international linear collider

Study of the process of scalar top pairs production at ILC

A.Bartl **(Univ. of Vienna)**

W.Majerotto **HEPHY (Vienna)**

K.Moenig **DESY (Zeuthen)**

A.N.Skachkova, N.B.Skachkov

JINR (Dubna)

The Photon beams at ILC

The option of a photon collider at ILC will be achieved by using backscattered photon beams by Compton scattering of laser beams with electron ones.

Unlike the situation at e^+e^- collider, the energy of the backscattered photon beams will vary from event to event.

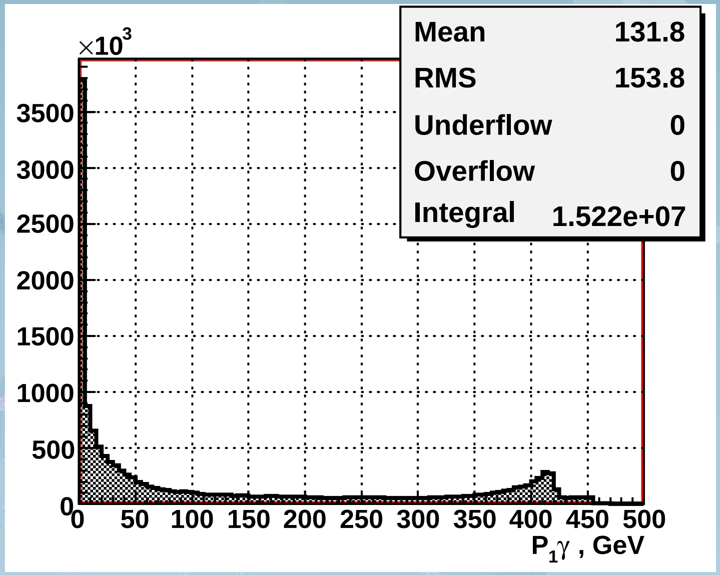
Circe2 program gives the energy spectra of the colliding backscattered photons & the values of photon beam luminosities.

Energy spectrum from CIRCE 2

shows the degree of monochromaticity of the backscattered photons

We used as a reasonable approximation the CIRCE2 output spectra generated for $E^{tot}_{e+e-} = 800\ GeV$ and scaled them (by 1000/800) to the higher beam energy

$$2E^e_{beam} = 1000\ GeV$$



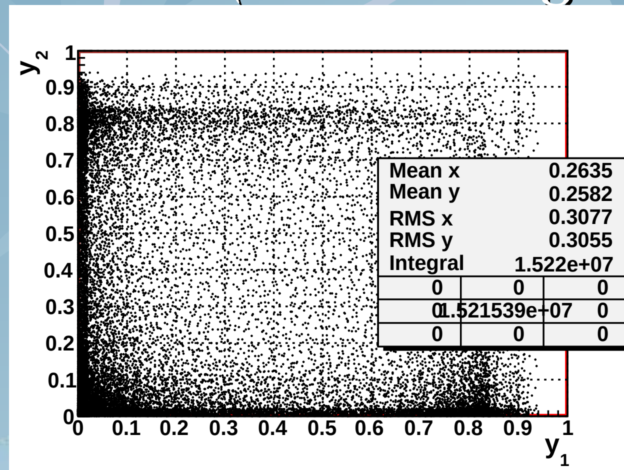
- The left peak is caused by multiple Compton scattering and beamstrahlung photons
- The right one at the energy fraction $Y = E_i^{\gamma} / E^e_{beam} \approx 0.83$ (i=1,2) is due to the hard photon production

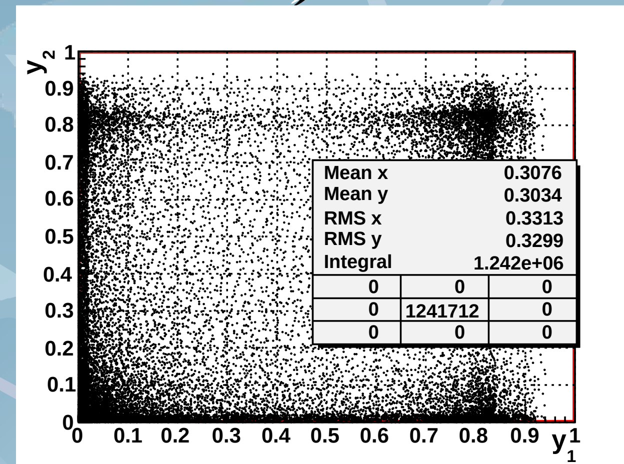
Only on a 0.3% the γγ energy is high enough for γγ → stop stop bar production

γ-energy correlation Y_1/Y_2 spectra for J=0 enhanced

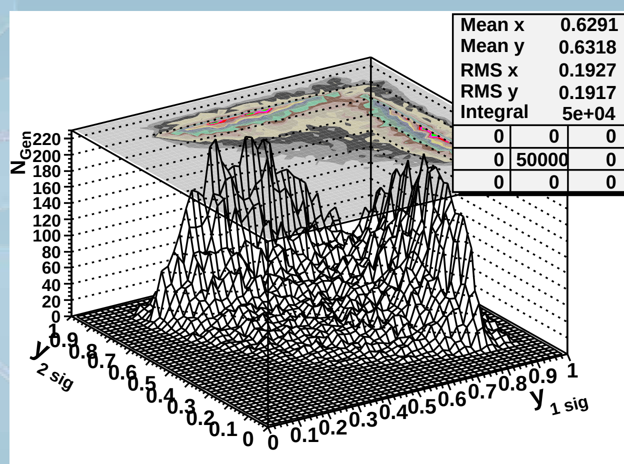
(J – total angular momentum)

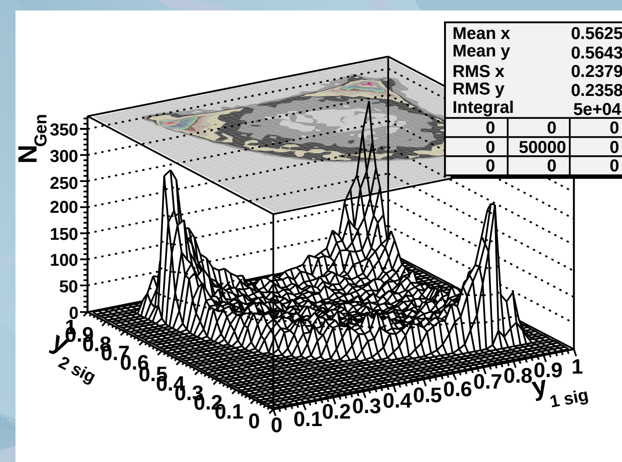
Whole γ spectrum





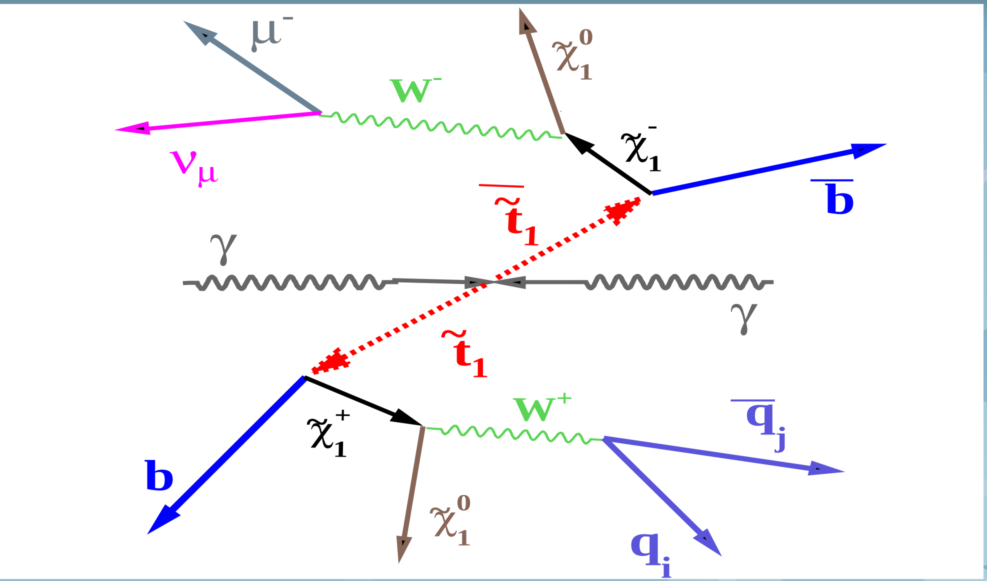
γ spectra above stop pair production threshold





Polarizations + - /- +

Polarizations + +/- -



$e^+ e^-$ CM energy = 1000 GeV

STOP pair production cross sections

σ = 2.03 fb "+ –" & "– +"

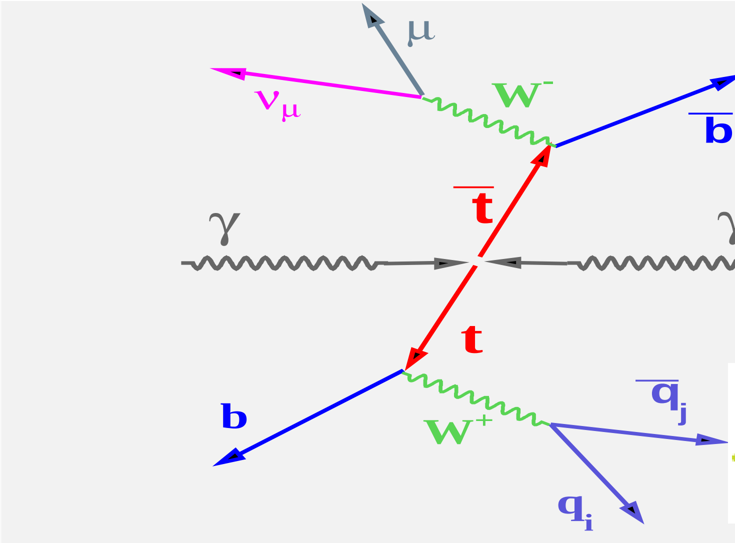
σ = 3.46 fb "+ +" & "– –"

4-6 factor difference

TOP pair production cross sections

σ = 13.17 fb "+ –" & "– +"

σ = 15.57 fb "+ +" & "– –"



PYTHIA 6.4 + cross section distribution formula taken from S.Berge et al. hep-ph/0008081

The subsequent decay channels have been considered:

- STOP STOP $\rightarrow b\ \chi_1^+\ b_{bar}\ \chi_1^- \rightarrow b\ b_{bar}\ q_i\ q_{j\,bar}\ \mu^-\ \nu_\mu\ \chi_1^o\ \chi_1^o$
- $t\ t \rightarrow b\ W^+\ b_{bar}\ W^- \rightarrow b\ b_{bar}\ q_i\ q_{j\,bar}\ \mu^-\ \nu_\mu$

The only difference of STOP / TOP production is the presence of the two non-detectable neutralinos in the case of stop pair production.

Both the signal and background events have the same experimental signature (b & b_{bar} - jets, 2 jets from W → $q_i\ \bar{q}_j$ decay and μ^-).

The quarks hadronize into jets. Jets are determined by use of PYCLUS jetfinder based on "Durham" cluster distance measure algorithm.

In order to simulate the STOP pair production, we assumed the following scenario for the MSSM model parameters:

- $M_{\sim Q} = M_{\sim t\,L}$ = 270 GeV (left squark mass)
- $M_{\sim U} = M_{\sim t\,R}$ = 270 GeV (right squark mass)
- At = -500 GeV (top and bottom trilinear coupling)
- μ = - 370 GeV
- tanβ = 5
- M_1 = 80 GeV
- M_2 = 160 GeV

Corresponds to

M_{stop1} = 167.9 GeV, $M_{\chi 1^o}$ = 80.9 GeV

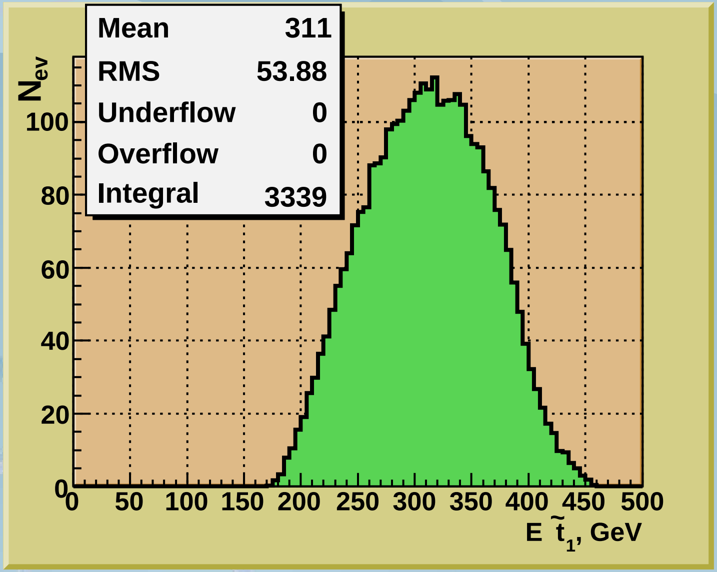
M_{stop2} = 409.9 GeV, $M_{\chi\,1+}$ = 159.2 GeV

Our aim is:

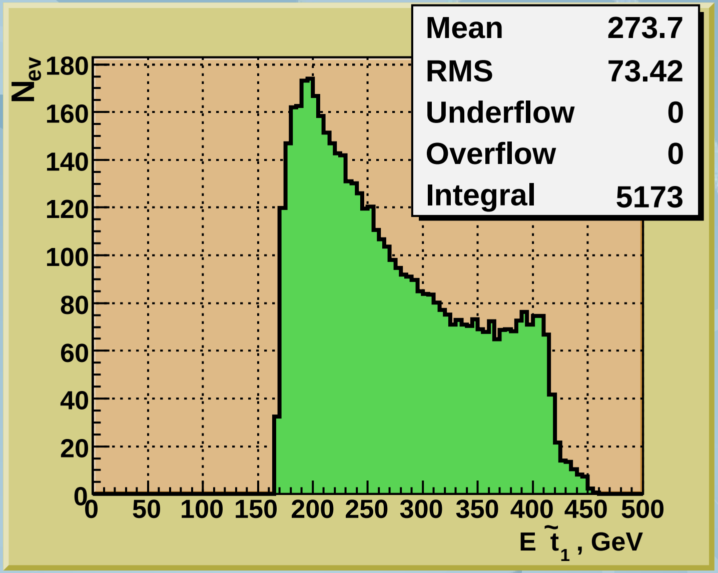
- *To find out physical variables (Energy, PT, angle and invariant mass distributions) most suitable for signal (stop) / background (top) separation*
- *To estimate the corresponding values of cuts on these variables*

STOP Energy distributions

The shapes of these spectra follow backscattered γ-energy distributions

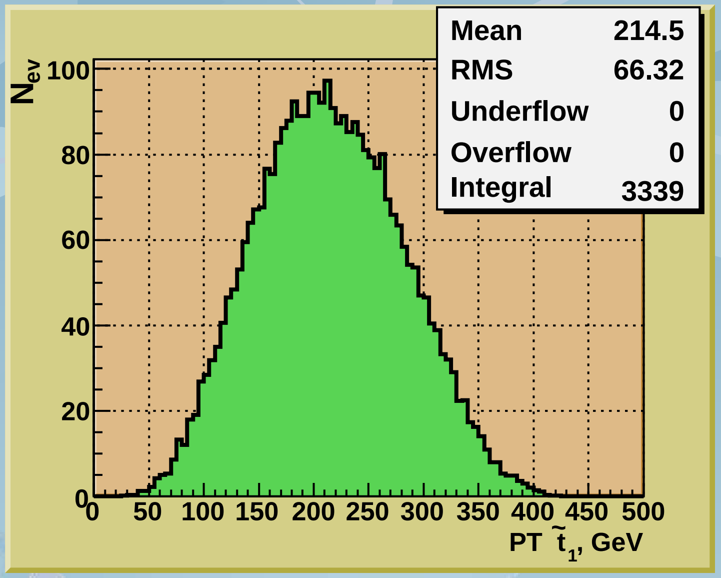


Polarization : +- / -+

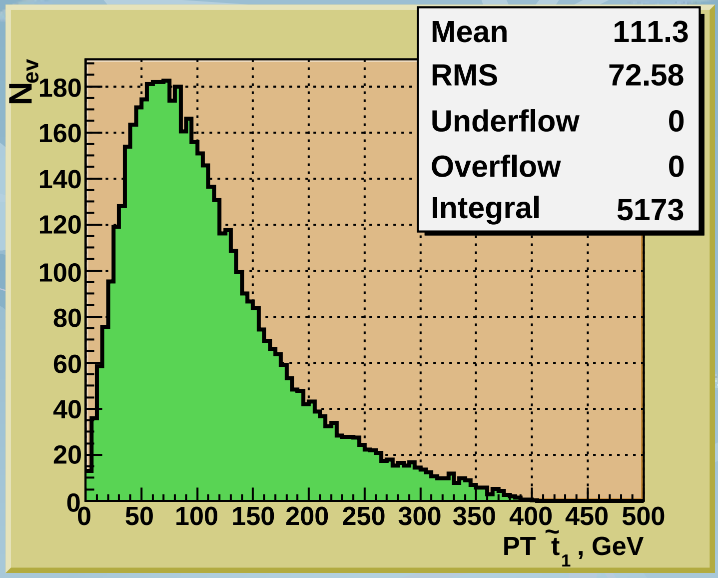


Polarization : ++/ --

STOP P_T distributions



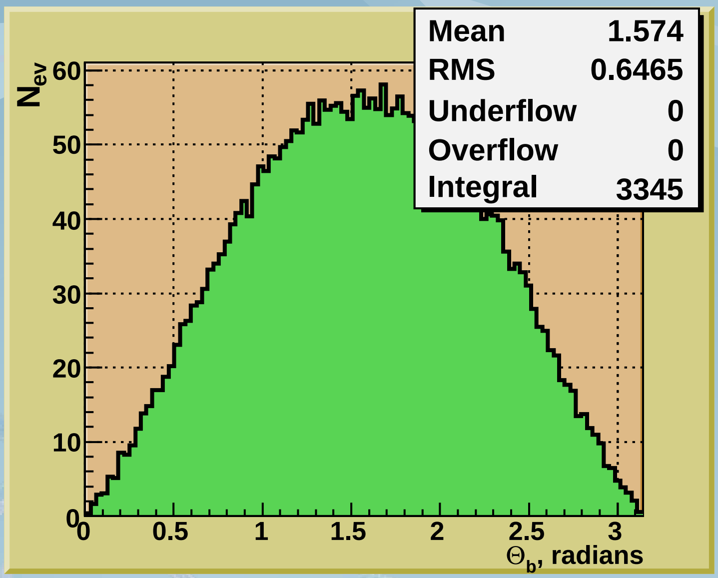
Polarization : +- / -+

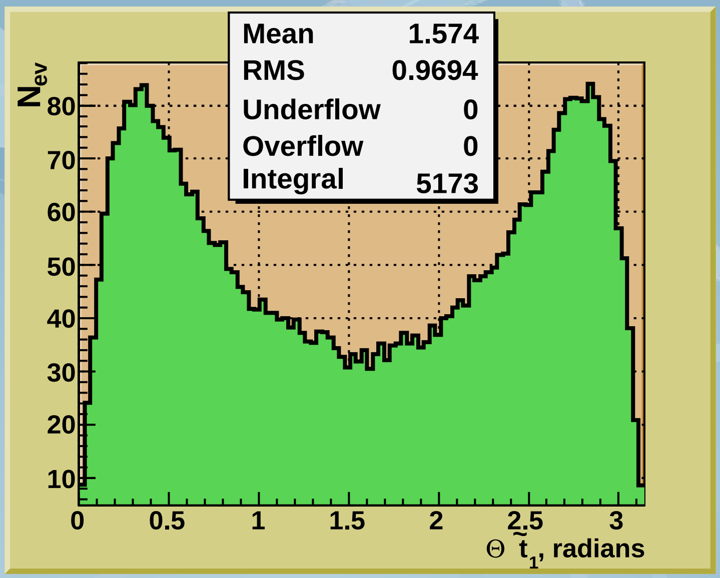


Polarization : ++/ --

The PT-spectrum for “++/--” polarization is much softer then for “+-/-+” polarization

STOP angle Θ distributions



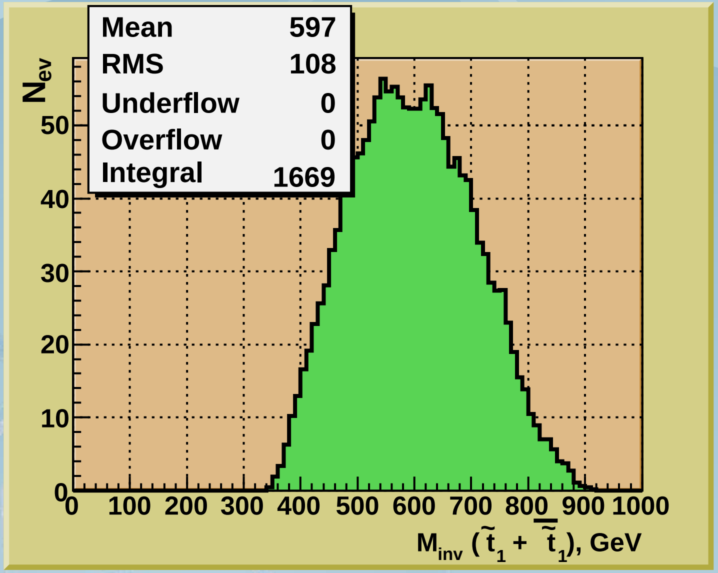


Polarization : +- / -+

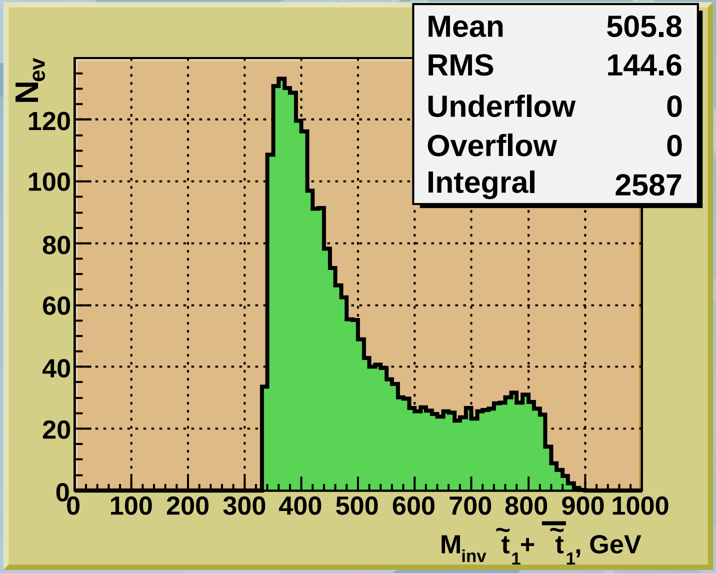
Polarization : ++/ --

M_{inv} (stop+stop$_{bar}$) = M_{inv} ($\gamma\gamma$) = $\sqrt{(P\gamma_1 + P\gamma_2)^2}$ distributions

The shapes of these spectra also follow backscattered γ-energy distributions



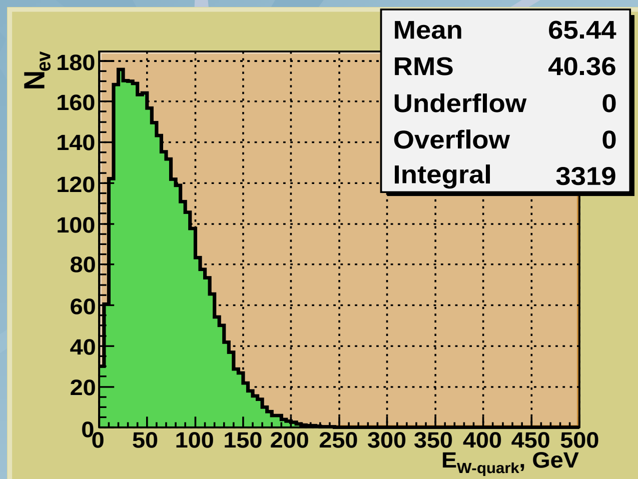
Polarization : +- / -+

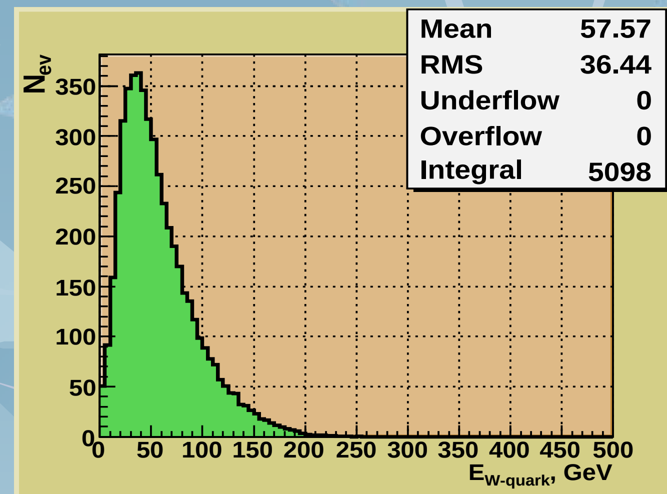


Polarization : ++/ --

E- spectra of quarks from W

STOP





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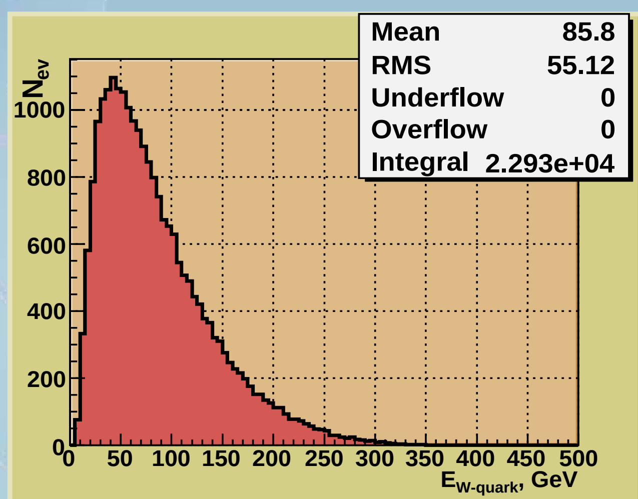
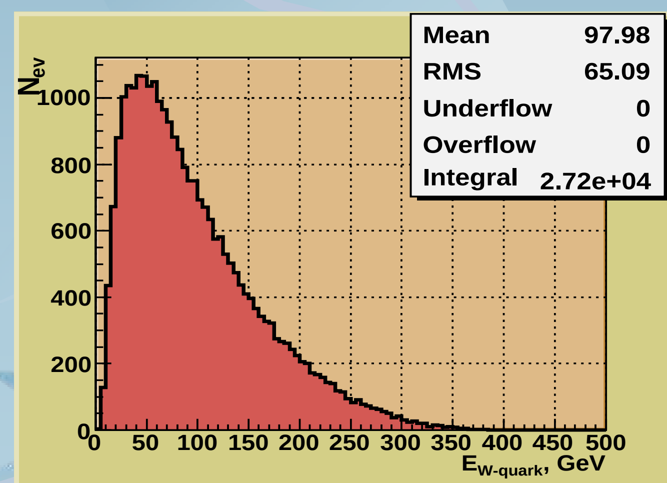


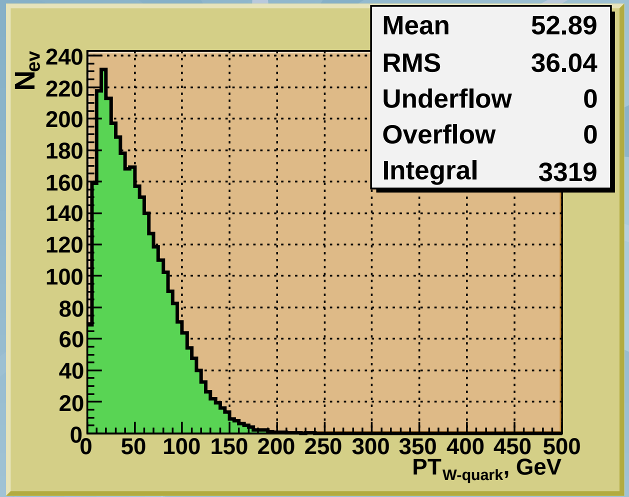


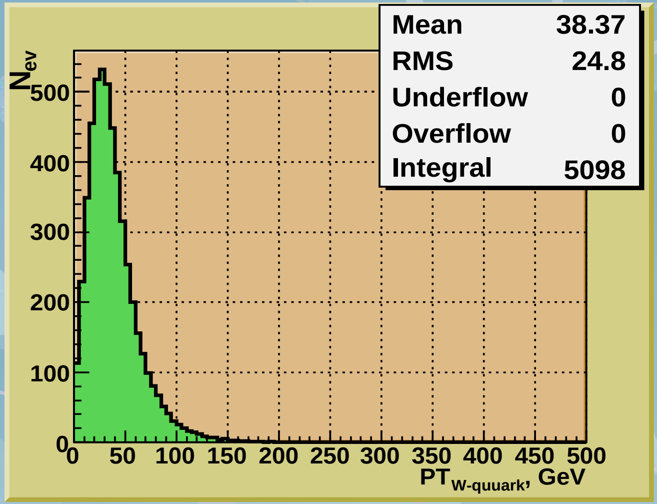
Polarization : +- / -+

Polarization : ++/ --

PT- spectra of quarks from W

STOP





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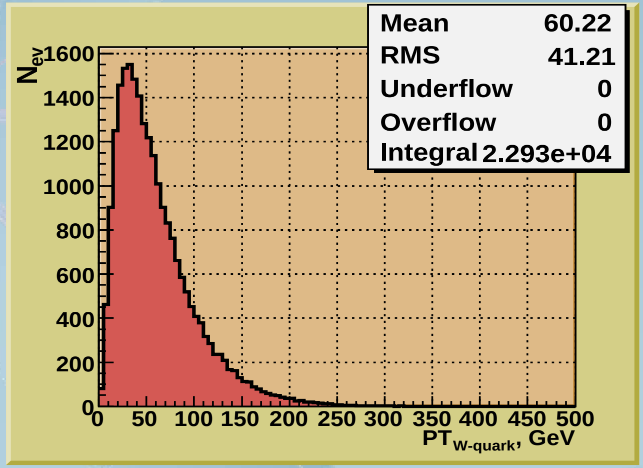
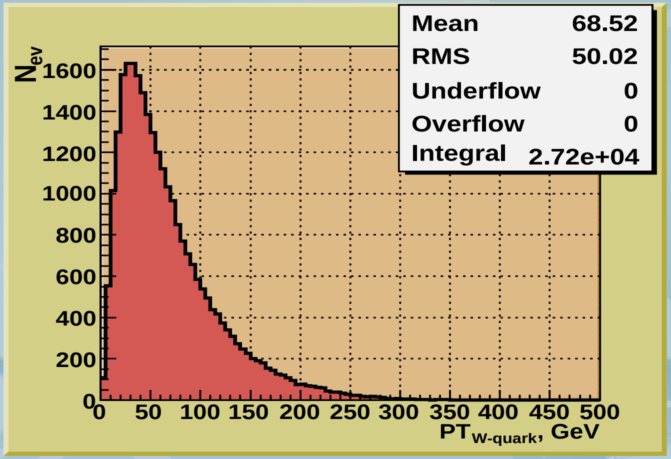




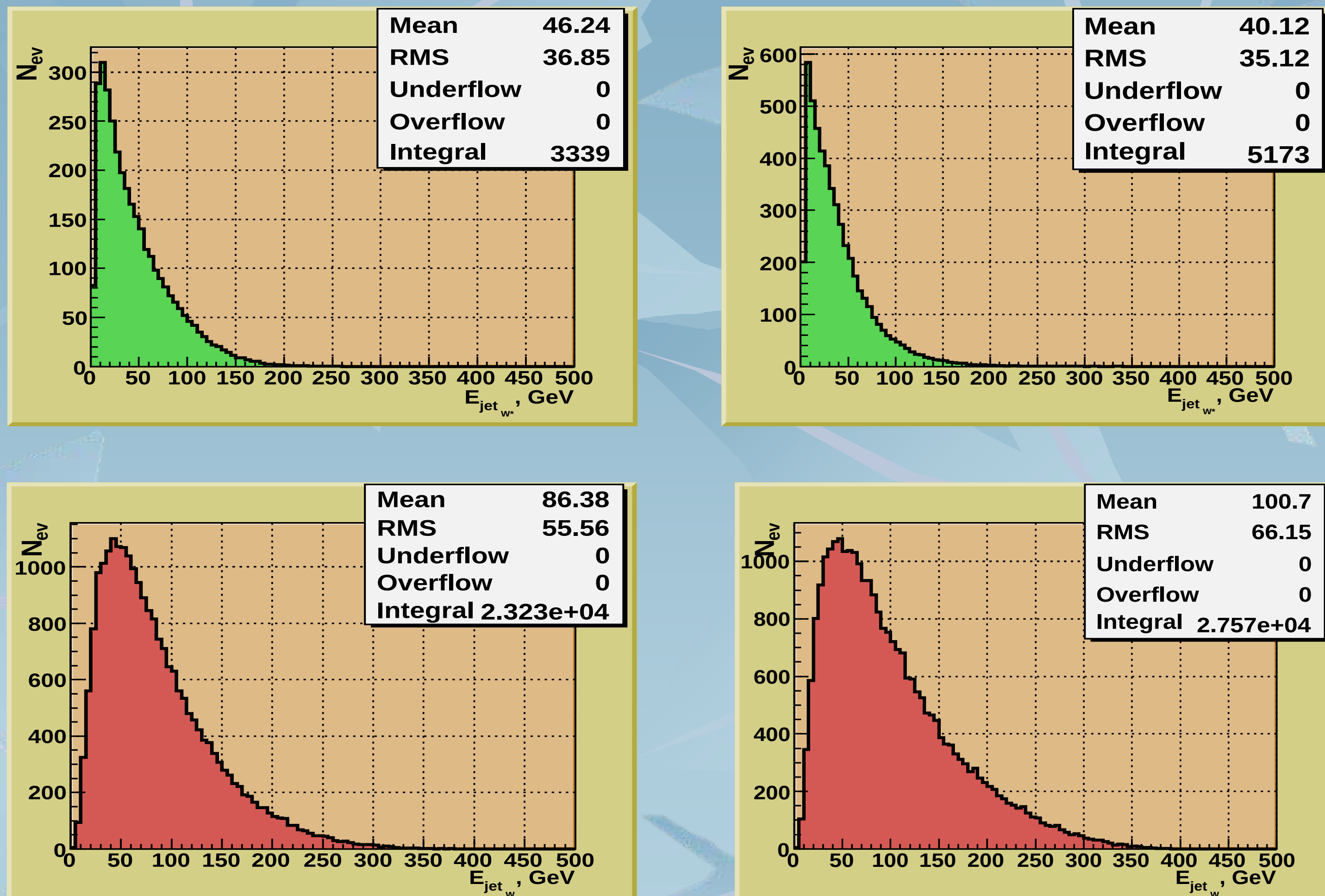
Polarization : +- / -+

Polarization : ++/ --

E- spectra of jets from W

STOP

TOP

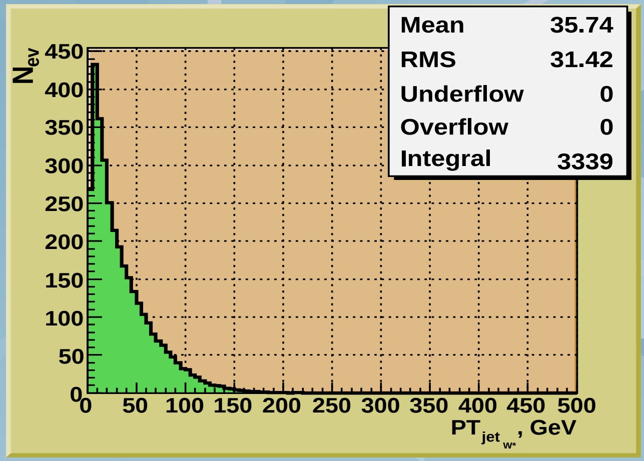


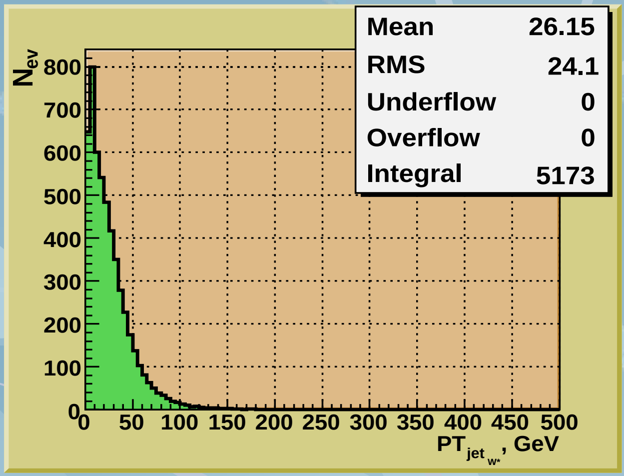
Polarization : +- / -+

Polarization : ++/ --

PT- spectra of jets from W

STOP





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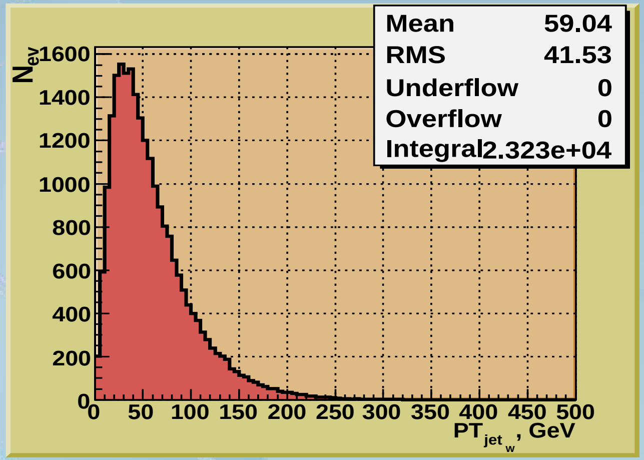
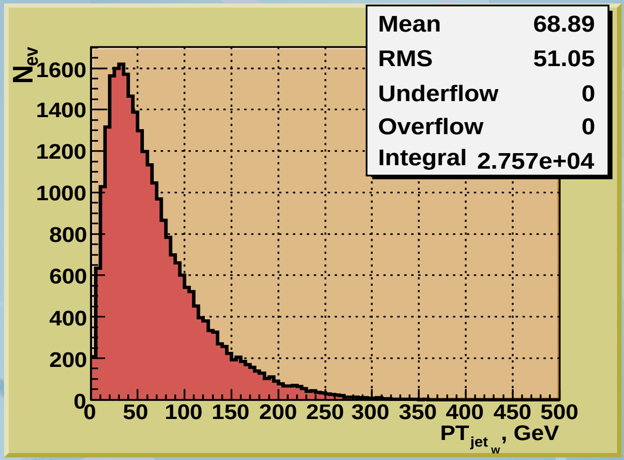




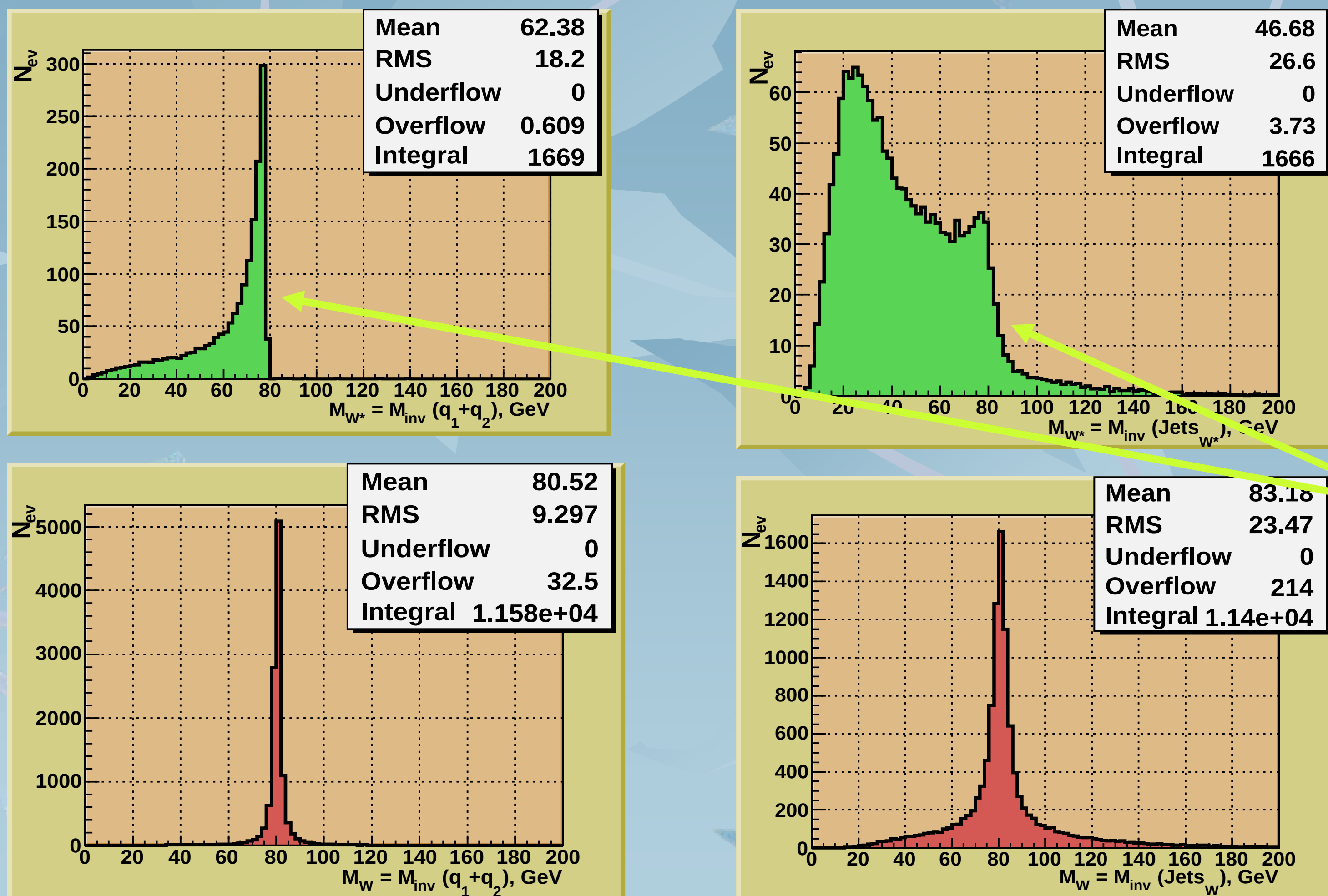
Polarization : +- / -+

Polarization : ++/ --

W mass reconstruction as M_{inv} of 2 W_{jets}

STOP

TOP

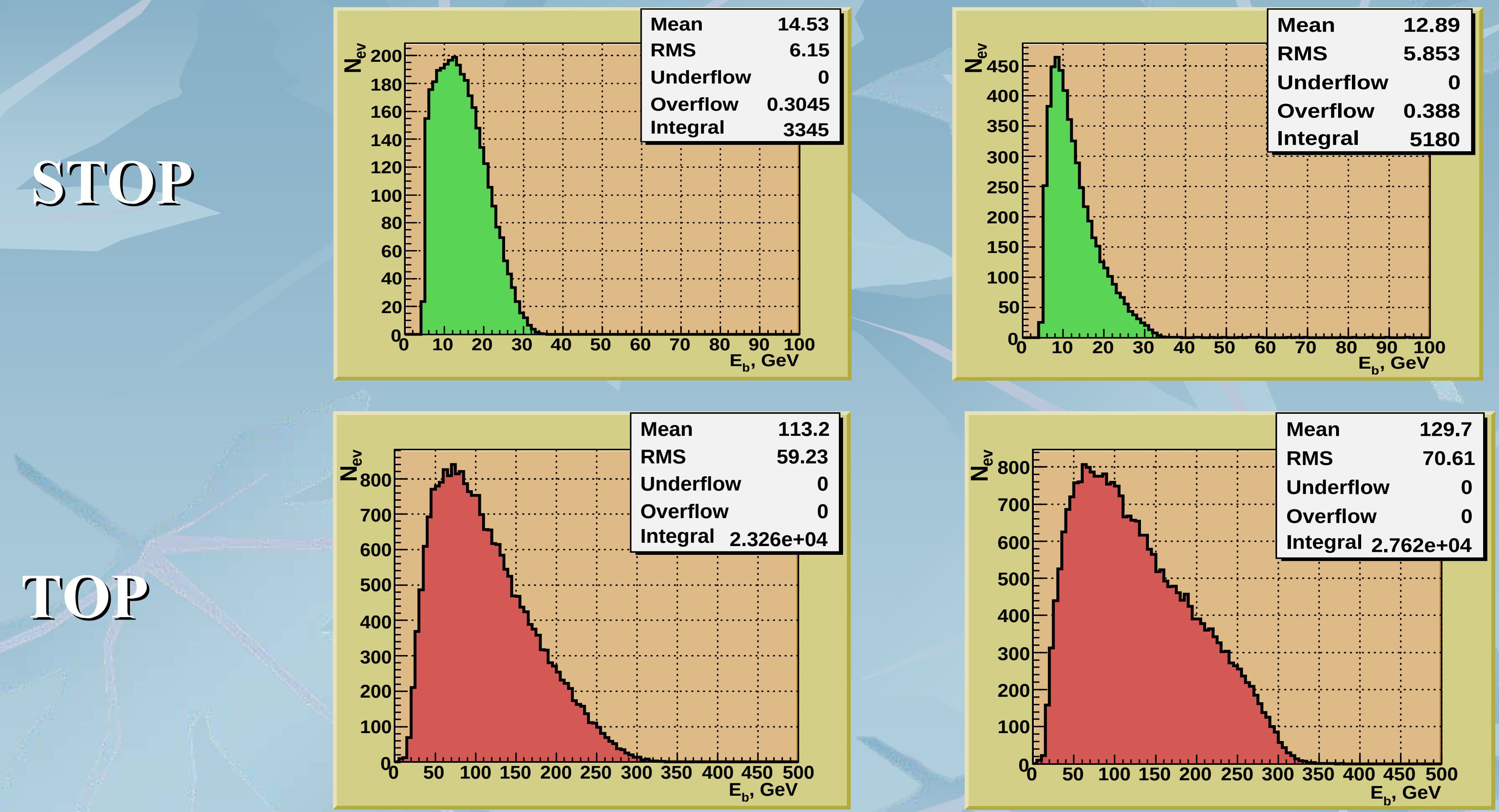


Partonic level

Level of jets

Clear seen visible *virtual nature* of W boson

E- spectra of b-quarks

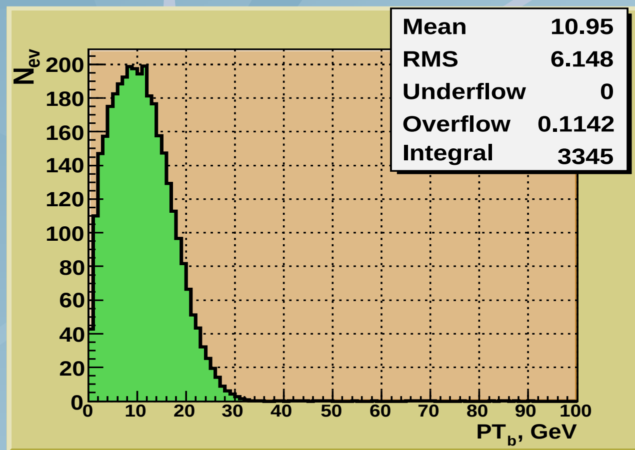


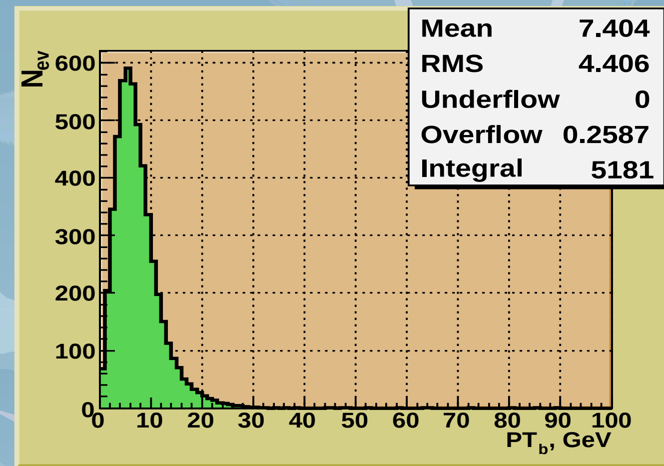
Polarization : +- / -+

Polarization : ++/ --

PT- spectra of b-quarks

STOP





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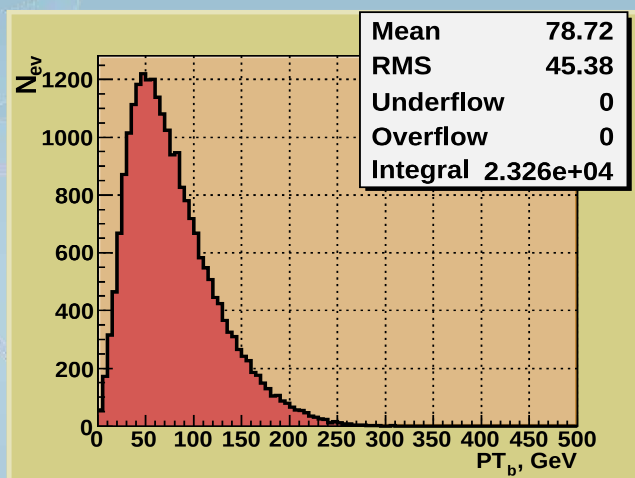
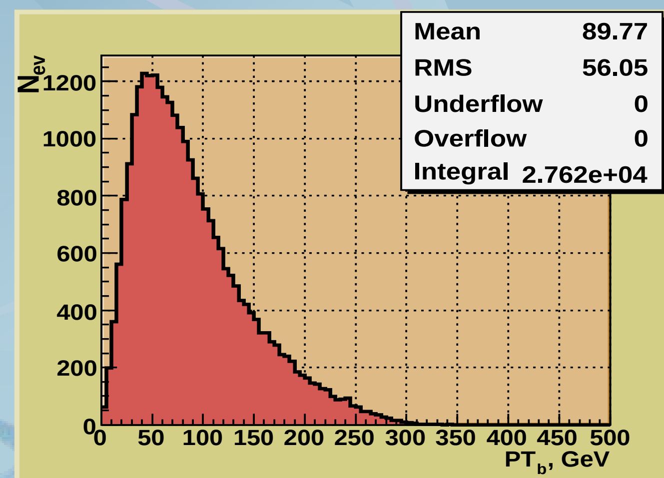




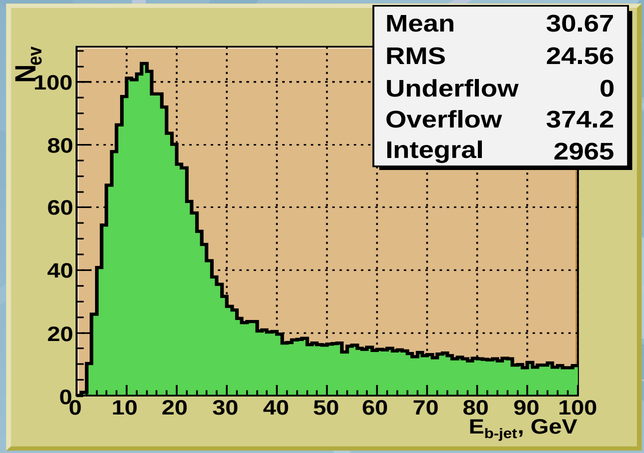
Polarization : +- / -+

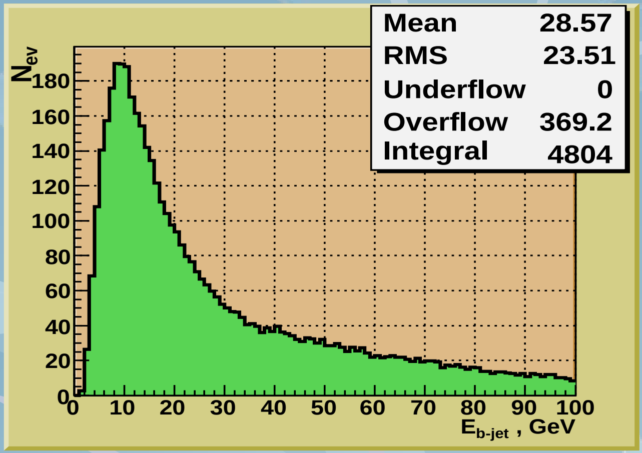
Polarization : ++/ --

E- spectra of *b*-jets

(B-jet is determined as a jet that includes b-meson)

STOP





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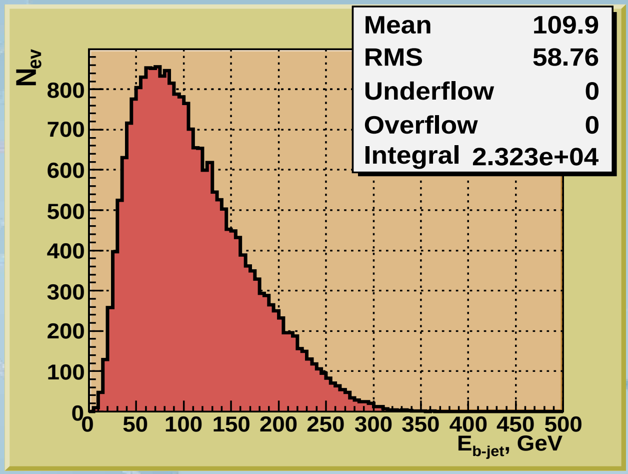
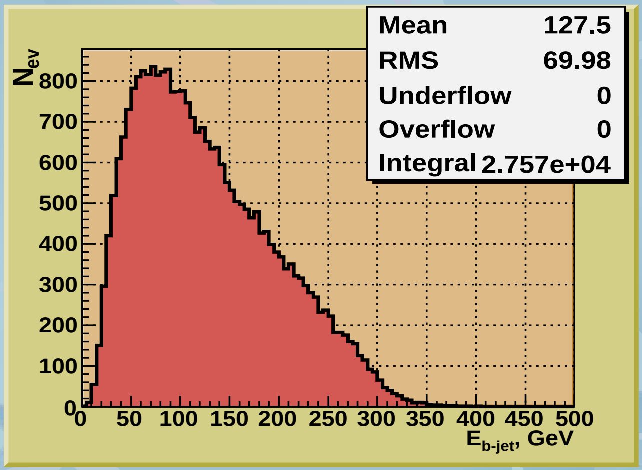
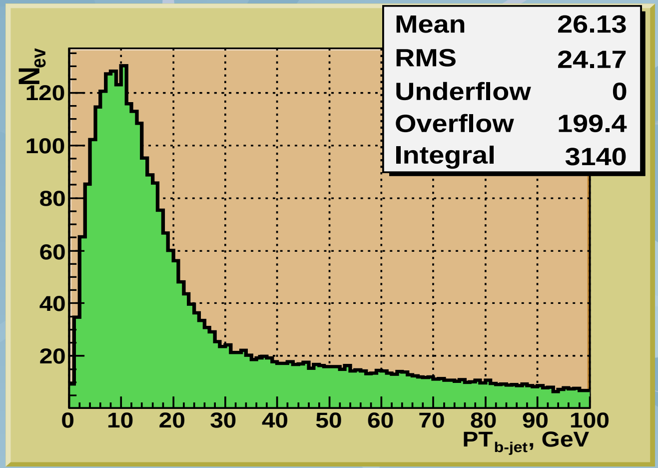


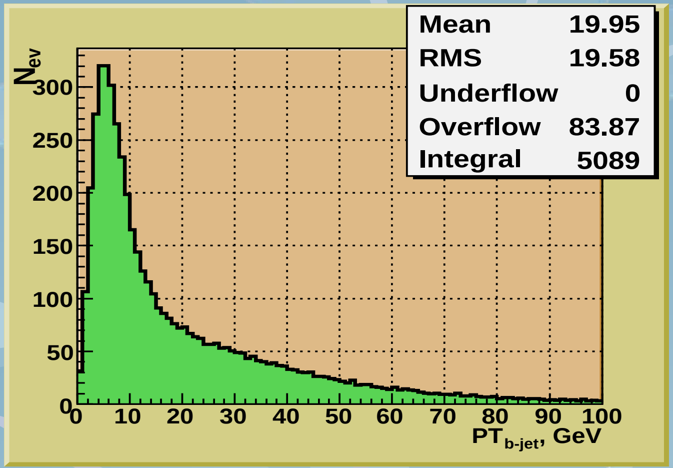


Polarization : +- / -+ **Polarization : ++/ --**

PT- spectra of *b*-jets

STOP





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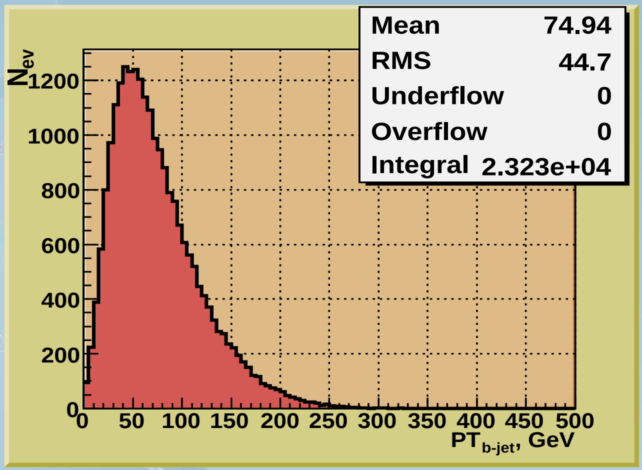
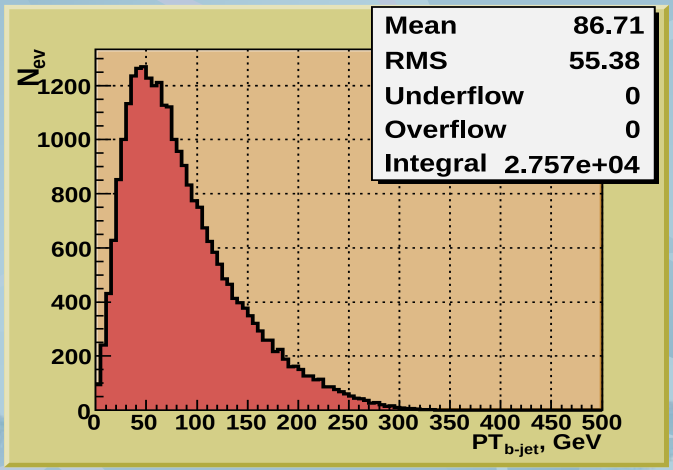
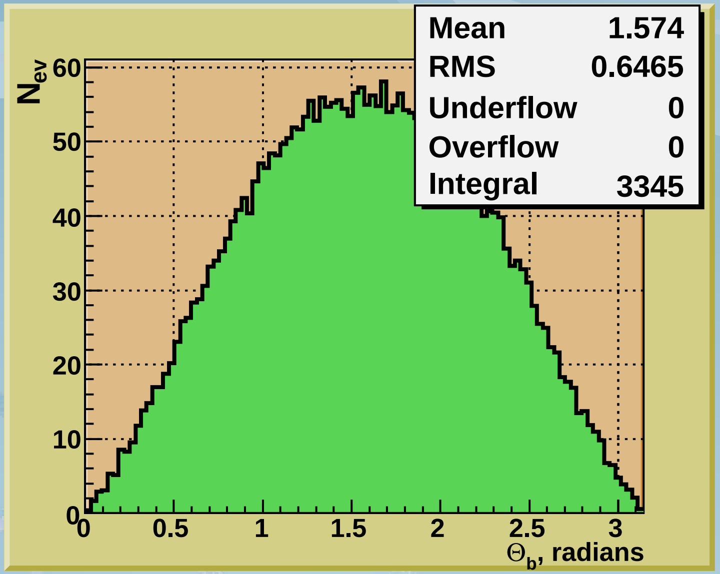




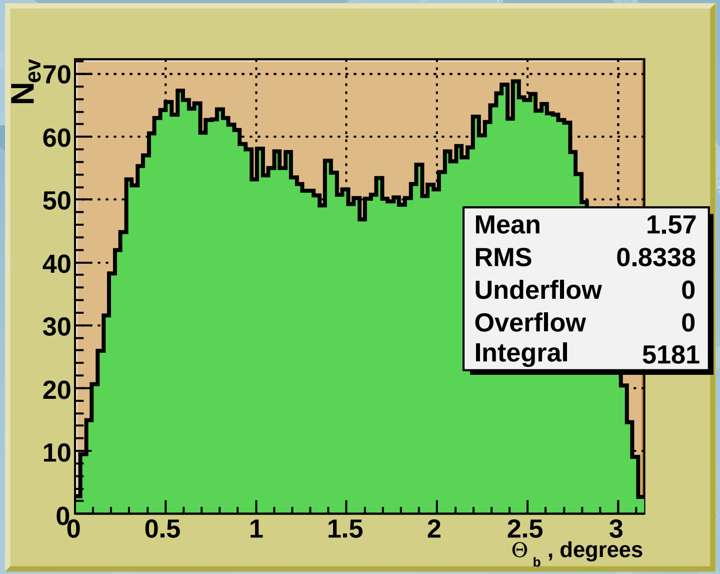
Polarization : +- / -+

Polarization : ++/ --

θ of b-quarks for stop production

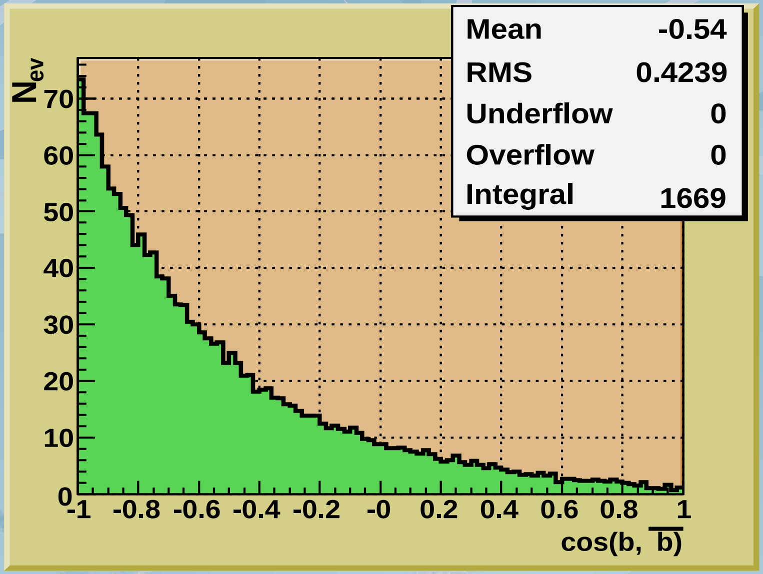


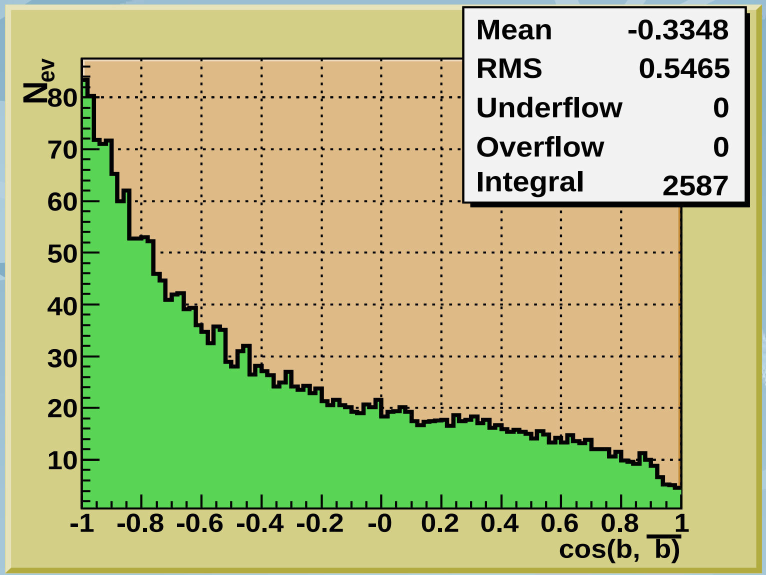
Polarization : +- / -+



Polarization : ++/ --

Cos (b, b_{bar}) spectra for Stop pairs production





Polarization : +- / -+

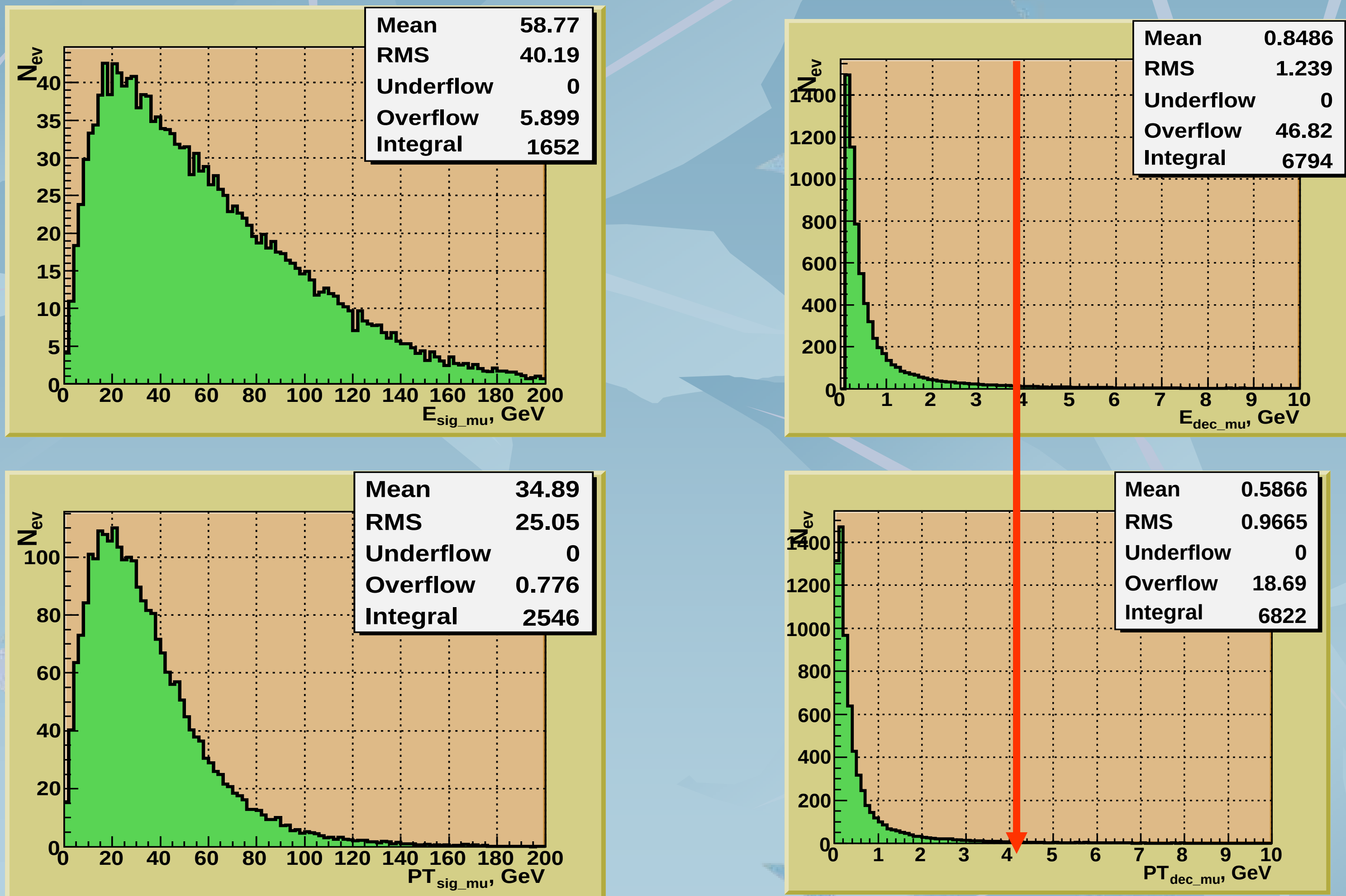
Polarization : ++ / --

Most of *b*- and *b bar* – jets move approximately in the opposite directions, but some are in the same hemisphere

μ distributions in the signal events

Eμ

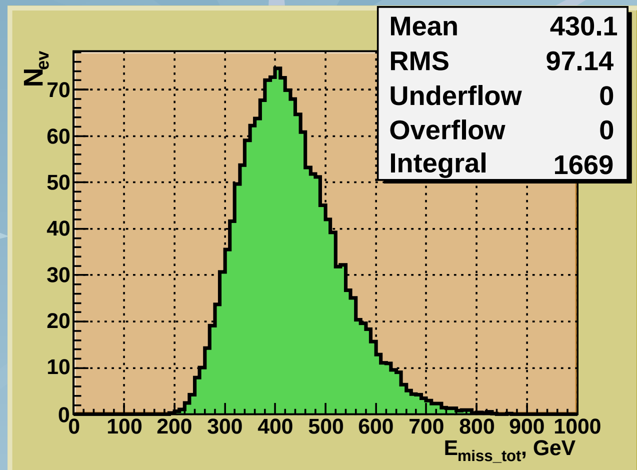
PTμ

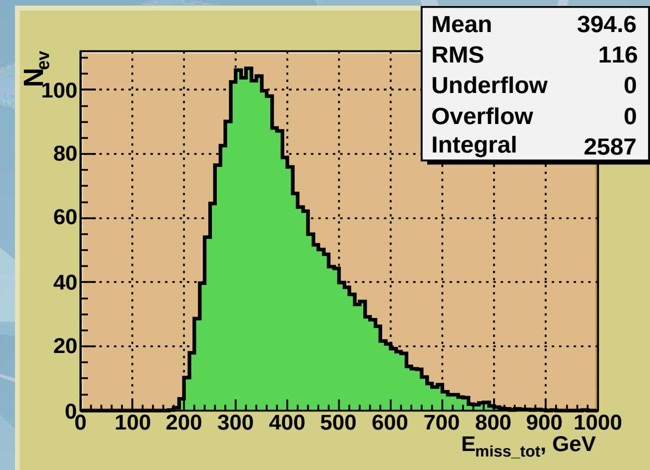


Signal μ's Fake μ's

Missing energy (ν_μ, $\sim\chi_1^{\circ}$, beam pipe) distributions

STOP





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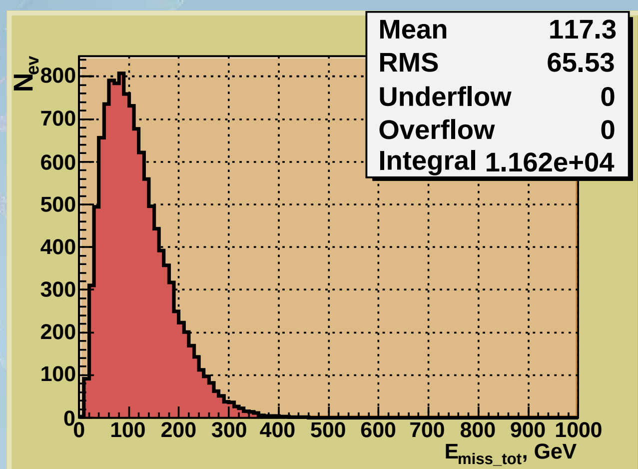
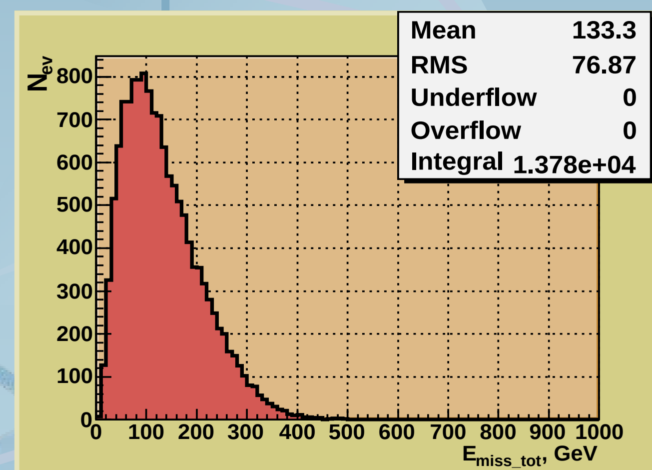




Polarization : +- / -+

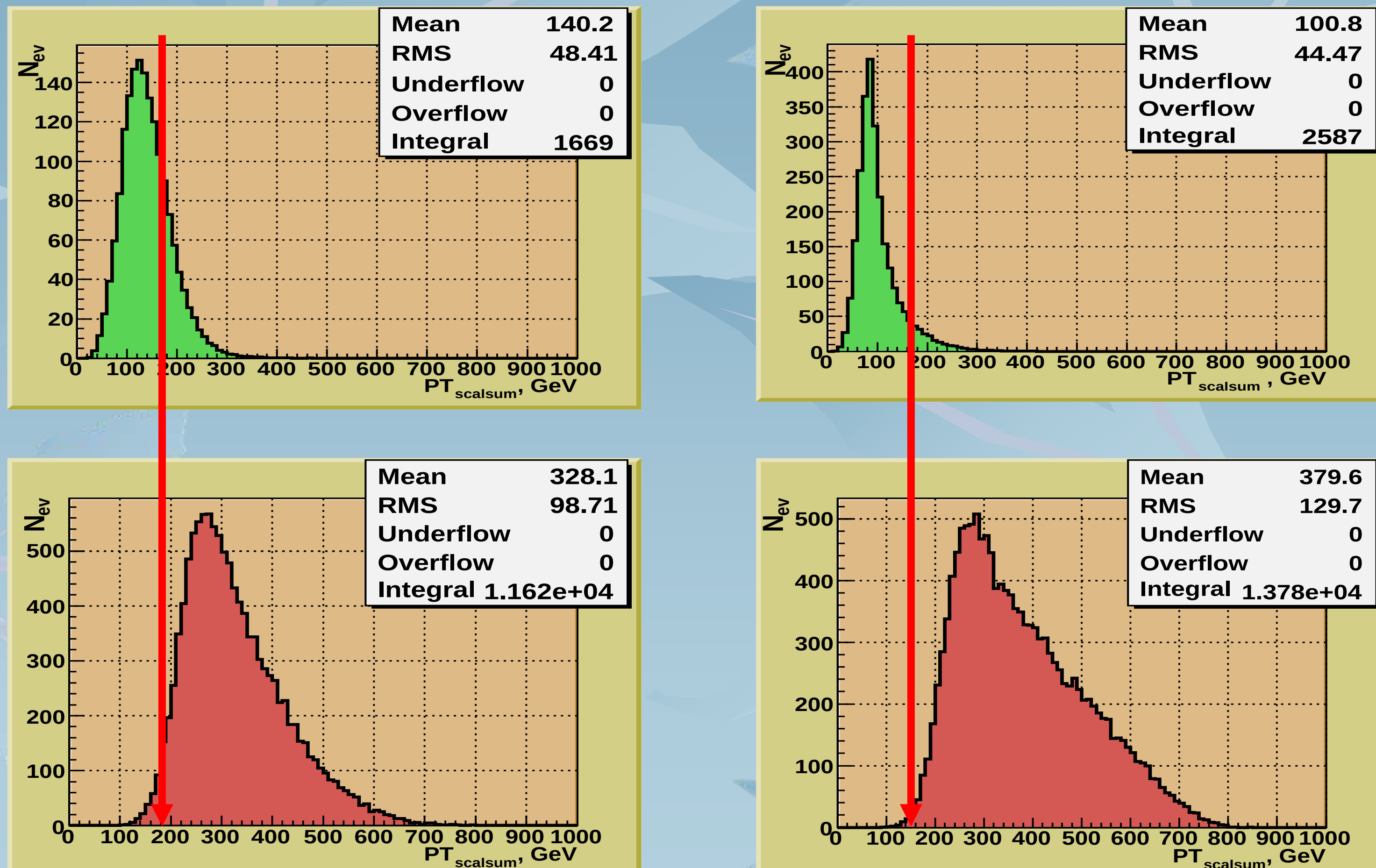
Polarization : ++ / --

Total scalar $\Sigma^{n}_{i=1} |PT_{i}|$ variable

A cut $PT_{skalsum}$ < 180 GeV would lead to a good Signal / Background separation

STOP

TOP



Polarization : +- / -+

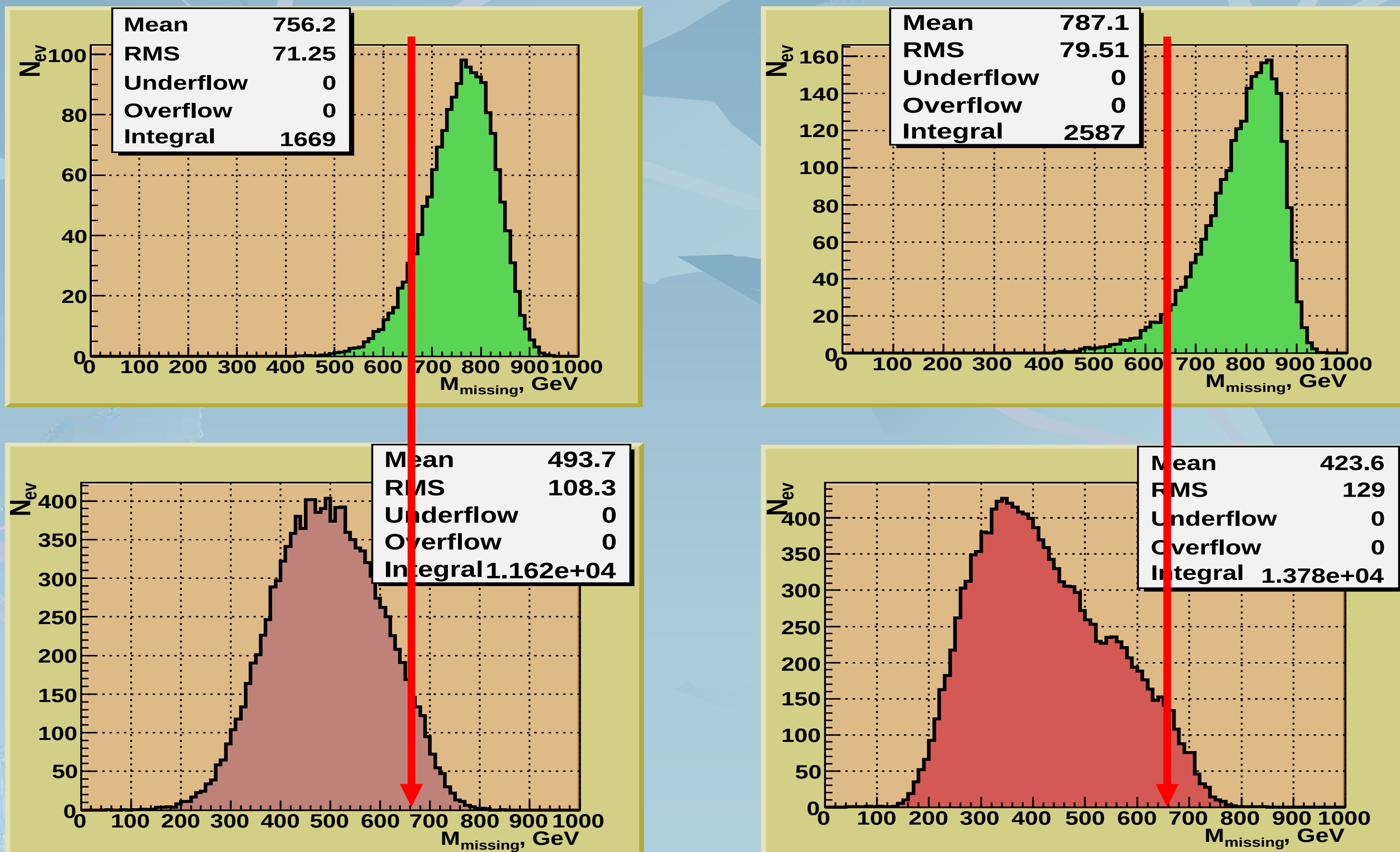
Polarization : ++/ - -

Missing mass

$$M_{missing} = \sqrt{(\sqrt{s}-(\Sigma^{Njet}_{n=1}E^{n}_{jet}+E_{\mu}))^2-(\Sigma^{Njet}_{n=1}P^{n}_{jet}+P_{\mu})^2}$$

STOP

TOP



Polarization : +- / -+ Polarization : ++/ --

Good for Signal / Background separation !

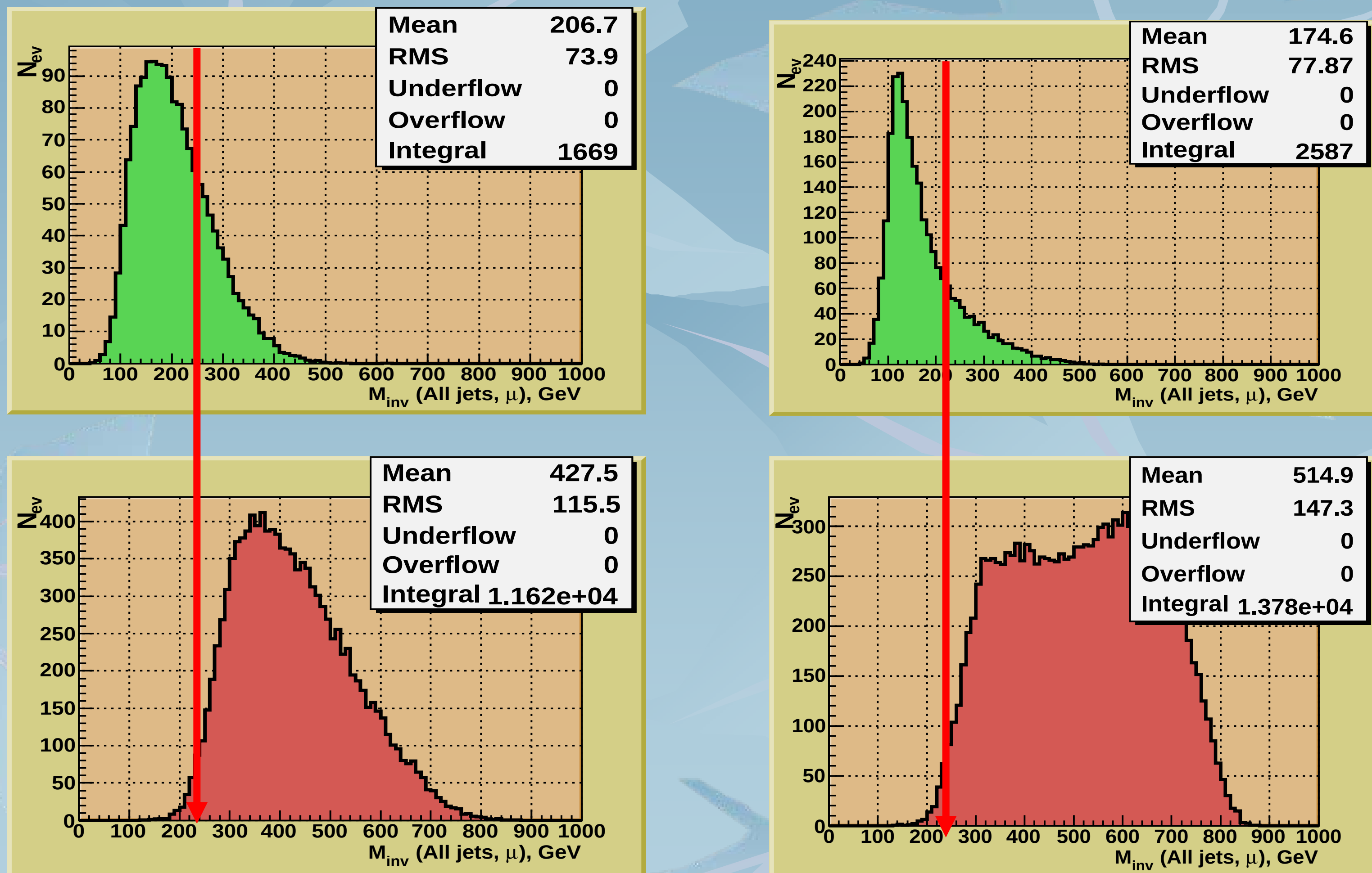
$M_{missing} > 650$ GeV

Invariant mass of 4jets + μ

Good for Signal / Background separation with a cut < 230 GeV!

STOP

TOP



Polarization : +- / -+

Polarization : ++ / --

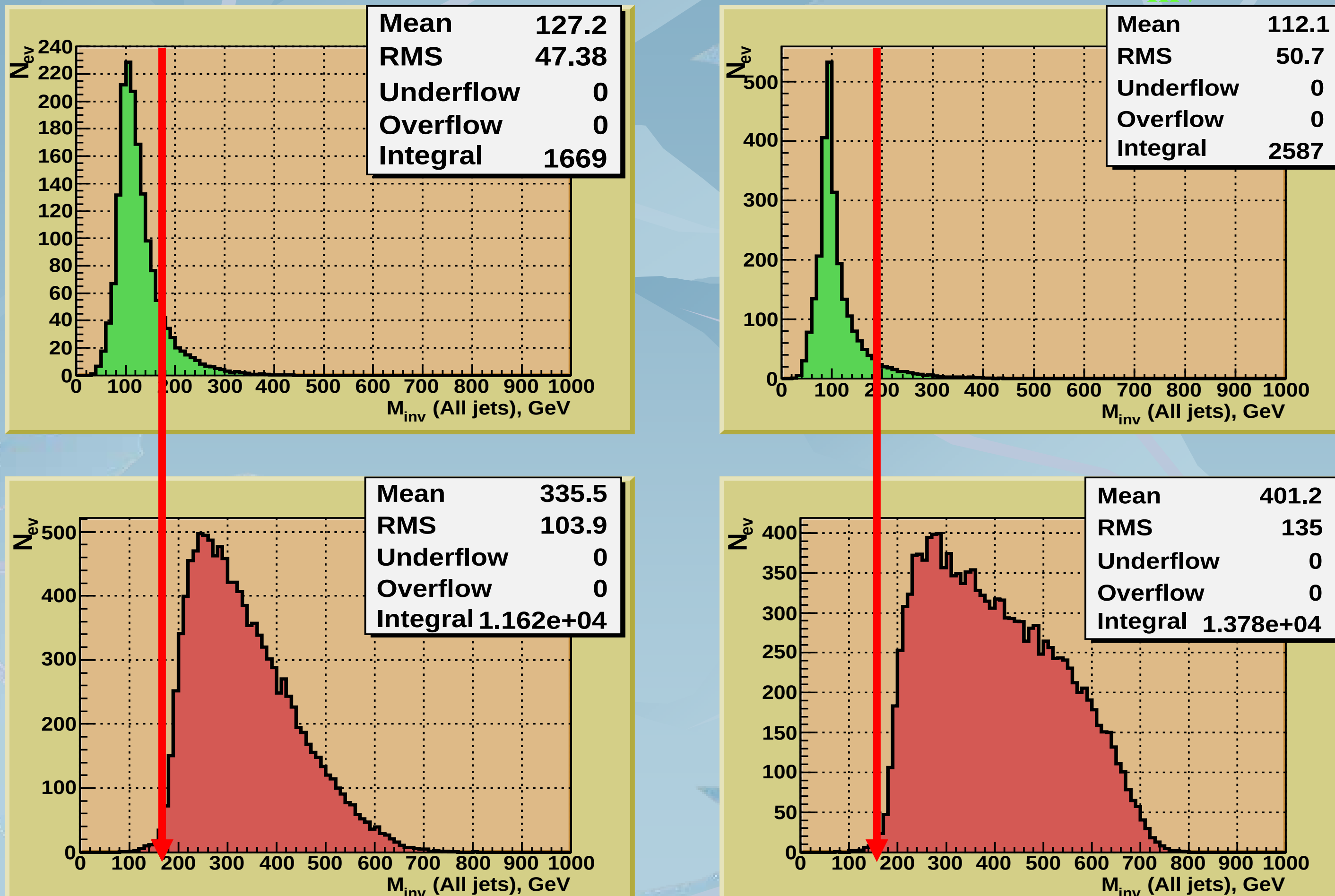
Invariant mass of 4 jets

$$M_{inv}(All\ jets)=\sqrt{(\Sigma_{i=1,2,3,4}P^{i}_{jet})^2}$$

Perfect for Signal / Background separation with cut M_{inv} < 180 GeV!

STOP

TOP



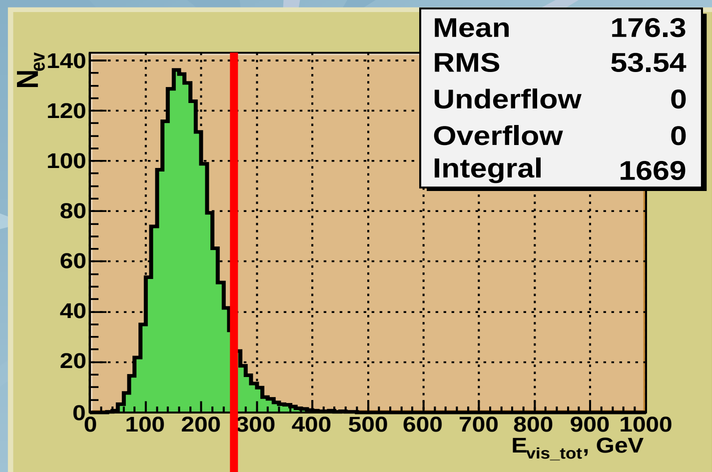
Polarization : +- / -+

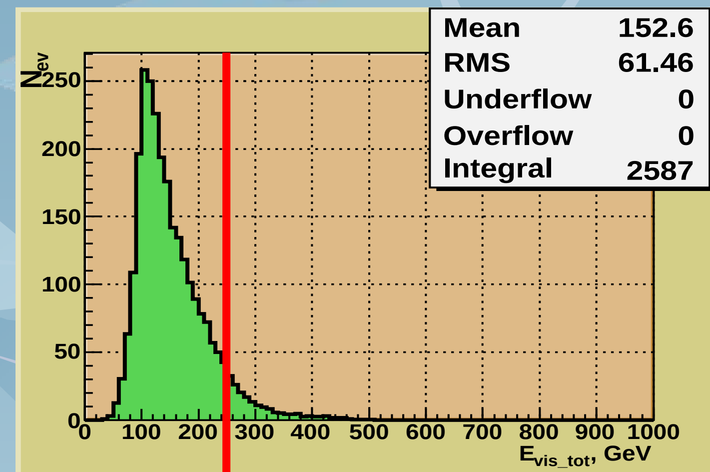
Polarization : ++ / --

Detected (visible) energy distributions

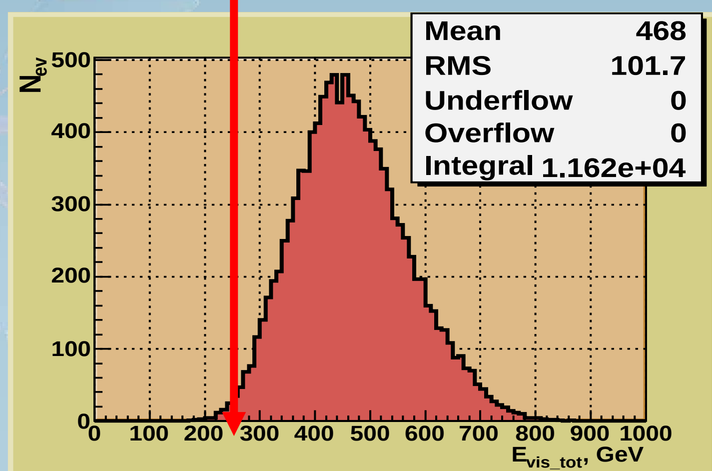
Perfect for Signal / Background separation with a cut $E_{vis\_tot} < 250$ GeV !

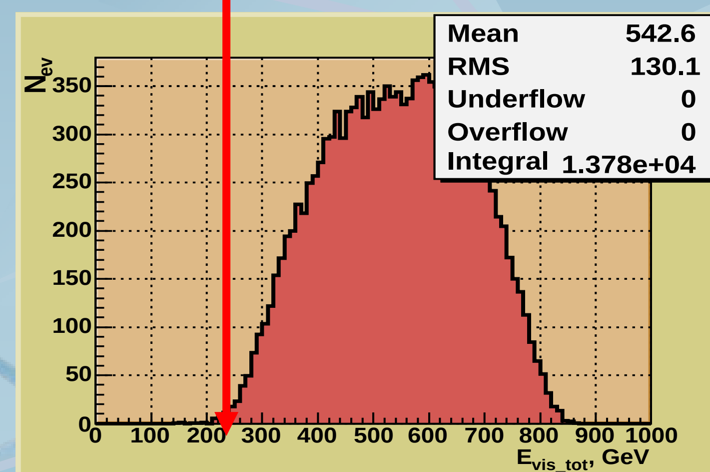
STOP





TOP





Polarization : +- / -+

Polarization : ++ / --

Used cuts for S/B separation

Polarization : +- / -+ | Polarization : ++ / --

1.) The events with clear recognized 2 B-jets (according to PYTHIA)

Polarization : +- / -+	Polarization : ++ / --
Stop cut efficiency = 0.88	*Stop cut efficiency = 0.80*
Top cut efficiency = 0.94	*Top cut efficiency = 0.94*

But, in the experiment only 50% efficiency of the B-jets and B_{bar}-jets separation and the 80% of the corresponding purity is expected

2.) Invariant mass of all jets M_{inv}(All jets) < 180 GeV

together with the cut above

Polarization : +- / -+	Polarization : ++ / --
Stop cut efficiency = 0.89	*Stop cut efficiency = 0.92*
Top cut efficiency = 0.012	*Top cut efficiency = 0.008*

3.) Visible energy < 250 GeV

together with the cut above

Polarization : +- / -+	Polarization : ++ / --
Stop cut efficiency = 0.98	*Stop cut efficiency = 0.98*
Top cut efficiency = 0.176	*Top cut efficiency = 0.175*

Final results of S/B separation

Polarization : +- / -+	Polarization : ++ / --

Achieved S/B ratio

59	***120***

With a loss of signal events

23 %	***28 %***

The rest of *Background events* per year is only

24	***19***

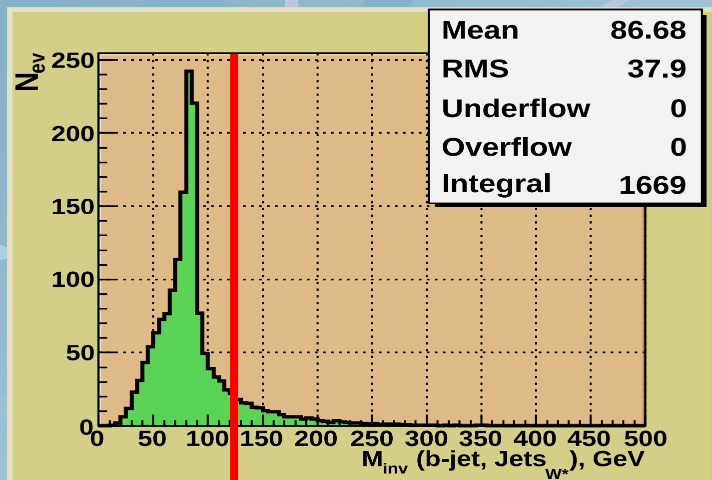
while the estimated rate of Signal events per year

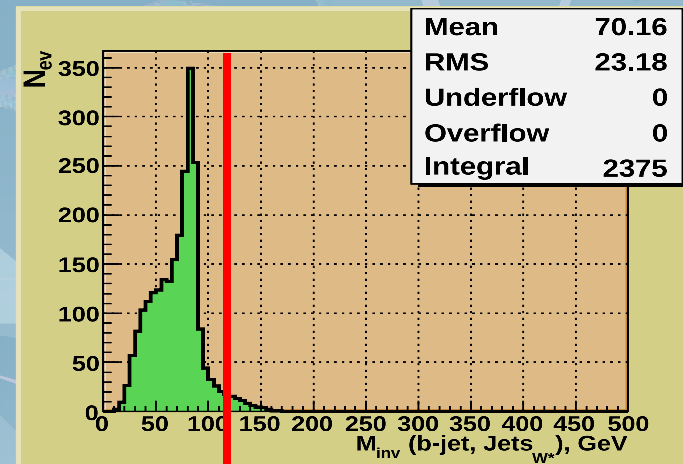
1484	***2375***

Invariant mass of B_{jet} & $2jets_W$

Can also be used for Signal / Background separation with a cut < 120 GeV!

STOP





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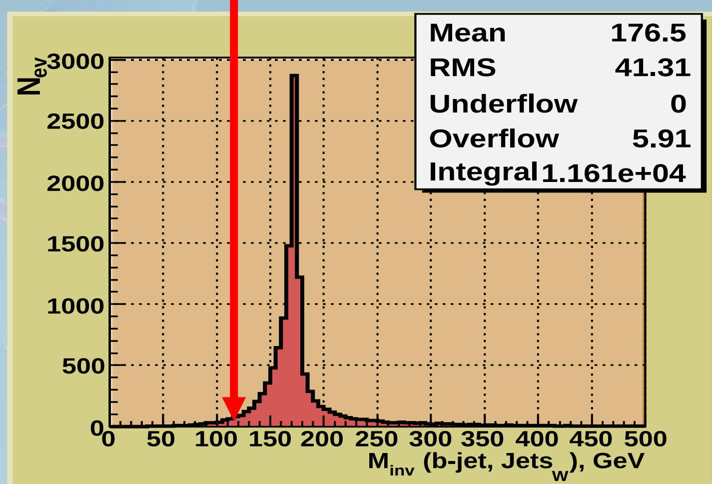
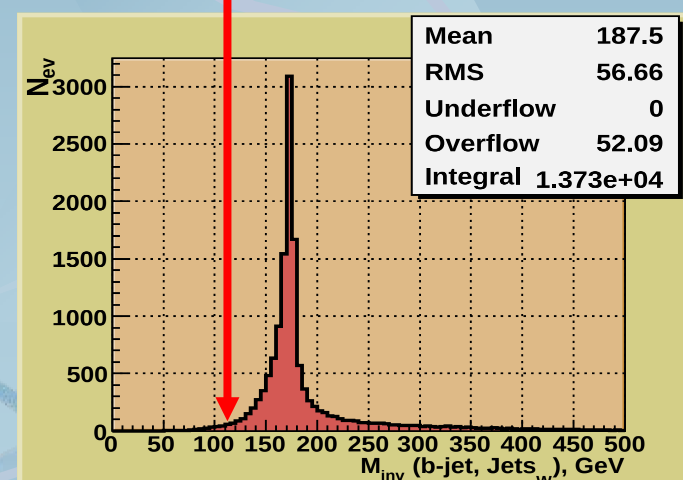




Polarization : +- / -+

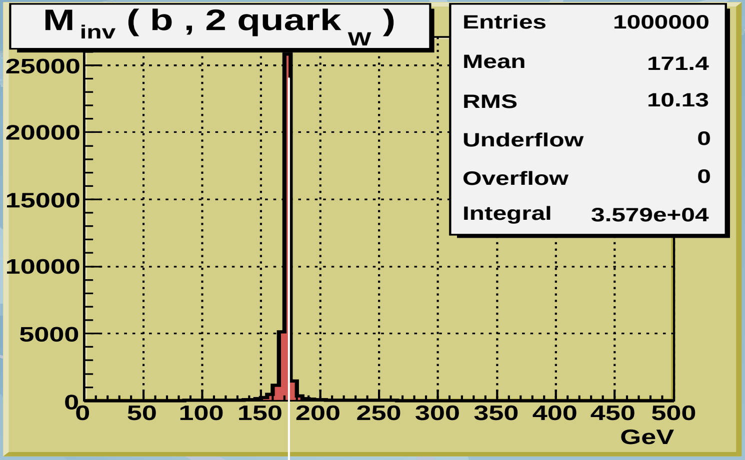
Polarization : ++ / --

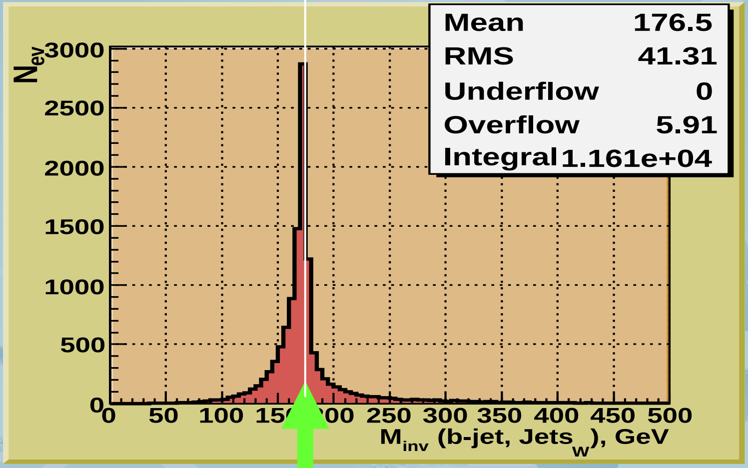
The most important variable - invariant mass of B_{jet} & $2jets_W$

In the case of *TOP pair* production it gives

The mass reconstruction of the top-quark M_{Top} (175 GeV) :

$$M_{inv}(B_{jet} \,\&\, 2jets_W) = M_{Top}$$





Stop invariant mass

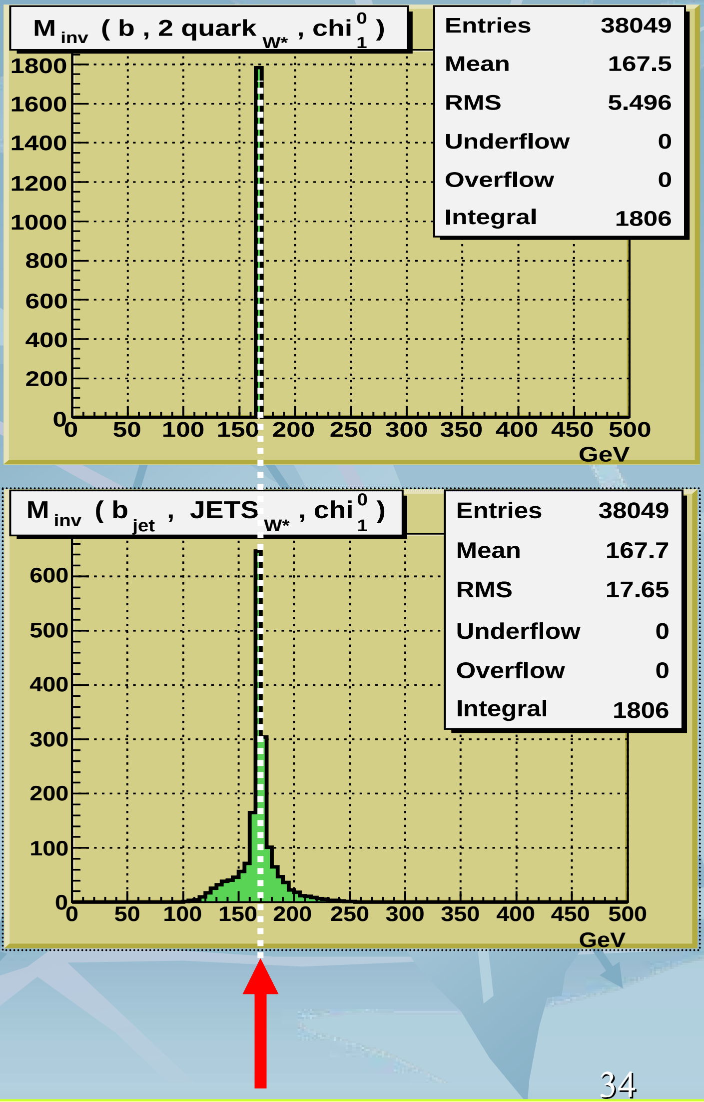
The reconstruction of the STOP invariant mass M_{STOP} (167.9 GeV):

$$M_{inv}(STOP) =$$

$$M\chi_1^o + M_{inv}(b_{jet}, 2jets_W) =$$

$$= M\chi_1^o + \sqrt{(P_{b_{jet}} + P_{jet1_W} + P_{jet2_W})^2}$$

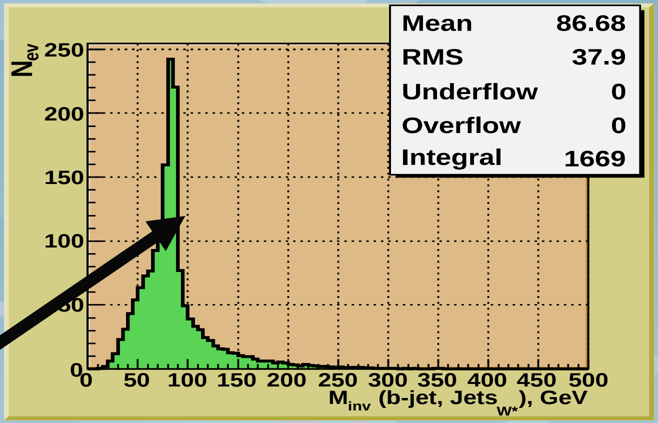
But χ_1^o – is not detectable particle

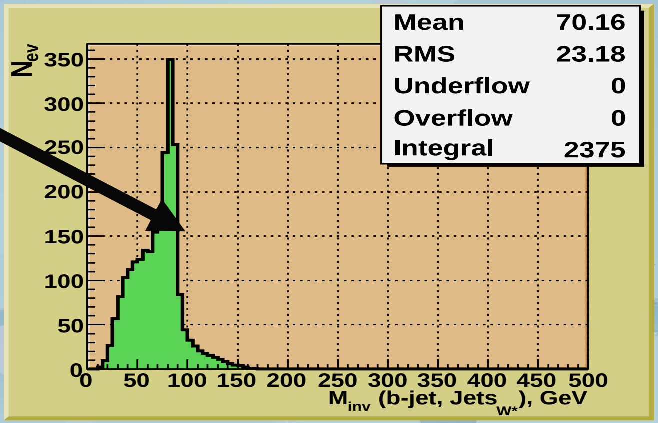


Invariant mass of B_{jet} & $2jets_W$

For the case of ***STOP pair*** production gives

$M_{inv}(B_{jet}, 2jets_W) = M_{inv}(STOP) - M\chi_1^o$





Right edge of M_{inv} (Bjet , 2jetW) ≈ 87 GeV

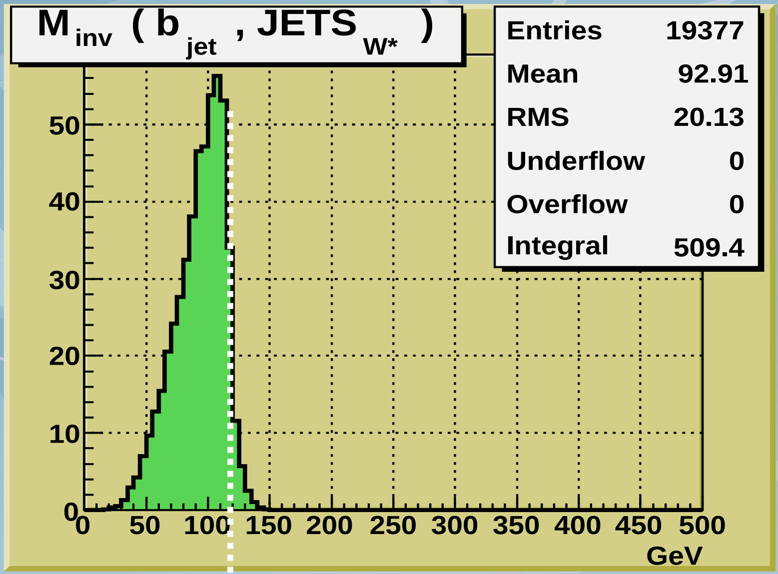
$M\chi_1^o \approx 80$ GeV

$M_{stop} = M\chi_1^o + M_{inv}$(Bjet , 2jetW) =

= 167 GeV

The test of the other Scalar top mass

- $M_{stop} = 200.1$ GeV
- $M_{\chi_1^o} = 80.9$ GeV
- $M_{\chi_1^+} = 159.6$ GeV



Right edge of the peak of M_{inv} (b_{jet} , $2jet_W$) ≈ 120 GeV

$M \chi_1^o \approx 80$ GeV

$M_{stop} = M \chi_1^o + M_{inv}(b_{jet}, 2jet_W) = 200$ GeV

Polarization :	+- / -+	++/--
Events/year :	347	1379

Conclusion

The main results:

1. New code for cross section of STOP pairs production that allows to take into account the polarizations of colliding photons is implemented into PYTHIA 6.

   An account of the energy spectrum of colliding photons is done by use of CIRCE 2.

2. It is shown also that the invariant mass of the final jets and the visible energy variables turns out to be most efficient for signal / background separation.

3. A possibility of a good M_{STOP} reconstruction from right-hand edge point of 3 jets (Bjet + 2 jets_W) is demonstrated.

So, finally, it is shown that in a region of small values of stop mass ~ 167 GeV the channel

$$STOP\ STOP \rightarrow b\ \chi_1^+\ \bar{b}\ \chi_1^- \rightarrow \bar{b}\ b\ \bar{q}\ q'\ \mu^-\ \nu_\mu\ \chi_1^o\ \chi_1^o$$

is very promising for the STOP-quark search!

Publications

- *"Pair production of scalar top quarks in polarized photon-photon collisions at ILC. "*

Authors: A.Bartl, W.Majerotto, K.Mönig, A.N.Skachkova, N.B.Skachkov

arXiv: 0804.1700v2, ILC-NOTE-2007-036

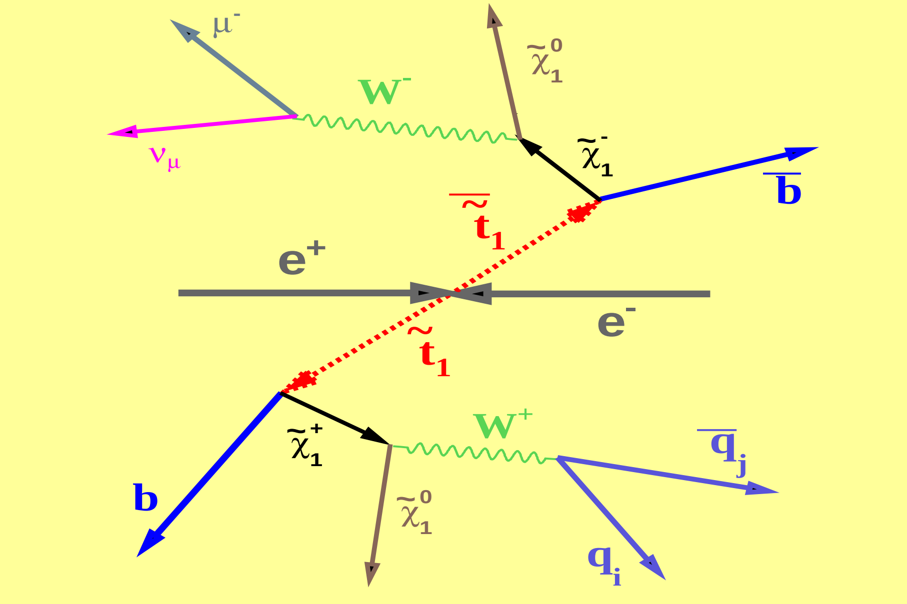
- *"Scalar top quarks production in polarized photon-photon collisions at ILC"*

Authors: A.Bartl, W.Majerotto, K.Moenig, A.N.Skachkova, N.B.Skachkov

Phys.Part.Nucl.Lett. V.9, N1(171), P.53-76, 2012

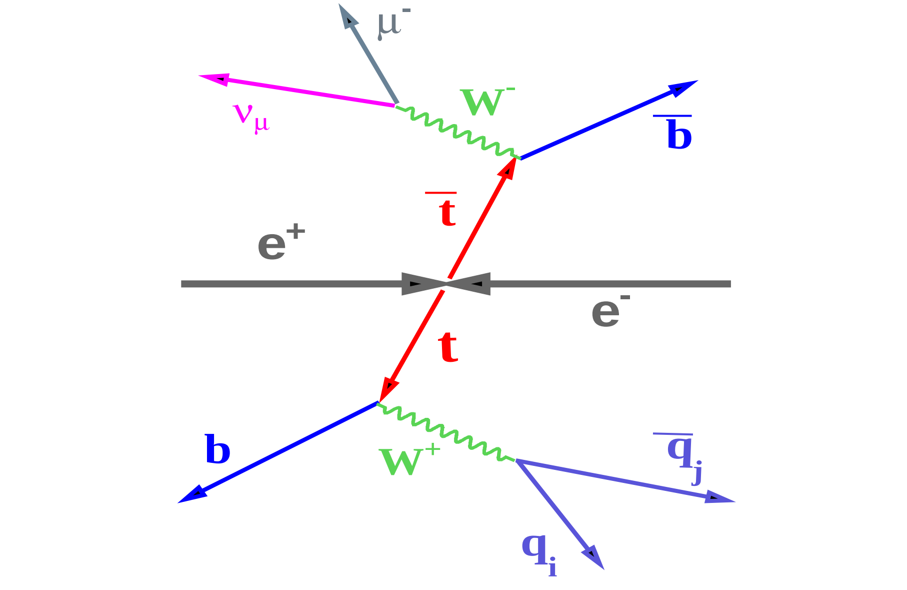
The case of e^+e^- collisions

$e^+ e^-$ CM energy = 500 GeV



STOP pair production cross section

σ = 2.37 fb



TOP pair production cross section

σ = 35.9 fb

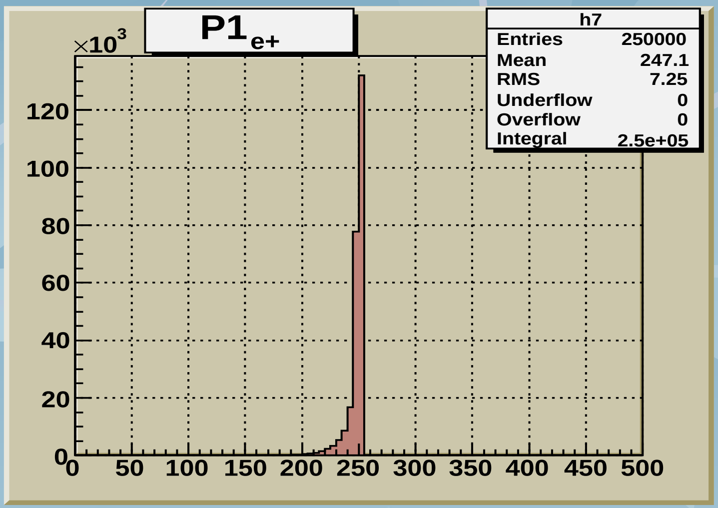
Simulation is done by use of PYTHIA 6.4 + CIRCE 1

Cross section dependence on E_{beam}

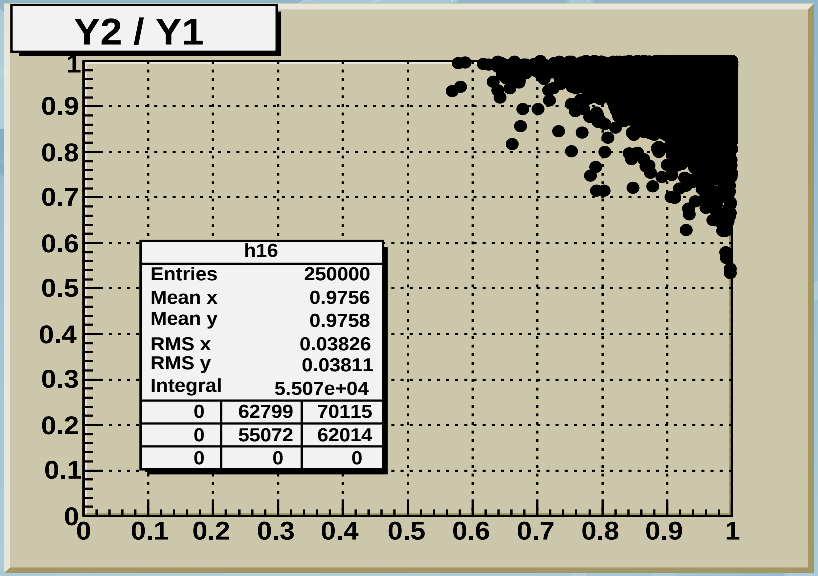
(without any cuts)

$2E_{beam}$[GeV]	σ_{stop} [fb]	N_{stop}	σ_{top} [fb]	N_{top}
350	0.23	233	13.76	13750
400	1.34	1347	38.79	38740
<u>500</u>	<u>2.37</u>	<u>2378</u>	<u>35.94</u>	<u>35950</u>
800	1.89	1809	17.36	17359
1000	1.42	1265	11.66	11656

e^+, e^- beam energy spectrum from CIRCE 1



Electron e^- (positron e^+) beam energy with account of beamstrahlung



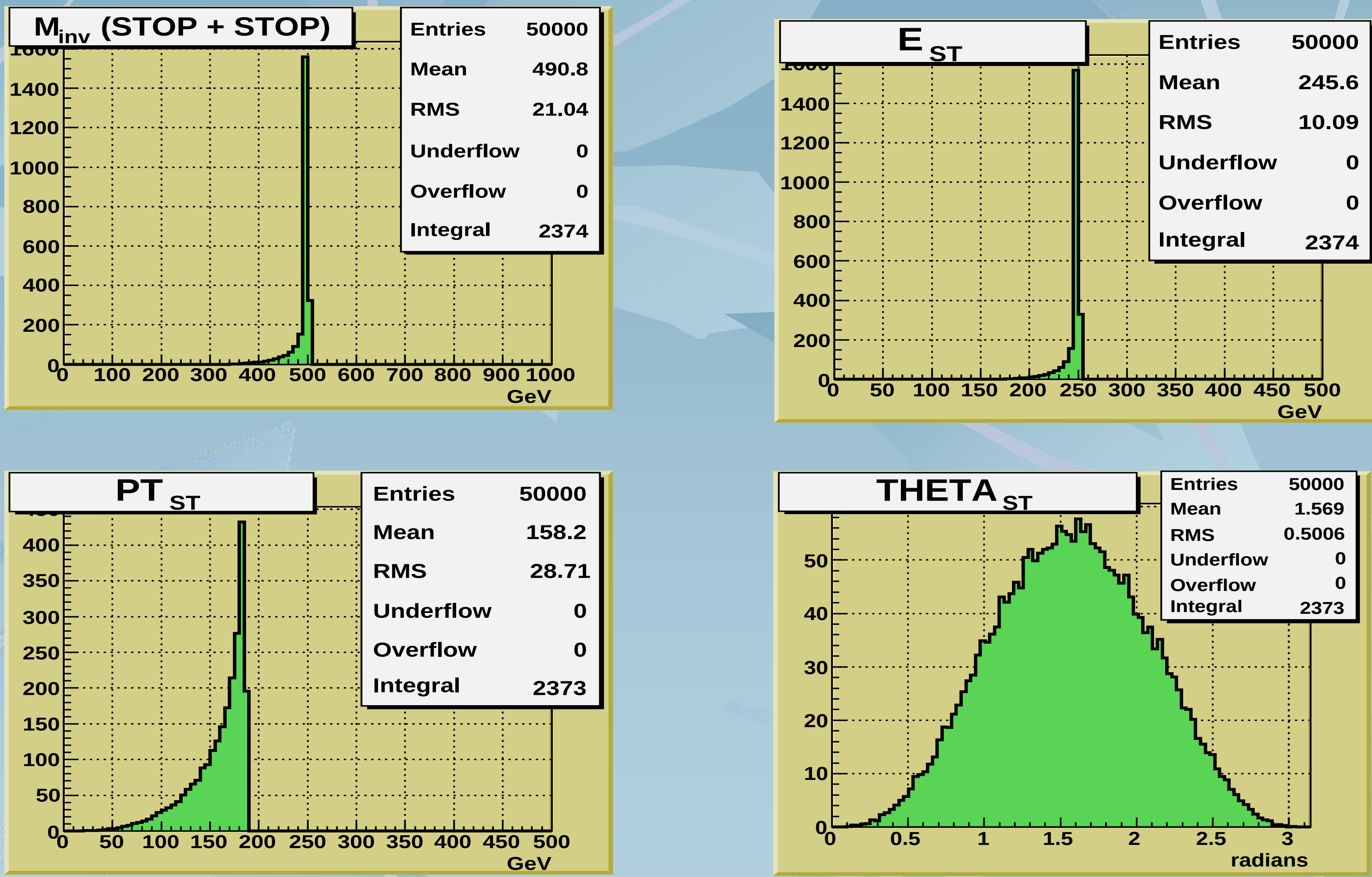
Correlation between e^+ and e^- beam spectra

$Y_i = E^i / E^i_{beam}$ $(i = e^+, e^-)$

The peak luminosity is supposed to be $2 \cdot 10^{34} cm^{-2} s^{-1}$.

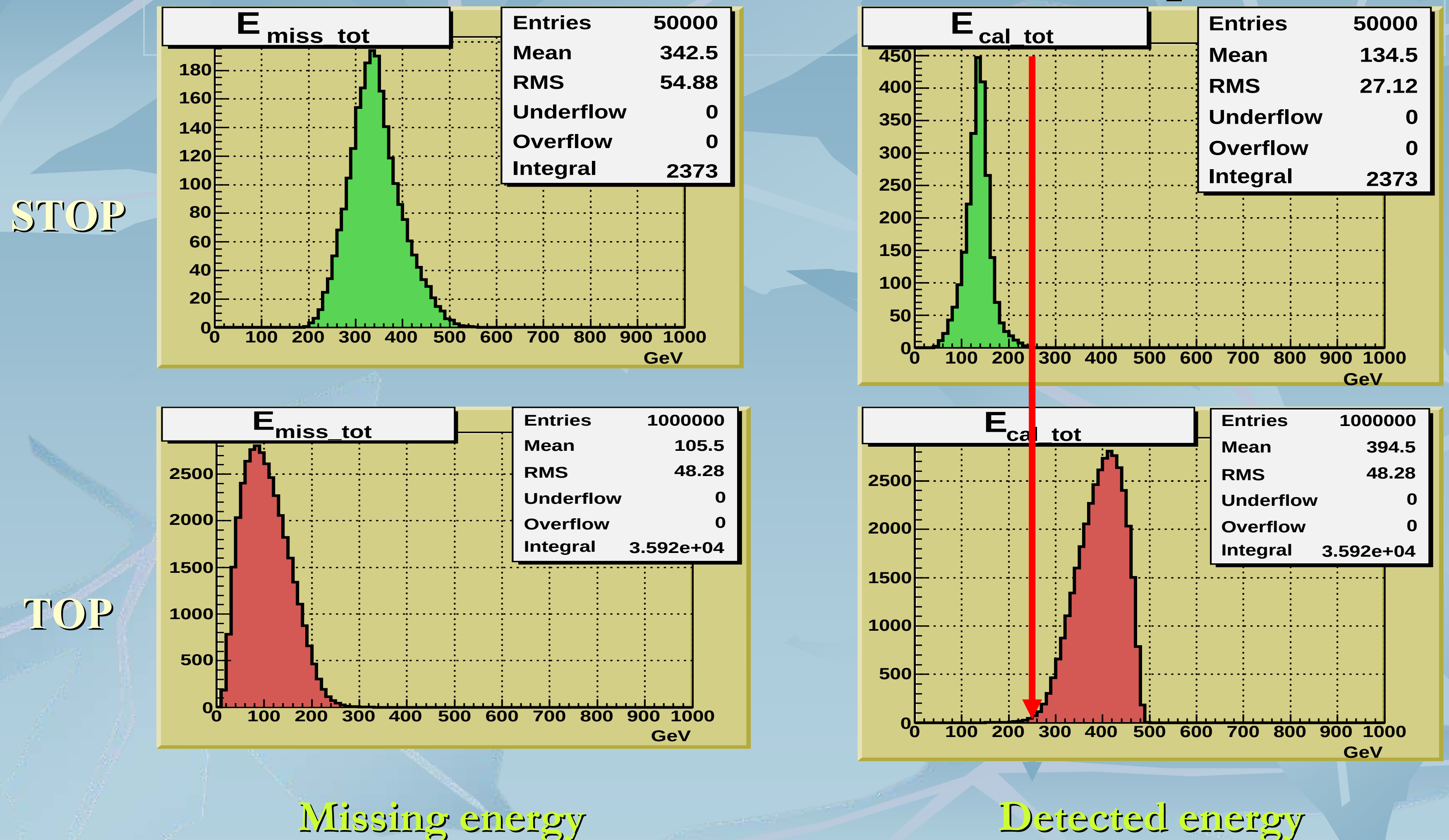
The total luminosity required is 1000 fb^{-1} during the first phase of operation at $2E^e_{beam} = \sqrt{S_{ee}} = 500$ GeV.

Main Scalar top quark distributions



Missing energy (ν_μ, $\sim\chi_1^o$, beam pipe) and detected (visible) energy distributions

Good for Signal / Background separation with cut E_{cal_tot} < 220 GeV

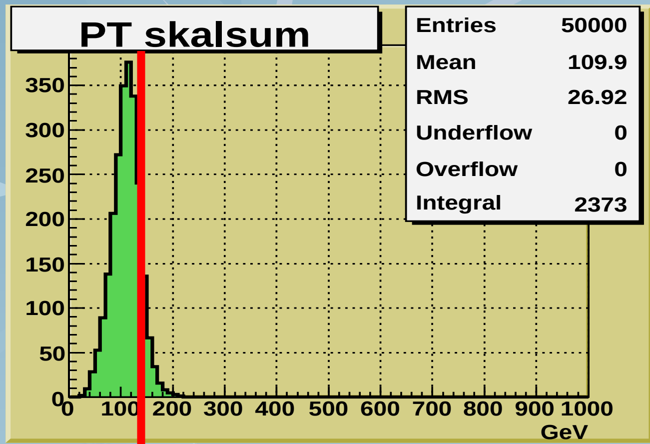


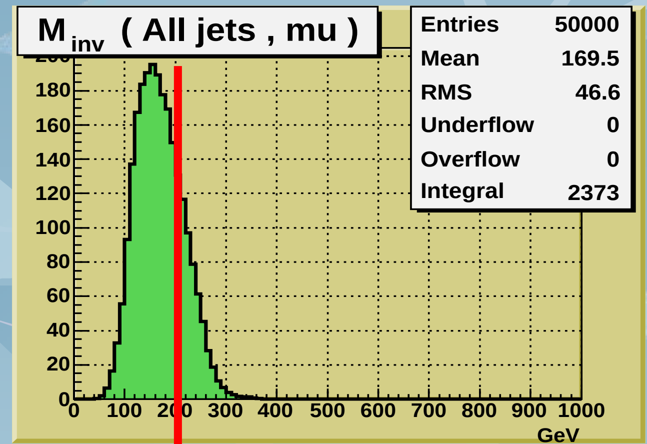
Total scalar Σ PT and Invariant mass of 4jets + μ

Good for Signal / Background separation with the cuts

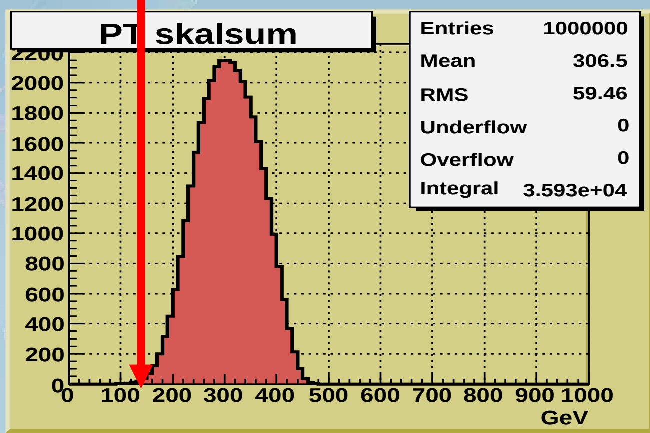
$PT_{skalsum}$ < 150 GeV and M inv (4 jets + μ) < 200 GeV !

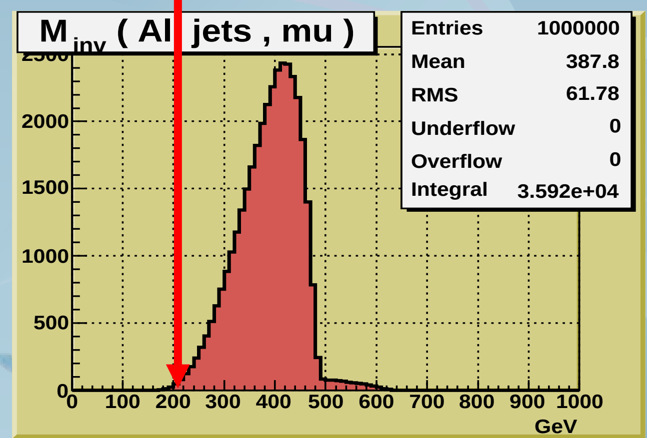
STOP





TOP





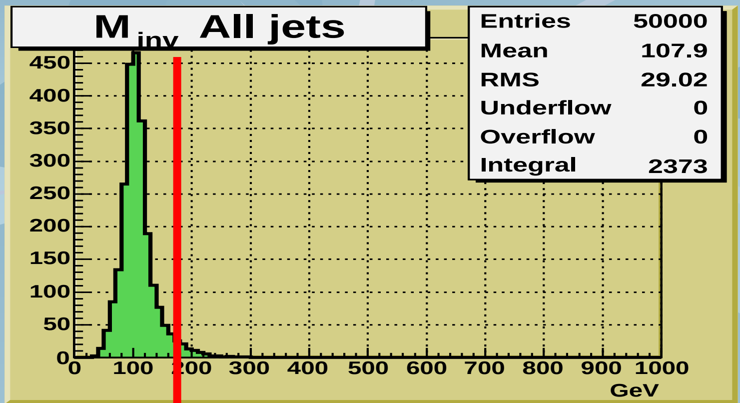
Scalar Σ PT   **M_{inv} (4 jets + μ)**

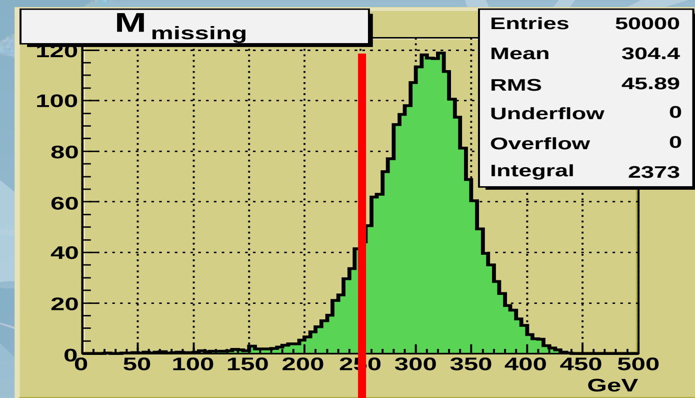
Invariant mass of 4 jets and $M_{missing}$ variable

***PERFECT* for Signal / Background separation cut**

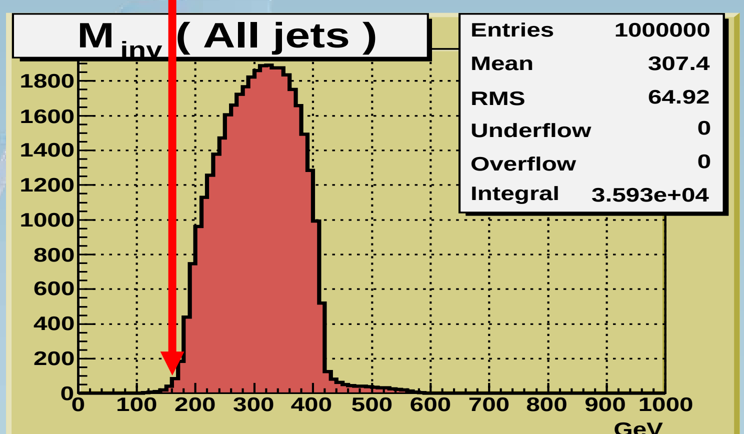
M_{inv} (4 jets) < 160 GeV and $M_{missing}$ > 250 GeV

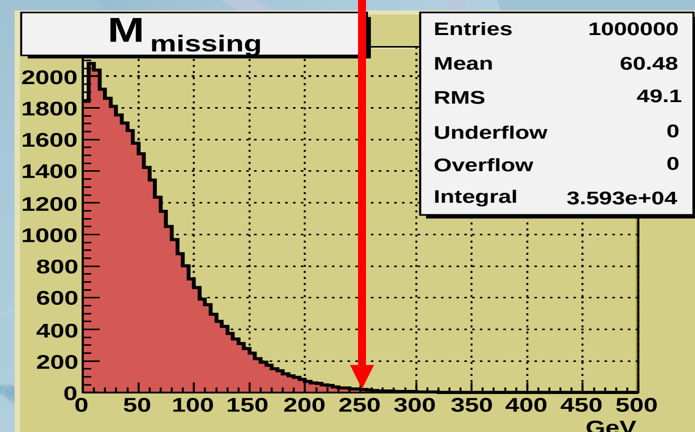
STOP





TOP





M_{inv} (4 jets)

$M_{missing}$

Used cuts for S/B separation

1.) The events with clear recognized 2 B-jets (according to PYTHIA)

(B-jet is determined as a jet that includes b-meson)

Stop cut efficiency = 0.84 *Top cut efficiency = 0.94*

But, in the experiment only 50% efficiency of the B-jets and B_{bar}-jets separation and the 80% of the corresponding purity is expected

2.) Invariant mass of 4 jets (b_{jet}, $bbar_{jet}$, $2jets_W$) M_{inv} (All jets) < 160 GeV

together with the cut above

Stop cut efficiency = 0.78 *Top cut efficiency = 0.001*

3.) Invariant Missing mass $M_{missing}$ > 250 GeV

together with the cuts above

Stop cut efficiency = 0.76 *Top cut efficiency = 3.3×10^{-4}*

Achieved S/B ratio = 143

***The rest is only 13 background events per year, while for the Signal events – 1086/year** (for the integrated Luminosity L=1000 fb^{-1}/year)*

Cross section dependence on E_{beam}

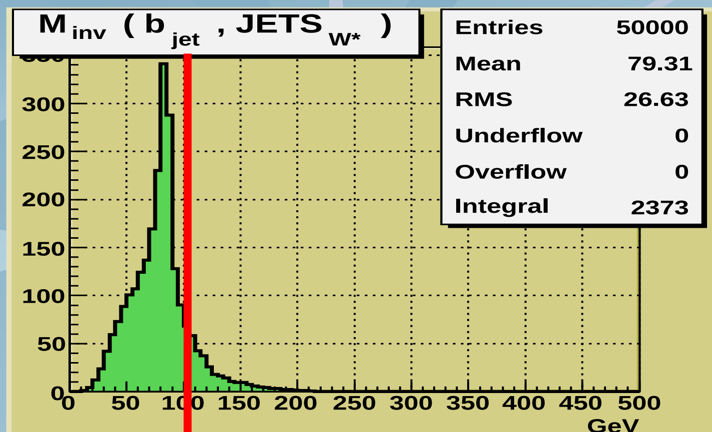
(with the cuts above)

$2E_{beam}$[GeV]	σ_{stop} [fb]	N_{stop}	σ_{top} [fb]	N_{top}
350	0.0089	8	0	0
400	0.52	521	$2.32 * 10^{-4}$	0.2
<u>500</u>	<u>1.80</u>	<u>1806</u>	<u>$2.26 * 10^{-2}$</u>	<u>12.6</u>
800	0.99	995	$1.08 * 10^{-2}$	10
1000	0.41	410	$6.26 * 10^{-3}$	6

Invariant mass of b_{jet} & $2jets_W$

Can also be used for Signal / Background separation cut M_{inv} (b_{jet}, $2jets_w$) < 100 GeV!

STOP



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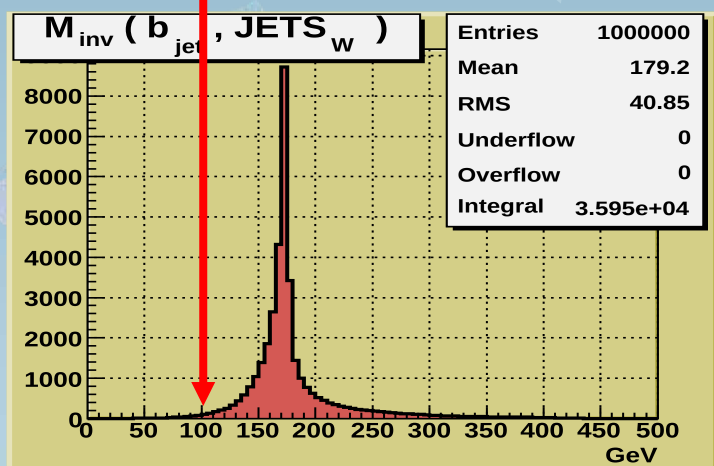


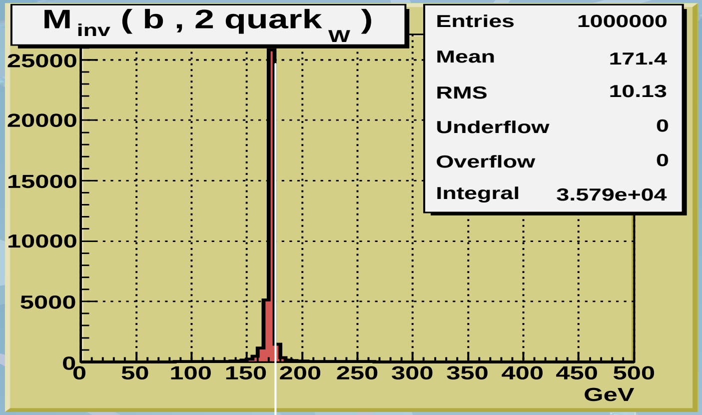
Minv (b-jet, $2jets_W$)

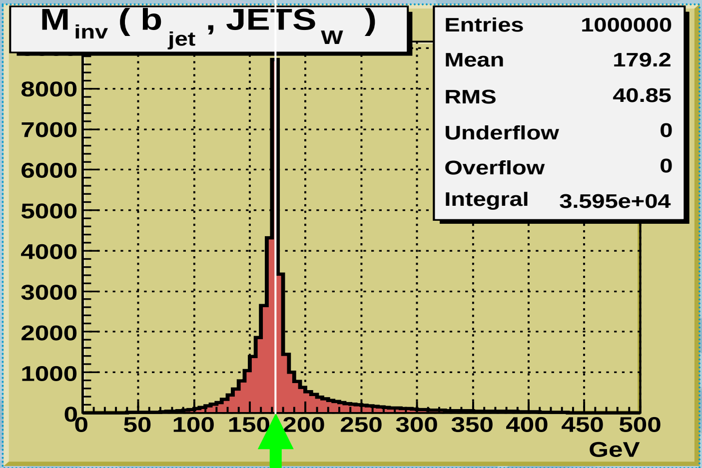
The most important variable - invariant mass of b_{jet} & $2jets_W$

In the case of *TOP pair* production it gives

The mass reconstruction of the top-quark M_{Top} (175 GeV) :

M_{inv} (B_{jet} & $2jets_W$) = M_{Top}





Stop invariant mass

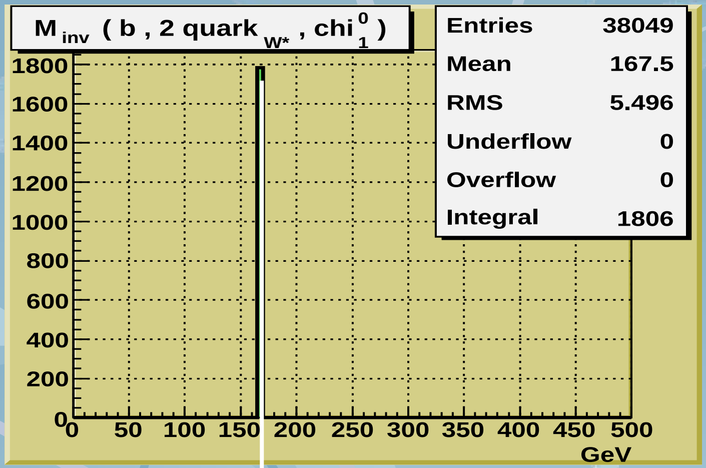
The reconstruction of the STOP invariant mass M_{STOP} (167.9 GeV):

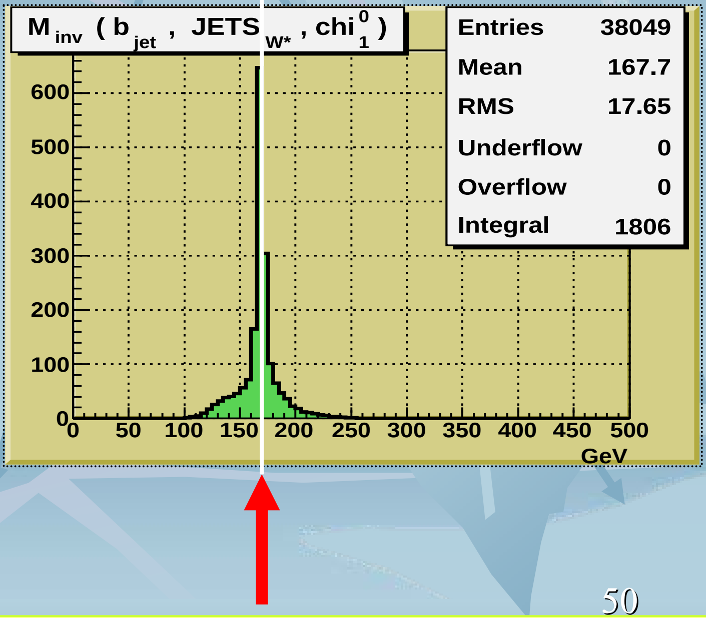
$$M_{inv}(STOP) =$$

$$M\chi_1^o + M_{inv}(b_{jet}, 2jets_W) =$$

$$= M\chi_1^o + \sqrt{(P_{b_{jet}} + P_{jet1_W} + P_{jet2_W})}$$

But χ_1^o – is not detectable particle





Invariant mass of B_{jet} & $2jets_W$ gives

For the case of ***STOP pair*** production gives

$M_{inv}(B_{jet}, 2jets_W) = M_{inv}(STOP) - M_{\chi_1^o}$

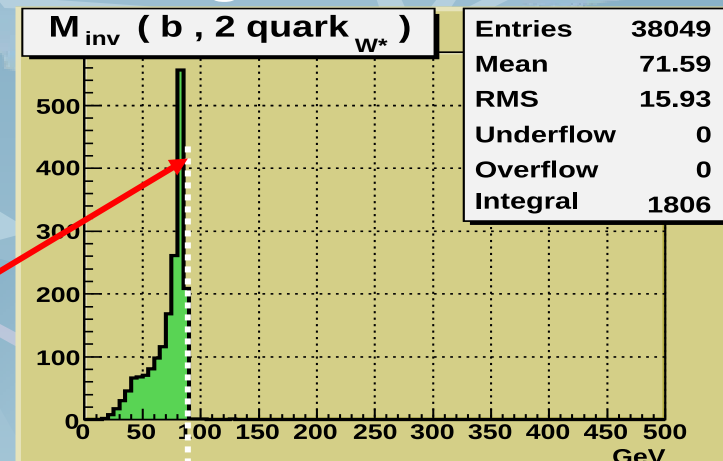
The right edge of the peak of

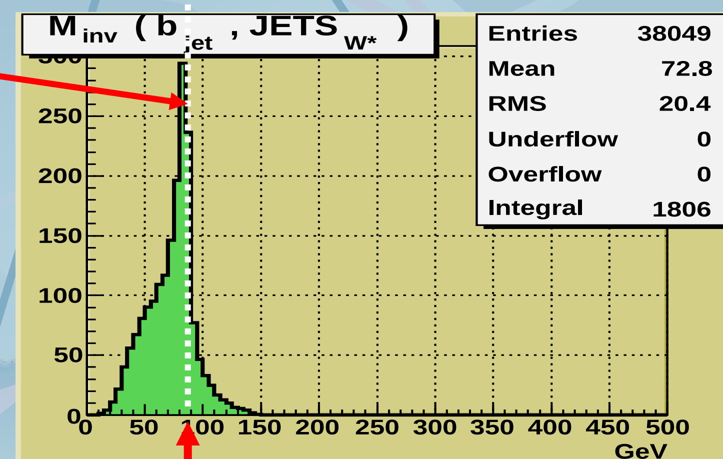
$M_{inv}(b_{jet}, 2jets_W) \approx 87$ GeV

$M_{\chi_1^o} \approx 80.9$ GeV

$M_{stop} = M_{\chi_1^o} + M_{inv}(b_{jet}, 2jets_W) =$

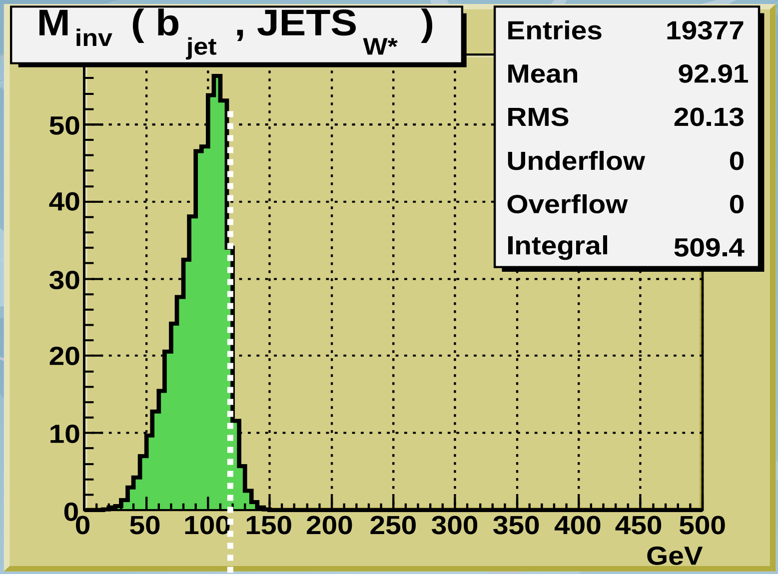
$= 167.9$ GeV





The test of the other Scalar top mass

- $M_{stop} = 200.1$ GeV
- $M_{\chi_1^o} = 80.9$ GeV
- $M_{\chi_1^+} = 159.6$ GeV



Right edge of the peak of M_{inv} (b_{jet}, $2jet_W$) ≈ 120 GeV

509 events

S/B = 40

$M \chi_1^o \approx 80$ GeV

$M_{stop} = M \chi_1^o + M_{inv}(b_{jet}, 2jet_W) = 200$ GeV

Conclusion

1. The MC (PYTHIA 6.4 + CIRCE 1) study of stop pair production in e^+e^- collisions was done at $\sqrt{S}_{ee}$ = 350, 400, 500, 800, 1000 GeV.

2. The detailed analysis done at $\sqrt{S}_{ee}$ = 500 GeV has shown that proposed 3 cutes allow to reach S/B = 143.

3. A possibility of a good reconstruction of the M_{STOP} from the peak position of M_{inv} (3 jets, i.e. b_{jet} + 2 $jets_W$) distribution is demonstrated.

So, finally, the channel

$$STOP\ STOP \to b\ \chi_1^+\ \bar{b}\ \chi_1^- \to b\ \bar{b}\ q\ \bar{q}'\ \mu^-\ \bar{\nu}_\mu\ \chi_1^\circ\ \chi_1^\circ$$

is very promising for STOP quark search!

Publications

- *"Pair production of scalar top quarks in e^+e^- collisions at ILC. "*

  Authors: A.Bartl, W.Majerotto, K.Möniq, A.N.Skachkova, N.B.Skachkov

  arXiv: 0804.2125v3, **ILC-NOTE-2008-042**

- *"On pair production of scalar top quarks in e+e- collisions at ILC and a possibility of their mass reconstruction"*

  Authors: A.Bartl, W.Majerotto, K.Moenig, A.N.Skachkova, N.B.Skachkov

arXiv:0906.3805, Phys.Part.Nucl.Lett.6,:181-189, 2009

Outback

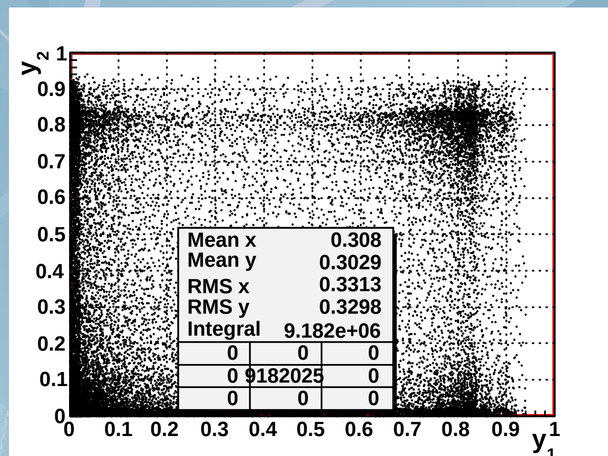
Photon beam characteristics

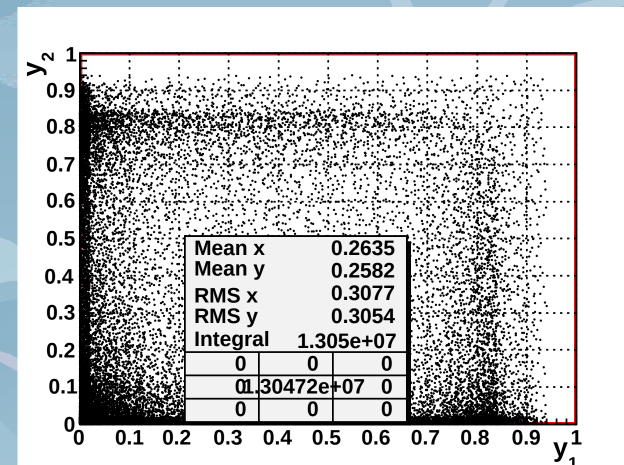
The ***monochromaticity*** of the backscattered photon beams is considerably increased if the mean helicities λ_e and P_c of the electron beam and laser photon beam are chosen such that $2\lambda_e P_c \approx -1$.

In this case the relative ***number of hard photons*** becomes nearly ***twice as large*** in the region of the photon energy fraction $Y = E_i^\gamma / E^e_{beam} \approx 0.7\text{-}0.85$ (i=1,2) and the ***luminosity*** in collisions of these photons increases by a factor of ***3-4***.

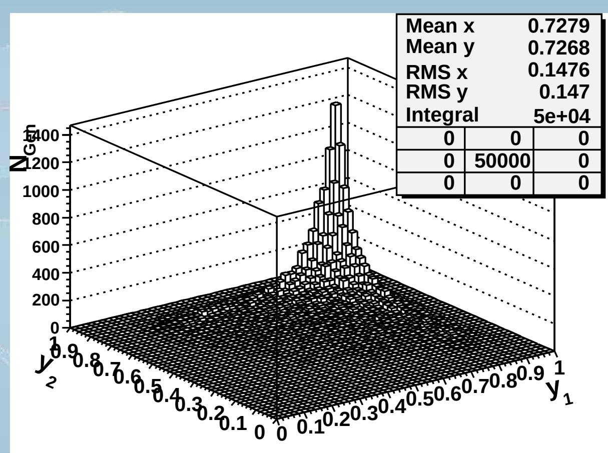
γ-energy correlation Y_1/Y_2 spectra for J=2 enhanced

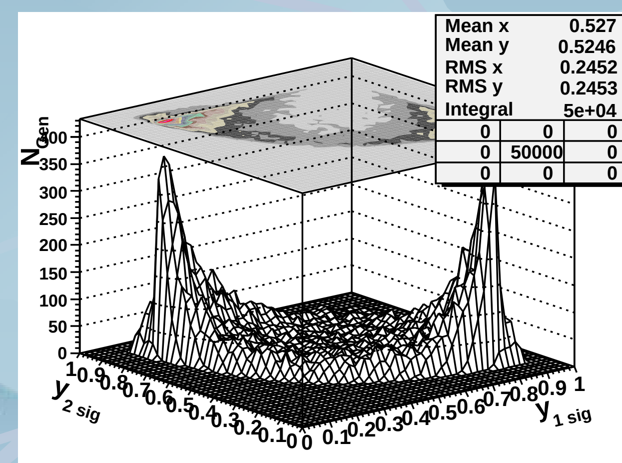
Whole γ spectrum





γ spectrum above stop pair production threshold

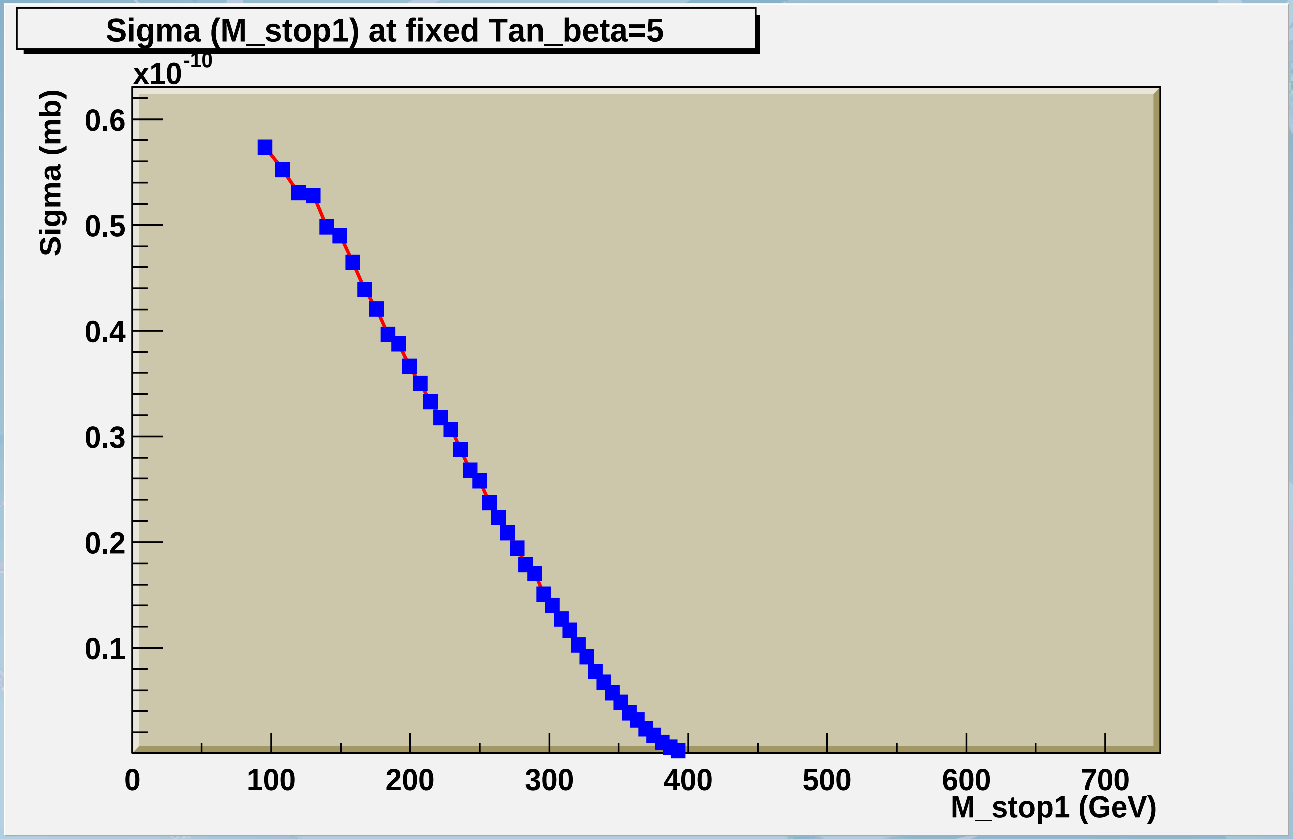




Polarizations + - / - +

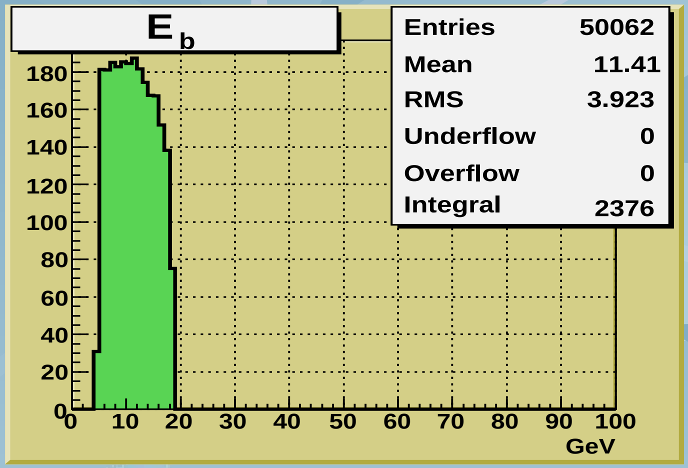
Polarizations + + / - -

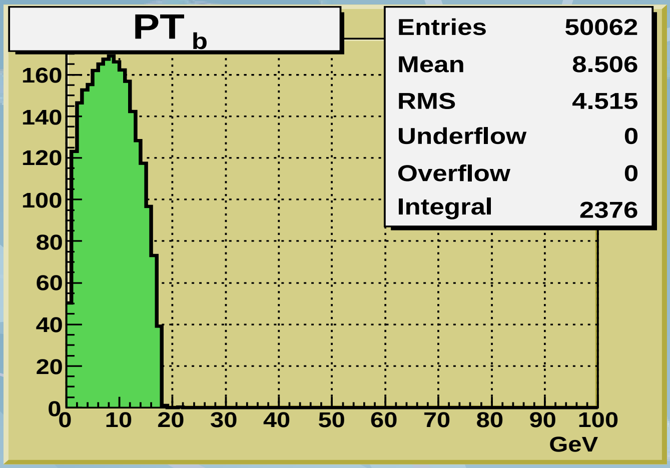
Cross-section σ dependence on M_{stop}



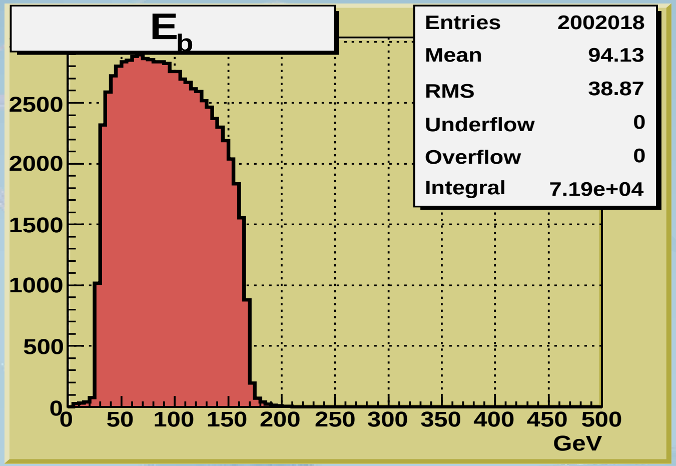
B-quarks distributions

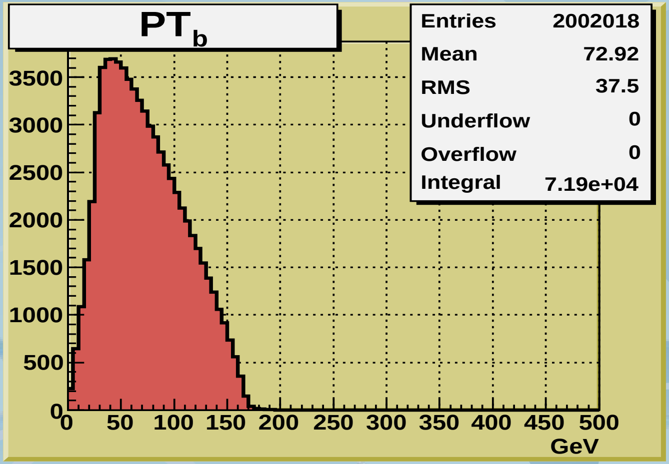
STOP





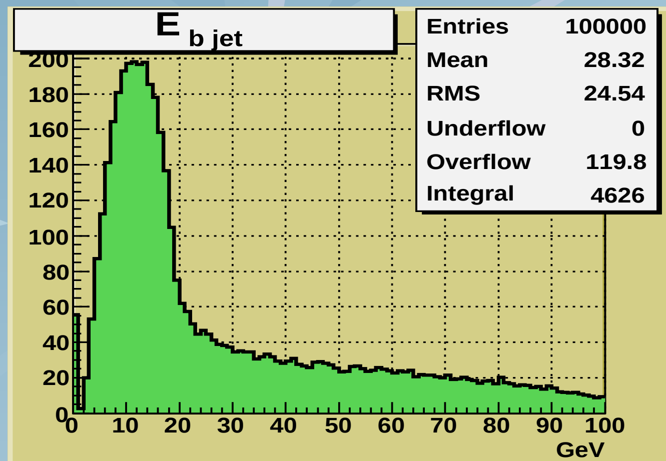
TOP

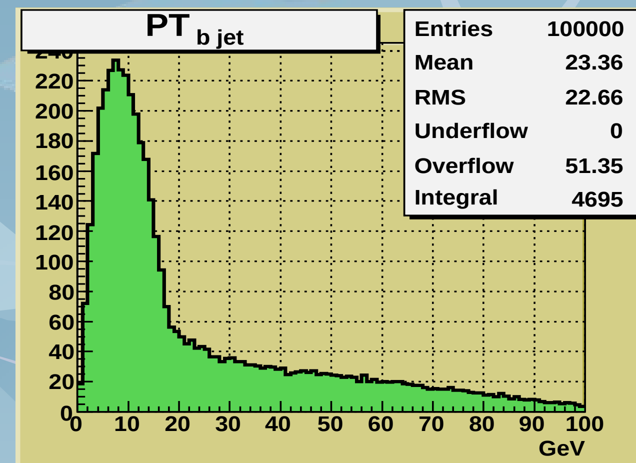




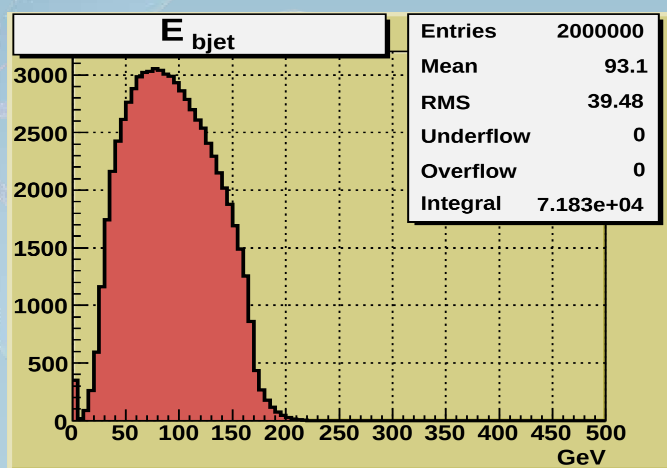
B-jets distributions

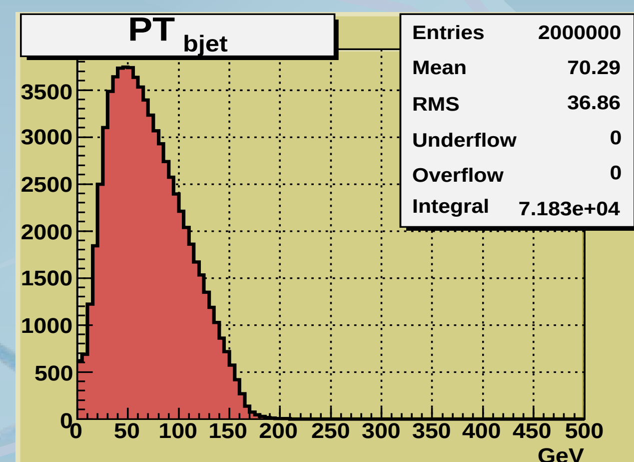
STOP



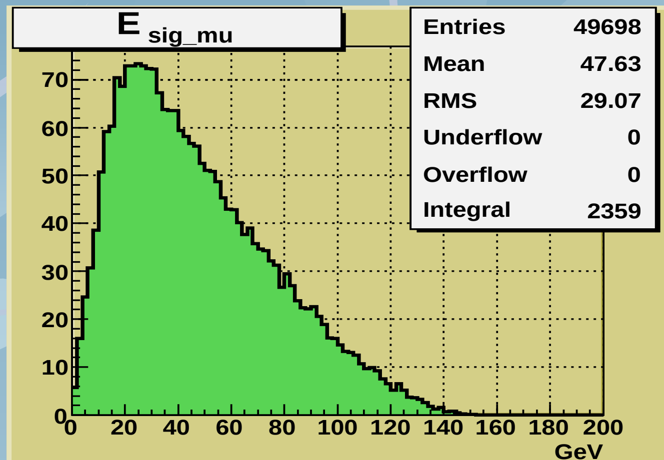


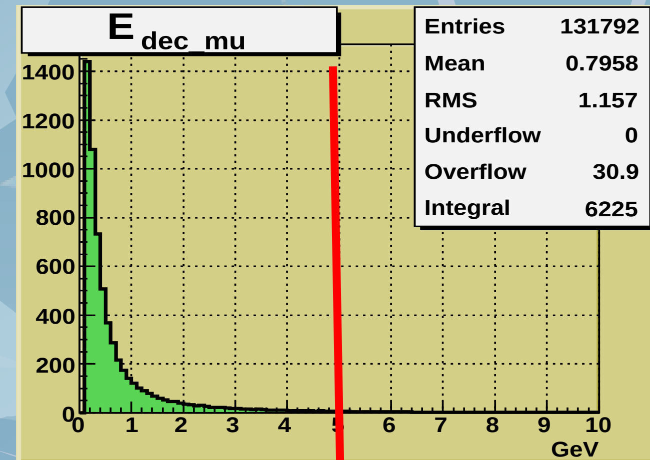
TOP

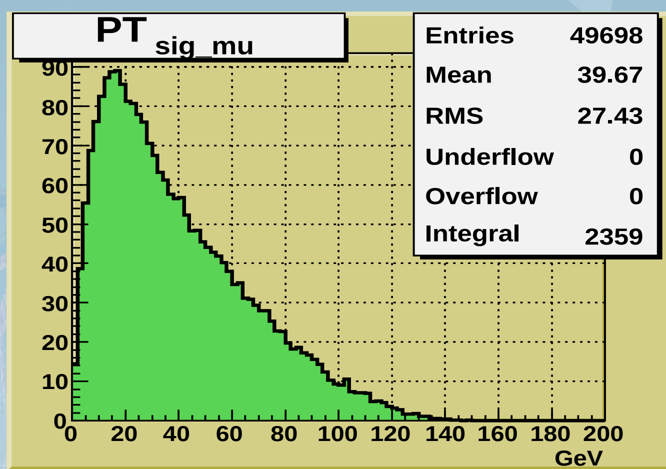


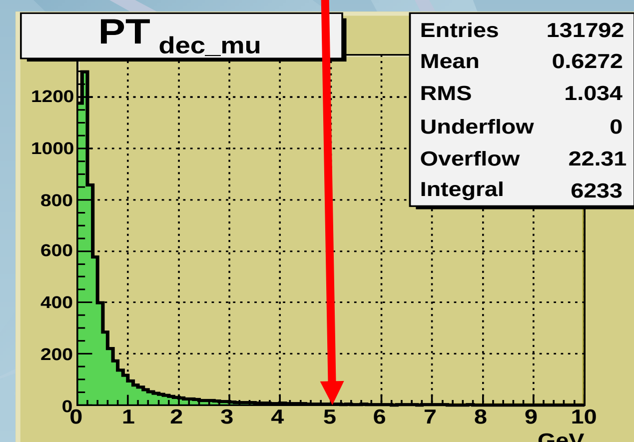


μ distributions in the signal events









Signal μ's

Fake μ's

Supersymmetrical particles classification

Particles		Spin	R	Particles	Spin	R
“left” quarks	qL	½	+1			
“right” quarks						
“left” leptons						
“right” leptons						
Gluon						
charged boson						
Edvdev						
charged Higgs						
photon						
neutral boson						
Sdfv						
neutral Higgs						
Graviton						