

*..... and dulcis in fundo .....*

## *Borexino, CTF and the CNGS neutrino beam*

*Laura Perasso - INFN Milano*

### *Content:*

- I. The CNGS beam: its latest schedule
- II. Preliminary rate values for the detected CNGS beam induced muons
- III. Conclusions

*Thanks to :*

George Korga

Igor Machulin

Emanuela Meroni

Alessandro Razeto

*April 6<sup>th</sup> Workshop at LNGS*

The last meeting:  
**CNGS START-UP**

LNGS, 6th April 2006  
14:00 'E. Majorana' lecture hall

CNGS Project: Primary Beam	(35')	M. Meddahi (CERN/AB)
CNGS Project: Secondary Beam (CERN/AB)	(35')	E. Gschwendtner
CNGS Simulated Beam Fluxes	(5')	P. Sala (INFN/Milano)
Timing and Data Exchange btw. CERN and LNGS	(30')	D. Autiero (IN2P3/Lyon)

(from D. Autiero)

## *June 22<sup>nd</sup> Workshop at LNGS*

### *“Waiting for the beam”*:

Continuation more focused on the event signatures of the CNGS beam in the LNGS experiments.

#### Presentations by:

1. Dario Autiero : “Update on the CNGS beam”
2. Stefano Dusini : “CNGS beam monitoring with OPERA detector”
3. Gabriella Sartorelli : “CNGS beam monitor with LVD”
4. Laura Perasso: “Borexino, CTF and the CNGS neutrino beam”

(all on the LNGS web pages)

## The CNGS beam

$\langle E_{\nu\mu} \rangle \sim 18 \text{ GeV}$   
 Fluxes @  $E_\nu \sim 18 \text{ GeV}$   
 [ $\nu/\text{cm}^2/10^{19}\text{pot}$ ]:

$$\longrightarrow \nu_\mu \sim 3.2 \cdot 10^5$$

$$\bar{\nu}_\mu \sim 6.4 \cdot 10^3$$

$$\nu_e \sim 1.4 \cdot 10^3$$

$$\bar{\nu}_e \sim 1.8 \cdot 10^2$$

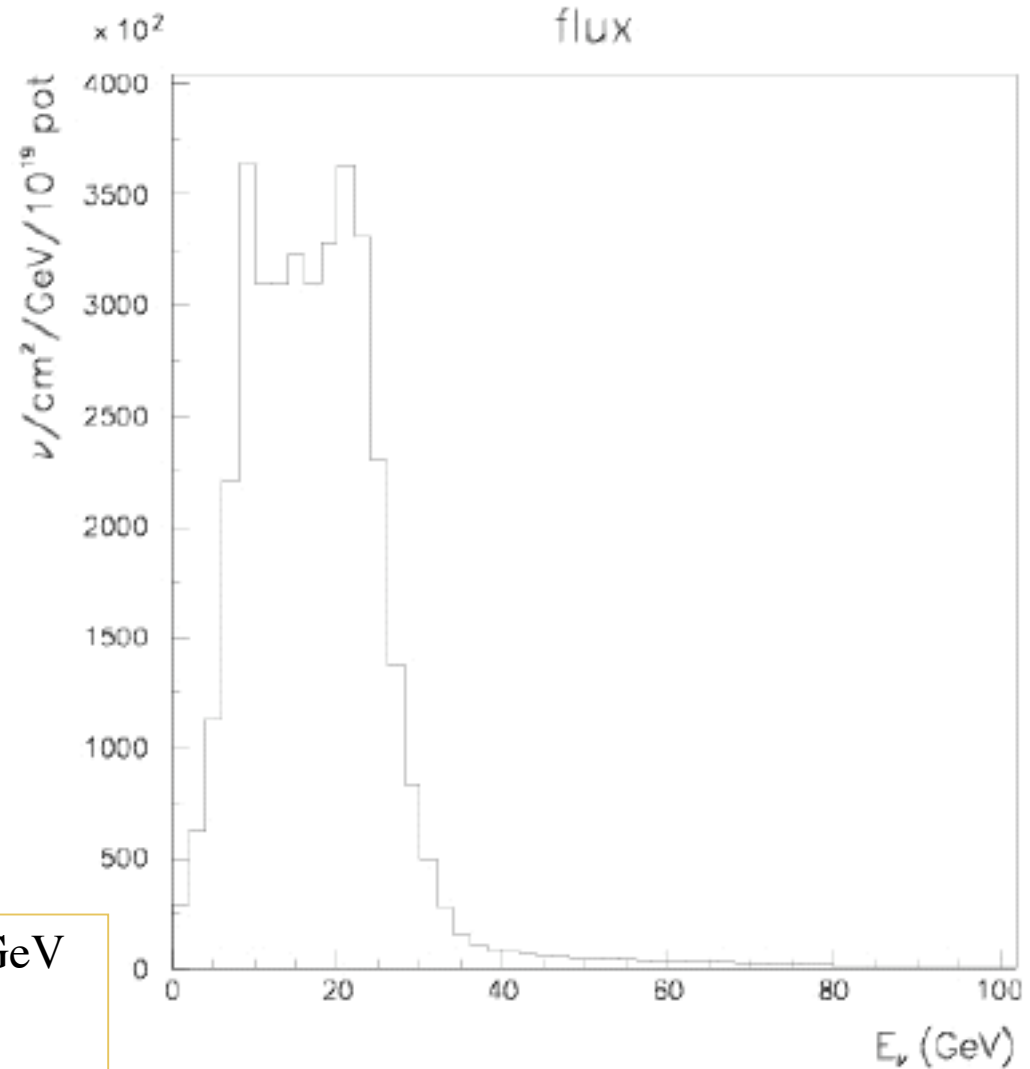
$$(\nu_\mu + \bar{\nu}_\mu) \sim 99.5\% \quad (2\% \bar{\nu}_\mu/\nu_\mu)$$

$$(\nu_e + \bar{\nu}_e) \sim 0.48\%$$

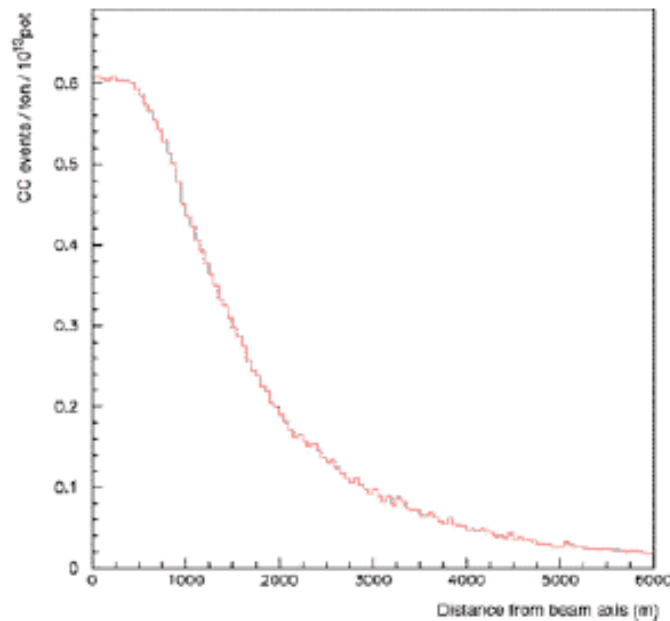
For comparison, MINOS,  $\langle E_{\nu\mu} \rangle \sim 3 \text{ GeV}$

$$(\nu_\mu + \bar{\nu}_\mu) \sim 98.5\% \quad (6.5\% \bar{\nu}_\mu)$$

$$(\nu_e + \bar{\nu}_e) \sim 1.5\%$$



## CNGS Geodesy:



Radial beam distribution at LNGS:

Full width at half maximum: 2.8 Km

Flat region at  $\pm 500$  m

effect on cc events

**horn off axis by 6mm** < 3%

**reflector off axis by 30mm** < 3%

**proton beam on target** < 3%

**off axis by 1mm**

**CNGS facility misaligned** < 3%

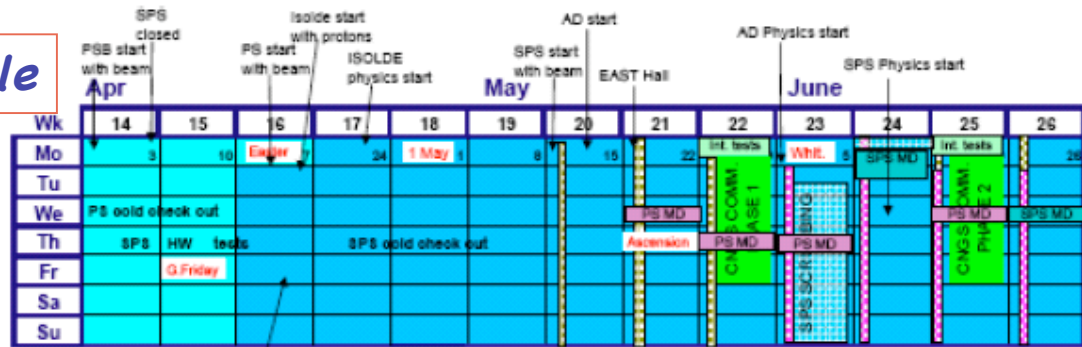
**by 0.5mrad (beam 360m off)**

Angular accuracy of CNGS direction: 0.05 mrad  $\rightarrow$  37 m over 730 Km

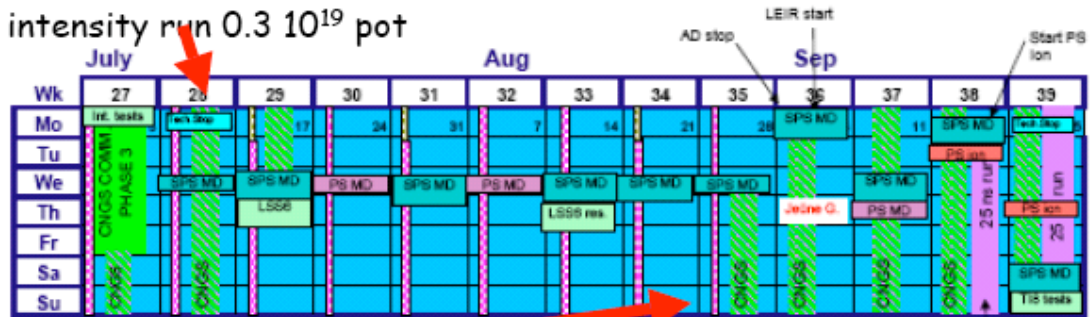
This uncertainty has practically no effect on the observed rates

G. Sartorelli, *Waiting for the neutrino beam*, LNGS, June 22<sup>nd</sup> 2006

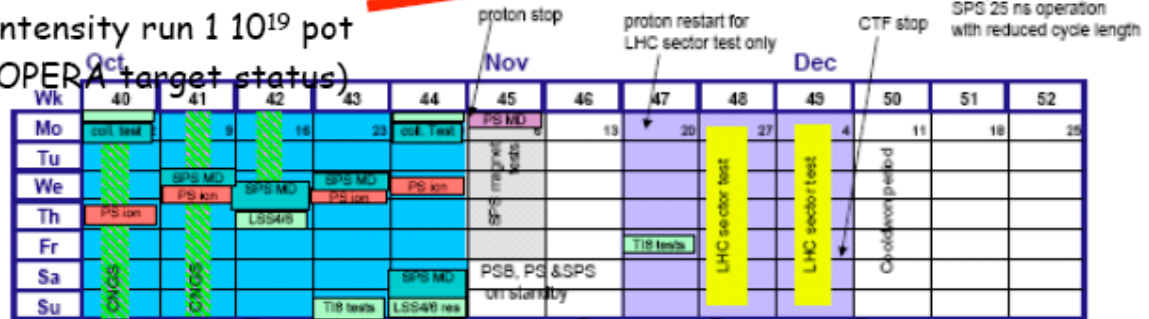
## Initial 2006 SPS schedule



CNGS low intensity run  $0.3 \cdot 10^{19}$  pot



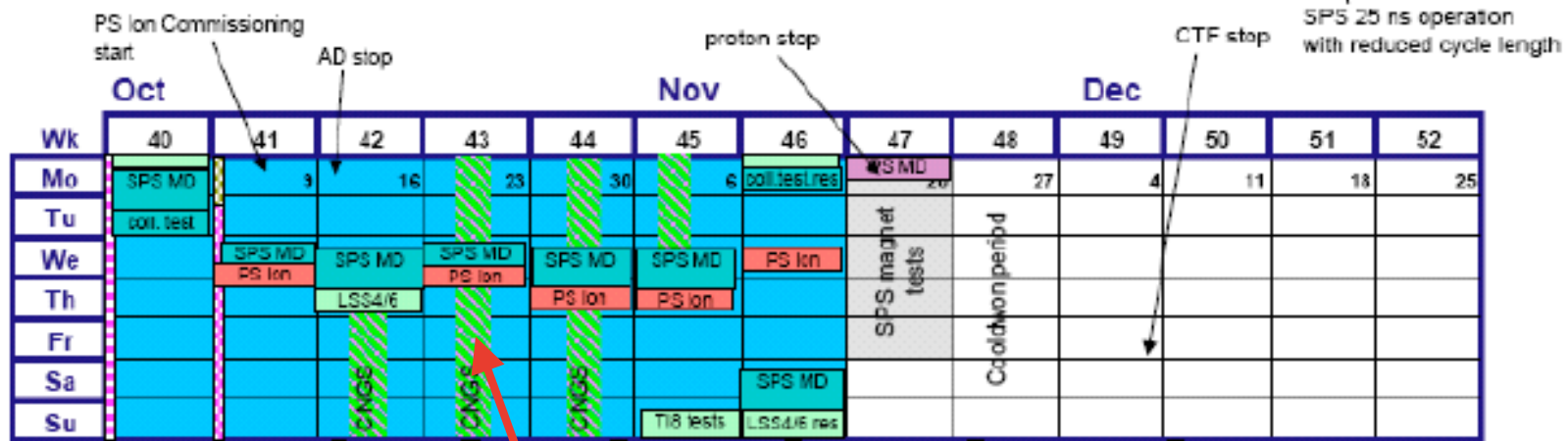
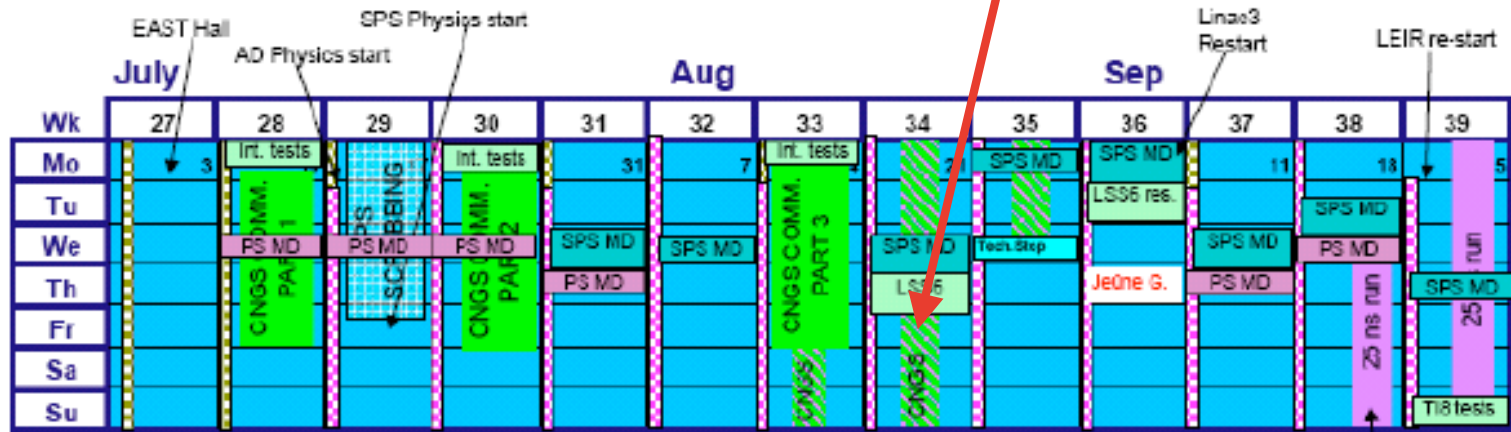
CNGS high intensity run  $1 \cdot 10^{19}$  pot  
(subject to OPERA target status)



Modified due to a PS power supply (installed in 1968!!) fault on 18/5/2006  
It has been replaced....

**New SPS schedule**  
(approved by the RB on 7/6/2006)

18-30 Aug 2006  
low intensity (Scycle= 18 s)



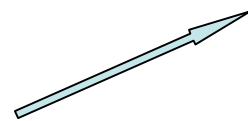
20 Oct-8 Nov



*The CNGS beam monitoring at LNGS*

The CNGS  $\nu_\mu$  beam can be monitored detecting the **muons** produced by the neutrino interactions

in the detectors

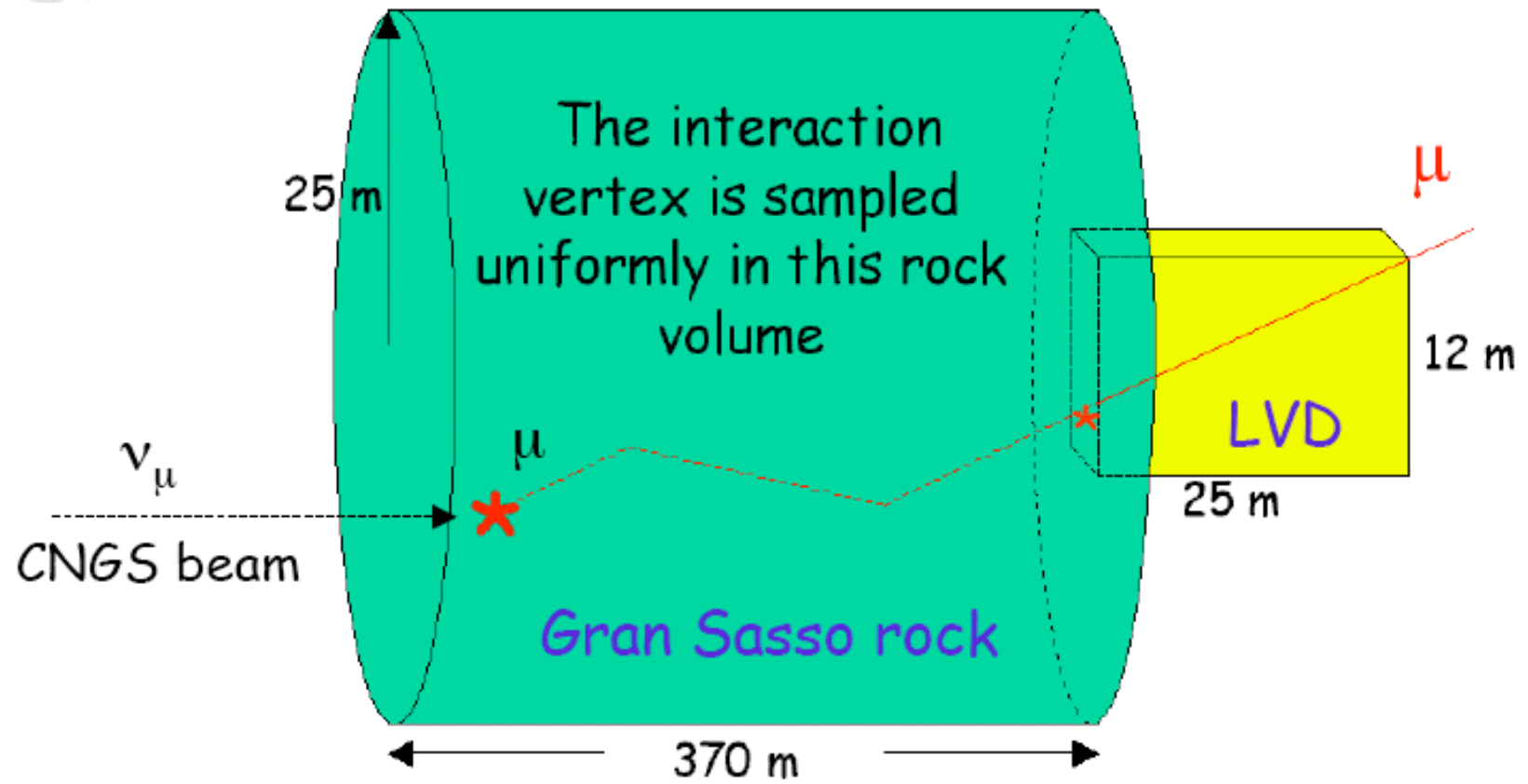


in the rocks in front of the detectors



*with muon identification systems*

# Event Generation

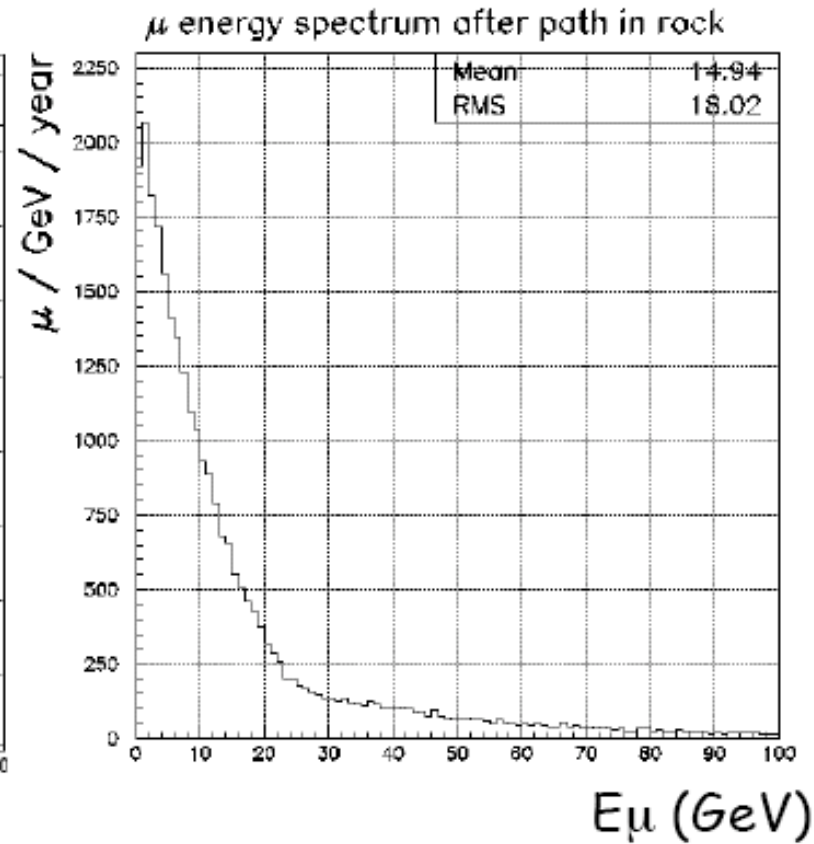
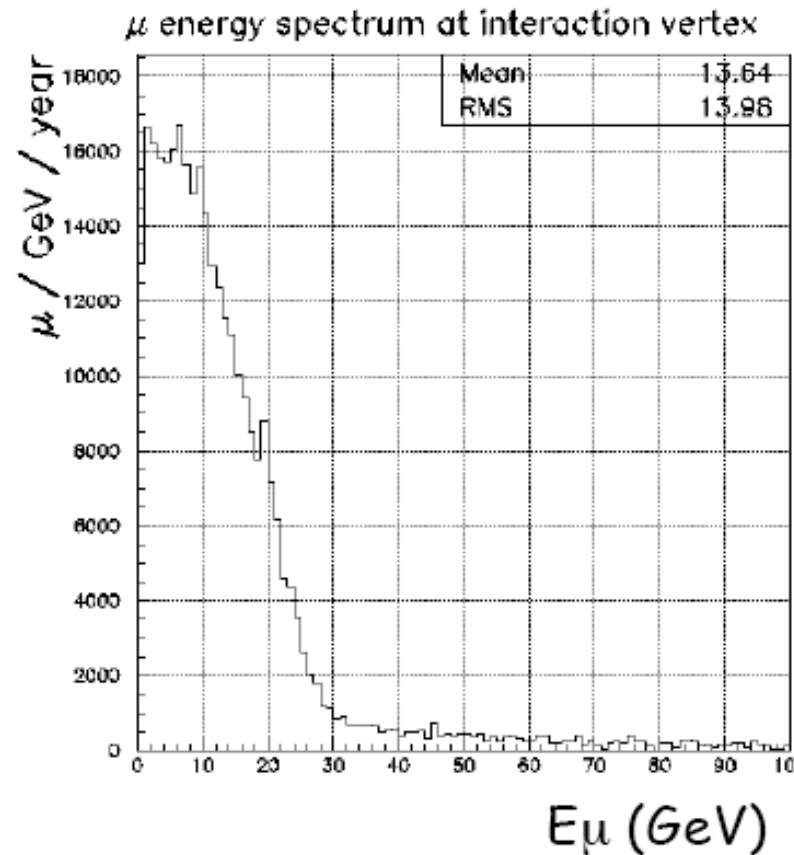
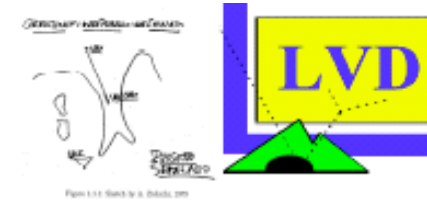


Interaction kinematics with LIPARI code

Muon transport in rock with MUSIC

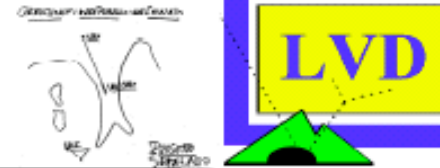
LVD detector simulation with GEANT

# $\mu$ energy spectrum



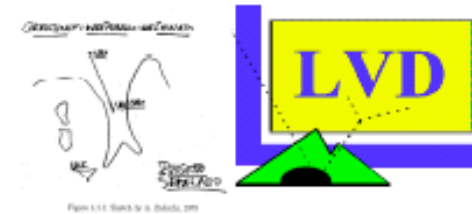
G. Sartorelli, *Waiting for the neutrino beam*, LNGS, June 22<sup>nd</sup> 2006

# Number of $\mu$ from the rock



Rock Mass	1969 ktons
Nominal CNGS intensity	$4.5 \times 10^{19}$ pot/year
CC interaction rate	$5.85 \times 10^{-17}$ CC/pot/year
$\nu_{\mu}$ CC in rock	$5.18 \times 10^6$ / year
Number of $\mu$ in LVD "mother volume"	33600 / year
LVD geometric efficiency	79%
LVD global efficiency	72%
Detected $\mu$ in LVD	<b><math>\sim 120</math> / day</b>

# Number of internal $\nu$ events



Scintillator Mass	1000 tons
Steel Mass (tank and portatank)	850 tons
$\nu_{\mu}$ CC in LVD	4770 / year
$\nu_{\mu}$ NC in LVD	1460 / year
selection efficiency	97% (CC) 91% (NC)
Detected internal events in LVD	<b>~ 30 / day</b>

***Preliminary rate values for the CNGS induced muons in Bx and CTF***

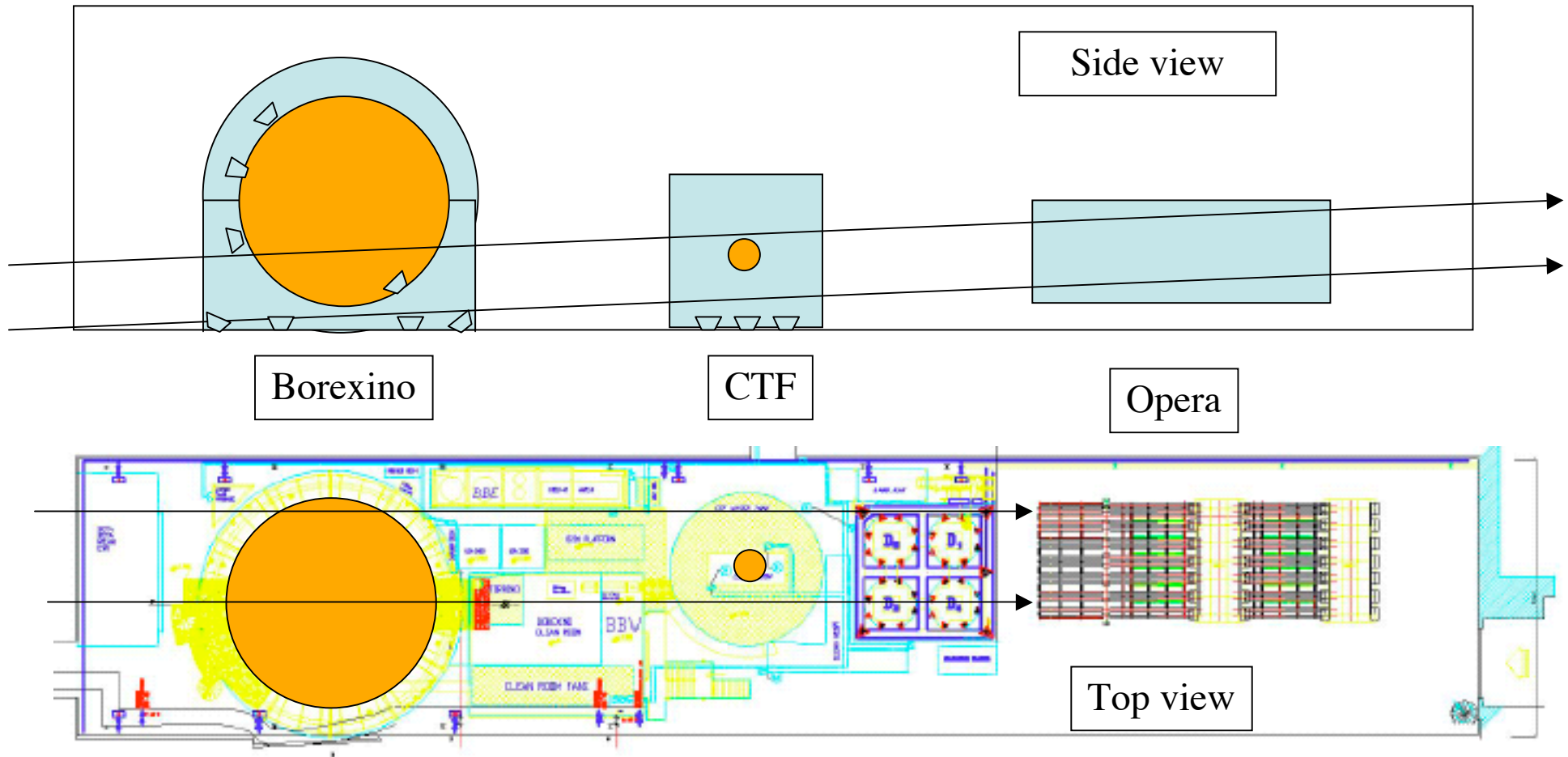
***With the help of Igor Machulin and Emanuela Meroni***

***!! Warning !!***

***!! all these numbers are from very simplified calculations !!***

***!! no MC done so far !!!***

## Hall C side and top view :



## How many $\nu_{\mu}$ induced muon from the rocks do we have ??

### Procedure:

Scaling the LVD results [M.Aglietta et al., hep-ex/0304018 v1 18 april 2003],  
with the usual assumptions:

33600  $\mu$  hitting the LVD “*mother volume*”/year

$$\Rightarrow 33600 / (\text{LVD sup}) \times (\text{Bx sup}) = 33600 / (13.75\text{m} \times 12\text{m}) \times 266 \text{ m}^2 =$$
$$54167 \mu/\text{year}$$
$$\Rightarrow 271 \mu/\text{day in Borexino}$$

$$\Rightarrow 33600 / (\text{LVD sup}) \times (\text{CTF sup}) = 33600 / (13.75\text{m} \times 12\text{m}) \times 110\text{m}^2 =$$
$$22400 \mu/\text{year}$$
$$\Rightarrow 112 \mu/\text{day in CTF}$$



## How many CC + NC events do we have in the detectors ??

### Assumptions:

these CNGS event rates in Borexino and CTF have been calculated assuming:

- Nominal CNGS beam intensity =  $4.5 \cdot 10^{19}$  pot/year
- CC interaction probability =  $4.96 \cdot 10^{-17}$  CC/pot/kton mass for  $E_\nu < 30$  GeV  
[P.Sala]
- One year = 200 days

For:

mass(Borexino) = 3.327 ktons      mass(CTF) = 0.950 ktons

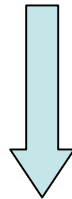
$\Rightarrow N_{\text{CCint}}(\text{Borexino}) \Rightarrow 37 \text{ CC } \mu/\text{day} (+ 11 \text{ NC ev/day})$   
 $\sim 48 \text{ ev/day in Borexino}$

$\Rightarrow N_{\text{CCint}}(\text{CTF}) \Rightarrow 11 \text{ CC } \mu/\text{day} (+ 3 \text{ NC ev/day})$   
 $\sim 14 \text{ ev/day in CTF}$

The total CNGS  $\nu_\mu$  induced muons (from CC in the detector itself or in the upstream rocks) or hadrons (from NC in the detector) calculated rates are:

$$48(\text{CC}+\text{NC}) + 271 \text{ (from rocks)} = 319 \text{ ev/day in Borexino}$$

$$14(\text{CC}+\text{NC}) + 112 \text{ (rocks)} = 126 \text{ ev/day in CTF}$$



How do they compare to our cosmic muon bkgnd ??

How many are detected, taking into account the detector efficiencies ??

## CNGS muons vs. cosmic muons

Cosmic  $\mu$  flux [ $\mu$ /day] in Borexino (expected) :



IV	2025
Buffer	3125
SS Sphere	5150
Water tank	9900

and in CTF (measured):



IV	130
Water tank	2900

Considering the 10.5  $\mu$ s spill length (with a 50ms interspill gap) in a 18 s cycle, we have a reduction factor  $\sim 10^{-6}$  corresponding to a cosmic  $\mu$  flux in coincidence with the CERN spill :

*$\sim 3 \cdot 10^{-2}$  ev/day in Borexino*

*$\sim 1 \cdot 10^{-2}$  ev/day in CTF*

Total CNGS  $\nu_{\mu}$  induced events:

- **319 ev/day cross Borexino = 3% of the cosmics**
- **126 ev/day cross CTF = 4% of the cosmics**



**BX and CTF *must* use the beam spill window (10.5 microseconds) info to identify the CERN  $\mu$**

Expected CNGS performance:  $4.5 \cdot 10^{19}$  pot/year

⇒ "standard" SPS cycle:  $t = 16.8s = 12s$  FT +  $4.8s$  MD

⇒ CNGS commissioning:  $t = 18.0s = 12s$  FT +  $6s$  CNGS

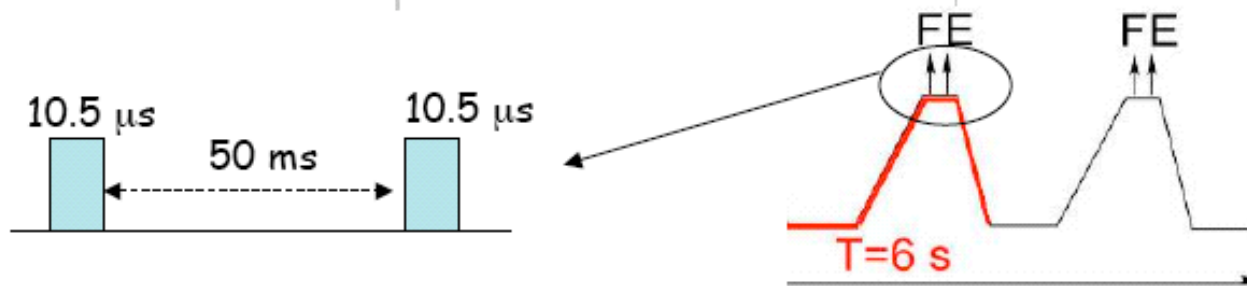
⇒ CNGS low intensity:  $t = 18s = 12s$  FT +  $6s$  CNGS ( $0.3 \cdot 10^{19}$  pot)

⇒ CNGS high intensity:  $t = 34.8s = 12s$  FT +  $3 \times 6s$  CNGS +  $4.8s$  MD ( $1 \cdot 10^{19}$  pot)

Beam parameters	Nominal CNGS beam
Nominal energy [GeV]	400
Normalized emittance [ $\mu\text{m}$ ]	H=12 V=7
Emittance [ $\mu\text{m}$ ]	H=0.028 V= 0.016
Momentum spread $\Delta p/p$	0.07 % +/- 20%
# extractions per cycle	2 separated by 50 ms
Batch length [ $\mu\text{s}$ ]	10.5
# of bunches per pulse	2100
Intensity per extraction [ $10^{13}$ p]	2.4
Bunch length [ns] ( $4 \sigma$ )	2
Bunch spacing [ns]	5

# pot for FT reduced to 40%

CNGS cycles

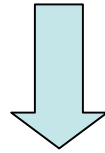


(from D.Autiero)

To correlate the events recorded by the experiments with the beam spill windows (10.5 microseconds):

$$T(\text{LNGS}) = T(\text{kicker at CERN}) + \text{TOF}$$

Using UTC times recorded at CERN and LNGS



UTC clocks synchronizations and calibrations needed

*From Autiero's presentation:*

- the *early warning signal*: the next neutrino spill can be predicted in advance of several seconds and this info can be transmitted through their network  
***⇒ implemented and tested since March***  
already used by OPERA ;  
*to be decided*: the list of machines which should receive the signal
- the *complete calibration of the time distribution chain of OPERA*  
***⇒ in progress***
  - Alessandro Razeto had contacts with LNGS Computer Center and Opera  
*for eventual use of this information by BX and CTF*
- the *CERN-LNGS UTC clocks intercalibration* for the neutrino spill synchronization  
***⇒ finished***:
  - understood and taken account of the 356 ns offset
  - $\Delta t < 100$  ns

- the *CNGS-LNGS database* (ORACLE based, 1TB/day info):
    - to correlate the events recorded by the experiments with the beam spill windows (10.5 microseconds) :  $\Delta t < 100$  ns
    - the LNGS exp. will be able to write the events observed in correlation to the spills
- => *in progress*: access being tested by OPERA, docs available

***Final rates taking into account the detector geom efficiencies***

***In Borexino :***

muons generated		Det eff.	Final rate[ev/day]
inside the det.	48	~98%*	47
in the rocks	271	~99%	268
Total rate	319		315 [ev/day]
Cosmic muon rate bk			<b><math>3 \cdot 10^{-2}</math> ev/day</b>

***In CTF:***

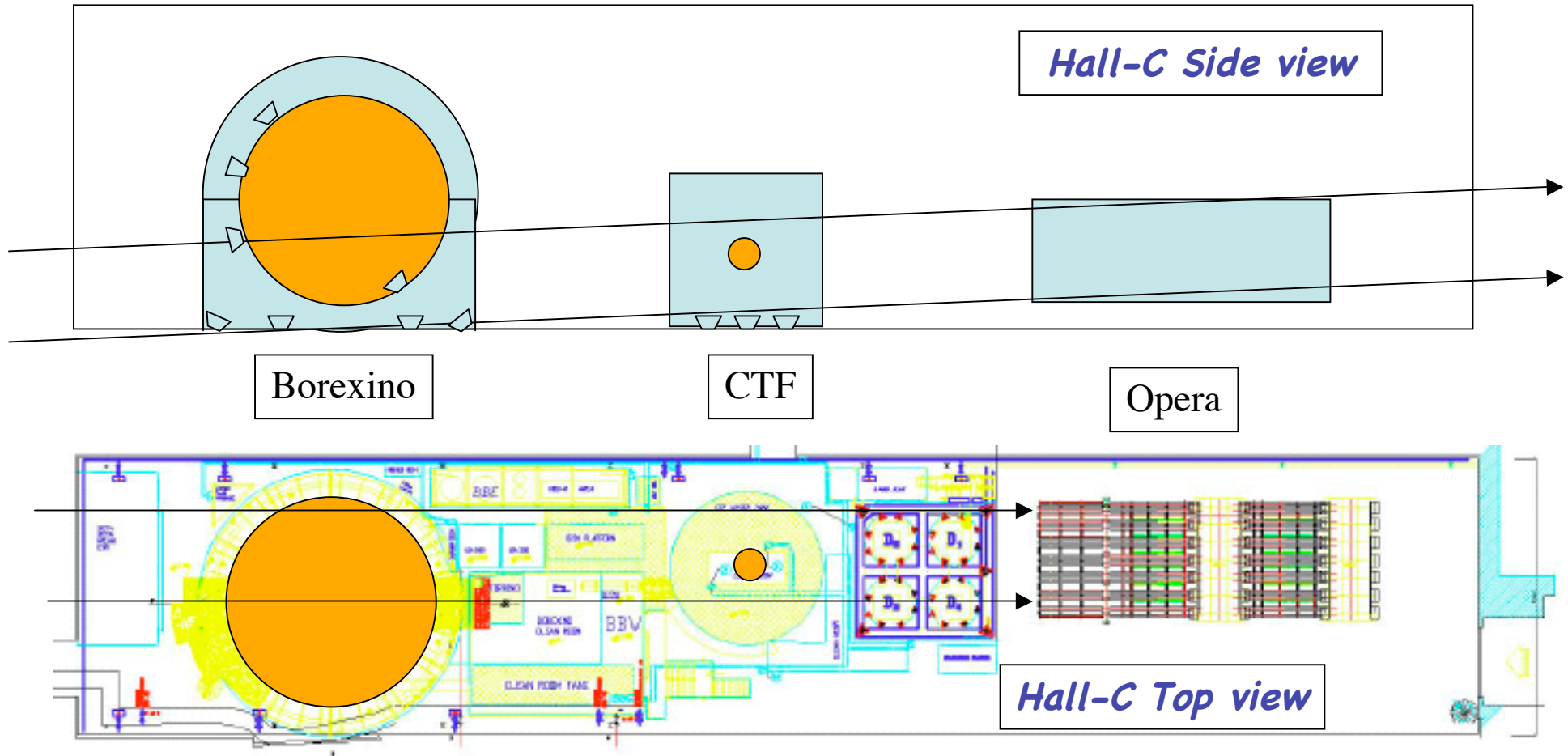
muons generated		Det eff.	Final rate [ev/day]
inside the det.	14	~50%*	7
in the rocks	112	~98%	110
Total rate	126		117 [ev/day]
Cosmic muon rate bk			<b><math>1 \cdot 10^{-2}</math> ev/day</b>



***Final detected event rates in the first runs:***

Run #		LVD	BX	CTF
nominal	4.5 10 <sup>19</sup> pot/year	~ 150 /day	315/day	117/day
<b>1</b>	<b>2 10<sup>16</sup> pot/week</b>	<b>~ 13/week</b>	<b>28/week</b>	
<b>2</b>	<b>3 10<sup>16</sup> pot/week</b>	<b>~ 20/week</b>	<b>42/week</b>	<b>15/week</b>
<b>3</b>	<b>5 10<sup>16</sup> pot/week</b>	<b>~ 33/week</b>	<b>70/week</b>	<b>26/week</b>

*We can have BX-CTF-Opera coincidences*



How many  $\nu_{\mu}$  induced muon from the rocks do we detect both in Opera and in Borexino and CTF ??

Scaling the LVD results [M.Aglietta et al., hep-ex/0304018 v1 18 april 2003], with the usual assumptions:

33600  $\mu$  hitting the LVD “*mother volume*”/year

$$\Rightarrow 33600 / (\text{LVD sup}) \times (\text{Bx sup}) = 33600 / (13.75\text{m} \times 12\text{m}) \times (6.7 \times 6.7) \text{m}^2 =$$

9141  $\mu$ /year  
45  $\mu$ /day

## Conclusions

- **Can Borexino/CTF monitor the CNGS  $\nu$  beam ??**      **Yes !**

In LNGS - HallC we will have :

- **$\sim 315$  ev/day in Borexino** ( $\sim 150$  detected ev/day in LVD )  
 **$\sim 60$   $\mu$ /day hit OPERA**
- **$\sim 117$  ev/day in CTF**

Corresponding to a 3% stat. error in:    **3.5 days for Borexino (7 for LVD)**  
**9.5 days for CTF**

### **What we have to do ??**

**These are very preliminary results**

$\Rightarrow$ MC- calculate all the acceptances of the detectors for these *horizontal* muons

- **What is needed for monitoring ??**

Spill timing information

- **Can Bx do something else ??**

Yes !! Beam burst structure, Calibrations, Track algorithm checks, ....  
?? Some physics??     $\sigma_{cc}$ ???

## Conclusions for us:

*What we have to do ??*

*Decide if/how we want:*

- *to study this new bkgnd*
- *to monitor the CNGS beam*

=> decide which actions to do , who does what, by when

- *to take advantage of it*

=> decide which actions to do , who does what, by when

*Needed:*

Software:

- MC simulations
- Interface with the CNGS database (read and write)

Hardware:

- spill info read-out (BX clock calibrations)

*•Can Bx do something else ??*

*- Think about it !!*