Playing with GLoBES

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IFIRSE - ICISE

NuGroup Meeting, January 18, 2018

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   - Problem 6: Confidence regions in the $\theta_{13} - \delta_{CP}$ plane
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Introduction

- In this presentation, I will follow the instruction in the package *T2K-tutorial*.
- *T2K-tutorial* is used for precision measurement of oscillation parameters θ_{23} and Δm^2_{31}, and later for θ_{13} and δ_{CP}.

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Introduction

The rules for given code

Table 2: Number of events and reduction efficiency of "standard" 1ring e-like cut and π^0 cut for 5 year exposure (5×10^{21} p.o.t.) OA2°. For the calculation of oscillated ν_e,$\Delta m^2 = 3 \times 10^{-3}$ eV^2 and $\sin^2 2\theta_{\mu e} = 0.05$ is assumed.

OAB 2°	ν_μ C.C.	ν_μ N.C.	Beam ν_e	Oscillated ν_e
1) Generated in F.V.	10713.6	4080.3	292.1	301.6
2) 1R e-like	14.3	247.1	68.4	203.7
3) e/π^0 separation	3.5	23.0	21.9	152.2
4) 0.4 GeV< E_{rec} < 1.2 GeV	1.8	9.3	11.1	123.2

Table 3: Summary of the event rate of the NC candidates. $f(X)$ is the fraction of the events from X interaction.

Beam	#NC Events	Beam exposure	$f(\nu_\mu$NC)	$f(\nu_\mu$CC)	(ν_eCC)
WBB	315	1 years	0.88	0.09	0.03
LE2π	250	5 years	0.80	0.13	0.07
OA2°	700	5 years	0.84	0.09	0.07

Taken from: hep-ex/0106019

Introduction

The rules for given code

```
rule(#NU_E_Appearance_QE)<
        /* Signal channels and associated
systematical errors */
     @signal = 0.50498@#nu_e_appearance_QE
     @signalerror = 10. : 0.0001      /* Format is
<normalization error> : <energy "tilt" error> */

        /* Background channels and associated
systematical errors */
     @background =  0.00032671
@#nu_mu_disappearance_CC  : 0.0056373@#NC_bckg  :
0.50498@#nu_e_beam : 0.50498@#nu_e_bar_beam
     @backgrounderror = 0.05 : 0.05 /* follow hep-
ph/0504026: 5 per cent background tilt error */
```

Introduction

The rules for given code

```
rule(#NU_MU_Disapperance_QE)<
      @signal = 0.9@#nu_mu_disappearance_QE
      @signalerror = 0.025 : 0.0001

      @background = 0.0056373@#NC_bckg
      @backgrounderror = 0.2 : 0.0001

      @sys_on_function = "chiTotalRatesTilt"
      @sys_off_function = "chiSpectrumTilt"
>
```

Introduction

The rules for given code

```
rule(#NU_E_Appearance_CC)<
      @signal = 0.50498@#nu_e_appearance_CC
      @signalerror = 0.05 : 0.0001
/* follow hep-ph/0504026: 5 per cent norm errors
for appearance */

      @background =  0.00032671
@#nu_mu_disappearance_CC  : 0.0056373@#NC_bckg  :
0.50498@#nu_e_beam : 0.50498@#nu_e_bar_beam
      @backgrounderror = 0.05 : 0.0001
/* do not use 0.05 for BG tilt here, since
introduced twice uncorrelated then! */
```

Introduction

The rules for updated code (PhysRevD.96.092006)

TABLE XIV. Event reduction for the ν_e CC selection at the far detector. The numbers of expected MC events divided into five categories are shown after each selection criterion is applied. The MC expectation is based upon three-neutrino oscillations with the parameters as shown in Table XIII.

		$\nu_\mu + \bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$	$\nu + \bar{\nu}$	$\bar{\nu}_\mu \to \bar{\nu}_e$	$\nu_\mu \to \nu_e$	
ν-beam mode	MC total	CC	CC	NC	CC	CC	Data
Interactions in FV	744.89	364.32	18.55	326.16	0.39	35.47	...
FCFV	431.85	279.88	18.09	98.72	0.38	34.78	438
Single ring[a]	223.49	153.40	11.15	28.68	0.32	29.95	220
Electronlike[b]	66.94	6.46	11.06	19.53	0.31	29.57	70
$E_{\rm vis} > 100$ MeV[c]	61.78	4.59	11.01	16.81	0.31	29.06	66
$N_{\text{Michel-e}} = 0$[d]	50.60	0.97	8.97	14.24	0.31	26.11	51
$E_\nu^{\rm rec} < 1250$ MeV[e]	40.71	0.25	4.26	10.85	0.22	25.14	46
Not π^0-like[f]	28.55	0.09	3.68	1.35	0.18	23.25	32
$\bar{\nu}$-beam mode							
Interactions in FV	312.38	164.04	9.00	132.75	4.30	2.29	...
FCFV	180.48	123.24	8.75	42.05	4.20	2.24	170
Single ring	96.06	73.21	5.51	11.87	3.74	1.73	94
Electronlike	21.55	2.31	5.48	8.36	3.70	1.71	16
$E_{\rm vis} > 100$ MeV	20.05	1.83	5.46	7.39	3.68	1.69	14
$N_{\text{Michel-e}} = 0$	16.40	0.33	4.71	6.24	3.66	1.46	12
$E_\nu^{\rm rec} < 1250$ MeV	11.40	0.08	1.89	4.83	3.42	1.19	9
Not π^0-like	6.28	0.02	1.58	0.60	3.04	1.05	4

Introduction

The rules for updated code (PhysRevD.96.092006)

TABLE XV. Event reduction for the ν_μ CC selection at the far detector. The numbers of expected MC events divided into four categories are shown after each selection criterion is applied. The MC expectation is based upon three-neutrino oscillations with the parameters as shown in Table XIII.

		ν_μ	$\bar{\nu}_\mu$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$	$\nu + \bar{\nu}$	
ν-beam mode	MC total	CCQE	CCQE	CC nonQE	CC	NC	Data
Interactions in FV	744.89	100.17	6.45	257.70	54.41	326.16	...
FCFV	431.85	78.75	4.85	196.28	53.25	98.72	438
Single ring[a]	223.49	73.49	4.70	75.21	41.41	28.68	220
Muonlike[b]	156.56	72.22	4.65	70.06	0.47	9.16	150
$p_\mu > 200$ MeV$/c$[c]	156.24	72.03	4.65	70.00	0.47	9.08	150
$N_{\text{Michel-e}} \leq 1$[d]	137.76	71.28	4.63	52.61	0.46	8.78	135
$\bar{\nu}$-beam mode							
Interactions in FV	312.38	20.04	30.77	113.23	15.59	132.75	...
FCFV	180.48	15.04	24.95	83.26	15.19	42.05	170
Single ring	96.06	13.52	24.28	35.41	10.98	11.87	94
Muonlike	74.52	13.40	23.96	33.56	0.09	3.52	78
$p_\mu > 200$ MeV$/c$	74.42	13.39	23.92	33.54	0.09	3.48	78
$N_{\text{Michel-e}} \leq 1$	68.26	13.18	23.85	27.79	0.09	3.35	66

Introduction

The rules for updated code (PhysRevD.96.092006)

- How to define new channel: $\nu_\mu + \bar{\nu}_\mu$ CC nonQE?

```
/* 5 */
channel(#nu_mu_disappearance_QE)<
      @channel =       #JHFplus:  +:    m:    m:    #QE:     #ERES
>

/* 6 */
channel(#nu_e_appearance_CC)<
      @channel =       #JHFplus:  +:    m:    e:    #CC:     #ERES
>
/* 7 */
channel(#nu_mu_beam_nonQE)<
      @channel =       #JHFplus:  +:    m:    m:    #QE:     #ERES
>
```

Introduction

The rules for updated code (PhysRevD.96.092006)

```
rule(#NU_E_Appearance_QE)<
     @signal = 0.64829@#nu_e_appearance_QE
      @signalerror = 0.01 : 0.0001

      @background =  0.00020819@#nu_mu_disappearance_CC
: 0.0042492@#NC_bckg  : 0.19838@#nu_e_beam : 0.17556
@#nu_e_bar_beam
      @backgrounderror = 0.05 : 0.05    /* follow hep-
ph/0504026: 5 per cent background tilt error */
```

Introduction

The rules for updated code (PhysRevD.96.092006)

```
rule(#NU_MU_Disapperance_QE)<
      @signal = 0.7173982@#nu_mu_disappearance_QE
      @signalerror = 0.01 : 0.0001

      @background = 0.026432@#NC_bckg : 0.0078571
@#nu_e_beam : 0.21675@#nu_mu_beam_nonQE
      @backgrounderror = 0.2 : 0.0001
```

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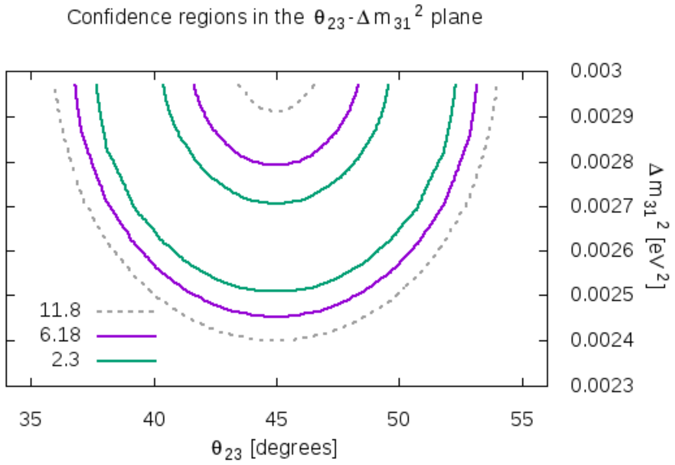
The rules for updated code (PhysRevD.96.092006)

```
rule(#NU_E_Appearance_CC)<
      @signal = 0.64829@#nu_e_appearance_CC
      @signalerror = 0.01 : 0.0001     /* follow hep-
ph/0504026: 5 per cent norm errors for appearance */

      @background =  0.00020819@#nu_mu_disappearance_CC
: 0.0042492@#NC_bckg  : 0.19838@#nu_e_beam : 0.17556
@#nu_e_bar_beam
      @backgrounderror = 0.05 : 0.0001    /*     do
not use 0.05 for BG tilt here, since introduced twice
uncorrelated then! */
```

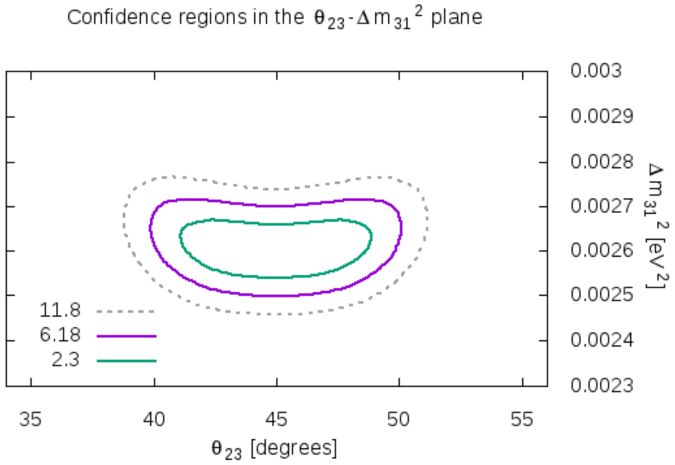
Precision measurement of θ_{23} and Δm^2_{31}

Problem 1: Warm-up



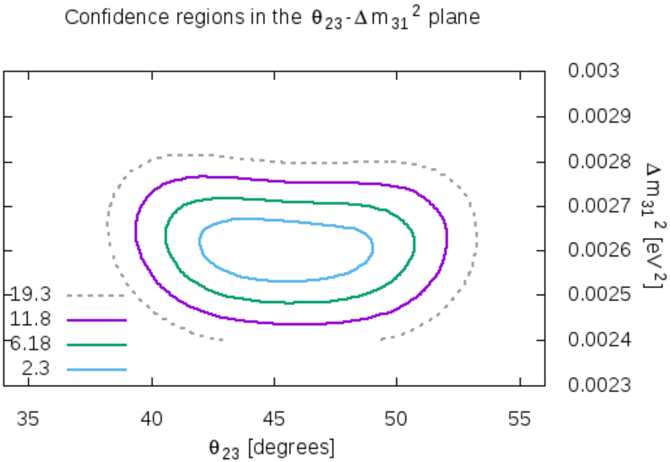
Precision measurement of θ_{23} and Δm^2_{31}

Problem 2: Spectral analysis vs. total rates



Precision measurement of θ_{23} and Δm^2_{31}

Problem 2: Spectral analysis vs. total rates



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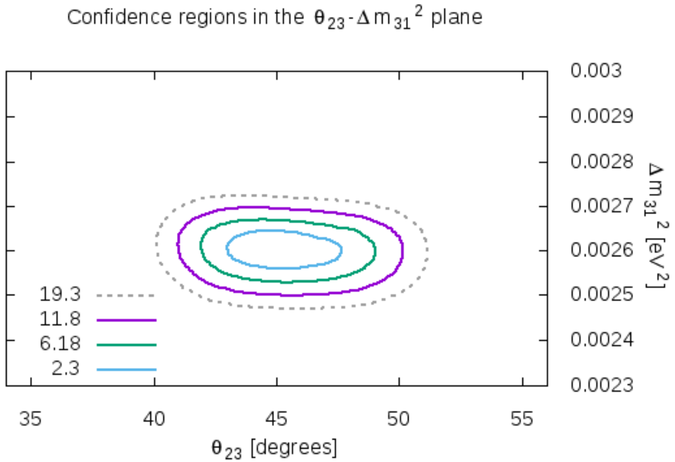
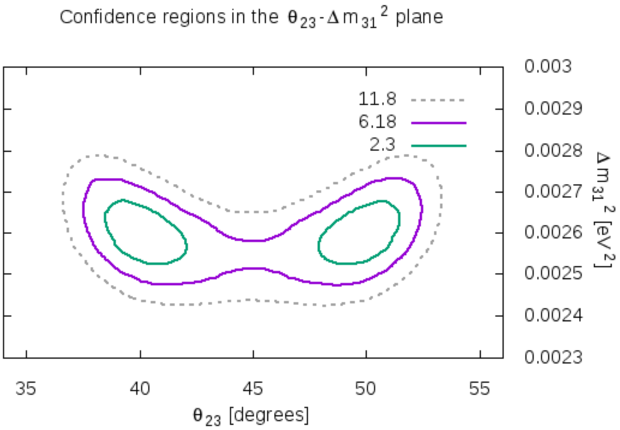


Precision measurement of θ_{23} and Δm^2_{31}

Problem 3: The octant degeneracy

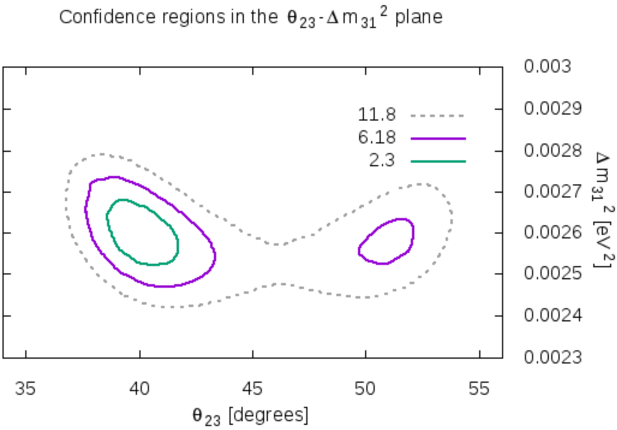
$\theta_{23} = 40^o$, $\sin 2\theta_{13} = 0$ and 2 years running



Precision measurement of θ_{23} and Δm^2_{31}

Problem 3: The octant degeneracy

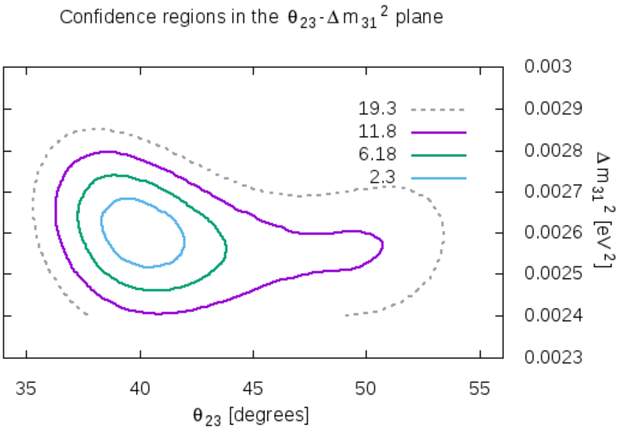
$\theta_{23} = 40^o$, $\sin 2\theta_{13} = 0.1$ and 2 years running



Precision measurement of θ_{23} and Δm^2_{31}

Problem 3: The octant degeneracy

$\theta_{23} = 40^o$, $\sin 2\theta_{13} = 0.1$, updated sys. uncert. and 2 yrs running



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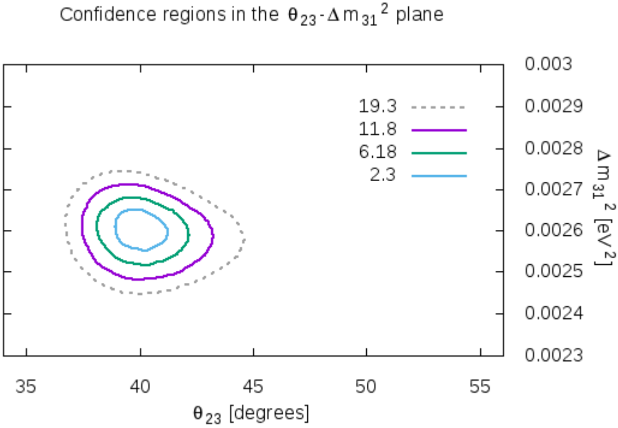
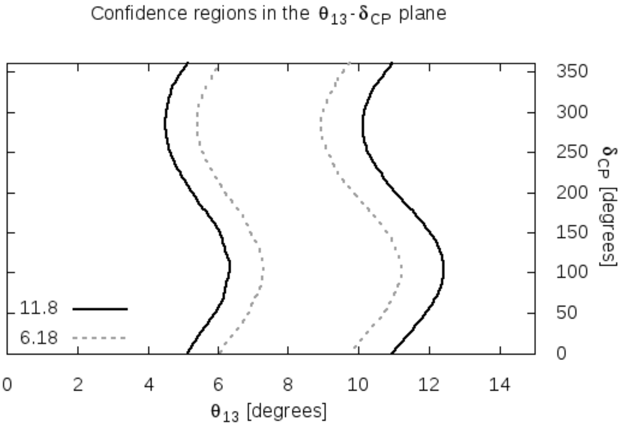


Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 6: Confidence regions in the $\theta_{13} - \delta_{CP}$ plane

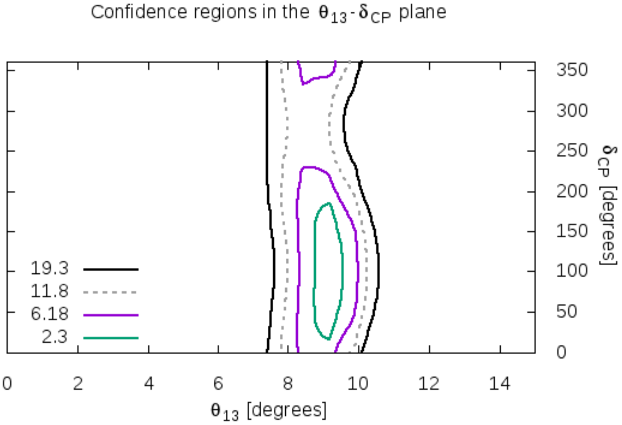
$\theta_{23} = 45^o$, $\sin 2\theta_{13} = 0.1$



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 6: Confidence regions in the $\theta_{13} - \delta_{CP}$ plane

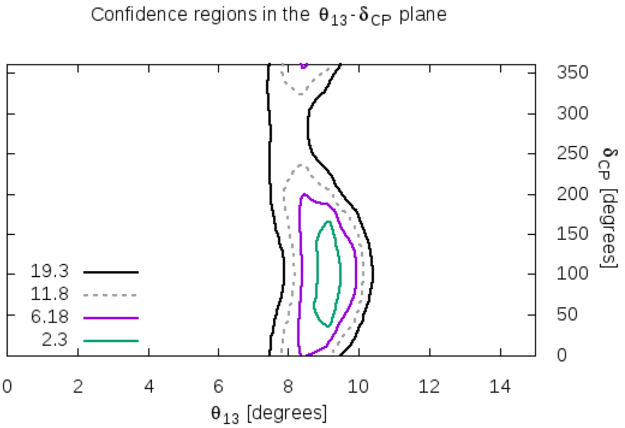
$\theta_{23} = 45^o$, $\sin 2\theta_{13} = 0.1$, updated sys. uncert. and 2 yrs running



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 6: Confidence regions in the $\theta_{13} - \delta_{CP}$ plane

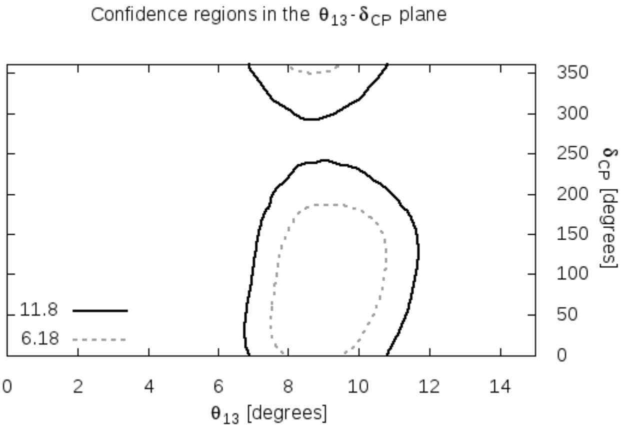
$\theta_{23} = 45^o$, $\sin 2\theta_{13} = 0.1$, updated sys. uncert. and 6 yrs running



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 7: Improving the sensitivity by anti-neutrino running

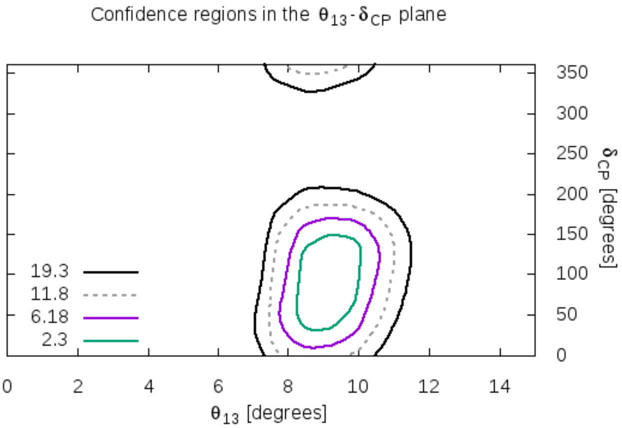
2 years neutrino and 6 years anti-neutrino running



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 7: Improving the sensitivity by anti-neutrino running

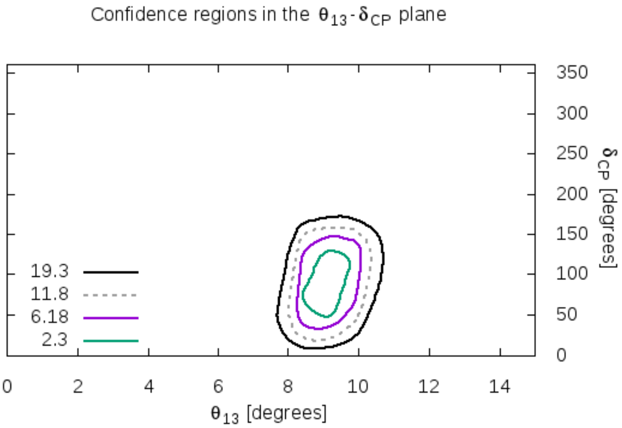
2 yrs neutrino & 6 yrs anti-neutrino running & updated sys. uncert.



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 7: Improving the sensitivity by anti-neutrino running

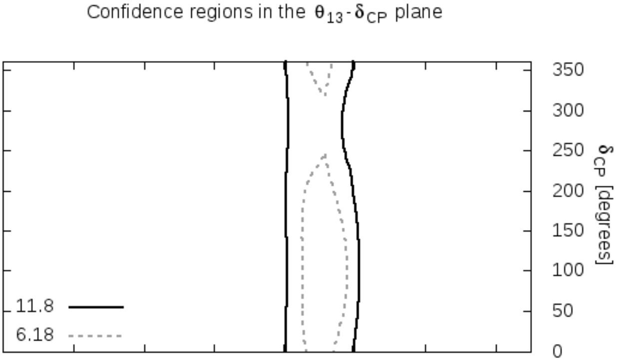
6 yrs neutrino & 18 yrs anti-neutrino running



Generic three-flavor effects: θ_{13} and δ_{CP}

Problem 8: Improving the sensitivity by incorporating reactor results

2 yrs neutrino & 6 yrs anti-neutrino running, incorporating with Reactor2.glb



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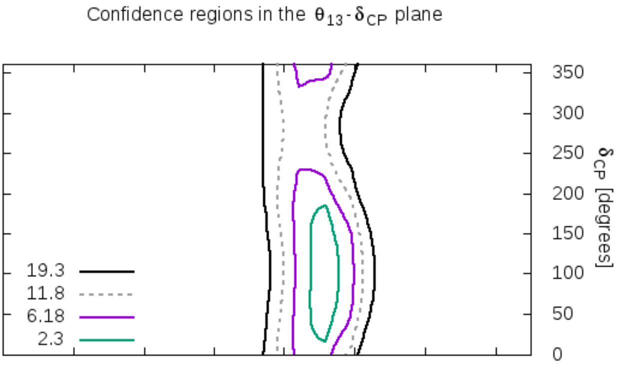

Generic three-flavor effects: θ_{13} and δ_{CP}

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6 yrs neutrino & 18 yrs anti-neutrino running, updated sys. uncert., incorporating with Reactor2.glb