Overview of Physics Benefits of STT

STT review, 12 March 1998

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Outline

- **Gains from STTpp**
  - better momentum resolution
  - E_T/p_T cut possible at L2
  - determination of track impact parameter ($r\phi$) and its significance
- **Physics Benefits**
  - t ($t\bar{t}$, single top)
  - Associated Higgs production
  - $Z \to b\bar{b}$ events
  - b-physics
- **z-vertex finding for use in L3**
  - sharper electron and jet turn-on curves

Present RunII Trigger Scheme

- **Bandwidth Allocations:**
  - **L1 in: 7MHz, out: 5-10kHz ; time: 4.2μs**
  - **L2 in: 10kHz, out: 1kHz ; time: 100μs**
  - **L3 in: 1kHz, out: 20Hz ; time: 100 ms/ 50 nodes**
- **Current Configuration:**
  - **L1: Uses Calorimeter, Fiber tracker (CFT), Muon and Preshower objects.**
    ⇒trigger on Cal E_T (em and jets),
    muon p_T (use CFT),
    track p_T,
    track-preshower stubs
  - **L2: trigger combines L1 objects into electrons, muons, jets.**
- **use of SMT information in trigger:**
  - **Currently L1 and L2 track triggers do not make use of hits in the Silicon detector.**
  - **Questionable if L3 will be able to use Silicon information for triggering, as cpu constraints may require starting from L2 object seeds!**

Possible Benefits of a Silicon Track Trigger

1. **Add Silicon hits in track fit to improve momentum resolution**
   ⇒sharper p_t thresholds,
   E/p for electrons at L2;
   - **Potentially benefits ANY trigger**
2. **Trigger on high impact parameter tracks**
   ⇒trigger on events containing b-quarks;
   - **Benefits specific physics channels otherwise difficult to trigger on *e.g.* b-physics, $Z \to b\bar{b}$, Higgs$\to b\bar{b}$, t-physics, ...**
3. **Use Silicon detector (90° stereo) information for fast z-vertex position**
   ⇒sharper electron and jets p_T thresholds at L3,
   beam tilt → need z for impact parameter determination;
   - **Benefits ANY trigger**
4. **Hit Finder for Level3**
   ⇒Save processing time in L3 by providing hits positions for r/ϕ and stereo (both 90° and 2°, enabling efficient/possible use of Silicon information.

Tasks of the STT (L2 preprocessor)

- **finds hit clusters in Silicon Detector**
- **finds tracks in Silicon Detector (in roads from CFT)**
- **determines track parameters ($\vec{p}$, impact parameter)**
- **find z-vertex from 90° stereo hits**
- **ships information to global L2 processor for decision**
- **ships z-vertex and hit cluster to L3**

Performance Studies

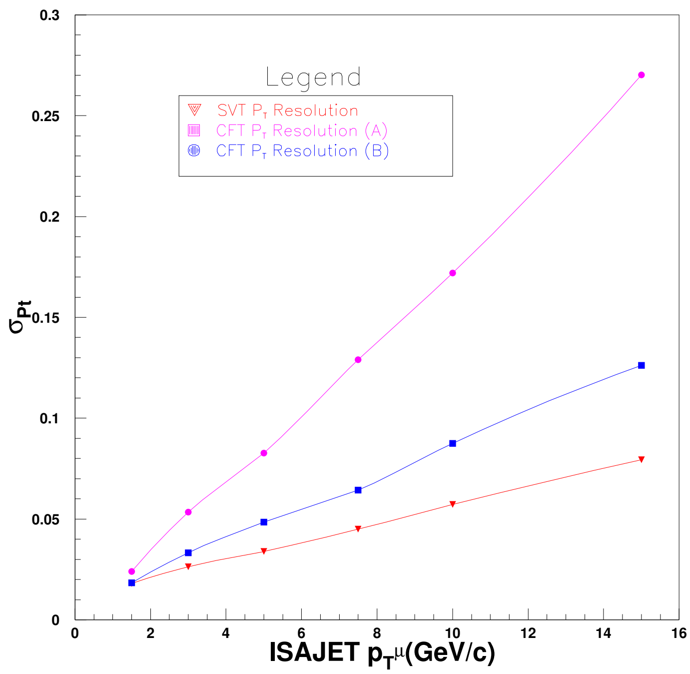
Use single track events, μ and e ($|\eta|\lesssim 1.0, 1.5\lesssim p_T \lesssim 15$ GeV)

p_T resolution

- **CFT momentum computed two ways**

  (a) use fibers in inner and outer layer only (L2).

  (b) use p_t^{min} and p_t^{max}, the momentum limits from CFT track eqn (L1)
  $\Rightarrow \frac{1}{p_t} = \frac{1}{2}(\frac{1}{p_t^{min}} + \frac{1}{p_t^{max}})$



- **resolution using STT improves compared to CFT**

  – **for p_T = 3 GeV** $\Rightarrow \frac{\sigma(STT)}{\sigma(CFT(a))} \approx 0.5$

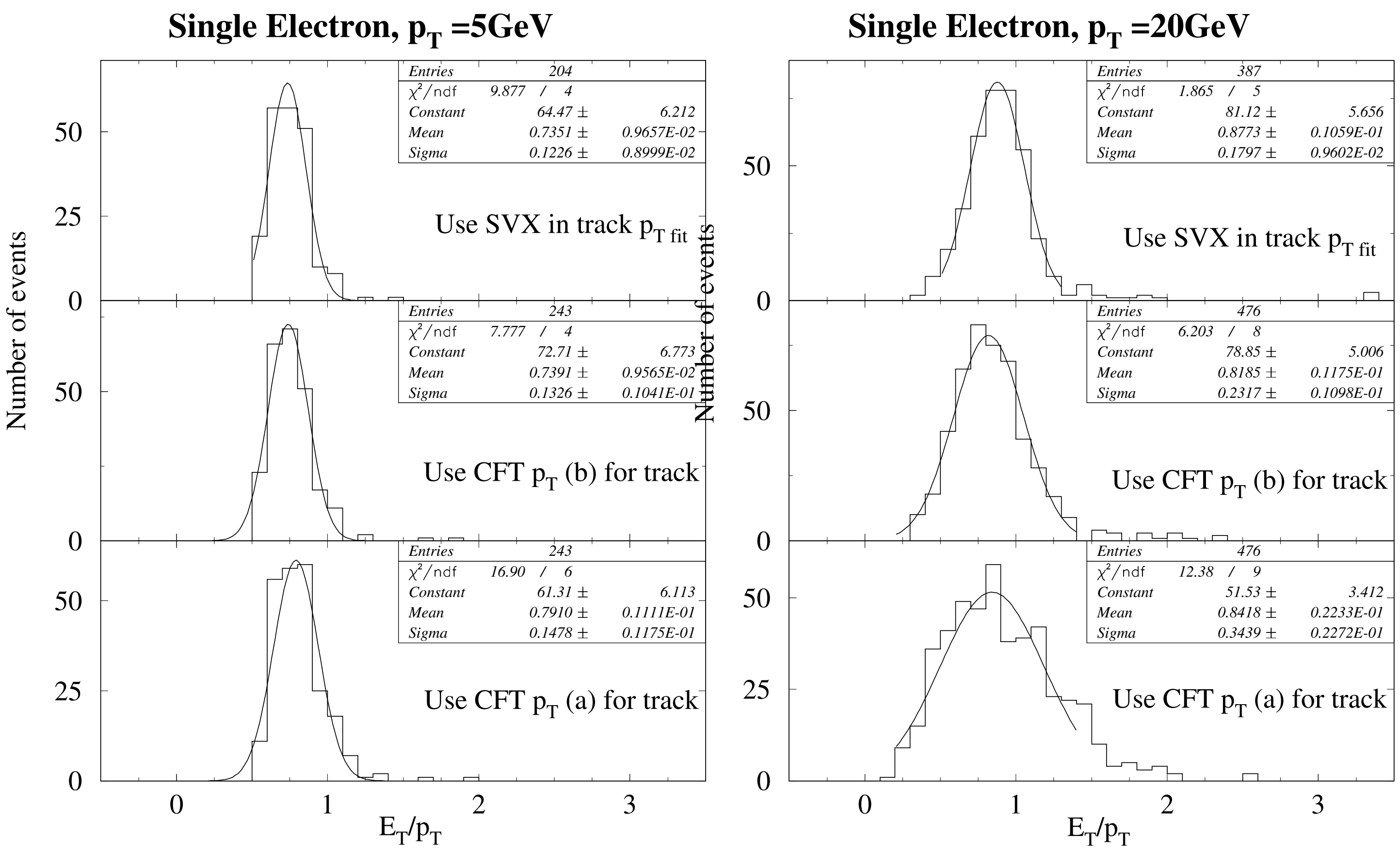
  $\frac{\sigma(STT)}{\sigma(CFT(b))} \approx 0.8$

  – **for p_T = 15 GeV** $\Rightarrow \frac{\sigma(STT)}{\sigma(CFT(a))} \approx 0.3$

  $\frac{\sigma(STT)}{\sigma(CFT(b))} \approx 0.6$

Using E_T/p_T at L2

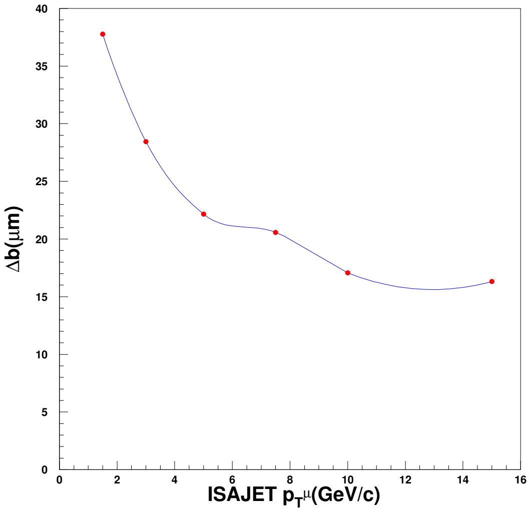
Compare E_T/p_T for tracks with and without SVX info.
note : Use both types of CFT momentum calculation.



- E_T/p_T resolution is better by a factor of 2 for high p_T electrons.
- Rejection and efficiency relative to the 'standard isolated' electron definition :

p_T type	$p_T(ele)$ = 20 GeV Eff. (%)	Bkg Rej.	$p_T(ele)$ = 5 GeV Eff. (%)	Bkg Rej.
CFT (a)	90	x3	99	x2
STT+CFT	87	x5	99	x8

Impact Parameter Resolution



- **resolution $\sim$ 15 μm at p_T = 15; 35 μm at 2 GeV.**
- **Tuning of impact parameter errors performed with single pion samples (p_T = 2 to 15 GeV/c.)**
- **Using the parameterization:**

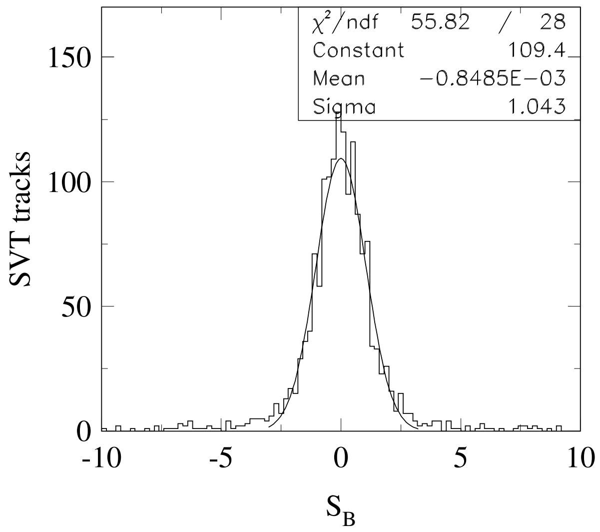
$$\sigma_B^2 = \sigma_0^2 + (\frac{\alpha_{ms}}{P_T})^2$$

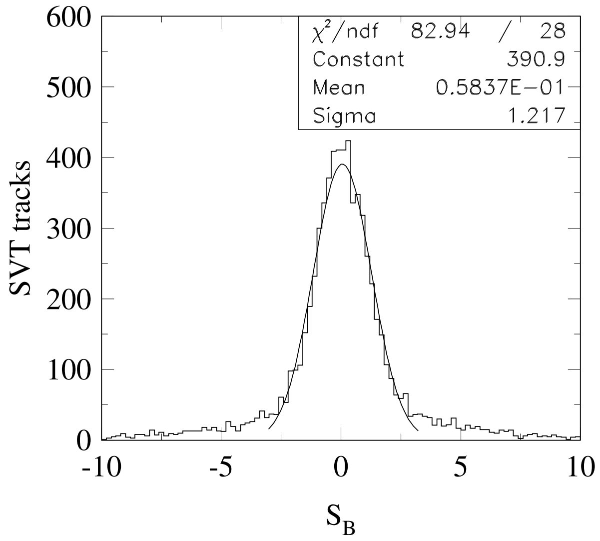
- **Find** $\sigma_0 = 12.6$ **μm**
  $\alpha_{MS} = 49.7$ **(GeV/c)** $\cdot$ **μm.**
- **Define IP significance as:**

$$S_B = \frac{B}{\sigma_B(p_T)}$$

Impact Parameter Resolution

- Check impact parameter resolution in $b\bar{b}$ (upper plot) and $t\bar{t}$ events (lower plot) for STT tracks matched to MC tracks coming from the primary vertex:

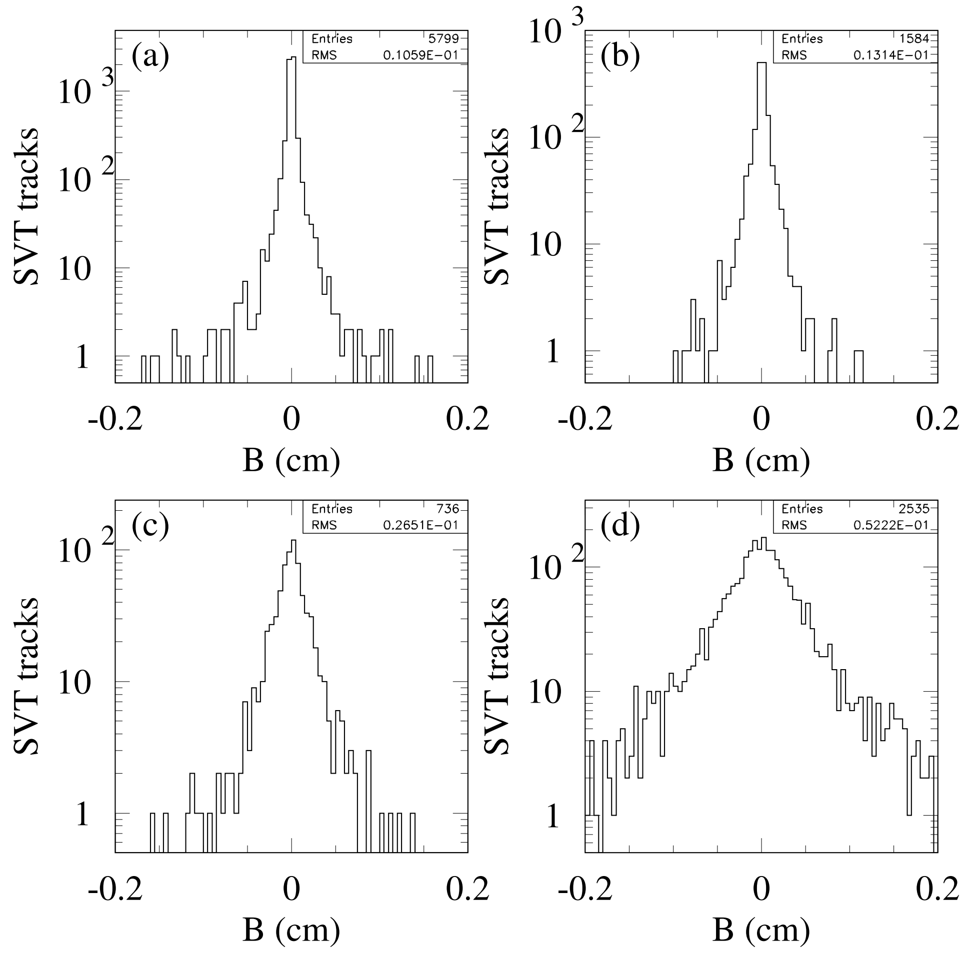




- The parameterization of impact parameter errors derived from single pion events is also valid for $b\bar{b}$ and $t\bar{t}$ events.

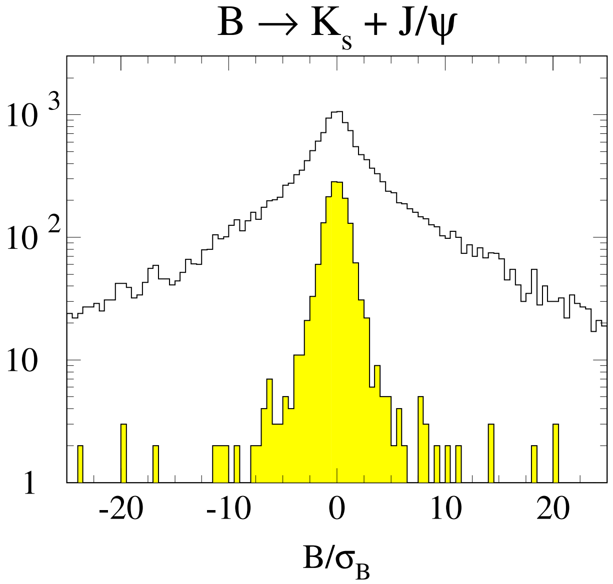
Track Selection

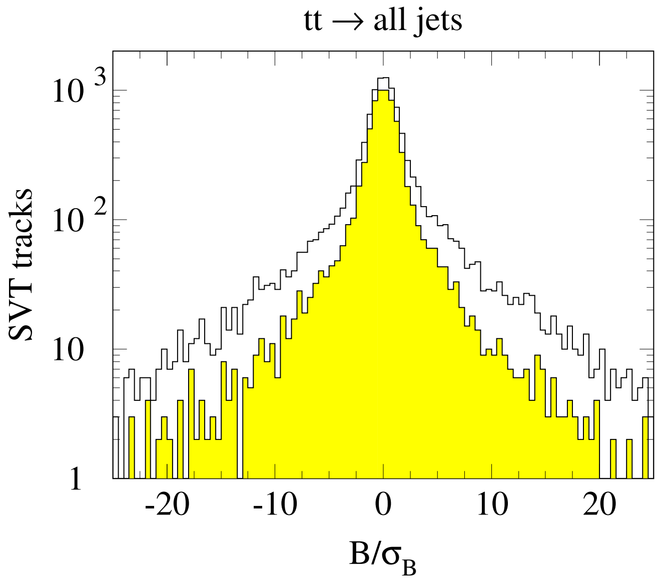
- **Select good STT tracks using quality cuts:**
  1. $N_{layer} \geq 3$;
  2. **Track fit reduced $\chi^2 \leq 4$.**
     Note : tracks with $\chi^2 \geq 4$ are refitted after dropping the hit with the largest χ^2 and the cut is reasserted. This leads to 30% gain in efficiency
- **χ^2 cut removes badly reconstructed tracks**
  - **plot shows increase in the width of impact parameter distribution for primary tracks for different χ^2 ranges : 0–2, 2–4, 4–10, $\geq$ 10.**



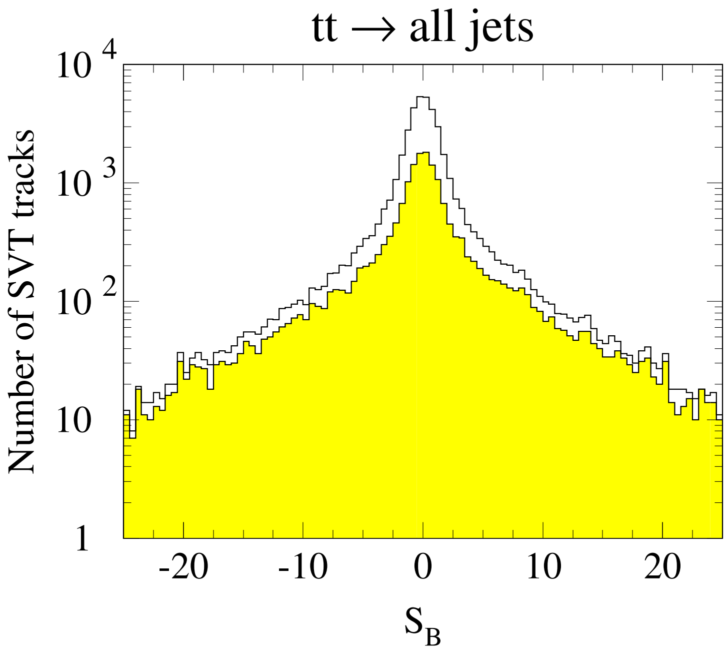
Impact Parameter Significance

- IP significance distribution for matched tracks:
  - Yellow → tracks coming from primary vertex





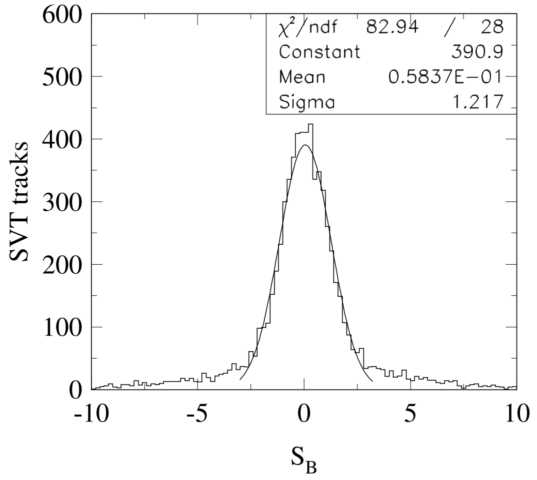
- Correlation between high impact parameter tracks and tracks from b-quark decays (yellow histogram)

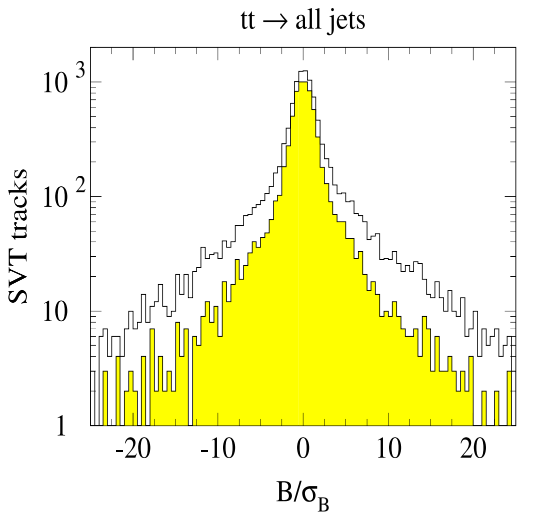


$t\bar{t}$ Events

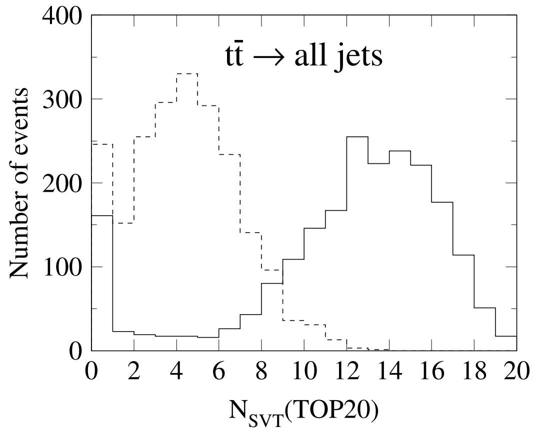
- **Signal samples (ISAJET):**
  1. $t\bar{t} \rightarrow all\ jets$ **events (+0, +3 min.bias)**
  2. $t\bar{t} \rightarrow \mu + jets$ **events**

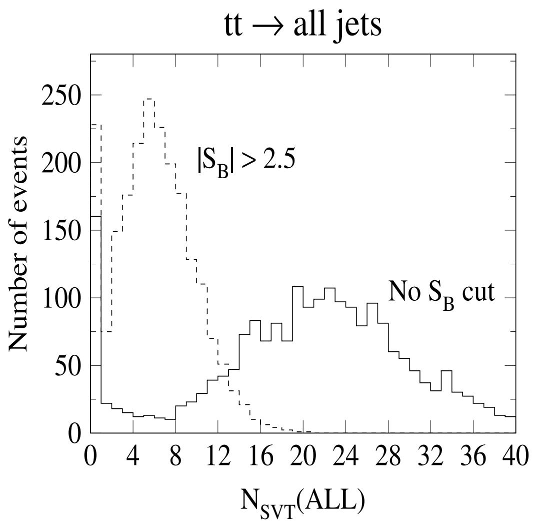
- **Background Samples :**
  - **'Standard' QCD background samples generated in 6** p_T **bins**
  - **samples with 1, 3, 5, 7 additional interactions mixed to simulate** $\mathcal{L} = 2 \cdot 10^{32}$ **cm**$^{-2}$**s**$^{-1}$ **and beam crossing time = 132 ns;**





- **high multiplicity of STT tracks, even after** $\mid S_B \mid > 2.5$ **cut**





Efficiency Versus Rates

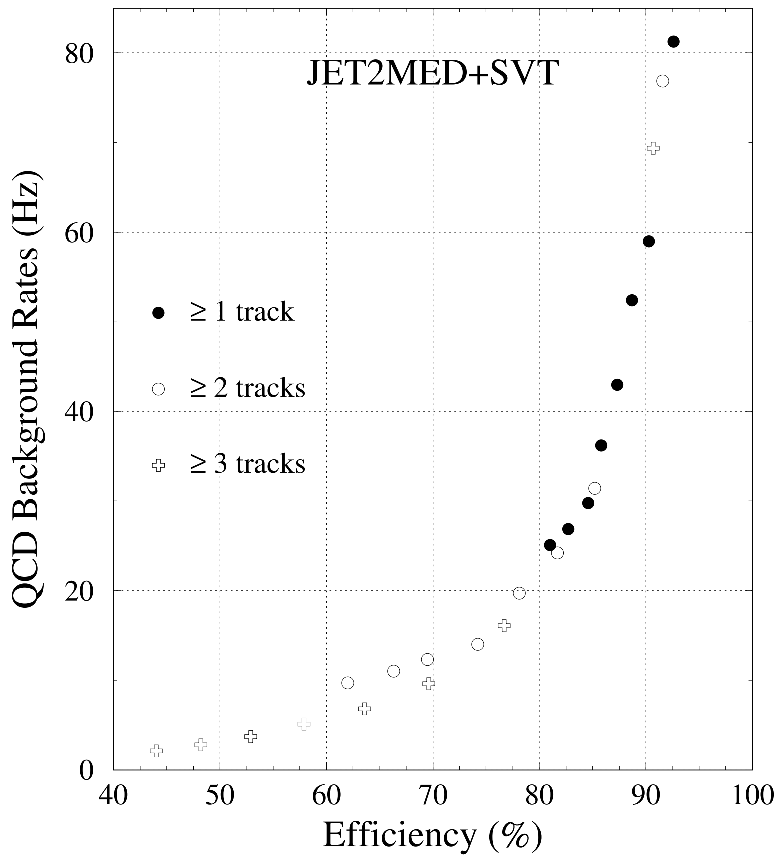
- **Calorimeter–only trigger (JET2MED):**

  Level 1: $\geq$ 2 jets with $E_T > 7$ GeV

  Level 2: $\geq$ 2 jets with $E_T > 20$ GeV

$\Rightarrow$ ***$t\bar{t} \rightarrow$ all jets* efficiency = 98.3%**
L2 background rate = 85 Hz

- **JET2MED + STT**



$\Rightarrow$ **Factor of $\sim$ 4 background rejection for signal efficiency = 80%**

$t\bar{t}$ Trigger Scheme

- **Optimize signal efficiency by combining various triggers**

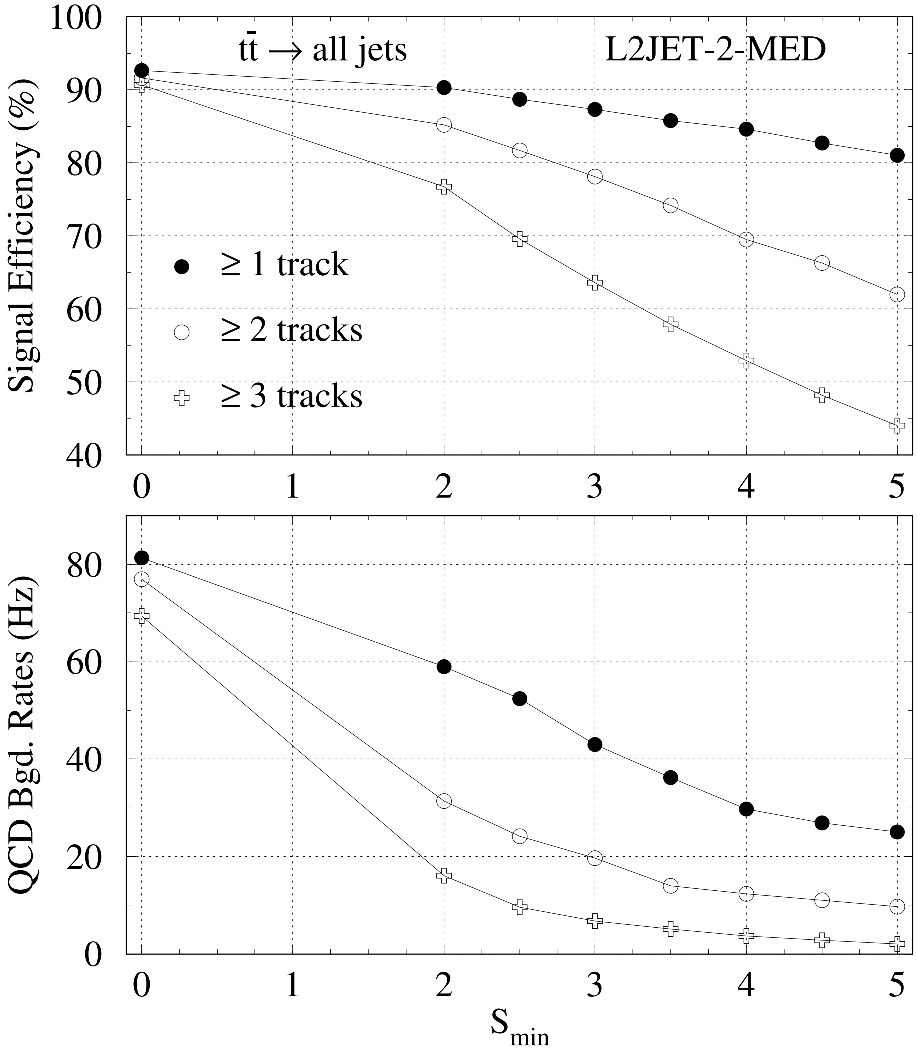
	Bgd.(Hz)		$t\bar{t} \to \mu + jets$		$t\bar{t} \to all\ jets$	
Trigger	**L1**	**L2**	**L1(%)**	**L2(%)**	**L1(%)**	**L2(%)**
1–JMULT	**49.7**	**2.1**	**88.9**	**27.4**	**98.6**	**69.8**
2–MJTMET	**55.2**	**3.3**	**93.4**	**68.5**	**82.0**	**48.7**
3–JMAX	**49.7**	**13.0**	**88.9**	**68.3**	**98.6**	**84.2**
4–MUJET	**64.1**	**41.6**	**75.4**	**74.3**	**53.2**	**53.6**
5–JET2MED	**186**	**85.2**	**96.5**	**88.3**	**99.3**	**98.3**
$\Sigma\,(1 \to 3)$	**82.5**	**17.2**	**96.0**	**86.0**	**99.6**	**96.2**
$\Sigma\,(1 \to 5)$	**239**	**113**	**98.4**	**96.1**	**99.9**	**99.8**
$\Sigma\,(1 \to 3)+$ $\Sigma(4 \to 5) \times STT$	**239**	**38.5**	**98.4**	**92.9**	**99.9**	**98.6**

JMULT: ≥ 4 jets with $E_T \geq 15$ GeV
MJTMET: $\geq 3\ E_T^{jet} \geq 10$ GeV + missing $E_T \geq 20$ GeV
JMAX: ≥ 1 jet with $E_T \geq 45$ GeV
MUJET: $\geq 1\ p_T^{\mu} \geq 6$, $E_T^1 \geq 20$ GeV and $E_T^2 \geq 10$ GeV
JET2MED: ≥ 2 jets with $E_T \geq 20$ GeV
STT: at least 2 tracks with $|\ S\ | \geq 2.5$ ($\epsilon_{signal} = 80\%$)

$\Rightarrow$ **The STT would allow to optimize the trigger efficiency for $t\bar{t}$ events without leading to a large background rate increase.**

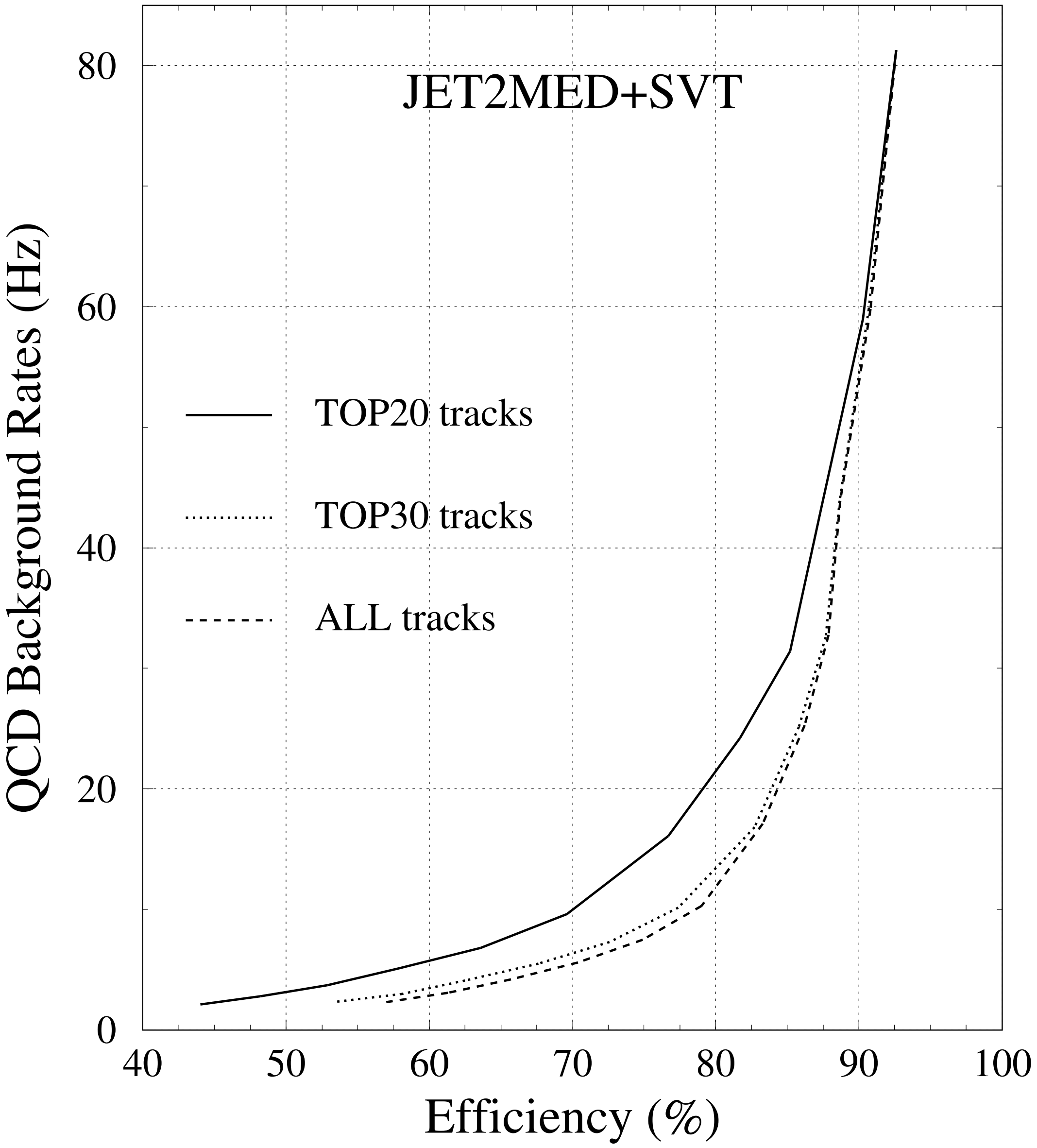
Efficiency and Background for $t\bar{t}$ Events

- **L2JET_2_MED trigger defined as :**
  $\geq$ 2 jets with $E_T \geq$ 20 GeV.
- **Signal efficiency and QCD background trigger rates for the trigger combination L2JET_2_MED * STT:**



- ***e.g*** **requiring at least 1 track with $|S_B| \geq 3$**
  $\Rightarrow$a factor 2 reduction of the background rates while keeping a 87% efficiency for the signal.

Efficiency versus Background ($t\bar{t}$)



Higgs Search

- Signal Sample : $p\bar{p} \to W + H^0, Z + H^0$

with $H \to b\bar{b}$ and and $W \to q\bar{q}$ (67%); $Z \to q\bar{q}$ (70%)

- Background : "standard sample"
- Tev2000 study

$$p\bar{p} \to W(\to e\nu, \mu\nu) + H^0(\to b\bar{b})$$

M_{Higgs}	$\int \mathcal{L}$ fb^{-1}
80	5
100	10
120	25

- extend study beyond leptonic W decays, and include also $Z \to \nu\nu$ and $Z \to hadrons$
- Specific study :

$$p\bar{p} \to W + H^0 \to q\bar{q}b\bar{b}$$

- jet trigger rate and efficiencies :

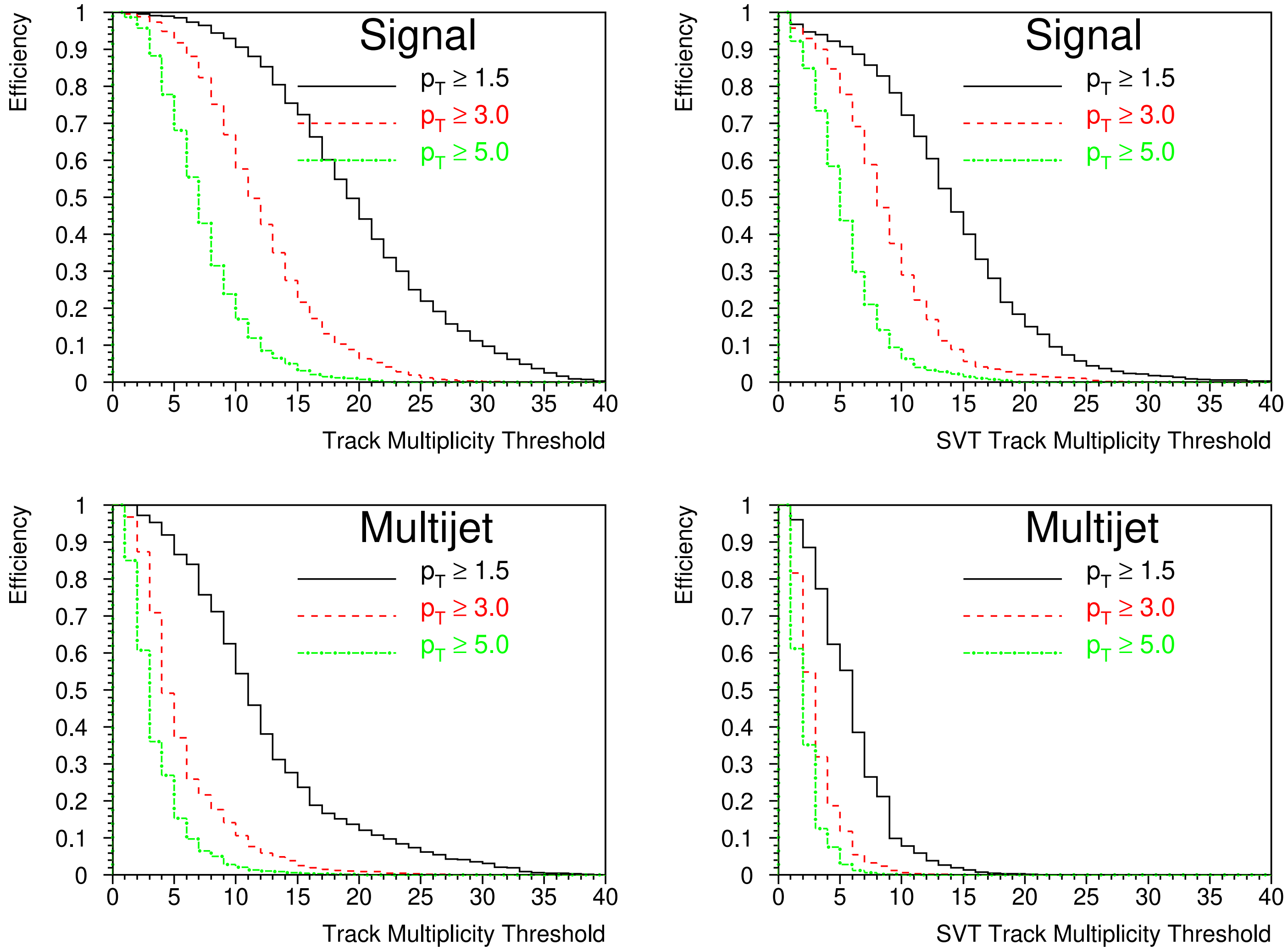
Trigger	Cal. Thresh. n (L1,L2) GeV	L1 r (Hz)	L1 ϵ(%)	L2 r(Hz)	L2 ϵ(%)
JET_3_LOW	3 (3,5)	2000	100	140	78
JET_3_MED	3 (5,10)	200	91	63	74
JET_3_HIGH	3 (7,15)	52	71	15	52
JET_4_LOW	4 (3,5)	670	98	13	36
JET_5_LOW	5 (3,5)	250	93	2.0	8

- All studies relative to JET_3_MED trigger

Track multiplicity

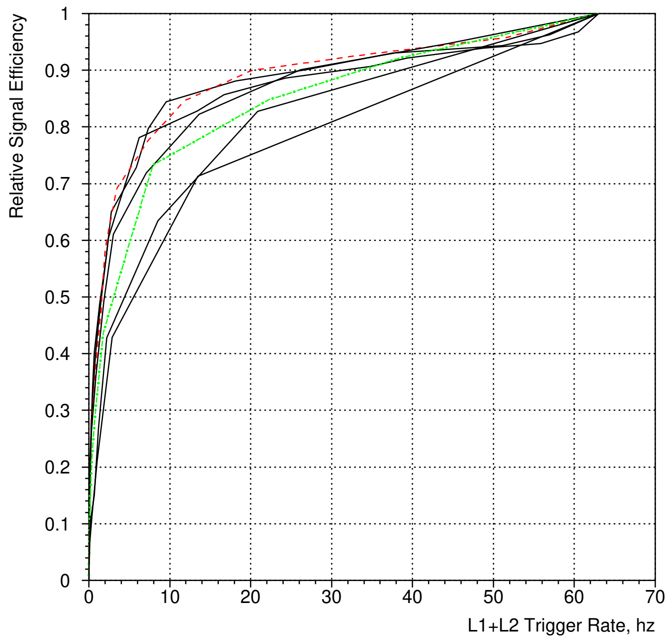
Track multiplicity for signal and background for various track p_T thresholds

CFT tracks **STT tracks**

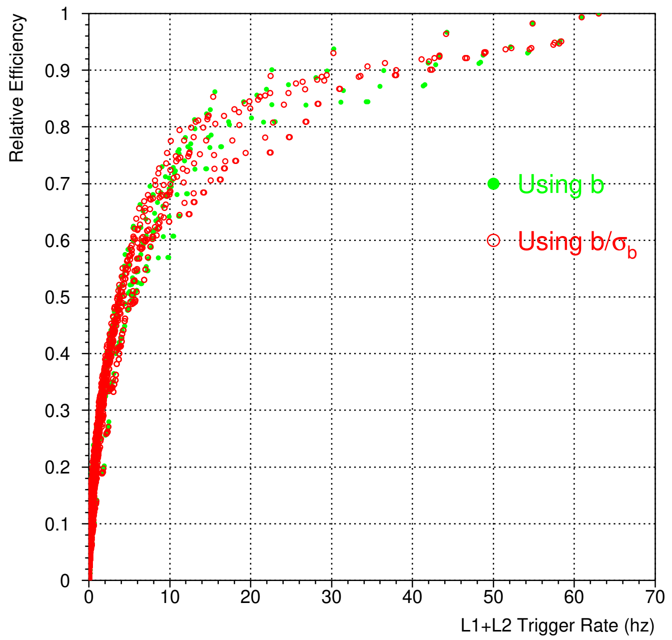


Efficiency vs. Background Rate

STT p_T threshold



Impact parameter and Significance



Benefits of STT for Higgs triggers

Trigger	Background Rejection for $\epsilon =$ 90%	80%	50%	10%
N CFT tracks $w/p_T \geq 3$	2.5	4.7	10	35
N STT tracks $w/p_T \geq 3$	3.1	7.5	40	1000
$w/b \geq 30$	2	3.8	27	900
N STT tracks $\overline{b_{25}} \geq X$	2.2	3.8	21	300
$w/S_{25} \geq X$	2	5	27	200
N $w/p_T \geq 3$ and $\overline{S_{25}} \geq X$	2.8	7.1	33	650

- rejection(STT)/rejection(CFT)
  $\approx$ 1.2 for $\epsilon_{signal} = 90\%$
  $\approx$ 1.5 for $\epsilon_{signal} = 80\%$
  $\approx$ 4 for $\epsilon_{signal} = 50\%$
  $\approx$ 10 for $\epsilon_{signal} = 10\%$
- can maintain L2 trigger rate of
  20 Hz with efficiency $= 68\%$

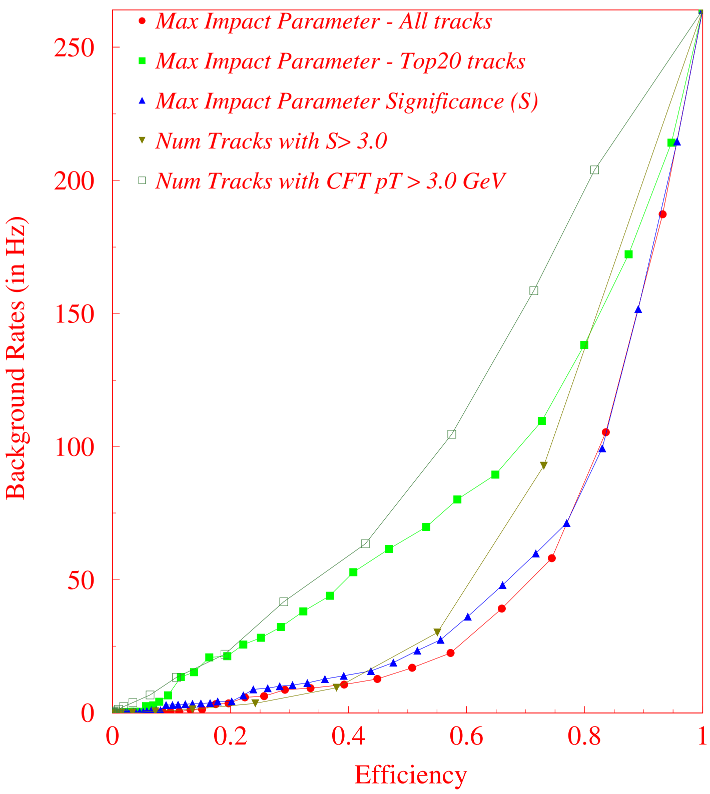
Triggering on $Z \rightarrow b\bar{b}$

- Control sample for
  - top mass measurement
  - Higgs$\rightarrow b\bar{b}$
- Check b-jet energy scale
- Optimize/check $b\bar{b}$ mass resolution
- Signal Sample : $Z \rightarrow b\bar{b}$ – 10k events
- Background : "standard sample"
- Trigger rates and efficiencies using Cal and CFT objects

Trigger	Cal n(L1,L2)	L1 r (Hz)	L1 ϵ(%)	L2 r(Hz)	L2 ϵ(%)
JET_2_MIN	2(3,10)	8028	82	1390	67
JET_2_MED	2(5,15)	621	56	264	41
JET_2_MAX	2(7,20)	186	32	85	20
JET_3_MIN	3(3,10)	1502	68	132	9
JET_3_MED	3(5,15)	167	31	25	4
	Cal/CFT n(L1,L2)+(n,p_T)				
JET_2_MIN_T1	2(3,10)+(2,3)	2389	67	866	57
JET_2_MIN_T2	2(3,10)+(3,3)	1319	57	541	50
JET_2_MED_T1	2(5,15)+(2,3)	450	48	201	35

- cannot trigger with Cal/CFT only

$Z \to b\bar{b}$: Improvement with STT



Trigger	Cal/CFT r (Hz)	Cal/CFT ϵ(%)	Silicon Trigger r(Hz)	Silicon Trigger ϵ(%)	Silicon Trigger r(Hz)	Silicon Trigger ϵ(%)
JET_2_MIN	1390	67	60	35	20	19
JET_2_MED	264	41	110	35	20	23
JET_2_MIN_T1	866	57	62	35	20	20
JET_2_MIN_T2	541	50	77	35	20	19
JET_2_MED_T1	201	35				
JET_3_MED	25	4				

- $\Rightarrow$Signal efficiency of 20% with a background rate of 20Hz is achievable

- $Z \to b\bar{b}$: expected signal

$$\begin{aligned}
\sigma(p\bar{p} \to Z \to b\bar{b}) &\sim 1 \text{ nb} \\
\epsilon(trigger) &= 20\% \\
\epsilon(offline) &= 25\% \quad \text{(double b-tag)} \\
\Rightarrow \sigma(vis) &= 5 \times 10^4 \text{ fb}
\end{aligned}$$

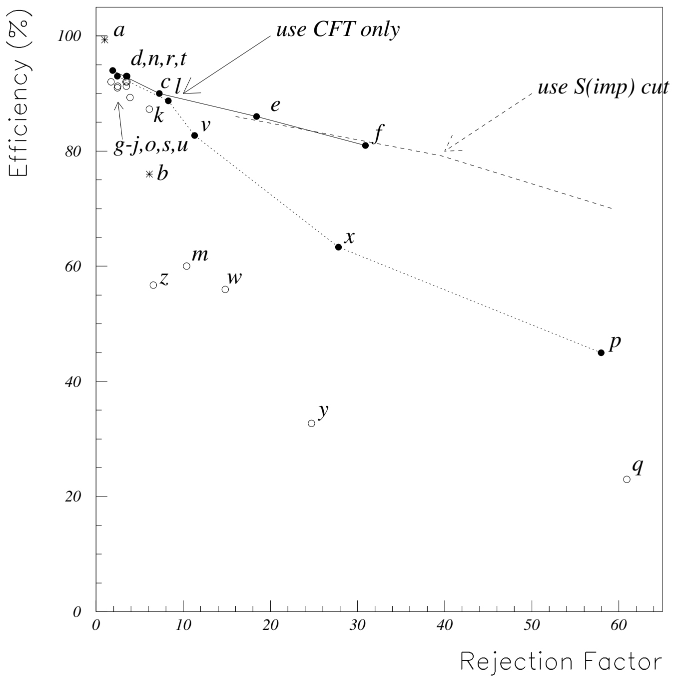
- ... over background

$$\begin{aligned}
\sigma = 20\text{Hz}/2 \times 10^{32}/\text{cm}^2/\text{s} &= 100 \text{ nb} \\
\epsilon(offline) &= 10\% \quad \text{(double b-tag)} \\
\Rightarrow \sigma(vis) &= 10^7 \text{ fb}
\end{aligned}$$

- for 1 fb^{-1} : $\text{S/B} = 5 \times 10^4/10^7$
  $\text{S}/\sqrt{\text{B}} = 17$

SUSY 4 b Signature

- **$\tilde{g}\tilde{g} \to 4b$ could give us a handle on the region of SUSY parameter space**
- **B($\tilde{g}\tilde{g} \to 4b$) is very model dependent.**
- **Trigger sets are extensions of the JetMax trigger and include CFT and/or STT information.**
- **Rejections determined relative to JetMax trigger $\sim$ 13 Hz.**

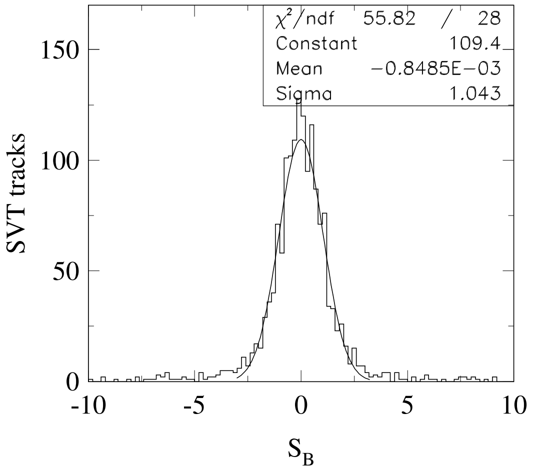


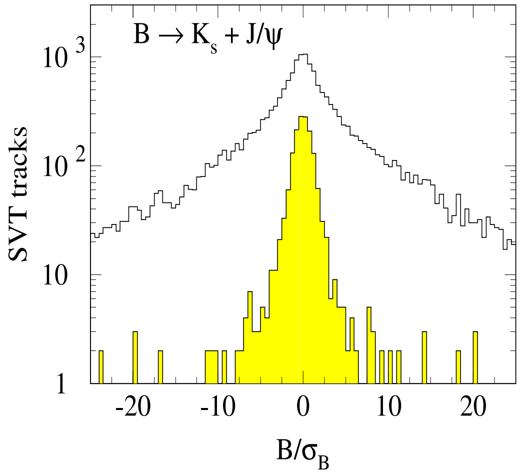
JetMAx: Four L1 jets with $E_T > 5$ GeV and one L2 jet with $E_T > 45$ GeV.

- **CFT and STT give comparable eff/rejections for this channel as the track multiplicity in these events are extremely high**

B-physics

- STT studies using various samples:
  1. $B_d^\circ \to K_s^\circ + J/\psi,\ J/\psi \to \mu^+\mu^-$ (CP asymmetry)
  2. $B_s^\circ \to D_s^- + 3\pi^\pm,\ D_s^- \to K^+K^-\pi^-$ (B_s mixing)
  3. $B_s^\circ \to D_s^- + \mu^+ + \nu_\mu,\ D_s^- \to K^+K^-\pi^-$ (B_s mixing)
- Low multiplicity of charged particles





- Investigate various combinations of muon triggers and STT.
- Possible trigger scheme for $b\bar{b}$ events.

Trigger	rate	$\psi\, K_s$	$D_s^- + \mu^+$	$D_s^- + 3\pi^\pm$
• Single muon	38.6 Hz	23.9%	11.8%	4.6%
• Dimuon +STT	7.6 Hz	14.9%	5.5%	0.3%
• Single + dimuon	45.0 Hz	31.9%	15.6%	4.9%

- $\epsilon_{trig}(B_d^\circ \to J/\psi\, K_s) = 32\%$ $\Rightarrow$ 8.5k — 13k fully reconstructed events

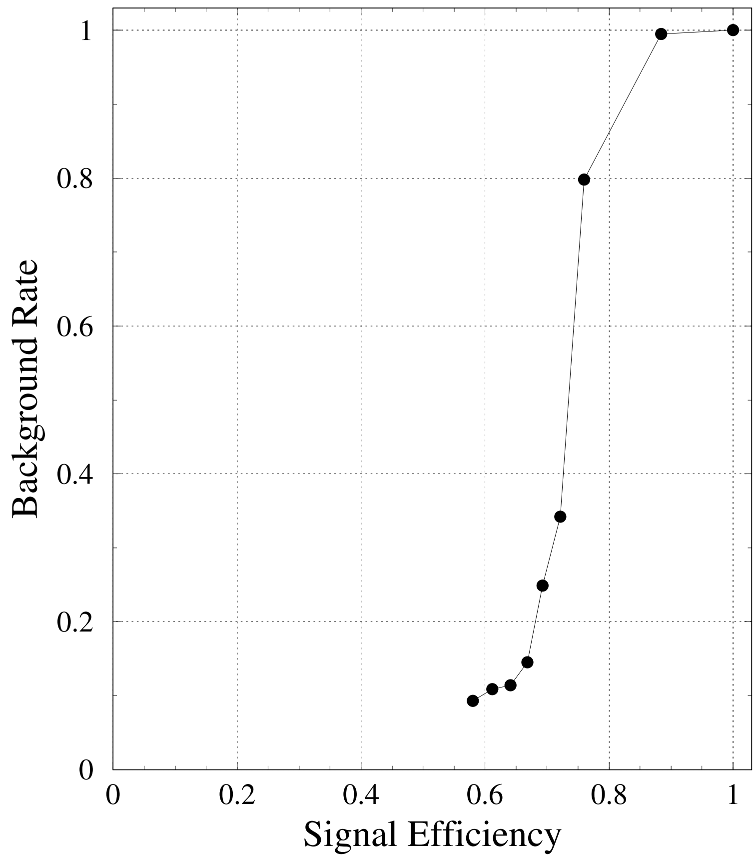
Single Muon Triggers

- Investigate various options of a single muon trigger.

Trigger Conf.	L2 rate	ψK_s	$D_s^- + 3\pi^\pm$
• $p_T > 6$, $\mid \eta \mid < 2$	13.5 Hz	10.8%	1.4%
• $p_T > 4$, $\mid \eta \mid < 2$	38.6 Hz	23.9%	4.6%
• $p_T > 4$ + CFT	21.0 Hz	13.5%	2.0%
• $p_T > 4$ + STT	13.2 Hz	17.3%	2.5%

- In case the single muon trigger rate would need to be reduced, the STT would be very helpful to preserve a good signal efficiency.

Single muon + SVT

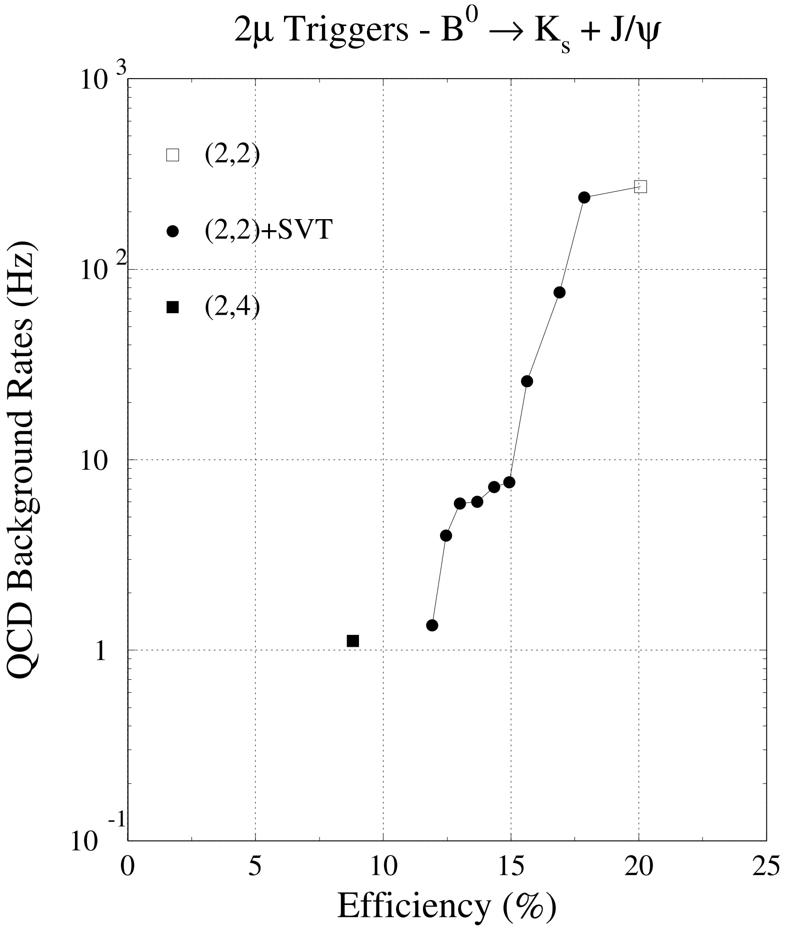


Dimuon Triggers

- Play with p_T threshold on both muons:

Trigger	L2 rate	$\psi\, K_s$	$D_s^- + \mu^+$
• (2 GeV, 4 GeV)	1.1 Hz	8.8%	2.5%
• (2 GeV, 2 GeV)	272 Hz	20.1%	8.2%
• (2,2) + STT	7.6 Hz	14.9%	5.5%
• (2,2)+ $E_T^{jet} > 10$ GeV	102 Hz	0.9%	0.5%

- The STT allows to reduce the rate of the low threshold trigger (2,2) while preserving a better efficiency than (2,4). It is much more efficiency than asking for a jet.



z vertex Determination

Use hits in Layer1 and Layer3 of the 4 inner barrels of the Silicon detector instrumented with 90° stereo strips for fast z-vertex position determination

Possible algorithms for z_vertex finding:

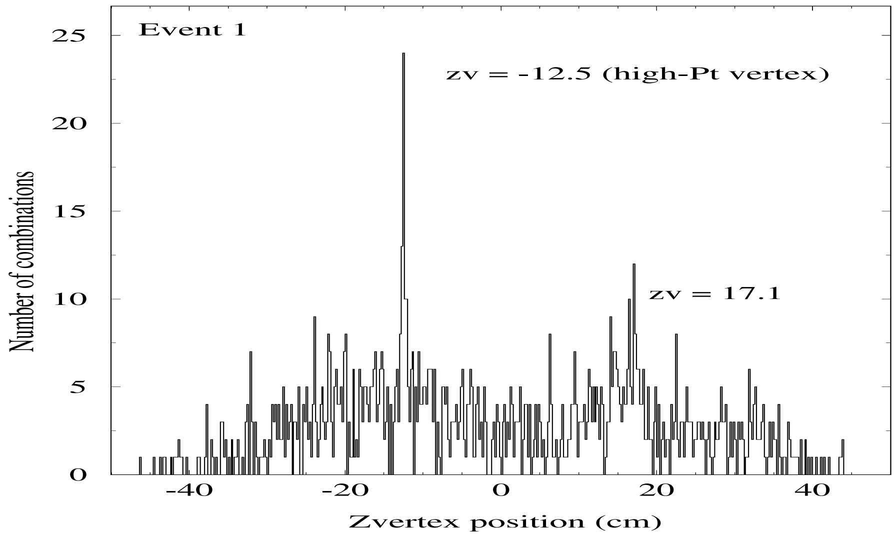
1. **Form all possible tracks connecting the hits in both layers, intersect with beam axis and look for peak(s) in resulting z-distribution to find the vertex;**
   - **number of combinations formidable (4000+) for high multiple interaction events**
2. **Move along z-axis (in bins), connect with hit on outer layer, look for matching hit on inner layer; look for z-bins with many matching hits (find peak(s) in z-distribution).**
   - **Possible to implement this by scaling the inner layer hits to outer layer radii and looking for possible coincidences.**
   - **Independent of number of interaction in the events**

- **z-vertex finding region limited to $\sim \pm 25$cm due to limited # of barrels with 90° stereo strips.**

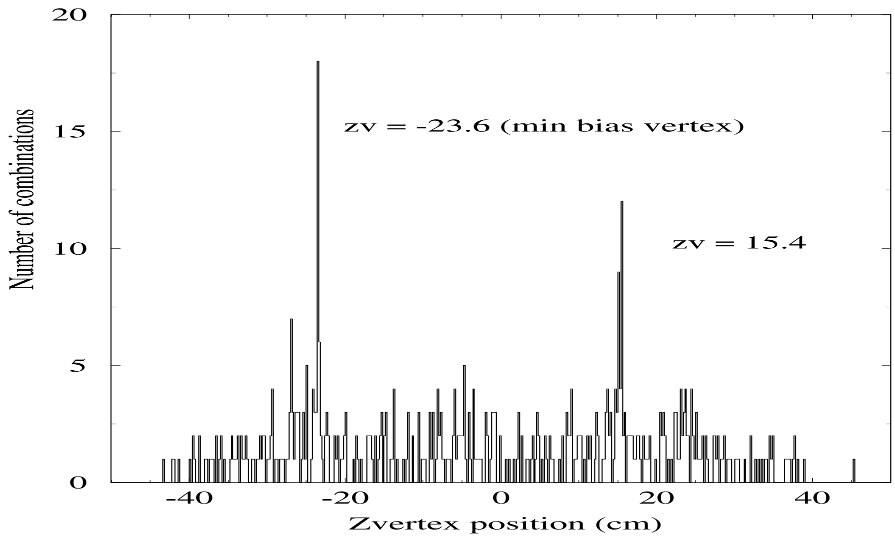
Event vertices

$Z \rightarrow b\bar{b}+$ 2 minbias events

- **Event 1:**
  - High p_T vertex correctly identified
  - 3rd vertex at 45 cm

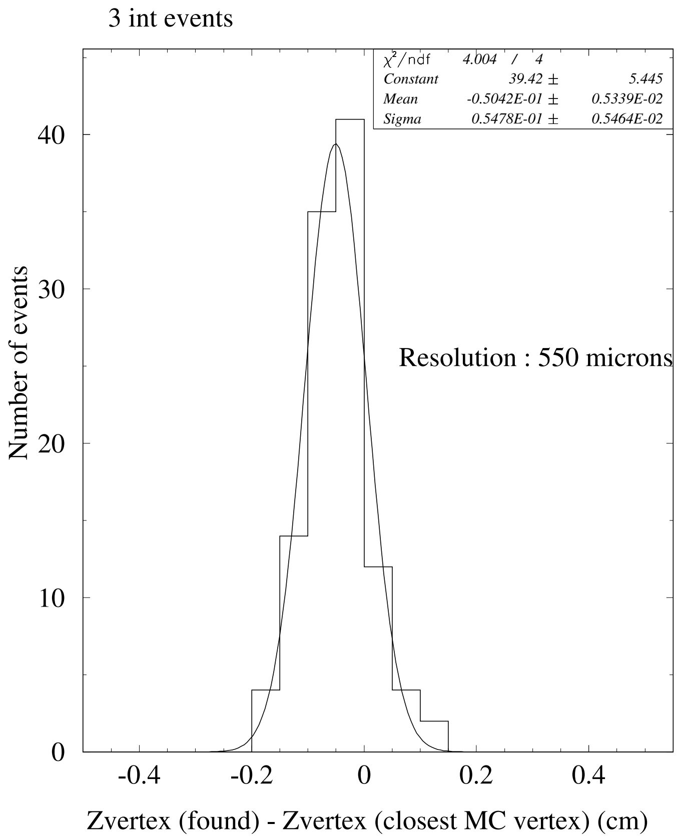


- **Event 2:**
  - Min Bias vertex identified as high p_T vertex
  - High p_T vertex at 15.5 cm
  - 3rd vertex at -71 cm



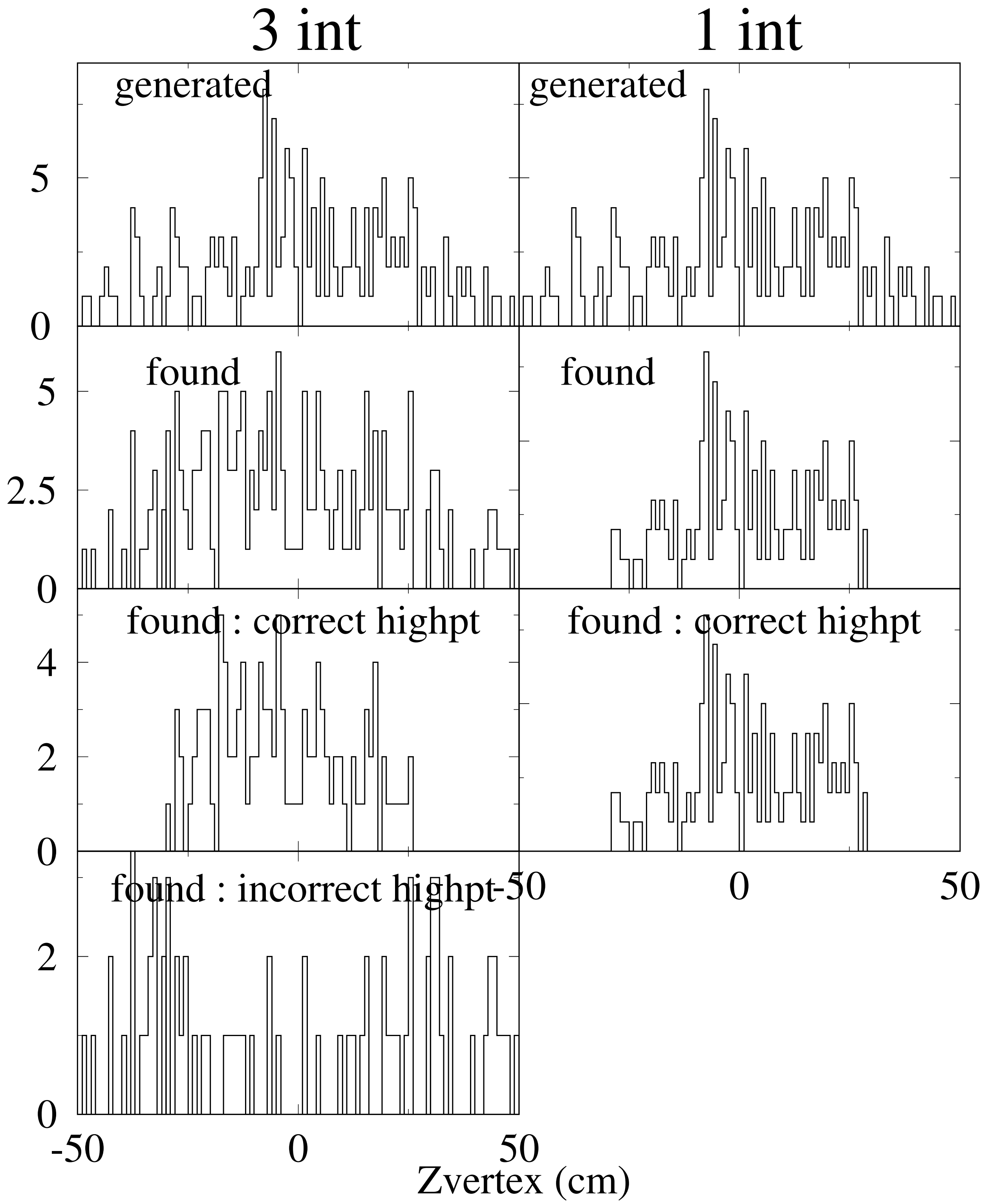
z-vertex Resolution and efficiencies

- Sample used :
  - $Z \to b\bar{b}$ events (199 events)
  - $Z \to b\bar{b}+$ 2 minbias events (199 events)
- z-vertex resolution $\sim 600\mu$m
  $\Rightarrow$independent of additional interactions in the event



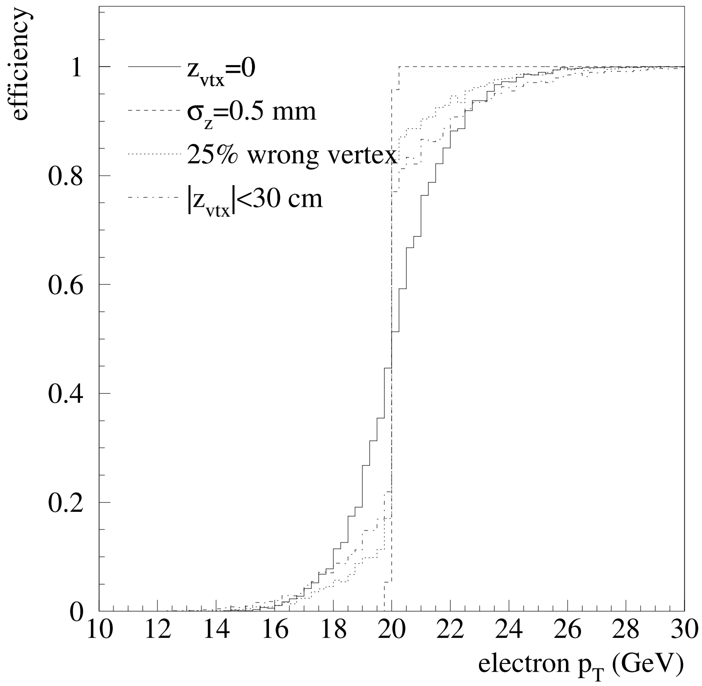
No of events	199	199
Found at least one vertex	145	196
vertex not found	54	3
High p_T vertex $\|z\|\lesssim$ 30cm	153	153
Found vertex is High p_T vertex	145	112
High p_T vertex ($\|z\|\lesssim$ 30cm)		
Efficiency of finding High p_T vertex	95%	73%
"wrong vertex" events	-	26%

z-vertex Distributions

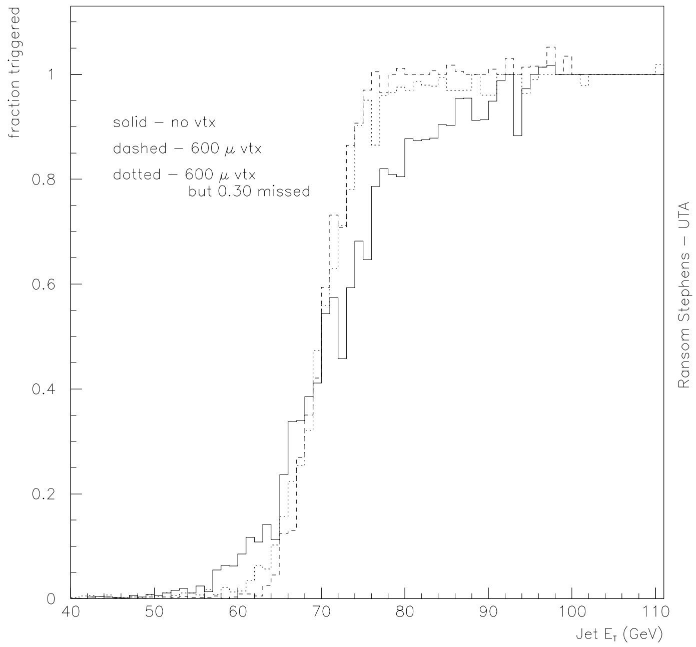


Gain for electron and jet thresholds at L3

- Electrons :



- Jets : (Ransom Stephens)



- Sharper turn-on for electron and jets at L3
- (Not clear if fast vertexing available at L3)

Conclusions

- use of Si detector hits in track fit
  $\Rightarrow$improve momentum resolution
  $\Rightarrow$sharper p_t thresholds,
  E/p for electrons at L2;

- trigger on tracks with high impact parameter
  $\Rightarrow$trigger on events containing b-quarks;
  - provides very powerful handle for background rejection, with good signal efficiency, for many interesting physics channels:
    * B-physics,
    * $Z \to b\bar{b}$,
    * Higgs$\to b\bar{b}$,
    * $t\bar{t}$,
    * single top
    * ...

- use Si detector (90° stereo) information for fast z-vertex position
  $\Rightarrow$ sharper electron and jet p_T thresholds at L3

- Hit finder for L3
  $\Rightarrow$ save processing time in L3 by providing hit positions for r/ϕ and stereo (both 90° and 2°), making use of Si detector information at L3 possible or more efficient.

SUMMARY

- have done simulations of performance of STT as realistic as possible with the available tools;
- have made assessment of incremental gains in rejection power over that possible with existing trigger tools;
- simulation of performance was done with algorithms similar to what can be implemented in hardware;
- have shown that STT expands capabilities of presently foreseen trigger system,
  adding additional handles for background rejection and rate control.