Angular correlations between fragments and neutrons in the spontaneous fission of ^{252}Cf

Andreina Chietera

on behalf of the

CORA collaboration

UNIVERSITÉ DE STRASBOURG

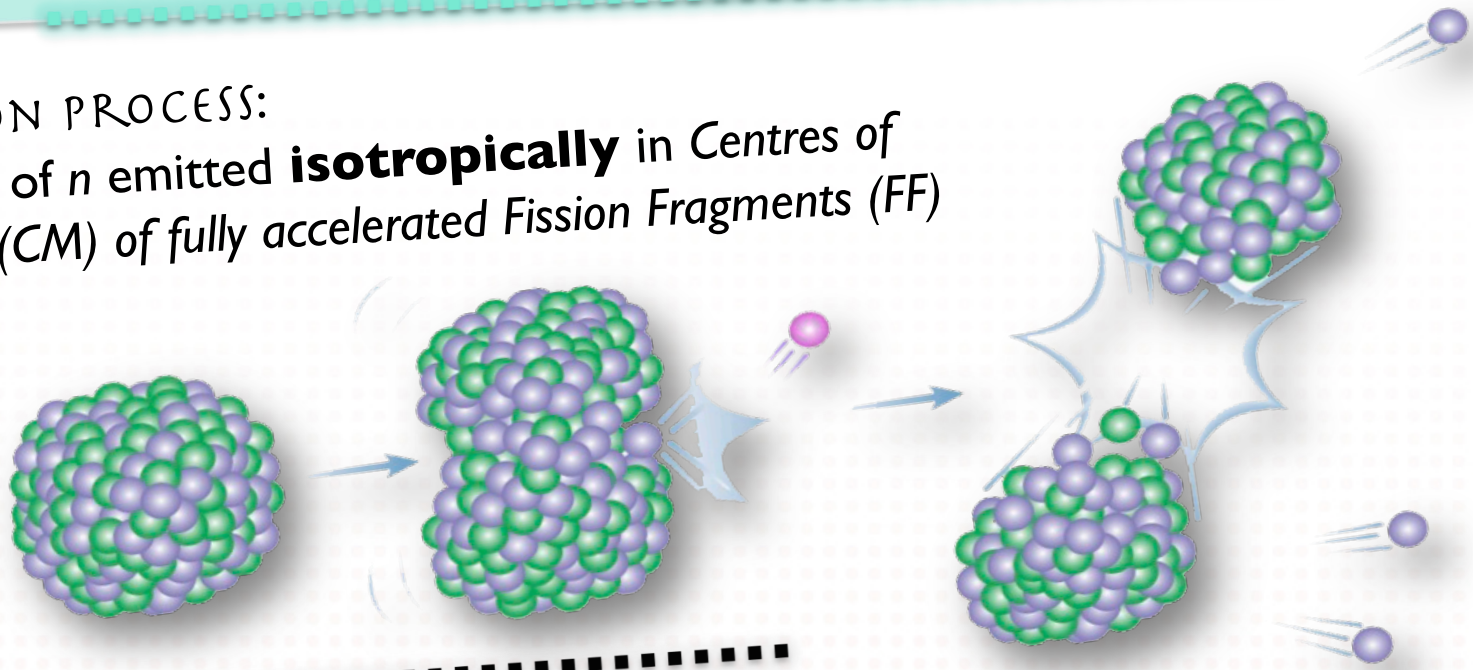
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

cnrs IN2P3 Les deux infinis

MOTIVATIONS

FISSION PROCESS:

- bulk of *n* emitted **isotropically** in *Centres of Mass (CM) of fully accelerated Fission Fragments (FF)*



but

Discrepancies between experimental neutron angular distributions and pure isotropic evaporation are observed.

MOTIVATIONS

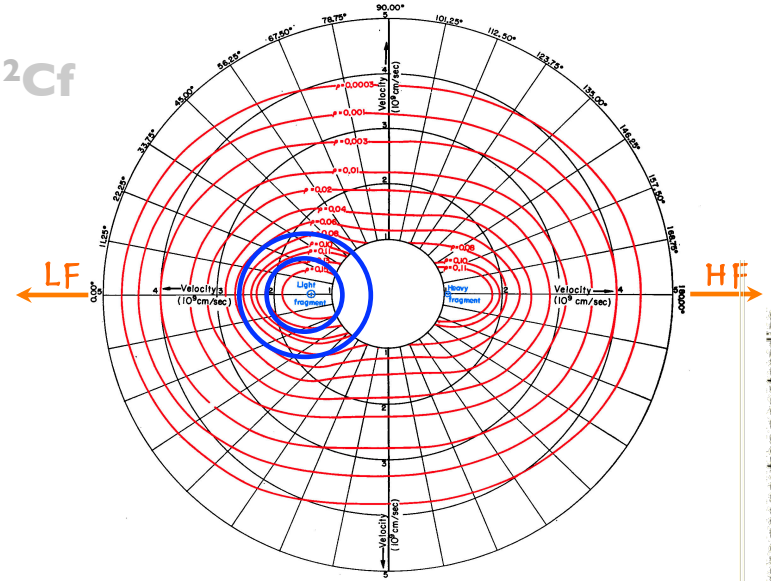
neutron density distribution $\rho(V,\theta)$

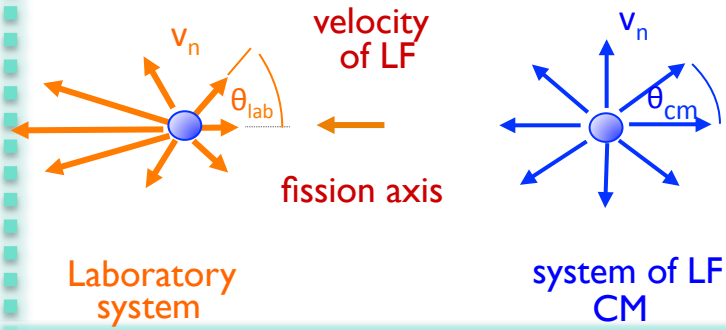
Density of neutrons in velocity space:

$$\rho(V)d^3V = \rho(V,\theta_{lab})\,V^2\,dV\,d\omega$$

H.R. Bowman et al, PR126-6 (1962) 2120

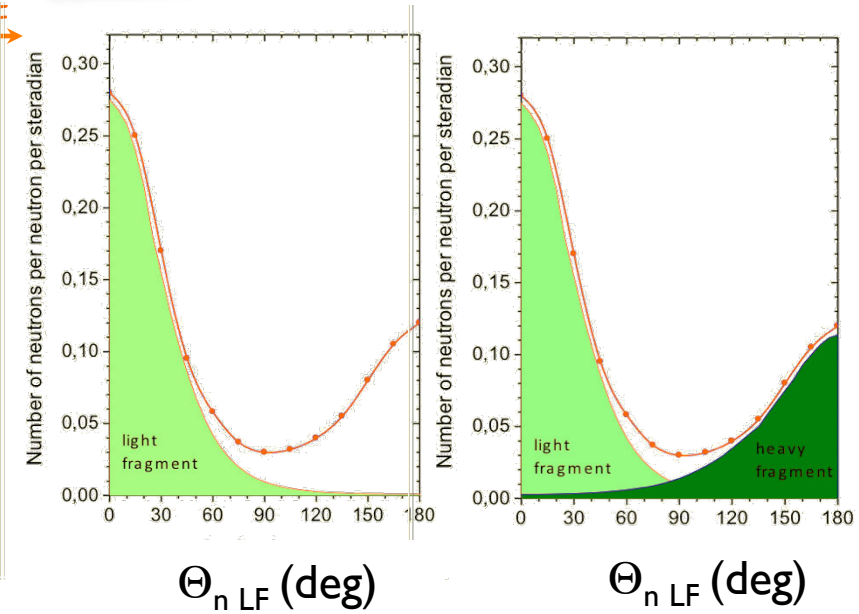
^{252}Cf





>> in the lab the angular distribution of neutrons is no longer isotropic:

KINEMATIC FOCUSING



MOTIVATIONS

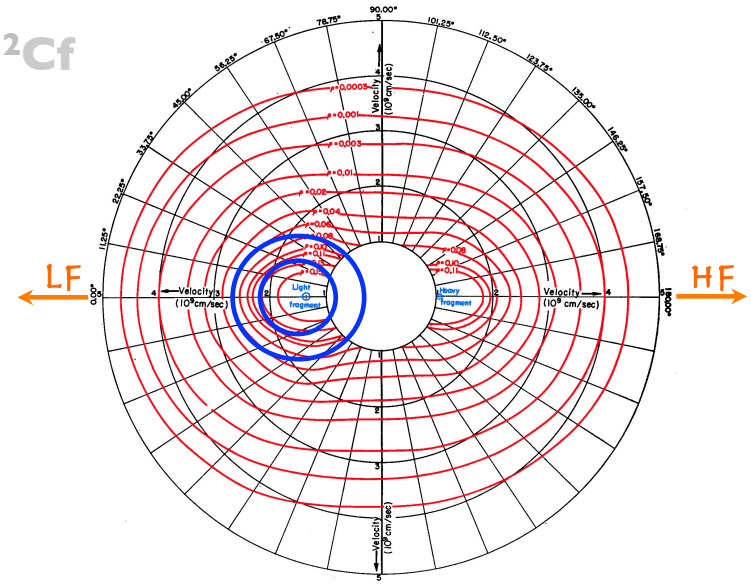
neutron density distribution $\rho(V,\theta)$

Density of neutrons in velocity space:

$$\rho\,(V)d^3V = \rho\,(V,\theta_{lab})\,V^2\,dV\,d\omega$$

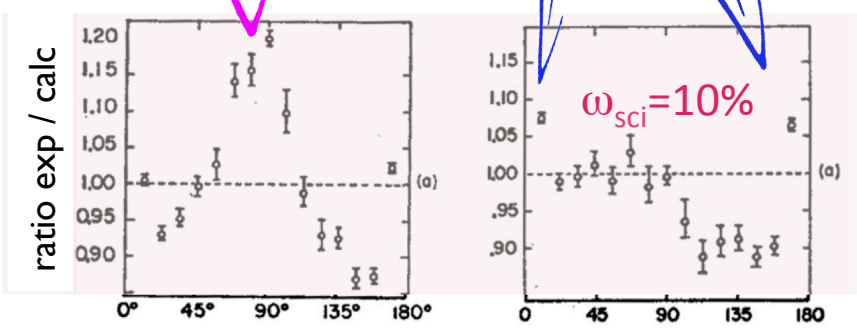
H.R. Bowman et al, PR126-6 (1962) 2120

^{252}Cf



excess of n

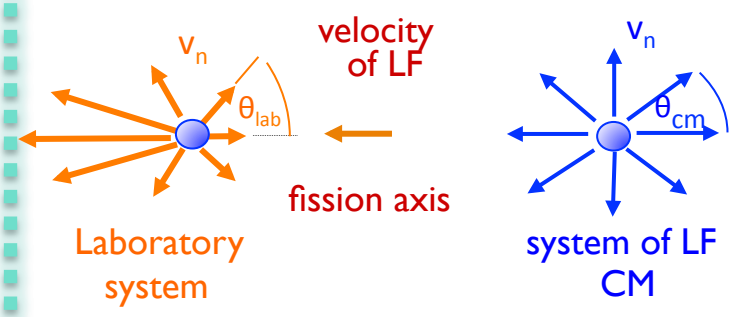
excess of n



$\Theta_{n\ LF}$ (deg)

$\Theta_{n\ LF}$ (deg)

KINEMATIC FOCUSING



>> more anisotropy sources:

SCISSION NEUTRONS

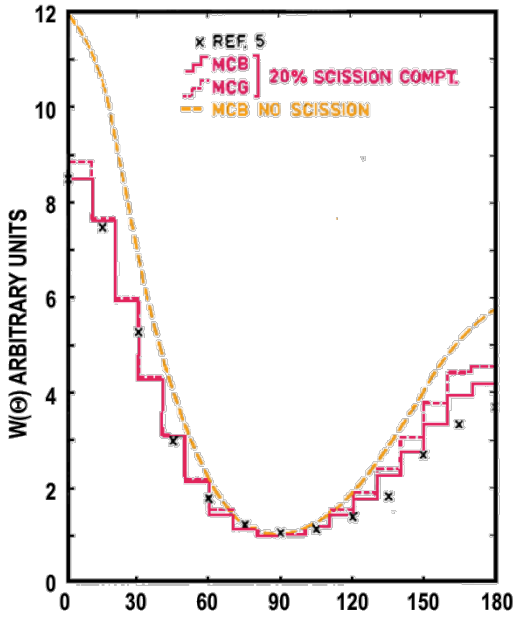
DYNAMICAL ANISOTROPY

MOTIVATIONS

SCISSION NEUTRON EFFECT

early stage *n* emission

H. R. Bowman (1962) - first introduction



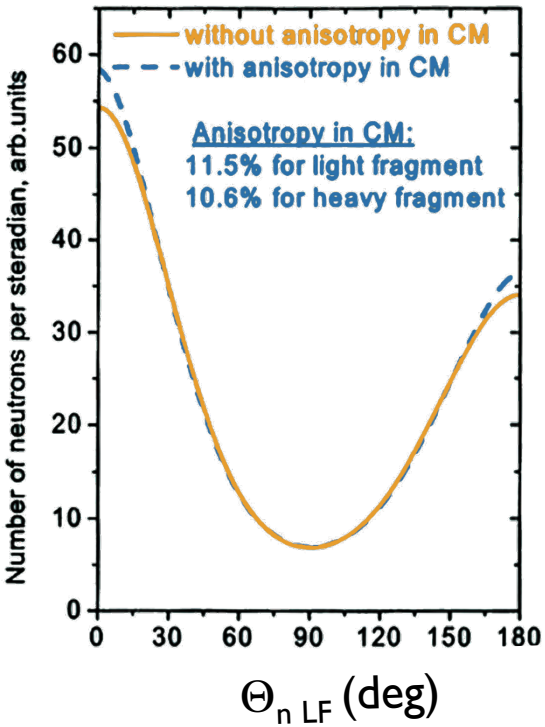
C.B. Franklyn et al PLB 564, 1978

- *add scission n*

⇢ excess of neutrons is still observed at *forward/backward* angles in lab system

DYNAMICAL EFFECT

A .Gavron (1976) - first introduction



V. Bunakov, I. Guseva et al, ISINN-13, 2006, p293

- introduction of *n* **anisotropy** in the *CM* of FF

CORA EXPERIMENT

… about *n* distribution discrepancies

CORA

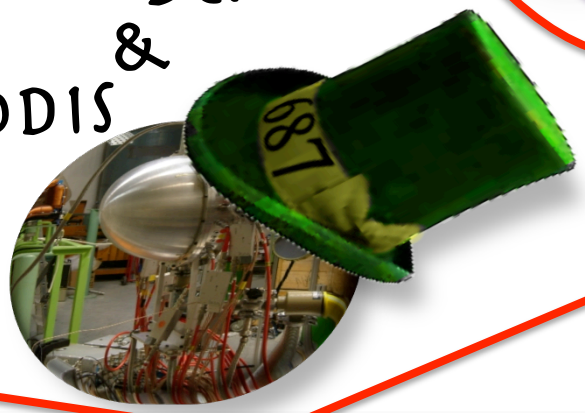
coincidences between *FF* and *n* in *spont* fission of ^{252}Cf to observe and disentangle :

SCISSION NEUTRONS

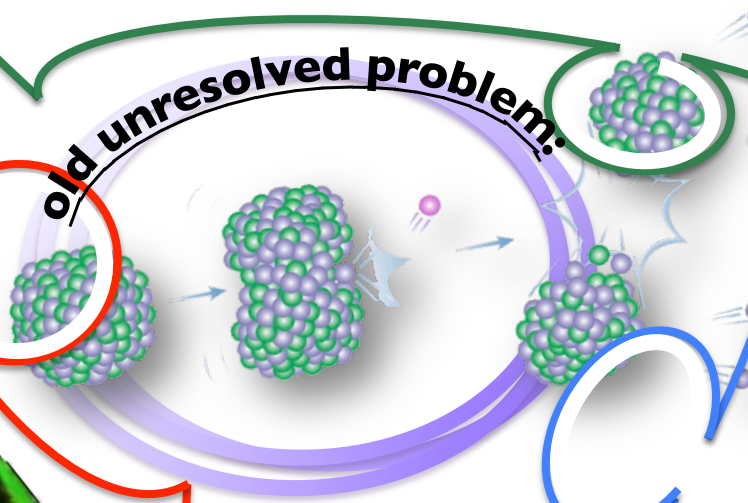
DYNAMICAL ANISOTROPY

in the same experiment

DEMON & CODIS



- many experiments & theoretical calculations but lots of discrepancies



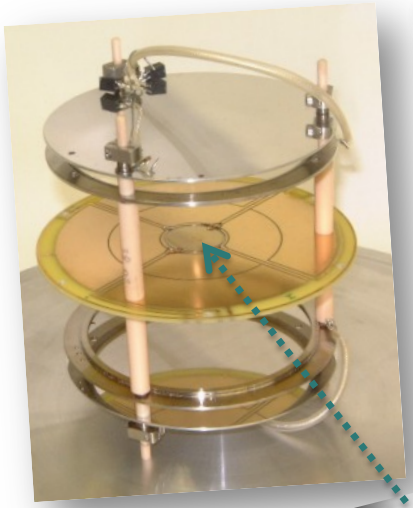
- up to now no experiment with simultaneous access to both

SCISSION NEUTRONS

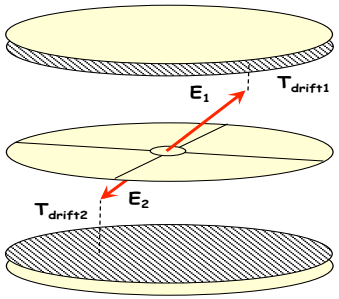
DYNAMICAL ANISOTROPY

CORA EXPERIMENTAL SETUP

CODIS- FISSION CHAMBER



double ionisation chamber for 4 π detection of FF



>> FF :

E, A, θ, Φ

- **sectored cathode**

DEMON

- ***n* detection:**

60 individual cells of liquid scintillator (NE213)

- ToF measurement
- *n* - γ discrimination
- central position of each cell >> θ_0, ϕ_0

>> *n* :

E, θ_0, Φ_0

duration: 5 months

~ 10^{10} FF

~ 10^9 FF-2n

ANALYSIS METHOD

CORA: multiple parameter experiment ⟹ **complex**

many experimental biases:

- geometrical acceptance
- pileup
- detector threshold
- intrinsic efficiency
- cross talk
- θ_n, Φ_n ⟹ DEMON central angles (θ_0, Φ_0)

>> careful simulation mandatory ⟹

- **c++ code**
- **GEANT4**

SIMULATIONS

GENERAL FEATURES OF *n* GENERATION

❑ *FFs* attributes

- type: heavy/light
- position: isotropic cos θ_{ff}, Φ_{ff}
- mean velocity v_{ff}
- nucleus temperature T_{ff}
- *n* multiplicity ν ⟹ Gaussian *n* distribution & covariance ρ=−0.2

parameter \ type	light	heavy
v_{ff} (cm/ns)	1.355	1.022
T_{ff} (MeV)	0.91	0.93
<ν>	2.056	1.710
σ	0.94	1.07

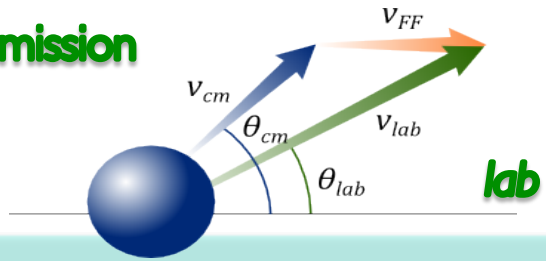
A.S. Vorobyev et al, AIP 2, p55 (2005)
N.V. Kornilov et al, IAEA 2, p61 (2001)

❑ Fission neutrons

*CM*s of FF *n* emission:

- Φ_{cm}, cos θ_{cm} : $W(\theta_{cm}) = 1 + A_{nJ} \sin^2 \theta_{cm}$
- energy ⟹ $\varphi(\eta) \sim \sqrt{\eta}\, e^{-\eta/T_{ff}}$

to *lab* system emission



❑ Scission neutrons

ϕ, cosθ: isotropic in the lab

- energy ⟹ $\varphi(E_{sci}) \sim E_{sci}\, e^{-E_{sci}/T_{sci}}$

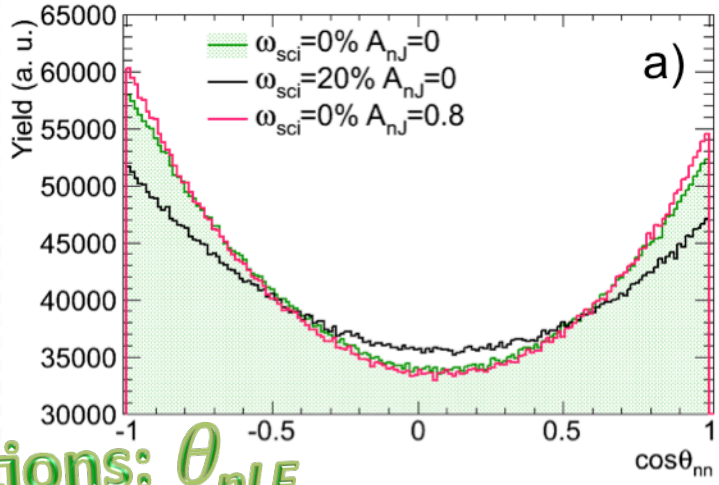
  T_{sci}=1.2 MeV (A. Gagarski)
- *n* multiplicity ν recomputed

  $\langle \nu'_{LF} \rangle = \langle \nu_{LF} \rangle (1 - \omega_{sci})$

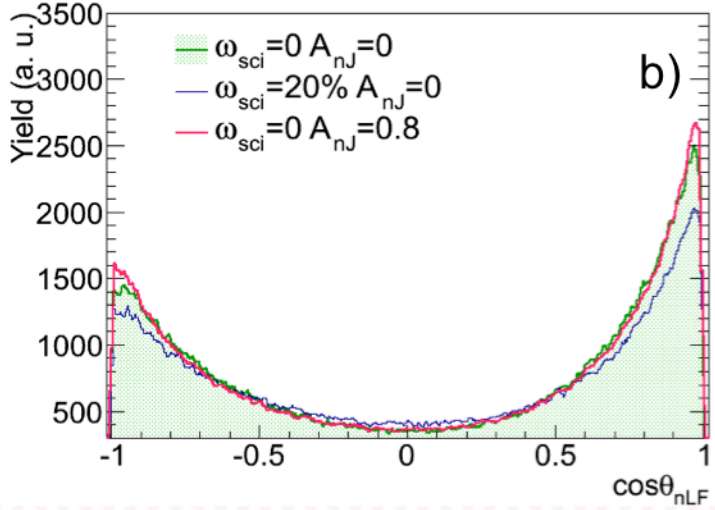
  $\langle \nu'_{HF} \rangle = \langle \nu_{HF} \rangle (1 - \omega_{sci})$

SIMULATIONS

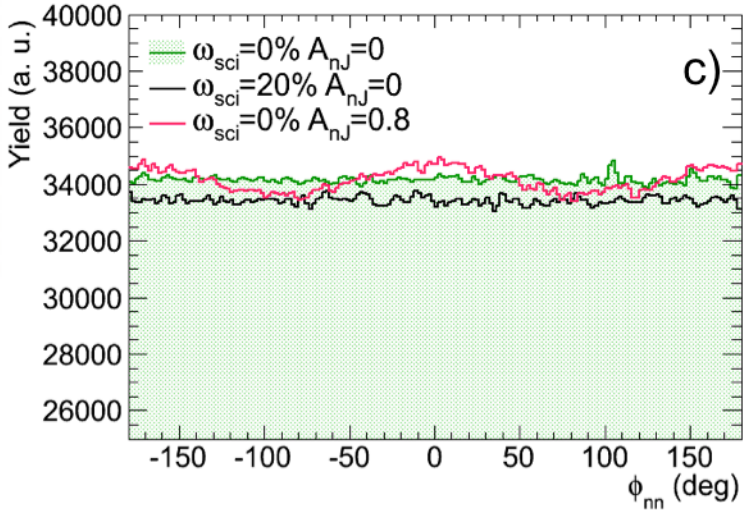
correlations: θ_{nn}



correlations: θ_{nLF}



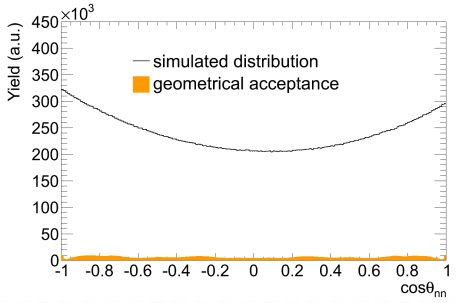
correlations: $\phi_{nn/LF}$



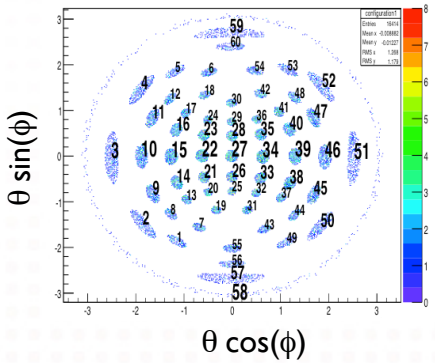
« theoretical » simulated distributions

SIMULATIONS

« theoretical » distribution



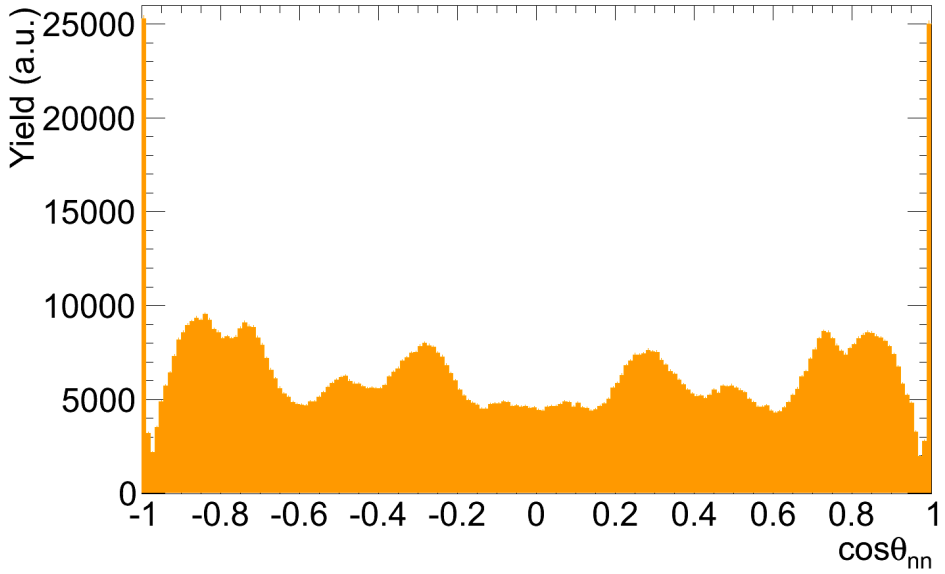
- **geometrical acceptance**



total $\Omega \sim 17\%$ of 4π

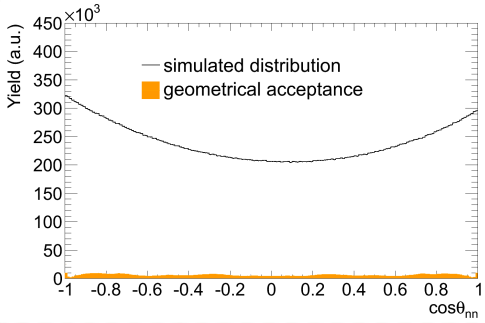
$\Delta\theta_{min} = 2.2°$ $\Delta\theta_{max} = 5.8°$

>> **remaining ~3%**



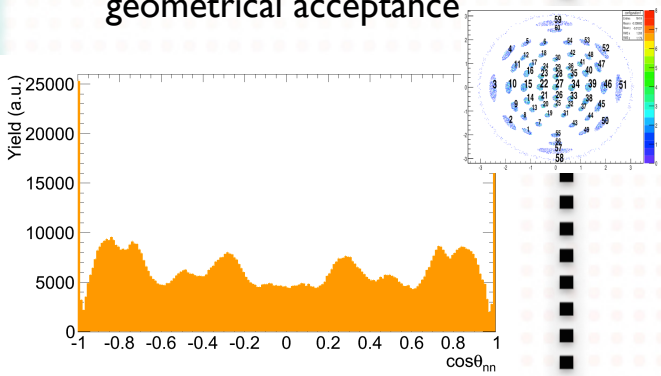
SIMULATIONS

« theoretical » distribution

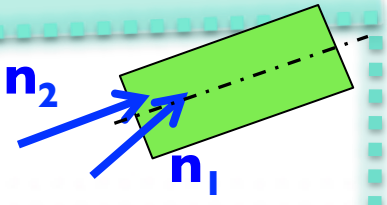


+

geometrical acceptance



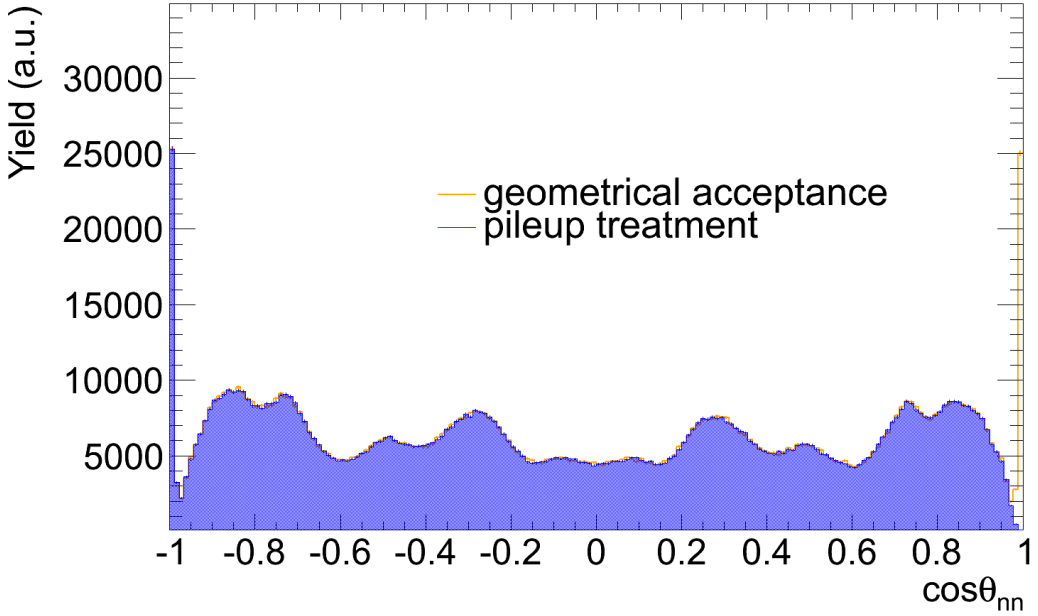
- **pileup treatment**



2n as **1n**

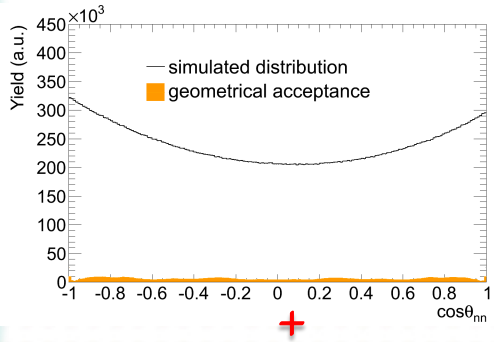
>> n° ~2% in nn correlations

(**~1%** nLF correlations)



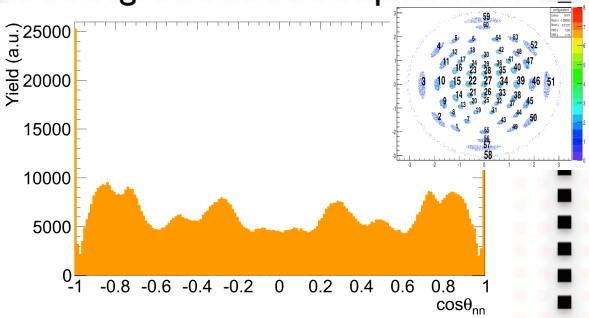
SIMULATIONS

« theoretical » distribution



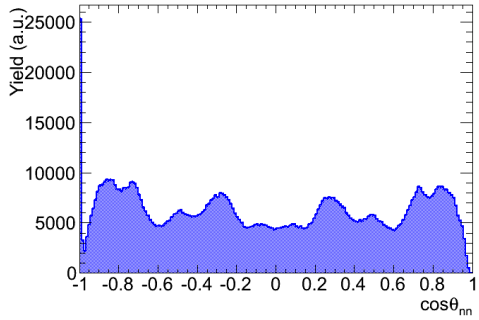
+

geometrical acceptance



+

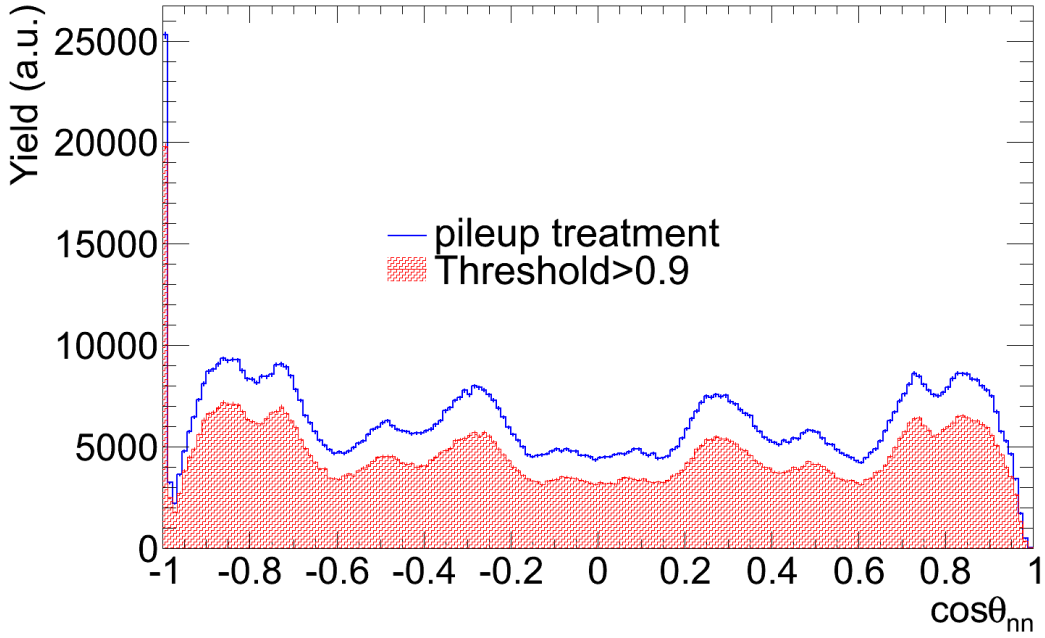
pileup



- **detector threshold**

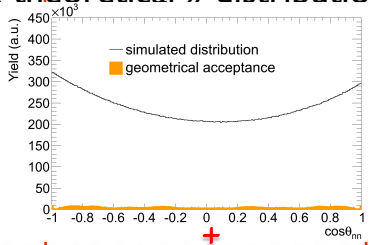
E_n > 0.9 MeV

>> remaining ~70%

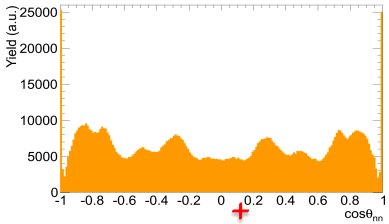


SIMULATIONS

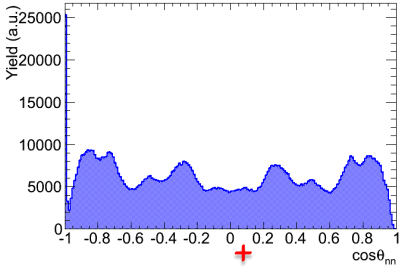
« theoretical » distribution



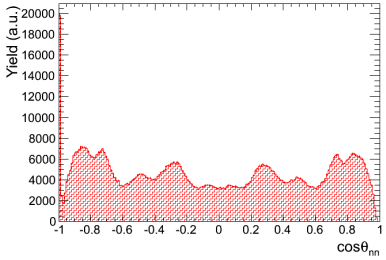
+ geometrical acceptance



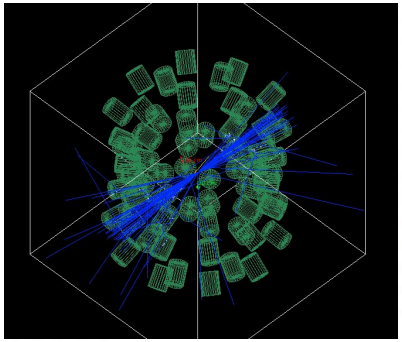
+ pileup



+ threshold



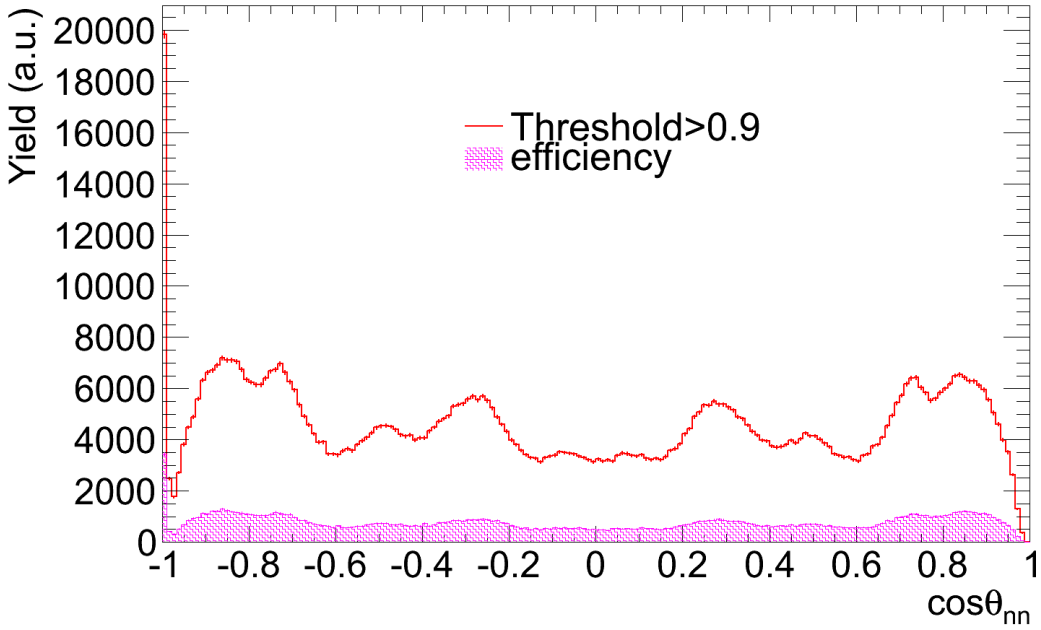
- **intrinsic efficiency**



Menate_R code – interaction processes

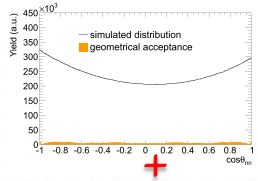
P. Désesquelles et al, NIM A307 (1991) 366
B. Roeder, EURISOL Design Study, 2008,38-44

>> remaining ~20%



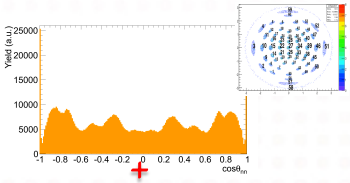
SIMULATIONS

« theoretical » distribution



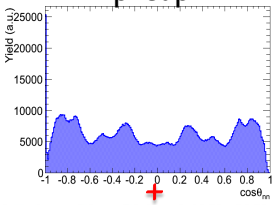
+

geometrical acceptance



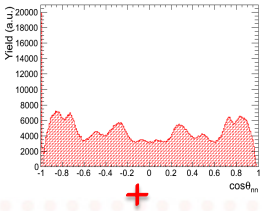
+

pileup



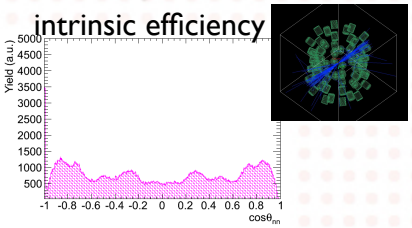
+

threshold



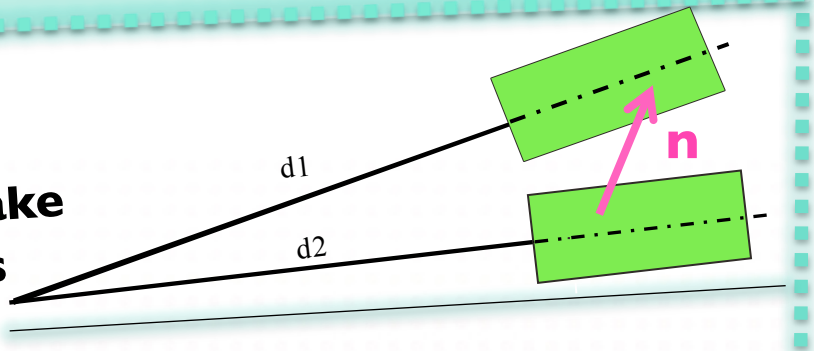
+

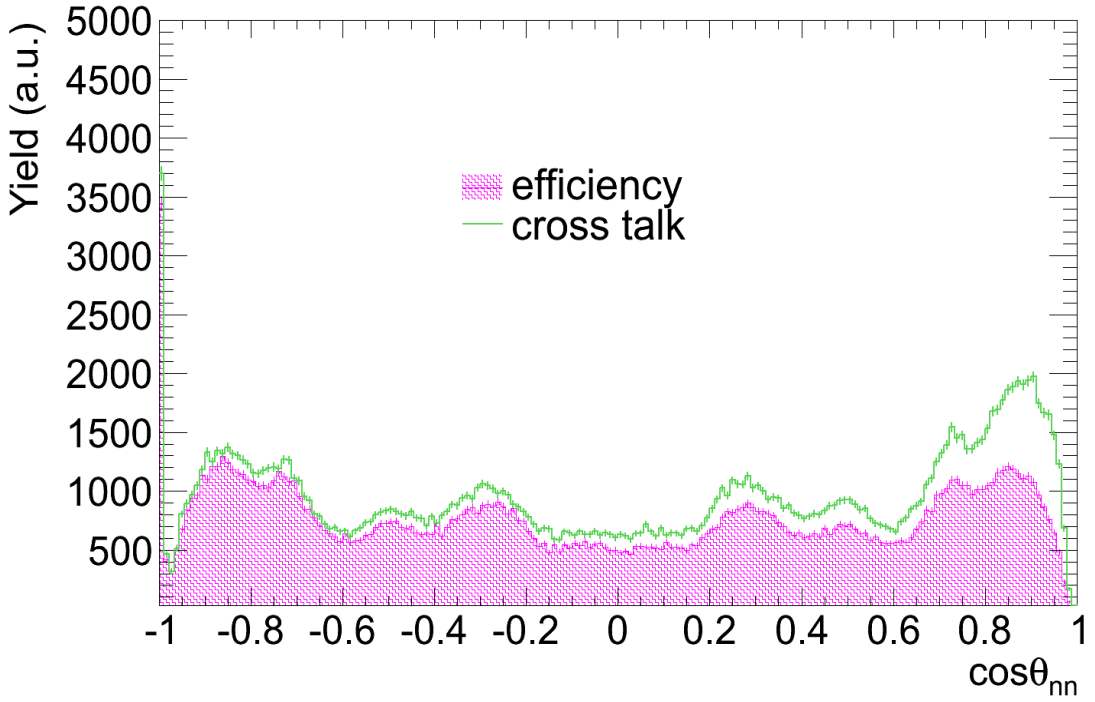
intrinsic efficiency



- **cross talk**

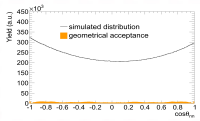
>> add ~20% of fake correlations





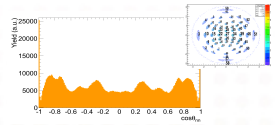
SIMULATIONS

« theoretical » distribution



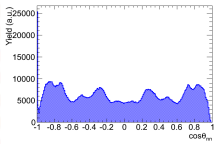
+

geometrical acceptance



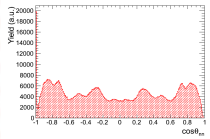
+

pileup



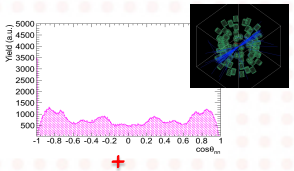
+

threshold



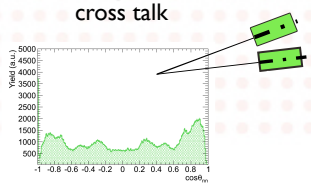
+

intrinsic efficiency

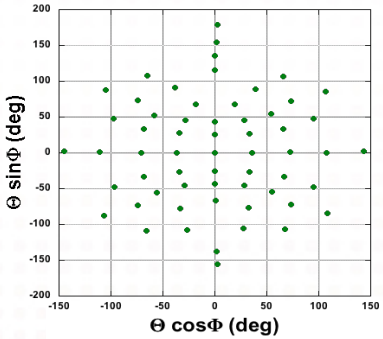


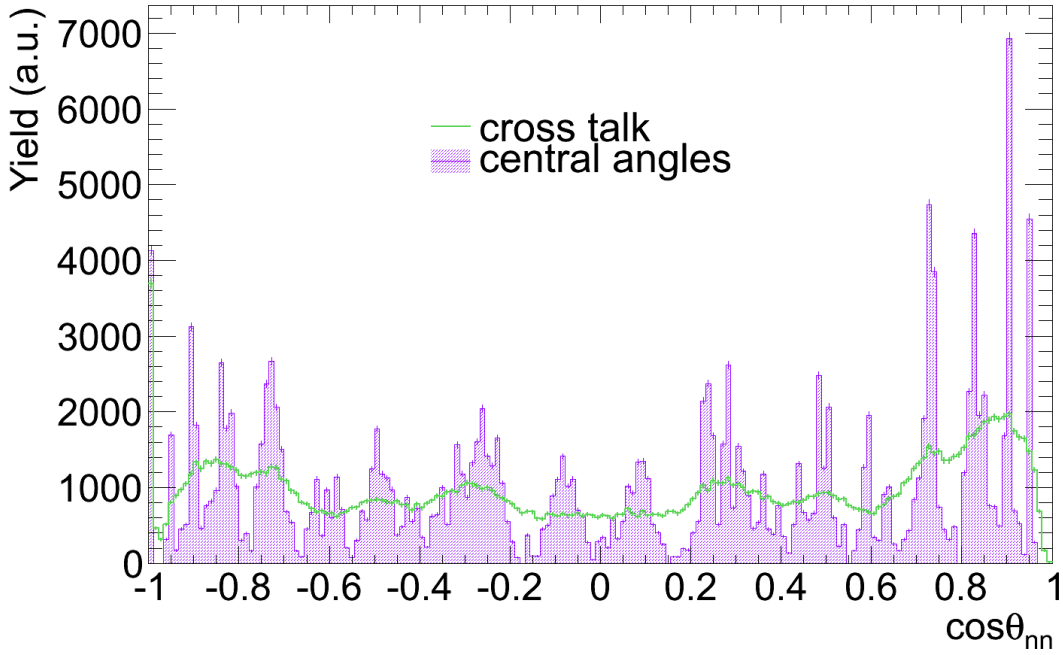
+

cross talk



- **central angles**

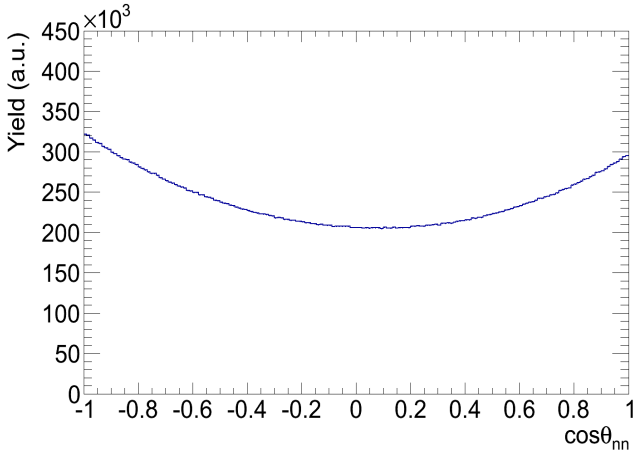




SIMULATION / EXPERIMENT

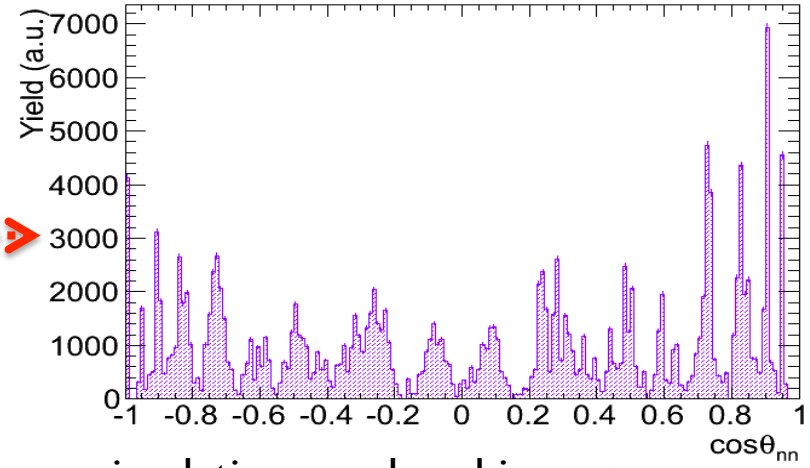
$\cos\Theta_{nn}$

« theoretical » distribution



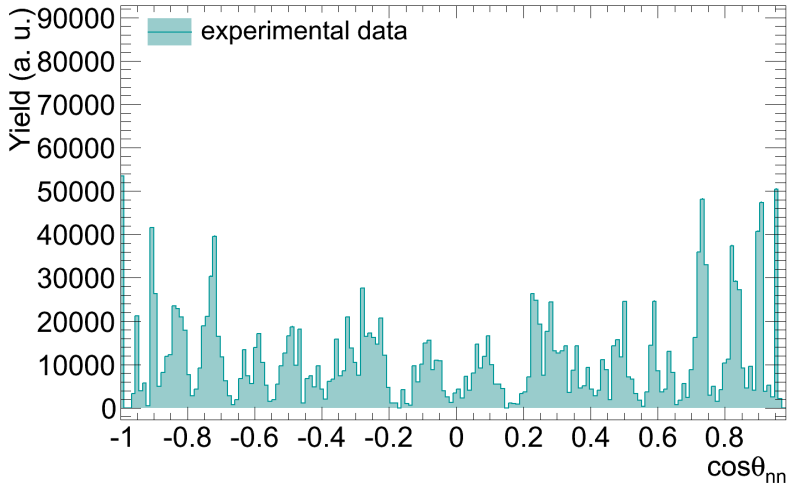
+

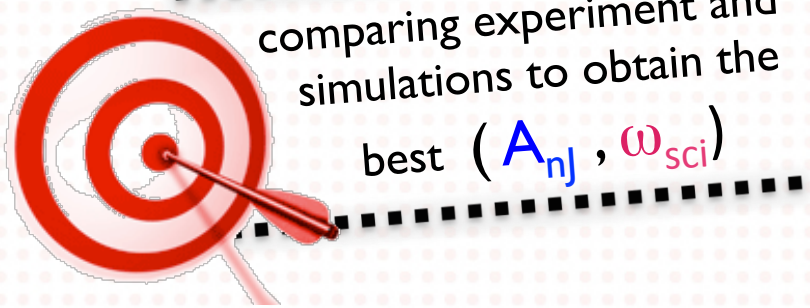
experimental filter



simulations analysed in same way as experiment

experimental distribution



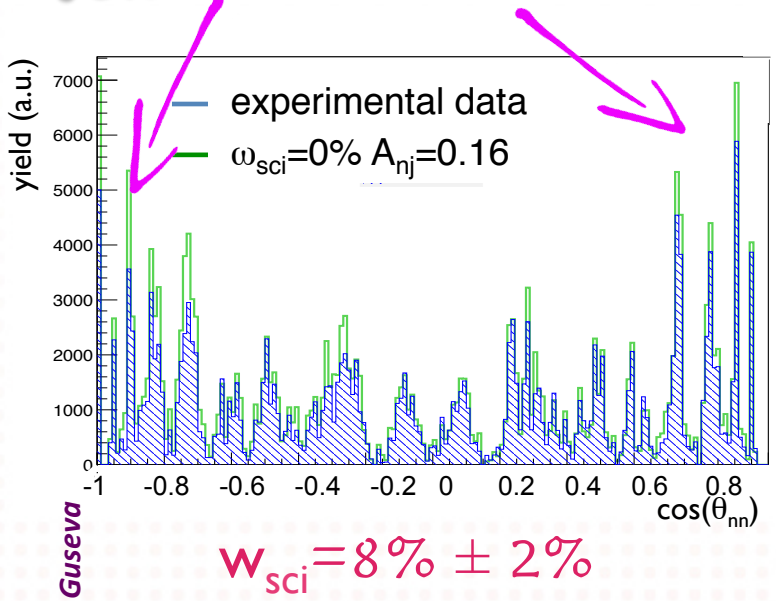


comparing experiment and simulations to obtain the best (A_{nJ}, ω_{sci})

SIMULATION / EXPERIMENT

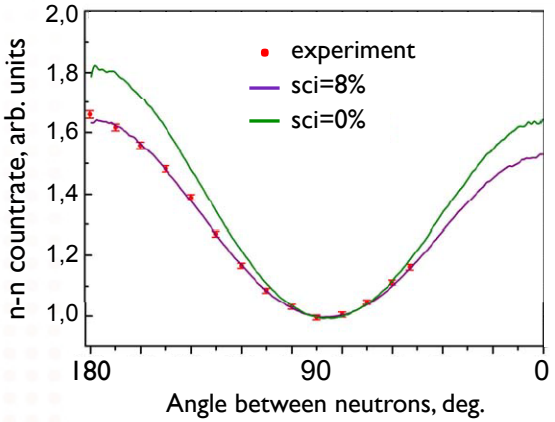
$\cos\Theta_{nn}$

SCISSION NEUTRONS...?

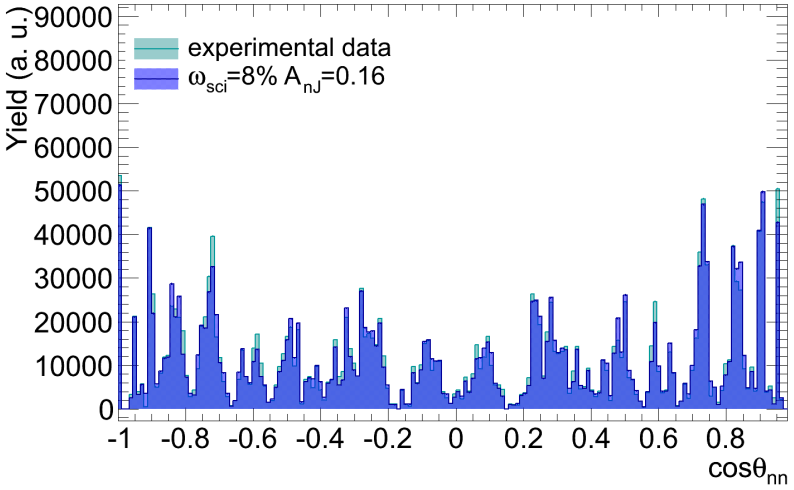


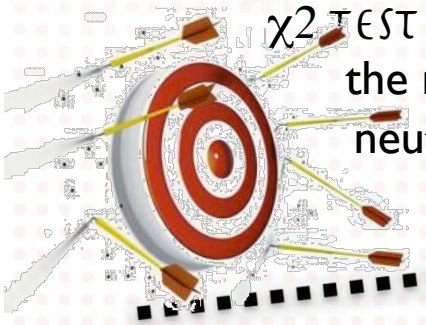
Guseva

$w_{sci} = 8\% \pm 2\%$



A. Gagarski et al, ISINN-20, 2012

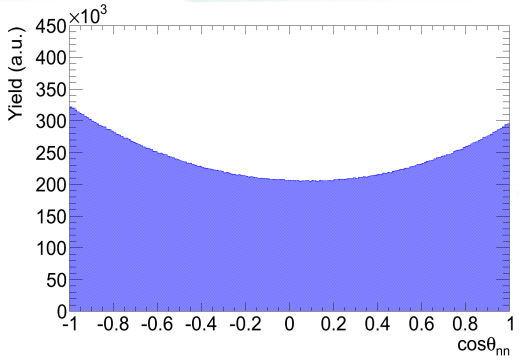


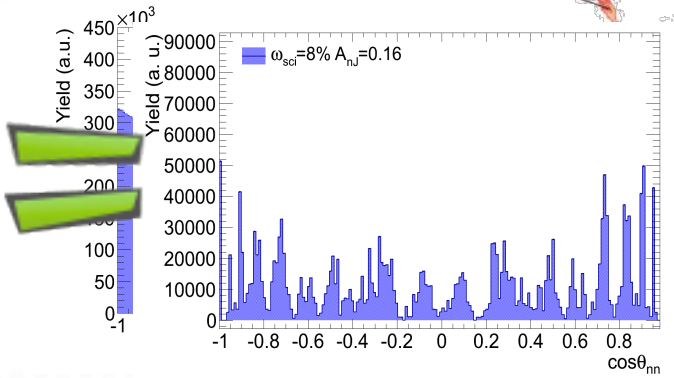


χ^2 TEST ON THE CENTRAL ANGLES:
the narrow structures hide the neutron emission mechanisms

SIMULATION / EXPERIMENT

$\cos\Theta_{nn}$

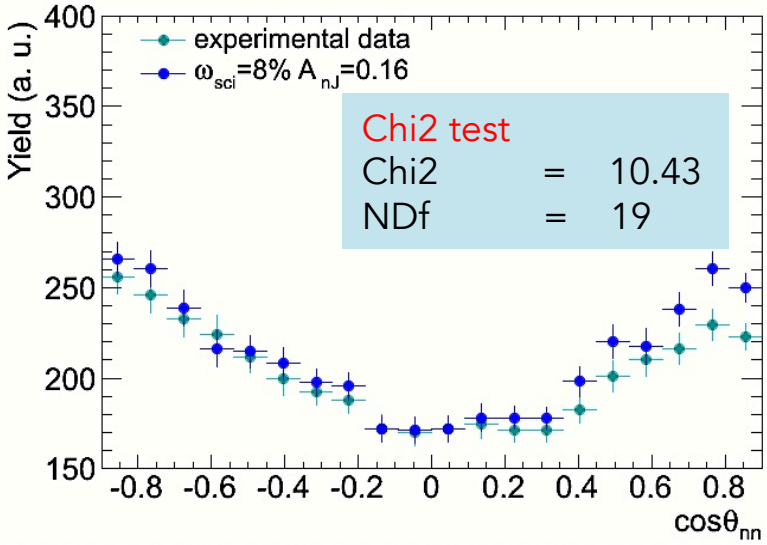


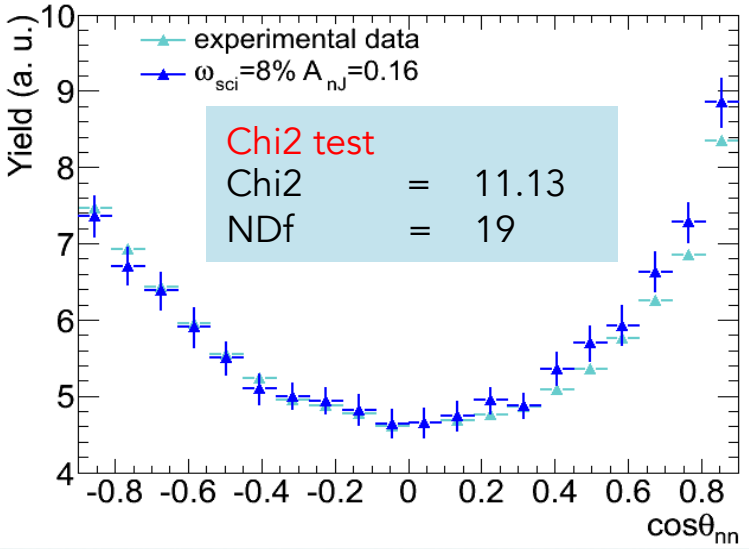


efficiency

1. Simulate the detector response for isotropy in the lab system

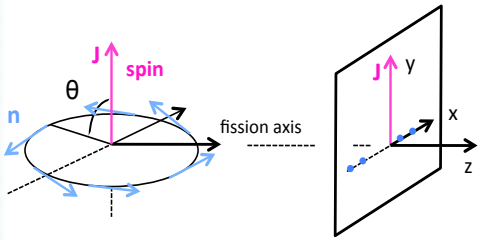
2. Uncorrelated events of:
   - simulated data
   - expermental data





$\Phi_{nn|LF}$

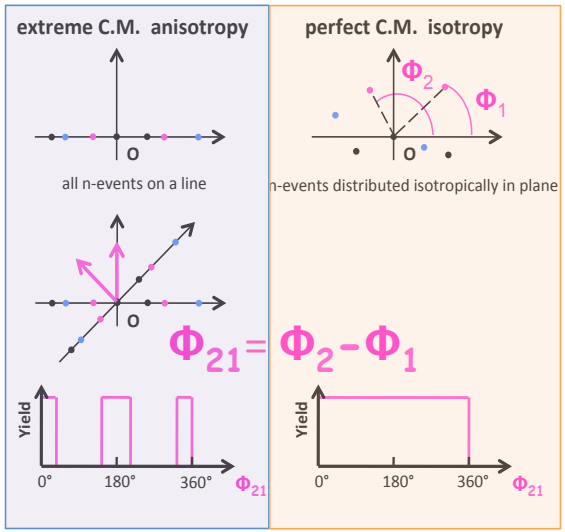
DYNAMICAL ANISOTROPY



>> new method

TRIPLE COINCIDENCES METHOD

F. Gönnenwein



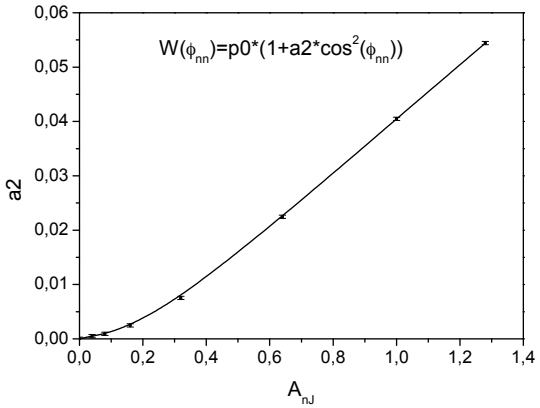
project fission axis and all n events on a plane ⊥ **to fission axis**

➤➤ **all neutron events will be aligned on a single line, the x-axis**

The Φ_{nn} distribution is fitted by

$$W(\phi_{nn}) = p_0\left(1 + a_2 \cos^2 \phi_{nn}\right)$$

$a_2 \dashrightarrow A_{nJ}$



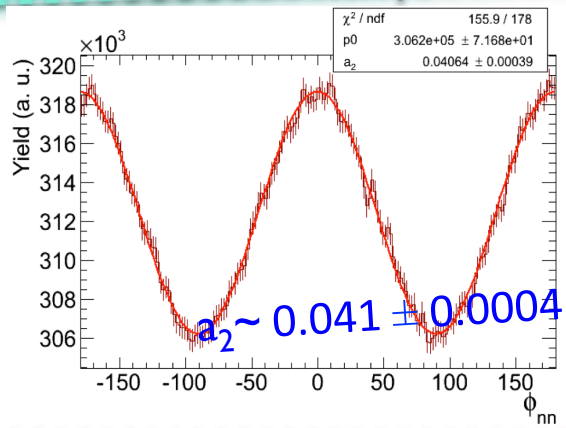
Guseva

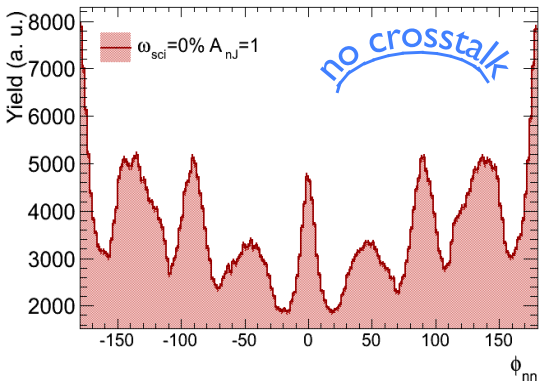
TEST OF THE ANALYSIS METHOD ON Φ_{nn} !LF

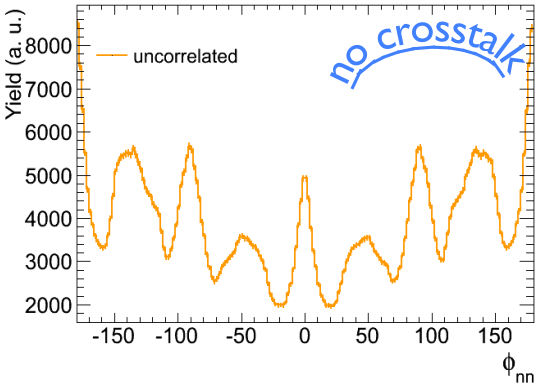
Test for (A_{nJ}=1 , ω_{sci}=0%) ⇢ $a_2 \sim 0.04$

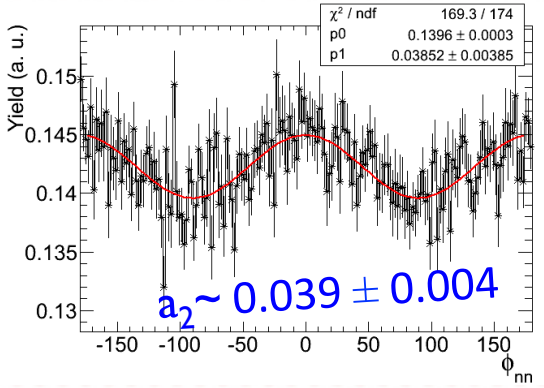
The <<theoretical>> curve is fitted

The reconstruction method is applied:





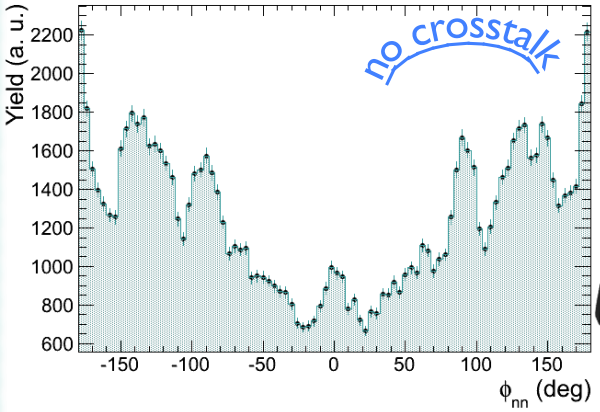




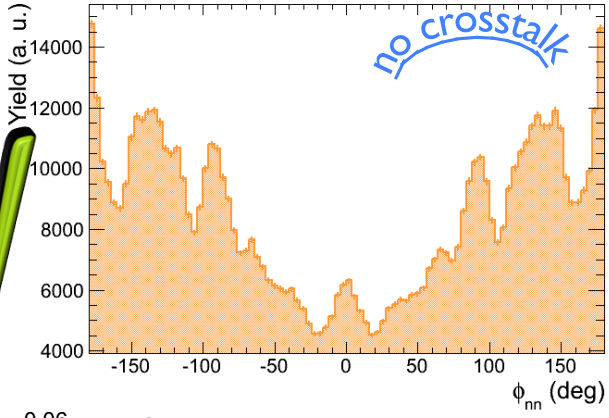
EXPERIMENTAL $\Phi_{nn|LF}$ DISTRIBUTION

APPLY THE UNCORRELATED METHOD TO THE EXPERIMENT

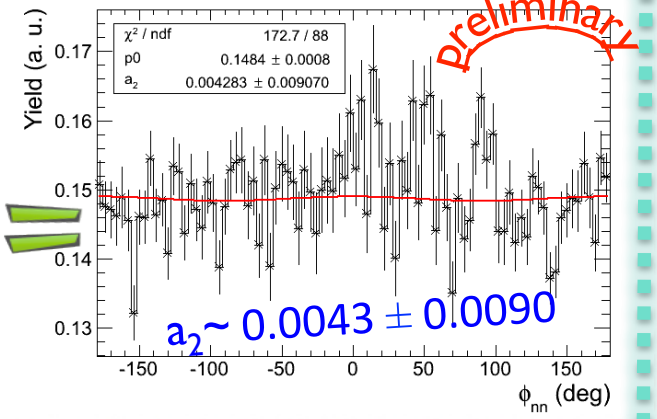
experiment



uncorrelated experiment

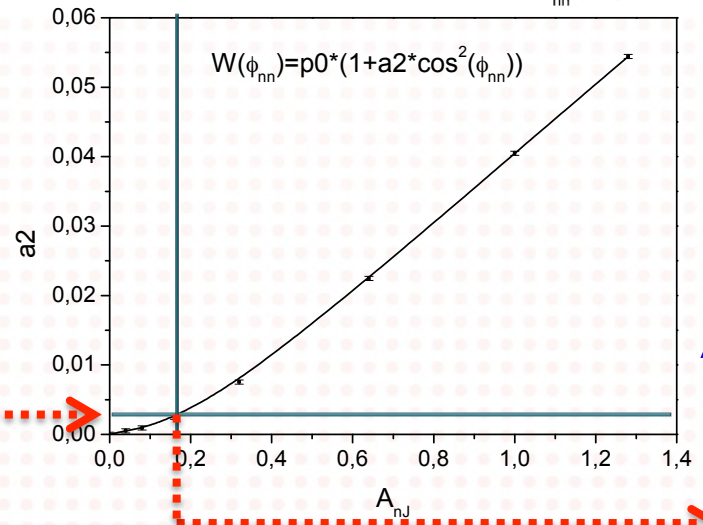


ratio



Experiment:

$a_2 = 0.0043 \pm 0.0090$



Guseva

$A_{nJ} = 0.16$

Theory

$A_{nJ} = 0.16 \pm 0.02$

Guseva

CONCLUSIONS...

...ABOUT $\Phi_{nn|LF}$

$a_2 = 0.0043 \pm 0.0090$

$A_{nJ} = 0.16 \pm 0.02$

$w_{sci} = 8\% \pm 2\%$

Guseva

Guseva

...ABOUT θ_{nn}

SIMULATION PARAMETERS		No Cross talk NDF =14
A_{nJ}	ω_{sci}	$\chi 2$/NDF
0	0	0.87
0.16	0	0.59
0	8	0.35
0.16	8	0.24
1	20	3.24

...ABOUT θ_{nLF}

SIMULATION PARAMETERS		No cross talk NDF =14	
A_{nJ}	ω_{sci}	$\chi 2$/NDF	P-VALUE
0	8	1.7	<0.00001
0.16	8	1.01	0.45

...SUMMARY...

first experiment giving access simultaneously to:

- A_{nJ}
- ω_{sci}

θ_{nn}, θ_{nLF}, $\Phi_{nn|LF}$

independent determination of anisotropy

A_{nJ}=0.16

clear indication that both phenomena

ω_{sci} + A_{nJ}

coexist in the spontaneous fission of ^{252}Cf

2015

...AND PERSPECTIVES

...ABOUT CORA3

- experiment:

  1. more statistics
  2. suppress/reduce cross talk

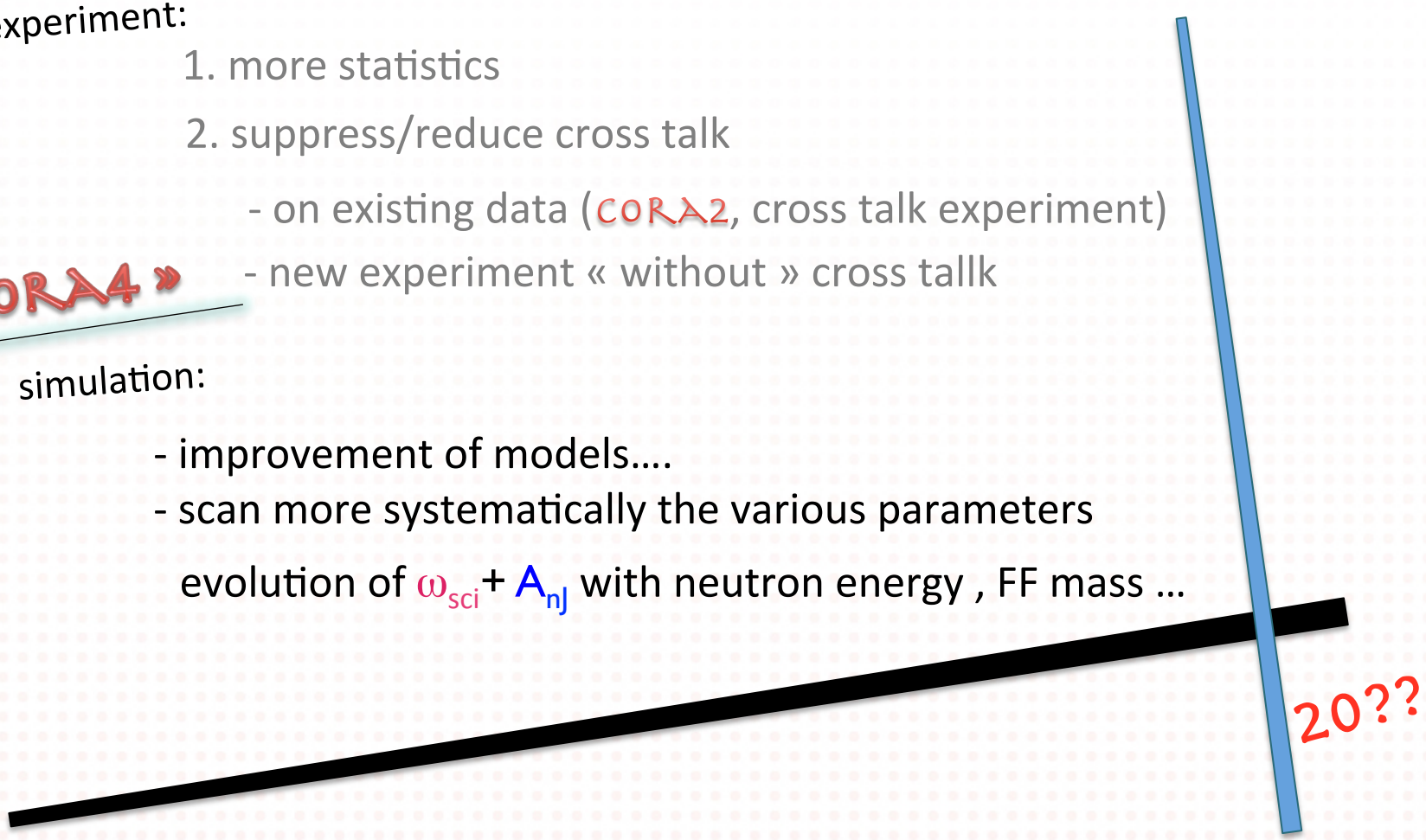
     - on existing data (CORA2, cross talk experiment)
     - new experiment « without » cross tallk

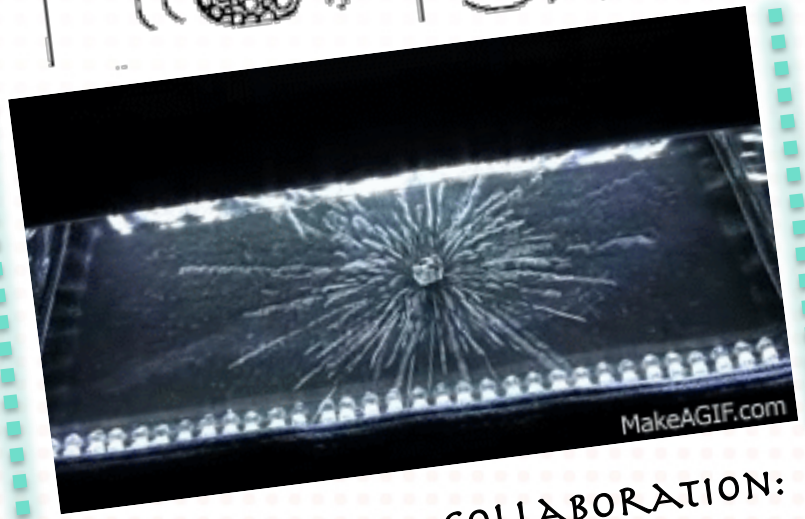
« CORA4 »

- simulation:

  - improvement of models....
  - scan more systematically the various parameters

  evolution of ω_{sci} + A_{nJ} with neutron energy , FF mass ...





CORA COLLABORATION:

- A. CHIETERA, L. STUTTGÉ, O. DORVAUX: IPHC, STRASBOURG, FRANCE
- F. GÖNNENWEIN: UNIVERSITY OF TÜBINGEN, GERMANY
- M. MUTTERER: GSI, DARMSTADT, GERMANY
- YU. KOPATCH, Z. MEZENTSEVAH, S. TELEZHNIKOV: FLNP, DUBNA, RUSSIA
- A. GAGARSKI, I. GUSEVA: PETERSBURG PNPI, GATCHINA, RUSSIA
- F. HANAPPE: ULB, BRUSSELS, BELGIUM
- F.J. HAMBSCH: EC-JRC, GEEL, BELGIUM

UNIVERSITÉ DE STRASBOURG

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

cnrs IN2P3 Les deux infinis