e+e- ➛ γ A’(to invisible)

PADME EXPECTED LIMITS FROM MONTE CARLO STUDIES

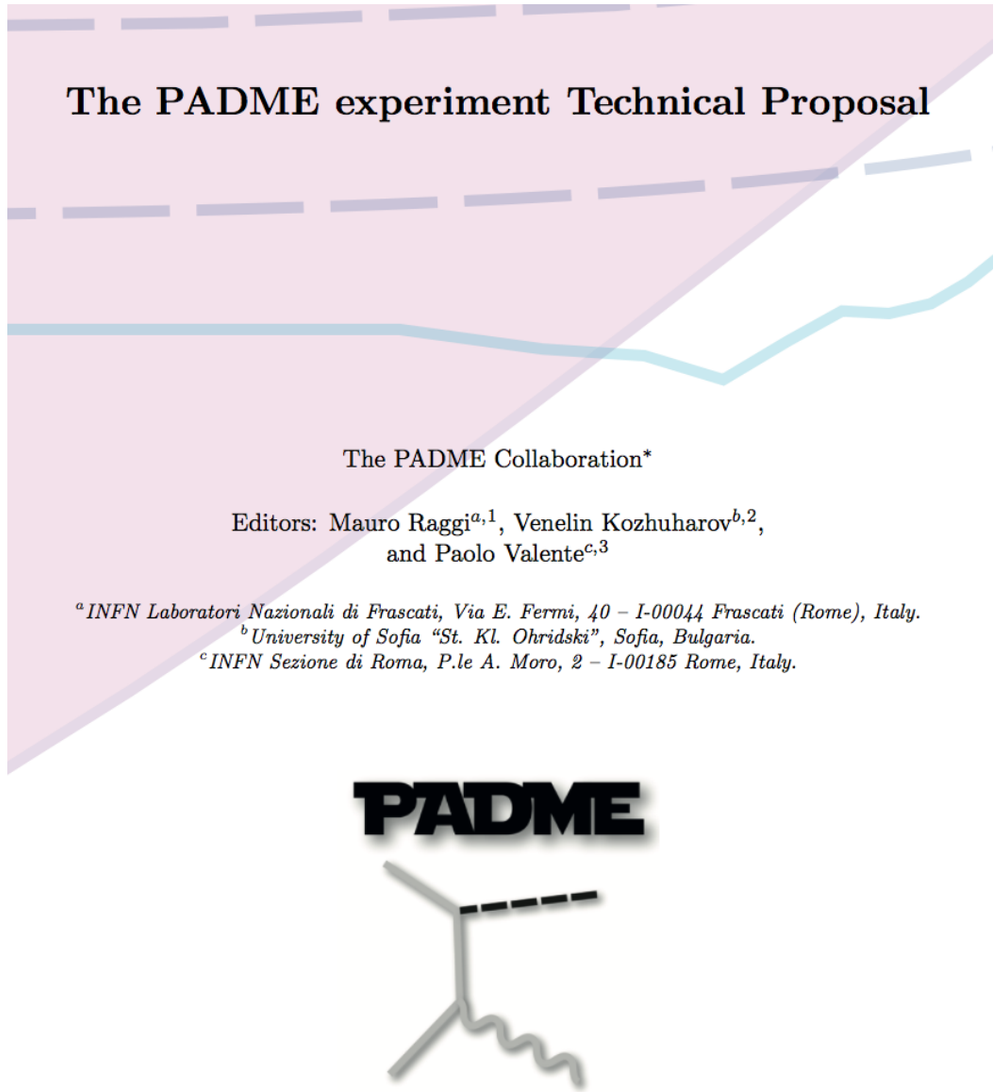
Isabella Oceano
and
G. Chiodini, F. Oliva, V. Scherini, S. Spagnolo
+ Konstantinos Bachas

OUTLINE

- Goal
- The software setup
- MC samples
- Cross sections and predictions from CompHEP
- A simple cut based analysis strategy
  - the γ definition
  - the e+ veto rejection criteria
- efficiency for the signal and expected background yield
- squared-missing mass resolution and signal yield
- limits on ε^2 at 68% CL and 95% CL
- limits on ε^2 at 95% CL with the CLs method
- A first look at Deep Neural Network performance

GOAL

- using a recent PADME MC version to implement an **analysis strategy for**
  - **the efficient selection of e+e- ➛ γ A' (invisible)**
  - **estimate of the background**
- compare with the expected performance quoted in
  - M. Raggi, V. Kozhuharov, "Proposal to search for a dark photon in positron on target collisions at DAΦNE Linac", Advances in High Energy Physics Volume 2014, Article ID 959802, http://dx.doi.org/10.1155/2014/959802 (mainly) **AdvHEP2014**
  - The PADME Technical Proposal Draft of Sept 2015 **PADME-TP**


The PADME experiment Technical Proposal

The PADME Collaboration*

Editors: Mauro Raggi[a,1], Venelin Kozhuharov[b,2], and Paolo Valente[c,3]

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PADME

THE SOFTWARE SETUP

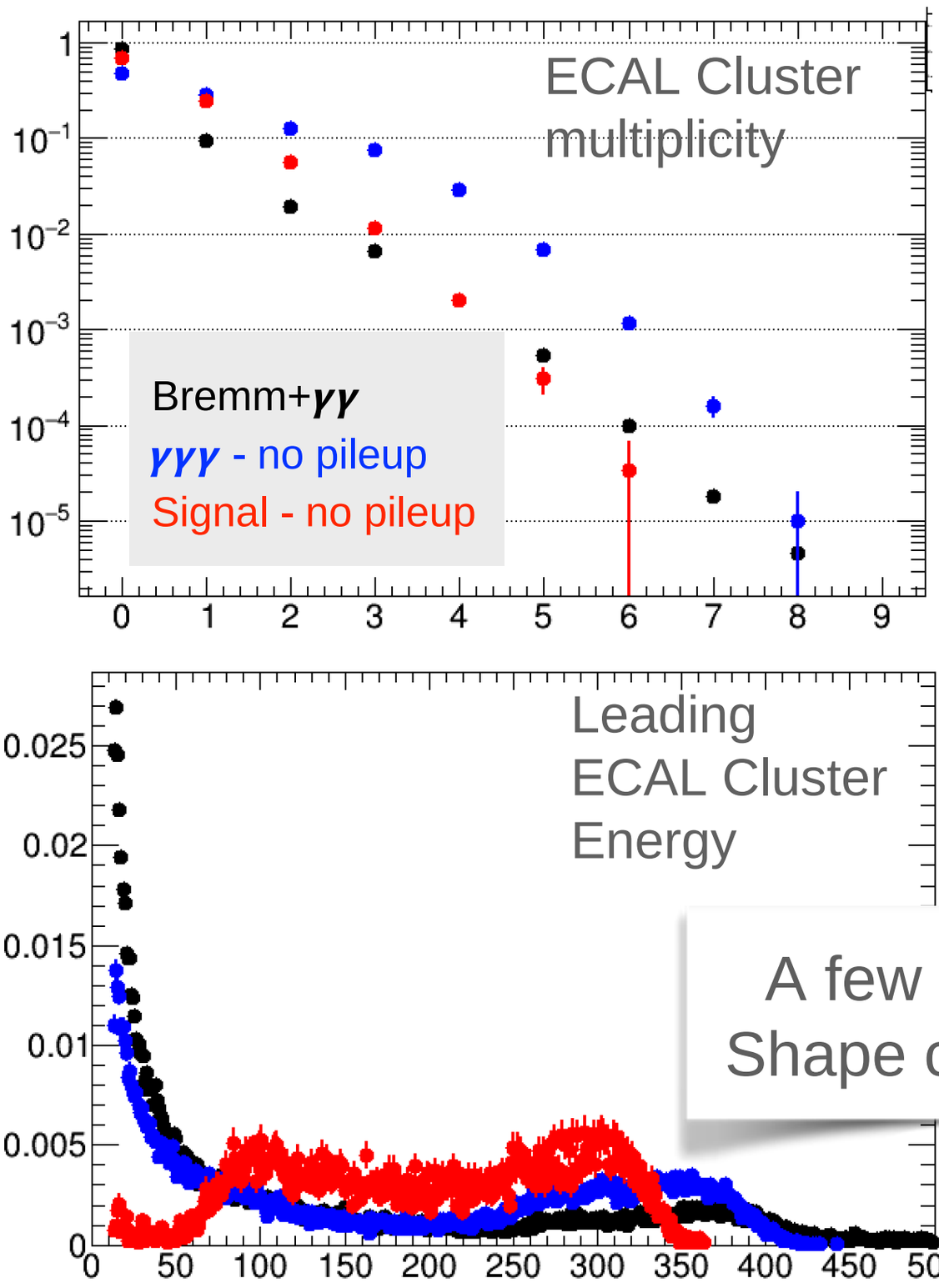
- **Detector Layout** main features
  - **Simulation development branch Sep 2017**
    - 100 μm thick diamond target
    - ECAL-target distance 3 m, ECAL radii 5-30 cm -> **theta: 0.95-5.7 deg**
  - **AdvHEP2014:**
    - 50 μm thick diamond target
    - ECAL-target distance 1.75 m, ECAL radii 3-15 cm -> **theta: 0.98-4.9 deg**
- **Beam**
  - **This simulation**
    - 550 MeV, pileup 5×10^3 e+ in 40 ns long bunches,
    - energy spread 1% (for signal, bremmstrahlung, $\gamma\gamma$, NOT for 3γ), divergence 1mrad
    - beam spot at the target ?
  - **AdvHEP2014:**
    - pileup 4×10^3 *not on the entire sample*

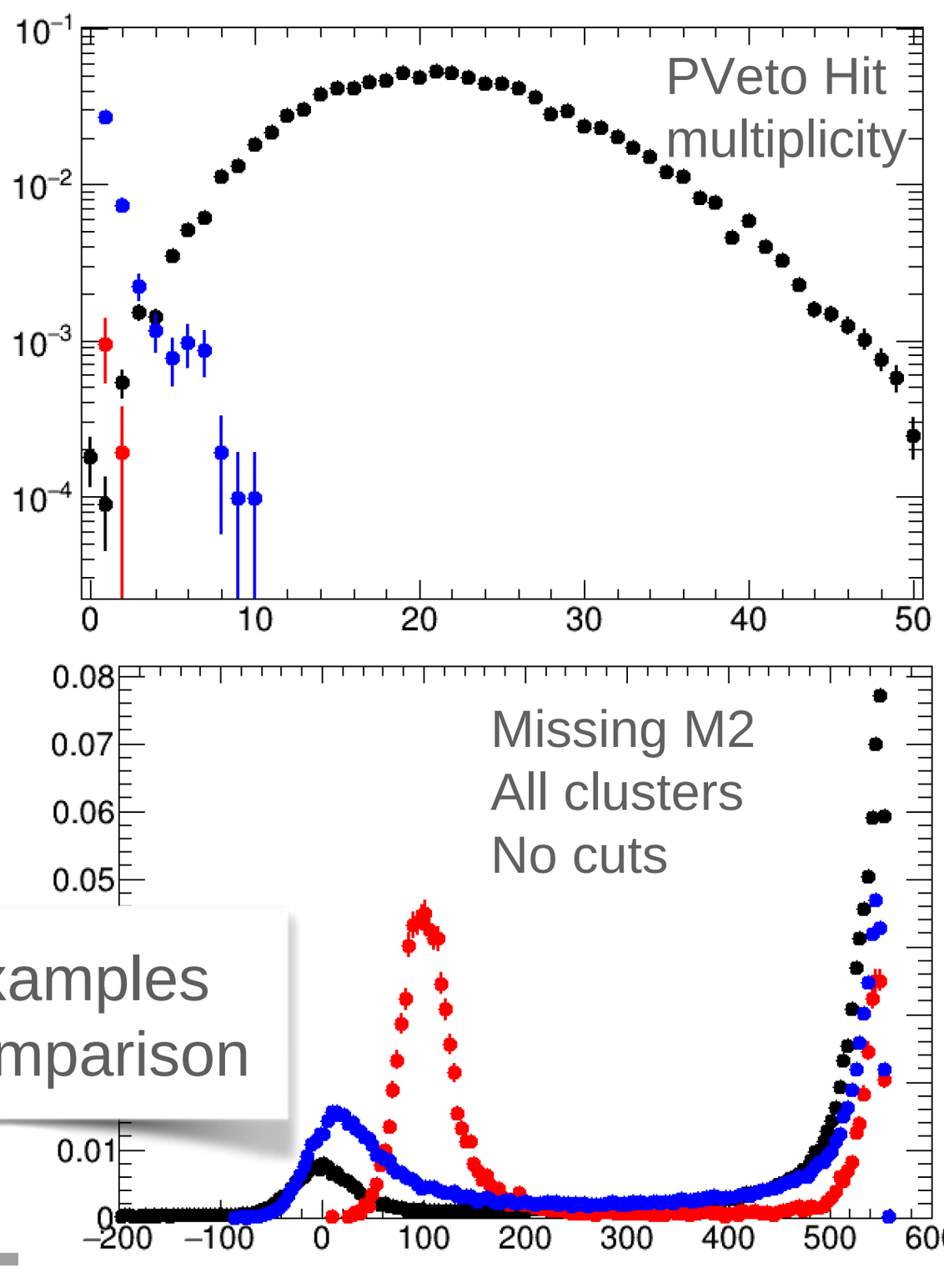
- **S/√N *this simulation expected to be* ~ √2 x (S/√N) *in* AdvHEP2014**

MC SAMPLES

- 2.580.000 events (5000 e+/bunch) generated and simulated with GEANT4
  - **bremmstrahlung and $\gamma\gamma$**
  - **1.29 x 10^{10} POT** = 5000x2.58x10^{6}
- 100.000 events with 1 **e+e- ➛3γ** out of 5000e+/bunch
  - generator CALCHEP, input 4-vector files from Venelin at
    - http://heph.phys.uni-sofia.bg/veni/padme/calchep/ events_ee-3g-550MeV-10M-new.txt.bz2
  - **1.33 x 10^{11} POT** = 1x10^{5}/(σ(3γ) x N_{e^-}/S)
    - assuming σ(e+e- ➛ 3γ)=7.5x10^{-5}b [from the header of the sample], N_{e^-}/S=0.0105 b^{-1}
- 50000 events with 1 **e+e- ➛A'γ** out of 5000e+/bunch ($M_{A'}$=10 MeV + $M_{A'}$ from 2.5 MeV to 20 MeV) + 50000 events with 1 single signal event (no pileup) at each mass
  - PadmeMC internal generator
  - ~**1.28 x 10^{15} POT** (for $M_{A'}$=10 MeV) = 0.5x10^{5}/(σ(A'γ) x N_{e^-}/S)
    - assuming σ(A'γ)=22nb (per C atom) i.e. ε^2=10^{-6}, N_C/S=1.75x10^{-3} b^{-1}

KIN. VARIABLES FOR SIGNAL/BKG PROCESSES



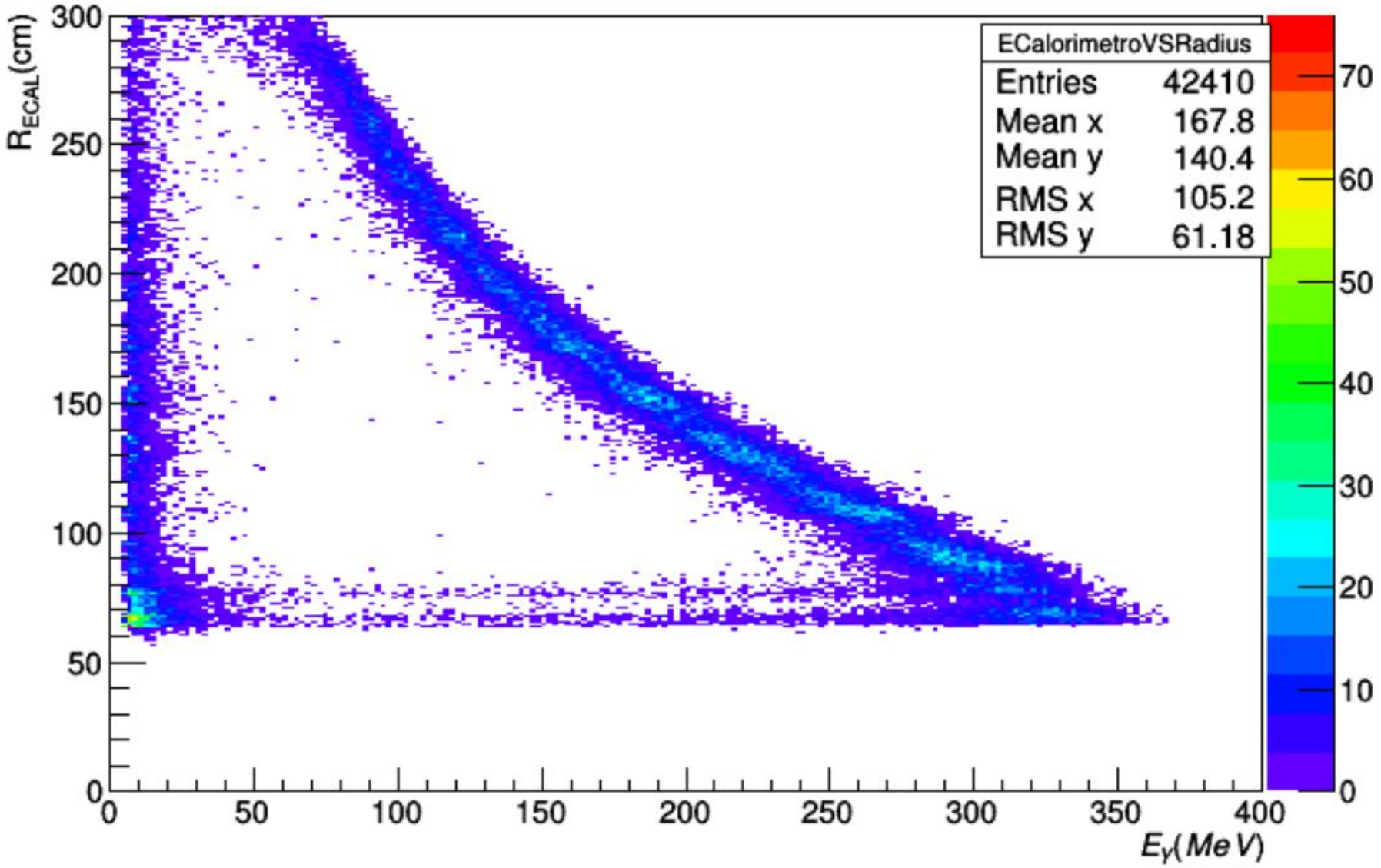


A few examples
Shape comparison

CLUSTERS IN ECAL

Signal M_A'=10 MeV
no pileup

All clusters in ECAL
$\sqrt{(x^2+y^2)}$ vs E

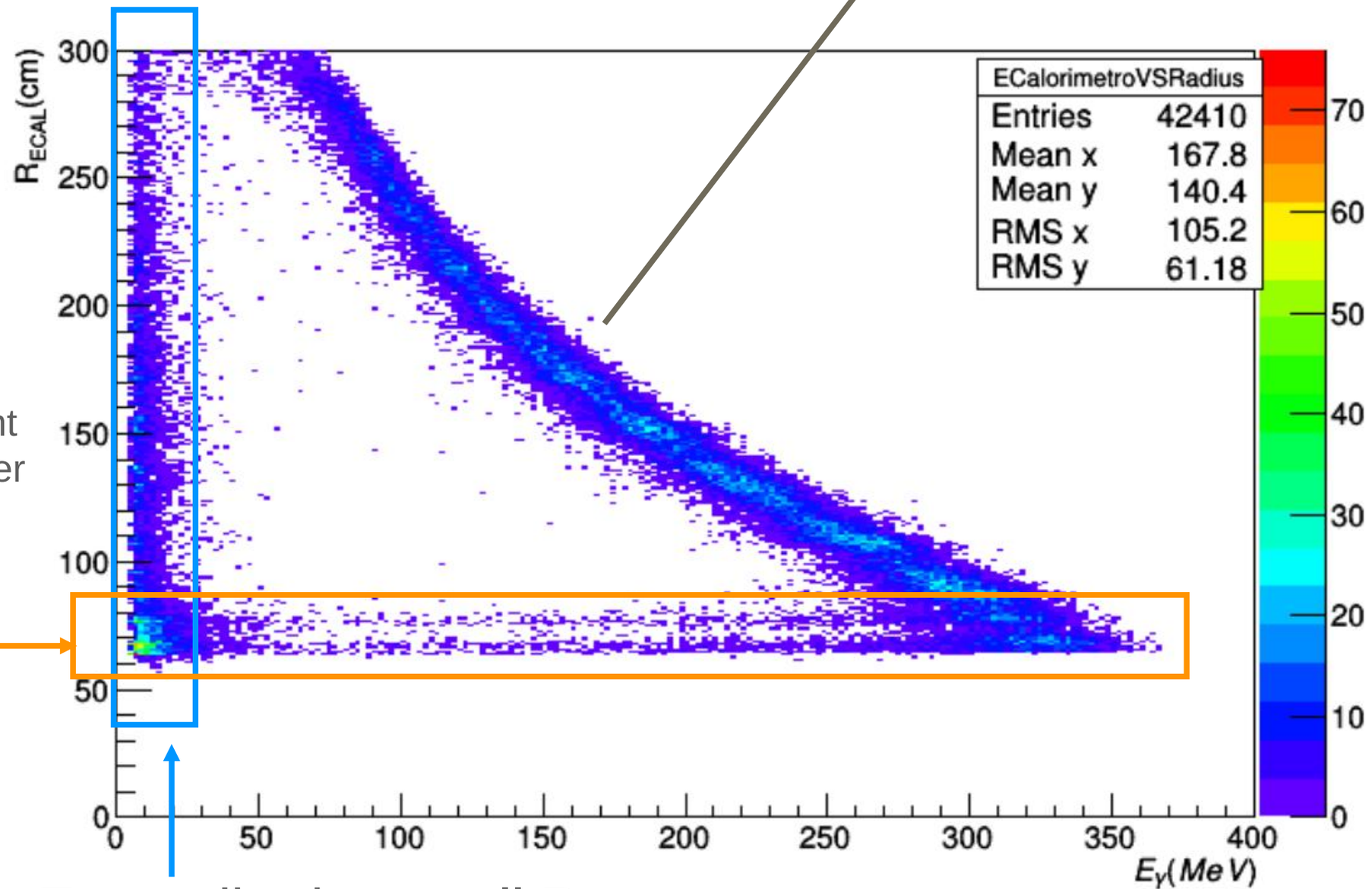


CLUSTERS IN ECAL

Signal $M_{A'}$=10 MeV
no pileup

All clusters in ECAL
$\sqrt{(x^2+y^2)}$ vs E

mass dependent
kinematic constraint



un-complete
containement
at ECAL inner
radius

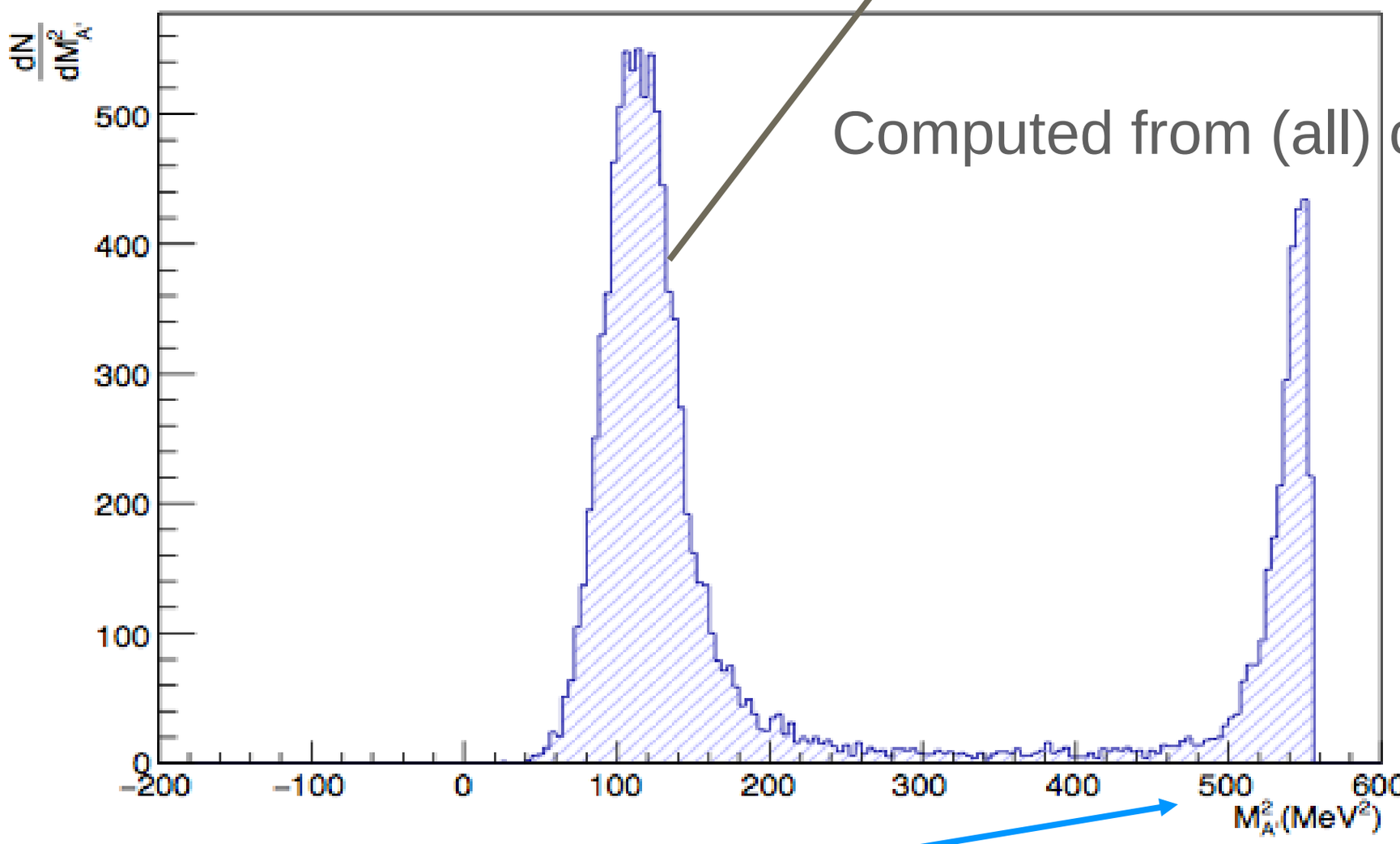
low E contribution at all R

CLUSTERS IN ECAL

Signal M_A'=10 MeV
no pileup

All clusters in ECAL
$\sqrt{(x^2+y^2)}$ vs E

mass dependent
kinematic constraint



Computed from (all) cluster energy

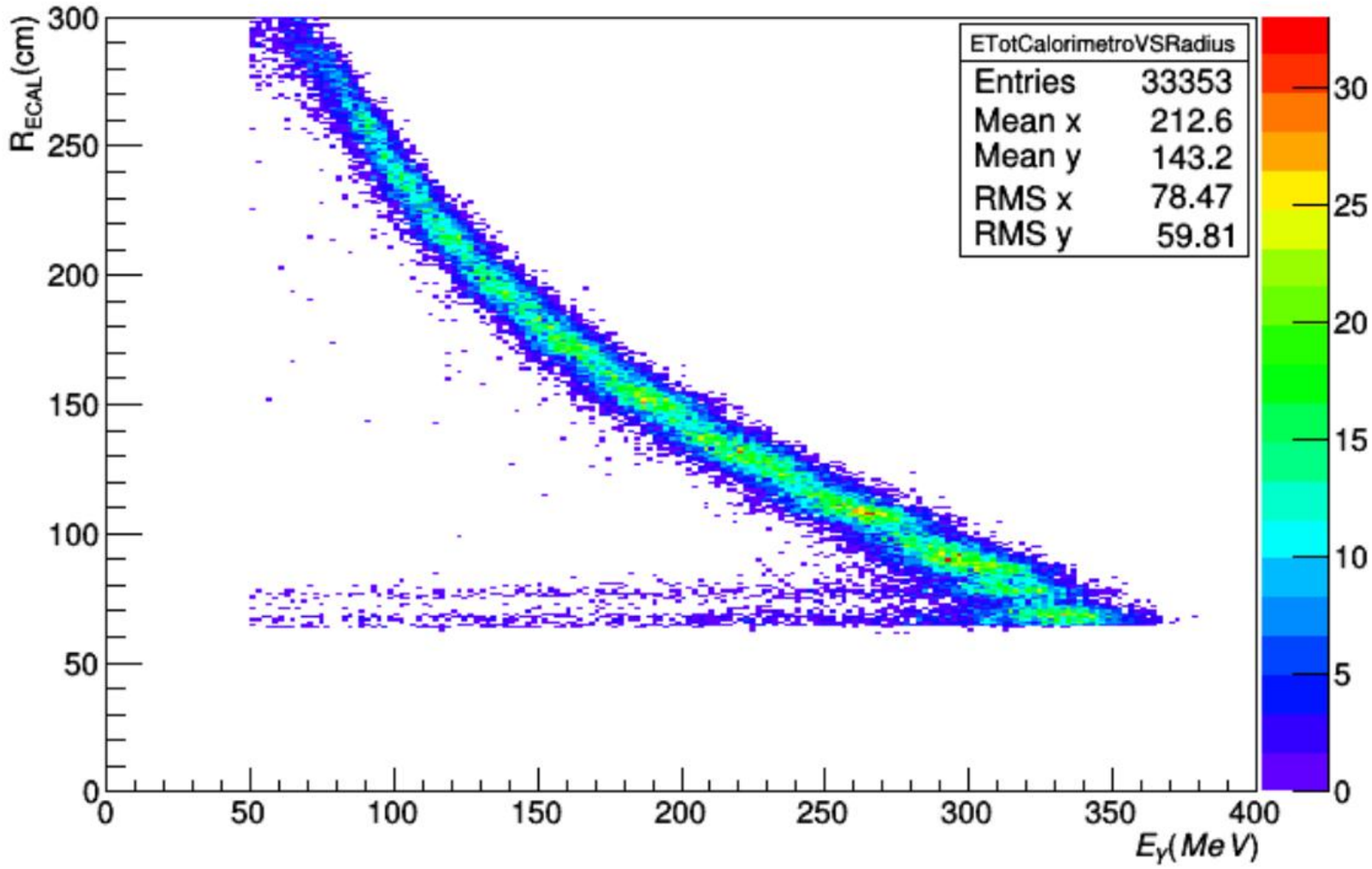
low E contribution at all R

CLUSTERS IN ECAL

Signal M_A'=10 MeV
no pileup

ECAL cluster multiplicity ≤ 4

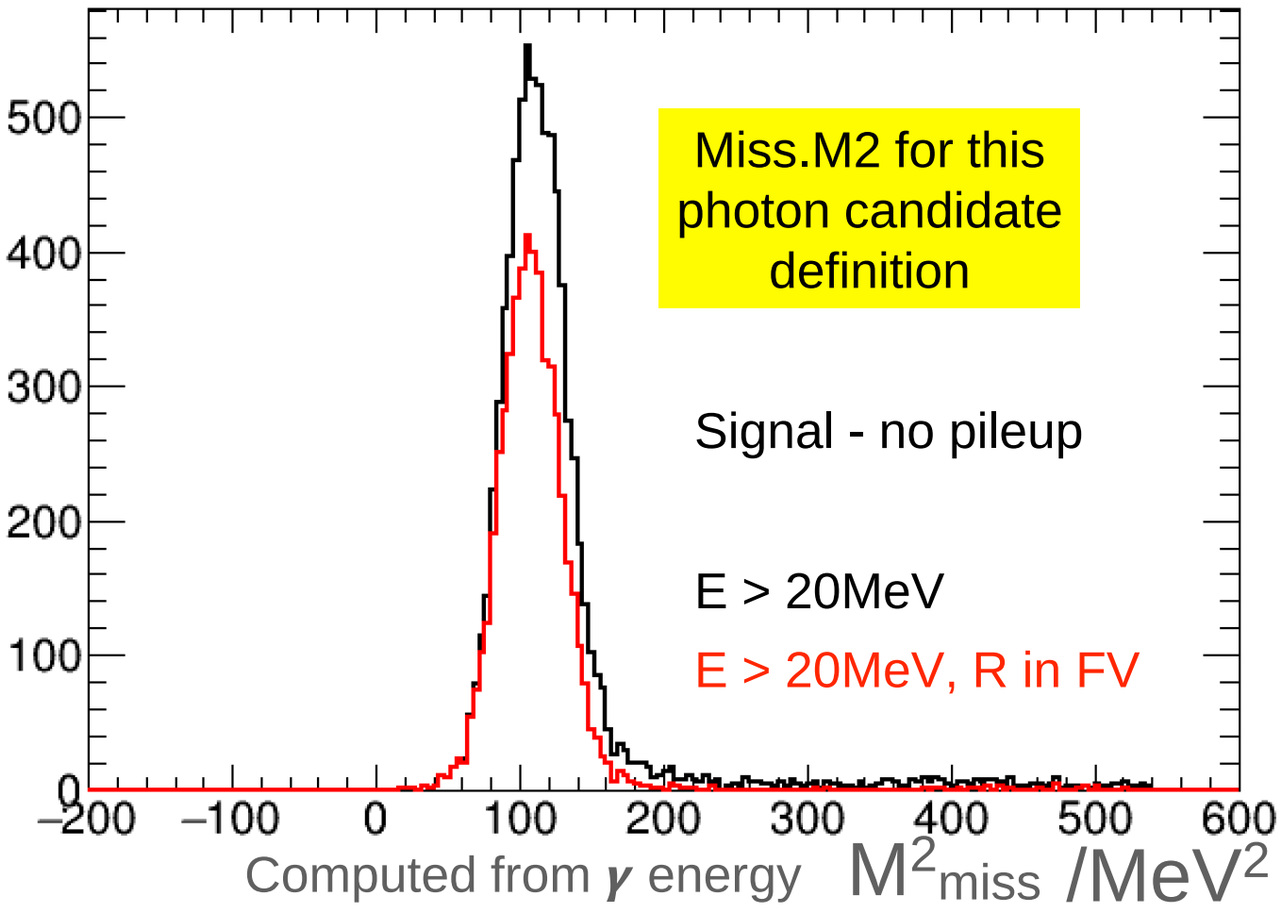
Consider one single cluster with $E = \Sigma E_i$, i=1,…,4
at (x,y) = (x,y) of the leading cluster

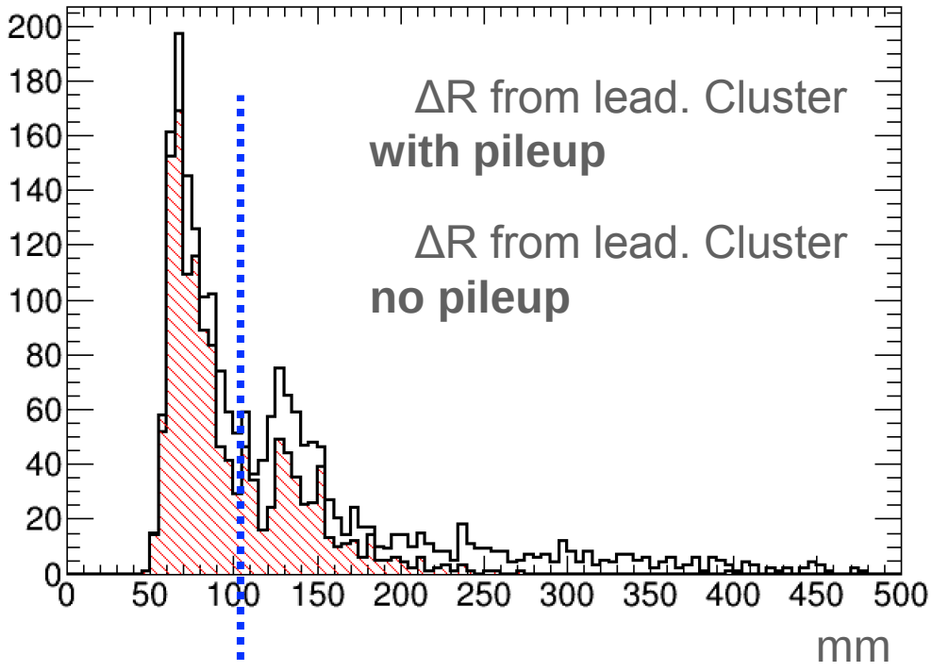


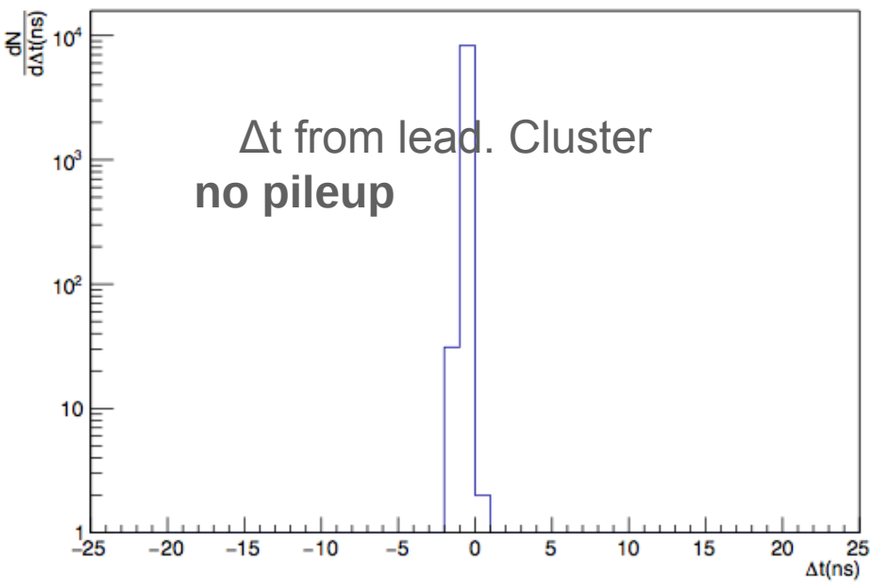
➥ The clustering algorithm (input to UBTF ntuple) misses small contributions to the shower - *useful to correct for this effect*

CORRECTING ENERGY OF LEADING ECAL CLUSTER

- Photon candidate is the leading cluster after "correction"
  - Energy = Sum of all energies of clusters at ΔR<10 cm and Δt<2.5 ns from the leading cluster
  - X,Y and time = energy weighted sum of X,Y, t of all clusters at **ΔR<10 cm and Δt<2.5 ns** from the leading cluster



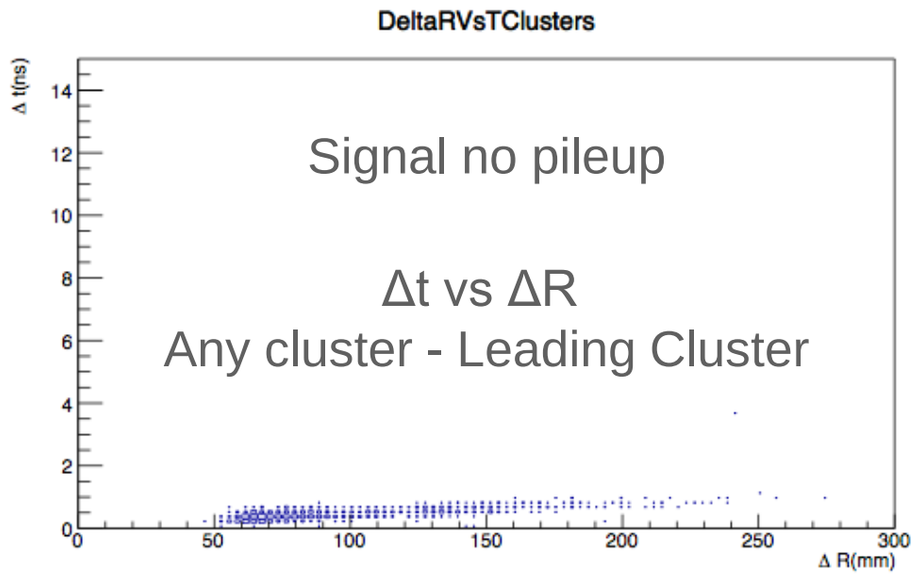


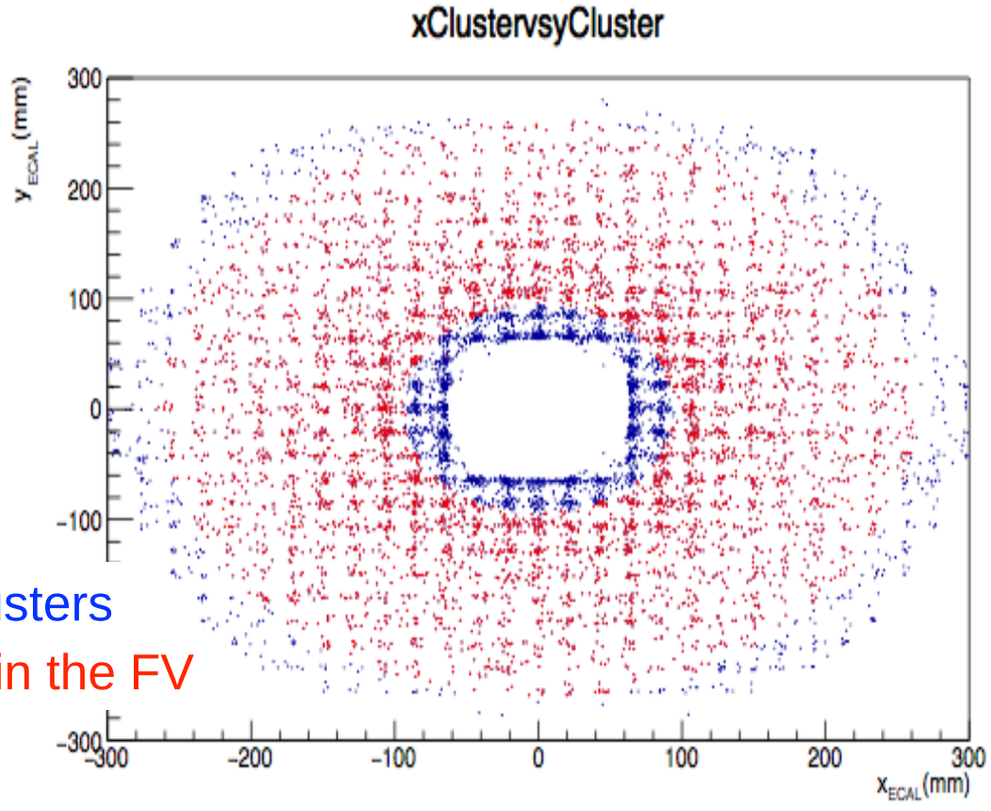


PHOTON DEFINITION FOR ANY $M_{A'}$

- 1 ECAL cluster with E > 20 MeV -> photon candidate
  - energy in ECAL at ΔR<10.0 cm and Δt<2.5 ns is summed to the ECAL cluster
    - energy, position in ECAL and time are re-evaluated
  - allowing for other ECAL clusters in the event[bunch] with E< 0.6x20MeV and Δt > 2.5 ns and ΔR > 10 cm from the selected cluster

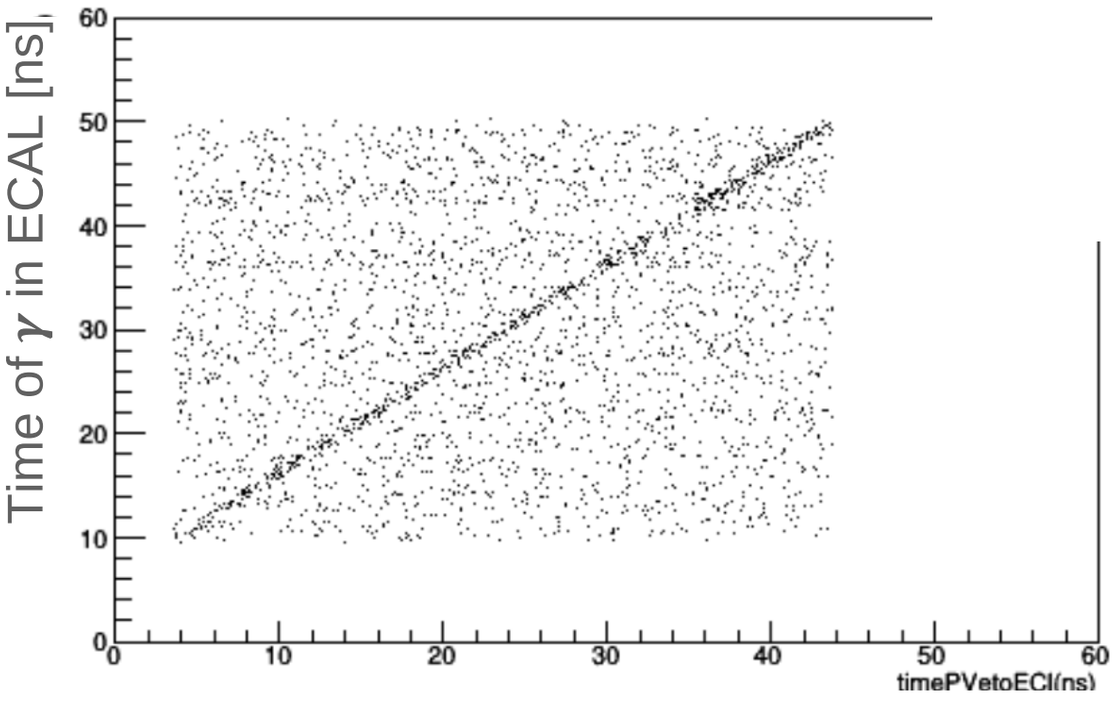
- Radius in 94.5 - 262.5 mm (center of the cluster must not lie in the 2 innermost or outermost rings of crystals)

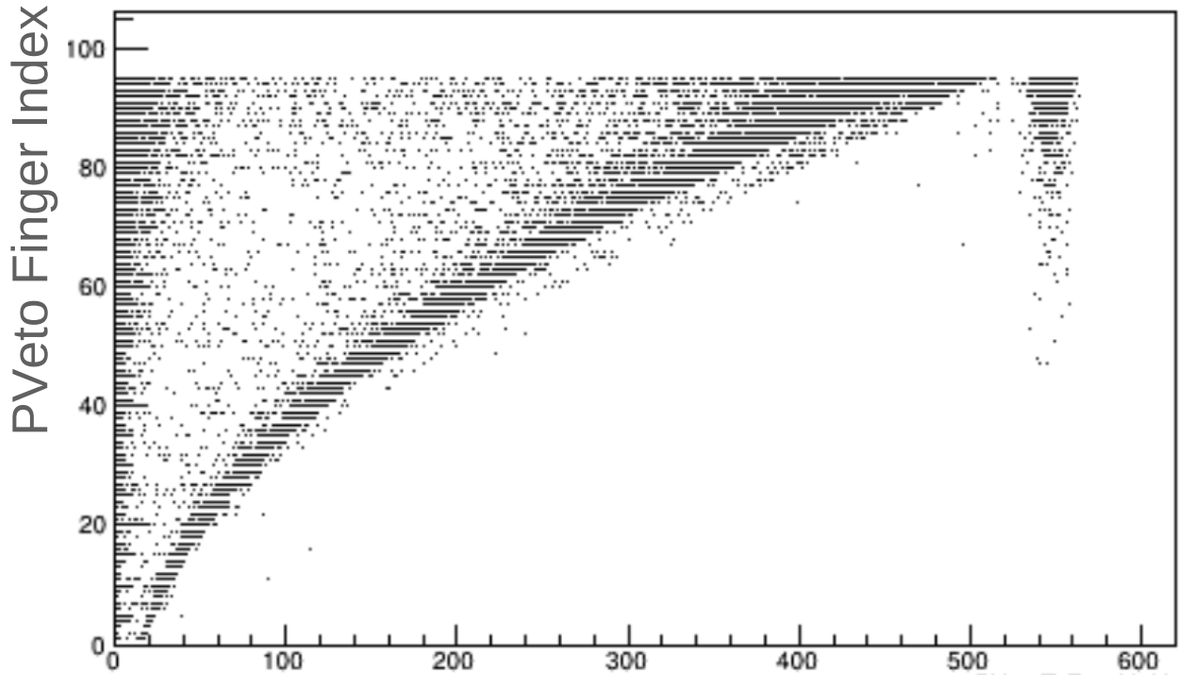




BREMMSTRAHLUNG REJECTION CUTS

- Bremmstrahlung + $\gamma\gamma$ sample
- clear correlations:





- no PVeto hits with
  - T_{PVeto}-T_{γ} compatible with the correlation observed within 1.5ns
  - in finger such that 500 MeV < Kin.E(finger index)+E_{γ} < 650 MeV

SELECTION CUTS

- 1 ECAL cluster with E > 20 MeV -> photon candidate
  - energy in ECAL at ΔR<10.0 cm and Δt<2.5 ns is summed to the ECAL cluster
    - energy, position in ECAL and time are re-evaluated
  - allowing for other ECAL clusters in the event[bunch] with E< 0.6x20MeV and Δt > 2.5 ns and ΔR > 10 cm from the selected cluster

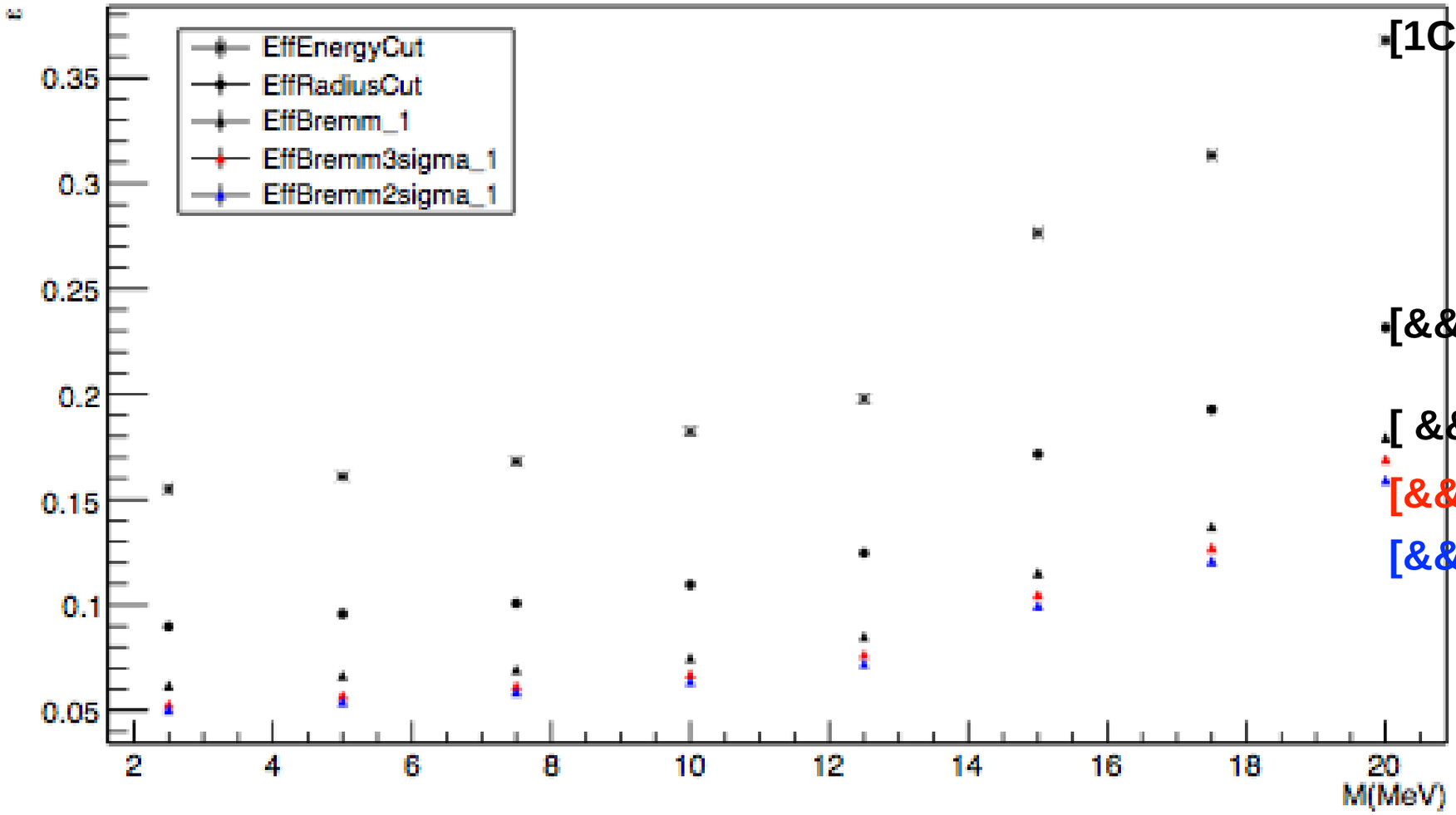
- Radius in 94.5 - 262.5 mm (center of the cluster must not lie in the 2 innermost or outermost rings of crystals)

- e+ Veto Cut (γ-e+ in time [2ns] and e+ energy+ECAL cluster energy in 500-650 MeV)

- no A'-mass dependent cuts (details in backup)
- no use of SAC, HEPVeto, EVeto

SIGNAL [WITH PILEUP] EFFICIENCY

- As a function of $M_{A'}$ mass
- 1) For 1 cluster selection above threshold **[1ClusterAbove20MeV]**
- 2) For 1) & R in the fiducial region **[&& R in the fiducial region]**
- 3) For 2) and positron veto cuts **[&& e+ veto passed]**
- 4) For 3) and in 3 and 2 sigma around the signal peak region **[&& M^2 in 3σ]** **[&& M^2 in 2σ]**



[1ClusterAbove20MeV]

[&& R in the fiducial region]

[&& e+ veto passed]

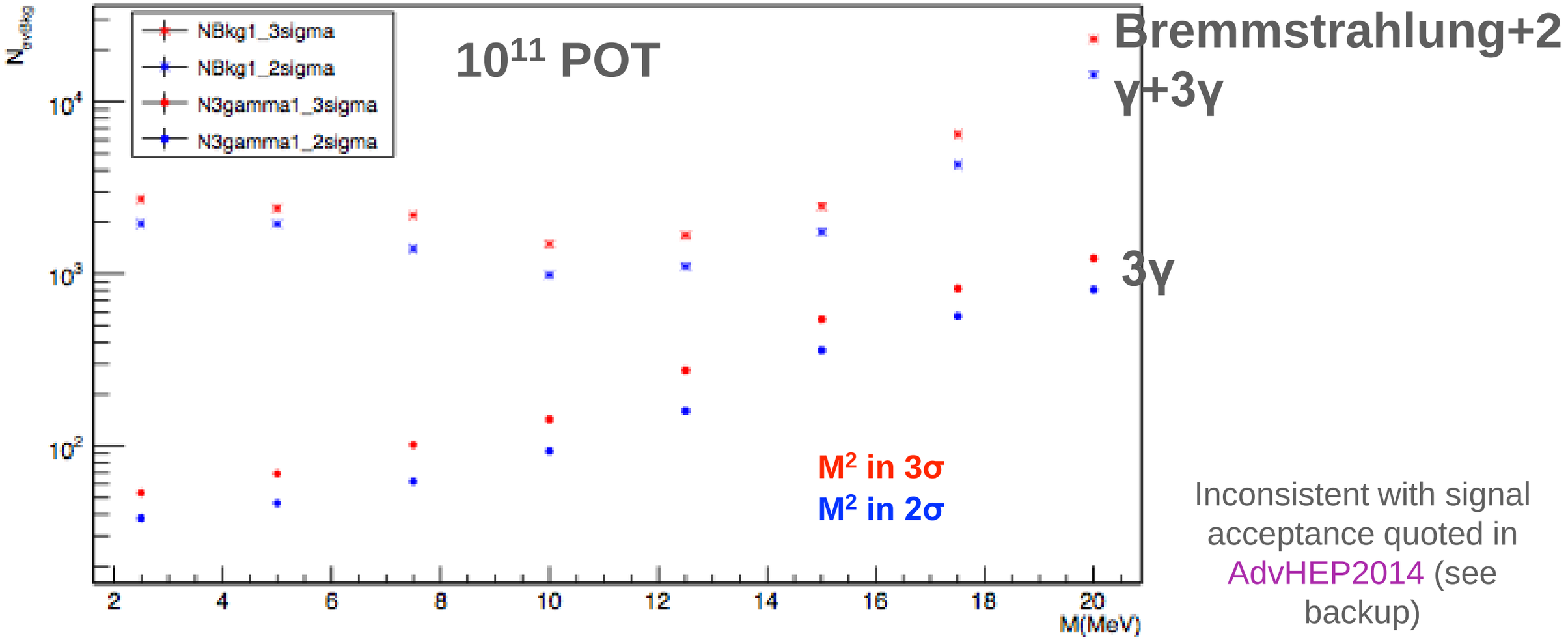
[&& M^2 in 3σ]

[&& M^2 in 2σ]

Inconsistent with signal acceptance quoted in AdvHEP2014 (see backup)

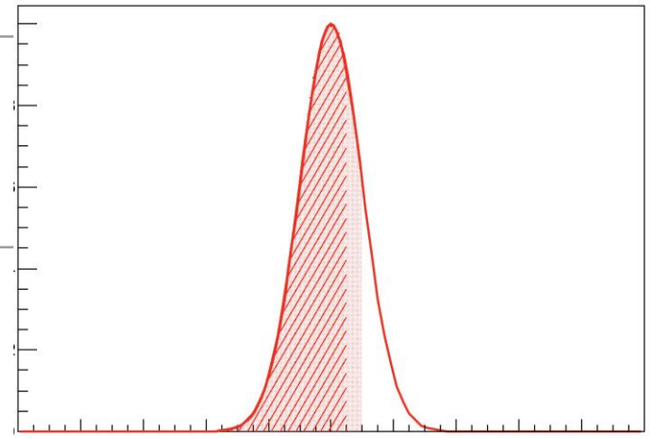
BACKGROUND YIELD VS $M^2_{A'}$

- At 10^{11} POT bremmstrahlung+2γ and 3γ superimposed
- As a function of $M_{A'}$ mass
  - dependence comes only from the M^2 window (resolution)



Inconsistent with signal acceptance quoted in AdvHEP2014 (see backup)

CL LIMITS ON MIXING PARAMETER

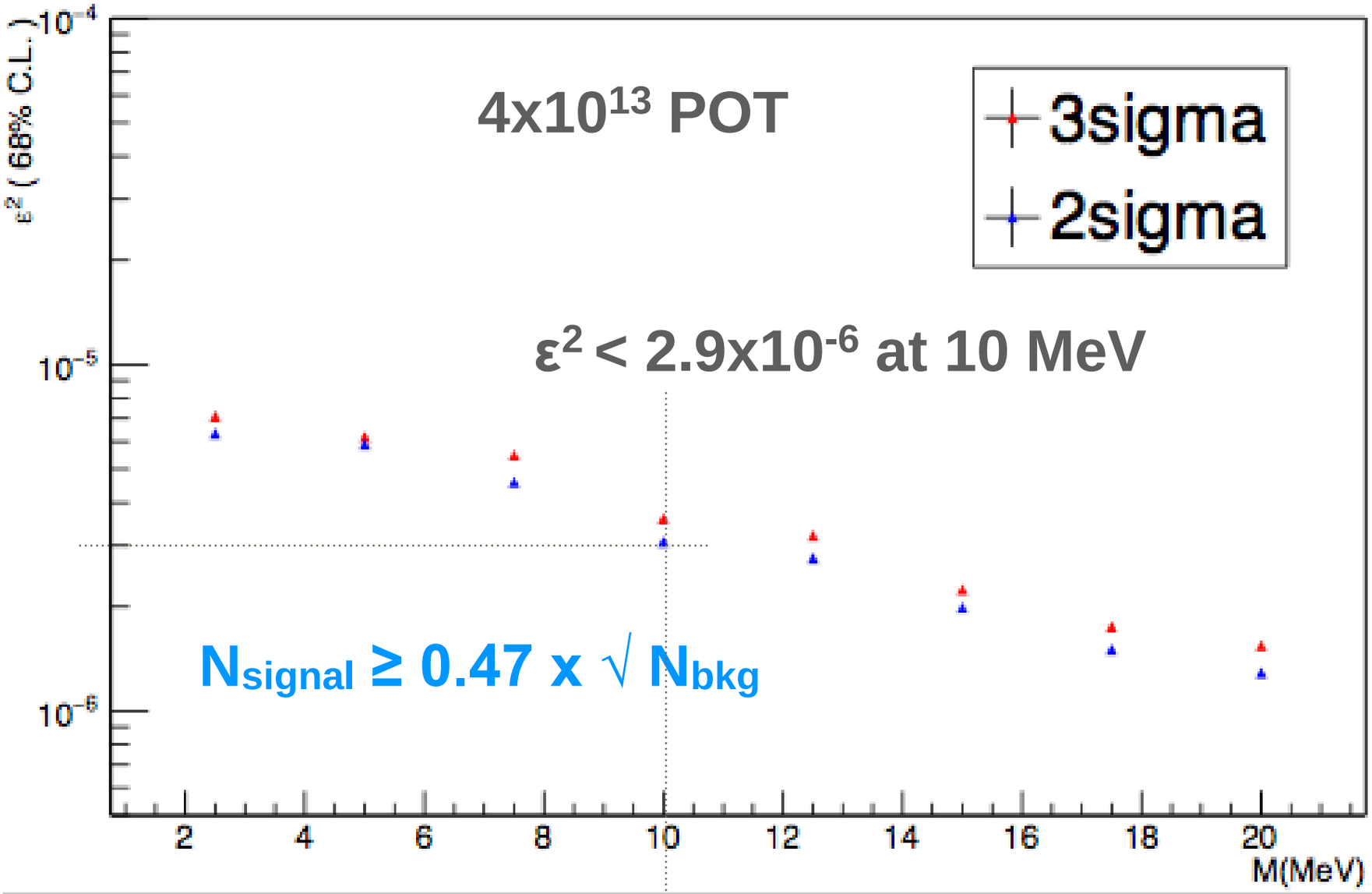


- Vs $M^2_{A'}$

$P\ (\ N_{bkg}^{obs} < N_{bkg}+0.47\ \sqrt{N_{bkg}}\ ) = 68\%$

ε^2 such that $N_{signal}(\varepsilon^2) \geq 0.47\sqrt{N_{bkg}}$ excluded at 68%

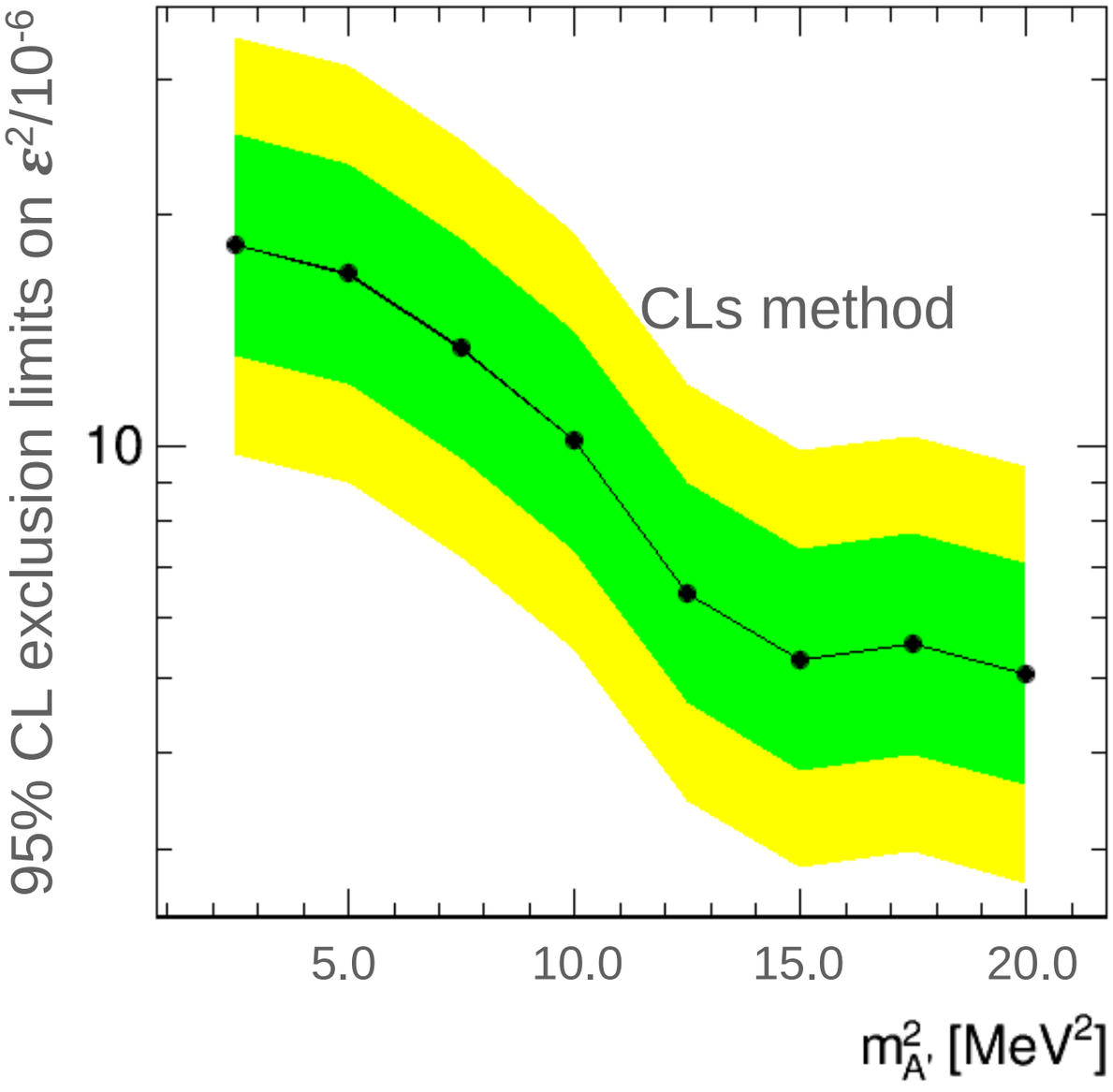
68% CL exclusion limits



68% CL exclusion limits in AdvHEP2014

$\varepsilon^2 < 3x10^{-6}$ in the proposal

EXCLUSION LIMITS - COMPARISON WITH PAST ESTIMATES



AdvHEP2014

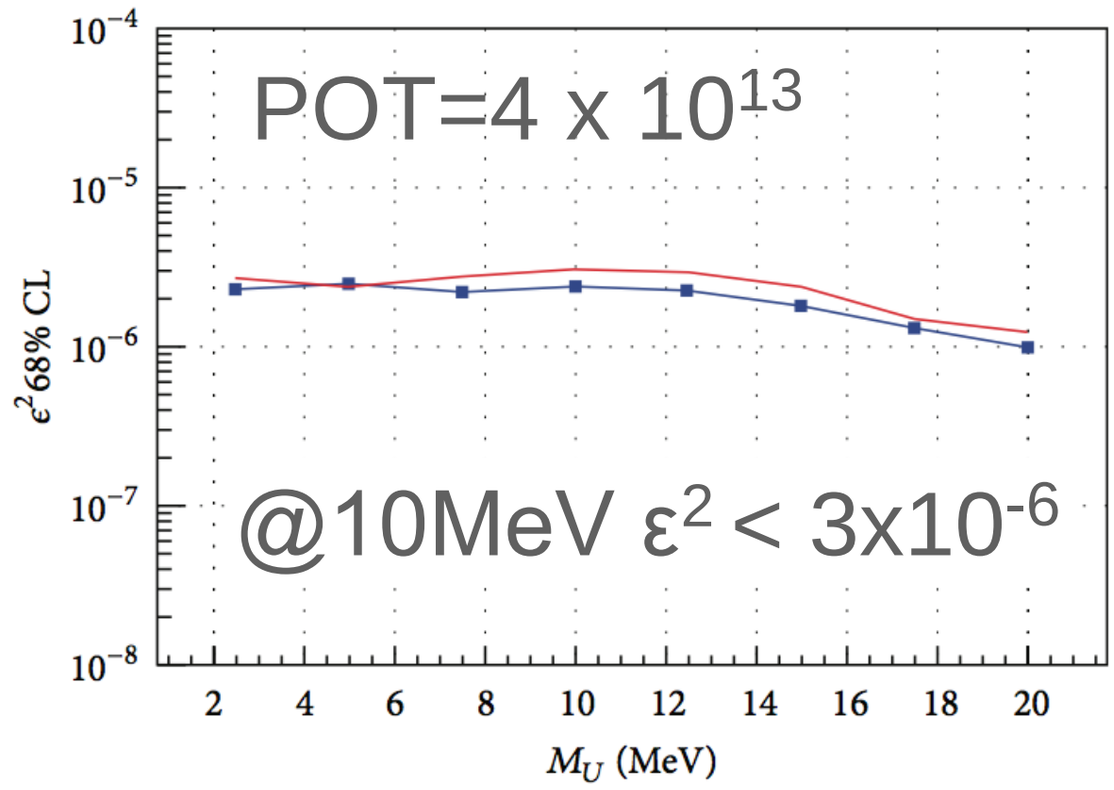


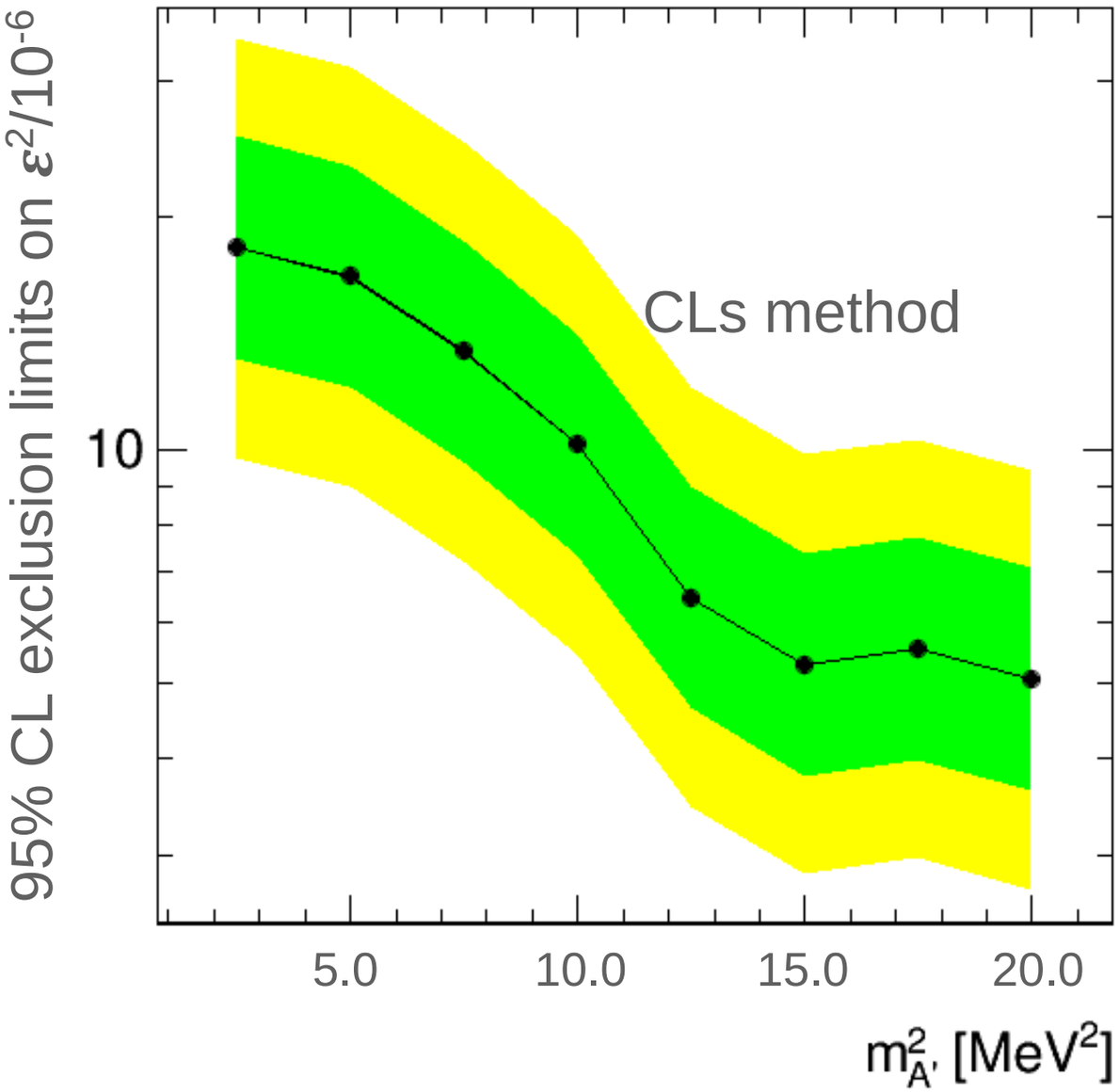
FIGURE 20: Expected exclusion limits in the $\epsilon - M_U$ plane in case of no signal.

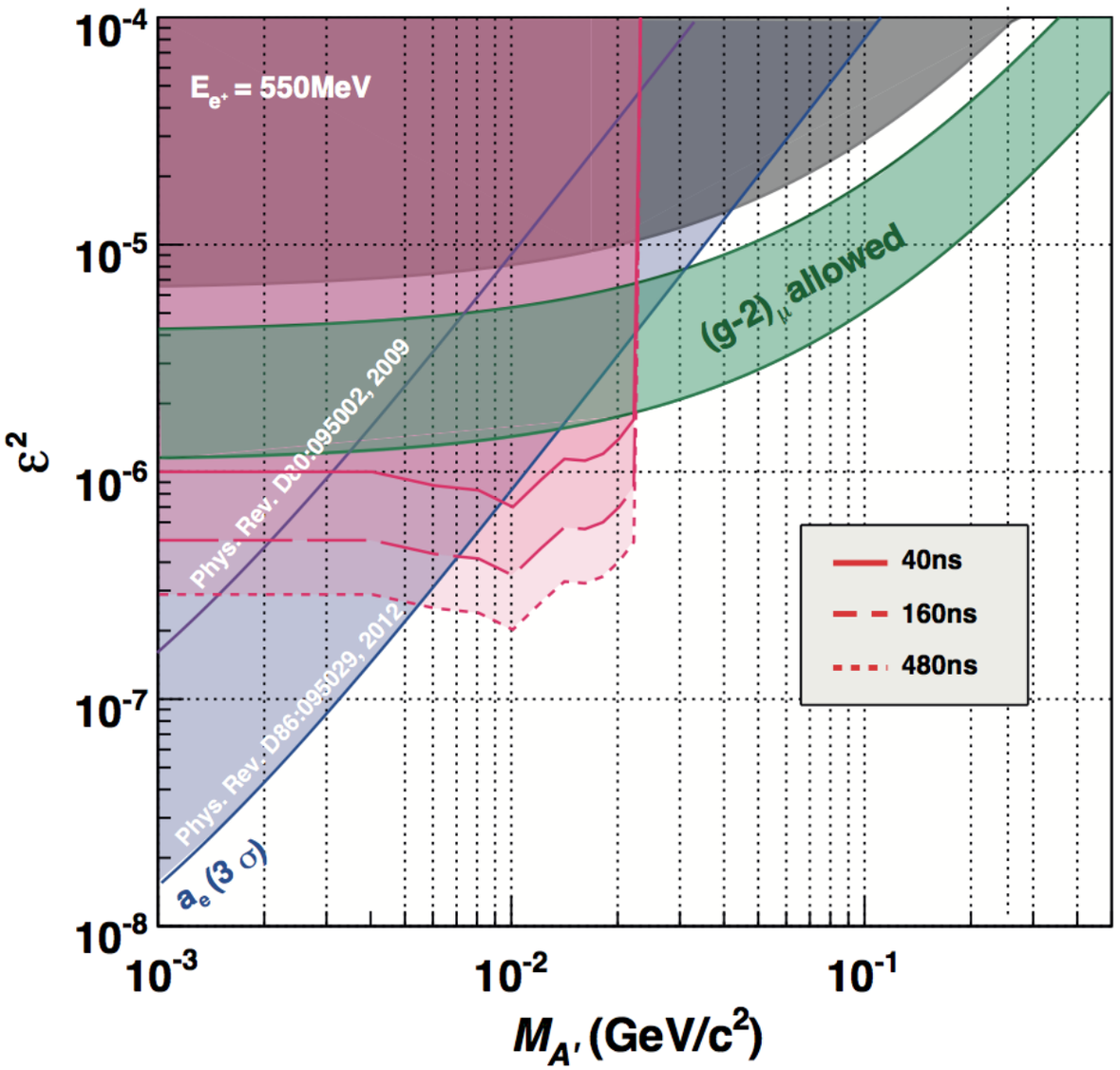
➥ pretty consistent in trend and values

EXCLUSION LIMITS - COMPARISON WITH PAST ESTIMATES

➥why a different trend with $M_{A'}$?

PADME-TP





➥why a different trend in PADME-TP and **AdvHEP2014** ?

beyond the cut-based selection

a trendy approach

A DEEP NEURAL NETWORK FOR A'γ AT PADME

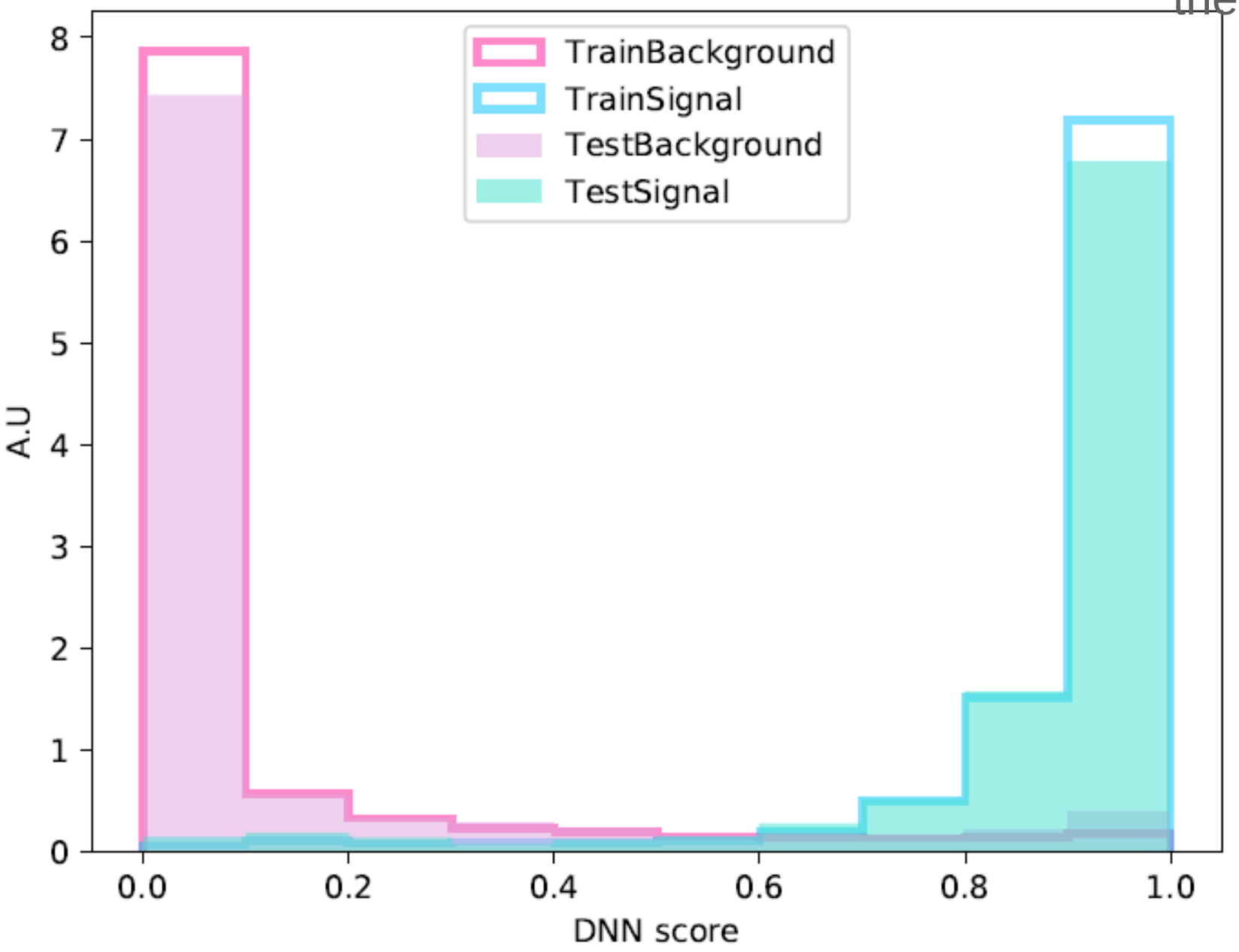
To compare the efficiency of the cut based analysis with DNN efficiency, we'll use a new ntupla with the variables used in the standard analysis:

- In events with no more than 3 ECAL clusters with $E \geq 0.6 \cdot 20MeV$, we store:
  - Number of clusters in ECAL;
  - Number of clusters with $E \geq 0.6 \cdot 20MeV$ in ECAL;
  - $(E_{cl}, X_{cl}, Y_{cl}, t_{cl})$ of leading cluster, subleading cluster and eventually of the subsubleading;
  - Index of PVeto fingers which recorded a signal and time of the hit (finger index and time are energy weighted over all hits with Δt<1.5 ns in nearby fingers).
  - Overall N=55 variables

Neural network structure: width=128 (N. of neurons in one layer), depth=2 (N. Of hidden layers), epochs=200 (maximum N. of iterations in the DNN training process).

Network trained on bremmstrahlung, $2\,\gamma$, $3\,\gamma$ and signal ($M'_A = 10MeV$) with pileup.

DNN OUTPUT



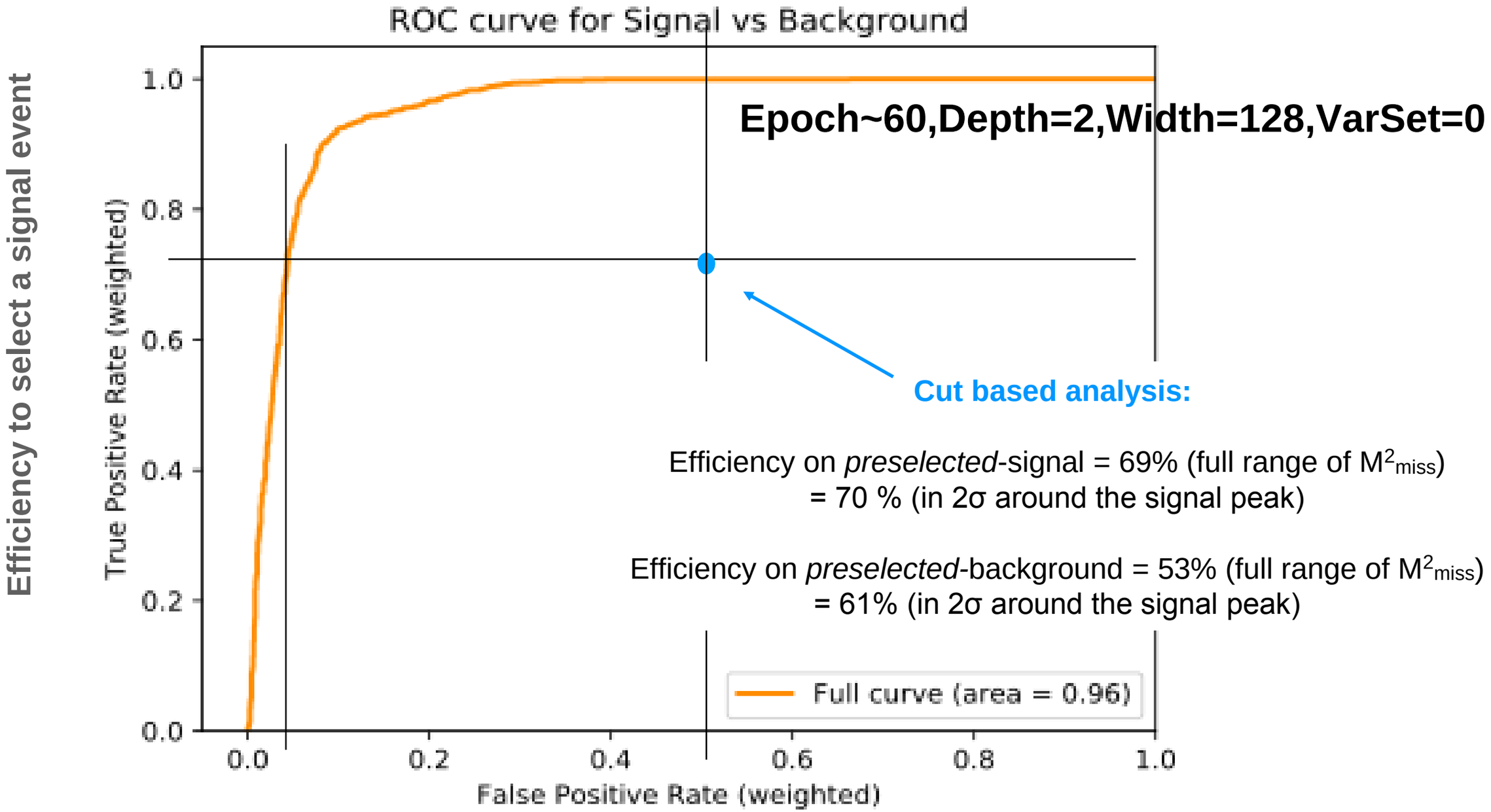
Outuput of the neural network for the training and test samples

Cutting at given value of the DNN score, we get a signal efficiency and corrisponding background rejection

Good separation between signal and background

A Deep Neural Network approach

- For signal (10 MeV) / background discrimination



CONCLUSIONS

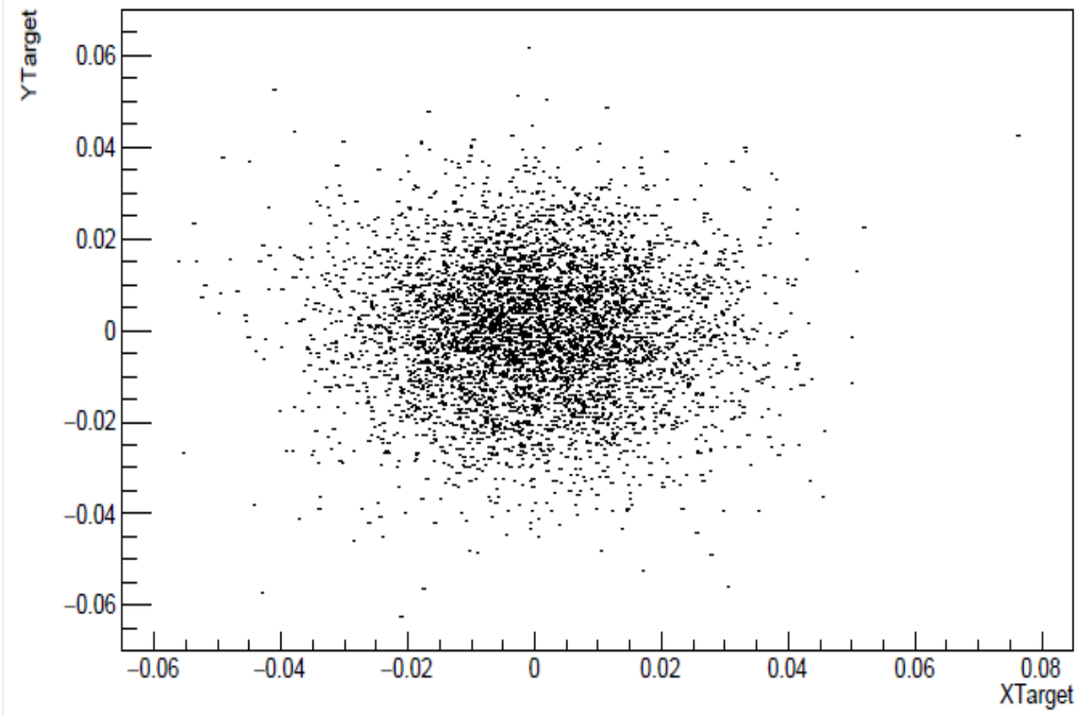
- Simulation and layout are not final.
- Results overall consistent with past studies
  - However many details to be understood
- $4 \cdot 10^{13} POT$ with $5 \cdot 10^{3}$ pileup costraint $\epsilon^2 \lesssim 10^{-5}$
- Info from same detectors not used (SAC, HEPVeto, EVeto)
- Potential for improvement with artificial intelligence based selection
- Modern limit exstruction methodologies excercised.

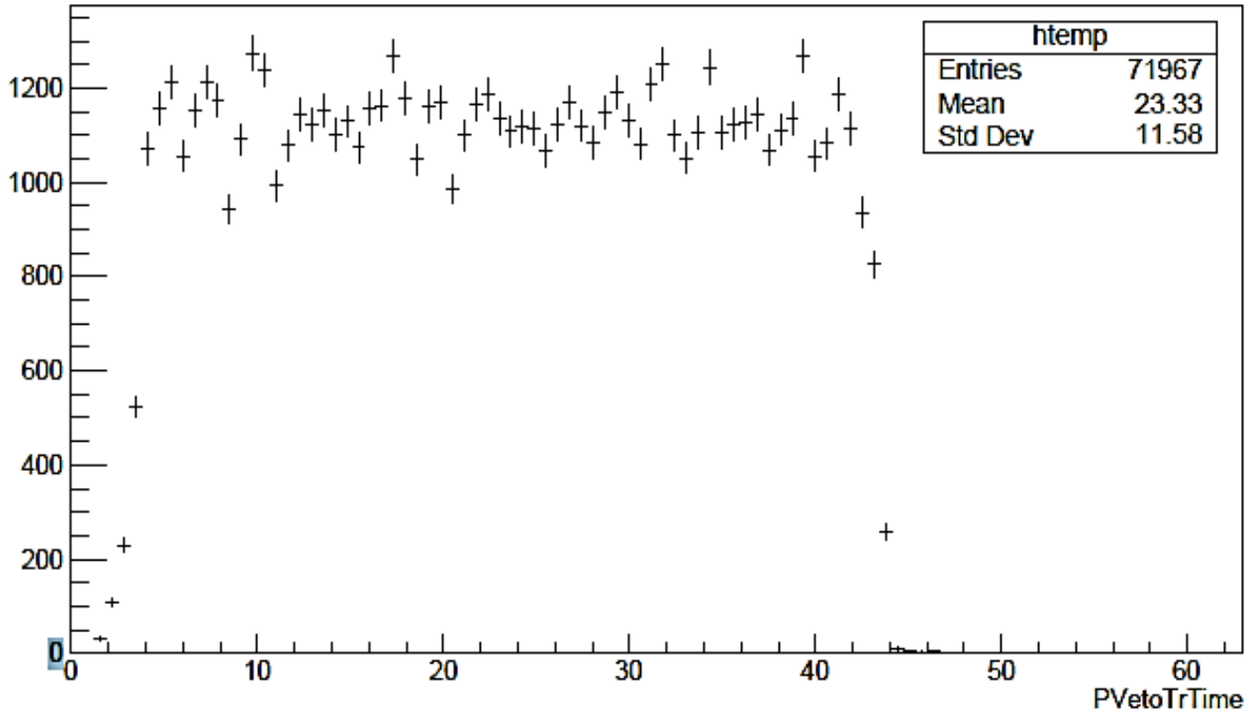
BACKUP material

. . .

THE SOFTWARE SETUP

- PLOTS for
  - pileup $5x10^3$ e+ in 40 ns long bunches,
  - energy spread 1% (for signal, bremmstrahlung, $\gamma\gamma$, NOT for 3γ), divergence 1mrad
  - beam spot at the target

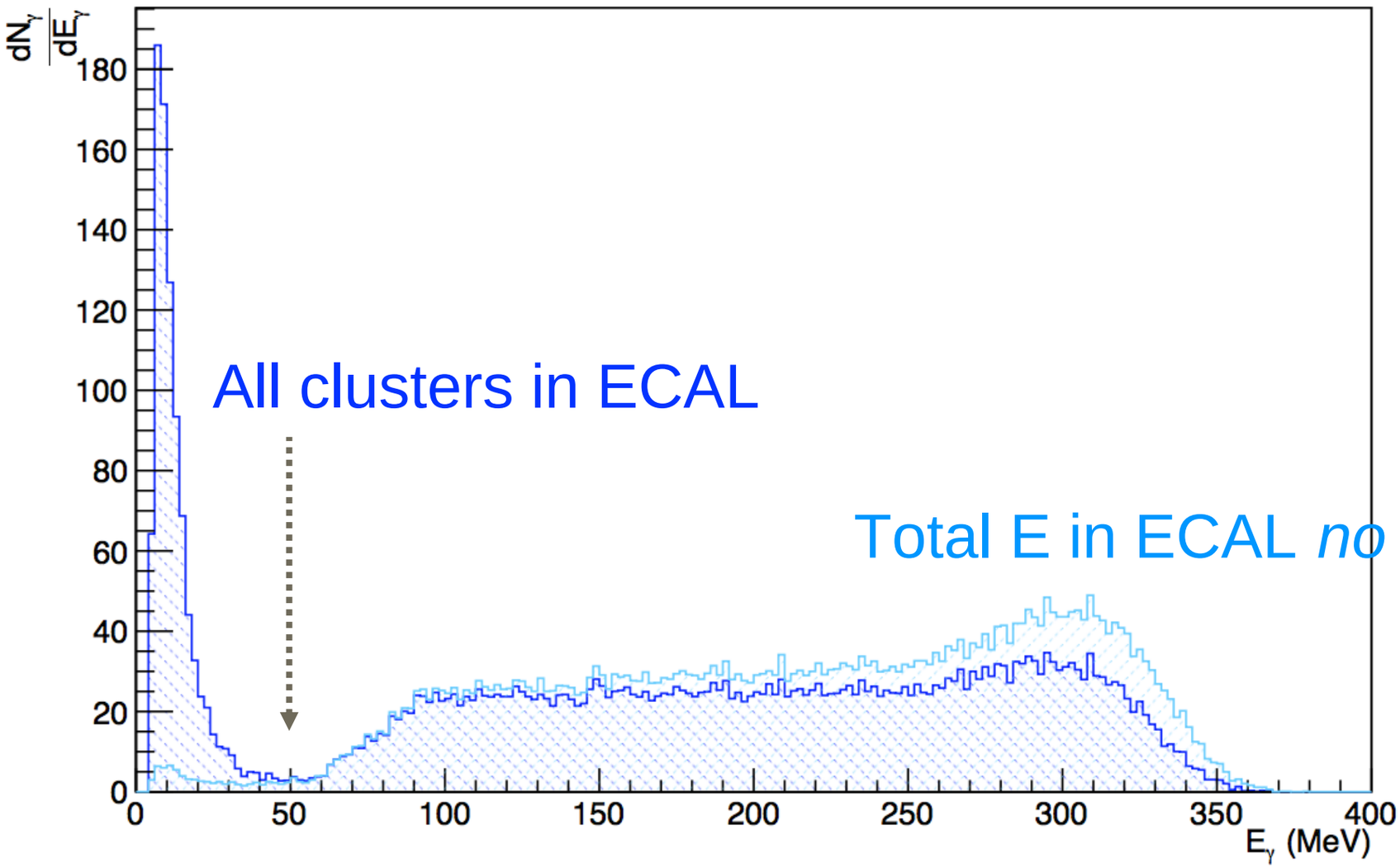




CLUSTERS IN ECAL

Signal $M_{A'}$=10 MeV
no pileup

Energy distribution



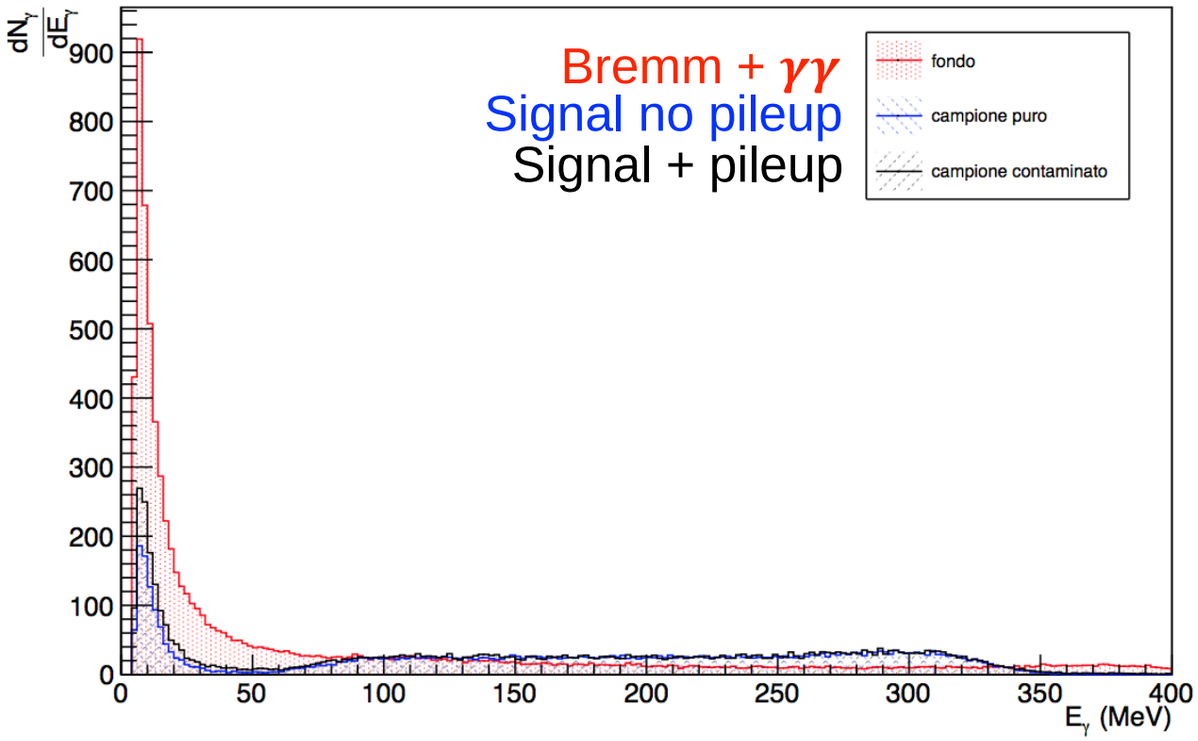
➥ Suggesting Energy threshold of 50 MeV

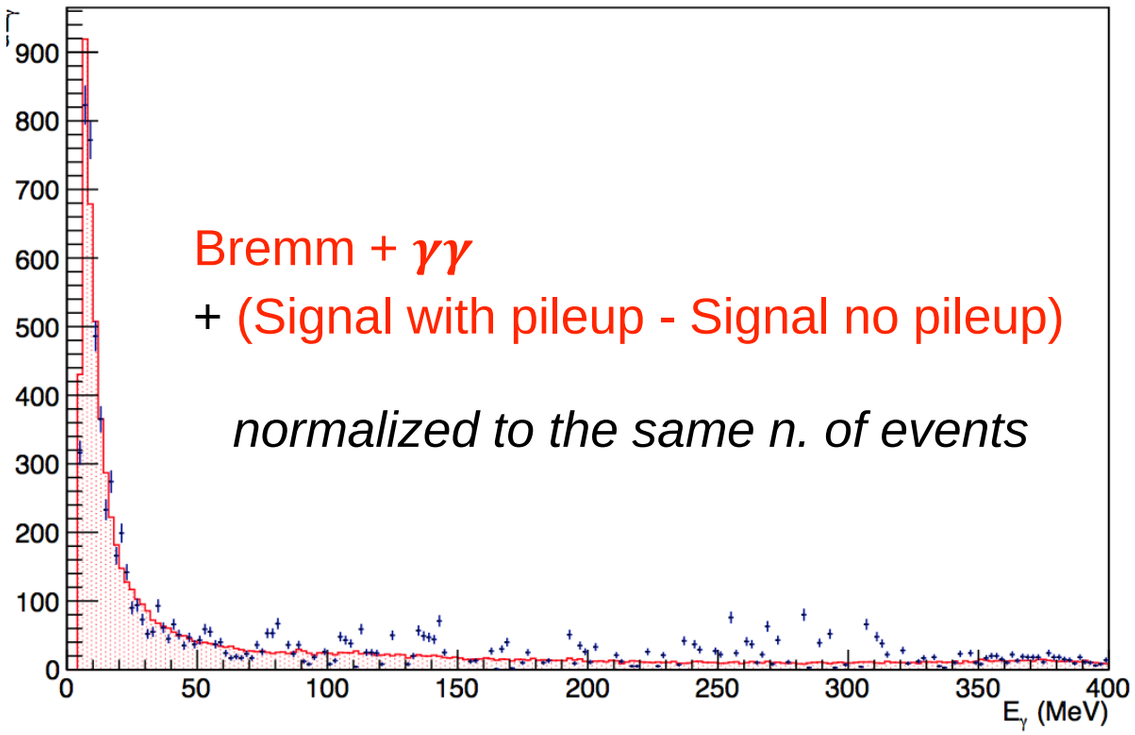
CLUSTERS IN ECAL

Background and
Signal $M_{A'}$=10 MeV (no pileup)

All clusters in ECAL

Energy distribution





Low E tail in the sample of signal with pileup slightly higher than Low E tail in the sample of signal w/o pileup

E distribution for signal w/ pileup - signal w/o pileup compatible in shape with bremmstrahlung+$\gamma\gamma$

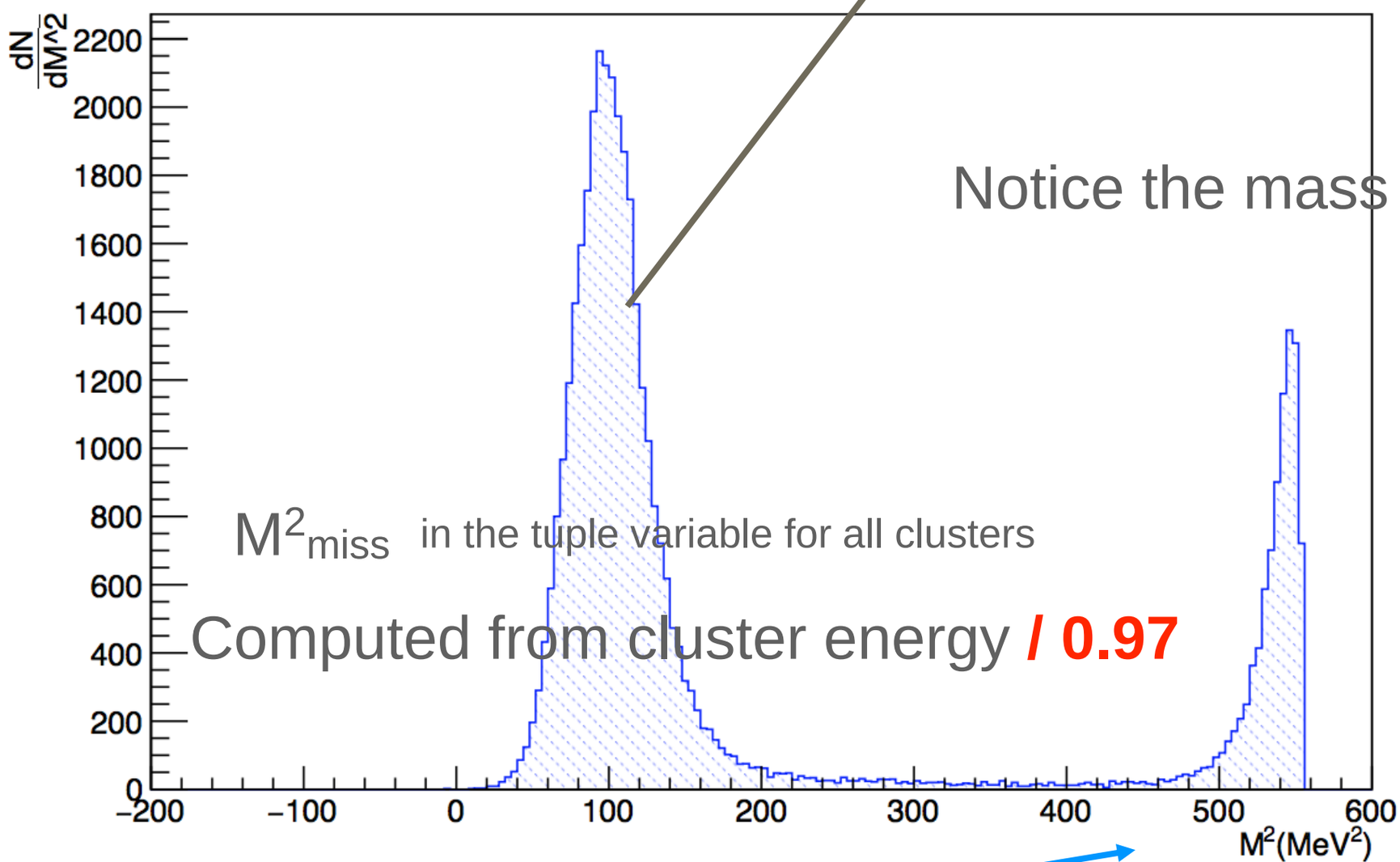
➥ Suggesting Energy threshold of 50 MeV

CLUSTERS IN ECAL

Signal M_A'=10 MeV
no pileup

All clusters in ECAL
$\sqrt{(x^2+y^2)}$ vs E

mass dependent
kinematic constraint



Notice the mass shift w.r.t.

M^2_{miss} in the tuple variable for all clusters

Computed from cluster energy **/ 0.97**

low E contribution at all R

How to define the signal photon ?

- select events with
  - only 1 ECAL Cluster in ECAL and E>50MeV
  - only 1 ECAL Cluster with E>50 MeV
  - no more than 3 ECAL clusters with E > 50MeV, leading cluster = signal γ
  - 1 corrected cluster with **E>50 MeV**, no other clusters in ECAL
  - 1 corrected cluster with E>50 MeV, other clusters in ECAL with E<50 MeV allowed if distance in space > 10 cm and time > 2,5ns

METHOD	ε no-pileup	ε w/pileup	1/ε for background
only 1 cluster	0.383	0.241	2183.12
only 1 cluster w/ E>50MeV	0.446	0.302	1607.11
1≤Ncl≤3 w/ E>50MeV, use lead.	0.446	0.309	569.73
1 corr. w/ E>50MeV, no others	0.447	0.301	1762.08
1 corr. w/ E>50MeV, allow distant cl. E<0.6x50 MeV	0.434	0.290	1840.98
1 corr. w/ E>50MeV, + up to 2 with E>0.6x50 MeV	0.447	0.310	607.61
1 corr. w/ E>50MeV, + up to 2 with E>0.6x50 MeV if distant in space/time	0.434	0.297	1794.12

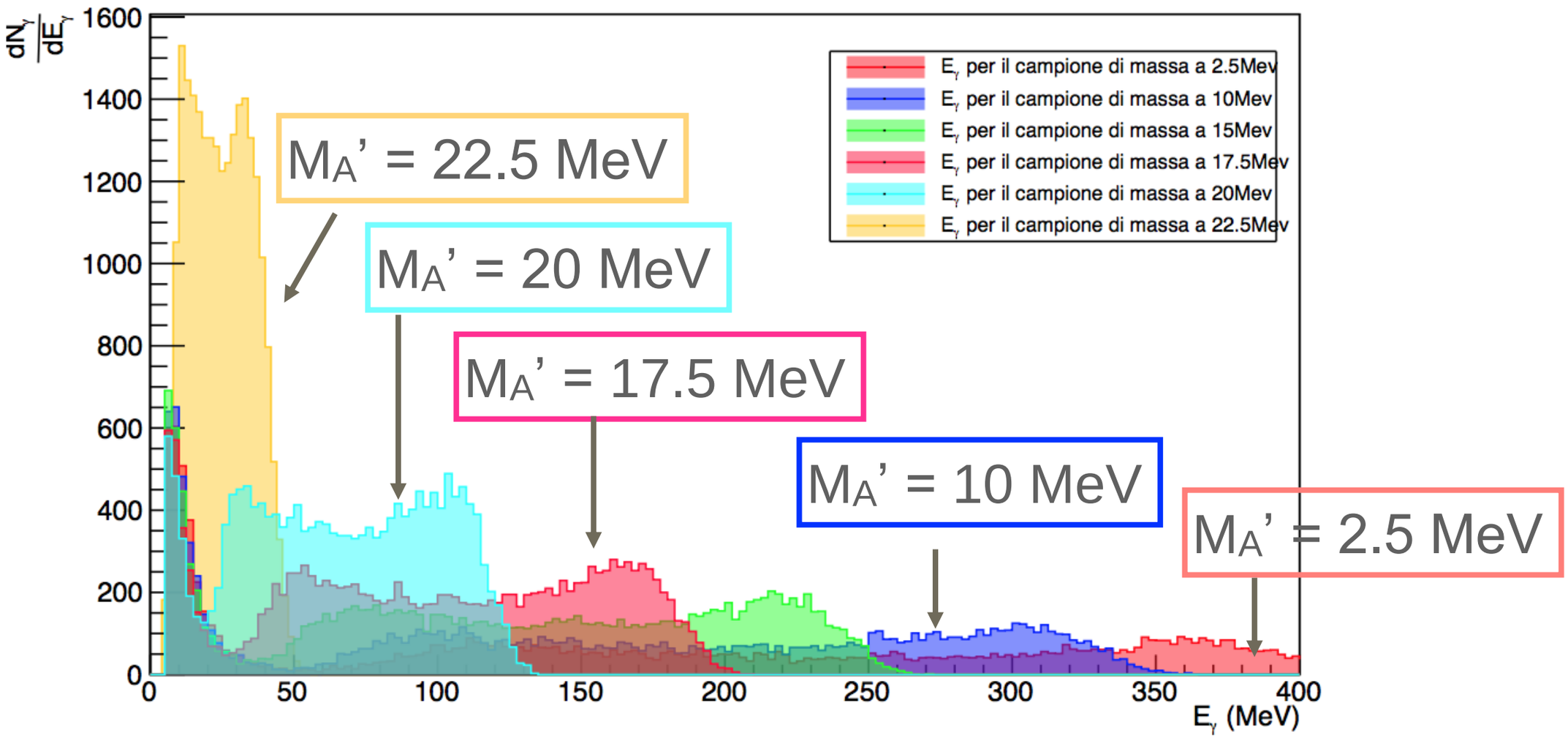
best performance

These efficiencies include angular cuts on the γ and bremm. veto cuts

PHOTON DEFINITION VS $M_{A'}$

Signal
no pileup

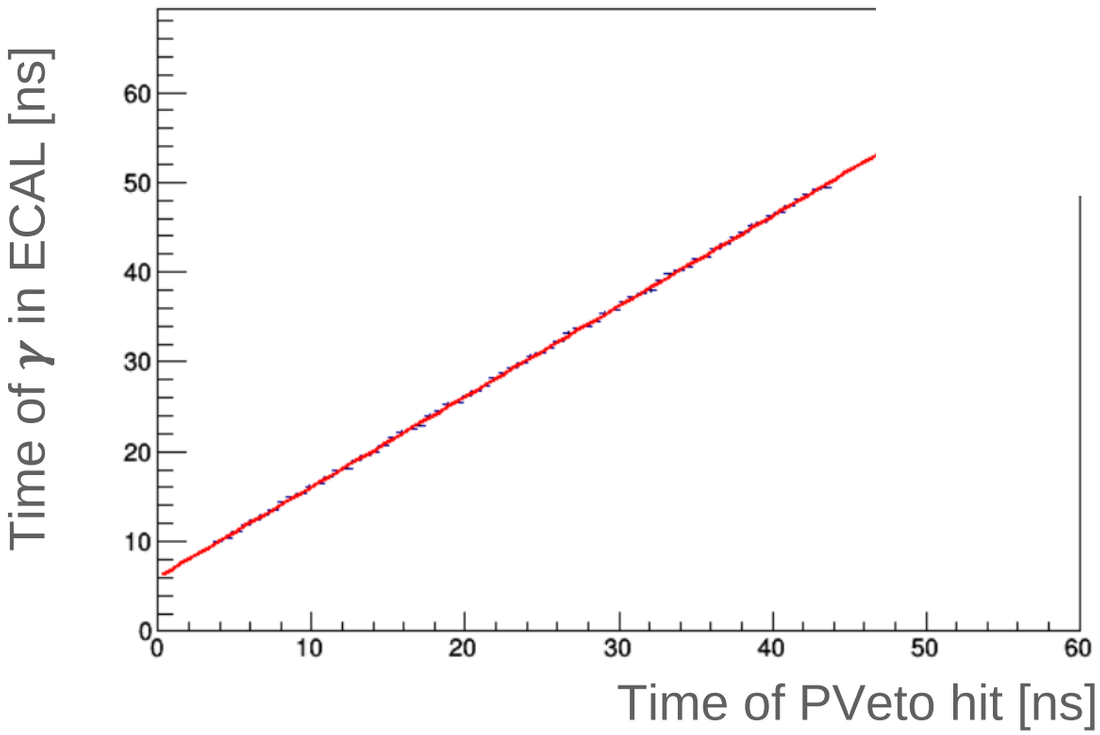
Energy distribution for various A' masses

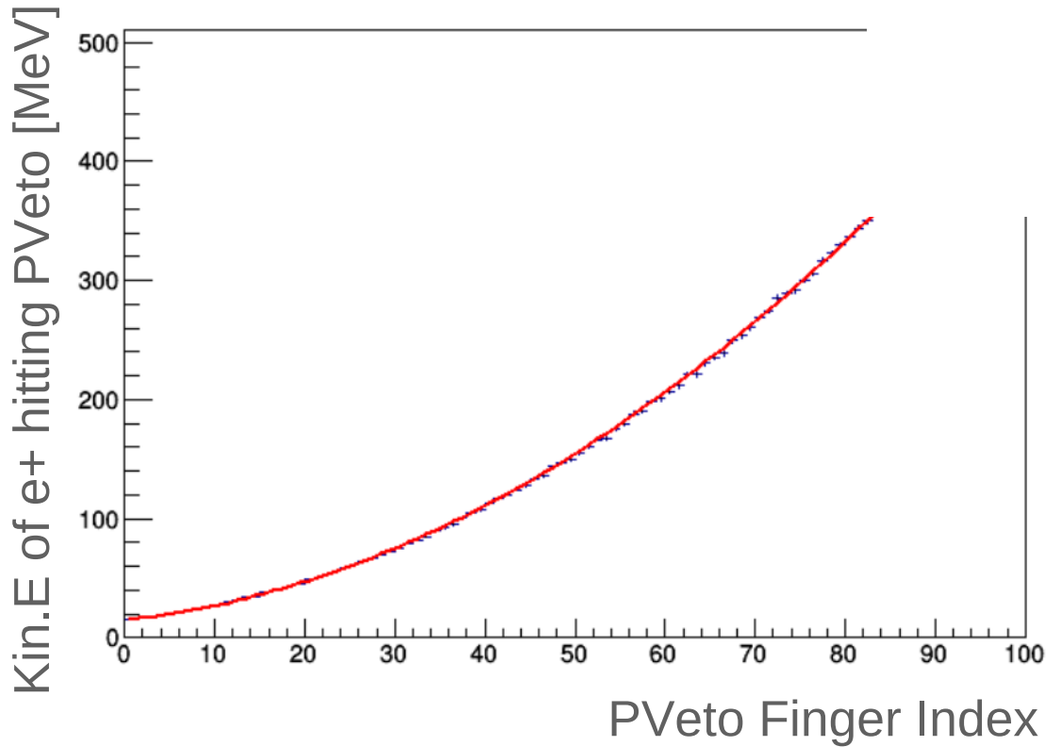


➥ for $M_{A'}$ >15 MeV loss of efficiency if $E_{threshold}$ = 50 MeV

BREMMSTRAHLUNG REJECTION CUTS

- Bremmstrahlung + $\gamma\gamma$ sample
- clear correlations:

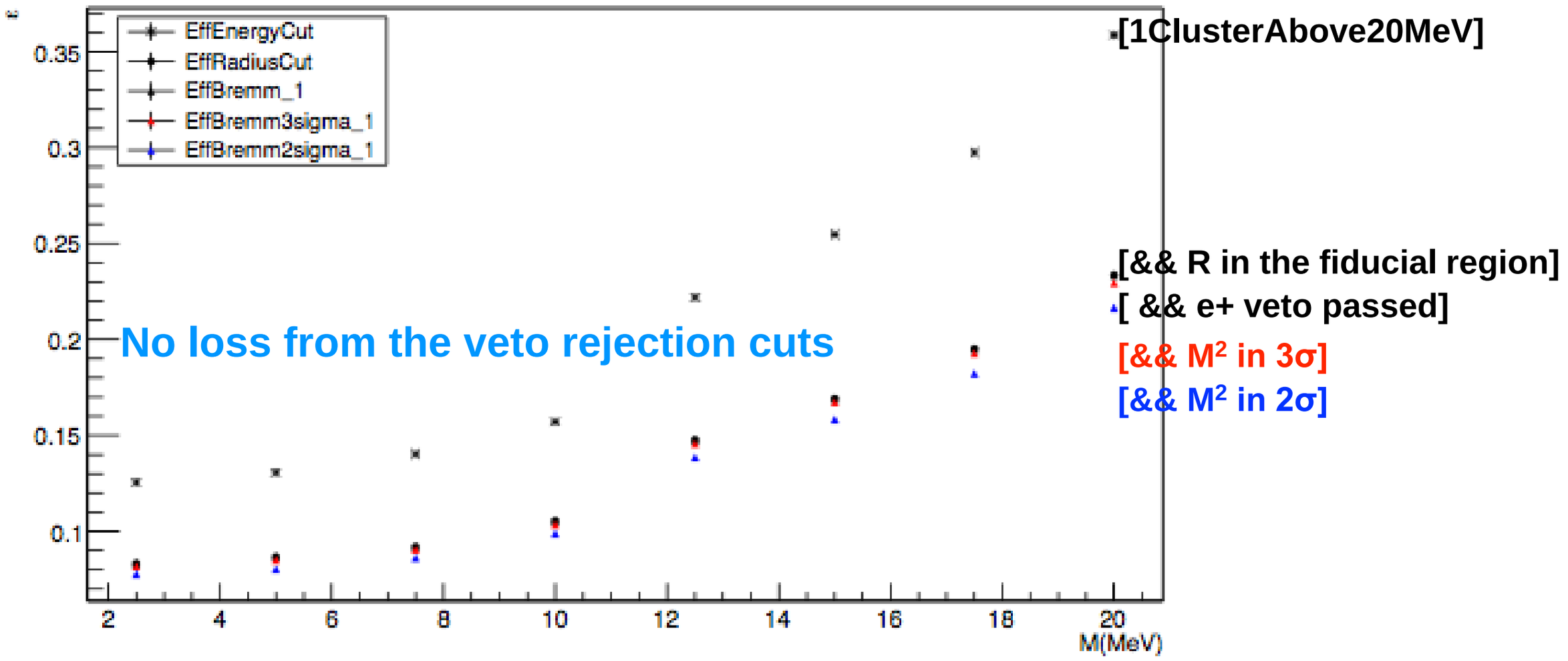




- no PVeto hits with
  - T_{PVeto}-T_{γ} compatible with the correlation observed within 1.5ns
  - in finger such that 500 MeV < Kin.E(finger index)+E_{γ} < 650 MeV

SIGNAL [NO PILEUP] IDEAL-EFFICIENCY

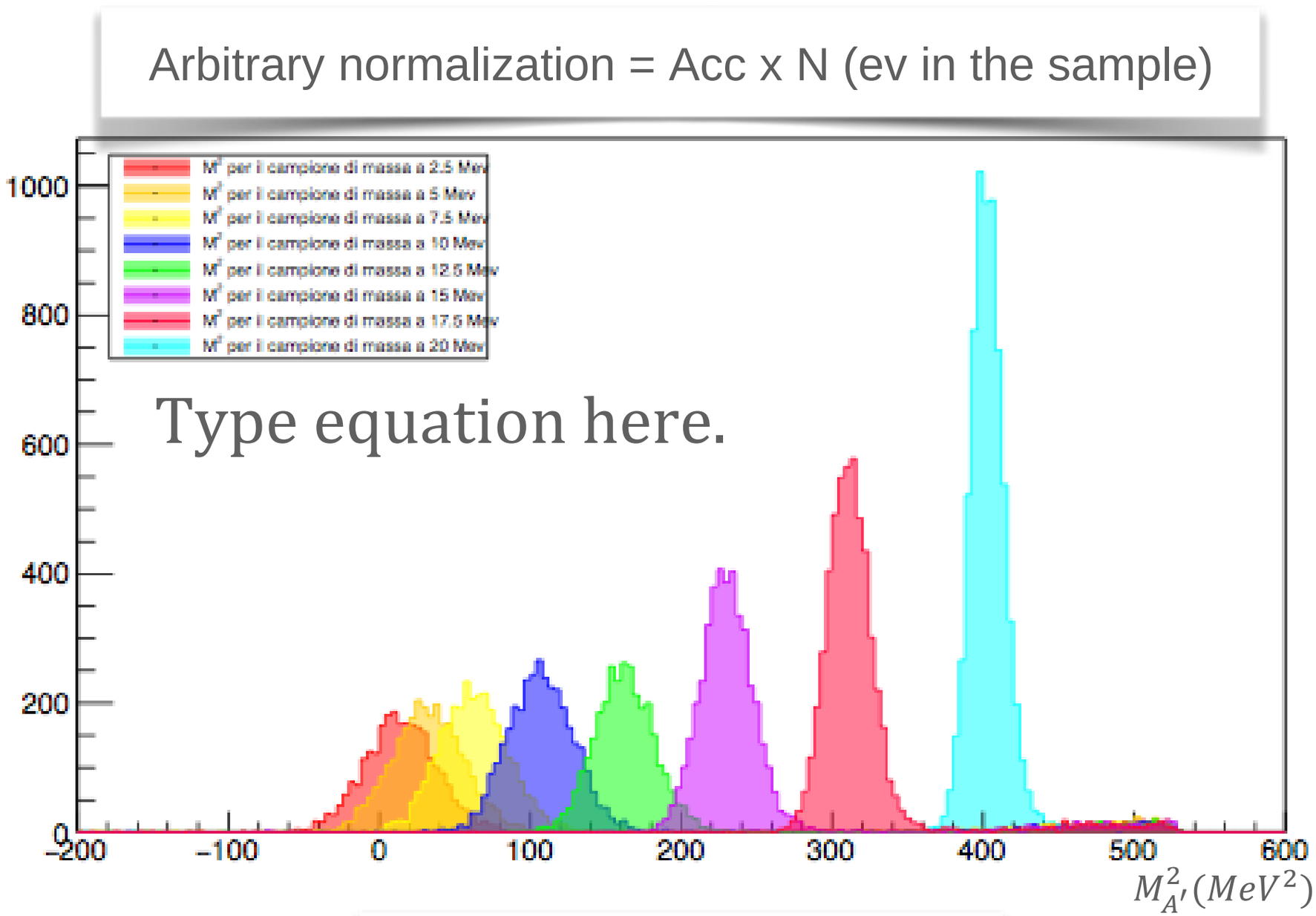
- As a function of $M_{A'}$ mass
- 1) For 1 cluster selection above threshold **[1ClusterAbove20MeV]**
- 2) For 1) & R in the fiducial region **[&& R in the fiducial region]**
- 3) For 2) and positron veto cuts **[&& e+ veto passed]**
- 4) For 3) and in 3 and 2 sigma around the signal peak region **[&& M^2 in 3σ]** **[&& M^2 in 2σ]**



SIGNAL RESOLUTION

- Signal samples **with pileup**

Arbitrary normalization = Acc x N (ev in the sample)



Type equation here.

After the positron-veto cuts

10^{11} POT COMPARING EXPECTED BACKGROUND

- **in 10^{11} POT**: 180000 bremm+2γ, 6300 3γ (entire spectrum)
  - 1300 and 138 in 3 sigma => **1440** Total background and **138** 3γ

total bkg in the proposal:

200

1/2 target thickness -> **400 expected in MC, in disagreement with 1440 observed**

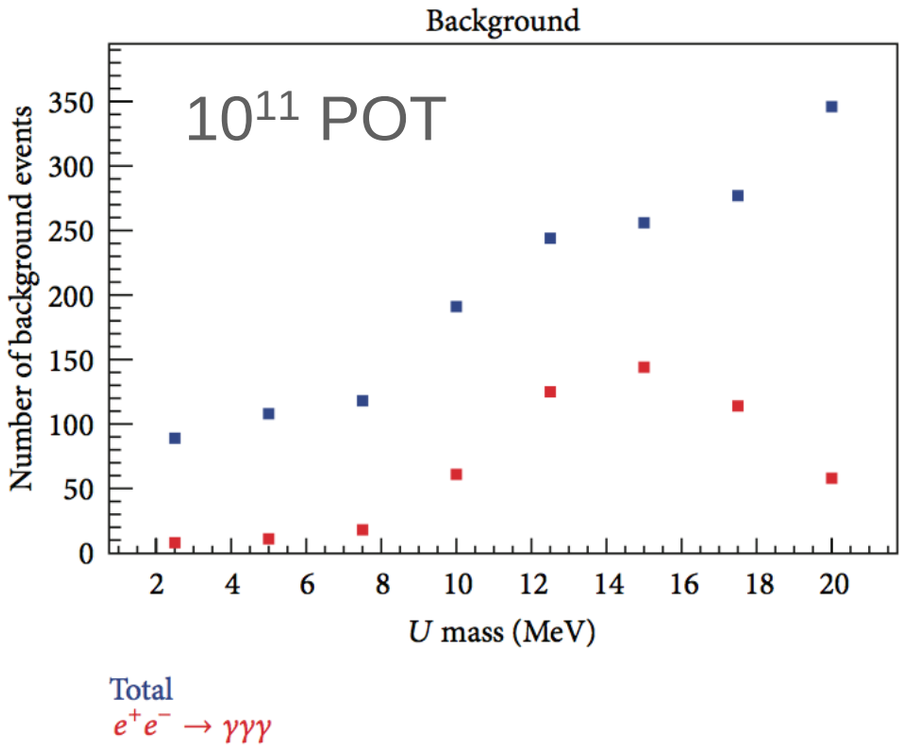


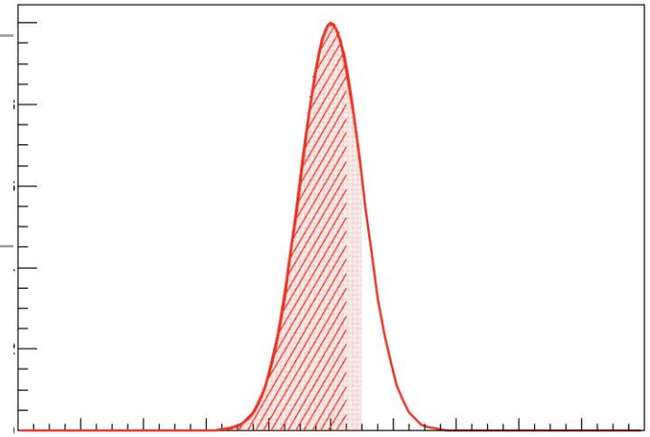
FIGURE 19: Background contribution as a function of the U boson mass.

3γ in the proposal:

60

1/2 target thickness -> **120 expected in MC, in agreement with 138 observed**

CL LIMITS ON MIXING PARAMETER



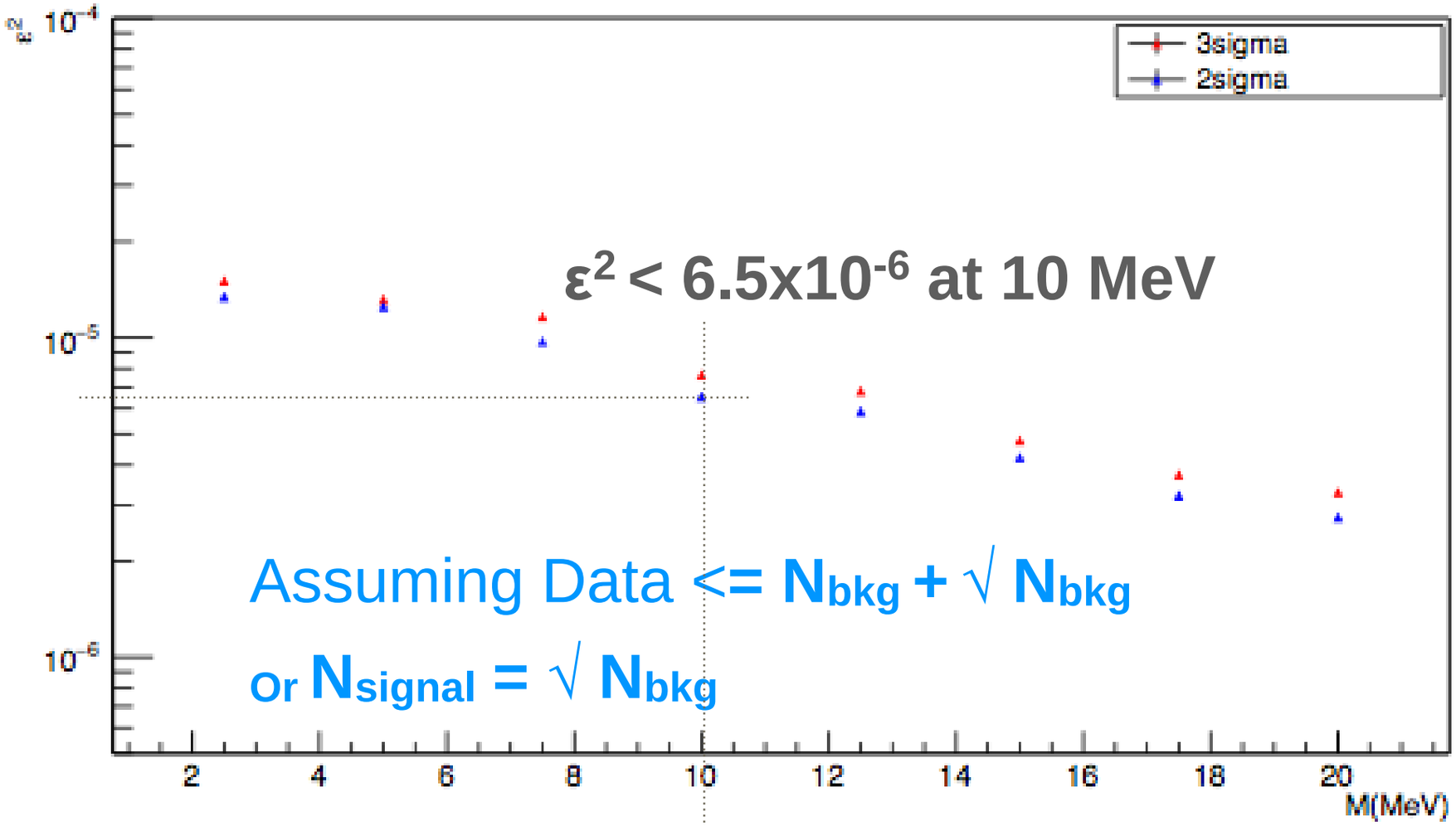
- Vs $M^2_{A'}$

$P\ (N_{bkg}^{obs} < N_{bkg}+\sqrt{N_{bkg}}) = 84\%$

ε^2 such that $N_{signal}(\varepsilon^2) \geq \sqrt{N_{bkg}}$ excluded at 84%

84% CL exclusion limits

$4x10^{13}$ POT



68% CL exclusion limits in AdvHEP2014

$\varepsilon^2 < 3x10^{-6}$ in the proposal

SELECTION CUTS

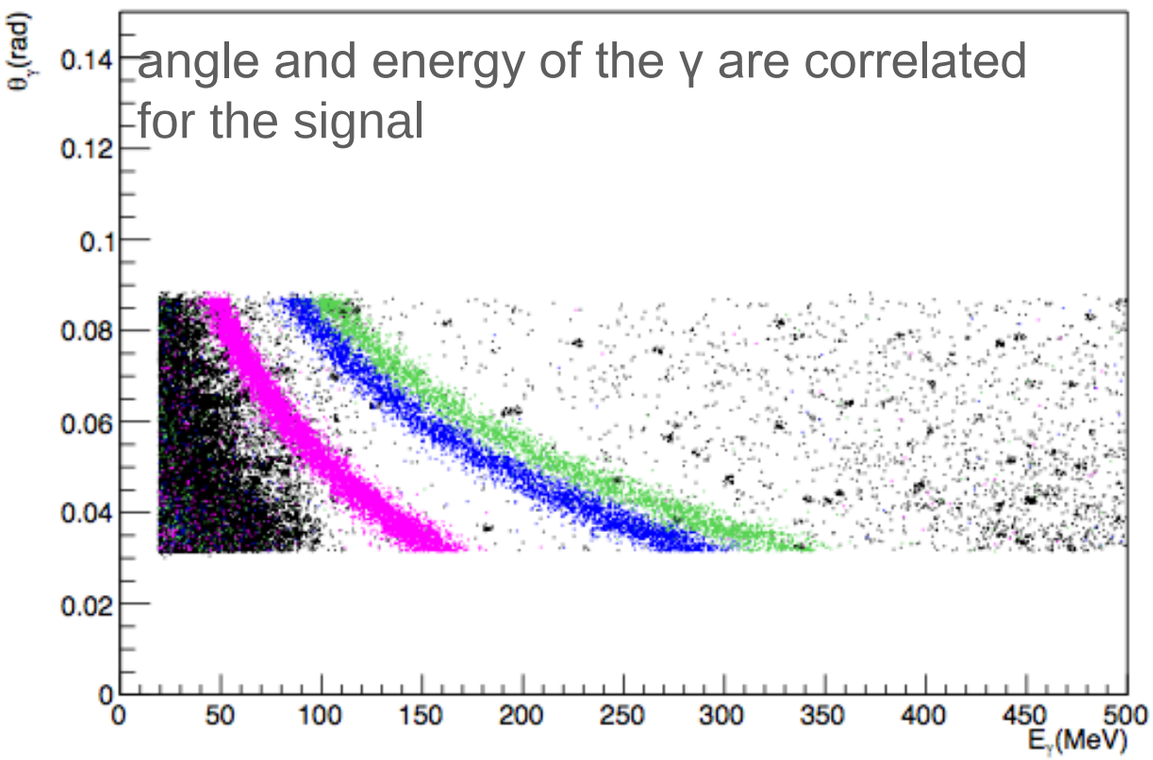
- 1 ECAL cluster with E > 20 MeV -> photon candidate
  - energy in ECAL at ΔR<10.0 cm and Δt<2.5 ns is summed to the ECAL cluster
    - energy, position in ECAL and time are re-evaluated
  - allowing for other ECAL clusters in the event[bunch] with E< 0.6x20MeV and Δt > 2.5 ns and ΔR > 10 cm from the selected cluster

- Radius in 94.5 - 262.5 mm (center of the cluster must not lie in the 2 innermost or outermost rings of crystals)

- e+ Veto Cut (γ-e+ in time [2ns] e+ energy+ECAL cluster energy in 500-650 MeV)

- no A'-mass dependent cuts
- no use of SAC, HEPVeto, EVeto

CUTTING ON E_γ BASED ON $M_{A'}$ HYPOTHESIS



After the positron-veto cuts

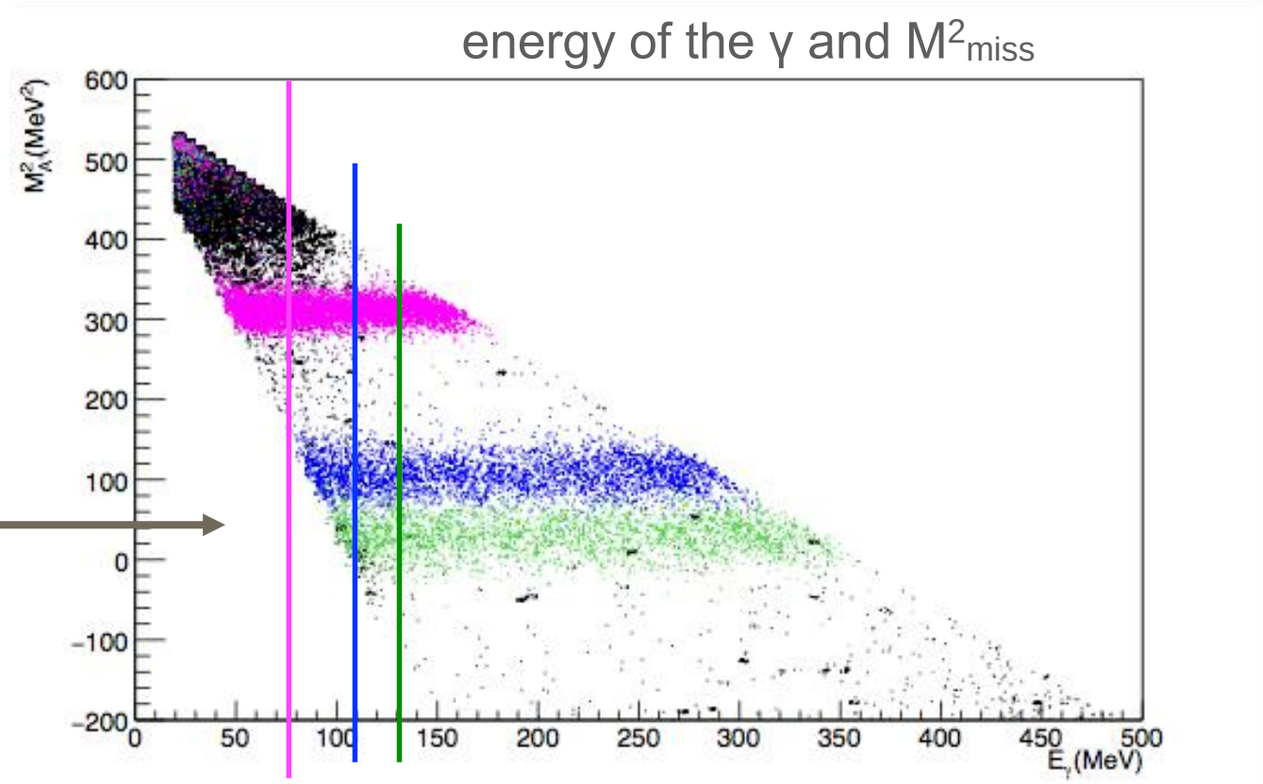
$M_{A'}$ = 5 MeV
$M_{A'}$ = 10 MeV
$M_{A'}$ = 17.5 MeV

In black bremmstrahlung+$\gamma\gamma$

Requiring compatibility with the E vs θ correlation (depends on $M_{A'}$) does not reduce the number of background events under the signal peak

Can a sharp cut (depending on $M_{A'}$) on E_γ enhance the sensitivity ?

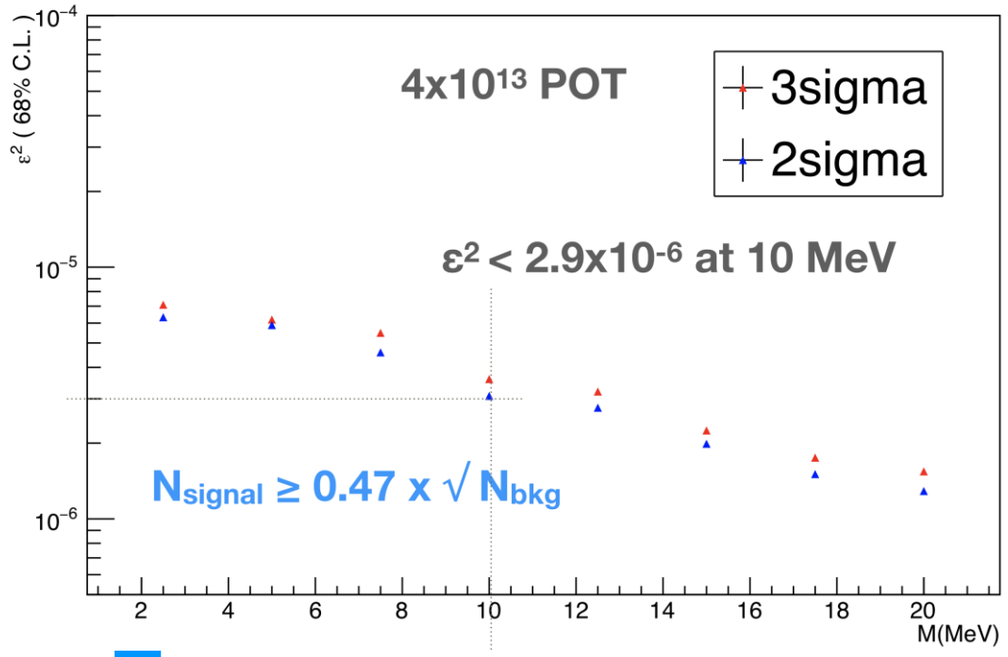
E_γ min. defined (depending on $M_{A'}$) to retain a constant (vs $M_{A'}$) fraction of events (70%, 80%, 90%)



$M_{A'}$ -DEPENDENT CUT ON E_γ

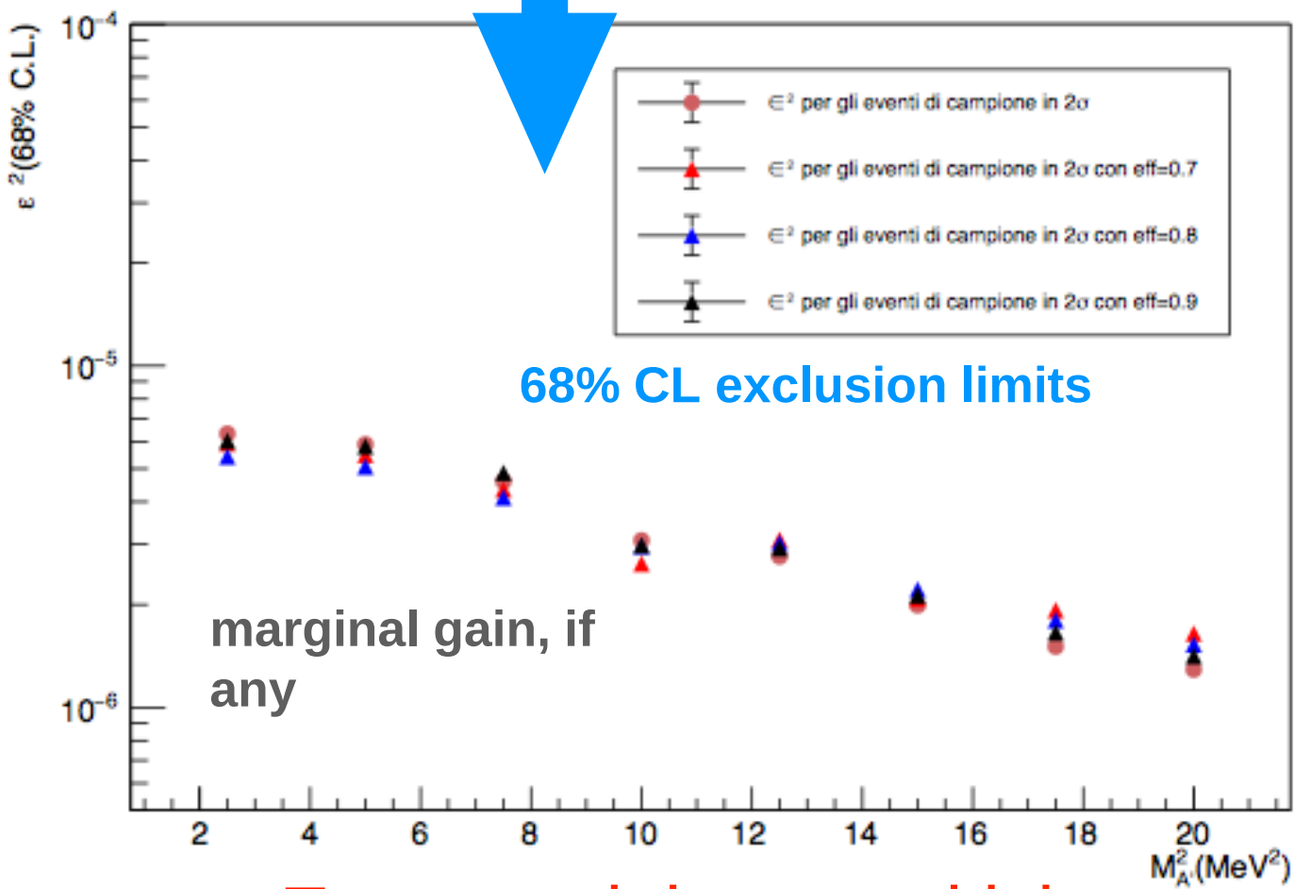
- 4 variations of the γ energy threshold:
  - Defined by requiring the on the signal (w.r.t. the sample of events surviving the bream-veto cut) =
    - 70%
    - 80%
    - 90%
    - 100 %

68% CL exclusion limits



ε² < 2.9x10⁻⁶ at 10 MeV

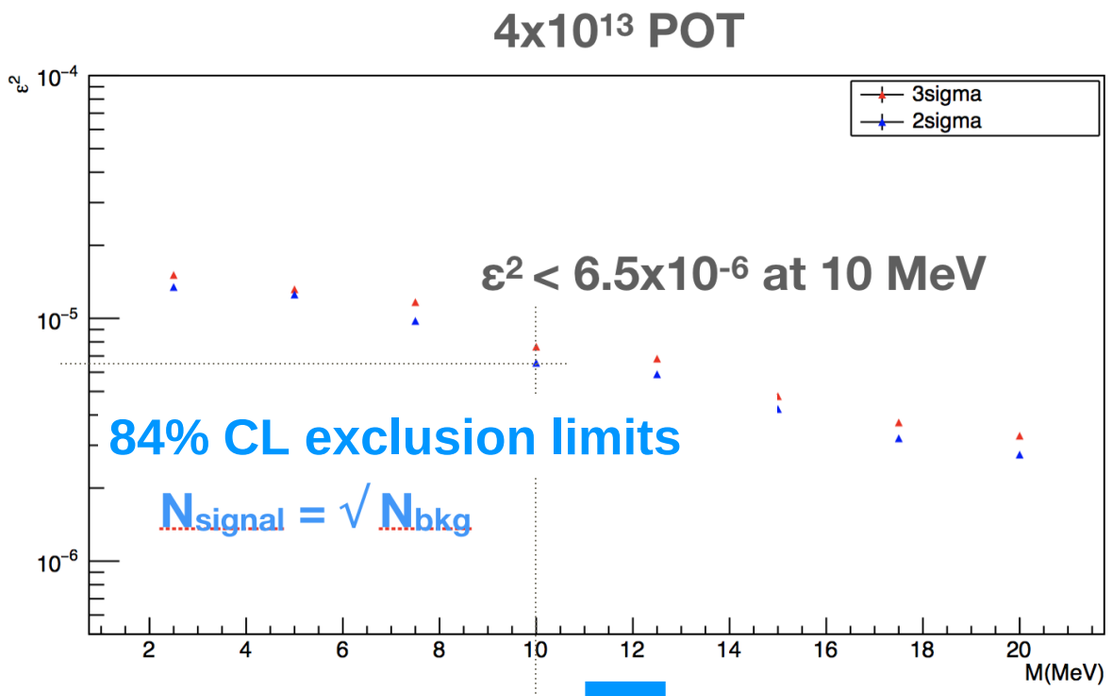
ε² <~ 2.7x10⁻⁶ at 10 MeV

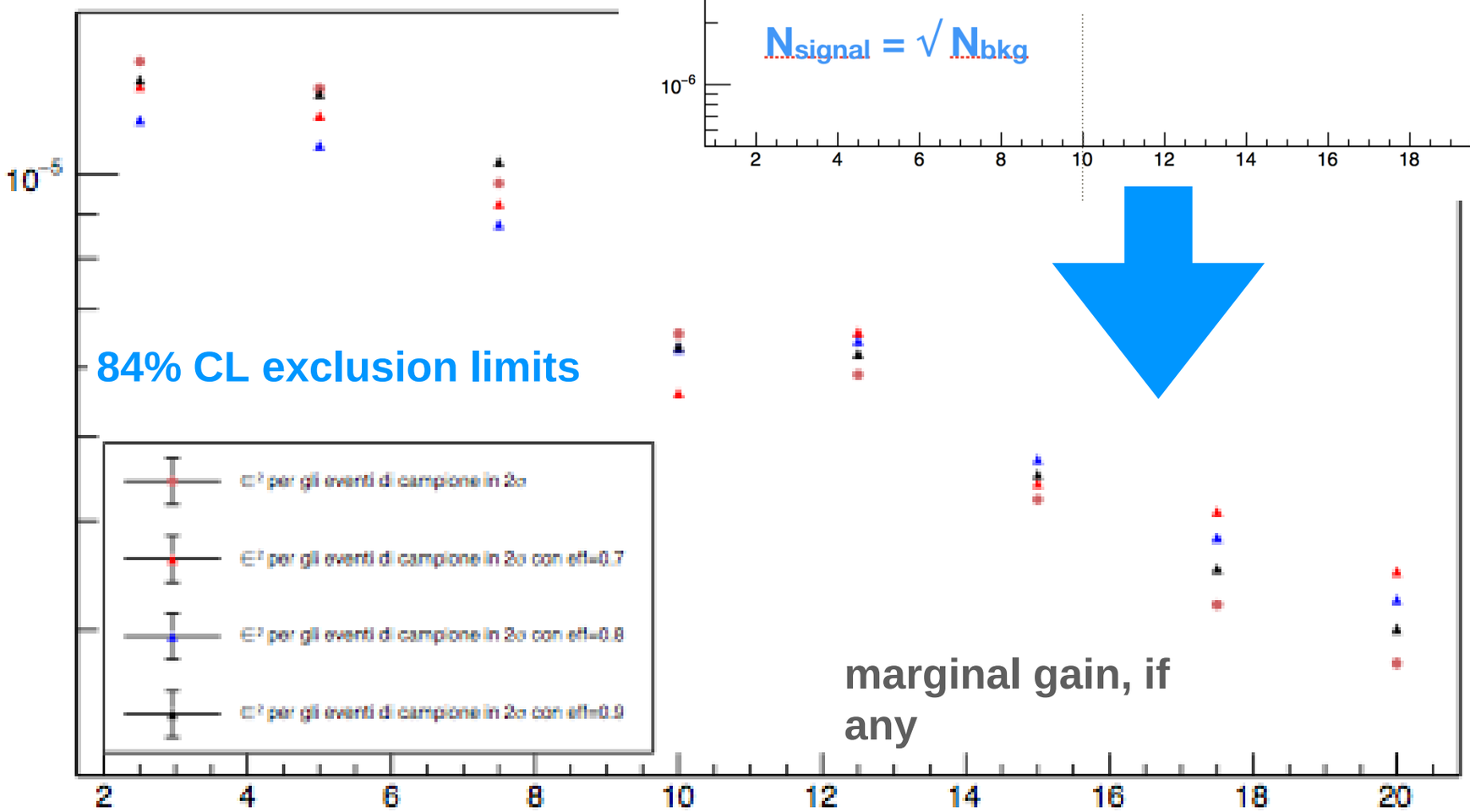


➥ $M_{A'}$ dependent cut on $E\gamma$ not gaining sensitivity

$M_{A'}$ -DEPENDENT CUT ON E_γ

- 4 variations of the γ energy threshold:
  - Defined by requiring the on the signal (w.r.t. the sample of events surviving the bream-veto cut) =
    - 70%
    - 80%
    - 90%
    - 100 %





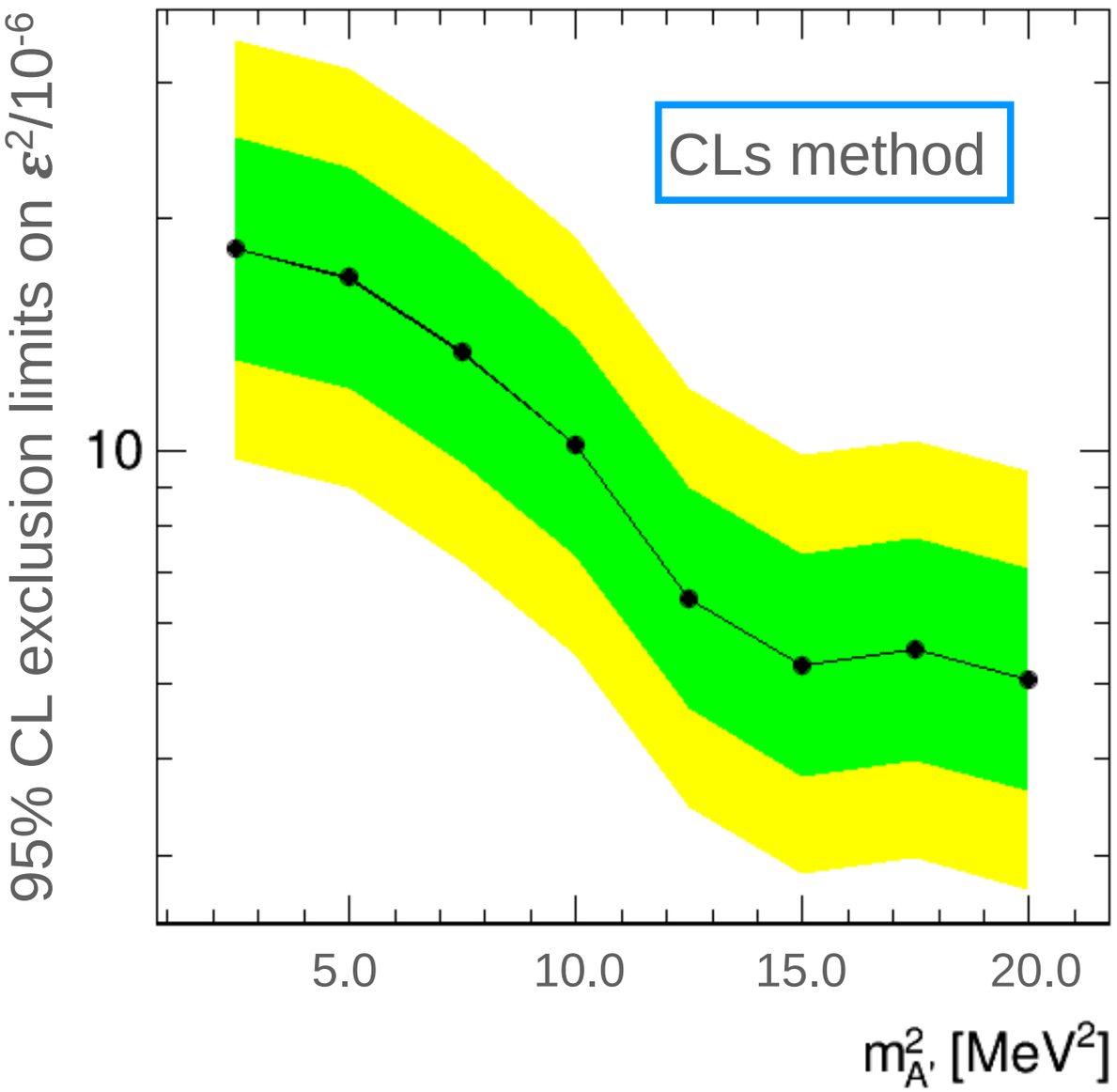
$\varepsilon^2 < 6.5 \times 10^{-6}$ at 10 MeV

$\varepsilon^2 < 5.4 \times 10^{-6}$ at 10 MeV

➥ $M_{A'}$ dependent cut on $E\gamma$ not gaining sensitivity

EXCLUSION LIMITS ON ε^2 IF DATA = MC EXPECTATION W/O SIGNAL

- **Exclusion limits on signal strength (μ) at 95% CL [nominal σ($\varepsilon^2 = 10^{-6}$)]**
  - equivalent to 95% CL exclusion limits on $\varepsilon^2/10^{-6}$

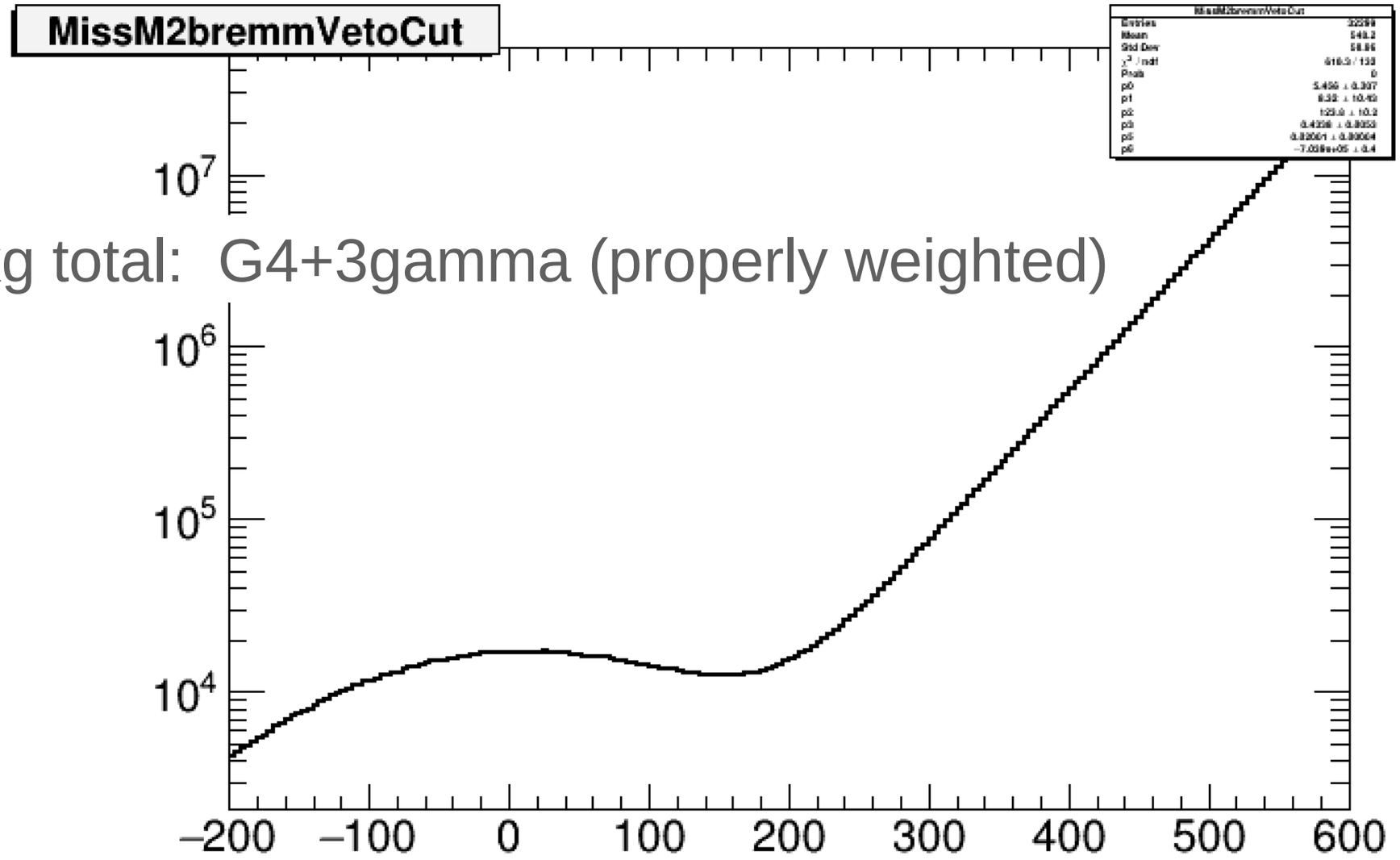


CLs = p(q | S+B) / [1 - p(q | B)]
conservative; prevent over-constraining in case of bkg downward fluctuations

Massa	CLs+b	CLs	Counting experiment
2.5 MeV	15.3	18.3	16.1
5.0 MeV	13.4	16.8	14.9
7.5 MeV	11.3	13.5	11.8
10 MeV	8.7	10.2	9.1
12.5 MeV	5.4	6.4	5.7
15 MeV	4.4	5.3	4.6
17.5 MeV	4.6	5.5	5.1
20 MeV	4.2	5.1	4.5

Standard Likelihood for S+B hypo

EXCLUSION LIMITS - INPUT TO THE FIT

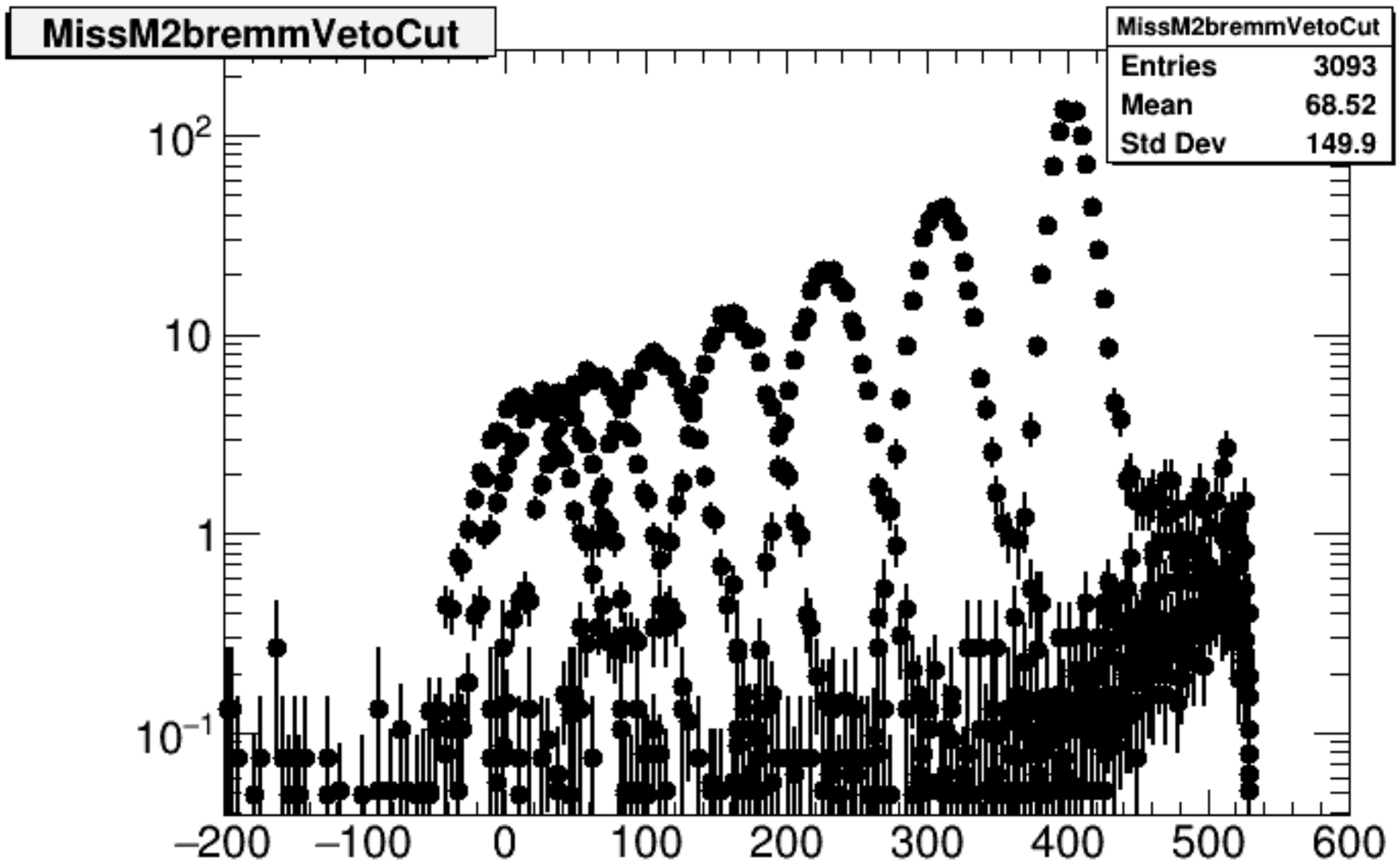


Bkg total: G4+3gamma (properly weighted)

4x10^13 POT (from a fit to the histograms corresponding to the original Intlumi of the background samples ~1.3x10^10, scaled to 4x10^13 and smeared -bin by bin- to the statistical fluctuations expected at 4x10^13)

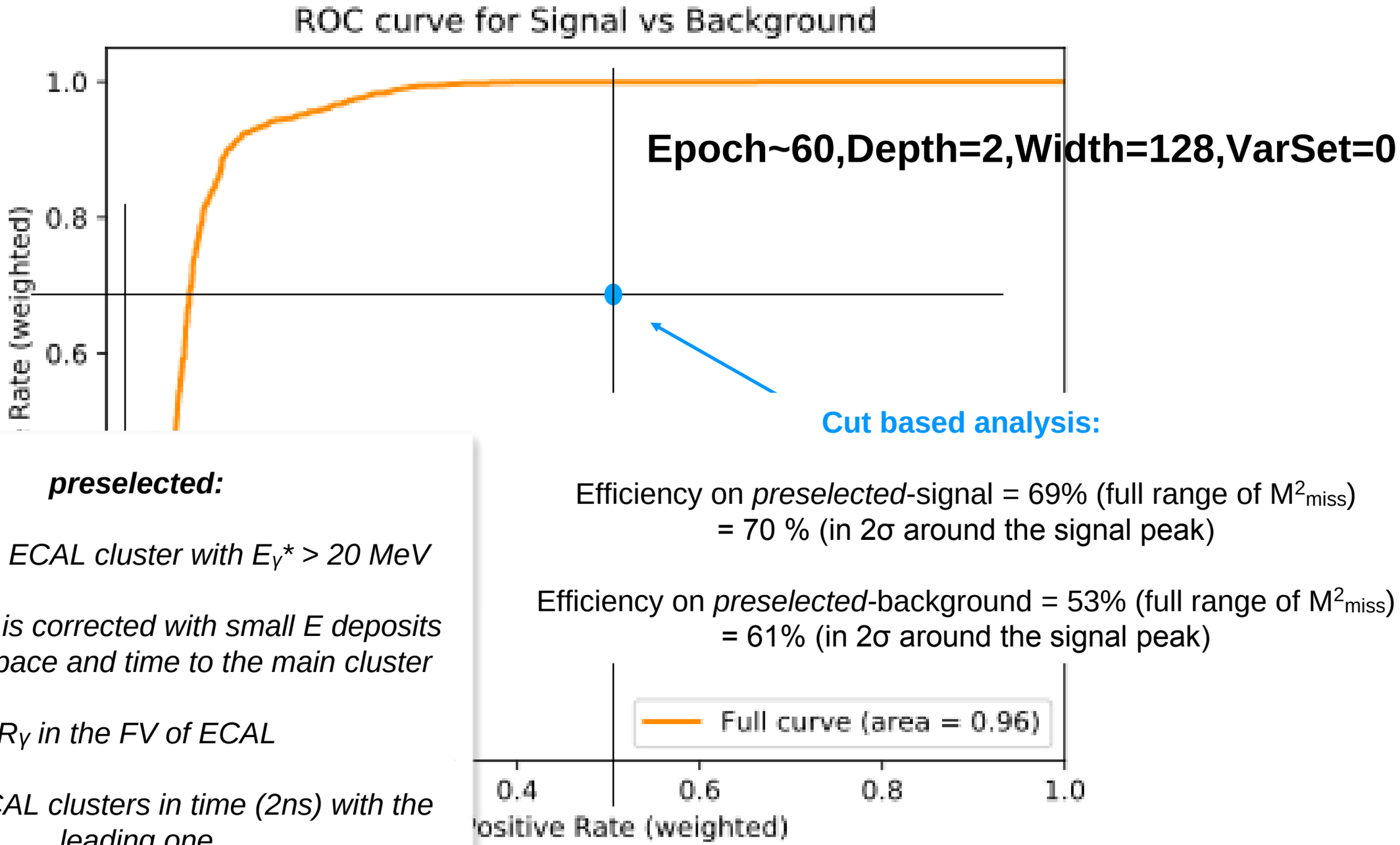
EXCLUSION LIMITS - INPUT TO THE FIT

4x10^13 POT
from original Intlumi of the signal samples ~(0.3-1.5)x10^15 corresponding to 20MeV - 2.5MeV



A Deep Neural Network approach

- For signal (10 MeV) / background discrimination



preselected:

At least one ECAL cluster with $E_\gamma^* > 20$ MeV

* *=> energy is corrected with small E deposits close in space and time to the main cluster*

R_γ in the FV of ECAL

No other ECAL clusters in time (2ns) with the leading one

INTRODUCTION

- comparison with the PADME proposal: Venelin & Mauro 2014, Adv in High Energy Physics

- **Proposal:**
  - 50 μm thick diamond target
  - ECAL-target distance 1.75 m, ECAL radii 3-15 cm -> theta: 0.98-4.9 deg
  - signal acceptance at $M_{A'}$=10 MeV ~18%
  - 3γ background after cuts for 10^{11} POT ~60
  - total background after cuts for 10^{11} POT ~200

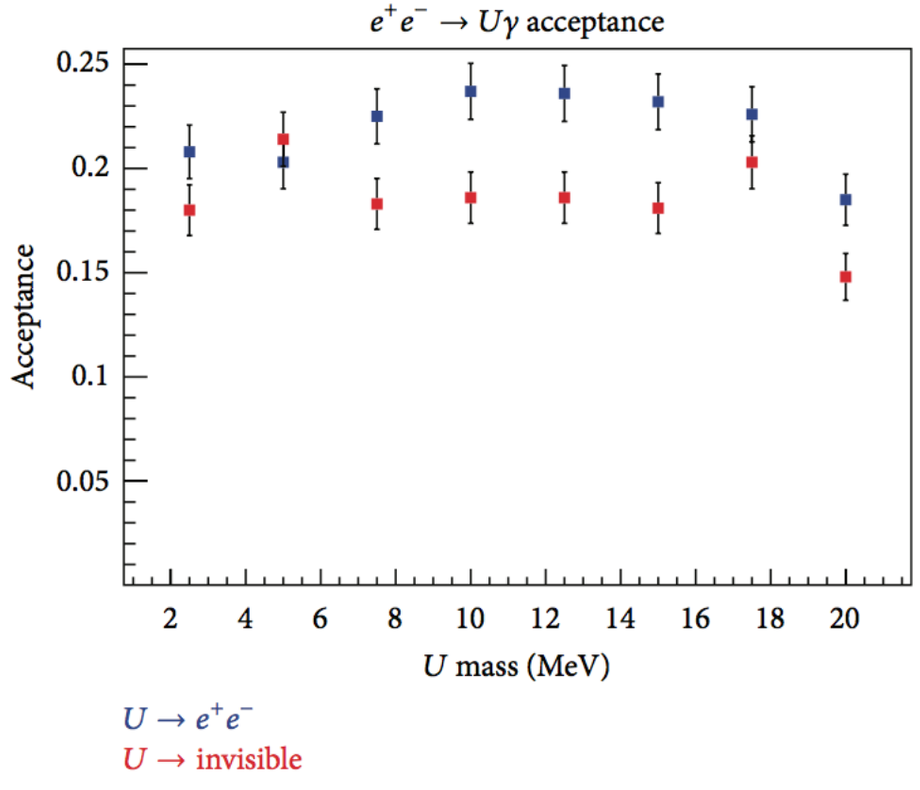


FIGURE 18: Acceptance for U boson detection as a function of its

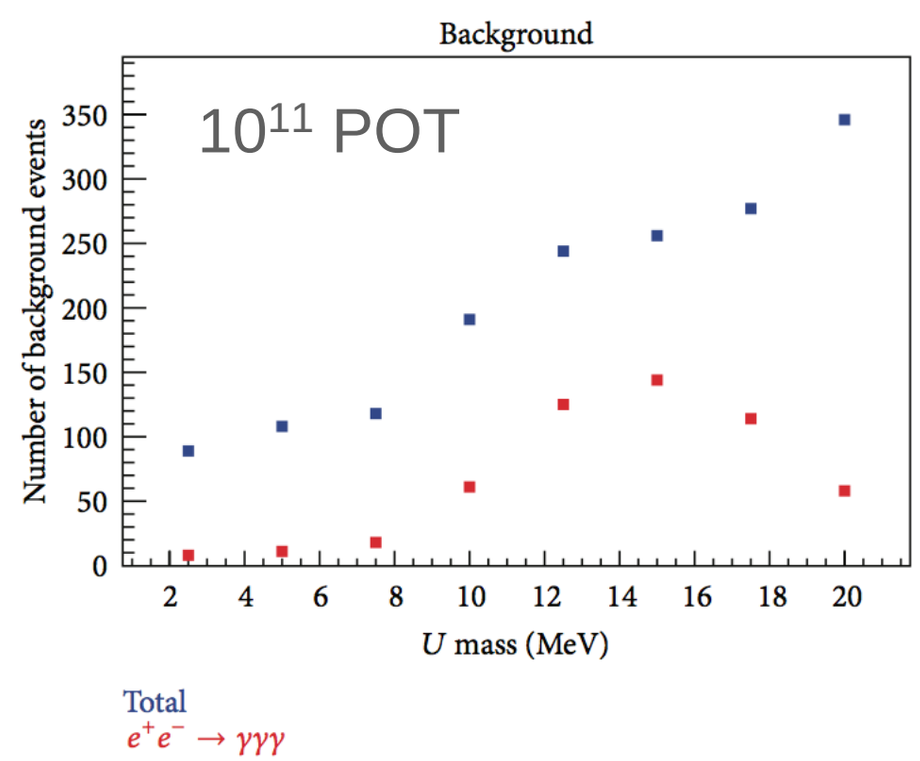


FIGURE 19: Background contribution as a function of the U boson mass.

GENERALITIES

- Cross section for e+e- ➛ 2γ at E_{beam}=550 MeV 1.55 mb (from comphep, Gabriele)
  - in agreement with proposal 0.01 b (cross section per C atom)
- Cross section for e+e- ➛ 3γ at E_{beam}=550 MeV 7.5×10^{7} pb (calchep samples from Venelin)
- Cross section A'γ / γγ at E_{beam}=550 MeV, $M_{A'}$=>0 MeV, $\varepsilon=10^{-3}$ => 2×10^{-6}
- Number of targets / unit surface in the PADME diamond target
  - 100μm, e- => 0.0105 b^{-1}
  - 50μm, e- => 0.00525 b^{-1}
  - 100μm, C atom => 1.75×10^{-3} b^{-1}
  - 50μm, C atom => 0.875×10^{-3} b^{-1}

2.5	5.0	7.5	10.	12.5	15.	17.5	20.	22.5	M(A') / MeV
2,0000	2,0000	2,2000	2,4000	3,0000	4,0000	5,8500	10,3000	30,0000	σ(A'γ)/σ(γγ) @ ε=1E-3
1,5361E+05	1,5361E+05	1,3965E+05	1,2801E+05	1,0241E+05	7,6805E+04	5,2516E+04	2,9827E+04	1,0241E+04	Lint MC signal sample
1,4286E+05	1,4286E+05	1,2987E+05	1,1905E+05	9,5238E+04	7,1429E+04	4,8840E+04	2,7739E+04	9,5238E+03	Lint MC signal sample
1,5500E-03	1,0000E-02	1,0500E-02	1,7500E-03	5,0000E+04	4,0000E+03	1,0000E-06	1,2900E+00	1,3000E+01	1,0000E-10	N signal in 2σ
3,1950E+03					6,3710E+03				N bremm+2γ in 2σ
1,1200E+02					1,7410E+03				N 3γ in 2σ
1,1900E+02					1,0410E+03				N bkg @ N_POT
3,8390E+05					5,7188E+06				N signal @ N_POT & ε_NOM
9,9837E+01					8,5439E+02				ε^2 excl. at 68% CL
2,9169E-06					**1,3155E-06**				ε^2 excl. at 95% CL
1,0054E-05					**4,5343E-06**				

σ(ee->γγ) [barn]

σ(eC->γγ) [barn]

N_e_targets/S [barn-1]

N_C_targets/S [barn-1]

ε_NOM

N_POT

Lint MC G4 sample

Lint MC 3γ sample

SELECTION

- 1 ECAL cluster with E > 20 MeV -> photon candidate
  - energy in ECAL at ΔR<10.0 cm and Δt<2.5 ns is summed to the ECAL cluster
    - energy, position in ECAL and time are re-evaluated
  - allowing for other ECAL clusters in the event[bunch] with E< 20MeV and distance in time from the selected cluster < 2.5 ns
- Radius in 94.5 - 262.5 mm (center of the cluster must not lie in the 2 innermost or outermost rings of crystals)
- e+ Veto Cut (γ-e+ in time [2ns] e+ energy+ECAL cluster energy in 500-650 MeV)
- no A'-mass dependent cuts
- no use of SAC, HEPVeto, EVeto

- Signal $M_{A'}$ = 10 MeV: 3751 / 50000 (in no pileup samples 5267/50000) = 7.5% [3373 / 3195 in 3/2 sigma around $M^2_{A'}$ peak, 6.7% / 6.4%]
- Geant4 bkg 23724 / 2580000 = 0.9% [174 / 115 in 3/2 sigma around $M^2_{A'}$ peak , $67x10^{-6}$ / $44x10^{-6}$]
- 3γ background 8378/100000 = 8.4% [184 / 120 in 3/2 sigma around $M^2_{A'}$ peak, $1.8\ x10^{-3}$ / $1.2x10^{-3}$]

4 x 10^{13} POT

COMPARING SIGNAL EXPECTED YIELD

- **in 4x10^{13} POT**: ~100 A'γ after selection cuts according to MC efficiencies
- **Nsignal** = 3751 x 1,5 x 10^{15}/ 4 x 10^{13} = 100 [efficiency ~7.5%]
  - scaling by 1/2 (100μm thickness -> 50μm [proposal]) -> 50 events if ε^2 in 10^{-6}
  - scaling by 3 (68% CL on ε^2 in ~3x10^{-6}) -> ~150 events [fig 20]
    - in the proposal this was ~300 = √80000 = √ 400 x 200 (fig 19)
    - *~As expected since signal acceptance in fig 18 => 18% (while we measure ~7.5%)*

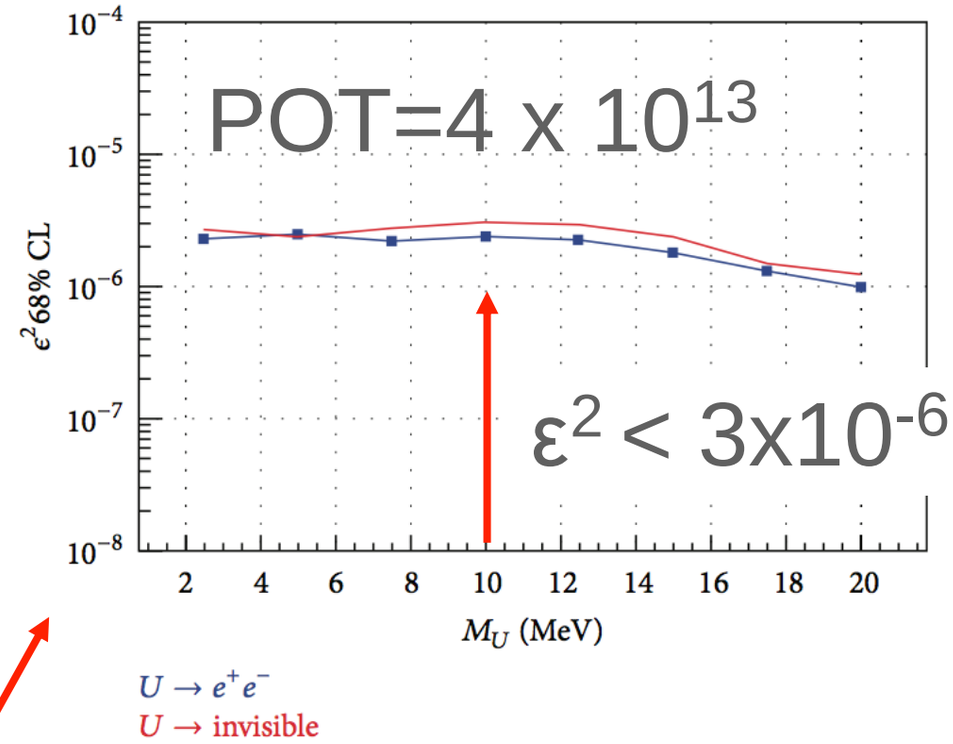


FIGURE 20: Expected exclusion limits in the $\epsilon - M_U$ plane in case of no signal.

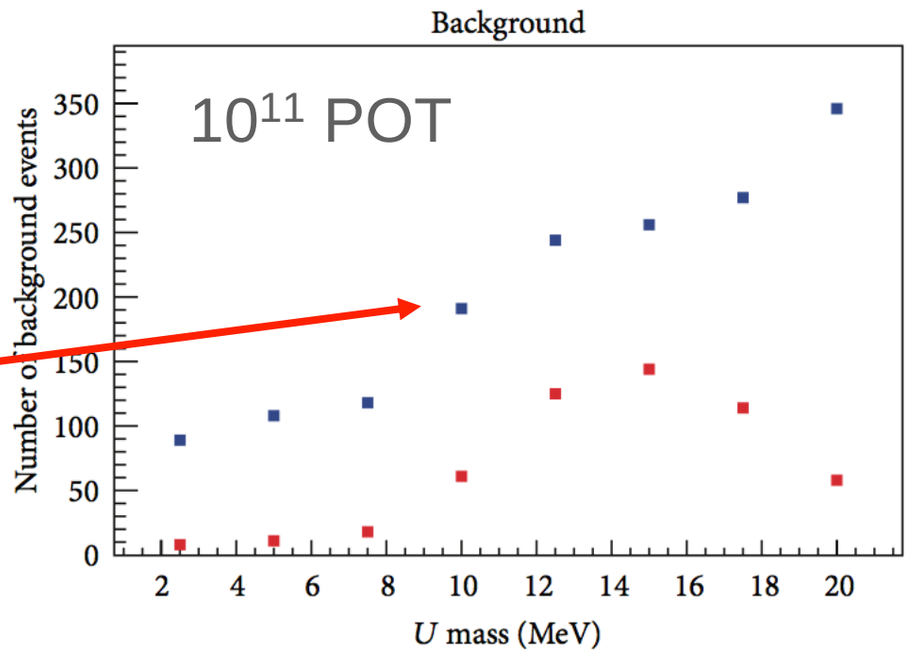
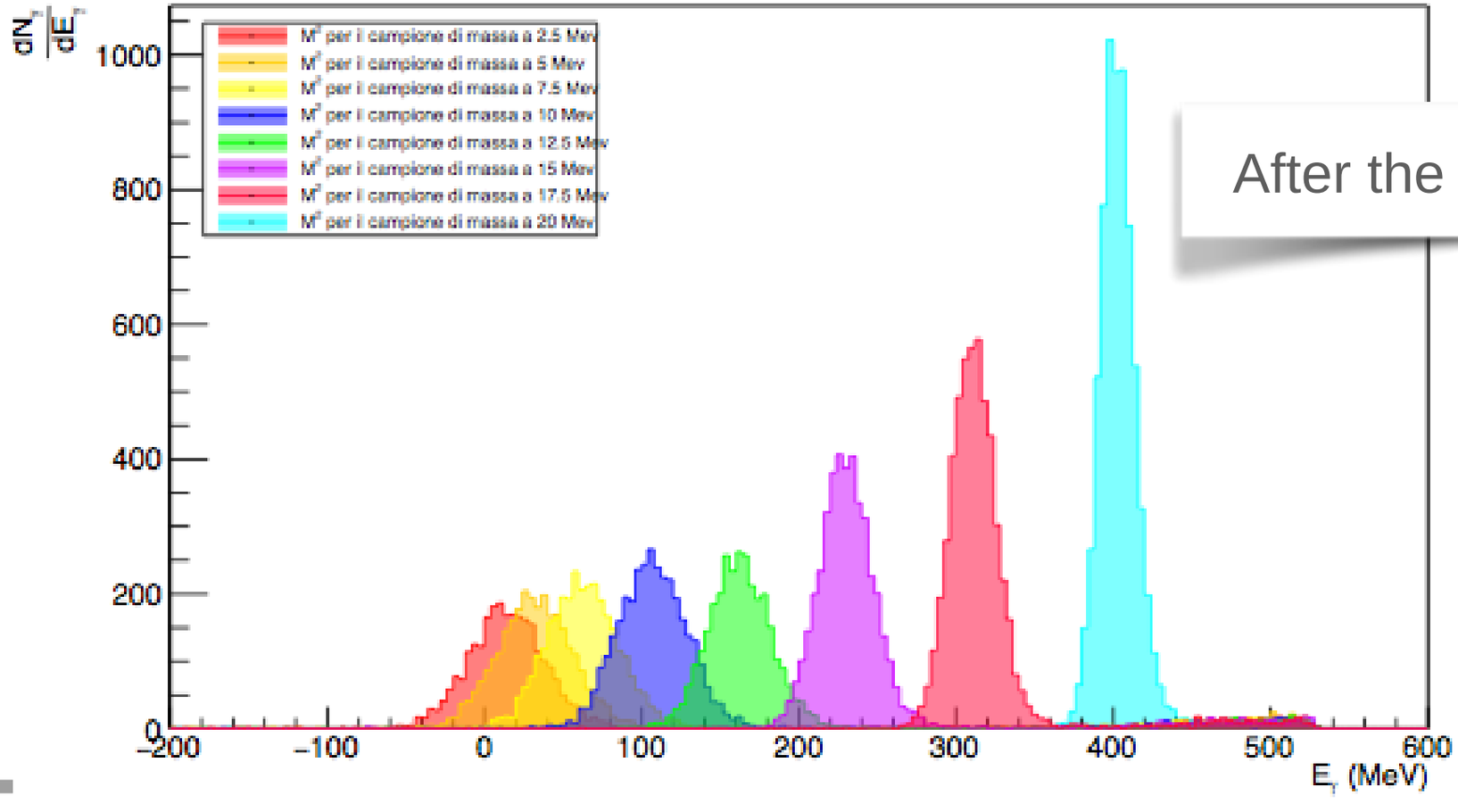


FIGURE 19: Background contribution as a function of the U boson mass.

~agreement [factorising the eff. problem] on expected signal yield

SIGNAL RESOLUTION

- Signal samples without pileup (Superimposed for all masses)
  - $M^2_{A'}$ spectrum for all clusters (before anything)
  - $M^2_{A'}$ spectrum at the end of the cuts (up to bremm veto cuts)
  - $M^2_{A'}$ spectrum before radius cut
  - $M^2_{A'}$ spectrum before bremm-veto cut



After the positron-veto cuts

SIGNAL RESOLUTION

- In signal samples with pileup
  - $M^2_{A'}$ spectrum at the end of the cuts (up to bremm veto cuts)
    - Superimposed for all masses
  - $M^2_{A'}$ spectrum before any cut
- In signal samples without pileup
  - $M^2_{A'}$ spectrum at the end of the cuts (up to bremm veto cuts)
    - Superimposed for all masses
  - $M^2_{A'}$ spectrum before radius cut

CUTTING ON EPHOTON DEPENDING ON MA'