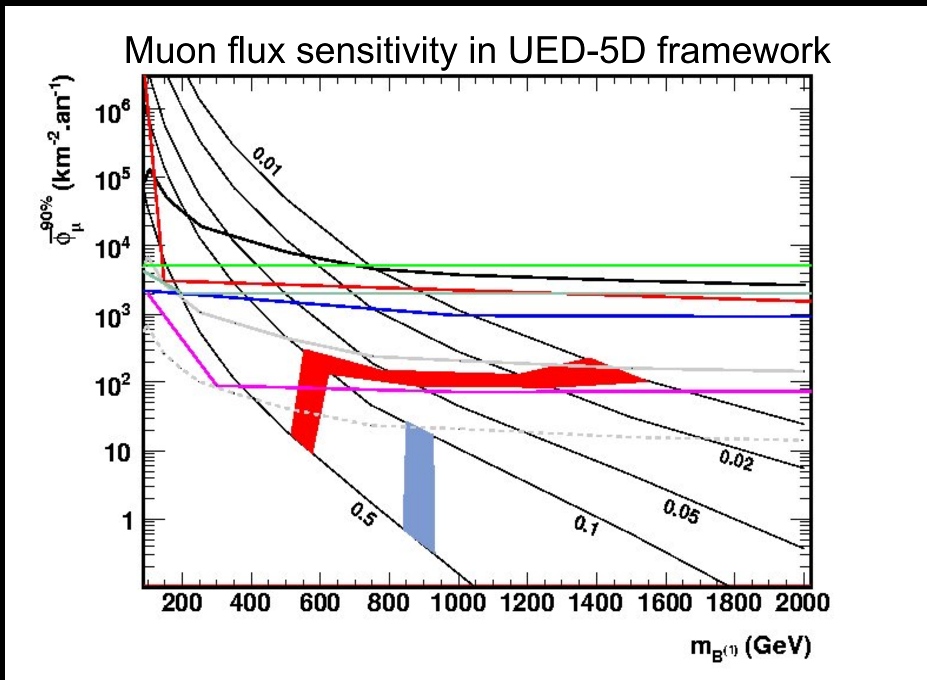
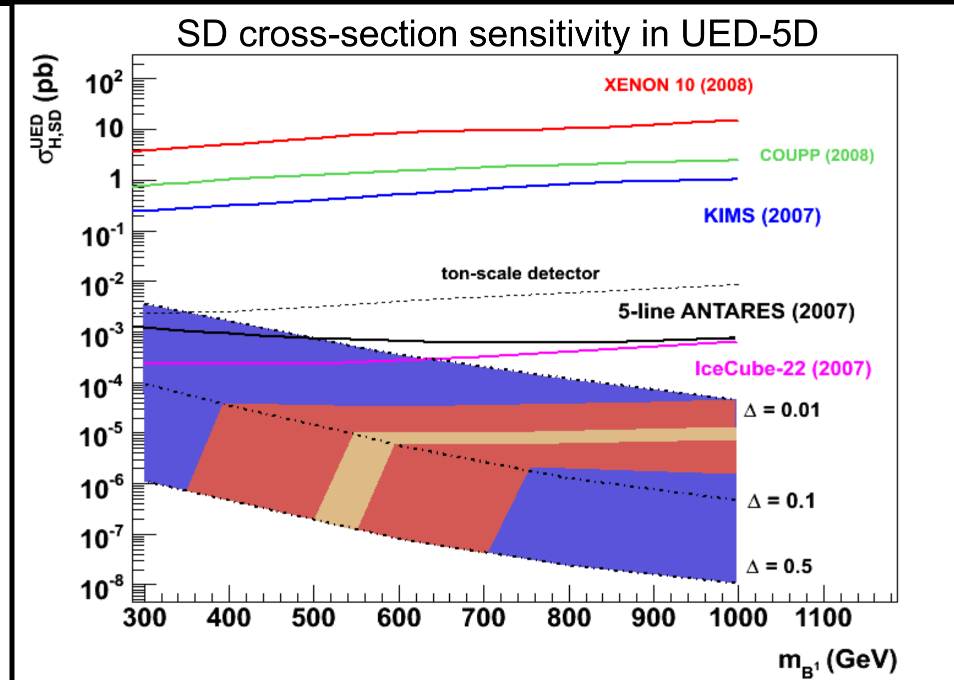
Indirect Dark Matter search in the Sun direction using the data 2007-2008 for the two common theoretical framework (CMSSM, mUED)

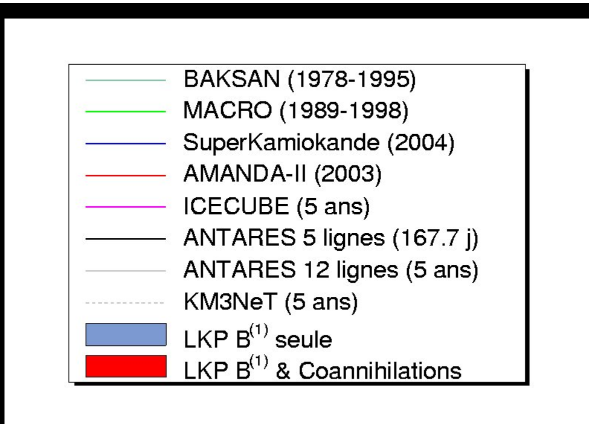
Guillaume LAMBARD on behalf of the ANTARES collaboration
IFIC/CSIC/MultiDark project

12/10/2011

Previous results







From 5-line scrambling data constraints in (Δ, m_{LKP})

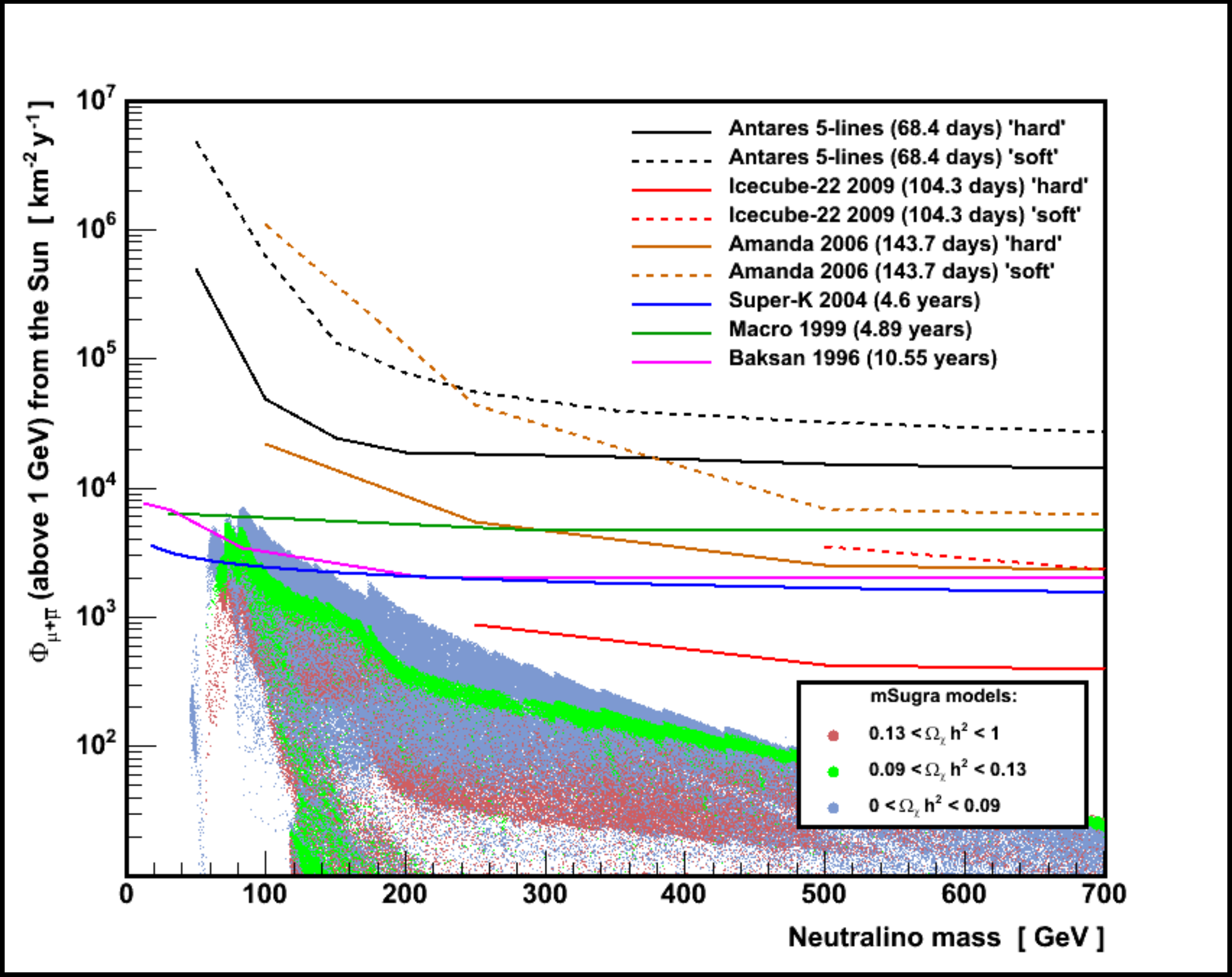
Prospectives for 12-line (5 years)
Closed to the WMAP constraints

Allowed (Δ, m_{LKP})
$0.05 < \Omega_{CDM}h^2 < 0.20$
$0.1037 < \Omega_{CDM}h^2 < 0.1161$
(WMAP, 1σ)

IceCube-22 (~104 days)
ANTARES 5-line (~135 days)
XENON 10, COUPP (2008)
KIMS (2007)

Previous results

Muon flux sensitivity in CMSSM framework



Comparison:

IceCube: Phys. Rev. Lett. 102, 201302 (2009):

104.3 effective days

Amanda: Astropart. Phys. 24, 459 (2006)

257.7 days (tot. data taking period) *

0.789 (deadtime correction) *

0.707 (sun below horizon) =

143.7 effective days

SuperK: Phys. Rev. D 70, 083523 (2004)

5.3 years (tot. data taking period)

→ 4.6 effective years

Macro: Phys. Rev. D 60, 082002 (1999)

10 years (tot. data taking period)

→ 1.38+0.41+3.1=4.89 effective years

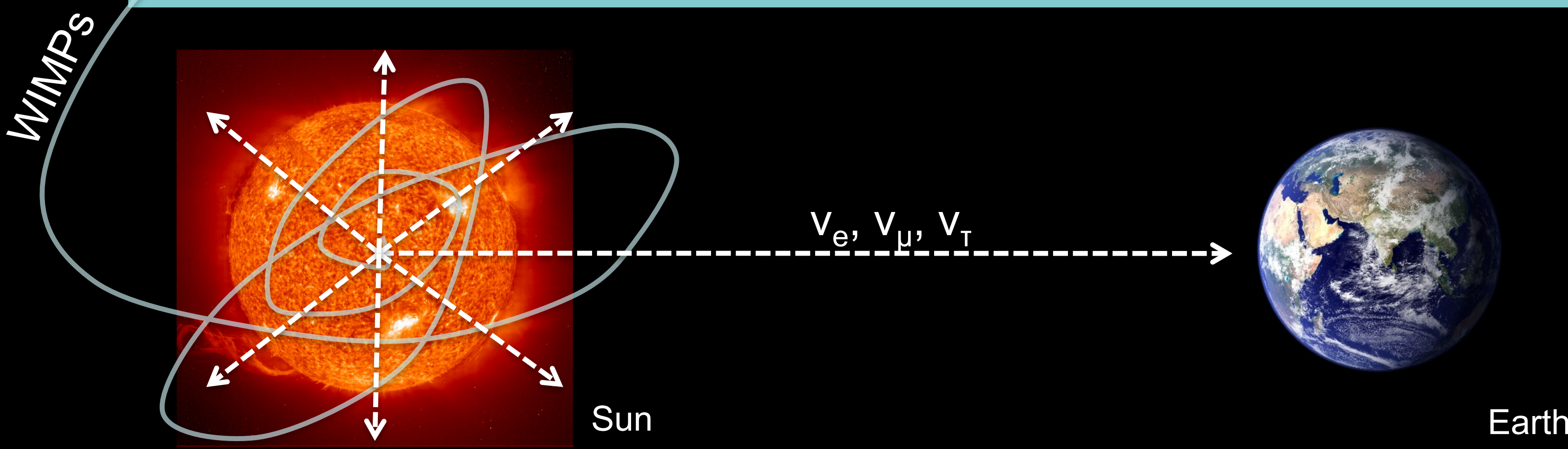
Baksan: Proc. DARK' 96 Heidelberg (1996)

15 years (tot. data taking period)

→ 10.55 effective years

Dark Matter Simulation

Independent-model production

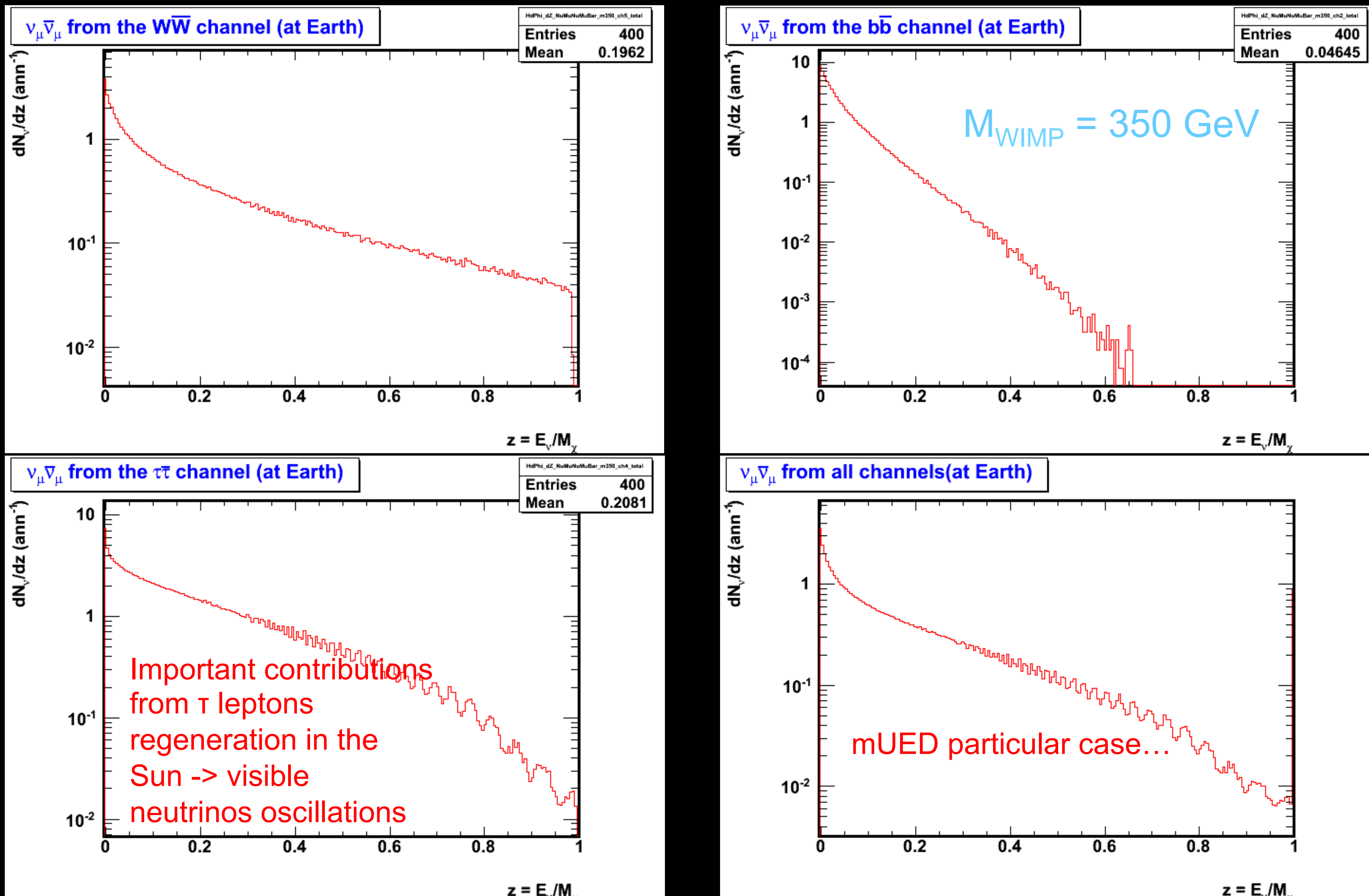


- Blennow, Edsjö, Ohlsson (03/2008): “WIMPSIM” model-independent production
- Great statistics with 12×10^6 WIMPs annihilations (CC-Lyon)
- Capture rate and annihilations in equilibrium at the Sun core
- Annihilations in c,b and t quarks, τ leptons and direct channels
- Interactions taken into account in the Sun medium
- Three flavors oscillations, regeneration of τ leptons in the Sun medium (Bahcall et al.)
- available parameters (WIMPs mass, oscillations parameters, ...)

Dark Matter Simulation

Independent-model production

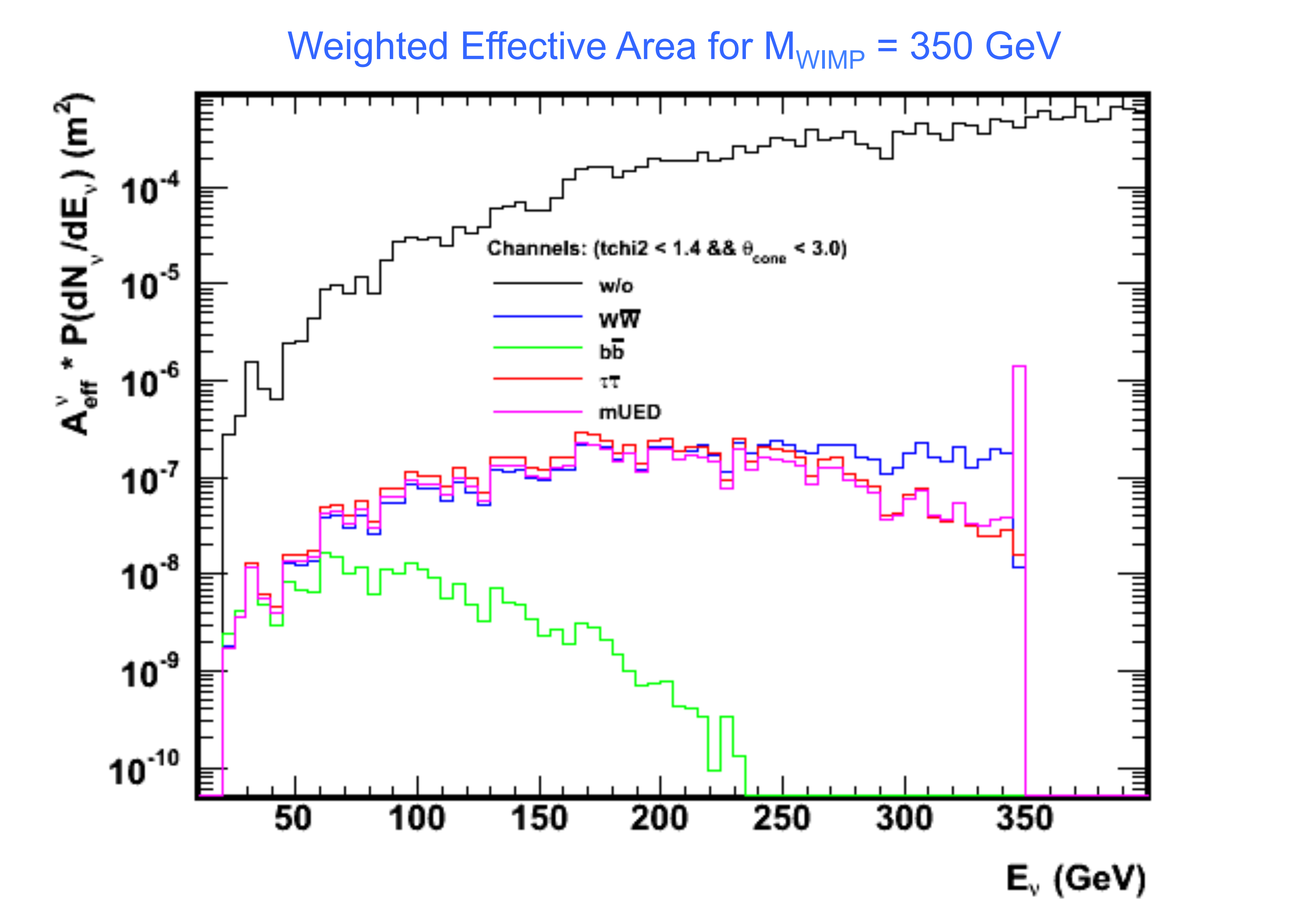
MAIN ANNIHILATION



CHANNELS

Dark Matter Simulation

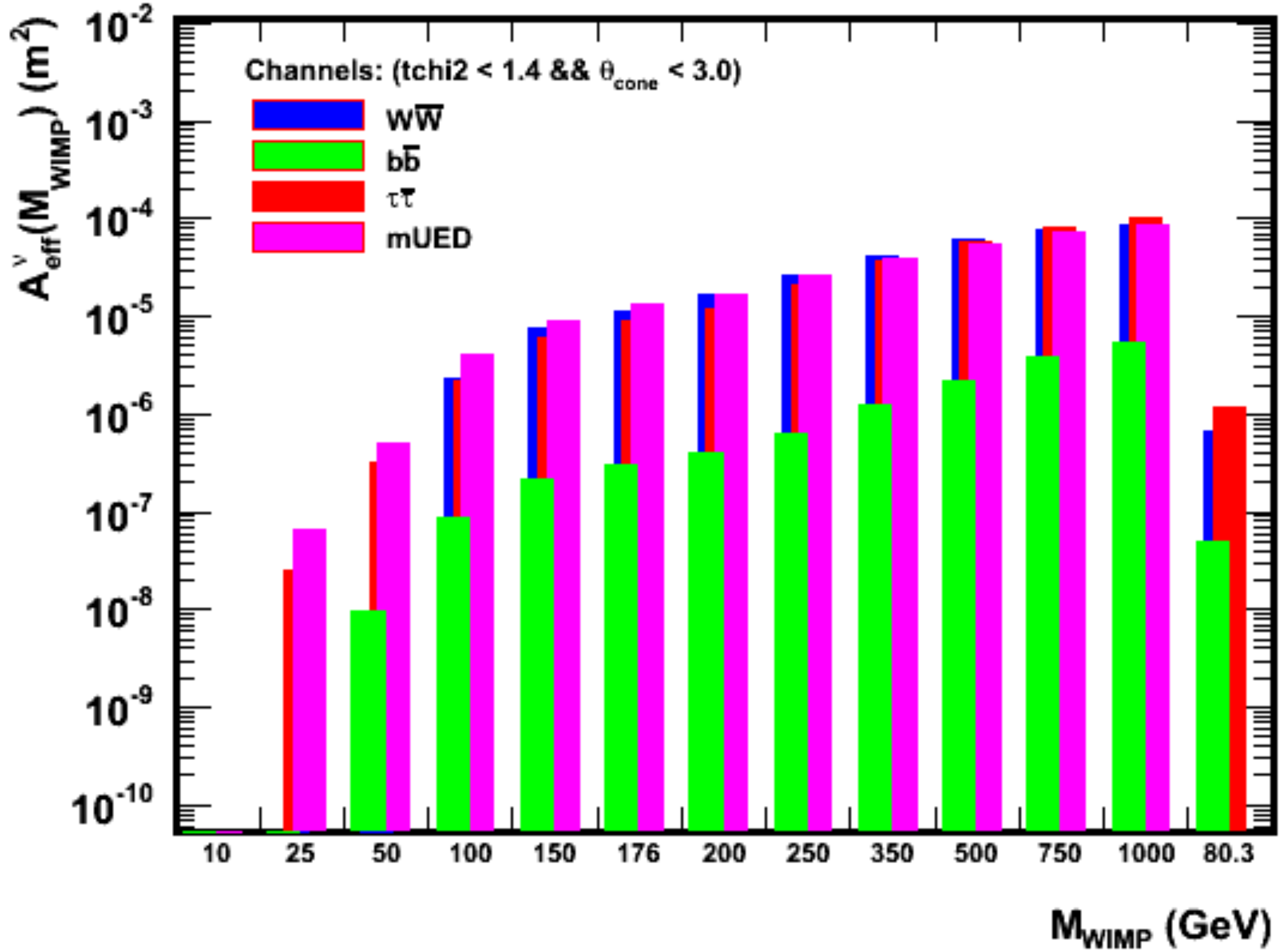
Independent-model production



Dark Matter Simulation

Independent-model production

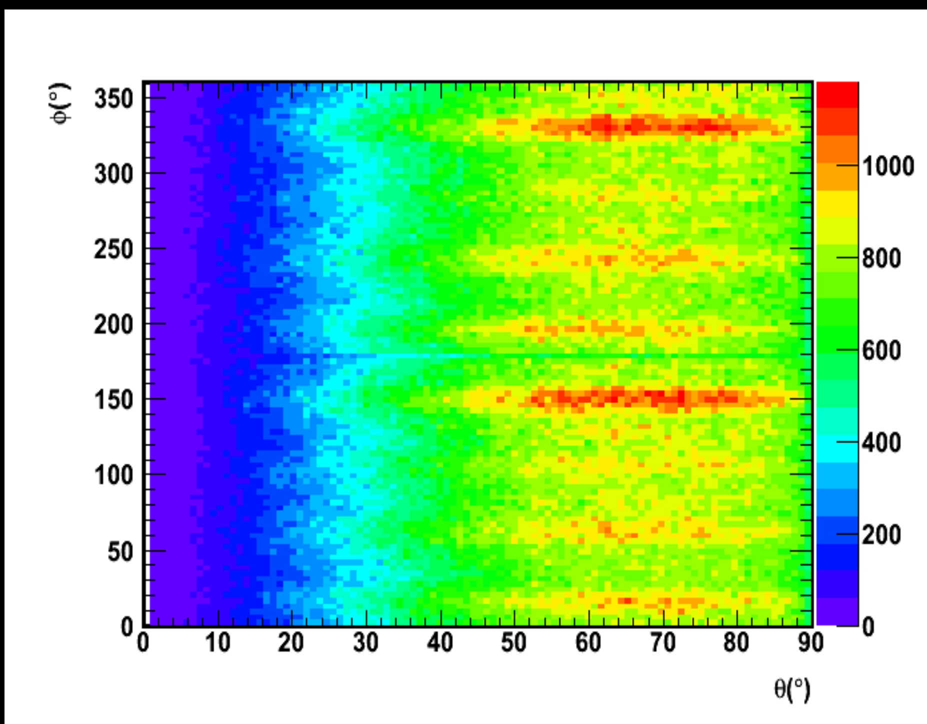
Define an Effective Area per channel per WIMP mass



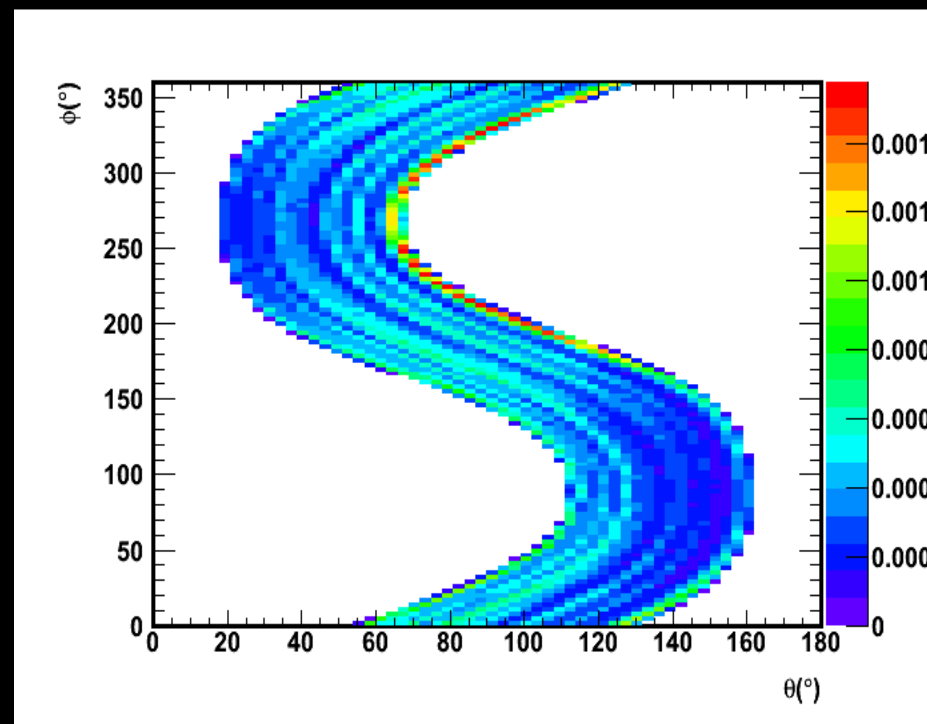
Background in the Sun direction

- Using the scrambled data 2007-2008 (from 5 to 12 lines) in (theta, phi), time (Modified Julian Date) (~294.6 days)
- Fast algorithm for muon track reconstruction (Astro. Phys. 34 (2011) 652-662)
- Using the Sun distribution weighted by its visibility for Antares
- Same « astro » package used for both, consistent MJD check, from Seatray

All upward-going events from 2007-2008 data



Example of Sun tracking in horizontal coordinates

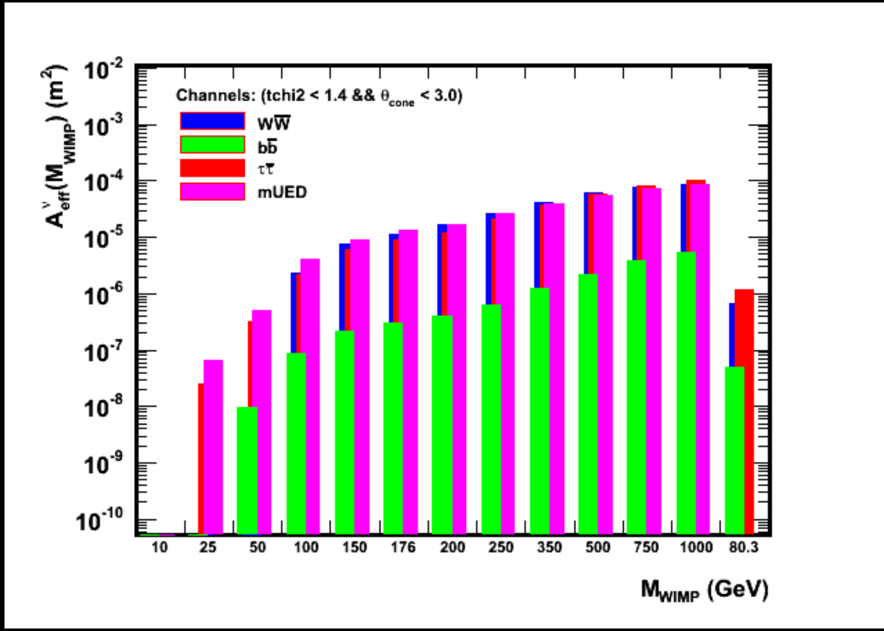


Dark Matter Signal and cuts optimisation

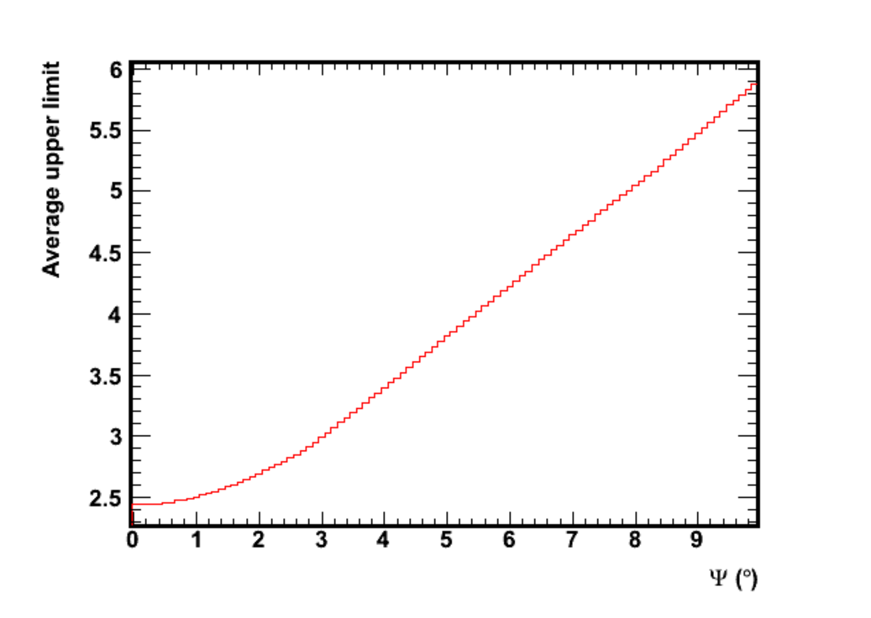
- Neutrino flux at the earth, from the Dark Matter coannihilation, are convoluated with the efficiency of the detector for a cuts parameter space (Q,cone)
- Neutrino background from the scrambled data in the Sun direction is evaluated in the same space
- Minimize this quantity:

$$Sensitivity = \frac{\bar{\mu}_{90}}{Aeff(Mwimp) * Teff}$$

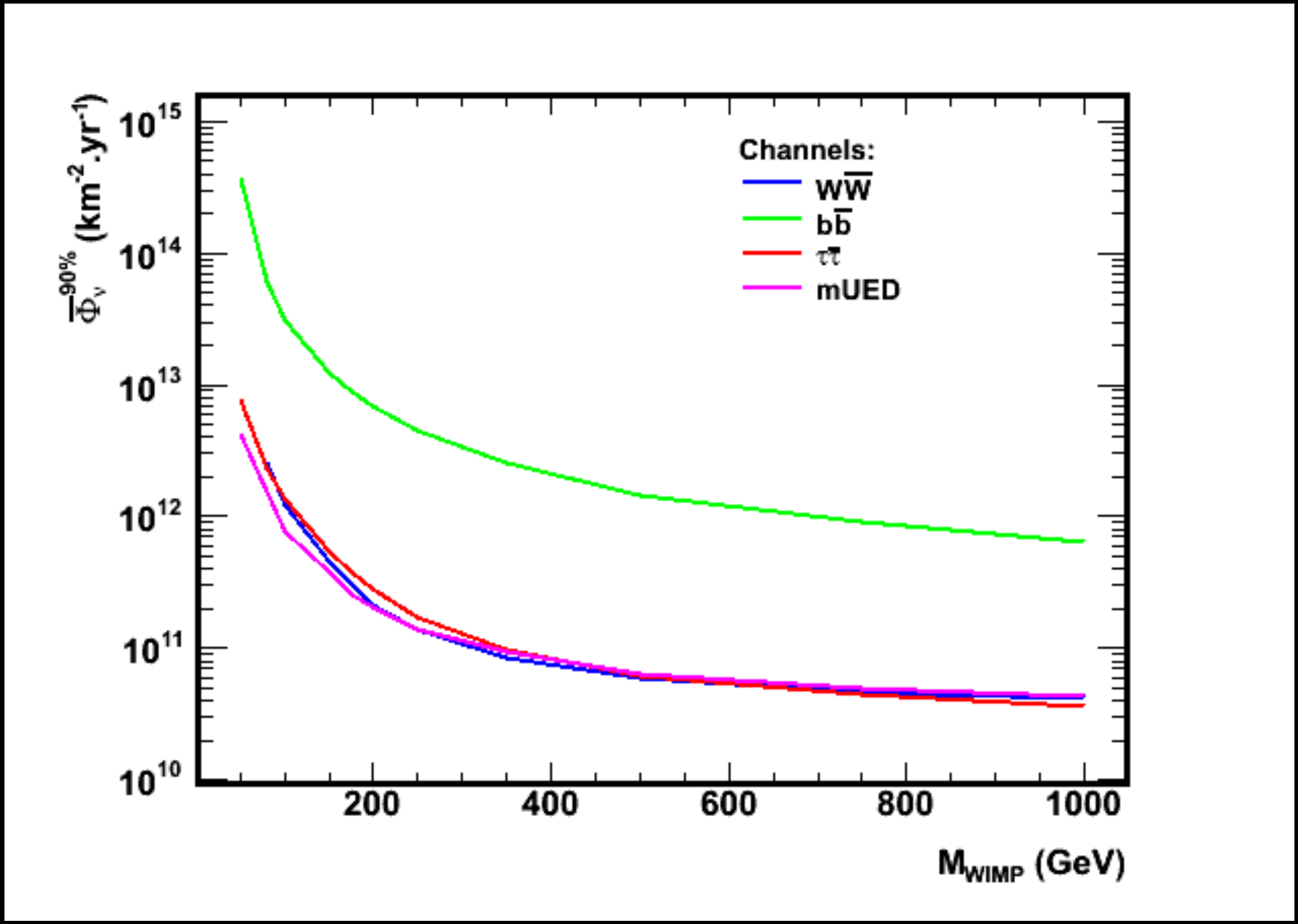
Effective area to be estimated for different sets (Q,cone)



Average upper limit (Feldman-Cousins)



Dark Matter Signal and Neutrino flux sensitivity



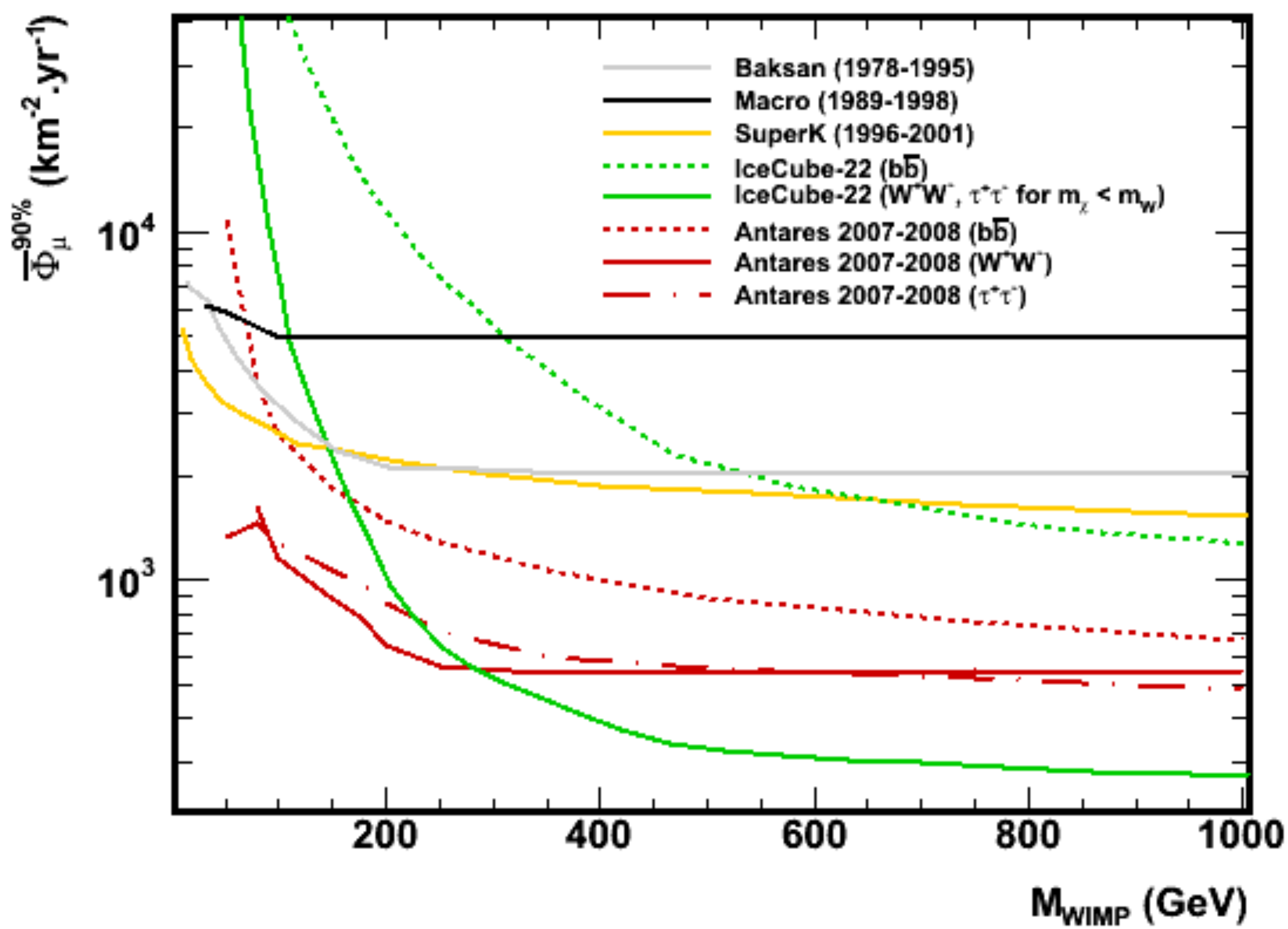
For CMSSM:
Branching ratios = 1
(WW, bb, ττ)

For mUED:
Theoritical branching ratios taken into account

<u>Reason:</u>
High dependence of branching ratios over CMSSM parameter space

Φ_ν X σ_ν X R_μ X Nucleon density X $P_{earth} \longrightarrow \Phi_\mu$

Dark Matter Signal and CMSSM Muon flux sensitivity



Flux Φ_μ

↕

Annihilation rate Γ

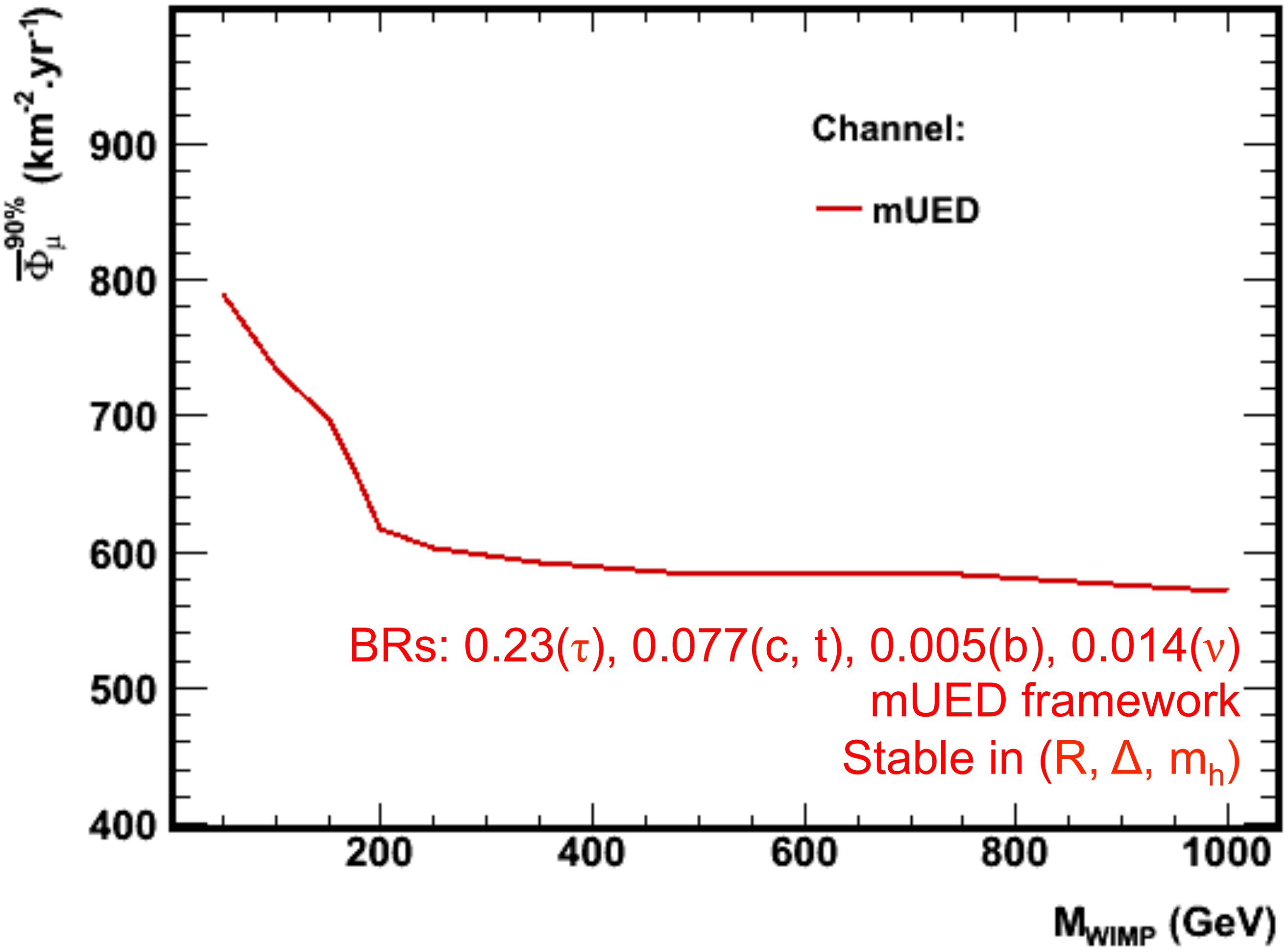
↕

Capture rate C

↕

Cross-section σ_{SD}

Dark Matter Signal and mUED Muon flux sensitivity



Flux Φ_μ

↕

Annihilation rate Γ

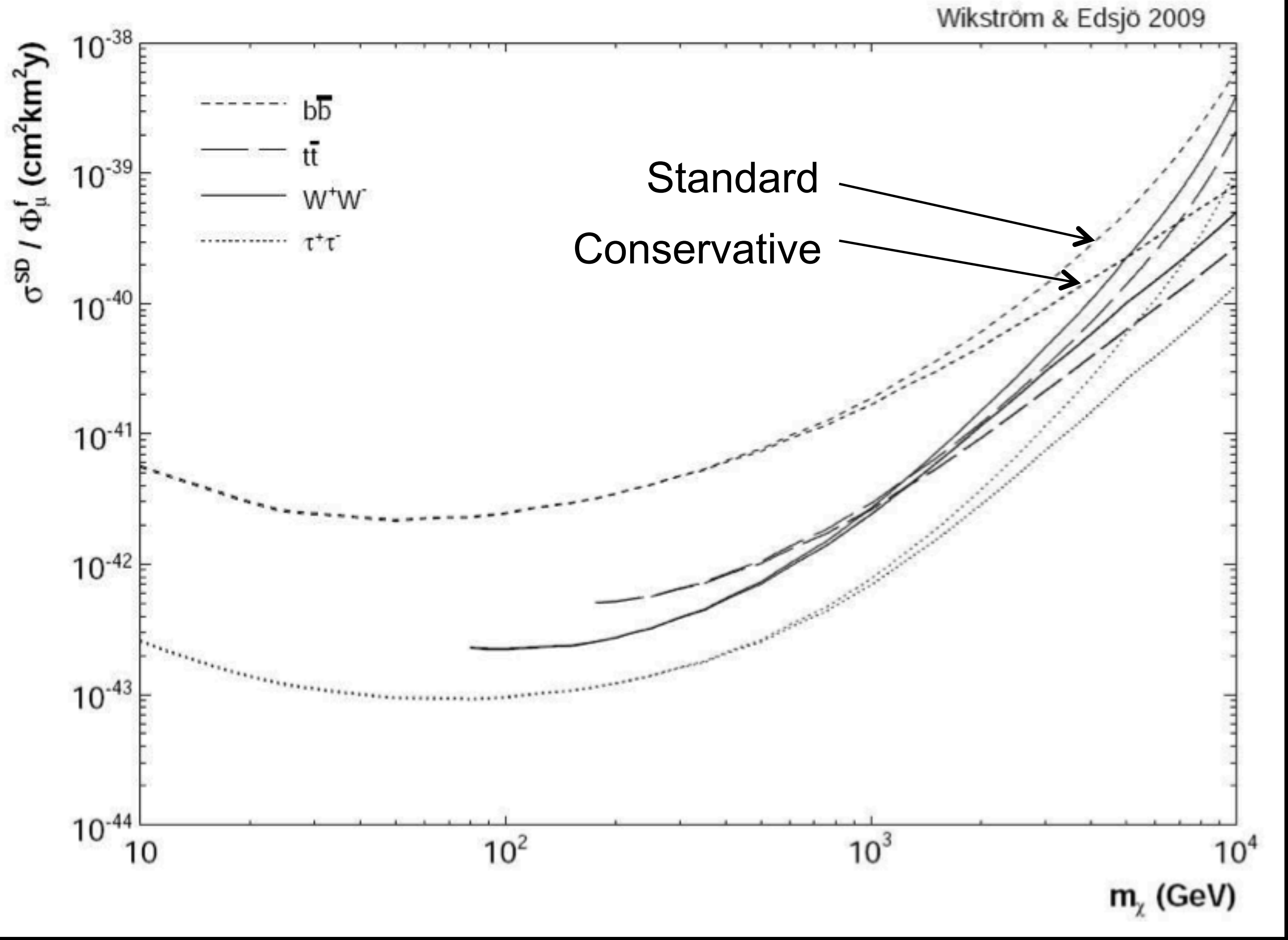
↕

Capture rate C

↕

Cross-section σ_{SD}

From Dark Matter muon flux to the SD cross-section



Conservative:

- Jupiter Effect
- w/o additional disk in the dark matter halo
- local density 0.3 GeV.cm^{-3}

(arxiv:0903.2986v2)

Signal computation method

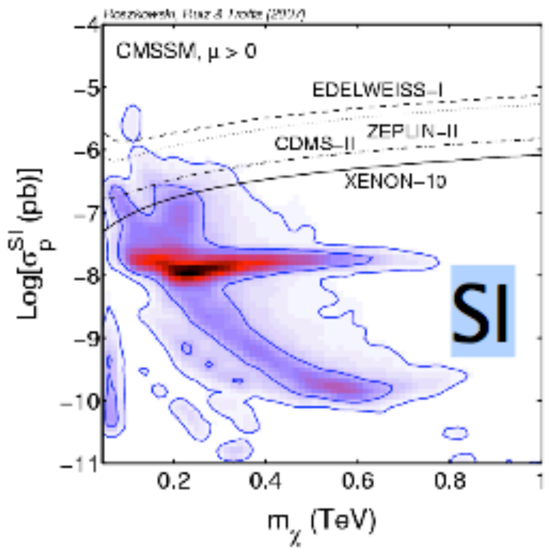
- Usually, we need :
  - Flux (example: WW) at the surface of the Earth
  - Capture rate into the Sun, dependent on the SD, SI cross-section
  - Annihilation rate Γ ~ 0.5 * C (equilibrium condition)

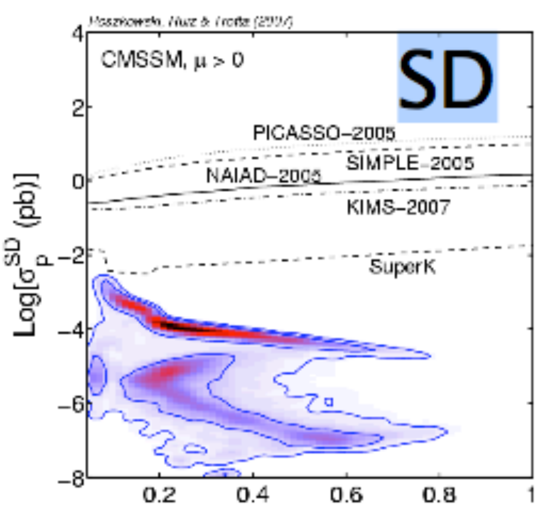
$$\frac{d\varphi}{dEd\Omega} = \frac{\Gamma}{4\pi d^2}\sum_{\iota} B_{\iota}\frac{dN_{\iota}}{dE_{\iota}}$$

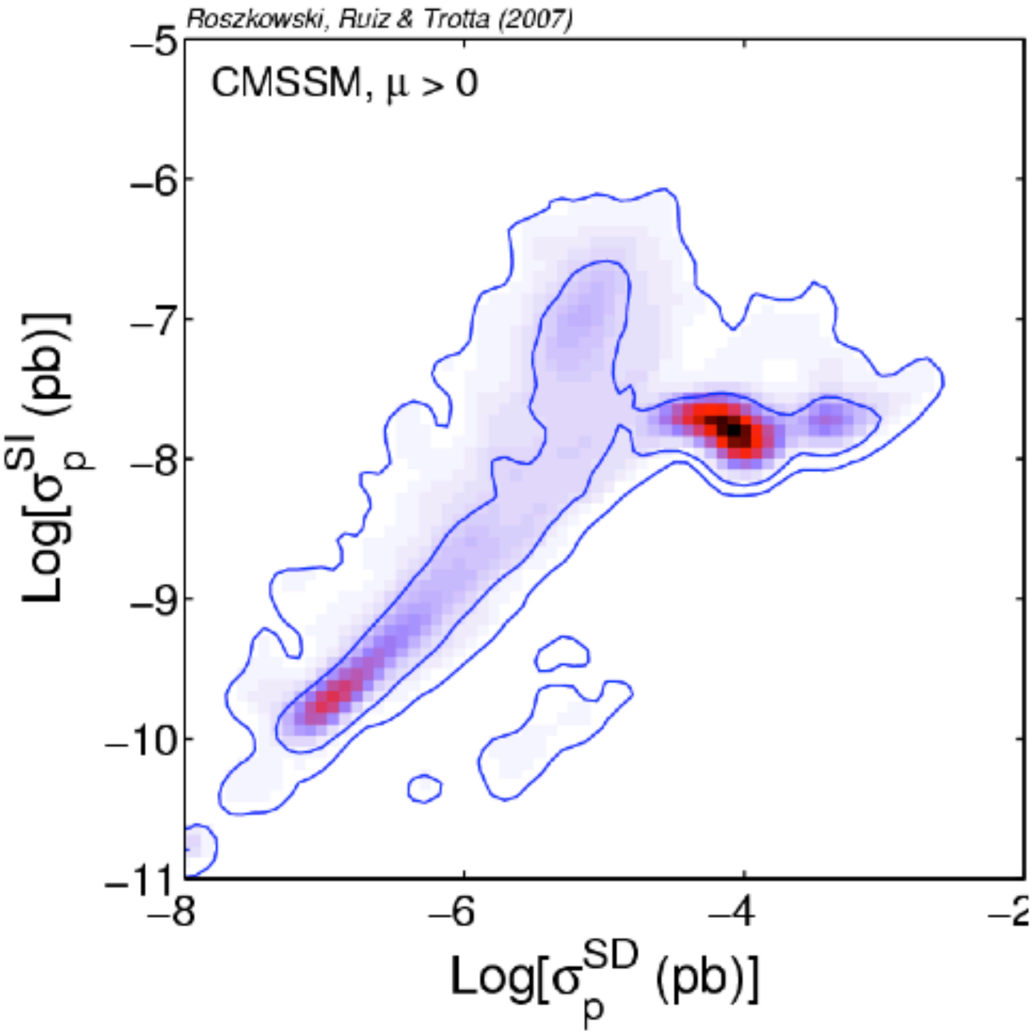
$$C_{\otimes} \simeq 3.35\times 10^{18} s^{-1} \times \left(\frac{\rho_{local}}{0.3\,GeV.cm^{-3}}\right) \times \left(\frac{270\,km.s^{-1}}{v_{local}}\right) \times \times \left(\frac{\sigma_{H,SD}}{10^{-6}\,pb}\right) \times \left(\frac{TeV}{M_{WIMP}}\right)^2$$

  - Flux from WIMPSIM
  - Cross-section from Analytic computation, or simulation in the parameter space of the models
  - For Kaluza-Klein, Branching ratio not so dependent on the location in the parameter space (R, Δ, and SM Higgs mass m_h)
  - For CMSSM, it's different… Equilibrium in the Sun well/not reached, SD/SI very dependent on the parameter space, branching ratios very dependent, main channel chosen is not so obvious -> large systematic from the sensitivity computed
  - Need a simulation, and fast one, to compute the cross-sections, the capture rate, etc, for the allowed parameter space

SuperBayes v1.35







SuperBayes v1.35

Supersymmetry Parameters Extraction Routines for Bayesian Statistics

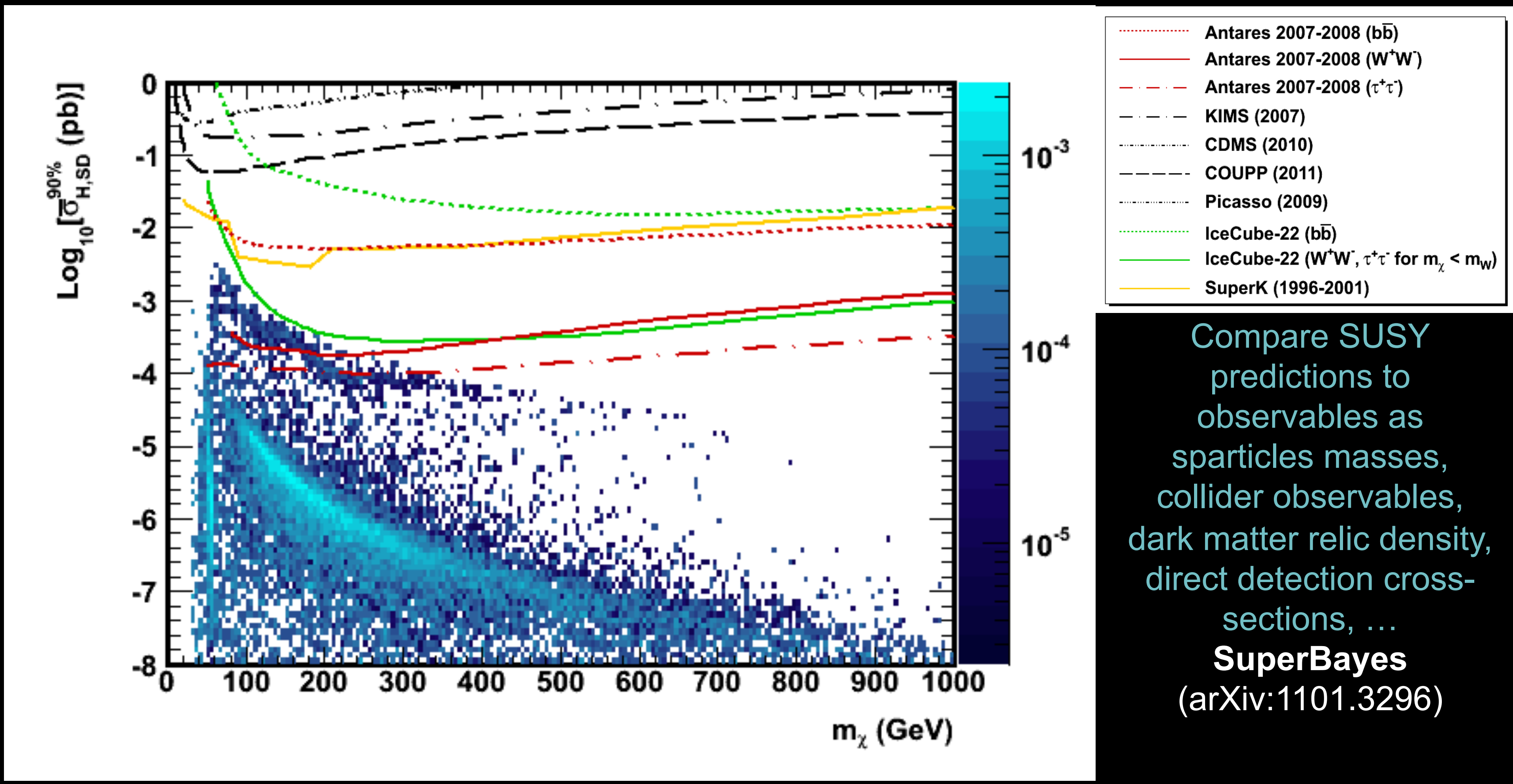
- Multidimensional SUSY parameter space scanning
- Compare SUSY predictions to collider observables, dark matter relic density, direct detection cross-sections, …
- Using a new generation Markov Chain Monte Carlo for a full 8-dim scan of CMSSM
- Using PISTOO farm at CC-Lyon to run it

- Well documented (articles, Website), as DarkSUSY package

- Parameter set of CMSSM (m_0, $m_{1/2}$, A_0, $\tan\beta$) (fixing sgn(μ)>0)
- « Nuisance parameters » from SM (m_t, m_b, α_{em}, α_s)

Dark Matter Signal and CMSSM SD cross-section sensitivity

Spin-dependent cross-section sensitivity for ANTARES 2007-2008



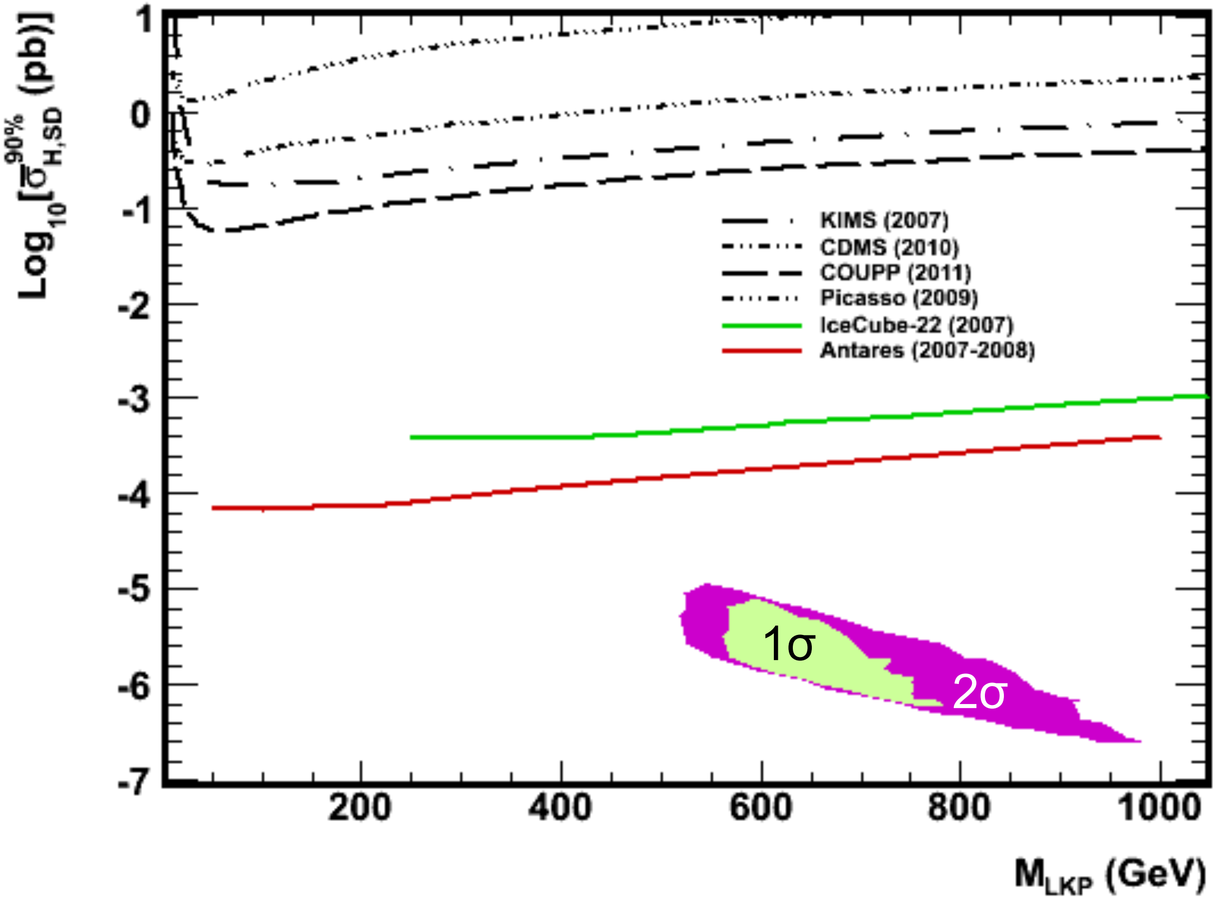
Compare SUSY predictions to observables as sparticles masses, collider observables, dark matter relic density, direct detection cross-sections, …

SuperBayes
(arXiv:1101.3296)

Dark Matter Signal and

mUED SD cros-section sensitivity

Spin-dependent cross-section sensitivity for ANTARES 2007-2008



Compare mUED predictions to observables as KK masses, collider observables, relic density, direct detection cross-sections, …
SuperBayes
modified version
(Physical Review D 83, 036008 (2011))

Summary &

Open questions

- Reached the sensitivities for the CMSSM, and mUED, in muon flux, and spin-dependent cross-section, with comparisons to the other experiments
- Antares and IceCube gives an opportunity to constraint the dark matter parameter spaces
- Huge complement to the direct detection experiments

- Limits from unblind data 2007-2008 in progress...
- Next step, similar analysis with the ANTARES data 2007-2010 (in progress…) for the Sun, galactic center, and halo

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- Presentation of the results?
- Sensitivities in muons (neutrino experiments) and neutrinos (theorists)?
- Theoretical parameter space directly constrained (theory) or not (detectors ability)?
- Mixing tau and W channels?
- What kind of Dark Matter models? (mUED, CMSSM, pMSSM, NMSSM-7, …)

- What kind of galactic halos (NFW, Moore, Einasto, Isotherm, …)? All I guess
- Rule on the local density parameter [0.3;0.4] GeV.cm^{-3}

BACK-UP

BBFit MC Versus Data

- Data 2007-2008 Versus Monte-Carlo needed
- Arguments to use the scrambled data
- Arguments to use the Effective Area as a factor of efficiency to compute the signal

- Using a recent BBFit (v4r0) to reconstruct events from MC and Data
- A time smearing of 2ns for MC, off for data
- Angular acceptance « dic08 »
- High Threshold 3pe and 10pe for each period of data taking
- Well documented basic cuts, nline > 1, nhits > 5, Abs(tcosth) < 0.9998, tchi2 < bchi2

- Comparison MC VS Data / periods / HT
- Comparison MC VS Data /periods (HT merged)
- Comparison MC VS Data in global (All periods, All HT merged)
- All of them for nline, nhit (number of floors used for reco), Amplitude (pe), Elevation, Sin(Elevation), tchi2 (All, and just up-going)

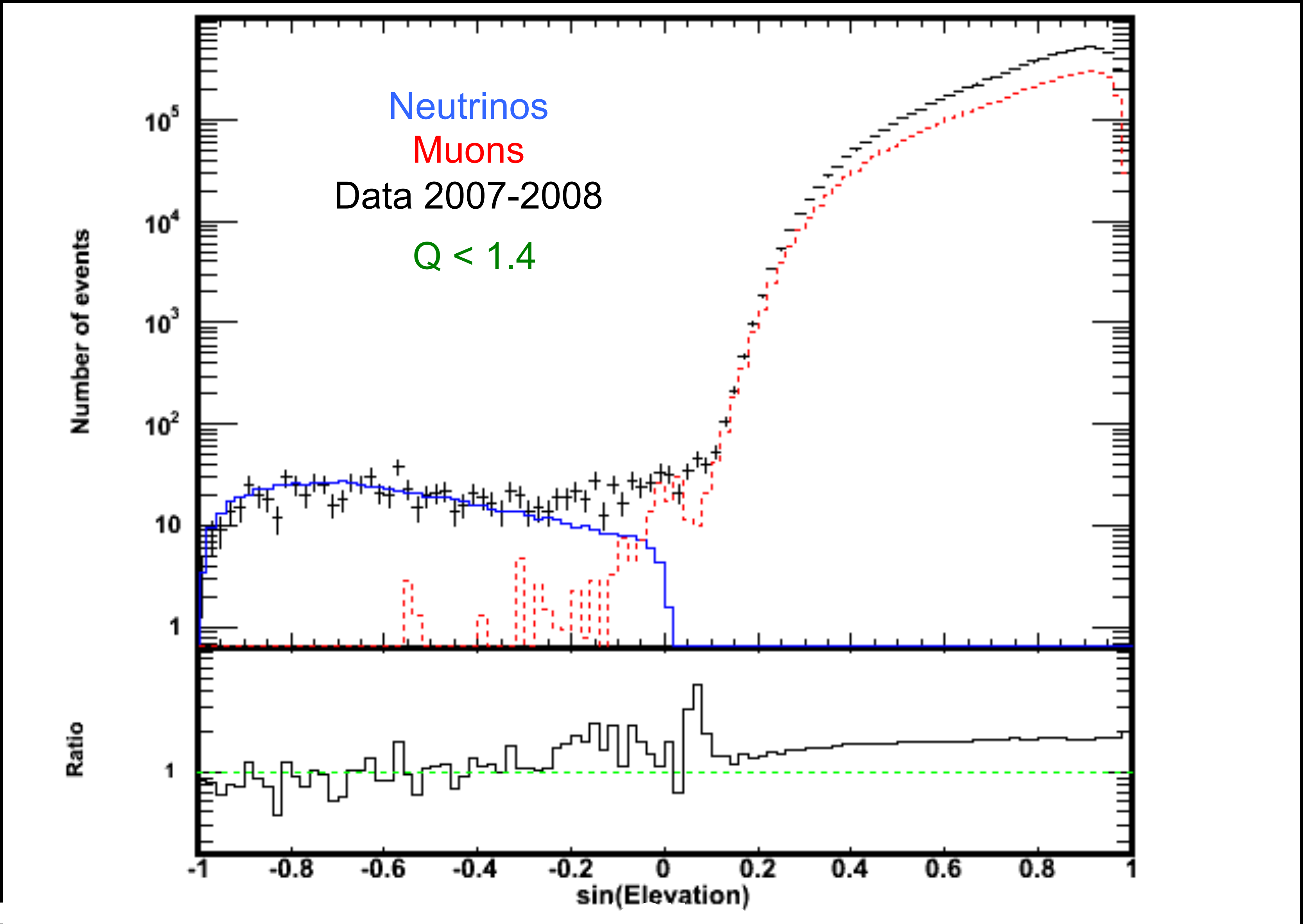
BBFit MC Versus Data
« Right » Run List

- Take into account all runs from 2007-2008 period
- Avoid all Preliminaries, SCAN, Sparking runs
- Using the Data Quality list

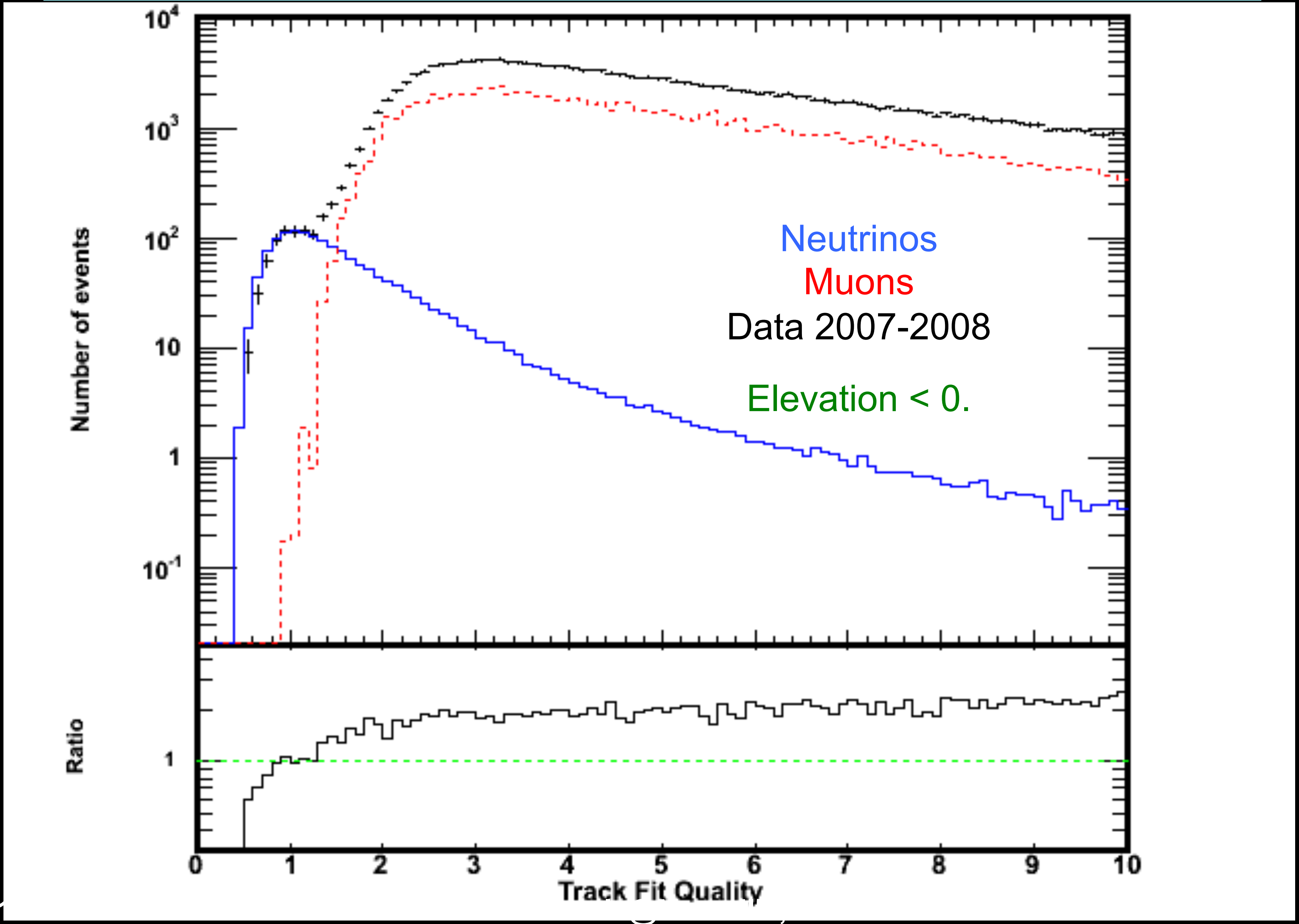
- Compute the live time for each period for a right MC Versus Data comparison

- At the end, live time for 5, 10, 9, and 12 lines periods with crossover for a few runs found (10 lines runs in 5 lines period, etc…)
- Total live time ~294.6 days (2693 runs), very close to the Point Source Analysis one

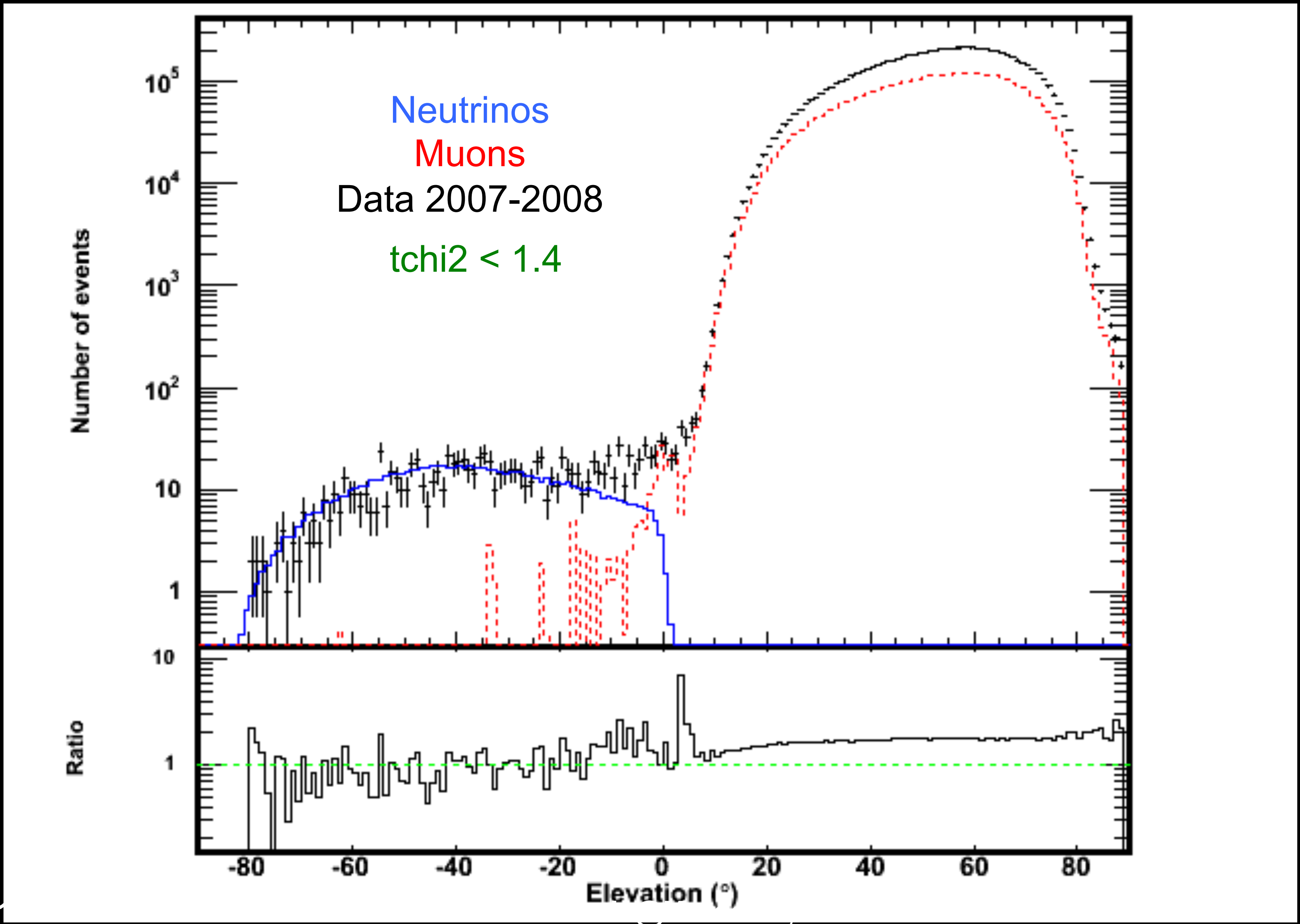
BBFit MC Versus Data
Sin(Elevation)



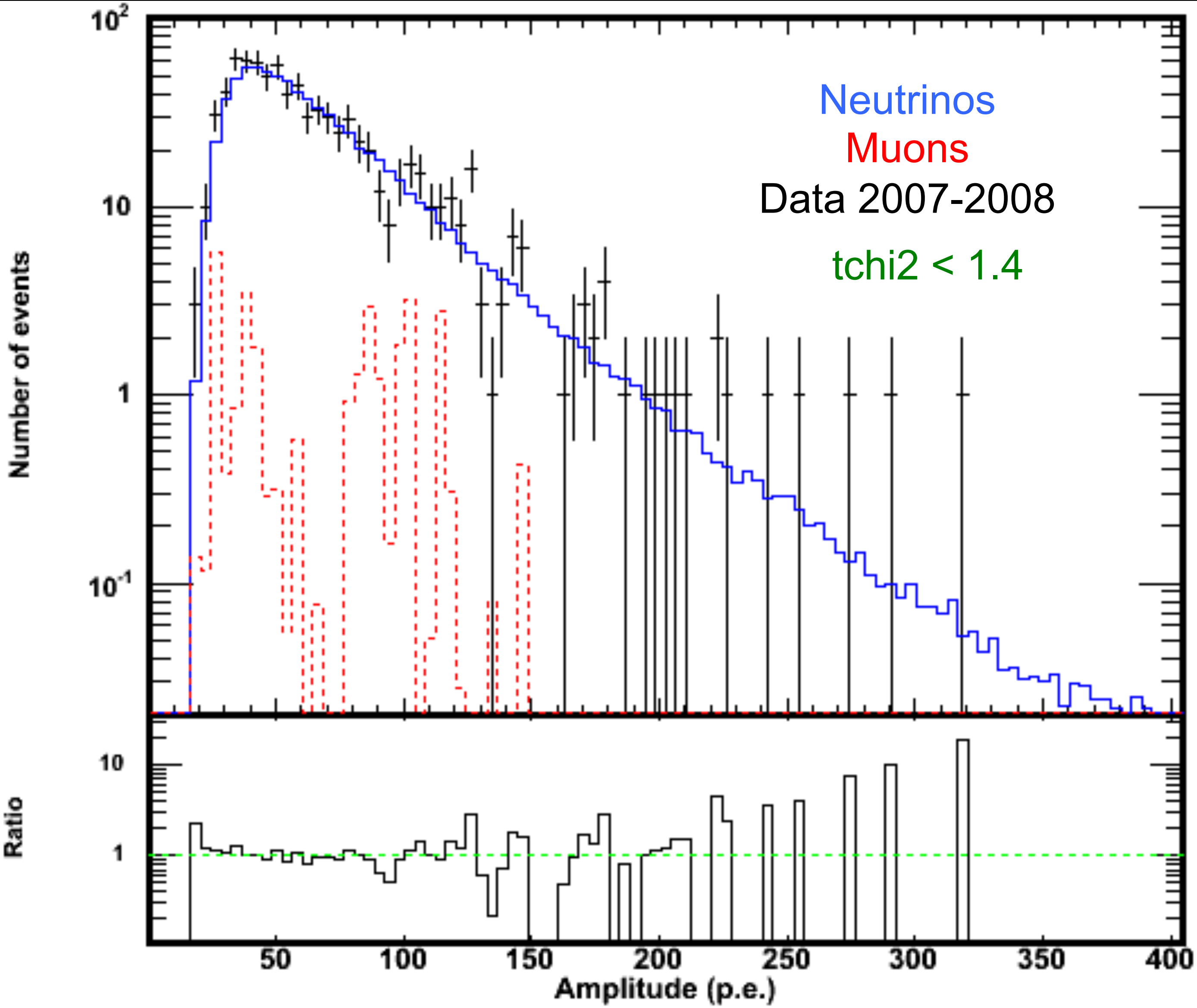
BBFit MC Versus Data
Track Fit Quality cut



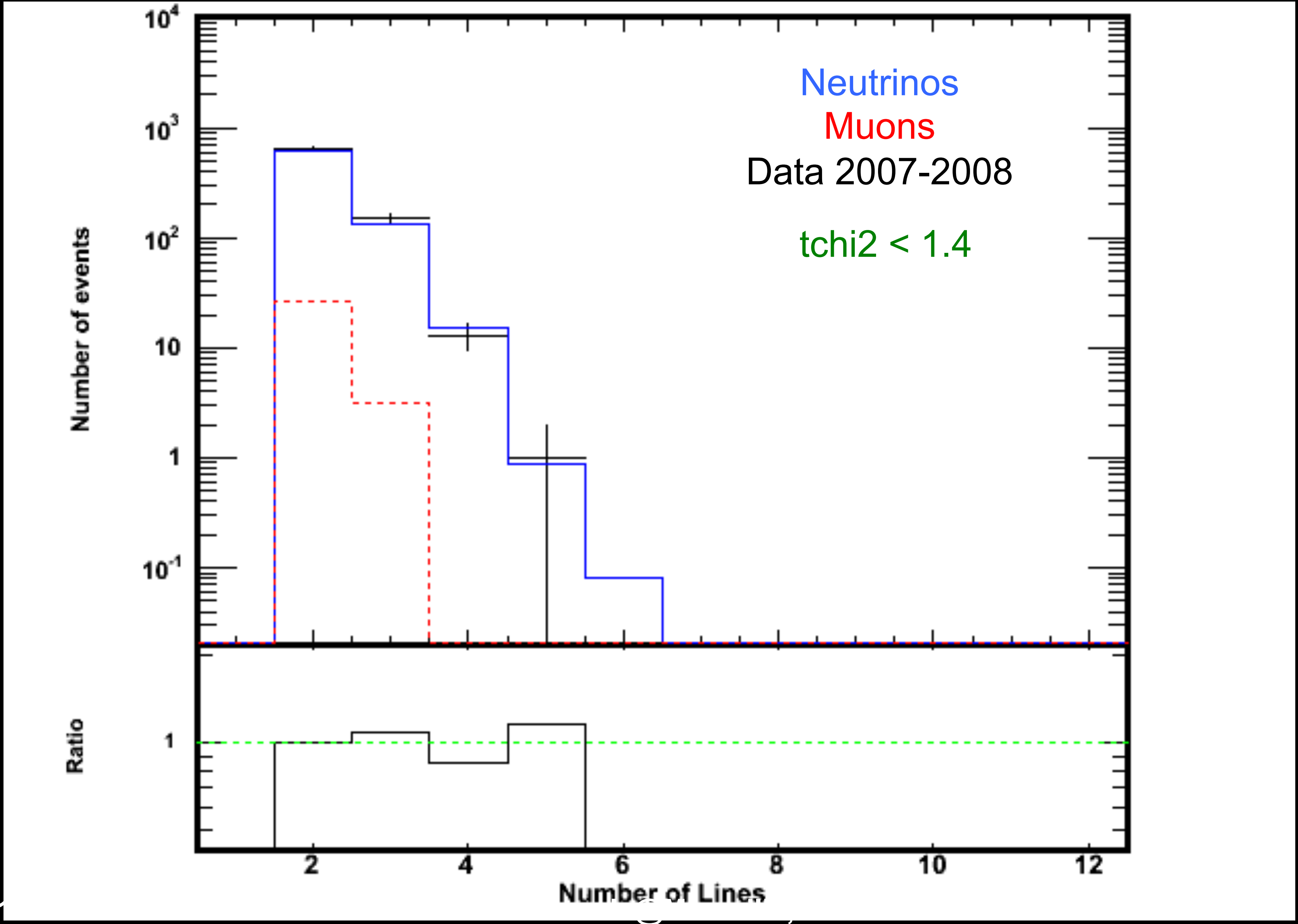
BBFit MC Versus Data
Elevation



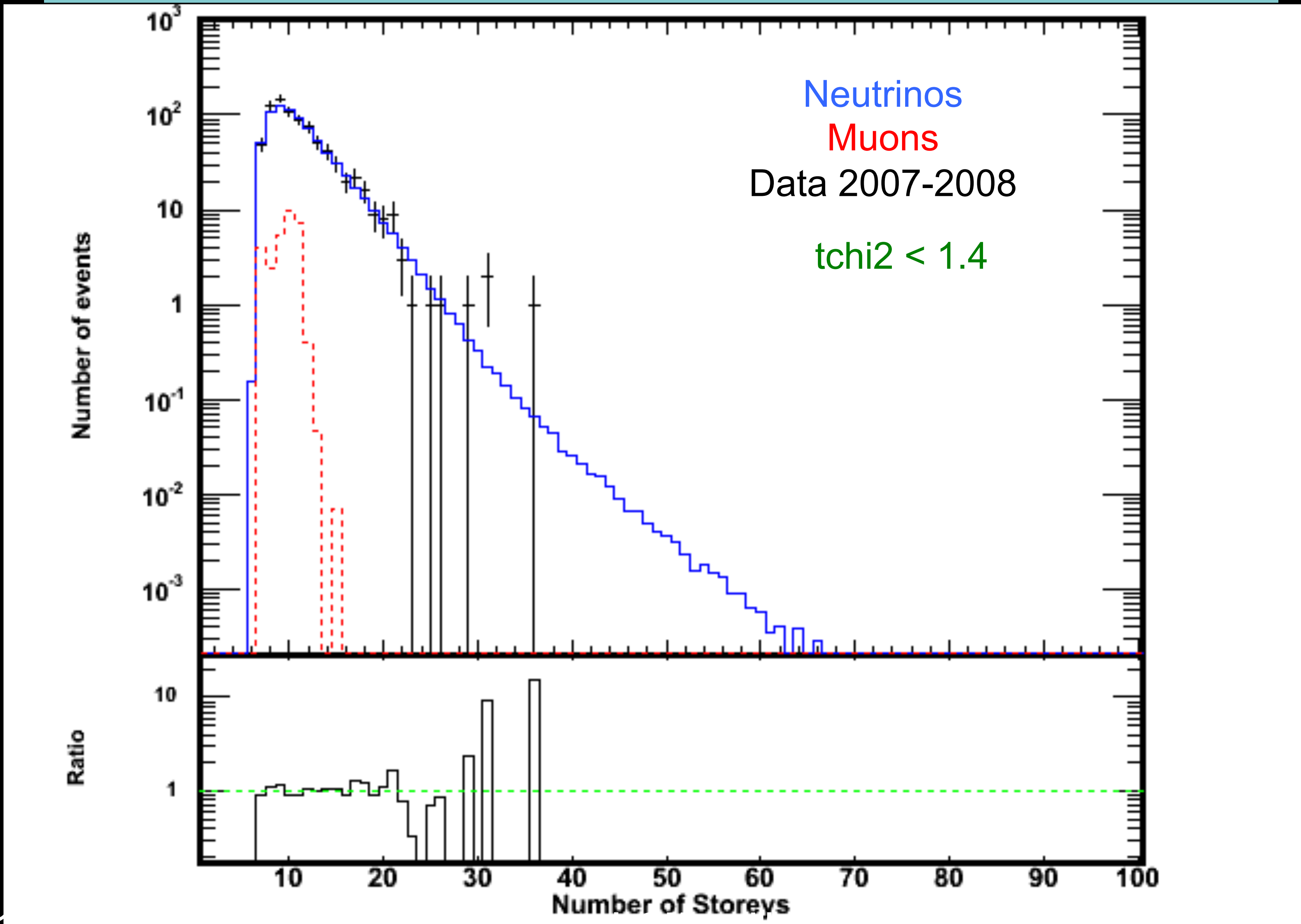
BBFit MC Versus Data Amplitude



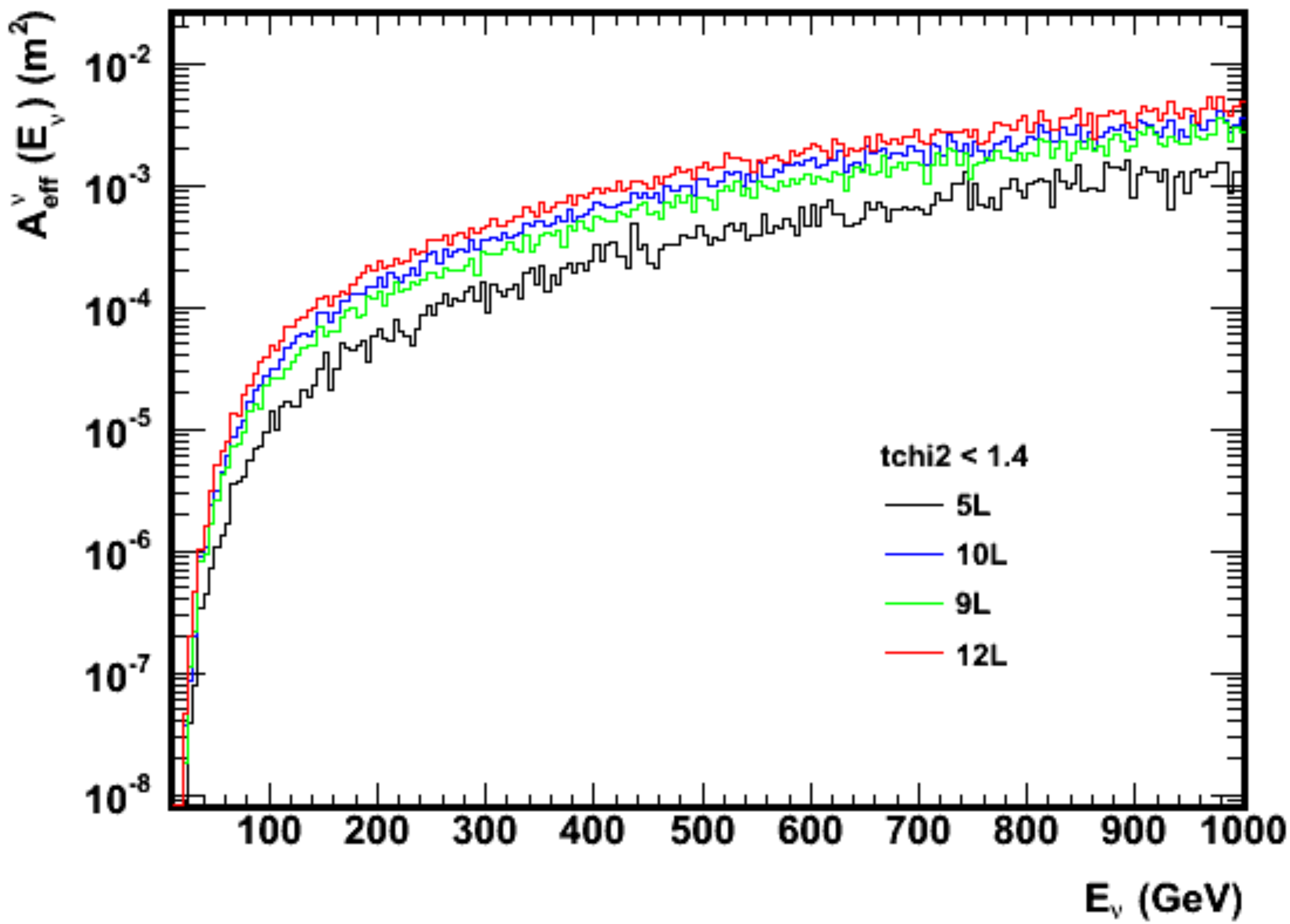
BBFit MC Versus Data
nline



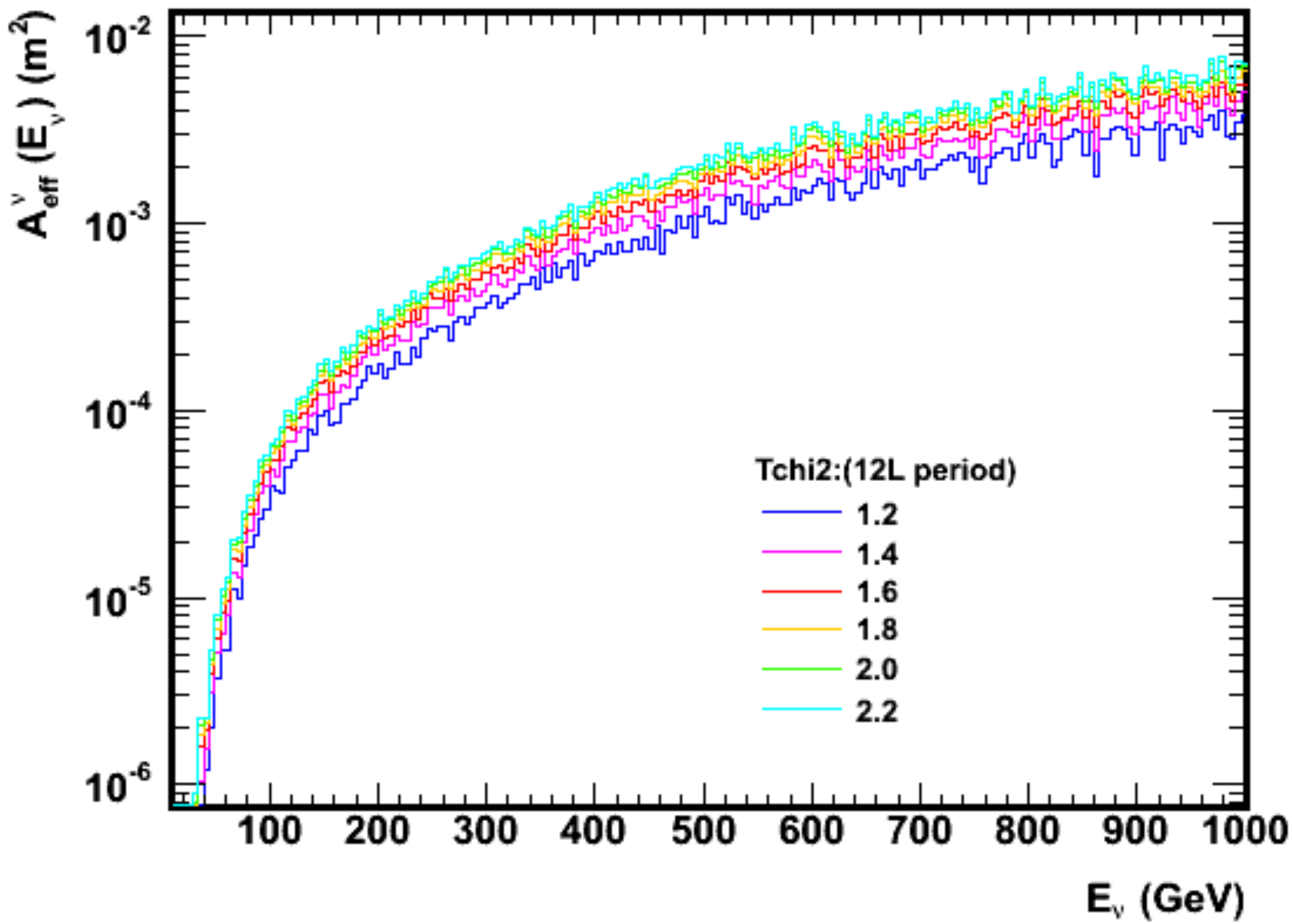
BBFit MC Versus Data
nhit



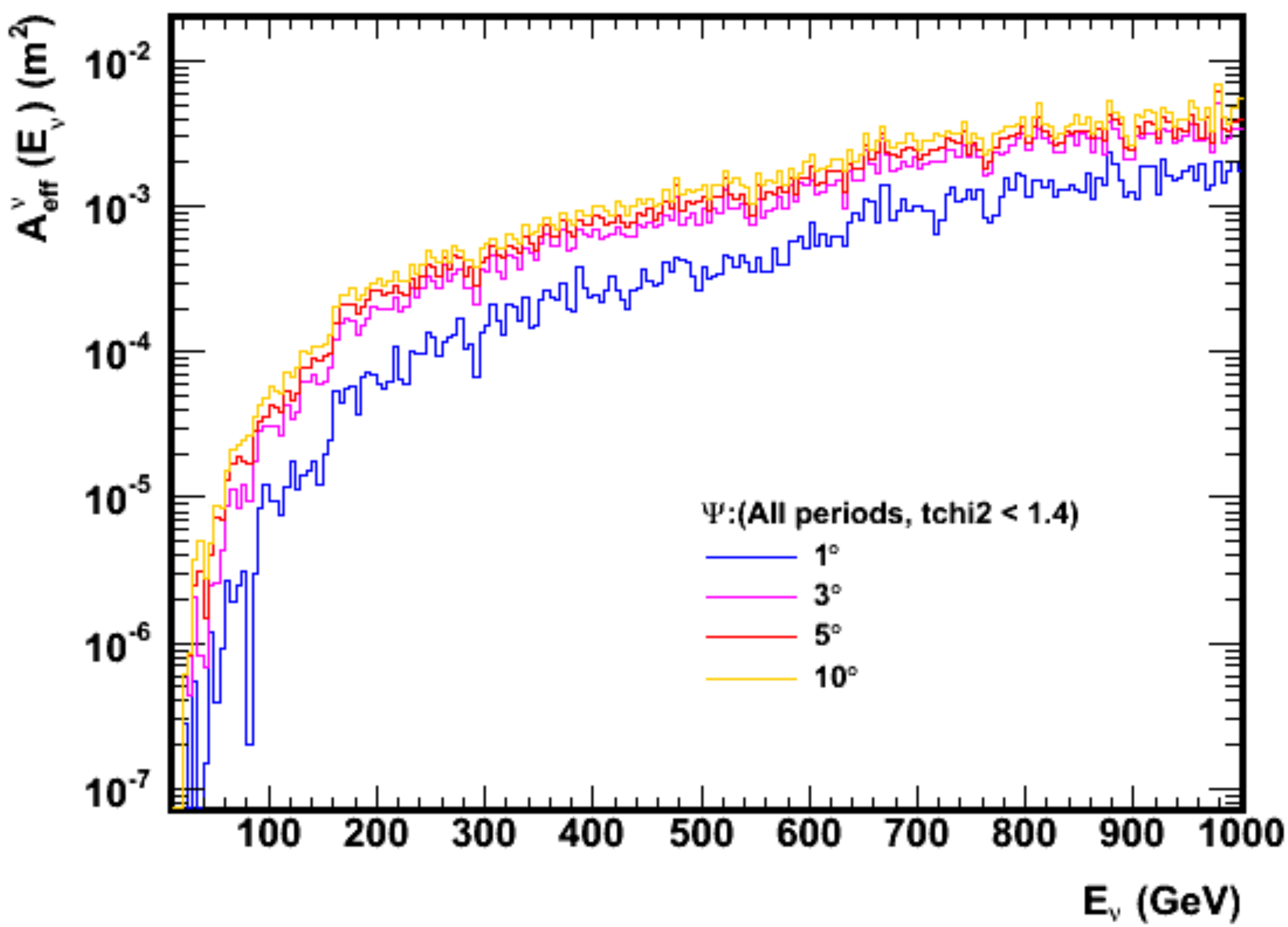
Effective Area



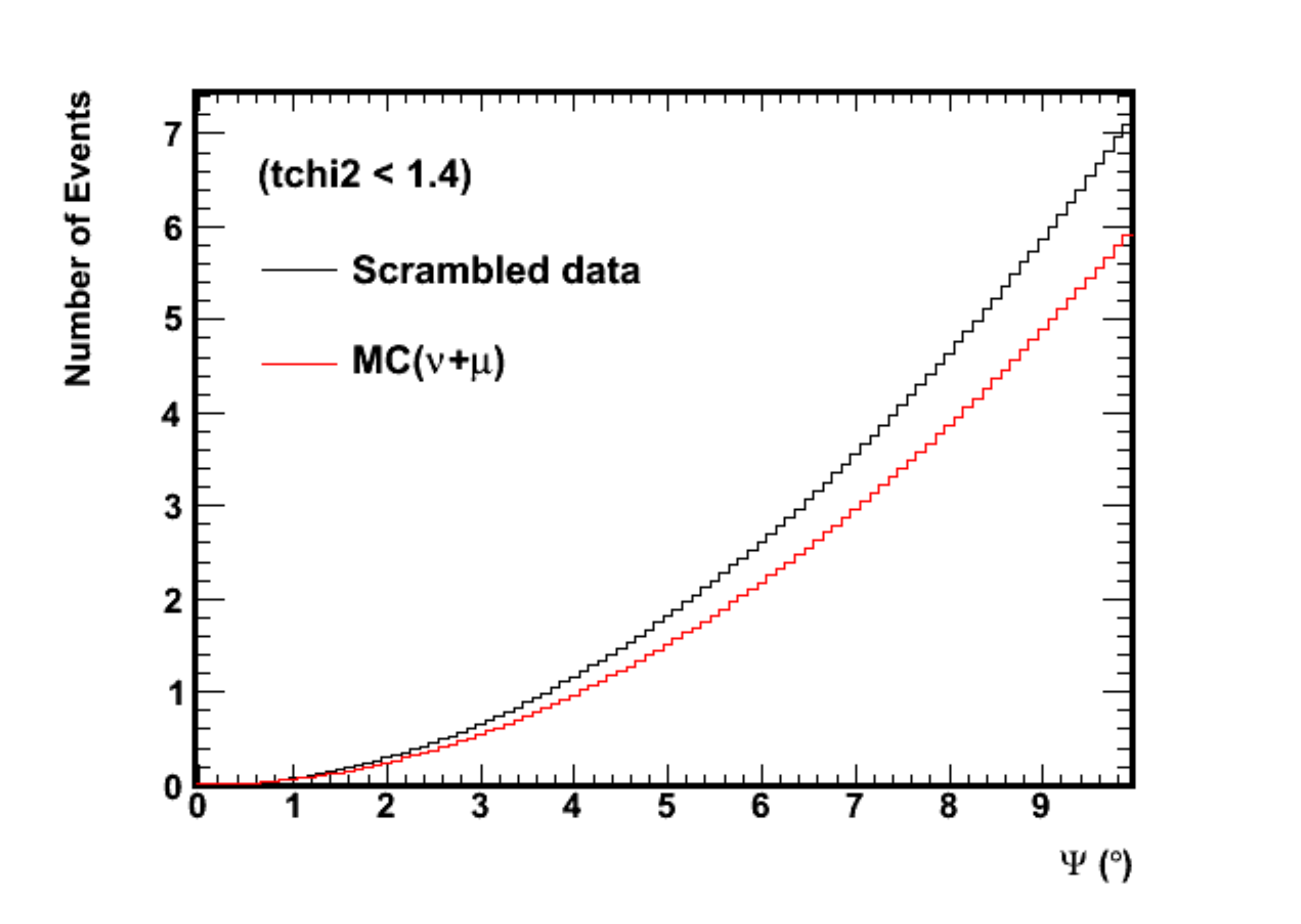
Effective Area



Effective Area



Background in the Sun direction



Dark Matter Signal and cuts optimisation

For the ττ channel:

Tchi2 almost stable

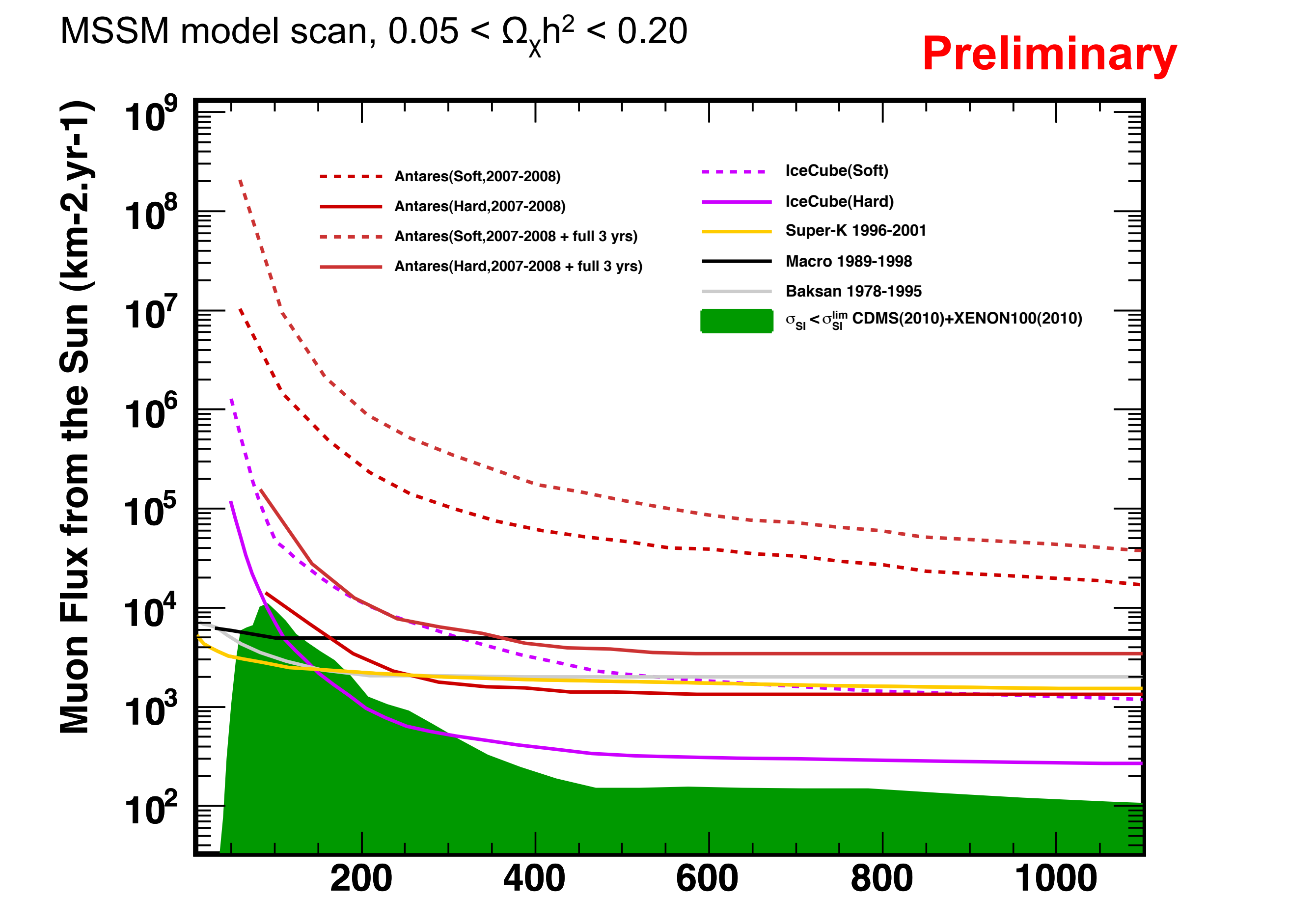
Mwimp (GeV)	Tchi2	Cone (°)
50	1.3	5.8
100	1.3	5.6
150	1.3	5.6
176	1.4	4.5
200	1.4	4.5
250	1.4	4.5
350	1.4	3.9
500	1.4	3.6
1000	1.4	3.6

More signal, smallest n_b/n_s

Same kind of table for bb, and WW, or « mUED »…
Masses at 10, 25 GeV cannot be treated (lack of statistics from the very low energy range in MC)

Dark Matter muon flux sensitivity

- Dark Matter neutrino flux multiplied by the MRF minimized reachs to the best sensitivity with ANTARES using 2007-2008 scrambled data



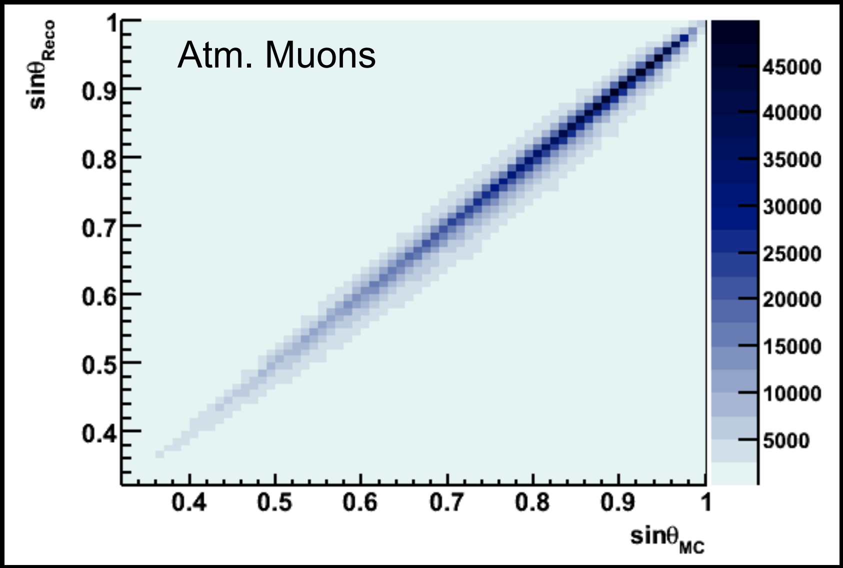
$$\overline{\phi}_\mu^{90} = \phi_\mu \times MRF$$

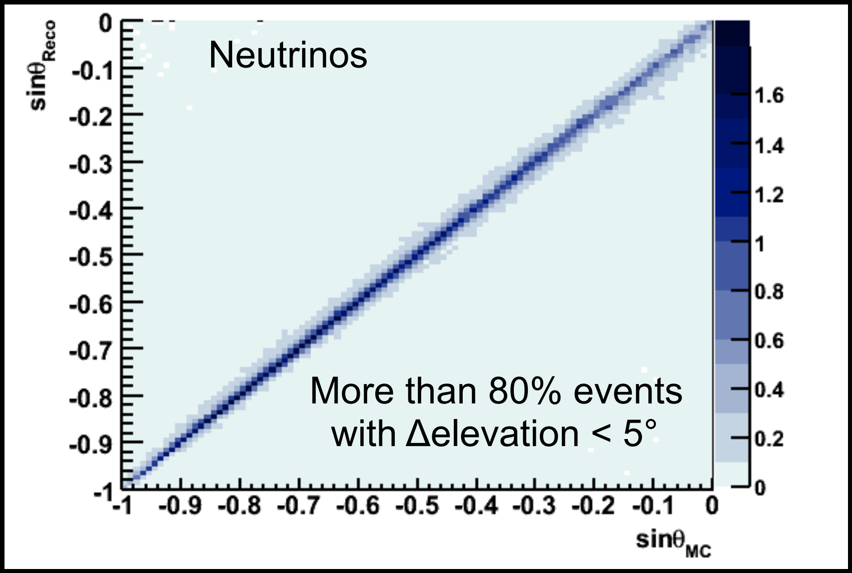
Fast algorithm and Monte-carlo/Data comparions I

- Fast and robust reconstruction of neutrino induced upward-going muons discriminated from downward-going atmospheric muon background
- Algorithm of reconstruction is employed to a hit merging and hit selection procedure by fitting steps for a track hypothesis and a point-like light source
- Point-like light source in the detector approximate light from hadronic and electromagnetic showers, to be discriminated from muon tracks
- Main quality function Q simillar to a standard χ^2 fit based on the arrival hit times from a track or a bright point

For more details: « A fast algorithm for muon track reconstruction and its application to the ANTARES neutrino telescope », Astro. Phys. 34 (2011) 652-662

FROM MC

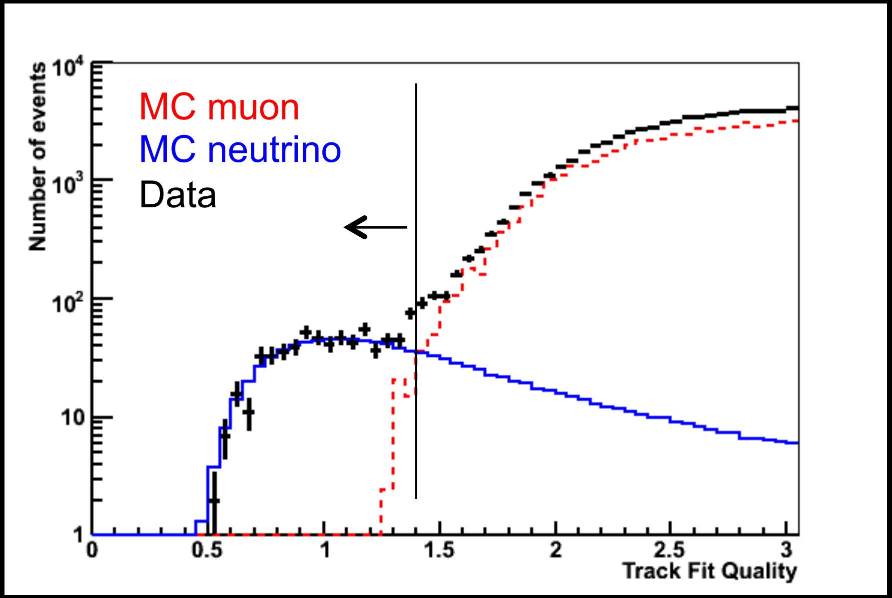




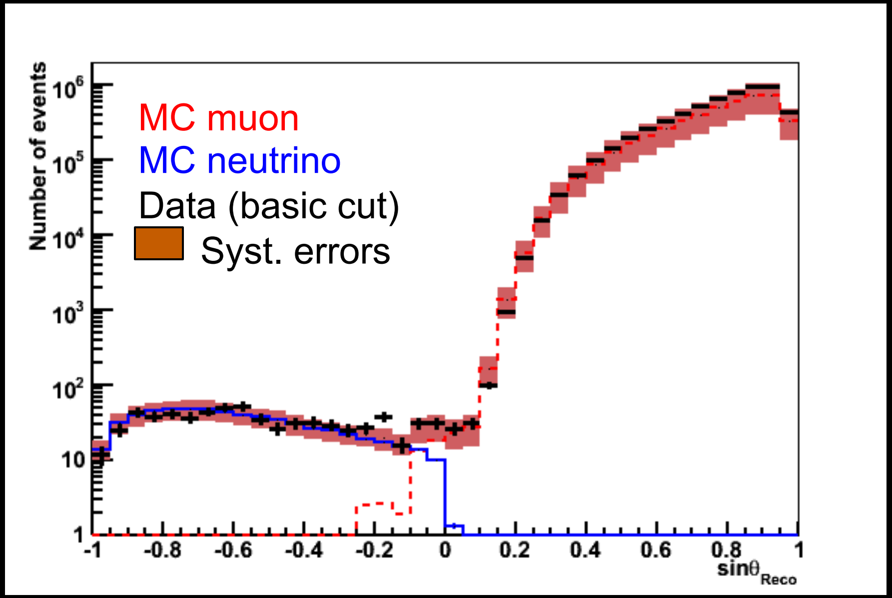
Fast algorithm and Monte-carlo/Data comparions II

Comparison MC(μ+ν)/Data

In the Track Fit Q plan



As a function of Sin(Elevation) reco.



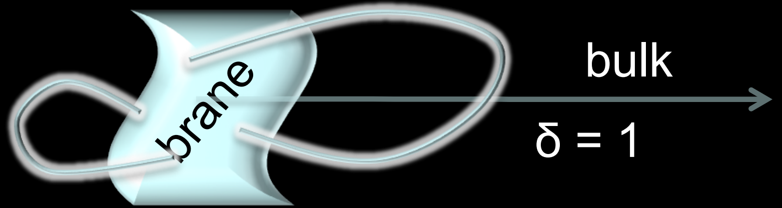
Just upward-going multi-line tracks are considered
For example : for Q < 1.4, purity at 90% in neutrino

All systematics taken into account, data are compatible with the chosen flux models for the atm. neutrinos and muons
The reconstruction procedure is enough robust to be used for the present study

Excellent agreement atm.ν_{MC}-data is observed in the upward-going dial
30% excess of data observed with respect to the atm.μMC
Systematic errors from PMTs effective area, water absorption, PMTs angular acceptance

Dark Matter,

Phenomenological model UED



- First gravity-electromagnetism unification : T. Kaluza, 1921

➔ 1 metric extra-dimension

- models evolution, taken into account : weak and strong fields.

  ADD (Arkani-Hamed, Dimopoulos, Dvali) and RS (Randall-Sundrum) models

  ➔ 1 or n metric extra-dimensions compactified with a radius R

- gravity propagation inside the extra-dim can explain its weakness
- if R is enough tiny, each field can propagate in the extra-dim

- UED (Universal Extra-Dimension) model : space-time with (3+1) dimensions (brane) evoluates in 3+1+(δ = 1) (bulk), all SM fields propagate in the bulk

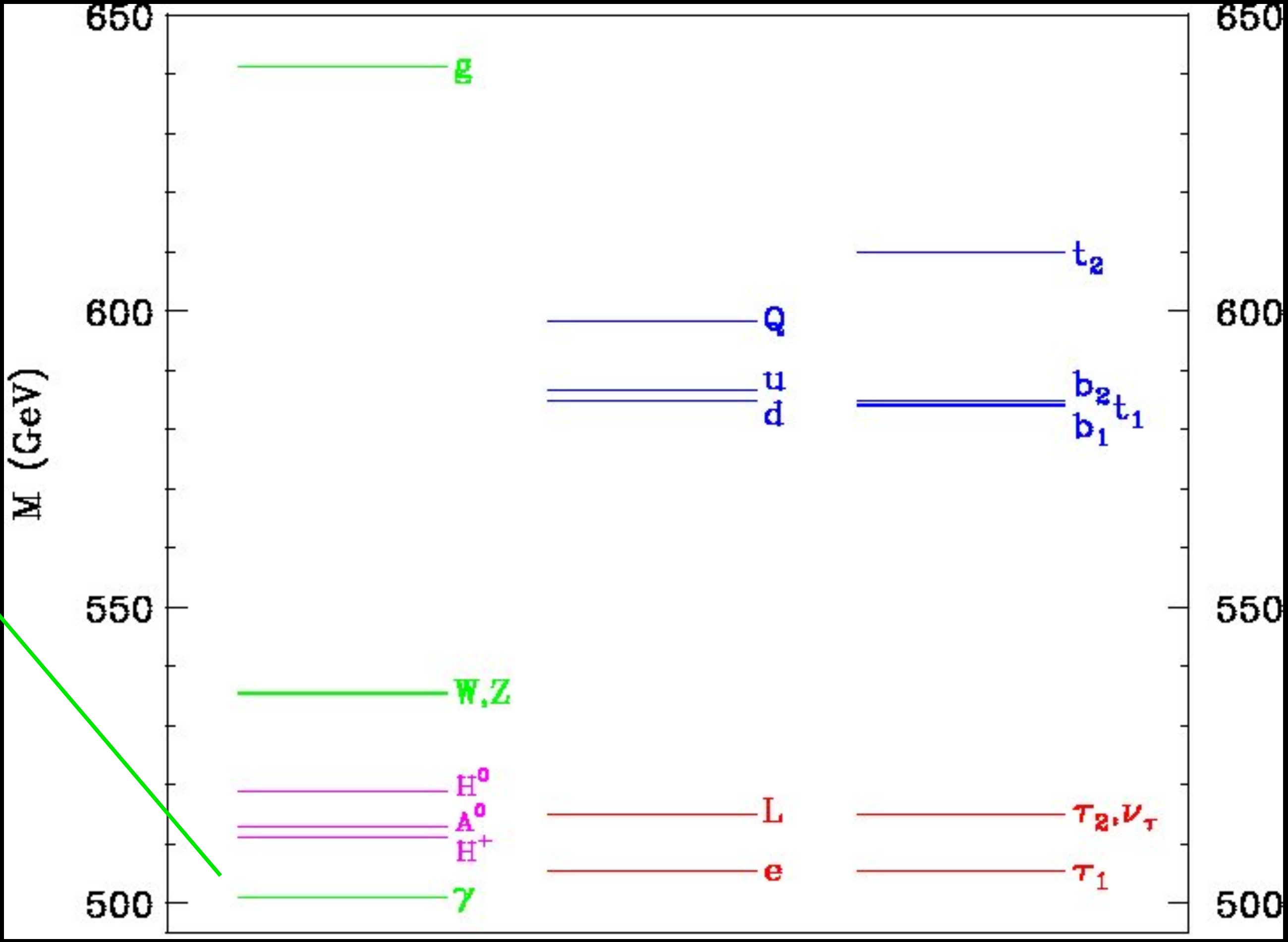
  ✓ mass hierarchy problem : Planck scale reduced around electroweak scale

- field decomposition in Fourier modes in the bulk, Kaluza-Klein (KK) states appear in the brane like KK towers such a mass spectrum

$$m_n \alpha \, n / R, \text{ n modal index}$$

Interest : production of stable candidates for the dark matter nature…

Mass spectrum of KK states at first level :



$\gamma \approx B^{(1)}$
Dark Matter candidate
KK state of the hypercharge gauge boson

The LKP
(Lightest KK Particle)

SM particles production just by self-annihilation

R^{-1} = 500 GeV, m_h = 120 GeV, Λ = 20 R^{-1}

UED specific model : in the spectrum mass development, all boundary kinetic terms are assumed to vanish at a cut-off scale $\Lambda > R^{-1}$
➔ Basis of the minimal UED model (MUED), virtually common used in the litterature
➔ The most predictive model with only three free parameters :

R, Δ, and SM Higgs mass m_h

Dark Matter,

Phenomenological model UED

First Constraints:

• Branching ratios with weak dependence to the degeneration of the mass spectrum

Neutrinos: Direct and indirect productions

États initials	États finals	Rapports de branchement
$B^{(1)}B^{(1)}$	$\nu_e\overline{\nu_e}$, $\nu_\mu\overline{\nu_\mu}$, $\nu_\tau\overline{\nu_\tau}$	0.014
	e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$	0.23
	$u\overline{u}$, $c\overline{c}$, $t\overline{t}$	0.077
	$d\overline{d}$, $s\overline{s}$, $b\overline{b}$	0.005
	$\phi\phi^\star$	0.027

Direct production of muons, but quickly absorbed in the propagation medium

great interest for the neutrino telescopes, direct production

➔ Direct link to the LKP mass at E_ν

• $R^{-1} \geqq 350$ GeV (LEP II constraints) - $\Omega_{CDM}h^2 = 0.11 \pm 0.006$ (WMAP, 5 yrs)

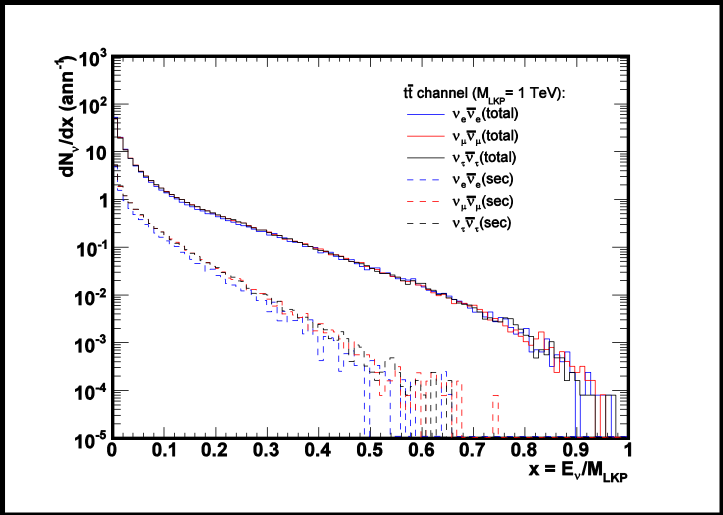
• Coannihilations or not LKP–NextLKP ⇨ $\Delta \equiv (m_{NLKP} - m_{LKP}) / m_{NLKP}$, model-dependent
MUED ➔ $\Delta = 0.14$

Dark Matter,

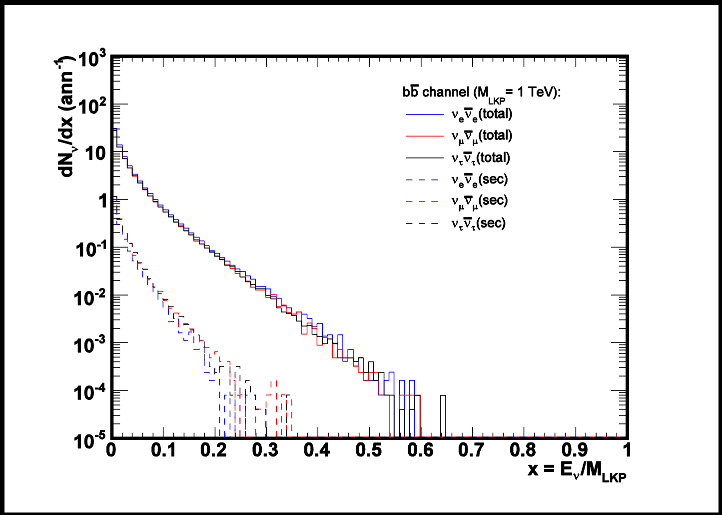
Neutrinos at the surface of the Earth

M_{WIMP} = 1 TeV

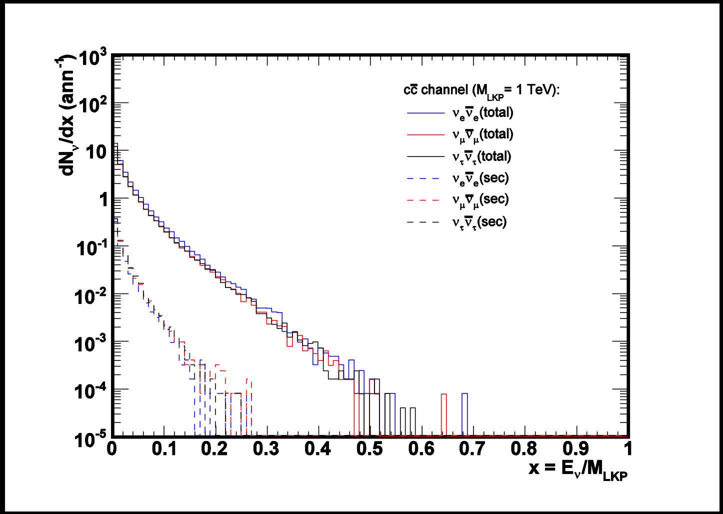
Canal top



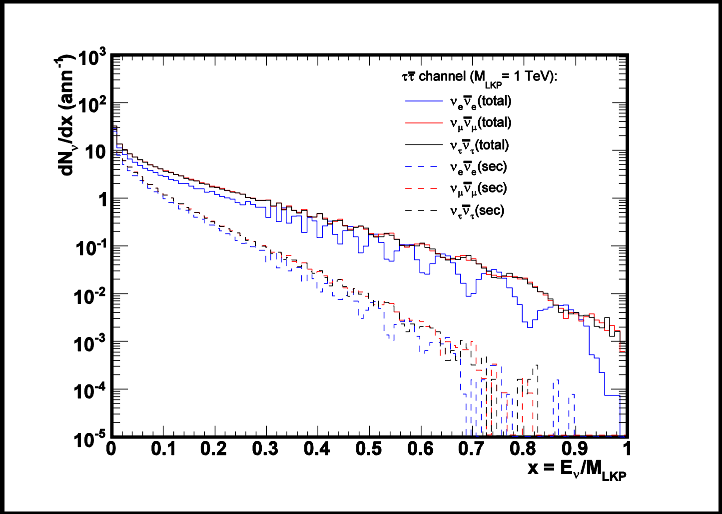
Canal b



Canal c



Canal τ

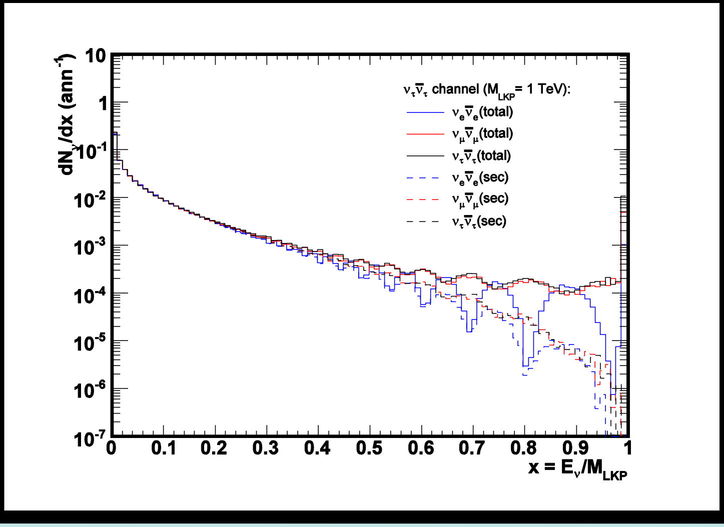


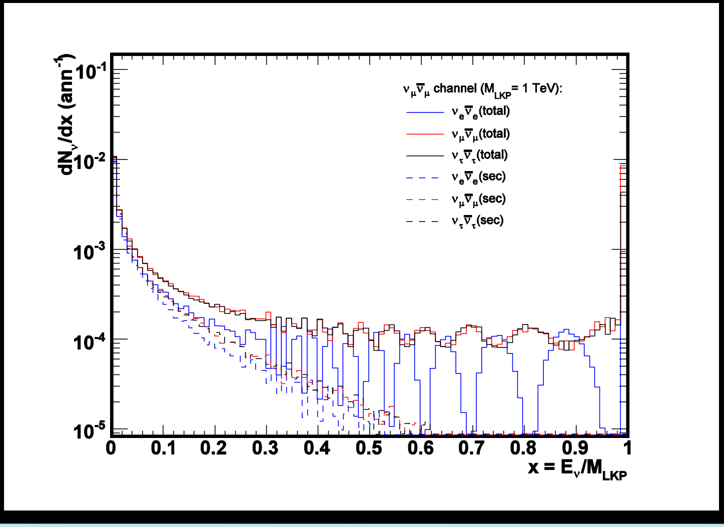
Dark Matter,

Neutrinos at the surface of the Earth

M_{WIMP} = 1 TeV

ν_τ





ν_μ

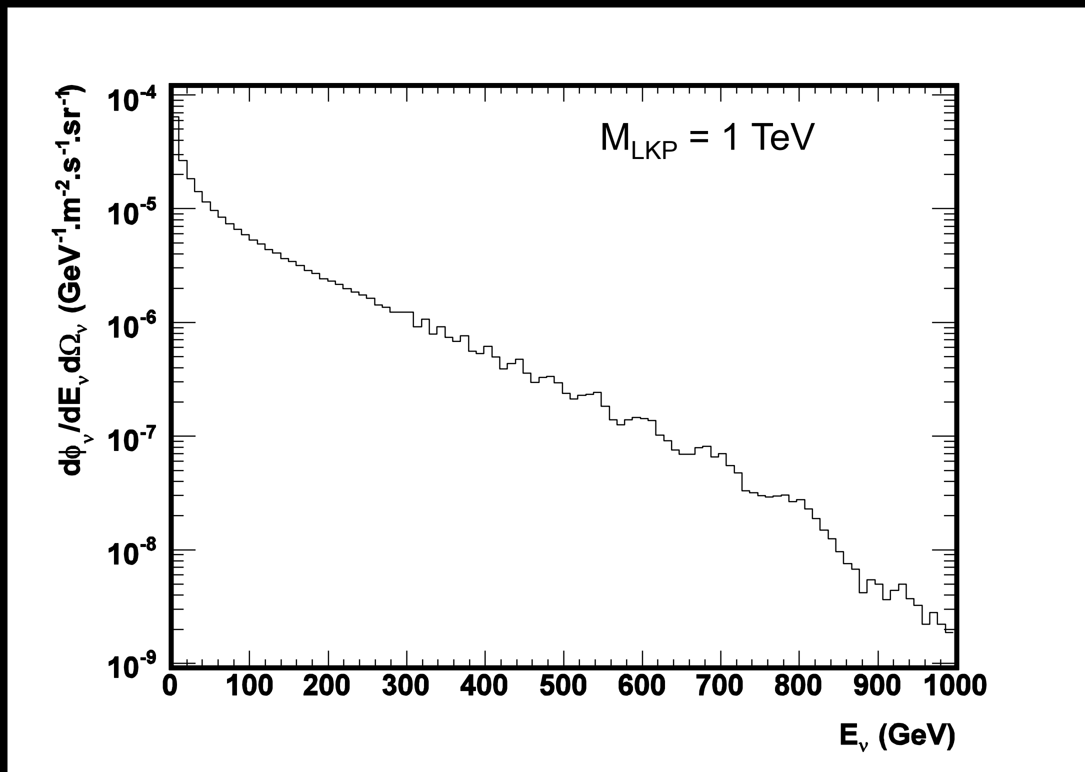
Main secondary production from τ and top channels, and primary production from ν_τ and ν_μ direct channels

\+ constraints of MUED dark matter on :

- ✓ Self-annihilation rate $\Gamma \propto \sigma_{MUED,SD}$ (spin-dependent cross section)
- ✓ Branching ratios

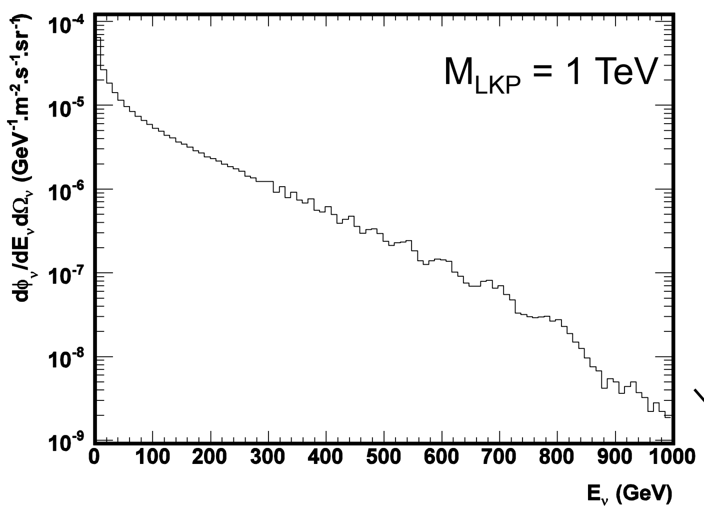
Global flux at Earth :

$$\frac{\quad}{dEd\Omega} = \frac{\quad}{4\pi d^2}\sum_i B_i \frac{\quad}{dE_i}$$

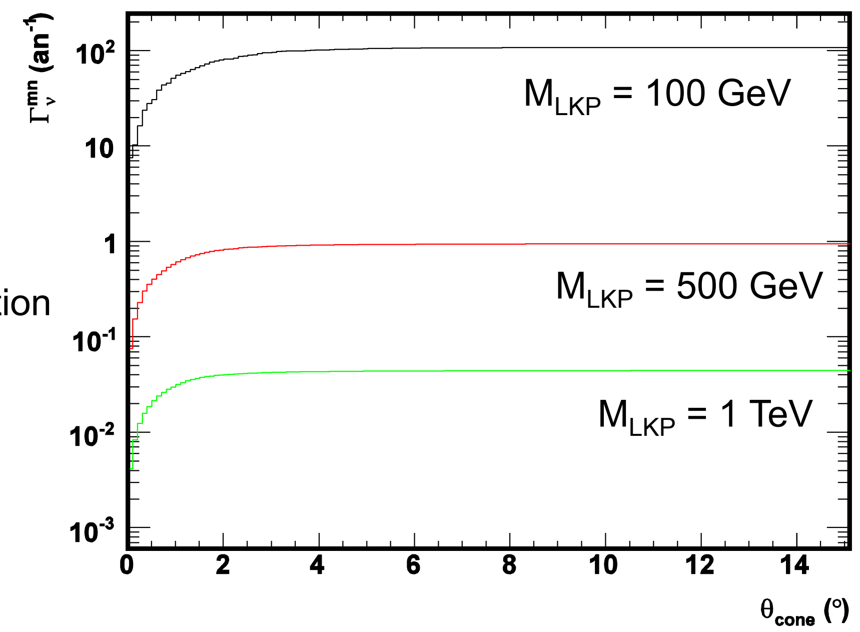


Dark Matter,

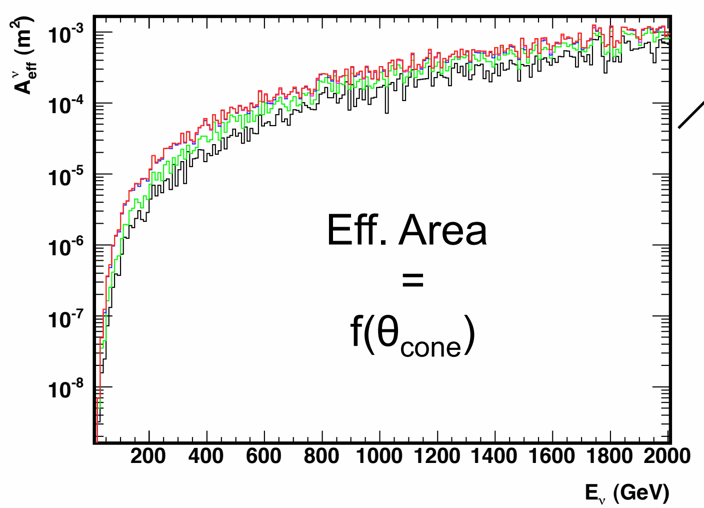
Expected Rates



Neutrinos rate = $f(\theta_{cone}, M_{LKP})$



ution



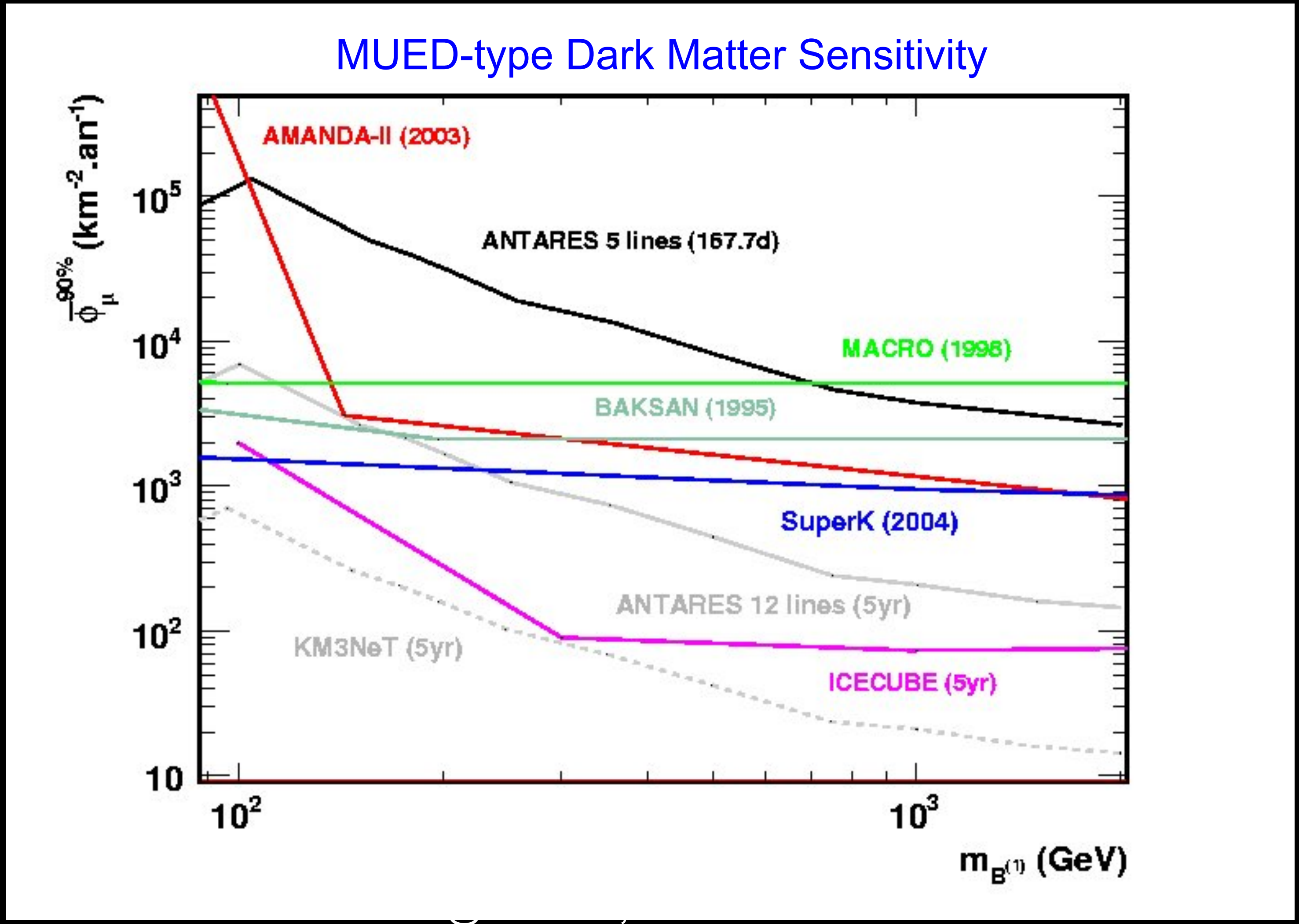
Eff. Area from background study, similar to Gordon's MSSM study with Aart's strategy (linear prefit, $\cos\theta > 0.1$, $\Lambda > -5.0$)

Background VS Dark Matter Signal

ANTARES sensitivity for the MUED-type Dark Matter

Flux from the dark matter simulation

$$\overline{\phi}_{\mu}^{90} = \phi_{\mu} \times MRF$$

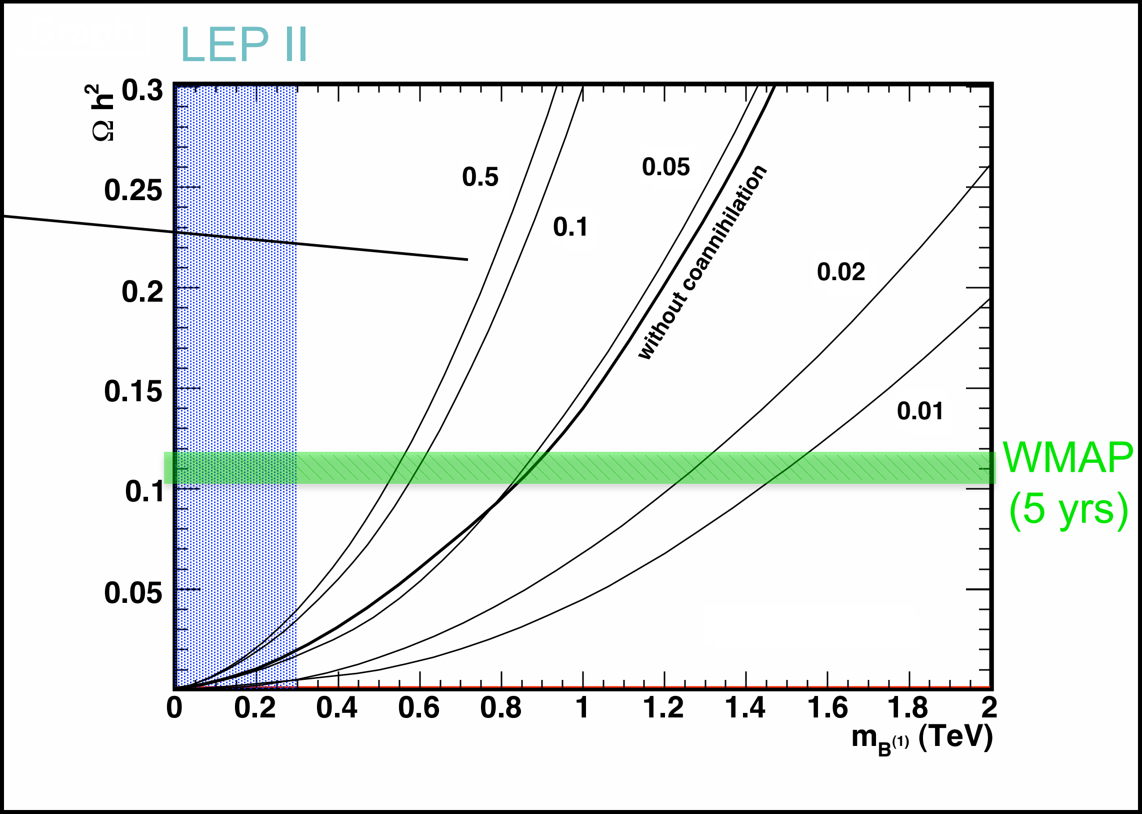


Sensitivity computed for t =167.7 days (integrated time for all of the 5-line silver runs)

Mass spectrum, relic density and LKP mass range

$m_{B(1)}$-dependence of $\Omega_{CDM}h^2$ with coannihilations or not

$\Delta > 0.5$, NLKPs contribution degeneration

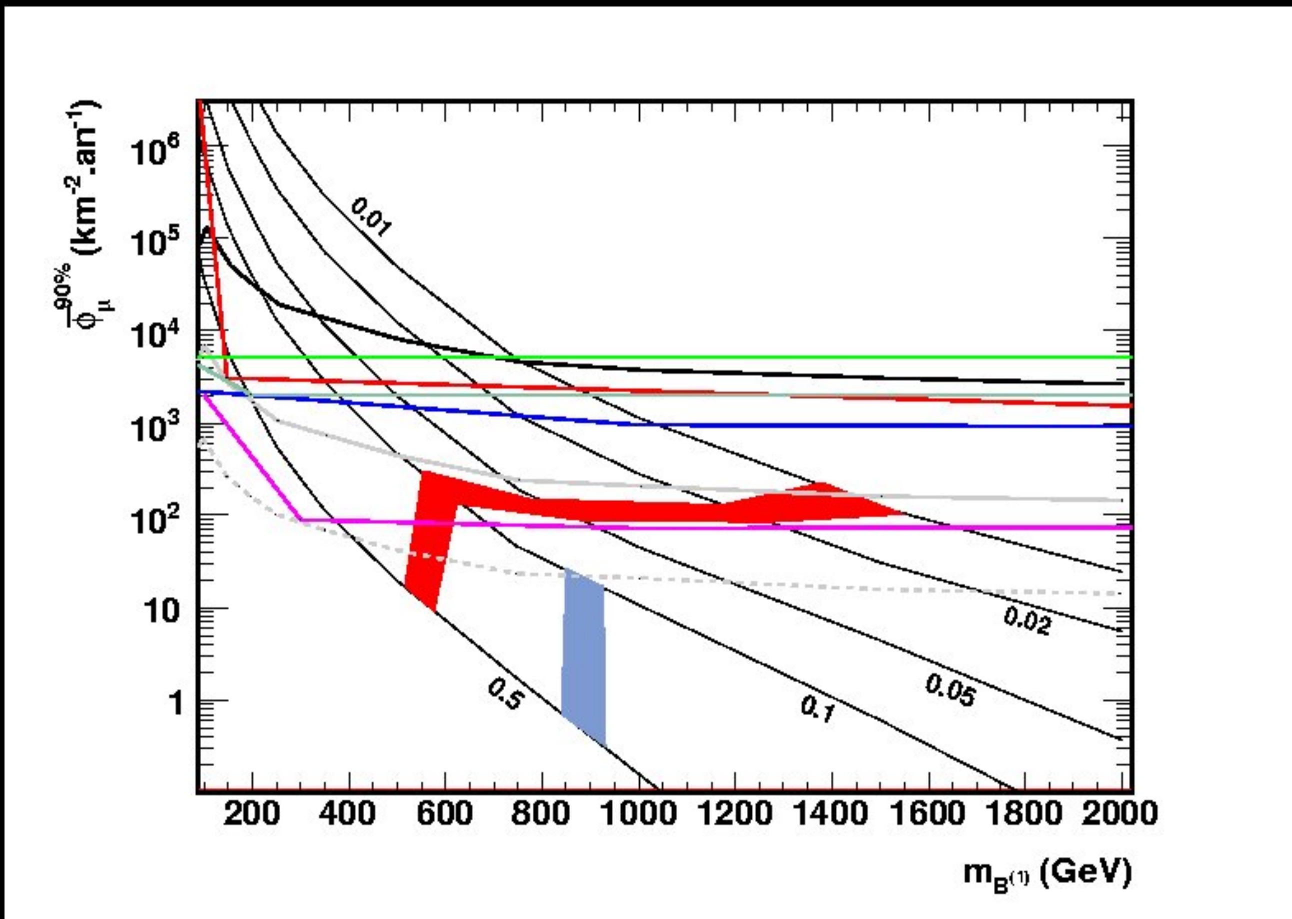


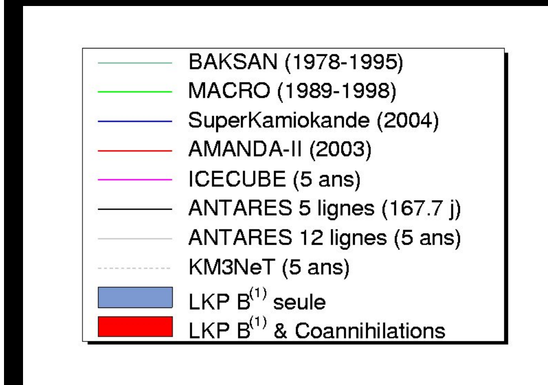
Cold Dark Matter relic density constraints by LEP II & WMAP
Δ values constrains the relic density at *freeze out*

Dark Matter sensitivity

Phenomenological constraints

$$\overline{\phi}_{\mu}^{90} = \phi_{\mu} \times MRF$$





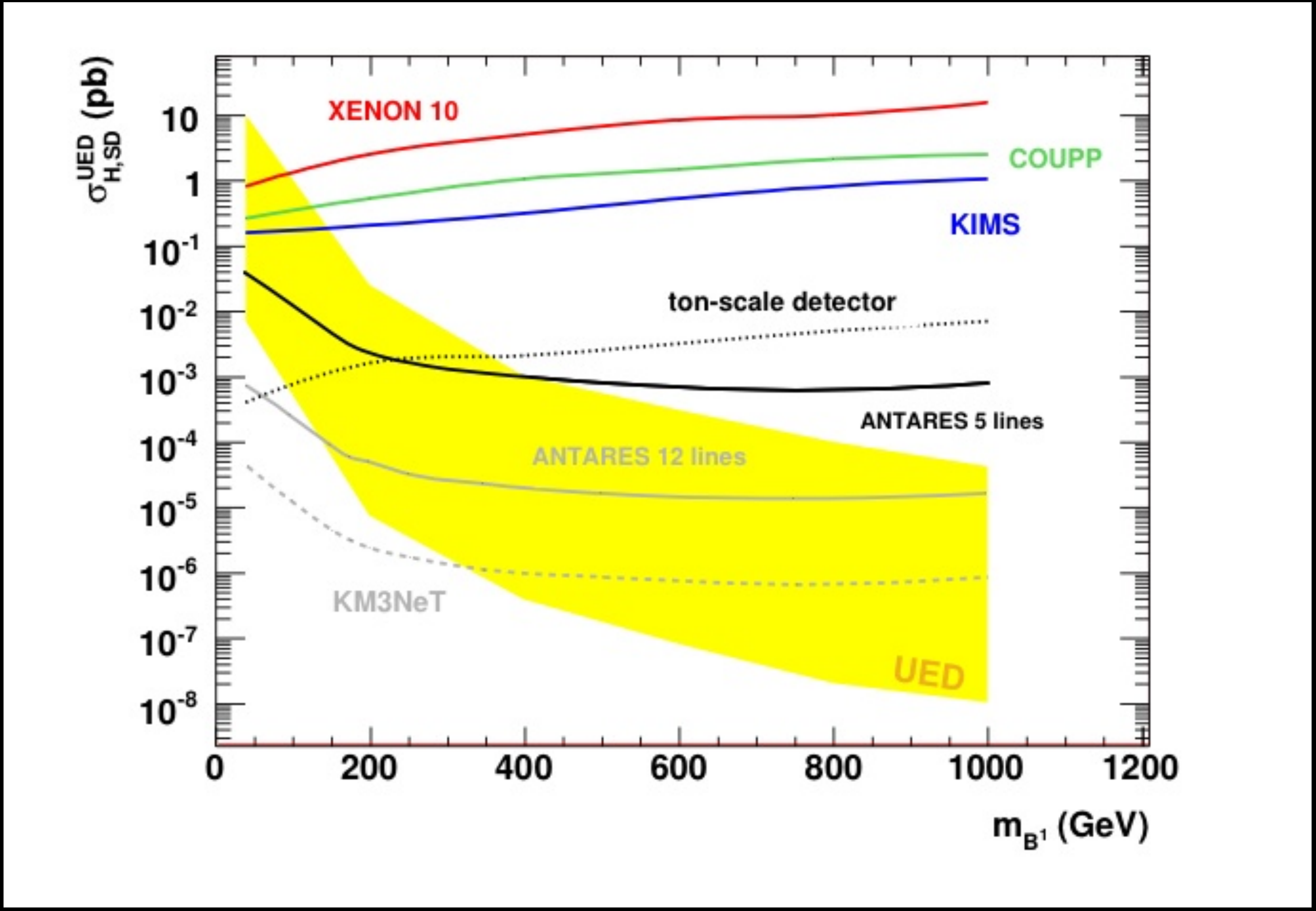
From 5-line constraints (Δ,m_{LKP})

From 12-line (5 years)
Close to the WMAP constraints

With Icecube, and KM3NeT (5 years)
Strong constraints expected

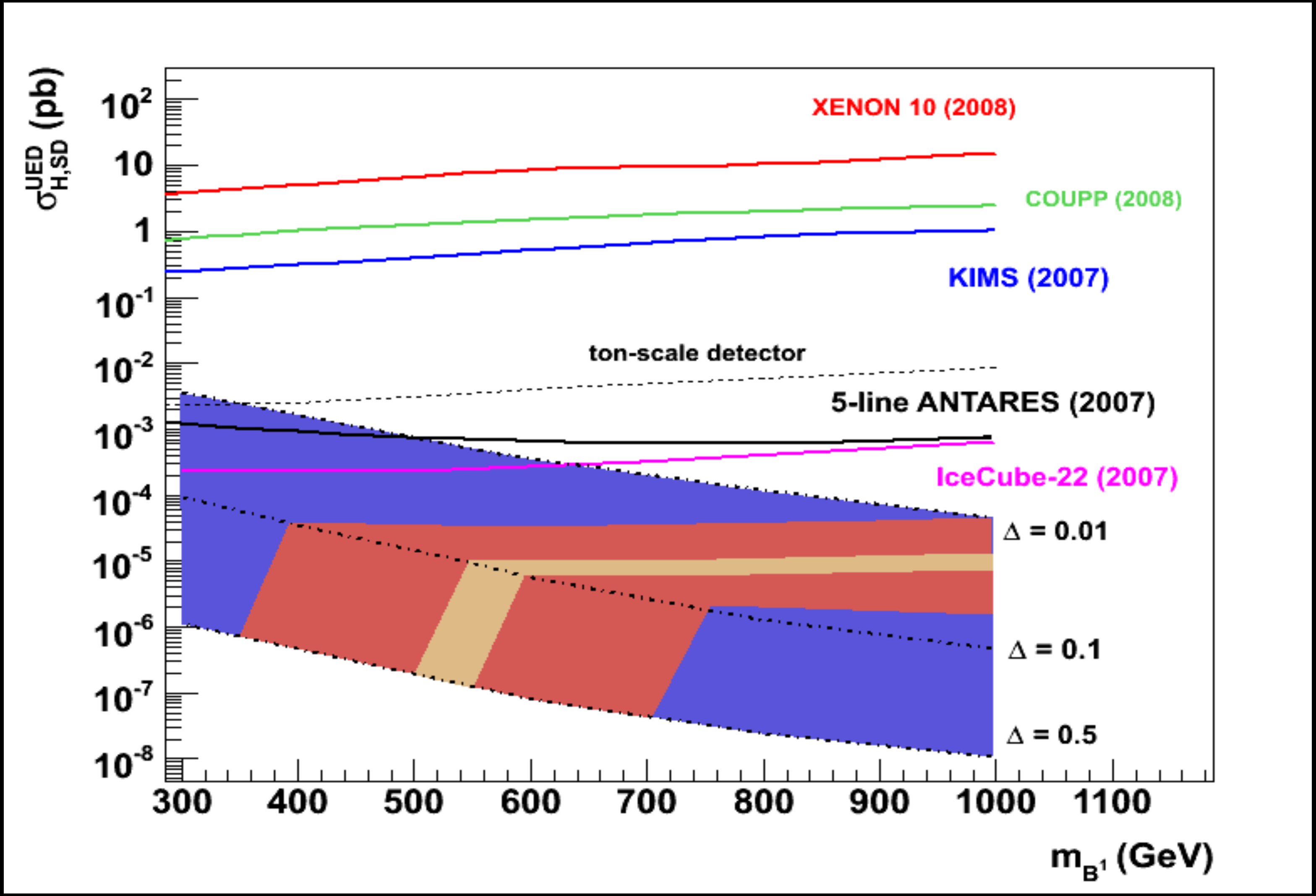
Dark Matter sensitivity

Phenomenological constraints

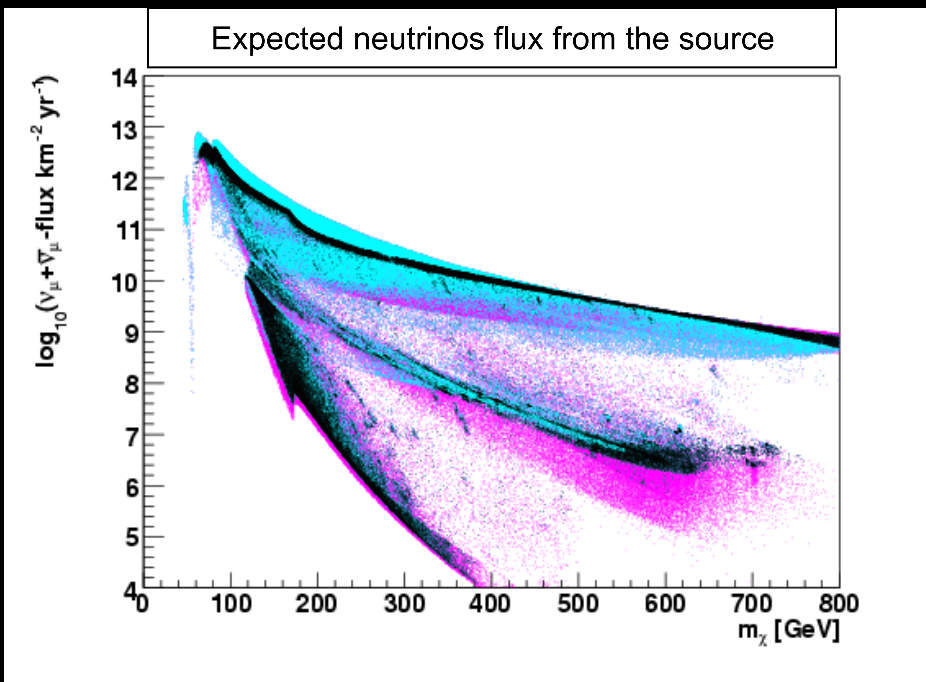


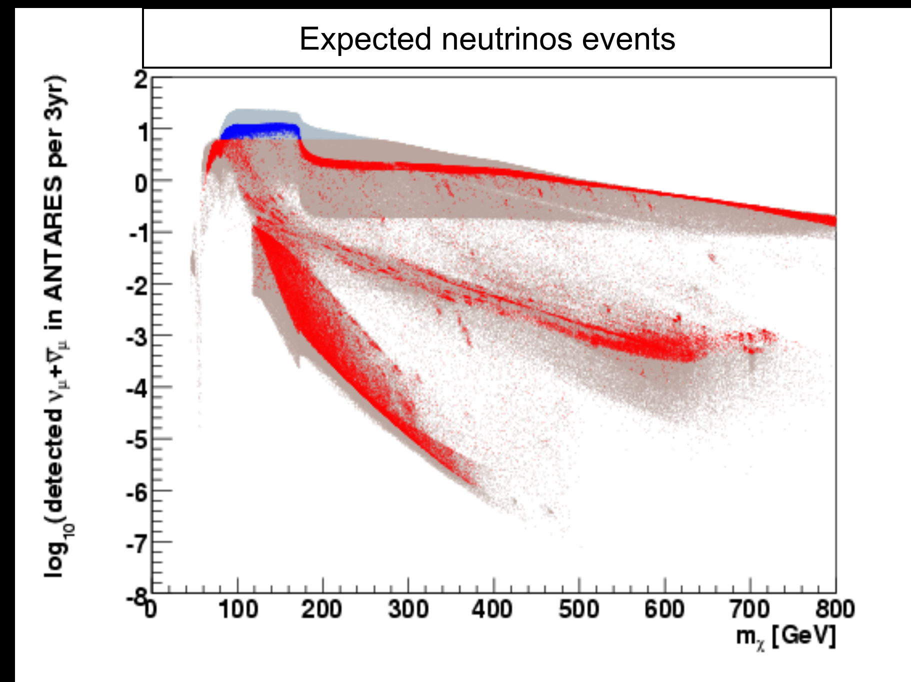
Dark Matter sensitivity

Phenomenological constraints



Expected neutrino flux from the Sun





All models studied

All models studied

$0{,}094 < \Omega h^2 < 0{,}129$ (WMAP 3yr constraint)

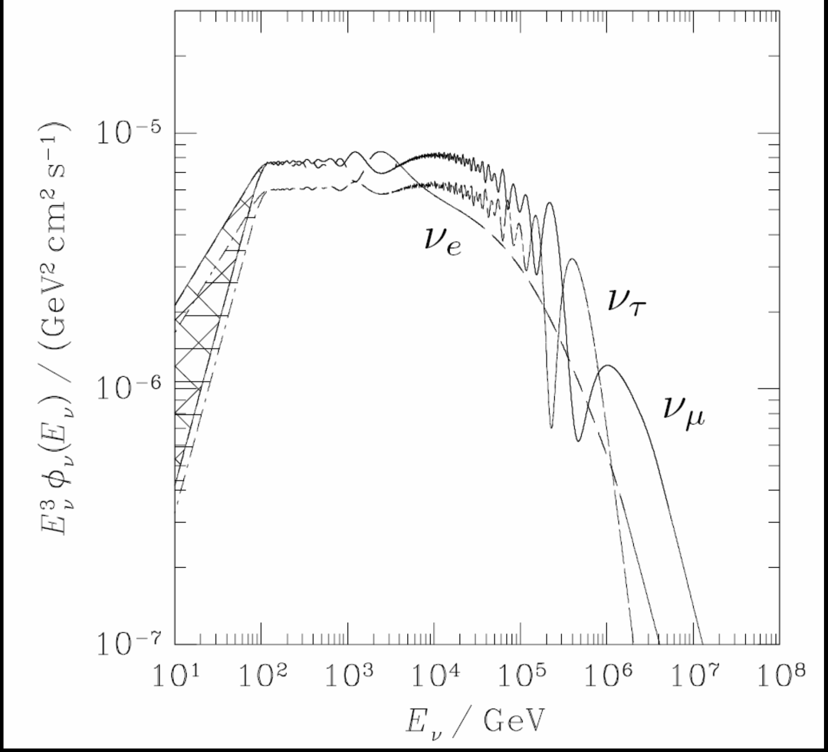
$\Omega h^2 < 0{,}094$

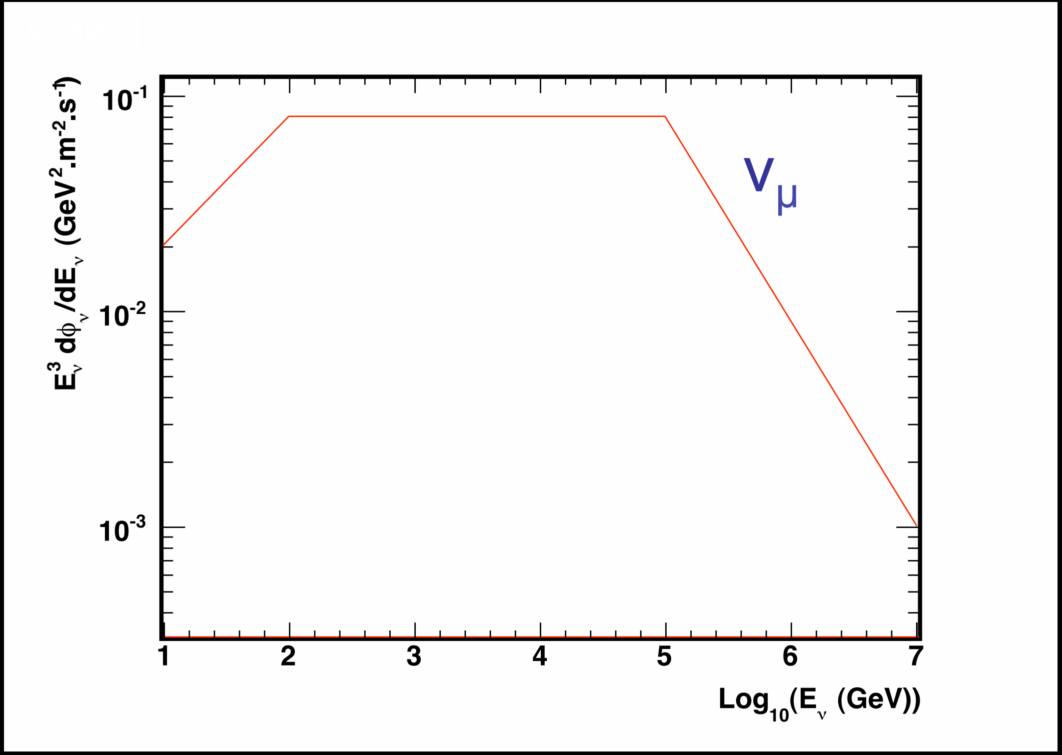
Average upper limit signal

Solar Background
(interactions CRs – Solar atmosphere)

- Interactions p-p give a production of neutrinos through the decay products

De C. Hettlage et al., Astropart.Phys. 13 (2000) 45-50 Simple parameterization averaged on the oscillations





It doesn't represent more than 10^{-3} events per year in a 5 lines configuration (few events for a km^3), 0.4% of the total atmospheric background…