מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

TOP B PHYSICS

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arXiv: 1212.4611

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INTRODUCTION

- The LHC is a *top-factory*:

  8 TeV: about 4 million top-pairs

  14 TeV (300 fb^{-1}): expected to 240 million top pairs

- 100 TeV *pp* collider (300 fb^{-1}): 10^{10} top pairs are expected

INTRODUCTION

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  explore the **top properties** or search for heavy new physics

- We point out that tops can also be used for **flavor precision measurements**:

Probe CPV in heavy flavor mixing and decays

OUTLINE

- Brief introduction
- The proposed measurement and its relation to CP-violation (CPV) sources
- LHC sensitivity (preliminary)
- Summary

INTRODUCTION

- Existing analyses of CPV in B-physics rely on production of bottom pairs:

  B-factories: resonance decay $\Upsilon\left(4\mathrm{S}\right) \to b\bar{b}$

  Tevatron/LHCb: gluon splitting $g \to b\bar{b}$

INTRODUCTION

- Existing analyses of CPV in B-physics rely on production of bottom pairs:

B-factories: resonance decay $\Upsilon(4\mathrm{S}) \to b\bar{b}$

Tevatron/LHCb: gluon splitting $g \to b\bar{b}$

- Consider for example: D0 like-sign dimuon asymmetry

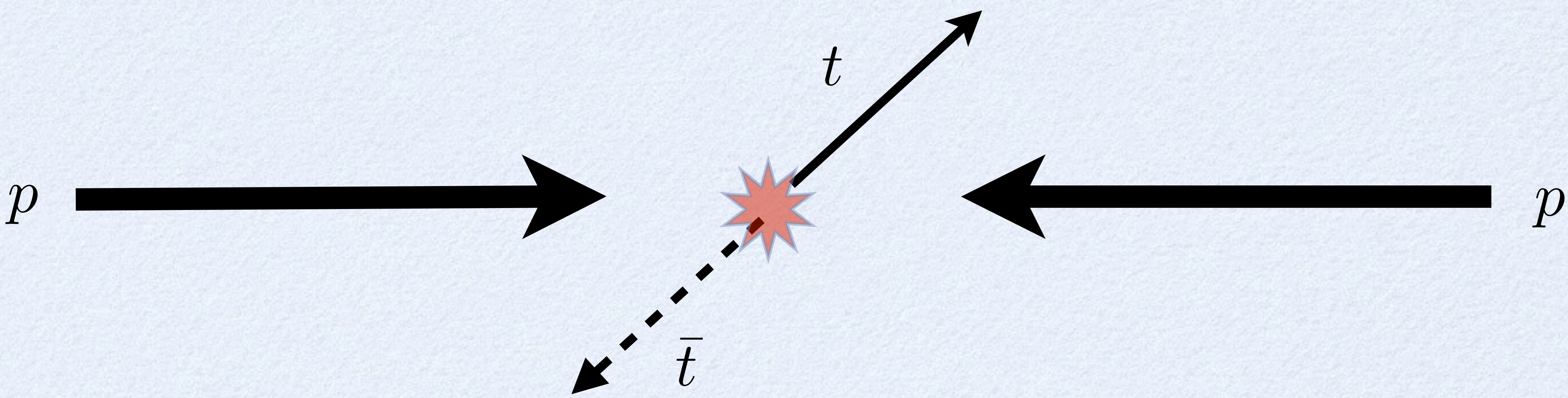
$$p\bar{p} \to b\bar{b} \to \mu^{\pm}\mu^{\pm} X$$

↑

$B - \overline{B}$ mixing

$$A^b_{\rm sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \qquad (3.8\sigma \text{ from SM})$$

The proposed measurement



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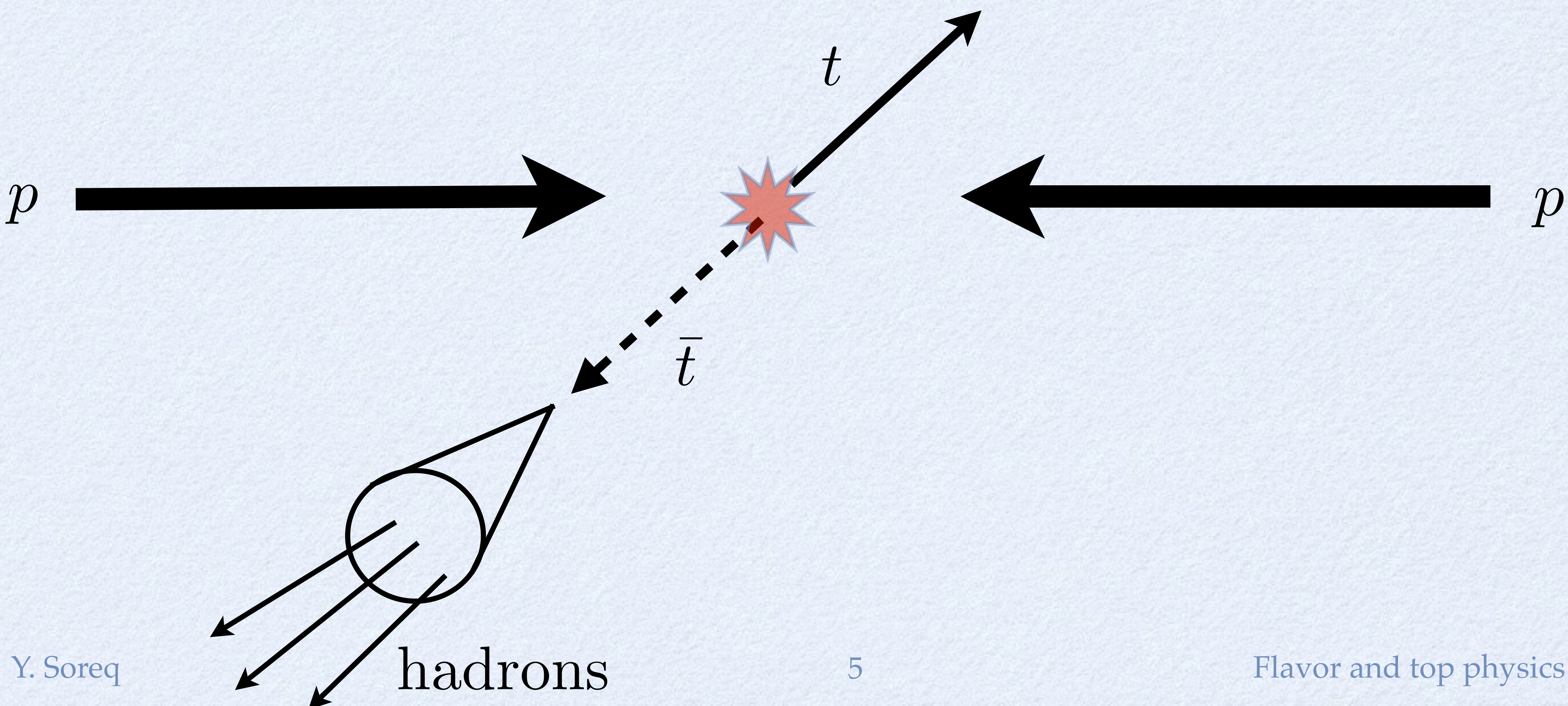

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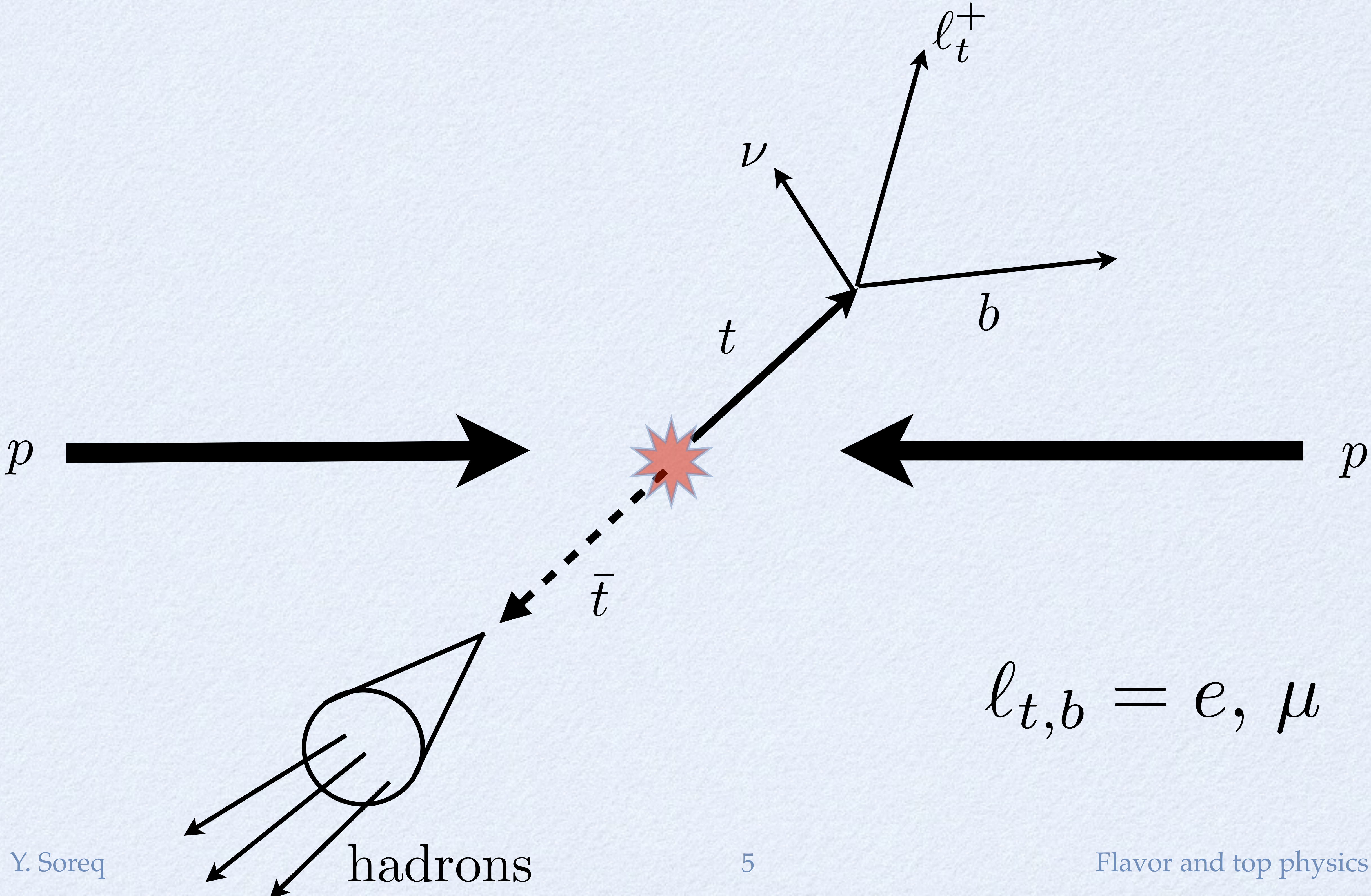
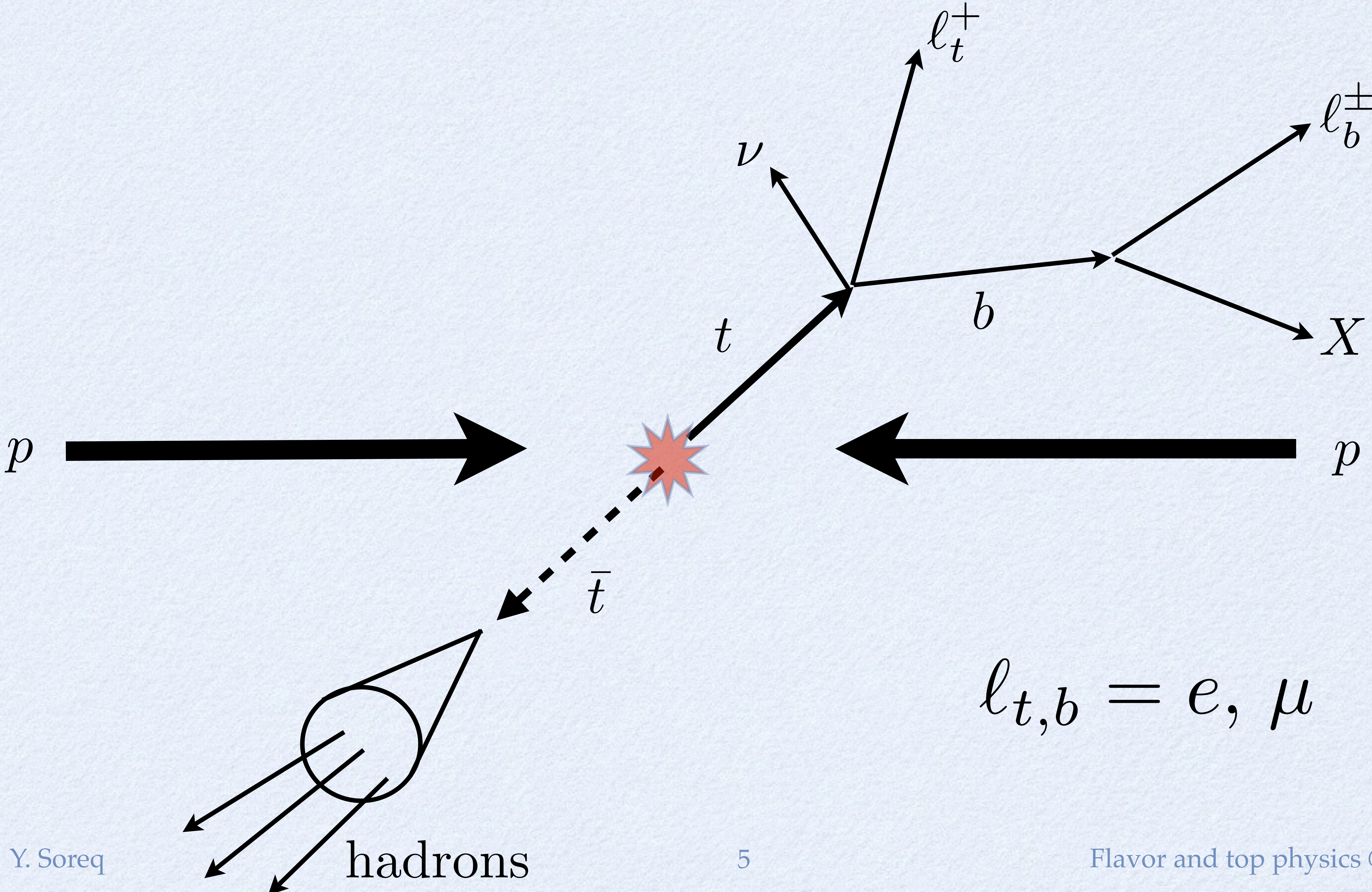


$$\ell_{t,b} = e,\ \mu$$

The Proposed Measurement



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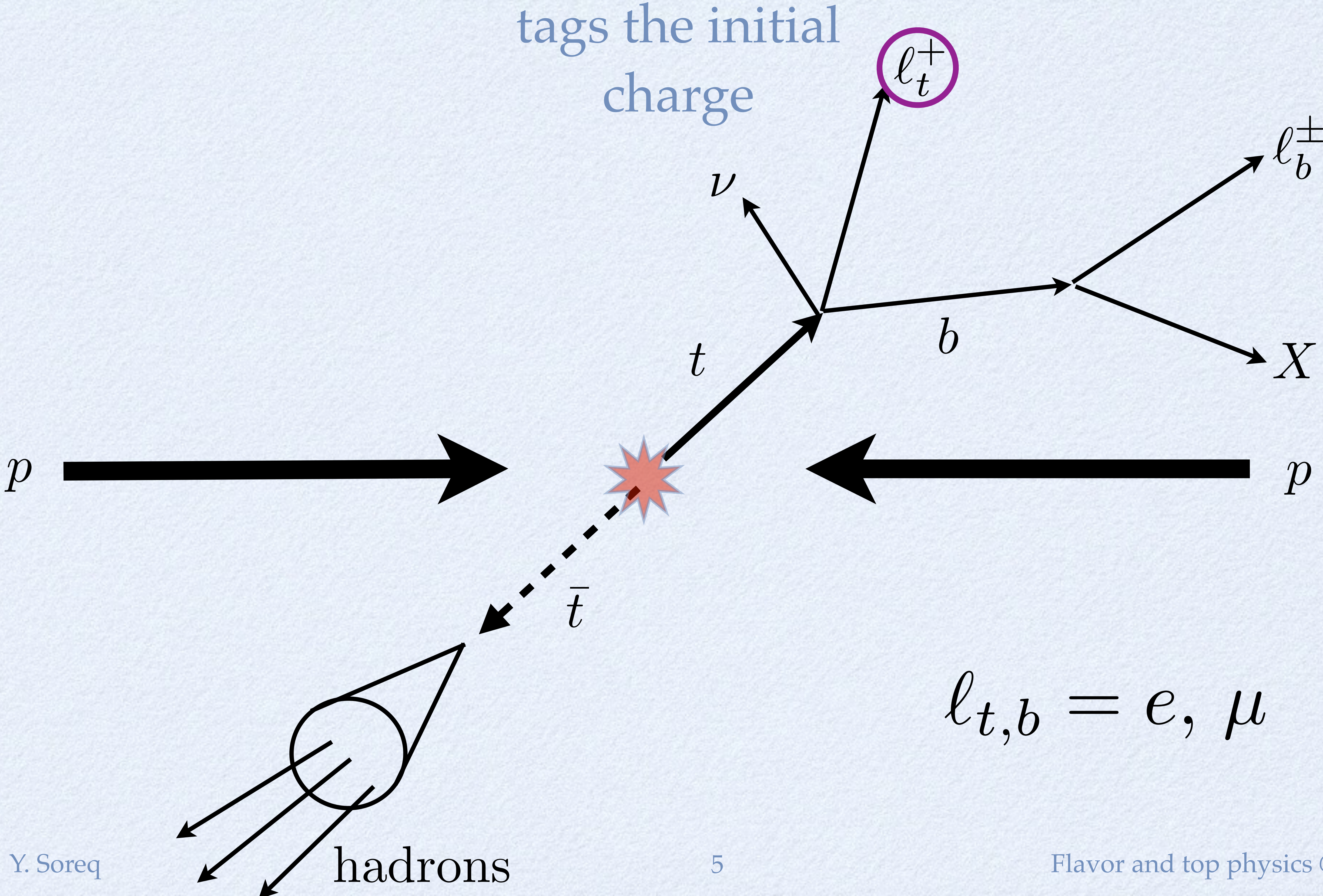

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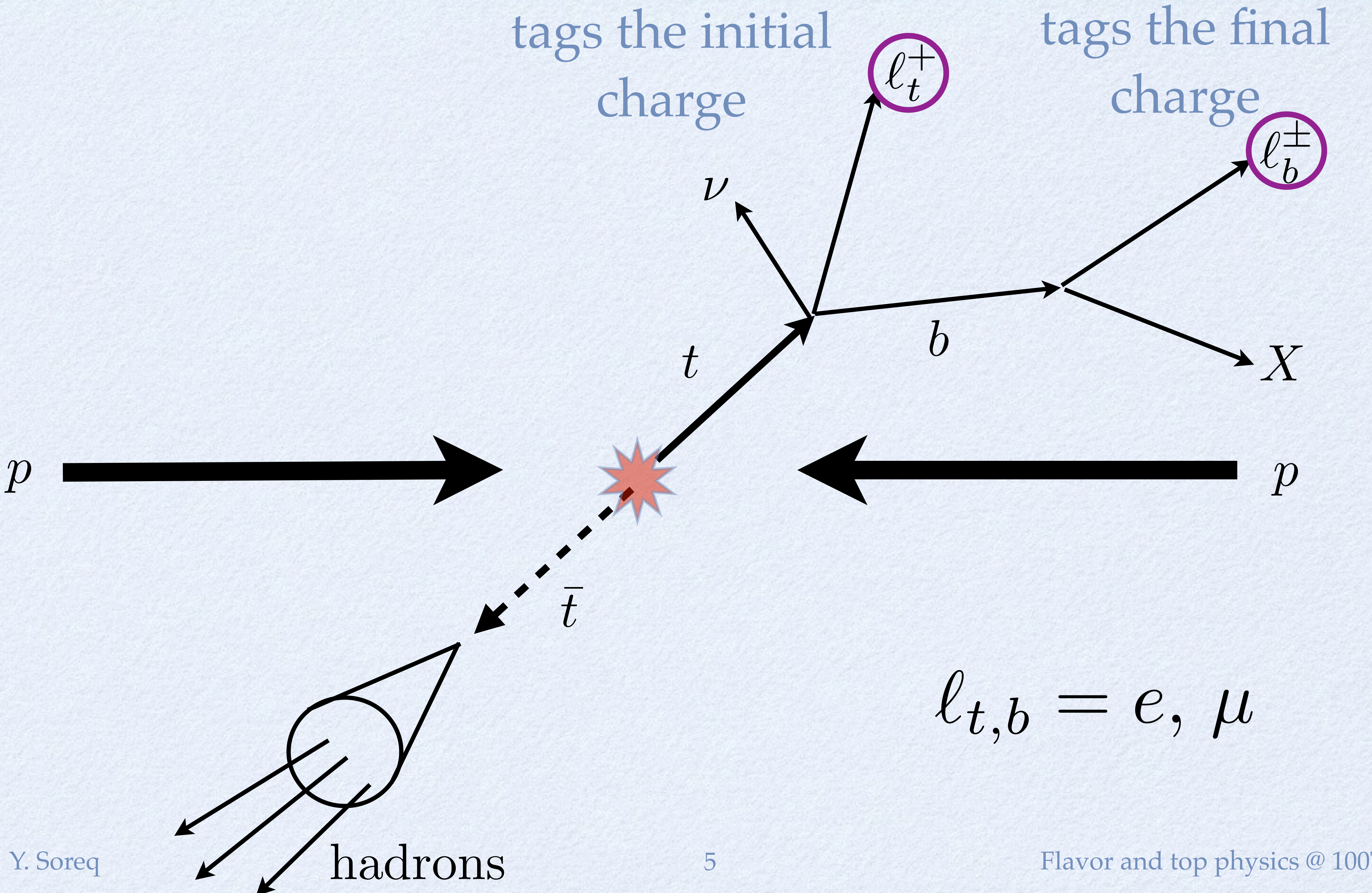

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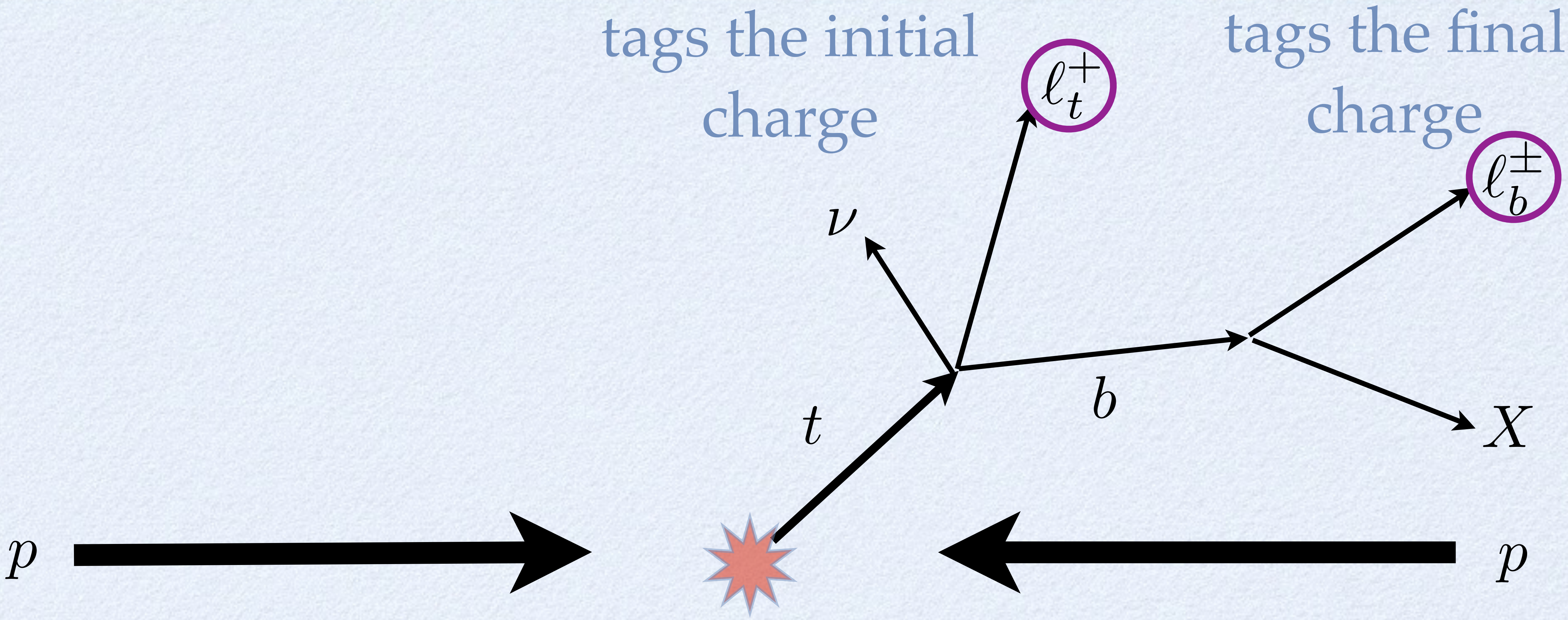
The proposed measurement



Two type of events:

Same Sign: $\text{Charge}\,(\ell_t) = \text{Charge}\,(\ell_b)$

Opposite Sign: $\text{Charge}\,(\ell_t) \neq \text{Charge}\,(\ell_b)$

Constructing the asymmetries

Same-Sign (SS) Opposite-Sign (OS)

Assume that light mesons (u,d,s) can be rejected, but not Charm mesons.

Constructing the asymmetries

Same-Sign (SS)

Opposite-Sign (OS)

$$t \to \ell^+ \nu\, b \to \ell^+ \, \ell^+ \, X$$

$$b \to \bar{b} \to \ell^+$$

$$b \to c \to \ell^+$$

$$b \to \bar{b} \to c\, \bar{c} \to \ell^+$$

$$A^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

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Constructing the asymmetries

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Opposite-Sign (OS)

$$t \to \ell^+ \nu\, b \to \ell^+\, \ell^-\, X$$

$$b \to \ell^-$$

$$b \to \bar{b} \to \bar{c} \to \ell^-$$

$$b \to c\,\bar{c} \to \ell^-$$

$$A^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}}$$

Assume that light mesons (u,d,s) can be rejected, but not Charm mesons.

CP violation sources

CP violation in meson anti-meson mixing:

$B \Leftrightarrow \overline{B}$ mixing

$A_{\rm mix}^{b\ell}$

$A_{\rm mix}^{bc}$

neglect CPV in $D - \overline{D}$ mixing

CP violation sources

CP violation in meson anti-meson mixing:

$B \Leftrightarrow \overline{B}$ mixing $\quad A^{b\ell}_{\rm mix} \quad A^{bc}_{\rm mix}$

neglect CPV in $D - \overline{D}$ mixing

Direct CP violation in meson decay:

b decay $\quad A^{bc}_{\rm dir} \quad A^{b\ell}_{\rm dir}$

c decay $\quad A^{c\ell}_{\rm dir}$

ignore direct CPV in $b \to c\bar{c}$ for simplicity

Same sign asymmetry

$$t \to \ell^+ \nu\, b \to \ell^+\, \ell^+\, X$$

measured
CP asymmetry

$$A^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

CP violation
sources

Same Sign Asymmetry

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measured
CP asymmetry

CP violation
sources

$$A^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = r_b A^{b\ell}_{\rm mix}$$

$$b \to \bar{b} \to \ell^+$$

$$0.16$$

r_q – the fraction of events from each sub-process

Same sign asymmetry

$$t \to \ell^+ \nu\, b \to \ell^+\, \ell^+\, X$$

measured CP asymmetry

CP violation sources

$$A^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = r_b A^{b\ell}_{\rm mix} + r_c \left(A^{bc}_{\rm dir} - A^{c\ell}_{\rm dir}\right)$$

$b \to \bar{b} \to \ell^+$ $\quad$ $b \to c \to \ell^+$

0.16 $\quad$ 0.82

r_q – the fraction of events from each sub-process

Same sign asymmetry

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$$A^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = r_b A^{b\ell}_{\rm mix} + r_c \left(A^{bc}_{\rm dir} - A^{c\ell}_{\rm dir}\right) + r_{c\bar c} \left(A^{bc}_{\rm mix} - A^{c\ell}_{\rm dir}\right)$$

$b \to \bar b \to \ell^+$	$b \to c \to \ell^+$	$b \to \bar b \to c\bar c \to \ell^+$
0.16	0.82	0.02

r_q – the fraction of events from each sub-process

Opposite sign asymmetry

$$t \to \ell^+ \nu\, b \to \ell^+\, \ell^-\, X$$

measured
CP asymmetry

CP violation
sources

$$A^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}}$$

Opposite sign asymmetry

$$t \to \ell^+ \nu\, b \to \ell^+\, \ell^-\, X$$

measured
CP asymmetry

CP violation
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$$A^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}} = \tilde{r}_b A_{\rm dir}^{b\ell}$$

$b \to \ell^-$

0.79

$\tilde{r}_q$ – the fraction of events from each sub-process

Opposite sign asymmetry

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measured CP asymmetry

CP violation sources

$$A^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}} = \tilde{r}_b A^{b\ell}_{\rm dir} + \tilde{r}_c \left(A^{bc}_{\rm mix} + A^{c\ell}_{\rm dir}\right)$$

$b \to \ell^-$ $\quad$ $b \to \bar{b} \to \bar{c} \to \ell^-$

0.79 $\quad$ 0.08

$\tilde{r}_q$ – the fraction of events from each sub-process

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measured CP asymmetry

CP violation sources

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$b \to \ell^-$	$b \to \bar{b} \to \bar{c} \to \ell^-$	$b \to c\bar{c} \to \ell^-$
0.79	0.08	0.13

$\tilde{r}_q$ – the fraction of events from each sub-process

LHC sensitivity (preliminary)

- Naive estimation of the statistical uncertainty (systematics are not included)

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- Event Selection:
  - ✦ Semi-leptonic top pair events with two b tags
  - ✦ Association of the *b* with the appropriate top (by using the Matrix Element Method)
  - ✦ Can also use the *b* from the hadronic top

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  - ✦ Semi-leptonic top pair events with two b tags
  - ✦ Association of the *b* with the appropriate top (by using the Matrix Element Method)
  - ✦ Can also use the *b* from the hadronic top
- The backgrounds are expected to be small

LHC sensitivity (preliminary)

Estimated number of events per sub-process:

$$N_q = \sigma_{t\bar{t}}\,\mathrm{BR}(t\bar{t} \to \mathrm{SL})$$

semi-leptonic top-pair production cross section

LHC sensitivity (preliminary)

Estimated number of events per sub-process:

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semi-leptonic top-pair production cross section

integrated luminosity

LHC sensitivity (preliminary)

Estimated number of events per sub-process:

$$N_q = \sigma_{t\bar{t}}\,\mathrm{BR}(t\bar{t} \to \mathrm{SL})\,\mathcal{L}\,\epsilon$$

semi-leptonic top-pair production cross section

integrated luminosity

efficiency:

pre-selection cuts 55%

b-tagging $(60\%)^2$

b-association 70%

total efficiency - 14%

LHC sensitivity (preliminary)

Estimated number of events per sub-process:

$$N_q = \sigma_{t\bar{t}}\, \mathrm{BR}(t\bar{t} \to \mathrm{SL})\, \mathcal{L}\, \epsilon\, \mathcal{B}_q$$

semi-leptonic top-pair production cross section

integrated luminosity

rate per sub-process

efficiency:

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LHC Sensitivity (preliminary)

Sensitivity for the Asymmetries:

$$\delta A^{ss} \sim \frac{9.0}{\sqrt{\sigma_{t\bar{t}}\mathcal{L}}} \sim 6\,(1) \times 10^{-4} \qquad \delta A^{os} \sim \frac{7.6}{\sqrt{\sigma_{t\bar{t}}\mathcal{L}}} \sim 5\,(0.8) \times 10^{-4}$$

$$\sqrt{s} = 14\,(100)\,\text{TeV} \quad \mathcal{L} = 300\,\text{fb}^{-1}$$

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For CP violation only in mixing (no direct CPV):

$$\delta A^{b\ell}_{\rm mix} \sim 3\,(0.5) \times 10^{-3}$$

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Bounds on direct CP violation sources (95% CL):

	current	8TeV	14TeV, 50
$A^{b\ell}_{\text{dir}}$	1.2%	1%	0.3%
$A^{c\ell}_{\text{dir}}$	6%	1%	0.3%
A^{bc}_{dir}	?	1%	0.3%

Descotes-Genon and Kamenik, 1207.4483

Summary

- Propose to probe CP violation in B mixing and in *b* and *c* decays in top-pair events, by exploiting the *b*-charge tagging ability inherent to the top semi-leptonic decay.

SUMMARY

- Propose to probe CP violation in B mixing and in *b* and *c* decays in top-pair events, by exploiting the *b*-charge tagging ability inherent to the top semi-leptonic decay.
- This is an independent measurement with different systematics sources than LHCb and the B-factories (lower sensitivity for CPV in mixing, but better for direct CPV).

Summary

- Within the standard model:

$$A^{ss}(\mathrm{SM}),\ A^{os}(\mathrm{SM}) \lesssim 10^{-4}$$

$A^{ss},\ A^{os} \neq 0$ ⟹ new physics beyond the SM

given the expected sensitivity

SUMMARY

- Within the standard model:

$$A^{ss}(\text{SM}),\ A^{os}(\text{SM}) \lesssim 10^{-4}$$

$A^{ss},\ A^{os} \neq 0$ ➡ new physics beyond the SM

given the expected sensitivity

- New results (bounds on direct CPV sources) can be obtained already with the 8 TeV data.

Backup slides

CP violation sources

$$A^{b\ell}_{\rm mix} = \frac{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) - \Gamma\left(\bar{b} \to b \to \ell^- X\right)}{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) + \Gamma\left(\bar{b} \to b \to \ell^- X\right)}$$

$$A^{bc}_{\rm mix} = \frac{\Gamma\left(b \to \bar{b} \to \bar{c}\; X\right) - \Gamma\left(\bar{b} \to b \to c\; X\right)}{\Gamma\left(b \to \bar{b} \to \bar{c}\; X\right) + \Gamma\left(\bar{b} \to b \to c\; X\right)}$$

CP violation sources

$$A_{\rm dir}^{b\ell} = \frac{\Gamma\left(b \to \ell^- X\right) - \Gamma\left(\bar{b} \to \ell^+ X\right)}{\Gamma\left(b \to \ell^- X\right) + \Gamma\left(\bar{b} \to \ell^+ X\right)}$$

$$A_{\rm dir}^{bc} = \frac{\Gamma\left(b \to c\; X_{\rm light}\right) - \Gamma\left(\bar{b} \to \bar{c}\; X_{\rm light}\right)}{\Gamma\left(b \to c\; X_{\rm light}\right) + \Gamma\left(\bar{b} \to \bar{c}\; X_{\rm light}\right)}$$

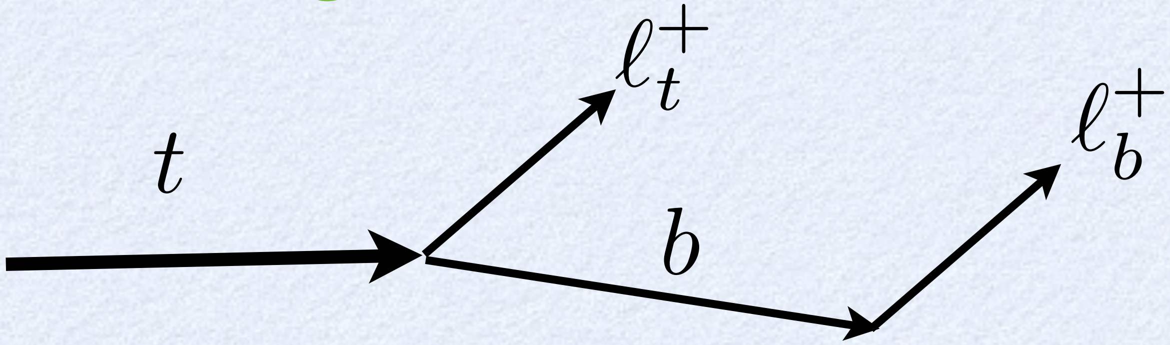
$$A_{\rm dir}^{c\ell} = \frac{\Gamma\left(\bar{c} \to \ell^- X_{\rm light}\right) - \Gamma\left(c \to \ell^+ X_{\rm light}\right)}{\Gamma\left(\bar{c} \to \ell^- X_{\rm light}\right) + \Gamma\left(c \to \ell^+ X_{\rm light}\right)}$$

neglect CPV in $D - \overline{D}$ mixing

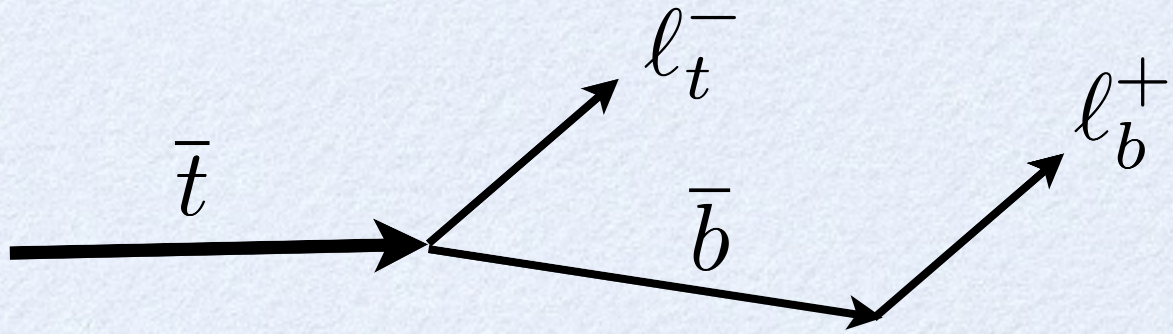
ignore direct CPV in $b \to c\bar{c}$ for simplicity

Wrong association effect

right association



wrong association



same sign and opposite sign samples are mixed

$$A^{ss} \Leftrightarrow A^{os}$$

Wrong association effect

Wrong association effect

measured asymmetries

$$A_*^{ss} \approx A^{ss} - \epsilon_{\rm F}\,\frac{N^{+-}}{N^{++}}\,(A^{os} + A^{ss})$$

$$A_*^{os} \approx A^{os} - \epsilon_{\rm F}\,\frac{N^{++}}{N^{+-}}\,(A^{os} + A^{ss})$$

probability for wrong association

Wrong association effect

measured asymmetries

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$$A_*^{os} \approx A^{os} - \epsilon_{\rm F} \frac{N^{++}}{N^{+-}} \left(A^{os} + A^{ss}\right)$$

probability for wrong association

$$\Rightarrow \ \epsilon_{\rm F} \lesssim 10\%$$

Relation to D0 dimuon anomay

$$B_q - \bar{B}_q \, \text{mixing} : A^{bl}_{\text{mix}}(\text{D0}) = (-7.87 \pm 1.96) \times 10^{-3}$$

$$\text{direct CPV in } b \text{ decay} : A^{bl}_{\text{dir}}(\text{D0}) = (3 \pm 1) \times 10^{-3}$$

$$\text{direct CPV in } c \text{ decay} : A^{cl}_{\text{dir}}(\text{D0}) = (9 \pm 3) \times 10^{-3}$$

Descotes-Genon and Kamenik, 1207.4483

D0 from direct CPV in c decay: A^{ss} at 2.8σ $(14\,\text{TeV},\ 50\,\text{fb}^{-1})$

D0 from CPV in B_q mixing: A^{ss} at 2.1σ $(14\,\text{TeV},\ 300\,\text{fb}^{-1})$

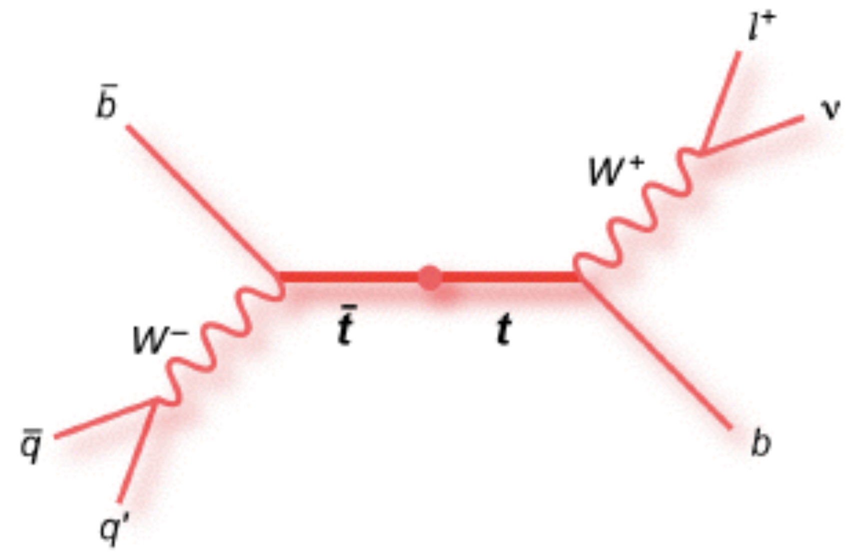
D0 from direct CPV in b decay: A^{os} at 2.9σ $(14\,\text{TeV},\ 300\,\text{fb}^{-1})$

’Automation of the matrix element reweighting method’ (arXiv :1007.3300)

For each event, computes the probability that it originates from some process, defined by its born amplitude :

$$P(x) = \frac{1}{\sigma} \int dy |M(y)|^2 T(x|y)$$

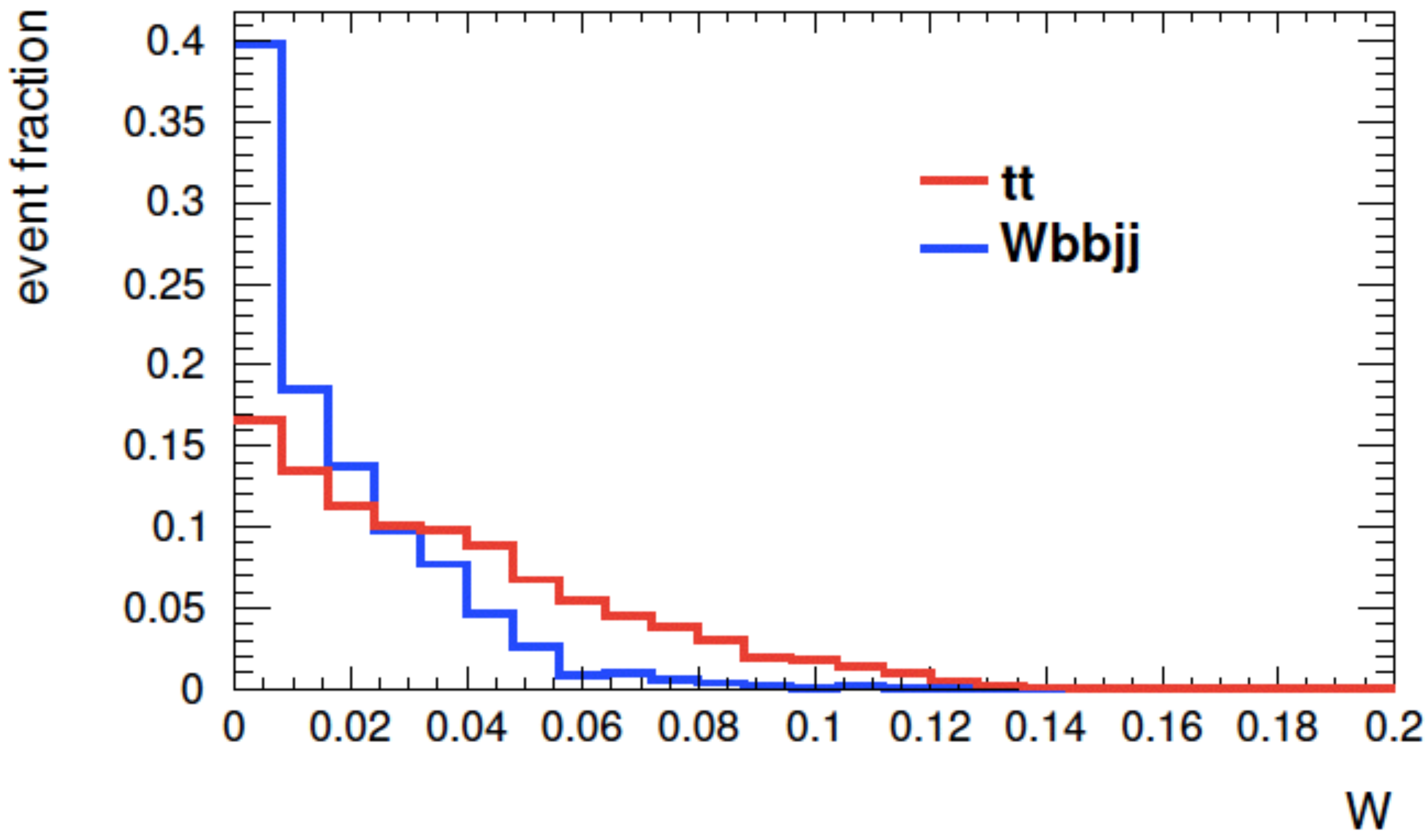
- σ : effective cross section,
- M : born amplitude
- T : transfer function, gives probability of reconstructing particles of momenta x originating from parton level momenta y.



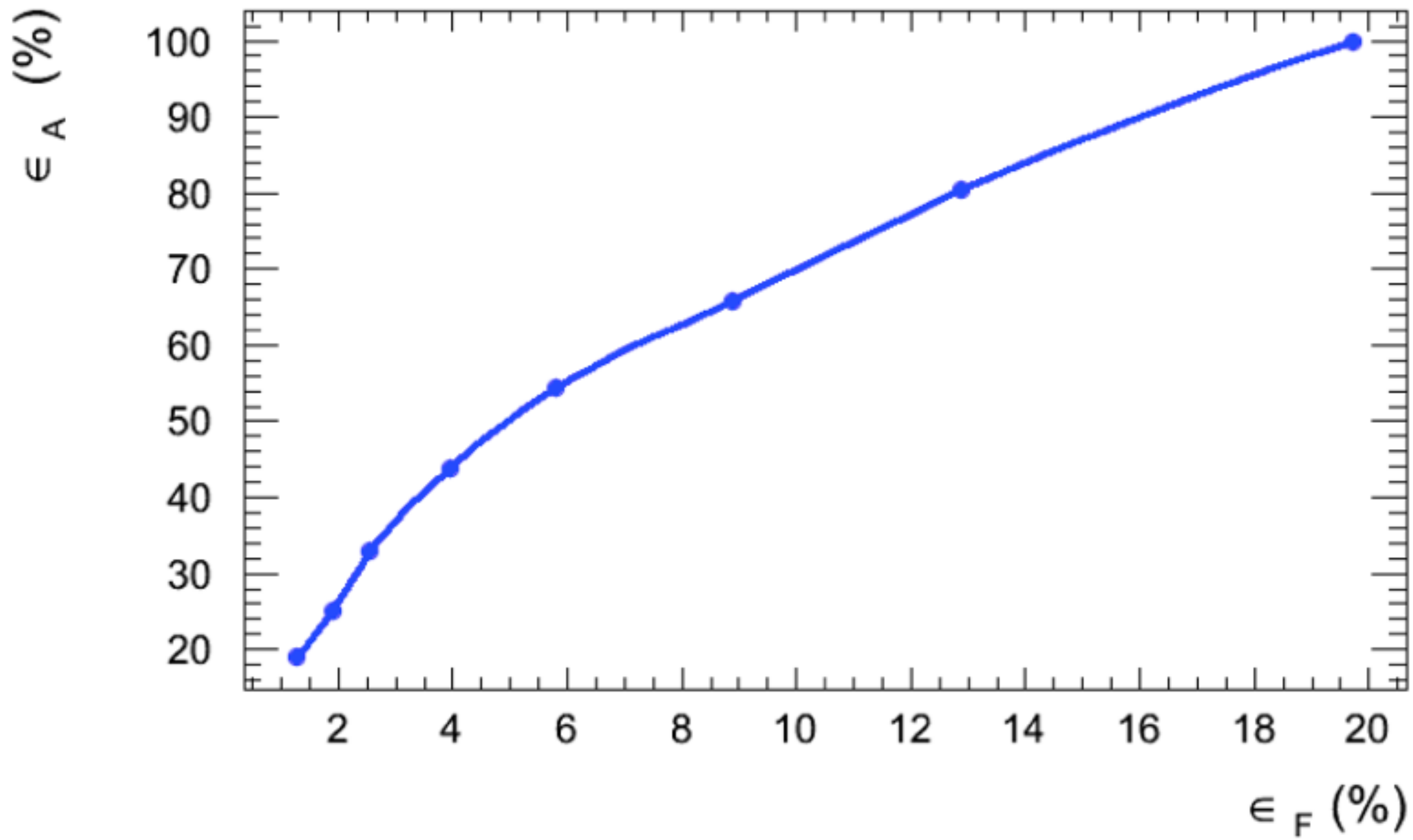
- Transfer function : double gauss p_T for jet, δ function for leptons
- correct for ISR by boosting back in ref. frame where $p_T = 0$
- In previous formula, MadWeight averages over possible final state permutations
- We want to extract the probability of each permutation :
  - no ambiguity for ℓ and E_T^{miss}
  - b-jets ($\times 2$)
  - light jets ($\times 2$) $\to$ degenerate !

For each event, probabilities P_1 and P_2 of two possible choices of the b-charge can be computed.

$$\text{define } W = \left|\frac{P_1 - P_2}{P_1 + P_2}\right|$$



- large values of W correspond to good discrimination between the two association hypothesis
- sample with correct association can be selected.
- bonus : background rejection ! !



Can achieve $\leq$ 10% mis-association rate with $\approx$ 70% signal efficiency.