Overview of AEDL

and the Implementation of Accelerator Experiments

Mark Rolinec
Technische Universität München

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Outline

- Pre-defined experiments
- Event rate calculation
- Experiment Implementation
  - Neutrino source implementation
  - Matter density profile
  - Energy smearing implementation
  - Channel and Rule definitions
- New Features in GLoBES 3.0
  - Lists as variables
  - Interpolation function
  - β-Beam flux built-in function
  - `@norm` - Historical problem cleaned up

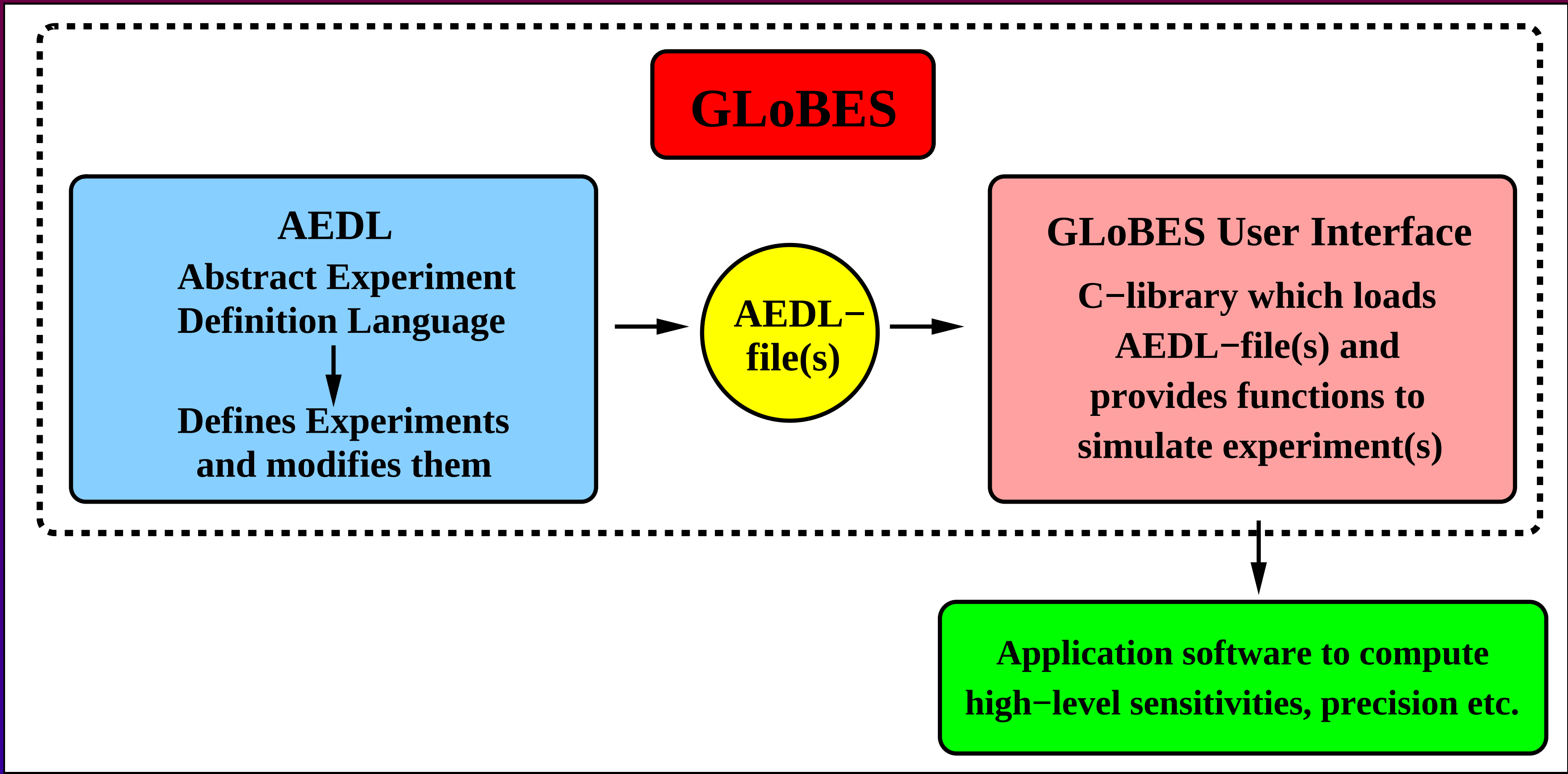
Abstract Experiment Definition Language

AEDL allows to describe a large number of complex and very different setups by a limited number of parameters within one data structure or syntax.

The experiment can be described within one file:

`Name.glb`

AEDL within GLoBES



Pre-defined AEDL-Files available with GLoBES

Pre-Defined Experiments

Superbeam Experiments

Experiment	File	Runtime	Power	Baseline	Detector	Mass
T2K	`T2K.glb`	2 yr ν/6 yr $\bar{\nu}$	0.77 MW	295 km	WC	22.5 kt
T2HK	`T2HK.glb`	4 yr ν/4 yr $\bar{\nu}$	4 MW	295 km	WC	500 kt
NOνA	`NOvA.glb`	3 yr ν/3 yr $\bar{\nu}$	1.12 MW	812 km	TASD	25 kt
SPL	`SPL.glb`	2 yr ν/8 yr $\bar{\nu}$	4 MW	130 km	WC	500 kt

Reactor Experiments

Experiment	File	Runtime	th. Power	Baseline	Det.	Mass
Small	`Reactor1.glb`	5 yr $\bar{\nu}$	4 GW	1.7 km	LS	20 t
Large	`Reactor2.glb`	8 yr $\bar{\nu}$	10 GW	1.7 km	LS	100 t
Double Chooz	`D-Chooz_near.glb`	5 yr $\bar{\nu}$	2×4.2 GW	0.1 km	LS	10.16 t
	`D-Chooz_far.glb`	5 yr $\bar{\nu}$	2×4.2 GW	1.05 km	LS	10.16 t

Pre-Defined Experiments

β-Beam Experiments

Experiment	File	Runtime	γ	Baseline	Det.	Mass
Low γ	`BB_100.glb`	4 yr ν/4 yr $\bar{\nu}$	100	130 km	WC	500 kt
Medium γ	`BB_350.glb`	4 yr ν/4 yr $\bar{\nu}$	350	730 km	WC	500kt
Variable γ	`BBvar_WC.glb`	4 yr ν/4 yr $\bar{\nu}$	variable	variable	WC	500 kt
Variable γ	`BBvar_TASD.glb`	4 yr ν/4 yr $\bar{\nu}$	variable	variable	TASD	50 kt

Neutrino Factories

Experiment	File	Runtime	E_μ	Baseline	Det.	Mass
Standard	`NFstandard.glb`	4yrν/4yr$\bar{\nu}$	50 GeV	3000 km	MID	50 kt
Variable	`NFvar.glb`	4yrν/4yr$\bar{\nu}$	variable	variable	MID	50 kt
Gold+Silver	`NF_GoldSilver.glb`	4yrν/4yr$\bar{\nu}$	variable	variable	MID ECC	50 kt 5 kt
Hybrid det.	`NF_hR_lT.glb`	4yrν/4yr$\bar{\nu}$	variable	variable	Hybrid	50 kt

Implementing an experiment in AEDL

Event Rate Computation

Differential event rates:

$$\frac{dn_\beta^{\mathrm{IT}}}{dE'} = N \int\limits_0^\infty \int\limits_0^\infty dE\, d\hat{E} \underbrace{\Phi_\alpha(E)}_{\text{Production}} \times$$

$$\underbrace{\frac{1}{L^2} P_{(\alpha\to\beta)}(E, L, \rho; \theta_{12}, \theta_{13}, \theta_{23}, \Delta m_{31}^2, \Delta m_{21}^2, \delta_{CP})}_{\text{Propagation}} \times$$

$$\underbrace{\sigma_f^{\mathrm{IT}}(E) k_f^{\mathrm{IT}}(E - \hat{E})}_{\text{Interaction}} \times$$

$$\underbrace{T_f(\hat{E}) V_f(\hat{E} - E')}_{\text{Detection}}$$

Event Rate Computation

Event rates per energy bin:

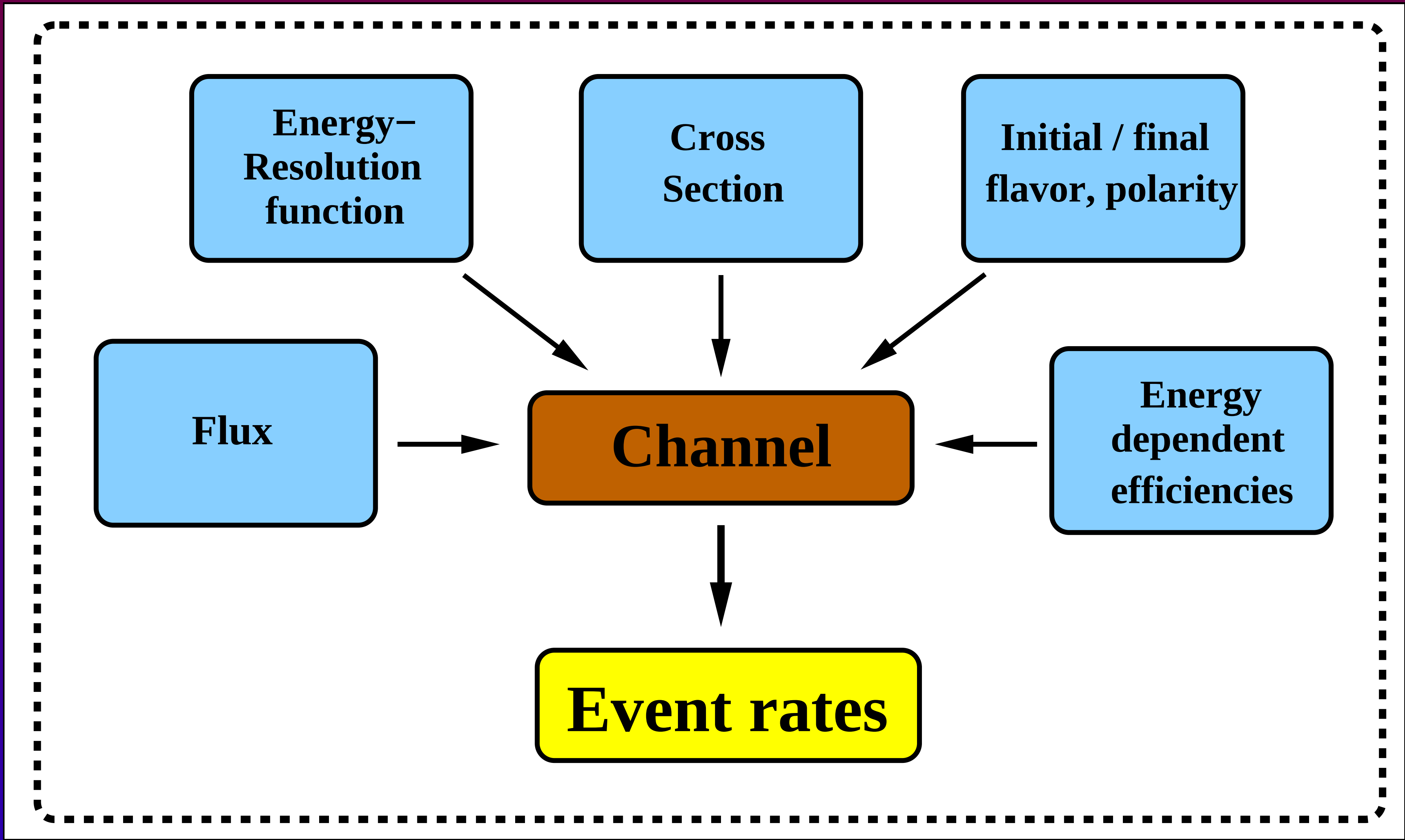
$$n_i^c = \int_{E_i-\Delta E_i/2}^{E_i+\Delta E_i/2} dE' \quad \frac{dn_\beta^{\mathrm{IT}}}{dE'}(E')$$

Effective event rate calculation:

$$n_i^c \;=\; \frac{N}{L^2} \int_{E_i-\Delta E_i/2}^{E_i+\Delta E_i/2} dE' \;\times$$

$$\times \int\limits_0^\infty dE \; \Phi^c(E)\, P^c(E)\, \sigma^c(E)\, R^c(E,E')\, \epsilon^c(E')$$

Contributions to a Channel



Neutrino Source Implementation

Flux and cross sections can be loaded from external files:

```
nuflux(#user_flux)<
@flux_file = "user_flux_file.dat"
@time = 5.0 /* years */
@power = 4.0 /* MW */
@norm = 1.0
>
```

```
cross(#CC)<
@cross_file = "XCC.dat"
>
cross(#NC)<
@cross_file = "XNC.dat"
>
```

Flux files are given with 501 lines of equidistant energy steps and seven columns:

$$\mathrm{E}_\nu\ [\mathrm{GeV}] \quad \Phi_{\nu_e} \quad \Phi_{\nu_\mu} \quad \Phi_{\nu_\tau} \quad \Phi_{\bar{\nu}_e} \quad \Phi_{\bar{\nu}_\mu} \quad \Phi_{\bar{\nu}_\tau}$$

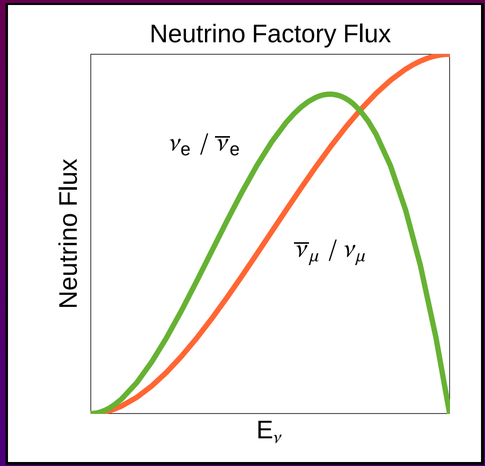
Cross section files are given with 1001 lines of equidistant logarithmic energy steps and seven columns:

$$\log_{10} \mathrm{E}_\nu\ [\mathrm{GeV}] \quad \frac{\sigma_{\nu_e}}{\mathrm{E}_\nu} \quad \frac{\sigma_{\nu_\mu}}{\mathrm{E}_\nu} \quad \frac{\sigma_{\nu_\tau}}{\mathrm{E}_\nu} \quad \frac{\sigma_{\bar{\nu}_e}}{\mathrm{E}_\nu} \quad \frac{\sigma_{\bar{\nu}_\mu}}{\mathrm{E}_\nu} \quad \frac{\sigma_{\bar{\nu}_\tau}}{\mathrm{E}_\nu}$$

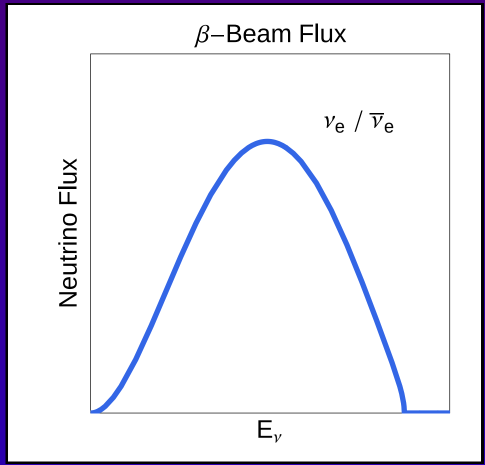
Neutrino Source Implementation

For Neutrino Factories or β-Beams GLoBES 3.0 provides a builtin flux:

```
nuflux(#nf_flux_mu_plus)<
@builtin = 1
@parent_energy = 50.0 /* GeV */
@stored_muons = 1.066e+21
@time = 4.0 /* years */
>
```




```
nuflux(#bb_nu_e_flux)<
@builtin = 3
@gamma = 100.0
@end_point = 0.0034 /* GeV */
@stored_muons = 2.2e+18
@time = 4.0 /* years */ >
```



Experiment Baseline and Matter Density

Three different matter density profiles can be used with GLoBES:

```
$profiletype = 1
$baseline = 3000.0 /* km */
$density = 2.7 /* g cm^-3 */
```

Density Profile #1

Baseline

Constant Average Density

```
$profiletype = 2
$baseline = 3000.0 /* km */
$densitysteps = 5
```

Density Profile #2

Baseline

PREM Profile - Equidist. Steps

```
$profiletype = 3
$lengthtab = {1200.0,600.0,.1200.0} /* km */
$densitytab = {2.7,3.6,2.7} /* g cm^-3 */
```

Density Profile #3

Baseline Intervals

corresp. av. Matter Density

Energy Window of the Analysis

```
$target_mass = 50.0 /* kt */
```

Mass of detector (fiducial volume)

```
$emin = 4.0 /* GeV */
$emax = 50.0 /* GeV */
$bins = 20

$sampling_min = 4.0 /* GeV */
$sampling_max = 50.0 /* GeV */
$sampling_points = 20
```

Energy window:
Reconstructed neutrino energy
Analysis level (after energy smearing)

Energy window:
True neutrino energy
Integral Evaluation (before energy smearing)

```
$binsize = {1.5,2.0,2.5,...}
```

INSTEAD of `$bins`: Variable Binsize

```
$sampling_stepsize = {1.5,2.5,...}
```

INSTEAD of `$sampling_points`

Implementation of Energy Smearing

GLoBES internal energy resolution function:

$$R(E,E') = \frac{1}{\sqrt{2\pi}\sigma(E)}\, e^{-\frac{(E-E')^2}{2\sigma^2(e)}}$$

```
energy(#ERES)<
@type = 1
@sigma_e = (alpha,beta,gamma) >
```

Gaussian energy resolution function:

with width σ:

$\sigma(E) = \alpha \times E + \beta \times \sqrt{E} + \gamma$

Manually defined smearing matrix:

```
energy(#manual_smearing_matrix)<
@energy =
{0,2,0.863,0.182,0.00267}:
{0,3,0.151,0.697,0.151,0.00101}:
...
{16,19,0.00936,0.278,0.483,0.136};
>
```

Manual energy smearing:

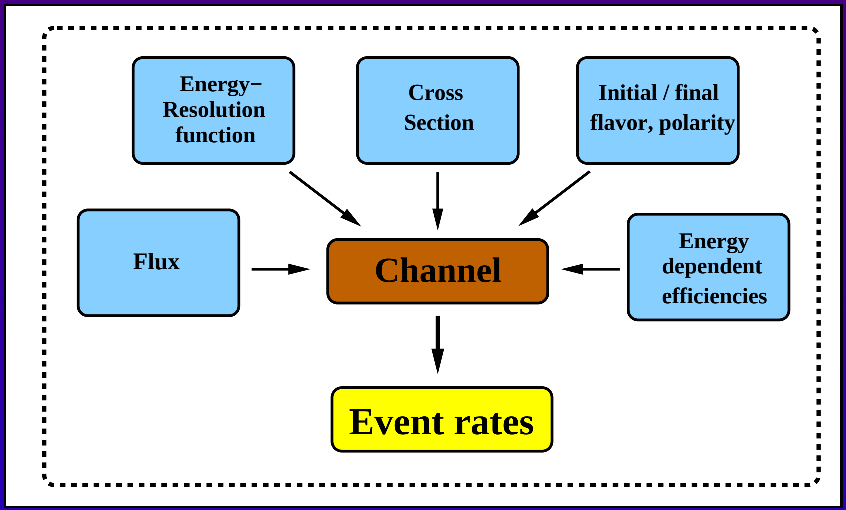
energy smearing matrix M_{ij}

- number of rows: `$bins`
- number of columns: `$sampling_points`

Definition of Channels

```
channel(#nu_mu_dissappearance)<
@channel = #user_flux :  +:  m:  m:  #CC: #ERES
@pre_smearing_efficiencies = {0.333,0.666,0.999,1.,1., ...  ,1.,1.}
>
```

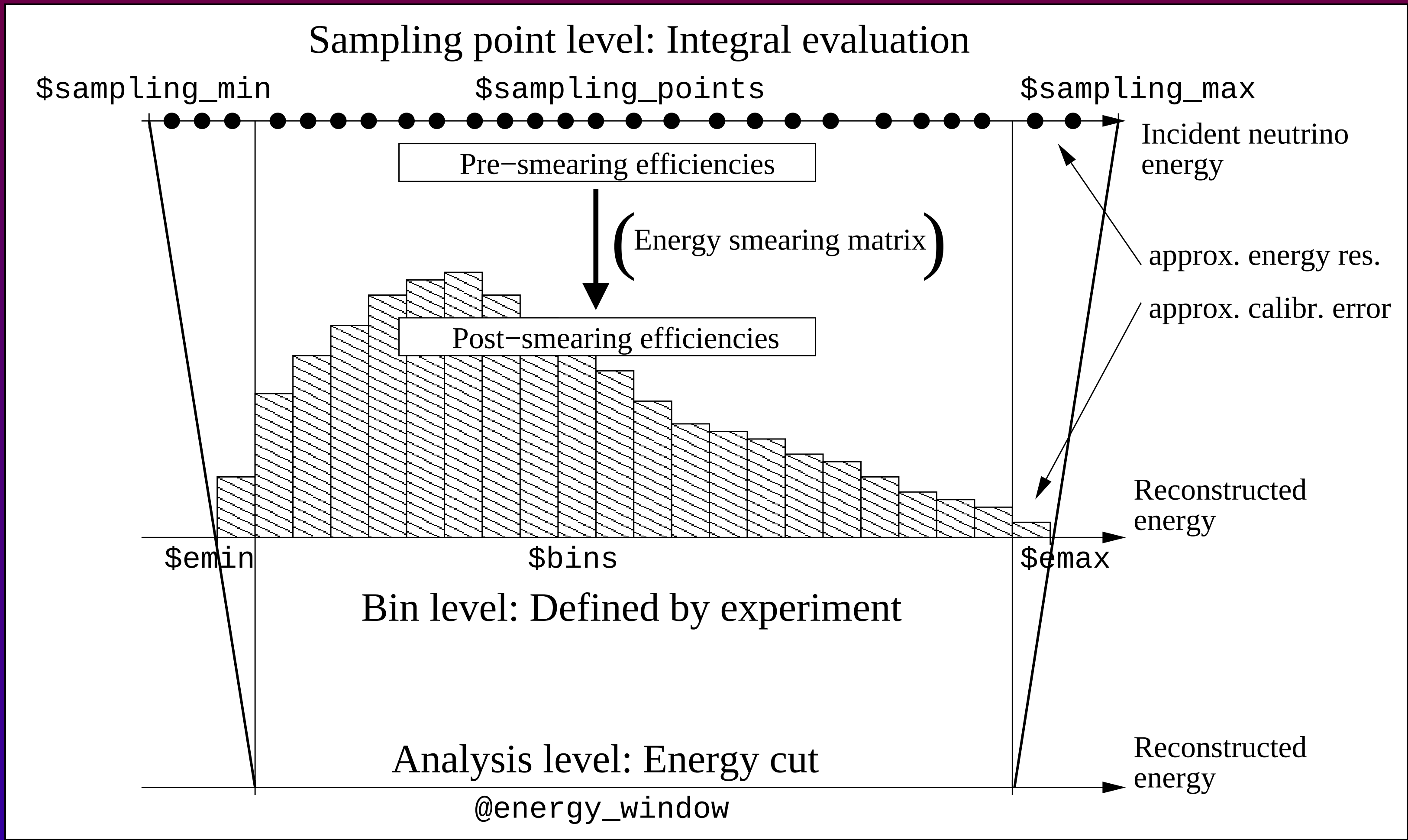
```
channel(#nu_mu_NC_bckg)<
@channel = #user_flux :  +:  NOSC_m:  NOSC_m:  #NC:
#manual_smearing_matrix
>
```



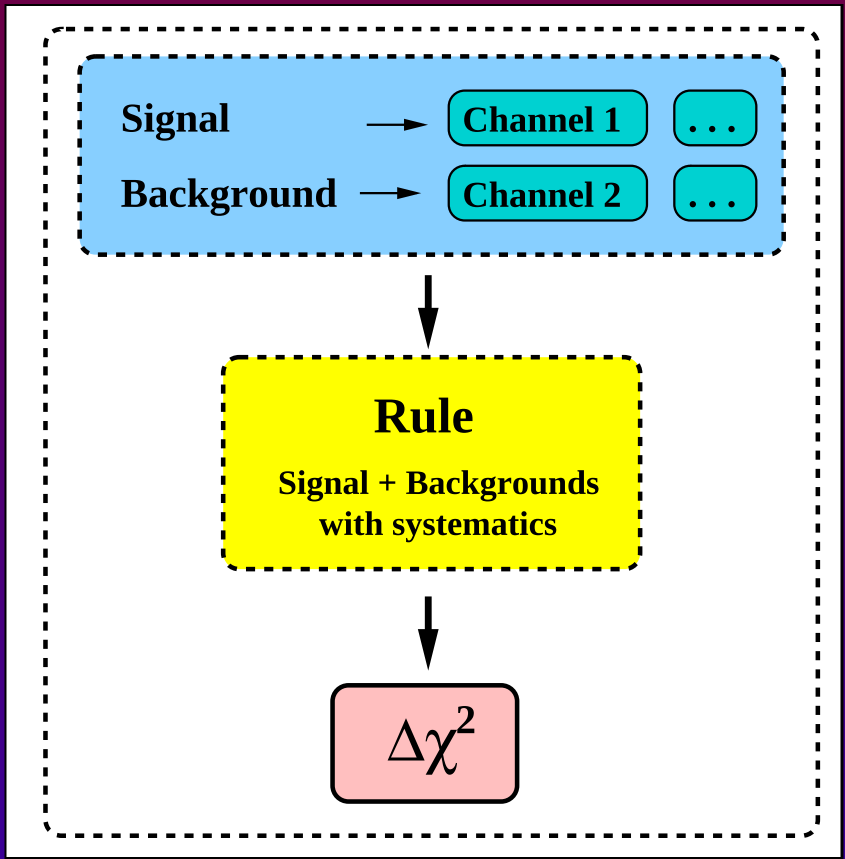
Additional features:

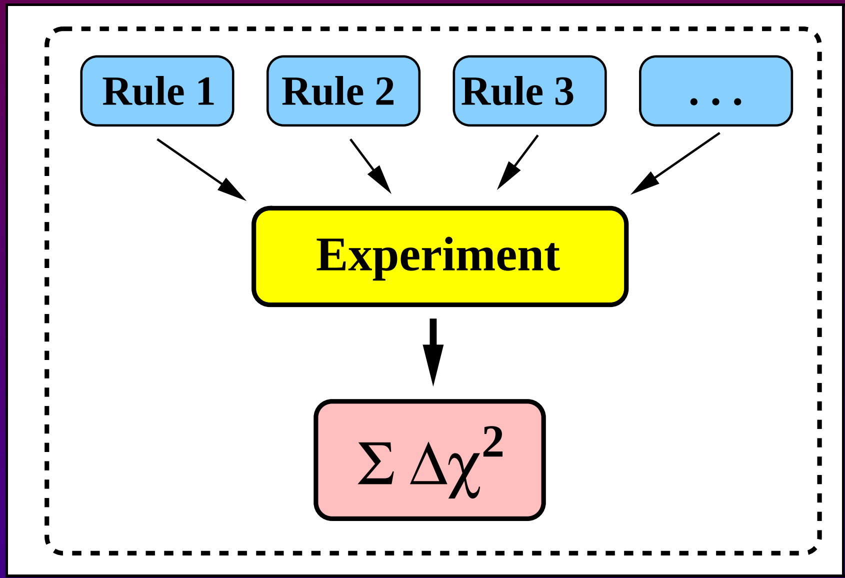
- @post_smearing_efficiencies
- @pre_smearing_background
- @post_smearing_background

Evaluation levels



From Channels to Rules





Implementation of Rules

```
rule(#Nu_Mu_DIS)<
@signal = 0.86@#nu_mu_disappearance
@signalerror = 0.04 :  0.0001

@background = 0.11@#nu_mu_NC_bckg :  0.11@#nu_e_NC_bckg :  0.05@#BCKG_3
@backgrounderror = 0.05 :  0.0001

@sys_on_function = "chiSpectrumTilt"
@sys_off_function = "chiNoSysSpectrum"

@energy_window = 4.0 :  50.0
>
```

New Feature: Systematics function called by a string

Systematics Functions

Systematics function	a	b	c	d	Tilt/Calibr.	Dim.	Remarks
Standard systematics:							
`chiSpectrumTilt`	+	+	+	+	T	0	Systematics with tilt
`chiNoSysSpectrum`	-	-	-	-	-	2	No systematics, but spectral information
`chiTotalRatesTilt`	+	+	+	+	T	4	Total rates
`chiSpectrumOnly`	∞	-	-	-	-	7	Spectrum only
`chiNoSysTotalRates`	-	-	-	-	-	8	Total rates, no syst.
`chiSpectrumCalib`	+	+	+	+	C	9	Systematics with calibr.
User-defined systematics:							
`chiZero`	-	-	-	-	-	n/a	Passive rule (χ^2 returns zero)
Any other name	User-defined behavior					n/a	User-defined syst.

Implementation of User-Defined Systematics

```
rule(#Nu_E_BAR_DIS)<
@signal = 1.0@#nu_e_bar_disappearance

@background = 1.0e-6@#bckg

@sys_on_function = "NAME_UserDefinedFunction"
@sys_on_errors = {0.1,0.05,0.2} /* e.g.  three sys.  errors */

@sys_off_function = "chiNoSysSpectrum"
@sys_off_errors = { }
>
```

New Features - `nuflux`

Former Times:

$$\texttt{@norm} = \frac{1}{5.2}\left(\frac{\mathrm{GeV}}{\Delta E}\right)\left(\frac{\mathrm{cm}^2}{A}\right)\left(\frac{L}{\mathrm{km}}\right)^2\left(\frac{\tau}{m_u}\right)\times 10^{-38}\times\left(\frac{\mathcal{L}_u}{\mathcal{L}}\right)$$

Older Versions		GLoBES 3.0

`flux(#user_flux)<`
`@flux_file =`
`"flux_file.dat"`
`@time = 5.0 /* years */`
`@norm = 1/5.2`
`>`
	=	`nuflux(#user_flux)<`
		`@flux_file =`
		`"flux_file.dat"`
		`@time = 5.0 /* years */`
		`@norm = 1.0`
		`>`

`flux`		`nuflux`

`nuflux` does not apply to built-in fluxes (no change of normalization factors)

New Features - Lists as Variables in AEDL

List Interpolation in AEDL:

```
%effs = {0.333,0.666,0.999,1.0,1.0, ...  ,1.0,}
%energ = {0.5,1.0,1.5,2.0, ...  ,50.0}
%bc = bincenter()
%neweffs = interpolation(%energ,%effs,1,%bc)
```

Implementation to Channels:

```
channel(#nu_mu_dissappearance)<
@channel = #user_flux :  +:  m:  m:  #CC: #ERES
@pre_smearing_efficiencies = copy(%neweffs)
>
```

- Allowed interpolation orders: 1 (linear) and 2 (cubic)
- Provided: `bincenter()` and `samplingbincenter()`

New Features - Summary

- β-Beam built-in flux provided
- Systematics functions as strings in AEDL
- Used-defined systematics available
- `nuflux` - Historical normalization problem cleaned up
- Lists as variables in AEDL
- Interpolation feature