Searching for a resonance on HPS Spring 2016 run data

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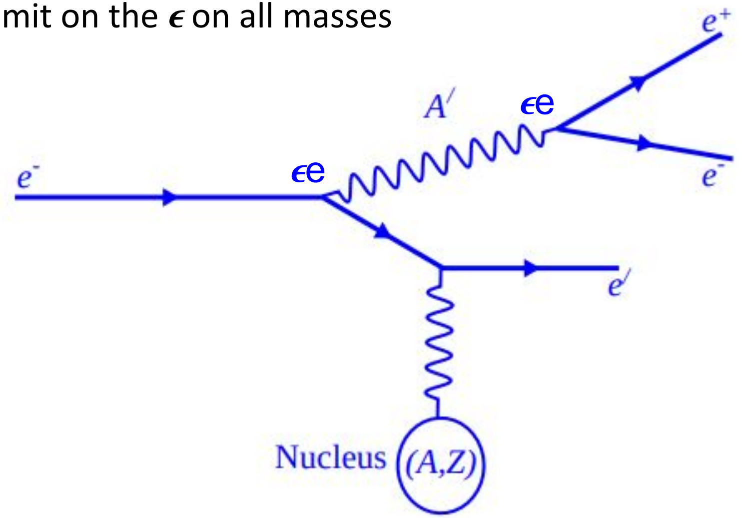
HPS Collaboration meeting: Nov 18-20, 2020

The production mechanism of A'

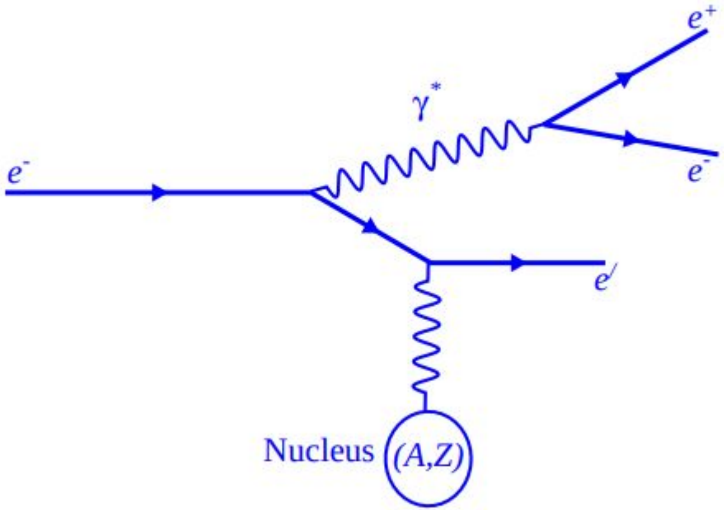
Goal: We want to measure this resonance, if we don't find then we should put an upper limit on the ϵ on all masses within our experiment reach.



Signature: enhancement of events at a certain e^-e^+ mass

Background process

Timelike photon production (aka radiative photon production)



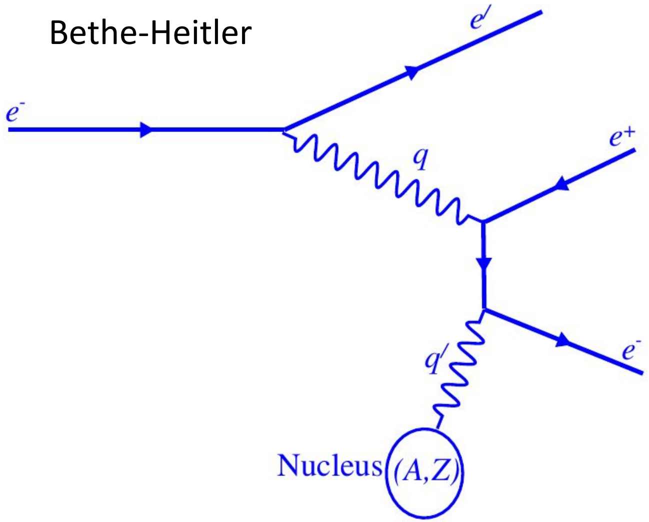
Very similar process: the only difference is A' has a certain mass, while γ^* is continuum.

Even more: for a given mass they have identical kinematic distribution, and cross-sections are related as:

$$\sigma_{A'} = \frac{3\pi m_{A'}\epsilon^2}{2N_{\mathrm{eff}}\alpha}\,\frac{\mathrm{d}\sigma_{\gamma^*}}{\mathrm{dm}}\bigg|_{m=m_{A'}}$$

Background process

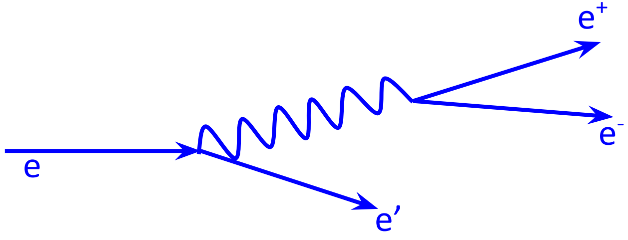
Bethe-Heitler

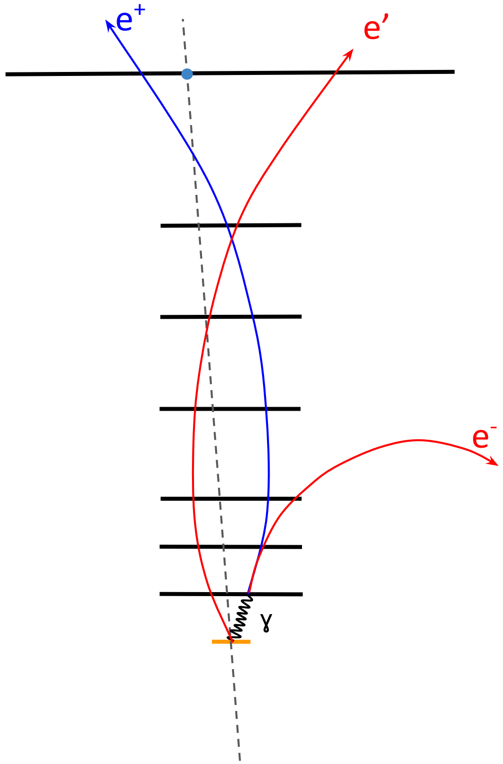


Bethe-Heitler: Same final state, has large x-sec, but has different kinematic.

Background process

Converted WAB





Two step process, Bremsstrahlung then pair production.
Positrons converted at the target, L1 or the stereo sensor of L2, have potential to reconstructed.

This will mimic the trident final state.

Background process

Measured mass spectrum is a sum of: Tri-trig (= tri + Rad + Interference) + cWAB + A’

The rate of A’ ~ to the rate of Rad, while
cWAB and BH will only weaken the sensitivity to the signal.

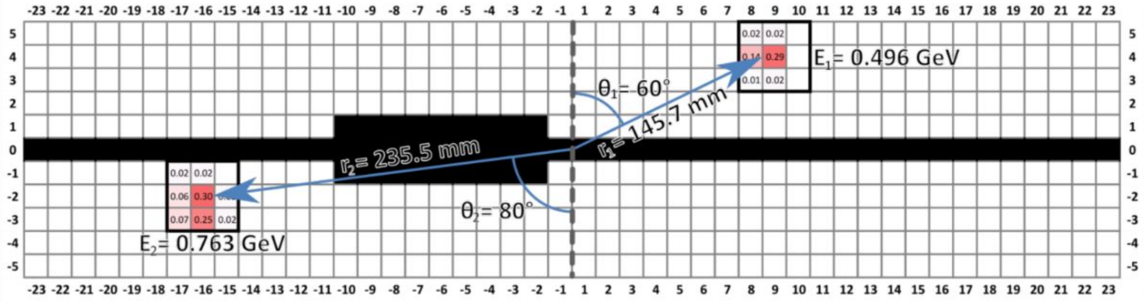
$$\mathrm{FOM} = \frac{\mathrm{N_{Rad}}}{\sqrt{\mathrm{N_{Tot}}}}$$

The main idea behind event selection cuts is to maximize the sensitivity of the signal:

Run conditions

Production runs

Target: 4μ Tungstene
I_{Beam}: 200 nA
Trigger: pair1
Total 81 runs.



Pair1 trigger:

Cut description	Cut value
Hits Per Cluster Min:	2
Cluster Time Coincidence:	+/-12 ns
Cluster Energy Min:	150 MeV
Cluster Energy Max:	1400 MeV
2-Cluster Energy-Sum Min:	600 MeV
2-Cluster Energy-Sum Max:	2000 MeV
2-Cluster Energy-Diff Max:	1100 MeV
Coplanarity Maximum:	40 deg
Energy-Dist Slope:	5.5 MeV/mm
Energy-Dist Minimum:	700 MeV

Run	Total luminosity [nb^{-1}]	# of all files	# of unblinded files	unblinded luminosity [nb^{-1}]
Total	10703.81	15934	1625	1096.27

Preselection

Make Objects Useful Standardization Exercise (MOUSE)

Final State Particles	
e^-	Negative Track $\chi^2_{\text{track}} < 12$ Goodness of PID < 10 $\lvert t_{\text{track}} - t_{\text{cluster}}\rvert < 6\,\text{ns}$ $P < 2.15\,\text{GeV}$
e^+	Positive Track $\chi^2_{\text{track}} < 12$ Goodness of PID < 10 $\lvert t_{\text{track}} - t_{\text{cluster}}\rvert < 6\,\text{ns}$
γ	Unmatched Cluster

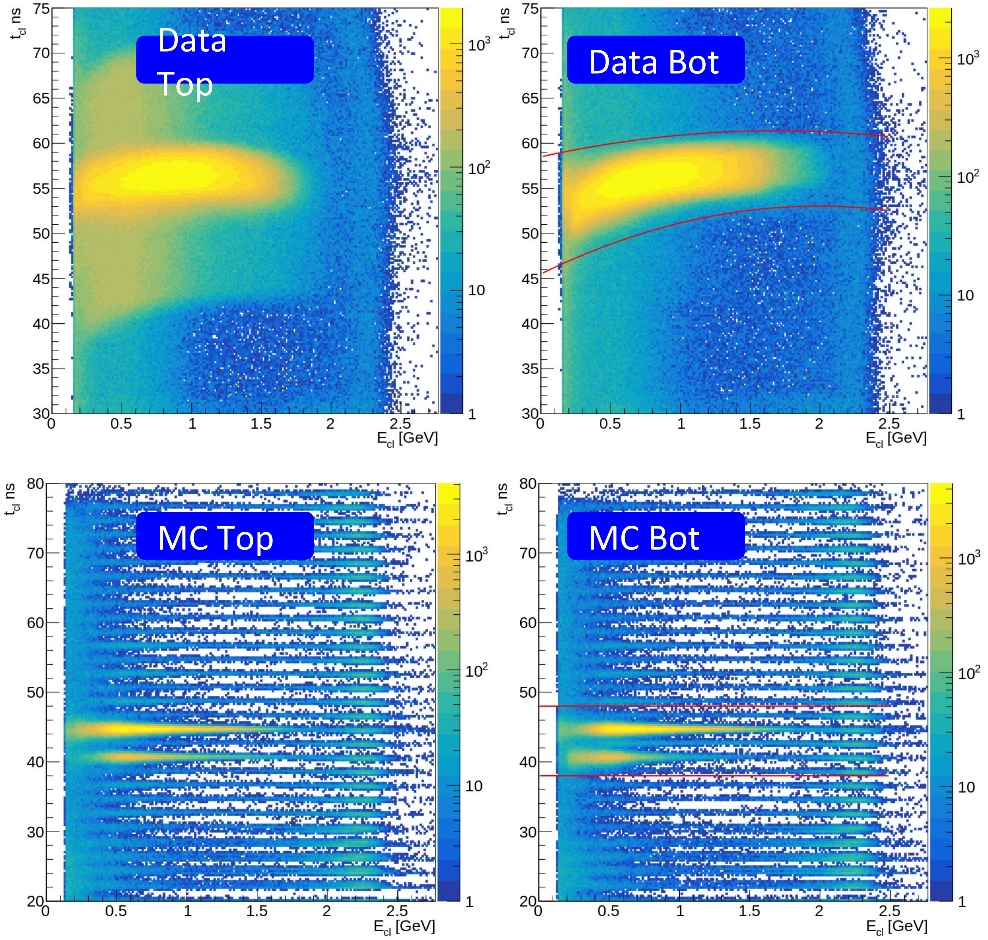
Three types of V0 candidates, UC, TC, BSC

V0 candidates are formed out of Final State Particles:

- Opposite halves
- Oppositely charged
- $P_{Sum} < 1.2E_b$.
- $\Delta t < 2.5$ ns

In the resonance search we have used the Target Constrained (TC) V0s, where the z coordinate of the vertex is constrained to be at the target Z and x,y are constrained to the beam spot.

Cluster time cut



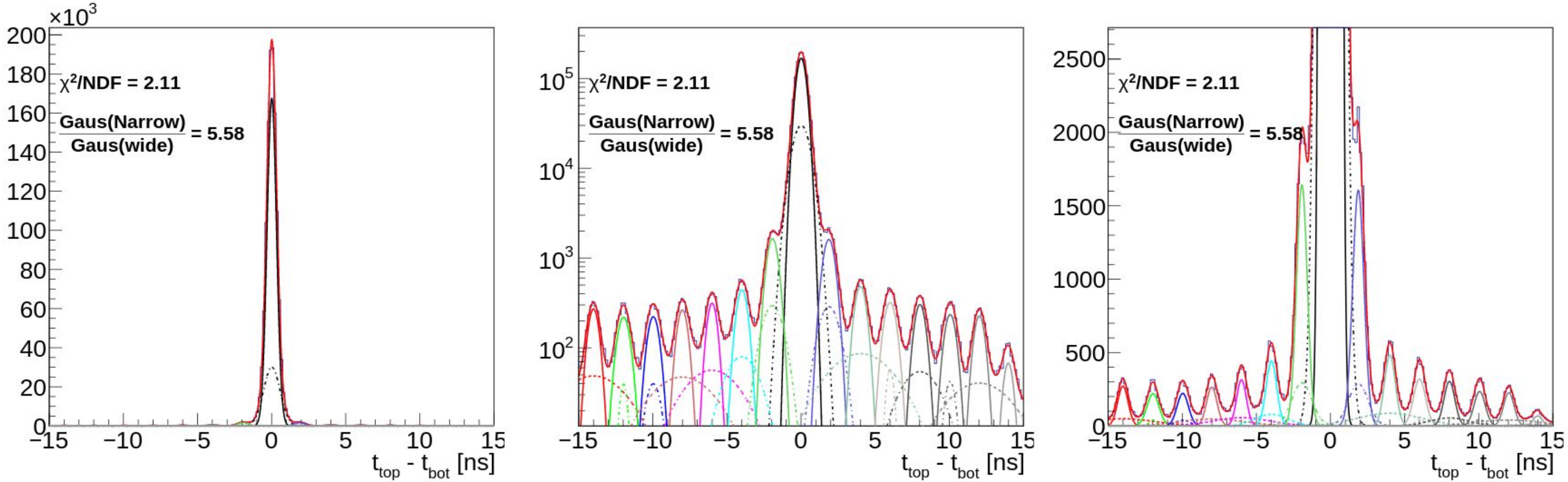
The trigger time is defined by the bottom cluster time.

Exclude clusters that are clearly not from the trigger

The energy dependence of cuts is because of the time walk affect which was not accounted for.

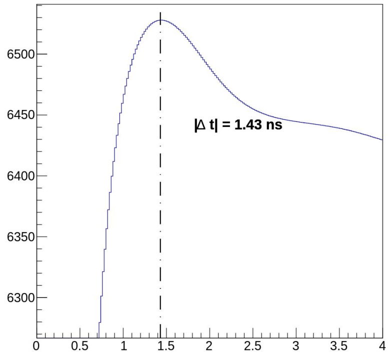
No time walk effects present in MC, and hence cluster time cut doesn't depend on the cluster energy.

Cluster time difference cut

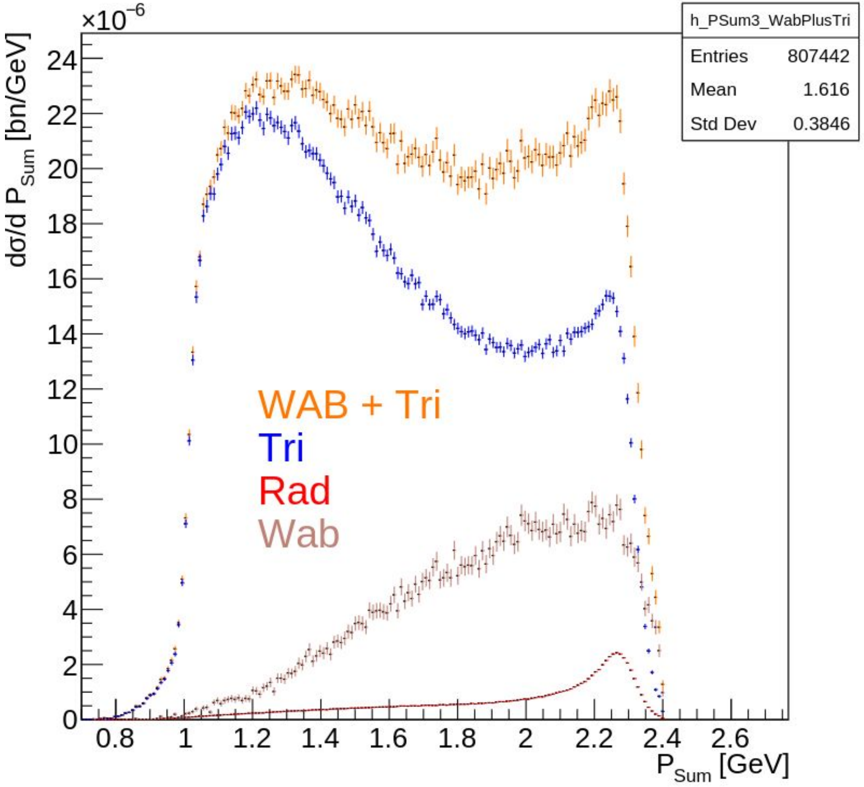


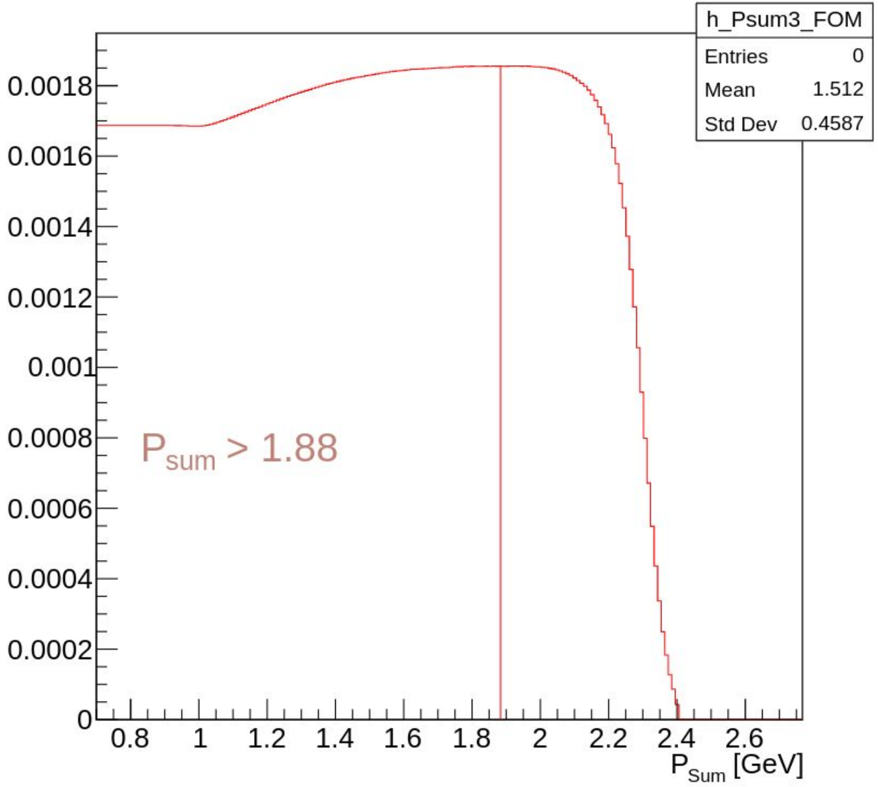
$$F = \sum_{i=0}^{N_{\rm peak}} a_i \cdot \left(\mathrm{Gaus}(x-\mu_i, \sigma_i^1) + b \cdot \mathrm{Gaus}(x-\mu_i, \sigma_i^2)\right)$$

$$\mathrm{FOM} = \frac{\mathrm{S}}{\sqrt{\mathrm{S} + \mathrm{Bkg}}}$$



PSum Min cut

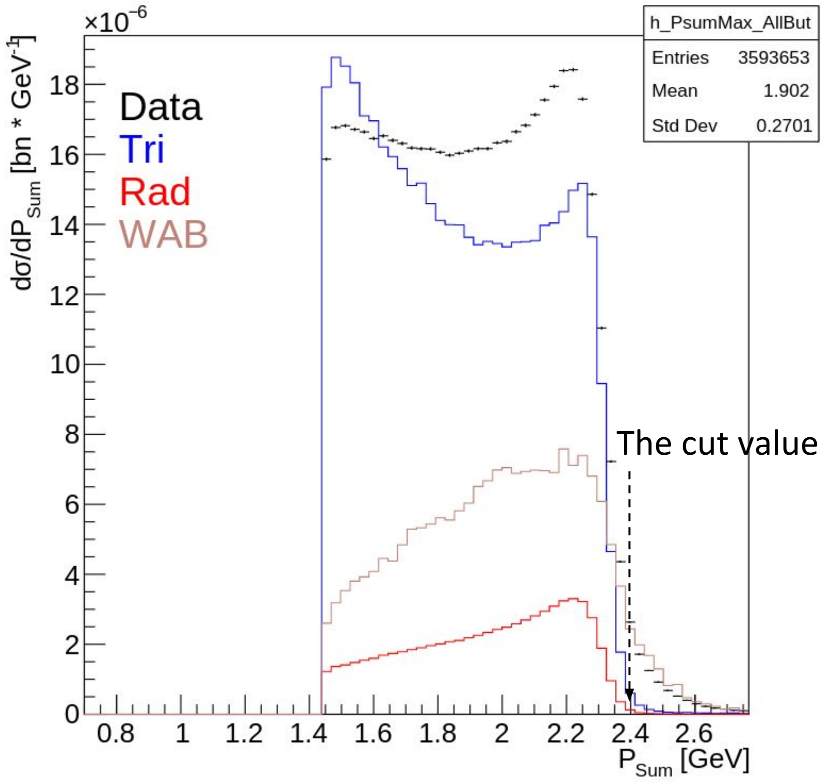




$$\mathrm{FOM} = \frac{\mathrm{N_{Rad}}}{\sqrt{\mathrm{N_{Tot}}}}$$

The Psum > 1.9 GeV was used.

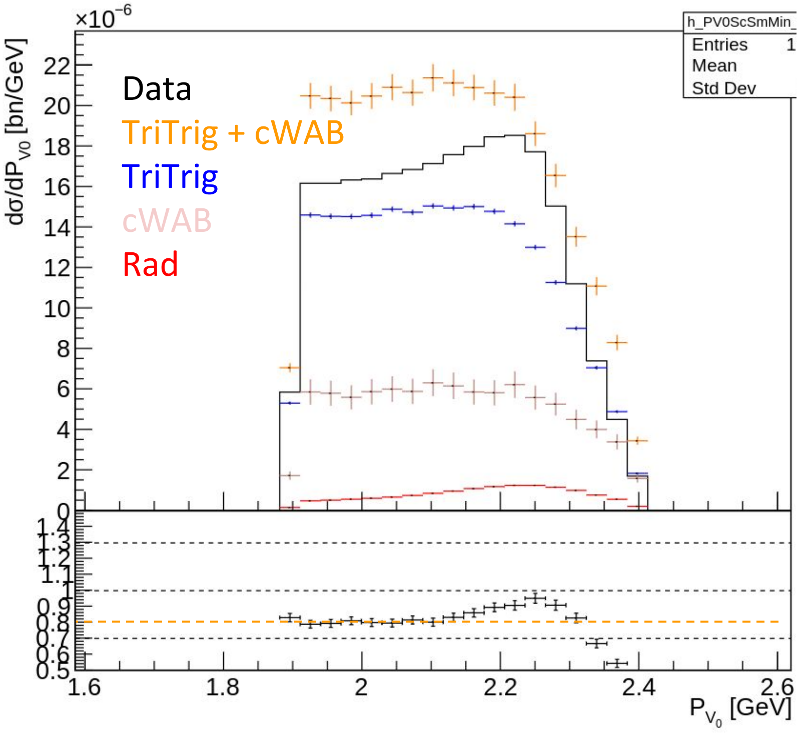
PSum Max cut



Tridents and Rad don't have a big tail, and more than 99% of events are below the 2.4 GeV.

MC suggests the tail at high PSum is because of WAB.

PSum distribution after all cuts



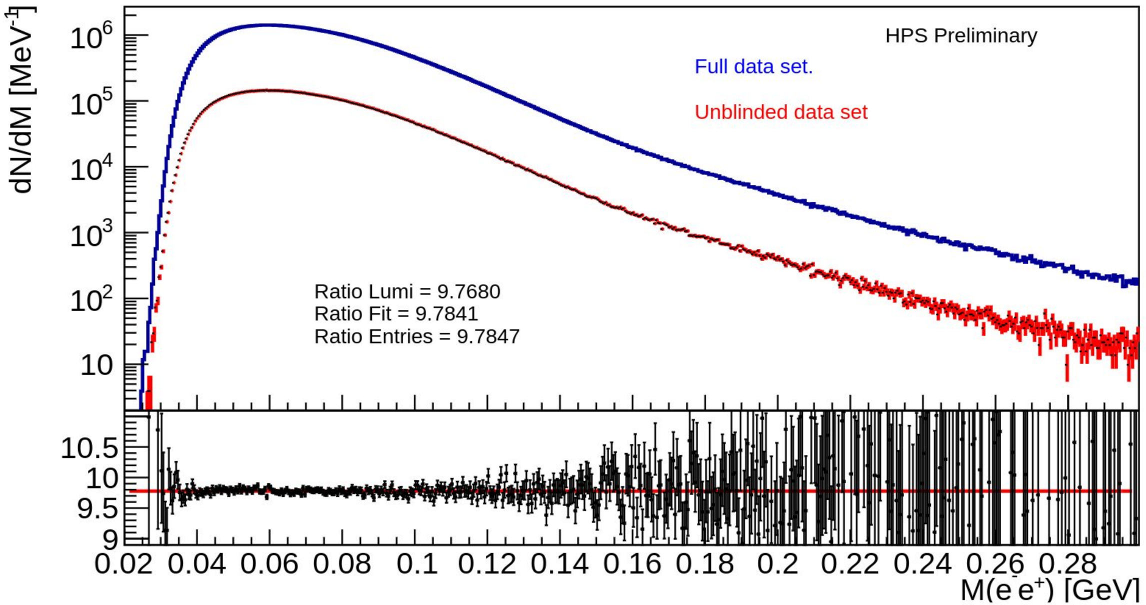
The ratio is flat in the 1.9 - 2.1 GeV region.

Above 2.1 GeV, because of the not perfect resolution match between the data and MC, at the peak we observe fluctuation of the ratio.

Note: Track killing (developed by Matt G.) was applied too on the MC sample.

An additional cut: only chose events with only one V0 candidate in the event.

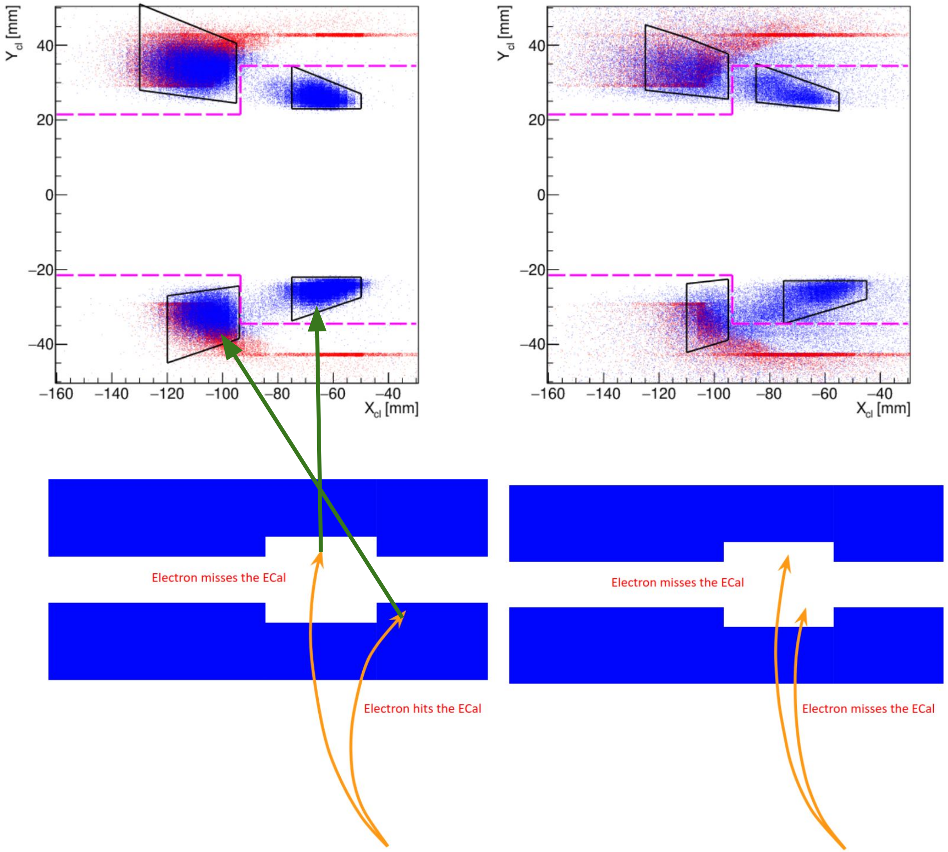
The final mass spectrum

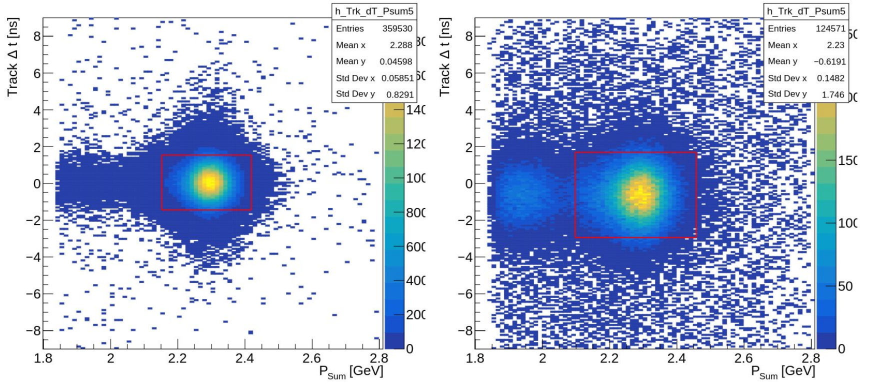


Cut Variable \ Data Set	Data		Tri-beam	Rad-beam	Wab-beam	Tri + Wab
	V_0 Count	Cut Fraction	Cut Fraction	Cut Fraction	Cut Fraction	Cut Fraction
Preselection	2.682e+9	1	1	1	1	1
$P_{\text{sum}} < 2.4\,\text{GeV}$	9.015e+06	0.965025	0.993267	0.989399	0.923153	0.969074
$P_{\text{sum}} > 1.9\,\text{GeV}$	2.540e+07	0.342541	0.283286	0.643565	0.553658	0.337454
$\Delta t_{\text{cluster}} < 1.43\,\text{ns}$	8.951e+06	0.971969	0.993217	0.989819	0.992752	0.993064
Single V_0 Candidate	8.700e+06	0.860186	0.916546	0.928019	0.893524	0.908462

The mass resolution

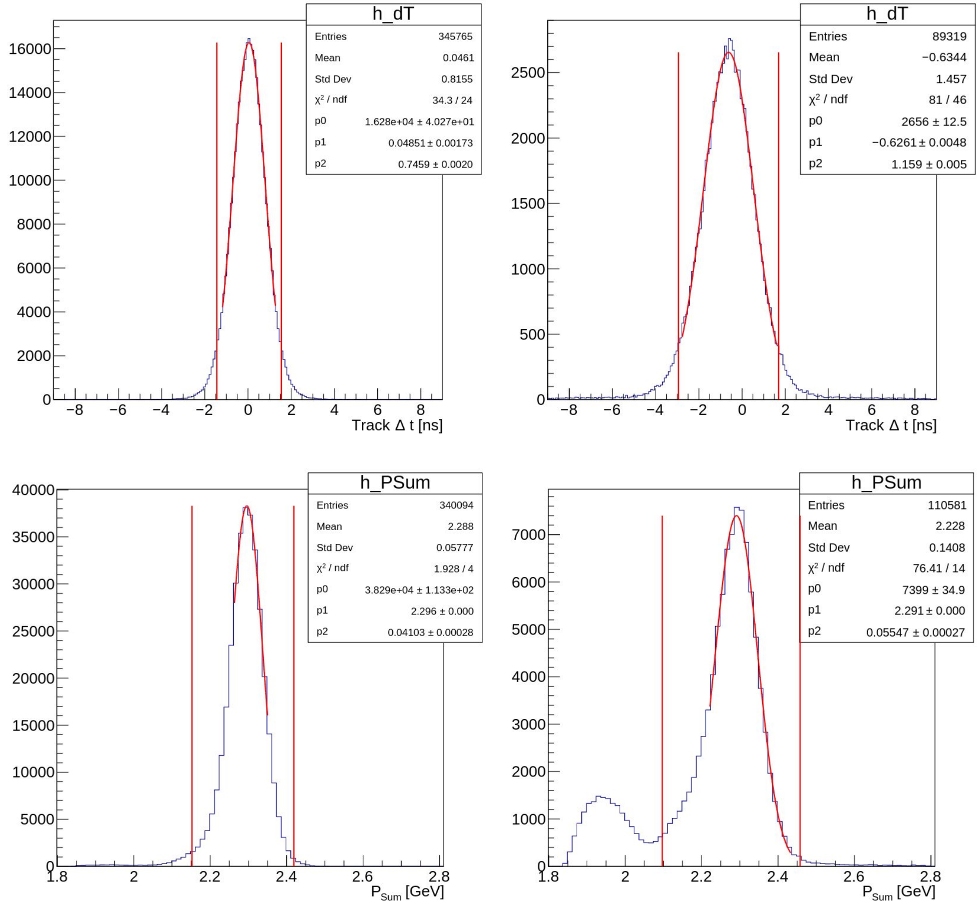
As in the case of 2015 Data analysis, here we have used Moeller process, to check the mass resolution.





To make selection cleaned “Fiducial” cuts are applied to track positions in the ECal face.

Δt and PSum cuts



Moeller selection cut strategy is: better to have a clean sample rather than maximum signal efficiency.

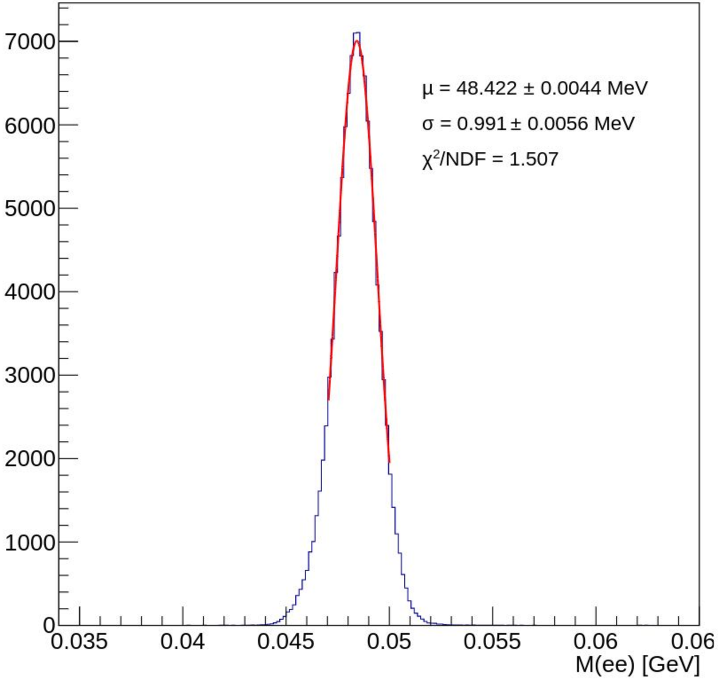
As the efficiency is not a big concern, 2σ cuts are applied on Δt.

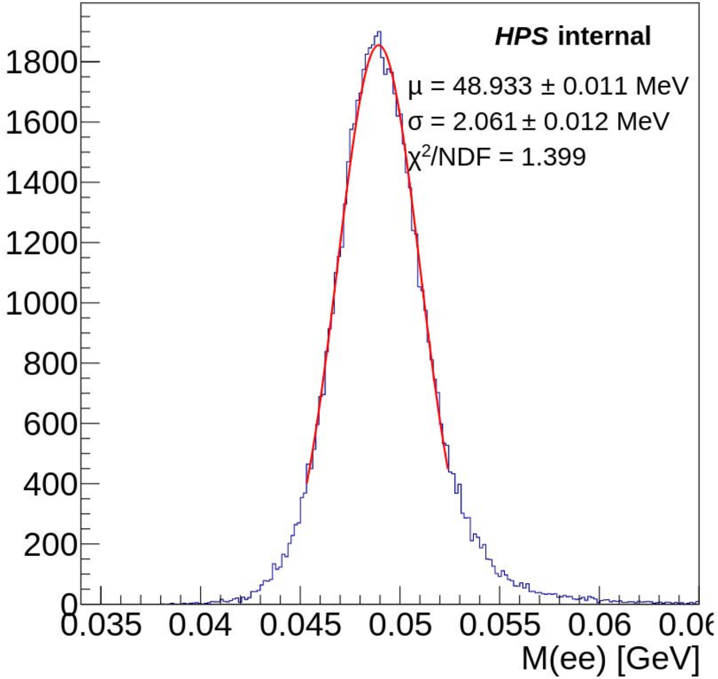
The lower tail in the PSum is the radiative tail. To keep as much as possible a 3.5σ cut is applied on the lower side of the PSum.

Cut Variable / Data sample	Δt_{min} [ns]	Δt_{max} [ns]	$P_{\mathrm{sum,min}}$ [GeV]	$P_{\mathrm{sum,max}}$ [GeV]
Data	-2.94	1.69	2.1	2.45
MC	-1.44	1.54	2.15	2.42

Cut Variable / Data sample	$\Delta x^{\mathrm{top}}_{\mathrm{min}}$ [mm]	$\Delta x^{\mathrm{top}}_{\mathrm{max}}$ [mm]	$\Delta x^{\mathrm{bot}}_{\mathrm{min}}$ [mm]	$\Delta x^{\mathrm{bot}}_{\mathrm{max}}$ [mm]
Data	-4.72	6.15	-7.51	2.98
MC	-4.89	4.82	-4.98	4.52

Moeller mass distributions





About x2 larger resolution in the data!

This prompted to additional studies about the source of this discrepancy

Moeller mass

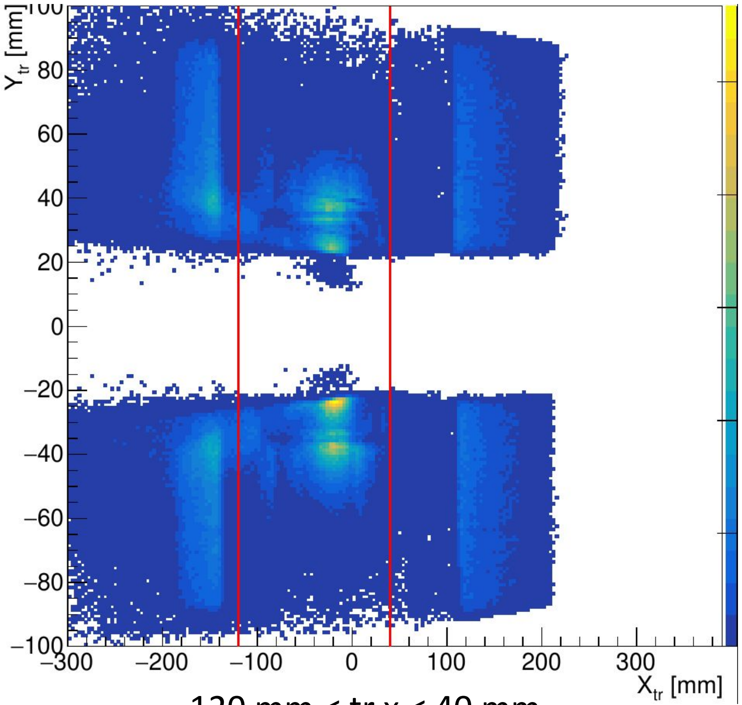
$$M(\text{ee}) = 2\sqrt{P_1 P_2} \cdot \sin\left(\frac{\theta}{2}\right)$$

Discrepancies in the momentum and angular resolutions will translate into discrepancies in the mass resolution.

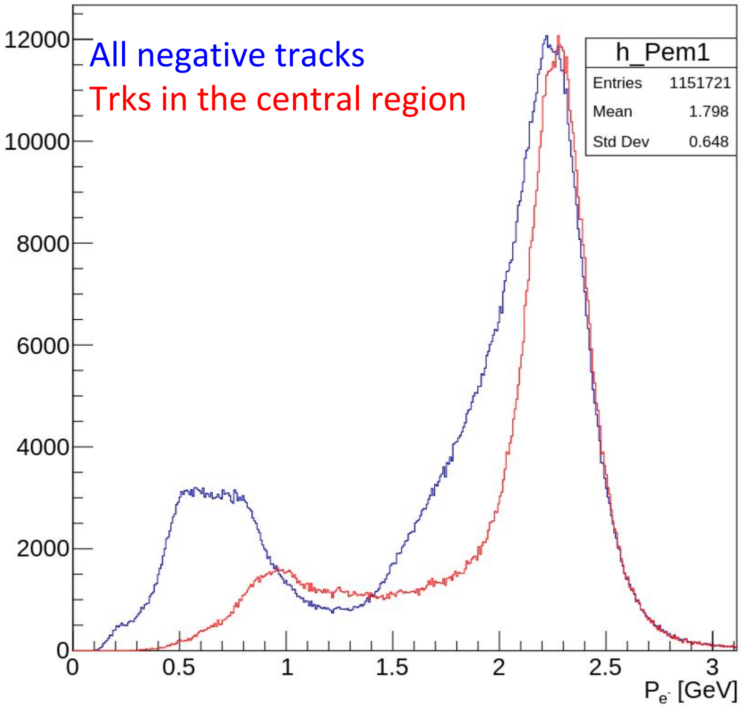
The easiest is to check how momentum resolution in data and MC agree to each other.

We will used FEEs for this studies.

Selecting FEEs

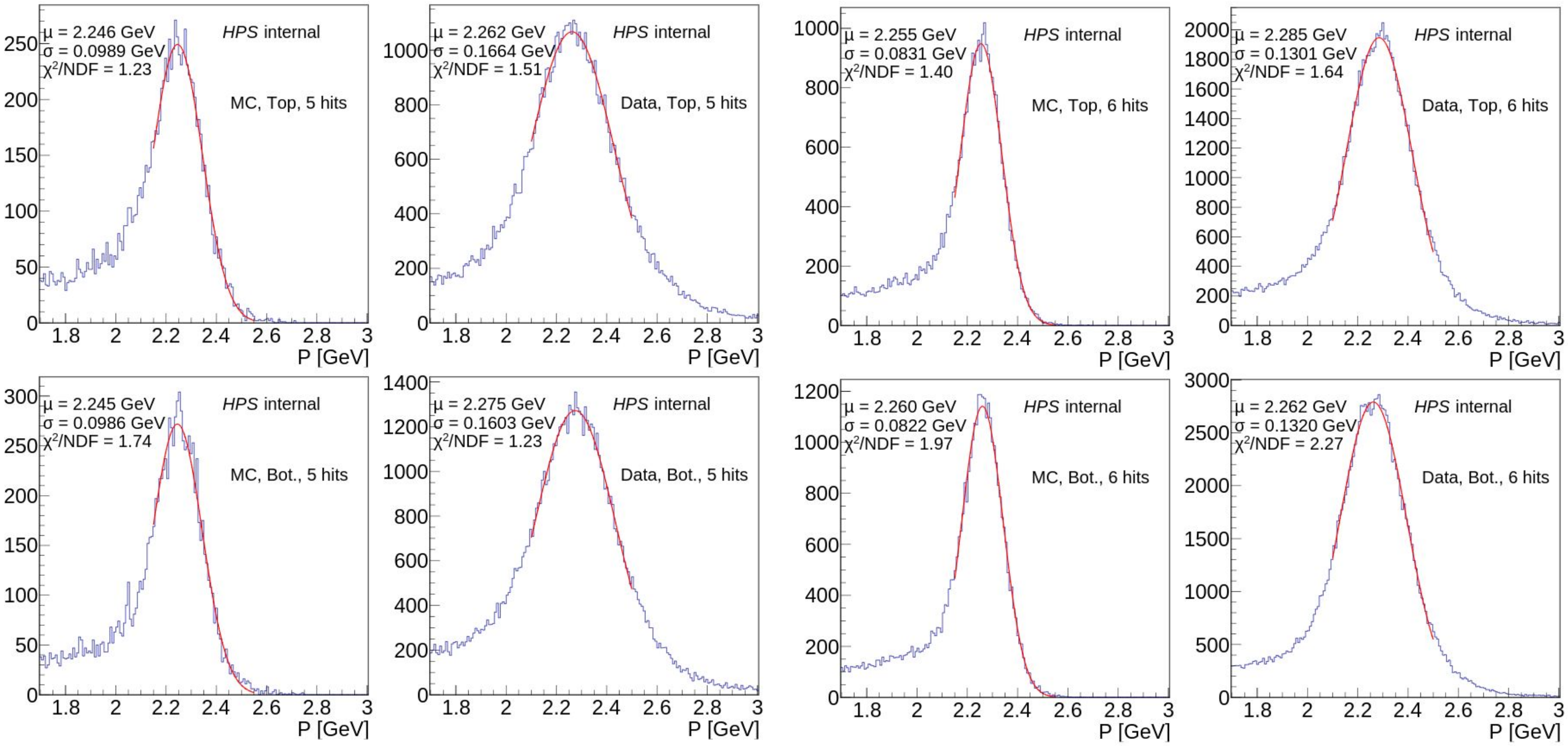


− 120 mm < tr x < 40 mm



- We cut on track x coordinate on the ECal face to have a clean FEE peak
- Later we studied Momentum resolutions depending on Top/Bot and 5hits/6hits

MC and Data FEE resolutions



The FEE peak width in the data is **<u>1.5-1.7</u>** times wider than in MC.

Momentum smearing

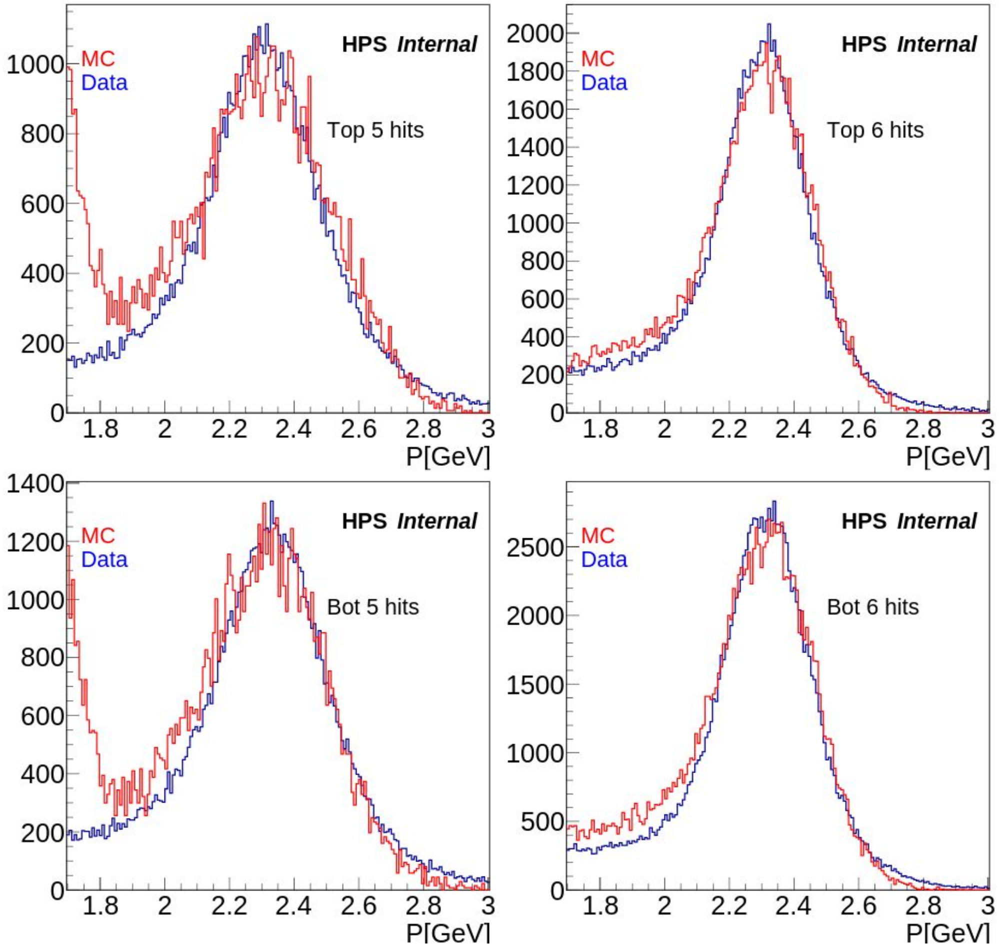
MC resolution is smeared to match data resolution

Smearing coefficients:

$$\Sigma_{\text{smear}} \equiv \frac{\sigma_{\text{smear}}}{P_{\text{MC}}} = \sqrt{\left(\frac{\sigma_{\text{data}}}{\mu_{\text{data}}}\right)^2 - \left(\frac{\sigma_{\text{MC}}}{\mu_{\text{MC}}}\right)^2}$$

For each category Top/Bot, 5hit/6hit, MC resolution is smeared according above coefficients.

MC momentum resolution after smearing

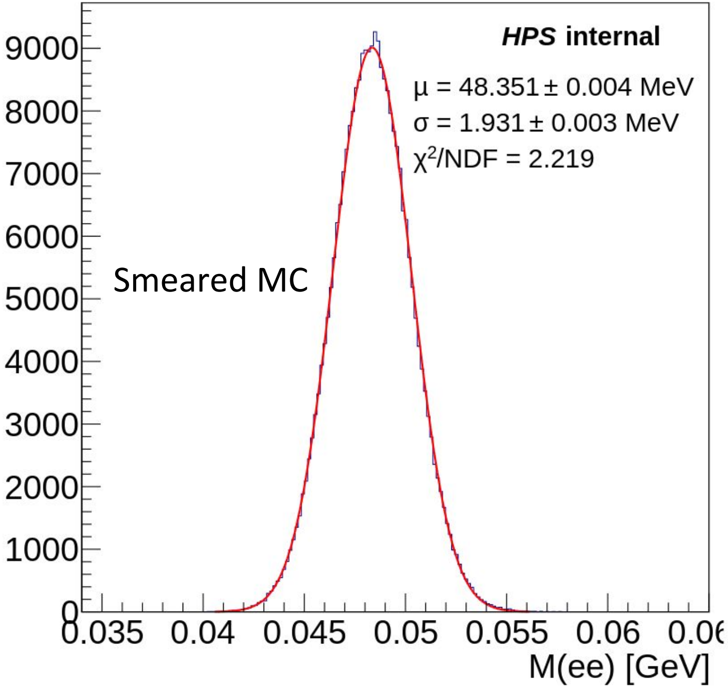


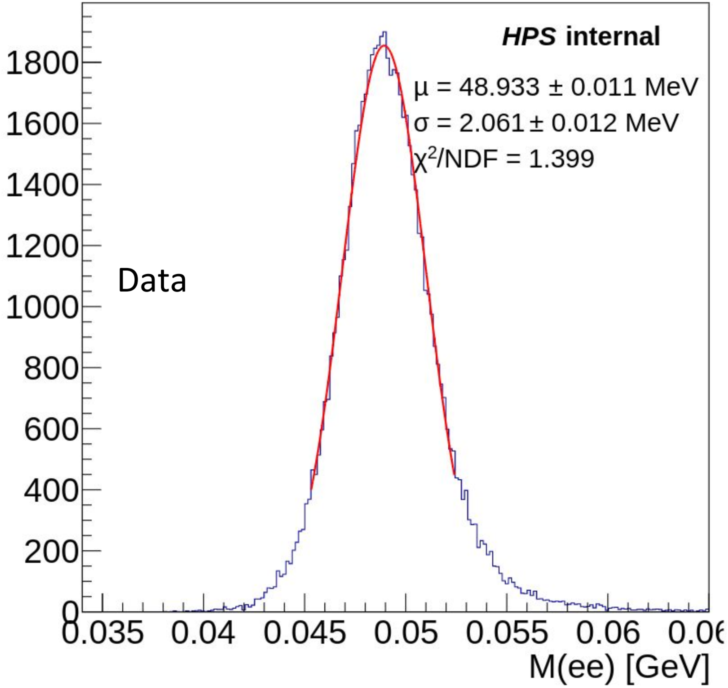
As a sanity check, smeared FEE distributions plotted on top of the.

Reasonable agreement of cores of distributions

Smeared mass

$$M(\text{ee})^{\text{smear}} = 2\sqrt{P_{1,\text{smear}}P_{2,\text{smear}}} \cdot \sin\left(\frac{\theta}{2}\right) = 2\sqrt{\frac{P_{1,\text{smear}}}{P_{1,\text{rec}}}P_{1,\text{rec}}\frac{P_{2,\text{smear}}}{P_{2,\text{rec}}}P_{2,\text{rec}}} \cdot \sin\left(\frac{\theta}{2}\right) = \sqrt{\frac{P_{1,\text{smear}}}{P_{1,\text{rec}}}\frac{P_{2,\text{smear}}}{P_{2,\text{rec}}}} \cdot M(\text{ee})$$



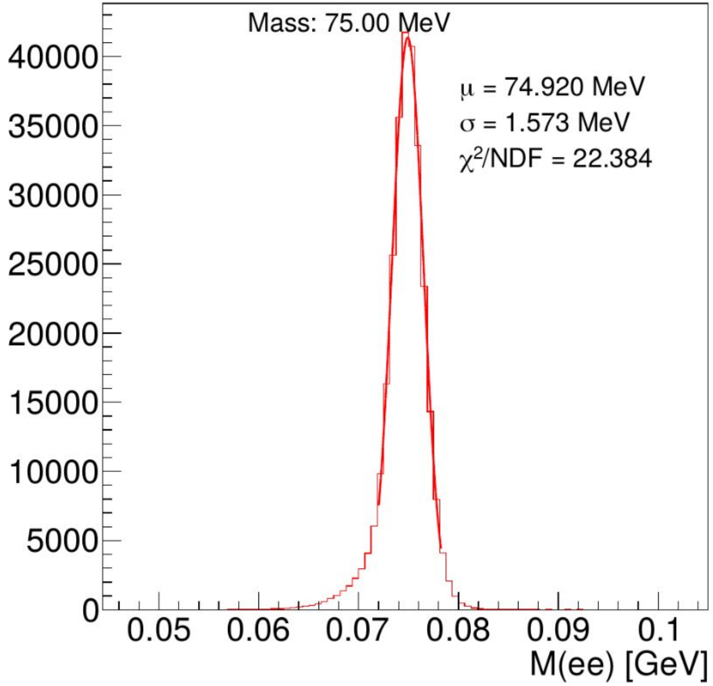


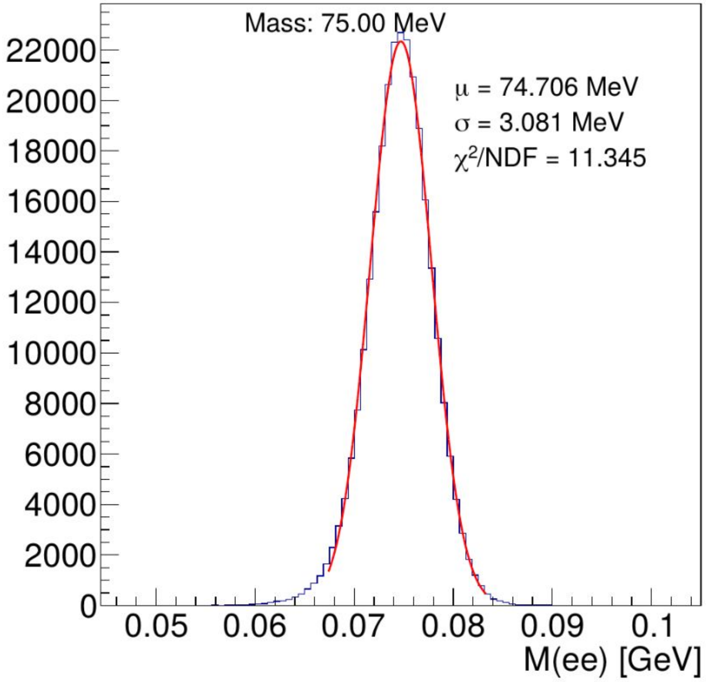
Assuming the angular discrepancy between MC and data can be neglected

Parametrizing the mass resolution

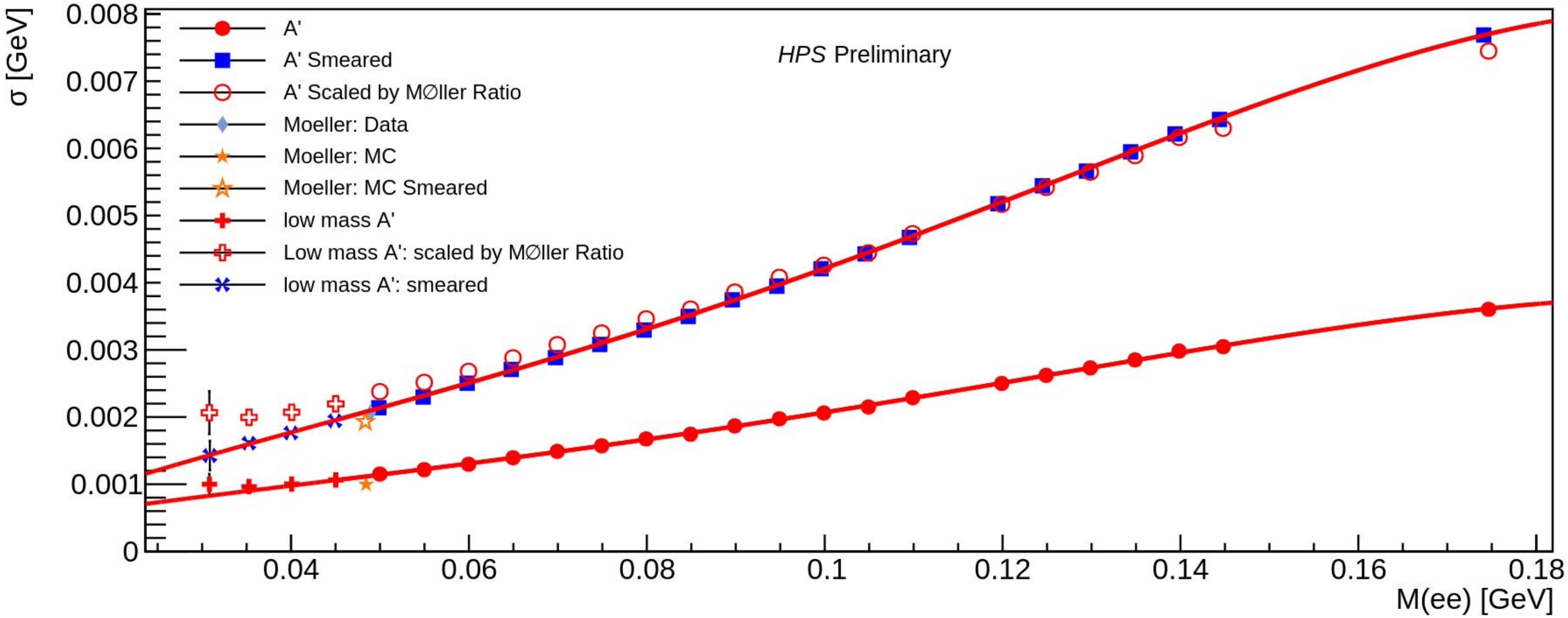
We have multiple MC simulations for different A' masses across the whole mass range
For each mass A' mass MC sample the e- and e+ moment are smeared, and consequently the smeared mass is calculated.

As one particular example: 75 MeV mass simulation





Parametrizing the mass resolution



The Radiative fraction

Reminder: $$\sigma_{A'} = \frac{3\pi m_{A'}\epsilon^2}{2N_{\text{eff}}\alpha}\frac{\mathrm{d}\sigma_{\gamma^*}}{\mathrm{dm}}\Big|_{m=m_{A'}}$$

When we find/or don't find A', then the ϵ^2 can be calculated as:

$$\epsilon^2 = \frac{2\alpha N_{\text{sig}}^{\text{up}}}{3\pi m_{A'}\frac{\mathrm{dN}_{\gamma^*}}{\mathrm{dm}}}$$

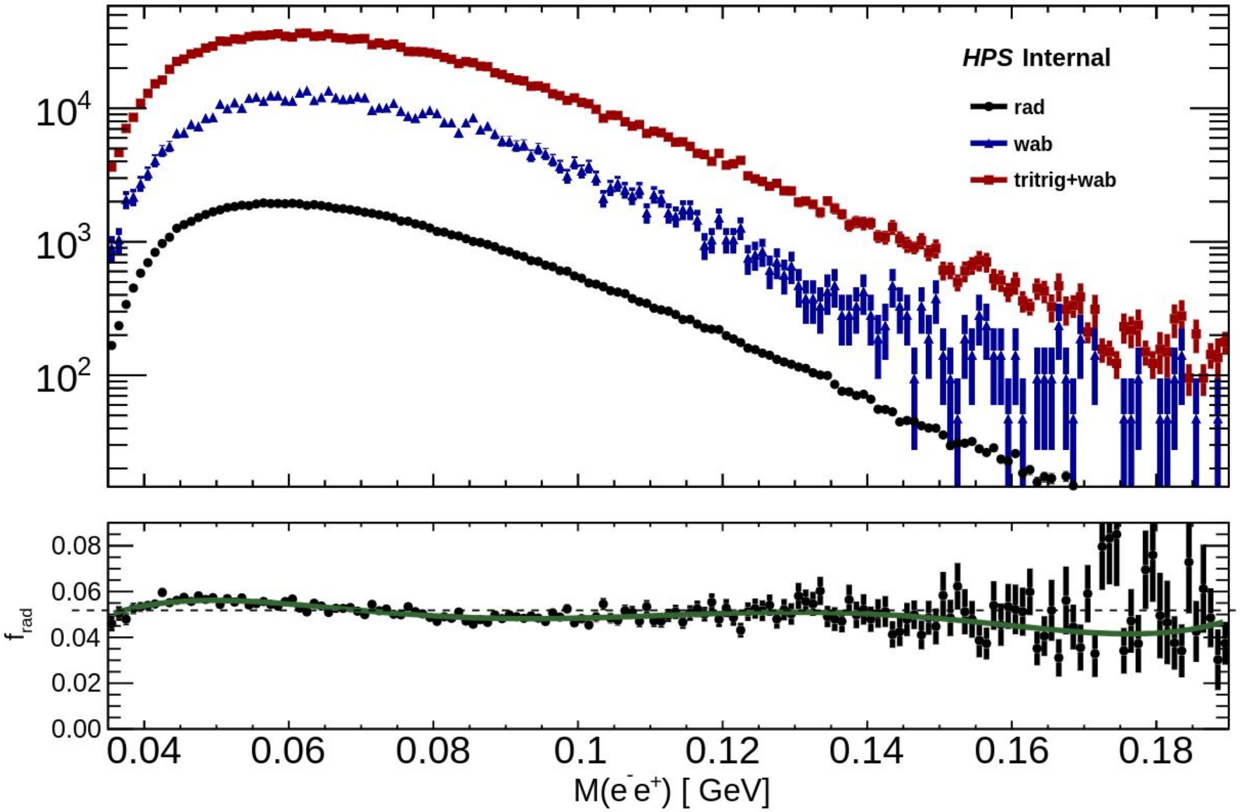
However we don't measure $\frac{dN_\gamma^*}{dm}$ However we measure the total rate: $\frac{dN_{Tot}}{dm}$

$$f_{\text{rad}} = \frac{\frac{\mathrm{dN}_{\gamma^*}}{\mathrm{dm}}}{\frac{\mathrm{dN}_{\text{bkg}}}{\mathrm{dm}}} = \frac{\frac{\mathrm{dN}_{\gamma^*}}{\mathrm{dm}}}{\frac{\mathrm{dN}_{\text{tri}}}{\mathrm{dm}} + \frac{\mathrm{dN}_{\text{wab}}}{\mathrm{dm}}}$$

Is determined purely from MC.

$$\epsilon^2 = \frac{2\alpha N_{\text{sig}}^{\text{up}}}{3\pi m_{A'} f_{\text{rad}}\frac{\mathrm{dN}_{\text{bkg}}}{\mathrm{dm}}}$$

The Radiative fraction



It was required the electron to be the daughter of Rad Photon!

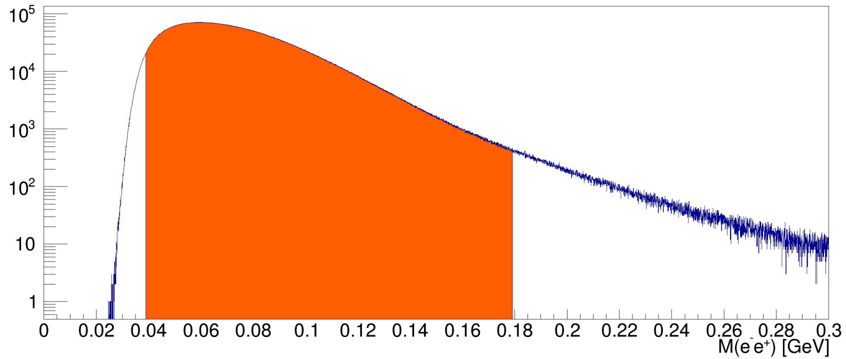
In average the f_{Rad} is 5% across the whole mass range.

Parameterized with 5-th order Polynomial

Searching for the peak

General Methodology

- If the A’ exists, it is expected to appear as a Gaussian peak over the mass spectrum.
- The Width of the peak is expected to be the detector resolution for the given mass.
- As we don’t know the mass of the A’ (if it exists), we need to perform search for all possible masses.
- We have performed search in the in the 39 MeV - 179 MeV range, with 1 MeV steps.
- First: Tools are developed on 10% sample, then in the second step search was performed on 100% sample.



$$P(m_{e^+e^-}) = \mu \cdot \phi(m_{e^+e^-} | m_{A'}, \sigma_{m_{A'}}) + 10^{L_N(m_{e^+e^-}|\vec{t})}$$

Signal yield　　Gaussian PDF　　Background

- The background model is a “Odd order” Legendre Polynom of the first kind.
- For each mass the search range is scaled to be -1 to 1

Test Statistics

$$\lambda(\mu) = \frac{\mathcal{L}(\mu, \hat{\hat{\theta}})}{\mathcal{L}(\hat{\mu}, \hat{\theta})}$$

The likelihood ratio is used to characterize the consistency of the data with the presumed signal strength μ .

Commonly used test statistics

$$\tilde{q}_0 = \begin{cases} -2\ln\lambda(0) & \hat{\mu} > 0 \\ +2\ln\lambda(0) & \hat{\mu} \leq 0 \end{cases}$$

The probability of a null hypothesis is true is given by

$$p = \int_{\tilde{q}_{0,\mathrm{obs}}}^{\infty} f(\tilde{q}_0|0)\,d\tilde{q}_0$$

$f(q_0)$ is expected to be Normal distribution of q_0.

p-value:

$$p = \begin{cases} 1 - \Phi(\sqrt{\tilde{q}_0}) & \tilde{q}_0 \geq 0 \\ 1 - \Phi - \sqrt{-\tilde{q}_0} & \tilde{q}_0 < 0 \end{cases}$$

$\mathbf{\Phi}$ Is a Gaussian CDF

To be compared to the threshold α in order to claim a discovery

α is usually chosen to be $5\boldsymbol{\sigma} = 3*10^{-7}$.

Look elsewhere effect: $p_{global} = 30*p_{local}$. (More detailed explanation is in the backup)

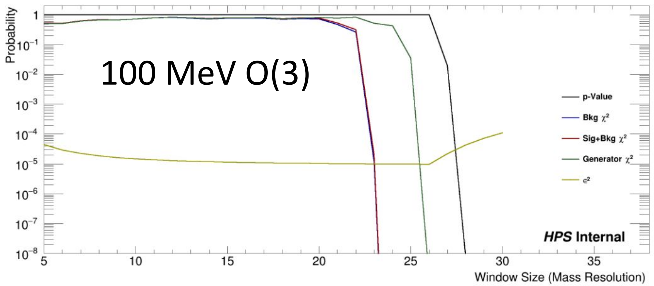
Bgr Model selection

Poly. order: 3 and 5
Window size: from 5$\boldsymbol{\sigma}$ to 30$\boldsymbol{\sigma}$ was studied.

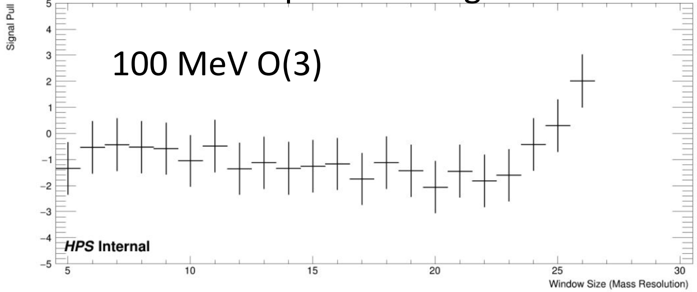
The unblinded (10%) data was used in these studies.

Each model is tested for each mass by generating 10K Toy distributions (pdf is obtained by fitting w/ O(N+2) function).

Make sure bgr only fit χ^2 is good

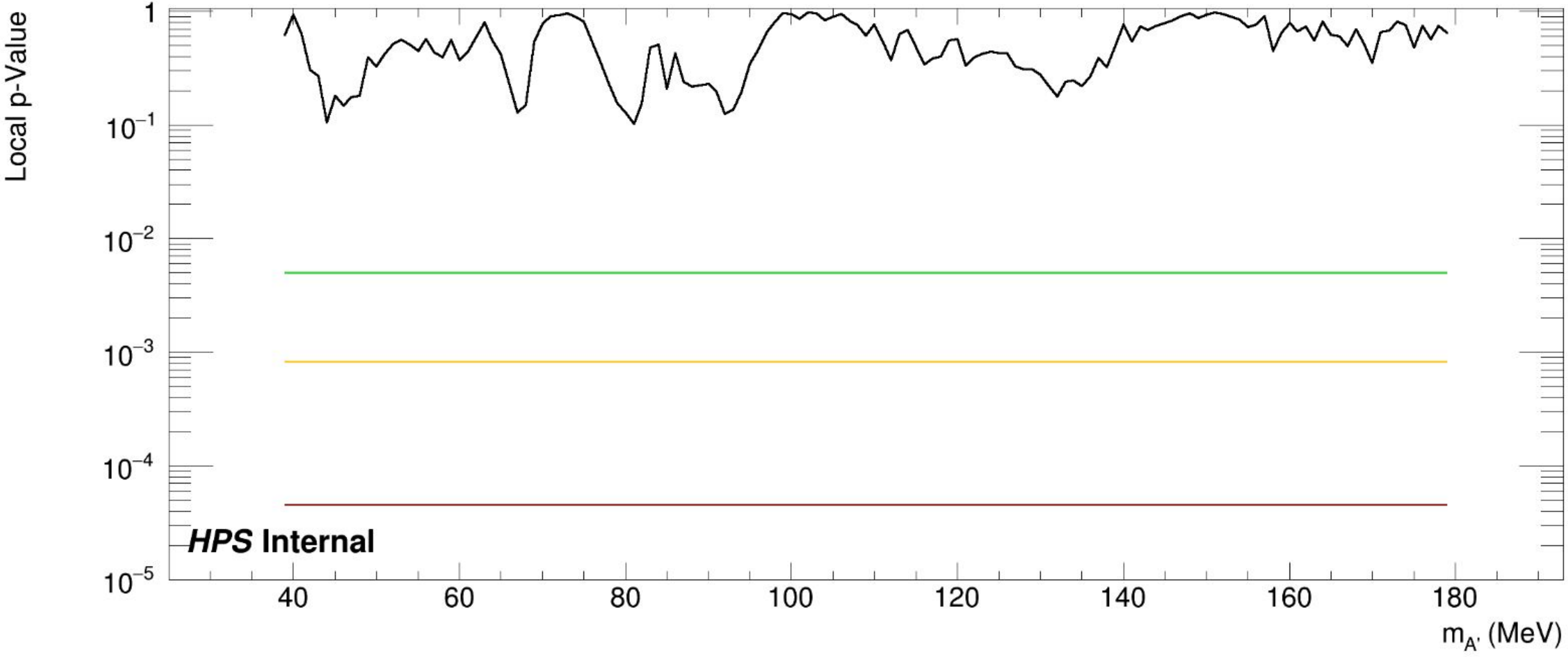


Make sure no pull is not significant



During unblinded studies, for each mass, if there is 5 or more consecutive windows present, then then model with tme size in the middle is chosen. Then if this condition satisfied for both O(3) and O(5), then the O(3) is chosen.

Resonance search with 10% sample



There is no any significant pull.

The upper limit

For putting the upper limit we compare likelihoods of μ w/ $\hat{\mu}$

$$\tilde{\lambda}(\mu) = \begin{cases} \frac{\mathcal{L}(\mu,\hat{\hat{\theta}}_{\mu})}{\mathcal{L}(\hat{\mu},\hat{\theta}_{\hat{\mu}})} & \hat{\mu} \geq 0 \\ \frac{\mathcal{L}(\mu,\hat{\hat{\theta}}_{\mu})}{\mathcal{L}(0,\hat{\hat{\theta}}_{0})} & \hat{\mu} < 0 \end{cases}$$

The test statistics

$$\tilde{q}_{\mu} = \begin{cases} -2\ln\lambda(\mu) & \hat{\mu} \leq \mu \\ +2\ln\lambda(\mu) & \hat{\mu} > \mu \end{cases}$$

p-value of the signal

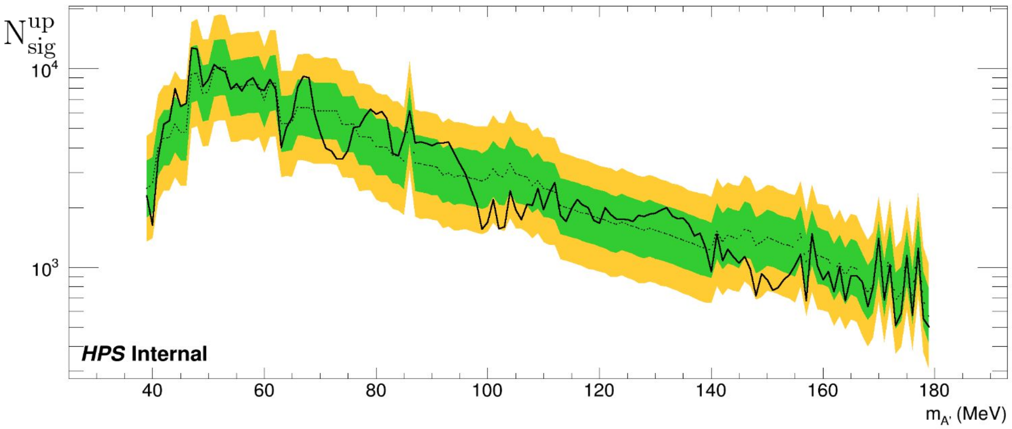
$$p_{\mu} = \begin{cases} 1 - \Phi(-\sqrt{-\tilde{q}_{\mu}}) & \tilde{q}_{\mu} < 0 \\ 1 - \Phi(\sqrt{\tilde{q}_{\mu}}) & 0 \leq \tilde{q}_{\mu} \leq \mu^2/\sigma^2 \\ 1 - \Phi(\frac{\tilde{q}_{\mu}+\mu^2/\sigma^2}{2\mu/\sigma}) & \mu^2/\sigma^2 < \tilde{q}_{\mu} \end{cases}$$

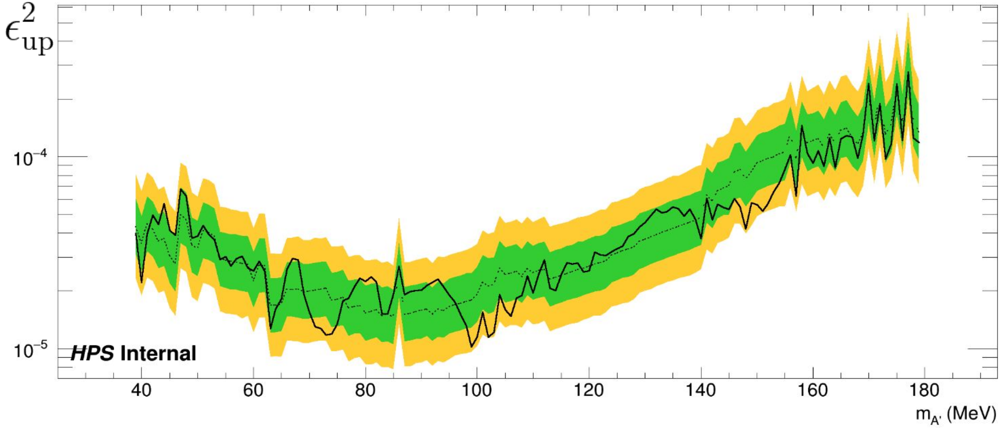
p-value of the background

$$p_{b} = \begin{cases} \Phi(-\sqrt{-\tilde{q}_{\mu}} - \mu/\sigma) & \tilde{q}_{\mu} < 0 \\ \Phi(\sqrt{\tilde{q}_{\mu}} - \mu/\sigma) & 0 \leq \tilde{q}_{\mu} \leq \mu^2/\sigma^2 \\ \Phi(\frac{\tilde{q}_{\mu}-\mu^2/\sigma^2}{2\mu/\sigma}) & \mu^2/\sigma^2 < \tilde{q}_{\mu} \end{cases}$$

$$\mathrm{CL}_s(\mu) = \frac{p_{\mu}}{1 - p_b}$$

Upper limits with 10% sample



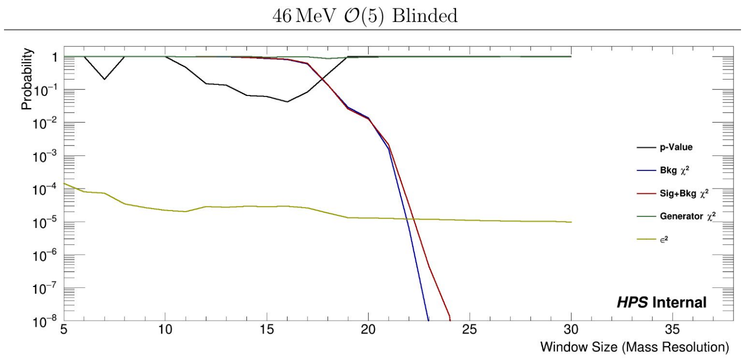


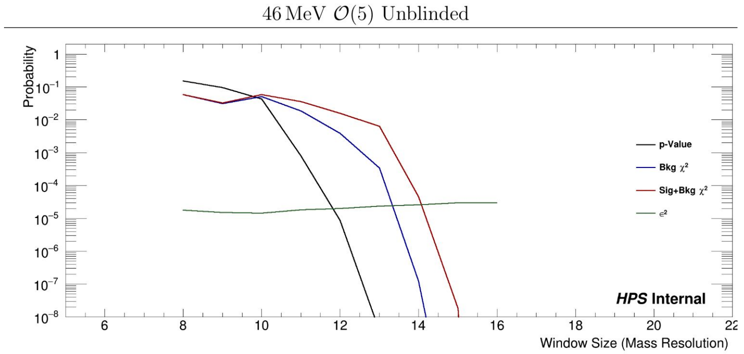
Full data set

Upon unblinding some issues were observed related bgr model selection.

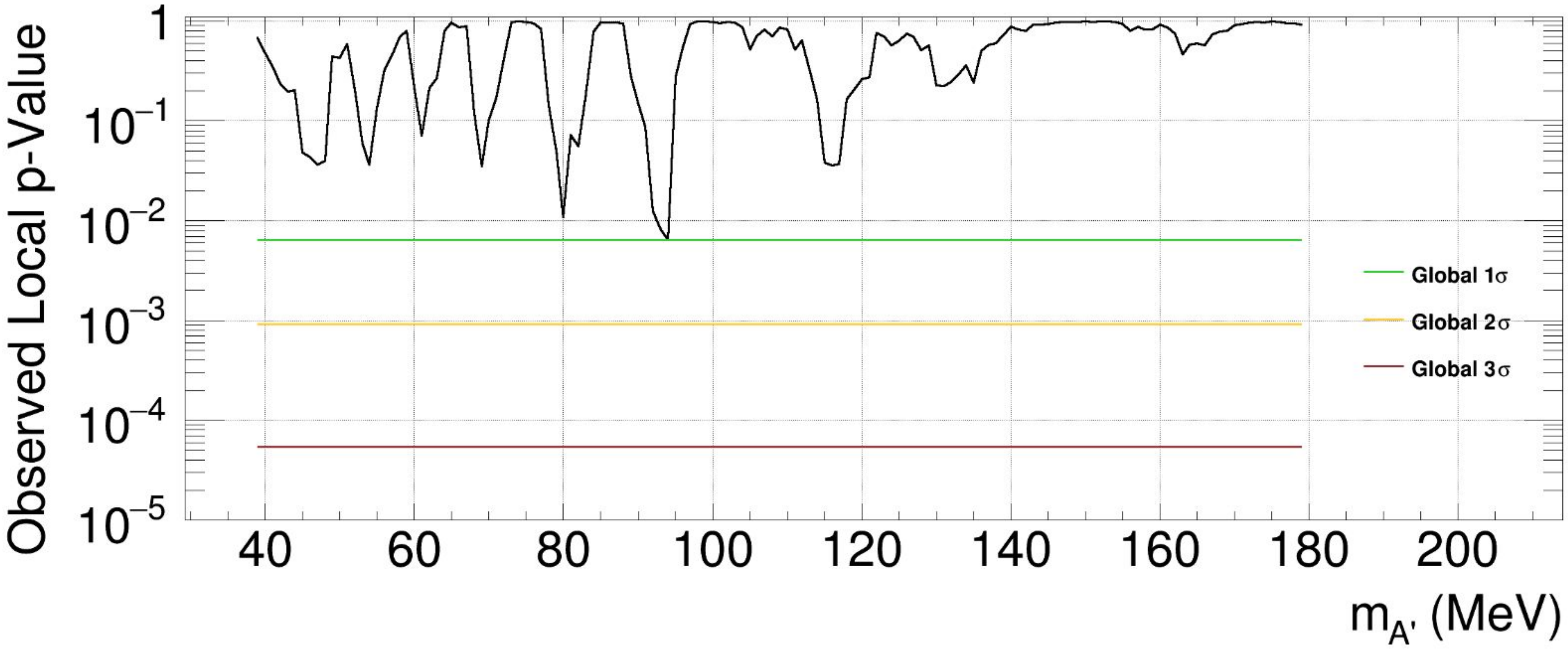
In some masses, selected models were not conservative enough and failed to be a “good” bgr model, created significant pull.

- Window sizes were reduced
- Mass-to-mass variations if window sizes were smoothed out
- All masses above 66 MeV used 3-rd order poly

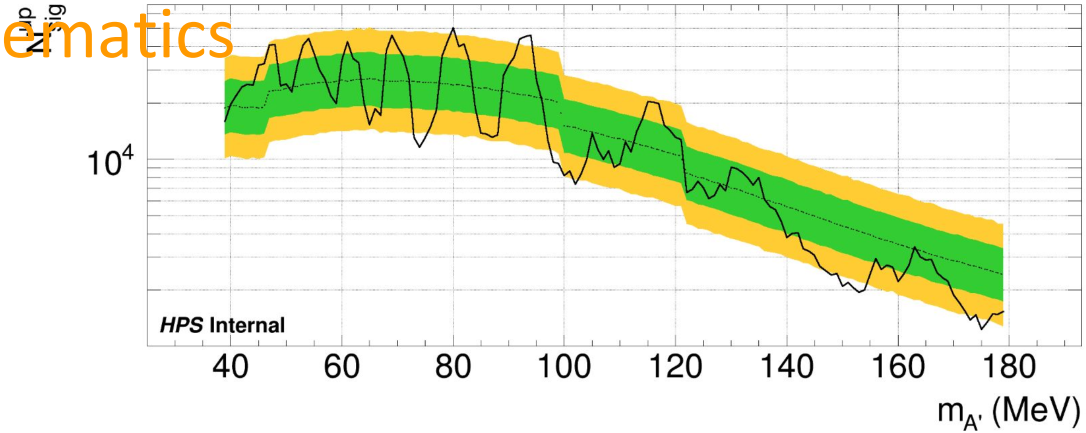


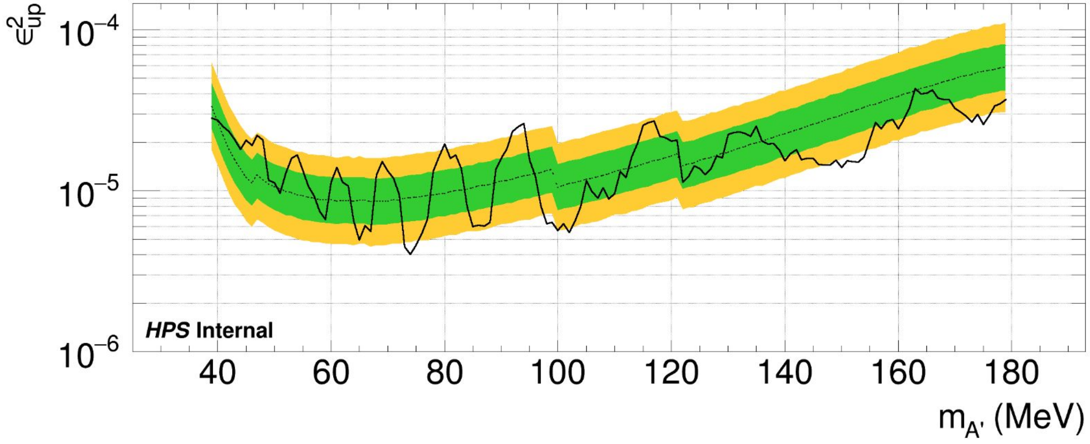


p-values with the full statistics

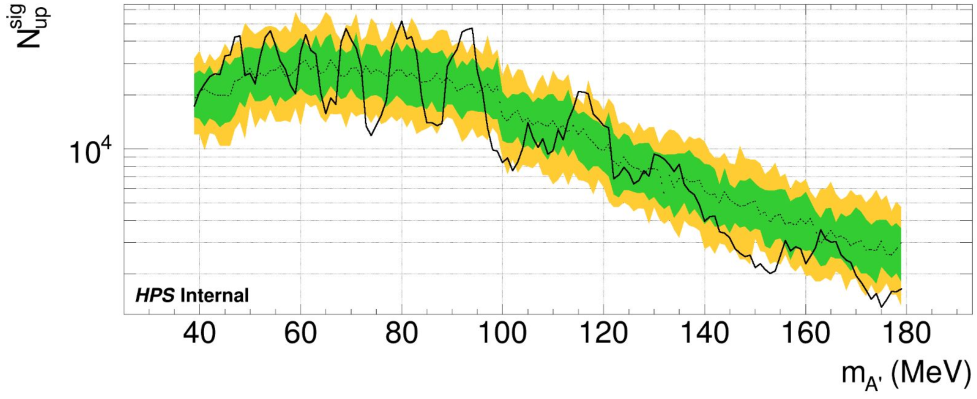


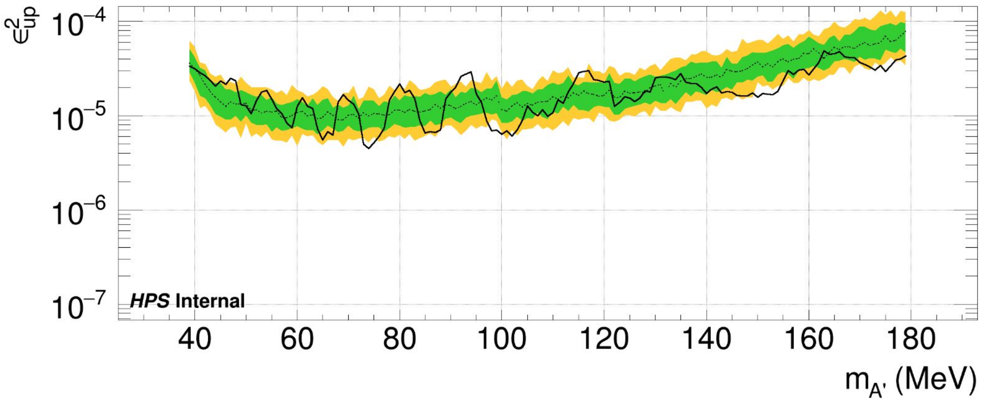
Upper limits with Full data set: No Systematics





Limits with Systematics included





Mass resolution related systematics

10K Fits, each time the mass resolution was chosen as a Gaussian according to the massresol systematics.

The upper limit is chosen as the 84% quantile of 10K upper limits.

f_{Rad} related systematics

f_{Rad} uncertainty doesn't affect the signal upper limit, but it does affect ϵ^2.

Effectively f_{Rad} is replaced by $f_{Rad}(1-\sigma_{Sys})$.

Systematic uncertainties

$$\epsilon^2 = \frac{2\alpha \boxed{N_{sig}^{up}}}{3\pi m_{A'} \boxed{f_{rad}} \frac{dN_{bkg}}{dm}}$$

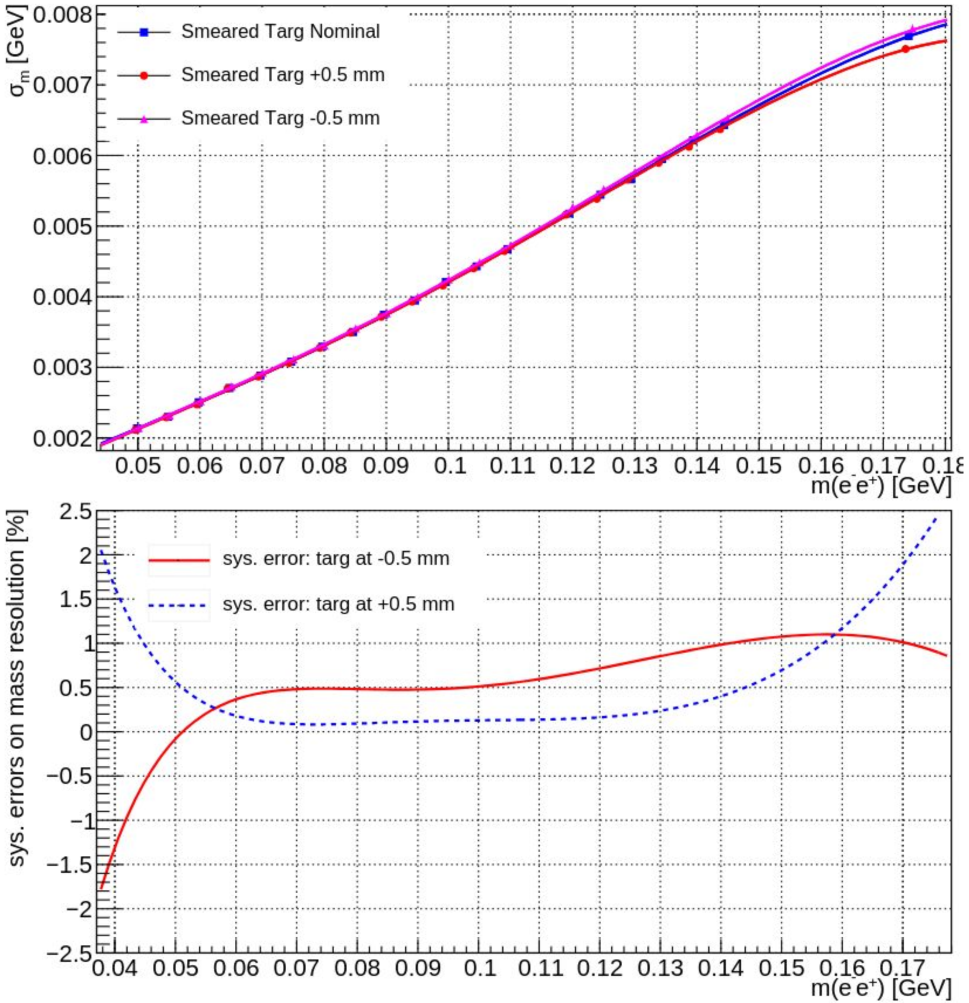
Mass resolution related uncertainties contribute to the N^{up}, and consequently to the ϵ^2.

Uncertainties on f_{Rad} affect only ϵ^2.

Following sources of uncertainties were considered

Uncertainty source	**propagates to**
Target position	mass resolution
Momentum smearing	f_{Rad} and mass resolution
Track killing	f_{Rad}
MC cross-sections	f_{Rad}
Event Selection cuts	f_{Rad} and mass resolution.

Uncertainty of the target position

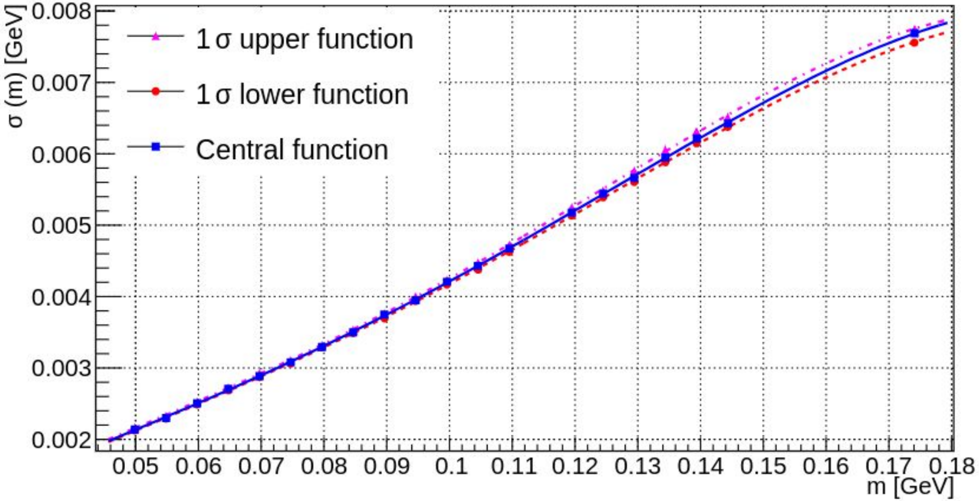


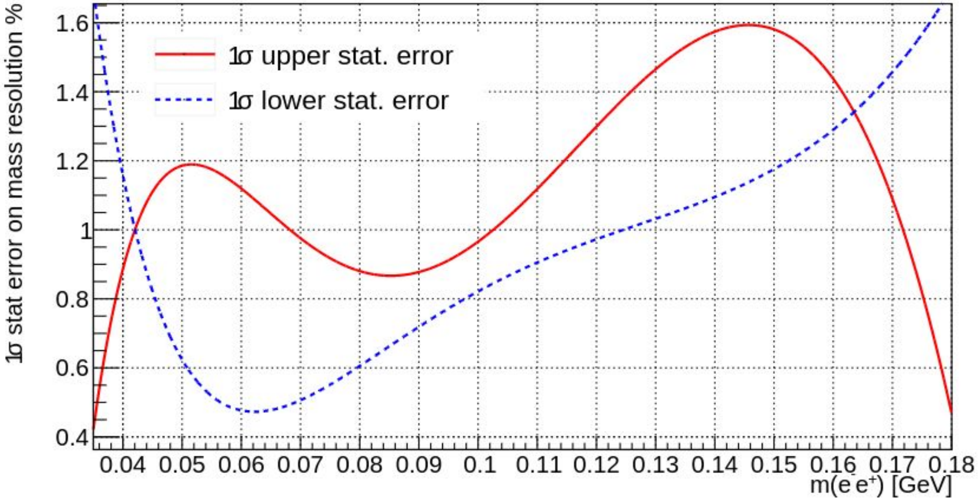
A’ samples generated at vz = +/- 0.5 mm and at 0 mm

For each case the difference between the corresponding **σ** and the **σ** at 0mm is calculated.

The uncertainty is taken as the maximum of absolute values of the two (+0.5 mm -0.5 mm)

Uncertainty of smearing coefficients





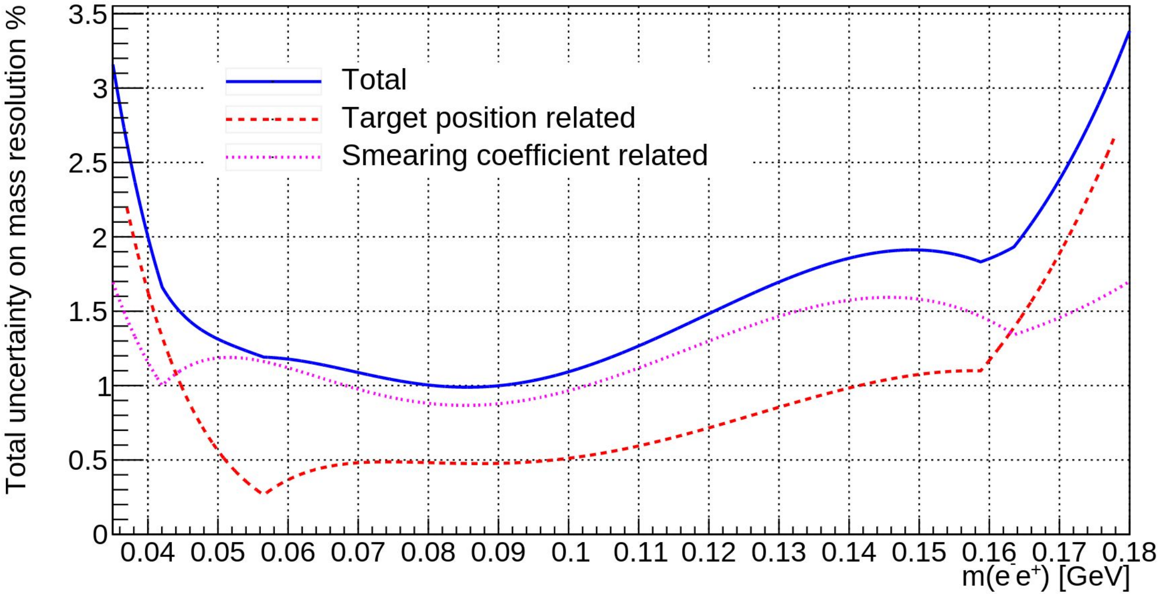
Generated A’ samples were smeared with +/- 1**σ** smearing coefficients.

Two differences between the smeared and non-smeared are constructed.

The maximum of two at a given mass is considered as smearing related uncertainty on the mass resolution.

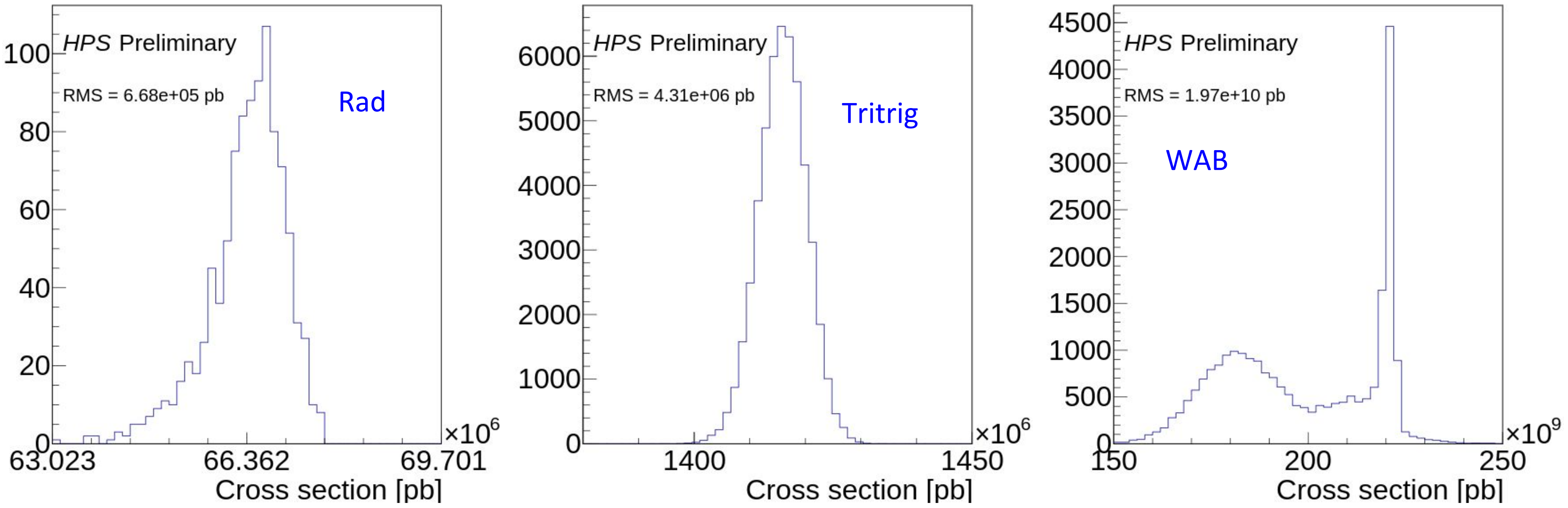
Total uncertainty on mass resolution

$$\mathrm{Err}_{\sigma_{\mathrm{total}}} = \sqrt{\mathrm{Err}^2_{\sigma_{\mathrm{target}}} + \mathrm{Err}^2_{\sigma_{\mathrm{smear}}}}$$



Uncertainties on f_{Rad}

Two main sources: Uncertainties on MadGraph cross-sections, and limited phase space of the generator.



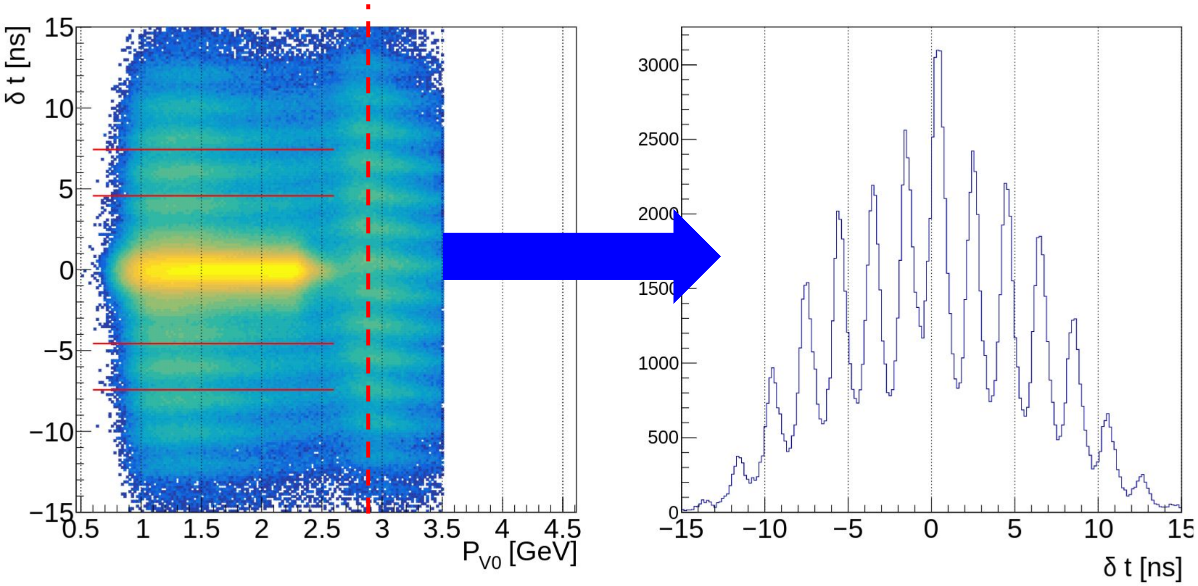
Take 1% on fRad uncertainty, and 19.8% WAB cross-section (2*RMS) .
As WAB accounts only aout 32% in the denumerator, the uncertainty of denumerator is ≈ 6.35%
We rounded up 7% on fRad from the x-sec uncertainty.

Uncertainties on f_{Rad}

In the generator we have a cut on particle angle (5mRad) and three momentum (50 MeV).

<u>IF, a positron will be in coincidence with a beam accidental electron, then small angle electrons that were cut in the generator could pass all event selection cuts, and contribute to the final mass distribution.</u>

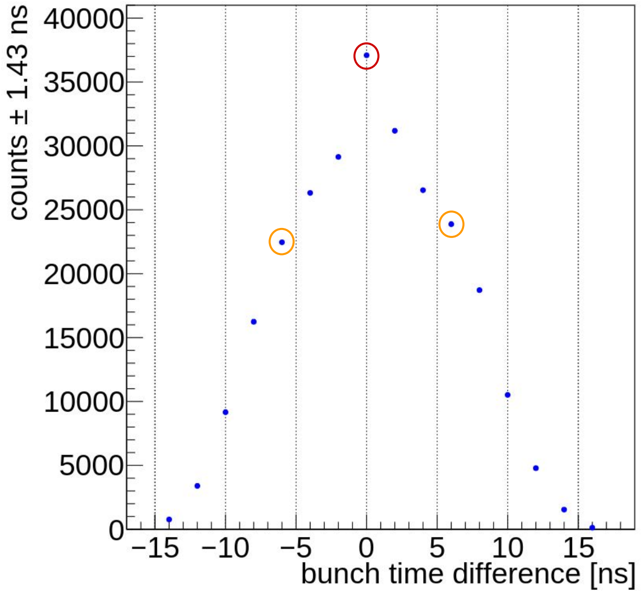
We took a very conservative approach: i.e. estimated the background under the main peak

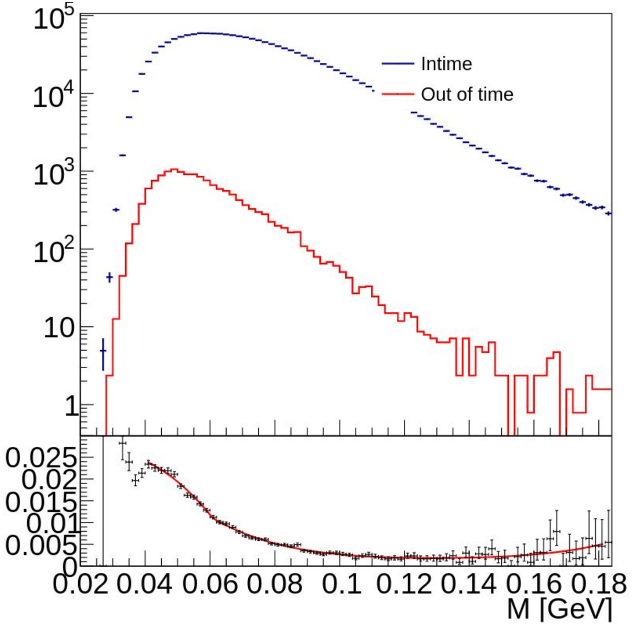


We estimate the ratio of accidental bgr under the given beam bunch to the bgr under the main peak.

Uncertainties on f_{Rad}

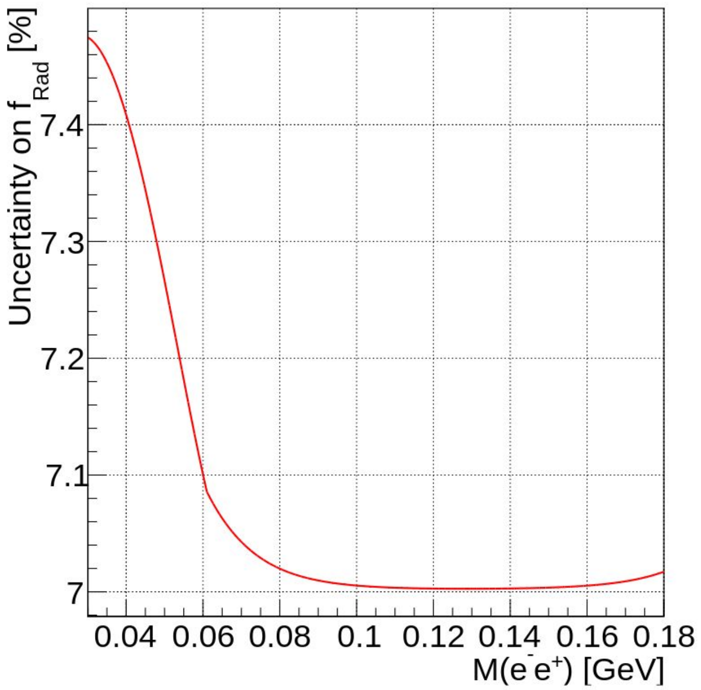
The same analysis was performed with Δt at +/- 6ns +/- 1.43 ns, then the ratio obtained from the left graph is used to estimate the background under the main peak.



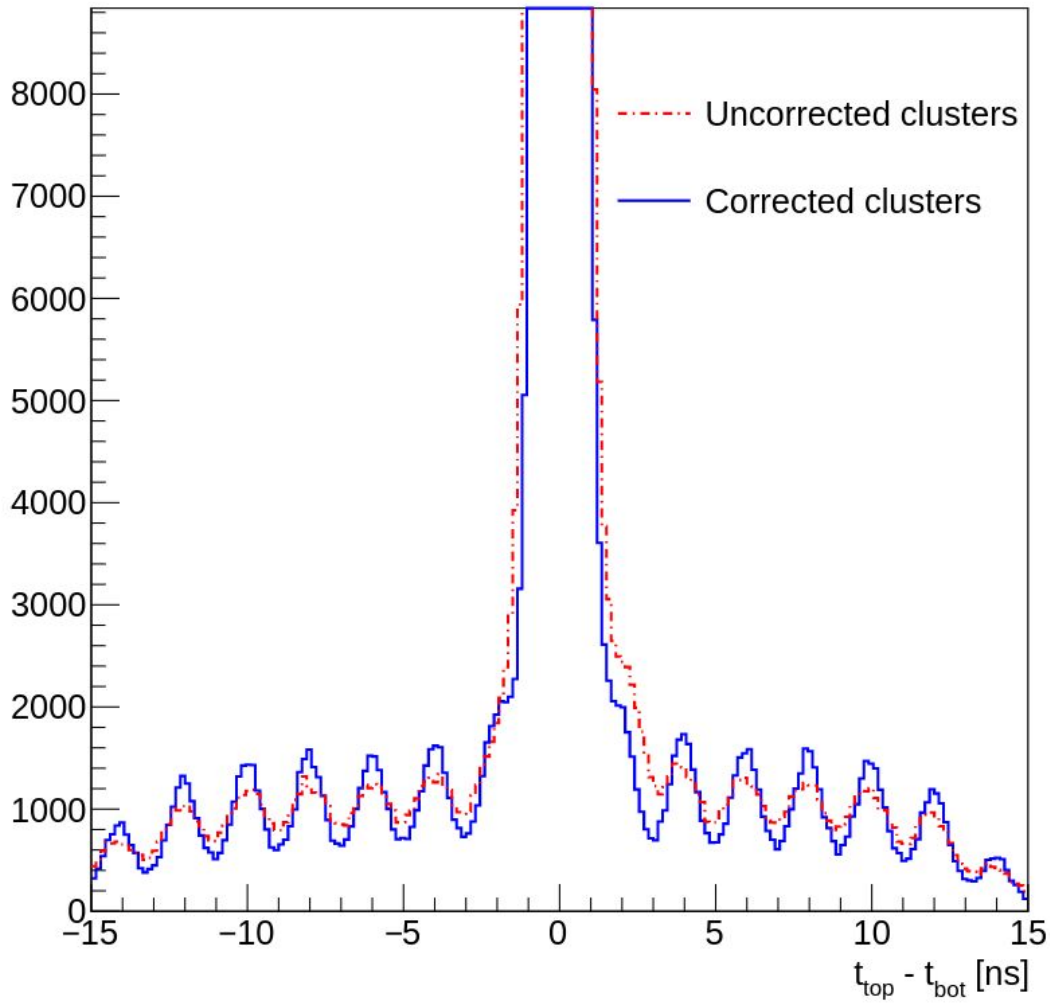


The bgr ratio is parametrized as a function of mas and added to the 7% uncertainty

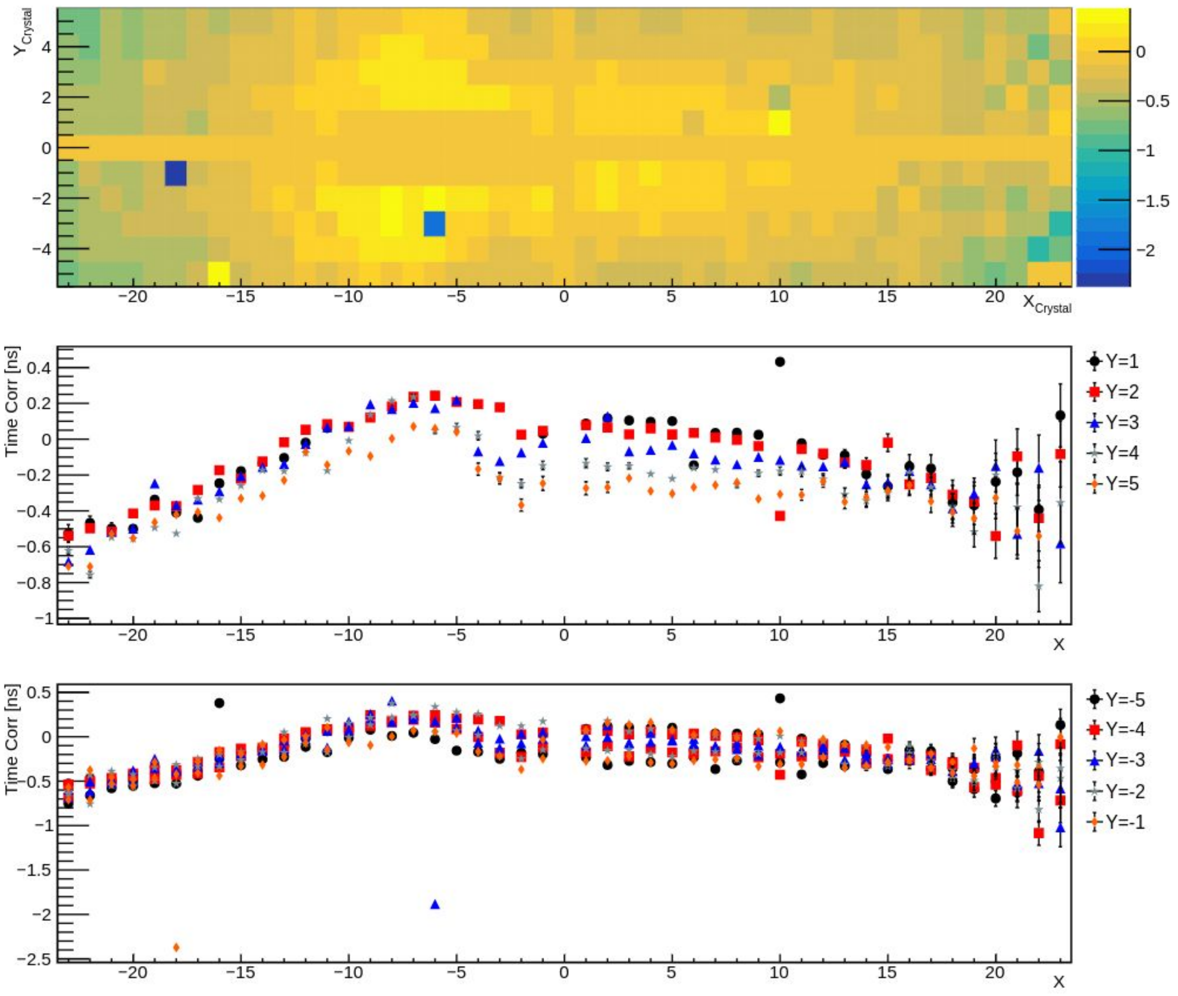
Total uncertainty on f_{Rad}



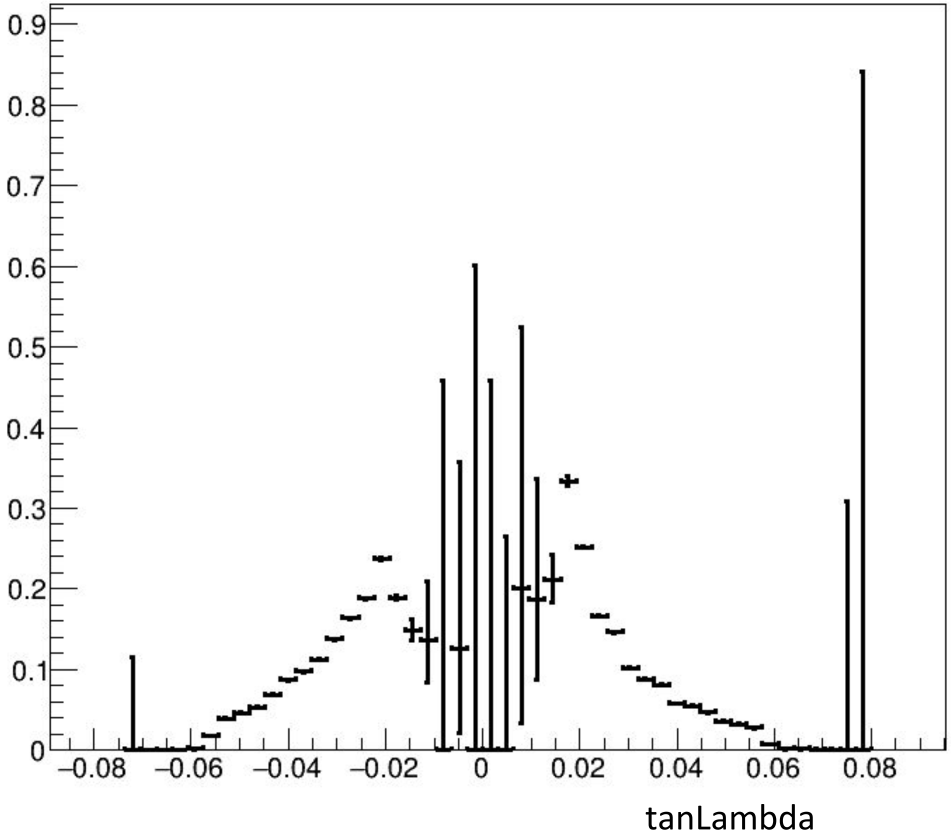
Backup



8000
7000
6000
5000
4000
3000
2000
1000
0
−15
−10
−5
0
5
10
15
Uncorrected clusters
Corrected clusters
t_{top} - t_{bot} [ns]

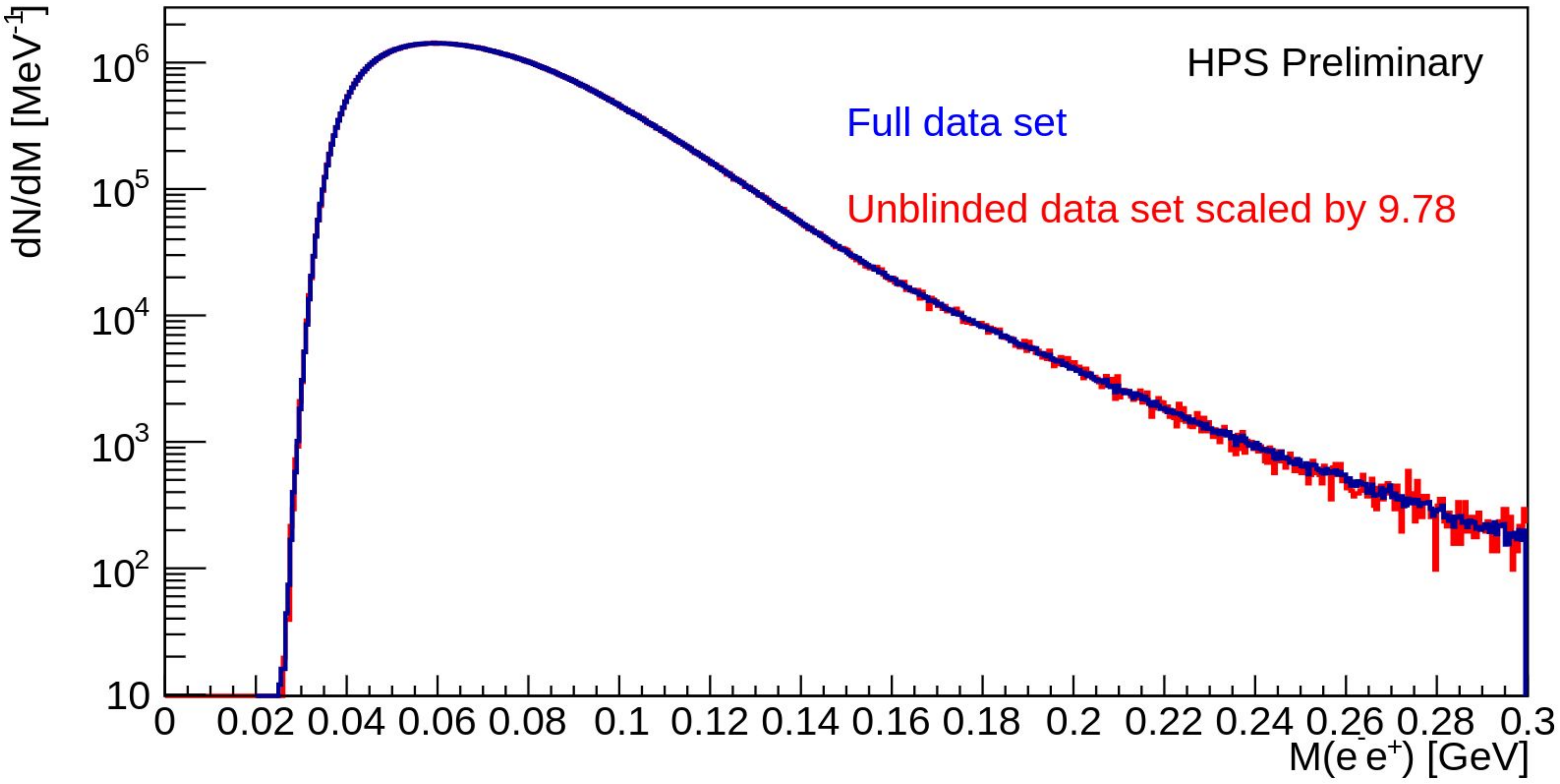


Ad-hoc crystal time corrections.

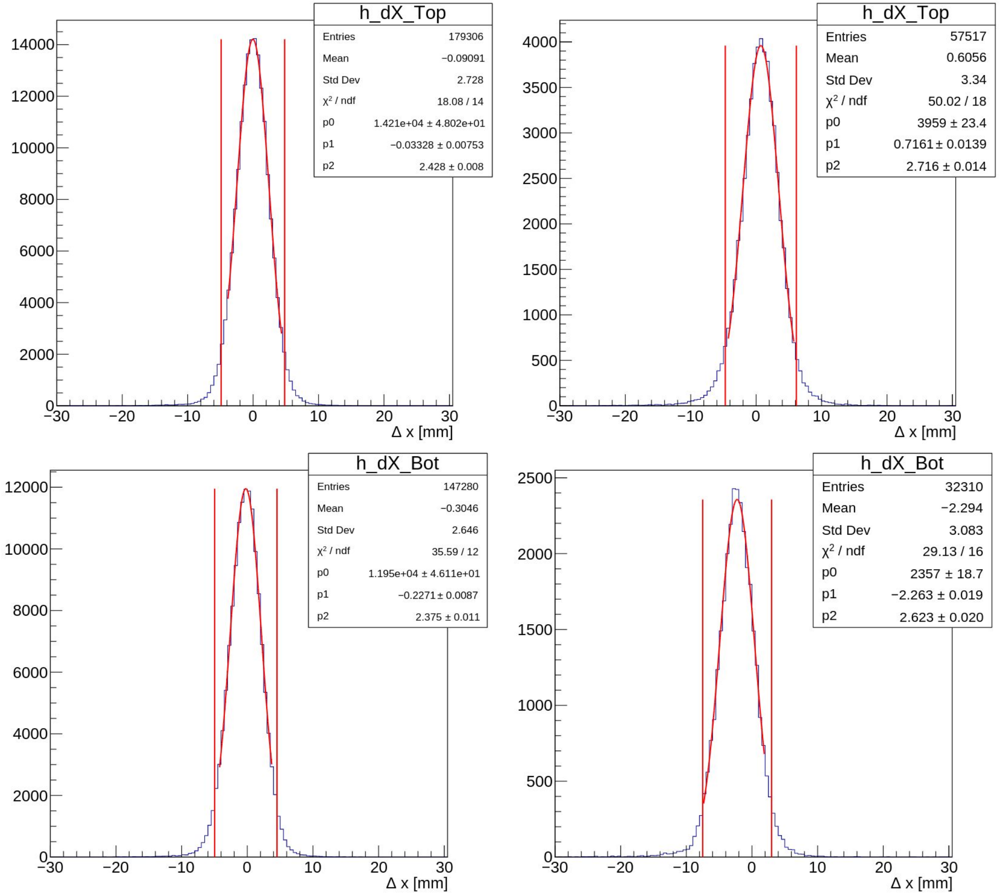


- If the track has 6 hit, then it is not killed
- If the track has 5 hits, the it is killed according to the graph depending on tanLambda of the track.

Comparison of Blinded and unblinded mass spectra



Moellers Delta_x distributions



The Look elsewhere effect

The p-value represents the probability of measured test statistics to be consistent with the given signal hypothesis μ.

In reality we don't do a single measurement.

Imagine we have an infinitely long mass spectrum. We will find a mass where just because of statistical fluctuations we will have the p-value below the discovery threshold.

We need to correct the the fact that we do measurement for more than once:

$$p_{global} = N_{Reg} * p_{local}.$$

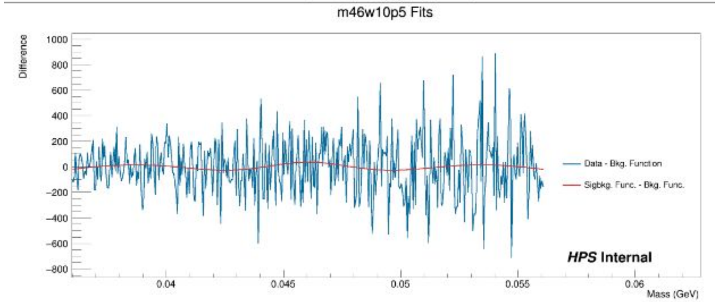
N_{Reg} is the number of independent measurements.

$$\mathrm{N_{Reg}} \approx \frac{\mathrm{Tot.Width}}{\sigma_{\mathrm{avg}}} \approx 30$$

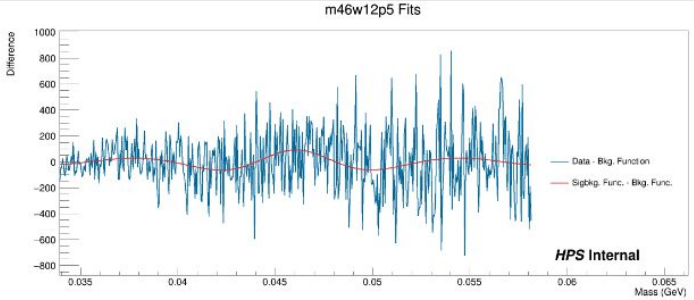
Selected Bgr Models with 10% sample

$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ
39	5	18	68	3	7	97	3	13	126	3	13	155	3	8
40	5	19	69	5	11	98	3	13	127	3	13	156	3	7
41	5	14	70	5	11	99	3	13	128	3	13	157	3	9
42	5	13	71	5	11	100	3	12	129	3	13	158	3	7
43	5	13	72	5	11	101	3	10	130	3	12	159	3	8
44	5	11	73	5	11	102	3	11	131	3	12	160	3	8
45	5	12	74	3	8	103	3	11	132	3	12	161	3	8
46	5	12	75	3	8	104	3	14	133	3	12	162	3	9
47	5	8	76	3	8	105	3	10	134	3	12	163	3	8
48	5	8	77	3	9	106	3	10	135	3	12	164	3	9
49	5	9	78	3	9	107	3	10	136	3	12	165	3	8
50	5	9	79	3	9	108	3	11	137	3	12	166	3	8
51	5	8	80	3	10	109	3	10	138	3	12	167	3	9
52	5	8	81	3	10	110	3	11	139	3	12	168	3	10
53	5	8	82	3	10	111	3	11	140	3	12	169	3	9
54	5	9	83	3	11	112	3	11	141	3	9	170	5	10
55	5	9	84	3	11	113	3	14	142	3	10	171	3	9
56	5	9	85	3	12	114	3	14	143	3	9	172	5	10
57	5	9	86	3	7	115	3	14	144	3	9	173	3	10
58	5	9	87	3	12	116	3	14	145	3	9	174	3	9
59	5	9	88	3	12	117	3	14	146	3	8	175	5	10
60	5	10	89	3	12	118	3	14	147	3	8	176	3	9
61	5	9	90	3	12	119	3	14	148	3	9	177	5	9
62	5	9	91	3	12	120	3	14	149	5	13	178	3	9
63	3	8	92	3	14	121	3	14	150	3	8	179	3	11
64	3	8	93	3	13	122	3	14	151	3	8			
65	3	8	94	3	14	123	3	13	152	3	8			
66	3	7	95	3	13	124	3	13	153	3	8			
67	3	7	96	3	13	125	3	13	154	3	8			

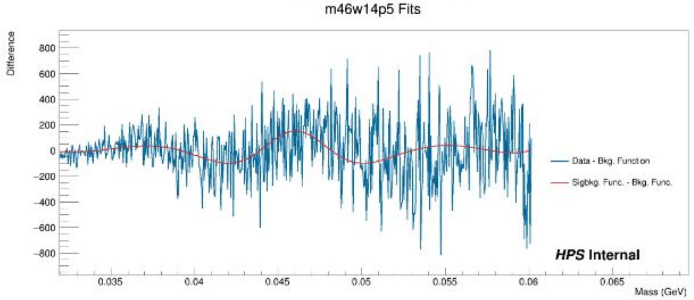
$46\,\mathrm{MeV},\ \mathcal{O}(5),\ n_\sigma = 10$



$46\,\mathrm{MeV},\ \mathcal{O}(5),\ n_\sigma = 12$



$46\,\mathrm{MeV},\ \mathcal{O}(5),\ n_\sigma = 14$

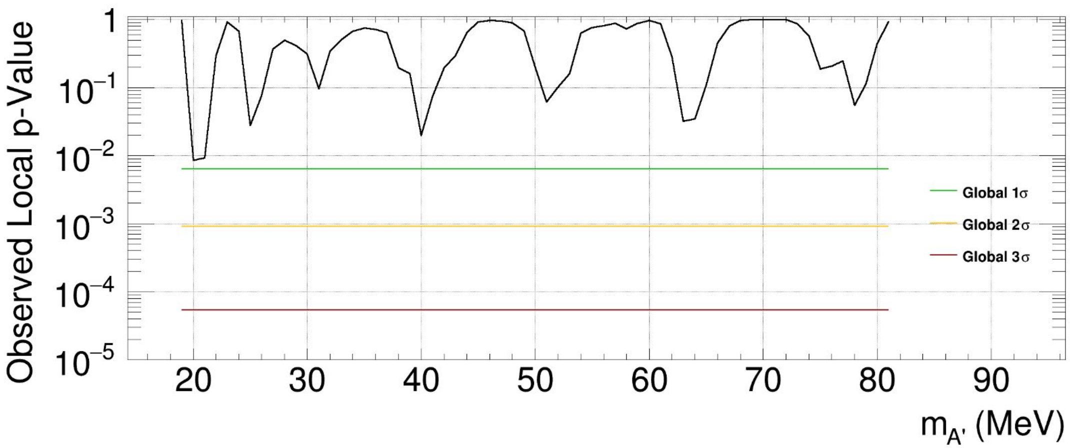


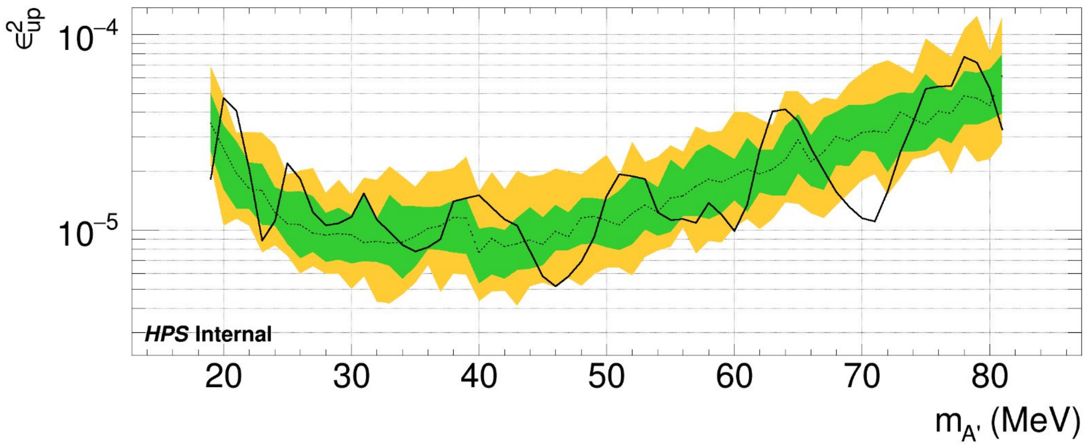
Demonstration that increasing the window size creates and artificial pull.

Bgr models after unblinding

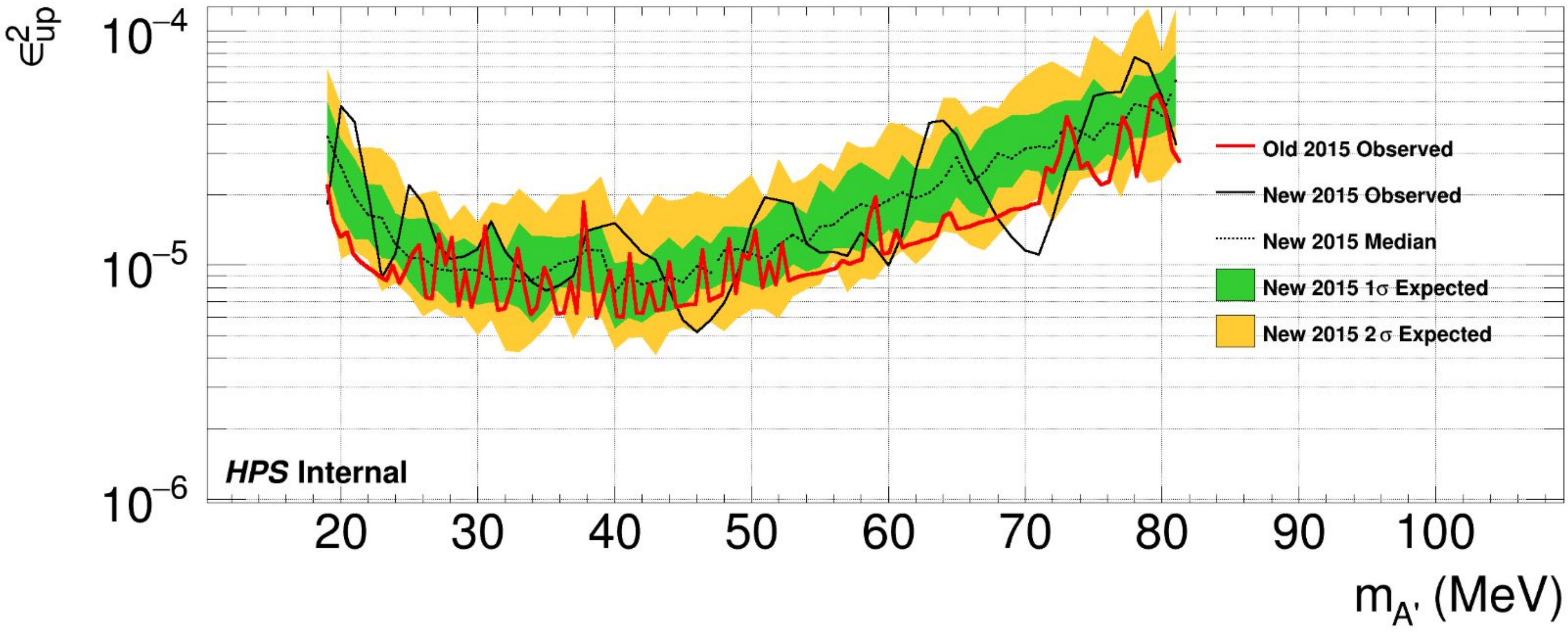
$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ	$m_{A'}$	$\mathcal{O}(N)$	n_σ
39	5	10	68	3	6	97	3	6	126	3	8	155	3	8
40	5	10	69	3	6	98	3	6	127	3	8	156	3	8
41	5	10	70	3	6	99	3	6	128	3	8	157	3	8
42	5	10	71	3	6	100	3	7	129	3	8	158	3	8
43	5	10	72	3	6	101	3	7	130	3	8	159	3	8
44	5	10	73	3	6	102	3	7	131	3	8	160	3	8
45	5	10	74	3	6	103	3	7	132	3	8	161	3	8
46	5	10	75	3	6	104	3	7	133	3	8	162	3	8
47	5	9	76	3	6	105	3	7	134	3	8	163	3	8
48	5	9	77	3	6	106	3	7	135	3	8	164	3	8
49	5	9	78	3	6	107	3	7	136	3	8	165	3	8
50	5	9	79	3	6	108	3	7	137	3	8	166	3	8
51	5	9	80	3	6	109	3	7	138	3	8	167	3	8
52	5	9	81	3	6	110	3	7	139	3	8	168	3	8
53	5	9	82	3	6	111	3	7	140	3	8	169	3	8
54	5	9	83	3	6	112	3	7	141	3	8	170	3	8
55	5	9	84	3	6	113	3	7	142	3	8	171	3	8
56	5	9	85	3	6	114	3	7	143	3	8	172	3	8
57	5	9	86	3	6	115	3	7	144	3	8	173	3	8
58	5	9	87	3	6	116	3	7	145	3	8	174	3	8
59	5	9	88	3	6	117	3	7	146	3	8	175	3	8
60	5	9	89	3	6	118	3	7	147	3	8	176	3	8
61	5	9	90	3	6	119	3	7	148	3	8	177	3	8
62	5	9	91	3	6	120	3	7	149	3	8	178	3	8
63	5	9	92	3	6	121	3	7	150	3	8	179	3	8
64	5	9	93	3	6	122	3	8	151	3	8	180	3	8
65	5	9	94	3	6	123	3	8	152	3	8			
66	5	9	95	3	6	124	3	8	153	3	8			
67	3	6	96	3	6	125	3	8	154	3	8			

Reanalysis of 2015 data





Some bugs were discovered in 2015 analysis. Mass resolution was not properly scaled at the fit range to (-1,1) range transition.



ϵ^2_{up}
10^{-4}
10^{-5}
10^{-6}
Old 2015 Observed
New 2015 Observed
New 2015 Median
New 2015 1σ Expected
New 2015 2σ Expected
HPS Internal
20
30
40
50
60
70
80
90
100
$m_{A'}$ (MeV)

So in the e^-e^+ final state Major contributors are