Gamma Factory at CERN (and elsewhere)
Extraordinary Tool for Extraordinary Tasks

PIs:

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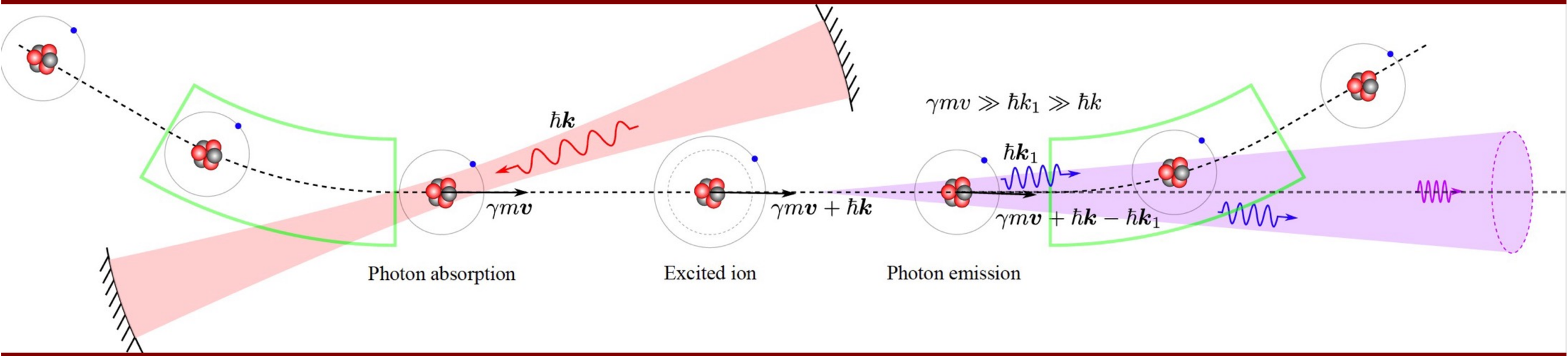
Dmitry Budker, Mikhail Gorshteyn (JGU Mainz)

Town meeting Hadron Physics in Horizon Europe, Nantes July 1-2 2025

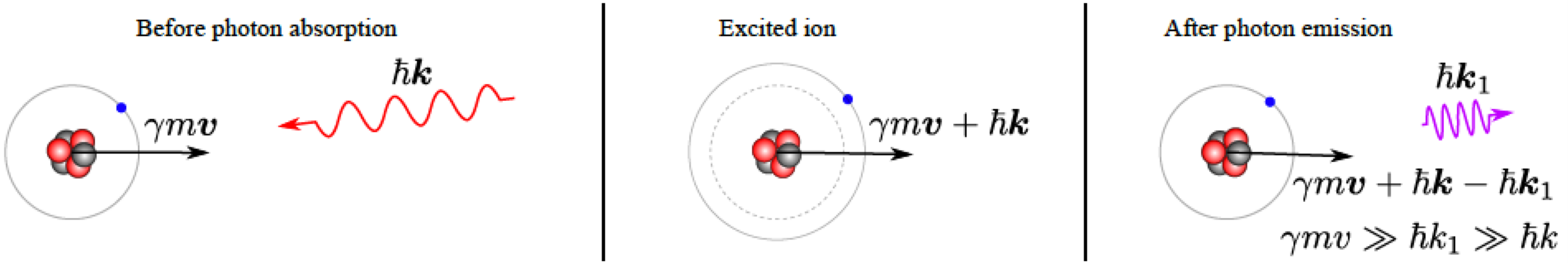
Gamma Factory @ CERN



- Proposal: M. W. Krasny (2015)
- Up to 10^{17} photons/s with energies up to 400 MeV
- Physics with primary, secondary, and tertiary beams
- “Table-top” physics with the LHC ?

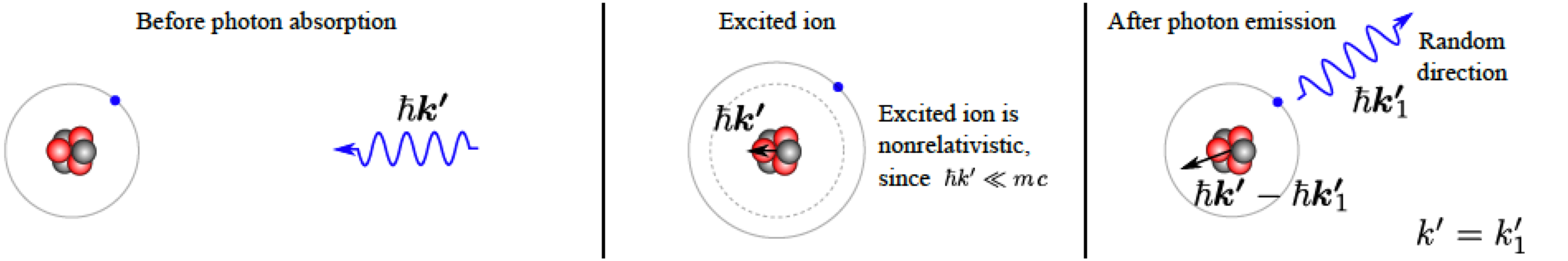
Photon scattering on relativistic ions

In the laboratory reference frame:



Photon-energy boost: $2\gamma_L \times 2\gamma_L$
backward emission angle: $1/\gamma_L$

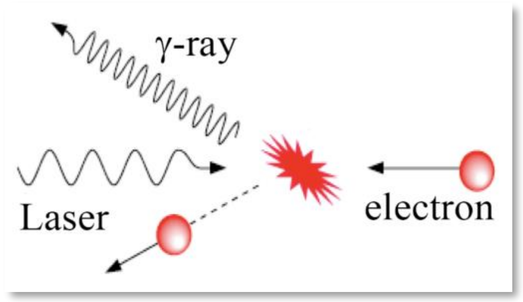
In the initial ion reference frame:



Photon-energy boost: $2\gamma_L$

The Gamma Factory Intensity Leap

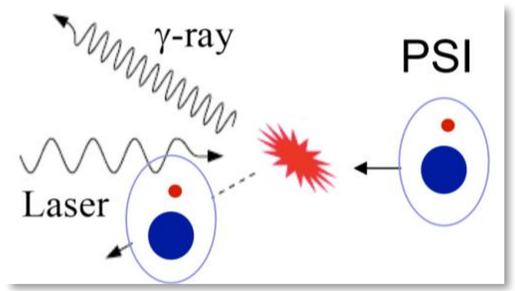
Compton backscattering



Cross-section	Requirements	Features
Electrons:	E_{beam} = 1.5 GeV	➢ Relatively "compact"
$\sigma_e = 8\pi/3 \times r_e^2$	LINAC or LWFA	➢ Large laser system
r_e - classical electron radius	Electron fractional energy loss: emission of 150 MeV photon: $E_\gamma/E_{beam} = 0.1$	➢ Low γ photon flux (10^9 ph/s)
$\sigma_e = 6.6 \times 10^{-25}$ cm^2	(electron is lost!)	

⇩ σ x 10^9 ⇩ x 10^7 ph/s

Gamma Factory



Example: Pb, hydrogen-like ions, *stored in LHC* γ_L = 2887

Partially Stripped Ions:	E_{beam} = 574 000 GeV	➢ Unique Gamma-ray beam
$\sigma_{res} = \lambda_{res}^2/2\pi$	(LHC)	➢ Modest laser requirements
λ_{res} - photon wavelength in the ion rest frame	Electron fractional energy loss: emission of 150 MeV photon: $E_\gamma/E_{beam} = 2.6 \times 10^{-7}$	➢ Ultrahigh γ photon flux (10^{16} ph/s)
$\sigma_{res} = 5.9 \times 10^{-16}$ cm^2	(ion undisturbed!)	➢ Transparent to accelerators
		➢ Beam cooling capability

Tune laser frequency to resonant atomic transition —> ~every photon in the bunch interacts

Where is GF in the global context?

LHC — huge rel. factor γ

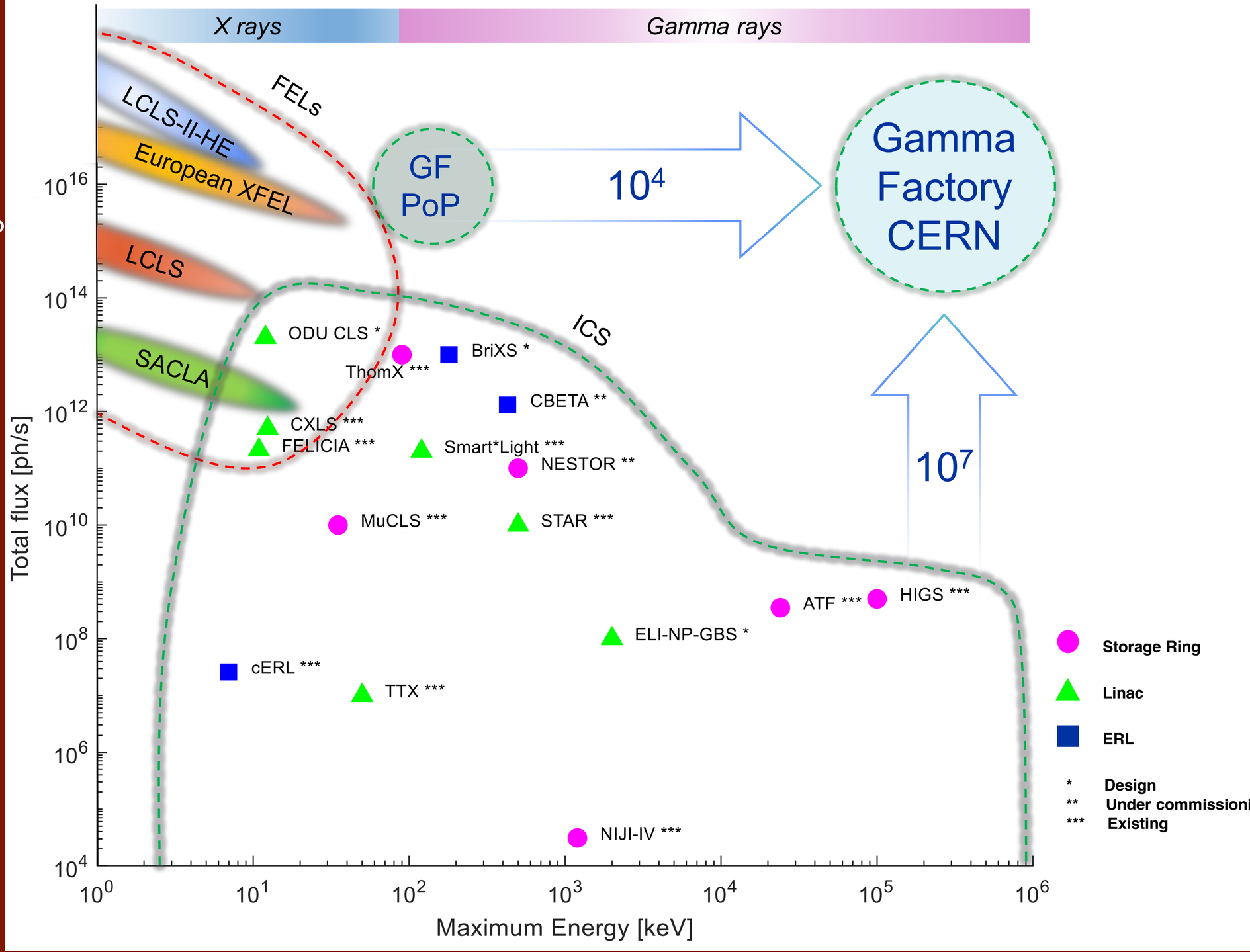
PSI — huge cross section

XFEL at ≤ 400 MeV energy!

Proof-of-Principle (PoP)

experiment

at SPS in preparation for 2028



PSI @ LHC

Is this possible?

A major news from CERN! (July 2018)

During a special one-day run, LHC operators injected lead "atoms" containing a single electron into the machine (Image: Maximilien Brice/Julien Ordan/CERN)

Protons might be the Large Hadron Collider's bread and butter, but that doesn't mean it can't crave more exotic tastes from time to time. On Wednesday, 25 July, for the very first time, operators injected not just atomic nuclei but lead "atoms" containing a single electron into the LHC. This was one of the first proof-of-principle tests for a new idea called the Gamma Factory, part of CERN's Physics Beyond Colliders project.

Gamma Factory PBC study group

90 scientists
35 institutes
>10 countries

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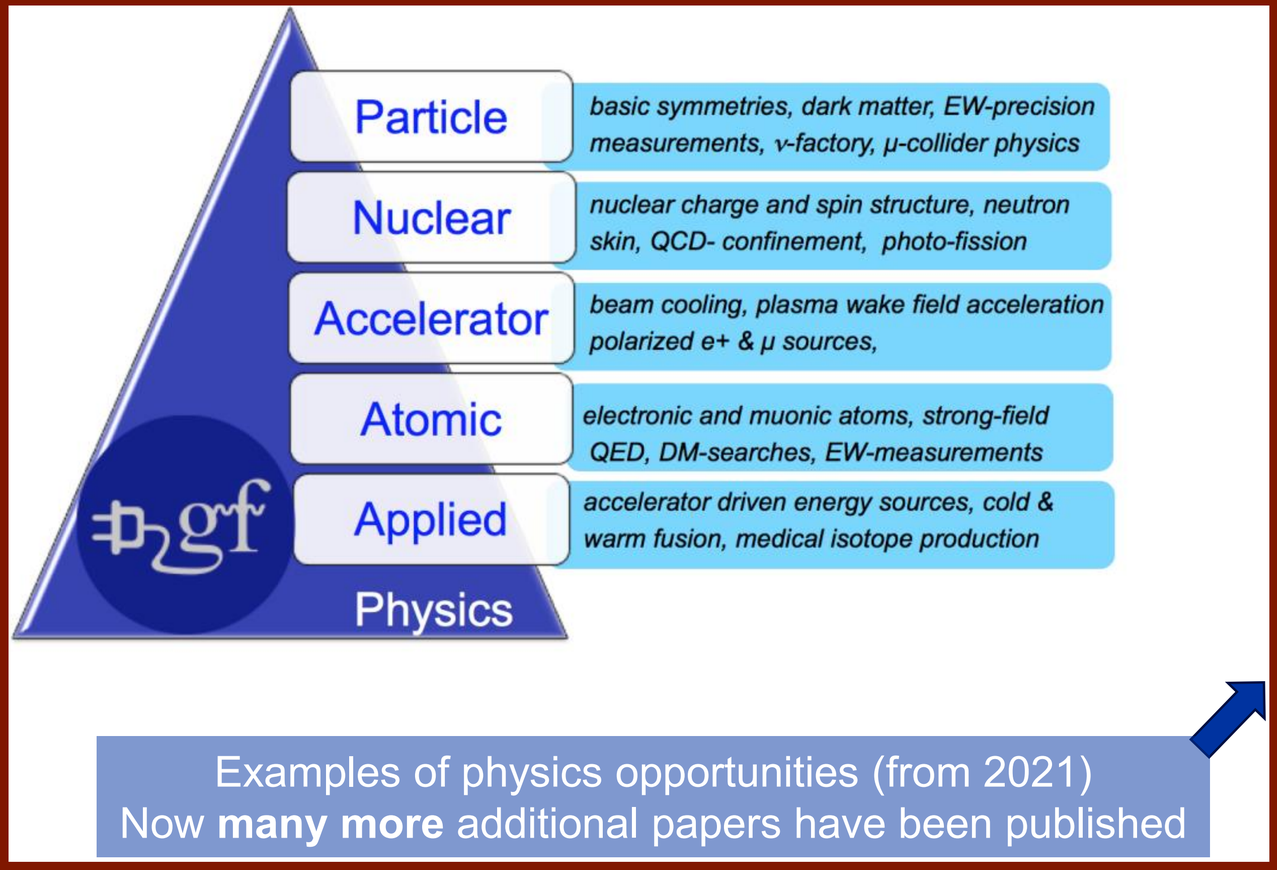
CERN Physics Beyond Colliders

Prof. Dr.
Witold Krasny

GF group is open to everyone willing to contribute to this initiative!

Gamma Factory virtual MITP workshop in 2020
Great response from the community
Special issue in Annalen der Physik



Examples of physics opportunities (from 2021)
Now **many more** additional papers have been published

Volume 534, Issue 3

Special Issue: Physics Opportunities with the Gamma Factory

March 2022

Issue Edited by: Dmitry Budker, Mikhail Gorchtein, Mieczyslaw Witold Krasny, Adriana Pálffy, Andrey Surzhykov

Review

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- [ ] Expanding Nuclear Physics Horizons with the Gamma Factory

Research Articles

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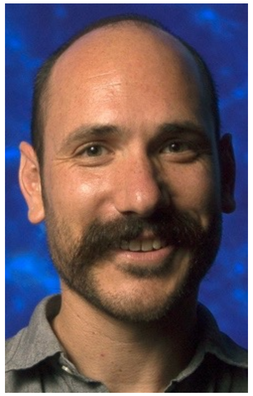
- [ ] Polarization of Photons Scattered by Ultra-Relativistic Ion Beams





Expanding Nuclear Physics Horizons with Gamma Factory

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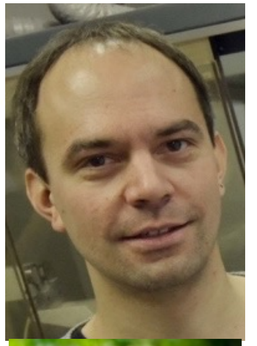
(Dated: February 16, 2021)

Ann. Phys. (Berlin)
2021, 2100284
arXiv:2106.06584





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Selected physics highlights

Secondary Photons ($\omega_2 = 40\,\mathrm{keV} - 400\,\mathrm{MeV}$) on Fixed Target

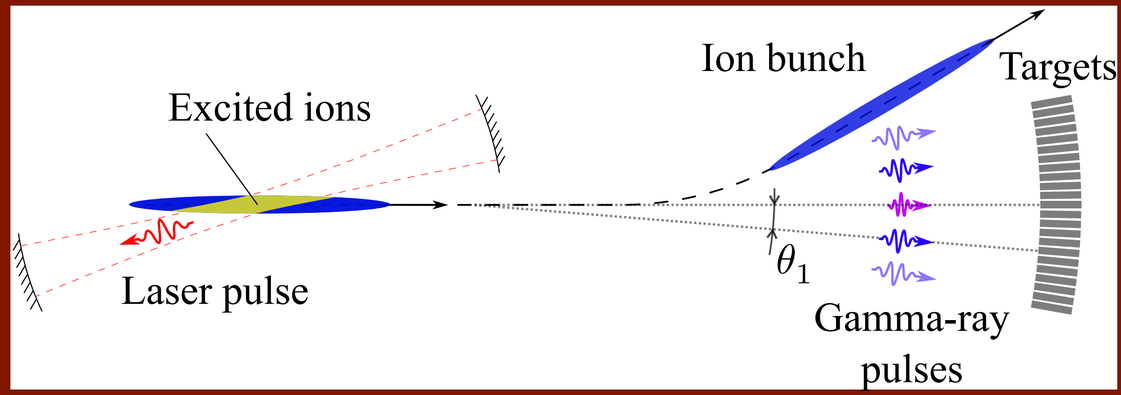
Angle-correlated energy resolution ~$10^{-4/5}$

+ 100% polarization —>

Study narrow states, identify quantum numbers

Photophysics with radioisotopes (proximity of ISOLDE)

P-violation with real photons in hadronic range

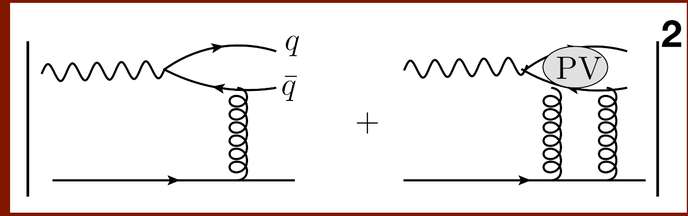


Secondary Photons in Colliding Mode on p/ion beam ($\sqrt{s} \leq 100\,\mathrm{GeV}$)

Circular photon polarization —> assess parity violating part of CS (F_3)

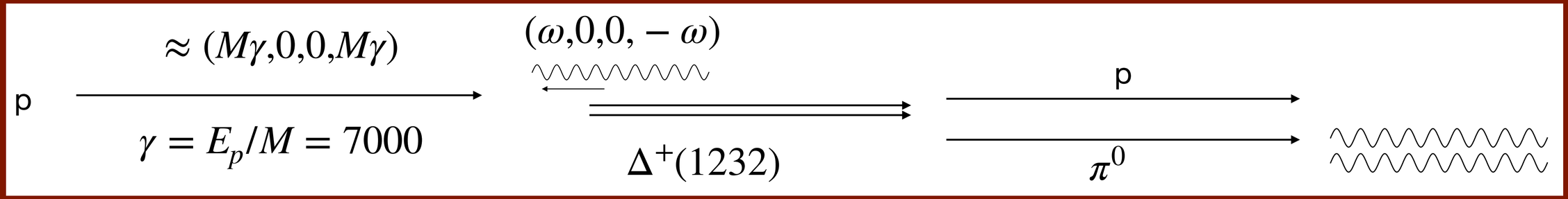
With PV can access **odderon** () without the need for anti-particle beam!

Parity-Conserving F_1: C+, P+ (pomeron) — Parity-Violating F_3: C-, P- (odderon)



Tertiary VHEGR Photons $\omega_3 \leq 3.2\,\mathrm{TeV}$

Tune the gamma ray to be on the Delta resonance (in the rest frame of the proton beam)



$$p + \gamma \rightarrow \Delta \rightarrow p + \pi^0 \rightarrow p + 2\gamma$$

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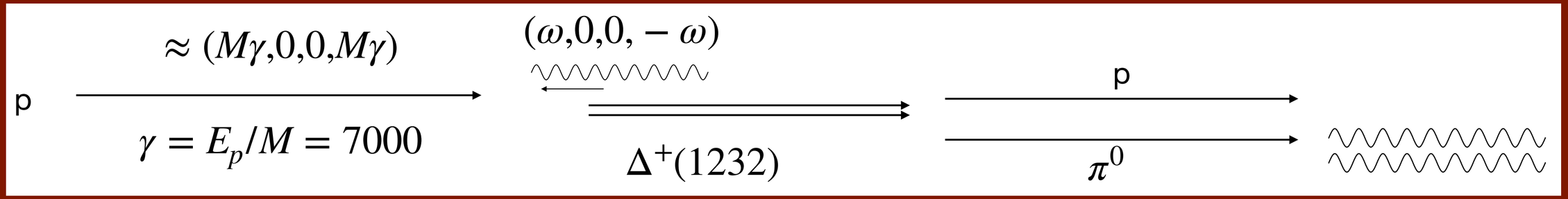

$$p + \gamma \rightarrow \Delta \rightarrow p + \pi^0 \rightarrow p + 2\gamma$$

Incident beam: $\omega \approx 300\,\mathrm{MeV}/2\gamma \sim 22\,\mathrm{keV}$ —> pion produced at $\omega_\pi \sim 2\gamma\,230\,\mathrm{MeV} = 3.2\,\mathrm{TeV}$

All pions will decay into 2 photons within $\gamma\tau_{\pi^0} \approx 2.5 \times 10^{-13}\,s$

Rate estimate: 4300 photons/s

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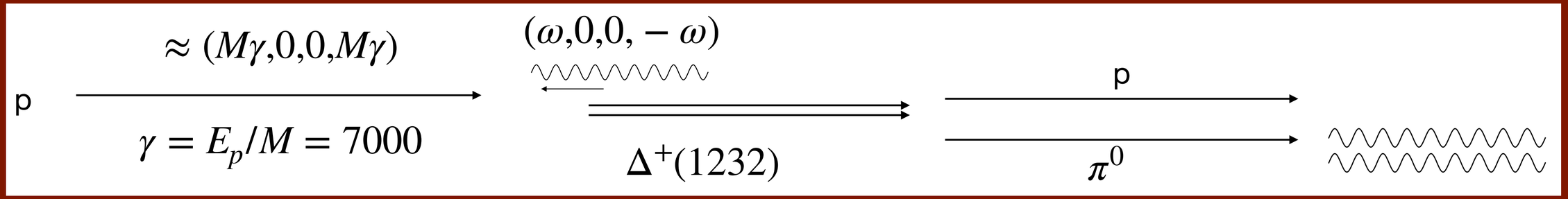

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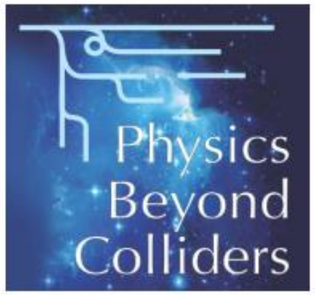
The highest photon energy produced in the lab - studies relevant e.g. for astrophysics

Summary

- The Gamma Factory @ LHC: a unique gamma source
- Unprecedented photon flux, wide energy range, high energy resolution, 100% polarized
- A wide range of physics tasks with photons from 40 keV to 3.2 TeV
- Will deliver crucial insights in atomic, nuclear, hadronic, particle physics, BSM searches

Gamma Factory Collaboration:



100+ physicists from 40 institutes in 15 countries contributed to the GF studies in its various aspects

LOI endorsed by

JGU & Helmholtz-Institut Mainz (Budker, Gorshteyn)
Sorbonne U. (Krasny)
CERN (Dutheil)
IJCLab, Orsay France (Martens)
GSI Darmstadt (Litvinov)
FSU & Helmholtz-Institut Jena (Karbstein)
FAU Erlangen-Nürnberg (Palffy)
PTB Braunschweig (Surzhykov)
LMU München (Thirolf)
MPIK Heidelberg (Weidenmüller, Oreshkina)
Jagellonian U. Krakow, Poland (Placzek)
JLab, Newport News, USA (Wojtsekhovsky)
MSU, East Lancing, USA (Zelevinsky)
U. New South Wales, Sydney, Australia (Flambaum, Berengut)

Goals

GF collaboration exists and already produced scientific results:
- Review papers and special issues of Annalen der Physik with case studies
- Technical group preparing the PoP experiment at SPS

Maintain the collaboration and promote its contribution to PBC
Further elaborate the physics case for GF @ CERN —> service to CERN

Study application of GF principle to other machines (EIC, GSI/FAIR, …)

Budget

2 workshops á 15 k€ = 30 k€ (ECT* and CERN natural choice, also MITP)

Travel money for networking 25 k€/year = 100 k€

1 PD position for 2 years at Mainz = 150k€