Title: Beyond the Standard Model â€“ Experiment: Precision measurements

Date: Jul 08, 2015 10:15 AM

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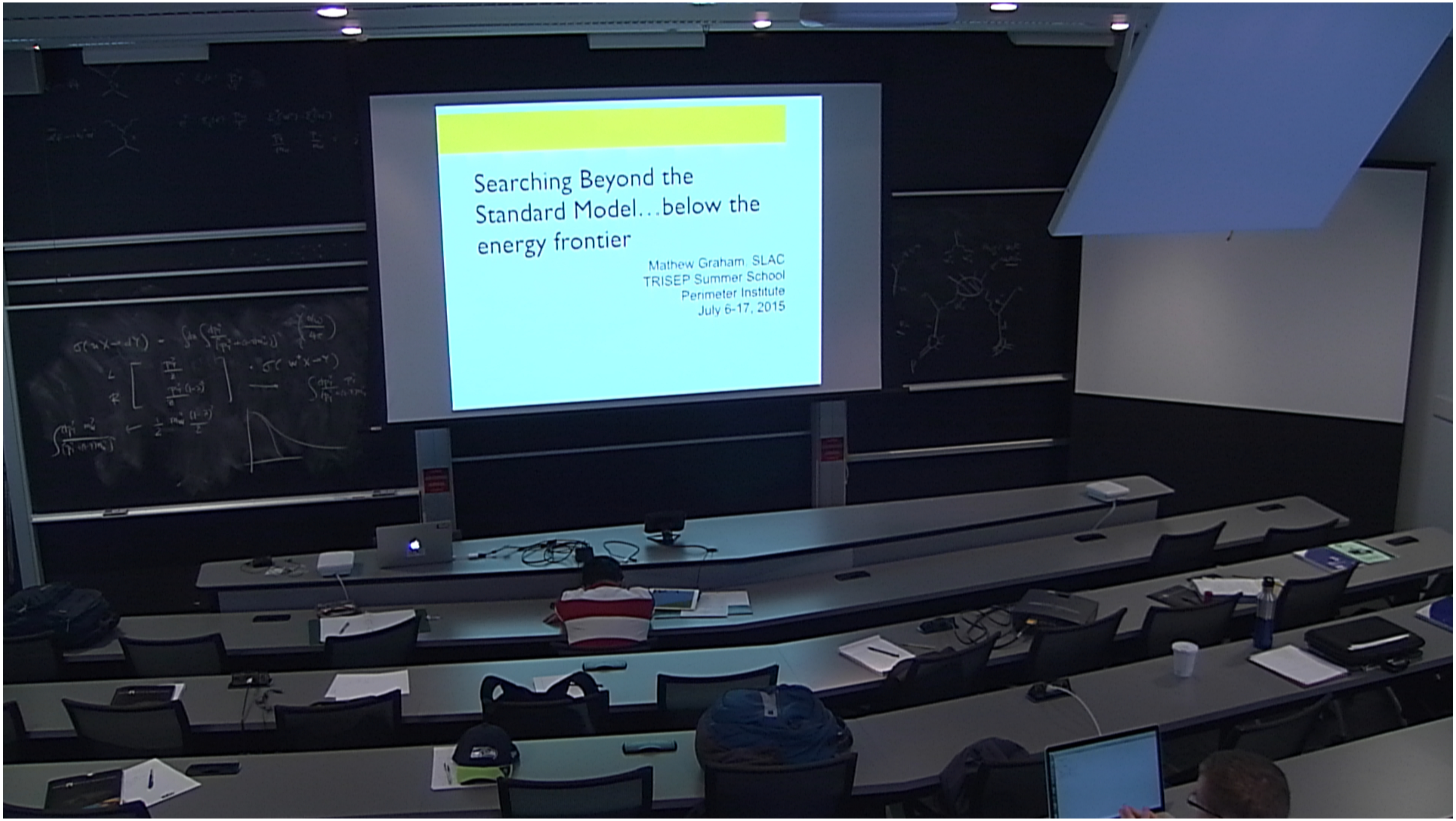
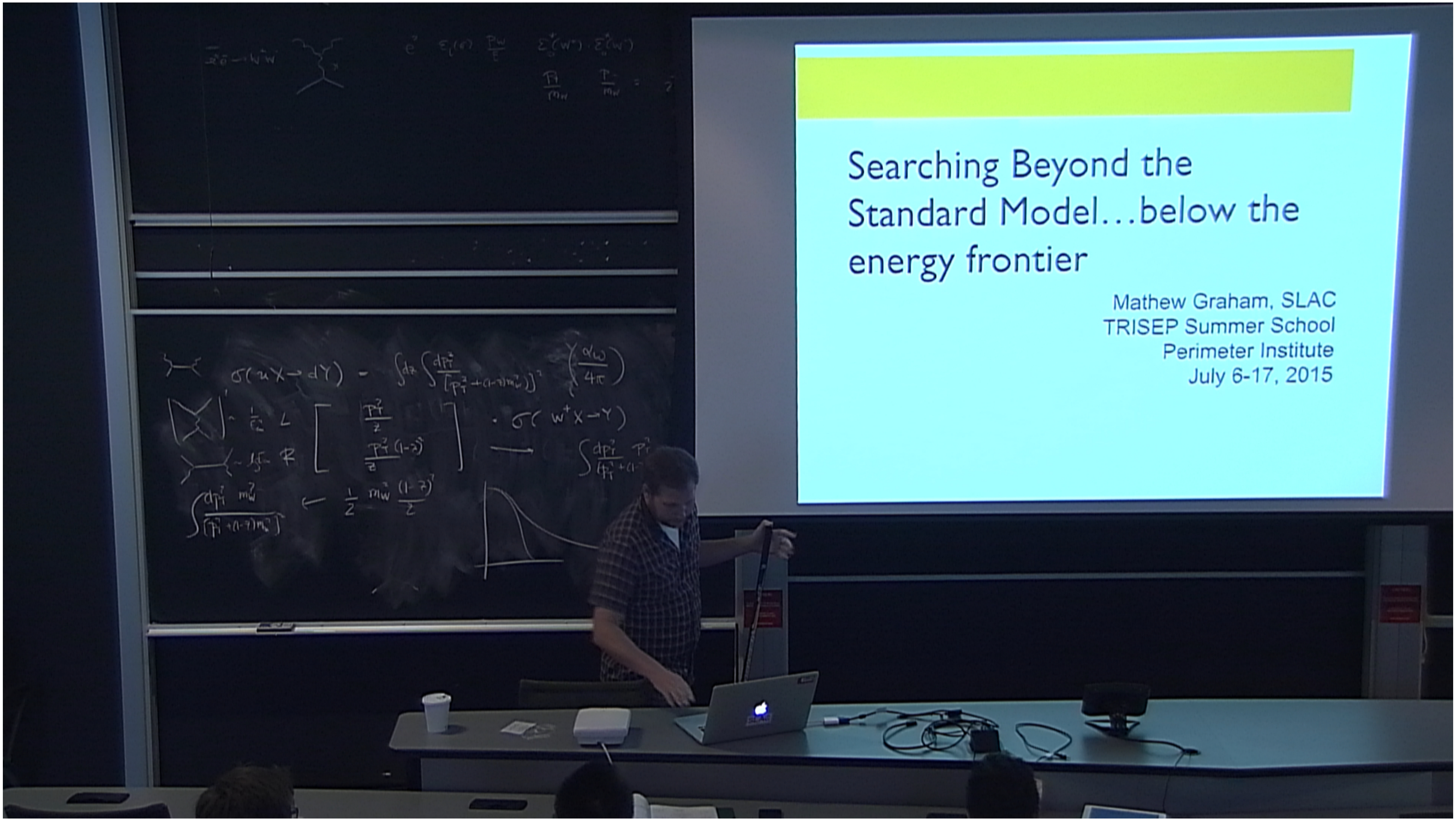
Abstract:


Searching Beyond the Standard Model…below the energy frontier
Mathew Graham, SLAC
TRISEP Summer School
Perimeter Institute
July 6-17, 2015


Searching Beyond the Standard Model…below the energy frontier
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Not quite done…

No RH ν
in the SM!

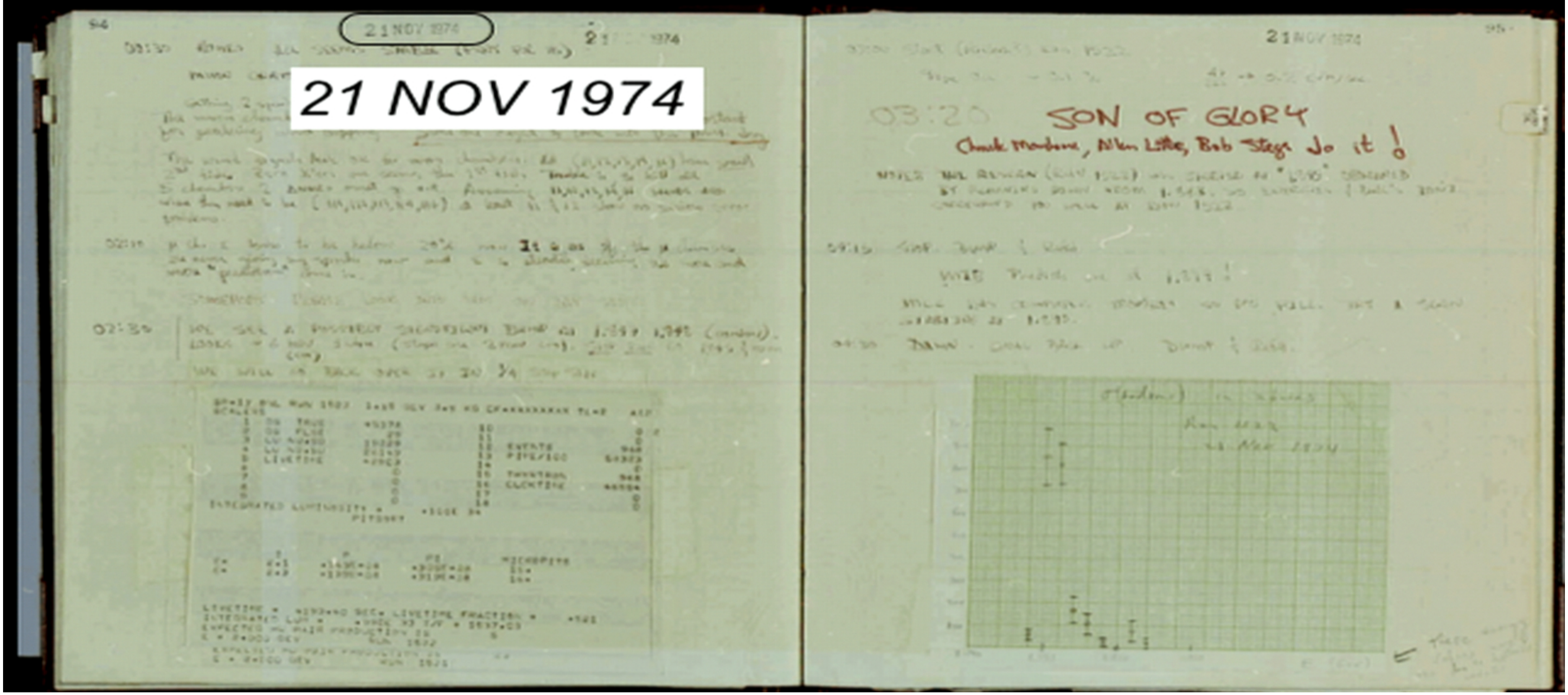
Big Problems!
…strong CP problem…
…dark matter…
…CP of the universe…
…origin & nature of neutrino mass…

minor issues…
…"naturalness" & hierarchy (problems)…

How to look for new physics

- Go to higher and higher energies!
  - directly produce new particles at scales unobtainable before!
  - has worked in the past…

How do discover new physics @ low energies…



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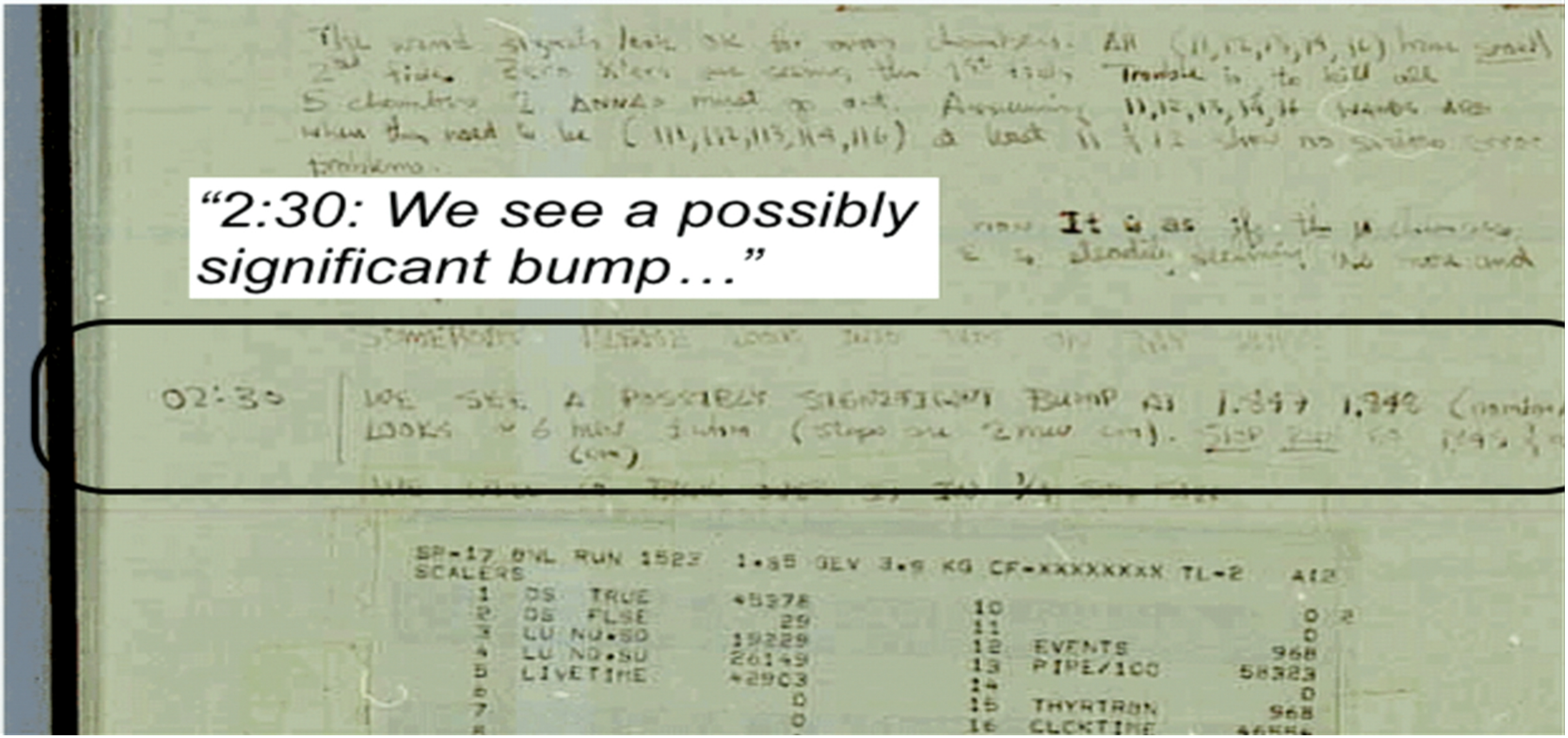
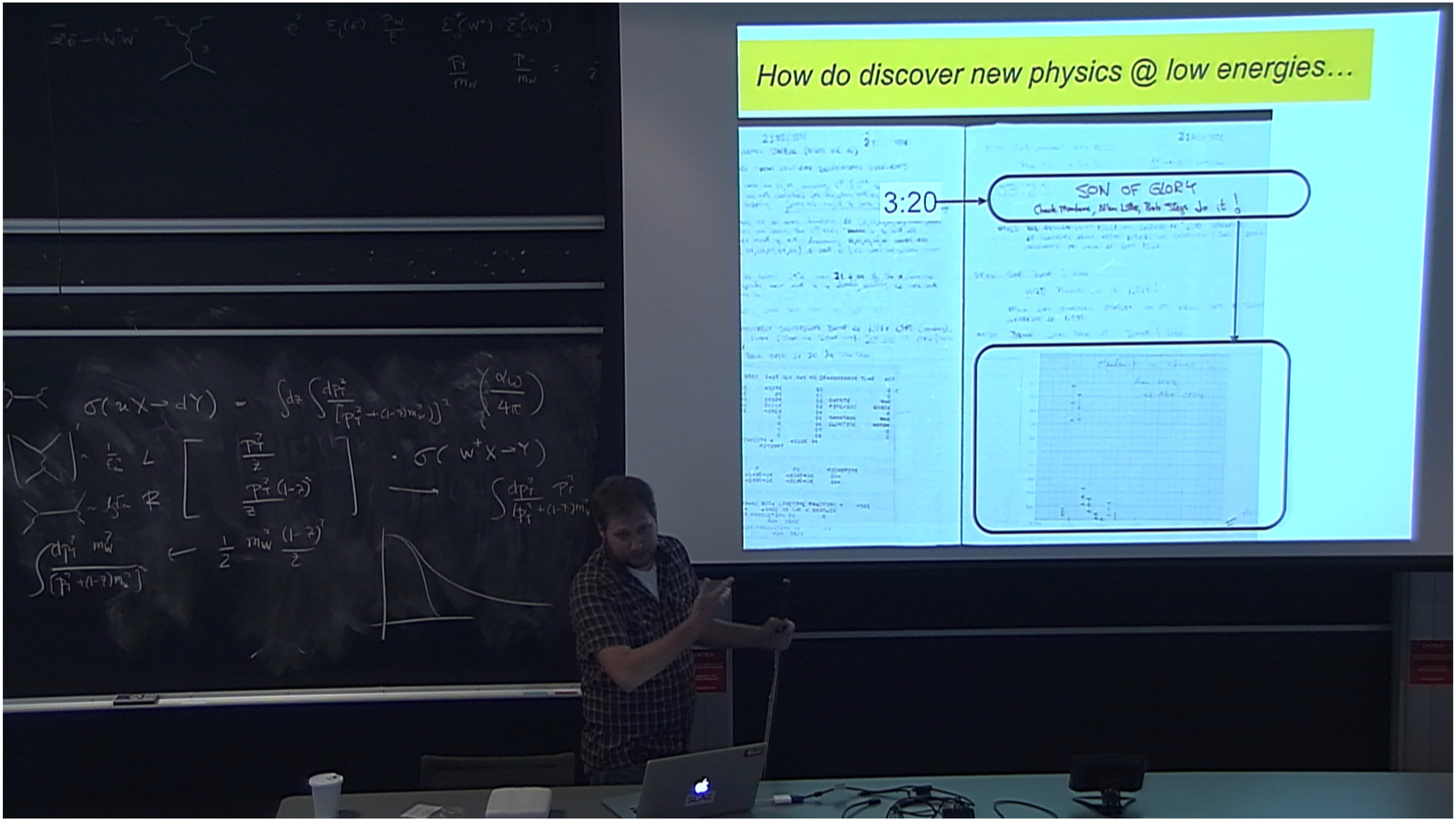
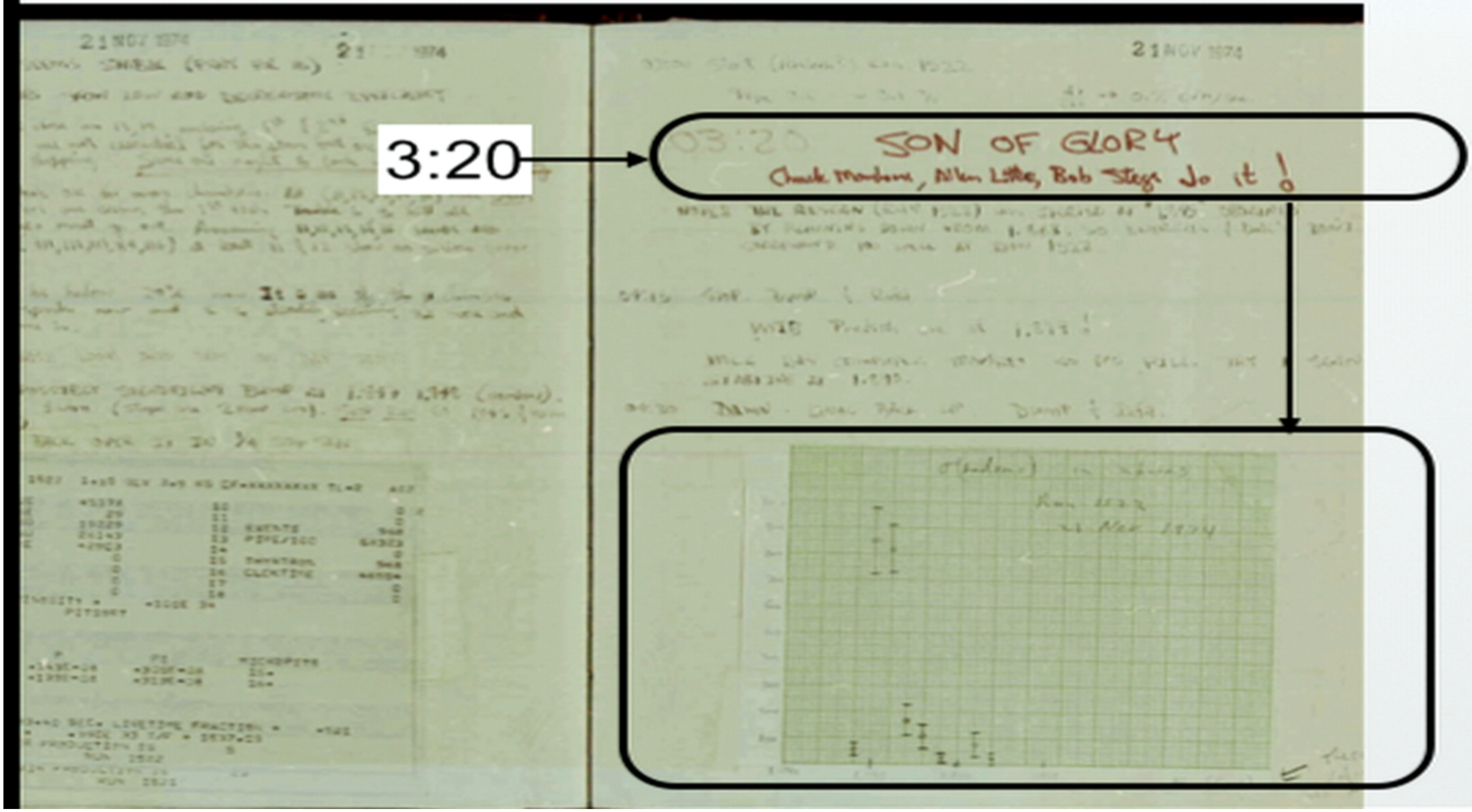



How do discover new physics @ low energies…
3:20
SON OF GLORY
Chuck Mondone, Allan Little, Bob Siegel Jr. it !

How do discover new physics @ low energies…



How to look for new physics

- Go to higher and higher *energies*!
  - directly produce new particles at scales unobtainable before!
  - has worked in the past…
- Go to higher and higher *intensities*!
  - rare production modes
  - rare decay modes
  - precise measurements of SM predictions
- Look somewhere *"new"****!
  - neutrinos!
  - particle-astrophysics

****neither of these are new, but definitely room for growth*

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Searching For BSM @ "low-energies"

- Low Energy != Low Scale
  - Loops are our friend!

…high mass scales of NP particles in the loops is not suppressed like they are @ tree level (direct production)
Also! Typically don't have tree-level SM processes to compete against→lower background

Searching For BSM @ "low-energies"

- Low Energy != Low Scale
  - Loops are our friend!
  - Rare or forbidden decays
    - Lepton flavor violation searches
  - precision measurements of well predicted parameters
    - muon g-2
    - CKM unitarity triangle (& related measurements)
- Looking in new places — Neutrinos!
  - we haven't fully explored neutrino sector (it's hard)
  - mixing matrix still has many open questions
    - is it unitary? Are there more "neutrinos"
    - what's the CP phase…is it 0? Some other interesting number?
  - What's the deal with the neutrino mass(es)?
    - ordering of masses? SM-like or inverted
    - where does it come from?
- Direct production, but with very intense sources
  - A ton of experiments were done in the old days that looked for crazy things…now we have much more intense beams, better detectors & electronics. Some crazy things may be there!
    - Dark sector searches

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Today

"Theory"

$$|\mathcal{A}_{Tot}|^2 = \boxed{|\mathcal{A}_{SM}|^2} + |\mathcal{A}_{NP}|^2 + 2Re\left(\mathcal{A}_{SM}\mathcal{A}^*_{NP}\right)$$

If SM is large → Tough… $\mathcal{S} \sim \sqrt{\mathcal{L}} \times \frac{|\mathcal{A}_{NP}|^2}{|\mathcal{A}_{SM}|}$

$\mathcal{S}$ = Significance

$\mathcal{L}$ = Integrated Luminosity

“Theory”

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"Theory"

$$|\mathcal{A}_{Tot}|^2 = |\mathcal{A}_{SM}|^2 + |\mathcal{A}_{NP}|^2 + 2Re\left(\mathcal{A}_{SM}\mathcal{A}^*_{NP}\right)$$

If SM is (very) small

Easy! $\mathcal{S} \sim \mathcal{L} \times |\mathcal{A}_{NP}|^2$

$\mathcal{S} = \text{Significance}$
$\mathcal{L} = \text{Integrated Luminosity}$

"Theory"

$$|\mathcal{A}_{Tot}|^2 = |\mathcal{A}_{SM}|^2 + |\mathcal{A}_{NP}|^2 + 2Re\left(\mathcal{A}_{SM}\mathcal{A}^*_{NP}\right)$$

If SM is ~ NP

Get tricky, measure the interference. Sensitive to A_{NP} (not ^2)...

$\mathcal{S}$ = Significance

$\mathcal{L}$ = Integrated Luminosity

BUT FIRST!

…some words about detectors…

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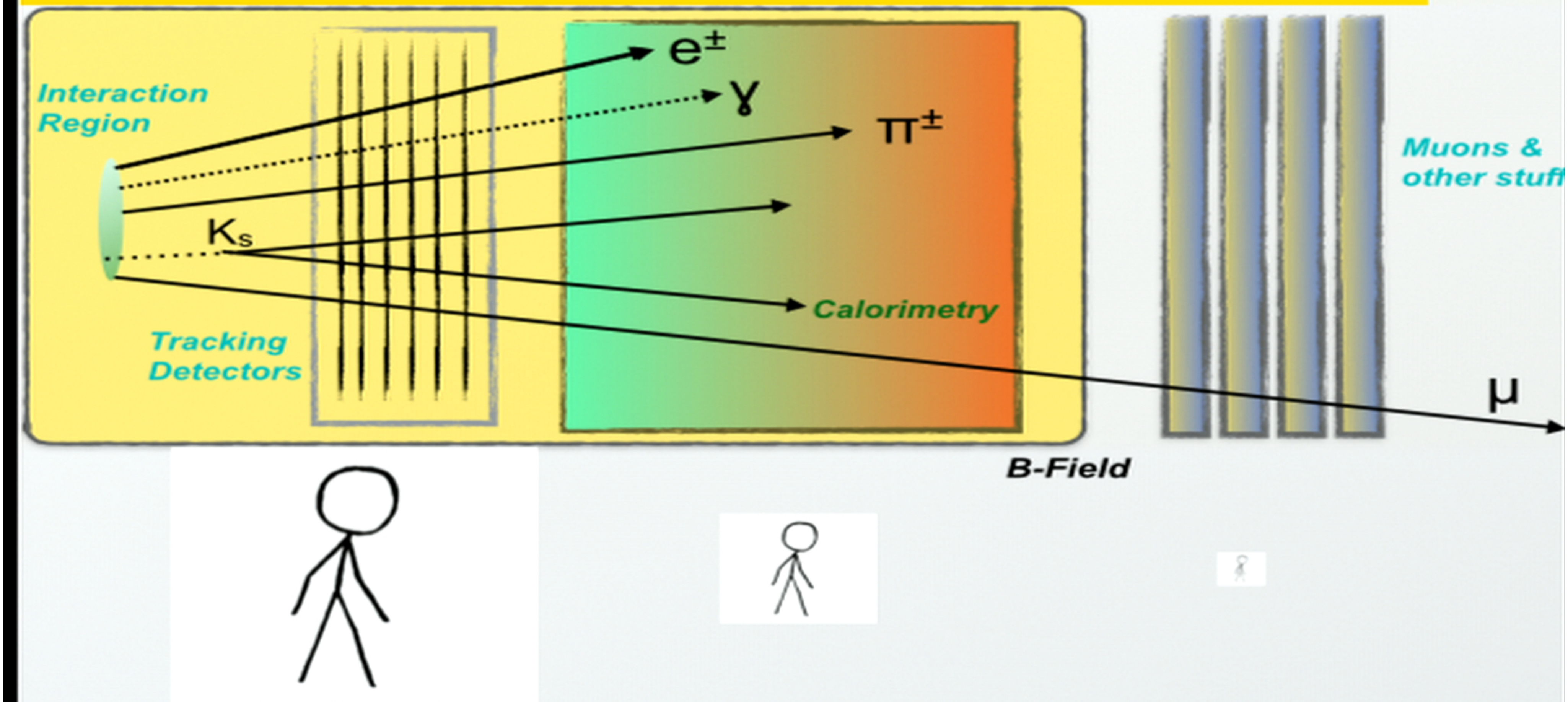
Every* Particle Physics Detector



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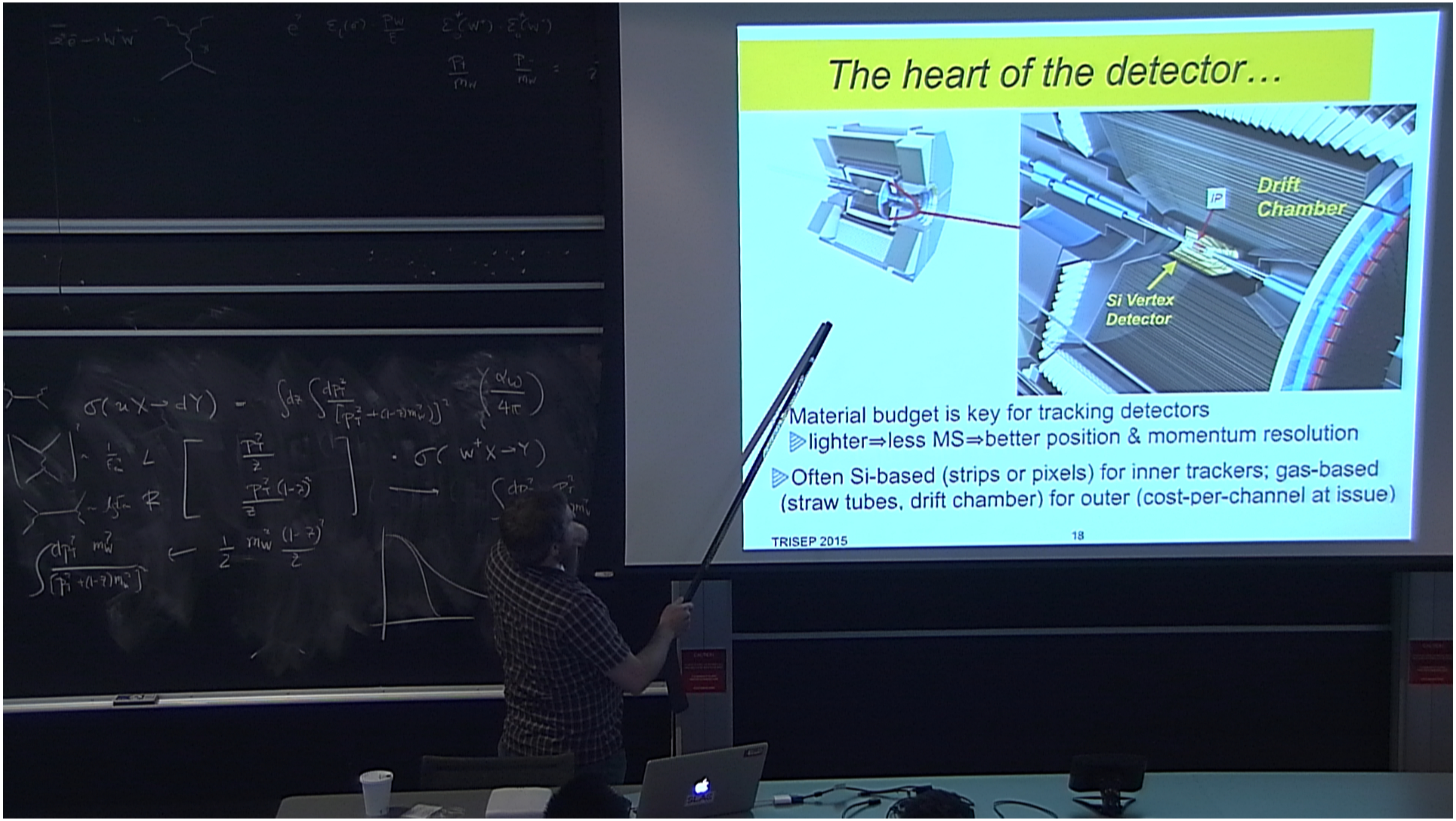
*may not be strictly true


The heart of the detector…
Drift Chamber
IP
Si Vertex Detector
Material budget is key for tracking detectors
lighter⇒less MS⇒better position & momentum resolution
Often Si-based (strips or pixels) for inner trackers; gas-based (straw tubes, drift chamber) for outer (cost-per-channel at issue)
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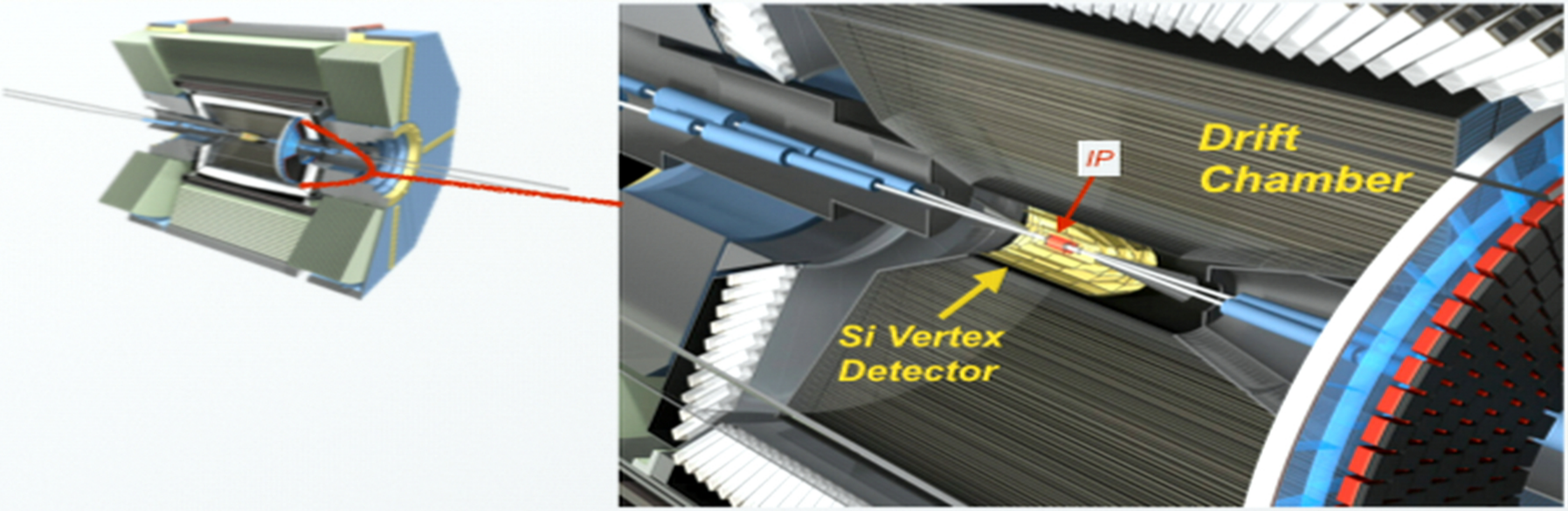
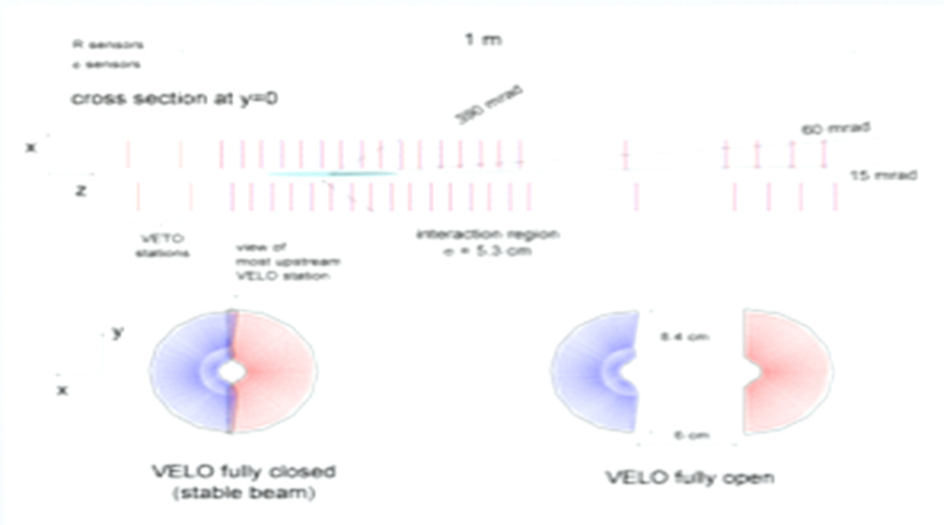
The heart of the detector…



- Material budget is key for tracking detectors
  - lighter⇒less MS⇒better position & momentum resolution
- Often Si-based (strips or pixels) for inner trackers; gas-based (straw tubes, drift chamber) for outer (cost-per-channel at issue)

A very cool thing.

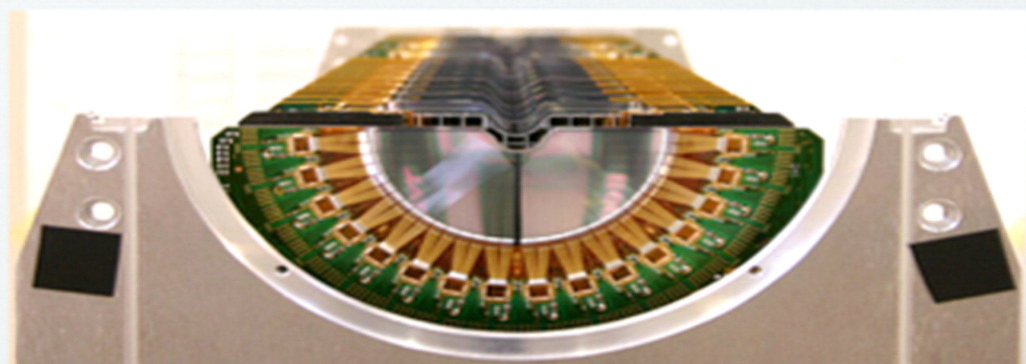


The LHCb VELO is great example of a "vertex-tracker"…

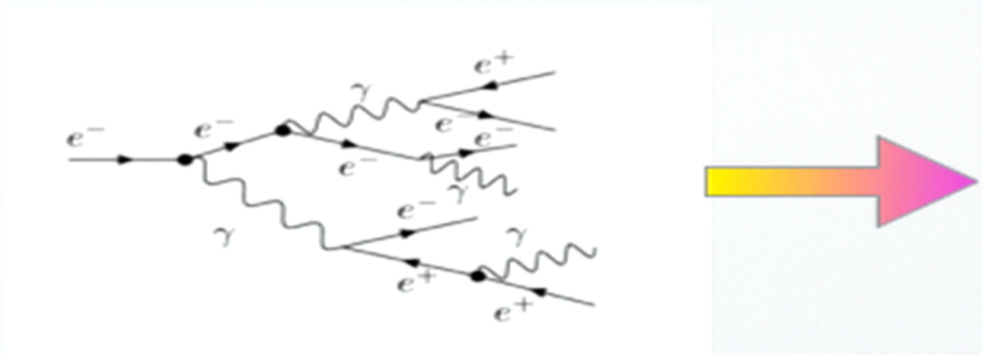
- ➡ encircles the LHC beam, aligned perpendicular to the beam direction
- ➡ designed to detect the B-meson decays slightly displaced from primary pp interaction

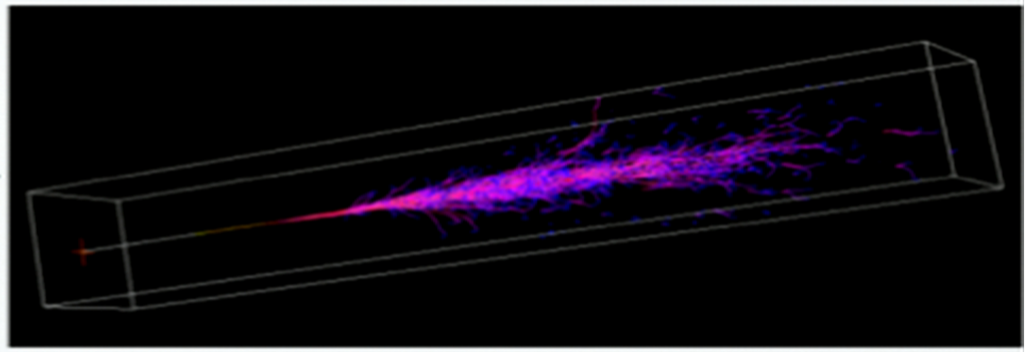
…retracts during beam tune and closes up for data taking

consists of pairs of radial-axial half-circle Si-strip layers

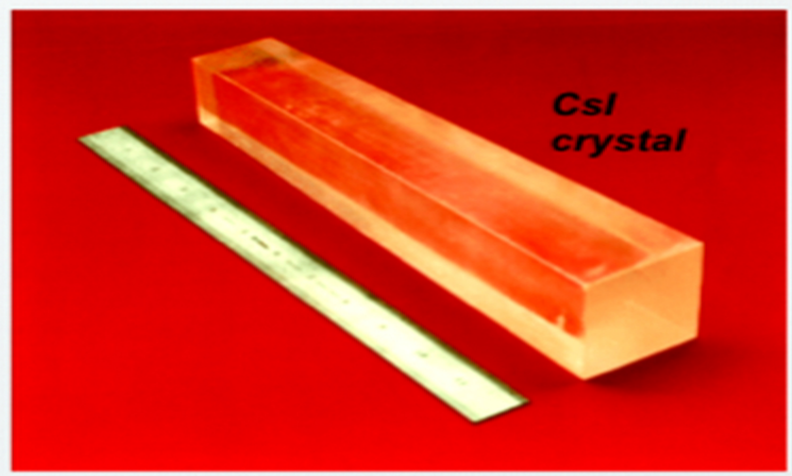


(EM) Calorimetry





- …opposite of trackers, put lots of material in the way…want to ***cause*** showers
  - high density, high Z materials
- Pb glass, PbW, CsI, LAr
- Measure the energy either from Cerenkov radiation/scintillation light (via PMTs or APDs) or from ionization charge (in LAr detectors);

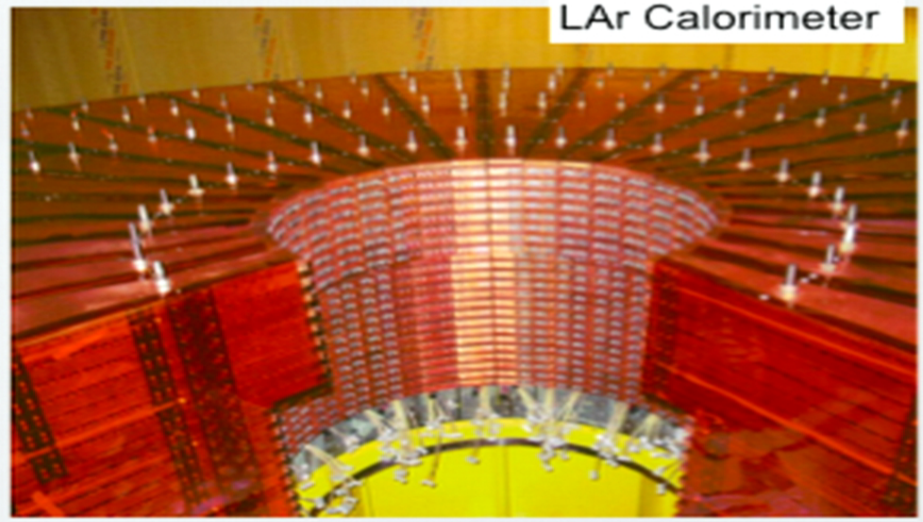


Two ECal Examples

BaBar Central
Calorimeter

Calorimeters tend to be ***fast***, both the physics and the readout…trigger systems rely heavily on EM calorimetry

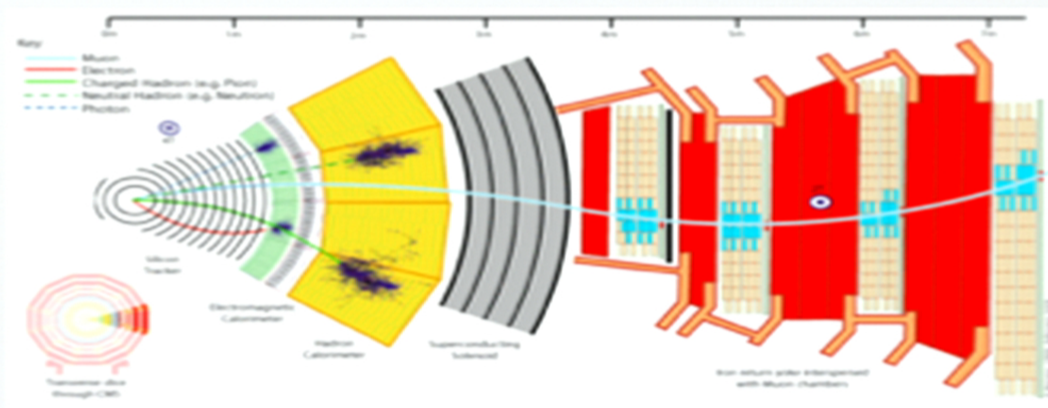
ATLAS Endcap
LAr Calorimeter

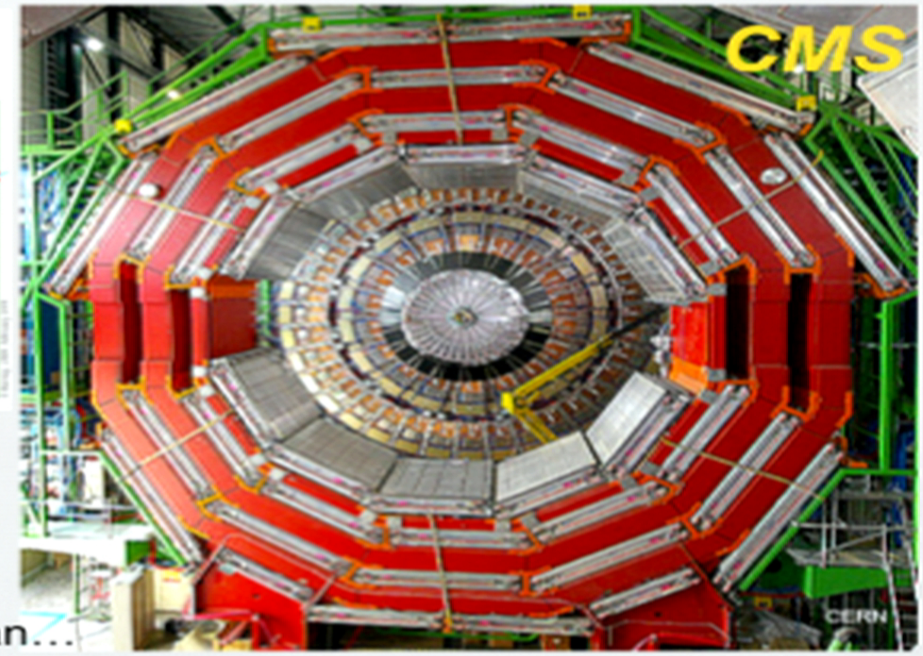


…also key for particle ID (photons! but also electrons/muons/pions).

For hadron calorimetry, missing energy is a huge deal; need XCal systems to be ~hermetic.

Muon ID

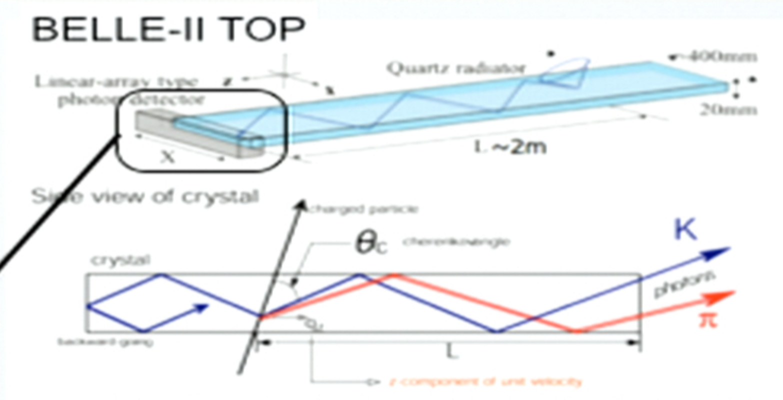


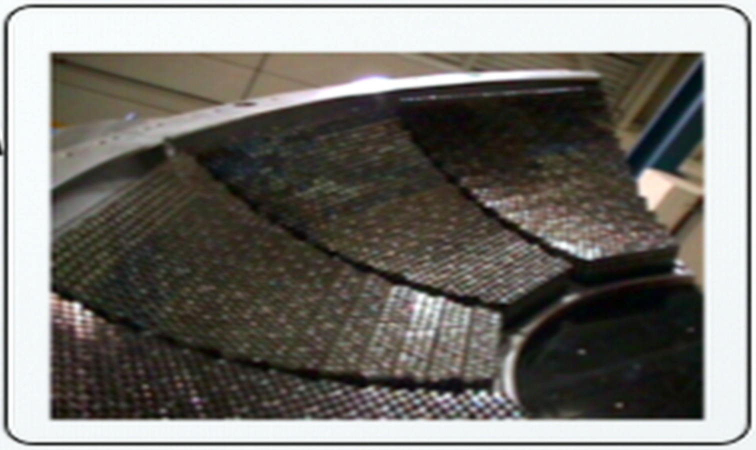


"Muons are probably the most important particle in particle physics" — Matt Graham

- easy to create, detect, identify, theoretically clean…
- muons pass through entire detector, just leaving MIP signals; Muon ID systems are the outermost system
- need to be cheap because they cover large area; sandwich detectors between iron is very common…if a particle gets all the way though it's a muon
  - scintillating paddles; **R**esistive **P**late **C**hambers; streamer tubes…etc

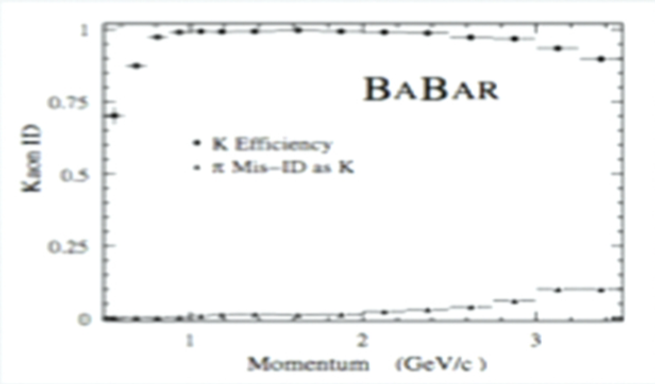
Specialists…PID





Particularly at low-ish energies (GeV) it's important to decipher π/K(/p/d etc…);

for π/K separation at GeV, Cherenkov-based detectors are very powerful



Searching Beyond the Standard Model: Precision Measurements & Rare Decays

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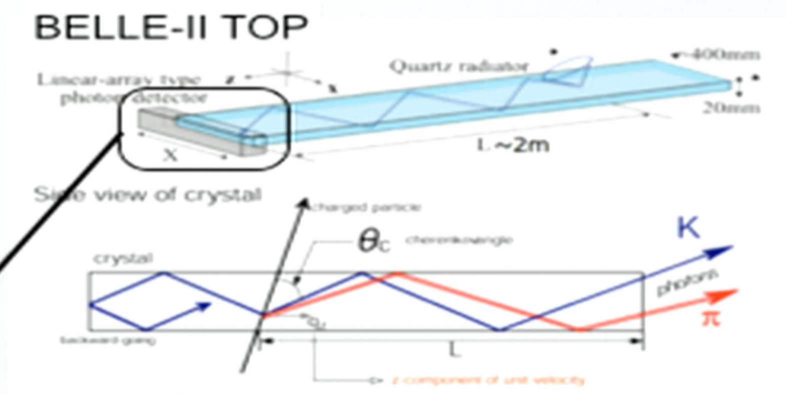

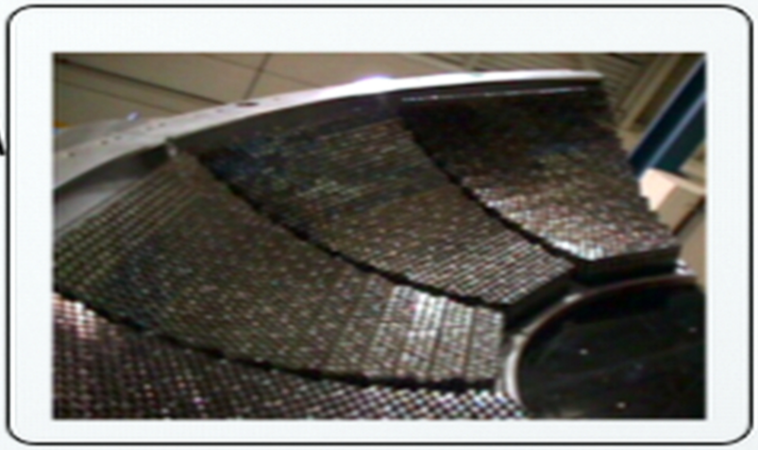

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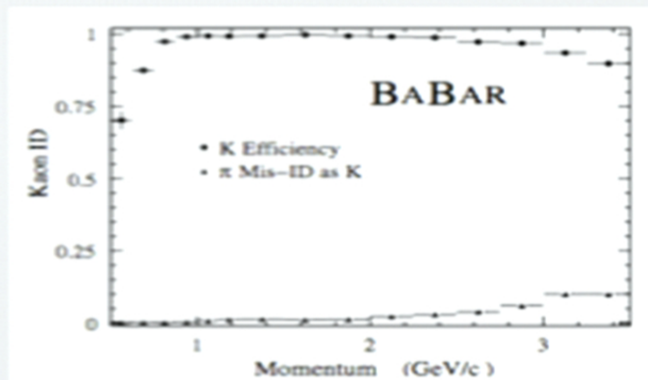

Searching Beyond the Standard Model: ~~Precision Measurements & Rare Decays~~

Flavo(u)r

Mathew Graham, SLAC

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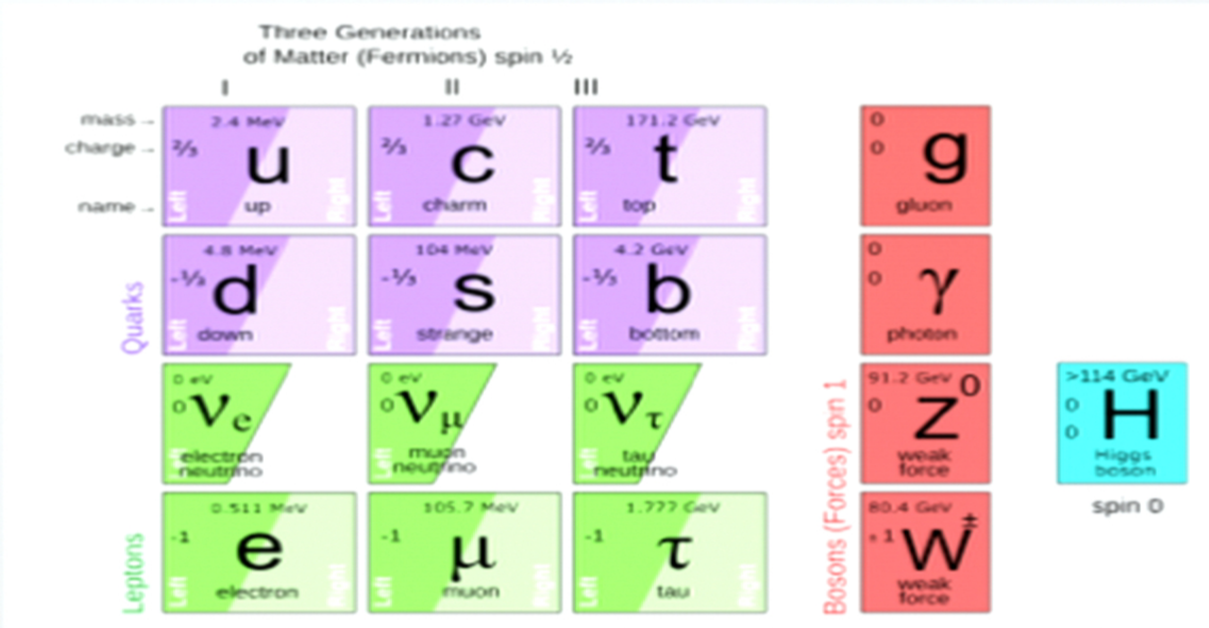
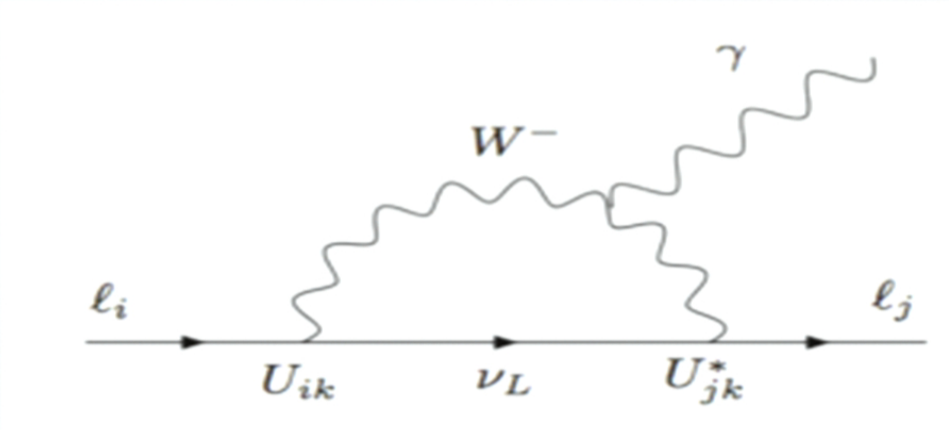
This talk…intro: Flavor



- flavor, i.e. “u-ness”, “μ-ness”, “ν_τ-ness” etc, is ***not*** conserved in the SM
- there is no mechanism for flavor-changing neutral currents ***at tree-level*** in the SM

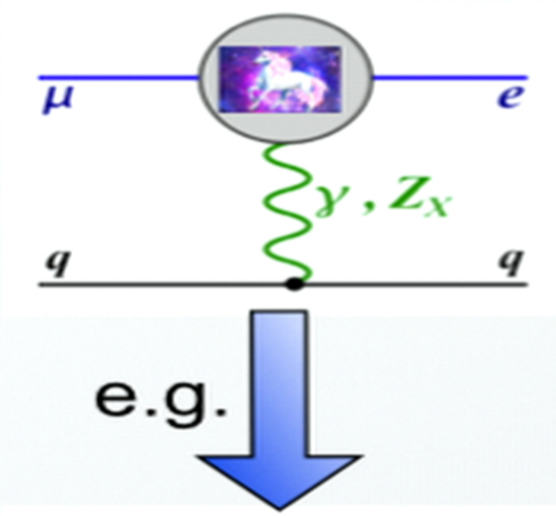
(Charged) Lepton-Flavor Violation

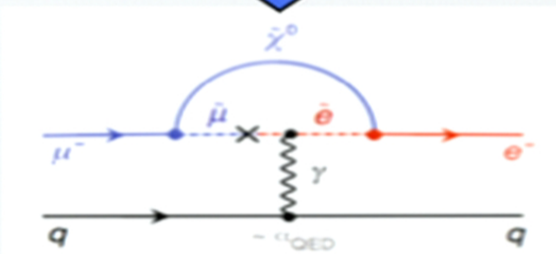


$$\mathrm{Br}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 < 10^{-54},$$

this is very, very small

$\mu \rightarrow eX$





Three ways to look for μ→e:

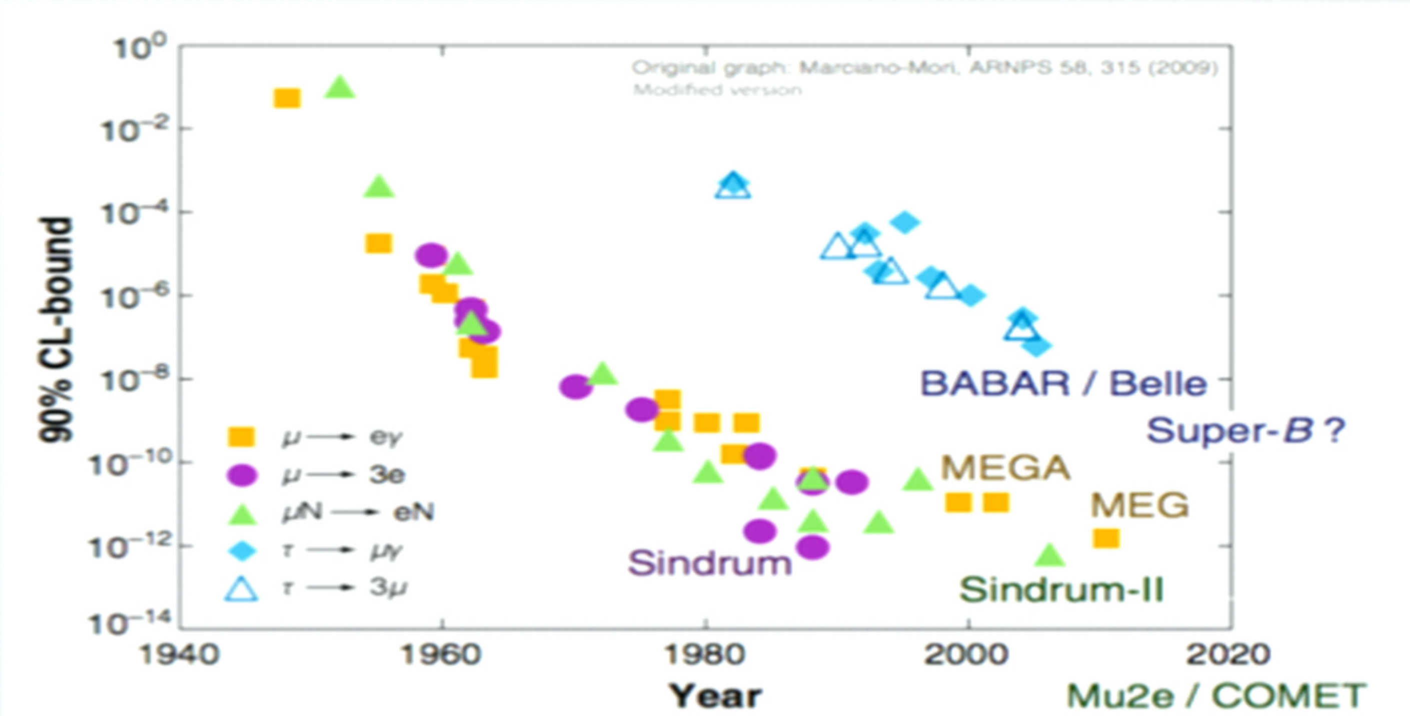
- $\mu^- \rightarrow e^- \gamma$
- $\mu^- \rightarrow e^- e^+ e^-$
- $\mu^- N \rightarrow e^- N$

These are ***complimentary*** probes sensitive to different ***classes*** of models

	$\mu \to 3e$	$\mu \to e\gamma$	$\mu \to e$ conversion
$O^{4\ell}_{S,V}$	✓	–	–
O_D	✓	✓	✓
O^q_V	–	–	✓
O^q_S	–	–	✓

Cirigliano@Beauty2014

So far, so nothing.



…current limits on μ→e probe up to ***10⁴ TeV***

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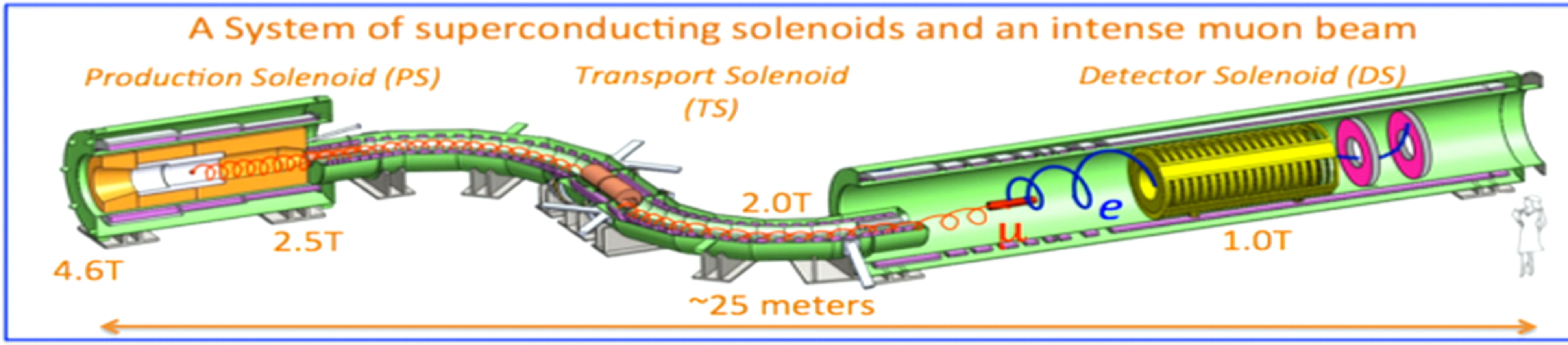
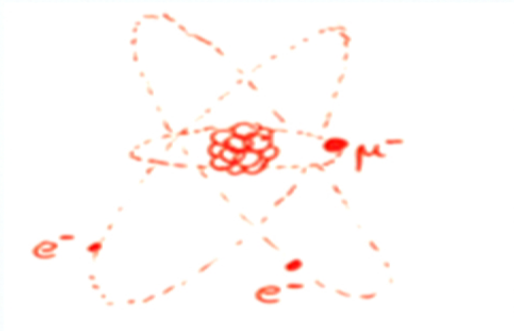
The μ2e Experiment @ FNAL



- 8 GeV Booster protons→muons (and pions, neutrons, gammas …)
- crazy, curvy beam line to get rid of any line-of-sight background
- muons steered into Al "stopping" target, where the magic happens

Stopping muons



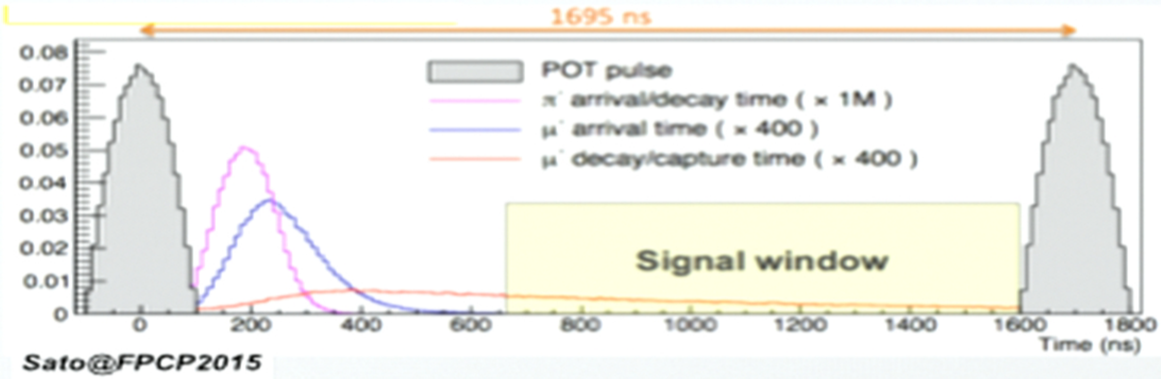
stopped muon replaces an electron in the Al atom…

…most of the time, the muon either is "captured" (releasing ν_μ) or decays in-orbit

primary background are "***DIO***" decays…but energy spectrum is different from signal

symmetry magazine

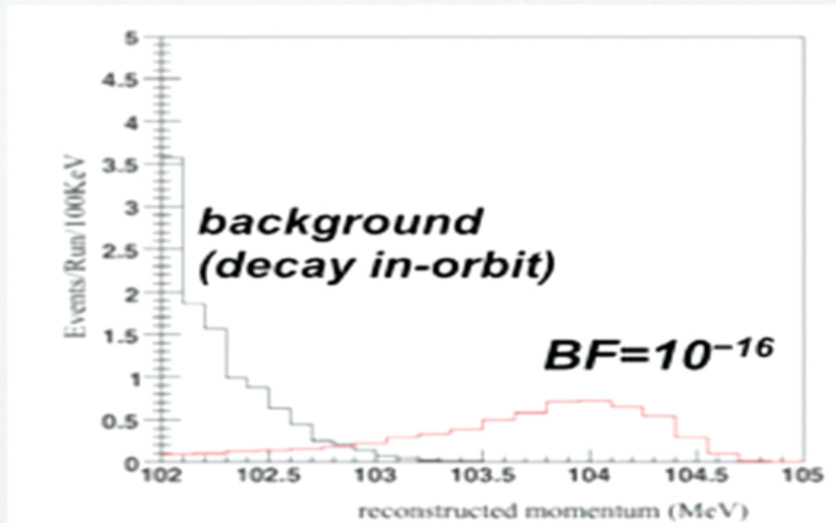
μ2e Signatures



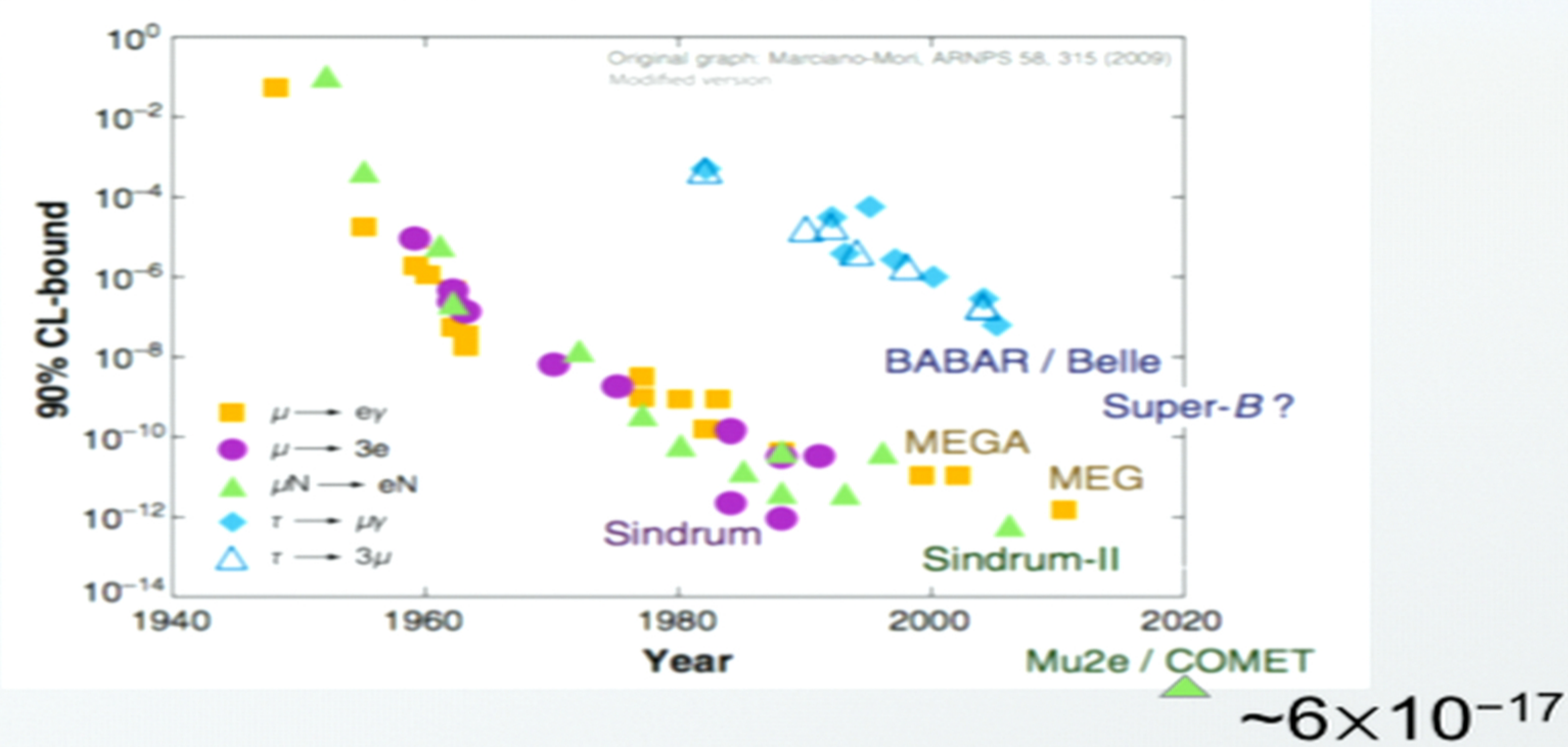
1. pulsed beam→wait until all is quite

2. measure energy of the electron; μ→e conversions peak at ~m(μ) while decays cut off before that

Gives ~ background free signal region



μ2e Sensitivity



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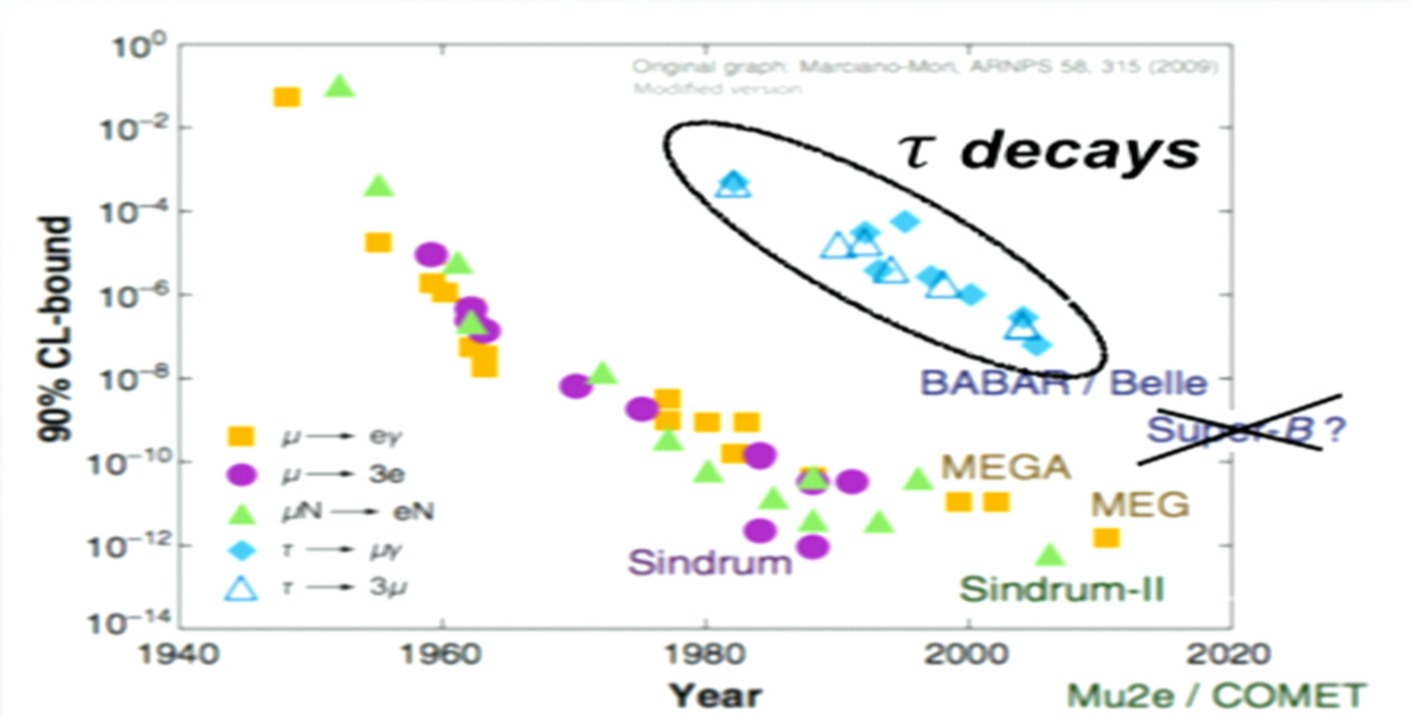
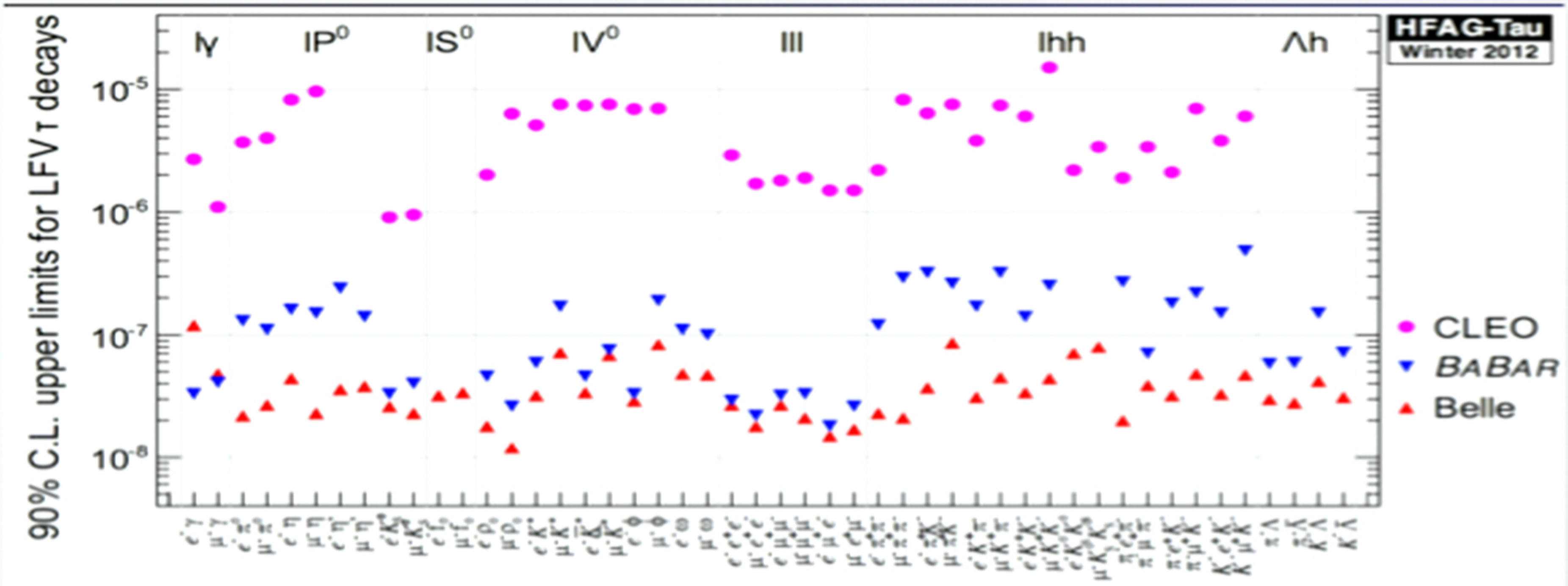
Tau decays too…



…many, many tau decays



…these should go down by x10 by ~2025 (Belle-II)

(C)LFV Recap

- Charged lepton flavor violating reactions are a great place to look for physics BSM…the first one we see will be a huge discovery
  - very clean theoretically AND experimentally…the limiting factor is how many muons or taus we can produce
  - can probe very high energy scales
  - good complementarity with the energy frontier
- Unfortunately, there's no indication that it's right around the corner
  - that's not a reason to not look…just keep digging!
- Upcoming experiments take a nice step forward:
  - mu2e (FNAL)
  - COMET (J-PARC)
  - mu3e (PSI)

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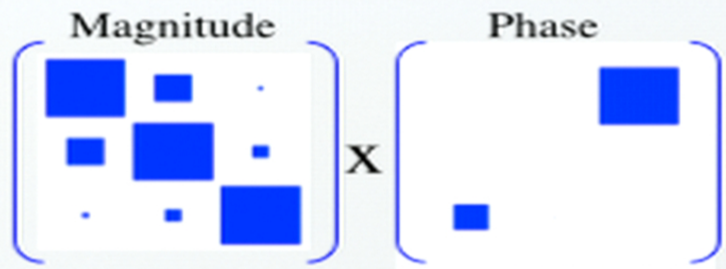
CKM Matrix & CP-Violation in the quark sector

$$V_{pq} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \alpha$$



$$\approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda = \sin\theta_C = 0.22$$

Unitarity Conditions:

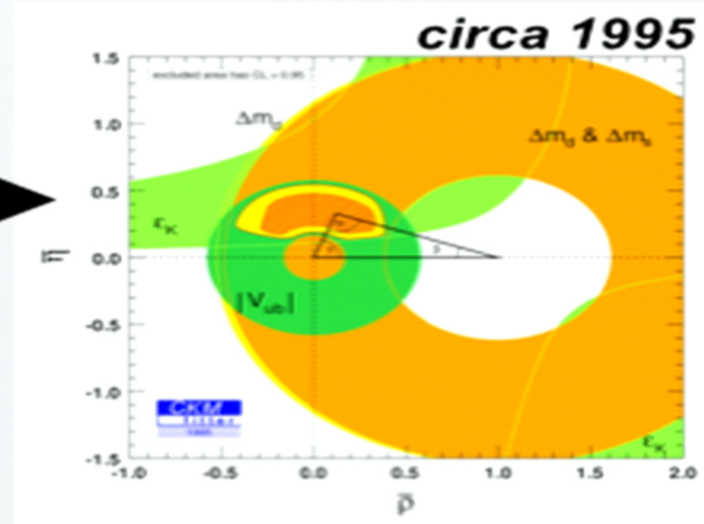
$$|V_{i1}|^2 + |V_{i2}|^2 + |V_{i3}|^2 = 1$$

$$V_{i1}V_{j1}^* + V_{i2}V_{j2}^* + V_{i3}V_{j3}^* = 0$$ "Unitarity Triangles"

THE Unitarity Triangle

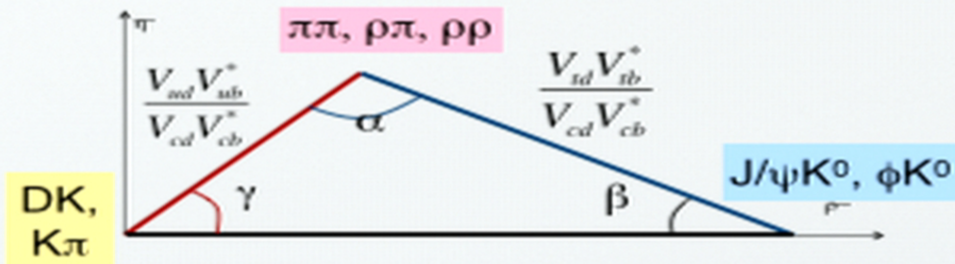
There are 6 triangle relations but most have very un-equal sides== large/small angles == small CPV effects

...EXCEPT!!!



THE UT = Column 1 (***d***) * Column 3(***b***)

Unitarity condition: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$



One of the ***main goals of B-Factories is to see if this triangle closes***...if it doesn't, it would be sign of **physics beyond the Standard Model!**

CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], updated results and plots available at: http://ckmfitter.in2p3.fr