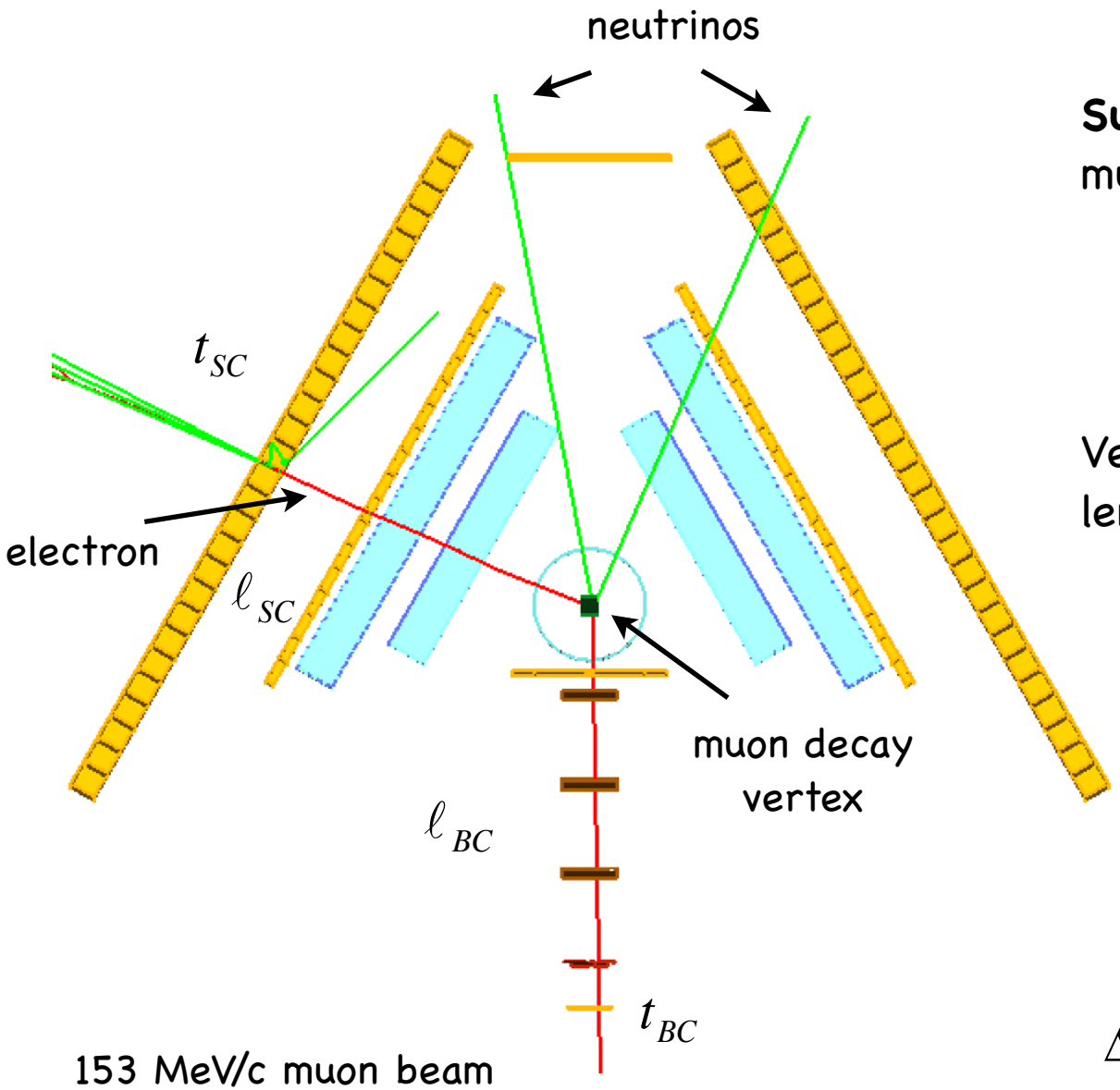
MUSE Simulations
Muon Decay In Flight

Steffen Strauch
University of South Carolina

MUSE Collaboration Meeting,
Washington, DC, Oct. 8-9, 2015

Muon decay in flight

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$



153 MeV/c muon beam

Suppression of background from muon decay

- Target vertex cut
- Time of flight

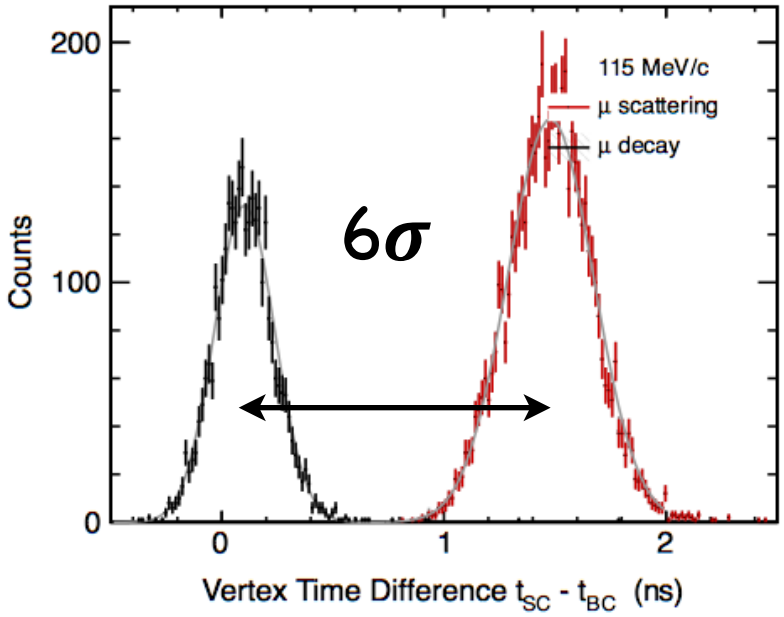
Vertex-time difference from path lengths and measured times

$$\Delta t = \left(t_{SC} - \frac{\ell_{SC}}{c} \right) - \left(t_{BC} - \frac{\ell_{BC}}{\beta_\mu c} \right)$$

assuming electron after muon decay, $\beta_e = 1$

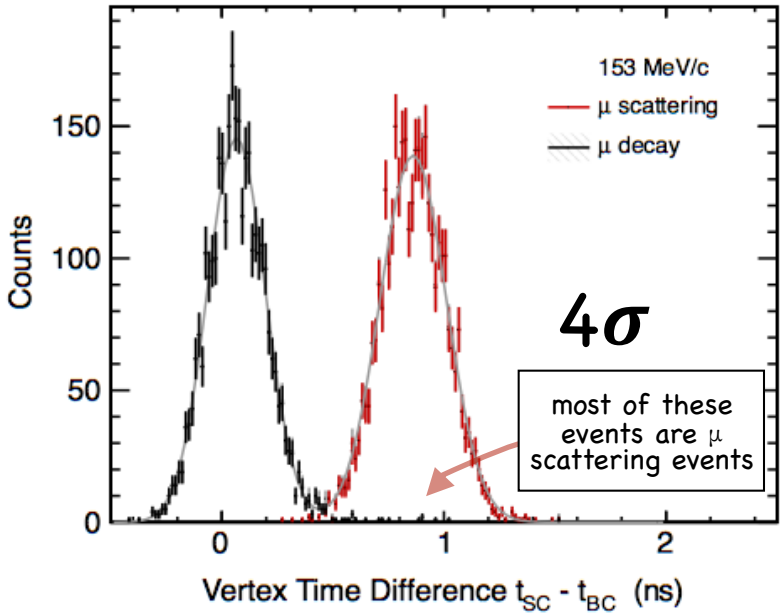
$\Delta t \approx 0$, for muon decay in target

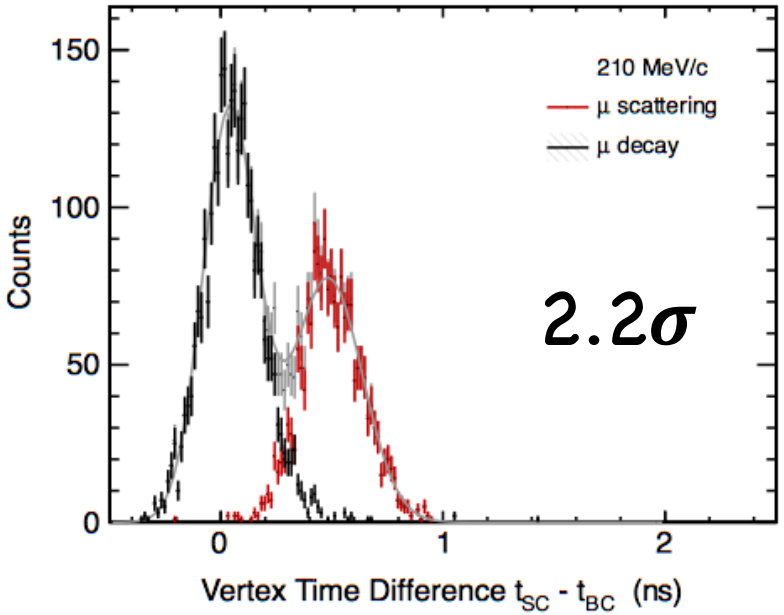
Muon decay in flight — vertex-time difference



Detection of muon decay by path-length corrected time-of-flight:

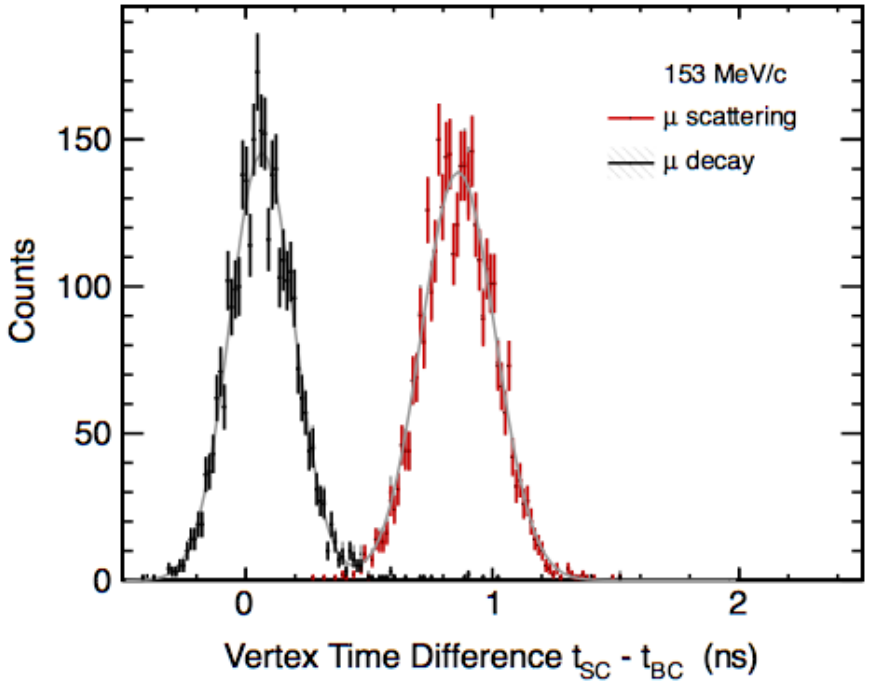
- time-of-flight walls (t_{SC}, σ = 50 ps)
- upstream beam Cherenkov (t_{BC}, σ = 100 ps)



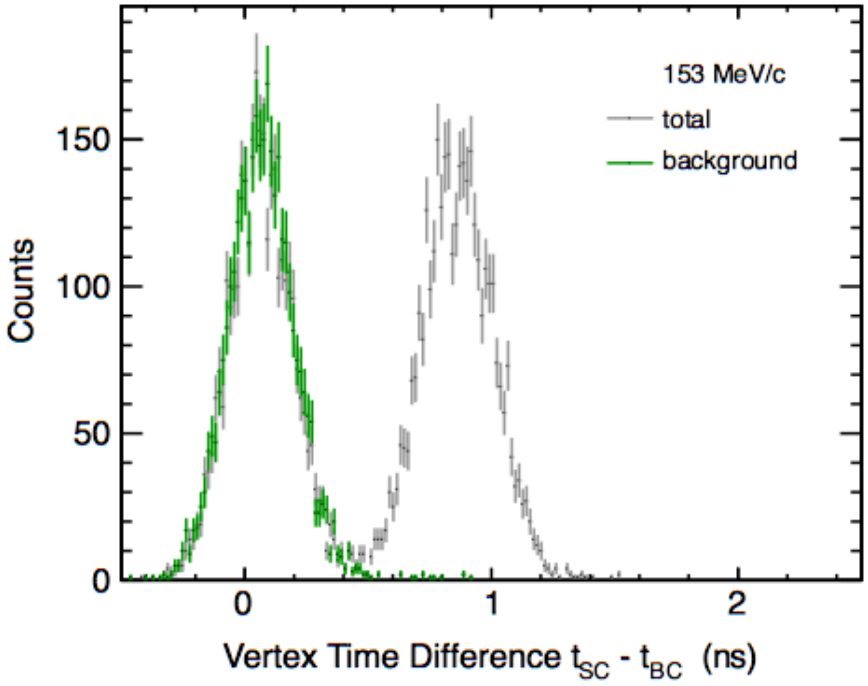


Direct measurement of the muon decay in flight background

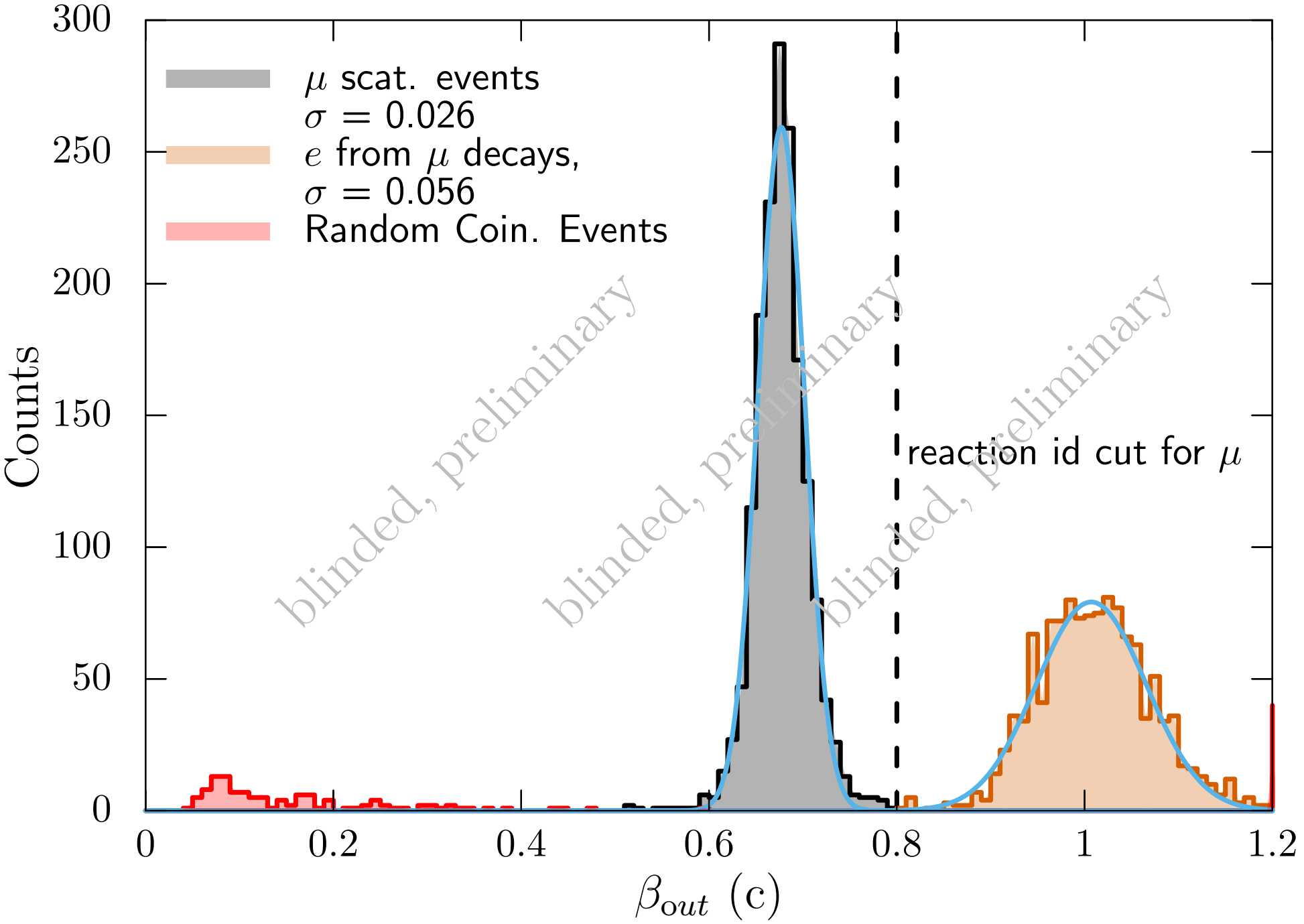
Muon decay flagged in simulation

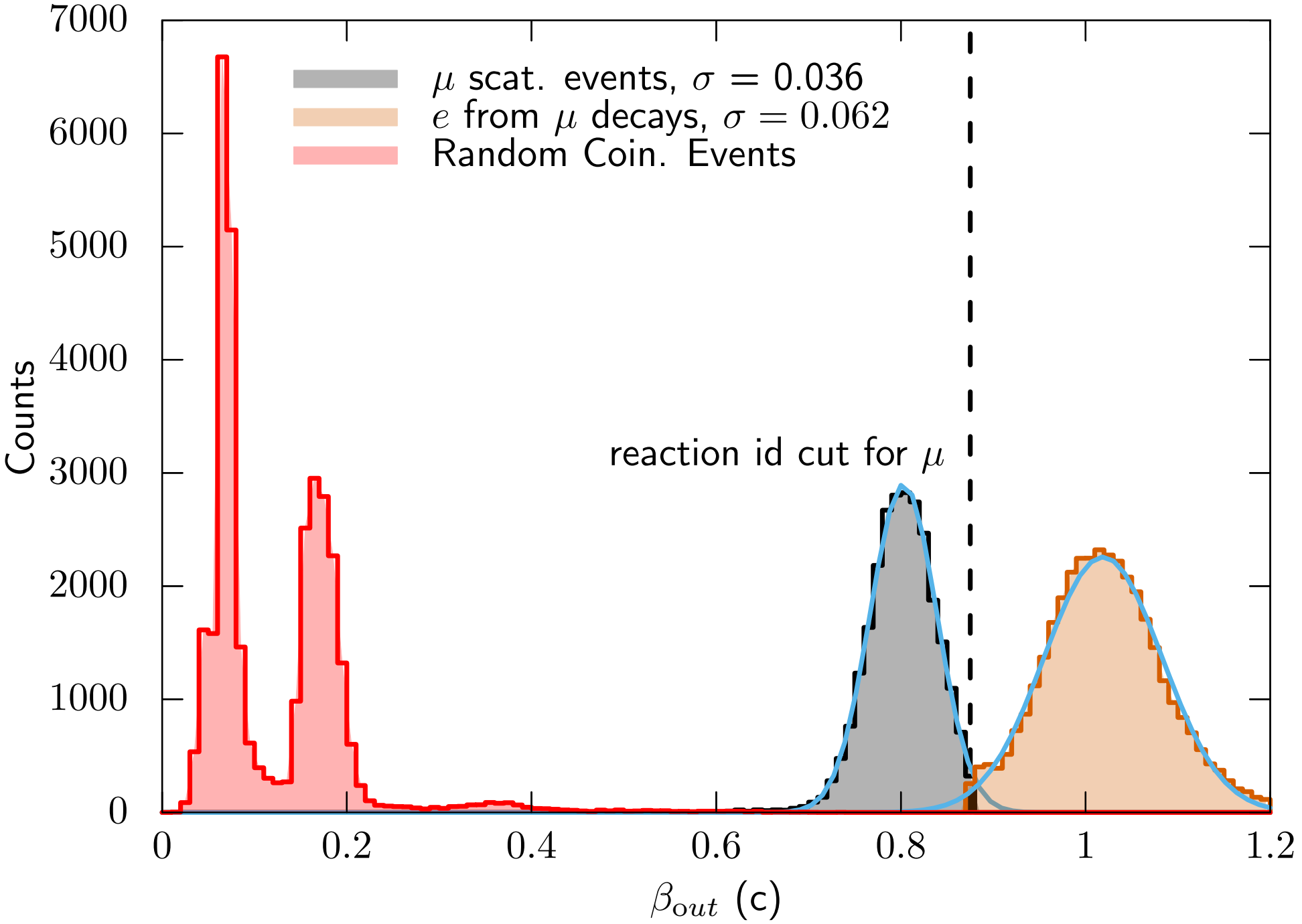


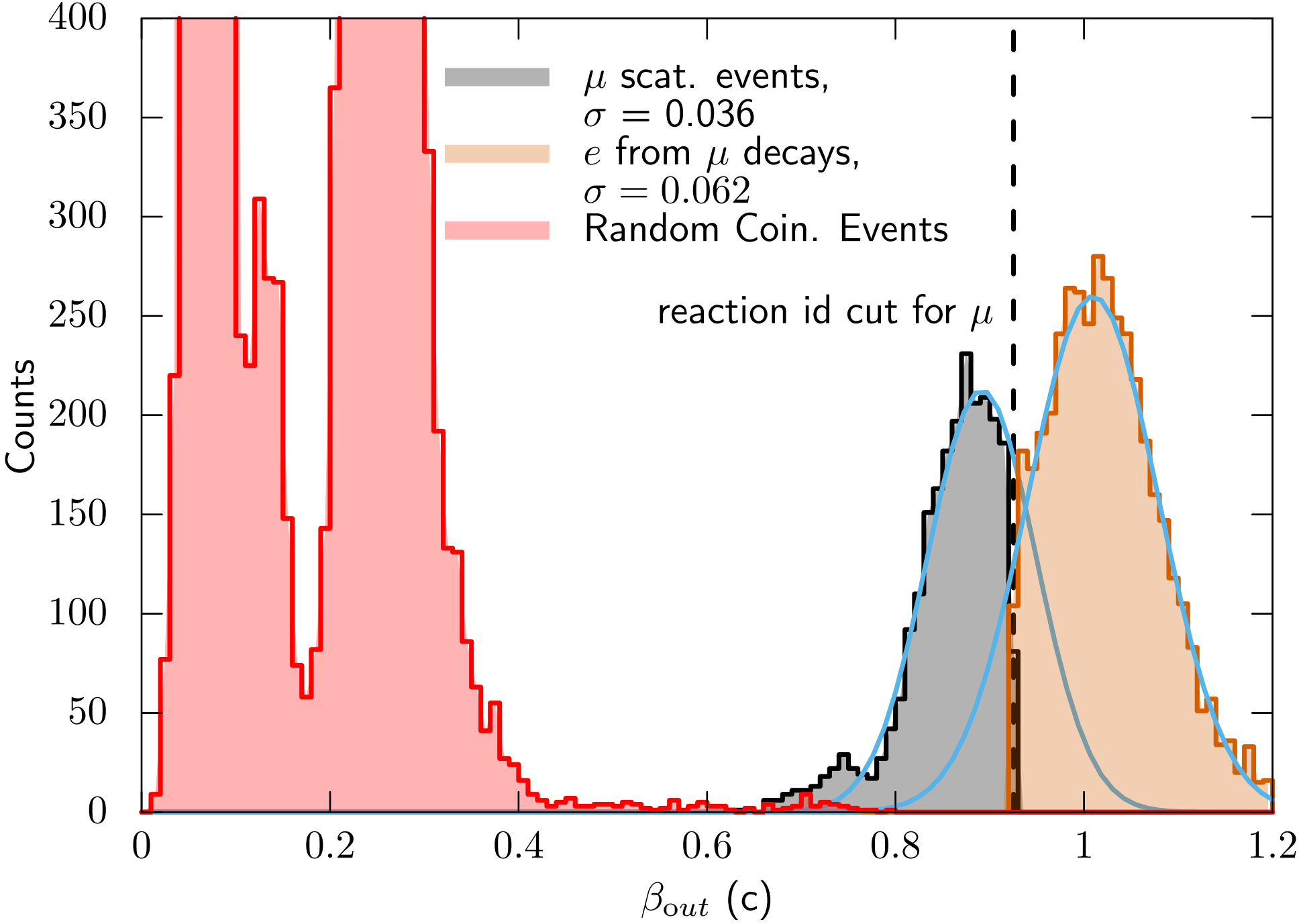
Muon decay distribution measured



In situ measurement of muon decay-in-flight background from events upstream & downstream of the target.


300
250
200
150
100
50
0
Counts
0
0.2
0.4
0.6
0.8
1
1.2
β_{out} (c)
μ scat. events
$\sigma = 0.026$
e from μ decays,
$\sigma = 0.056$
Random Coin. Events
reaction id cut for μ
blinded, preliminary
blinded, preliminary
blinded, preliminary


μ scat. events, $\sigma = 0.036$
e from μ decays, $\sigma = 0.062$
Random Coin. Events
reaction id cut for μ
Counts
β_{out} (c)
0
1000
2000
3000
4000
5000
6000
7000
0
0.2
0.4
0.6
0.8
1
1.2


μ scat. events,
$\sigma = 0.036$
e from μ decays,
$\sigma = 0.062$
Random Coin. Events
reaction id cut for μ
Counts
β_{out} (c)
0
50
100
150
200
250
300
350
400
0
0.2
0.4
0.6
0.8
1
1.2

High fraction of scattering events are detectable without significant background contribution

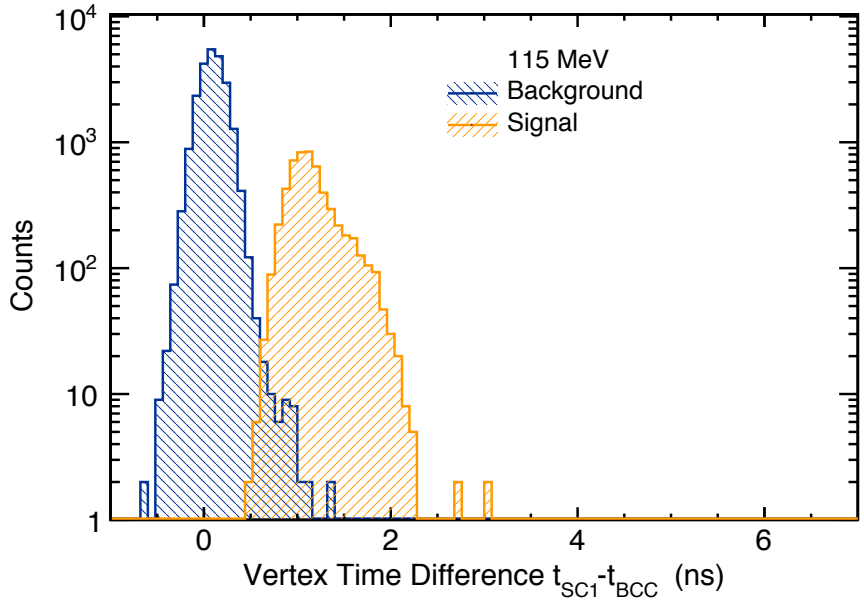
μ momentum	Vertex-time difference cut on scattering event distribution	
	$-\sigma < t_{SC} - t_{BC}$	$-3\sigma < t_{SC} - t_{BC}$
115 MeV/c	Signal 85(2)% Background 0.0(0.0)%	**Signal 100(2)%** **Background 0.0(0.0)%**
153 MeV/c	Signal 87(2)% Background 0.3(0.1)%	**Signal 100(2)%** **"Background" 1.6(0.2)%**
210 MeV/c	**Signal 90(3)%** **Background 3.1(0.2)%**	Signal 100(4)% Background 63(1)%

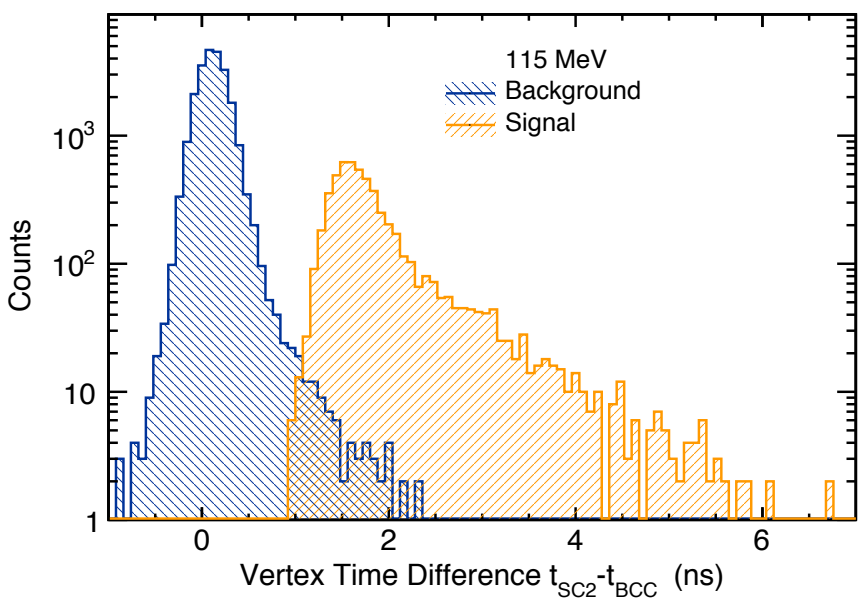
- The time-of-flight technique can reduce the muon-decay in flight background to < 4% prior to any correction of subtraction.
- In practice, vary cut to optimize final uncertainties.

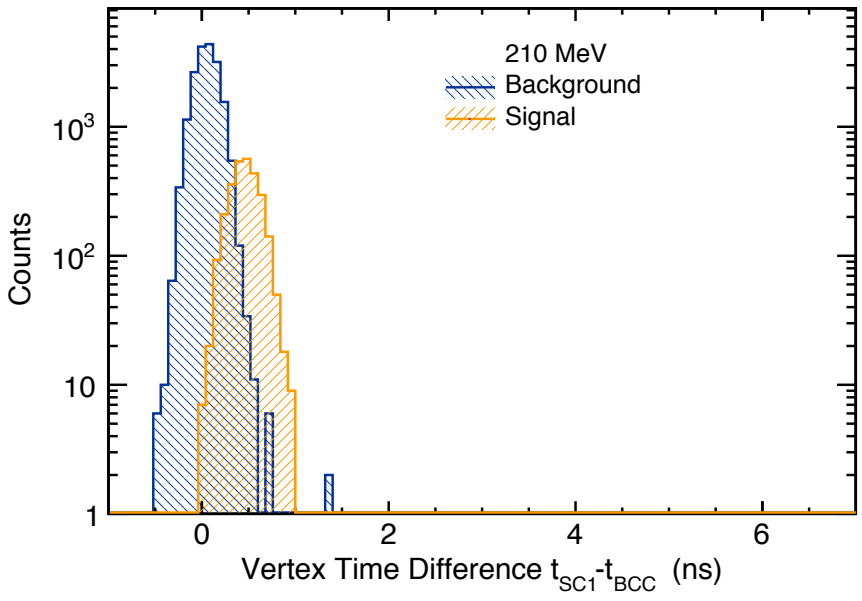
Time-of-Flight Information

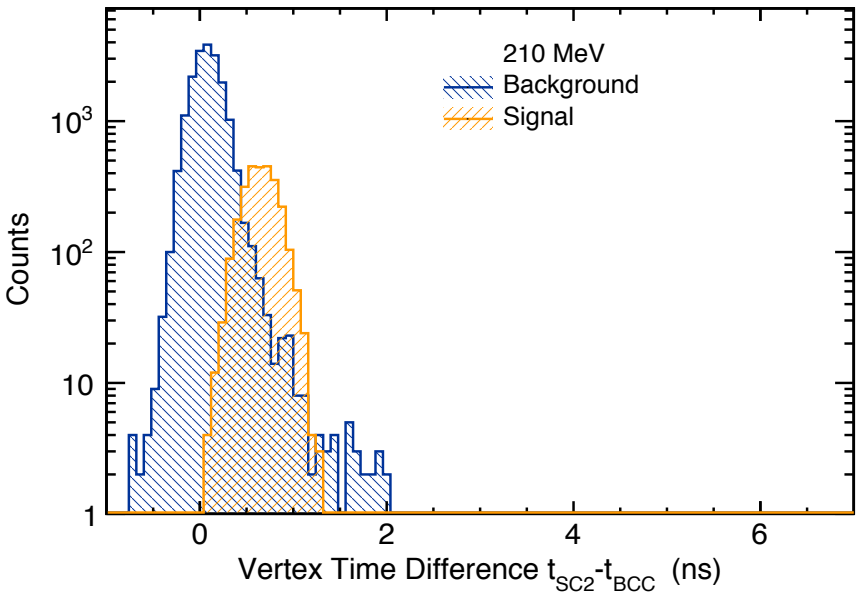
$\sigma_{BCC} = 100$ ps

$\sigma_{SC} = 50$ ps

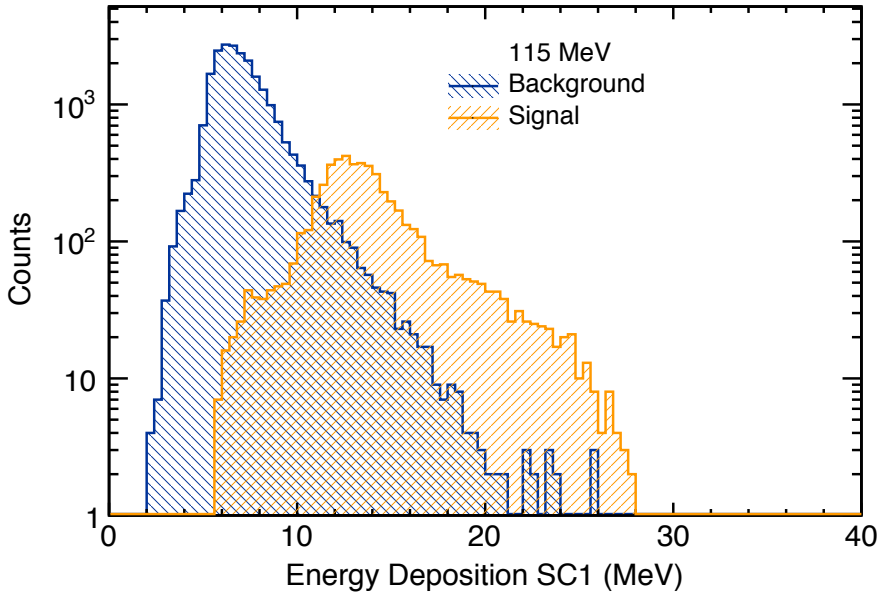


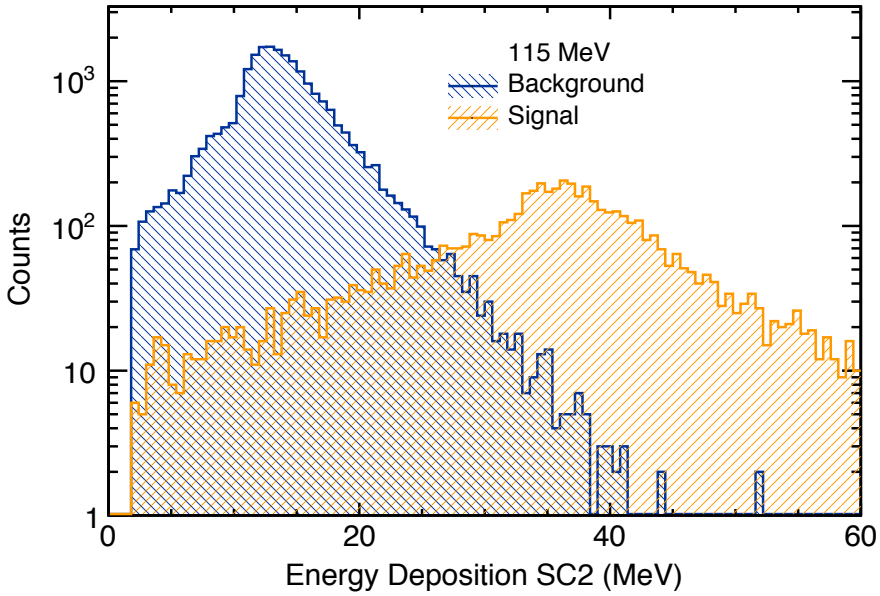


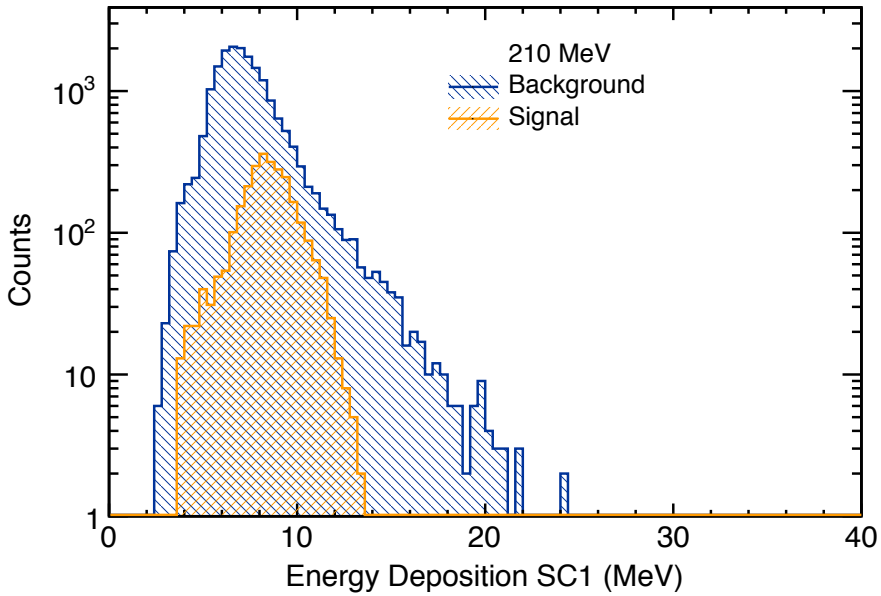


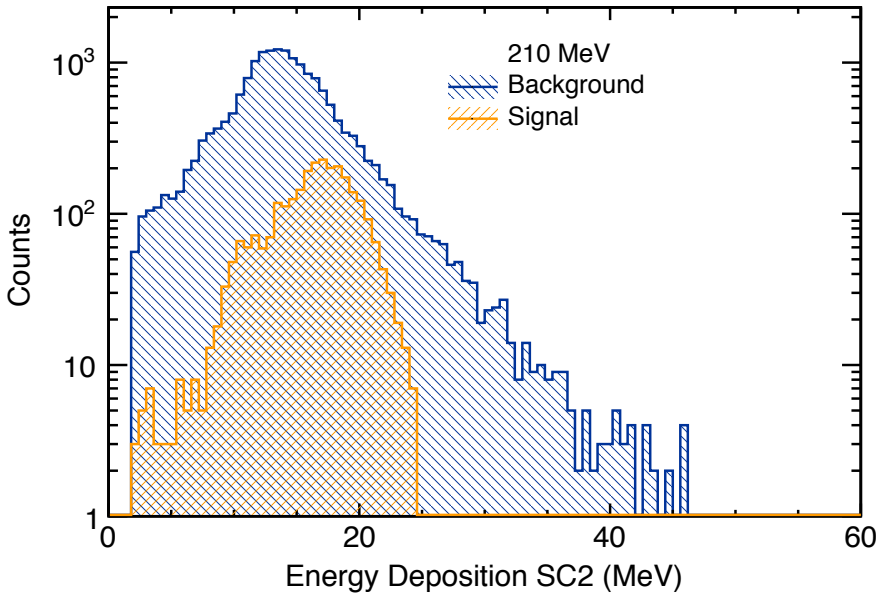


Energy deposition of electrons and muons in the scintillator bars differ slightly

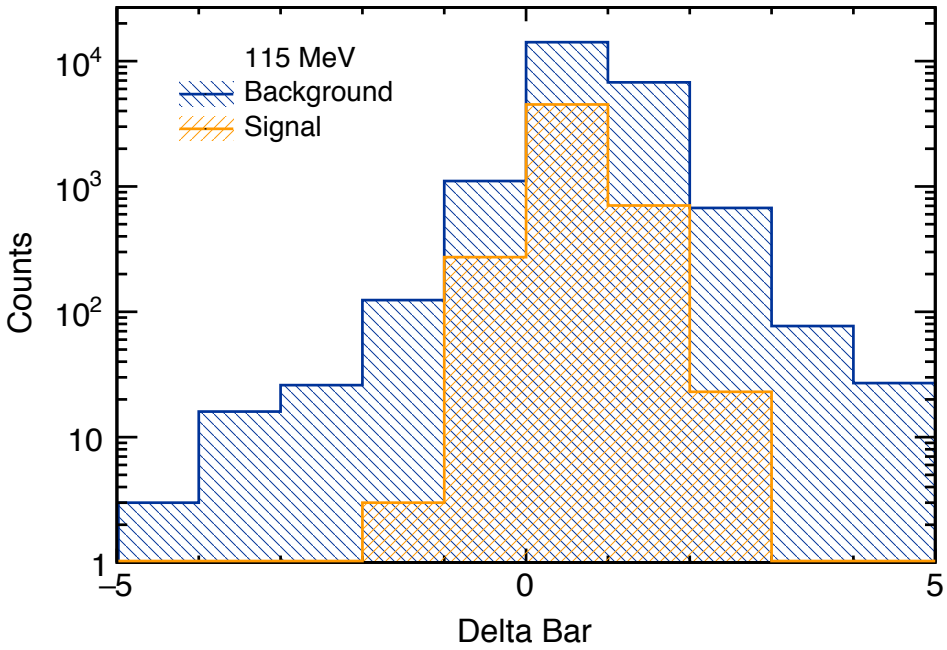


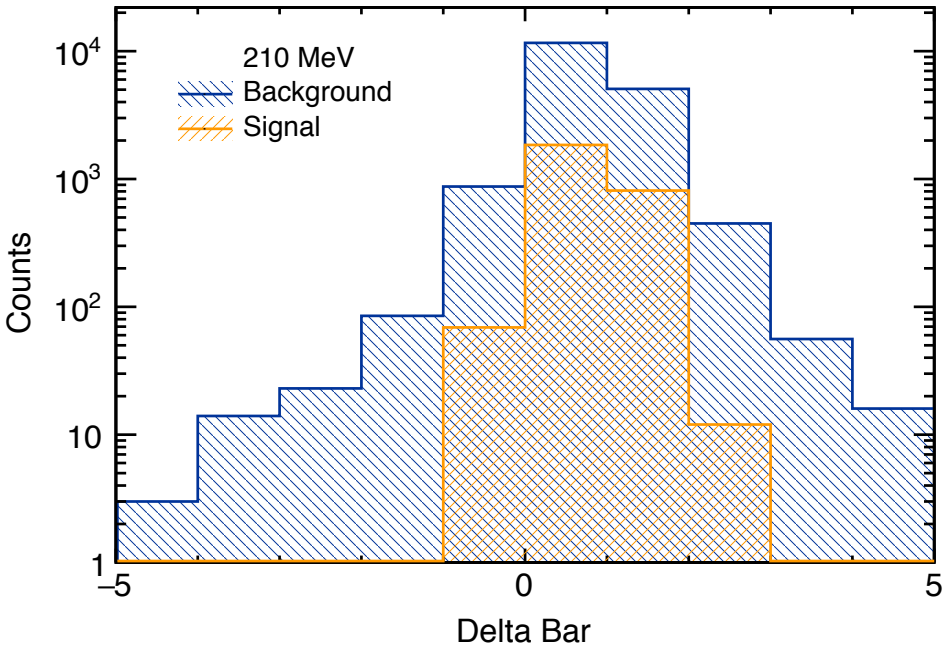






Paddle-number correlations

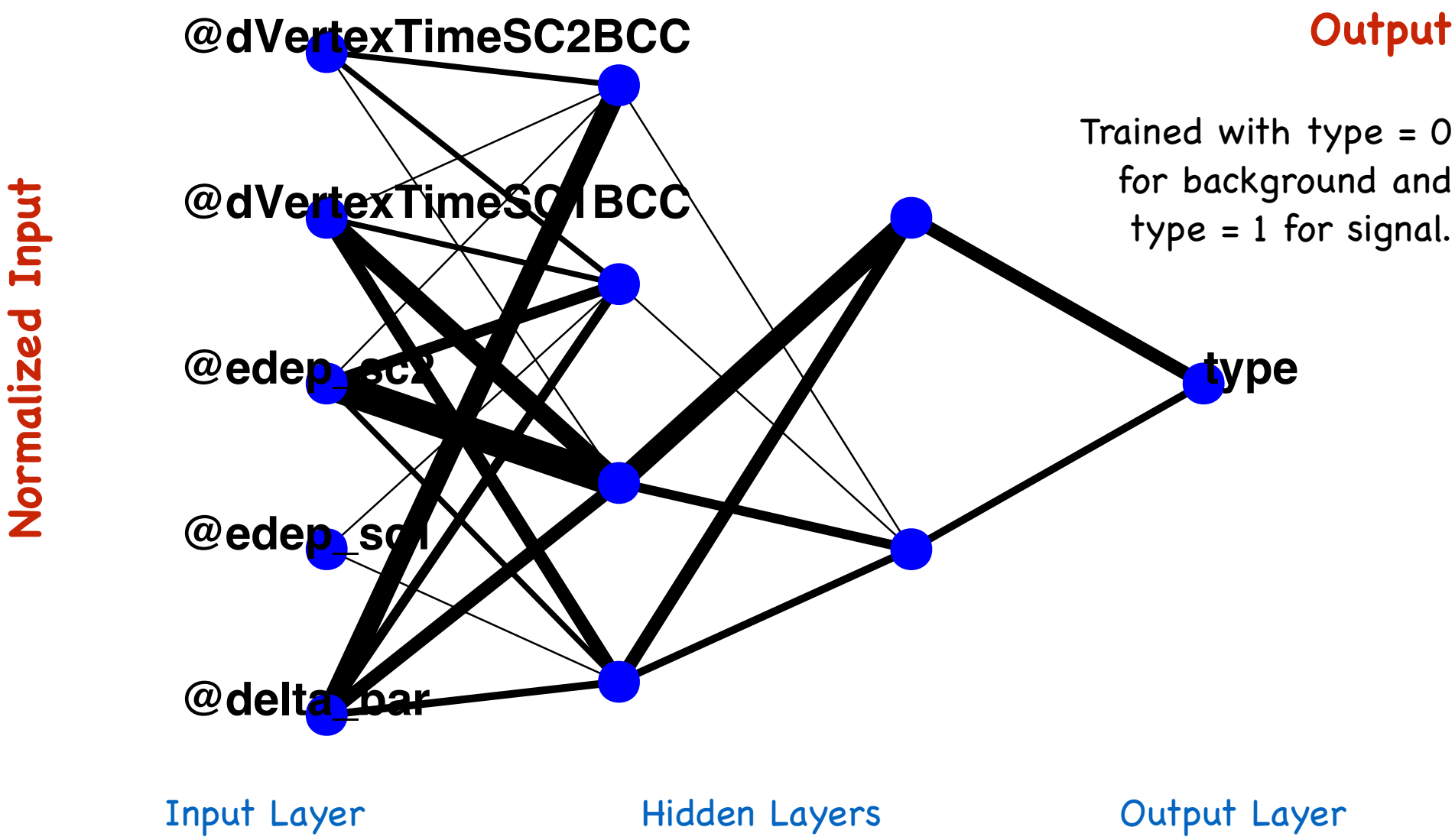




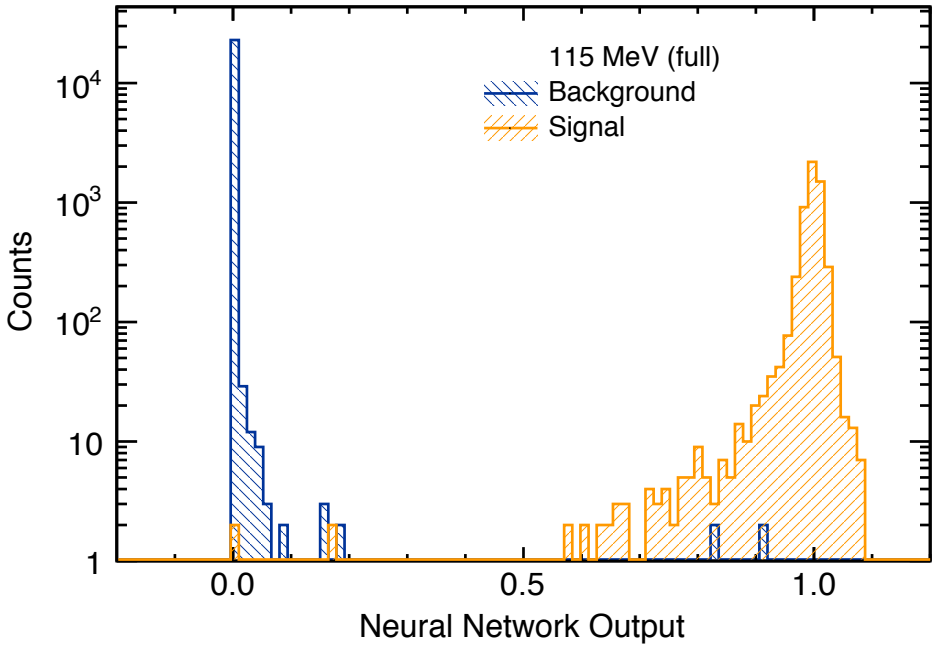
Muon decay-in-flight events loose slightly their front-bar rear-bar correlation; why?

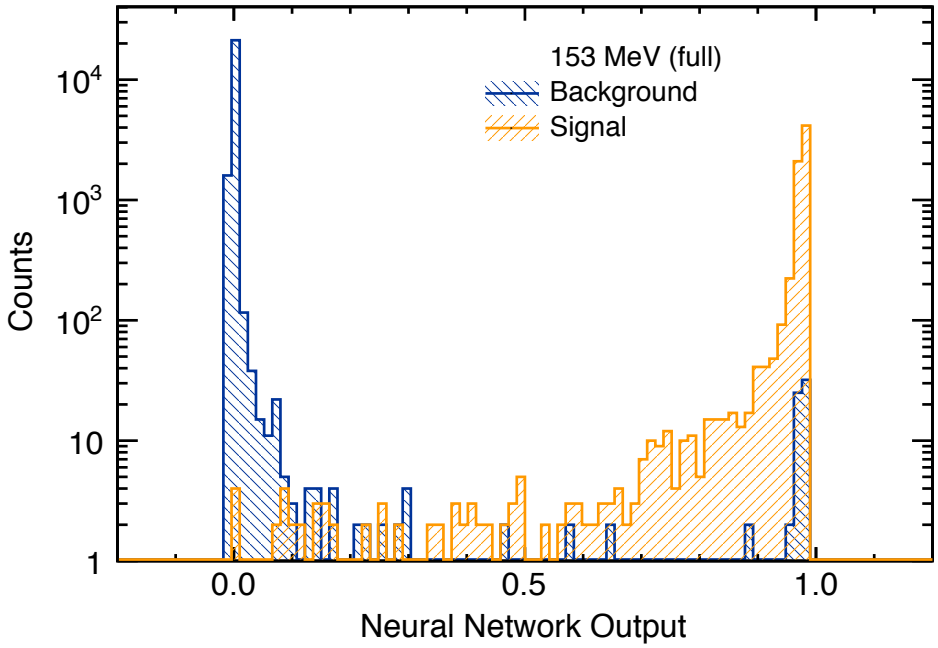
Additional information, not yet included: bar multiplicity.

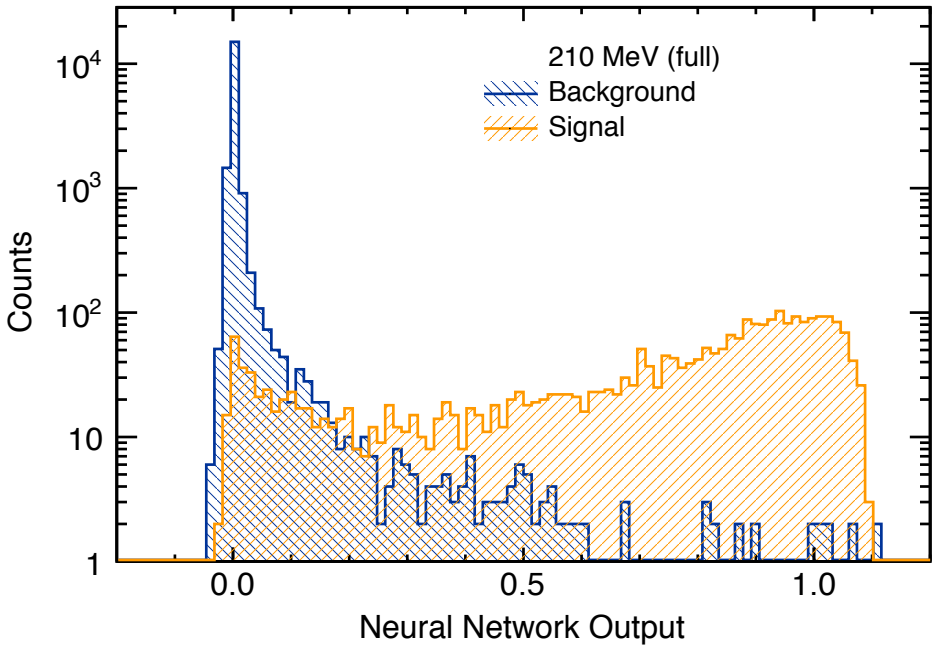
Neural Network



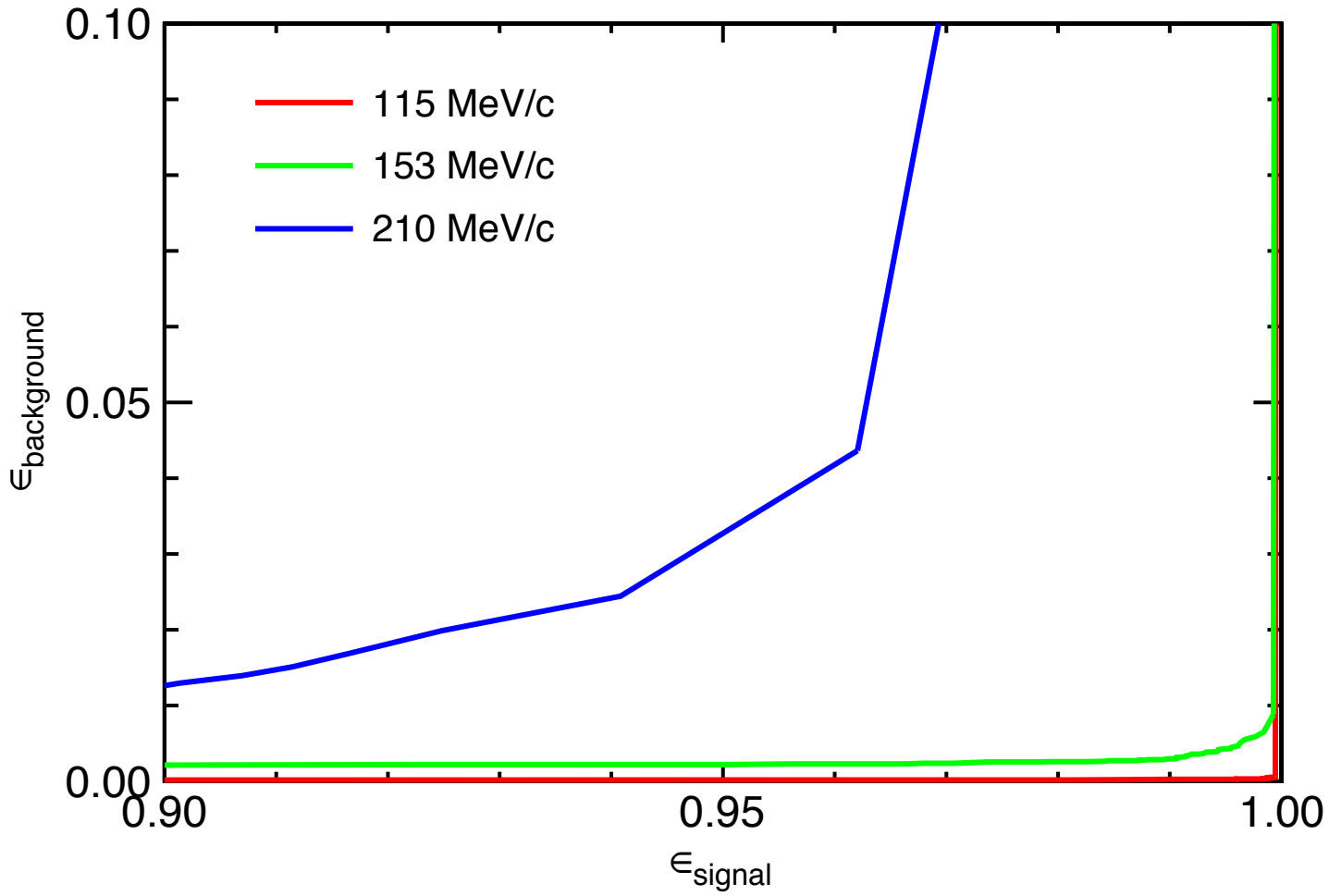
Neural Network Results







High efficiency of the signal / background discrimination for 115 MeV/c and 153 MeV/c settings



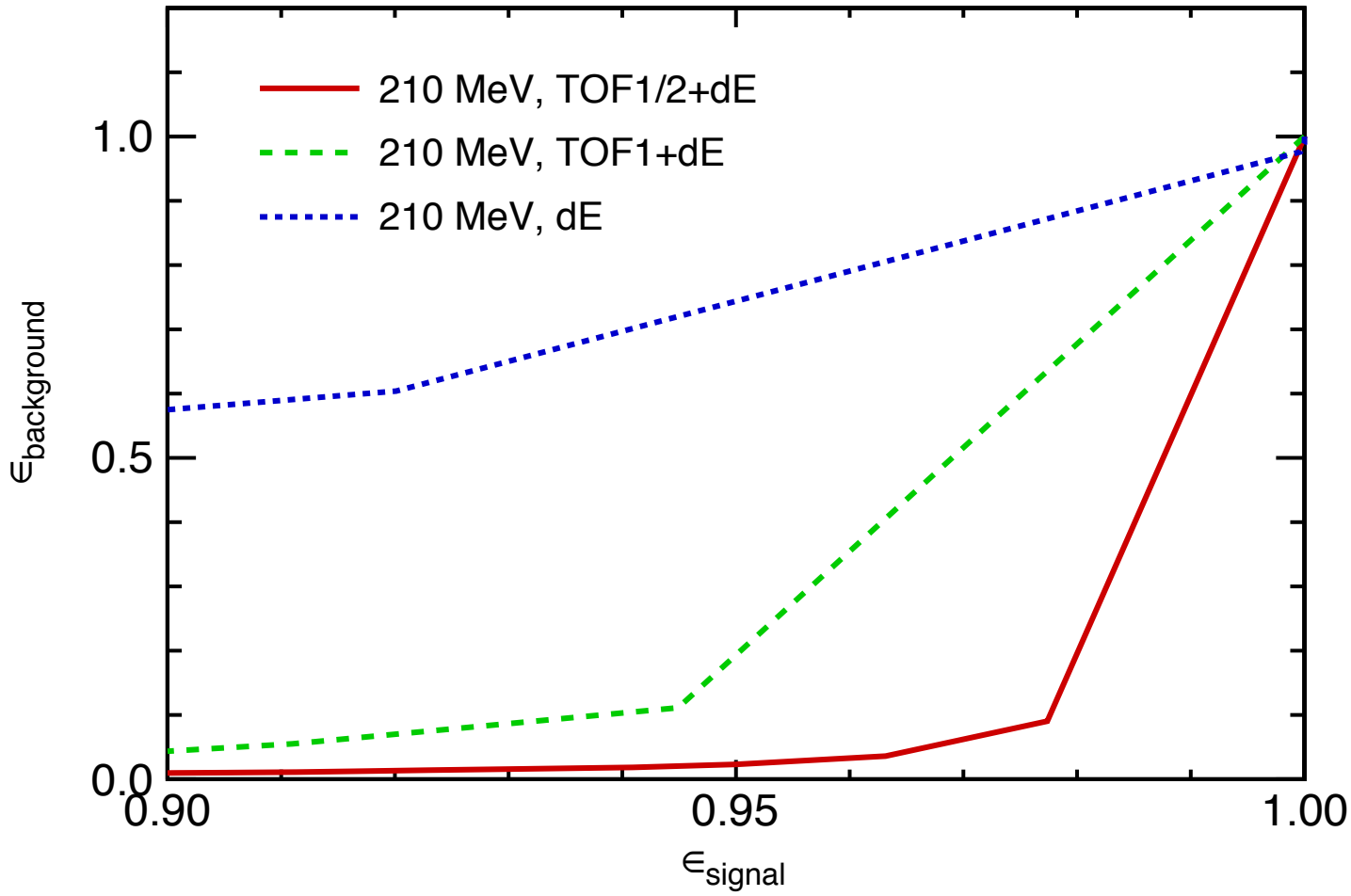
210 MeV/c
≈ 96% signal
with ≈ 4%
background

153 MeV/c
> 99.5% signal
with ≈ 0.5%
background

115 MeV/c
100% signal
with ≈ 0%
background

Note: 1% signal and 1% background are not the same yields!

High efficiency of the signal / background discrimination for 115 MeV/c and 153 MeV/c settings



dE
pulse-height
alone
insufficient

TOF1
improved s/b
separation

TOF1 + TOF2
much
improved s/b
separation

Should we increase the flight path and push the rear wall further back?