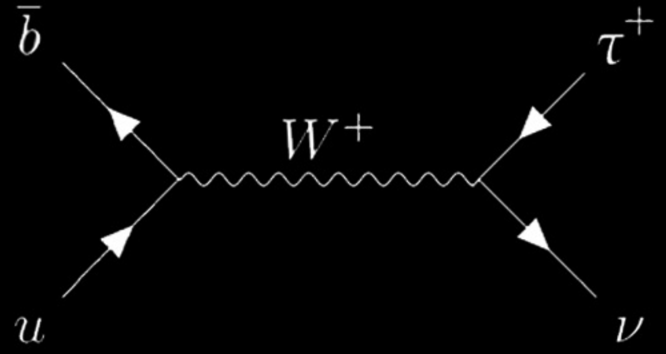
Sensitivity study of $B \to \tau\nu$ with Hadronic Tagging at the Belle II experiment

Giovanni Gaudino (INFN Napoli)
Master Thesis



$$\mathcal{BR}(B \to \ell\nu) = \frac{G_F m_B m_\ell^2}{8\pi}\left[1 - \frac{m_\ell^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_B$$

Supervisors
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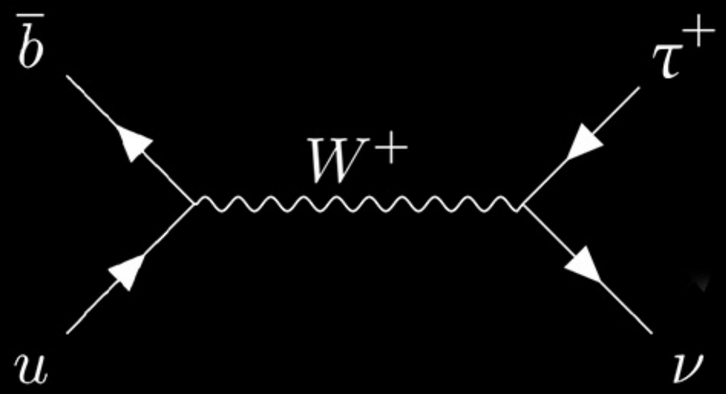
Mario Merola (INFN Napoli)

Riunione Gruppo 1 – 21/12/21

Leptonic B decays: $B \to \tau\nu$



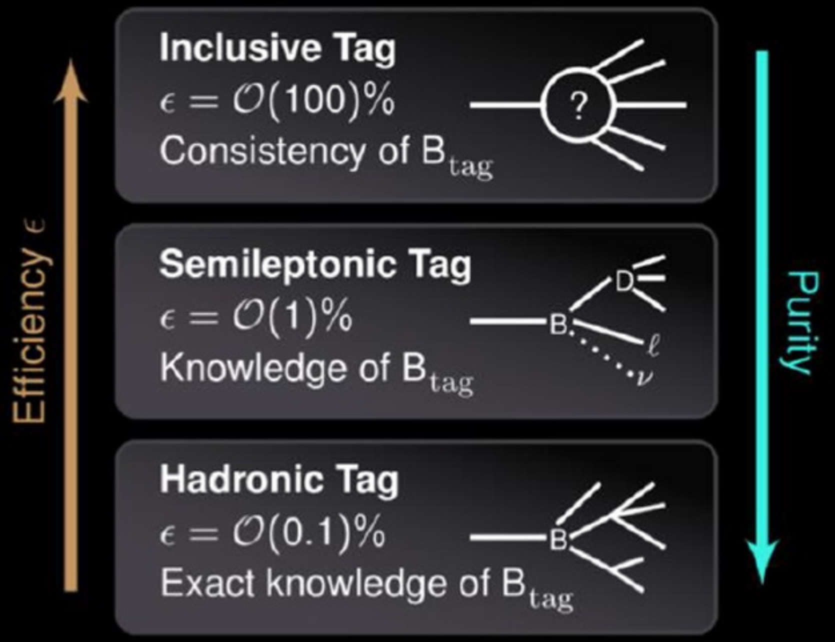
$$\mathcal{BR}(B \to \ell\nu) = \frac{G_F m_B m_\ell^2}{8\pi}\left[1 - \frac{m_\ell^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_B$$

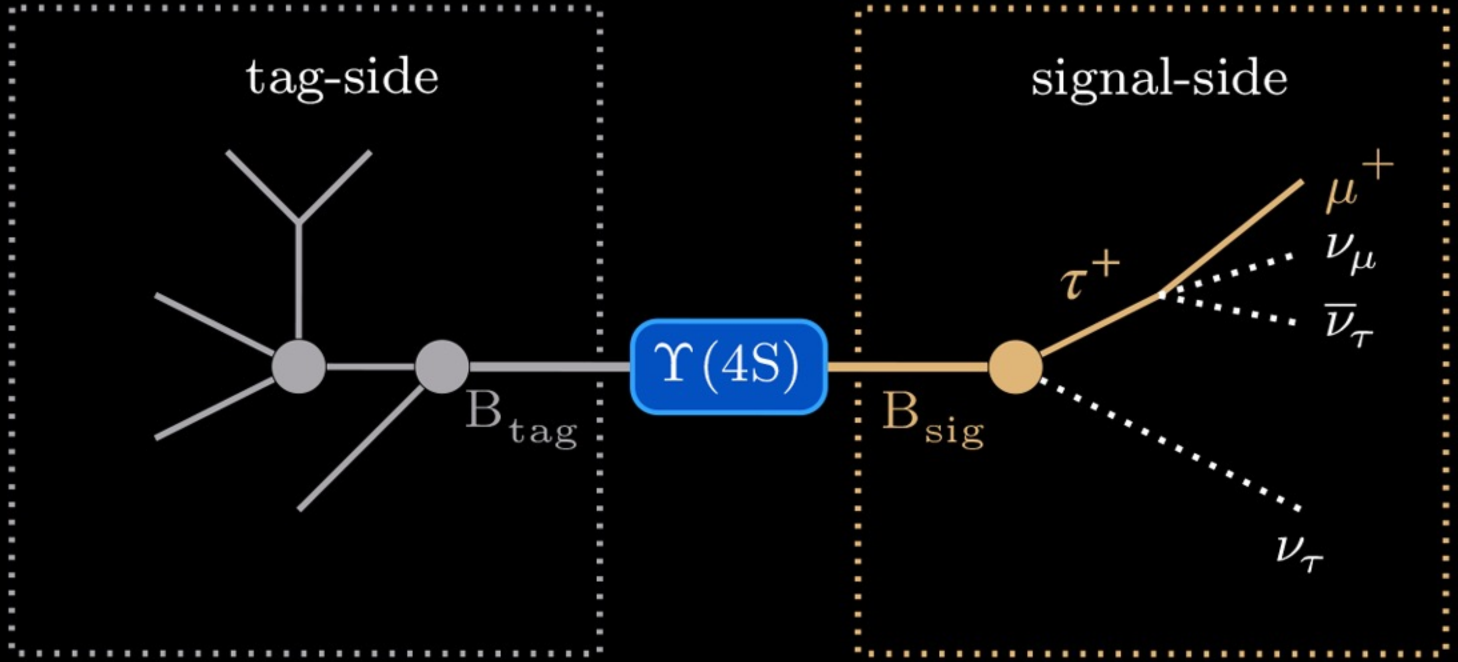
	$\mathcal{BR}(B \to \tau\nu)$	Luminosity
Belle	$(0,72^{+0,27}_{-0,25}(\text{stat.}) \pm 0,11(\text{sist.})) \times 10^{-4}$	711 fb^{-1}
BABAR	$(1,83^{+0,53}_{-0,49}(\text{stat.}) \pm 0,29(\text{sist.})) \times 10^{-4}$	426 fb^{-1}
SM	$(1,18 \pm 0,16) \times 10^{-4}$	

L_{data}= 62,8 fb^{-1}

Ricostruzione dell'evento

Full Event Interpretation - FEI

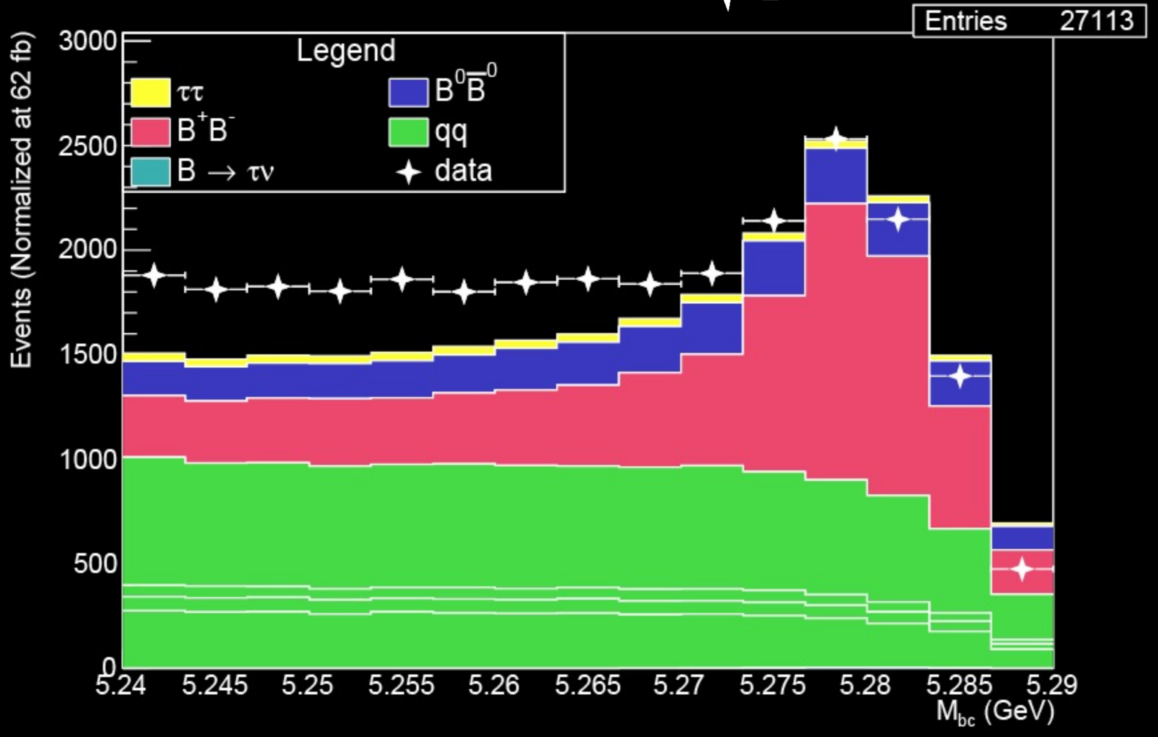


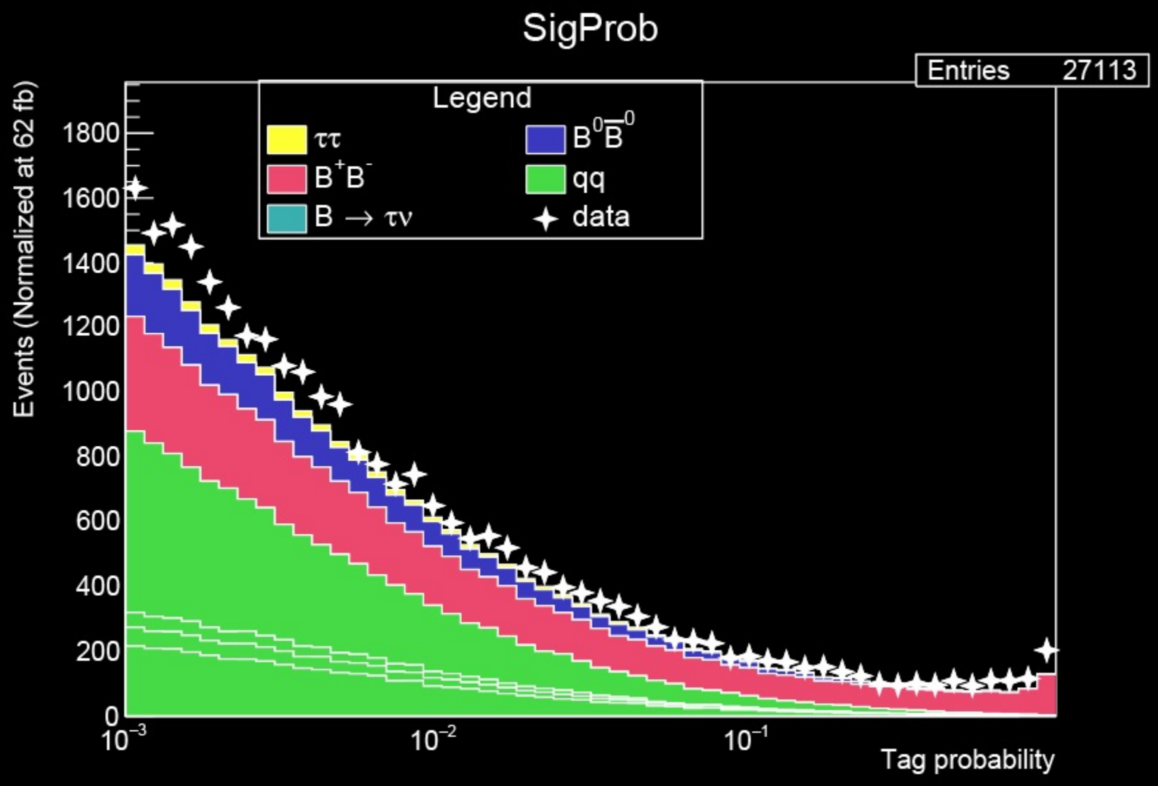


Variables

FEI

$$M_{bc} = \sqrt{E_{beam}^{*2} - \left|\mathbf{p}_B^*\right|^2} = \sqrt{\frac{s}{4} - p_B^2}$$





Signal Selection

Channel selection

τ Decay Mode	Branching Ratio (%)
$\tau \to \mu\nu\nu$	17,39
$\tau \to e\nu\nu$	17,82
$\tau \to \pi\nu$	10,81
$\tau \to \rho\nu$	25,49

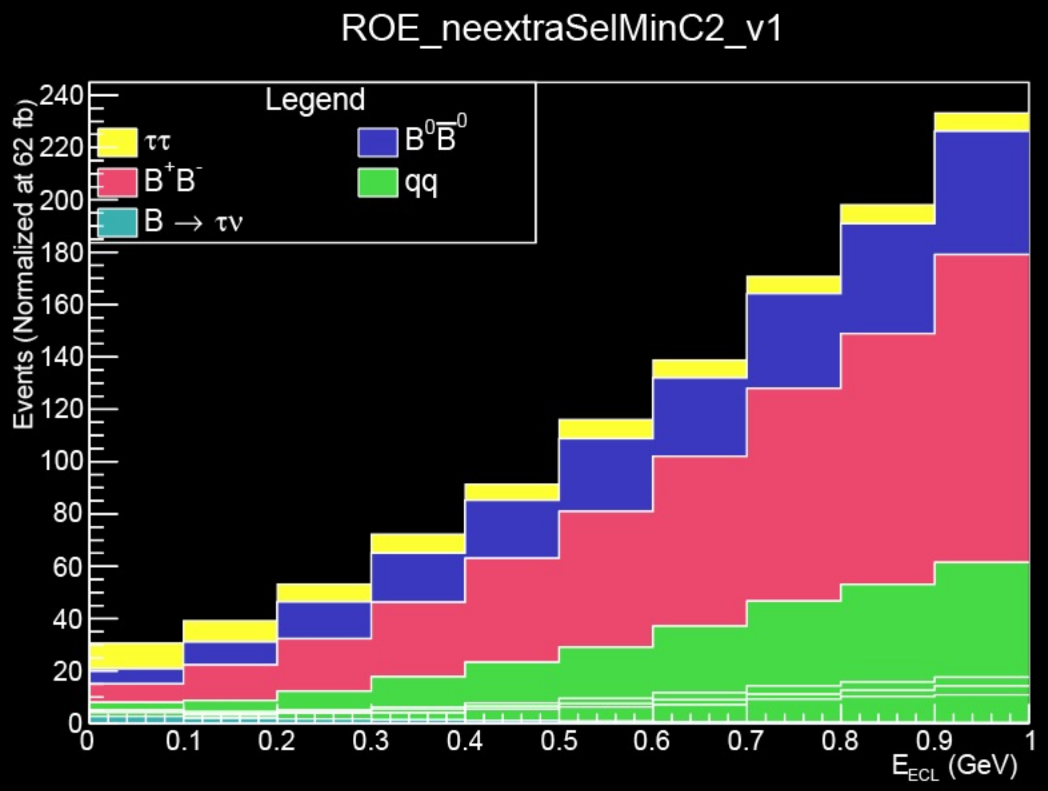
- e: $\text{Prob}(\mathcal{L}_e) > 0.9$
- μ: $\text{Prob}(\mathcal{L}_\mu) > 0.9$
- π: $\text{Prob}(\mathcal{L}_e) < 0.9$ && $\text{Prob}(\mathcal{L}_e) < 0.9$

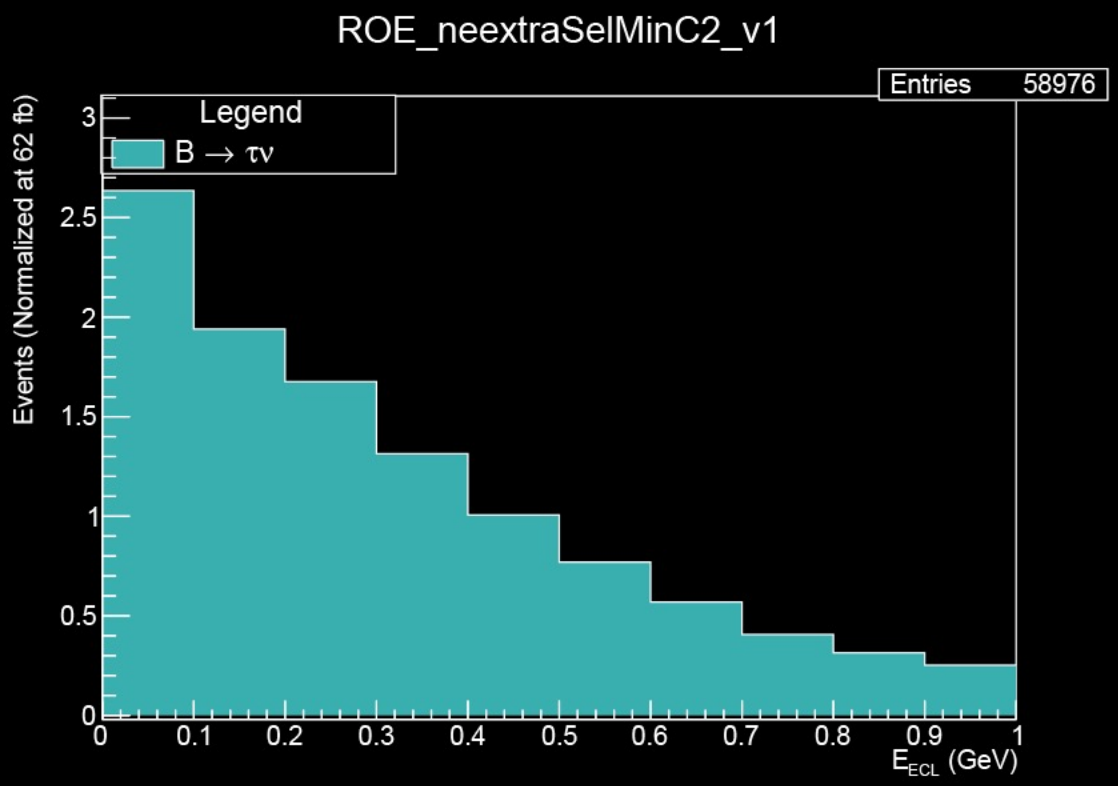
$\rho \to \pi\pi^0 \to \pi\gamma\gamma$

$$120\,\text{MeV} < m_{\gamma\gamma} < 150\,\text{MeV}$$
$$620\,\text{MeV} < m_{\gamma\gamma\pi} < 920\,\text{MeV}$$

Branching Ratio measurement

Single Fit





$$\mathcal{BR}_{MC} = 1{,}09 \times 10^{-4}$$

Signal Selection

$$\mathcal{L}_k = \frac{e^{-(n_{s,k}+n_{b,k})}}{N_k!} \prod_{i=1}^{N_k} \left\{ n_{s,k}\mathcal{P}_k^s(E_{i,k}) + n_{b,k}\mathcal{P}_k^b(E_{i,k}) \right\}$$

$$n_{s,k} = 2L_{\text{int}}\sigma_{B^+B^-}\varepsilon_k \mathcal{BR}(B \to \tau\nu) = 2L_{\text{int}}\sigma_{B^+B^-}\frac{N^{\text{reco}}(\tau \to k)}{N^{\text{gen}}(B \to \tau\nu)}\mathcal{BR}(B \to \tau\nu)$$

	SigProb	$\cos\theta_{\text{thrust.}}$	$R2$	$E_{\text{miss}} + p_{\text{miss}}$ (GeV)	p_{cand} (GeV)	Relative Error
e	0.020	1	0.66	3.75	0.4	0.305
μ	0.026	1	0.60	3.75	0.4	0.346
π	0.037	1	0.40	3.75	1.10	0.390
ρ	0.042	1	0.40	3.75	1.11	0.411

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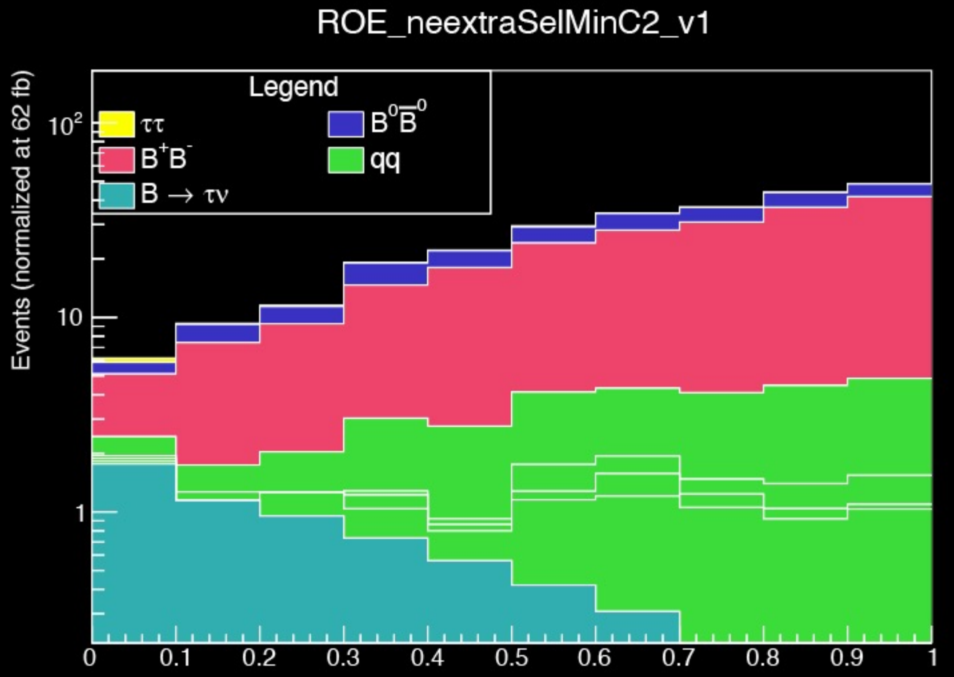
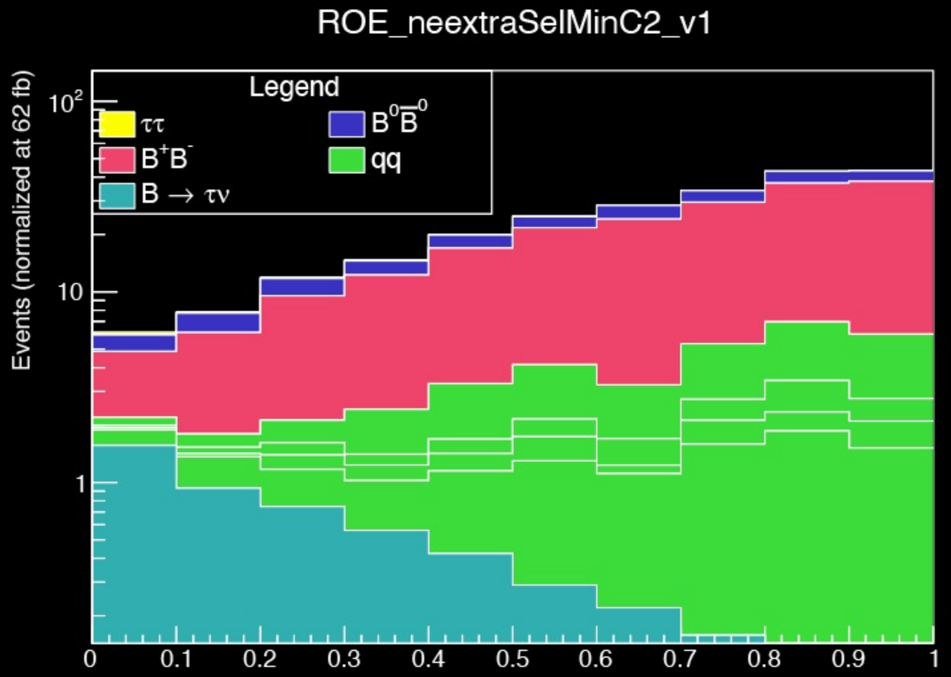
An additional cut in the ϱ channel has been implemented in the algorithm: $E_{\pi^0} > 50$ MeV

Branching Ratio measurement

Single Fit



$\tau \rightarrow e\nu\nu$



$\tau \rightarrow \mu\nu\nu$

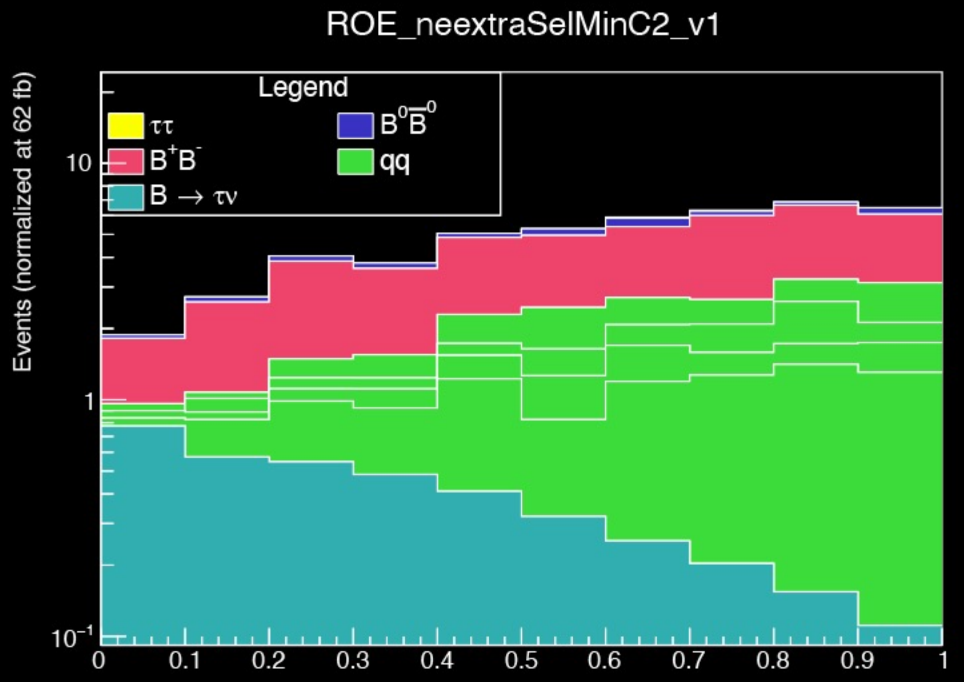
$\mathcal{BR} = (1.09 \pm 0.34) \times 10^{-4}$

$\mathcal{BR} = (1.10 \pm 0.39) \times 10^{-4}$

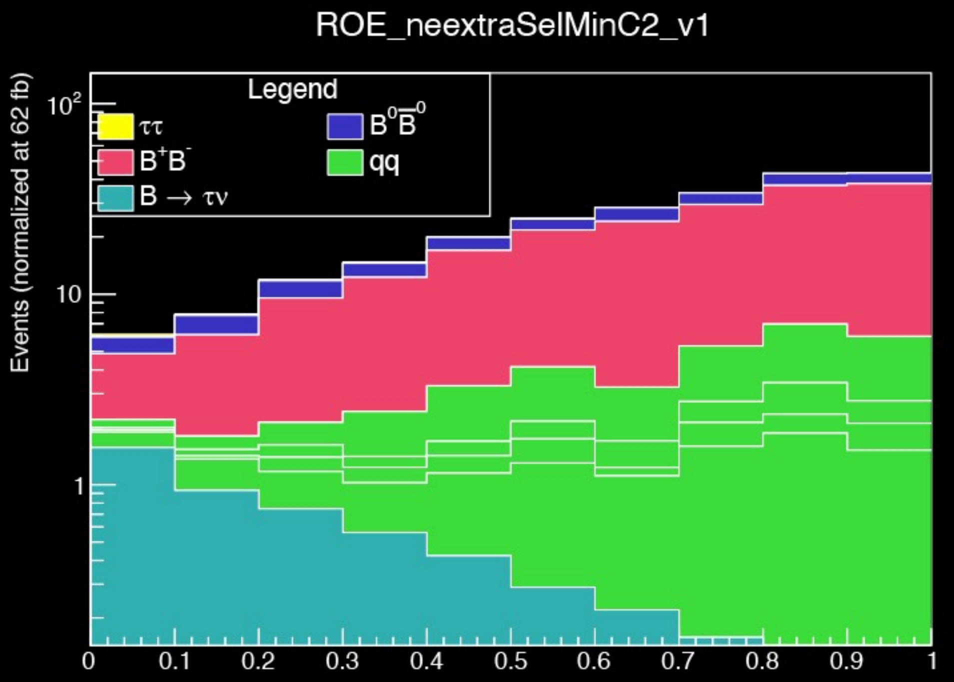
$\mathcal{BR}_{MC} = 1{,}09 \times 10^{-4}$

Branching Ratio measurement

Single Fit



$\tau \to \pi\nu$



$\tau \to \rho\nu$

$$\mathcal{BR} = (1.09 \pm 0.43) \times 10^{-4}$$

$$\mathcal{BR} = (1.10 \pm 0.47) \times 10^{-4}$$

$$\mathcal{BR}_{MC} = 1{,}09 \times 10^{-4}$$

Branching Ratio measurement

Simultaneous Fit

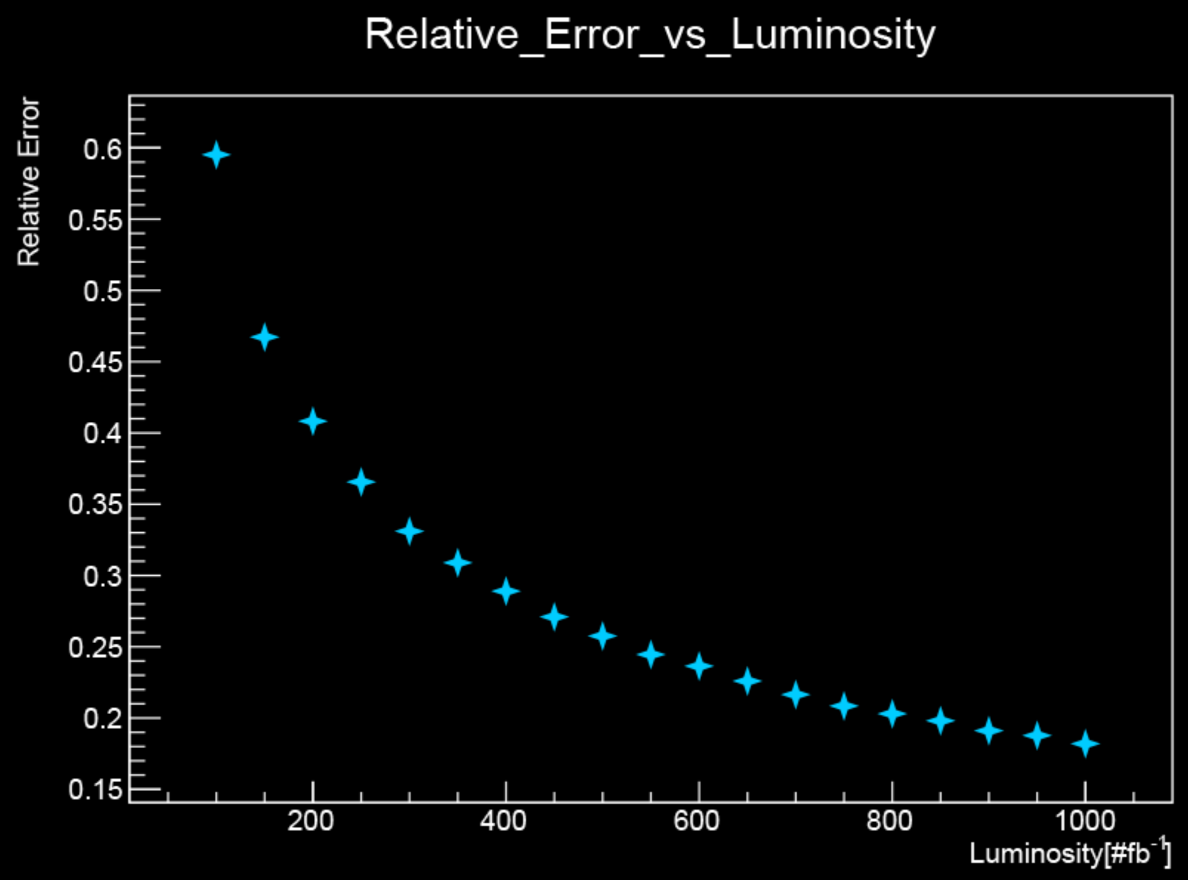
$$\mathcal{L} = \prod_{k=1}^{4} \frac{e^{-(n_{s,k}+n_{b,k})}}{N_k!} \prod_{i=1}^{N_k} \left\{ n_{s,k}\mathcal{P}_k^s(E_{i,k}) + n_{b,k}\mathcal{P}_k^b(E_{i,k}) \right\}$$

$$\mathcal{BR} = (1{,}09 \pm 0{,}20) \times 10^{-4}$$

$$\mathcal{BR}_{MC} = 1{,}09 \times 10^{-4}$$

Branching Ratio measurement

Simultaneous Fit



To do list:

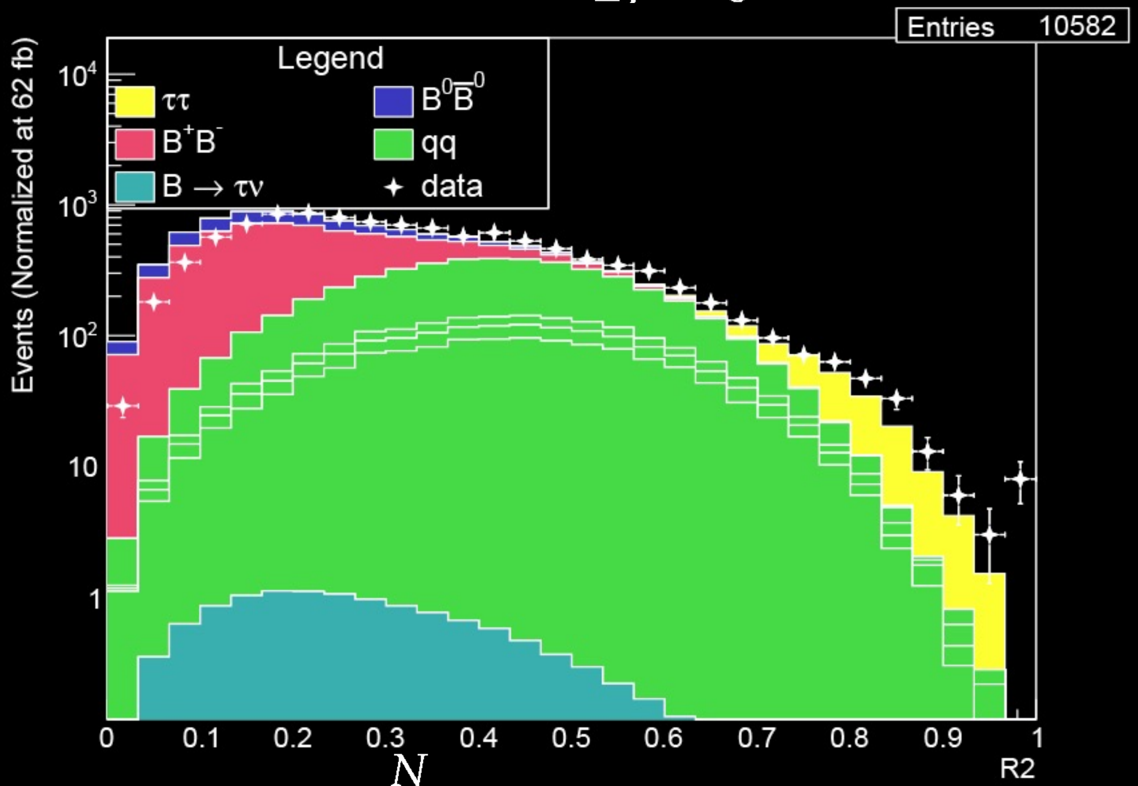
- Study and better undertand missing E/ p/ θ/ miss vs E_{ECL} correlation;
- Investigate more robust optimization algorithm (w.r.t. scan the variables) and more aggressive selection criteria (ML based);
- Study B^+B^- background peaking at E_{ECL} using "signal MC" of most abundant decay modes;

Backup

Variables

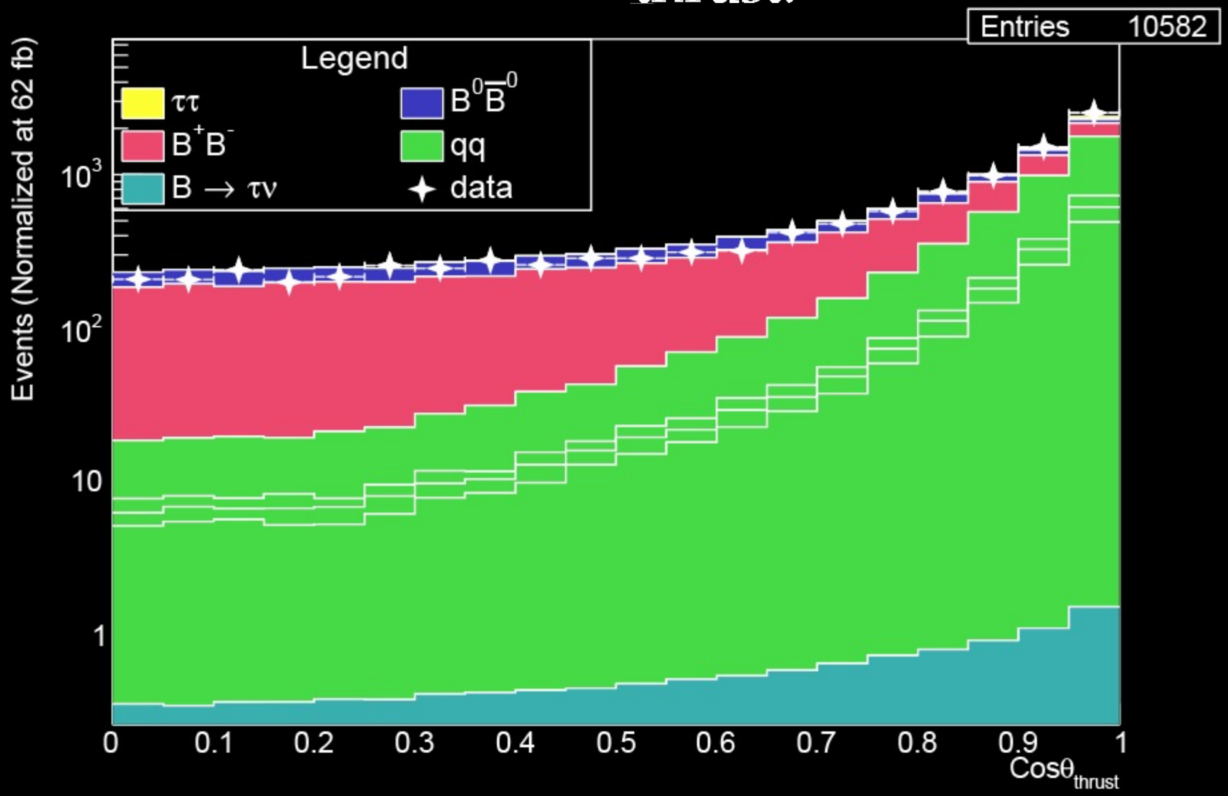
Event geometric distribution

$$R2 = H_2/H_0$$



$$H_l = \sum_{i,j}^{N} |p_i|\,|p_j|\,P_l(\cos\theta_{i,j})$$

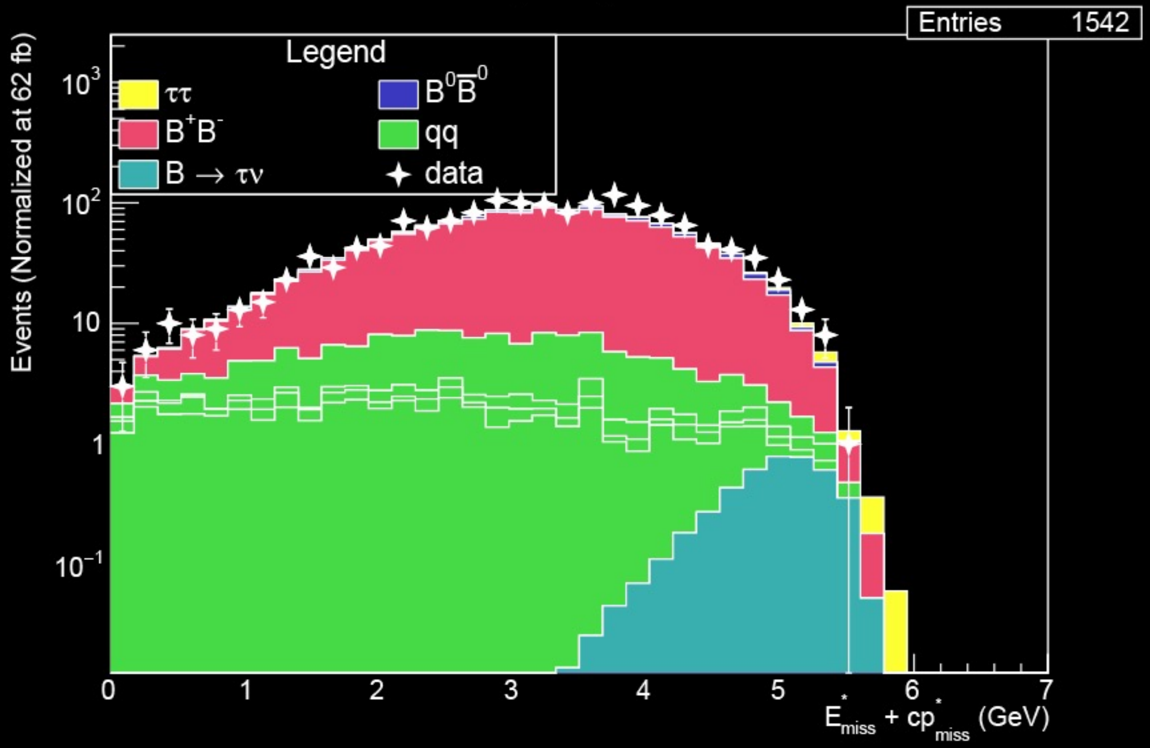
$$\cos\theta_{\text{thrust.}}$$



Variables

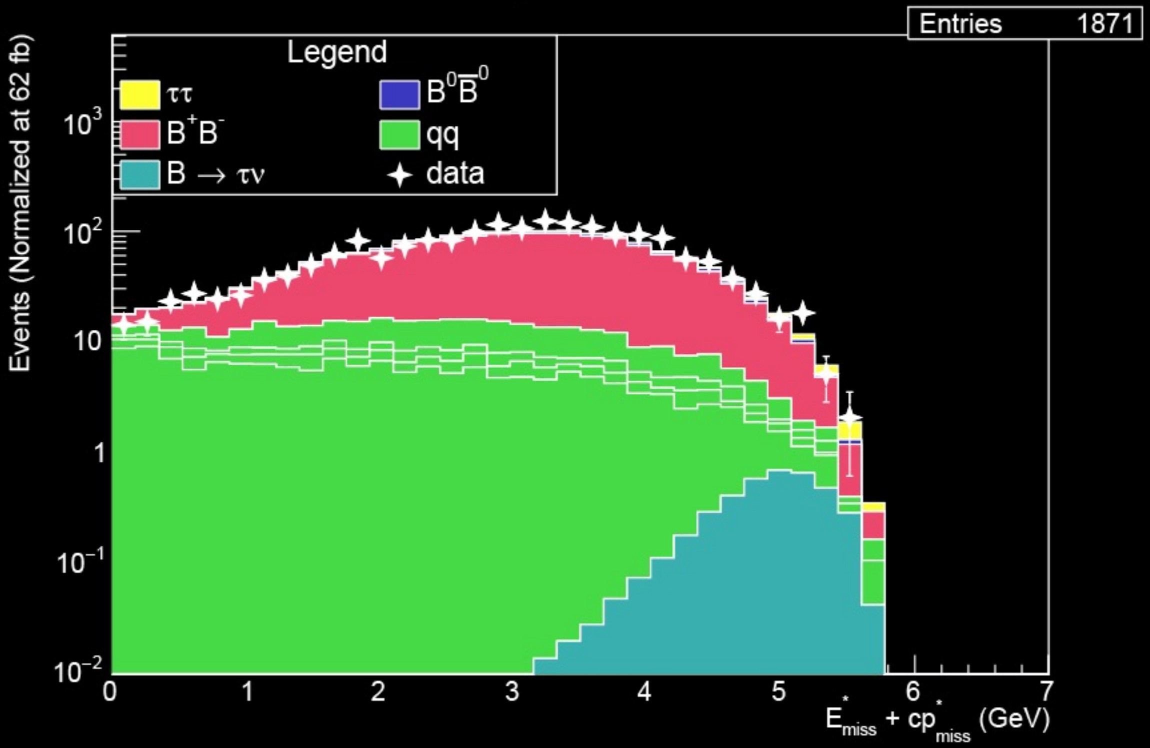
Lepton kinematics

$E_{\text{miss}} + p_{\text{miss}}$



$\tau \to e\nu\nu$

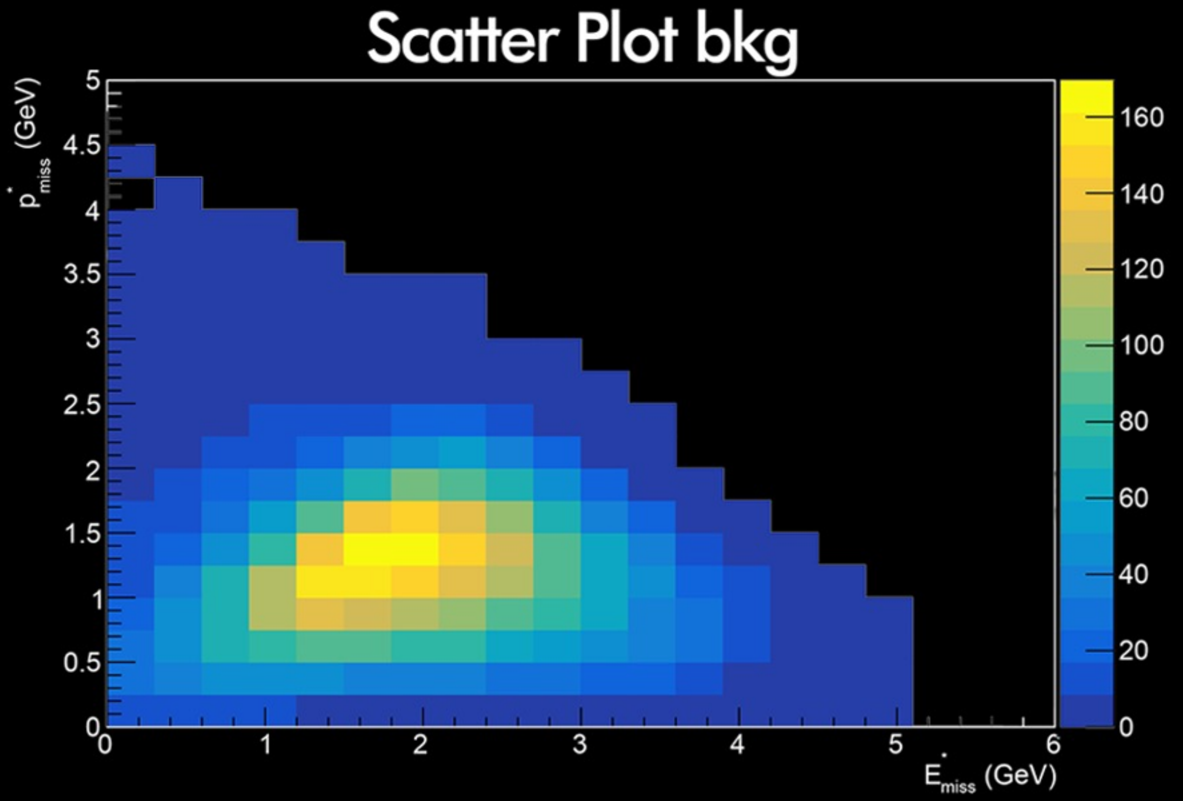
$E_{\text{miss}} + p_{\text{miss}}$

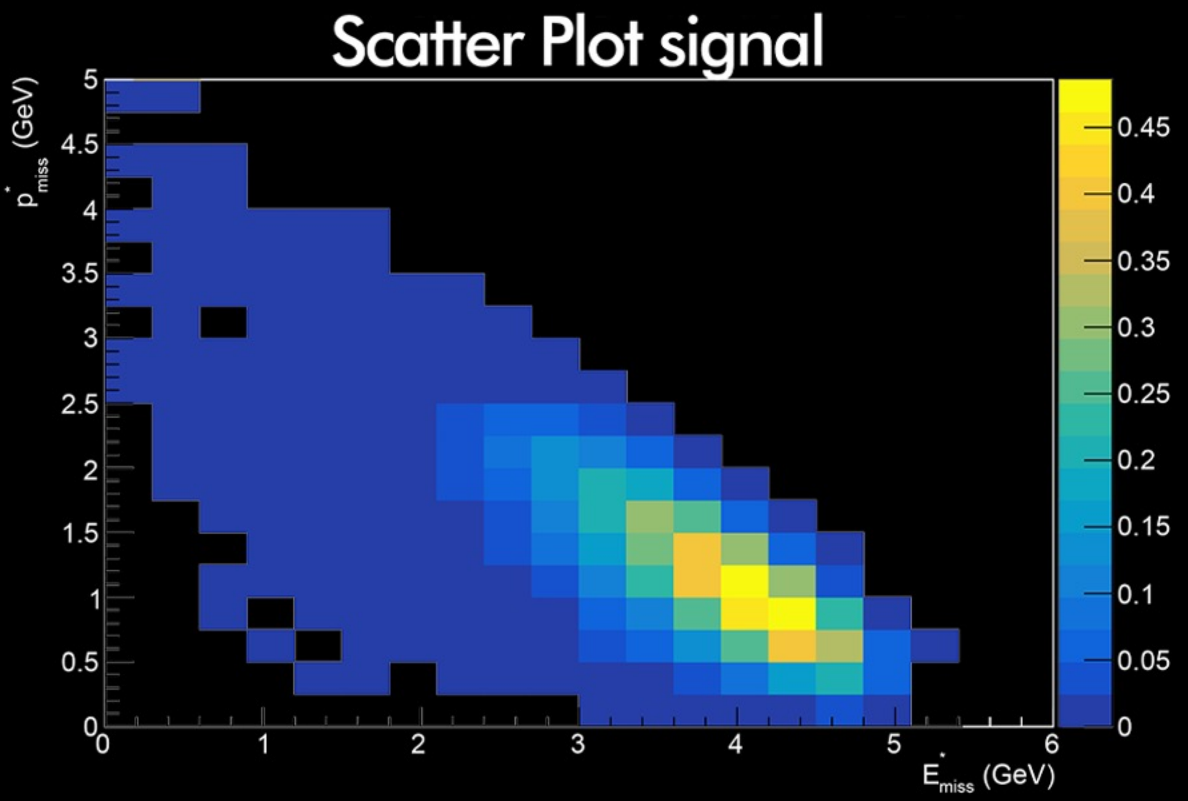


$\tau \to \mu\nu\nu$

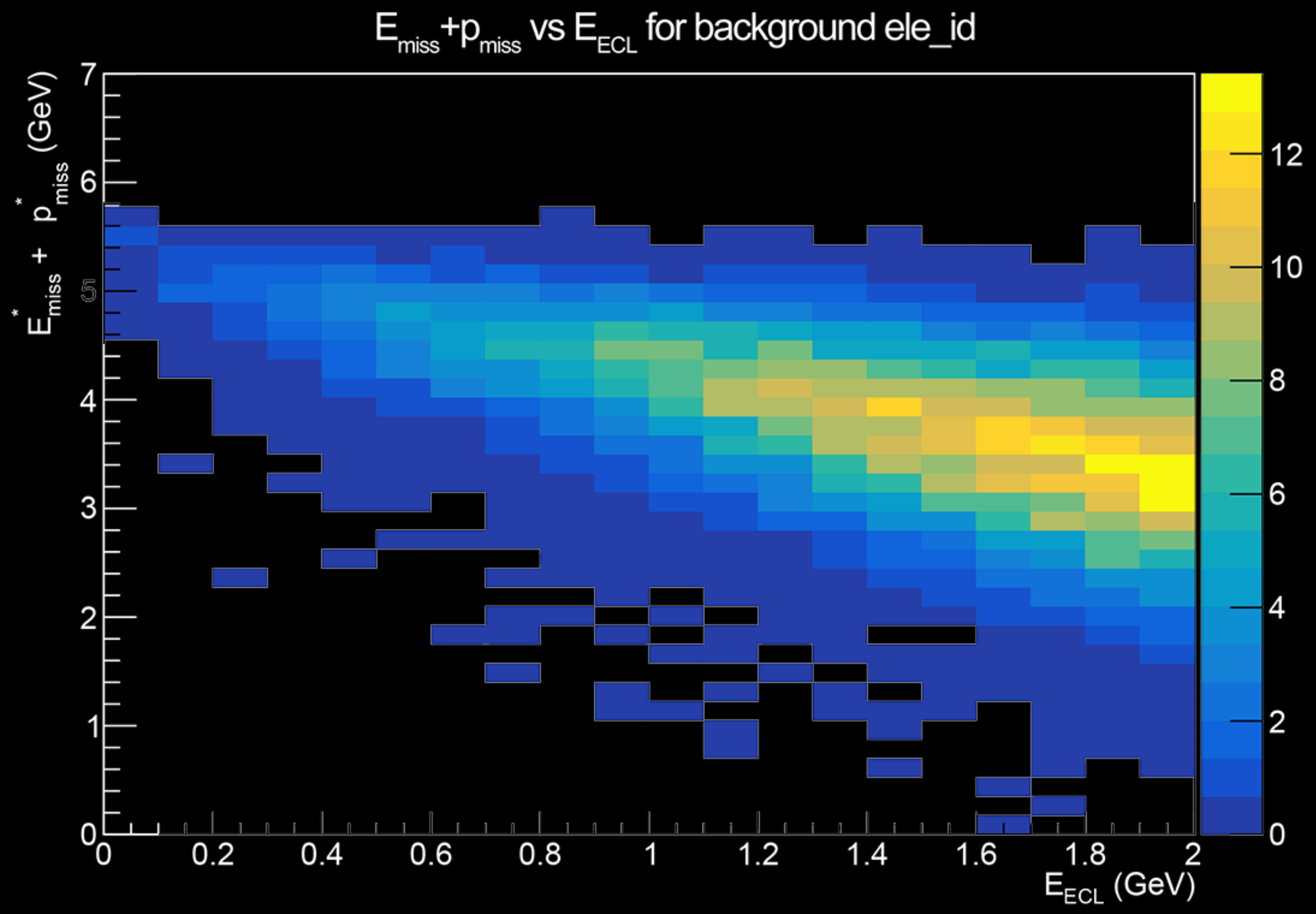
Variables

Lepton kinematics





Signal Selection

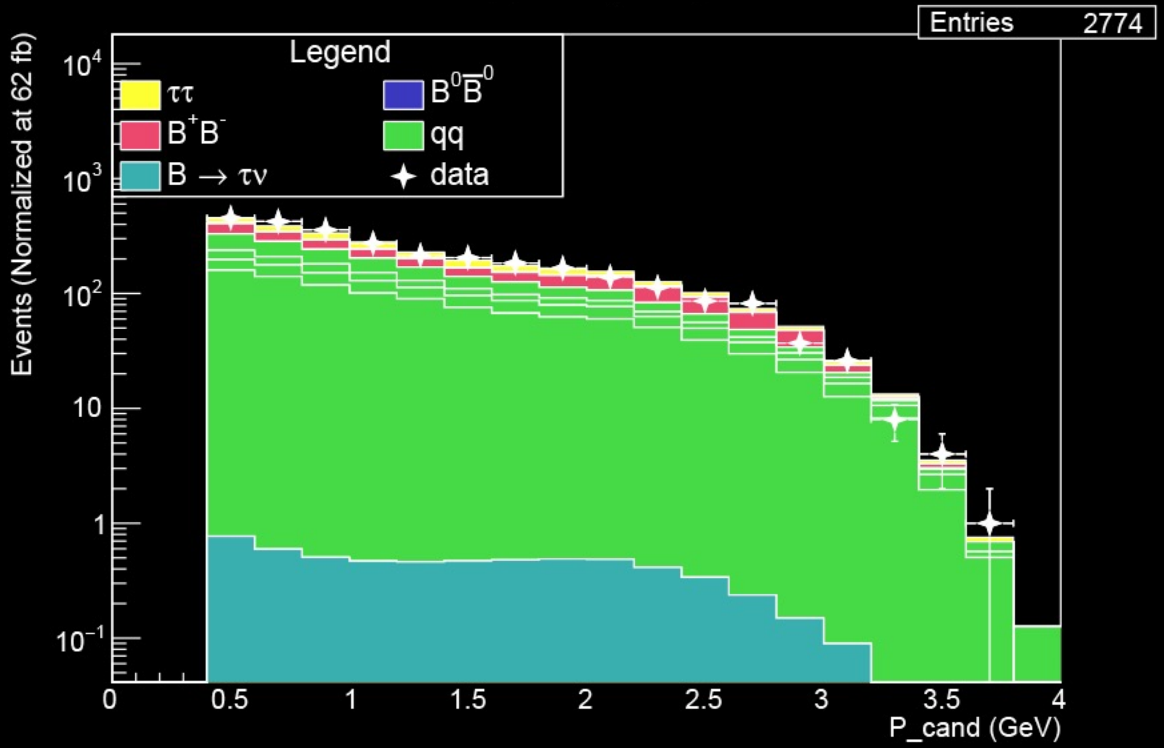


Missing Energy + Missing P is correlated with E_{extra}

Variables

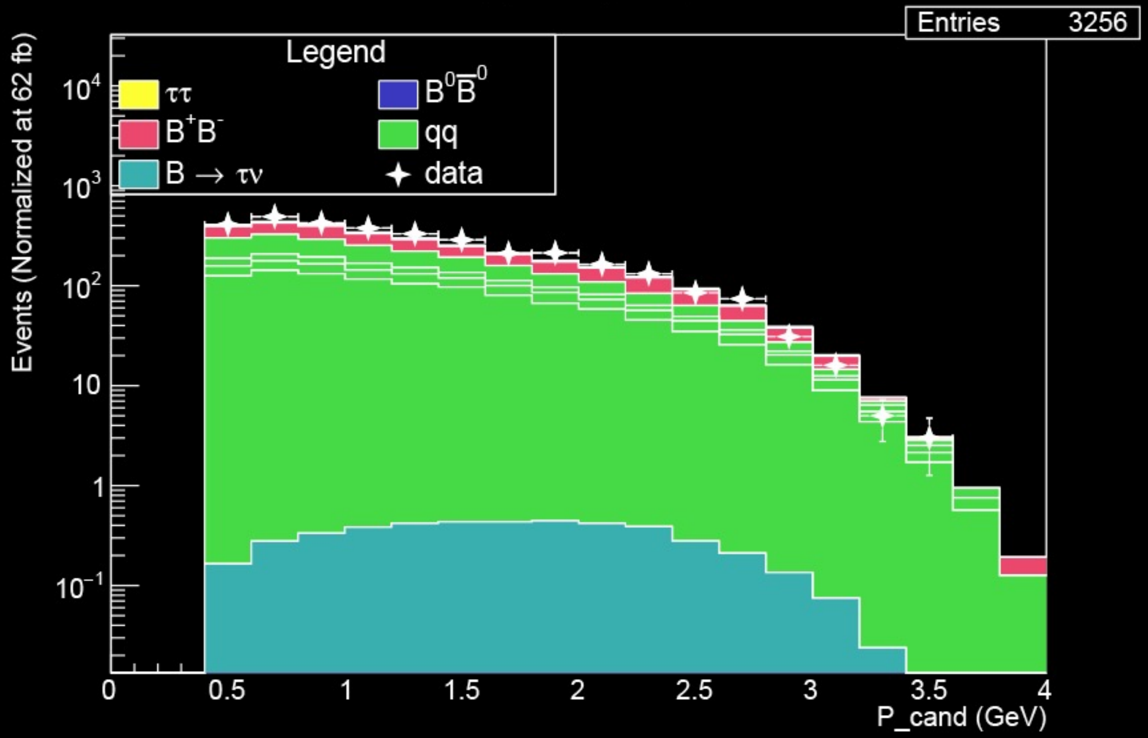
Hadron kinematics

P_{cand}



$\tau \rightarrow \pi\nu$

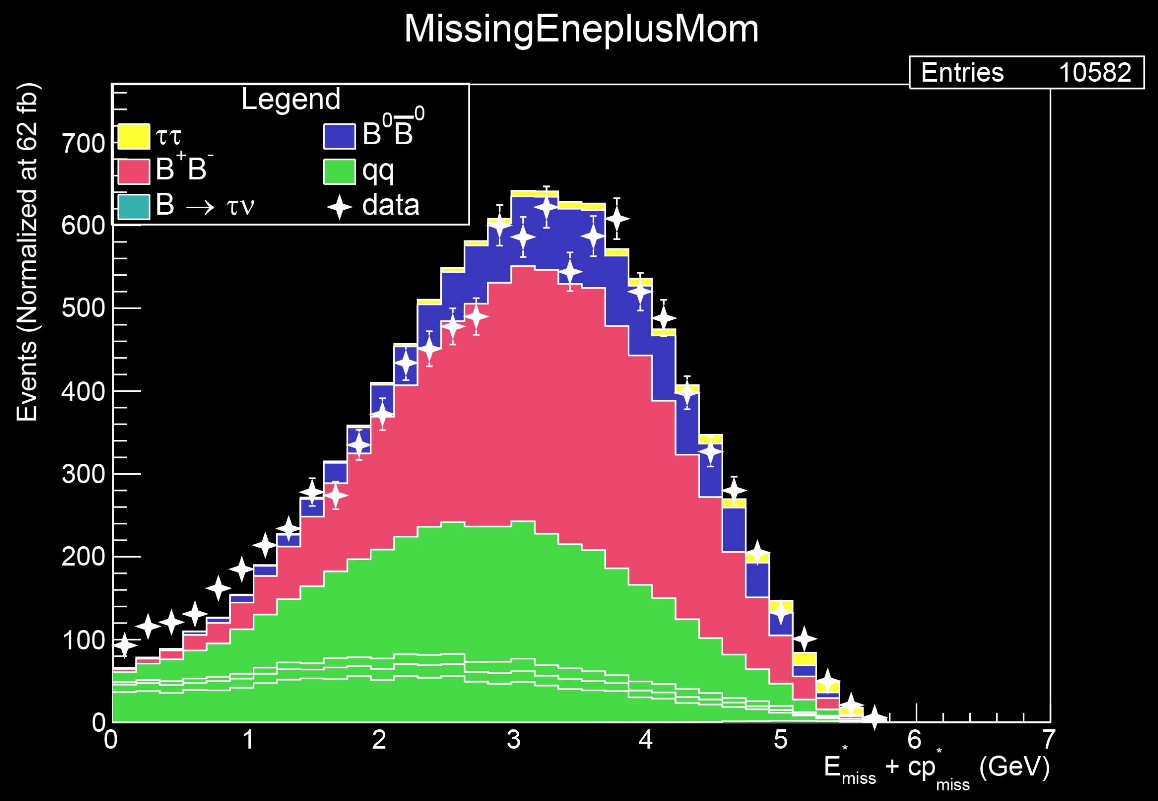
P_{cand}

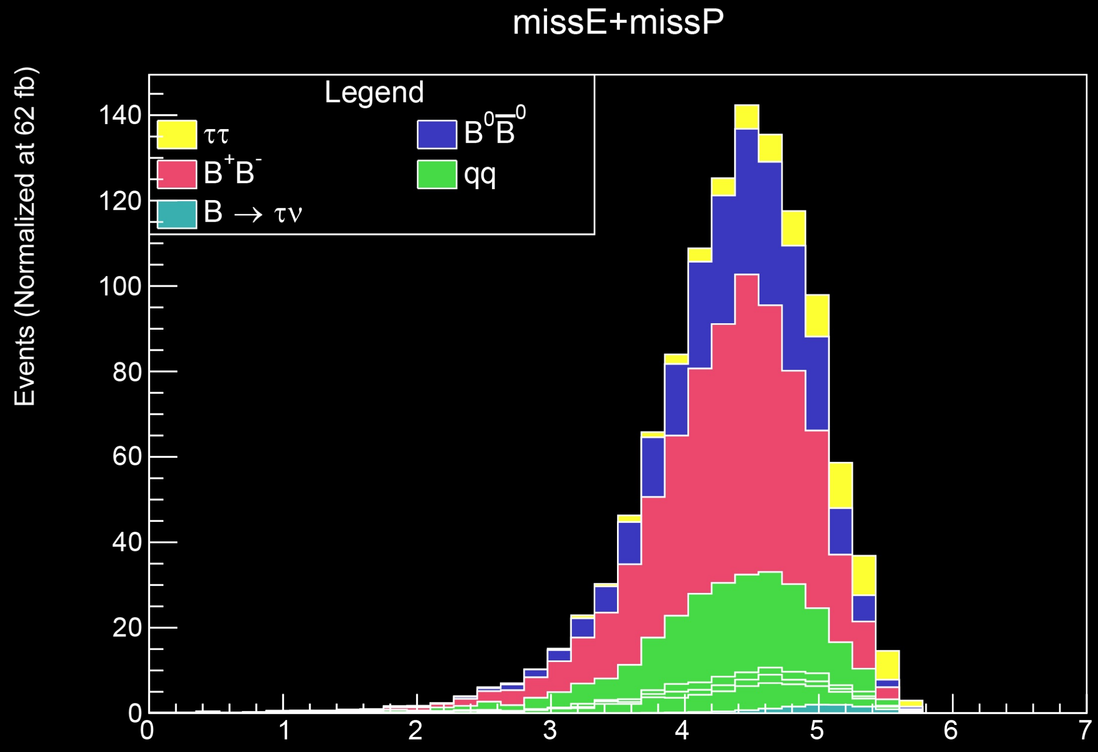


$\tau \rightarrow \rho\nu$

Signal Selection

Missing Energy + Missing P is correlated with E_{extra}

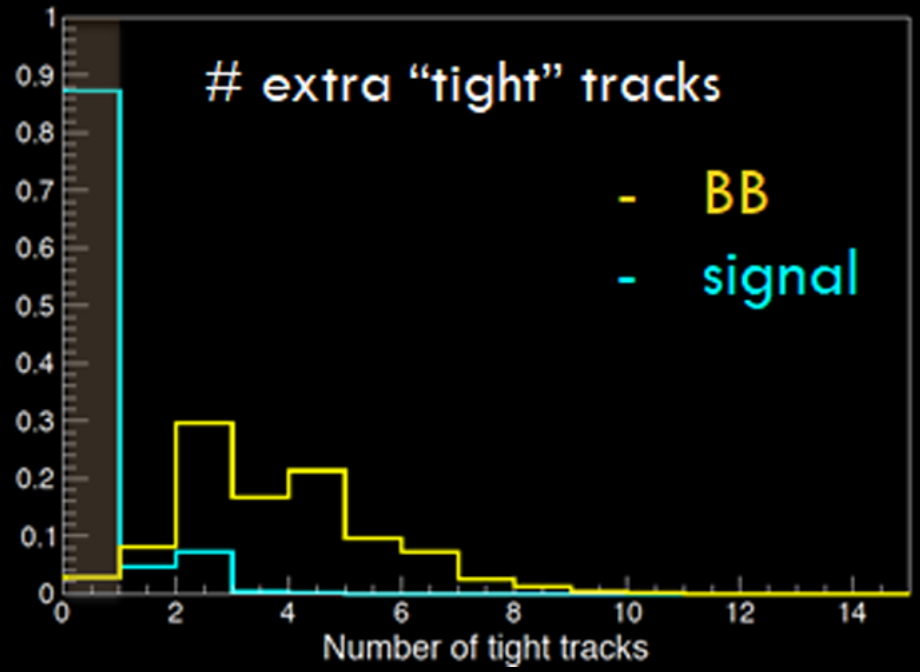


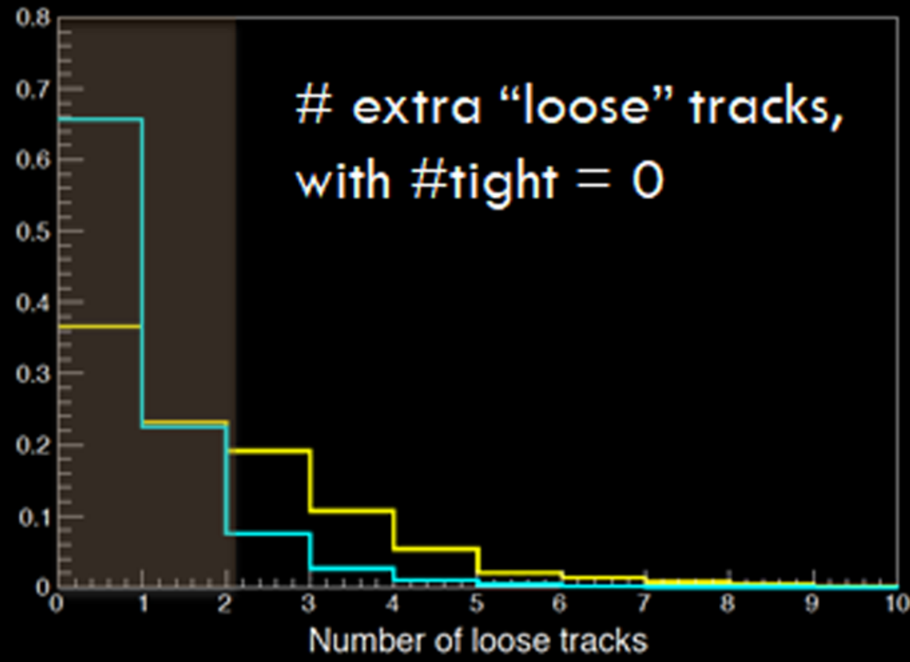


$E_{ECL} < 1\ GeV$

Signal Selection

Missing Energy + Missing P is correlated with E_{extra}



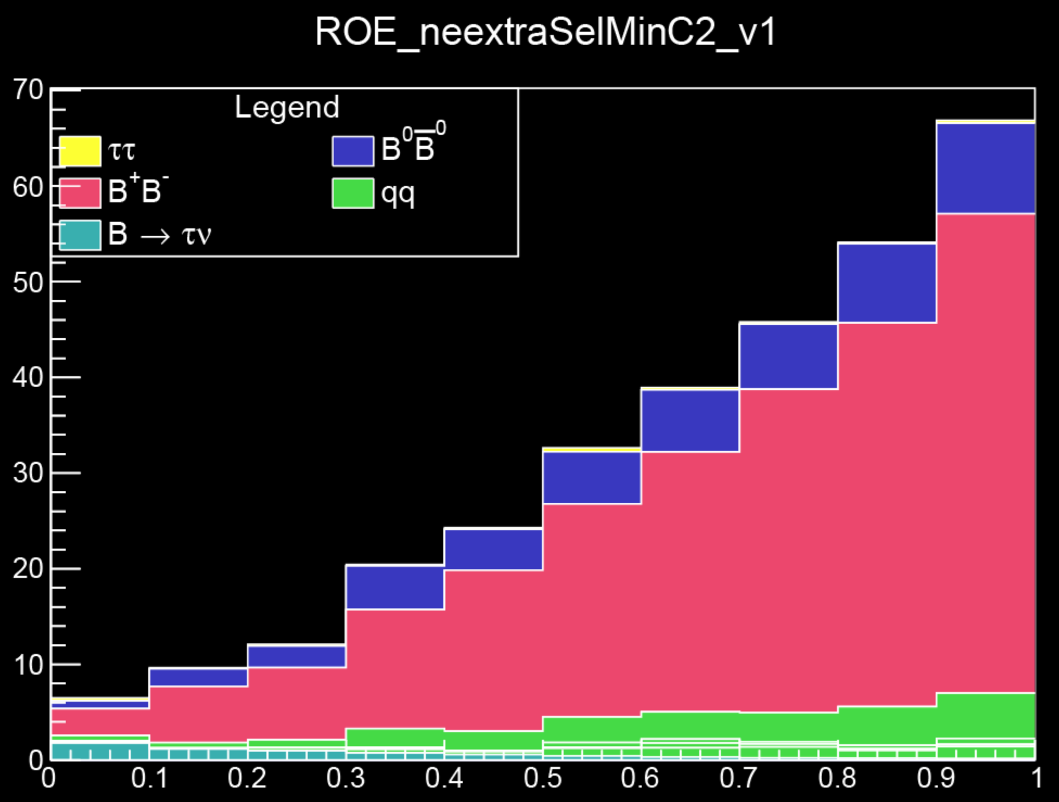


Definitions:

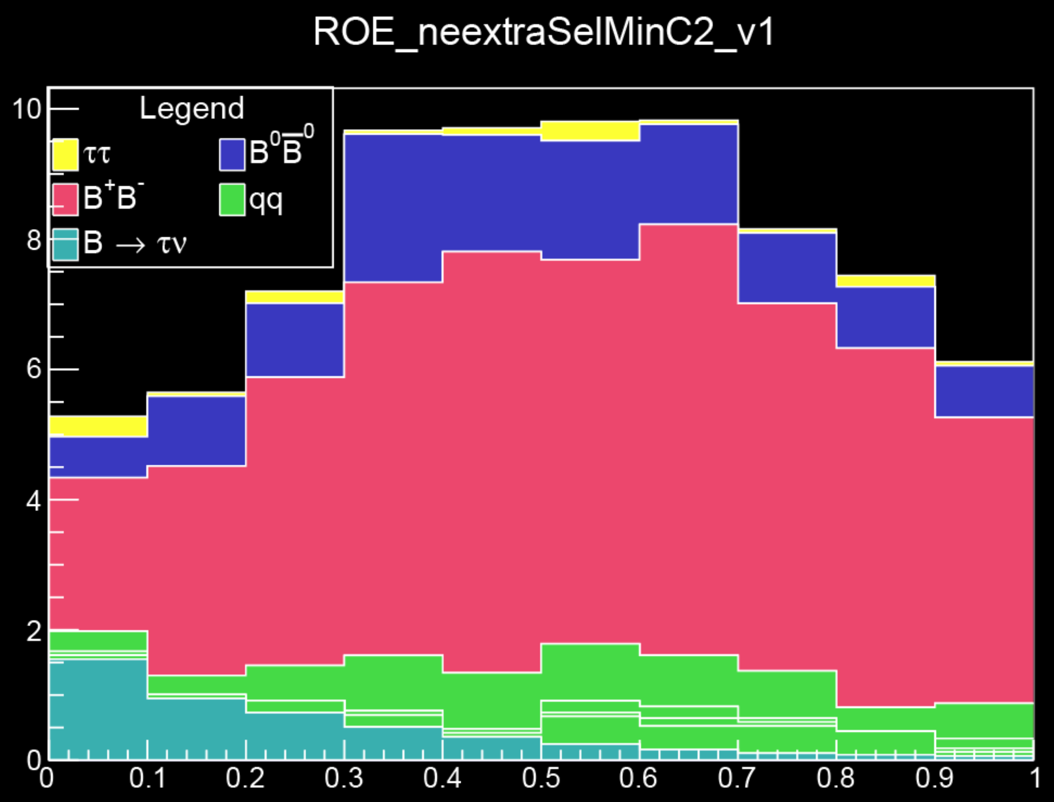
- Loose extra tracks: p>50 MeV
- Tight extra tracks: p>100 MeV, |d0| < 0.5 cm, |z0| < 2 cm

Under study !

Optimization Algorithm



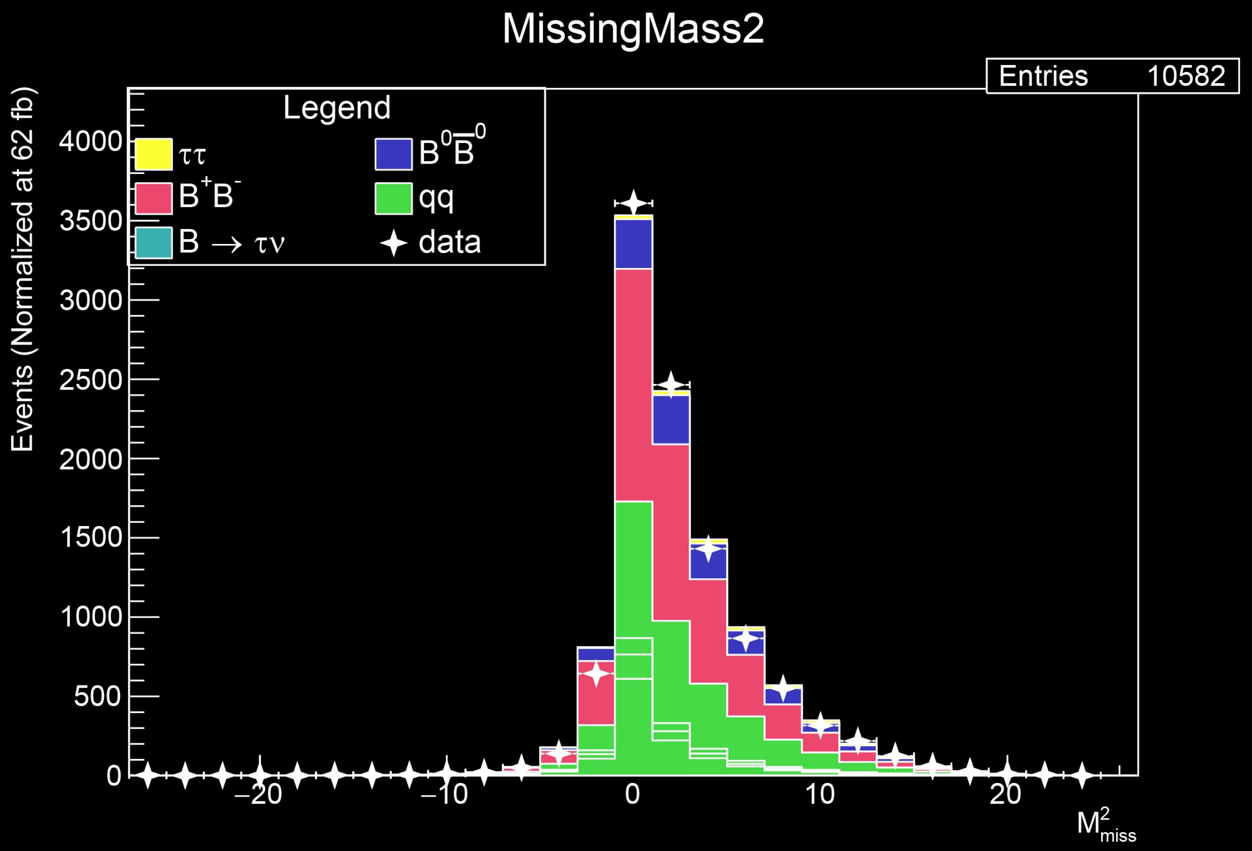
E_{ECL} *without cut*

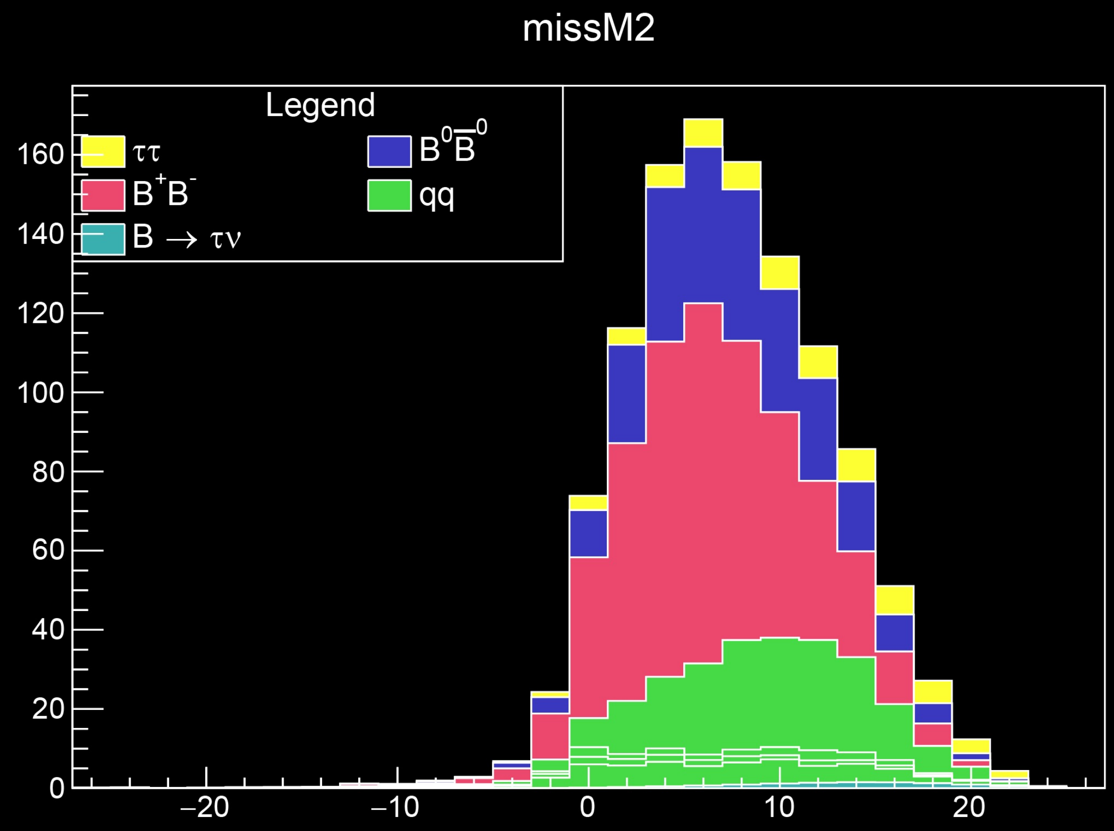


E_{ECL} *with cut*

Signal Selection

Missing Energy + Missing P is correlated with E_{extra}

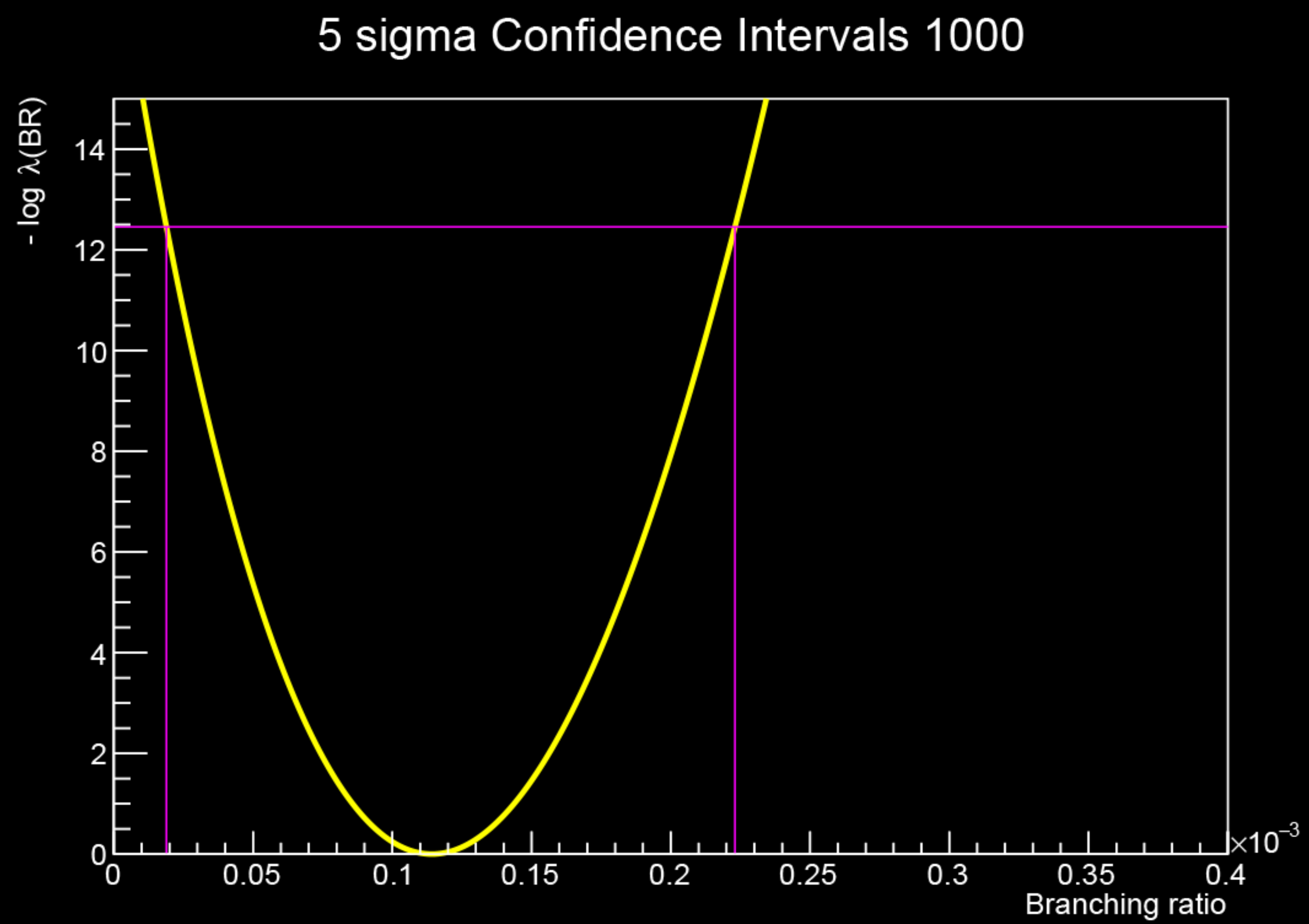




$E_{ECL} < 1\ GeV$

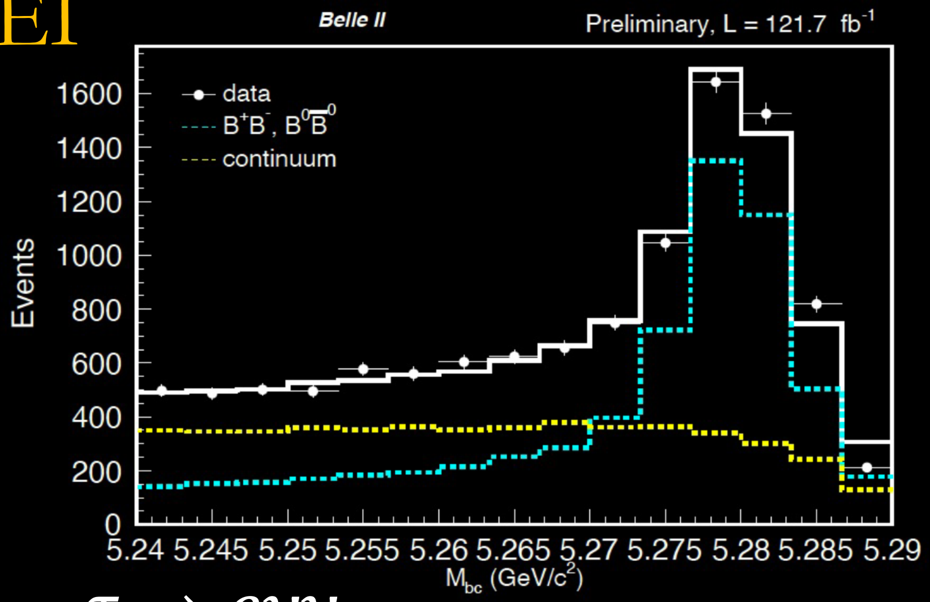
Branching Ratio measure study

Simultaneous Fit

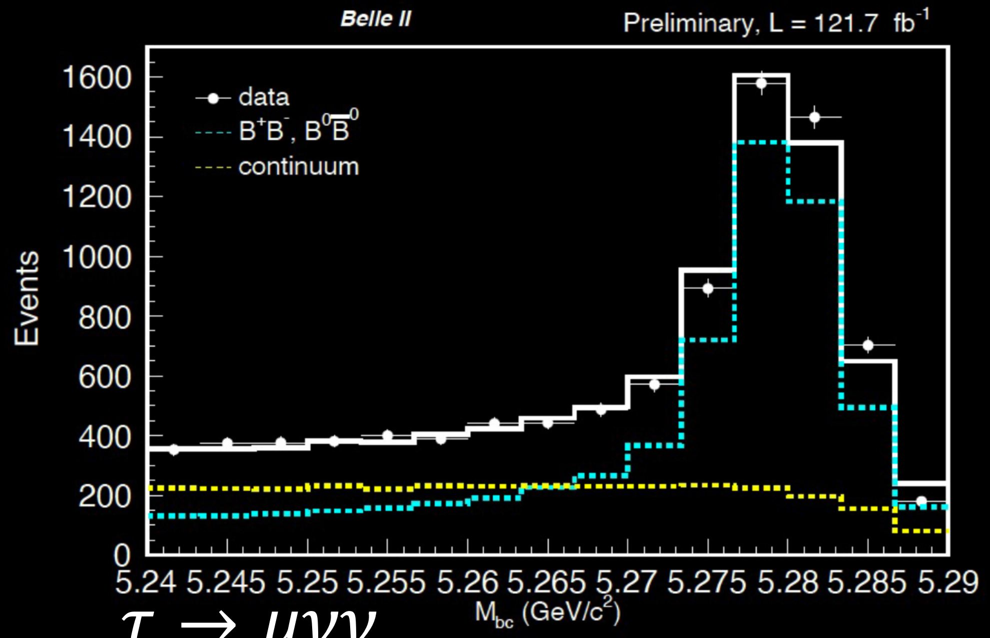


Variables

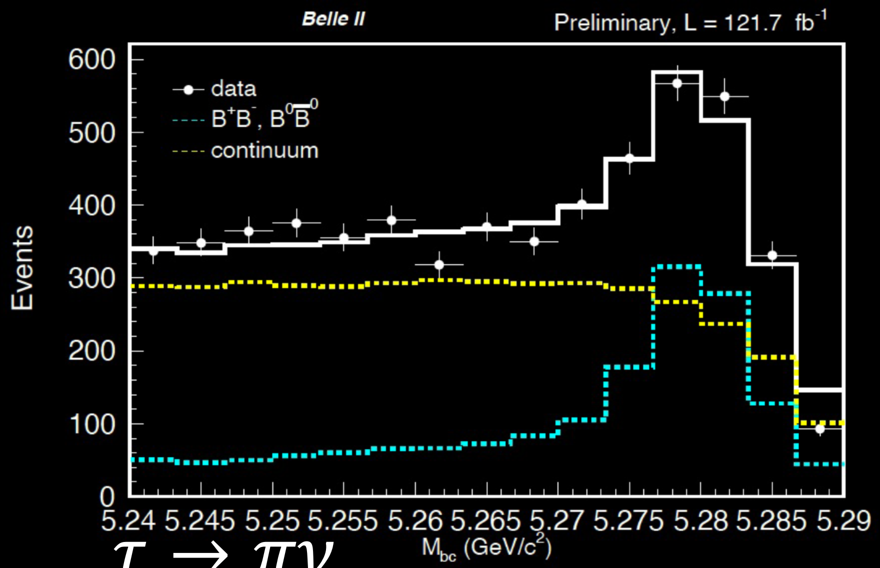
FEI



$\tau \to e\nu\nu$



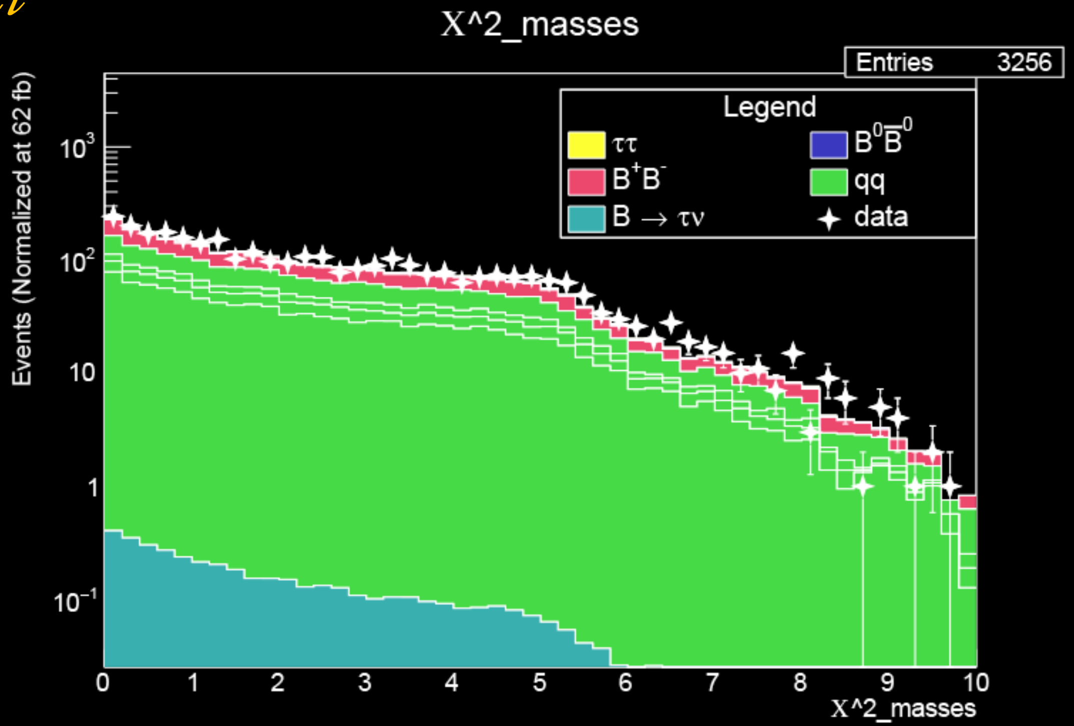
$\tau \to \mu\nu\nu$

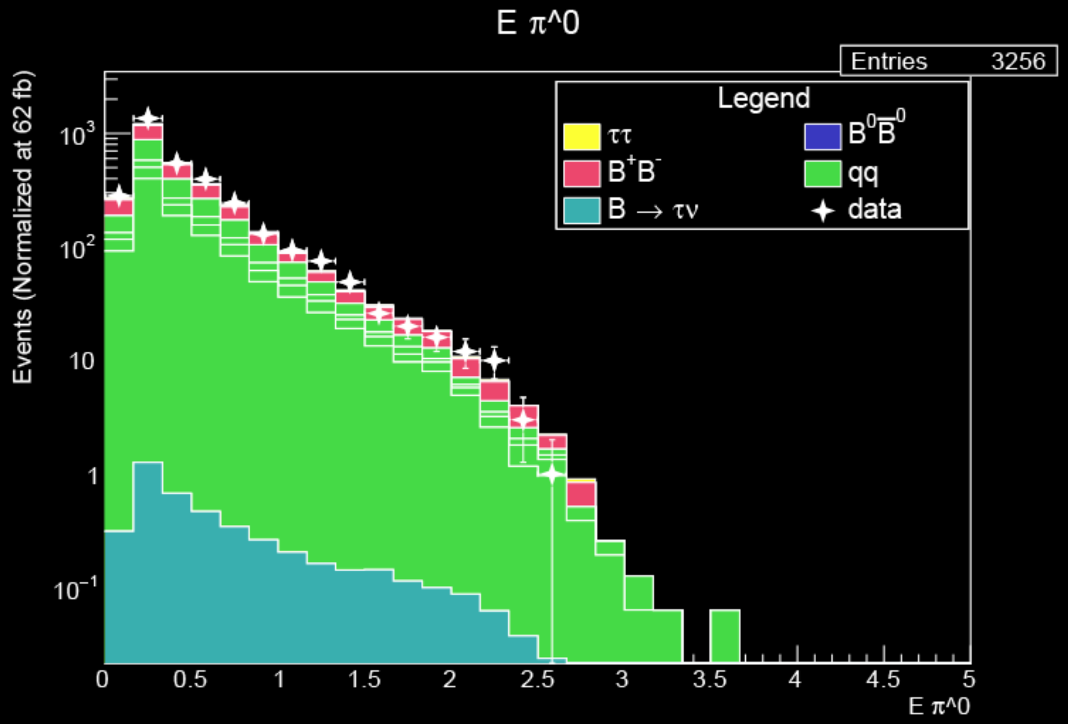


$\tau \to \pi\nu$

Optimization Algorithm

Fit





$$\chi^2_{mm} = \frac{(m_\rho - m_\rho^{(\text{true})})^2}{\sigma^2_{m_\rho}} + \frac{(m_{\pi^0} - m_{\pi^0}^{(\text{true})})^2}{\sigma^2_{m_{\pi^0}}}$$

$$E_{\pi^0} = E_\gamma^{(1)} + E_\gamma^{(2)}$$

Optimization Algorithm

Fit

$\chi^2_{mm} = \frac{(m_\rho - m_\rho^{(\text{true})})^2}{\sigma^2_{m_\rho}} + \frac{(m_{\pi^0} - m_{\pi^0}^{(\text{true})})^2}{\sigma^2_{m_{\pi^0}}}$	$E_{\pi^0} = E_\gamma^{(1)} + E_\gamma^{(2)}$

Risultato

Nessun taglio su χ^2_{mm}	$E_{\pi^0} > 50\ \text{MeV}$

Branching Ratio measure study

Simultaneous Fit