Study of Δ^{++} single production via VBF process

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Each selection is optimized to $M^{++} = 300 - 500$ **GeV.**
(To know what we can see with low-luminosity data...)

Background Monte Carlo

Process	σ	Number of Processed Event	Generator (PDF)
$t\bar{t}$	676pb	42,600,000	Pythia (CTEQ5L)
$\tau\tau jj$ (multi-peripheral)	191fb	189,836	CompHep (CTEQ5L)
$Zjj,\ Z\to\tau\tau$ (QCD)	159pb	16,777,216	CompHep (CTEQ5L)
$Zjj,\ Z\to\tau\tau$ (EW)	609fb	1,655,517	CompHep (CTEQ5L)
$WWjj$	701fb	50,941	CompHep (CTEQ5L)
$b\bar{b}g,\ g\to \mathrm{q\bar{q}}$	1.11nb	10,000,000	Pythia (CTEQ5L)
WZ	25.9pb	10,000,000	Pythia (CTEQ5L)
ZZ	10.6pb	10,000,000	Pythia (CTEQ5L)
WWW	135fb	135,970	CompHep (CTEQ5L)
WWZ	106fb	105,962	CompHep (CTEQ5L)
WZZ	33.1fb	33,194	CompHep (CTEQ5L)
ZZZ	103.8fb	10,912	CompHep (CTEQ5L)
Wt	61.5pb	4,000,000	CompHep (CTEQ5L)
$W\mathrm{t\bar{t}}$	468pb	889,331	CompHep (CTEQ5L)
Wtb	33.4pb	1,998,920	CompHep (CTEQ5L)

—— is main background.

All background were generated by S. Asai.

Signal Monte Carlo

Only Δ_L^{++} single production via VBF are considered in this study.
These samples are generated by Pythia(6.2).

- **Pythia input**
  - *PMAS(353,1)* Δ_L^{++} **mass in GeV**
  - *PARP(191)=0.64* g_R
  - *PARP(192)=9* v_L **in GeV**
  - *PARP(181-189)* **Lepton Yukawa couplings (diag=0.1,0.1,0.3)**
  - *MSUB(351)=1* $qq^{'} \rightarrow \Delta_L^{++}$

- **Signal Monte Carlo Sample**

Process	Number of Processed Events	mass points (GeV)
$\Delta_L^{++} \rightarrow \tau\bar{\tau}$ (VBF)	20k	300,500,700
$\Delta_L^{++} \rightarrow e\bar{e}$ (VBF)	20k	300,500,700
$\Delta_L^{++} \rightarrow \mu\bar{\mu}$ (VBF)	20k	300,500,700
$\Delta_L^{++} \rightarrow WW$ (VBF)	20k	300,500,700

Lepton Identification, Efficiency and HLT

Fortran-based ATLFAST is used in this analysis with DICE correction (ALT-PHYS-2002-008).

- **Lepton Identification**
  - **90 % for leptons ($|\eta| < 2.5$)**
  - **50 % for hadronic tau decays ($|\eta| < 2.5$)**
    But mistag for non-τ jet is not taken into account for $P_{\mathrm{T}} > 150$ GeV.
  - **60 % for b-jet ($|\eta| < 2.5$)**

- **Inefficiency**
  - **3.7 % for Central Jet Veto due to minimum bias jets**

- **At least one of the following HLT flags is required.**

electron	e25 GeV, 2e15 GeV
muon	μ20 GeV, 2μ10 GeV
tau& E_T^{miss}	τ35 GeV, xE45 GeV
Muon & electron	μ10 GeV + e15 GeV

Forward Jet Tag and Central Jet Veto

- **Forward Jet Tag**
  - $P_{Tjet1} > 40$ **GeV and** $P_{Tjet2} > 20$ **GeV**
  - $|\eta_{jet}| < 4.9$
  - $\eta_{jet1} \times \eta_{jet2} < 0$
  - $\Delta\eta > 3.8, M_{jet1-jet2} > 500$ **GeV**
- **Central Jet Veto**
  - $P_{Tjet} > 20$ **GeV**
  - $\eta_{jet_{min}} + 0.7 < \eta < \eta_{jet_{max}} - 0.7$

$\Delta_L^{++} \to \tau^+\tau^+$ (single lepton)

Selection is similar to $H^0 \to \tau\tau$.
But Zjj(QCD+EW) background level is not so severe after mass cut.

- N_ℓ**=1 or** N_τ**=1 (**$P_T^e > 15$ **GeV,** $P_T^\mu > 10$ **GeV,** $P_T^\tau > 35$ **GeV,** $|\eta| < 2.5$**)**
- **Forward Jet Tag + Central Jet Veto**
- $P_T^{miss} > 30$ **GeV**
- $\Sigma \overrightarrow{P}_T^{all} (= \overrightarrow{P}_T^{\ell_1} + \overrightarrow{P}_T^{\ell_2} + \overrightarrow{P}_T^{jet_1} + \overrightarrow{P}_T^{jet_2} + \overrightarrow{P}_T^{miss}) < 25$ **GeV**
- $\eta_{jet_{min}} < \eta_{\ell,\tau} < \eta_{jet_{max}}$ **and** $\Delta\eta_{\ell-jet} > 1.5$
- $P_T^\tau > 70$ **GeV,** $P_T^\ell > 20$ **GeV**

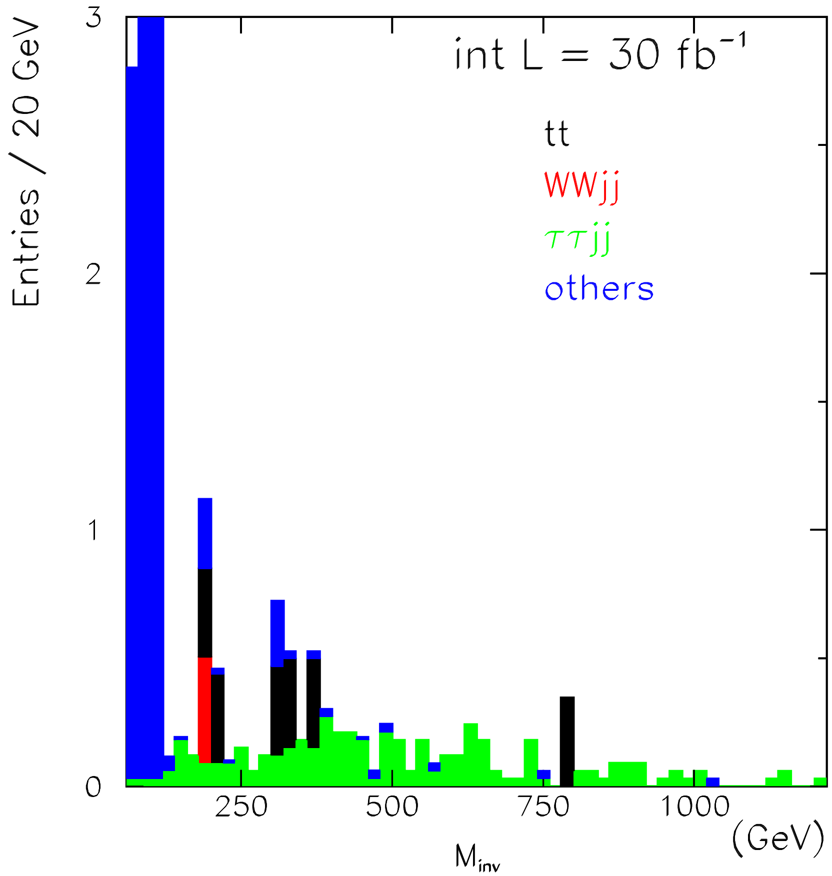
Main Background after all selection (except Zjj)

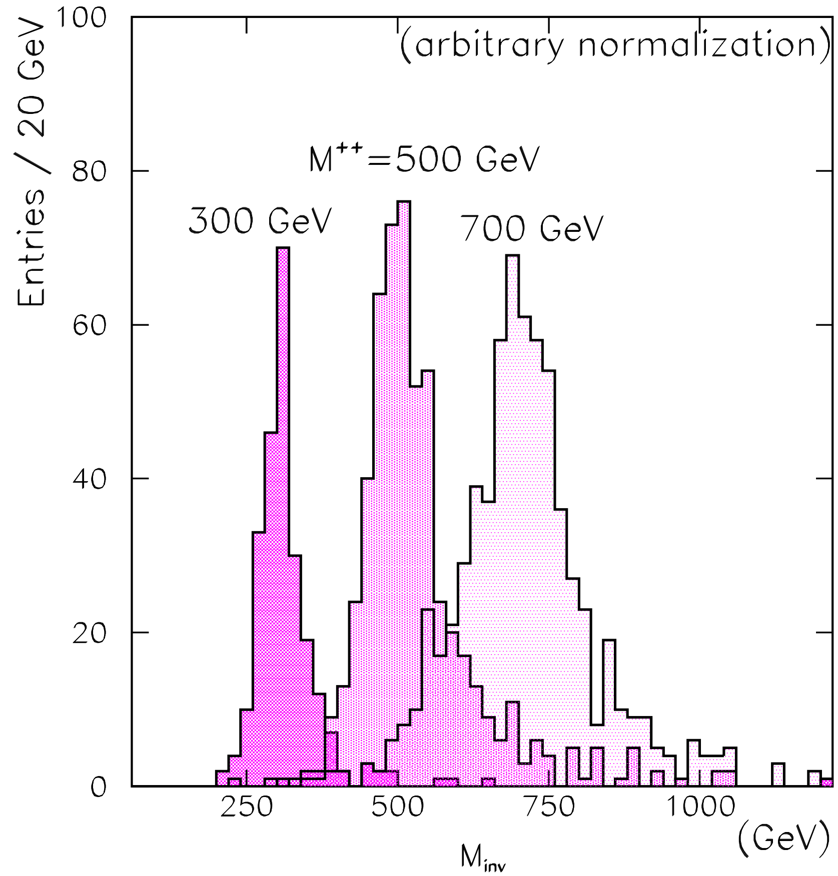
$\tau\tau jj(0.16fb)$, $bbqq(0.1fb)$, $tt(0.06fb)$, $WWjj(0.02fb)$

- **Signal efficiency (without any cut on $M_{\tau\tau}$)**

Δ^{++} mass	300	500	700
efficiency (%)	1.1	2.4	3.1

$M_{\tau\tau}$ in $\Delta_L^{++} \to \tau\tau$ (single lepton)





$\Delta_L^{++} \to \tau^+\tau^+$ (di-lepton)

Selection is similar to $\Delta_L^{++} \to \ell^+\ell^+$.
But, background is more severe because of less energetic leptons and $\Delta\phi_{\ell\ell} \neq \pi$.

- $N_e + N_\mu = 2$ **(**$P_{\rm T}^e > 15$ **GeV,** $P_{\rm T}^\mu > 10$ **GeV,** $|\eta| < 2.5$**)**
- **Forward Jet Tag + Central Jet Veto**
- **Same sign**
- $P_{\rm T}^{miss} > 30$ **GeV**
- $\eta_{jet_{min}} < \eta_\ell < \eta_{jet_{max}}$ **and** $\Delta\eta_{\ell-jet} > 1.5$
- $P_{\rm T}^{\ell 1st} > 50$ **GeV**
- $\Sigma \overrightarrow{P}_{\rm T}^{all} < 25$ **GeV**

$\to$ **0.5 event (**tt **and** WZ**) is remained with 30/fb data.**

- **Signal efficiency**

Δ^{++} mass	300	500	700
efficiency (%)	0.7	1.4	1.6

$\Delta_L^{++} \rightarrow \ell^+\ell^+$

The branching ratio may be too small, but signal is very clean.
Two energetic leptons with same flavor and same sign are required.

- $N_e = 2$ **or** $N_\mu = 2$ **(**$P_{\mathrm{T}}^e > 15$ **GeV,** $P_{\mathrm{T}}^\mu > 10$ **GeV,** $|\eta| < 2.5$**)**
- **Forward Jet Tag + Central Jet Veto**
- **Same sign**

Main background after same sign cut

$bbqq(2.9fb)$, $tt(1.5fb)$, $Wt(0.19fb)$, $WZ(0.14fb)$

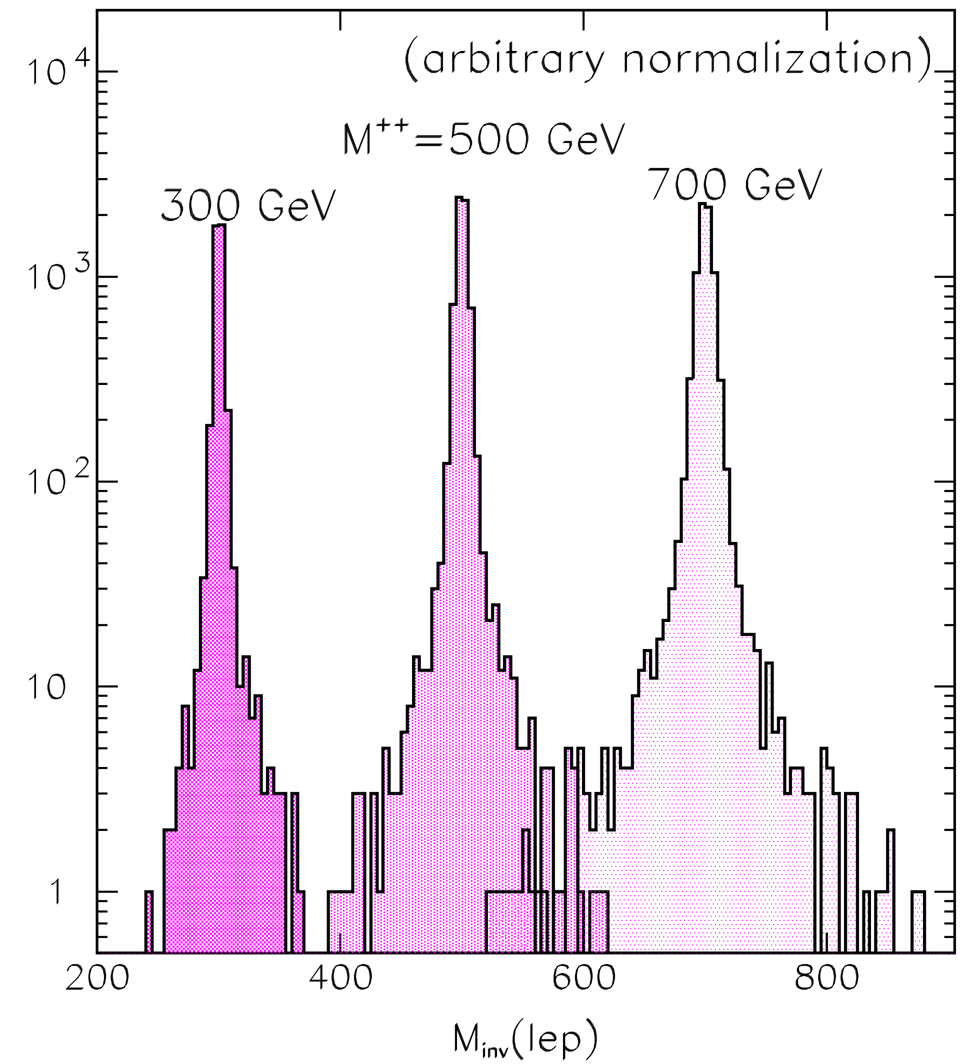
- $\eta_{jet_{min}} < \eta_\ell < \eta_{jet_{max}}$
- $P_{\mathrm{T}}^{miss} < 20$ **GeV**
- $\Delta P_{\mathrm{T}}^\ell > 250$ **GeV**

$\rightarrow$ **3.3 event (bbqq) background is remained.**

- **Signal efficiency**

Δ^{++} mass	300	500	700
efficiency (%)	16	27	31

M_{ee} in $\Delta_L^{++} \to e^+e^+$



Result (Preliminary)

Required cross-section σ_5 is calculated for 5σ discovery with $\int \mathcal{L} = 30^{-1}$ for some Δ_L^{++} mass.

$\Delta_L^{++} \to \tau^+\tau^+$ (single-lepton)

The number of expected background is calculated on the assumption of flat background level ($M_{\tau\tau} = 250 \sim 850$ GeV) to a first approximation.
(because of less statistics of background Monte Carlo sample).

Δ^{++} mass	300	500	700
Mass Cut ($M \pm \Delta M$)	$\pm$ 40 GeV	$\pm$ 80 GeV	$\pm$ 100 GeV
efficiency (%)	0.9	2.0	2.3
N_b	0.73	1.5	1.8
σ_5 (fb)	16	9.9	9.7

Conclusion

- Following three topologies are studied in single Δ_L^{++} production via VBF with low-luminosity Monte Carlo sample.
  Cut is optimized to $M^{++} = 300 - 500$ GeV.
  (DICE correction and inefficiency are taken into account in this result.)
  - $\Delta_L^{++} \rightarrow \ell^+ \ell^+$
  - $\Delta_L^{++} \rightarrow \tau^+ \tau^+$ (di-lepton)
  - $\Delta_L^{++} \rightarrow \tau^+ \tau^+$ (single lepton)
- Required production cross-section for 5 sigma discovery with low luminosity data (30/fb) are calculated.
  - $\sigma_5 > 16 fb$ for $M^{++} = 300$ GeV
  - $\sigma_5 > 9.9 fb$ for $M^{++} = 500$ GeV
  - $\sigma_5 > 9.7 fb$ for $M^{++} = 700$ GeV
- To obtain the discovery potential, more realistic estimation of background level is necessary.

Outlook

- Estimate background level with more reliable way.
- Study $\Delta_L^{++} \to W^+W^+$ decay channel.
- Analysis must cover the wide range of doubly charged higgs mass.

Light doubly charged higgs ($<$ 200 GeV)

- Is it realistic in the little higgs model (i.e. small f/v)?
- Higgs working group almost established selection for $H \longrightarrow \tau\tau$ and $H \longrightarrow WW^{(*)}$.
  $\to$ It is useful to apply it for light Δ^{++} (and also to check the consistency).
- Study Δ_L^{++} pair production via Drell-Yan process?
  (Montreal already have some result.)

Heavy doubly charged higgs ($>\sim$ 1 TeV)

- Study this with high-luminosity Monte Carlo sample.

Outlook (con'd)

- **Montreal already started the analysis of** $\Delta_L^{++} \to W^+W^+ \to \ell\nu + \ell\nu$**.**
  - **We will also try this with high luminosity sample.**
  - $\boldsymbol{\sigma(qq \to qqW^{\pm}W^{\pm})}$ **(SM EW process) depends on** m_H**.**
    $\boldsymbol{\sigma_{WWjj}(m_H = 1TeV)/\sigma_{WWjj}(m_H = 100GeV) = 1.5 - 3}$
    (depends on cut).

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- W_R **and** Δ_R^{++} **are degenerate in mass in the little higgs model.**
  Should we study Δ_R^{++} **single production via Drell-Yan with s-channel** W_R **exchange?**

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