Implications of the top pair forward-backward asymmetry

Gilad Perez

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R. Alon, E. Duchovni, GP & P. Sinervo, for the CDF col., CDF/PUB/JET/PUBLIC/10199; CDF/ANAL/TOP/PUBLIC/10234;

A. Kagan, J. Kamenik, GP, S. Stone, 1103.3747.

C. Delaunay, O. Gedalia, Y. Hochberg, GP, Y. Soreq, 1103.2297.

K. Blum, C. Delaunay, O. Gedalia, Y. Hochberg, S. Lee, Y. Nir, GP, Y. Soreq, 1102.3133.

Y. Eshel, O. Gedalia, GP, Y. Soreq, 1101.2898.

C. Delaunay, O. Gedalia, S. Lee, GP, E. Ponton, 1007.0243; 1101.2902.

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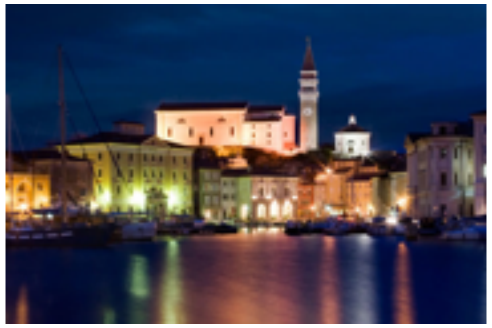
The Role of Heavy Fermions in Fundamental Physics?!



Outline

Tops forward-backward asym' (AFB) from hard new physics (NP), effective field theory (EFT).

(see also talk by Aguilar-Saavedra)

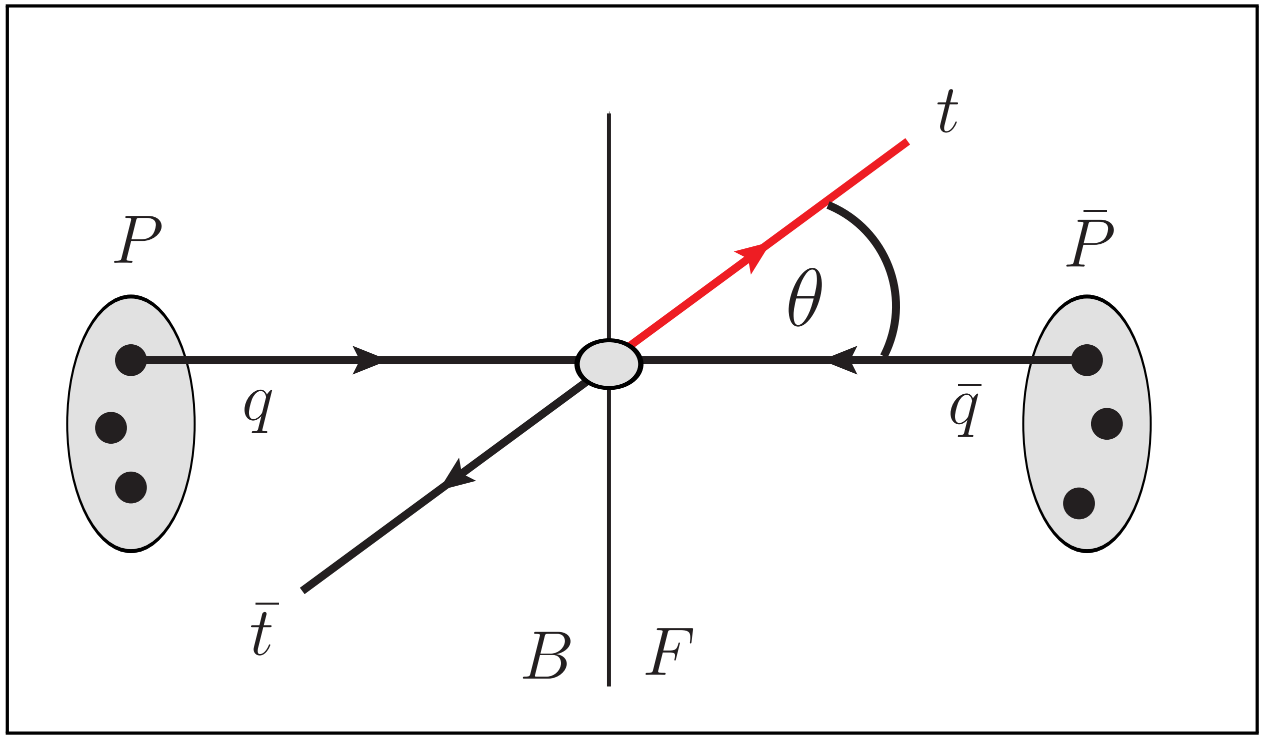
CDF boosted top search.

tLHCb.

[Warped flavor triviality (see talk by Seung Lee)]

Summary.

AFB



AFB Data (see also Marina Cobal's talk)

- D0 inclusive (not-unfolded):

$$A_{fb} = (8 \pm 4(\text{stat}) \pm 1(\text{syst}))\%$$

- CDF had-lep:

$$A^{\mathrm{t\bar{t}}}(M_{t\bar{t}} < 450 \text{ GeV}/c^2) = -0.116 \pm 0.153$$
$$A^{\mathrm{t\bar{t}}}(M_{t\bar{t}} \geq 450 \text{ GeV}/c^2) = 0.475 \pm 0.114$$

$$A^{\mathrm{t\bar{t}}}(|\Delta y| < 1.0) = 0.026 \pm 0.118$$
$$A^{\mathrm{t\bar{t}}}(|\Delta y| \geq 1.0) = 0.611 \pm 0.256$$

- CDF di-lepton inclusive (unfolded):

$$A_{\text{true}} = 0.417 \pm 0.148(\text{stat.}) \pm 0.053(\text{syst.})$$

- CDF di-lepton (not-unfolded):

$$A_{\text{obs}}^{<450 \text{ GeV}} = 0.104 \pm 0.066(\text{stat.}) \qquad (\text{Pred.}: \ 0.003 \pm 0.031)$$
$$A_{\text{obs}}^{>450 \text{ GeV}} = 0.212 \pm 0.096(\text{stat.}) \qquad (\text{Pred.}: \ -0.040 \pm 0.055) \ .$$

AFB via EFT

Delaunay, Gedalia, Hochberg, GP, Soreq, 1103.2297;
Blum, Delaunay, Gedalia, Hochberg, Lee, Nir, GP, Soreq, 1102.3133;
Aguilar-Saavedra, Perez-Victoria, 1103.2765.

- Heavy NP yield a simple description: (dim' 8 not important)

$$\mathcal{L}_{\text{eff}} = \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i \,,$$

i. Two leading op' interfere to contribute to AFB:

(chromo-magnetic not important)

$$\mathcal{O}^8_A = (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)\,, \quad \mathcal{O}^8_V = (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)\,.$$

ii. The rest: (focus on vectors only to simplify)

$$\mathcal{O}^8_{AV} = (\bar{u}\gamma_\mu\gamma^5 T^a u)\,(\bar{t}\gamma^\mu T^a t)\,, \qquad \mathcal{O}^8_{VA} = (\bar{u}\gamma_\mu T^a u)\,(\bar{t}\gamma^\mu\gamma^5 T^a t)\,,$$

$$\mathcal{O}^1_V = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}^1_A = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,,$$

$$\mathcal{O}^1_{AV} = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}^1_{VA} = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,.$$

Relevant observables

- Heavy NP phys. affect more hard physics, signal:

$$A_{450}^{t\bar{t}} \equiv A^{t\bar{t}}(M_{t\bar{t}} \geq 450 \text{ GeV}) = +0.475 \pm 0.114\,,$$

- Main Tevatron constraints:

$$|N_{700}| \equiv \left|\sigma_{700}^{\rm NP}/\sigma_{700}^{\rm SM}\right| \lesssim 0.5\,, \qquad |N_{450}| \equiv \left|\sigma_{450}^{\rm NP}/\sigma_{450}^{\rm SM}\right| \lesssim 0.2\,.$$

Simple basis & relations

- "Radial" coordinates:

$$w_\pm^2 \equiv \frac{1}{2}\left\{\left(c_{VA}^8 \pm c_{AV}^8\right)^2 + \frac{9}{2}\left[\left(c_V^1 \pm c_A^1\right)^2 + \left(c_{VA}^1 \pm c_{AV}^1\right)^2\right]\right\},$$

$$R^2 \equiv w_+^2 + w_-^2\,, \qquad \tan\theta \equiv w_-/w_+\,.$$

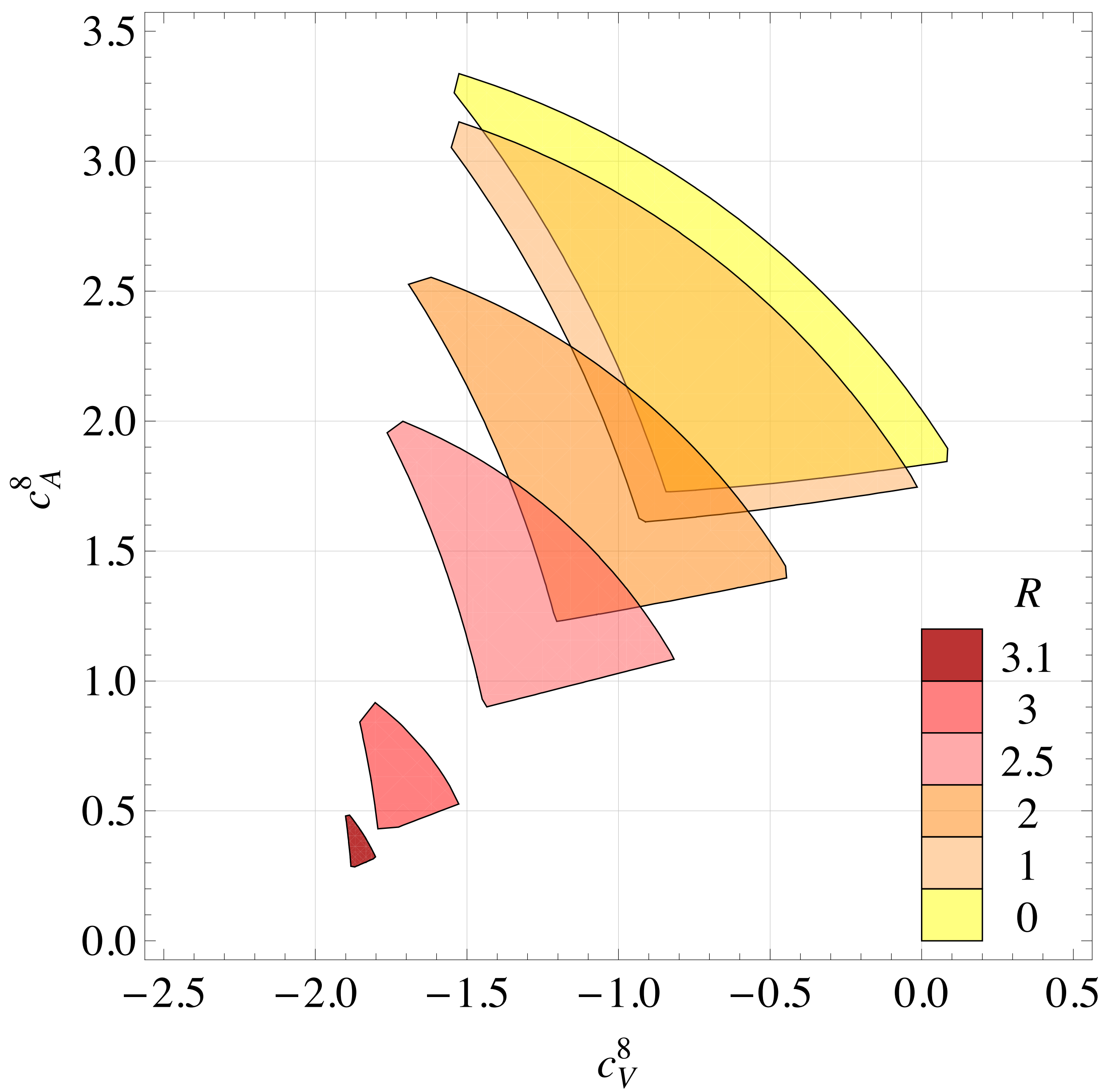
- The relevant observables then take simple form:

$$\begin{aligned} N_X &\simeq a_X c_V^8 + b_X (c_V^8)^2 + d_X (c_A^8)^2 + e_X R^2\,, \\ A_{450}^{t\bar{t}} &= \left(\alpha c_A^8 + \beta c_A^8 c_V^8 + \frac{\beta}{2} R^2 \cos 2\theta\right)(1 + N_{450})^{-1}\,, \end{aligned}$$

$$\begin{aligned} (a,b,d,e)_{450} &= 0.35,\ 0.043,\ 0.023,\ 0.033\,, \\ (a,b,d,e)_{700} &= 0.76,\ 0.16,\ 0.11,\ 0.14\,, \\ (a,b,d,e)_b &= 1.5,\ 0.57,\ 0.46,\ 0.51\,, \\ \alpha, \beta &= 0.17,\ 0.043\,, \end{aligned}$$

Result

Delaunay, Gedalia, Hochberg, GP, Soreq, 1103.2297;



The observables under consideration presented in the $c_V^8 - c_A^8$ plane: Each region corresponds to 1σ ranges for $A_{450}^{t\bar{t}}$, N_{450} and N_{700} , for different values of R .

Intermediate conclusions

- As R grows, the allowed region becomes smaller,

  and the maximal possible value is $R \simeq 3.1$.

- The allowed range for the vector octet operator is $-2 \lesssim c_V^8 \lesssim 0$.

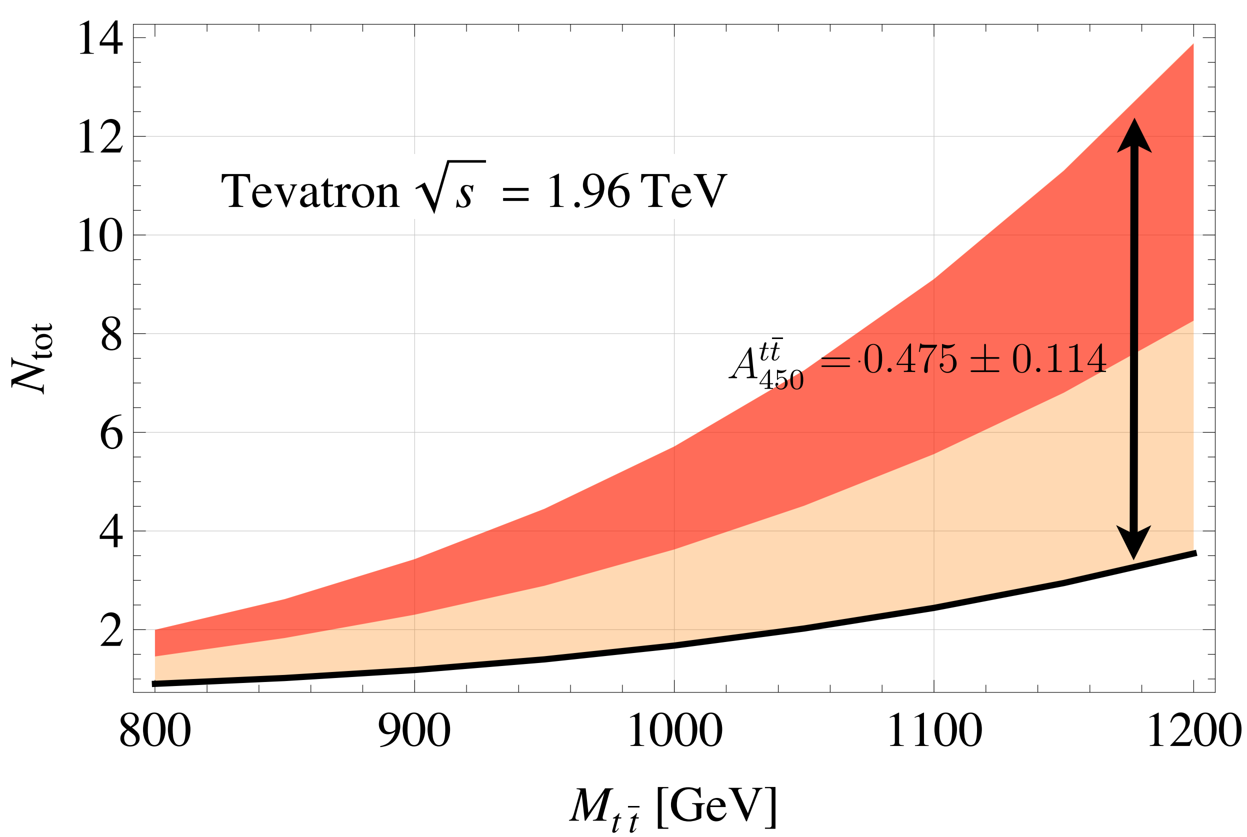
- The allowed range for the axial octet contribution is $0.3 \lesssim c_A^8 \lesssim 3.3$.

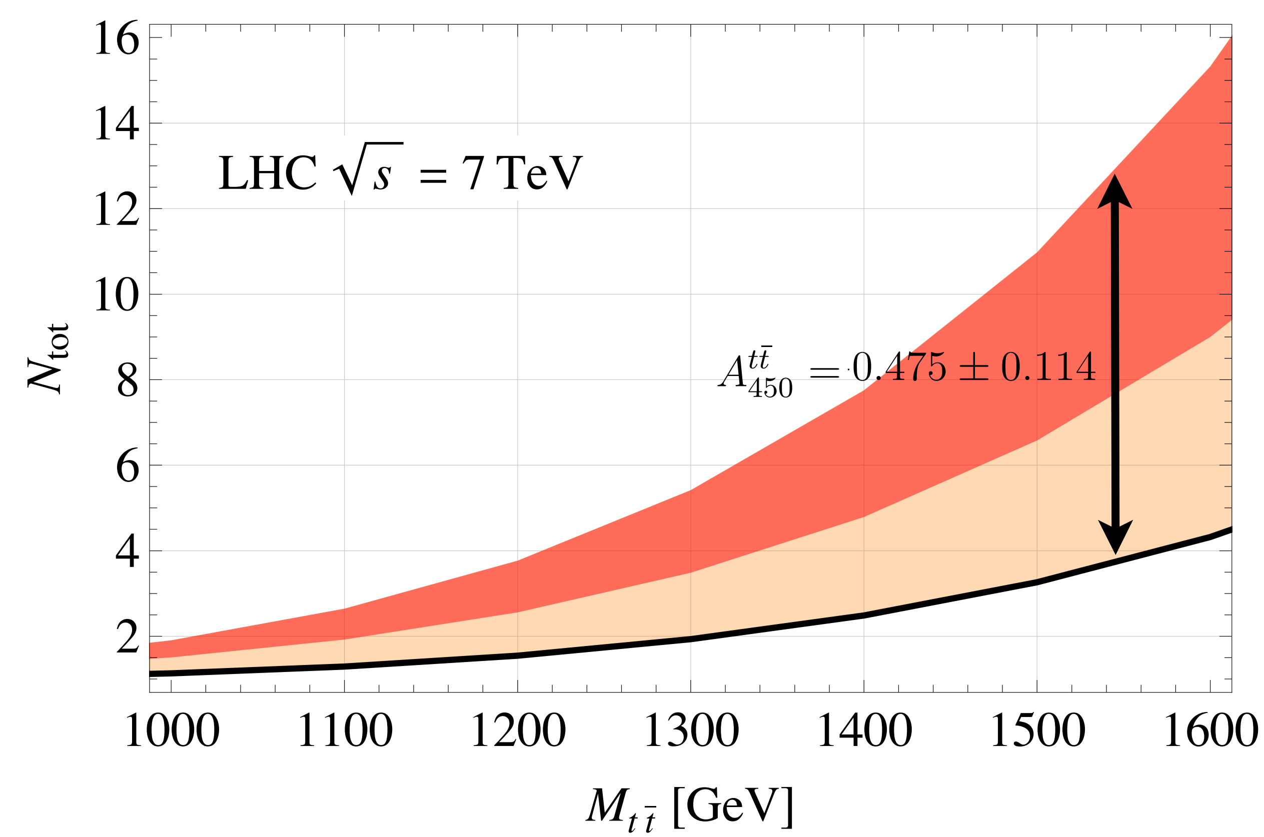
Consistent with the robust & beautiful Fig. 1 of: Grinstein, Kagan, Trott, Zupan, 1102.3374.

Predictions: anomalies in spectrum

Delaunay, Gedalia, Hochberg, GP, Soreq, 1103.2297;

$$N_{\rm tot} \equiv \frac{d\sigma^{\rm SM+NP}/dM_{t\bar{t}}}{d\sigma^{\rm SM}/dM_{t\bar{t}}}\,,$$





Smoking guns

$$N_{\rm tot}(M_{t\bar{t}} = 1\,{\rm TeV}) \gtrsim 2 \qquad \text{at the Tevatron}\,,$$
$$N_{\rm tot}(M_{t\bar{t}} = 1.5\,{\rm TeV}) \gtrsim 3 \qquad \text{at the LHC with } \sqrt{s} = 7\,{\rm TeV}\,.$$

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Anything else ?

“Postdiction”

$$N_b \equiv \sigma_b^{\mathrm{NP}} / \sigma_b^{\mathrm{SM}}$$

where σ_b is the cross section of hadronically-decaying $t\bar{t}$ with a p_T cut of 400 GeV on the leading jet

$$N_b > 0.5$$

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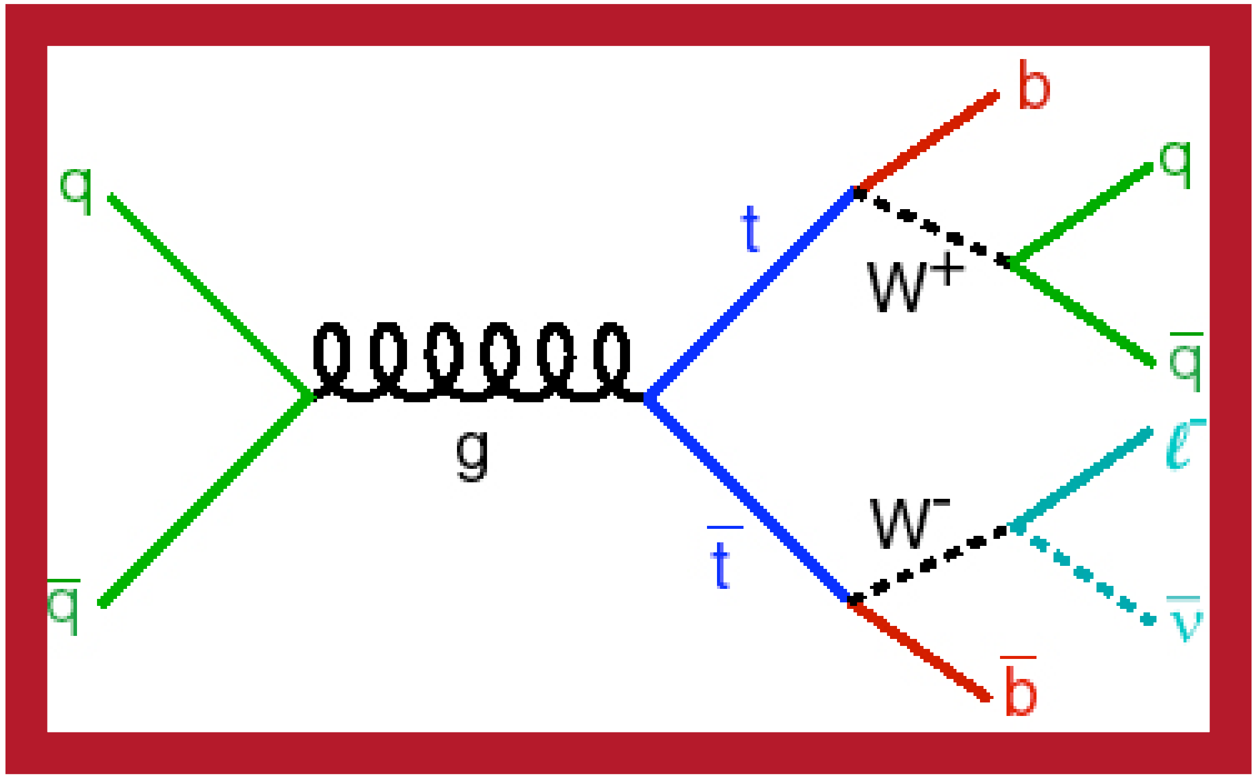
How to measure ?

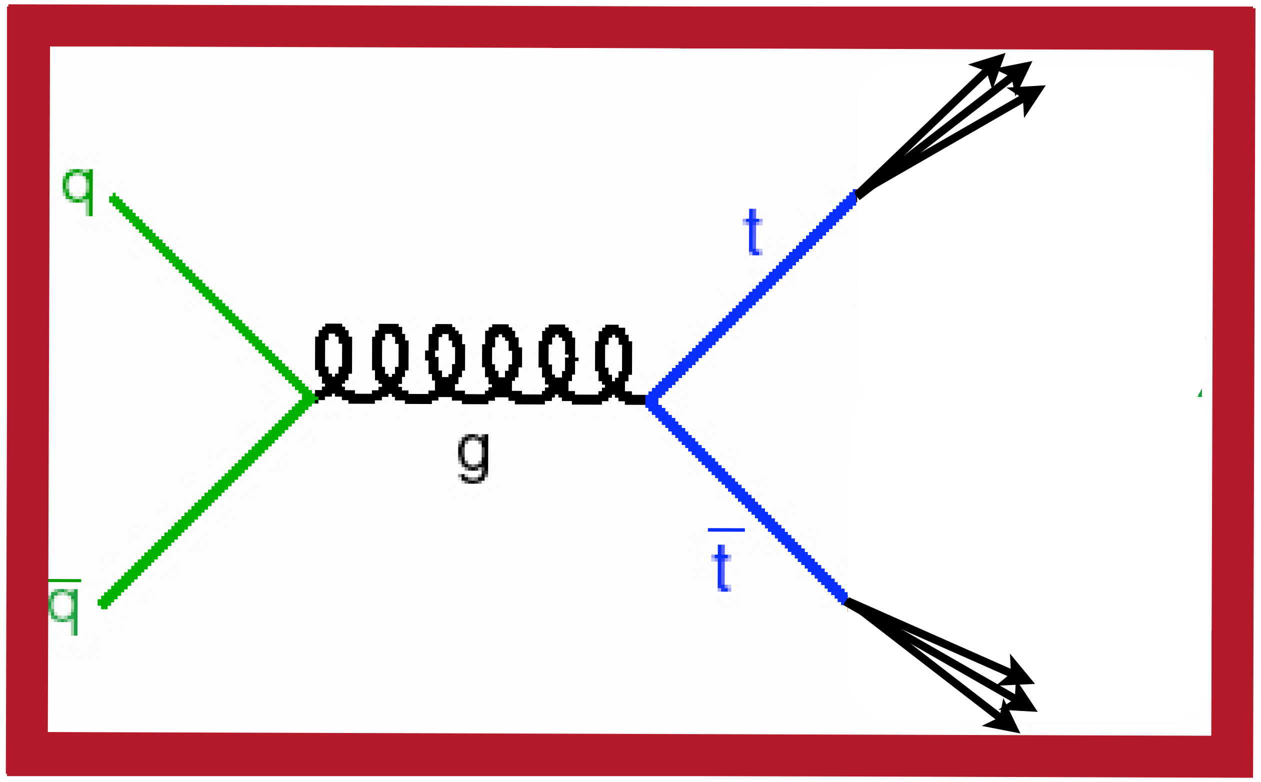
Boosted Massive Jets



(i) Brief theory.

(ii) First measurements @ CDF.

Boosted Massive Jets



(i) Brief theory.
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Jet Mass-Overview

- Jet mass-sum of "massless" momenta in h-cal inside the cone: $m_J^2 = (\sum_{i\in R} P_i)^2$, $P{i}^2 = 0$

Non trivial top-jet mass distribution

- Naively the signal is $J \propto \delta(m_J - m_t)$
- In practice $m_J^t \sim m_t + \delta m_{QCD} + \delta m_{EW}$

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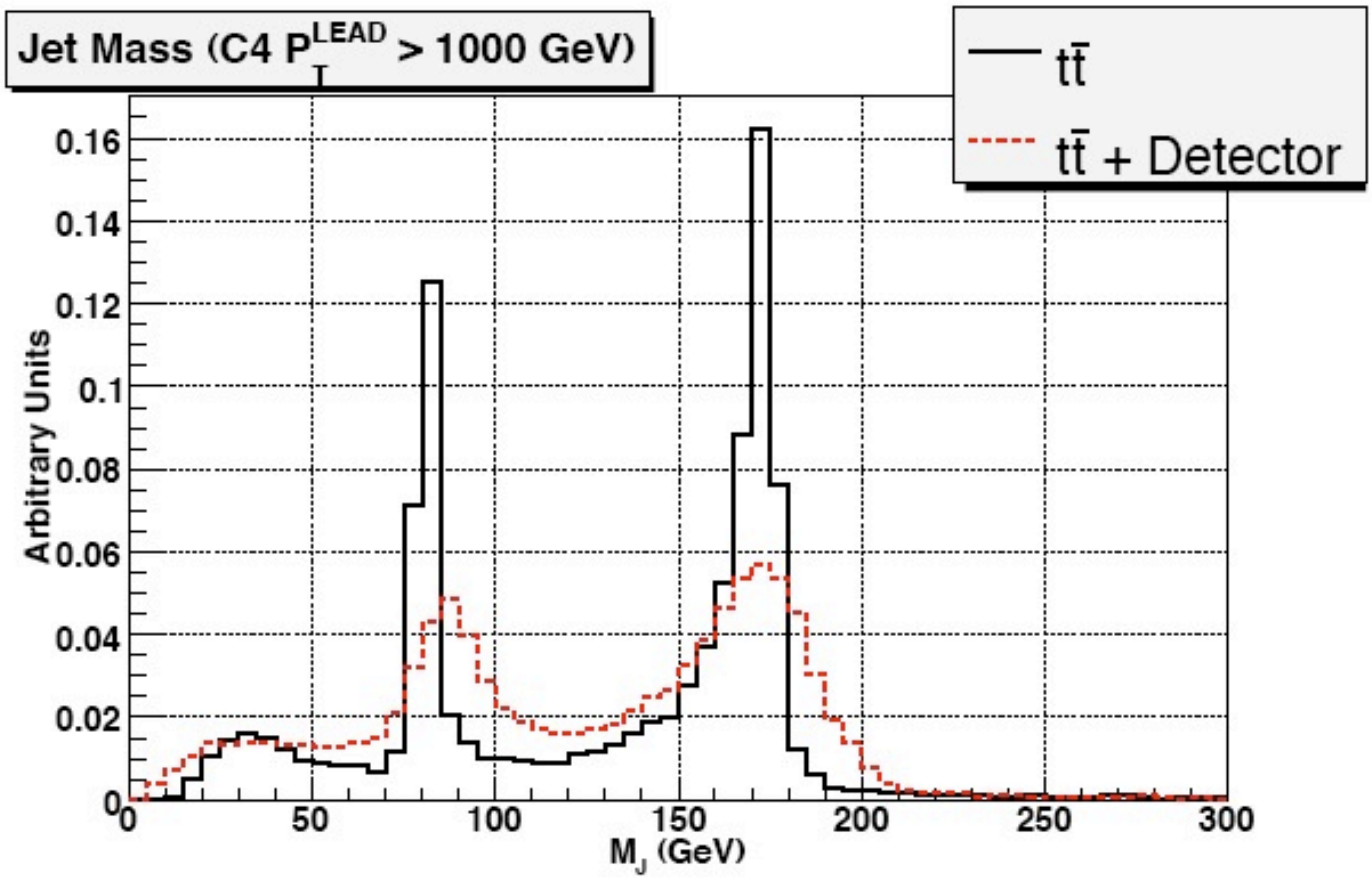
- In practice $m_J^t \sim m_t + \delta m_{QCD} + \delta m_{EW}$

  + detector smearing.

Almeida, Lee, Perez, Sung,& Virzi (08), see also Fleming, Hoang, Mantry, Stewart (07,08).

Sherpa => (CKKW) Transfer functions,



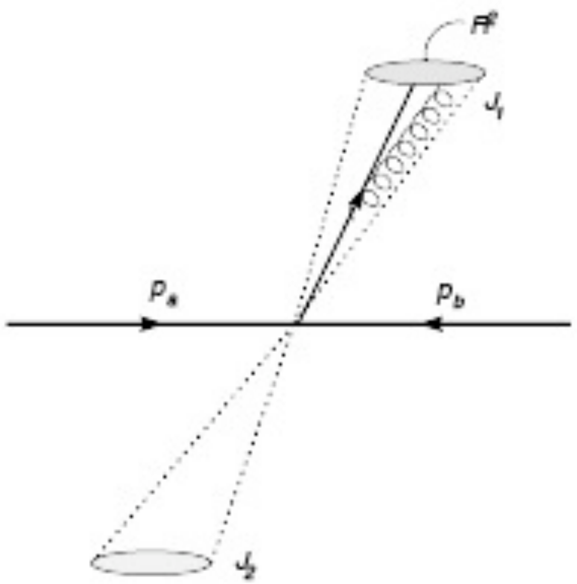
QCD jet mass distribution

Ellis, Huston, Hatakeyama, Loch and Tonnesmann (07); Almeida, Lee, GP, Sung, & Virzi; Almeida, Lee, GP, Sterman, Sung, & Virzi (08).

✦ Boosted QCD Jet via factorization:

$$\frac{d\sigma^i}{dm_J} = J^i(m_J, p_T^{min}, R^2)\, \sigma^i\left(p_T^{min}\right)$$

$$\int dm_J\, J^i = 1 \qquad i = Q, G$$



- can interpret the jet function as a probability density functions for a jet with a given pT to acquire a mass between m_J & $m_J + \delta m_J$

QCD jet mass distribution, Q+G

$$J^{(eik),c}(m_J, p_T, R) \simeq \alpha_S(p_T)\frac{4C_c}{\pi m_J}\log\left(\frac{R\,p_T}{m_J}\right)$$

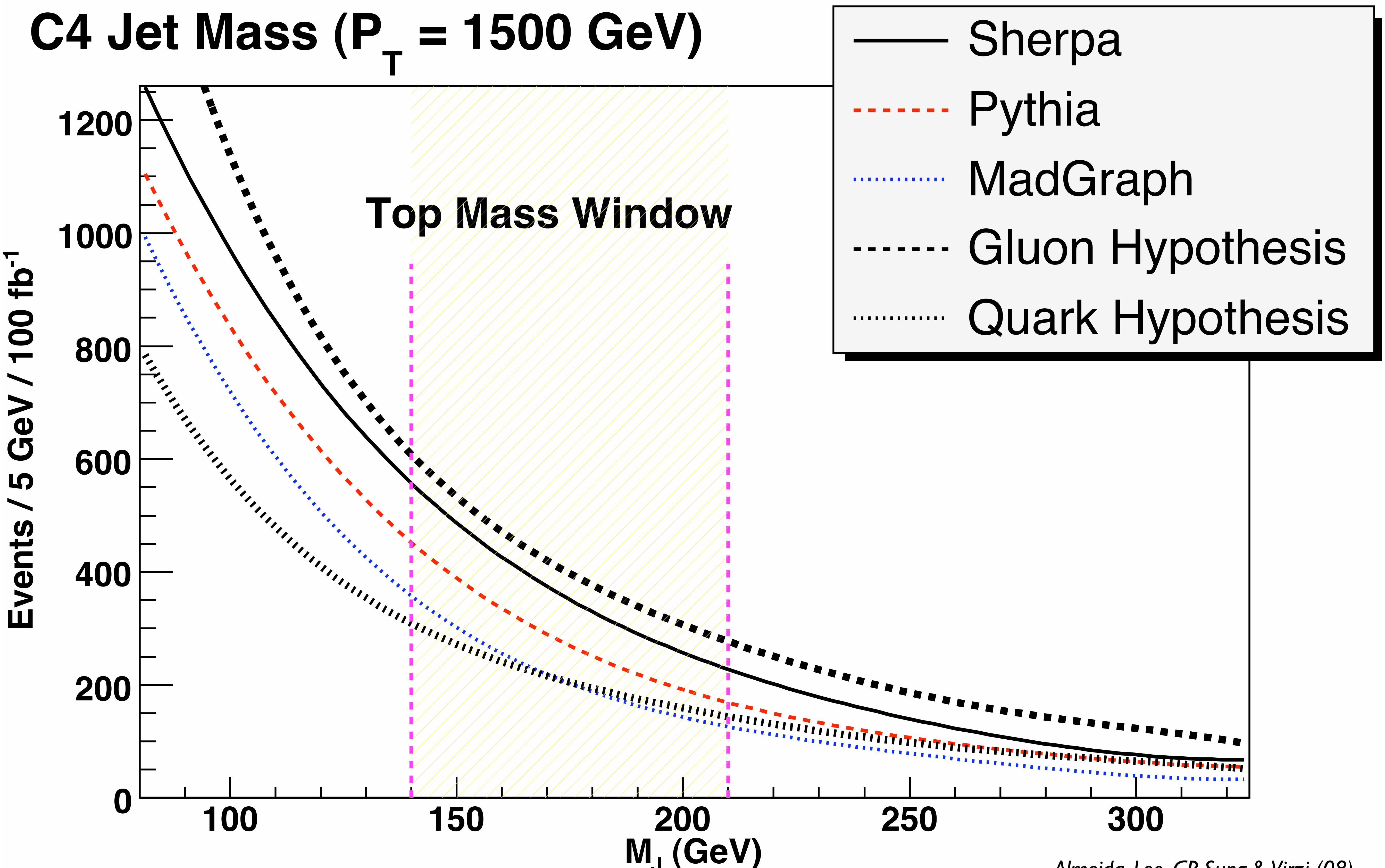
$C_F = 4/3$ for quarks, $C_A = 3$ for gluons.

Data is admixture of the two, should be bounded by them:

$$\frac{d\sigma_{pred}(R)}{dp_T dm_J}_{upper\ bound} = J^g(m_J, p_T, R)\sum_c\left(\frac{d\sigma^c(R)}{dp_T}\right) ,$$

$$\frac{d\sigma_{pred}(R)}{dp_T dm_J}_{lower\ bound} = J^q(m_J, p_T, R)\sum_c\left(\frac{d\sigma^c(R)}{dp_T}\right) ,$$

Jet mass distribution theory vs. MC (LHC 14TeV)



Almeida, Lee, GP, Sung,& Virzi (08)

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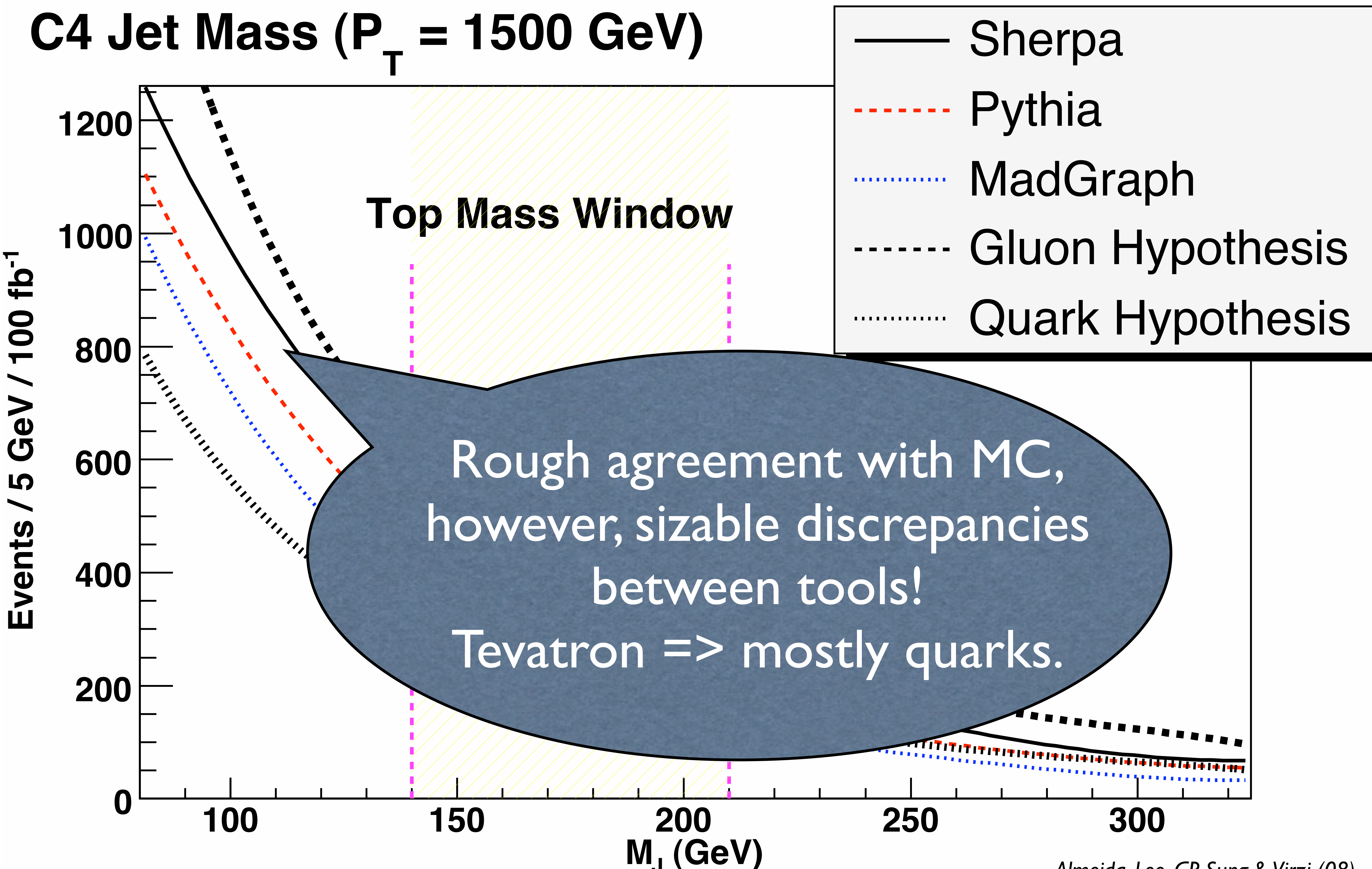


Almeida, Lee, GP, Sung,& Virzi (08)

Boosted Massive Jets @ CDF

R, Alon, E. Duchovni, GP & P. Sinervo, for the CDF, CDF/PUB/JET/PUBLIC/10199; CDF/ANAL/TOP/PUBLIC/10234;

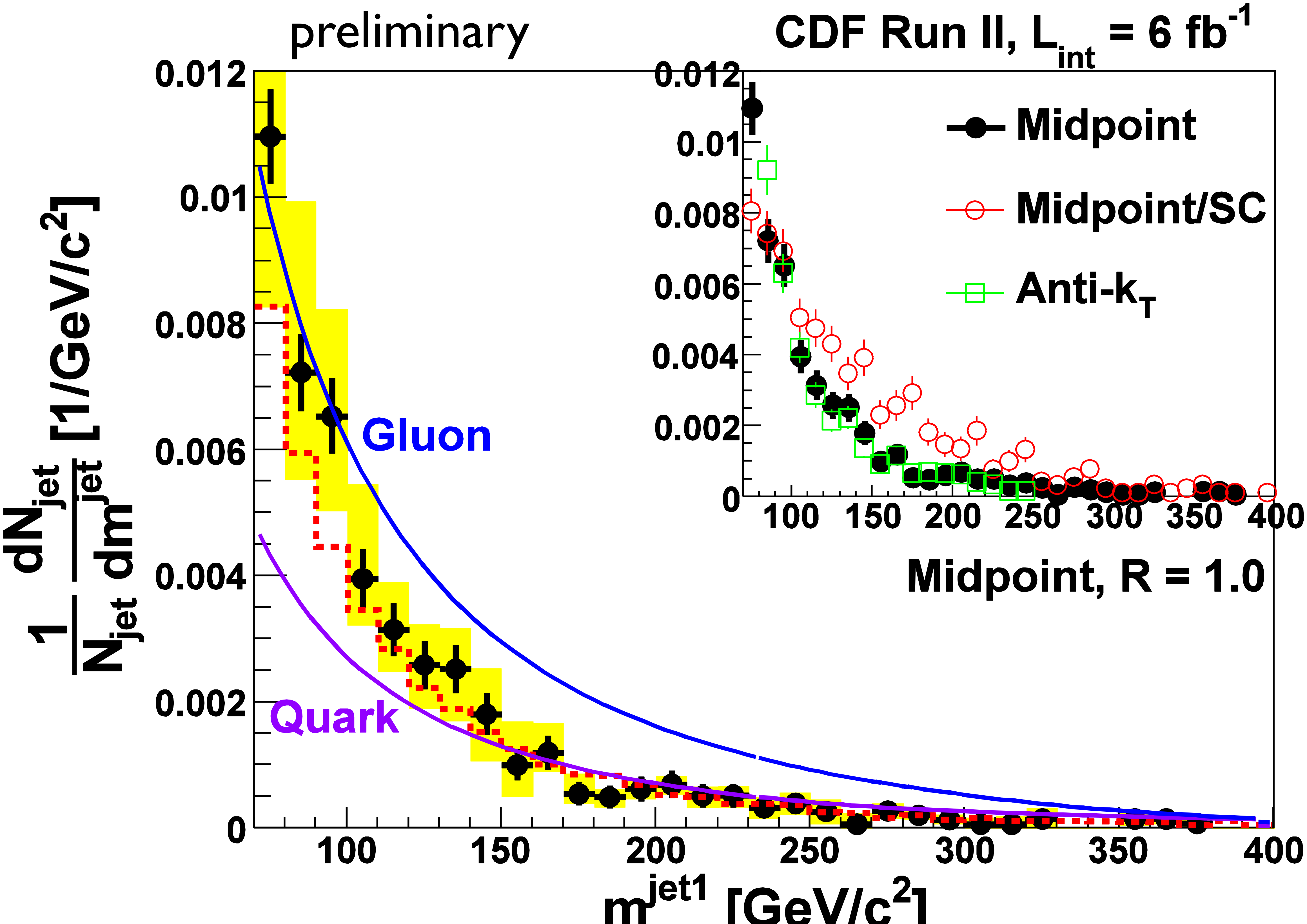
experimentalist

The preliminary data to be looked at

Cut Flow		
	R = 0.4	R = 0.7
All Data, 5.95 fb^{-1}	75,764,270 events	
At least one jet with $p_T > 400$ GeV/c, $0.1 < \|\eta\| < 0.7$, and event quality cuts	2,153	2,700
$m^{jet2} < 100$ GeV/c^2 and $S_{MET} < 4$ (with $p_T^{jet2} > 100$ GeV/c and MI corrections)	1,837	2,108

Top rejection cut.

Jet mass distribution, high mass region



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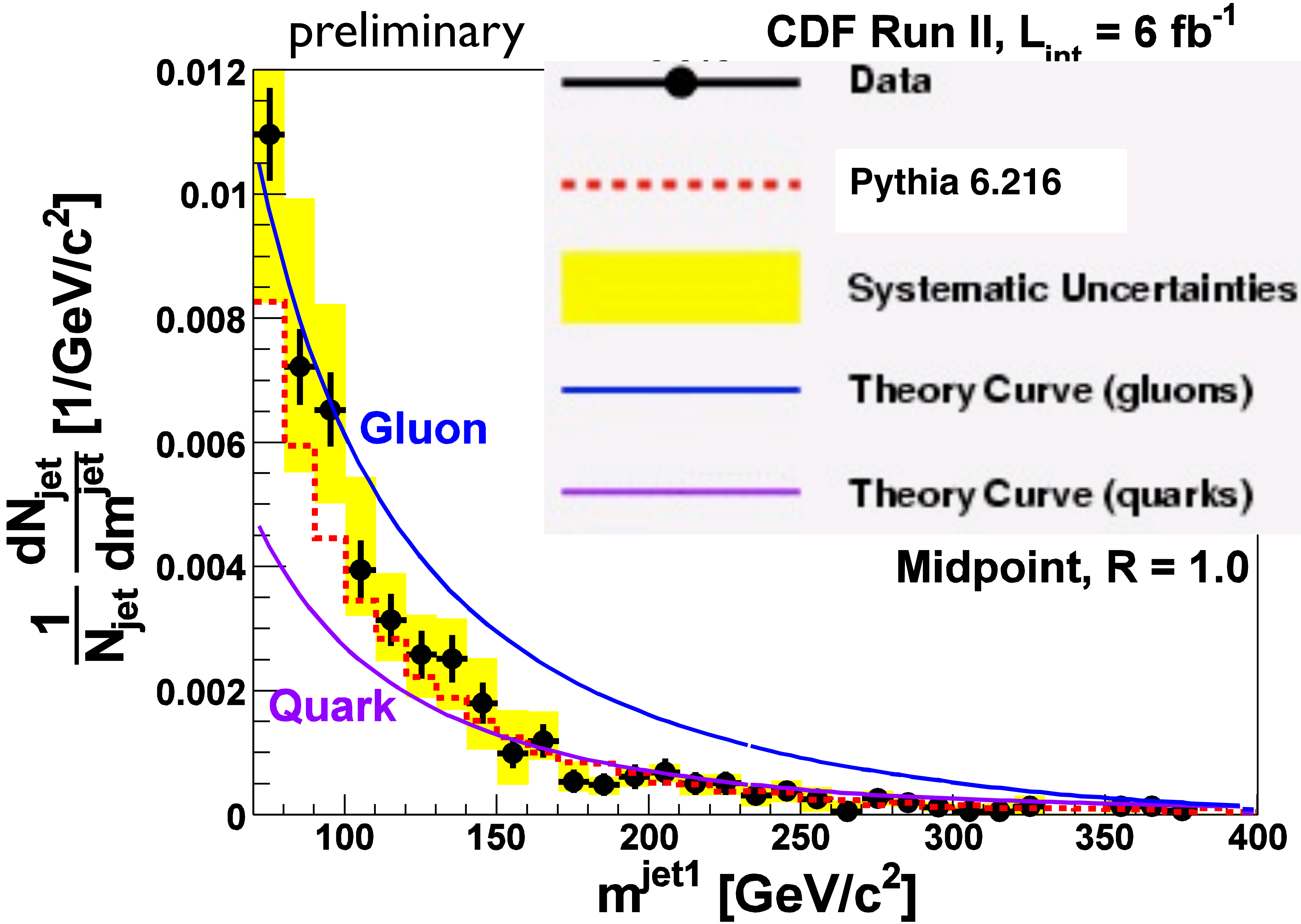

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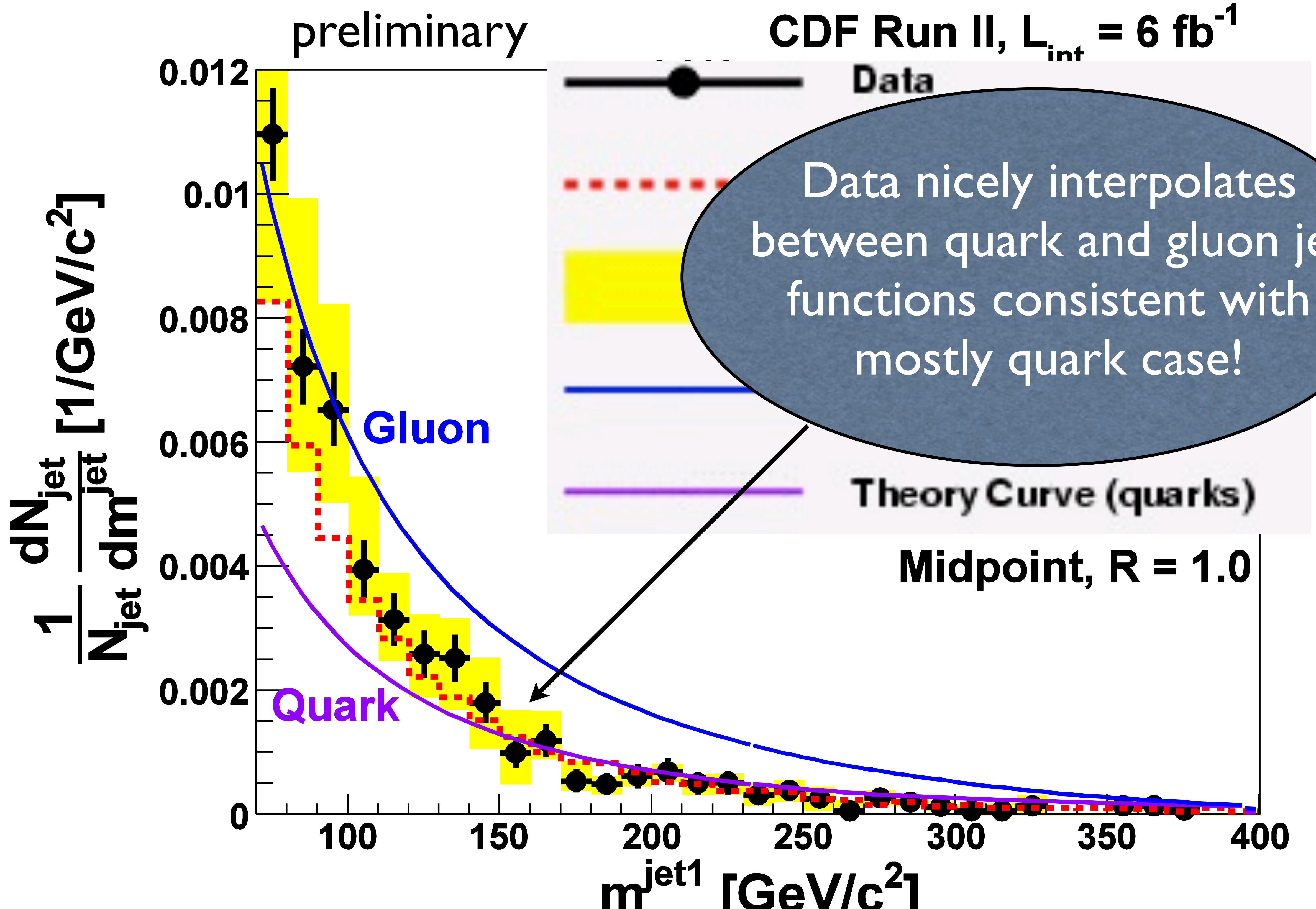
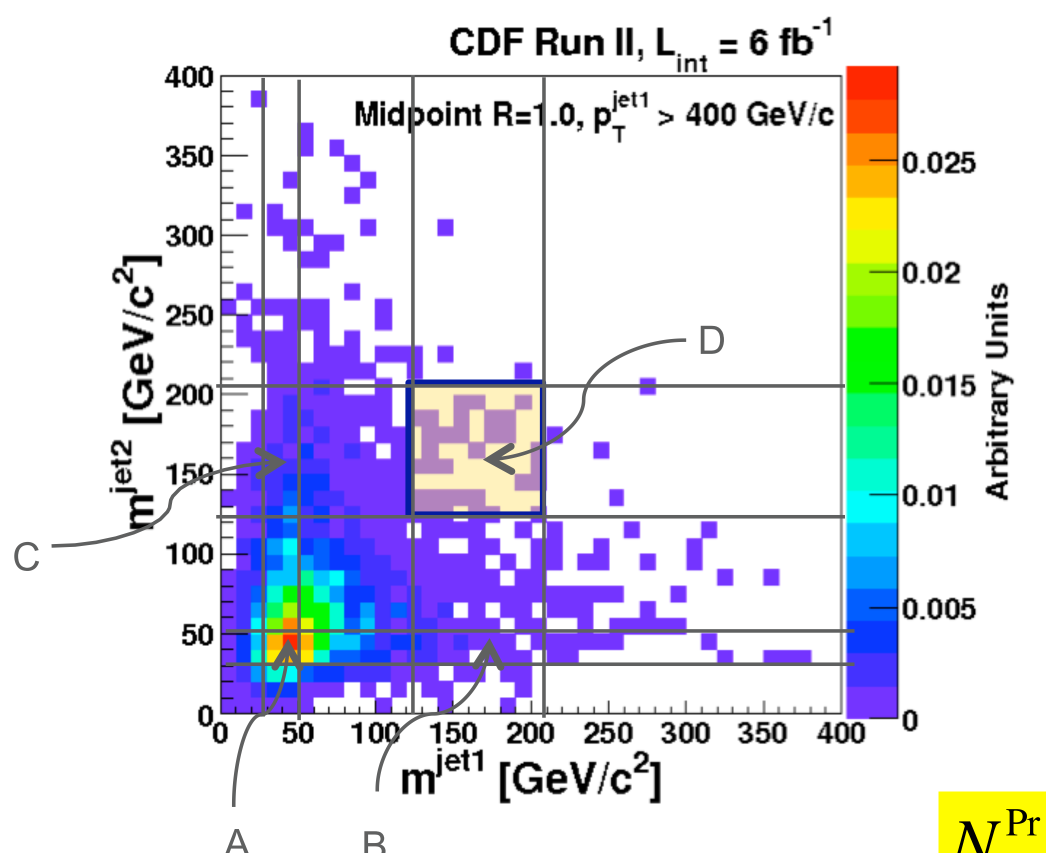


Search for massive boosted particles

- With R=1.0 cones, m^{jet1} and m^{jet2} are equally powerful
  - Use jet mass (130,210) GeV/c^2 to define ttbar candidates
  - Expect 3.0±0.5 top quark events to populate this region



- Employ data to estimate backgrounds
  - Define mass windows
    $m^{jet} \in (130,210)$ GeV/c^2
    $m^{jet} \in (30,50)$ GeV/c^2
    - Use fact that m^{jet} distributions uncorrelated for background
    - Signal is region D
    - In "1+1" sample, predict 13±2.4 (stat) bkgd events

$$N_D^{Pred} = N_C(N_B / N_A)$$

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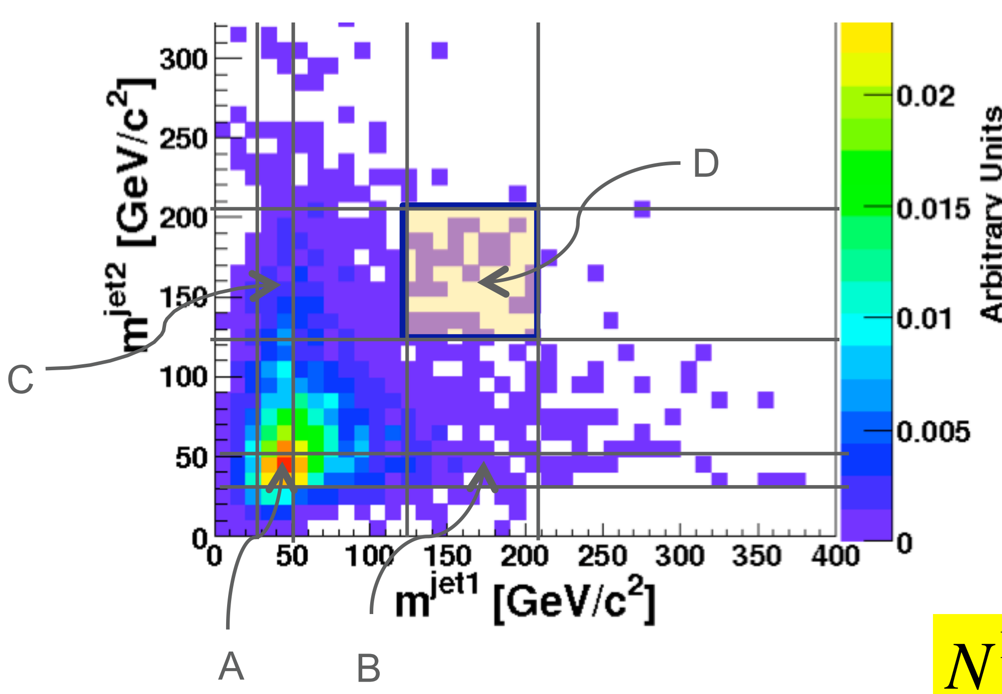
Observe N_D=32 events



$$N_D^{Pred} = N_C (N_B / N_A)$$

Possible excess in di-massive jets

$$R_{\rm mass} \equiv \frac{n_{\rm B} n_{\rm C}}{n_{\rm A} n_{\rm D}} \sim 1 \qquad \Rightarrow \qquad n_D = \frac{n_B n_C}{n_A} R^{-1}_{\rm mass}$$

$$\text{Excess} \sim \left[3.4 - 6.1\left(1 - R_{\rm mass}\right)\right]\sigma$$

$$\sigma_b \equiv \sigma^{t_h \bar{t}_h}(p_T > 400\,\text{GeV}) \sim \left[21 - (8.7 \pm 3.1)\, R^{-1}_{\rm mass}\right]\,\text{fb},$$

K. Blum, C. Delaunay, O. Gedalia, Y. Hochberg, S. Lee, Y. Nir, GP, Y. Soreq, 1102.3133.

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Assessing the significance of the excess

- Simplest explanation is QCD:
  not coming from PDF, since the ratio is close to unity.
- Value of R from MC:

MC tools	Matching	$R_{\rm mass}$
Sherpa	Yes	0.88 ± 0.03
MadGraph	Yes	0.86 ± 0.04
MadGraph	No	0.76 ± 0.04
Herwig	No	0.86 ± 0.02

$R_{\rm mass} \sim 1$ => tension is slightly reduced but is still there!

Assessing the significance of the excess

- Simplest explanation is QCD:

  not coming from PDF, since the ratio is close to unity.

- Value of R

Consistent with the conclusion of the EFT AFB analysis shown, that predicts excess in the boosted top region!

Herwig ... ± 0.02

$R_{\rm mass} \sim 1$: ... there!

Delaunay, Gedalia, Hochberg, GP, Soreq, 1103.2297

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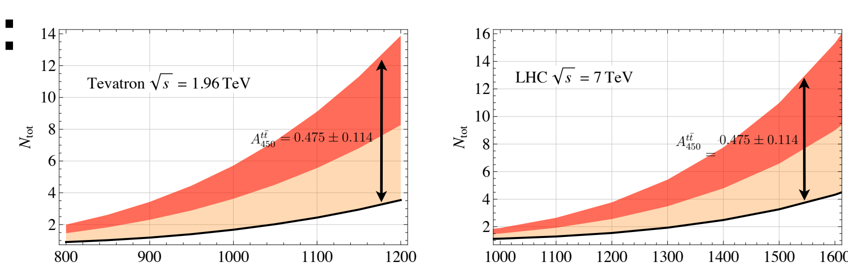

"Postdiction"

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$$N_b > 0.5$$

tLHCB

theorist

A. Kagan, J. Kamenik, GP, S. Stone, 1103.3747.

LHCb unique forward top detection potential

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Also motivated by models with t-channel light particle exchange.

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LHCb unique forward top detection potential

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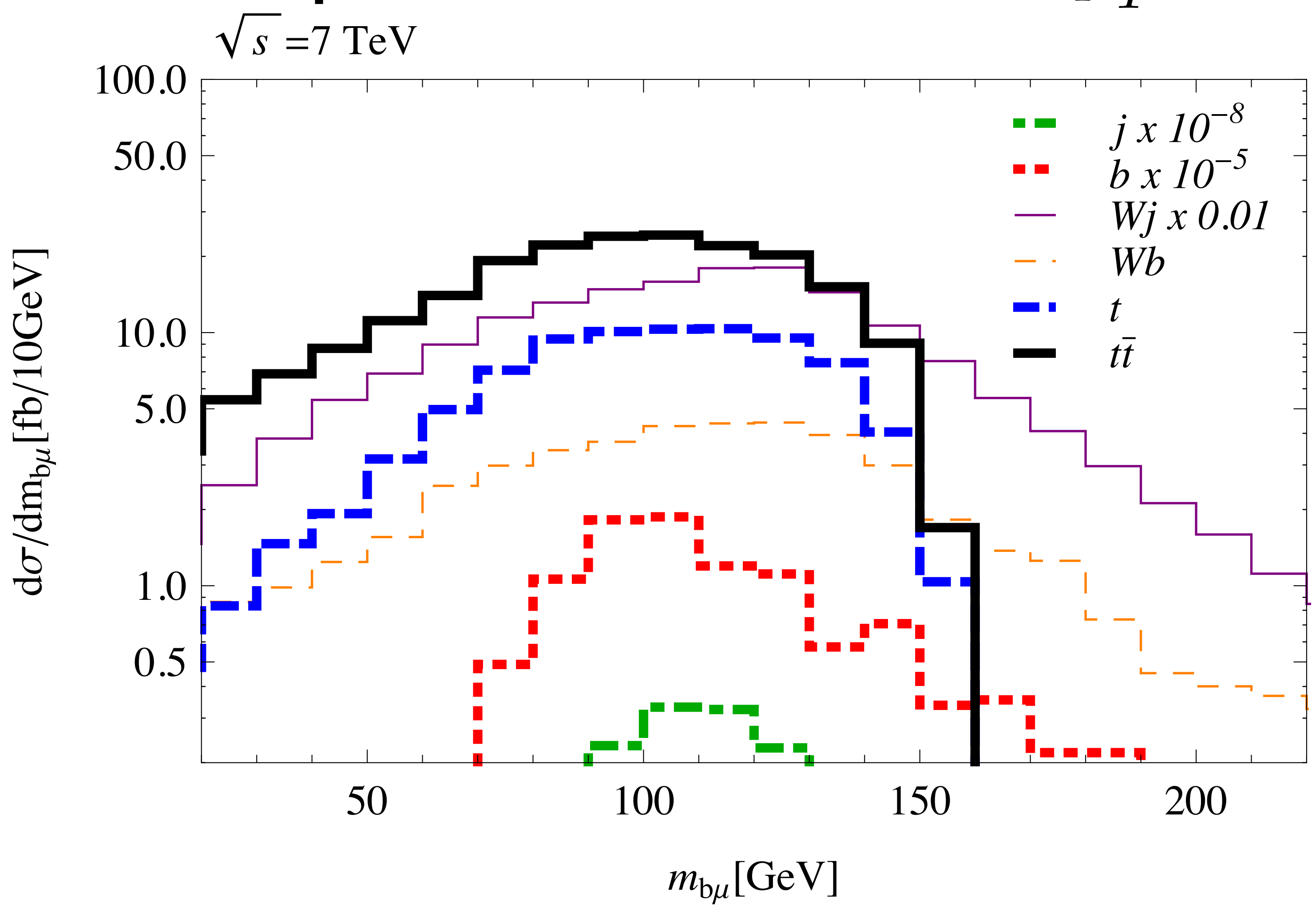
Also motivated by models with t-channel light particle exchange.

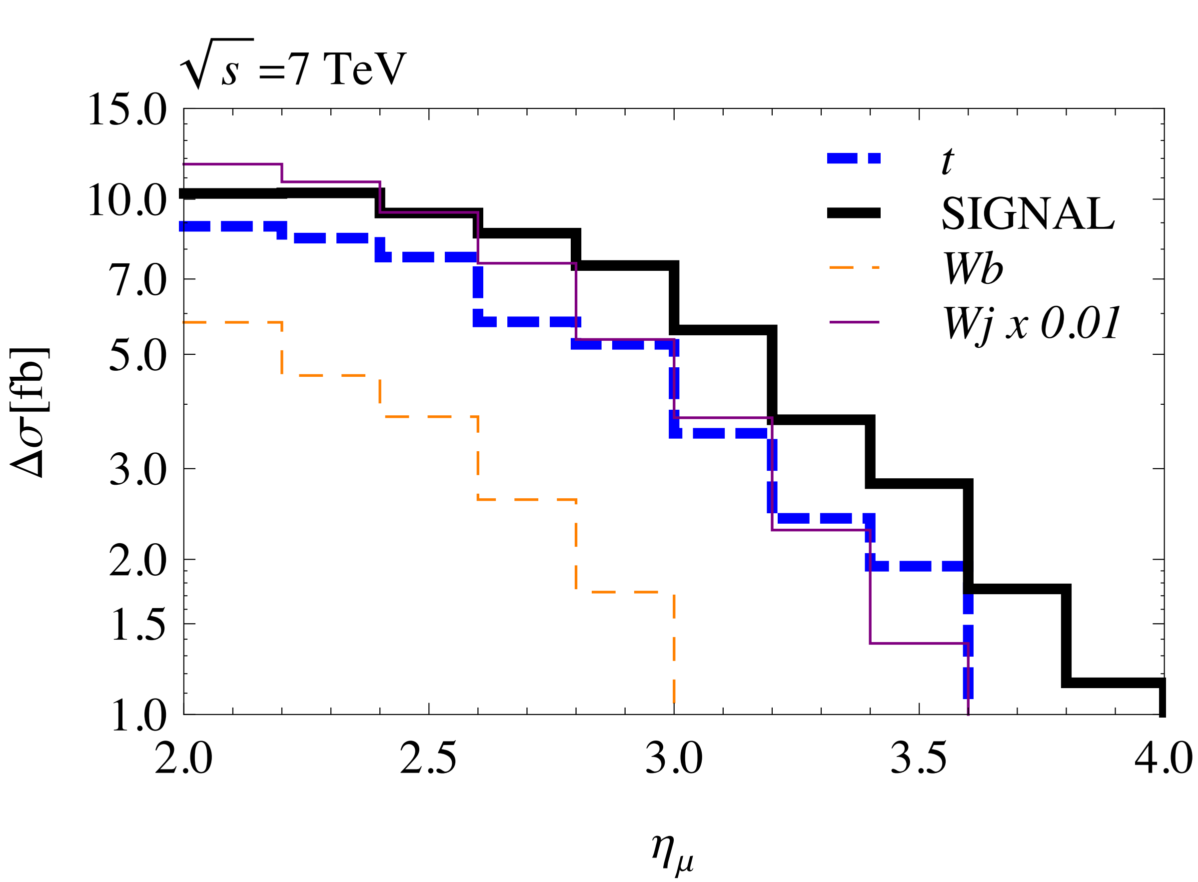
- What's top? b & isolated ℓ with $p_T^{b,\ell} > 50, 20\,\text{GeV}$ & $m_{b\ell} > 50\,\text{GeV}$.

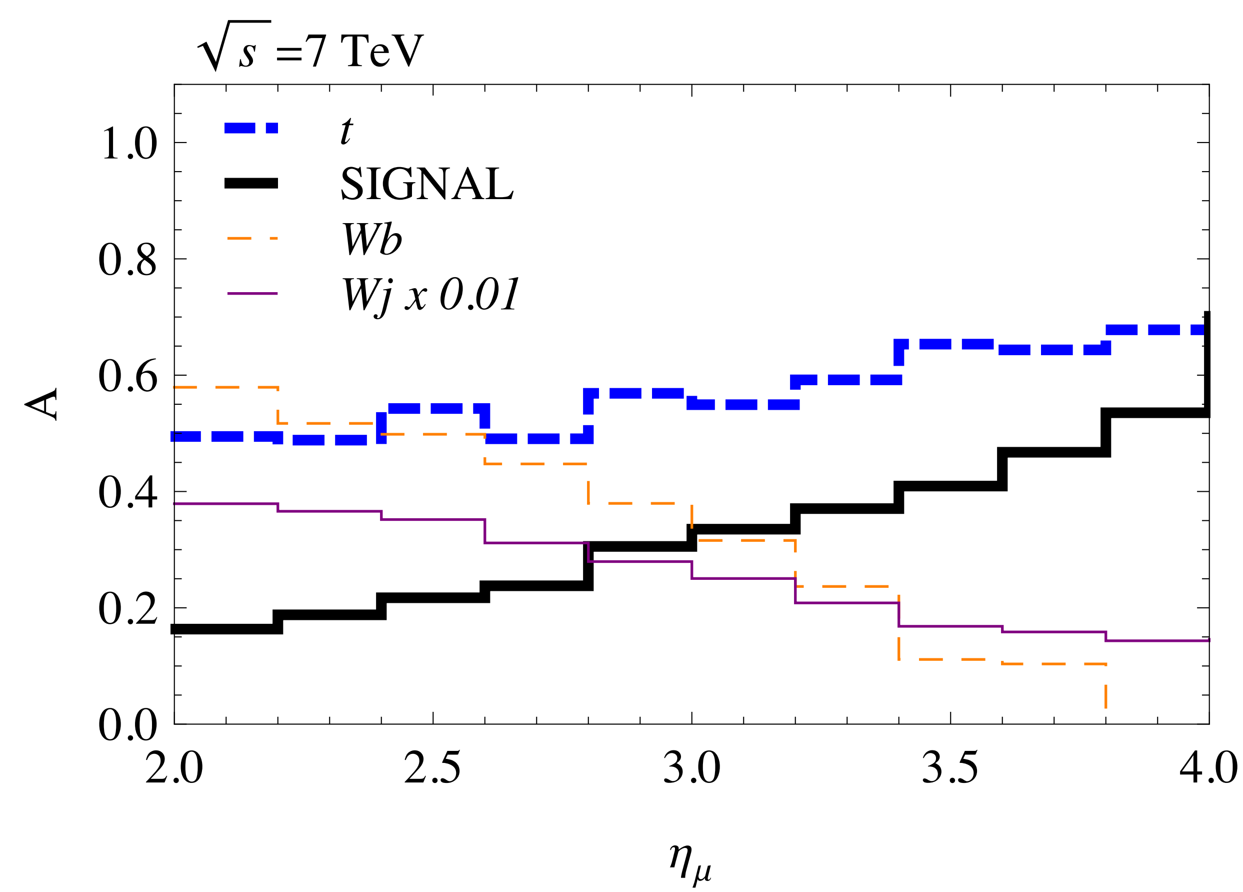


LHCb unique forward top rate asym' detection potential

✦ Even though LHC symmetric, a rate asym' is induced by the AFB:

$$A_{\eta}^{t\bar{t}} = \left(\frac{d\sigma^t/d\eta - d\sigma^{\bar{t}}/d\eta}{d\sigma^t/d\eta + d\sigma^{\bar{t}}/d\eta} \right)_{\eta \in 2-5}$$





Summary

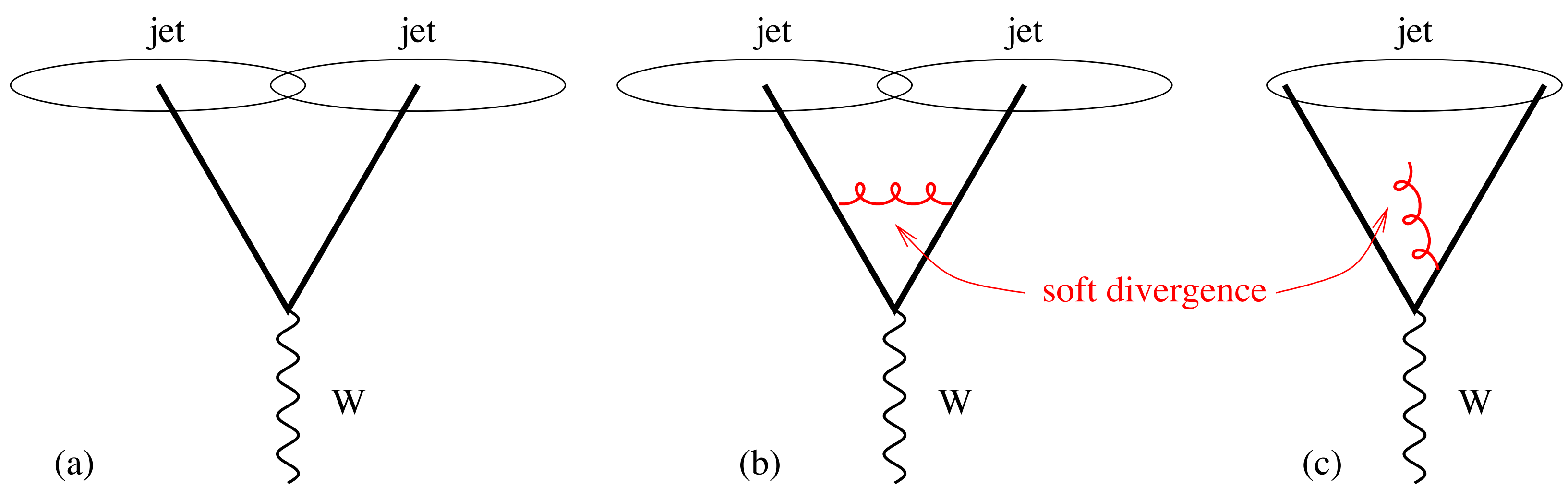
- ✦ Simple EFT description of AFB => smoking guns for Tevatron & LHC.
- ✦ Soon to be tested, overlap with boosted massive jet search
- ✦ Interesting excess of di-massive jet events @ CDF (not in ones \w MET)
- ✦ LHCb has unique potential to probe forward region for tops, including SM rate & asym' (especially for light t-channel).

Backups

IR-collinear sensitivity & jet mass

MidPoint searchcone IR_{2+1} => harder jets.

Salam, Eur. Phys. J. (2010)



2 perturbative massless jets

massive jet

IR-collinear sensitivity & jet mass

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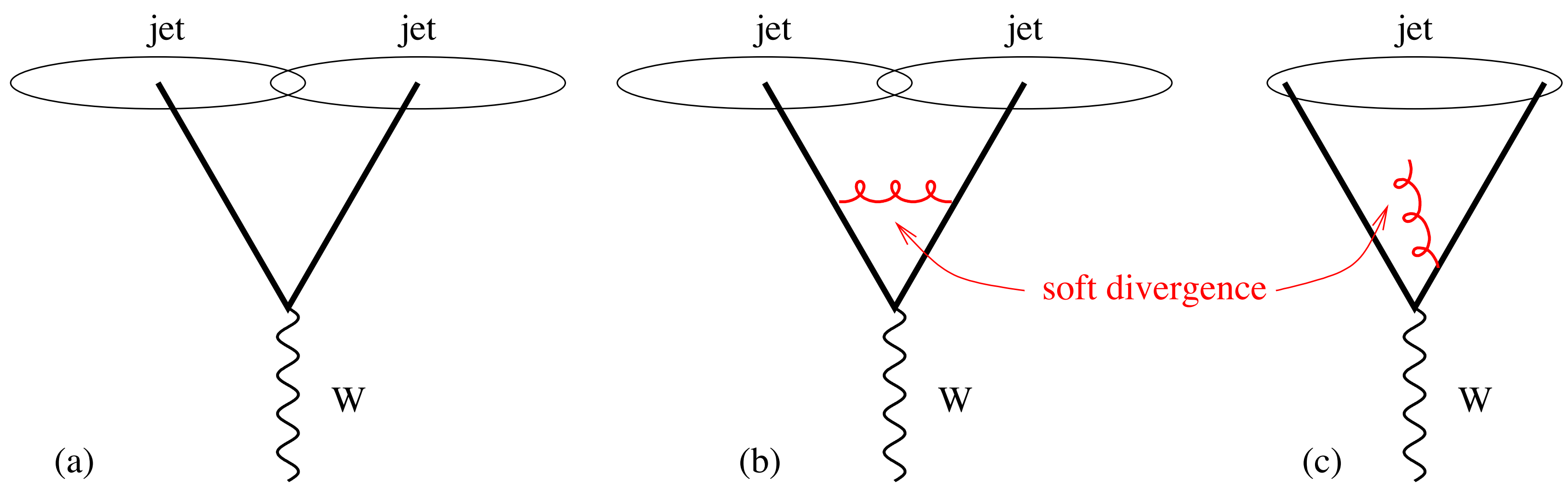

2 perturbative massless jets

massive jet

MidPoint IR_{3+1} => problem postponed to NLO.