New Scintillators

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Alessandro Biondi

Vincenzo Patera
Michela Marafini
Adalberto Sciubba
Riccardo Mirabelli

Leonardo Mattiello
Alessandro Belardini

Introduction

Lo scopo di questo lavoro è la ricerca e la caratterizzazione di nuovi **scintillatori plastici organici** performanti per *fast detector*.

Le caratteristiche fisiche studiate sono:

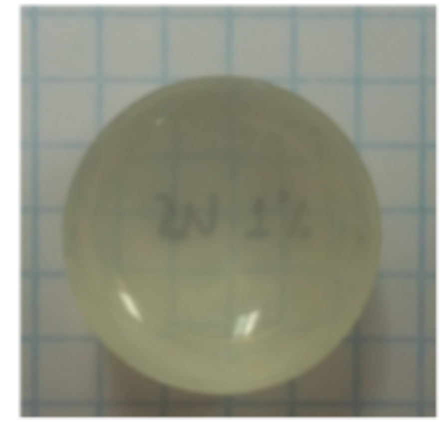
- il Light Yield (in % rispetto all'Antracene);
- il guadagno in carica (in % rispetto all'Antracene);
- la risoluzione temporale;
- il rise time;
- la costante di decadimento.

Introduction

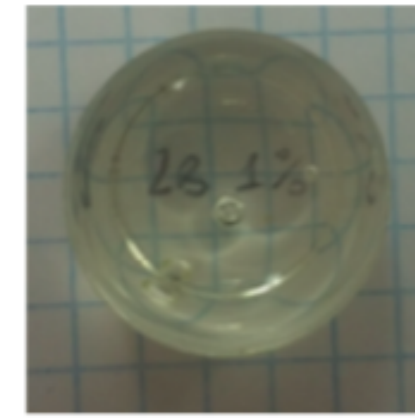
Il gruppo LEOS (Laboratory of Electro-Chemistry and Organic Synthesis) ha fornito soluzioni prima in forma liquida, successivamente in forma solida.
Tramite il dipartimento di SBAI si sono effettuate misure di spettroscopia e successivamente (tramite l'ausilio dei moduli VME QDC, TDC e WVD) misure di guadagno in carica, risoluzione temporale, tempo di salita e tempo di decadimento.

Antracene

2N



2B



1N

P2 [1]

T2

*** new scintillators**

Vial

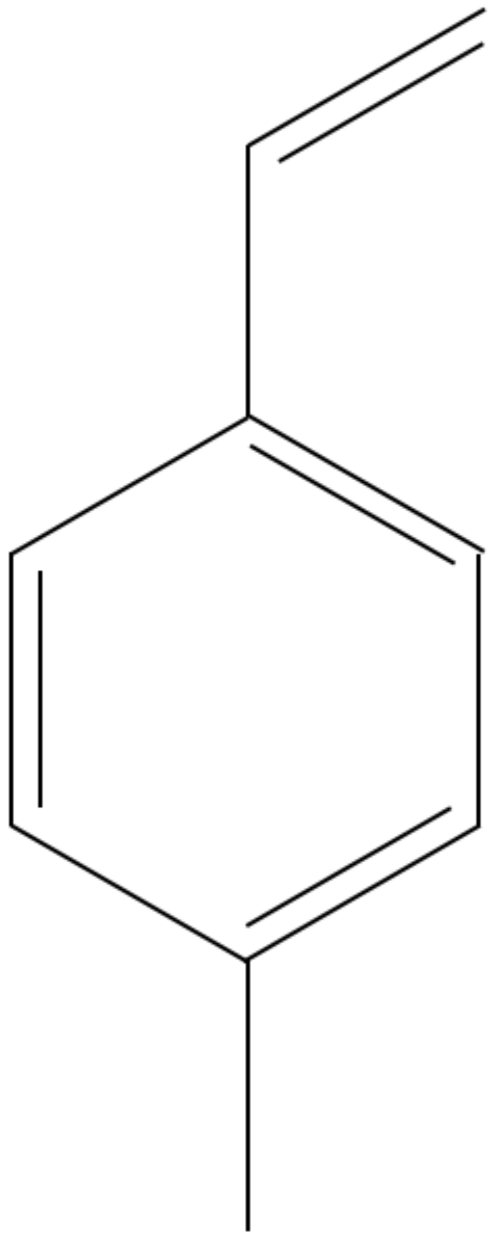
[1] Yemam, Henok A., et al. Highly Soluble p-Terphenyl and Fluorene Derivati- ves as Efficient Dopants in Plastic Scintillators for Sensitive Nuclear Material Detection. Chemistry-A European Journal, 2017, 23.37: 8921-8931.

Introduction

SOLVENTE: PVT

Gli scintillatori liquidi e solidi sono preparati in vial di uguale geometria. Nella prima fase viene inserita una soluzione costituita principalmente da **vyniltoluene** (con formula chimica C_9H_{10} e peso molecolare MW = 354,537 g/mol) e da una piccola percentuale di Azobisisobutirronitrile (con formula chimica $[(CH_3)_2C(CN)]_2N_2$) la cui funzione è quella di iniziare il processo di polimerizzazione. Si ottiene quindi il **Poli-VynilToluene**, materiale con cui è composto lo scintillatore commerciale di riferimento BC-412.

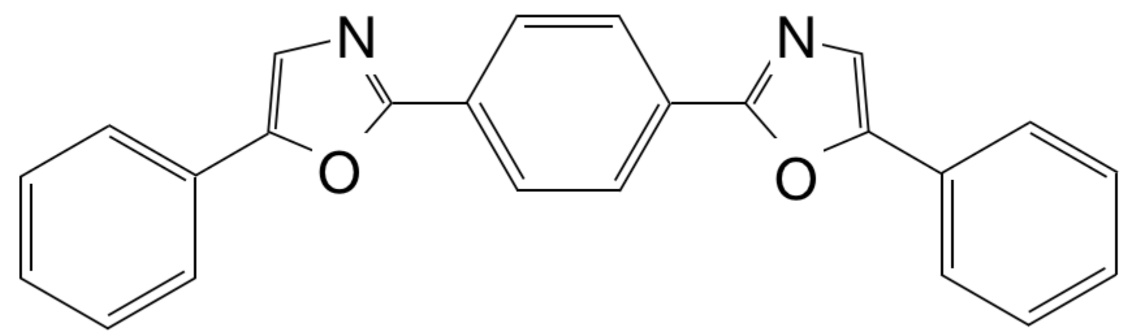
La concentrazione di materiale scintillante all'interno del solvente costituisce l'1% della soluzione. Al fine di limitare fenomeni come il ri-assorbimento, sono immesse quantità di dopante waveshifter pari allo 0,1% della soluzione.

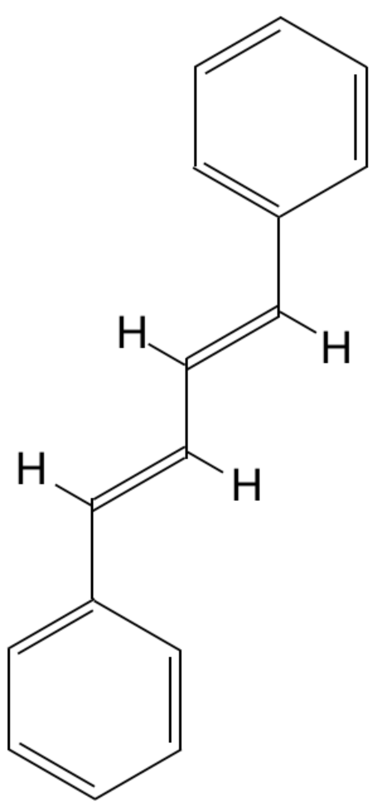


Introduction

Dopanti Waveshifter

Il **POPOP** o 1,4-Bis(5-phenyl-2-oxazol-2-yl)benzene è uno scintillatore con formula chimica $C_{24}H_{16}N_2O_2$, peso molecolare MW = 364,40 g/mol e picco dello spettro in trasmissione λ^t_{peak} = 474 nm mentre il picco in riflessione è λ^r_{peak} = 410 nm.

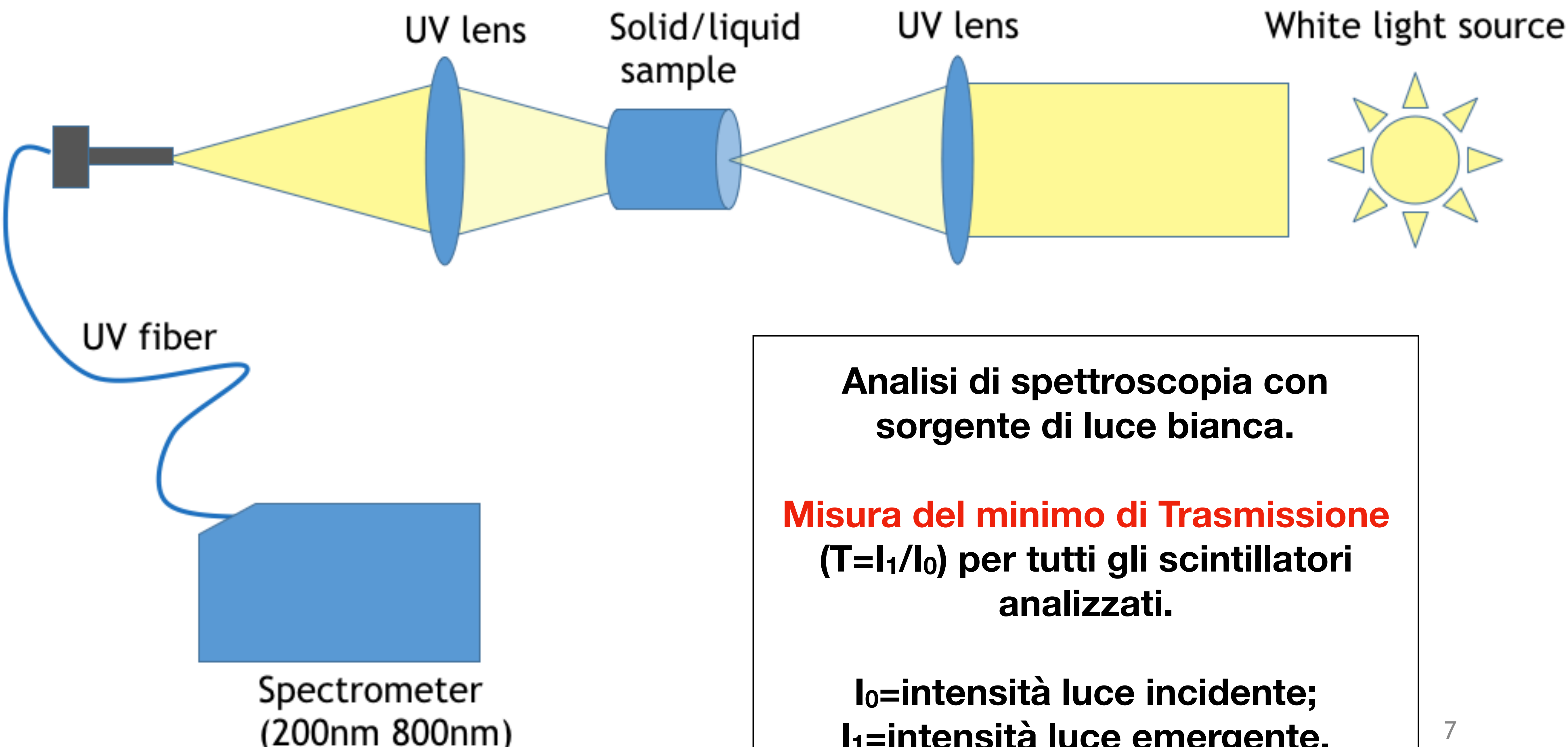




Il DPB o 1,4-Diphenyl-1,3- butadiene è un materiale scintillante con formula chimica $C_{16}H_{14}$, peso molecolare MW = 206,29 g/mol e picco dello spettro in trasmissione λ^t_{peak} = 463 nm.

Spectroscopy

Transmission setup

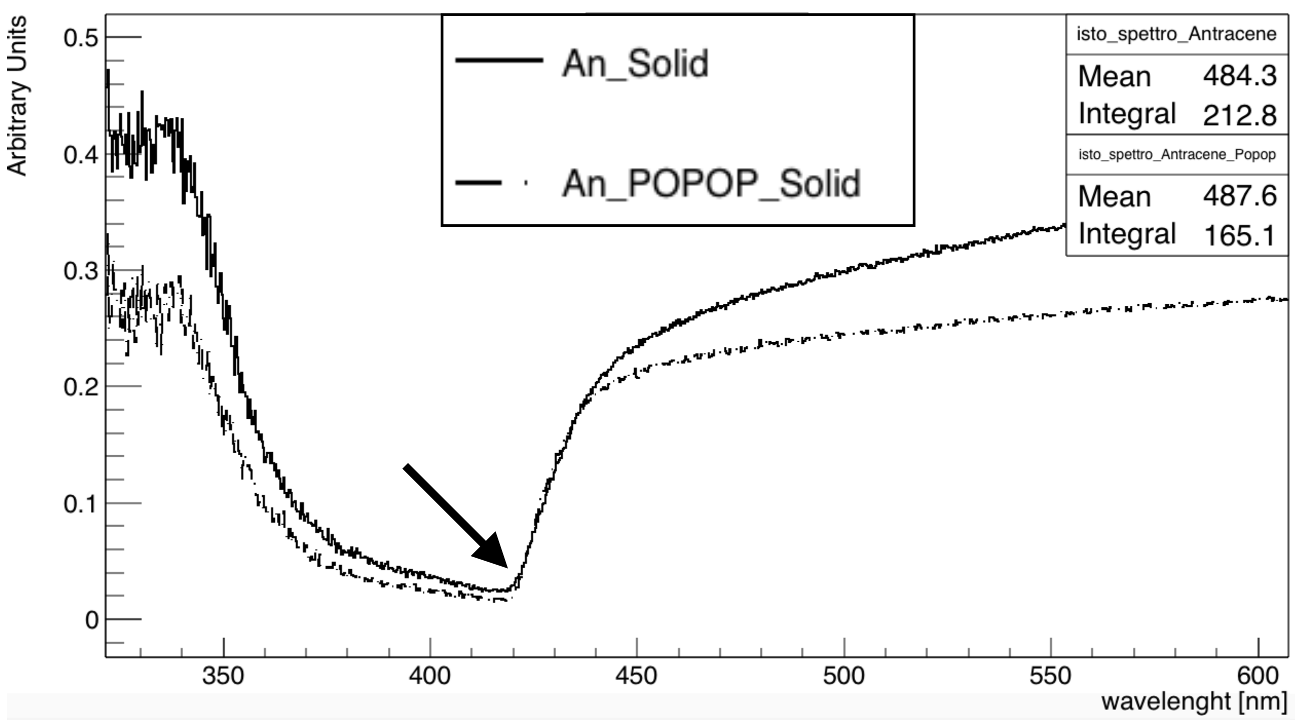


Analisi di spettroscopia con sorgente di luce bianca.

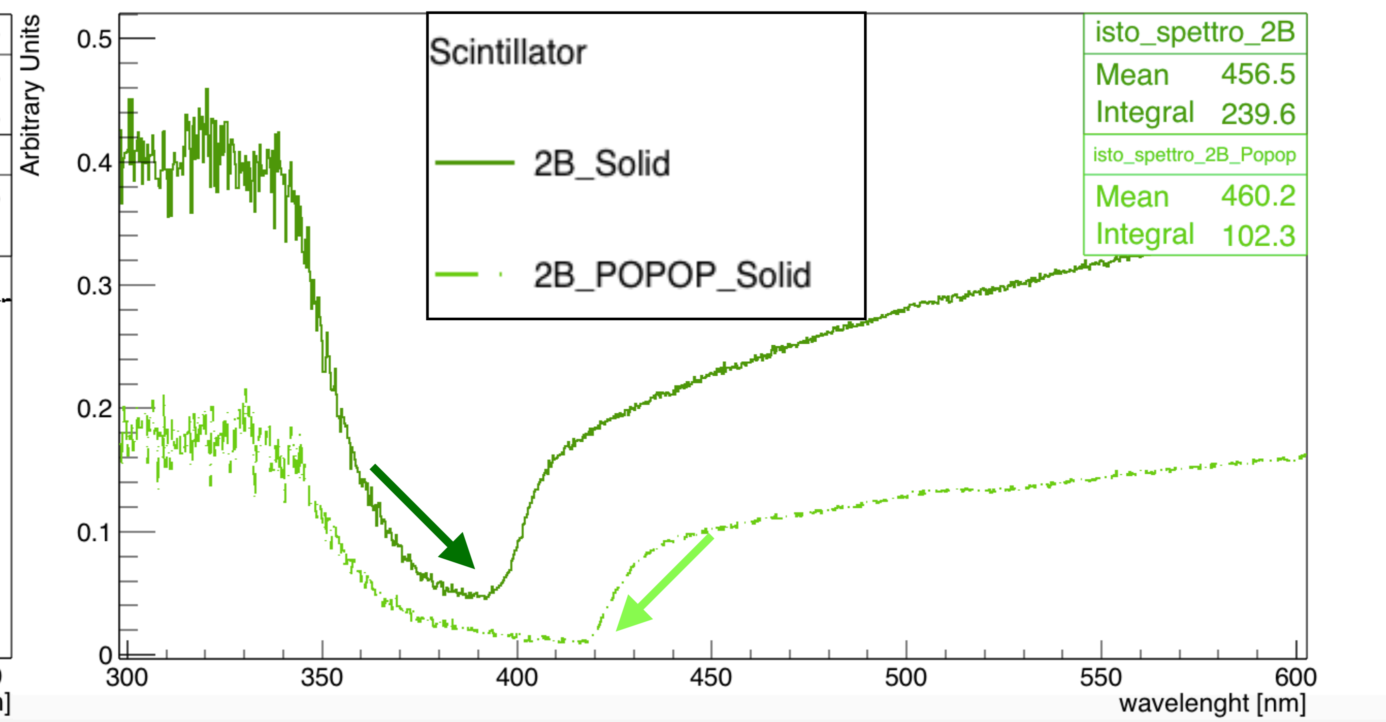
Misura del minimo di Trasmissione **($T=I_1/I_0$) per tutti gli scintillatori analizzati.**

I_0=intensità luce incidente;
I_1=intensità luce emergente.

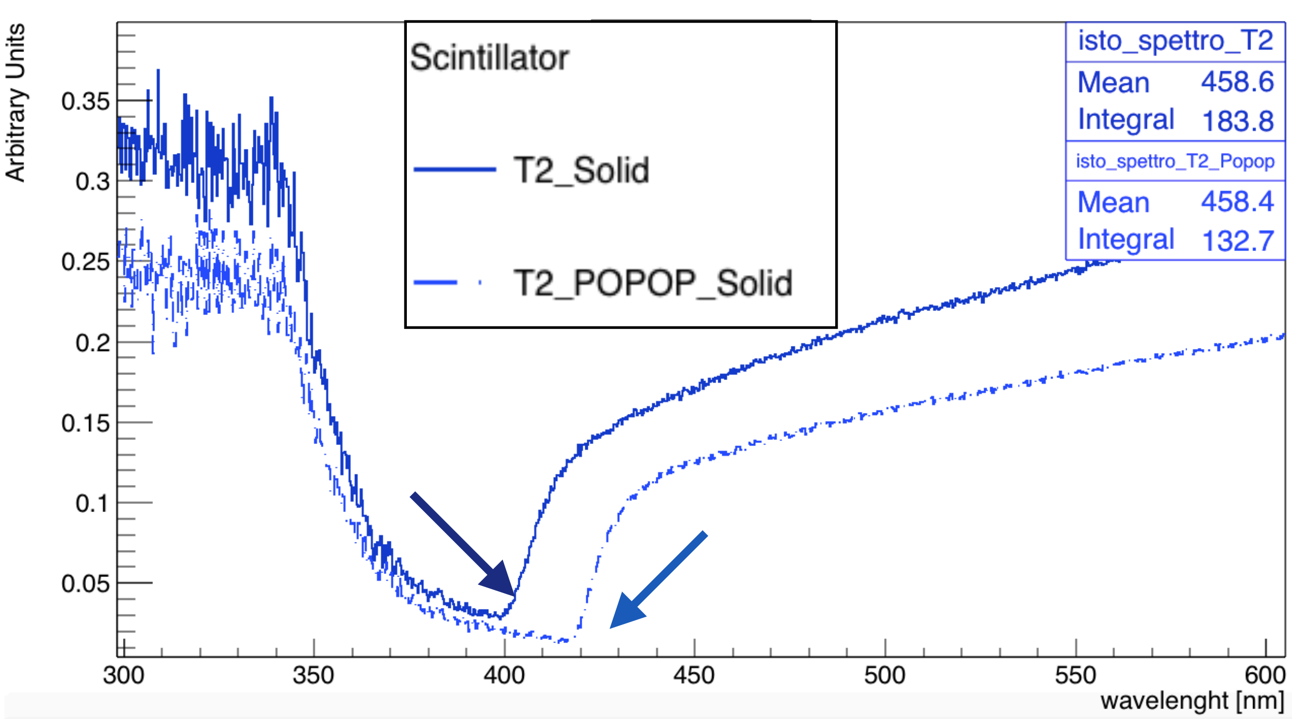
Spectroscopy in trasmission



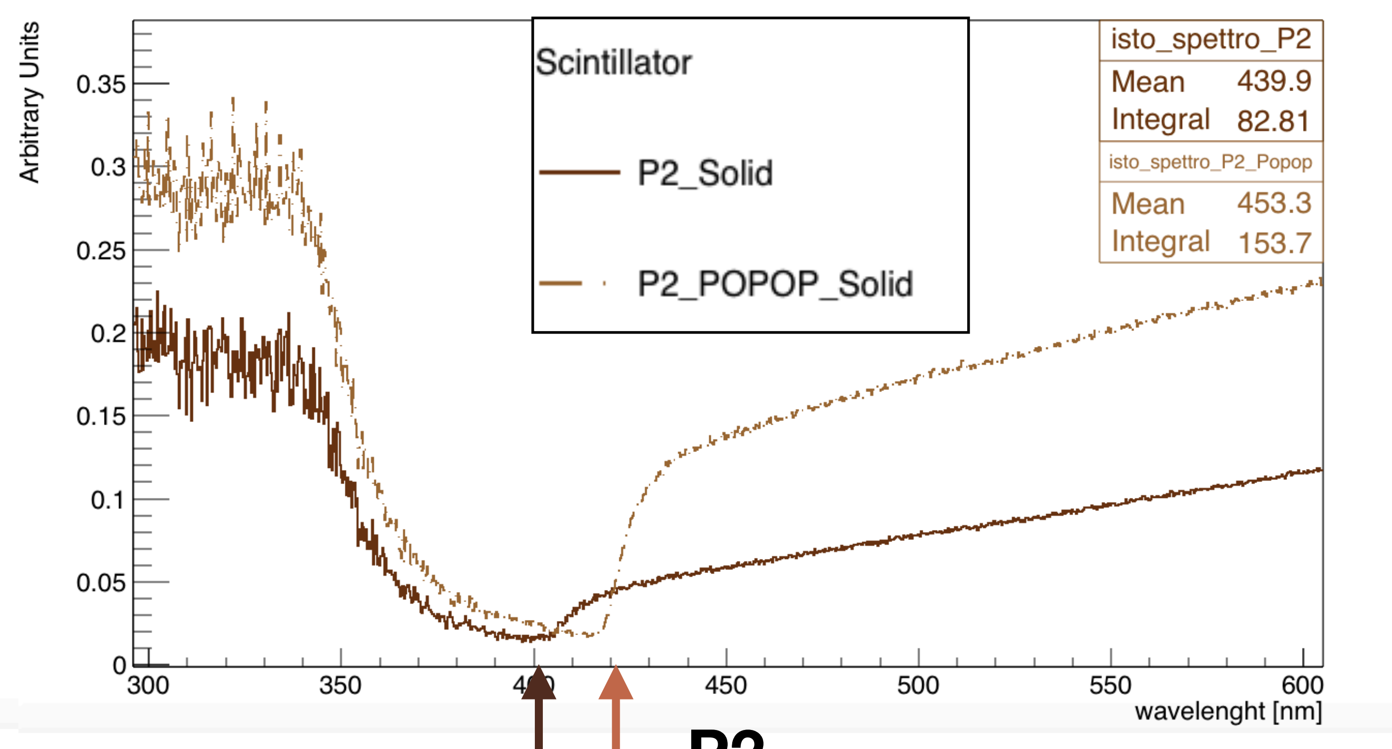
ANTHRACENE



2B



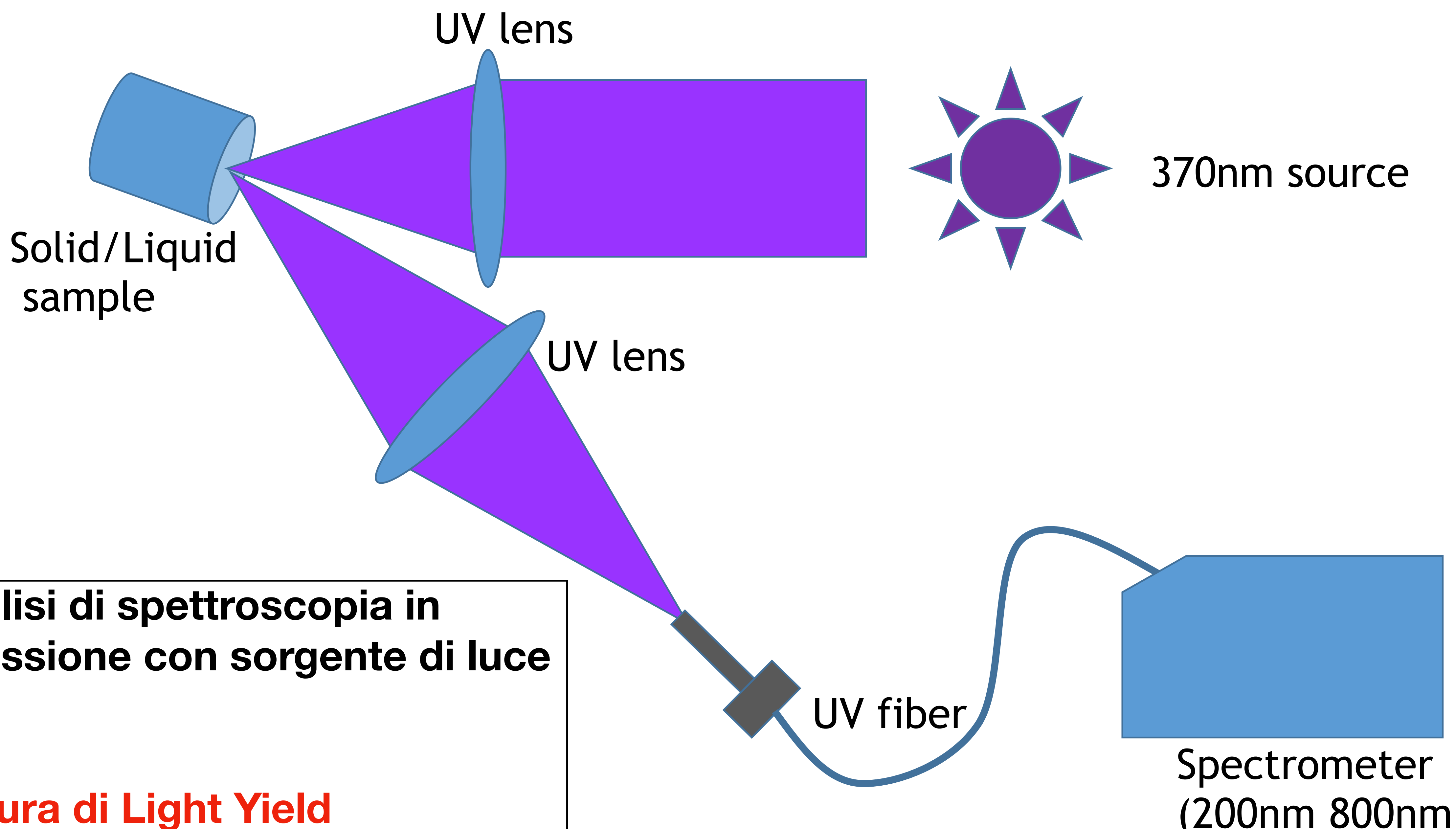
T2



P2

Transmission Minimum (nm)	Scintillator	Scintillator + POPOP
An	397 ± 1	399 ± 1
2N	402 ± 1	401 ± 1
1N	388 ± 1	397 ± 1
2B	380 ± 1	399 ± 1
P2	402 ± 1	398 ± 1
T2	379 ± 1	398 ± 1
BC-412	386 ± 1	X

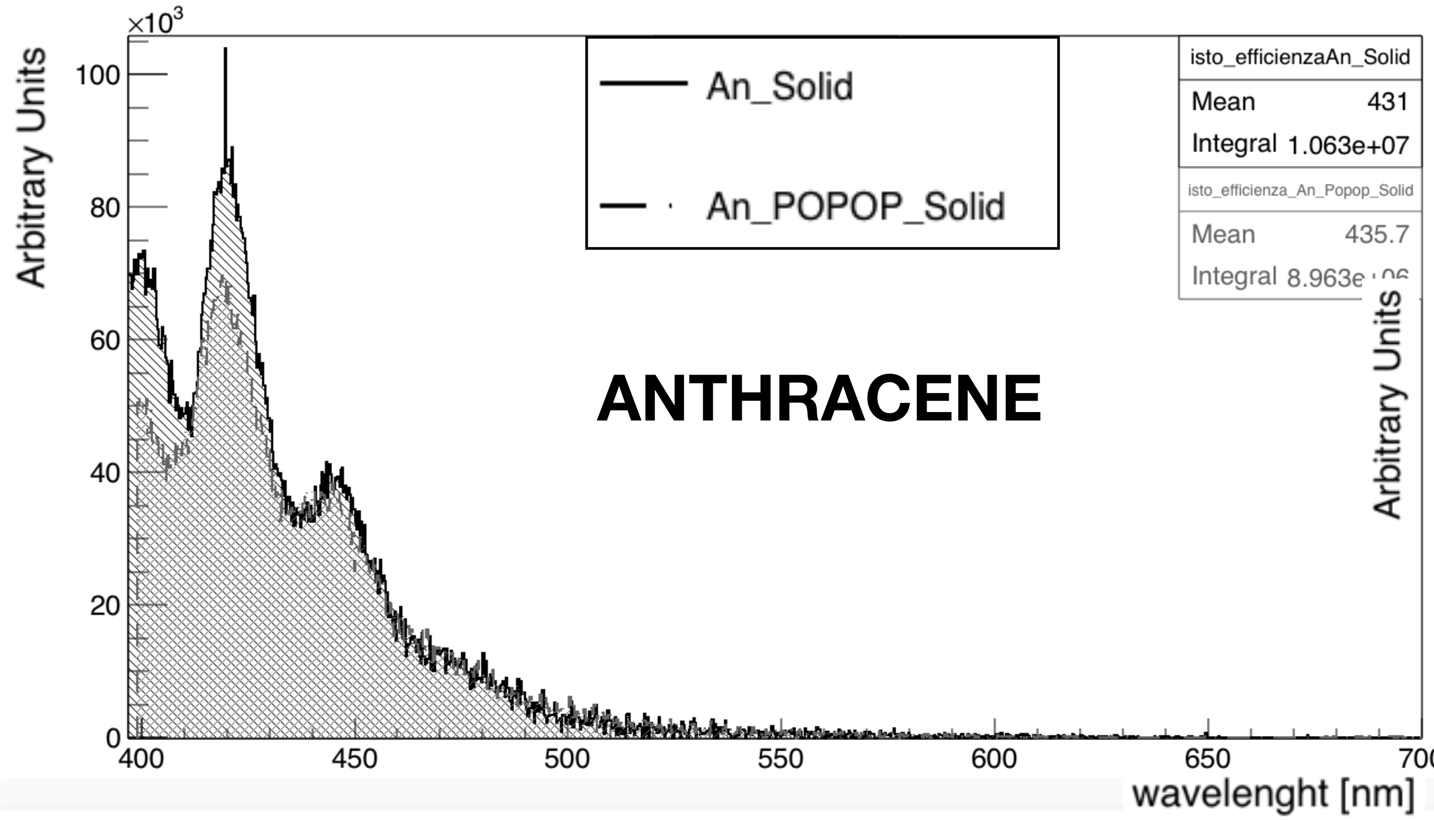
Luminescence in reflection Setup

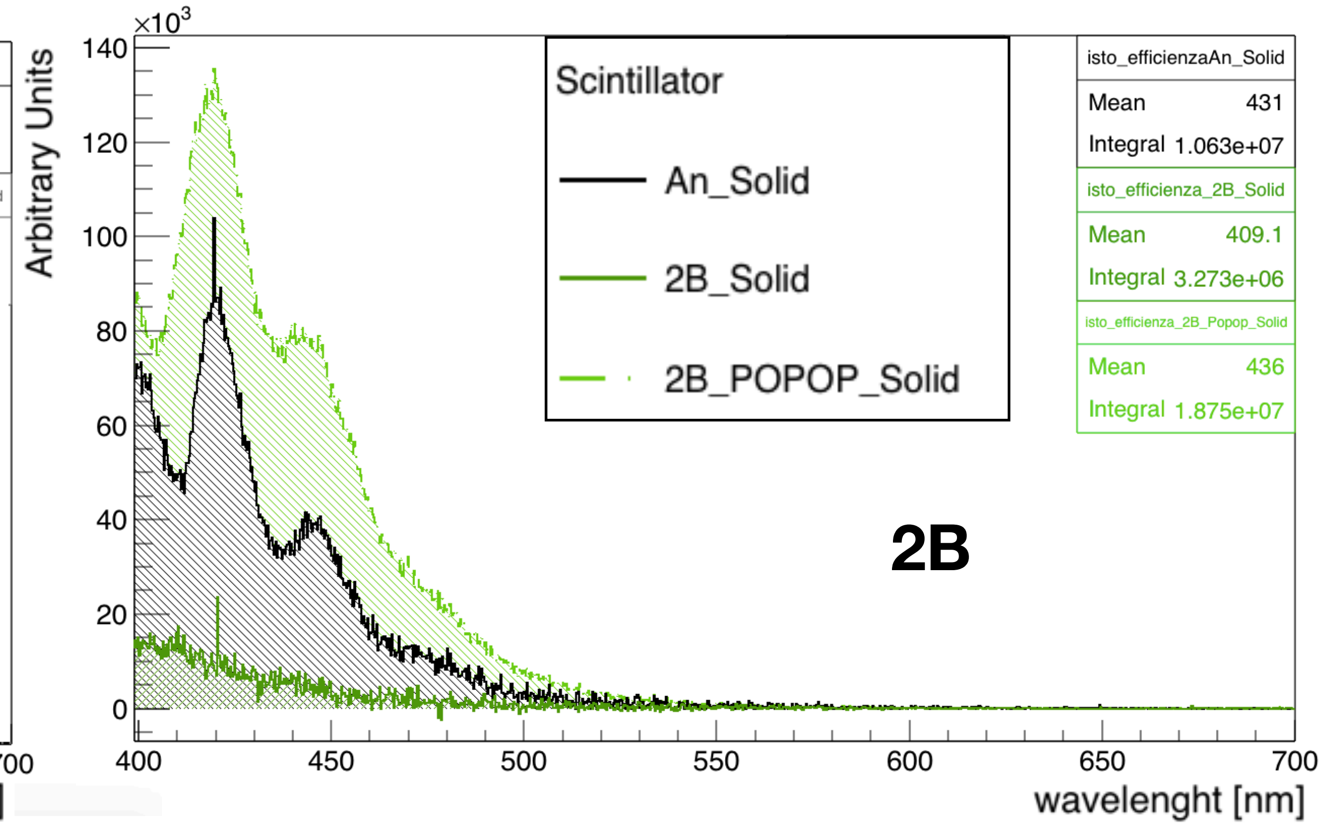


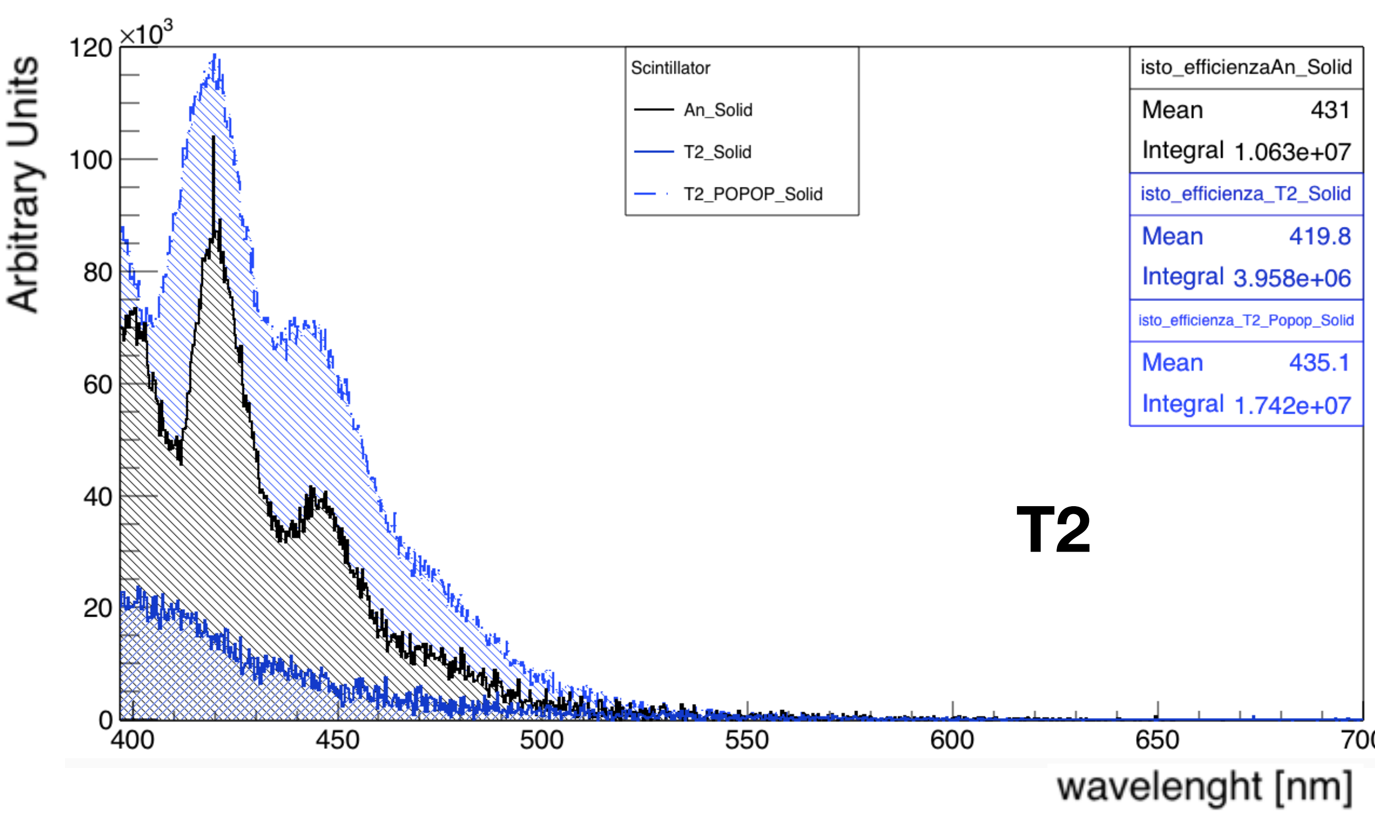
Analisi di spettroscopia in riflessione con sorgente di luce UV.

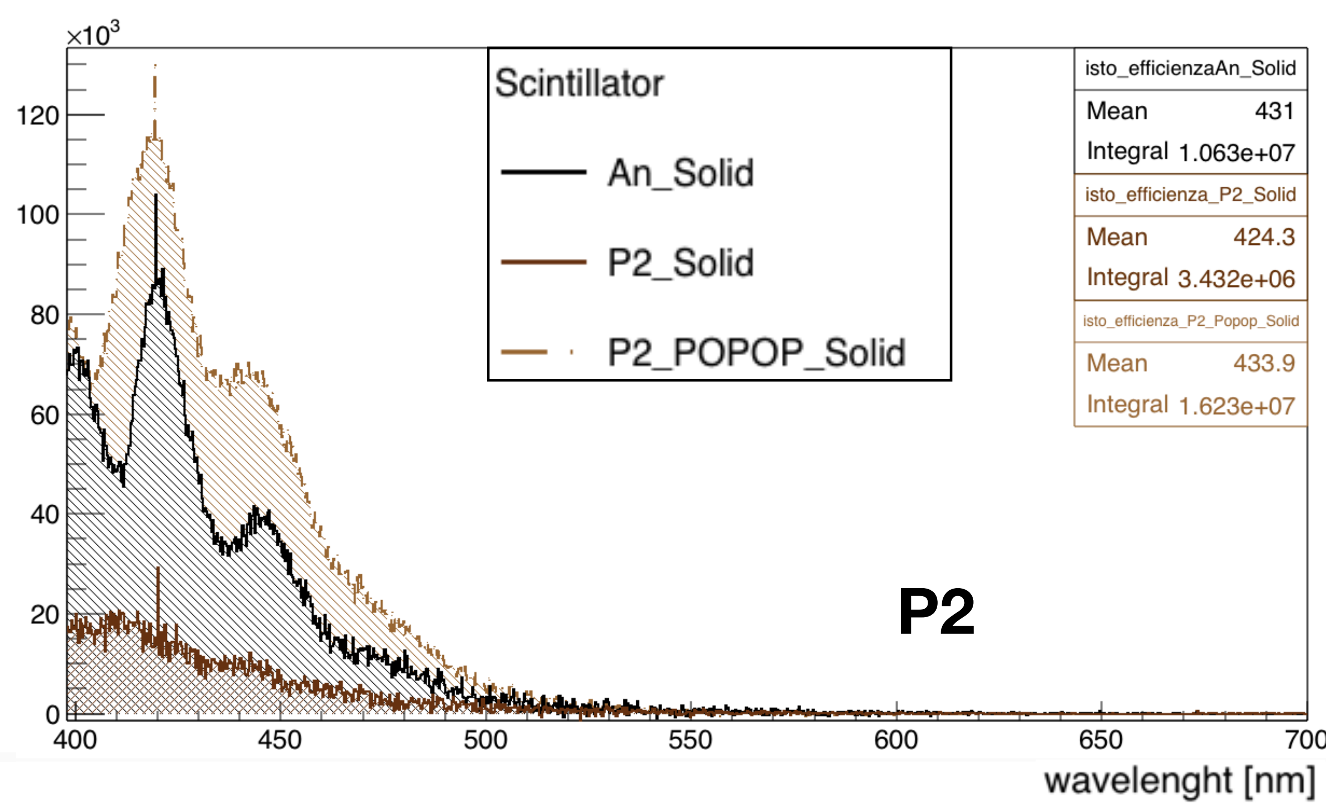
Misura di Light Yield
(in % rispetto all'Antracene) per tutti gli scintillatori analizzati.

Luminescence spectroscopy in reflection





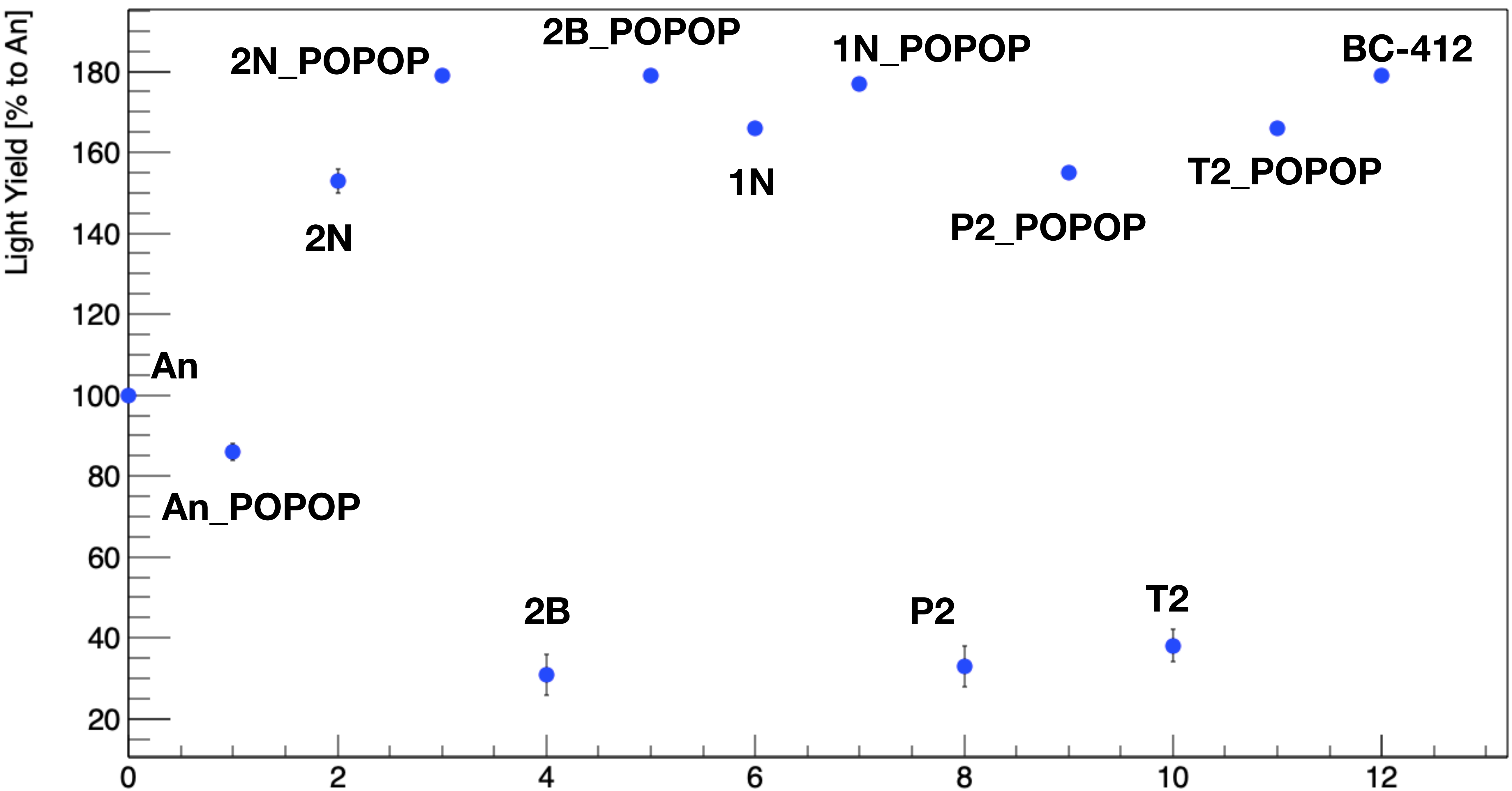




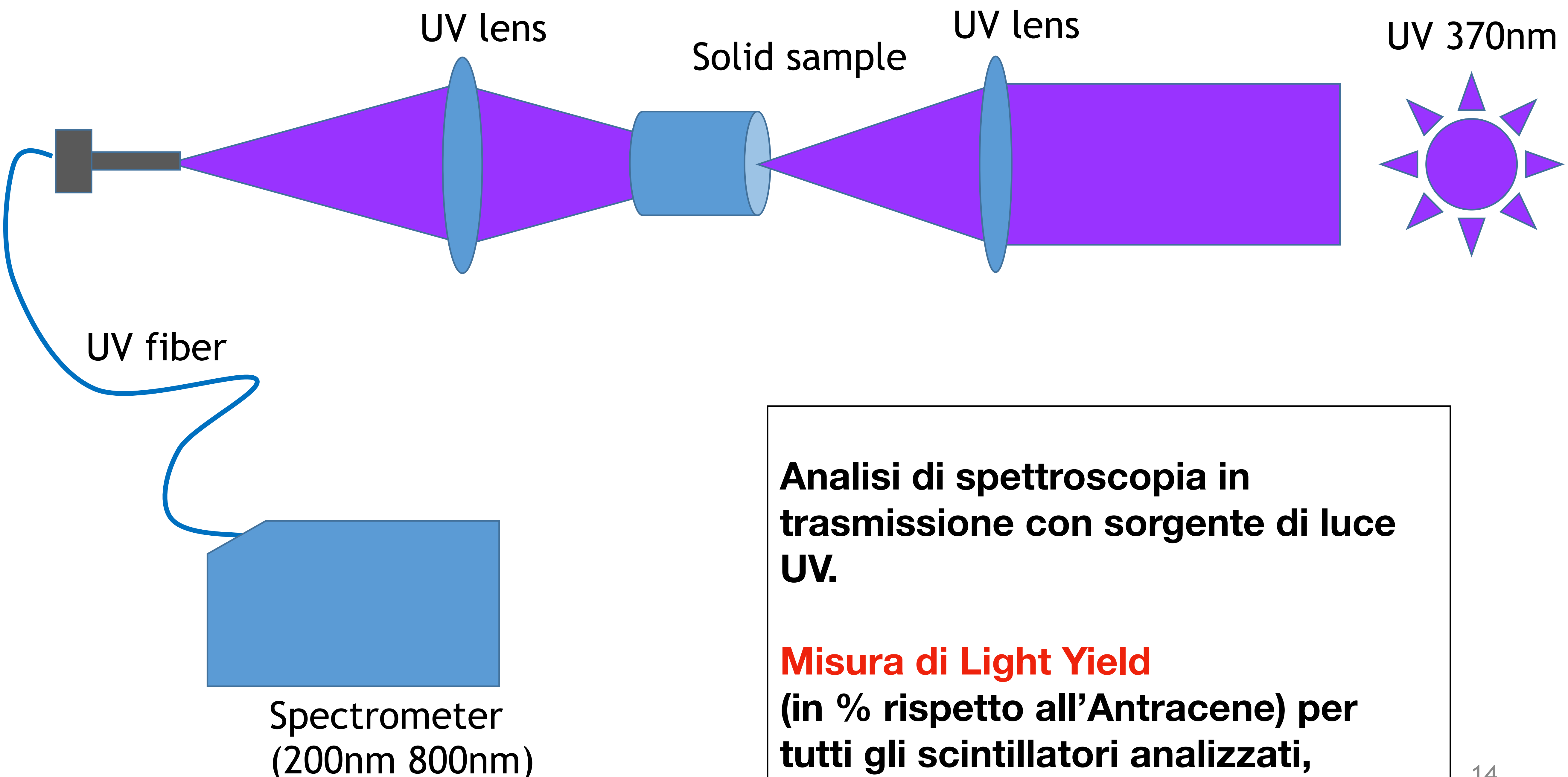
Light Yield (% to Anthracene)	Scintillator	Scintillator + POPOP
A	100.00	86 ± 2
2N	153 ± 3	179 ± 1
2B	31 ± 5	179 ± 1
1N	166 ± 1	177 ± 1
P2	33 ± 5	155 ± 1
T2	38 ± 4	166 ± 1
BC 412	179 ± 1	X

Nota:
Questi valori non tengono conto dei fenomeni di ri-assorbimento interni agli scintillatori.

Plot Light Yield [% to An] (in reflection) Scintillators



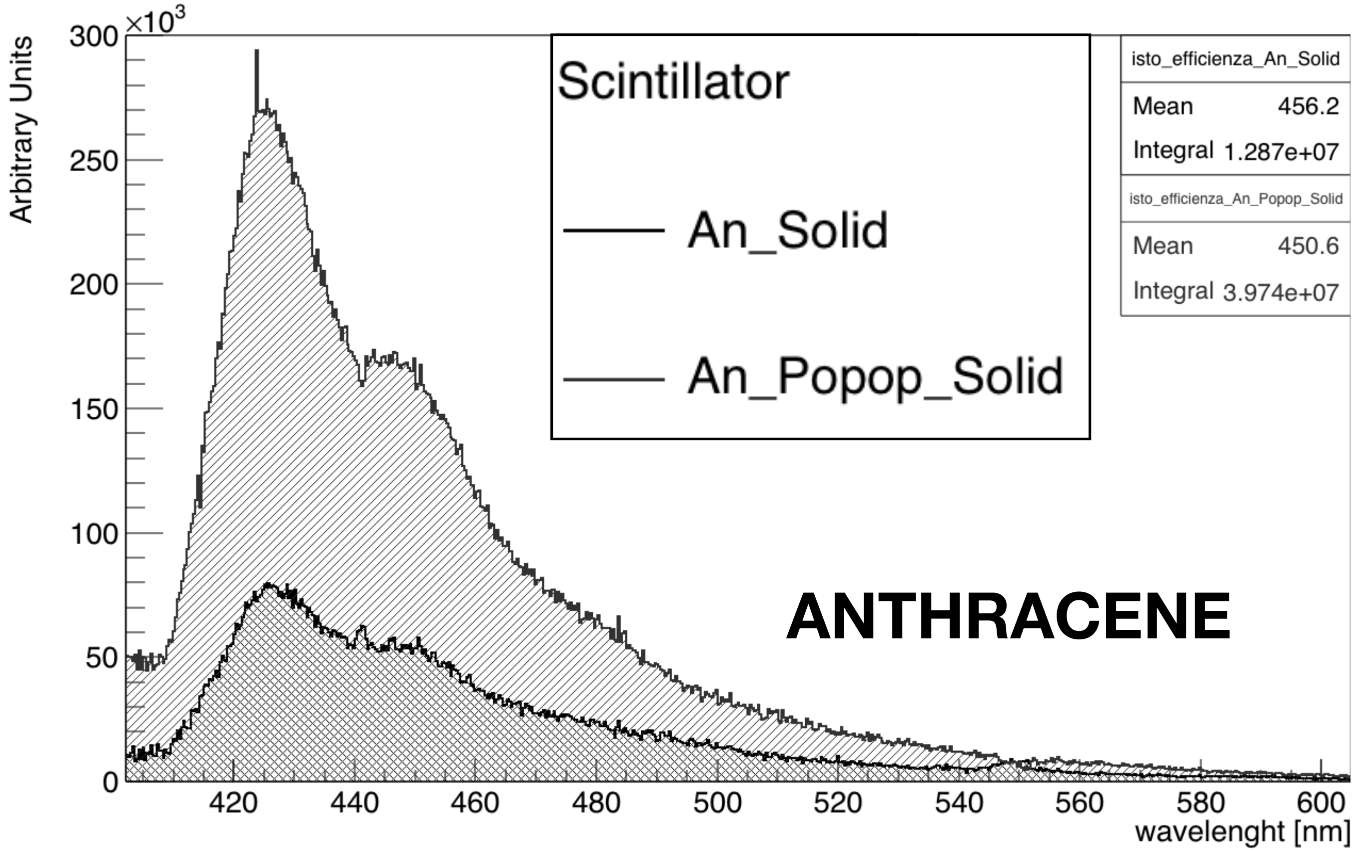
Luminescence in transmission setup

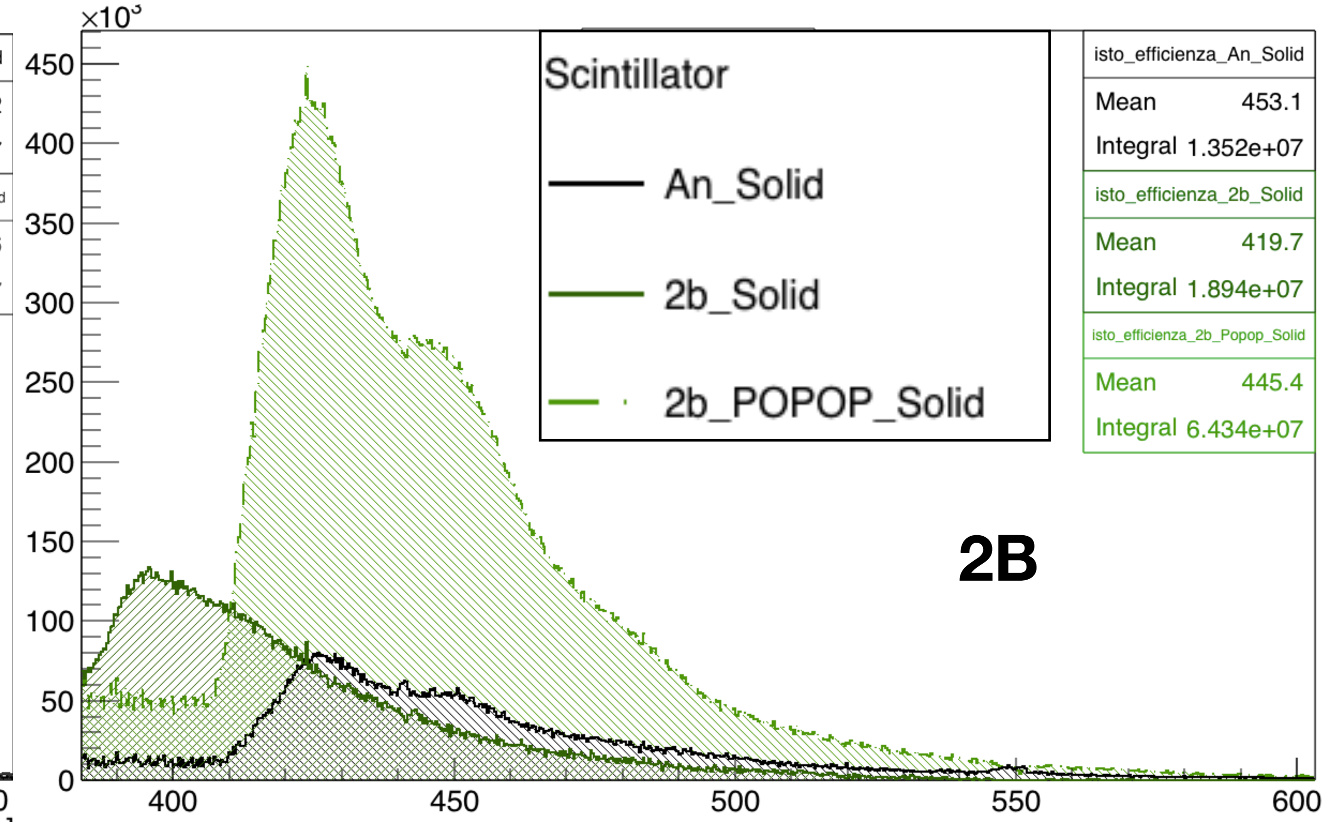


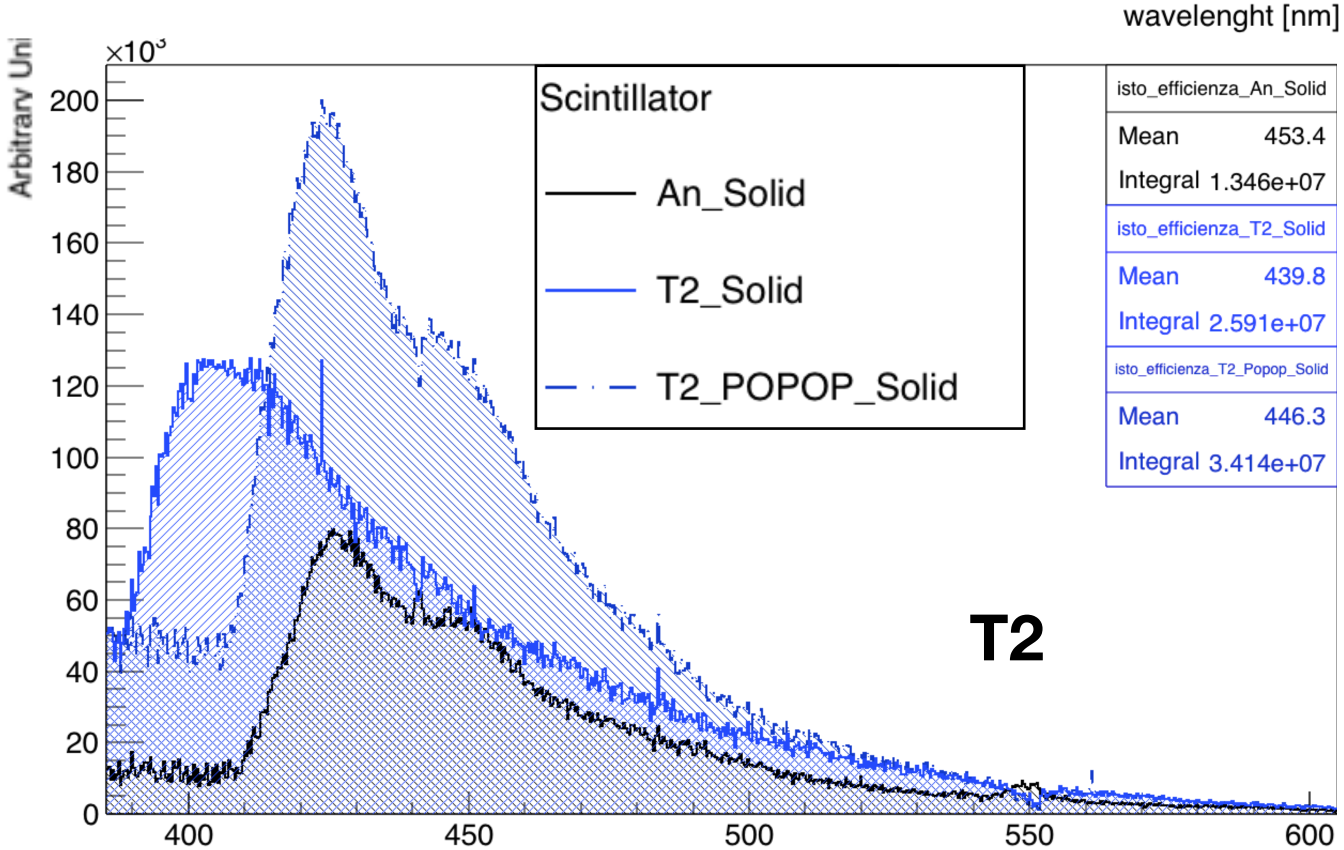
Analisi di spettroscopia in trasmissione con sorgente di luce UV.

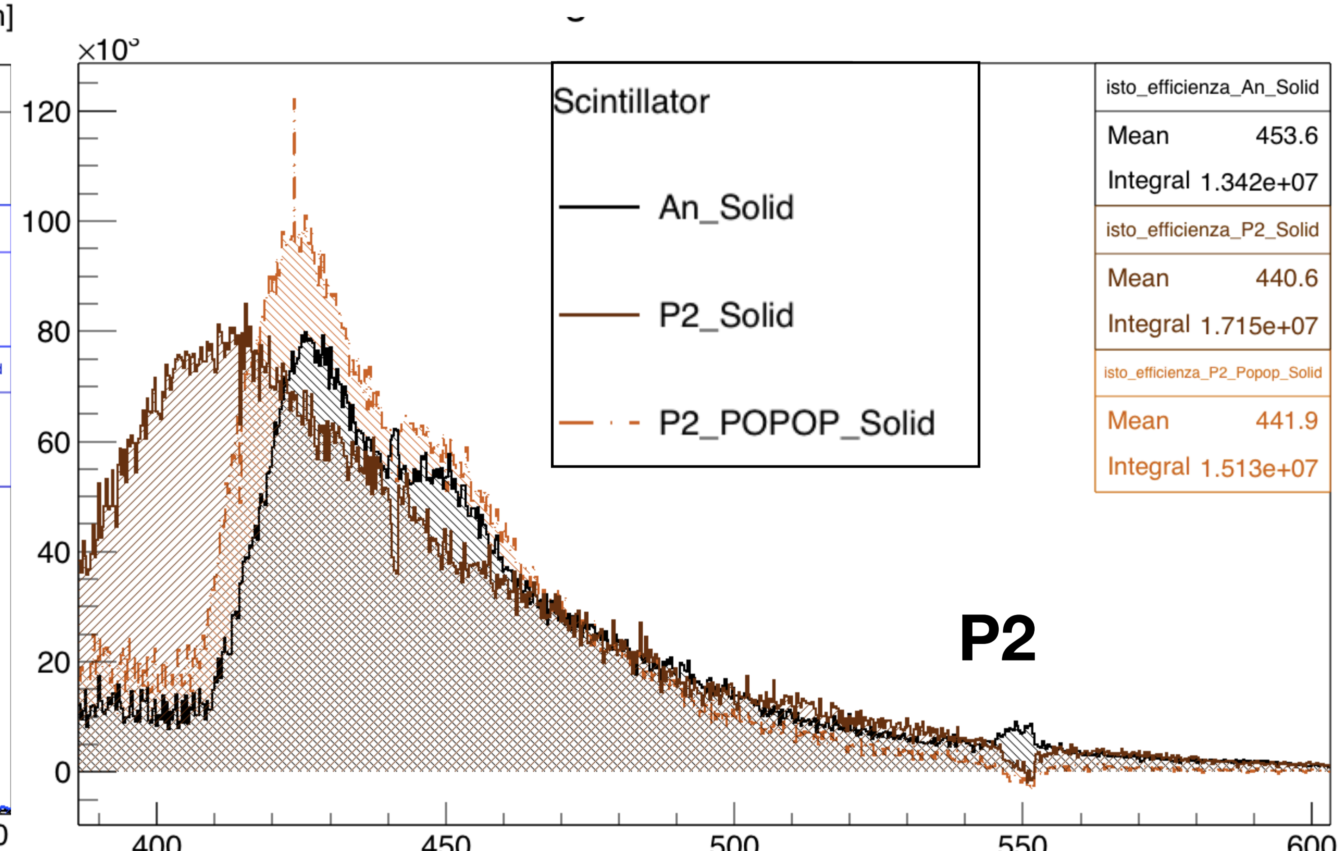
Misura di Light Yield
(in % rispetto all'Antracene) per tutti gli scintillatori analizzati, tenendo conto del ri-assorbimento.

Luminescence spectroscopy in trasmission



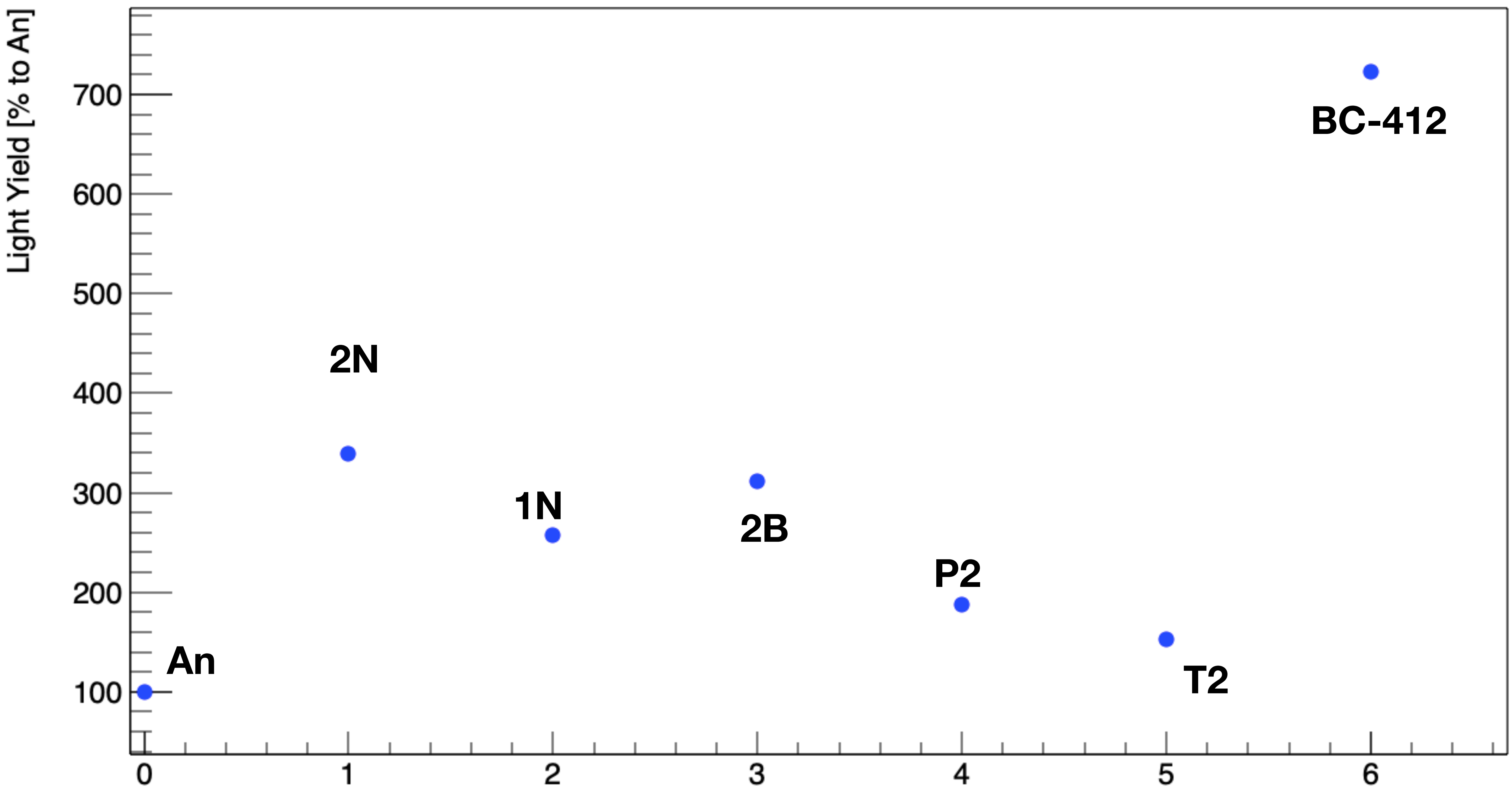




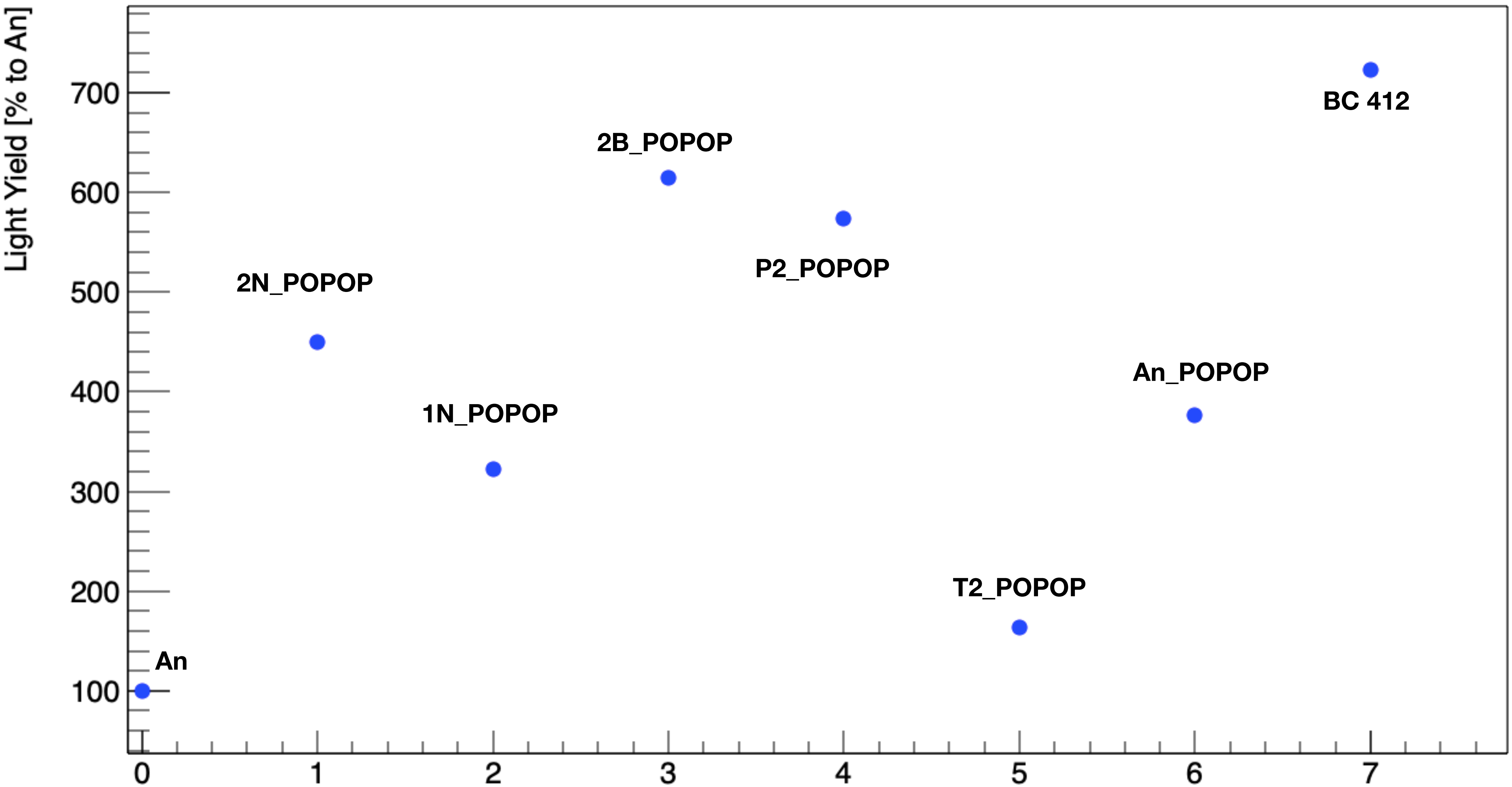


Light Yield (% to Anthracene)	Scintillatori	Scintillatori POPOP
BC 412	723 ± 1	X
An	100.00	450 ± 1
2N	339 ± 1	322 ± 1
2B	257 ± 1	615 ± 1
1N	312 ± 1	574 ± 1
P2	188 ± 1	163 ± 1
T2	253 ± 1	377 ± 1

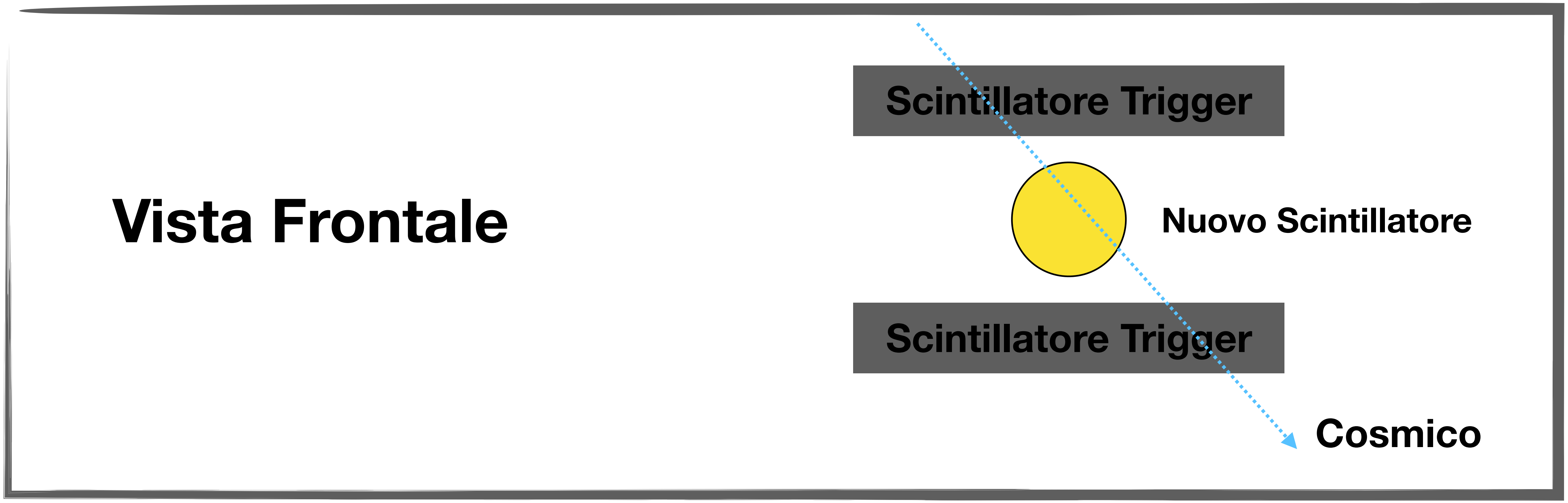
Plot Light Yield [% to An] (in trasmission) Scintillators



Plot Light Yield [% to An] (in trasmission) Scintillators + POPOP



Setup Sperimentale Solidi



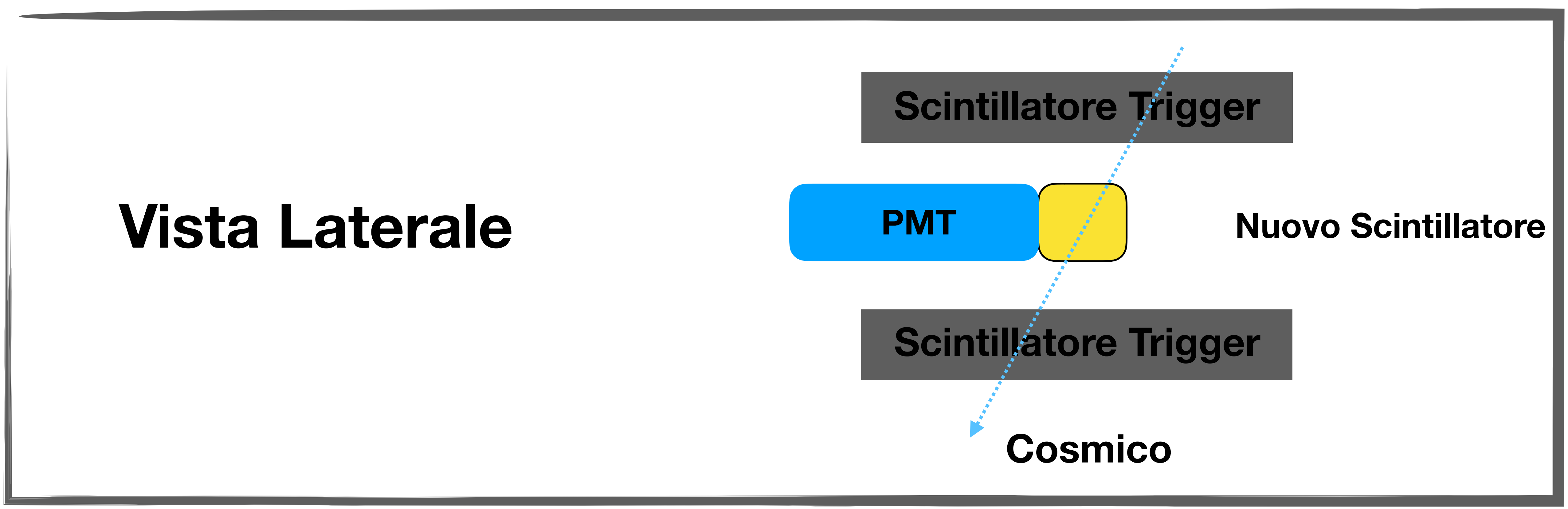
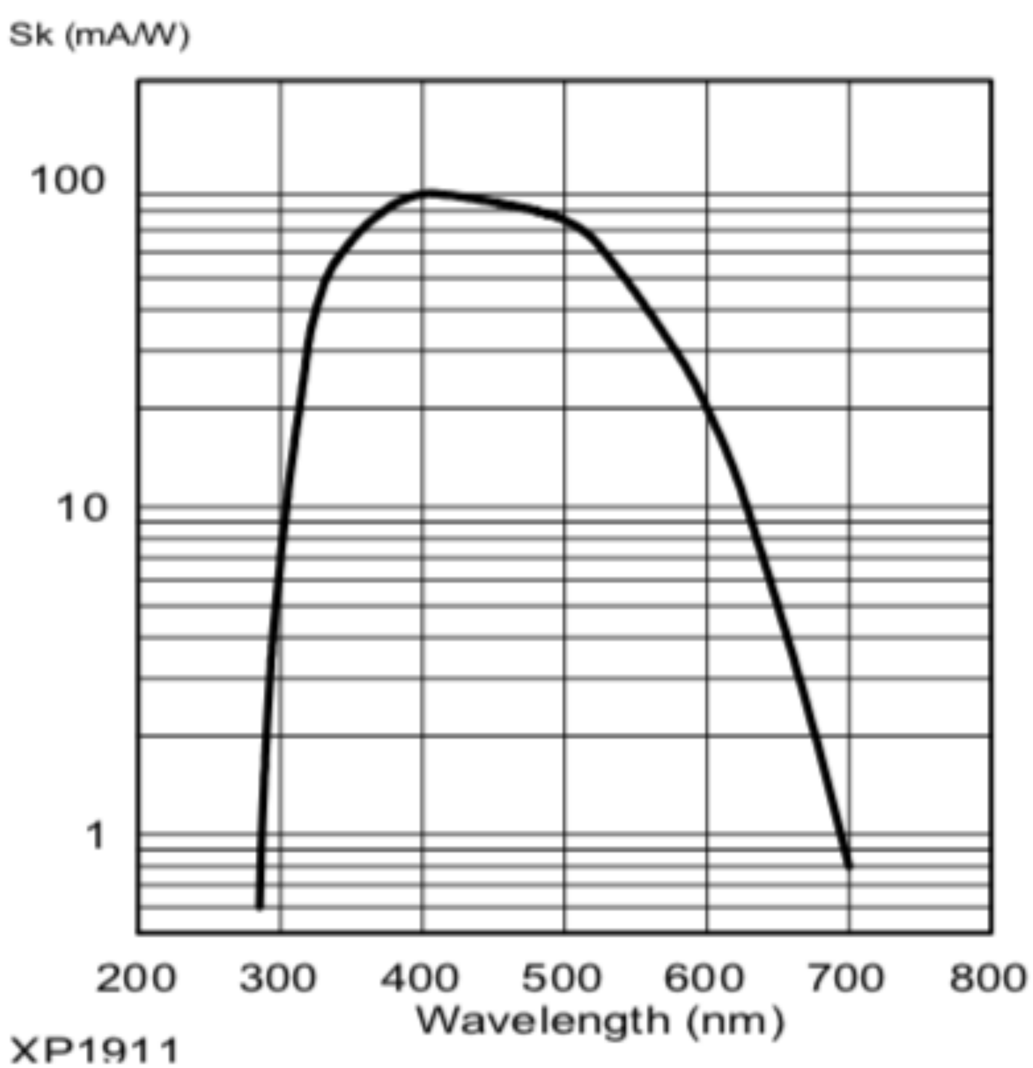


Photo Multiplier Tube

PMT Properties	QE (% at peak)	Gain (1500V)	Rise Time (ns)	Wavelength (nm)
XP1911	~31	$5.1 \cdot 10^6$	2.5	300 to 700

Typical spectral characteristics

$$QE = \frac{S \cdot 1240}{\lambda} \cdot 100(\%)$$



Typical gain curve

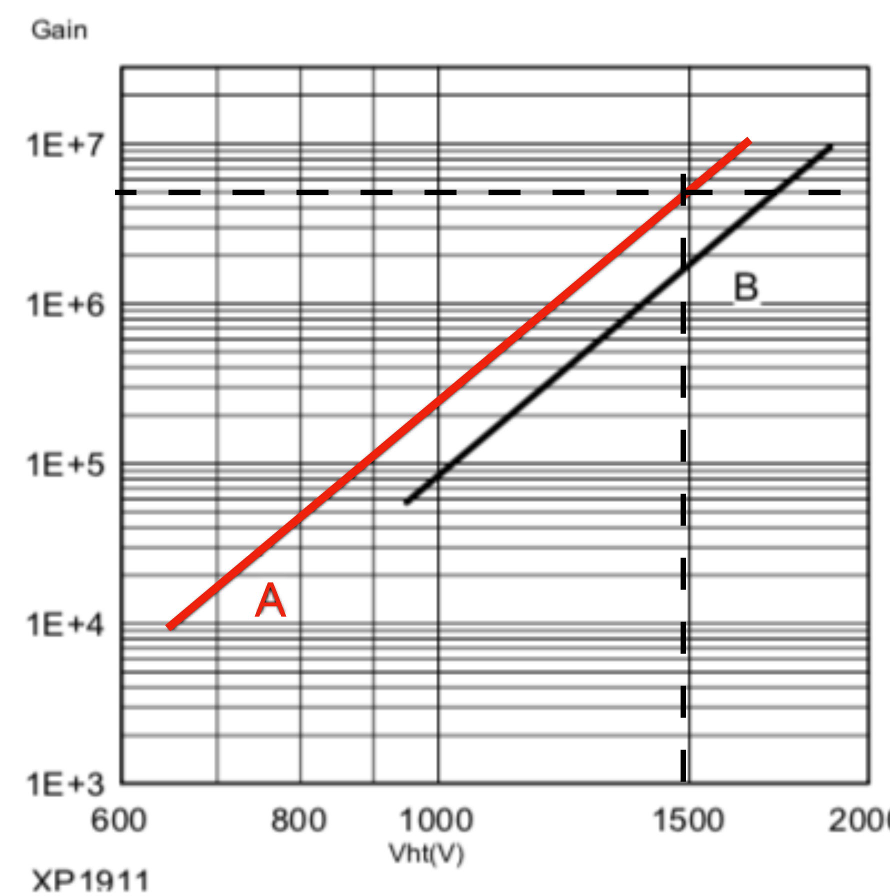


Photo Multiplier Tube

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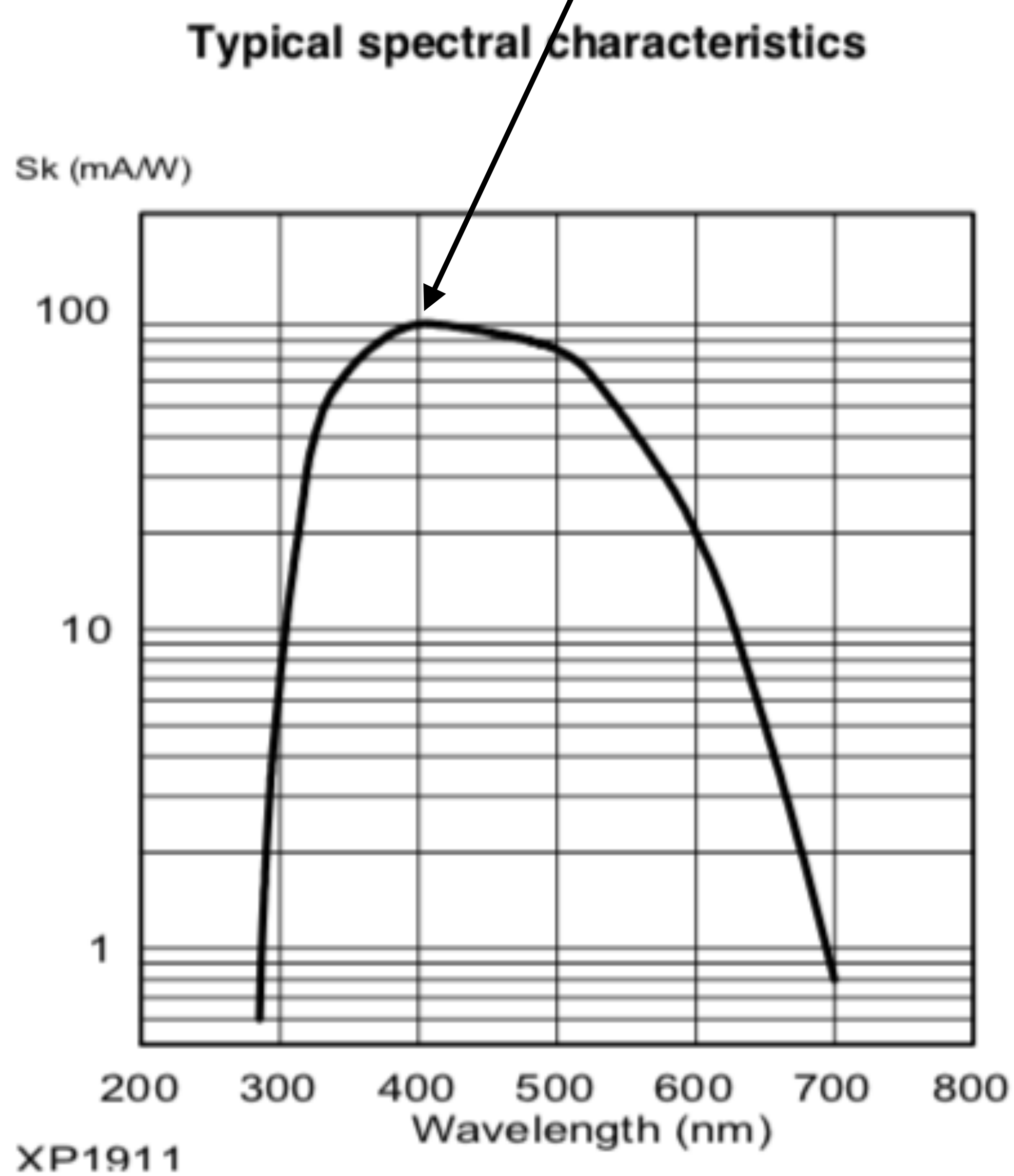

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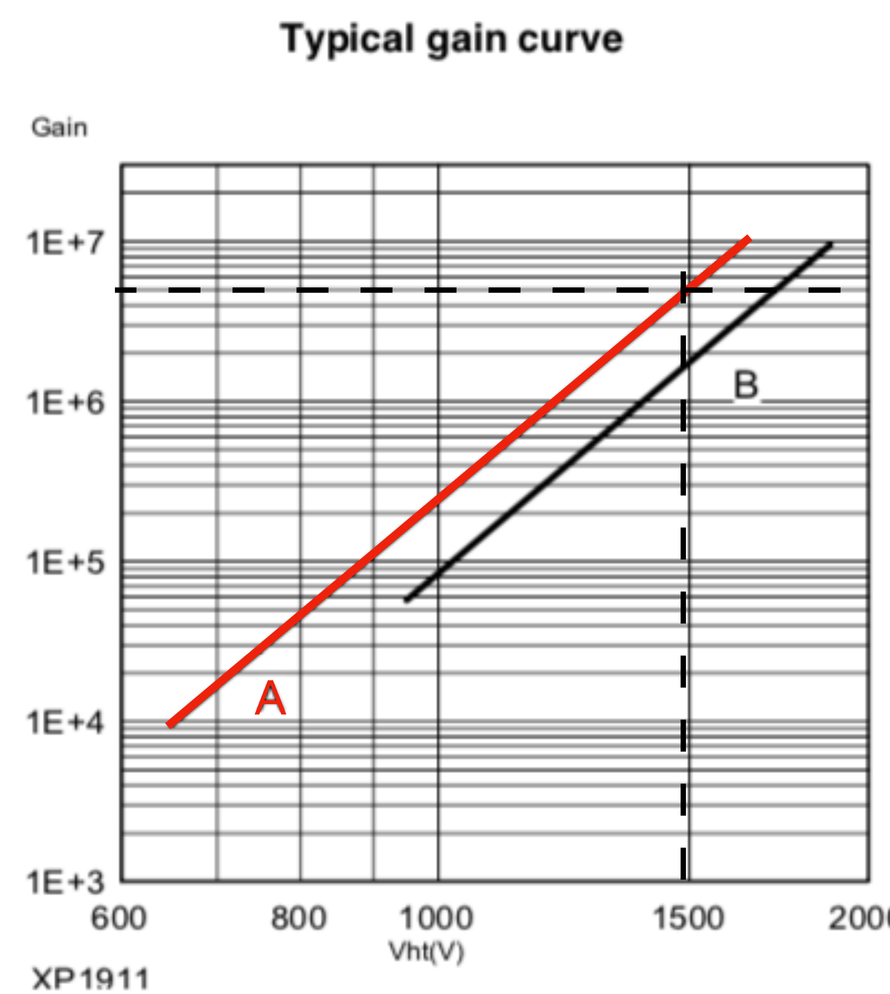

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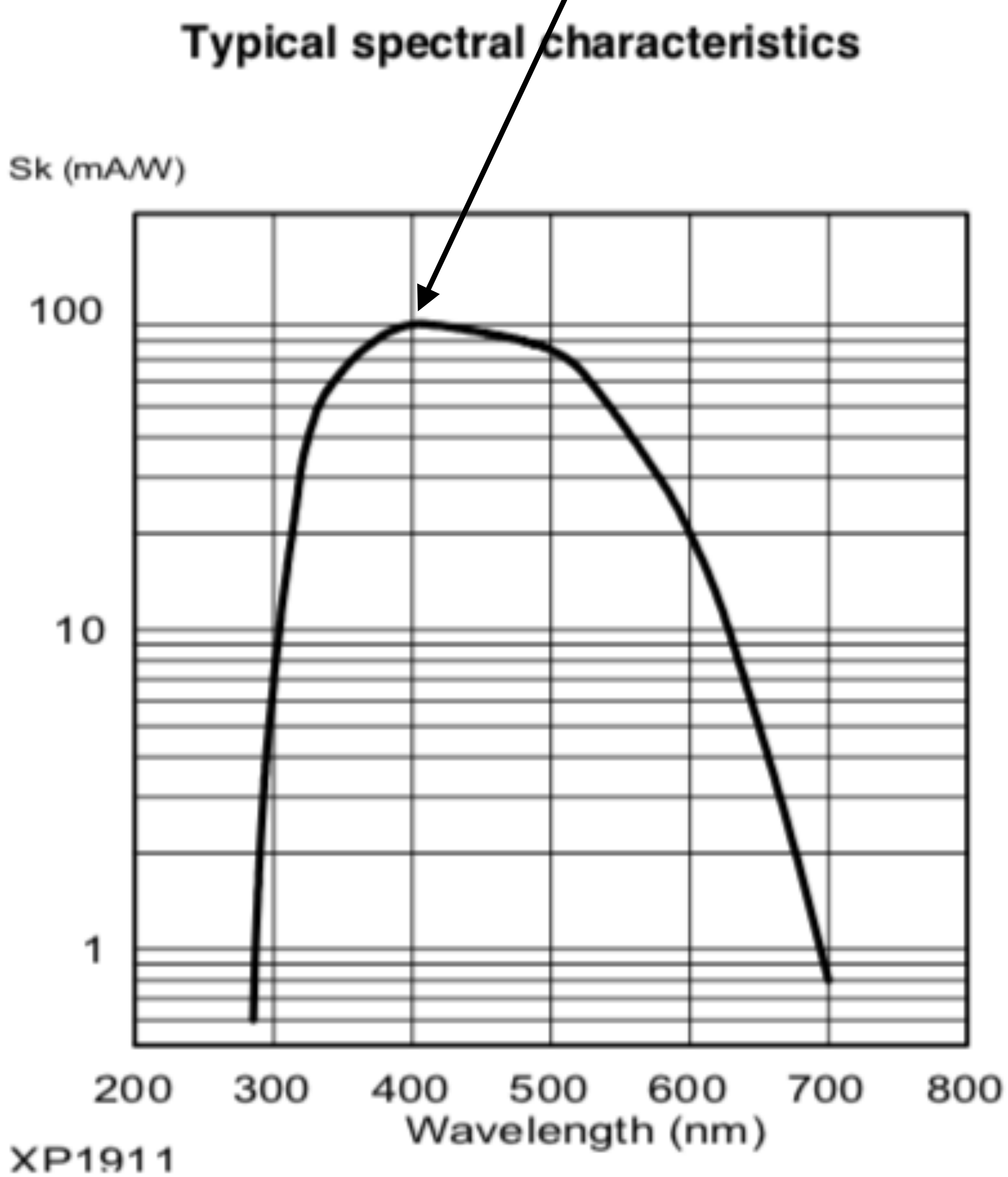
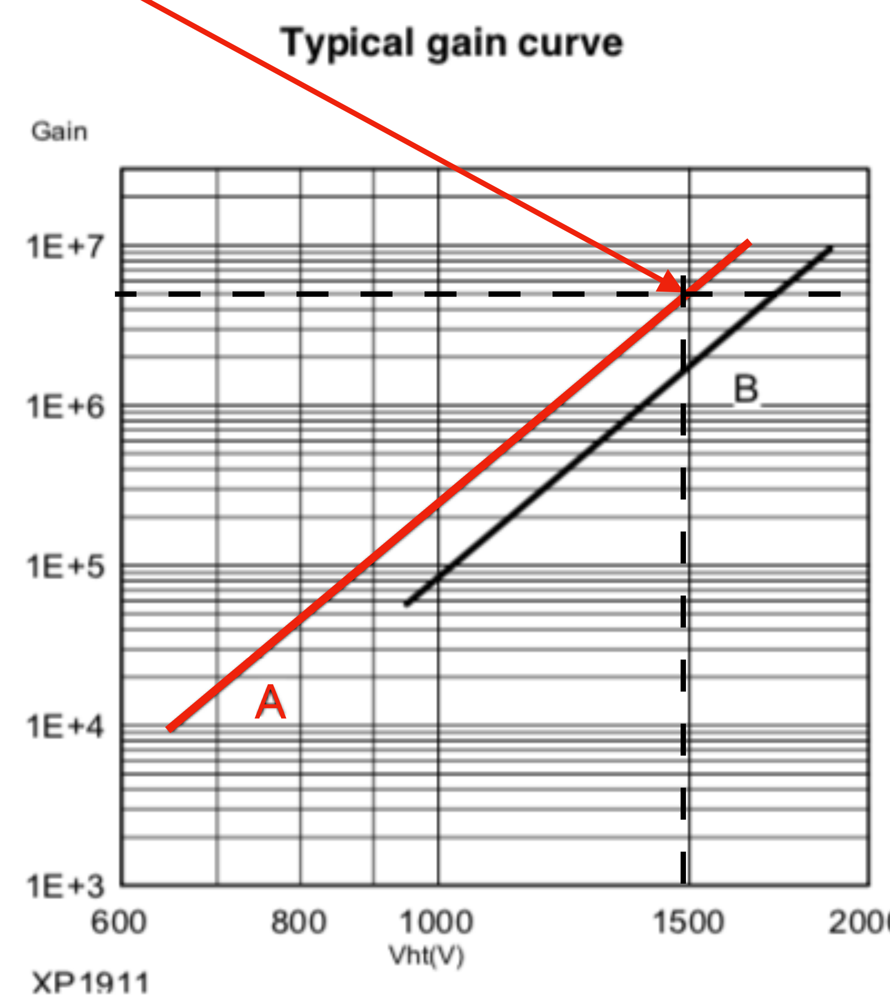


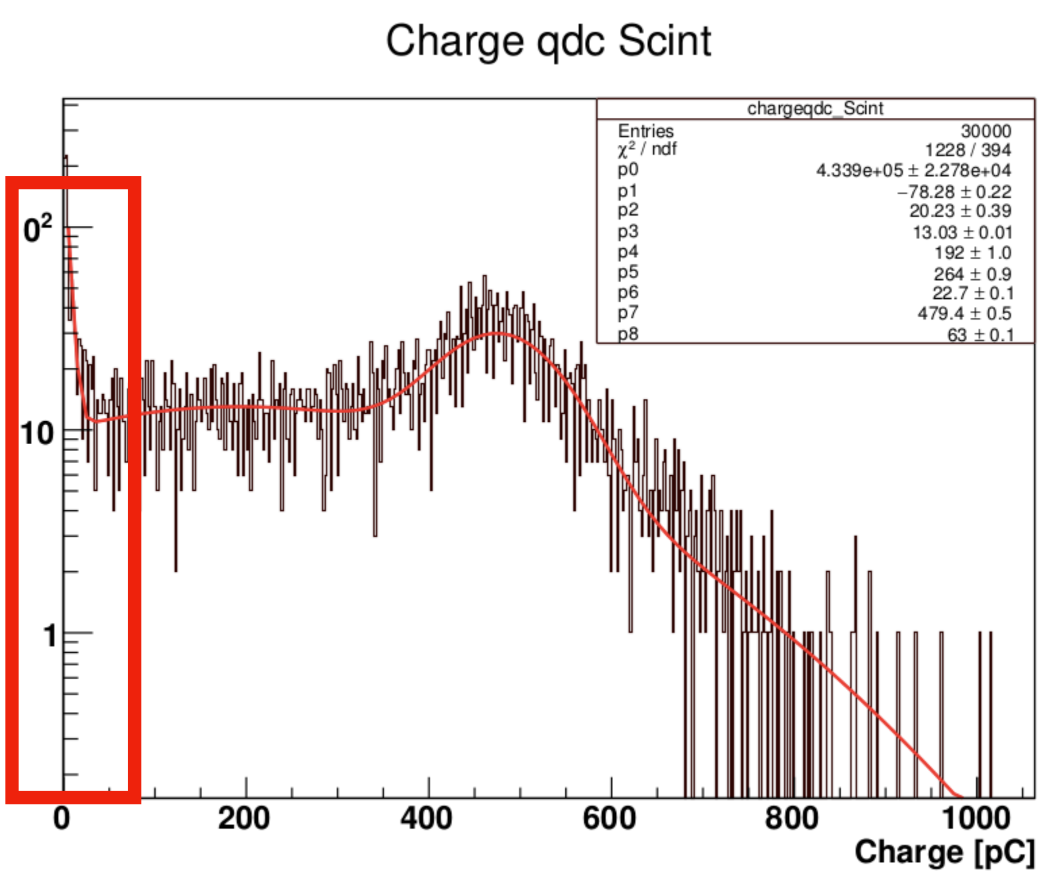


Charge

Cosmic ray effects

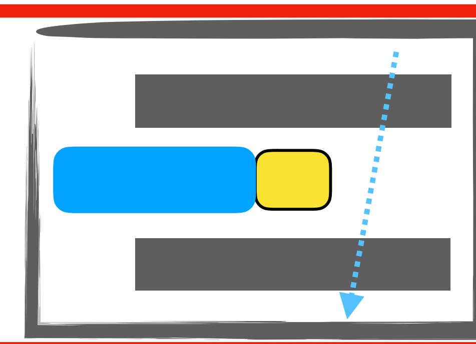
Le distribuzioni di guadagno in carica degli scintillatori sono fittate con una somma di tre gaussiane, di cui solo l'ultima riguarda il fenomeno studiato.

$$f(x) = p0*\exp(-0.5*((x-p1)/p2)^\wedge 2)) + p3*\exp(-0.5*((x-p4)/p5)^\wedge 2)) + p6*\exp(-0.5*((x-p7)/p8)^\wedge 2))$$

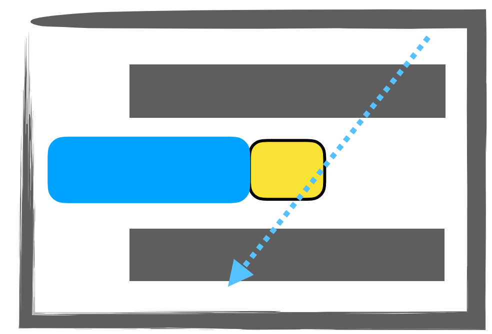


NB: Nella tesi verrà effettuato un Rebin

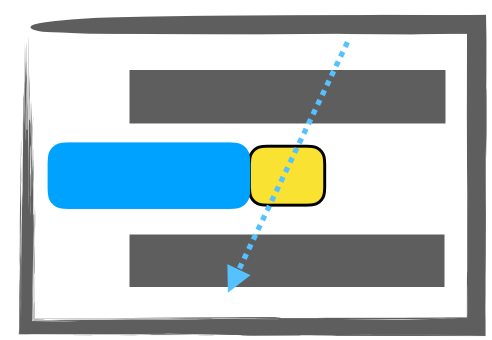
Gaussiana 1 ——> Piedistallo elettronico;



Gaussiana 2 ——> Attraversamento marginale del mezzo da parte di raggi cosmici;



Gaussiana 3 ——> Segnale (attraversamento totale del mezzo);



Nei casi in cui il guadagno in carica è molto basso (come per l'Anthracene), le tre gaussiane si sovrappongono, per cui viene effettuato un unico fit gaussiano nell'unico picco di segnale evidente.

Cosmic ray effects

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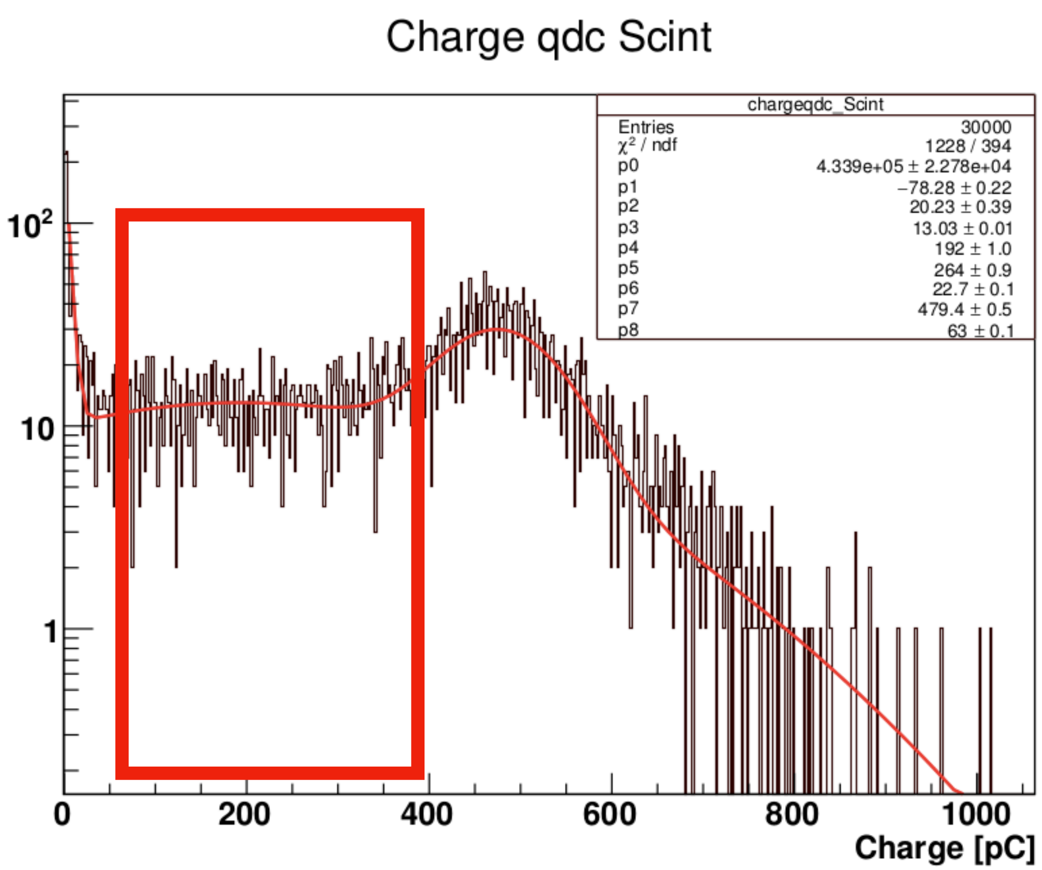

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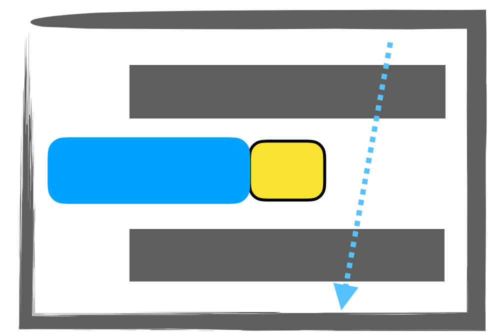
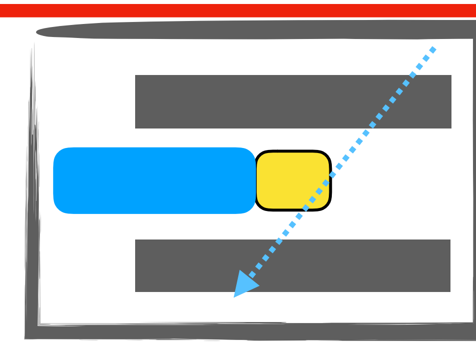
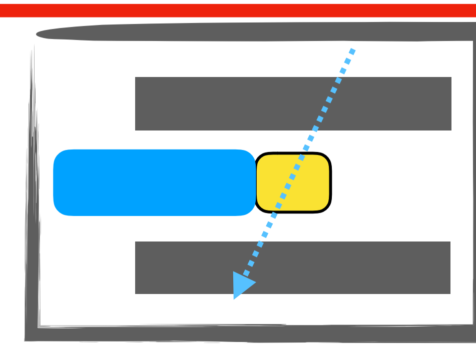


Gaussiana 2 ——> Attraversamento marginale del mezzo da parte di raggi cosmici;



Gaussiana 3 ——> Segnale (attraversamento totale del mezzo);



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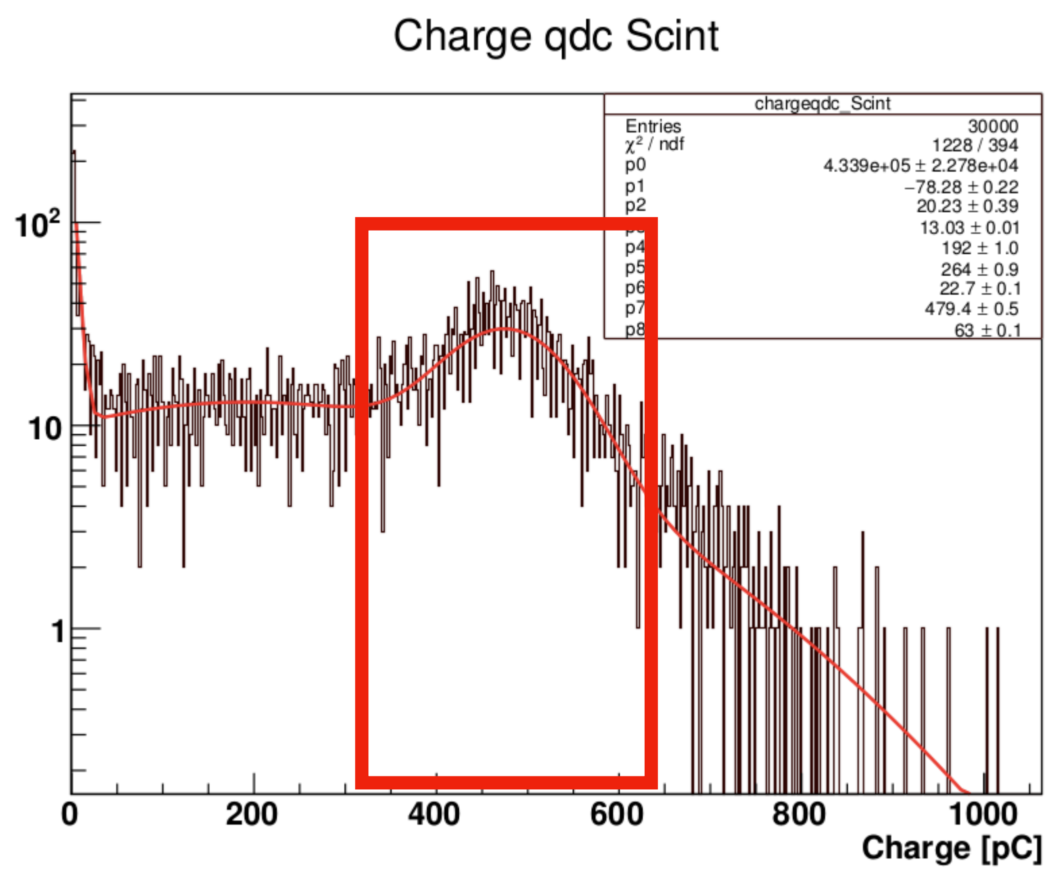

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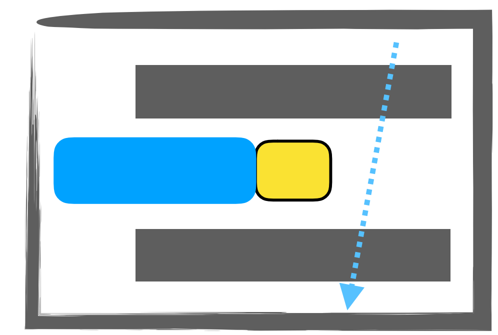

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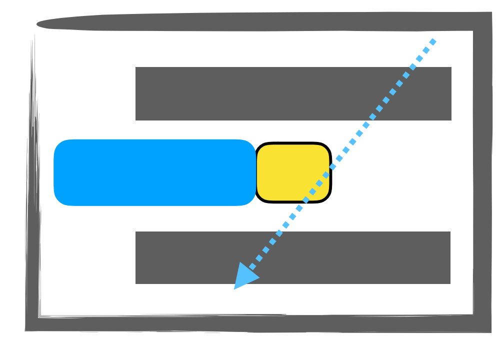

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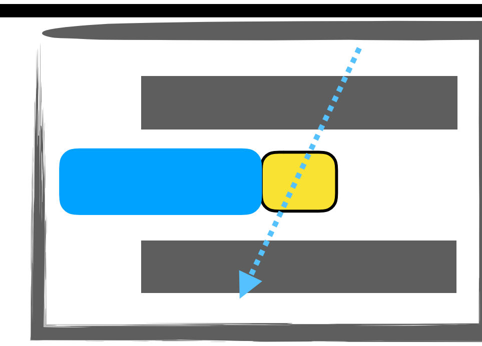

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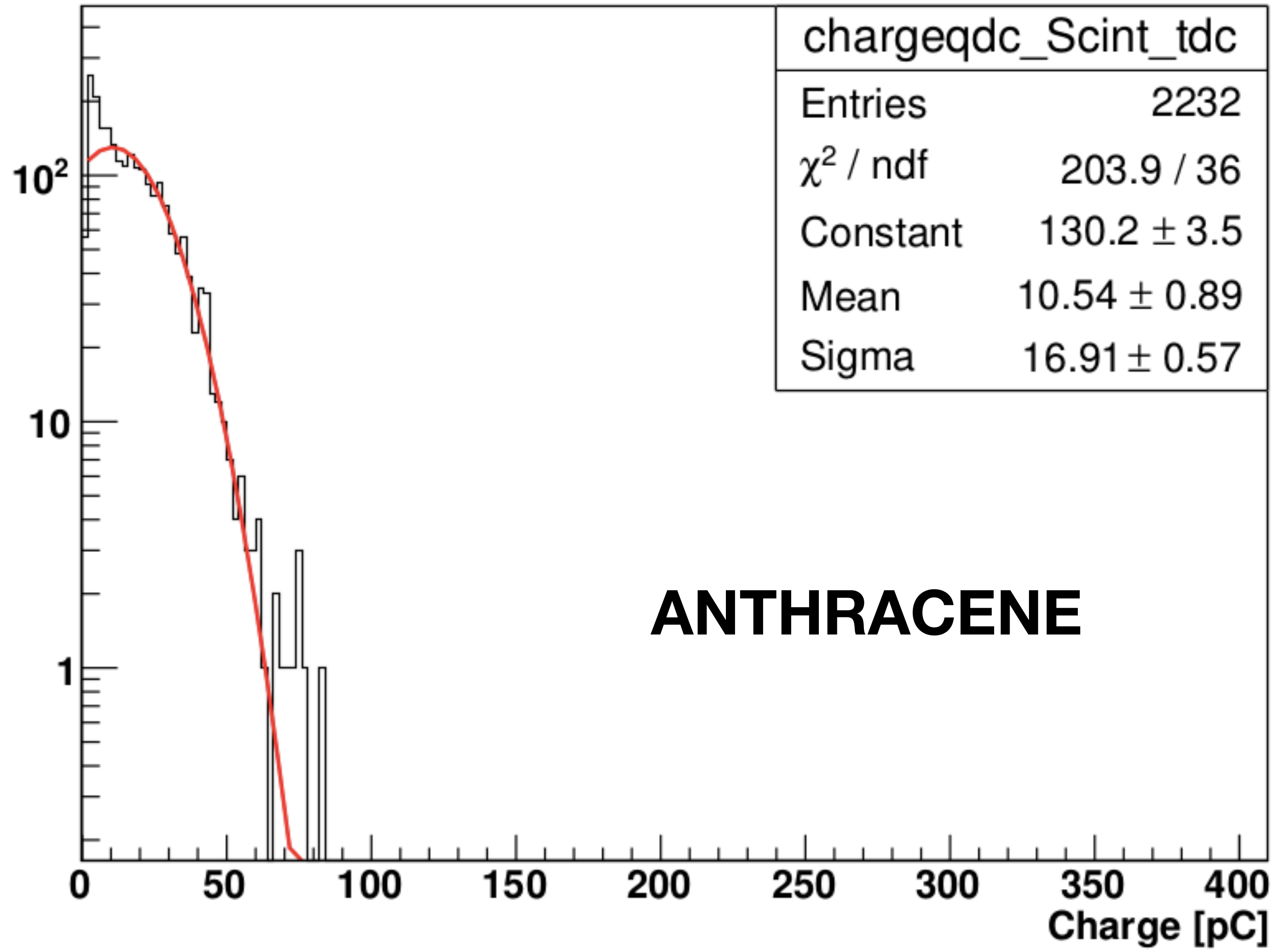
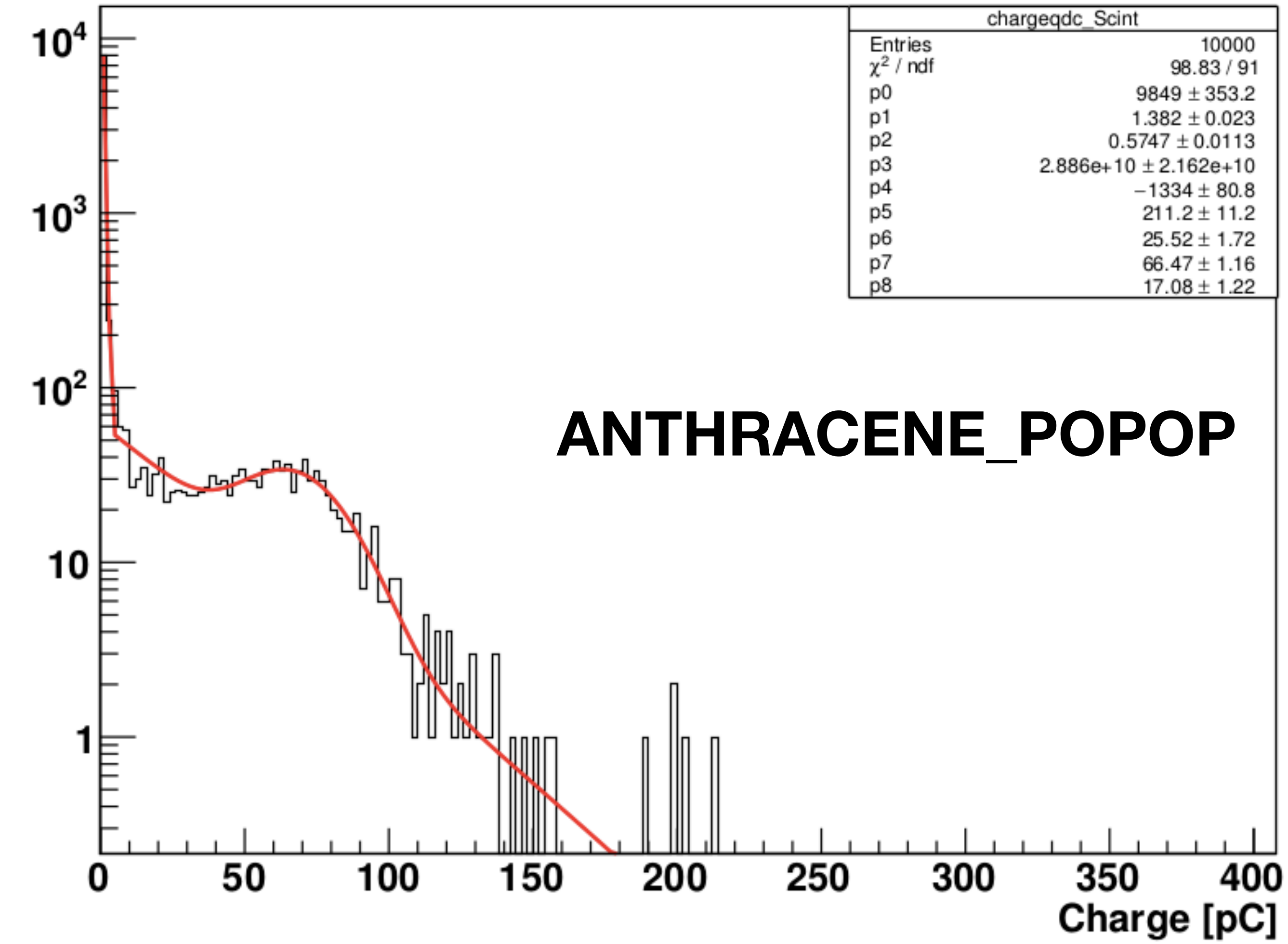
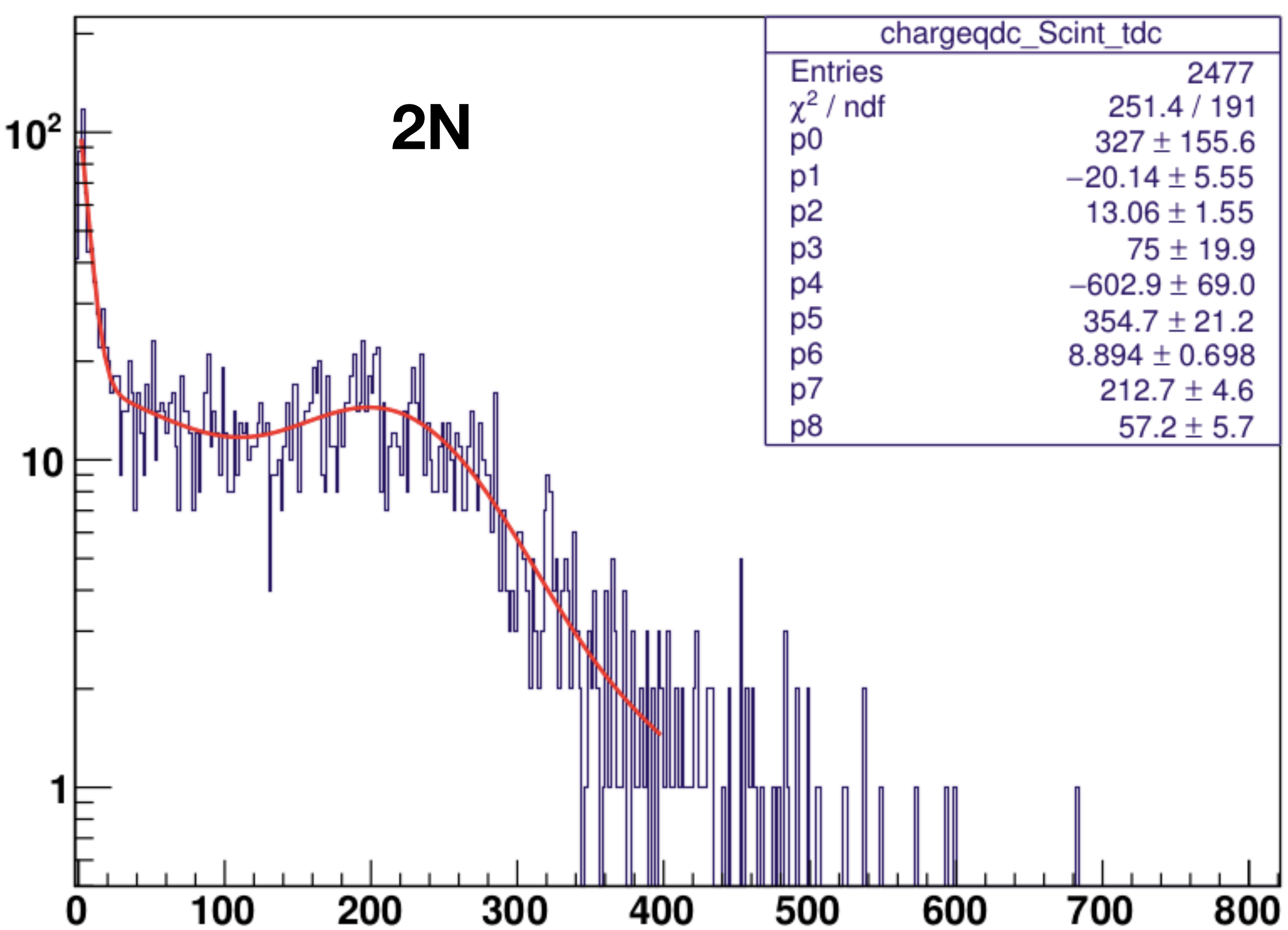
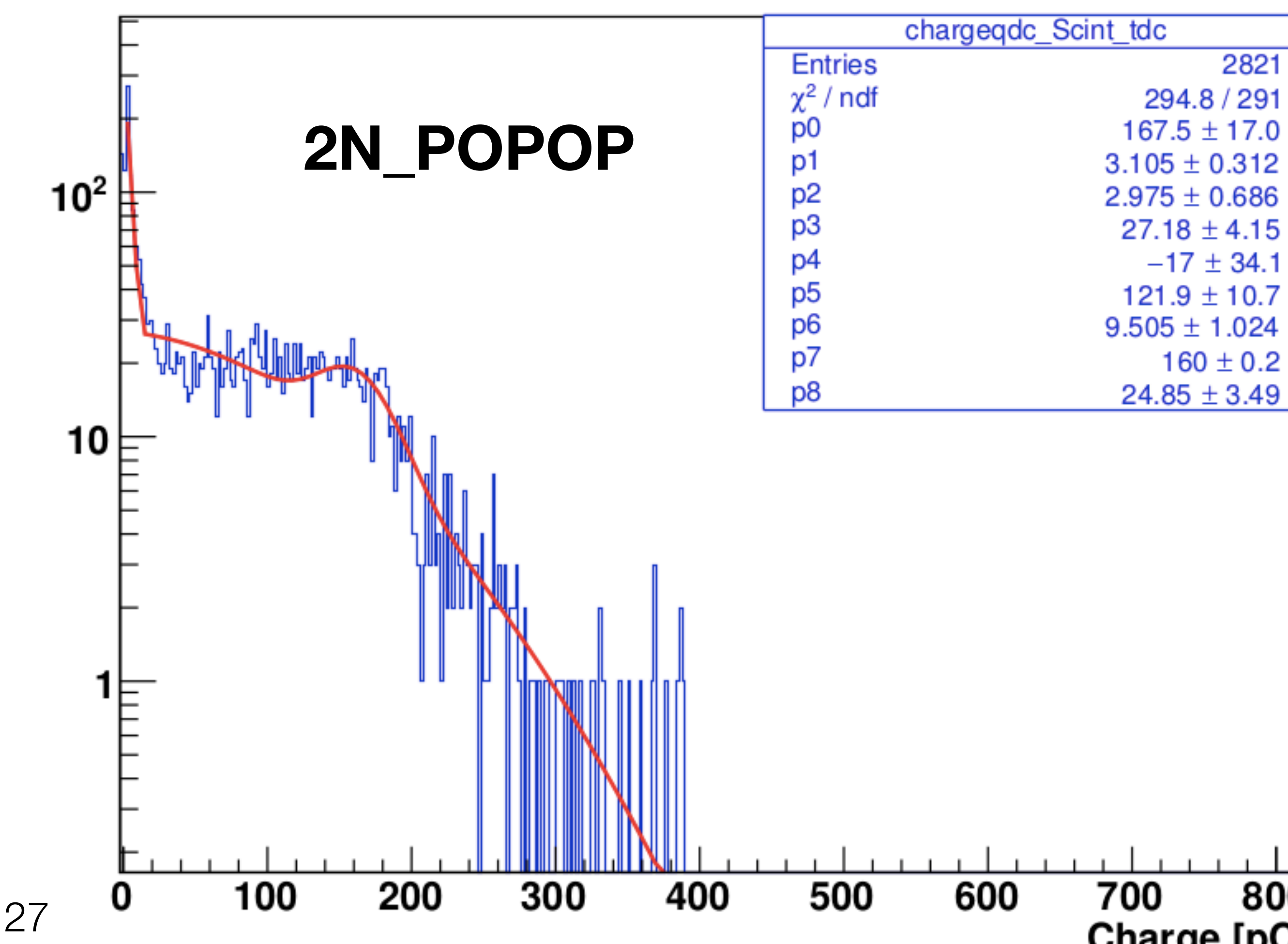
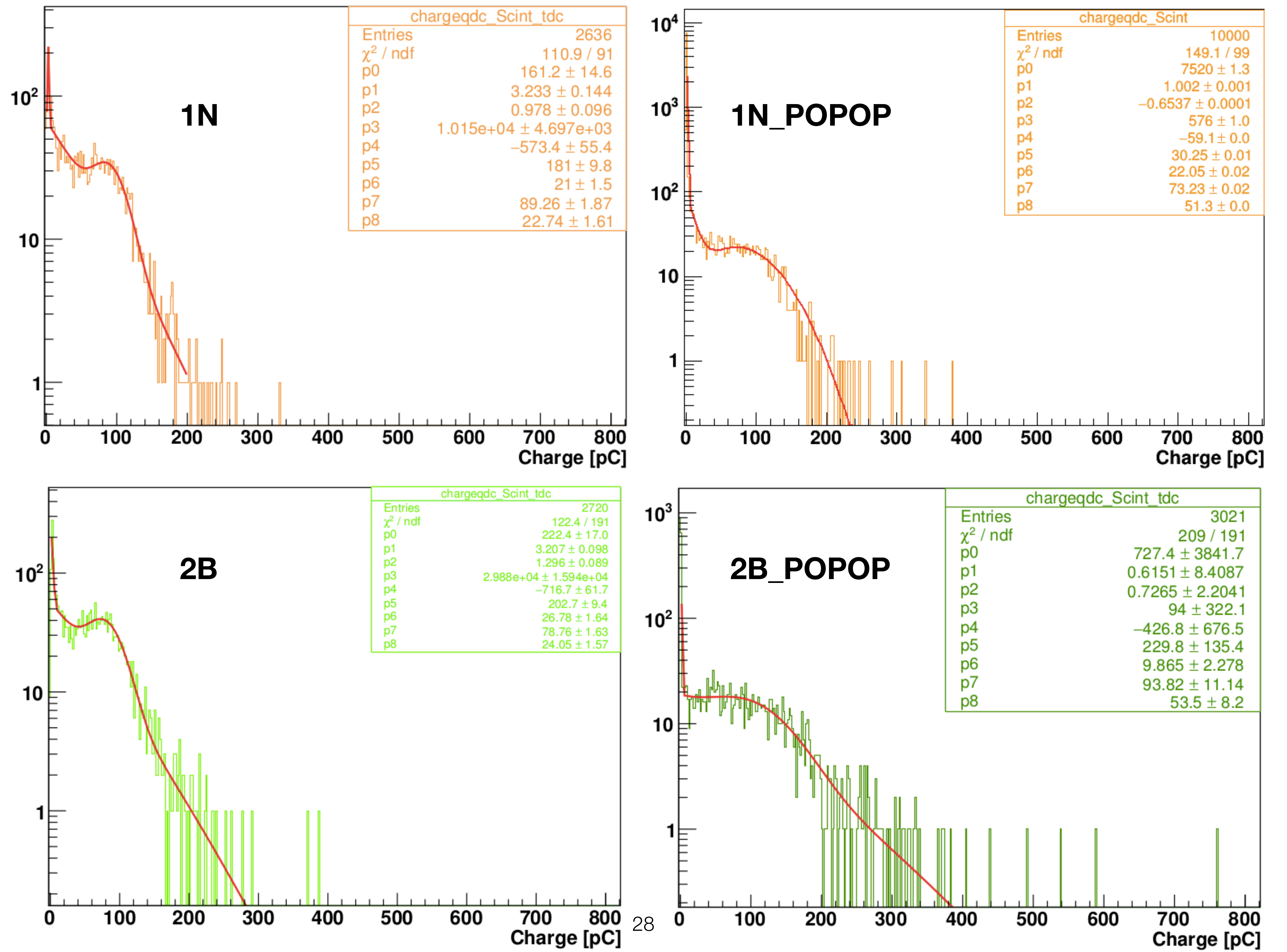


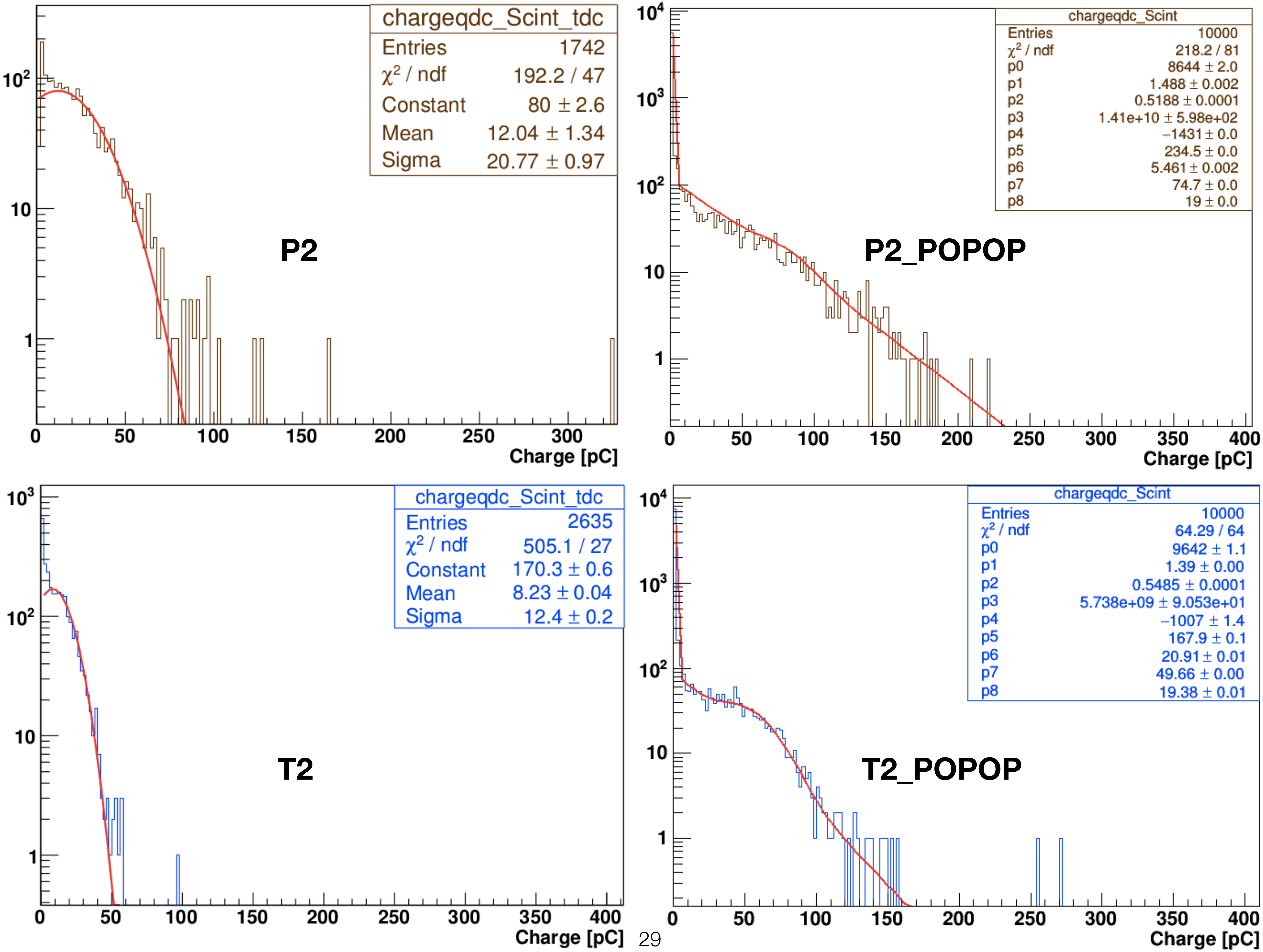




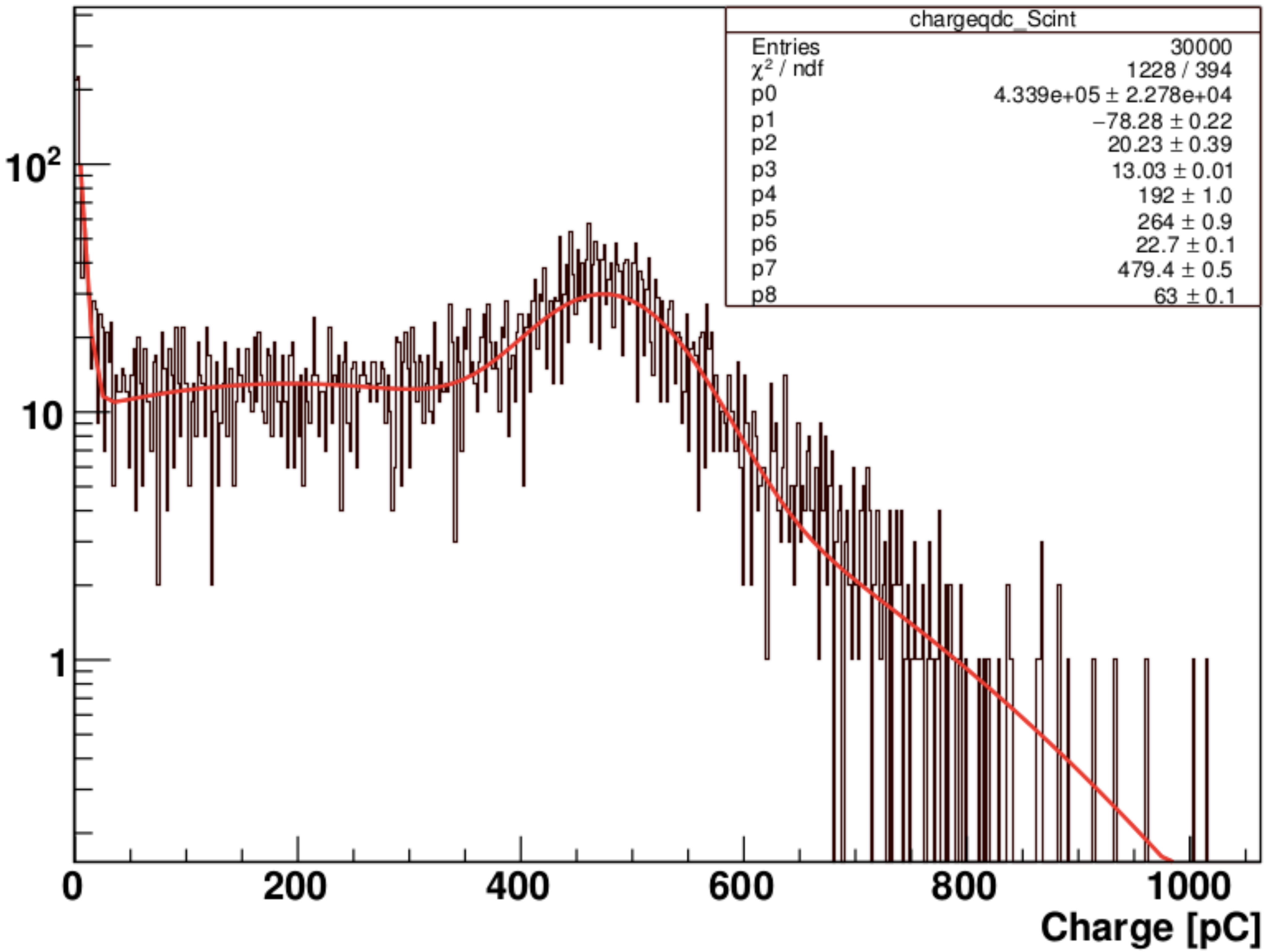


NB: Nella tesi faremo Rebin


1N
chargeqdc_Scint_tdc
Entries 2636
χ² / ndf 110.9 / 91
p0 161.2 ± 14.6
p1 3.233 ± 0.144
p2 0.978 ± 0.096
p3 1.015e+04 ± 4.697e+03
p4 −573.4 ± 55.4
p5 181 ± 9.8
p6 21 ± 1.5
p7 89.26 ± 1.87
p8 22.74 ± 1.61
Charge [pC]
1N_POPOP
chargeqdc_Scint
Entries 10000
χ² / ndf 149.1 / 99
p0 7520 ± 1.3
p1 1.002 ± 0.001
p2 −0.6537 ± 0.0001
p3 576 ± 1.0
p4 −59.1 ± 0.0
p5 30.25 ± 0.01
p6 22.05 ± 0.02
p7 73.23 ± 0.02
p8 51.3 ± 0.0
Charge [pC]
2B
chargeqdc_Scint_tdc
Entries 2720
χ² / ndf 122.4 / 191
p0 222.4 ± 17.0
p1 3.207 ± 0.098
p2 1.296 ± 0.089
p3 2.988e+04 ± 1.594e+04
p4 −716.7 ± 61.7
p5 202.7 ± 9.4
p6 26.78 ± 1.64
p7 78.76 ± 1.63
p8 24.05 ± 1.57
Charge [pC]
2B_POPOP
chargeqdc_Scint_tdc
Entries 3021
χ² / ndf 209 / 191
p0 727.4 ± 3841.7
p1 0.6151 ± 8.4087
p2 0.7265 ± 2.2041
p3 94 ± 322.1
p4 −426.8 ± 676.5
p5 229.8 ± 135.4
p6 9.865 ± 2.278
p7 93.82 ± 11.14
p8 53.5 ± 8.2
Charge [pC]


P2
chargeqdc_Scint_tdc
Entries 1742
χ2 / ndf 192.2 / 47
Constant 80 ± 2.6
Mean 12.04 ± 1.34
Sigma 20.77 ± 0.97
Charge [pC]
P2_POPOP
chargeqdc_Scint
Entries 10000
χ2 / ndf 218.2 / 81
p0 8644 ± 2.0
p1 1.488 ± 0.002
p2 0.5188 ± 0.0001
p3 1.41e+10 ± 5.98e+02
p4 −1431 ± 0.0
p5 234.5 ± 0.0
p6 5.461 ± 0.002
p7 74.7 ± 0.0
p8 19 ± 0.0
Charge [pC]
T2
chargeqdc_Scint_tdc
Entries 2635
χ2 / ndf 505.1 / 27
Constant 170.3 ± 0.6
Mean 8.23 ± 0.04
Sigma 12.4 ± 0.2
Charge [pC]
T2_POPOP
chargeqdc_Scint
Entries 10000
χ2 / ndf 64.29 / 64
p0 9642 ± 1.1
p1 1.39 ± 0.00
p2 0.5485 ± 0.0001
p3 5.738e+09 ± 9.053e+01
p4 −1007 ± 1.4
p5 167.9 ± 0.1
p6 20.91 ± 0.01
p7 49.66 ± 0.00
p8 19.38 ± 0.01
Charge [pC]

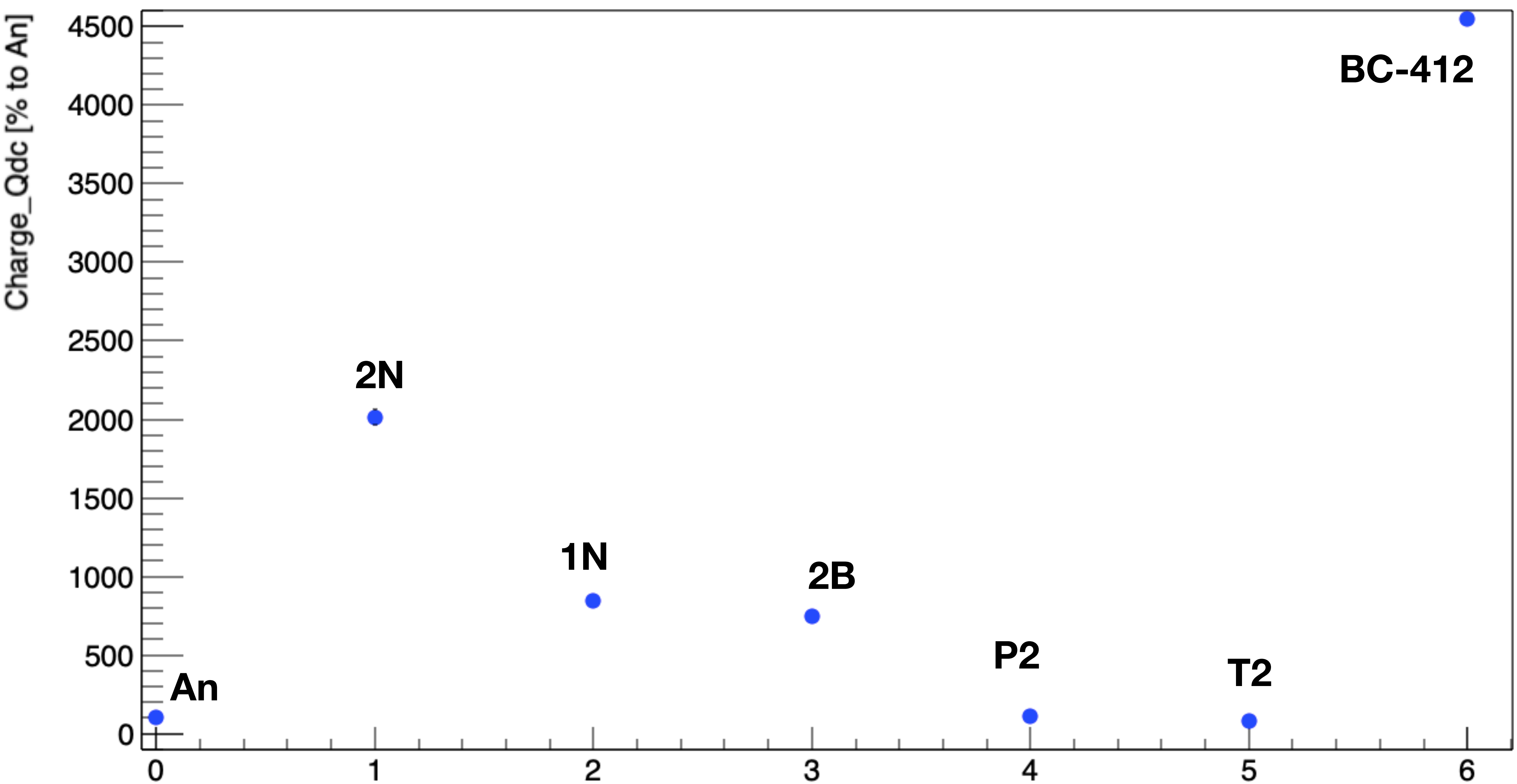
BC 412



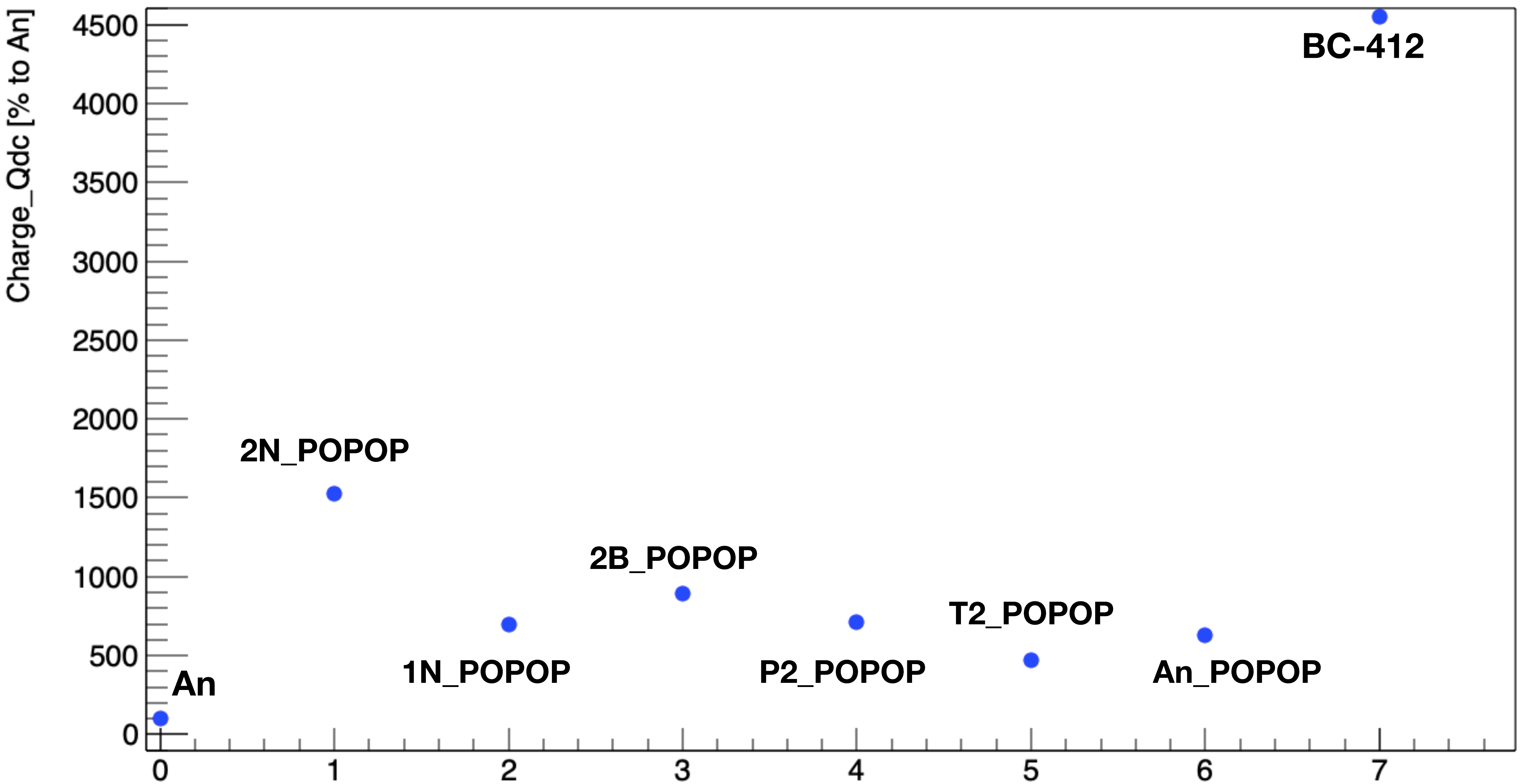
chargeqdc_Scint
Entries 30000
χ^2 / ndf 1228 / 394
p0 4.339e+05 ± 2.278e+04
p1 −78.28 ± 0.22
p2 20.23 ± 0.39
p3 13.03 ± 0.01
p4 192 ± 1.0
p5 264 ± 0.9
p6 22.7 ± 0.1
p7 479.4 ± 0.5
p8 63 ± 0.1
10^2
10
1
0
200
400
600
800
1000
Charge [pC]

Mean Charge (% to An)	Scintillator	Scintillator + POPOP
BC 412	4548.3 ± 21.9	X
An	100	630.6 ± 11.0
2N	2013.4 ± 48.8	1523.8 ± 28.9
1N	846.9 ± 17.7	694.9 ± 12.9
2B	747.2 ± 15.5	890.1 ± 15.7
P2	114.2 ± 12.7	708.7 ± 16.5
T2	78.1 ± 0.4	471.2 ± 10.6

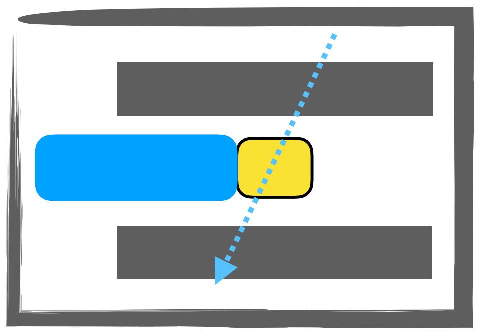
Plot Charge [% to An]
Scintillators



Plot Charge [% to An]
Scintillators + POPOP



Time Resolution



Calculation

Le risoluzioni temporali sono ricavate attraverso le seguenti relazioni.

1) Dal grafico STS1-STS2 (per semplicità ΔTime), si ricava la $\sigma=\sigma_{\Delta time}$,da cui: ($\sigma_{STS1}=\sigma_{STS2}$)

$$\sigma_{\Delta time} = \sqrt{\sigma_{STS1}{}^2 + \sigma_{STS2}{}^2} = \sqrt{2}\sigma_{STS2}\,.$$

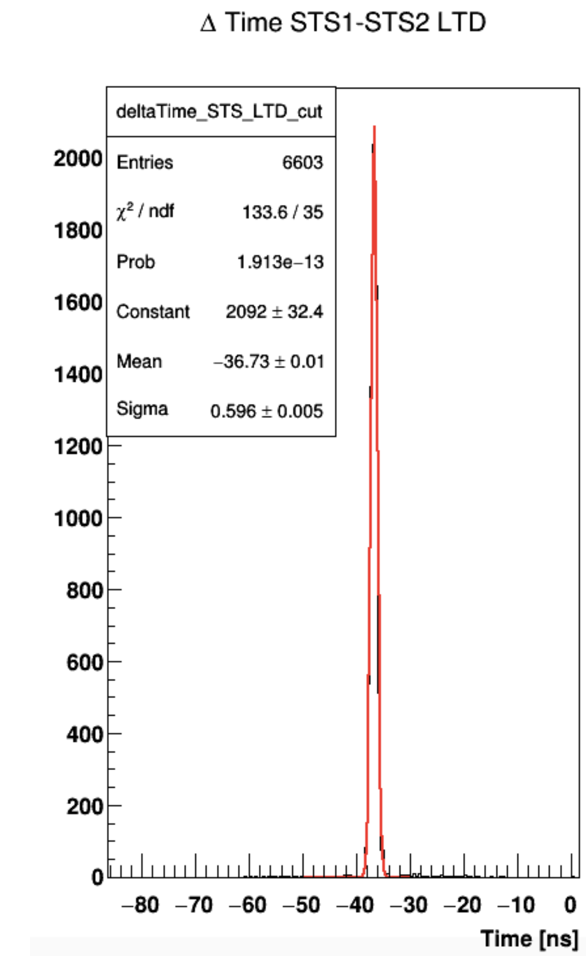
2) Dal grafico Scint-STS2, si ricava la $\sigma=\sigma_{Scint\text{-}STS2}$, da cui:

$$\sigma_{Scint-STS2} = \sqrt{\sigma_{Scint}{}^2 + \sigma_{STS2}{}^2}\,.$$

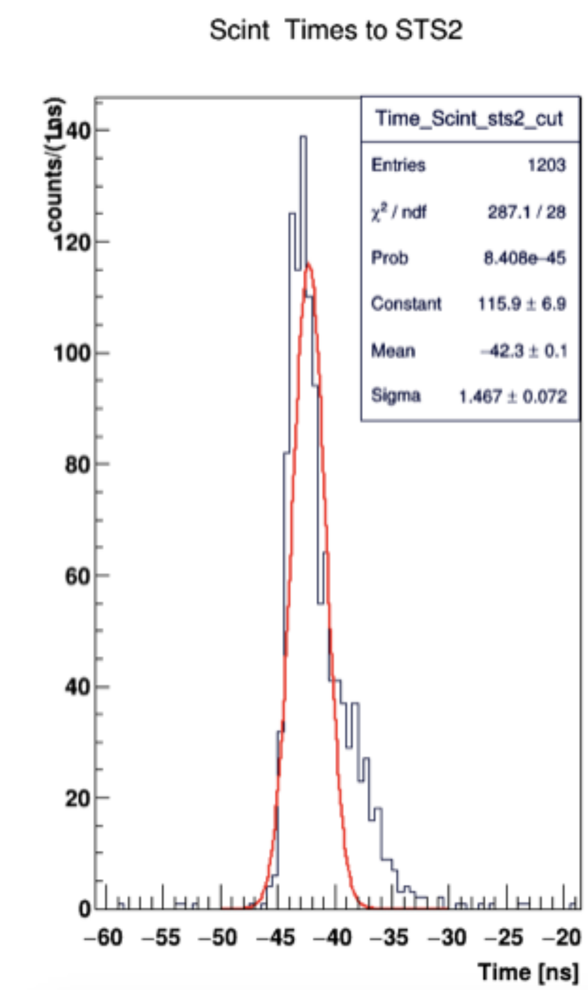
3) Si ottiene quindi il valore della risoluzione temporale dello scintillatore confrontando i due risultati ottenuti graficamente, per cui:

$$\sigma_{Scint} = \sqrt{\sigma_{Scint-STS2}{}^2 - \sigma_{STS2}{}^2}\,.$$

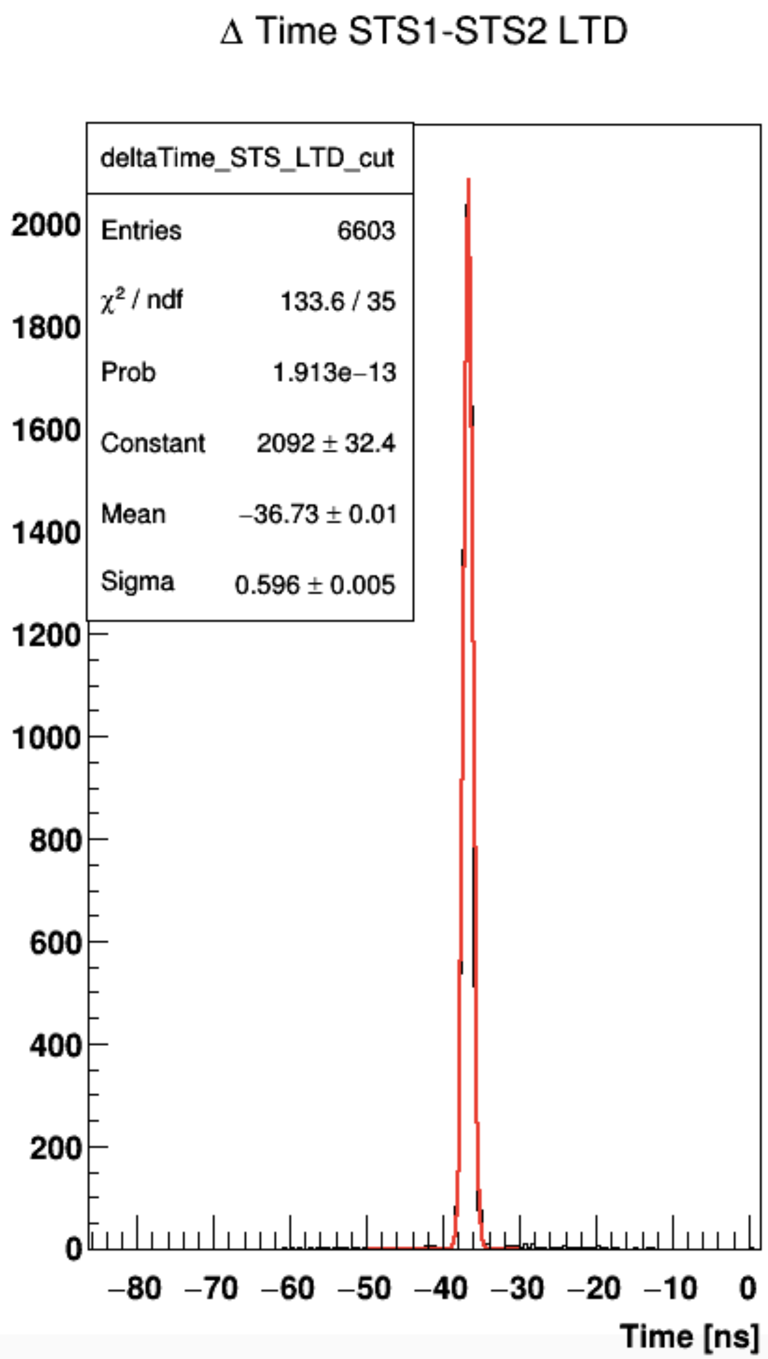
Discriminatore

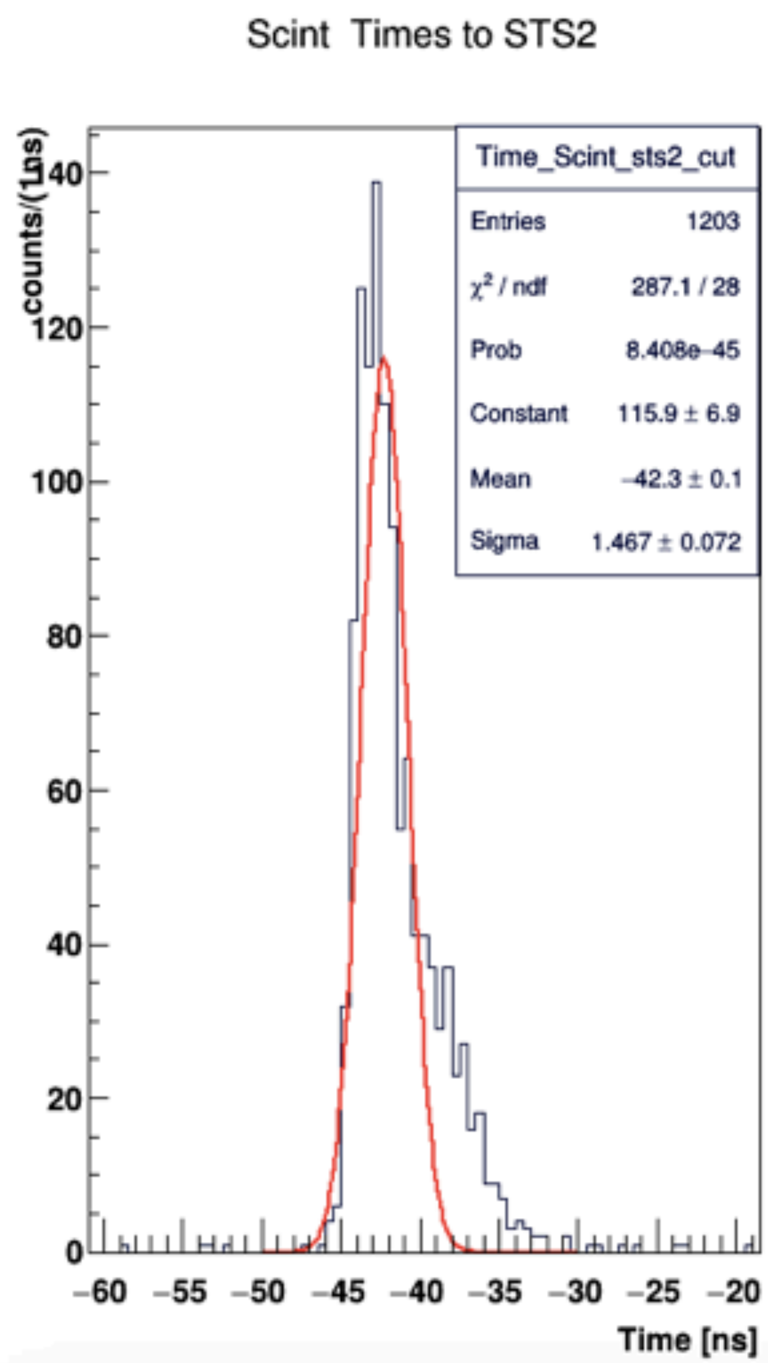


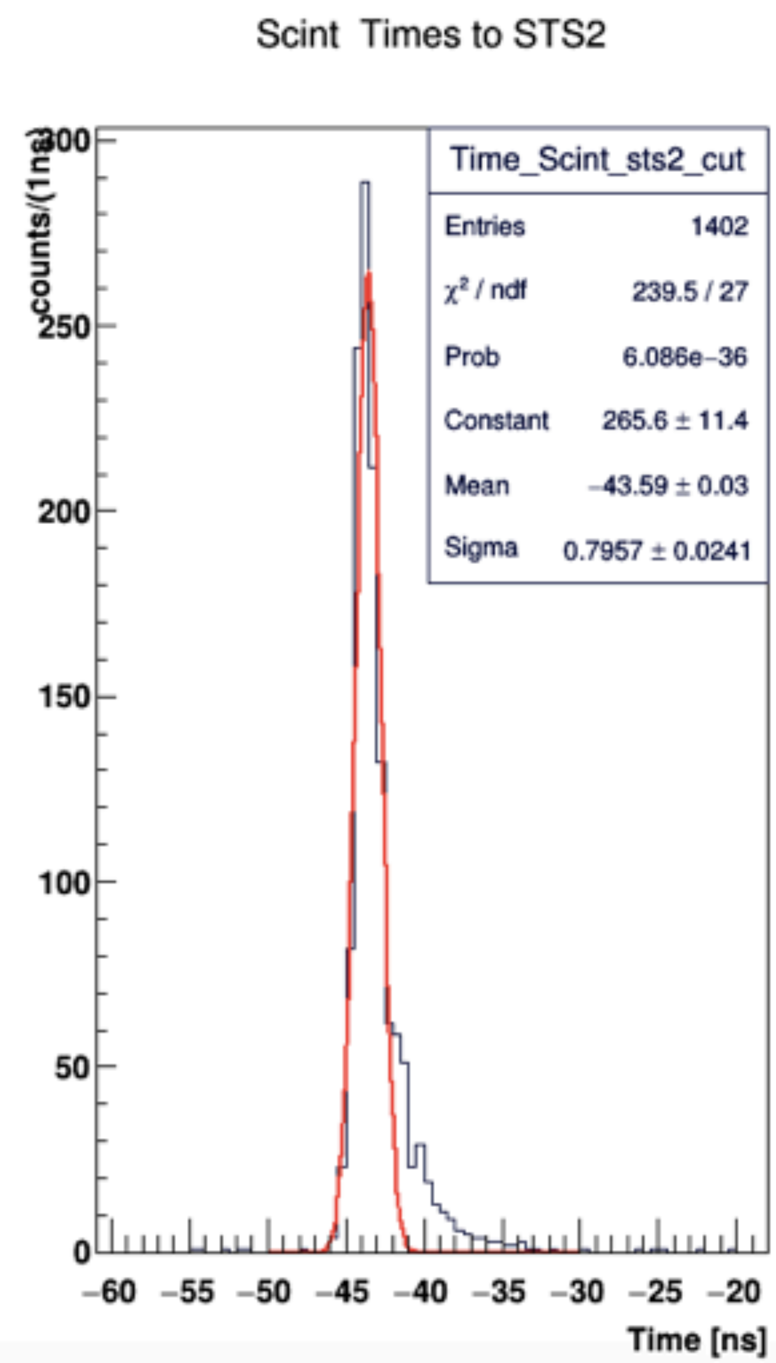
Constant Fraction



	AN(1%)_Solido	AN(1%)_Solido_POPOP



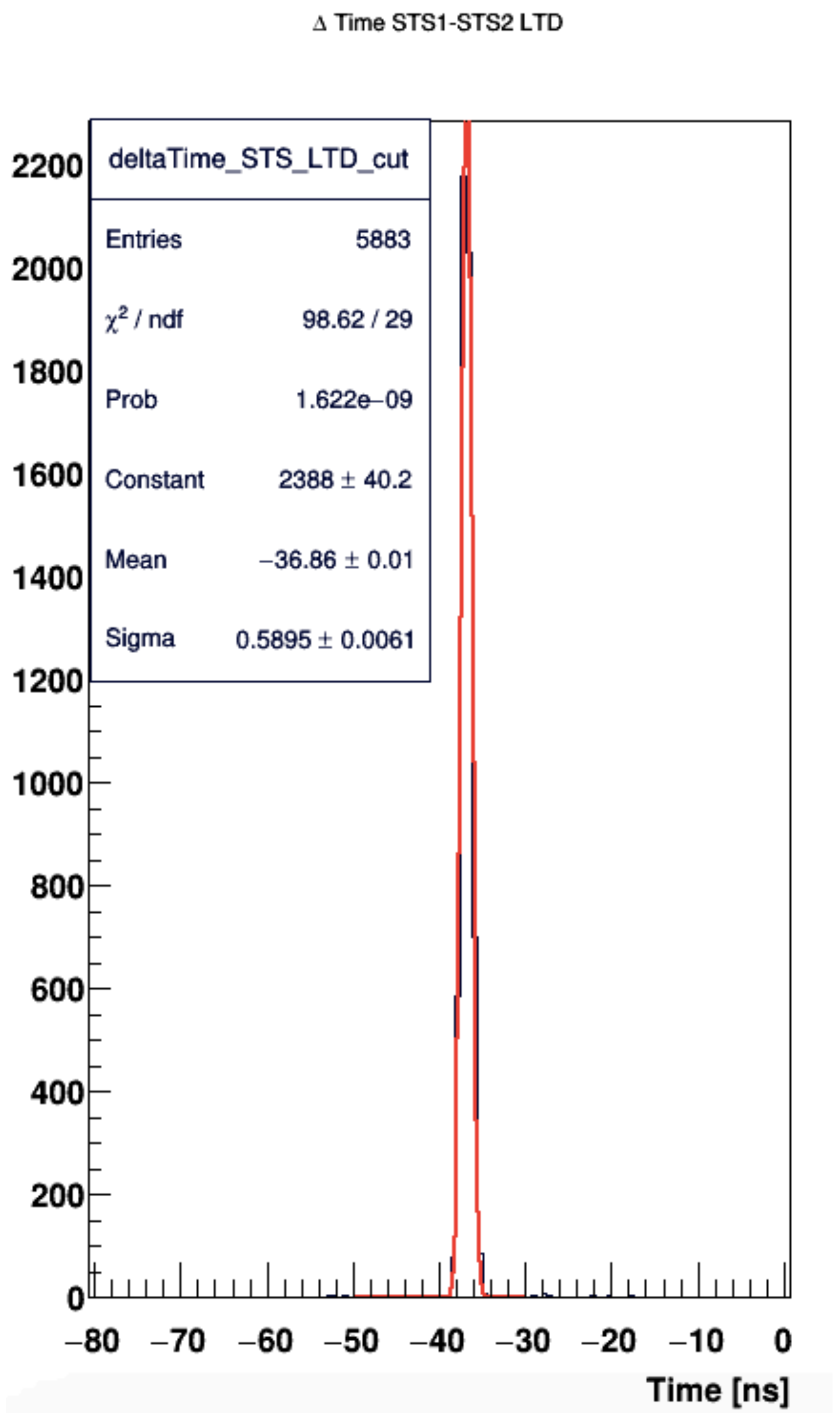


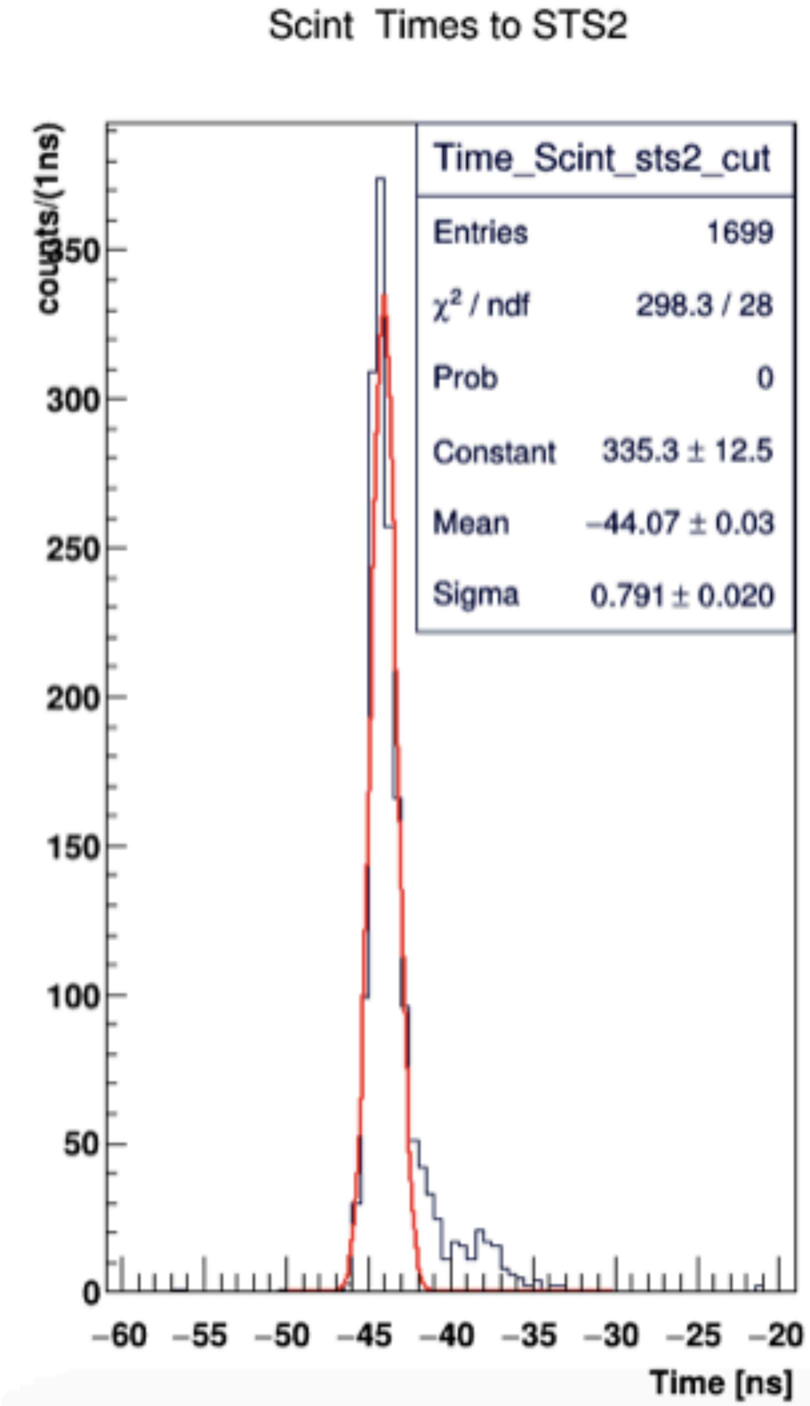


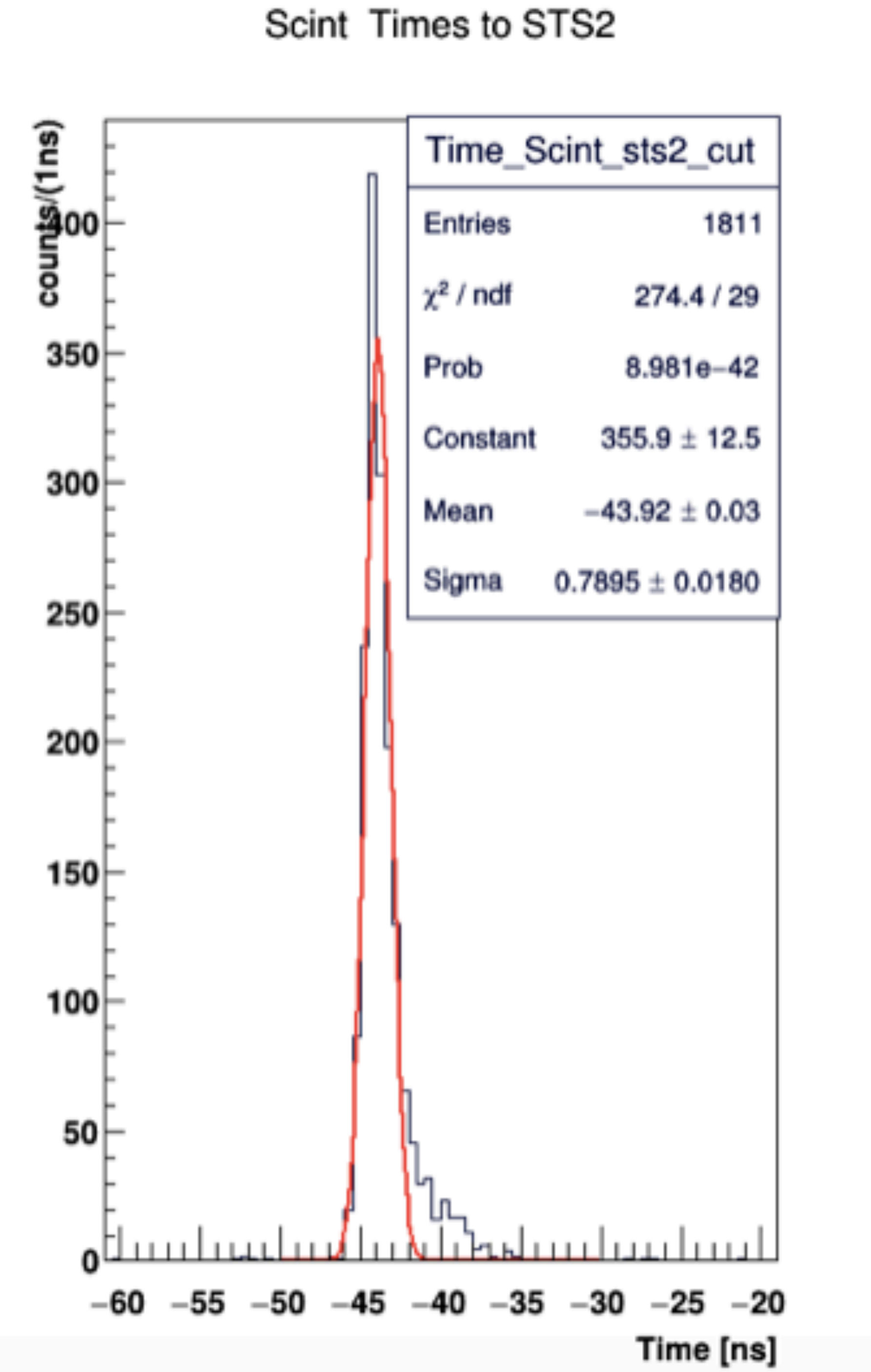
σ_sts2=0.421 ± 0.004 ns **σ=1.467 ± 0.072 ns** **σ=0.796 ± 0.024 ns**

2N(1%)_Solido

2N(1%)_Solido_POPOP





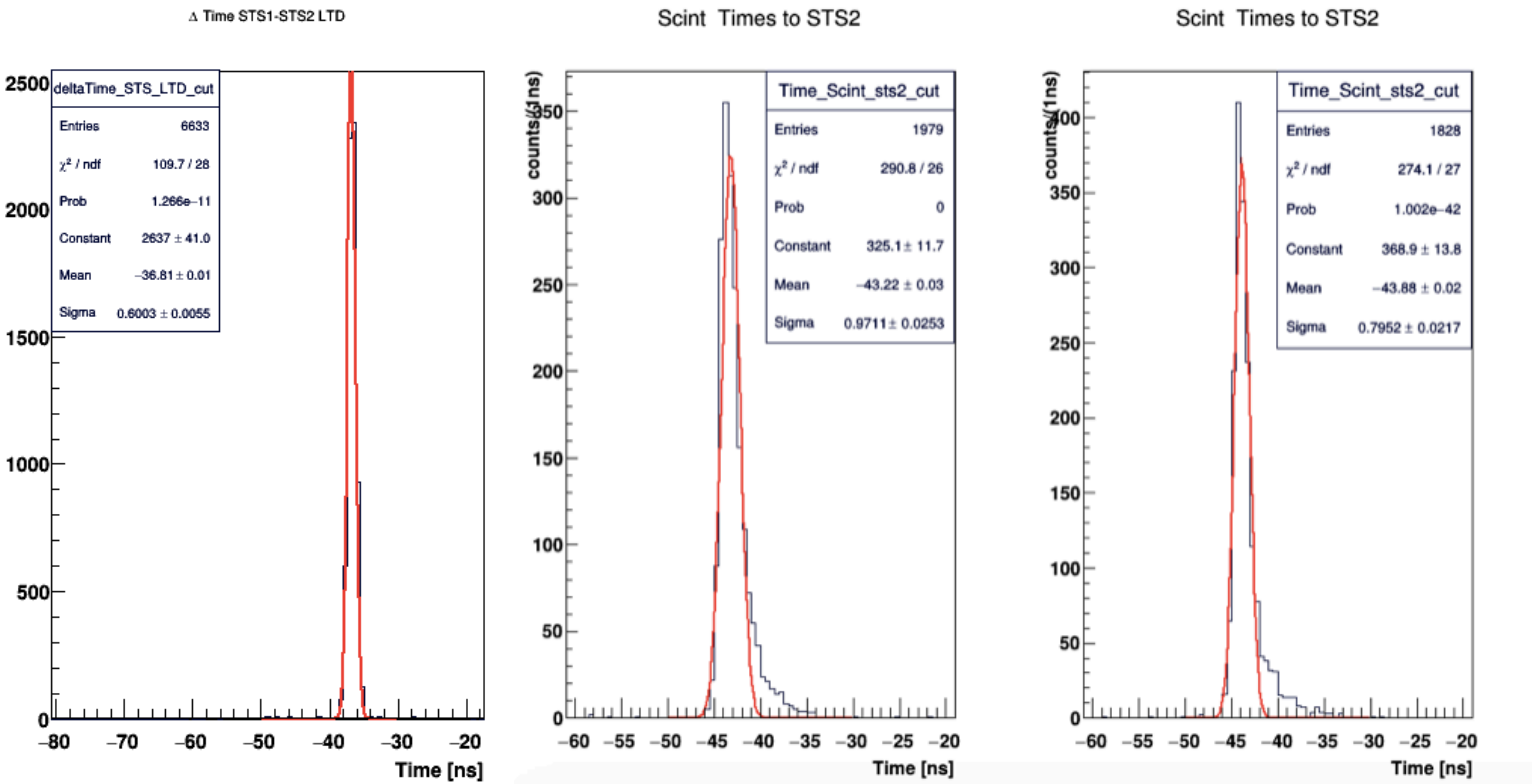


σ_sts2=0.417 ± 0.004 ns

σ=0.791 ± 0.020 ns

σ=0.790 ± 0.018 ns

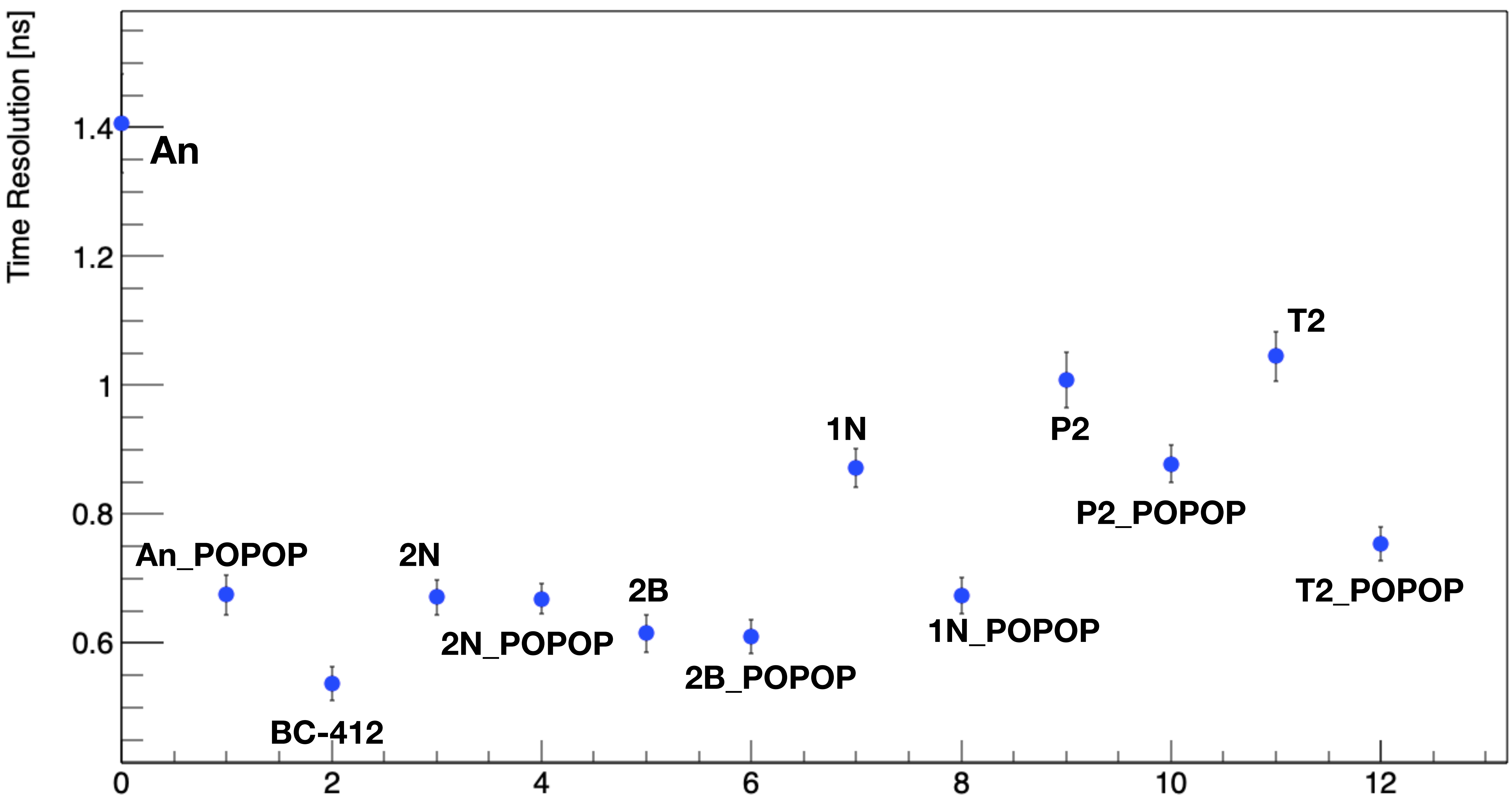
2B(1%)_Solido **2B(1%)_Solido_POPOP**



σ_sts2=0.426 ± 0.004 ns **σ=0.971 ± 0.025 ns** **σ=0.795 ± 0.022 ns**

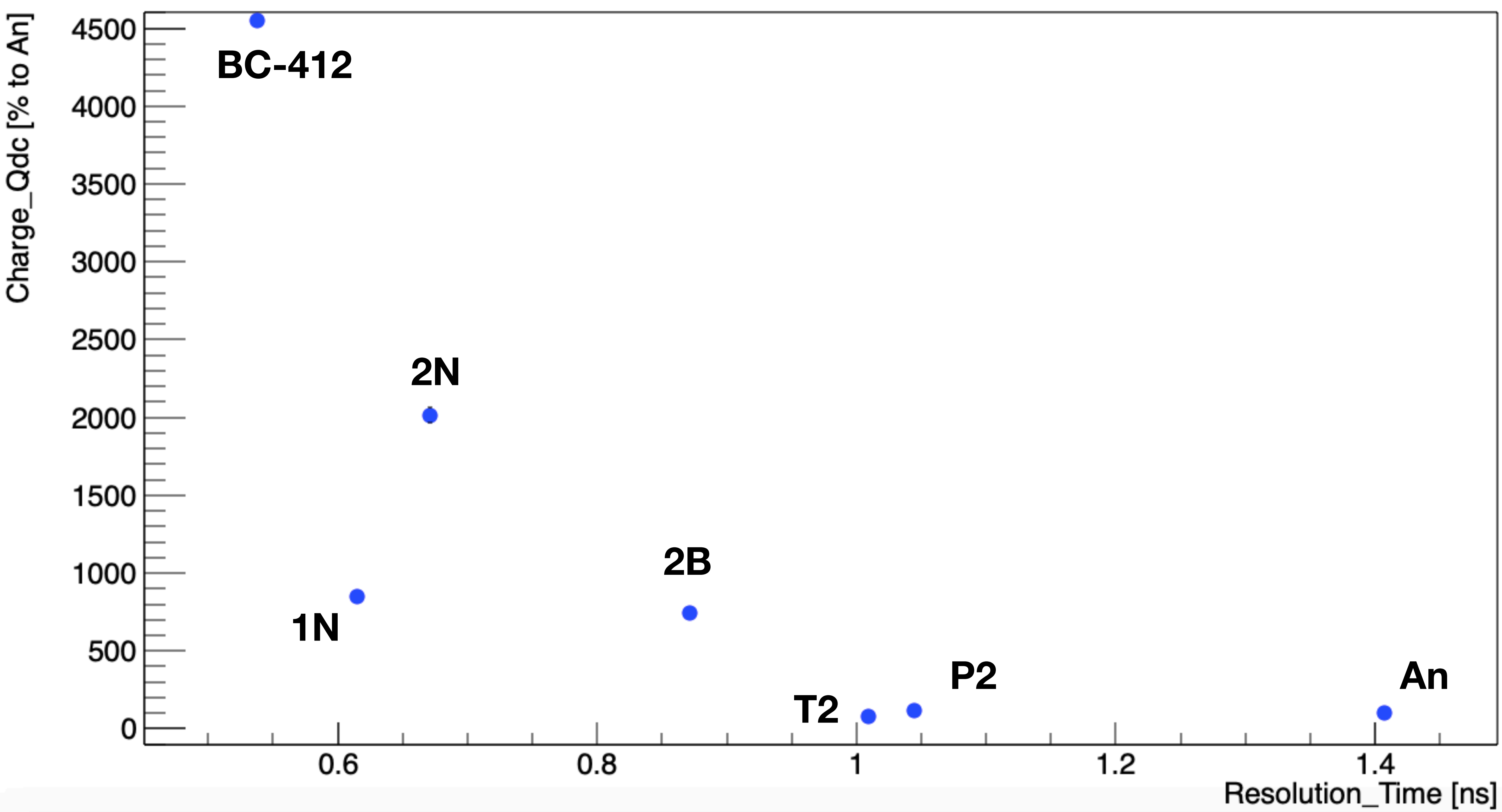
σ_res (ns)	Scintillator	Scintillator + POPOP
An	1.407 ± 0.077	0.675 ± 0.031
BC-412	0.538 ± 0.026	X
2N	0.671 ± 0.027	0.669 ± 0.024
1N	0.615 ± 0.029	0.610 ± 0.026
2B	0.871 ± 0.030	0.673 ± 0.028
T2	1.009 ± 0.043	0.878 ± 0.029
P2	1.045 ± 0.038	0.754 ± 0.027

Plot Time Resolution [ns]
Scintillators + POPOP

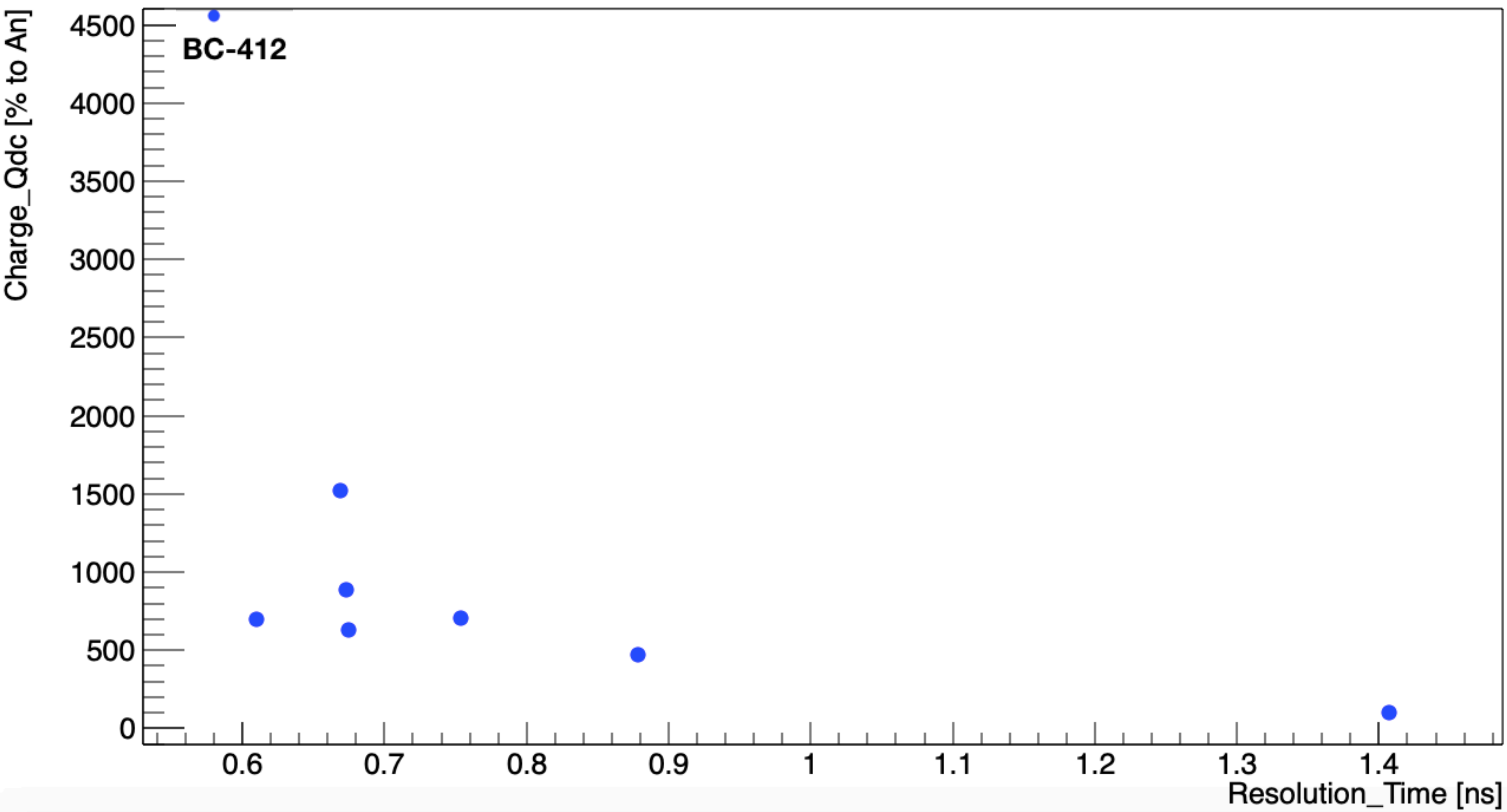


Plot Charge vs Time Resolution

Plot Charge [% to An] vs Time Resolution [ns] Scintillators



Plot Charge [% to An] vs Time Resolution [ns] Scintillators + POPOP

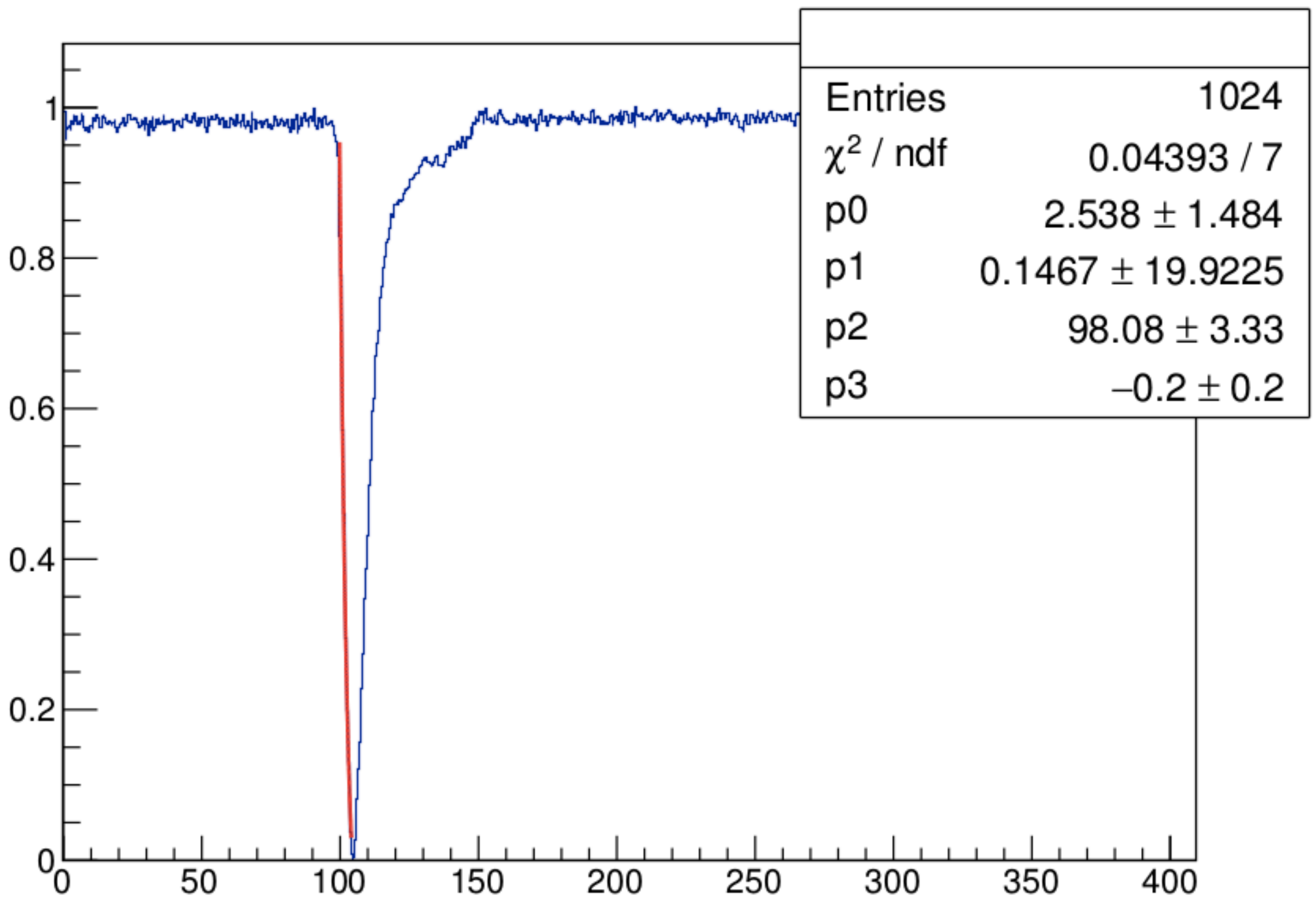


Rise Time

Fit del tempo di salita sulla singola onda

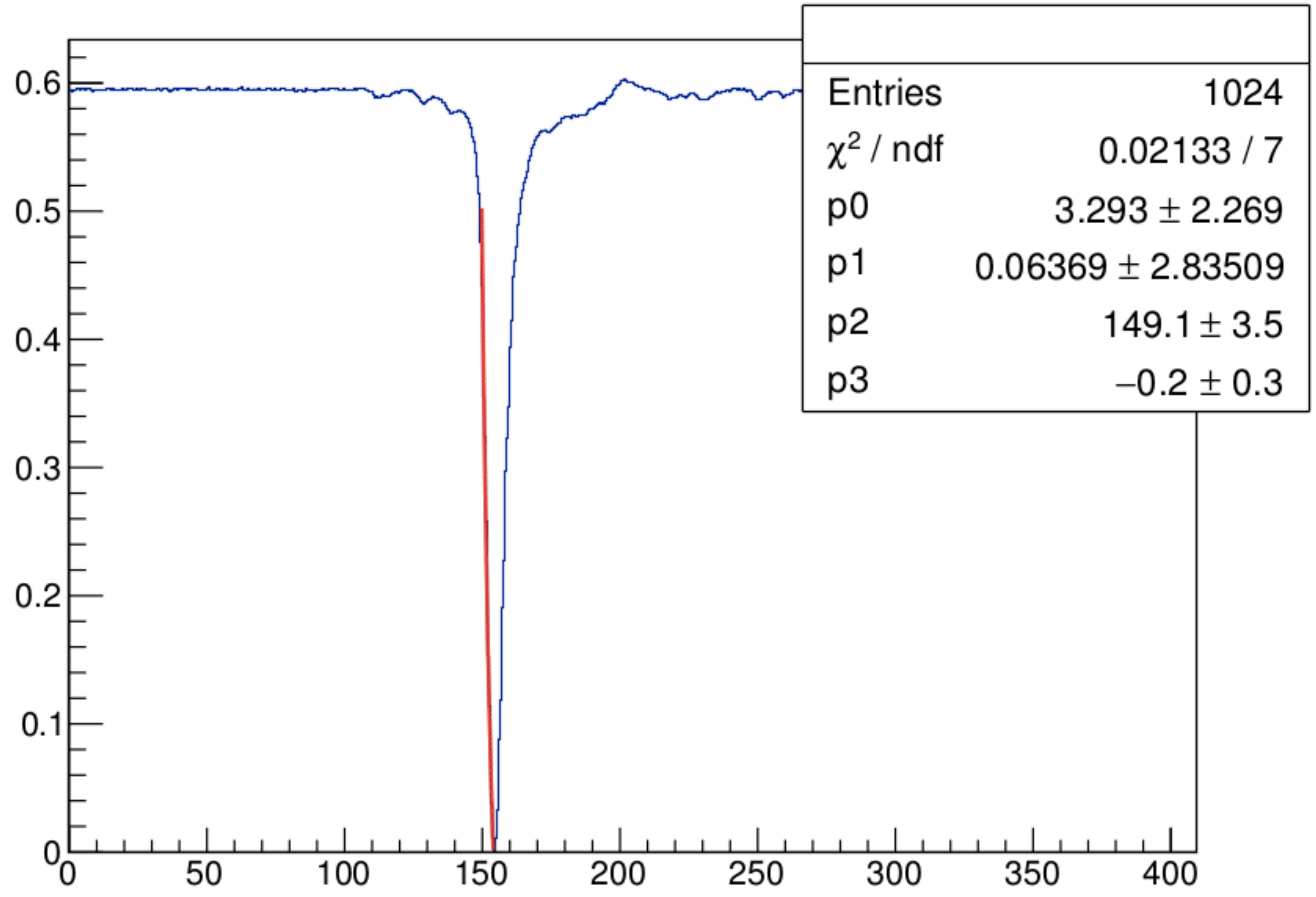
Il segnale in funzione del tempo nella regione della salita dell'onda

$$V(t) = V_0 + \frac{At}{{\tau_s}^2} e^{-\frac{t - t_0}{\tau_s}}$$

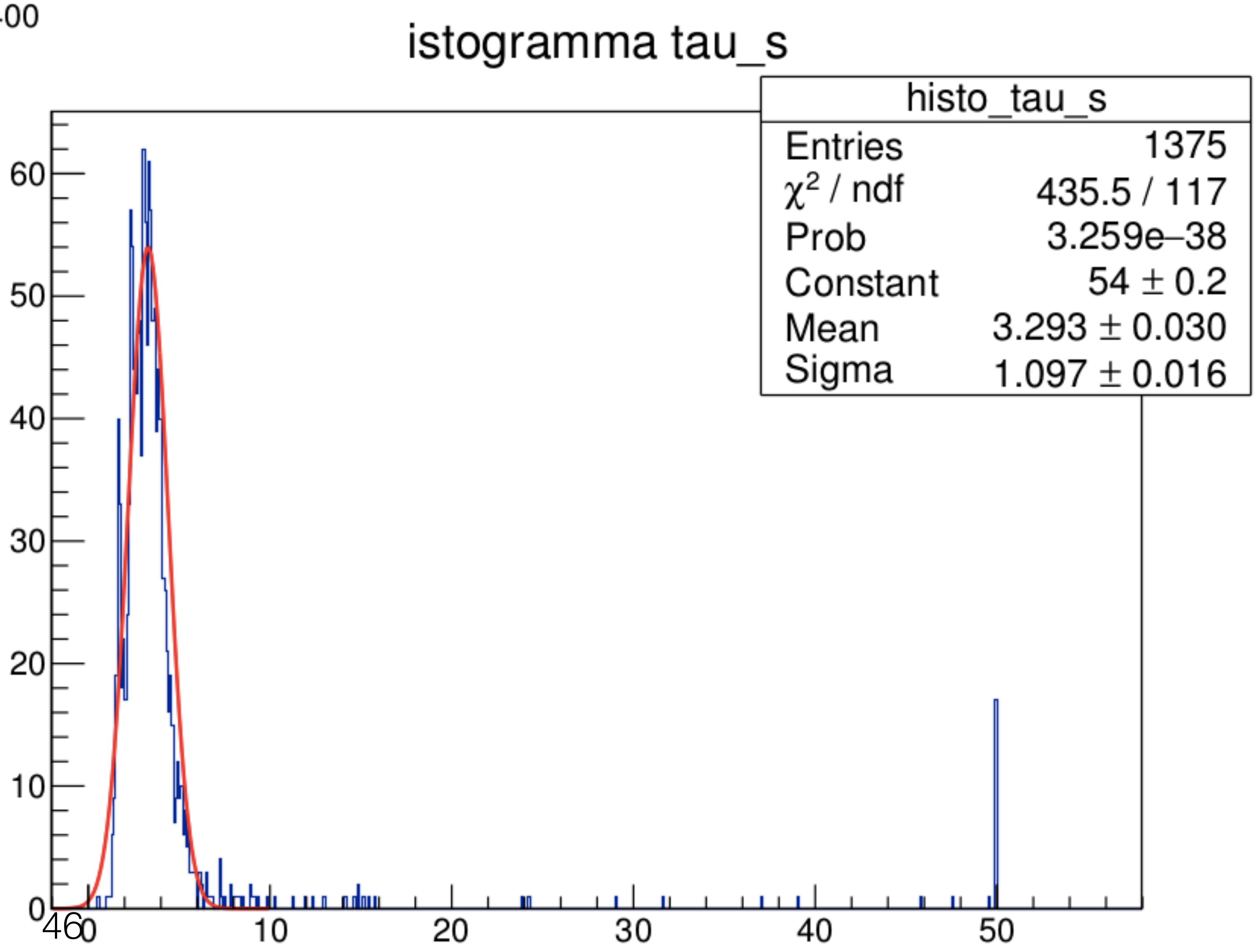


1) $\mathbf{p_0} = \tau_s$ = Rise time;
2) $\mathbf{p_1}$ = A = Constant;
3) $\mathbf{p_2}$ = t_0 = Initial time;
4) $\mathbf{p_3}$ = V_0 = Offset.

PMT

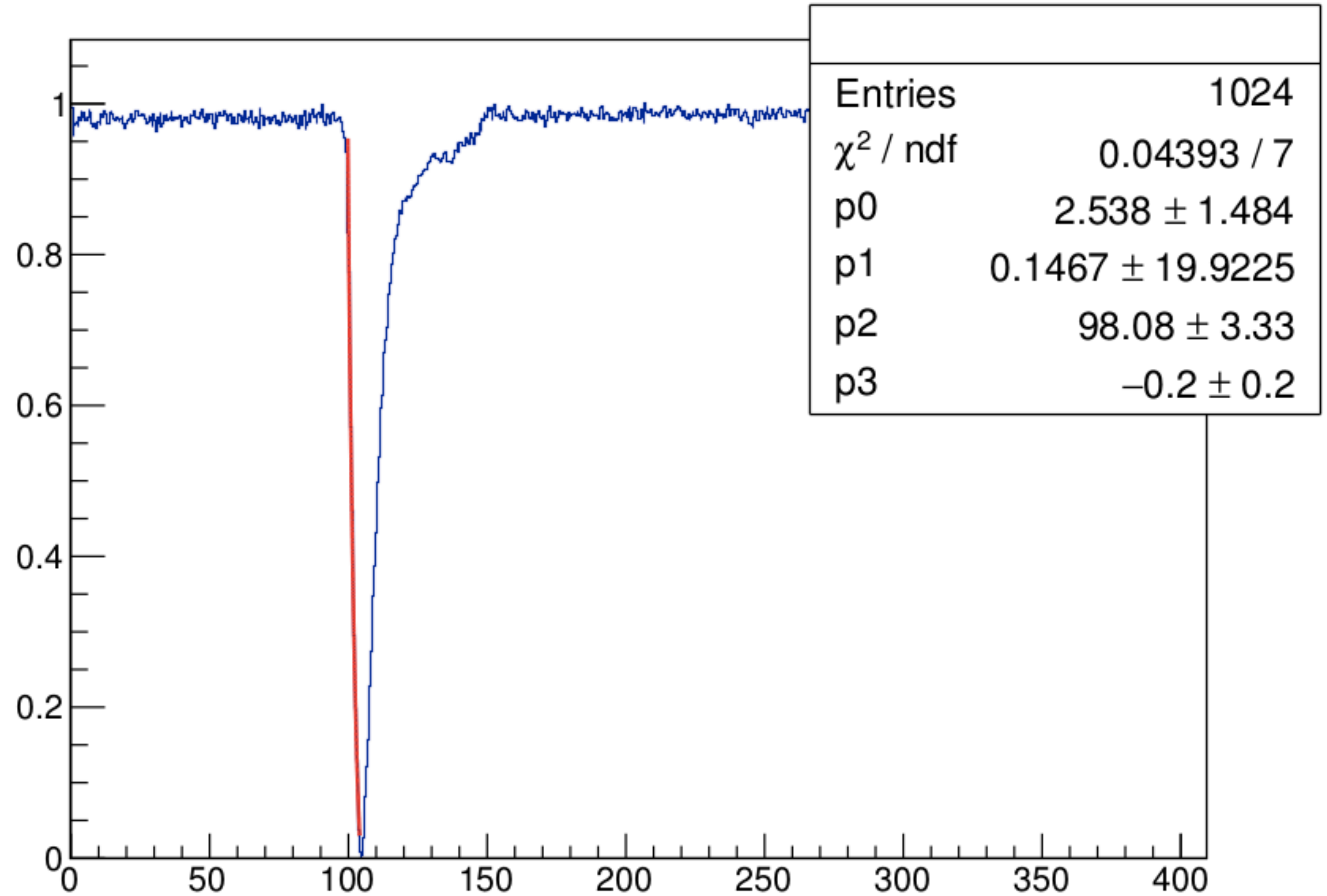


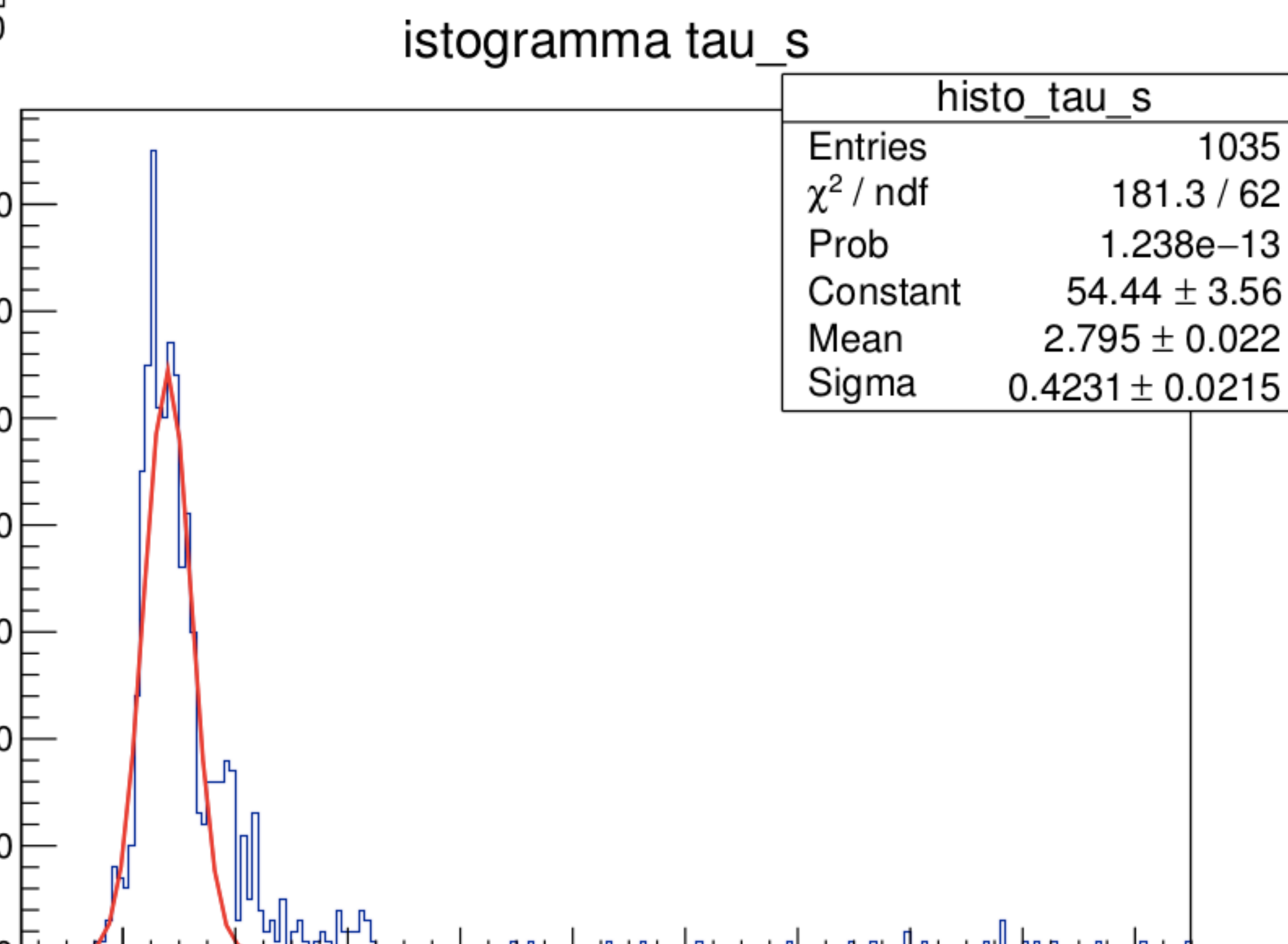
Entries 1024
χ² / ndf 0.02133 / 7
p0 3.293 ± 2.269
p1 0.06369 ± 2.83509
p2 149.1 ± 3.5
p3 −0.2 ± 0.3



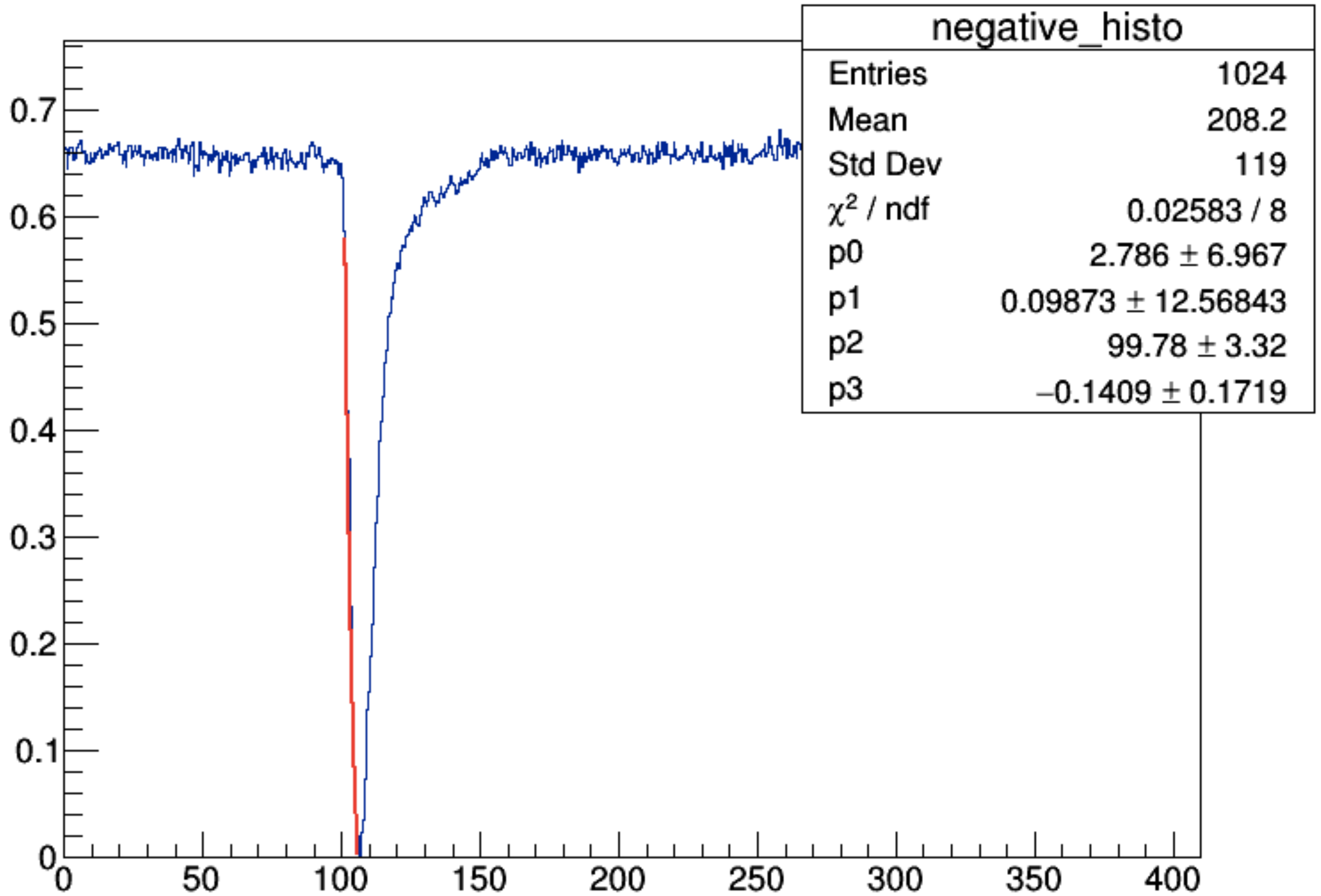
istogramma tau_s
histo_tau_s
Entries 1375
χ² / ndf 435.5 / 117
Prob 3.259e−38
Constant 54 ± 0.2
Mean 3.293 ± 0.030
Sigma 1.097 ± 0.016

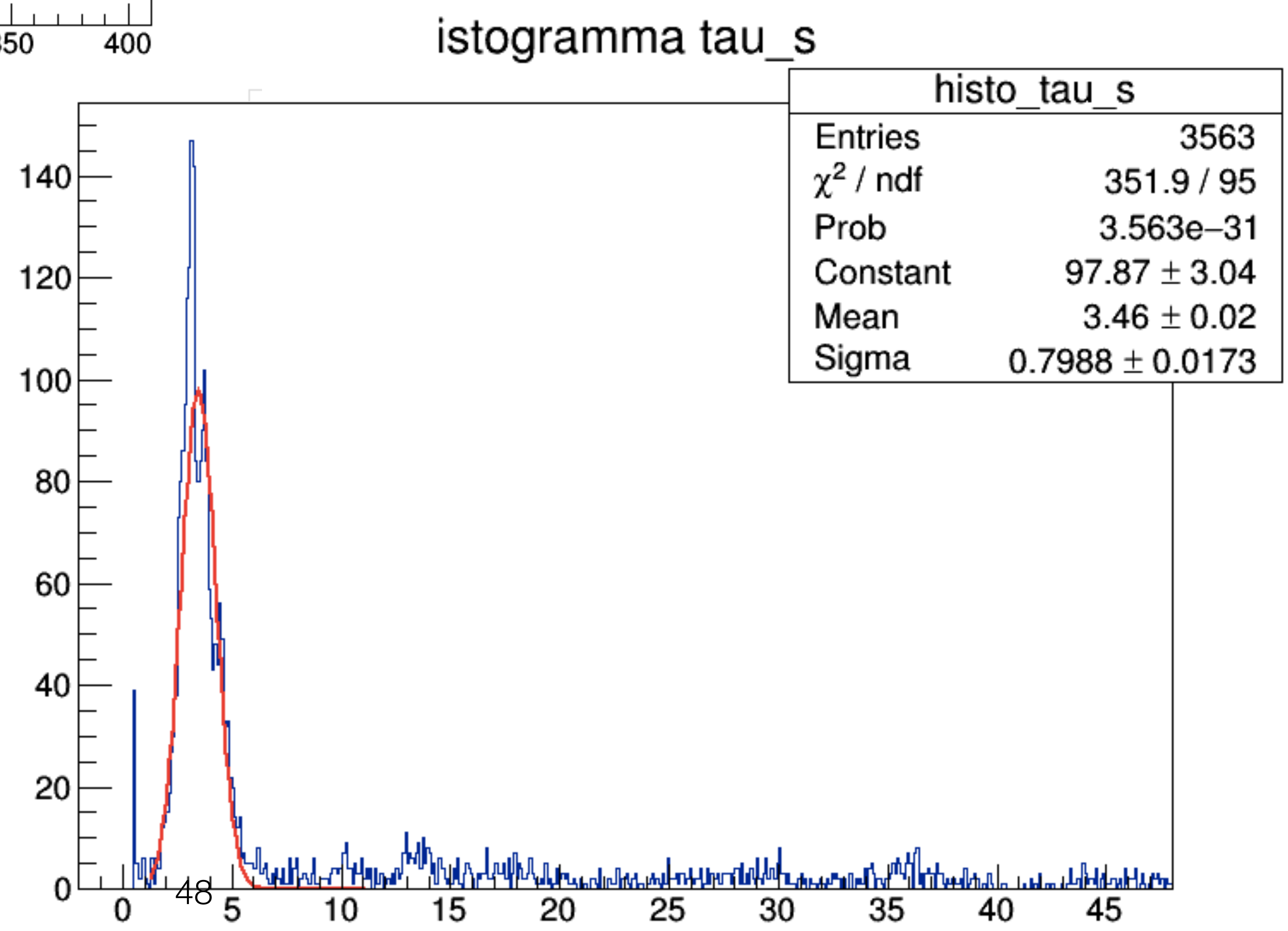
2N


Entries 1024
χ² / ndf 0.04393 / 7
p0 2.538 ± 1.484
p1 0.1467 ± 19.9225
p2 98.08 ± 3.33
p3 −0.2 ± 0.2

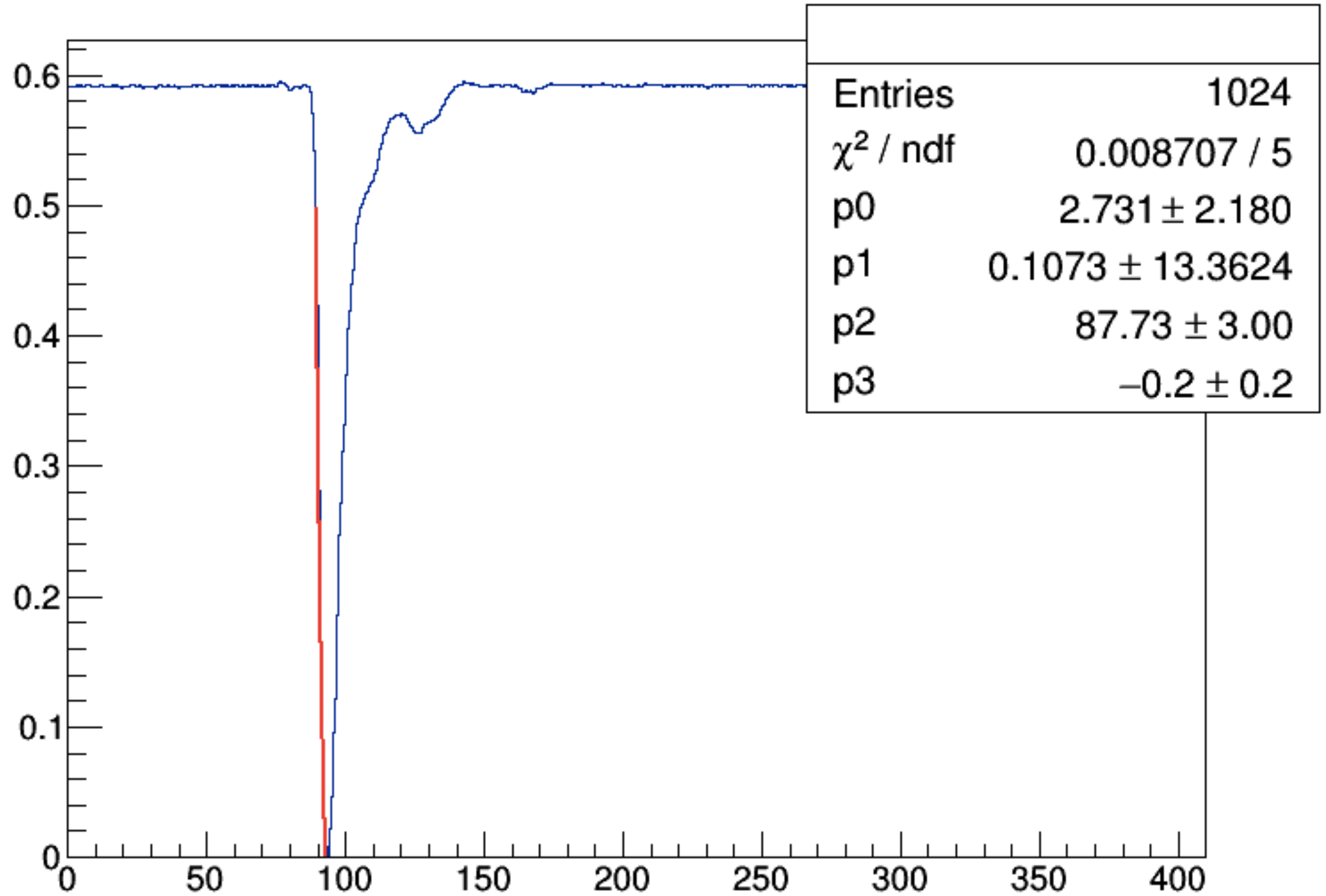

istogramma tau_s
histo_tau_s
Entries 1035
χ² / ndf 181.3 / 62
Prob 1.238e−13
Constant 54.44 ± 3.56
Mean 2.795 ± 0.022
Sigma 0.4231 ± 0.0215

2N_POPOP

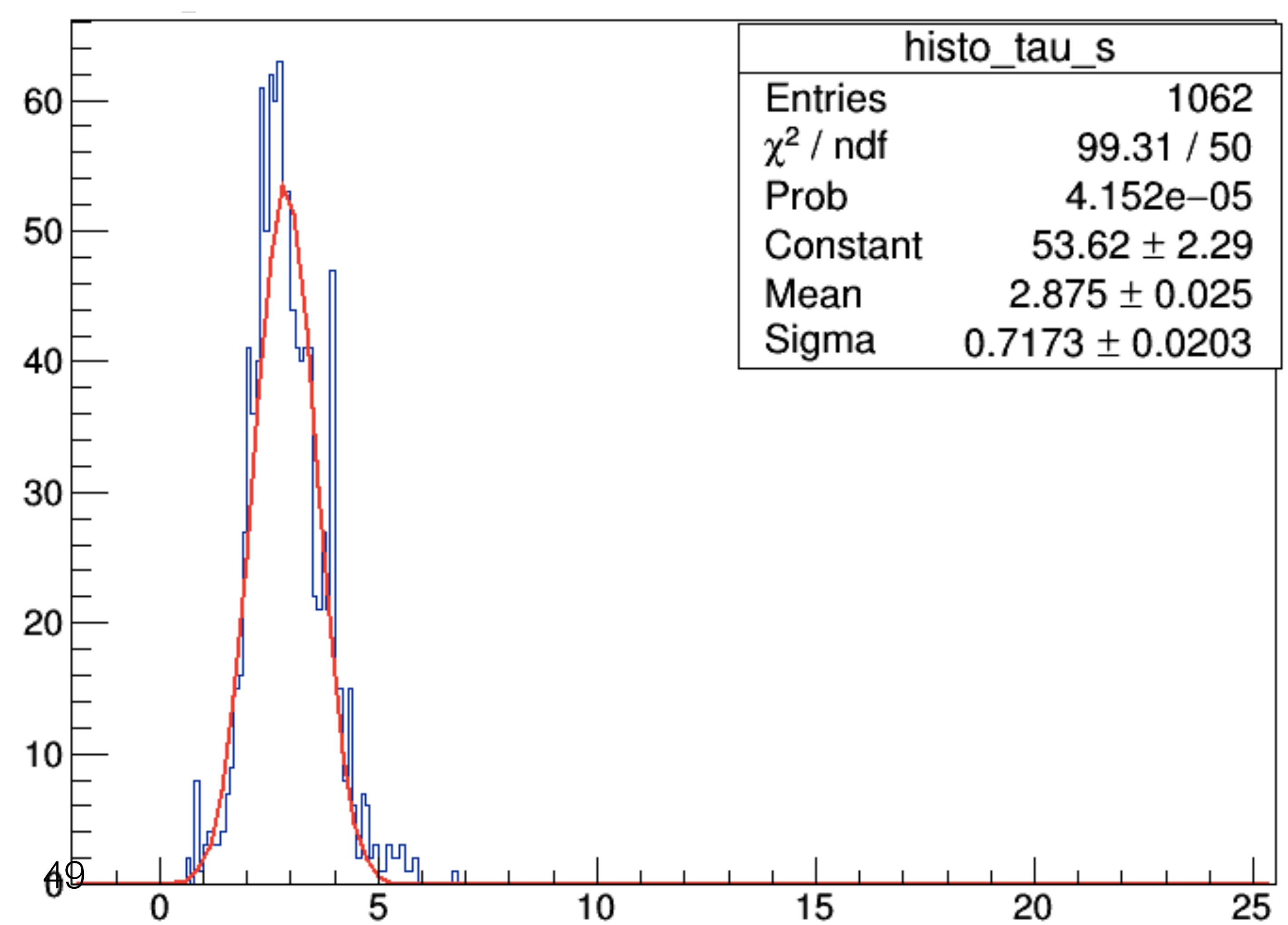

negative_histo
Entries 1024
Mean 208.2
Std Dev 119
χ^2 / ndf 0.02583 / 8
p0 2.786 ± 6.967
p1 0.09873 ± 12.56843
p2 99.78 ± 3.32
p3 −0.1409 ± 0.1719


istogramma tau_s
histo_tau_s
Entries 3563
χ^2 / ndf 351.9 / 95
Prob 3.563e−31
Constant 97.87 ± 3.04
Mean 3.46 ± 0.02
Sigma 0.7988 ± 0.0173

2B



istogramma tau_s

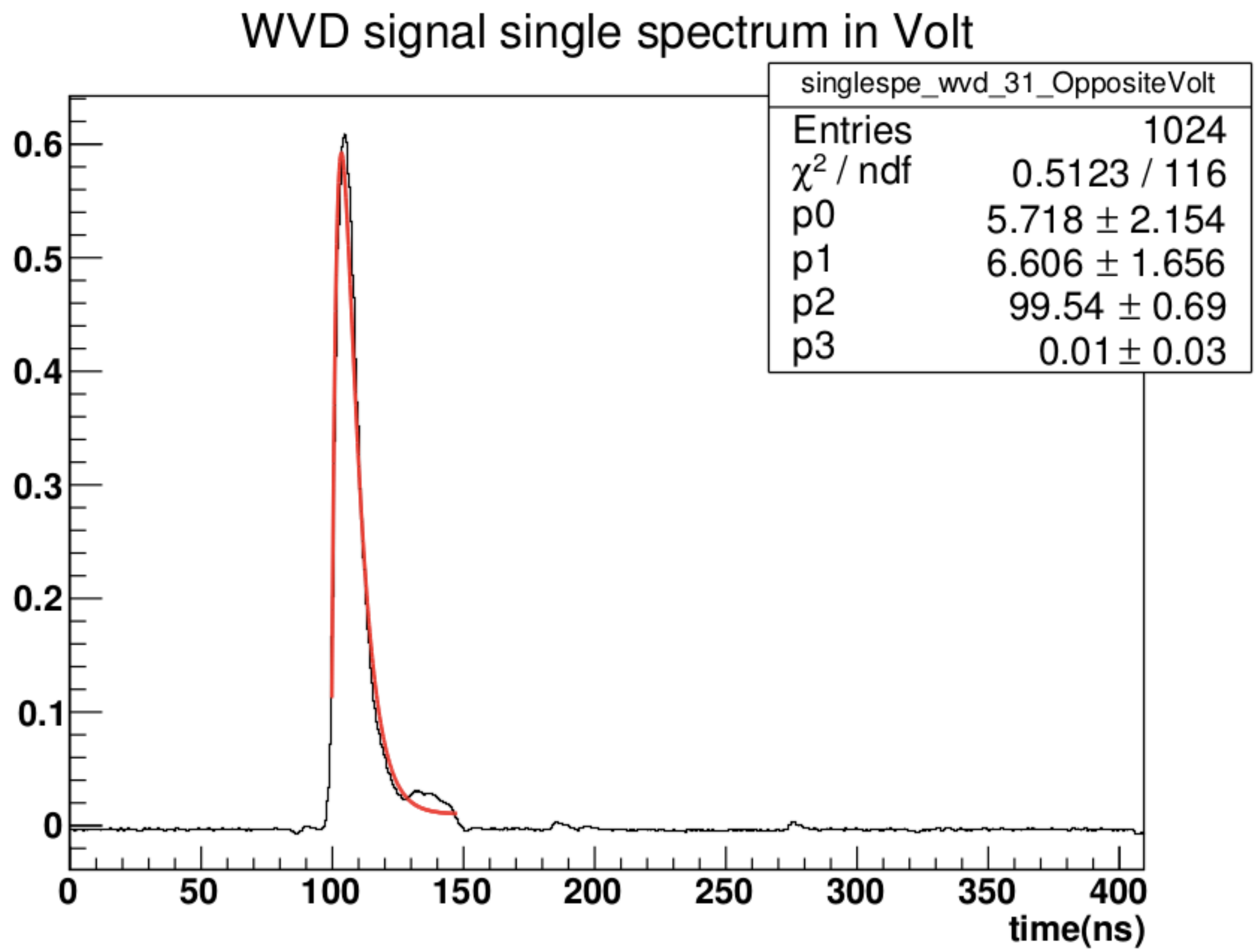


Decay Constant

Fit del tempo di decadimento sulla singola onda

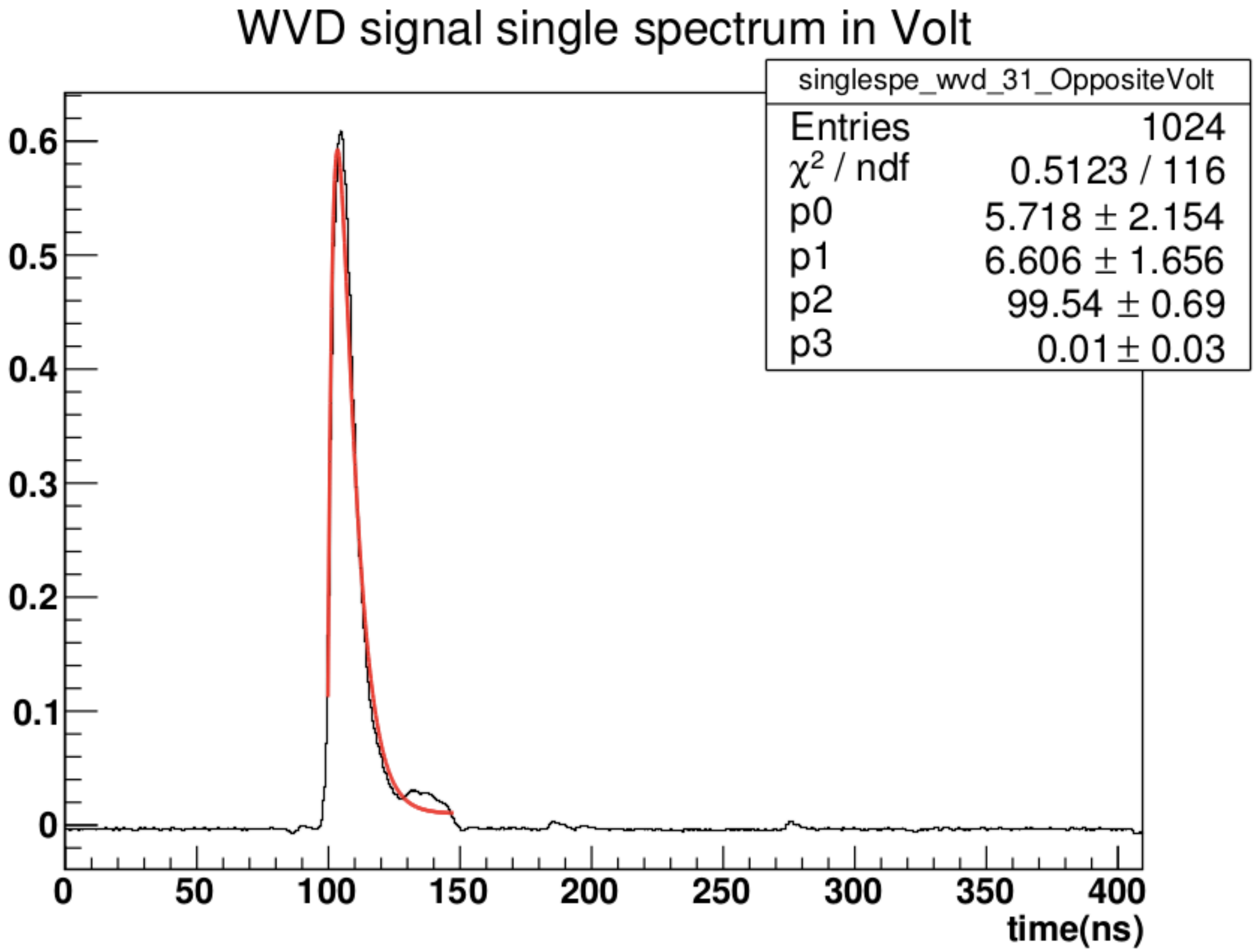
Il segnale in funzione del tempo

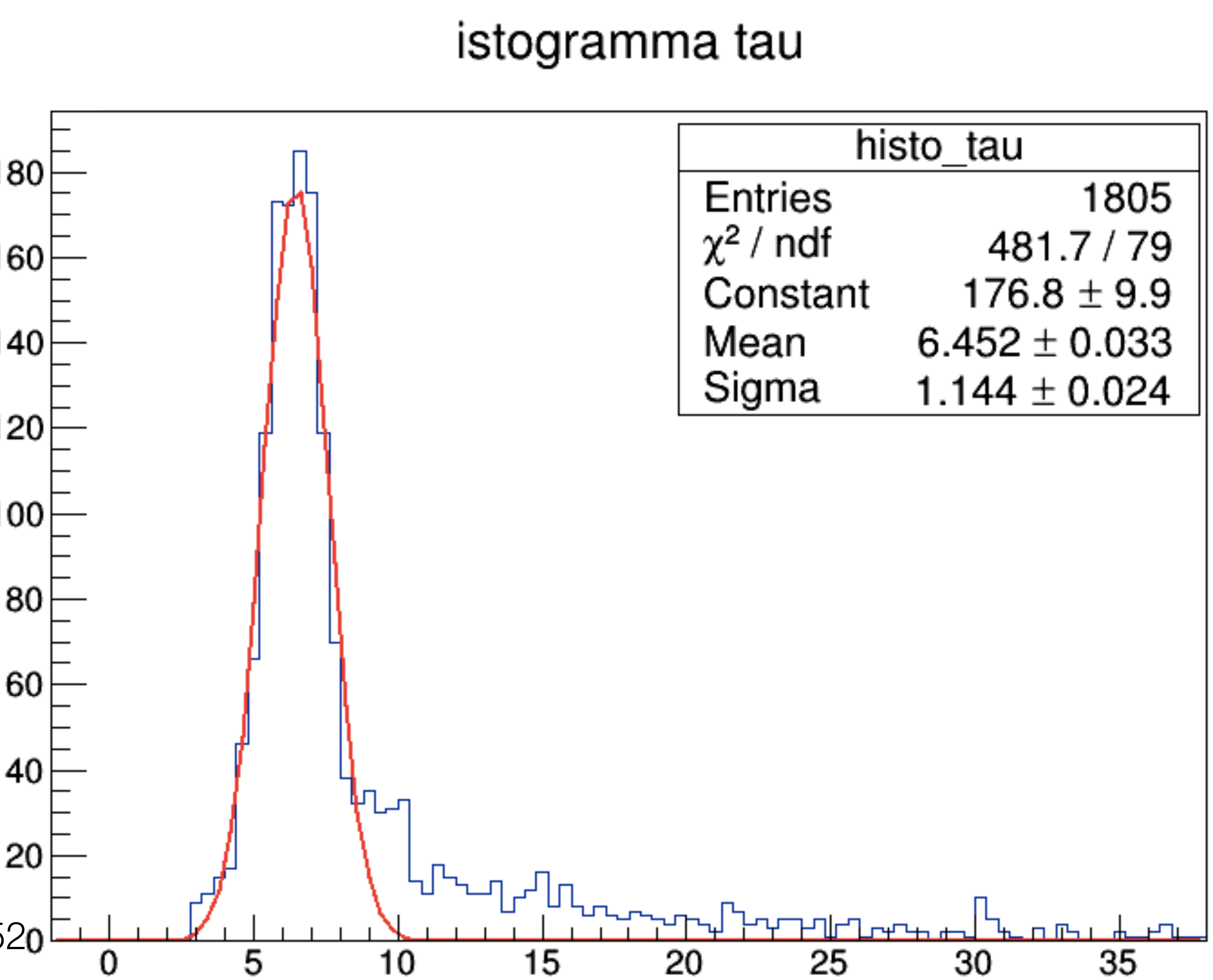
$$V(t) = V_0 + \frac{A}{\tau - \tau_s}\left(e^{-\frac{t-t_0}{\tau_s}} - e^{-\frac{t-t_0}{\tau}}\right)$$

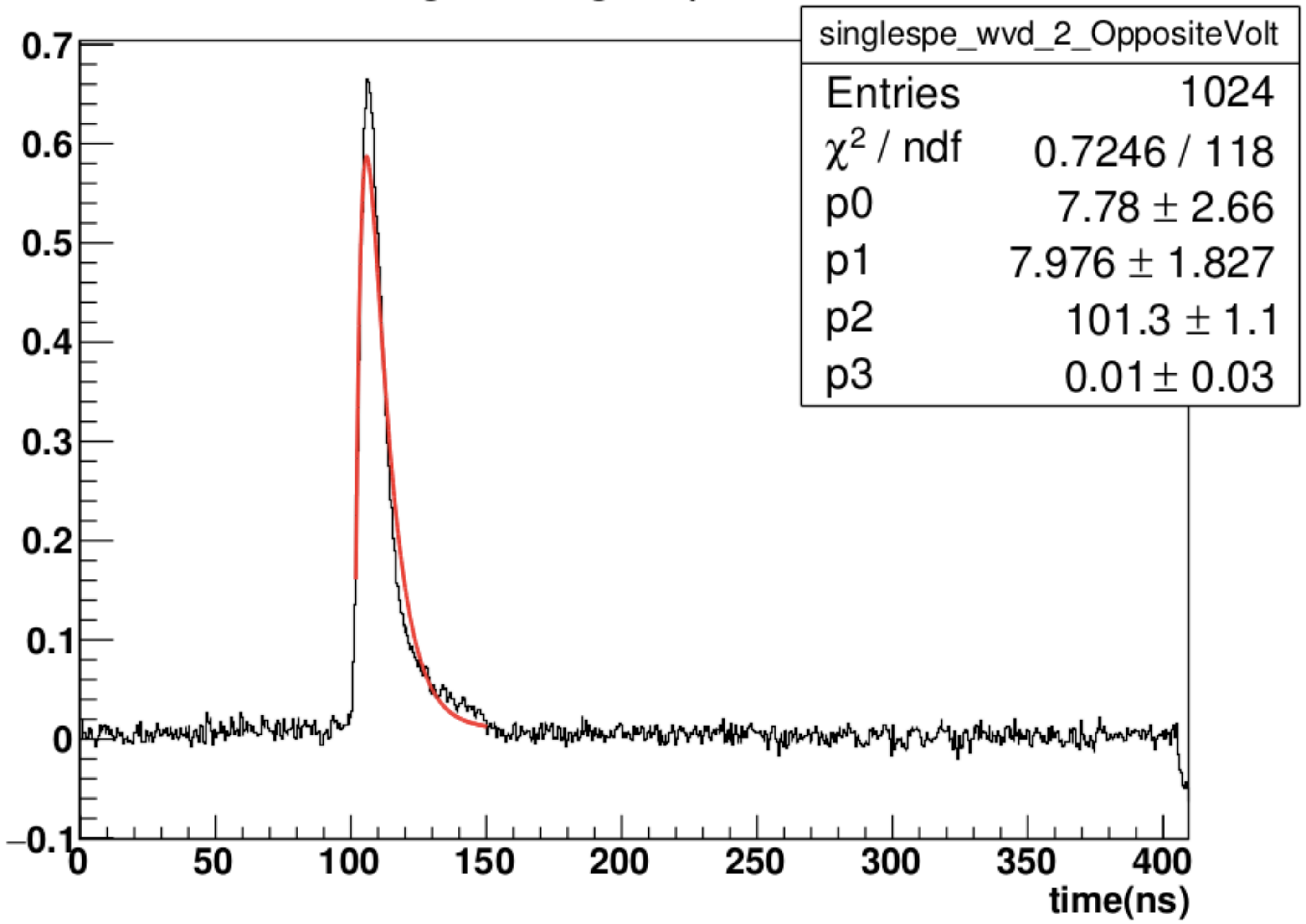


1) **p_0** = τ = Decay constant;
2) **p_1** = A = Constant;
3) **p_2** = t_0 = Initial time;
4) **p_3** = V_0 = Offset;
5) **p_4** = Fixed Rise Time.

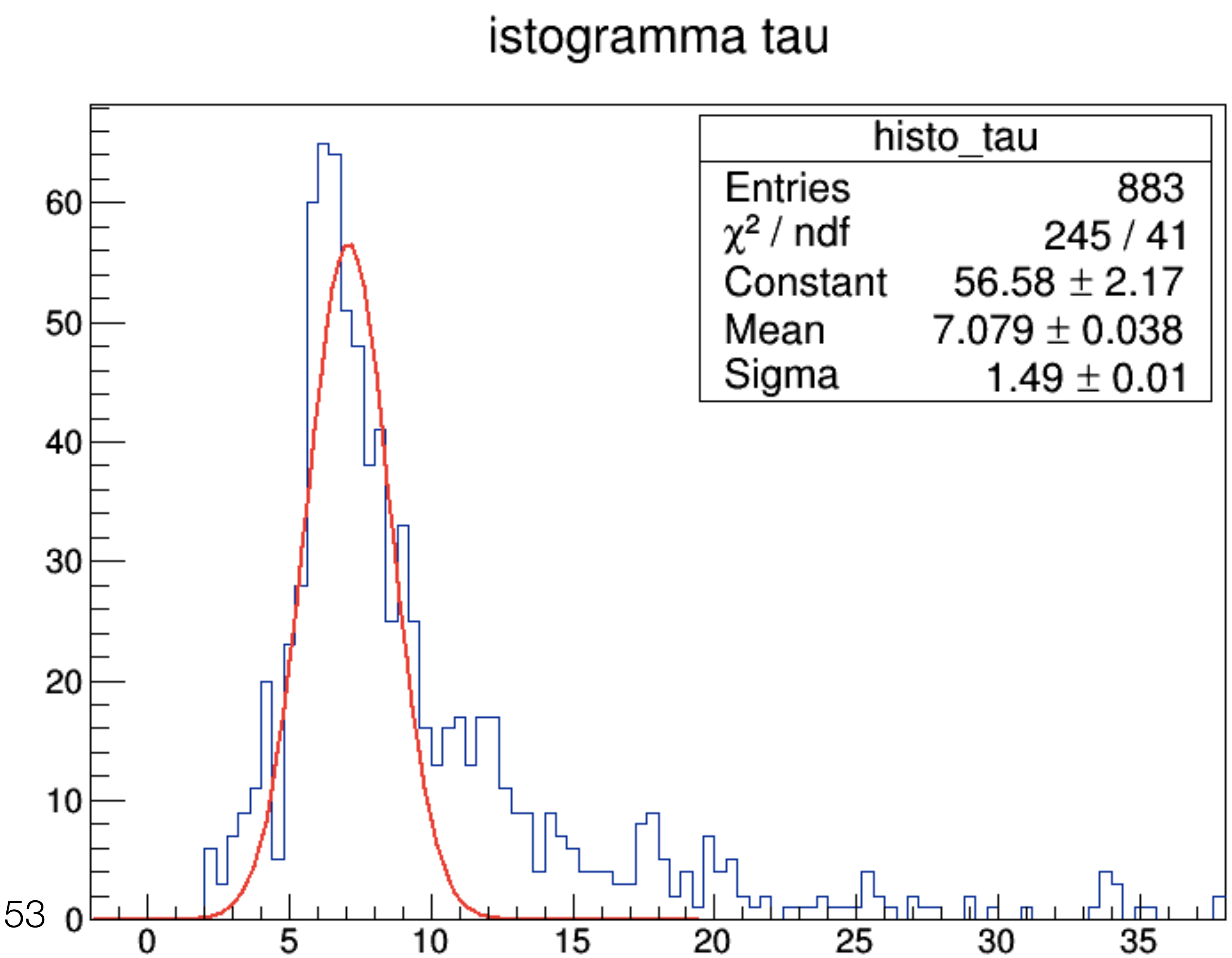
2N

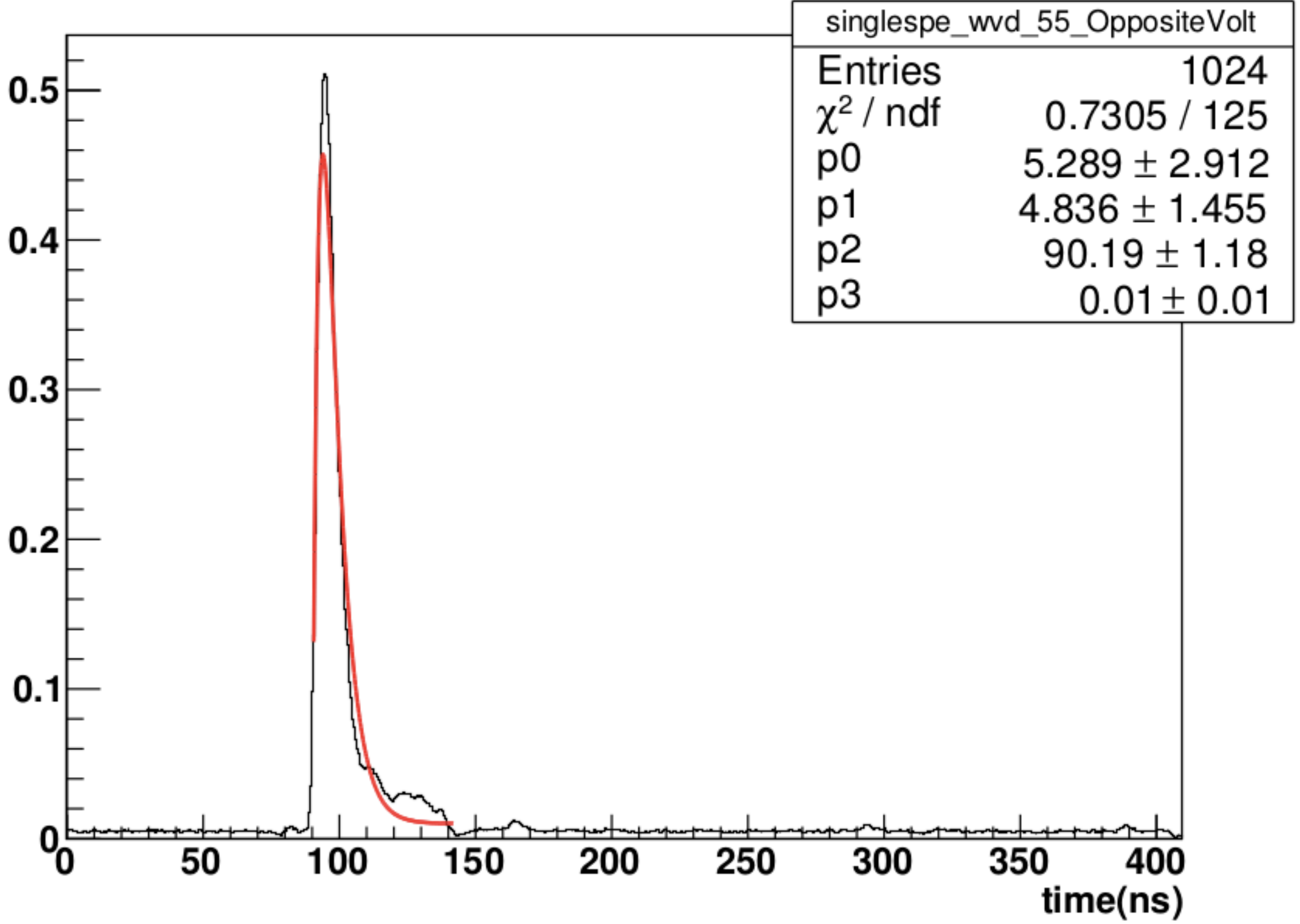

WVD signal single spectrum in Volt
singlespe_wvd_31_OppositeVolt
Entries 1024
χ2 / ndf 0.5123 / 116
p0 5.718 ± 2.154
p1 6.606 ± 1.656
p2 99.54 ± 0.69
p3 0.01 ± 0.03
time(ns)


istogramma tau
histo_tau
Entries 1805
χ2 / ndf 481.7 / 79
Constant 176.8 ± 9.9
Mean 6.452 ± 0.033
Sigma 1.144 ± 0.024

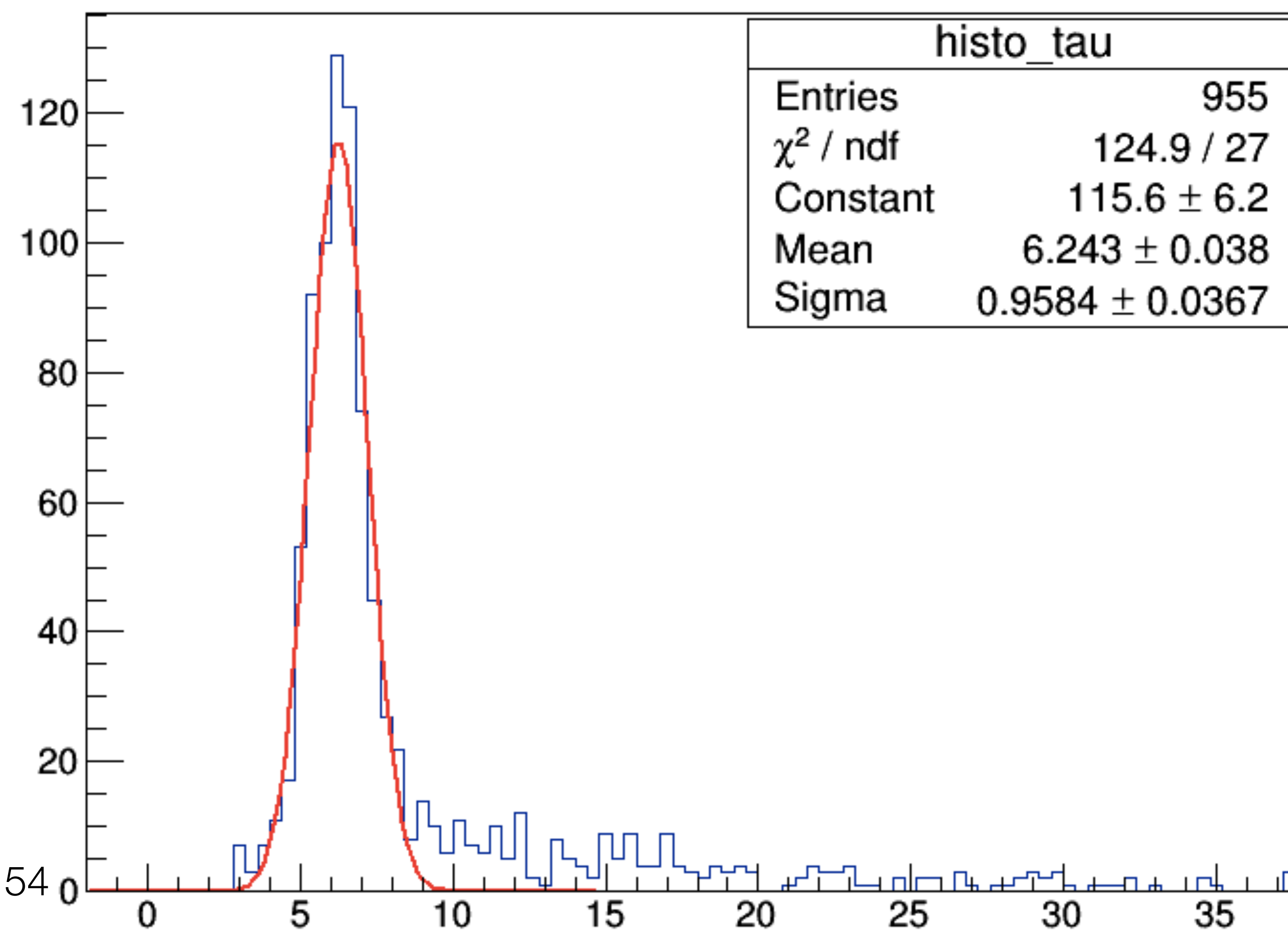

singlespe_wvd_2_OppositeVolt
Entries 1024
χ² / ndf 0.7246 / 118
p0 7.78 ± 2.66
p1 7.976 ± 1.827
p2 101.3 ± 1.1
p3 0.01 ± 0.03
time(ns)

2N_POPOP


istogramma tau
histo_tau
Entries 883
χ² / ndf 245 / 41
Constant 56.58 ± 2.17
Mean 7.079 ± 0.038
Sigma 1.49 ± 0.01

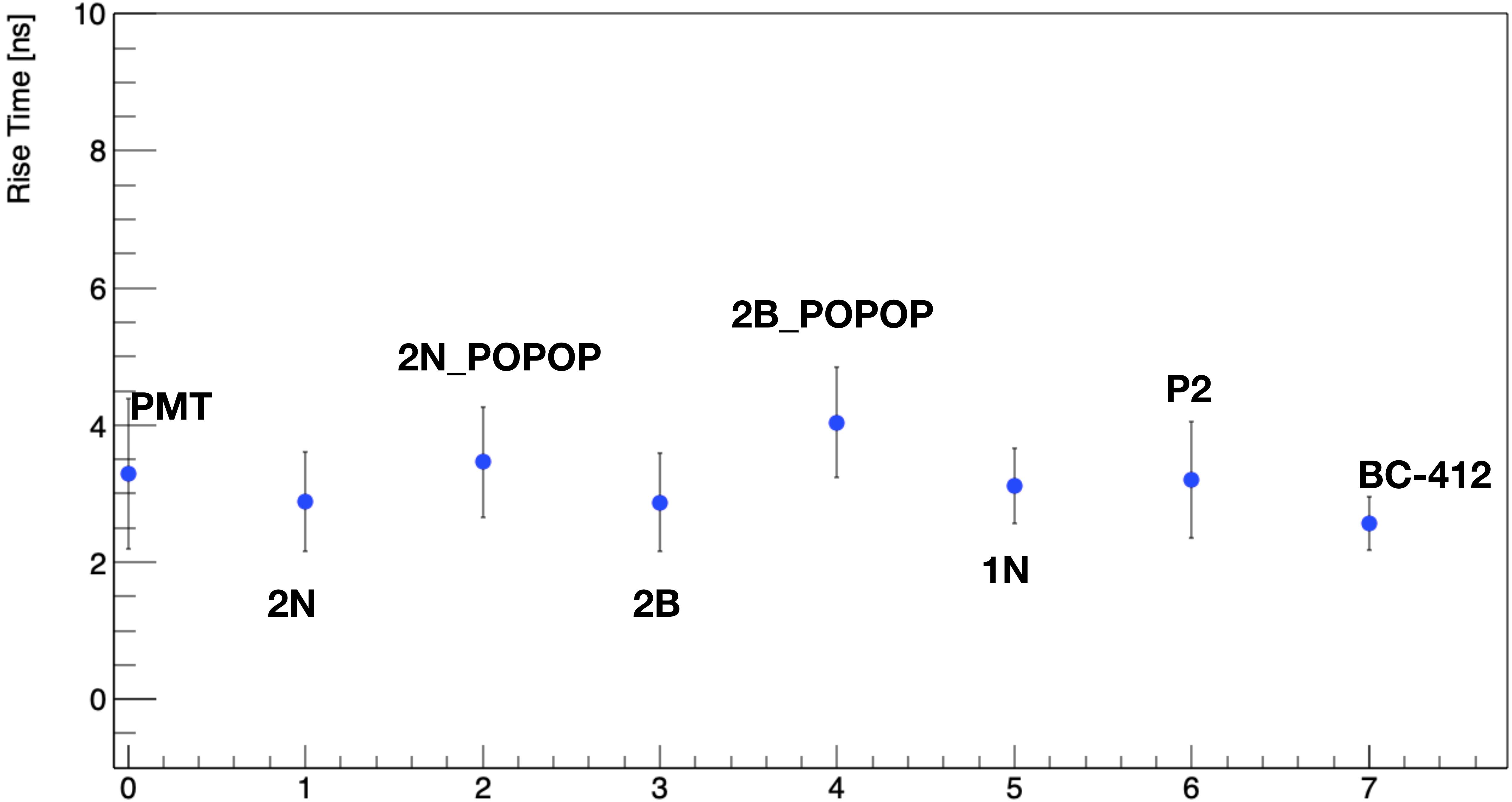

singlespe_wvd_55_OppositeVolt
Entries 1024
χ2 / ndf 0.7305 / 125
p0 5.289 ± 2.912
p1 4.836 ± 1.455
p2 90.19 ± 1.18
p3 0.01 ± 0.01
time(ns)

2B

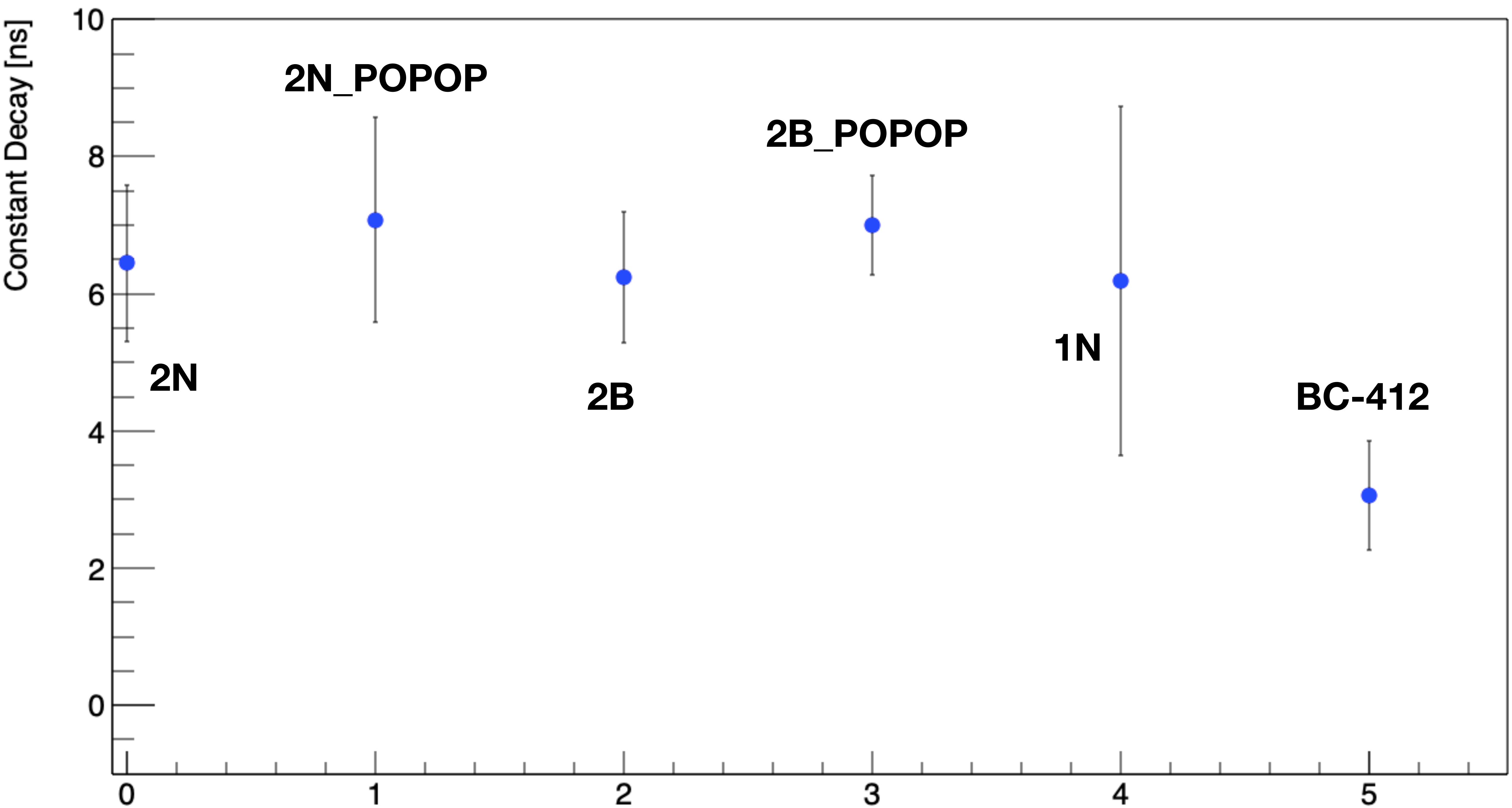

histo_tau
Entries 955
χ2 / ndf 124.9 / 27
Constant 115.6 ± 6.2
Mean 6.243 ± 0.038
Sigma 0.9584 ± 0.0367

	Rise Time (ns)	Constant Decay (ns)
PMT	3.29 ± 1.10	X
2N	2.88 ± 0.72	6.45 ± 1.14
2N POPOP	3.46 ± 0.80	7.08 ± 1.49
2B	2.87 ± 0.72	6.24 ± 0.96
2B POPOP	4.04 ± 0.81	7.00 ± 0.73
1N	3.11 ± 0.55	6.19 ± 2.54
P2	3.20 ± 0.85	X
BC-412	2.56 ± 0.39	3.06 ± 0.79

Plot Rise Time [ns]
Scintillators



Plot Constant Decay [ns] Scintillators



Conclusions

1. In base alle 4 proprietà fisiche principali ricavate (il guadagno in carica, la risoluzione temporale, il tempo di salita ed il tempo di decadimento), gli scintillatori più promettenti sono: il 2N, il 2B e l'1N.
2. Il confronto di questi parametri ha mostrato una netta differenza di prestazioni tra i nuovi scintillatori ed il commerciale BC-412, suggerendo la necessità di elementi aggiuntivi performanti.
3. Tutti i tempi di salita degli scintillatori analizzati, eccettuato l'antracene, sono talmente piccoli che la sensibilità del pmt non permette di rivelarli. (↘Rise Time —-> ↘Time Resolution)
4. Utilizzando il tempo di salita del pmt, è stato comunque possibile ricavare i tempi di decadimento degli scintillatori, i quali risultano (tranne che per l'Antracene) tutti al di sotto dei 10 ns, come atteso.

Scint	Charge [% to An]	Time Resolution [ns]	Rise time [ns]	Constant Decay [ns]
PMT	X	X	3.29 ± 1.10	X
An	100	1.407 ± 0.077	X	13.00 ± 2.47
2N	2013.4 ± 48.8	0.671 ± 0.027	2.88 ± 0.72	6.45 ± 1.14
2B	747.2 ± 15.5	0.871 ± 0.030	2.87 ± 0.72	6.24 ± 0.96
2B POPOP	890.1 ± 15.7	0.673 ± 0.028	4.04 ± 0.81	7.00 ± 0.73
T2	78.1 ± 0.4	1.009 ± 0.043	X	X
T2 POPOP	471.2 ± 10.6	0.878 ± 0.029	X	X
P2	114.2 ± 12.7	1.045 ± 0.038	3.20 ± 0.85	X
1N	846.9 ± 17.7	0.615 ± 0.029	3.11 ± 0.55	6.19 ± 2.54
1N POPOP	694.9 ± 12.9	0.610 ± 0.026	X	X
BC-412	4548.3 ± 21.9	0.538 ± 0.026	2.56 ± 0.39	3.06 ± 0.79

To do per la tesi

1. Finalizzare la scrittura del cap. 3 e 4 (le misure);
2. Perfezionare l’analisi sulle forme d’onda e sulle distribuzioni di carica;
3. Acquisire il 2B 5%;
4. Post scrittura: Cross-Check risoluzione temporale con il waveform;

To do per luminarie

1. Cambiare il pmt (mettere uno più performante);