Outline

1. nGood requirement
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3. $\Delta\phi$ cut range
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5. Momentum cut range
6. Cross section
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Selection Criteria

- $N_{\text{good}} = 2$, $Q_{\text{tot}} = 0$ ($|V_r| < 1\ cm$, $|V_z| < 10\ cm$, $|\cos\theta| < 0.8$)
- $0.2\ E_{beam} < P_{\ell^\pm} < 1.1 E_{beam}$
- Back-to-back, $|\Delta\theta_{\ell^\pm}| = |\theta_1 + \theta_2 - 180^o| < 10^o$, $|\Delta\phi_{\ell^\pm}| = \big||\phi_1 - \phi_2| - 180^o\big| < 5^o$

nGood requirement

It is required that there are at least two good charged tracks in one event, and satisfy the cut on $\cos\theta$ and momentum. At the same time, it is necessary to ensure that the two tracks with the largest momentum are satisfying $|\Delta\theta_{\ell^\pm}| < 10^o, |\Delta\phi_{\ell^\pm}| < 5^o$ to measure the control sample is pure.

process	number	process	number
collision	9458006	EEeta	12
bhabha	7899554	EEetap	171
digam	14781	EEkk	3887
dimu	341326	EEpipi	6684
ditau	140326	EEuu	2627
EEee	32847	qqbar	875512

The table shows the number of events without the $|\Delta\theta_{\ell^\pm}|$ and $|\Delta\phi_{\ell^\pm}|$ cut conditions, where the background contamination reaches 11.4%, indicating that the control sample is not sufficiently pure.

nGood requirement

process	number	process	number
collision	7589578	EEeta	1
bhabha	7252093	EEetap	4
digam	286	EEkk	391
dimu	293484	EEpipi	636
ditau	1916	EEuu	298
EEee	4888	qqbar	17002

process	number	process	number
collision	7553823	EEeta	1
bhabha	7252093	EEetap	3
digam	108	EEkk	387
dimu	293424	EEpipi	629
ditau	1418	EEuu	279
EEee	4888	qqbar	7166

The first table shows the number of events with at least two good charged tracks in one event, where the background contamination reaches 0.3%, indicating that the control sample is sufficiently pure. The second table shows the number of events with two good charged tracks in one event, we can calculate the efficiency of both data and MC.

ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1$
0.9984	0.9987	0.3%

$\Delta\theta$ cut range

It is required that there are two good charged tracks in one event, and satisfy the cut on momentum, $\cos\theta$ and $\Delta\phi$.

$$(|\Delta\theta_{\ell^\pm}| = |\theta_1 + \theta_2 - 180^o| < 20^o)$$

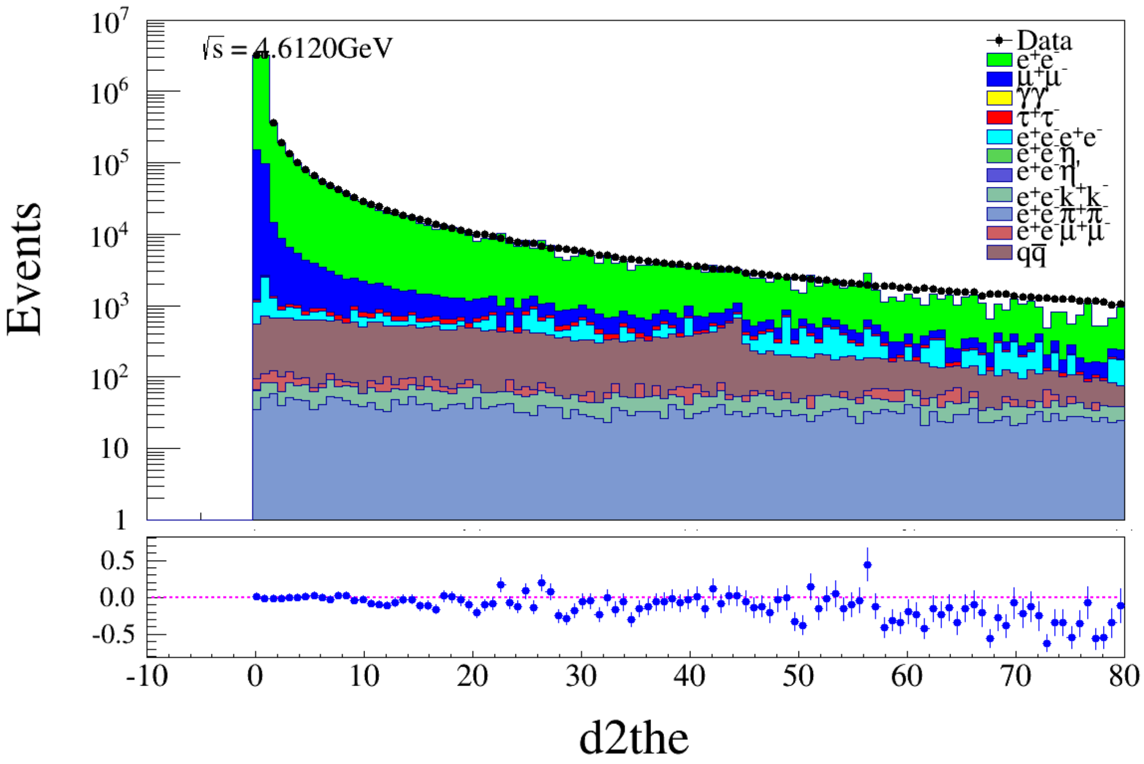
process	number	process	number
collision	7782484	EEeta	2
bhabha	7434008	EEetap	3
digam	108	EEkk	738
dimu	304648	EEpipi	1166
ditau	2656	EEuu	529
EEee	6256	qqbar	12856

$$(|\Delta\theta_{\ell^\pm}| = |\theta_1 + \theta_2 - 180^o| < 10^o)$$

process	number	process	number
collision	7553823	EEeta	1
bhabha	7242042	EEetap	3
digam	108	EEkk	387
dimu	293424	EEpipi	629
ditau	1418	EEuu	279
EEee	4790	qqbar	7166

Background ratio	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1$
0.31%	0.9718	0.9737	0.2%

$\Delta\theta$ cut range



$\Delta\phi$ cut range

It is required that there are two good charged tracks in one event, and satisfy the cut on momentum, $\cos\theta$ and $\Delta\theta$.

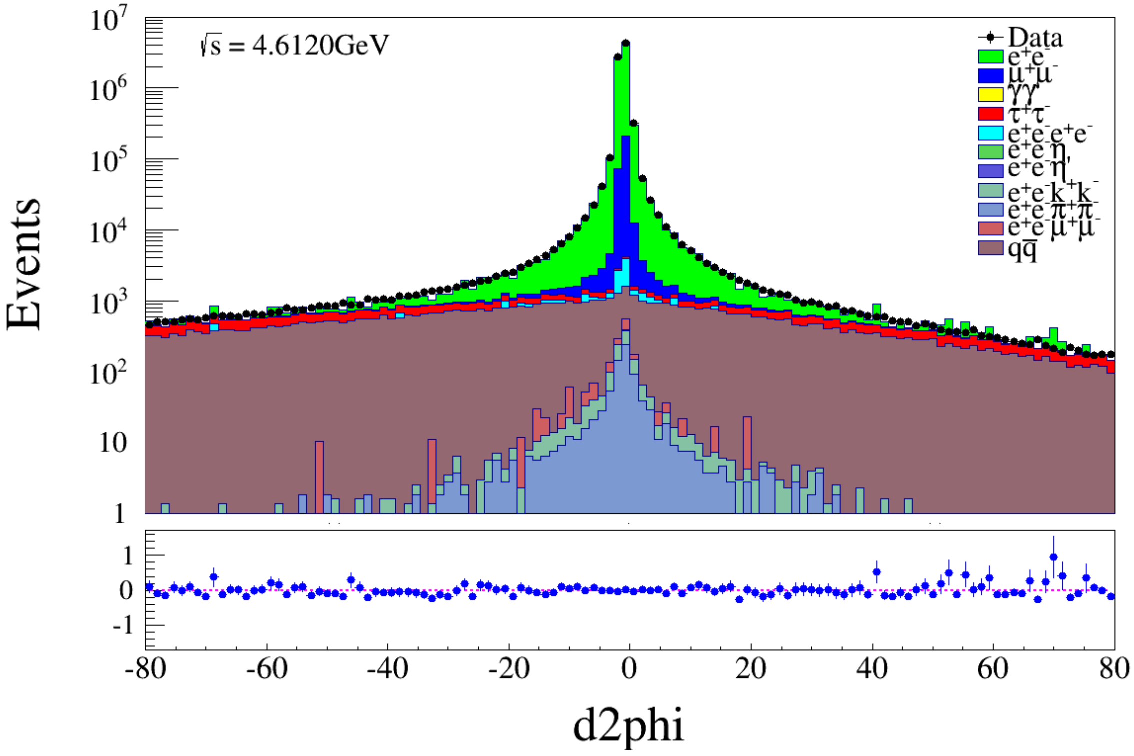
$$\left|\Delta\phi_{\ell^{\pm}}\right| = \left||\phi_1 - \phi_2| - 180^o\right| < 5^o$$

process	number	process	number
collision	7798789	EEeta	1
bhabha	7377664	EEetap	4
digam	890	EEkk	574
dimu	301210	EEpipi	906
ditau	24436	EEuu	481
EEee	6256	qqbar	81124

process	number	process	number
collision	7553823	EEeta	1
bhabha	7242042	EEetap	3
digam	108	EEkk	387
dimu	293424	EEpipi	629
ditau	1418	EEuu	279
EEee	4790	qqbar	7166

Background ratio	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1$
1.5%	0.9811	0.9813	-0.02%

Δϕ cut range



$\cos\theta$ cut range

It is required that there are two good charged tracks in one event, and satisfy the cut on momentum, $\Delta\theta$ and $\Delta\phi$.

$(|\cos\theta| < 0.82)$

process	number	process	number
collision	7984929	EEeta	1
bhabha	7667382	EEetap	2
digam	108	EEkk	393
dimu	297875	EEpipi	640
ditau	1393	EEuu	288
EEee	5376	qqbar	6265

$(|\cos\theta| < 0.8)$

process	number	process	number
collision	7551878	EEeta	1
bhabha	7241192	EEetap	2
digam	106	EEkk	384
dimu	293414	EEpipi	625
ditau	1368	EEuu	279
EEee	4790	qqbar	6125

Background ratio	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1$	total
0.18%	0.9457	0.9459	0.02%	0.04%

Momentum cut range

It is required that there are two good charged tracks in one event, and satisfy the cut on $\cos\theta$, $\Delta\theta$ and $\Delta\phi$.

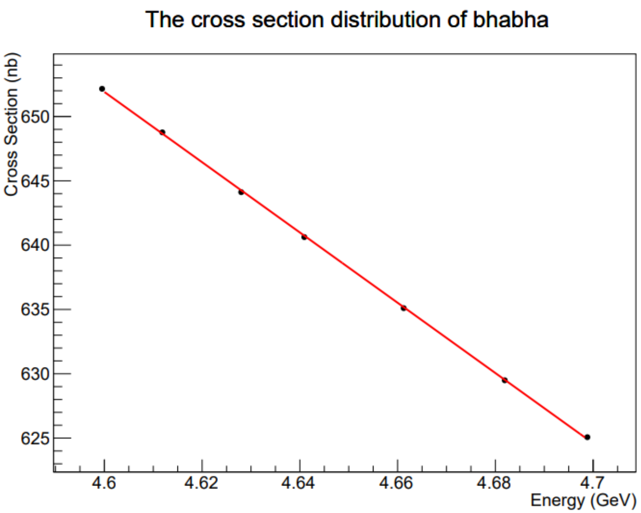
$$(0.2\, E_{beam} < P_{\ell^{\pm}} < 1.1 E_{beam})$$

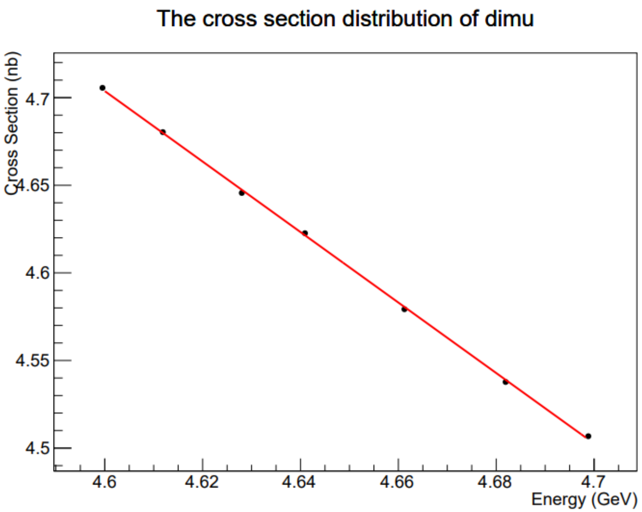
process	number	process	number
collision	7580538	EEeta	1
bhabha	7282884	EEetap	19
digam	76	EEkk	417
dimu	293149	EEpipi	755
ditau	1531	EEuu	375
EEee	6256	qqbar	2773

process	number	process	number
collision	7507239	EEeta	1
bhabha	7209127	EEetap	2
digam	76	EEkk	384
dimu	292811	EEpipi	628
ditau	1118	EEuu	269
EEee	4399	qqbar	2145

Background ratio	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1$	total
0.16%	0.9907	0.9902	-0.05%	0.1%

Cross section





$$\sigma^{obs}_{e^+e^-\to e^+e^-} = -273.185 * E_{cm} + 1908.56$$

$$\sigma^{obs}_{e^+e^-\to \mu^+\mu^-} = -2.01132 * E_{cm} + 13.9558$$

4.61186 GeV	$\sigma^{obs}_{e^+e^-\to e^+e^-}$ (nb)	$\sigma^{obs}_{e^+e^-\to \mu^+\mu^-}$ (nb)	Lum.(pb^{-1})	Sys.
old	648.7677	4.6803	103.6992	0.05%
new	648.3958	4.6779	103.7553	

MC statistic

The systematic uncertainty of Monte Carlo statistics is estimated by:

$$\frac{1}{\sqrt{N}} \cdot \sqrt{\frac{(1-\epsilon)}{\epsilon} \cdot N}$$

where N is the number of MC events and ϵ is the detection efficiency.

	N	ϵ	$\delta\epsilon$
bhabha	950000	0.1077	0.0003
dimu	1000000	0.6049	0.0005

Lum.(pb^{-1})(Nol)	Lum.(pb^{-1})	Lum.(pb^{-1})	Lum.(pb^{-1})	Lum.(pb^{-1})	Sys.
103.6992	103.4332	103.4398	103.9884	103.9951	0.3%

Systematic uncertainties in the tracking efficiencies

- There is at least one good charged track; N_{Good}>= 1;
  - $|V_{xy}|$ < 1 cm;
  - $|V_z|$ < 10 cm;
  - |cos θ| <0.93;
- For the charged track
  - The momentum: p > 1.8 GeV/c;
  - Deposited energy in EMC: E_{EMC}>1.0 GeV, E_{EMC}/p > 0.8 and E_{EMC} /p < 1.2.
- photon selection
  - E_γ > 0.025 GeV for |cosθ| < 0.80 (Barrel part of EMC);
  - E_γ > 0.050 GeV for 0.86 < |cosθ| < 0.92 (EndCap part of EMC);
  - 0 =< TDC <= 14;
  - $\Delta\theta_{\gamma-c}$> 10° .
- At least one photon is reconstructed in EMC;
  - E_γ > 0.1 GeV;
  - The angle between photon and the missing charged track should be less than 20°.

Systematic uncertainties in the tracking efficiencies

- Assuming one charged track ($e^{\pm}$) is missing, the kinematic fit is performed on γ plus the detected $e^{\mp}$ combinations, with $\chi^2 < 5$.

- Then we search for the other one charged track originating from the vertex region defined by:
  - $|V_{xy}| < 1$ cm;
  - $|V_z| < 10$ cm;
  - $|\cos\theta| < 0.93$;

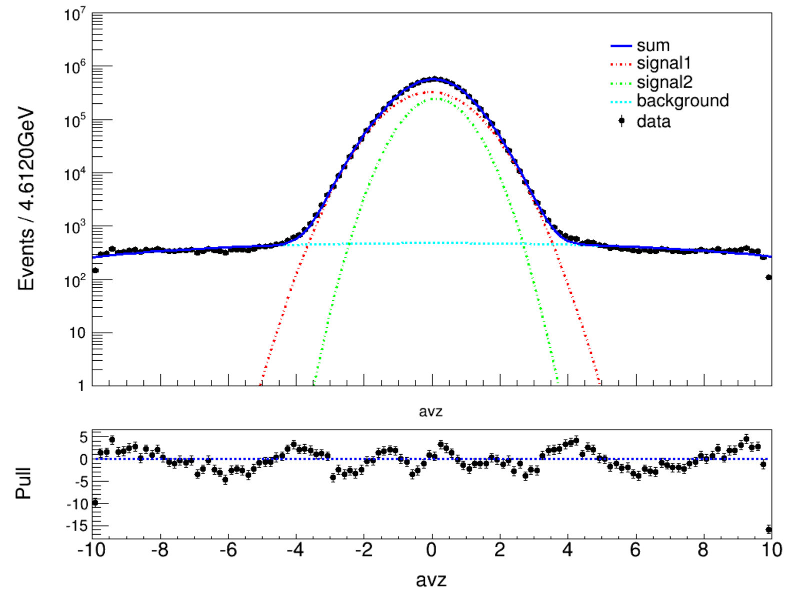
- If we can find one charged track, we call it as the "found" e +/−; otherwise, we call it as "un-found" e +/−.

- The tracking efficiency of electron for data/MC is determined by:

$$\epsilon_{\text{trk}} = \frac{N^{\text{found}}}{N^{\text{found}} + N^{\text{un-found}}}$$

Background estimation

```
COVARIANCE MATRIX CALCULATED SUCCESSFULLY
FCN=-1.02436e+08 FROM HESSE     STATUS=OK             73 CALLS         343 TOTAL
                    EDM=0.00332626    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   INTERNAL      INTERNAL
 NO.   NAME        VALUE            ERROR       STEP SIZE       VALUE
  1  frac         6.46653e-01   9.37826e-03   2.00945e-04   2.97683e-01
  2  mean0       -5.44284e-02   1.60238e-03   5.74043e-05  -5.44553e-02
  3  mean1        1.11483e-01   2.50043e-03   4.64202e-04   1.11716e-01
  4  nbkg         4.90826e+04   3.55421e+02   6.46118e-04  -1.83485e-02
  5  nsig         7.54763e+06   2.76132e+03   9.30280e-05   7.43044e-01
  6  pa1          1.03810e-02   8.00799e-03   1.56251e-04   1.03810e-03
  7  pb1         -2.89034e-01   1.15837e-02   3.78688e-05  -2.89074e-02
  8  sigma0       9.94202e-01   2.02748e-03   4.11132e-05  -6.46403e-01
  9  sigma1       7.23673e-01   3.82612e-03   4.21185e-05  -7.90252e-01
                                 ERR DEF= 0.5
```

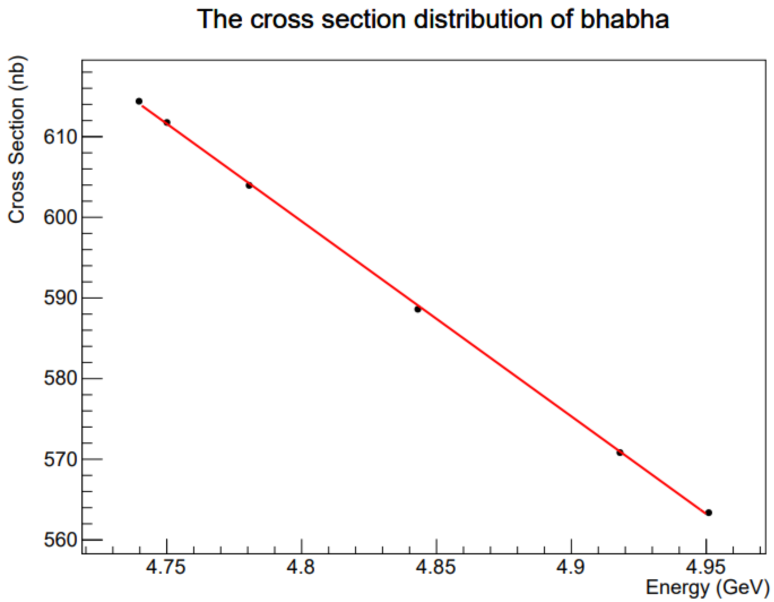


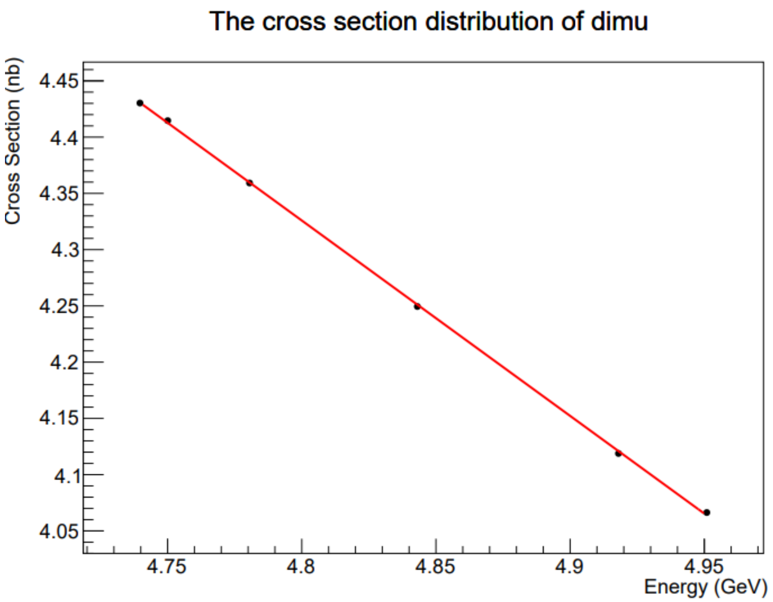
N_{sig}	N_{bkg}	Lum.(pb^{-1})	Lum.(pb^{-1}) (NoI)	Sys.
7547630	49083	103.4501	103.6992	0.2%

Background estimation

Source	Systematic Uncertainty(%)
Tracking efficiency	0.3
Uncertainty of Generator	0.1
nGood requirement	0.3
momentum cut range	0.1
$cos\theta$ cut	0.04
$\Delta\theta$ cut	0.2
$\Delta\phi$ cut	0.02
cross section	0.05
MC statistics	0.3
Background estimation	0.2
Total	0.61

Cross section





$$\sigma^{obs}_{e^+e^-\to e^+e^-} = -241.891 * \ E_{cm} + 1760.58$$

$$\sigma^{obs}_{e^+e^-\to \mu^+\mu^-} = -1.73669 * \ E_{cm} + 12.662$$

Cross section

E_{cm} (GeV)	$\sigma^{obs}_{e^+e^-\to e^+e^-}$ (nb)		$\sigma^{obs}_{e^+e^-\to\mu^+\mu^-}$ (nb)		Lum.(pb^{-1})		Sys.
4.73970	614.0892273	613.8473	4.43061	4.428874	166.6399	166.7056	0.04%
4.75005	611.5856555	611.3438	4.412636	4.410899	370.5507	370.6973	0.04%
4.78054	604.2103989	603.9685	4.359684	4.357947	516.6072	516.814	0.04%
4.84307	589.0849546	588.8431	4.251089	4.249352	530.2178	530.4356	0.04%
4.91802	570.9552242	570.7133	4.120924	4.119187	209.929	210.018	0.04%
4.95093	562.9945914	562.7527	4.063769	4.062033	161.0535	161.1227	0.04%

$\Delta\phi$ cut range

E_{cm}	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1(\%)$
4.59953	0.9813	0.9814	0.01
4.61186	0.9811	0.9813	0.02
4.62800	0.9810	0.9814	0.04
4.64091	0.9809	0.9816	0.06
4.66124	0.9809	0.9816	0.07
4.68192	0.9809	0.9817	0.08
4.69882	0.9810	0.9813	0.03
4.73970	0.9808	0.9810	0.02
4.75005	0.9808	0.9811	0.03
4.78054	0.9810	0.9812	0.02
4.84307	0.9813	0.9817	0.04
4.91802	0.9813	0.9813	-0.01
4.95093	0.9810	0.9819	0.09

$\Delta\theta$ cut range

E_{cm}	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1(\%)$
4.59953	0.9719	0.9729	0.1
4.61186	0.9718	0.9737	0.2
4.62800	0.9718	0.9730	0.1
4.64091	0.9718	0.9732	0.1
4.66124	0.9719	0.9719	0.005
4.68192	0.9717	0.9731	0.1
4.69882	0.9717	0.9722	0.05
4.73970	0.9718	0.9728	0.1
4.75005	0.9717	0.9742	0.2
4.78054	0.9718	0.9727	0.1
4.84307	0.9717	0.9731	0.1
4.91802	0.9717	0.9720	0.02
4.95093	0.9716	0.9729	0.1

Momentum cut range

E_{cm}	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1(\%)$
4.59953	0.9908	0.9904	-0.04
4.61186	0.9907	0.9902	0.05
4.62800	0.9905	0.9905	0.004
4.64091	0.9906	0.9905	-0.005
4.66124	0.9905	0.9906	0.01
4.68192	0.9904	0.9896	0.08
4.69882	0.9905	0.9904	0.01
4.73970	0.9903	0.9900	-0.03
4.75005	0.9903	0.9904	0.01
4.78054	0.9904	0.9907	0.03
4.84307	0.9903	0.9903	0.001
4.91802	0.9902	0.9903	0.01
4.95093	0.9900	0.9896	-0.04

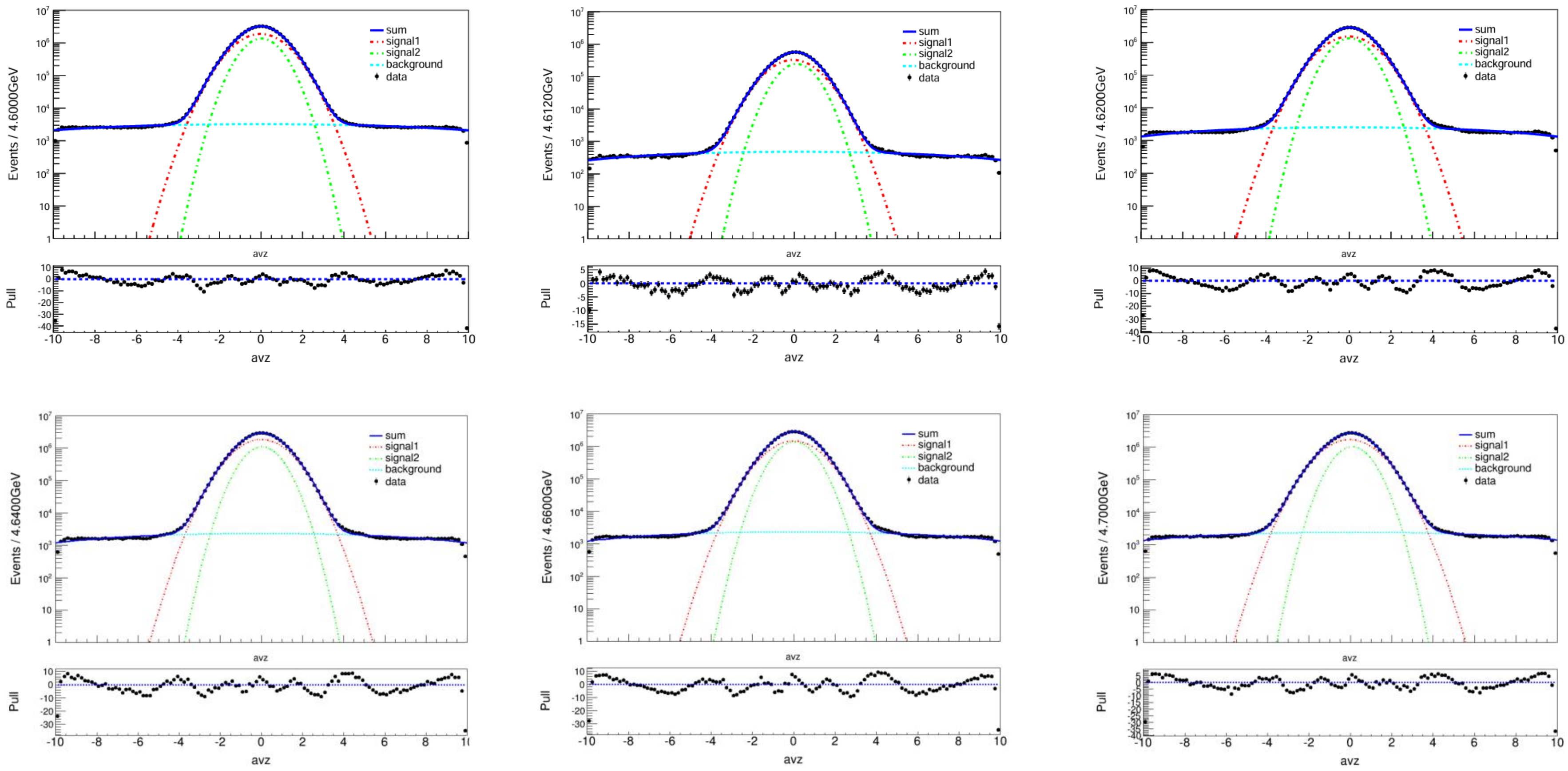
nGood requirement

E_{cm}	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1(\%)$
4.59953	0.9983	0.9987	0.04
4.61186	0.9984	0.9987	0.03
4.62800	0.9983	0.9986	0.03
4.64091	0.9983	0.9987	0.04
4.66124	0.9983	0.9988	0.05
4.68192	0.9983	0.9988	0.05
4.69882	0.9983	0.9987	0.04
4.73970	0.9983	0.9986	0.03
4.75005	0.9983	0.9988	0.05
4.78054	0.9983	0.9986	0.03
4.84307	0.9983	0.9988	0.05
4.91802	0.9983	0.9988	0.05
4.95093	0.9983	0.9987	0.04

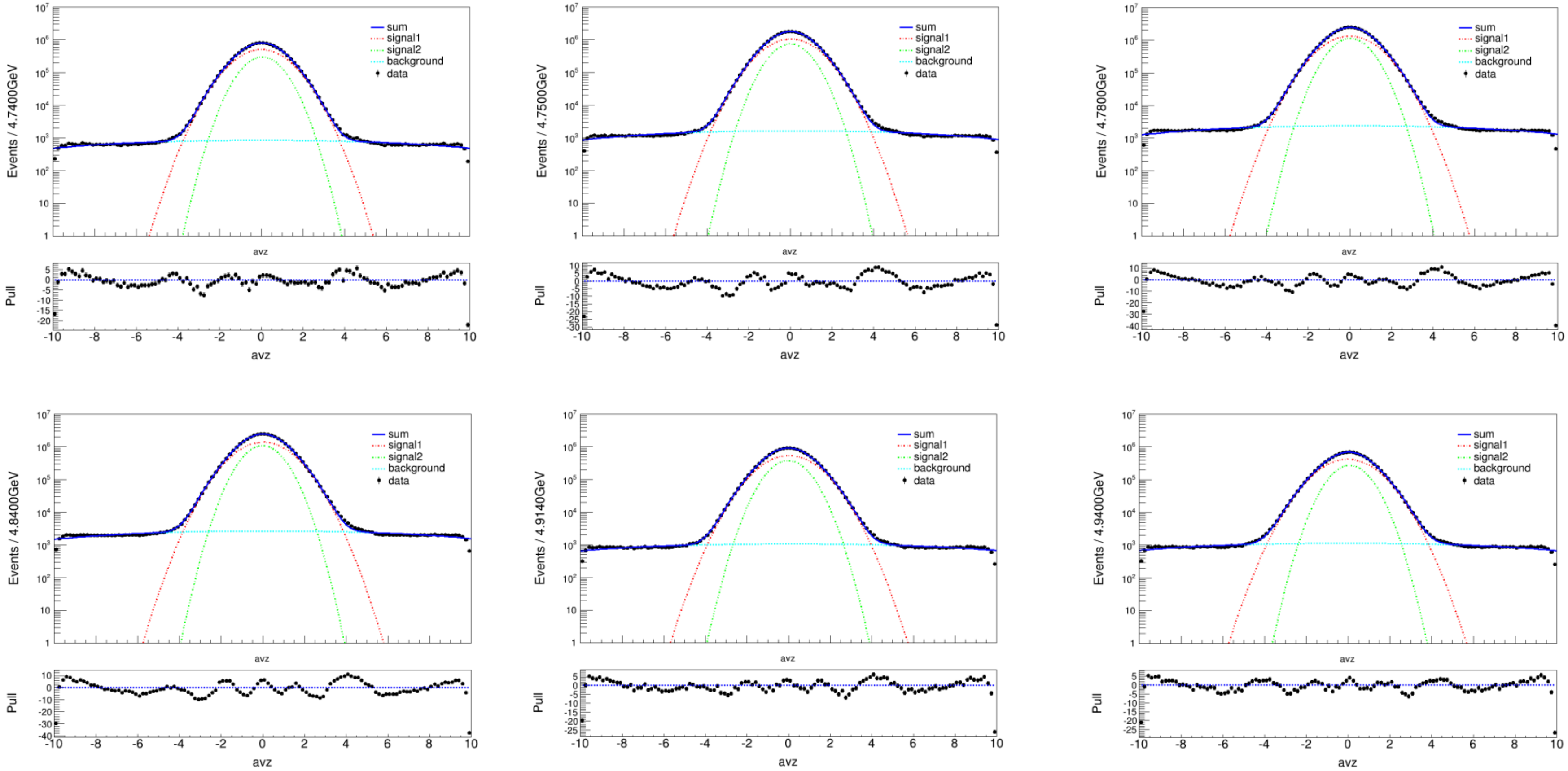
$cos\theta$ cut range

E_{cm}	ϵ_{data}	ϵ_{MC}	$\frac{\epsilon_{MC}}{\epsilon_{data}} - 1(\%)$
4.59953	0.9471	0.9470	-0.01
4.61186	0.9458	0.9459	0.01
4.62800	0.9452	0.9471	0.2
4.64091	0.9454	0.9470	0.17
4.66124	0.9456	0.9465	0.09
4.68192	0.9454	0.9467	0.13
4.69882	0.9455	0.9462	0.07
4.73970	0.9457	0.9462	-0.04
4.75005	0.9464	0.9456	-0.08
4.78054	0.9455	0.9462	-0.08
4.84307	0.9459	0.9483	-0.2
4.91802	0.9461	0.9458	0.03
4.95093	0.9463	0.9459	0.04

Background estimation



Background estimation



Background estimation

E_{cm} (GeV)	N_{sig}	N_{bkg}	Lum.(pb^{-1})	Lum.(pb^{-1}) (NoI)	Sys.(%)
4.59953	43208300	342498	589.4369	589.0285	0.3
4.61186	7547630	49083	103.4501	103.6992	0.2
4.62800	37757500	255765	525.4781	525.2063	0.3
4.64091	40014500	232864	559.3112	559.0387	0.2
4.66124	37817700	235568	530.9847	531.2564	0.3
4.68192				1674.4855	
4.69882	37647700	250112	536.0112	535.8374	0.2
4.73970	11375700	87513	166.6359	166.2389	0.2
4.75005	25338100	165444	371.4452	370.4422	0.3
4.78054	34889600	241533	518.3798	516.8131	0.3
4.84307	34999700	276726	532.2928	530.6321	0.3
4.91802	13405500	112390	210.7626	209.9776	0.4
4.95093	10144400	119921	161.6474	160.9437	0.4