BSM Opportunities in Heavy Ions UPC

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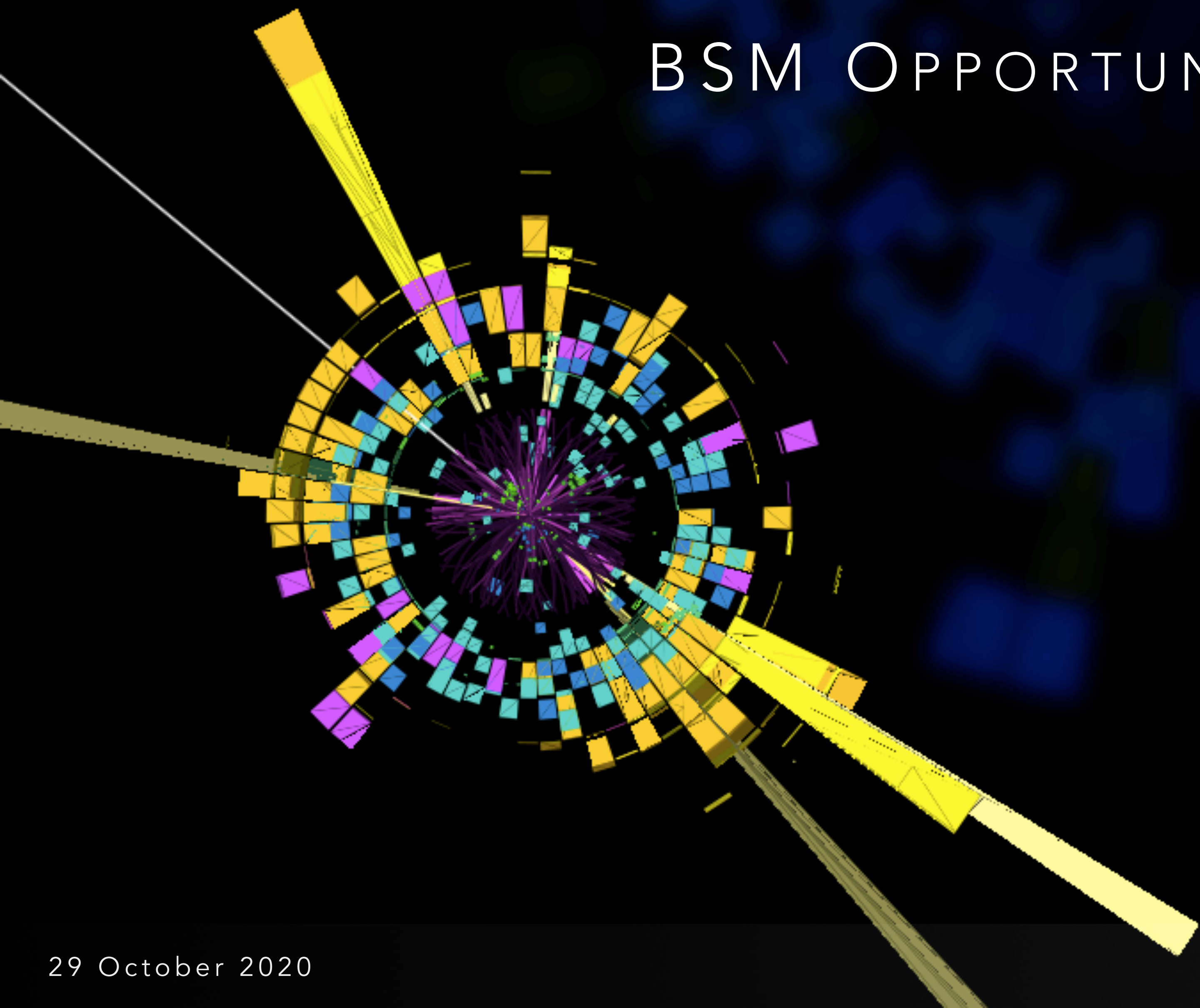


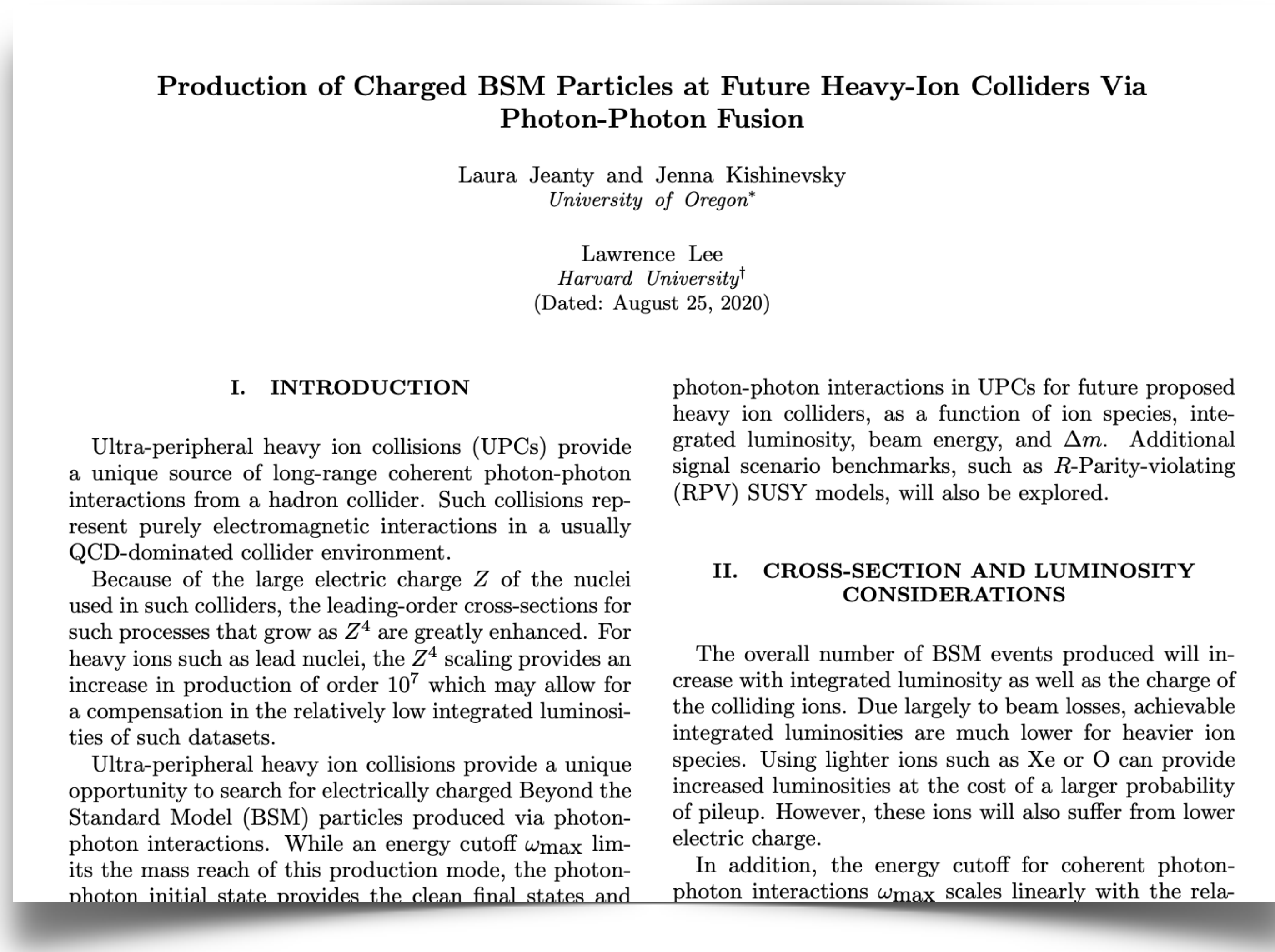
29 October 2020

- LoI: Link

- A lot in common with the previous presentation! LoI [Link]

- We focus on specific use cases that are motivated by SUSY

    - Do heavy ion colliders present unique sensitivity in SUSY reach?



Production of Charged BSM Particles at Future Heavy-Ion Colliders Via Photon-Photon Fusion

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(Dated: August 25, 2020)

I. INTRODUCTION

Ultra-peripheral heavy ion collisions (UPCs) provide a unique source of long-range coherent photon-photon interactions from a hadron collider. Such collisions represent purely electromagnetic interactions in a usually QCD-dominated collider environment.

Because of the large electric charge Z of the nuclei used in such colliders, the leading-order cross-sections for such processes that grow as Z^4 are greatly enhanced. For heavy ions such as lead nuclei, the Z^4 scaling provides an increase in production of order 10^7 which may allow for a compensation in the relatively low integrated luminosities of such datasets.

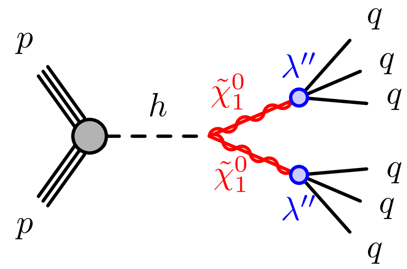
Ultra-peripheral heavy ion collisions provide a unique opportunity to search for electrically charged Beyond the Standard Model (BSM) particles produced via photon-photon interactions. While an energy cutoff $\omega_{\max}$ limits the mass reach of this production mode, the photon-photon initial state provides the clean final states and photon-photon interactions in UPCs for future proposed heavy ion colliders, as a function of ion species, integrated luminosity, beam energy, and Δm. Additional signal scenario benchmarks, such as R-Parity-violating (RPV) SUSY models, will also be explored.

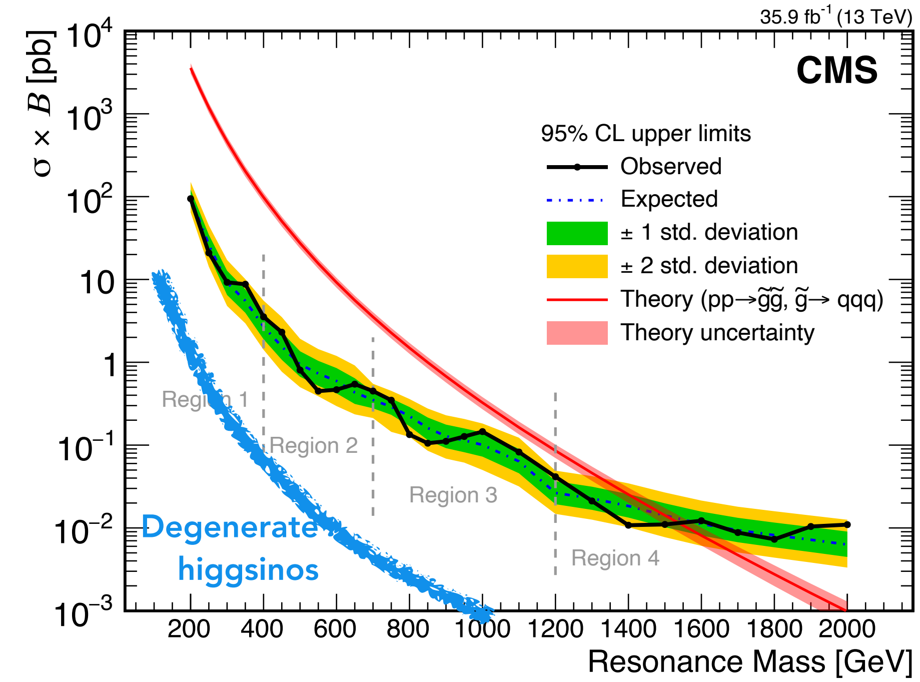
II. CROSS-SECTION AND LUMINOSITY CONSIDERATIONS

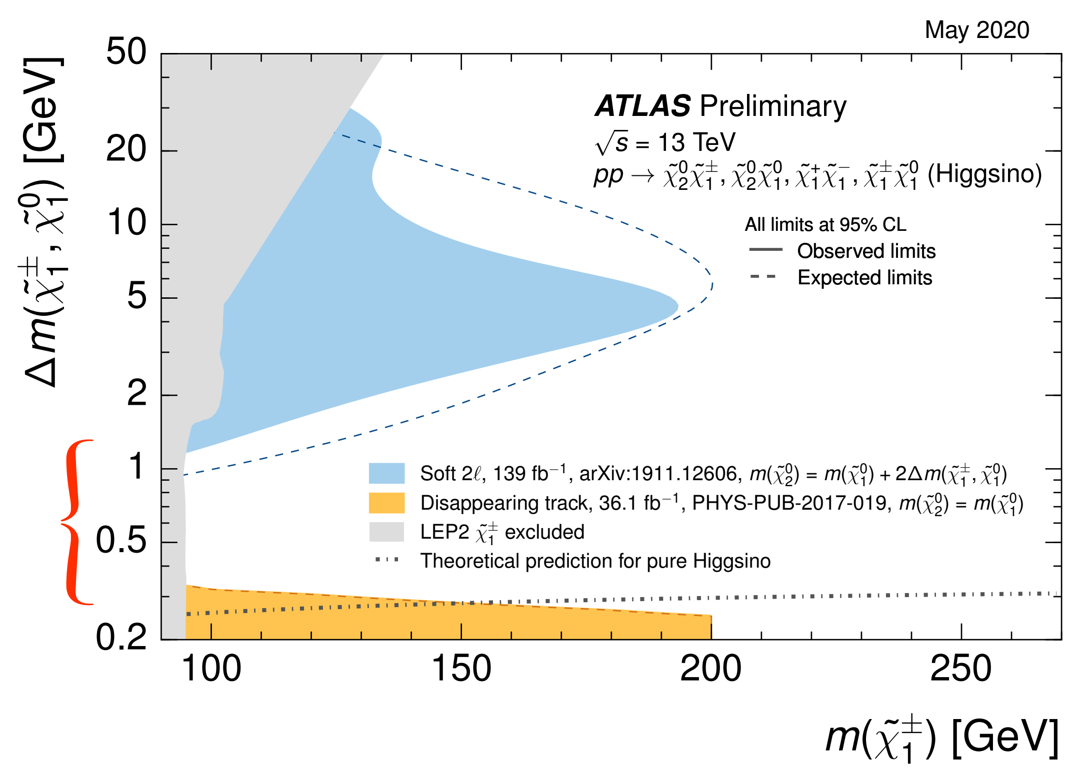
The overall number of BSM events produced will increase with integrated luminosity as well as the charge of the colliding ions. Due largely to beam losses, achievable integrated luminosities are much lower for heavier ion species. Using lighter ions such as Xe or O can provide increased luminosities at the cost of a larger probability of pileup. However, these ions will also suffer from lower electric charge.

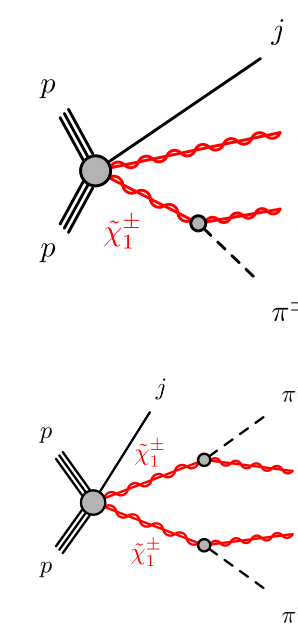
In addition, the energy cutoff for coherent photon-photon interactions $\omega_{\max}$ scales linearly with the rela-

- ∃ several cases where the best limits are from LEP
    - Especially for EWKinos
- **B-violating RPV EWKinos:**
    - No sensitivity anywhere since LEP!
- **Light higgsinos:**
    - Naturalness arguments strongly suggest that the SUSY Higgsino be light
    - The LHC has a blind spot! Small mass-splitting region very hard for LHC!
        - Very soft decay products
        - Non-zero lifetimes when very compressed
        - Both are challenging because of **backgrounds from unrelated detector activity**









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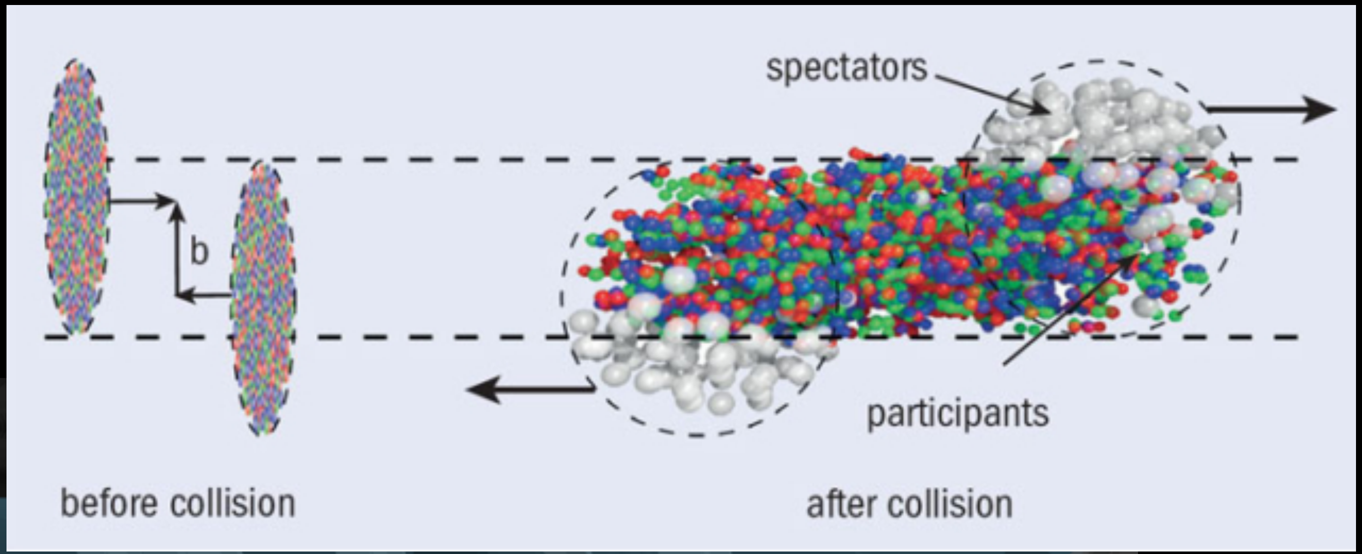
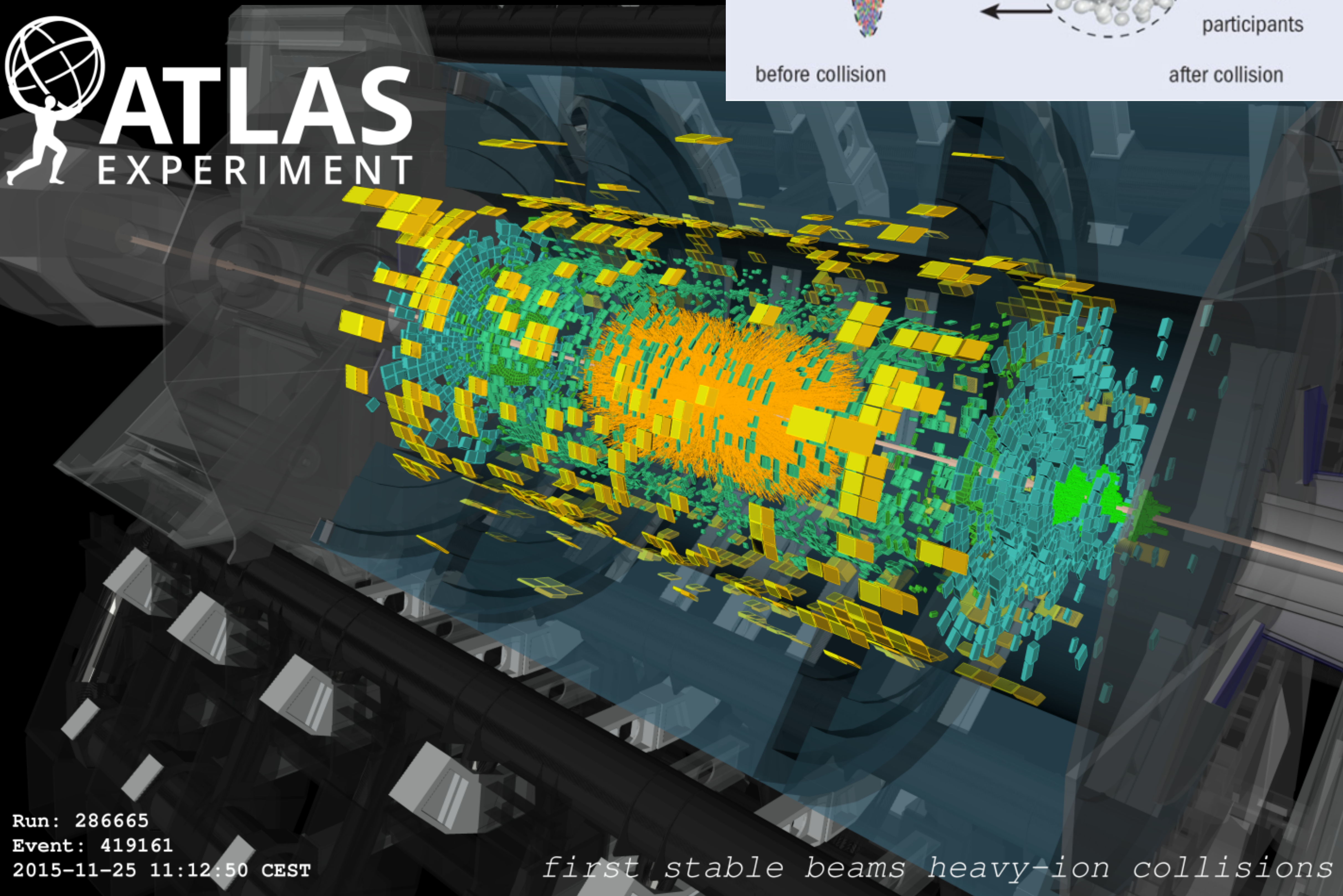
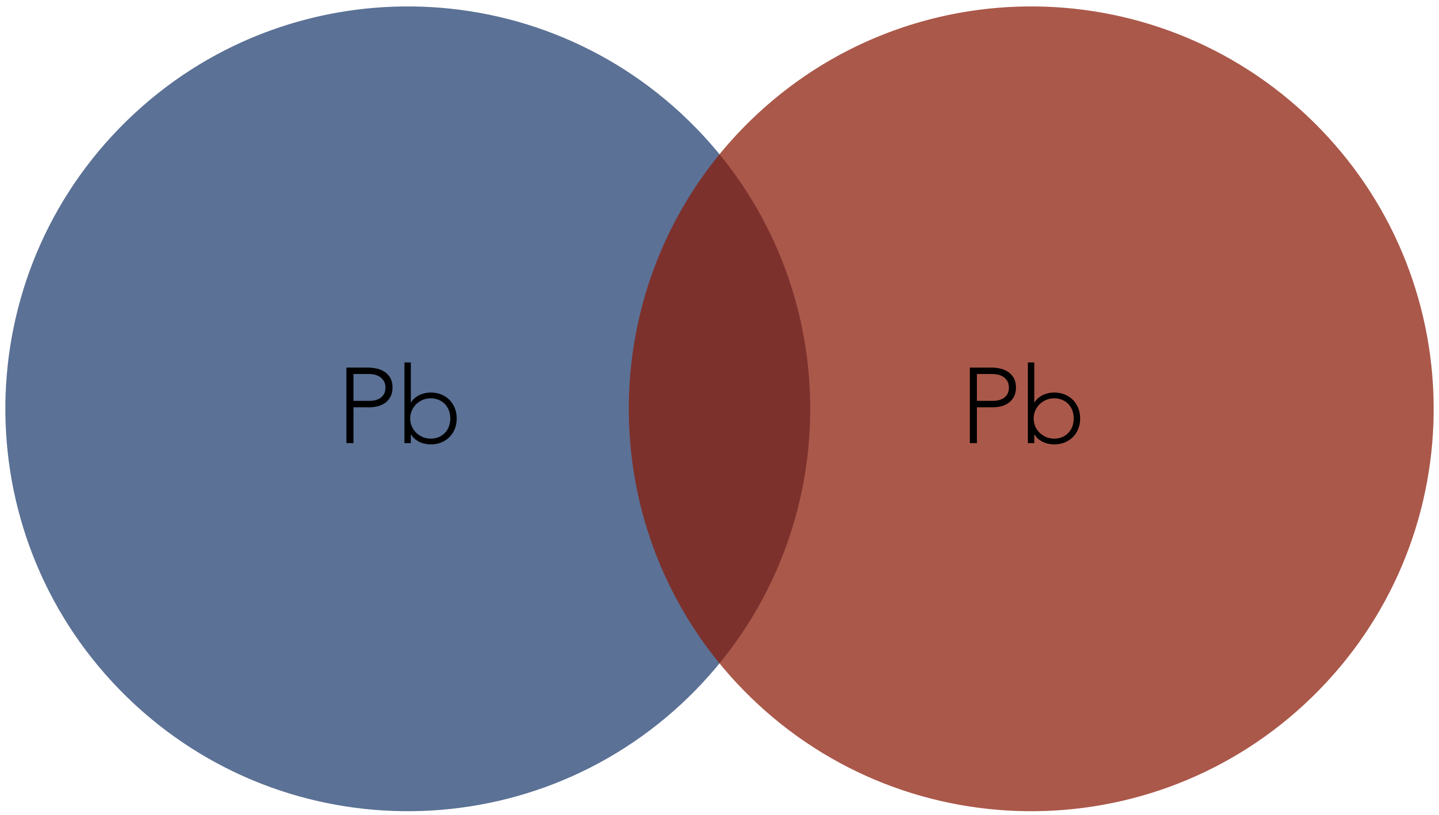

spectators
b
participants
before collision
after collision

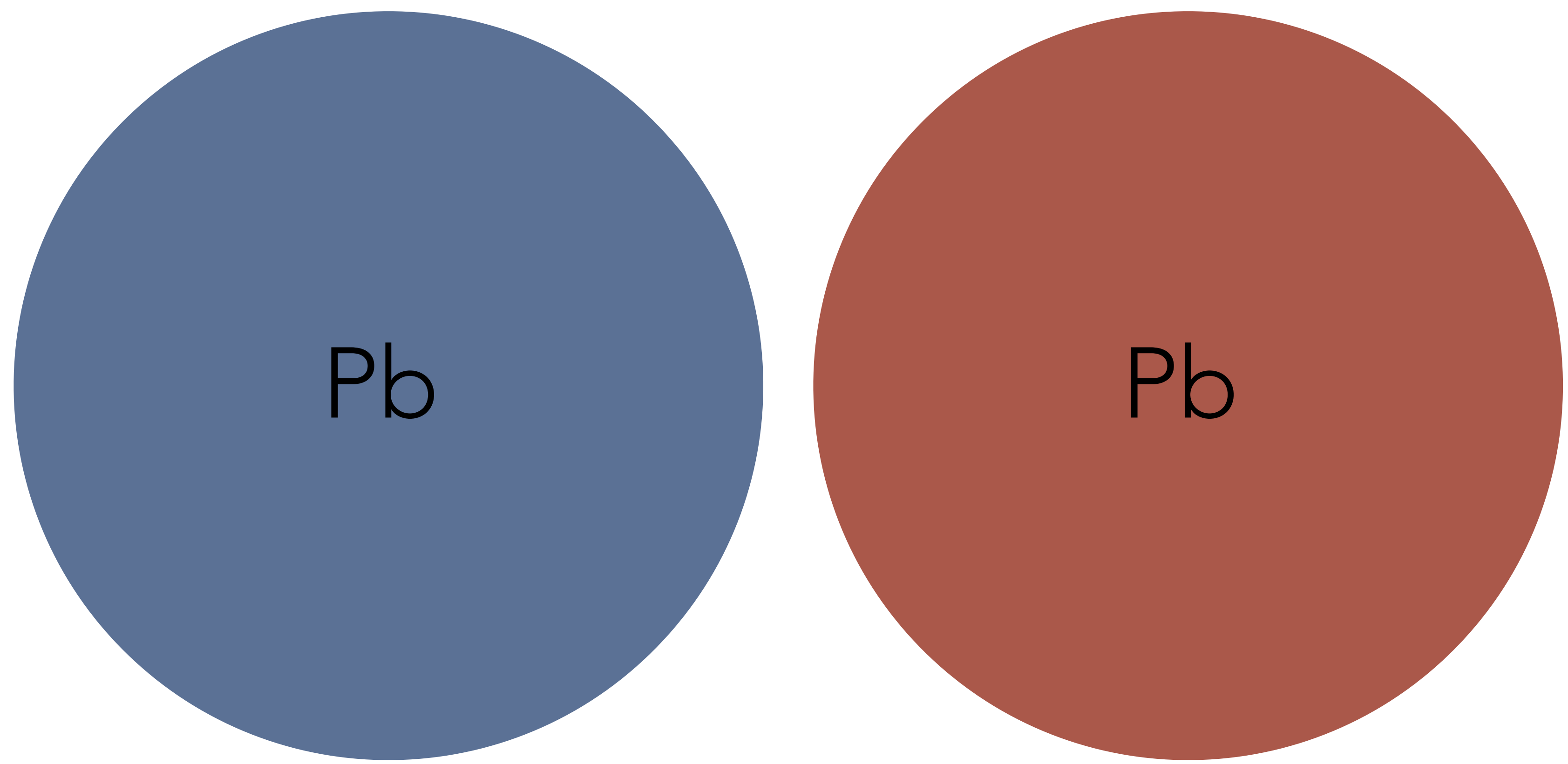

ATLAS
EXPERIMENT
Run: 286665
Event: 419161
2015-11-25 11:12:50 CEST
first stable beams heavy-ion collisions

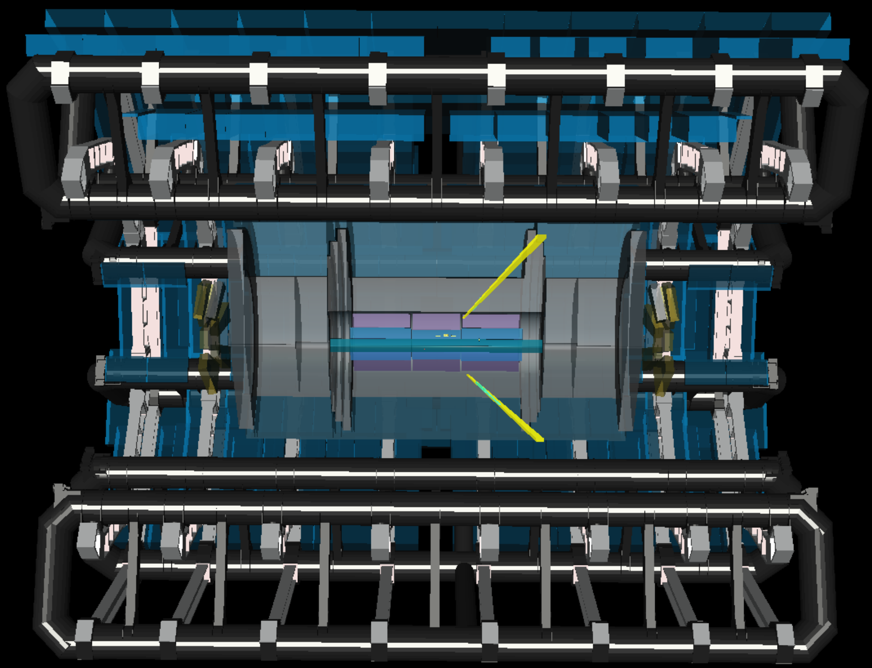


Grazing Collisions - "Peripheral"

Ultra Peripheral!

Nuclei don't really "touch" in a QCD sense. Only long-range EM interactions.





ATLAS EXPERIMENT

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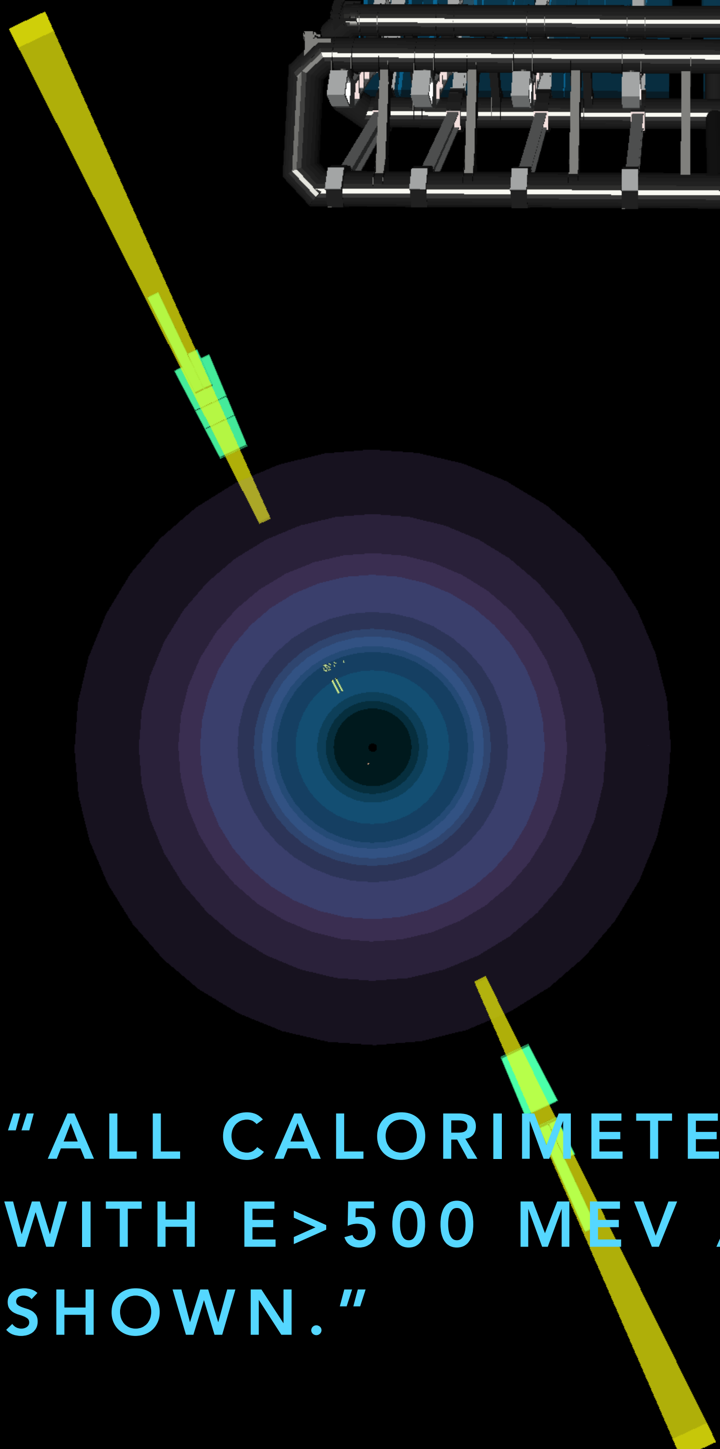
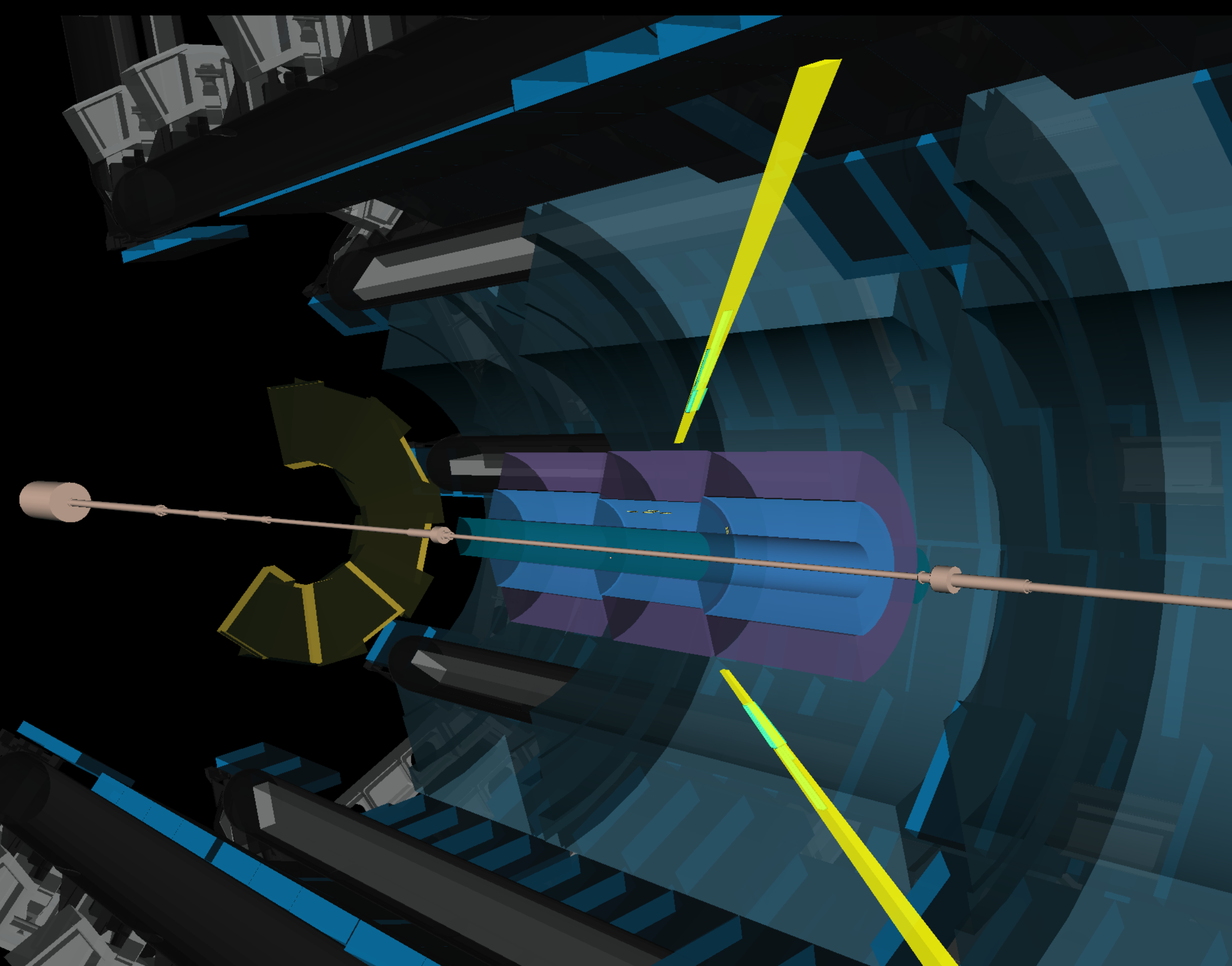
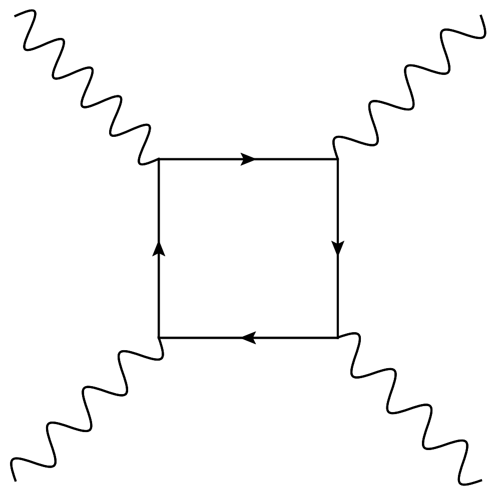
Event: 461251458
2015-12-13 09:51:07 CEST





"ALL CALORIMETER CELLS WITH E>500 MEV ARE SHOWN."

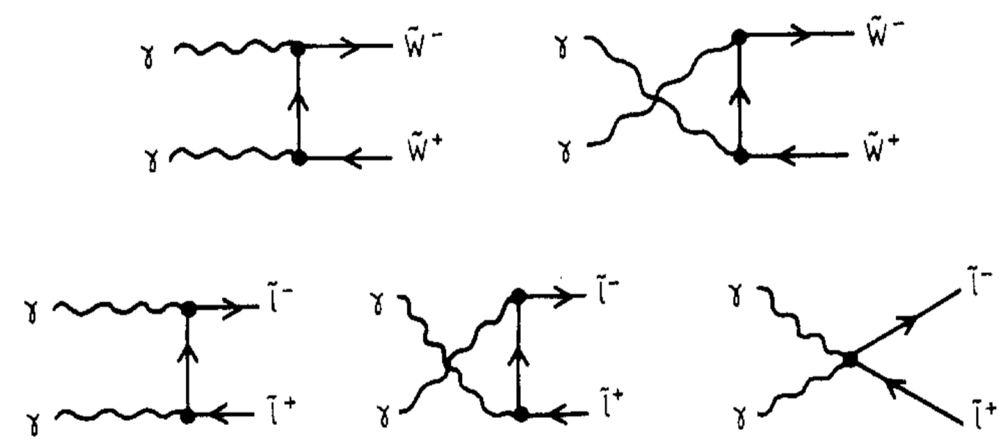


That measurement focused on light-by-light scattering process

But any particle with EM charge can be produced in these collisions!

These diagrams for Wino and slepton production

{n.b. I think since this only couples to charge, the details of the EWKino mixing don’t matter here!}



http://iopscience.iop.org/article/10.1088/0954-3899/16/2/010/pdf e.g. Photon-induced pair-production of charginos in a remarkably clean environment!

Removes reducible backgrounds that make soft-particle reco or short disappearing tracks **very** difficult!

Two main questions:

As a function of mass, collider, ion species

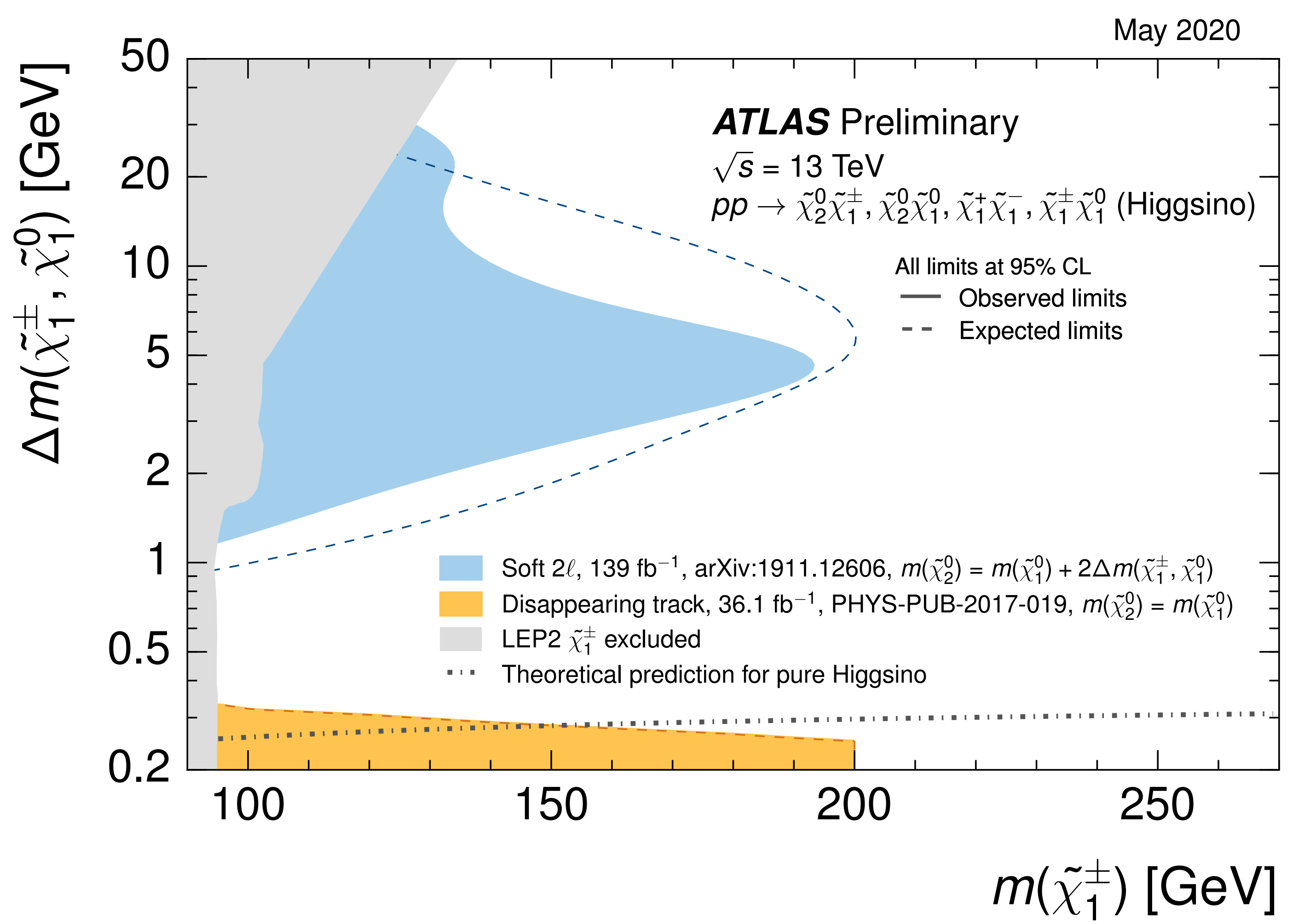
Production cross section?

Background rates/kinematics?

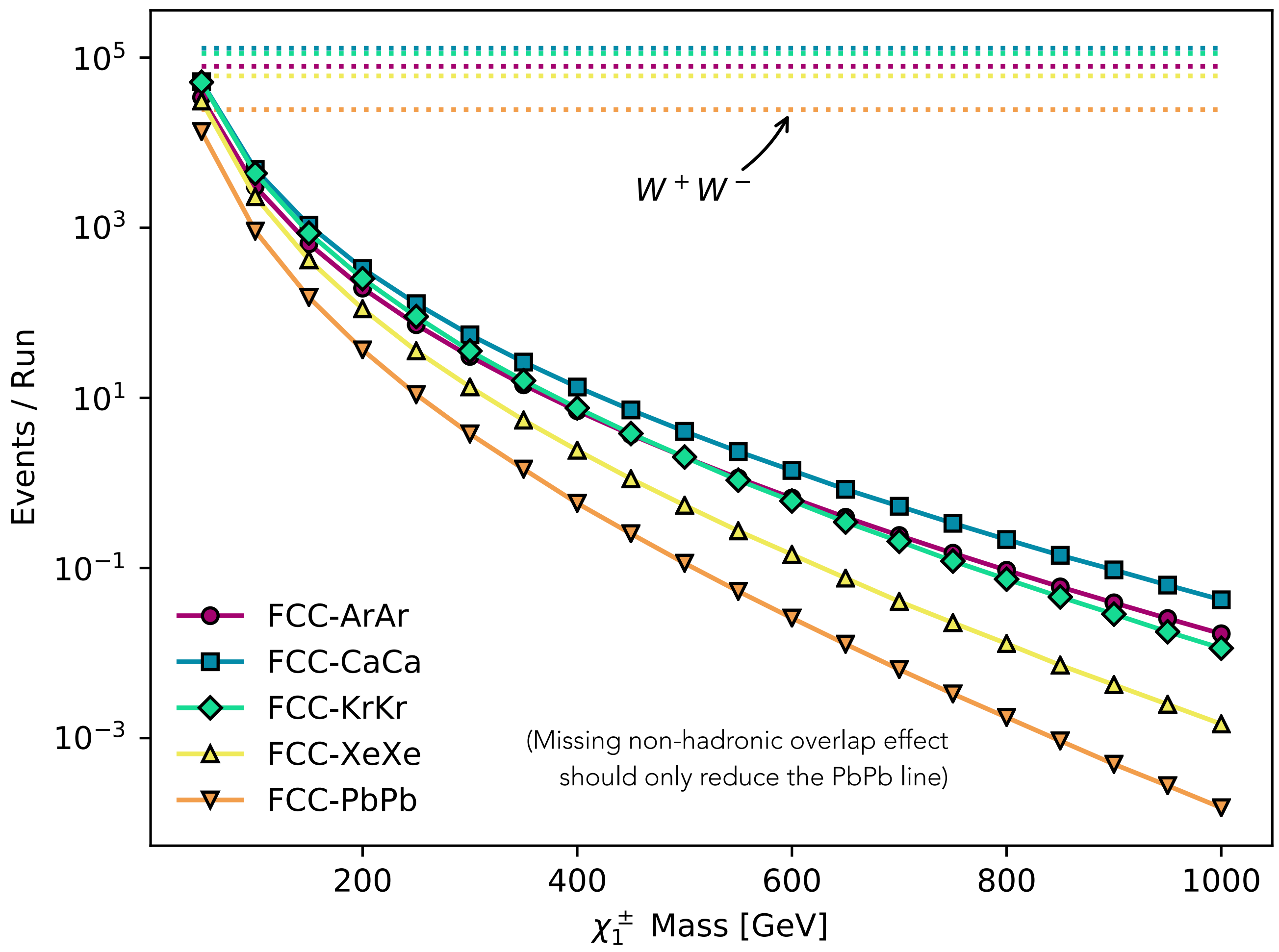
Can irreducible backgrounds be coped with?

$$\omega_{max} \sim \frac{\gamma}{1.2 \text{ fm} \times A^{1/3}}$$

- Energy cutoff (ω_{max}) limits mass reach
- Low (relativistic) gamma factor means smaller attainable energies
- **ω_{max} ~ 80 GeV at the PbPb LHC**
  - **This can't do better than LEP!**
- So to have more mass reach, we need more boosted beams
  - Bigger collider (FCC-hh)
  - Lighter ions
  - Or both!

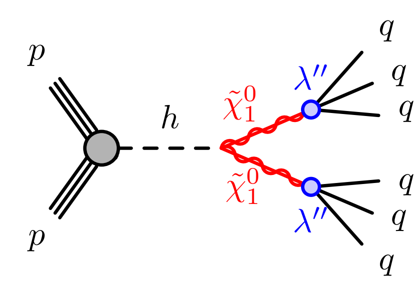


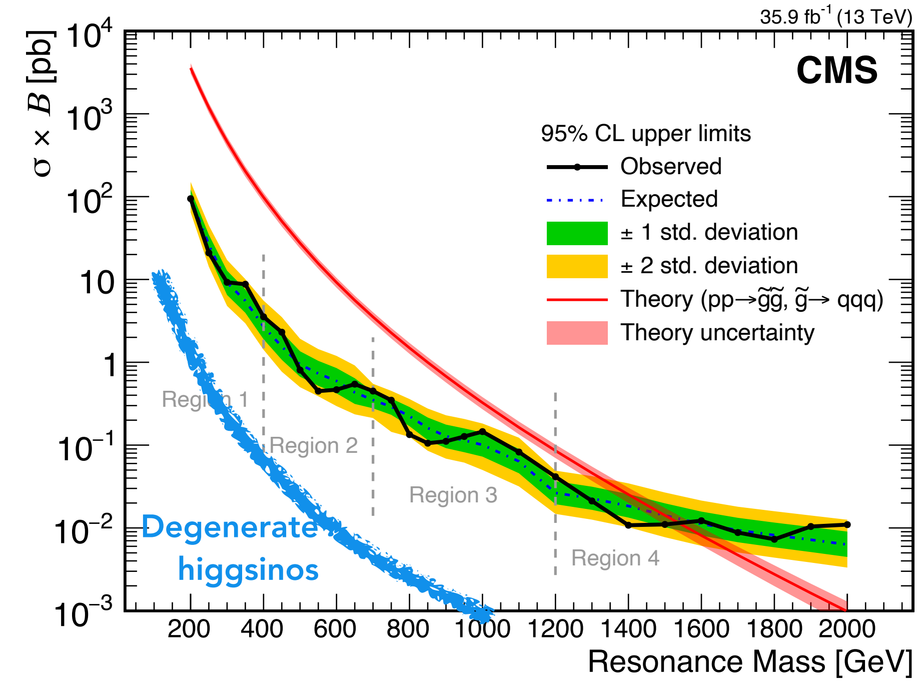
- Cross sections for photon-photon interactions scale like Z^4
  - Ca has much lower Z^4 than Pb
- But folding in the luminosities, CaCa collisions give the largest rates of chargino production **per run (i.e. per ~month)**
- 10 events per month for 400 GeV charginos
  - Out of reach for e.g. ILC500 or FCC-ee

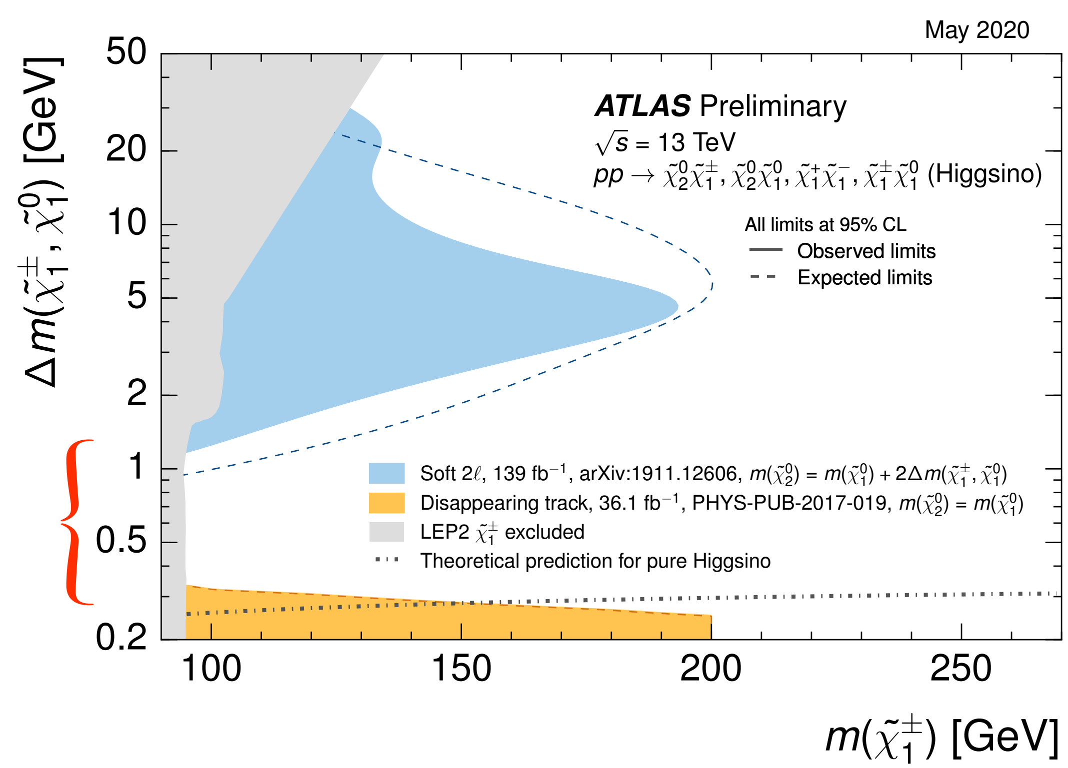


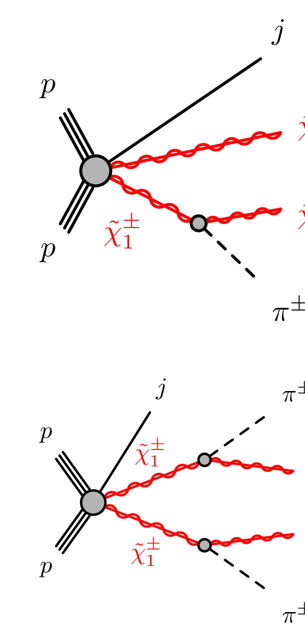
Major guidance and technical help from David d'Enterria

- We aim to further study production cross sections
- Moving now to Delphes-based kinematic studies for handling irreducible backgrounds
  - tau-tau production will probably look very much like the higgsino case
  - Clean environment may be perfect for all-hadronic RPV chargino decays.
    - ttbar probably dominates!



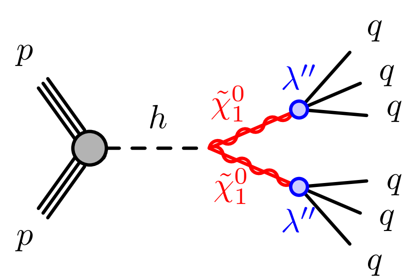


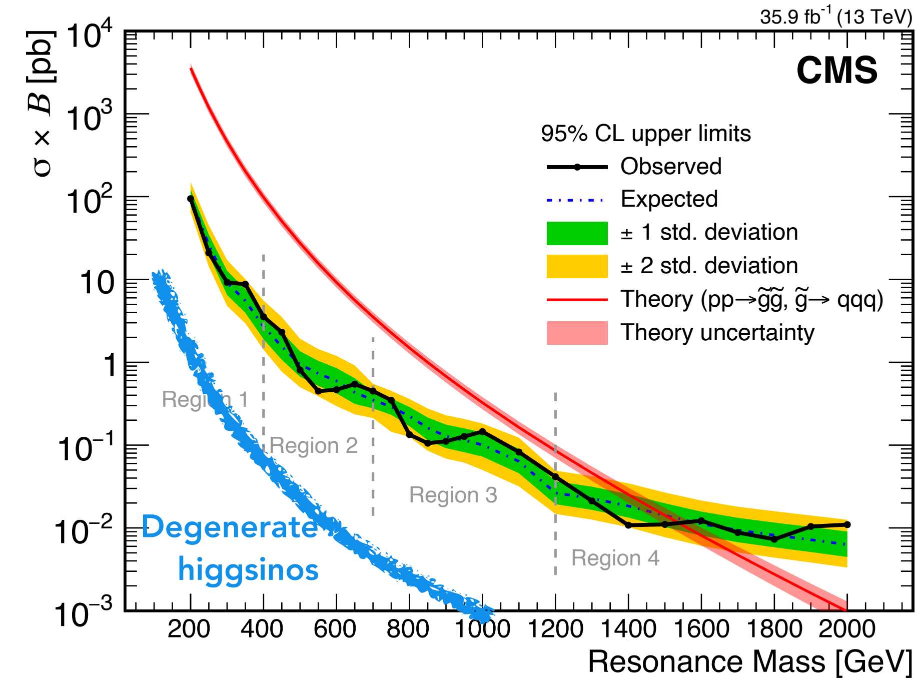


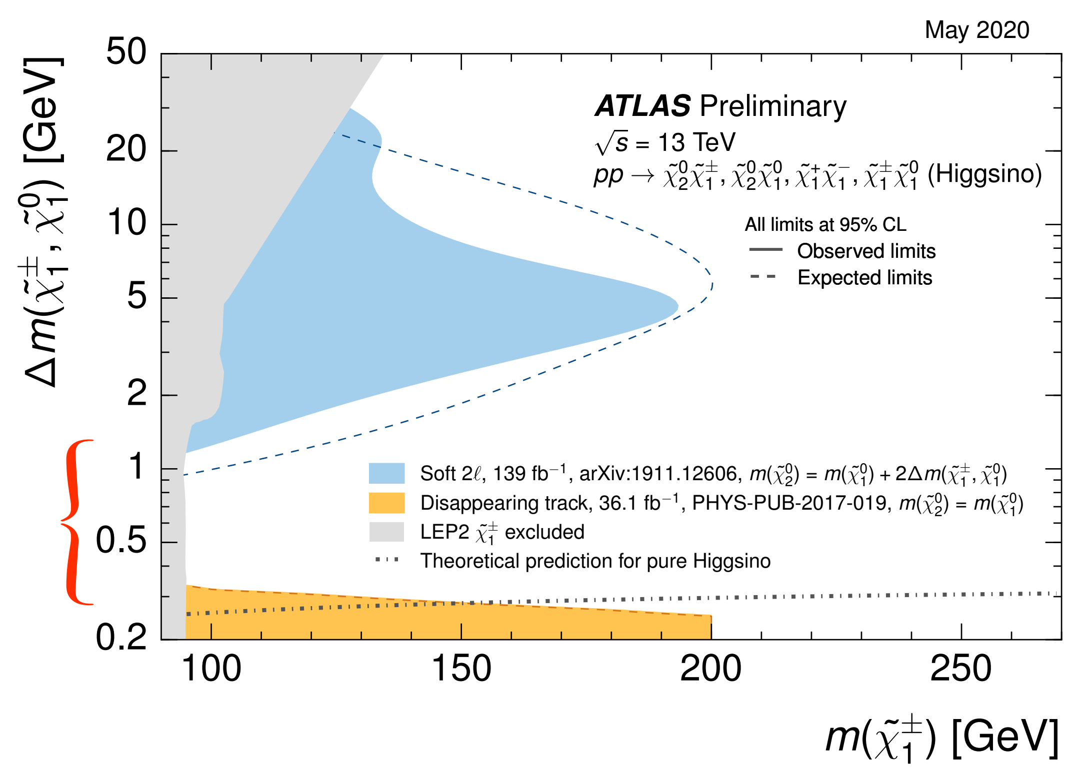


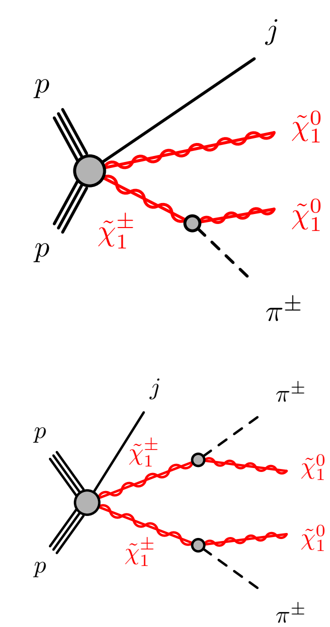
etc…

- We aim to be able to produce sensitivity curves (hopefully) in higgsino and RPV summary plots
- Would fit into:
  - Compressed EWK pMSSM
  - RPV Benchmarks
- We are not seeking central datasets from the MC taskforce since these are weird samples
  - But we'd like to use common param cards as much as possible
  - (What's the best way for us to get those?)

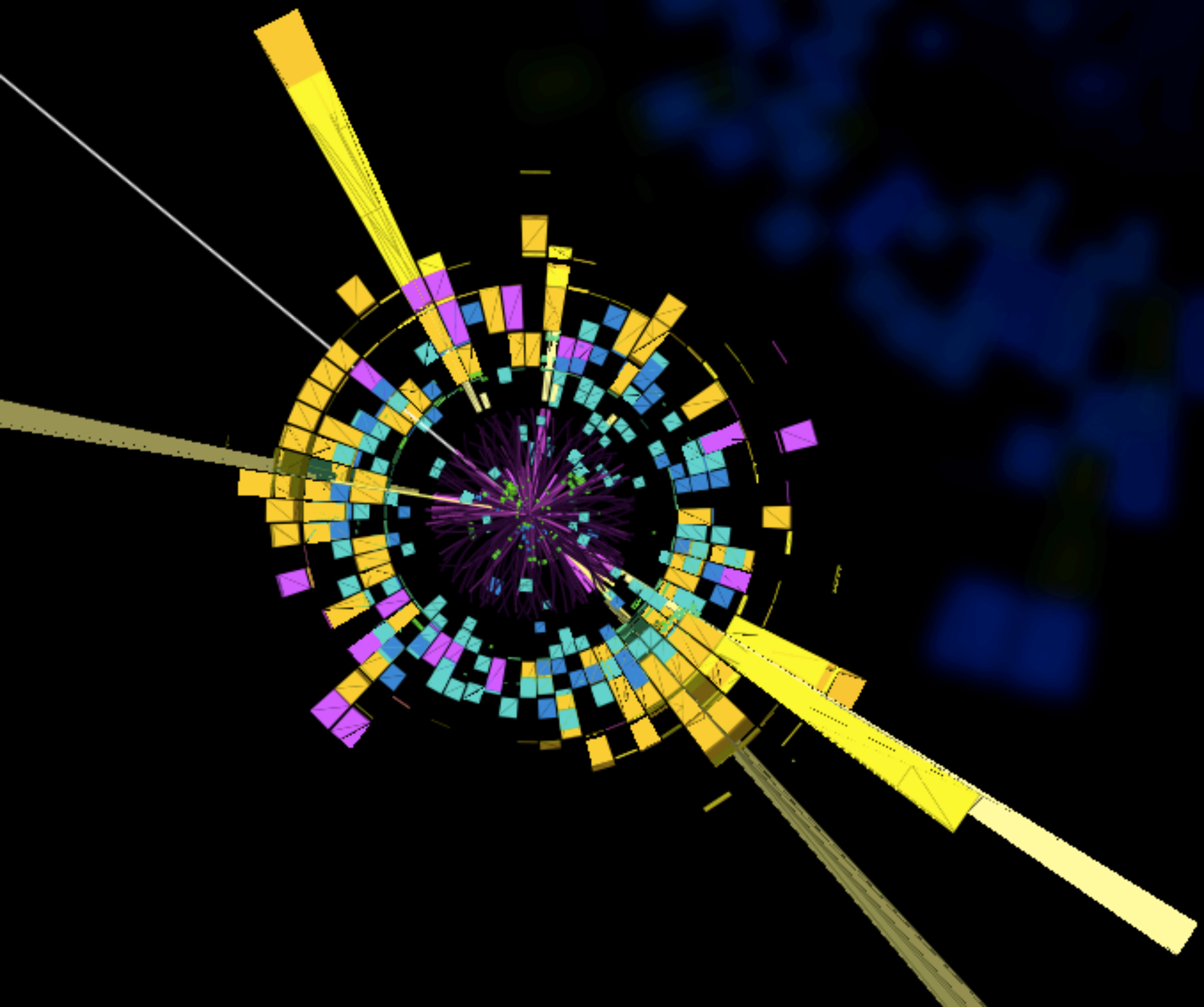








etc…



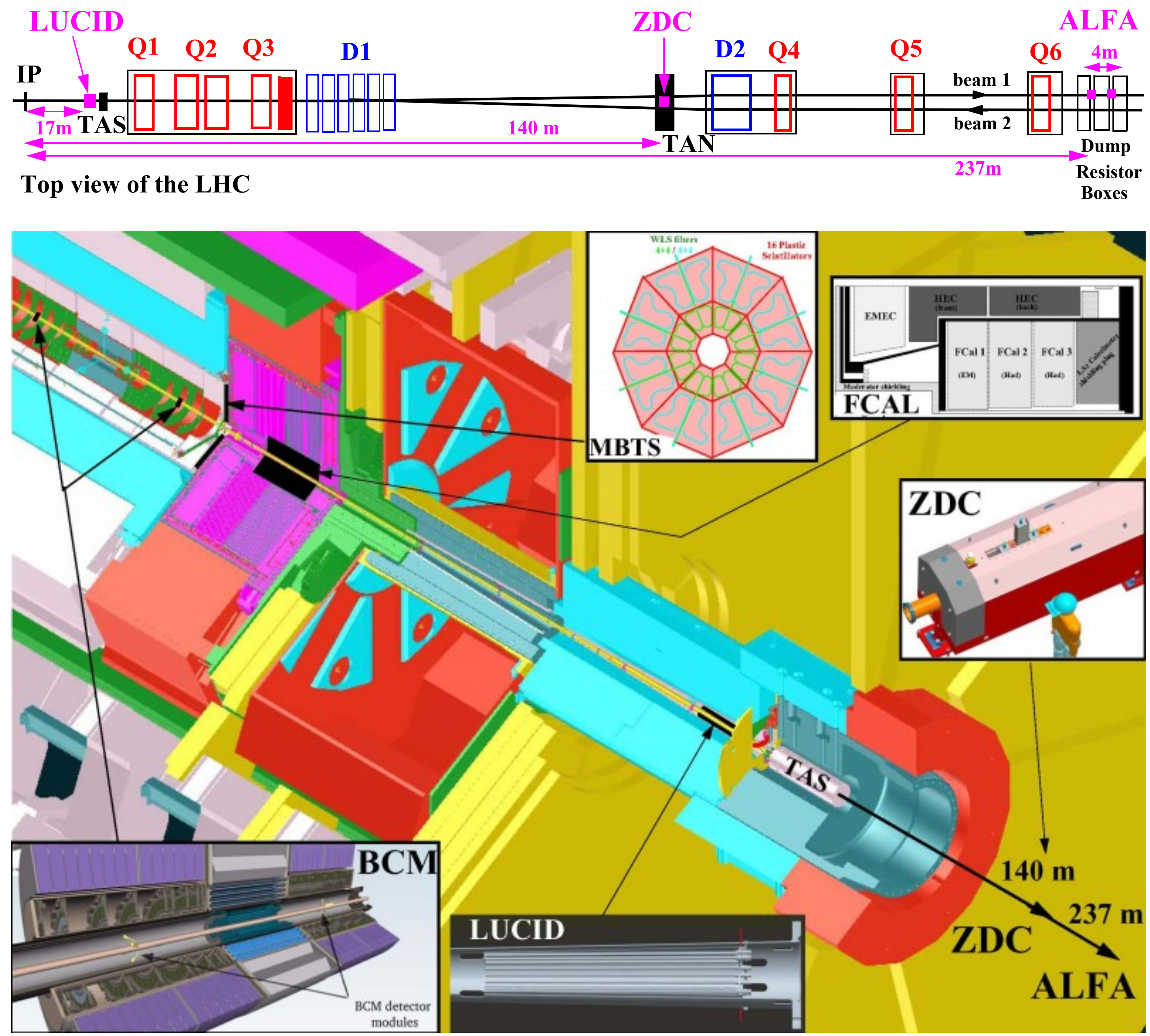
Backup

BEYOND CROSS-SECTION

- I expect the big challenge will be to reduce the background by a few orders of magnitude
- Focusing on decays of chargino→W+neutralino
- Focus on hadronic W decays to maximize BR
- For large mass splittings (on-shell Ws):
  - All-hadronic WW should be nicely balanced in transverse plane
  - Signal should have significantly non-zero MET-significance
- For small mass splittings (~100s MeV) as favored in pure higgsino scenarios
  - Likely the big background will become tau-tau production
  - May be useful to study how LEP handled this in their chargino searches

TRIGGERS

- Triggers are really interesting for UPCs!
- ~30% of these photon interactions will free a neutron from the nucleus at infinite eta
  - ATLAS has zero-degree calorimeters (ZDCs) after the beams are separated
  - Look for energy deposition in ZDCs but veto on Minimum Bias Trigger Scintillators (MBTS) activity
- Enables very loose triggers on central objects



- From the YR [1812.06772]…
- Kr or Ca could have much more lumi than Pb
- Pb beams have a short lifetime. Lighter species would be able to run longer giving even larger gains in integrated lumi
- Therefore, some weeks spinning Kr could have the same photon lumi with much higher mass reach

	$^{16}O^{8+}$	$^{40}Ar^{18+}$	$^{40}Ca^{20+}$	$^{78}Kr^{36+}$	$^{129}Xe^{54+}$	$^{208}Pb^{82+}$
γ	3760.	3390.	3760.	3470.	3150.	2960.
$\sqrt{s_{NN}}$/TeV	7.	6.3	7.	6.46	5.86	5.52
σ_{had}/b	1.41	2.6	2.6	4.06	5.67	7.8
σ_{BFPP}/b	2.36×10^{-5}	0.00688	0.0144	0.88	15.	280.
σ_{EMD}/b	0.0738	1.24	1.57	12.2	51.8	220.
σ_{tot}/b	1.48	3.85	4.18	17.1	72.5	508.
N_b	1.58×10^{10}	3.39×10^{9}	2.77×10^{9}	9.08×10^{8}	4.2×10^{8}	1.9×10^{8}
ϵ_{xn}/μm	2.	1.8	2.	1.85	1.67	1.58
f_{IBS}/(m Hz)	0.168	0.164	0.184	0.18	0.17	0.167
W_b/MJ	175.	84.3	76.6	45.2	31.4	21.5
$L_{AA0}/\mathrm{cm}^{-2}s^{-1}$	9.43×10^{31}	4.33×10^{30}	2.9×10^{30}	3.11×10^{29}	6.66×10^{28}	1.36×10^{28}
$L_{NN0}/\mathrm{cm}^{-2}s^{-1}$	2.41×10^{34}	6.93×10^{33}	4.64×10^{33}	1.89×10^{33}	1.11×10^{33}	5.88×10^{32}
P_{BFPP}/W	0.0199	0.601	0.935	11.	60.6	350.
P_{EMD1}/W	32.	55.6	52.2	78.3	107.	141.
τ_{L0}/h	6.45	11.6	13.1	9.74	4.96	1.57
T_{opt}/h	5.68	7.62	8.08	6.98	4.98	2.8
$\langle L_{AA}\rangle$ cm^{-2}s^{-1}	4.54×10^{31}	2.45×10^{30}	1.69×10^{30}	1.68×10^{29}	2.95×10^{28}	3.8×10^{27}
$\langle L_{NN}\rangle$ cm^{-2}s^{-1}	1.16×10^{34}	3.93×10^{33}	2.71×10^{33}	1.02×10^{33}	4.91×10^{32}	1.64×10^{32}
$\int_{month} L_{AA}$ dt/nb^{-1}	5.89×10^{4}	3180.	2190.	218.	38.2	4.92
$\int_{month} L_{NN}$ dt/pb^{-1}	1.51×10^{4}	5090.	3510.	1330.	636.	213.
R_{had}/kHz	1.33×10^{5}	1.12×10^{4}	7540.	1260.	378.	106.
μ	10.6	0.893	0.598	0.1	0.03	0.00842

FROM THE YR [1812.06772]...

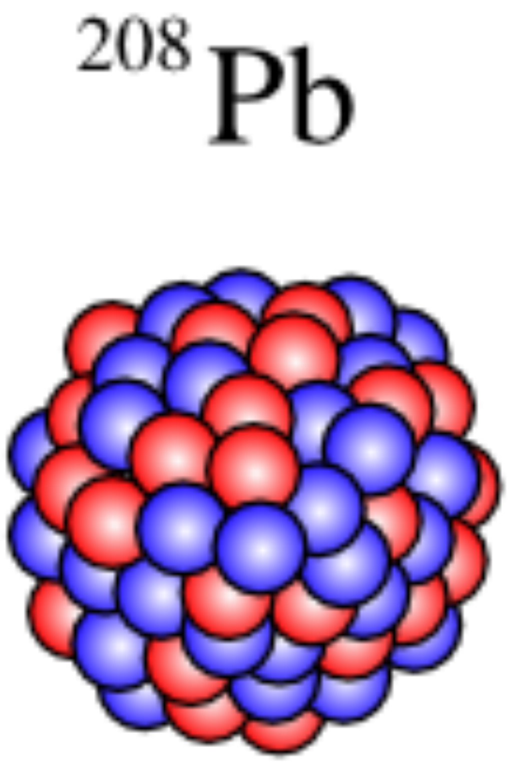
Based on this requirements, the proposed updated running schedule is reported in the following table. It can be seen that the physics programme for Run 3 and Run 4 discussed in this report is achievable by a modest increase of the "heavy-ion running" time from 12 to 14 weeks per run.

Year	Systems, $\sqrt{s_{\mathrm{NN}}}$	Time	L_{int}
2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 $\mu\mathrm{b}^{-1}$ and 200 $\mu\mathrm{b}^{-1}$
2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
	pp reference	1 week	

Not likely that the HI community would support anything other than Pb, p, and a tiny but of O

... until Run 5! Already considering a long run of another species. It would be interesting to understand if SUSY-needs could influence this decision (i.e. how much do they care that it's Ar instead of Kr, or whatever)

A NOTE ABOUT LUMI



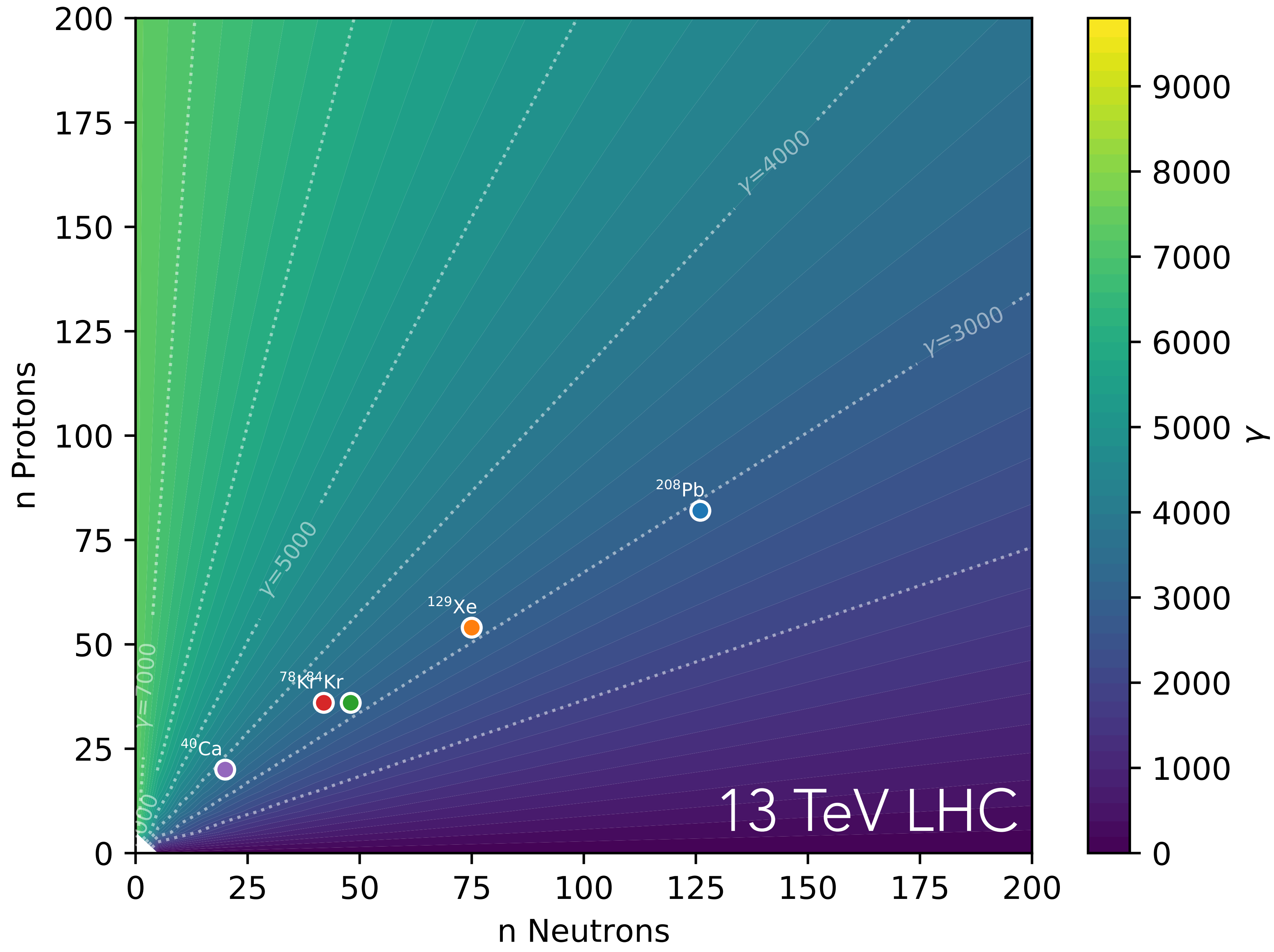
- ~O(inb) sounds like a tiny amount of data
- **But photon-photon luminosities grow as Z^4**
  - **For PbPb, this is a factor of 82^4 ~ 45 Million!**
  - Huge effective luminosities (1 inb x 1e7 ~ "10 ifb")

$Z = 82$

$Z^4 \sim 1e7$

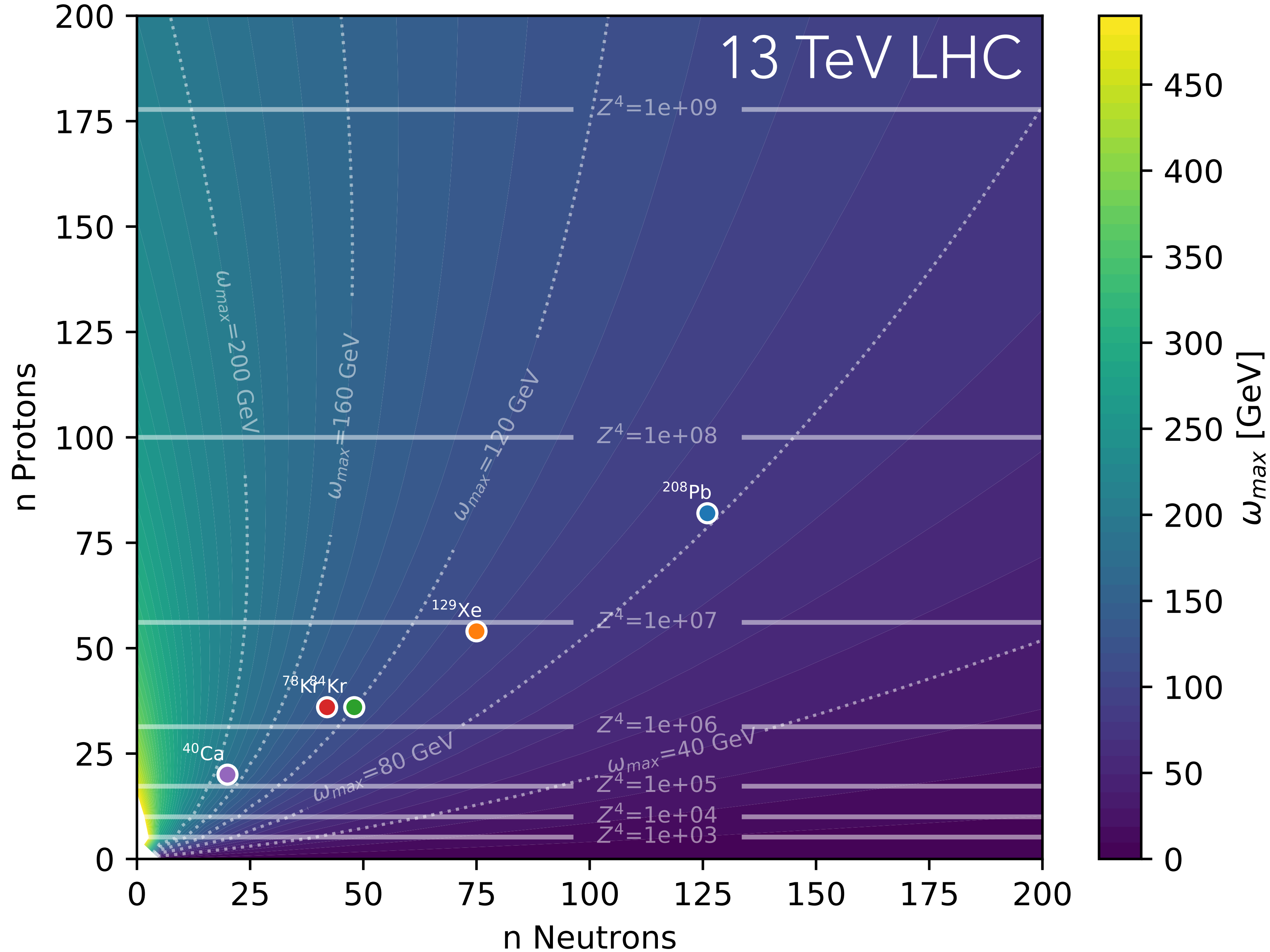
$$\omega_{max} \sim \frac{\gamma}{1.2\ \mathrm{fm} \times A^{1/3}}$$

- What about other ion species…
- Can we find a particle we can throw faster?



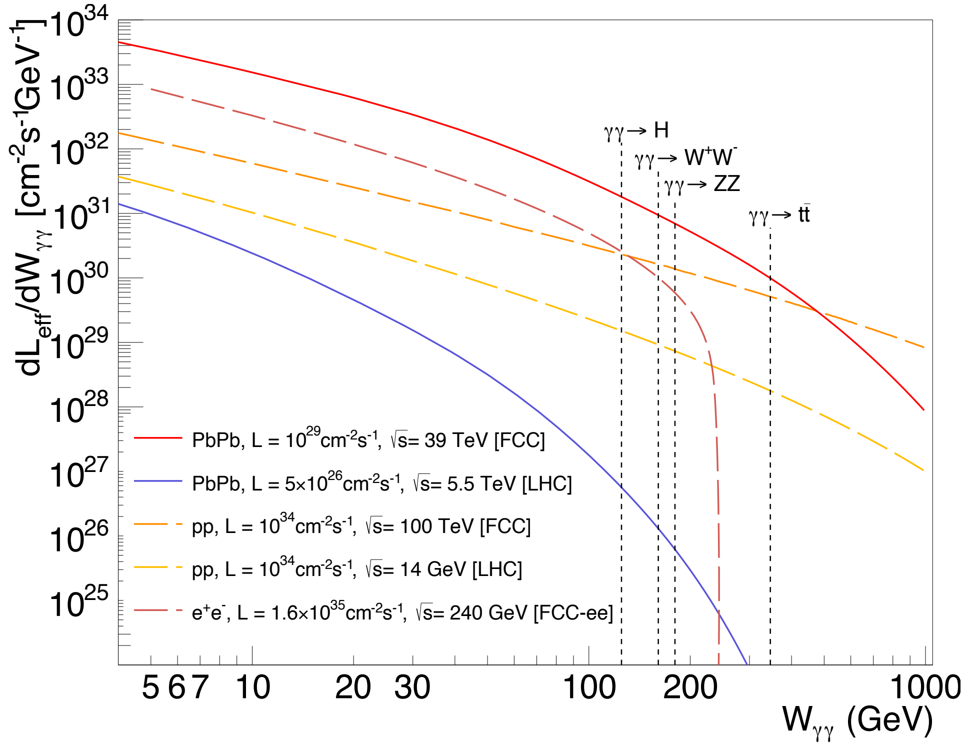
We want a ~stable nucleus with:
as many protons as possible (to increase Z^4)
and as few neutrons as possible (to increase gamma)

- Drawing Z^4 values and ω_{max}
- e.g. ^{78}Kr:
    - 50% more omega_max than ^{208}Pb
    - ~20-30x less Z^4 scaling
    - Maybe compensated with larger inst lumi
- Important to scan mass reach of various nuclei



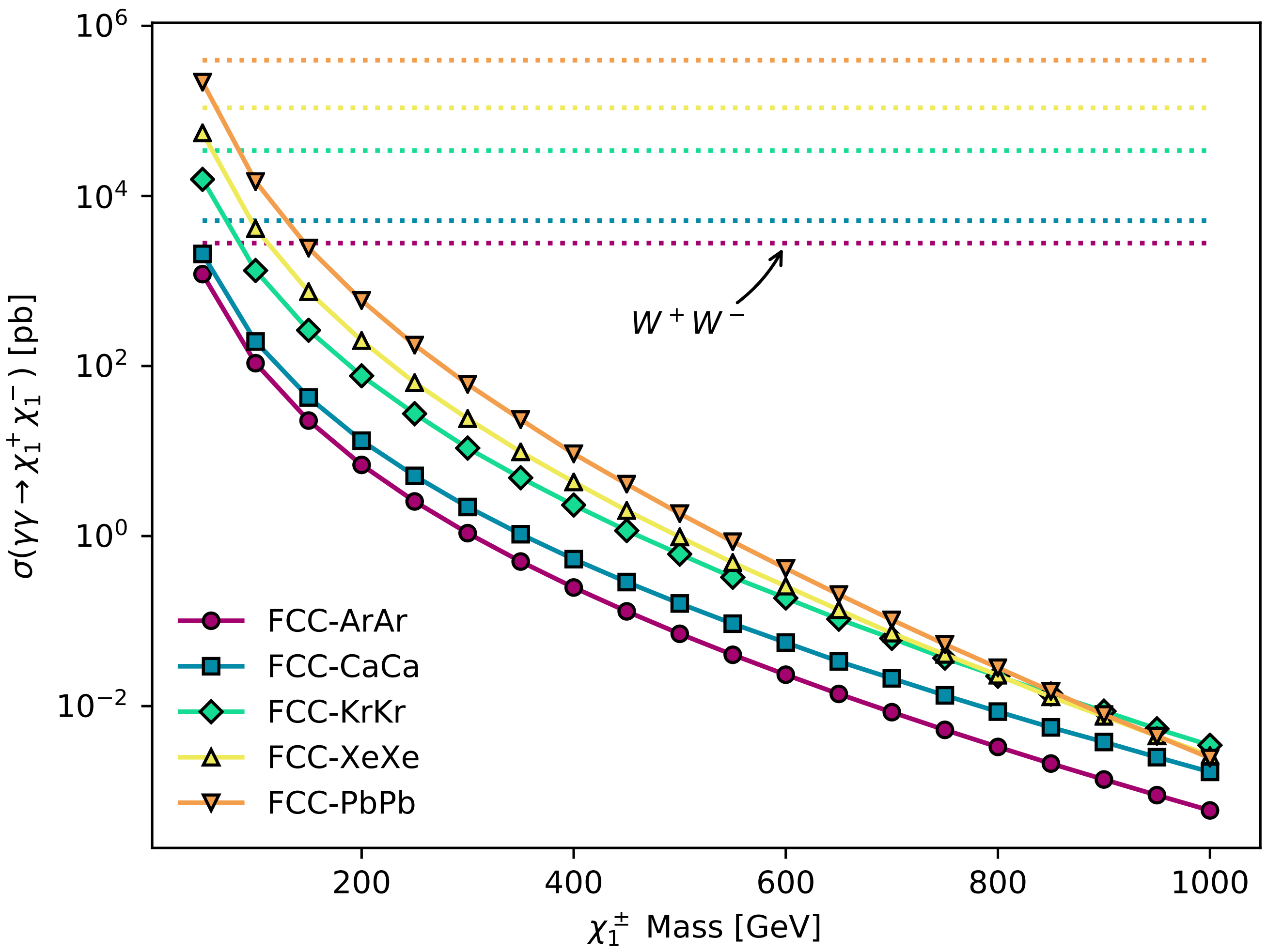
- We’re interested in mapping out EWKino sensitivity of future colliders in UPCs
  - Calculations could be done for generic (electrically) charged fermions
  - Requires playing with some generators, thinking about the parameters of these future colliders {ion type, energy, lumi}

https://indico.cern.ch/event/604619/attachments/1450211/2884812/Proceedings_of_the_PHOTON_2017_Conference.pdf



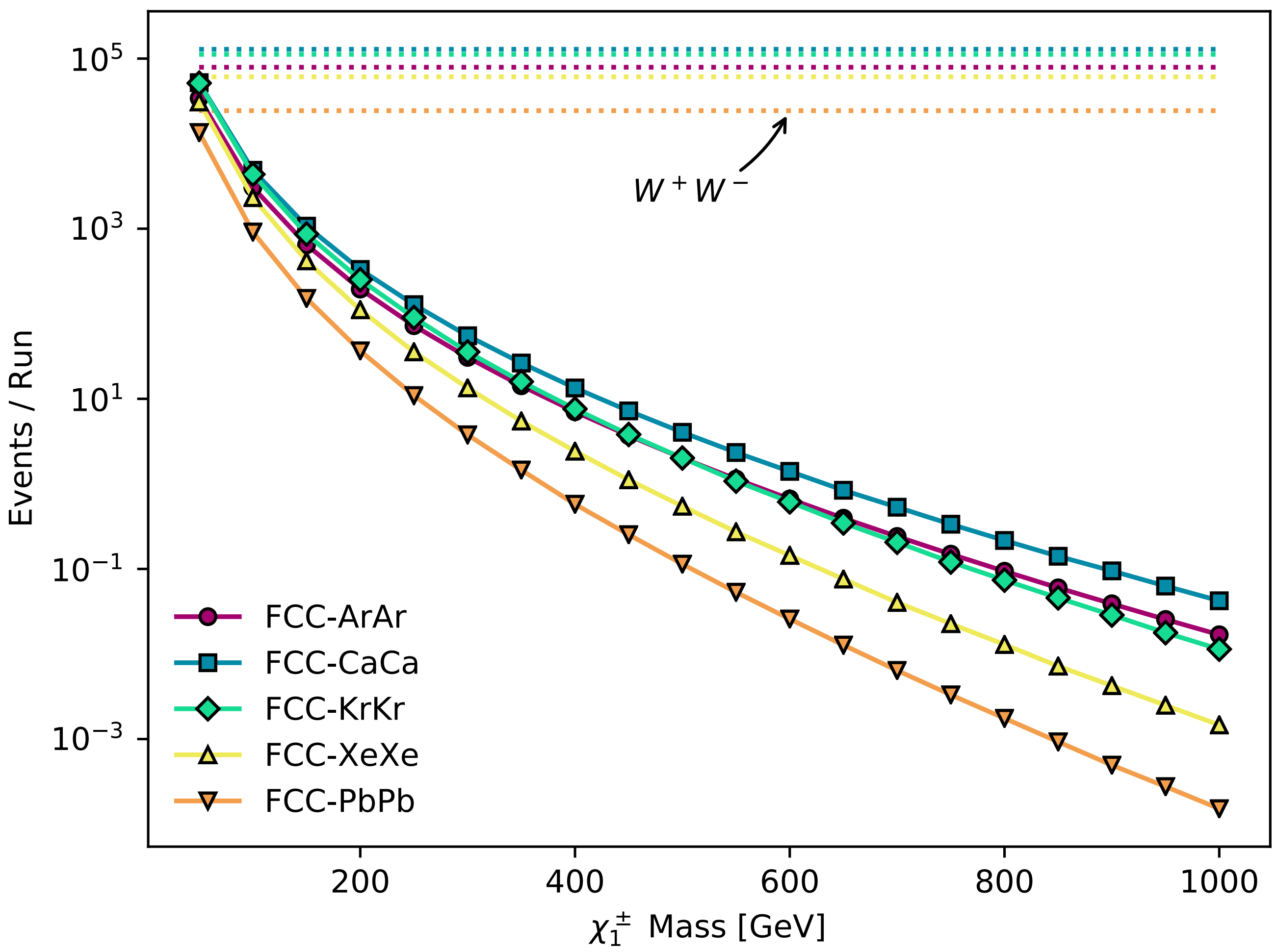
CHARGINO PRODUCTION

- Major guidance and technical help from David d'Enterria
- Calculating leading-order cross-sections as a function of ion species and chargino mass
    - For now — Only FCC-hh
- Comparing to WW production rate for reference
- As expected, PbPb has largest cross section from significantly larger Z^4 scaling
    - PbPb cross sections should be reduced by an additional non-hadronic overlap correction. **Not applied here.**



ACCOUNTING FOR LUMI

- But if lighter ions can
  - Reach larger masses because of increased ω_{max}
    - Smaller slope of XS vs chargino mass
  - Reach much larger luminosities. Taking numbers from YR.
- Folding in the projected integrated luminosities, CaCa collisions give the largest rates of chargino production **per run**
- **Missing non-hadronic overlap effect should only reduce the PbPb line**



Ion Species Optimization

- Scanning over ion species for fixed chargino mass
  - **CaCa is clearly favored**
- Two effects not considered here:
  - For very light nuclei (around ArAr) pileup starts to become an issue
  - For very heavy ions (PbPb), non-hadronic overlap corrections further reduce cross section