

**Heavy Ions and Hidden Sectors**

Dec. 4-5, 2018

**Concluding Remarks**

Andrea Giammanco, CP3

# Disclaimers

- This is not a summary
  - Biased selection
  - Take it just as my workshop-inspired flux of consciousness
- Not every speaker will be cited
  - (but I cite the source talk to help a-posteriori navigation to the original discussion)

# Why is it interesting to use Heavy Ions for new physics?

■ Heavy-ions collisions have 2 important drawbacks:

- Low sqrt(s): PbPb runs at 5.5 TeV compared to 14-TeV pp [ $\times 2.5$  less]
  - Low lumis:  $L_{\text{PbPb}} = A^2 \cdot 6 \cdot 10^{27} \text{ cm}^{-1}\text{s}^{-2} = 2.5 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1} \ll L_{\text{pp}} = 2 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  [ $\times 100$  less]
- [integrated:  $\times 10^3$  less]

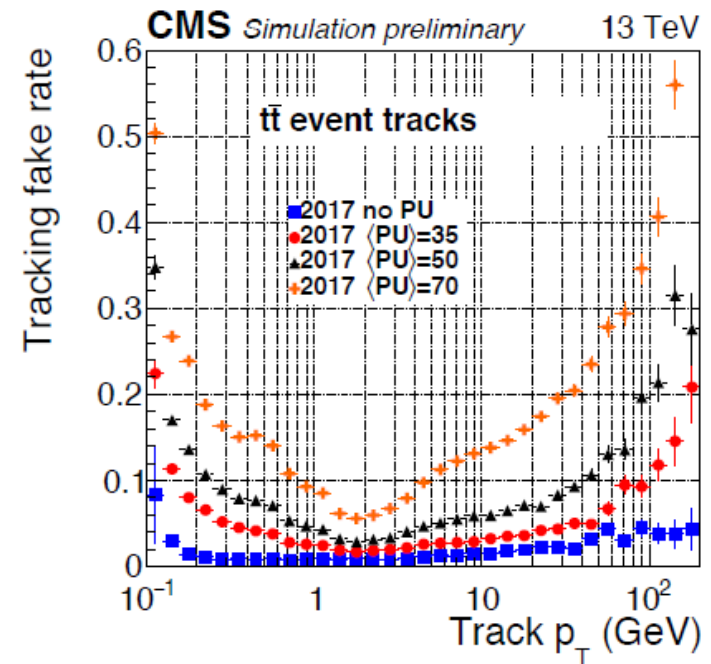
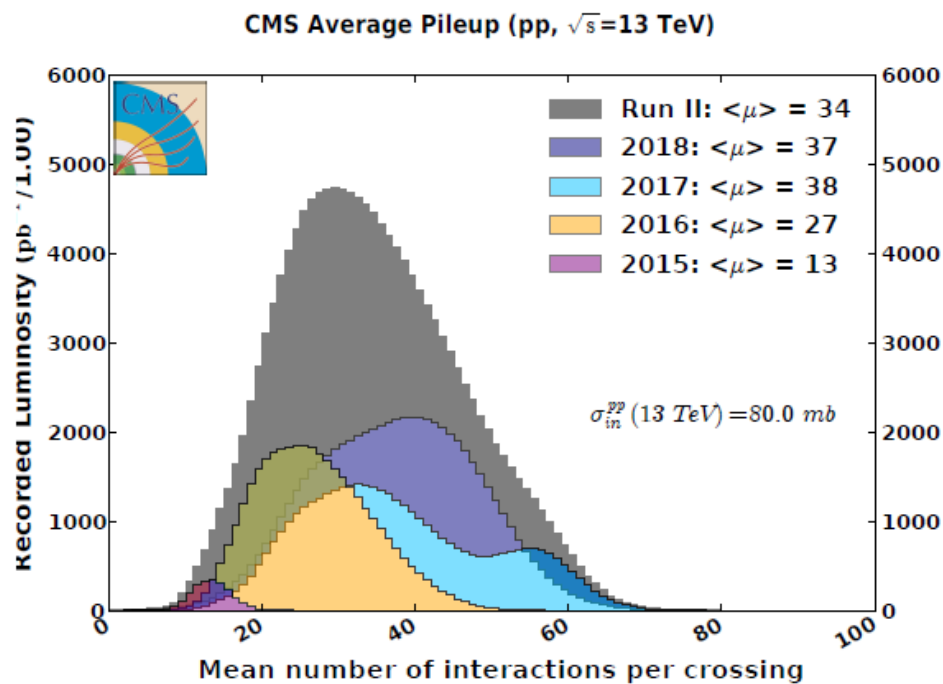
■ Heavy-ions collisions have 2 advantages:

- No pileup: Excellent vertexing, Lower kin. trigger thresholds [ $\times 2?$  lower  $p_T$  values]
- Large  $\gamma$  lumis:  $L_{\text{pbPb}}(\gamma)/L_{\text{pp}}(\gamma) = Z^4 \times L_{\text{pbPb}}/L_{\text{pp}} = 4.5 \cdot 10^7 \times (6 \cdot 10^{27}/2 \cdot 10^{34}) \sim 12$  [ $\times 10$  more]

David D'Enterria

# Pileup sorrows (in pp runs)

– No pileup: Excellent vertexing, Lower kin. trigger thresholds [ $\times 2?$  lower  $p_T$  values]



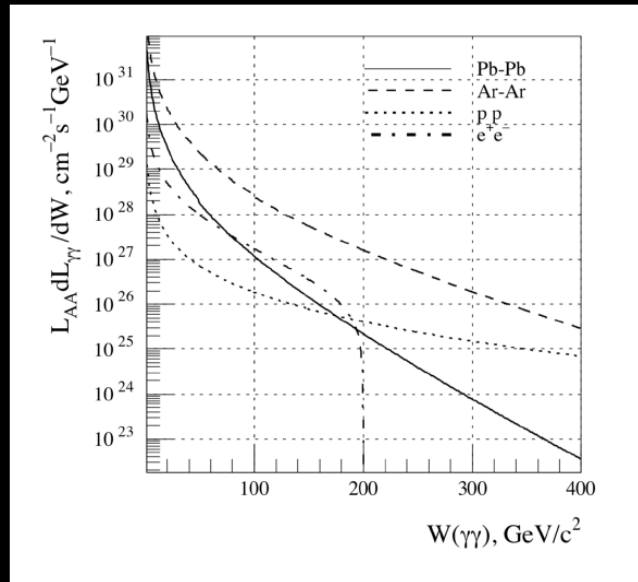
Jessica Prisciandaro

# When is it interesting to use Heavy Ions for new physics?

Simon Knapen

## Future directions? (I)

(Or “why I didn’t write more papers”)



The pdf falls like a rock

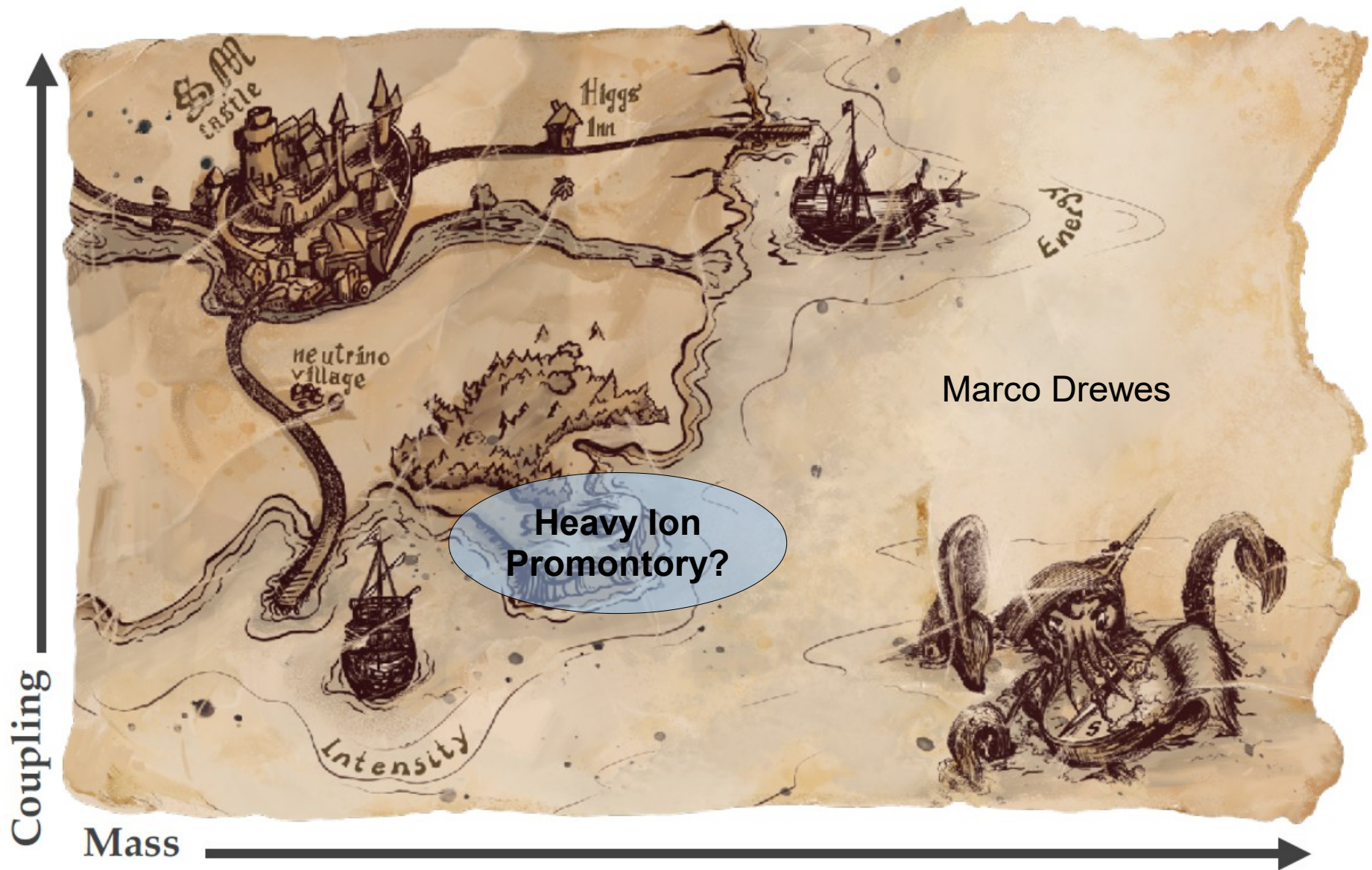
You have to be light-ish AND only pay small parameter once

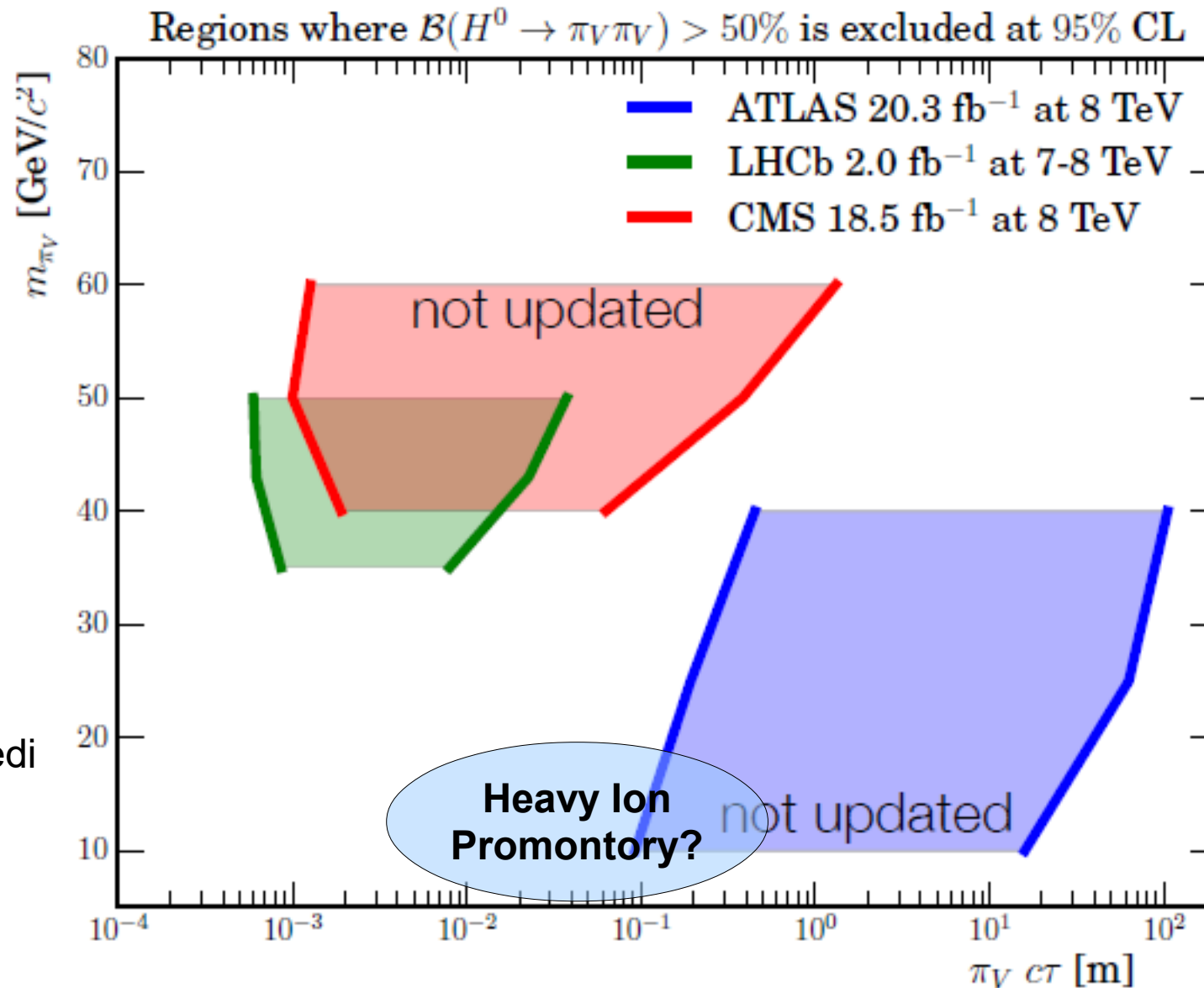
Baur et. al. 0112211

Checked: chargino's, dark photons, milicharged particles, ...

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# WHERE IS THE NEW PHYSICS HIDING?





Federico Redi

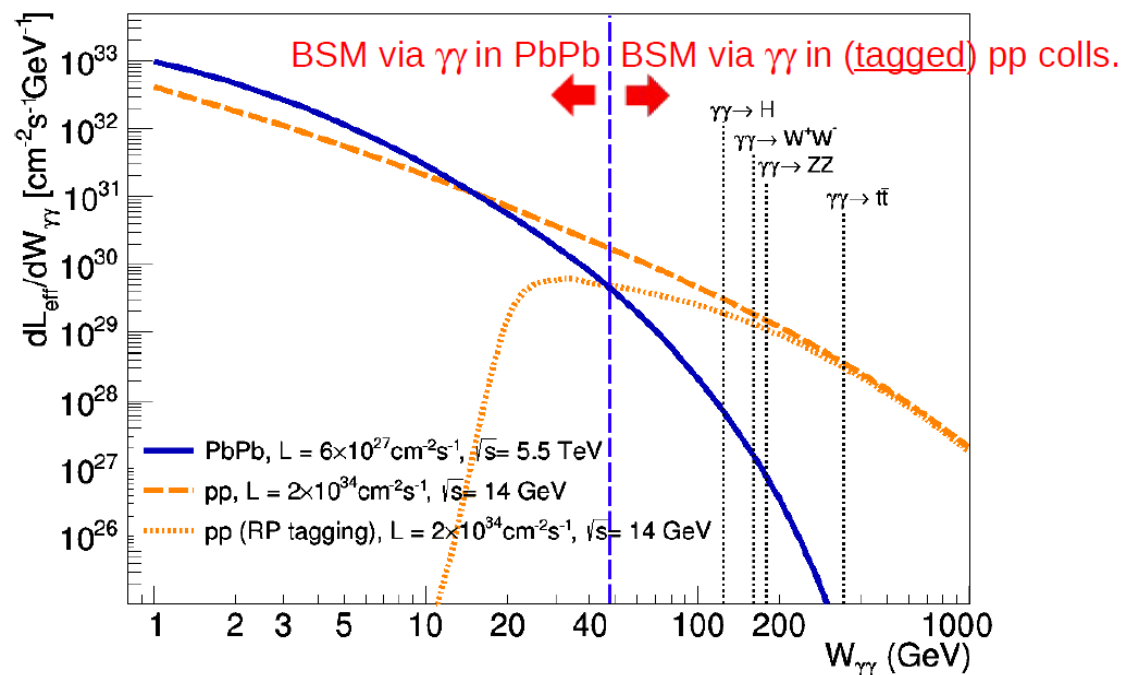
Eur. Phys. J. C77 (2017) 812



# When is it interesting to use Heavy Ions for new physics?

## Effective $\gamma\gamma$ luminosities at the LHC

- Competitive mass range for BSM searches in UPCs PbPb collisions:  
 $W_{\gamma\gamma} \sim 0.5\text{--}45\text{ GeV}$  ( $W_{\gamma\gamma}^{\min} \sim 0.5\text{ GeV}$  for ALICE/LHCb, 4 GeV for ATLAS/CMS)



David D'Enterria

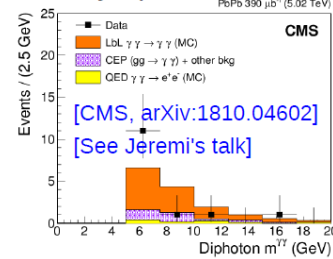
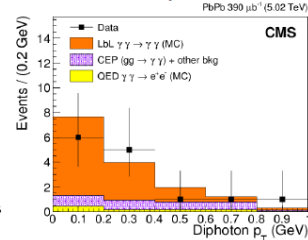
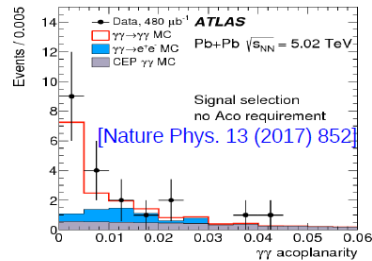


# Where we stand (1)

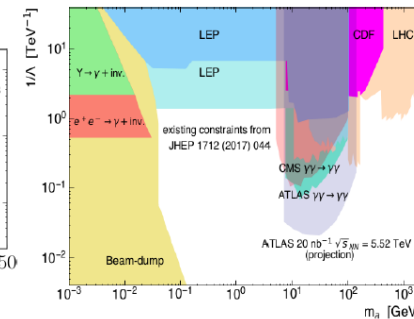
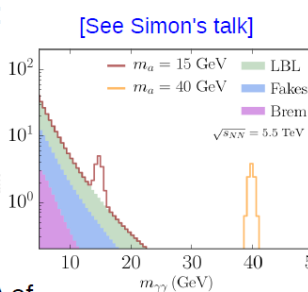
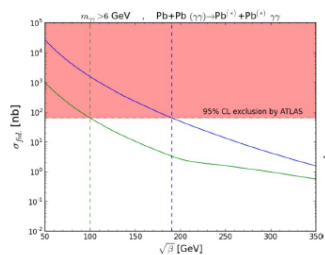
## First BSM searches & limits from $\gamma\gamma \rightarrow \gamma\gamma$

■ ATLAS, CMS measured 13, 14 exclusive di- $\gamma$  counts (2.6, 3.8 backgds)

consistent (4.3 $\sigma$ , 4.1 $\sigma$ ) with LbL prediction:



■ BSM searches limits:



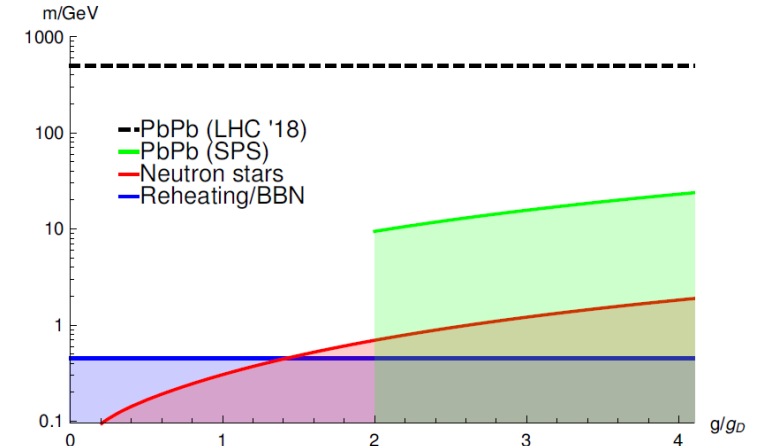
Limits on scale (>100 GeV) of

Born-Infeld non-linear QED extensions

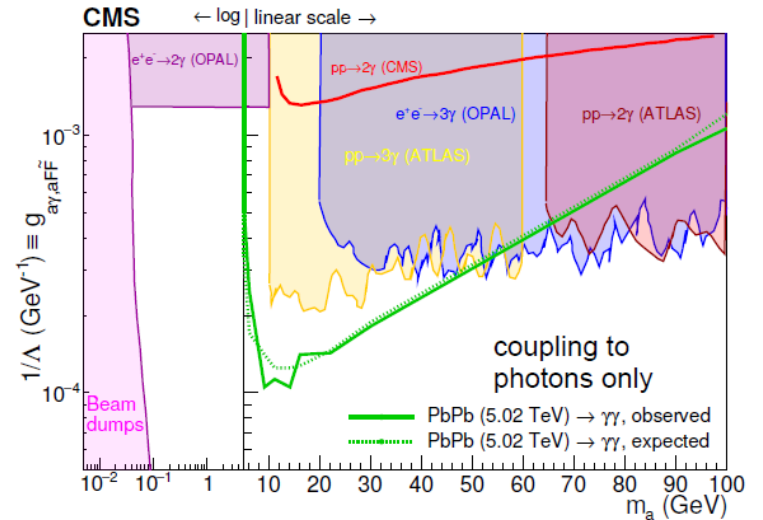
[J. Ellis et al., PRL118 (2017) 261802]

HI & Hidden Sectors, UCLouvain, Dec 2018

David D'Enterria

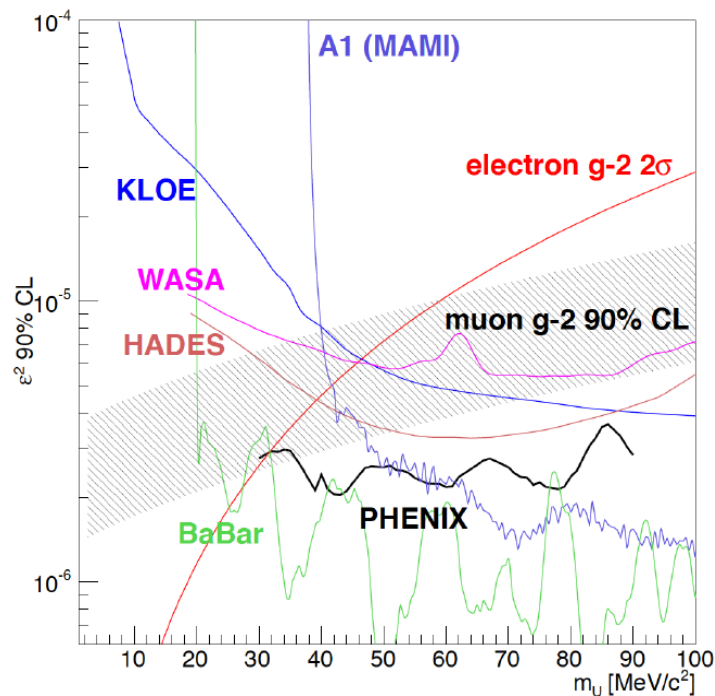


Oliver Gould



Jeremi Niedziela

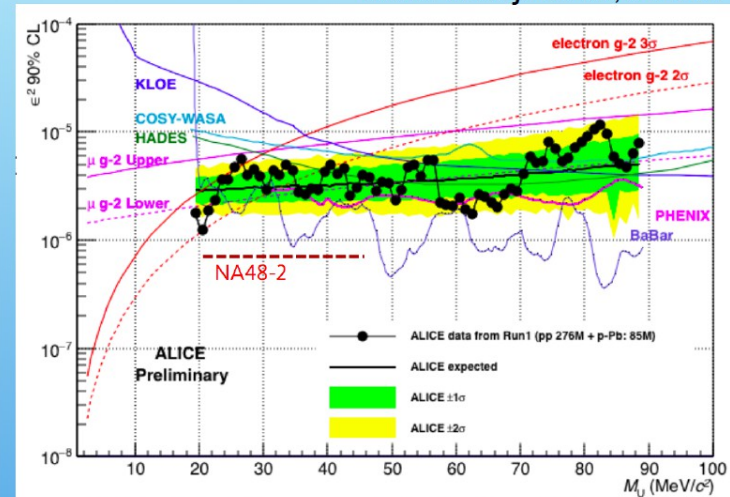
# Where we stand (2)



Sonia Kabana

## Comparison to ALICE and other data

Taku Gunji et al, ALICE collaboration



ALICE:  
Similar  $\epsilon^2$  at 90% CL  
compared to other  
experiments

Worse than  
NA48-2 and BaBar

**Comparison. HI data: ALICE, PHENIX, HADES**  
**Dark photon to  $e^+e^-$ , is excluded as source of the**  
**muon  $g-2$  anomaly but it may be source of positron**  
**excess in space or not have  $e^+e^-$  as final state**

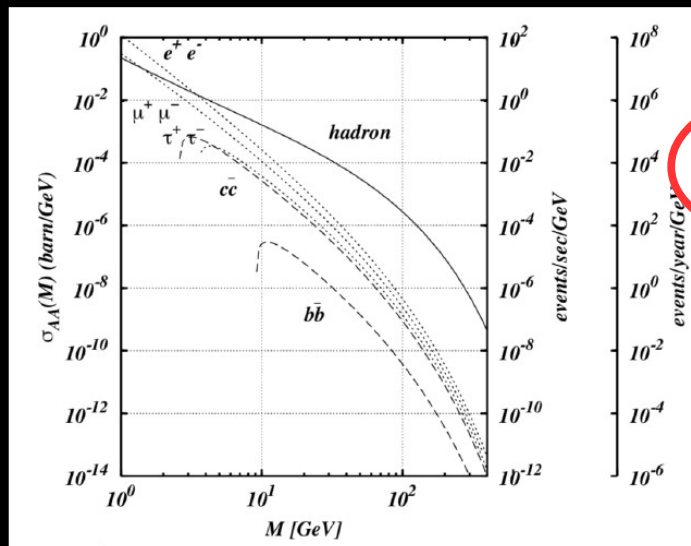
Sonia Kabana, Heavy Ions in non-LHC experiments, 4-5 December 2018, Louvain La Neuve, Belgium

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# The problem with UPCs

## Future directions? (II)

(Or “why I didn’t write more papers”)



Baur et. al. 0112211

Many backgrounds  
are also  $Z^4$  enhanced

Diphoton final state is the  
exception, not the rule

Simon Knapen

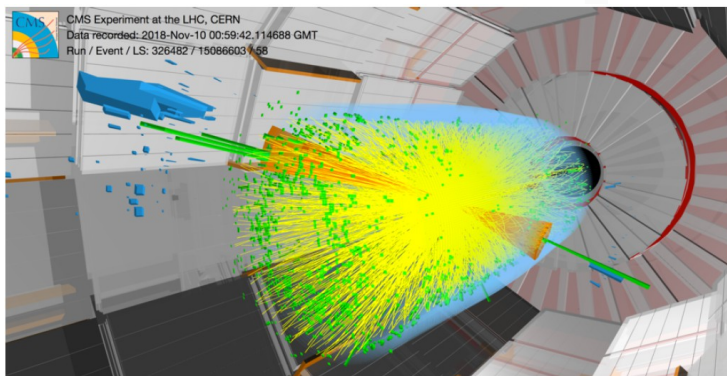
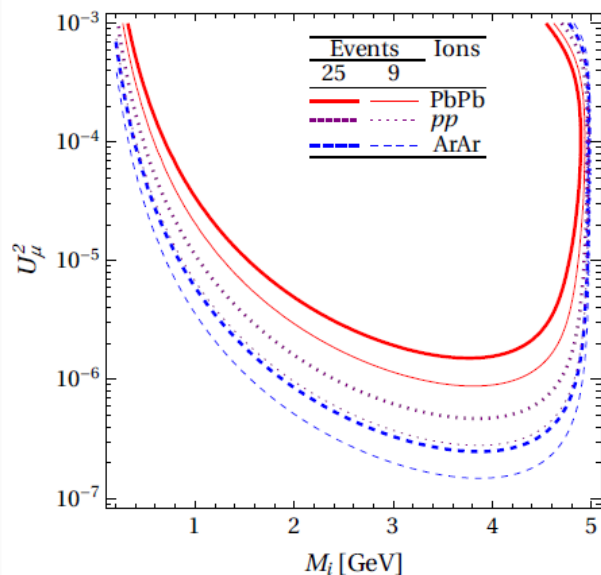
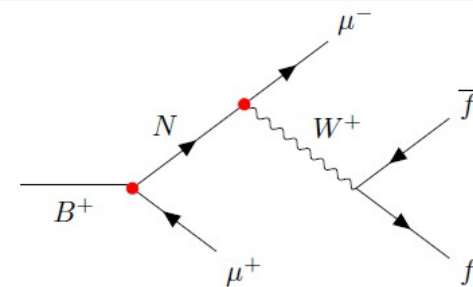
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# LLPs from b hadrons

Jan Hajer

*B*-meson mediator

- lower trigger possible:  
e.g.  $p_T > 3 \text{ GeV}$
- already probed at LHCb
- considered by CMS using parked data.



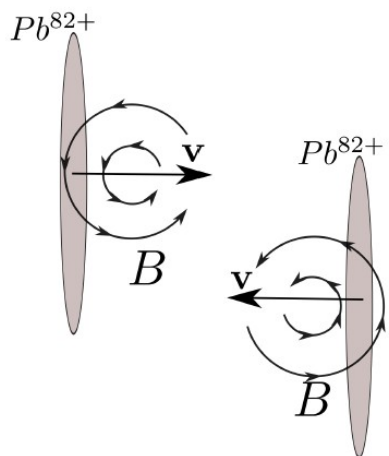
Jets from b's in HI (Pieter David)

## Discussion:

- Considering generic b quarks: gain statistics
- Or stick to specific hadron(s) but apply mass cuts to reduce backgrounds (if any)
- Consider same-sign muons: much much cleaner, but theoretically controversial?

# Magnetic Monopoles

Magnetic fields in heavy-ion collisions are the strongest known in the universe,  $O(10\text{GeV}^2) = O(10^{16}\text{T})$  at LHC energies.



Oliver Gould

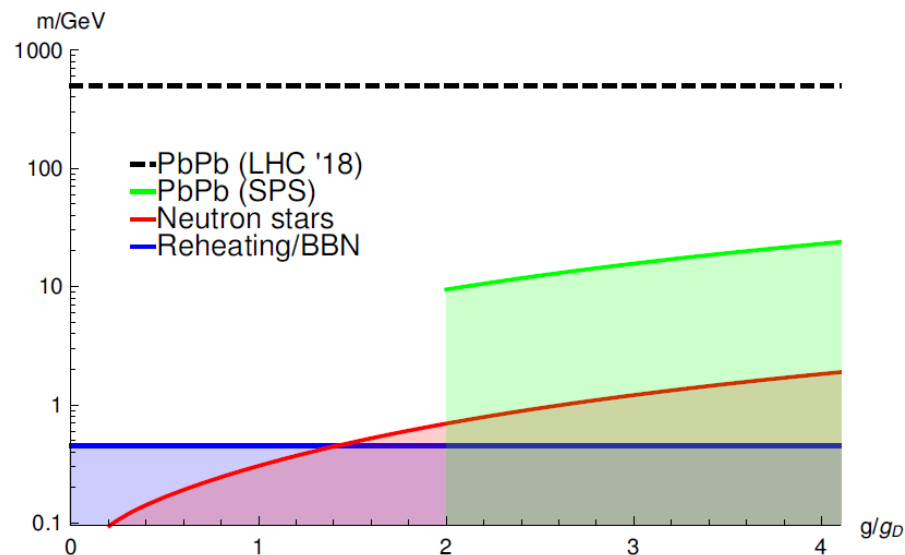


Figure: adapted from OG & Arttu Rajantie '17.

- 1 If **composite** magnetic monopoles exist, how can they be created?

~~$pp$  collisions,  $e^+e^-$  collisions ...~~

$PbPb$  collisions ✓,  $AuAu$  collisions ✓, ...

- 2 If **elementary** magnetic monopoles exist, how can they be created?

$pp$  collisions?  $e^+e^-$  collisions? ...

$PbPb$  collisions ✓,  $AuAu$  collisions ✓, ...

## Discussion:

- How do we trigger on that?
- Parabolic tracks; a problem? (UPC: few tracks anyway)

# Sexaquarks

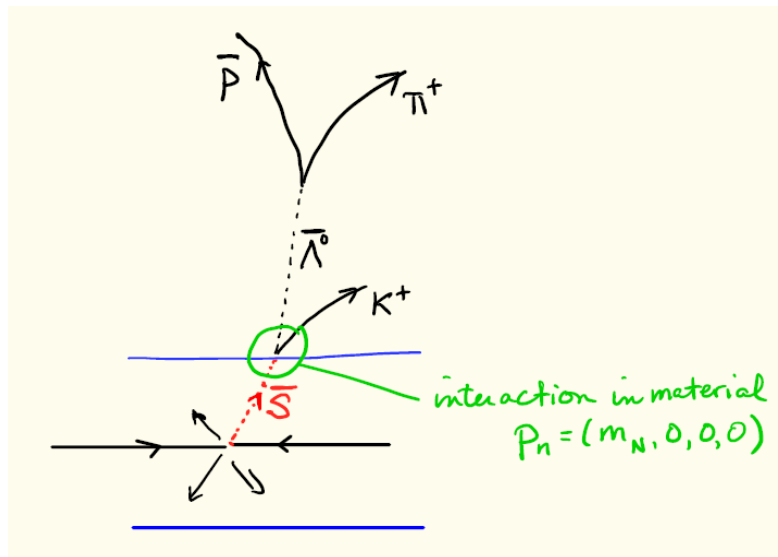
Glennys Farrar

**Prediction:**  $\Omega_{\text{DM}} / \Omega_{\text{b}} = 4.5 \pm 1$

determined by *stat mech*, *quark masses* &  
*temp of QGP-hadronization transition*

( $\Omega_{\text{DM}} / \Omega_{\text{b}}$  observed =  $5.3 \pm 0.1$ )

- Heavy ion collisions produce more particles — feasible to reconstruct ???



Discussion:

- LHCb and ALICE have very good hadron-id, should be able to distinguish  $\pi$ , K, p



# Is the LHC beampipe's vacuum actually full of sexaquarks?

# LHC beam lifetime

- DM capture by Earth => DM atmosphere

Neufeld, GRF, McKee, ApJ2018

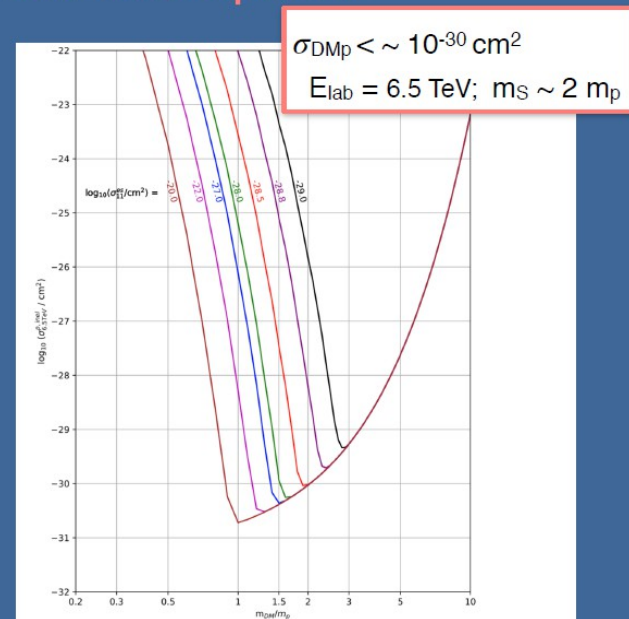
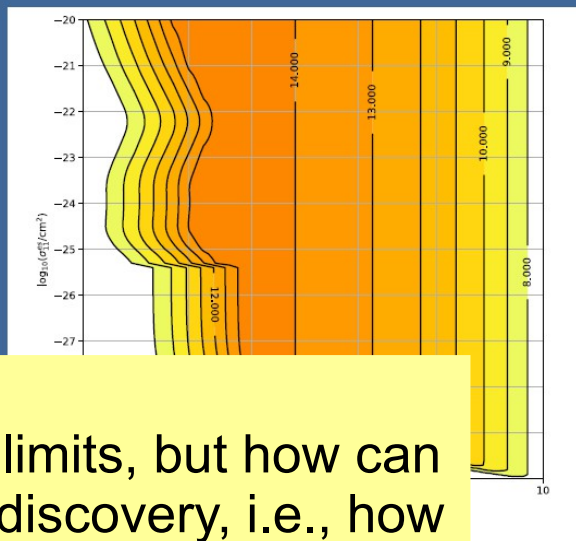


Fig. 7.— Upper limits on  $\sigma_{6.5\text{ TeV}}^{\text{inel}}$  implied by an LHC beam lifetime of 100 hr. Results are shown for five values of  $\sigma_{\text{th}}^{\text{th}}$  for which the LSS lies in the crust ( $10^{-20.0}$ ,  $10^{-28.8}$ ,  $10^{-28.5}$ ,  $10^{-28}$ , and  $10^{-27}\text{ cm}^2$ ), and two values for which the LSS lies in the atmosphere ( $10^{-22}$  and  $10^{-20}\text{ cm}^2$ ). The curves are labeled with  $\log_{10}(\sigma_{\text{th}}^{\text{th}})$ .

## Discussion:

- You can set limits, but how can you claim a discovery, i.e., how do you exclude that an anomaly is yet another poorly known instrumental effect?



# Strangelets

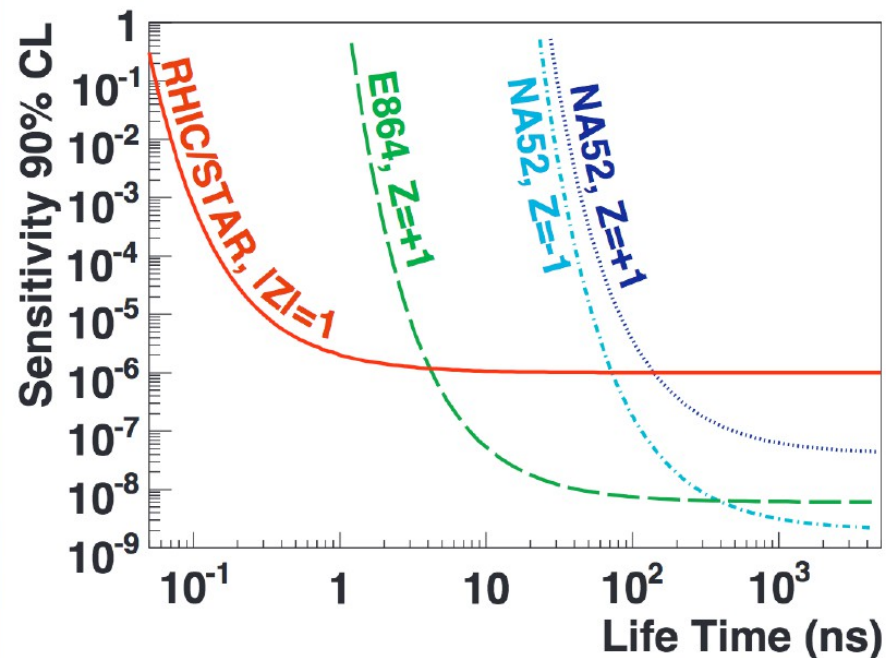
## STAR Strangelet Search at the BNL Relativistic Heavy Ion

STAR Phys.Rev. C76 (2007) 011901

Search done in  
61 million  
central  
Au+Au events

strangelet  
mass > 30 GeV.

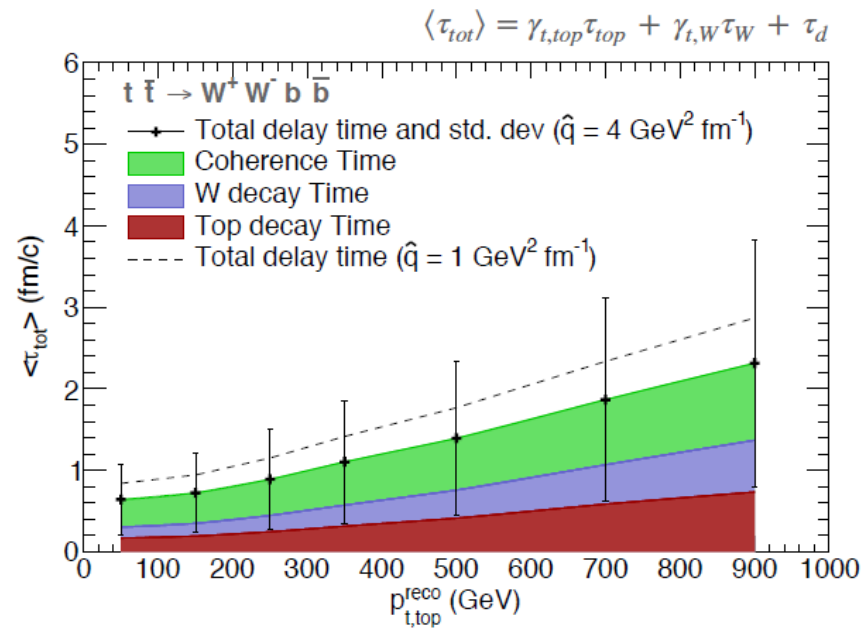
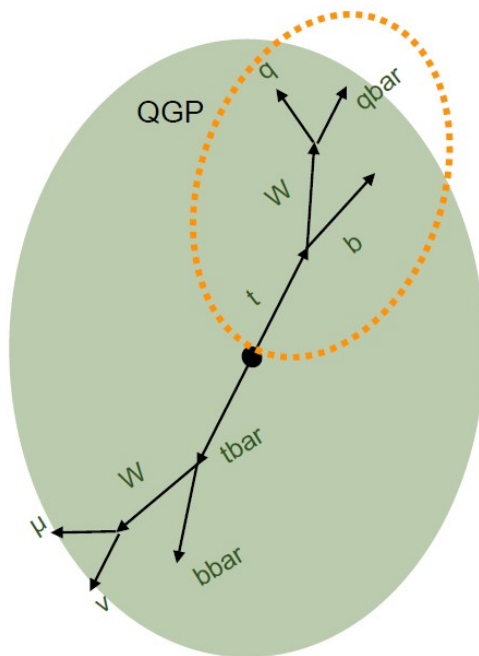
lifetime >  
0.1 nsec



Sonia Kabana, Heavy Ions in non-LHC experiments, 4-5 December 2018, Louvain La Neuve, Belgium

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# What can we do with a yoctosecond chronometer?

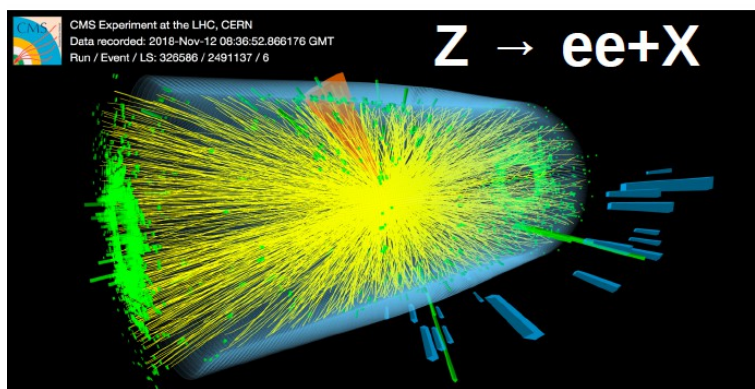


Guilherme Milhano

*although all of this was strictly physics of QGP  
the yoctosecond chronometer could [should] be used  
to explore physics of both short and long lived new  
states that decay into jets*

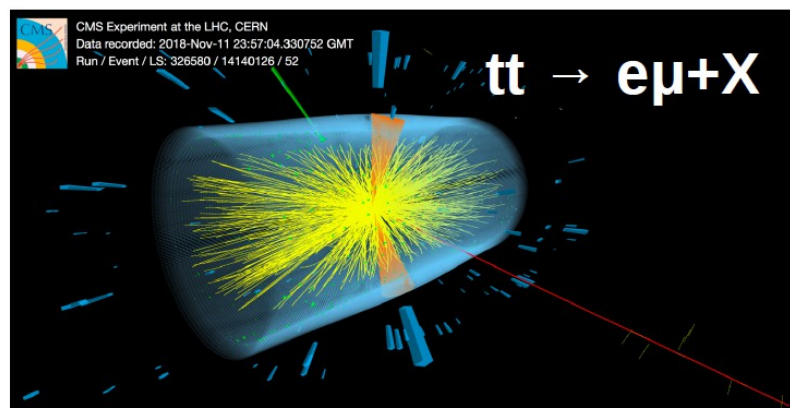
# PbPb 2018

First events with “hard probes” ☺




CMS-PHO-EVENTS-2018-010-19

CMS-PHO-EVENTS-2018-010-21



Georgios Krintiras

# How far can LHC go?

 **Pb luminosity limits**

- Direct limitations on instantaneous luminosity as well as on the parameters determining luminosity
- Additional limits on integrated luminosity: availability and turnaround time

Bunch intensity:  
Injectors, blowup,  
collimation

intensity

Number of bunches:  
injectors,  
collimation

$$\mathcal{L} = \frac{N_1 N_2 f_{\text{rev}} k_B}{4\pi\beta^* \epsilon_{xy}} F$$

Luminosity:  
collisional  
losses,  
Experimental  
detectors

Optical focusing:  
Aperture, magnet  
strengths

Beam emittance:  
injectors, blowup

Geometric reduction  
factor: beam-beam  
No dramatic gains  
possible  
  

$$\frac{1}{\sqrt{1 + \left(\frac{\sigma_s}{\sigma_x} \frac{\phi}{2}\right)^2}}$$

*Beam size*

R. Bruce, 2018.12.05 8

Roderik Bruce

# Limiting effects

Cross sections for Pb-Pb collisions at 2.76 TeV / nucleon

Process	Cross section (b)
Bound-free pair production	281
Electromagnetic dissociation	226
Hadronic nuclear inelastic	8
Total	515

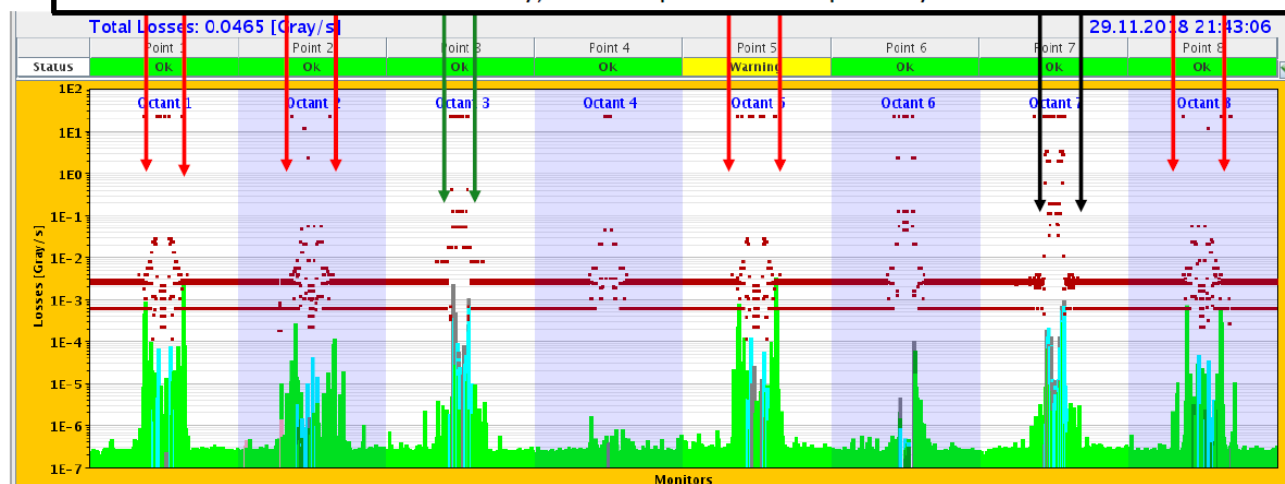
## Observations of BFPP during operation

- Beam loss monitors around LHC ring show positions of losses
- Large BFPP spikes seen around the experiments

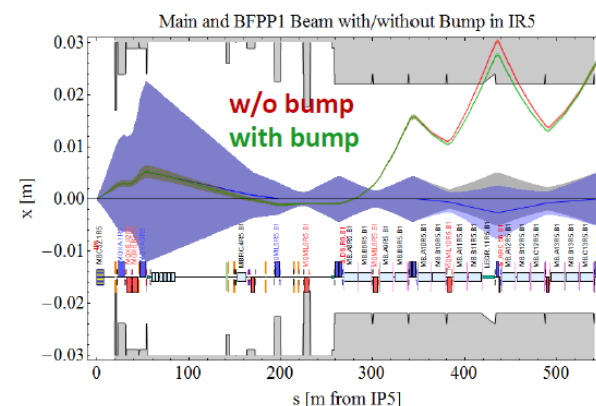
Bound-free pair production secondary beams from IPs

IBS & Electromagnetic dissociation at IPs, taken up by momentum collimators

Losses from collimation inefficiency, nuclear processes in primary collimators



Roderik Bruce

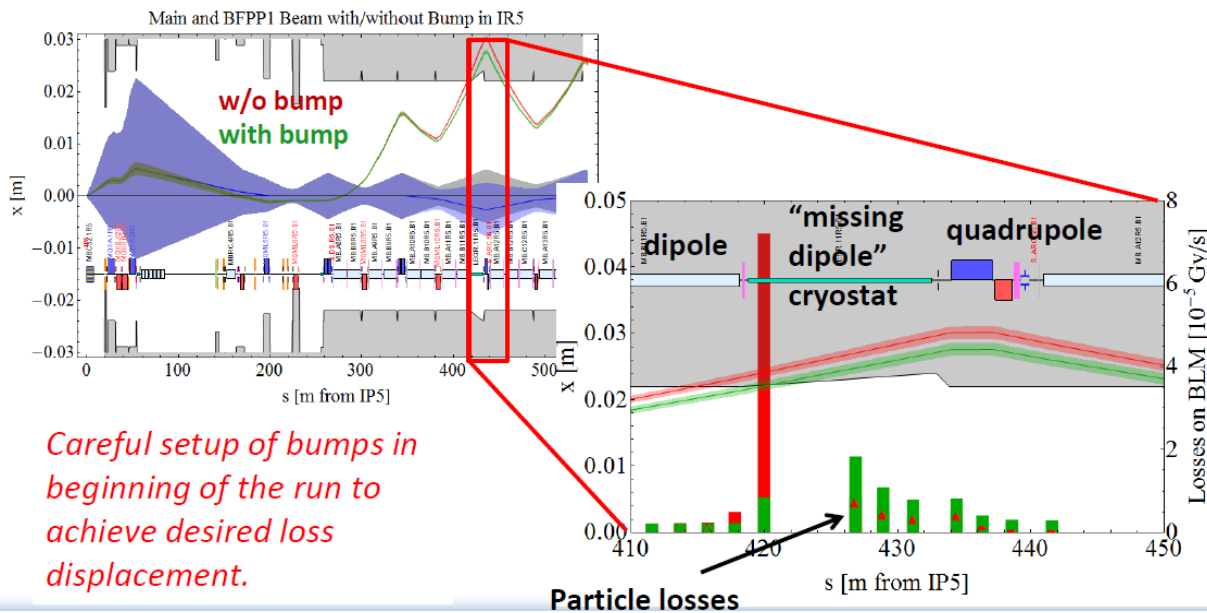


Careful setup of bumps in beginning of the run to achieve desired loss displacement.

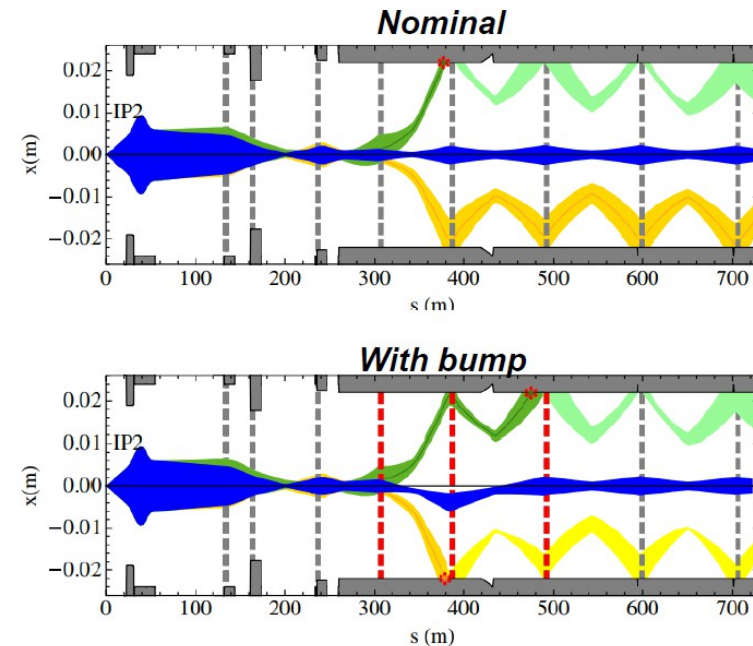
# Alleviating actions

## ATLAS/CMS:

- With bumps, achieved  $\sim 6 \text{E}27 \text{ cm}^{-2}\text{s}^{-1}$  in ATLAS / CMS



## Partial solution in ALICE:

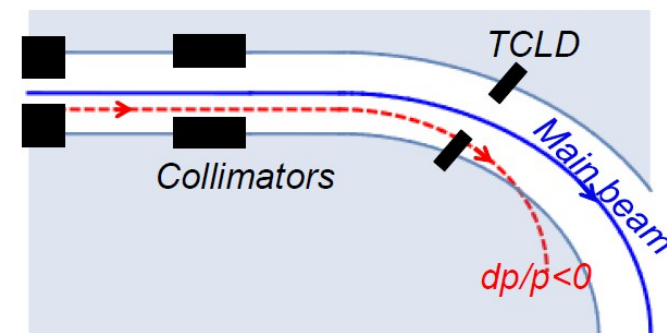
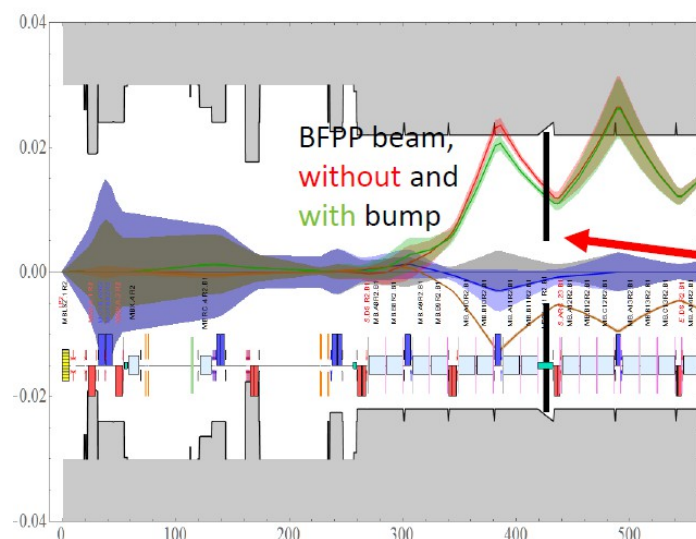


ALICE anyway leveled at  $1 \text{E}27 \text{ cm}^{-2}\text{s}^{-1}$

Roderik Bruce



# Future alleviation: collimators



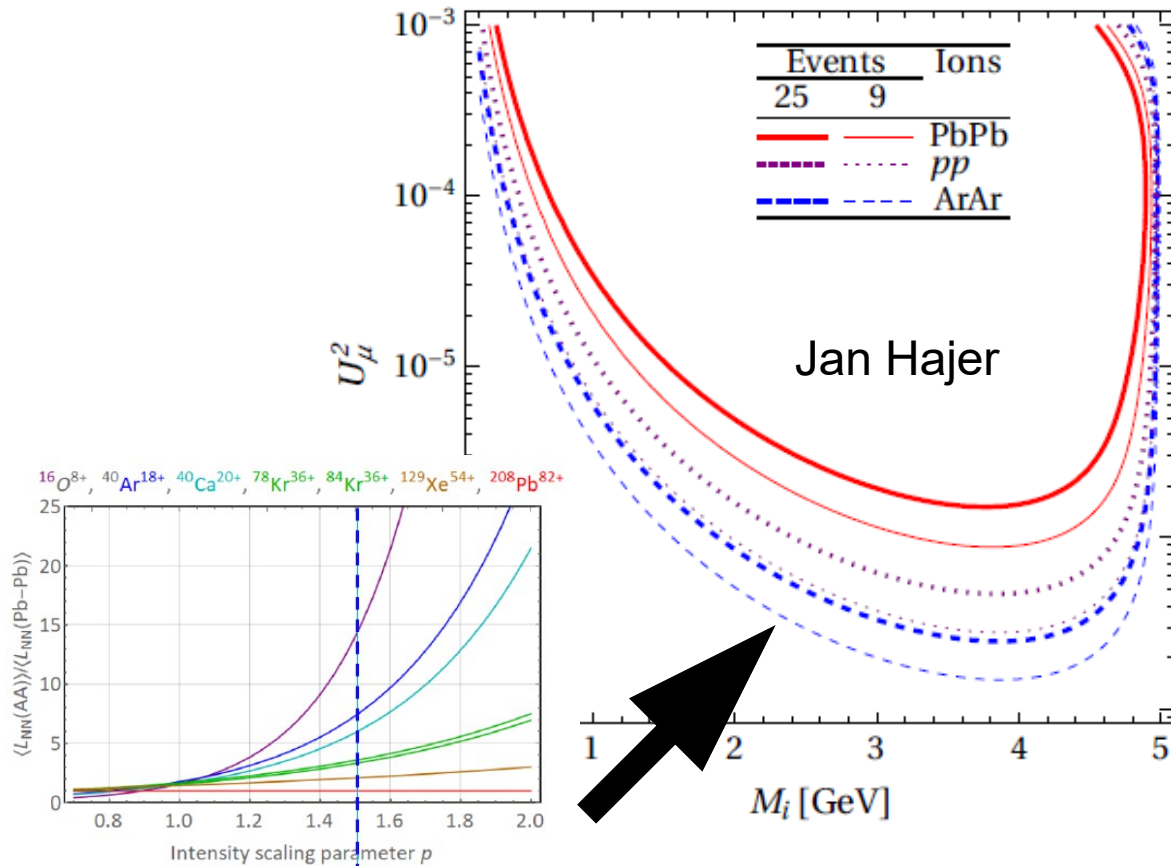
Roderik Bruce

- LHC collimation much less efficient with nuclear beams than with protons
  - Very high probability of nuclear breakup in primary collimator
  - Fragments very often miss downstream collimation stages
  - Different charge-to-mass ratio => fragments bent wrongly and lost in the first few dipoles

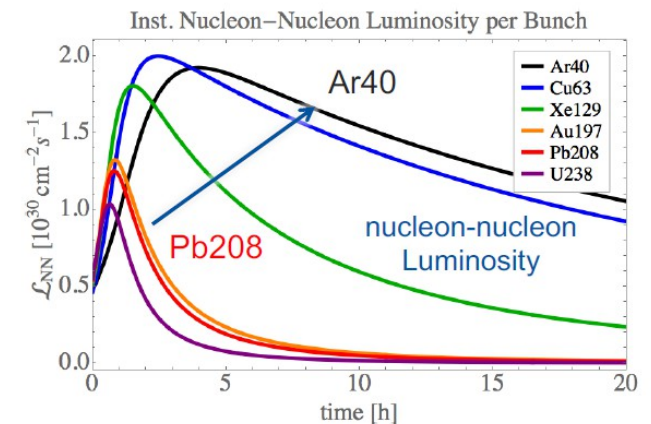
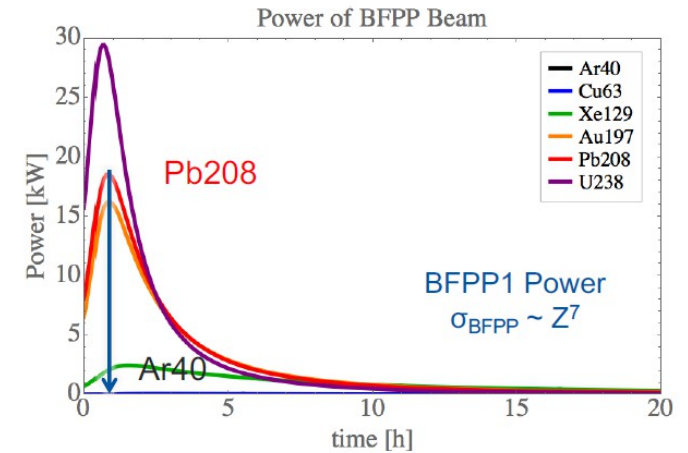
- Measured leakage to cold magnets factor ~100 worse of Pb ions than protons



# Lighter ions



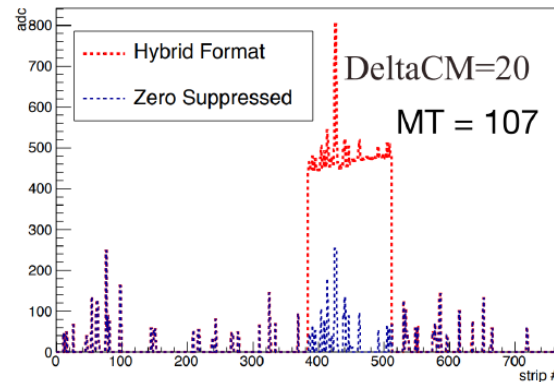
**Nucleon-nucleon luminosity**  
in 1-month run: **gains** ranging  
up to a **factor ~13** for lightest  
considered ion (O) at  $p=1.5$



Michaela Schaumann

# Detectors suffering: CMS examples

- zero-suppression in the detector frontend electronics (as in proton-proton) would reduce efficiency
- 2015 solution: no zero-suppression (big events limiting trigger rate)
- 2018 hybrid readout: zero-suppression only when baseline as expected

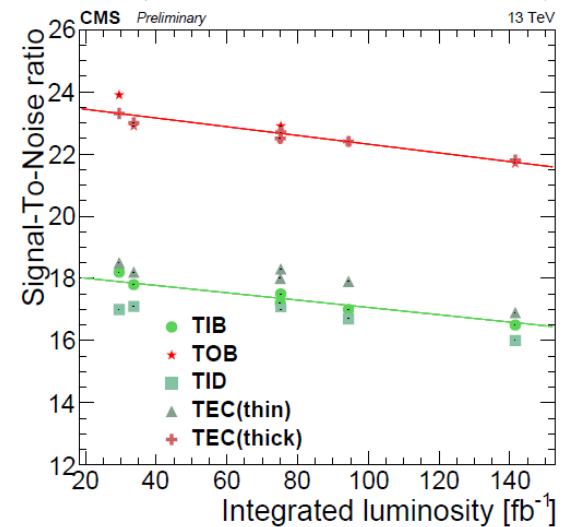


Also

- hardware trigger / readout
- high-level trigger (online reconstruction)
- offline reconstruction (computing resources)

Pieter David

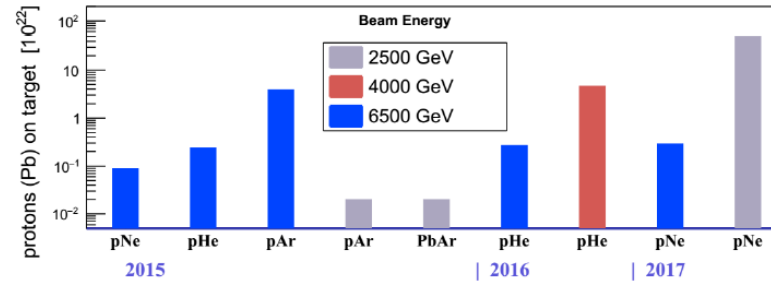
An example: ageing of the CMS strip tracker (relevant for HSCP searches)



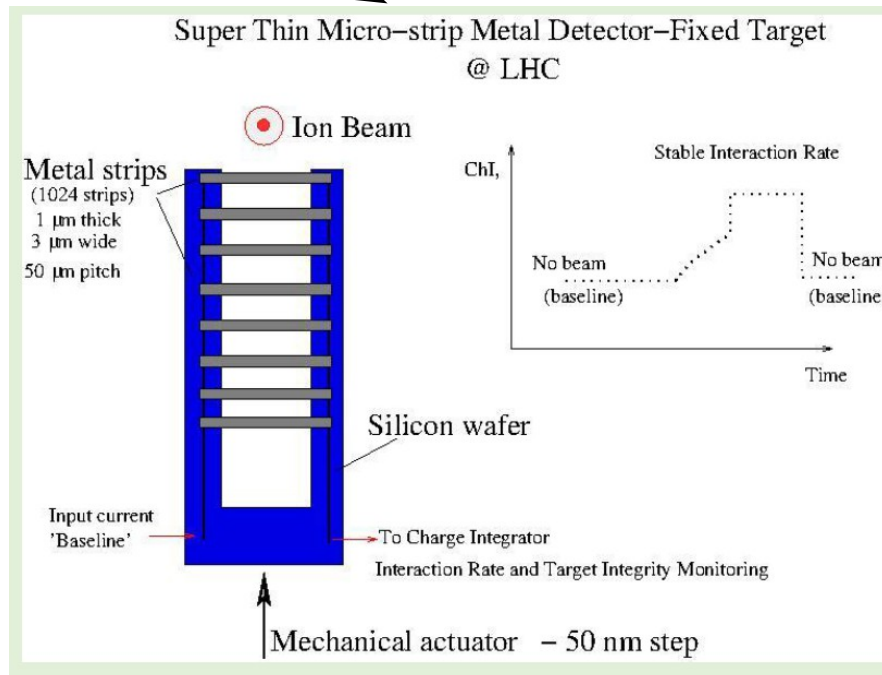
# Fixed target

Today →

Tomorrow? ↘



Valerii Pugatch

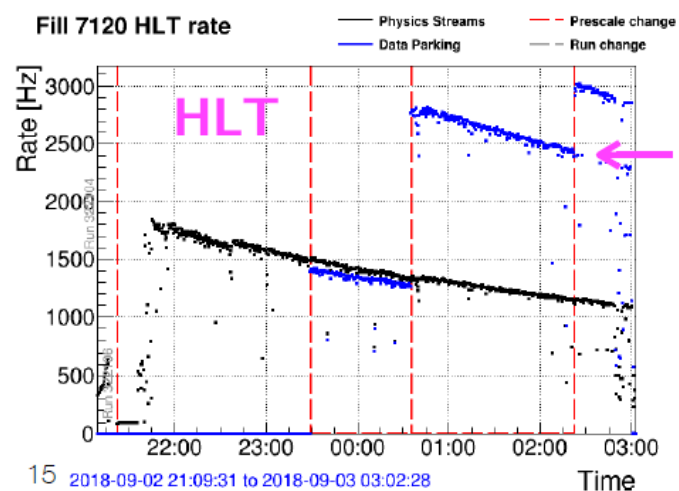
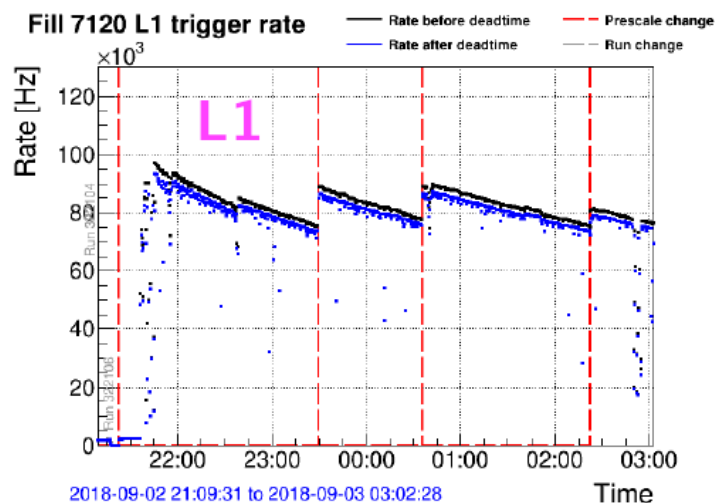
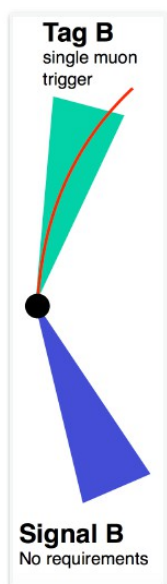


Metal Microstrip Detector –MMD-1024.

Nano-technologies evolve fast  
– already nowadays- carbon nano-tubes,  
fullerene structures, graphenes, ...  
May become a nano-wire target components.

# Parking, i.e. "better late than never"

The current use case in CMS is of relevance for  $B \rightarrow$  new physics, but the concept is general:



Swagata Mukherjee,  
Jessica Prisciandaro

## Discussion:

- How to factor parking in HL-LHC projections?
- And what about parking also in HI context?

# Scouting, i.e. "do more with less"

Trigger Bandwidth =  $\text{Event Rate} \times \text{Event Size}$

$\sim 1 \text{ kHz}$   $\times$   $\sim 1 \text{ MB}$

If we want to **increase** rate  
(i.e. decrease threshold)

We need to **decrease**  
event size

## Advantage

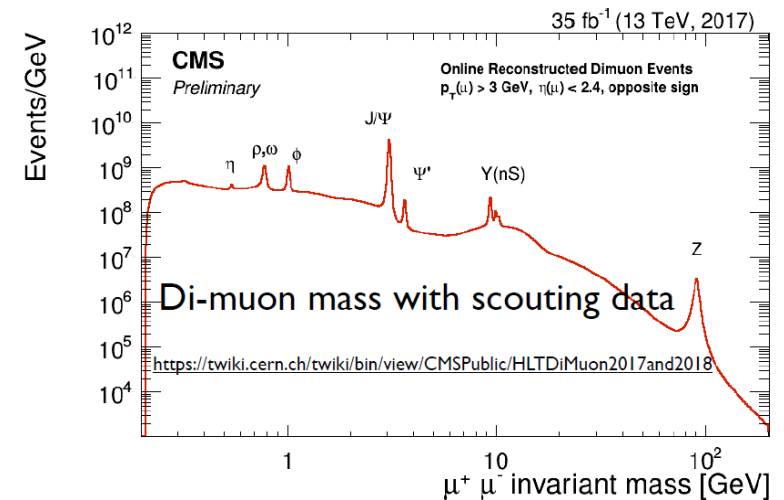
(I) Save low  $p_T$  objects (II) Probe low mass regions

Dedicated di-muon scouting trigger designed for **prompt** and **displaced** di-muon search.

Loose HLT requirement:

At least 2 muons with  $p_T > 3$  (1) GeV in 2017 (2018). **No mass cut.**

Di-muon vertex can be displaced, upto  $\sim 10$  cm, w.r.t primary vertex.

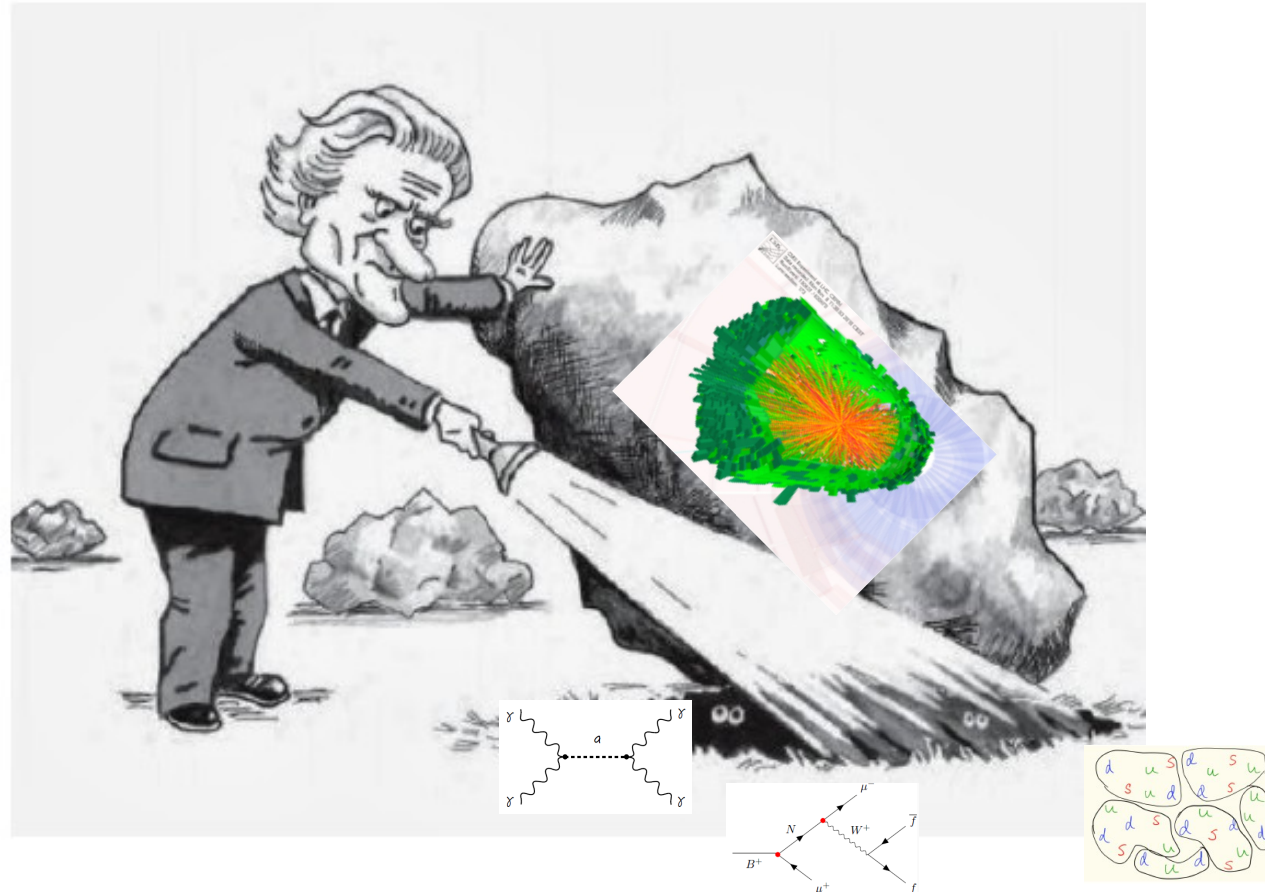


Swagata Mukherjee

# Homework!

- Document on the perspectives to find "New Physics" in HI collisions to the EPPS (see [guidelines](#))
  - Possible topics: ALPs, monopoles, LLPs, exotic QCD states (including sexaquarks), exotic plasma effects (e.g. chiral magnetic) or the general potential of HI as  $\gamma\gamma$  collider
- Join this effort by writing up a very brief paragraph here: <https://www.overleaf.com/6996454583xrjpgpgpsznw>
  - physics case
  - references and a few numbers
  - how the heavy ion program beyond 2029 could be optimised for this proposal (e.g. choice of isotopes etc.)

# Concluding the conclusions





# ***Thanks!***

I learned a lot in these two days