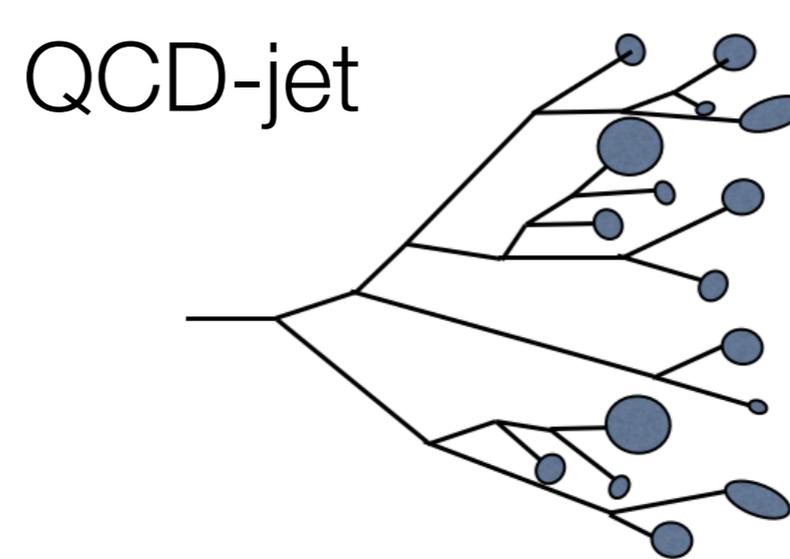
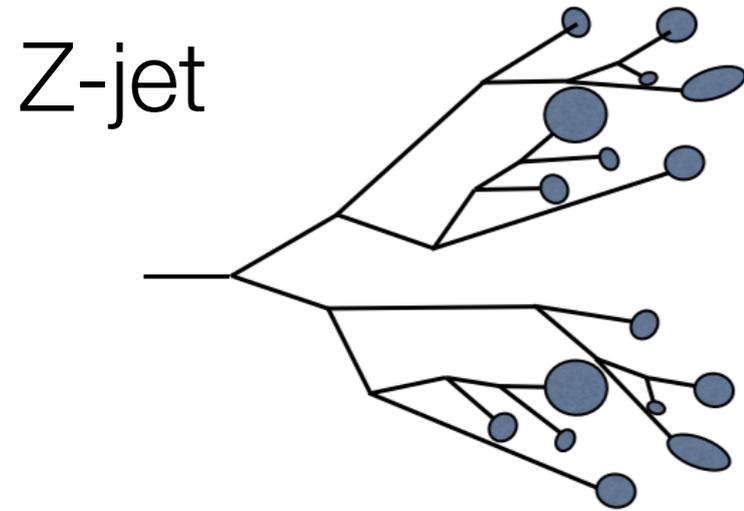


- 400GeV で $R=0.5$ のconeに入る (2jではWを探せなくなる)
- クラスタリングアルゴリズムで1つのジェットとして得られる

- $h \rightarrow bb$: 内部構造はDecayのMEで計算可能+PS Phys.Rev.Lett.100:242001(2008)
[J. M. Butterworth, A. R. Davison, M. Rubin, G. P. Salam]

- 組み合わせBGをコントロールしやすく便利  積極的に利用: fatjet ($R > 1.0$)

Mass drop

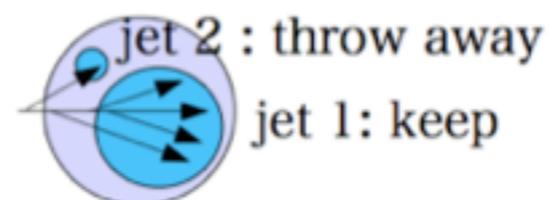
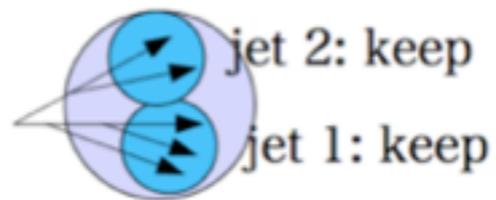


どうやって区別するか

- 同じmassのジェットでも、ヒストリーを逆にたどると

$$j = j_1 + j_2$$

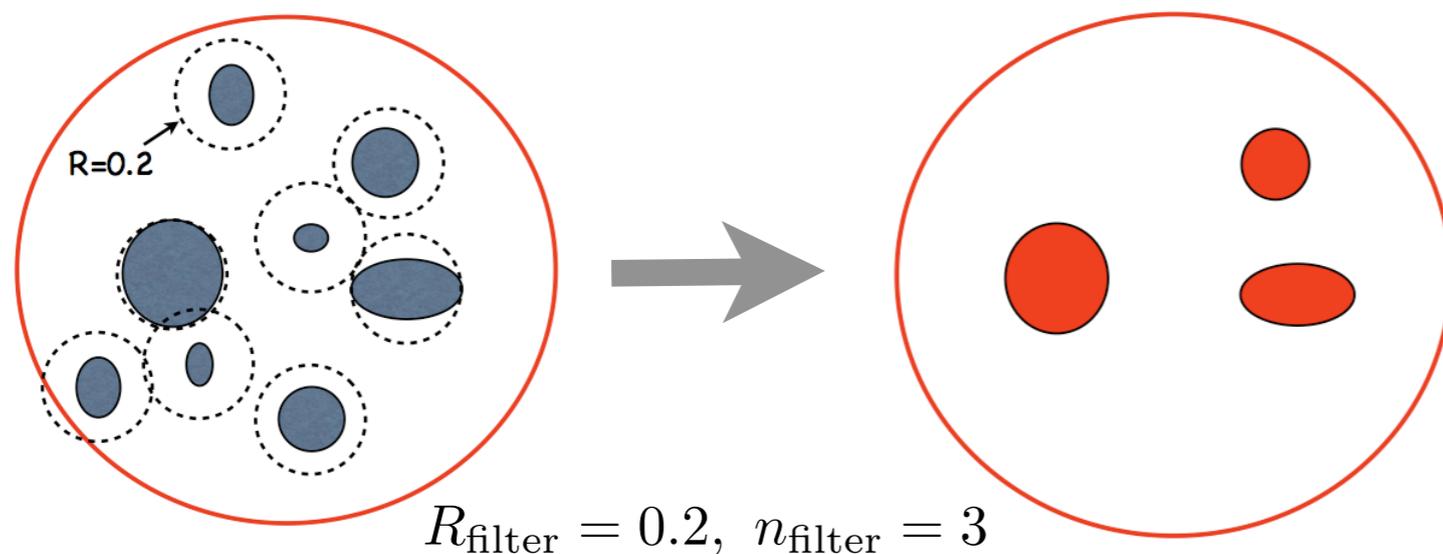
$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)} \leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$



重い粒子の崩壊ならば、mass dropが見られる

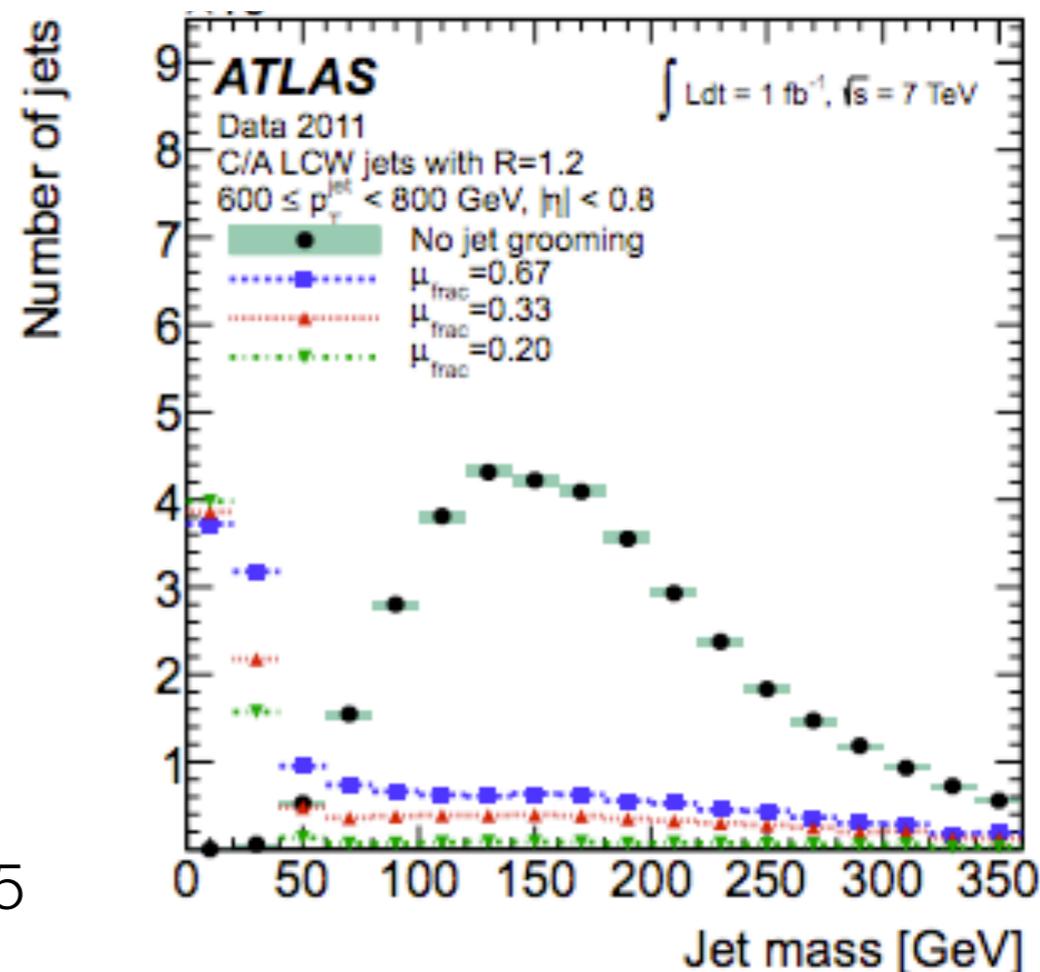
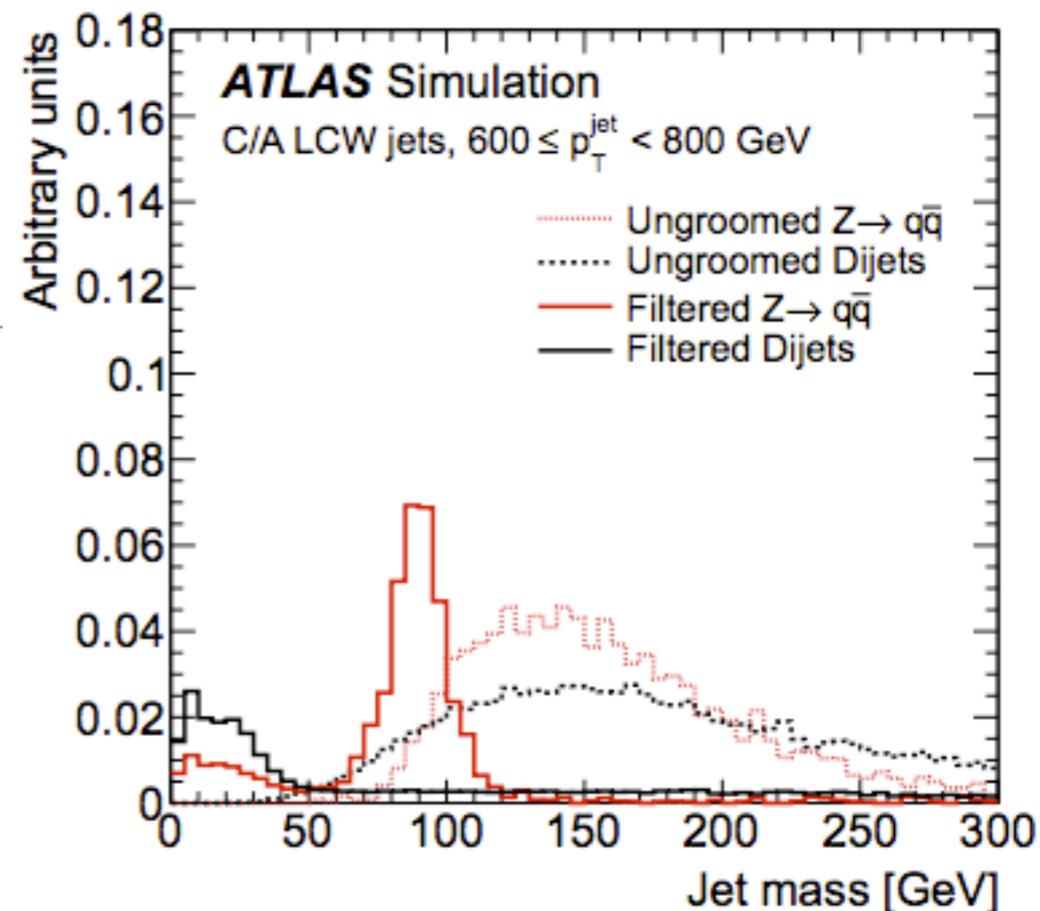
Filtering

- 大きいR : pile-up, underlying eventsの影響大
- ジェットの実効面積を減らす必要



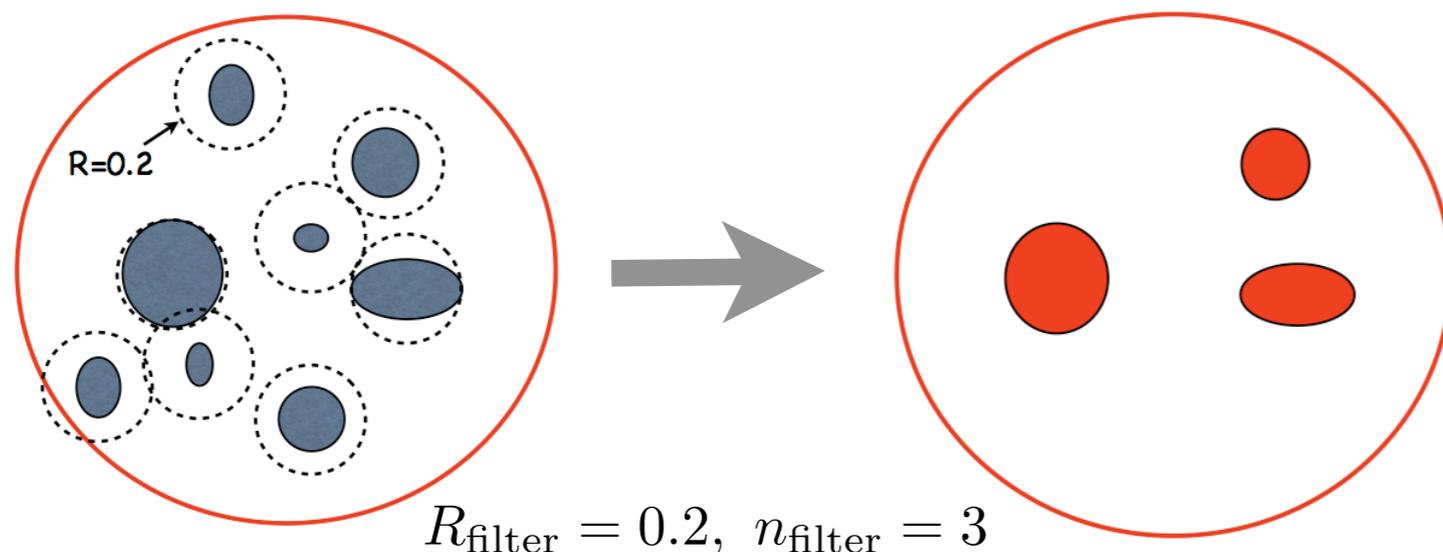
- 小さいRで再クラスタリング
- jet massのprimary vertex数の依存性が減る

arXiv:1306.4945



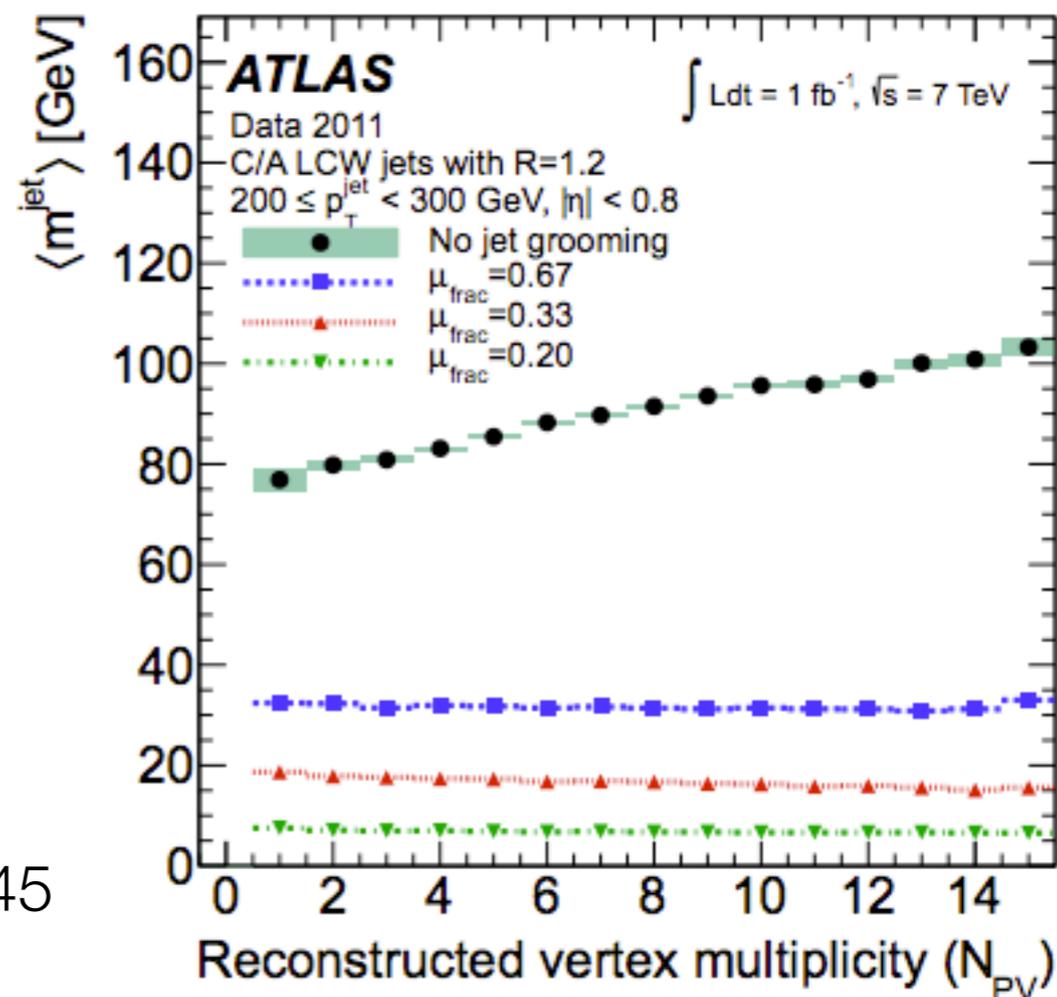
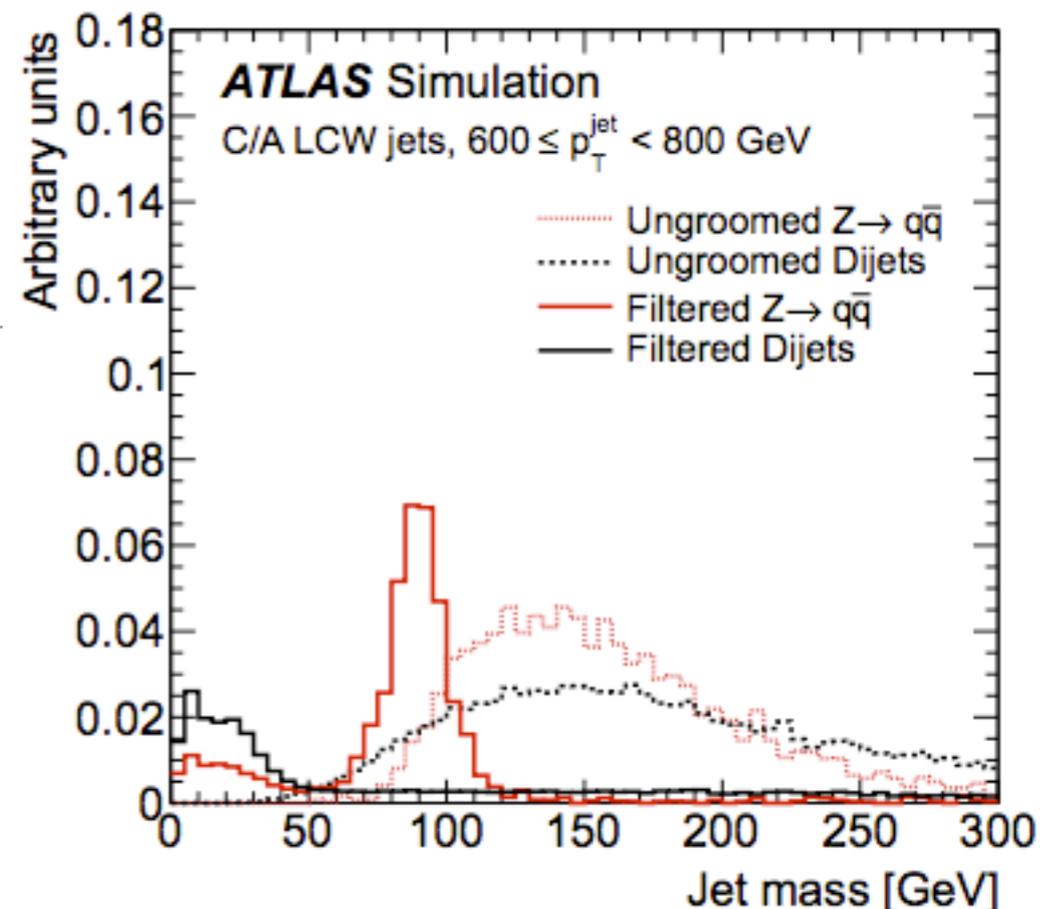
Filtering

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- 小さいRで再クラスタリング
- jet massのprimary vertex数の依存性が減る

arXiv:1306.4945



Boosted Tops (HEPTopTagger)

- jet substructure
- top physics

top ジェットの利用

- top : New physics に最も近い
 - $\tilde{t}\tilde{t}^* \rightarrow t\bar{t}\chi\chi$: stop search
 - $t\bar{t}H$: largest yukawa coupling y_t
 - $t\bar{t}+\text{jets}$: main background for new physics search

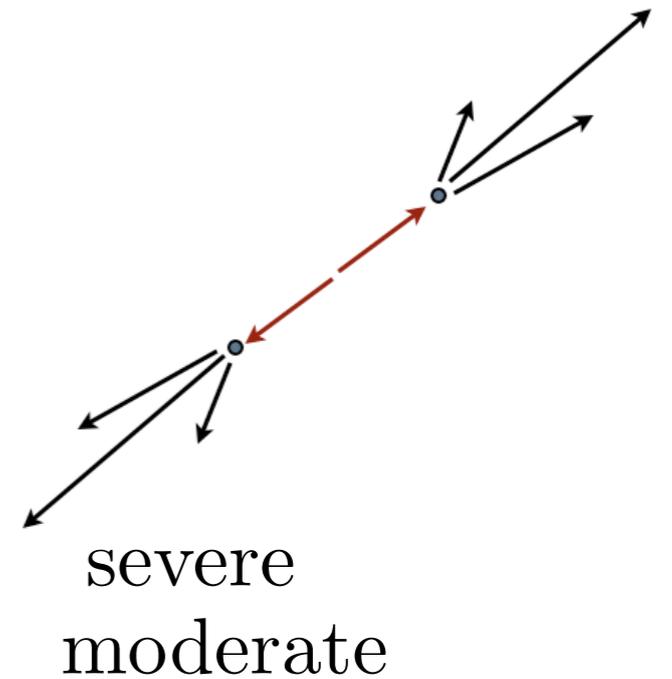
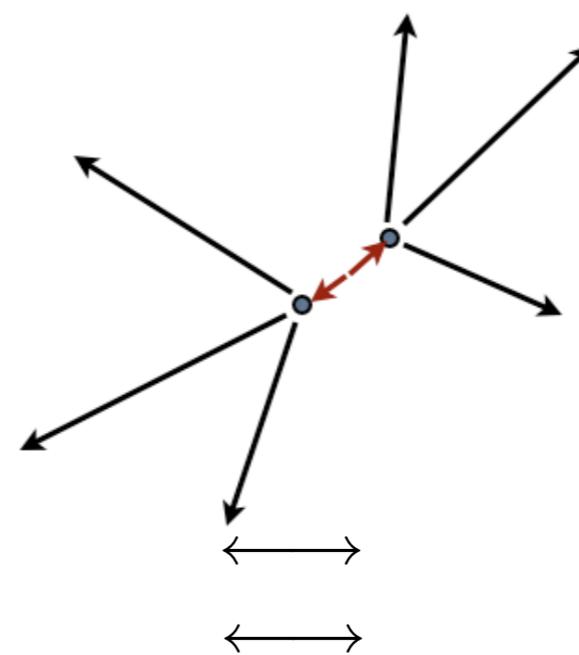
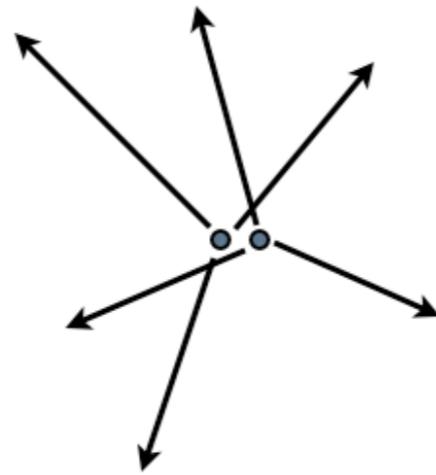
- ハドロニックモード
 - 利点：運動量再構成
 - 欠点：QCD、組み合わせBG問題大 (+ISR) → fatjet & 内部構造

- $R \sim \frac{2m}{p_T}$: $\sim 150\text{GeV}$ で $R=1.5$ の cone に入る

- top: 3体崩壊 (標準模型で唯一、質量 $\sim 173\text{GeV}$)

Boosted Tops

$p_{T,t}$ によって見え方が違う

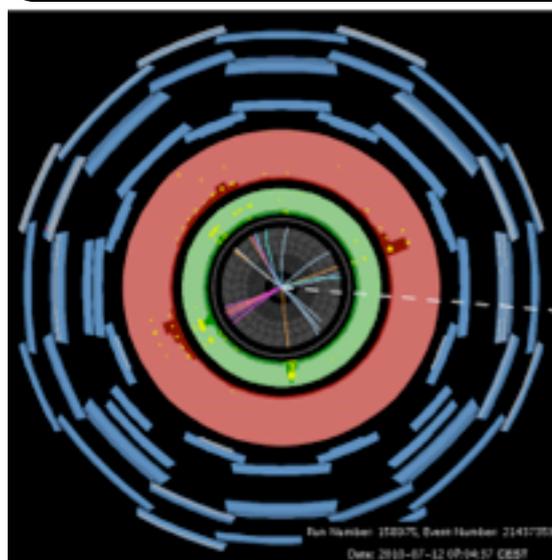
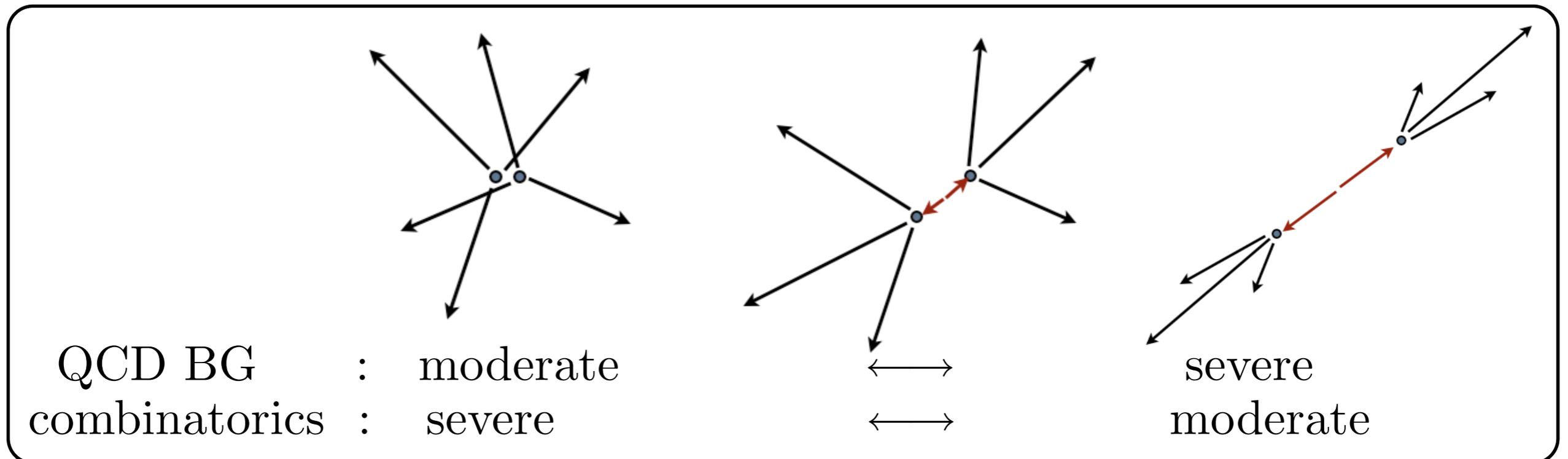


QCD BG : moderate
combinatorics : severe

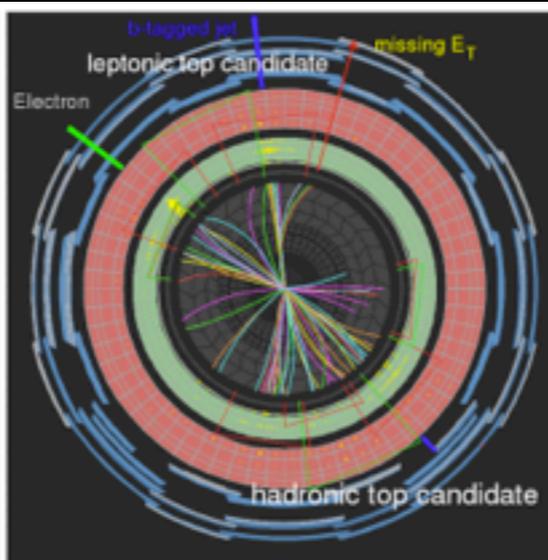
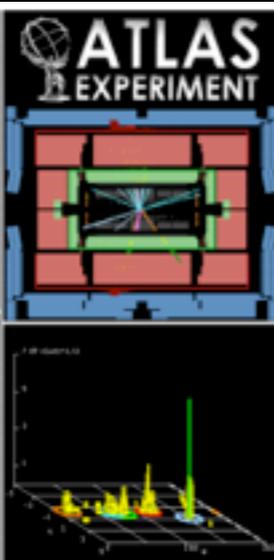
severe
moderate

Boosted Tops

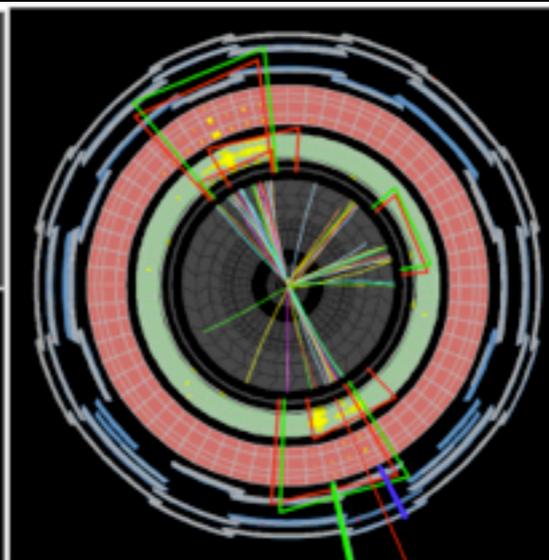
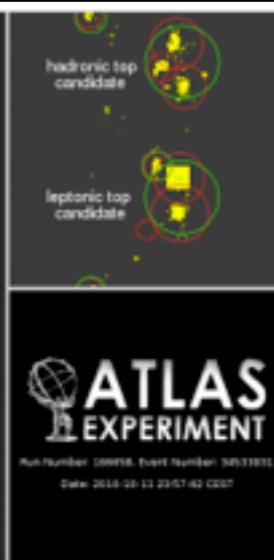
$p_{T,t}$ によって見え方が違う



Early "l+jets" candidate
ATLAS-CONF-2010-063



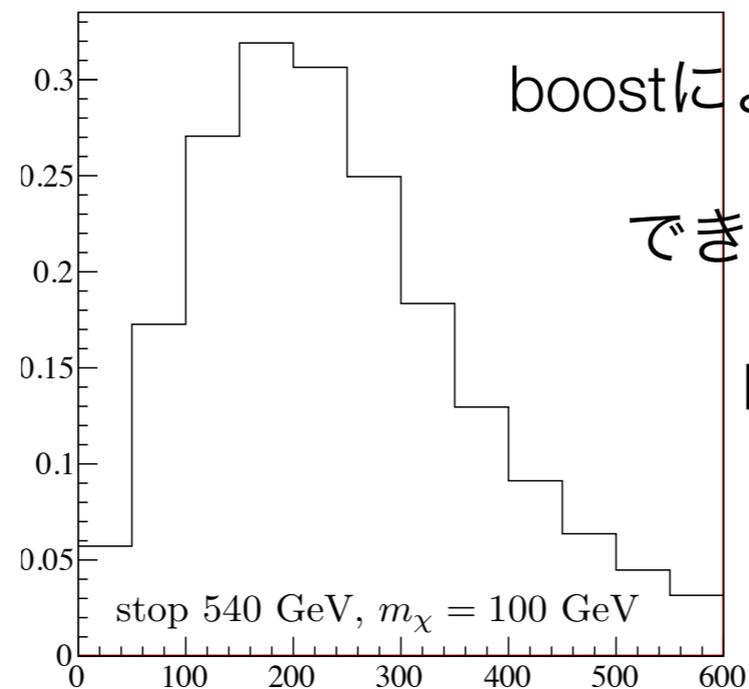
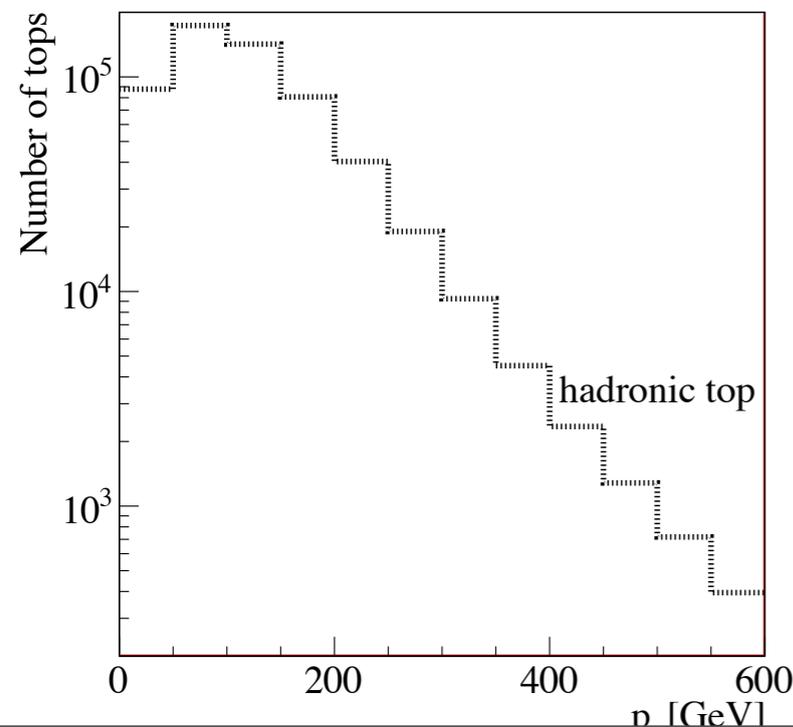
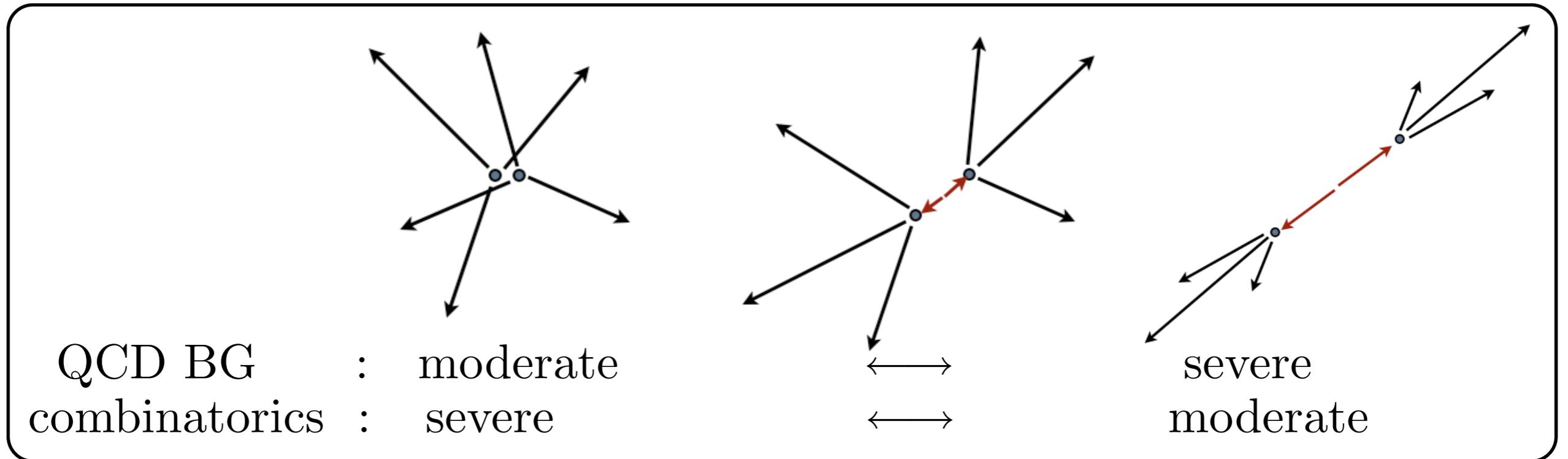
First boosted top quark
ATLAS-CONF-2011-073



$m_{tt} > 1 \text{ TeV}$
ATLAS-CONF-2011-083

Boosted Tops

$p_{T,t}$ によって見え方が違う



boostによって組み合わせBGが自動的に解ける

できるだけlow p_T までこのメリットを利用

$R=1.5$ で 200 GeV 程度までfatjetに入る

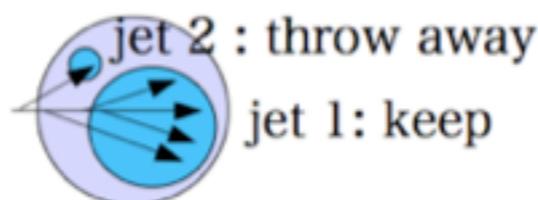
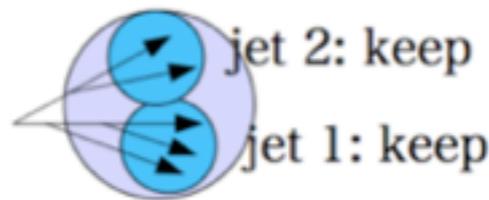
HEP TopTagger Algorithm

1. fatjetを定義 $C/A, R=1.5$

2. mass drop で subjets を探す $(t \rightarrow bW, W \rightarrow jj)$

$$j = j_1 + j_2$$

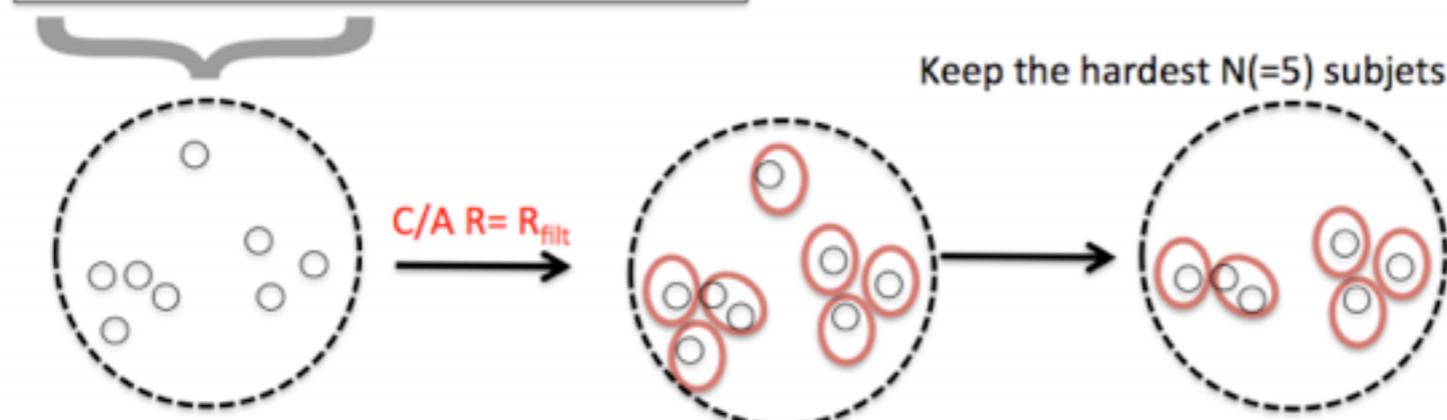
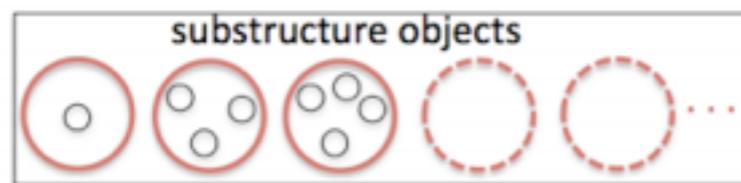
$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)} \leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$



$$m_{j_1}/m_j < 0.8$$

$$m_j^{\text{sub}} < 50 \text{ GeV}$$

3. top質量に最も近いfiltered massを持つ組を選ぶ



$$R_{\text{filt}} = \min\left[0.3, \frac{\Delta R_{j_1, j_2}}{2}, \frac{\Delta R_{j_1, j_3}}{2}, \frac{\Delta R_{j_2, j_3}}{2}\right]$$

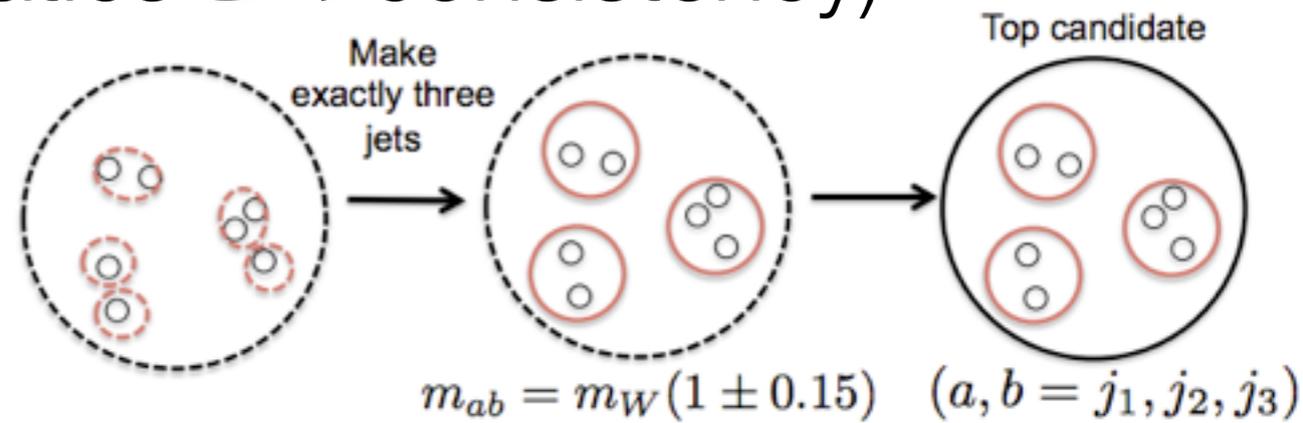
$$|m_{jjj}^{\text{filt}} - m_t| < 25 \text{ GeV}$$

→ top candidate

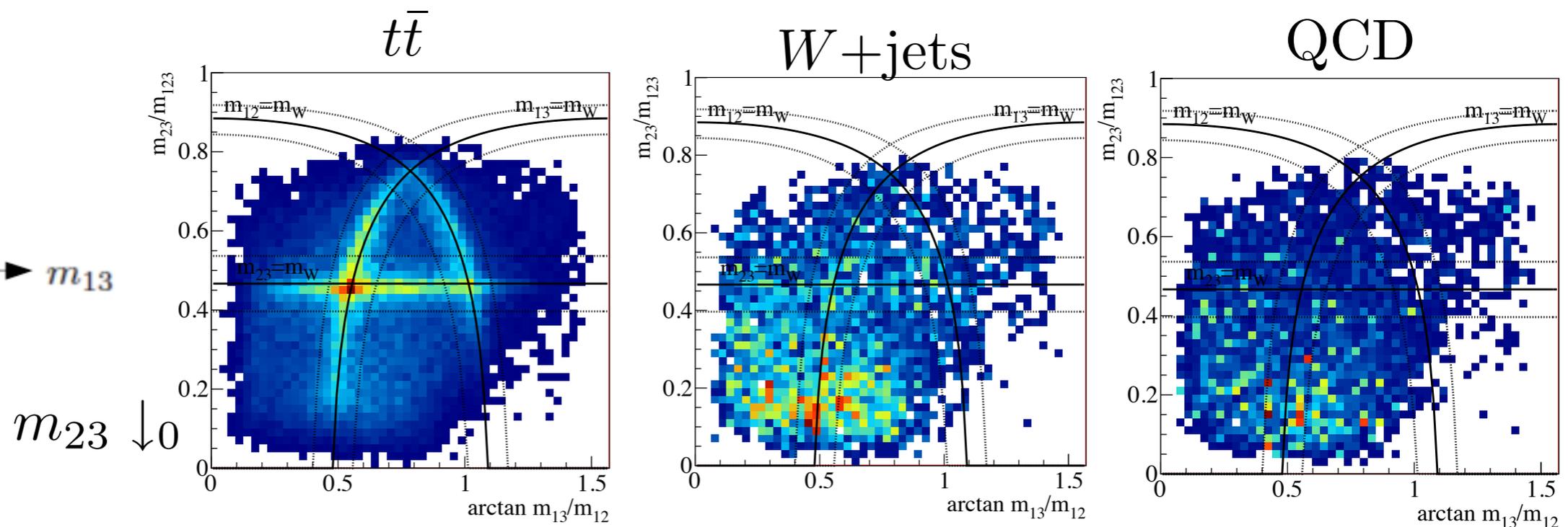
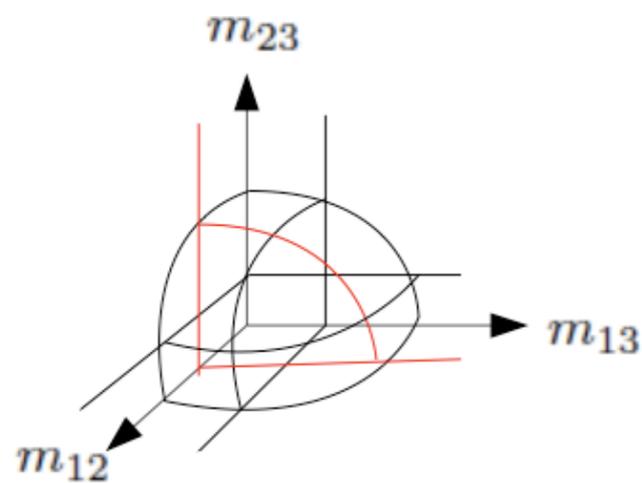
HEP TopTagger Algorithm

4. mass ratio check (top kinematics と の consistency)

3 subjets: $p_1, p_2, p_3 \rightarrow m_{12}, m_{13}, m_{23}$



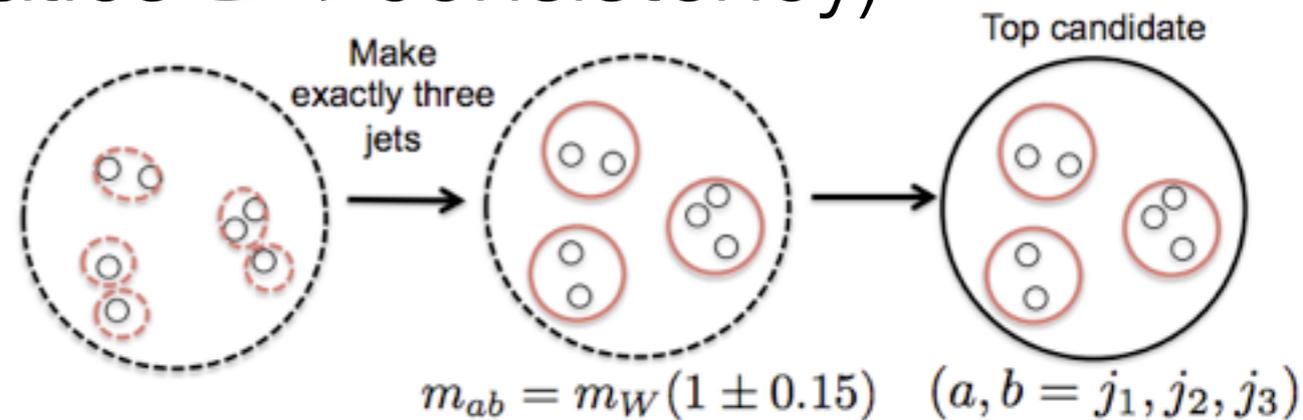
$m_t^2 \simeq m_{123}^2 \simeq m_{12}^2 + m_{13}^2 + m_{23}^2 \rightarrow$ 2D mass ratios



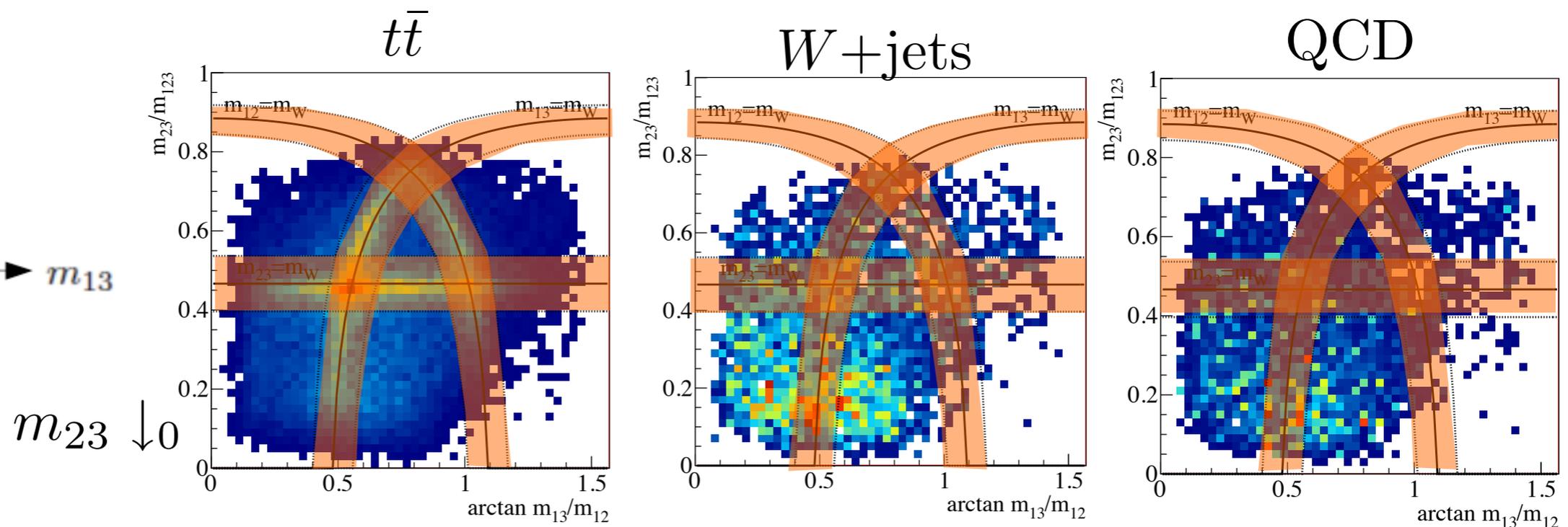
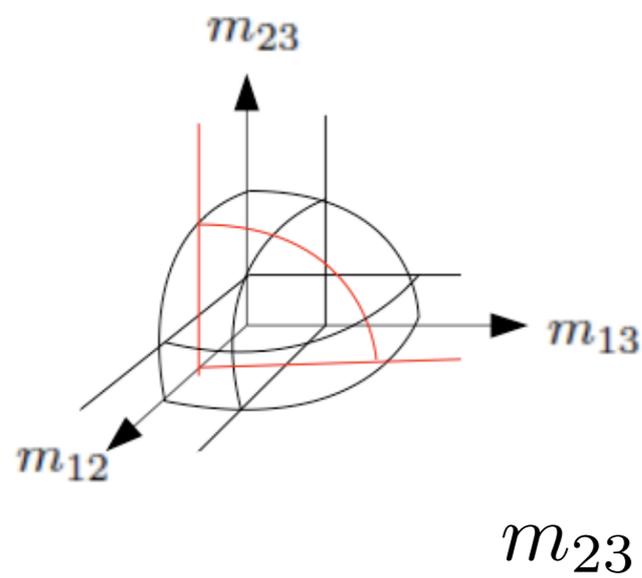
HEP TopTagger Algorithm

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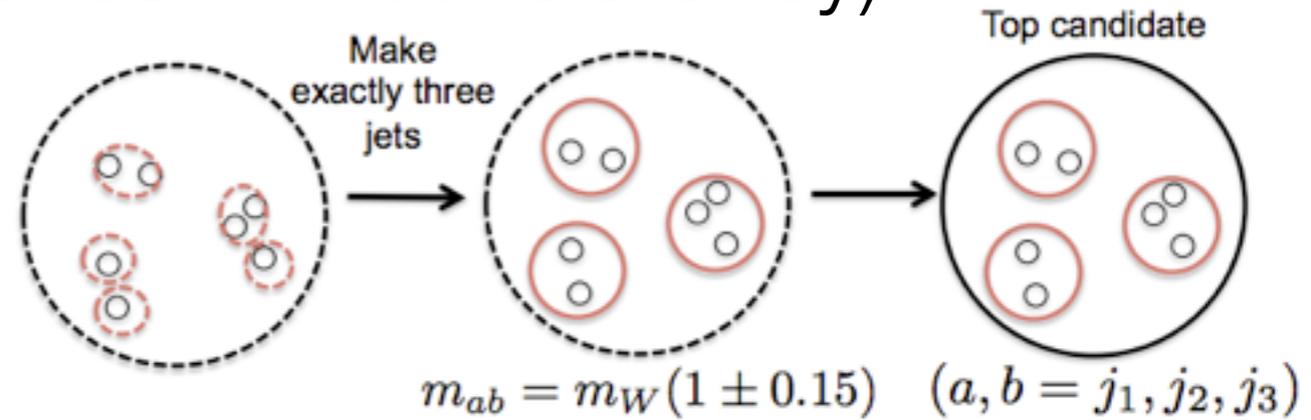


W mass condition $|m_{ij}/m_{123} - m_W/m_t| < 0.15$

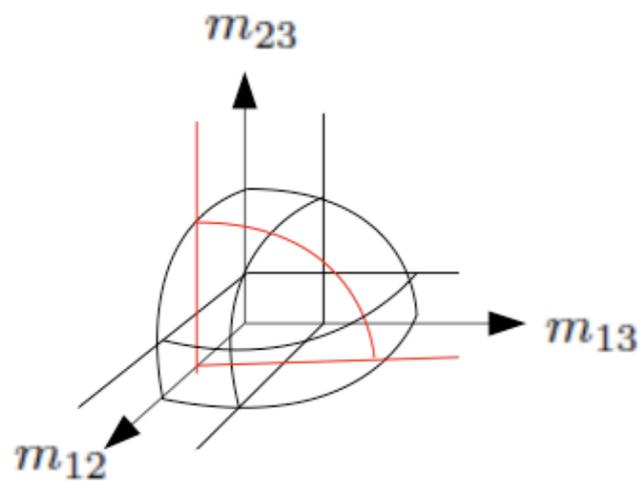
HEP TopTagger Algorithm

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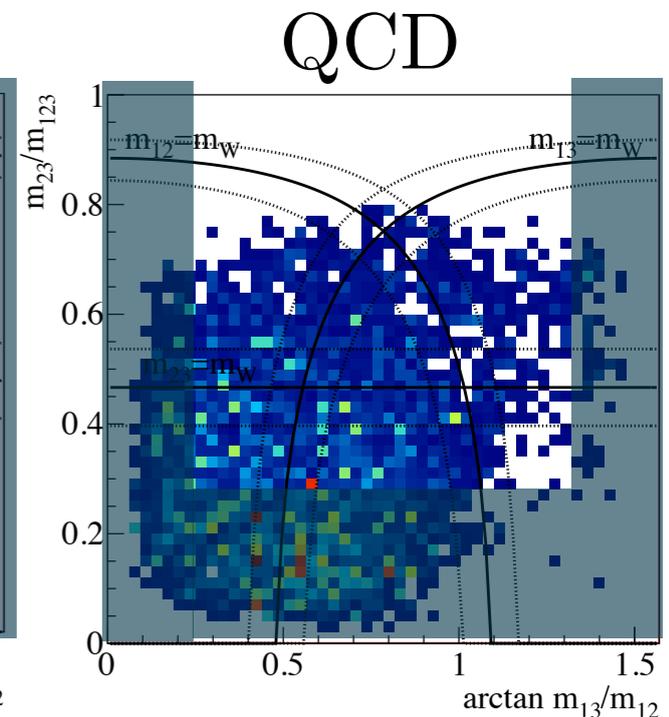
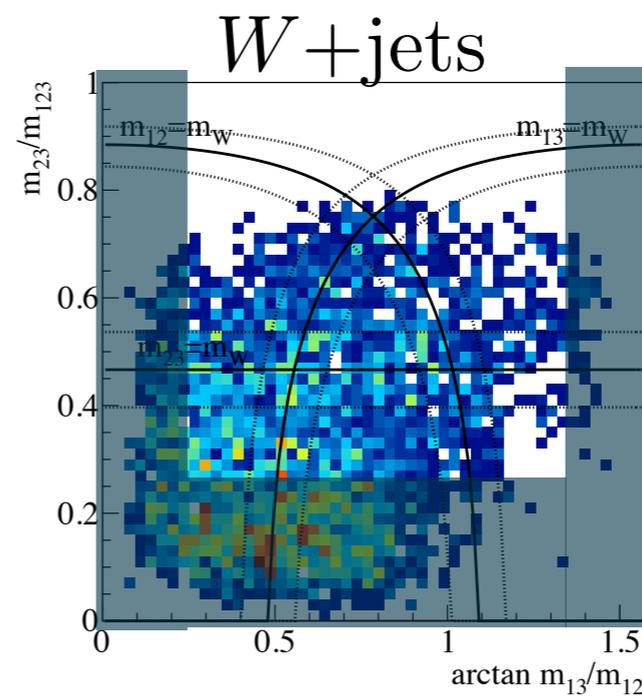
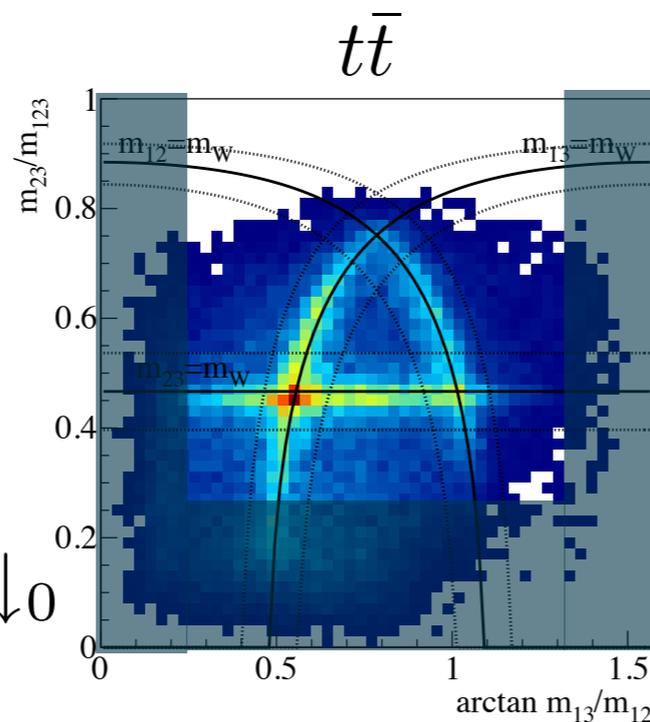
3 subjets: $p_1, p_2, p_3 \rightarrow m_{12}, m_{13}, m_{23}$



$m_t^2 \simeq m_{123}^2 \simeq m_{12}^2 + m_{13}^2 + m_{23}^2 \rightarrow$ 2D mass ratios



$m_{23} \downarrow 0$



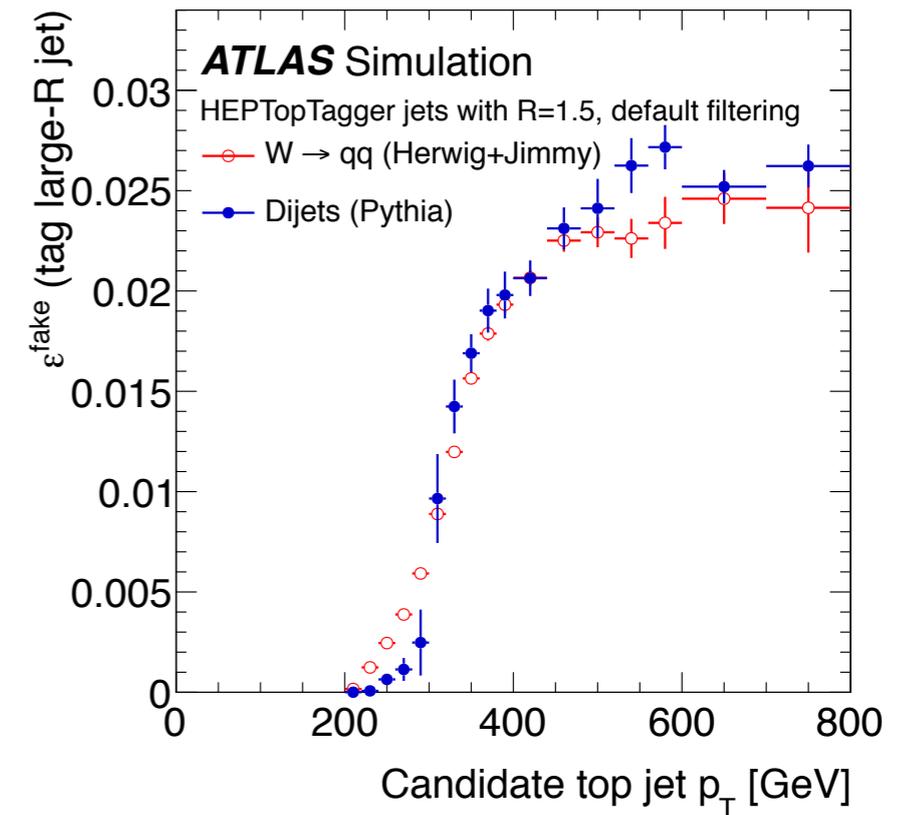
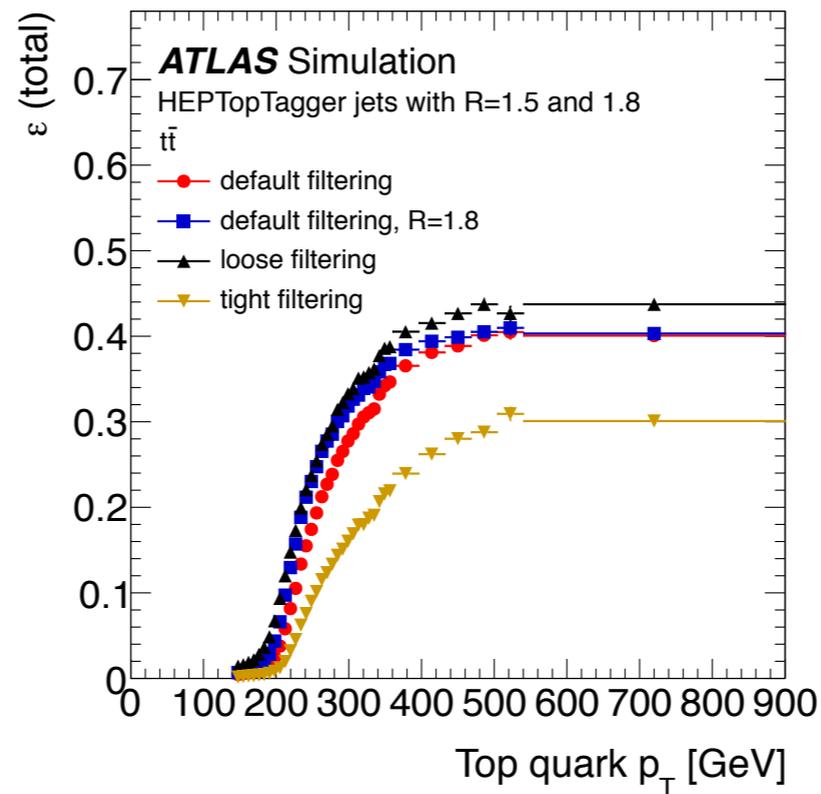
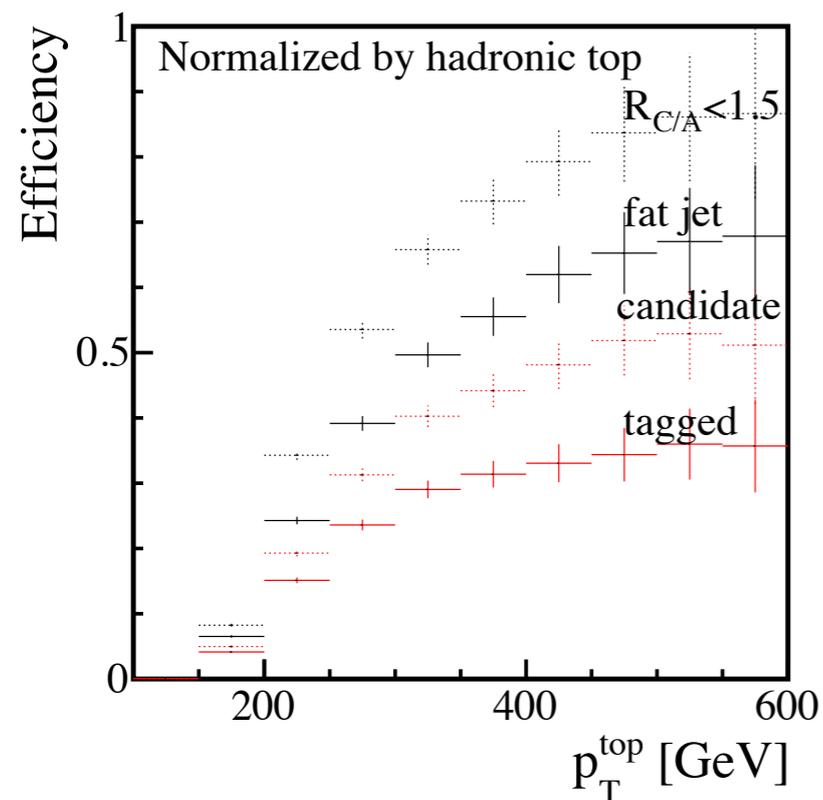
W mass condition $|m_{ij}/m_{123} - m_W/m_t| < 0.15$



tagged top

soft-collinear cut

HEPTopTagger efficiency



efficiency: $\sim 30\text{-}40\%$, mistag $\sim 2\text{-}3\%$

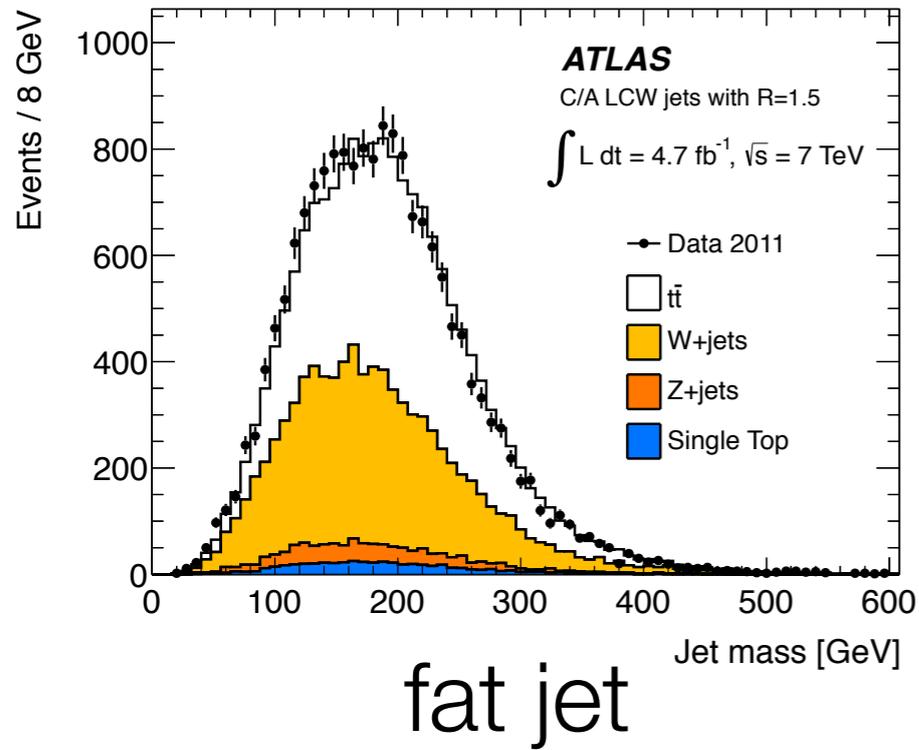
validated by ATLAS

[G. Kasieczka, S. Schätzel, A. Schöning]
arXiv:1360.4945

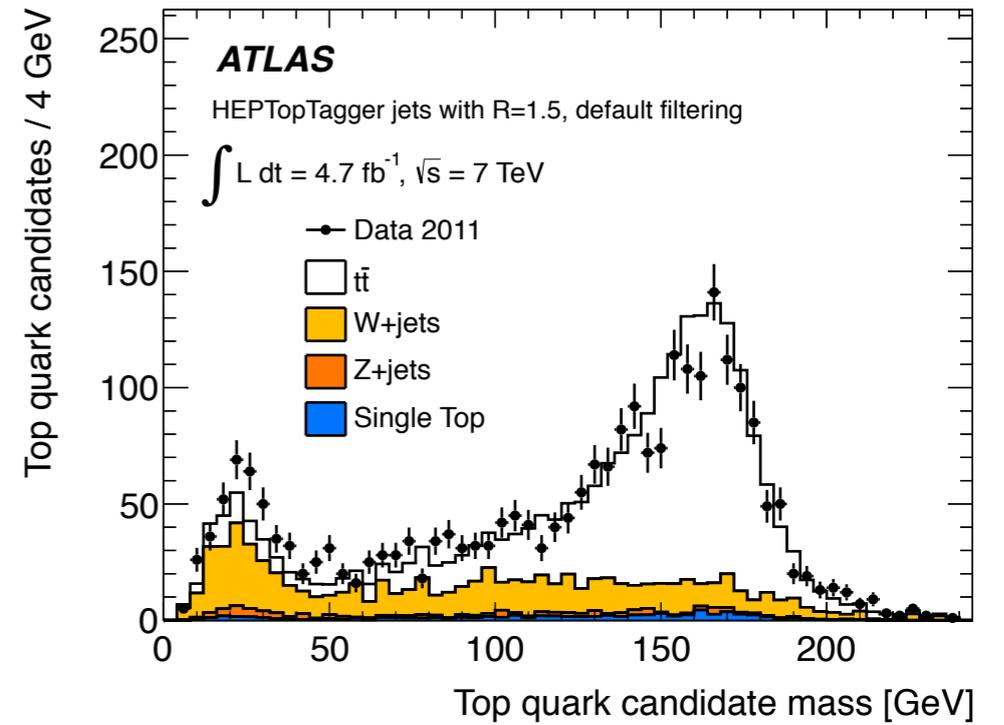
Validation with data

arXiv:1360.4945

tagged top



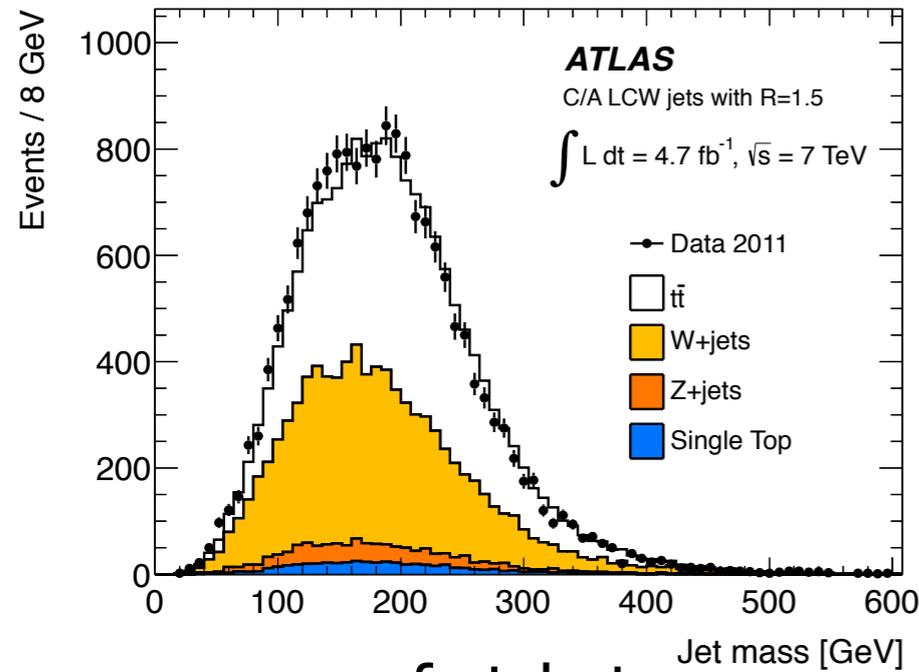
HEPTopTagger



Validation with data

arXiv:1360.4945

tagged top

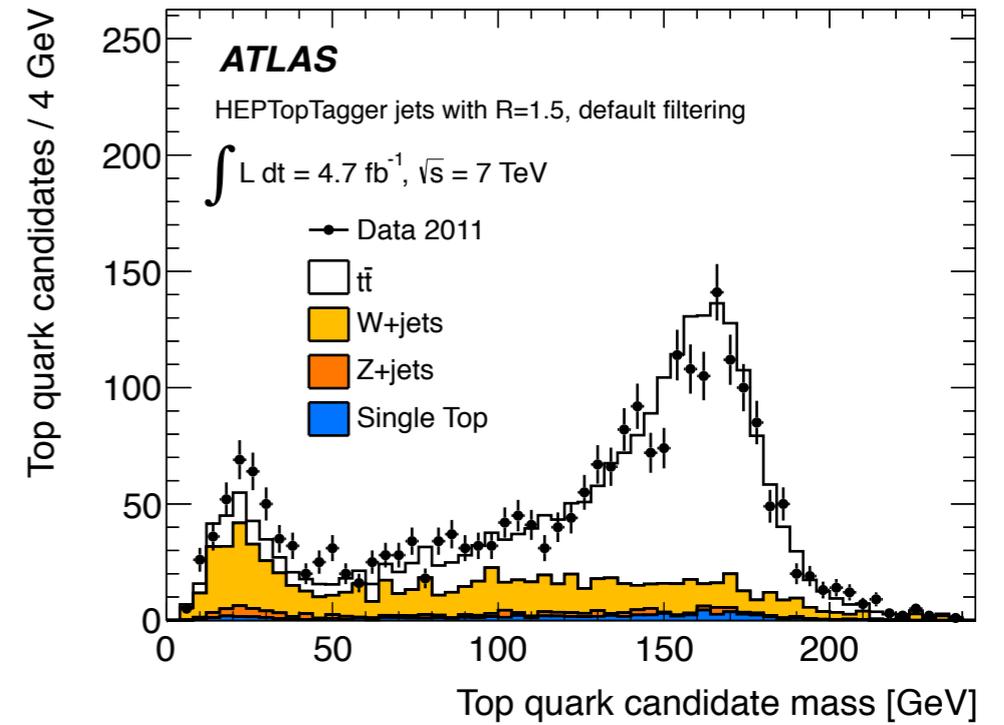


fat jet

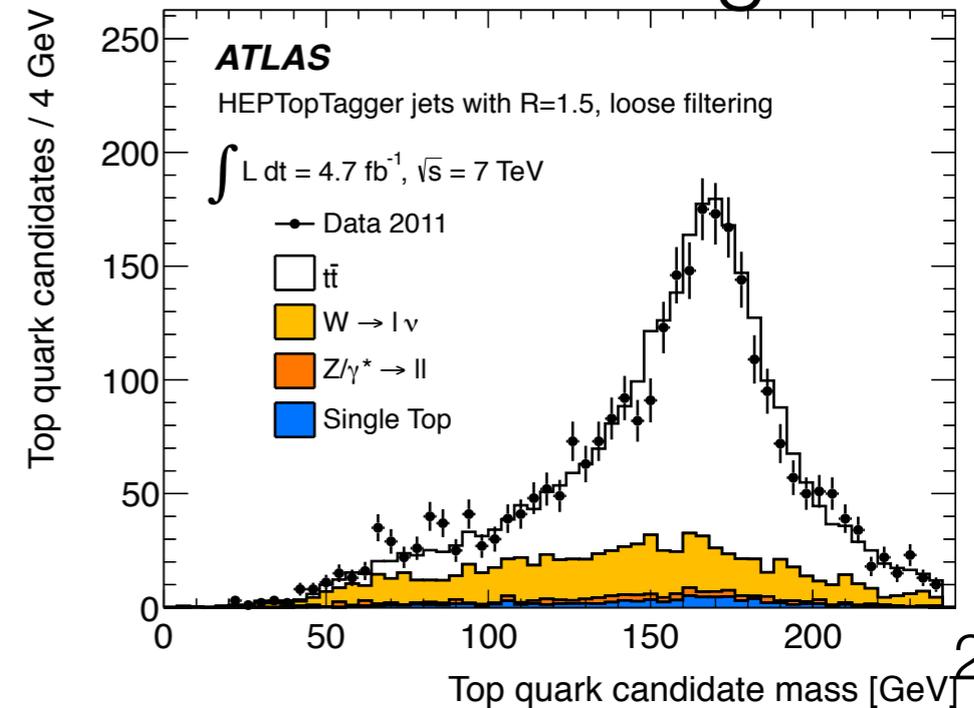
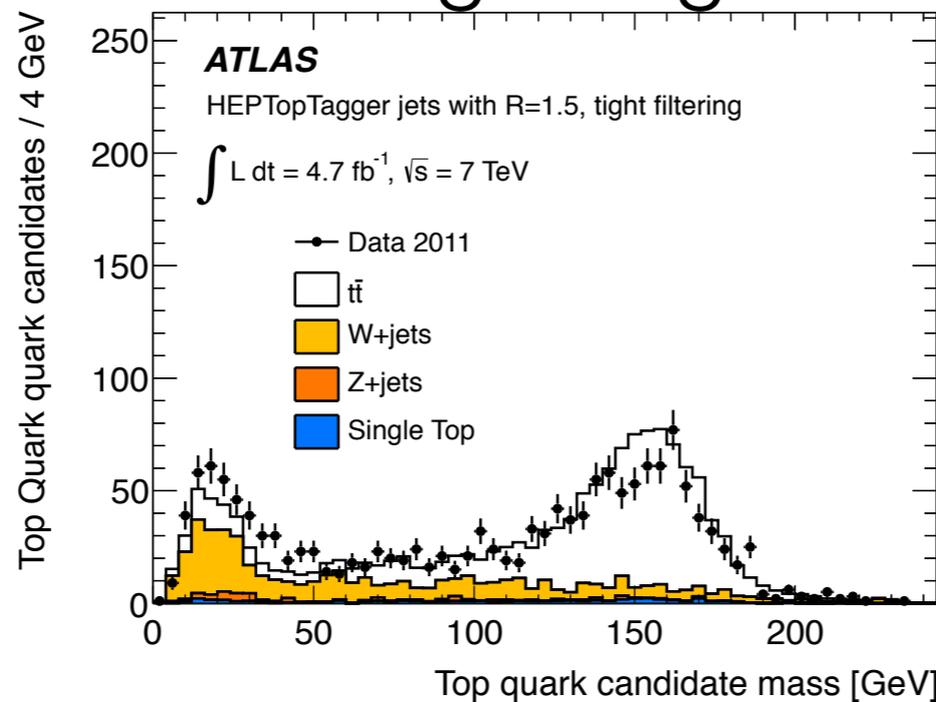
HEPTopTagger



tight tag



loose tag

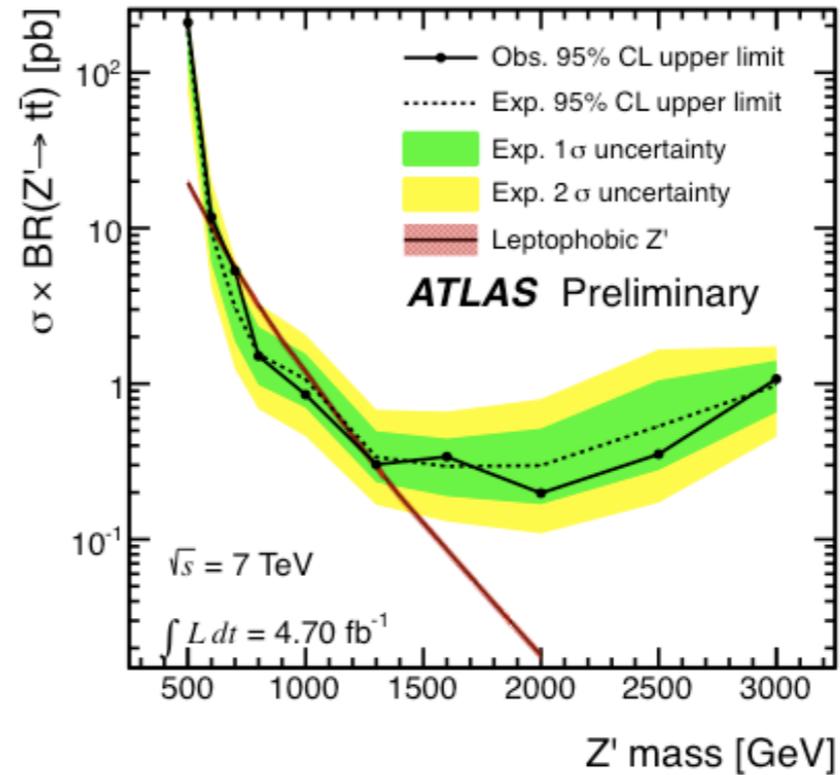
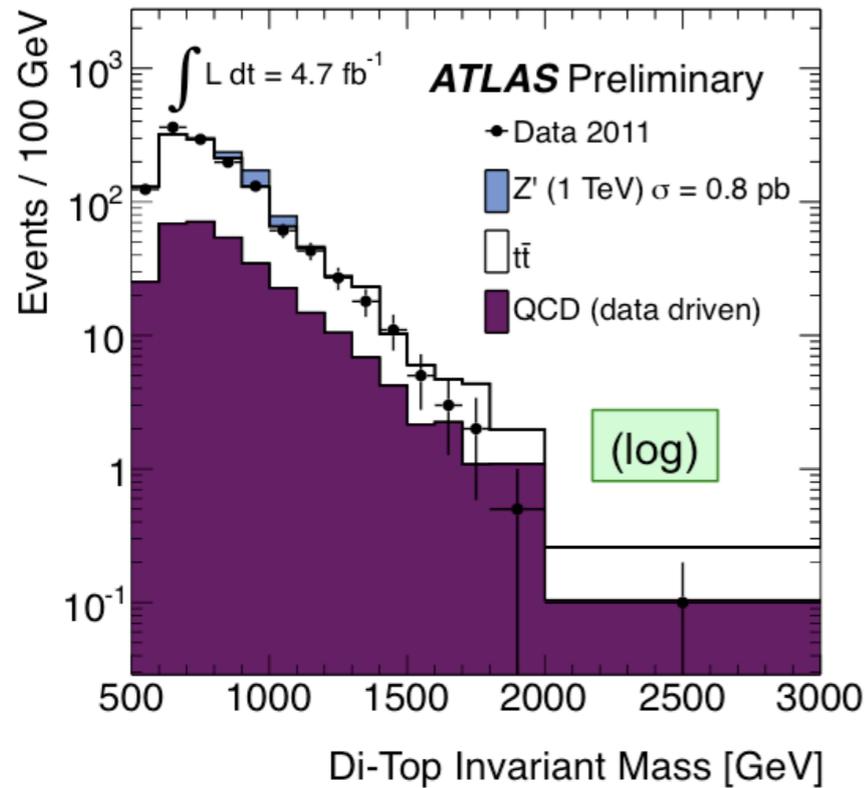


20/45

top-tag はb-tag 的に
扱える時代に

Z' search with HEPTopTagger

[ATLAS-CONF-2012-065]



	$e+e, \mu+\mu$ and $e+\mu$ 6.5%	$e+jets$ 17% $\mu+jets$ 17%	<i>Boosted</i> $e+jets$ 17% $\mu+jets$ 17%	<i>Boosted</i> alljets 46%
Article/ Note	arXiv: 1205.5371	arXiv: 1205.5371	arXiv: 1207.2409	ATLAS- CONF-2012-102
Integrated Luminosity	2 fb^{-1}	2 fb^{-1}	2 fb^{-1}	4.7 fb^{-1}
Z' limits $\Gamma/m = 1.2\%$	-	0.5-0.88 TeV	0.6-1.15 TeV	0.7-1.3 TeV
KKG limits $\Gamma/m = 15.3\%$	0.5-1.08 TeV	0.5-1.13 TeV	0.6-1.5 TeV	0.7-1.5 TeV

boosted topを利用すると
high p_T での sensitivity up

Boosted Tops (HEPTopTagger) の利用

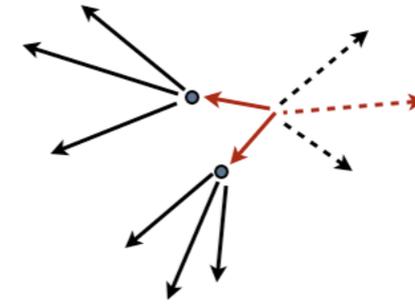
- stop search
- single top
- top forward-backward asymmetry

stop search

top-tagできたら、解析はb-tagと同じくシンプル

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]

- $\tilde{t}_1 \tilde{t}_1^* \rightarrow (t \tilde{\chi}_1^0)(\bar{t} \tilde{\chi}_1^0): m_\chi = 100 \text{ GeV}$
- main BG: $t\bar{t}$ +jets, W +jets and QCD

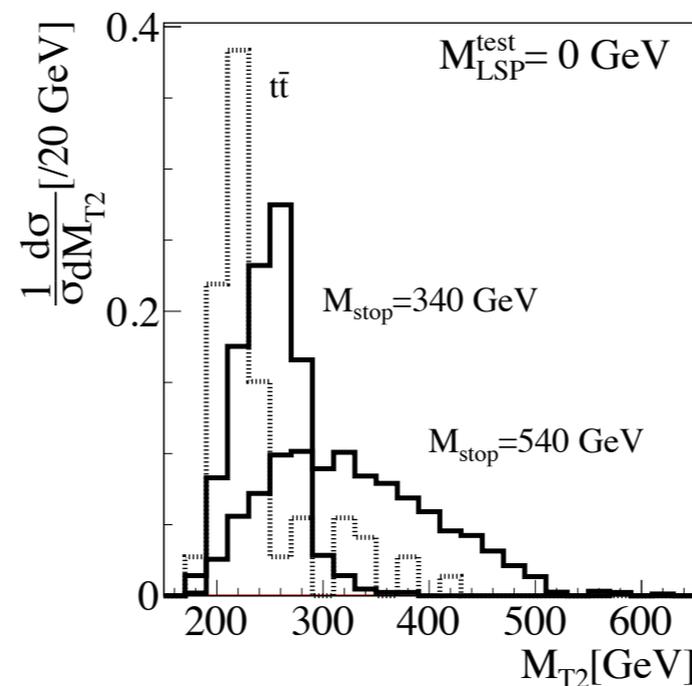


events in 1 fb^{-1}	$\tilde{t}_1 \tilde{t}_1^*$					$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10 \text{ fb}^{-1}}$
$m_{\tilde{t}} [\text{GeV}]$	390	440	490	540	640						390
$p_{T,j} > 200 \text{ GeV}, \ell \text{ veto}$	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$\sim 10^{-5}$	
$\cancel{E}_T > 150 \text{ GeV}$	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$\sim 10^{-3}$	
first top tag	91	75	57	42	15	743	7590	90	114	0.01	
second top tag	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	0.07	
b -tag for 1 st top tag	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.34	5.0
$m_{T2} > 250 \text{ GeV}$	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	1.0	7.1

W, Z : 2 top tag で無視出来る

QCD : 1 b-tag で無視出来る

tt : M_{T2} で減らせる



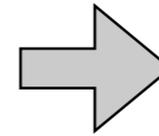
stop mass $\sim 400 \text{ GeV}$

$$S/B \sim 1, S/\sqrt{B} > 5$$

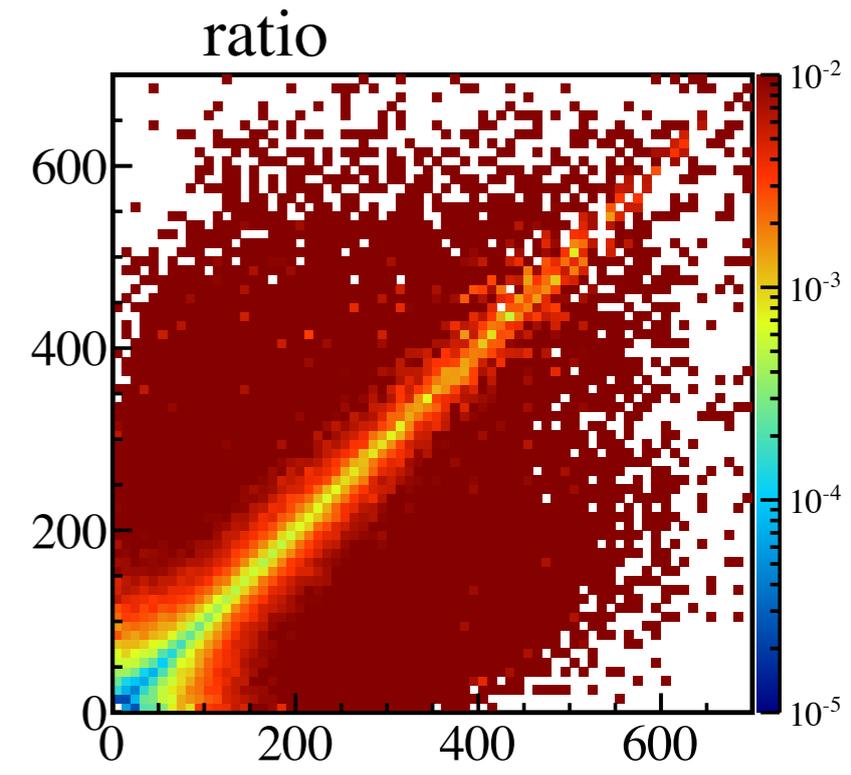
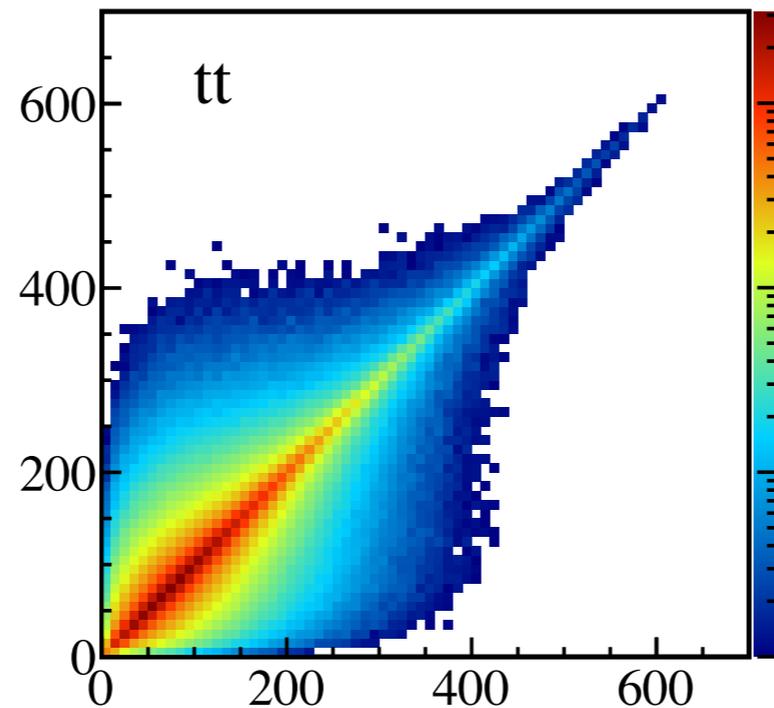
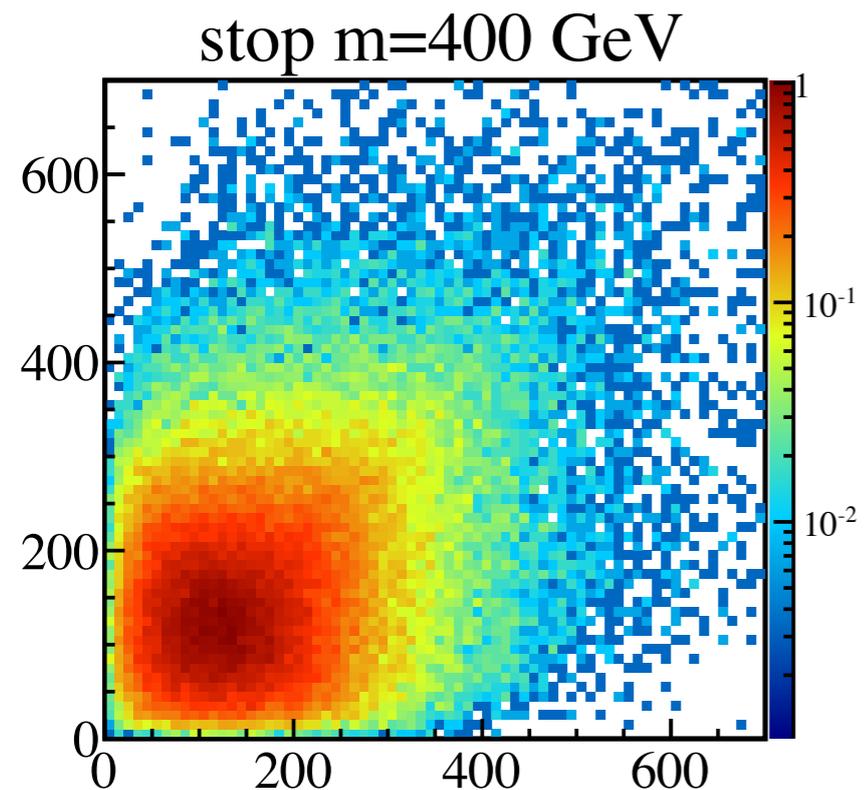
stop search at 8TeV

[arXiv:1205.2696 T. Plehn, M. Spannowsky, MT]

$$\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}} \quad \text{signal, ttbar 両方}$$



2 top tag だとシグナル少ない



1 top tag & 1 non-boosted topを狙う

0 lep : 1 top tag & 1 b-jet + missing

$$m_T(b, \cancel{E}_T) > 200 \text{ GeV} \quad S/B \sim 1, S/\sqrt{B} \sim 5$$

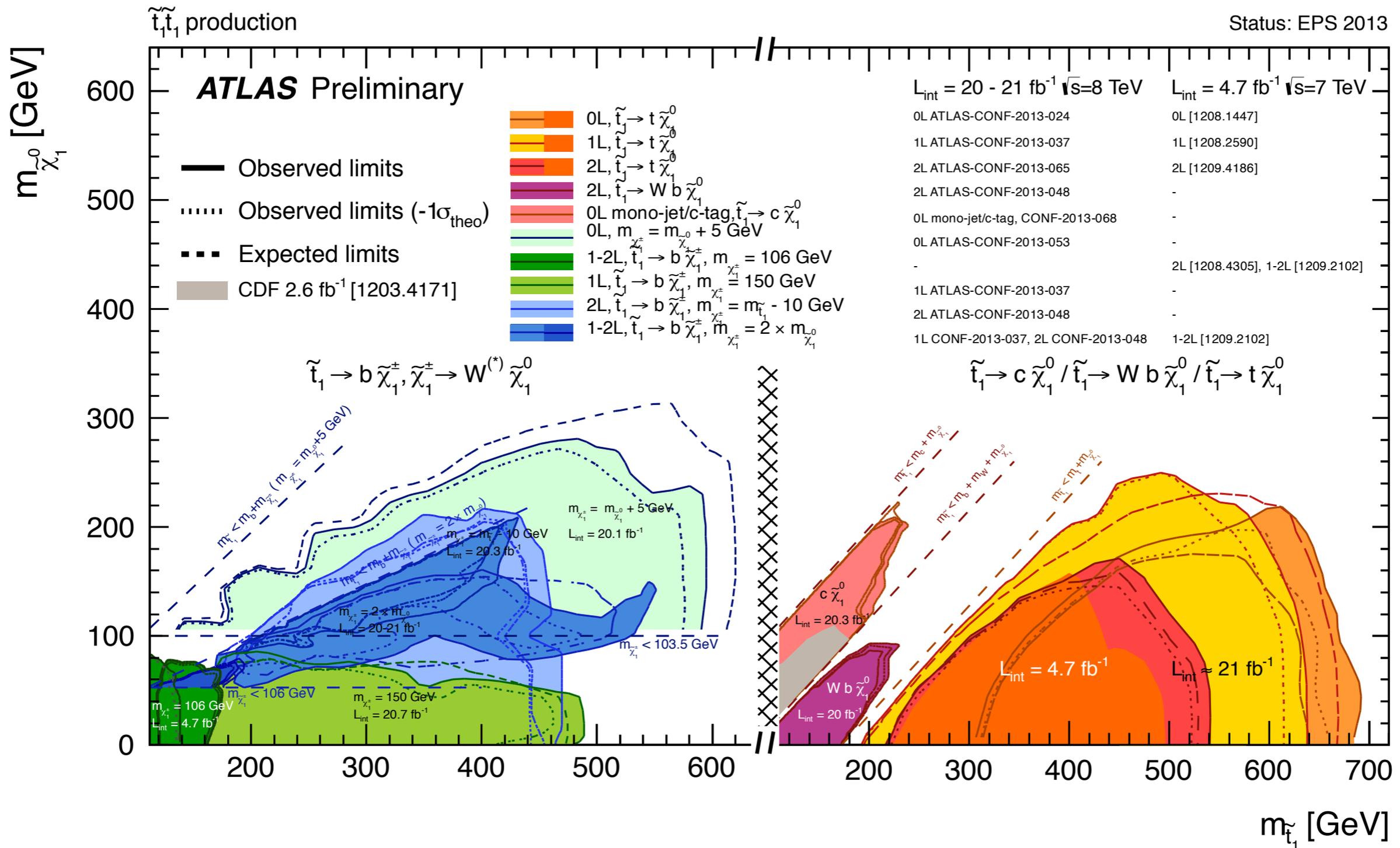
1 lep : 1 top tag & 1 lepton + missing

$$m_T(\ell, \cancel{E}_T) > 150 \text{ GeV} \quad S/B \sim 4, S/\sqrt{B} \sim 10$$

(for $m = 600$ GeV, $S/B \sim 1, S/\sqrt{B} \sim 2$)

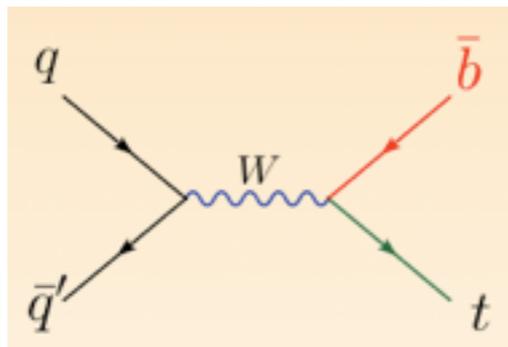
stop search at 8TeV

upto 660 GeV excluded 95% C.L.

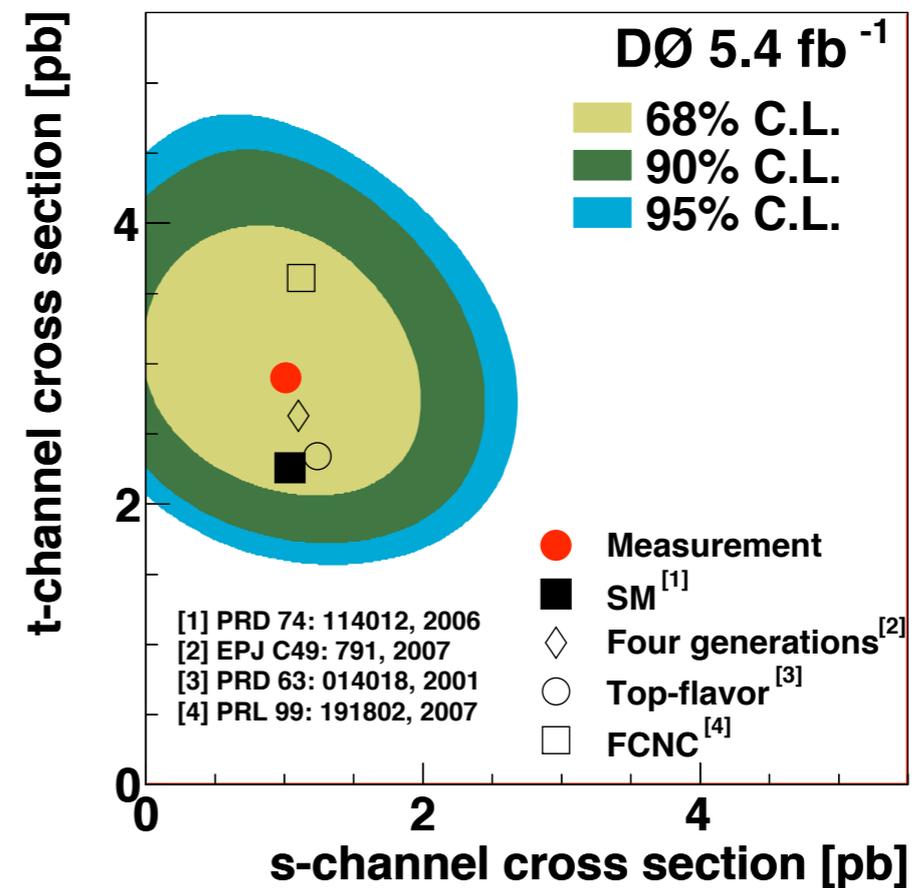
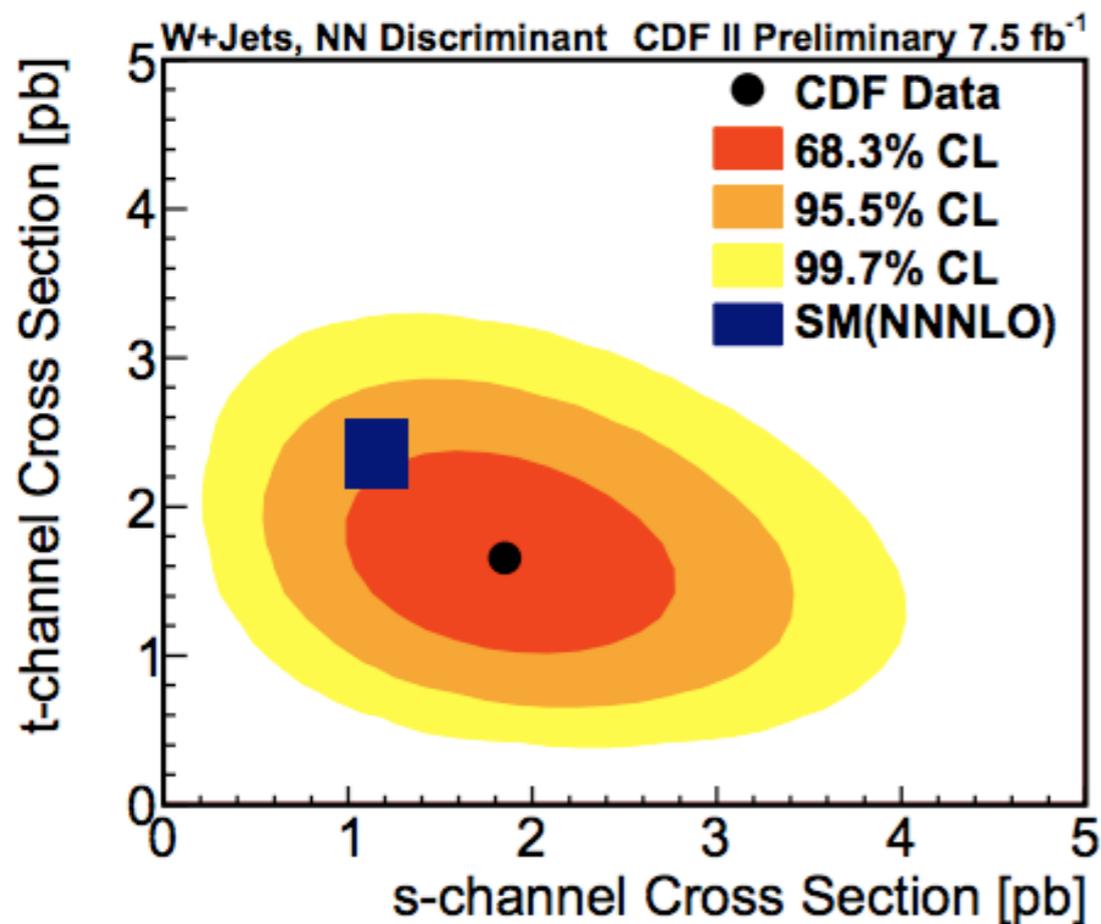
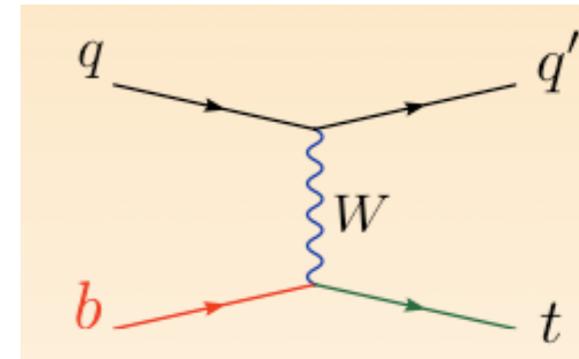


single tops with HEPTopTagger

s-channel



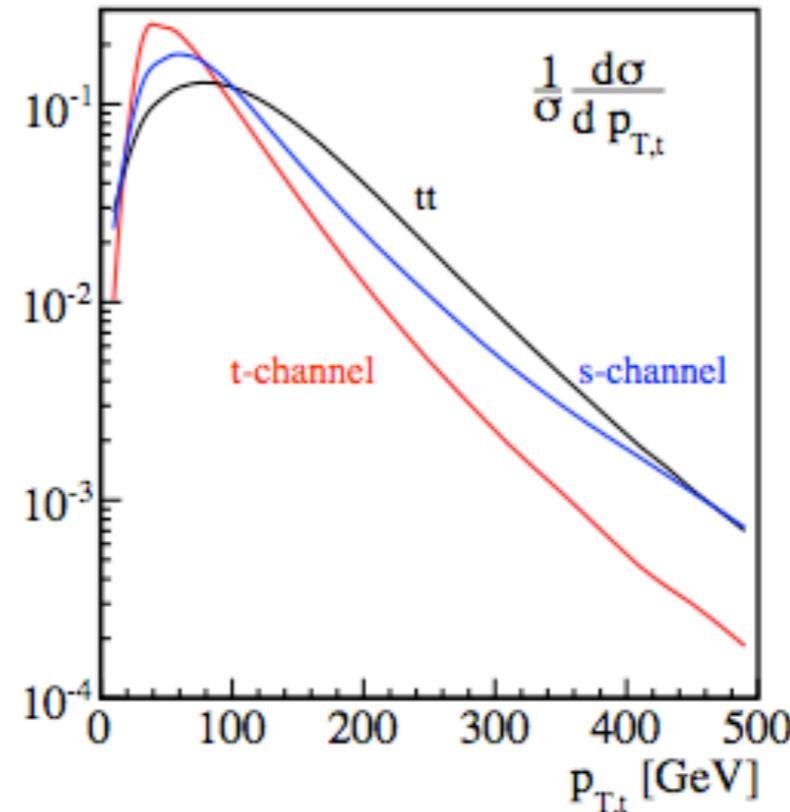
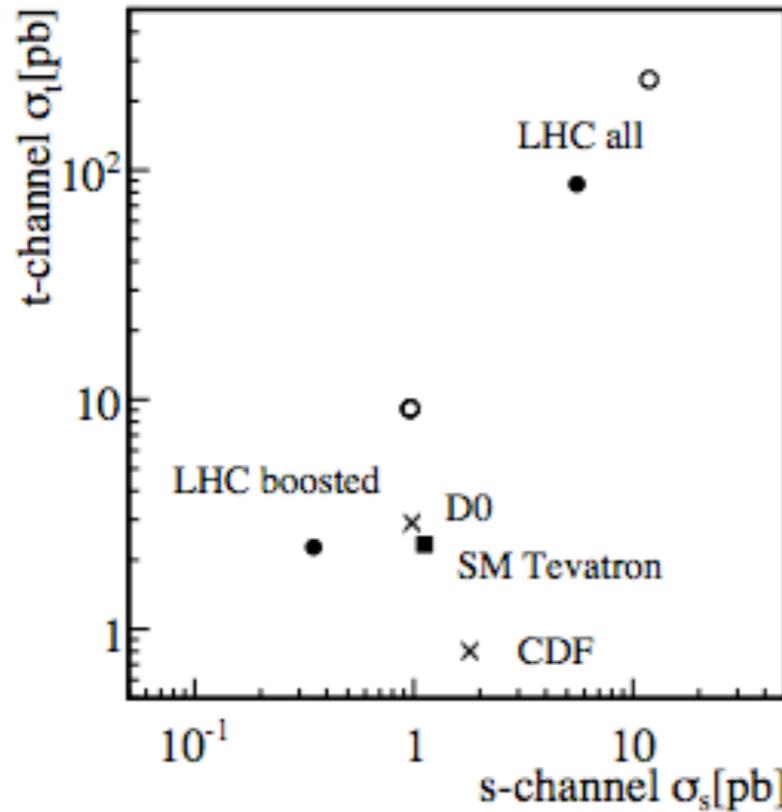
t-channel



At Tevatron SM : $\sigma_t \sim 2\sigma_s$

CDF と DØ の結果は 3σ くらいずれてる

single tops with HEPTopTagger



– small \bar{q} and large $g \rightarrow b\bar{b}$
 $\rightarrow \sigma_t \sim 16\sigma_s$ at LHC

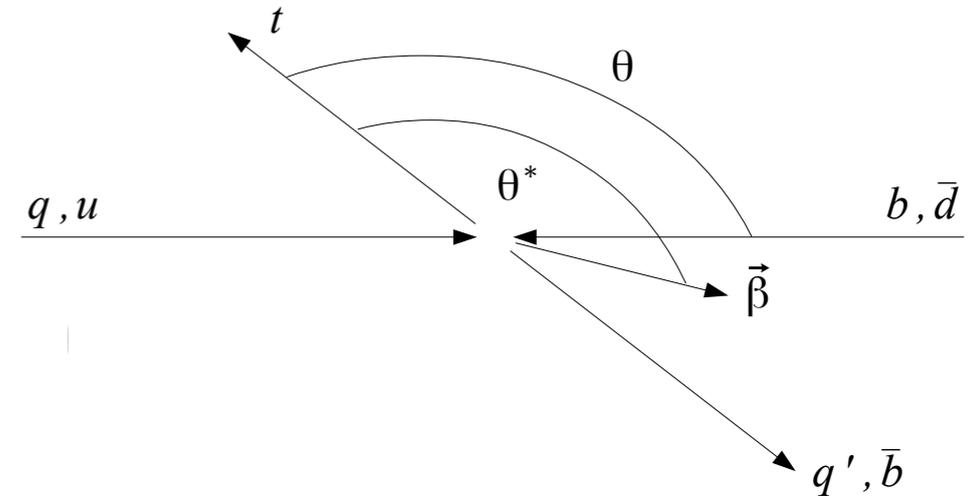
8 TeV: $p_{T,t}^{\min}$	0	100	200	300	400	500
σ_s [fb]	5548	1784	349	86.4	26.5	9.54
σ_t [fb]	86829	18167	2273	409.2	95.7	26.0
$\sigma_{t\bar{t}}$ [fb]	234731	137274	34640	7560	1850	519
σ_s/σ_t (%)	6.4	9.8	15.4	21.1	27.7	36.7
$\sigma_s/\sigma_{t\bar{t}}$ (%)	2.36	1.29	1.00	1.14	1.43	1.83

σ_s/σ_t improves
in boosted regime
 \rightarrow top tagger

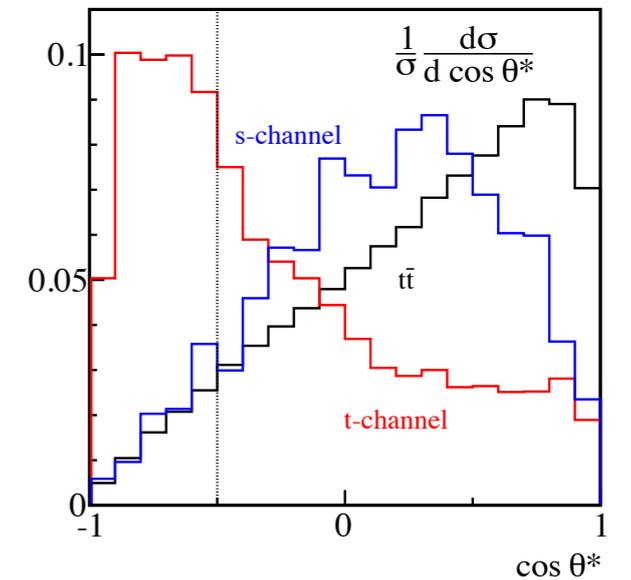
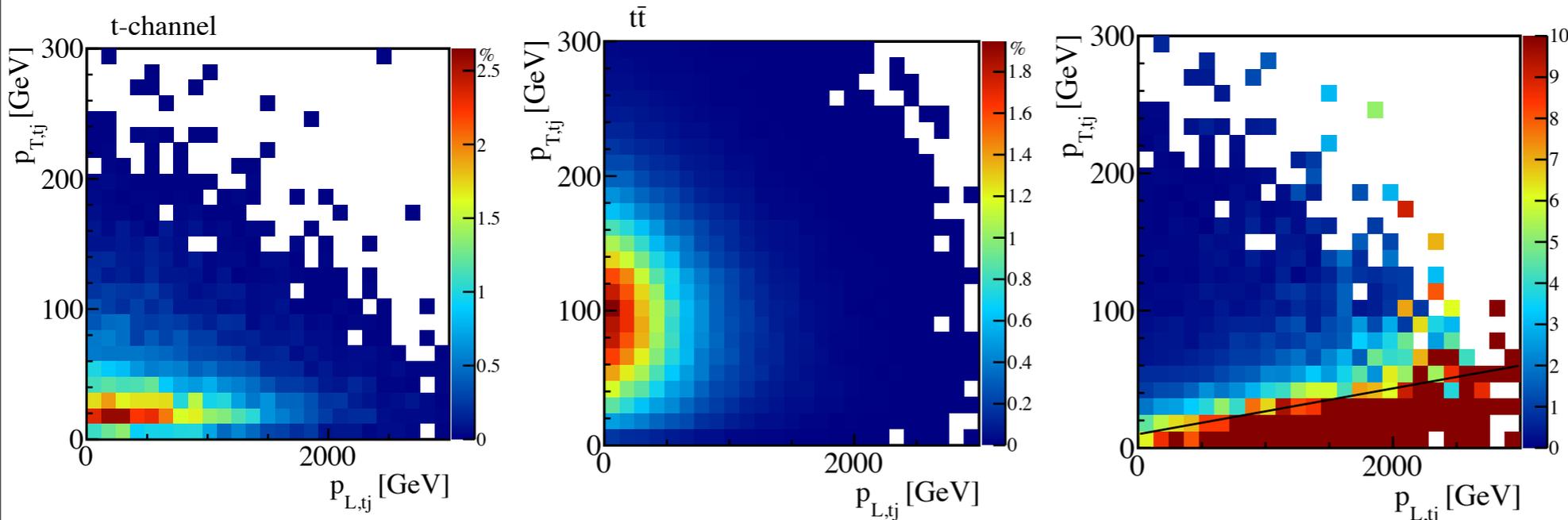
single tops with HEPTopTagger

no lepton, 2 fat jets (one top tag), b-tag in top tag

➔ main BG ttbar



tj-system momentum (← ttbar はバランスしていない)



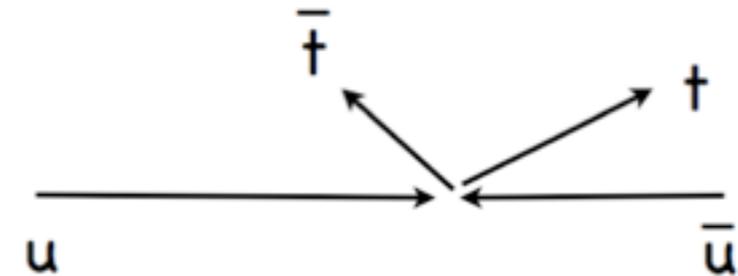
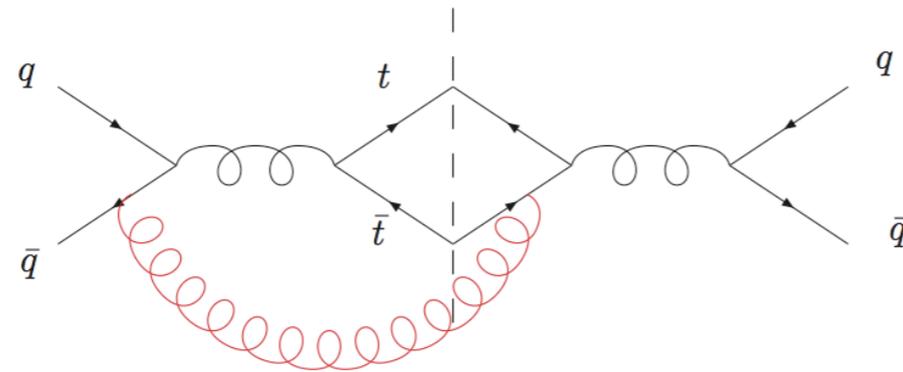
t-channel : $S/B > 1, S/\sqrt{B} > 10$ for 10fb^{-1}

s-channel : $S/B = 2, S/\sqrt{B} = 4$ for 25fb^{-1}

top forward-backward asymmetry with HEPTopTagger

Tevatron $A_{FB}^t \sim 6\%$ QCD NLO effect

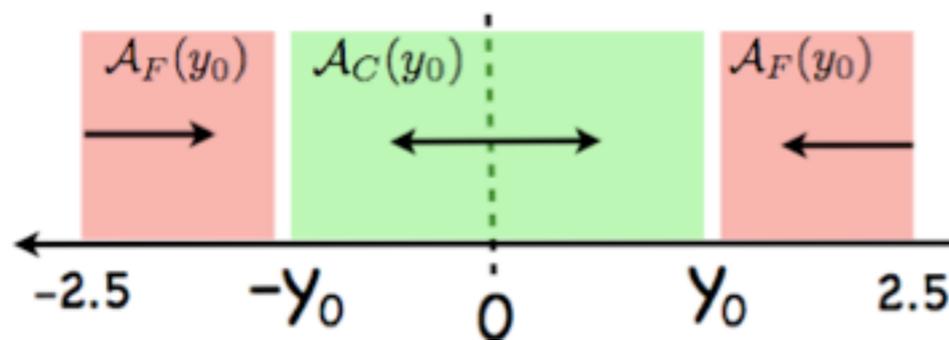
top は quark と同じ向きに出がち



D0, CDF: 予言より大きな A_{FB}^t を測定、特に high m_{tt} のところでより大きい

high pT top \rightarrow top tagger

LHC でも PDF の違いのおかげで、測定可能



$$\mathcal{A}_C(y_0) = \frac{N_t(|y| < y_0) - N_{\bar{t}}(|y| < y_0)}{N_t(|y| < y_0) + N_{\bar{t}}(|y| < y_0)} < 0$$

$$\mathcal{A}_F(y_0) = \frac{N_t(|y| > y_0) - N_{\bar{t}}(|y| > y_0)}{N_t(|y| > y_0) + N_{\bar{t}}(|y| > y_0)} > 0$$

anti-top が central に出がち

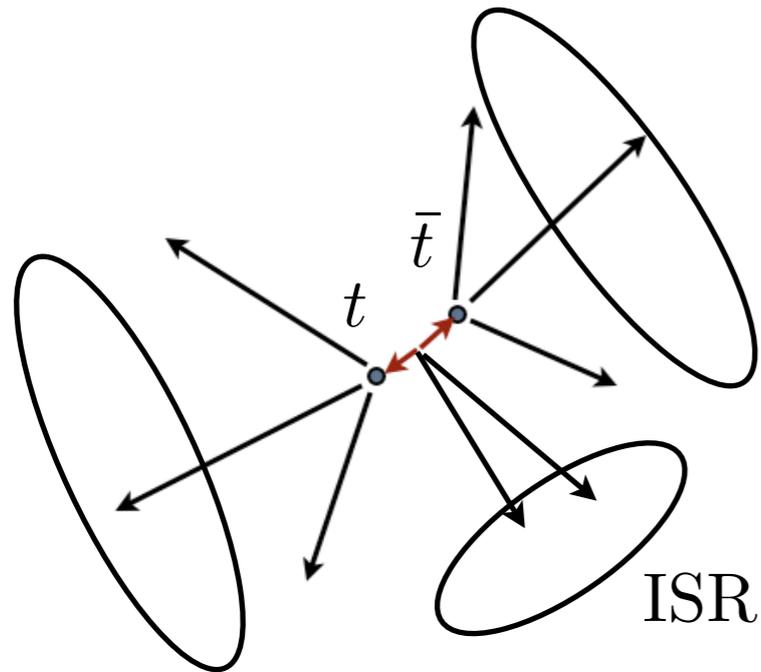
1 top tag & 1 isolated lepton

SM: 5σ with 60 fb^{-1} (14 TeV)

Buckets of Tops [arXiv:1302.6238]

- 更にlow p_T \wedge ($\sim 100\text{GeV}$)
HEPTopTager: down to $p_T \sim 200\text{ GeV}$
- ttH (130fb at 8 TeV, 500fb at 13 TeV)
 - signalを減らさないことが重要

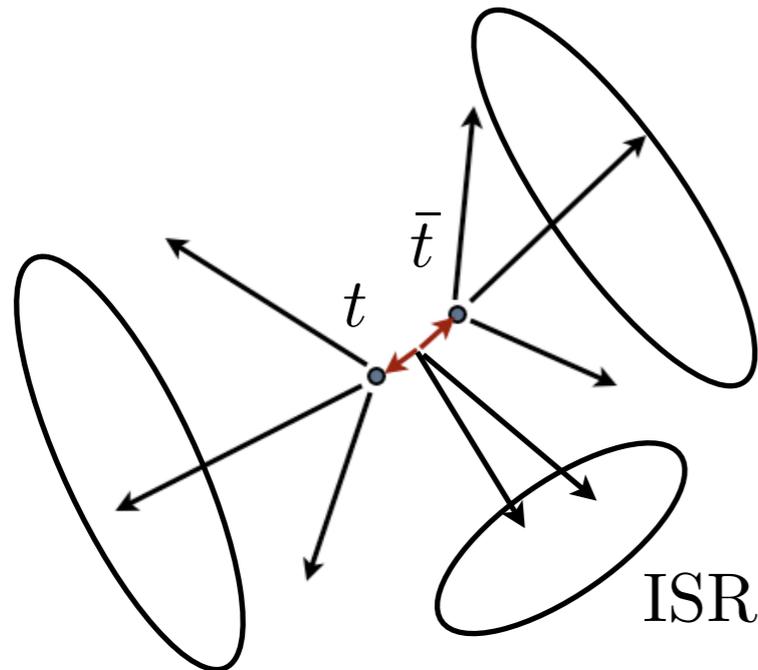
Buckets of tops



start with standard jets ($C/A R = 0.5$)

目標：2 topに対応するジェットを探す

Buckets of tops



start with standard jets (C/A $R = 0.5$)

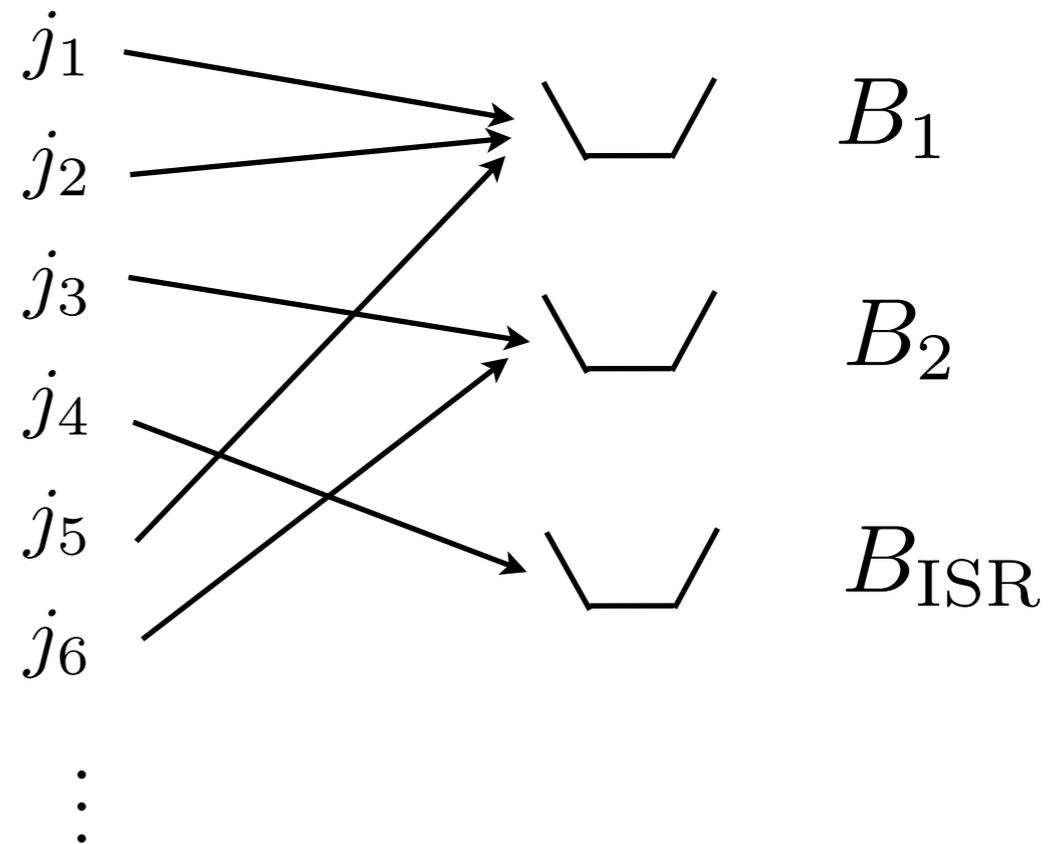
目標：2 topに対応するジェットを探す

scan all permutation,
select the grouping minimizing

$$\Delta^2 = \omega \Delta_{B_1}^2 + \Delta_{B_2}^2 \quad (\omega = 100)$$

$$\Delta_{B_i} = |m_{B_i} - m_t|$$

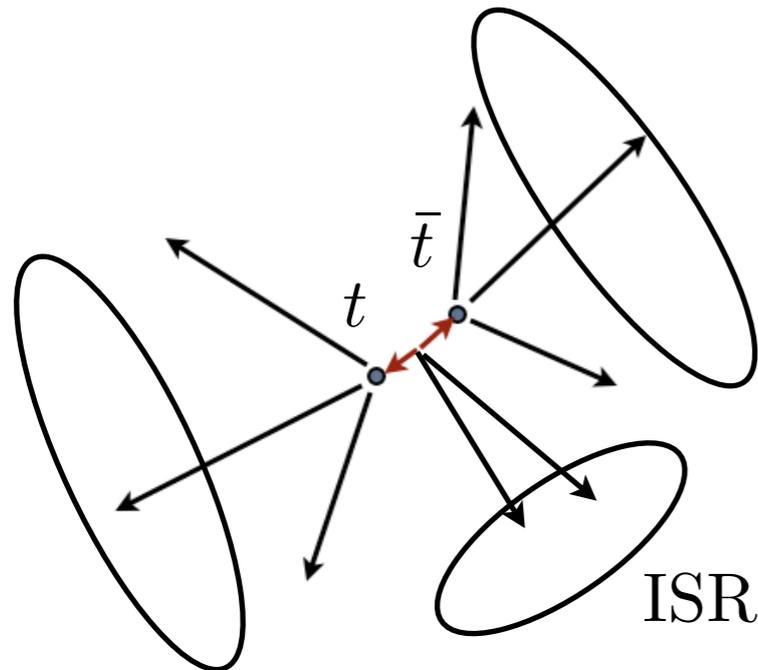
$$m_{B_i}^2 = \left(\sum_{j \in B_i} p_j \right)^2$$



One event provides $\{B_1, B_2, B_{\text{ISR}}\}$

always 2 top tags 29/45

Buckets of tops



start with standard jets (C/A $R = 0.5$)
with 2 b -jets

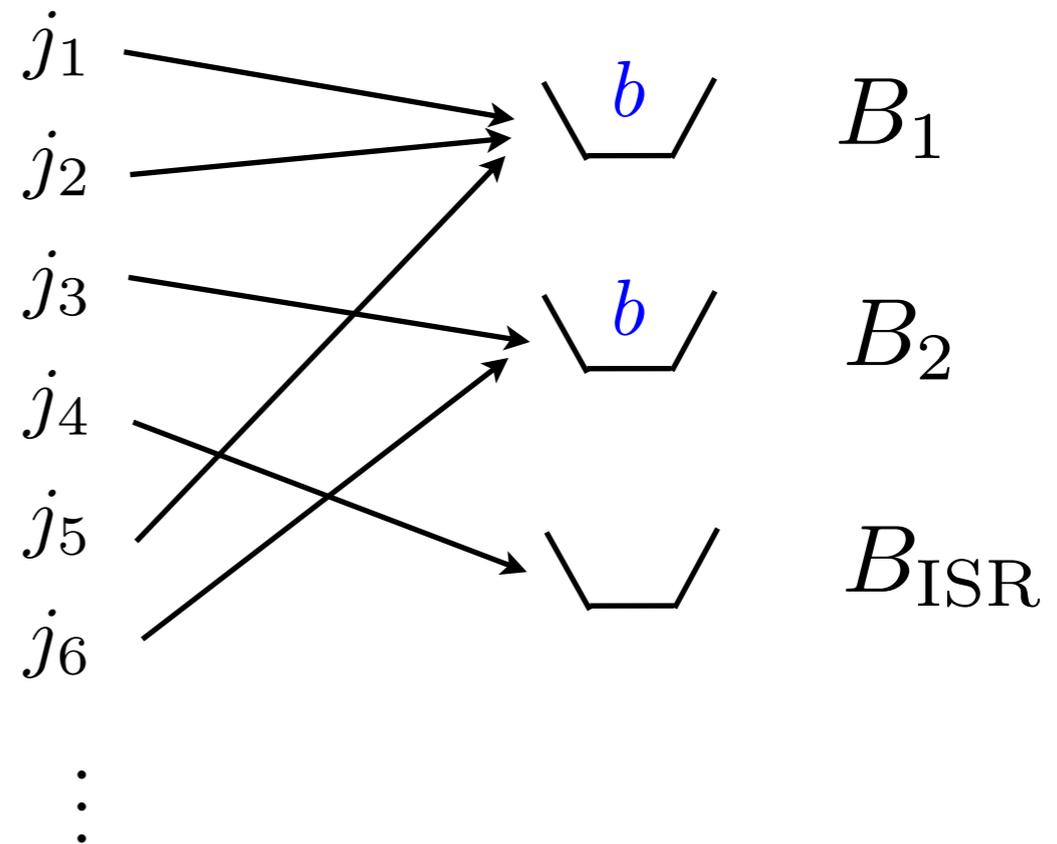
目標：2 topに対応するジェットを探す

scan all permutation,
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$$\Delta^2 = \omega \Delta_{B_1}^2 + \Delta_{B_2}^2 \quad (\omega = 100)$$

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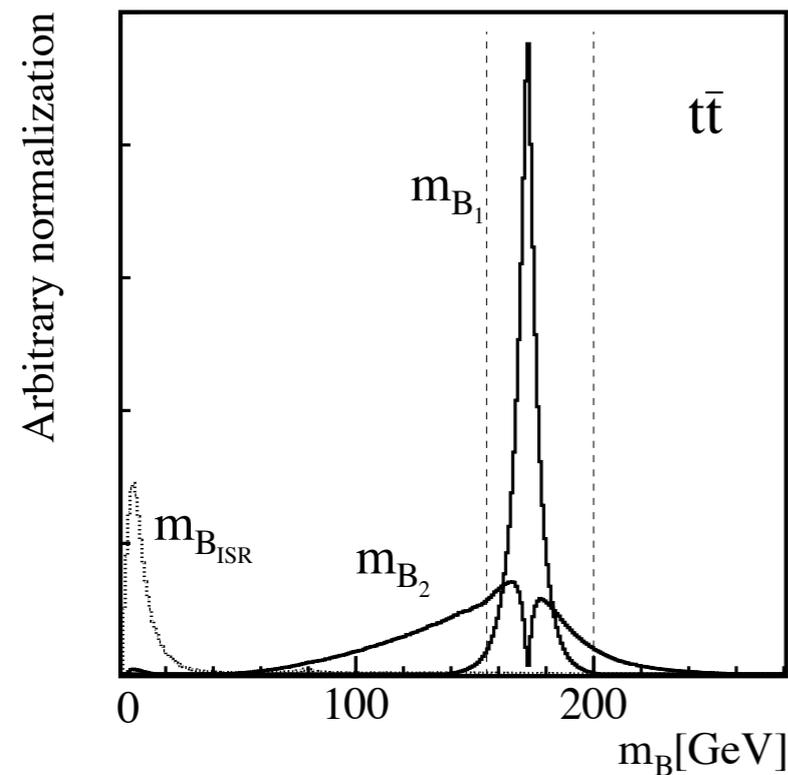
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One event provides $\{B_1, B_2, B_{ISR}\}$

always 2 top tags 29/45

Bucket mass, W condition



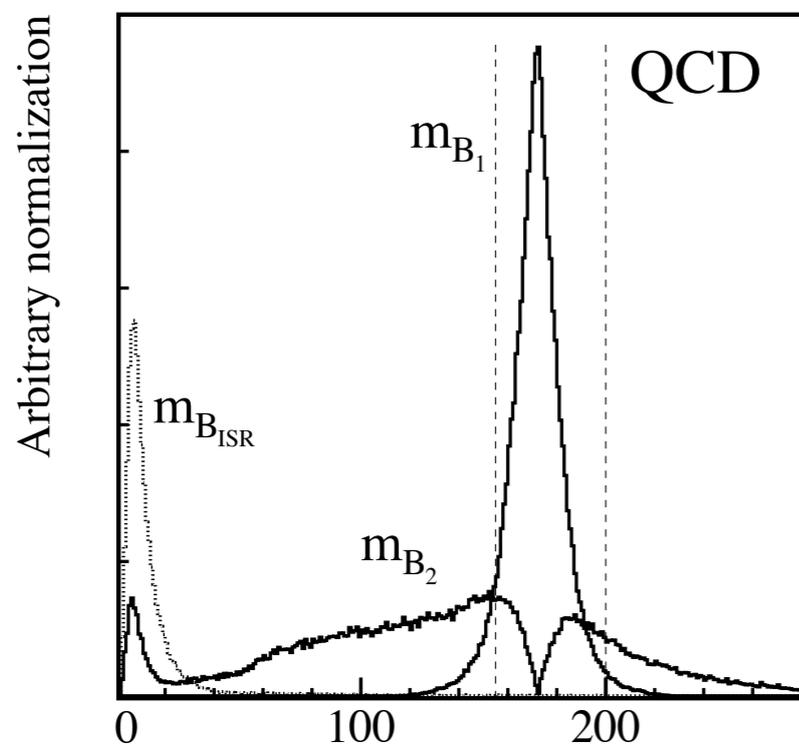
- top mass window

$$155 \text{ GeV} < m_{B_{1,2}} < 200 \text{ GeV}$$

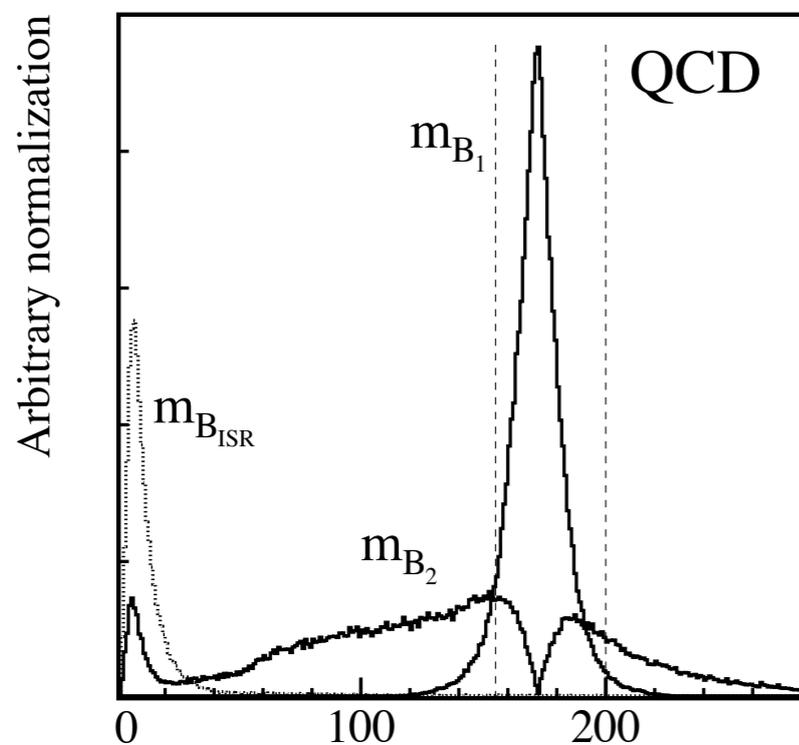
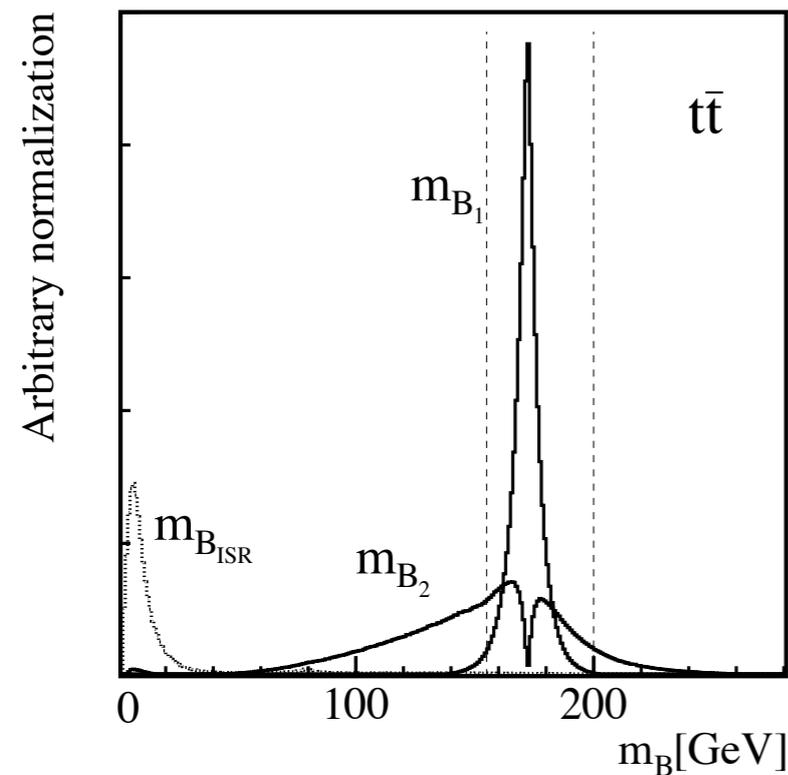
- W mass window

regard B_i contains W if 2 jets in a bucket satisfy

$$\left| \frac{m_{kl}}{m_{B_i}} - \frac{m_W}{m_t} \right| < 0.15$$



Bucket mass, W condition



- top mass window

$$155 \text{ GeV} < m_{B_{1,2}} < 200 \text{ GeV}$$

- W mass window

regard B_i contains W if 2 jets in a bucket satisfy

$$\left| \frac{m_{kl}}{m_{B_i}} - \frac{m_W}{m_t} \right| < 0.15$$

→ 4 categories

$$(t_w, t_w) : B_1 \ni W, B_2 \ni W$$

$$(t_w, t_-) : B_1 \ni W, B_2 \not\ni W$$

$$(t_-, t_w) : B_1 \not\ni W, B_2 \ni W$$

$$(t_-, t_-) : B_1 \not\ni W, B_2 \not\ni W$$

Efficiency & Momentum reconstruction

$R_i < 0.5$: good reconstruction

$$R_i = \Delta R(B_i, p_t^{\text{MCtruth}})$$

	$t_h \bar{t}_h + \text{jets}$ [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, 2b-tag	21590		16072	1.36
(t_w, t_w)	2750	68.9%	126.2	21.8
(t_w, t_-)	2517	23.4%	727.1	3.5
(t_-, t_w)	1782	21.8%	596.5	3.0
(t_-, t_-)	2767	9.0%	2002	1.4

(t_w, t_w) provide reasonable momentum, $\epsilon_{(t_w, t_w)} \sim 13\%$

t_- not reconstruct correct momentum

only 45% double tagged in total

Efficiency & Momentum reconstruction

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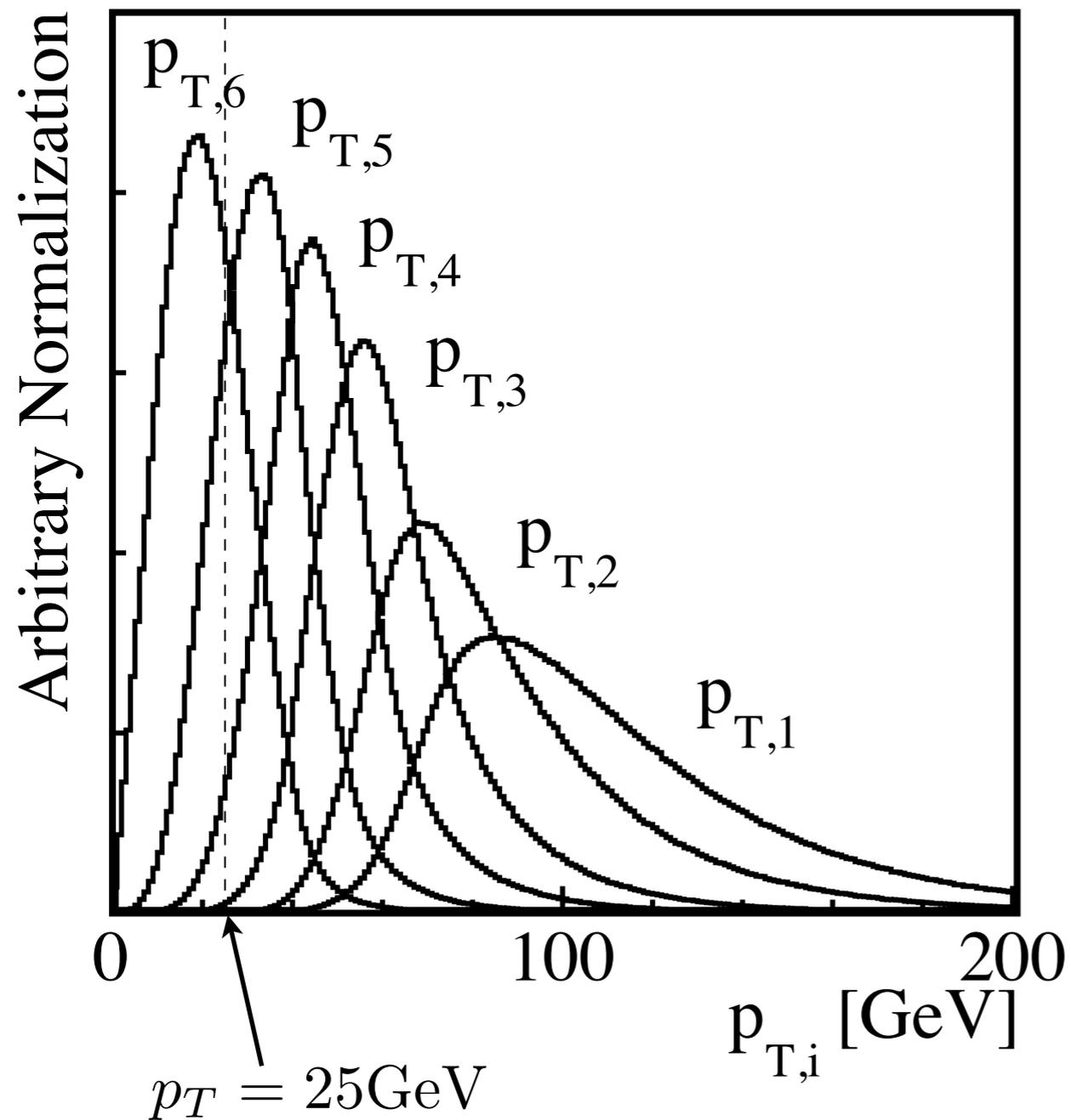
t_- not reconstruct correct momentum

only 45% double tagged in total

6 jets not often survive due to jet p_T threshold

Jet p_T threshold

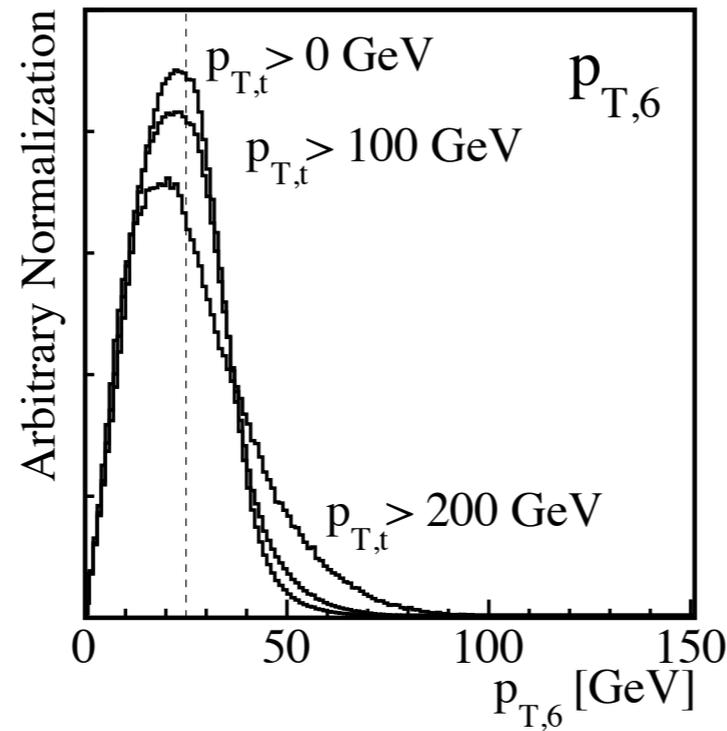
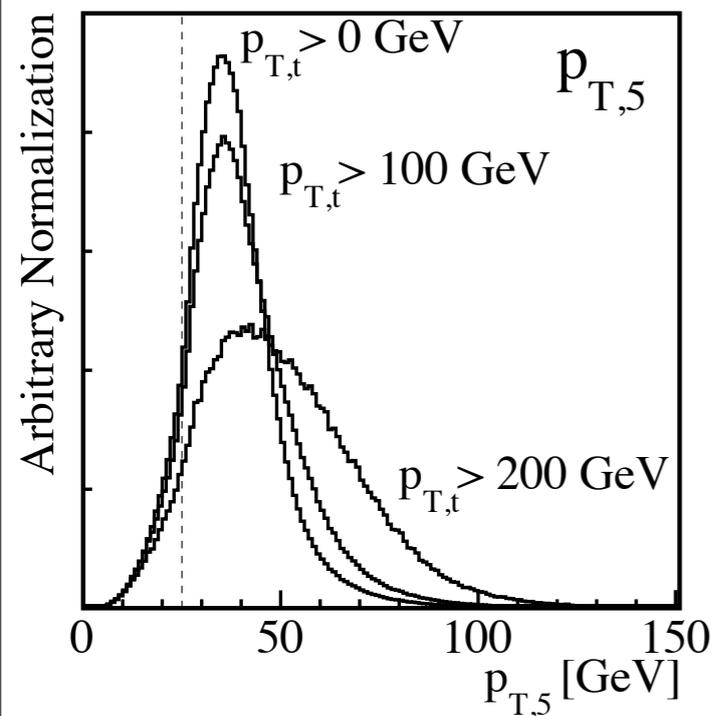
6 partons from top pair decays



$p_{T,j} > 25 \text{ GeV}$ kills 6th jet

98% of j_6 from W

Jet p_T threshold



$p_{T,j} > 25 \text{ GeV}$ kills 6th jet

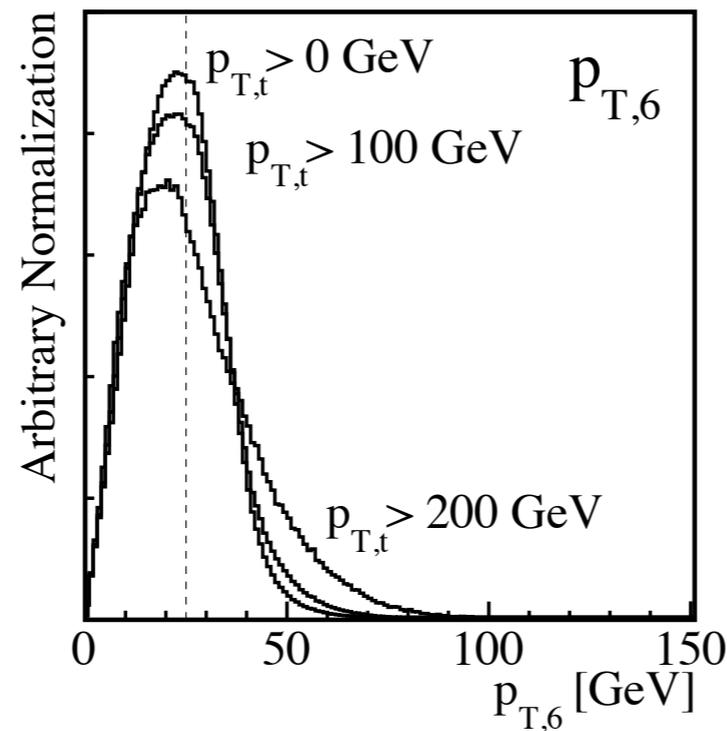
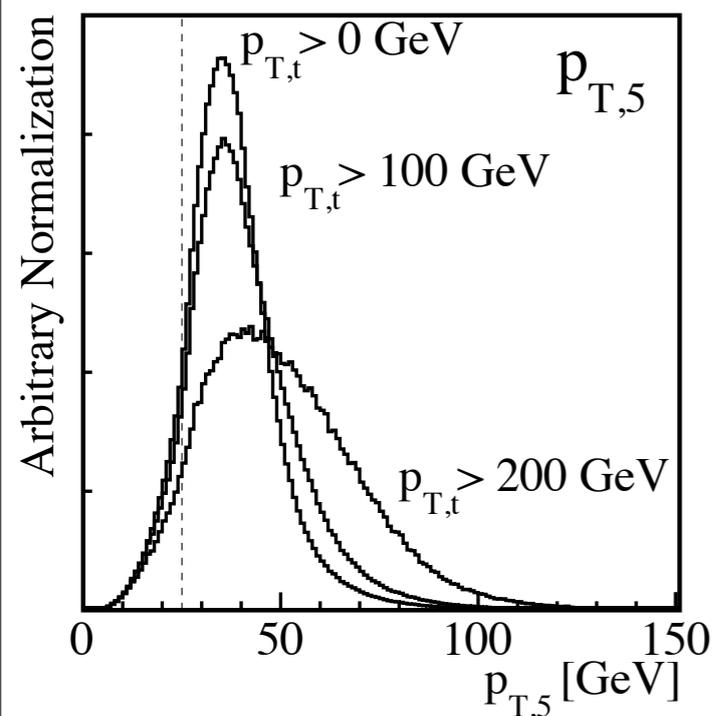
98% of j_6 from W

distributions:

weak top p_T dependence

	$t_h \bar{t}_h + \text{jets}$ [pb]	$p_{T,6} > 25 \text{ GeV}$	$p_{T,5} > 25 \text{ GeV} > p_{T,6}$
lepton veto	104.1	33.4%	44.9%
$n_j \geq 5$	70.5	42.5%	46.4%
$n_j \geq 6$	36.7	54.7%	38.0%
$n_j \geq 5$ $p_{T,t_2} > 100 \text{ GeV}$	32.7	43.6%	46.2%
$n_j \geq 5$ $p_{T,t_2} > 200 \text{ GeV}$	6.7	47.4%	44.7%

Jet p_T threshold



$p_{T,j} > 25 \text{ GeV}$ kills 6th jet

98% of j_6 from W

distributions:

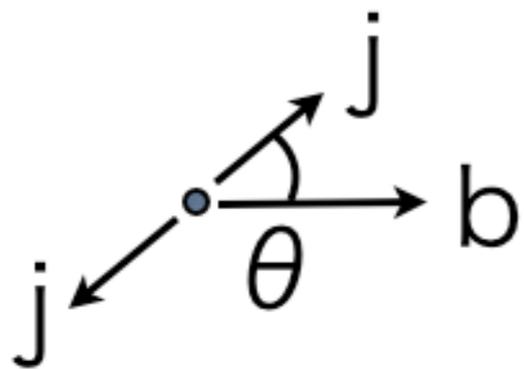
weak top p_T dependence

What can we do with 5 jets?

	$t_h \bar{t}_h + \text{jets}$ [pb]	$p_{T,6} > 25 \text{ GeV}$	$p_{T,5} > 25 \text{ GeV} > p_{T,6}$
lepton veto	104.1	33.4%	44.9%
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bj -buckets

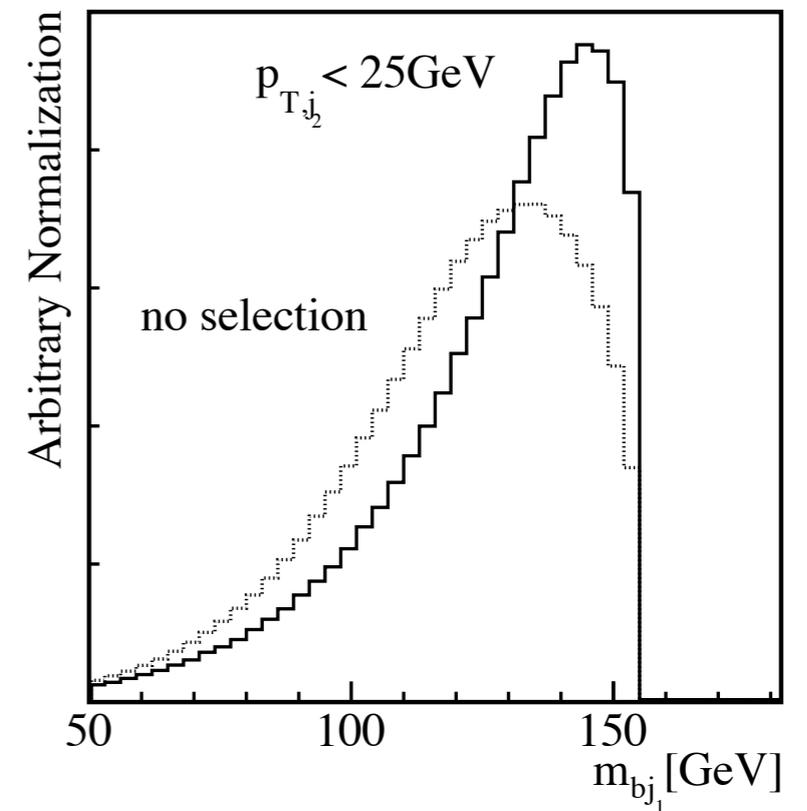
- m_{bj} -peak from top decay kinematics



$$m_{bj} < \sqrt{m_t^2 - m_W^2} \sim 155\text{GeV}$$

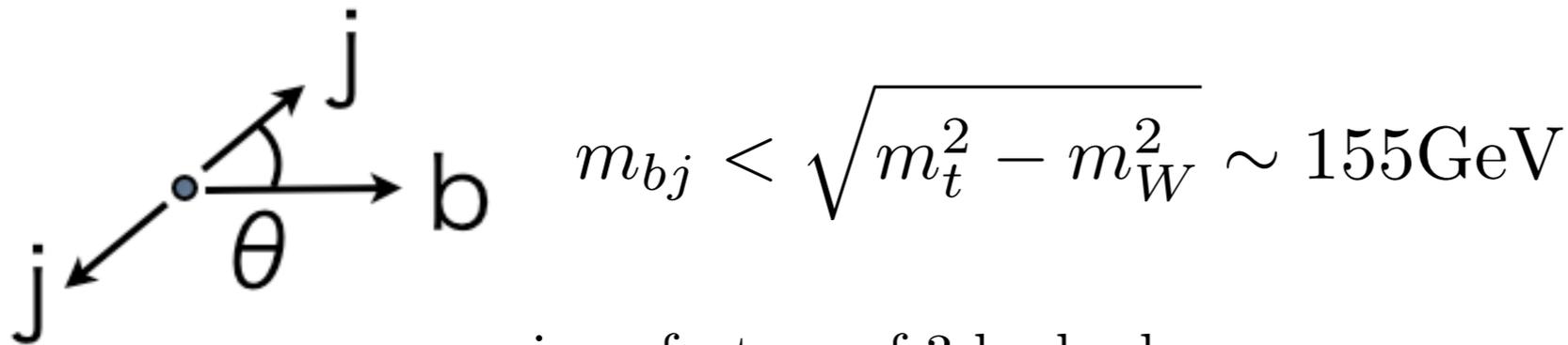
unique feature of 3 body decay

more pronounced peak with $p_{T,3} < 25\text{GeV}$



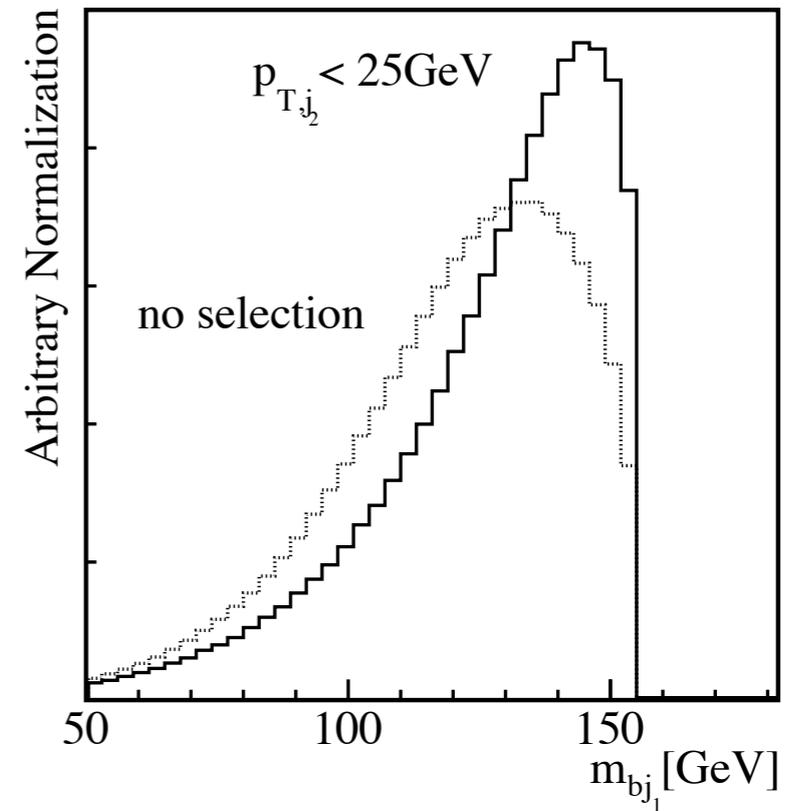
bj -buckets

- m_{bj} -peak from top decay kinematics

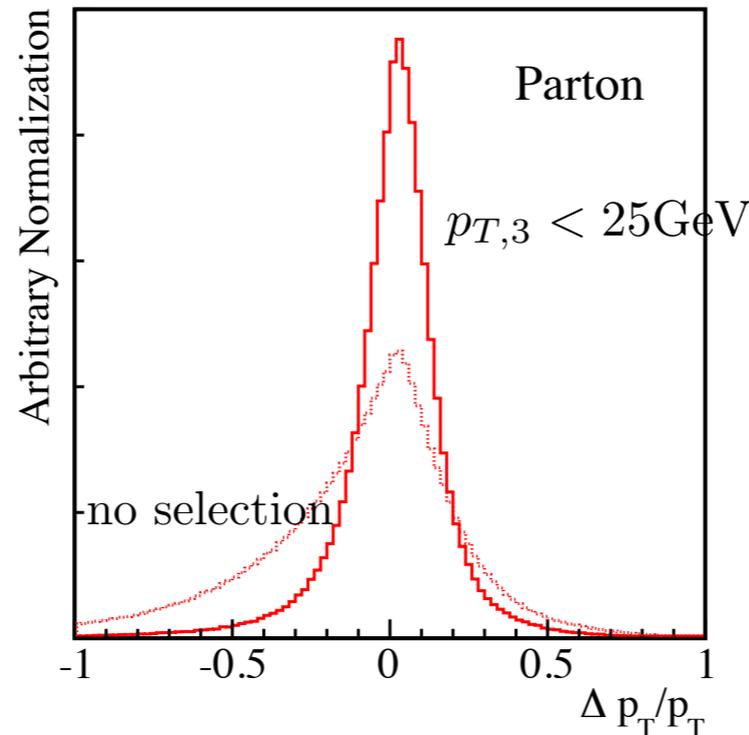
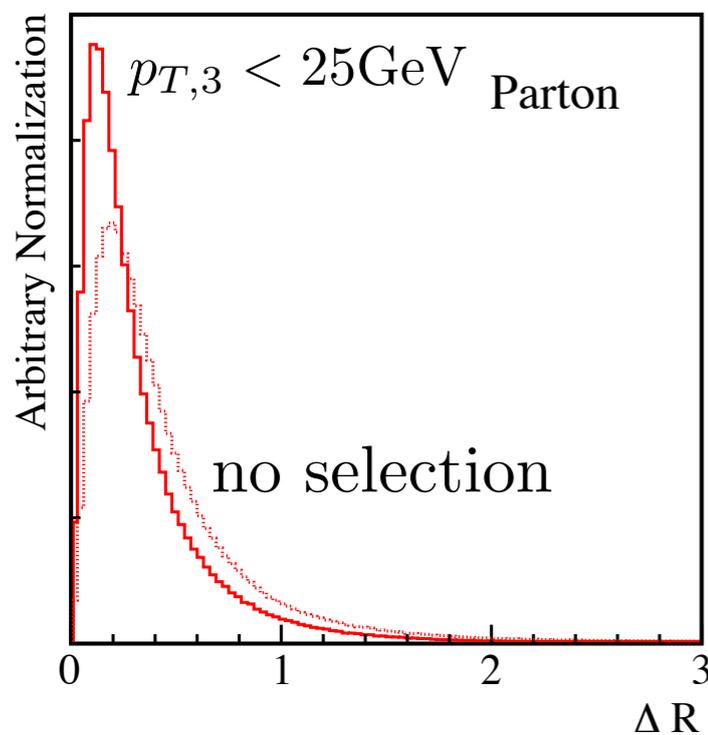


unique feature of 3 body decay

more pronounced peak with $p_{T,3} < 25\text{GeV}$

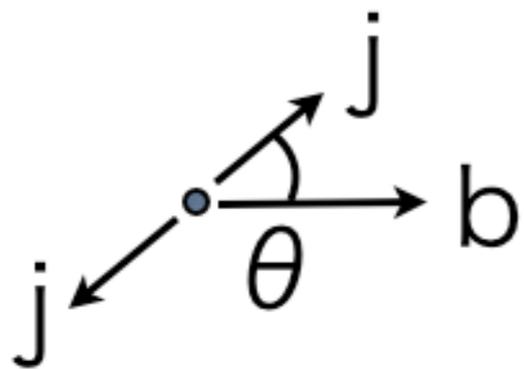


- acceptable momentum reconstruction



bj -buckets

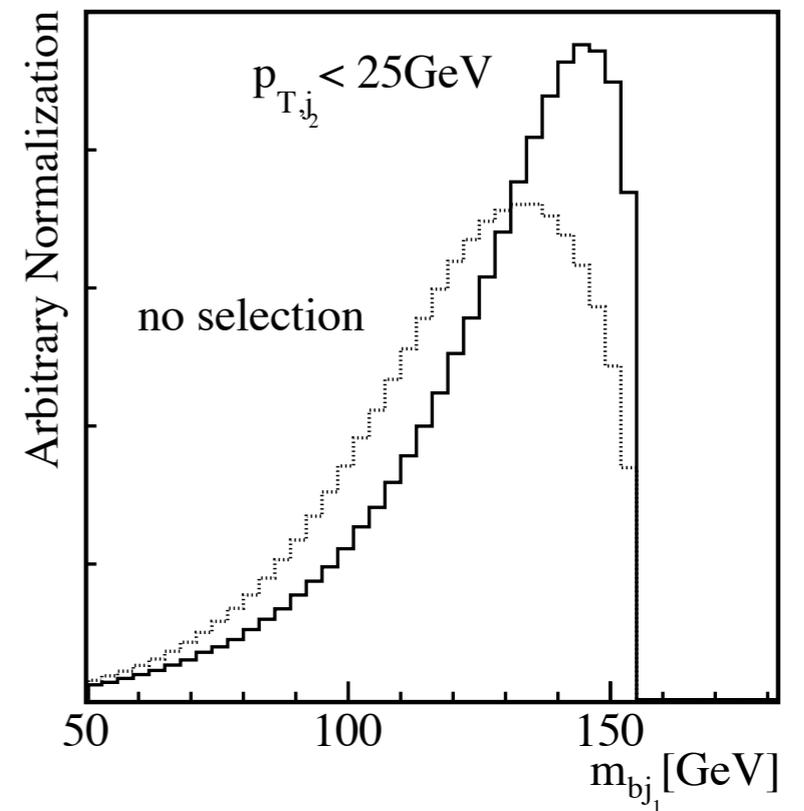
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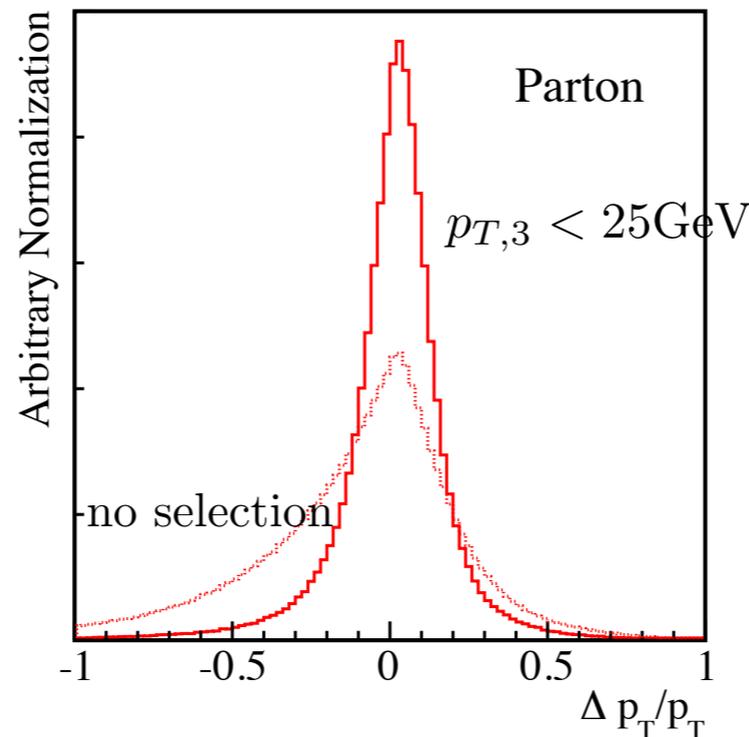
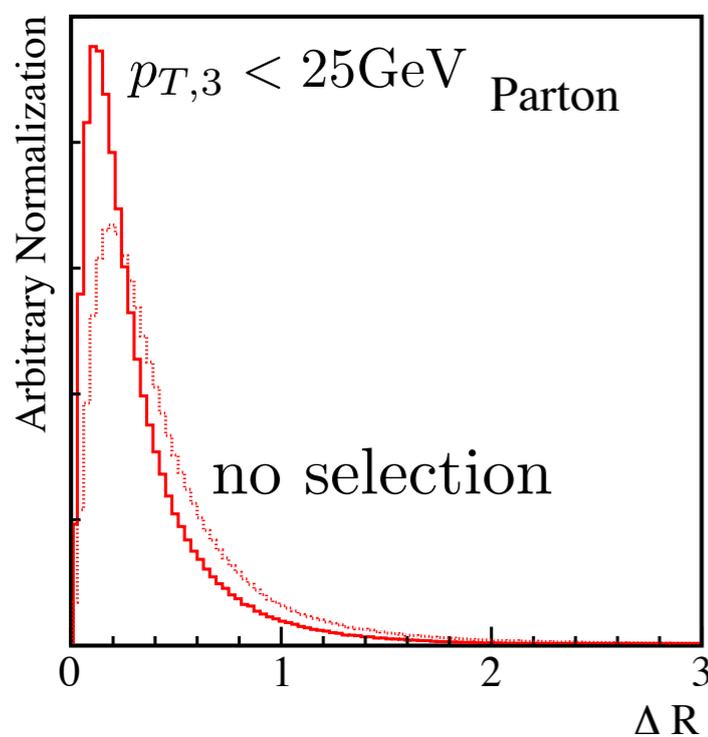
$$m_{bj} < \sqrt{m_t^2 - m_W^2} \sim 155\text{GeV}$$

unique feature of 3 body decay

more pronounced peak with $p_{T,3} < 25\text{GeV}$



- acceptable momentum reconstruction



new metric:

$$\Delta_B^{bj} = |m_B - 145\text{GeV}|$$

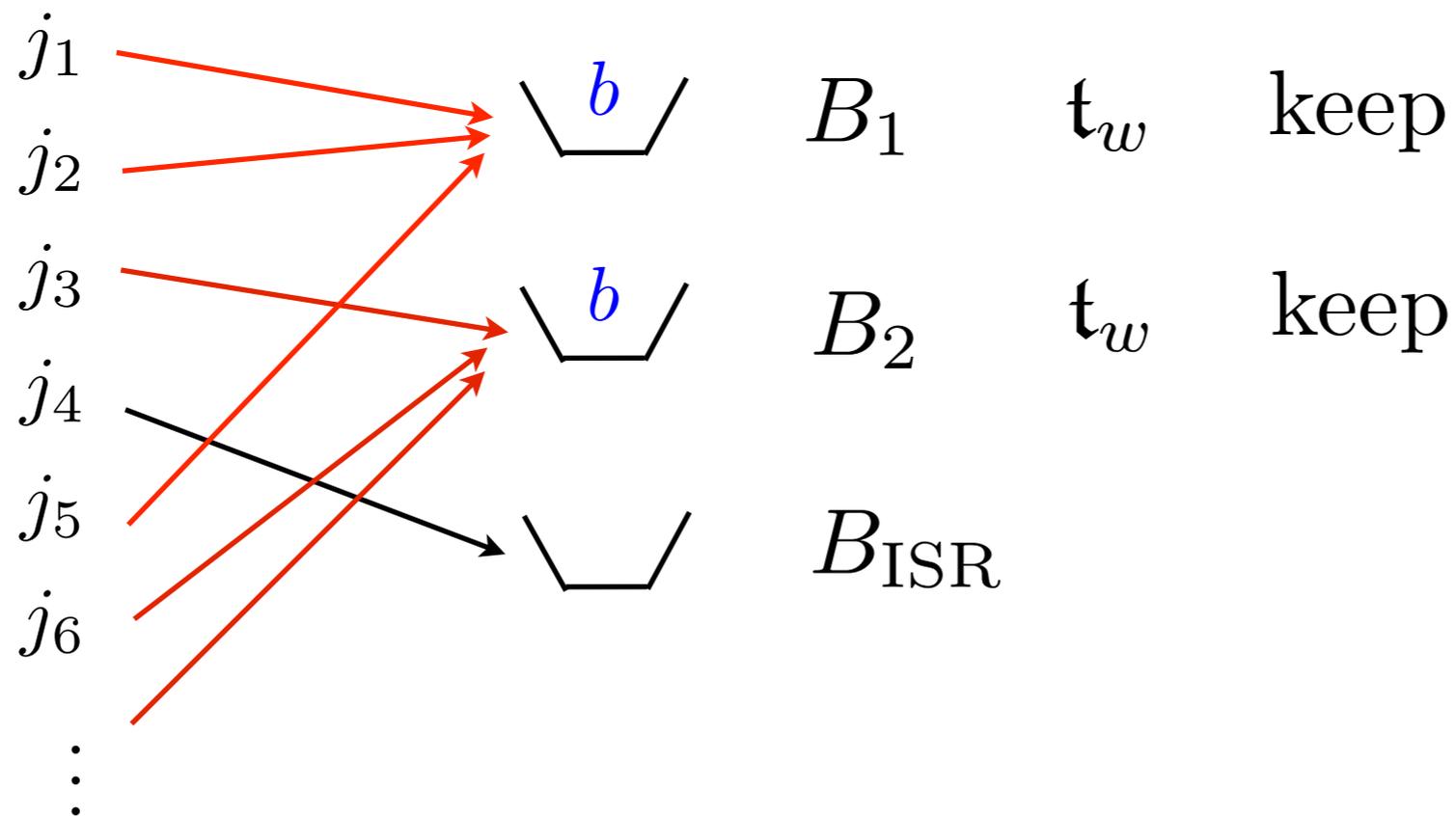
if $m_B > 155\text{GeV}$, thrown away

Modified algorithm

$(\mathbf{t}_w, \mathbf{t}_w)$: keep them

$(\mathbf{t}_w, \mathbf{t}_-)$: reconstruct \mathbf{t}_- with Δ_B^{bj}

$(\mathbf{t}_-, \mathbf{t}_-)$: reconstruct \mathbf{t}_- to minimize $\Delta_{B_1}^{bj} + \Delta_{B_2}^{bj}$

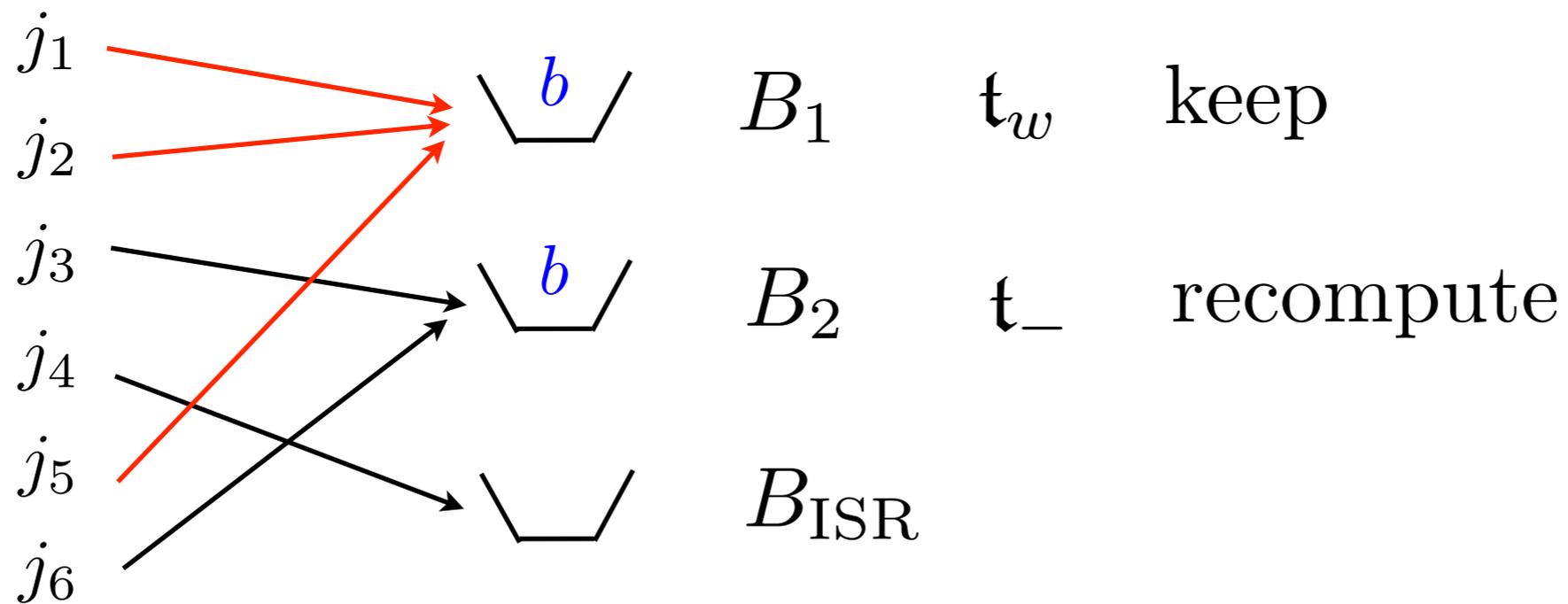


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$$\vdots \quad \Delta_{B_i} = |m_{B_i} - m_t|$$

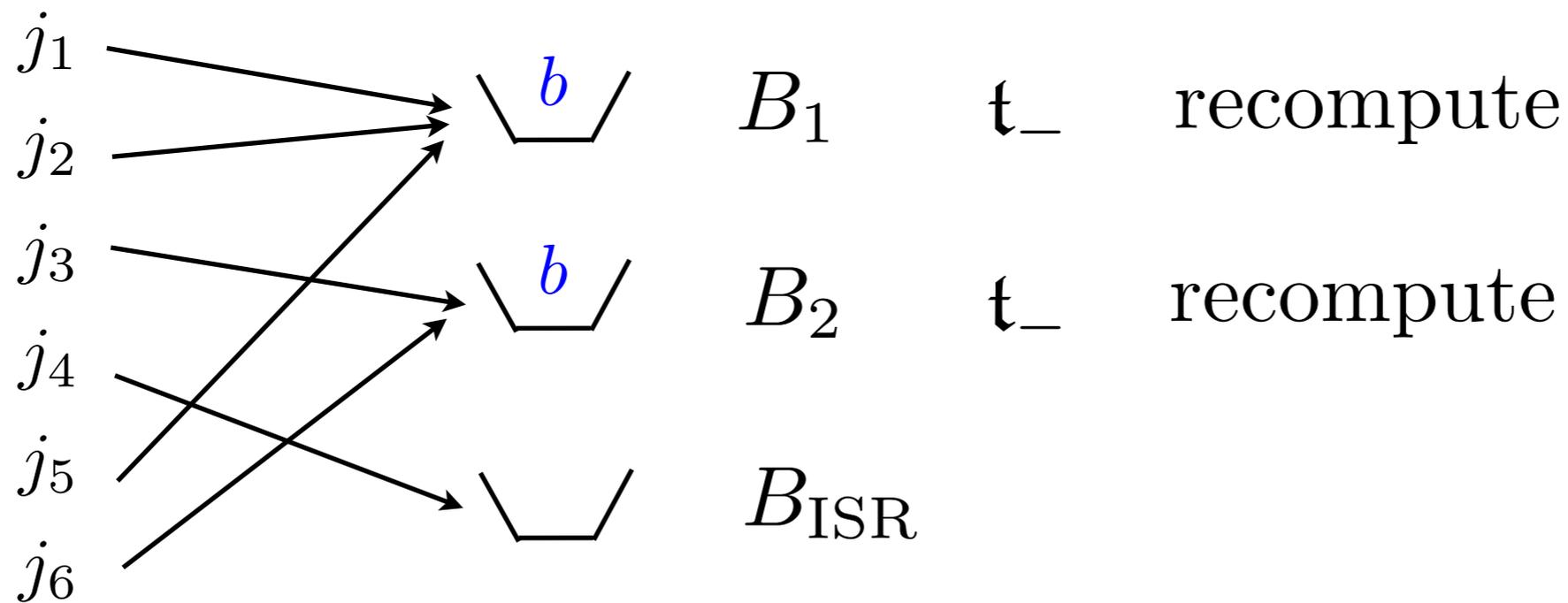
$$\Delta_B^{bj} = |m_B - 145\text{GeV}|$$

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⋮

$$\Delta_{B_i} = |m_{B_i} - m_t|$$

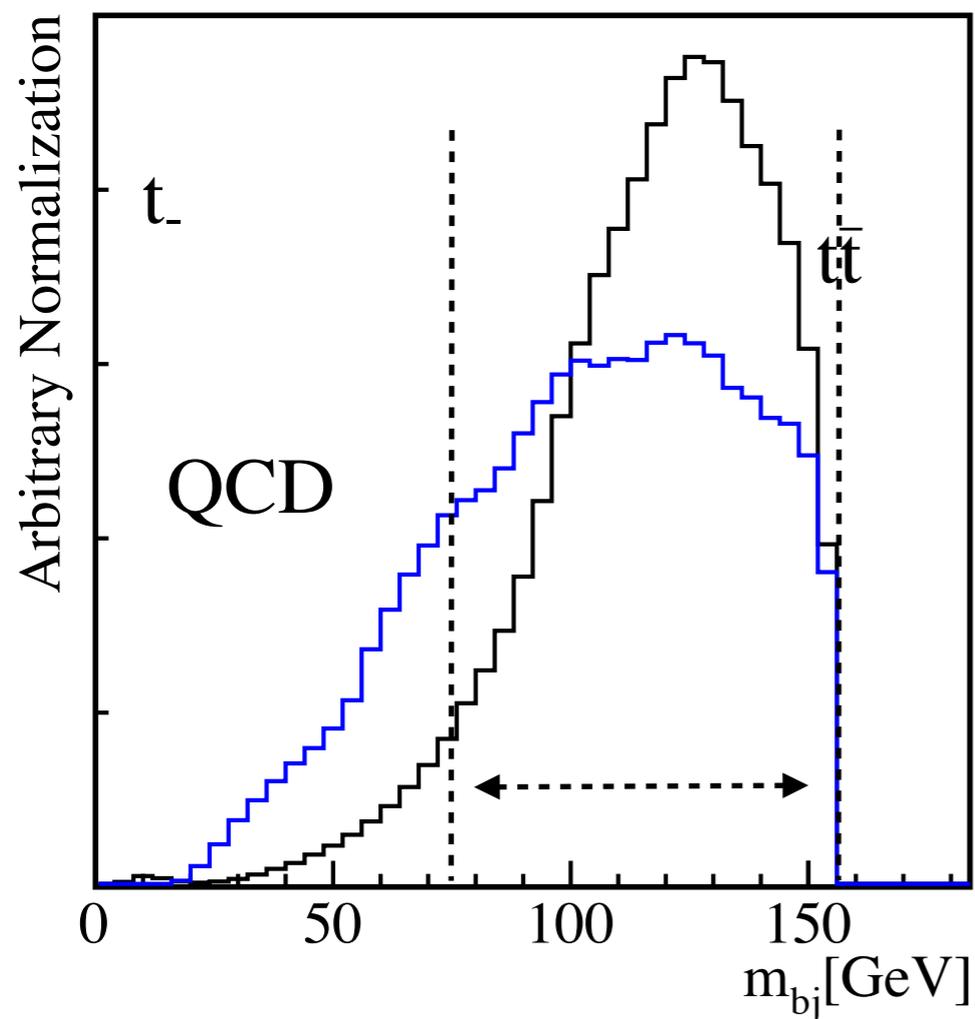
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Modified algorithm

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$(\mathbf{t}_w, \mathbf{t}_-)$: reconstruct \mathbf{t}_- with Δ_B^{bj}

$(\mathbf{t}_-, \mathbf{t}_-)$: reconstruct \mathbf{t}_- to minimize $\Delta_{B_1}^{bj} + \Delta_{B_2}^{bj}$



$m_{\mathbf{t}_-} (= m_{bj})$ distribution

accept \mathbf{t}_- as a top

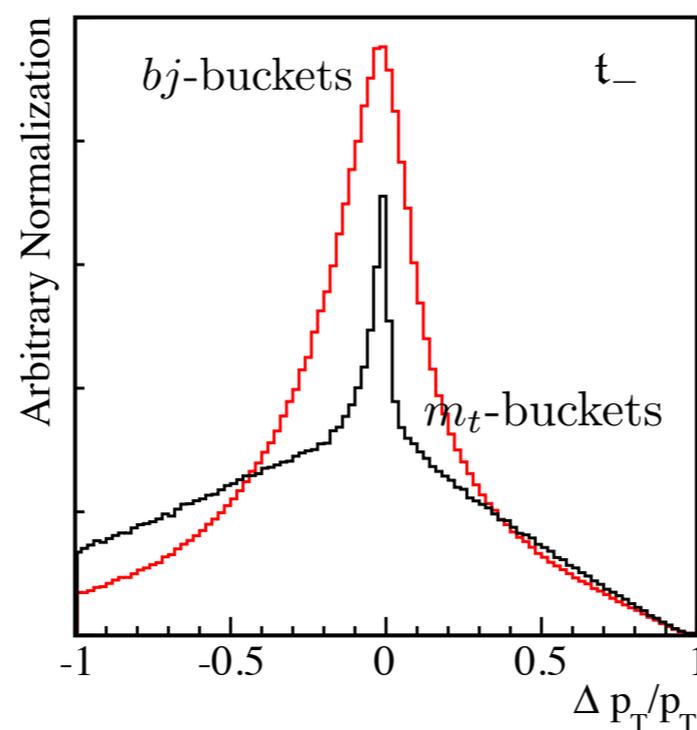
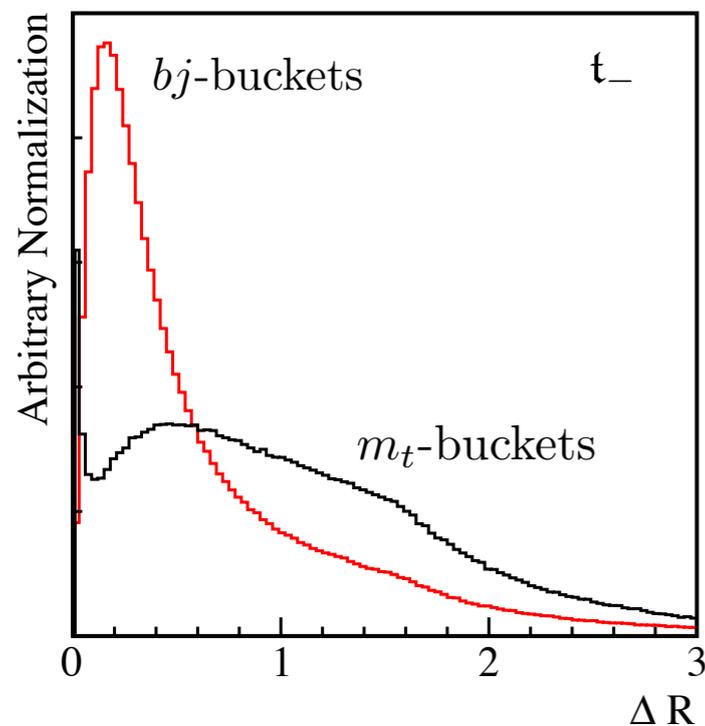
$$75 \text{ GeV} < m_{bj} < 155 \text{ GeV}$$

Efficiency and momentum reconstruction

unchanged →

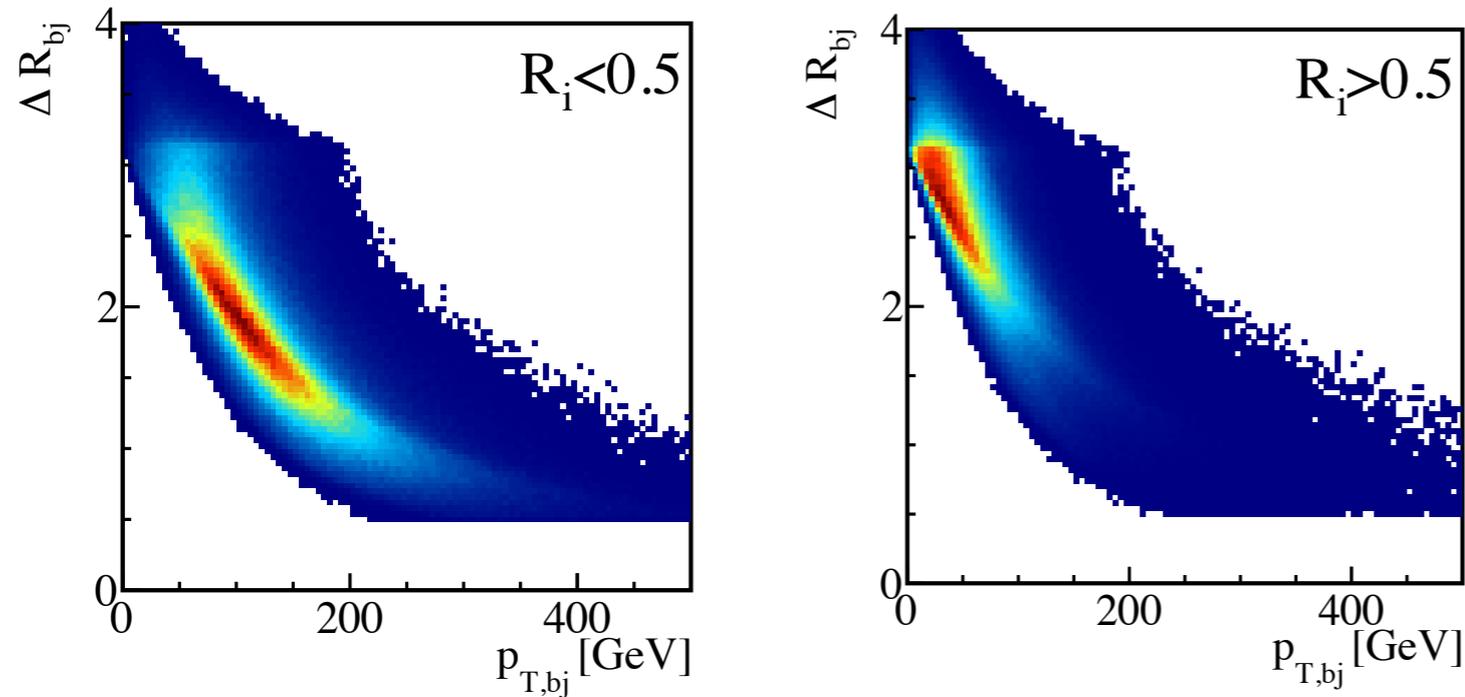
	$t_h \bar{t}_h + \text{jets}$ [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, 2b-tag	21590		16072	1.4
(t_w, t_w)	2750	68.9%	126.2	21.8
(t_w, t_-)	7787	47.3%	2259	3.4
(t_-, t_w)	1093	27.3%	190.5	5.7
(t_-, t_-)	4887	28.5%	4077	1.2

increase in number and quality
70% double tagged in total



better reconstruction

Consistency check



to enhance $R_i < 0.5$

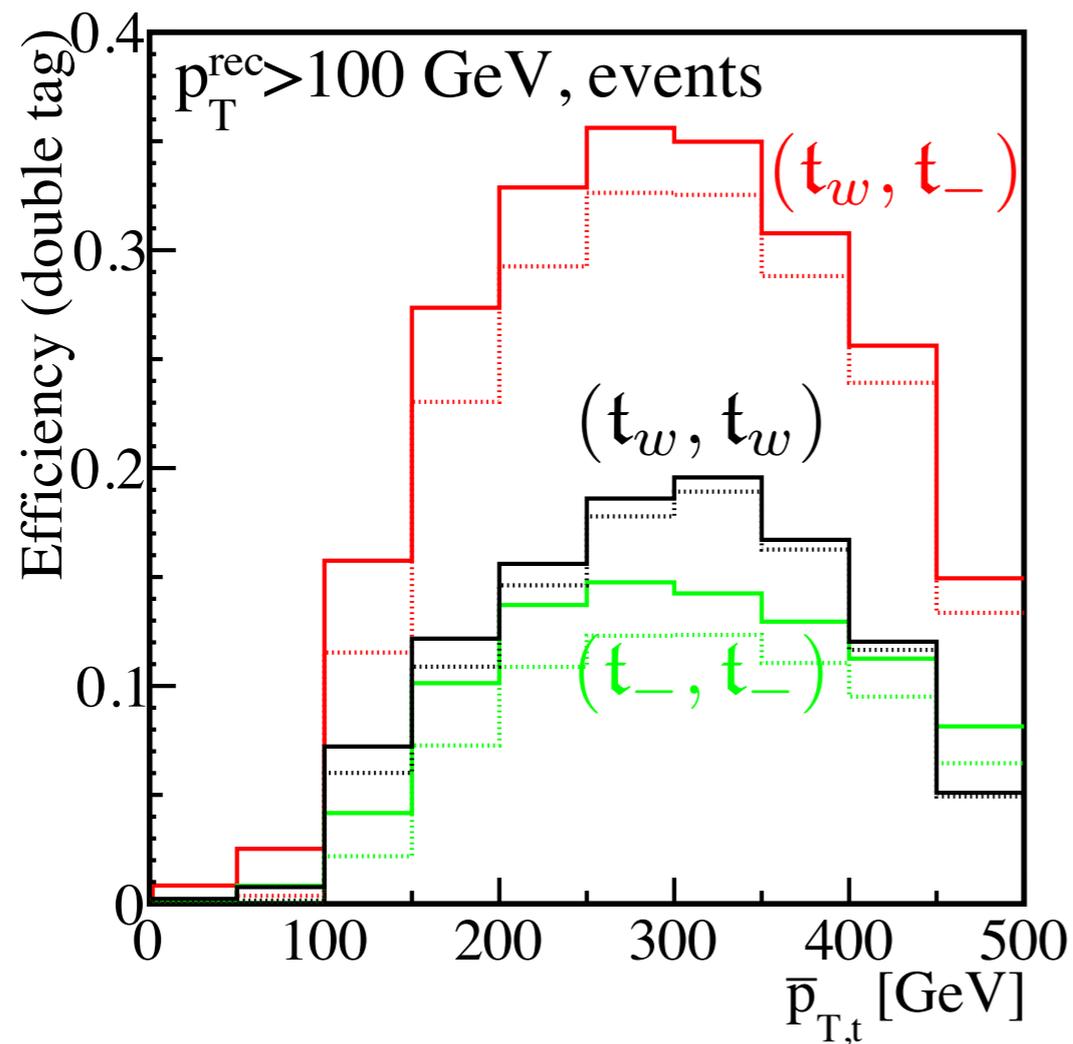
$$p_T^{\text{rec}} > 100 \text{ GeV}$$

	$t_h \bar{t}_h + \text{jets}$ [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, 2b-tag	21590		16072	1.36
$(t_w, t_w), p_T^{\text{rec}} > 100 \text{ GeV}$	1417	86.4%	27.1	52.3
$(t_w, t_-), p_T^{\text{rec}} > 100 \text{ GeV}$	2805	80.5%	305.4	9.2
$(t_-, t_w), p_T^{\text{rec}} > 100 \text{ GeV}$	287.9	60.5%	26.4	10.9
$(t_-, t_-), p_T^{\text{rec}} > 100 \text{ GeV}$	1084	67.7%	339.3	3.2
total, $p_T^{\text{rec}} > 100 \text{ GeV}$	5593	78.5%	698.2	8.0

$\sim 80\%$ provide good momentum for both tops

Efficiency as functions of p_T

base number: after $5j$ with $2b$ -tag selection

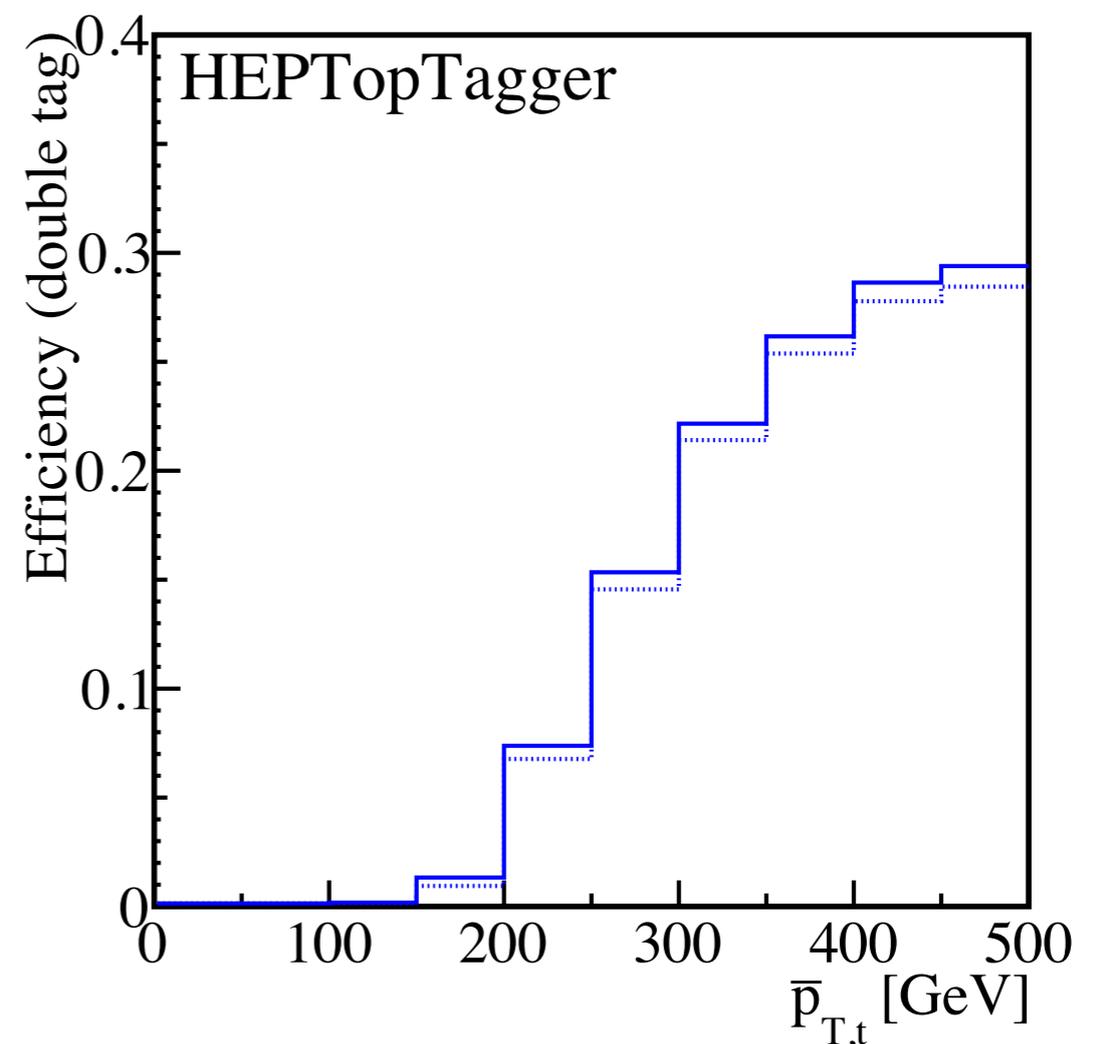
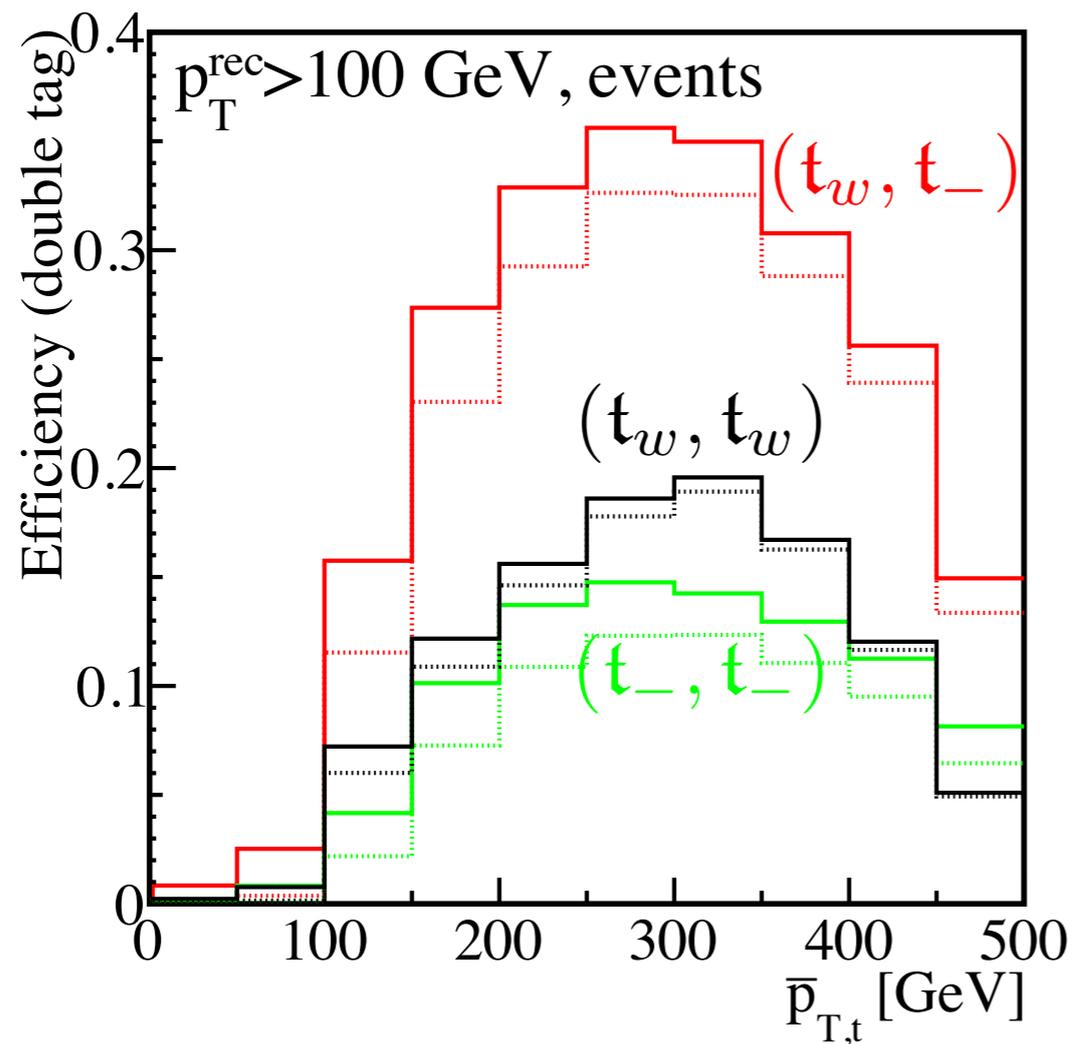


$\bar{p}_{T,t} = 100 - 150 \text{ GeV}$: 30% (double top tags)

$\bar{p}_{T,t} = 150 - 300 \text{ GeV}$: 50-70% (double top tags)

Efficiency as functions of p_T

base number: after $5j$ with $2b$ -tag selection



$\bar{p}_{T,t} = 100 - 150 \text{ GeV}$: 30% (double top tags)

$\bar{p}_{T,t} = 150 - 300 \text{ GeV}$: 50-70% (double top tags)

for $\bar{p}_{T,t} > 300 \text{ GeV}$, jet substructure method start to be efficient

Stop pair search

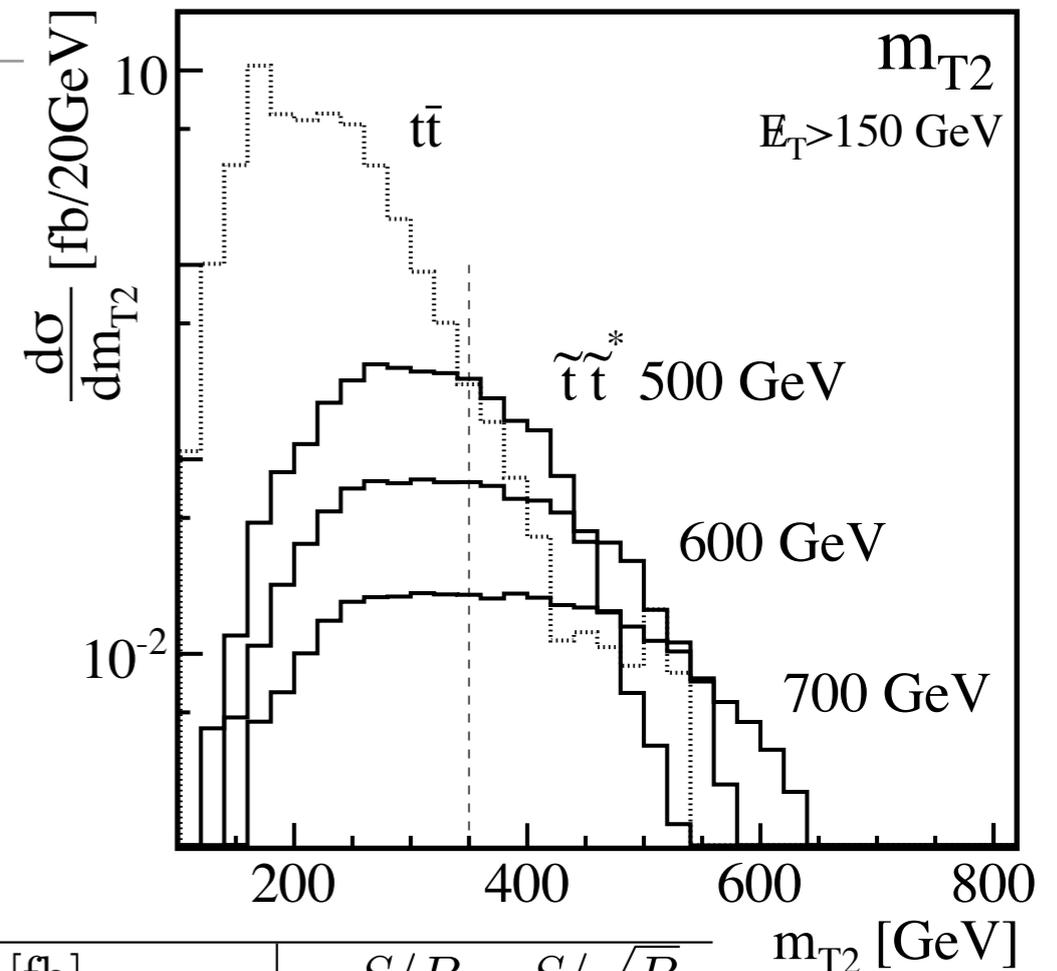
[arXiv:1302.6238[hep-ph] M. Buckley, T. Plehn, MT]

- $\tilde{t}\tilde{t}^* \rightarrow t\bar{t}\chi\chi: t\bar{t} + \cancel{E}_T$

typically 10^4 difference in cross section

- include t_{\perp} increase both signal and BG
- LHC 8 TeV with 25 fb^{-1} :

$$S/B \sim 1 \text{ for } m_{\tilde{t}} = 600 \text{ GeV}$$



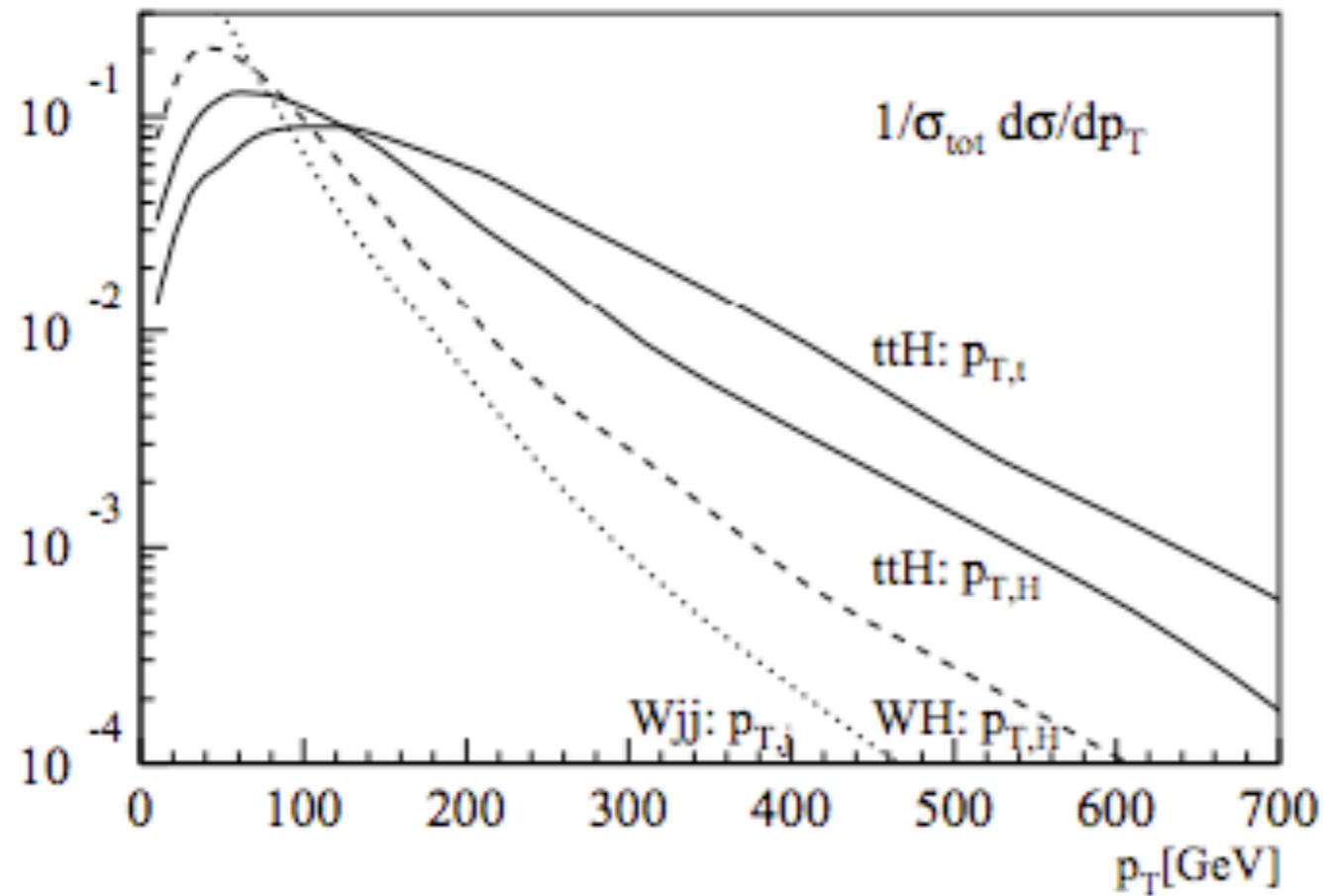
$m_{\tilde{t}}$ [GeV]	$t\bar{t}+\text{jets}$ [fb]	$\tilde{t}\tilde{t}^*$ [fb]			S/B S/\sqrt{B}	
		500	600	700	600	
before cuts	234×10^3	80.50	23.00	7.19		
veto lepton	157×10^3	50.45	14.38	4.46		
≥ 5 jets	85.9×10^3	37.87	10.90	3.37		
2 b -tags	28.0×10^3	11.41	3.30	1.02		
2 tops reconstructed, $p_{T,t}^{\text{rec}} > 100 \text{ GeV}$	6.32×10^3	3.90	1.23	0.38	0.0002	0.08
$\cancel{E}_T > 150 \text{ GeV}$	44.71	2.80	0.98	0.33	0.02	0.7
$m_{T2} > 350 \text{ GeV}$	0.45	0.79	0.44	0.18	1.0	3.3
100% τ rejection	0.14	0.73	0.40	0.16	2.8	5.3

Buckets of tops

- top : tool for new physics search
- keep low p_T signal tops : $p_{T,t} = 100 - 350$ GeV
- buckets help to solve combinatorics
- bj -buckets provide ~ 4 times the signal

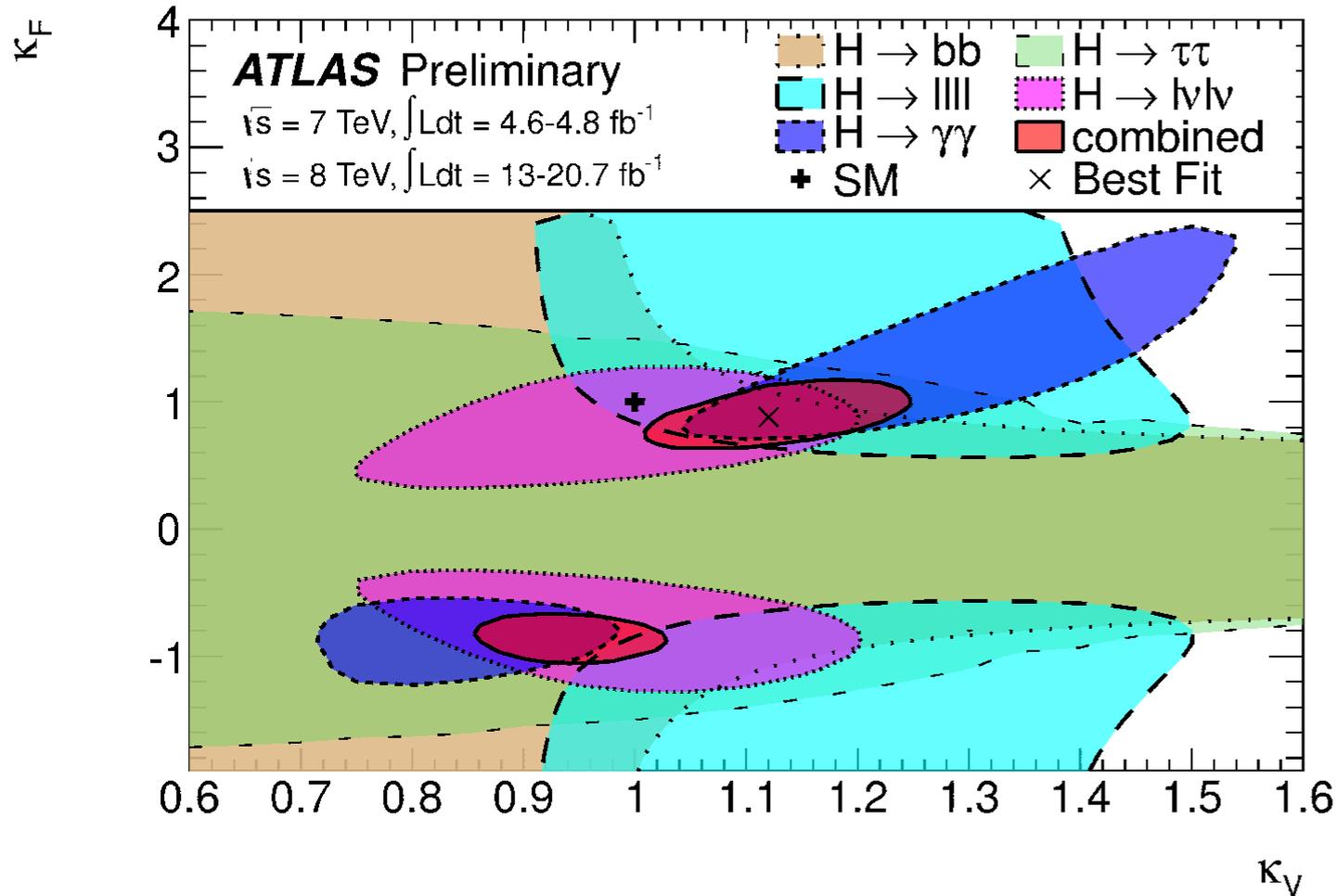
他に面白そうなこと

- ttH production : 一番大事な湯川結合の直接測定
- moderate boostが助けになるか



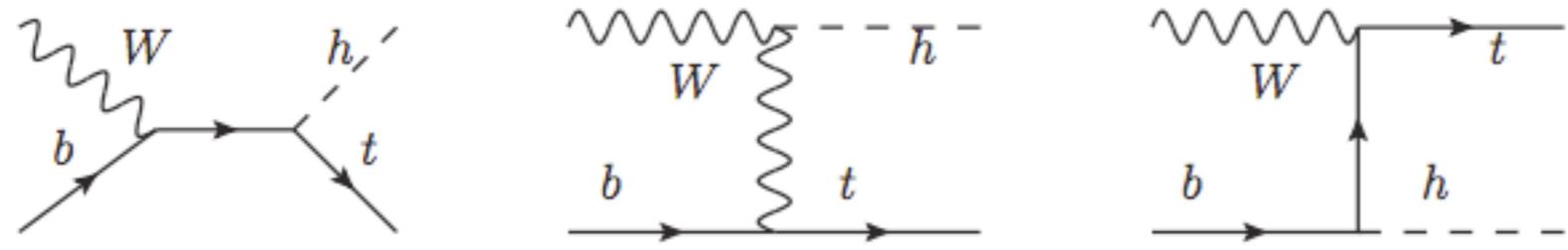
他に面白そうなこと

- tH production : 干渉項で湯川の符号決定



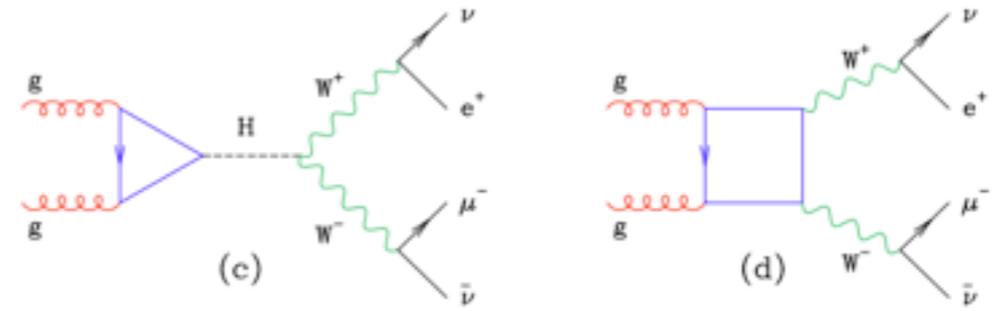
$$\kappa_F^2 \sim \sigma_{gg \rightarrow H}$$

$$|\kappa_V - 0.2\kappa_F|^2 \sim BR(H \rightarrow \gamma\gamma)$$

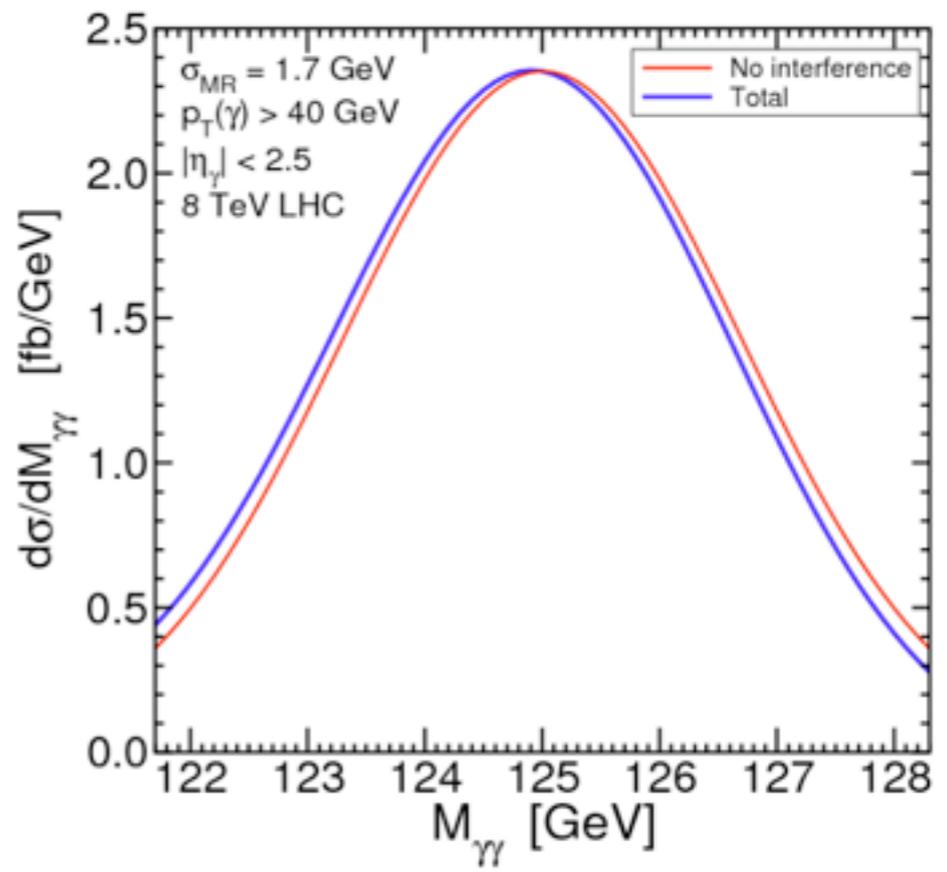
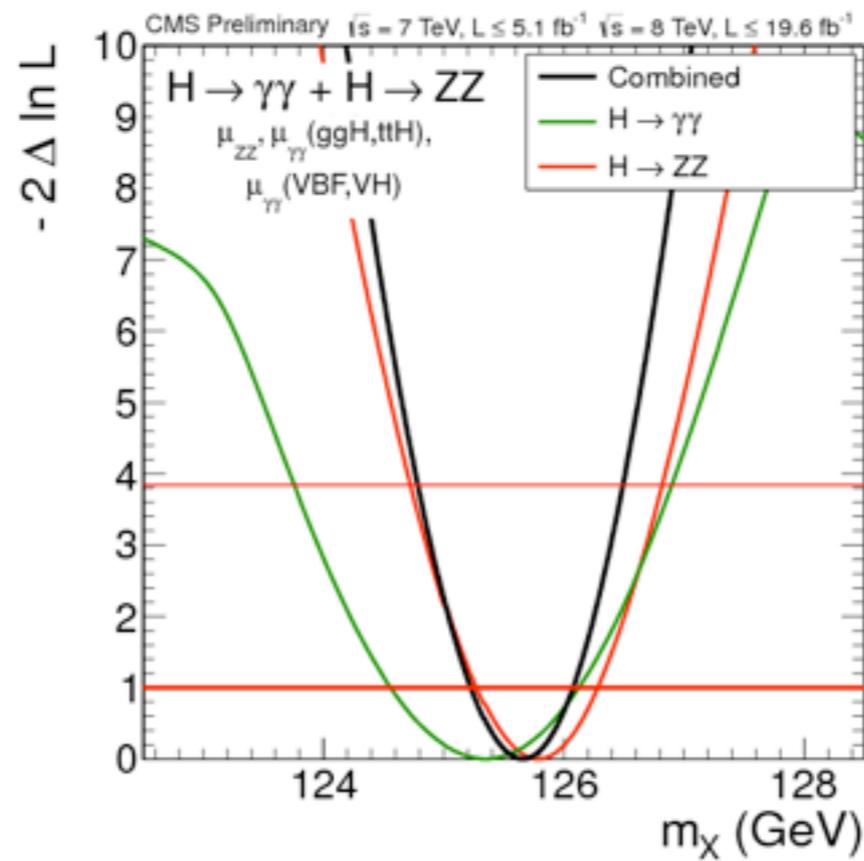
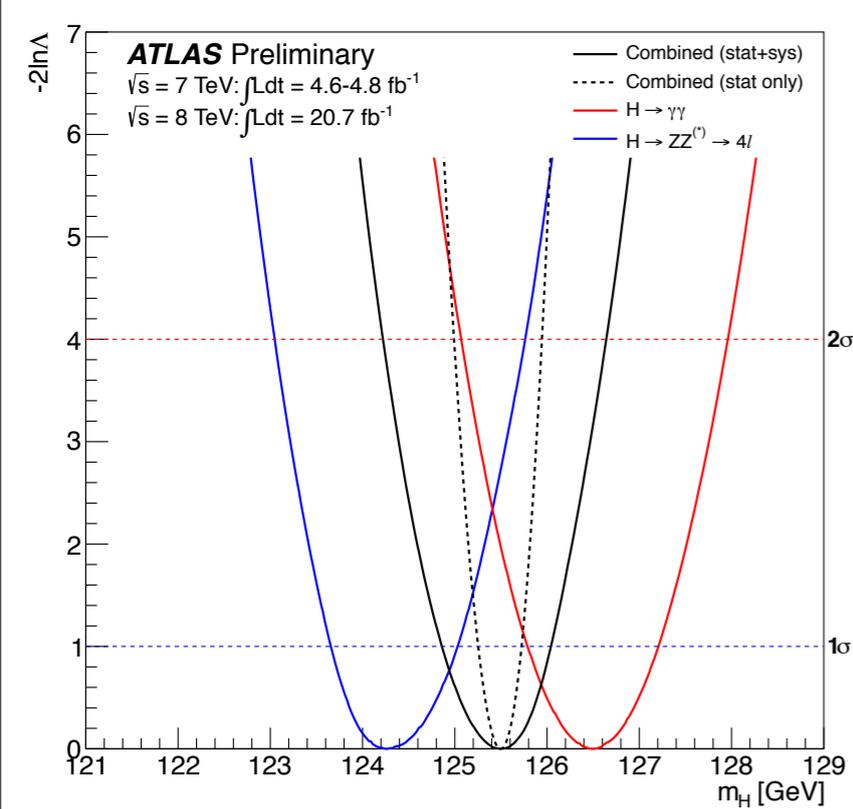


	$\sigma^{\text{NLO}}(pp \rightarrow thj) \text{ [fb]}$	
	$c_F = 1$	$c_F = -1$
8 TeV	$18.28^{+0.42}_{-0.38}$	$233.8^{+4.6}_{-0.}$
14 TeV	$88.2^{+1.7}_{-0.}$	$982^{+28}_{-0.}$

他に面白そうなこと



- $H \rightarrow \gamma\gamma$: 干渉でピークが100MeVくらいずれる
- $H \rightarrow WW, ZZ, bb$? 全部あわせると? invisible width?



他に面白そうなこと

- WWが少し多い (2 lepton mode)

$$\sigma_{WW,7TeV}^{ATLAS} = 51.9 \pm 2.0 \pm 3.9 \pm 2.0 \text{ pb}$$

$$\sigma_{WW,7TeV}^{CMS} = 52.4 \pm 2.0 \pm 4.5 \pm 1.2 \text{ pb}$$

$$\sigma_{WW,8TeV}^{CMS} = 69.9 \pm 2.8 \pm 5.6 \pm 3.1 \text{ pb}$$

$$\sigma_{WW,7TeV}^{NLO} = 44.7 \pm 2.0 \text{ pb}$$

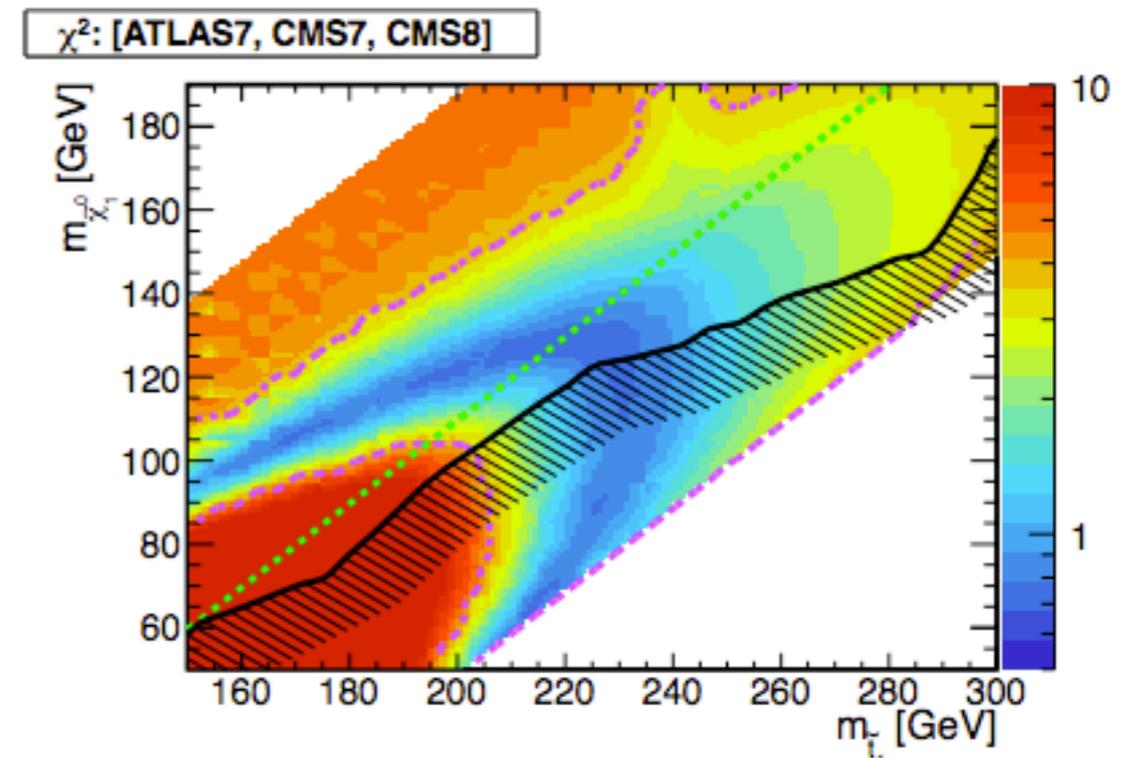
$$\sigma_{WW,8TeV}^{NLO} = 57.3^{+2.4}_{-1.6} \text{ pb}$$

- arxiv:1303.5696 [K. Rolbiecki, K. Sakurai]

$$\tilde{t}_1 \rightarrow \tilde{\chi}_1^\pm b \rightarrow \tilde{\chi}_1^0 W^{(*)} b \rightarrow \tilde{\chi}_1^0 \ell \nu b.$$

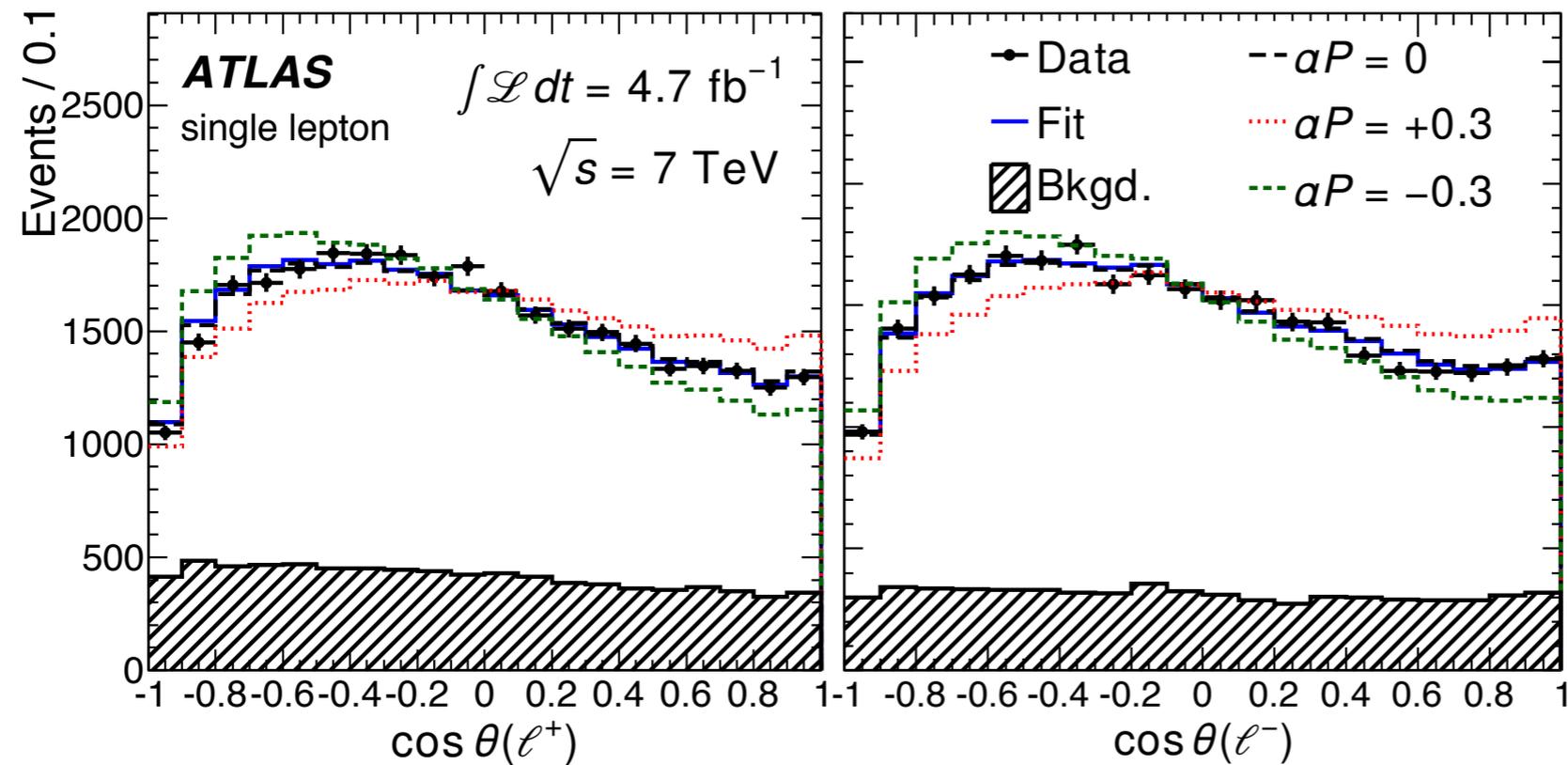
$$\sigma(m_{\tilde{t}^*} = 200 \text{ GeV}) > 10 \text{ pb}$$

- WZも少し多い, ZZもATLAS多い



他に面白そうなこと

- top 偏極



$$\alpha_\ell P_{CP C} = -0.035 \pm 0.014(\text{stat}) \pm 0.037(\text{syst})$$

$$\alpha_\ell P_{CP V} = 0.020 \pm 0.016(\text{stat})^{+0.013}_{-0.017}(\text{syst})$$

Summary

- Naturalnessを信じれば

