Explosion rate of type Ia supernovae as function of redshift from SuperNova Legacy Survey

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SNLS SuperNova Legacy Survey

Snla Rate : Motivation

- Sub-types
- Evolution
- Progenitors : SD main sequence, SD red giants, DD
- Others(galaxy enrichment,…)
- Survey Design

The SuperNova Legacy Survey

Main goal : measurement of cosmological parameters using type Ia supernovae.

Method :

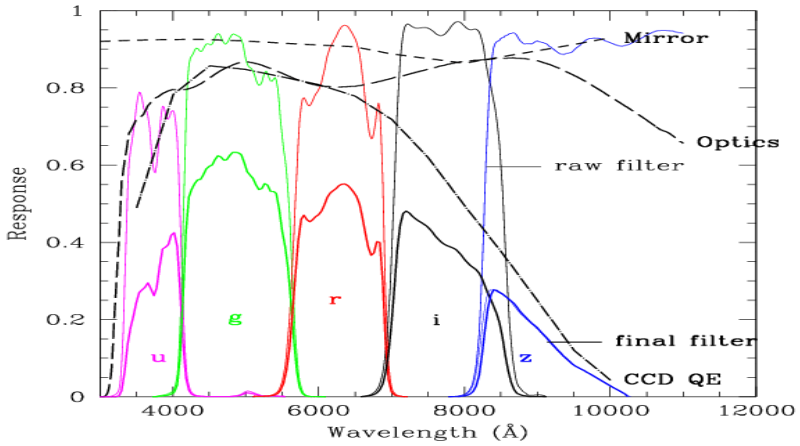
- 5 years on 4 one square degree fields at CFHT (megacam + 4 filters)
- Spectroscopic follow-up (VLT, Keck, Gemini)

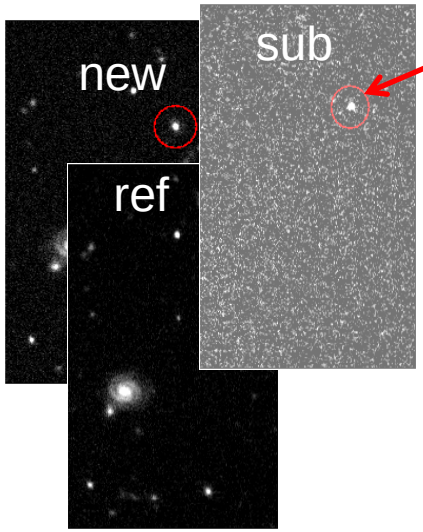
Results : about 300 type Ia supernovae up to $z = 1.0$ with spectroscopic identification during the 3 first years.

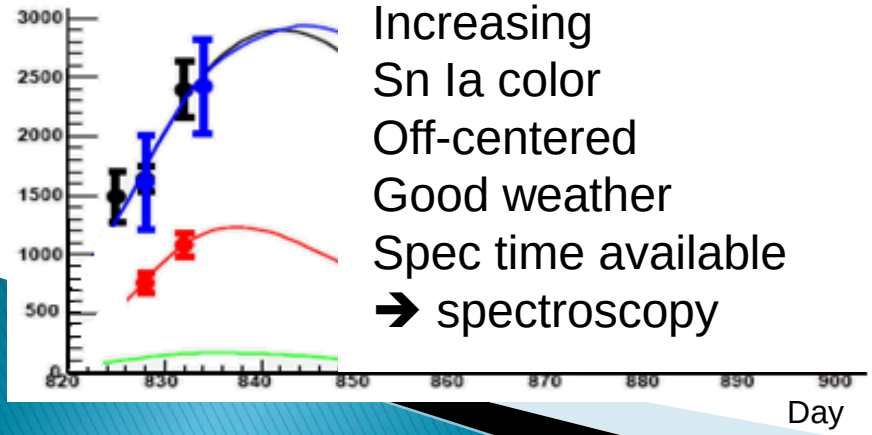
Opportunity to accurately measure SN Ia rate vs z

Real time detection Pipeline

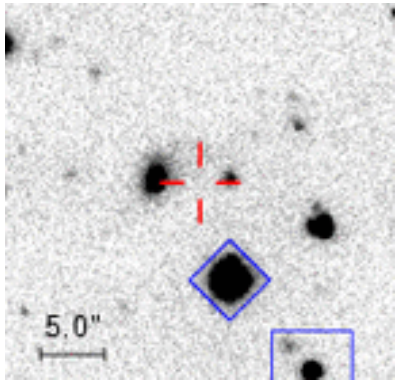
- 4 fields observed every 3-4 days in 4 bands (“rolling search”)
- Variable object detection method : **PSF matched image subtraction**







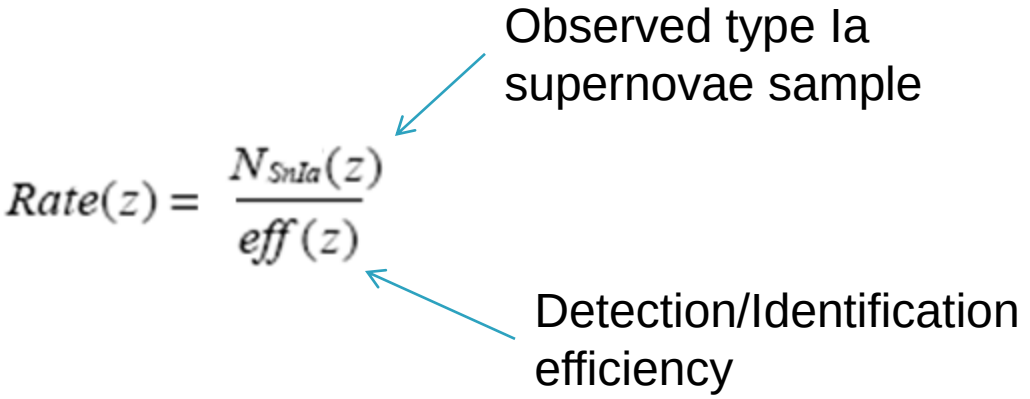
Increasing
Sn Ia color
Off-centered
Good weather
Spec time available
➔ spectroscopy



Spectroscopy:
z = 0.81
Type : Sn Ia

How to measure supernovae explosion rate in the SNLS ?

A simple division :



but Real Time spectroscopic identification efficiency is almost impossible to model due to spectroscopic selection (human selection, weather, available time,…).

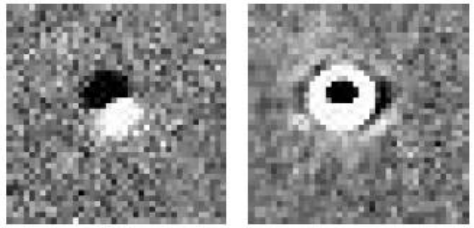
➔ Human free photometric detection/identification pipeline

Variable object detection

Dataset : 3 years of SNLS images reprocessed

First level selection : Variables objects

- Images subtraction
- Each detection is scored with a neural network and shapelet to remove artifacts
- At least 5 good detections with S/N greater than 5.
- Cut on field area and date to avoid edge effects.

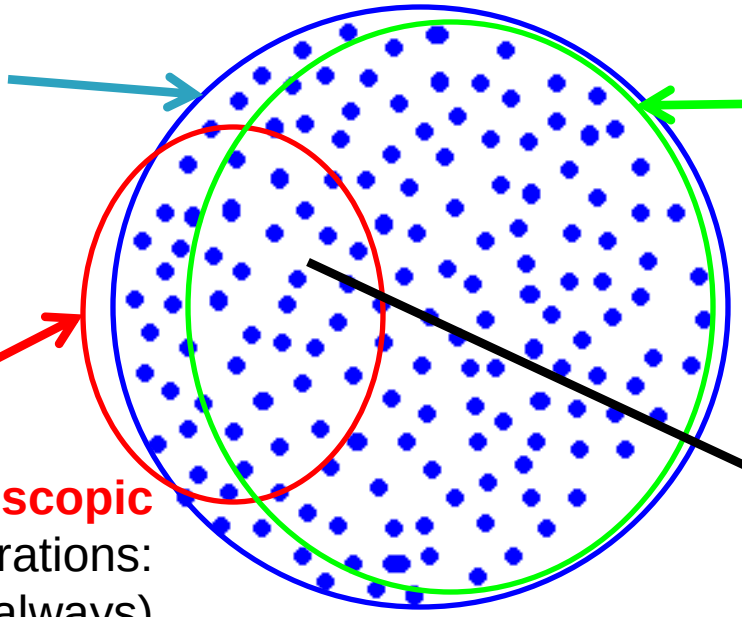


Spurious subtraction residuals

Selected objects are mostly physical objects : AGNs, variable stars, supernovae (all types).

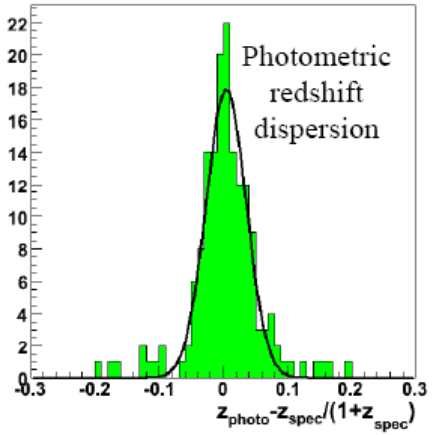
Selected objects

3051 variable objects



Host galaxy photometric redshift : Ilbert et al. 2006

289 objects with **spectroscopic data** from real-time operations: redshift and type (not always)
Used as **control sample**
Redshift accuracy : 0.001



$\sigma_{dz/1+z} = 0.03$ + outliers

SnIa	Sn?	SnII	SnI b/c	AGN
196	53	24	7	9

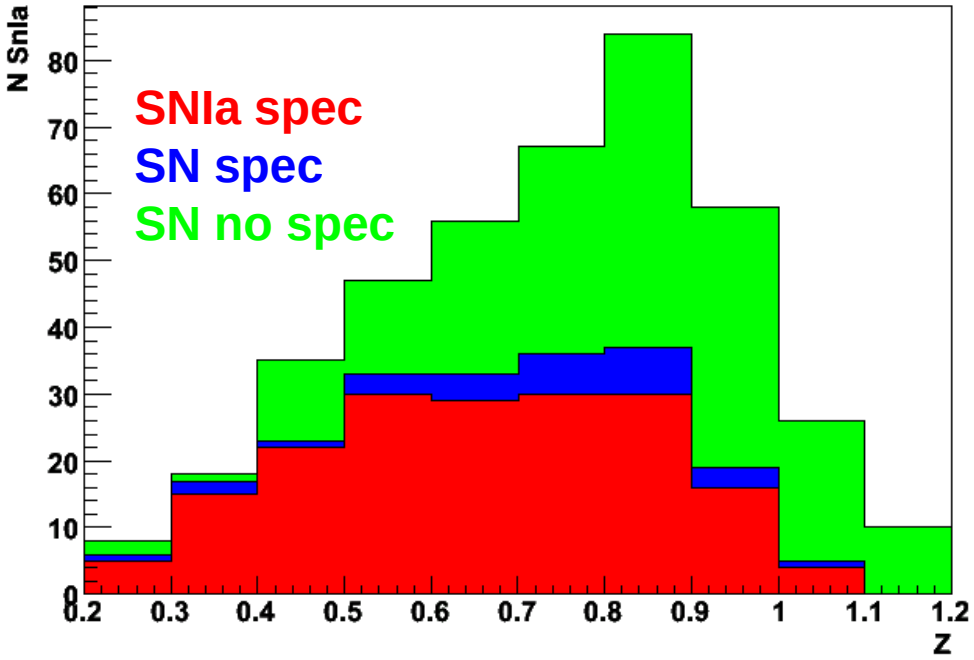
SN Ia photometric selection

Level II Selection : Type Ia supernovae

- **Cut I** : multi-color Lightcurve fit (SALT2)
  - Redshift fixed (spectroscopic or photometric)
  - Fitted parameters : stretch, color and magnitude
  - *X^2 selection*
- **Cut II** : Color Cut : $-0.4<color<0.4$
  - minimize contamination by type II
- **Cut III**: loose cut on brightness
  - gets rid of catastrophic redshift

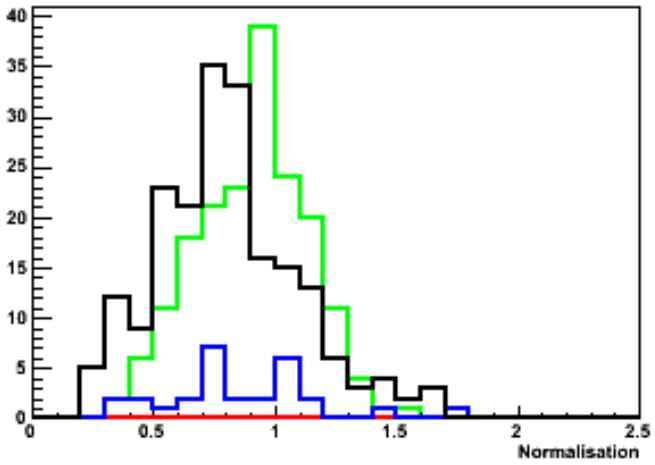
Results

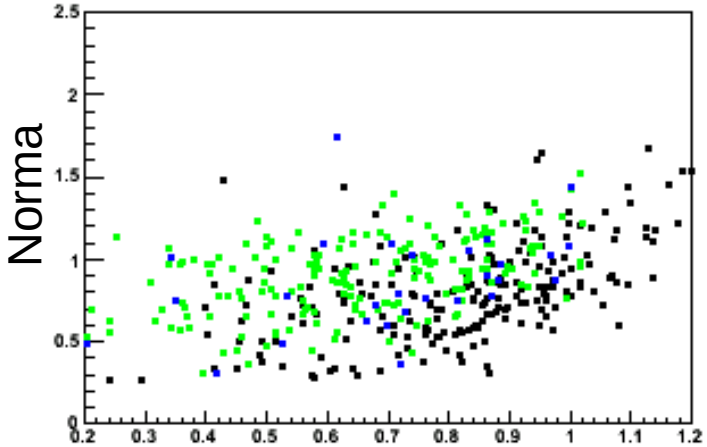
- 409 selected objects
- **No contamination** with spectroscopic redshift
- **2% Contamination** with photometric redshift
- Photometric redshift accuracy improved

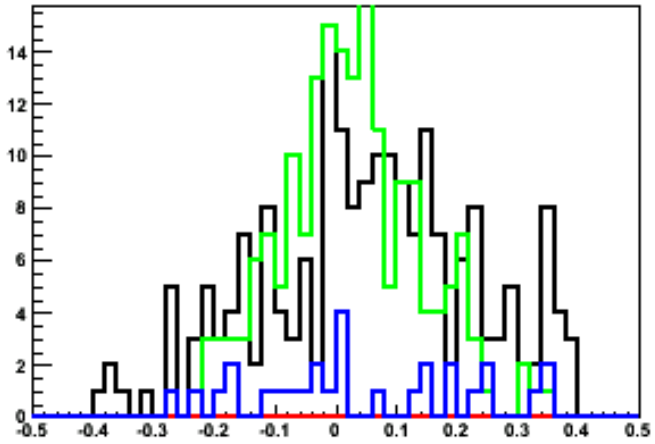


Spec type	Detected	Selected
Sn Ia	196	181
Sn	53	28
Sn II	24	0
Sn Ib/c	7	0
AGN/Var	9	0
No Spec	2762	200

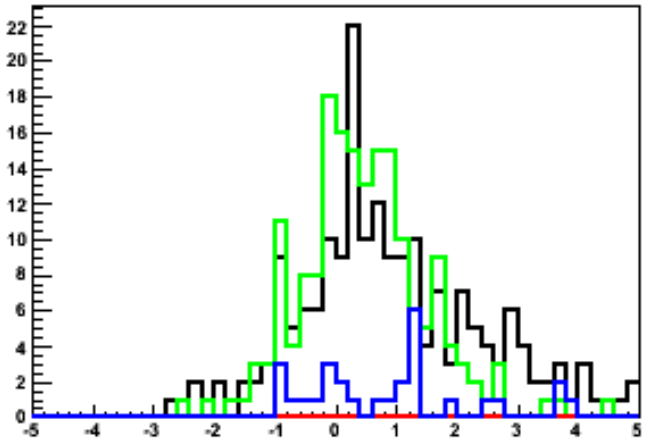
SNIa spec
SN spec
SN no spec







color



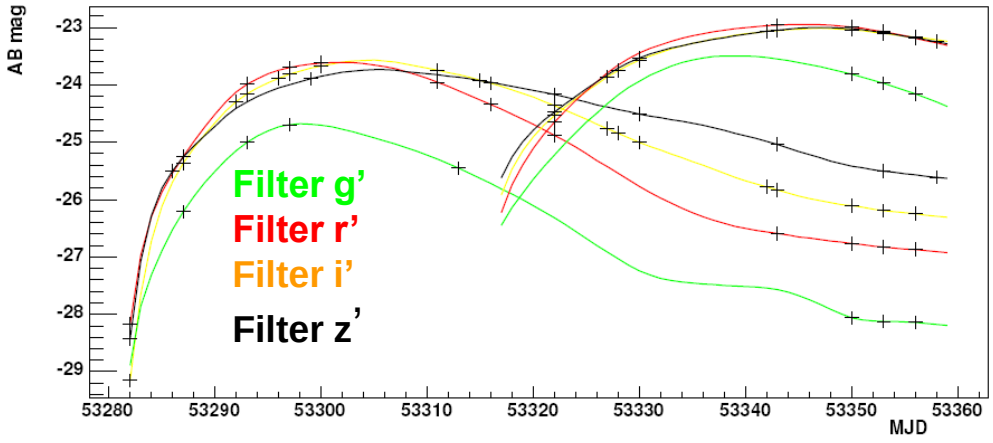
X1 i.e. stretch

Detection and selection efficiency

On image
SN Ia simulation

Main parameters:

- Ra/Dec: coordinates
- z : Redshift (from photoZ catalogue)
- D0: Date of maximum
- s : Stretch
- c : Color (extinction)
- disp : intrinsic dispersion
- (α, β, Rv,…)



Lightcurves simulated with SALT2

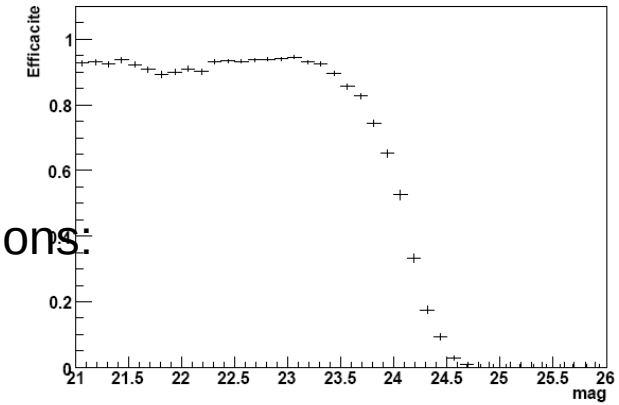
Simulated supernovae added on all images

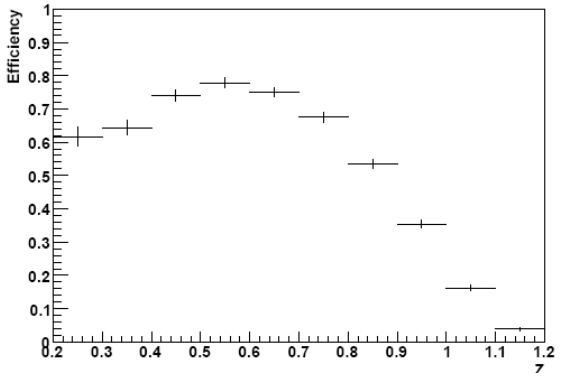
➔ Simulated images processed with the photometric detection pipeline

Detection/Selection Efficency

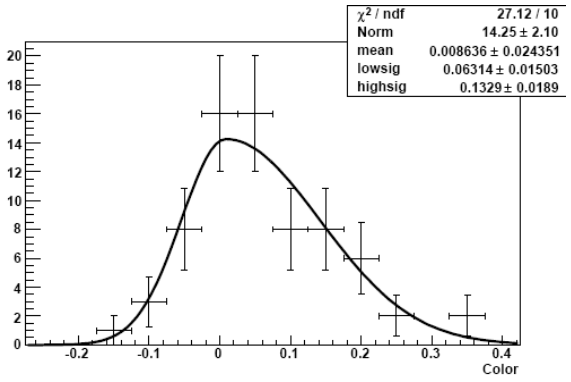
2.5 years of data processed (15 To)
720000 simulated supernovae

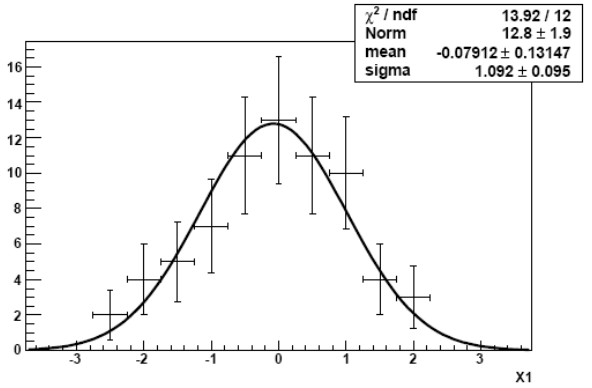
MC distributions tuned to match observed distributions:
- Color
- Stretch
- Intrinsic dispersion
- S/N
- position on host



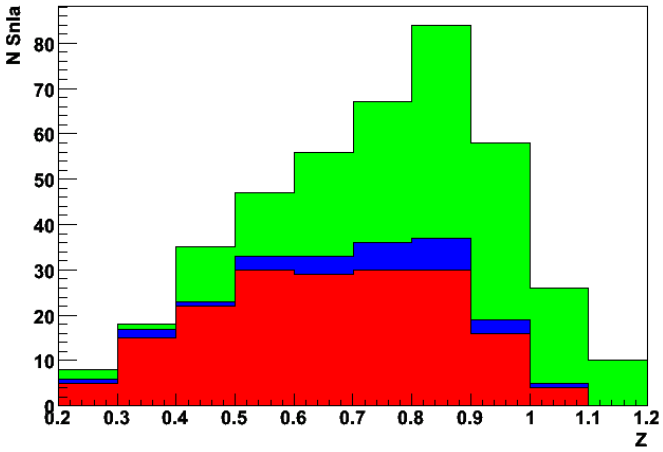


I' mag vega





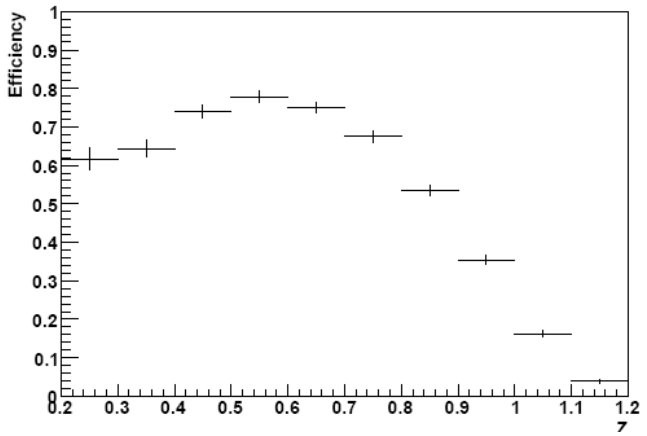
Rate calculation



Time dilatation correction

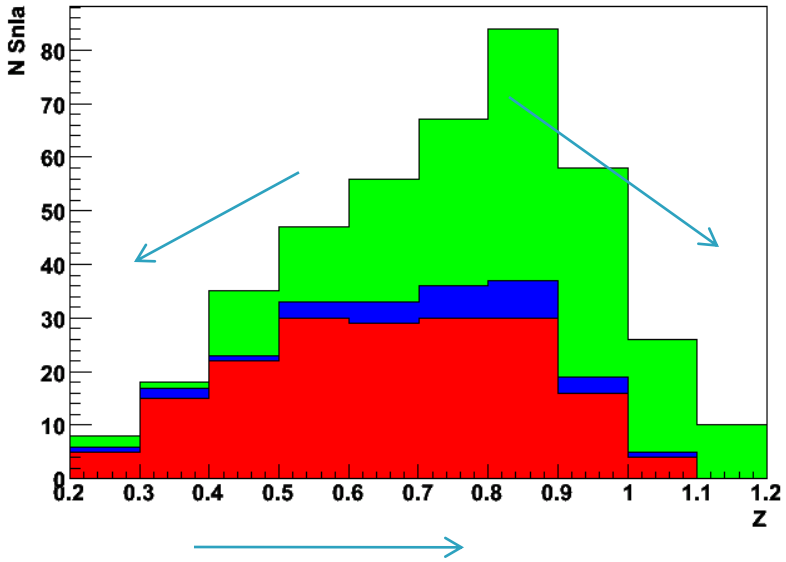
$$Rate(z) = \frac{(1+z)}{\Delta t \times V(z,\Delta z)} \frac{N_{SnIa}}{eff\,(z)}$$

Comoving volume



Corrections

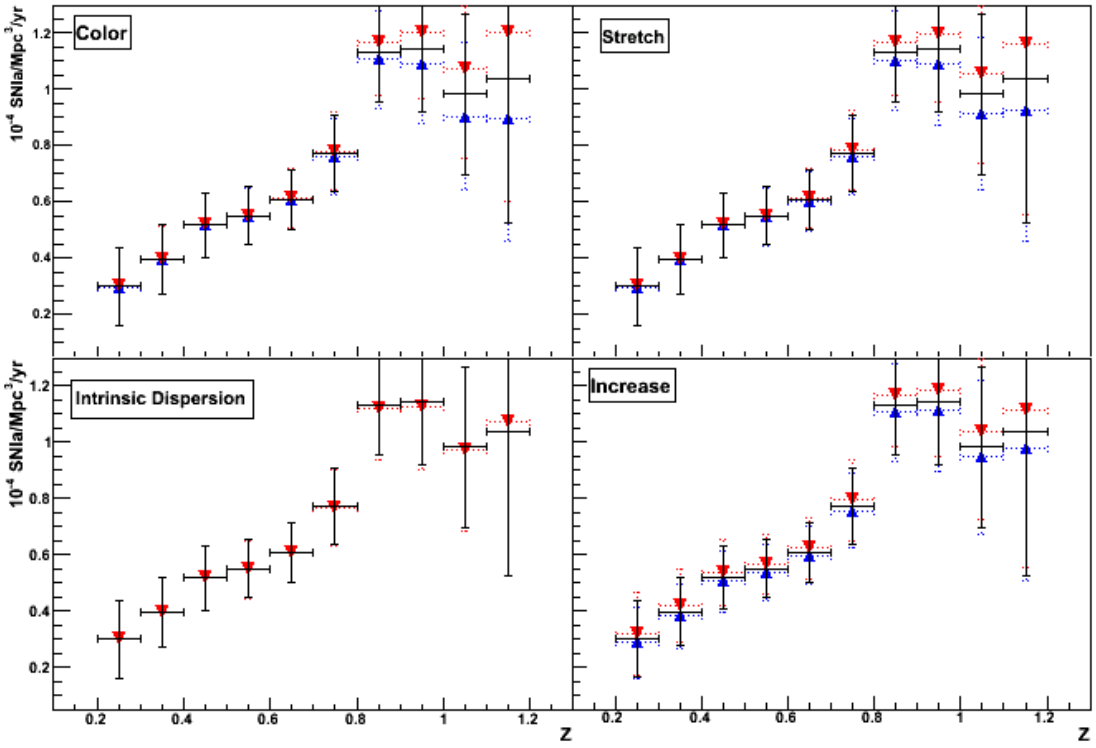
- Photometric Redshift dispersion
- Photometric Redshift inefficiency
- Contamination



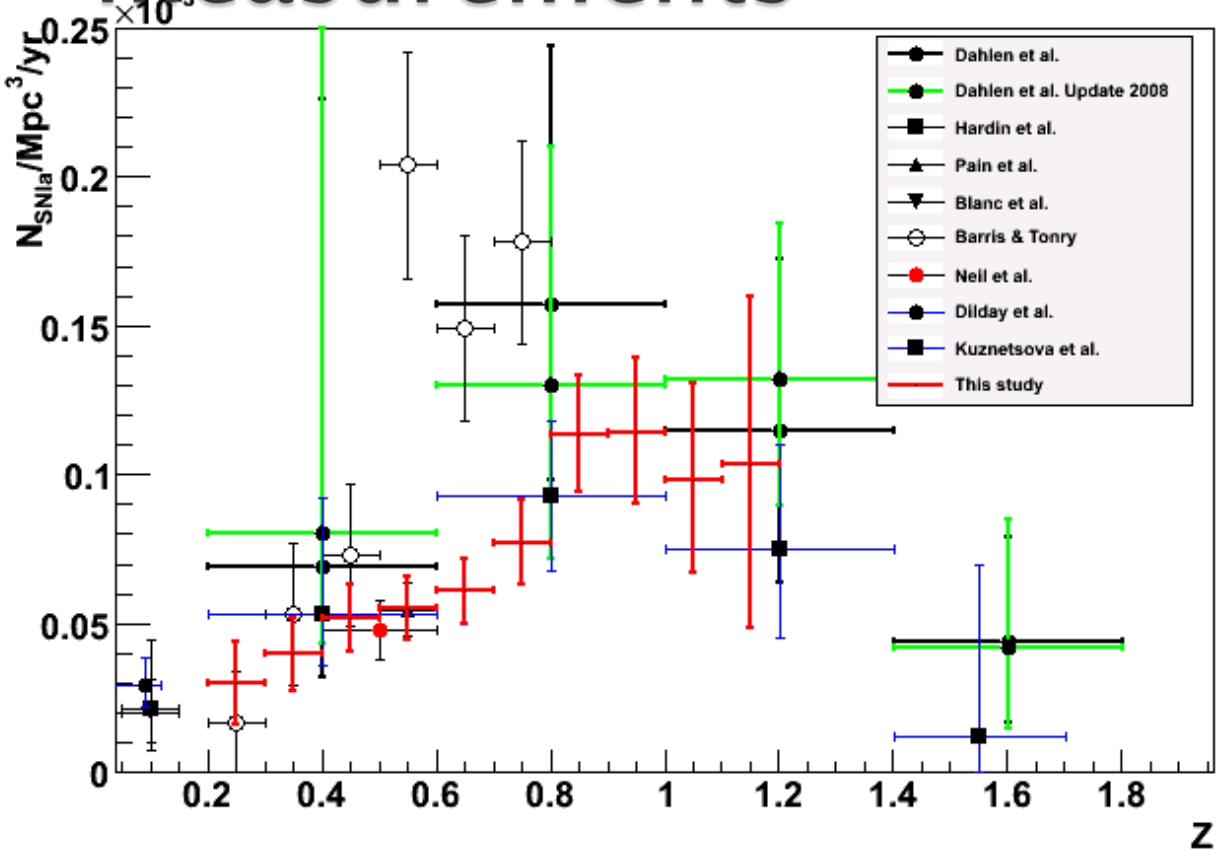
Type II

Systematic Errors

- Efficiency calculation : distributions (stretch/dispersion/color)
- Photometric Redshift dispersion
- Contamination



Comparison with previous measurements

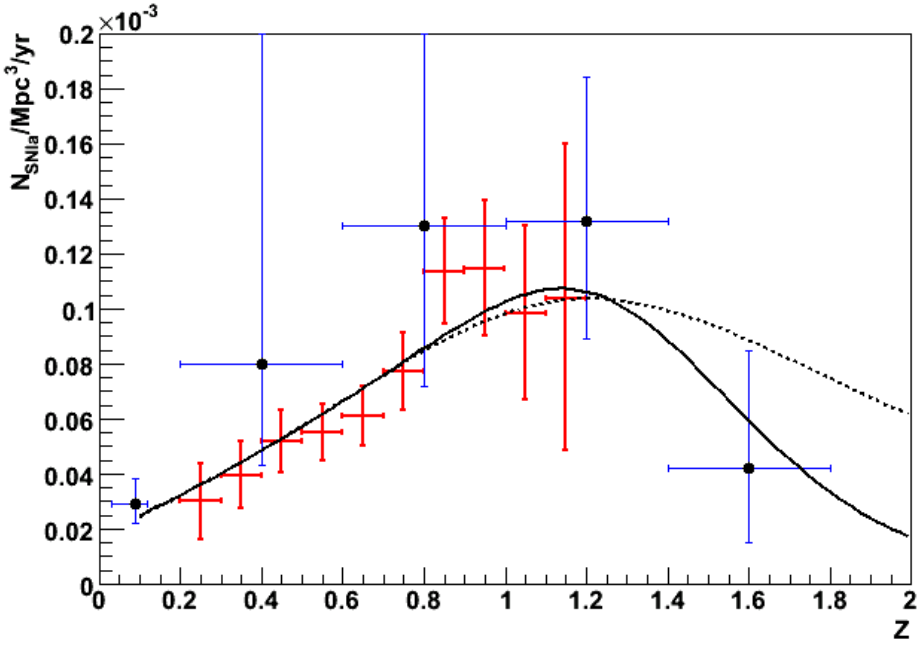


Selection method

Spectro	mixed	Photo

Réf	Nb	Spec Ia
Hardin et al.	4	100%
Pain et al.	38	97%
Blanc et al.	16	100%
Barris & Tonry	98	23%
Niell et al.	77	75%
Dilday et al.	17	94%
Kuznetsova et al.	57	57%
Dahlen et al.	56	59%
This study	435	48%

Rate and Models



Rate = star formation rate (SFR) ∗ delay time function $\Phi(t)$

$$Rate(t) = k\int_{tF}^{t} SFR(t')\times\phi(t-t')dt'$$

$$\phi(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{t-\tau}{\sigma}\right)^2}$$

$\sigma/\tau=0.2$ $\tau=2.52\pm$ 0.44 Gyr

$\sigma/\tau=0.7$ $\tau=1.76\pm$0.32 Gyr

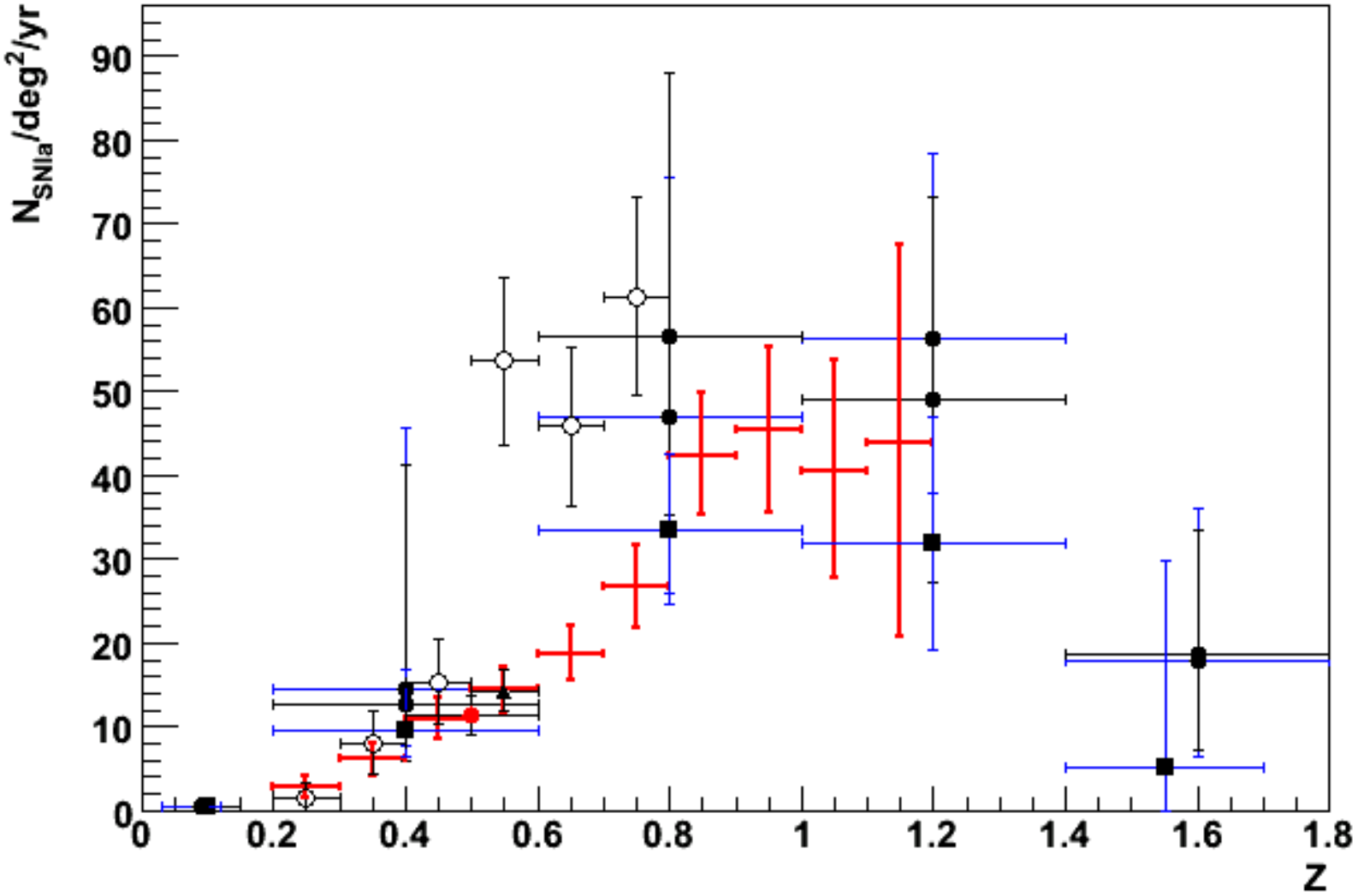
(SFR from Hopkins et Beacom 2006])

Rate and Models

Model / Parameter	SNLS	SNLS+SDSS2	SNLS+HST+SDSS2
$R_0(1+z)^\alpha$			
R_0	$1.98 \pm 0.54 \times 10^{-5}$	$2.14 \pm 0.44 \times 10^{-5}$	-
α	2.38 ± 0.49	2.24 ± 0.38	-
Delayed SFR			
τ	2.57 ± 0.71	2.62 ± 0.64	2.53 ± 0.44
σ/τ	0.2	0.2	0.2
Delayed SFR			
τ	1.45 ± 0.69	1.52 ± 0.58	1.76 ± 0.32
σ/τ	0.7	0.7	0.7
$A\rho + B\dot{\rho}$			
A	$-6.6 \pm 13.6 \times 10^{-15}$	$4.55 \pm 8.81 \times 10^{-15}$	$9.45 \pm 8.25 \times 10^{-15}$
B	$10.2 \pm 1.7 \times 10^{-4}$	$8.98 \pm 1.3 \times 10^{-4}$	$8.09 \pm 1.19 \times 10^{-4}$

Conclusion

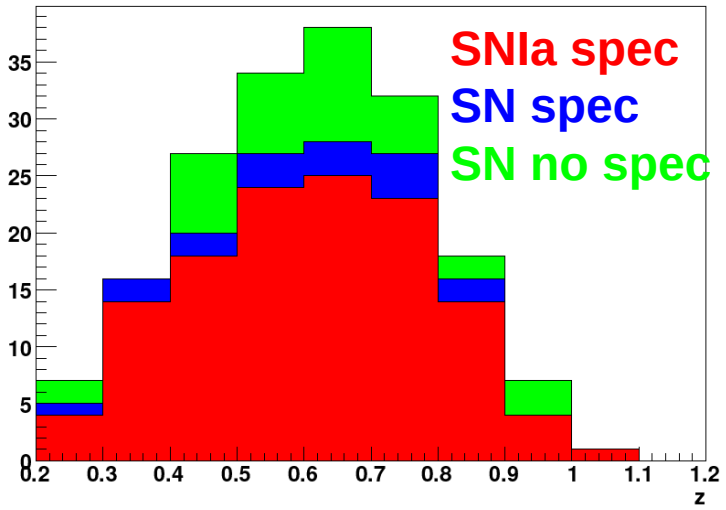
- Photometric detection and Identification using 4 bands photometry
- Low contamination (~2%)
- We have derived a photometric SN Ia rate vs z up to redshift 1.2
- Tested against a spectroscopic sample (48%)
- Rate increase with redshift. Possible flattening around $z = 1$

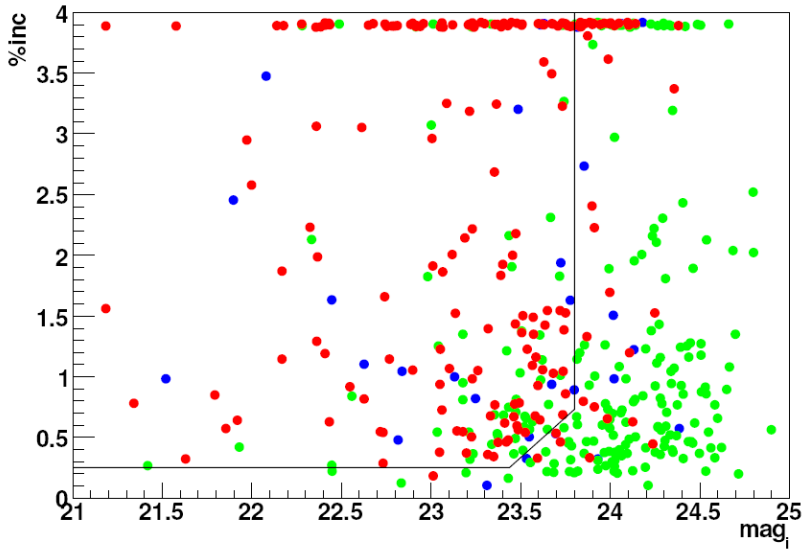

$N_{SNIa}/deg^2/yr$
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
z

The End

Taux spectroscopique (1)

- Nouvelles coupures : sélection spectroscopique
  - Coupure sur le χ^2 de l'ajustement et sur la normalisation (**Coupures I & II**). L'ajustement est fait avec le *redshift* spectroscopique s'il est disponible.
  - Au moins une détection de S/N $>$ 3 entre -2 et -60 avant le maximum de luminosité
  - Au moins une détection de S/N $>$ 5 entre 10 et 60 après le maximum de luminosité
  - Une détection dans le filtre i avec : $mag_{imindetected} < 23.8$
  - Un contraste pas trop faible : $inc > 0.25$
  - $inc > \frac{mag_{imindetected} - 23.25}{0.75}$



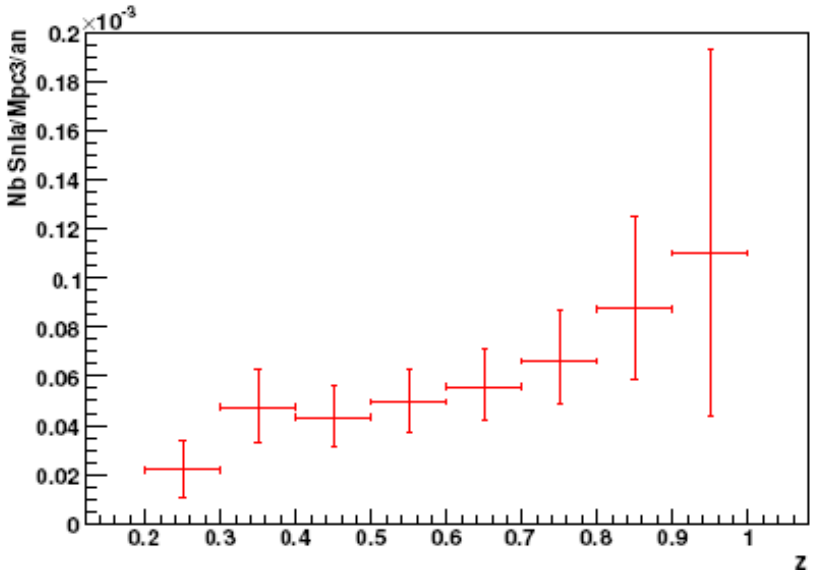


Taux spectroscopique (2)

On suppose que **l'absence de spectroscopie est aléatoire** (temps disponible, météo)

➔ on estime l'efficacité spectroscopique : 69% ±10%

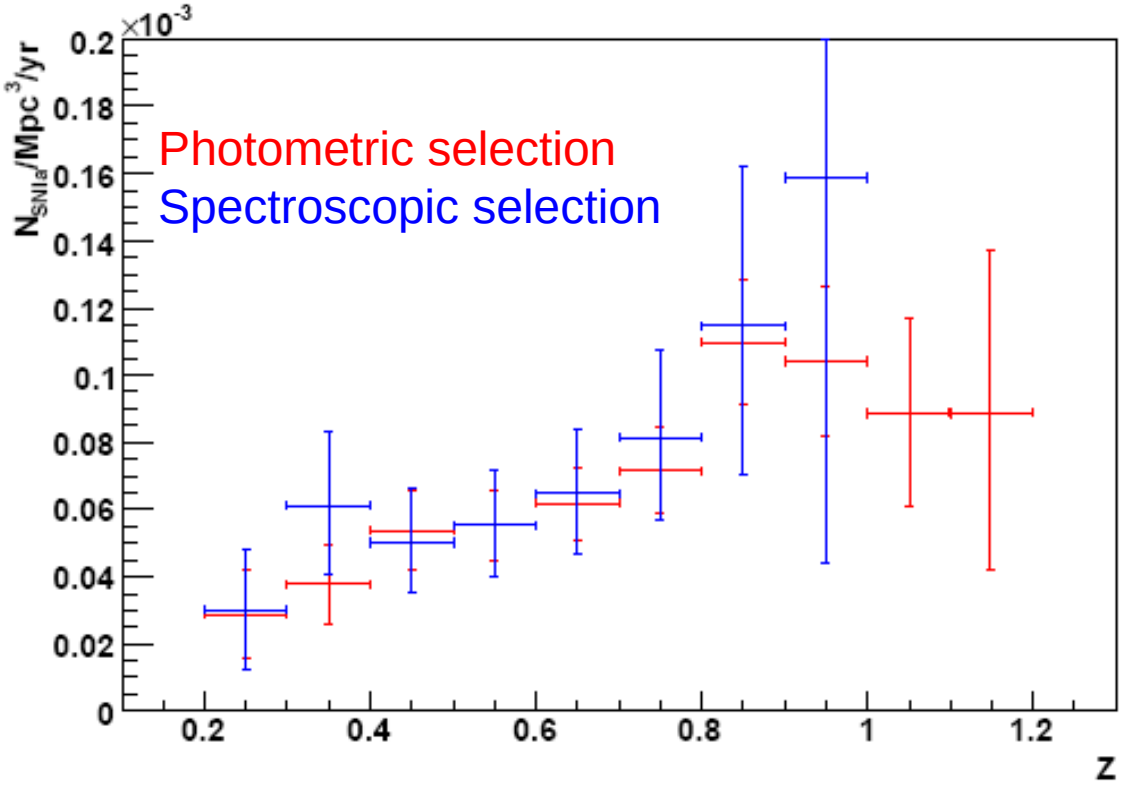
On n'utilise que les supernovae la identifiées



- **Pas d'erreur sur les redshifts**
- **Pas de contamination**
- **Nouvelle systématique d'efficacité spectro**

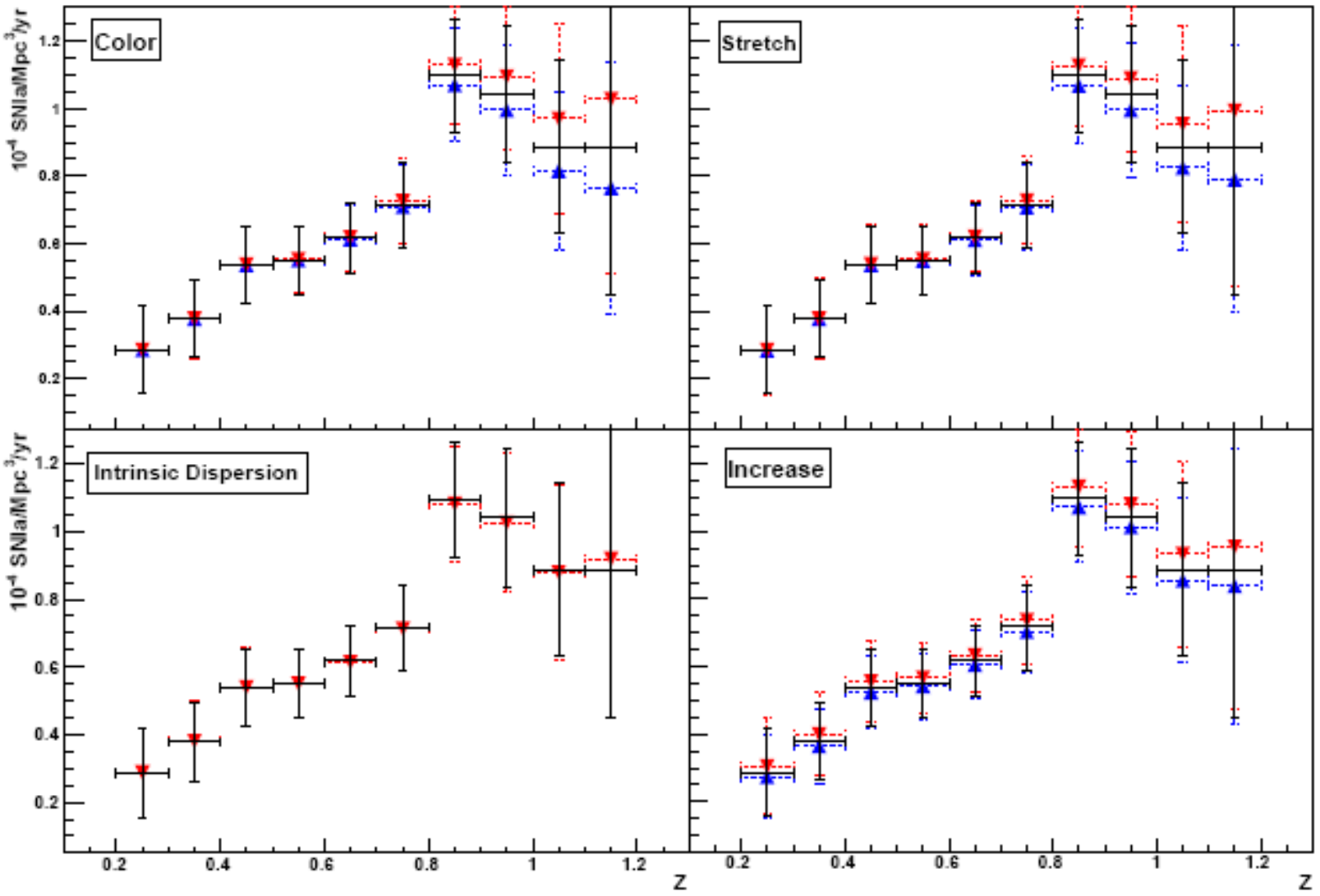
Pas de spectroscopie pour z >1

Type Ia SN rate

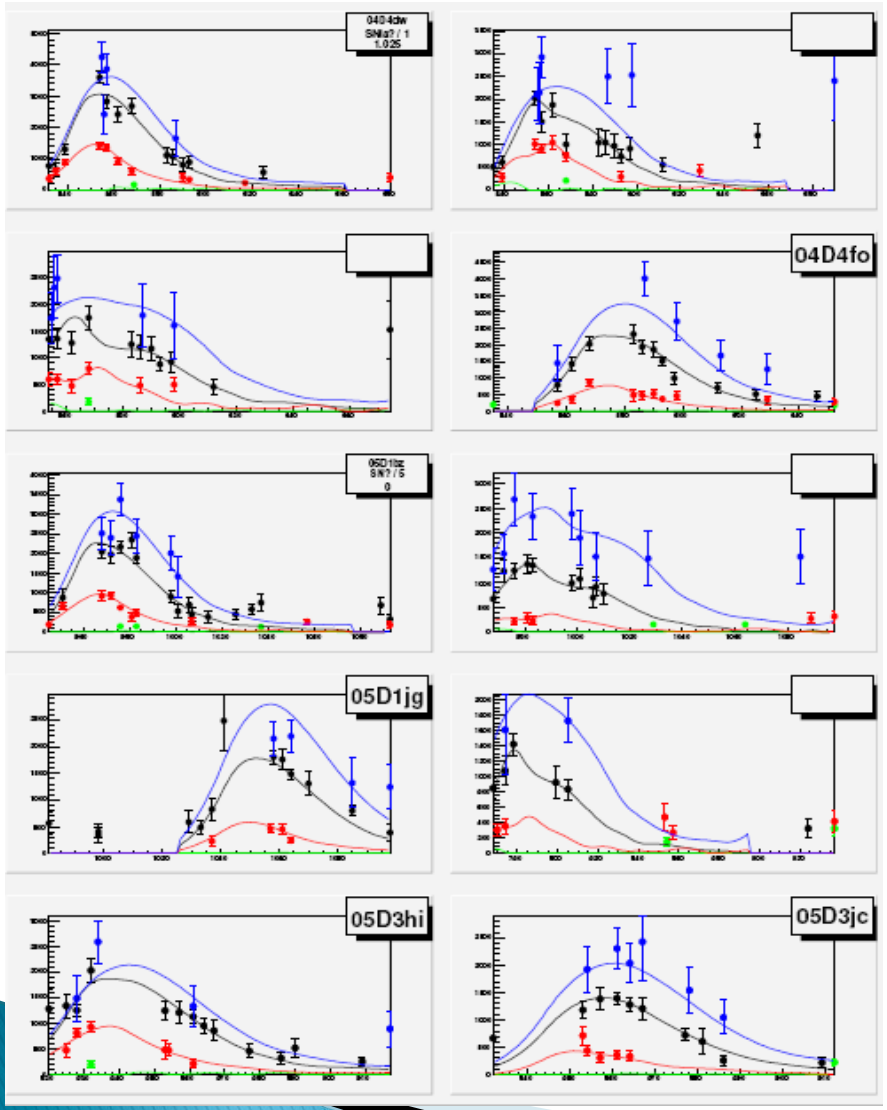


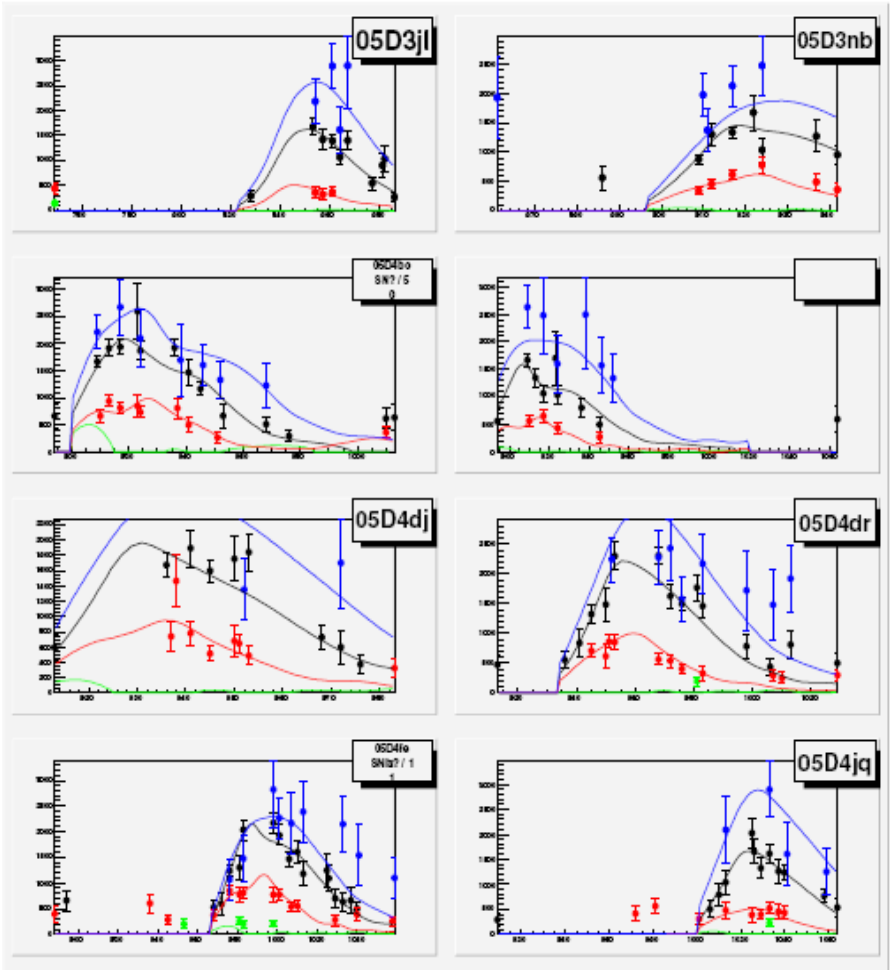
Rest frame Rate (z)

assumed cosmology : LCDM (0.3,0.7)


Color
Stretch
Intrinsic Dispersion
Increase
10^{-4} SNIa/Mpc^3/yr
z
0.2
0.4
0.6
0.8
1
1.2

(Z >1)


04D4fo
05D1jg
05D3hi
05D3jc


05D3jl
05D3nb
05D4dj
05D4dr
05D4jq