PADME dump proposal

Mauro Raggi, and V. Kozhuharov

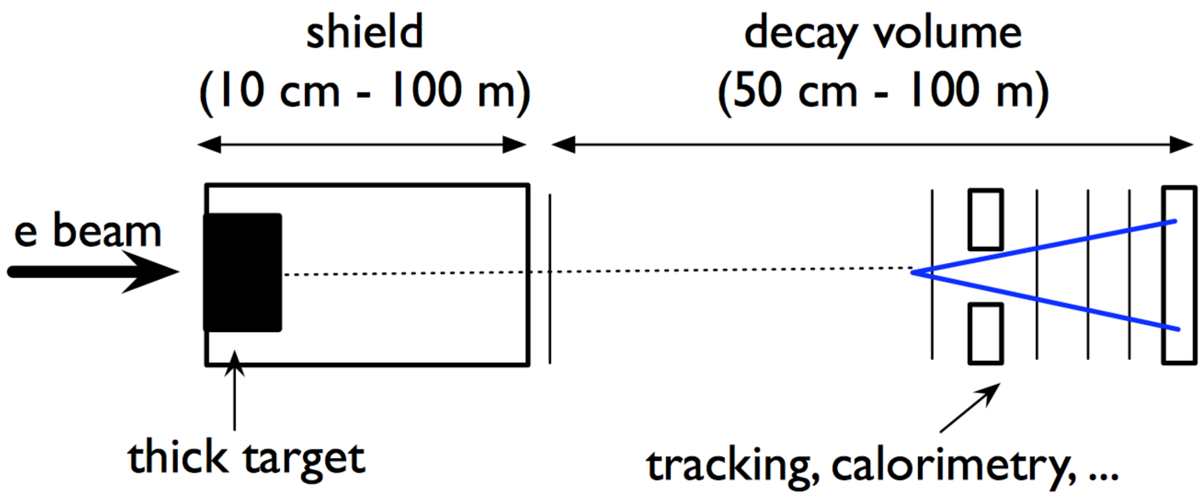
What Next LNF,

Frascati, November 11th 2014

Searching for new physics in dump

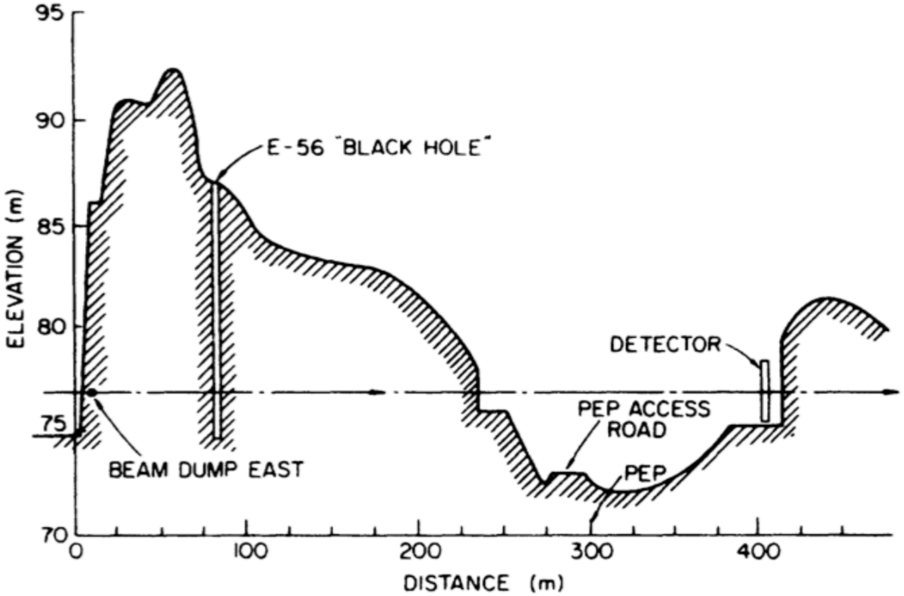
- Dump experiments are able to provide extreme sensitivity to low couplings because the whole beam charge is spent (~10^{20} particles)
  - Sensitivity to extremely rare production processes
  - Sensitive to every long living particles which can even escape LHC experiment acceptance
- They provide general searches for new states
  - Interpretation of data by many different models is possible even 20 year after the end of the experiments (E137 E714)!
- Due to that recently new generation of dump experiments has been proposed
  - **SHIP** at CERN for heavy lepton searches and dark photons
  - **BDX** at JLAB for dark photon searches (see A. Celentano talk)
  - **PADME** dump at LNF to search for dark photon

Dump experiments concept

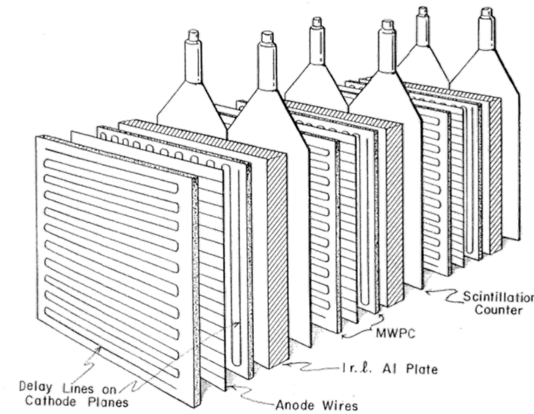


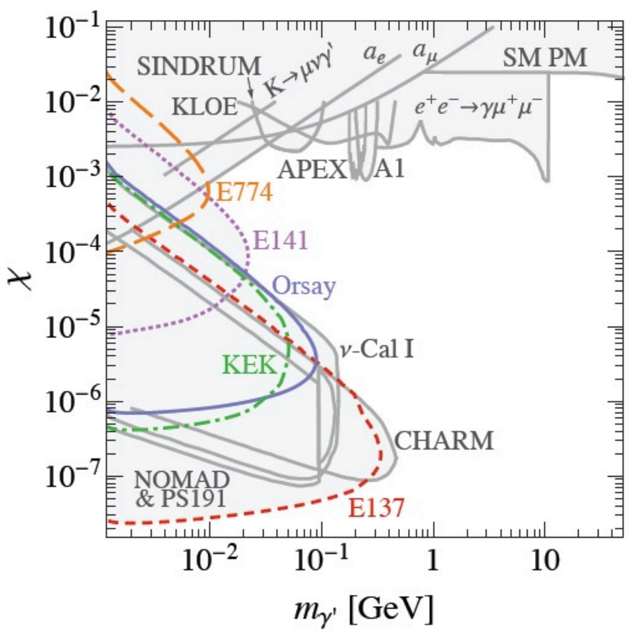
- Very intense beam over a massive high Z target
  - Produce a dark photon through bremsstrahlung into the target
  - Absorb all standard model particle in huge shielding
  - Dark photon traverse the dump due to his small interaction with ordinary matter
  - Dark photon decays into SM particles after the dump in the decay region
  - Electron or muon are detected in the far detector

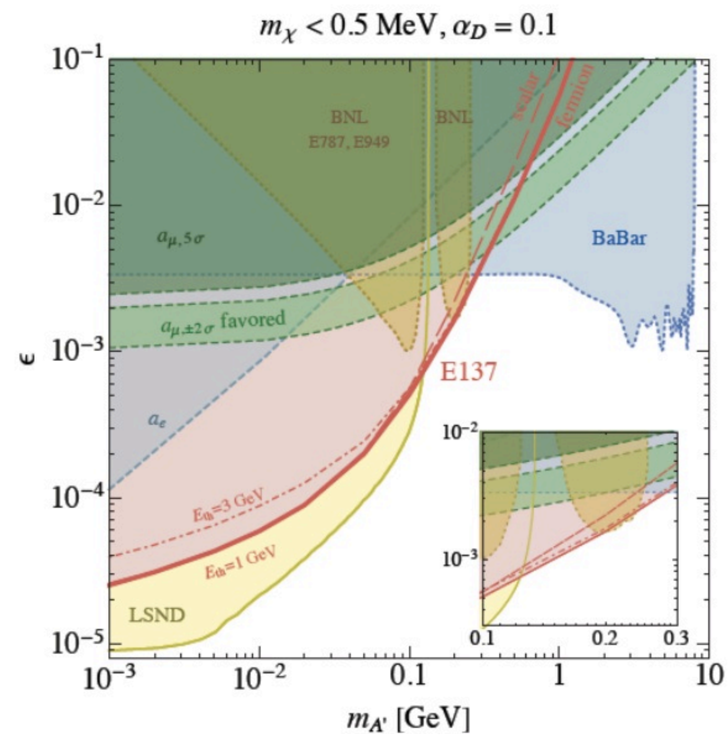
Dump experiment example: E137



- ~10^{20} EOT







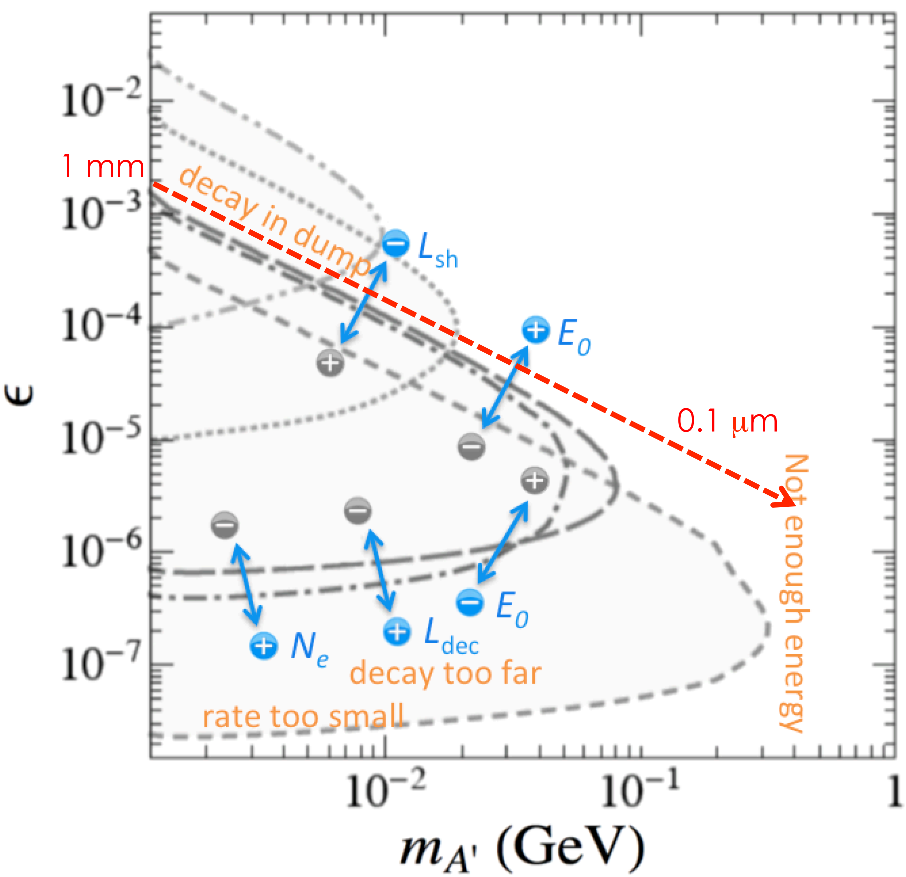
Beam dump limitations

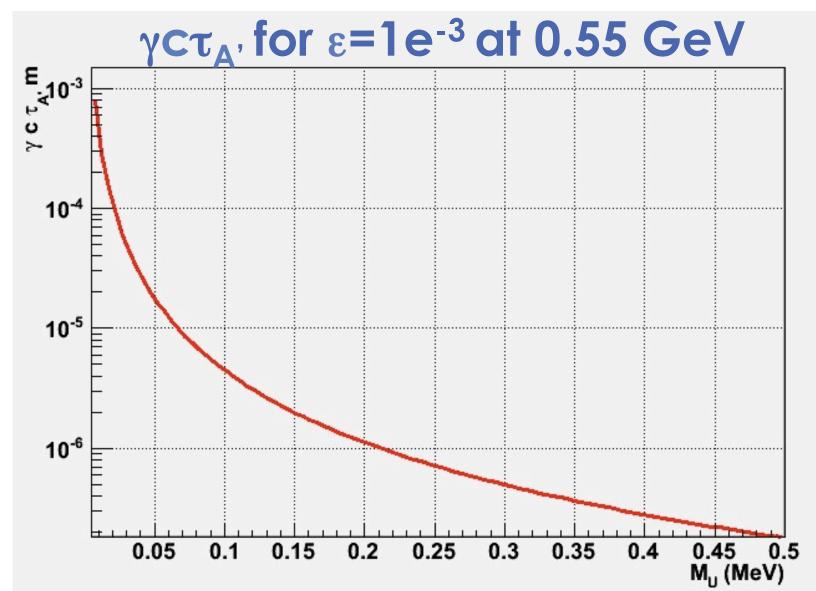
- Main limitations comes from decay length of the dark photon

$$\Gamma_{A'} = \frac{\alpha\varepsilon^2}{3} m_{A'} \left(1 + 2\frac{m_e^2}{m_{A'}^2}\right) \sqrt{1 - 4\frac{m_e^2}{m_{A'}^2}}$$

$$L_{A'} = \gamma\beta\tau_{A'}\hbar c = \frac{E_{A'}}{m_{A'}} \sqrt{1 - \frac{M_{A'}^2}{E_{A'}^2}} \frac{\hbar c}{\Gamma_{A'}}$$

$$L_{A'} \approx \frac{E_{A'}}{m_{A'}^2 \varepsilon^2}$$

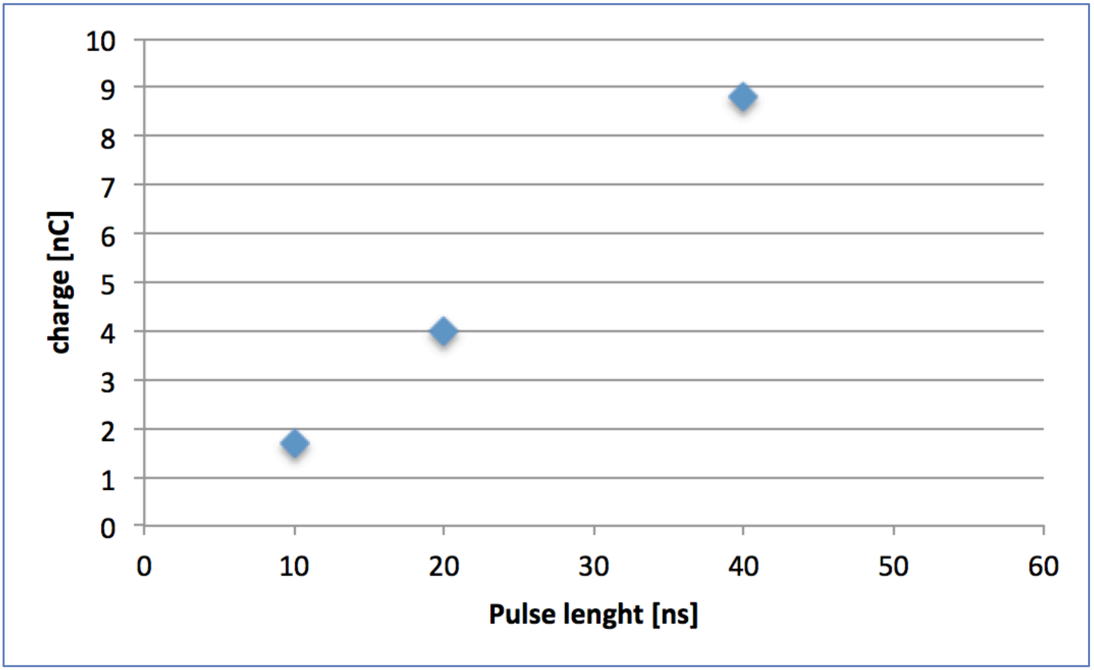




A dump at Frascati Linac: why?

- No dedicated electron dump experiment so far to search for dark photon
- All results by dump are coming from data mining by theoreticians
- DAFNE linac is able to provide more than 10C electrons per year
  - Almost the same order of JLAB accelerator
- Possibility of tuning the parameters to access unexplored regions
  - Beam energy
  - Beam geometry
  - Dump length shape and material
  - Detector acceptance (decay region and detector geometry)

Improving BTF performance

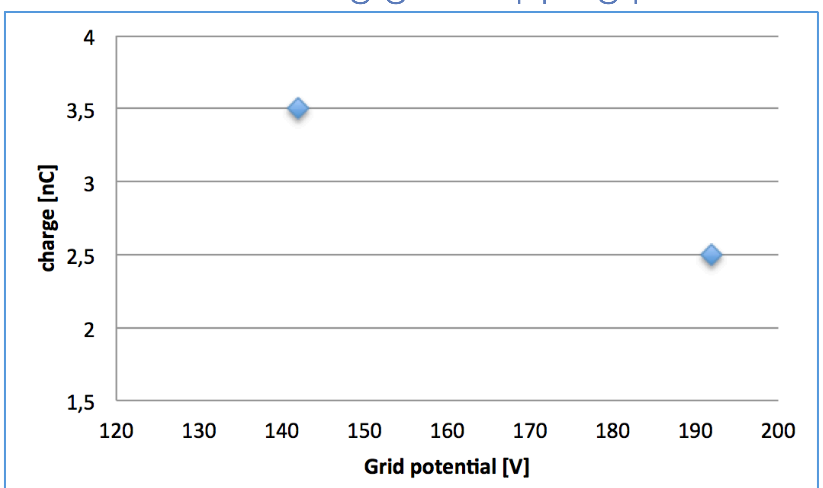


E_{beam} = 725 MeV

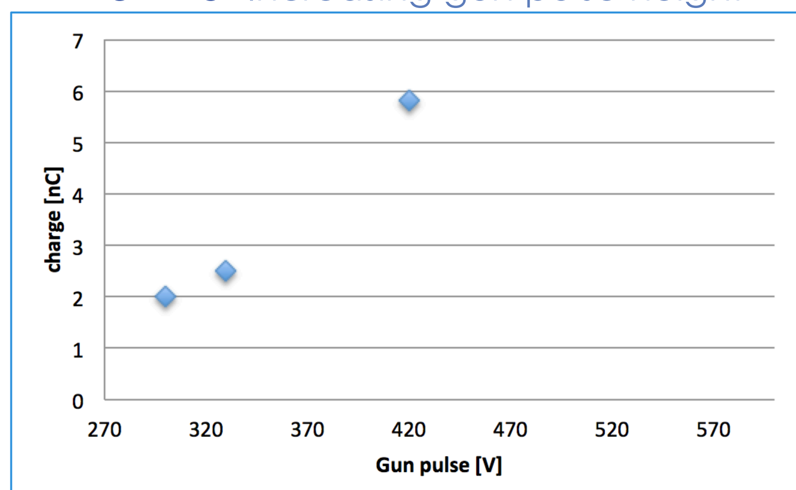
×4 increasing pulse length

P. Valente: LINAC and BTF: looking at the future

+30% Decreasing grid stopping potential



×3 - ×5 Increasing gun pulse height



Maximum current of BTF dump

- Measured maximum energy (2014) E=725 MeV
- **Conservative value: Q=25 nC/bunch at 40ns duration**
  - Extrapolation of 8.5 nC ×3 gain using grid and gun pulse height
  - $N_e = 1.6 \cdot 10^{11}$ e/pulse× 49 pulse/s= $0.784 \cdot 10^{13}$ e/s
  - $0.784 \cdot 10^{13}$ e/s × $3 \cdot 10^{7}$ s = $2.4 \cdot 10^{20}$ eot

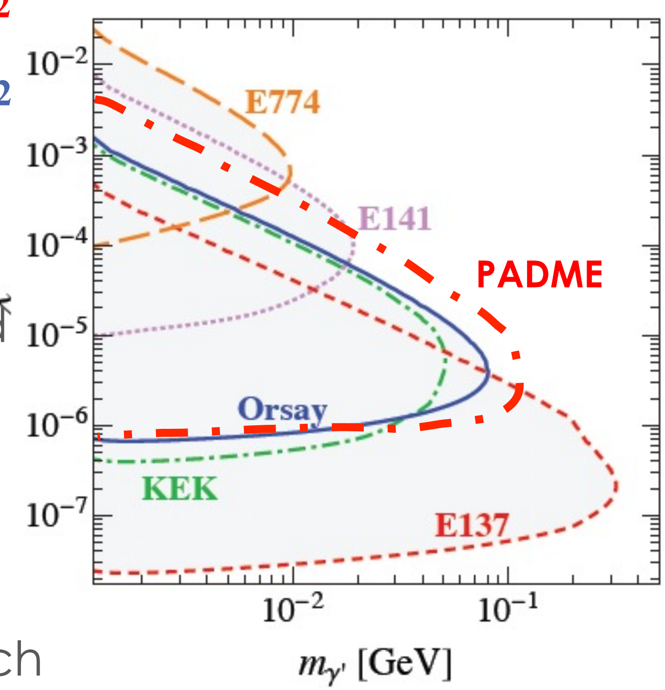
P. Valente: LINAC and BTF: looking at the future

- Further increase by enlarging the pulse time width to >100 ns
  - Gun extraction saturation and beam loading effects to be checked
- **Full gain extrapolation: Q = 50 nC/bunch at >100 duration**
  - Single factors well measured
  - $N_e = 3.2 \cdot 10^{11}$ e/pulse× 49 pulse/s× $3 \cdot 10^{7}$ s = $5 \cdot 10^{20}$ e/year
  - But the combination of pulse height, length and grid voltage has to be tested
- The main limitation can come from radio-protection issues

Status of e⁻ dump experiments

Experiment	target	E_0 [GeV]	N_{el} electrons	N_{el} Coulomb	L_{sh} [m]	L_{dec} [m]	N_{obs}	$N_{95\%up}$
E141 [47]	W	9	2×10^{15}	0.32 mC	0.12	35	1126^{+1312}_{-1126}	3419
E137 [48]	Al	20	1.87×10^{20}	30 C	179	204	0	3
E774 [49]	W	275	5.2×10^{9}	0.83 nC	0.3	2	0^{+9}_{-0}	18
KEK [39]	W	2.5	1.69×10^{17}	27 mC	2.4	2.2	0	3
Orsay [40]	W	1.6	2×10^{16}	3.2 mC	1	2	0	3
PADME	**W**	**0.8**	**$1\cdot10^{16}$**	**~1.6mC**	**0.1**	**2**		
PADME DUMP	**W**	**1.2**	**$2\cdot10^{20}$**	**~30 C**	**0.1-0.2**	**1-2**		

S. Andreas: arXiv:1209.6083v2

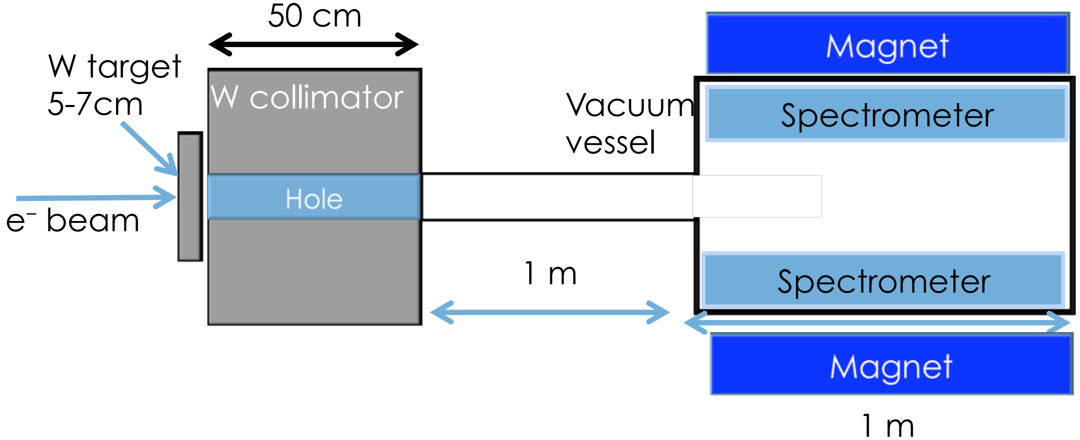


- **PADME** estimate was made by S. Andreas(2013)
- Due to authorization of LNF site we cannot exceed
  - Total limit on Year at BTF = **9.8×10^{17} e⁻/Year**
- **PADME DUMP** (E_{e-} 1.2 GeV)
  - e⁻/Year=$1.2\times10^{11}\times50\times3.15\times10^{7}$=**$2\times10^{20}$ e⁻/Year**
  - We can get **4.5×10^{17}** in **3 days** at 3×10^{10} e⁻/bunch

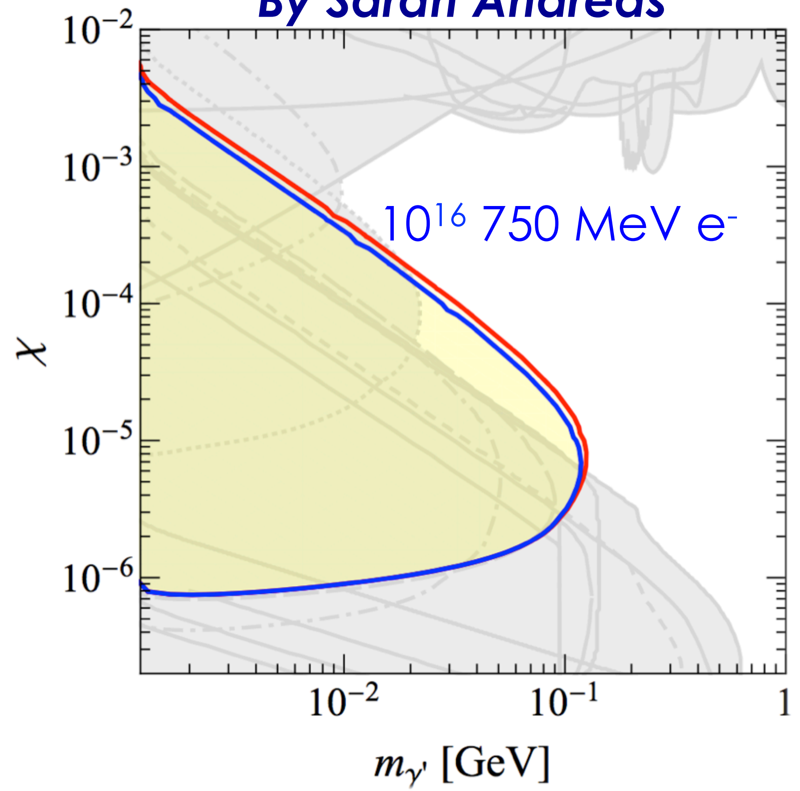
PADME early sensitivity estimate

- Uses the same detector
  - Change the target with 5-7.5 cm W one
  - Build a W collimator

PADME early schematic



By Sarah Andreas

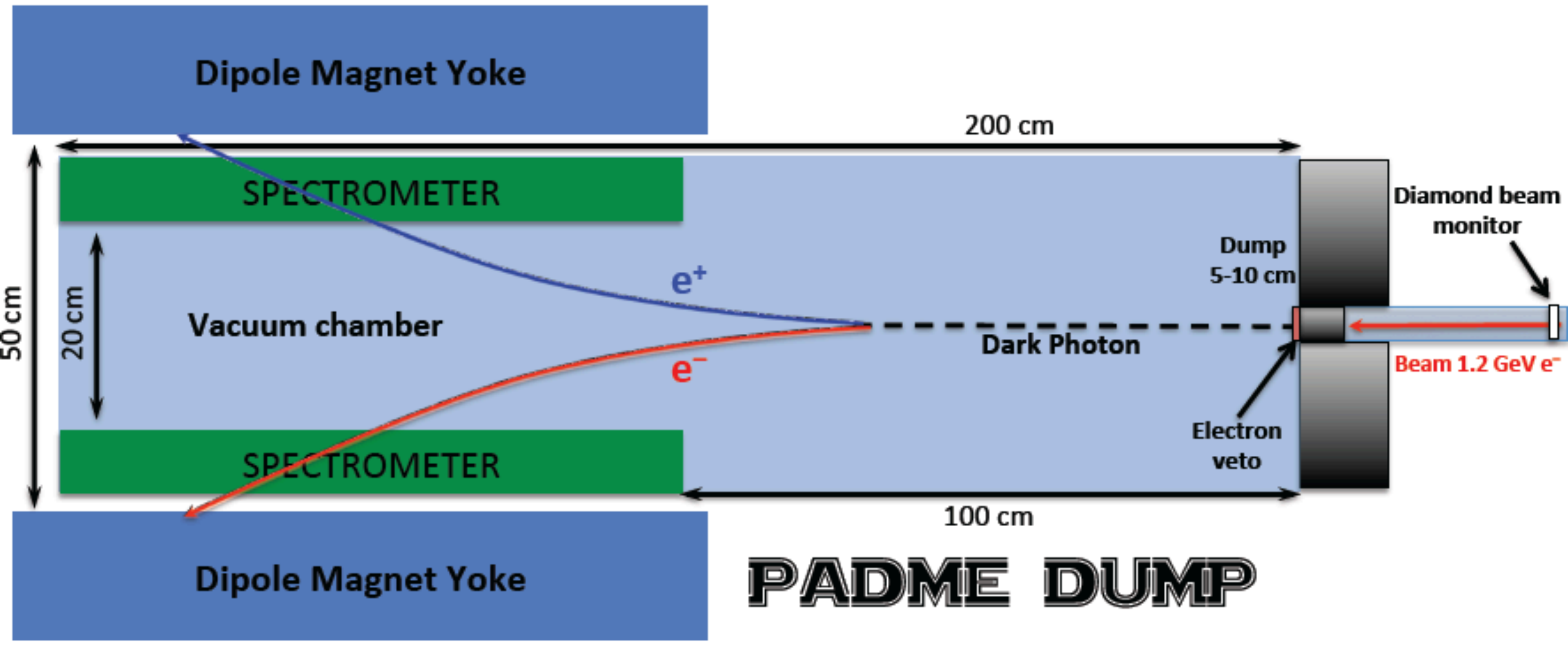


- Early study for a beam dump experiment @ LNF (Sarah Andreas)
  - 1E7 electrons of energy 750 MeV per bunch in 50 bunch/s over 1 year
  - Total e⁻ on target being: $50*1x10^7*3.15x10^7 = 1.6x10^{16}$ (we use $1x10^{16}$)
  - Study based on 0 BG events observed after the dump. (not easy to achieve)

The PADME DUMP concept

- Thin dump experiment (order 10 cm W or U dump)
  - Allow to explore region of high couplings (short lifetimes)
  - Maximize DUMP containment with very high Z materials
- In vacuum decay region (thinner dump required)
  - Allow to contain only charged component of the shower in the dump
- SM particle veto after the dump
  - Allow to veto charged remnants of the beam to reduce BG
- Kinematic to suppress background (bump hunting)
  - Use the spectrometer M^2_{miss} resolution to reduce BG in each of the mass regions explored.
- Near detector to maximize acceptance
  - Use the magnet to collect almost all tracks in to the chambers

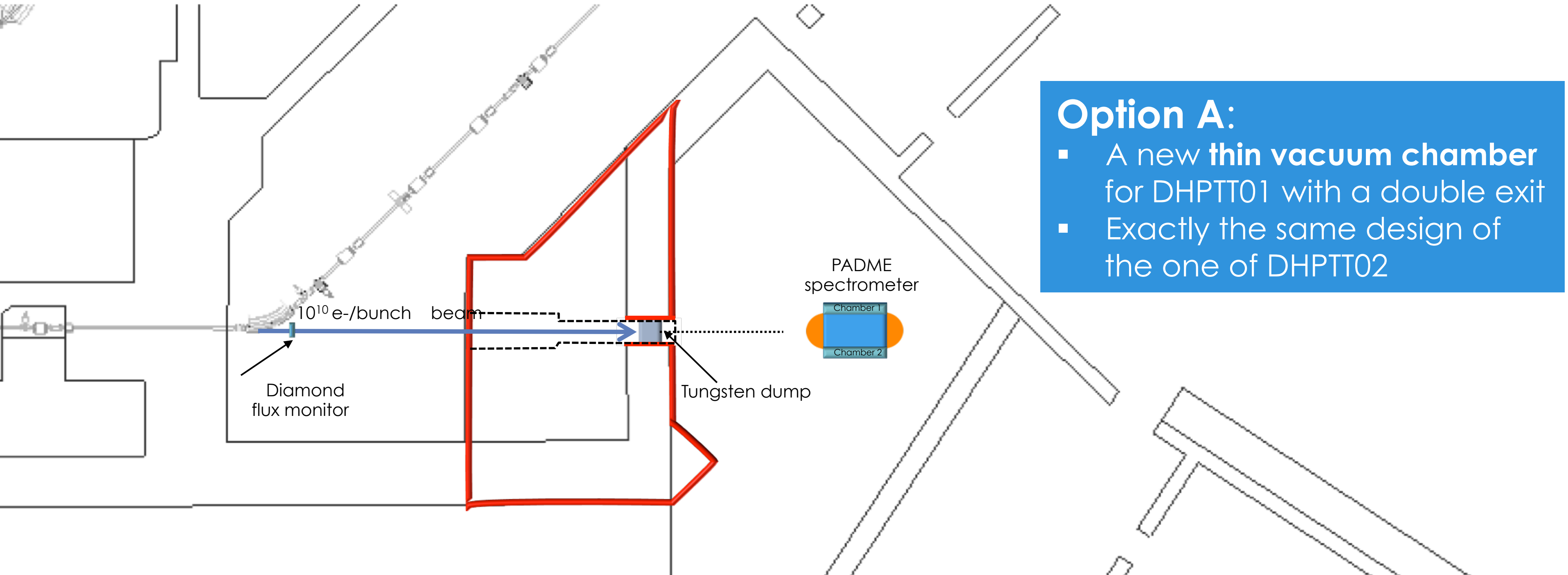
PADME dump layout



PADME DUMP location

Option A:

- A new **thin vacuum chamber** for DHPTT01 with a double exit
- Exactly the same design of the one of DHPTT02



PADME dump toymc

- Try to evaluate driving design parameters for the PADME dump
- Toymc includes:
  - Production cross section calculated by MADgraph (thanks to A. Celentano)

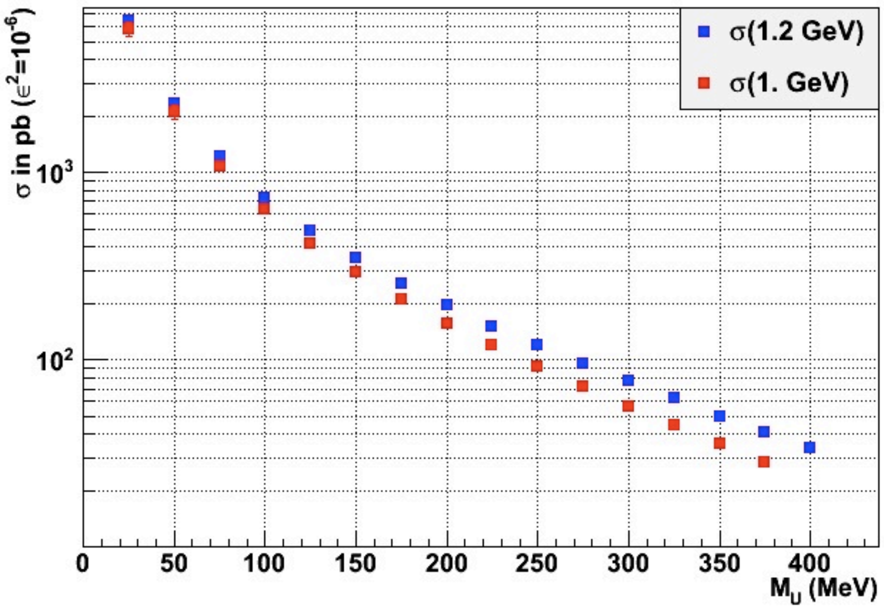
$$\frac{d\sigma_{\gamma'}}{dx_e\, d\cos\theta_{\gamma'}} = 8\alpha^3\chi^2 E_e^2 x_e\, \xi(E_e, m_{\gamma'}, Z, A)\sqrt{1-\frac{m_{\gamma'}^2}{E_e^2}} \left[\frac{1-x_e+\frac{x_e^2}{2}}{U^2} + \frac{(1-x_e)^2 m_{\gamma'}^4}{U^4} - \frac{(1-x_e)x_e m_{\gamma'}^2}{U^3}\right],$$

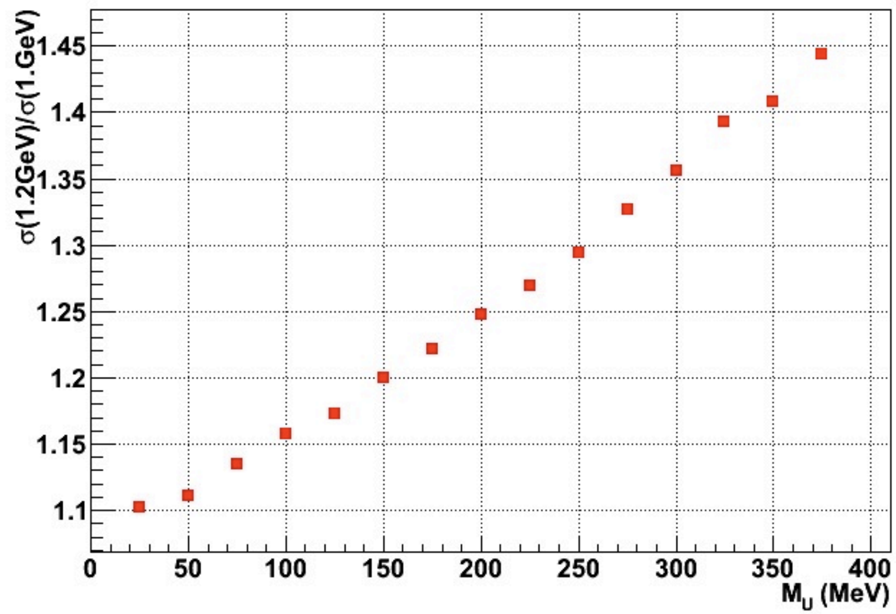
  - Evaluate the produced number of dark photons

$$N_{\gamma'} = \sigma_{\gamma'}\, N_e\, n_{\rm sh}\, L_{\rm sh} = \sigma_{\gamma'}\, N_e\, \frac{N_0}{A}\, \rho_{\rm sh}\, L_{\rm sh}\,,$$

  - Scale by decay length acceptance $$\frac{dP(l)}{dl} = \frac{1}{l_{\gamma'}}\, e^{-l/l_{\gamma'}}$$
  - Scale by electron acceptance in the detector using kinematical distribution from a toy
    - Distribution have been compared with MADGraph for several M_U

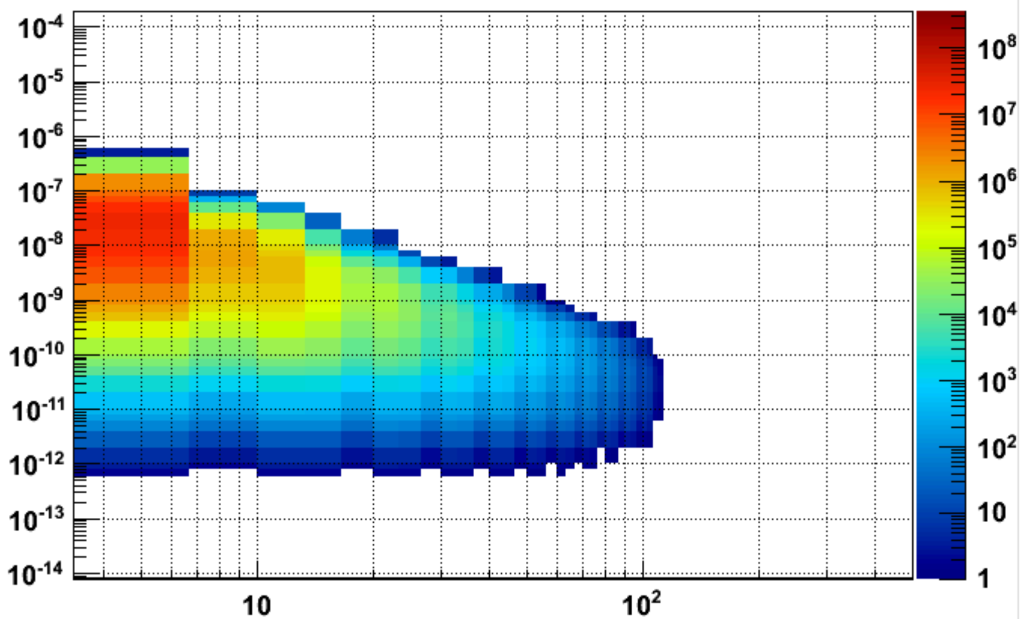
U-strahlung cross section MADgraph

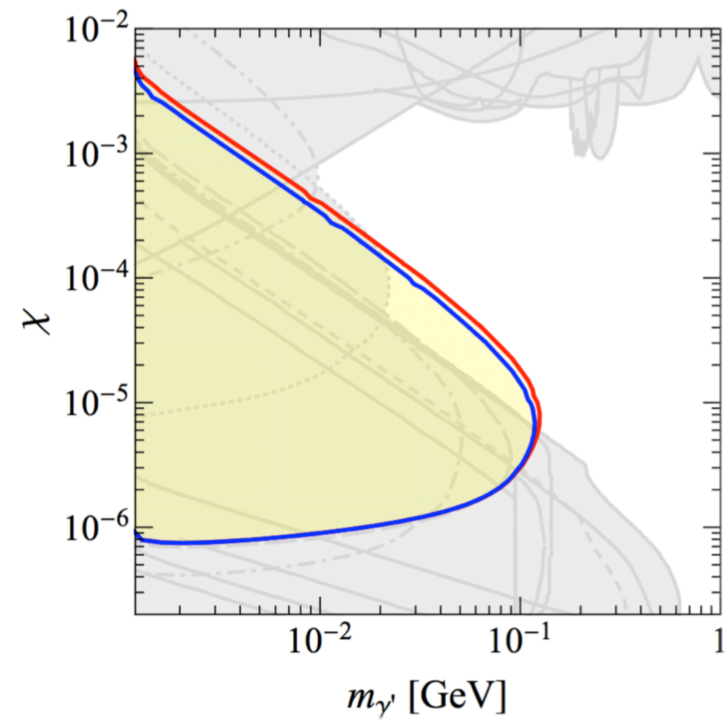


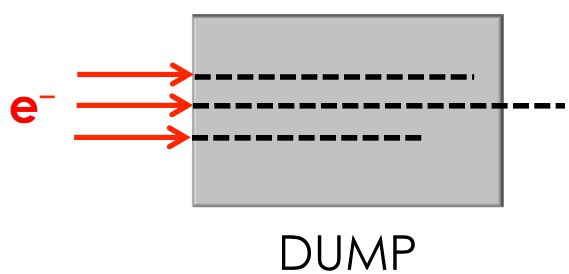


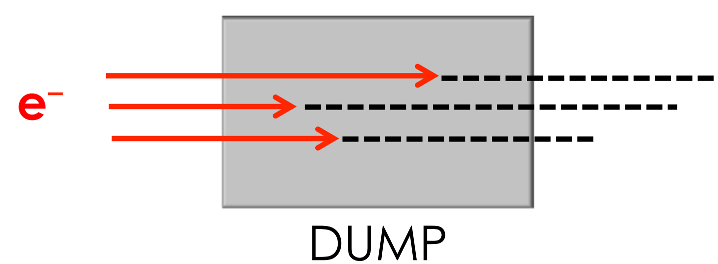
- Cross section on tungsten for $\varepsilon^2=10^{-6}$
- Increasing beam energy improves cross section
  - Higher cross section up to 45% for higher masses with just 200 MeV
  - Better boost for short living particles (most massive one!)

Comparison with S. Andreas



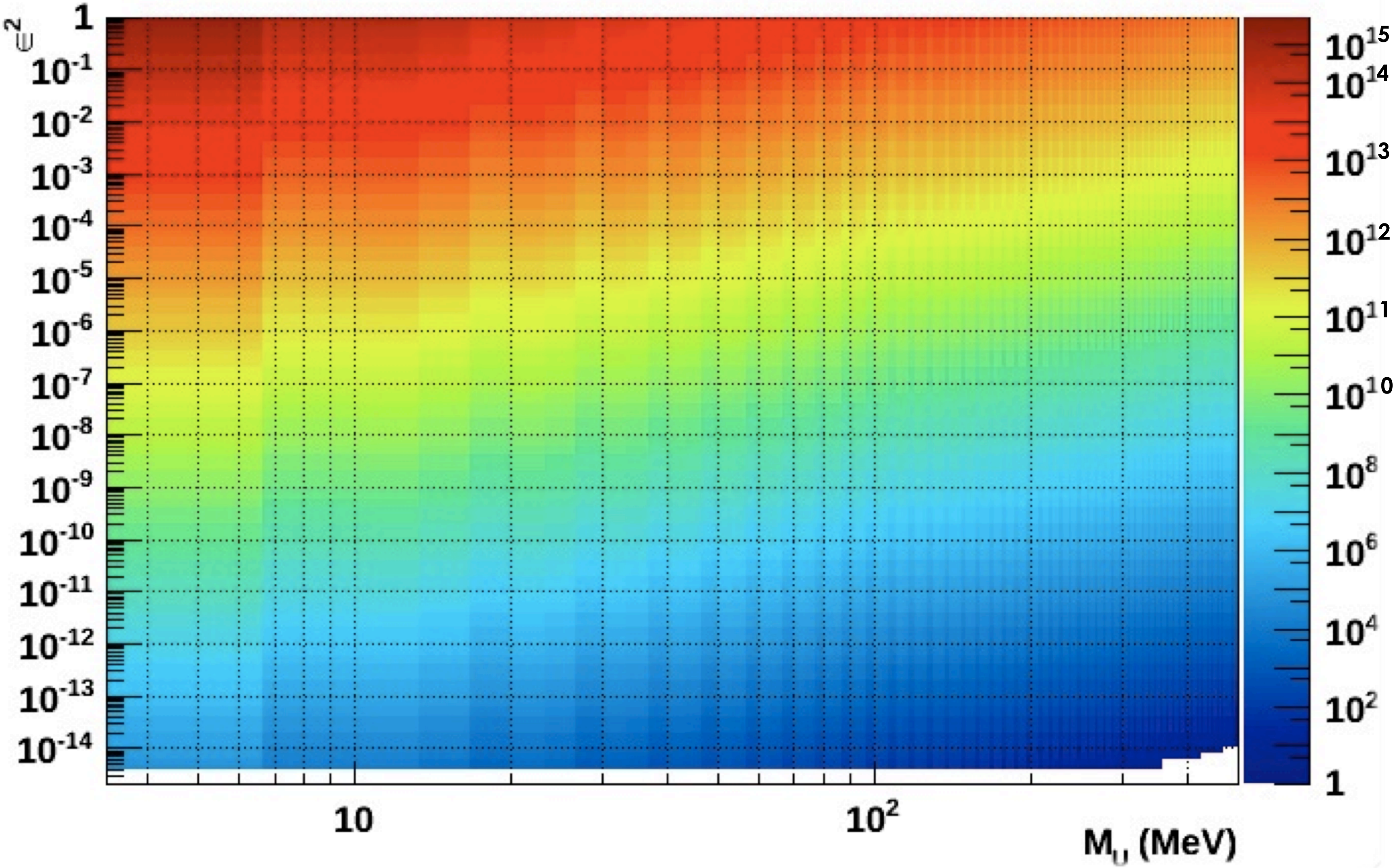






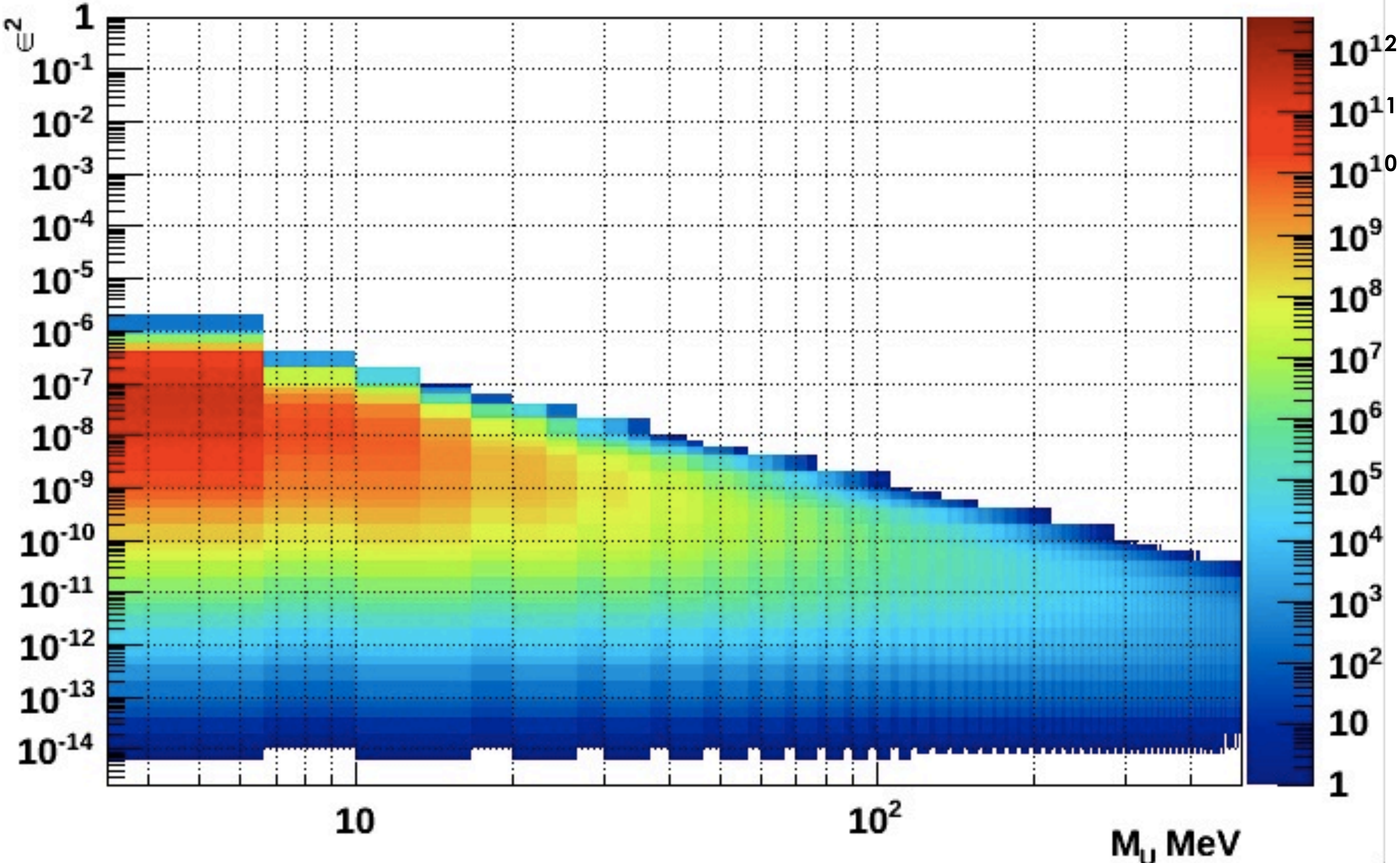
My montecarlo doesn't implement the in depth production
Bigger suppression of short lining particles

Dark photon production



No problem in production up to 500 MeV dark photons!

… after U decay acceptance



Just cutting out what decay in the dump or too far!

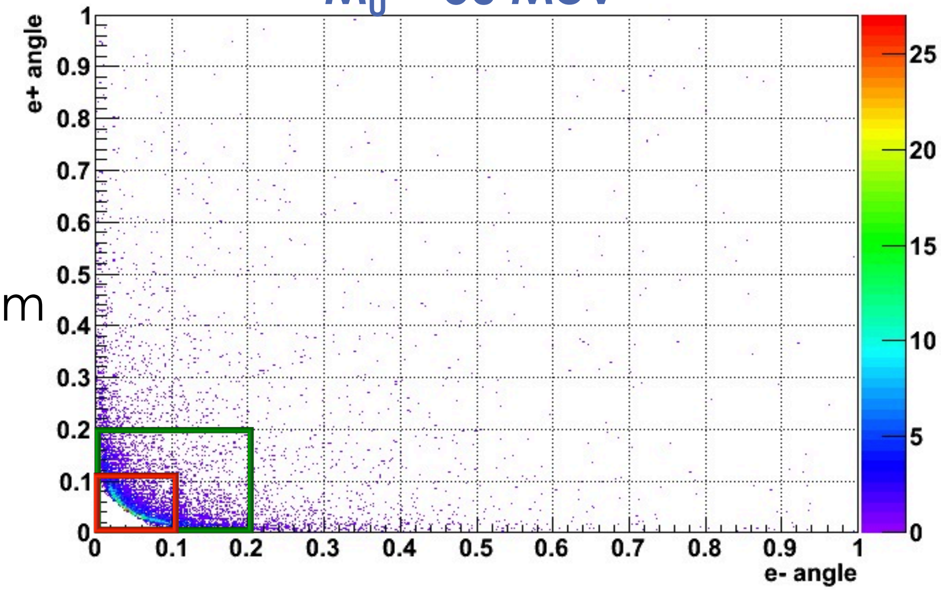
Detector acceptance E_b=1.2 GeV

e$^+$e$^-$ acceptance

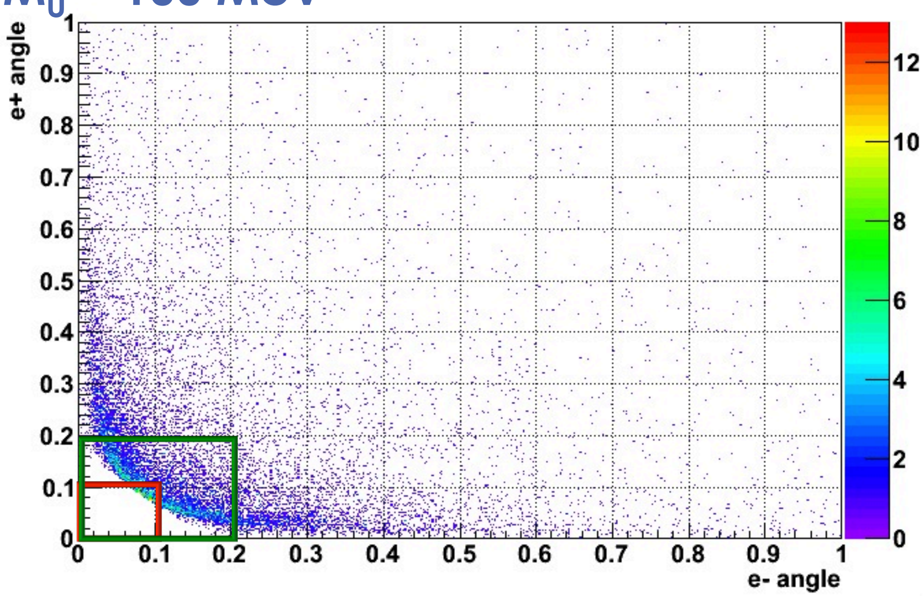
±10 cm at 1m

±10 cm at 0.5 m

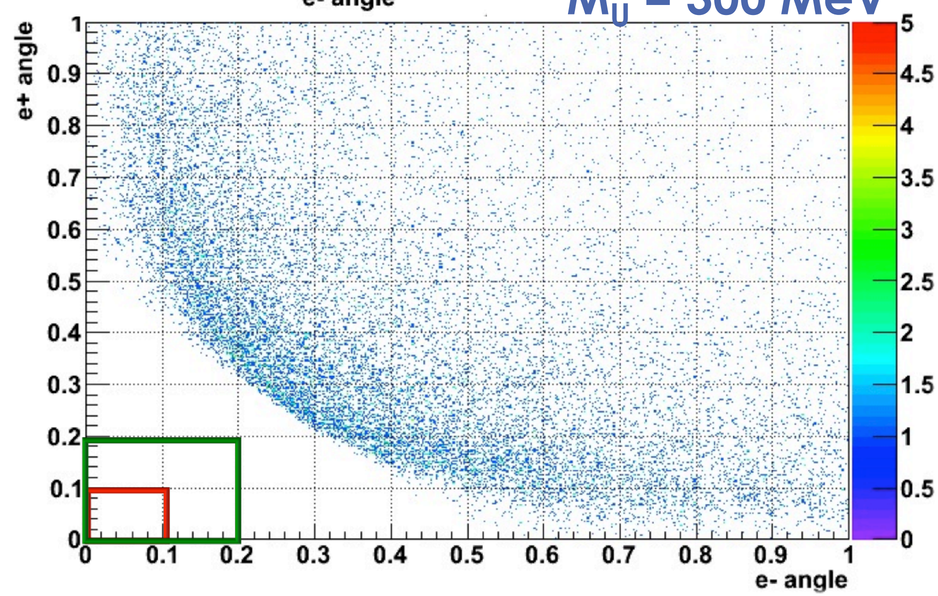
M_U = 50 MeV



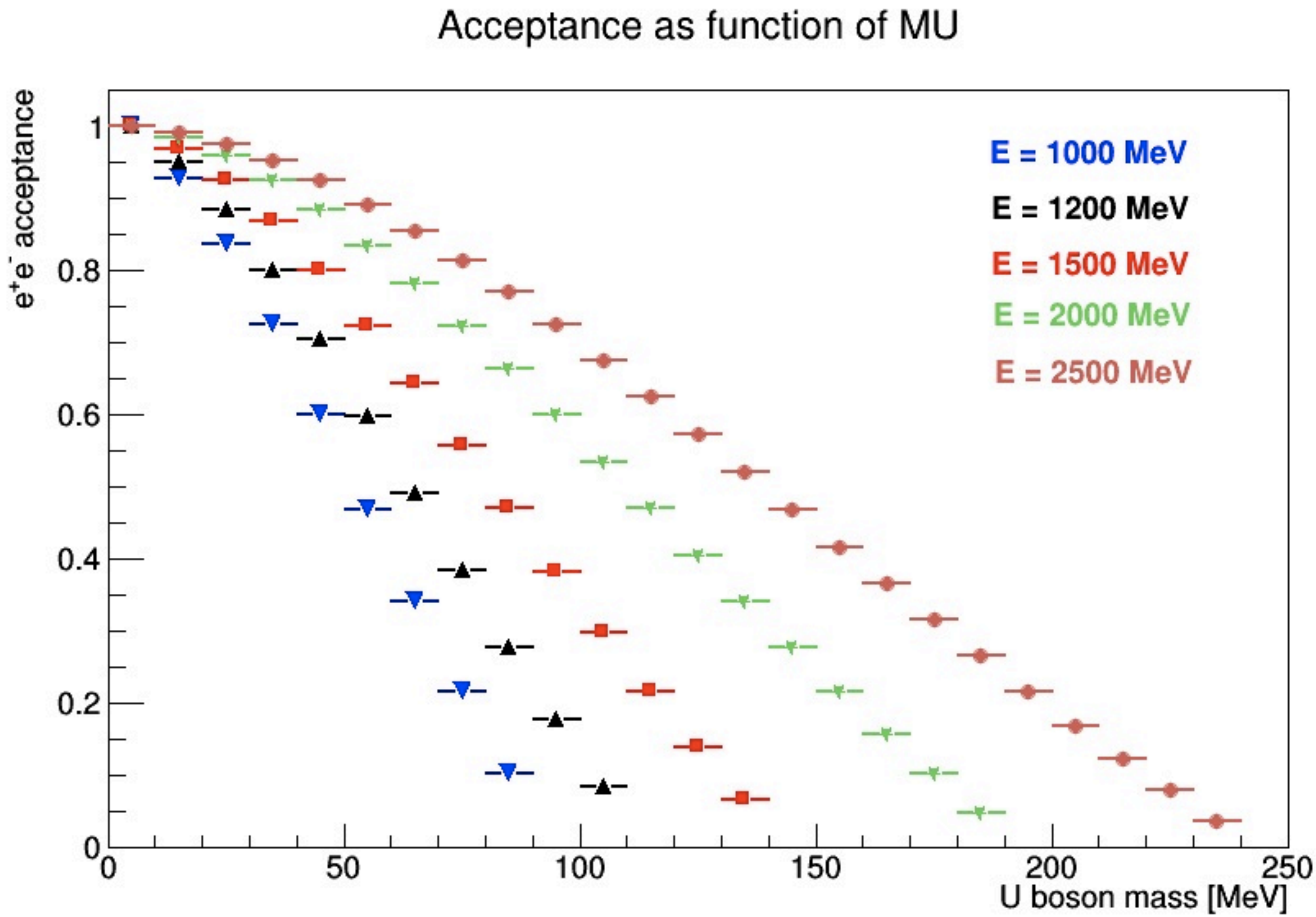
M_U = 100 MeV



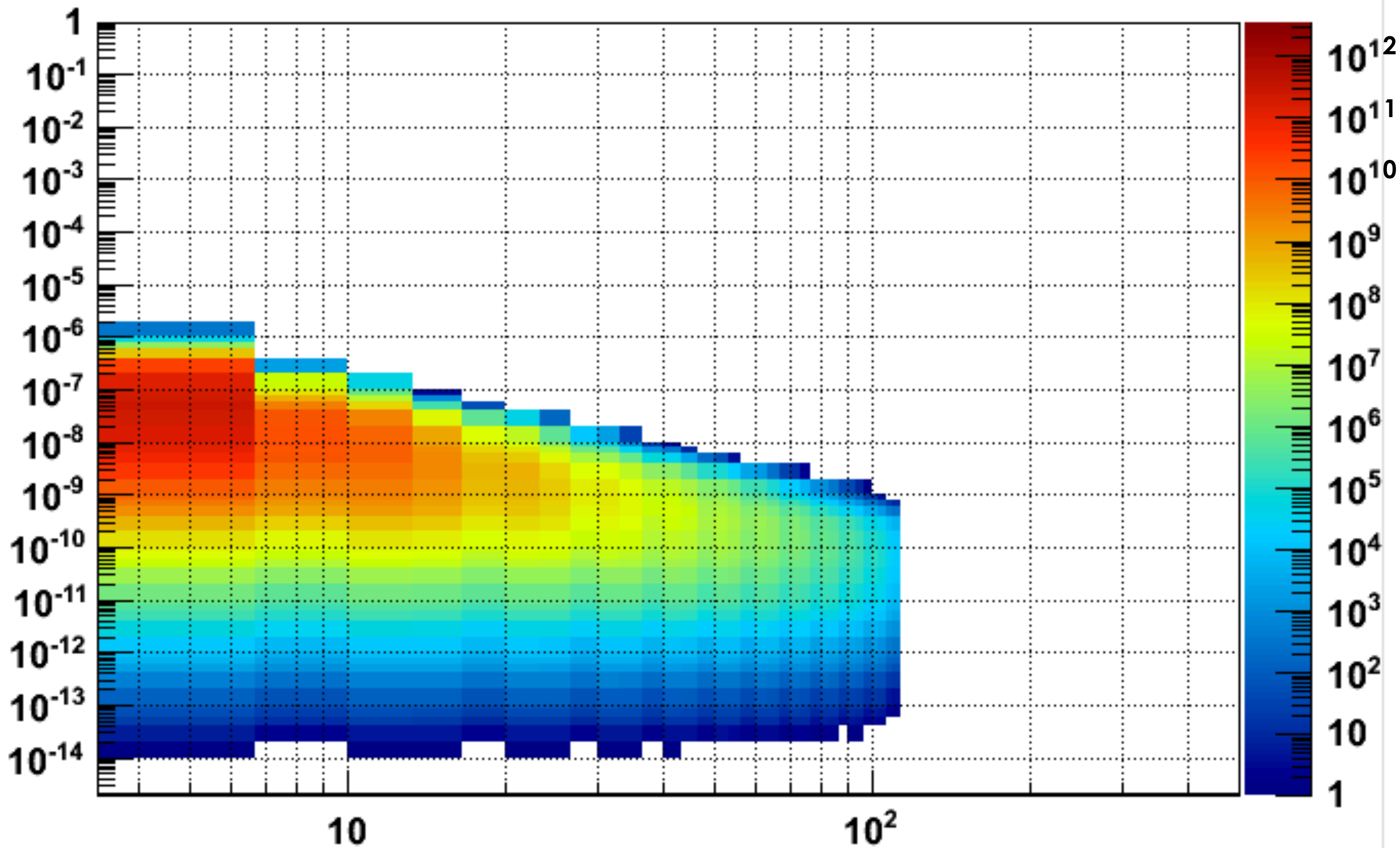
M_U = 300 MeV



e^+e^- in acceptance vs energy

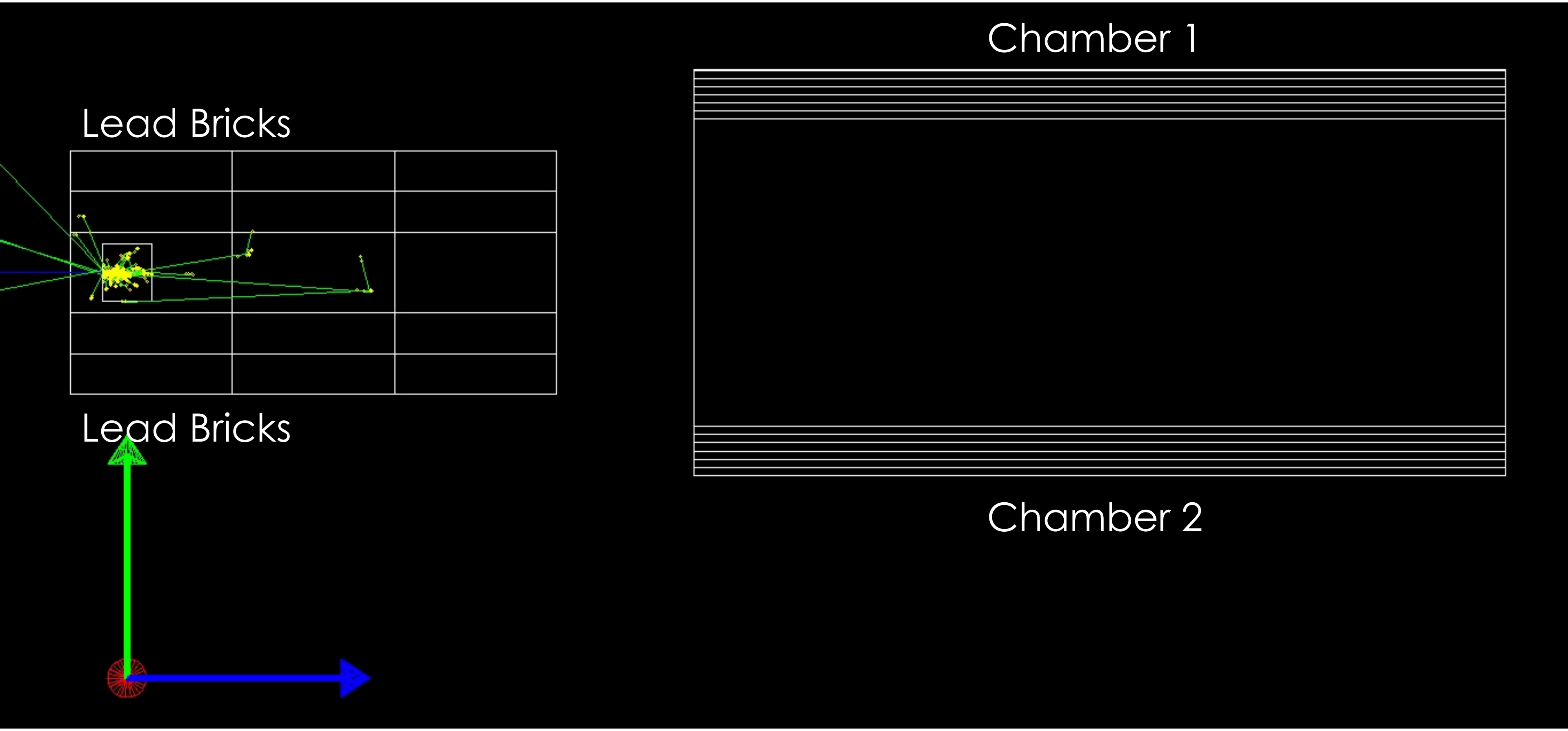


After adding e^+e^- acceptance



Includes only ee acceptance
Muons can provide access to mass region above 200 MeV

PADME dump MC model



A MC simulation in G4 to understand the BG has been started but 10^{20} e^- will be never explored.
Only reliable estimate of the BG can be obtained with test runs
1s at BTF ($7 \cdot 10^{12}$ electrons) is equal to 2 month of MC generation

Conclusion

- The LINAC of DAFNE is a high current source for e^- up to 10C/year
- There is an interesting region of the parameter space that can be explored by PADME dump experiment
- A toy simulation allowed to identify driving parameters for the dump experiment design.
  - Refinement are still needed to obtain a reliable sensitivity plot
  - Background need to be study for different dump thickness
- Limiting factor on mass achievements with current geometry is the electron acceptance
  - Can improve much by upgrading the LINAC energy
  - Is a dedicated design needed for the dump experiment?
- Limiting factor on coupling constant sensitivity is the decay region length:
  - What about a 100MeV run for long living particles?