Stop quark search with MEM

+ Status of MadWeight

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Ongoing work, in collaboration with

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- Part I: MadWeight status (2 slides)

- Part II: Stop quark search with the MEM

MadWeight

P.A., V. Lemaître, F. Maltoni, O. Mattelaer

$$P(\boldsymbol{x}_i, \alpha) = \frac{1}{\sigma^{obs}} \frac{1}{N} \sum_{\text{jet perm.}} \int d\phi_{\boldsymbol{y}} |M|^2(\boldsymbol{y}) W(\boldsymbol{x}_i, \boldsymbol{y}).$$

integration on the parton-level phase-space

tree-level matrix element

transfer function

- MadWeight= generator of **optimized phase-space mappings** $d\phi_y$ for the evaluation of the weights in the Matrix Element Method

- the module is integrated in **madgraph**, (same philosophy of automated and user-friendly framework)

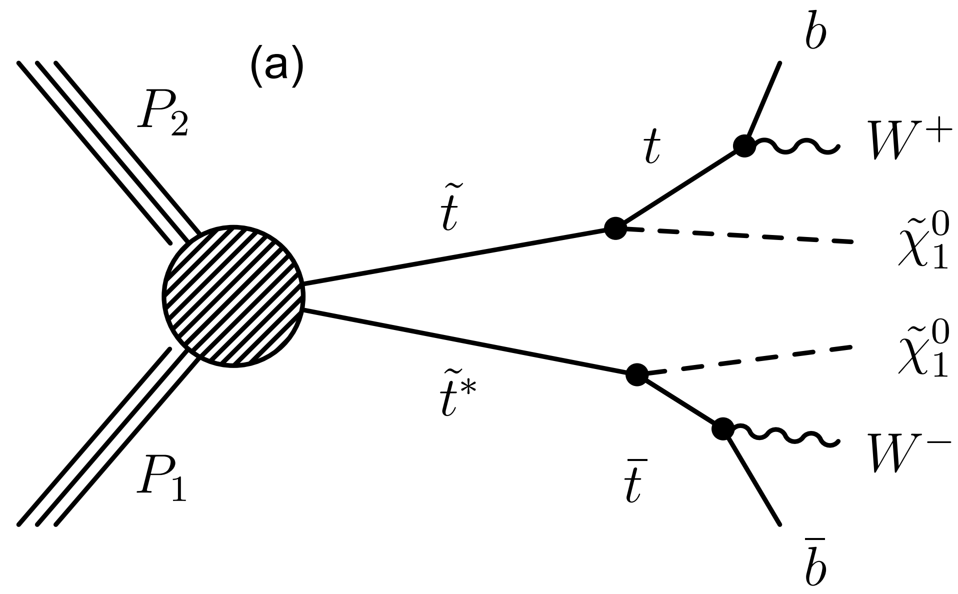
MadWeight: status

- 2009 implementation in MGv4
    - multichannel integrator as described in JHEP 1210 (2010) 068
- 2011 implementation in mg5 (‘madweight’ branch)
    - access to much lager set of matrix elements
    - effective treatment for ISR
    - subprocesses grouping
    - NWA
- 2013 new branch (‘madweight_mc_perm’)

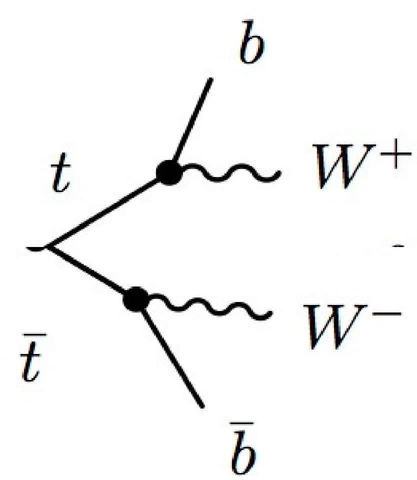
  https://code.launchpad.net/~maddevelopers/madgraph5/madweight_mc_perm
    - improved submission of jobs
    - NWA (cont’)
    - MC over parton-jet assignments
    - pre-training of the grid
- 2014 merge into the trunk version of madgraph expected soon

Stop pair production at the LHC

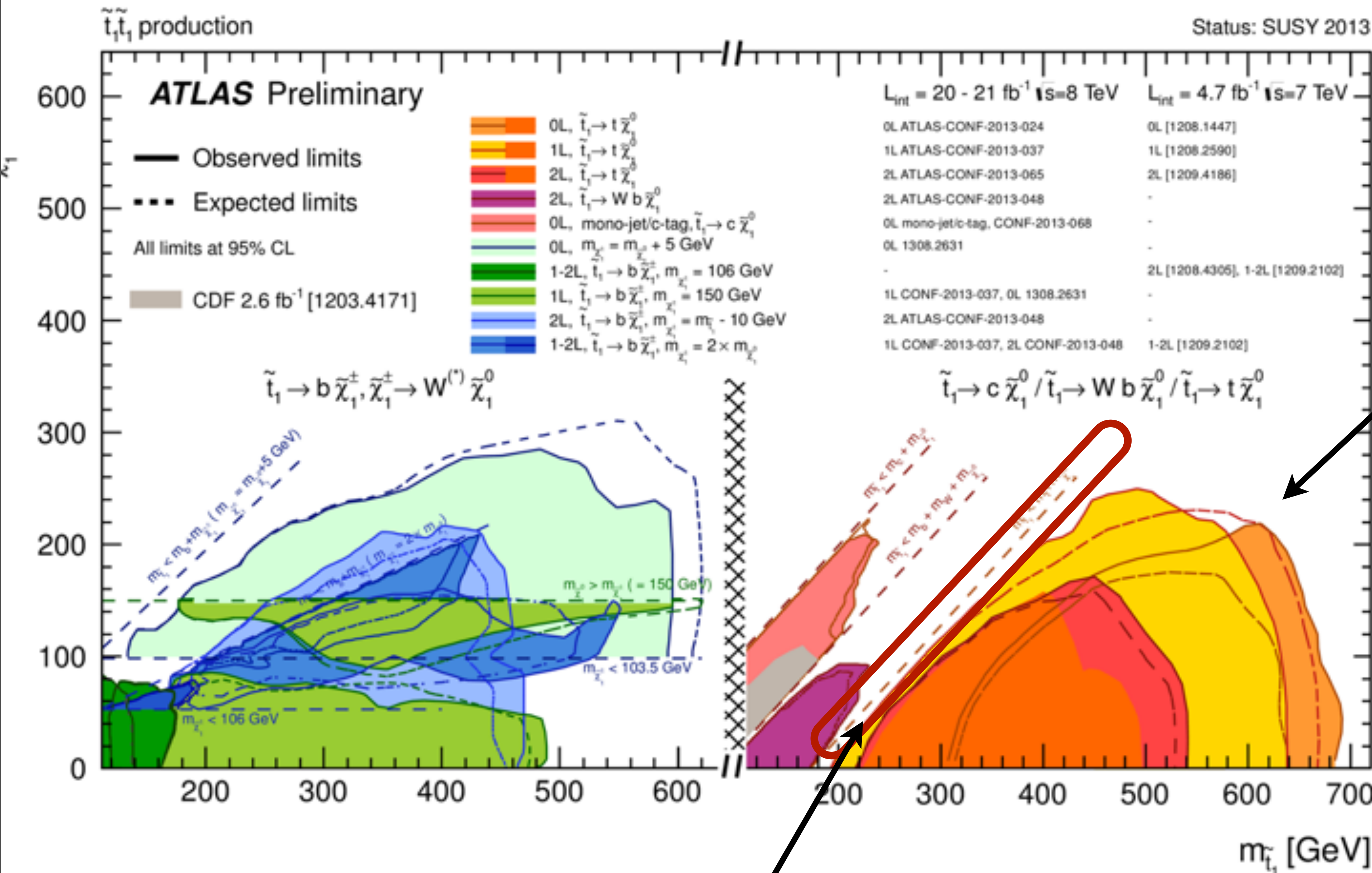
- study case: $\tilde{\chi}^0$ is the stable lightest supersymmetric particle (LSP), $\tilde{t}$ is the second lightest supersymmetric particle



- main background = ttbar: typically less missing energy



Exclusion limits from ATLAS

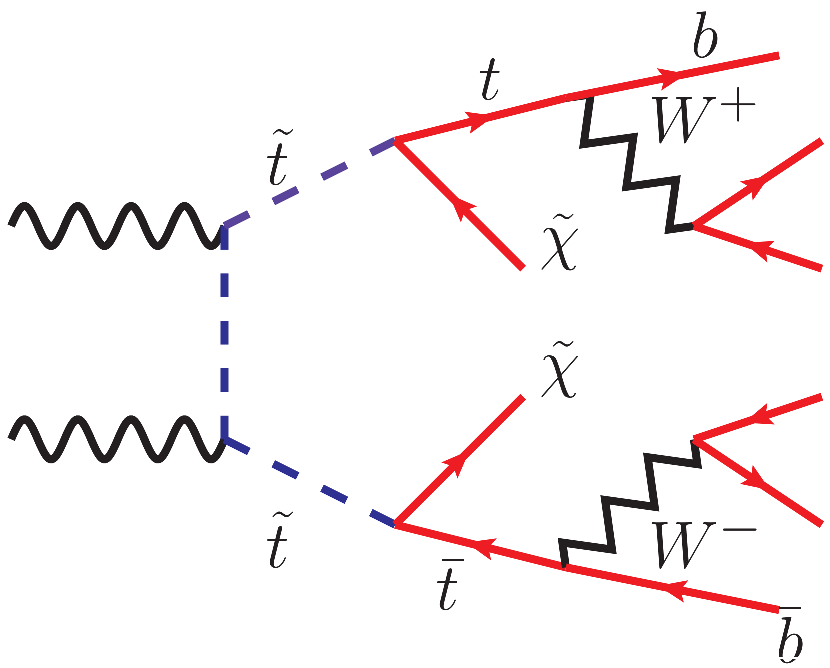


multivariate analyses typically make use of variables sensitive to MET (M_T, MET,...).

region of interest in this talk: $m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}}$
signal and bkg events show very similar phase-space distributions, which makes the discrimination more difficult

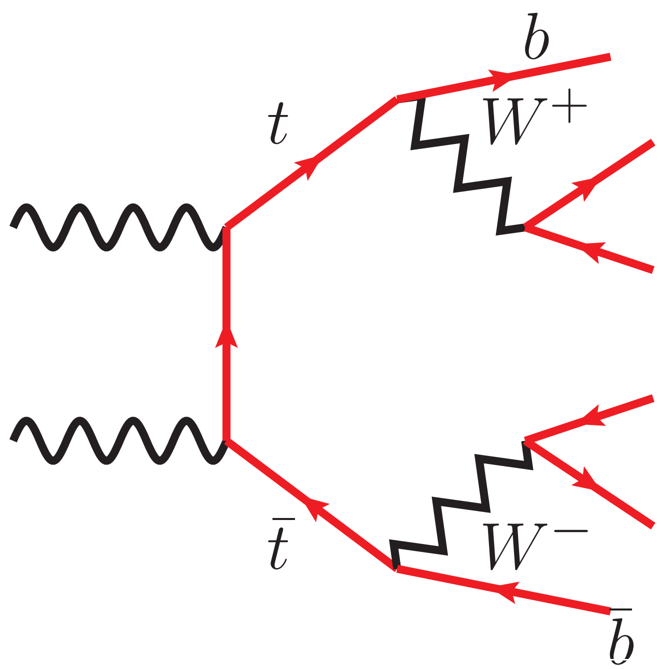
Working assumptions

signal



- pure left-handed stop,
- stop decays into neutralino + top quark with 100% proba
- $m_{\tilde{t}} = 200$ GeV, $\quad m_{\tilde{\chi}} = 27.5$ GeV
  $\Gamma_{\tilde{t}} = 0.25$ MeV

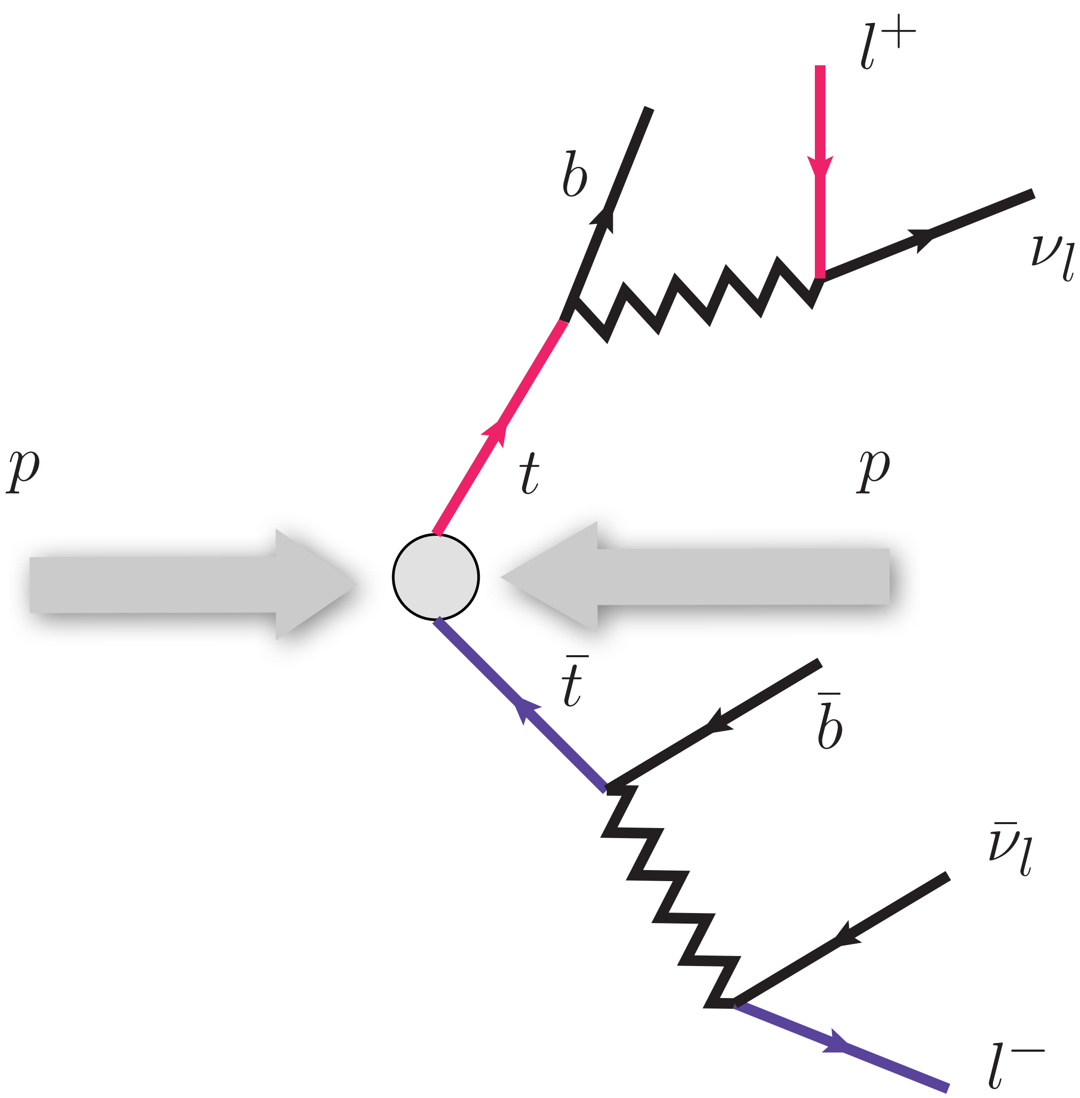
background



- only bkg = tt in the corresponding decay channel
- $m_t = 172.5$ GeV

Angular distributions

signal vs bkg discrimination based on **polarization effects** ?



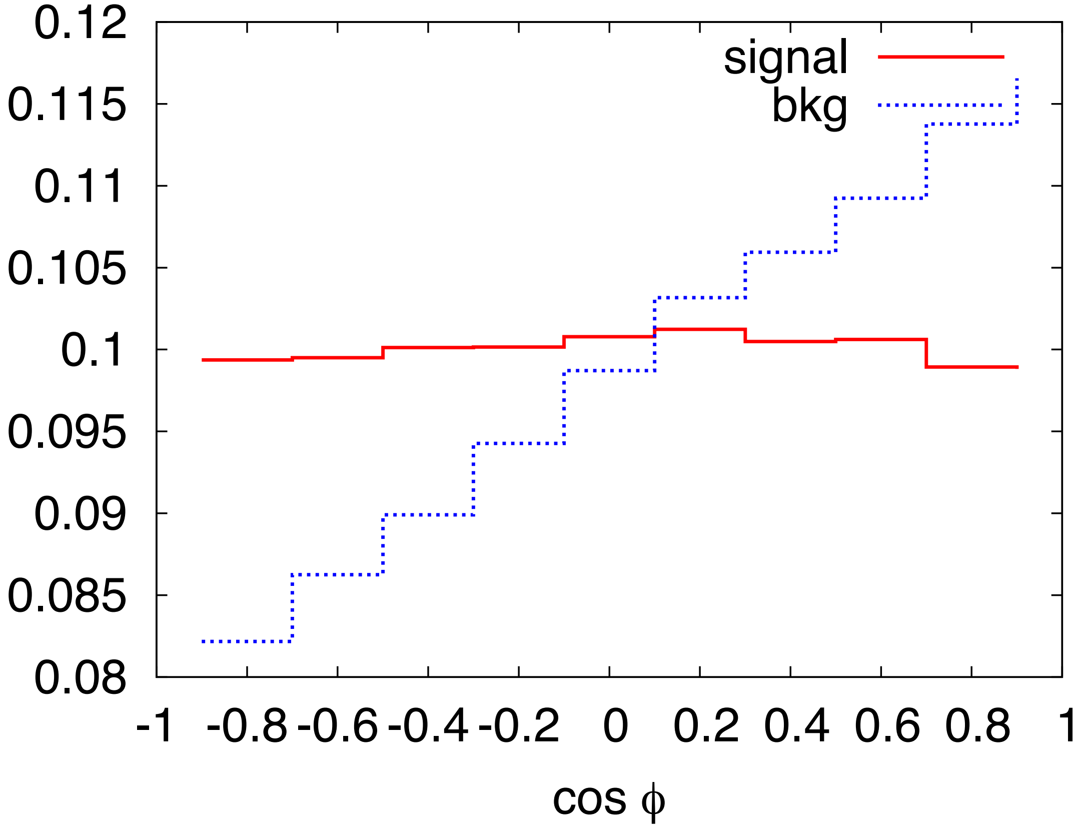
observables sensitive to polarization of the top quarks:

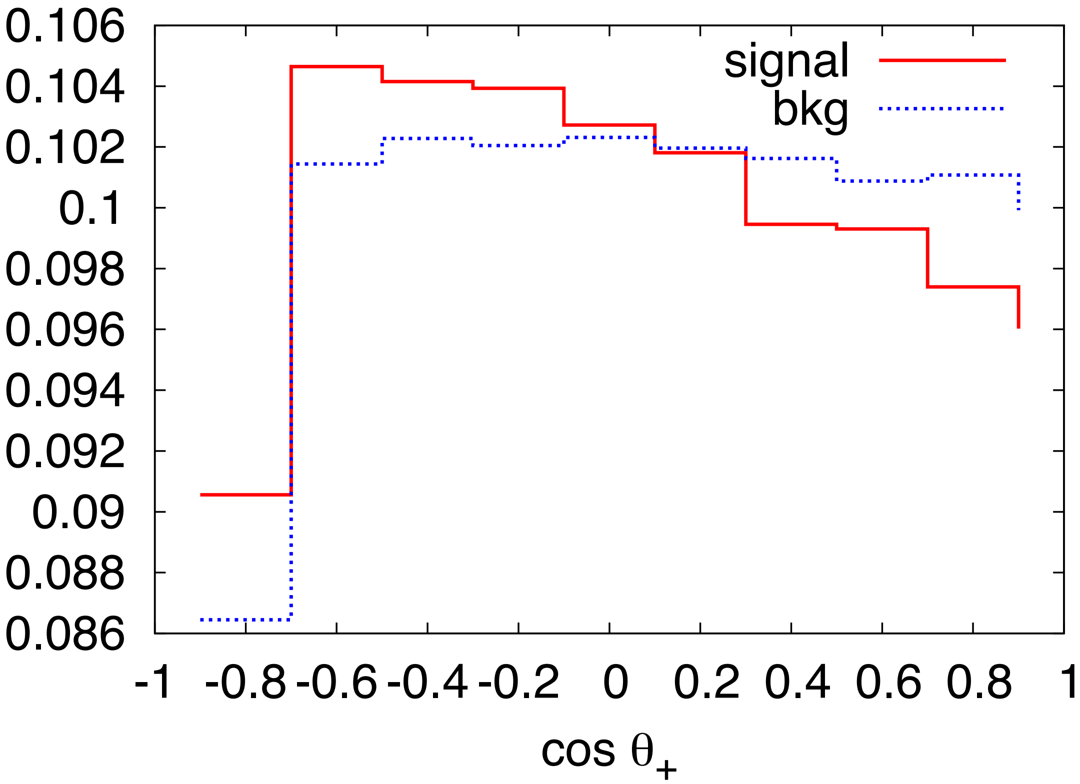
θ_+ polar angle between the **direction of flight of the l⁺** in the **top rest frame** (polar axis = $\boldsymbol{p}_{\text{top}}$ in the lab frame)

θ_- polar angle between the **direction of flight of the l⁻** in the **antitop rest frame** (polar axis = $\boldsymbol{p}_{\text{antitop}}$ in the lab frame)

ϕ angle between the **direction of flight of the l⁺** in the **top rest frame** and the **direction of flight of the l⁻** in the **antitop rest frame**

Angular distributions





parton-level, loose cuts

- SM tt production: **correlation** between the angular distributions of the decay products in the **two decay branches**
- stop pair production: **no such correlation** since stop quark = scalar particle
- polarization effects **inside a given decay branch** also lead to slightly different angular distributions for sig and bkg hypotheses

➡ **ideal study case for the matrix element method**

Goal

- does the **Matrix Element Method** provide additional leverage to exclude stop pair production in the **funnel region** ?

- how competitive is the **MEM discriminating power** in comparison with other **multivariate techniques** ?

Calculation of the weights (bkg)

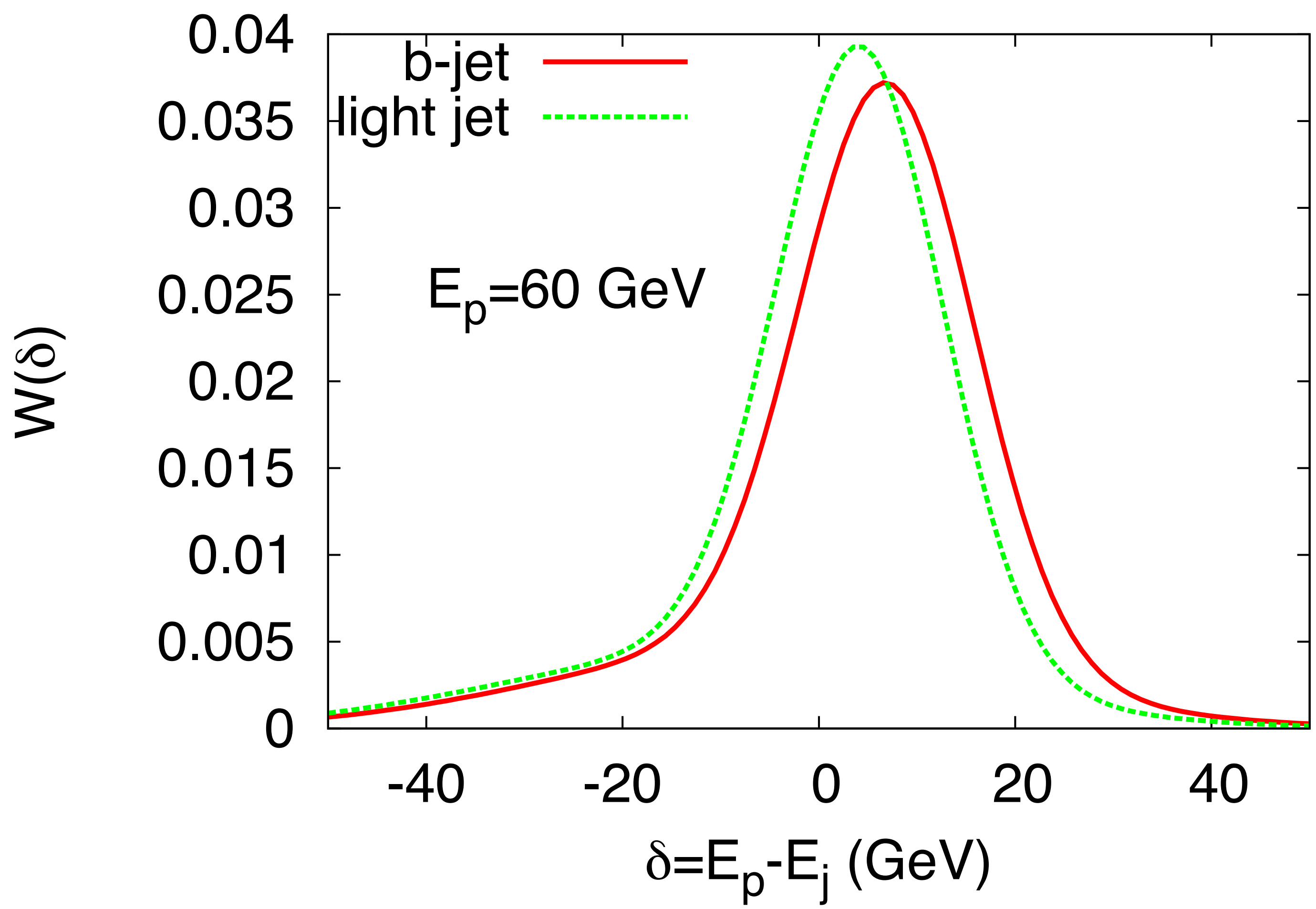
$$P(\boldsymbol{x}_i, B) = \frac{1}{\sigma^{obs}} \frac{1}{N} \sum_{\text{jet perm.}} \int d\phi_{\boldsymbol{y}} |M_B|^2(\boldsymbol{y}) W(\boldsymbol{x}_i, \boldsymbol{y})$$

$d\phi_{\boldsymbol{y}}$
- parton-level phase-space measure for tt (production+decay),
- **ISR treatment**: $p_T(tt)$=-$p_T(isr)$,
- Monte Carlo phase-space generation with **MadWeight**.

$|M_B|^2(\boldsymbol{y})$
- **LO matrix element** for tt (production+decay)
- generated with madgraph5

$W(\boldsymbol{x}_i, \boldsymbol{y})$
- transfer function on **light jet and b-jet energies** only
- determined from an independent tt sample where well separate jets are matched to the corresponding partons

Transfer function (TF)



- the shape of the transfer function is set to a sum of two Gaussian distribution,
- the energy dependence of each parameter p_i (bias, widths, relative strength) is set to

$$p_i = a_i + b_i E_p$$

$$W(\delta) = \frac{1}{\sqrt{2\pi(p_2+p_3p_5)}}\left(\exp\left(-\frac{(\delta-p_1)^2}{2{p_2}^2}\right) + p_3\exp\left(-\frac{(\delta-p_4)^2}{2{p_5}^2}\right)\right)$$

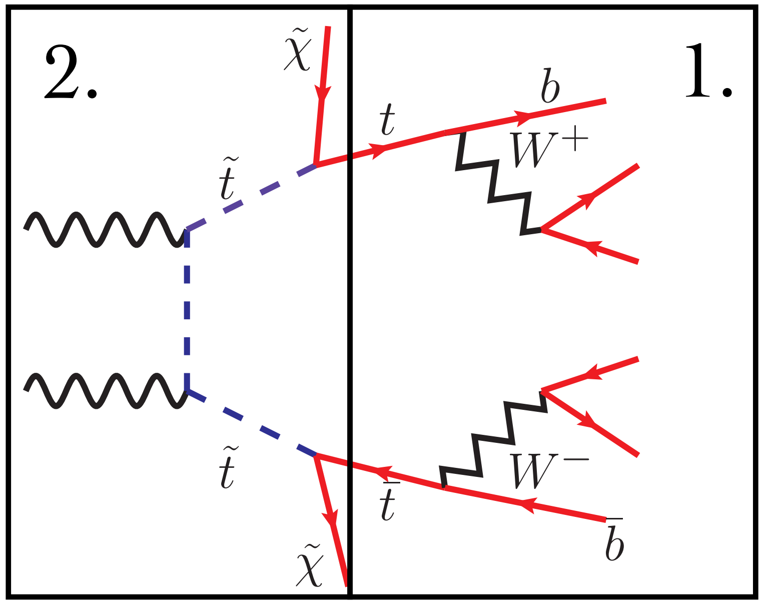
Calculation of the weights (signal)

$$P(\boldsymbol{x}_i, S) = \frac{1}{\sigma^{obs}} \frac{1}{N} \sum_{\text{jet perm.}} \int d\phi_{\boldsymbol{y}} |M_S|^2(\boldsymbol{y}) W(\boldsymbol{x}_i, \boldsymbol{y})$$

specific treatment for the phase-space measure $d\phi_{\boldsymbol{y}}$:

in the funnel region, the decay products of each stop quark have almost **no relative momentum**, since $m_{\tilde{t}} = m_t + m_{\tilde{\chi}}$

1. generate the kinematics of the tt system, with
   $p_T(t\bar{t}) = -p_T(isr)\frac{m_t}{m_{\tilde{t}}}$
2. set the momenta of the supersymmetric partners assuming no relative momentum |b| t and $\tilde{\chi}$



good approximation if the widths $\Gamma_{\tilde{t}}, \Gamma_t$ are negligible

Discriminating power (MEM, dilepton)

Three distinct MEM analyses:

parton 1: ★ events at the parton-level (no showering)

cuts: $\Delta R > 0.3$, $p_T(j) > 30$ GeV, $|\eta(j)| < 2.5$, $|\eta(l)| < 2.4$, $p_T(l) > 20$ GeV

★ weights calculated with infinite resolution on E_p

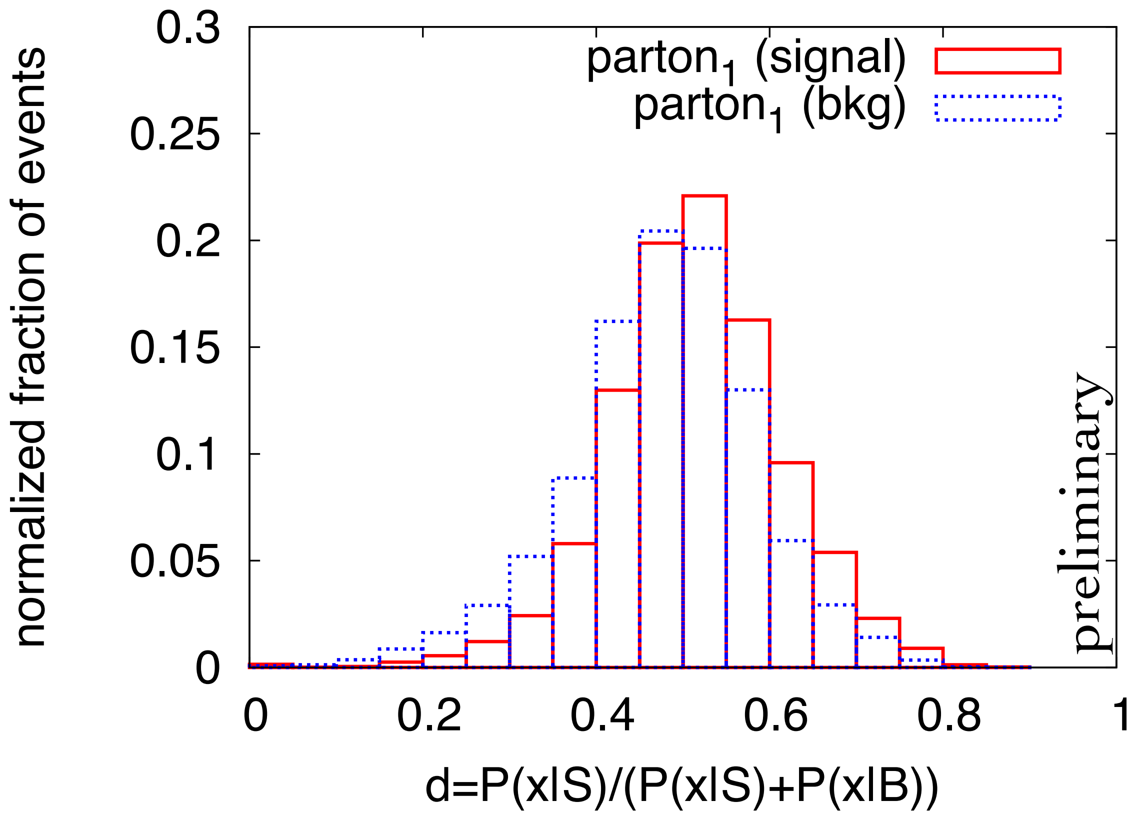
parton 2: ★ events at the parton-level + smearing of E_p
cuts after smearing:
$\Delta R > 0.3$, $p_T(j) > 30$ GeV, $|\eta(j)| < 2.5$, $|\eta(l)| < 2.4$, $p_T(l) > 20$ GeV

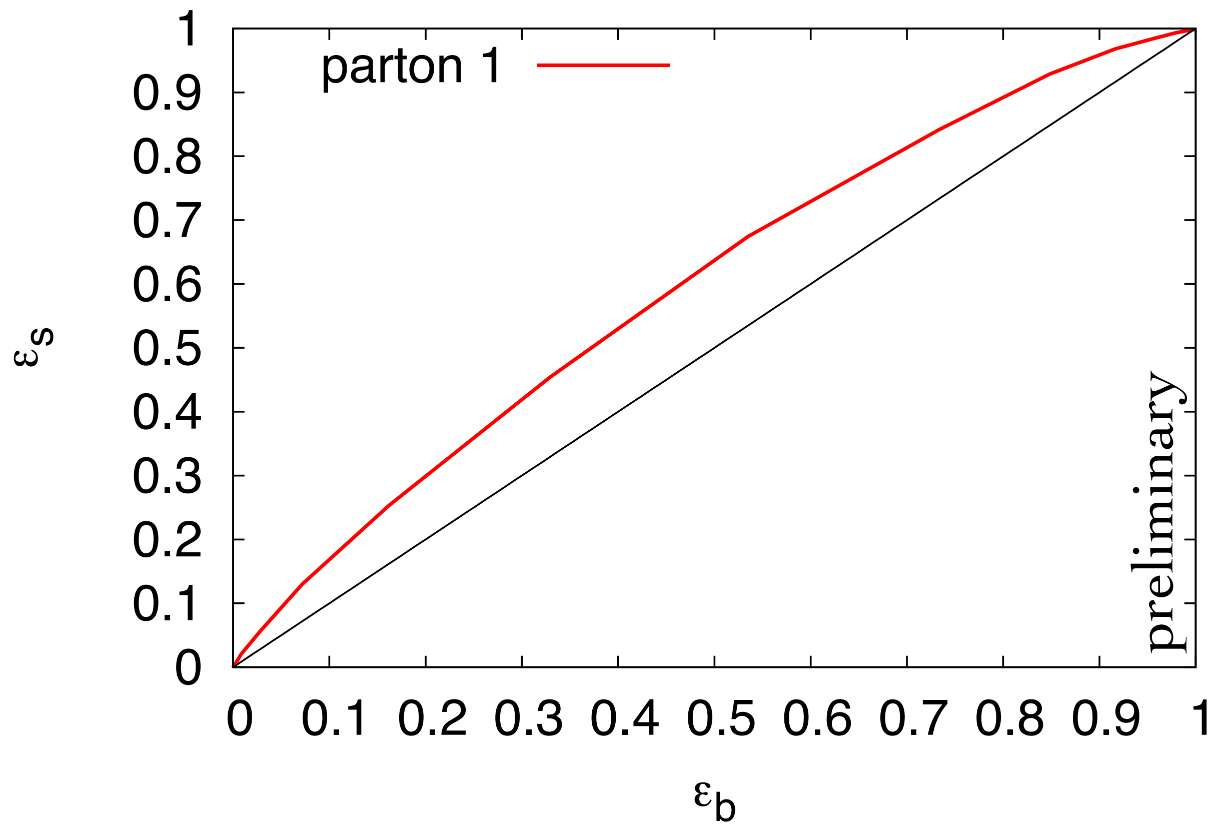
★ weights calculated with the previously-defined TF

reco: ★ events generated with MadGraph + Pythia + Delphes,
2 isolated leptons with $|\eta(l)| < 2.4$, $p_T(l) > 20$ GeV
2 jets (at least 1 b-tag) with $p_T(j) > 30$ GeV, $|\eta(j)| < 2.4$,

★ weights calculated with the previously-defined TF

MEM discriminating power, dilepton channel



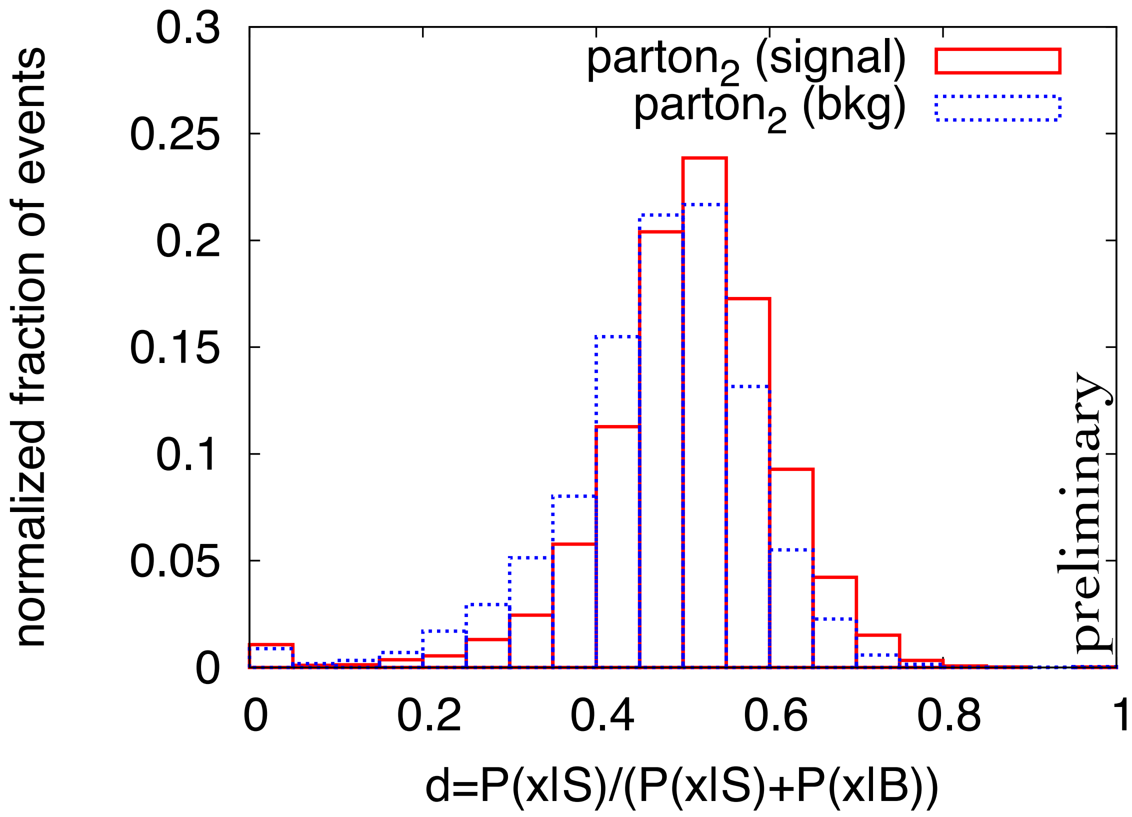


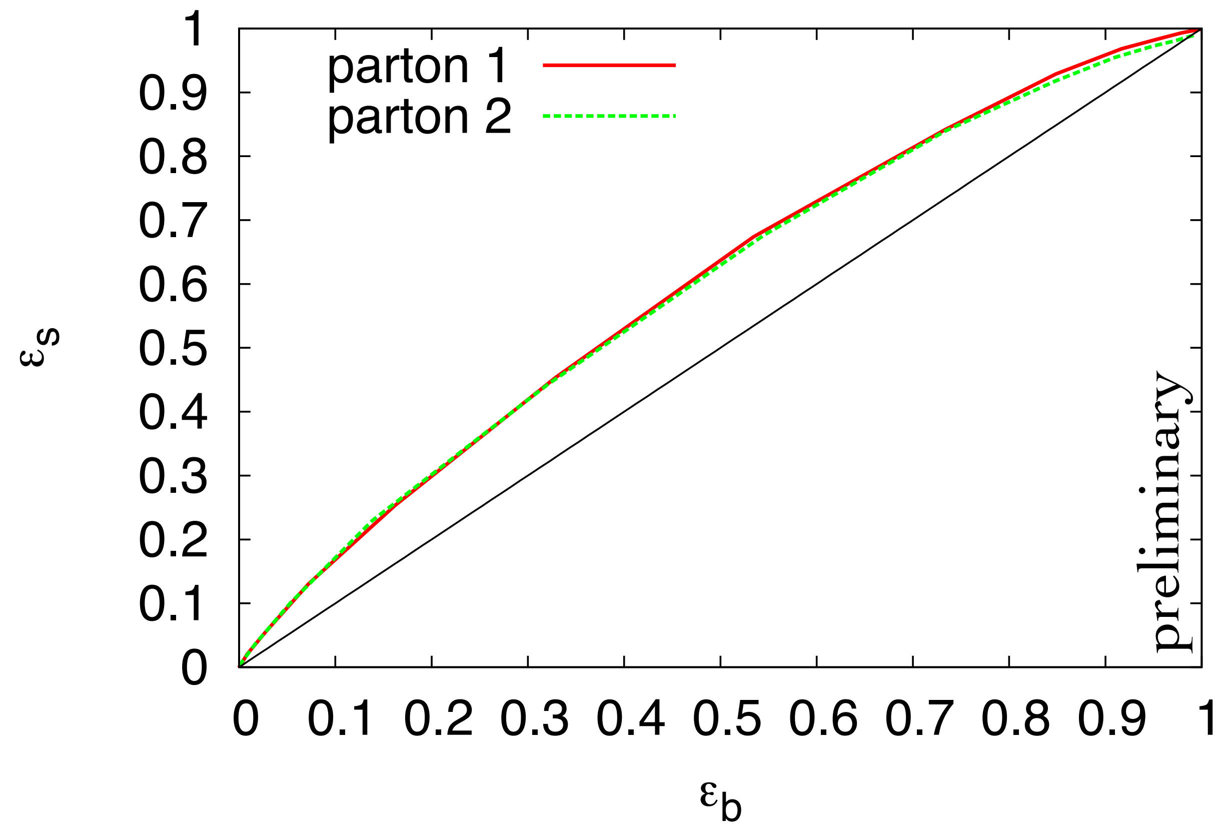
parton 1:

signal and background event distributions w.r.t the MEM-based discriminator are very similar

$\epsilon_s, \epsilon_b =$ signal and bkg efficiencies resulting from a cut on the MEM-based discriminator d, slightly better than a random cut

MEM discriminating power, dilepton channel



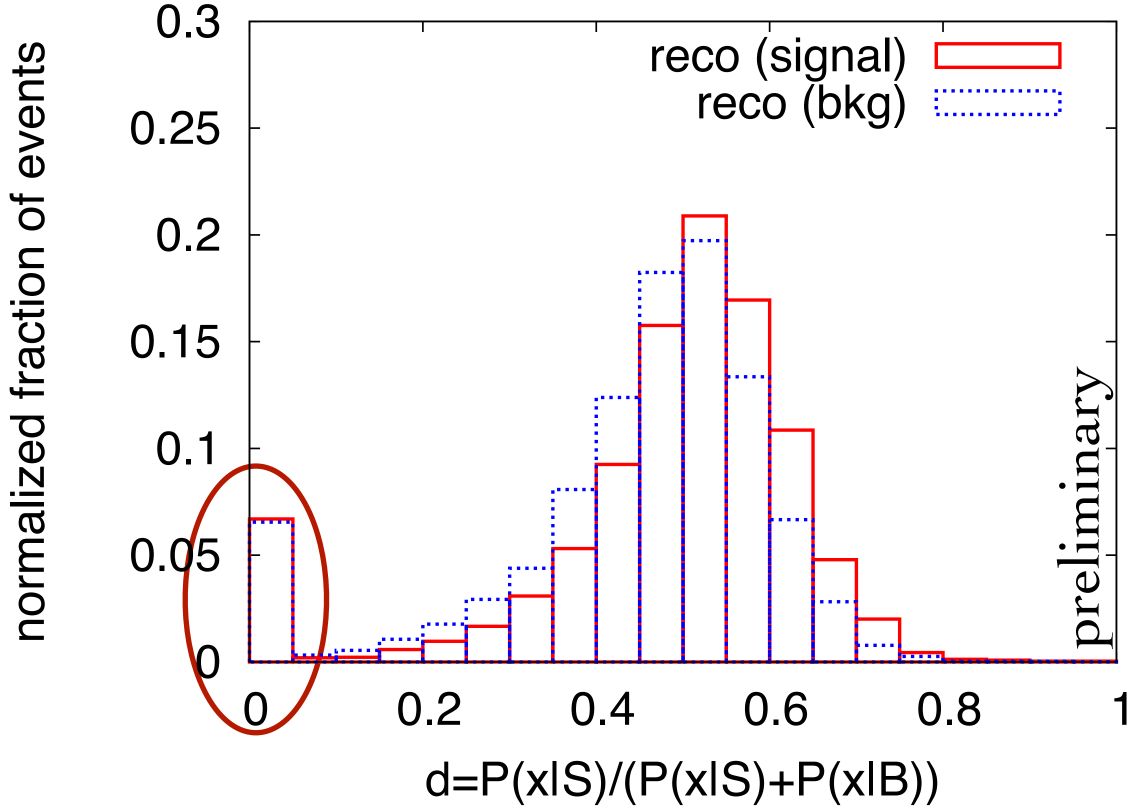


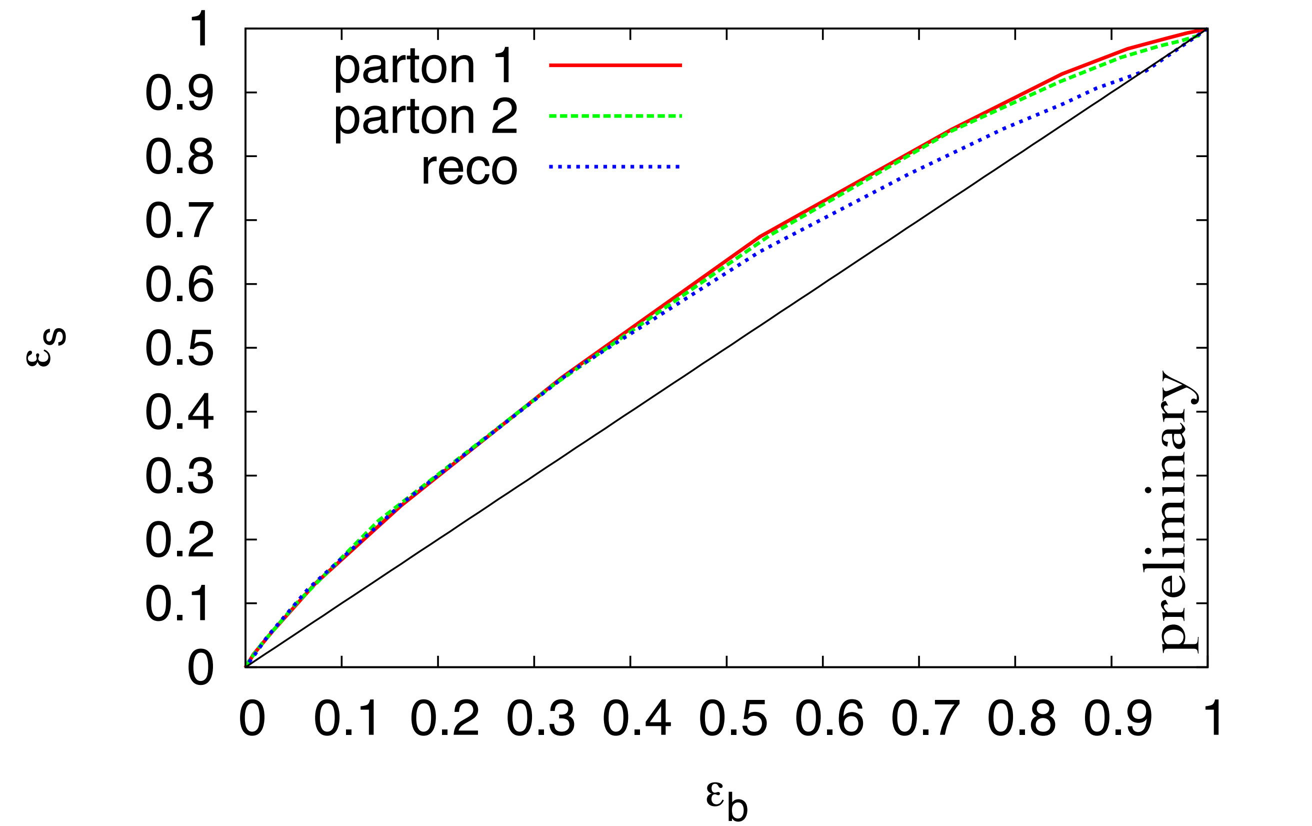
parton 2:

E_p smearing makes the distributions w.r.t the MEM-based discriminator slightly different

ϵ_s versus ϵ_b plot is unchanged

MEM discriminating power, dilepton channel





reco :

for 7% of the events, the weight under the signal assumptions is much smaller

⟷ ISR treatment ?

ϵ_s versus ϵ_b plot is unchanged, except in the region close to 1 (see first bin in the left-hand plot)

Discriminating power (MEM, single lepton)

Three distinct MEM analyses:

parton: ★ events at the parton-level + smearing of E_p
cuts after smearing:
$\Delta R > 0.3,\ p_T(j) > 30$ GeV, $|\eta(j)| < 2.5$, $|\eta(l)| < 2.4$, $p_T(l) > 20$ GeV

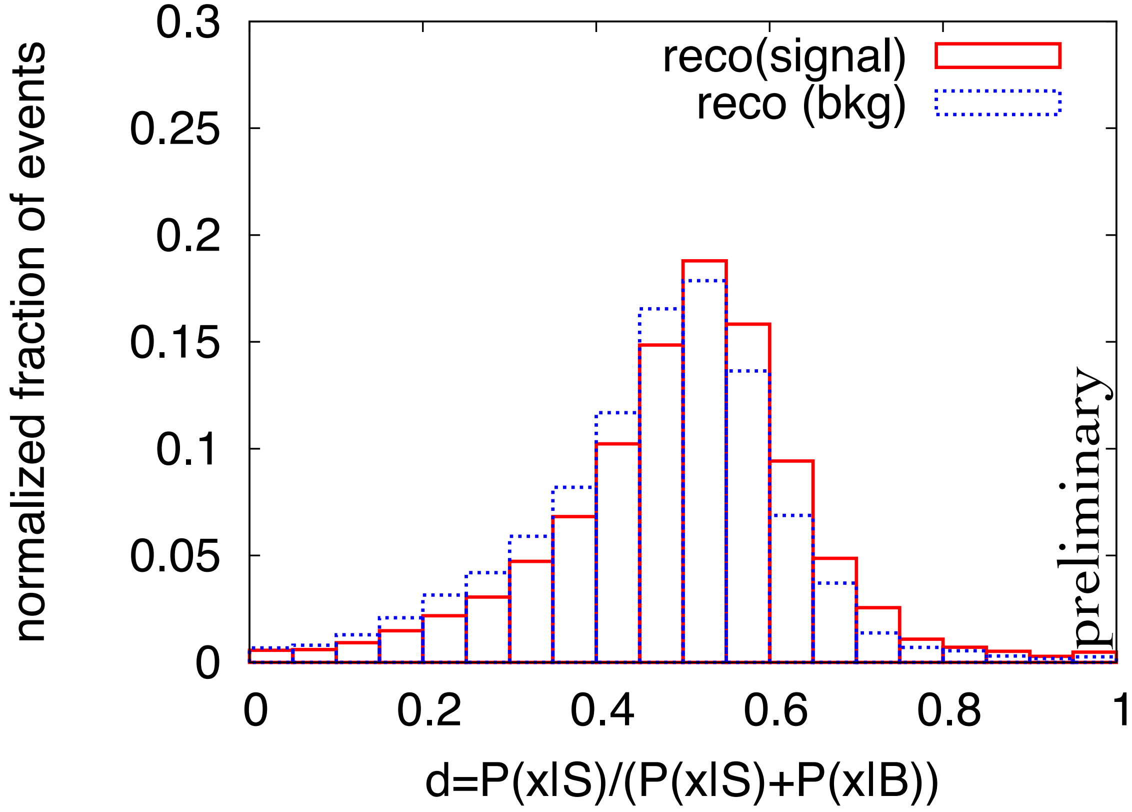
★ weights calculated with the previously-defined TF

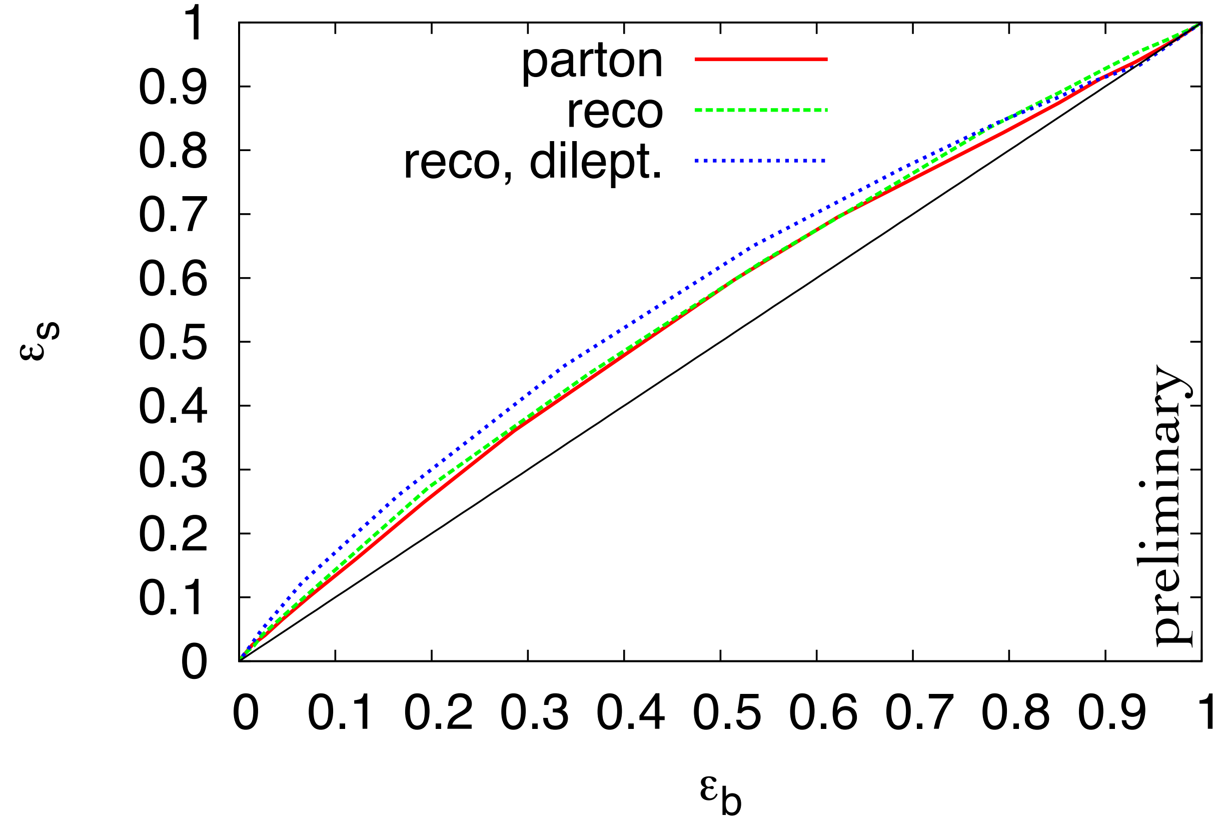
reco: ★ events generated with MadGraph + Pythia + Delphes,
2 isolated leptons with $|\eta(l)| < 2.4$, $p_T(l) > 20$ GeV
jets selected if $p_T(j) > 30$ GeV, $|\eta(j)| < 2.4$,

if more than 4 jets, select the set of 4 jets that reconstruct the best the mass of the W bosons and top quarks [see JHEP 10 (2013)167]

★ weights calculated with the previously-defined TF

MEM discriminating power, single-lepton channel



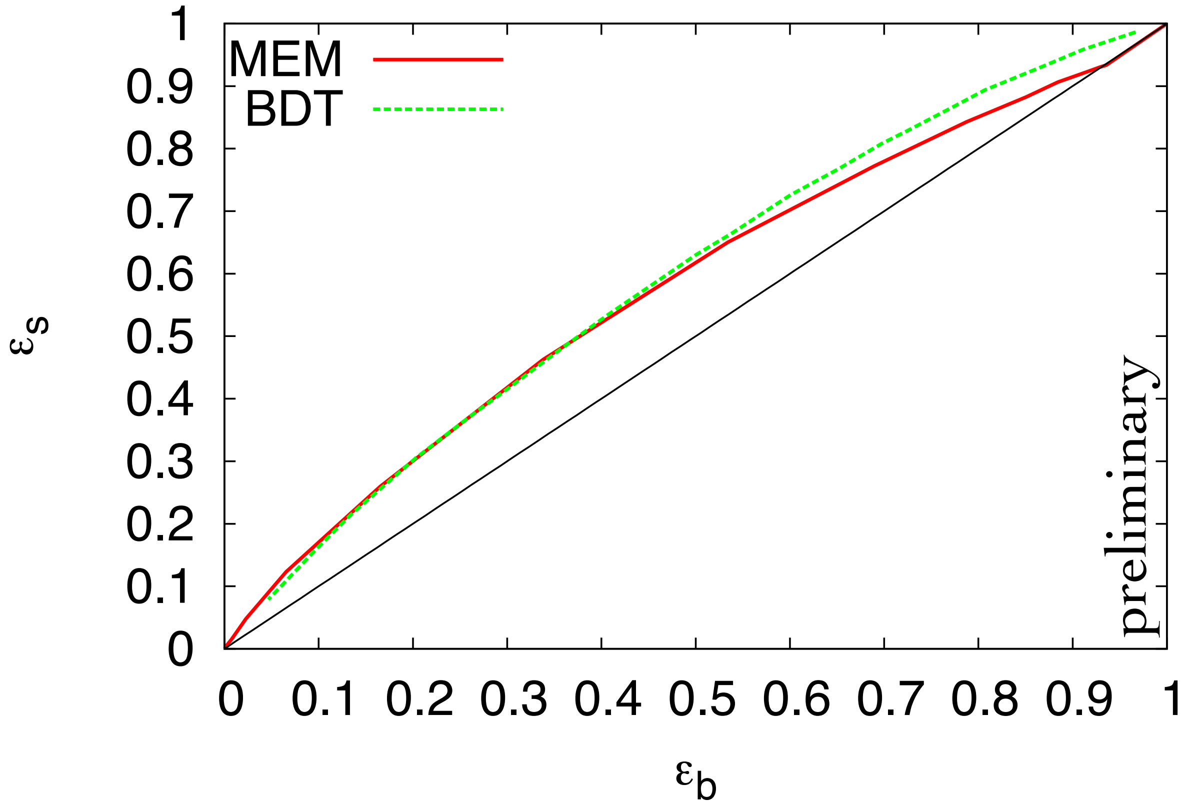


discriminating power very similar at the parton level and at the reconstructed level, a bit worse than in the dilepton case

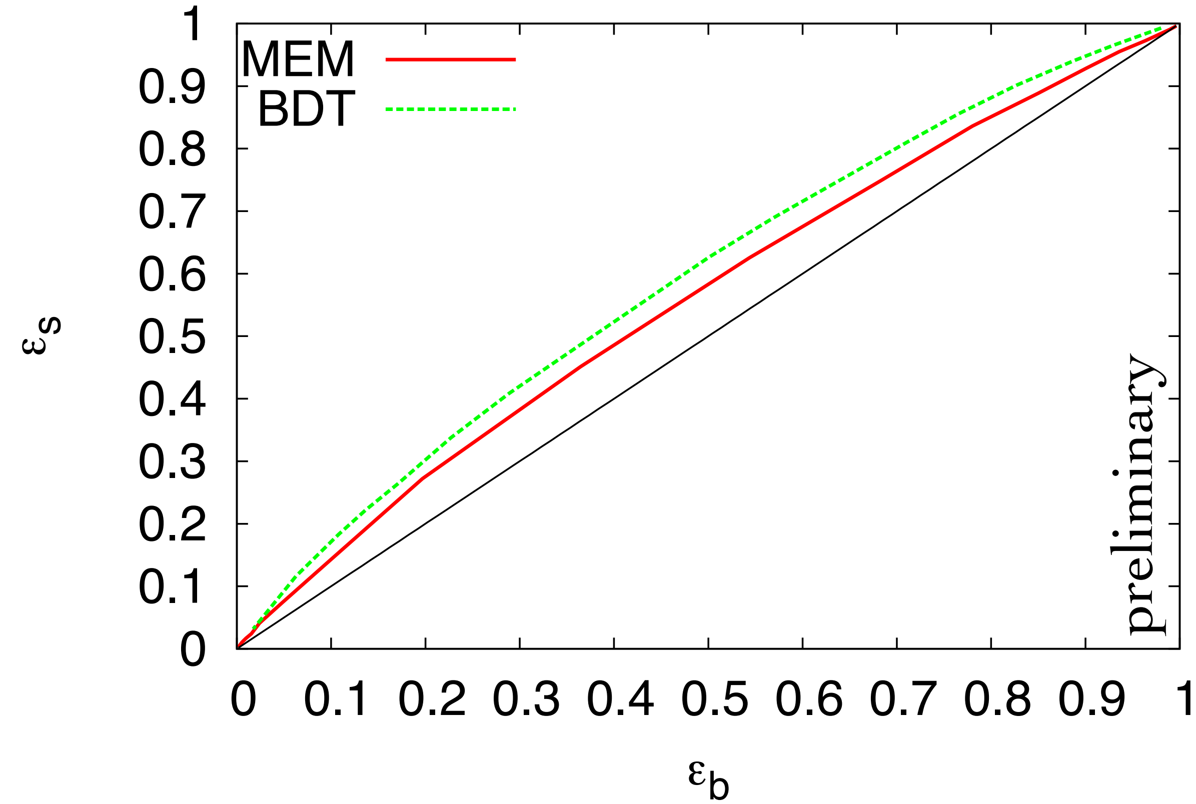
Discriminating signal and bkg events with BDT

- **Boosted decision trees** trained with signal and background at the **reconstruced level**
- training has been performed with the **TMVA package** in root, with the parameters held at their default values (1000 trees)
- **discriminating variables** taken from the literature (see Eur. Phys. J. C(2013) *73:2677* for the single-lepton channel and arxiv:1303.5776 for the dilepton channel) and from Alexis Kalogeropoulos' thesis

Comparison MEM versus BDT



dilepton channel



single-lepton channel

MEM (as implemented in this analysis) brings no improvement w.r.t. to a multivariate analysis

Conclusion

- we have investigated the use of matrix element reweighting techniques for stop searches in the region
  $m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}}$

- no significant decrease in the discriminating power is observed when applying the MEM to reconstructed events rather than parton level events

- the MEM discriminating power is slightly higher in the dilpton channel than in the single lepton channel (presumably because of the combinatorial background in the latter case)

- no improvement with respect to BDT