Commissione Scientifica Nazionale IV
Gruppo Teorico LNF

Gennaro Corcella

1. **Informazioni su gruppo ed anagrafica**

2. **Attività sigle locali CSN4**

Anagrafica Provvisoria 2024-25 – dipendenti e associati senior

Nome	Posiz.	Qual.	AMPLITUDES	ENP	TASP	TIME2QUEST(CS)	PRIN	DOT4	Tot
Bagnaschi Emanuele	Dip.	Ric.		75	25				100
Bellucci Stefano	Ass.	Ass.Sen.				100			100
Corcella Gennaro	Dip.	I Ric.		100					100
Del Duca Vittorio	Dip.	I Ric.	100						100
Gionti Gabriele	Ass.	I Ric.						50	50
Mescia Federico	Dip.	Dir.Ric.			80		20		100
Nardi Enrico	Ass.	Ass.Sen.			80		20		100

Assegnisti di ricerca

D. Sengupta (Cabibbo fellow, ENP): LNF sino a Novembre 2024, poi INFN Roma I

F. A. Aragón (Cabibbo fellow, TAsP): LNF sino a Settembre 2025

V. Susic (PRIN ‘Axion Origins’/TAsP) sino ad Ottobre 2025

A.P. Lind (Cabibbo fellow, ENP) da Settembre 2024

F. Alessio (Amplitudes) da Ottobre 2024

I. Gnilitskyi e C. Vacacela (Time2Quest CS)

Associato: A. Maffucci (Prof. Ordinario U.Cassino, Time2Quest CS)

IS Exploring New Physics (ENP) – Nodi: LNF, RM1, RM2, NA, PG

Responsabile Nazionale: G.Corcella (2024-26)

ENP valutata in prima fascia da referee esterni

Nodo LNF:

G. Corcella (100%, Ric. II Livello), E.A. Bagnaschi (75%, Ric. III Livello), D.Sengupta and A.Lind (100%, assegnisti ‘Cabibbo’)

Attività di ricerca su vari aspetti di fenomenologia dei collider:

- Test di precisione del Modello Standard: fenomenologia dei quark pesanti e Higgs, QCD perturbativa e non, implementazione Monte Carlo, SMEFT, $g-2$

- Fisica BSM: modelli e scenari non ancora esclusi, e.g., 331 (bileptoni), supersimmetria (MSSM, DMSM), materia oscura

Gennaro Corcella:

1. Fisica del top e QCD

ACE per l'analisi di ATLAS sulla misura della massa del top da muoni soffici (JHEP'23): $t \to bW,\ W \to \ell\nu,\ b \to B \to X\mu \Rightarrow m_t = (174.41 \pm 0.80)$ GeV: studio sistematico di incertezza da frammentazione

Top a FCC-ee: $e^+e^- \to t\bar{t}$, $t \to jjb$, $\bar{t} \to XY$ con $\bar{t}$ che non passa criterio di selezione del top $\Rightarrow$ limiti model-independent su decadimenti BSM del top (G.C., D.Sengupta, B.Mele)

Costante di accoppiamento forte efficace $\tilde{\alpha}_S(Q^2)$ priva del polo di Landau per includere effetti non perturbativi (broadening, EEC in e^+e^-) in luogo di modelli fenomenologici con parametri liberi, e.g. $\tilde{\alpha}_S(Q^2) = \frac{1}{\beta_0}\left[\frac{1}{\ln(Q^2/\Lambda^2)} - \frac{\Lambda^2}{Q^2-\Lambda^2}\right]$ (G.C., U.Aglietti and G.Ferrera)

2. Fisica BSM

Bileptoni $Y^{\pm\pm}$ ($L = \pm 2$) e quark esotici Q di massa $\mathcal{O}(\mathrm{TeV})$ e carica $5/3$ o $4/3$ da vari modelli, come il 331, basato sulla simmetria $SU(3)_C \times SU(3)_L \times U(1)_X$

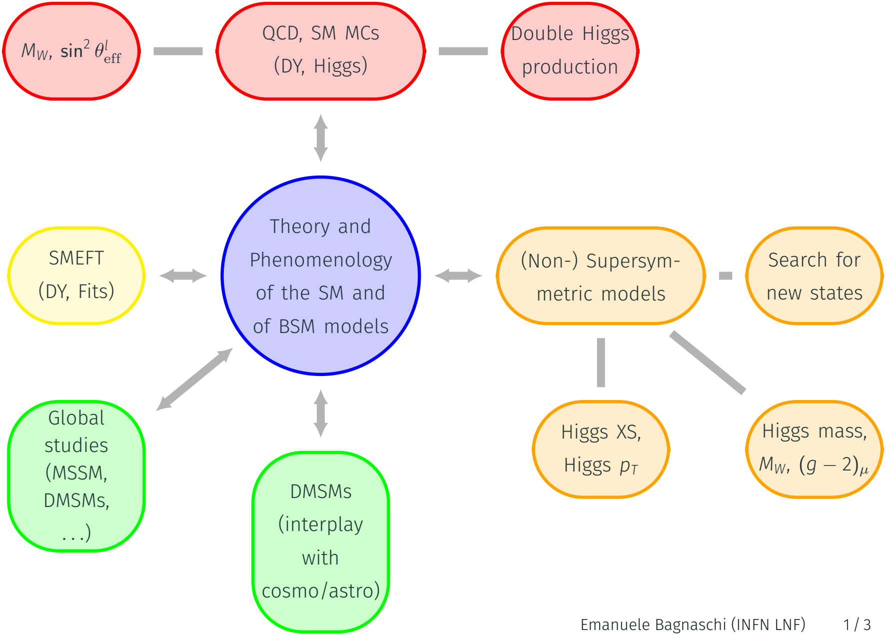
In corso: bileptoni a LHC (ATLAS Bologna): $pp \to Y^{++}Y^{--} \to (\ell^+\ell^+)(\ell^-\ell^-)$

Produzione di quark pesanti nel 331: $pp \to T\bar{T} \to Y^{++}bY^{--}\bar{b} \to b\bar{b}\mu^+\mu^+\mu^-\mu^-$

(G.C.,C.Corianò, P.H.Frampton, D.Melle)

Chairman di Spring School 'Bruno Touschek' (LNF)

Overview of the research lines



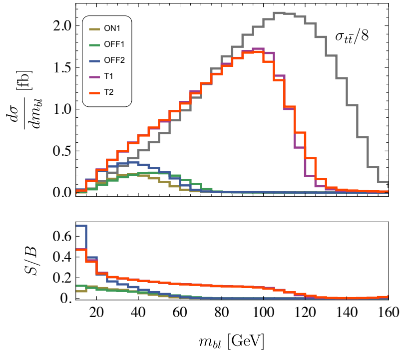
Selection of currently active projects

TAsP related

- Study of the Dark Matter Simplified Models (DMSMs) with t-channel mediators in the context of a Dark Matte Working Group (DMWG) White Paper (Monte Carlo studies at colliders, NLO-QCD corrections, recast of existing analyses, interplay with cosmo/astro bounds)
- Global likelihood study of s-channel leptophilic vector mediated models

ENP related

- Double Higgs production at NLO+PS in the POWHEG including an extra resonance, with complete inclusion of interference effects
- Dilepton production in SMEFT at NLO-QCD/NLO-EW in the POWHEG approach and related phenomenology
- Running effects in SMEFT fits
- Probing BSM effects in $t\bar{t}$ production (with G. Corcella, R. Franceschini and D. Sengupta – accepted for publication on PRL)
- BSM effects in Higgs p_T (involved the incoming Cabibbo fellow, A. Lind)



[2312.09794, accepted for publication on PRL]

Selection of working group and networking activities

International networking

- LNF is now a node of the IRN Terascale network (http://terascale.in2p3.fr/) [ENP]
- IRN Terascale is a theory-experimental network dedicated to the study of new physics at the EW scale (and also a bit below)
- IRN Terascale Workshop in Frascati (15-17 April 2024) was a success, with 60 registered participants, of which around 40-45 in person at LNF (https://indico.in2p3.fr/event/31806/)

Roman area networking

- Taught a PhD level course on "Monte Carlo for High-Energy Physics" at Sapienza (April-May 2024) [ENP]
- Co-supervision of a master student with M. Bonvini at Sapienza (ongoing) [ENP]
- Collaborations with R. Franceschini and G. Degrassi at Roma Tre (ongoing) [ENP]

Working groups

- Convener of the MSSM subgroup of the LHC Higgs working group [ENP]
- Contribution to the DMWG white paper on t-channel DM simplified models [TAsP]
- One of the two theory experts in the ECFA working group for future Higgs/Top/EW factories, subgroup two-fermions [activity connected to the update of the European Strategy, ENP]
- Co-organizer, with the Italian ECFA Early Career Researchers (ECR) panel members, of the workshop on future colliders for ECR at LNF (I was ECFA ECR panel member from 2022 to 2023, when we planned these workshops at the European level) [activity connected to the update of the European Strategy, ENP] https://agenda.infn.it/event/42205/

Dibyashree Sengupta (INFN, Laboratori Nazionali di Frascati)

CURRENT RESEARCH

1. Solving the ambiguity in Top Mass

The mass of the top quark is ambiguous in that the relation between the pole mass and the $\bar{M}S$ for the top quark is not accurately known. Our goal is to address this issue by forming Top Hadrons hypothetically.

2. Constraining the masses of supersymmetric particles in the current and upcoming runs of the LHC

LHC searches for Weak scale supersymmetry (SUSY) has pushed the mass limits on sparticles well beyond the early upper limits from naturalness and gives rise to the question whether SUSY is now unnatural. The older notions of naturalness can be updated based on the more conservative electroweak naturalness measure. Such natural SUSY models can give rise to several smoking gun signatures at the LHC. A detailed phenomenological study of these models in the current and upcoming runs of the LHC can help us to derive 5σ reach and 95 $\%$ CL on masses of various sparticles.

3. New physics at muon colliders

Muon colliders are extremely advantageous as leptons are fundamental and hence entire beam energy is available for the hard collision whereas in hadron collider only a fraction of the proton-beam energy that is carried by the colliding partons is available for collision thereby yielding higher physics reach in muon colliders. Also since muons are heavier than electrons, therefore in muon colliders synchrotron radiation is much suppressed as compared to that in electron colliders.

FUTURE RESEARCH

1. Top Phenomenology at FCC-ee

Production of top quarks in $e^+ \ e^-$ collider happens in a much cleaner environment rather than in hadron colliders. Hence, a precise study of top quark phenomenology in such clean scenario can reveal new light physics.

2. Axion phenomenology

Axion can very effectively solve the strong CP problem as well as serve as a good cold dark matter candidate. I intend to study the interactions between axions and various standard model particles to seek a potential smoking gun signal that can lead to axion discovery.

3. Explore solutions to Axion quality problem

Although Axion is an extremely well-motivated BSM particle due to reasons mentioned above, it arises due to breaking of a global symmetry which is why it suffers from the "Axion Quality Problem" that arises on incorporating quantum gravity in presence of a fundamental global symmetry. Since quantum theory of gravity will eventually get included, it is important to look for a proper fundamental symmetry that can solve the axion quality problem. I have some experience in addressing this issue in the context of supersymmetry. I plan to do the same in non-supersymmetric scenarios.

4. Constraining BSM scenarios by existing experimental constraints

In one of my previous work in 2023, we suggested a new strategy to search for new physics at the LHC via precise measurement of various observable properties of the top quark. In this work we studied various parameter space points for a BSM scenario and used SModelS to check if these points are excluded by experiments or not. As a follow up to this work we aim to ensure that all the experimental constraints are correctly applied by not only combining several signal regions but also combining all the relevant analyses.

Relazione sull'attività di ricerca 2024

Vittorio Del Duca

Linee di ricerca

- sviluppare uno schema per il calcolo di sezioni d'urto al NNLO in α_s e oltre in modo indipendente dal particolare processo [1], usando l'universalità delle divergenze infrarosse

- potenziare il calcolo di ampiezze di scattering in teorie di gauge, mediante l'analisi nel limite di Regge [2]

- calcolare l'emissione di onde gravitazionali da un sistema binario di oggetti massivi compatti mediante ampiezze di scattering in uno spazio curvo [3]

[1] V. Del Duca, C. Duhr, F. Guadagni, P. Muckerjee, G. Somogyi, F. Tramontano
``Colour singlet production in hadron collisions in NNLO subtraction methods"
to appear soon

[2] E.P. Byrne, V. Del Duca, E. Gardi, J.M. Smillie
''A minimal set of variables for multi-Regge kinematics", to appear soon

[3] S.S. Chava, V. Del Duca, R. Gonzo
''Self-force meets amplitudes: a non-perturbative framework", to appear soon

Progetti per il 2025

- da ottobre 2024, avremo un AR con tema di ricerca "Ampiezze di scattering e modellizzazione dell'emissione di onde gravitazionali" finanziato dai LNF, per cui è stato selezionato il dott. Francesco Alessio attualmente affiliato a Nordita all'Università e al Royal Institute of Technology di Stoccolma

Advanced Theoretical methods for emerging 2D materials in Quantum Information Technology Studies: Time2Quest

- *S. Bellucci, Unical (gruppo CS, A. Sindona), RM2 (G. Stefanucci), UNIMI (G. Onida)*

CSN4 research line: statistical physics and field theory

Main research issues

Spectroscopies, Electron correlations, Density Functional Theory, Modeling-Simulations and low-dimensional systems

Richiesta 2024 7.5 KE Missioni

Personnel associated in 2024, as of today

S. Bellucci (100%), M. Benfatto (30%), Iaroslav Gnilitskyi (AR, 100%),

Antonio Maffucci (PO, 100%), Cristian Vacacela (AR, 100%), Matteo La Pietra

and Federico Micciulla (guests)

FTE 4.3

Time2Quest started 2021 evaluated AAA by referees.

Advanced Theoretical methods for emerging 2D materials in Quantum Information Technology Studies: Time2Quest

- S. Bellucci Unical (gruppo CS, A. Sindona), RM2 (G. Stefanucci), UNIMI (G. Onida), continued

Collaborations in 2024

African Union-EU Collaborative Research and Innovation projects on renewable energy, "RCLIB: Recycling of the cathodes, based on carbon nanotubes and conducting polymers, from spent rechargeable Li batteries", 2023-2025, S. Bellucci, and Catalina Curceanu

Publications by the LNF unit in 2024

21 papers su rivista: Journal of Superconductivity and Novel Magnetism, RSC advances, Heliyon, Journal of Adhesion Science and Technology, Applied Physics A, Optical Materials, Journal of Alloys and Compounds Scientific Reports, Frontiers in Physics, Polymers, Catalysts, Journal of Functional Biomaterials, Emerging Science, Frontiers in Earth Science, Frontiers in Digital Health,

Advanced Theoretical methods for emerging 2D materials in Quantum Information Technology Studies: Time2Quest
- *S. Bellucci Unical (gruppo CS, A. Sindona), RM2 (G. Stefanucci), UNIMI (G. Onida), continued*

Talks in 2024

LNF 29April 2024, U.Cassino@LNF Lectures
S. Bellucci: **Nanomaterials for sensors and electronics applications**

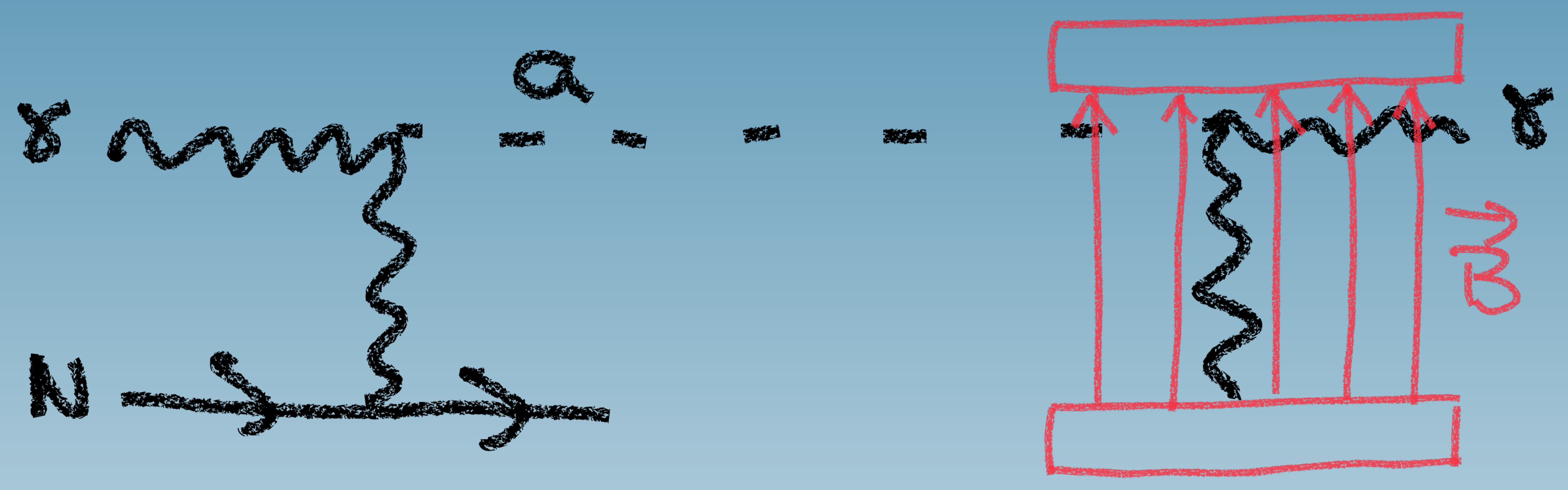
LNF 6 May 2024, U.Cassino@LNF Lectures
S. Bellucci: **Nanocomposite materials for electromagnetic compatibility**

LNF 6 June 2024 XXIII International Conference on Nanoscience and Nanotechnology
S. Bellucci: **Biological effects of metal oxide nanoparticles**

Research Activities 23-24

FAA, Vedran Brdar, Jérémie Quevillon, **Phys. Rev. Lett.** 132 (2024) 21, 211802

- ALPs produced at nuclear reactors can be detected with magnetic fields



Survival Prob

$$\frac{d\Phi_a}{dE_a} = \frac{1}{4\pi D^2}\, e^{-\frac{D}{\tau}}\, \frac{\sigma_{Prim}(E_a)}{\sigma_{Tot}(E_a)}\, \frac{5{,}8\cdot 10^{30}}{\text{MeV s}} \left(\frac{P}{\text{GW}}\right) e^{-1.1\frac{E_a}{\text{MeV}}}$$

Spherical Flux

Photon Flux in Reactor

Research Activities 23-24

FAA, Vedran Brdar, Jérémie Quevillon, **Phys. Rev. Lett.** 132 (2024) 21, 211802

- ALPs produced at nuclear reactors can be detected with magnetic fields

NEUTRONS FOR SOCIETY

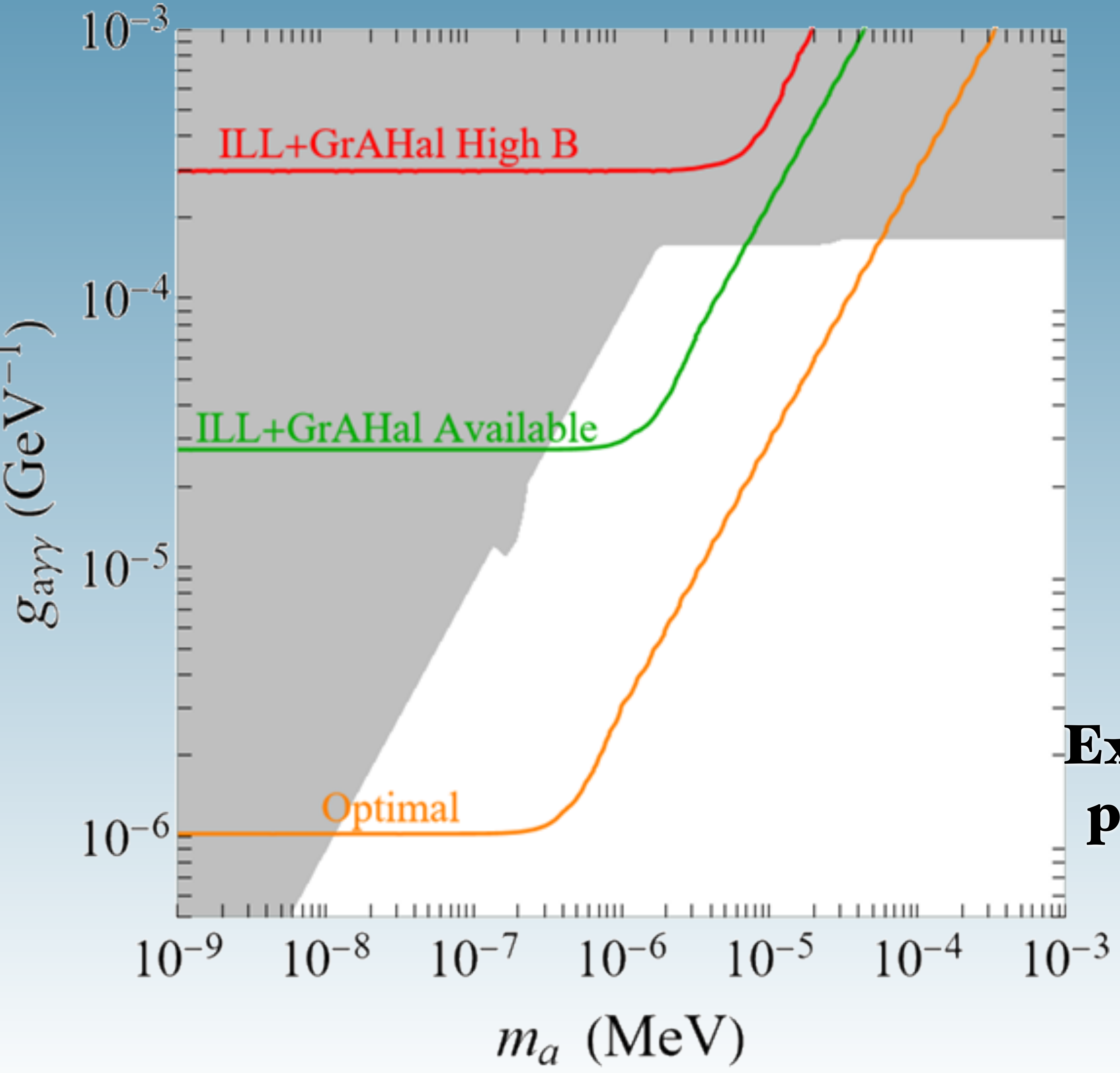
GrAHal

Research Activities 23-24

FAA, Vedran Brdar, Jérémie Quevillon, **Phys. Rev. Lett.** 132 (2024) 21, 211802

- ALPs produced at nuclear reactors can be detected with magnetic fields

B = 43 T
R = 1,7 cm
L = 3,4 cm
P = 58 MW
D = 700 m
B = 9,5 T
R = 40 cm
L = 80 cm



P = 8,2 GW
D = 50 m
B = 2 T
R = 35 cm
L = 10 m

Extends the parameter space probed by lab experiments!

Effects of atomic electron momentum distribution on resonant dark sector production

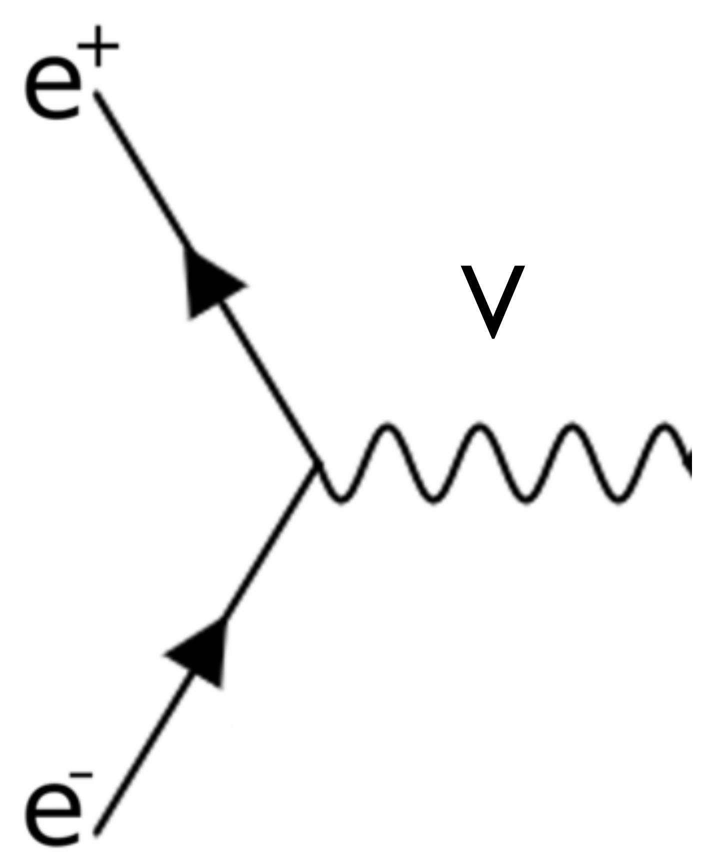
F. Arias Aragon, L. Darmé, G. Grilli di Cortona, E. Nardi

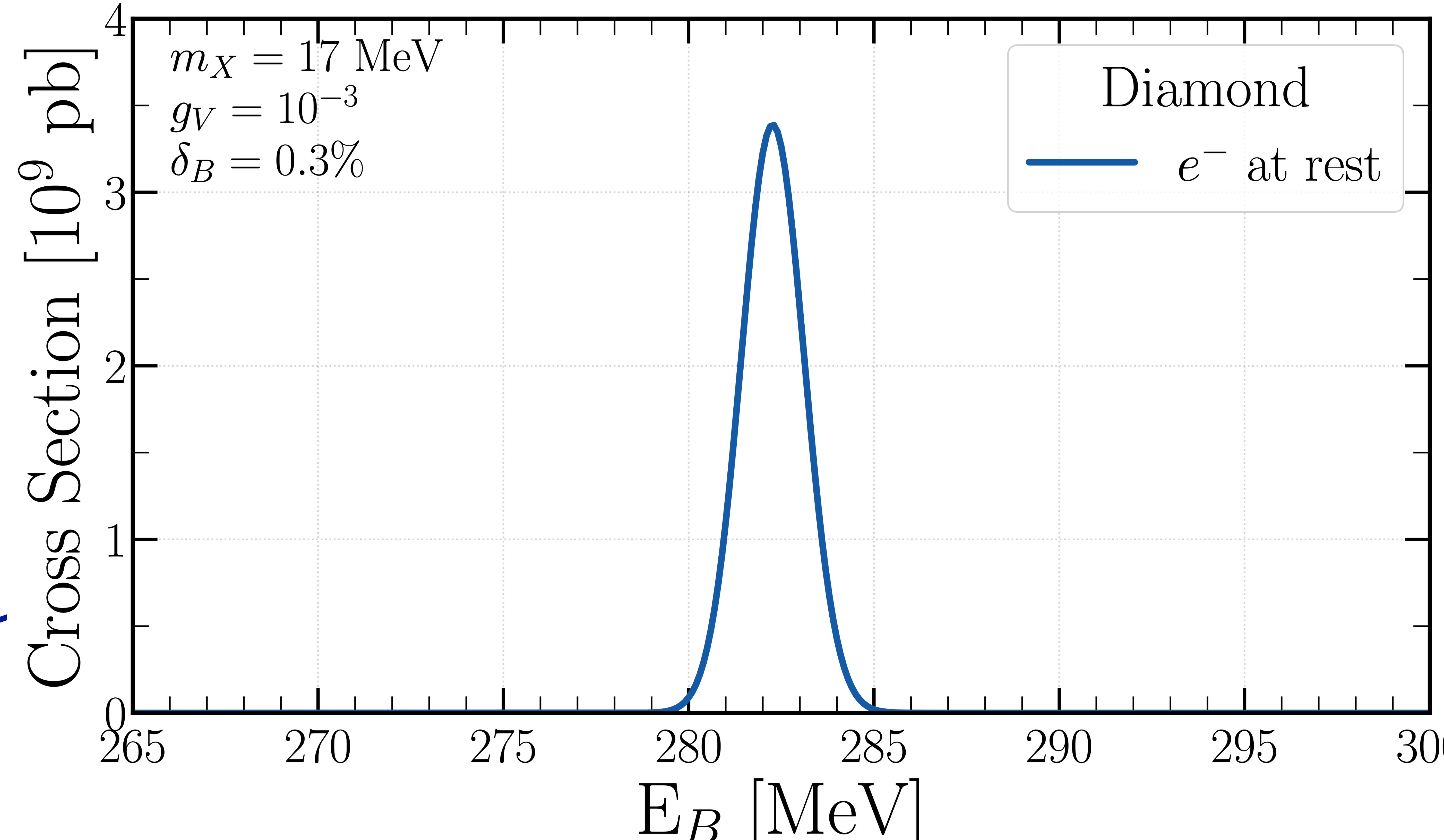
Physical Review Letters 132 (2024) 26, 261801 arXiv: 2403.15387

Resonant production

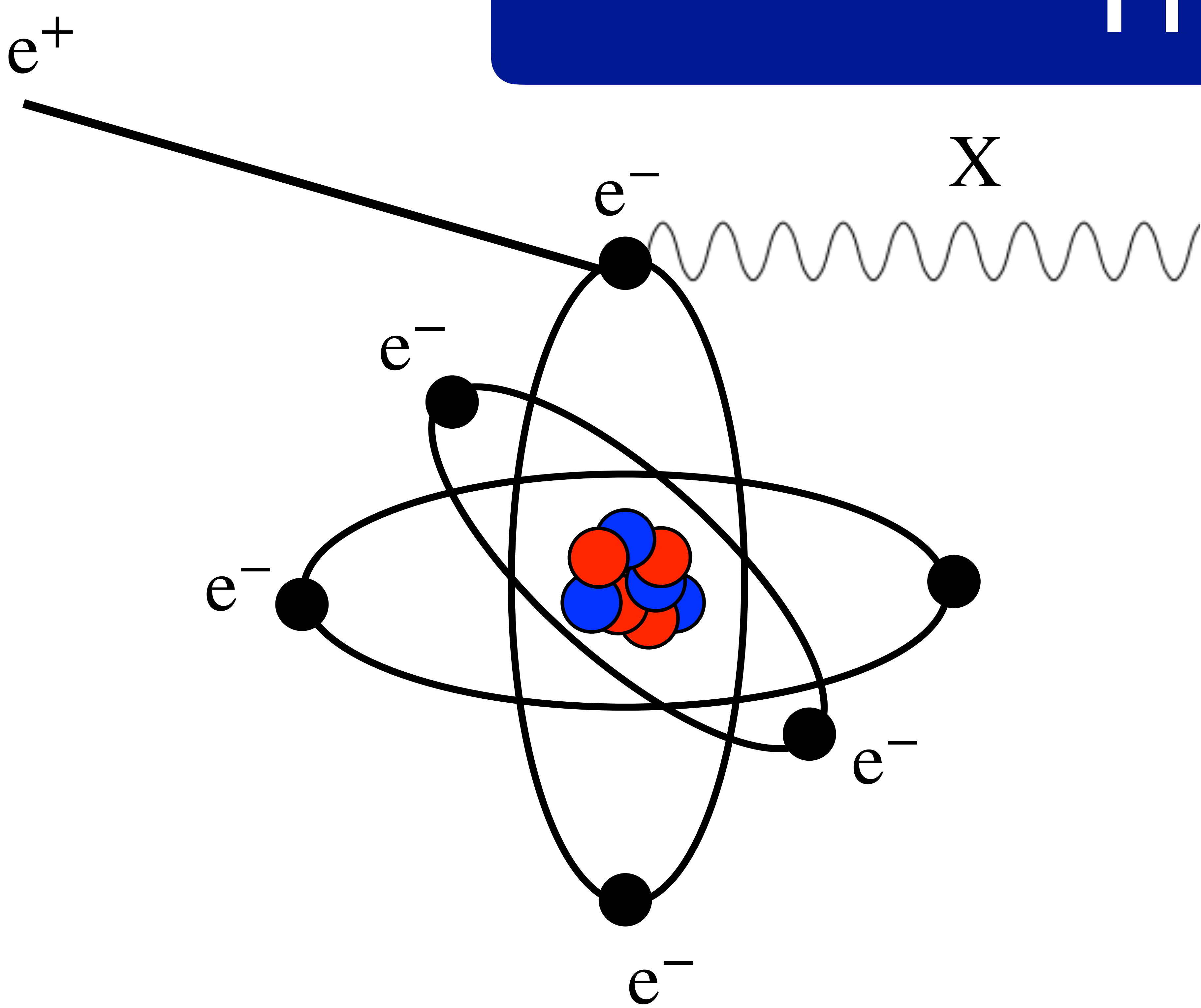
$$\sigma_{\rm res}(E) \simeq \frac{\pi g_V^2}{2m_e}\mathcal{G}(E, E_{\rm res}, \sigma_{E_B})$$

$$E_{\rm res} = \frac{m_V^2}{2m_e} - m_e$$





The problem



$$p^+ \simeq (E_b, E_b)$$
$$p^- = (\gamma m_e, \pm \gamma m_e \beta)$$
$$s' = 2m_e^2 + 2\gamma m_e E_b (1 \pm \beta)$$

[J. Chem. Phys. 47 (1967) 4 1300-1307]

Naive estimate: $\langle \beta_{n\ell} \rangle = \alpha Z_{\rm eff}^{n\ell}$

$Z_{\rm eff}^{1s} = 5.67$ $\quad \langle \beta_{1s} \rangle = 0.041$

$Z_{\rm eff}^{2s} = 3.22$ $\quad \langle \beta_{2s} \rangle = 0.024$

$Z_{\rm eff}^{2p} = 3.14$ $\quad \langle \beta_{2p} \rangle = 0.023$

using $\beta = \langle \beta_{1s} \rangle = 0.04$

$\sqrt{s} = 16.99\,\text{MeV}$ $\quad (E_b \sim 282.0\ \text{MeV})$

$\sqrt{s'_+} = 17.33\,\text{MeV}$ $\quad (E_b \sim 293.5\ \text{MeV})$

$\sqrt{s'_-} = 16.66\,\text{MeV}$ $\quad (E_b \sim 271.5\ \text{MeV})$

Centre of mass energy for positron annihilation can differ sizeably with respect to the electrons at rest assumption!

What should we compute?

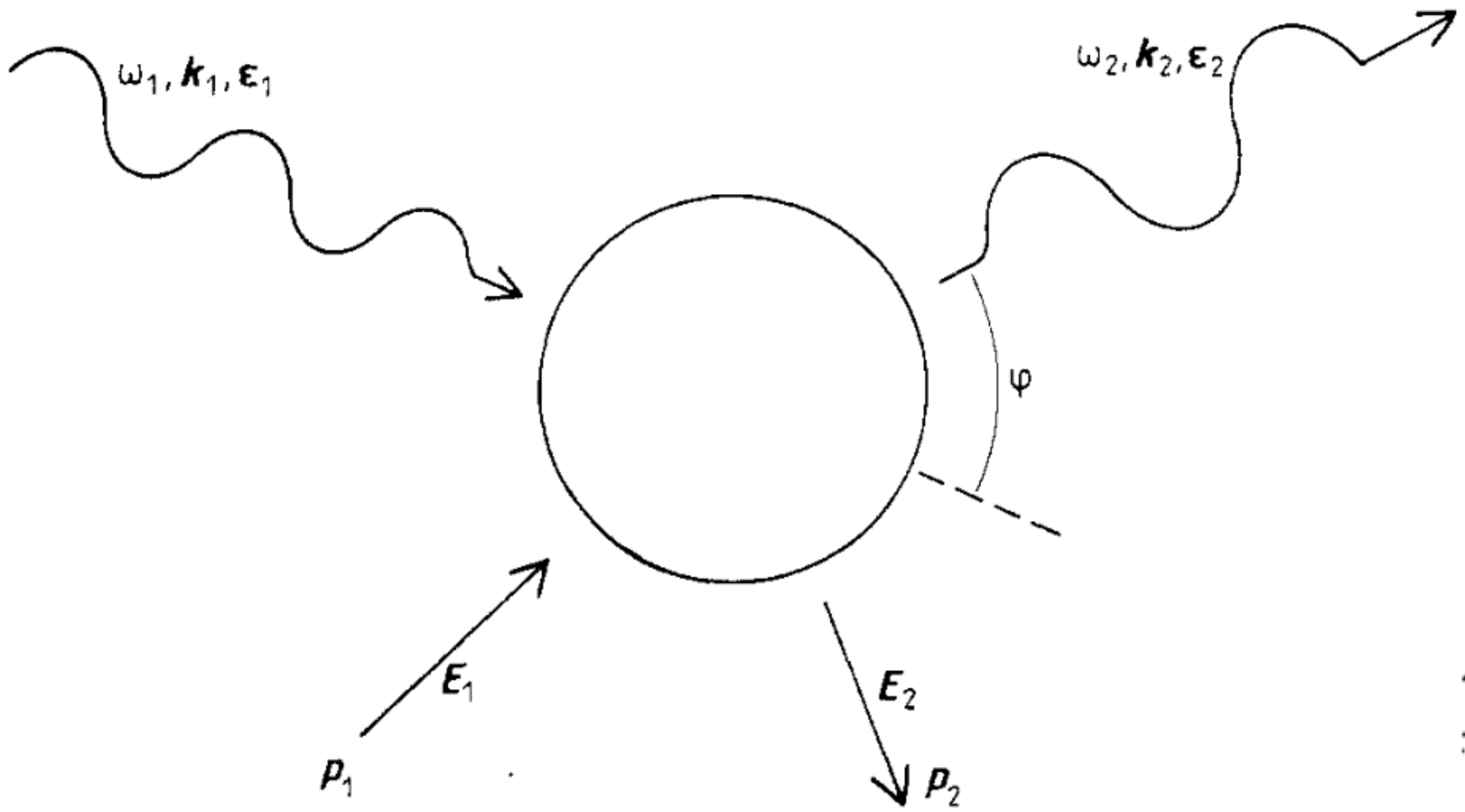
$$d\sigma = \frac{d^3 p_X}{(2\pi)^3} \int \frac{d^3 k_A}{(2\pi)^3} \frac{(2\pi)^4}{8 E_X E_A E_B |v_A - v_B|} n\left(\vec{k}_A\right) |\mathscr{M}|^2 \delta^{(4)}(k_A + p_B - p_X)$$

$$n(\vec{k}_A) = \sum_{n,\ell} |\phi_{n,\ell}(\vec{k}_A)|^2$$

theory: use Slater Type Orbitals, hybridization, Hartree Fock computations for atomic carbon, …

data: obtain $n(k)$ from data: Compton Profile

Compton Profile

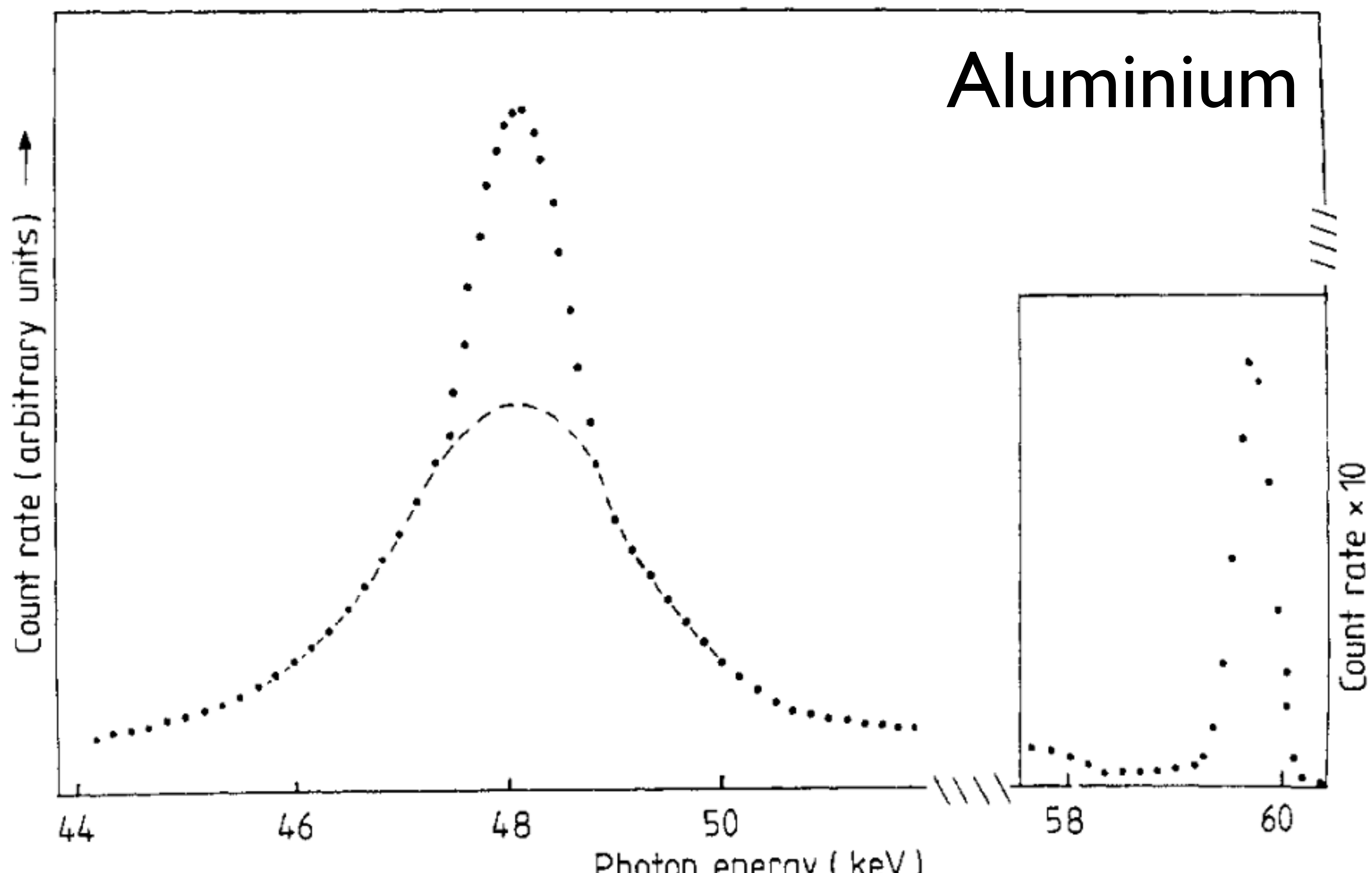


$$\omega_1 - \omega_2 = \frac{1}{2}m_e\,[\vec{p} + (\vec{k}_1 - \vec{k}_2)]^2 - \frac{|\vec{p}\,|^2}{2m_e}$$

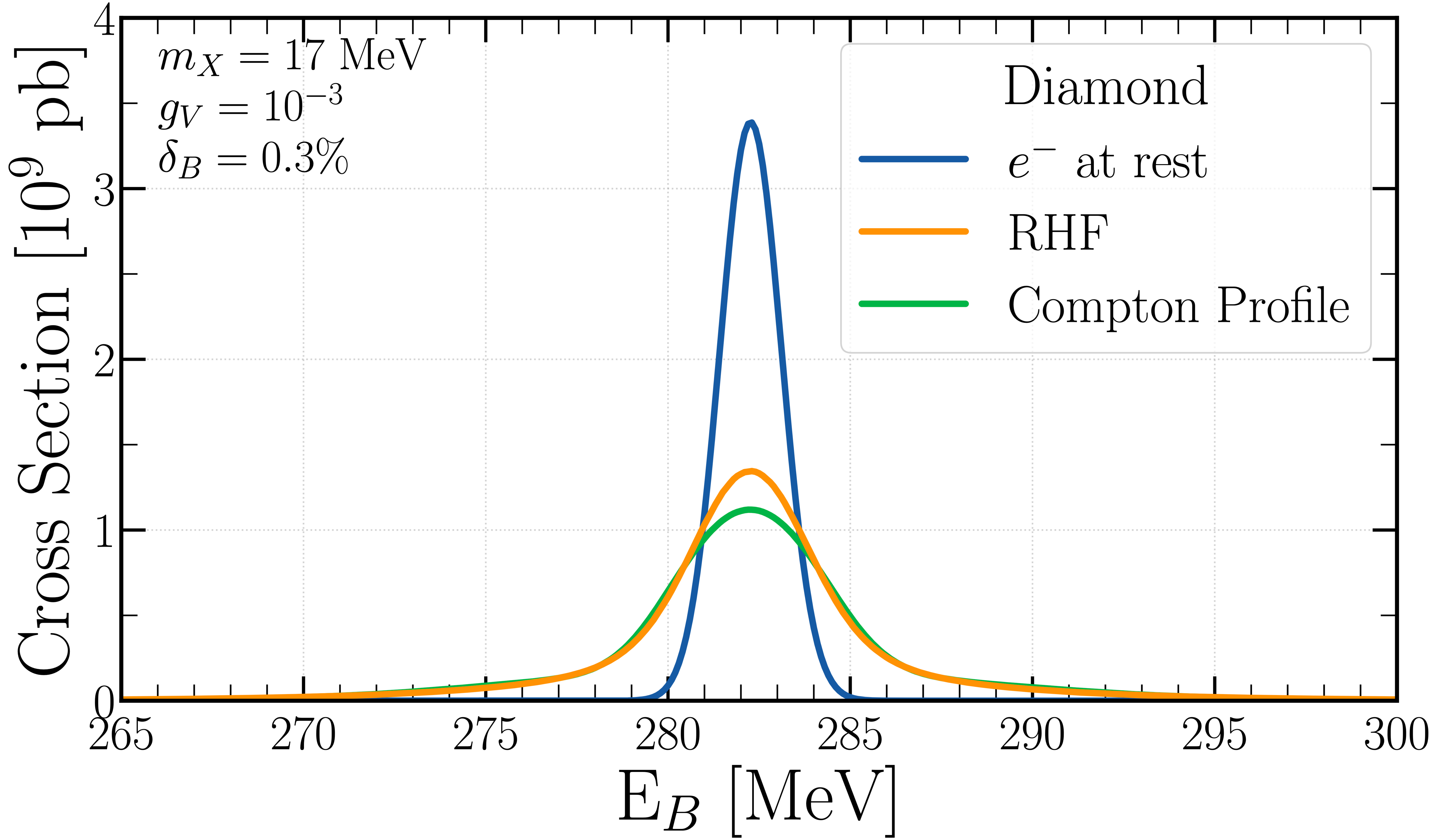
$$= \frac{|\vec{k}_1 - \vec{k}_2|^2}{2m_e} + \frac{(\vec{k}_1 - \vec{k}_2)\cdot\vec{p}}{m_e}$$

$$\simeq \frac{2\omega_1}{m_e}\sin(\phi/2)p_z$$

M J Cooper 1985 Rep. Prog. Phys. 48 415



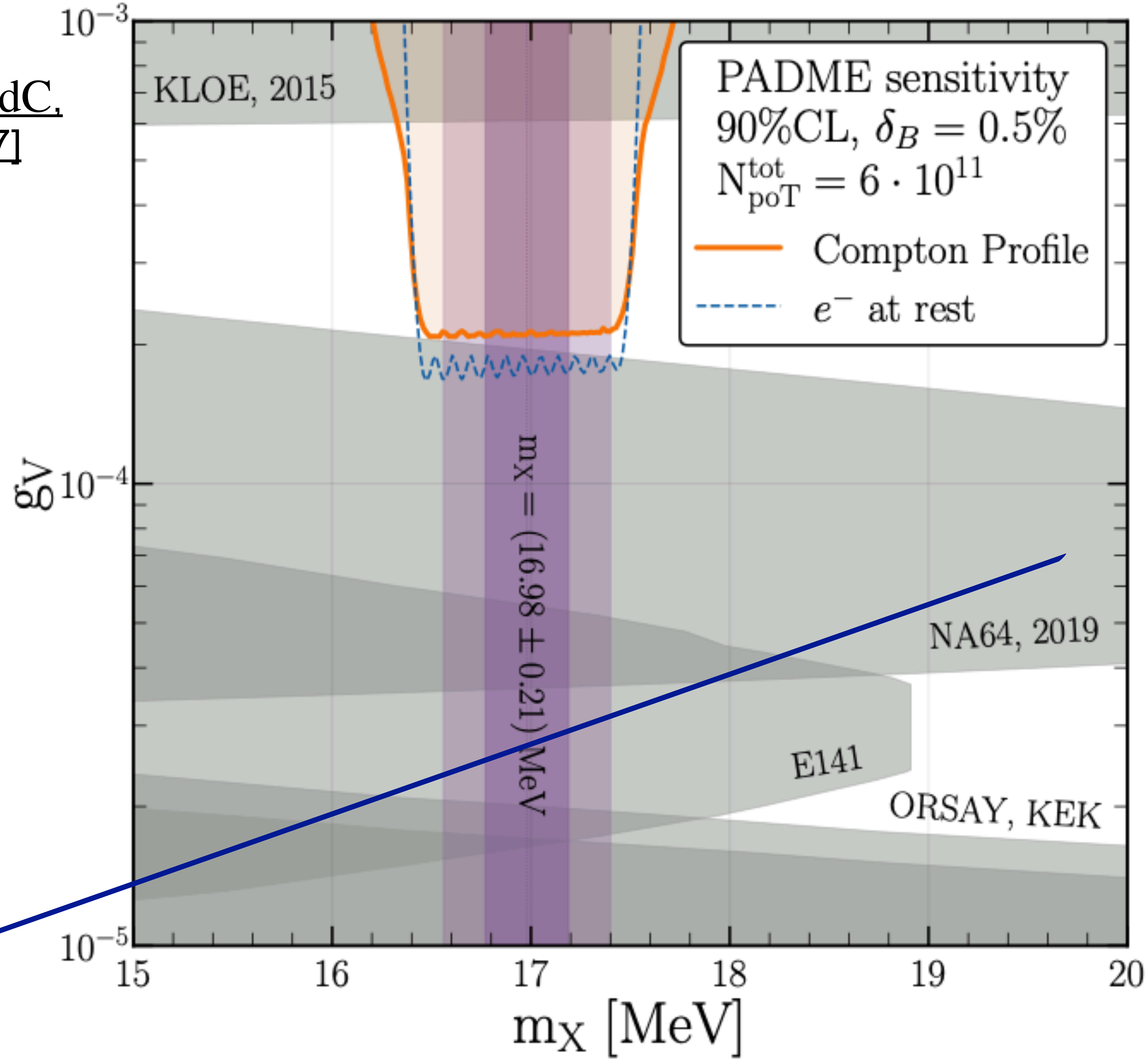
Comparison



$m_X = 17$ MeV
$g_V = 10^{-3}$
$\delta_B = 0.3\%$
Diamond
e^- at rest
RHF
Compton Profile
Cross Section [10^9 pb]
E_B [MeV]
0
1
2
3
4
265
270
275
280
285
290
295
300

PADME ultimate sensitivity

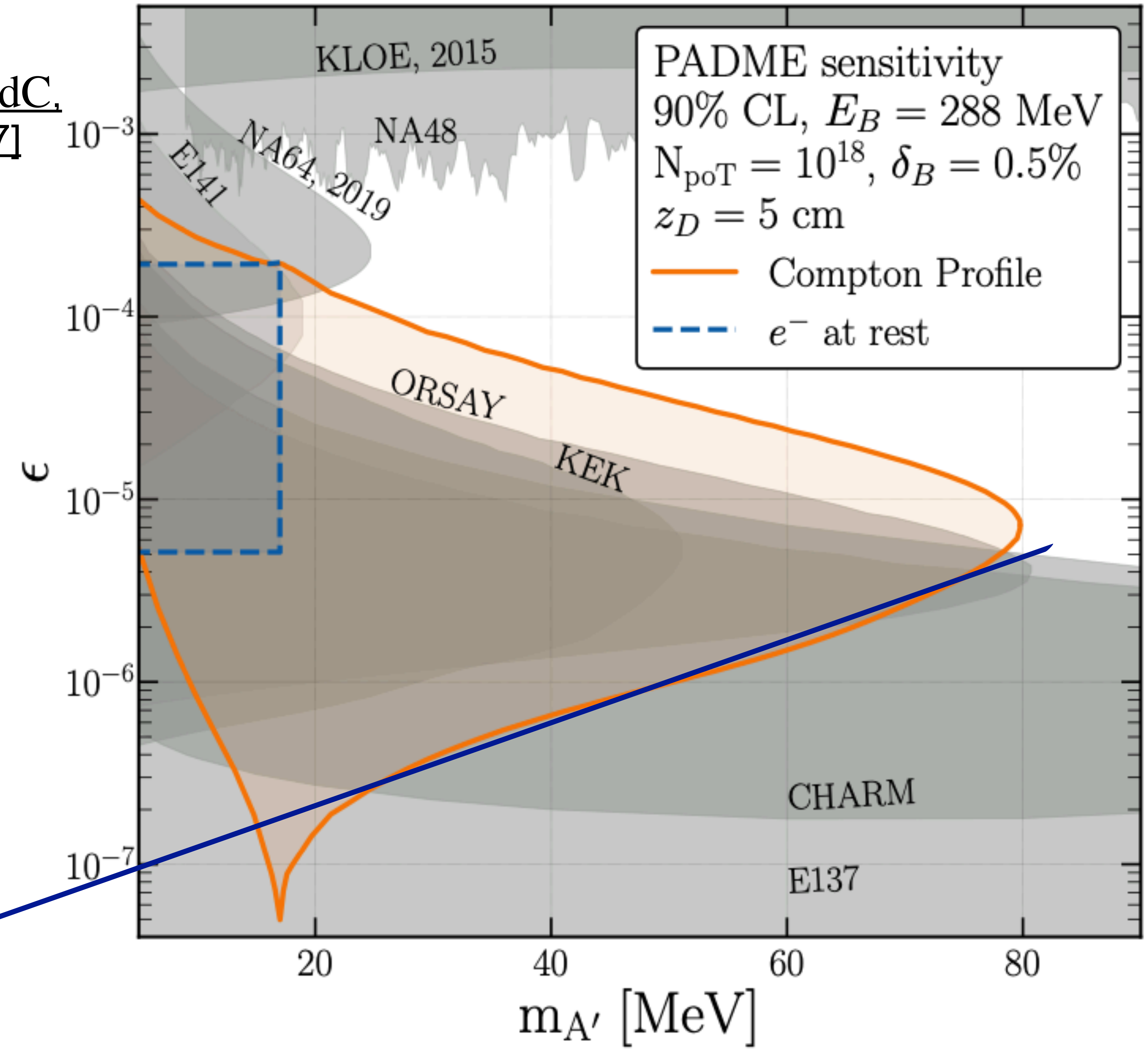
[Arias-Aragon, Darmé, G²dC, Nardi, arXiv:2403.15387]



negligible systematics

Dark photons

[Arias-Aragon, Darmé, G^{2}dC, Nardi, arXiv:2403.15387]



Can the QCD axion feed a DE component?

With: Kristjan Müürsepp (NICPB, Tallinn) & Clemente Smarra (SISSA & INFN, Trieste) [arXiv:2405.00090]

Energy Density of non-rel. particles: $\rho = \frac{n\,m}{Vol}$; $Vol = a^3 \sim T^{-3}$

a scale factor, T temperature

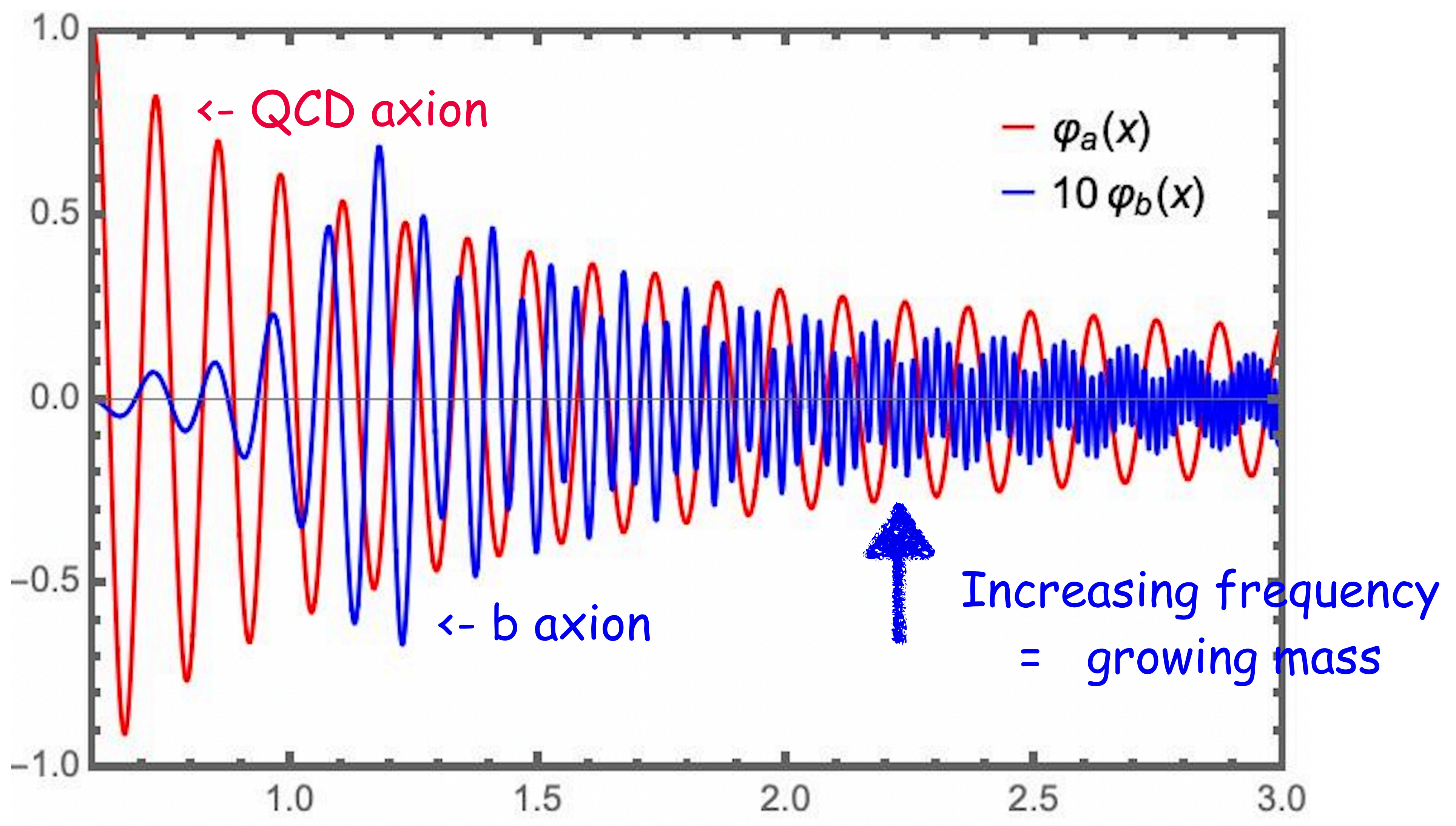
A particle with T dependent mass $m \sim T^{-n}$, with $n \sim 3$ $\Rightarrow \rho = const$

If $\rho > \rho_{DM}$, the cosmological expansion accelerates, much alike with a Cosmological Constant !

At the QCD phase transition: axion mass grows almost as needed $m_a(T) \sim T^{-3.6}$. Today m_a =const.

We assume SU(N) in a dark sector, undergoing confinement now, and a b-axion with $m_b(T) \sim T^{-3}$

A level-crossing with the QCD axion populates n_b



This provides a particle physics interpretation of the cosmic acceleration phenomenon.

Conclusioni

Eccellente produzione scientifica del gruppo teorico dei LNF

Collaborazioni internazionali e locali con gruppi ai LNF e dell'area romana (PRIN, Assegni Cabibbo)

Responsabili nazionali di Iniziative Specifiche di LNF

Continua interazione con gruppi sperimentali in loco e non (ATLAS, CMS, PADME, DarkSide, JLAB, FLASH)

Intenso programma ospiti ed attività seminariale

Assegno di ricerca Cabibbo ben consolidato nella comunità internazionale

Manifestazioni di interesse in dottorato con membri di LNF-TH

Significativa espansione del gruppo, auspicabile ulteriore rafforzamento alla luce dei pensionamenti

Richieste: spazi (collaborazioni, workshops), altro assegno, fondi missione